Mem. S.A.It. Vol. 85, 408

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Tidal dwarf galaxies and the luminosity-metallicity relation

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Abstract. We present a recalibration of the luminosity-metallicity relation for gas-rich, star-forming dwarfs to magnitudes as faint as $M_R \sim -13$. We use the Dopita et al. (2013) metallicity calibrations to calibrate the relation for all of the data in this analysis. Metal-rich dwarfs classified as tidal dwarf galaxy (TDG) candidates in the literature are typically of metallicity $12 + \log(O/H) = 8.70 \pm 0.05$, while SDSS dwarfs fainter than $M_R = -16$ have a mean metallicity of $12 + \log(O/H) = 8.28 \pm 0.10$, regardless of their luminosity. Our hydrodynamical simuations predict that TDGs should have metallicities elevated above the normal luminosity-metallicity relation. Metallicity can therefore be a useful diagnostic for identifying TDG candidate populations in the absence of tidal tails. At magnitudes brighter than $M_R \sim -16$ our sample of 53 star-forming galaxies in 9 HI gas-rich groups is consistent with the normal relation defined by the SDSS sample. At fainter magnitudes there is an increase in dispersion in metallicity of our sample. In our sample we identify three (16% of dwarfs) strong TDG candidates ($12 + \log(O/H) > 8.6$), and four (21%) very metal poor dwarfs ($12 + \log(O/H) < 8.0$), which are likely gas-rich dwarfs with recently ignited star formation. Further details of this analysis are available in Sweet et al. (2013, ApJ submitted).

Key words. galaxies: groups – galaxies: dwarf – star formation – HI – metallicity

1. Introduction

Over the past decades, it has been shown that galaxies display an increasing metallicity with luminosity (e.g. Lequeux et al. 1979; Tremonti et al. 2004). This is generally explained by the concurrent

i) merging of dark matter (DM) haloes and their respective galaxies, increasing the galaxies' luminosity, and
ii) self-enrichment due to supernovae, causing an increase in metallicity.

However, not all dwarf galaxies are formed out of metal-poor gas in their own DM halo. Tidal interactions between giant galaxies cause knots of star formation in tidal tails, which self-gravitate without the need for a DM halo. The dwarf galaxies formed in this way are known as tidal dwarf galaxies (TDGs), and have high metallicity due to the pre-enriched matter from which they form (e.g. Mirabel et al. 1992; Duc et al. 2000; Weilbacher et al. 2003).

In this paper we investigate the trend of metallicity with respect to luminosity of these objects in order to identify a population of candidate TDGs. Here we define 'metallicity' as the gas-phase oxygen abundance relative to hydrogen, 12+log(O/H).

2. Sample selection and observations

Our sample consists of galaxies in small gas-rich groups named Choir groups (Sweet et al. 2013). The groups were selected from the HIPASS (HI Parkes All-Sky Survey, Barnes et al. 2001), being the HI detections that were shown to contain four or more emission line galaxies (SINGG, Meurer et al. 2006).

We observed 53 Choir member galaxies in 9 groups with the integral field Wide Field Spectrograph (WiFeS, Dopita et al. 2007) on the ANU 2.3m telescope.

The best-known advantage of integral field unit (IFU) spectroscopy is the acquisition of spatially-resolved spectra. However, for this study we integrate over a number of spaxels (spatial pixels) per galaxy, so instead the advantages are increased signal to noise and an improved sampling over the entire galaxy.

We measured emission line fluxes using UHSPECFIT (Rich et al. 2010). This IDL-based program fits a Bruzual & Charlot (2003) stellar population to remove absorption, before fitting Gaussian components to each emission line.

3. Results and discussion

We constructed the luminosity-metallicity relation for our Choir member galaxies and comparison samples, using the same metallicity calibration (and where possible, reddening correction) for all of the measurements.

3.1. Metallicity calibrations

Calibrations of gas-phase metallicity typically fall into three main categories:

i) classical electron temperature and ionization correction factor technique,
ii) recombination line method, and
iii) strong emission line (SEL) method.

The first two methods rely on weak emission lines, so are reserved for bright and/or nearby galaxies. The galaxies in our sample are mostly high-metallicity, faint and not very nearby, so most do not display the required lines for either the electron temperature or recombination line methods. We therefore adopt the SEL method for this work. Unfortunately, the three categories of methods give different results, so it is difficult to compare metallicities that have been calibrated with different methods. There is even wide variation within the various SEL methods, as seen in Figure 4 of Kewley & Ellison (2008). Furthermore, when analysing metallicities by the SEL method, it is important to choose (i) a single metallicity calibration (so that the sample is self-consistent), that (ii) is as free of degeneracy as possible. For these reasons, we adopt the log [OIII]/[SII] vs. log [NII]/[SII] diagnostic given in Dopita et al. (2013, their Fig. 21).

3.2. Control samples

SDSS

We use the Sloan Digital Sky Survey Eighth Data Release (SDSS DR8, Aihara et al. 2011) for our bright galaxy comparison sample. Following Tremonti et al. (2004), we restrict our SDSS sample to a selection of high-confidence detections. Our resulting SDSS sample contains 94,863 sources. A turnover can be seen in the luminosity-metallicity relation (Fig. 1.); we identify two sub-populations by Gaussian mixture modelling.

Additional dwarf galaxy control samples

We include two isolated gas-rich dwarfs KK[98] 246 and HIPASS J1609-04 (Nicholls et al. in press). Both are consistent with SDSS.

We include additional HII regions and isolated dwarfs of van Zee et al. (1998) and van

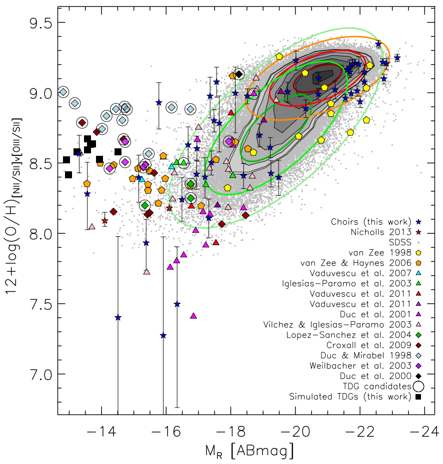

Fig. 1. Luminosity-metallicity relation for our SDSS control sample, with Gaussian mixture modelling overlaid; the two sub-populations are shown in red and green 1-, 2-, 3-σ ellipses. Choirs are shown as blue stars. Pentagons denote isolated galaxies, triangles denote gas-rich galaxies, and diamonds denote dwarf galaxies very near a host. Tidal dwarf galaxy candidates are circled. Our Choir galaxies have a wide range in metallicity; three are significantly above the normal SDSS relation and are therefore strong TDG candidates.

Zee & Haynes (2006) as pentagons in Fig. 1. The bright galaxies are consistent with the SDSS sample, but the faint end is elevated above SDSS, at a constant metallicity with luminosity (12 + log(O/H) = 8.46 ± 0.04)

We plot cluster dwarf galaxies as triangles in Fig. 1: Virgo (Vaduvescu et al. 2007; Vílchez & Iglesias-Páramo 2003), Hercules (Iglesias-Páramo et al. 2003), Fornax (Vaduvescu et al. 2011), and Hydra (Vaduvescu et al. 2011; Duc et al. 2001). These objects tend towards lower metallicity with faint luminosity.

We also include group dwarfs as diamonds: NGC5291 (Duc & Mirabel 1998) and Arp245N (Duc et al. 2000) (both in pairs), the compact group HCG31 (López-Sánchez et al. 2004), the larger ~30-member group M81 (Croxall et al. 2009), and various other interacting systems (Weilbacher et al. 2003).

4. Discussion

4.1. Tidal dwarf galaxies

A number of the galaxies from the existing literature shown in Fig. 1 are claimed by their authors to be TDG candidates (circled points). These galaxies display an enhanced average metallicity (12 + log(O/H) = 8.70 ± 0.05). Some of them are clearly elevated above the luminosity-metallicity relation of SDSS bright galaxies and van Zee & Haynes (2006) isolated dwarfs (e.g. Arp245N, black diamond, Duc et al. 2000), but many are consistent with SDSS (e.g. HCG31 TDG candidates, dark green diamonds, López-Sánchez et al. 2004). Some of those TDG candidates were identified because they have a higher metallicity than normal / isolated dwarfs using different metallicity calibrations. This overlap therefore simply confirms that using different methods to measure metallicity will give different results.

4.2. Simulations

We have conducted hydrodynamical simulations of TDG candidates, to be presented in Bekki et al. (in prep., 2013), shown in Figure 1 as black, filled squares. The mean metallicity is 8.57 ± 0.03, within 3σ of the mean observed TDG candidate metallicity of 8.70 ± 0.05.

4.3. Choir dwarf galaxies

Choir galaxies brighter than M_R = -16 are mostly consistent with SDSS. The SDSS contours provide a simple diagnostic of the significance of any outlying results. For example, the two most metal-rich dwarfs at $M_R \sim$ -17.5, being more than 3σ from the mean SDSS population, are bona-fide TDG candidates.

Choir galaxies have an increased scatter at the low luminosity end, spanning the full 1.5 dex metallicity range observed for all types of dwarfs. Some groups (e.g. HIPASS J0400-52) even span this range. The size of the error bars compared with the scatter suggests that this is not a measurement error, but a true dispersion in the population. We consider that the Choir dwarf galaxy population is inherently dispersed, probably due to a wide variation in gas content and environment (distance to host) of the Choir member galaxies.

We identify i) 3 (16%) strong TDG candidates (J0205-55:S7, J0400-52:S8, J0400-52:S9) with metallicity > 12 + log(O/H) = 8.6 and ii) 4 (21%) very metal poor dwarfs (J0400-52:S2, J1051-17:S4, J1403-06:S3, J1403-06:S4) with metallicity < 8.0.

5. Conclusions

In this paper we have used the new Dopita et al. (2013) metallicity calibrations to calibrate the luminosity-metallicity relation for a range of galaxy types. Importantly, we used the same calibration for our population of galaxies in HI-rich groups as for our control samples.

We make the following points:

i) Isolated dwarf galaxies have a constant metallicity with magnitude of 12 + log(O/H) = 8.46 ± 0.04, similar to SDSS dwarfs.
ii) TDG candidates from the literature and our simulated TDGs have mean metallicities of 12 + log(O/H) = 8.70 ± 0.05 and 12 + log(O/H) = 8.57 ± 0.03 respectively, significantly above SDSS dwarfs.
iii) Based on metallicity, we identify three (16% of dwarfs) strong TDG candidates (12+log(O/H) > 8.6), which are significantly above the SDSS control sample at 12 + log(O/H) = 8.28 ± 0.10; J0205-55:S7, J0400-52:S8, J0400-52:S9.
iv) We also identify four (21%) very metal-poor galaxies (12+log(O/H) < 8.0); J0400-52:S2, J1051-17:S4, J1403-06:S3, J1403-06:S4.

Thus, metallicity can be an important diagnostic for identifying populations of candidate TDGs in the absence of optical tidal streams.

Acknowledgements. We thank David Rohde for helpful discussions about Gaussian mixture modelling, and Jeff Rich, Mort Canty and James R A Davenport for providing IDL routines. We acknowledge funding support from the UQ-UWA Bilateral Research Collaboration Award. This research has made use of NASA's Astrophysics Data System. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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