The Astrophysical Journal Letters, 724:L104–L108, 2010 November 20 doi:10.1088/2041-8205/724/1/L104

THE RAVE SURVEY: RICH IN VERY METAL-POOR STARS*

Jon P. Fulbright[1], Rosemary F. G. Wyse[1], Gregory R. Ruchti[1], G. F. Gilmore[2], Eva Grebel[3], O. Bienaymé[4], J. Binney[5], J. Bland-Hawthorn[6], R. Campbell[7], K. C. Freeman[8], B. K. Gibson[9], A. Helmi[10], U. Munari[11], J. F. Navarro[12], Q. A. Parker[13], W. Reid[13], G. M. Seabroke[14], A. Siebert[4], A. Siviero[12,15], M. Steinmetz[15], F. G. Watson[6], M. Williams[15], and T. Zwitter[16]

[1] Department of Physics & Astronomy, Johns Hopkins University, 366 Bloomberg Center, 3400 North Charles Street, Baltimore, MD 21218, USA
[2] Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK
[3] Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg, Mönchhofstr. 12–14, D-69120 Heidelberg, Germany
[4] Observatoire de Strasbourg, 11 Rue de L'Université, 67000 Strasbourg, France
[5] Rudolf Pierls Center for Theoretical Physics, University of Oxford, 1 Keble Road, Oxford OX1 3NP, UK
[6] Anglo-Australian Observatory, P.O. Box 296, Epping, NSW 1710, Australia
[7] Western Kentucky University, Bowling Green, KY, USA
[8] RSAA Australian National University, Mount Stromlo Observatory, Cotter Road, Weston Creek, Canberra, ACT 72611, Australia
[9] Jeremiah Horrocks Institute for Astrophysics & Super-computing, University of Central Lancashire, Preston, UK
[10] Kapteyn Astronomical Institute, University of Groningen, Postbus 800, 9700 AV Groningen, The Netherlands
[11] INAF Osservatorio Astronomico di Padova, Via dell'Osservatorio 8, Asiago I-36012, Italy
[12] University of Victoria, P.O. Box 3055, Station CSC, Victoria, BC V8W 3P6, Canada
[13] Macquarie University, Sydney, NSW 2109, Australia
[14] Mullard Space Science Laboratory, University College London, Holmbury St Mary, Dorking, RH5 6NT, UK
[15] Astrophysikalisches Institut Potsdam, An der Sternwarte 16, D-14482 Potsdam, Germany
[16] Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, Ljubljana, Slovenia
Received 2010 September 7; accepted 2010 October 13; published 2010 November 2

ABSTRACT

Very metal-poor stars are of obvious importance for many problems in chemical evolution, star formation, and galaxy evolution. Finding complete samples of such stars which are also bright enough to allow high-precision individual analyses is of considerable interest. We demonstrate here that stars with iron abundances [Fe/H] $<$ -2 dex, and down to below -4 dex, can be efficiently identified within the Radial Velocity Experiment (RAVE) survey of bright stars, without requiring additional confirmatory observations. We determine a calibration of the equivalent width of the calcium triplet lines measured from the RAVE spectra onto true [Fe/H], using high spectral resolution data for a subset of the stars. These RAVE iron abundances are accurate enough to obviate the need for confirmatory higher-resolution spectroscopy. Our initial study has identified 631 stars with [Fe/H] $\leqslant -2$, from a RAVE database containing approximately 200,000 stars. This RAVE-based sample is complete for stars with [Fe/H] $\lesssim -2.5$, allowing statistical sample analysis. We identify three stars with [Fe/H] $\lesssim -4$. Of these, one was already known to be "ultra metal-poor," one is a known carbon-enhanced metal-poor star, but we obtain [Fe/H] $=$ -4.0, rather than the published [Fe/H] $= -3.3$, and derive [C/Fe] $= +0.9$, and [N/Fe] $= +3.2$, and the third is at the limit of our signal-to-noise ratio. RAVE observations are ongoing and should prove to be a rich source of bright, easily studied, very metal-poor stars.

Key words: Galaxy: abundances – Galaxy: stellar content – stars: abundances – stars: Population II

1. INTRODUCTION

Very metal-poor (VMP) stars, defined conventionally as having [Fe/H] < -2 (Beers & Christlieb 2005), are of interest in many outstanding problems in star formation and galaxy evolution. For example, the detailed shape of the metal-poor tail of the metallicity distribution of field stars of the Milky Way can distinguish different models of chemical evolution, constraining gas flows, the nature of the progenitor systems in which stars form, and pregalactic enrichment (e.g., Prantzos 2009). Elemental abundance patterns of VMP stars are sensitive to the high-redshift stellar initial mass function, star formation process, and possibly identify the sources responsible for reionization of the universe (Bromm & Larson 2004).

Detailed elemental abundances of metal-poor stars require high-resolution high-quality spectroscopy. Thus, apparently bright targets with high probability of being truly very metal-poor are desirable. We demonstrate in this Letter that the Radial Velocity Experiment (RAVE) survey is an ideal source of bright metal-poor stars; these can be identified directly from the RAVE data, with no need for confirmatory higher-resolution spectroscopy. We derive the calibration by which the RAVE parameters may be placed on a true iron abundance scale, valid for [Fe/H] values as metal-poor as -4 dex, into the regime of "ultra metal-poor stars" in the nomenclature of Beers & Christlieb (2005).

2. IDENTIFYING VERY METAL-POOR STARS IN THE RAVE SURVEY

2.1. The RAVE Survey

The RAVE (Steinmetz et al. 2006; Zwitter et al. 2008) is a spectroscopic survey of apparently bright stars, $I \lesssim 13$, with some 350,000 stars observed to date. RAVE uses the six-degree-field (6dF) multi-object, fiber-fed spectrograph on the UK Schmidt telescope. Spectra of $\sim$100 targets are obtained simultaneously. The dominant target population belongs to the thin disk, but includes many thick disk and halo giant stars. The spectra are centered on the infrared calcium triplet, cover

* Based in part on observations collected at the European Organization for Astronomical Research in the Southern Hemisphere, Chile, in the framework of proposals 081.B-0900 and 080.B-0927.

the wavelength range region λλ8410–8795 and have resolving power $R \sim 7500$. This is significantly higher than that which is typically employed in surveys to find metal-poor candidates for later confirmation—for example, the Hamburg/ESO survey (HES; Christlieb et al. 2004) is based on objective-prism spectra with $R \sim 400$ at the Ca II K line at 3934 Å. We show here that RAVE has the resolution to determine the metal-poor nature of a star directly from the survey spectra, without the need for follow-up confirmation, providing ideal targets for later detailed analysis.

The RAVE spectral analysis pipeline provides estimates for each star of the line-of-sight velocity and the stellar parameters ($T_{\rm eff}$, $\log g$, [m/H], and $v \sin i$) through χ^2 fits to a grid of synthetic spectra.[17] RAVE pipeline metallicities ($[{\rm m/H}]_{\rm RAVE}$) have uncertainty of ∼0.2 dex, derived from an external calibration of high-quality spectra of predominantly metal-rich stars, which dominate the sample (Zwitter et al. 2008). The grid of synthetic spectra utilized extends to $[{\rm m/H}] = -2.5$, requiring additional analysis below this limit: we provide that here.

2.2. *Isolating Candidate Very Metal-poor Stars in RAVE*

The RAVE survey is designed primarily to obtain excellent line-of-sight velocities. This has been achieved, with accuracy and precision of a few km s^{-1} for the vast majority of the stars (Steinmetz et al. 2006). A large subset of the spectra has sufficiently high signal-to-noise ratio (S/N) for the RAVE pipeline also to provide good quality estimates of the values of stellar parameters (Zwitter et al. 2008). At the start of the present investigation, the RAVE (internal) database contained over 147,000 spectra from which stellar parameters were derived. How do we identify VMP stars among these? Stars with true metallicity near or below the lower limit of the synthetic spectra in the RAVE pipeline (−2.5 dex) will be assigned metallicities close to that lower limit. A metallicity cut in the RAVE database of, say, 3σ above the lower bound, $[{\rm m/H}]_{\rm RAVE} \leqslant -1.8$, should then isolate probable VMP stars. Adopting this cut and isolating only normal stars gives a sample of 622 potential metal-poor stars.

Furthermore, extremely metal-poor stars will be erroneously assigned to significantly higher metallicities by the RAVE pipeline. The RAVE spectrum of a typical VMP star is nearly featureless, with only the Ca triplet lines being measurable, as shown in Figure 1. There exists a degeneracy between the stellar parameters and metallicity, in that the strengths of the Ca triplet lines can be equal for both a lower-metallicity cooler giant and a higher-metallicity hotter turnoff star. A temperature difference of 100 K corresponds to a $[{\rm m/H}]_{\rm RAVE}$ difference of about 0.1 dex, assuming the parameters of the star still lie along an appropriately metal-poor old evolutionary track. Hence, stars for which the RAVE $T_{\rm eff}$ value is significantly hotter than the value that is derived by other indicators are likely to be stars whose real [m/H] values are significantly lower than $[{\rm m/H}]_{\rm RAVE}$. This expectation is confirmed by identification in the RAVE database of several known VMP stars, incorrectly allocated $[{\rm m/H}]_{\rm RAVE} > -1.8$, including CD $-38^\circ 245$ with $[{\rm Fe/H}] = -4.2$ (Cayrel et al. 2004) and CS 29502-092 with $[{\rm Fe/H}] = -2.76$ (Aoki et al. 2007). As anticipated, known VMP stars with anomalously high $[{\rm m/H}]_{\rm RAVE}$ values also have anomalously high estimated stellar effective temperatures from the RAVE pipeline.

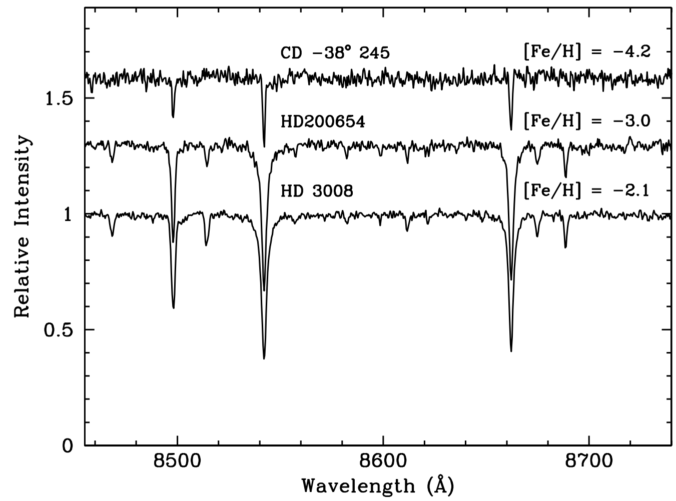

Figure 1. RAVE spectra of three metal-poor stars, with our derived iron abundance estimates (consistent with previous estimates in the literature). Note the dominance of the Ca II triplet lines, and the growing strength of Fe I and other species as [Fe/H] increases.

Temperature anomalies may be identified using photometric temperatures. Photometry from the Two Micron All Sky Survey (2MASS; Cutri et al. 2003) is available for the RAVE sample, so that an effective temperature, $T_{\rm phot}$, may be calculated using the (de-reddened) color–$T_{\rm phot}$ relationship of Alonso et al. (1999), with due care to use the two-color relations to check for cool binary companions. The mean value of $E(B-V)$ for our candidate metal-poor stars is 0.11 mag (median 0.06 mag). We assume conservatively that the stars of interest are beyond the reddening layer, since their estimated distances based on the stellar parameters are typically several hundred parsecs to a few kiloparsecs from the Sun.

These $T_{\rm phot}$ values allow us to adopt the following modified criterion to define a candidate VMP star:

$$[{\rm m/H}]_{\rm RAVE} - 0.1((T_{\rm RAVE} - T_{\rm phot})/(100\,{\rm K})) < -1.8.$$

Application of this selection criterion to the RAVE database of non-variable stars within the appropriate temperature range to be halo turnoff/red giant stars ($7000\ {\rm K} < T_{\rm RAVE} < 3800\ {\rm K}$) yields 320 stars in addition to those selected by the straight cut $[{\rm m/H}]_{\rm RAVE} \leqslant -1.8$. The total number of stars we selected for further analysis of their RAVE spectrum, based on the above criteria, is then 942.

3. DERIVATION OF [FE/H] ABUNDANCES

3.1. *Equivalent-width Analysis of RAVE Spectra*

For each candidate VMP star, we measure the equivalent width (EW) of the Ca triplet and Fe I lines from the RAVE spectrum.[18] These EW values are then the input for an abundance analysis using the MOOG program (Sneden 1973), assuming LTE and one-dimensional, plane-parallel Kurucz model atmospheres.[19] We adopted the NLTE corrections of Starkenburg et al. (2010) for all our stars (in the end significant only for stars with $[{\rm Fe/H}] < -2.5$).

[17] The quantity [m/H] here designates the total amount of metals with respect to the solar value. We will use [Fe/H] to refer to only the iron content.

[18] At least one of the Ca II lines is too strong in the majority of the candidates. All three Ca II lines could be used in 132 stars; for these the mean dispersion is 0.26 dex, consistent with our final estimated error.

[19] The most recent versions of the Kurucz atmospheres can be found at http://kurucz.harvard.edu/.

The estimates of stellar gravity from the RAVE pipeline analysis identify most VMP candidates as giants: 86% of these stars have RAVE log $g < 3$, with the mean RAVE log g value being 1.0 ± 0.9. Stellar gravity values from the RAVE pipeline are accurate to better than 0.5 dex for the typical metal-rich stars in the RAVE database (Zwitter et al. 2008). For metal-poor stars, the lower-metallicity cutoff of the synthetic spectrum grid biases the pipeline analysis to overestimate, systematically, both $T_{\rm eff}$ and log g values, so the actual fraction of true giants in the VMP sample should be even higher. Indeed, there were only four stars whose location on a reduced proper-motion diagram indicated that they were dwarfs. For these we adopt log $g = 4.5$. The stellar surface gravity for the remaining stars was obtained by fitting to an old (12 Gyr) Yonsei-Yale isochrone (Demarque et al. 2004) with a metallicity matching the current metallicity estimate of the star (the procedure is iterated). The gravity value derived from the isochrone fitting was adopted in the calculation of the model atmosphere (while the Yonsi-Yale isochrones do not extend beyond the red giant branch, <0.1 dex error in final abundance results should a star be actually on the asymptotic giant branch). Our analysis was iterated until the derived (from CaT) metallicity did not differ by more than 0.1 dex from the value used in calculating the model atmosphere and isochrone fit. We were able to derive Ca abundances for 771 stars out of our 942 star initial selection from RAVE: these 771 stars form our VMP candidate sample.

The next step is to provide an external calibration of our abundance scale, derived from high signal-to-noise echelle spectra.

3.2. Metallicity Calibration via Echelle Observations

We obtained echelle spectroscopic data for 112 candidate metal-poor stars selected from the RAVE database using a preliminary version of the criteria described above. The observations were carried out with several telescope/spectrograph combinations, including Magellan-Clay/MIKE, APO-3.5m/ARCES, AAT/UCLES, Max Planck-2.2m/FEROS, CFHT/Espandons, and VLT/UVES. Full details of the data acquisition and reduction are deferred to our Letter on the derived elemental abundances (J. P. Fulbright et al. 2011, in preparation). Briefly, all spectrographs delivered a resolving power greater than 30,000 and, with the exception of the UCLES setup, the wavelength region covered from below 4000 Å to beyond 8000 Å, albeit with some coverage gaps. The effective wavelength range for the UCLES spectra is 4460–7260 Å. In each case the data were reduced using standard methods for echelle data, utilizing pipeline programs when available. The typical S/N level of the spectra is greater than 100 pixel^{-1} and often exceeds 200 pixel^{-1}.

The abundance analysis utilized Kurucz stellar atmospheres and the MOOG program, with now the metallicity of the stellar atmosphere for each star set equal to the value of [Fe II/H] derived from the analysis. The value of the stellar effective temperature was derived using the excitation temperature method based on Fe I lines. The mean difference of $T_{\rm ex} - T_{\rm phot}$ is -66 ± 138 K. The value of the stellar gravity was again taken to be that value corresponding to the derived $T_{\rm eff}$ on an old (12 Gyr) Yonsi-Yale isochrone of the appropriate metallicity. The microturbulent velocity was set to the value that minimized the slope of the relationship between the iron abundance derived from Fe I lines and the value of the reduced EW of each line. The Fe I lines measured in the RAVE spectra are usually too weak in true VMP stars to give reliable results. The iron abundances derived from these lines were useful, however, in rejecting from the analysis those (few) stars for which the Ca triplet lines appeared weak, but the Fe I lines were strong. Further inspection of the spectra of these stars revealed that the Ca lines are likely weakened by emission cores.

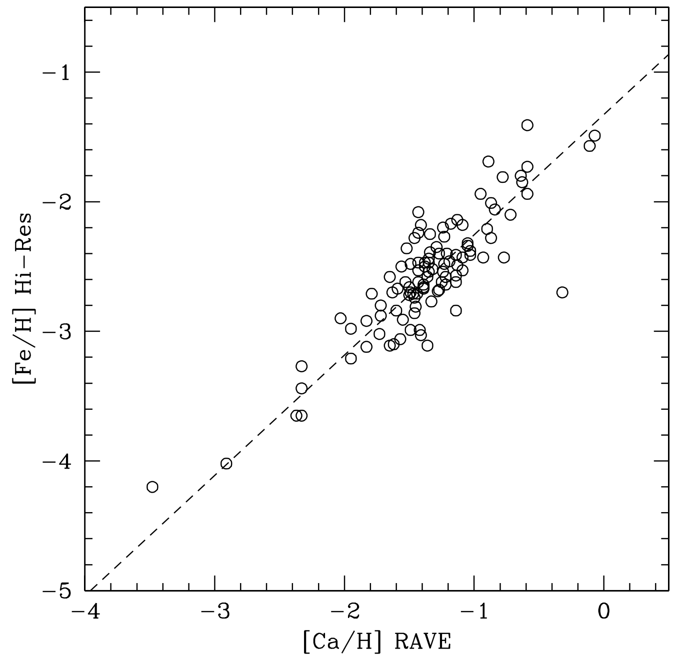

Figure 2. Calibration of the calcium abundance derived from the RAVE spectra onto iron abundance, using [Fe/H] from high-resolution echelle spectra, for 112 stars.

The iron abundances from the echelle data provide an immediate check on our selection criteria. The result is encouraging: of the 92 stars with echelle data for which we predicted [Fe/H] < -2 from the RAVE data, 87 (95%) indeed have [Fe/H] values below -2.

Calibration of the RAVE EW abundances is then achieved through least-squares fitting between the echelle-based iron abundance, $[\mathrm{Fe/H}]_{\rm Hi-Res}$, and the EW-based calcium abundance from the RAVE spectra, $[\mathrm{Ca/H}]_{\rm RAVE}$. The correlation between these two quantities is shown in Figure 2 and the relationship is

$$[\mathrm{Fe/H}]_{\rm Hi-Res} = 0.93[\mathrm{Ca/H}]_{\rm RAVE} - 1.33,$$

with a correlation coefficient of 0.82 and standard deviation of the residuals of 0.25 dex.

4. THE STELLAR [FE/H] ABUNDANCE DISTRIBUTION FUNCTION AT LOW METALLICITY

The calibration obtained from the echelle data was applied to the 771 VMP candidates from RAVE for which the MOOG analysis provided the calcium abundance. The RAVE-based [Fe/H] abundance distribution function that resulted is shown as the solid line histogram in Figure 3; this contains a total of 612 stars with true iron abundance [Fe/H] < -2 dex.

4.1. Distribution Function Completeness

Given that our candidate sample had an upper metallicity cutoff determined by uncertain quantities, significant incompleteness at the high-metallicity end is expected. We check this using published catalogs of candidate VMP stars and a second RAVE study.

A SIMBAD-aided literature search showed that only 47 of our 612 very metal-poor stars ([Fe/H] < -2 dex) have

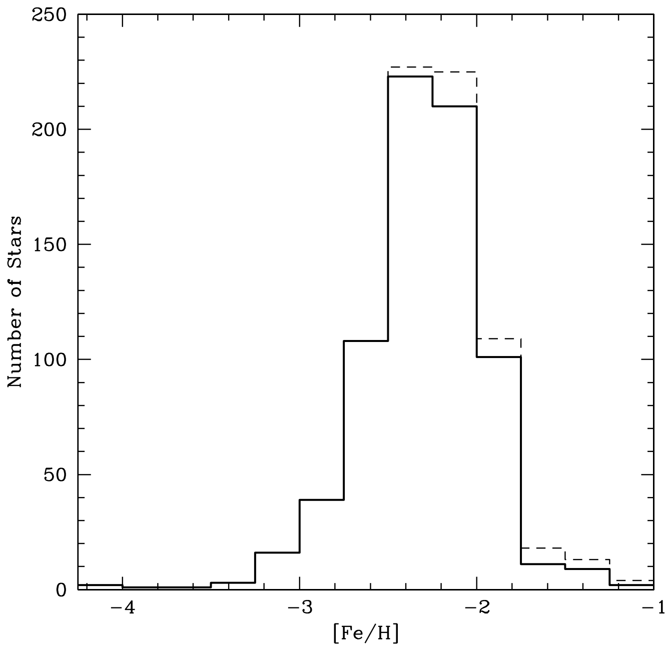

Figure 3. Distribution of calibrated iron abundances [Fe/H], for the sample of VMP stars selected from the RAVE database (solid line). The dashed histogram includes the VMP stars from the re-analysis of RAVE spectra for candidates from the HES survey and from Ruchti et al. (2010).

previously been proposed as being metal-poor, from low-resolution spectroscopic analyses, including 21 from Frebel et al. (2006) and 11 from Bond (1980). Ten of the 138 stars for which we derive $-2 <$ [Fe/H] < -1 also have entries in SIMBAD identifying them as VMP candidates.

The most uniform comparison is with the HES catalog of over 20,000 candidate VMP stars (Christlieb et al. 2008). Cross-identification with the RAVE database (at that time with 200,000 entries) yielded 473 matches, with HES metallicity estimates for 296 stars, all with $[\mathrm{Fe/H}]_{\mathrm{HES}} \leqslant -2$. One hundred nine of these stars are included in our RAVE VMP sample. The RAVE pipeline gave $[\mathrm{m/H}]_{\mathrm{RAVE}} < -1$ for 76 of the remaining 187 stars. We re-analyzed these RAVE spectra as above, obtaining [Fe/H] < -1 for only 22 stars, with just 4 with [Fe/H] < -2, of which the most metal-poor has [Fe/H] $= -2.26$. These stars are therefore all very close to the VMP threshold.

The high-resolution sample of Ruchti et al. (2010) was selected from the same RAVE catalog as this study and includes 20 stars for which those authors derive [Fe/H] < -2 from their echelle spectra but which were not selected by our VMP criteria. We re-analyzed the RAVE spectra of these stars following the procedures developed above and found good agreement: [Fe/H] < -2.0 for 15 stars, and all 20 stars having [Fe/H] < -1.7. The lowest iron abundance of this group is -2.41 dex, within 2σ of our calibration. Approximately half of these stars have $[\mathrm{m/H}]_{\mathrm{RAVE}}$ between -1.5 and -1.8, the remainder having RAVE spectra of low quality. As expected, measuring errors in our parent RAVE sample lead to increasing incompleteness in our final sample, at above [Fe/H] ~ -2.5.

4.2. The Low-metallicity Tail of the Distribution Function

At very low metallicities, we test for true VMP stars observed by RAVE, but excluded from our sample, by cross-matching the RAVE database with published catalogs of confirmed VMP stars. There are 253 RAVE stars in the HERES project (Barklem et al. 2005), which provides high-resolution follow-up for HES catalog stars. There are only two candidate VMP matches: J112243.4-020936 (RAVE) is HE1120-0153 (HERES) and J132244.1-135531 (RAVE) is HE1320-1339 (HERES). Our VMP star criteria identified both, and our calibration gave each an iron abundance of [Fe/H] $= -2.6$. The HERES values are [Fe/H] $= -2.77$ and -2.78, respectively, in excellent agreement. No confirmed very metal-poor star has been excluded from our RAVE sample.

There are three stars in our RAVE sample at or below -4 dex. These are C0022448-172429 for which we derive, from this calibration, [Fe/H] $= -4.0$ dex, CD $-38°245$ for which we derive [Fe/H] $= -4.2$ dex, and a third star, with a RAVE spectrum at our minimum acceptable RAVE S/N cutoff, which our calibration gives [Fe/H] $= -4.0$ dex. Our echelle-based result for C0022448-172429 is $[\mathrm{Fe/H}]_{\mathrm{Hi-Res}} = -4.02$, and for CD $-38°245$ is $[\mathrm{Fe/H}]_{\mathrm{Hi-Res}} = -4.20$. CD $-38°245$ was previously confirmed from echelle data to have [Fe/H] $= -4.2$ by Cayrel et al. (2004). Our RAVE-based calibration is indeed providing true iron abundances to $\sim$0.25 dex accuracy, even at the lowest known metallicities.

Our analysis is the first confirmation of the "ultra metal-poor" nature, [Fe/H] < -4 dex, of C0022448-172429. The low-resolution, objective-prism HES spectrum for C0022448-172429 (Christlieb et al. 2008, where this star is identified as HE0020-1741) provided estimates of -3.0 and -3.3, depending on which methods those authors used. Christlieb et al. further estimate that C0022448-172429 is carbon-rich, with [C/Fe] $= +1.0$. Our echelle analysis confirms the carbon-rich nature, with our value being [C/Fe] $= +0.9$, and we find that this star has an extremely high nitrogen abundance, [N/Fe] $= +3.2$. Thus, this star joins the select group of carbon-enhanced metal-poor (CEMP) stars (see Norris et al. 2010 for a recent discussion of this class of object).

Although this makes our selection function not internally consistent, adding the identified extra VMP stars after re-analysis of their RAVE spectra (15 from Ruchti et al., plus 4 from the HES cross-check) to our main sample of 612 VMP stars, results in the dashed histogram in Figure 3. This contains 631 stars with [Fe/H] $\leqslant -2$ dex, i.e., "very metal-poor," and two stars with [Fe/H] < -4, i.e., "ultra metal-poor" and one at ~ -4 dex. Five hundred sixty seven of these VMP stars were not known to be VMP previously, and one of the two ultra metal-poor stars is a new confirmation. The remaining star at ~ -4 dex has no previous published abundance determination and due to its marginal quality RAVE spectrum remains as a candidate, awaiting scheduled high-resolution follow-up; if confirmed this would be a new discovery.

5. CONCLUSIONS

The RAVE Survey allows identification of large and complete samples of apparently bright, very metal-poor (VMP) stars, ideal for subsequent detailed analysis. We have defined a sample of 612 stars with [Fe/H] < -2, based on some 200,000 spectra in the RAVE database (which currently contains 350,000 spectra). This includes two stars with [Fe/H] $\leqslant -4$ dex, one of which was previously known, the other of which is a new ultra metal-poor star, with the previous estimate of iron abundance being too high by 0.7–1.0 dex. This star belongs to the interesting CEMP class, having [C/Fe] $= +0.9$, and [N/Fe] $= +3.2$. A third (new) metallicity -4 candidate remains to be confirmed. Only six (Frebel 2010) such ultra metal-poor stars were known prior to this study. Comparison to other samples indicates that our completeness limit at the metal-rich end is [Fe/H] ≈ -2.5.

It is very likely that our sample is complete for more metal-poor stars.

We note here, and will discuss elsewhere, that the shape of our metallicity distribution function below [Fe/H] ~ -2.8, where we are complete, is in excellent agreement with the independent determinations from the (low-resolution) HES survey (Schörck et al. 2009; Li et al. 2010).

Our technique uses a selection criterion based on the values of $[m/H]_{RAVE}$ and effective temperature from the RAVE pipeline analysis, plus a photometric effective temperature. The original RAVE spectrum of a star that passes the criterion is re-analyzed to determine the EWs of the Ca T lines and Fe I lines. We calibrate the (re-measured) RAVE metallicity onto true iron abundance, [Fe/H], through an echelle-based calibration derived in this Letter. The efficiency of our technique for finding VMP stars is very high, demonstrated by the fact that ~95% of the stars that we determine by our calibration to have [Fe/H] $<$ -2 indeed have echelle-based [Fe/H] in this range. There is no need for follow-up, higher spectral resolution data to confirm this derived iron abundance. Since the mean *I* magnitude of the RAVE sample of VMP stars is ~10.5, follow-up detailed elemental abundance analyses are both straightforward and efficient. The RAVE survey is ongoing, and the final RAVE database should at least triple the current sample size.

We thank the staff of Siding Spring Observatory, Apache Point Observatory, and Las Campanas Observatory for their assistance. J.P.F. thanks Jennifer Johnson and Howard Bond for useful suggestions. J.P.F., R.F.G.W., and G.R.R. acknowledge support through grants from the W. M. Keck Foundation and the Gordon and Betty Moore Foundation, to establish a program of data-intensive science at the Johns Hopkins University. This publication made use of 2MASS, a joint project of the University of Massachusetts and IPAC/Caltech, funded by NASA and the NSF, and of the VizieR databases, operated at CDS, Strasbourg, France. R.F.G.W. and G.R.R. acknowledge support from the NSF through grant AST-0908326. Support for RAVE (www.rave-survey.org) has been provided by institutions of the RAVE participants and by their national funding agencies. R.F.G.W. thanks the Aspen Center for Physics for providing a stimulating environment during the writing of this Letter.

Facilities: UKST (6dF), ARC (ARCES), CFHT (Espandons), Magellan:Clay (MIKE), VLT:Kueyen (UVES), Max Planck:2.2m (FEROS)

REFERENCES

Alonso, A., Arribas, S., & Martinez-Roger, C. 1999, A&AS, 140, 261
Aoki, W., Beers, T. C., Christlieb, N., Norris, J. E., Ryan, S. G., & Tsangarides, S. 2007, ApJ, 655, 492
Barklem, P. S., et al. 2005, A&A, 439, 129
Beers, T. C., & Christlieb, N. 2005, ARA&A, 43, 531
Bond, H. E. 1980, ApJS, 44, 517
Bromm, V., & Larson, R. B. 2004, ARA&A, 42, 79
Cayrel, R., et al. 2004, A&A, 416, 1117
Christlieb, N., Scharck, T., Frebel, A., Beers, T. C., Wisotzki, L., & Reimers, D. 2008, A&A, 484, 721 (HES)
Christlieb, N., et al. 2004, A&A, 428, 1027
Cutri, R. M., et al. 2003, 2MASS All-Sky Catalog of Point Sources, VizieR, II/246
Demarque, P., Woo, J.-H., Kim, Y.-C., & Yi, S. K. 2004, ApJS, 155, 667
Frebel, A. 2010, Astron. Nachr., 331, 474
Frebel, A., et al. 2006, ApJ, 652, 1585
Li, H., et al. 2010, A&A, 521, L10
Norris, J. E., Gilmore, G., Wyse, R. F. G., Yong, D., & Frebel, A. 2010, ApJ, 722, L104
Prantzos, N. 2009, in IAU Symp. 254, The Galaxy Disk in Cosmological Context, ed. J. Andersen, J. Bland-Hawthorn, & B. Nordström (Cambridge: Cambridge Univ Press), 381
Ruchti, G., et al. 2010, ApJ, 721, L92
Schörck, T., et al. 2009, A&A, 507, 817
Sneden, C. 1973, ApJ, 184, 839
Starkenburg, E., et al. 2010, A&A, 513, 34
Steinmetz, M., et al. 2006, AJ, 132, 1645
Zwitter, T., et al. 2008, AJ, 146, 421