

Mass loss from galaxies: feeding the IGM, recycling in the IGM

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Abstract. As a result of internal processes or environmental effects like ram-pressure stripping or collisions, galaxies lose a significant part of their stellar and gaseous content. Whereas the impact of such stripping on galaxy evolution has been well studied, much less attention has been given to the fate of the expelled material in the intergalactic or intracluster medium (IGM/ICM). Observational evidence exists showing that a fraction of the injected matter is actually recycled to form a new generation of galaxies, such as the Tidal Dwarf Galaxies discovered near numerous interacting systems. Using a set of multiwavelength data, we are now able to roughly analyze the processes pertaining to their formation: from an instability in the HI clouds, through the formation of molecular gas, and to the onset of star formation.

1. Loss of galactic material during galaxy evolution

Galaxy evolution goes hand in hand with the loss of interstellar matter. Many processes, of internal or external origin, contribute to strip galaxies from their raw material. Starbursts and associated superwinds or active galactic nuclei via jets cause the ejection of plasmoids at distances of up to ten kpc. Such mechanisms do not involve large quantities of matter but play a major role in enriching the IGM/ICM with heavy elements and at the same time in regulating the chemical evolution of galaxies. External processes have an even more dramatic effect on galaxy evolution. Whereas in clusters ram-pressure exerted by the ICM is efficient at stripping gaseous material, tidal forces act both on stars and gas, pulling them out up to distances of 100 kpc. Figure 1 illustrates several of these mechanisms.

2. Galactic material in the IGM/ICM

Besides hot gas and dark matter, the intracluster medium contains matter more usually found in galaxies. Star streams were discovered on deep optical images of clusters (Gregg & West, 1998). Various surveys found numerous planetary nebulae (Ford et al., 2001) and red-giant stars (Ferguson et al., 1998) floating between galaxies. From their numbers, it was extrapolated that the intracluster stellar population may contribute between 5 and 50% to the total stellar mass in clusters. The



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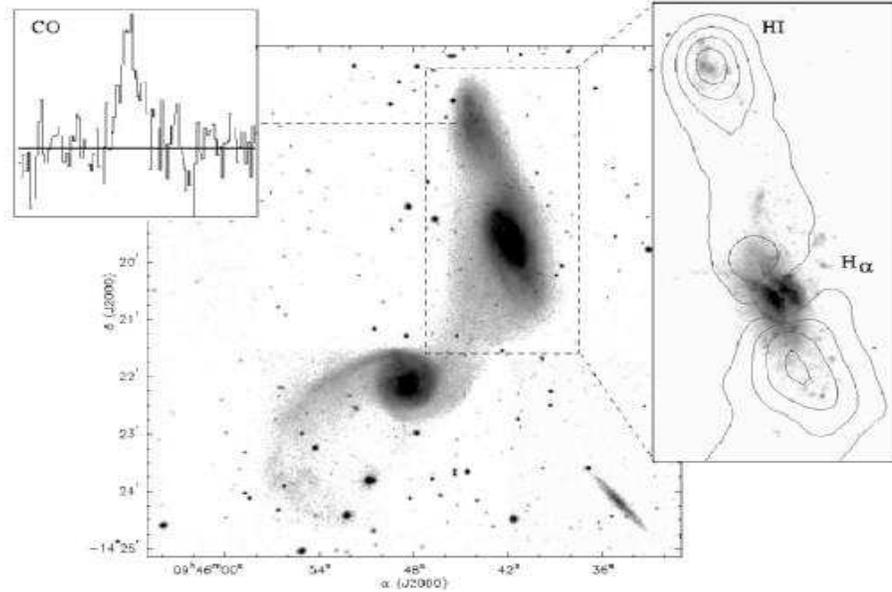


Figure 1. Outflows in the interacting system Arp 245. The inset to the right is a close-up of the spiral NGC 2992 and its tidal tail. VLA HI contours are superimposed on an $H\alpha$ image. This map exhibits a 30 kpc-long HI tail together with 10 kpc-long $H\alpha$ filaments, escaping from the disk and which likely originate in an AGN. Atomic, molecular (see the CO spectrum to the left) and ionized gas concentrate at the tip of the tail fueling a starburst. Adapted from Duc et al. (2000) and Braine et al. (2001).

neighborhood of colliding galaxies contains large quantities of atomic hydrogen. The percentage of extragalactic HI gas observed in emission at 21 cm typically ranges between 50 and 90% of the total HI content of interacting systems. Even more surprisingly, extragalactic molecular gas, as traced by the millimetre CO line, was detected in several groups, in particular in Stephan's quintet (see Fig. 2) where we measured more than $3 \times 10^9 M_{\odot}$ of H_2 .

Where does such intergalactic material come from? A cosmological origin can be excluded. Indeed, optical spectroscopy indicates metallicities typical of galactic disks that are inconsistent with primordial clouds. Therefore, this matter could either be the remnant of totally disrupted galaxies or expelled galactic material.

3. Fate of stripped material

The fate of galactic debris or ejecta will largely depend on their nature, distance from the progenitors and on time scales. First of all, simple

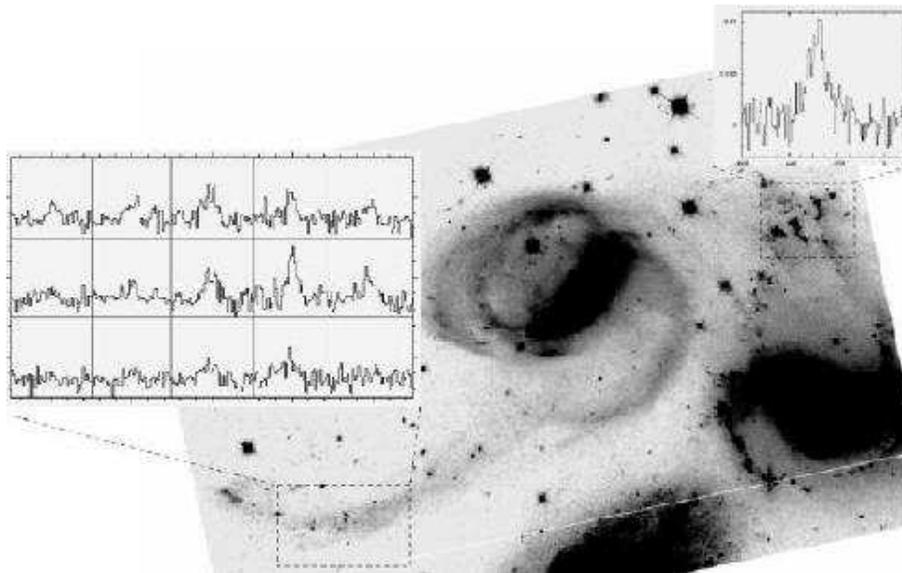


Figure 2. Intergalactic molecular clouds in the Hickson Compact Group HCG 92 (Stephan's quintet). CO(1-0) spectra obtained with the IRAM 30m antenna are superimposed on an HST image of the group (Lisenfeld et al. 2002, in prep.)

gravitation will cause the ejecta to fall back, eventually, on to the parent galaxies. (Re)accretion has since long been taken into account in semi-analytic models of galaxy evolution and studied in detail using numerical simulations of galaxy collisions (Hibbard & Mihos, 1995) or ram pressure stripping (Vollmer et al., this volume). Time scales for reaccretion vary between several Myr and one Hubble time depending on how far stripped material had been ejected. Lost material may be so diluted in the ICM that it becomes barely visible. The stellar component will light up as a diffuse background. The low-column density atomic hydrogen hitting the hot intracluster medium will evaporate or become ionized, becoming invisible in the 21 cm line.

Finally, part of the 'lost' material is recycled directly within the intergalactic environment. This is the origin of the so-called tidal dwarf galaxies (TDGs), made out of tidal material pulled out from colliding galaxies. These gas-rich, dynamically young objects are now commonly observed near interacting systems (Weilbacher et al., 2000), in groups or clusters of galaxies. From our multiwavelength observations, we are now able to roughly analyze several processes pertaining to their formation. Using Fabry-Perot H α datacubes, we identified kinematically distinct entities decoupled from the streaming motions which characterise the kinematics in the gaseous tidal tails. Their position-velocity diagrams (see Fig. 3) show velocity gradients of typically 50 km s $^{-1}$ over scales

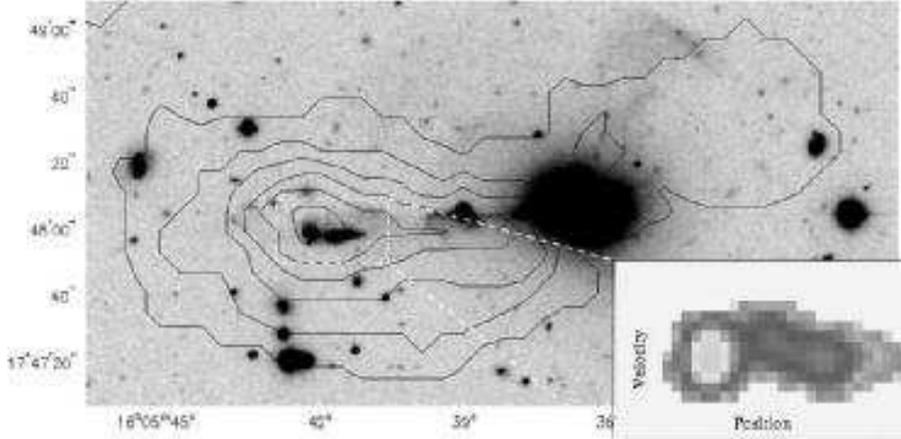


Figure 3. A tidal dwarf galaxy near the merger IC 1182, in the Hercules cluster. VLA HI contours are superimposed on an optical image of the system. The TDG – the compact object to the left – is associated with a large HI condensation. The inset presents a position-velocity diagram in the ionized component obtained from Fabry-Perot observations at CFHT. It exhibits a strong velocity gradient, which is likely linked with the formation of the TDG.

of a 1–5 kpc. Spatially, such objects are located at the peak of the HI column density. This is also precisely where we detected abundant quantities of molecular gas which most likely was produced in situ from the HI (Braine et al., 2001). The scenario accounting for the formation of TDGs would hence involve an instability in the tidal HI, its collapse and further transformation in to H_2 and the onset of star-formation. Unfortunately in order to confirm this, we still lack the support from numerical simulations that so far failed to produce tidal objects similar to those observed. Other pending questions are the global amount of material involved in such cosmic recycling and the survival time of TDGs.

References

- Braine, J., Duc, P.-A., Lisenfeld, U., et al., 2001, *A&A* 378, 51
 Duc, P.-A., Brinks, E., Springel, V. et al., 2000, *AJ* 120, 1238
 Ferguson, H. C., Tanvir, N. R. and von Hippel, T., 1998, *Nature* 391, 461
 Ford, H., Peng, E. and Freeman, K., 2001, *astro-ph/0111035*
 Gregg, M. D. and West, M. J., 1998, *Nature* 396, 549
 Hibbard, J. E. and Mihos, J. C., 1995, *AJ* 110, 140
 Weilbacher, P., Duc, P.-A., Fritze-v. Alvensleben, U. and Fricke, K. J., 2000, *A&A* 358, 819