Dwarf Galaxies: From the Deep Universe to the Present
Proceedings IAU Symposium No. 344, 2019
K. B. W. McQuinn & S. Stierwalt, eds.

doi:10.1017/S174392131800649X

Red Supergiants as Chemical Abundance Probes: The Local Group dwarf NGC6822

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Abstract. Red Supergiant Stars (RSGs) are important probes of stellar and chemical evolution in star-forming environments. They represent the brightest near-IR stellar components of external galaxies and probe the most recent stellar population to provide robust, independent abundance estimates. The Local Group dwarf irregular galaxy, NGC6822, is a reasonably isolated galaxy with an interesting structure and turbulent history. Using RSGs as chemical abundance probes, we estimate metallicities in the central region of NGC6822, finding a suggestion of a metallicity gradient (in broad agreement with nebular tracers), however, this requires further study for confirmation. With intermediate resolution Multi-object spectroscopy (from e.g. KMOS, EMIR, MOSFIRE) combined with state-of-the-art stellar model atmospheres, we demonstrate how RSGs can be used to estimate stellar abundances in external galaxies. In this context, we compare stellar and nebular abundance tracers in NGC 6822 and by combining stellar and nebular tracers we estimate an abundance gradient of -0.18 ± 0.05 dex/kpc.

Keywords. stars: abundances, (stars:) supergiants, galaxies: abundances, galaxies: dwarf, infrared: stars

1. Red Supergiant Stars as Abundance Probes

The power of Red Supergiant stars (RSGs) as chemical probes of external galaxies has been developed and demonstrated in many recent studies (Davies *et al.* 2010, Evans *et al.* 2011, Gazak *et al.* 2014, Davies *et al.* 2015, Patrick *et al.* 2015, Lardo *et al.* 2015, Gazak *et al.* 2015, Patrick *et al.* 2016, Patrick *et al.* 2017, Davies *et al.* 2017, Tabernero *et al.* 2018). Where these authors exploit spectral regions in the *I*- and *J*-bands, where molecular absorption features that plauge the optical regions of cool-star spectra, are not present and instead these regions are dominated by well separated elemental absorption features (e.g. Ti I, Si I, Mg I, Fe I, for the *J*-band observations).

In the case of the *J*-band observations, the well separated nature of these spectral features means that the spectral resolving power required to perform this analysis is R$\sim$3000, therefore, these studies can be undertaken using Multi-Object Spectrographs operating at near-IR wavelengths (e.g. VLT-KMOS, Keck-MOSFIRE, GTC-EMIR). This is an important consideration, as in order to build an accurate picture of the metal-content and -distribution of external galaxies, many sources are required over the full spatial extent of the galaxy. With single-object spectrographs obtaining this information can be an order of magnitude less efficient. Accurate metallicity distributions advance our understanding of the target galaxy to a much greater extent than relying on a single measurement to define the metallicity of complex stellar aggregates like galaxies.

The present day metal-content and -distribution of star-forming galaxies in the Local Universe are vital tracers for our understanding of the chemical evolution of galaxies further afield. Dwarf galaxies in particular represent the most abundant galaxy type and Local Group examples can be studied in great detail and provide insight into their high-redshift counterparts.

2. Abundance Tracers of the Young Stellar Population of NGC 6822

NGC 6822 is a Local Group Dwarf irregular galaxy with a turbulent past. This galaxy has a known population of massive stars (Venn *et al.* 2001) and H II regions (Lee *et al.* 2006) and is reasonably well isolated within the Local Group at d$\sim$0.5 Mpc (McConnachie 2012 and references therein).

A comparison between abundance young tracers in Local Group galaxies is of primary importance given the applicability of nebular tracers utilising strong emission lines arising from H II regions over large distances (e.g. Tremonti *et al.* 2004). In their study of the Sculptor Group galaxy NGC 300, Gazak *et al.* 2015, demonstrated that abundances estimated from RSGs, Blue Supergiant stars (BSGs) and H II regions can have an excellent agreement over the full spatial scale of a galaxy. However, in the dwarf irregular companion galaxy to NGC 300, NGC 55, the comparison appears to be much poorer (Kudritzki *et al.* 2016, Patrick *et al.* 2017, Magrini *et al.* 2017).

In NGC 6822, abundance measurements of the young stellar population are limited to the following:

- In the first study estimating stellar abundances for single stars in NGC 6822, Venn *et al.* 2001 compiled UV and visual spectroscopy to estimate elemental abundances, including iron, for two A-type supergiants.
- Lee *et al.* 2006 specifically set out to address the subject of an oxygen gradient in NGC 6822 by obtaining H II region oxygen abundances for a total of 19 H II regions within this galaxy. Their dataset consists of five H II regions where the [OIII] λ4363 emission line is detected, hence allowing 'direct'abundance estimates. These direct line estimates are thought to provide the most accurate results (Lee *et al.* 2006), as ionisation temperature can be measured. Using only their highest quality data these authors obtain an oxygen abundance gradient of -0.14 ± 0.07 dex kpc^{-1}.
- Patrick *et al.* 2015 defined $\sim$60 RSG candidates in NGC 6822 using a combination of optical and near-IR colours and spectroscopically confirmed 18 as RSGs members of NGC 6822. The sample of Patrick *et al.* 2015 remain the largest consistent set of metallicity measurements for the young stellar population within NGC 6822 and using this data these authors estimated a barely-significant abundance gradient of -0.5 ± 0.4 dex kpc^{-1}, in broad agreement with the H II region results.

In Figure 1, we compare these abundance tracers. In order to do this we assume the following: the iron abundances estimated for the BSGs is a direct analogue of the overall metallicity (i.e. [Fe/H] = [Z]) and that the oxygen abundances from the H II region measurements can be directly converted to overall metallicities using the solar abundance (i.e. $12 + \log(\mathrm{O/H}) - \log(\mathrm{O/H})_\odot = [Z]$; where $\log(\mathrm{O/H})_\odot = 8.69$, Asplund *et al.* 2009) Asplund *et al.* 2009. This implicitly assumes a solar-like [α/Fe], which is one of the limitations of this comparison.

https://doi.org/10.1017/S174392131800649X Published online by Cambridge University Press

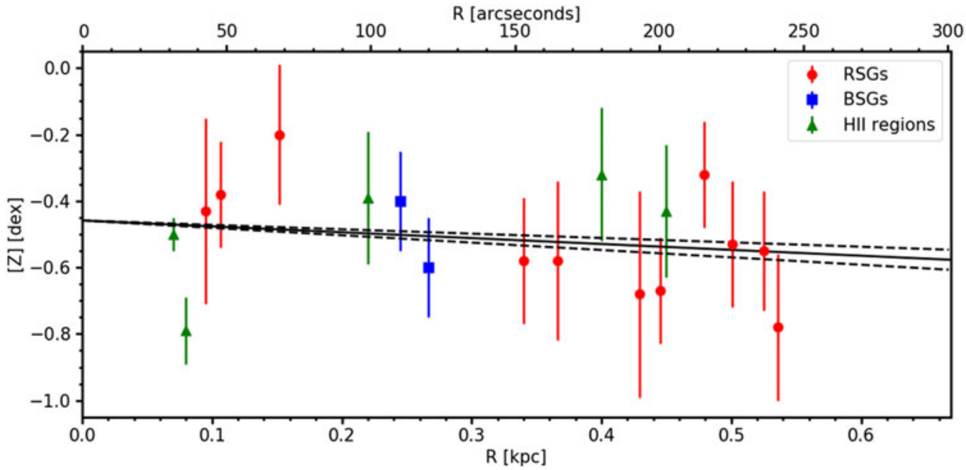

Figure 1. Radial distance from the centre of NGC 6822 against overall metallicities measurements for the young abundance tracers in this galaxy. Red points show RSGs from Patrick *et al.* 2015, blue squares from Venn *et al.* 2001 and H II region measurements from Lee *et al.* 2006 using only the highest quality data where the [OIII]4363 auroral line is measured. The black solid line shows a linear least-squared fit to the data where the dashed lines highlight the errors obtained from this fit. The fit to the data from the three tracers results in a metallicity gradient of -0.18 ± 0.05 dex/kpc.

A least squares fit to the data (shown with a solid black line and 1σ uncertainties with dashed black lines in Figure 1), results in a significant abundance gradient of -0.18 ± 0.05 dex/kpc, which is consistent with the independently estimated abundance gradients from both RSGs (Patrick *et al.* 2015) and H II regions (Lee *et al.* 2006). This intriguing result requires confirmation by either, improving the sample size considered here (11 RSGs, 2 BSGs and 5 H II regions), decreasing the uncertainties on the RSG results in particular or by using additional tracers of the young stellar population (or preferentially all three).

3. Discussion and Conclusions

The young abundance tracers in the dwarf irregular galaxy NGC 6822 has been re-examined. Using stellar abundance measurements from RSGs and BSGs yields a very consistent picture and adds to the evidence that these abundance tracers demonstrate excellent agreement in extragalactic systems (see Davies *et al.* 2017). Using a selection of the highest quality nebular abundance tracers from H II regions (Lee *et al.* 2006), a comparison of the stellar and nebular tracers in NGC 6882, again, shows very consistent results (see Figure 1).

By examining this population of young abundance tracers as a whole we find evidence for a significant abundance gradient within NGC 6822 (-0.18 ± 0.05 dex/kpc). This result is in good agreement with the oxygen abundance gradient estimated for H II regions as well as the overall metallicity gradient estimated using RSGs. One of the limitations of this comparison is the assumption of a solar-like [α/Fe], to improve our understanding of this, in a future publication, we will further develop the J-band analysis technique to include this effect, allowing estimates of this important ratio with RSG observations.

To better test these conclusions in more detail, additional data must be obtained improving the number and quality of abundance measurements in this galaxy. To this end we propose to observe an additional sample of $\sim$20 RSGs in NGC 6822, which will improve the spatial coverage and increase the number of samples by over a factor of two.

This is an important test to undertake as dwarf irregular galaxies are typically assumed to consist of a reasonably simple stellar population and studies such as this, that utilise multiple different stellar and nebular abundance tracers contribute to challenge that view.

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