Hα images of nearby galaxy groups NGC193 and NGC940

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Abstract. A significant fraction of the baryons in galaxy groups and clusters is not locked up in stars and the interstellar medium (ISM), but exists in the form of extended multi-phase gas. The advantage of nearby galaxy groups is that this multi-phase gas can be studied via X-ray observations probing the hot gas ($\approx 10^7 K$), and optical emission line observations (e.g. Hα filaments) probing the ionised warm gas. Another advantage ~~of groups~~ is that the effects of the galaxies' heating process ~~effects~~ of their surrounding gas (e.g. feedback from AGN) are more visible due to lower density and mass, and ~~containing fewer galaxies , as opposed to~~ because groups contain fewer galaxies than rich clusters. Interaction between the different phases is important for galaxy formation and evolution due to the fact that at least 50% of galaxies can be found in groups and clusters.

The Complete Local-Volume Groups Sample (CLoGS) is an optically selected sample of 53 groups within 80 ~~Mpc~~ Mpc of which the X-ray observations (*Chandra* / *XMM-Newton*) have already been done and can be used to infer important physical properties~~of galaxy groups~~, such as gas temperature and X-ray luminosity. In this project the Hα images, observed using the WIYN 0.9m telescope on Kitt Peak, are analysed with the aim to compare the Hα filaments to the X-ray emission images. Here we present preliminary results and a multi-wavelength comparison for two rich galaxy groups: NGC193 and NGC940. Despite their differences, we detect Hα in the central members of both galaxy groups.

1. Introduction

In this study, we investigate the dominant early-type galaxy and surrounding members of two galaxy groups, NGC193, a galaxy group with its main member an X-ray bright radio galaxy with a powerful central jet, and the other group NGC940, with its main member an X-ray faint galaxy with only a weak radio point source.

2. ~~Introduction~~

~~In this study, we investigate the dominant early-type galaxy and surrounding members of two galaxy groups , NGC193 and NGC940,~~ The two groups are part of the high-richness subsample of ~~The~~ the Complete Local-volume Groups Sample (CLoGS). CLoGS ~~,~~ is an optically-selected ~~,~~ and statistically-complete sample of groups in the nearby Universe~~,~~. Probing the luminous intra-group medium (IGM), CLoGS is specifically chosen and studied with optical observations for this project, since radio and X-ray bands ~~(Kolokythas, in prep.) probing the luminous intra-group medium (IGM),~~ [1] are already available. Important physical properties of the IGM are gas temperature and the total X-ray luminosity, both probing the environment in which the group members are located [~~1~~2]. Together, the CLoGS observations can be used to investigate the role of active galactic nuclei (AGNs) in maintaining the thermal balance of the IGM, to name one example. The CLoGS galaxy groups were observed using the Giant Metrewave Radio Telescope (GMRT) in dual-frequency 235/610 MHz mode ~~(Kolokythas, in prep.)~~[1], with *Chandra* / *XMM-Newton*, and now also in Hα with the WIYN 0.9m telescope.

The brightest, dominant early-type galaxies of groups are known for their typically high luminosity, and are old galaxies located near the centres of the IGMgoup. These brightest group galaxies often reveal activity in their nuclei by radio emission & jets; depositing their energy back to the IGM. If conditions are favourable, the gas surrounding the brightest group member can cool down to form stars and feed the black hole. The latter results in AGN heating, which can heat the gas and cause the cycle to continue.
In this article, we study two of the 53 groups, and we give a brief overview of their properties below.

NGC0193 [1]
This central dominant, jet-dominated, early-type galaxy, at the centre of the group , NGC193, is a currently-active large-scale jet system and located at located at a right ascension of 09:49:38.64 and declination of 03:19:52.7900h39m18.6s and a declination of +03d19m52s. Its jet components extends extend several tens of *kpc* kpc away from the host galaxy, and are seen as very bright, straight jets. These radio jets contribute to the heating of the IGM by balancing the radiative energy losses and also maintaining the long-term thermal equilibrium [23].

The radio jets, known for their large cavities or "cocoon"-like structures, cause disturbances in the X-ray emitting gas (Kolokythas, in prep.). These two bright, straight jets are revealed by the radio contours (see the right image of figure 2) . The two jets and are in a low-surface brightness "cocoon", extending perpendicular to the jet axis, out to a projected distance of $\sim 30 kpc$ from the center. The radio jets extend $\sim$ 30 kpc from the centre - beyond the possible central cavity - and show very little correlation with the substructures detected in the X-ray image. Opposed to this, a correlation is observed between the outer border of the "cocoon" and the bright X-ray rim of the cavity in the northern region [34]. This may suggest that the cavity is possibly filled by the radio plasma in the diffuse "cocoon". The X-ray bright rim represents a shell of gas, brightened on its edge, leaving little cool gas in the galaxy core.

In addition, this central member has X-ray emission-shells that surround its radio-lobes. The *Chandra* image (see the left image of figure 2), shows a bright ring with radius $\sim 20 kpc$ $\sim$ 20 kpc around the nucleus of the central X-ray peak. This bright ring is either the outer shell of a large single X-ray cavity projected towards the group centercentre, or the result of the superposition of two cavities along the line of sight [34].

NGC0940 [2]
This central dominant early-type galaxy in the centre of the group, NGC940, located at a right ascension of 37:21:52.38 02h29m27.5s and declination of 31:38:27.10+31d38m27.3s, shows vastly different properties than that of to NGC0193. The radio emission shows a point source presenting a greater flux density at 610 MHz than in at 235 MHz. No hot gas halo is detected in the X-rays [45].

The *XMM-Newton* image (see the left image of figure 75) shows a $\sim 4 kpc$ $\sim$ 4 kpc radius bright ring around the nucleus of the central X-ray peak, with the contours indicated in black.
Figure 7 5 (see the image on the right) shows the 610 MHz contours (indicated with green colours), overlaid on the smoothed optical Digital Sky Survey (DSS) image.

2. Observational DataObservations

Hα is a strong spectral line visible in the red part of the optical eletromagnetic spectrum, which makes it easily traceable. This spectral line has a rest wavelength of 6562.8$\AA$ and is emitted when a hydrogen atom falls from its third ($n = 3$) to second ($n = 2$) lowest energy level.

In this project, the wide-field Hα-images used for both galaxy groups contain group members of different morphological types. One example of this is a spiral galaxy (refer to figure 43). This type is known for its spiral structure from its center centre into the galactic disc and this morphological type make makes up approximately 60% of the [6] of the local galaxy population in the current Universe. These galaxies contain more young, massive and bright stars in the spiral arms and therefore appear very bright.

Another type of galaxy is an elliptical galaxy, which has an elliptical shape with almost no features but much more structure, with its stars in orbits around the center of this galaxya much more concentrated

[1] Since the galaxy groups are named after their brightest early-type members, we denote the galaxy as NGC0193, and the group as NGC193.
[2] Similarly, we denote the other brightest early-type member as NGC0940, and the group as NGC940.

/ compact structure. Such an example is shown in figure 3, the NGC0193 galaxy. The stars found in elliptical galaxies are older than the young bright stars found in the spiral arms of a spiral galaxy, and are known to be low-mass stars (opposed to the massive stars in spiral arms).

The Hα-filter, $I_{H\alpha}$, used ~~for~~ to observe both galaxy groups for this project had a bandwidth of 81.33$\AA$ ($k_{H\alpha}$) and a transmission rate of 90.58% ($\tau_{H\alpha}$), whereas the r-band, I_r, had a bandwidth of 1475.17$\AA$ (k_r) and a transmission rate of 92.83% (τ_r). To see the ionised gasses clearly, the r-band images must be used to subtract the continuum (i.e. stellar emission).

These images were scaled by using the formula [~~5~~7]:

$$I_{[H\alpha]} = \frac{I_{H\alpha} \cdot k_r - I_r \cdot k_{H\alpha}}{\tau_{H\alpha} \cdot k_r - \tau_r \cdot k_{H\alpha}} \tag{1}$$

where the intensity I is in counts/sec.

This method then effectively ~~presented (what will be shown in the two following sections)~~ shows the ionised hydrogen gasses very ~~clear, with focus on~~ clearly, with prominent clumps of stars visible, especially in the spiral galaxy members of both galaxy groups. Such an example can be seen in figure 6 where the clumps of stars are clearly visible.

3. Discussion

3.1. NGC193

~~Since the main member of this group, NGC0193, is a radio-jet galaxy, it appears as if most of the ionised hydrogen gas (Hα) was ejected from this member.~~ Radio jets are known for its large cavities, heating the surrounding gas, which are often used to look at the power output of these jets [~~1~~2]. The size of cavities are defined by matching an ellipse to their apparent shape. This ~~group~~ is a very compact ~~galaxy group , since it contains fifteen members, most of them very bright, which are close together~~group since it has a higher density of galaxies in the centre (see Figure 1).

~~The names of each member with their corresponding magnitude. Name Magnitude (B-band)PGC002175 -17.92 PGC002207 -18.14 PGC089883 -18.42 NGC0186 -20.04 NGC0202 -19.17 NGC0203 -19.69 NGC0193 -21.25 NGC0194 -21.49 PGC002171 -17.27 NGC0182 -21.31 NGC0198 -21.50 NGC0200 -21.45 IC0040 -20.12 NGC0208 -19.28 PGC002449 -19.38~~

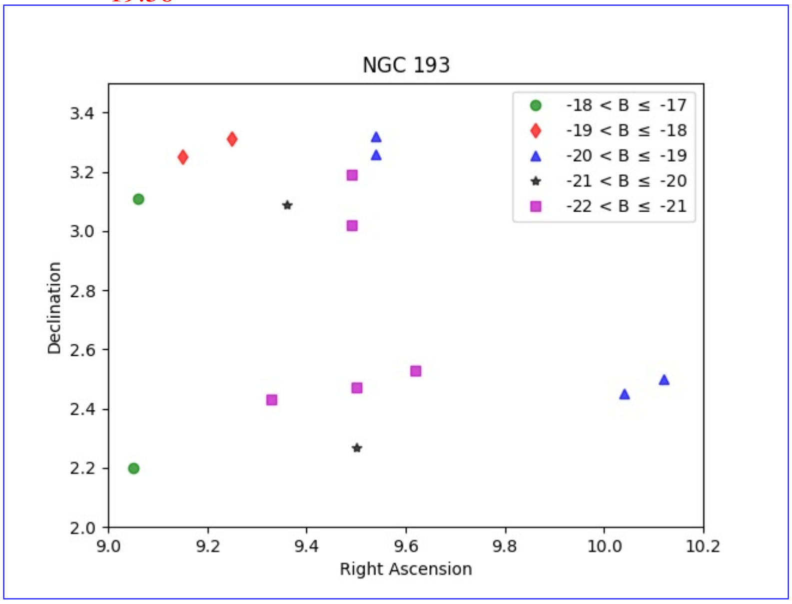

Figure 1. 15 Members of galaxy group NGC193 plotted according to their projected location in the group, colour-coded by brightness. The range in which each galaxy's magnitude lies, is indicated by the letter B.

~~This graph~~ Figure 1 corresponds to the coordinates of the members on the Hα image taken on the WIYN 0.9m telescope on Kitt Peak and the members were colour-coded according to their magnitudes ~~(making use of table 1).~~ where we show members with B-magnitude values between -18 and -21. Figure 1 shows that the main member, NGC0193 (number 7) is surrounded by five other bright members (purple indicated squares) of this galaxy group.

X-ray and radio data for this group's main member, NGC0193, indicate full- and low-resolution contours on the Chandra and optical image, respectively (see Figure 2). The two very bright jet components are revealed by radio contours.

For three members of this group, NGC0193, NGC0198 and NGC0200, the r-band was subtracted from the continuum and scaled (see Figure 3) by a formula [7] discussed in the previous section. The ionised hydrogen gasses are shown very clearly for these three members with prominent clumps of stars for NGC0198 and NGC0200 (images on the right).

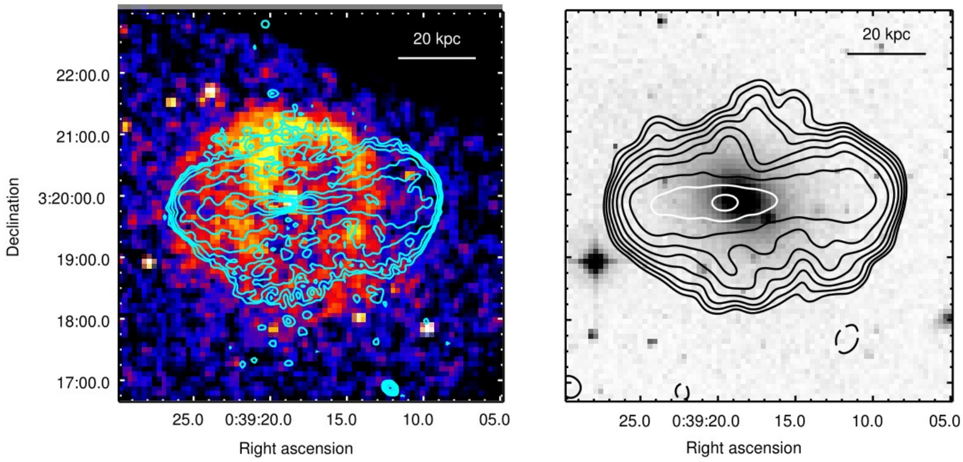

Figure 2. ~~Both images'~~ X-ray and radio ~~contours are spaced by a factor of 2.~~ data for group NGC193. *Left:* GMRT 610 MHz full-resolution contours overlaid on the smoothed, 0.3-2.0 keV Chandra image. *Right:* GMRT 235 MHz low-resolution contours on the optical image. Both images' radio contours are spaced by a factor of 2 [~~Credit:*Giacintucci S et al 2011*~~4]

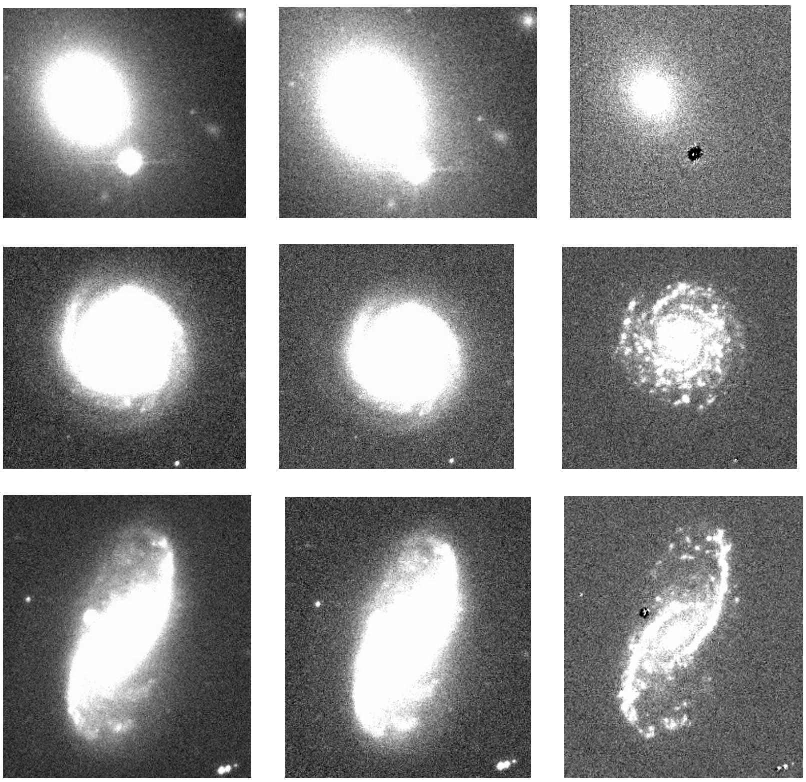

Figure 3. Three bright members ~~,~~ NGC0193, NGC0198 and NGC0200 (in order from top to bottom) of ~~this~~ the galaxy group NGC193. Hα filter images (left), r-band images (middle) and the r-band subtracted from the Hα (right).

3.2. NGC940

For this galaxy group, no diffuse hot halo has been detected in X-ray observations, but rather a point-source. This galaxy group is much less compact in terms of galaxies, since it only has nine members with the main member (see Figure 6) one of the brighest galaxies in this group, which was expected.

The names of each member with their corresponding magnitude. Name Magnitude(B-band)UGC01909 -19.52 PGC009386 -19.64 UGC01980 -20.99 PGC009400 -17.27 NGC0940 -21.49 NGC0931 -21.21 UGC01963 -20.50 PGC009501 -19.42 PGC009548 -19.61

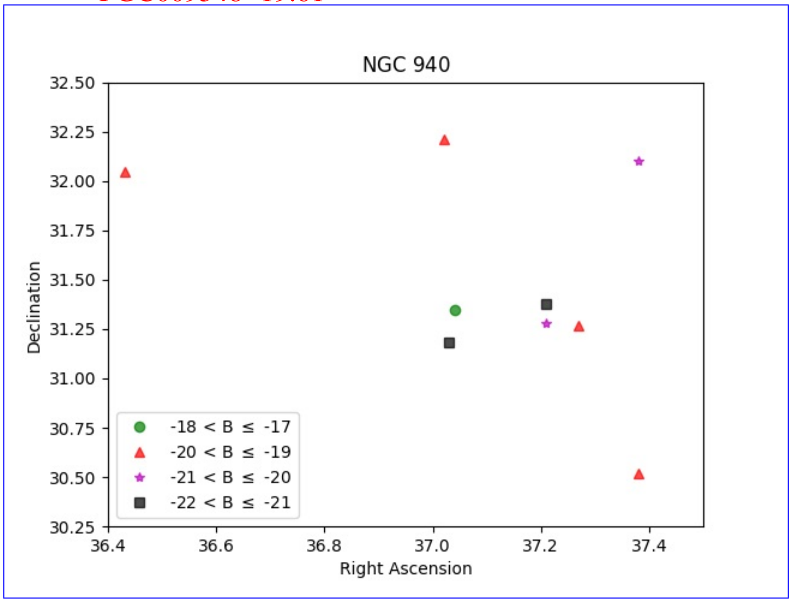

Figure 4. Nine members of galaxy group NGC940 plotted according to their projected location in the group, colour-coded by brightness. The range in which each galaxy's magnitude lies, is indicated by the letter B.

The figure above Figure 4 indicates that the main member, NGC0940 (number 5) is surrounded by one other bright member (purple indicated squares) of this galaxy group. This graph was plotted by making use of table 2. The members were colour-coded according to their B-magnitude values between -18 and -21.

X-ray and radio data for main member NGC0940 reveal low- and full-resolution contours on the *XMM-Newton* and optical DSS image, respectively (see Figure 5). The contours overlaid on both images indicates no jet components, since this main member does not have a hot halo but is rather detected as a point source.

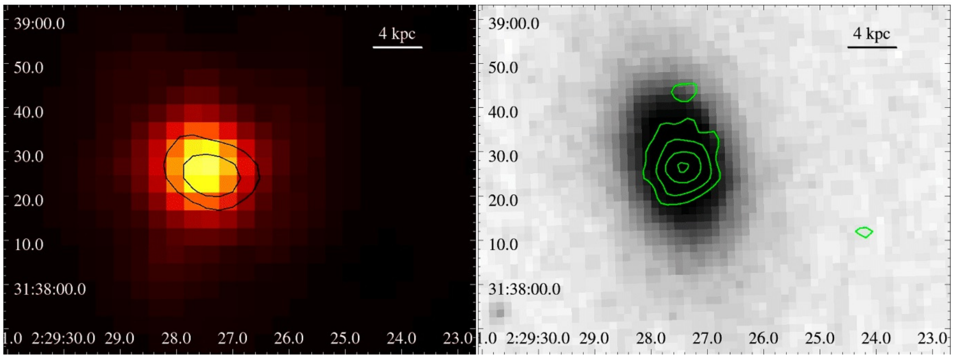

Figure 5. X-ray and radio data for group NGC940. *Left:* GMRT 235 MHz low-resolution contours in black overlaid on the adaptively smoothed, 0.3-2.0 KeV of *XMM-Newton* image. *Right:* GMRT 610 MHz full-resolution contours in green overlaid on the optical DSS image. [~~Credit: Kolokythas K et al 2018~~1]

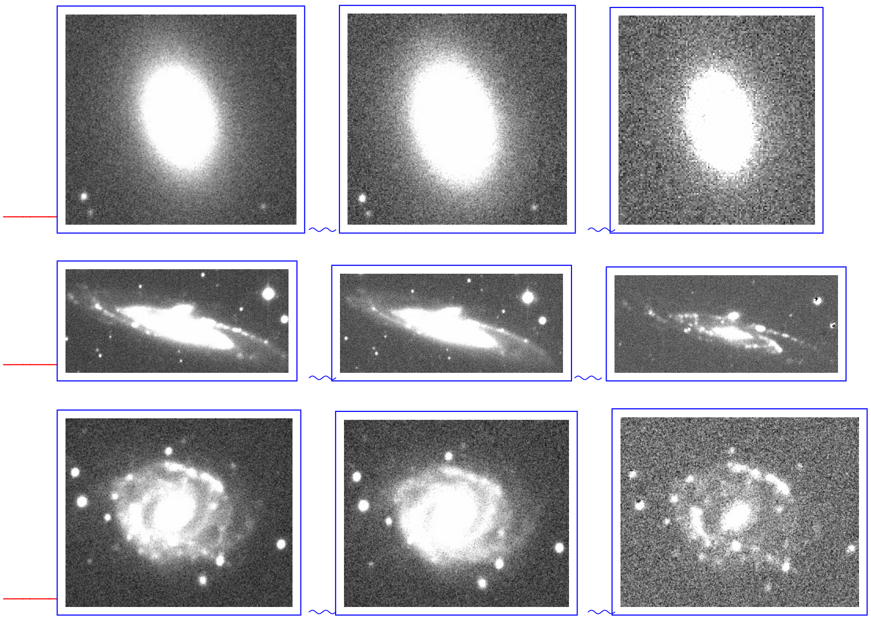

Figure 6. Three bright members, NGC0940, NGC0931 and UGC01963 (in order from top to bottom) of ~~this~~ the galaxy group NGC940. Hα filter images (left), r-band images (middle) and the r-band subtracted from the continuum (right).

4. ~~Conclusions~~

~~As~~ Figure 6 shows that three bright members were scaled by making use of the formula [7] as discussed in the ~~Introduction, galaxy groups~~ previous section. After the r-band of each member was subtracted from the continuum (images on the right), the ionised hydrogen gasses were clearly visible, showing the prominent clumps of stars in members NGC0931 and UGC01963.

4. Conclusions

In this study we have investigated surrounding members of two rich galaxy groups, NGC193 and NGC940 ~~show vastly~~ which are part of the CLoGS sample and can be used to investigate the role of AGNs to maintain the thermal balance of the IGM. Here we present preliminary results for both galaxy groups, detecting Hα in their central members - despite of the two galaxies' different properties from X-ray and radio observations (e.g. jet-dominated vs point-source). Therefore, the environment and the IGM surrounding their dominant central galaxies are very diverse. Yet, intriguingly, Hα-emission is detected in both dominant galaxies, and the physical connection between the different phases (e.g. hot gas, and warm ionised gas) is not obvious. It will be interesting to now investigate the other members of the galaxy groups (surrounding the dominant member), as well as extend the study to include more CLoGS groups to thoroughly explain the origin of the ionised Hα gas.

5. ~~Acknowledgments~~

Acknowledgments

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5. ~~Referenees~~

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