A 325 SQUARE DEGREE SURVEY OF B-TYPE STARS AT HIGH GALACTIC LATITUDES

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ABSTRACT

Final results from model atmosphere analyses of all blue stars in a ~ 325 square degree region of the Galactic halo are presented. A kinematic analysis reveals the presence of one star which cannot have been ejected from the disk according to contemporary theories. Ten other objects have, however, evolutionary times consistent with classification as disk runaway stars. Our results therefore imply the existence of some 200 stars in the Galaxy unexplainable in terms of disk ejection models, and set a lower limit of 10,000 runaway halo B-type stars.

Subject headings: stars: abundances — stars: atmospheres — stars: distances — stars: early-type

1. INTRODUCTION

Since the first photographic survey of the Galactic halo (Humason & Zwicky 1947), it has been known that hot main-sequence stars exist at high Galactic latitudes. Blaauw (1961) proposed that these objects were runaway stars, ejected from binary systems following a supernova explosion. More recently, models that envisage ejection occurring from the cores of open clusters have been developed (Leonard & Duncan 1988; Clarke & Pringle 1992). There remains, however, some faint blue stars (Greenstein & Sargent 1974; Keenan, Dufton, & McKeith 1982; Tobin 1984; Kilkenny et al. 1991; Conlon et al. 1992), whose apparent magnitudes imply they are at distances (z) from the plane (e.g., PG 0832 + 676 at z = 18 kpc; Brown et al. 1989) and which cannot be explained by simple disk ejection models. At least three scenarios may explain these objects. First, they may be evolved and subluminous, with chemical compositions that mimic Population I stars (Carrasco, Aguilar, & Recillas-Cruz 1982). This would appear to be incompatible with model atmosphere analyses of high resolution, high signal-to-noise spectra (Conlon et al. 1992) which have shown them to be distinct from subdwarfs as well as post-AGB objects (McCausland et al. 1992). Secondly, they may have been ejected from the plane. In particular Leonard & Hills (1992) have proposed a modified mechanism involving the merging of a condensed star with the runaway B star. Finally, stars may form away from the Galactic disk, and Dyson & Hartquist (1983) have developed such a model based on collisions between high-velocity clouds (HVC) in the halo.

Recently, Hambly et al. (1993, hereafter Paper I) presented results for blue objects in the magnitude range 12 ≤ V ≤ 16 in the 325 square degree region b = 45°−65°; l = 285°−355°. Here we supplement these data with observations of brighter targets in the same region to estimate the space density of B-type stars in the halo.

2. OBSERVATIONS AND DATA REDUCTION

High resolution optical stellar spectra of 27 UKST bright survey stars (V < 12) identified as potential OB-type objects from UBV colors (Mitchell, Miller, & Boyle 1990) were obtained during an observing run between 1992 April 15 and 22 at the Northern Hemisphere Observatory, La Palma. Twenty-four of these objects were observed using the Richardson-Brealey spectrograph in conjunction with an EEV5 GEC CCD on the Jacobus Kapteyn Telescope (JKT), while the remaining three fainter stars were recorded with the ISIS double spectograph and a large format TEK CCD mounted on the William Herschel Telescope (WHT). Both instrumental setups provided dispersions of approximately 0.4 Å pixel⁻¹. Continuous spectral coverage from 3850−4500 Å was achieved on the JKT with three wavelength settings, while the WHT observations covered a more restricted wavelength interval, 4250−4600 Å. Individual stellar exposures were normally limited to 10 minutes to minimize contamination from cosmic rays, but total observing times per target were optimized to provide signal-to-noise ratios of greater than 70, (which in general required one JKT exposure on V < 9 targets and two integrations for the fainter stars). CuAr arc images were alternated with stellar frames and tungsten continuum lamp flat-field exposures were recorded at the end of each night.

Only a brief outline of the reduction procedures employed will be given here; for further details see, for example, Paper I. The CCD images were initially processed using the STARLINK package FIGARO (Shortridge 1991). Stellar images were bias subtracted before normalization by co-added nightly flat-fields. Cosmic-ray cleaning, sky subtraction, and extraction of star frames were then performed prior to wavelength calibration with contiguous CuAr arcs.

The stellar spectra were subsequently analyzed using the STARLINK package DIPS0 (Howarth & Murray 1988). Initial inspection of the stellar spectra revealed 21 of our stars to be of spectral type A or later, and these objects will not be discussed further. Observational details for the remaining 6 early-type candidates are presented in Table 1. The spectra were normalized by fitting low-order polynomials and the metal and non-diffuse helium line equivalent widths were then estimated using nonlinear least-squares fitting techniques (see Paper I for details). Equivalent widths are not reproduced here, but are available on request from the authors. Stellar radial velocities were deduced from the line center estimates for the least-square fits and are listed in Table 2 as $V_{hel}$. Also tabulated
are the velocities relative to the stars' own local standard of rest \( (V_{\text{LSR}}) \), based on its implied distance (see § 3.1) and the Galactic rotation curve of Fich, Blitz, & Stark (1989). Stellar projected rotational velocities were also estimated (and listed in Table 2) by degrading synthesized spectra until they matched the observations (see Little et al. 1994 for details).

3. METHOD OF ANALYSIS AND RESULTS

3.1. Stellar Analysis

Analyses of the stellar spectra were based upon the line blanketed model atmospheres of Kurucz (1991). Local thermodynamic equilibrium (LTE) was assumed for line formation calculations, although account has been taken of the non-LTE contribution to silicon line strengths (Lennon et al. 1986). Further details can be found in, for example, Rolleston et al. (1993).

Initial estimates of the effective temperatures were normally obtained from photometric colors. Table 1 lists the color systems used, where the calibration of Lester, Gray, & Kurucz (1986) was applied to the reddening free indices of Strömgren, and that of Napiwotzki, Schönbberger, & Wenske (1993) used for \( UBV \) colors. Corresponding gravity estimates were then obtained from the \( H \gamma \) profiles. Improved atmospheric parameters were then deduced from either the \( ubvy \) photometry and/or the \( \text{Si} \, ii/\text{Si} \, m/\text{Si} \, iv \) ionization equilibria (for effective temperature) and the Balmer line-profiles (for gravity). Figure 1 shows a typical fit for \( H \gamma \) in the spectrum of HD 121968. For HD 118246 and UKST 1315+002, neither \( ubvy \) photometry nor \( \text{Si} \, ii/\text{Si} \, m \) line strengths (due to a large projected rotational velocity for the former and a low temperature for the latter) were available. For these stars the \( \text{He} \, i \) lines were used as an additional temperature indicator, assuming the photospheric helium abundance to be normal.

The adopted effective temperatures \( (T_{\text{eff}}) \) and logarithmic gravities \( (\log g) \) are listed in Table 2, and are consistent with stars lying on or near the hydrogen-burning main sequence. Hence a microturbulent velocity of 5 km s\(^{-1}\) used for the silicon ionization equilibria, and in the subsequent abundance analyses, should be appropriate (see, for example, Rolleston et al. 1993, and references therein). Table 2 also contains a estimate of the interstellar reddening \( E(B-V) \) toward each of the program stars based on the intrinsic \( (B-V)_0 \) calibration of Deutschman, Davies, & Schild (1976).

Errors in fitting the observed Balmer line profiles imply an uncertainty in \( \log g \) of \( \pm 0.2 \) dex. For the effective temperatures, an error estimates is difficult to evaluate, but we believe that a typical uncertainty of \( \pm 1000 \) K is reasonable. Tabulated in Table 3 are the stellar atmospheric abundances (on a logarithmic scale with hydrogen equal to 12) where the quoted errors refer to the standard deviation in the mean (if the spectrum contained sufficient lines for a given element). Hence they do not include systematic effects due to errors in the atmospheric parameters, which on the basis of the values adopted above would lead to an overall uncertainty of typically less than \( \pm 0.4 \) dex.

Presented in Table 4 are the estimated masses and calculated \( z \)-distances for each star, assuming them to be young objects on or near the hydrogen-burning main sequence. The former were deduced from the evolutionary tracks of Maeder & Meynet (1988), (which, at the suggestion of the referee, were checked with the more recent tracks of Schaller et al. 1992 and found to be in good agreement), \( z \)-distances were calculated using the bolometric magnitudes from the tracks, the bolometric corrections of Kurucz (1979), and the reddening \( E(B-V) \), apparent \( V \)-magnitude and Galactic latitude. Typical uncertainties of 10% are implied for these estimates.

3.2. Individual Stars

Below we discuss the model atmosphere analysis for each star:

**HD 121968.**—The effective temperature, presented in Table 2, is based primarily on the silicon ionization equilibria, while a Population I stellar chemical correction is found (see Table 3). For this star, Conlon et al. (1992) have previously analyzed

<table>
<thead>
<tr>
<th>Star</th>
<th>( T_{\text{eff}} ) (K)</th>
<th>( \log g )</th>
<th>Spectral Type</th>
<th>( E(B-V) )</th>
<th>( V_{\text{hel}} ) ( (\text{km s}^{-1}) )</th>
<th>( V_{\text{mic}} ) ( (\text{km s}^{-1}) )</th>
<th>( V \sin i ) ( (\text{km s}^{-1}) )</th>
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<tr>
<td>HD 121968</td>
<td>25000</td>
<td>4.0</td>
<td>B1 V</td>
<td>0.05</td>
<td>50 ( \pm 30 )</td>
<td>64 ( \pm 30 )</td>
<td>160</td>
</tr>
<tr>
<td>BD +02 2711</td>
<td>19000</td>
<td>4.3</td>
<td>B4 V</td>
<td>0.03</td>
<td>-22 ( \pm 5 )</td>
<td>-18 ( \pm 5 )</td>
<td>35</td>
</tr>
<tr>
<td>HD 120086</td>
<td>23000</td>
<td>4.2</td>
<td>B2 V</td>
<td>0.03</td>
<td>29 ( \pm 5 )</td>
<td>32 ( \pm 5 )</td>
<td>100</td>
</tr>
<tr>
<td>HD 118246</td>
<td>18000</td>
<td>3.5</td>
<td>B4 V</td>
<td>0.04</td>
<td>-10 ( \pm 20 )</td>
<td>-3 ( \pm 20 )</td>
<td>270</td>
</tr>
<tr>
<td>UKST 1315+002</td>
<td>13000</td>
<td>3.7</td>
<td>B7 V</td>
<td>0.03</td>
<td>30 ( \pm 20 )</td>
<td>40 ( \pm 20 )</td>
<td>280</td>
</tr>
<tr>
<td>HD 129956</td>
<td>11500</td>
<td>3.5</td>
<td>B9 V</td>
<td>0.05</td>
<td>9 ( \pm 15 )</td>
<td>9 ( \pm 15 )</td>
<td>90</td>
</tr>
</tbody>
</table>
high-resolution spectra, recorded with an IPCS. The limitations of the signal-to-noise achievable with this detector (as compared with a CCD used for the current observations) combined with the relatively large \( \sin i \) (\( \approx 160 \text{ km s}^{-1} \)) of the star, prevented detection of absorption from elements other than hydrogen and helium. Hence their effective temperature of 22,000 K was estimated from \( u \beta u \) photometry. We notice that adopting a temperature of 22,000 K would result in helium and carbon underabundances in our observations, and nitrogen and oxygen overabundances. Although we believe that the atmospheric parameters presented here should be preferred, the kinematical analysis of Conlon et al. remain similar to ours and confirm our conclusion (see § 3.3) that HD 121968 could not have reached its current position during its lifetime following disk ejection.

**BD +02 2711**.—The effective temperature of this star was again derived from silicon ionization equilibria, but in this case is in good agreement with that deduced by Tobin (1985) from \( u \beta u \) photometry. The Population I chemical composition indicates the BD +02 2711 is a normal hydrogen-burning star on the main sequence. By contrast, its logarithmic gravity is 0.1 dex larger than that predicted by evolutionary models (Hjeslen 1980; Maeder & Meynet 1988), but would be compatible with BD +02 2711 being a fast rotator (Jaschek & Jaschek 1990, and references therein). An observed projected rotational velocity of 35 km s\(^{-1}\) for BD +02 2711 would then imply that we are observing the star pole-on. Alternatively the discrepancy could reflect errors in the model atmosphere analysis, although a similar discrepancy was found for 791 – 2 (Paper I), which also had a small projected rotational velocity.

**HD 120086**.—The silicon ionization equilibrium was again used to estimate the effective temperature, while a normal chemical composition was found.

**HD 118246**.—All but the strongest metal lines were unobservable due to the extremely high projected rotational velocity (\( \approx 270 \text{ km s}^{-1} \)), preventing evaluation of the effective temperature from silicon ionization equilibria. The temperature determination is further complicated by the lack of \( u \beta u \) photometry, but has been achieved by assuming the star to be helium normal. The best-fit atmospheric parameters estimated from this method have then been used to determine the metal abundances presented in Table 3. We emphasize that the equivalent width estimates on which these abundances are based may be unreliable due to the effect of rotation (e.g., the silicon lines 4128.07 Å and 4139.89 Å were completely blended). The large rotational velocity of HD 118246 is evidence that it is not an evolved object such as a horizontal branch star, or Post-AGB object (Jaschek & Jaschek 1990).

**UKST 1315 +002**.—No record of other observations (either spectroscopic or photometric) have been obtained for this object from our literature search. In view of this, and the star’s large projected rotational velocity (\( \approx 280 \text{ km s}^{-1} \)), we again estimate the effective temperature from the helium spectrum. As with HD 118246, the photospheric abundances presented in Table 3 may be unreliable, but if they do reflect the star’s chemical composition, then in particular the iron content suggests that this star is normal, while the large projected rotational velocity again appears incompatible with a horizontal branch or PAGB evolutionary status.

**HD 129956**.—The spectrum of HD 129956 is characterized by the absence of He I lines, weak Si II lines, a strong magnesium line and many iron, titanium and chromium lines. A temperature estimate could only be achieved by using the \( u \beta u \) photometry of Hauck & Mermilliod (1980). As suggested by its spectral vignetted, HD 129956 is cooler than the other program stars, while its gravity and near Population I chemical composition are compatible with it lying on the hydrogen-burning main sequence.

### 3.3. Kinematical Analysis

The results of the kinematic analysis reproduced in Table 3 are based on the assumption that \( V_{\text{star}} \approx V_r \), where \( V_r \) is the star’s velocity perpendicular to the Galactic plane and \( V_{\text{star}} \) is the radial velocity of the star in its own local standard of rest. This approximation should be reasonable, since the stars con-

<table>
<thead>
<tr>
<th>Star</th>
<th>He</th>
<th>C</th>
<th>N</th>
<th>O</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>Fe</th>
</tr>
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<tr>
<td>Normal Star</td>
<td>10.99</td>
<td>8.2</td>
<td>8.0</td>
<td>8.8</td>
<td>7.4</td>
<td>6.3</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>HD 121968</td>
<td>10.95 ± 0.13 (4)</td>
<td>8.3</td>
<td>7.9</td>
<td>8.8</td>
<td>7.3</td>
<td>...</td>
<td>7.3 ± 0.2 (2)</td>
<td>...</td>
</tr>
<tr>
<td>BD +02 2711</td>
<td>10.85 ± 0.17 (5)</td>
<td>8.1</td>
<td>...</td>
<td>...</td>
<td>7.8</td>
<td>...</td>
<td>7.26 ± 0.18 (3)</td>
<td>...</td>
</tr>
<tr>
<td>HD 120086</td>
<td>10.95 ± 0.05 (7)</td>
<td>7.9</td>
<td>8.3</td>
<td>8.7 ± 0.25 (3)</td>
<td>8.0</td>
<td>6.1</td>
<td>7.3 ± 0.12 (4)</td>
<td>...</td>
</tr>
<tr>
<td>HD 118246</td>
<td>10.9 ± 0.1 (4)</td>
<td>8.1</td>
<td>8.8</td>
<td>...</td>
<td>7.6</td>
<td>...</td>
<td>6.93 ± 0.03 (2)</td>
<td>...</td>
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<tr>
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<td>11.0 ± 0.1 (2)</td>
<td>8.5</td>
<td>...</td>
<td>...</td>
<td>7.1</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>HD 129956</td>
<td>10.8 ± 0.18 (2)</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>7.2</td>
<td>...</td>
<td>7.2 ± 0.2 (2)</td>
<td>7.6 ± 0.1 (4)</td>
</tr>
</tbody>
</table>
TABLE 4

<table>
<thead>
<tr>
<th>Star</th>
<th>$M/M_\odot$</th>
<th>log $L/L_\odot$</th>
<th>$z$ (pc)</th>
<th>$V_\phi$ (km s$^{-1}$)</th>
<th>$T_\phi$ (Myr)</th>
<th>$T_r$ (Myr)</th>
<th>$T_{\phi,\max}$ (Myr)</th>
<th>$T_{\phi,\min}$ (Myr)</th>
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<tr>
<td>HD 121968</td>
<td>11.5</td>
<td>4.09</td>
<td>3140</td>
<td>135</td>
<td>9</td>
<td>30</td>
<td>15</td>
<td>24</td>
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<tr>
<td>BD +02 2711</td>
<td>6.0</td>
<td>3.00</td>
<td>1345</td>
<td>75</td>
<td>&lt;1</td>
<td>41</td>
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<td>37</td>
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<tr>
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<td>3.57</td>
<td>640</td>
<td>53</td>
<td>4</td>
<td>14</td>
<td>16</td>
<td>12</td>
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<tr>
<td>HD 118246</td>
<td>8.1</td>
<td>3.82</td>
<td>1270</td>
<td>65</td>
<td>32</td>
<td>31</td>
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<tr>
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<td>4.0</td>
<td>2.75</td>
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<td>122</td>
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<td>3.2</td>
<td>2.34</td>
<td>128</td>
<td>14</td>
<td>200</td>
<td>10</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

HD 121968.—The minimum initial ejection velocity, $V_\phi = 256$ km s$^{-1}$, does not lie beyond theoretically predicted limits for cluster ejection, although such a perturbation would require an interaction with stars more massive typically by a factor of more than 10. The likelihood of this occurring is remote given that HD 121968 has a minimum mass of 10 solar masses. Moreover, the implied transverse velocity, $V_r = 212$ km s$^{-1}$, for the star would imply a significant proper motion of $0\cdot015$ yr$^{-1}$. Hence we conclude that HD 121968 probably did not originate in the Galactic disk.

4. DISCUSSION

Results from the UKST faint star survey (Paper I) are summarized in Table 6 together with those for the bright targets. The stars have been divided into two distinct groups:

**Group A.**—Stars with z-distances too large to be explained from disk ejection models. Only one object definitely qualifies for membership of this group, namely HD 121968. Star 866—1 has an evolutionary lifetime less than the flight time, but might have been ejected from the disk using the same arguments as given for BD +02 2711.

The survey has considered all blue objects to a limiting magnitude of $m_v = 16.5$, allowing, for example, detection of a B8 V star up to $z \sim 25$ kpc (see 863—4, Table 6) and a B0 V star up to $z \sim 80$ kpc. Although we cannot rule out normal B-stars at even greater z-distances, we believe that the survey includes effectively the full extent of the upper halo. Furthermore, given the criteria that stars belonging to group A necessarily have large z-distances, we assume that these objects are distributed with spherical symmetry, homogeneously throughout the Galaxy. Then as the UKST survey has sampled 0.9% of the sky, the order of 10$^2$ such objects should exist in our Galaxy.

This result is consistent with the findings of Tobian (1984) who considered distant early-type stars with $|b| \geq 45^\circ$ as well as the estimates of Kilkenny et al. (1991) from their sample of lower latitude ($b \sim 40^\circ$) B-type stars. Agreement of these results does suggest that our hypothesis of spherical homogeneity may be appropriate, but any conclusions based on such a small halo sample should be treated with great caution.

As discussed in §1, the failure of established disk ejection mechanisms to account for these distant young stars has led many authors (Keenan 1992, and references therein) to speculate that stars can form in the Galactic halo. Moreover, Dyson & Hartquist (1983) have modeled collisions between clouds in high-velocity gas conditions typical of the halo (Giovanelli 1980) and predict that in some circumstances gas densities can reach the Jeans limit, thus allowing star formation to proceed. We note that the tip of the Chimney high-velocity complex (Hulsbosch & Wakker 1988) is located approximately 8$^\circ$ from HD 121968, strengthening the hypothesized connection.

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between HVC and star formation. The star-generation rate envisaged by Dyson & Hartquist (1983) is also consistent with the number of 200 such objects suggested above. However, if star formation does occur it is unlikely to be restricted (as are stars in group A) to the upper regions of the halo since HVC are known also to exist at intermediate z-distances (Little et al. 1994). Consequently, if the range 10^2 is an underestimate (i.e., if stars formed in the halo have been wrongly assigned to group B), the production rate expected from their model may be too low.

An alternative explanation of such objects has recently been proposed by Leonard & Hills (1992). They suggest that in some cases neutron stars may fall into the cores of normal stellar companions, thereby greatly extending the apparent main-sequence lifetime via mass accretion. However, because the mass accretion luminosity should greatly exceed that of a ≤ 10 M_☉ star, their theory cannot offer an explanation for HD 121968. Indeed, the m_☉ ≈ 16.5 magnitude limit in this survey implies a selection effect in favor of any higher luminosity and consequently larger mass stars. Since no objects with implied masses greater than 12 M_☉ have been detected, neutron star capture in runaways does not appear relevant to our current sample.

Group B.—The runaway stars, where membership has been assigned solely as a consequence of their failure to fulfill the criteria for group A (i.e., some of them may indeed have formed away from the Galactic plane).

A very rough estimate of the total number of runaway stars in the Galactic halo can be made by assuming the number of runaway stars (m) with z ≤ 5 kpc in our sample have all been produced by massive OB stars (number β) directly below in the disk (approximated here to within 0.5 kpc of the Sun). Adopting the Galactic scale distances of Bahcall (1984) for young populations then leads to a solar ejection frequency f_☉ of

\[ f_☉ = 2m/β ≈ 0.1\% \]  (1)

where a space density of k = 0.13 pc^{-3} for young stars in the solar neighborhood (Wielen 1974) has been adopted in the estimation of β and the factor 2 arises from including the contributions to both below and above the Galactic plane. Then assuming f is independent of Galactocentric distance, the total number of runaways (n) in the Galaxy would be

\[ n = 2m(α/β) \sim 10,000 \]  (2)

where (α/β) is the ratio of OB-stars in the solar vicinity to those in the entire Galaxy, calculated using the Galactic scale distances of Bahcall (1984). This may be an underestimate because f should be greater for tighter bound open clusters and binary systems in the more dense inner parts of the Galaxy and only runaways within 5 kpc of the disk have been considered.

Runaway star frequencies have previously been estimated for disk samples from the number observed above some cutoff peculiar radial or space velocity (Blauw 1961; Conti & Ebbets 1977; Lynds 1980; Stone 1979, 1991) where a current best estimate of f_☉ ~ 4% has been obtained by Stone (1991) for B stars within 0.6 kpc of the Sun. The large difference with our estimate probably arises from the different method of definition of runaways. For example, Stone fitted a binomial distribution to his sample to include all peculiar motions down to 0 km s^{-1}, while we have constrained our definition to determine rates only for those orbits ejected into the Galactic halo.

5. CONCLUSION

A 325 square degree region of the Galactic halo has been surveyed to detect young blue stars. Eleven main-sequence objects have been identified, of which one (HD 121968) cannot be accounted for in terms of disk ejection models. Assuming this region to be typical of the Galactic halo implies the existence of hundreds rather than thousands of such stars. The projected number density of this is consistent with the model proposed by Dyson & Hartquist (1983) for star formation in the halo. The ejection model enunciated by Leonard & Hills (1992) is not supported by our results. A lower limit of 10,000 runaway stars in the halo has been estimated, with an ejection frequency in the solar neighborhood of ~0.1%.

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REFERENCES

Schaller, G., Schaerer, D., Meynet, G., & Maeder, A. 1992, AAS, 96, 269
———. 1985, A&S, 60, 459