GMRT observations and AGN feedback implications of brightest group galaxies in the Local Universe

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Konstantinos Kolokythas, IUCAA

Indo-French school talk

Outline

- Introduction
- Heating by Active Galactic Nuclei (AGN): Feedback (what is it?)
- Environment of research: Groups of Galaxies (why?)
- The CLoGS project (Complete Local-Volume Groups Sample)
- Results on CLoGS
- Details on interesting individual systems
- Energetics and power balance

Introduction

- In the centres of galaxy clusters gas in the ICM cools via X-ray emission

- High density leading to significant loss of energy in a short time ($<<1/H_o$)

- Steady inflow of gas towards cluster center in absence of heating mechanism:

  Classical cooling flow model (Fabian et al. 1994)

CAVEATS

- High cooling rates predicted from *ROSAT* data in centers of galaxy clusters are not observed (e.g. McNamara et al 2007)

- High resolution *XMM-Newton* RGS spectra have not found expected amounts of cool gas in their cores (e.g. Sanders et al. 2008)

Introduction

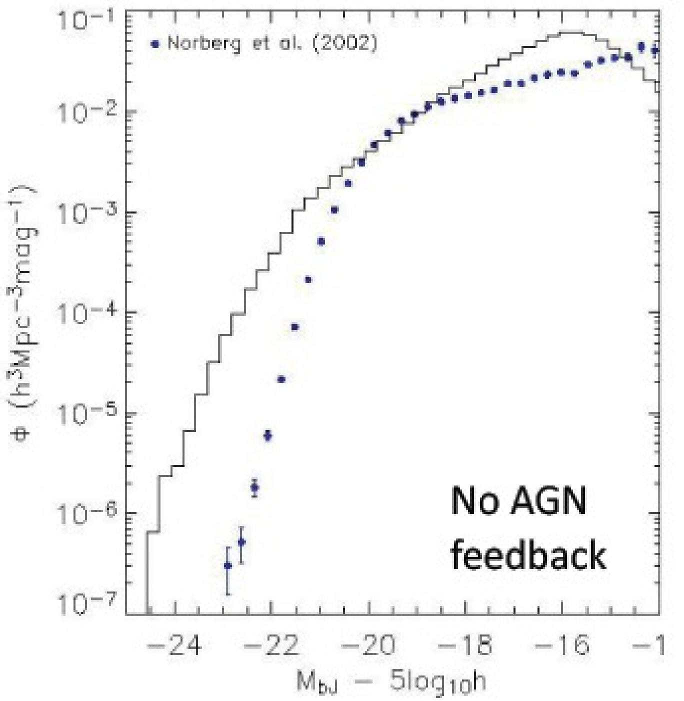
- Simple cosmological simulations predict too many faint & bright galaxies with largest of those being star forming (e.g. Norberg et al., 2002)

- NOT observed in nature! Largest galaxies found to be passive, with less star formation in the centers of clusters

- Star formation rates & CO emission in BCGs far below the predicted amount (Edge & Frayer 2003)

- High-mass end truncation of galaxy distribution (e.g., Benson et al. 2003)

- A heating mechanism is needed to overcome the cooling flow problem (stop cool gas collapse)



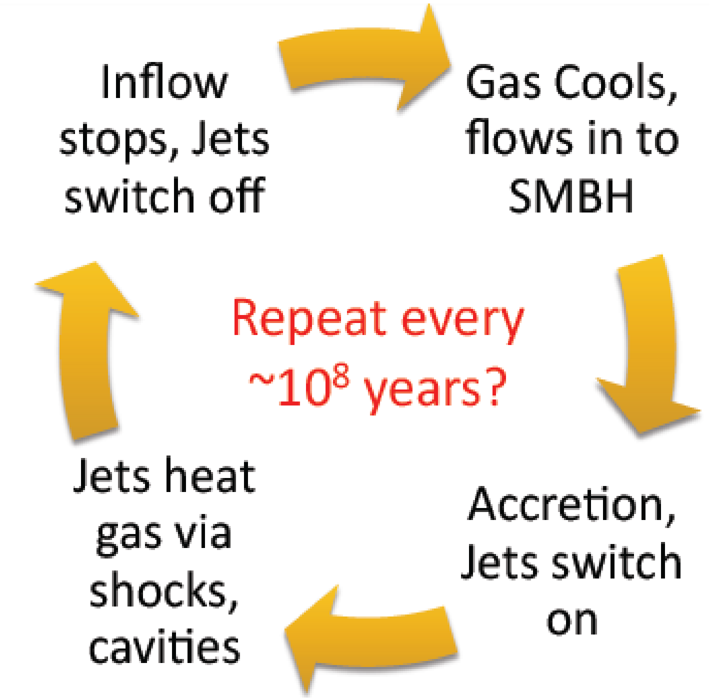
Heating by AGN: Feedback

- Galaxies can influence the gas through non-gravitational processes

- AGN feedback is being the current favored mechanism to explaining cooling in clusters of galaxies

- AGN presence can heat & blow gas out of central regions of clusters & groups

- Numerous studies have contributed to comprehensive picture (e.g. Gitti et al. 2011) that AGN heating is important in galaxy formation and evolution



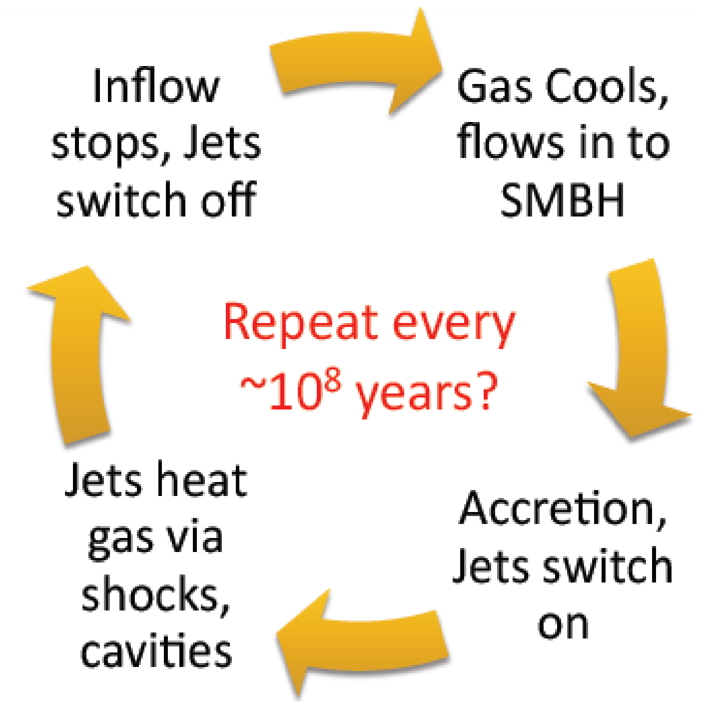
Heating by AGN: Feedback

- Heating by AGN?

- Conversion of radio AGN outflow energy into heating of the circumgalactic medium is adequate to provide the heating needed

AGN feedback:

Loop process where energy in some form is produced from the central regions of the galaxy, which can heat up the inflowing gas, preventing it from cooling



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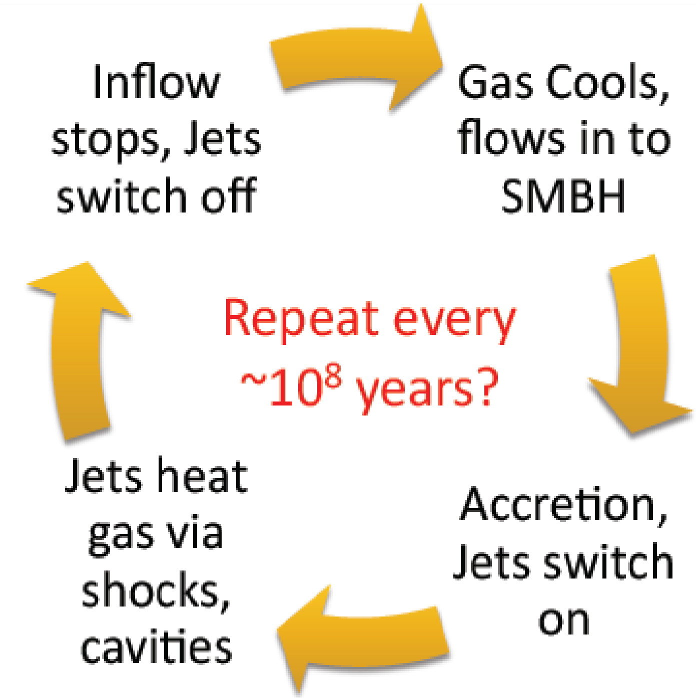


Groups vs Clusters

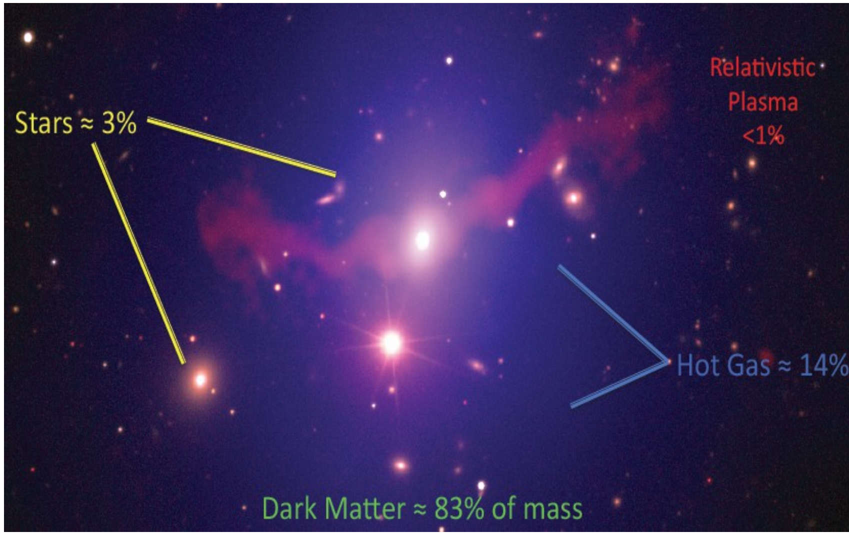
- Galaxy groups are often simplistically considered scaled down versions of clusters

- However, groups and clusters have notable differences:

✓ Lack of dominance of the ICM over the galactic component (Giodini et al. 2009)

✓ Groups have a smaller baryon fraction than clusters

✓ Main cooling mechanism in groups is line emission while in clusters thermal bremsstrahlung



Groups vs Clusters

- Comparison of group and cluster samples requires caution, since galaxy groups cannot be simply treated as scaled-down versions of clusters.

- For example, The ICM in galaxy clusters usually dominates the baryonic budget, whereas in groups the baryonic mass of the member galaxies can be greater than that of the ICM (e.g. \citealt{Giodini09}).

- Due to their inherently different scaling properties (X-rays, radio, optical, environment etc) in order to perform a fair comparison between a cluster sample and the observations of our central group galaxies, we take into consideration the selection criteria that was used for each cluster sample and apply the same criteria to our groups sample.

Why Groups of Galaxies?

- >50% of galaxies in Local Universe resides in Groups (Eke et al. 2006)

- Most of the evolution of galaxies takes place in the group environment :

  - close proximity at low relative velocities
  - promoting tidal interactions, mergers

- Extensive halos of hot gas; short central cooling times, fuel star formation & active nuclei

- Shallower gravitational potential thus AGN heating and galactic winds can in principle have stronger imprints on the group ICM than in clusters

- Therefore feedback in groups has the greatest impact on galaxy formation and galaxy evolution

- Obstacle:Lack of statistically complete radio/X-ray nearby groups sample

Previous studies in galaxy groups

- Most earlier studies selected samples from optical or X-ray catalogues

- Optically selected groups inevitably include a fraction of false groups; chance associations and uncollapsed groups still in process of formation

- X-ray selection of catalogues based on shallow observations, most likely to miss fainter systems (*RASS*, *Einstein*), biased toward cool cores with central X-ray peak (Dong et al. 2010, as in clusters, Eckert et al. 2011)

- *Chandra* & *XMM-Newton* offer deep observations at moderate redshifts providing though minimal information (e.g. luminosity) for detailed studies

- A number of X-ray bright, non-cool-core groups are yet to be discovered

Probe method? Optical plus X-rays

- Use of optical selection to identify groups and sufficient deep X-ray observations to confirm the presence of a hot halo

- Optical sample selection avoids any bias toward systems with highly concentrated cool-core halos

- X-ray follow up confirms that the groups are fully collapsed systems

- A number of samples have used this approach with success to identify unbiased samples of groups (e.g. Rasmussen et al. 2006, Miniati et al. 2016)

BUT! These samples targeted more distant systems, good approach for cosmological studies, less useful for a detailed study of interaction between galaxies, AGN and the IGM

Radio plus X-rays

- Combination of multi-frequency radio data and high-quality X-ray observations is required to provide insight into the processes involved

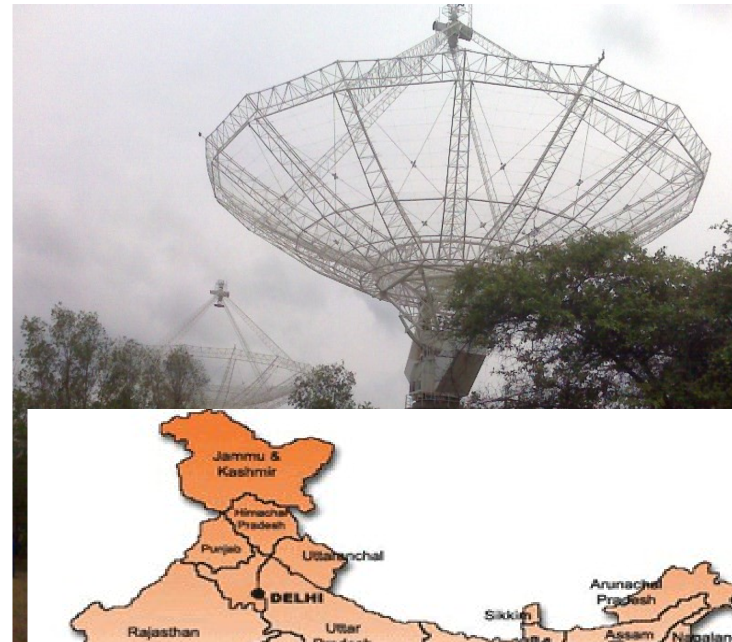
- Evidence of AGN heating: Detection of X-ray structures (cavities, shocks etc) correlated with radio jets and lobes in numerous cool-core groups and clusters (e.g. McNamara et al 2000, Birzan et al. 2004, O'Sullivan et al. 2011, Panagoulia et al. 2014)

X-ray provides
Location/properties of most baryons and estimation of energy in cavities, shocks etc

Radio provides
Timescales via synchrotron aging, constraints on source geometry and direct view of AGN/gas interactions

Giant Metrewave Radio Telescope (GMRT)

Placed about 80 km north of Pune, in India:



- 30 totally steerable huge parabolic antennas of 45m diameter each
- Maximum distance reaching up to 25 km with a frequency range 50 - 1450 MHz
- Dishes have been build of wire mesh in a parabolic configuration
- Due to design each antenna has minor wind loading - low total weight, hence GMRT low cost of construction.

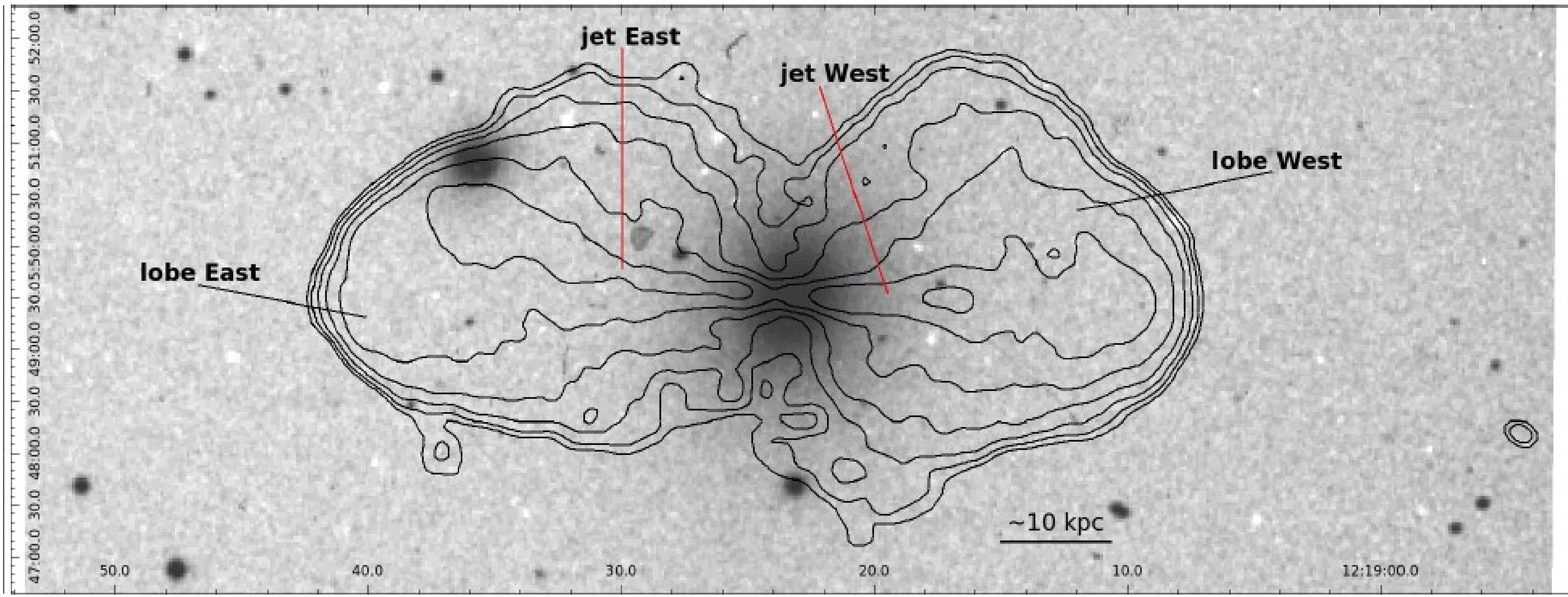
Main science goals CLoGS project

- Determine the physical properties of a representative sample of groups
- Characterization of AGN population in groups
- Impact of group central AGN on intra-group gas & member galaxies (*eg. Radio* power output, *study of spectral ageing of synchrotron emission*)
- Study possible mechanisms of feedback heating (Are shocks / cavities dominant?)
- Examining the temperature and density structure of the gaseous halos of groups, the ability of groups to retain gas
- Identification of new groups and new classes of groups such as the high entropy systems predicted by simulations (e.g., McCarthy et al. 2010)

Results: Radio emission in BGEs

- GMRT low-frequency images are shown as overlaid contours on **red-band optical images** from Digitized Sky Survey (DSS) and on X-ray images from *Chandra* or *XMM-Newton* observations

- Their physical scale ranges from a few kpc (point sources; galactic scale) to several tens of kpc (large jets; group/cluster scales)



Results: BGEs Radio Morphology

- Owing to the morphological variety of the radio emission that our galaxies exhibit, we classify the radio sources in 6 categories:

I. No radio source detected

II. Pointlike – Unresolved radio sources

III. Extended but no jets - `diffuse' emission with no preference in orientation (blob) bigger than beam but without an obvious jet axis

IV. Small-scale jets - smaller than <20 kpc

V. Large-scale jets - full-sized double lobed radio galaxies

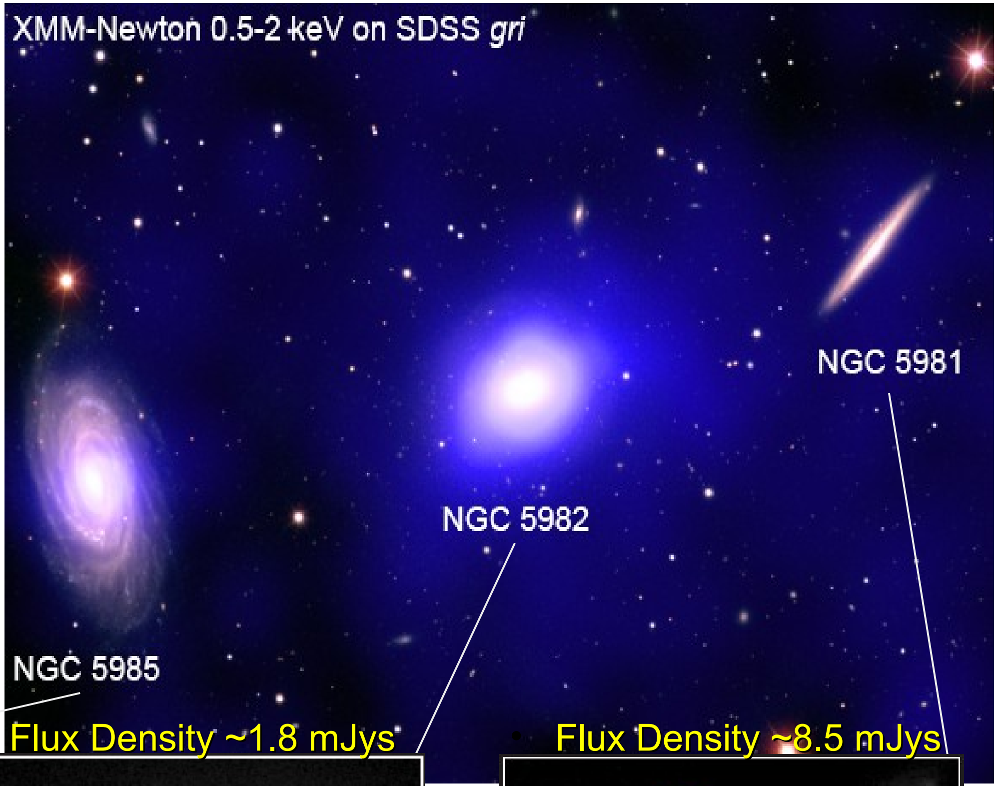
VI. Remnant jets - radio galaxies with old outbursts

Radio Diversity: NGC 5982 (Draco Trio)

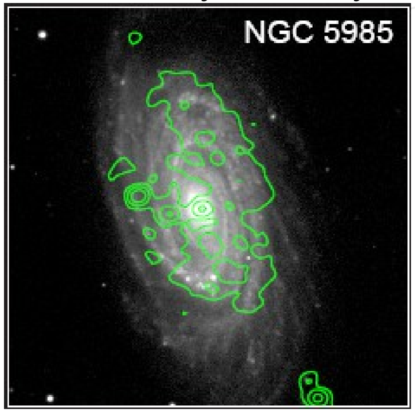
- ~12ksec XMM pointing detects ~0.5 keV group halo to ~85 kpc

- Central point sources co-existing with diffuse radio emission from the disks (AGN+SF)

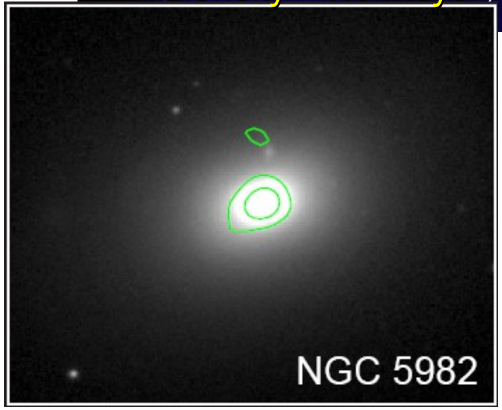
Dynamically young group!



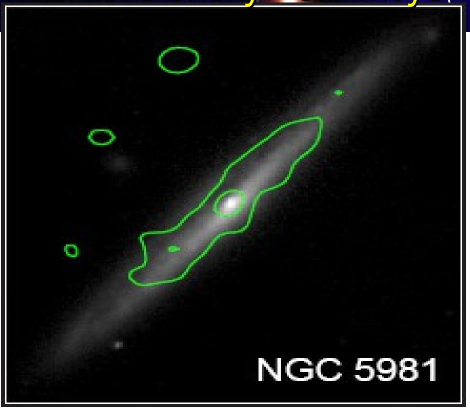
Flux Density ~83 mJys



Flux Density ~1.8 mJys



Flux Density ~8.5 mJys



First Results: BGEs Radio Morphology

- Radio point source environment is different but with some common characteristics

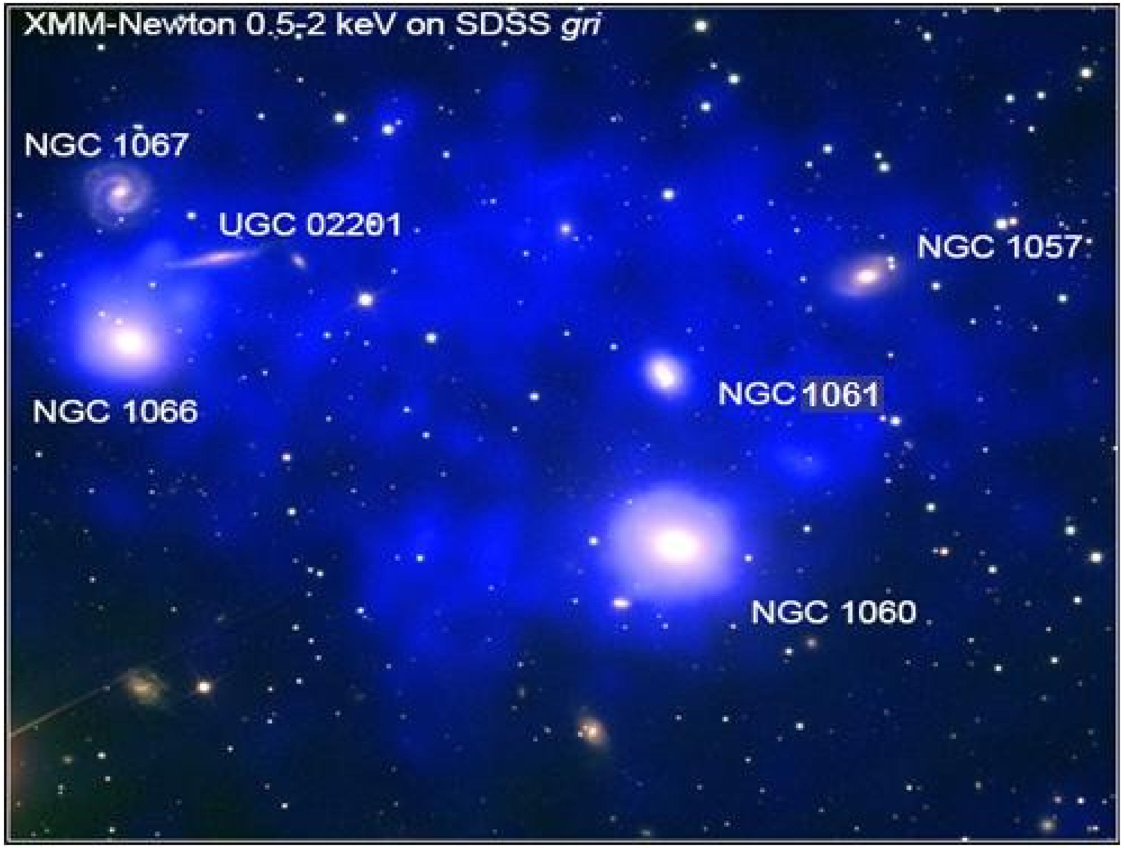
- Preferably lie in groups where most of companions are spiral galaxies (high spiral fraction -Fsp- >70%)

Newly confirmed group: LGG72/NGC1060 Disturbed?

- X-rays

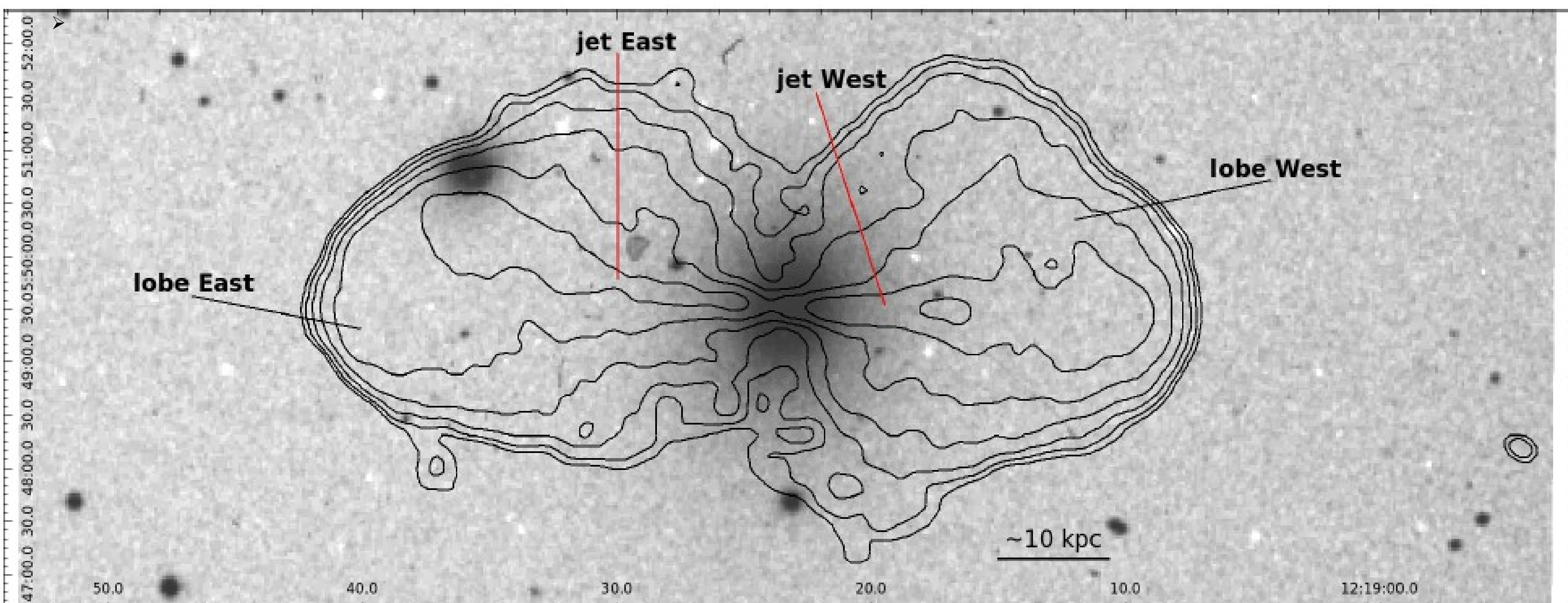
➢ A ~36 ksec XMM observation traces the ~1 keV halo out to 310 kpc

➢ The X-ray halo is disturbed - NGC 1066 may be falling through the group



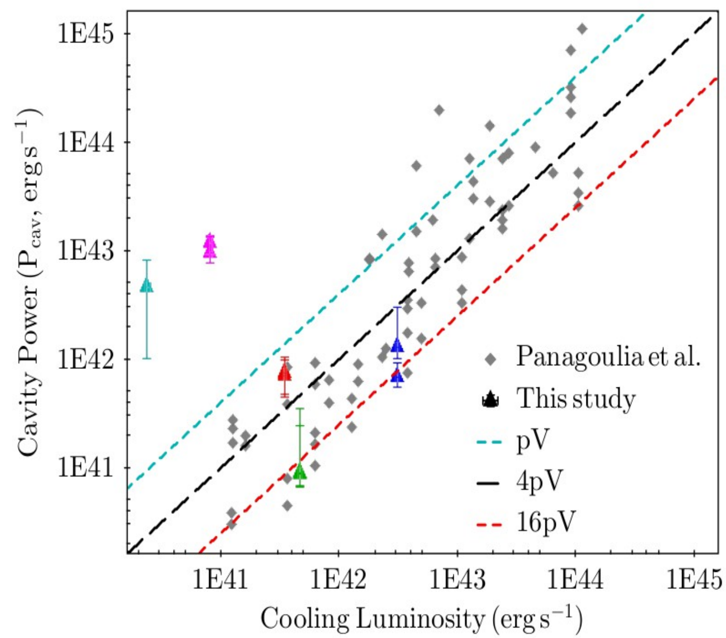
Individual systems: LGG 278 NGC4261

- LGG 278 is a group at the outskirts of the Virgo cluster (z~0.0075)
- Its dominant elliptical NGC 4261 hosts the brightest radio source in the CLoGS sample, 3C270 (19 Jys at 1.4 GHz, Condon et al 2002)



Energetics: Heating vs Cooling

- Examine the balance between heating by the central AGN source and the radiative cooling of the IGM core
- L_{cool} measured for the region where cooling time is 3 Gyr
- Small-scale jet systems NGC 1060 and NGC 5846, along with the remnant jet in NGC 5044, lie within the scatter about the relation, indicating approximate thermal balance
- The large-scale jet systems NGC~193 and NGC~4261 fall well above the relation, suggesting that they are significantly over-powered. It is notable that in both systems the size of the jets and lobes greatly exceeds that of the cooling region.



*__X-ray CLoGS:__ O' Sullivan E., Ponman T.J., **Kolokythas K.** et al., 2017, MNRAS, 472, 1482 (Paper I)*
*__Radio CLoGS:__ **Kolokythas K.,** O' Sullivan E. et al., 2018 - To be submitted (Follow up Paper II)*

Energetics: Heating vs Cooling

- L_{cool} measured for the region where cooling time is 3 Gyr

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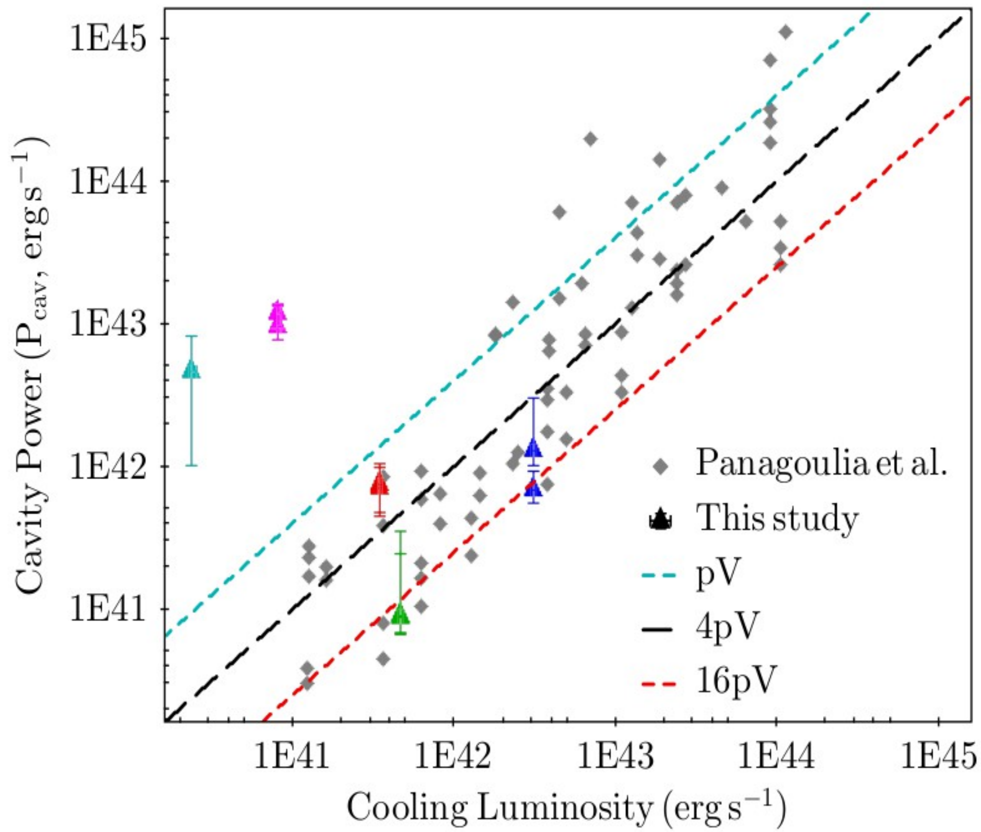
- NGC 193 & NGC 4261 fall well above the relation, suggesting that they are significantly over-powered



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Energetics in NGC 193 & NGC 4261

- For NGC~193, the outburst seems to have inflated a single huge cavity or cocoon, driving most of the hot gas away from the galaxy but the study of \citet{Bogdan14} argues there are multiple large cavities. Presumably in NGC~193, the jet activity is fuelled by what is left - if so it will shortly cease. The entropy at 10~kpc for this system is found to be enhanced in Paper~I, because most of the gas has been driven out from this area and the density is low.

- In NGC~4261, it's essentially the cool core, where it is previously known that the jets have cut channels through that, and only expand into lobes outside of it \citep{ewan4261}. Therefore we see a disconnect for this system - the jet is heating a region outside the core, but the core is providing the fuel for the jet. Until the core is heated, the jet will not stop. This also explains the low entropy found for this system \citep[Paper~I]{ewan4261} - as entropy is a measure of the core, which is largely unaffected by the jets.

NGC 193

NGC 4261

Summary (Take home points)

24/26 BGEs are detected at either radio frequency, with the majority exhibiting a `pointlike' radio morphology

BGEs with no radio emission are found in X-ray faint groups

~1/3 of the X-ray confirmed groups have a central jet source

All jet systems found in groups with cool cores

Jet activity correlated to short central cooling times rather than low central entropies

Imbalance between cooling and heating is also seen in jet mode đ

The end!