A DETAILED ANALYSIS OF THE CORES OF *HIFLUGCS* GALAXY CLUSTERS: ICM cooling and AGN heating

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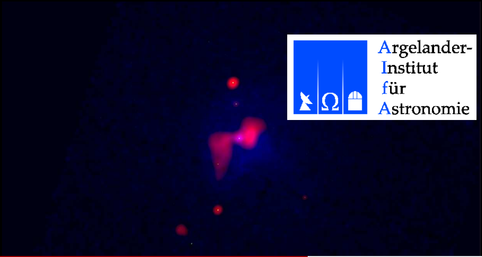

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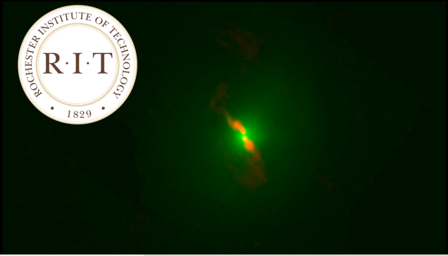


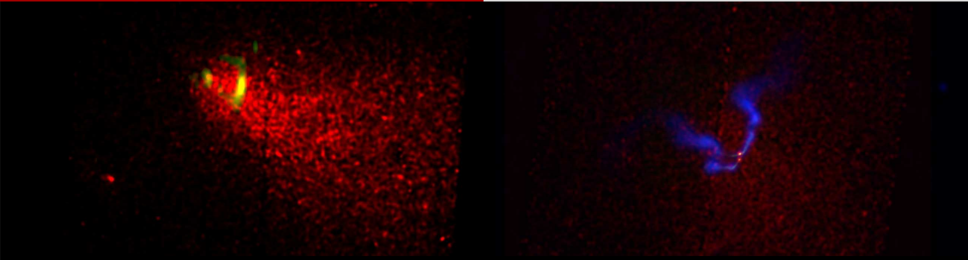
Issues addressed in this work

1. What is the best diagnostic for determining a cool-core cluster?
2. How can the recent cool-core formation be ruled out?
3. What is the current census of the AGN fraction in cool-core clusters?
4. Is there a quantitative correlation between the AGN output and cool-core parameters?
5. How does AGN heating impact the $L_X - T_{vir}$ scaling relation on the scale of clusters?

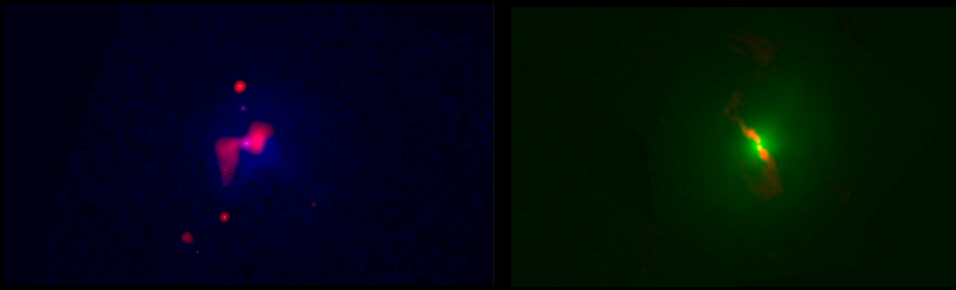
The Cluster Sample: X-ray and Radio data

HIFLUGCS – The 64 brightest galaxy clusters

- Based on the ROSAT All Sky Survey, $|b| > 20^\circ$.
- $f_X(0.1 - 2.4)\,\mathrm{keV} \gtrsim 2 \times 10^{-11}$ ergs/sec/cm^2.
- $\langle z \rangle \sim 0.05$; $z_{\max} = 0.21$
- All have observations with *Chandra* observations.
- All have radio observations. Measurements for our study taken either from literature or archives.
  - 65 % have data below 500 MHz
  - 46 % have data below 80 MHz

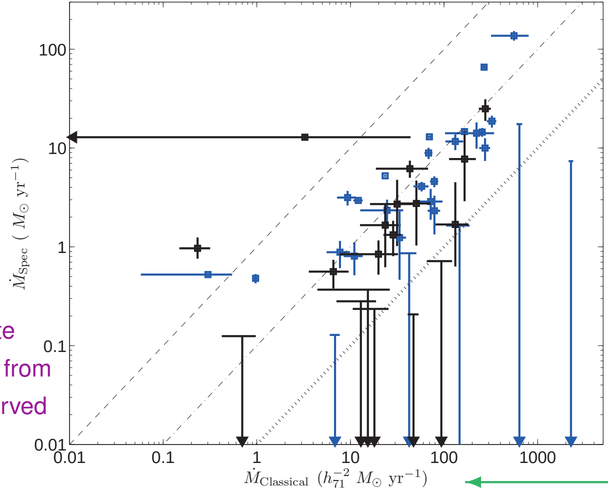


Recent cool-core formation hypothesis



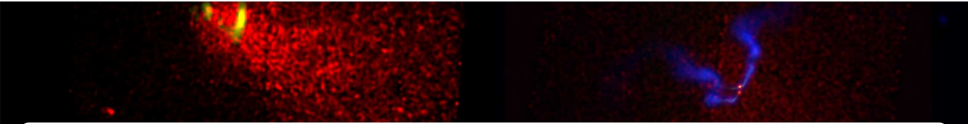
Cooling Flow Discrepancy (Hudson et al. 2009)

The spectral MDR (measured) an order of magnitude lower than the classical MDR (predicted).



Spectral Mass Deposition Rate as determined from fitting the observed spectrum

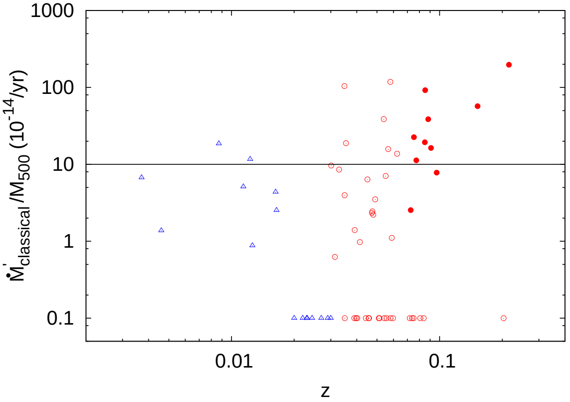
Classical Mass Deposition Rate $= \frac{M(<r)}{\tau(r)}$



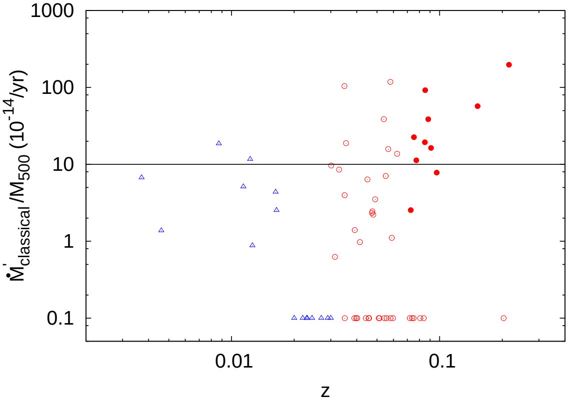
The test is based on the assumption that both high-z clusters and low-clusters originate from the same underlying population of clusters.

1. Divide the sample into 4 redshift bins.
2. Forward-evolve the redshift bin 2, 3 and 4 clusters to the lowest redshift bin.
3. Determine the mass-deposition rates of the forward-evolved high-z clusters and compare them to the low-z clusters.

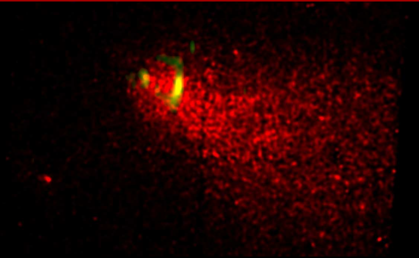
Recent CC Formation?

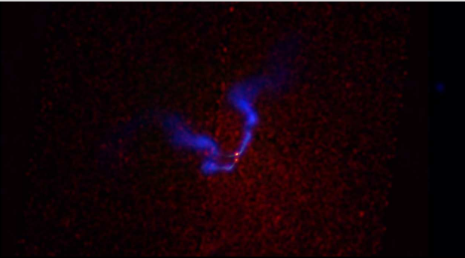


Recent CC Formation?

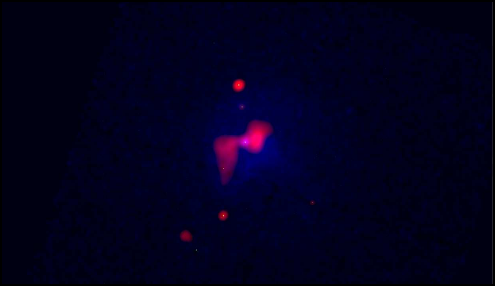


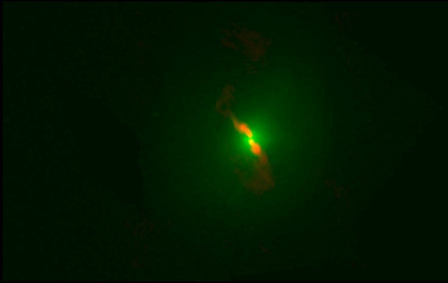
The probability of the two subsamples (the lowest- and highest-redshift clusters) being drawn from the same distribution is less than 3%.



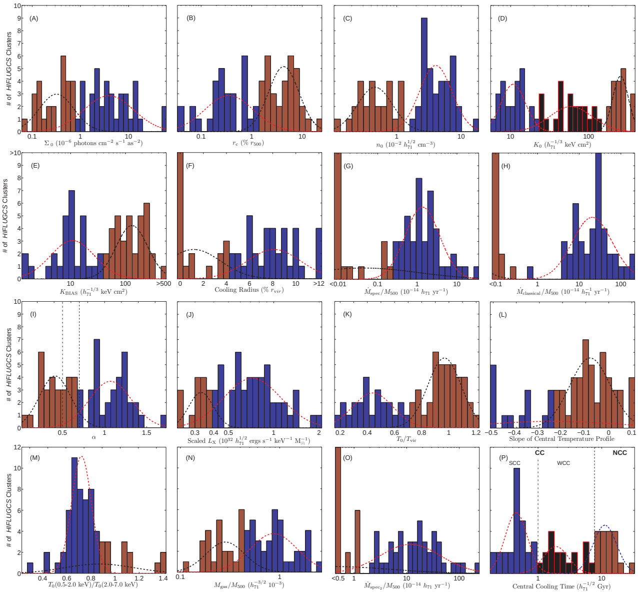


The determining parameter for a CC cluster



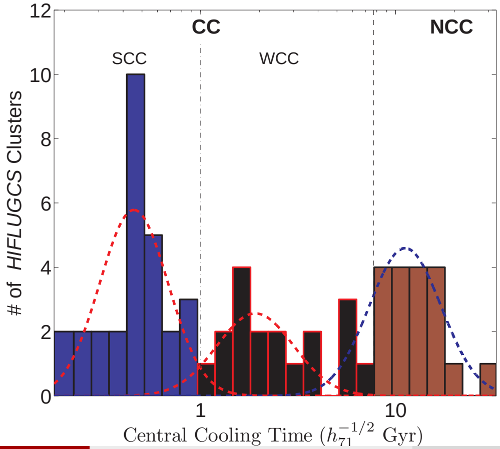


The defining parameter for a cool-core (Hudson et al. 2009)

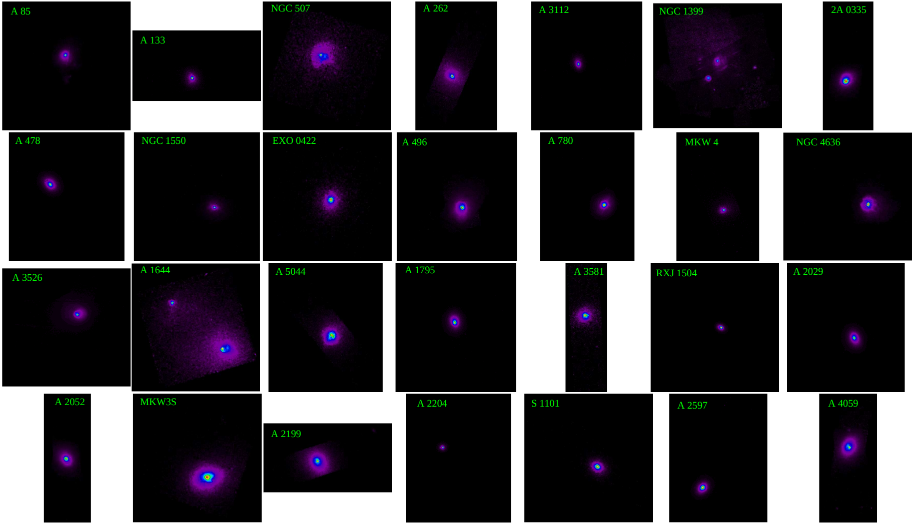


Central Cooling Time

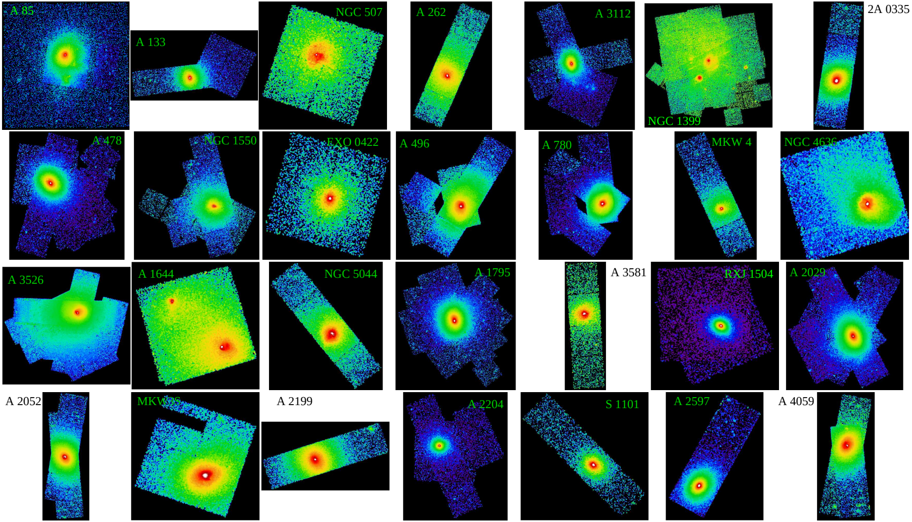
- Strong cool-core clusters $\rightarrow \tau < 1$ Gyr
- Weak cool-core clusters $\rightarrow 1$ Gyr $< \tau < 7.7$ Gyr
- Strong cool-core clusters $\rightarrow \tau > 7.7$ Gyr



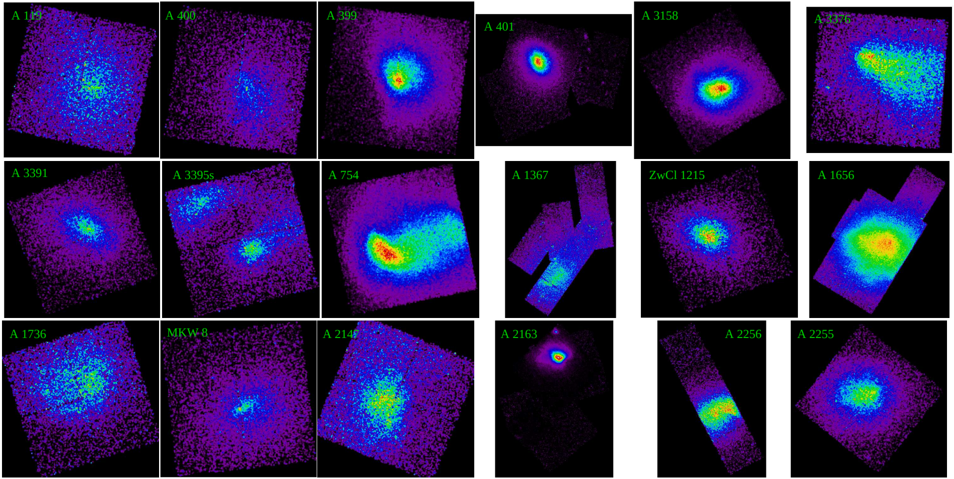
Strong Cool-Core clusters

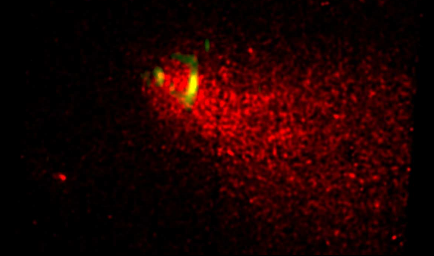


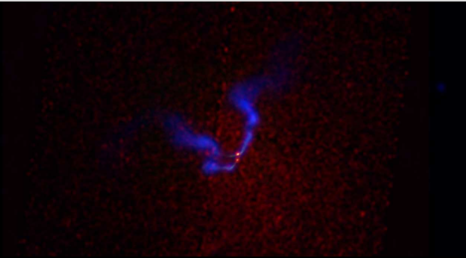
Strong Cool-Core clusters



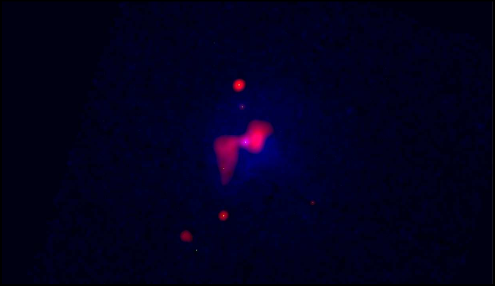
Non-Cool-Core clusters

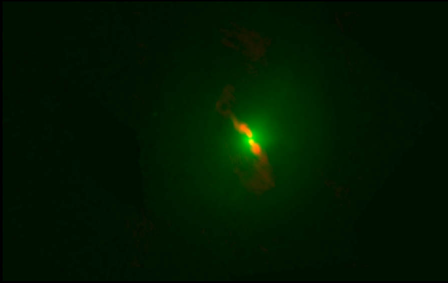






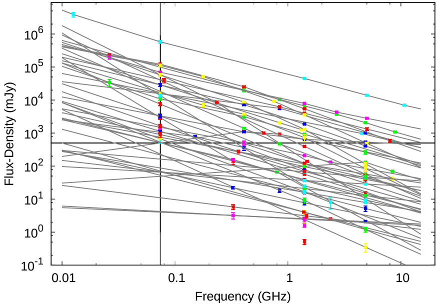
ICM cooling and AGN heating interrelation

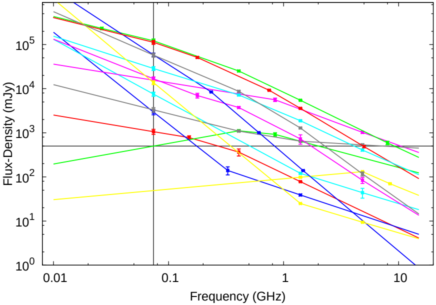




Spectra of CCRSs in the *HIFLUGCS* sample

→ 49 of 64 GCs have a central radio source

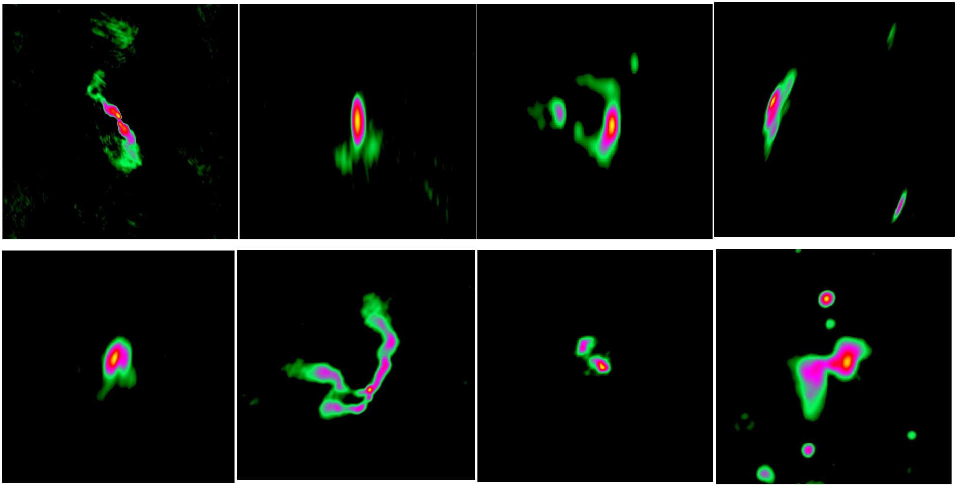




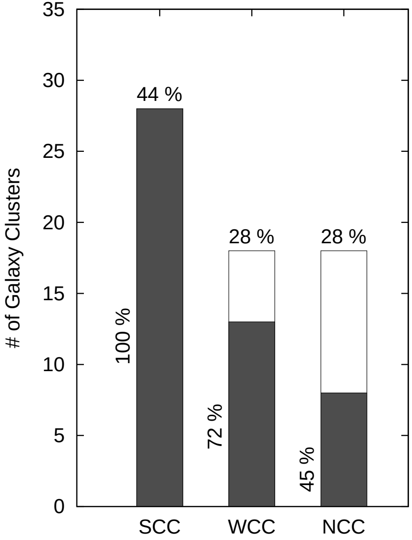
$$t \sim \frac{B^{0.5}}{B^2 + \frac{2}{3} B_{\mathrm{CMB}}} \nu_{\mathrm{b}}^{-0.5}$$

(Mittal et al. 2009, also see Birzan arXiv:0806.1929)

A few well-known radio galaxies in the sample...

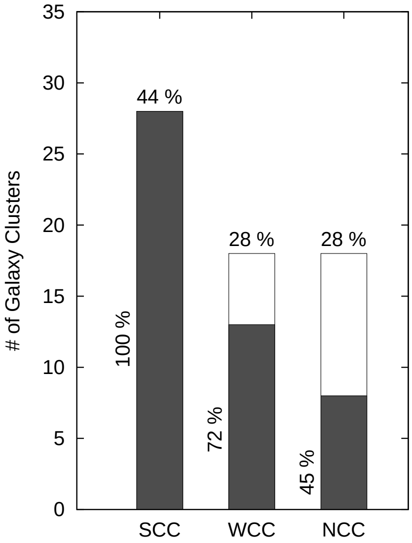


SCC, WCC and NCC fractions: With and without a CRS (Mittal et al. 2009)



The probability of finding a CRS is a strong function of the cooling time.

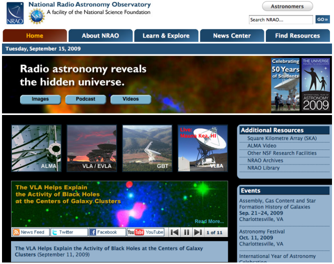
SCC, WCC and NCC fractions: With and without a CRS (Mittal et al. 2009)



The probability of finding a CRS is a strong function of the cooling time.

All SCC clusters (with $\tau < 1$ Gyr) have a radio active AGN at their center!

Press Release based on the article "AGN heating and ICM cooling in the HIFLUGCS sample of galaxy clusters", by R. Mittal et al., A & A, 2009, vol. 501-3, p. 835



A fresh log on a smouldering fire

Bonn researchers explain the activity of black holes at the centre of galaxy clus

Astronomers at the University of Bonn have clarified the connection betw holes at the centre of galaxy clusters and surrounding gas, which serves "food". The scientists have produced a ground-breaking study of what co "cosmic feeding". It has now been published in the prestigious scientific j Astronomy and Astrophysics (Volume 501, Issue 3, 2009, pp. 835-850).

A black hole is the term give by astronomers to a cosmic object whose gravitati strong that it draws in everything in the immediate vicinity. Not even light can es Scientists expect to find such phenomena at the centres of all major galaxies. B considerably in size. Like boxers, they come in different "weight classes". Super holes can have a mass that is millions, or even billions, of times greater than ou

"Supermassive black holes are not always 'active'," explains Dr. Thomas H. Rei most black holes simply 'smoulder' away." Dr. Reiprich works at the Argelander Astronomy in Bonn, where he heads the Emmy Noether Research Group for "S Nature of Dark Energy with Galaxy Clusters". He is particularly interested in unc black holes in the cores of galaxy clusters, which are the largest objects in the u looking at the radiation in the vicinity of a black hole, astronomers are able to dr conclusions about their "food situation". The radiation derives from material that slowly absorbed by the black hole. This "food" is mainly ingested by the insatiat bodies in the form of hydrogen gas.

For black holes, gas is only "edible" if it is cooled down sufficiently – much like i particles in hot gas move too quickly for them to come close enough to be pulle hole," says Dr. Reiprich. His colleague Dr. Rupal Mittal, the study's principal aut that to happen, the gaseous mixture must cool down. Just how long the cooling can vary. A billion years is very a short period by cosmic standards." The black l centre of a galaxy cluster in which the gas cools "quickly" enough will receive "e abundance and be correspondingly active. The centres of galaxy clusters in whi processes take considerably longer are, in turn, far less lively.

As part of their study, the researchers in Bonn combined the measurement of radio waves with X-ray images of more than sixty galaxy clusters. Thanks to improved data, they were able to examine these phenomena more closely than previous investigations managed to do. Using the X-ray observations they determined which galaxy clusters contain, in their cores, gas that can serve as food for black holes. And, by means of radio data, the Bonn-based scientists analysed the activity of supermassive black holes.

Our picture: The galaxy cluster NGC507 as seen in three wavelengths. Blue shows the X-ray emission as observed by the Chandra satellite; red depicts the radio waves, which mark the activity of the supermassive black hole, as received by the Very Large Array in New Mexico; and green shows an optical image from the Digitized Sky Survey. The radio waves, and therefore indirectly the black hole's influence, cover a region that extends about 200,000 light years; i.e., they reach the outskirts of the central galaxy in this cluster. (Credits: R. Mittal, Bonn University, CXO, VLA)

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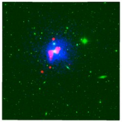
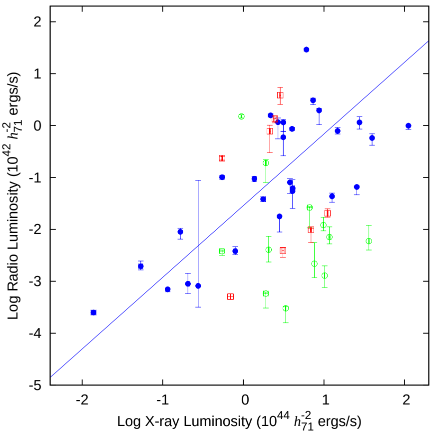
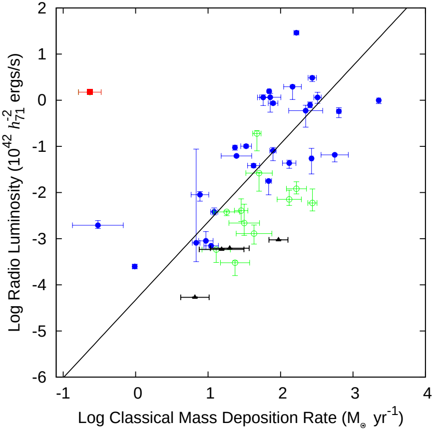


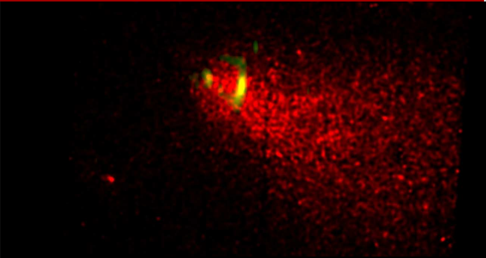
X-ray – Radio correlation

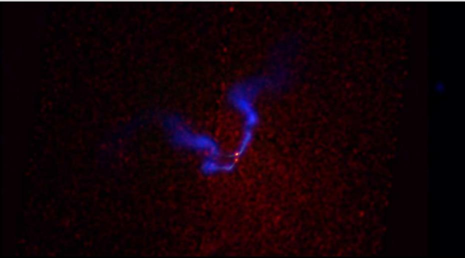




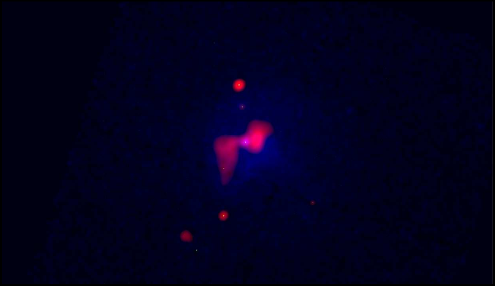
$L_R \propto L_X^{1.38\pm0.16}$ $\qquad$ $L_R \propto \dot{M}_{\rm classical}^{1.69\pm0.25}$

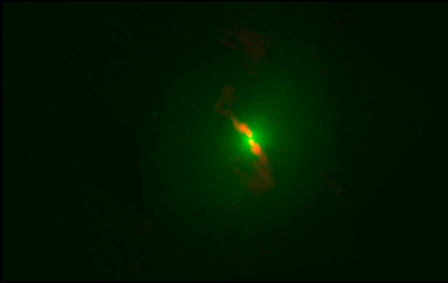
(Mittal et al. 2009)



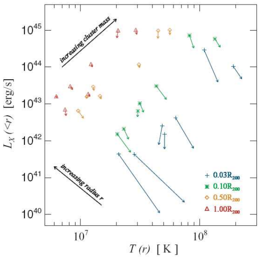


$L_X - T_{vir}$ scaling relation

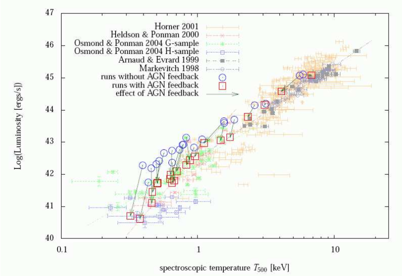




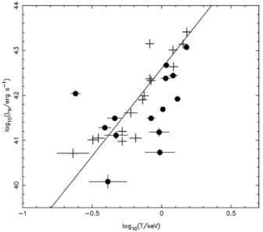
Effect of AGN heating on the $L - T$ relation



Sijacki et al. (2006)

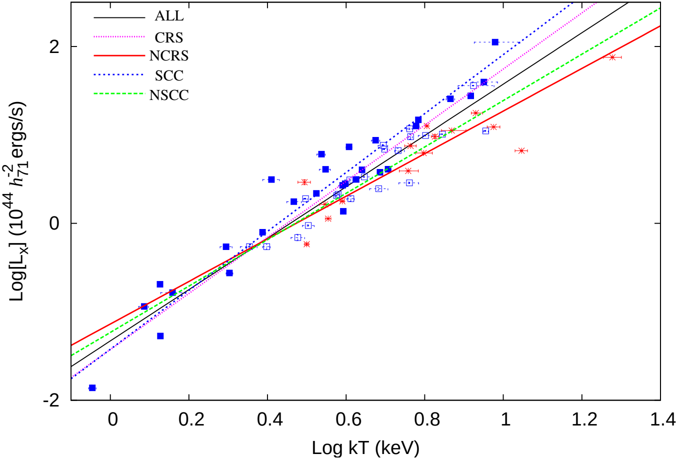


Puchwein et al. (2008)



Croston et al. (2006)

- • With a central radio source
- + Without a central radio source



$L(\mathrm{ALL}) \sim T^{2.9}$

$L(\mathrm{CRS}) \sim T^{3.2}$
$L(\mathrm{NCRS}) \sim T^{2.4}$

$L(\mathrm{SCC}) \sim T^{3.3}$
$L(\mathrm{NSCC}) \sim T^{2.6}$

Scatter in the $L - T$ relation

$$\frac{L_X}{10^{44}\ h_{71}^{-2}\ \mathrm{erg/s}} = \alpha \times \left(\frac{T_{vir}}{4\ \mathrm{keV}}\right)^{\beta}$$

Category	#	α	β	$\sigma_{int,\ L_X}$ (in %)	$\sigma_{int,\ T_{vir}}$ (in %)
ALL	64	2.62±0.20	2.90±0.16	**45.6**	15.6
NSCC	36	2.21±0.17	2.62±0.20	48.1	18.3
SCC	28	3.82±0.38	3.33±0.15	**51.7**	16.0
WCC	18	2.30±0.20	3.25±0.32	34.7	10.7
NCC	18	2.12±0.26	2.31±0.18	**49.4**	21.4

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NCC	18	2.12±0.26	2.31±0.18	**49.4**	21.4

After subtracting the core (5% of R_{500}), the total scatter go down to 42.2%

Conclusions

1. Cooling-flow discrepancy can only be explained by invoking a heating mechanism.
2. The probability for the BCG to harbor an active AGN increases with decreasing cooling time. All SCCs have a central radio source.
3. The radio luminosity is a good indicator of cooling activity.
4. Cooling dominates the $L_{\mathrm{X}} - T_{\mathrm{vir}}$ relation on cluster scale. No evidence for the scatter in $L_{\mathrm{X}} - T_{\mathrm{vir}}$ being solely due to cooling.