Abundance Ratios in the Galactic Bulge and Super Metal-Rich Type II Nucleosynthesis: Pitfalls of the Analysis

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We present abundance results from our Keck/HIRES observations of giants in the Galactic Bulge. We confirm that the metallicity distribution of giants in the low-reddening bulge field Baade’s Window can be well-fit by a closed-box enrichment model. We also confirm previous observations that find enhanced $[\text{Mg/Fe}]$, $[\text{Si/Fe}]$ and $[\text{Ca/Fe}]$ for all bulge giants, including those at super-solar metallicities. However, we find that the $[\text{O/Fe}]$ ratios of metal-rich bulge dwarfs decrease with increasing metallicity, contrary to what is expected if the enhancements of the other $\alpha$-elements is due to Type II supernovae enrichment. We suggest that the decrease in oxygen production may be due to mass loss in the pre-supernova evolution of metal-rich progenitors.

1. INTRODUCTION

The Galactic Bulge contains about 20 percent of the Galaxy’s stellar mass. Theories of its formation include a primordial free-fall collapse, remnants of accretion episodes, or secular evolution of bar instabilities ([1]). Accurate stellar abundance determinations can help distinguish between these models.

Early investigations of bulge stars [2] found a range of metallicity in the bulge, including a population of metal-rich stars. McWilliam & Rich [3] obtained the moderate-resolution echelle data for 11 bulge K giants. The analysis of these spectra found enhancements in the $[\text{X/Fe}]$ ratios for the $\alpha$-elements Mg and Ti, including stars with overall metallicities greater than solar. These enhancements can be best explained by a rapid chemical evolution history dominated by Type II supernovae [5].

The limited quality and sample size of the McWilliam & Rich data demanded a renewed effort to study stellar abundances in the bulge. We have been engaged in a long-term program to study the composition of stars in the Galactic bulge, with the aim of constraining the conditions of the bulge’s formation and chemical evolution at a level of detail that is impossible to obtain with any other method.

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2. DATA

The observational data consist of Keck/HIRES spectra of 28 bulge giants observed between 1998 and 2001. All of the target stars are located within Baade’s Window, a region of low reddening located about 4 degrees from the Galactic center.

The spectra have a resolving power of 45,000 to 60,000. Typical signal-to-noise levels are about 50:1. The spectrograph settings allow for a wavelength coverage of approximately 5400–7800 Å, but there are considerable gaps in the coverage toward the red. The spectra were reduced using T. Barlow’s pipeline reduction program MAKEE.

In addition to the bulge stars several bright local disk giants were observed using the 2.5-m du Pont telescope and its echelle spectrograph. Although the resolution of these spectra is slightly lower than the Keck data, the signal-to-noise ratio of these spectra generally exceed 200:1. These giants were picked to have similar stellar parameters as the bulge giants in order to act as a comparison sample.

3. ANALYSIS

The abundance analysis employs the LTE 1-D spectrum synthesis program MOOG [6] and the grid of LTE model atmospheres from the Kurucz web page (http://kurucz.harvard.edu). The Fe line list was created by searching the Kurucz line list for all Fe lines in the wavelength region that are unblended and of the appropriate range of strengths. Many of these Fe lines do not have laboratory gf-values available, so we conducted our analysis differentially from Arcturus, a well-studied nearby giant. This should help reduce any systematic errors in the analysis related to atomic data and stellar atmospheres.

Additional details on the analysis method, including determining continuum regions, finding stellar parameters, and the details of the abundance analysis of the non-iron lines will be presented in a series of papers in the near future.

4. RESULTS

4.1. Metallicity Distribution Function

The metallicity distribution function (MDF) is an indicator of the enrichment history of a system. Large samples can be obtained [3, 7] using low resolution spectra in order to measure the MDF of Baade’s Window. Sadler et al. found that the mean metallicity is greater than solar and the MDF is well-fit by a closed-box gas exhaustion model.

Our high-resolution sample can be used to recalibrate the earlier low-resolution works. When this is done to the 268 stars of the Sadler et al. sample, we find that our recalibration finds an exponential distribution of \(Z/Z_\odot\) similar to that found in the earlier results. However, this preliminary recalibration assumes \(Z\) goes as \([\text{Fe}/H]\), which may not be fully accurate. As we will see later Baade’s Window giants to not show solar ratios of many of the alpha elements. Correcting for this would increase the values of \(Z\) for bulge stars.

4.2. Oxygen and Magnesium Abundances

Oxygen is the third most common element in the Universe behind only hydrogen and helium. Enhanced \([\text{O}/\text{Fe}]\) ratios have traditionally been used to indicate a population heavily enriched by Type II supernovae. If the bulge enrichment pattern was dominated
by Type II supernovae, as indicated by the enhancement of other alpha elements (bottom panel of Figure 1), then the [O/Fe] ratios as well should be uniformly enhanced in bulge stars. However, in Figure 1 we see that the [O/Fe] distribution among bulge stars follows the same trend seen in the local disk giants.

Figure 1: The distribution of [O/Fe] (top) and [Mg/Fe] (bottom) vs. [Fe/H] for stars of various populations. The solid circles denote the Baade’s Window sample, the solid squares the local disk giant comparison sample, and the smaller shapes literature samples of various populations. The literature data come from [8, 9].
The bulge distribution of the other α-elements follows the pattern predicted to be produced by Type II supernovae. This creates a quandary: Type II models (e.g. [10]) predict that O and Mg are produced in similar mass progenitors. There are no major producers of Mg other than Type II supernovae. Therefore, why do O and Mg not show similar distributions?

A possible solution may be due to the fact that while O and Mg should come from similar stars, they are not formed in similar layers within those stars. Oxygen is produced during hydrostatic helium burning while magnesium comes from hydrostatic carbon and neon burning. In high-metallicity high-mass stars, post main-sequence mass loss can remove a large fraction of the star’s original mass. During this Wolf-Rayet phase it may be possible that the final hydrostatic He-burning layer could be greatly reduced or even lost completely while the C-burning layer could be preserved. The Wolf-Rayet progenitor models of ref. [10] do not predict this amount of mass loss, so further work is necessary to confirm this hypothesis.

5. FUTURE DIRECTIONS

The analysis of the bulge data continues. The spectra exhibit absorption lines of many elements not discussed here, including C, N, Na, Al, Fe-group elements and many elements heavier than the Fe-group, including several of the traditional indicators of the s- and r-processes. In addition, we have obtained data in three other fields at different Galactic latitudes. This will allow for the investigation of the homogeneity of the chemical properties of the bulge to be studied, which may reveal evidence of galactic accretion or multiple star formation events.

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