Young, High-Velocity A Stars

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A thesis submitted for the degree of Doctor of Philosophy
of the Australian National University

September, 1986

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Canberra

Erratum

Page 38.

Eg. 2.2 should read $\beta = \dfrac{Z}{2.3 \log (D_o/D_z)}$

Page 190, line 3 should read

- instead that for Gould's Belt stars it was +14 km/s/kpc.

The work described in this thesis is that of the candidate alone, except where acknowledged otherwise in the text.

Catherine Lance

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To my mother, Margaret

To my son, Alexander

And especially, to my husband, Gregg.

Acknowledgements.

I would never have been able to come to Mt Stromlo and actually do this postgraduate course if it had not been for two people. One was my undergraduate advisor, Dr Jim Emerson, of Queen Mary College, London University, whose assistance and encouragement helped me to make the daunting transition from Biology to Physics. The other was my mother, Margaret Lance, without whose practical and emotional support I would not have been able to finish my undergraduate degree.

I have benefited enormously from the skills and knowledge of the whole academic community at Mt Stromlo. There is probably not one person here who has not contributed in some way to this thesis. Primarily, I wish to thank my supervisor Dr Alex Rodgers, for offering this fascinating topic for study, for many interesting and productive conversations, and for his work on the development of the Photon Counting Array, which made it possible for large amounts of data to be acquired here at Mt Stromlo on the 74" telescope.

I would also like to thank the electronics department and the technical and workshop staff for their assistance with the PCA, the 74" telescope, and the 30" telescope, particularly John Wach, Dennis Bullock, John Findlay, David King, and Dave Irons.

I would like to particularly thank Paul Harding for his frequent and good-humoured assistance in setting up the telescope and detector, his work on the PCA, and his help with data reduction, Renault clutch plates, and spare parts. Thanks also to my dear friend Heather Morrison, for the encouragement that helped me over several difficult times during the last few years, and for so many enjoyable and informative conversations.

Particular appreciation is due to Dr John Norris, for his careful critical reading of early drafts of this thesis, and for some most enjoyable arguments.

Thanks also to Dr Ken Freeman for useful conversations on several cloudy nights at Siding Spring, and to Dr Olin Eggen for advice about proper motions and the Yale stars.

Dr Mike Bessell contributed greatly to my understanding and knowledge of photometry. Thanks also to Steve Russell, Steve Meatheringham, Greg Wilson, Jim Lewis, Lilia Ferrario, and Dr Dave Carter, for programs used in the course of the thesis work, and to Michael Ashley for getting Tex onto the computer system.

I would like to thank Dr Betsy Green for her dedicated work on the Revised Yale Isochrones; Dr Agris Kalnajs, who assisted with a program and helpful conversations; and Gerhardt Meurer and Dr Bob Gingold, both for information and for their pleasant company.

Thanks to the people in the Computer section, and to the administrative and clerical staff, all of whom have have been friendly and efficient over the last four years; and to the other students here, who have been a wonderful mix of personalities that have contributed greatly to the lively and enjoyable atmosphere, both at work and at play.

Finally, special thanks to my five-year-old son Alexander, who has had the great good fortune to spend three years of his life living on Mt Stromlo, and who has coped calmly both with my observing runs and our complicated existence. I could not have done this work without the support in every way of my husband, Gregg Rowley, whose contribution to my enjoyment of the last four years has been beyond measure.

Sherlock Holmes to Dr Watson:

'How often have I said to you that when you have eliminated the impossible, whatever remains, *however improbable*, must be the truth.'

From *The Sign of Four*, by Sir Arthur Conan Doyle.

Abstract.

This thesis examines the group of high-velocity SGP A stars, discussed by Rodgers, Harding, and Sadler (1981, RHS), which had been observed at distances from the plane of more than 1 kpc. RHS found them to be main-sequence stars, with a velocity dispersion perpendicular to the plane of 66 km/s, and a range of abundances from -0.5 dex to 0.0 dex (around one third of Population I to normal Population I abundance).

This combination of properties had not been previously observed in any population of stars, and after exploration and rejection of several alternative possibilities, RHS were led to suggest that the stars had been formed from the recent coalescence with the Galactic plane of metal-poor gas from a satellite galaxy undergoing a merger with the Milky Way.

The rejection of alternative hypotheses was consequent upon the accuracy of all of the properties measured by RHS. If one or more of the parameters were to be incorrect, then it might be that the stars were actually misidentified members of other populations, such as blue stragglers, metal-rich horizontal branch stars, or normal disk stars accelerated by some unknown mechanism.

In order to explore this possibility, in this thesis the parameters found by RHS have been re-derived and critically examined in the light of alternative hypotheses. A catalogue has been compiled of all early-type stars that have been identified (from many sources) in 217 square degrees at the SGP, to augment the sample of high-velocity stars. In addition a number of high-velocity stars in the Solar neighbourhood have also been studied.

The results of this work are that:

1) The majority of the high-velocity stars are undoubtedly on the main-sequence.

2) Their rotational velocities (*v sin i*) are high, typical of young, Population I

stars. They do not have the lower rotational velocities found for blue stragglers or horizontal branch stars.

3) They are all younger than around 0.6 billion years, in contrast to a control group of disk A stars with stochastic ages of formation of up to 2 billion years. They appear to be coeval, suggesting that they were formed as the result of a single event, rather than randomly over time.

4) They are relatively metal-poor, with [Ca/H] from around -0.4 dex to 0.0 dex, in comparison to young disk A stars which usually have abundances from about -0.1 dex to 0.2 dex.

5) Their W velocity dispersion was found to be 62 km/s, in very good agreement with RHS.

6) They are observed to be at distances of up to 6.5 kpc from the Galactic plane, and some stars may travel as far as 10 kpc from the plane in their orbits. The majority of stars seen are at less than 3 kpc distance because of the magnitude limit of the original survey: this is a selection effect. The stars would have to be observed to 16th magnitude to obtain a larger sample of the more distant, fainter stars.

7) The exponential scale height for the young stars at distances greater than 1 kpc is estimated to be around 700 pc.

8) The nearby young, high-velocity stars lag behind Solar rotation in the disk by around 40 km/s.

9) The nearby stars have large (30 to 40 km/s) and almost isotropic velocity dispersions in U, V and W. Their ratios of UVW velocity dispersions are unlike any other known group of stars.

10) The high-velocity A stars comprise around one percent of normal disk A stars.

11) The amount of gas required to form the observed density of high-velocity

stars was estimated to be equivalent to the gas content of a galaxy at least midway in size between the Small and Large Magellanic Clouds.

These results were discussed and compared to those that would be predicted by hypotheses proposed to account for the existence of the A stars.

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Chapter 1

Introduction

1.1 The Problem.

In 1971 Rodgers published a study of fifty-four A stars between 12th and 15th magnitudes in the region of the South Galactic Pole. His remarkable result was that twenty-one of these stars, at distances of from one to several kiloparsecs from the galactic plane, appeared to be of near-solar composition.

This was such an unexpected finding because stars at large distances from the plane are usually considered to be members of an old metal-poor population formed during the early stages of galactic evolution. As a consequence of much work on the abundances and kinematics of stellar groupings in the 1950's and 1960's, an hypothesis of galactic structure and evolution had arisen, due particularly to the influential study of Eggen, Lynden-Bell and Sandage (1962).

They had found a correlation between metallicity and orbital eccentricity in a sample of high-velocity stars that indicated that the more metal-poor stars would travel to greater distances from the plane than more metal-rich stars. They suggested that the Galaxy had collapsed on a relatively short timescale from an enormous spheroidal system of low rotation and low metal content. As the system collapsed, progressively more metal-abundant stars on more circular orbits were formed, until a disk with spiral arms of young metal-rich stars evolved.

Stars of low rotation (which appear to have high velocities when viewed from the Sun rotating with the disk) were old, with low metallicities and eccentric orbits that took them into the galactic halo, far from the plane. Stars rotating with the disk were younger, of higher metal abundance and modest kinematics, oscillating from tens to a few hundreds of parsecs about the plane. There was no place in such a scenario for young relatively metal-rich stars to be either formed at, or to be capable of travelling to, great distances from the galactic disk.

1.2 The Complication.

Before discussion of the history of high latitude blue stars, it may be useful to describe the major complication of any of these studies, which is that in the A star spectral range there appear stars of several distinctly different evolutionary stages.

The larger group, young main-sequence (MS) A stars, have surface gravities of around 4.0 dex to 4.2 dex, are composed of about 1.5 to 2.8 solar masses of hydrogen enriched with metals to solar or greater abundance, have rotational velocities averaging 130 km/s, absolute visual magnitudes from about 0.7 to 2.7 (class V), B−V from 0.0 to 0.3, and remain on the main sequence for about 200 to 1000 million years. (The cavalier usage of the term 'young' in this context may be illustrated by the fact that most A stars observed today were formed when animal life on Earth had not yet evolved onto the land.)

A subset of normal A stars are the blue stragglers. They are usually observed in the region of the main sequence of galactic clusters (and less frequently in globular clusters) where they are assumed to be of the same age as the other stars that have evolved to the red giant branch. They appear to have extended main sequence lifetimes, perhaps from acquiring mass from a companion, or from some postulated mixing mechanism that would supply hydrogen for a longer period of core-burning.

Galactic cluster blue stragglers have ages appropriate to the old disk and some have abundances from around one third solar to solar metallicity. Peterson, Carney and Latham (1984) argue that it is because binaries survive disruption more frequently in areas of low star density that they may form blue stragglers more often in open clusters rather than the more dense globular clusters.

Mermilliod (1982) found that they are also observed in quite young open clusters, that nearly all clusters older than 100 million years had at least one blue straggler. Around 60% of them in the late B and early A star range (Abt, 1985) have spectral peculiarities, with magnetic (Bp, Ap) or metallic (Am) line characteristics. The binary hypothesis cannot hold for all blue stragglers, however, because Ap stars have a very low incidence of binarism. Abt (1985) suggested that magnetic mixing may extend the main sequence lifetimes of Ap blue stragglers.

The O and early type B blue stragglers rotate at velocities higher than normal for their spectral type, (thus very high (mean of 220 km/s) rotation may be yet another possible mixing mechanism in the case of the hottest blue stragglers). However the late B and early A blue stragglers have slower than normal rotation, a characteristic also of Am and Ap stars. Out of 13 blue stragglers in this range, Abt (1985) found rotational velocities of less than 50 km/s for 12 of them. (The thirteenth one had a value around 200 km/s, but Mermilliod (1982) indicated that its photometry may be uncertain.) Peterson, Carney and Latham (1984) found for four blue stragglers in the open cluster M67, rotational velocities of 120, 70, 65 and less than 10 km/s.

If mass gain from a companion star is a method of blue straggler formation then low rotational velocities would be not unexpected, as the low mass progenitors of blue stragglers would also be slow rotators. In addition, if a large percentage of them are Ap and Am stars, of which the majority have rotational velocities less than 70 km/s, then slow rotation would again be a predicted feature. As described above, from the few studies that have been done it is also an observed feature for almost 90 percent of those stars studied.

Blue stragglers have main-sequence or slightly evolved surface gravities, so that old blue stragglers in the field, without a coeval red giant branch population to indicate that their main sequence lifetimes had been extended, would be almost indistinguishable from normal A stars apart from their rotational velocities. (Blue stragglers from globular clusters would be too metal-poor to be confused with young A stars, so in subsequent discussion it is old disk blue stragglers that are being considered.)

Longer main sequence lifetimes naturally imply that blue stragglers will gain a larger W velocity dispersion due to normal disk dispersive mechanisms. After 5 billion years the dispersion is estimated to be 21 km/s in W, and after 10 billion years around 33 km/s (Mihalas and Binney, 1981, p436). Note, however, that blue stragglers must eventually evolve off the main sequence: a prolonged main sequence lifetime of ten billion years would be most unlikely.

Another group of metal-poor main sequence A stars are the λ Boo stars (Baschek and Searle, 1969), while Cowley *et al* (1982) found a sample of mildly metal-poor early A stars with otherwise normal spectra, similar to λ Boo stars. These are all low-velocity stars, with disk kinematics.

The other major group of A stars are those of the horizontal branch (HB). They are evolved low-mass stars which have passed through the red giant phase. Metal-rich stars are found on the red horizontal branch, (in the F star range), while metal-poor stars of low core mass appear on the blue horizontal branch. Between the red and blue parts of the HB occurs the instability strip where variables such as RR Lyraes are found. HB stars in general have greater luminosities and lower gravities (log 2.9 to 3.6) than mid to late MS A stars, but at higher temperatures HB gravities become larger and approach the locus of main-sequence early A stars. The two sequences overlap in the very early A and late B star range (log g of 3.7 to 4.1).

Here also the distinctive metallicity indicator of the CaII K line at 3933Å falls to a fraction of an angstrom in equivalent width, so for late B and early (intermediate gravity) A spectra of anything other than extremely high resolution, it is very difficult to distinguish between young and evolved stars. This is one of the major complications of early-type A star studies, because metal-poor horizontal branch stars are also often high velocity stars.

In the later-type A stars there is also an area of possible confusion. In the instability strip (from $b-y$ around 0.10 to 0.30) there are old disk RR Lyrae stars of type c. They have periods less than or equal to 0.4 days and comprise around 10 percent of all RR Lyrae stars. They are seen in large numbers towards the galactic centre, and are very rarely seen at high latitudes. They are thought to be post red giant branch descendants of relatively metal rich disk stars, with only a thin hydrogen envelope covering their helium cores, because they have undergone substantial mass loss (around $0.5m_{\odot}$, which is around half of the total mass of the progenitor). They are thus instability strip horizontal branch stars of near solar metallicity and old disk kinematics which appear in the A star range. Theoretically, a very restricted mass range of these stars may occasionally evolve onto the horizontal branch bluewards of the instability strip (Taam, Kraft and Suntzeff, 1976).

At hotter temperatures than A stars the horizontal branch extends to higher gravities, of log 4.5 and greater. Bw stars are found below the main sequence in the temperature range from 10,000 to 20,000 K, and at higher temperatures subdwarf B and subdwarf O stars are observed (Greenstein and Sargent, 1974).

The separation of members of a group of A stars into MS and HB stars is not a trivial problem. In a statistical sense, given a sufficiently large sample of stars, the majority of lower gravity A stars will be HB and higher gravity ones will be MS. However the luminosity of a star on the HB is very sensitive to variations in helium abundance and core mass (Sweigart and Gross, 1976) so the HB may be broad, and low core mass stars may appear in the intermediate gravity range.

More importantly, it must be recognised that the normal evolutionary path of a young A star between the zero age main sequence and the base of the red giant branch passes through the gravity-temperature range occupied by the HB (see fig. 1.1), and for A star masses, *between 10 and 20 percent* of this total dwarf/subgiant evolutionary time can occur at gravities as low as log 3.3 to log 3.8 (Iben, 1967).

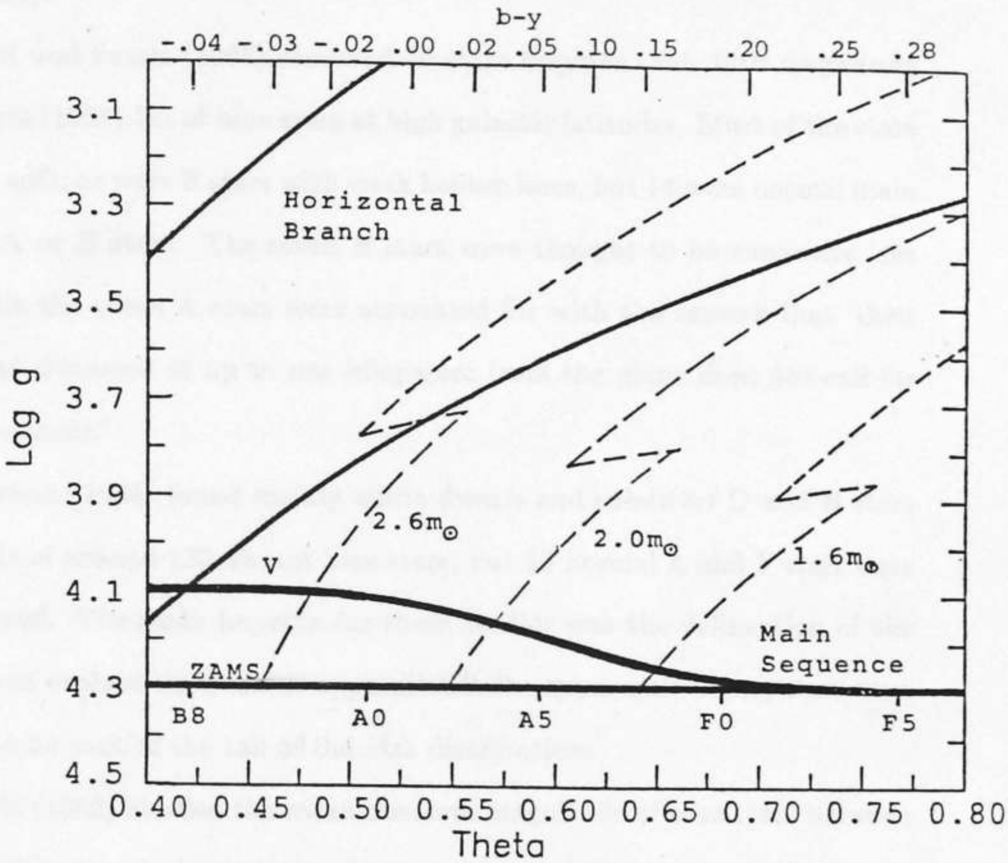
For this reason, studies that utilise photometric gravity indices alone (Philip, 1974) as their MS/HB criteria, while statistically appropriate, will lead to misclassifications for specific stars. It is important that another criterion, such as metallicity, be used. While the Strömgren index m_1 is a rough metallicity indicator for F stars and for some late-type Am stars, it is not at all useful for most A stars. It is very luminosity (and gravity) sensitive, and for hotter A stars in particular, gravity/metallicity effects become ambiguous. For instance, an early A star of gravity log 3.5 and one tenth solar metallicity will have the same m_1 index as one with log 4.0 gravity and solar abundance (Kurucz, 1979).

The most useful metallicity criterion (available from low to medium dispersion spectra) is the CaII K line equivalent width, which correlates well with general metal abundance. (The exceptions to this, of course, are the Am stars which show the lower calcium (and/or scandium) abundances indicative of stars several spectral types earlier than their other metal lines would indicate. Strömgren photometry is helpful, in this case, for identification of these stars.) Without an abundance indicator such as the CaII K line, accurate classification on the basis of gravity alone is not possible.

Although horizontal branch morphology is sensitive to factors such as helium abundance, age, and mass loss, in general metallicity will strongly affect whether a star reaches the blue HB. A metal-rich star that by other mechanisms (such as major envelope mass loss) evolves to the HB instability strip will have the kinematic properties of its main sequence progenitor, that is, old disk motions. In this case, the frequently encountered usage of the term 'horizontal branch' as a synonym for 'halo' and 'high velocity' will be misleading. HB stars that do have halo kinematics will usually be very metal-poor, from -1.0 dex (one tenth solar) downwards.

In summary, then, A stars of high gravity and high metallicity may be young, main sequence Population I or older blue stragglers. Some stars of high gravity may be relatively metal-poor (λ Boo) but otherwise are normal Population I. Stars of low gravity and low metal abundance are certainly horizontal branch, Population II. Some stars of low gravity and high metal abundance are old disk such as RR*c* Lyrae stars, or young, evolving Population I stars in the same colour-magnitude range as Population II stars.

FIG. 1.1– Log gravity against Θ (5040/effective temperature) for A stars. The main sequence (Allen, 1973) is shown for the ZAMS and Class V. The extent of the horizontal branch is from Greenstein and Sargent (1974) and Newell, Rodgers and Searle (1969). Three evolutionary mass tracks are shown, for 2.6, 2.0, and 1.6 solar masses (data kindly supplied by E. M. Green, from revised Yale isochrones, not yet published). The $b - y$ colours for log g of 4.0, along top axis, are from Kurucz (1979).


b-y
-.04 -.03 -.02 .00 .02 .05 .10 .15 .20 .25 .28
Log g
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
Horizontal
Branch
2.6m⊙
2.0m⊙
1.6m⊙
V
Main
Sequence
ZAMS
B8
A0
A5
F0
F5
0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80
Theta

1.3 The History.

Surveys of blue stars at high latitudes had previously been reported by, among others, Humason and Zwicky (1947), Feige (1958), Iriarte and Chavira (1957), Chavira (1958), Luyten (1966 and references therein) and Slettebak and Stock (1959).

Sargent and Searle (1968) observed 30 stars brighter than 12th magnitude from Feige's (1958) list of blue stars at high galactic latitudes. Most of the stars were sdB, sdO, or were B stars with weak helium lines, but 14 were normal main sequence A or B stars. The seven B stars were thought to be runaways (see later) while the seven A stars were accounted for with the remark that 'their presence at distances of up to one kiloparsec from the plane does not call for special comment.'

Greenstein (1965) found mainly white dwarfs and subdwarf O and B stars in a sample of around 120 distant blue stars, but 19 normal A and F stars were also observed. The main impetus for these studies was the delineation of the properties of evolved stars and it appears that the apparently young stars were assumed to be part of the tail of the disk distribution.

Klemola (1962) studied the mean absolute magnitude of blue stars between 10th and 12th magnitudes at high galactic latitudes. Most of the stars appeared to fall on the horizontal branch in the sdO and sdB range, but a small sample, at spectral types A1 to A5 seemed to be a mixture of main-sequence and horizontal-branch stars.

Roman (1965) pointed out that in her catalogue of high velocity stars, three percent were late B and A type dwarfs. The A stars showed no spectral peculiarities, and were found to be distinct from O and B subdwarfs, late-type subdwarfs and horizontal branch stars. Again, these potentially interesting stars were overlooked by later studies.

Perry (1969) studied the galactic force law K_z using early A stars at the North Galactic Pole. He found evidence for 'two groups of A stars in the Z direction, drifting independently of each other across the galactic plane.' One group, from the solar neighbourhood, had a velocity dispersion of 7 km/s and an e-folding scale hight of 45 pc. The halo sample had a dispersion of 49 km/s and a scale height of 450 pc. Perry collected Strömgren *uvby* data for his sample (which utilises the gravity-sensitive index c_1), so that HB stars had been selected out.

The scale height is that point at which the number of stars have fallen by a factor of e relative to the number at the disk. For solar neighbourhood stars responding to the gravitational potential of the disk, the W velocity dispersions (perpendicular to the plane) correlate well with specific exponential scale heights for each population of stars. For instance, young disk A stars have a W velocity dispersion of 9 km/s and a scale height of 50 to 120 pc. Old disk stars have dispersions of 15 to 20 km/s and scale heights of 300 to 400 pc. Proposed thick disk stars have dispersions around 60 km/s and scale heights of 1500 pc or more (Gilmore and Reid, 1983). Halo stars have dispersions of 60 to 120 km/s and scale heights from 2000 pc to greater than 3000 pc. (Mihalas and Binney, 1981).

In this thesis the quantity s will be used for the measure of dispersion, that is, the sample estimator of the true standard deviation σ of the entire population, as this is more appropriate for small samples.

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \tag{1.1}$$

Eggen (1969) criticised Perry's work on the grounds that some of the stars were actually as late as F0, and the larger scale height may have reflected the predominance of old disk stars (including possible blue stragglers) at greater Z heights. However, the scale height of F stars is 190 pc (Mihalas and Binney 1981, p252), much lower than Perry's result of 450 pc which is similar only to stars as old as white dwarfs. A very large part of the sample would have to be blue stragglers to bias it in such a distinctive manner, but out of the 109 stars in Perry's sample 35 are classified as Am or Ap, which is a little less than the usual proportion (about 35%) in A stars (Wolff, 1983), and certainly not indicative of a preponderance of blue stragglers (60 percent of which are Ap or Am).

Philip and Sanduleak (1968) reported an objective prism survey of stars earlier than A7 in a 230 square degree region at the South Galactic Pole. None of the stars were further than 8° from the SGP. Two lists were compiled: 118 stars previously surveyed in Cordoba or Bonner Durchmusterungen, and 62 stars without CD and BD numbers (a few of these were from previous surveys of Haro and Luyten (1962) and Chavira (1958)).

The second list was the basis of observations by Rodgers (1971). He reported UBV observations provided by Eggen, and radial velocity and CaII K line equivalent width (W(K)) measurements of fifty-four stars. Three sdB and two sdF stars were identified. Thirteen other stars had CaII K lines smaller than the detector limit of 0.4Å. Of the remaining 36 stars, 15 were metal-poor A and F stars while 21 were found to follow the Population I relation for W(K) as a function of $(B-V)_0$. W(K) was shown to be only weakly dependent on gravity, so it was a good indicator of metal abundance independent of evolutionary status. The exceptions to this, as mentioned above, are Am stars which would have been selected against in this study.

Rodgers approximated the temperatures and surface gravities of the stars from the widths at 80% of the continuum, D(.80), of the $H\beta$ and $H\delta$ lines, and $(B-V)_0$. The derived surface gravities were considered to be only 'slightly better than estimates' and ranged from log 3.0 to log 4.0. Rodgers concluded that the stars were mostly evolved objects, that their calcium abundances were similar to Population I values, and that their velocity dispersion was 66 km/s (from radial velocities, almost equal to their W velocities at such high latitudes). He suggested that they may have been ejected from the disk at high velocities like runaway OB stars, but pointed out that the hypothesis had theoretical difficulties where A stars were concerned.

1.4 A Digression: OB Stars.

Runaway OB stars were thought to be created by the 'binary slingshot' mechanism suggested by Blaauw (1961). This proposed that one of a massive pair of stars evolves quickly to the supernova stage and the subsequent explosion recoil either accelerates the centre of mass of the system, or the primary is completely destroyed in the explosion and all the orbital angular momentum is transferred to the secondary, accelerating it by a few tens of kilometres per second.

Stone (1979) discussed models of the evolution of O star primaries with O or B secondaries. After the primaries had completed core hydrogen burning they expanded to fill their Roche lobes and transferred around 60 percent of their mass to the secondary before exploding. He found for a wide range of conditions that the post-mass-transfer secondary then had a mass equal to the pre-mass-transfer primary. A star masses are from 1.5 to 3 $m_{\odot}$, B stars from 3 to 17 $m_{\odot}$ and O stars from 17 to 90 $m_{\odot}$. Sixty percent of even the lowest mass O star is over 10 $m_{\odot}$ and would be around 25 $m_{\odot}$ for an average one. Thus any secondary of such a system would have to be at least as massive as an early B star and could not plausibly be an A star.

Observationally he found from a sample of low and high space motion OB stars that in the high velocity group (greater than 25 km/s) almost all had masses greater than 35 $m_{\odot}$, which again suggested that lower mass stars do not become runaways. Another serious constraint for the mechanism is that the lifetime of a high-mass primary is shorter than the time taken by an A (or later-type) star to collapse to the main sequence. A proto-A star would probably not even be dense enough to survive disruption by a supernova explosion.

Gies and Bolton (1986) have re-examined theories of the origin of runaway stars, in a study of the frequency of binaries in a sample of high velocity OB stars. Carrasco *et al* (1980) had suggested that they might actually be subluminous Population II UV-bright stars (UV as in 'UBV' and not as in 'ultraviolet'), but Gies and Bolton found that most of their stars were confirmed to be Population I. They also examined the supernova hypothesis. If this theory is correct, then most runaways should have neutron star or black hole companions, which would be indicated by their radial velocity variations. Gies and Bolton found instead that the binary frequency in runaways was a factor of two to four lower than among normal early-type stars, and that there was no evidence of radial velocity variability that could be attributed to collapsed companions in their sample of runaways, so they rejected the supernova origin hypothesis.

From n-body simulations of the dynamical evolution of young clusters, it had been found that binaries and multiple systems form in the cluster core and their interactions may eject high velocity stars from the cluster. (The original definition by Blaauw (1961) of runaway stars included only those stars whose space velocity direction indicated that the star had originated in a known OB association.) The dynamical processes tended to produce more high velocity objects when larger stellar masses were involved, which may explain the higher fraction of O stars among runaways, but occasional lower mass stars might also be ejected (see section 1.7).

Greenstein and Sargent (1974) in a study of 189 faint blue halo stars within 30° of the galactic poles found that 26% of the sample were spectroscopically normal, with the high rotational velocities and metal-line strengths typical of main sequence B stars. Only seven of the stars had main sequence lifetimes longer than a complete vertical oscillation, indicating that they were apparently observed soon after formation and ejection from the galactic plane. They concluded that there were perhaps a few very high velocity, very blue stars that may have been genuine runaways, but that the majority were from a normal, young population. From their data I calculated that the radial velocity dispersion of the young stars was 63 km/s (for 45 stars), excluding several that they indicated were probably not Population I stars. This is a most unusual velocity dispersion for young stars, yet it is almost the same as that found by Rodgers (1971), of 66 km/s, for A stars at the SGP.

Others have also reported apparently main sequence B stars far from the galactic plane (Tobin and Kilkenny 1981, Tobin and Kauffman 1984). More recent work by Tobin (1986) and Keenan, Brown and Lennon (1986) with high dispersion and IUE spectra indicate that the stars have Population I metal abundances, indistinguishable from disk stars. Some appear to be at distances such that their travel times are longer than their main sequence lifetimes would allow, if they were truly ejected by some mechanism from the disk.

1.5 Further Work on A Stars.

Philip (1974) observed A stars in part of the SGP area surveyed by Philip and Sanduleak (1968), with the Strömgren *uvby* system. He agreed with Rodgers (1971) that there were normal Population I stars at large distances from the galactic plane. He found that three stars that Rodgers had classified as metal-poor in fact had normal indices, one of which was an Am star. He found three others that Rodgers classified as metal-rich to have evolved indices, but on closer examination (see Chapter 3) only one of these is truly a horizontal branch star. The surface gravities of the Population I stars, derived from the c_1 index (a better gravity indicator than Rodgers had available) were entirely normal for main sequence A stars.

Relyea, Matlock and Philip (1975) used Strõmgren photometry to derive surface gravities, temperatures and a metallicity criterion for A stars of various populations. At both the North and South Galactic Poles they found stars with [m/H] greater than -0.5 (*ie* greater than one third solar) at distances of up to five kpc away from the plane.

Rodgers, Harding and Sadler (1981, hereafter RHS) aquired flux-calibrated spectra and medium and high resolution spectra of some of the SGP A stars. Three of the later-type A stars were photometrically monitored for periodic light variations, which were not observed. This was important, because it suggested that they were therefore not horizontal branch metal-rich RR Lyrae variables. They found that the U-B colours from Rodgers (1971) had been systematically 0.05 too red (which had indicated lower gravities). (This is shown also by comparison with values obtained by Drilling, 1977).

To derive surface gravities and effective temperatures they used Kurucz (1979) models (method described in Chapter 3). The high resolution spectra were used to investigate whether the calcium abundance reflected the abundance of other metal lines, such as the iron triplet at 4045Å, 4063Å and 4071Å. This was found to be so, and the spectra also appeared to be well matched by MK standards for Population I stars.

From the derived gravities (which were found to be normal for Population I stars) and temperatures, the mass/luminosity ratio values were calculated and interpolated into Iben's (1967) evolutionary tracks to find ages and distances of 19 of the stars. Their distances ranged from one to four kpc from the plane, with maximum possible distances of up to eight kpc for two of the stars. Due to an error in the age calibration the ages found by RHS were overestimated by a factor of two to three times. RHS derived ages of from 0.8 billion to 2.5 billion years, whereas A stars actually evolve to the red giant branch in 0.2 to 1 billion years. However, within the limits of their gravity and temperature calculations, RHS thought that there was no evidence that the stars were not coeval.

Despite the error in the age calculations, even the greater ages found by RHS are still too small for the stars to have been much affected by normal disk dispersive mechanisms. They are also highly inconsistent with the W velocity dispersion of 66 km/s, and the number of stars found at distances greater than one kpc from the plane. Even for a large sample of young disk A stars, their Z scale height of 120 pc indicates that very few would be seen further than 600 pc from the plane, and in the area studied by RHS, none at all should be seen above 1 kpc.

The extrapolated number density at the disk was around one per 800 disk A stars for an e-folding scale height of 700 pc. The density at 1 kpc was found to be almost identical to the density found there by Perry (1969) for his halo group of main sequence A stars.

The calcium abundances were also unusual, ranging from one third of the Population I metallicity to normal Population I values (-0.5 to 0.0 dex). Young disk A stars have metallicities from -0.1 to 0.1 dex (Wolff, 1983). Mihalas and Binney, (1981, p173) plot a graph derived from Pagel and Patchett (1975), showing the abundance distribution for disk stars over the last 10 billion years. Abundances as low as -0.5 have not been generally observed in disk stars formed within at least the last seven billion years, yet the A stars appear to be much younger than that timescale. Halo star metallicities, on the other hand, are usually less than -1.0 dex (one tenth solar abundance). This is quite different from the A star abundances, yet the velocity dispersions of the A stars and halo stars are very similar.

In sum, not one of the three parameters of age, abundance or kinematics was consistent with any other. Their kinematics were appropriate to very old stars; their abundances were intermediate; and their ages were those of recently formed stars. RHS considered several hypotheses for the origin of the high-velocity stars. The runaway mechanism was discarded, and it was clear that they did not form in the collapse-enrichment sequence of galactic formation, as star formation in the halo ceased many billion of years before these stars appeared.

They were led to propose the hypothesis that a small satellite galaxy had merged with the Milky Way and that the stars had been recently created in the collision of gas from the satellite with galactic disk gas. This would account for their unusual metal abundance and their large velocities perpendicular to the galactic plane.

While models and proposed candidates for galaxies undergoing mergers had previously appeared in the literature, this paper was controversial in that it offered putative evidence for such a dramatic event in the recent history of our own galaxy. Toomre (1977) described a sample of galaxies that appeared to be undergoing mergers, all as recently as within the last 500 million years. He estimated that the merger rate would have been substantially larger in the past, and that there was evidence that some galaxies may have simply 'swallowed' a small, gas-rich companion. He suggested that galactic mergers may be a frequent occurrence and may even be a major method of large galaxy formation.

With respect to the Milky Way, Searle and Zinn (1978) found, contrary to what would be expected from a galaxy that uniformly collapsed and underwent progressive enrichment, that there was no radial abundance gradient in the system of globular clusters in the outer halo of the Galaxy and that the clusters had a broad range of ages and may have 'formed in a number of small protogalaxies that subsequently merged to form the present galactic halo'.

Rodgers and Paltoglou (1984) found a group of globular clusters that were chemically homogeneous but had systematic retrograde motions relative to other clusters and to the rotation of the disk. They suggested that globular clusters with systematic motions may be a remnant of the coalescence of small galaxies into the galactic halo, in agreement with Searle and Zinn (1978).

It is clear that globular cluster formation has not occurred in this galaxy in recent epochs. It has however occurred over a long period of time up to the present in the gas-rich disks of the Magellanic Clouds (Freeman, Illingworth and Oemler, 1983), and such dwarf galaxies may provide the optimum environment for their formation.

The correlation found by Eggen, Lynden-Bell and Sandage (1962) between halo kinematics and low abundances has been shown by Norris, Bessell and Pickles (1985) to have been biased due to kinematic selection effects. They found a population of metal-weak stars with disk kinematics, while Rodgers' (1971) sample, on the other hand, are metal-rich stars with halo kinematics. In a most complementary manner the existence of both groups of stars breaks down the greatly simplified metallicity-kinematics correlation (Freeman, 1985, private communication).

The hypothesis of a smoothly-collapsed, isolated, progressively metal-enriched galaxy appears to be being replaced by a view of the Milky Way as having a 'more chaotic origin' (Searle and Zinn, 1978), particularly for halo populations. However, the collapse of the disk and the bulge is still found to be well-modelled by this hypothesis.

1.6 Recent Studies.

It may be useful to mention at this point that although A stars are primarily discussed in this work, this does not imply that *only* A stars are involved. In any star-forming event an entire range of stellar masses is usually created.

Main sequence stars of lower mass than than A stars presumably exist at large distances from the plane but are simply too faint to be seen in studies limited to 14th magnitude. Stetson (1981b) found good evidence for the presence of high velocity main sequence F stars in the solar neighbourhood, and as mentioned, Greenstein and Sargent (1974) found high velocity main sequence OB stars far from the plane.

Carney (1984) described a survey of high proper motion stars, including all F and G stars to the Lowell (NLTT) catalogue limit, around 16th magnitude. He plotted metallicity against W velocity for the sample, and a few percent of the stars, with abundances in the same range as RHS ([Fe/H] greater than -0.5), had W velocities between 70 and 180 km/s, again very similar to the SGP A star velocities.

More recent work on high velocity A stars was reported by Stetson (1981a, 1981b, 1983), who attempted to find a sample of these stars in the solar neighbourhood. He used proper motions from a range of catalogues, Strömgren photometry and spectra to derive evolutionary status, distances, radial velocities and an index of rotational velocity. Not all of his data has yet been published but he concluded that the 'evidence strongly favours the existence of main-sequence A stars with abnormally large space motions'.

Stetson found a radial velocity dispersion of 57 km/s, in good agreement with the value of 63 km/s derived from Greenstein and Sargent (1974) and Rodgers' (1971) result of 66 km/s. He listed an index from which $v \sin i$ rotational velocities may be derived. The rotational velocities for some of the stars are indeed high, typical of young A stars. A few that have low indices and that were also studied in this thesis were found (Chapter 4) to be HB stars.

Pier (1983) studied halo field AB stars selected from a survey for metal-poor stars. He calculated CaII K line equivalent widths from a variety of synthetic spectra and found excellent agreement with the Population I calibration used by Rodgers (1971). Some of Rodgers' SGP A stars were (inadvertently) included in his analysis. He found generally good agreement with Rodgers' W(K) and $H\delta$ values, but disagreed with some of the radial velocities. However, for the eight Population I stars (by my classification, see Chapter 3) in common to both studies the velocity dispersion using Rodger's radial velocities is 55.6 km/s, and using Pier's radial velocities is 56.4 km/s, certainly not a significant difference (see Table 2.1, Chapter 2).

Pier stated, while agreeing with Rodgers' findings in general, that the metal-rich A stars are 'members of an old disk population with the scale height found by Gilmore and Reid (1983)' for their proposed thick disk. The reasons for his identification of a young group of stars as members of an evolved population were not discussed.

Philip (1984) presented *uvby* photometry of a large sample of distant high latitude blue horizontal branch and main sequence stars, and stated that 'a current problem is to explain the presence of normal Population I stars at distances of up to 3 kpc from the plane'.

Hartkopf and Yoss (1982) reported a kinematic and abundance survey of G and K giants at the galactic poles. They found support for Searle and Zinn's (1978) theory that the halo formed by the merging of a number of star-forming regions. Out of 83 giants at distances of from one to five kpc from the plane, 26 were found to be metal-rich, using a criterion equivalent to Rodgers' range of -0.5 to 0.0 dex. The sources of the Hartkopf and Yoss data were many, of different limiting magnitudes and areas surveyed, with incomplete radial velocity data. However, using stars from one of the surveys complete to 13.5 magnitudes (Bok areas I to III), I calculated an approximate scale height of 1000 to 1500 pc. Hartkopf and Yoss suggested that their metal-rich giants may be recent descendants of the high-velocity A stars.

Rose (1985) found a class of moderately metal-poor (one tenth solar to solar) red horizontal branch stars in the disk, similar to those found in metal-rich globular clusters. They had a scale height between 500 and 1000 pc, and Rose suggested that they were part of the thick disk (Gilmore and Reid, 1983). The relationship, if any, of the SGP A stars to these more evolved stars of somewhat similar metallicity and kinematics, will be examined in Chapter 5.

1.7 Some Possible Disk Sources.

The question arises as to whether it is necessary to consider the A stars as remnants of a discrete, somewhat cataclysmic event in the history of the Galaxy, or whether they could arise from normal disk evolutionary processes and merely have been misidentified. Two types of unusual star are possibilities for the latter case, the *c*-type RR Lyraes and the blue stragglers.

The metal rich RR Lyraes are less likely to be involved for several reasons. Firstly, only around one-third of the whole A star sample falls into the colour range of the instability strip. Even if all of the stars in that range were variables, the problem would still remain of explaining the other two-thirds of the sample. Secondly, some of the stars in that colour range have been photometrically observed for variability, and have not shown any variation. Thirdly, even if all the high velocity A stars were derived from the population of high mass-loss stars that include HB metal-rich RR Lyraes, they would have radial velocities appropriate to the old disk, and would not show the large dispersion found by Rodgers and confirmed by Pier (1983). (Although, as discussed below, if the radial velocities were found to be incorrect, this point would not hold.)

A stronger possibility is that the stars could be old disk blue stragglers. As described, the are indistinguishable from main sequence A stars in terms of gravity, and they have range of metallicities, -0.5 to 0.0 dex, shown by the

SGP A stars. The ages derived for the A stars would then be wrong (and no longer a constraint), as they assume a normal main sequence lifetime, not an extended one. Blue stragglers would also have kinematics apropriate to the old disk. (Blue stragglers old enough to have halo kinematics would be much more metal poor than old disk ones.)

If either or both of the values of abundances or kinematics were shown to be in error, then identification of the A stars as blue stragglers would become a possibility. A large downward revision of the radial velocities would mean that both the abundances and radial velocities were then consistent with old disk BS stars; or if the abundances were somewhat reduced, then both the radial velocities and abundances would be consistent with thick disk BS stars. Whatever the combination, the A stars would then fit into a recognised population, and cease to be anomalous.

An important test of the blue straggler hypothesis is the measurement of rotational velocities. As discussed in greater detail in Chapter 2, a low value of $v \sin i$ does not necessarily exclude an A star from the main sequence, but a high $v \sin i$ is statistically inconsistent with membership of a blue straggler population, and is a strong indicator that the star is truly young.

In this thesis, abundances and radial velocities have been measured from new and higher resolution data, and $v \sin i$ value have been found for a sample of the stars. These results are presented in Chapters 2 and 3, and at those points the blue straggler hypothesis will be discussed further.

The above hypotheses demand that the A stars have been misidentified, and that one or more of the parameters found by RHS (and other studies) are incorrect. If there are indeed large errors in the parameters of the A stars, it might even be possible that they are simply low-gravity horizontal branch stars.

However, if the parameters are in fact correct, then an alternative to the suggestion of RHS (that the A stars were formed as the result of a single event like a satellite galaxy accretion) is that they are instead the results of rare but continuous events in the galactic disk, that is, they could simply be the non-Gaussian high velocity tail of the disk distribution (Stetson, 1983). Among such events could be the formation of stars from the compression of gas and dust at the fast-moving outer edges of supernova bubbles (Herbst and Assousa, 1977). Stars created out of high velocity material that had been accelerated in the Z direction might appear as young high-latitude stars.

Another possibility is the Galactic fountain model, which proposes that hot gas is constantly being thrown up into the halo by supernova explosions where it condenses and falls back into the plane, presumably creating stars when it collides with disk gas (Bregman, 1980). High velocity clouds of HI are observed approaching the plane (see review by Van Woerden, Schwartz and Hulsbosch, 1985), although their distances, densities, sizes and metallicities are unknown.

The mechanism discussed by Gies and Bolton (1986), of ejection of high velocity OB stars from binary interactions in young clusters, might be found to occasionally accelerate lower mass A stars. Another suggestion (Ipser and Semenzato, 1985) is that encounters with proposed black-hole remnants of 'hypothetical Population III pregalactic supermassive stars' may accelerate normal disk stars into the halo.

However, all of these possibilities have two requirements: that the stars be formed stochastically, ie. randomly over time, as opposed to RHS's suggestion that they should be coeval; and that they be formed of normally enriched matter from the disk, as opposed to the low abundance range found by RHS. In this thesis the A star ages, metallicities, and radial velocities will be re-examined, and these hypotheses will be discussed in the light of more accurate measurements (Chapter 5). Table 1.1 summarises the parameters of the A stars from RHS, and the predicted values from other theories.

TABLE 1.1

Observed parameters of high-velocity A stars, and those predicted by theories of their origin.

	RHS (observed)	Disk (any accelerating source)	Old disk blue stragglers	Thick disk blue stragglers	RRc Lyrae-type stars	Horizontal Branch
Average gravity (dex)	4.1	4.1	3.9	3.9	3.3	3.3
Ages (yrs)	coeval –	stochastic $\leq 10^9$	stochastic –	stochastic –	stochastic –	stochastic $\sim 10^{10}$
Abundances (dex)	-0.5 – 0.0	-0.1 – 0.1	-0.5 – 0.0	-1.0 – -0.4	-0.5 – 0.0	$\leq$ -1.0
W dispersion (km/s)	66	?	30	40–60	30	60–120
$v \sin i$ (km/s)	–	130	<70	<70	<70	<70
Scale height (pc)	700	?	350	1500	350	2000–3000
Status	Pop I	Pop I	evolved Pop I	Intermediate	evolved Pop I	Pop II

1.8 Questions To Be Addressed.

Assuming that the previously found parameters of the high velocity A stars approach reliability, then the most interesting aspect of their study is simply that they are anomalous. It is to be hoped that this introduction has indicated how truly unusual they may be as a population.

From *kinematical* criteria alone the stars should be more than 10 billion years old and of very low metallicity. From *abundance* criteria they should be from five to ten billion years old and show a substantially smaller velocity dispersion. From *evolutionary* criteria they should be less than one billion years old and have a negligible velocity dispersion.

Norris, Bessell and Pickles (1985) define that 'a stellar population is characterised by the trivariate function describing the distribution of its component stars with respect to age, composition, and kinematics'. Yet for the A stars, their age-composition-kinematics relation is highly inconsistent with respect to accepted theories of Galactic and stellar evolution.

If the parameters of the A stars are correct, and if they cannot be accounted for within the standard evolutionary hypotheses, they indicate either that the hypotheses may be incomplete, or that the origin of the stars is different in some way to normal galactic stellar formation mechanisms. When enough is known about the A stars, thories concerning their origin may become testable. At this point, arguments for or against the evidence of a galactic merger are premature.

What appears to be most useful at this stage, and what has been attempted in this thesis, is to clarify their properties, to determine if errors have substantially affected measurements of their ages, abundances or kinematics, to identify possible relationships with other stellar groups, and to consider some of the implications that may flow from this information.

Among questions to be addressed are:

1) Are the A stars really young?

2) Are their abundances unusual?

3) Do they have high radial velocities?

4) What are their *v sin i* velocities?

5) Do they rotate with the disk?

6) What is their accurate scale height?

7) Were they formed uniquely or continuously?

8) What is their relationship to other stellar populations?

1.9 Structure of the Thesis.

This thesis studies the A stars in two areas, at the SGP (Chapters 2 and 3) and in the solar neighbourhood (Chapter 4).

Chapter 2: SGP Observations.

2.1 Introduction.

2.2 The Catalogue: the incompleteness of previous studies is examined. A catalogue of all the blue stars to a limiting magnitude and area has been partially completed and is described.

2.3 Enlarging the sample: possibilities of finding additional members of the high velocity population, and some selection effects involved, are discussed.

2.4 Strömgren photometric observations are described.

2.5 Medium resolution spectra: their acquisition and reduction is discussed, as are the derived radial velocities, hydrogen line widths and CaII K line measurements.

2.6 High resolution spectra: a large sample of *v sin i* values from a catalogue were used to define a normal range of values for main sequence A stars; eight SGP stars for *v sin i* measurements were acquired, and the observed measurements were compared to the main sequence rotational velocity distribution.

2.7 Summary.

Chapter 3: SGP results.

3.1 Introduction.

3.2 The derivation of stellar atmospheric quantities such as surface gravity and effective temperature are derived from comparison with Kurucz (1979) models.

3.3 Abundances are derived relative to solar, for appropriate gravities and temperatures.

3.4 Classification and Distances: Population I and II stars are identified. Masses are obtained from gravity-temperature mass tracks appropriate to the stellar abundances and classifications. Absolute visual magnitudes and distances are derived.

3.5 Results: the Population I high velocity group is identified and compared with previous findings.

3.6 Kinematics: A velocity dispersion and scale height are discussed.

3.7 Ages: Isochrones appropriate to abundances are used to find the ages of the stars.

3.8 Comparison and Discussion: hypotheses proposed in Chapter 1 are discussed.

3.9 Summary.

Chapter 4: Yale Stars Observations.

4.1 Introduction.

4.2 Selection of the sample: The declination band $-40°$ to $-51°$ from the Yale Proper Motion Catalogue was used in a search for solar neighbourhood high velocity A stars. The selection procedure is described.

4.3 Observations: photometry and spectra are obtained for a sample of possible young high velocity A stars, and are reduced as in Chapter 2. High dispersion spectra for *v sin i* measurements are discussed.

4.4 Gravities, Temperatures, Abundances, Distances and Ages: surface gravities and effective temperatures are found from Kurucz (1979) models. Masses are found from gravity-temperature mass tracks, abundances relative to solar are found, and Population I or II stars are identified. Absolute visual magnitudes, distances and ages are derived.

4.5 *UVW* Velocities: from proper motions, distances and radial velocities, the velocities in three dimensions (U, V, W), and the X, Y, Z distances, are found.

4.6 Selection effects are discussed.

4.7 The Solar neighbourhood: Other groups of stars in the Solar neighbourhood with motions similar to the Yale stars are discussed.

4.8 Some other unusual stars: Four other high-velocity stars were studied, and their data is discussed.

4.9 Summary.

Chapter 5: Discussion.

5.1 Work on other stellar groups and their relationships to the A stars are discussed.

5.2 Consequences of a merger: Predictions of other relevant work are considered.

5.3 Gould's Belt: The temporal and spatial structure of this unusual local feature is examined in relation to suggestions presented in Section 5.2.

5.4 Summary.

Chapter 2

SGP Observations

2.1 Introduction.

There are three main areas of discussion in this chapter. Firstly the incompleteness of previous SGP surveys is described and it is discussed why it seemed possible to augment the original sample of A stars. Selection effects that had biased interpretations of some of the characteristics of the high velocity A stars also made it desirable to obtain a larger sample of the A stars to a limiting volume, which had not previously been attempted.

Secondly, the collection and reduction of photometry and spectra is described. Spectral indices such as CaII K line equivalent widths, the hydrogen line widths and radial velocities have been measured and compared to other studies. Interpretation and usage of these indices to derive stellar atmospheric characteristics has not been attempted in this chapter, but will be dealt with in detail in Chapter 3.

Finally, stellar rotational velocities are discussed. A catalogue of such velocities was analysed to obtain a typical range of values for main sequence A stars, and Am and Ap stars. High resolution spectra were obtained for some of the SGP A stars and the procedure for the derivation of their *v sin i* velocities was described. The results of this analysis are presented, compared to typical values, and discussed in relation to the blue straggler hypothesis for the origin of the high velocity A stars.

2.2 The Catalogue.

The list of previously uncatalogued blue stars to about 14th magnitude at the SGP (List II of Philip and Sanduleak (1968, hereafter PS) which was used by Rodgers (1971), has been found to be incomplete at all magnitudes.

Slettebak and Brundage (1971) (hereafter SB) surveyed objective prism plates of 840 square degrees around the SGP to spectral type F0 (with a limiting magnitude of about 14.5) and found many stars that were overlooked in the PS survey.

PS stated that they had searched for spectral types to A7, but in a comparison with other classifications, SB showed that PS had in fact systematically classified F0 stars as A7, so their spectral type limit was actually the same as SB. In the area covered by both surveys, from 6th to 14th magnitude, PS overlooked 25 percent of all the stars that were identified by SB, and 32 percent of the total number of stars from all sources (fig. 2.1). SB missed 8 percent of the stars listed by PS and 15 percent of the total. Some, though not all, of the stars missed by both surveys were late A and F0 types.

In order to have a complete list of early-type stars at the SGP, an area of 218 square degrees that was covered by both PS and SB was used as the basis of a blue-star catalogue, and runs from $-20°$ to $-35°$ in declination, and from 0^h16^m to 1^h22^m in R.A.. The total number of stars now in the catalogue is 305, to 15th visual magnitude and to $B-V$ of 0.35. They were initially taken from PS, SB, Chavira (1958), and Philip and Stock (1972) (hereafter SP), who surveyed a strip 5° wide centred on the SGP, which covered one-third of the catalogue area. Philip and Stock found a further nine stars in the strip that were not found by either PS or SB, suggesting that at least 18 more stars could be found to the SB limit of 14.5 magnitude. Between 14th and 15th magnitude the catalogue is about 75% complete. A few other stars were found from photometric sources, principally Bok and Basinski (1964), Eriksson (1978) and Ratnatunga (1983).

The catalogue should be complete from the brightest nearby early-type stars to almost 14th magnitude stars in the central strip, and about 90% complete to that limit in the other two regions. As it became clear during the course of this thesis that it would not be possible to carry out observations on all the stars in the catalogue, an area within it of 100 square degrees near SA141 was selected for intensive study, hereafter inelegantly termed the 'box'. The box area had been covered by the three objective prism surveys mentioned above, many of its stars had also been photometrically observed, and it was very nearly complete to 14th magnitude and to spectral type F0 (fig. 2.2). Its coordinates are from $-23°40'$ to $-33°40'$ in declination, and from 0^h36^m to 1^h22^m in R.A..

Photometry, both broad-band and Strömgren intermediate-band, for the catalogue stars has been drawn from Bok and Basinski (1964), Eriksson (1978), Ratnatunga (1983, for stars fainter than 13th magnitude only), Philip (1974), Eggen (1985, private communication), Graham and Slettebak (1973), McFadzean, Hilldich and Hill (1983), Eggen and Bessell (1978), Eggen (in Rodgers, 1971), Drilling (1977), Albrecht and Maitzen (1980), Westerlund (1963), Iriarte (1970), Andrews and Thackeray (1973), Penston and Wing (1972), Pier (1983), Cousins and Stoy (1963), Wegner (1980), Hanes and Grieve (1982), Philip (1986, private communication), and this thesis. In addition to photometry, radial velocities from Abt and Biggs (1972), and radial velocities and CaII K line measurements from Rodgers (1971), Pier (1983) and this thesis have also been compiled.

Appendix I, Table 1 is a list of all the stars in the catalogue, their various nomenclature, 1950 coordinates, spectral types from other sources (some very approximate), their apparent visual magnitudes and any broad-band (UBV) photometry from the literature. Some of the coordinates are less accurate than others. This reflects their source. Most of these fainter stars have finding charts in PS, SB and Chavira (1958). (Other appendices that contain spectral, photometric and derived data will be later described.)

FIG. 2.1– The sources of stars in the SGP blue star catalogue.

PS: Philip and Sanduleak (1968).

SB: Additional stars found by Slettebak and Brundage (1971) in the same area.

CoD: Cordoba Durchmusterung, mainly late A and F0 stars.

SP: Philip and Stock (1972), additional stars in one third of the area, not found by either PS or SB.

Ch: Chavira (1958).

Phot: Photometric studies, mostly late A and F0, from Bok and Basinski (1964), Eriksson (1978) and Ratnatunga (1983).

Other: Pier (1983), Drilling (1977), CSI list (Ochsenbein, Bischoff, and Egret, 1981).

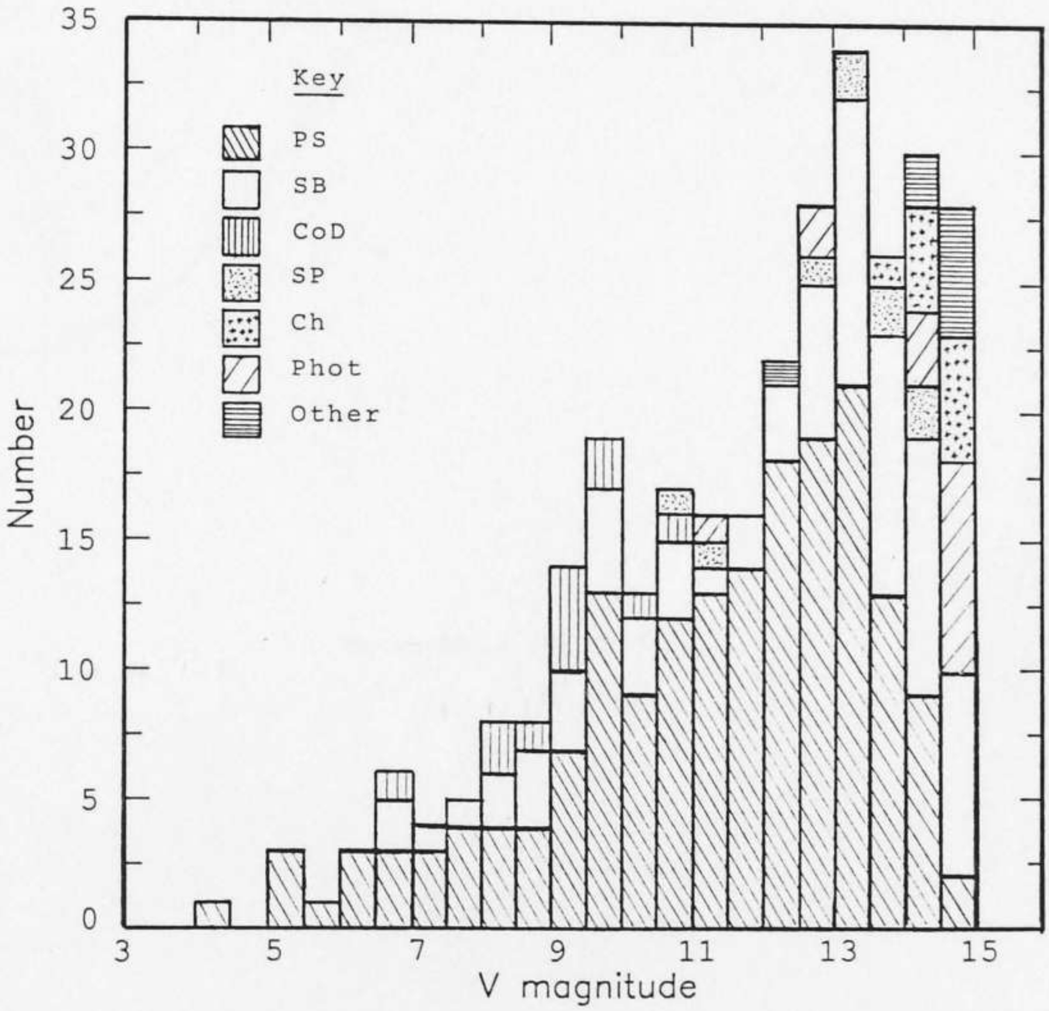
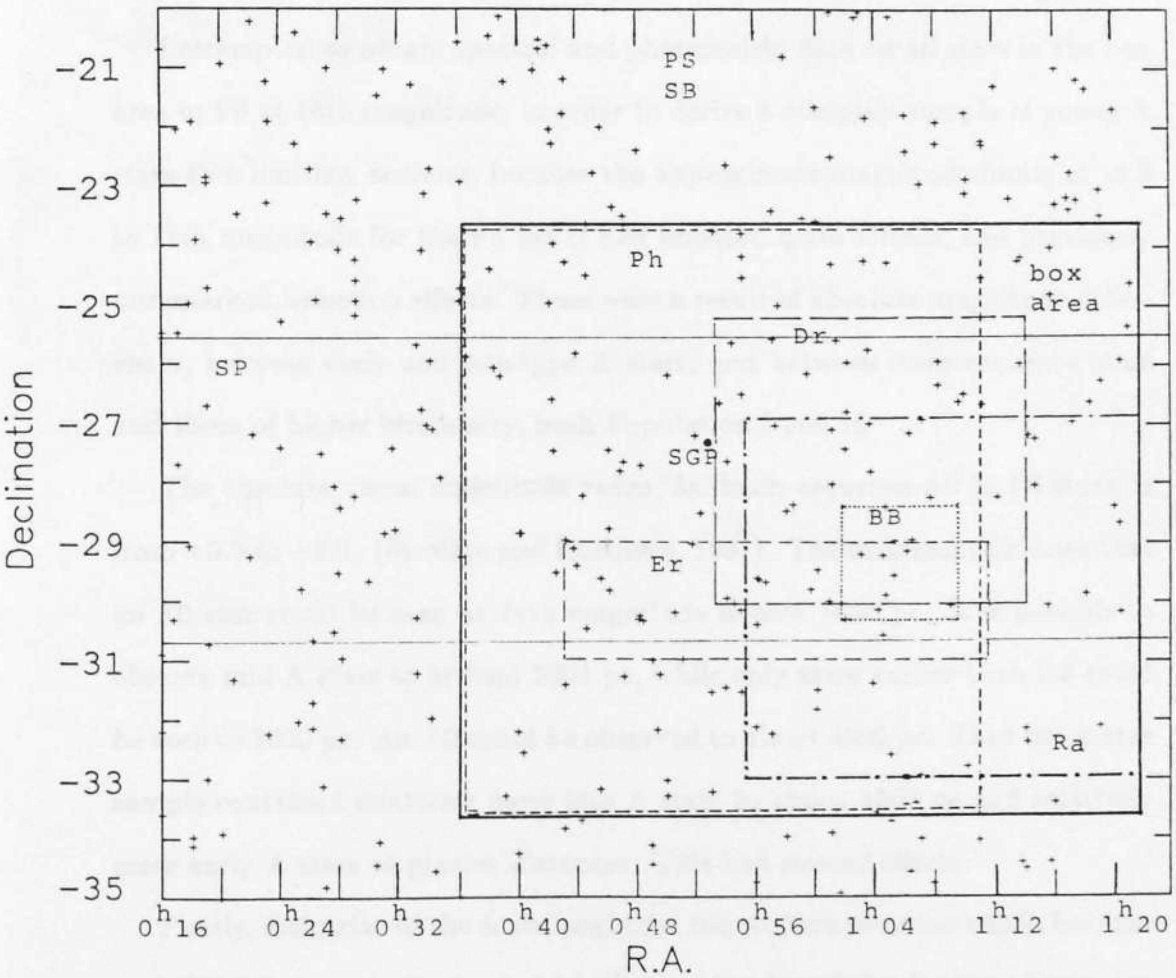

Key
PS
SB
CoD
SP
Ch
Phot
Other
Number
V magnitude
0
5
10
15
20
25
30
35
3
5
7
9
11
13
15

FIG 2.2– Positions of stars in the total SGP catalogue area (218 square degrees) and box area (100 square degrees). PS, SB and SP areas surveyed by objective prism. Philip (1974) (Ph) used Strömgren photometry, Drilling (1977) (Dr), Eriksson (1978) (Er), Bok and Basinski (1964) (BB) and Ratnatunga (1983) (Ra) used *UBV* or *BV* photometry.


PS
SB
Ph
box
area
Dr
SP
SGP
BB
Er
Ra
Declination
-21
-23
-25
-27
-29
-31
-33
-35
R.A.
0h16
0h24
0h32
0h40
0h48
0h56
1h04
1h12
1h20

2.3 Enlarging the Sample.

It seemed probable that more metal-rich A stars were present at the SGP than had been observed, not only because the PS list II was incomplete, but because PS list I, of stars with BD and CD numbers, actually contained stars of 12th and even 13th magnitude from the CD survey, which went much deeper (in parts) than the BD limit of 10th to 11th magnitudes. PSII, the source list of the metal-rich A stars, started at about 12th magnitude, but reported only 60 percent of the actual number of A stars between 12.5 and 14th magnitude.

I attempted to obtain spectral and photometric data on all stars in the box area to F0 at 14th magnitude, in order to derive a complete sample of young A stars to a limiting *distance*, because the approximate magnitude limits of 13.5 to 14th magnitude for the PS list II had imposed quite serious, and previously unremarked, selection effects. These were a result of absolute magnitude differences, between early and late-type A stars, and between main sequence stars and those of higher luminosity, both Population I and II.

The absolute visual magnitude range, for main sequence A0 to F0 stars, is from +0.7 to +2.9. (Straižys and Kuriliene, 1981). The maximum distance that an F0 star could be seen at 14th magnitude is only 1660 pc. It is possible to observe mid A stars to around 2000 pc, while only stars earlier than A3 could be seen to 3000 pc. An A0 could be observed to about 4500 pc. Thus the A star sample contained relatively more late A stars to about 1500 pc and relatively more early A stars at greater distances. This had several effects.

Firstly, estimates of the scale height for the A stars were too small, because scale heights are usually derived by plotting the log of the density of stars (at particular Z heights) against the run of Z. For an exponential distribution, the points will fall on a straight line. The density at a particular Z height is defined by

$$D_z = D_0 e^{-Z/\beta} \tag{2.1}$$

where D_0 is the density at the plane. The scale height β is found from

$$\beta = \frac{Z}{2.3(D_0 - D_z)} \tag{2.2}$$

So a scale height derived in this way from the A star sample will be underestimated because too few stars in distant bins will be included, relative to nearby stars. A line through the plotted points will have too steep a slope. This may explain why the scale height of 700 pc found by RHS is not consistent with their velocity dispersion of 66 km/s, which would normally indicate a scale height of more than 1000 pc (see section 1.3). Perry's (1969) study may also have shown this effect. His velocity dispersion of 49 km/s would normally be consistent with a larger scale height than his value of 450 pc. (If the A stars are not well-mixed, however, there is no reason why their velocity dispersion and distribution would be consistent with older, well-mixed solar neighbourhood stars.)

The second selection effect is that the most distant observed A stars, the early-type ones, are also those that are most vulnerable to classification errors, both from the proximity of the horizontal branch near A0, and from the small size of the CaII K line, which may be overestimated if interstellar calcium is present on the line of sight.

This latter possibility is not serious for the high velocity A stars, for two reasons. One is that disk calcium, relatively at rest, will be offset from the stellar calcium line in high radial velocity stars. At lower radial velocities, the K line will appear asymmetric if interstellar calcium is a substantial component of the line. (To counter that, in this study, K lines were measured symmetrically, relative to the side of the line that was not displaced.) The other reason is that the effect is very small at the SGP. Pier (1983) measured the eqivalent widths of interstellar calcium lines and from his data for stars in the SGP area, the mean amount, when large enough to be measured, was only 0.17Å.

However, because the earliest A stars are those that are at the greatest distances and also those that are most open to disagreement as to their evolutionary status, a spurious argument has arisen (Pier, 1983), (Philip, 1986, private communication), that since *reliably* Population I stars (mid to late A) are seen only to 2 or 3 kpc, then they simply do not exist beyond 3 kpc.

While it was the strikingly large distances (over 4 kpc) of the earliest-type stars from RHS that emphasised how unusual the group was as a whole, the characteristics of the sample were in no way defined by those most distant stars. It was the less startling but larger sample of main sequence mid to late A stars, seen from 1000 to 2000 pc, that were in fact the most significant group.

The velocity dispersion and scale height defined by those stars imply from simple kinematic principles that others of the same sort (whatever their evolutionary status) must exist at very great distances from the plane. That they have not been observed in large numbers beyond 2 or 3 kpc is a simple function of the magnitude limit for stars observed to the present time. Future studies would have to go to at least 15th or 16th magnitude before significant numbers of the whole range of A star spectral types would be seen to greater distances.

It is interesting to note that the large sample of main sequence OB stars found at both Galactic Poles by Greenstein and Sargent (1974), with very similar properties to the A stars, are observed to distances of at least seven kpc; while their radial velocities (again like those of the A stars) indicate that they will travel even further than that in their orbits from the plane.

A further selection effect is that the numbers of horizontal branch stars relative to Population I stars will be overestimated. For instance, Philip (1974) discussed the relative numbers of both types of stars at the SGP and at the NGP without taking into consideration the probability that the numbers of HB stars, intrinsically more luminous, will be drawn from a larger volume than lower luminosity stars if a magnitude limit is the selection criterion.

All these difficulties suggested that it would be most useful to acquire a volume-limited sample of early-type stars. Due to the incompleteness of the A star surveys discussed in section 2.2, many stars at the SGP had never been observed, and to include as many of them as possible would enhance their statistical reliability. It was decided to concentrate on the box area as it had the most complete photometric coverage from other sources.

To derive accurate gravities and temperatures, both Strömgren *uvby* photometry and spectral indices were needed. I obtained further photometry (section 2.4) for a large proportion of the stars without previous data from 9th to 14th magnitude in the box area, and spectra (section 2.5) for all but two of the stars between the same limits, apart from some such as sdO, sdB and sdF stars, whose classification was immediately obvious from *uvby* photometry. An interesting result of this more thorough search was the identification of a further seven apparently Population I stars at Z distances greater than 1000pc in the box area alone (Chapter 3).

In addition, many of the RHS young A stars were re-observed at higher resolution than had previously been obtained, some photometry for them was acquired by me, and some was very kindly supplied by Philip (1986) prior to publication. High resolution spectra (section 2.6) were obtained for eight of the stars to measure their $v \sin i$ values. (At a later date, these spectra will be also be useful for more detailed abundance studies.)

2.4 Photometry.

Strömgren *uvby* measurements are particularly suitable for measuring some of the characteristics of A stars. Observations are made with four intermediate-band filters, of from 180 to 300Å wide and centred at 3500Å (u), 4110Å (v), 4670Å (b), and 5470Å (y). The y magnitude is almost identical to a broad-band V magnitude. The colour index $b - y$ is equivalent to $0.74(B - V)$ in the A star range, but relative to each other those indices vary slightly with gravity. Spectral class A0 is around $b - y$ of -0.01; and at F0, $b - y$ of 0.2 is equivalent to $B - V$ of 0.3.

The index m_1 measures metal line blanketing in F stars, and is helpful for identifying Am stars and F subdwarfs. As described in the introduction, its usefulness otherwise in the A star range is limited. It is found from

$$m_1 = (v - b) - (b - y) \tag{2.3}$$

The index c_1 is most useful as a gravity indicator for A stars. It is sensitive for A stars up to as early as A0, but then the gravity-colour loci collapse for stars hotter than that. It is good for identification of sdO and sdB stars, and white dwarfs. As also described in the introduction, usage of it alone as an MS/HB discriminator may lead to misidentifications. It is defined as

$$c_1 = (u - v) - (v - b) \tag{2.4}$$

There are also narrow-band β filters which measure the strength of the $H\beta$ line. The β index is useful for de-reddening the other indices. However, these filters were not used in this study, because they are difficult to utilise with faint stars on smaller telescopes, and in any case the gravity-temperature determinations used in Chapter 3 (section 3.1) are effective for reddening estimates.

Major calibrations of the *uvby* system were reported by Strömgren (1966), and Crawford (1975, 1977, 1979). Philip, Miller and Relyea (1976) describe methods of analysis of the indices. Kurucz (1979) lists values of $b - y$, m_1 and c_1 for stellar models with a range of effective temperatures, gravities and metallicities.

On the nights of the 4th and 6th October 1985, *uvby* observations were obtained for 25 SGP stars using the Two Channel Chopper on the 40" (1.0m) telescope at Siding Spring. The TCC simultaneously uses two galium arsenide detectors and two sets of filters. (One set was kindly supplied by Dr B. Shobbrook, and both sets had been manufactured in the same batch.) Standard stars from the list of Grønbech and Olsen (1976) were observed throughout each night. Acquisition and reduction programs used were written by Dr M. S. Bessell and S. Russell. Results from both detectors were found to be consistent.

Two stars observed had also been observed by Eggen (1985, private communication) and the agreement with his values was very good. However, since it was possible only to do one series of observations of each star (due to weather) there may be random errors in the data, although the colours and gravities derived from the data are generally highly consistent with the appearance of the relevant spectra.

Very recently, data from Philip (1986, private communication) became available for twelve of the stars I had observed. The differences between our measurements, in the sense of my data − Philip's data were:

$\Delta V = -0.014 \pm 0.054$

$\Delta(b-y) = 0.008 \pm 0.011$

$\Delta m_1 = -0.015 \pm 0.025$

$\Delta c_1 = -0.001 \pm 0.047$

Although systematic differences are small, there is scatter in the comparison, so I have used Philip's values where possible as they were from the mean of several observations. The $b-y$, m_1 and c_1 indices are listed in *Appendix I, Table 2* together with values from other sources.

2.5 Medium Resolution Spectra.

a) Acquisition and Reduction.

These were obtained on the Mt Stromlo 74" (1.9m) telescope. One series of observations was at coudé focus, using the 'A' grating of 300 lines/mm in first order, yielding around 40Å/mm at the detector, with 1.2Å resolution. The spectral range varied a little, but all spectra covered from 3820Å to 4170Å, (to around 4300Å in many cases).

The detector was the Mt Stromlo two-dimensional Blue Photon Counting Array (BPCA), an intensified CCD of great sensitivity at blue wavelengths. Spectra obtained had total peak counts of around 1000 for brighter stars (with Poisson statistical noise of 3%) and were obtained in short exposure times (10-20 minutes). Fainter stars had maximum counts of around 700 (4% noise) and the faintest had 300-400 counts (5-6% noise) and took one to several hours to obtain.

An iron-argon lamp was observed before and after each exposure. Working at coudé meant that the detector was highly stable, and any drift (measured by relative arc shifts) over a whole night was very small. For long exposures, arcs were taken around every 3000 seconds and the separate spectra of a single star were added after reduction to a wavelength scale.

The other series of observations were also done on the Mt Stromlo 74" telescope with the BPCA detector at Cassegrain focus. A 600 line/mm grating (blazed at one micron in first order) was used in second order. A BG38 glass filter was used to remove first order wavelengths, which would not be strong in any case where A stars were concerned. The Cassegrain spectrograph was less stable than the coudé. Spectra were exposed for 1000 seconds only at a time, and Fe-Ar lamps were observed before and after each exposure. Again, the several spectra for a single star were added after reduction to an accurate wavelength scale. This format yielded around 45Å/mm of detector, with 1.4Å resolution.

Observations of SGP stars were carried out on the nights of 14th and 15th August 1984, 8th to 11th October 1984, 23rd to 28th July 1985, and 8th and

9th September 1985.

The spectra were reduced using the Mt Stromlo 'PANDORA' series of interactive programs, which operate on files in SAD (Standard Astronomical Data) format, utilising 'headers' with details of coordinates, sidereal times, dates, star names, comments and the parameters for plotting data in various formats.

The spectra were initially divided through by a flat field (taken separately for each observing run) with at least 3000 to 6000 counts per pixel of the detector array. A cross-section of the spectrum was then plotted to identify the rows of the array on which the spectrum and the sky had been recorded. The average of the sky rows was subtracted from all the spectral rows.

The spectra were filtered using a 3-point Hanning mean to remove up-down noise superimposed on the spectra by the detector electronic system. Arc spectra were cross-correlated to check if any channel shift had occurred while the spectra were being recorded. Any shift was usually negligible for coudé spectra, and equivalent to only a few kilometres per second for Cassegrain spectra. The before and after arcs were summed.

A program was then run that determines the coefficients of quadratic equations used to reduce arc spectra to linear wavelength scales. Misidentified arc lines and blends could be removed interactively for greater accuracy. To check that the wavelength scale was correctly calibrated and consistent, the arcs were 'scrunched' with their appropriate coefficients and cross-correlated. If the coefficients were found to be accurate, the spectra were then scrunched with them. They could be calibrated into wavelength or log wavelength bins.

Spectra in wavelength format were plotted on a large scale and used to measure the $H\delta$ line widths, and radial velocities from the CaII K lines. Small-scale spectra were useful for checking the overall appearance of the hydrogen line profiles for consistency with derived surface gravity values (section 3.1). A 'boxy'-shaped profile indicated a lower gravity, compared to the broadly curved profiles of higher gravity stars.

b) Radial Velocities.

The spectra were also scrunched into log wavelength format, which has the advantage that the wavelength increment is then the same amount over the whole spectrum. Programs by G. Wilson wrote heliocentric velocity corrections to the headers, to be used in a cross-correlation program also by G. Wilson, adapted from one by Dr D. Carter. Several radial velocity standard template stars had been acquired separately for each observing run, and were cross-correlated with program stars to derive the radial velocity shifts.

While the cross-correlation method is usually successful for late-type stars with distinct metal lines, it had difficulties with A stars at the dispersion used (40Å/mm). This is because measurable metal lines are almost absent in early A stars, and are weak in later ones. The high rotational velocities of many main sequence A stars also smear them out to little better than the level of noise in the spectrum.

On the other hand, the strong hydrogen lines give very broad cross-correlation peaks, of 20 to 30 km/s which also lead to random inaccuracies. A range of Fourier wavenumber filters was experimented with (cross-correlating templates of known radial velocity against each other), but it was not possible to increase accuracy to better than 10 to 15 km/s by this method.

However, both high (10Å/mm) and medium resolution spectra had been recorded for 26 of the Yale stars (Chapter 4) and for eight of the SGP stars. Accurate radial velocities were derived from the high resolution spectra by simply measuring the wavelength shifts of the CaII K line and the iron triplet (4045Å, 4063Å, 4071Å) lines (when present), and correcting them for heliocentric velocities.

Usually two high resolution spectra had been obtained at different times, centred at 3933Å and at 4050Å, so that probable radial velocity variable stars were apparent. By comparison with CaII K line shifts from medium resolution spectra of the same stars it was possible to check the accuracy of the latter.

The differences between the high resolution radial velocities and values derived from cross-correlations had a mean of −2.8 km/s and a dispersion about the mean of 11.7 km/s (Fig. 2.3a).

The differences between the high resolution radial velocities and those measured from medium resolution CaII K lines had a mean of +3.1 km/s and a dispersion of 10.0 km/s (Fig 2.3b).

However, if the average values were taken from both medium resolution methods, the differences then from the high resolution values fell to a mean of 0.3 km/s with a dispersion of 8.2 km/s, an improvement over either method used alone (fig. 2.3c).

The mean radial velocities for all SGP stars were derived in this way. A plot of radial velocity values of all stars in common with either Pier (1983) or Rodgers (1971) is shown in Fig. 2.4. The eight Population I stars mentioned in the introduction common to both those studies and this one are listed in Table 2.1, together with the means and velocity dispersions. Note that while there is disagreement between individual values, the dispersion is almost identical from three studies.

As mentioned, my error is about 8 km/s, Pier estimated the standard error in his determinations to be 11 km/s, while Rodger's values, from much lower resolution spectra, were accurate only to around 30 km/s. The differences between my values and those of Pier (Fig. 2.4) are higher in some cases than our quoted errors. Either orbital velocity variations have occurred, or as discussed earlier, at the resolution used both by myself and Pier the cross correlation method (the single technique Pier used) had larger random errors than he estimated. For A stars, it seems that the traditional method of hand measurement may be more accurate than automated techniques, although the mean of both methods seems preferable to either.

If the differences between some of my radial velocities and those of Pier are due to orbital velocity variations, the effect on the radial velocity dispersion is estimated to reduce the dispersions by less than 2 km/s. A discussion of the velocity dispersion to be derived from the whole sample of radial velocities will be left until Chapter 3, after the stars have been classified into Populations I and II. The radial velocities from my spectra and from any other available sources are listed in *Appendix I, Table 2.*

TABLE 2.1

Radial velocities (km/s) of Population I stars common to three studies.

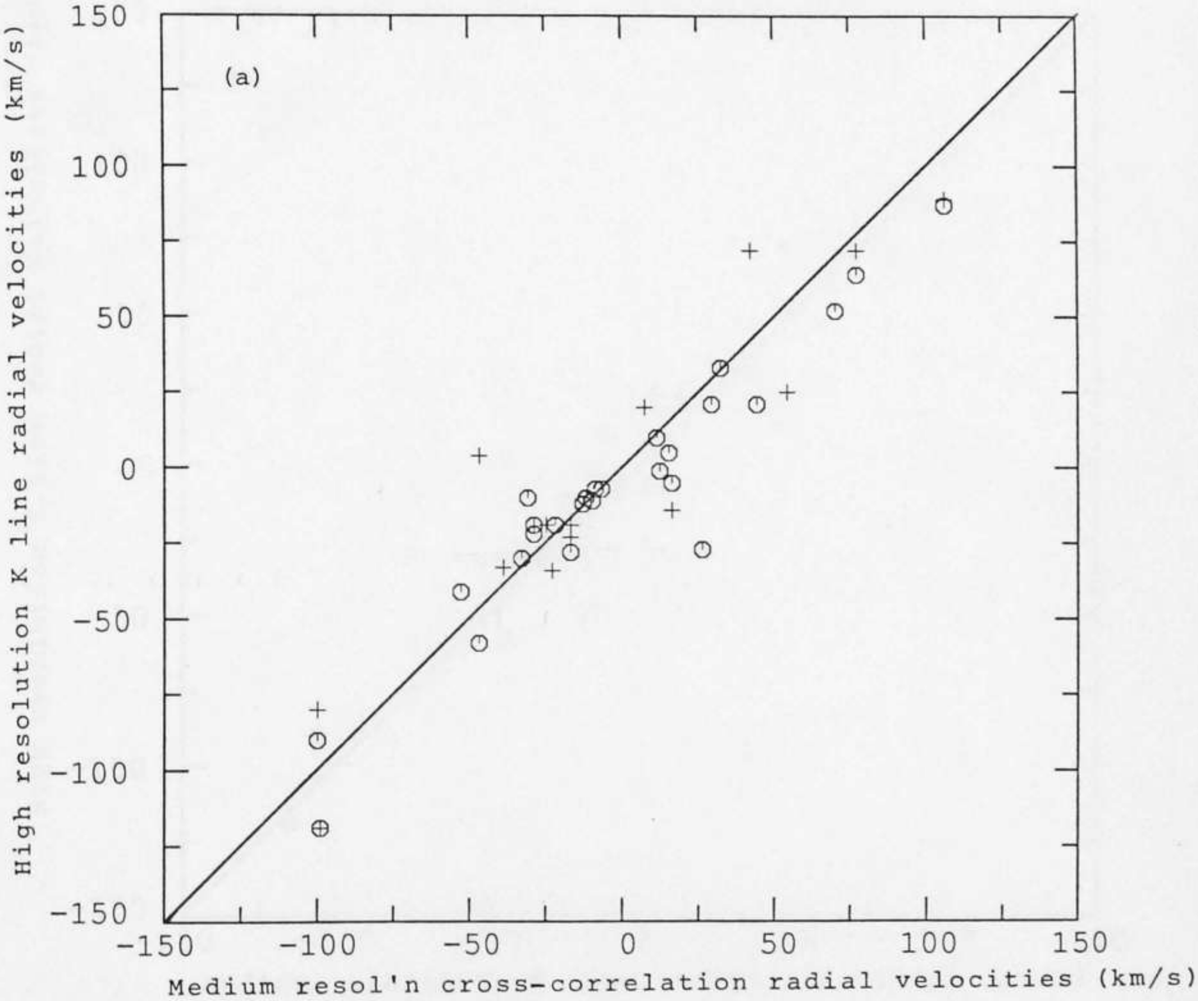
Star	Rodgers	Pier	Lance
PS4II	-34	-94	-55
PS7II	-31	-23	-12
PS10II	105	76	109
PS20II	45	15	57
PS30II	25	65	44
PS32II	-60	-50	-46
PS37II	-35	0	-22
PS39II	-33	-15	-15
mean	-2.3	-3.3	7.5
disp.	55.6	56.4	56.8

FIG. 2.3– Derivation of radial velocities (from SGP and Yale data).

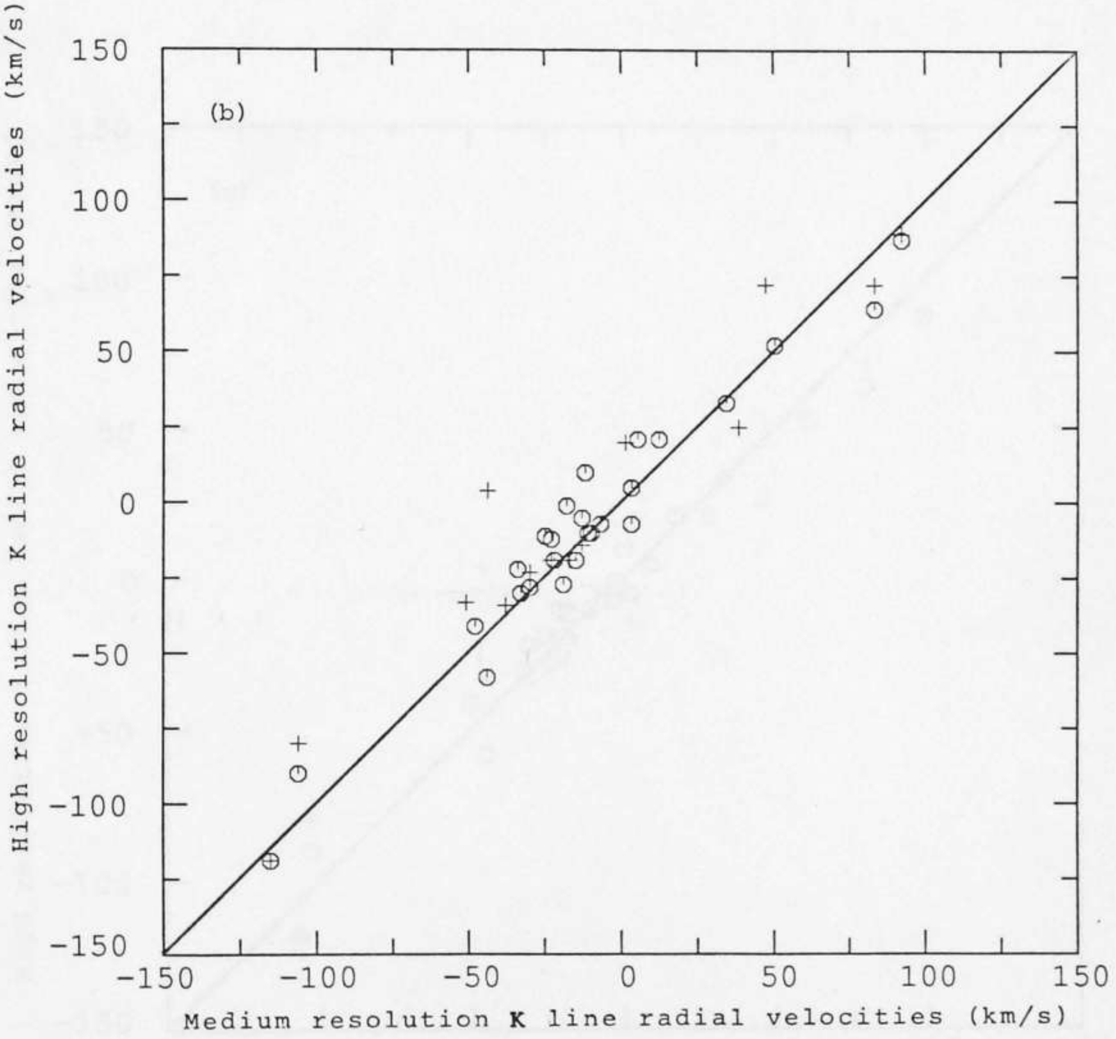
(a) High resolution K line radial velocities against radial velocities from medium resolution cross correlated spectra. Hexagons–my data, crosses–Stetson's high resolution data for some of the same Yale stars (Chapter 4). Dispersion around mean is 11.7 km/s.

(b) Same as (a), except abcissa is medium resolution K line radial velocities. Dispersion is 10.0 km/s.

(c) Same as (a), except abcissa is the mean of both K line and cross correlation methods. Dispersion is 8.2 km/s. Note that mean is more accurate than either method alone.



(a)
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
High resolution K line radial velocities (km/s)
Medium resol'n cross-correlation radial velocities (km/s)


(b)
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
High resolution K line radial velocities (km/s)
Medium resolution K line radial velocities (km/s)

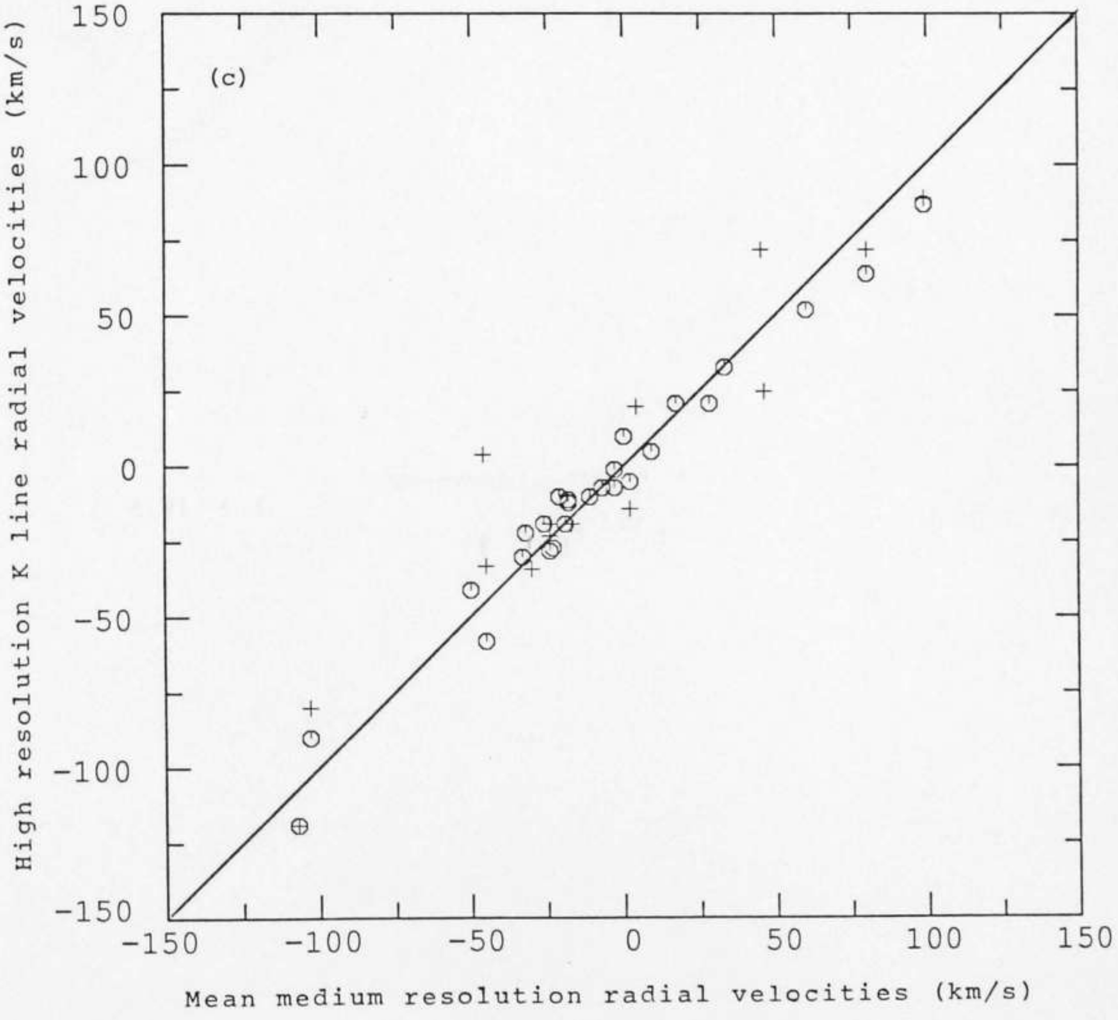
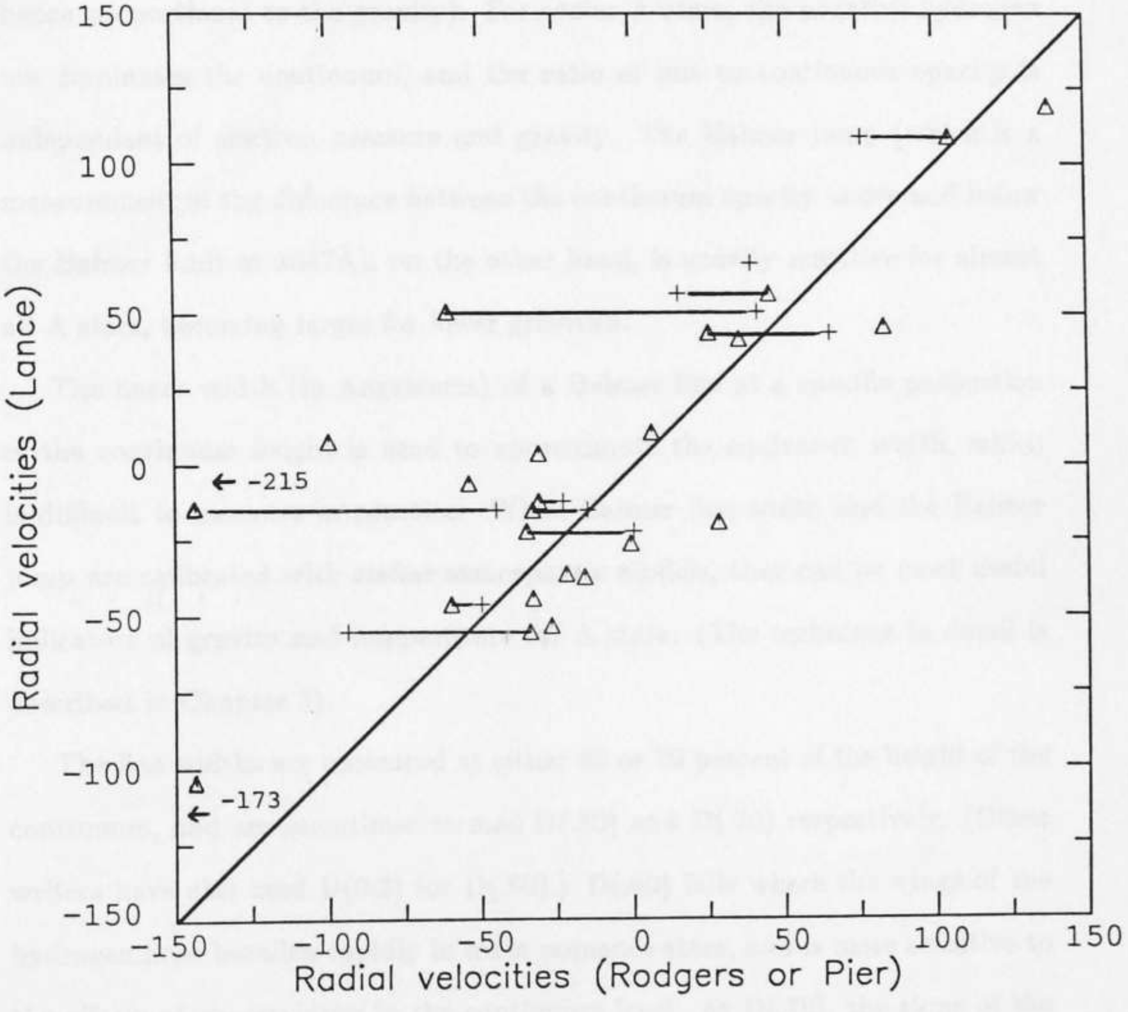

(c)
High resolution K line radial velocities (km/s)
Mean medium resolution radial velocities (km/s)
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150

FIG. 2.4– My derived radial velocities against those found by Pier (crosses) and Rodgers (triangles). Values for the same stars are joined by lines. Note that three of Rodgers values are highly discrepant, presumably due to errors from lower resolution spectra. Otherwise, of ten stars (either Population I or II) common to all three studies, I have better agreement with five of Rodgers' values than Pier's; and for the other five, the reverse holds (although Pier's results have clearly less scatter than those of Rodgers).


Radial velocities (Lance)
Radial velocities (Rodgers or Pier)
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
← -215
← -173

c) **Hydrogen Line Widths.**

The equivalent widths of the Balmer series of hydrogen lines in A stars are a function of temperature for the whole A star range, and are also particularly sensitive to gravity effects for the early A star spectral types, due to Stark broadening of the line wings, and the ratio of line absorbers to continuum opacity for neutral hydrogen atoms (proportional to the electron pressure, hence proportional to the gravity). For cooler A stars, the negative hydrogen ion dominates the continuum, and the ratio of line to continuous opacity is independent of electron pressure and gravity. The Balmer jump (which is a measurement of the difference between the continuum opacity above and below the Balmer limit at 3647Å), on the other hand, is gravity sensitive for almost all A stars, becoming larger for lower gravities.

The linear width (in Angstroms) of a Balmer line at a specific proportion of the continuum height is used to approximate the equivalent width, which is difficult to measure in practice. When Balmer line width and the Balmer jump are calibrated with stellar atmospheric models, they can be most useful indicators of gravity and temperature for A stars. (The technique in detail is described in Chapter 3).

The line widths are measured at either 80 or 70 percent of the height of the continuum, and are sometimes termed D(.80) and D(.70) respectively. (Other writers have also used D(0.2) for D(.80).) D(.80) falls where the wings of the hydrogen lines broaden rapidly in main sequence stars, and is more sensitive to the effects of uncertainties in the continuum level. At D(.70), the slope of the wings are at about 45°, and it is consequently a more accurate index. D(.80) can be derived from D(.70) via Kurucz models, if the gravity and temperature are known.

The D(.70) values were measured by assigning a pseudo-continuum to the peak spectral counts around 80 to 100Å either side of $H\delta$. For spectra with fewer counts (and a higher noise level) the continuum was set below the peaks of the spectrum, as it was found that random events exaggerated their height. For spectra with high count levels, the continuum was usually well indicated.

Lines were drawn through the wings of the profiles (on large-scale plots), using small-scale plots as a guide to the average of the points. The width of the line in angstroms at 70 percent of the continuum was then measured. Pier (1983) used a technique of fitting an asymptotic Stark profile of $(\Delta\lambda)^{-5/2}$ to the hydrogen lines, but pointed out that for cooler A stars that fitting procedure sometimes failed due to the presence of many small absorption lines, resulting in 'an unreliable estimate of the continuum'.

The technique used here, although more tedious in practice, meant that possible errors from relative noise, residual sky counts from the mercury (street-lamp) lines at 4046Å and 4077Å, and small absorption line effects, could be considered individually for each spectrum, and the best possible fit made, taking into account all relevant information. The error in the measured D(.70) values is estimated to be no more than ±1.5Å. The values found, and a few from other sources, are listed in *Appendix I, Table 2.*

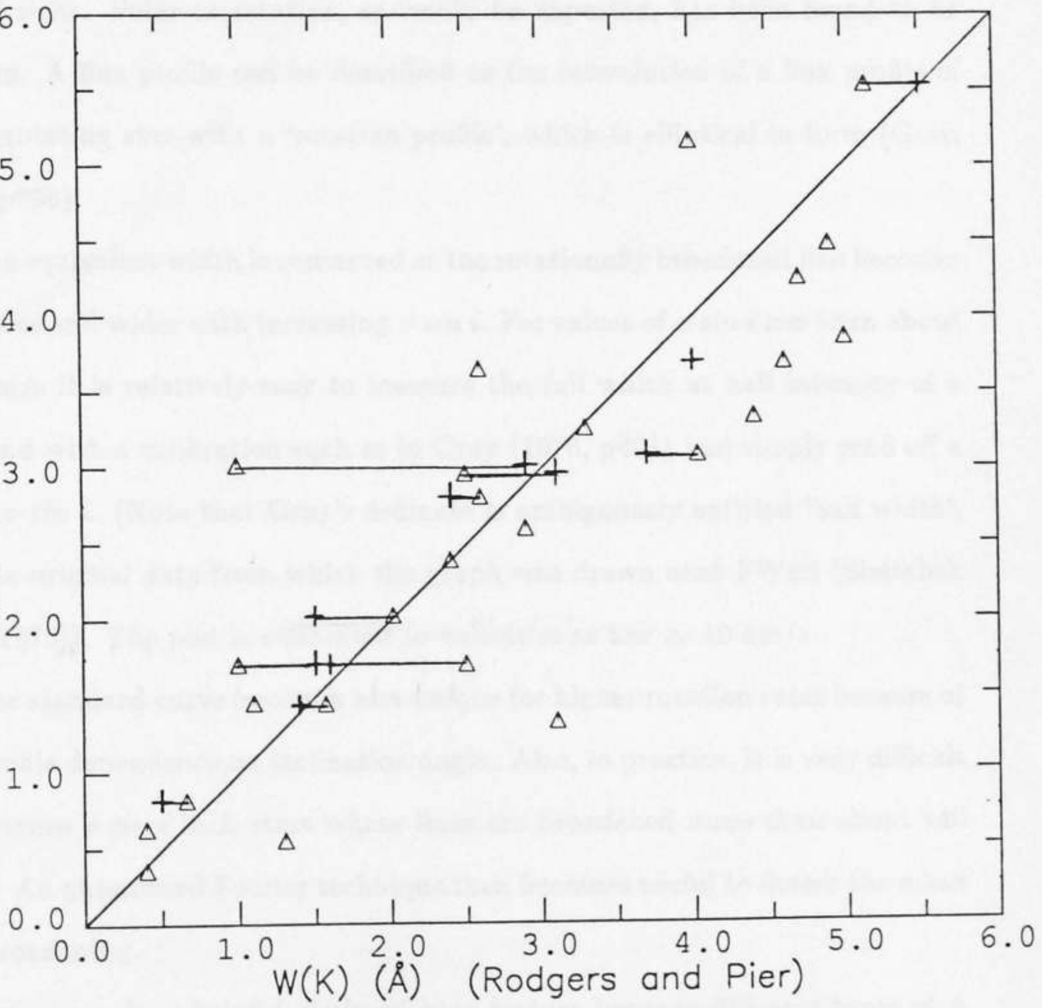
d) Calcium K Lines.

The equivalent widths of the CaII K line at 3933.7Å were measured with an interactive program which plots and fits a Gaussian to the line. The accuracy of this method was checked by comparison with values obtained from a planimeter, which were found to be in good agreement. The entire sample was measured at least three times on occasions several months apart, which meant that random errors of judgement of the continuum level were minimised.

The continuum level was sometimes less certain due to noisy spectra, or from strong hydrogen line broadening at 3889Å and 3970Å in high gravity stars. Conversely, it was more clearly defined for low gravity stars. The scatter between different measurements for the same line was small, no more than ±0.1Å in most cases.

The values measured, with a few from other sources, are listed in *Appendix I, Table 2.* Figure 2.5 shows the values compared to those found by Pier (1983) and Rodgers (1971). The derivation of calcium abundances relative to solar values for particular gravities and temperatures will be described in Chapter 3, section 3.3.

FIG. 2.5– CaII K line equivalent widths, my measurements against Pier (1983) (crosses) or Rodgers (1971), RHS (1981), (triangles). The agreement with Pier's values is good; Rodgers' results (from lower resolution spectra) show a larger scatter. Values for the same stars are joined by lines.


W(K) (Å) (Lance)
W(K) (Å) (Rodgers and Pier)
0.0
1.0
2.0
3.0
4.0
5.0
6.0

2.6 High Resolution Spectra.

a) *v sin i* Rotational Velocities.

Spectral lines are broadened by the relative Doppler shifts of light emitted from different parts of the stellar disk. The amount observed depends upon the inclination of the axis of rotation, with angle i at zero when the pole is in the line of sight. Polar orientation, as would be expected, has been found to be random. A line profile can be described as the convolution of a flux profile of a non-rotating star with a 'rotation profile', which is elliptical in form (Gray, 1976, p398).

The equivalent width is conserved as the rotationally broadened line becomes shallower and wider with increasing $v \sin i$. For values of $v \sin i$ less than about 140 km/s it is relatively easy to measure the full width at half intensity of a line, and with a calibration such as in Gray (1976, p401) and simply read off a mean $v \sin i$. (Note that Gray's ordinate is ambiguously entitled 'half width', but the original data from which the graph was drawn used FWHI (Slettebak *et al*, 1975)). The plot is calibrated to velocities as low as 10 km/s.

The standard curve becomes non-unique for higher rotation rates because of the profile dependence on inclination angle. Also, in practice, it is very difficult to measure $v \sin i$ in A stars whose lines are broadened more than about 140 km/s. An automated Fourier technique then becomes useful to detect the mean line broadening.

$v \sin i$ can be a helpful distinguishing feature between different types of A star. Stars with spectral peculiarities such as Am and Ap stars often also have low values of rotational velocity. Am stars (30 percent of all A stars) are most apparent among the later-type A stars, where the proportion of them rises to 50 percent at $B - V$ of 0.20 ($b - y$ of 0.15) (Wolff, 1983). Around 85 percent of Am stars have $v \sin i$ less than 80 km/s, while the majority of these have values between 20 and 70 km/s (see discussion below of the Uesugi and Fukuda (1970) catalogue).

The Ap (magnetic) stars comprise around 8 percent of normal A stars. 70 percent of their *v sin i* values are usually less than 60 km/s, with 90 percent less than 100 km/s. It is thought that in their case, magnetic fields may have a braking effect, whereas for Am stars (the vast majority of which are in binary systems), orbital braking may have slowed them down (Wolff, 1983).

Blue stragglers (see introduction) generally have low *v sin i* values. As discussed in Chapter 1, either or both of the possible formation mechanisms (mass transfer onto a low mass star, or magnetic or some other form of mixing) will lead to low rotational velocities. From these theoretical considerations and the few *v sin i* measurements available, it seems that up to 90 percent of them may have rotational velocities less than 70 km/s.

Normal A stars have *v sin i* values of around 20 km/s to 300 km/s. The higher velocity stars are less frequent in later-type A stars. Slettebak *et al* (1975) in a major report of a system of standard stars for *v sin i* determinations, found that previous values had been measured at around 5 percent too high. García and Levato (1984) quantified the derivation of new *v sin i*'s from old measurements, and found for AF stars the relation

$$v\,sin\,i_{(new)} = 0.92\,(v\,sin\,i_{(old)}) - 2.0\,km/s \qquad (2.5)$$

In order to examine the distribution of *v sin i* with spectral class, all the values for A stars with luminosity class V, Am or Ap classifications from the Uesugi and Fukuda (1970) *v sin i* catalogue were tabulated (904 stars). These had all been calibrated to the old Slettebak system, and García and Levato's relation was used to convert them to the new system.

Figure 2.6 (a and b) shows the distribution of *v sin i* values for the A stars. The 'old' Slettebak calibration *v sin i* velocities may be derived from the 'new' the 'new' ones that have been plotted: the abcissa values of the histograms (in km/s) are 'new' 35 = 'old' 40, 72 = 80, 108 = 120, 145 = 160, 182 = 200, 219 = 240, 256 = 280, 292 = 320.

Table 2.2 shows the total number, mean and standard deviation of the $v \sin i$ values in each group. The mean for all normal A stars is 116 km/s, which when converted to the old system gives 128 km/s, very close to the mean value of 130 km/s from Gray (1976).

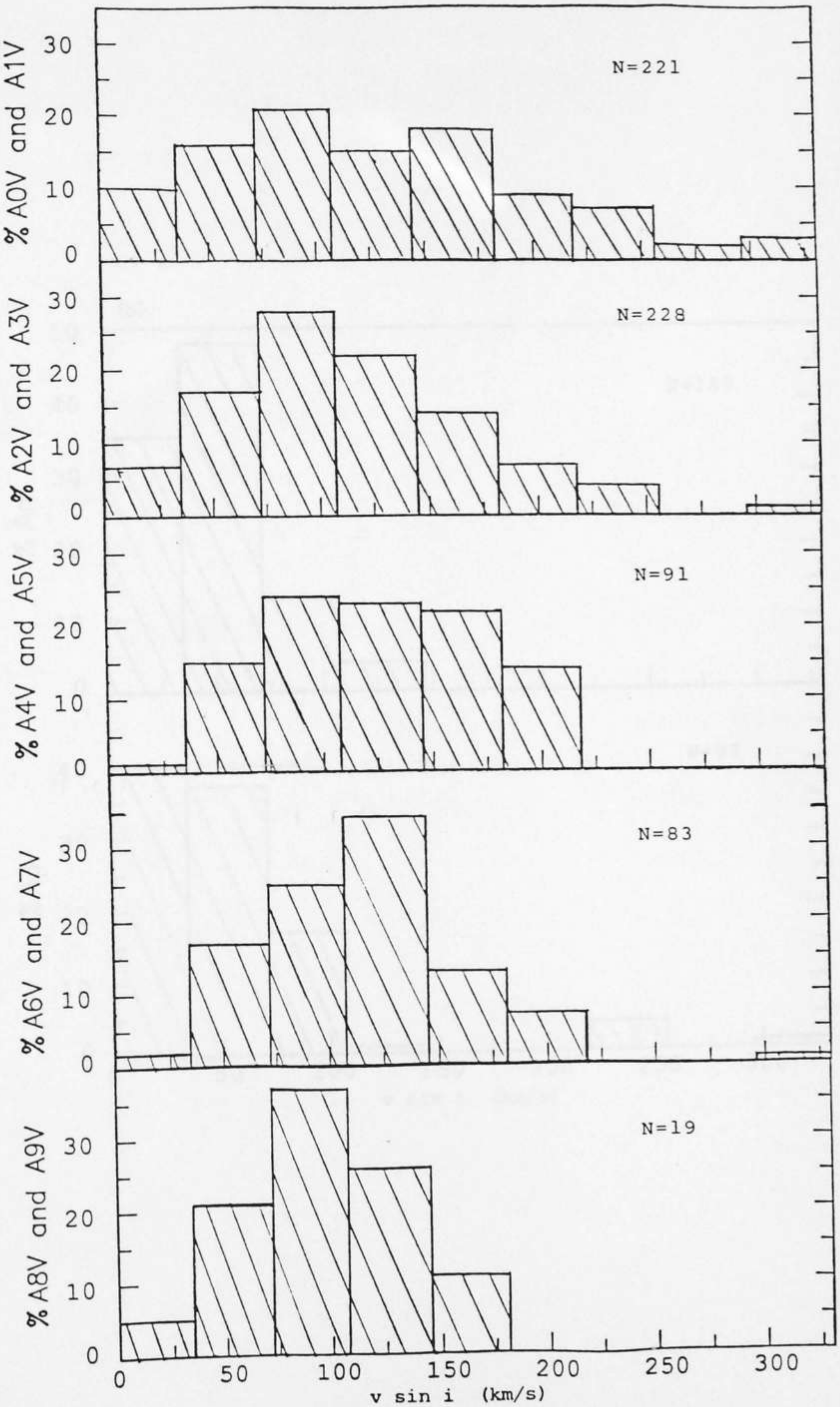
A selection effect to be considered that may have biased observations (from many sources) for the catalogue, is the possibility that more narrow-lined stars may have been collected as they are intrinsically easier to measure. If the proportion of narrow-lined stars (Am and Ap) are considered relative to the whole sample of A stars, it is found that the Ap stars comprise 11 percent (around 8 percent would be expected), and the Am stars are 18 percent (substantially less than the approximately 30 percent expected). If the catalogue had a bias towards low velocity stars, it is likely that a much higher proportion would have been Am or Ap, so it may be assumed that the catalogue is relatively free of such a bias.

From figures 2.6 (a) and (b) it is clear that many young A stars are fast rotators, but it is important to recognise that a large percentage of apparently normal stars may have rotation velocities less than 80 km/s. On the other hand, it is extremely rare for Am, Ap and blue straggler stars to have values higher than 100 km/s.

FIG. 2.6 – (a) The percentages of the total number in each spectral type grouping for A stars, class V, against *v sin i* values from the Uesugi and Fukuda (1970) catalogue.

(b) As for (a), for Am and Ap stars.

(a)


N=221
N=228
N=91
N=83
N=19
% A0V and A1V
% A2V and A3V
% A4V and A5V
% A6V and A7V
% A8V and A9V
0
10
20
30
50
100
150
200
250
300
v sin i (km/s)

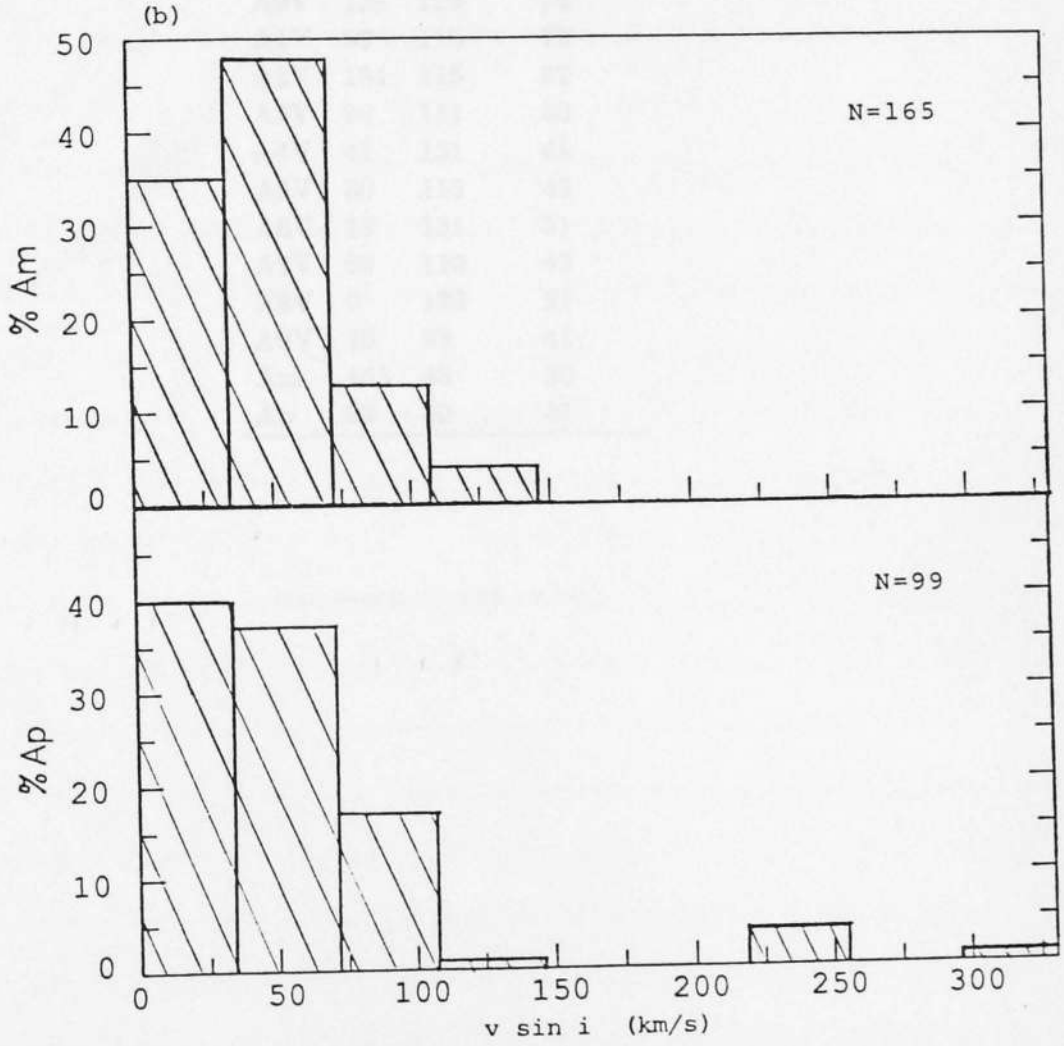

(b)
N=165
N=99
% Am
% Ap
v sin i (km/s)

Table 2.2

The numbers of stars, mean and dispersion of the $v \sin i$ values from the Uesugi and Fukuda (1970) catalogue.

Sp	no.	mean (km/s)	disp. (km/s)
A0V	128	129	74
A1V	92	116	72
A2V	134	115	62
A3V	94	111	50
A4V	41	131	45
A5V	50	115	48
A6V	13	131	51
A7V	69	110	43
A8V	9	120	31
A9V	10	83	41
Am	165	48	30
Ap	99	50	51

b) Observations.

Five of the SGP high velocity A stars and three *v sin i* templates were observed on the Anglo-Australian Telescope at Siding Spring on the night of 20th October 1985. The 82 cm camera with the 1200B grating in second order was used, giving around 11Å/mm at the Image Photon Counting System detector, equivalent to 0.30Å resolution. Copper-argon arcs were exposed before and after each spectrum. The spectra were flat-fielded and reduced as described in section 2.5.

To obtain the *v sin i* values, programs were used, written by Dave Carter utilising the technique described by Sargent, Schechter, Boksenberg and Shortridge (1977, hereafter SSBS). This method is normally used to find the velocity dispersions of galaxies, by minimising the difference between the Fourier transformed spectrum of a shifted, broadened template, and a program galaxy. The broadening function used is Gaussian, and gives an estimate of the FWHM of broadened lines.

As mentioned, the *v sin i* rotation profile is actually elliptical in shape, and was thus systematically underestimated by the fitted Gaussian. To allow for this systematic difference, a calibration curve (fig. 2.7) was derived from *v sin i* values from the FeI lines at 4045Å, 4063Å, and 4071Å measured by hand for high resolution SGP and Yale star spectra (Chapter 4) for values up to around 140 km/s (using Gray's calibration (1976), p401), set against the velocities derived from the SSBS program. (Since the SSBS velocities had been derived relative to the already somewhat broadened templates, the actual values of *v sin i* for the three template stars were added in quadrature to the SSBS values before the curve was drawn.)

The average of the three SSBS results for the program stars was found, and a value of *v sin i* was then read from the calibration curve. Since the mean minimum value that could be found by the templates (due to their own *v sin i* broadening) was about 38 km/s, the narrow lines of stars below that value were simply measured by hand, again using Gray's calibration of line FWHI against *v sin i*.

Two sets of wavenumber Fourier filters were used. SSBS recommended 10 and 110 for the upper and lower wavenumbers (for spectra of 1024 channels) but it was found that 11 and 110 gave similar but not identical results, and in some cases were more consistent between the three templates, so the mean of six measurements was ultimately taken. The error of the SSBS determination was estimated by the standard deviation of the six values.

Three other SGP stars were observed at coudé focus on the Mt Stromlo 74" telescope, with the 'B' 600 lines/mm grating and 32" camera, with a reciprocal dispersion of 11.4Å/mm, almost identical to that obtained from the AAT. The AAT template stars were used for these spectra as well, because for the program stars, the intersection of the SSBS values using the AAT templates, against measured *v sin i*, fell consistently on the calibration curve. In addition, for two of the stars it was possible to measure their *v sin i* values by hand, and these values were consistent with the SSBS output.

Seven of the stars with *v sin i* measurements were also studied by Stetson (1983) (see *Appendix II, Table 2* for values). Figure 2.8 shows a comparison between our respective *v sin i* measurements. It can be seen that the agreement is very good, except for the star with the highest rotation. This is probably because the calibration curve was extrapolated as conservatively as possible, leading to a slight underestimation of the highest velocities. There is clearly no indication that the *v sin i* values derived from this technique have been overestimated in any way.

Table 2.3 shows the name, the approximate spectral type (from the colour), the mean and dispersion of the SSBS output, the *v sin i* measurements from spectral plots, and the final calibrated *v sin i* values for the AAT and 74" program stars, and details of the template stars. Five out of the eight stars, with results of 131, 188, 111, 172 and 123 km/s have velocities that indicate that they are normally rotating young A stars.

Three others have lower *v sin i* values. They appear to be either Am or Ap stars, although these classifications cannot be definitive, as they are normally derived from objective prism spectra. PS2II (47 km/s) showed the strong SrII line at 4077Å indicative of an Ap star in the mid-A range (Morgan, Keenan and Kellman, 1942). The equivalent width of the line at 4077Å was 0.33Å, while that of the template (HR 8949) was 0.36Å. In comparison, PS30, a normal A star around one spectral class later than PS2, had an equivalent width at 4077Å of only 0.14Å.

PS29II (*v sin i* of 36 km/s), is almost certainly an Am star as its spectrum is very similar to the template star HR178 (A7m). To quantify this, the mean equivalent width of the iron triplet lines at 4045, 4063 and 4071Å was calculated. The template had a mean equivalent width of 0.52Å; PS29 had a mean equivalent width of 0.42Å; while PS62 (a little cooler than PS29 so it would be expected to have stronger metal lines) had a mean equivalent width of only 0.13Å. PS29 had an m_1 index of 0.193. Am stars are often indicated by m_1 indices greater than 0.200, but the normal range for Am stars at the $b - y$ of 0.139 shown by PS29 is from 0.170 to 0.240 (Kilkenny and Hill, 1975), so the m_1 index of PS29 is not inconsistent with the Am classification.

The spectrum of PS57II (*v sin i* 30 km/s) also shows enhanced metal lines and appears to be a marginal Am star. Its mean equivalent width of the iron triplet was 0.29Å, while PS37II, a normal A star of around the same temperature, had a mean equivalent width of only 0.15Å.

To find three out of eight A stars with Am and Ap spectral line peculiarities is close to the normal main sequence proportion of 35 percent. Since around 60 percent of blue stragglers also show these peculiarities, the status of these stars is not directly determinable from rotational velocities, and must be found from other measures (see Chapter 3).

The other five stars, with *v sin i* values between 100 and 200 km/s, are almost certainly not blue stragglers. These stars were some of the brighter ones of the A star group; their distances (Chapter 3) are between 1 and 2 kpc. Thus, if any of the A stars were to be blue stragglers, these ones had the greatest likelihood, because they are within 3 to 6 old disk scaleheights (350 pc) of the plane, at not impossible distances for a few of a large time-dispersed BS population to reach. That these stars, then, are most unlikely to be blue stragglers, indicates that it is even less likely that the other A stars, of similar properties and at larger distances, would be found to be old disk blue stragglers.

Nonetheless, the question shall be re-examined in terms of the A star abundances and kinematics in Chapter 3, so that all relevant aspects may be considered. Figure 2.9 shows the derived *v sin i* values for the eight SGP stars relative to the Uesugi and Fukuda distributions for the respective A star spectral types.

Table 2.3

SGP program stars and *v sin i* templates: approximate spectral types (program stars), mean and dispersion from SSBS output, *v sin i* from spectral plots, and the adopted values of *v sin i*.

Name	Sp. Type	<*v sin i*> SSBS	disp. SSBS	*v sin i* hand	*v sin i* adopted
(AAT) PS3II	A9V	92	10	129	131
(AAT) PS8II	A7V	138	7		188
(AAT) PS29II	A8Vm	42	3	36	36
(AAT) PS30II	A4V	76	7	111	111
(AAT) PS62II	A8V	125	16		172
(74") PS2II	A3Vp	44	5	47	47
(74") PS37II	A4/5V	85	8	124	123
(74") PS57II	A5Vm:	38	7	30	30
(Temp) HR8949	A2Vp			23	23
(Temp) HR7990	A3m			44	44
(Temp) HR178	A7m			38	38

FIG 2.7–The calibration curve used for derivation of $v \sin i$ values from SSBS output.

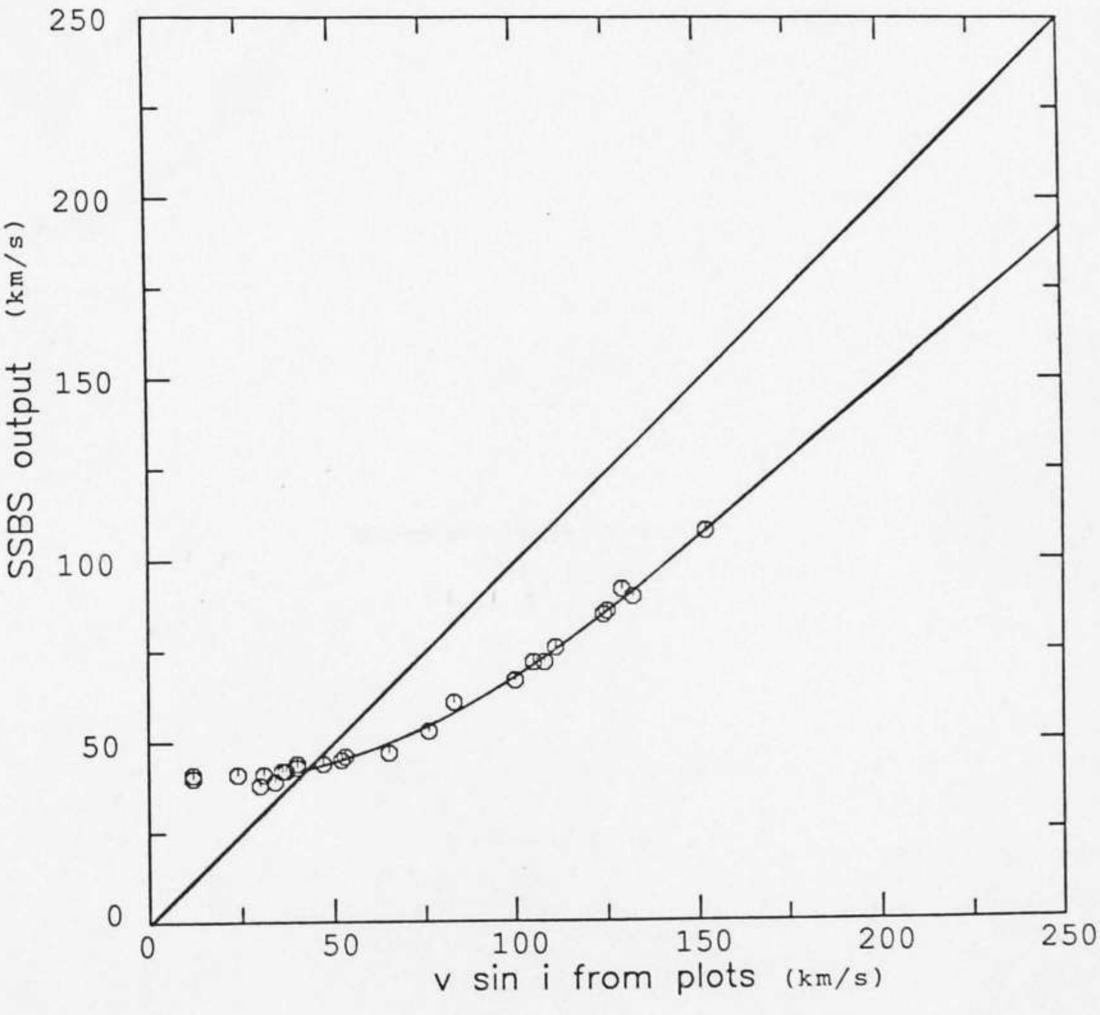

250
200
150
100
50
0
SSBS output (km/s)
0
50
100
150
200
250
v sin i from plots (km/s)

FIG 2.8–The derived *v sin i* values for seven stars measured both by the technique described in this chapter and by Stetson (1983).

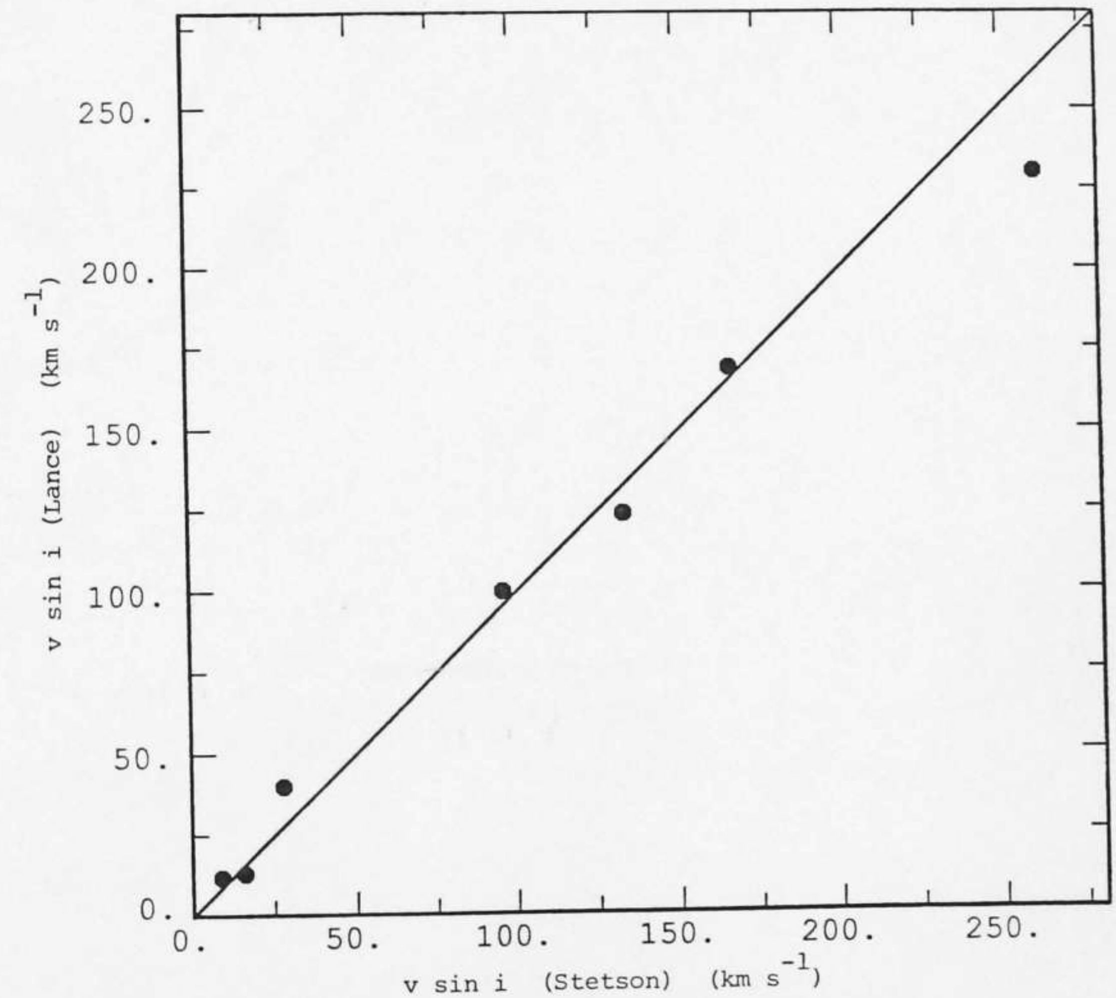
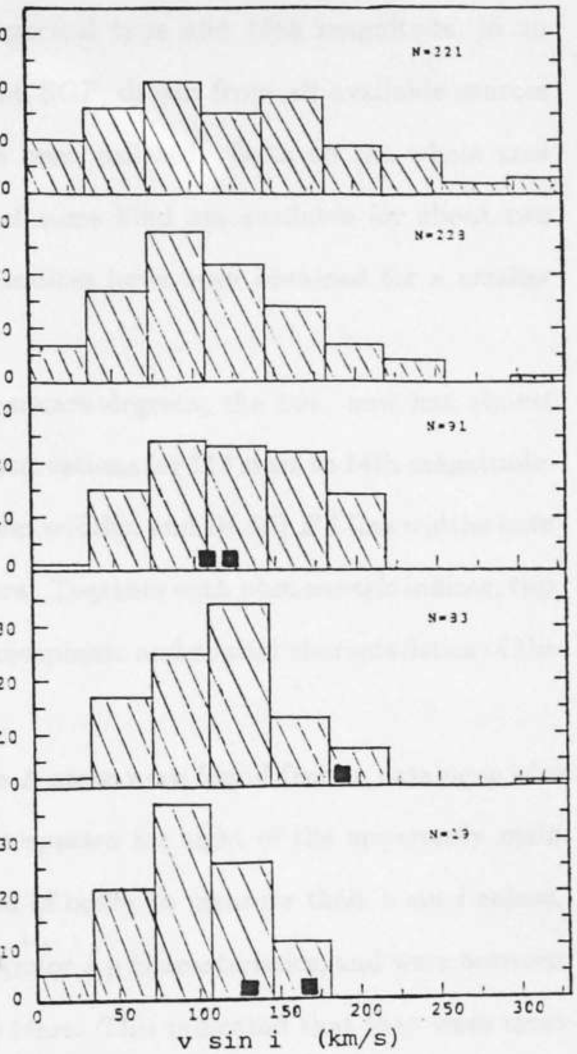
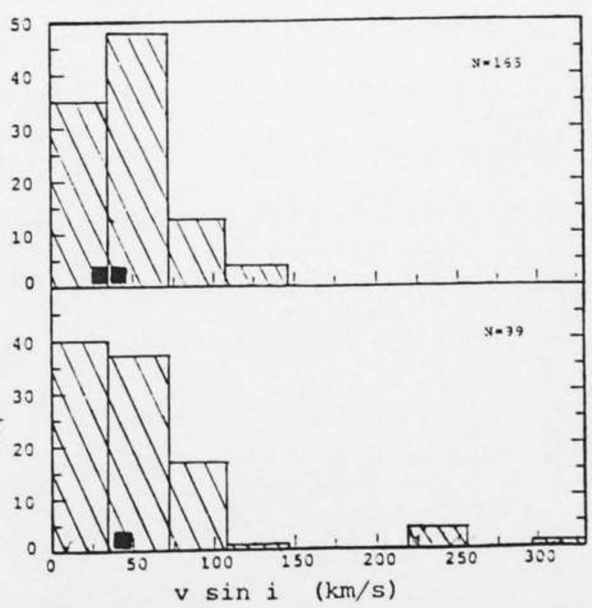

v sin i (Lance) (km s^{-1})
v sin i (Stetson) (km s^{-1})
0.
50.
100.
150.
200.
250.

FIG 2.9–The *v sin i* values of the SGP program stars relative to the Uesugi and Fukuda catalogue results for A star spectral classes.


% A0V and A1V
N=221
% A2V and A3V
N=223
% A4V and A5V
N=91
% A6V and A7V
N=33
% A8V and A9V
N=19
v sin i (km/s)


% Am
N=165
% Ap
N=99
v sin i (km/s)

2.7 Summary.

A catalogue of 305 stars to F0 spectral type and 15th magnitude, in an area of 218 square degrees around the SGP, drawn from all available sources (both photometric and spectral) has been collated. Data on the whole area is incomplete. Photometric indices of some kind are available for about two thirds of the total sample; spectral indices have been obtained for a smaller proportion.

An area of the catalogue of 100 square degrees, the box, now has almost complete spectral and photometric observations for 113 stars to 14th magnitude. Radial velocities, CaII K line equivalent widths, and D(.70) $H\delta$ line widths have been measured for the available spectra. Together with photometric indices, this data will be used to derive stellar atmospheric and spatial characteristics of the sample of stars in Chapter 3.

Typical values for main sequence A stars were found from a catalogue of $v \sin i$ measurements. High resolution spectra for eight of the apparently main sequence SGP A stars were obtained in order to measure their $v \sin i$ values, which were low for three stars with Am or Ap characteristics, and were between 100 and 200 km/s for the other five stars. This indicated that they were most unlikely to have been drawn from a population of blue stragglers.

Chapter 3

SGP Results.

3.1 Introduction.

This chapter describes the techniques by which the ages, abundances and distances of stars from the SGP blue star catalogue are found. The derivation of stellar atmospheric parameters such as surface gravity and effective temperature are discussed. The calcium abundances of the stars relative to solar abundance are found, and they are then classified into Populations I and II on the basis of gravity and metallicity. Their masses, distances, ages, (and for Population I) velocity dispersion and scale height are found.

A comparison is made with the results of Rodgers (1971) and Rodgers, Harding and Sadler (1981), for their unusual age, abundance and kinematic results for the distant young stars. Theories of possible sources of the A stars in the galactic disk, particularly with regard to the blue straggler hypothesis, are examined relative to the findings of this chapter.

3.2 Surface Gravities and Effective Temperatures.

Before the evolutionary status of a star can be determined, it is first necessary to locate its position in the temperature-gravity plane. This is conceptually equivalent to a colour-magnitude diagram. The technique used here for the derivation of stellar surface gravities and effective temperatures is independent of any assumptions regarding the evolutionary stage of a program star. It is based on the work of Kurucz (1979), who reported hydrogen and metal line blanketed stellar atmosphere models for a range of gravities from log 1.0 to log 4.5 (log 5.0 for some O star models), temperatures from 5500 K to 50,000 K, and abundances of solar, one tenth solar and one hundredth solar. *UBV* and *uvby* colours, m_1 and c_1 indices, and hydrogen line profiles were also listed. When using the Kurucz c_1 indices, a minor correction to the zero point was included, of 0.008, as suggested by Moon and Dworetsky (1985).

The technique utilises the fact that for A stars, both the hydrogen line width (measured by D(.70)) and the c_1 index are systematically affected by temperature; and that for all A stars the c_1 index is gravity sensitive, as is the width of hydrogen lines for early and mid A stars. (c_1 cannot be used to discriminate between gravities for $b-y$ bluer than -0.03.) Thus, given values of both indices describe unique loci in the gravity-temperature plane. These loci intersect at two points, on the blue and the red sides of the Balmer line width maximum (which is at around $b-y$ of 0.05).

A third index, such as $b-y$ or $B-V$, is used to define which of the two possible gravity-temperature intersections is the correct one, although accurate spectral type, if independently determined, may also be helpful to discriminate. The $b-y$ value is usually a small amount redwards of the D(.70) and c_1 intersection. This is a most useful guide to the differential reddening, E_{b-y}, which is found from the difference between the observed $b-y$ locus, and $(b-y)_0$ for the point of intersection. (See Figure 3.1 for examples of the method). The effective temperature is used in the form of Θ_{eff}, equivalent to 5040/effective temperature.

There has been some argument in the literature regarding the average reddening at the Poles. Not surprisingly, interstellar extinction there has been found to be patchy. At the SGP Philip (1974) found an E_{b-y} of 0.013 ± 0.018, Albrecht and Maitzen (1980) obtained E_{b-y} of 0.019, both Eggen (1970) and Rodgers, Harding and Sadler (1981) derived E_{B-V} of 0.024, equivalent to E_{b-y} of 0.018; and for both Poles Nicolet (1982) found E_{b-y} of 0.030, while McFadzean, Hilditch and Hill (1983) obtained around zero out to 400 pc from the

Sun, but cautioned that 'it cannot be overemphasized that there are areas of significant reddening ($E_{b-y} > 0.100$) at high galactic latitudes'.

Knude (1984) found an average E_{b-y} of 0.020 at the SGP. His distribution of reddening values was asymmetric, with a tail to 0.080, in qualitative agreement with the above comment of McFadzean, Hilditch and Hill. The mean E_{b-y} at the SGP found from this thesis work was 0.020, with a dispersion of 0.025, for 92 stars, consistent with other values and indicating that this technique is reliable for reddening estimates.

For most of the stars in the SGP area brighter than 9th magnitude, spectra (thus D(.70)s and CaII K lines) were not obtained. Instead, the intersection of the c_1 index and $b - y$ in the gravity-temperature plane was found. From both the Strömgren indices and the position close to the plane of most of these stars, it was clear that the majority were Population I, and did not require confirmation of their status from K line abundances. Most had radial velocities listed in Abt and Biggs (1971).

Photometry for these stars (brighter than 9th magnitude) was obtained from McFadzean, Hildich and Hill (1983), who found zero reddening for them. The mean of my values for 9th magnitude stars alone was only 0.002, so for the brighter stars, E_{b-y} was assumed to be zero. For a few stars fainter than 12th magnitude for which there were no spectra, but which had photometry from other sources, $b-y$ was corrected for E_{b-y} of 0.020, consistent with other surveys at those magnitudes. For sdO and sdB stars, identified from Strömgren photometry (Kilkenny and Hill, 1975), the gravity-temperature values were more approximate so no attempt was made to correct for reddening, as any correction would have been within the errors.

The nearby stars were collected in order to find the run of main sequence stars as a function of Z height from the plane outwards. There were so many bright stars near the plane that it was estimated that if a few misclassifications occurred it would not affect the results. In fact it was found that the gravity-temperature values for stars that had D(.70) available as well as c_1 and $b-y$, were almost identical to those that would have been derived if only c_1 and $b-y$ had been available; that is, D(.70) was useful for confirmation of the other indices, (particularly if a non-average reddening was present), rather than being absolutely necessary for the gravity-temperature determinations.

However, for stars *fainter* than 9th magnitude as many spectra as possible were obtained, particularly in the box area. Thus D(.70) results were available for the more distant stars, to confirm the gravity and temperature values and to minimise possible photometric errors; and most importantly, the K line was available to ensure that their calcium abundances were well defined. This was not so important for the nearby disk A stars as their Population I status was not under such close examination as it was for the distant A stars.

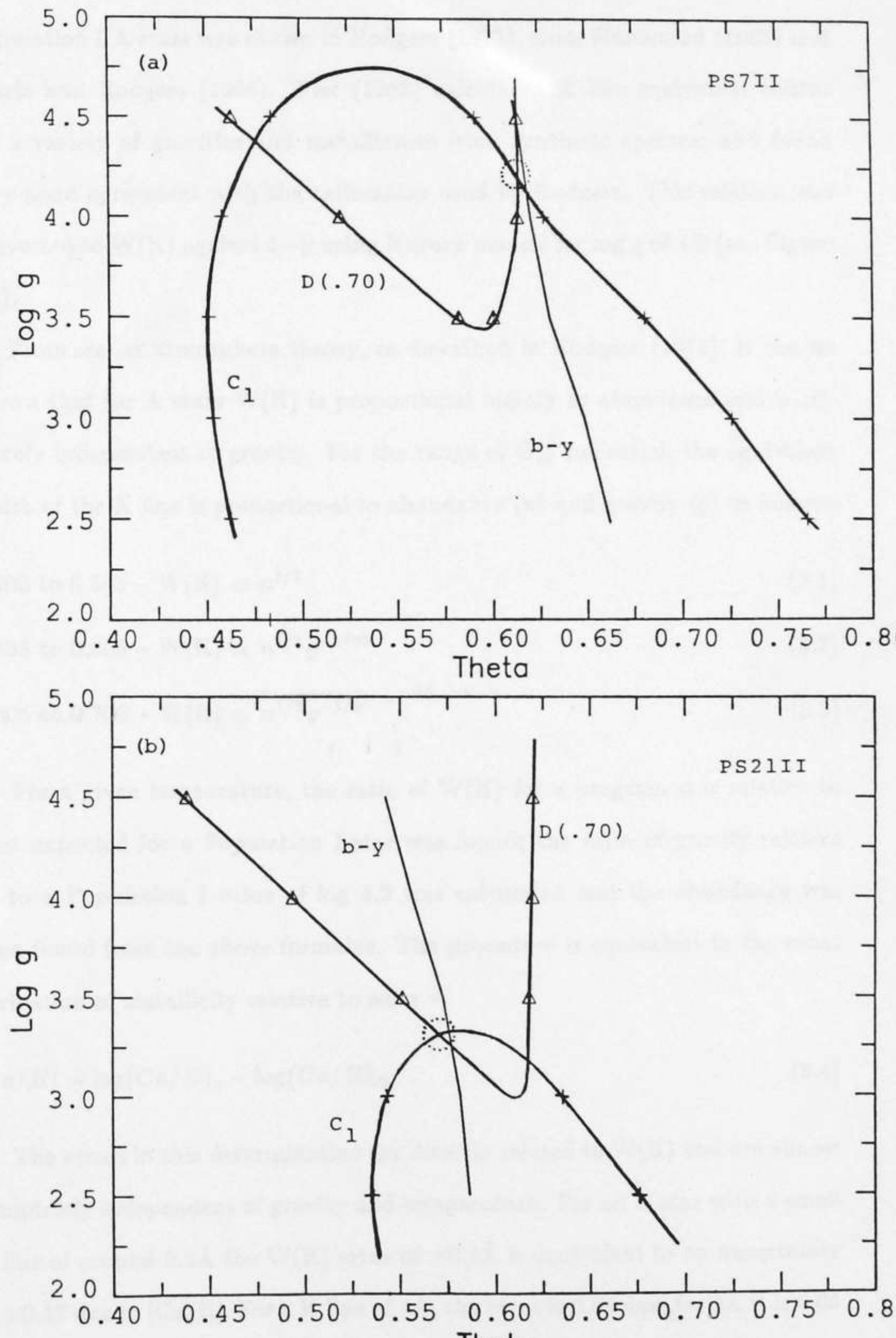
For a few faint stars outside the box area for which I did not have spectra, but which had D(.80) values from Rodgers (1971), D(.70)s were derived via Kurucz models for particular gravities and temperatures. These were generally very consistent, and in fact mostly confirmed the horizontal branch status of those few stars involved.

When this procedure and that of gravity-temperature derivation from c_1 and $b-y$ alone has been used, it was indicated as such in the listings of *Appendix I, Tables 3 and 4* which contain the values of log surface gravity, Θ_{eff}, E_{b-y} and $(b-y)_0$. The error in the derived surface gravities is calculated to be 0.08 dex, and in Θ_{eff} is 0.008, from the individual errors in c_1 and D(.70) added in quadrature. (Table 3 lists those stars found to be Population I or possible blue stragglers; while Table 4 lists the horizontal branch, O and B subdwarf, white dwarf and F subdwarf stars.)

Fig. 3.1 – Two examples of the derivation of surface gravity and effective temperature values from D(.70), c_1 and $b-y$.

a) PS7II was found to be a Population I star, with a main sequence gravity of log 4.18 and an effective temperature of 8222K, (=5040/0.613). E_{b-y}, the difference between the observed $b-y$ and $(b-y)_0$, is equal to 0.014.

b) PS21II is a Population II star, with gravity of log 3.28, effective temperature of 8842K (=5040/0.570), and E_{b-y} of 0.004. The locus of $b-y$ clearly defines which of the two possible intersections is the correct one.


(a)
PS7II
D(.70)
C1
b-y
Log g
Theta
5.0
4.5
4.0
3.5
3.0
2.5
2.0
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
(b)
PS21II
D(.70)
b-y
C1
Log g
Theta
5.0
4.5
4.0
3.5
3.0
2.5
2.0
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80

3.3 Abundances.

A relation between the equivalent width of the CaII K line and $B-V$ for Population I A stars was shown in Rodgers (1971), from Sinnerstad (1961) and Searle and Rodgers (1966). Pier (1983) calculated K line equivalent widths for a variety of gravities and metallicities from synthetic spectra, and found very good agreement with the calibration used by Rodgers. This relation was converted to W(K) against $b-y$ using Kurucz models for log g of 4.2 (see Figure 3.2).

From stellar atmosphere theory, as described in Rodgers (1971), it can be shown that for A stars W(K) is proportional mainly to abundance and is relatively independent of gravity. For the range of Θ_{eff} indicated, the equivalent width of the K line is proportional to abundance (n) and gravity (g) as follows:

$$0.500 \text{ to } 0.595 - W(K) \propto n^{1/2} \tag{3.1}$$

$$0.595 \text{ to } 0.605 - W(K) \propto n^{1/2} g^{-1/10} \tag{3.2}$$

$$0.605 \text{ to } 0.700 - W(K) \propto n^{1/2} g^{-1/6} \tag{3.3}$$

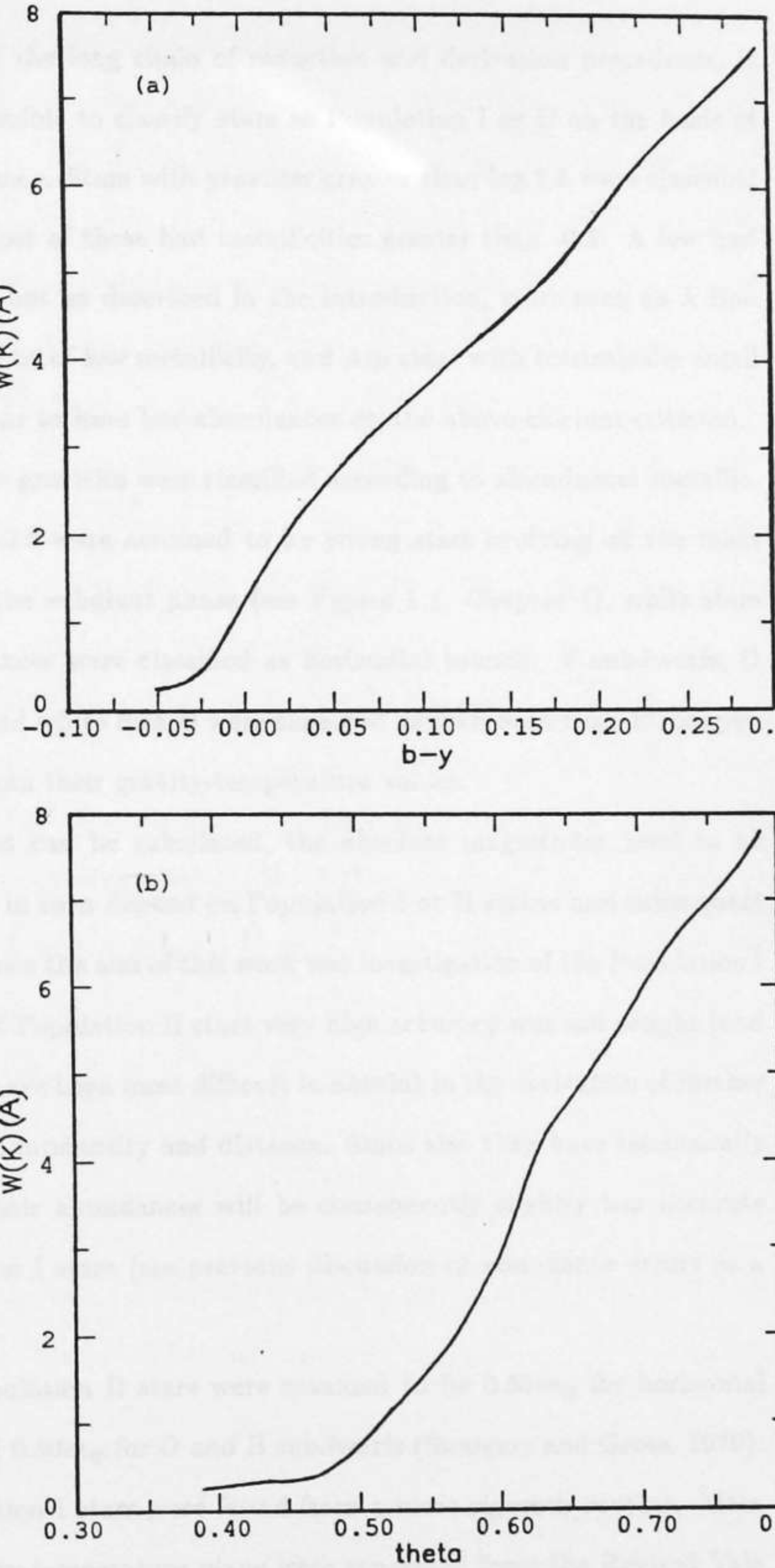
For a given temperature, the ratio of W(K) for a program star relative to that expected for a Population I star was found; the ratio of gravity relative to to a Population I value of log 4.2 was calculated and the abundance was then found from the above formulae. The procedure is equivalent to the usual derivation of metallicity relative to solar –

$$[Ca/H] = \log(Ca/H)_{\star} - \log(Ca/H)_{\odot} \tag{3.4}$$

The errors in this determination are directly related to W(K) and are almost completely independent of gravity and temperature. For an A star with a small K line of around 0.5Å the W(K) error of ±0.1Å is equivalent to an uncertainty of ±0.17 dex in [Ca/H]. For a K line of 1Å, the error is 0.09 dex; for 2Å it is 0.05

dex, for 3Å it is 0.03 dex, and for 4Å and 5Å it is around 0.02 dex. (Of the stars that have been found to be distant Population I stars (see later and section 3.4) only four out of twenty-seven had K lines smaller than 1Å, so that for most of them the abundance has been very well defined.) The [Ca/H] values have been listed for all stars with spectra in *Appendix I, Tables 3 and 4*, together with a few results from other sources.

Fig. 3.2 – a) Calcium K line equivalent width plotted against $b - y$, and b) against Θ_{eff}, for Population I stars of surface gravity 4.2. Points were derived from Pier (1983) and Rodgers (1971).


(a)
W(K) (Å)
8
6
4
2
0
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
b−y
(b)
W(K) (Å)
8
6
4
2
0
0.30
0.40
0.50
0.60
0.70
0.80
theta

3.4 Classification and Distances.

At this stage of the long chain of reduction and derivation procedures, it at last becomes possible to classify stars as Population I or II on the basis of gravity and abundance. Stars with gravities greater than log 3.8 were classified as Population I. Most of these had metallicities greater than -0.5. A few had lower metallicities, but as described in the introduction, stars such as λ Boo are main sequence but of low metallicity, and Am stars with intrinsically small K lines would appear to have low abundances on the above calcium criterion.

Stars with lower gravities were classified according to abundance: metallicities greater than -0.5 were assumed to be young stars evolving off the main sequence through the subgiant phase (see Figure 1.1, Chapter 1), while stars with lower abundances were classified as horizontal branch. F subdwarfs, O and B subdwarfs and white dwarfs were classified as such both from Strömgren photometry and from their gravity-temperature values.

Before distances can be calculated, the absolute magnitudes need to be determined, which in turn depend on Population I or II status and subsequent mass estimates. Since the aim of this work was investigation of the Population I stars, in the case of Population II stars very high accuracy was not sought (and at any rate would have been most difficult to obtain) in the derivation of further parameters such as luminosity and distance. Since also they have intrinsically smaller K lines, their abundances will be consequently slightly less accurate than the Population I stars (see previous discussion of abundance errors as a function of W(K)).

Masses for Population II stars were assumed to be $0.55m_{\odot}$ for horizontal branch A stars and $0.50m_{\odot}$ for O and B subdwarfs (Sweigart and Gross, 1976). Masses for Population I stars were found from a more rigorous routine. Mass tracks in the gravity-temperature plane were generated from the Revised Yale

Isochrones, a major work undertaken in recent years by Elizabeth M. Green, and kindly supplied in advance of publication.

The mass tracks were generated for a helium abundance (Y) of 0.25, and metallicities (Z) of 0.0170, 0.0153, 0.0136, 0.0119, 0.0102, 0.0085, 0.0068, and 0.0051, corresponding respectively to solar abundance, 90 percent, 80, 70, 60, 50, 40, and 30 percent of solar. Such accuracy was required because the positions of isochrones in the gravity-temperature plane are most sensitive to metallicity effects: for instance, parts of an isochrone for 500 million years at solar metallicity are at roughly the same gravities and temperatures as one of 900 million years for 40 percent of solar abundance. Helium was assumed to be the same for all metallicities as all present-day Population I A stars would have been formed within around the last 1.5 billion years.

From the position of a Population I star in the gravity-temperature plane, a mass was found from the mass tracks, appropriate to the abundance of the star. The only possible area of ambiguity was where the tracks formed overlapping 'hooks' (see Figure 1.1), and there the mean of the several possible masses was taken (usually the uncertainty was over only 0.2 solar masses in any case). The majority of the stars fell where the values were unambiguous, so most of the masses are accurate to $\pm 0.1 m_{\odot}$.

From the relation between luminosity and temperature

$$L = 4\pi R^2 \sigma T_{eff}^4 \tag{3.5}$$

where R=stellar radius, T_{eff}=effective temperature, and $\sigma = 5.66956 \times 10^{-8} W m^{-2} K^{-4}$; and the relation between gravity and mass

$$g = \frac{Gm}{R^2} \tag{3.6}$$

where m=stellar mass and $G = 6.672 \times 10^{-11} N m^2 kg^{-2}$, luminosity was derived from

$$L/L_{\odot} = C \frac{M/M_{\odot}}{g\,\Theta_{eff}^4} \tag{3.7}$$

where $C = 1.59504 \times 10^2$.

Bolometric magnitude was found from

$$M_{bol} = -2.5 \log L/L_{\odot} + M_{bol(\odot)} \tag{3.8}$$

where $M_{bol(\odot)} = 4.76$.

The bolometric corrections listed by Straižys and Kuriliene (1981) were used to derive absolute visual magnitudes from bolometric magnitudes. Since $E_{B-V} = 1.35\,E_{b-y}$, the extinction A_v was found from $3\,E_{B-V}$, and the distance (d) was derived from the distance modulus

$$(m_v - M_v - A_v) = 5\,log\,(d/10) \tag{3.9}$$

The Z distance from the plane was found from the distance from the Sun multiplied by the sin of the galactic latitude (b). Distances are estimated to be accurate to around ± 150 pc for mid to late A stars and ± 300 pc for early A stars.

The maximum distances from the plane that the stars could reach, given their present positions and their radial velocities, were found from a force law calculated by Gregg Rowley. This used a computer model consisting of a combination of three disks of different radial scale factors, of the form given by Miyamoto and Nagai (1975), which was normalised to give a disk that was exponential in radius for four to five scale lengths.

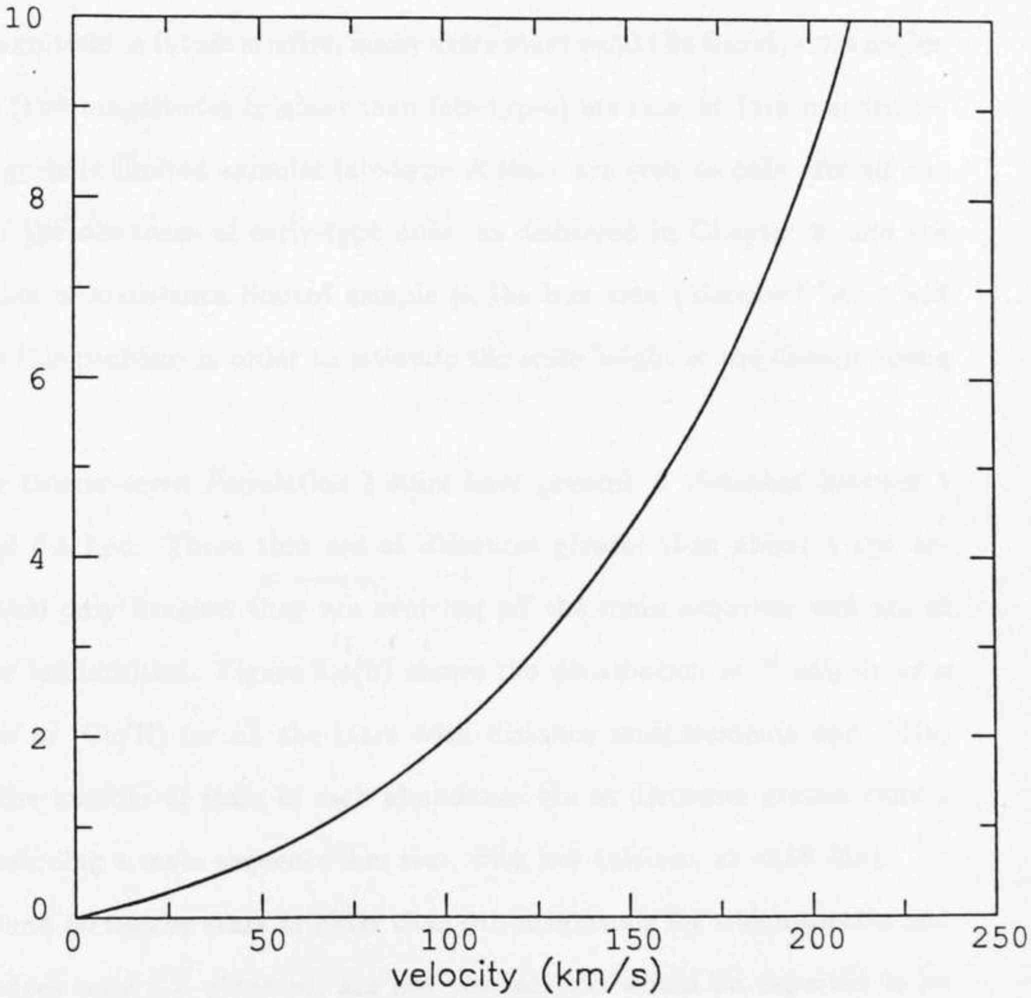
The advantage of this technique is that the potential of these disks is a known analytic function and the force law is thus easily calculated. The radial scale lengths of the disks were 6.66 kpc, 19.98 kpc and 33.30 kpc. The Z scale height was 0.4 kpc, and the total mass of the three disks was $0.9 \times 10^{11} m_{\odot}$. The functional form for the three potentials was

$$\Phi_i(R,Z) = \frac{Gm_i}{[R^2 + (a_i + (Z^2 + b^2)^{1/2})^2]^{1/2}} \tag{3.10}$$

where G is the gravitational constant, m_i is the disk mass, a is the radial scale length, b is the Z scale height, R is the radial distance and Z is the distance above the disk. The total potential was the sum of the three disk potentials.

The resultant force law is similar to that proposed by Oort (1961); and the density distribution in Z, at the solar radius, is very much like that found from observations by Gilmore and Reid (1983). Using the total potential, maximum Z heights for the program stars were found from the velocities at the disk (see figure 3.3). Masses, absolute magnitudes, Z distances, and maximum Z distances are listed in *Appendix I, Tables 3 and 4* for all stars with available data.

Fig. 3.3 – The Z distance to which a star could travel, given a particular velocity at the plane, from the model by G. Rowley.



Z distance (kpc)
0
2
4
6
8
10
velocity (km/s)
0
50
100
150
200
250

3.5 Results of Classification and Distance Calculations.

The major result of the above analysis is that over the whole 218 square degree SGP area, twenty-seven stars were identified as Population I at distances greater than 1 kpc from the plane. It is estimated that around another eight stars remain to be found in the SGP area outside the box area, to 14th magnitude alone. If later-type A stars were to be systematically observed to around 16th magnitude in future studies, many extra stars would be found, since earlier A stars (two magnitudes brighter than late-types) are seen at 14th magnitude. For magnitude limited samples late-type A stars are seen to only around one sixth of the distances of early-type ones, as discussed in Chapter 2, and the derivation of a distance limited sample in the box area (discussed later) will address this problem in order to estimate the scale height of the distant young stars.

The twenty-seven Population I stars have present Z distances between 1 kpc and 6.5 kpc. Those that are at distances greater than about 4 kpc are observable only because they are evolving off the main sequence and are at brighter luminosities. Figure 3.4(b) shows the distribution of Z heights as a function of [Ca/H] for all the stars with distance measurements and 3.4(a) shows the number of stars in each abundance bin at distances greater than 1 kpc (excluding a main sequence Am star, with low calcium, at -0.58 dex).

Around 50 nearby stars brighter than 9th magnitude for which spectra and abundances were not obtained, are not plotted, but would be expected to be found in the hatched area at metallicities of from -0.1 to +0.25 (Mihalas and Binney, 1981, p173). Note that the only stars found in this analysis to be at metallicities greater than +0.005 are within 500 pc of the plane, and that the Population I stars above 1 kpc have an upper limit of metallicity around 0.0 dex.

Note also that they seem to have a lower limit of calcium abundance around -0.4, and apart from the main sequence Am star in the interval between -0.4 and -0.8, there are no other high velocity stars to be found there. The vast majority of stars with abundances less than -0.8 have gravities less than log 3.6 and are assumed to be evolved thick disk or halo stars. Three stars with abundances less than -2.0 are not plotted.

Four stars with metallicities less than about -0.8 have main sequence gravities and may be Population II blue stragglers. Some of the nearby stars with [Ca/H] around -0.5 may also be true old disk blue stragglers. The question of whether or not the Population I stars above 1 kpc might also be blue stragglers is examined in section 3.8.

Table 3.1 lists the twenty-seven distant Population I stars. They are either main sequence dwarfs or young subgiants evolving off the main sequence to the red giant branch. All have abundances greater than -0.4 dex, apart from the Am star, PS26II; and PS14I, for which I unfortunately had no spectrum, but which is classified as Population I by Philip (1986, private communication). The inclusion of PS14I makes no difference to later velocity dispersion or scale height derivations. (For both these stars the mean abundance of -0.16 dex was assigned for their age determinations.)

For consistency I used Philip's (1986, private communication) photometry where possible, although this led to the exclusion of two stars which had been classified as Population I by Rodgers, Harding, and Sadler (1981). These were PS15II and PS16II. They appeared to have near main sequence gravities from Balmer Jump measurements reported by RHS, and from their spectra, neither has the extreme 'boxy' shaped hydrogen line profiles expected from the gravities derived from Philip's c_1 indices; their gravities I would estimate to be no lower than log 3.9 or log 4.0 from comparison with other spectra.

Interestingly, these two were also the only ones for which the D(.70) and c_1 loci did not intersect: either their c_1 values were too high, or their $H\delta$ lines widths were too broad. An error such that a hydrogen line might appear to be too *narrow* might be possible from, say, first order continuum light contaminating a second order spectrum if there was a red leak in the filter, but it is difficult to imagine a process by which a line could be made accidently *broader*. That these broader lines are indicative of the actual gravities of the stars, and that the c_1 indices may be in error, would seem to be the only conclusion to be drawn at the moment; but for consistency, they have not been included in the Population I group, which contains only those stars that have very well defined gravities, temperatures and abundances.

Fifteen of the original 21 stars from Rodgers (1971) are confirmed (not including PS15II and PS16II which are still in question); of the other four, PS44II is main sequence but was found to be at only 650 pc from the plane and may be a disk star, while PS18II, PS38II and PS60II are horizontal branch stars.

PS29II, PS37II and PS46II were thought to be weak CaII K line stars by Rodgers (1971), but more accurate W(K) and photometric values indicate that they are in fact Population I. PS26II is an Am star, and was overlooked because of the K line strength criterion for selection. A further eight Population I stars have also been identified from this thesis work over the whole SGP area.

Figure 3.5 shows all the SGP stars, both nearby and distant, in the gravity-temperature plane. Figure 3.6 shows only the Population I stars (at distances greater than 1 kpc), in the same plane, in greater detail. Note that none appear in the low-gravity instability strip area: there were no metal rich low-gravity stars in that region, indicating that none of this group were possible RR Lyrae horizontal branch stars. If there had been metal rich HB stars in the sample, they would have been most likely to be found in the instability strip (or on the red HB), rather than on the blue HB. That there are no metal rich instability strip stars at all argues against there being any metal rich blue HB stars in the same sample.

This then suggests that the four lower gravity metal rich stars in the region of the blue horizontal branch are genuinely young stars evolving off the main sequence. It might be argued that there are more stars evolving through this region than would be expected relative to the number of main sequence stars. However the volume in which the lower gravity, higher luminosity stars have been sampled is around thirty times greater than than the volume in which the main sequence stars were found (due to the magnitude limit), so that the chances of observing a few stars evolving quickly through this brighter stage were reasonably good. As pointed out in Chapter 1, from Iben's (1967) evolutionary tracks, stars in the A star mass range may spend between 10 and 20 percent of their dwarf/subgiant lifetimes at gravities between 3.3 dex and 3.8 dex.

Note, however, that none of the subsequent derivations of velocity dispersion, mean abundance, scale height, or mean age for the whole group depend in any way upon the four low-gravity stars identified here as Population I, nor upon the few early A stars with weak K lines.

The properties of the sample are entirely defined by the large number of main sequence mid to late A stars, and not the small number of stars with less certain classifications. The lower gravity stars are included for completeness, because they fulfill the abundance criterion, and because their other properties are highly consistent with the whole sample. If they were to be omitted, it would make no difference to the results of this chapter.

Fig. 3.4 – The calcium abundance of the SGP A stars plotted against their distance from the plane.

(a) The numbers of stars in each abundance bin for stars at distances greater than 1 kpc from the plane.

(b) Abundance against distance. The hatched area covers the expected loci of main sequence A stars formed within the last one billion years. The Population I stars above 1 kpc are clearly distinct from Population II stars. The fall-off in their relative numbers at distances greater than 1.6 kpc is a function of the observational magnitude limit, and is no guide to the actual numbers of stars that might be found at those distances if A stars in the SGP area were to be observed systematically to fainter than 14th magnitude.

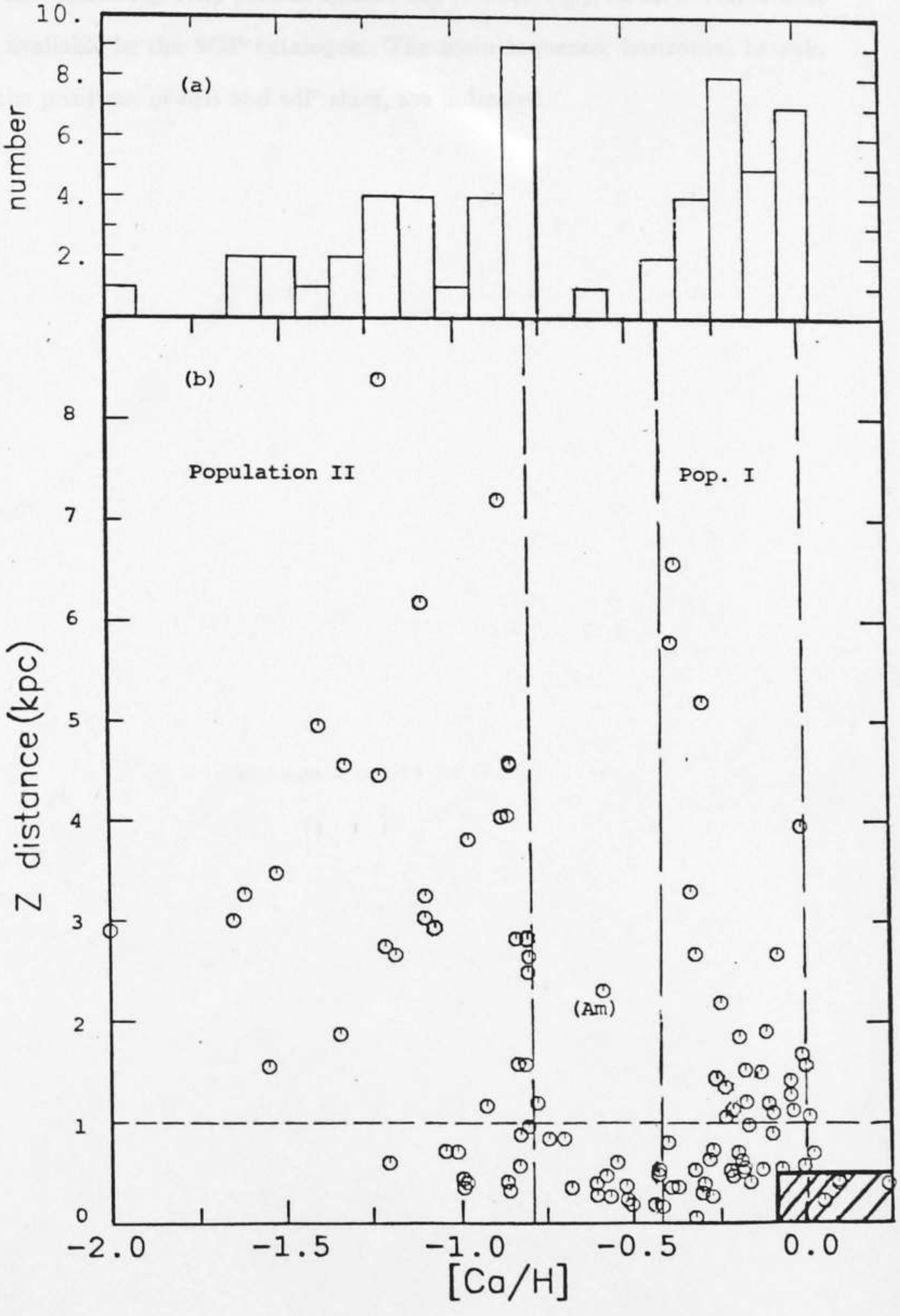

10.
8.
6.
4.
2.
number
(a)
(b)
Population II
Pop. I
(Am)
8
7
6
5
4
3
2
1
0
Z distance (kpc)
-2.0
-1.5
-1.0
-0.5
0.0
[Ca/H]

Fig. 3.5 – Surface gravity plotted against Θ_{eff} ($=5040/T_{eff}$), for all the stars with data available in the SGP catalogue. The main sequence, horizontal branch, and the positions of sdB and sdF stars, are indicated.

3·5

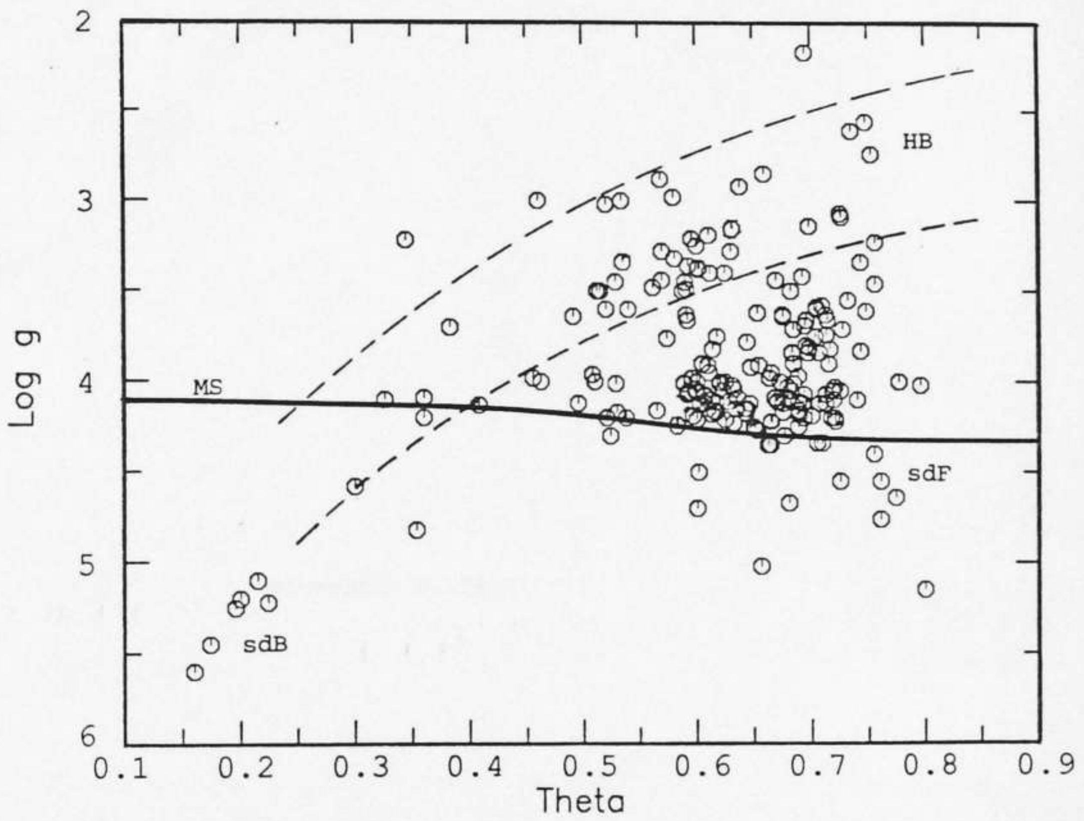


Fig. 3.6 – Surface gravity plotted against Θ_{eff} for the stars found to be Population I and greater than 1 kpc from the disk. Note that none appear in the instability strip, and that the majority are unarguably main sequence stars.

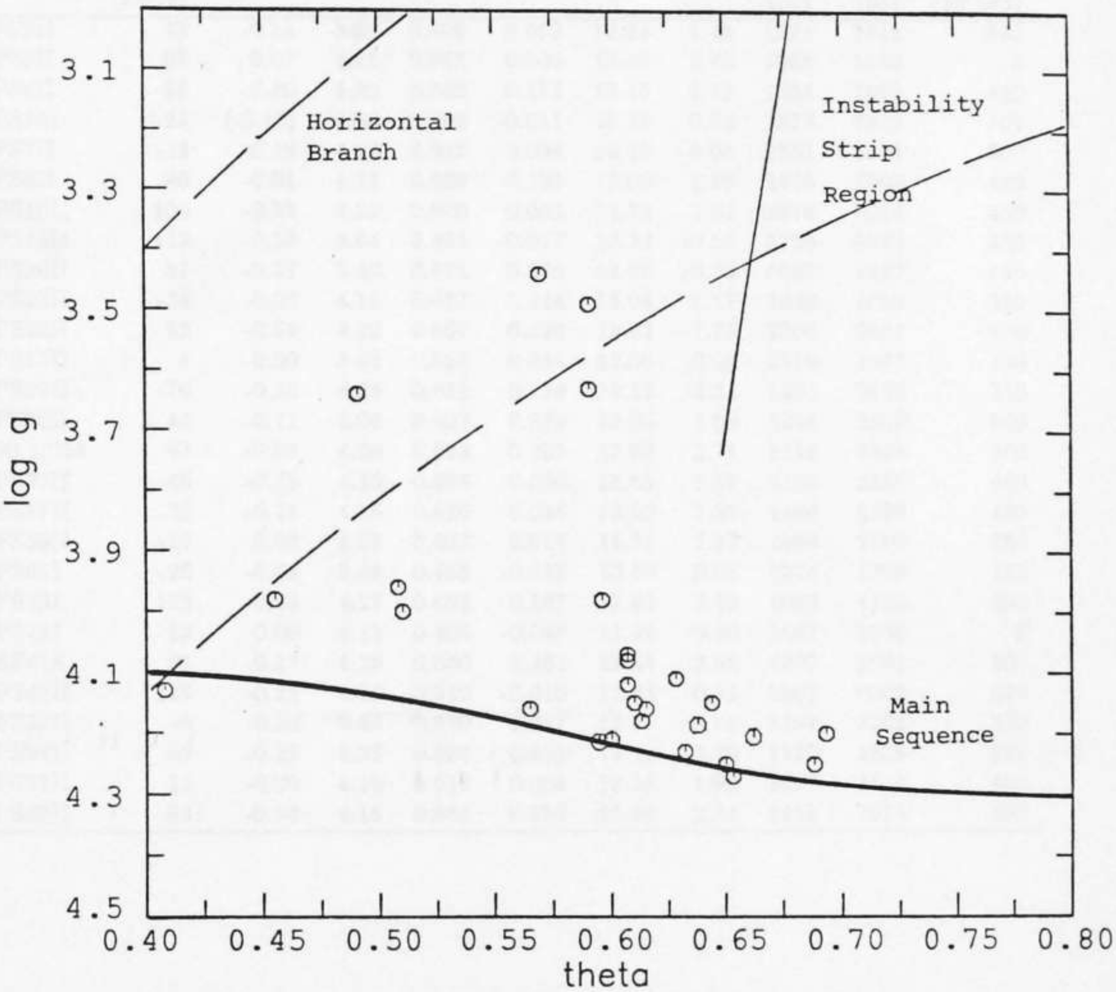

Horizontal Branch
Instability Strip Region
Main Sequence
log g
theta
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80

TABLE 3.1

The Population I SGP A stars at distances greater than one kpc from the disk.

Star	RV (km/s)	[Ca/H]	log g	Θ_{eff}	$b-y_0$	m_v	M_v	Z (pc)	Z_{max} (pc)	Age ($10^6 yrs$)
PS2II	42	-0.18	3.98	0.596	0.052	12.24	1.19	1521	1835	550
PS3II	67	0.01	4.25	0.688	0.200	13.07	2.79	1064	1833	0
PS4II	-55	-0.20	4.20	0.662	0.172	13.15	2.51	1334	1867	450
PS14I	23	(-0.16)	3.96	0.508	-0.011	11.15	0.53	1323	1413	300
PS7II	-12	-0.19	4.18	0.613	0.094	13.42	2.01	1851	1878	500
PS8II	46	-0.01	4.11	0.628	0.135	13.09	1.86	1676	2062	450
PS10II	109	-0.32	4.21	0.600	0.065	14.22	1.94	2676	5014	450
PS14II	-119	-0.38	3.64	0.491	-0.017	13.32	-0.55	5796	9938	250
PS20II	57	-0.37	3.49	0.591	0.034	14.00	-0.32	6569	7407	350
PS22II	-36	-0.26	4.16	0.637	0.144	13.04	2.17	1443	1669	550
PS26II	42	-0.58	4.12	0.607	0.080	13.62	1.73	2308	2611	500
PS27II	8	0.00	3.63	0.591	0.034	13.06	0.08	3950	3963	450
PS29II	-76	-0.13	4.23	0.632	0.139	13.32	2.31	1501	2526	250
PS30II	44	-0.11	4.08	0.607	0.079	13.00	1.60	1898	2249	500
30.1.036	87	-0.03	4.20	0.693	0.202	12.99	2.71	1118	2444	300
PS32II	-46	-0.25	4.16	0.595	0.030	13.65	1.52	2192	2556	400
PS37II	-22	-0.11	4.15	0.610	0.086	12.30	1.85	1188	1269	400
PS39II	-15	-0.08	4.07	0.607	0.078	13.71	1.57	2669	2709	550
PS65I	-26	-0.04	3.98	0.455	-0.032	10.58	0.03	1274	1389	150
PS75I	132	-0.24	4.27	0.653	0.167	12.83	2.62	1053	4183	200
PS78I	23	0.00	4.13	0.408	-0.045	11.19	0.10	1567	1660	0
SB418	91	-0.17	4.25	0.650	0.164	13.24	2.52	1205	2661	200
PS46II	119	-0.33	4.00	0.510	-0.010	13.38	0.71	3302	6302	350
PS55II	-6	-0.29	3.44	0.570	0.017	12.97	-0.68	5194	5201	250
PS98I	55	-0.23	4.23	0.593	0.053	12.24	1.96	1120	1635	350
PS57II	11	-0.09	4.16	0.615	0.098	12.16	1.92	1097	1116	400
PS62II	-53	-0.04	4.15	0.644	0.153	12.96	2.14	1415	1914	450

3.6 Kinematics.

Philip's (1986, private communication) photometry was available for all but three of the 27 Population I stars found. He classified these stars on the basis of Strömgren photometry into Population I A stars, Population I B stars, intermediate, and field horizontal branch (FHB). The 'intermediate' class stars are at gravities that are too high for the horizontal branch. It has been shown from abundance measurements that, in evolutionary terms, they are most likely to be young subgiants.

Philip distinguished horizontal branch stars from main sequence stars on the simplistic basis of gravity, which, as discussed in Chapter 1, is sometimes an inadequate classification discriminant. He also characterized two stars as 'low m_1' rather than as Population I, although, as he points out, the m_1 index has no value as a metallicity indicator for stars with $b - y$ bluer than 0.150. The stars he has so indicated are in fact bluer than $b - y$ of 0.150, and appear to otherwise be normal Population I stars.

For the twenty-seven stars at more than 1 kpc from the plane found in this study to be of Population I, the radial velocity dispersion is calculated to be 62.3 km/s.

If those that Philip has classified as Population I alone are considered, the dispersion becomes 59.1 km/s (for 16 stars). If those that he classified as Population I B stars and 'intermediate' are considered, the dispersion is then 65.4 km/s for 21 stars. The inclusion of the additional three stars with my photometry (shown in section 2.3 to be consistent with Philip's) leads to a dispersion of 65.5 km/s for 24 stars, while the inclusion of the three stars that Philip classified as FHB *lowers* the dispersion to the above value for 27 stars of 62.3 km/s. Note that the three supposed FHB stars have velocities consistent with (and even slightly lower than) the others. If only the stars with gravities higher than

3.9 dex are considered (for which there is no possibility of confusion with HB stars), the dispersion is then 59.9 km/s.

From the above, it is clear that even by the most exclusive definition of 'Population I' by an independent investigator (that is, considering only unarguably main sequence dwarf A stars, without taking into account any normal evolutionary effects on young stars) the *minimum* velocity dispersion to be found is 60 km/s. From the work reported in this thesis, utilising more information than Philip had available (such as spectral indices) and a more theoretically rigorous approach to considerations of stellar abundance and evolution, it would seem that the velocity dispersion is closer to 62 km/s, in very good agreement with that derived from Greenstein and Sargent (1974) of 63 km/s for young high velocity OB stars at the Poles; 57 km/s found by Stetson (1983) for high velocity main sequence A and F stars at all latitudes; and 56 km/s for the eight SGP Population I stars also studied by Pier (1983).

As discussed in Section 2.2, the box area was observed in detail. A 98 percent complete sample of the stars to 14th magnitude was obtained. The distance limit for completeness was around 1600 pc. To that limit, the numbers of Population I stars per cubic parsec at specific Z heights, is plotted as (log density + 10) against Z height in Figure 3.7. Table 3.2 lists the numbers of stars, volumes, and densities involved in the derivation. Section 2.2 described how an exponential scale height may be derived from simply fitting a straight line to the points, with the y intercept indicating the density to be expected at the disk.

Least squares fits were used to find the slopes and intercepts of the lines used. From Figure 3.7 it can be seen that the nearby stars have a scale height, β, of 121 pc, in excellent agreement with that expected for main sequence A stars, of 120 pc (Mihalas and Binney, 1981, p252). The density of nearby stars at the disk, $4 \times 10^{-4} pc^{-3}$, is also quite consistent with that found for main sequence A stars in the solar neighbourhood, of $5 \times 10^{-4} pc^{-3}$ (Allen, 1973).

The more distant stars indicate a scale height of 621 pc, but unfortunately there were simply not enough stars in the bins to accurately define it. For instance, the error in the three most distant bins was around plus or minus two stars, yet the addition of a single star to each of the two furthest bins would increase β to around 1000 pc. At the other end of the range, within the errors, the scale height may be only 500 pc. A scale height of around 700 parsecs might still be considered to be the best estimate.

In Section 3.7, the ages of the Population I stars are derived. They are all young, which might suggest that the approximate exponential scale height/velocity dispersion relation found for older stars in the Solar neighbourhood may not be appropriate, and that the inconsistency discussed in Section 2.3 between the high velocity dispersion and the relatively low scale height may be because the stars are young, and not yet well-mixed.

The density at the disk is equivalent to one high velocity A star in 196 disk A stars. Within the errors, the range in this is from around one in 100 to one in 300 hundred disk A stars.

Fig.3.7 – The log density of Population I A stars in the box area, plotted against their distance from the galactic plane. Two scale heights are indicated: the nearby disk dwarfs with a scale height of 121 pc, and the distant young stars with a scale height of 621 pc.

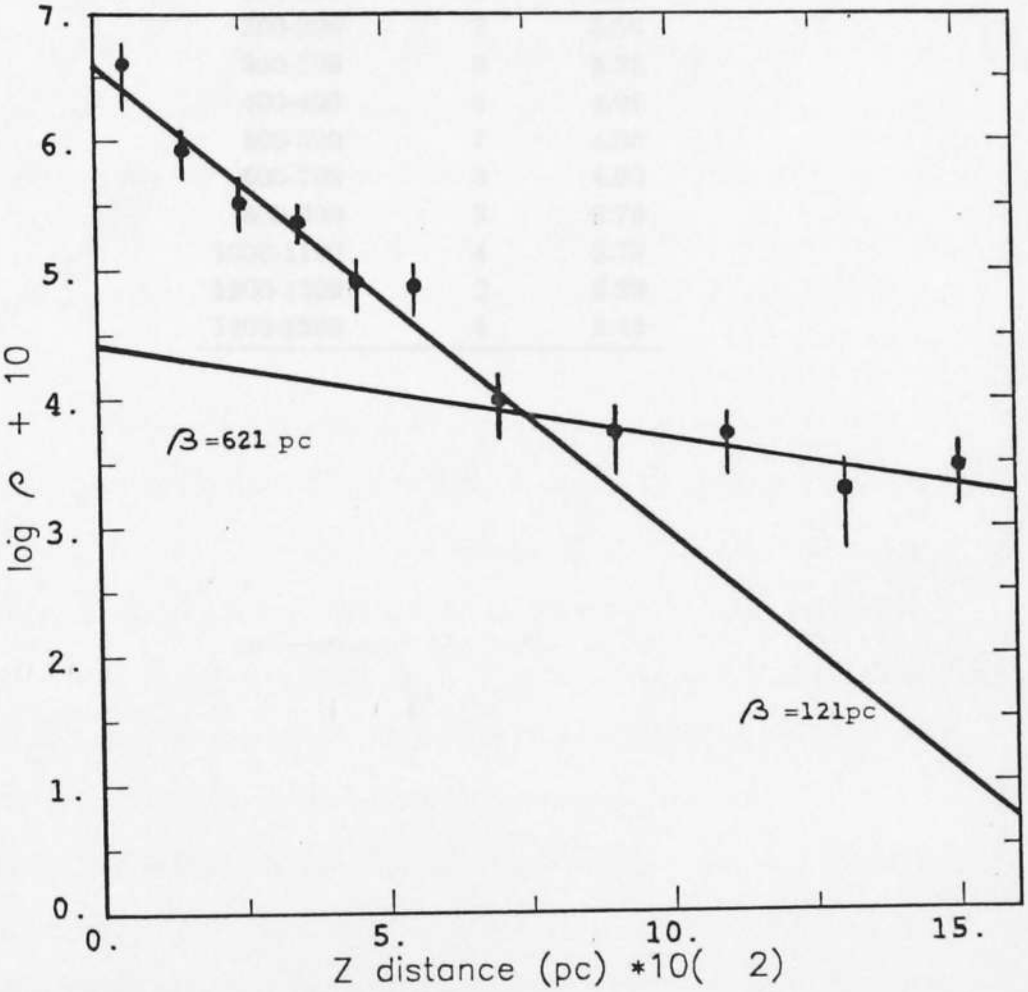

7.
6.
5.
4.
3.
2.
1.
0.
log ρ + 10
β =621 pc
β =121pc
0.
5.
10.
15.
Z distance (pc) *10(2)

TABLE 3.2

Scale height derivation for SGP Box area.

Z(pc)	No.Stars	$\log \rho + 10$
0-99	4	6.60
100-199	6	5.93
200-299	7	5.56
300-399	9	5.38
400-499	5	4.91
500-599	7	4.88
600-799	3	4.00
800-999	3	3.78
1000-1199	4	3.73
1200-1399	2	3.29
1400-1599	4	3.46

3.7 Ages.

The Revised Yale Isochrones were used to generate isochrones for the range of metallicities described in section 3.4, in the gravity-temperature plane. The isochrones were for ages of from 50 million years (5×10^7) to 2 billion years (2×10^9) in 50 million year increments. (Isochrones for stars older than about 1.5×10^9 years fall in the F star range). Population I stars were plotted in this plane, for their appropriate metallicities, and their ages to the nearest fifty million years were found. They are listed in *Appendix I, Table 3.* Errors for stars with Θ_{eff} less than 0.600 are around ± 50 million years; between 0.600 and 0.650 around ± 100 million years, and greater than 0.650 about ± 150 million years.

The disk Population I A (and a few early F) stars up to 500 pc from the plane, not surprisingly, were found to have been formed randomly at all ages from around 2 billion years ago to the present time. This demonstrates that the technique of age determination utilised in this study is capable of indicating the ages of stars as old as 2 billion years. Figure 3.8 shows the distribution of Population I stars within 500 pc of the disk in the gravity-temperature plane (relative to solar abundance isochrones for illustrative purposes).

Figure 3.9 shows the distribution of Population I stars further than 1 kpc from the disk plotted in the same plane, and it shows a distinct and significant difference from Figure 3.8: *not one distant Population I A star is older than 600 million years.* (As plotted, it appears that 500 million years is the limit, but some of the actual ages found for slightly more metal poor stars (see Table 3.1) are up to 600 million years.)

The unoccupied portion of Figure 3.9 is where A stars from 0.6 to 1.0 magnitudes brighter than main sequence stars would normally be found. That intrinsically less luminous late-type A stars are seen on the main sequence below that area indicates that it is not a magnitude or spectral type cutoff that has led to this result. Errors in the gravity-temperature determinations also would not scatter plotted stars into the unoccupied region.

A late-type 14th magnitude main sequence A star with an absolute magnitude of around 2.7 could be seen to 1800 pc from the plane, whereas to the same limit an evolved late A star of around 1.7 in absolute magnitude could be seen to 2900 pc. For the area observed at the SGP, the ratio of the volumes in which these stars could be sampled is 1 to 3.6; that is, in this survey, *distant Population I A stars older than 600 million years had greater than three times the probability of being observed than lower-luminosity stars of the same colour, yet not one was found.*

From Figure 3.8 it is clear that among such an equivalently derived sample of nearby disk stars (observed, reduced, and ages found by the same methods as the distant stars), a significant number will be found at those evolved luminosities and greater ages. Interestingly, Figure 3.8 also illustrates a volume limited sample of stars; if it had been magnitude limited, then even more intrinsically brighter evolved young A stars would have been plotted relative to main sequence stars. In other words, Figure 3.8 indicates the *lower* limit of relative numbers of Population I stars that would normally be found both older and younger than 600 million years in the colour range of this survey, rather than an upper limit.

Figure 3.10 shows the relative proportion of stars in the each sample as a function of age. The implication of these findings is that, while the young disk Population I A stars have been formed randomly at all epochs, distant high velocity Population I A stars have a restricted and significant range of ages. This suggests that they are not the products of events continuous in time, but instead appear to be the result of a discrete and relatively recent event which initiated a burst of star formation at around 6×10^8 years ago.

Fig 3.8 – Surface gravity plotted against temperature for a control group of Population I SGP A stars, all within 500 pc of the galactic disk in the Z direction, with isochrones for 10^8 years. They were observed and reduced in the same way as the distant A stars, and appear to have random ages of formation from within the last 50 million years up to 2 billion years ago. $(b-y)_0$ of 0.220 was the approximate completeness limit of the SGP catalogue.

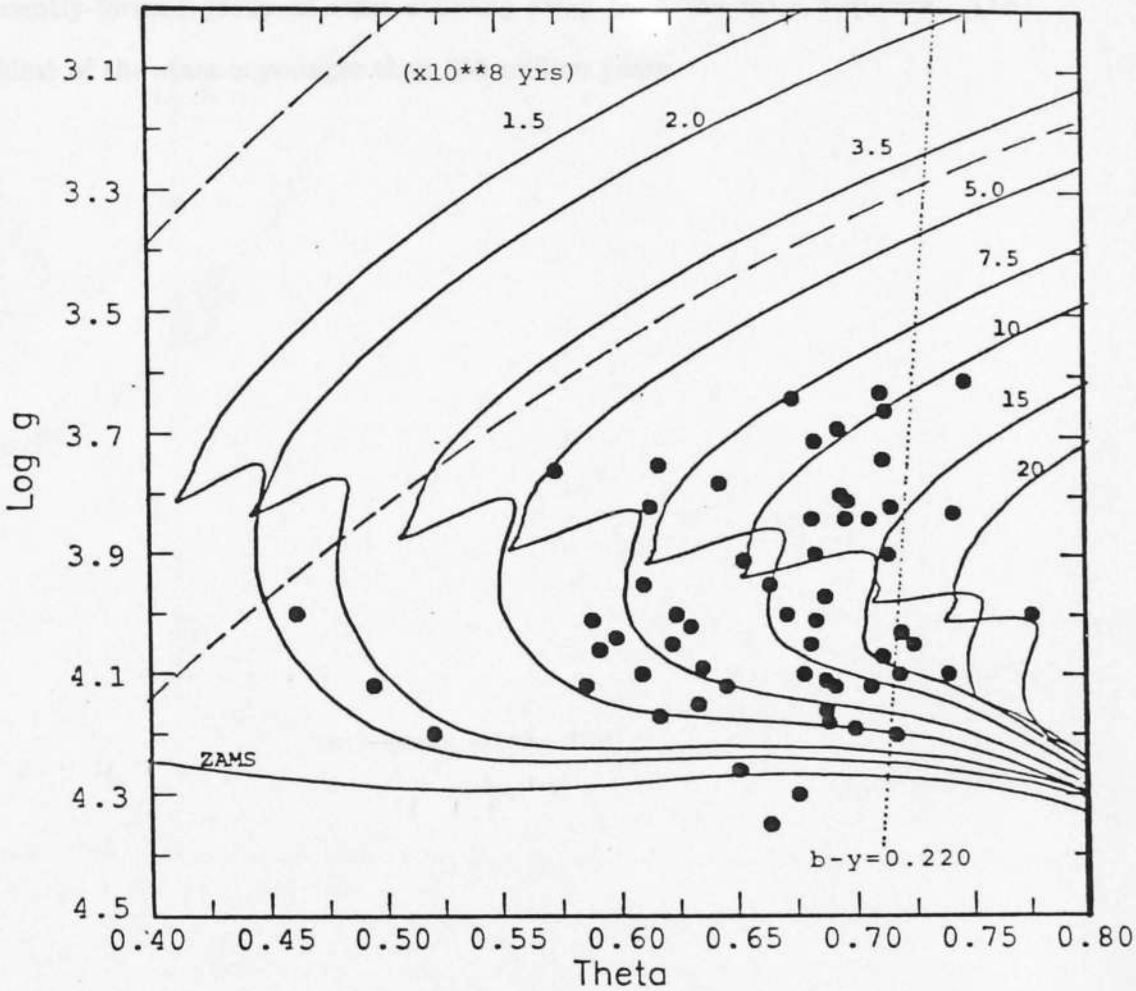

(x10**8 yrs)
1.5
2.0
3.5
5.0
7.5
10
15
20
ZAMS
b-y=0.220
Log g
Theta
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80

Fig. 3.9 – Surface gravity plotted against temperature for the Population I A stars at distances of more than 1 kpc from the plane, with the same isochrones, and the same completeness limit. They have the distinctive appearance of a recently-formed group of stars evolving away from the main sequence. The oldest of the stars is younger than 600 million years.

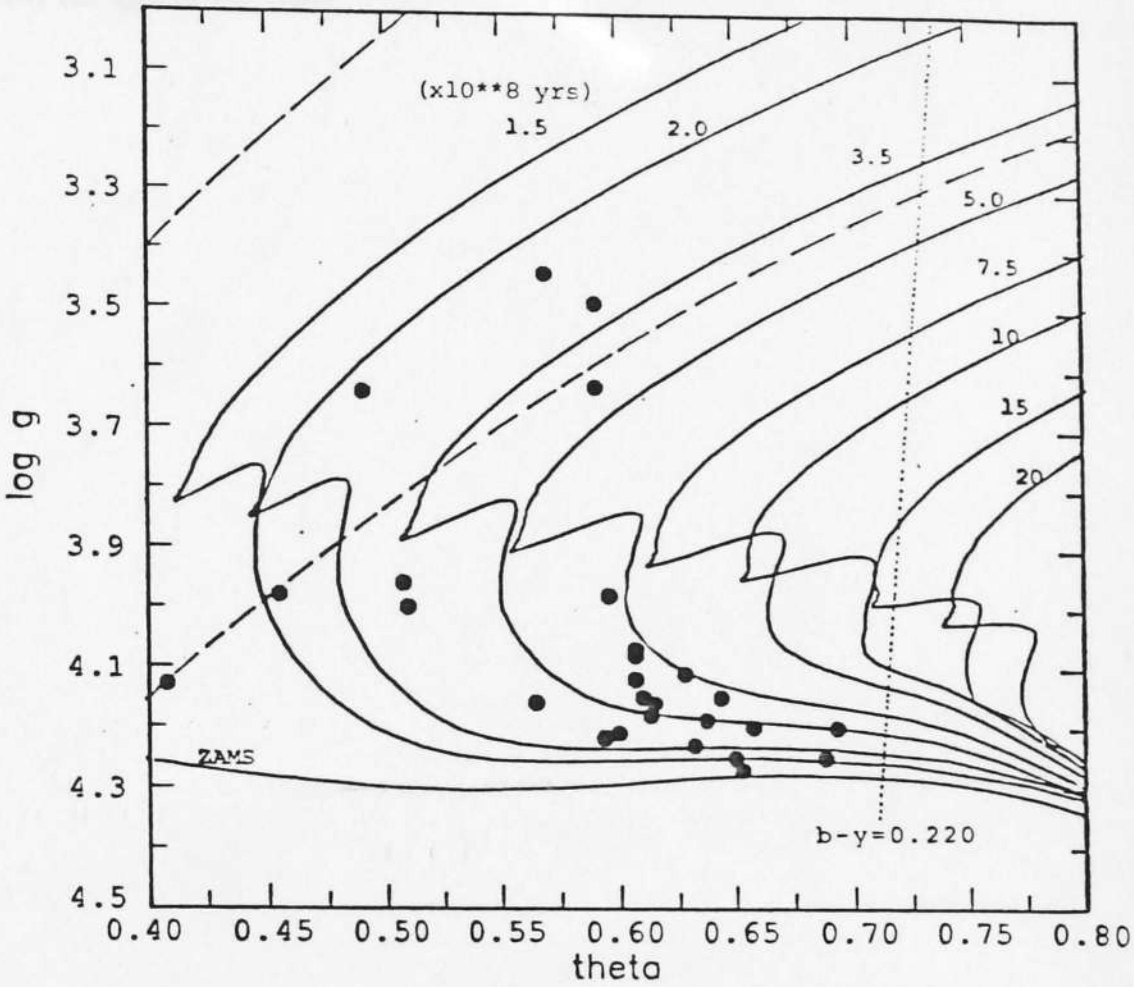
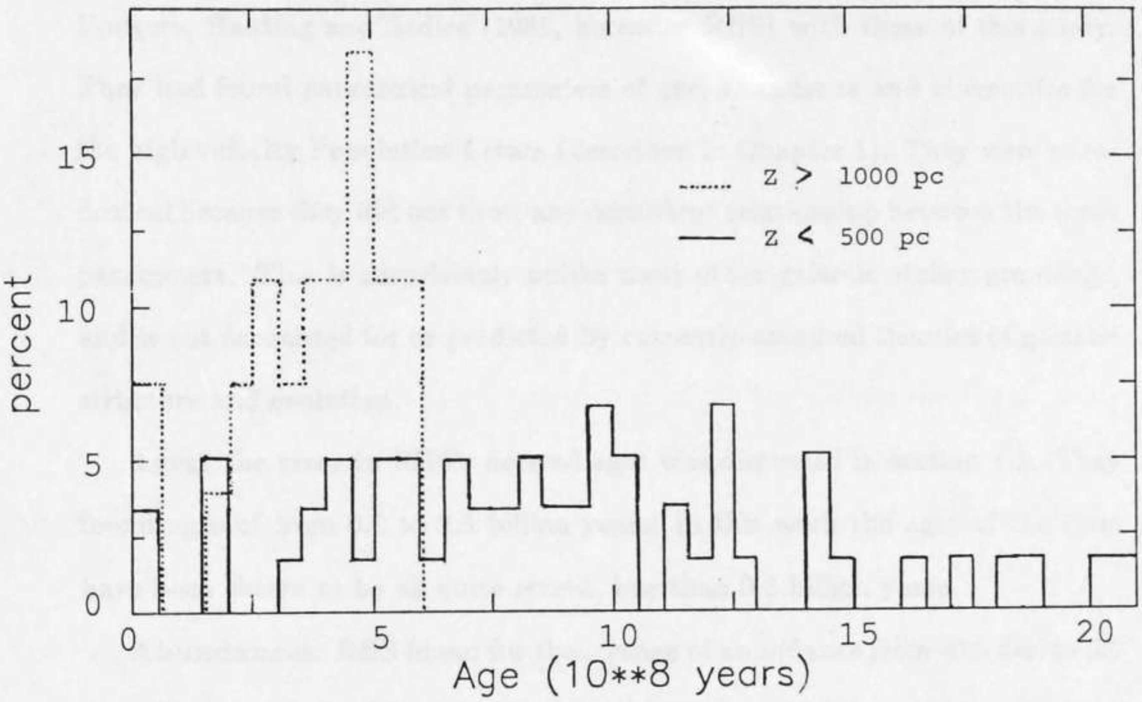

(x10**8 yrs)
1.5
2.0
3.5
5.0
7.5
10
15
20
ZAMS
b-y=0.220
log g
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
theta

Fig. 3.10 – The relative percentage of the members of each group of Population I stars (at less than 500 pc, and at greater than 1000 pc from the plane), plotted against the ages of the stars.



percent
15
10
5
0
0
5
10
15
20
Age (10**8 years)
Z > 1000 pc
Z < 500 pc

3.8 Comparison and Discussion.

At this stage it is appropriate to compare the results of Rodgers (1971) and Rodgers, Harding and Sadler (1981, hereafter RHS) with those of this study. They had found paradoxical parameters of age, abundance and kinematics for the high velocity Population I stars (described in Chapter 1). They were paradoxical because they did not show any consistent relationship between the three parameters. This is surprisingly unlike most other galactic stellar groupings, and is not accounted for or predicted by currently-accepted theories of galactic structure and evolution.

Ages: the error in RHS's derived ages was discussed in section 1.5. They found ages of from 0.8 to 2.5 billion years: in this work the ages of the stars have been shown to be all quite recent, less than 0.6 billion years.

Abundances: RHS found for their range of abundance from -0.5 dex to 0.0 dex. Their result has been confirmed by this study, which found the range to be from around -0.4 dex to 0.0 dex, 40 percent of the Population I abundance to normal Population I values. The mean was -0.16 dex (70 percent of Population I metallicity); this is a high value compared to halo stars, but is still surprisingly low relative to young disk stars.

Kinematics: Rodgers (1971) had found a velocity dispersion of 66 km/s; this study found a value of 62 km/s. Again, both results are in very good agreement.

In section 1.7 a number of possible sources of the stars other than that originally suggested by RHS were discussed (see Table 1.1). They were that:

1) The stars are the high velocity tail of a non-Gaussian disk distribution.

2) They are formed at the outer edges of fast-moving supernova bubbles.

3) They are formed from the impact on the disk of infalling gas thrown up from the plane by supernovae.

4) They are disk stars accelerated by encounters with black holes.

5) They are from the same population as metal rich RR Lyrae horizontal branch stars.

6) They have incorrect gravities and abundances, and are just misidentified horizontal branch stars.

7) They are blue stragglers from the old disk or thick disk.

Hypotheses 1) to 4) are dependent upon the high velocity A stars being identical to young disk A stars apart from having been accelerated by some mechanism. Upon comparison, it appears that none of these four theories is viable. With regard to abundance, they all predict that the stars be of at least solar metallicity (young disk A stars are from -0.1 dex to 0.25 dex), and in the case of 2) and 3), that they would probably be enriched to greater than solar abundance from material ejected by supernovae. Relative to their ages, there would be no reason why any of these mechanisms would become effective at only 600 million years ago: they would be expected to occur randomly over time. Thus, while these theories might account for the kinematics of the stars, they cannot account for their abundances or ages.

Hypothesis 5), that they might be from the same population as metal rich RR Lyrae HB stars, is disproven from the fact that none of the high velocity A stars falls into that region of the gravity-temperature plane, and any bluewards extension of such a population would be unlikely to exist without some RR Lyrae stars being present. In addition, the metal-rich RR Lyrae stars are descendants of old disk stars, which would be expected to have a velocity dispersion of only around 30 km/s.

Hypothesis 6) that their abundances and gravities are incorrect, and that they are really just horizontal branch stars, is most unlikely. The parameters found here, to a high level of accuracy, show that the majority of the stars are at main sequence gravities and abundances, distinct from any possible confusion with horizontal branch stars.

Hypothesis 7), that they may be blue stragglers, has already been shown to be unlikely from consideration of their rotational velocities (Chapter 2). In addition, if they were to be old disk blue stragglers (and consistent with the abundances found here) their velocity dispersion of 62 km/s is around twice the value that would be expected for old disk stars. If they were to be halo or thick disk blue stragglers (consistent with the large dispersion), their mean metallicity is too high, by a factor of four for the thick disk and a factor of eight or more for the halo. Both the abundance and velocity dispersion measurements in this work are well enough defined that these limitations are quite stringent.

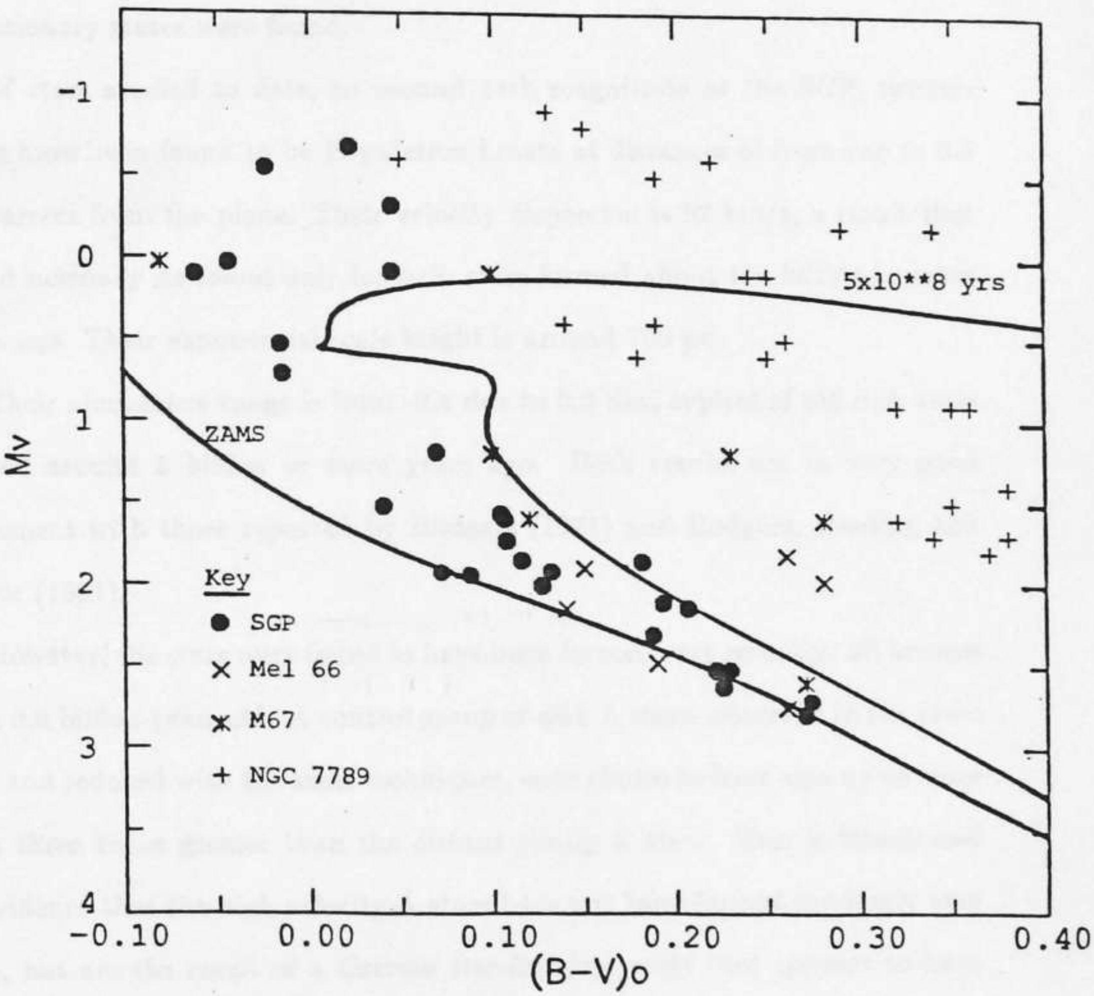
With regard to ages, if they were blue stragglers the actual ages found here would naturally not be applicable; but it would be most unlikely that a population of blue stragglers, randomly formed over long periods of time, and which are known to appear at the whole range of main sequence gravities and temperatures, would be so distributed as to give the appearance of young coeval stars.

In other words, blue stragglers are indeed to be found in the region of the gravity-temperature plane that is unoccupied by the high velocity A stars. (See Figure 3.11 for a plot of some known blue stragglers and the SGP distant high velocity A stars in the equivalent plane of M_v against $(B-V)_0$). Thus there are three lines of evidence (kinematics, isochrones, and rotational velocities) upon which to reject the hypothesis that the young high velocity A stars might be old disk blue stragglers; and three lines of evidence (abundances, isochrones, and rotational velocities) upon which to reject the suggestion that the high velocity stars might be thick disk or halo blue stragglers.

Thus far, discussion has centered on what is *not* the origin of the A stars. To arrive at conclusions about what their source may actually have been, it may be useful to first describe results from a search for them among Solar neighbourhood stars. This is reported in Chapter 4, while a discussion of the possible origin and relationship of the high velocity stars to other galactic populations is to be found in Chapter 5.

Fig. 3.11 – The location of the young distant SGP A stars and some cluster blue stragglers in a colour-magnitude diagram. Melotte 66 is an open cluster of around -0.5 dex metallicity, aged $6 - 7 \times 10^9$ years (Anthony-Twarog *et al*, 1979); M67 is an open cluster of solar metallicity, aged 3×10^9 years (Hagen, 1970); and NGC 7789 is also a metal rich open cluster aged around 1.6×10^9 years (Hagen, 1970).

It is clear from this diagram that, whatever may be the true ages of blue stragglers, they do not give the appearance of coevality; and that they are just as likely to be found redwards of the locus of a 500 million year isochrone as bluewards, unlike the SGP A stars.



5x10**8 yrs
ZAMS
Mv
(B−V)o
Key
SGP
Mel 66
M67
NGC 7789
-1
0
1
2
3
4
-0.10
0.00
0.10
0.20
0.30
0.40

3.9 Summary.

The derivation of surface gravities, effective temperatures, and abundances relative to solar calcium abundance, for the stars in the SGP blue star catalogue, is described. The stars were classified into Population I or II with respect to those derivations. Masses and distances appropriate to their abundances and evolutionary states were found.

Of stars studied to date, to around 14th magnitude at the SGP, twenty-seven have been found to be Population I stars at distances of from one to 6.5 kiloparsecs from the plane. Their velocity dispersion is 62 km/s, a result that would normally be found only for halo stars formed about ten billion or more years ago. Their exponential scale height is around 700 pc.

Their abundance range is from -0.4 dex to 0.0 dex, typical of old disk stars formed around 5 billion or more years ago. Both results are in very good agreement with those reported by Rodgers (1971) and Rodgers, Harding and Sadler (1981).

However, the stars were found to have been formed very recently: all are less than 0.6 billion years old. A control group of disk A stars, observed in the same field and reduced with the same techniques, were shown to have ages up to more than three times greater than the distant young A stars. This is interpreted as evidence that the high velocity A stars have not been formed randomly over time, but are the result of a discrete star-forming event that appears to have begun around 6×10^8 years ago.

The finding of RHS that their ages, abundances and kinematics are unlike any other known population of stars, has been supported; and the new result of a distinct and recent epoch of formation for the stars has emphasized their unusual status.

Hypotheses suggested in Chapter 1 as potential disk sources for the high velocity stars have been examined relative to the findings of this study. None of the theories can fully account for their range of properties. The blue straggler hypothesis in particular has been shown to be not feasible. Further discussion of the possible origin of the high velocity stars is reserved until Chapter 5.

Chapter 4

High Velocity A Stars in the Solar Neighbourhood.

4.1 Introduction.

The density at the disk of young, high-velocity A stars was suggested to be around one in 800 of disk A stars by Rodgers, Harding and Sadler (1981). From a more complete sample, it was found in Chapter 3 that the density may actually be higher, from around one in 300 to one in 100. Stetson (1981a, 1981b, 1983) studied nearby A and F stars and found a number that had large space motions and were also Population I by photometric criteria.

He used the SAO proper motions, after confirmation from other studies that the proper motions were relatively consistent. The SAO catalogue and the confirmation catalogues are derived from many sources of proper motions, which are of varying quality and consistency. Stars were accepted as high velocity candidates on the basis of spectral type and a lower limit of total proper motion. The spectral types were from the HD catalogue, so they were fairly approximate, and naturally they were not classified with regard to luminosity.

The acceptance criterion for each declination band was different, depending on the agreement between the SAO and confirmation catalogue values for the total proper motions in the declination band. Stars in the confirmation catalogue which had a lower limit of total proper motion between 0.050 arcseconds/yr and 0.075 arcseconds/yr were then retained as high velocity candidates.

These selection procedures may have biased Stetson's sample, so that statistical information derived from it may not be reliable. However, Stetson was most successful in identifying a number of nearby young, high-velocity A and F stars. The sample had a radial velocity dispersion of 57 km s^{-1}, similar to the value of 62 km s^{-1} found in this study for the SGP stars. It seems reasonable to postulate, as Stetson did, that the nearby stars are members of the SGP population presently travelling through the solar neighbourhood.

In order to obtain a complete sample of local high-velocity A stars for statistical analysis, a single declination band was chosen for intensive study. Eggen (1984, private communication) pointed out that the band from $-40°$ to $-50°$, had proper motion results from two surveys in the Yale Zone catalogue (Hoffleit, 1970) with a high degree of accuracy and consistency, so this declination band was chosen.

The results of that study are reported in this chapter. The selection procedure used is described. The observations and reductions are discussed, from which information such as surface gravities, temperatures, ages, metallicities and radial velocities were derived in the same way as the SGP stars. In addition, the UVW velocities have been calculated. (U is positive in the direction of the galactic anticentre, V is positive in the direction of galactic rotation, and W is positive towards the North Galactic Pole.) These velocities describe the three-dimensional motion of the stars in the Galaxy and yield a great deal of useful information.

In particular, it is important to find out if the A stars rotate with the young galactic disk; or if they rotate like a halo population, lagging behind the disk by hundreds of kilometres a second; or if they rotate at velocities between these extremes. This information may help determine possible origins of the stars.

The selection effects on kinematic results derived from a sample in a single declination band are examined in detail. Some high resolution spectra were obtained for $v \sin i$ measurements (which were also used in the calibration described in Chapter 2, section 2.6). Some of the stars in the declination band were also observed by Stetson, which offered useful comparisons and external reliability estimates.

4.2 Selection of the Sample.

Rather than using a cutoff technique based on proper motions with varying selection criteria and less accurate spectral types, as Stetson did, it was decided instead to calculate the transverse velocities of the stars (henceforth called Yale stars) from an estimated distance modulus and the proper motion. This is conceptually a similar procedure, but it was possible to attain a higher level of accuracy and consistency. The stars with large tranverse velocities were then studied in greater detail in order to derive more accurate absolute magnitudes and distances.

All the catalogues used were on computer tapes obtained from the Centre de Stellaires Données, Strasbourg, and without them it would not have been possible to correlate such large amounts of information.

Two dimensional MK spectral types from the invaluable Michigan Spectral Catalogue (Houk, 1978, volume 2) were used to estimate the absolute magnitudes of the Yale stars, using the spectral type and luminosity calibrations of Straižys and Kuriliene (1981). In order to correlate the Yale Zone catalogue stars (listed by Cape number and CoD number), with the Michigan stars in the same declination band (listed by HD number), the Catalogue of Stellar Identifications (Ochsenbein, Bischoff, and Egret 1981) was used.

Stars of luminosity classes I to III were excluded, so that most horizontal branch giants were discarded from the sample. Some stars in the Yale Zone catalogue were fainter than the HD limit of the Michigan catalogue, and did not have accurate spectral types, only the Cape spectral type estimates. These were retained in the sample as only a few stars were involved. Altogether it was found that there were 3,256 A stars of luminosity classes IV, IV/V and V, including Am and Ap stars, in the Yale Zone catalogue. Note that *all* A stars in these luminosity classes were considered, there was no selection until the transverse velocities were calculated as below.

Their distances were initially found from the distance modulus (see equation 3.9) then an estimate of the extinction in the direction of each star as an function of the distance was included, derived from Fitzgerald, (1968). The new distance and extinction calculations were then iterated until they were consistent.

Their transverse velocities (in km s^{-1}) were found from

$$T_v = 4.74\, d\, \mu_{tot} \tag{4.1}$$

where d is the distance (in parsecs) and μ_{tot} is the total proper motion (in seconds of arc). Of the 3,256 A stars, 93 had estimated transverse velocities greater than 70 km s^{-1}, and these stars were chosen as the sample for investigation.

The Yale Zone catalogue lists two sets of proper motions: those from the Yale survey alone, and those from the mean of the Yale and Cape results (which were the proper motions used for selection of the sample). However, the Yale survey had found systematic differences between the proper motions in declination for the two surveys, and made adjustments to the *Cape* values before taking the mean. These adjustments were usually small (less than -0.004 arcseconds) but for 9th to 11th magnitude stars, from 7 to 19 hours R.A., the adjustments were from -0.006 to -0.010 arcseconds. It was precisely from this magnitude and R.A. grouping that many of the A stars had been selected, some with apparently large negative proper motions in declination, which may have been an artifact of this adjustment.

The Yale catalogue compilers also plotted their mean proper motions in R.A. and declination, as a function of R.A., relative to a theoretical curve (their Figure 2). There was good agreement between the predicted and measured mean proper motions in declination for most apparent magnitudes, except for 9th to 11th magnitude, where the measured proper motions were around 0.010

arcseconds more negative than the predicted ones. This may indicate either that the stars actually have a mean motion towards negative declinations that is not predicted by local kinematic models, or perhaps that the systematic difference between the Cape and Yale values was not an error in the Cape results, as assumed by the Yale compilers, but an error instead in the Yale results.

In order to determine what would have been the effect of using the Cape survey alone for the selection of the sample, the selection procedure was repeated using the Cape proper motions, and those stars with estimated transverse velocities higher than 70 km s^{-1} were compared to those selected with the 'mean' Yale proper motions. The SAO catalogue was actually used for the selection, because for the vast majority of stars in the declination band $-40°$ to $-50°$ it lists the Cape proper motions, on the FK4 system (like the Yale catalogue).

The result was that, while the Yale survey estimated that there were 93 A stars with transverse velocities greater than 70 km s^{-1}, the Cape survey did not select 22 of these stars; instead, only 75 stars were estimated by the Cape survey, three stars of which had not been selected by the Yale survey. This suggests that the 'mean' Yale values generally overestimated the proper motions, but that the vast majority of those stars indicated by the Cape survey to have high transverse velocities also had high transverse velocitites from the Yale proper motions.

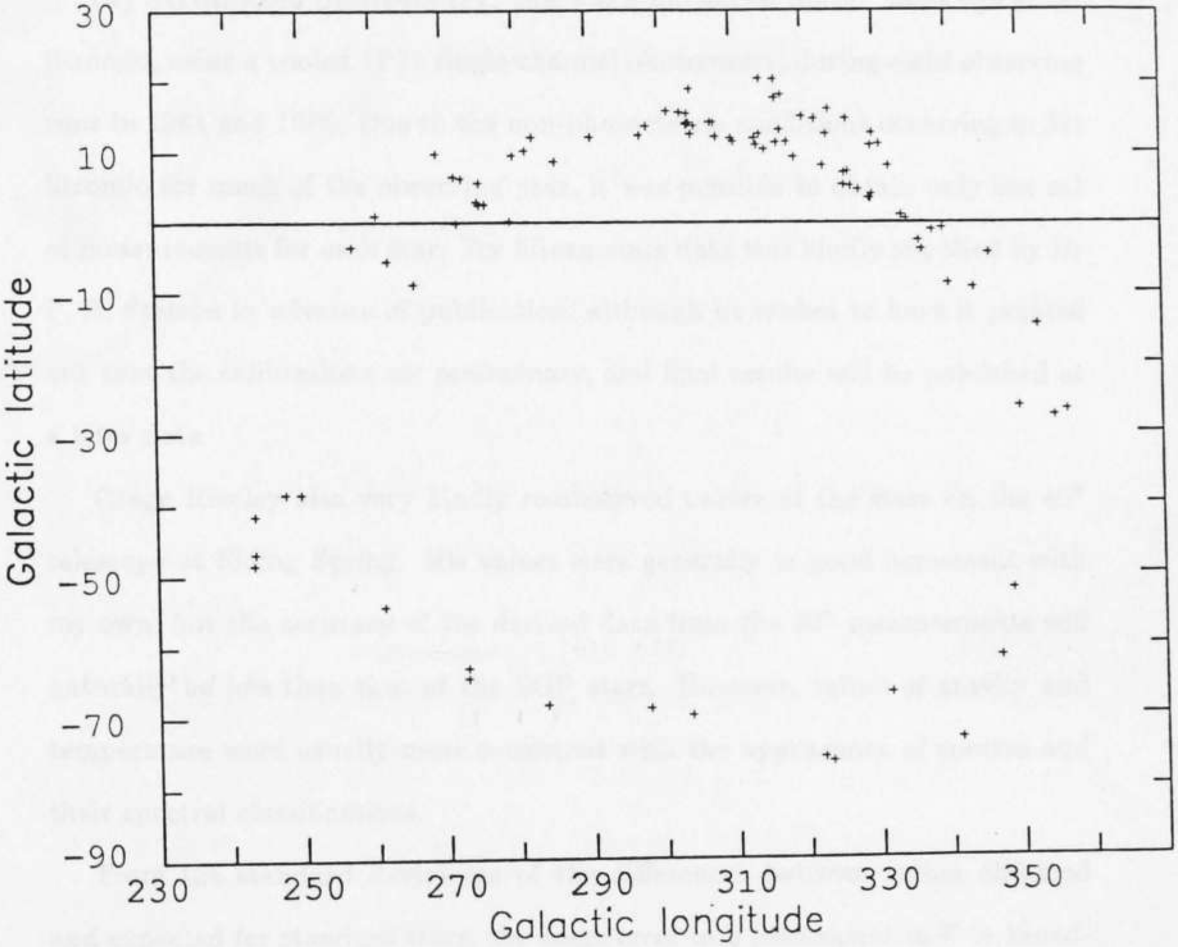
It appears then that the selection procedure found most of the high proper motion A stars in both catalogues, plus some stars with possibly overestimated proper motions from the Yale survey. It would seem that very few true high proper motion stars were missed by using the 'mean' Yale values. In the calculations of more accurate distances and space motions (Sections 4.4 and 4.5), results were derived from using the Yale proper motions alone, the Cape proper motions alone, and the true *unadjusted* mean proper motions.

The latter were accepted as the proper motion values with the highest weight, as it it possible that some of the apparently overestimated Yale values may actually be correct, and an unadjusted mean seems to be the only way to allow for this. The proper motions in R.A. also had a minor correction to put them into the highly accurate FK5 coordinate system (Fricke, 1982), of +0.00085 arcseconds/yr.

The galactic coordinates of the A star sample are plotted in Figure 4.1. From this it can be seen that the declination band goes from about $l = 320°$, $b = -80°$, through the galactic plane at around $l = 270°$, up to $l = 320°$, $b = +20°$, and through the plane again at $l = 340°$. The line of sight of the declination band projects into a hollow cone mainly in the fourth quadrant, trailing the sun and mostly inside the solar radius.

The 93 A stars selected for observation are listed in *Appendix II, Table 1*, which gives the HD, Cape and SAO numbers, the 1950 equatorial coordinates, the galactic coordinates, the Michigan spectral types, and the unadjusted mean proper motions of the Yale and Cape values. Four other interesting high velocity stars (numbers 94 to 97) are also listed. They were observed and reduced in the same way as the Yale stars, and are discussed in Section 4.8.

Figure 4.1 – The Galactic coordinates of the Yale star sample. There would seem to be more high velocity candidate stars at $l = 310°$ to $330°$ above the galactic plane, rather than at the plane, as would be expected if the stars were randomly situated among disk stars.


30
10
−10
−30
−50
−70
−90
Galactic latitude
230
250
270
290
310
330
350
Galactic longitude

4.3 Observations.

Photometric and spectral observations were required in order to derive gravities, temperatures, abundances, radial velocities, distances and ages, in the same way as the SGP stars.

(a) Strömgren photometry: this was obtained on the 30" telescope at Mt Stromlo, using a cooled 1P21 single-channel photometer, during eight observing runs in 1984 and 1985. Due to the non-photometric conditions occurring at Mt Stromlo for much of the observing year, it was possible to obtain only one set of measurements for each star. For fifteen stars data was kindly supplied by Dr P. B. Stetson in advance of publication, although he wishes to have it pointed out that the calibrations are preliminary, and final results will be published at a later date.

Gregg Rowley also very kindly re-observed twelve of the stars on the 40" telescope at Siding Spring. His values were generally in good agreement with my own, but the accuracy of the derived data from the 30" measurements will naturally be less than that of the SGP stars. However, values of gravity and temperature were usually most consistent with the appearance of spectra and their spectral classifications.

From the standard deviations of the differences between values obtained and expected for standard stars, the mean error in y (equivalent to V in broadband) is ± 0.065; in $b-y$ is ± 0.006; in m_1 is 0.011, and in c_1 is ± 0.023; however, program stars might be expected to have larger errors than standards because they were several magnitudes fainter.

(b) Medium resolution spectra: These were observed on the Mt Stromlo 74" telescope at coudé focus, and acquired and reduced in exactly the same way as was described for the SGP stars in Chapter 2, section 2.5(a). Nights of observations were 21st June, 14th August, 8th, 9th, 10th October, all in 1984;

and 29th January and 23rd July in 1985.

Radial velocities, CaII K line and D(.70) measurements were also obtained using the same techniques described in sections 2.5(b), (c), and (d). In Figure 2.3(a, b, c), the cross symbols show the comparison of my radial velocities with those found by Stetson (1983). Figure 2.3(c) shows the adopted mean method values, and there is good agreement with Stetson's results.

(c) High resolution spectra: Again, these were obtained on the 74" telescope at Mt Stromlo, and reduced as described in section 2.6(b). Rotational velocity values were found from the calibration also described in that section. Figure 2.9 shows $v \sin i$ results for seven stars in common with Stetson (1983). The agreement is good.

The results of this section are listed in *Appendix II, Table 2*, which shows the HD number, the results of Strömgren photometry, the radial velocity, the D(.70) values, the CaII K line equivalent width, and the rotational velocities (where obtained).

4.4 Gravities, Temperatures, Abundances, Distances and Ages.

The technique for derivation of the surface gravities and the effective temperature is the same as that described in Chapter 3, section 3.2, utilising $b-y$, c_1, and D(.70). This was slightly less straightforward than the SGP stars because sometimes significant amounts of differential reddening were involved.

Many of the stars had only a small amount of differential reddening as they were out of the galactic plane, but for eight stars in the plane at $l = 330°$ to $340°$ it was between 0.1 and 0.2 magnitudes. For a few of these stars either of the two intersections of c_1 and D(.70) were indicated, but from the appearance of the spectrum and the Michigan spectral type it was possible to decide which one was correct. In general, the errors in log g are estimated to be around ± 0.12 and in Θ_{eff} are ± 0.012.

Since the stars were close to the disk, interstellar calcium may have contributed to the strengths of the calcium lines. A correction to the CaII K line equivalent width was made according to a relation found by Searle and Rodgers (1966), between the amount of interstellar calcium and the differential reddening, $E_{(B-V)}$ (equivalent to $1.35E_{(b-y)}$).

$$W(K)_{int} = 0.580\, E_{(B-V)} + 0.070 \qquad (4.2)$$

This amount was subtracted from the measured equivalent width, then the calcium abundances were found as described in section 3.3. This calibration was not used for SGP stars because Searle and Rodgers found it was applicable only in the plane and not at high latitudes. (In any case, the amount of interstellar calcium was expected to be very small at the SGP, see section 2.3).

Because of the uncertainty in the exact amount of interstellar calcium present at different positions in the plane, the abundances for the Yale stars may be slightly less accurate than the SGP stars. For most of the stars, the amount of interstellar calcium indicated by the above relation is small, and only the few stars in areas of high extinction and with weak calcium lines would be significantly affected by it.

The stars were classified into Populations I and II on the basis of gravity and abundance, as for the SGP stars. There were fewer horizontal branch stars in this sample because, as mentioned, only luminosity classes IV to V were considered, while most HB stars are class III giants. Fourteen out of ninety-three stars were both metal poor and low gravity, and were classified as Population II horizontal branch stars.

Five stars had main sequence gravities and low calcium abundances (less than -0.5 dex) and may be blue stragglers (they did not appear to be Am stars). Seventy-four stars had abundances greater than -0.5 dex, with main sequence or slightly evolved gravities, and were classified as Population I.

Of these stars, forty-four had total space motions (from transverse and radial velocities) greater than 70 km s^{-1}. These stars are discussed later as members of the high-velocity group. The remaining thirty Population I stars had space velocities less than seventy km s^{-1}, and had UVW velocities that indicated that they are probably from the high velocity tails of the normal disk distribution. They are discussed later as the low-velocity group of stars.

The Population I stars were assigned masses on the basis of their abundances, gravities and temperatures, as for the SGP stars (section 3.4), and the HB stars were assumed to be $0.55m_{\odot}$. Luminosities, absolute visual magnitudes, and distances and ages were then derived as in section 3.4.

The distances of the majority of stars ranged from about 100 to 600 parsecs, with a few high luminosity stars at greater distances, to 1300 pc.

The ages found for all but four of the young, high-velocity stars were around 600 million years or younger. The error in the Yale star ages is higher than in the SGP star ages, but both groups fall in the same area of the gravity-temperature diagram. The positions of all the Yale stars in the gravity-temperature plane are plotted in Figure 4.2, and the high space motion main sequence stars are plotted in Figure 4.3, with isochrones (as in Figure 3.8).

The other four stars were older than 600 million years, but none of these was a high W motion star (see section 4.5). Given the mechanism of binary interactions in young clusters as a source of some high velocity stars (Gies and Bolton 1986), it is not unlikely that a few disk stars, probably unconnected with the SGP stars, would be found to have high space motions.

The gravities, temperatures, $E_{(b-y)}$, $(b-y)_0$, abundances, masses, absolute magnitudes, and ages, are listed in *Appendix II, Table 3.* The stars have been separated into Population I with total space motions higher than 70 km s^{-1}, Population I with total space motions lower than 70 km s^{-1}, possible blue stragglers, and horizontal branch stars.

Figure 4.2 – The positions of the 93 Yale star high-velocity candidates plotted in the gravity-temperature plane, with isochrones for solar metallicity stars.

Figure [illegible] – The high space motion Population I stars found from the Yale star sample, plotted in the gravity-temperature plane, with isochrones for solar metallicity class [illegible] (Figure [illegible]). There is more scatter in this diagram, due to the larger errors in gravity and temperature for the stars.

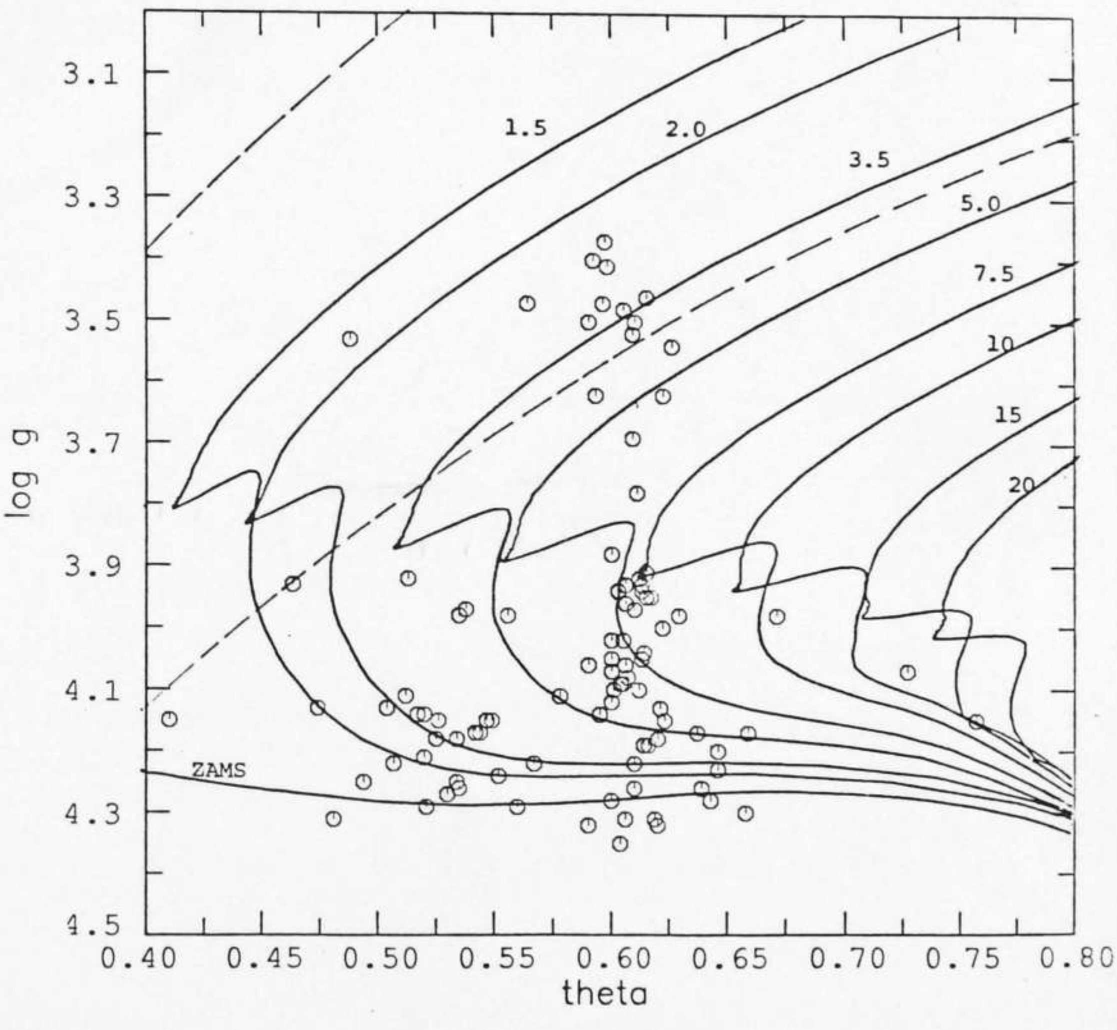
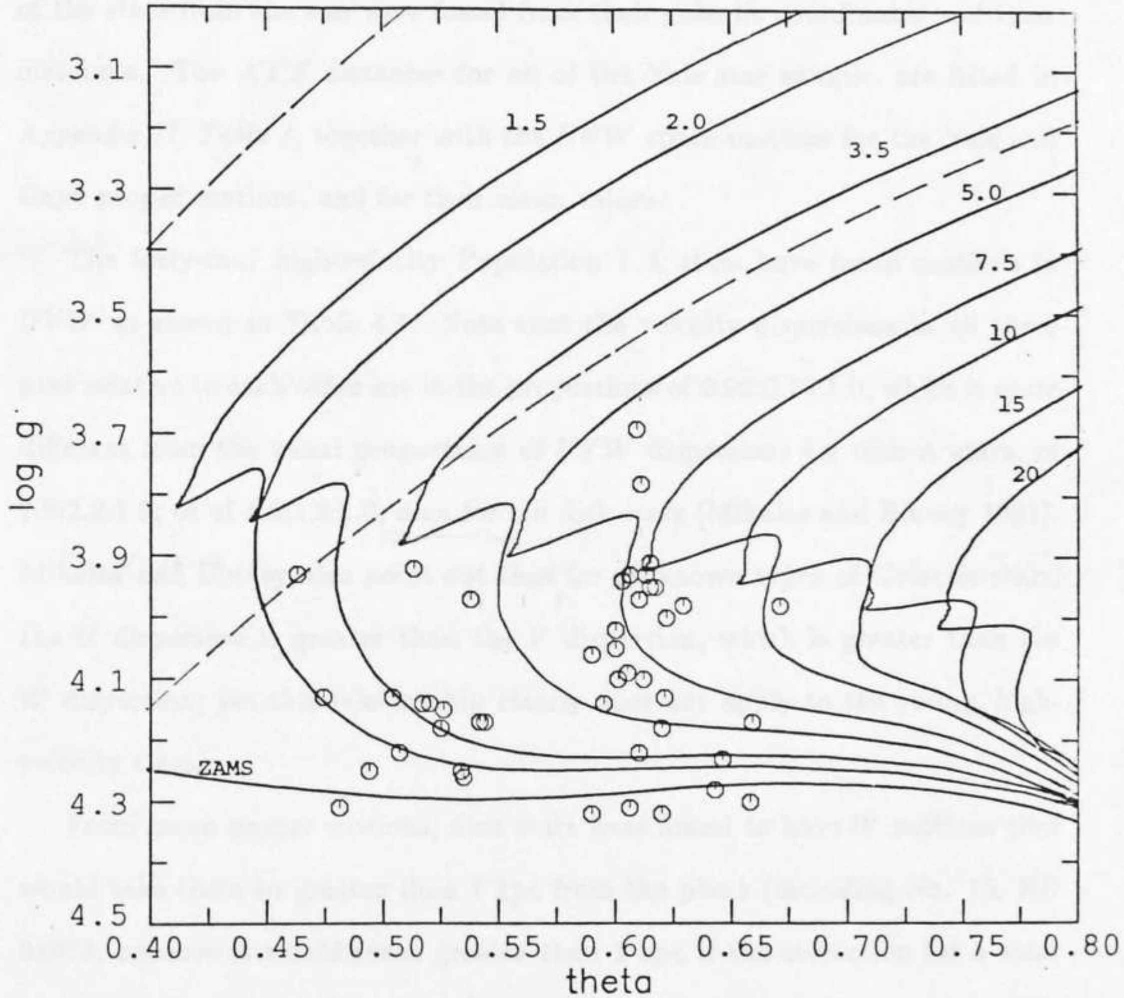


Figure 4.3 – The high space motion Population I stars found from the Yale star sample, plotted in the gravity-temperature plane, with isochrones for solar metallicity stars (*cf* Figure 3.8). There is more scatter in this diagram, due to the larger errors in gravity and temperature for the Yale stars.


log g
theta
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
1.5
2.0
3.5
5.0
7.5
10
15
20
ZAMS

4.5 *UVW* Velocities.

The derivation of the space motions requires that the radial velocity, the proper motions in R.A. and declination, and the distance be known. The algorithm is described by C. A. Murray in an Appendix of Royal Observatory Bulletin no. 41, and Dr J. E. Norris supplied a program which used this algorithm to calculate the space motions. The three-dimensional XYZ distances of the stars from the sun were found from their galactic coordinates and their distances. The XYZ distances for all of the Yale star sample, are listed in *Appendix II, Table 4*, together with the UVW space motions for the Yale and Cape proper motions, and for their mean values.

The forty-four high-velocity Population I A stars have mean motions in UVW as shown in Table 4.1. Note that the velocity dispersions in all three axes relative to each other are in the proportions of 0.93:0.73:1.0, which is quite different from the usual proportions of UVW dispersions for disk A stars, of 2.2:2.2:1.0; or of 1.9:1.2:1.0, seen for old disk stars (Mihalas and Binney 1981). Mihalas and Binney also point out that for all known types of Galactic stars, the U dispersion is greater than the V dispersion, which is greater than the W dispersion; yet this relationship clearly does not apply to the young, high-velocity stars.

From mean proper motions, nine stars were found to have W motions that would take them to greater than 1 kpc from the plane (including No. 13, HD 31973, because it would reach greater than 1 kpc if the correction for a solar W motion of $+7$ km s^{-1} had been included). The maximum Z distances that the Yale stars would reach are listed in *Appendix II, Table 4*, without any solar motion correction.

Six of the nine high W stars would be able to travel to greater than 1 kpc if either of the Yale or Cape proper motions had been used. Of the other three, two stars according to the Yale catalogue, and one according to the SAO catalogue, would get to greater than 1 kpc; but each star would only get to between 800 pc to 1 kpc according to the alternative catalogue. So at least six stars are confirmed high W motion stars, while three others are very probable high W stars. Five of the six confirmed high W motion stars are older than 450 million years.

Over time, these stars would be observed at high latitudes and would then be indistinguishable from the distant Population I A stars seen at the SGP. The high W stars are mostly all within a few hundred parsecs of the Sun, so that future studies are possible in order to find out whether or not they show any abundance peculiarities. The nine high W stars have calcium abundances in the same range as the SGP stars, from -0.4 dex to 0.0 dex. Interestingly, most of the other stars with high U and V velocities also had the same range of calcium abundances, apart from six with normal disk abundances from 0.12 dex to 0.33 dex.

For the nine high W stars, the mean UVW velocities are also listed in Table 4.1. Note that out of the nine stars, eight of them have negative W velocities, that is, moving in the direction of the SGP. An indication of a similar bias was found with the SGP stars, with a preponderance of positive radial velocities. This is perhaps not unexpected, because if the stars were formed around six hundred million years ago, they would have undergone only a few orbital cycles and would not be very well mixed.

Another interesting feature is that the V velocities, for both the nine high W stars and the 44 high space motion stars, show a systematic lag behind the Sun, of 37 to 40 km s^{-1}. Young disk A stars do not normally show an asymmetric drift of this kind (Mihalas and Binney, 1981), their rotation velocities are usually distributed around the mean of the local standard of rest. Old thick disk stars have an asymmetric drift of around 40 kms^{-1}, but their W velocity dispersion and abundances are lower than those of the the young, high-velocity stars. It is clear that the high-velocity stars also do not show the large negative V velocities (relative to the LSR) that would be indicative of halo stars.

The sample of 44 high space motion stars was divided on the basis of [Ca/H] into those with abundances higher or lower than -0.26. There were no statistically significant differences between the means and dispersions of each axis between the two groups. Similarly, the sample was divided into those older and younger than 350 million years. There were statistical differences at the 0.05 level (*ie* one chance in twenty that they are random values) between the U and V dispersions, and the V means between each group, but given the proximity of isochrones for later A stars and the possible errors involved, these differences probably are not significant. These values are also listed in Table 4.1. (Four Am stars have been excluded from the abundance groups.)

It is not clear whether it is statistically meaningful to compare the small group of high W motion stars to the rest, as the selection for high W immediately introduces an unknown bias in the U and V velocities. However, there are no statistically significant differences between the dispersions of the high W group relative to the whole high space motion group. The difference between the U means of the two groups may be significant at the 0.05 level, (and naturally there is a significant difference between the W means).

Overall, there appear to be no major differences between the high space motion group and the high W group, in radial velocities, calcium abundances, ages, or direction of motion in the galactic plane (towards about $l = 213°$ to $226°$).The mean velocity in this direction is about 73 km s^{-1}.

Since the stars were all selected in the same way, and there are no major differences between the stars with regard to several different criteria, there appears to be no justification for separating the high W stars from the rest. The exponential projection of the SGP scale height to the plane implied that the members of that population with low W motions were also included in the estimated density at the disk, which within the errors would predict that between eleven and thirty-three SGP population stars might be found among the disk sample of 3,256 A stars.

Since forty-four main sequence high-velocity stars (in all directions) were identified in the Yale star sample, this is fairly consistent with the SGP projection. The implication, of course, is that the high W motion A stars seen at the SGP are just the tail of the W distribution of a population of stars that have high velocities in all directions. From this sample, one in 74 disk A stars, or 1.4 percent, are members of this population, but only one in about 360 to 540 disk A stars is a high W motion star, like those seen at the SGP.

It is possible that among the 44 stars there are some that have been accelerated by the cluster binary mechanism discussed by Gies and Bolton (1986, see Chapter 1). It would be difficult to decide which stars might have been formed by such a mechanism. However, they might be expected not to show a mean motion in any direction, as they would be expelled randomly. They would also not show any age dependence, presumably being formed at all epochs. They would not show the lower metallicities of the SGP stars, so that the several Yale stars with higher than solar abundances may be candidates. The mean motion and age limitations shown by the whole Yale star sample would argue that there should only be a small number of cluster binary accelerated stars among them.

Taking into account possible errors, overlap with the tails of the disk distributions, and stars that may have been accelerated by other mechanisms, a conservative estimate is that around one in 100 young disk A stars has a high space motion in any direction, and one in 400 young disk A stars is able to travel to greater than one kpc from the plane.

Since this is such a young population, there would be a correspondingly smaller proportion of high velocity stars among later spectral types, but it is possible that among *kinematically* selected samples of late-type stars, a few of these high velocity stars may occur in sufficient numbers to bias the sample.

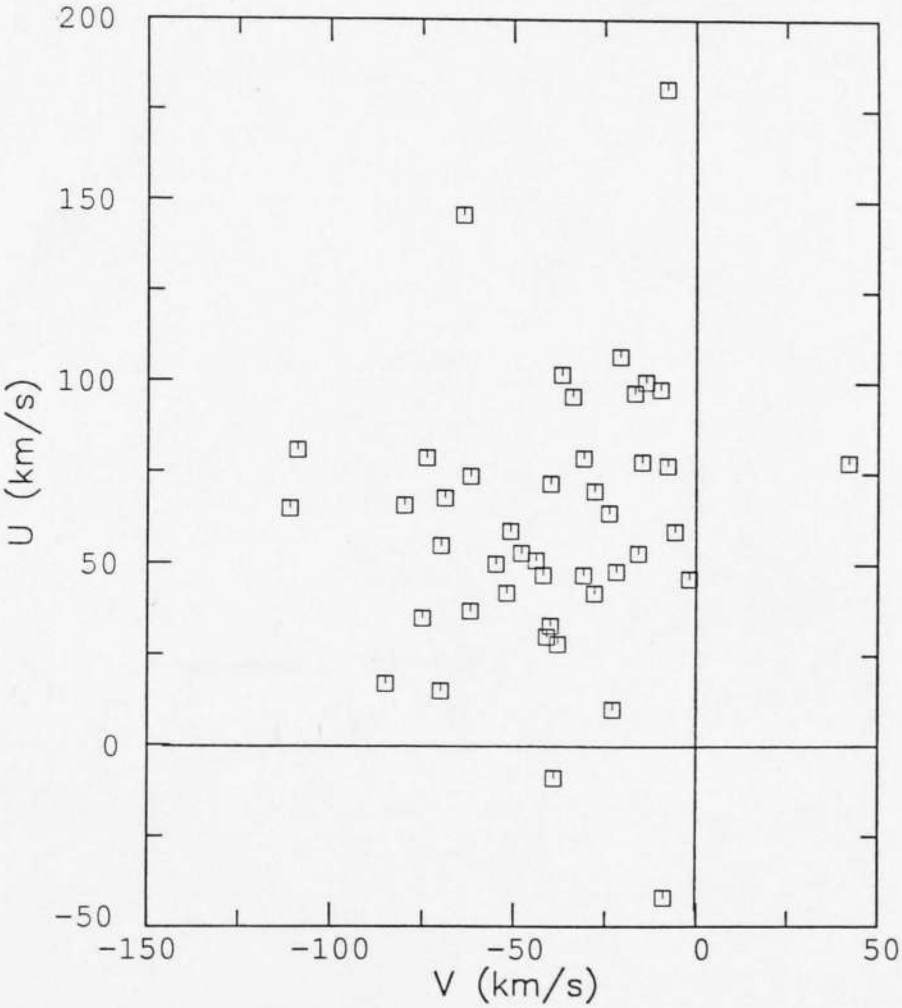
Figure 4.4(a) shows the values of U plotted against V for the high velocity Population I stars, and Figure 4.4(b) shows U against W. These velocities have not been corrected for the peculiar motion of the Sun: it is at (0, 0) in the following diagrams. Figure 4.5(a) shows the same stars in the X, Y plane, with their velocities indicated by vectors, and Figure 4.5(b) shows the stars in the X, Z plane (one star at X=1148 pc was not plotted). Their distribution in space is both a function of the projected declination band, and also the clumping and systematic motions of the stars themselves.

Figure 4.6 (a, b, c, d) illustrate the effects on the positions and velocities of altering the proper motions, distances and radial velocities by the extremes of their possible errors, for the stars in the (X,Y) plane. Figure 4.7 (a, b, c, d) illustrates the same procedure on the stars in the (X, Z) plane. It can be seen that errors would not greatly affect the overall results. The UVW means and dispersions that would arise from these extreme cases are listed in Table 4.1.

The 30 low space motion Population I stars have UVW velocities as in Table 4.1. Interestingly, their direction of motion is towards $l = 211°$, with a mean velocity of 13 km s^{-1}. These stars are still generally higher velocity stars than normal A stars, but this is probably because they were selected from the tails of the disk distributions. Their dispersions (27,14,18) are close to the proportions that would be expected if only stars from the tails of the young A star distributions (20, 9, 9), were examined. They appear to indicate a mean motion towards the SGP, however, which is also shown by local disk stars, and does not appear to be a result of the Yale catalogue differences from the Cape proper motions (Section 4.2), as UVW velocities from the Cape proper motions show the same result.

The selection effects of deriving the kinematics of A stars in a declination band, with a transverse velocity cutoff criterion, must now be examined.

Figure 4.4(a) – U velocity plotted against V velocity for the high space motion Population I stars. Positive U is towards the Galactic anticentre, and positive Y is in the direction of Galactic rotation. The Sun is at (0, 0).



200
150
100
50
0
-50
U (km/s)
-150
-100
-50
0
50
V (km/s)

Figure 4.4(b) – As above for U plotted against W. Positive W is towards the NGP.

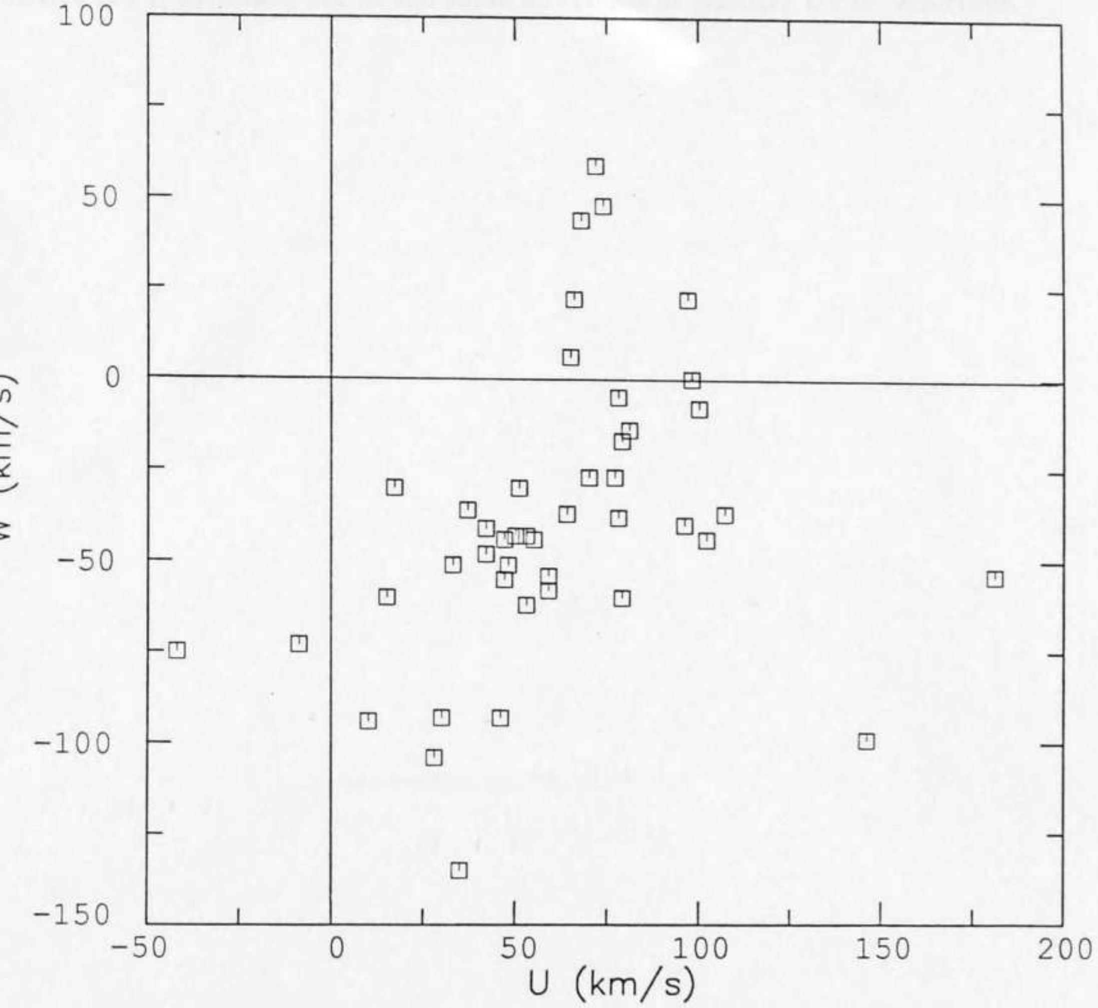

100
50
0
-50
-100
-150
W (km/s)
-50
0
50
100
150
200
U (km/s)

Figure 4.5(a) – The same stars in the X, Y plane, with their velocities indicated by vectors. The scale of the vectors is approximately 100 km s^{-1} per 12mm. Positive XYZ distances are in the same directions as positive UVW velocities.

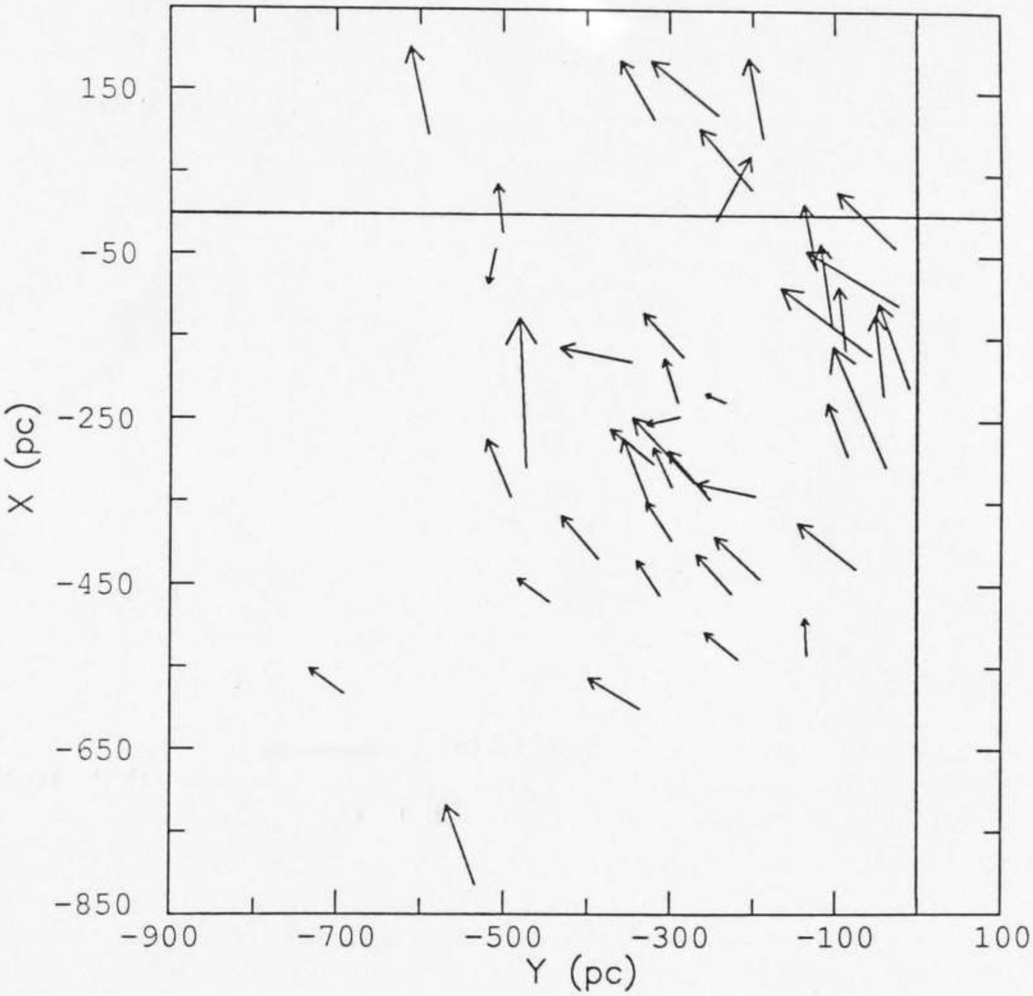

150
-50
-250
-450
-650
-850
X (pc)
-900
-700
-500
-300
-100
100
Y (pc)

Figure 4.5(b) – As above, for the X, Z plane.

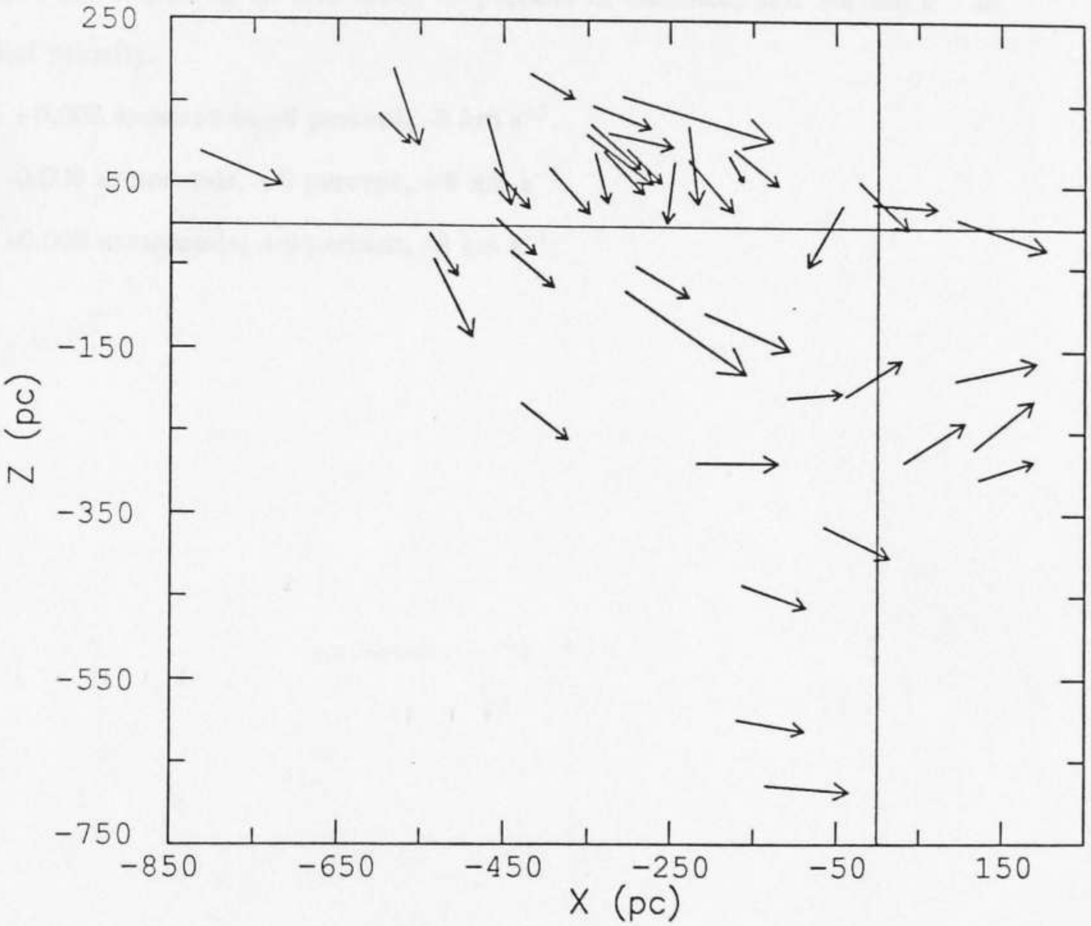

250
50
-150
-350
-550
-750
Z (pc)
-850
-650
-450
-250
-50
150
X (pc)

Figure 4.6 – The effects on the positions (in X and Y) and velocities of the high space motion stars of taking the extremes of possible errors in proper motion (from Yale catalogue estimate), distance (from errors in absolute and apparent magnitudes) and radial velocity (see Section 2.5(b)). (a) +0.006 arcseconds in proper motion in R. A. and Dec., -6 percent in distance, and +8 km s^{-1} in radial velocity.

(b) +0.006 arcseconds, -6 percent, -8 km s^{-1}.

(c) -0.006 arcseconds, +6 percent, +8 km s^{-1}.

(d) -0.006 arcseconds, +6 percent, -8 km s^{-1}.

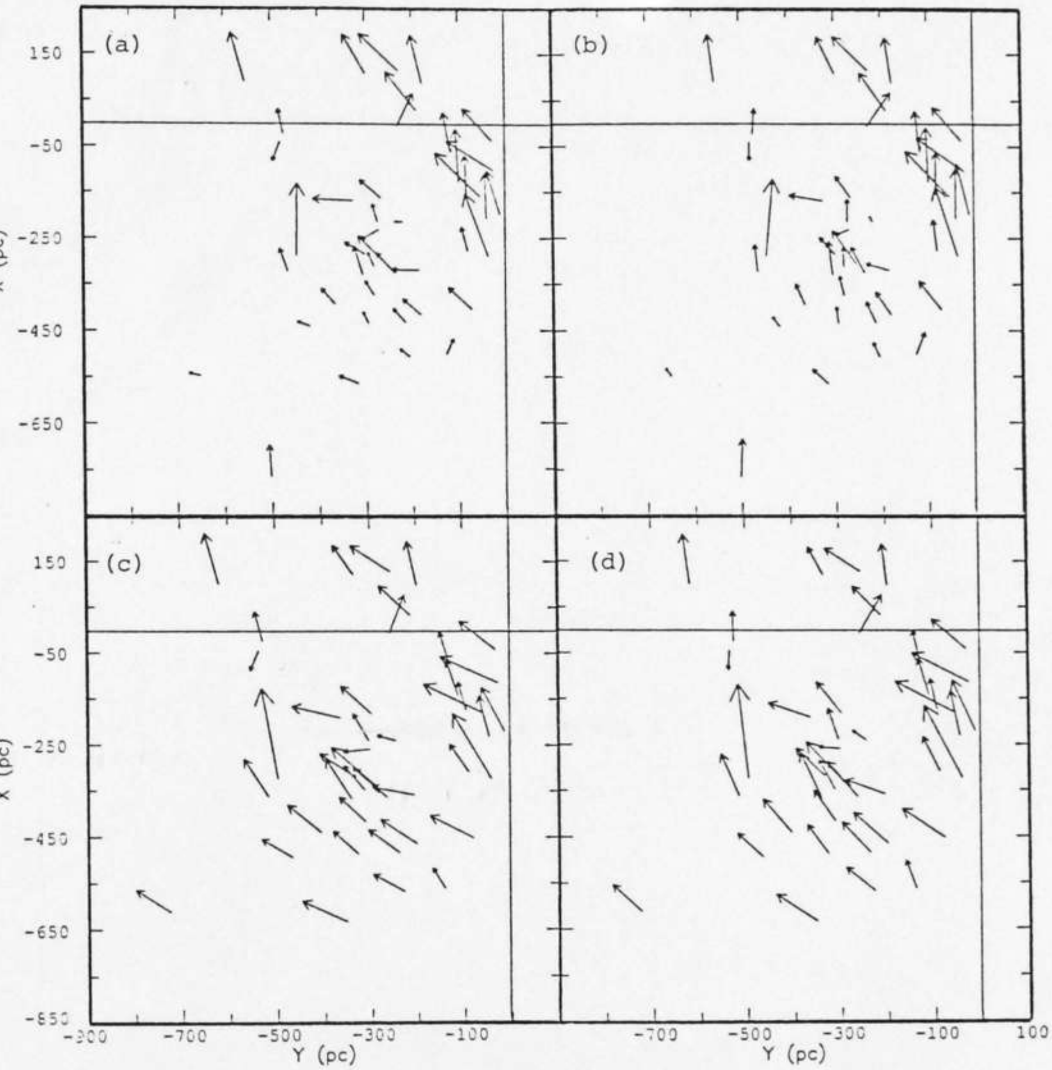

(a)
(b)
(c)
(d)
X (pc)
X (pc)
150
-50
-250
-450
-650
-850
Y (pc)
Y (pc)
-900
-700
-500
-300
-100
100

Figure 4.7 – As for Figure 4.6, in the X, Z plane.

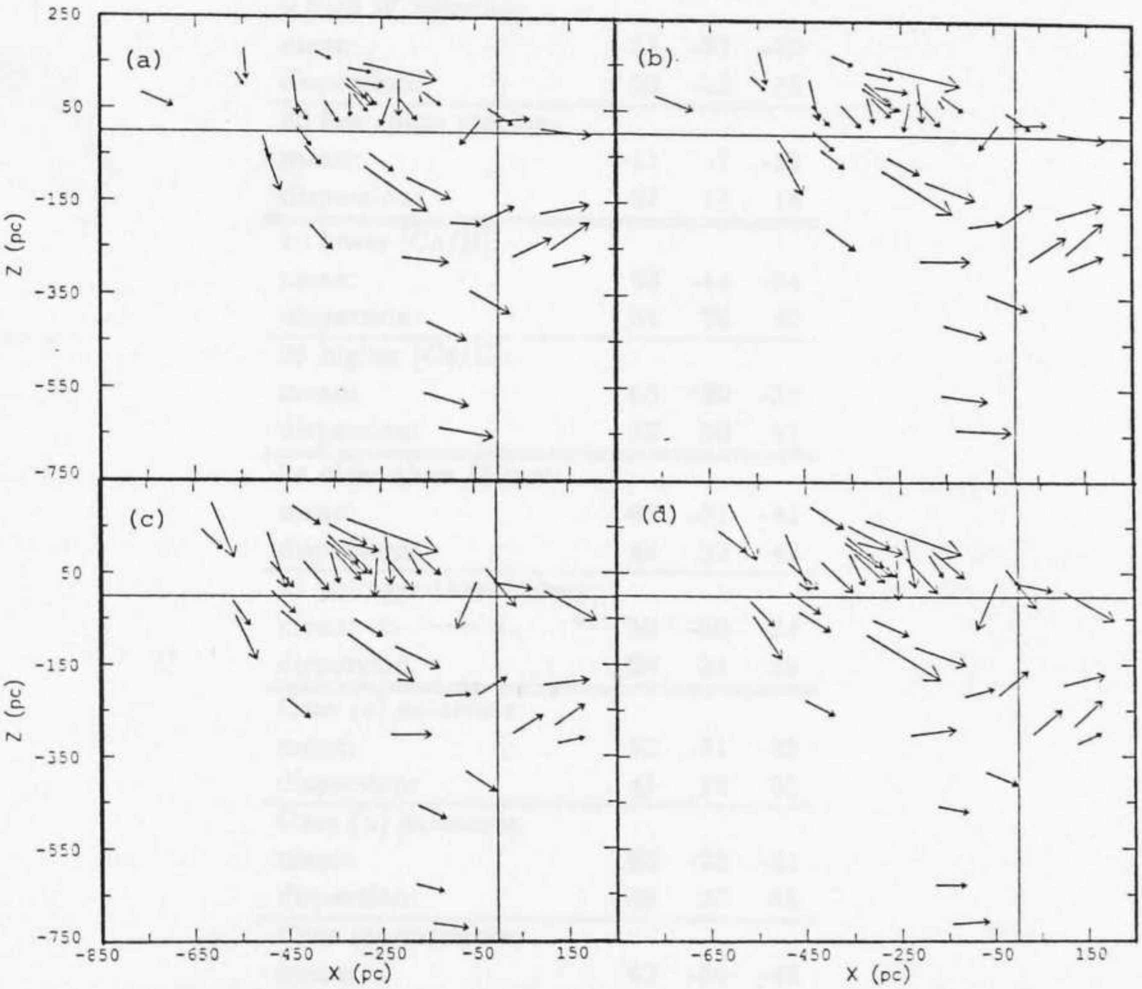

(a)
(b)
(c)
(d)
250
50
-150
-350
-550
-750
Z (pc)
-850
-650
-450
-250
-50
150
X (pc)

TABLE 4.1

Mean velocities and dispersions of Population I Yale stars.

Sample	U	V	W
44 high space motion:			
mean:	61	-40	-39
dispersion:	38	30	41
9 high W velocity:			
mean:	35	-37	-79
dispersion:	53	-23	55
30 low space motion:			
mean:	11	-7	-22
dispersion:	27	14	18
15 lower [Ca/H]:			
mean:	58	-44	-34
dispersion:	31	29	42
25 higher [Ca/H]:			
mean:	65	-39	-38
dispersion:	43	30	41
24 older than 350my:			
mean:	63	-31	-44
dispersion:	45	22	42
21 younger than 350my:			
mean:	59	-50	-34
dispersion:	29	34	39
Case (a) extremes:			
mean:	52	-31	-33
dispersion:	41	28	35
Case (b) extremes:			
mean:	60	-23	-31
dispersion:	38	29	38
Case (c) extremes:			
mean:	62	-59	-48
dispersion:	37	33	42
Case (d) extremes:			
mean:	70	-50	-46
dispersion:	37	34	47
Model input (Sec. 4.6):			
mean:	41	-30	-25
dispersion:	37	30	36

4.6 Selection Effects.

To model the selection effects of the transverse velocity criterion, the space motion derivation was reversed. The assumption was made that the high velocity Yale stars were the tails, in UVW, of a normally distributed population, and a procedure was followed that would estimate what the actual means and distributions of that population might be, before a bias was imposed onto the space motions by the selection method of using transverse velocities only, in a limited and specific region of space.

Gaussian distributions with particular means and dispersions in U, V, and W, were generated for a model group of stars, which had the actual positions of the original 3,256 Yale stars in the declination band, and the distances that had been estimated for them in the selection procedure.

The program that had previously calculated UVW velocities from proper motions and radial velocities was now inverted, so that model proper motions were found from the generated UVW motions. The transverse velocities were found from the proper motions and distances, then those that had transverse motions greater than 70 km s^{-1} were selected. The means and dispersions of the UVW motions of the model high transverse velocity group were found, and compared to the actual values for the real stars. This procedure was iterated until the real means and dispersions could be generated from a model population. It was found that only a very limited range (within one km s^{-1}) of model means and dispersions could generate the observed values.

There are of course several assumptions in this procedure that may not be valid. The distributions may not be Gaussian; or the high velocity stars may be a unique population, and not the tails of any sort of lower velocity distribution, or they may not be from a single population, but from several accelerating sources. What in fact the procedure tested was whether or not a normal group of A stars, with zero mean UVW velocities and disk A star dispersions (of 20, 9, and 9 km s^{-1} respectively, Mihalas and Binney, 1981) could be so selected that they then appeared to have the distinctive systematic mean motions and large dispersions of the high velocity Yale stars.

This was found not to be so: it appeared to be impossible for these stars to have been drawn from the normal disk distribution. Even for a model population with zero mean UVW motions and much higher dispersions than are normally observed, the final selected group still had zero mean motions, and even higher dispersions. It became clear that the systematic motions of the Yale stars were real, and not a selection effect. If the high velocity Yale stars are in fact the tails of Gaussian distributions, their parent population would still have motions as listed in Table 4.1, where it can be seen that the magnitude of the means and dispersions is smaller, but the systematic motions and high dispersions remain.

So regardless of whether the Yale stars are a unique group of high velocity stars, or whether they are the tails of normal distributions in UVW, or whether they arise from different sources, when considered as a whole they still show a mean systematic motion towards around $l = 213°$, $b = -28°$, and their velocity dispersions are still very different from disk ones. These findings do not seem to be the result of selection effects. (From the extremes of the possible errors listed in Table 4.1, the direction of motion may be between 200° to 223°).

4.7 The Solar Neighbourhood.

The question may be posed at this point as to whether there are any other stars in the Solar neighbourhood with systematic motions like the Yale stars. The answer is that there are in fact several groups of stars with similar motions. One group, the Hyades supercluster (Eggen 1984), has a mean motion towards $l = 204°$, with a U velocity of 41 km s^{-1} and a V velocity of -18 km s^{-1}. This group of stars, however, has a very small velocity dispersion of only a few km s^{-1} in each direction, and could not be part of the Yale star population.

The reason for this is that a genuine moving group may start with a larger velocity dispersion, but over time the faster stars will move ahead of the group and the slower stars will lag, so that the velocity dispersions of stars observed in any single region of space will contract until only those stars with velocities almost identical to each other will still be travelling together.

This is obviously different from the case of the Yale stars, which cannot be regarded as a single moving group. Instead, an observed group of stars with a mean motion and a large dispersion is likely to be the effect of observing several or many overlapping groups, formed at varying but fairly similar epochs, and with varying but similar mean motions, so that the stars as a whole appear to have a mean motion while each group contributes to the dispersion around that overall mean.

Another local group motion is what Kapteyn (1905) called Star Stream I. From proper motions he found that all nearby stars fell into one of two groups, I and II. Stream I has a mean direction of $l = 220°$, $b = -17°$, and contains up to 70 percent of local stars, most aged around 500 million years or less. Stream II has a mean direction of $l = 333°$, $b = -26°$, and contains about 30 percent of local stars, which appear to be generally older than 500 million years (Eddington, 1914; Clube, 1985). The Sirius supercluster (Eggen, 1984) appears to follow a similar motion to Stream II, but again, these stars have a very small velocity dispersion, while Stream II has larger dispersions.

Halm (in Eddington, 1914) suggested that there were in fact three streams, with apices at $l = 207°, 245°$, and $345°$. The group at $245°$ is delineated by the Pleiades and Goulds Belt stars. The stream hypothesis was surplanted by Schwartzchild's concept of the velocity ellipsoid, which appeared to provide a single mathematical description of the motions of all the groups of stars. However the numerically greater (and brighter) Stream I stars were then overemphasized in subsequent derivations of the Local Standard of Rest, leading several authors to suggest future redefinitions of the LSR in terms of older, more distant stars (Yuan 1983, Upgren 1979, Clube 1985). The Stream hypothesis may actually be the more fruitful, upon reconsideration, as it emphasises some important and interesting *differences* between local groups of stars, rather than attempting to fit all the stars into a single kinematic solution.

The stars in each Stream may have been formed over time from disk gas that had such peculiar motions. Many local early-type stars have ages around 0.6 billion years (excluding the very young OB stars), so they are not yet well mixed and could show such mean motions. The Yale stars with space motions *less than* 70 km s^{-1} also show a mean motion towards $l = 211°$, but their velocity in that direction is only 13 km s^{-1}. Most of these lower velocity Yale stars are also younger than 600 million years. This may be partially, but not completely, an effect of the earlier spectral type cutoff (of A9 rather than F0 as for the SGP stars), which would mean that the oldest Yale stars observed would be around only 1.0 to 1.5 billion years old.

It would appear that there may have been a burst of formation of young disk stars at around 0.6 billion years (the same time the SGP stars were formed) both because of the Yale stars and because young Stream I stars are more numerous locally than older stars. Palouš and Hauck (1986) found an age for the Sirius supercluster of 490 ± 130 million years.

The movement of the Yale and SGP stars in a similar direction as Stream I suggests that at least a part of the gas of which they are formed was from Stream I disk gas. It would appear that this matter was somehow accelerated in all directions to velocities not usually observed in disk stars; and 'diluted' with metal-poor gas, in an event that occurred some 600 million years ago, which also sparked off a burst of general star formation in the disk.

Chapter 5 will examine possible causes of these properties of the Yale and SGP stars, and seek to relate them to other local and galactic phenomena.

4.8 Some Other Unusual Stars.

Four other known high-velocity stars were also studied. Their acquisition and reduction procedures were the same as the SGP and Yale stars. Two stars, CD$-48°$6657 and CD$-53°$3099, were found to have normal photometric indices by Stetson (1981b), and two others, HD 26298 and HD 85504 (7 Sextantis), were found by Rodgers (1972) to have normal calcium abundances.

a) CD$-48°$6657: Stetson found this star to have a radial velocity of +344 km s^{-1}, in good agreement with my value of +351 km s^{-1}. He found that its photometric indices indicated that it was a normal A star. My value of surface gravity was 4.08 dex, also in good agreement. However, the calcium abundance found in this study was -1.12, indicating that it is a low metallicity star with main sequence gravity, possibly a blue straggler. Its V velocity is -248 km s^{-1}, so it does not rotate with the disk.

b) CD$-53°$3099: (=SAO 237534) This is a late F star for which Stetson found 'solar metallicity and photometric indices that place it exactly on the mean Population I main sequence...but which has a transverse velocity of 250 km s^{-1}'. This study found it to have an abundance of 0.03, in excellent agreement with Stetson, and an even higher transverse velocity of 348 km s^{-1}. This value is higher because the $(b-y)_0$ of 0.272 found here was bluer than Stetson found (0.303), so the absolute magnitude was brighter. This star has a very high U velocity of 330 km s^{-1}, a V of -60, and a W of -14.

c)HD 26298: This early F star was found by Rodgers (1972) to have a calcium abundance of -0.37, while this study found -0.30. Rodgers' gravity was

3.8 dex, while this study found 4.07 dex. It appears to be a normal Population I star, with slightly lower than normal abundance.

d) HD 85504: Sargent, Searle and Wallerstein (1964) found that 7 Sex was a normal young A star, perhaps a runaway, while Rodgers and Wood (1970) concluded that its orbital parameters were inconsistent with a runaway origin from a supernova explosion, and preferred to consider it an old disk horizontal branch star. Rodgers and Wood found θ_{eff} to be 0.49, in excellent agreement with my value of 0.488; and a gravity of 3.45 dex, while I found 3.53 dex, again in good agreement. The calcium abundance from this study is 0.07, but this may be uncertain due to the high temperature of the star and the small W(K).

Its $v \sin i$ is around 15 km s^{-1} (Norris, in Rodgers and Wood, 1970), which may indicate that it is a HB star, although from the analysis of a rotational velocity catalogue, in Chapter 2, it was found that normal A0V stars may have quite low rotational velocities. If it is a Population I star, its U velocity is 339 km s^{-1}, V is 0 km s^{-1}, and W is -89 km s^{-1}, so that it would be capable of travelling to around 1600 pc from the plane.

The radial velocity of 7 Sex in Abt and Biggs (1972) is 97 km s^{-1}, with no evidence of variability, so it was used as a radial velocity template on several nights of observing program stars. Fortunately, other templates were also observed, as it became clear during reductions that 7 Sex is actually highly variable in radial velocity, from 30 km s^{-1} to 122 km s^{-1}.

What was most unusual is that the width of the Hδ line also varied greatly, from 11.8Å to 19.8Å. Table 4.2 lists the dates of observations, the radial velocities and the D(.70) values. There seems to be a systematic relation between the radial velocities and the D(.70) values, in that the largest radial velocities are associated with the widest D(.70) measurements. Eight spectra were obtained at coudé focus, five at 1.2Å resolution, for which radial velocities and D(.70) values are available, and three others at 0.30Å, of the CaII K line, for which only the radial velocities were available.

Golay (1972) indicated that photometric variations had occurred in Geneva Observatory observations of 7 Sex, but gave no details. Rufener and Bartholdi (1982) list observed or suspected variables from the catalogue of Geneva observations, but do not mention 7 Sex, although their list may not be complete. Eggen (1985, private communication) has observed the star 'four times in the last forty years and the V mag is always within one hundredth of a mag'.

Variations in the hydrogen line widths (at 70 percent of the continuum) of 8Å should be reflected in photometric variations, but these appear to be either small or non-existent. The difference between the largest and smallest D(.70) of 8Å is equivalent to 13.3 pixels, or more than six times the instrumental width of 1.2Å resolution, hence the differences seem unlikely to be attributable to instrumental effects or errors. 7 Sex is an A0 star, so it is too hot to be an instability strip variable. If the star was for instance an eclipsing variable, it would show distinctive photometric changes.

It is not possible to suggest at this point what might be the cause of this unusual hydrogen line width variation.

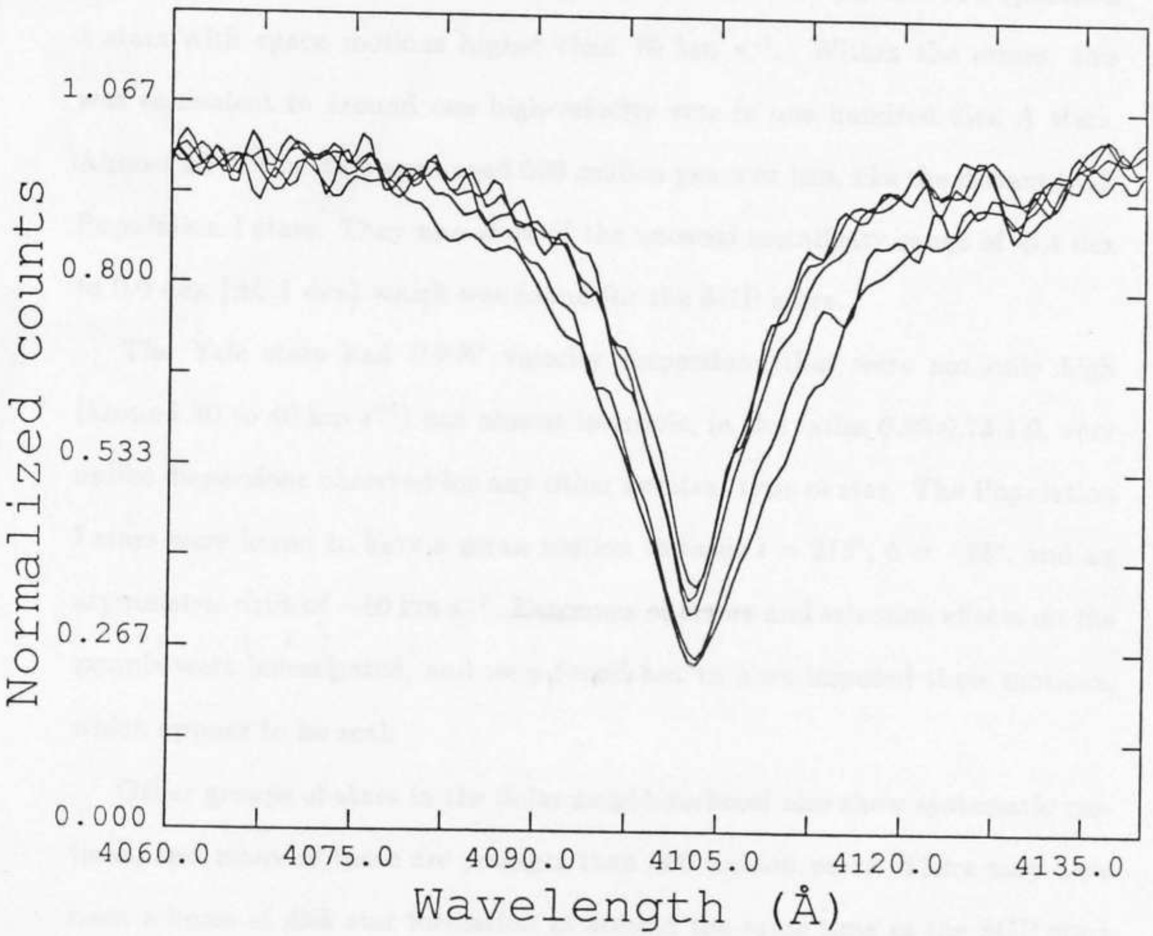
The parameters of these four stars are listed in the appendices with the Yale stars, as star numbers 94 to 97. The Hδ line widths are plotted in Figure 4.8.

TABLE 4.2

Radial velocities and D(.70) values for 7 Sextantis.

Date	RV (km s^{-1})	D(.70) (Å)
10.1.85	122	18.4
11.1.85	93	12.3
12.1.85	98	11.8
13.1.85	112	13.7
29.1.85	117	19.8
18.2.86	101	
19.2.86	30	
20.2.86	63	

Figure 4.8 – The Hδ line widths for five spectra of 7 Sextantis. Each spectrum had around 700 or more counts in the continuum.



Normalized counts
1.067
0.800
0.533
0.267
0.000
4060.0
4075.0
4090.0
4105.0
4120.0
4135.0
Wavelength (Å)

4.9 Summary.

Proper motions for a band of declination, between $-40°$ and $-50°$, were used to find a complete sample of high-velocity nearby A stars, on the basis of estimated transverse velocity. The ages, metallicities, and UVW velocitites were found for an initial sample of 93 candidate stars, which yielded 44 Population I stars with space motions higher than 70 km s^{-1}. Within the errors, this was equivalent to around one high-velocity star in one hundred disk A stars. Almost all of the stars were aged 600 million years or less, like the distant SGP Population I stars. They also showed the unusual metallicity range of -0.4 dex to 0.0 dex (± 0.1 dex) which was found for the SGP stars.

The Yale stars had UVW velocity dispersions that were not only high (around 30 to 40 km s^{-1}) but almost isotropic, in the ratios 0.93:0.73:1.0, very unlike dispersions observed for any other spectral type of star. The Population I stars were found to have a mean motion towards $l = 213°$, $b = -28°$, and an asymmetric drift of -40 km s^{-1}. Extremes of errors and selection effects on the sample were investigated, and were found not to have imposed these motions, which appear to be real.

Other groups of stars in the Solar neighbourhood also show systematic motions, and many of these are younger than 600 million years. There may have been a burst of disk star formation at around the same time as the SGP stars were formed. The high-velocity SGP and Yale stars appear to have some proportion of disk matter in their composition, but since they are substantially more metal poor than young disk stars it would seem that they are not entirely composed of normally enriched disk gas.

In Chapter 5, the possible origins, and the relationship of the high velocity stars to other Galactic populations, are examined.

Chapter 5

Discussion.

5.1 Other Groups of Stars.

In Chapter 1 studies on other groups of stars that might be related to the high-velocity stars were described. Hartkopf and Yoss (1982, hereafter HY) had found K giants at distances greater than 1 kpc from the plane, with abundances like those of the SGP A stars, and suggested that they might be the descendants of the high-velocity stars. There are two reasons that this hypothesis is not now supported.

Firstly the W velocity dispersion found for the SGP A stars was 62 km/s. The radial velocities of the K giants are generally lower than for the A stars. Not all of HY's sample had radial velocity results, but for the 29 stars at distances greater than 1 kpc and metallicities greater than -0.5, the velocity dispersion is only 31.2 km/s. If only those 14 stars above 1.5 kpc are considered (in case contamination of the sample with old disk stars has occurred) the dispersion is still only 29.0 km/s. There is thus almost no possibility that the K giants and the A star sample were drawn from the same population.

Secondly, the number of K giants is much higher than that of the A stars. The K giants were drawn from many surveys, but the number of metal-rich distant K giants in one region that was completely observed to 13.5 magnitudes (Bok regions I, II and III), was 16 stars found in 8.4 square degrees, almost two stars per square degree. The number of A stars found was 27 in 217 square degrees, 0.12 A stars per square degree.

The relative numbers of stars to be expected on the red giant branch compared to those still on the early main sequence, for a coeval group of stars, may be estimated from the Hyades, which are at least as old as the SGP A stars and possibly several hundred million years older. Mermilliod (1981) plotted the colour-magnitude array of the Hyades. For 81 stars still in the A star range, only 18 stars are observed on the red giant branch, a ratio of 4.5 A stars to K giants. The ratio of SGP A stars to SGP (Bok area) K giants is 0.065, equivalent to almost seventy times more K giants than would be expected if the A stars and K giants were from the same population.

It would seem more likely that the K giants are members of the thick disk population, or old disk stars. They could not have been formed at the same time as the A stars, and they do not show the same kinematics.

Rose's (1985) red horizontal branch stars are unlikely to be associated with the A stars for the same reasons. They are found in large numbers: they may comprise around 5 percent of the entire giant-branch population in the disk, and their velocity dispersion was around 40 km/s. Relative to the A stars there are too many of them to be their descendants, and again, their velocities are too low.

High velocity OB stars might be thought to be part of the A star population, but there are also too many of them, and most are well accounted for by the cluster binary interaction mechanism (Gies and Bolton, 1986). They find that about 2 percent of B stars and 10 to 25 percent of O stars are runaways. They estimate the fraction of high-velocity A stars, from Stetson's (1981b, 1983) data to be 0.5 to 1 percent, in good agreement with my upper limit from the Yale stars of 1.4 percent.

It would seem that only a fraction of the high velocity OB stars might be from the same population as the A stars. It may be significant in this context that Carrasco *et al.* (1980) found that some high-velocity OB stars lag behind disk rotation by around 20 km/s. They interpreted this to mean that some of the stars were Population II stars, but as discussed in Chapter 1, this is not now thought to be the case. If a few young OB stars show an asymmetric drift like the Yale stars it suggests that they might be related.

An interesting problem associated with some OB stars that are seen at great distances from the Galactic plane is that if they were ejected from the disk, their evolutionary lifetimes are shorter than the time they would have taken to reach their present positions. Keenan, Brown and Lennon (1986) found that a sample of these stars had abundances that were the same as young disk OB stars, and they suggested that the stars may have been formed in condensing gas clouds above the disk, from matter thrown up by supernovae (the galactic fountain mechanism).

A simpler alternative explanation might be instead that they are genuine young disk OB stars, accelerated away by the cluster binary interaction mechanism (hence their normal abundances). However, if they were to be observed in a colour-magnitude array relative to the other stars in their original coeval cluster, they would appear as blue stragglers. In other words, they have acquired extended main sequence lifetimes, by whatever the mechanism might be that extends the lifetimes of the massive stars discussed by Mermilliod (1982). He found that blue stragglers were a feature common to all open clusters.

Abt (1985) suggested that the high rotation velocities of O and early B stars might cause mixing that would extend their main sequence lifetimes. Other authors (see Chapter 1) have proposed mass transfer as the mechanism. Whatever is eventually found to be the cause of blue stragglers in young clusters, it is clear that they form a consistent proportion of all cluster stars, and they provide a simple explanation for the existence of high latitude OB stars at distances greater than could be attained in a 'normal' main sequence lifetime. It is a little ironic that the proposal of blue stragglers as the explanation for the A stars should have been rejected in this thesis, but that in the consideration of a different associated problem, blue stragglers might yet offer a satisfactory solution.

The young high-velocity A stars (and lower-mass main sequence analogues) appear to be unique. Their descendants would not yet occur in sufficient numbers that they could be selected and identified. It is only in the A star range that their turn-off ages are long enough that we might observe them, but short enough that some age discrimination is possible; and it is only in the A star range that they are bright enough to be seen to large distances, but numerous enough that they might be found in reasonably-sized surveys.

The young, high-velocity stars are unlike any other stellar population yet observed in the Galaxy. Most groups of stars show enough of a relationship between their characteristics of age, abundance and kinematics, that they may be identified as members of recognizable populations with well-accepted theoretical evolutionary sequences. The A stars show no such relationship.

It would seem that they might have a formation history that differs from normal galactic populations. Their velocities indicate that they have been formed under circumstances that have imparted significant kinetic energy to the stars; their abundances indicate that the matter of which they are composed is not the same kind of metal rich disk gas that is seen in low velocity A stars; and their ages indicate that their origin was from a distinctive and recent event, rather than from the random processes that form normal A stars. (These parameters have been thoroughly tested in this present work, and the possibility that errors are the explanation for the anomalous range of properties is now most unlikely.)

Hypotheses of the origins of the high velocity stars must account for all of these characteristics. Of those theories (apart from that of RHS) listed in Table 1.1 and discussed in Chapter 3, all are inadequate in one or more aspect: if the stars are normal young disk stars accelerated by *any* mechanism, they would not show their abundance peculiarities, and the mechanism would not suddenly start occurring at 0.6 billion years ago. Hypotheses such that the stars are misidentified horizontal branch stars, or blue stragglers, were explored in Chapter 3, where it was shown that there is substantial evidence that they are incorrect.

It is quite possible that at some future time new observations or ideas will arise that will find an explanation for these stars that has not yet been considered. However, *upon the present evidence*, there is only one hypothesis left of all those that have been advanced to account for the existence of the young, high-velocity A stars, which might yet be able to provide a consistent explanation.

This is the suggestion by Rodgers, Harding and Sadler (1981), that a small satellite galaxy merged with the Milky Way, and that the impact of the lower abundance satellite gas with normal abundance disk gas formed stars with high space motions and unusual metallicities. This is consistent with the 'event'-like nature of the ages found for the stars, as well as the abundances and kinematics. The theory needs to be considered in greater detail before acceptance or rejection could take place.

It is necessary to discuss whether there is any independent evidence that infalling matter has ever merged with the disk; how much accreted matter would be needed to form the observed density of high-velocity stars; what actually is thought to be the consequences of such impacts; and whether or not this information is consistent with what is known about the A stars.

5.2 Consequences of a Merger.

Tenorio-Tagle (1981) has described calculations of the effects of a collision between a gas cloud and a galactic disk. He found that for infall velocities of the clouds greater than about 300 km/s, if the cloud was denser than the disk then it would simply pass through the disk; and if the disk was denser than the cloud there would be a fast re-expansion of the infalling gas, which would be observed as a giant loop or supershell of HI (Heiles, 1979). For velocities less than about 250 km/s, the two streams of gas would coalesce, a shock front would move through both the disk and the gas cloud, and a shell of HI would be formed.

A cavity would be blown into the disk, with star formation occurring in all directions at its edges, in regions of high density such as molecular clouds. The energy released in a collision between a gas cloud and a galactic disk is consistent with the energy requirements to blast the large (0.5 to 1 kpc diameter) cavities that have been observed in other galaxies, but for which no other appropriate energy source is known (Tenorio-Tagle, 1980).

Mirabel (1982) described radio observations of a high velocity gas cloud presently colliding with the Galactic disk towards the anticentre. The energy involved in such a collision is estimated to be many times that of a supernova, around $10^{53} - 10^{54}$ ergs. (Supernovae of Type II release around 10^{49} ergs, while those of Type I release about 10^{51} ergs. The previously postulated very high energy Type III supernovae are now thought to have been normal Types I and II (Oke and Searle, 1974)).

Kulkarni, Dickey and Heiles (1985) observed the supershell of HI in the anticentre region associated with the high velocity cloud observed by Mirabel. They found that the shell was one-sided, as might be expected from a collision, with a calculated kinetic energy of 10^{53} ergs, and is expanding at more than 90 km/s. They also suggested that the shell is the result of the collision of a high velocity cloud with the disk.

There are a large number of high velocity hydrogen clouds now catalogued. The very high velocity clouds (VHVCs) seem to be distinct from the high (HVCs) and intermediate velocity clouds. Giovanelli (1981) discussed their characteristics. The highest velocity clouds occur only with negative velocities, that is, they are all falling towards the disk, and they do not appear to rotate with it. They are found only in the galactic quadrant $0° < l < 180°$ and $b < 0°$. The lower velocity clouds rotate to some degree with the disk, with a range from rotation at disk velocities to almost no rotation at all, and are seen in all quadrants, while some have positive velocities.

The VHVCs would behave like those described by Tenorio-Tagle (1981). They would probably pass through the disk, losing some energy in the interaction and gaining some rotation velocity from the 'kick' of the disk rotation. They would then travel out again into the halo, then fall towards the disk at somewhat lower velocities, interacting further with the disk, and possibly merging or forming stars during later passages. These clouds after one or more passages through the disk would then be seen as HVCs and IVCs.

Giovanelli suggested that the high velocity clouds were gas from the tip of the Magellanic Stream. This is a series of elongated neutral hydrogen clouds that stretches from the diffuse HI envelope around the LMC and SMC, spreading over 60° of the southern sky. The negative radial velocities of each cloud systematically increase from the lowest velocity near the Magellanic Clouds, to the highest velocity one at the tip of the Stream, where the structure of the clouds is most fragmented.

If the HVCs were gas from the Magellanic Stream then the tip of the Stream (in the middle of the VHVC galactic quadrant, at about $l = 90°, b = -35°$)

would need to be relatively close to the Galaxy. Tidal models by Lin and Lynden-Bell (1982) and Murai and Fujimoto (1980) indicated that the tip might be as far away as 60 kpc from the Galaxy.

However, recent work (Gingold, 1984) has suggested that the tidal stripping hypothesis for the Stream has quite a number of theoretical difficulties. If it occurred, stars, as well as gas, should be found in the Stream, yet despite searches none have been observed. The theory also needs to assume that the Magellanic Clouds are on bound orbits, but there is evidence that this may not be so (Gingold, 1984). In addition, some of the tidal disruption seen in Murai and Fujimoto's simulations may simply result from model dynamical resonances. Their results are also dependent upon very restricted model initial conditions.

Other objections are outlined in Meurer, Bicknell and Gingold (1985), who describe a drag-dominated model in which the ram-pressure of the Galactic halo strips gas from the Clouds, which are on a first approach to the Galaxy. This model reproduces the position and run of radial velocities of the Stream as well as tidal models, while the tip of the Stream is found to lie around 20 kpc from the disk, which lends support to Giovanelli's suggestion.

It can be seen from the above that it is possible to make high velocity stars from the impact of a gas cloud; that gas is actually being observed undergoing collisions with the disk at the present; and that a source for some of that gas may be from satellite galaxies of the Milky Way. It must be considered now whether gas from presently observed infalling clouds could be a formation mechanism for the high velocity A stars. If the Clouds were on a first approach to the Galaxy, it might then account for star formation commencing at a specific time.

Van Woerden, Schwartz and Hulsbosch (1985) reviewed the subject of HVCs. They mentioned that an infall rate of gas might be $1m_{\odot}$ per year. In discussion of the paper, Ostriker pointed out that such an infall rate was highly inconsistent with observed X-ray data, and that a level of $0.01 m_\odot$ per year would be more realistic. Over 0.6 billion years, the latter rate would imply an accretion of $6 \times 10^6 m_\odot$ of gas. The infall rate would have begun slowly, as the gas began to be stripped and to respond to the gravity of the Galaxy. Since the Clouds are thought to be near or just past perigalacticon (Meurer, Bicknell and Gingold, 1985) the loss rate would be at a maximum now and would have been less in the past. This is difficult to reconcile with the evidence that formation of most of the SGP stars began in a burst from 0.6 to 0.4 billion years ago, with fewer stars formed since that time.

From the SGP and Yale star data, it is possible to estimate the amount of matter that might have gone into formation of the high-velocity stars. Taking the most conservative case that only about half of the observed Yale high velocity stars are part of the SGP population, the mass surface density for A stars was integrated for an exponential distribution from the disk to 3 kpc, and was found to be $3.92 \times 10^{-3} m_\odot pc^{-2}$. The initial mass function, appropriate for a burst of star formation that has not evolved over long periods of time (Allen, 1973, section 118), was used to estimate the fraction of mass that might have gone into lower mass stars. It was found to be around $6 - 8$ times the mass that had been observed in A stars. (The mass function for evolved stars led to a factor of over 15 times the observed mass, hence the IMF assumption again is the most conservative).

The volume considered was of an annulus of the disk, from about 6 to 12 kpc in radius (the inner and outer extent of the Yale star orbits), to 3 kpc above and below the disk. In that volume might be found from $8 \times 10^6 m_\odot$ to $2 \times 10^7 m_\odot$ of high velocity stars. Around half of this matter might have been contributed from the disk, so 0.4 to $1 \times 10^7 m_\odot$ might have come from infalling matter.

The star formation rate from infall (Tenorio-Tagle, 1981) would be around 1 percent efficiency, so that 0.4 to $1 \times 10^9 m_\odot$ of gas would have had to have been accreted to form the estimated high velocity star density. If this gas had been stripped from a galaxy with the ratio of gas to total matter observed in the Solar neighbourhood (Allen, 1973, section 119), of 5.3, then a conservative estimate is that the galaxy would have had a total mass of 2 to $5 \times 10^9 m_\odot$. From recent work, the Magellanic Clouds are now thought to be less massive than had been previously estimated. Dopita, Ford, Lawrence and Webster (1985) found a mass of $9 \times 10^8 m_\odot$ for the SMC, and Meatheringham and Dopita (1986) estimate the LMC to be $4 \times 10^9 m_\odot$.

If the infall matter had actually come from the Magellanic Clouds in the past, they would have lost a substantial fraction of their total hydrogen, and would now be gas-poor systems. However, they are both observed to be gas-rich galaxies, with around 10-12 percent of the LMC and 24-28 percent of the SMC in the form of neutral hydrogen. It would seem that the amount of gas needed to form the high velocity stars from infall is much greater than could have been provided by the present Magellanic Cloud system, or from the HVCs. The star formation event could not have been normal, small, or localised. It must have been an extraordinary and large-scale occurrence.

To account for this amount of infall, according to the theory of RHS, it would seem necessary to postulate the accretion of a satellite galaxy with a mass of *at least* midway between that of the SMC and the LMC. If it had been physically associated with the Clouds in the past, it is possible that the Magellanic Stream is hydrogen that was stripped off the satellite galaxy as it was accreted. (The MS contains around $1 \times 10^8 m_\odot$ of hydrogen).

It is interesting to consider how the remnants of a merged galaxy might appear to present-day observers. In such a galaxy, as in our own, there would be an evolved population of stars, globular clusters, and a main sequence, as well as gas and dust. The metallicity of the LMC is around -0.5, and that of the SMC about -1.0. Much of the metal-poor gas would fall in with the stars, which would remain on orbits that would travel far out into the halo, and which might retain some of the orientation of their initial trajectory, while the gas would eventually interact with the disk.

Rodgers and Paltaglou (1984) presented evidence, discussed in Chapter 1, for systematic motion of a group of globular clusters, and in agreement with Searle and Zinn (1978), suggested that all globular clusters have come from accreted satellite galaxies.

Horizontal branch stars from an accreting galaxy would have the characteristics of the observed galactic halo population: they would be metal-poor and would not rotate with the galaxy. Freeman (1986) describes evidence that all halo stars may be from accreted galaxies in the early stages of the evolution of the Milky Way. The young, high-velocity A stars, in a few billion years time, would simply appear as relatively metal-rich evolved halo stars and there would then be no way to distinguish them from other halo stars.

The high mass stars from a main sequence of a galaxy accreted 0.6 billion years ago would have evolved to later stages. The remnants of the main sequence might be observed today as late A and lower-mass stars, with main sequence gravities and low metallicities – like the four stars at the SGP that were characterised as 'blue stragglers'. They would not rotate with the disk, like the local high velocity star CD$-48°$6657 (Chapter 4), with a surface gravity of 4.08 dex, a calcium abundance of -1.12, and a V velocity of -200 km/s. Another star in this category might be HD 9566 from the Yale star sample, with a gravity of 3.86 dex, abundance of -0.57, and a V velocity of -283 km/s.

Some of the gas from the accreted satellite would form stars, as described by Tenorio-Tagle (1981). The acceleration of gravitationally collapsing gas in *all directions* from an expanding cavity might be the formation mechanism of the high-velocity local Yale stars, which were found to have large and almost isotropic velocity dispersions in U, V and W, unlike any other disk star distribution. (The distant SGP stars would be the tail of the W distribution.)

Depending on how many orbital cycles of interaction with the disk the infalling gas might have undergone before coalescence, and upon the ratio of disk-to-accreted gas, the formed stars would lag behind disk rotation to a smaller or larger extent. The mean amount of asymmetric drift found for the Yale stars was 40 km/s. If the accreted galaxy was not in an exact polar orbit, then during infall it would gain some rotational angular momentum, either with or against the direction of disk rotation.

From the abundances of the Yale stars, the average mixture of gases may be estimated to be around 50/50, because accreted gas of about -1.0 dex [Ca/H] combined in this proportion with disk gas of about 0.1 dex [Ca/H] would give the mean abundance of the SGP stars of about -0.16 dex. So the average lag behind disk rotation of the stars formed from this mixture would be expected to be around 110 km/s. If the accreting galaxy gained a small amount of angular momentum in the direction of disk rotation, this would account for the lower asymmetric drift of the Yale stars.

Alternatively, the accreting gas from which they were formed may have interacted enough with the disk before coalescence to have gained some V motion. Whichever may have occurred, what is most interesting is that the young stars do have a significant asymmetric drift, indicative that they could not have been formed entirely from matter rotating normally with the disk.

The phenomenon of the young Stream I stars may also have some relation to an accretion event. They seem to have been formed from gas with small systematic motions similar to the direction of motion of the high-velocity stars; they comprise up to 70 percent of local stars (an unusually high proportion for young stars); and most were formed around and since 600 million years ago, the time the SGP and Yale high-velocity stars were formed. An occurrence such as a merger, beyond the specific consequences of high-velocity gas impacts, would also cause systematic disturbances of the normal disk gas, which would lead to an increased rate of young star formation from that gas.

The hypothesis of the recent accretion of a satellite galaxy by the Milky Way appears to be consistent with both observations and indirect evidence. This does not mean, of course, that it is proven, only that its use as a framework for further investigations may prove to be both productive and informative. Future studies may test this framework with greater rigour and either accept it or find alternative explanations. For the present, it would seem to be a useful working hypothesis. In the next section, an interesting local feature of galactic structure was investigated in terms of the possible consequences of a small accretion event.

5.3 Gould's Belt.

The nature of this local feature appears to have become accepted over time, yet it is quite an extraordinary structure. It is a plane of bright young stars, nebulae, neutral hydrogen and dust, tilted at nearly 20° from the galactic plane. The Sun is relatively close to the centre of the structure where it passes through the disk. Various estimates of the size of the Belt have been given. From Lucke's (1978) Figure 7, and Westin's (1985) plots of OB stars it can be seen to extend from about 400 pc inside the solar radius and above the plane, to around 800 pc away towards $l = 210°$ and below the plane. It is around 700 pc wide from side to side, and a few tens of parsecs thick.

Projected onto the sky it appears as a cosine curve of bright OB stars, above the plane towards the galactic centre and below the plane towards the anticentre. The ages of its stars are from about 65 million years to the present. Several attempts have been made to fit the observed motions of the stars to models of expanding gas, such as Lesh (1968), Olano (1982) and Westin (1985). They are only partially sucessful in explaining the observed features. Spiral density wave effects have been investigated by Strauss, Poeppel and Vieira (1979) and Westin (1985), who found from an extensive study of over 2200 bright stars, that both the density wave model and the expansion model were not capable of accounting for the properties of Gould's belt.

Frogel and Stothers (1977) suggested that 'some disturbance knocked a slab of gas and dust out of the galactic plane' at about 6×10^7 years ago, and that the slab oscillates, having passed through the plane again at 2×10^7 years ago. Both the numerous dark dust clouds of the Belt and the young stars show a local perturbation of the general galactic velocity field, called the K term, first seen as a small positive residual in the peculiar velocities of the brighter B stars. It is generally attributed to expansion of the system, but for models of expanding systems or even for those in purely differential galactic rotation, the gradient of V velocity in the X direction is expected to be negative. Lesh (1972) found instead that for Gould's Belt stars it was +14 km/s.

Eggen (1975) studied the bright Pleiades members of Gould's Belt. He found that they had a distinctive V velocity of -25 km/s, and from his data, the mean U velocity is 11 km/s and the mean W is -8 km/s. They are travelling towards $l = 246°$. He also listed some OB stars that had unusually high velocities, characterising them as 'runaways', but admitted in the text that there were difficulties with that interpretation. Those stars also had mean U motions of 11 km/s, mean V of -27 km/s, and mean W of -8 km/s, only with much higher dispersions (58, 31, 26) than the few km/s for the Pleiades group.

If the orbits of the Pleiades group and the Sun are traced back over 65 million years (using a galactic model program by L. Ferrario), they would have originated at around 1.2 kpc from the Sun, in the direction of about $l = 340°$, in the inner (Saggitarius) arm of the galaxy. In other words, the Sun may appear today to be in an almost central, privileged position with regard to Gould's Belt, but it is really only moving through it at present: the Belt was actually formed in a different part of the Galaxy.

Westin (1985) found that the Gould's Belt stars older than 60 million years were inclined by only 1° to the plane. Stars aged between 30 and 60 million years were inclined by 14°. Those younger than 30 million years were inclined by 18°, while the most recently formed stars, those younger than 20 million years, were inclined by 19° to the plane. It is difficult to avoid the impression that star formation in the Belt initially began closer to the plane, and has been moving away from it over time, as might be produced by the kind of star-forming shock front described by Tenorio-Tagle (1981).

Gould's Belt stars are obviously much younger than the high velocity A stars.

There is no suggestion here that the postulated initial merger of a satellite galaxy was involved in the formation of Gould's Belt. Instead, it might be suggested that some of the high velocity gas from that event, having interacted with the disk over time, and losing much kinetic energy, finally coalesced with a small region of the Saggitarius arm rich in molecular clouds. Stars formed from a combination of the gases would show the asymmetric drift of the Gould's Belt stars. The ring or slab-like nature of the system would follow from the induced shock front, while the generally low velocities of the Belt stars would suggest that the W velocity of the infalling cloud was not high. Tenorio-Tagle's (1981) calculations show that even low-velocity infalling clouds may easily form stars over a wide range of gas densities in the disk.

Tenorio-Tagle had also shown that a collision between a small gas cloud and the disk would have a kinetic energy of around 10^{53} to 10^{54} ergs, and would form a shell of neutral hydrogen. It might be questioned whether there is any evidence that such a structure is seen associated with Gould's Belt. In fact, Lindblad's (1967) feature 'A', observed in HI, and the same ring observed in OH emission (Hughes and Routledge, 1972) might be such a structure.

Hughes and Routledge state that it appears to be an elliptical ring of major and minor axes of 1300 and 560 pc, with an expansion velocity of 6 km/s, an age of 65 million years, and an expansion energy of 2×10^{53} ergs. Their model for an expanding ring from a single source has the same problems as other such models. Hughes and Routledge attribute the source of the feature to a Type III supernova, but as mention previously, Oke and Searle (1974) suggest that these postulated supernovae may be misclassified Types I or II, and may not actually exist.

Tenorio-Tagle (1980) pointed out that the expansion velocity of the feature 'A' is in agreement with collision models, and that the temperature and density calculations for a collision-induced cavity are consistent with X-ray observations in the Solar vicinity.

Herbst and Sawyer (1981) found, in agreement with previous studies, that the Sun appears to be near the centre of a mass density enhancement, of low-mass stars (as distinct from the early-type stars of Gould's Belt). For around 500 pc in all directions, the stellar density appears to be around twice that of regions at greater distances, even after all possible errors from extinction have been taken into account. The Sun is thought to be in an inter-arm region, where a lower stellar density might be expected. Spiral density-wave effects in any case are on a much smaller scale than was measured by Herbst and Sawyer. If, however, a quantity of gas had coalesced with the disk and formed the Gould's Belt feature, that region would have approximately double the normal density of gas, and presumably, double the usual numbers of stars of all masses would have been able to form there.

It can be seen that the age, energy and dimensions of the feature 'A', and the temporal and spatial structure of Gould's Belt are consistent with the proposition that a merger of a small gas cloud with a part of a spiral arm of the galaxy may have occured 65 million years ago.

If such an event took place, the abundances in Gould's Belt might also be expected to be unusual. Pagel and Edmunds (1981) state that there is little difference between the abundances of the Sun, young stars, and the local ISM, but that 'the most disturbing discrepancy is that oxygen and nitrogen seem to be underabundant in Orion (and other nearby galactic H II regions)'. Part, but not all of the discrepancy in Orion could be accounted for by condensation upon grains. Orion and the other nearby H II regions are, of course, distinctive features of Gould's Belt.

Walborn (1976) found that all of the O9.5 to B0.7 supergiants in the Belt of

Orion and in the nucleus of SCO OB1 (also part of Gould's Belt) were systematically deficient in nitrogen, in comparison to other supergiants of the same spectral types. (This differential comparison overcame some of the problems associated with measuring abundances in supergiant atmospheres). The nitrogen deficiency was not associated with a carbon overabundance as is usually seen in OB stars with CN abundance anomalies. Neither of these results is in any way conclusive evidence, but they are suggestive that the abundances of some parts of Gould's Belt may be unusual.

It would seem from the above that consideration of this local structure from the viewpoint of a gas cloud accretion might account for many of the features that have so far eluded a consistent explanation. It would also seem that the hypothesis of a satellite accretion in the recent history of the Galaxy is consistent with the unusual characteristics of the population of young high-velocity stars. This theory is the only one of those proposed to account for the A stars that is presently supported by the data. Future studies will be necessary in order to test the hypothesis further.

Research in the past has often concentrated on global characteristics of the Galaxy, seeking to uncover large-scale patterns of structure and evolution. If such an event as a galactic merger has ocurred once or many times in the history of the Galaxy, it may only be possible to understand what is presently observable by taking such past events into consideration.

5.4 Summary.

The relationship of the young A stars to other stellar groups was examined. Two evolved types of stars, red giants at the SGP and some disk red horizontal branch stars, were found to be too dissimilar in relative numbers and in kinematics to be related to the young, high-velocity stars. Runaway OB stars were also found to be too numerous for all of them to be high-mass members of the A star population. A few of them do show a similar asymmetric drift, however, and may be related.

An explanation was proposed to account for the high latitude OB stars that are observed at distances from the disk greater than they could travel in their normal main sequence lifetimes. It was suggested that they are the kinds of blue straggler that are seen in all normal disk clusters, ejected like other OB stars from clusters by the binary interaction mechanism. They have extended main sequence lifetimes, which would allow them to travel to the great distances at which they are seen.

From the determinations of the parameters of the young, high-velocity stars in this work, it was clear that all but one of the theories advanced to account for their existence were not viable. The only remaining hypothesis was that of the accretion of a satellite galaxy around 6×10^8 years ago, in which metal-poor gas from the satellite combined with metal-rich gas from the Galactic disk, to form young, mildly metal-poor stars with high velocities.

It was shown that predicted consequences of gas collisions with a galactic disk were consistent both with observational and indirect evidence. The amount of gas needed to form the observed density of high-velocity stars was conservatively estimated to be equivalent to the gas content of a galaxy at least midway in size between the Small and Large Magellanic Clouds. If such a galaxy had been previously physically associated with the Clouds, the Magellanic Stream might be gas stripped off the satellite as it was accreted.

The gas accretion theory was used to examine the unusual local feature of Gould's Belt. A consistent and satisfactory explanation of all of the properties of the Belt has previously eluded other investigators, who have usually concentrated on single-point expansion, or density-wave, models. A reconsideration of the evidence in terms of the coalescence, around 65 million years ago, of a small infalling gas cloud with part of the Saggitarius arm of the Galaxy, was found to be consistent with the ages, energy, dimensions, stellar density, HI feature, and temporal structure of Gould's Belt.

It was proposed that the merger theory be accepted as a working hypothesis, subject to further investigation. It seems likely that understanding of our local stellar environment will be enhanced by consideration of the possible consequences of such an event in the recent history of the Galaxy.

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APPENDIX I: DATA FOR SGP STARS.

TABLE 1: Nomenclature, coordinates, spectral types and UBV photometry for SGP catalogue stars.

No	SB	PS	HD	CD, others	B	R.A.	Dec (1950)	Sp type	m_V	B-V	U-B	S
1	122			CD -31 99		0 16 04	-30 53 48	A0	12.75	0.14	0.18	P
2	123					0 16 12	-20 42 0	A0	12.9			
3	124		1492			0 16 24	-33 36 0	A5	8.82			
4			CH148			0 16 24	-32 12 0	B	14.47	-0.17	-1.07	BI
5	125		CH149	CD -25 92		0 16 42	-25 29 0	A	12.72	-0.01	0.13	AT
6	126		CH150	CS22882-03		0 16 45.4	-30 18 27	A0	14.53	0.01	0.08	P
7			SP222			0 17 02.4	-27 42 04	A0	13.5			
8	131			BD -22 46		0 17 24	-22 03 0	F0	10.6			
9	133	1II		CS22882-07		0 17 46.9	-29 04 14	A0	14.46	0.04	0.10	P
10	134	1I	1619	CD -25 99		0 17 48.6	-24 58 47	A0	8.64	0.35	0.14	BW
11	135	2I		CD -25 101		0 17 54	-25 29 0	A7	11.8			
12	136	2II				0 18 04.9	-21 54 52	A3	12.27	0.15	0.15	EG
13			1667	CD -24 104		0 18 17.2	-23 54 26	F0	6.77			
14	137	3I		CD -34 99		0 18 18	-34 07 0	F0	11.9			
15	143			GD603		0 18 42	-33 58 0	A	14.62			
16			SP224			0 18 59.9	-26 42 53	DA	13.8			
17			CH153			0 19 06	-22 51 0	A	14.7			
18		3II				0 19 23	-32 59 12	A7	13.01	0.32	0.12	EG
19	146	4I		CD -23 112		0 19 24	-22 57 0	A5	11.0			
20	147		CH154	GD605		0 19 30	-24 43 0	B	14.48	-0.33	-1.23	BI
21	149					0 19 48	-30 43 0	F0	13.0			
22	151	5I		CD -34 111		0 20 00	-33 55 0	A5	13.2			
23	152	6I	1869	BD -21 41		0 20 24	-20 56 0	A7	10.5			
24	153	7I	1909	CD -31 138		0 20 42.5	-31 18 46	B9IVMN	6.55	0.00	-0.31	BW
25			CH155			0 21 30	-23 28 0	A	14.9			
26	161	8I	2026	CD -29 106		0 21 48.5	-29 15 26	A1V	8.14	0.14	0.16	BW
27	162	9I	2037	CD -27 110		0 21 59.3	-27 11 37	A5IV	8.36	0.29	-0.02	BW
28	163		2080			0 22 24	-20 13 0	F0	8.82			
29	167	10I	2178	BD -22 65		0 23 11.3	-21 54 29	A1Vn	7.63	0.06	0.05	BW
30	169			LB7736		0 23 30	-21 14 0	B	13.98			
31	171		CH157			0 23 48	-23 17 0	B6	14.60			
32	172	11I		CD -32 128		0 23 52	-32 13 54	A0	12.40	-0.02	0.00	P
33	173			GD612		0 23 52.8	-27 25 13	A	14.47			
34		12I		CD -25 145		0 24 12	-25 17 0	A7	12.1			
35	178					0 25 0	-22 17 0	F0	13.18			
36	179	4II				0 25 05.2	-32 01 26	A9	13.14	0.31	-0.02	EG
37	181	13I	2395	BD -20 67		0 25 6.3	-20 24 39	A7IV	6.80	0.22	0.13	BW
38	182	14I	2415	CD -30 127		0 25 17.7	-29 47 21	B9/A0V	11.15	0.05	-0.02	BW
39	188					0 26 12	-22 43 0	A7	12.8			
40		15I	2527	CD -25 155		0 26 20.6	-24 54 46	F0IIIn	7.13	0.13		CS
41	191	5II	CH158			0 26 36	-23 56 0	A0	14.02	0.06	0.19	EG
42			SP229			0 26 37.5	-27 30 50	OB	13.2			
43			CH159			0 26 42	-30 39 0	A	14.4			
44	193	16I		CD -32 152		0 26 42	-32 08 0	A7	11.3			
45	192	6II		CS22882-33		0 26 46	-31 42 18	A	14.23	0.06	0.13	P
46	194	7II				0 26 47.8	-33 06 26	A0	13.42	0.19	0.10	EG
47	197	17I	2613	CD -23 173		0 27 5.3	-23 27 39	A2	10.28	0.32	0.02	BW
48	195			CD -35 150		0 27 00	-34 49 0	A3	13.3			
49	198	8II				0 27 10.9	-21 00 12	A5	13.03	0.22	0.09	EG
50	199	18I	2641	CD -30 138		0 27 28.7	-30 30 25	A0V	9.52	0.15	0.10	BW
51			SP231			0 27 32.4	-28 03 49	Aw	11.3			
52		9II				0 27 47.2	-29 31 10	F	12.22	0.41	-0.19	EG
53	202	10II		CS22882-15		0 27 54.8	-28 25 32	A0	14.26	0.16	0.11	P
54	203	19I	2696	CD -24 179		0 27 52.7	-24 3 50	A3/5V	5.18	0.13		CS
55	207	20I		CD -32 160		0 28 18	-32 19 0	A7	12.3			
56	208	11II				0 28 36	-30 57 0	A	14.28	0.06	0.20	EG
57		12II				0 28 48	-23 32 0	A0	14.51	0.07	0.09	EG
58	210	13II		CS22882-14		0 28 53.9	-28 14 02	A0	12.99	0.02	0.06	P
59	211		CH162			0 29 00	-24 14 0	A	13.5			
60	212	14II				0 29 00	-25 11 0	A0	13.32	0.00	0.02	EG
61	213	21I	2846	CD -23 186		0 29 8.9	-23 13 19	A3	10.61			
62	214					0 29 12	-24 35 0	A	13.4			
63	215			CD -25 182		0 29 24	-24 56 0	F0	12.3			
64			SP235			0 29 50.2	-29 39 35	A5w	12.9			

APPENDIX I, TABLE 1 continued.

No	SB	PS	HD	CD, others	B	R.A.	Dec (1950)	Sp type	m_V	B-V	U-B	S
65			2980	CD -34 180		0 30 25.0	-34 26 44	F2	8.94			
66	221	15II				0 30 34.5	-21 27 52	A0	13.99	0.12	0.13	EG
67	222	22I	3002	CD -34 181		0 30 36.2	-34 3 5	A5IV/V	9.57	0.24	0.10	BW
68	225	16II		CS22882-18		0 30 54.2	-28 50 58	A0	14.26	0.10	0.14	P
69			CH163	GD619		0 31 25.0	-27 24 56	A	14.2			
70	230					0 31 30	-21 01 0	A0	13.8			
71	231	17II		CS22882-19		0 31 36.2	-28 47 11	A0	13.18	-0.01	-0.03	P
72	235	18II				0 32 51.8	-21 17 13	A0	12.6			
73	236	23I	3244	CD -26 173		0 33 3.9	-25 40 27	A7III	8.20	0.28		CS
74	238	24I		CD -27 171		0 33 21.7	-26 46 17	F0	10.2			
75				CS22882-22		0 33 23	-30 16 42	AB	14.99	0.10	0.19	P
76			3300	CD -24 224		0 33 26.9	-24 4 35	A3	10.28			
77	242	25I	3326	CD -23 220		0 33 37.6	-23 6 58	A7p	6.05	0.30		CS
78			3338	CD -27 174		0 33 43.5	-27 2 7	F0	8.48			
79				CS22882-25		0 33 54	-31 12 30		14.91	0.03	0.12	P
80				CD -26 179		0 33 59.0	-25 56 54	A7	9.8			
81	246	19II				0 34 06	-22 42 0	A0	13.66	0.17	0.16	EG
82		26I	3417	CD -34 206		0 34 21.1	-34 33 26	A8V	10.76			
83		27I		CD -28 170		0 34 36.7	-27 54 38	A7	12.1			
84	248		3436			0 34 24	-31 58 0	F0	9.81			
85	250	28I		CD -27 179		0 34 54	-27 06 0	A3	13.0			
86	254	29I	3559	CD -25 233		0 35 55.9	-24 56 15	A5	8.53			
87	256	30I	3580	BD -21 84		0 36 1.9	-20 34 16	B8V	6.74	-0.11	-0.57	BW
88	257	20II		CS22882-20	#	0 36 10	-29 14 54	A0	14.01	0.14	0.16	P
89	259	21II			#	0 36 12	-24 43 0	A0	13.95	0.06	0.23	EG
90	264					0 36 24	-34 59 0	A5	13.23			
91	263	31I	3622	CD -26 196	#	0 36 24.6	-25 52 11	A5V	7.77	0.22		CS
92	265	32I		CD -23 239		0 36 30	-22 55 0	F0	10.8			
93	272	22II			#	0 38 14.9	-26 03 17	A5/7	13.04	0.25	0.07	EG
94	273	33I		CD -24 266	#	0 38 18	-24 23 0	B	12.69			
95	276	23II			#	0 38 40.3	-26 12 06	A0	13.82	0.13	0.16	EG
96	277	34I	3885	BD -20 118		0 38 48.6	-20 8 13	A0	9.79	-0.08	-0.24	BW
97	279	24II				0 38 54	-20 28 0	A7	12.05			
98	280					0 39 24	-21 14 0	A0	14.0			
99	283	25II			#	0 39 42	-33 17 0	A	14.54	0.08	0.21	EG
100	284	35I	3999	CD -32 254	#	0 39 53.7	-32 11 25	A2V	9.32	0.13	0.09	BW
101	285	26II			#	0 39 57.8	-28 50 48	A3	13.62	0.18	0.12	EG
102	286	37I	4011	CD -34 245		0 39 57.2	-34 15 50	A9V	9.57	0.34	0.12	BW
103	287	36I		CD -29 201	#	0 40 03.5	-28 51 01	A2	11.29	0.12	0.08	BW
104	288	38I	4052	CD -32 257	#	0 40 14.4	-32 32 29	A5	10.59			
105	292					0 41 18	-21 02 0	A0	12.9			
106	294	39I	4158	BD -21 99		0 41 24.9	-20 40 22	A9	9.56	0.27	0.02	BW
107	293	40I	4157	BD -21 100		0 41 27.4	-20 31 14	A2	9.59	0.02	-0.04	BW
108			SP249	CD -27 224	#	0 42 10.8	-26 35 24	A8	10.5			
109	298	27II			#	0 42 14.3	-27 27 21	A2	12.97	0.07	0.16	EG
110		41I	4247	BD -22 127		0 42 15.6	-22 16 39	F2V	5.23	0.33		CS
111	299	42I	4248	CD -24 297	#	0 42 19.7	-23 57 0	A3	10.35			
112	300		4259			0 42 24	-20 37 0	F0	8.93			
113	301				#	0 42 24	-24 58 0	A	13.5			
114	302	28II			#	0 42 26.6	-29 30 42	A0	14.16	0.13	0.10	EG
115	304	43I		CD -22 243		0 42 54	-22 02 0	A0	12.4			
116	306	45I	4329	CD -29 213	#	0 43 5.2	-28 57 28	A0	10.12	0.18	0.09	BW
117	307	44I	4327	BD -21 106		0 43 8.3	-21 10 54	A0V	9.51	0.14	0.11	EG
118	310	46I		BD -22 130		0 43 18	-21 46 0	A0	11.9			
119	312	47I	4399	CD -29 215	#	0 43 37.9	-29 5 59	A9V	9.64	0.28	0.03	BW
120	313	48I		CD -34 276		0 43 42	-33 50 0	F0	11.6			
121				CS22942-04	#	0 43 46	-24 15 42		14.61	0.17	0.06	P
122	314	49I	4414	CD -26 247	#	0 43 48.0	-25 48 36	F0V	9.05	0.29	0.01	PH
123	315			E 29.2.002	#	0 43 49.8	-29 23 27	A0	13.63	0.26		E
124	316	50I		CD -31 285	#	0 43 54	-31 24 0	F0	11.40			
125	317	29II			#	0 44 14.5	-28 12 38	A5	13.42	0.29	0.13	EG
126	318	51I	4485	CD -34 280		0 44 13.3	-33 41 32	A0IV	10.52	0.09	0.01	BW
127	320	52I	4507	CD -24 321	#	0 44 31.9	-24 29 20	A5	7.50			
128	322	30II		CS22942-06		0 44 34.2	-23 37 16	A5	12.90	0.18	0.08	P
129	323			CD -30 230	#	0 44 32.2	-30 27 14	F0	10.35	0.30	0.08	E

APPENDIX I, TABLE 1 continued.

No	SB	PS	HD	CD, others	B	R.A.	Dec (1950)	Sp type	m_V	B-V	U-B	S
130	326	53I		CD -23 308		0 45 24	-22 46 0	F0	13.0			
131	327		4623	CD -30 240	#	0 45 30.3	-29 37 0	F0III	7.57	0.32	0.07	E
132	329	54I	4622	BD -22 134		0 45 32.6	-21 59 40	B9V	5.57	-0.05	-0.12	BW
133	330	31II			#	0 45 29.7	-33 10 04	A	12.99	0.40	-0.13	EG
134	332			E 54	#	0 46 8	-27 27 6	A	14.81	0.27	0.12	E
135	333		4691		#	0 46 15	-28 46 6	F0	6.76	0.35	-0.01	E
136			4689	CD -23 311		0 46 20.7	-23 20 20	A5	9.42			
137	335	55I		CD -30 248	#	0 46 35	-29 48 30	A7	10.69	0.33	0.07	PH
138	337	56I		CD -28 251	#	0 46 47.9	-27 48 05	A5	11.45	0.26	0.06	PH
139	338				#	0 47 0	-27 39 0	A3	13.42			
140	340	57I	4772	CD -24 347		0 47 5.7	-23 38 1	A2/3V	6.26	0.14	0.13	BW
141				CS22942-09		0 47 26	-23 29 30		14.76	0.29	-0.04	P
142	342	58I		CD -31 306	#	0 47 48	-31 16 0	A0	12.45			
143	344	59I		CD -30 253	#	0 48 08.7	-30 14 24	A2	11.46	0.18	0.09	PH
144	343		4876	CD -28 260	#	0 48 10.2	-27 42 24	A9III/IV	9.43	0.36	0.08	E
145	345					0 48 12	-22 23 0	A0	13.9			
146				E30.1.036	#	0 48 22.6	-30 19 24	F	12.99	0.35		E
147				E30.1.041	#	0 48 51	-30 17 36	F	11.45	0.35		E
148			4974	CD -35 285		0 49 2.2	-35 3 15	A5	9.48			
149				E30.5.048	#	0 49 13	-30 59 06	B	14.40	-0.30		E
150	350	32II		HL6772	#	0 49 22.0	-32 10 01	A0	13.65	0.09	0.15	EG
151	351	61I		CD -34 317		0 49 24	-34 27 0	A3	12.80			
152		62I	5024	CD -31 319	#	0 49 29.4	-31 13 48	A9V	9.22	0.34	0.07	E
153	353			CS22942-13	#	0 50 13	-26 10 42	A	14.61	0.19	0.17	P
154	354	33II			#	0 50 24	-33 01 0	A0	13.53	-0.06	-0.12	EG
155	355			E 30.1.053	#	0 50 32.0	-30 10 52	A	14.07	0.09		E
156	360	34II		GD659	#	0 50 54	-33 17 0	B	13.36	-0.22	-1.15	EG
157				E30.5.071	#	0 51 33	-30 58 18	F	14.12	0.32		E
158	361	63I		CD -29 259	#	0 51 41.4	-29 01 21	A5	11.06	0.21	0.11	PH
159	362	35II	HL685	CS22942-15	#	0 51 54.0	-27 11 54	A0	13.08	0.07	0.16	P
160	363	36II			#	0 52 16.0	-28 30 10	A3	13.78	0.19	0.17	EG
161	366	37II		CS22942-20	#	0 53 09.8	-23 44 44	A5	12.30	0.21	0.06	P
162	367	64I		CD -31 353	#	0 53 12	-31 32 0	A3	11.76			
163	371	38II			#	0 53 32.7	-26 39 12	A3	13.59	0.34	0.04	DR
164	373	39II			#	0 53 48	-33 13 0	A0	13.64	0.20	0.19	EG
165	375	65I	5496	CD -31 362	#	0 53 58.3	-31 27 14	B9/A0V	10.58	-0.07	-0.19	BW
166				E29.5.101	#	0 54 16	-29 56 24	A	14.96	0.18		E
167	377	66I	5524	CD -26 303	#	0 54 22.7	-25 37 59	A5V	7.22	0.15	0.04	DR
168	379	67I	5546	CD -30 283	#	0 54 30.0	-30 1 51	A5IV/V	10.23	0.22	0.09	BW
169			CH179		#	0 54 36	-27 38 0	A	14.8			
170			CH180			0 54 42	-22 38 0	A	14.2			
171				E30.0.073	#	0 54 56.2	-30 08 18	A	14.72	0.08	0.13	E
172	384	68I		CD -31 372	#	0 55 06	-31 32 0	F0	12.6			
173	386		5630		#	0 55 18	-26 30 0	F0	9.99			
174	387	70I		CD -24 415	#	0 55 48	-23 47 0	A7	12.12			
175	388	69I		CD -24 414	#	0 55 49	-24 10 12	A0	12.35	-0.03	-0.09	P
176	389			CS22942-26	#	0 55 57	-24 31 54	A0	14.38	0.18	0.06	P
177	390	71I	5737	CD -30 297	#	0 56 11.9	-29 37 37	B7III	4.31	-0.18	-0.52	BW
178				E29.3.097	#	0 56 18	-29 35 54	A	14.35	0.17		E
179	391			CD -35 332		0 56 30	-34 45 0	A3	11.70	0.10	0.21	P
180	393	73I	5769	CD -30 299	#	0 56 36.7	-29 40 17	A4V	9.31	0.19	0.07	DR
181	398		5824	CD -32 395	#	0 57 3.2	-32 14 4	A9V	9.64	0.32	0.00	E
182	399	74I		CD -27 317	#	0 57 16.0	-27 01 54	A3/5	11.12	0.17	0.10	DR
183				CD-25 390	#	0 57 28.9	-25 0 0	A7	10.61			
184	402					0 57 54	-23 24 0	A5	13.6			
185	404			CS22942-28	#	0 57 59	-25 33 54	A3	13.55	0.31	0.04	DR
186	403	41II				0 58 00	-20 48 0	A5	11.6			
187	405			CD -28 307	#	0 58 00	-28 28 0	A	13.15			
188	408	42II			#	0 58 27.7	-28 21 37	A2	14.23	0.21	0.04	DR
189	410	43II	CH183			0 58 54	-33 59 0	B	12.57	-0.16	-0.99	AT
190		44II				0 59 09.7	-23 31 47	A7	12.15	0.36	-0.07	EG
191			6088	CD -26 334	#	0 59 23.9	-26 9 20	A5	9.75			
192	411	75I		CD -30 314	#	0 59 37.4	-29 47 22	A5	12.83	0.29	-0.02	DR
193	414	77I	6178	CD -32 410	#	1 00 3.2	-31 49 14	A1/2IV	5.49	0.10	0.12	E
194	413	76I		CD -31 412	#	1 00 4.6	-31 29 28	A8	10.42	0.32	0.08	E

APPENDIX I, TABLE 1 continued.

No	SB	PS	HD	CD, others	B	R.A.	Dec (1950)	Sp type	m_V	B-V	U-B	S
195				CS22942-37		1 00 38	-23 34 36	A	14.15	0.10	0.21	P
196	415					1 00 42	-21 39 0	A	13.8			
197	416	78I	GD673	CD -30 324	#	1 00 49.5	-29 59 42	B9/A0	11.19	-0.01	-0.33	PH
198	418			E 29.2.132	#	1 00 52	-29 27 36	A5	13.24	0.21	-0.03	DR
199	421				#	1 01 18	-28 1 0	B	13.08			
200			CH186		#	1 01 19.3	-25 35 04	A5	13.91	0.24	0.04	DR
201	420	79I		CD -24 469	#	1 01 24	-24 17 12	A0	12.77	0.09	0.14	P
202			CH185		#	1 01 18	-27 06 0	A	14.6			
203	423	45II				1 01 36	-33 55 0	A0	13.83	0.06	0.10	EG
204	426	80I	6340	CD -35 361		1 01 38.5	-34 56 40	A2V	8.99	0.08	0.03	BW
205	425			CD -22 371		1 01 42	-22 30 0	A7	11.2			
206	429			BD -20 189		1 01 54	-20 03 0	F0	10.4			
207	431	82I	6365	CD -30 330	#	1 01 53.5	-30 17 23	A3III/IV	9.81	0.26	0.05	E
208	430	81I	6364	CD -27 345	#	1 01 53.7	-27 25 21	A5/7III	9.62	0.28	0.03	BW
209	432		CH189	CS22942-31	#	1 02 11	-26 47 48	A	14.98	0.08	0.14	P
210			DR19	CS22942-32	#	1 02 36	-25 58 0	A2	14.63	0.22	0.01	DR
211	433	84I	6451	BD -20 191		1 02 45.9	-20 7 19	A7V	8.56	0.24	0.16	BW
212				BOK358F	#	1 02 57.9	-29 11 36	F	14.80	0.34		B
213	435	46II			#	1 03 13.7	-24 14 16	A0	13.38	-0.03	-0.11	EG
214	439			BD -20 193		1 03 24	-20 03 0	A2	10.7			
215			6515	BD -22 193		1 03 24.7	-21 50 1	A5	8.48	0.37		CS
216	440		6516		#	1 03 27.3	-25 44 57	A9V	9.22			CS
217	441	83I	6532	CD -27 355	#	1 03 31.4	-26 59 45	A2m	8.43	0.15	0.06	DR
218	442			CD -28 345	#	1 03 36.8	-27 48 11	A7	12.09			
219				KR3	#	1 03 44.3	-31 22 53		14.65	0.06		KR
220				BOK312F	#	1 04 07.6	-30 07 53	F	14.50	0.32		B
221	446	47II	CH191	GD679	#	1 04 24	-33 34 0	B	13.58	-0.30	-1.12	EG
222				BOK255F	#	1 04 26.7	-29 13 05	F	14.79	0.34		B
223			SP280		#	1 04 26.9	-30 34 16	A2w	13.08			
224	449	48II			#	1 04 34.6	-28 23 45	A0	13.15	0.22	0.01	DR
225	451	85I	6670	CD -30 348	#	1 04 38.1	-29 52 56	A9V	9.38	0.34	-0.04	DR
226	450	86I	6668	CD -24 496	#	1 04 47.3	-24 15 45	A5	6.36	0.17	0.09	BW
227	453	49II			#	1 05 00	-32 35 0	F0	12.88			
228			6724	CD -29 334	#	1 05 11.3	-29 33 13	F0V	9.29	0.35		E
229	455	87I	6723	CD -29 335	#	1 05 12.6	-28 58 16	A8V	9.08	0.28	0.01	DR
230	456					1 05 12	-33 43 0	A	14.1			
231	457					1 05 48	-20 07 0	A2	12.8			
232	458	89I		BD -22 206		1 06 4.7	-22 23 59	A5	11.90			
233	459	88I	CH192	CD -33 417	#	1 06 4.5	-32 59 31	B	12.23	-0.23	-0.98	CS
234			CH193	CI-331061	#	1 06 12	-32 56 0	A	14.5			
235	460	90I	CH194	CD -27 372	#	1 06 13.4	-27 9 06	B6	12.58	-0.15	-0.61	DR
236			6855	CD -34 439		1 06 20.5	-34 34 47	F0V	9.44	0.38		CS
237			KR7	BOK125F	#	1 06 23.3	-28 57 16	F	14.69	0.33		B
238				E29.0.197	#	1 06 25	-29 08 36	F	12.52	0.34		E
239	462	50II				1 06 30	-21 47 0	A0	13.36	0.07	0.20	EG
240				CI-331066	#	1 06 36	-33 26 0	B	12.05			
241	463	91I	CH195	CD -33 421	#	1 06 42.4	-33 23 58	B4	12.16	-0.15	-0.1	GW
242	464	92I		CD -33 423	#	1 07 00.4	-32 55 41	A2	12.5			
243	466	51II				1 07 06	-22 57 0	A3	12.88	0.28	0.04	EG
244	467				#	1 07 04.8	-26 55 43	F0	13.36	0.41	-0.21	DR
245	469				#	1 07 35.5	-28 14 29	A	13.10	0.36	-0.14	DR
246	471	93I		CD -34 450		1 07 48	-34 01 0	F0	10.7			
247			7038	CD -35 407		1 07 55.2	-34 46 8	F1	9.38			
248	474	52II		HL3361	#	1 08 07.0	-26 20 42	A0	13.18	-0.02	-0.05	DR
249	473			HL7200	#	1 08 07.4	-25 56 40	A0	14.28	0.01	0.03	DR
250	477	94I		BD -22 210		1 08 36	-22 16 0	F0	10.7			
251	480	53II		CS22946-01		1 08 51	-21 54 48	A0	13.04	0.00	0.06	EG
252				BOK 96F	#	1 08 56.1	-30 03 40		14.90	0.34		B
253	481	95I	7184	CD -27 389	#	1 09 26.7	-26 37 18	A2III/IV	9.88	0.21	0.07	DR
254	485	54II	CH201	GD691	#	1 09 48.0	-26 29 20	A0	13.15	-0.24	-1.04	DR
255	486	55II				1 09 59.4	-21 44 15	A0	12.96	0.08	0.11	EG
256	488	96I		CD -23 439		1 10 00	-23 06 0	A0	12.6			
257	493	97I		CD -23 448		1 10 36	-22 52 0	A3	11.8			
258	496			CD -34 465		1 10 52.7	-34 2 9	A5/F0	10.5			
259	495	56II			#	1 10 54	-32 47 0	A	12.78			

APPENDIX I, TABLE 1 continued.

No	SB	PS	HD	CD, others	B	R.A.	Dec (1950)	Sp type	m_V	B-V	U-B	S
260	497			CD -22 422		1 11 07.1	-22 17 03	A7	12.3			
261	499		7400		#	1 11 24	-24 31 0	F0	9.73			
262	502	98I		CD -30 389	#	1 11 33.1	-30 02 15	A3	12.24			
263	503				#	1 11 36	-26 40 0	A5	14.25	0.24	-0.03	DR
264	504	99I		BD -22 217		1 11 48	-22 13 0	F0	11.1			
265	505	57II				1 11 59.8	-21 17 40	A5	12.16	0.21	0.12	EG
266			DR44		#	1 12 30	-28 14 0	A2	14.00	0.29	-0.04	DR
267	509	100I	7553	CD -23 462		1 12 56.3	-23 11 6	A5	9.57			
268	511		7629	CD -24 548	#	1 13 29.5	-24 14 11	F0III	7.13	0.30		CS
269	512	101I		CD -26 414	#	1 13 37.2	-25 58 22	A7	11.99	0.29	-0.01	DR
270	514	102I	7652	CD -24 549	#	1 13 42.3	-24 10 4	A1V	10.07	0.11	0.08	BW
271	515		7676	CD -34 483		1 13 47.5	-34 24 44	A3m	8.38			
272	516		CH202	KR12	#	1 14 09.2	-27 11 15	A1	14.81	0.08	0.19	DR
273	517	103I		CD -32 498	#	1 14 18	-32 08 0	A3	11.6			
274	519	58II		KR13	#	1 14 36.0	-27 14 48	A0	13.45	0.03	0.10	DR
275	520		CH203	KR14	#	1 14 36.0	-28 01 46	A0	14.54	0.05	0.09	DR
276	521					1 14 48	-34 31 0	A	14.3			
277	522	104I		CD -32 501	#	1 14 54	-32 22 0	A2	11.59			
278			SP295		#	1 15 28.4	-30 02 57	Aw	14.0			
279	528	105I	7875	CD -24 562	#	1 15 40.6	-24 0 16	A2	9.71	0.30	0.13	BW
280	529	107I	7876	CD -25 515	#	1 15 41.7	-24 48 7	A2	10.05	0.20	0.07	BW
281	530	106I	7898	CD -34 494		1 15 44.3	-34 24 0	A9IV	7.74	0.26		CS
282	531	108I	7908	CD -23 477		1 16 1.0	-23 16 31	A7III	7.29	0.28		CS
283	532	59II			#	1 16 00	-33 23 0	A0	13.65	0.08	0.21	EG
284		60II		GD696		1 16 48.4	-23 10 02	A0	14.38	0.00	0.02	EG
285	534					1 16 42	-20 59 0	F0	13.0			
286	535	109I	8033	CD -23 483		1 16 58.2	-23 22 10	F0V	9.19	0.31		CS
287	537	62II			#	1 17 07.2	-26 57 33	A7	12.96	0.28	0.10	EG
288	539			CD -23 488		1 17 26.9	-23 12 4	A5/F0	9.0			
289	543	110I	8091	BD -21 213		1 17 32.4	-21 10 44	A5	10.6			
290	544	111I		CD -23 492		1 17 36	-22 45 0	A2	12.5			
291			8145	CD -30 434	#	1 18 3.6	-29 51 41	F2V	8.45	0.32		CS
292		112I	8163	CD -27 443	#	1 18 19.6	-26 37 46	A9/F0V	10.18			
293	549	113I		BD -21 217		1 18 54	-21 20 0	A2	11.3			
294	551	114I		CD -26 442	#	1 19 5.4	-26 16 11	A0	10.79	0.21	0.07	PW
295	552	115I		CD -23 500		1 19 12	-23 02 0	A3	11.5			
296	554				#	1 19 36	-32 6 0	A0	13.92			
297	557	116I		CD -23 504		1 19 48	-23 28 0	A0	11.1			
298	559	117I		CD -24 590	#	1 20 00	-23 51 0	A0	12.3			
299			SP298		#	1 20 24.5	-28 40 10	A1w	14.25			
300		118I		CD -28 421	#	1 20 30	-28 23 0	A7	11.67			
301	561		8380			1 20 18	-21 41 0	F0	8.09			
302	562			CD -26 452	#	1 20 28.0	-25 54 59	A7	11.51			
303	563		CH211		#	1 20 29.2	-30 10 15	A	14.47			
304	567		8472	CD -25 554	#	1 21 1.9	-25 20 42	A0	10.31	-0.07	-0.38	BW
305	568		8487	CD -25 555	#	1 21 11.9	-24 36 47	A7Vn	6.65	0.24		CS

Column 1) Catalogue number.
Column 2) SB: Slettebak and Brundage (1971).
Column 3) PS: Philip and Sanduleak (1968), lists I and II.
Column 4) HD number, CH: Chavira (1958), SP: Philip and Stock (1972), DR: Drilling (1977).
Column 5) CD number, BD number, CS: Pier (1983), E: Eriksson (1978), KR: Ratnatunga (1983), BOK: Bok and Basinski (1964), CI: CSI (1979), LB: Luyten (1966), HL: Haro and Luyten (1962), GD: Giclas, Burnham and Thomas (1972).
Column 6) # means that star is in 'box' area.
Column 9) Spectral types with luminosity classifications are from Michigan spectral Catalogue (Houk, 1978); others are estimates from original finding lists.
Column 10) Magnitudes to two decimal places are from *UBV* or *uvby* photometry. Those to one decimal place are estimates from original finding lists.
Column 13) Sources for *UBV* photometry: AT: Andrews and Thackeray (1973), B: Bok and Basinski (1964), BI: Iriarte (1970), BW: Westerlund (1963), CS: Cousins and Stoy (1963), E: Eriksson (1978), EG: Eggen (Rodgers, 1971), DR: Drilling (1977), P: Pier (1983), PH: in Philip (1974), PW: Penston and Wing (1972).

Four stars from PS, (60I, 72I, 40II, and 61II) were omitted from the catalogue as they are all later spectral types than F stars.

APPENDIX I (cont).

TABLE 2: *uvby* photometry, radial velocity, D(.70), and W(K) values for SGP catalogue stars.

No	ID	$b-y$	m_1	c_1	RV (km/s)	D(.70) (Å)	W(K) (Å)	S	comments
1	122						P1.0		
2	123								
3	124	0.190	0.184	0.704				HH	*
4	CH148								
5	125 CH149								
6	126				+32		P0.3		
7	SP222								
8	131								
9	133 1II	0.048	0.127	1.354	-115	16.0	P0.5	Ph	
10	134 1I	0.202	0.235	0.734	+29A			Ph	*
11	135 2I								
12	136 2II	0.080	0.170	1.056	+42	26.9	2.39	Ph	
13	1667	0.172	0.197	0.857				HH	*
14	137 3I								
15	143	-0.090	0.270	-0.250				GS	*
16	SP224								
17	CH153								
18	3II	0.229	0.166	0.583	+67	12.3	5.53	Ph	
19	146 4I								
20	147	-0.175	0.054	-0.204				GS	
21	149								
22	151 5I								
23	152 6I								
24	153 7I	-0.029	0.138	0.659	-5A			AM	*
25	CH155								
26	161 8I	0.059	0.221	1.002	-5A			HH	*
27	162 9I	0.184	0.125	0.796	+13A			HH	*
28	163	0.221	0.166	0.580				HH	*
29	167 10I	0.024	0.168	1.097	+1A			HH	*
30	169	-0.121	0.067	-0.168				GS	*
31	171	-0.073	0.111	0.485				GS	*
32	172 11I	0.008			+11	20.8	0.57		
33	173	0.105	0.130	1.290				EB	*
34	12I								
35	178	0.301	0.086	0.339				HH	*
36	179 4II	0.166	0.194	0.645	-55	14.2	3.70	Ph	? variable
37	181 13I	0.147	0.250	1.298	+14A			Ph	* ? variable
38	182 14I	-0.011	0.158	1.044	+23A			Ph	*
39	188								
40	15I	0.188	0.170	0.936	+19A			HH	*
41	191 5II	0.251	0.239	0.950	-132		R0.4	Ph	*
42	SP229								
43	CH159								
44	193 16I								
45	192 6II	0.054	0.166	1.254	0		P0.7	Ph	*
46	194 7II	0.108	0.188	0.885	-12	22.7	2.81	Ph	
47	197 17I	0.235	0.129	0.553				HH	*
48	195								
49	198 8II	0.156	0.182	0.849	+46	18.4	4.25	Ph	
50	199 18I	0.050	0.208	0.993	+34	25.1	1.47	HH	
51	SP231								
52	9II	0.293	0.109	0.377	-36		R2.1	Ph	*
53	202 10II	0.097	0.177	0.930	+109	26.8	2.03	Ph	
54	203 19I	0.079	0.152	1.047	+1A			HH	*
55	207 20I								
56	208 11II	0.039	0.172	1.342			R0.4	Ph	*
57	12II						R0.4		
58	210 13II	0.016	0.136	1.255	+22		P0.5	Ph	*
59	211								
60	212 14II	-0.005	0.141	1.043	-119	16.0	R0.4	Ph	! D70 from D80
61	213 21I	0.207	0.165	0.711				HH	*
62	214								
63	215								
64	SP235								

APPENDIX I, TABLE 2 continued.

No	ID	$b-y$	m_1	c_1	RV (km/s)	D(.70) (Å)	W(K) (Å)	S	comments
65	2980	0.215	0.167	0.726				HH	*
66	221 15II	0.077	0.132	1.313	-105	23.2	1.33	Ph	o
67	222 22I	0.131	0.191	0.856				HH	*
68	225 16II	0.066	0.157	1.280	-15	25.8	0.82	Ph	o
69	CH163								
70	230								
71	231 17II	0.013	0.112	1.179	-50	17.4	P0.5	Ph	! D70 from D80
72	235 18II	0.008	0.137	1.242	-37	24.1	0.55	Ph	variable
73	236 23I	0.171	0.149	0.773	+6A			HH	*
74	238 24I								
75	C22882-22				+92		P0.5		
76	3300	0.288	0.162	0.428				HH	*
77	242 25I	0.165	0.230	0.723	+14A			HH	*
78	3338	0.223	0.156	0.645				HH	*
79	C22882-25				+19		P0.5		
80	CD -26179								
81	246 19II	0.131	0.128	1.232	+6	21.8	R1.2	Ph	
82	26I	0.185	0.178	0.710				HH	*
83	27I								
84	248	0.198	0.182	0.631				HH	*
85	250 28I								
86	254 29I	0.116	0.201	0.908				HH	*
87	256 30I	-0.070	0.125	0.490	+9A			HH	*
88	257 20II	0.090	0.131	1.242	+57	24.3	1.71	Ph	
89	259 21II	0.019	0.166	1.268	-9	20.0	R0.5	Ph	! D70 from D80
90	264	0.242	0.092	0.644				GS	*
91	263 31I	0.115	0.206	0.812	+22	5.7	5.37	HH	o
92	265 32I								
93	272 22II	0.161	0.161	0.809	-36	17.0	3.34	Ph	
94	273 33I	0.244	0.088	0.506				GS	*
95	276 23II	0.075	0.170	1.202	+92	17.0	R1.2	Ph	
96	277 34I	-0.060	0.182	0.685				HH	*
97	279 24II	0.228	0.136	0.658	-44	12.8	3.86	Ph	
98	280								
99	283 25II	0.031	0.124	1.222	-32	21.0	R0.7	Ph	! D70 from D80
100	284 35I	0.040	0.219	0.987	-10	21.7	2.65	HH	
101	285 26II	0.097	0.218	0.925	+42	25.0	R1.7	Ph	! D70 from D80
102	286 37I	0.217	0.140	0.856				HH	*
103	287 36I	0.061	0.207	0.969	-24	24.1	1.14	Ph	
104	288 38I	0.155	0.214	0.779	-39	10.9	2.41	HH	
105	292								
106	294 39I	0.210	0.109	0.752				GS	*
107	293 40I	0.001	0.154	1.070				HH	*
108	SP249						2.22	L	
109	298 27II	0.034	0.178	1.208	+8	25.5	2.60	Ph	
110	41I	0.230	0.137	0.553	+14A			HH	*
111	299 42I	0.133	0.210	0.851	+54	17.4	3.53	HH	
112	300	0.223	0.151	0.632				HH	*
113	301				-84	12.3	2.39		
114	302 28II	0.055	0.201	1.006		27.0	R0.4	Ph	! D70 from D80
115	304 43I								
116	306 45I	0.074	0.209	1.033	-4	29.3	2.14	Ph	
117	307 44I	0.077	0.188	1.059	+24	29.3	2.96	HH	
118	310 46I								
119	312 47I	0.169	0.201	0.784	-15	15.6	3.38	Ph	
120	313 48I								
121	C22942-04				+95		P1.0		
122	314 49I	0.192	0.167	0.722	-17A			Ph	*
123	315				+82	20.8	3.12		
124	316 50I	0.251	0.145	0.669	-11	7.1	4.35	L	
125	317 29II	0.170	0.193	0.756	-76	17.0	3.65	Ph	
126	318 51I	0.051	0.179	0.952	-24	27.4	1.08	HH	
127	320 52I	0.121	0.219	0.907	+17	16.0	3.27	HH	
128	322 30II	0.079	0.205	0.953	+44	24.6	2.96	Ph	
129	323	0.193	0.192	0.739	-9	12.3	3.73	L	

APPENDIX I, TABLE 2 continued.

No	ID	$b-y$	m_1	c_1	RV (km/s)	D(.70) (Å)	W(K) (Å)	S	comments
130	326 53I								
131	327	0.196	0.169	0.736	+10A			HH	*
132	329 54I	-0.016	0.137	0.968	+19A			Ph	*
133	330 31II	0.222	0.105	0.489	+51	11.8	1.71	Ph	
134	332								
135	333	0.224	0.155	0.580	+4	10.4	4.07	HH	
136	4689	0.255	0.165	0.489				HH	*
137	335 55I	0.198	0.190	0.769	+21	14.2	4.39	Ph	
138	337 56I	0.173	0.152	0.880	-16	11.8	3.41	Ph	
139	338	0.179	0.127	0.956				GS	* RR Lyrae
140	340 57I	0.084	0.165	1.206	+6A			Ph	*
141	C22942-09				-5		P1.6		
142	342 58I	0.230	0.118	0.512	+27	9.9	1.43	GS	
143	344 59I	0.111	0.195	0.936	-8	26.0	1.96	Ph	
144	343	0.212	0.226	0.618	-18	11.8	5.99	HH	
145	345								
146	E30.1.036	0.211	0.130	0.595	+87	11.3	5.47	L	
147	E30.1.041	0.288	0.134	0.562	+37	9.0	5.84	L	
148	4974	0.219	0.160	0.684				HH	*
149	E30.5.048								
150	350 32II	0.134	0.160	1.045	-46	29.7	1.45	Ph	α
151	351 61I								
152	62I	0.219	0.162	0.700	+4A			HH	*
153	353				+31		P0.6		
154	354 33II	-0.001	0.109	0.932	+68	9.5	P0.1	Ph	
155	355								
156	360 34II	-0.114	0.129	-0.209	-4		R0.4	Ph	*
157	E30.5.071								
158	361 63I	0.150	0.193	0.886	+3	19.8	2.74	Ph	
159	362 35II	0.064	0.157	1.254	-32	20.0	P0.5	Ph	! D70 from D80
160	363 36II	0.129	0.117	1.200	+106	18.0	R1.7	Ph	! D70 from D80
161	366 37II	0.104	0.199	0.888	-22	23.6	3.02	Ph	
162	367 64I	0.204	0.173	0.774	+20	11.3	2.12	L	
163	371 38II	0.235	0.135	0.870	-19	9.4	3.85	Ph	RR Lyrae, UV Scl.
164	373 39II	0.078	0.193	0.971	-15	24.0	3.09	Ph	
165	375 65I	-0.028	0.144	0.878	-26A	16.5	0.33	Ph	
166	E29.5.101								
167	377 66I	0.057	0.201	1.028	+32	19.8	2.47	Ph	
168	379 67I	0.121	0.183	0.926	-24	23.1	2.72	Ph	
169	CH179								
170	CH180								
171	E30.0.073								
172	384 68I				-18	10.9	4.11		
173	386	0.202	0.200	0.704	-61	11.8	3.95	HH	
174	387 70I	0.210	0.157	0.749	-90	10.8	2.91	L	
175	388 69I	-0.009			+78	18.9	0.42		
176	389				-28		P1.1		
177	390 71I	-0.050	0.097	0.494	+10A			Ph	*
178	E29.3.097								
179	391								
180	393 73I	0.111	0.194	0.926	+10A			Ph	*
181	398	0.189	0.159	0.716	-7	10.9	3.05	HH	
182	399 74I	0.095	0.222	1.005	-10	22.7	3.09	Ph	
183	CD-25 390	0.300	0.081	0.633	-16	7.1	3.46	L	
184	402								
185	404				+34		P3.2		
186	403 41II	0.228	0.150	0.722	-63	13.7	5.44	Ph	
187	405	0.237	0.075	0.972				GS	* RR Lyrae
188	408 42II	0.142	0.171	0.913	-14	22.0	R0.9	Ph	! D70 from D80
189	410 43II	-0.114	0.066	-0.049	+59		R0.4	Ph	*
190	44II	0.252	0.139	0.499	+4	8.5	5.16	Ph	
191	6088	0.213	0.165	0.630	-12	11.3	4.25	HH	
192	411 75I	0.191	0.183	0.694	+132	15.1	3.55	Ph	
193	414 77I	0.041	0.187	1.069	+4A			AM	*
194	413 76I	0.194	0.193	0.680	-11	12.8	4.58	HH	

APPENDIX I, TABLE 2 continued.

No	ID	$b-y$	m_1	c_1	RV (km/s)	D(.70) (Å)	W(K) (Å)	S	comments
195	C22942-37				-98		P1.4		
196	415								
197	416 78I	-0.018	0.183	0.705	+23	15.1	0.34	Ph	
198	418	0.241	0.096	0.691	+91	13.2	3.80	L	
199	421	0.328	0.084	0.233				GS	*
200	CH186				-82		3.20		
201	420 79I	0.051			+145	24.0	2.16		
202	CH185								
203	423 45II				-41		P0.3		
204	426 80I	0.041	0.212	1.004	-2A			HH	*
205	425								
206	429								
207	431 82I	0.150	0.164	0.822	-1	13.7	2.41	HH	
208	430 81I	0.157	0.220	0.707	+13	13.2	2.64	Ph	
209	432				+2		P0.4		
210	DR19				+72		P1.5		
211	433 84I	0.116	0.257	0.885	-5A			HH	*
212	BOK358F								
213	435 46II	0.007	0.124	1.044	+119	22.2	0.63	Ph	
214	439								
215	6515	0.223	0.167	0.583	+16A			HH	*
216	440	0.236	0.142	0.527	+25	9.0	3.93	HH	
217	441 83I	0.084	0.236	0.838	0A			Ph	*
218	442	0.329	0.061	0.303	-94	5.2	3.30	GS	
219	KR3								
220	BOK312F								
221	446 47II	-0.121	0.088	-0.150	+21		R0.4	Ph	*
222	BOK255F								
223	SP280	0.325	0.086	0.290	-17	5.7	3.18	L	
224	449 48II	0.170	0.113	0.935	+82	15.0	R1.0	Ph	! D70 from D80
225	451 85I	0.213	0.150	0.652	+22	11.3	3.30	HH	
226	450 86I	0.140	0.209	0.829	+15A			Ph	*
227	453 49II	0.265	0.118	0.851	+28		R0.4	Ph	* RR Lyrae
228	6724	0.253	0.145	0.615	+1A			HH	*
229	455 87I	0.178	0.171	0.746	+2A			HH	*
230	456								
231	457								
232	458 89I								
233	459 88I	-0.112	0.109	-0.033	+1	15.6	0.10	Ph	
234	CH193								
235	460 90I	-0.069	0.128	0.404	+182	15.1	0.30	Ph	
236	6855	0.231	0.164	0.572	+11A			HH	*
237	KR7								
238	E29.0.197	0.283	0.197	0.417	+1	8.0	6.41	L	
239	462 50II	0.035	0.138	1.348	+147	17.6	R0.5	Ph	! D70 from D80
240	CI-331066	0.357	0.203	0.383	+13	4.7	6.61	L	
241	463 91I	-0.078	0.120	0.269	+259	11.8	0.33	Ph	
242	464 92I				-36	29.8	1.30		
243	466 51II	0.184	0.178	0.685	+26		R2.2	Ph	*
244	467								
245	469	0.253	0.088	0.526				GS	*
246	471 93I								
247	7038	0.252	0.179	0.565				HH	*
248	474 52II	0.002	0.129	1.138	-34	17.0	R0.4	Ph	! D70 from D80
249	473								
250	477 94I								
251	480 53II	0.004	0.134	1.209	+85	17.5	R0.1	Ph	! D70 from D80
252	BOK 96F								
253	481 95I	0.116	0.213	0.879	+18	20.8	2.36	Ph	
254	485 54II	-0.105	0.083	-0.055	-42		R0.4	Ph	*
255	486 55II	0.031	0.150	1.271	-6	21.7	1.46	Ph	
256	488 96I								
257	493 97I								
258	496								
259	495 56II	0.187	0.124	0.790	-2	16.0	R1.6	Ph	! D70 from D80, ?variable

APPENDIX I, TABLE 2 continued.

No	ID	$b-y$	m_1	c_1	RV (km/s)	D(.70) (Å)	W(K) (Å)	S	comments
260	497				+14	13.7	3.83		
261	499	0.209	0.175	0.711	+14	8.0	3.04	HH	
262	502 98I	0.059	0.198	0.924	+55	29.8	2.05	L	
263	503								
264	504 99I	0.189	0.215	0.609				Ph	*
265	505 57II	0.102	0.183	0.875	+11	21.7	3.26	Ph	
266	DR44								
267	509 100I	0.213	0.168	0.684				Ph	*
268	511	0.184	0.179	0.755	-1A			HH	*
269	512 101I	0.200			-47	12.8	2.79		
270	514 102I	0.061	0.224	1.022	0	19.0	1.88	Ph	
271	515	0.085	0.280	0.715	+11A			HH	*
272	516								
273	517 103I				+247	28.3	1.75		
274	519 58II	0.013	0.167	1.260	+200	22.0	R0.4	Ph	! D70 from D80
275	520								
276	521								
277	522 104I	0.043			+58	19.4	1.72	L	
278	SP295								
279	528 105I	0.165	0.239	0.832	-72	15.6	2.59	HH	
280	529 107I	0.085	0.211	0.992	+31	26.9	1.56	HH	
281	530 106I	0.158	0.182	0.821	+3A			HH	*
282	531 108I	0.196	0.136	0.660	+11A			HH	*
283	532 59II	0.042	0.169	1.246	+26		R0.4	Ph	*
284	60II	-0.011	0.163	1.152	-26	17.0	0.36	Ph	
285	534								
286	535 109I	0.179	0.205	0.645	+15A			HH	*
287	537 62II	0.166	0.191	0.775	-53	16.1	4.48	Ph	
288	539								
289	543 110I								
290	544 111I								
291	8145	0.192	0.196	0.772	-5A			HH	*
292	112I				-18		2.81		
293	549 113I								
294	551 114I	0.110	0.165	0.914	-41	18.4	3.25	L	
295	552 115I				+5	27.4	2.75		
296	554	0.140	0.090	1.230				GS	*
297	557 116I				+2	25.5	1.89		
298	559 117I				-7	24.6	2.54		
299	SP298	0.221	0.144	0.397	-21	14.6	1.10	L	
300	118I	0.300	0.089	0.548	+16	8.0	4.42	L	
301	561	0.233	0.273	0.687				HH	*
302	562	0.218	0.094	0.689	+28	12.7	2.96	L	
303	563	0.069	0.108	1.146	+191	25.5	0.41	L	
304	567	-0.018	0.113	0.601	-26	10.9	0.13	HH	
305	568	0.138	0.209	0.815	-1A			HH	*

Notes:
Column 1) Catalogue number.
Column 2) Three-digit numbers are SB, numbers with 'I' or 'II' are PS, others are as in Table 1.
Column 3) Where $b-y$ alone is given, it has been derived from $B-V$ via Kurucz (1979) models.
Column 6) 'A' next to radial velocity means value is from Abt and Biggs (1972).
Column 8) 'P' next to W(K) means value is from Pier (1983); 'R' means value is from Rodgers (1971) or Rodgers, Harding and Sadler (1981). In these cases, the radial velocity cited is also from those papers.
Column 9) The sources of the *uvby* photometry: HH: McFadzean, Hildich and Hill (1983), Ph: Philip (1974) and private communication (1986), GS: Graham and Slettebak (1973), EB: Eggen and Bessell (1978), AM: Albrecht and Maitzen (1980), L: Lance, this thesis.
Column 10) '*' means that no spectrum was available, so that gravities and temperatures were found from *uvby* photometry only. '! D70 from D80' means that the value of D(.70) used was derived from Rodgers (1971) D(.80) values. 'O' means that the photometry was not consistent with spectral indices – PS15II and PS16II are discussed in Section 3.5. For PS32II, $b-y$ was derived from Eggen's $B-V$, as it was consistent with other measures, rather than Philip's $b-y$. For PS31I, the spectral type is around F2, in contrast to $b-y$ of 0.115.

APPENDIX I (cont).

TABLE 3: Gravities, temperatures, reddenings, colours, abundances, masses, Z distances, maximum Z distances, and ages, for Population I and 'blue straggler' stars from the SGP catalogue.

No	ID	log g	θ_{eff}	E_{b-y}	$b-y_0$	[Ca/H]	$m_{\odot}$	M_V	Z (pc)	Z_{max} (pc)	age 10^6yrs		type
3	124	4.01	0.684	0.000	0.190	–	1.69	2.04	224	0	850		
10	134 1I	3.81	0.698	0.000	0.202	–	1.78	1.57	257	472	1250		Am
12	136 2II	3.98	0.596	0.028	0.052	-0.18	1.99	1.19	1521	1835	450	*	Ap:
13	1667	3.64	0.675	0.000	0.172	–	1.96	0.89	148	0	750		
18	3II	4.25	0.688	0.029	0.200	0.01	1.50	2.79	1064	1833	0	*	
24	153 7I	4.00	0.462	0.000	-0.029	–	3.00	0.13	190	199	150		B9IVp
26	161 8I	4.04	0.599	0.000	0.059	–	2.00	1.35	226	234	450		A1V
27	162 9I	3.71	0.684	0.000	0.184	–	2.05	1.08	284	331	950		A5IV
28	163	4.12	0.707	0.000	0.221	–	1.50	2.59	173	0	650		
29	167 10I	3.76	0.574	0.000	0.024	–	2.31	0.34	284	284	500		A1Vn
36	179 4II	4.20	0.662	-0.006	0.172	-0.25	1.49	2.51	1334	1867	450	*	
38	182 14I	3.96	0.508	0.000	-0.011	–	2.53	0.53	1323	1413	300	*	B9A0V
46	194 7II	4.18	0.613	0.014	0.094	-0.19	1.66	2.01	1851	1878	500	*	
47	197 17I	4.05	0.725	0.000	0.235	–	1.50	2.53	352	0	1200		
49	198 8II	4.11	0.628	0.021	0.135	-0.01	1.78	1.86	1676	2062	450	*	
50	199 18I	4.20	0.521	0.052	-0.002	0.24	2.27	1.31	395	652	150		A0V
53	202 10II	4.21	0.600	0.032	0.065	-0.32	1.73	1.94	2676	5014	450	*	Am
54	203 19I	3.82	0.614	0.000	0.079	–	2.02	0.90	71	72	700		A3/5V
60	212 14II	3.64	0.491	0.012	-0.017	-0.38	2.91	-0.55	5796	9938	250	*	
61	213 21I	3.75	0.703	0.000	0.207	–	1.70	1.50	658	0	1150		
65	2980	3.63	0.712	0.000	0.215	–	1.83	1.18	352	0	950		
67	222 22I	4.02	0.631	0.000	0.131	–	1.88	1.60	389	0	550		A5IV/V
73	236 23I	3.95	0.665	0.000	0.171	–	1.84	1.67	201	214	750		A7III
76	3300	4.00	0.777	0.000	0.288	–	1.40	2.81	310	0	2000		
77	242 25I	4.26	0.651	0.000	0.165	–	1.60	2.51	50	159	0		A7p
78	3338	3.82	0.716	0.000	0.223	–	1.60	1.83	213	0	1450		
82	26I	4.03	0.679	0.000	0.185	–	1.68	2.06	543	0	800		A8V
84	248	4.16	0.688	0.000	0.198	–	1.53	2.55	282	0	400		
86	254 29I	4.00	0.625	0.000	0.116	–	1.82	1.54	249	0	550		
87	256 30I	4.10	0.326	0.000	-0.070	–	6.50	-1.08	363	383			B8V
88	257 20II	3.49	0.591	0.056	0.034	-0.37	2.50	-0.32	6569	7407	350	*	
93	272 22II	4.16	0.637	0.017	0.144	-0.26	1.59	2.17	1443	1669	550	*	
97	279 24II	4.17	0.675	0.033	0.195	-0.27	1.40	2.58	729	1057	850		
100	284 35I	3.95	0.611	-0.042	0.082	-0.30	1.80	1.33	394	418	700		A2V
101	285 26II	4.12	0.607	0.017	0.080	-0.58	1.79	1.73	2308	2611	500	*	Am
103	287 36I	4.17	0.530	0.057	0.004	-0.10	2.15	1.30	892	984	250		
107	293 40I	4.01	0.529	0.000	0.001	–	2.42	0.78	574	0	250		
109	298 27II	3.63	0.591	0.000	0.034	0.00	2.40	0.08	3950	3963	450	*	
110	41I	4.10	0.719	0.000	0.230	–	1.47	2.64	32	154	800		F2V
111	299 42I	4.04	0.632	0.000	0.133	-0.22	1.74	1.74	526	1055	800		
112	300	3.90	0.715	0.000	0.223	–	1.56	2.05	235	0	1600		
116	306 45I	4.07	0.592	0.026	0.048	-0.18	1.89	1.44	517	521	550		
117	307 44I	4.06	0.592	0.029	0.048	0.10	2.00	1.36	402	537	400		A0V
119	312 47I	4.12	0.646	0.013	0.156	-0.30	1.57	2.15	307	364	950		A9V
122	314 49I	4.05	0.682	0.000	0.192	–	1.64	2.16	238	326	800		F0V
125	317 29II	4.23	0.632	0.031	0.139	-0.13	1.59	2.31	1501	2526	250	*	Am
126	318 51I	4.30	0.524	0.049	0.002	-0.07	2.10	1.65	538	657	0		A0IV
127	320 52I	3.78	0.644	-0.021	0.142	-0.44	1.73	1.18	183	283	1100		Am
128	322 30II	4.08	0.607	0.000	0.079	-0.11	1.84	1.60	1898	2249	500	*	
129	323	3.90	0.684	0.004	0.189	-0.43	1.47	1.91	482	500	1850		
131	327	3.80	0.695	0.000	0.196	–	1.70	1.58	157	195	1200		F0III
132	329 54I	4.12	0.495	0.000	-0.016	–	2.55	0.82	88	235	150		B9V
135	333	4.19	0.700	0.013	0.211	-0.32	1.32	2.86	58	73	900		
136	4689	4.10	0.740	0.000	0.255	–	1.40	2.83	207	0	1400		
137	335 55I	3.98	0.663	0.028	0.170	-0.18	1.65	1.85	555	646	850		
143	344 59I	4.12	0.603	0.040	0.071	-0.40	1.68	1.77	802	814	800		
144	343	4.18	0.689	0.013	0.199	0.06	1.52	2.61	225	325	300		A9III/IV
146	E30.1.036	4.20	0.693	0.009	0.202	-0.03	1.49	2.71	1118	2444	300	*	
147	E30.1.041	4.05	0.718	0.057	0.231	-0.13	1.40	2.56	537	811	1450		
148	4974	3.74	0.713	0.000	0.219	–	1.69	1.55	381	0	1200		

APPENDIX I, TABLE 3 continued.

No	ID	log g	θ_{eff}	E_{b-y}	$b-y_0$	[Ca/H]	$m_\odot$	M_V	Z (pc)	Z_{max} (pc)	age 10^6yrs		type
150	350 32II	4.16	0.565	0.104	0.030	-0.25	1.90	1.52	2192	2556	400	*	
152	62I	3.66	0.714	0.000	0.219	–	1.78	1.30	382	386	1000		A9V
158	361 63I	4.11	0.617	0.047	0.103	-0.28	1.68	1.85	637	638	750		
161	366 37II	4.15	0.610	0.018	0.086	-0.11	1.76	1.85	1188	1269	400	*	
164	373 39II	4.07	0.607	0.000	0.078	-0.08	1.86	1.57	2669	2709	550	*	
165	375 65I	3.98	0.455	0.004	-0.032	-0.04	3.05	0.03	1274	1389	150	*	B9A0V
167	377 66I	3.75	0.618	-0.038	0.095	-0.50	1.83	0.86	186	469	900		A5V
168	379 67I	4.10	0.610	0.036	0.085	-0.21	1.76	1.72	469	596	650		A5IV/V
173	386	3.97	0.688	0.006	0.196	-0.37	1.40	2.17	362	1073	2050		
177	390 71I	3.22	0.345	0.000	-0.050	–	15.00	-4.12	484	507			B7III
180	393 73I	4.00	0.621	0.000	0.111	–	1.94	1.44	373	397	550		A4V
182	399 74I	3.91	0.610	0.016	0.079	-0.17	2.00	1.11	975	990	600		
186	403 41II	4.09	0.668	0.049	0.179	0.03	1.64	2.17	697	1365	600		
190	44II	4.22	0.721	0.017	0.235	-0.19	1.30	3.09	627	630	500		
191	6088	4.12	0.692	0.013	0.200	-0.28	1.42	2.55	268	310	1400		
192	411 75I	4.27	0.653	0.024	0.167	-0.24	1.50	2.62	1053	4183	200	*	
193	414 77I	4.01	0.589	0.000	0.041	–	2.09	1.16	73	84	400		A12IV
194	413 76I	4.10	0.679	0.006	0.188	-0.16	1.54	2.33	408	437	1000		
197	416 78I	4.13	0.408	0.027	-0.045	0.00	3.33	0.10	1567	1660	0	*	
198	418	4.25	0.650	0.077	0.164	-0.17	1.54	2.52	1205	2661	200	*	
204	426 80I	4.12	0.586	0.000	0.041	–	1.97	1.48	314	315	350		A2V
211	433 84I	4.05	0.623	0.000	0.116	–	1.86	1.63	240	249	500		A7V Am
213	435 46II	4.00	0.510	0.017	-0.010	-0.33	2.38	0.71	3302	6302	350	*	
215	6515	4.07	0.712	0.000	0.223	–	1.53	2.48	157	250	1000		
216	440	4.20	0.717	0.005	0.231	-0.42	1.20	3.10	165	359	1700		A9V
217	441 83I	4.50	0.602	0.000	0.084	–	1.60	2.77	135	0			
226	450 86I	4.09	0.636	0.000	0.140	–	1.78	1.87	78	181	500		
228	6724	3.61	0.748	0.000	0.253	–	1.73	1.43	372	373	1100		F0V
229	455 87I	4.00	0.672	0.000	0.178	–	1.74	1.90	271	273	800		A8V
236	6855	4.03	0.720	0.000	0.231	–	1.55	2.42	251	290	1200		F0V
240	CI-331066	4.02	0.796	0.048	0.309	0.00	1.30	3.06	571	606	2500		
247	7038	3.83	0.743	0.000	0.252	–	1.52	2.09	284	0	1800		
253	481 95I	4.17	0.617	0.012	0.104	-0.39	1.57	2.07	355	433	850		A2III/IV
255	486 55II	3.44	0.570	0.014	0.017	-0.29	2.79	-0.68	5194	5201	250	*	
262	502 98I	4.23	0.593	0.006	0.053	-0.23	1.71	1.96	1120	1635	350	*	
264	504 99I	4.30	0.676	0.000	0.189	–	1.50	2.84	444	0	0		
265	505 57II	4.16	0.615	0.004	0.098	-0.09	1.74	1.92	1097	1116	400	*	Am:
267	509 100I	3.84	0.707	0.000	0.213	–	1.62	1.81	354	0	1400		
268	511	3.84	0.683	0.000	0.184	–	1.72	1.59	127	128	1100		F0III
270	514 102I	4.00	0.600	0.000	0.061	-0.43	1.70	1.44	529	529	750		A1V
271	515	4.70	0.601	0.000	0.085	–	1.50	3.33	101	155			A3m
281	530 106I	3.91	0.654	0.000	0.158	–	1.90	1.47	177	180	650		A9IV
282	531 108I	4.11	0.688	0.000	0.196	–	1.57	2.39	94	150	600		
286	535 109I	4.35	0.664	0.000	0.179	–	1.53	2.87	182	261	0		F0V
287	537 62II	4.15	0.644	0.013	0.153	-0.04	1.67	2.14	1415	1914	450	*	
291	8145	3.69	0.694	0.000	0.192	–	1.82	1.22	277	284	950		F2V
294	551 114I	4.01	0.620	0.000	0.110	-0.20	1.81	1.54	703	998	700		
300	118I	4.12	0.712	0.077	0.223	-0.32	1.38	2.71	531	586	1600		
305	568	4.15	0.634	0.000	0.138	–	1.72	2.04	82	83	350		A7Vn
90	264	3.71	0.727	0.020	0.222	–	1.53	1.67	1952	0		?	
96	277 34I	4.09	0.360	0.000	-0.060	–	6.00	-0.89	1353	0		?	
304	567	3.70	0.383	0.032	-0.050	x	10.00	-2.30	3104	3222		?	

APPENDIX I, TABLE 3 continued.

No	ID	log g	θ_{eff}	E_{b-y}	$b-y_0$	[Ca/H]	$m_\odot$	M_V	Z (pc)	Z_{max} (pc)	age 10^6yrs		type
114	302 28II	4.20	0.538	0.045	0.010	-1.10	1.82	1.56	3036	3036		B	
188	408 42II	4.10	0.613	0.049	0.093	-1.21	1.62	1.83	2749	2783		B	
208	430 81I	4.11	0.670	-0.022	0.179	-0.60	1.42	2.39	279	327		B	A5/7III
225	451 85I	4.07	0.693	0.012	0.201	-0.52	1.37	2.47	234	371		B	A9V
243	466 51II	4.12	0.675	0.000	0.184	-0.78	1.37	2.48	1194	1307		B	
259	495 56II	4.15	0.642	0.038	0.149	-0.93	1.45	2.28	1163	1164		B	
279	528 105I	3.92	0.647	0.012	0.153	-0.61	1.54	1.67	393	1334		B	
280	529 107I	4.06	0.600	0.023	0.062	-0.58	1.73	1.57	472	677		B	
302	562	4.09	0.679	0.041	0.177	-0.55	1.40	2.41	607	763		B	

Notes:

Column 5) A dash in Column 7 means there was no spectrum available, so the value of E_{b-y} was estimated (discussed in Section 3.2).

Column 7) An 'x' indicates that the spectrum was available, but that the abundance calibration was not valid for such hot stars.

Column 10) Z distances were not calculated for stars with θ_{eff} less than 0.300.

Column 11) Maximum Z distances were not calculated for stars without radial velocities.

Column 13) '*' denotes the Population I stars at distances greater than 1 kpc. '?' denotes apparently Population I stars at large distances, for which more data is required. 'B' indicates that the stars may be field blue stragglers, as they have main sequence gravities and calcium abundances less than -0.50 dex; or they might be unidentified Am stars. In the case of those at large distances from the plane, other possibilities were considered in Section 5.3.

Column 14) Spectral types with luminosity classifications are from Houk (1978). 'Am' and 'Ap' are my notations for stars that may be of those types, as indicated by their photometry or spectra.

APPENDIX I (cont).

TABLE 4: Gravities, temperatures, reddenings, colours, abundances, masses, Z distances and maximum Z distances for horizontal branch, white dwarf, and F subdwarf stars from the SGP catalogue.

No	ID	log g	θ_{eff}	E_{b-y}	$(b-y)_0$	[Ca/H]	$m_{\odot}$	M_V	Z (pc)	Z_{max} (pc)	type
9	133 1II	2.88	0.569	0.036	0.012	-1.21	0.55	-0.32	8397	~ 14000	
30	169	5.20	0.200	0.000	-0.121	–	0.50	–	0	0	sdB
31	171	4.20	0.360	0.000	-0.073	–	0.55	1.98	3312	0	sdB
32	172 11I	3.60	0.540	0.007	0.001	-0.81	0.55	1.37	1574	1595	
33	173	2.92	0.638	0.020	0.085	–	0.55	0.23	6755	0	
37	181 13I	2.17	0.695	0.000	0.147	–	0.55	-1.27	406	453	
40	15I	3.14	0.698	0.000	0.188	–	0.55	1.17	154	281	
41	191 5II	2.56	0.748	0.020	0.231	-3.03	0.55	0.05	5971	~ 12000	
45	192 6II	3.21	0.596	0.020	0.034	-1.40	0.55	0.66	4953	4953	
56	208 11II	3.02	0.520	0.020	0.019	-0.88	0.55	-0.10	7207	7207	
58	210 13II	3.00	0.534	0.020	-0.004	-0.86	0.55	-0.14	4062	4165	
66	221 15II	3.25	0.600	0.037	0.040	-0.88	0.55	0.79	4043	6490	
68	225 16II	3.50	0.588	0.035	0.031	-0.97	0.55	1.33	3822	3867	
71	231 17II	3.45	0.529	0.018	-0.005	-0.80	0.55	0.99	2649	3088	
72	235 18II	3.45	0.590	-0.023	0.031	-1.34	0.55	1.22	1874	2126	
81	246 19II	3.40	0.612	0.067	0.064	-1.18	0.55	1.25	2664	2670	
89	259 21II	3.28	0.570	0.004	0.015	-1.22	0.55	0.68	4462	4480	
95	276 23II	3.48	0.605	0.020	0.055	-1.07	0.55	1.40	2933	4587	
99	283 25II	3.48	0.562	0.016	0.015	-0.85	0.55	1.15	4589	4815	
102	286 37I	3.09	0.726	0.000	0.217	–	0.55	1.23	462	0	
104	288 38I	3.59	0.704	-0.005	0.160	-1.00	0.55	2.34	445	764	
106	294 39I	3.58	0.709	0.000	0.210	–	0.55	2.34	275	0	
124	316 50I	3.23	0.756	-0.005	0.256	-0.75	0.55	1.77	840	861	
138	337 56I	3.42	0.692	-0.012	0.185	-0.70	0.55	1.83	838	883	
139	338	3.44	0.669	0.020	0.159	–	0.55	1.73	2093	0	
140	340 57I	3.40	0.625	0.000	0.084	–	0.55	1.34	96	115	
154	354 33II	3.00	0.460	0.024	-0.025	-1.10	0.55	-0.54	6187	7373	
156	360 34II	5.25	0.196	0.000	-0.114	x	0.50	–	0	0	sdO
159	362 35II	3.19	0.611	0.012	0.052	-2.00	0.55	0.72	2902	3081	
160	363 36II	3.28	0.630	0.035	0.094	-1.09	0.55	1.08	3253	5565	
162	367 64I	3.66	0.695	0.008	0.196	-1.05	0.55	2.45	714	791	
163	371 38II	3.07	0.725	0.017	0.218	-0.84	0.55	1.17	2828	2892	
174	387 70I	3.60	0.704	0.006	0.204	-0.83	0.55	2.36	882	2279	
175	388 69I	3.60	0.520	0.000	-0.009	-0.83	0.55	1.35	1582	2661	
183	CD-25 390	3.46	0.756	0.040	0.260	-0.87	0.55	2.35	416	477	
187	405	2.61	0.735	0.020	0.217	–	0.55	0.09	3944	0	
189	410 43II	5.45	0.174	0.000	-0.114	x	0.50	–	0	0	sdB
201	420 79I	3.10	0.615	0.000	0.051	-0.80	0.55	0.52	2810	7345	
207	431 82I	3.63	0.675	-0.022	0.172	-0.86	0.55	2.25	324	324	
221	446 47II	5.10	0.215	0.000	-0.121	x	0.50	–	0	0	sdB
224	449 48II	3.62	0.653	0.026	0.144	-1.55	0.55	2.08	1555	2747	
227	453 49II	2.74	0.753	0.020	0.245	-2.97	0.55	0.53	2829	2966	
233	459 88I	5.22	0.224	0.026	-0.138	x	0.50	–	0	0	sdO
235	460 90I	4.82	0.354	-0.005	-0.064	x	0.50	3.51	651	7271	sdB
239	462 50II	2.98	0.580	0.017	0.018	-1.32	0.55	-0.02	4559	10500	
241	463 91I	4.58	0.300	0.022	-0.100	x	0.50	2.68	748	~ 26000	sdB
248	474 52II	3.50	0.515	0.012	-0.010	-0.80	0.55	1.08	2495	2697	
251	480 53II	3.34	0.542	0.002	0.002	-2.34	0.55	0.73	3005	4403	
254	485 54II	5.60	0.160	0.000	-0.105	x	0.50	–	0	0	sdO
261	499	3.34	0.743	-0.034	0.243	-0.99	0.55	1.96	355	402	
269	512 101I	3.50	0.682	0.023	0.177	-0.81	0.55	1.97	962	1317	
274	519 58II	3.36	0.593	-0.021	0.034	-1.65	0.55	1.01	3012	~ 15000	
283	532 59II	3.32	0.581	0.020	0.022	-1.52	0.55	0.84	3482	3607	
284	60II	3.50	0.512	0.000	-0.011	-0.85	0.55	1.06	4567	4716	
296	554	2.85	0.659	0.020	0.120	–	0.55	0.19	5302	0	
301	561	3.55	0.732	0.000	0.233	–	0.55	2.42	134	0	
303	563	3.66	0.592	0.030	0.039	-1.62	0.55	1.76	3269	~ 14000	
15	143	8.14	0.300	0.000	-0.090	–	1.40	10.57	63	0	DA

APPENDIX I, TABLE 4 continued.

No	ID	log g	θ_{eff}	E_{b-y}	$(b-y)_0$	[Ca/H]	$m_{\odot}$	M_V	Z (pc)	Z_{max} (pc)	type
35	178	4.55	0.761	0.020	0.281	–	1.00	4.45	531	0	sdF
52	9II	4.40	0.755	0.020	0.273	-0.99	0.96	4.09	406	689	sdF
94	273 33I	4.34	0.709	0.020	0.224	–	1.05	3.54	649	0	sdF
133	330 31II	4.67	0.680	0.022	0.200	-0.83	1.11	4.12	570	1038	sdF
142	342 58I	4.34	0.705	0.010	0.220	-1.20	1.06	3.51	602	747	sdF
199	421	5.15	0.800	0.020	0.308	–	0.80	6.43	205	0	sdF
218	442	4.64	0.774	0.036	0.293	-0.57	0.96	4.80	267	1895	sdF
223	SP280	4.76	0.761	0.041	0.284	-0.52	0.93	5.06	371	440	sdF
238	E29.0.197	4.55	0.725	0.039	0.244	0.10	1.00	4.22	423	423	sdF
245	469	4.20	0.720	0.020	0.233	–	0.98	3.34	861	0	sdF
299	SP298	5.02	0.656	0.043	0.178	-1.01	1.15	4.80	711	796	sdF

Notes:

Stars in this table are horizontal branch stars unless otherwise indicated in Column 12.

Column 5) If there is a dash in Column 7 then there was no spectrum available, hence the value of E_{b-y} was estimated (discussed in Section 3.2).

Column 7) An 'x' indicates that a spectrum was available, but the abundance calibration was not valid for such hot stars.

Column 10) Z distances were not calculated for stars with θ_{eff} less than 0.300.

Column 11) The maximum Z distances were not caculated for stars without radial velocities.

Column 12) sdF stars were identified on the basis of low m_1 indices, low [Ca/H], and higher gravities than main sequence values.

APPENDIX II: DATA FOR YALE STARS.

TABLE 1: Nomenclature, coordinates, spectral types and mean proper motions for the Yale stars.

No	HD	Cape	SAO	R.A.(1950)	Dec.	l^{II}	b^{II}	Sp. type	μ_α ″.0001	μ_δ ″.001
1	2320	180	215098	0 24 27.0	-40 09 29	323.2	-76.3	A9 V	69	-36
2	2339	181	215099	0 24 33.7	-40 46 08	322.1	-75.7	A0 V	17	11
3	4850	366	215253	0 47 41.3	-47 33 52	303.6	-69.8	A0 V	67	12
4	6208	471	215340	1 00 16.0	-48 28 13	297.8	-68.8	A0 V	31	24
5	9566	721	215552	1 30 44.8	-47 31 07	283.7	-68.3	A8 IV/V	139	-94
6	13107	986	215774	2 04 59.0	-48 16 28	272.8	-64.4	A2MA3-F2	21	36
7	13780	1042	215821	2 10 59.7	-49 17 14	272.8	-63.0	A1 IV	-11	-68
8	20686	1571	216249	3 16 14.1	-49 28 02	261.2	-54.3	A0 V	57	13
9		2029		4 02 41.4	-39 54 03	243.3	-48.4		33	10
10	26760	2096	216687	4 10 27.6	-40 04 23	243.5	-46.8	A0 V	-32	16
11		2383		4 39 07.0	-39 56 23	243.5	-41.4		25	62
12	31943	2569	217082	4 56 06.5	-43 06 26	247.8	-38.4	A2 IV	90	-64
13	31973	2574	217085	4 56 19.4	-44 42 18	249.9	-38.4	AP SRCREU	30	28
14	68864	5542	219606	8 10 56.6	-40 18 05	257.3	-3.5	A7 (IV)	-17	34
15	69260	5601	235820	8 12 25.9	-50 24 00	265.9	-8.8	A0 V	-10	-19
16	70101	5719	219756	8 16 36.2	-45 29 13	262.2	-5.5	A3 IV	5	-24
17	74399	6362	220308	8 40 32.5	-40 23 02	260.7	1.0	A3 IV/V	-38	20
18	80764	7260	221072	9 18 04.6	-49 35 59	272.0	-0.1	A0 V	-20	-11
19	84745	7771	221469	9 43 54.4	-49 43 53	275.1	2.6	A2 V	-26	-13
20	84743	7772	221473	9 44 02.7	-44 28 57	271.7	6.6	A1/2 V	-56	42
21	84805	7782	221482	9 44 32.8	-40 26 51	269.2	9.8	A0 V	-69	27
22	84846	7788	221485	9 44 43.9	-49 16 52	274.9	3.0	A2 V	-16	-35
23	85133	7813	221506	9 46 36.5	-45 19 36	272.7	6.3	A3 V	-42	-3
24	85283	7832	237375	9 47 24.2	-50 12 26	275.9	2.6	A0 IV	-18	-23
25	85410	7850	237386	9 48 13.4	-50 07 50	275.9	2.7	A2 IV/V	-9	-29
26	86504	8008	221641	9 55 39.7	-47 19 23	275.1	5.7	A0 V	-28	8
27	91554	8676	222143	10 31 15.8	-46 50 27	279.9	9.5	A2 IV	-30	-2
28	93067	8850	222280	10 41 51.7	-47 05 44	281.6	10.2	A2 IV	-29	-3
29	94519	9028	222406	10 51 44.6	-45 48 39	282.6	12.1	A0 V	-28	7
30	95701	9152	238701	10 59 48.1	-50 10 56	285.7	8.7	A3 IV	1	-24
31	106845	10241	223332	12 14 45.9	-49 57 28	297.4	12.3	A0/1 V	-42	-19
32	107872	10346	223408	12 21 18.9	-48 43 40	298.3	13.6	A0 V	-17	-15
33	110332	10605	223606	12 38 54.9	-46 49 52	301.2	15.7	A1MA3-F0	-52	-26
34	111752	10751	223719	12 49 10.6	-47 00 04	303.0	15.6	A5 V	-64	-10
35	112407	10832	223781	12 54 10.7	-48 41 33	303.9	13.9	A7/9 (V)	-56	-21
36	112468	10842	223787	12 54 33.2	-47 08 48	304.0	15.4	A2 IV	-27	-20
37	112480	10843	223788	12 54 37.4	-48 37 03	304.0	14.0	A0 V	-13	-15
38	112686	10864	223802	12 56 14.7	-48 26 55	304.2	14.1	A2/3 IV	-24	-16
39	112725	10871	223809	12 56 30.0	-43 43 20	304.4	18.9	A3/5 (IV)	-29	-17
40	112982	10907	240481	12 58 18.3	-50 03 40	304.5	12.5	A2 V	-26	-25
41	113235	10934	223861	13 00 07.1	-48 54 29	304.9	13.7	A2 V	-34	-9
42	115190	11134	224020	13 13 21.3	-48 12 10	307.2	14.2	A0 V	-18	-12
43	115528	11164	224052	13 15 30.3	-48 11 26	307.6	14.2	A1MA3/5-A9	-17	-22
44	116134	11226	240788	13 19 30.4	-50 08 08	308.0	12.2	A7/9 V	-35	-35
45	118044	11454	240978	13 32 17.7	-50 08 37	310.1	11.9	A0 V	-17	-23
46	118368	11484	241005	13 34 31.3	-50 26 35	310.4	11.5	A8/9 V	-11	-44
47	120015	11677	224431	13 44 38.5	-41 01 38	314.2	20.3	A2/3 V	-10	-57
48	121239	11817	224536	13 52 13.3	-49 26 09	313.4	11.9	A1 V	-35	-27
49	121692	11866	241336	13 55 01.0	-50 17 32	313.7	11.0	A1 V	-22	-28
50	121701	11868	224576	13 54 56.5	-40 41 33	316.2	20.2	A3 IV	-41	-5
51	121735	11870	224580	13 55 17.2	-48 37 50	314.1	12.5	A0 V	-25	-13
52	122274	11926	224625	13 58 53.0	-43 10 21	316.3	17.6	A1 V	-23	-5
53	122874	11983	224668	14 02 26.9	-42 33 39	317.1	18.0	A0 V	-27	-16
54	122923	11988	241438	14 02 52.1	-50 29 02	314.8	10.4	A3 IV/V	-22	-32
55	124255	12122	224775	14 10 29.8	-47 16 42	317.0	13.1	A0/1 V	-33	-31
56	124310	12125	224778	14 10 56.5	-49 08 10	316.5	11.3	A7 IV	-13	-36
57	125600	12235	224863	14 18 36.1	-48 35 49	317.9	11.4	A5/6 IV	-23	-28
58	126297	12295	224915	14 22 40.4	-44 26 36	320.1	15.0	AP CREUSR	-52	-25
59	127277	12385	241770	14 28 39.3	-50 12 17	318.9	9.3	A1 V	-14	-13
60	127954	12444	225045	14 32 19.5	-44 13 53	321.8	14.6	A1 V	-18	-31

APPENDIX II, TABLE 1 continued.

No	HD	Cape	SAO	R.A.(1950)	Dec.	l^{II}	b^{II}	Sp. type	μ_α ."0001	μ_δ ."001
61	129068	12552	225130	14 38 37.2	-42 11 21	323.8	16.0	A2 V	-30	-36
62	130201	12645	225199	14 45 00.8	-45 27 40	323.4	12.5	A0 IV/V	-7	-51
63	131656	12781	225300	14 53 01.3	-42 19 49	326.2	14.6	A0 IV	-5	-24
64	131854	12800	225323	14 54 18.1	-49 35 30	322.9	8.1	A3 IV	-19	-30
65	135376	13131	225606	15 13 07.8	-48 57 29	325.9	7.1	A1 IV/V	-15	-24
66	135732	13161		15 14 48.2	-42 18 49	329.8	12.6	A0MA2-A7	-20	-47
67	135799	13176	225645	15 15 29.4	-48 35 55	326.4	7.2	A1/2 IV/V	-11	-9
68	136315	13239	242450	15 18 29.8	-50 26 00	325.8	5.4	A1 IV/V	-13	-23
69	136390	13250	225702	15 18 37.1	-43 53 11	329.5	10.9	A2 V	-21	-14
70	137325	13374	242548	15 23 47.8	-50 08 17	326.7	5.2	A0 V	-20	-16
71	137342	13375	225794	15 23 35.1	-43 01 05	330.7	11.1	A0 V	-20	-21
72	138567	13575	225926	15 31 26.3	-49 57 07	327.8	4.7	A1 IV	-5	-19
73	139961	13817	226097	15 39 25.3	-44 47 04	332.0	8.0	A0 V	-178	-83
74	329972	13922	226171	15 42 54.5	-49 59 27	329.3	3.5		-7	-26
75	329944	13933	226178	15 43 12.0	-49 24 43	329.7	4.0		9	-25
76	329975	13976	226208	15 44 08.5	-49 59 49	329.5	3.4		-5	-25
77	146257	14529	226624	16 13 55.5	-49 03 56	333.7	1.0	A2 IV	-14	-30
78	147199	14640	226697	16 19 03.7	-48 55 21	334.4	0.5	A0/1 V	-11	-20
79	150504	15167	227112	16 40 05.8	-49 47 20	336.1	-2.6	A0 IV/V	-10	-14
80	150547	15179	227119	16 40 17.6	-47 26 30	337.9	-1.1	A1 V	-6	-26
81	151228	15305	227237	16 44 38.5	-46 05 22	339.4	-0.8	A0/1 IV/V	12	-22
82	151662	15373	244201	16 47 27.7	-50 18 42	336.5	-3.9	A1 V	-14	-36
83	157613	16182	227957	17 22 42.1	-43 14 12	345.8	-4.4	A0/1 IV	17	-25
84	157922	16222	244778	17 24 56.8	-50 19 57	340.1	-8.7	A1 V	1	-34
85	160579	16589	228320	17 39 21.9	-47 44 32	343.6	-9.3	A9 V	4	-40
86	170625	17471	229101	18 28 50.4	-42 21 21	352.5	-14.6	A4/5 V	43	-85
87	183156	18214	229718	19 26 44.5	-48 24 32	349.9	-26.2	A0 V	9	-39
88	185493	18330	229814	19 37 37.3	-42 36 42	356.6	-26.7	A9 IV/V	50	-56
89	185994		229836	19 40 12.6	-44 25 26	354.8	-27.6	A4 IV	-26	-24
90	209838	19742	230988	22 04 14.8	-48 06 12	348.7	-52.1	A0/1 V	38	-3
91	217271	20219	231384	22 57 19.4	-45 12 23	346.9	-61.6	A4 V	65	-83
92	223161	20679	231780	23 44 38.3	-46 59 25	331.5	-66.7	A0 V	26	12
93	224399	20781	214877	23 54 59.3	-39 57 24	341.2	-73.2	A0 V	28	-21
94	−48°6657			11 34 28.3	-48 43 35	290.6	+12.1	A7 V	90	-12
95	−53°3099		237534	09 55 58.4	-54 09 56	279.4	0.3	F8 V	-371	214
96	26298			04 06 51.4	-16 31 57	210.3	-43.2	F2 V	37	176
97	85504			09 49 37.2	+02 41 18	235.0	+40.6	A0 V	-184	88

Notes:
Column 9) Spectral types are from Houk (1978). Columns 10) and 11) Proper motions are the unadjusted mean values of the Cape and Yale survey results.

APPENDIX II (cont).

TABLE 2: *uvby* photometry, radial velocity, D(.70), W(K) and $v \sin i$ values for the Yale stars.

No	HD	m_V	$b-y$	m_1	c_1	RV (km/s)	D(.70) (Å)	W(K) (Å)	$v\sin i_L$ (km/s)	$v\sin i_S$ (km/s)	S
1	2320	8.887	0.202	0.154	0.725	-46	14.6	4.30	100	96	*
2	2339	10.264	0.023	0.163	1.029	-9	24.6	1.15			
3	4850	9.625	0.051	0.125	1.275	-30	25.0	0.97		3	*
4	6208	9.420	0.017	0.189	1.037	28	27.4	1.06	54		
5	9566	9.616	0.222	0.122	0.736	42	11.3	3.50		133	*
6	13107	9.342	0.139	0.251	0.825	15	20.3	2.60			
7	13780	9.803	0.086	0.113	1.278	46	23.1	1.31		7	*
8	20686	8.556	0.026	0.170	1.003	4	23.1	0.86		14	*
9	Y2029	9.363	0.069	0.203	0.974	51	27.0	1.97			
10	26760	10.638	0.029	0.135	1.180	58	25.5	1.02	166		
11	Y2383	9.071	0.093	0.187	0.925	30	22.7	2.14			
12	31943	8.255	0.085	0.142	1.221	99	23.1	1.72	12	9	*
13	31973	9.440	0.079	0.202	0.969	12	23.2	3.50			
14	68864	8.958	0.182	0.196	0.807	38	16.5	3.50			
15	69260	10.310	0.046	0.236	0.712	33	22.2	0.74	< 30		
16	70101	9.560	0.123	0.186	1.014	-23	24.1	1.93			
17	74399	9.216	0.099	0.182	1.090	38	23.6	3.86			
18	80764	9.871	0.021	0.150	1.112	-3	26.0	1.43	226		
19	84745	9.581	0.074	0.186	0.975	0	24.6	2.80	193		
20	84743	8.269	0.016	0.172	1.041	-45	26.5	1.53			*
21	84805	7.577	0.193	0.191	0.758	19	16.0	3.30			
22	84846	9.854	0.063	0.190	1.040	9	28.8	2.47	152		
23	85133	9.432	0.118	0.220	1.044	-3	25.0	2.96			
24	85283	9.714	0.114	0.214	0.876	17	26.0	1.83	75		
25	85410	9.720	0.102	0.192	0.959	0	27.4	2.09			
26	86504	9.146	0.067	0.152	1.065	30	26.0	2.64			
27	91554	9.795	0.046	0.231	0.955	16	30.2	1.59			
28	93067	9.482	0.067	0.244	0.900	24	27.5	2.67			
29	94519	9.887	0.056	0.176	1.041	20	26.5	1.38			
30	95701	9.842	0.150	0.185	0.891	26	24.1	2.82			
31	106845	9.475	0.036	0.208	0.990	60	27.4	1.21	31		
32	107872	9.878	0.068	0.157	1.041	10	23.6	1.00			
33	110332	9.608	0.128	0.238	0.896	2	23.6	1.57	40	28	*
34	111752	10.001	0.111	0.191	0.979	-103	21.7	4.09	169	166	*
35	112407	8.613	0.176	0.178	0.733	-16	9.0	4.37			
36	112468	9.925	0.123	0.188	0.948	-11	24.1	3.58	158		
37	112480	9.949	0.057	0.169	1.007	-19	25.5	1.28	107		
38	112686	9.811	0.138	0.163	0.998	-3	20.8	3.35	129		
39	112725	9.590	0.080	0.222	1.001	-14	22.2	3.19			
40	112982	9.550	0.078	0.194	0.997	-23	26.9	2.49	107		
41	113235	9.633	0.118	0.188	1.068	-23	21.8	2.80			
42	115190	10.284	0.058	0.173	0.975	-15	26.9	1.15			
43	115528	10.132	0.138	0.249	0.868	-4	20.8	1.81			
44	116134	9.598	0.154	0.198	0.876	-33	18.9	4.00	63		
45	118044	10.372	0.011	0.121	0.917	-7	18.9	0.50	116		
46	118368	10.237	0.218	0.200	0.756	21	16.0	3.29			
47	120015	9.209	0.097	0.181	1.002	-24	17.0	2.88	230	261	
48	121239	9.289	0.032	0.214	0.946	0	23.6	0.87			
49	121692	10.213	0.102	0.184	1.064	-21	19.4	2.04	88		
50	121701	8.621	0.066	0.246	1.084	-2	29.8	2.58			
51	121735	9.900	0.109	0.203	0.781	-13	21.3	0.61			
52	122274	9.796	0.047	0.200	0.963	-20	27.0	1.82			
53	122874	9.893	0.054	0.191	0.973	-17	24.5	1.00			
54	122923	9.455	0.155	0.182	0.883	-13	20.8	3.36			
55	124255	9.128	0.056	0.197	1.015	-50	24.6	1.29	34		
56	124310	10.371	0.164	0.189	0.936	-15	19.0	4.26	148		
57	125600	10.039	0.200	0.151	0.884	-30	19.0	2.89			
58	126297	9.464	0.189	0.180	0.935	-17	18.0	4.44		11	*
59	127277	9.538	0.091	0.185	0.951	8	22.2	1.36			
60	127954	9.447	0.072	0.208	0.981	-18	28.8	2.35	37		

APPENDIX II, TABLE 2 continued.

No	HD	m_V	$b-y$	m_1	c_1	RV (km/s)	D(.70) (Å)	W(K) (Å)	$vsini_L$ (km/s)	$vsini_S$ (km/s)	S
61	129068	9.519	0.074	0.210	1.030	-32	26.0	2.91	40		
62	130201	10.116	0.062	0.113	1.238	80	22.7	0.81	13		*
63	131656	9.172	0.072	0.221	0.966	-21	30.2	1.16			
64	131854	9.593	0.153	0.173	1.008	-26	21.3	2.93	193		
65	135376	9.651	0.074	0.134	0.994	-25	25.0	1.87			
66	135732	9.255	0.080	0.211	0.989	8	20.8	1.58			
67	135799	10.214	0.044	0.188	1.025	-21	25.5	2.30			
68	136315	9.116	0.070	0.159	1.091	16	24.1	1.24			
69	136390	9.813	0.038	0.258	1.044	-31	27.0	2.47			
70	137325	9.841	0.120	0.130	1.068	- 5	20.8	1.50			
71	137342	9.727	0.047	0.156	1.091	-9	23.6	1.61			
72	138567	9.938	0.087	0.093	1.154	-26	20.3	1.94			
73	139961	8.872	0.078	0.117	1.285	145	23.1	0.83			*
74	329972	10.502	0.120	0.077	1.178	-46	23.1	0.96			
75	329944	10.295	0.140	0.113	0.696	-31	14.2	0.34			
76	329975	10.238	0.100	0.090	0.938	0	16.1	0.45			
77	146257	9.655	0.203	0.127	0.990	-24	24.1	3.03			
78	147199	10.162	0.112	0.001	1.251	-30	20.8	0.64			
79	150504	9.883	0.281	-0.036	1.109	3	18.4	1.02			
80	150547	9.529	0.138	0.185	1.052	-15	24.6	2.36			
81	151228	9.463	0.261	-0.021	0.977	0	21.7	1.54			
82	151662	9.917	0.279	0.099	0.905	-21	25.0	2.32			
83	157613	9.721	0.179	0.251	1.036	-37	26.7	2.35			
84	157922	9.397	0.106	0.186	0.966	0	25.5	2.89	125		
85	160579	9.872	0.186	0.200	0.757	-48	15.6	3.34			
86	170625	8.704	0.117	0.204	0.997	-107	22.2	4.20	124	133	*
87	183156	9.489	0.039	0.178	0.905	-18	22.2	0.81	24		
88	185493	9.374	0.239	0.191	0.690	-70	14.6	3.29			
89	185994	9.480	0.151	0.133	0.853	45	18.5	2.09			
90	209838	9.994	0.061	0.198	0.922	-58	30.2	1.84			
91	217271	9.270	0.146	0.160	0.801	-24	19.8	2.46			*
92	223161	9.822	0.142	0.059	0.966	0	28.0	1.56			
93	224399	10.063	0.001	0.184	1.016	2	24.1	1.36			
94	$-48°6657$	10.910	0.103	0.184	0.967	351	25.5	1.02			*
95	$-53°3099$	9.287	0.330	0.159	0.435	16	6.6	7.60		25	*
96	26298	8.156	0.253	0.129	0.548	66	8.5	4.96			*
97	85504	6.028	-0.017	0.142	1.037	97	14.6	0.70	19	15	*

Notes:

Column 10) *v sin i* values from Lance.

Column 11) *v sin i* values from Stetson (1983).

Column 12) '*' indicates that the photometry was supplied by Stetson (1984, private communication).

APPENDIX II (cont).

TABLE 3: Gravities, temperatures, reddenings, colours, abundances, masses, absolute magnitudes, and ages for the Yale stars.

No	HD	log g	θ_{eff}	E_{b-y}	$(b-y)_0$	[Ca/H]	$m_\odot$	M_V	age 10^6yrs	type
1	2320	4.17	0.659	0.032	0.170	-0.14	1.54	2.38	500	
2	2339	4.14	0.520	0.026	-0.003	-0.03	2.30	1.14	200	
4	6208	4.17	0.544	0.004	0.013	-0.38	1.88	1.47	450	
8	20686	4.13	0.504	0.037	-0.011	-0.06	2.43	0.97	200	
9	Y2029	4.26	0.535	0.061	0.008	0.27	2.12	1.54	50	
11	Y2383	4.10	0.612	0.003	0.090	-0.48	1.62	1.83	1000	
13	31973	3.97	0.610	0.000	0.079	-0.06	2.02	1.25	550	
17	74399	3.69	0.609	0.029	0.070	-0.06	2.19	0.45	550	
20	84743	4.17	0.542	0.004	0.012	-0.02	2.16	1.31	200	
22	84846	4.06	0.590	0.018	0.045	-0.07	1.99	1.35	450	
23	85133	3.94	0.603	0.053	0.065	-0.11	2.03	1.12	550	
31	106845	4.25	0.534	0.028	0.008	-0.16	2.01	1.57	200	
33	110332	4.22	0.610	0.040	0.088	-0.71	1.69	2.07	300	
34	111752	3.95	0.615	0.019	0.092	0.02	2.03	1.23	500	
41	113235	3.78	0.611	0.040	0.078	-0.34	1.92	0.83	850	
44	116134	4.13	0.621	0.041	0.113	-0.01	1.79	1.86	400	
45	118044	4.13	0.474	0.032	-0.021	-0.04	2.68	0.64	150	
46	118368	4.28	0.643	0.062	0.156	-0.29	1.55	2.54	200	
47	120015	4.10	0.601	0.030	0.067	-0.08	1.84	1.61	450	
48	121239	4.25	0.494	0.048	-0.016	0.12	2.38	1.21	0	
53	122874	4.22	0.507	0.063	-0.009	0.01	2.35	1.25	100	
55	124255	4.15	0.526	0.055	0.001	-0.02	2.29	1.18	200	
56	124310	4.00	0.622	0.055	0.109	-0.01	1.94	1.45	550	
57	125600	4.18	0.620	0.089	0.111	-0.29	1.59	2.10	550	
58	126297	3.98	0.629	0.054	0.135	-0.04	1.92	1.46	600	
61	129068	4.02	0.600	0.013	0.061	-0.07	1.99	1.32	500	
64	131854	3.93	0.613	0.066	0.087	-0.28	1.76	1.32	750	
65	135376	4.18	0.525	0.073	0.001	0.33	2.26	1.27	150	
66	135732	3.91	0.615	-0.009	0.089	-0.84	1.86	1.22	600	
70	137325	3.92	0.513	0.129	-0.009	0.27	2.67	0.40	250	
71	137342	3.97	0.538	0.041	0.006	0.06	2.44	0.66	300	
76	329975	3.93	0.463	0.128	-0.028	-0.23	2.56	0.13	200	
77	146257	4.09	0.605	0.128	0.075	-0.12	1.84	1.61	500	
80	150547	3.93	0.606	0.067	0.071	-0.39	2.31	0.97	1100	
82	151662	4.31	0.606	0.197	0.082	-0.32	1.58	2.34	150	
83	157613	4.05	0.600	0.115	0.064	-0.28	1.83	1.48	550	
85	160579	4.23	0.646	0.026	0.160	-0.30	1.45	2.51	400	
86	170625	3.95	0.617	0.019	0.098	0.02	2.02	1.25	500	
87	183156	4.31	0.481	0.060	-0.021	0.30	2.32	1.29	0	
88	185493	4.30	0.658	0.066	0.173	-0.34	1.44	2.77	150	
90	209838	4.32	0.590	0.009	0.052	-0.33	1.63	2.21	150	
91	217271	4.32	0.620	0.031	0.115	-0.37	1.49	2.52	200	
92	223161	4.14	0.595	0.087	0.055	-0.57	1.64	1.79	450	
93	224399	4.14	0.517	0.005	-0.004	0.18	2.36	1.10	200	
6	13107	4.31	0.619	0.027	0.112	-0.31	1.61	2.41	0	L
14	68864	4.17	0.637	0.037	0.145	-0.24	1.57	2.21	550	L
18	80764	3.98	0.556	0.003	0.018	-0.22	2.20	0.88	450	L
19	84745	4.02	0.605	0.000	0.074	-0.18	1.90	1.40	600	L
21	84805	4.26	0.639	0.043	0.150	-0.28	1.50	2.50	300	L
24	85283	4.35	0.604	0.037	0.077	-0.47	1.49	2.49	200	L
25	85410	4.12	0.600	0.039	0.063	-0.35	1.70	1.74	750	L
26	86504	3.88	0.600	0.010	0.057	-0.18	1.94	1.00	800	L
27	91554	4.29	0.560	0.019	0.027	-0.17	1.84	1.86	100	L
28	93067	4.28	0.600	0.000	0.067	-0.09	1.72	2.13	50	L
29	94519	4.18	0.534	0.049	0.007	-0.05	2.17	1.31	200	L
30	95701	4.26	0.610	0.060	0.090	-0.17	1.67	2.18	150	L
32	107872	4.11	0.512	0.075	-0.007	-0.08	2.34	1.01	250	L
35	112407	4.20	0.646	0.020	0.156	-0.07	1.63	2.30	250	L
36	112468	4.06	0.606	0.046	0.077	0.03	1.94	1.49	450	L

APPENDIX II, TABLE 3 continued.

No	HD	log g	θ_{eff}	E_{b-y}	$(b-y)_0$	[Ca/H]	$m_\odot$	M_V	age 10^6yrs	type
37	112480	4.21	0.520	0.060	-0.003	0.05	2.27	1.33	150	L
38	112686	3.94	0.613	0.061	0.077	-0.15	1.95	1.23	600	L
39	112725	3.92	0.612	-0.003	0.083	-0.18	1.97	1.16	600	L
40	112982	4.07	0.600	0.015	0.063	-0.20	1.84	1.53	600	L
42	115190	4.29	0.521	0.058	0.000	-0.06	2.13	1.60	0	L
43	115528	4.19	0.616	0.036	0.102	-0.65	1.68	2.04	250	L
50	121701	4.11	0.578	0.031	0.035	0.09	2.02	1.38	350	L
52	122274	4.27	0.530	0.042	0.005	0.26	2.12	1.56	0	L
54	122923	4.19	0.614	0.060	0.095	-0.08	1.73	1.99	350	L
60	127954	4.24	0.552	0.052	0.020	0.26	2.03	1.60	100	L
63	131656	4.22	0.567	0.043	0.029	-0.54	1.86	1.69	200	L
67	135799	4.15	0.547	0.030	0.014	0.29	2.14	1.29	200	L
68	136315	3.98	0.535	0.066	0.004	-0.17	2.32	0.74	350	L
69	136390	4.15	0.549	0.021	0.017	0.34	2.14	1.30	200	L
84	157922	4.09	0.604	0.033	0.073	-0.11	1.84	1.61	500	L
5	9566	3.86	0.695	0.022	0.200	-0.57	1.42	1.92		B
16	70101	3.96	0.606	0.051	0.072	-0.56	1.65	1.41		B
59	127277	4.05	0.613	0.000	0.091	-0.91	2.40	1.28		B
81	151228	4.04	0.614	0.168	0.093	-0.90	2.36	1.28		B
89	185994	4.15	0.623	0.034	0.117	-0.61	1.53	2.09		B
3	4850	3.50	0.590	0.018	0.033	-0.93	0.55	1.34		H
7	13780	3.41	0.598	0.044	0.042	-0.91	0.55	1.17		H
10	26760	3.62	0.593	0.010	0.019	-0.91	0.55	1.66		H
12	31943	3.48	0.605	0.028	0.057	-0.81	0.55	1.40		H
15	69260	3.40	0.592	0.013	0.033	-1.21	0.55	1.11		H
49	121692	3.62	0.622	0.006	0.096	-0.79	0.55	1.87		H
51	121735	3.50	0.610	0.043	0.066	-1.87	0.55	1.49		H
62	130201	3.47	0.596	0.022	0.040	-1.32	0.55	1.31		H
72	138567	3.46	0.615	0.012	0.075	-0.81	0.55	1.42		H
73	139961	3.37	0.597	0.040	0.038	-1.34	0.55	1.07		H
74	329972	3.52	0.609	0.053	0.067	-1.41	0.55	1.53		H
75	329944	4.15	0.410	0.188	-0.048	-0.89	0.55	2.11		H
78	147199	3.47	0.564	0.098	0.014	-1.17	0.55	1.13		H
79	150504	3.54	0.626	0.180	0.101	-1.62	0.55	1.70		H
94	$-48°6657$	4.08	0.607	0.023	0.080	-1.12	1.50	1.82		B
95	$-53°3099$	4.15	0.757	0.058	0.272	0.03	1.33	3.12	850	
96	26298	4.07	0.727	0.013	0.240	-0.30	1.39	2.68	1850	
97	85504	3.53	0.488	0.003	-0.020	0.07	3.60	-1.08	150	

Notes:
Column 11) No entry in this column denotes a Population I star with total space motion greater than 70 km/s. 'L' denotes a Population I star with total space motion less than 70 km/s. 'B' indicates a possible blue straggler, and 'H' denotes a horizontal branch star.

APPENDIX II (cont).

TABLE 4: Radial velocities, transverse velocities, XYZ distances, maximum Z distances and UVW velocities from mean proper motions, and UVW velocities from the Yale and Cape proper motions, for the Yale stars.

							Mean			Yale			Cape			
No	RV	TV	X	Y	Z	Z_{max}	U	V	W	U	V	W	U	V	W	type
1	-46	96	-40	-29	-206	678	68	-69	44	69	-76	45	67	-61	43	
2	-9	102	-135	-105	-678	692	100	-14	-8	114	-19	-10	90	-9	-7	
4	28	85	-65	-124	-365	698	78	-15	-38	55	-26	-30	102	-4	-47	
8	4	109	31	-202	-286	793	74	-62	48	78	-57	44	70	-68	51	
9	51	95	122	-242	-307	431	66	-80	22	71	-78	22	62	-85	24	
11	30	97	94	-188	-186	339	97	-17	22	105	-15	23	91	-19	20	
13	12	102	116	-319	-270	998	72	-40	59	67	-36	52	80	-44	68	
17	38	111	96	-590	10	498	107	-21	-37	105	-20	47	112	-22	-121	
20	-45	77	-7	-245	28	69	78	42	-5	68	43	2	88	41	-13	
22	9	87	-43	-511	26	1256	-42	-9	-75	-13	-12	-77	-69	-7	-78	
23	-3	85	-23	-502	55	899	59	-6	-58	66	-7	-70	53	-5	-50	
31	60	71	-180	-348	85	388	17	-85	-30	31	-99	-57	4	-72	-3	
33	2	85	-173	-285	93	609	53	-48	-43	50	-47	-44	57	-51	-42	
34	-103	160	-308	-474	158	846	181	-8	-54	183	-10	-57	179	-7	-54	
41	-23	78	-344	-493	146	384	70	-28	-27	82	-41	-41	56	-15	-17	
44	-33	77	-228	-292	80	981	53	-16	-62	48	-17	-82	59	-15	-42	
45	-7	107	-582	-692	190	1820	30	-41	-93	40	-60	-129	20	-23	-57	
46	21	81	-246	-290	77	1208	-9	-39	-73	-8	-44	-87	-11	-34	-61	
47	-24	94	-228	-235	121	1829	10	-23	-94	32	-35	-76	-10	-12	-112	
48	0	80	-303	-321	93	579	42	-52	-41	61	-68	-35	25	-37	-47	
53	-17	74	-418	-388	185	450	51	-44	-30	58	-41	-10	44	-46	-51	
55	-50	92	-351	-327	111	945	79	-31	-60	89	-31	-29	71	-33	-93	
56	-15	113	-470	-446	129	2191	28	-38	-104	56	-75	-134	5	-4	-71	
57	-30	68	-331	-299	90	761	48	-22	-51	64	-40	-49	32	-6	-52	
58	-17	110	-326	-272	113	229	79	-74	-17	75	-66	-7	84	-85	-28	
61	-32	91	-346	-253	123	840	59	-51	-54	56	-53	-68	65	-52	-41	
64	-26	75	-396	-299	70	838	47	-31	-55	50	-39	-70	44	-25	-43	
65	-25	66	-462	-313	69	705	42	-28	-48	57	-51	-53	28	-6	-42	
66	8	93	-342	-199	88	931				15	-70	-60				
70	-65	90	-814	-534	88	548	96	-34	-40	130	-84	-33	65	12	-44	
71	-9	81	-600	-337	135	501	37	-62	-36	37	-64	-38	39	-64	-34	
76	0	159	1148	-676	79	3506	35	-75	-135	49	-106	-189	22	-48	-87	
77	-24	74	-460	-227	8	622	47	-42	-44	51	-52	-34	43	-35	-53	
80	-15	72	-540	-219	-11	745	33	-40	-51	43	-62	-79	25	-21	-25	
82	-21	83	-442	-192	-32	589	50	-55	-43	67	-91	-59	33	-20	-25	
83	-37	98	-535	-135	-42	1768	46	-2	-93	49	-15	-91	43	8	-95	
85	-48	61	-293	-86	-50	488	64	-24	-37	67	-35	-37	61	-14	-37	
86	-107	155	-306	-40	-80	2001	146	-64	-99	140	-55	-80	152	-75	-118	
87	-18	98	-430	-76	-215	680	55	-70	-44	65	-87	-58	46	-53	-31	
88	-70	95	-209	-12	-106	625	102	-37	-44	102	-36	-43	103	-39	-45	
90	-58	81	-219	-43	-288	288	98	-10	0	80	-8	13	116	-12	-13	
91	-24	127	-109	-25	-208	224	65	-111	6	64	-108	6	65	-116	7	
92	0	83	-164	-89	-436	606	77	-8	-27	77	-3	-28	81	-12	-28	
93	2	139	-170	-58	-598	642	81	-109	-14	114	-126	-22	51	-94	-7	
6	15	56	-5	-109	-230	322	55	-1	-17	64	0	-18	47	-3	-16	L
14	38	40	52	-233	-14	114	45	-29	10	52	-28	24	40	-29	-4	L
18	-3	47	-22	-630	-1	641	-0	3	-45	-15	3	-73	14	2	-18	L
19	0	44	-38	-434	19	579	8	-2	-42	-0	-2	-53	16	-3	-33	L
21	19	39	1	-109	19	103	37	-20	-9	42	-19	-7	32	-20	-10	L
24	17	34	-30	-295	13	400	-12	-17	-32	-15	-17	-35	-10	-17	-28	L
25	0	58	-43	-422	20	630	-36	1	-45	-40	1	-55	-33	1	-37	L
26	30	44	-38	-430	43	100	38	-34	-8	62	-34	15	16	-34	-30	L
27	16	42	-67	-389	66	254	29	-25	-21	43	-26	-16	17	-23	-26	L
28	24	29	-58	-284	52	145	17	-30	-12	26	-33	-16	8	-28	-11	L
29	20	58	-121	-543	119	121	50	-32	-2	65	-35	2	35	-30	-7	L
30	26	46	-101	-361	57	357	-39	-20	-28	-51	-17	-28	-26	-24	-28	L
32	10	55	-314	-584	160	710	7	-28	-47	13	-42	-86	1	-14	-8	L
35	-16	46	-103	-153	45	252	41	-14	-21	46	-19	-27	37	-9	-16	L
36	-11	69	-285	-422	140	755	37	-28	-50	26	-28	-72	51	-30	-28	L

APPENDIX II, TABLE 4 continued.

								Mean			Yale			Cape		
No	RV	TV	X	Y	Z	Z_{max}	U	V	W	U	V	W	U	V	W	type
37	-19	44	-320	-475	143	661	14	0	-45	13	-7	-72	17	5	-20	L
38	-3	61	-317	-467	142	613	30	-30	-42	60	-56	-62	1	-3	-22	L
39	-14	64	-258	-377	157	579	42	-27	-40	12	-5	-34	72	-50	-45	L
40	-23	59	-228	-332	89	761	34	-9	-51	50	-28	-85	20	9	-19	L
42	-15	44	-357	-470	149	488	27	-12	-34	33	-20	-45	23	-6	-24	L
43	-4	49	-262	-340	108	622	13	-18	-43	13	-26	-68	14	-12	-19	L
50	-2	52	-200	-192	102	119	38	-34	5	50	-36	23	27	-32	-13	L
52	-20	37	-331	-316	145	164	38	-13	-7	46	-19	-2	31	-9	-14	L
54	-13	56	-240	-241	62	652	27	-21	-46	43	-38	-52	12	-4	-41	L
60	-18	63	-310	-244	103	746	29	-29	-50	36	-43	-64	24	-16	-37	L
63	-21	39	-273	-183	85	561	16	-5	-40	15	-5	-46	19	-7	-35	L
67	-21	28	-533	-354	80	279	26	-6	-22	55	-51	-28	0	34	-13	L
68	16	59	-440	-299	50	575	5	-44	-42	24	-76	-69	-12	-13	-13	L
69	-31	48	-444	-261	99	216	47	-25	-17	59	-48	-26	37	-4	-5	L
84	0	63	-353	-127	-57	645	21	-38	-45	32	-67	-47	10	-6	-47	L
5	42	302	-31	-129	-335	958	95	-283	55	95	-291	58	96	-276	52	B
16	-23	62	63	-461	-44	52	-63	14	-2	-104	8	3	-24	20	-6	B
59	8	29	-333	-291	72	242	4	-22	-20	21	-42	-25	-10	-4	-16	B
81	0	87	-563	-211	-8	1544	4	-8	-86	17	-43	-90	-8	26	-81	B
89	45	46	-281	-25	-148	153	-44	-45	-3	-39	-47	-13	-49	-43	5	B
3	-30	171	-89	-134	-439	516	160	-61	18	153	-52	16	167	-71	19	H
7	46	186	-12	-261	-515	592	-138	-131	18	-161	-138	22	-118	-121	13	H
10	58	94	193	-388	-462	2143	33	37	-97	29	58	-116	38	20	-80	H
12	99	147	73	-179	-154	473	-19	-172	33	-31	-172	26	-6	-173	40	H
15	33	64	50	-698	-108	590	-49	-30	-42	-92	-30	-61	-5	-29	-24	H
49	-21	70	-325	-340	91	875	38	-22	-57	55	-45	-84	22	-0	-32	H
51	-13	51	-352	-363	112	302	38	-26	-23	49	-32	-10	30	-22	-37	H
62	80	145	-471	-349	130	2462	-48	-112	-111	-40	-118	-97	-56	-108	-127	H
72	-26	46	-432	-272	42	603	30	-5	-43	36	-19	-68	25	5	-19	H
73	145	368	-341	-181	54	2003	51	-378	99	53	-385	90	50	-373	109	H
74	-46	84	-588	-349	41	1158	61	-21	-71	73	-44	-100	50	0	-45	H
75	-31	88	-530	-310	43	1650	24	7	-89	43	-29	-123	4	45	-56	H
78	-30	73	-691	-331	6	658	51	-38	-46	63	-63	-29	41	-17	-59	H
79	3	40	-552	-244	-27	292	11	-30	-24	28	-72	5	-3	6	-52	H
94	351	319	-236	-628	144	3092	-410	-200	126							B
95	16	347	-31	-187	1	244	339	-72	-21							
96	66	113	80	-46	-87	145	129	21	11							
97	97	349	115	-164	173	1919	348	-12	-96							

Notes:
Column 17) Types are as for previous Table.