CHEMICAL EVOLUTION OF LATE-TYPE DWARF GALAXIES

The windy starburst dwarfs NGC 1569 and NGC 1705

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Abstract

Thanks to the capabilities of modern telescopes and instrumentation, it is now possible to resolve single stars in external dwarf galaxies, provided they are bright enough. For galactic regions with deep enough photometry, detailed colour-magnitude diagrams are constructed, from which the star formation history and the initial mass function can be inferred by comparison with synthetic diagrams. Both the star formation history and the initial mass function are free parameters of galactic chemical evolution models. In this contribution we show how constraining them through high resolution photometry in principle allows us to better understand the mechanisms of dwarf galaxy formation and evolution.

Keywords: Galaxies: evolution, formation, individual: NGC 1569, NGC 1705

1. Introduction

Low-luminosity galaxies – dwarf galaxies and related systems – are found numerous in the nearby universe. Here we deal with the subclasses of dwarf irregulars (DIGs) and blue compact dwarfs (BCDs). Both have low mass, low metallicity, large gas content and mostly young stellar populations. However, while BCDs are rather compact objects, with centrally concentrated starburst, gas and star distributions, DIGs are dominated by scattered bright H II regions in the optical. The disturbed H I morphologies could be related either to the occurrence of galactic winds or to episodes of mass accretion and/or ingestion of low-mass companions (e.g., Kobulnicky & Skillman 1995; Stil & Israel 1998,
In some cases, both mechanisms are competing to determine the physical properties of the galaxy.

2. **NGC 1569 and NGC 1705**

Whatever its (unknown) cause, the strong recent star formation activity in NGC 1569 triggered a galactic outflow whose signature can be observed in different bands (Martin et al. 2002). In NGC 1705, the H\(\text{I}\) kinematics is quite regular (Meurer et al. 1998). Yet, its spectacular galactic wind (Meurer et al. 1992; Heckman et al. 2001) bears witness to the recent rather exceptional star formation activity (Annibali et al. 2003). In the following, we will concentrate on these two windy starburst dwarfs.

### Table 1. Observational properties.

| Quantity   | NGC 1569      | Ref. | NGC 1705      | Ref. |
|------------|---------------|------|---------------|------|
| Distance   | 2.2 ± 0.6 Mpc | 1    | 5.1 ± 0.6 Mpc | 6    |
| Gas mass   | (1.5 ± 0.3) \(\times\) \(10^8\) \(M_\odot\) | 1    | \(1.7 \times 10^8\) \(M_\odot^a\) | 7    |
| Total mass | \(3.3 \times 10^8\) \(M_\odot\) | 1    | \(3.4 \times 10^8\) \(M_\odot^a\) | 7    |
| \(Z\)     | 0.004         | 2    | 0.004         | 8    |
| \(\log(O/H)+12\) | 8.19–8.37 | 3, 4, 5 | 8.21 ± 0.05 | 9 |
| \(\log(N/O)\) | \(-1.39 ± 0.05\) | 5    | \(-1.75 ± 0.06^b\) | 9    |

\(^a\) Gaseous and total masses were modified to reflect the distance used here.

\(^b\) The mean value is higher, \(-1.63 ± 0.07\), if the anomalously low nitrogen abundance measured in region B4 is ignored (Lee & Skillman 2004).

1– Israel (1988); 2– González Delgado et al. (1997); 3– Calzetti et al. (1994); 4– Martin (1997); 5– Kobulnicky & Skillman (1997); 6– Tosi et al. (2001); 7– Meurer et al. (1992); 8– Storchi-Bergmann et al. (1994); 9– Lee & Skillman (2004).

Despite being differently classified (as a DIG NGC 1569 and as a BCD NGC 1705) they display fairly similar global properties (except for the nitrogen abundance – see Table 1). The reported chemical abundances refer to the present time (being measured from H\(\text{II}\) region optical lines). Therefore, they have to be compared with the final points of the theoretical tracks. The star formation history (SFH) and initial mass function (IMF) have been deduced from deep optical and near infrared \(HST\) photometry by applying the synthetic colour-magnitude diagram (CMD) method (Tosi et al. 1991). An almost continuous star formation activity has been derived for both galaxies in the last \(\sim 1\) Gyr (Greggio et al. 1998; Annibali et al. 2003; Angeretti et al. 2005). The youngest burst in NGC 1705, started 3 Myr ago, is still ongoing. Its rate, \(\sim 0.3\) \(M_\odot\) yr\(^{-1}\) according to Annibali et al. (2003), is comparable to that of the latest, strongest burst occurred in NGC 1569 (Greggio et al. 1998). As back as the observations can go – up to \(\sim 1–2\) Gyr ago for NGC 1569 (Greggio et al. 2002; Cannon et al. 2004).
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1998; Angeretti et al. 2005) and up to ~5 Gyr ago for NGC 1705 (Annibali et al. 2003) – there is always evidence that the galaxy was forming stars at that time. The IMF is found to be close to the Salpeter value for both objects.

Chemical evolution model results

Taking advantage of the constraints put on SFH and IMF by the CMD analysis, we construct detailed chemical evolution models for NGC 1569 and NGC 1705 aimed at understanding how these galaxies form and evolve. We make the working hypothesis that each galaxy can be described by a one-zone model, a reasonable assumption as long as significant abundance gradients are not observed in these systems.

The basic equations we use in order to follow the temporal evolution of several chemical species in the gas are the same described in Bradamante et al. (1998). The stellar lifetimes are taken into account in detail, i.e., the instantaneous recycling approximation is relaxed. Up-to-date stellar nucleosynthesis is included in the model and galactic winds are assumed to originate when the thermal energy of the gas equates its binding energy. The thermal energy of the gas increases due to supernova (SN) explosions and stellar winds; according to Recchi et al. (2001), a higher thermalization efficiency is assigned to Type Ia SNe, because they explode in a warm medium, rarefied by previous Type II SN explosions. The binding energy of the gas depends on the dark matter (DM) amount and distribution; a massive \( M_{\text{dark}}/M_{\text{lum}} = 10 \), diffuse \( R_{\text{eff}}/R_{\text{dark}} = 0.1 \) DM halo is assumed. For late-type dwarfs, mostly metals are expected to be carried away in the outflow, while only a smaller fraction of unprocessed gas is likely to be affected (De Young & Gallagher 1990; Mac Low & Ferrara 1999; D’Ercole & Brighenti 1999).

Fig. 1 displays some results obtained with different models for NGC 1569. The star formation rate, metallicity, oxygen abundance, and carbon (nitrogen) to oxygen abundance ratios in the gas are shown as a function of time for six models differing in the adopted SFH at epochs where no constraints are available from HST photometry, galactic wind efficiency and stellar nucleosynthesis. In particular, Models 1aN, 2aN and 2bN assume that only one small burst of star formation preceded the strong last Gyr activity detected with HST. For Models 3cN and 3cW, the most ancient activity consists of three weak short-lasting bursts, while Model 4aN adopts a continuous, low-level star formation in the past. The metal ejection efficiency due to galactic winds is higher for Model 2bN than for Models 1aN, 2aN and 4aN, while it is slightly lower for Models 3cN and 3cW. All the models share the same stellar nucleosynthesis prescriptions (van den Hoek & Groenewegen 1997 yields with constant mass loss parameter along the AGB for low- and intermediate-mass stars, plus Nomoto et al. 1997 yields for massive stars), but Model 3cW (van den Hoek
Figure 1. Temporal behaviour of (i) star formation rate, (ii) metallicity, (iii) oxygen abundance, (iv) carbon to oxygen, and (v) nitrogen to oxygen abundance ratios in the gas of NGC 1569 for six different chemical evolution models (see text). Predictions from different models (blue solid curves) are displayed together with the observational values when available (yellow horizontal bands). The star formation rate is actually an input quantity for the models. Notice that measured abundances refer to H II region composition and must then be compared with the end points of the theoretical tracks.

& Groenewegen 1997 yields with metallicity-dependent mass loss parameter along the AGB for low- and intermediate-mass stars, plus Woosley & Weaver 1995 yields for massive stars).

Detailed discussion of the model results will be presented elsewhere, here we limit ourselves to some basic considerations. The first thing to notice is the high degree of uncertainty which affects model predictions due to uncertainties
in the stellar nucleosynthesis. By comparing the fourth and fifth columns of Fig. 1, it can be seen that the theoretical C/O and N/O may vary by $\sim 0.3-0.4$ dex, depending on the assumed stellar yields. In particular, the set with the yields by van den Hoek & Groenewegen (1997; metallicity-dependent mass loss parameter along the AGB) plus Woosley & Weaver (1995) overestimates the nitrogen abundance actually seen in NGC 1569. Part of the discrepancy is likely due to the fact that primary nitrogen production from intermediate-mass stars is overestimated by this yield set (see also Chiappini et al. 2003).

Another important issue is that of the galactic wind efficiency. The most recent, violent star formation activity in NGC 1569 naturally triggers and sustains an outflow on a galactic scale in our model. The more efficient the star formation process, the more effective must be the wind in removing the newly produced metals in order to explain the H II region data. For instance, Model $2aN$ (Fig. 1, second column), computed by assuming a star formation efficiency higher than Model $1aN$ (Fig. 1, first column) during the last Gyr, overproduces the present-day oxygen content and overall metallicity of the galaxy, unless the efficiency of gas removal from the galaxy is increased (Model $2bN$, Fig. 1, third column).

Finally, it is worth stressing that, besides the standard bursting mode of star formation (strong bursts of star formation alternating long quiescent phases) often attributed to DIGs and BCDs by chemical evolution modellers (e.g. Bradamante et al. 1998 and references therein), assuming a continuous low-level star formation rate in the past also produces results in good agreement with the observations (Model $4aN$, Fig. 1, last column). Because of the small differences in the model predictions in the two cases, it is unlikely that future measurements such as abundance determinations for single stars tracing the whole chemical enrichment history of the galaxy will allow us to discriminate between the two opposite scenarios. However, it should be noted that the observational evidence points against long periods of quiescence between successive bursts, at least for the look-back times actually surveyed by the observations.

Models for NGC 1705 are similarly constructed by adopting the SFH and IMF inferred from the observations (Annibali et al. 2003). The stellar yields, galactic wind onset conditions and efficiency are the same adopted by successful models for NGC 1569. While the total and gaseous mass of the system at the present time as well as its current metallicity and oxygen content are easily reproduced, the predicted nitrogen abundance turns out to be always higher than measured from H II regions (cfr. Figs. 2a and 2b).

**Interpreting the N/O data.** Understanding the origin of nitrogen is one of the major goal of modern astrophysics. Since the pioneering work of Edmunds & Pagel (1978), a stellar source of primary N has became strongly in demand. Recent abundance data for very metal-poor Galactic halo stars
(Spite et al. 2004; Israeli et al. 2004) suggest that an important production of primary N actually took place in the first generation of massive halo stars, while delayed primary N production from intermediate-mass stars likely overwhelms any massive star contribution at later times (e.g. Chiappini et al. 2003). However, current stellar yields probably overestimate the amount of primary nitrogen produced through hot bottom burning in intermediate-mass stars. Clearly, changing the nucleosynthesis prescriptions in such a way that the N/O ratio measured for NGC 1705 is reproduced, immediately destroys the agreement between model predictions and observations for NGC 1569, since a too low N/O ratio is obtained in this case. On the other hand, modifying the intermediate- and high-mass star stellar mass spectrum within the range allowed by HST observations does not offer a viable solution, either. One is left with the possibility that the relative fractions of nitrogen and oxygen lost from the two galaxies are different. Alternatively, in NGC 1705 we might be seeing localized self-pollution due to dying young massive stars born during the last 3 Myr of star formation activity. Both such hypotheses wait for detailed hydrodynamical computations in order to be verified.

Notes

1. A smaller effect is seen in the C/O and N/O ratios, since carbon, nitrogen and oxygen are always ejected in the same proportions in the outflow for all the models.

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