Report on the Conference on

Groups of Galaxies in the Nearby Universe

held in Santiago de Chile, 5–9 December 2006

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For every galaxy in the field or in clusters, there are about three galaxies in groups. Therefore, the evolution of most galaxies actually happens in groups. The Milky Way resides in a group, and groups can be found at high redshift. The current generation of 10-m-class telescopes and space facilities allows us to study members of nearby groups with exquisite detail, and their properties can be correlated with the global properties of their host group. Finally, groups are relevant for cosmology, since they trace large-scale structures better than clusters, and the evolution of groups and clusters may be related.

Strangely, there are three times fewer papers on groups of galaxies than on clusters of galaxies, as revealed by an ADS search. Organising this conference was a way to focus the attention of the community on the galaxy groups. We also wanted to offer a venue where people coming from various research fields could meet and discuss groups from different perspectives. All this happened in a friendly atmosphere created by Hotel Torremayor in Santiago.

The discussion was organised in seven sessions, introduced by invited reviews: Eva Grebel (Local Group versus Nearby Groups), Vince Eke (Groups Searches and Surveys), Chris Conselice (The Evolution of Galaxies in Groups – Observations), Gary Mamon (The Evolution of Galaxies in Groups – Theory), Ann Zabludoff (Evolution of Groups as Systems), Trevor Ponman (Interstellar Medium and Intragroup Medium), Stefano Borgani (Groups in a Cosmological context), and finally Ken Freeman (Conference Summary). There were almost 50 contributed talks and 30 posters. Most speakers agreed to share their presentations with the astronomical community at *http://www.sc.eso.org/santiago/science/NGG/finalprogram.html*. Here we give a short summary of the main conference ideas, mostly based on the invited reviews.

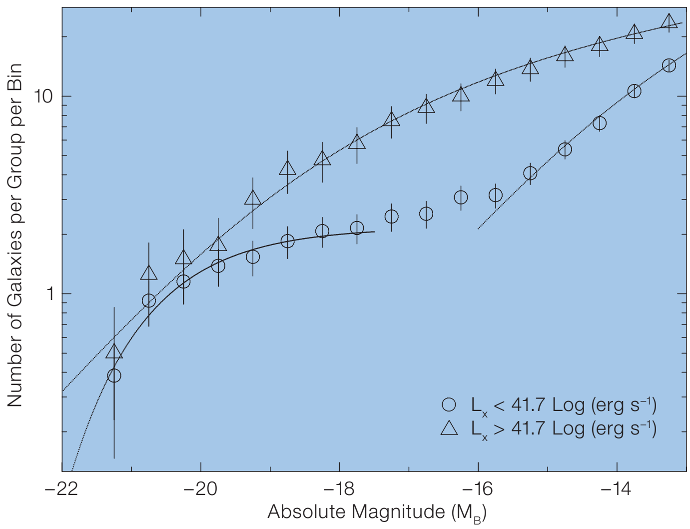

Figure 1: Cumulative *B*-band luminosity function of 25 GEMS groups of galaxies grouped into X-ray-bright and X-ray-faint categories, fitted with one or two Schechter functions, respectively (Miles et al. 2004, MNRAS 355, 785; presented by Raychaudhury). Mergers could explain the bimodality of the luminosity function of X-ray-faint groups.

All you wanted to know about groups (but were afraid to ask)

Groups are bound structures with masses in the range $M = 10^{12-14}\ M_\odot$ (Eke), containing less than fifty galaxies (Conselice), and with typical sizes of a few Mpc. Groups detected in X-rays have luminosities of $L_X = 10^{41-43}$ erg sec^{-1} and gas temperatures of kT = 0.1–3 keV (Ponman). Most of the stellar mass in the present Universe is in groups similar to the Local Group with masses ~ $2 \times 10^{12}\ M_\odot$ and only 2 % is in clusters with $M > 5 \times 10^{14}\ M_\odot$ (Eke). Groups were already present at redshifts $z > 1$ (Conselice). Cosmological simulations predict a much larger number of galaxy satellites than observed, and H I high-velocity clouds cannot fill in this gap (Pisano). Groups follow a fundamental plane (Muriel), and the most massive ones have an X-ray halo with an extended component (Zabludoff).

A special class of groups are the so-called 'fossil groups' – isolated ellipticals with properties similar to a group, which could be the final stage of a collapsed group. However, most isolated ellipticals are not collapsed groups (Forbes). There are only 15 fossil groups known to date.

The evolution of low-velocity dispersion groups is dominated by mergers, which could explain the bimodal mass function of the X-ray-faint groups (X-ray-faint groups tend to have low-velocity dispersion, and vice versa), if intermediate-mass members merge to build the largest group members (Raychaudhury). The bimodal mass function (see Figure 1), similar to that of clusters, is confirmed in compact groups (Bomans). Compared to compact groups, the loose ones tend to have fewer low-mass members.

The results presented here were obtained thanks to large observational efforts (Table 1). Historically, the first group catalogues were biased toward compact groups, which are the easiest to identify from imaging surveys. Modern redshift surveys allow selections including recession velocities, and finding algorithms can be tested on mock catalogues generated with dark matter (DM) simulations (Eke).

Galaxies in groups

Galaxies in groups can be affected by processes like ram pressure stripping, in-

Table 1: Summary of the state-of-the-art group catalogues and surveys discussed at the meeting.

Name	Description	Reference
160 and 400 square-degree ROSAT surveys	14 groups were studied to compute the mass and compare mass-to-light ratios with simulations	Vikhlinin et al. 1998, ApJ 502, 558 (presented by A. Hornstrup)
2PIGG (2dFGRS Percolation-Inferred Galaxy Group) catalogue	The largest available homogeneous sample of galaxy groups, public	Eke et al. 2004, MNRAS 348, 866
ALFALFA (Arecibo Legacy Fast Alfa (= Arecibo L-Band Feed Array)) survey	Large-scale survey of extragalactic H I over 7000 square degrees of sky, up to *cz* = 18000 km/s. Spectral resolution is 5 km/s. It can detect H I clouds with more than 10^7 $M_\odot$ throughout most of the Local Supercluster	Giovanelli 2005, AAS 207, #192.03
AMIGA project (Analysis of the Interstellar Medium of Isolated Galaxies)	Multiwavelength database of isolated galaxies, including optical (B and Hα), infrared (FIR and NIR) and radio (continuum plus H I and CO lines)	Verdes-Montenegro et al. 2005, A&A 436, 443
CNOC2 (Canadian Network for Observational Cosmology) survey	Spectroscopically selected catalogue of 200 groups at intermediate redshift over 1.5 square degrees on the sky	Carlberg et al. 2001, ApJ 552, 427
GEMS (Group Evolution Multiwavelength Study) project	Catalogue of 60 galaxy groups at 15–130 Mpc distance. Plus: X-ray (ROSAT PSPC 10000 sec, 1.5 degrees), optical imaging (0.5 degrees), Parkes H I mapping (5.5 degrees), ATCA H I follow-up, 6 dFGS spectra, 2 MASS *K*-band photometry, XMM/Chandra imaging, Mock catalogues	presented by Forbes
H I survey of six loose groups	Observations of six spiral-rich, loose groups between 10.6–13.4 Mpc, over 25–35 square degrees: Parkes Multibeam and ATCA; Mass sensitivity of 5–8 x 10^5 $M_\odot$	presented by Pisano
LVHIS (Local Volume H I Survey)	H I imaging of all nearby (distance less that 10 Mpc), gas-rich galaxies; deep 20-cm radio continuum imaging with ATCA and VLA; deep H-band and Hα imaging	presented by Koribalski
Sharc (Serendipitous High-redshift Archival ROSAT Cluster) survey	638 ROSAT PSPC observations with |b| > 20 degrees and exposure time greater than 10000 seconds; total 178.6 square degrees; found the most distant fossil group at $z = 0.59$	Romer et al. 2000, ApJS 126, 209 (presented by F. Durret)

teractions and harassment, mergers, group tidal field, gas loss and suppressed star formation (also known as strangulation or suffocation). Merging is the most important of them because of the low relative velocities of galaxies in groups in comparison with the galaxies in clusters. Simulations show that mergers induce an intense and brief (of the order of a hundred Myrs) surge of star formation before the final coalescence into a spheroid, which evolves passively afterwards. Simultaneously, mergers transfer momentum from the interacting galaxies to the group as a whole, thereby increasing the group velocity dispersion. Indeed, observations show that there are more spheroids in groups with higher velocity dispersion (Zabludoff).

Eventually, the feedback from the residual black-hole and active galactic nucleus (AGN) reduces the star formation by a factor of ten or more. At least 50 % of galaxies in compact groups are low-luminosity AGNs (Martinez), while the field fraction is only 30 %. Moreover, the cores of X-ray groups are often disturbed, which could be additional evidence for AGN feedback (O'Sullivan). The selective suppression of star formation in larger group members could explain the downsizing phenomenon – the decrease of the maximum luminosity of star-forming galaxies at lower redshifts. Mergers occur mostly at redshifts $z > 1$: for example at $z = 2.5$ about 50 % of bright galaxies are undergoing mergers, while today only 2 % of galaxies merge per Gyr (Conselice). Most of the stars in group members also formed between redshifts $z = 2.5$ and 1.

Locally, environmental effects can be traced directly by reconstructing star-formation histories of individual galaxies. For example, the fraction of intermediate-age stars of Milky Way dwarf satellites depends on their distance from the Galaxy. On the contrary, this fraction is constant in M81 satellites (Da Costa), probably due to the compactness of the M81 group, where multiple close encounters have homogenised their star-formation histories.

The evolution of groups

The origin of groups is probably related to large-scale gaseous filaments at high redshift. Before virialisation, smooth accretion, supernovae and AGN activity enhance the entropy, and the metal-enriched gas cannot be retained by the shallow potential of pre-collapse groups (Ponman, Borgani). During the virialisation, the central spheroidals grow via mergers. Early-type stars and enriched gas become part of the intragroup environment. Eventually, common dark matter and hot (X-ray) gas halos are formed (Zabludoff). The X-ray emission increases, and the X-ray halo becomes more and more regular. Later, the diffuse DM distribution will reduce the merger rate and moderate the evolution of groups. At least a fraction of groups end their lives as fossil groups.

Most low-redshift groups are just detaching from the Hubble flow, as suggested by the time evolution of the virial mass-to-light ratio (Mamon). In particular, the detachment for the Local Group occurred at $z < 0.7$ (Freeman). The mass-temperature and mass-luminosity distributions in the X-rays for clusters and groups can constrain the cosmological parameters (Borgani).

To summarise, as a group evolves, the dwarf-to-giant ratio, early-type galaxy fraction, intragroup starlight and metallicity, the velocity dispersion, and the mass of the central giant elliptical grow. The metallicity of the intragroup medium also increases thanks to the intragroup stars, whose ejecta do not have to overcome galactic potential wells (Zabludoff).

Observations are consistent with this scenario. As mentioned above, groups with higher velocity dispersions have higher fractions of early-type galaxies. And the intragroup medium can be responsible for stripping, e.g. of NGC 2276 in the NGC 2300 group (Ponman). In turn, stripping enhances the fraction of passive galaxies in groups. Further observational support for this evolutionary scheme are the constant radial profiles of velocity dispersion, which point to a common DM halo. Next, if the early enrichment history of the intragroup gas is dominated by type II supernovae, and the late history by type Ia supernovae, then this could explain the observed decrease of the overall metallicity toward the outskirts of the group, and the alpha-enhancement in the outer parts of groups (Rasmussen) because the early ejecta had time to spread across the group.

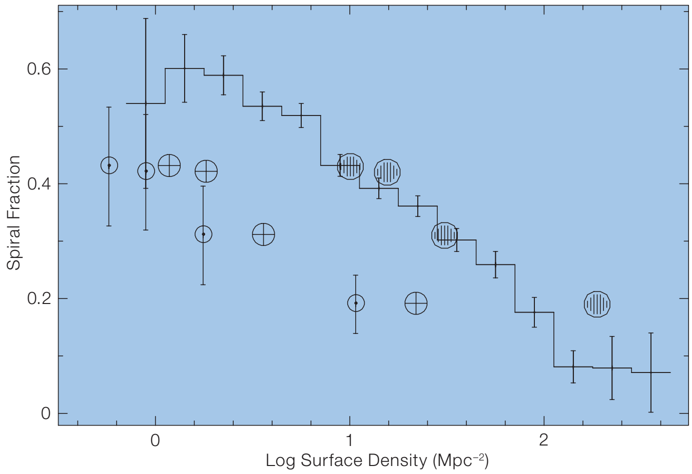

Figure 2: Spiral fraction (including irregulars) as a function of surface density (averaged over radial bins). The histogram represents the local clusters, and the open circles with error bars are the group data. Crossed and shaded circles represent group points after estimated corrections for 3D density and merging rates, respectively (for clarity the error bars are omitted from these points). Direct type mergers in groups convert late-type galaxies into spheroidal galaxies more efficiently than grazing mergers in clusters (Helsdon and Ponman 2003, MNRAS 339, L29; presented by Mamon).

Groups and clusters of galaxies

It was realised during the conference that groups are important for the evolution of clusters as well. Clusters may grow by accretion of groups, as exemplified by the Eridanus Super-group infalling toward Fornax (Brough). Therefore, some cluster properties might be explained by groups, such as the X-ray medium, high dwarf-to-giant galaxy ratio, brightest cluster galaxies, and the early-type galaxy fraction (especially in more massive groups).

Likewise, the evolution of galaxies in clusters might be dominated by group-scale environment, driving e.g. the morphology-environment relation, the Butcher-Oemler effect, and the brightest cluster galaxies formation. For example, the intracluster light in Virgo probably originates in tidal interactions inside group-size structures (Mihos), favoured by their low velocity dispersion. Since tidal features are erased as clusters evolve, the presence of such features would indicate that the cluster is dynamically young, still 'fragmented' in groups.

Although mergers can happen both in clusters and groups, the high velocity dispersion in clusters leads to less efficient orbital-decay-type mergers, while more efficient, direct head-on mergers are common in groups, especially the evolved, X-ray bright ones (Mamon). This can explain the higher fraction of early-type galaxies in this class of groups compared to the field and clusters (Figure 2).

These few paragraphs can only give a brief sense of the stimulating discussion during the five days of the conference, and we hope that all participants went away with fresh views on the current status of galaxy groups studies. The proceedings will be published later this year in the ESO Astrophysics Symposia series.

Acknowledgements

We would like to express our gratitude to the members of the SOC, and especially to the SOC chair Duncan Forbes, for their efforts that made it possible to organise this meeting. Last but not least, the success of the conference would have been impossible without the excellent work of Maria Eugenia Gómez, Paulina Jiron and Ismael Martínez, and the financial support of ESO.

Almost all conference participants can be seen in this photograph, taken in the hotel frontyard. The exception is Valentin Ivanov, who's taking the picture!