THE EXTRAORDINARY GALAXY GROUP HCG 22

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Abstract

An earlier study with Chandra has shown that there are some galaxy groups with bona fide hot intergalactic gas which have velocity dispersions so low, that it difficult to see how they can satisfy the overdensity criterion required of collapsed systems in the standard picture of cosmological structure formation. A new survey of the X-ray and optical properties of groups has revealed that the compact galaxy group HCG22 has properties far more extreme than any reported previously in an X-ray bright group, with a velocity dispersion of only 25+/-11 km/s. We propose to investigate the dynamical status of this unique system in detail, using Chandra in conjunction with galaxy velocities from the IMACS multi-object camera.

1. Background and motivation

According to hierarchical theories of structure formation, groups form from the turn-around and collapse of larger structures within which galaxies have already formed. Gas falling into the deepening potential well will be compressed and shock heated to the virial temperature of the system, whilst the galaxies will interact and in some cases merge. The final product should be a relaxed system containing $\sim 10^7$ K gas and a number of merger remnant ellipticals, much like a small galaxy cluster. Hoever, studies of the scaling properties of galaxy groups (e.g. Mulchaey 2000) have shown that the hot gas in groups does not, in general, follow the same scaling properties as rich clusters. It has been argued (Ponman, Cannon & Navarro 1999) that this is related to the effects of energy injection from the epoch of galaxy formation, &/or from AGN. The possibility of using scaling properties as a lever to improve our poor understanding of the complex baryon physics (shock, cooling, feedback etc.) which is involved in structure formation has generated a great deal of interest recently.

In the most extensive detailed study of the hot gas in galaxy groups to date, Osmond & Ponman (2004), extracted X-ray (ROSAT PSPC) and optical properties for the "GEMS" sample of 60 groups, within a fixed overdensity radius, and examined a variety of scaling properties. Three of the key scaling plots, including a comparison with the large cluster sample of Horner (2001), are shown in Fig.1. Groups marked as squares on this plot are believed to contain genuine hot intergalactic gas, whilst in those plotted as open circles, the emission appears to arise from a single galaxy halo associated with the central galaxy of the group.

The most strikingly discrepant group in these plots is HCG 22 – marked as a bold square. This group is remarkable chiefly on account of its very low velocity dispersion (σ=25±11 km s^{-1}), though it is also one of the coolest groups in the GEMS sample. Despite its low temperature, the value of $\beta_{\rm spec}$ (the ratio of the specific energy in galaxies to gas) in this system is 0.01, compared to the canonical value of 1! If this system has collapsed out of the Hubble flow, as the apparent presence of hot intergalactic gas suggests that it must have, then it should have an overdensity in excess of 100 (relative to the critical density of the Universe). For objects on the scale of galaxy groups, it can be readily shown that this requires the velocity dispersion to be at least 100-200 km s^{-1} (Mamon 1994). It has been apparent for some time (Helsdon & Ponman 2000) that there are some groups with reasonably bright X-ray emission which have $\sigma \sim 100$ km s^{-1} or less, and we have targeted two of these (NGC 1587 and NGC 3665) with Chandra previously, to establish whether this emission really arises from hot intergalactic gas. The result of this study (Helsdon, Ponman & Mulchaey 2004) confirm that this is the case, although $\sim$ 35% of the ROSAT-derived X-ray luminosity is found

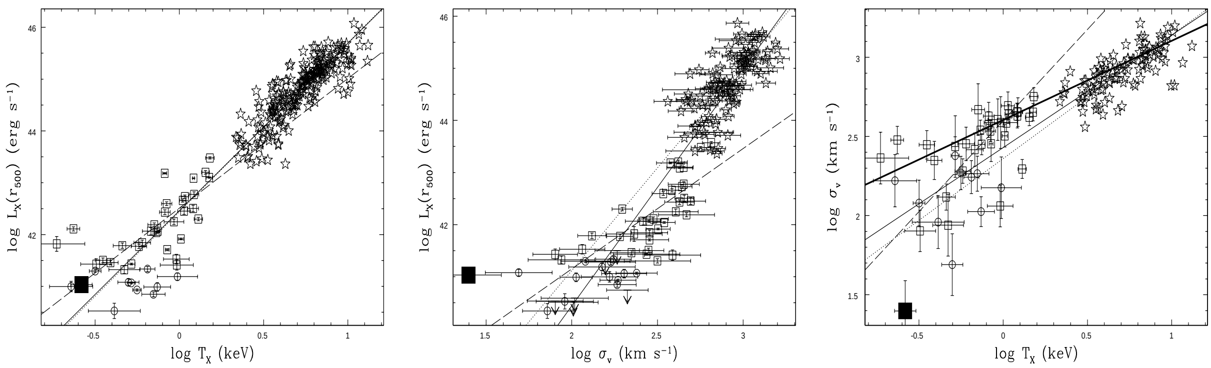

Figure 1: (a) The L-T relation for groups and clusters, where L_X is extrapolated to a fixed overdensity radius (500 times the critical density of the Universe). Stars represent clusters from Horner (2001), whilst circles and squares are galaxy groups (see text for more detail). (b) L-σ relation – where σ is the velocity dispersion of the group/cluster galaxies. (c) σ-T relation. In each plot the dashed line shows an orthogonal regression to those groups (squares) with intergalactic hot gas, the dotted line to the clusters only, and the thin solid line to both. The thick solid line in Fig.1c is the line $\beta_{\mathrm{spec}} = 1$, along which the specific energy is gas and galaxies is equal. HCG 22 is marked by the large solid square in each plot.

to be attributable to point source contamination. Since NGC 1587 and NGC 3665 have velocity dispersions of 117 km s^{-1} and 70 km s^{-1}, respectively, this already poses a serious challenge to our understanding of the formation and dynamics of galaxy systems.

Following this work, a study is now underway, using the GEMS sample, to explore the dynamics of groups in greater detail by scaling and co-adding the distribution of galaxy velocities for the sample, to derive mean velocity dispersion profiles. Our aim is to examine whether the surprisingly low values of σ seen in some groups can be explained by effects such as orbital circularisation, dynamical friction and tidal interactions and mergers of galaxies. If these efforts fail, then a radical re-evaluation of our picture of the way in which structures detach from the Hubble flow and collapse will be required, with far-reaching implications.

The most extreme cases pose the greatest challenge, and this extreme is HCG 22. We therefore propose to image this group with Chandra, to establish firmly the nature and properties of its diffuse X-ray emission, and to perform a detailed redshift survey, down into the dwarf regime, with the IMACS multi-object camera on the 6.5m Magellan I telescope at Las Campanas, to which we have excellent access.

2. The target group

Some key properties of HCG 22 are given in Table 1, and an overlay of the contours of smoothed ROSAT PSPC flux on a DSS image is presented in Fig.2. We searched the NED database for accordant galaxies within the r_{500} radius, derived from the temperature of the group (see Osmond & Ponman (2004) for details), and found a fourth galaxy which was added to the three catalogued by Hickson. These galaxies are labelled 1-4 in the Figure. The X-ray properties of the system, listed in Table 1, exclude emission from the bright background point source in the north, and other unrelated point sources. As can be seen, some of the X-ray emission forms a halo around the brightest group galaxy (BGG) NGC 1199 (1), but the bulk of it is located to the south of this, close to galaxy (4). This is most unusual, since group emission is normally concentrated on the dominant

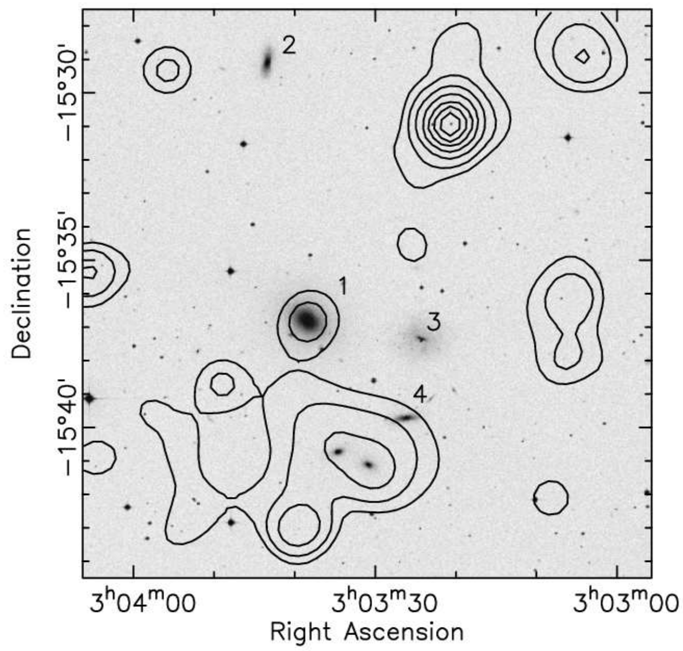

Figure 2: Contours of smoothed PSPC emission are overlaid on an optical DSS image of HCG 22. The four group galaxies are numbered.

early-type galaxy (Mulchaey 2000). Some of this southern component appears to be centred on the two galaxies to the south of galaxies (1) and (4). These galaxies lie in the background, at $v \approx 9500$ km s^{-1} – corresponding to almost four times the distance of HCG 22.

One possibility, is that the emission we have associated with HCG 22 is in fact mostly arising from a background system. In this case, HCG 22 itself need not be a collapsed system at all, and its low velocity dispersion would pose less of a problem. Two factors suggest that this is unlikely to be the case. Firstly, the luminosity of the X-ray emission would in this case be higher by a factor of 13, in which case its very low temperature would be surprising. This is is reinforced by the rather large velocity difference of 343 km s^{-1} between these two background galaxies, which would lead one to expect a characteristic temperature $T{\sim}1$ keV if it corresponded to the velocity dispersion of a background group (see Fig.1b). In contrast, it can be seen from Fig.1a that at the HCG 22 distance of 39 Mpc, the X-ray properties fall nicely onto the observed L-T relation. Secondly, the very compact nature of the galaxy configuration in HCG 22 makes it unlikely that this is a system near turnaround, unless we are viewing a filamentary structure end-on, at a fortuitous angle.

3. Scientific aims

Our primary aim for this observation is to establish the nature of the X-ray emission from HCG 22, so as to clarify the group's dynamical status. If our X-ray observation confirms that this is a collapsed group with hot intergalactic gas, then our parallel dynamical study with IMACS will enable us to define its internal dynamics, and hence to explore possible explanations for its extraordinarily low velocity dispersion.

The Chandra data will enable us to:

- Define the morphology of the X-ray emission, eliminating point source contamination.
- Derive uncontaminated luminosities, and temperatures for the main components of the system, centred on NGC 1199, and to the south.

D	$\log L_X$	T	σ	N_H	ACIS-S flux	Exposure
Mpc	erg s^{-1}	keV	km s^{-1}	10^{20} cm^{-2}	ct s^{-1}	ksec
39	40.71±0.13	0.26±0.04	25±11	4.2	0.058	75

Table 1: Properties of HGC 22, and predicted ACIS-S count rate, based on the detected (rather than extrapolated) ROSAT flux.

- Map the hardness distribution in the hot gas, and search for signs of recent major disturbance, which might account for the offset of much of the emission from the BGG.

In our parallel optical study, we will establish group membership for all galaxies in HCG 22 using the IMACS spectrograph on the 6.5m Magellan I telescope in Chile. The field of view of IMACS ($\sim 27'$) allows one to probe out to almost one half of the virial radius of HCG 22 in a single pointing. Based on our current spectroscopic programme with this instrument, we estimate that we can determine membership for all galaxies brighter than M_B=-14. Our previous studies suggest we can expect to find ~ 50 group galaxies within the virial radius of the system down to this limit. This will not only establish the velocity dispersion and luminosity function of the group, but will permit us to look for velocity substructure, and derive a rough velocity dispersion profile, which will impose constraints on the anisotropy of the orbits (Lokas & Mamon 2001).

4. Observing plans and feasibility

Our main aim in these observations is to resolve the structure and determine the temperature of the diffuse emission, separating out any contaminating point sources. Given the low energy of the emission, the back-illuminated detectors are much to be preferred, and the $8'$ S3 chip will just encompass the entire emission region, provided that it is centred approximately $4'$ S of NGC 1199.

In the 75 ksec requested (Table 1) we will obtain $\sim$4000 counts from the main southern component, and 350 counts from the BGG halo. The background (from the *POG*) of 2.5×10^{-3} ct s^{-1} $arcmin^{-2}$ in the soft (0.5-2.0 keV) band will be reduced by a factor ~ 2 by the use of VF mode, so that the background counts in the region of interest will be approximately equal to our source counts. Under these conditions, similations show that for the spectral properties of HCG 22, a 1000 source count spectrum can constrain T to 20% at the 1σ level. For the halo emission centred on NGC 1199, the background emission will be a minor contributor, and it is still possible to derive temperature to 25% using the 350 count spectrum we will obtain.

5. References

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