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RECYCLING INTERSTELLAR AND INTERGALACTIC MATERIAL

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RESUMEN

Como resultado de procesos internos -como la pérdida de gas inducida por brotes estelares o actividad AGN, o por efectos ambientales -como la pérdida de gas inducida por presión de choque o por colisiones, las galaxias pueden perder material estelar y gaseoso. Aunque el impacto de estas pérdidas sobre la evolución galáctica ha sido bien estudiado, se le ha prestado poca atención al destino del material expulsado en el medio intergaláctico o intra-cúmulo. En parte, este material volverá a caer sobre las galaxias progenitoras, dando origen a renovada formacion estelar, en parte se evaporará o dispersará. Los elementos pesados enriquecerán el medio intra-cúmulo. Finalmente, parte del gas perdido por las galaxias se recicla para formar una nueva generación de galaxias, como las galaxias enanas de marea, descubiertas cerca de sistemas ricos de galaxias en interacción. Usando un conjunto de cubos de datos en diversas longitudes de onda, podemos estudiar en detalle los procesos de formación de estas galaxias partiendo de una inestabilidad en las nubes de HI, seguida por la formación in situ de gas molecular y por el inicio de la formación estelar.

ABSTRACT

Following internal processes, such as starburst or AGN driven outflows, or environmental effects like ram-pressure stripping or collisions, galaxies may loose large amounts of stellar and gaseous material. 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/intracluster medium. Part of it will fall back on their progenitors, eventually fueling new star-formation episodes; another part will be evaporated or dispersed; injected heavy elements will enrich the ICM. Finally a fraction of the gas lost by galaxies is recycled to form a new generation of galaxies, such as the Tidal Dwarf Galaxies discovered near numerous interacting systems. Using a set of multiwavelength datacubes, we are now able to detail the processes by which these galaxies form: from an instability in the HI clouds, via in situ formation of molecular gas and further onset of star formation.

Key Words: **GALAXIES: INTERACTIONS — GALAXIES: INTERGALACTIC MEDIUM**

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 super-winds 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.

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 red-giant stars (Ferguson et al., 1998) and planetary nebulae (e.g. Arnaboldi et al., 2002) floating between galaxies. From their numbers, it was extrapolated that the intracluster stellar population may contribute up to 40% to the total stellar mass in clusters. The neighborhood of colliding galaxies, and compact groups (Verdes-Montenegro et al., 2001), contains large quantities of atomic hydrogen outside stellar disks. 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, molecular gas, as traced by the millimetre CO line, was detected between galaxies in several groups, in particular in Stephan's quintet (see Fig. 1) where we measured more than 3×10^9 $M_\odot$ of H_2 (Lisenfeld et al., 2002).

Where does such intergalactic material come from? A cosmological origin can be excluded for

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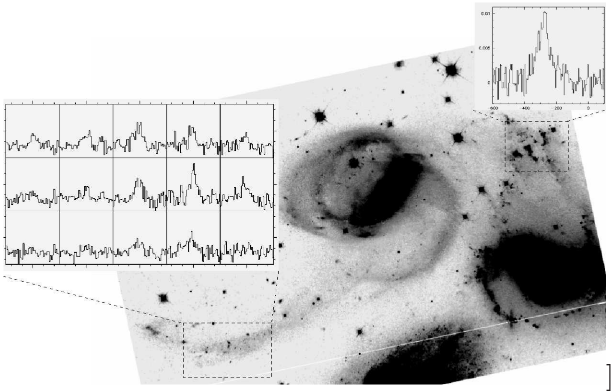

Fig. 1. Intergalactic molecular clouds in the Hickson Compact Group HCG 92 (Stephan's quintet). CO(1-0) spectra obtained with the IRAM 30m antenna are superimposed on an HST image of the group (Lisenfeld et al. 2002)

these intergalactic clouds. Indeed, optical spectroscopy indicates metallicities typical of galactic disks that are inconsistent with primordial clouds (e.g. Duc & Mirabel, 1998; Duc et al., 2001). Therefore, this matter could either be the remnant of totally disrupted galaxies or expelled galactic material.

3. RECYCLING 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 gravitation will cause the ejecta to fall back, eventually, onto 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., 2001). 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 that is still to be quantified 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 (Sakai et al., 2002). From our multiwavelength observations, we are now able to roughly analyze several processes pertaining to their formation. Using Fabry-Perot Hα datacubes, we identified kinematically distinct entities decoupled from the streaming motions which characterise the kinematics in the gaseous tidal tails. Their position-velocity diagrams show velocity gradients of typically 50 km s^{-1} over scales 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 starformation. Unfortunately in order to confirm this, we still lack the support from numerical simulations that so far have 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.

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