Cambridge X-Ray Astronomy

Relating Accretion Rate and Jet Power in Elliptical Galaxies

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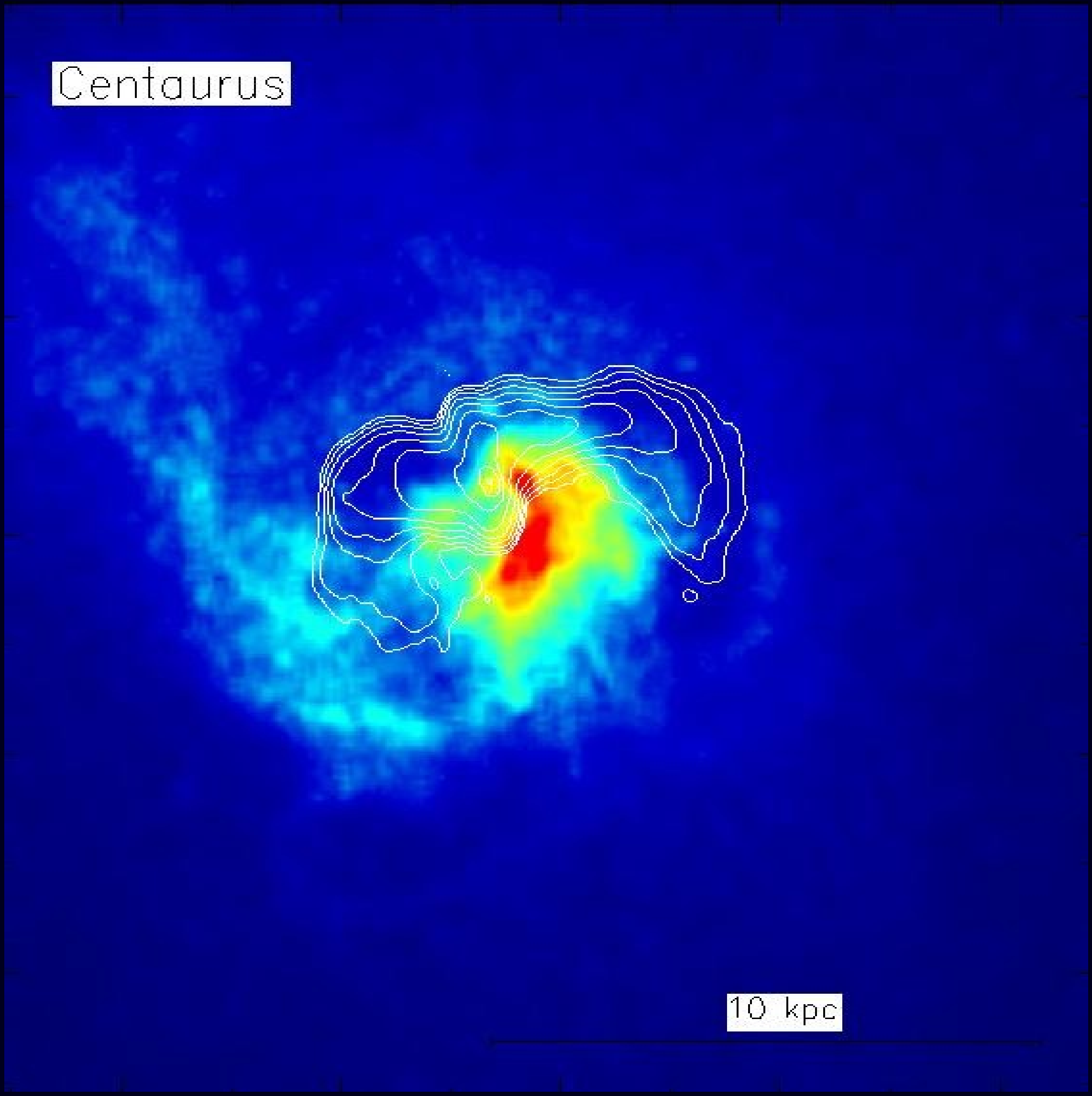
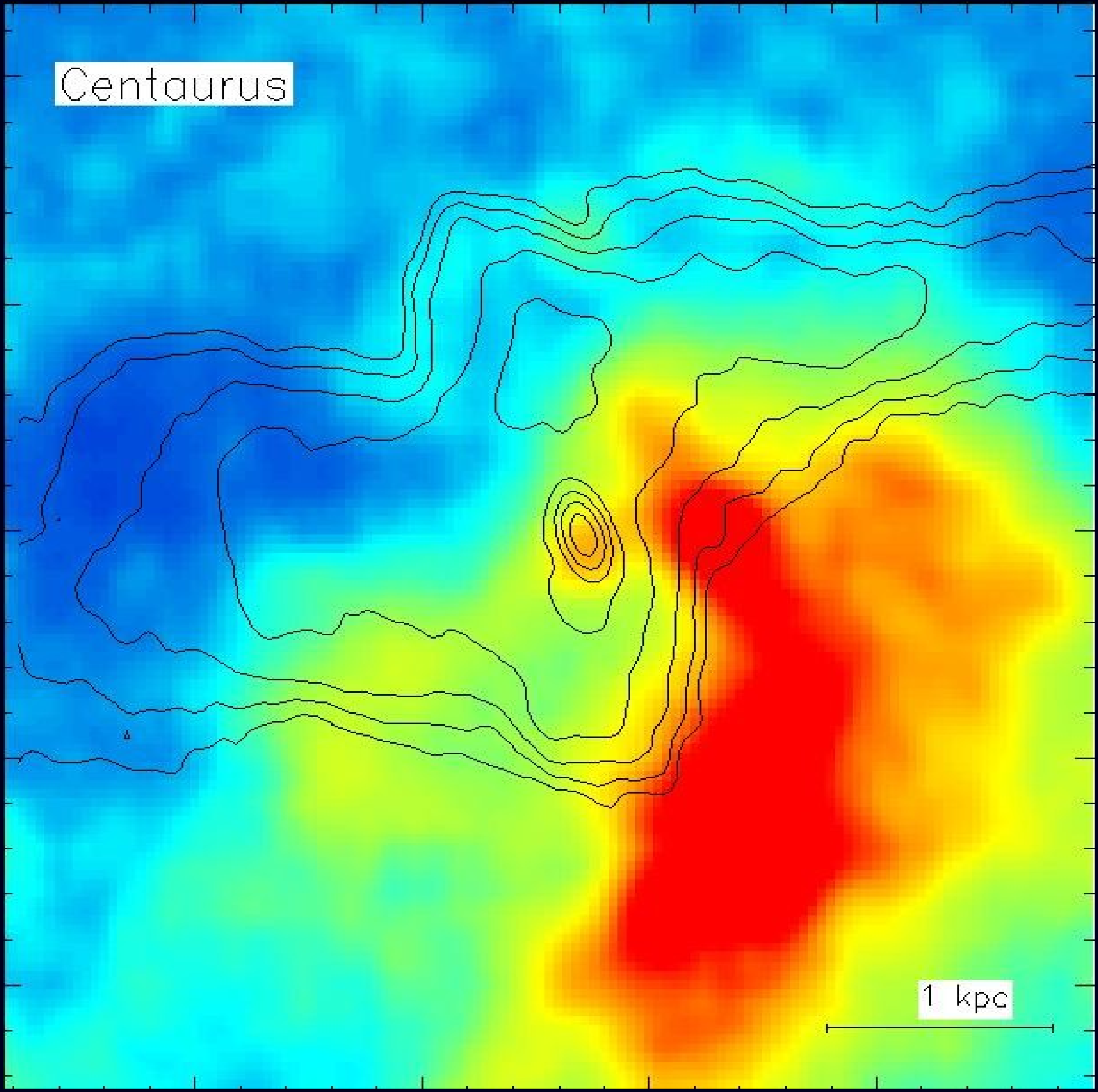
AGNs in Ellipticals

- The observed luminosities of AGN in ellipticals are also much lower than those expected from standard Bondi accretion (assuming an efficiency of 10%).

- Di Matteo *et al.* 2003 and Taylor *et al.* 2005 investigated this in M87, NGC4696 & NGC6166.
  - Although the bolometric luminosities are a factor ~1000 below the Bondi rates, the powers inferred from X-ray cavities are comparable (to a factor ~few).



Taylor *et al.* 2006, 5GHz & 8GHz radio contours on *Chandra* X-rays.



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  - Although the bolometric luminosities are a factor ~1000 below the Bondi rates, the powers inferred from X-ray cavities are comparable (to a factor ~few).

- The origin of the galaxy luminosity function and the mechanism which truncates the star formation in the largest ellipticals is still a subject for debate (e.g. Benson *et al.* 2003, Croton *et al.* 2005).

Accretion Rates

- The exquisite resolution of *Chandra* allows regions close to the Bondi radius to be resolved.

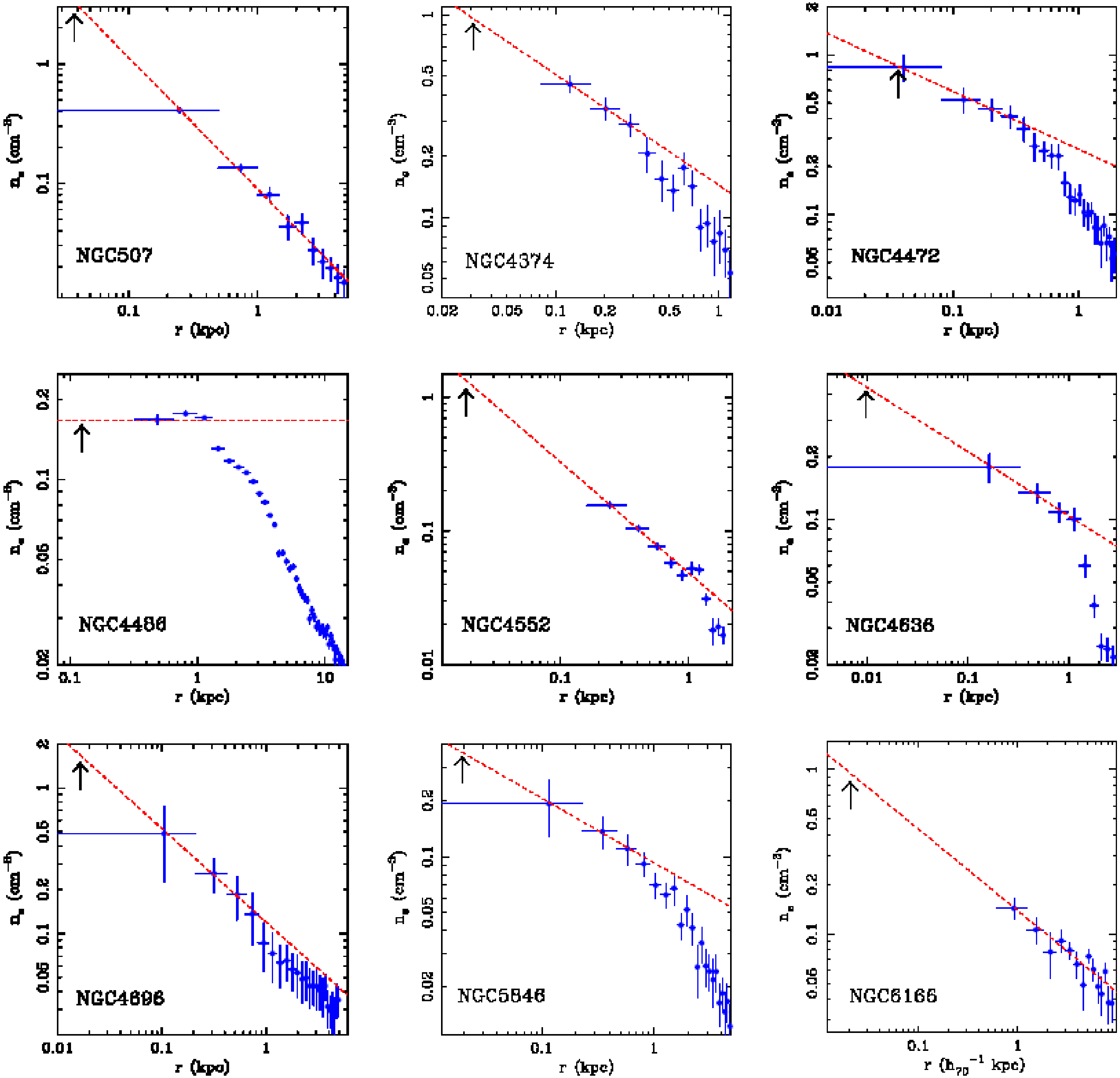
- The Bondi accretion rate is

$$\dot{M}_{\rm Bondi} = \pi (GM_{\rm BH})2c_{\rm s}^{-3}\rho = \frac{\pi c_{\rm s} \rho r_{\rm A}^{2}}{4}$$

- We chose a sample of nine ellipticals which were all closer than $d_{\rm L}$~100Mpc.

- As a result for an efficiency η, the Bondi accretion power is

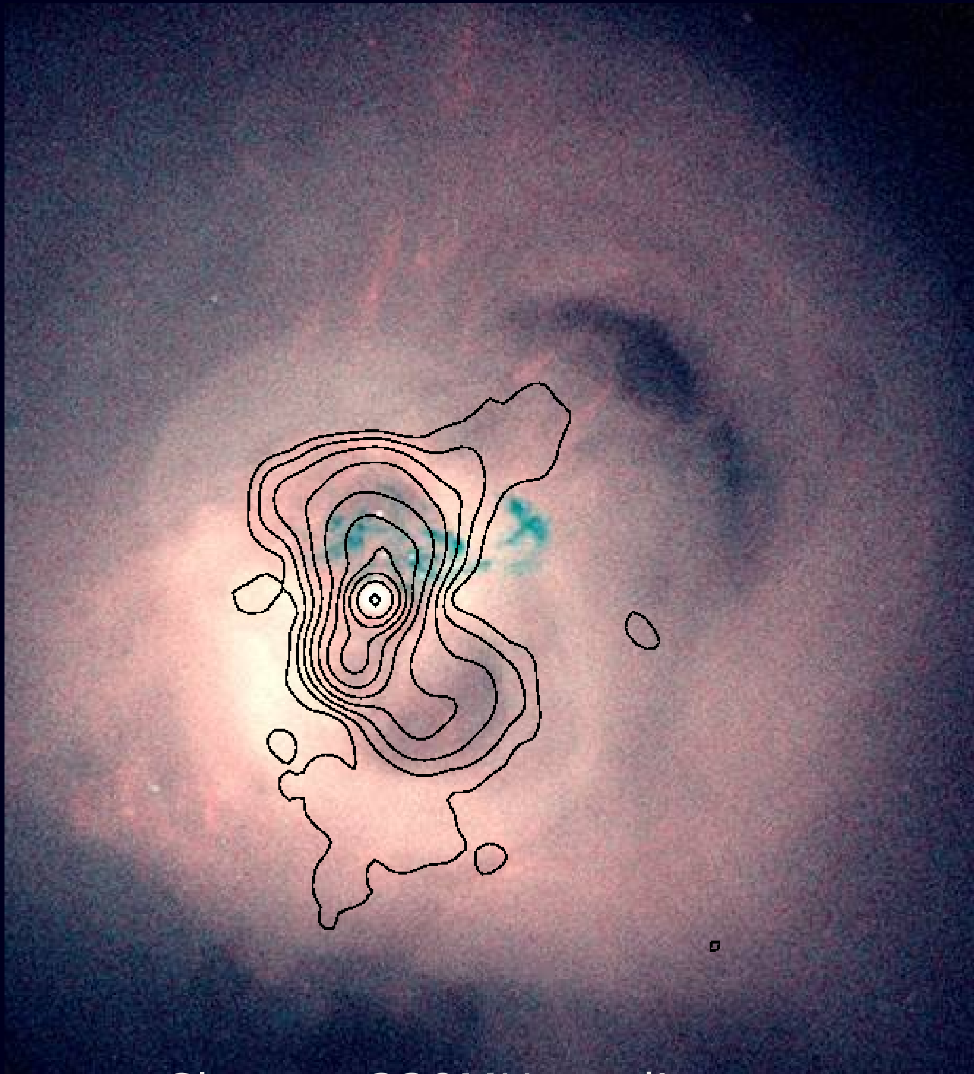
$$P_{\rm Bondi} = \eta \dot{M}_{\rm Bondi} c^{2}$$



NGC507
NGC4374
NGC4472
NGC4486
NGC4552
NGC4636
NGC4696
NGC5846
NGC6166
n_e (cm^{-3})
r (kpc)
r (h_{70}^{-1} kpc)

X-ray Bubbles

- When AGN are embedded in a thermal plasma, e.g. in clusters, the relativistic jets inflate cavities of radio-emitting plasma.
- These cavities are buoyant and detach from the central AGN and rise up through the thermal plasma.
- These have been termed “bubbles.”



Fabian *et al.* 2006, Perseus Cluster, 330MHz radio contours

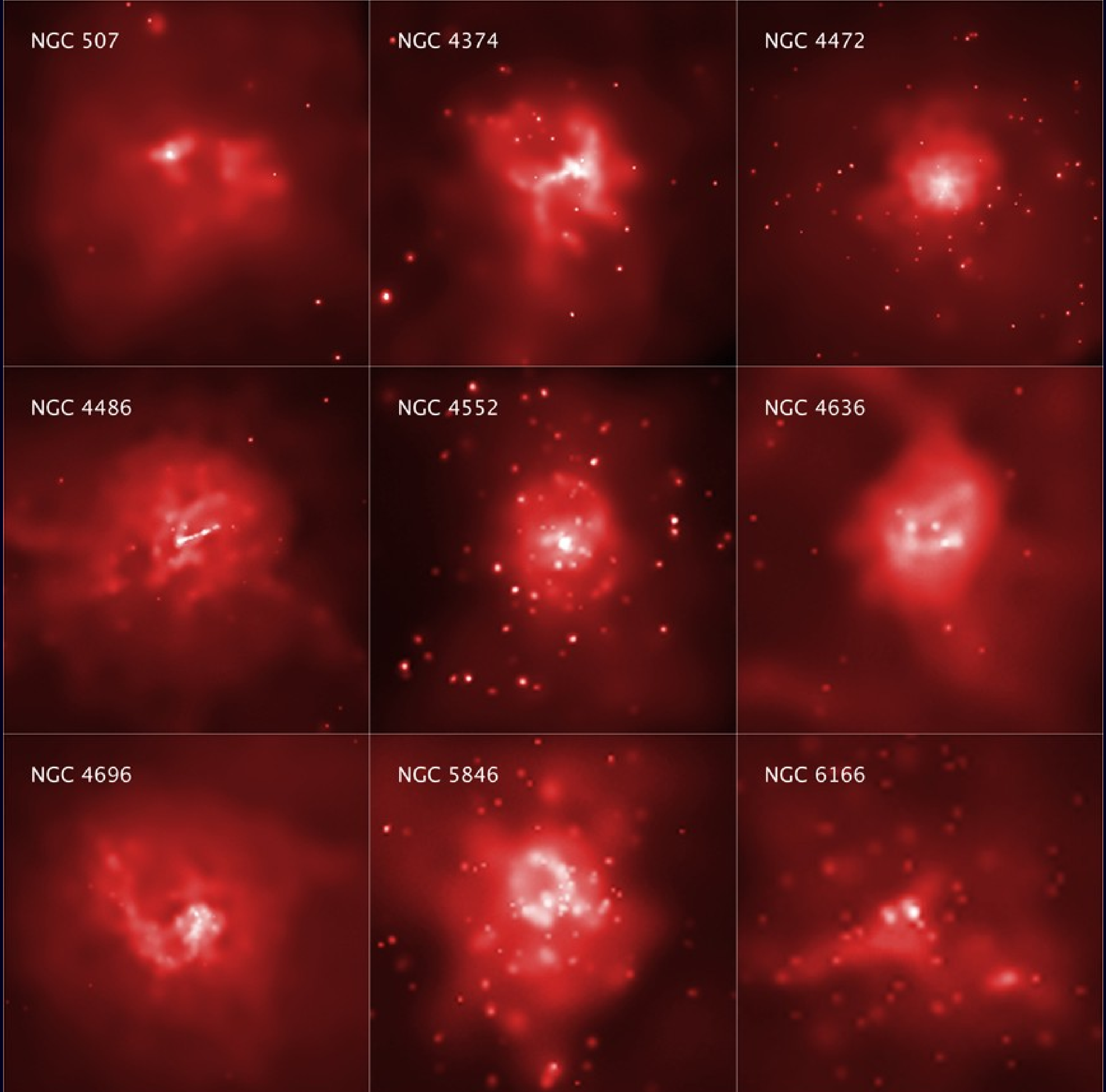
X-ray Cavity measurements

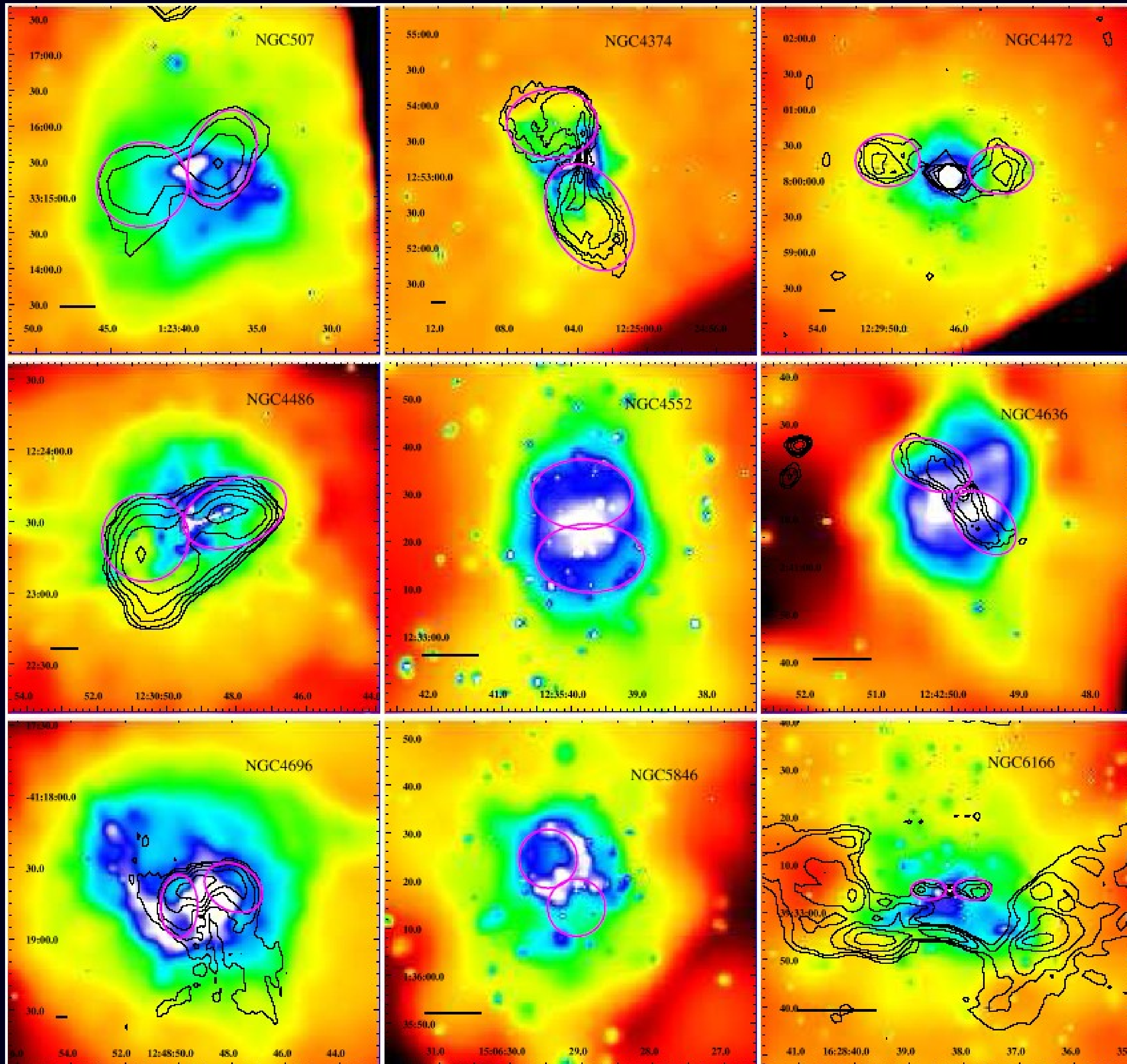
- The energy contained within these bubbles can be estimated from the work done in inflating the cavities; $E=4pV$
  - We ignored the extra energy which goes into sound waves (e.g. Churazov *et al.* 2002) as it is likely to be small.

- As most of the bubbles in these ellipticals are still attached to their radio cores, they must be young and so we estimate their ages assuming that they are expanding at the sound speed.

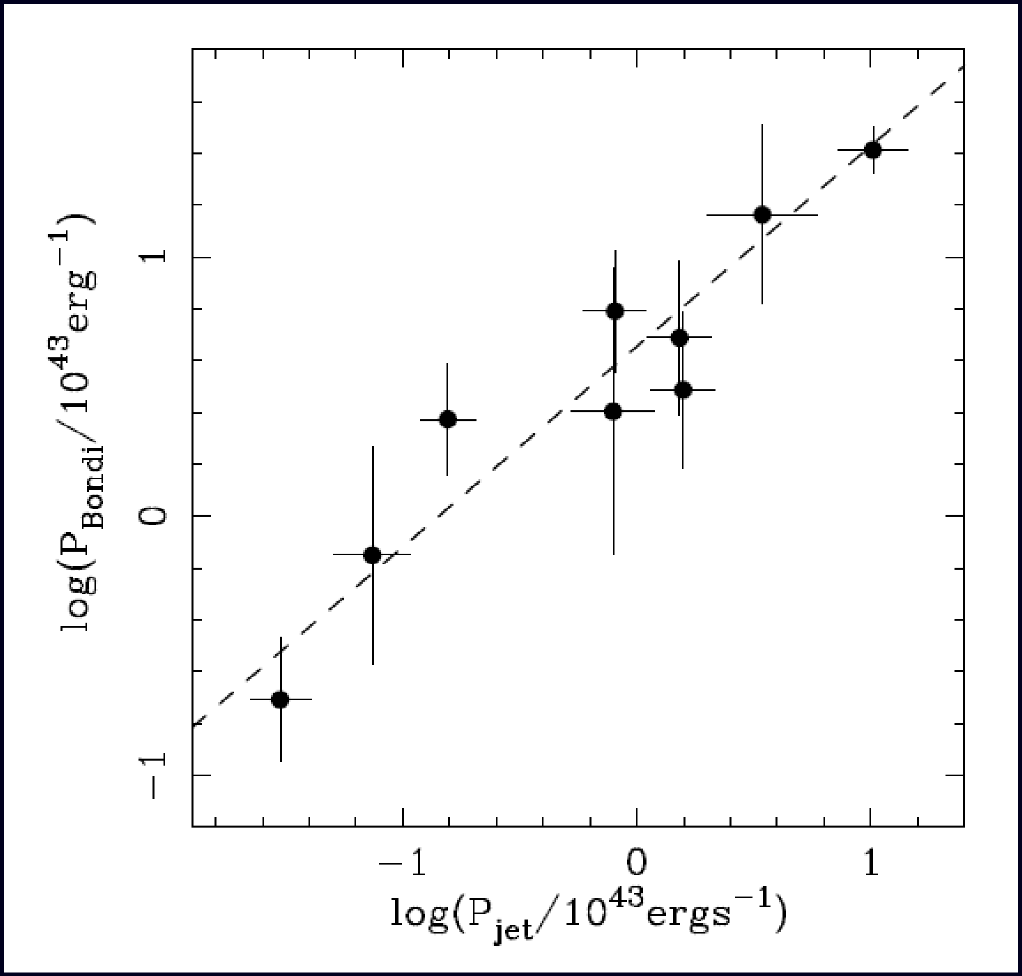
- Hence

$$P_{\mathrm{jet}} = \frac{4pV}{t_{c_{\mathrm{s}}}} = \frac{4pV}{R/c_{\mathrm{s}}}$$


NGC 507
NGC 4374
NGC 4472
NGC 4486
NGC 4552
NGC 4636
NGC 4696
NGC 5846
NGC 6166


NGC507
NGC4374
NGC4472
NGC4486
NGC4552
NGC4636
NGC4696
NGC5846
NGC6166

Results



Allen, Dunn *et al.* 2006, *MNRAS*, in press, astro-ph/0602549

- Fitting the clear correlation with a power-law

$$\log(P_{\mathrm{Bondi}}/10^{43}\,\mathrm{erg/s}) = A + B\log(P_{\mathrm{jet}}/10^{43}\,\mathrm{erg/s})$$

- A=0.65±0.16, B=0.77±0.20, using an estimator than accounts for errors on both axes (BCES(Y|X) from Akritas & Bershady 1996).

- The plotted quantities have some variables in common – d_{L} T and ρ .
  - However, none of these could introduce the observed positive correlation.

Implications

- The correlation means that a significant fraction (~2%) of the energy associated with the rest mass of the material entering the Bondi accretion radius emerges in relativistic jets.

- This tight correlation suggests that the Bondi formalism provides a good description of the accretion process.

- Most of the material which passes through the accretion radius flows all the way down to the black hole.
  - Little material is lost from the accretion flow en route to the region of jet formation

- The accretion flows must be stable over the lifetimes of the bubble $\sim 10^7$ years.

- The *observed* efficiency of the feedback of the accreted matter is similar to that *assumed* in semi-analytic models (e.g. Croton *et al.* 2005).

- For the galaxies observed here, the power fed back into the X-ray gas is sufficient to offset the cooling, and so prevent further star formation.

- In clusters, however, the cooling rate is much larger (~10^{45} erg/s)
  - If the black hole masses and accretion rates are not *much* larger then those in these ellipticals, then it is unlikely that the jet power will be sufficient to balance cooling.

Summary

- There exists a tight correlation between the Bondi accretion rates and the Jet power

$$\log(P_{\mathrm{Bondi}}/10^{43}\,\mathrm{erg/s}) = A + B\log(P_{\mathrm{jet}}/10^{43}\,\mathrm{erg/s})$$

- A=0.65±0.16, B=0.77±0.20

- A significant fraction (~2%) of the energy associated with the rest mass of the material entering the Bondi radius emerges in relativistic jets.

- The Bondi formulae provide a good description of accretion

- In ellipticals, the black holes feed back sufficient energy to stem cooling and star formation.