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YOUNG, HIGH-VELOCITY A STARS. II. MISIDENTIFIED, EJECTED, OR UNIQUE?

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ABSTRACT

Rodgers, Harding, and Sadler identified a group of A stars at the south Galactic pole with properties unlike those of any other stellar population. They found the stars to be at distances from the disk of 1 kpc to more than 4 kpc, with a velocity dispersion perpendicular to the plane of 66 km s^{-1}, yet they appear to be young stars, with calcium abundances of one-third solar to solar metallicity.

In this study, the ages, abundances, and kinematics of a large number of early-type stars at the SGP have been derived in order to examine the properties and augment the sample of high-velocity stars, and to investigate hypotheses concerning their origin. It is found that up to one-half of the A-type stars at distances from 1 kpc to at least 4 kpc from the plane are main-sequence (or just-evolved) Population I stars.

In striking contrast to a comparative group of normal A stars near the disk (with ages randomly distributed up to 2×10^9 yr), the high-velocity A stars were all formed within the last 6.5×10^8 yr, so they appear to be the consequences of an astronomically recent and nonstochastic event. Their calcium abundances range from -0.5 dex to 0.0 dex, and their W velocity dispersion is 62 km s^{-1}, both results in good agreement with Rodgers, Harding, and Sadler.

The exponential scale height for the young stars at distances of more than 1 kpc from the plane is estimated to be 1000–1600 pc. They are found to exist at distances of up to 11 kpc from the Galactic disk (for an observational limit of 14th magnitude). It is shown that the stars are not misidentified horizontal-branch stars. Their unique age distribution indicates that they are unlikely to be blue stragglers or normal disk stars randomly ejected from the plane. It is suggested that at around 6.5×10^8 yr ago, a major source of relatively low abundance hydrogen was accreted by the Galactic disk, forming young high-velocity stars that do not partake of the age-abundance-kinematics relationships shown by other stellar groupings.

Subject headings: stars: evolution — stars: high-velocity — stars: stellar statistics

I. INTRODUCTION

a) Origins of the Young, High-Velocity A Stars

The history of observations of distant high-latitude, early-type, apparently Population I stars, is discussed in Lance (1988, hereafter Paper I). Briefly, Rodgers, Harding, and Sadler (1981, hereafter RHS) observed A-type stars at the south Galactic pole and found that some of the stars had surface gravities that were normal for main-sequence (MS) stars, yet they were at distances of 1 kpc to more than 4 kpc from the disk. A-type MS lifetimes are much too short for normal disk dispersive mechanisms to scatter the stars so far from the plane. Rodgers (1971) found a value of 66 km s^{-1} for their W velocity dispersion, similar to thick disk (40 km s^{-1}) or halo stars (60 to 120 km s^{-1}).

The RHS calcium abundances are also unusual, ranging from one-third of the Population I metallicity to normal Population I values (-0.5 to 0.0 dex). Young A stars usually have abundances from -0.1 to 0.2 dex. Disk stars with abundances as low as -0.5 are usually more than nine billion years old (Twarog 1980), yet no normal MS A star could possibly be older than two billion years. Not one of the parameters of age, abundance, or kinematics is consistent with any other, in terms of the standard picture of galactic evolution. The velocities of the distant A stars are characteristic of the oldest stellar populations; their abundances are intermediate; yet they appear to be young, possibly coeval, stars.

Hypotheses proposed to account for the distant A stars fall into three categories:

1. *They are misidentified abnormal or evolved stars*, blue stragglers or blue horizontal branch (HB) stars.
2. *They are randomly ejected young disk stars*, formed and/or accelerated by normal Galactic energetic processes such as supernova bubbles, galactic fountains, cloudlet-cloudlet collisions in the halo, black hole encounters, supernova explosions in close binary systems, or ejection from young associations by binary interactions.
3. *They are the result of an unusual and recent event*: they were formed from a mixture of Galactic gas, and lower metallicity gas accreted during the merger of a small satellite galaxy with the Milky Way.

Category (1) hypotheses were examined with respect to rotational velocities, $v \sin i$, in Paper I. Eight stars more than 1 kpc from the plane, classified by RHS as Population I, were observed at high resolution. Five of the stars has $v \sin i$ values between 100 and 200 km s^{-1} (with a mean of 145 km s^{-1}), typical of MS A stars; while the other three, two normal Am stars and one Ap star, had the lower velocities (around 40 km s^{-1}) expected for their spectral type. HB stars usually have very low $v \sin i$ values, averaging around 13 km s^{-1}, so it is clear that the distant A stars cannot be either normal metal-poor HB stars, or a blue HB extension of a metal-rich RR Lyrae population (see Paper I).

Am and Ap stars usually rotate at velocities less than 70 km s^{-1}. There is some evidence from Peterson, Carney, and Latham (1984) that mid-to-late A-type blue stragglers may also rotate more slowly (around 85 km s^{-1}) than normal A stars, but their sample was only three stars, too few to consider this to be a definite result. Abt (1985) finds that all but one of a group of 13 late B and early A blue stragglers rotate at less than 50 km s^{-1}. While 60% of these are Ap and Bp stars, the rest appear to be normal, yet they are also slowly rotating. These results are suggestive, but their statistical validity is not strong enough to test the blue straggler hypothesis on the grounds of rotation alone. In addition, Twarog and Tyson (1985) indicate that Abt's finding of a high proportion of stars with Ap characteristics (hence low rotation) among blue stragglers may not actually hold for later A-type stars, as they found fewer than expected Am and Ap stars among NGC 7789 blue stragglers.

Another aspect of the blue straggler hypothesis is discussed by Shields and Twarog (1987), who model the distribution of blue stragglers among disk stars, accumulated over time, with a series of scale height and star formation scenarios. They find that the eventual scale height of the longer lived blue stragglers is naturally greater than that of the younger disk stars, and suggest that stochastically accelerated old disk blue stragglers offer a reasonable explanation for the existence of high-velocity A stars, particularly in view of the old-disk–like range of calcium abundances found by RHS.

Indicators such as surface gravity may be useful to discriminate between different types of star (see Table 2 and Fig. 1 of Paper I). HB stars have gravities generally lower (2.9–3.6 dex) than MS stars (around 4.1 dex). Twarog and Tyson (1985) found that the blue stragglers in NGC 7789 have Strömgren c_1 indices which indicate surface gravities of around 0.5 dex lower than MS values, in agreement with Mermilliod (1982), who found that 36 out of 39 hotter blue stragglers in Galactic clusters systematically lie 1.0–1.5 mag above the ZAMS. While these particular observations are well established, their interpretation with respect to theories of blue straggler formation is still open to argument. Even though it is not known whether *all* blue stragglers occupy this distinctive region of the H-R diagram, the A star temperature-gravity distribution (in combination with other parameters) may offer further insight.

Category (2) hypotheses suggest that the high-velocity A stars are the consequences of rare, stochastic Galactic mechanisms, which either form stars in accelerated matter, or eject normal stars out of the disk. Possibilities include star formation from the compression of gas and dust at the fast-moving outer edges of supernova bubbles (Herbst and Assousa 1977), or the Galactic fountain model, which proposes that hot gas, thrown into the halo by supernova explosions, condenses and falls back to the plane, presumably creating stars when it collides with the disk (Bregman 1980). In both these cases, it might be predicted that resultant stars would be enriched by supernovae to somewhat greater than normal abundances. Dyson and Hartquist (1983) propose that cloudlet-cloudlet collisions in the halo could form OB stars from gas with a velocity dispersion of 30 km s^{-1}. (However, it seems unlikely that this gas could form A stars with over 60 km s^{-1} dispersion, and the model indicates OB star formation rather than A stars.) Another suggestion (Lacey and Ostriker 1985, 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.

Blaauw (1961) suggested that high-velocity "runaway" OB stars were the result of supernova explosions in close binary systems. It is not clear that the OB runaways are associated with the high-velocity A star population. Stone (1979) shows that only massive O and B runaway stars may be formed in this way, because before exploding, the primary deposits substantial mass onto the subsequently accelerated star, leaving it too massive for the A star range. Yet another difficulty with the suggestion that the high-velocity A stars are runaways is that the lifetime of a supernova primary is shorter than the time needed for an A star (or less massive) secondary to collapse onto the MS, so a low-mass protostar would probably not survive disruption by the explosion.

An alternative theory of runaway star formation was discussed by Gies and Bolton (1986) in a study of the frequency of binaries in a sample of high-velocity OB stars. They confirm that most of the runaway stars belong to Population I, and suggest that they have been ejected from young associations as a result of binary or *n*-body encounters. Dynamical processes tend to produce more high-velocity objects when larger stellar masses are involved, which may explain the higher fraction of O stars relative to B stars among runaways, but occasionally lower mass A stars might also be ejected.

A clear consequence of all the category (2) hypotheses is that these normal galactic activities should occur randomly over time. Hence any high-velocity A stars derived from such mechanisms should cover the whole range of formation ages observable for MS A stars. The finding by RHS of calcium abundances generally less than young disk A star values also requires examination, as category (2) hypotheses would suggest that ejected disk stars have young disk abundances, or if resulting from supernova activity, perhaps even enhanced or unusual abundances.

The category (3) accretion hypothesis was proposed by RHS. Although models and candidates for galaxies undergoing mergers had previously appeared in the literature (Toomre 1977), RHS were the first to suggest that evidence might exist for such a recent event in the history of our own Galaxy. Tremaine (1986) discusses the total mass accreted by a typical galaxy in the form of small companions, and Quinn and Goodman (1986) use Tremaine's analysis to show that around 10% of the total mass of the Milky Way could have come from accreted companions. They state that "if this estimate is even roughly correct, then most spirals have absorbed several small companions during the last 10^{10} years."

Evidence is available that suggests satellite accretions may have been an important aspect of the *early* evolution of the Milky Way. Searle and Zinn (1978) found that there is no radial abundance gradient in the globular cluster system of the outer Galactic halo, that the clusters have a broad range of ages, and may have "formed in a number of small protogalaxies that subsequently merged to form the present galactic halo." (See also Rodgers and Paltoglou 1984; Zinn 1985.) In this context, it is interesting to note the similarity of the *kinematic* parameters of the thick disk stars to the SGP A stars. The thick disk has a W velocity dispersion around 40 km s^{-1} and a scale height of 1000 pc. It has been suggested by several authors that the thick disk may be a consequence of satellite galaxy accretion (Gilmore and Wyse 1985; Norris 1986; Freeman 1987).

For the category (3) theory to be at least plausible, the RHS kinematics must be confirmed; the stars should have abundances that are different from normal disk A stars; and they should show a nonrandom formation history. Table 2 in Paper I summarizes the parameters observed by RHS and those predicted by other hypotheses.

II. OBSERVATIONS AND RESULTS

a) The SGP Catalog Observations

Paper I describes the compilation of a catalog of 305 early-type stars, to spectral type F0 and to 15th visual magnitude, in 218 deg^2 at the SGP. Strömgren photometry, medium resolution (1.2 Å) spectra, and data from other sources were obtained for almost two-thirds of the catalog stars (including most of the RHS A stars). Details of the observation and reduction procedures are in Paper I. Radial velocities, Hδ line widths [$D(0.70)$], Balmer Jump (c_1) and Ca II line [W(K)] measurements are listed in Paper I, while the subsequent derivation of surface gravities, abundances, distances, kinematics, and ages of the stars are described below.

b) Surface Gravities and Effective Temperatures

One technique of determining the evolutionary status of an A star is to locate its position in the temperature-gravity plane, conceptually equivalent to a color-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 or mass of a program star. It is based on the stellar atmosphere models of Kurucz (1979), with a minor correction to the zero point of the c_1 indices, of 0.008, as suggested by Moon and Dworetsky (1985). The technique utilizes the fact that for A star models, given values of the hydrogen line width [$D(0.70)$] and the Balmer Jump (c_1 index) systematically describe unique loci in the gravity-temperature plane, which intersect at two points, on each side of the Balmer line width maximum (around $b - y = 0.05$). A third index, such as $b - y$ or $B - V$, defines which of the two possible intersections is correct. The $b - y$ value is usually a small amount redward of the intersection. This is a useful guide to the differential reddening, E_{b-y}, found from the difference between the locus of observed $b - y$, and $(b - y)_0$ at the intersection. (See Fig. 1 for examples of the technique.) Temperatures were measured in the form of the index Θ_{eff}, equivalent to $5040/T_{\text{eff}}$. There is a minor abundance dependence on the derivation of surface gravity and temperature from c_1 and $D(0.70)$, but it is much less than the effect of uncertainty in the c_1 and $D(0.70)$ measurements. The $(b - y)_0$ values were iteratively corrected for abundance.

At the SGP Philip (1974) found a mean E_{b-y} of 0.013 ± 0.018, Albrecht and Maitzen (1980) obtained E_{b-y} of 0.019; 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 work was 0.025, with a dispersion of 0.025, for 85 stars, fairly consistent with other values and indicating that this may be a useful technique for reddening estimates.

For some of the stars in the SGP area brighter than ninth magnitude, spectra [thus $D(0.70)$s and Ca II K lines] were not obtained. Instead, the intersection of the c_1 index and $b - y$ only was used. It was found that the gravity-temperature values for stars that also had $D(0.70)$ available were almost identical to those that would have been derived if only c_1 and $b - y$ had been used; that is, $D(0.70)$ confirmed the other indices (particularly if a nonaverage reddening was present), but was not absolutely necessary for the gravity-temperature determinations. From both their gravities and positions close to the plane, it was clear that the majority of nearby stars were Population I, and did not require confirmation of their status from K line abundances. Their photometry was by McFadzean, Hilditch, and Hill (1983), who found zero reddening. 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, to be consistent with the other surveys at those magnitudes. For sdO and sdB stars, the gravity-temperature values were fairly approximate, and no attempt was made to correct for reddening.

However, for stars *fainter* than ninth magnitude as many spectra as possible were obtained, particularly in the "box" (100 deg^2 SGP area observed intensively, to derive a distance-limited sample; see Paper I and § II*e*). Thus $D(0.70)$ results were available for the more distant stars, to confirm the gravity and temperature values and to minimize possible photometric errors, and most importantly, the K line was available to ensure that their calcium abundances were well defined. For a few faint stars outside the box for which it was not possible to obtain spectra, but which had $D(0.80)$ values from Rodgers (1971), $D(0.70)$s were derived via Kurucz models for particular gravities and temperatures. These were generally very consistent, and in fact mostly confirmed the HB status of those few stars involved.

Tables 1 and 2 contain the values of surface gravity, Θ_{eff}, E_{b-y} and $(b - y)_0$. The error in the derived surface gravities is calculated to be ± 0.14 dex, and in Θ_{eff} is ± 0.016, from the individual observational errors in c_1, $D(0.70)$, and their small abundance uncertainty. (Table 1 lists those stars classified [see § II*d*] as Population I; while Table 2 lists the horizontal branch, O and B subdwarf, white dwarf and F subdwarf stars.)

c) Abundances

The relationship between the equivalent width of the Ca II K line and $B - V$ for Population I A stars is shown in Rodgers (1971). 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 $b - y$ and Θ_{eff} using Kurucz models for surface gravity of 4.2 dex (Fig. 2). From stellar atmosphere theory (Rodgers 1971), it can be shown that for A stars W(K) is proportional mainly to abundance and is relatively independent of gravity, particularly for early- and mid-A stars. For the range of Θ_{eff} indicated, the equivalent width of the K line is proportional to abundance (n) and gravity (g) as follows:

$$0.500\text{–}0.595: W(\text{K}) \propto n^{1/2} . \quad (1)$$

$$0.595\text{–}0.605: W(\text{K}) \propto n^{1/2} g^{-1/10} . \quad (2)$$

$$0.605\text{–}0.700: W(\text{K}) \propto n^{1/2} g^{-1/6} . \quad (3)$$

For a given Θ_{eff}, 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 a Population I value of 4.2 dex was calculated, and the abundance was then found from the above formulae. The error in [Ca/H] is estimated to be around ± 0.05 dex. [Ca/H] values have been listed for all stars with spectra in Tables 1 and 2, together with a few results from other sources.

d) *Classification and Distances*

Stars were classified as Population I or II on the basis of both gravity and abundance. Stars with gravities from 3.8 dex to about 4.4 dex were regarded as Population I on, or just evolving off, the MS. This classification was supported by the fact that the majority had metallicities greater than −0.5. Some had lower abundances, but Am stars (25% of MS A stars; Wolff 1983), with intrinsically small K lines, would appear to have low metallicities on the calcium criterion. Am stars often have negative Δm_1 indices (Crawford 1975, 1979) which are a good indication that the general level of metallicity is normal even though the calcium abundance is low. [Fe/H] values derived from Δm_1 were compared to [Ca/H] for the later A stars. A number of them appear to be Am types, and are indicated as such in Tables 1 and 3.

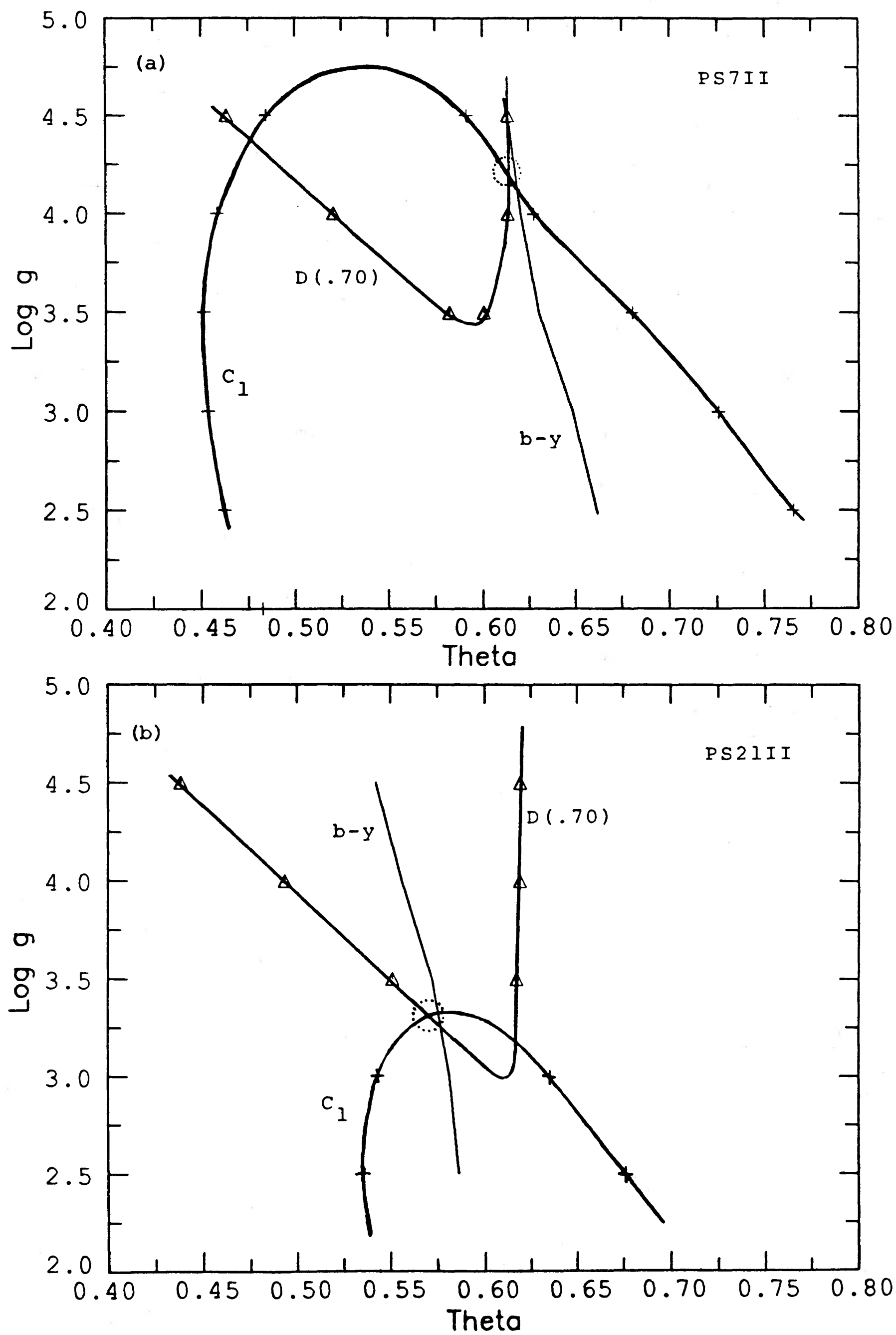

FIG. 1.—Two examples of the derivation of surface gravity and effective temperature values from $D(0.70)$, c_1 and $b - y$ [Tick marks on the $D(0.70)$ and c_1 loci have no significance.] (*a*) PS 7II was found to be a Population I star, with a main-sequence gravity of $\log g = 4.18$ and an effective temperature of 8222 K (= 5040/0.613). E_{b-y}, the difference between the observed $b - y$ and $(b - y)_0$, is equal to 0.014. (*b*) PS 21II is a Population II star, with $\log g = 3.28$, effective temperature of 8842 K (= 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.

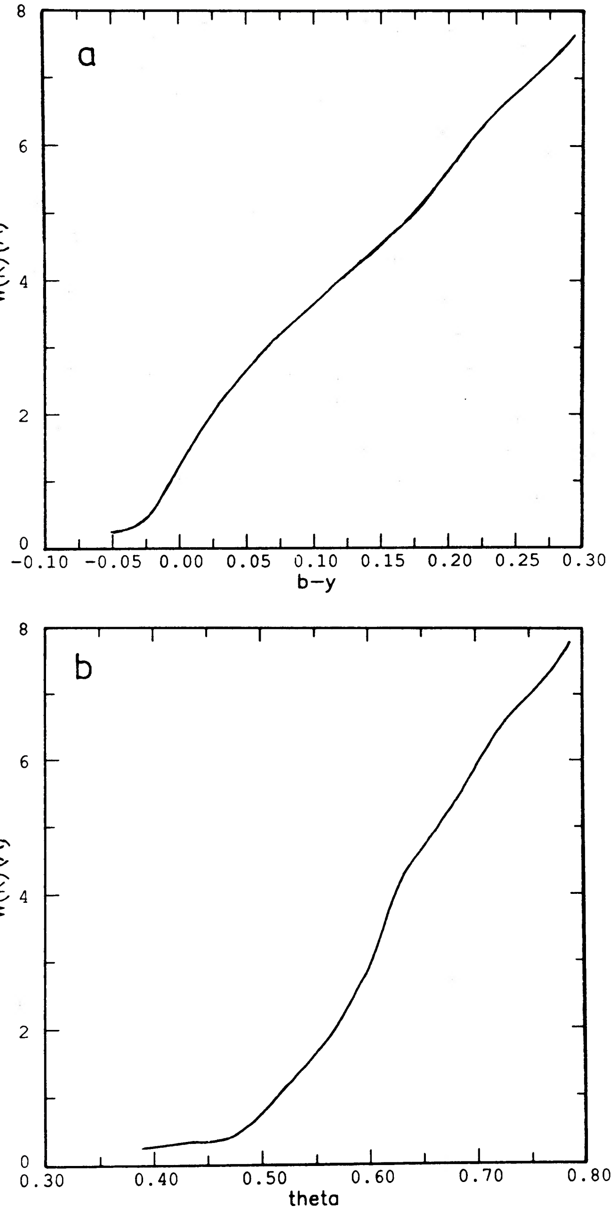

FIG. 2.—(*a*) Calcium K line equivalent width plotted against $b - y$, and (*b*) against $\Theta_{\rm eff}$, for Population I stars of surface gravity 4.2. Points were derived from Pier (1983) and Rodgers (1971).

As mentioned in Paper I, early A stars evolving from the MS to the base of the RGB spend around 10% of their dwarf/subgiant lifetimes at gravities as low as 3.4 to 3.8 dex, partly in the region of the HB (Iben 1967). Hence for stars with gravities in this range, abundance was used as the principal criterion. Stars with metallicities greater than around −0.5, or with Am characteristics, were classified as young stars evolving through the subgiant phase, while those with lower abundances were classified as Population II. O and B subdwarfs, F subdwarfs, and white dwarfs were obvious from their gravity-temperature values.

Before distances can be calculated, absolute magnitudes need to be determined, which in turn depend upon Population I or II status and subsequent mass estimates. (It was not possible to use Strömgren data to obtain absolute magnitudes, as those calibrations utilize the Hβ index, which was not available for the fainter stars.) 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 in the derivation of luminosity and distance. Their abundances are also slightly less accurate than Population I stars, due to their smaller K lines. Masses for Population II stars were assumed to be $0.55 m_\odot$ for HB A stars and $0.50 m_\odot$ for O and B subdwarfs (Sweigart and Gross 1976).

Masses for Population I stars were found by a much more rigorous routine. Mass tracks in the gravity-temperature plane were generated from the Revised Yale Isochrones (Green, Demarque, and King 1987), kindly supplied in advance of publication by E. M. Green. Eight series of mass tracks were generated for a helium abundance (Y) of 0.25, and metallicities (Z) corresponding to 30% of solar abundance, to 100%, in increments of 10%. Such precision was demanded because the positions of isochrones in the gravity-temperature plane are very sensitive to metallicity effects. Helium was assumed to be the same for all metallicities, as all present-day Population I A stars must have been formed within the same epoch. 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, accurate to around $\pm 0.1 m_\odot$.

The usual relations between luminosity and temperature, and surface gravity and mass, were used to derive the luminosity, so that

$$\frac{L}{L_\odot} = C \frac{M/M_\odot}{g\theta^4} , \qquad (4)$$

where $C = 1.593 \times 10^2$ and g is in units of m s^{-2}. Bolometric magnitude was found from the luminosity, and 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 $A_v = 3E_{B-V}$, and the distance was then derived from the distance modulus. The quantity Z was found from the distance from the Sun multiplied by the sine of the galactic latitude. Distances are estimated to be accurate to around ± 16%.

The maximum distances from the plane that the stars could reach, given their present positions and radial velocities, were

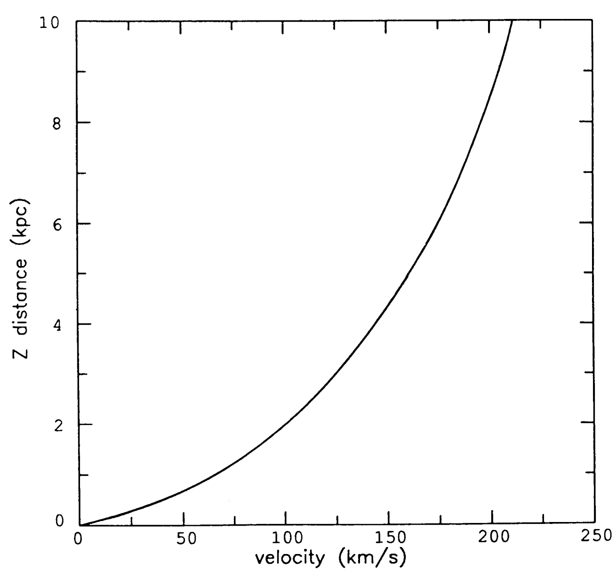

FIG. 3.—The Z distance to which a star could travel, as a function of its velocity at the plane, from the model by G. Rowley.

found from a model by G. Rowley. This consisted of a combination of three disks of different radial scale factors, of the form given by Miyamoto and Nagai (1975), which was normalized to give a disk that was exponential in radius for four to five scale lengths. The functional form for the three potentials is

$$\Phi_i(R, Z) = \frac{Gm_i}{\{R^2 + [a_i + (Z^2 + b^2)^{1/2}]^2\}^{1/2}}, \qquad (5)$$

where G is the gravitational constant, m_i is the disk mass, a_i 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 is the sum of the three disk potentials. The advantage of this technique is that the potential of these disks is a known analytic function, and the force law may be easily calculated. The radial scale lengths (a_i) of the three disks were 6.66, 19.98, and 33.30 kpc, with relative masses of 1, -0.7, and 0.26. The Z scale height (b) was 0.4 kpc, the radial scale length of the combined disks was 2.9 kpc, and their total mass was 0.9×10^{11} $m_\odot$. The resultant force law is similar to that proposed by Oort (1960). Using the total potential, maximum Z heights for the program stars were found from the velocities at the disk (see Fig. 3). Masses, absolute magnitudes, Z distances, and maximum Z distances are listed in Tables 1 and 2.

Out of 305 early-type stars in the SGP catalog, 191 had enough data to be classifiable as Population I or II and to have distances calculated. One hundred and twelve of these had K line measurements (104 from my spectra). Of these stars, 64 are more than 1 kpc from the disk, out of which 29 have been identified as belonging to Population I. (It is estimated that at least another nine stars remain to be found in the SGP area outside the box to 14th magnitude alone). The 29 Population I stars have present Z distances between 1 and 11 kpc. Those that are at distances greater than about 4 kpc are observable only because they are evolving off the MS and are at brighter luminosities. Figure 4 shows the distribution of Z heights as a

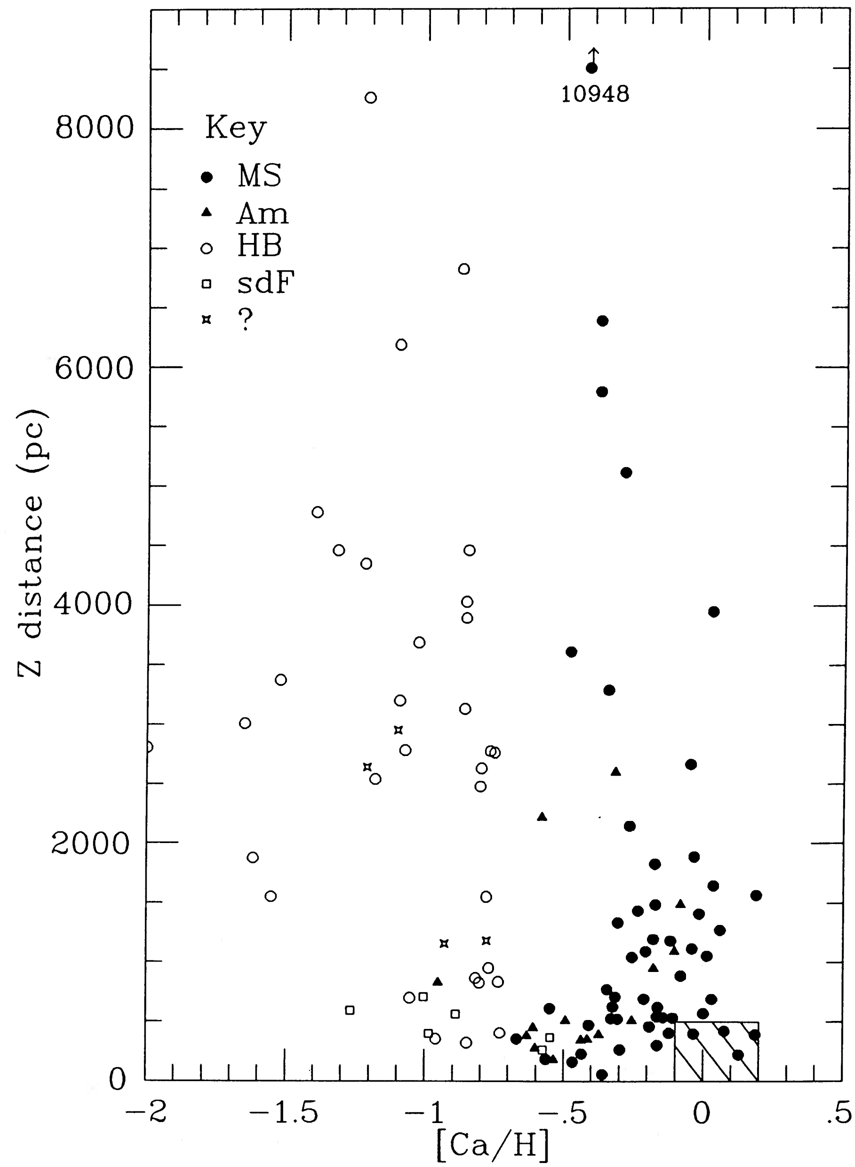

FIG. 4.—Calcium abundance of the SGP A stars plotted against their distance from the plane. Hatched area covers the expected loci of main-sequence A stars formed since 1 billion years ago. The Population I stars above 1 kpc are clearly distinct from Population II stars. The falloff in their relative numbers at distances greater than 1.6 kpc is a function of the observational magnitude limit.

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TABLE 1

DATA FOR POPULATION I STARS IN THE SGP CATALOG

No	ID	log g	θ_{eff}	E_{b-y}[a]	$b-y_0$	[Ca/H]	$m_\odot$	M_V	Z[d] (pc)	Z_{max}[e] (pc)	age 10^6yrs	type[i]
3	124	4.01	0.684	0.000	0.190	[b]	1.69	2.04	224	0	875	
10	134 1I	3.81	0.698	0.000	0.202	[b]	1.78	1.57	257	472	1275	Am
12	136 2II	3.98	0.596	0.040	0.040	-0.17	1.99	1.19	1487	1799	575	[f] Ap:
13	1667	3.64	0.675	0.000	0.172	[b]	1.96	0.89	148	0	775	
18	3II	4.25	0.688	0.032	0.197	0.01	1.50	2.79	1058	1826	25	[f]
24	153 7I	4.00	0.462	0.000	-0.029	[b]	3.00	0.13	190	199	175	B9IVp
26	161 8I	4.04	0.599	0.000	0.059	[b]	2.00	1.35	226	234	475	A1V
27	162 9I	3.71	0.684	0.000	0.184	[b]	2.05	1.08	284	331	975	A5IV
28	163	4.12	0.707	0.000	0.221	[b]	1.50	2.59	173	0	675	
29	167 10I	3.76	0.574	0.000	0.024	[b]	2.31	0.34	284	284	525	A1Vn
36	179 4II	4.20	0.662	-0.004	0.170	-0.31	1.49	2.51	1334	1867	625	[f]
38	182 14I	3.96	0.508	0.000	-0.011	[b]	2.53	0.53	1323	1413	275	[f] B9A0V
46	194 7II	4.18	0.613	0.021	0.087	-0.17	1.66	2.01	1827	1854	425	[f]
47	197 17I	4.05	0.725	0.000	0.235	[b]	1.50	2.53	352	0	1225	
49	198 8II	4.11	0.628	0.030	0.126	0.03	1.78	1.86	1648	2034	475	[f]
50	199 18I	4.20	0.521	0.053	-0.003	0.19	2.27	1.31	394	651	175	A0V
53	202 10II	4.21	0.600	0.048	0.049	-0.32	1.73	1.94	2598	4917	225	[f] Am
54	203 19I	3.82	0.614	0.000	0.079	[b]	2.02	0.90	71	72	725	A3/5V
60	212 14II	3.64	0.491	0.012	-0.017	-0.38	2.91	-0.55	5796	9938	275	[f]
61	213 21I	3.75	0.703	0.000	0.207	[b]	1.70	1.50	658	0	1175	
65	2980	3.63	0.712	0.000	0.215	[b]	1.83	1.18	352	0	975	
67	222 22I	4.02	0.631	0.000	0.131	[b]	1.88	1.60	389	0	575	A5IV/V
73	236 23I	3.95	0.665	0.000	0.171	[b]	1.84	1.67	201	214	775	A7III
76	3300	4.00	0.777	0.000	0.288	[b]	1.40	2.81	310	0	2025	
77	242 25I	4.26	0.651	0.000	0.165	[b]	1.60	2.51	50	159	25	A7p
78	3338	3.82	0.716	0.000	0.223	[b]	1.60	1.83	213	0	1475	
82	26I	4.03	0.679	0.000	0.185	[b]	1.68	2.06	543	0	825	A8V
84	248	4.16	0.688	0.000	0.198	[b]	1.53	2.55	282	0	425	
86	254 29I	4.00	0.625	0.000	0.116	[b]	1.82	1.54	249	0	575	
87	256 30I	4.10	0.326	0.000	-0.070	[b]	6.50	-1.08	363	383	25	B8V
88	257 20II	3.49	0.591	0.071	0.019	-0.38	2.50	-0.32	6388	7225	375	[f]
90	264	3.71	0.727	0.020	0.222	[b]	1.53	1.67	1952	0	...	[g]
93	272 22II	4.16	0.637	0.020	0.141	-0.23	1.59	2.17	1435	1661	575	[f]
96	277 34I	4.09	0.360	0.000	-0.060	[b]	6.00	-0.89	1353	0	...	[g]
97	279 24II	4.17	0.675	0.047	0.181	-0.32	1.40	2.58	729	1057	875	
100	284 35I	3.95	0.611	-0.024	0.064	-0.37	1.80	1.33	394	418	1175	A2V, Am
101	285 26II	4.12	0.607	0.039	0.058	-0.58	1.79	1.73	2215	2518	375	[f] Am
103	287 36I	4.17	0.530	0.059	0.002	-0.08	2.15	1.30	888	981	275	
104	288 38I	3.59	0.704	-0.041	0.196	-0.95	1.92	0.98	832	1077	825	Am
107	293 40I	4.01	0.529	0.000	0.001	[b]	2.42	0.78	574	0	275	
109	298 27II	3.63	0.591	0.000	0.034	0.03	2.40	0.08	3950	3963	475	[f]
110	41I	4.10	0.719	0.000	0.230	[b]	1.47	2.64	32	154	825	F2V
111	299 42I	4.04	0.632	0.000	0.133	-0.31	1.74	1.74	524	1054	875	
112	300	3.90	0.715	0.000	0.223	[b]	1.56	2.05	235	0	1625	
114	302 28II	4.20	0.538	0.060	-0.005	-1.10	1.82	1.56	2952	2952	...	[h]
116	306 45I	4.07	0.592	0.033	0.041	-0.26	1.89	1.44	511	514	625	Am
117	307 44I	4.06	0.592	0.030	0.047	-0.03	2.00	1.36	401	536	475	A0V
119	312 47I	4.12	0.646	0.017	0.152	-0.16	1.57	2.15	305	362	675	A9V
122	314 49I	4.05	0.682	0.000	0.192	[b]	1.64	2.16	238	326	825	F0V
125	317 29II	4.23	0.632	0.035	0.135	-0.08	1.59	2.31	1489	2515	125	[f] Am
126	318 51I	4.30	0.524	0.051	0.000	-0.14	2.10	1.65	536	656	125	A0IV
127	320 52I	3.78	0.644	-0.013	0.134	-0.54	1.73	1.18	183	283	825	Am
128	322 30II	4.08	0.607	0.003	0.076	-0.03	1.84	1.60	1888	2239	475	[f]
129	323	3.90	0.684	0.013	0.180	-0.41	1.47	1.91	474	493	1875	
131	327	3.80	0.695	0.000	0.196	[b]	1.70	1.58	157	195	1225	F0III
132	329 54I	4.12	0.495	0.000	-0.016	[b]	2.55	0.82	88	235	175	B9V
135	333	4.19	0.700	0.016	0.208	-0.36	1.32	2.86	58	73	1525	
136	4689	4.10	0.740	0.000	0.255	[b]	1.40	2.83	207	0	1425	
137	335 55I	3.98	0.663	0.037	0.161	-0.17	1.65	1.85	545	637	875	
143	344 59I	4.12	0.603	0.060	0.051	-0.35	1.68	1.77	773	785	825	

TABLE 1—*Continued*

No	ID	log g	θ_{eff}	E_{b-y}[a]	$b - y_0$	[Ca/H]	$m_\odot$	M_V	Z[d] (pc)	Z_{max}[e] (pc)	age 10^6yrs	type[i]
144	343	4.18	0.689	0.015	0.197	0.13	1.52	2.61	224	324	325	A9III/IV
146	E30.1.036	4.20	0.693	0.009	0.202	-0.04	1.49	2.71	1118	2444	325	[f]
147	E30.1.041	4.05	0.718	0.060	0.228	-0.11	1.40	2.56	534	809	1475	
148	4974	3.74	0.713	0.000	0.219	[b]	1.69	1.55	381	0	1225	
150	350 32II	4.16	0.565	0.116	0.018	-0.27	1.90	1.52	2143	2509	475	[f]
152	62I	3.66	0.714	0.000	0.219	[b]	1.78	1.30	382	386	1025	A9V
158	361 63I	4.11	0.617	0.055	0.095	-0.32	1.68	1.85	627	629	775	
161	366 37II	4.15	0.610	0.020	0.084	-0.12	1.76	1.85	1184	1264	425	[f]
164	373 39II	4.07	0.607	0.001	0.077	-0.05	1.86	1.57	2665	2704	525	[f]
165	375 65I	3.98	0.455	0.004	-0.032	0.06	3.05	0.03	1274	1389	175	[f] B9A0V
167	377 66I	3.75	0.618	-0.018	0.075	-0.56	1.83	0.86	186	469	925	A5V
168	379 67I	4.10	0.610	0.044	0.077	-0.19	1.76	1.72	462	590	675	A5IV/V
173	386	3.97	0.688	0.016	0.186	-0.41	1.40	2.17	355	1068	2075	Am
175	388 69I	3.60	0.520	0.003	-0.012	-0.48	2.90	-0.46	3613	4903	325	[f]
177	390 71I	3.22	0.345	0.000	-0.050	[b]	15.00	-4.12	484	507	...	B7III
180	393 73I	4.00	0.621	0.000	0.111	[b]	1.94	1.44	373	397	575	A4V
182	399 74I	3.91	0.610	0.028	0.067	-0.18	2.00	1.11	953	969	625	Am
186	403 41II	4.09	0.668	0.053	0.175	0.03	1.64	2.17	692	1360	625	
188	408 42II	4.10	0.613	0.071	0.071	-1.21	1.62	1.83	2638	2672	...	[h]
190	44II	4.22	0.721	0.020	0.232	-0.16	1.30	3.09	623	626	425	
191	6088	4.12	0.692	0.015	0.198	-0.30	1.42	2.55	267	310	1425	
192	411 75I	4.27	0.653	0.028	0.163	-0.26	1.50	2.62	1045	4172	225	[f]
193	414 77I	4.01	0.589	0.000	0.041	[b]	2.09	1.16	73	84	425	A12IV
194	413 76I	4.10	0.679	0.009	0.185	-0.12	1.54	2.33	406	435	825	
197	416 78I	4.13	0.408	0.027	-0.045	0.19	3.33	0.10	1567	1660	25	[f]
198	418	4.25	0.650	0.081	0.160	-0.18	1.54	2.52	1196	2651	225	[f]
204	426 80I	4.12	0.586	0.000	0.041	[b]	1.97	1.48	314	315	375	A2V
208	430 81I	4.11	0.670	-0.018	0.175	-0.60	1.42	2.39	279	327	575	Am
211	433 84I	4.05	0.623	0.000	0.116	[b]	1.86	1.63	240	249	525	A7V Am
213	435 46II	4.00	0.510	0.019	-0.012	-0.34	2.38	0.71	3290	6285	375	[f]
215	6515	4.07	0.712	0.000	0.223	[b]	1.53	2.48	157	250	1025	
216	440	4.20	0.717	0.010	0.226	-0.47	1.20	3.10	157	250	2175	A9V
217	441 83I	4.50	0.602	0.000	0.084	[b]	1.60	2.77	135	0	...	
225	451 85I	4.07	0.693	0.016	0.197	-0.44	1.37	2.47	232	370	1625	A9V
226	450 86I	4.09	0.636	0.000	0.140	[b]	1.78	1.87	78	181	525	
228	6724	3.61	0.748	0.000	0.253	[b]	1.73	1.43	372	373	1125	F0V
229	455 87I	4.00	0.672	0.000	0.178	[b]	1.74	1.90	271	273	825	A8V
236	6855	4.03	0.720	0.000	0.231	[b]	1.55	2.42	251	290	1225	F0V
238	E29.0.197	4.55	0.725	0.038	0.245	0.07	1.00	4.22	423	424	25	
240	CI-331066	4.02	0.796	0.048	0.309	0.00	1.30	3.06	571	606	2525	
243	466 51II	4.12	0.675	0.005	0.179	-0.78	1.37	2.48	1182	1296	...	[h]
247	7038	3.83	0.743	0.000	0.252	[b]	1.52	2.09	284	0	1825	
253	481 95I	4.17	0.617	0.022	0.094	-0.44	1.57	2.07	348	426	875	A2III/IV, Am
255	486 55II	3.44	0.570	0.224	0.009	-0.29	2.79	-0.68	5117	5124	275	[f]
259	495 56II	4.15	0.642	0.041	0.146	-0.93	1.45	2.28	1157	1157	...	[h]
262	502 98I	4.23	0.593	0.018	0.041	-0.21	1.71	1.96	1095	1607	325	[f]
264	504 99I	4.30	0.676	0.000	0.189	[b]	1.50	2.84	444	0	25	
265	505 57II	4.16	0.615	0.005	0.097	-0.10	1.74	1.92	1095	1114	425	[f] Am:
267	509 100I	3.84	0.707	0.000	0.213	[b]	1.62	1.81	354	0	1425	
268	511	3.84	0.683	0.000	0.184	[b]	1.72	1.59	127	128	1125	F0III
270	514 102I	4.00	0.600	0.019	0.042	-0.49	1.70	1.44	510	510	1275	A1V, Am
271	515	4.70	0.601	0.000	0.085	[b]	1.50	3.33	101	155	...	A3m
279	528 105I	3.92	0.647	0.025	0.140	-0.63	1.54	1.67	383	1328	675	Am
280	529 107I	4.06	0.600	0.046	0.039	-0.61	1.73	1.57	452	660	575	Am
281	530 106I	3.91	0.654	0.000	0.158	[b]	1.90	1.47	177	180	675	A9IV
282	531 108I	4.11	0.688	0.000	0.196	[b]	1.57	2.39	94	150	625	
284	60II	3.50	0.512	0.004	-0.015	-0.42	3.20	-0.85	10948	11100	275	[f]
286	535 109I	4.35	0.664	0.000	0.179	[b]	1.53	2.87	182	261	25	F0V
287	537 62II	4.15	0.644	0.014	0.152	-0.02	1.67	2.14	1412	1912	375	[f]
291	8145	3.69	0.694	0.000	0.192	[b]	1.82	1.22	277	284	975	F2V

TABLE 1—*Continued*

No	ID	log g	θ_{eff}	E_{b-y}[a]	$b-y_0$	[Ca/H]	$m_\odot$	M_V	Z[d] (pc)	Z_{max}[e] (pc)	age 10^6yrs	type[i]
294	551 114I	4.01	0.620	0.007	0.103	-0.21	1.81	1.54	694	991	725	
300	118I	4.12	0.712	0.080	0.220	-0.33	1.38	2.71	528	583	1625	
302	562	4.09	0.679	0.035	0.183	-0.55	1.40	2.41	614	769	1725	
304	567	3.70	0.383	0.032	-0.050	[c]	10.00	-2.30	3104	3222	...	[g]
305	568	4.15	0.634	0.000	0.138	[b]	1.72	2.04	82	83	375	A7Vn

[a] The value of E_{b-y} was estimated if there is a '*b*' in Column 7.
[b] Spectrum was not available.
[c] The spectrum was available, but the abundance calibration was not valid for such hot stars.
[d] Z distances were not calculated for stars with θ_{eff} less than 0.300.
[e] Maximum Z distances were not calculated for stars without radial velocities.
[f] denotes the Population I stars at distances greater than 1 kpc.
[g] denotes possible Population I stars for which more data is required.
[h] These may be unidentified Am stars or field blue stragglers, as they have main sequence gravities and low calcium abundances.
[i] Spectral types with luminosity classifications are from Houk 1978. 'Am' and 'Ap' are my notations for stars that may be of those types, as suggested by their photometry.

function of [Ca/H] for all the stars with available data (three stars with abundances less than −2.0 are not plotted). It can be seen from Figure 4 that around half of the A stars between 1 and 4 kpc have Population I calcium abundances. The actual ratio of MS to HB stars above 1 kpc may be larger than Figure 4 would indicate, because the HB stars are intrinsically more luminous than MS stars.

The distribution of abundances for stars closer to the disk in this figure is misleading. Spectra were not obtained for around 50 of the brightest nearby A stars, as their Population I status was derived directly from their photometry. This means that W(K) measurements were not available for the stars that are closest to the disk, so they do not appear in Figure 4 (but note that they do appear in Fig. 8, the age distributions; see below). They are expected to have abundances lying within the hatched region of Figure 4. The disk stars that are actually plotted are those that are older, fainter, and on average further from the disk. This group would contain a higher proportion of Am, blue straggler, F subdwarf, and other low calcium stars, relative to the youngest disk A stars that are not plotted.

The abundances of the stars in Figure 4 were found from comparison to the mean calcium abundance of some young local A stars (Rodgers 1971). The calibration of this relation was also tested with a sample of my own, of A stars in the plane, within about 500 pc of the Sun (spectra obtained, reduced, and K lines measured, using the same techniques as the SGP A stars), and it was found to be a good indicator of mean young A star calcium abundances. It is relative to this calibration that the range of abundance for the non–Am Population I stars more than 1 kpc from the plane is measured at around 33% to 100% of the mean disk A star calcium abundance, [Ca/H] of −0.5 to just over 0.0. (Two of the stars are plotted at +0.06 and +0.19, but these exact values have low weight, as the stars are the two hottest of the group, appearing in the late B range where the Ca II K line calibration becomes unreliable).

Apart from four stars discussed below, all the stars more than 1 kpc from the plane with abundances less than −0.7 have low gravities. Some of the stars may be blue stragglers like those in NGC 7789 (Twarog and Tyson 1985), with gravities around 3.6 dex, but the majority of the low-gravity, low abundance stars far from the Galactic plane are most likely to be true HB stars.

Four distant stars with abundances less than −0.7 have MS gravities. They were among the stars for which it was not possible to obtain spectra, so W(K) values from Rodgers (1971) were used. Since his spectra were of substantially lower resolution than those obtained for the stars in this study, the abundances found for these four stars may not be very accurate. Their Δm_1 values indicate [Fe/H] abundances typical of normal A stars, although they are not quite large enough to classify them as Am stars. Conversely, if they are genuinely low abundance stars, they may actually be blue stragglers. Higher resolution spectra would be necessary in order to classify them definitively. Excluding the recognized Am stars, the lower limit of −0.5 in [Ca/H] for the distant Population I stars appears to be well established, as spectra were obtained in this study for all but one of them.

Table 3 lists the 29 Population I stars more than 1 kpc from the plane. It includes PS 14I, which is classified as Population I by Philip (1986), but for which it was not possible to obtain a spectrum. (For PS 14I and the Am stars a mean abundance of 0.0 dex was assigned for the purpose of age determinations, see below.) Figure 5 shows the gravity-temperature distribution for the catalog stars of all classifications. Figure 6 shows only the Population I stars more than 1 kpc from the disk, in greater detail.

Note that the majority of stars in Figure 6 are close to the main sequence, with surface gravities from 3.9 to 4.3 dex. None of the metal-rich stars appear in the low-gravity instability strip, so metal-rich RR Lyraes are not present in this sample. This argues against the possibility that a hypothetical metal-rich blue HB population might exist (see Paper I). In any case, the surface gravities and rotational velocities of the metal-rich

TABLE 2

DATA FOR POPULATION II STARS IN THE SGP CATALOG

No	ID	log g	θ_{eff}	E_{b-y} [a]	$b-y_0$	[Ca/H]	$m_\odot$	M_V	Z [d] (pc)	Z_{max} [e] (pc)	type [f,g]
9	133 1II	2.88	0.569	0.045	0.003	-1.21	0.55	-0.32	8257	~ 14000	
15	143	8.14	0.300	0.000	-0.090	[b]	1.40	10.57	63	0	DA
30	169	5.20	0.200	0.000	-0.121	[b]	0.50	...	0	0	sdB
31	171	4.20	0.360	0.000	-0.073	[b]	0.55	1.98	3312	0	sdB
32	172 11I	3.60	0.540	0.015	-0.007	-0.78	0.55	1.37	1551	1572	
33	173	2.92	0.638	0.020	0.085	[b]	0.55	0.23	6755	0	
35	178	4.55	0.761	0.020	0.281	[b]	1.00	4.45	531	0	sdF
37	181 13I	2.17	0.695	0.000	0.147	[b]	0.55	-1.27	406	453	
40	15I	3.14	0.698	0.000	0.188	[b]	0.55	1.17	154	281	
41	191 5II	2.56	0.748	0.030	0.221	-3.03	0.55	0.05	5861	~ 12000	
45	192 6II	3.21	0.596	0.039	0.015	-1.40	0.55	0.66	4781	4781	
52	9II	4.40	0.755	0.020	0.273	-0.99	0.96	4.09	406	689	sdF
56	208 11II	3.02	0.520	0.049	-0.010	-0.88	0.55	-0.10	6827	6827	
58	210 13II	3.00	0.534	0.024	-0.008	-0.86	0.55	-0.14	4031	4135	
66	221 15II	3.25	0.600	0.057	0.020	-0.86	0.55	0.79	3895	6308	
68	225 16II	3.50	0.588	0.054	0.012	-1.03	0.55	1.33	3689	3732	
71	231 17II	3.45	0.529	0.022	-0.009	-0.80	0.55	0.99	2630	3068	
72	235 18II	3.45	0.590	-0.002	0.010	-1.62	0.55	1.22	1874	2126	
81	246 19II	3.40	0.612	0.093	0.038	-1.18	0.55	1.25	2538	2544	
89	259 21II	3.28	0.570	0.018	0.001	-1.22	0.55	0.68	4347	4365	
94	273 33I	4.34	0.709	0.020	0.224	[b]	1.05	3.54	649	0	sdF
95	276 23II	3.48	0.605	0.048	0.027	-1.07	0.55	1.40	2784	4398	
99	283 25II	3.48	0.562	0.031	0.000	-0.85	0.55	1.15	4462	4690	
102	286 37I	3.09	0.726	0.000	0.217	[b]	0.55	1.23	462	0	
106	294 39I	3.58	0.709	0.000	0.210	[b]	0.55	2.34	275	0	
124	316 50I	3.23	0.756	0.006	0.245	-0.80	0.55	1.77	831	852	
133	330 31II	4.67	0.680	0.025	0.197	-0.89	1.11	4.12	567	1036	sdF
138	337 56I	3.42	0.692	-0.002	0.175	-0.74	0.55	1.83	838	883	
139	338	3.44	0.669	0.020	0.159	[b]	0.55	1.73	2093	0	
140	340 57I	3.40	0.625	0.000	0.084	[b]	0.55	1.34	96	115	
142	342 58I	4.34	0.705	0.017	0.213	-1.27	1.06	3.51	594	740	sdF
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	[c]	0.50	...	0	0	sdO
159	362 35II	3.19	0.611	0.030	0.034	-2.00	0.55	0.72	2806	2986	
160	363 36II	3.28	0.630	0.044	0.085	-1.09	0.55	1.08	3199	5500	
162	367 64I	3.66	0.695	0.017	0.187	-1.05	0.55	2.45	702	780	
163	371 38II	3.07	0.725	0.027	0.208	-0.77	0.55	1.17	2776	2839	
174	387 70I	3.60	0.704	0.013	0.197	-0.82	0.55	2.36	871	2267	
183	CD-25 390	3.46	0.756	0.053	0.247	-0.73	0.55	2.35	406	468	
187	405	2.61	0.735	0.020	0.217	[b]	0.55	0.09	3944	0	
189	410 43II	5.45	0.174	0.000	-0.114	[c]	0.50	...	0	0	sdB
199	421	5.15	0.800	0.020	0.308	[b]	0.80	6.43	205	0	sdF
201	420 79I	3.10	0.615	0.009	0.042	-0.75	0.55	0.52	2763	7276	
207	431 82I	3.63	0.675	-0.016	0.166	-0.85	0.55	2.25	324	324	
218	442	4.64	0.774	0.038	0.291	-0.58	0.96	4.80	266	1894	sdF
221	446 47II	5.10	0.215	0.000	-0.121	[c]	0.50	...	0	0	sdB
223	SP280	4.76	0.761	0.046	0.279	-0.55	0.93	5.06	367	437	sdF
224	449 48II	3.62	0.653	0.028	0.142	-1.55	0.55	2.08	1550	2741	
227	453 49II	2.74	0.753	0.036	0.229	-2.97	0.55	0.53	2745	2883	
233	459 88I	5.22	0.224	0.026	-0.138	[c]	0.50	...	0	0	sdO
235	460 90I	4.82	0.354	-0.005	-0.064	[c]	0.50	3.51	651	7271	sdB
239	462 50II	2.98	0.580	0.029	0.006	-1.32	0.55	-0.02	4458	10500	
241	463 91I	4.58	0.300	0.022	-0.100	[c]	0.50	2.68	748	~ 26000	sdB
245	469	4.20	0.720	0.020	0.233	[b]	0.98	3.34	861	0	sdF
248	474 52II	3.50	0.515	0.016	-0.014	-0.80	0.55	1.08	2477	2678	
251	480 53II	3.34	0.542	0.011	-0.007	-2.34	0.55	0.73	2955	4339	
254	485 54II	5.60	0.160	0.000	-0.105	[c]	0.50	...	0	0	sdO
261	499	3.34	0.743	-0.022	0.231	-0.96	0.55	1.96	355	402	
269	512 101I	3.50	0.682	0.028	0.172	-0.77	0.55	1.97	953	1307	
274	519 58II	3.36	0.593	0.001	0.012	-1.65	0.55	1.01	3007	~ 15000	

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TABLE 2—*Continued*

No	ID	log g	θ_{eff}	E_{b-y}[a]	$b-y_0$	[Ca/H]	$m_\odot$	M_V	Z[d] (pc)	Z_{max}[e] (pc)	type[f,g]
283	532 59II	3.32	0.581	0.037	0.005	-1.52	0.55	0.84	3373	3495	
296	554	2.85	0.659	0.020	0.120	[b]	0.55	0.19	5302	0	
299	SP298	5.02	0.656	0.043	0.178	-1.00	1.15	4.80	711	796	sdF
301	561	3.55	0.732	0.000	0.233	[b]	0.55	2.42	134	0	
303	563	3.66	0.592	0.053	0.016	-0.86	0.55	1.76	3132	~ 14000	

[a] The value of E_{b-y} was estimated if there is a 'b' in Column 7.
[b] Spectrum was not available.
[c] Spectrum was available, but the abundance calibration was not valid for such hot stars.
[d] Z distances were not calculated for stars with θ_{eff} less than 0.300.
[e] Maximum Z distances were not calculated for stars without radial velocities.
[f] sdF stars were identified on the basis of Strömgren indices and [Ca/H].
[g] Stars in this table are classified as A-type horizontal branch stars unless otherwise indicated.

TABLE 3

POPULATION I A STARS AT DISTANCES GREATER THAN 1 KILOPARSEC FROM THE DISK

No	ID	RV ($km s^{-1}$)	log g	θ_{eff}	$b-y_0$	[Ca/H]	m_v	M_v	Z (pc)	Z_{max} (pc)	Age (10^6yrs)	type
12	2II	42	3.98	0.596	0.040	-0.17	12.24	1.19	1487	1799	575	Ap:
18	3II	67	4.25	0.688	0.197	0.01	13.07	2.79	1058	1826	25	
36	4II	-55	4.20	0.662	0.170	-0.31	13.15	2.51	1334	1867	625	
38	14I	23	3.96	0.508	-0.011	...	11.15	0.53	1323	1413	275	
46	7II	-12	4.18	0.613	0.087	-0.17	13.42	2.01	1827	1854	425	
49	8II	46	4.11	0.628	0.126	0.03	13.09	1.86	1648	2034	475	
53	10II	109	4.21	0.600	0.049	-0.32	14.22	1.94	2598	4917	225	Am
60	14II	-119	3.64	0.491	-0.017	-0.38	13.32	-0.55	5796	9938	275	
88	20II	57	3.49	0.591	0.019	-0.38	14.00	-0.32	6388	7225	375	
93	22II	-36	4.16	0.637	0.141	-0.23	13.04	2.17	1435	1661	575	
101	26II	42	4.12	0.607	0.058	-0.58	13.62	1.73	2215	2518	375	Am
109	27II	8	3.63	0.591	0.034	0.03	13.06	0.08	3950	3963	475	
125	29II	-76	4.23	0.632	0.135	-0.08	13.32	2.31	1489	2515	125	Am
128	30II	44	4.08	0.607	0.076	-0.03	13.00	1.60	1888	2239	475	
146	E30.1.036	87	4.20	0.693	0.202	-0.04	12.99	2.71	1118	2444	325	
150	32II	-46	4.16	0.565	0.018	-0.27	13.65	1.52	2143	2509	475	
161	37II	-22	4.15	0.610	0.084	-0.12	12.30	1.85	1184	1264	425	
164	39II	-15	4.07	0.607	0.077	-0.05	13.71	1.57	2665	2704	525	
165	65I	-26	3.98	0.455	-0.032	0.06	10.58	0.03	1274	1389	175	
175	69I	78	3.60	0.520	-0.012	-0.48	12.35	-0.46	3613	4903	325	
192	75I	132	4.27	0.653	0.163	-0.26	12.83	2.62	1045	4172	225	
197	78I	23	4.13	0.408	-0.045	0.19	11.19	0.10	1567	1660	25	
198	SB418	91	4.25	0.650	0.160	-0.18	13.24	2.52	1196	2651	225	
213	46II	119	4.00	0.510	-0.012	-0.34	13.38	0.71	3290	6285	375	
255	55II	-6	3.44	0.570	0.009	-0.29	12.97	-0.68	5117	5124	275	
262	98I	55	4.23	0.593	0.041	-0.21	12.24	1.96	1095	1607	325	
265	57II	11	4.16	0.615	0.097	-0.10	12.16	1.92	1095	1114	425	Am:
284	60II	-26	3.50	0.512	-0.015	-0.42	14.38	-0.85	10940	11100	275	
287	62II	-53	4.15	0.644	0.152	-0.02	12.96	2.14	1412	1912	375	

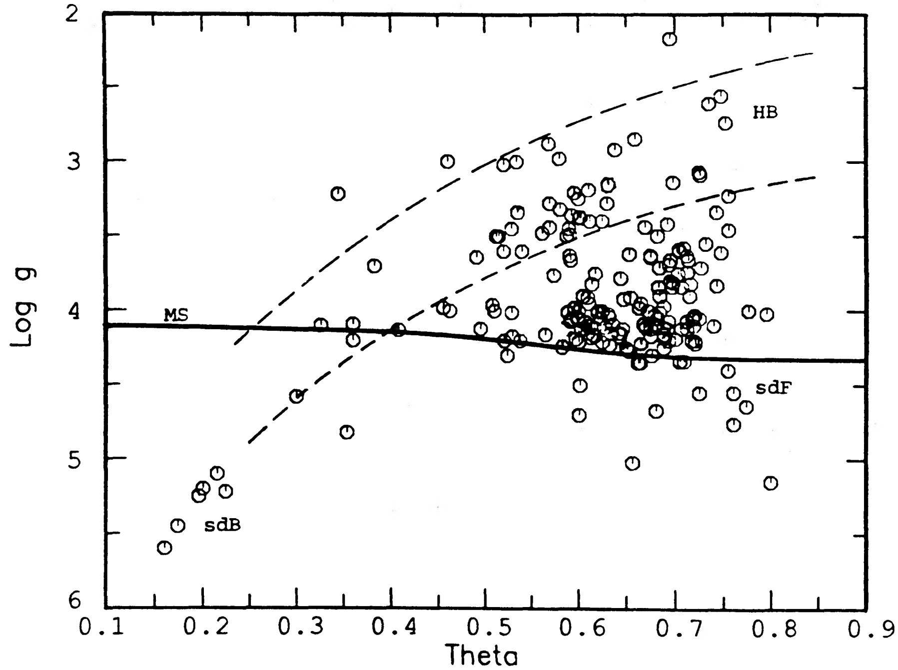

FIG. 5.—Surface gravity plotted against Θ_{eff} ($= 5040/T_{eff}$), for all the stars with data available in the SGP catalog. The main-sequence, horizontal-branch, and the positions of sdB and sdF stars, are indicated.

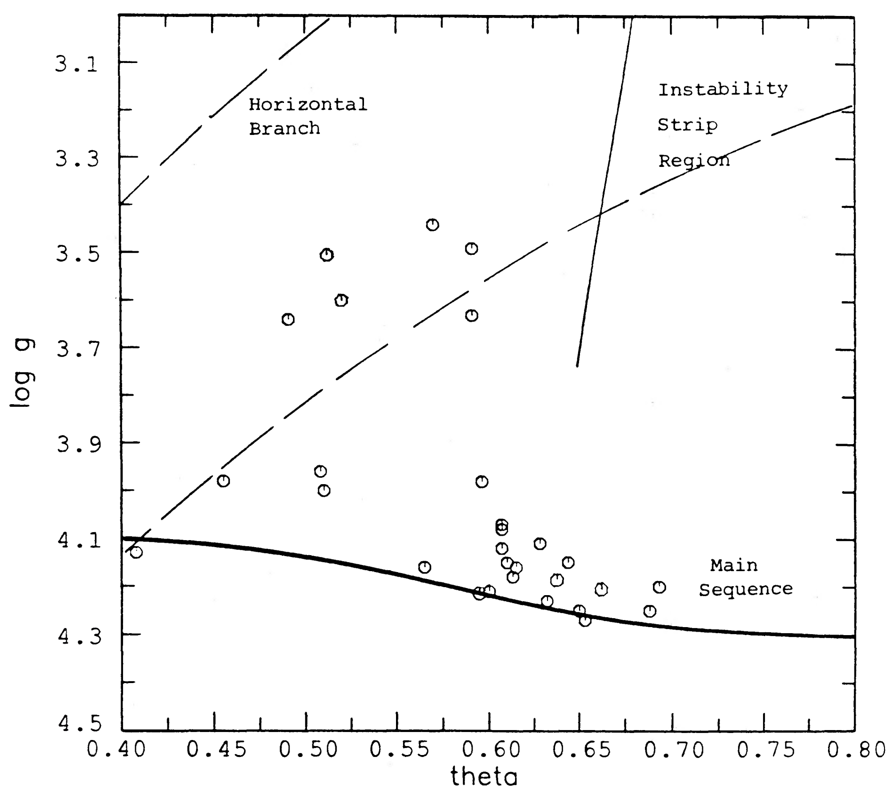

FIG. 6.—Surface gravity plotted against Θ_{eff} for the stars found to be Population I and greater than 1 kpc from the disk. Note that none appear in the instability strip, and that the majority are unarguably main-sequence stars.

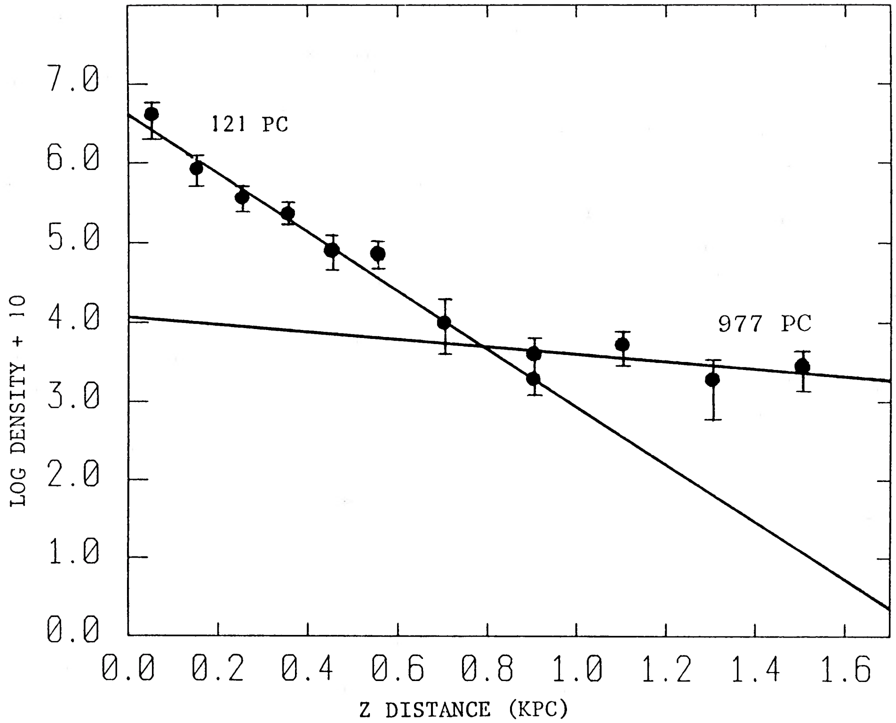

FIG. 7.—Log density of Population I A stars in the box area, plotted against their distance from the Galactic plane. Two scale heights are indicated: the nearby disk dwarfs with a scale height of 121 pc, and the distant young stars with a scale height of 977 pc.

A stars in this study clearly eliminate the suggestion that they are misidentified HB stars.

Some blue stragglers (see § I*a*) have lower surface gravities than the MS, and the possibility must be considered that the six stars with low gravities in the distant Population I group might be blue stragglers. However, it would seem an unnecessary complication to exclude the six stars on these grounds alone, as they have an equal likelihood of being young stars evolving away from the MS, and their kinematic and abundance properties are no different from the genuine MS stars. The overall problem of the existence of the other MS stars in the sample, selected upon identical criteria, would still remain even if the low-gravity stars were excluded.

It seems important to stress, however, that of the subsequent derivations of velocity dispersion, mean abundance, scale height, or mean age for the distant Population I group, none depend in any way upon the six low-gravity stars, nor upon the few early A stars with small K lines. *The properties of the sample as a whole are entirely defined by the large number of MS mid-to-late A stars, and not the small number of stars with less certain classifications.*

e) *Kinematics and Densities*

For the 29 Population I stars more than 1 kpc from the plane, the W velocity dispersion is 62 ± 8 km s^{-1}, in good agreement with Rodgers' result of 66 km s^{-1} and Stetson's (1983) value of 57 km s^{-1} for high-velocity MS A and F stars at all latitudes. If only the 21 unambiguously main-sequence stars (with gravities higher than 3.9 dex and $\Theta_{\rm eff} > 0.500$) are considered, the W dispersion remains 62 km s^{-1}.

The box area was observed in detail to derive the scale height (see Paper I, § I*d* for discussion of scale heights and velocity dispersions). The sample of stars to 14th magnitude was 98% complete, to a distance limit of around 1600 pc. To that limit, the numbers of Population I stars per 1 kpc^3 at specific Z heights, is plotted as (log density + 10) against Z height in Figure 7. Table 4 lists the numbers of stars, distances, and densities involved in the derivation. Least-squares fits were used to find the slopes and intercepts of the lines used. From Figure 7 it can be seen that the nearby stars have a scale height, β, of 121 pc, in excellent agreement with that expected for MS A stars, of 120 pc (Mihalas and Binney 1981).

It is clear from Figure 7 that the Population I stars further than 1 kpc from the plane are more numerous than would be expected if they were simply the tail of the young disk distribu-

TABLE 4

SCALE HEIGHT DERIVATION FOR SGP BOX AREA

Z (pc)	n	$\log \rho + 10$
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[a]	1	3.31
	2	3.61
1000–1199	4	3.73
1200–1399	2	3.29
1400–1599	4	3.46

[a] This bin divided into two groups: see text for discussion.

tion. One star, in the bin centered at 900 pc, would be expected (in the observed volume) to be a member of the young disk, and was plotted as such. The other stars in that bin are plotted as part of the more distant sequence, for which the scale height was found here to be 977 pc. Freeman (1987) discusses observations of thick disk stars (kinematically and spatially distributed like the A stars) and finds that their measured exponential scale height of 950 pc is consistent with an *in situ* observed and theoretically derived W dispersion of around 40 km s^{-1}.

Utilizing a similar analysis, the velocity dispersion of 62 km s^{-1} found for the A stars indicates an exponential scale height of around 1600 pc, larger than the measured value of 977 pc for the A stars. The sample used to derive the scale height was as complete as possible, but it was not large, and statistical fluctuations may have occurred. For instance, the error in the three most distant bins was about plus or minus two stars, yet the addition of a single star to each of the two furthest bins would increase β to over 2000 pc. At present, it would seem that the scale height of the distant Population I stars is of the order of 1000–1600 pc.

f) Ages

The Revised Yale Isochrones were used to generate isochrones for the range of metallicities described in § II*d*, in the gravity-temperature plane. The isochrones were for ages of up to 2 billion years, in 50 million year increments. Population I stars were plotted relative to isochrones for appropriate metallicities, and their ages to the nearest 50 million years were found. They are listed in Table 3. Errors for stars with $\Theta_{\rm eff}$ 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 stars with available age data were plotted in two groups for comparison. One group was the disk Population I stars up to 500 pc from the plane (including some that were classified Population I on the basis of photometry, not spectra, so they did not appear in Fig. 4), and the other group was the Population I stars more than 1 kpc from the disk. The stars within 500 pc were found to have been formed randomly, as expected, at all ages from around 2 billion years ago to the present time. Figure 8*a* shows their distribution in the gravity-temperature plane (relative to solar abundance isochrones for illustrative purposes).

The distribution of Population I stars further than 1 kpc from the disk, plotted in the same plane, is shown in Figure 8*b*. A distinct and significant difference from Figure 8*a* is apparent; *all of the distant Population I A stars are younger than 650 million years.* This is most unlikely to be a selection effect from, for instance, a magnitude or spectral type cutoff in the sample, as the empty section of Figure 8*b* is where would be found evolving A stars of up to 1 magnitude *brighter* than the observed MS stars in the same color range.

For example, a late-type 14th magnitude MS A star of absolute magnitude 2.7 can be seen to 1800 pc from the plane, whereas to the same limit an evolving late A star of absolute magnitude 1.7 can be seen to 2900 pc. The ratio of the volumes in which these stars may be sampled is 1 to 4; that is, distant Population I A stars *older* than 650 million years had *4 times* the probability of being observed than younger, lower luminosity stars of the same color, yet not one was found. The nearby disk stars (Fig. 8*a*) were observed and reduced in the same way as the distant A stars, and there are substantial numbers of them at evolved luminosities and greater ages. Figure 9 illustrates the relative percentage of stars in 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 Population I A stars have a restricted and significant range of ages. They appear to be the result of a discrete and relatively recent event which initiated a burst of high-velocity star formation at around 6.5×10^8 yr ago.

III. DISCUSSION

a) Other Types of Stars

Hartkopf and Yoss (1982, hereafter HY) report a kinematic and abundance survey of G and K giants at the Galactic Poles. Out of 83 giants at distances of 1–5 kpc from the plane, 31% are metal-rich, with abundances between −0.5 and 0.0 dex. HY suggest that their metal-rich giants may be recent descendants of the high-velocity A stars. For several reasons this hypothesis is not supported by the present study. The W velocity dispersion of the SGP A stars is 62 km s^{-1}, but the velocities of the K giants are significantly lower. For 29 HY stars at distances greater than 1 kpc and metallicities greater than −0.5, the velocity dispersion is 31 km s^{-1}. If only the 14 stars above 1.5 kpc are considered (in case contamination of the sample with old disk stars has occurred) the dispersion is only 29 km s^{-1}. Since the A stars are so young, their descendants must still exhibit essentially the same kinematic and spatial properties. There is thus almost no possibility that the K giants and the A stars have been drawn from the same population.

A second problem is that the density of K giants is much higher than that of the A stars, if they were to be members of a coeval population. The K giant sample was drawn from many surveys, of varying completeness limits. To obtain an estimate of the density of metal-rich distant K giants, one area was considered that was completely observed to 13.5 mag (Bok regions I, II, and III). HY found 16 stars in 8.4 deg^2, 1.90 stars per square degree. The number of A stars found was 29 in 218 deg^2. Including the estimated nine other stars of the same type yet to be found in the same field, this is equal to 0.17 A stars per square degree. (K giants are slightly more luminous than A dwarfs, but A star observations went to half a magnitude fainter, so both groups have been sampled to approximately the same distance.) For a coeval group of stars, the relative numbers expected on the red giant branch, compared to those still on the early MS, may be estimated from the Hyades (600 to 800 million years old), for which Mermilliod (1981) plotted the color-magnitude array. For 81 Hyades stars still on the A MS, only 18 stars are observed on the RGB, a ratio of 4.5 A stars to K giants. However, the ratio of SGP A stars to SGP K giants is 0.089, so that 50 times more K giants were observed than would be expected if the A stars and K giants were from a coeval population. It would seem more likely that the K giants are from the old disk or thick disk, and that very few descendants of the high-velocity stars have yet evolved to the giant branch.

It is useful now to examine the possible relationship of blue stragglers (§ I*a*) to the high-velocity A stars in the light of the present results. Rotational velocities appear to be an inconclusive discriminant. Surface gravity measurements show that the majority of the A stars have normal MS gravities, rather than the lower values found for blue stragglers by Twarog and Tyson (1985), but again, not enough is known about the properties of a large sample of blue stragglers for this to be definitive.

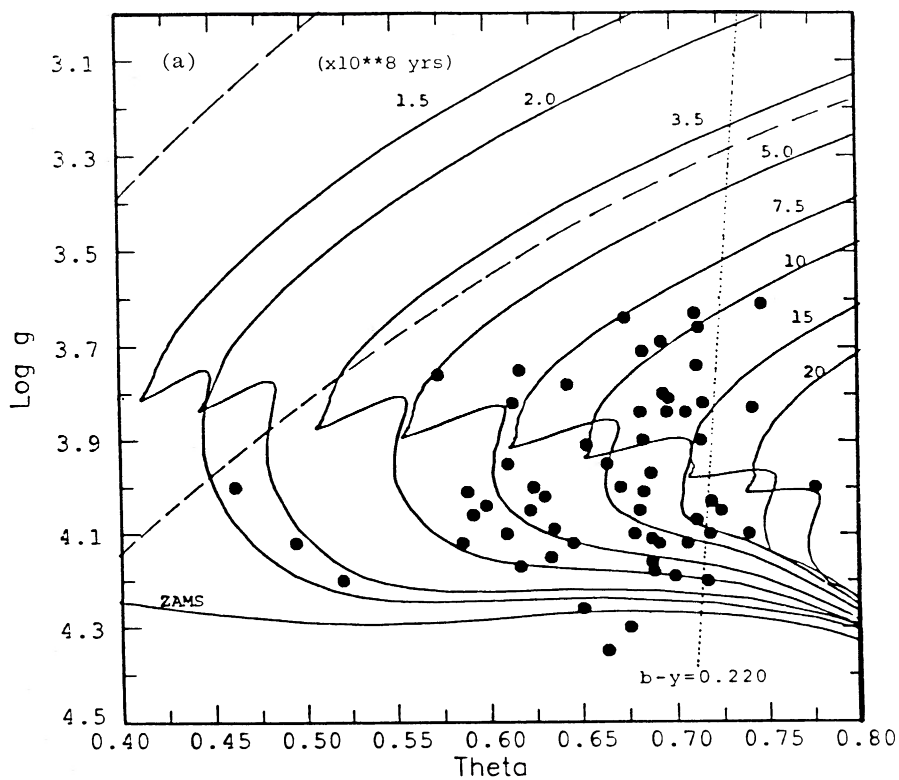

FIG. 8*a*

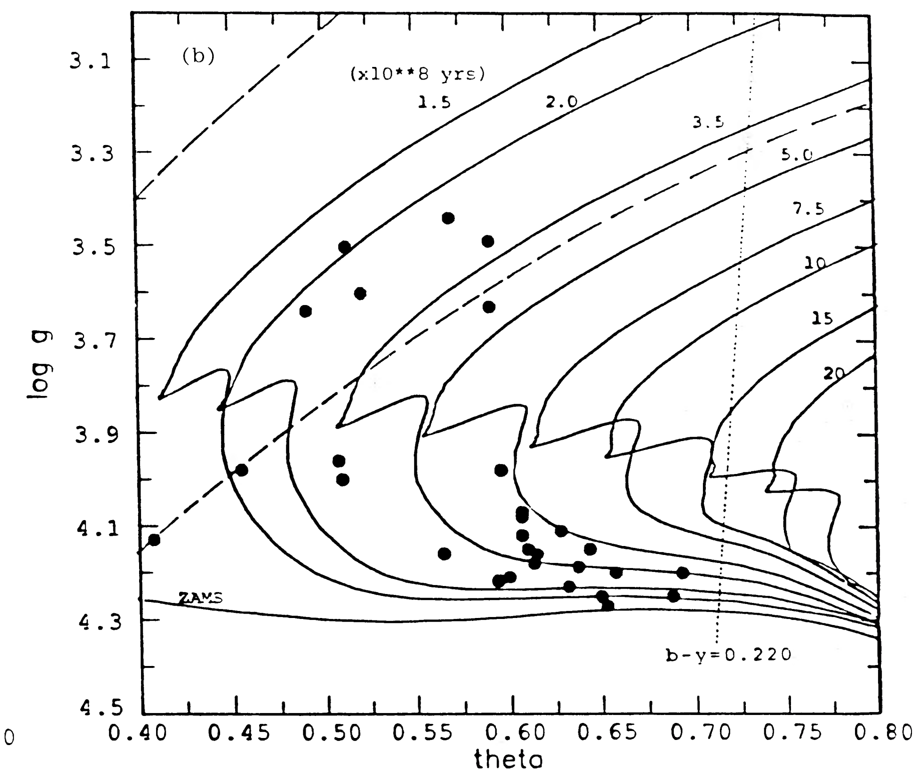

FIG. 8*b*

FIG. 8.—(*a*) 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 yr. 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 catalog]. (*b*) As for (*a*) for 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. All of these stars are younger than 650 million years.

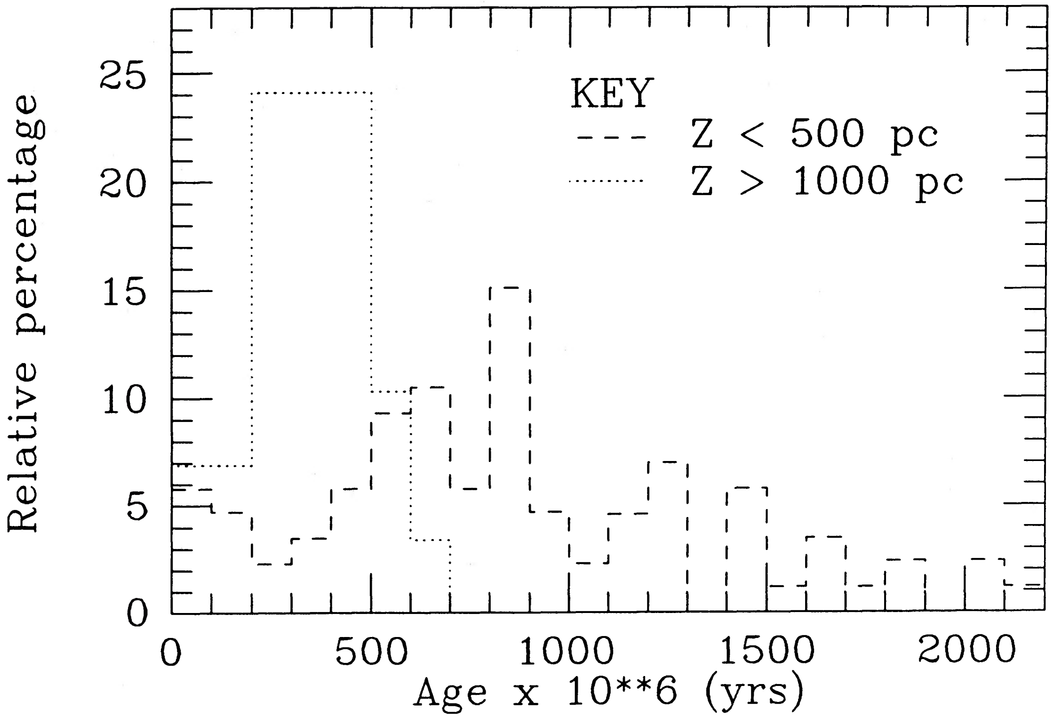

FIG. 9.—Relative percentage of the members of the two groups of Population I stars (at less than 500 pc, and at greater than 1000 pc from the plane), plotted against the ages of the stars.

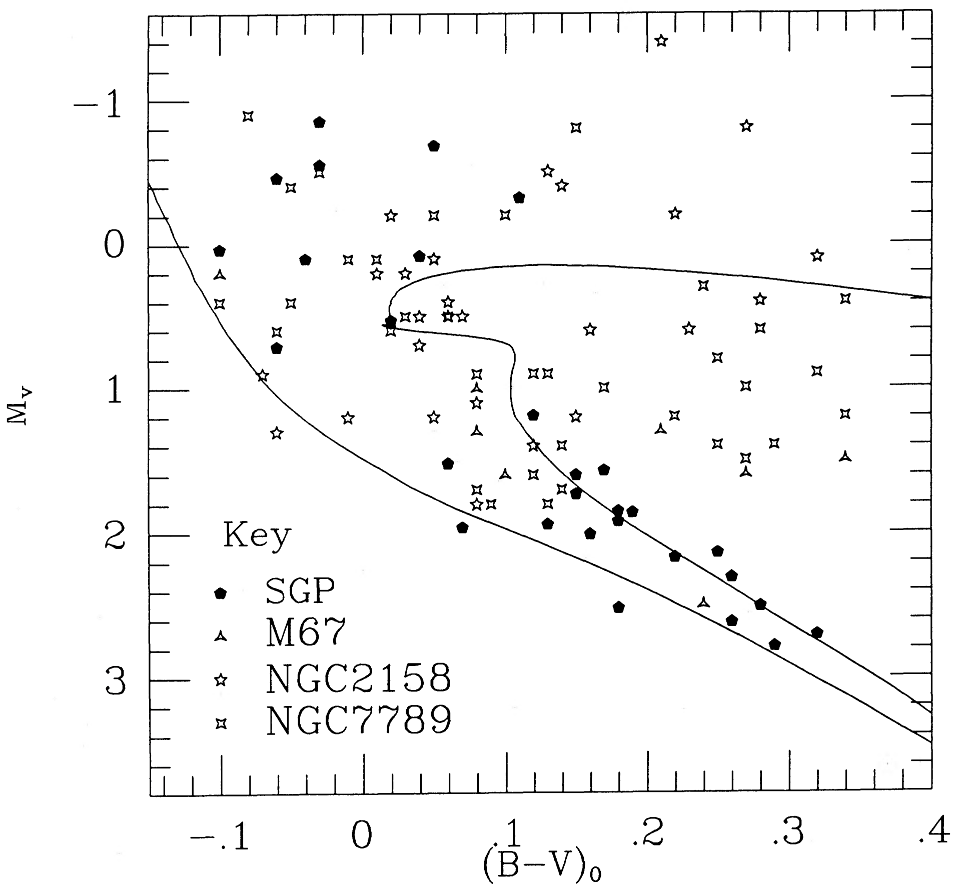

FIG. 10.—Location in a color-magnitude diagram of the young distant SGP A stars compared to some blue stragglers in open clusters. NGC 7789 is 1.6×10^9 yr old, NGC 2158 is 1.4×10^9 yr old, and M67 is 3.2×10^9 yr old. Data points are from Hagen (1970). It is clear from this figure that, unlike the SGP A stars, blue stragglers are just as likely to be found redward of a 5×10^8 yr isochrone as bluewards.

A more clearcut difficulty with the blue straggler theory is the result that the A stars have a distinct age limit, that is, they occupy a specific and restricted region of the H-R diagram. As shown in Figure 8*a*, randomly formed disk A stars (hence their blue straggler descendants) have no such limitation. They appear at all A star ages or, in the case of blue stragglers, apparent ages. It would be most unlikely that the gravity-temperature distribution of a set of blue stragglers, formed randomly and accumulated over long periods of time, would fortuitously mimic that of a group of young coeval stars. To illustrate this difficulty, Figure 10 shows the positions of some known blue stragglers, and those of the high-velocity A stars, in the M_v–$(B-V)_0$ plane.

Another problem with the theory is indicated by Shields and Twarogs's (1987) interesting finding that the largest contributor to the blue straggler population for a given temperature bin is the disk population only slightly older than the MS lifetime of a normal star of that temperature. They give an example of blue stragglers, at the same temperature as stars with MS lifetimes of 2×10^9 yr (the upper age limit of disk stars in this investigation), deriving from a disk population formed 3 to 5×10^9 yr ago, with the scale height and kinematic characteristics of the disk at that period. Yet the *W* velocity dispersion of a 5×10^9 yr old disk population, undergoing normal dispersive processes, would grow to only 21 km s^{-1} (Mihalas and Binney 1981). The extreme tail of such a population would, of course, show a greater *W* value if measured only at large *Z* distances, but even thick disk stars (with a larger scale height than old disk stars) sampled at the same *Z* distances as the A stars, have a *W* velocity dispersion of only 40 km s^{-1}, in contrast to the A star dispersion of 62 km s^{-1}.

It is possible that there are unrecognized selection effects in the kinematic and gravity-temperature-age parameters found here for the high-velocity A stars. If this were to be so, the above difficulties with the blue straggler theory would then not hold. The abundance range of the A stars is very like that of the old disk, and the percentage of A stars above 1 kpc is consistent with Shields and Twarogs's models, so the theory must remain under some consideration, at least until much more is known about the properties of blue stragglers. However, on the basis of the results of this study, it is difficult at present to support the hypothesis that the A stars are misidentified blue stragglers.

It seems unlikely that runaway OB stars have any connection to the A stars. Many have trajectories that may be traced back to young star clusters, so the majority are probably well accounted for by the cluster binary interaction mechanism discussed by Gies and Bolton (1986). If the acceleration of the A stars had occurred in this way, again the mechanism would be expected to operate stochastically. As with blue stragglers, it is difficult then to account for the restricted age range of the A stars. However, *some* high-velocity OB stars may well be from the same population as the A stars. Any OB stars formed in an event that occurred 650 million years ago would naturally have evolved off the MS by now. But it seems from Figure 9 that star formation has continued on a lesser scale since the initial event, so that some high-latitude B stars may be recently formed members of the A star cohort. At present it would be most difficult to distinguish between B stars accelerated by cluster binary interactions, and any B stars that might be related to the A stars.

An interesting problem associated with a few OB stars that are seen at great distances from the Galactic plane is that their evolutionary MS lifetimes are shorter than their travel times, if they had been truly ejected from the disk. 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. A simpler alternative explanation is that they are indeed genuine young disk OB stars, accelerated by cluster binary interactions (hence their normal abundances), but that it is *these* stars for which the blue straggler hypothesis might be invoked.

Mermilliod (1982) shows that blue stragglers are a common occurrence in almost all young Galactic clusters. The Pleiades and NGC 2516 groups (with MS turnoff spectral type of B7–B8) contain blue stragglers of type B2–B3 IVe, which would normally have MS lifetimes of only $\sim 10^7$ yr. Abt (1985) shows that these blue stragglers are actually as old ($\sim 10^8$ yr) as their cluster turnoff ages. So, even though the blue straggler theory is not supported in the case of the high-velocity A stars, it does provide a simple explanation for the existence of a small number of OB stars further from the plane than could be reached in a "normal" MS lifetime.

b) Hypotheses

This study finds that the ages of the distant A stars are all less than 6.5×10^8 yr, their abundances are from -0.5 dex to 0.0 dex, and their *W* velocity dispersion is 62 km s^{-1}. They have a scale height of 1000 to 1600 pc. Any theory of their origin must account for *all* of these factors. In § I*a* some possible sources of the A stars were suggested, as follows:

1. They are misidentified abnormal or evolved stars.
2. They are normal young disk stars, formed or ejected by some random acceleration process.
3. They are the consequences of the merger of a satellite galaxy with the Milky Way.

Category (1) hypotheses have been previously discussed. The A stars have MS gravities, abundances, and rotational velocities, and are clearly not HB stars. They are also unlikely to be misidentified blue stragglers.

Category (2) hypotheses are also unsupported. They demand that the stars be of at least normal A star metallicity, and in the case of supernova sources, enhanced abundances might be expected. Yet the A stars have metallicities generally lower than normal, from one-third solar to solar abundance, a range unique for young stars. It might be suggested that galactic fountain material could originate from anticenter regions with a generally lower abundance than the solar neighborhood, but it could also be argued that matter might be statistically as likely to originate from more metal-rich central Galactic regions. In any case, the major problem with the category (2) theories remains the age distribution of the high-velocity A stars. All the proposed acceleration processes would be expected to occur stochastically; there is no plausible reason why any of them would suddenly start operating at only 6.5×10^8 yr ago, yet be quite ineffective for the whole of the previous period of up to 20×10^8 yr ago.

It would appear, then, that none of the alternative hypotheses to the category (3) proposal is supported by the data. The young, high-velocity A stars are unlike any other stellar population yet observed in the Galaxy. The parameters found here are in good agreement with those found by RHS, and their suggestion of a merger remains plausible.

It is interesting to consider some of the implications if such an event has actually occurred within recent Galactic history. If the high-velocity A stars really are the result of a mixture of infalling gas with disk gas, then what quantity of hydrogen would be needed to form their observed density? The amount calculated depends upon whether or not the density of stars in the observed SGP region is typical of the density over the whole Galaxy. If the proposed merger continued for longer than a Galactic revolution (around 2.4×10^8 yr at the Sun) then gas would have been accreted over large areas of the rotating disk. Models by Quinn and Goodman (1986) show that infalling satellites may take of the order of 10^9–10^{10} yr to interact with and finally merge with a galaxy. If the high-velocity stars had been formed from a small amount of matter in a limited region, however, the present volume in which they are distributed would also be smaller, so they would then be merely a minor stellar stream passing through our part of the Galaxy. (In that case the problem might arise of why we should happen to be in such a privileged position and epoch to be able to observe an entirely unique group of stars.)

To obtain some idea of the possible extent of the high-velocity population in directions other than perpendicular to the plane, the sample of stars from Pier (1982, 1983) was examined in detail. Pier (1983, his Fig. 12) had assumed that $D(0.80)$ values greater than 30 Å imply high (MS) gravities, and that values less than 30 Å imply low (HB) gravities for the whole $B-V$ range for A stars. In fact, it may be shown from Kurucz (1979) Hδ line models, that at HB gravities (≤ 3.6 dex), $D(0.80)$ falls from 30 Å at $B-V = 0.09$ to as narrow as 12 Å at $B-V = 0.30$. Hence, some late A stars that Pier classified as HB are actually at MS gravities, and from Pier's K line calibration, many of these stars also have abundances greater than -0.5. Around 17 of Pier's stars more than 1 kpc from the plane have either near MS metallicities and surface gravities, or are low calcium abundance Am-type stars also with MS gravities (Pier showed that the Am-type stars had high abundances of metals other than calcium), or have MS abundances and low gravities (so are likely to be young subgiants). Table 5 lists data for these stars, excluding SGP A Stars that have already appeared in this paper.

Figure 11 shows the Pier main-sequence stars in the X-Z plane with radial velocity vectors. It appears that, along several lines of sight in different Galactic directions, distant young high-velocity stars occur with both positive and negative radial velocities, suggesting that overall they do *not* have a common streaming motion. In addition, stars more than 1 kpc from the plane occur with X positions of up to 5.5 kpc from the solar neighborhood in the direction of the Galactic center, and over 2 kpc away in the anticenter direction. Hence young high-velocity stars may be found from at least 3.5–11 kpc in Galactic radius (for a solar radius of 9 kpc). These are minimum values, given that the stars were drawn from a magnitude- and direction-limited sample. This would also suggest that the young high-velocity stars are not from a single stream, but are reasonably well distributed over a large part of the Galaxy.

Assuming that this is so, and using parameters from the SGP stars, their surface density may be found from

$$\Sigma_s = 2D_0 \beta , \qquad (6)$$

where D_0 is the local density at the disk and β is the scale height (Mihalas and Binney 1981). For $D_0 = 1.14 \times 10^{-6}$ stars pc^{-3} (from the y-intercept of Fig. 7), $\beta \approx 1300$ pc, and the

TABLE 5

POSSIBLE POPULATION I A STARS MORE THAN 1 KILOPARSEC FROM THE DISK, FROM PIER 1983

Star (CS 22/)	RV (km s^{-1})	W(K) (Å)	D(0.80) (Å)	log g[a]	$B-V$	m_V	M_V[b]	R[c] (pc)	X (pc)	Y (pc)	Z (pc)
172 12	80	4.5	22	4.0–4.5	0.28	13.74	2.63	1667	1013	−258	−1299
184-13	2	4.6	23	4.0–4.5	0.25	13.07	2.44	1337	648	−49	−1337
184-28[d]	136	1.7	28	4.0–4.5	0.20	13.70	2.10	2089	1086	−61	−1783
875-13	−133	3.1	22	~4.0	0.23	14.83	2.30	3206	−1726	42	−2701
875-23	108	0.4[e]	27	~4.0	−0.05	15.50	0.36	10666	−5587	−156	−9085
875-27	7	2.7	13	~3.0	0.09	14.47	1.40	4111	−2178	15	−3486
881-34	−66	0.9	27	3.0–3.5	−0.01	15.27	0.70	8204	−4853	−203	−6612
936-239	55	0.9	28	~4.0	−0.04	13.40	0.46	3873	−3719	169	−1061
935-250	32	1.7	29	3.0–3.5	0.06	14.66	1.20	4920	−4731	273	−1323
941-39[d]	41	1.1	28	4.0–4.5	0.24	15.68	2.37	4592	−1361	182	−4382
942-22	5	1.2	26	3.0–3.5	0.03	15.81	1.00	9162	516	478	−9135
942-26[d]	−28	1.1	38	4.0–4.5	0.18	14.38	1.98	3020	154	82	−3015
946-8[d]	32	1.6	33	4.0–4.5	0.21	12.79	2.18	1324	231	18	−1303
946-15	−139	0.5[e]	28	~4.0	−0.04	15.59	0.46	10617	2108	714	−10381
946-19[d]	25	1.4	34	~4.0	0.09	13.45	1.40	2570	410	216	−2528
949-4[d]	−24	1.8	25	4.0–4.5	0.24	13.09	2.37	1393	−248	682	−1189
963-18[d]	−34	1.3	33	4.0–4.5	0.23	13.64	2.30	1854	1132	−121	−1465

[a] Surface gravities are approximate only, because c_1 indices were not available for detailed derivations. Four of the stars have low gravities, but they also have abundances that are too high for HB stars. Star 875-27 in particular, has exactly solar abundance, desite its low gravity. As discussed in § II*d* for a few of the SGP stars, they are probably young subgiants at a lower gravity phase, during evolution from the MS to the base of the RGB.

[b] Absolute magnitudes from calibrations in Mihalas and Binney 1981 and Straižys and Kuriliene 1981, for main-sequence dwarfs. Stars with lower gravities will have brighter absolute magnitudes and greater distances, but these were not calculated as data are not of high accuracy. Thus distances in this table are the most conservative estimates, for the minimum possible absolute magnitudes.

[c] Distance from Sun.

[d] Star identified by Pier 1983 as Am (low calcium but high abundance in other metals).

[e] Star has small W(K), but large radial velocity. Pier identified and listed all occurrences of (low radial velocity) interstellar calcium lines, offset from small Ca II K lines in the spectra of high radial velocity stars. Hence if an interstellar component had been present in this spectrum, it would have been apparent and displaced from the measured K line, so it may be assumed that this W(K) is uncontaminated by interstellar calcium.

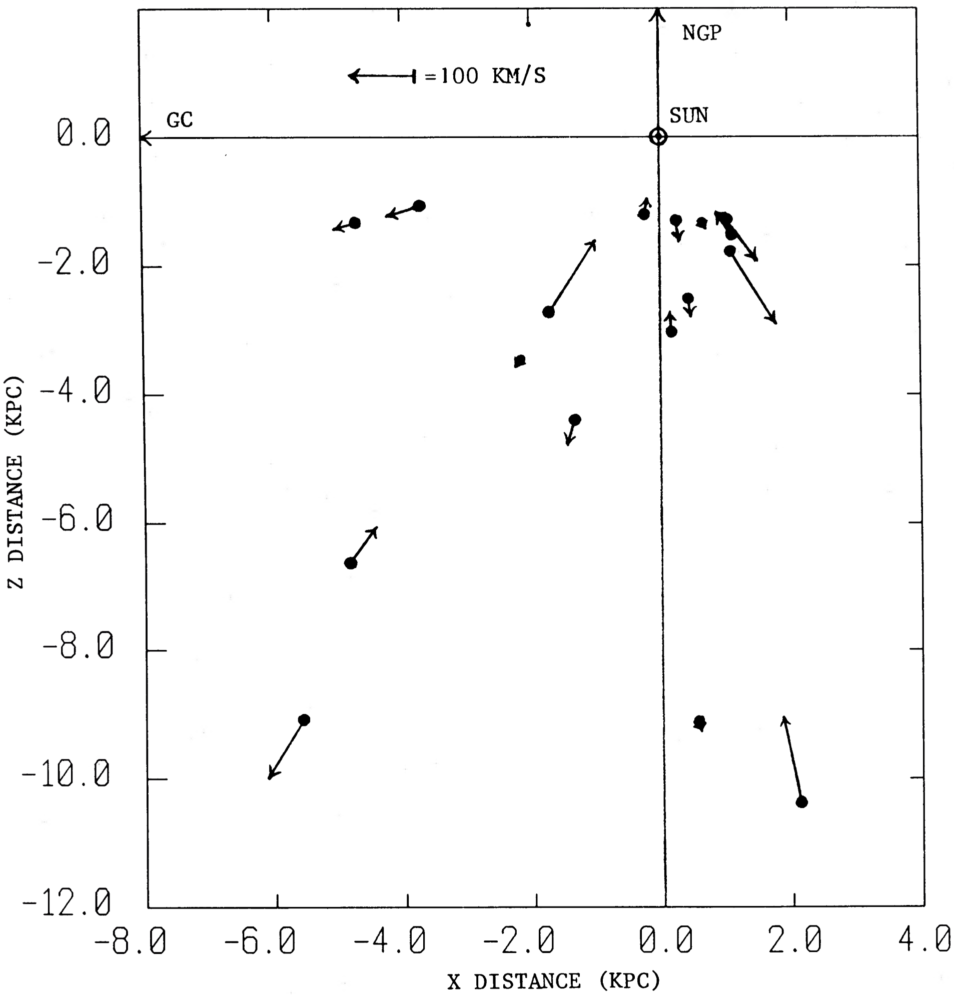

FIG. 11.—Positions of the Pier Population I A stars in the X-Z plane. (X is positive toward the Galactic anticenter, and Z is positive toward the north Galactic pole. The Y positions of the stars are close to a line from the Galactic center to the anticenter.) Heliocentric radial velocities of the Pier stars are indicated by vectors (a vector length of 1 kpc is equivalent to 100 km s^{-1} in radial velocity).

mean A star mass of $2m_\odot$, the surface mass density is 5.9 $\times 10^{-3} m_\odot$ pc^{-2}. The initial mass function, appropriate for an unevolved burst of star formation (Allen 1973), indicates that around 8 times the mass that has been observed in A stars will have gone into lower mass stars.

An annulus of the disk from 3.5 to 11 kpc in radius (equivalent to only one-quarter of the area of a 21 kpc radius Galactic disk) could contain around $1.6 \times 10^7 m_\odot$ of high-velocity stars. From the merger hypothesis around half of the gas content of the stars would be contributed by the disk, so only $8 \times 10^6 m_\odot$ might have come from infalling matter. The star formation rate from infall (Tenorio-Tagle 1981) is around 1% efficiency, so that $8 \times 10^8 m_\odot$ of gas needs to be accreted to form the estimated high-velocity star density. Dopita *et al.* (1985) find a mass of $9 \times 10^8 m_\odot$ for the SMC, with a gas content of 24%–28%; and Meatheringham and Dopita (1986) estimate the LMC to be $4 \times 10^9 m_\odot$, with a (10%–12%) gas content of around $4 \times 10^8 m_\odot$.

Given the not implausible premise that the high-velocity stars are fairly well distributed throughout, at minimum, one-quarter of the Galaxy, the quantity of accreted gas needed to form them is equivalent to twice the total content of a galaxy the size of the LMC. A varying mixture of disk gas with gas of the metallicity of the LMC (around -0.5 dex) would yield stars with the observed abundance range, while a satellite galaxy would be a suitable reservoir of the quantity of matter required to form the high-velocity stars in a short period of time. Since there is no other hypothesis presently available which is consistent with the data, this possibility demands further rigorous examination. Predictions of the consequences of such an event might generate a useful framework in which the theory could be tested further. It is fortunate that there has been substantial research in recent years into topics such as satellite accretion, thick disks, and galactic formation, so that the RHS hypothesis is not as surprising as it originally may have appeared.

It has been suggested (see § I*a*) that the thick disk resulted from accretion in the early stages of Galactic formation. If an accretion event also initiated high-velocity A star formation, it then follows that the A stars could be described as a young component of the thick disk; however, it might be conceptually more correct to classify them separately from the thick disk, because the proposed accretions would have occurred under very different evolutionary circumstances. It seems important to stress, however, given the kinematic similarities and the overlap with the metal-weak end of the A star abundance range, that low-mass thick disk MS stars would be most difficult to distinguish from low-mass MS members of the young high-velocity population: a clear evolutionary limitation, such as the short main-sequence lifetimes of early-type stars, is needed to be able to discriminate between them. However, only a very small proportion of the A star cohort would have had time to evolve to the red giant branch or later stages, so that thick disk *giants* should be uncontaminated with the recently formed stars.

Low-mass members of the young high-velocity population may also be overrepresented in *kinematically* selected surveys. This might be the reason why Sandage and Fouts's (1987) sample of "new subdwarfs" contains so many stars, identified by them as thick disk, which have abundances generally higher than the thick disk range [0.16–0.09 in $\delta(U-B)_{0.6}$]. Around one-third of their thick disk group (see their Fig. 16) and even some of their halo group (their Fig. 17) have both large space motions and $\delta(U-B)_{0.6}$ from 0.09 to less than 0.0 (from half Population I to Population I values), too high for the thick disk, but similar to the A star abundance range.

IV. SUMMARY

The findings of this work are the following:

1. Around one half of the A stars at distances between 1 and 4 kpc from the plane are Population I, MS stars.
2. They are all aged less than 6.5×10^8 yr, in contrast to a comparison group of disk A stars with stochastic ages of formation of up to 20×10^8 yr. They appear to be the consequences of a temporally distinct and nonrandom event.
3. In agreement with the result of RHS, their range of calcium abundance is found to be from around -0.5 dex to 0.0 dex.
4. Their W velocity dispersion was found to be 62 km s^{-1}, again in good agreement with RHS.
5. They are observed to be at distances of up to 11 kpc from the Galactic plane. The majority of stars in this sample are at less than 3 kpc distance because of the selection effect imposed by the magnitude limit of the original survey.
6. The exponential scale height for the young stars at distances greater than 1 kpc is from 1000 to 16000 pc.
7. It is shown that the young high-velocity A stars are not HB stars, and, due to their unique age distribution, they are most unlikely to be blue stragglers or normal disk stars accelerated out of the plane.
8. It is suggested that at around 6.5×10^8 yr ago, a major source of relatively low abundance hydrogen merged at high velocities with the disk of the Milky Way, forming stars that do not partake of the usual age-abundance-kinematics relationships shown by other Galactic stellar groupings.

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