Chemical Abundances in the Universe:
Connecting First Stars to Planets
Proceedings IAU Symposium No. 265, 2009
K. Cunha, M. Spite & B. Barbuy, eds.

doi:10.1017/S1743921310000451

The chemical history of the nearest starburst galaxy – IC10

Denise R. Gonçalves[1] **and Laura Magrini**[2]

[1]UFRJ - Observatório do Valongo, Ladeira Pedro Antonio 43, 20080-090 Rio de Janeiro, Brazil
email: denise@astro.ufrj.br

[2]INAF - Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy
email: laura@arcetri.astro.it

Abstract. The irregular dwarf galaxy IC10 is located within the Local Group (LG) at a distance of 750 kpc. Although several studies have revealed the existence of stellar populations with a broad range of ages, its star formation history (SFH) and age-metallicity (AM) relationship remain quite unknown. In this contribution we present our spectroscopic investigation of 15 H II regions, 9 planetary nebulae (PNe) and 1 symbiotic star –so far the farthest known symbiotic binary. Our main goal is to reconstruct the SFH of IC10 and to constrain its AM relationship using young and intermediate-age stars. The direct availability of the electron temperature in our emission-line spectra allows an accurate determination of the IC10 metallicity map at two different epochs. We find a non-homogeneous distribution of metals at both epochs, but similar average abundances for the two analyzed populations. The derived AM relationship shows a little global enrichment, which is interpreted as due to the loss of metals by supernovae winds and to differential gas outflows. Our results bring strong observational constraints to the chemical enrichment history of IC10, the formation of dwarf irregular galaxies and the evolution of the LG as well.

Keywords. galaxies: abundances, galaxies: evolution, Local Group, PNe, HII regions.

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1. The main properties of the LG dwarf galaxies

The rich variety of galaxies in the LG provides an opportunity to study in detail the formation and evolution of the most common types of galaxies in the Universe. One remarkable open question related to the evolution of dwarf galaxies is: are dwarf ellipticals and spheroidals the evolved descendants of previous star-forming dwarfs?

The LG dwarf spheroidal galaxy (dSph) NGC147 is gas and dust free, therefore dominated by its old stellar population. We studied the chemistry of this galaxy a couple of years ago (Gonçalves et al. 2007), confirming spectroscopically the presence of 7 PNe, which are characteristic of its old and intermediate-age stellar population.

On the other hand, the dwarf irregular galaxy (dIrr) IC10 has a high star formation rate, with a large number of H II regions, together with an old and intermediate-age stellar population. A number of PNe were confirmed spectroscopically by Magrini & Gonçalves (2009), and in the same work known H II regions were studied. An important by-product of the IC10's survey for emission-line objects, was the discovery of IC10-SySt-01, the farthest known symbiotic binary (Gonçalves *et al.* 2008).

The metallicity-luminosity relationship in dwarf galaxies of different morphological types is still uncertain. This is so because the metallicity is usually derived with different methods in dSphs and dIrrs: in the former it is given as [Fe/H] measured in stars, while in the latter [O/H] is measured from emission-line objects. Then they are converted on a common scale assuming a constant [O/Fe] (e.g. Skillman *et al.* 1989; Richer & McCall 1995). In order to by-pass this very uncertain conversion, we are deriving chemical

Table 1. Emission-line objects observed with GMOS in IC10

New PNe	12	Faint objects. Not found in previous surveys.
Known PNe	3	The brightest objects (Magrini *et al.* 2003; Kniazev *et al.* 2008).
Known H II regions	15	Hodge & Lee (1990).
New Symbiotic	1	IC10 SySt-1 (Gonçalves *et al.* 2008).

abundances of a significant sample of LG dwarf galaxies using PNe. PNe are indeed present in early- and late-type galaxies. In addition, their chemistry provides information about the distant past of the galaxy ISM (old and intermediate-age stars), whereas the simultaneous analysis of H II regions give access to the present time ISM chemistry. Together, these strong line emitters provide key constraints to the LG chemical evolution.

2. The emission-line objects of the dIrr IC10

The $5.5' \times 5.5'$ inner region of the nearby starburst galaxy IC10 was imaged with the Gemini North Multi-Object Spectrograph (GMOS) in two narrow-band filters, Hα and Hα-continuum (Hαc). The analysis of the Hα-Hαc image allowed us to identify several Hα emitters, targets of our spectroscopy. We used the same telescope and instrument to obtain optical ($\sim$3700 Å to $\sim$9100 Å) spectra of the sources, as described in Table 1. Details on the observations and data analysis are given in Magrini & Gonçalves (2009).

We adopt the usual (direct; Stasińska 2002) method to derive ionic (NEBULAR analysis package in IRAF/STSDAS; Shaw & Dufour 1994) and total (Kingsburgh & Barlow 1994) abundances of He, N, O, Ne, S and Ar for both PNe and H II regions in the sample. But, how can we interpret the chemical abundance of these emission-line objects? It is well known that the abundances of O, Ne, Ar and S (O and Ne in first approximation) reveal the ISM composition at the epoch when the PN progenitors were born (typically 0.3-8$\times 10^9$yr ago). On the other hand, He and N are produced by the PN progenitor stars, and give information on their nucleosynthesis processes. The same chemical elements in H II regions give the present time ISM abundances (Iben & Renzini 1983; Stasińska 2002).

3. Results-I: IC10's enrichment is non-homogeneously distributed

As can be easily noticed from Fig. 1, the distribution of metals in IC10's central region is not homogeneous. The average O/H=$2.31\pm1.59\times10^{-4}$ [12+log(O/H)=8.30 ± 0.20] has a dispersion similar to that found in other LG dIrrs and nearby groups, like NGC 6822 (Lee *et al.* 2006) and Sextans B (Kniazev *et al.* 2005; Magrini *et al.* 2005). The face value of the average O/H is also consistent with those found by previous studies of IC10 by Hodge & Lee (1990) and Richer *et al.* (2001). The average PN abundance is O/H=$2.07\pm1.30\times10^{-4}$, slightly lower but very close to that of H II regions.

So, although in average H II regions and PNe have similar oxygen abundance, the dispersion of their values is important, suggesting a clumpy distribution of the metals, at both epochs. From the analysis of the chemical distribution relative to the center (not shown here), we note that no radial metallicity gradient is present.

4. Results-II: Massive stars products take time to cool

In Fig. 2 (left panel) we compare abundance trends of blue compact galaxies (BCGs), by Izotov *et al.* (2006), with our H II region results. We find a good agreement. In particular, α element-to-oxygen abundance ratios, Ne/O, S/O and Ar/O, do not show large trends with oxygen abundance, as expected by their common origin. Due to the large

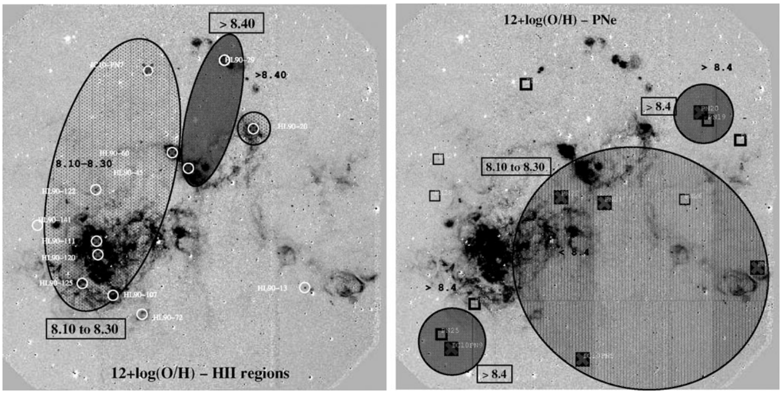

Figure 1. Metallicity maps of IC10. *Left*: from O/H of H II regions (present-time ISM). *Right*: from the old and intermediate-age population, PNe. Ellipses of different grey tones mark regions of various oxygen abundances.

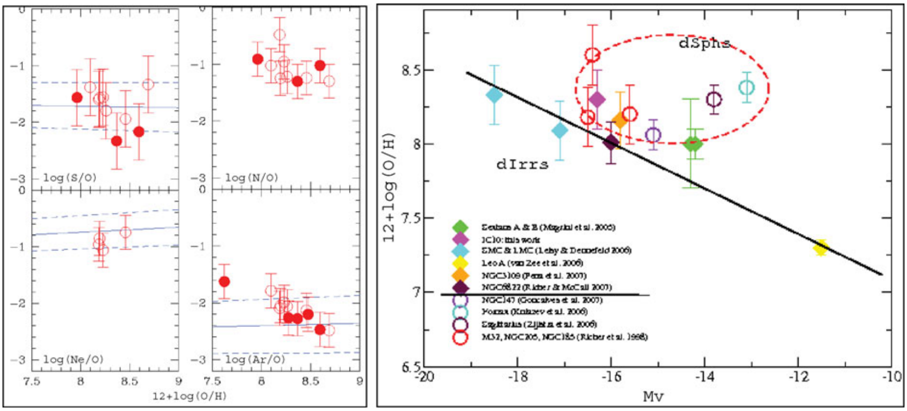

Figure 2. *Left*: Chemical abundance patterns for PNe (filled circles) and H II regions (empty circles), compared with the BCGs relations of Izotov *et al.* (2006) for the α-element to oxygen ratios, and their dispersion. *Right*: The dwarf galaxies metallicity-luminosity relation, which show our own results and others from the literature.

dispersion of N/O and the different stellar origin of nitrogen and oxygen, the relationship of this ratio with 12+log(O/H) is not plotted. In a starburst galaxy, as IC10, the N/O ratio should be lower than in BCGs, due to the time delayed nitrogen production if compared to the much faster production of oxygen. The reason why N/O in IC10 is consistent with other BCGs reflects the fact that nothing ejected by massive stars – whether oxygen by type II supernovae or nitrogen in the winds of WR stars–, will be immediately incorporated into the nebular gas. This ejected matter is too hot, and needs to cool before it can mix with the ISM and can be seen in the optical spectra of nebular gas.

Fig. 2 also shows that the abundance ratios of BCGs and IC10 PNe agree very well. Noting that PNe progenitors produce and dredge-up nitrogen during their lifetimes, the agreement of N/O ratio would appear unexpected. However, as noted by Richer & McCall (2007), the brightest PNe in starburst galaxies often behave in this way.

The similar abundance ratios of PNe and H II regions is an evidence that IC10 had small variations in the metal content from the PN progenitors formation to the present time. There are two possible explanations. *i)* PNe in dIrrs are very young, and thus they represent the same age as H II regions. However this hypothesis is ruled out by the absence of the HeII lines in their spectra, tracers of the most massive and youngest PNe. *ii)* PNe and H II regions belong to different epochs, and so their similar composition is a probe of the metal loss in dIrrs by strong winds and outflows which remove the chemical enriched material from the place they were formed. The winds mainly allow the loss of α-elements, through type II SN winds (MacLow & Ferrara 1999; Recchi *et al.* 2008).

5. Results-III: the dIrr and dSph PNe metallicity-luminosity relation

It has been proposed that dSphs are formed through the removal of the gas in dIrrs, either through ram pressure stripping, supernova driven winds or star formation (Kormendy & Djorgovski 1989). In this scenario, dSphs are expected to have, at a given luminosity, a higher metallicity than dIrrs. Fig. 2, right panel, shows the metallicity-luminosity relationship of dwarf galaxies: the continuous line is the weighted least-squares fit by Van Zee *et al.* (2006), obtained using oxygen abundances of H II regions in dIrrs, while the filled (empty) symbols are O/H in PNe of dIrrs (dSphs).

The location in the luminosity-metallicity diagram of dSphs does not exclude their formation from old dIrr-like galaxies, but excludes their formation from the present time dIrrs, since the differences between their metallicity start from their older populations. In fact, PNe in dSphs derive from very old progenitors, while PNe in dIrrs are generally younger. Thus, the offset in the metallicity-luminosity relationship indicates a faster enrichment of dSphs and a different evolutionary path for both types of galaxies.

References

Gonçalves D. R., Magrini L., Leisy P, & Corradi R. L. M., 2007, *MNRAS*, 375, 715
Gonçalves D. R., Magrini L., Munari U., Corradi R. L. M., & Costa R. D. D., 2008, *MNRAS*, 391, L84
Hodge P. & Lee M. G. 1990, *PASP*, 102, 26
Izotov Y. I., Stasinska G., Meynet G., Guseva N. G., & Thuan T. X., 2006, *A&A*, 448, 955
Iben I. Jr. & Renzini A., 1983, *ARA&A*, 21, 271
Kingsburgh R. L. & Barlow M. J., 1994, *MNRAS*, 271, 257
Kniazev A. Y., Grebel E. K., Pustilnik S. A., Pramskij A. G., Zucker D. B., 2005, *AJ*, 130, 1558
Kniazev A. Y., Pustilnik S. A., & Zucker D. B., 2008, *MNRAS*, 384, 1045
Kormendy J, & Djorgovski S., 1989, *ARA&A*, 27, 235
Lee H., Skillman E. D., Cannon J. M., Jackson D. C., Gehrz R. D., Polomski E. F., Woodward C. E., 2006, *ApJ*, 647, 970
Mac Low M.-M. & Ferrara A., 1999, *ApJ*, 513, 142
Magrini L., Corradi R. M. L., Greimel R., Leisy P., & Lennon D. J., 2003, *A&A*, 407, 51
Magrini L. Leisy P., Corradi R. M. L., Perinotto M., Mampaso A. & Vílchez J. M., 2005, *A&A*, 443, 115
Magrini L. & Gonçalves D. R., 2009, *MNRAS*, 398, 280
Recchi S., Spitoni E., Matteucci F., & Lanfranchi G. A., 2008, *A&A*, 489, 555
Richer M. G. & McCall M. L., 1995, *ApJ*, 445, 642
Richer M. G., Bullejos A., Borissova J., McCall M. L., Lee H., Kurtev R., Georgiev L., Kingsburgh R. L., Ross R., & Rosado M., 2001, *A&A*, 370, 34
Richer M. G. & McCall M. L., 2007, *ApJ*, 658, 328
Shaw R. A. & Dufour R. J., 1994, *ASPC*, 61, 327
Skillman E. D., Kennicutt R. C., & Hodge P. W., 1989, *ApJ*, 347, 875
Stasińska G. 2002, "Abundance determinations in HII regions and planetary nebulae", astro-ph/0207500
Van Zee L., Skillman E. D., & Haynes M. P., 2006, *ApJ*, 637, 269