AGN Feedback in the Hot Halo of NGC 4649

A. Paggi[1]

G. Fabbiano[1], D.-W. Kim[1], S. Pellegrini[2], F. Civano[3], J. Strader[4] and B. Luo[5]

[1]Harvard-Smithsonian Center for Astrophysics; [2]Department of Astronomy, University of Bologna; [3]Department of Physics and Yale Center for Astronomy and Astrophysics, Yale University; [4]Department of Physics and Astronomy, Michigan State University; [5]Department of Astronomy & Astrophysics, The Pennsylvania State University

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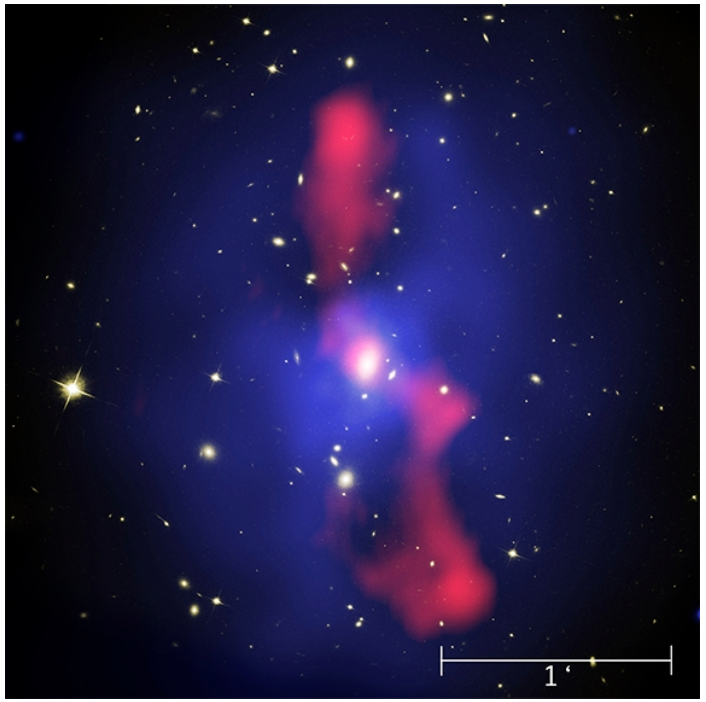
Outline

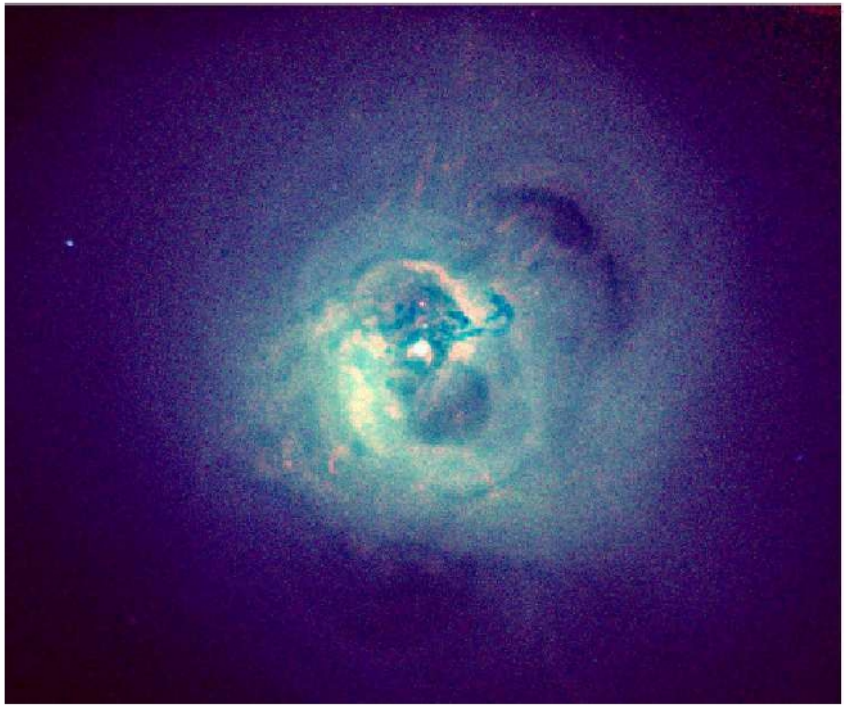
- Image + spectral analysis of ISM in NGC 4649 with deep *Chandra* observations
- Evidences of significant structures and cavities morphologically related with radio emission
- Non-thermal pressure component connected with radio emission
- Jet power from cavities
- Conclusions

AGN disturbances

- Evidence of the interaction of AGNs with the surrounding hot gas in nearby galaxies and clusters has been observed as morphological disturbances in the X-ray halos in the form of ripples and cavities (e.g., Fabian et al. 2000, 2003; Forman et al. 2005).



MS0735.6+7421 (McNamara et al. 2005).

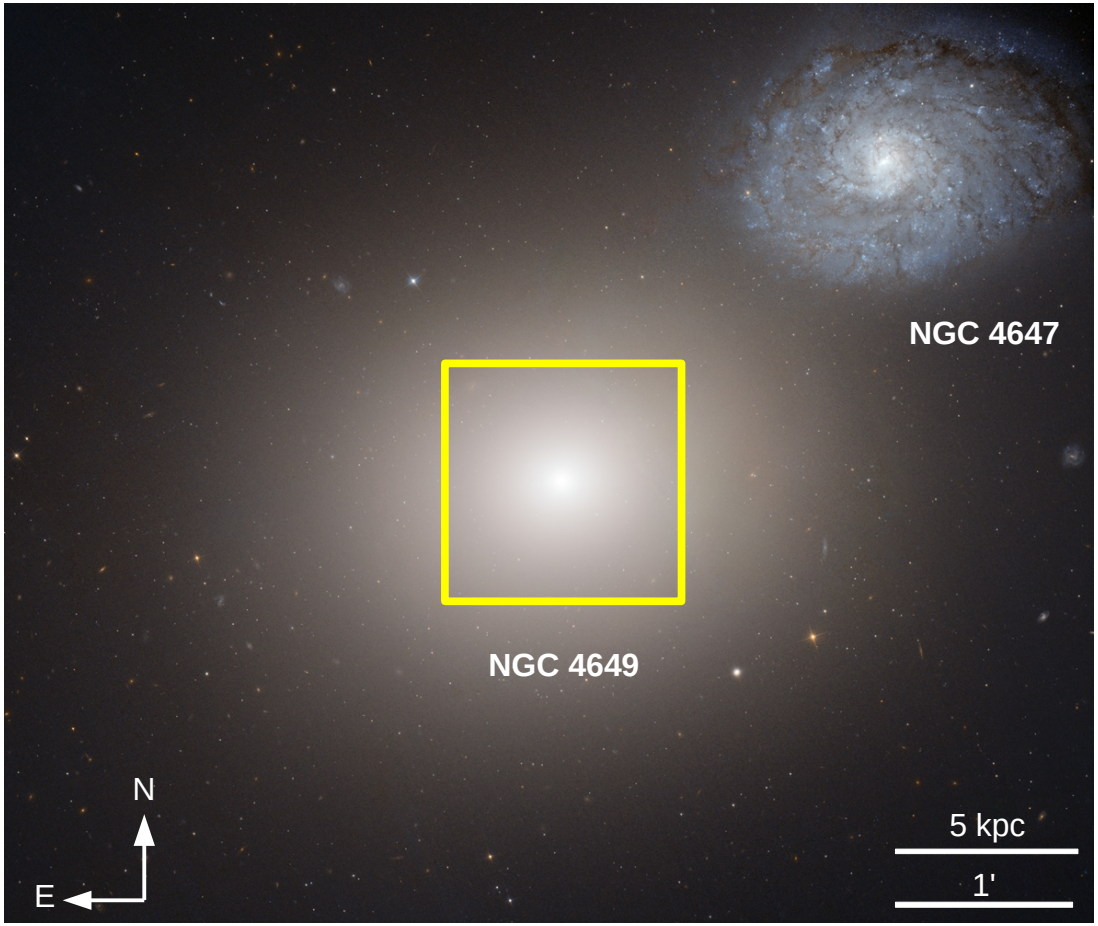


Perseus cluster (Fabian et al. 2006).

- AGN-induced disturbances have also been observed in the hot interstellar medium (ISM) in the halos of a number of normal elliptical galaxies (e.g,. Diehl & Statler 2007), and interpreted as a consequence of the thermal X-ray emitting gas being displaced by the AGN jets.

NGC 4649

- A.k.a. M60, nearby (~17 Mpc) X-ray bright, giant elliptical galaxy located in a group at the eastern edge of Virgo cluster.
- Faint radio source (Condon et al. 2002, Shurkin et al. 2008, Dunn et al. 2010).
- *Chandra* data indicate a generally relaxed X-ray morphology (Buote & Tsai 1995; Humphrey et al. 2008, 2013).
- But suggestions of AGN induced disturbances in the X-ray emitting gas (Randall et al. 2004, 2006; Shurkin et al. 2008; Dunn et al. 2010).

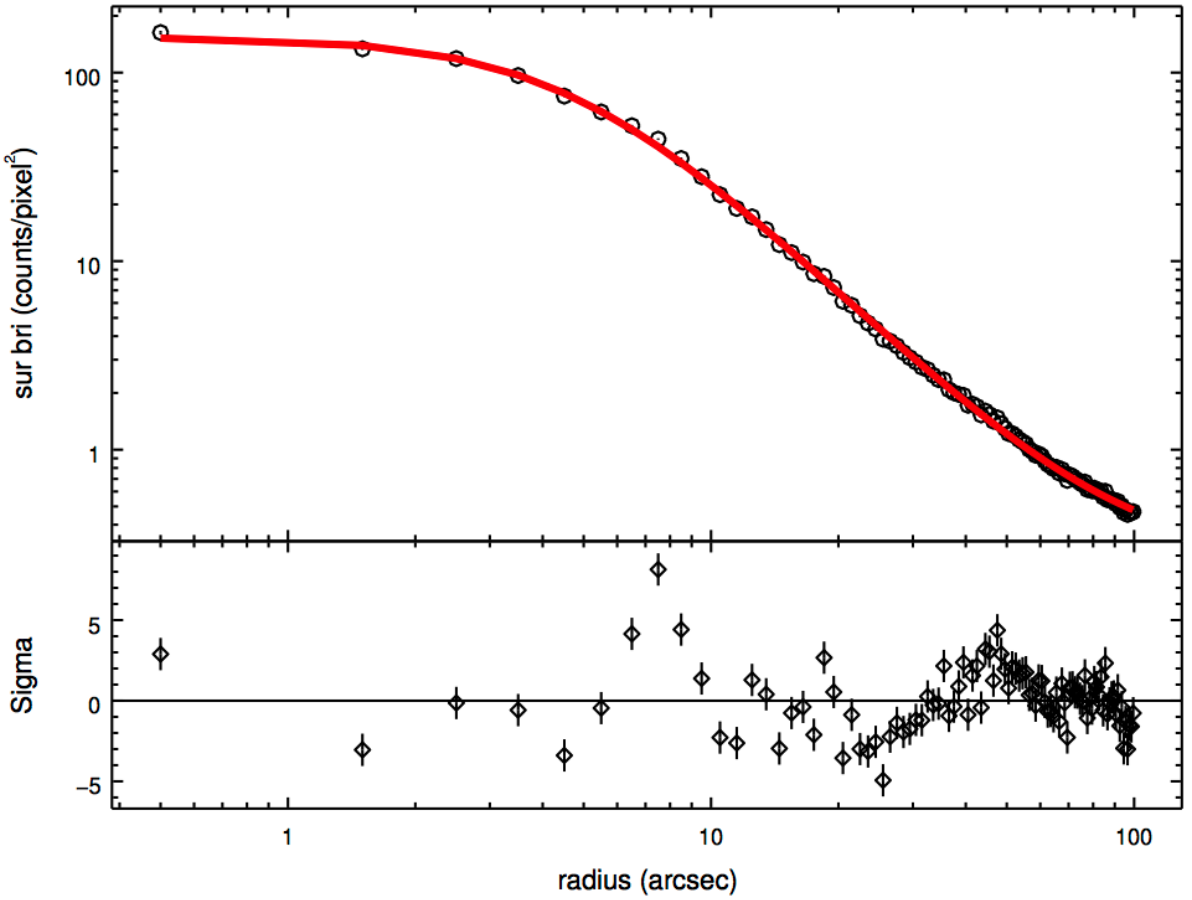


HST three color image (Credit: NASA, ESA, and Z. Levay STScI)

Chandra-ACIS total exposure ~ 280 ks (wrt ~ 90 ks of previous studies) allows an analysis of the diffuse emission with unprecedented detail.

Surface brightness profile

Study of the diffuse emission: remove sources detected with WAVDETECT (Luo et al. 2013) + replace data within each source ellipse with data from source-free nearby background adding Poisson noise.

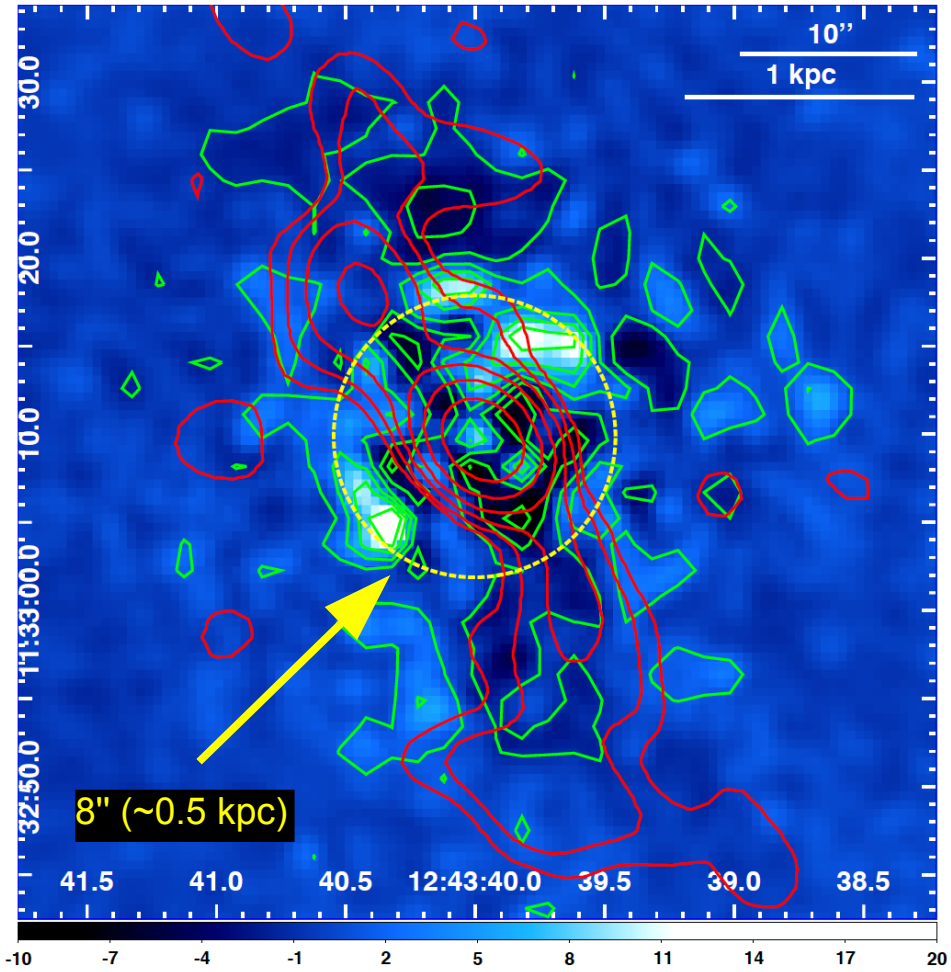


- Fit of the inner 100" (~ 8 kpc) with a β-model → poor fit (χ^2 ~ 4)
- A second β model does not improve the fit
- Significant deviations at 8” (~ 0.5 kpc) and 40" (~ 3 kpc)

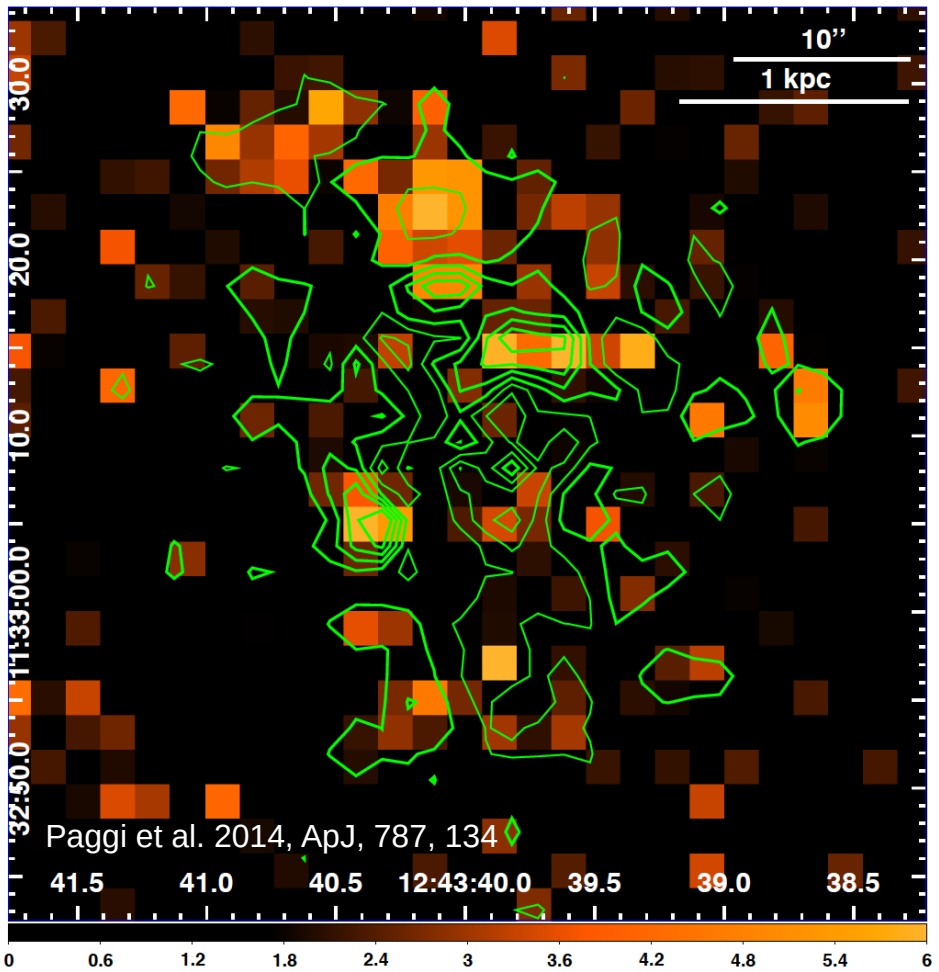
→ 2-D fitting to investigate structure distribution.

Inner structures

Residual wrt elliptical β model, VLA 1.4 GHz contours.



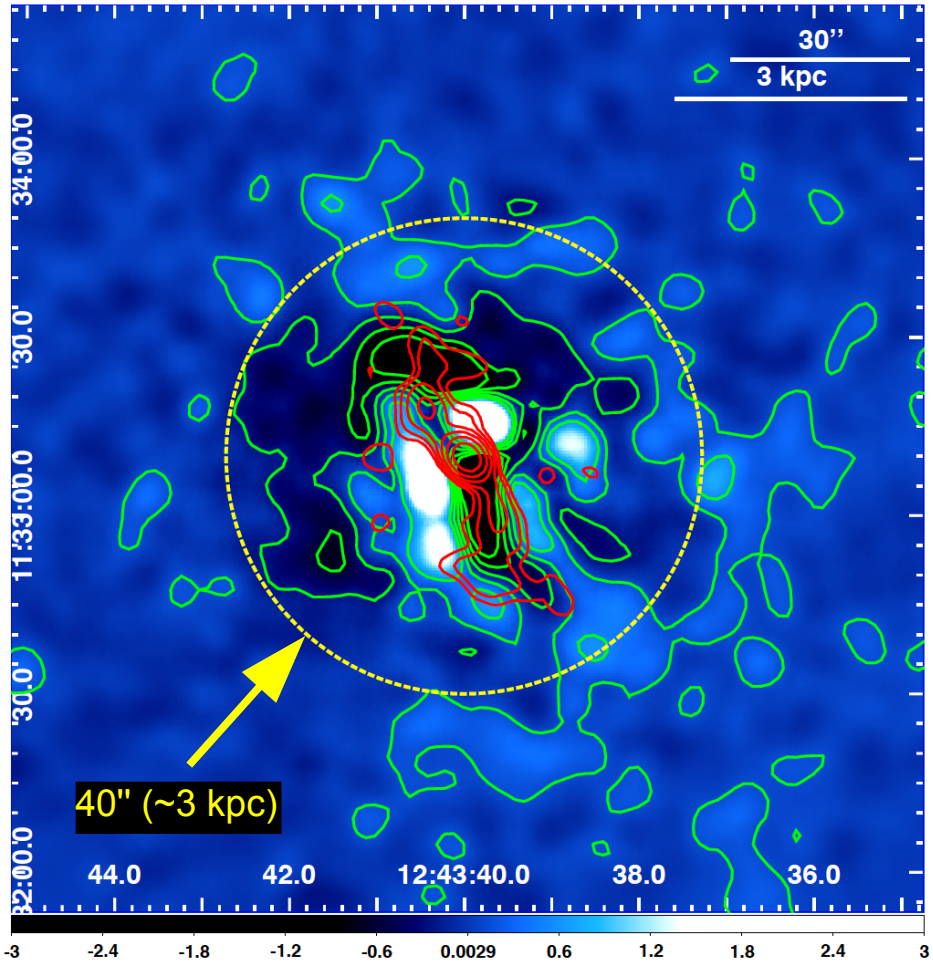
Residuals elliptical β model 3X3 FWHM gaussian smoothing.



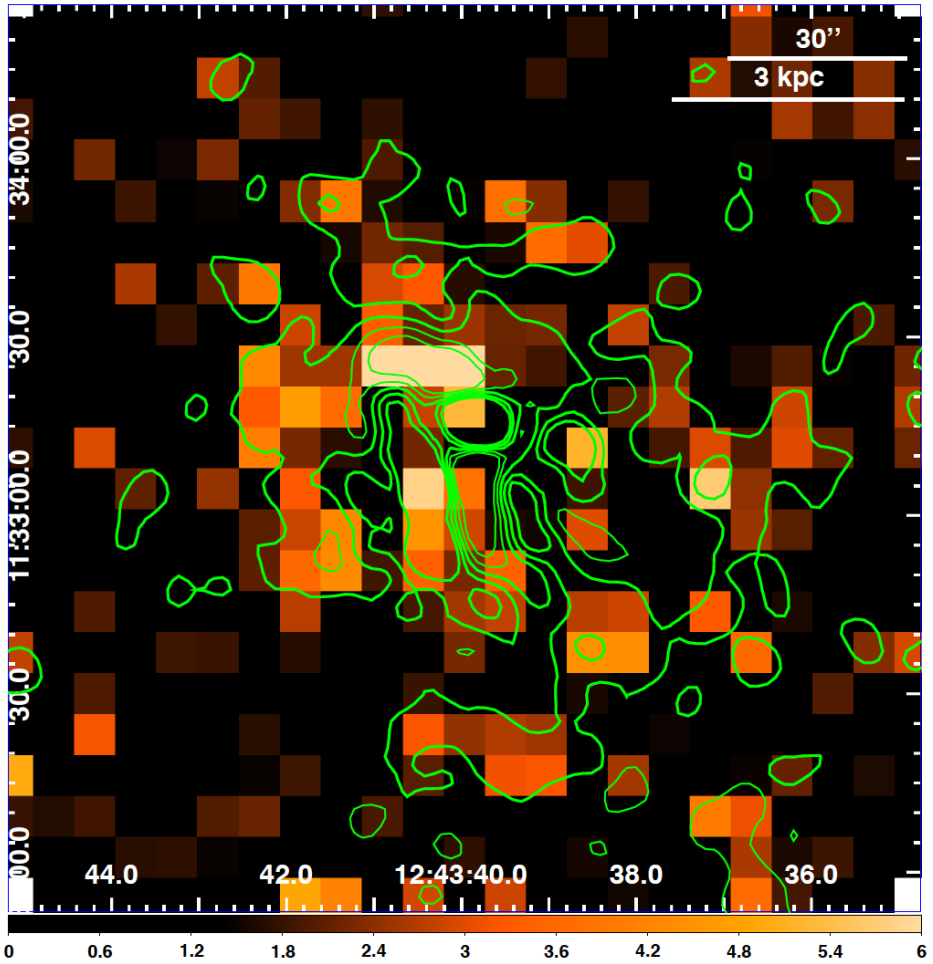
Residual S/N map (residuals / X-ray counts error) bin 4.

Cavities spatially related with radio emission, interaction with ISM.

Outer ring-like structures



Residuals elliptical β model 10X10 FWHM gaussian smoothing.



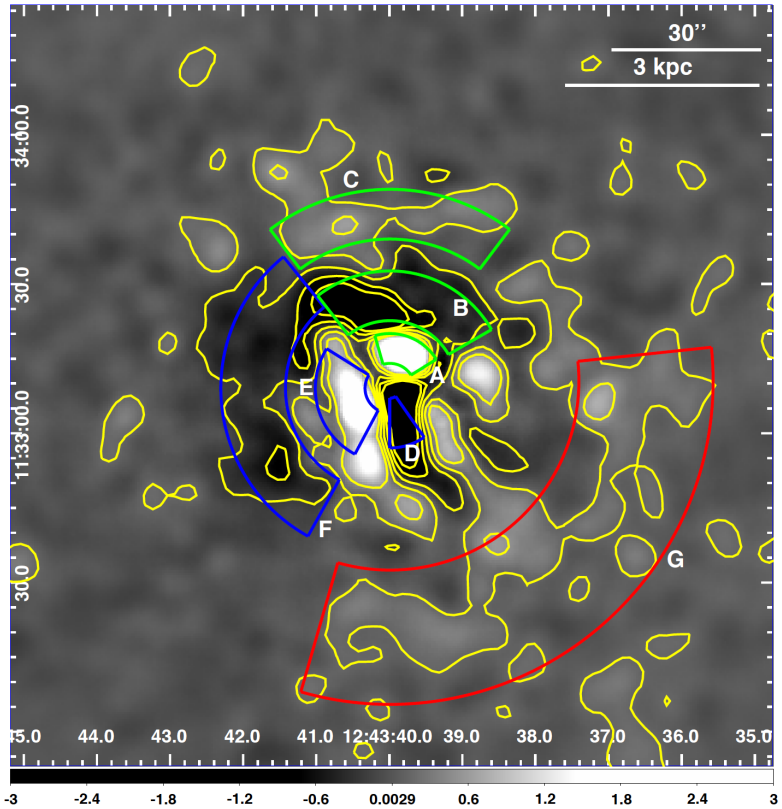
Residual S/N map (residuals / X-ray counts error) bin 14.

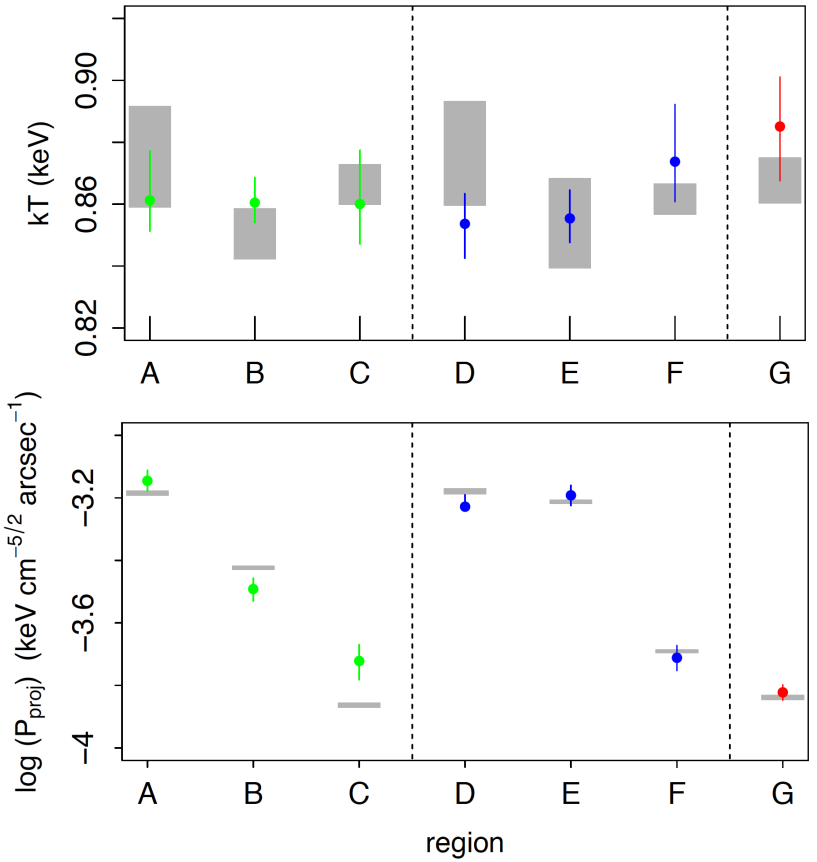
S/N in the observed structures ~ 3 or more, higher significance of the structures as a whole. Residual structures similar to those seen around NGC 1275 (Fabian et al. 2006).

Spatially resolved spectral fitting

VAPEC component + thermal bremsstrahlung component to account for undetected point sources (Irwin et al. 2003) + hot gas component from Virgo ICM (e.g. Gastaldello & Molendi 2002).

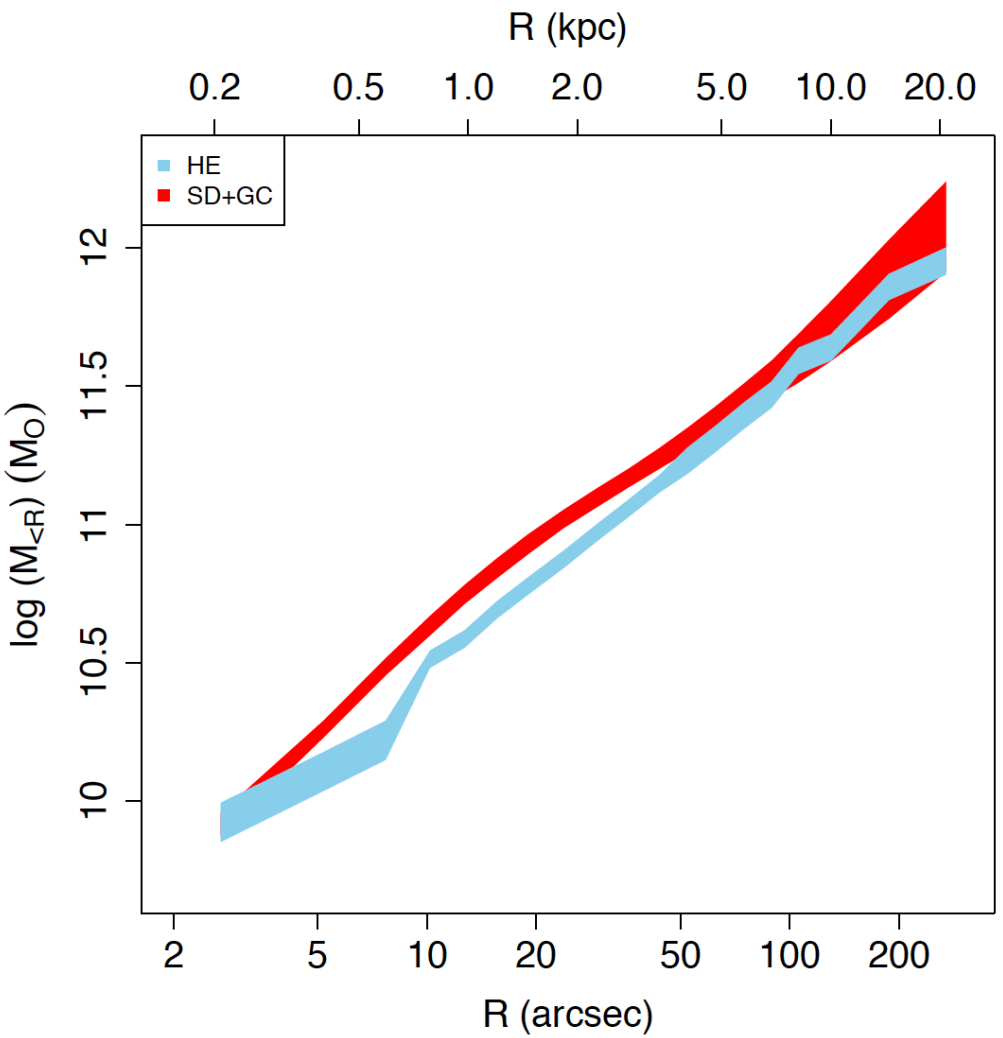
Cfr. with average gas properties (grey) → spectra extracted in concentric annuli with PROJCT model to account for projection effects.

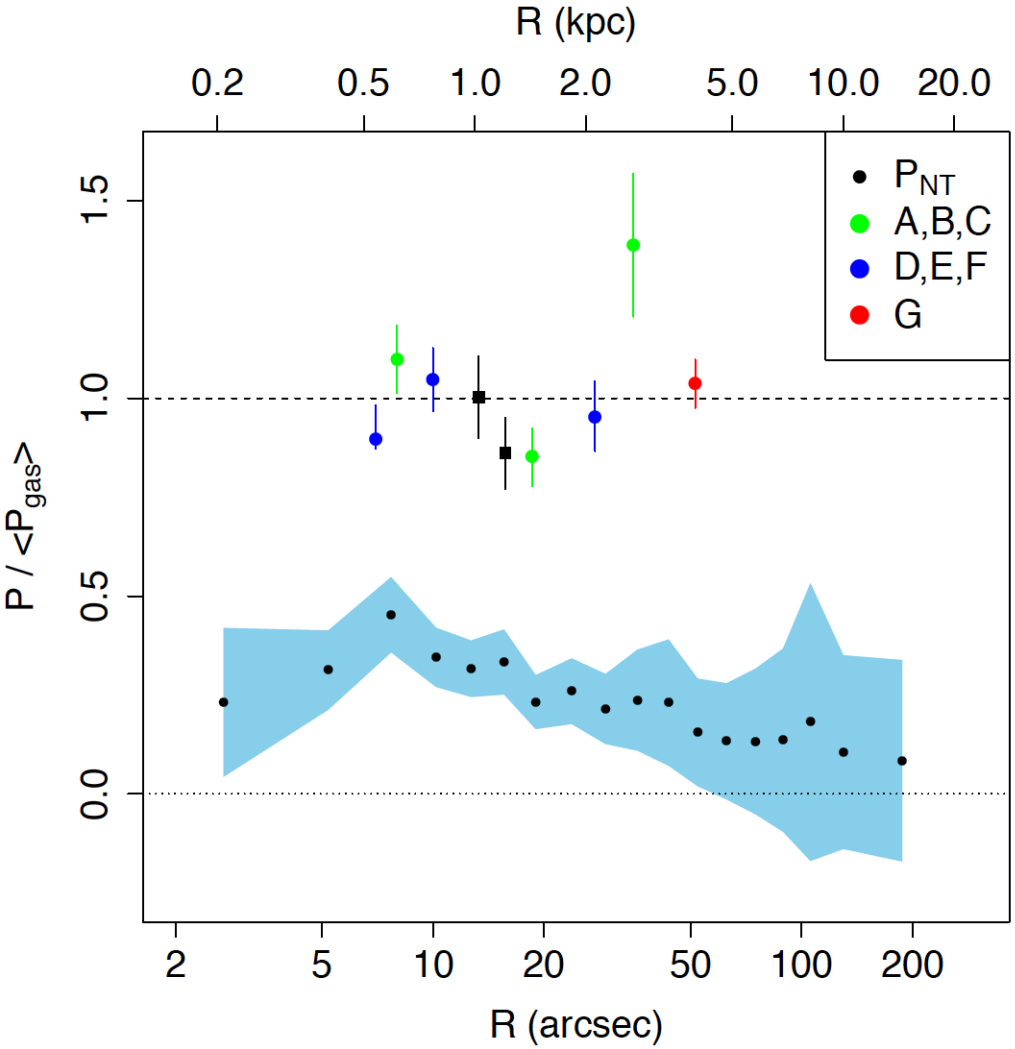




No significant temp. variations between under-dense and over-dense regions. Cfr. with NGC 1275 (Fabian et al. 2006), with no sign of hotter temperature component in higher pressure regions. Possibility for these structures to be isothermal waves dissipating energy by viscosity.

Non-thermal pressure

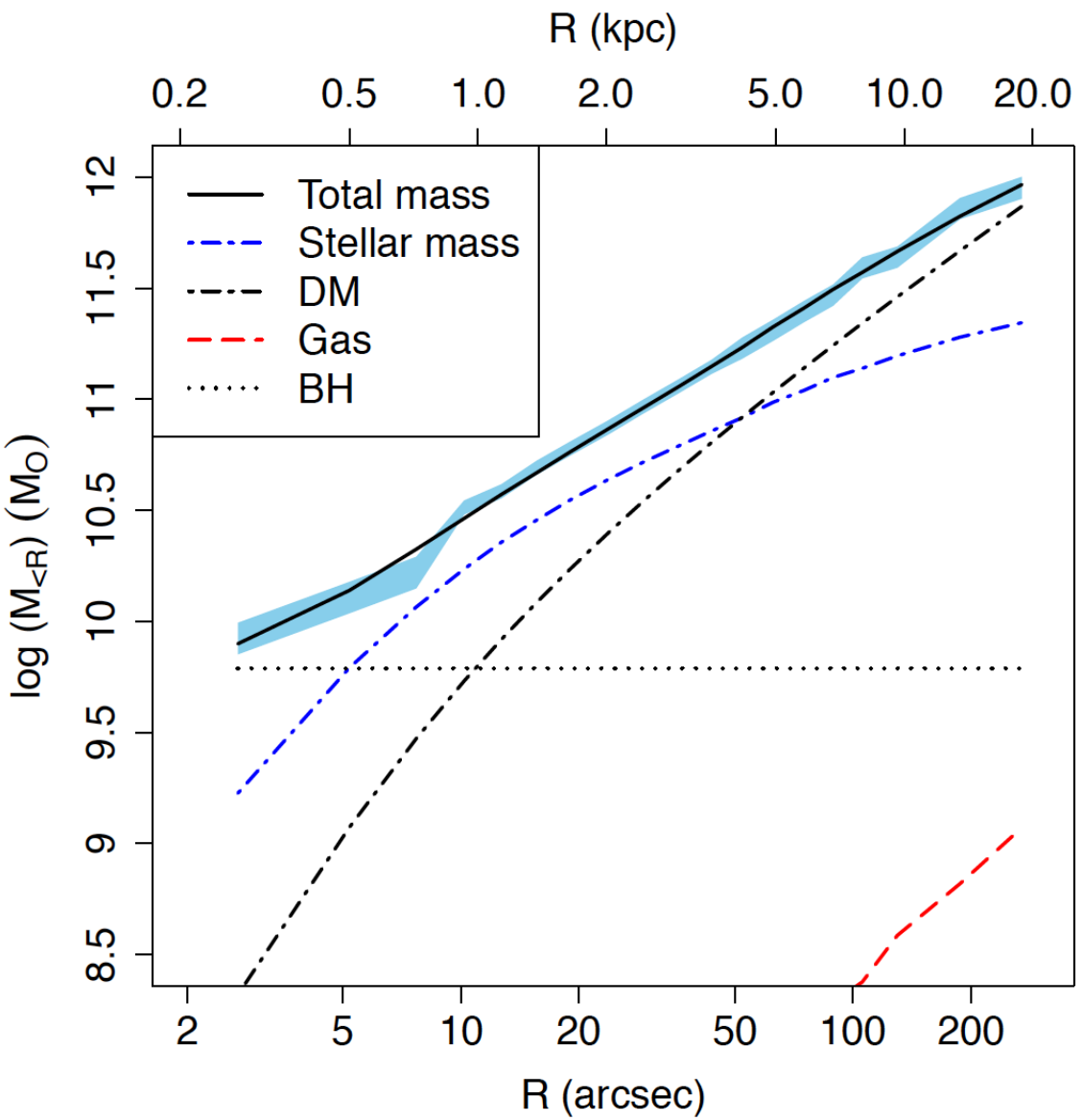




Comparison with mass profile from stellar kinematics and GC velocities (Shen & Gebhardt 2010). Deviations 0.5-3 kpc (same scale of the residual structures) → NT pressure accounts for ~ 30% of the gas pressure (Humphrey et al. 2013). Pressure peaks cross-correlation significant at 99%.

Cosmic ray injection into the ISM from the weak radio jets.

BH Mass Estimate



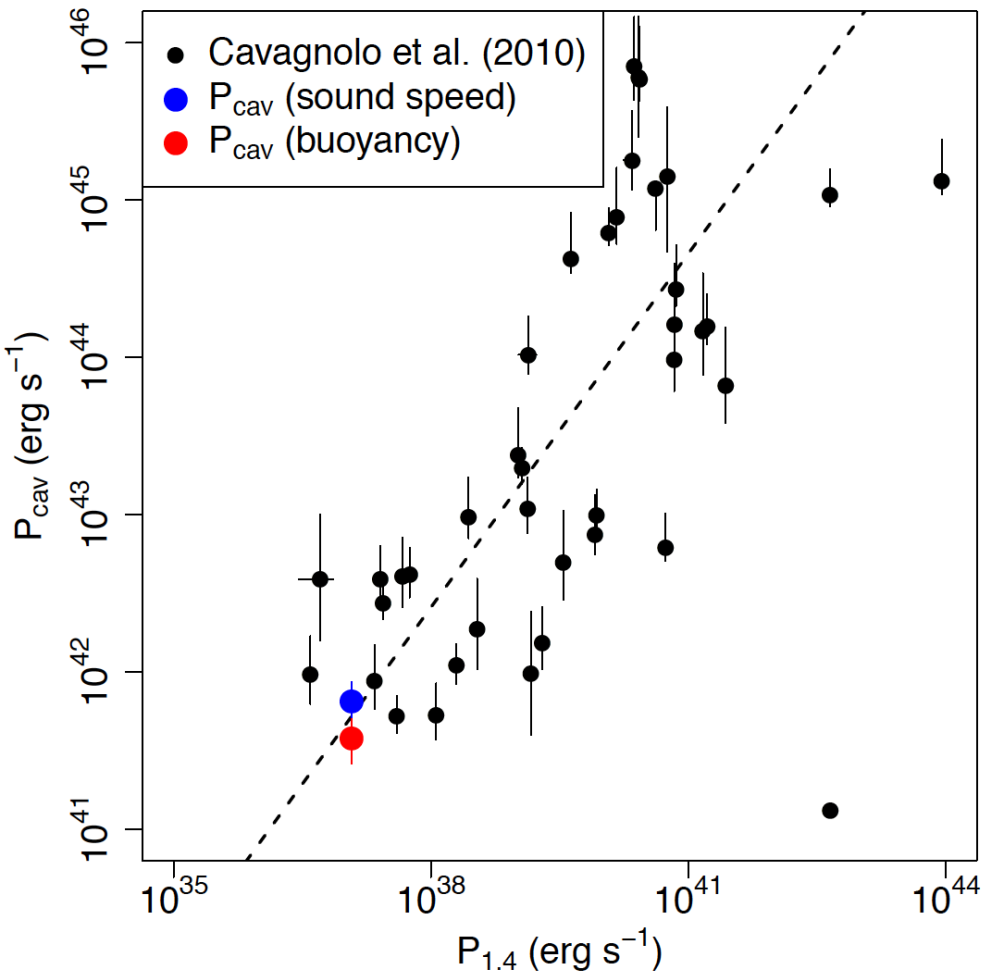
Mass components:

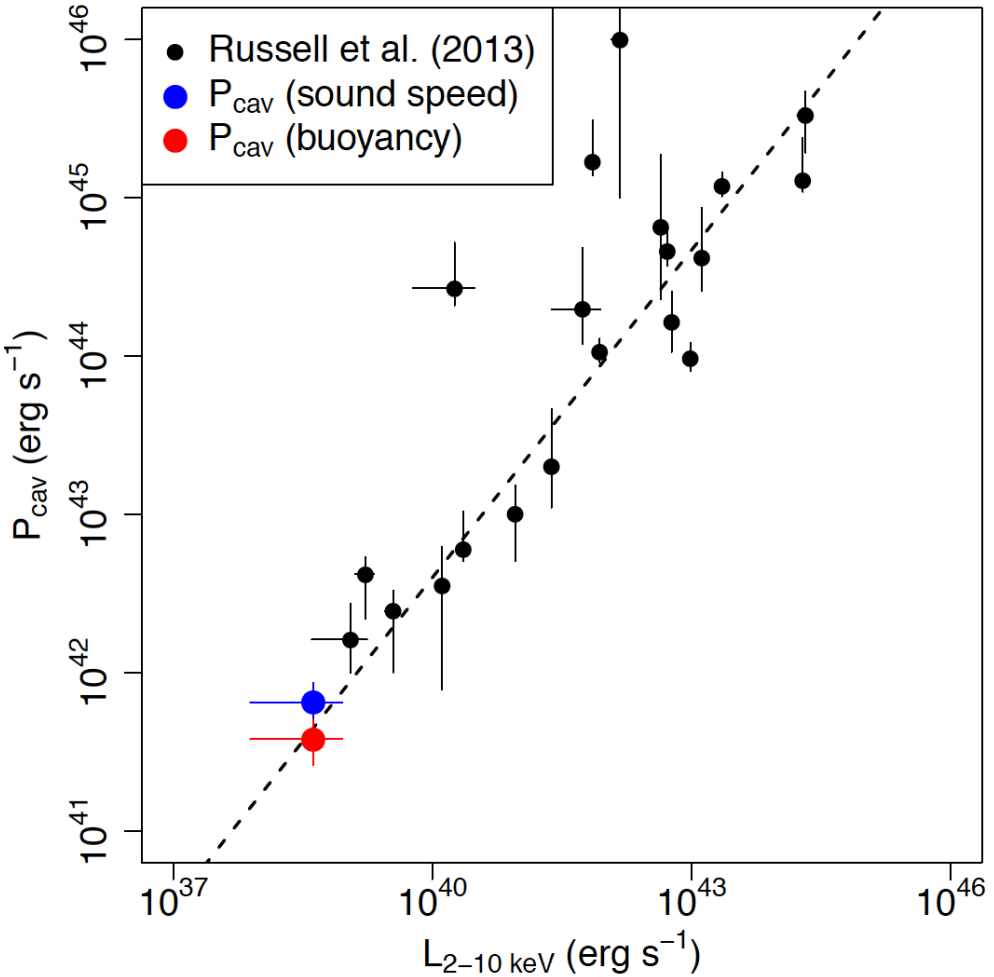
- Gas
- DM (NFW profile)
- Stellar mass from V-band luminosity (Kormendy et al. 2009)
- SMBH mass:

$$M_{BH} = (5.7 \pm 0.7) \times 10^9 M_O$$

- $(4.5 \pm 1.0) \times 10^9 M_O$ (Shen & Gebhardt 2010)
- $(3.4 \pm 1.0) \times 10^9 M_O$ (Humphrey et al. 2008) higher gas temp.

Cavity Power





NGC 4649 cavities follow Cavagnolo et al. (2010) scaling relation between kinetic power P_{CAV} and synchrotron luminosity at 1.4 GHz. They also follow the correlation between nuclear 2-10 keV luminosity and P_{CAV} (Russell et al. 2013).

Conclusions

- Deep *Chandra* observations of NGC 4649 show significant cavities and ring-like structures that appear to be connected with radio emission.
- No significant temp. variations in observed structures, possibly isothermal waves whose energy is dissipated by viscosity (cfr. NGC 1275, Fabian et al. 2006).
- HE vs SD mass estimates indicate presence of significant non-thermal pressure component (~30% of gas pressure) connected with radio emission.
- BH mass estimate: $M_{BH} = (5.7 \pm 0.7) \times 10^9 M_O$, cfr. with $(4.5 \pm 1.0) \times 10^9 M_O$ (Shen & Gebhardt 2010), $(3.4 \pm 1.0) \times 10^9 M_O$ (Humphrey et al. 2008) higher gas temperature (updated AtomDB).
- NGC 4649 seem to host cavities similar in nature to those of other giant ellipticals basing on relation between cavity power and radio luminosity/nuclear luminosity.