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FIRST STELLAR ABUNDANCES IN NGC 6822[1]

Kim A. Venn[2] and Lissa Miller

Macalester College, Saint Paul, MN

RESUMEN

Presentamos los primeros espectros en alta resolución de estrellas individuales en la galaxia irregular NGC 6822. Los espectros de las dos supergigantes tipo A fueron obtenidos en los observatorios VLT y Keck, usando UVES y HIRES, respectivamente. La abundancia promedio de hierro en estas estrellas es de $\langle[\mathrm{Fe/H}]\rangle = -0.49 \pm 0.22$. Esto confirma que la metalicidad en NGC 6822 es ligeramente mayor que en la SMC. La abundancia estelar promedio de oxígeno, $12+\log(\mathrm{O/H}) = 8.36\pm0.19$, es concordante con los resultados nebulares. El cociente O/Fe, $\langle[\mathrm{O/Fe}]\rangle = +0.02 \pm 0.20$, es similar al de las Nubes de Magallanes y apoya la idea de que la evolución química es más lenta en estas galaxias poco masivas. No existe una correlación del oxígeno con la distancia galactocéntrica, aunque un subconjunto de los mejores datos es consistente con un gradiente radial de abundancias.

ABSTRACT

We present the first high resolution spectra of individual stars in the dwarf irregular galaxy, NGC 6822. The spectra of the two A-type supergiants were obtained at the VLT and Keck Observatories, using UVES and HIRES, respectively. The mean iron abundance from these two stars is $\langle[\mathrm{Fe/H}]\rangle = -0.49 \pm 0.22$. This confirms that NGC 6822 has a metallicity that is slightly higher than that of the SMC. The mean stellar oxygen abundance, $12 + \log(\mathrm{O/H}) = 8.36 \pm 0.19$, which is in good agreement with the nebular oxygen results. Oxygen has the same underabundance as iron, $\langle[\mathrm{O/Fe}]\rangle = +0.02 \pm 0.20$. This O/Fe ratio is very similar to that seen in the Magellanic Clouds, which supports the picture that chemical evolution occurs more slowly in these lower mass galaxies. Combining all of the oxygen abundance information for NGC 6822 shows that there is no trend in oxygen with galactocentric distance. However, a subset of the highest quality data are consistent with a radial abundance gradient.

Key Words: **GALAXIES: ABUNDANCES — GALAXIES: INDIVIDUAL (NGC 6822) — GALAXIES: STELLAR CONTENT — STARS: ABUNDANCES — STARS: SUPERGIANTS**

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1. INTRODUCTION

Understanding the evolution of chemical abundances in galaxies provides an important constraint for uniquely determining their star formation histories. This is because prior stellar nucleosynthesis information is preserved in the metallicity distribution of both the stars and gas. The analysis of bright nebular emission lines of H II regions has been the most frequent approach to modeling chemical evolution of galaxies to date (cf., Pagel 1997). And yet, only a very limited number of elements can be examined and quantified when using this approach. The chemical evolution of a galaxy depends on the contributions of all its ISM-enriching constituents (e.g., type I supernovae, high mass stars, thermal pulsing intermediate AGB stars). Thus, more elements than just those observed from nebular studies need to be measured, and each yields information on different galactic constituents.

The need for abundances of heavy elements, and the new opportunities made possible by the 8- to 10-m telescopes and efficient high resolution spectrographs, have motivated us to determine elemental abundances in young stars in nearby galaxies. Here, we present the first results from an analysis of two A-type supergiants in NGC 6822.

2. OBSERVATIONS AND ANALYSIS

Star ‘cc’ (nomenclature from van den Bergh & Humphreys 1979) was observed by J.K. McCarthy at Keck I, using HIRES on 26 and 27 September 1997. Three one-hour exposures, with an extra half-hour exposure, were made with a 1.1″ slit, yielding $R = 35\,000$ and S/N = 36 to 56 over a 4 pixel resolution element. The spectra span $4300 \leq \lambda \leq 6700$ Å

[1] Based on observations obtained from the UVES commissioning at the VLT (Kueyen), ESO, Paranal, Chile, and the Keck Observatory, Hawaii. Full paper published as Venn et al. (2001).

[2] University of Minnesota, Minneapolis, MN.

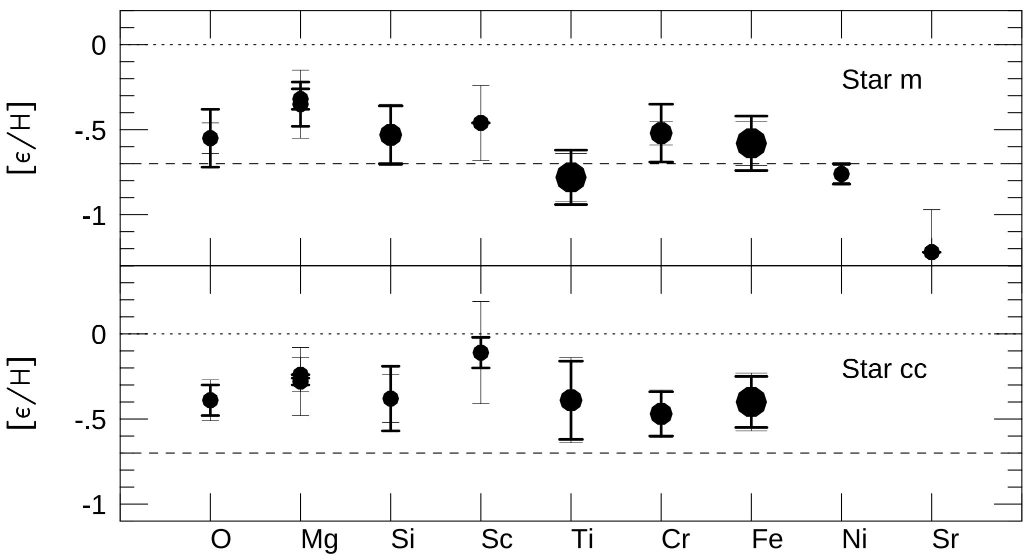

Fig. 1. Elemental abundances for Star 'm' (top) and Star 'cc' (bottom) relative to the the Sun. Two errorbars are shown for each point; *thick line* for the line-to-line scatter, and *thin line* for the systematic uncertainties in the model atmospheres analysis. The largest data points include ≥ 16 line abundances, and the smallest include ≤ 5. The mean SMC underabundance is noted by the *dashed line* (although note that the SMC A-supergiant Sr result is off the dashed line and this graph at -1.7).

in 30 echelle orders, although the wavelength coverage is incomplete beyond $\lambda\,5200$. Star 'm' was observed by A. Kaufer using UVES at the VLT on 8–10 October 1999, as part of the first UVES commissioning run at the second unit telescope UT2 ("Kueyen"). A two-hour exposure was taken on each night, using a predefined standard dichroic mode (Dichroic #1) with the blue central wavelength on cross-disperser #2 set to 390 nm and the red cross-disperser #3 to 564 nm, which gives nearly full wavelength coverage from < 3600 to 6657 Å. The resultant spectrum has $R = 30\,000$ and S/N = 50–70 over a 3 pixel resolution element.

Analyses of A-type supergiants requires a tailored analysis, where only weak spectral lines (preferably that form deep in the photosphere) are included. Weak lines helps to avoid uncertainties in the model atmospheres analysis due to neglected non-LTE and spherical extension effects in the atmospheric structure, as well as non-LTE and ξ effects in the line formation calculations. Elemental abundances were calculated using both spectrum synthesis and individual line width analyses. All calculations were done using a modified and updated version of LINFOR[3]. Averaged elemental abundances per star are plotted in Figure 1.

3. DISCUSSION

The Abundances: For the first time, the present-day iron-group abundances have been determined from stars in NGC 6822. The mean underabundance is [Fe/H] $= -0.49 \pm 0.22$, which is well supported by the other iron-group elements, e.g., [Cr/H] $= -0.50 \pm 0.20$. In Fig 1, all elemental abundances are shown relative to solar and the SMC.

The mean oxygen abundance is $12 + \log(\mathrm{O/H}) = 8.36 \pm 0.19$, which is consistent with the nebular results, 8.25 ± 0.07 (Pagel, Edmunds., & Smith 1980). Further, we note that the two stars analyzed here are located near the center of NGC 6822, where Pagel et al. report oxygen of 8.44 ± 0.25. That the oxygen abundance from the stars is consistent with that from the nebulae is not surprising. Similar results

[3]LINFOR was originally developed by H. Holweger, W. Steffan, and W. Steenbock at Kiel University. It has been upgraded and maintained by M. Lemke, with additional modifications by N. Przybilla.

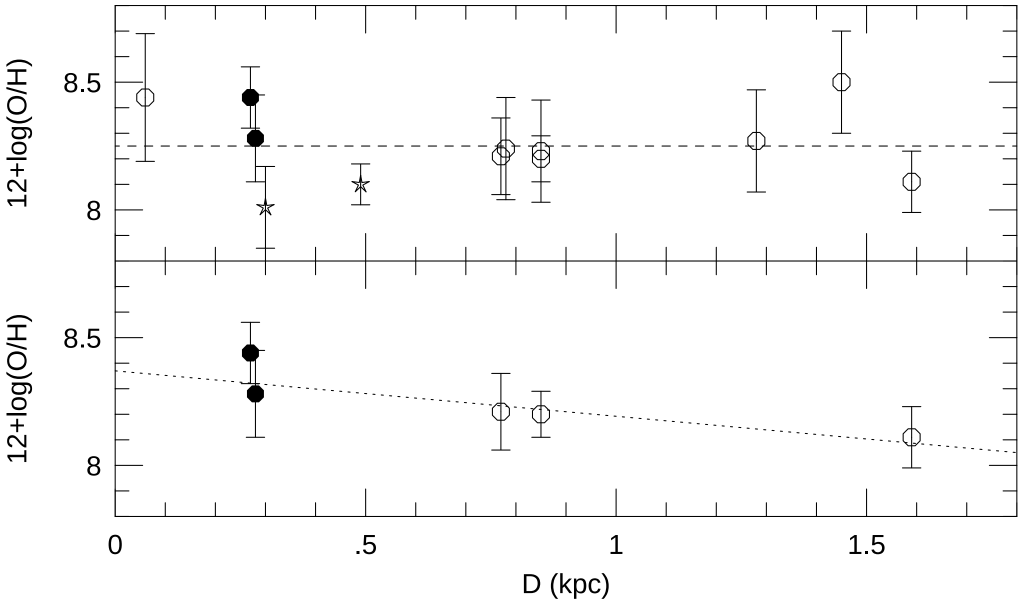

Fig. 2. Oxygen abundances versus NGC 6822 galactocentric distance. *Filled circles* represent the stellar data, *hollow circles* show the Pagel et al. (1980) nebular data, and *asterisks* note two planetary nebulae results from Richer & McCall (1995). The *dashed line* in the top panel shows the mean oxygen abundance from Pagel et al. ($12 + \log(O/H) = 8.25$). In the bottom panel, only the stellar abundances and those from H II regions where O III was detected are shown. A least squares fit to the data (*dotted line*) suggests a slope of -0.18 dex/kpc.

have been found from recent analyses of B-stars in Orion (cf., Cunha & Lambert 1994), the Galactic oxygen gradient from B-stars (cf., Rolleston et al. 2000, and references therein), and B-K supergiant analyses in the SMC (cf., Venn 1999, and references therein), M31 (Venn et al. 2000), and M33 (McCarthy et al. 1995; Monteverde, Herrero, & Lennon 2000).

Chemical Evolution of NGC 6822: It is well known that the O/Fe ratio is a key constraint for the chemical evolution model of a galaxy. We find a mean ratio of $[O/Fe] = +0.02 \pm 0.20$ (± 0.21) for the two stars analyzed here. This mean O/Fe ratio is very similar to that of the SMC and LMC stellar abundances. (To a lesser extent, O/Fe is also similar to that of the Galactic disk stars at $[Fe/H] = -0.5$; Edvardsson et al. (1993) show that [O/Fe] ranges from $\sim +0.1$ to $+0.25$ in Galactic F-G disk dwarfs at $[Fe/H] = -0.5$, which is slightly higher than our ratio but within our error range.)

Analytical chemical evolution models for the Magellanic Clouds have been published by Pagel & Tautvaišienė (1998). Our [O/Fe] and [Fe/H] results suggest that their models may be appropriate for NGC 6822, even though the star formation histories in the Clouds are thought to be somewhat different from that determined in NGC 6822 by Gallart et al. (1996a,b,c). In particular, the strength and timing of recent bursts of star formation, and the details of star formation in the older populations.

Our [Sr/Fe] ratio in Star m is also interesting since it helps to investigate the contributions from thermal-pulsing of intermediate-mass AGB stars. The Sr/Fe predictions in the Pagel & Tautvaišienė (1998) models for the Magellanic Clouds vary significantly. Our one Sr/Fe ratio suggests that SMC stars have lower Sr abundances, thus there's been less of a contribution from the intermediate-aged population.

Spatial Variations: Oxygen abundances from our two stars, Pagel et al.'s (1980) H II regions, and Richer & McCall's (1995) bright planetary nebulae are shown in Figure 2. To calculate the NGC 6822 galactocentric distances, we adopted the H I dynamical center coordinates ($19^h\,42^m\,06.7^s$ and

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$-14^\circ\,55'\,22.0''$, 1950), position angle (112°), and inclination angle (inner part, 50.1°) from Brandenburg & Skillman (1998). When all of the oxygen data are examined together, we find no evidence for an abundance gradient in NGC 6822 (top panel). Pagel et al. (1980) came to the same conclusion from examination of the H II region data alone. However, when only the most reliable of the data are examined, i.e., the stellar data and the three H II regions where O III λ4363 was detected (thus better electron temperatures), then a trend does emerge. There is the signature of an oxygen gradient with a slope near -0.18 dex/kpc (bottom panel).

A significant abundance gradient in NGC 6822 would be surprising, particularly one that is $\sim 3\times$ larger than that seen in the Galaxy (cf. Rolleston et al. 2000; Shaver et al. 1983). Several other dwarf irregular galaxies have abundances from multiple H II regions, and yet, with the exception of NGC 5253, there are no cases of significant internal chemical fluctuations or abundance gradients (see Kobulnicky & Skillman 1998 and references therein). The lack of abundance variations in dwarf irregular galaxies has been interpreted as evidence against in situ enrichment (e.g., the instantaneous recycling approximation used in galaxy chemical evolution models), and thus a counter example would be intriguing. We are currently following up this result with the analysis of more supergiants from new VLT+UVES spectra.

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Kim A. Venn and Lissa Miller: Macalester College, Department of Physics & Astronomy, 1600 Grand Avenue, Saint Paul, MN, 55105 (venn,mmiller@macalester.edu).

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