SURVEYS FOR METAL-POOR STARS IN THE GALAXY: A NEW WINDOW ON THE LOW-ABUNDANCE UNIVERSE

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1. Introduction

Measurement of the abundances of the light and heavy elements in stars of the Milky Way galaxy is the cornerstone for the study of numerous aspects of chemical evolution in galaxies and the Universe. We stand poised to enter an era of rapid understanding, as new-generation telescopes with apertures in the 8m-10m class enable astronomers to obtain high-resolution, high-signal-to-noise near-UV, optical, and IR spectra of the stars which have locked up the chemical history of our Galaxy in their outer atmospheres. It is thus appropriate to review present surveys for the low-metallicity stars of our Galaxy, as the stars we uncover today will be studied so intensively in the coming decades.

2. The Complex Environment of the Milky Way

Astronomers' view of the formation history of the Milky Way has changed dramatically in recent years, as we have recognized the importance of what appears to be an ongoing process of heirarchical assemblage within the Local Group. The terminology in modern use reveals this complexity. The visible components of our Galaxy, once summarized as the Bulge, Disk, and Halo, are now subdivided into the Bulge, the Bar, the Thin Disk, the Thick Disk, the Metal-Weak Thick Disk, the Low Halo, and the High Halo. Stars (*e.g.*, the BMPs, see Preston *et al.* 1994), as well as entire globular clusters (Layden and Sarajedini, 1997), have been discovered in the halo of the Milky Way which are likely to have been donated in the past by accreted dwarfs like Sagittarius. Thus the halo itself, once thought to be the home of exclusively "old" stars, probably contains stars of a wide range of ages (at least several billion years), even among the most metal-deficient stars (see Preston 1994 for a detailed discussion of one such star).

To a great degree, the realization of complexity has been driven by moderate- to high-resolution spectroscopic observations of stars with metal abundances [Fe/H] < -2.5, *lower* than the most metal-deficient globular clusters. As recently as ten years ago, such stars were not thought to exist in any great number. However, long-term survey efforts by a number of groups have smashed through this "chemical barrier," and forged toward ever-lower-abundance stars, presently as metal-deficient as [Fe/H] ~ -4.0. Below we summarize the known samples of these stars, comment briefly on their characteristics, and close with a discussion of future followup studies of these extremely metal-poor stars.

3. Present Surveys for Metal-Poor Stars

Beers *et al.* (1992) describe an objective-prism/interference-filter technique for the identification of large numbers of candidate low-metallicity stars in the Galactic halo. The HK survey, as it has come to be known, is based on some 300 prism plates covering roughly 1/6th of the sky in the northern and southern hemisphere. Visual inspection of the survey plates (with a 10 X microscope) has resulted in the selection of some 10,000 low-metallicity candidates in the magnitude range $10.5 \leq B \leq 15.5$. For the past 15 years, follow-up medium-resolution (1–2 Å) spectroscopy and

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TABLE 1. Summary of the Metal-Poor Star Sample

Sample	N ≤ -1.5	N ≤ -2.0	N ≤ -2.5	N ≤ -3.0	N ≤ -3.5	N ≤ -4.0
LCL/RN	578	256	79	11 (29)	4	1 (1)
HK (BPSII)	726	540	197	29 (73)	5	1 (1)
HK (NEW)*	1100	700	300	50 (150)	10	4 (8)
TOTAL*	2500	1500	600	100 (250)	20	5 (10)

* Approximate numbers

broadband *UBV* photometry of these stars has been obtained with 1m- to 2m-class telescopes from Las Campanas, Kitt Peak National Observatory, the European Southern Observatory, Siding Springs Observatory, and the Canary Islands. The observational efforts from Siding Springs, the Canary Islands, and Kitt Peak are essentially finished; observations from ESO will be completed by spring 1998. Spectra for roughly half of the low-metallicity candidates have been obtained to date; results based on some 3000 spectra will soon be submitted for publication. Broadband photometry has been obtained for some 3500 of these stars (Preston *et al.* 1991; Norris *et al.* 1997); narrowband photometry is available for a smaller subset, in particular the most metal-deficient stars (Schuster *et al.*, 1996) .

The HK survey is not the only source for stars of extremely low metal abundance. Other large survey efforts have contributed stars with [Fe/H] < -1.5, primarily based on proper-motion selection criteria. In Table 1 we summarize the available stars from three programs. The first set are the kinematically-selected samples of Ryan and Norris (1991) and Carney *et al.* (1994). The second is the published list of stars from the HK survey (Beers *et al.*, 1992), labelled here as BPS II (note that abundances for these stars have been estimated anew using a more recent calibration; see Beers *et al.* 1997). The third subsample is the combined set of HK candidates from recent (as yet unpublished) followup efforts.

Note that for the stars in Table 1 with [Fe/H] ≤ -3.0 and ≤ -4.0 we have listed parenthetically the numbers of stars with [Fe/H] ≤ -2.8 and ≤ -3.8, respectively, in order to emphasize the effect which small changes in metallicity estimates might have on the cumulative numbers of stars below a given abundance. The factor of two to three discrepancy seen in the numbers of stars with [Fe/H] ≤ -2.8 and [Fe/H] ≤ -3.0 underscores the need for a uniform set of high-resolution determinations of the abundances of ALL stars in our sample with [Fe/H] ≤ -2.5.

4. Interpretations

Several general conclusions have already been reached from analysis of the nature of the low metallicity tail of the Metallicity Distribution Function (MDF), based on the above surveys. First, the so-called "Simple Model" of galactic chemical evolution (Hartwick, 1976) fails in the sense that is predicts too many metal-poor stars with abundances less than [Fe/H] $= -3.0$. The apparent limit of metal deficiency among presently-observable stars in the Galaxy is [Fe/H] ~ -4.0, as foreshadowed from the analysis of Audouze and Silk (1995). If the Galaxy was able to produce significant numbers of stars with abundances below -4.0, they are presumably fainter than $B = 15.0$, and located well outside the solar neighborhood, beyond the reach of present-day surveys.

Tantalizing departures from expectations of a "smooth" MDF have been noticed among stars with [Fe/H] < -2.0 – an "overdensity" of stars in the metallicity range $-2.8 <$ [Fe/H] < -2.6 may be the signpost of the typical metallicity level obtained after the first generations of massive supernovae contributed their processed material into the interstellar medium (see Figure 1). Alternative explanations of this feature are possible. For example, it might be associated with the metallicity level reached by typical dwarf galaxies which have been subsequently disrupted and dispersed into the halo of the Milky Way.

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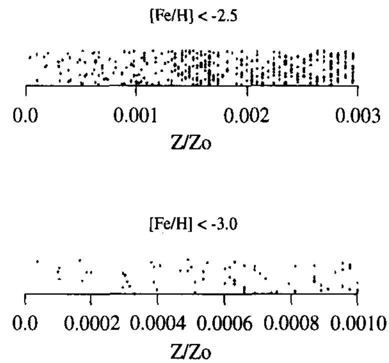

Figure 1. Density plots of observed abundances for stars in the combined sample. The position of each star has been randomized along the vertical direction.

5. Future Surveys

As the sample of low-metallicity stars enlarges, greater complexities have been revealed. We can expect this trend to continue in the near future. Thus, we should endeavor to devise new approaches for increasing the samples of stars identified as having the lowest possible elemental abundances. Several efforts are already underway to accomplish this task, and others will no doubt be launched. In the rush toward ever lower stellar metallicities, it is well to remember that stars of modest metal deficiency are also of great importance. For example, the transition from stars with disk-like to halo-like kinematics lies in the metallicity regime $-2.0 \leq [Fe/H] \leq -1.0$ (see Beers and Sommer-Larsen 1995). This is the same region where the dominant contributors to the chemistry of our Galaxy appears to change from primarily the ejecta from Type II supernovae to that of Type I supernovae.

The original HK survey plates are presently being scanned with the APM machine in Cambridge, in collaboration with Mike Irwin. Each plate typically yields 5000 classifiable spectra, hence we expect the final sample of stars available for automatic inspection to exceed one million, down to a magnitude of $B \sim 15.0$. A neural network is presently being implemented, and trained with the extensive set of metal-poor stars available from the visual survey. This approach is greatly aided by the existence of moderately-accurate color information obtained by recently-calibrated photographic surveys of the northern and southern sky. We anticipate the identification of additional metal-weak stars which were missed in the visual classification pass, in particular among the cooler stars where metal-deficiency is more difficult to recognize. As the peak of the halo MDF is at $[Fe/H] \sim -1.5$, we also expect to identify large numbers of stars centered around this abundance.

A new HK survey is planned with the UK Schmidt telescope, hopefully beginning in 1998. This new survey will consist of approximately 100 (unwidened) spectral plates, covering 3600 square degrees of the southern sky, to be taken with an interference filter which with a wider passband than the original survey. Test exposures indicate that we might expect to obtain roughly 50,000 classifiable spectra per plate down to a magnitude of $B \sim 18.0$. This deep sample of metal-poor stars will enable an *in-situ* study of the distant halo of our Galaxy, and should be ideal for investigations of possible changes in the MDF of stars far from the solar neighborhood. Other interesting objects, such as field horizontal-branch stars up to 20-30 kpc from the Sun, should be readily identifiable as well.

Another large survey, known as the ESO/Hamburg Survey (Reimers and Wisotzki 1997; Christlieb *et al.* 1997; Wisotzki *et al.* 1997), is presently yielding substantial numbers of metal-poor star candidates based on automated scans of some 425 plates covering 9000 square degrees of sky down to $B \sim 17$. Of particular importance, the ESO/Hamburg survey plates include coverage of portions of

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the southern sky which were not sampled by the HK survey. Thus, this survey should provide a large number of newly-discovered metal-poor stars with apparent magnitudes which are suitable for rapid follow-up high-resolution spectroscopic analysis (*i.e.*, in the magnitude range $13.5 \leq B \leq 14.5$).

6. Future Followup

Long lists of candidate metal-poor stars are only the first step. Plans are presently underway for conducting followup spectroscopic and photometric observations of as many of these newly-identified metal-poor stars as possible. Telescopes of aperture 1.5-2m are ideal for moderate-resolution (1-2 Å) spectroscopy of single stars, in the "one-by-one" mode which has proven so successful for followup of the HK candidates. New collaborative efforts with observatories having suitable equipment is a vital step in order for this long-term work to succeed. Multiple-star moderate-resolution spectroscopy (50-100 stars at a time) is now becoming possible using wide-field fibre spectrographs such as Watson's FLAIR (Parker, 1997). In order to fully exploit this approach, plans are underway for the design and construction of automatic fiber positioning equipment for FLAIR.

Intermediate-resolution (0.2-0.3 Å) spectroscopy in the "single-star" mode of thousands of metal-poor stars is presently being planned for the Hobby-Eberly telescope. These "quick-look" spectra should be ideal for the rapid identification of the most interesting candidates for futher detailed study at high resolution.

High-resolution (0.03-0.1 Å), high signal-to-noise ($S/N > 100/1$) spectroscopy in the single-star mode is the capstone project of the analysis of the most metal-deficient stars (see, *e.g.*, Ryan *et al.* 1996). Essentially all of the 8m-10m class telescopes will have suitable equipment for such work. What is required, however, is the commitment of the community in order to set aside the several MONTHS worth of large telescope time required to assemble this valuable data set. The ultimate reward will be high-quality data for samples of 500-1000 stars of the Milky Way with metallicities $[Fe/H] < -2.5$, from which vital clues to the evolution of elemental abundance patterns in the Universe can be extracted.

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