THE SPACE INTERFEROMETRY MISSION ASTROMETRIC GRID GIANT STAR SURVEY. I.
STEellar PARAMETERS AND RADIAL VELOCITY VARIABILITY

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ABSTRACT

We present results from a campaign of multiple-epoch echelle spectroscopy of relatively faint ($V = 9.5–13.5$ mag) red giants observed as potential astrometric grid stars for the Space Interferometry Mission (SIM PlanetQuest). Data are analyzed for 775 stars selected from the Grid Giant Star Survey, spanning a wide range of effective temperatures ($T_{\text{eff}}$), gravities, and metallicities. The spectra are used to determine these stellar parameters and to monitor radial velocity (RV) variability at the $100$ m s$^{-1}$ level. The degree of RV variation measured for 489 stars observed two or more times is explored as a function of the inferred stellar parameters. The percentage of RV-unstable stars is found to be very high—about two-thirds of our sample. It is found that the fraction of RV-stable red giants (at the $100$ m s$^{-1}$ level) is higher among stars with $T_{\text{eff}} \sim 4500$ K, corresponding to the calibration-independent range of infrared colors $0.59 < (J - K)_{\text{0}} < 0.73$. A higher percentage of RV-stable stars is found if additional constraints of surface gravity and metallicity ranges, $2.3 < \log g < 3.2$ and $-0.5 < [\text{Fe/H}] < -0.1$, respectively, are applied. Selection of stars based on only photometric values of effective temperature ($4300$ K $< T_{\text{eff}} < 4700$ K) is a simple and effective way to increase the fraction of RV-stable stars. The optimal selection of RV-stable stars, especially in the case in which the Washington photometry is unavailable, can rely effectively on the 2MASS colors constraint $0.59 < (J - K)_{\text{0}} < 0.73$. These results have important ramifications for the use of giant stars as astrometric references for the SIM PlanetQuest.

Key words: stars: abundances — stars: fundamental parameters — stars: late-type — stars: oscillations — techniques: radial velocities

On-line material: machine-readable tables

1. INTRODUCTION

The Grid Giant Star Survey (GGSS; Patterson et al. 2001) is a partially filled, all-sky survey to identify giant stars of 9 mag $\leq V \leq 17.5$ mag using the Washington $M$, $T_{\text{2}} +$ DDO51 filter photometric prescription outlined in Majewski et al. (2000). A primary motivation for the survey and a driver of its design is the selection of stars suitable for the astrometric grid of the Space Interferometry Mission (SIM PlanetQuest). These grid stars, which serve as astrometric references against which the motions of SIM targets are measured, must themselves be as astrometrically stable as possible. Thus, they must be free of stellar or significant planetary companions, as well as atmospheric activity (spotting/flaring), that will induce photocenter wobbles at the several microarcsecond level of order a decade (approximately the duration of SIM). G and K giants were selected by the SIM project as the primary stellar constituent of the SIM astrometric grid because these stars are the most luminous common stellar type found in all directions of the sky. High intrinsic luminosity places giant stars at greater distances for a given apparent magnitude, and this increased distance decreases the angular scale of any fixed linear astrometric wobble, thus making these particular stars less likely to be problematical as references. The GGSS project has been undertaken with the specific aim of identifying subsolar metallicity giant stars, which are intrinsically more luminous than solar-metallicity giants and also less likely to have planets (see Fischer & Valenti 2005 and references therein).

Despite consideration of such effects for careful selection, all SIM astrometric grid candidates require premission monitoring to assess their likelihood of astrometric stability during the mission. One method is to search for variability in other properties, such as brightness and radial velocity (RV). Indeed, we are presently involved, along with other groups, in a large campaign of echelle high-resolution RV monitoring of astrometric grid candidates. Fortunately, not all variability in RV (or luminosity) necessarily translates to detrimental astrometric variability. However, some intrinsic photometric and/or RV variability is due to processes that, although benign in terms of photocenter wobble (e.g., radial pulsations), can mask otherwise detectable signatures of problematic sources of variability, like astrometric wobbles due to planetary, brown dwarf, or stellar companions. Therefore, because campaigns to monitor RV variability to the precision needed for vetting SIM targets (i.e., $\sim 100$ m s$^{-1}$) are both expensive and time-consuming, it is useful to understand how intrinsic RV variability of giant stars depends on other stellar properties (like temperature, metallicity, and surface gravity) to optimize efficient selection of giant stars for the astrometric grid.

Although it has long been known that stars at the top of the red giant branch (RGB) are both brightness- and RV-variable (see,
e.g., Pryor et al. 1988; Cote et al. 1996), there has been little systematic study of this variability as a function of stellar atmospheric parameters, especially at fainter absolute magnitudes. Monitoring of RVs for bright red giants has indicated that their variations have a high probability of being at the level of 100 m s$^{-1}$ (see Hatzes & Cochran 1994 and references therein). Jorissen et al. (1997) found that red giants with spectral types from late G to early K are stable, and giants with later spectral types are all variable. At the same time, study of Hipparcos red clump giants (Adelman 2001) reveals photometric stability in this evolutionary phase. RV jitter at large amplitude is expected for metal-poor luminous red giants ($M_V < -1.4$) (see Carney et al. 2003).

In their assessment of the suitability of giant stars as SIM astrometric grid members, Frink et al. (2001) studied a proxy sample of 86 nearby giant stars selected from the Hipparcos catalog. Their study included three to eight epochs of high precision (5–8 m s$^{-1}$) echelle RV measurements on timescales from days to a year. Frink et al. found that most (73 of 84) of the giant stars they investigated have a stable RV at the level of <100 m s$^{-1}$, and the peak of the distribution of measured dispersions in velocity occurs at 20 m s$^{-1}$. However, Frink et al. do report that RV variation is more probable for redder stars ([B − V] > 1.2 in their sample). While the closest match to the survey presented here, the Frink et al. survey contains stars that are much brighter than the expected SIM grid sample; moreover, they did not probe variability as a function of metallicity, which is a key aspect of the stars being found in the GGSS.

Our goal here is to carry out an initial RV stability assessment of stars more like those expected to fill the astrometric grid by focusing on stars taken directly from the GGSS itself. The hope is that RV stability may correlate with some intrinsic stellar property, such as effective temperature, surface gravity, or metallicity. Although the precision of our RV measurements is an order of magnitude less than that of Frink et al. (2001), it is appropriate for finding RV wobbles at the level needed to identify faint and distant (>1 kpc) astrometrically detrimental grid candidates (and, indeed, it is the precision at which monitoring campaigns of SIM grid stars are being conducted). Moreover, our sample is almost an order of magnitude larger than that in the Frink et al. (2001) survey. The observations studied and discussed here were obtained under an initial JPL-sponsored program in which the internal RV accuracy was set at about 100 m s$^{-1}$.

2. OBSERVATIONS AND DATA REDUCTION

2.1. Sample Selection and Biases

The GGSS finds giant stars by photometry in the Washington $M, T_2$, DDO51 filters according to the methods described in Majewski et al. (2000). The ($M - T_2, M - DDO51$) two-color diagram (2CD) effectively distinguishes between late-type dwarfs and giants based on the surface-gravity-sensitive Mg b + Mg H feature near 5150Å (where the 130 Å wide DDO51 filter is centered). Photometry was obtained in 1302 evenly placed fields across the celestial sphere, each of area 0.5–1.0 deg$^2$. The 2CD (i.e., the Mg b + Mg H feature) is secondarily sensitive to metallicity, and the positions of stars in the 2CD can therefore be used to derive a crude estimate of the metallicity of the likely giant stars. Metal-poor giants are the stars in the 2CD most widely separated from the locus of dwarf stars; therefore, these are the easiest to identify with our methods. Additional details regarding the GGSS can be found in Patterson et al. (2001).

The selection of stars for the present study is biased according to the same specific set of criteria used in the original agreement of the GGSS collaboration with the SIM project regarding the selection of astrometric grid candidates from the GGSS.$^9$ Giant star candidates are identified from the 2CD and the assigned photometric metallicities therefrom. From the apparent magnitude, color, and metallicity, an estimate of the absolute magnitude and a photometric parallax distance is assigned (Rhee et al. 2001). For each field, all giant candidates with $V < 13.5$ mag were ranked according to distance, with the most distant star assigned highest priority. The top four ranked stars in each field, yielding more than 4000 candidates of 9.5 mag $\leq V \leq 13.5$ mag, were passed onto both medium- and high-resolution spectroscopic observing campaigns (the latter forming the database explored here). Typically, although not exclusively, the most distant giant candidates in each field were also among those with the lowest photometric metallicities brighter than $V = 13.5$ mag. Thus, our spectroscopic sample is biased toward more metal-poor and distant stars than would be found from a random selection of giant stars in the same magnitude range. From the above-described sample of more than 4000 stars, we explore here a random subsample of 775 stars in both celestial hemispheres, which constitutes those stars for which multiple high-resolution spectra have been obtained during the first 2 years of the GGSS follow-up program.

2.2. Spectroscopy

Spectroscopic observations of 434 stars in the northern subsample of GGSS candidates were conducted in the period from 2001 January to 2002 December. We made use of the 2.1 m telescope at the McDonald Observatory and the Sandiford Cassegrain echelle spectrograph, which provides $R = 55,000$ resolution. Th-Ar comparison spectra were taken right before every program star observation. The quality of the data was monitored by observing one or two RV-standard stars from Nidever et al. (2002) per night. The adopted setup of the spectrograph enabled us to cover the 5000–5900 Å spectral range and achieve a signal-to-noise ratio (S/N) level of order 20–40 in reasonable exposure times (10–30 minutes).

The observed spectra were reduced from two-dimensional to “echelle” format in a standard way with the IRAF$^{10}$ software package. Corrections for bias, flat field, and scattered light were applied, and cosmic ray hits were cleaned out by IRAF’s tasks in the CRUTIL package. The internal accuracy of the wavelength calibration via the Th-Ar lamp spectra was on average 0.001 Å (and not worse than 0.0018 Å), which corresponds to an RV accuracy of order 55 m s$^{-1}$ (and not worse than 100 m s$^{-1}$).

Resampling the spectra introduces systematic errors in the wavelength calibration that degrades the RV accuracy. Thus, to preserve the wavelength calibration, the spectrum orders were not concatenated to produce a single spectrum but rather were maintained individually at their natural sampling.

Southern hemisphere GGSS stars were observed with the 1.2 m Swiss telescope and CORALIE velocimeter in 2001–2004 at the ESO La Silla Observatory (Chile), as described by Arenas et al. (2002). CORALIE is an improved version of the ELODIE spectrograph (Baranne et al. 1996). The effective resolution of CORALIE is 50,000; it covers the wavelength range 3870–6800 Å,

$^9$ In the past year, the SIM project has modified somewhat the criteria for the selection of stars for the astrometric grid, with a focus on stars with magnitudes more typically $V \approx 9–11$ mag and chosen from both the GGSS and the Tycho-2 catalogs in a ratio of approximately 1:3. The Tycho stars are selected without foreknowledge of metallicity, and so are expected to be typically near solar metallicity and at smaller distances than stars from the GGSS. In this respect, all of our results are still relevant, however, since the stars included in the present study span the range of properties expected for both GGSS and Tycho-2 stars.

$^{10}$ IRAF is distributed by NOAO, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the NSF.
and it provides a precision of typically 30 m s\(^{-1}\) in the RVs. Typically a S/N of 10 was achieved for program targets. The RV and its accuracy comes directly from CORALIE’s reduction package TACOS (Baranne et al. 1996).

CORALIE provides RVs for 375 program stars directly from the TACOS software. We found that spectra with S/N \(\leq 4\) have systematically low RV accuracy and rejected them from further analysis. The whole sample of good S/N CORALIE candidates is thus reduced to 341 objects. While we cannot obtain abundances directly from CORALIE spectra, we incorporate the RVs of these stars in our analysis and adopt photometrically estimated stellar parameters for these stars.

Since the southern sample was observed with a smaller aperture telescope than the northern one, it is biased toward brighter stars: the distribution of the southern \(V\) magnitudes peaks at 11.6 mag, whereas the northern sample distribution peak is located at 12.7 mag.

3. DATA ANALYSIS

3.1. Radial Velocities

RVs from the McDonald spectra were measured using a cross-correlation methodology with the help of IRAF’s \texttt{fxcor} task. After the primary reduction, the continuum of each order looks almost flat except at its edges where the continuum level looks systematically lower and the S/N is degraded. For the RV analysis we discard the pixels at the order edges, which is about \(\sim 20\%\) of the total.

Each spectral order was cross-correlated against the RV template separately. The template chosen was the Arcturus spectrum (Hinkle et al. 2000). The cross-correlated pieces of the template spectrum were convolved with a Gaussian corresponding to the FWHM of the Th-Ar lines found for each order. In addition, the corresponding piece of the calibrating Th-Ar spectrum was cross-correlated with a laboratory Th-Ar template (Palmer & Engleman 1983). The Th-Ar template for each order was also convolved with the same Gaussian function as the stellar template in that order. The shift in the RV between the observed Th-Ar and the laboratory reference frame was subtracted from the stellar RV.

![Fig. 1.—Example of the order-to-order RV differences for the program star G1113+00.20. The wavelength corresponds to the middle of each respective order.](image)

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got obtained from the cross-correlation via the template. Thus, we not only took into account the varying instrumental profile by this order-by-order treatment, but we were able to make multiple estimates of the RV for a single observation and thereby assess the errors in our velocities for each star. A few of the spectral orders indicated significantly different RVs from the others because of poor wavelength calibration due to a sparse Th-Ar line sample. We discarded such “bad” orders from our analysis. The remaining orders’ RVs (\(\text{RV}_i\)) give us an independent assessment of the mean RV (\(\text{RV}_0\)) and its accuracy: \(\text{RV}_0 = \Sigma \text{RV}_i \omega_i / \Sigma \omega_i\), where \(\omega_i\) is the inverse square of the individual RV error provided by IRAF. The dispersion of this estimate, \(\delta\text{RV}\), was found as

\[
\delta\text{RV} = [\Sigma \omega_i (\text{RV}_i - \text{RV}_0)^2 / \Sigma \omega_i]^{1/2}.
\]

We show an example of the order-to-order RV difference assessed for the program star G1113+00.20 in Figure 1.

3.2. Stellar Parameters Derived from an Automated Spectroscopic Analysis

In addition to the measured RVs, physical stellar parameters can be derived for the red giants studied here. The effective temperature (\(T_{\text{eff}}\)) of giant stars can be determined from their broad-band colors. According to an observational calibration given by Alonso et al. (1999), near-infrared colors (\(J - K_s\)) can be used to estimate \(T_{\text{eff}}\) for red giants, even with no information on the stellar metallicity and surface gravity. The full release of the Point Source Catalog of the Two Micron All Sky Survey (2MASS) makes available the near-infrared colors of all GGSS candidates. Figure 2 shows the \(T_{\text{eff}}\) distribution of the combined northern and southern samples as estimated from (\(J - K_s\)) colors according to the Alonso et al. prescription. As may be seen, our candidates span a range of temperatures characteristic of red giants. The typical accuracy of 2MASS colors is 0.03 mag in our sample magnitude range. It corresponds to a 100 K accuracy in \(T_{\text{eff}}\).

The internal accuracy of the \(T_{\text{eff}}\) calibration in Alonso et al. (1999) from (\(J - K_s\)) is of order 125 K. On the other hand, Bessell et al. (1998) provide a calibration of the \(T_{\text{eff}}(J - K_s)\) relation for giant stars from NMARCS stellar atmosphere models. The Bessell et al. results are reproduced by the Alonso et al. data fairly well for typical values of the surface gravity (see Fig. 12 in Alonso et al. 1999). The relation from Bessell et al. (1998)
is metallicity-dependent, but the difference between stars of $\frac{1}{2} \text{Fe/H}$ and $0$ (which corresponds to the bulk of our objects; see below) affects $T_{\text{eff}}$ by less than 100 K and would not have a significant effect on the applied calibration procedure. From the previous two paragraphs, we expect a 160 K accuracy in our derived $T_{\text{eff}}$.

For the northern sample (434 stars) observed at McDonald Observatory, the reduced echelle spectra can be used to determine the surface gravity, $\log g$, and metallicity, $[\text{Fe/H}]$, by comparison to a library of synthetic stellar spectra. For this purpose we produced artificial spectra using the MOOG-2002 spectral synthesis package (Sneden 1973). The corresponding stellar models were computed by the ATLAS9 code (Kurucz 1993). We computed a model set covering the 3800–5600 K temperature range, $0.2 < \log g < 5.6$, and $-3.0 < [\text{Fe/H}] < +0.5$, with steps in these parameters of 200 K, 0.2 dex, and 0.2 dex, respectively. In all the models we assumed a typical value for the microturbulent velocity of 2 km s$^{-1}$.

We selected three pieces of spectra to estimate the stellar parameters. The Arcturus spectrum (used as an RV template in §3.1) was split into 40 pieces, and the optimal synthetic spectrum’s piece and corresponding model parameters were found by least-squares fitting. The stellar parameters of Arcturus (obtained by Griffin & Lynas-Gray 1999) were best reproduced in the regions of 5175–5215, 5215–5255, and 5700–5740 Å. These wavelength intervals used to derive the stellar parameters are not simply dominated by Fe absorption lines but also by (principally) lines of Mg, Ti, Cr, Ni, and to a lesser degree V. The abundances derived in this way are therefore not direct “Fe abundances,” but an overall “metallicity” defined by a mixture of both Fe-peak and -elements; we refer to this abundance simply as metallicity and denote it in the remainder of this paper as $[\text{Fe/H}]$.

Although significantly nonsolar abundance ratios, relative to Fe, could create additional noise in the metallicity estimates, the vast majority of stars in the sample are well above $\frac{1}{2} \text{Fe/H}$ and to a lesser extent Ti/Fe and Cr/Fe, are mildly nonsolar and typically enhanced. This may introduce a small trend of slightly larger derived overall metallicities as the Fe abundance decreases.

### Table 1

| Name            | R.A. (J2000.0) | Decl. (J2000.0) | $T_{\text{eff}}$ (K) | $[\text{Fe/H}]_\text{ph}$ (dex) | $D_{\text{ph}}$ (kpc) | $\Delta \log g_\text{ph}$ (dex) | $[\text{Fe/H}]_\text{ph}$ (dex) | $\Delta [\text{Fe/H}]_\text{ph}$ (dex) |
|-----------------|---------------|----------------|----------------------|-------------------------------|----------------------|-------------------------------|-------------------------------|--------------------------------|
| G2358+00.31     | 00 00 51.96   | 00 22 16.8     | 4290                | −0.3                          | 1.3                  | 4.87                          | 0.19                          | −2.80                          |
| G2358+00.92     | 00 01 36.38   | 00 14 09.9     | 4399                | −0.9                          | 1.1                  | 2.24                          | 0.13                          | −0.42                          |
| G0001+00.94     | 00 04 20.08   | 00 27 12.2     | 4324                | −0.7                          | 3.0                  | 2.67                          | 0.41                          | −0.46                          |
| G0011+05.87     | 00 14 18.85   | 05 57 37.5     | 4440                | −0.5                          | 0.7                  | 2.13                          | 0.19                          | −0.47                          |
| G0011+16.75     | 00 14 26.65   | 17 16 03.0     | 4594                | −0.8                          | 1.8                  | 1.47                          | 0.38                          | −0.67                          |

**Notes:** Columns are, from left to right: the name of the star, its right ascension and declination, effective temperature, photometric metallicity $[\text{Fe/H}]$, photometric distance, spectroscopic surface gravity $\log g$ and its accuracy, and spectroscopic metallicity and its accuracy. Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Table 1 is published in its entirety in the electronic edition of the Astronomical Journal. A portion is shown here for guidance regarding its form and content.

![Fig. 3.—Comparison of metallicities estimated from high-resolution spectroscopy (see text) and “photometric” $[\text{Fe/H}]$ (Rhee et al. 2001). The dashed line shows the “robust” least absolute deviation fit to the data. The values of $[\text{Fe/H}]$ for most of the stars with intermediate metallicity approximately follow a linear relation with dispersion of order 0.4 dex. The spectroscopic $[\text{Fe/H}]$ is systematically higher than the photometric one by about 0.16 dex.](image1)

![Fig. 4.—Relation between surface gravity and effective temperature for 434 stars from our northern sample.](image2)
To match the wavelength intervals defined above, spectra of program stars were corrected to zero RV incorporating the RVs defined in §3.1. The continuum level in the fragments of spectra was fitted by a linear function using the continuum task from IRAF. The pieces of synthetic spectra used for the comparison were convolved with a Gaussian function corresponding to the FWHM of each echelle order to reduce their spectral resolution to that in the observed data. Then we found the best-fit model for each piece by the least-squares method. The values and errors of log $g$ and [Fe/H] were finally obtained by averaging these same derived parameters across the set of three modeled pieces.

With this method we derived the stellar parameters ($T_{\text{eff}}$, log $g$, and [Fe/H]) for the 434 northern GGSS stars (see Table 1). The [Fe/H] for the whole GGSS sample has also been estimated photometrically (Rhee et al. 2001), and one can compare the values derived by each method (photometric and spectroscopic). Figure 3 shows that the two [Fe/H] estimates for most stars of intermediate metallicity ([Fe/H] = $-1.0$) follow a linear relation with dispersion of the order of 0.4 dex but systematically offset by

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0.16 dex (in the sense that the spectroscopic metallicities tend to be larger). This small offset could be due partially to mildly elevated Mg/Fe, Ti/Fe, or Cr/Fe ratios in the metal-poor stars. There are some extreme outliers in Figure 3. Some of these stars have large error bars in either their spectroscopic or photometric metallicities. Many of the outlying points in Figure 3 correspond to the hottest stars in our sample. These stars occupy the border region between giants and dwarfs on the giant-dwarf discrimination diagram from Majewski et al. (2000), and their stellar parameters determined from photometric data may be biased.

Figure 4 shows the relation between the surface gravity and effective temperature for the northern hemisphere sample. Most of the stars in Figure 4 span ranges typical for red giants. Here we see the success rate of the GGSS for photometrically identifying bona fide red giants to be extremely high; more than 98% of the stars that were photometrically identified by the Majewski et al. (2000) method to be giant stars have spectroscopic gravities supporting this characterization.

3.3. Errors in Atmospheric Parameters

In order to analyze the accuracy of the derived stellar parameters as a function of the quality of observed spectra, we performed Monte Carlo simulations deriving the basic stellar parameters for a set of selected synthetic spectra deteriorated by varying amounts of added noise. We considered a set of S/N from 3 to 30, which covers the typical range of S/N in our observed spectra. Besides random noise, we also added variations of $T_{\text{eff}}$ and RV into the model spectra, distributing them uniformly within $\pm 100$ K and $\pm 100$ m s$^{-1}$ ranges from the true values. Finally, we assumed that the microturbulence velocity might take an arbitrary value in the range 1–2 km s$^{-1}$. The stellar parameters were defined for 100 resulting synthetic spectra over the typical (see Fig. 4) values of $T_{\text{eff}}$ and log $g$. 4000 K and 1.4 dex, 4400 K and 2.6 dex, and 5000 K and 3.0 dex. The [Fe/H] took the values $-2$, $-1$, and 0 dex for each case. The resulting ranges of the estimated parameters (1 $\sigma$ level) are shown by the solid curves in Figure 5 about the mean values (diamonds). The dashed lines represent the initial true parameters (log $g$ or [Fe/H]) of the spectra. The figure shows that we obtain an accuracy in log $g$ of the order of 0.2 dex. A systematic difference in log $g$ of +0.1 dex is found and is primarily the result of the displacement of the microturbulent velocity $\xi$ from the adopted 2 km s$^{-1}$. The metallicity is defined with 0.1 dex accuracy, and a possible displacement of all estimated values (again due to the unknown $\xi$) is $-0.05$ dex. To check whether these results depend on the number of Monte Carlo simulations, we also evaluated some models based on sets of 400 deteriorated spectra instead of 100. No obvious differences can be seen compared with the case of 100 simulations.

We also extend the considered S/N ratio up to 100. High values of S/N do not improve the inferred parameters since the $\xi$ uncertainty introduces the most significant error. The next strongest factor introducing a systematic deviation between the "real" and estimated stellar parameters is the RV error. It is seen that starting with S/N = 10 and better one can estimate surface gravity and metallicity from our spectra with quite good accuracy. Most of our spectra in the northern sample satisfy this criterion. Note that the accuracy of the RVs also depends on S/N. This can be a reason for more significant errors in log $g$ and [Fe/H] obtained from our spectra.

3.4. Stellar Parameters Derived from a Classical Spectroscopic Analysis

Some of the higher S/N spectra from GGSS stars studied here are suitable for a detailed abundance analysis from which stellar parameters and iron abundances can be obtained via measurements of individual equivalent widths from a selected sample of Fe i and Fe ii lines. This is a different technique from the straightforward matching of observed and synthetic spectra used in §3.2, which we refer to as the "automated spectroscopic" method. When a strictly spectroscopic method (using a line-by-line analysis) is

| Table 2 | The Fe i and Fe ii Lines |
|---------|--------------------------|
| $\lambda$ (Å) | Species | $\chi$ (eV) | log $g$ |
| 5307.361 | Fe i | 1.608 | $-$2.970 |
| 5220.041 | Fe i | 2.279 | $-$2.840 |
| 5497.516 | Fe i | 1.011 | $-$2.840 |
| 5501.464 | Fe i | 0.958 | $-$2.957 |
| 5522.447 | Fe i | 4.209 | $-$1.400 |
| 5536.583 | Fe i | 2.832 | $-$3.812 |
| 5539.284 | Fe i | 3.642 | $-$2.660 |
| 5549.948 | Fe i | 3.695 | $-$2.904 |
| 5559.638 | Fe i | 4.988 | $-$1.829 |
| 5560.207 | Fe i | 4.435 | $-$1.040 |
| 5577.031 | Fe i | 5.033 | $-$1.551 |
| 5579.335 | Fe i | 4.231 | $-$2.406 |
| 5607.664 | Fe i | 4.154 | $-$2.258 |
| 5608.974 | Fe i | 4.209 | $-$2.402 |
| 5611.361 | Fe i | 3.635 | $-$2.993 |
| 5618.631 | Fe i | 4.209 | $-$1.260 |
| 5619.224 | Fe i | 3.695 | $-$3.256 |
| 5636.696 | Fe i | 3.640 | $-$2.608 |
| 5638.262 | Fe i | 4.220 | $-$0.720 |
| 5661.012 | Fe i | 4.580 | $-$2.432 |
| 5677.684 | Fe i | 4.103 | $-$2.694 |
| 5679.025 | Fe i | 4.652 | $-$0.770 |
| 5696.103 | Fe i | 4.549 | $-$1.997 |
| 5698.023 | Fe i | 3.640 | $-$2.689 |
| 5705.466 | Fe i | 4.301 | $-$1.360 |
| 5717.835 | Fe i | 4.284 | $-$0.980 |
| 5724.454 | Fe i | 4.284 | $-$2.627 |
| 5759.261 | Fe i | 4.652 | $-$2.073 |
| 5760.345 | Fe i | 3.642 | $-$2.490 |
| 5784.657 | Fe i | 3.397 | $-$2.673 |
| 5793.913 | Fe i | 4.220 | $-$1.697 |
| 5806.717 | Fe i | 4.608 | $-$0.900 |
| 5807.782 | Fe i | 3.392 | $-$3.404 |
| 5809.217 | Fe i | 3.884 | $-$1.690 |
| 5811.917 | Fe i | 4.143 | $-$2.427 |
| 5814.805 | Fe i | 4.283 | $-$1.820 |
| 5837.700 | Fe i | 4.294 | $-$2.337 |
| 5838.370 | Fe i | 3.943 | $-$2.337 |
| 5844.917 | Fe i | 4.154 | $-$2.940 |
| 5845.266 | Fe i | 5.033 | $-$1.818 |
| 5849.682 | Fe i | 3.695 | $-$2.993 |
| 5853.149 | Fe i | 1.485 | $-$5.268 |
| 5856.083 | Fe i | 4.294 | $-$1.640 |
| 5861.107 | Fe i | 4.283 | $-$2.452 |
| 5870.743 | Fe ii | 2.778 | $-$4.745 |
| 5904.440 | Fe ii | 2.891 | $-$1.213 |
| 5132.669 | Fe ii | 2.807 | $-$4.000 |
| 5234.625 | Fe ii | 3.221 | $-$2.240 |
| 5264.812 | Fe ii | 3.230 | $-$3.188 |
| 5284.098 | Fe ii | 2.891 | $-$3.010 |
| 5325.559 | Fe ii | 3.221 | $-$3.170 |
| 5414.046 | Fe ii | 3.221 | $-$3.620 |
| 5425.247 | Fe ii | 3.199 | $-$3.210 |
| 5534.847 | Fe ii | 3.244 | $-$2.770 |

Note.—Adopted excitation potentials and $g_f$-values for Fe i and Fe ii lines.
admitted, the effective temperatures can be obtained by forcing a zero slope in the relation between Fe\textsuperscript{i} abundances with line excitation potentials; surface gravities are obtained from the agreement between the abundances from Fe\textsuperscript{i} and Fe\textsuperscript{ii} lines. Another parameter that can be adjusted at the same time is the micro-
turbulence velocity, which is tuned so that the Fe\textsuperscript{i} abundances are independent of the equivalent widths.

This method can provide a consistency check on the metallicities and log \( g \) derived with the automated method presented in § 3.2. To test the degree of consistency, a small subsample of

| Star     | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|----------|----|----|----|----|----|----|----|----|----|----|
| 5307.361 | 132| 109| 185| 117| 118| 154| 154| 165| 116| 135|
| 5322.041 | 92 | 84 | 140| 86 | 85 | 114| 100| 118| 819| 102|
| 5497.516 | ...| 183| ...| 172| ...| ...| ...| ...| ...| ...|
| 5501.464 | ...| ...| 166| ...| ...| ...| ...| ...| ...| ...|
| 5522.447 | ...| 50 | ...| 47 | ...| 73 | ...| ...| ...| ...|
| 5536.583 | ...| 35 | 25 | ...| 17 | ...| 34 | ...| ...| ...|
| 5539.284 | 42 | ...| 54 | 23 | 32 | 45 | 45 | 44 | 28 | ...|
| 5549.948 | 32 | 15 | 44 | ...| ...| ...| 31 | 21 | ...| ...|
| 5559.638 | 18 | ...| 19 | ...| ...| ...| 15 | 11 | ...| ...|
| 5560.207 | 63 | ...| ...| 57 | 60 | 72 | 68 | 68 | 56 | 62|
| 5577.031 | ...| ...| 22 | ...| ...| ...| ...| 15 | ...| ...|
| 5579.335 | ...| 14 | 34 | 10 | ...| 25 | 23 | 16 | ...| ...|
| 5607.664 | ...| ...| 44 | ...| 25 | ...| 35 | 33 | ...| 27|
| 5608.974 | 25 | ...| 35 | ...| 24 | 31 | ...| 13 | ...| ...|
| 5611.361 | 31 | ...| 37 | 14 | 19 | ...| 37 | 27 | ...| 19|
| 5618.631 | 70 | 58 | 91 | 56 | 62 | 78 | 71 | 76 | 58 | 64|
| 5619.224 | 21 | 11 | 195 | 6 | 10 | 15 | 21 | 15 | ...| ...|
| 5636.626 | 40 | ...| 65 | 24 | ...| 48 | ...| 40 | 32 | ...|
| 5638.262 | 98 | 78 | 126| 78 | 89 | 99 | 92 | 98 | 77 | 96|
| 5661.012 | ...| ...| 15 | ...| ...| ...| 13 | ...| ...| ...|
| 5677.684 | 20 | ...| 24 | ...| 15 | 17 | 24 | 20 | ...| ...|
| 5679.626 | 66 | 54 | ...| 53 | 63 | 74 | 72 | 74 | 51 | 66|
| 5696.103 | 27 | 17 | ...| ...| 22 | ...| ...| 18 | 18 | ...|
| 5696.223 | ...| 28 | 50 | ...| 31 | 39 | 47 | ...| ...| 30|
| 5705.466 | 50 | 48 | 88 | 44 | 54 | 63 | 65 | ...| 47 | 52|
| 5717.835 | 76 | 69 | 105| 66 | 67 | 86 | 81 | 82 | ...| 72|
| 5724.454 | 19 | ...| 19 | ...| ...| ...| ...| 14 | 9 | ...|
| 5759.261 | ...| ...| 20 | ...| 13 | ...| 50 | 15 | 12 | 11|
| 5760.345 | 44 | ...| 65 | 29 | 41 | 53 | 23 | ...| 38 | 36|
| 5784.657 | 52 | 36 | 77 | 34 | 42 | 54 | 57 | 60 | 44 | 41|
| 5793.913 | 51 | 38 | 71 | 39 | 46 | 55 | 54 | 57 | 42 | ...|
| 5806.717 | 60 | 55 | 90 | 49 | 56 | 68 | 66 | 66 | ...| 64|
| 5807.782 | 27 | ...| 41 | 16 | 23 | 26 | 39 | 30 | 17 | ...|
| 5809.217 | 70 | 54 | 98 | 53 | 56 | 76 | 70 | 79 | ...| 70|
| 5811.917 | ...| 15 | 35 | ...| ...| ...| 29 | 25 | 16 | ...|
| 5814.805 | 36 | ...| 59 | ...| 37 | ...| 48 | 42 | ...| 33|
| 5837.700 | ...| 13 | ...| 12 | 16 | ...| 28 | 21 | ...| ...|
| 5838.370 | ...| 25 | ...| 21 | 32 | ...| 45 | ...| 31 | ...|
| 5844.917 | ...| ...| ...| ...| ...| ...| ...| 8 | ...| 8|
| 5845.266 | ...| 14 | ...| 31 | ...| 17 | 20 | 30 | 26 | 19 | 14|
| 5849.682 | ...| 32 | 67 | 22 | 32 | 55 | 58 | 57 | ...| 27|
| 5853.149 | ...| ...| ...| ...| ...| ...| ...| ...| ...| ...|
| 5856.083 | 51 | ...| 70 | ...| 42 | 51 | 53 | 56 | 39 | ...|
| 5861.107 | ...| ...| ...| ...| ...| ...| ...| 22.7 | ...| ...|
| 5000.743 | ...| ...| ...| ...| ...| ...| ...| ...| ...| ...|
| 5018.440 | ...| 175| 201| ...| ...| 222 | ...| 186 | 174 | 161|
| 5132.669 | 39 | ...| 37 | 41 | 35 | 49 | 45 | ...| ...| 25|
| 5234.625 | 87 | 71 | 100| 92 | 72 | 100 | 86 | 81 | 72 | 786|
| 5264.812 | 45 | 43 | 55 | 54 | 44 | 57 | 56 | 44 | 38 | 42|
| 5284.098 | 64 | 63 | 82 | 76 | ...| ...| ...| 67 | 62 | ...|
| 5325.559 | ...| ...| 42 | 54 | 56 | 47 | 57 | 56 | 45 | ...| 36|
| 5414.046 | ...| 30 | ...| 30 | ...| 37 | 34 | ...| 42 | 30 | 29|
| 5425.247 | 46 | 41 | 52 | 57 | 46 | 61 | 51 | 44 | 38 | 38|
| 5534.847 | ...| ...| 60 | 70 | 73 | 59 | 74 | 70 | ...| ...|

*Notes.*—Equivalent widths of Fe\textsuperscript{i} and Fe\textsuperscript{ii} lines (given in mA) for 10 stars. Stellar identifications are as follows: (1) G0858+00.192, (2) G0901+00.175, (3) G1007+00.5, (4) G1018–05.46, (5) G1030+00.15, (6) G1042–05.69, (7) G1053+00.4, (8) G1113+00.20, (9) G1147–05.31, and (10) G1147–05.49.
10 target stars, with larger than average S/N values, were selected as candidates for detailed spectroscopic analysis. Our approach consisted of adopting the same effective temperatures from the Alonso et al. (1999) photometric calibration for the target stars and to use a sample of Fe I and Fe II lines that were tested to produce good results for the Sun, as well as the well-studied red giant Arcturus. The sampled Fe lines and their atomic parameters are listed in Table 2: for each transition the excitation potential and g-value are listed. The equivalent width measurements are presented in Table 3. The same spectrum analysis code MOOG-2002 was used in the abundance computations based on the individual equivalent width measurements. The adopted effective temperatures and derived surface gravities, microturbulent velocities, and iron abundances are presented in Table 4. A comparison of surface gravities derived using the Fe I and Fe II lines with those obtained from the automated method finds a systematic mean offset of

\[
\left[ \log g_{\text{automated}} - \log g_{\text{Fe I/Fe II}} \right] = +0.4 \pm 0.4 \text{ dex.}
\]

As the Fe II lines are quite sensitive to stellar surface gravity, this systematic offset may suggest that the surface gravities derived from our automated method are somewhat overestimated.

The derived Fe abundances from this detailed analysis are intercompared in Figure 6 with the metallicities obtained from the automated spectroscopy (top) and Washington + DDO51 photometry (bottom). The metallicity distributions are in generally good agreement. The top panel shows the standard deviation of 0.18 dex and an offset of 0.18 dex in the average [Fe/H] between the classic and automated methods. Such an offset is within the quoted uncertainties in the metallicities obtained from the automated method. Moreover, because the automated method does not measure a true Fe abundance but an overall general metallicity affected by a mixture of elements, a mild offset between the two methods is not unexpected.

An important aspect of this additional verification of the results obtained with the automated method is a check on the derived surface gravities using Fe I and Fe II lines directly, via ionization equilibrium. As discussed previously, the GGSS targets were selected from Washington photometry 2CDs to be giant stars and not dwarfs. The values of log g derived for this subsample of stars, as can be seen in Table 4, confirm their evolved status as red giants. Both the direct analysis of Fe I and Fe II ionization equilibrium and the automated direct comparison with model spectra indicate that the Washington + DDO51 2CD is an effective method for identifying red giants.

4. RV STABILITY VERSUS STELLAR PARAMETERS

We now focus on the 148 stars of the northern sample whose RVs were measured two or more times with large epoch differences (a time between successive observations of the same star not less than 4 months). From these data we estimate the RV dispersion, which we designate as \( \sigma \), and use this as a measure of variability of the RV. Note that this is not the statistical standard deviation widely designated by \( \sigma \); the present \( \sigma \) is calculated from multiple RV measures after weighting each by the inverse square of the accuracy of each RV measure (\( w_j \)). RV: \( RV_m = \Sigma RV_j w_j / \Sigma w_j \), and

\[
\sigma = \sqrt{\Sigma w_j (RV_j - RV_m)^2 / \Sigma w_j}.
\]
TABLE 5

RV Variability for the 148 McDonald Repeated Stars

| Name               | $M$ (mag) | $T_{\text{eff}}$ (K) | $D_{\text{ph}}$ (kpc) | [Fe/H]$_{\text{ph}}$ (dex) | log $g_{\text{ph}}$ (dex) | $\Delta$ log $g_{\text{ph}}$ (dex) | [Fe/H]$_{\text{sp}}$ (dex) | $\Delta$ [Fe/H]$_{\text{sp}}$ (dex) | $\sigma$ (km s$^{-1}$) | $N$ |
|--------------------|-----------|----------------------|------------------------|----------------------------|--------------------------|-------------------------------|--------------------------|-------------------------------|------------------------|-----|
| G0118+05.38        | 11.97     | 4814                 | 0.9                    | -1.0                       | 3.13                     | 0.13                          | 0.00                     | 0.05                          | 0.165                  | 2   |
| G0131+00.86        | 11.55     | 4707                 | 0.9                    | -1.2                       | 2.34                     | 0.17                          | -0.80                    | 0.14                          | 0.919                  | 2   |
| G0142+05.56        | 10.91     | 3959                 | 2.2                    | -0.9                       | 1.20                     | 0.65                          | -0.60                    | 0.28                          | 0.489                  | 2   |
| G0142+05.70        | 12.27     | 4196                 | 2.3                    | -0.6                       | 1.93                     | 0.25                          | -0.67                    | 0.25                          | 0.287                  | 2   |
| G0151+00.72        | 11.29     | 4334                 | 1.7                    | -0.6                       | 2.34                     | 0.06                          | -0.07                    | 0.22                          | 0.287                  | 3   |

Notes.—Columns are, from left to right: the name of the star, Washington $M$ magnitude (which is approximately Johnson’s $V$), effective temperature, photometric distance, photometric metallicity [Fe/H], spectroscopic surface gravity log $g$ and its accuracy, spectroscopic metallicity [Fe/H] and its accuracy, RV variability, and number of RV observations for the northern sample objects. Table 5 is published in its entirety in the electronic edition of the Astronomical Journal. A portion is shown here for guidance regarding its form and content.

Here, $w_j$ is the weight. If the accuracy of the corresponding RV was better than 50 m s$^{-1}$, we assume it equals 50 m s$^{-1}$ because of the wavelength calibration uncertainty (see §3.2).

The derived values of $\sigma$ are shown in Table 5. Figure 7 (top) shows the distribution of the $\sigma$-values (in km s$^{-1}$). That the largest number of sources occur in the first bin reveals the accuracy of our estimates and confirms that the accuracy is of the order of 50 m s$^{-1}$, as it follows from the accuracy of the wavelength calibration (§ 2.2).

We next incorporate the repeated RV data obtained with CORALIE for the southern GGSS subsample (Arenas et al. 2002) in Figure 7 (bottom) with 341 stars in this sample (see Table 6). The variation of the RV $\sigma$ for the southern stars observed two or more times is estimated by equation (1). A Gaussian curve corresponding to a $\sigma$ of 100 m s$^{-1}$ is shown in Figure 7 by a dashed line. Both southern and northern subsamples exhibit similar behavior in their respective RV variability distributions.

We found no large, apparent systematic difference in the stellar parameters between the RV-stable (low $\sigma$) and RV-unstable (high $\sigma$) fractions of the sample. However, for stars with $\sigma < 100$ m s$^{-1}$ the ranges of the stellar parameters appear to be narrower than for red giants with $\sigma > 100$ m s$^{-1}$. Thus, the fraction of RV-stable stars is low among very cool stars ($T_{\text{eff}} < 4000$ K) as well as metal-poor stars with [Fe/H] < -1.0, in agreement with previous conclusions by Jorissen et al. (1997) and Carney et al. (2003).

The fraction of RV-stable and RV-unstable stars can be estimated from the distributions of $T_{\text{eff}}$, log $g$, [Fe/H], and absolute magnitude $M_V$ presented in the left panels of Figure 8; here the distributions of stars with $\sigma < 100$ m s$^{-1}$ (dashed lines) are shown in comparison with the distributions for all stars (dotted lines). An assessment of $M_V$ with $T_{\text{eff}}$, log $g$, and an assumption of fixed mass for the red giants (we assume it is equal to 0.9 $M_\odot$; variation of the mass introduces insignificant scatter in $M_V$). The right panels of Figure 8 show the fraction of stable stars in each bin of the histograms shown on the left. As seen in the figure, the fraction of stable stars has a peak in the range 4300–4700 K (secondary peaks at the wings of the distribution are caused by small-number statistics). Note that this range corresponds to the extinction-corrected ($J - K$)$_V$ values from 0.59 to 0.73 mag, and these values do not depend on the choice of color-temperature calibration. Figure 2 shows that the bulk of the giant stars selected from the GGSS Washington + DDO51 photometry survey

TABLE 6

RV Variability for the 341 CORALIE Repeat Observation Stars

| Name               | $M$ (mag) | $T_{\text{eff}}$ (K) | $D_{\text{ph}}$ (kpc) | [Fe/H]$_{\text{ph}}$ (dex) | log $g_{\text{ph}}$ (dex) | $\Delta$ log $g_{\text{ph}}$ (dex) | $\sigma$ (km s$^{-1}$) | $N$ |
|--------------------|-----------|----------------------|------------------------|----------------------------|--------------------------|-------------------------------|------------------------|-----|
| G0000–56.81        | 11.92     | 4066                 | 3.5                    | -1.1                       | 0.004                    | 0.04                          | 0.004                  | 3   |
| G0012–28.38        | 11.71     | 3891                 | 3.8                    | -1.0                       | 0.182                    | 0.182                         | 0.182                  | 3   |
| G0016–39.1207       | 11.46     | 4418                 | 4.3                    | -2.0                       | 1.104                    | 1.104                         | 1.104                  | 7   |
| G0016–39.2075       | 11.93     | 4580                 | 1.7                    | -1.0                       | 0.635                    | 0.635                         | 0.635                  | 2   |
| G0016–39.3290       | 11.41     | 4753                 | 0.8                    | -0.7                       | 2.060                    | 2.060                         | 2.060                  | 4   |

Notes.—Columns are, from left to right: the name of the star, Washington $M$ magnitude, effective temperature, photometric distance, photometric metallicity [Fe/H], RV variability, and number of RV observations for objects of the southern sample. Table 6 is published in its entirety in the electronic edition of the Astronomical Journal. A portion is shown here for guidance regarding its form and content.
occupy this range of temperatures, showing that the GGSS happens to be optimized for selecting stars in the most RV-stable temperature range.

A similar peak takes place at log $g = 2.3-3.2$ in the surface gravity distribution. We also find that the largest fraction of RV-stable stars happens for stars of slightly subsolar metallicity ($-0.5 \leq [\text{Fe/H}] \leq -0.1$), and then the fraction of stable stars appears to drop precipitously near solar metallicity. Note, however, that the latter conclusion needs an additional check since the most metal-rich bin is only sampled by six stars.

An analog of Figure 8 is drawn for the southern subsample in Figure 9. Here we use the “photometric” $[\text{Fe/H}]$ derived by Rhee et al. (2001). The surface gravity is established by way of interpolation of the isochrones published by Bergbusch & Vandenberg (1992). The histograms for $T_{\text{eff}}$, defined by the same method for both subsamples of northern and southern stars, are qualitatively similar in Figures 8 and 9. Although the other parameters are estimated by different means, the corresponding histograms for $[\text{Fe/H}]$, log $g$, and $M_V$ are qualitatively rather similar.

In order to better constrain what types of stars may be most RV-variable, we again focus on the McDonald data and the stellar parameters derived from these spectra. In Figure 10 the values of log $g$ are plotted versus the effective temperatures; this is a spectroscopic version of an H-R diagram. Figure 10 (top) contains those stars with RV variability of less than 100 m s$^{-1}$, while Figure 10 (bottom) contains the definite RV-variable stars having
Superposed on these stellar points are isochrone curves from Girardi et al. (2000); two metallicity isochrones are shown (the solid curves have $\frac{[\text{Fe}/\text{H}]}{\text{C138}} = 0.0$ while the dashed curves have $\frac{[\text{Fe}/\text{H}]}{\text{C138}} = 0.7$) with two ages for each metallicity (3.5 and 8.9 Gyr). Plotted this way, the initial RV results indicate that those stars exhibiting variability of less than $\sim 100$ m s$^{-1}$ tend to be more concentrated in the log $g$-T$_{\text{eff}}$ plane, near the core-He-burning clump for near-solar metallicities. The stars tending to show RV variability fall all along either the well-defined first-ascent RGB or the asymptotic giant branch (AGB), both at somewhat low metallicities. Given uncertainties in both of the models and the gravities and temperatures derived by us (which almost certainly also carry some systematic differences), the concentration of possibly RV-stable red giants near $T_{\text{eff}} \sim 4500$ K and log $g \sim 2.5-3.0$ coincides quite closely to the red giant clump for stars having metallicities near solar or slightly lower. Note that the real log $g$ may have systematically lower values than those shown in Figure 10 (see also §3.4).

The possible association of quasi–RV stability with the red giant clump can be investigated further by including the southern sample, although we do not have spectroscopically derived gravities for these stars. For a relatively old population, however, the effective temperature of the clump does not vary much if the metallicity does not vary by much; this can been seen by inspecting the isochrones in Figure 10. The indications from the McDonald results are that the RV-stable red giants are only mildly metal-poor with a relatively small dispersion in metallicity.

For the 36 McDonald RV-stable stars having $T_{\text{eff}} = 4500 \pm 200$ K...
correspond to the core-He-burning red giant phase of stellar evolution. The concentrated clump of RV-stable stars may correspond to the core-He-burning red giant phase of stellar evolution.

Fig. 10.—Spectroscopically derived surface gravity, \( \log g \), vs. \( T_{\text{eff}} \) for the McDonald northern sample. Top: Stars with \( \sigma < 100 \text{ m s}^{-1} \). Bottom: Stars with RV variability greater than 100 m s\(^{-1}\). The RV-stable stars are more concentrated in the \( \log g-T_{\text{eff}} \) plane than the variables. The continuous curves are isochrones from Girardi et al. (2000), with the dashed curves having [Fe/H] = −0.7 and the solid curves [Fe/H] = 0.0. The two isochrones for each metallicity have ages of 3.5 and 8.9 Gyr, respectively. The concentrated clump of RV-stable stars may correspond to the core-He-burning red giant phase of stellar evolution.

The mean metallicity is [Fe/H] = −0.5 ± 0.2. The combined northern and southern samples are plotted as effective temperature histograms in Figure 11, where the sample has been segregated using \( \sigma \). There is a clearly defined clump of potentially RV-stable stars with \( T_{\text{eff}} \approx 4500 \text{ K} \) that probably corresponds to core-He-burning red giants with mild metal deficiencies. The stars with \( \sigma > 100 \text{ m s}^{-1} \), shown in Figure 11 (bottom), are significantly more dispersed in \( T_{\text{eff}} \), with almost equal numbers over a range in effective temperature; our suggestion is that these are primarily first-ascent giants or AGB stars, as well as intrinsically RV-stable stars (such as clump giants) that have companions. The fraction of stars whose RV variability is caused by components is not known from our observations. Demonstrating the presence of companions will require many more repeated observations.

Preliminary results from monitoring of photometric variability of a subsample of GGSS stars by Bizyaev et al. (2004) reveal no correlation between RV and brightness variations. However, more precise and simultaneous photometric and spectroscopic observations are needed to shed light on the nature of the RV variations in red giants.

4.1. Strategies for Selecting SIM Astrometric Grid Stars

Our analysis gives insight into the optimal selection of giant stars for the SIM astrometric grid if time and resources are limited (as indeed they are) for ground-based vetting of large numbers of stars for the most RV-stable specimens.

As can be seen in Figure 11, a higher fraction of stars with \( \sigma < 100 \text{ m s}^{-1} \) can be found with 4300 K < \( T_{\text{eff}} \) < 4700 K. This is a simple, straightforward selection criterion resulting in an initial success rate of 50% in finding RV-stable red giants. As a point of reference, the entire northern sample contains 39% stable stars and the southern sample contains 32%. If high-resolution spectra are also used to derive surface gravities and metallicities, the additional constraints of −0.5 < [Fe/H] < −0.1 and \( 2.3 < \log g < 3.2 \) lead to a 81% and 40% success rate for the northern and southern samples, respectively, yet significantly narrow the sample. Note that the northern sample restricted simultaneously by all stellar parameters reveals the fraction of RV-stable stars to be close to findings by Frink et al. (2001).

More attention to exploring the solar and higher metallicity ranges is warranted because if the relatively low RV-stable fraction we find at these solar-like metallicities is borne out, it would have serious ramifications for the currently selected SIM astrometric grid sample, which is dominated by giant stars randomly selected from the Tycho catalog. Spectroscopic metallicities measured for nearly 500 Tycho giants by J. Crane (2006, in preparation) in the preferred magnitude range \( V < 11 \) for the SIM grid stars indicate a median metallicity for this sample of [Fe/H] = −0.1, and perhaps larger (i.e., 0.0 dex) if the arguments for the need of a +0.1 dex correction to the local metallicity scale are applied (Reid 2002; Haywood 2002). Thus, a significant fraction...
of the Tycho sample is at metallicities at which a large fraction of stars may have troublesome atmospheric jitter.

5. CONCLUSIONS

We are carrying out high-resolution spectroscopic observations of an all-sky sample of giants that was preselected based on the GGSS program of Washington photometry. The GGSS was intended to identify stars with the highest likelihood of astrometric stability, namely, subsolar-metallicity red giants. The main purpose of the present study is to make an initial assessment of the RV variability properties of GGSS stars as a function of their atmospheric characteristics. The RV variation was estimated for 489 stars with spectroscopy taken on both northern and southern telescopes. Basic stellar parameters were estimated for the northern subsample from high-resolution spectroscopy.

A surprisingly high fraction of investigated giant stars have unstable RVs at the 100 m s$^{-1}$ level: about two-thirds of our sample. Both of the samples, northern and southern, although having been observed independently and with different instruments and techniques, show similar distributions of RV variability. Although a number of obvious spectroscopic binaries are included in this sample, much of the low-amplitude RV variability is probably due to atmospheric motions and temperature inhomogeneities.

A higher fraction of stars with $\sigma < 100$ m s$^{-1}$ can be found among the objects with $3400 < T_{eff} < 4700$ K, which corresponds to $(J-K)_0 = 0.59-0.73$. If we incorporate spectroscopic metallicity and surface gravity information as well, and select only stars with $-0.5 < [\text{Fe/H}] < -0.1$ and $2.3 < \log g < 3.2$, it will help to identify RV-stable candidates more effectively but will narrow the sample of potential candidates substantially. From the point of view of minimizing expensive observations, the optimal method of preliminarily selecting RV-stable stars is to use the effective temperature, or more exactly, the calibration-independent range of near-IR colors as $0.59 < (J-K)_0 < 0.73$. This range encompasses 44% of stars with $\sigma < 100$ m s$^{-1}$ in both our southern and northern samples; 38.5% of the initial GGSS sample of candidate astrometric grid stars (1710 of 4440) lies in this range. The result obtained here will aid in the continuing efforts to define the astrometric reference grid for SIM.

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