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High resolution infrared spectra of bulge globular clusters

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Abstract.
Using the NIRSPEC spectrograph at Keck II, we have obtained high resolution, echelle spectra covering the range $1.5-1.8$ μm for 2 of the brightest giants in Liller 1 and NGC 6553, old metal rich globular clusters in the Galactic bulge. We use spectrum synthesis for the abundance analysis, and find [Fe/H] $=-0.3\pm0.2$ and [O/H] $=+0.3\pm0.1$ (from the OH lines) for the giants in both clusters. We measure strong lines for the alpha elements Mg, Ca, and Si, leading to a general [α/Fe] $=+0.3\pm0.2$ dex. The composition of the clusters is similar to that of field stars in the bulge and is consistent with a scenario in which the clusters formed early, with rapid enrichment.

Key words. Bulge – Globular Clusters – Abundances – IR spectroscopy

1. Introduction

Bulge globular clusters are a fundamental stellar population of our Galaxy. In order to understand the history of their formation and chemical enrichment, it is of primary importance to compare their detailed abundance patterns with those of the Galactic bulge field population (McWilliam, and Rich 1994).
Nevertheless, many of these bulge clusters suffer of huge foreground extinction as to largely preclude optical studies of any kind, particularly at high spectral resolution. Unlike the visual range, the near infrared spectral domain is particularly suitable to study these cool stellar systems, being the reddening corrections, the blanketing effects and the background contamination by Main Sequence stars much less severe, allowing to properly characterize the red stellar sequences even though strongly affected by extinction and crowding.
Here we present new, high resolution spectra taken with NIRSPEC, a high throughput infrared echelle spectrograph at the Keck Observatory (McLean 1998), of a few bright giants in the core of Liller 1 and NGC 6553.
Both are relatively massive globular clusters lying 2.5 kpc from the Galactic Center and reasonably coeval with the Galaxy's oldest populations (Coelho et al. 2001;

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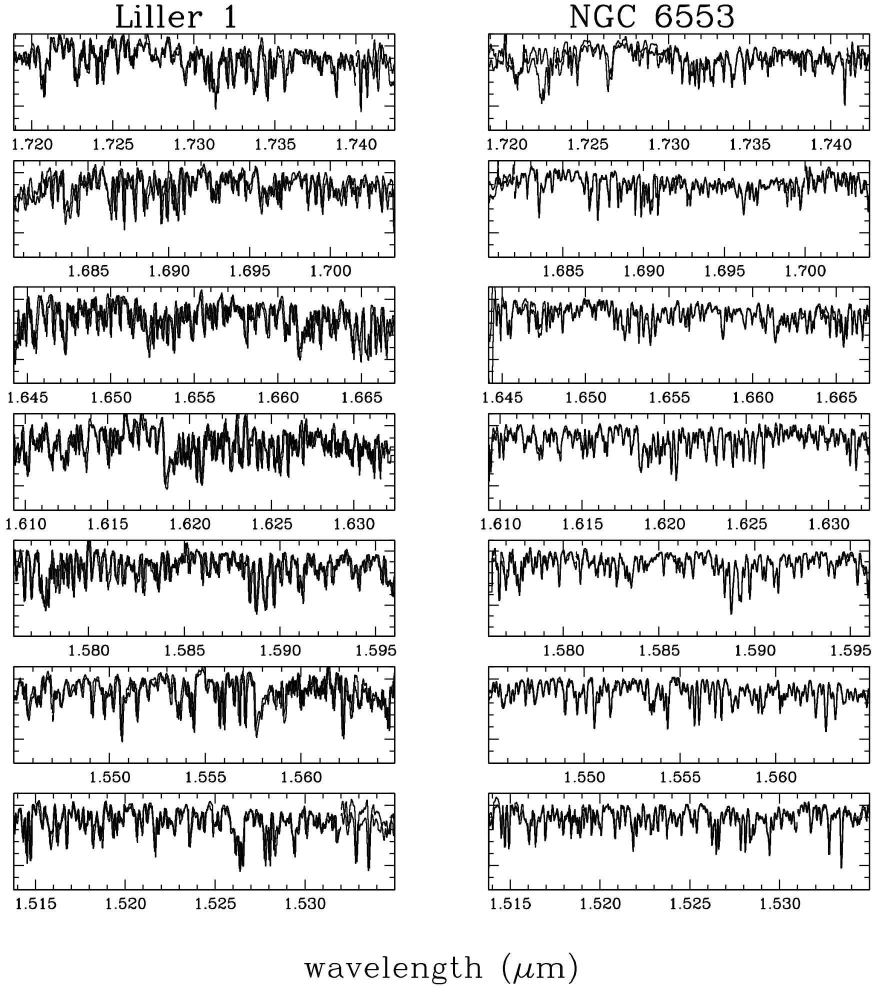

Fig. 1. High-resolution NIRSPEC echelle spectra of two bright giants in the cores of the bulge globular clusters Liller 1 and NGC 6553, obtained at Keck II.

Zoccali et al. 2001).

In the last few years these clusters have been the subject of both optical and near infrared photometry (Frogel, Kuchinski, and Tiede 1995; Ortolani, Bica, and Barbuy 1996; Guarnieri et al. 1998; Davidge 2000; Zoccali et al. 2001). Integrated spectra of their innermost core regions in the optical (Bica, and Alloin 1986; Armandroff, and Zinn 1988) and in the near infrared (Origlia et al. 1997; Frogel et al. 2001) are also available, while only for NGC 6553 optical spectra of individual red stars at both low (Minniti 1995; Coelho et al. 2001) and and high resolution (Barbuy et al. 1999; Cohen et al. 1999; Carretta et al. 2001) have been obtained. Despite the relative large number of photometric and spectroscopic measurements, the inferred abundances are still somewhat discrepant, leaving open the question of the cluster actual metallicities.

2. Observations and Spectral Analysis

Near infrared, high-resolution echelle spectra of two bright giants in the cores of the bulge globular clusters Liller 1 and NGC 6553 have been obtained on 26 July 2000. We used the infrared spectrograph NIRSPEC (McLean 1998) which is equipped with an ALADDIN 1024×1024 InSb array detector and mounted at the Keck II telescope. The spectrograph employs a single echelle grating in quasi-littrow mode with a 5° out-of-plane angle and a lower resolution grating with a smaller blaze angle and zero out-of-plane angle as cross disperser. The slit has a width of 0.43" (3 pixels) and a length of 12" and the nominal resolving power is R=25,000 (i.e. 12 km s^{-1}). We employed the standard NIRSPEC-5 setting, which uses the H-band filter and covers most of the 1.5-1.8 micron band with only small inter-order gaps.

The raw frames were background subtracted and flat fielded. Each order of the echellogram has been then extracted and straightened according to its tilt angle. The normalized 1D spectra have been obtained summing over the 3 brightest rows and dividing by the continuum, which was determined applying a low-pass smoothing filter through each spectrum. The atmospheric features have been removed using a reference O-star spectrum. The wavelength calibration uses the OH sky lines (Oliva, and Origlia 1992); we computed a quadratic spline in the dispersion direction with an overall accuracy of ≈0.16 Å or equivalently ≈3 km s^{-1}. The final spectra are reported in fig. 1.

By using the CO ($\Delta v = 3$) and OH ($\Delta v = 2$) molecular lines in the 1.5-1.8 μm spectral window we can infer reliable carbon and oxygen abundances (Lambert et al. 1984). Other metal abundances can be derived from the atomic lines of Fe I, Mg I, Si I and Ca I, although heavily saturated and somewhat less sensitive to the element abundance variation compared to the molecular lines.

Suitable synthetic spectra of giant stars by varying the stellar parameters and the element abundances have been computed, using an updated version of the code described in Origlia, Moorwood, and Oliva (1993). From the near infrared photometry of Liller 1 and NGC 6553 published by Frogel, Kuchinski, and Tiede (1995); Guarnieri et al. (1998) and their E(J–K) reddening of 1.70 and 0.41, respectively, we compute the $(J–K)_0$ colors and by using the color-temperature transformation of Montegriffo et al. (1995) specifically calibrated on globular cluster giants, we derive the stellar temperature of the observed stars. The two giants in Liller 1 are the brightest in the cluster and we infer T_{eff} ≈3700 and 3900 K, while those in NGC 6553 have T_{eff} ≈3900 and 4000 K. The expected uncertainty in the temperature estimate is ≤200 K. Concerning the stellar gravity, according to the theoretical evolutionary tracks, in the high metallicity domain the expected values for the stars in the upper part of red giant branch are log g≤1.0, depending on their actual luminosity and temperature (Origlia et al. 1997).

3. Results

By using the above reference stellar parameters, for both clusters the best fits to the line profiles and equivalent widths of the observed spectra have been obtained for half Solar [Fe/H], Solar [O/Fe] and a similar enhancement by a factor of ≈2 for the other α elements (Si, Mg, Ca).

We also find some ^{12}C depletion and ^{14}N enhancement (by a factor of ≈2, as well), as expected from the first dredge-up mixing process in the stellar interior during the evolution on the red giant branch (Boothroyd, and Sackmann 1999). The fit also gives the $[^{12}C/^{13}C]$≤5 ratio. Such a low value cannot be explained by first dredge-up alone and requires some extra-mixing processes occurring during the last ascent of the red giant branch (Boothroyd, and

Sackmann 1999).
Our iron abundance estimate is somewhat in between the values proposed by Barbuy et al. (1999) and by Cohen et al. (1999) as revised by Carretta et al. (2001). An overall excess of α-elements (by a factor of $\approx$2) is found by all the high resolution studies.
Our findings are consistent with recent abundance determinations for field stars in the Galactic bulge (Rich, and McWilliam 2000), for which [O/Fe] $\approx$ +0.3 at [Fe/H]=0 using the forbidden oxygen line at 6300 Å.
According to the long-held paradigm that massive star supernovae mainly enrich the interstellar medium with alpha-elements, while iron-like elements are predominantly produced at later epochs by supernovae with intermediate mass progenitors (Wheeler, Sneden, and Truran 1989; McWilliam 1997), our abundance patterns in NGC 6553 and Liller 1 add one more piece of evidence consistent with early and rapid bulge formation (Matteucci, Romano, and Molaro 1999; Wyse 2000).

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