Mem. S.A.It. Vol. 79, 503

Memorie della

Chemical abundances in the Galactic bulge

M. Zoccali[1], A. Lecureur[2], V. Hill[2], B. Barbuy[3], A. Renzini[4], D. Minniti[1], A. Gómez[2], and S. Ortolani[5]

[1] Departamento de Astronomía y Astrofí sica P. Universidad Católica de Chile Av. Vicuña Mackenna 4860, Macul, Santiago, Chile, e-mail: mzoccali, dante@astro.puc.cl
[2] Observatoire de Paris-Meudon, 92195 Meudon Cedex, France, e-mail: Aurelie.Lecureur, Vanessa.Hill, Ana.Gomez@obspm.fr
[3] Universidade de São Paulo, IAG, Rua do Matão 1226, Cidade Universitária, São Paulo 05508-900, Brazil, e-mail: barbuy@astro.iag.usp.br
[4] INAF - Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 2, I-35122 Padova, Italy, e-mail: alvio.renzini@oapd.inaf.it
[5] Università di Padova, Dipartimento di Astronomia, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy, e-mail: sergio.ortolani@unipd.it

Abstract. We spectroscopically characterize the Galactic Bulge to infer its star formation timescale, compared to the other Galactic components, through the chemical signature on its individual stars. O, Na, Mg, Al were obtained for 50 K giants in four fields towards the Galactic bulge from UVES spectra (R=45,000), while Fe was measured in more than 400 stars with a slightly low resolution (R=20,000) and the GIRAFFE spectrograph at VLT. Oxygen and Magnesium show a well defined trend with [Fe/H], with abundances larger than those measured in both thin and thick disk stars, supporting a scenario in which the bulge formed before and more rapidly than the disk. On the other hand the iron distribution peaks at solar metallicity and it is slightly narrower than that measured in previous works. Part of the present results have been published by Zoccali et al. (2006) and Lecureur et al. (2007), and part will be discussed in forthcoming papers.

Key words. Stars: abundances – Galaxy: bulge – Galaxy: abundances

1. Introduction

Chemical abundances in the Galactic bulge are important fossil records of its formation. Being the Galactic bulge the only galactic spheroid for which abundances can be derived from high resolution spectroscopy on individual stars, they are crucial for our understanding of the formation of spheroids in general. Until now, only two abundance studies have been carried on on bulge giants using high resolution spectroscopy. The first one, by McWilliam & Rich (1994), the only reference for many years, is based on high resolution (R=17,000) spectra for 11 stars, used to calibrate the iron abundance measured in a sample of 88 stars observed at lower resolution. Similarly, the latest such study by Fulbright, McWilliam & Rich (2006) use 27 calibrator stars observed at R=60,000 to re-calibrate the low resolution measurements by Sadler, Rich & Terndrup (1996) and Rich (1988). The lack of high-res multi-object spectrographs for did not allow to derive a metallicity distribution function where *all* the stars, and not only some calibrators, had accurate measurements. The situation has changed now: we have collected spectra for about 1000 bulge field stars at the VLT-UT2 with the FLAMES fibre

2. The Data

All the stars were observed with the GIRAFFE arm of the instrument, with resolution R=20,000, while 58 of them have *also* been observed with the UVES arm, at higher resolution R=45,000 in the range 5800-6800 Å. In the colour-magnitude diagram, these stars are located on the red giant branch, about 1 magnitude above the red clump, with the exception of 13 stars in Baade's Window that instead are on the red clump itself. The LTE abundance analysis was performed using well tested procedures (Spite 1967) and the new MARCS models (Gustafsson et al. 2002). Spectrum synthesis was performed with *turbospec* (Alvarez & Plez 1998) and counterchecked with Barbuy et al. (2003), including the effects of molecular lines on the derived atomic abundances. spectrograph.

3. Oxygen and Magnesium

The resulting [O/Fe] vs. [Fe/H] for the 50 UVES stars is shown in Fig. 1.

The upper panel of this figure shows that our results are in good agreement with previous measurements by McWilliam & Rich (2004) and Rich & Origlia (2005). Not shown here, but also overlapping with our data, are also the measurements of 27 stars by Fulbright, McWilliam & Rich (2007) and further 7 stars by Cunha & Smith (2006). The lower panel shows the [O/Fe] vs. [Fe/H] ratios in the bulge compared with those for the thick and the thin disks (Bensby, Feltzing & Ludström 2004). These measurements are as consistent as possible, in the sense that they come from the same line, and we have intentionally adopted the same atomic parameters both for oxygen and for nickel. The solar oxygen abundance to which the disk stars were referred was lower by 0.06 dex, so an identical downward shift was then applied to their measurements. This plot shows that the thin disk, thick disk, and bulge evolved through different chemical trajectories. In other words, bulge stars did not originate in the disk and then migrate inward to build up the bulge, but rather formed independently of the disk (Minniti 1995; Ortolani et al. 1995). Moreover, the chemical enrichment of the bulge, hence its formation timescale, has been faster than that of the thick disk, which in turn was faster than that of the thin disk (Matteucci, Romano & Molaro 1999).

4. Iron

At the moment, iron has been measured in the GIRAFFE spectra of three of the four fields, for a total of 720 stars. The resulting metallicity distribution function (MDF) is the first one obtained entirely from high resolution spectra. The MDF measured in each individual field is shown in Fig. 3. Also shown are the MDF for thin and thick disk stars, approximated with gaussians (mean and sigma from Nordström et al 2004), scaled to the percentage contamination estimated with the Besançon model of the Galaxy (Robin et al. 2003). A radial gradient is clearly seen, with the mean metallicity going from ¡[Fe/H]¿=−0.03 in Baade's Window ($b = -4°$) to ¡[Fe/H]¿=−0.28 in the field at $b = -12°$). No gradient was recently detected between Baade's Window and a more internal field at $b = -1°$ by Rich, Origlia & Valenti (2007), however they observed 14 and 17 stars, respectively, and the lack of gradient might be due to the low statistics.

Finally, Fig. 4 compares the MDF obtained in the present work for Baade's Window with the one in Fulbright, McWilliam & Rich (2006) for the same field. While the discrepancy between the two seems quite strong, it is important to remember that they measured only 27 stars (shown as black histogram). Indeed, the discrepancy between the two MDF at high metallicity is likely due to some systematics in the low resolution data, given that

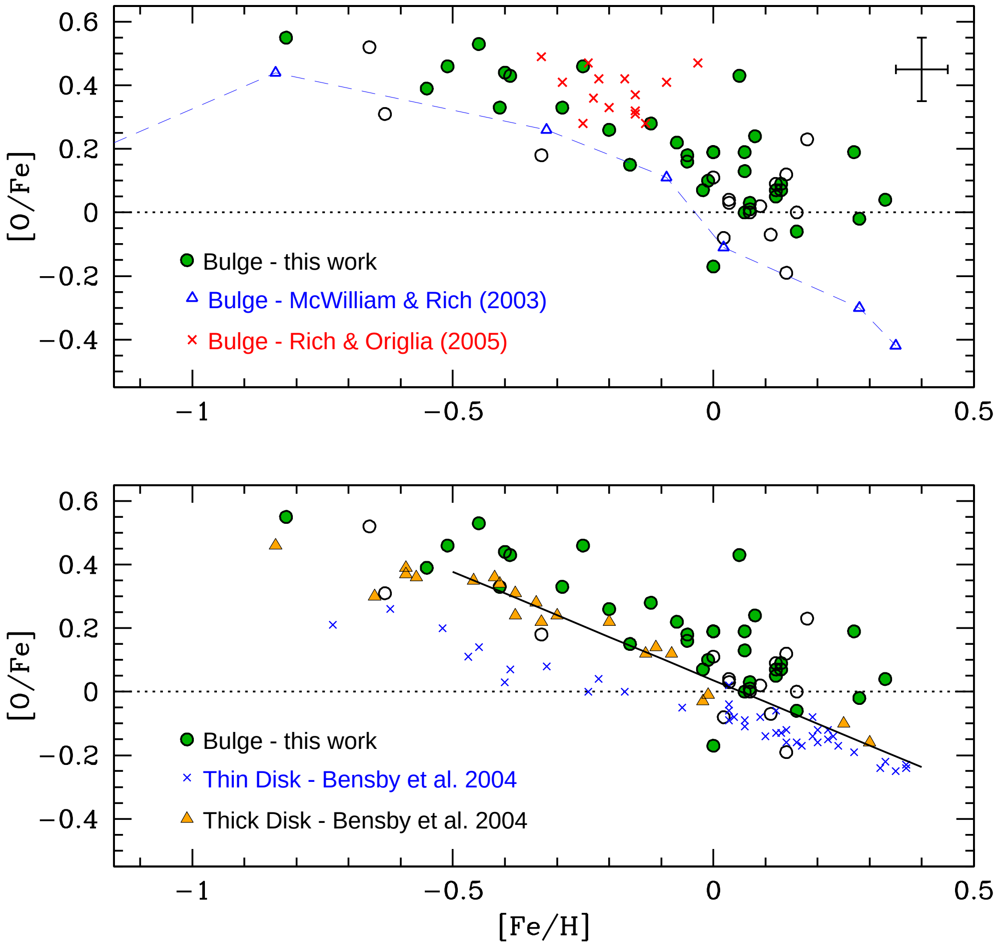

Fig. 1. Top panel: The bulge [O/Fe] vs [Fe/H] trend obtained in the present work compared with the previous results. Open circles are stars with lower quality measurements, due to a combination of colder temperature and slightly lower S/N. Bottom panel: Oxygen/iron trend in our bulge stars vs. that for thick and thin disk stars. The solid line shows a linear fit to the thick disk data points with [Fe/H]> −0.5 and is meant to emphasize that all bulge stars with −0.4 <[Fe/H]< +0.1 are more oxygen-enhanced than thick disk stars. This plot enlightens the systematic, genetic difference between bulge and disk stars, thus excluding that bulge stars were once disk stars that then migrated inward to build up the bulge.

the Fulbright et al. recalibration does not extend above [Fe/H]=+0.40.

Acknowledgements. This work has been partly funded by the FONDAP Center for Astrophysics 15010003 (MZ and DM). DM acknowledges the European Commission's ALFA-II programme, through its funding of the Latin-American European Network for Astrophysics and Cosmology (LENAC). BB and DM acknowledge grants from the CNPq and Fapesp. SO acknowledges the Italian Ministero dell'Università e della Ricerca Scientifica e Tecnologica (MURST) under the program "Fasi iniziali di evoluzione dell'alone e del bulge Galattico" (Italy).

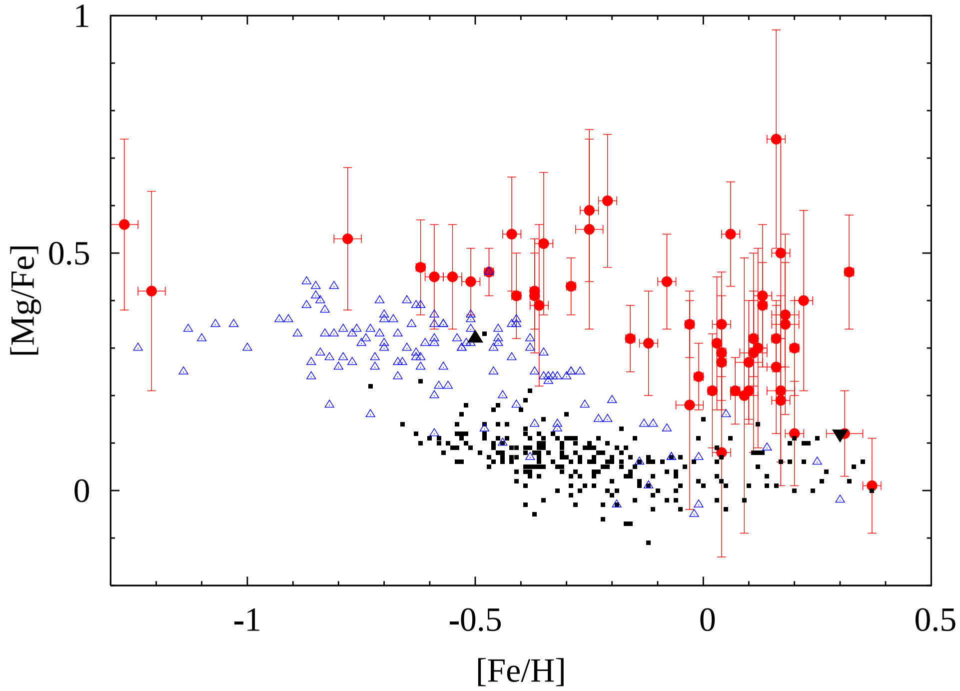

Fig. 2. Same as Fig. 1 for Magnesium in the bulge (full dots) thick (open triangles) and thin disk (small squares).

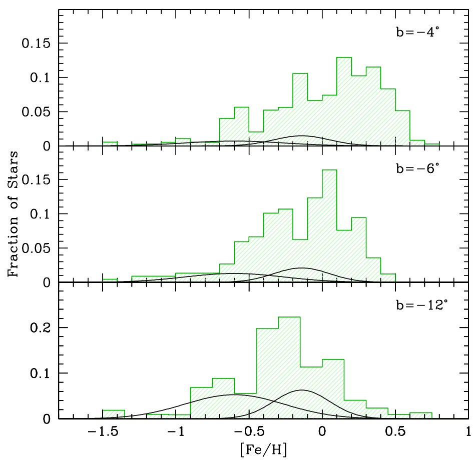

Fig. 3. The MDF in the three bulge fields, from the innermost one (Baade's Window, at $b = -4°$) to the outermost one at $b = -12°$.

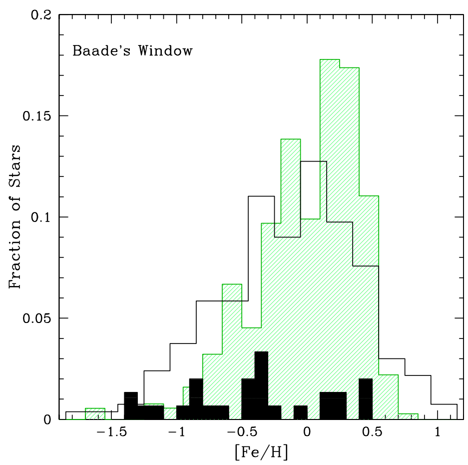

Fig. 4. Comparison with the MDF of Fulbright, McWilliam & Rich (2006).

References

Alvarez, R., & Plez, B. 1998, A&A, 330, 1109

Barbuy, B., Perrin, M.-N., Katz, D., Coelho, P., Cayrel, R., Spite, M., & Van't Veer-Menneret, C. 2003, A&A, 404, 661

Bensby, T., Feltzing, S., & Lundström, I. 2004, A&A, 421, 155

Cunha, K., & Smith, V.V. 2006, ApJ, 651, 491

Fulbright, J.P., McWilliam A., & Rich R.M. 2006, ApJ, 636, 821

Fulbright, J.P., McWilliam, A., & Rich R.M. 2007, ApJ, 661, 1152

Gustafsson, B., Edvardsson, B., Eriksson, K., Mizuno-Wiedner, M., Jorgensen, U.G., & Plez, B. 2002 in Stellar Atmosphere Modeling, I. Hubeny, D. Mihalas, K. Werner eds., ASP Conf. Ser., Vol. 288, 331

Lecureur, A., Hill, V., Zoccali, M., Barbuy, B., Gómez, A., Minniti, D., Ortolani, S., & Renzini, A. 2007, A&A, 465, 799

Matteucci, F., Romano, D., & Molaro, P. 1999, A&A, 341, 458

McWilliam, A. & Rich, R.M. 1994, ApJ, 91, 749

McWilliam, A. & Rich, R.M. 2004, in Origin and Evolution of the Elements, A. McWilliam and M. Rauch eds., Carnegie Observatories Astrophysics Series, (Cambridge: Cambridge Univ. Press), Vol. 4, in press

Minniti D. 1995, AJ, 109, 1663

Ortolani S., Renzini, A., Gilmozzi, R., Marconi, G., Barbuy, B., Bica, E., & Rich, R. M. 1995, Nature, 377, 701

Rich, R.M. 1988, AJ, 95, 828

Rich, R.M., & Origlia, L., 2005, ApJ, 634, 1293

Rich, R.M., Origlia, L., & Valenti E. 2007, ApJ, 665, L119

Robin, A.C., Reylé, C., Derrière S., & Picaud S., 2003, A&A, 409, 523

Sadler, E.M., Rich, R.M., & Terndrup, D.M. 1996, AJ, 112, 171

Spite, M. 1967, *Annales d'Astroph.*, 30, 211

Zoccali, M., Lecureur A., Barbuy, B., Hill, V., Renzini, A., Minniti D., Momany Y., Gómez A. & Ortolani S. 2006, A&A, 457, L1