Chemodynamical gas flow cycles and their influence on the chemical evolution of dwarf irregular galaxies

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Abstract. Here we investigate an exemplary chemodynamical evolutionary simulation of a dwarf irregular galaxy. By means of this model we demonstrate the existence of three gas mixing cycles: 1) An inner local cycle mixing the metals produced in stars locally, and 2) an outer galactic cycle on which hot gas is driven out of the galaxy by multiple supernovae type II and mixes on a short timescale with the available cold gas. 3) Only a small fraction of the metals leaves the galactic gravitational field and follows the global cycle with the intergalactic matter. The large-scale mixing results in a temporary depletion of supernova ejected metals. We will discuss this delayed recycling and its influence on the chemical evolution, especially on the nitrogen over oxygen ratio which is increased temporarily. These results presented here are also relevant for less sophisticated analytical approaches and chemical evolutionary models of galaxies which have to parameterize the metal loss through outflow.

1. Introduction

Many observations have been carried out to determine the chemical abundances in dwarf irregular galaxies (dIrrs) (e.g., Garnett 1990; Pilyugin 1992, 1993). They show a wide scatter both in metal abundances and in abundance ratios (e.g., van Zee et al. 1998). In spite of this, the metal distribution inside some of the galaxies is rather homogeneous (e.g., NGC 1569: Kobulnicky & Skillman 1997; I Zw 18: Izotov & Thuan 1999).

Metals produced in high-mass stars (HMSs) and intermediate-mass stars (IMSs) pollute different gas phases. Due to the diverse energy contents of supernovae (SNe) and planetary nebulae (PNe) their mass releases are stored in the hot intercloud medium (ICM) or the cold cloudy medium (CM), respectively. The CM-bound metals remain in the galactic body, while SN ejecta might leave the gravitational field of the galaxy. Some hydrodynamic simulations have shown on the one hand that galactic winds are able to expel the SN II-ejected gas (e.g., De Young & Gallagher 1990; Mac Low & Ferrara 1999) while in contrast others (e.g., D’Ercole & Brighenti 1999) allow the gas to be kept in the gravitational field of dIrrs if an extended gaseous halo exists. Tenorio-Tagle (1996) and Silich & Tenorio-Tagle (1998) describe scenarios where the gas leaves the galaxy but rains back to other locations. Additionally, Kobulnicky & Skillman (1997) have observed regions e.g. in NGC 5253...
with larger Nitrogen and Oxygen abundances what can be explained by local self-enrichment.

2. Chemodynamical models

We have performed self-consistent chemodynamical evolution simulations. The code distinguishes between two gas phases necessary to investigate the separated N and, respectively, O contamination and the abundance mixing processes. Three stellar mass ranges are treated to distinguish the different stellar properties for the element release. Additionally to gravitation all relevant mass and energy exchange processes between stars and gas and the gas phases themselves are taken into account such as star formation, stellar mass loss and death, evaporation, condensation, drag forces, cloud-cloud collisions and radiative ionisation as well as e.g. radiative cooling of the gas. Details of these simulations can be found in Rieschick & Hensler (2003). The chemodynamical treatment, its basic network of interaction processes and the numerical code are described in detail in the comprehensive paper by Samland et al. (1997). We assume that the galaxy starts from a protogalactic gas cloud with a Plummer-Kuzmin density distribution (Satoh 1980) and a baryonic mass of about $10^{10} \, M_\odot$ within a static dark matter halo according to Burkert (1995) of $10^{11} \, M_\odot$.

3. Results

Here we focus on the different mass exchange processes acting within the galactic body. Fig. 1 shows all relevant processes for the irregular phase of the dIrr model (see also Rieschick & Hensler 2000 where a different chemodynamical simulation was presented). On the top right-hand side the ”Infall” of CM from the gaseous outskirts into the galactic body is shown. In combination with evaporation and outflow of hot gas a large-scale cycle of mass flow is produced, because the ICM reaches the enveloping HI-halo where condensation rate exceeds evaporation. Therefore, the cycle is closed.

It is important to notice that local self-enrichment by PNe occurs in the forming disk, because the time for evaporation and blow out the complete CM (roughly $5 \cdot 10^8 \, M_\odot$) exceeds 1 Gyr. On the other hand, since the ICM phase contains much less mass (some $10^6 \, M_\odot$), the complete ICM gas is condensed onto the CM or blown out on a rather short timescale. Some of the SN II ejecta flow out directly, while another part leaves the galaxy not until it follows a detour through CM phase and evaporation process into ICM again. In total, only about 45% of the SN II metals are poluting the CM locally, while the rest is leaving the galactic body through ICM outflow.
We divide the passage of gas and its metal content into three cycles:

- **local cycle**: The metals contained in PNe remain in the CM. About half of the SN II ejecta are mixed into the local CM.

- **galactic cycle**: Gas leaves the galactic body by high velocity outflow and is mixed into the halo on a short timescale. The gas rains back into the galaxy with typical timescales of $\approx 100$ Myr up to 3 Gyr.

- **global cycle**: Less than five percent of the hot gas leaves the gravitational field polluting the intergalactic medium.

### 4. Discussion and conclusions

While PNe stay almost completely in the local SF regions, the chemodynamical dIrr simulations have shown that more than half of the SN II ejecta leave the galactic body before they reenter the inner, observable regions again. This *delayed recycling* has a distinct influence on the chemical evolution, especially on the ratio of nitrogen (N) to oxygen (O).

Taking up-to-date stellar yields into account (Woosley & Weaver 1995; van den Hoek & Groenewegen 1997), O is almost completely processed in HMSs while N is produced both in HMSs but mostly in IMSs.
In early evolutionary stages with lower metallicities only a small fraction of N originates from HMSs while e.g. for $Z = 0.1 \ Z_\odot$ about 65% of a single stellar population’s N yield is ejected by SNe II (secondary N production). Comparing delayed recycling with instantaneous local mixing the N/O ratio is shifted to higher values up to about 1.0 dex. This effect is due to the O deposition and separated analytically from other dynamical and evolutionary influences, e.g. the different lifetime of HMSs and IMSs which also influences the N/O ratio significantly (see e.g. Henry et al. 2000). It has a particular importance for very metal-poor systems, but varies with the evolutionary phase as well as with global dynamical processes going on. Therefore chemodynamical models which consider all relevant dynamical and energetical processes can provide a fundamental insight into matter exchange and metal deposition in these sensitively balanced galaxies.

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References

Burkert, A. 1995, ApJ, 447, L25
D’Ercole, A., Brighenti, F. 1999, MNRAS, 309, 941
De Young, D. S., Gallagher, J. S. 1990, ApJ, 356, L15
Garnett, D. R. 1990, ApJ, 363, 142
Henry, R. B. C., Edmunds, M. G., Köppen, J. 2000, ApJ, 541, 660
Izotov, Y. I., Thuan, T. X. 1999, in Proc. XVIII. Rencontre de Moriond, Les Arcs, Dwarf Galaxies and Cosmology, eds. T. X. Thuan, et al. (Gif-sur-Yvette: Frontières), 223
Kobulnicky, H. A., Skillman, E. D. 1997, ApJ, 489, 636
Kobulnicky, H. A., Skillman, E. D., Roy, J.-R., Walsh, J. R., Rosa, M. R. 1997, ApJ, 477, 679
Mac Low, M. M., Ferrara, A. 1999, ApJ, 513, 142
Pilyugin, L. S. 1992, A&A, 260, 58
Pilyugin, L. S. 1993, A&A, 277, 42
Rieschick, A., Hensler, G. 2000, Cosmic Evolution and Galaxy Formation: Structure, Interactions and Feedback, ASP Conf. Ser. eds. J. Franco, E. Terlevich, O. López Cruz & I. Aretxaga, Astron. Soc. Pac., San Francisco
Rieschick, A., Hensler, G. 2003, A&A, to be submitted
Samland, M., Hensler, G., Theis, Ch. 1997, ApJ, 476, 544
Satoh, C. 1980, PASJ, 32, 41
Silich, S. A., Tenorio-Tagle, G. 1998, MNRAS, 299, 249
Tenorio-Tagle, G. 1996, AJ, 111, 1641
van den Hoek, L. B., Groenewegen, M. A. T. 1997, A&AS, 123, 305
van Zee, L., Salzer, J. J., Haynes, M. P. 1998, ApJ, 497, L1
Woosley, S. E., Weaver, T. A. 1995, ApJS, 101, 181