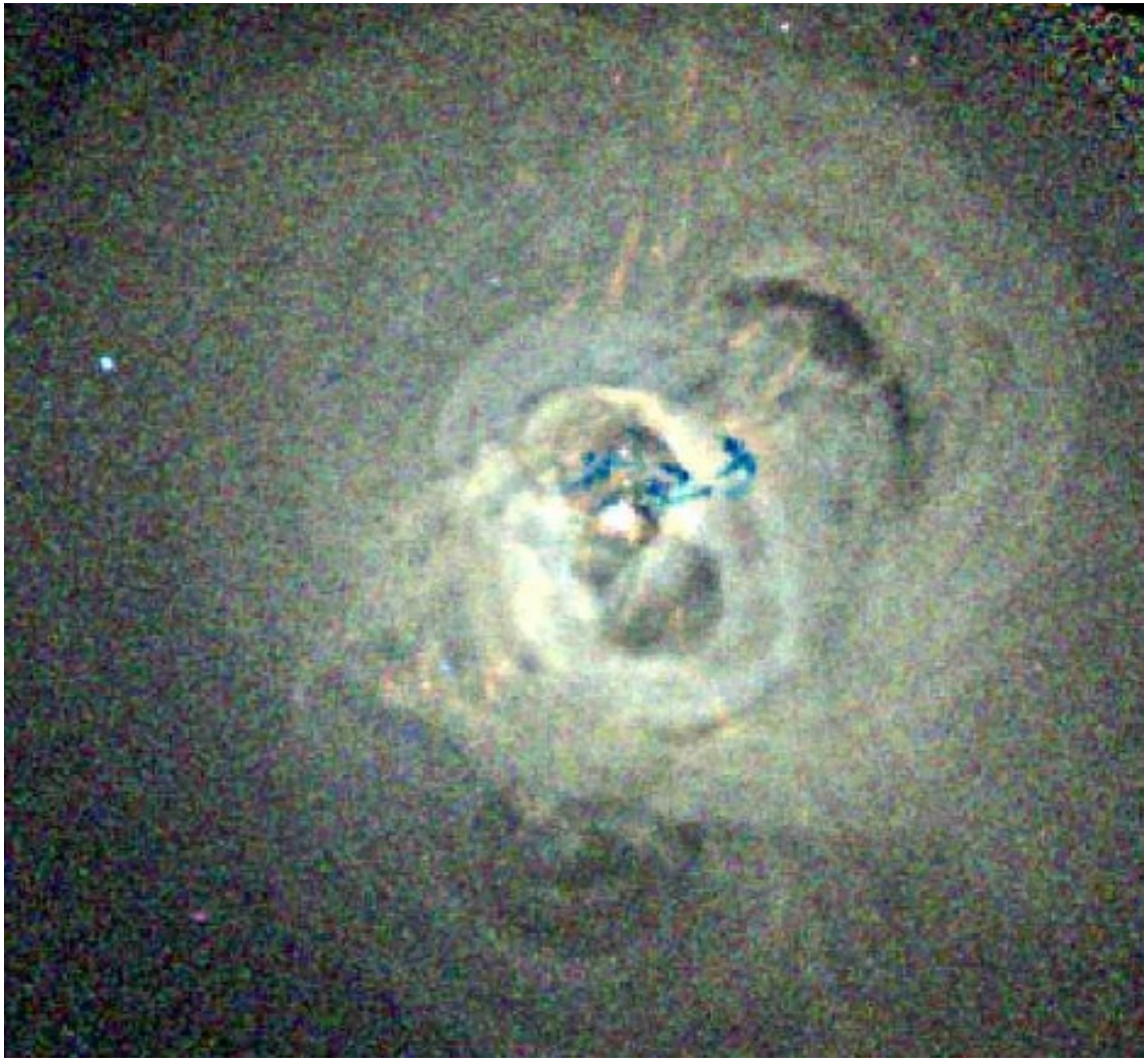
Astronomy 537



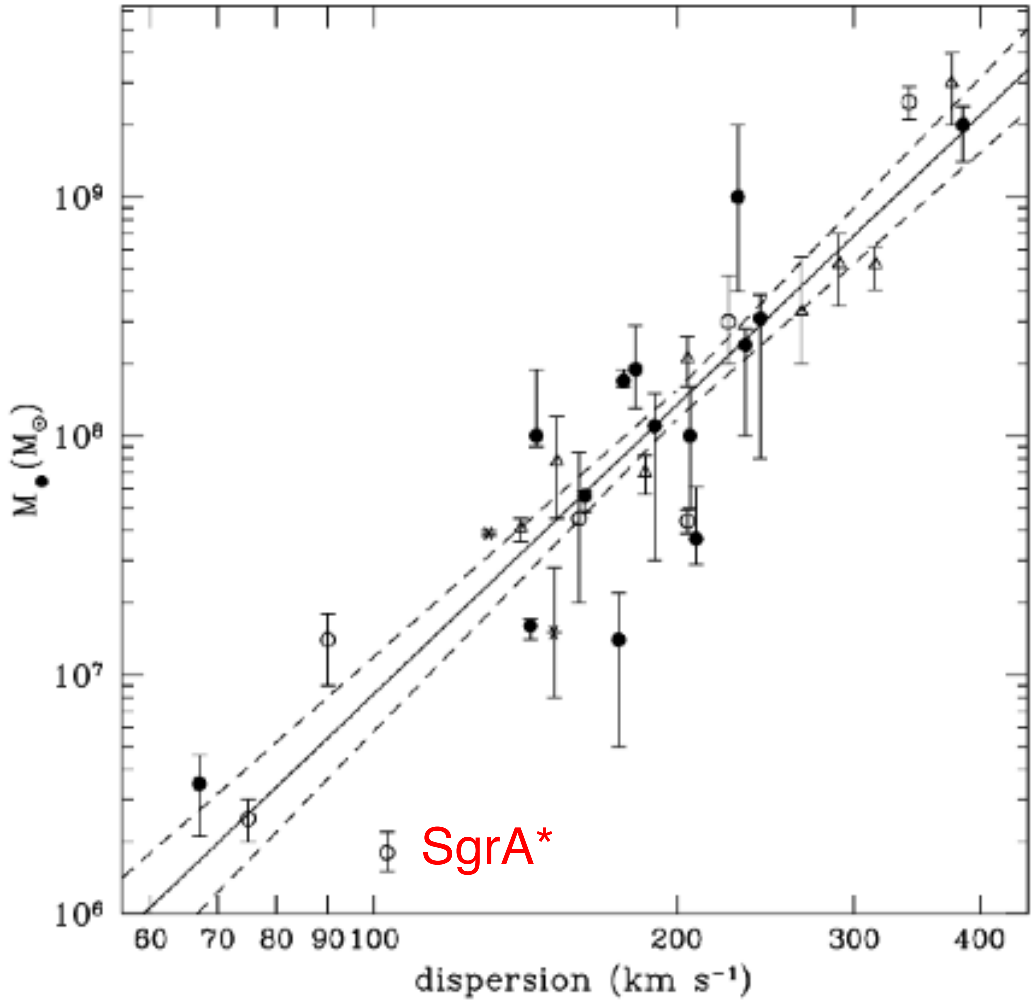
Lecture 13: Black Holes and Feedback

Key concepts:

Supermassive Black Holes

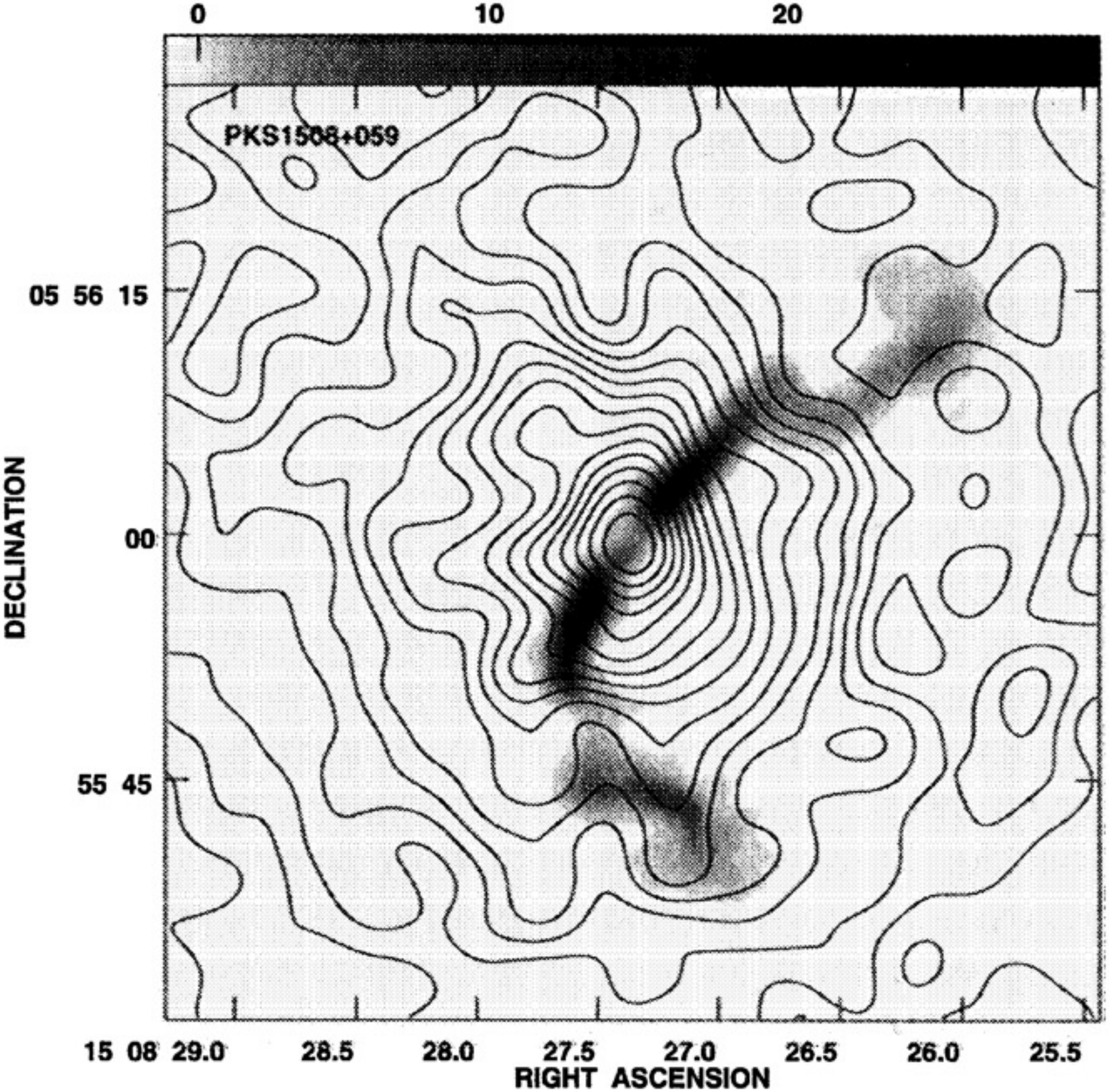
Feedback and its impact on evolution

Supermassive black holes (M-sigma relation)



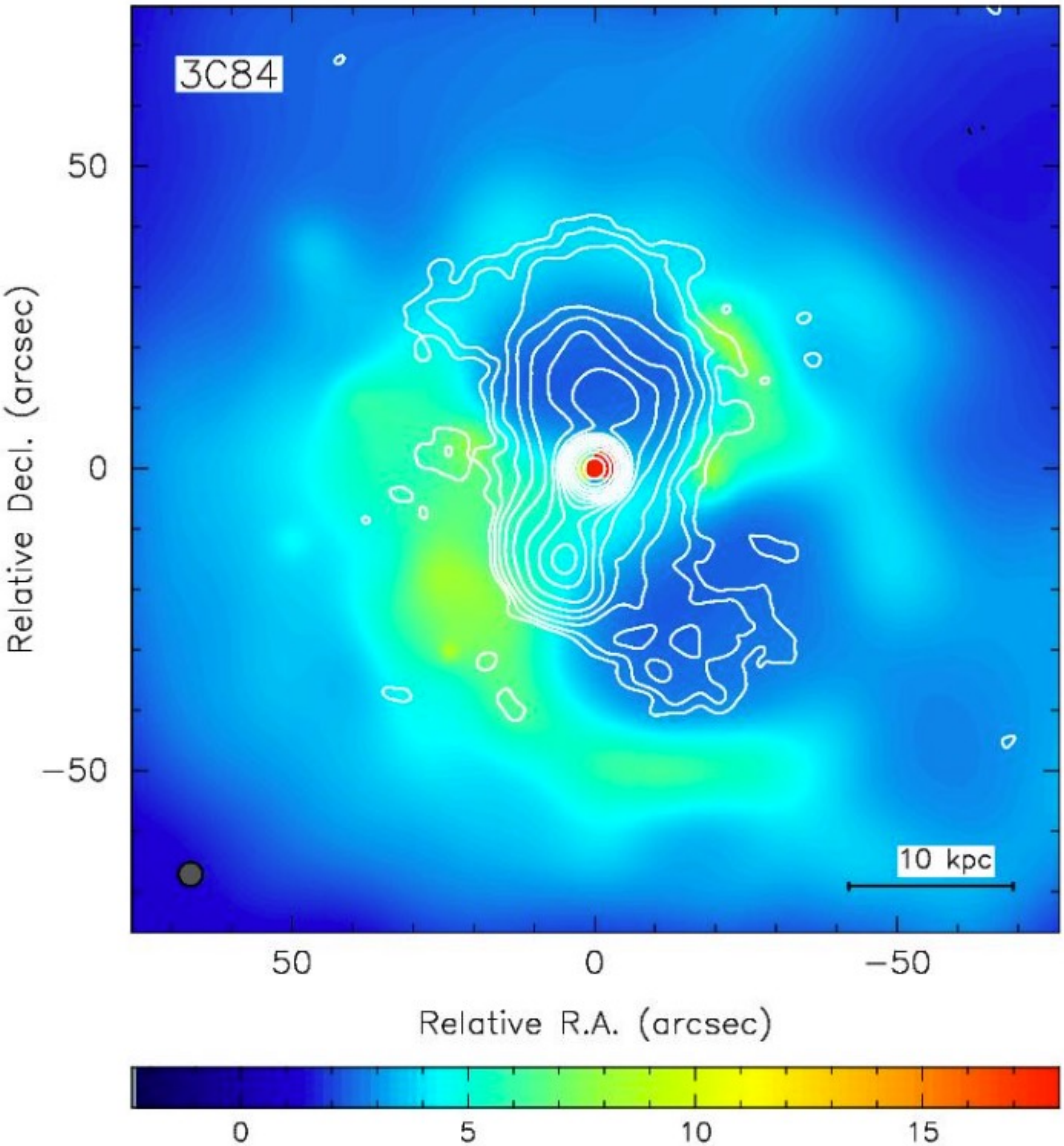
Ferrarese and Merritt (2000)

Correlation between black hole mass and velocity of bulge components. Indicates formation of galaxy is linked to formation of supermassive black hole.



Taylor, Barton & Ge (1994)

Radio + x-rays



Fabian et al. (2000)
X-ray + radio

Cluster AGN Luminosity Problem

1. Given the available fuel the AGN at the center of a cooling core cluster should be bright

• Observations show that it is underluminous by 4 orders of magnitude

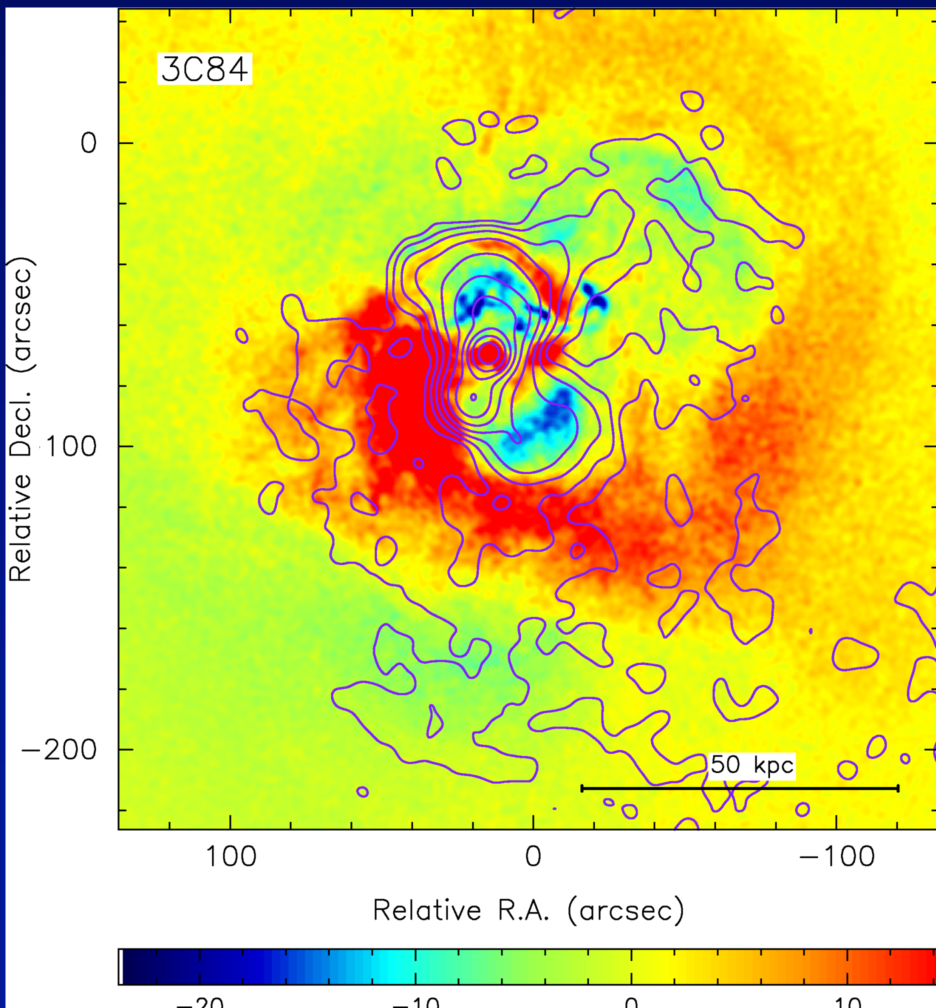
2. Absence of cooling flows suggests re-heating

• Could excess energy from AGN go into heating?

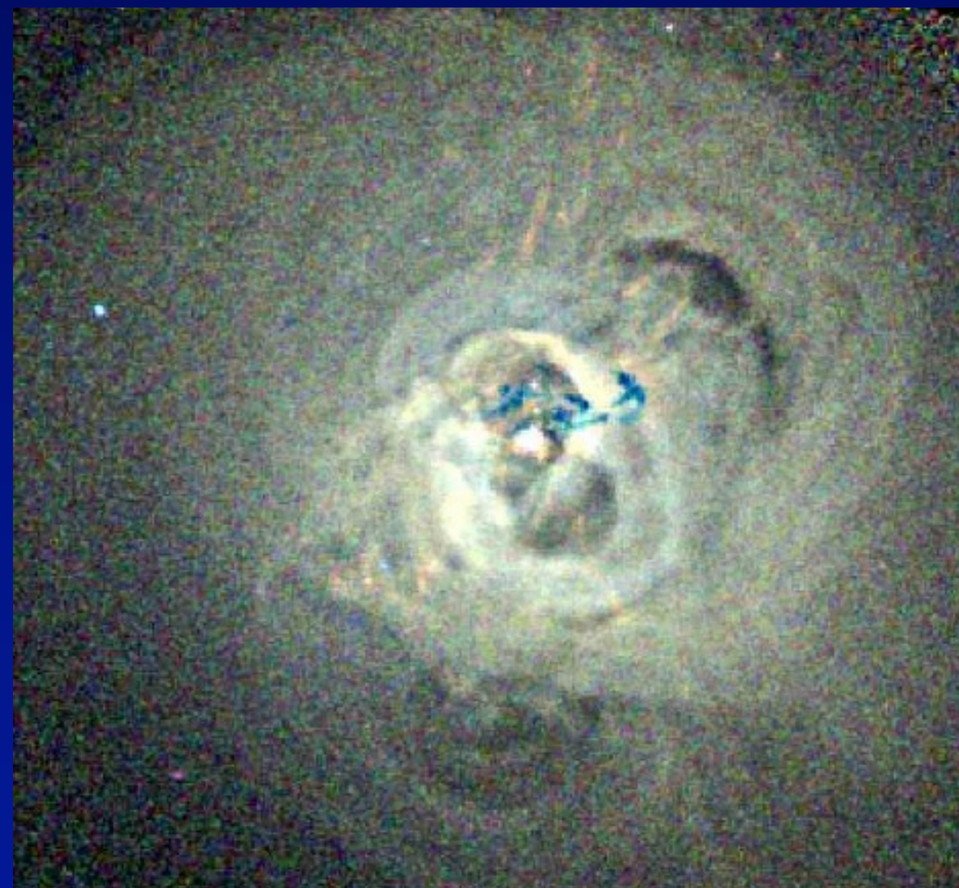
• Heater (1 pc), cluster (10^6 pc)

Fabian et al. 2003, 2005

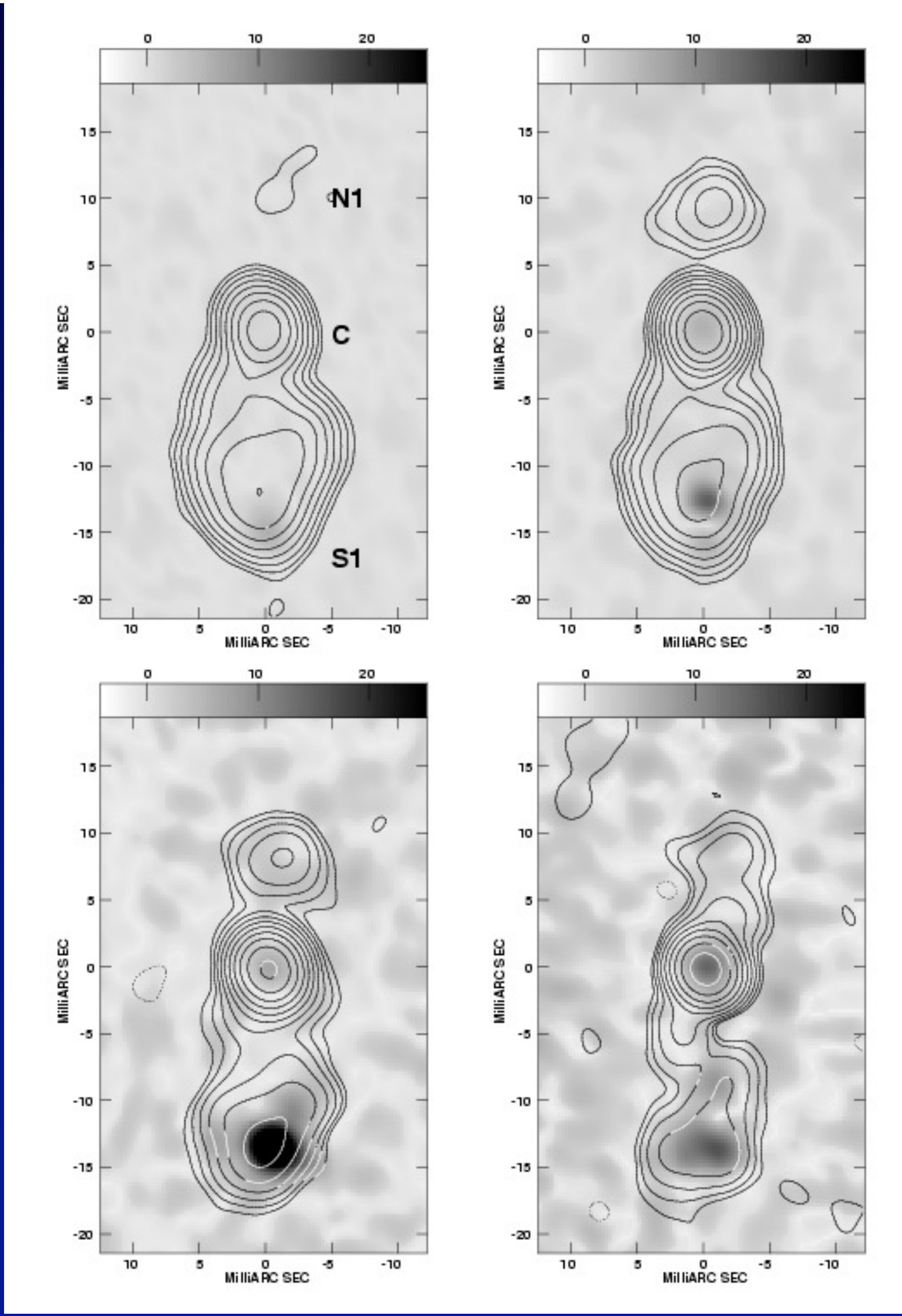
Chandra + VLA



Chandra - unsharp mask



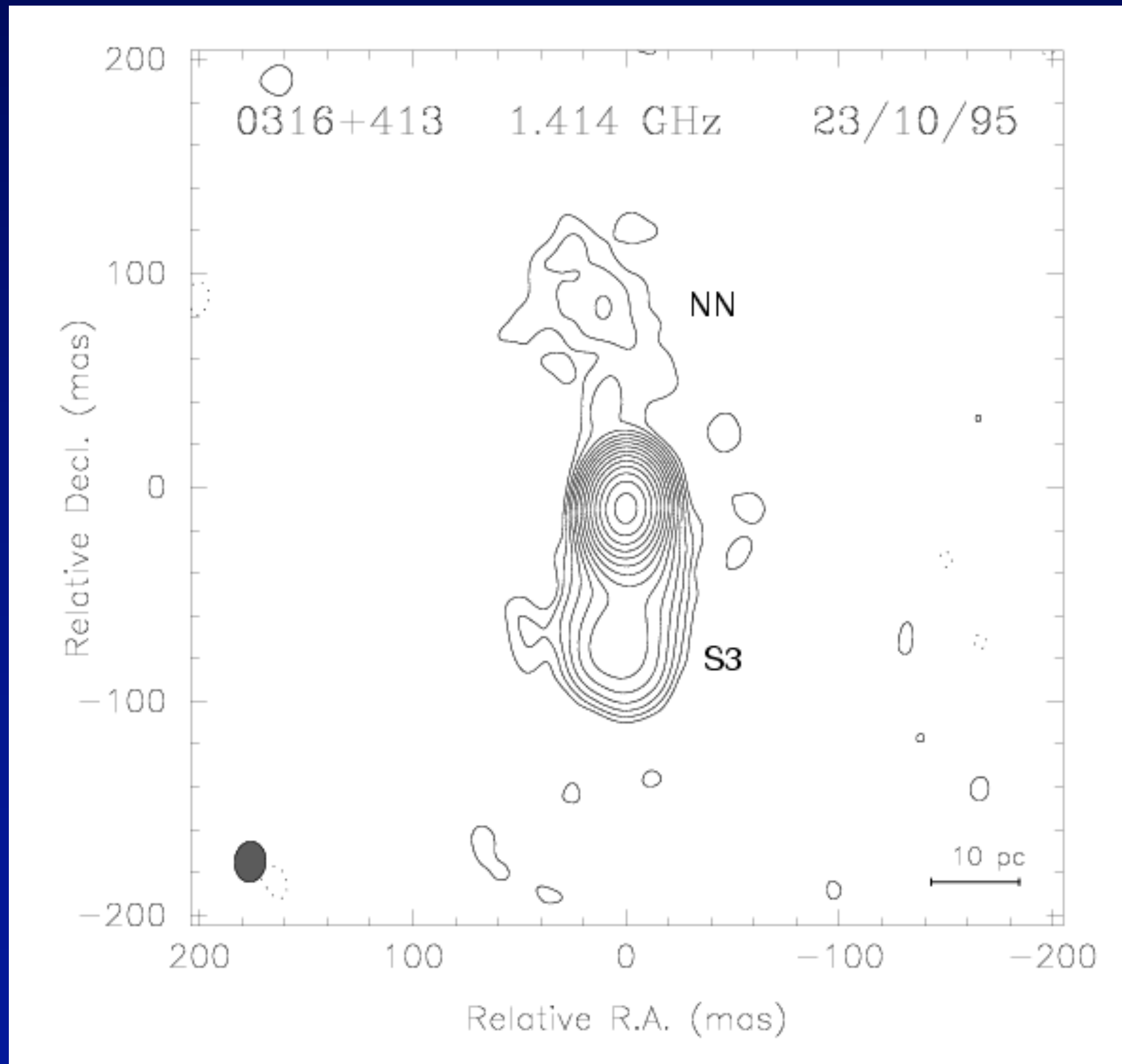
3C84 in Perseus



Detection of Linear Polarization

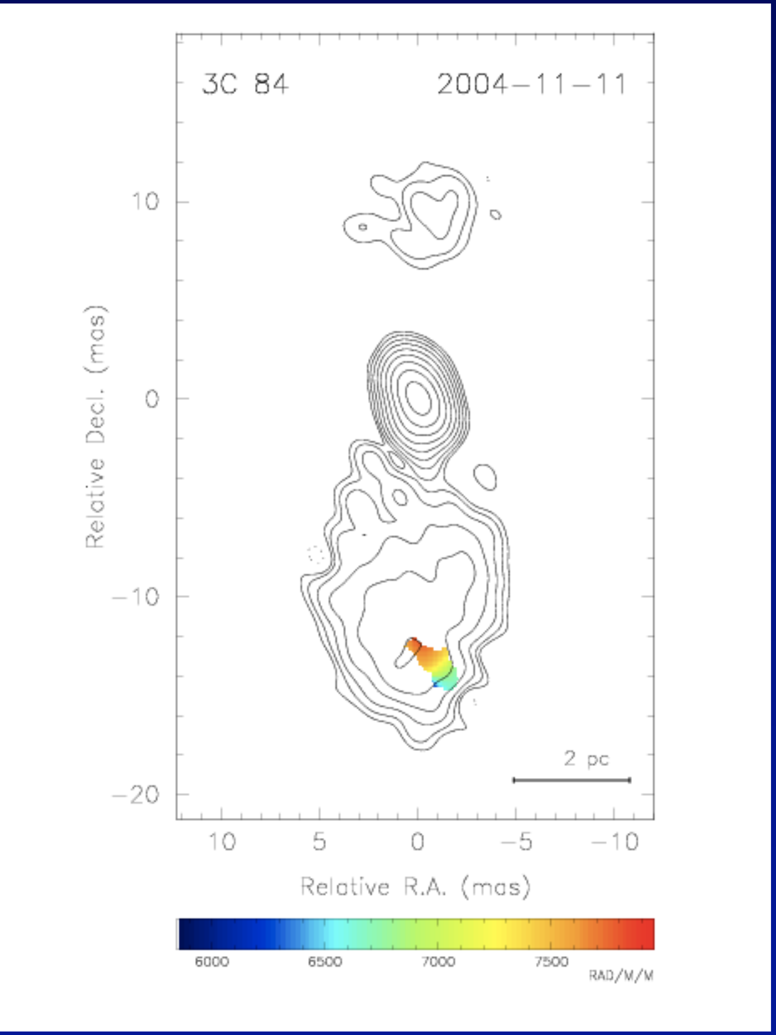
Taylor et al. 2006

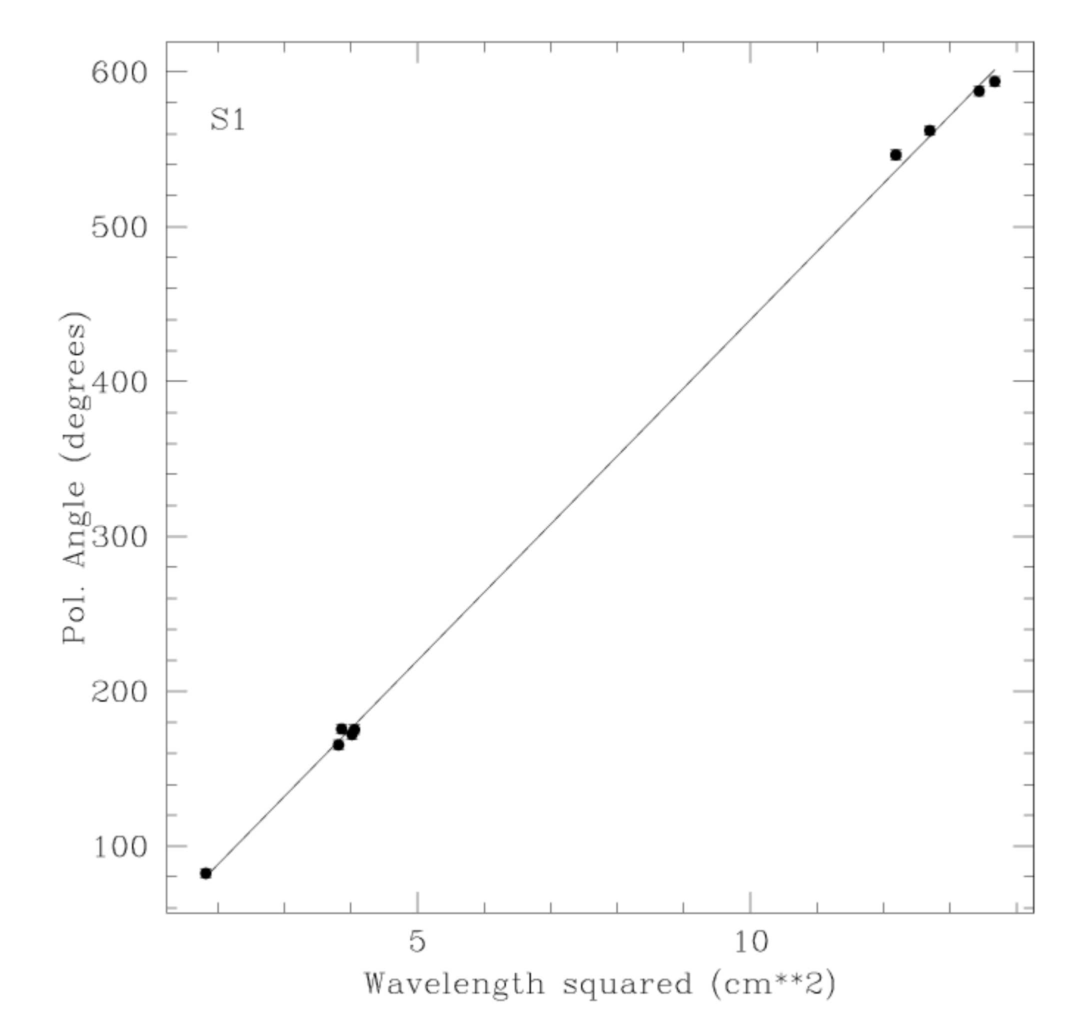
3C 84 at 1.4 GHz



Taylor & Vermeulen 1996

3C84 in Perseus

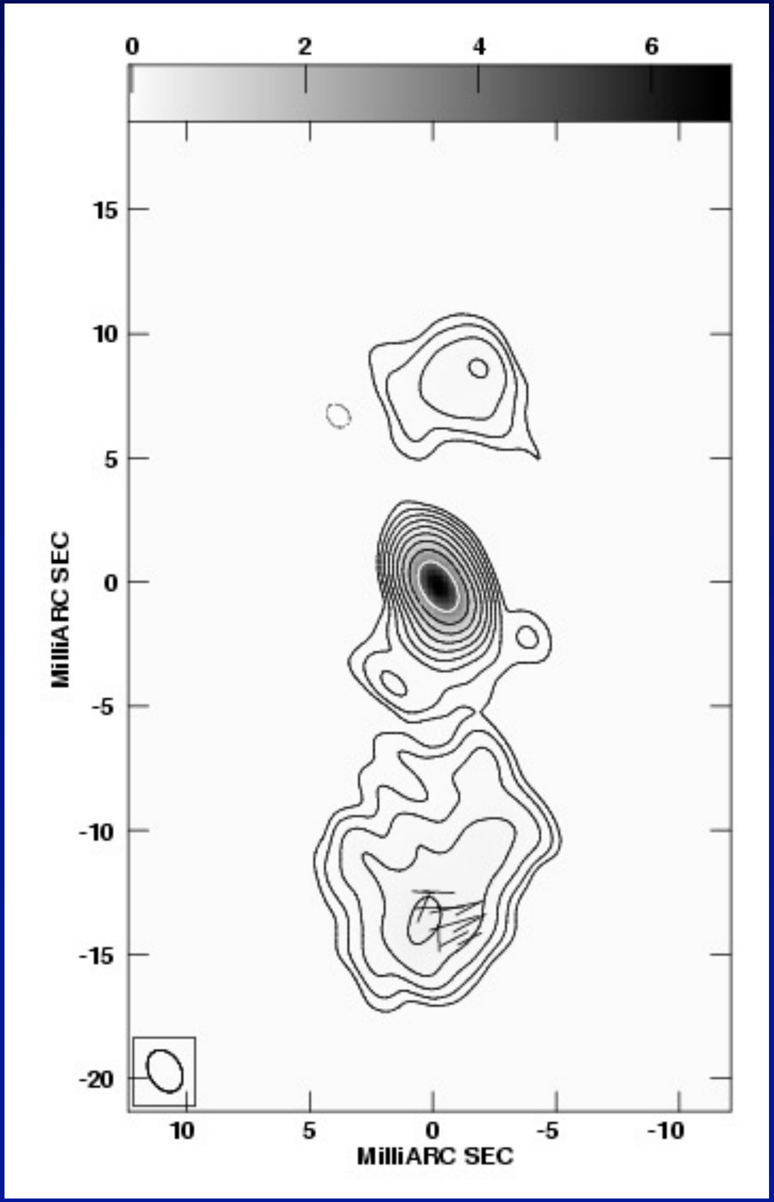




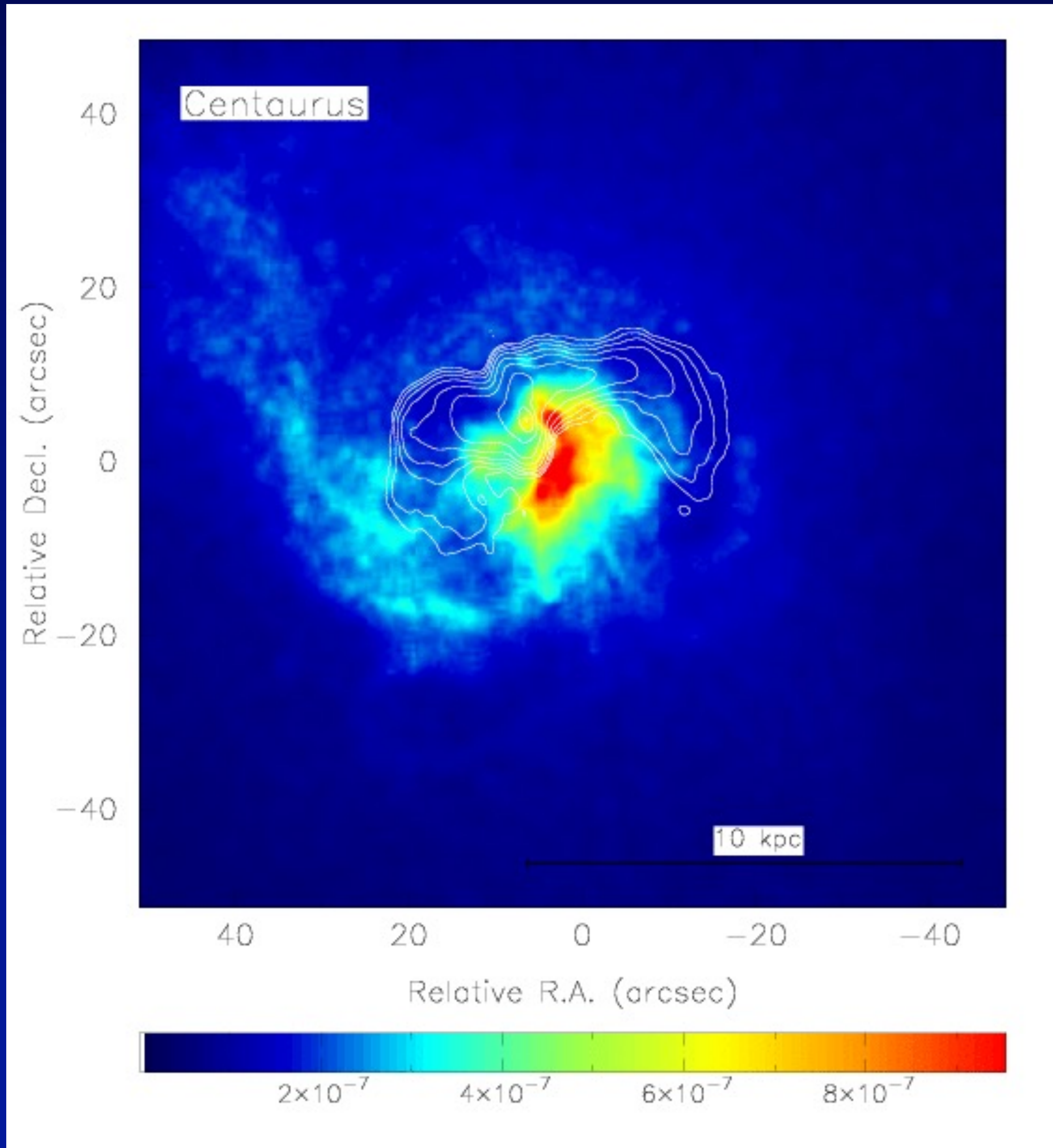
3C84 in Perseus

Summary:

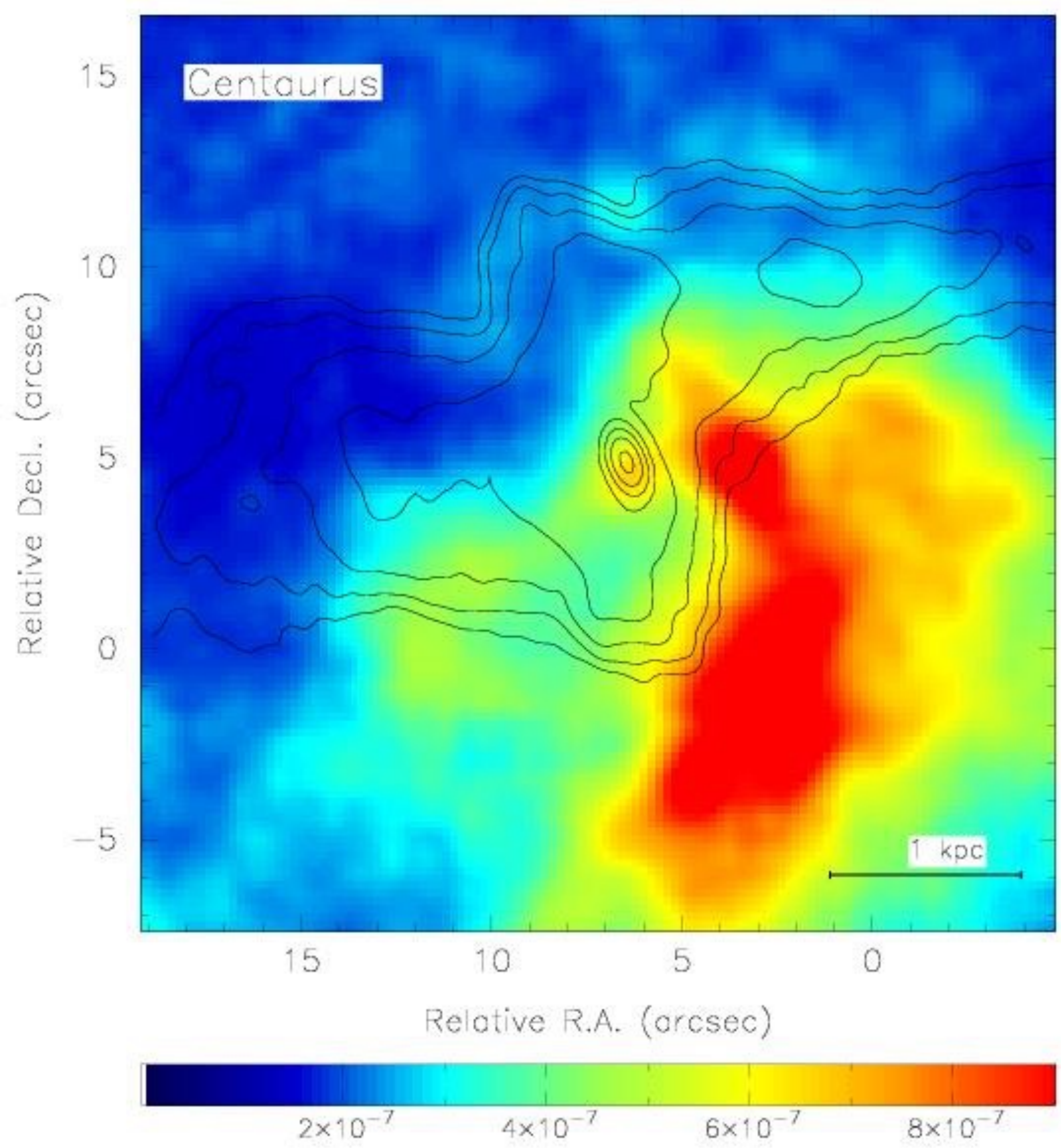
- AGN Feeding is episodic
- Jet components are launched into the intracluster medium (ICM)
- Bubbles drive sound waves
- Bubbles can sweep up ICM



PKS 1246-410 in Centaurus

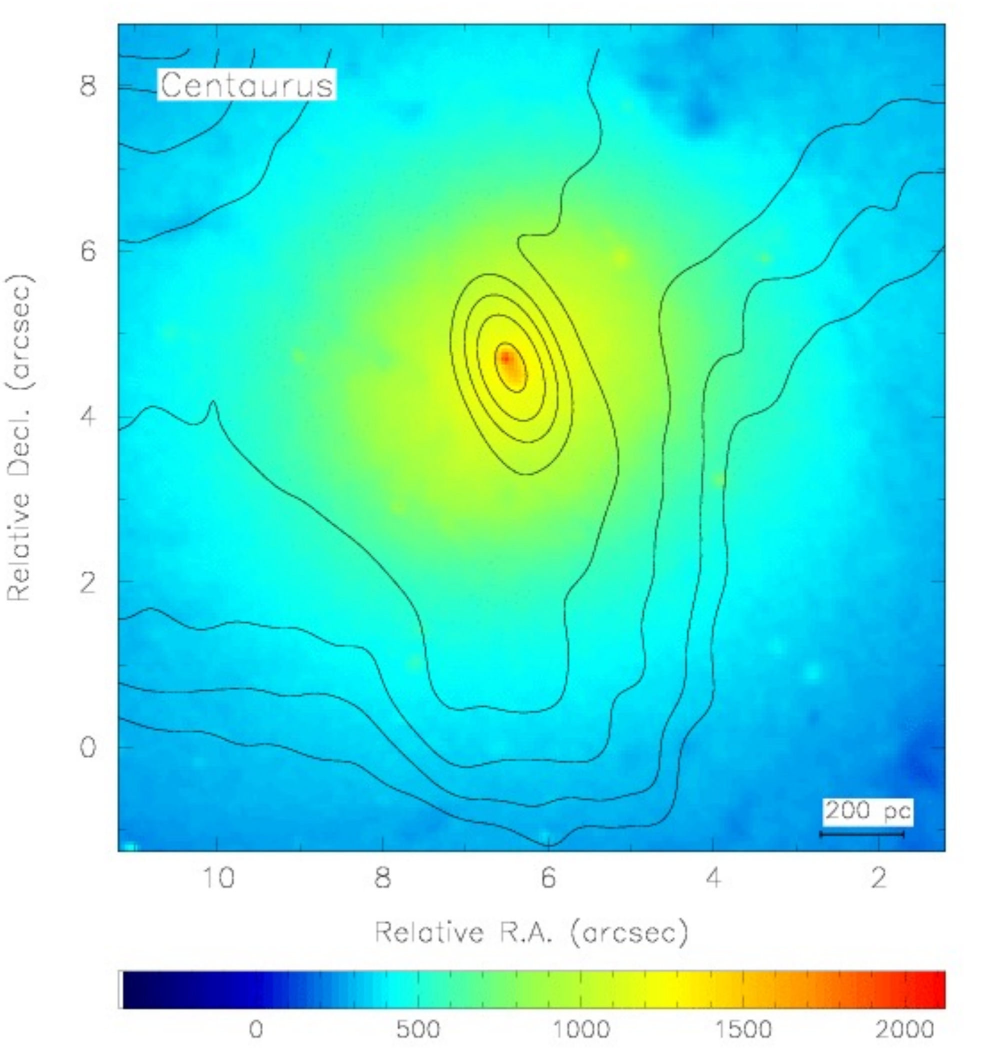


The nucleus of PKS 1246-410

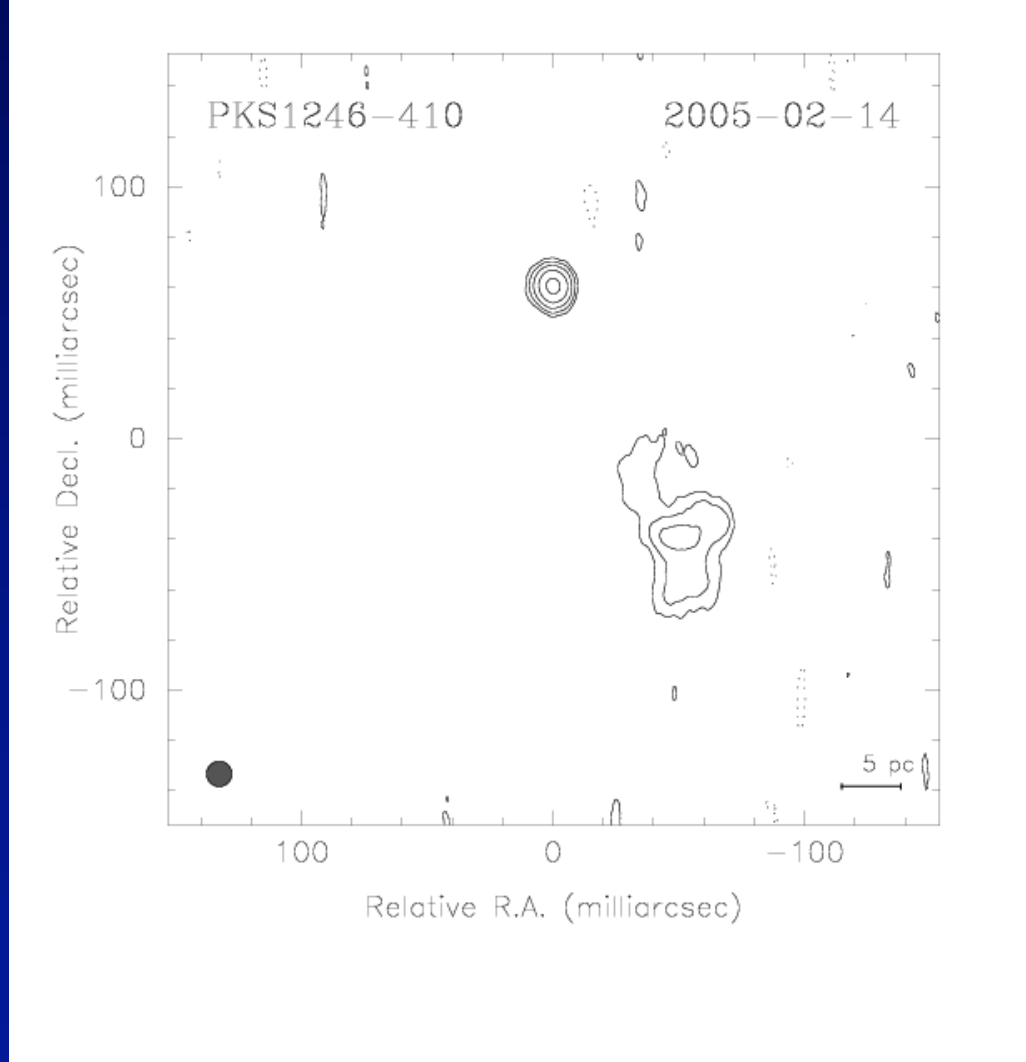


VLA + Chandra

The nucleus of PKS1246-410



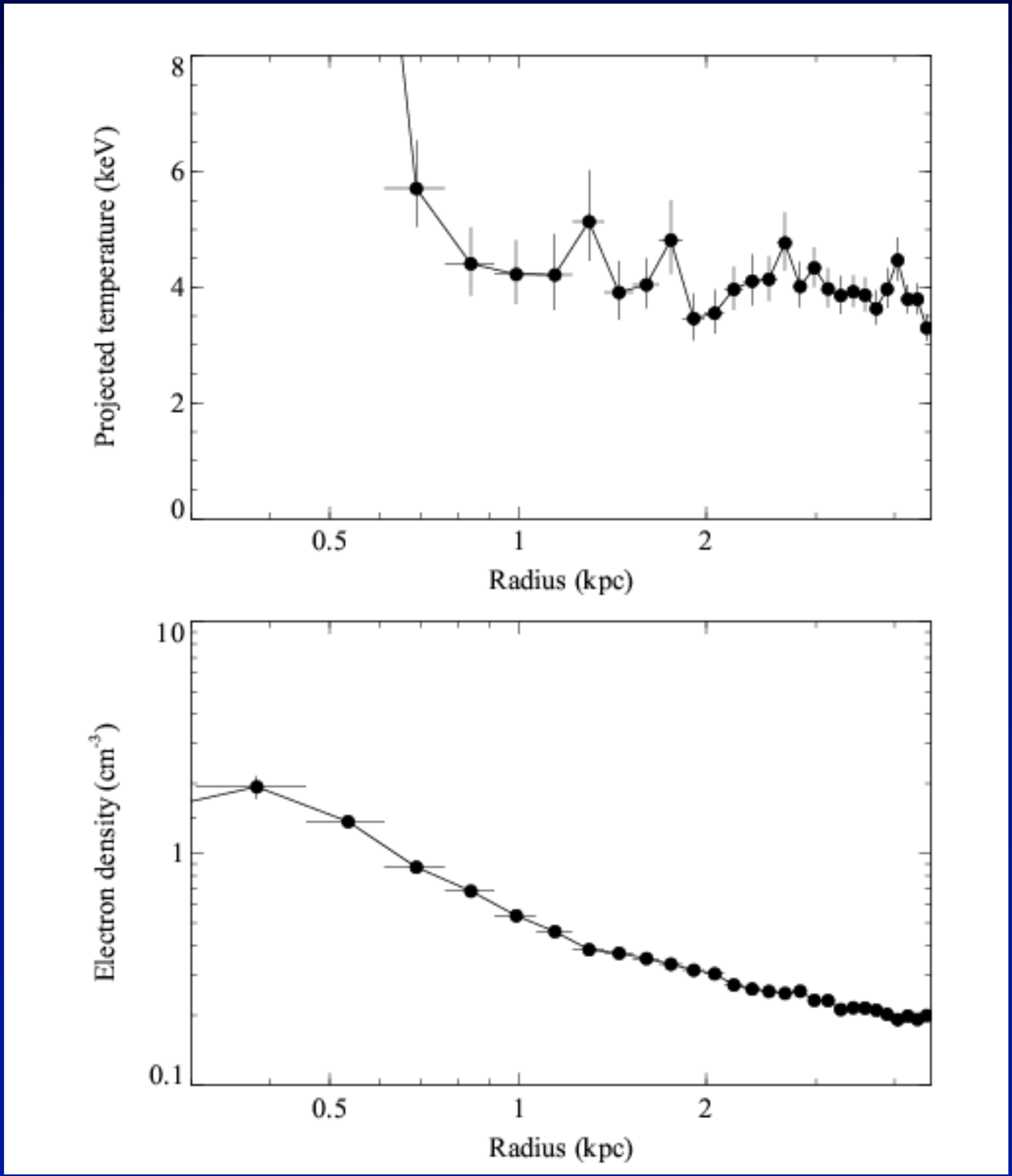
VLA + HST



VLBA at 5 GHz

Temperature profile

Density profile



Bondi Accretion

$R_b = R_{BH}\,(c/c_s)^2$

c_s = sound speed ~ $10^4 T^{1/2}$ cm/s

R_{BH} = Schwarzschild radius ~ $2GM/c^2$

$\dot{M} = 4\pi R_b^{\,2} \rho c_s$

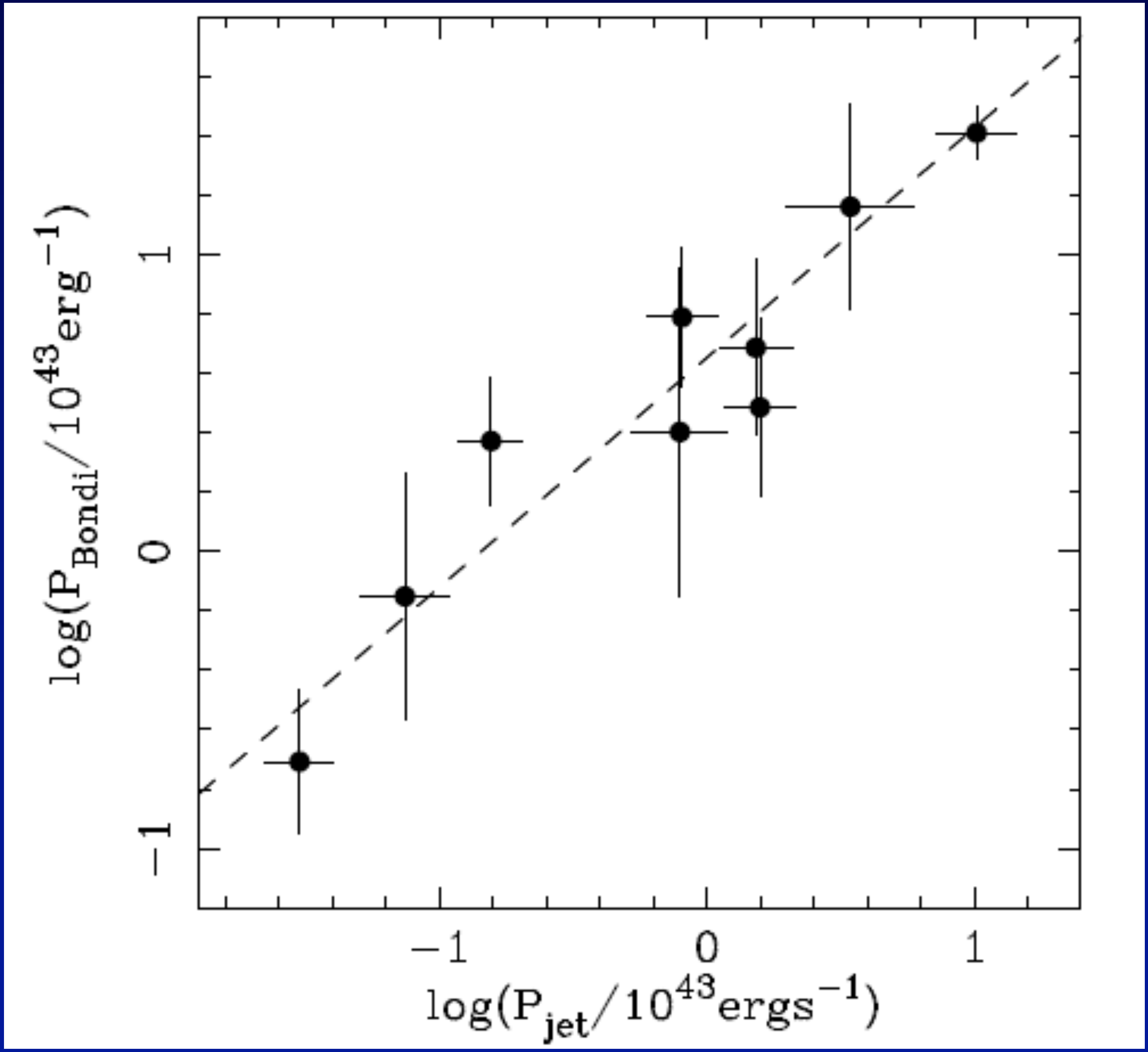
ρ is the density

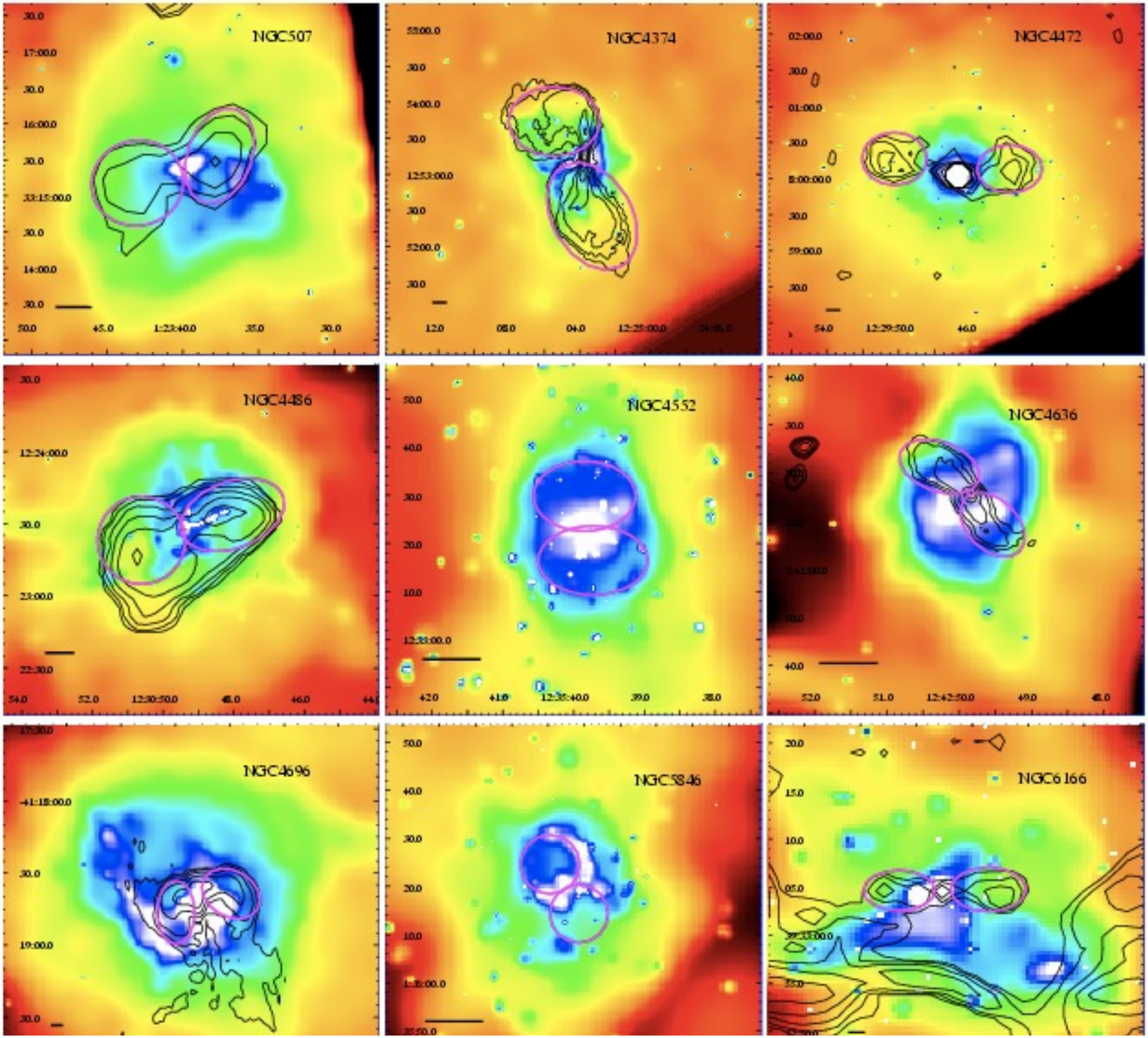
$= 0.013\ M_{sun}$/yr for PKS 1246-410

$L_b = 0.1\,\dot{M}\,c^2$

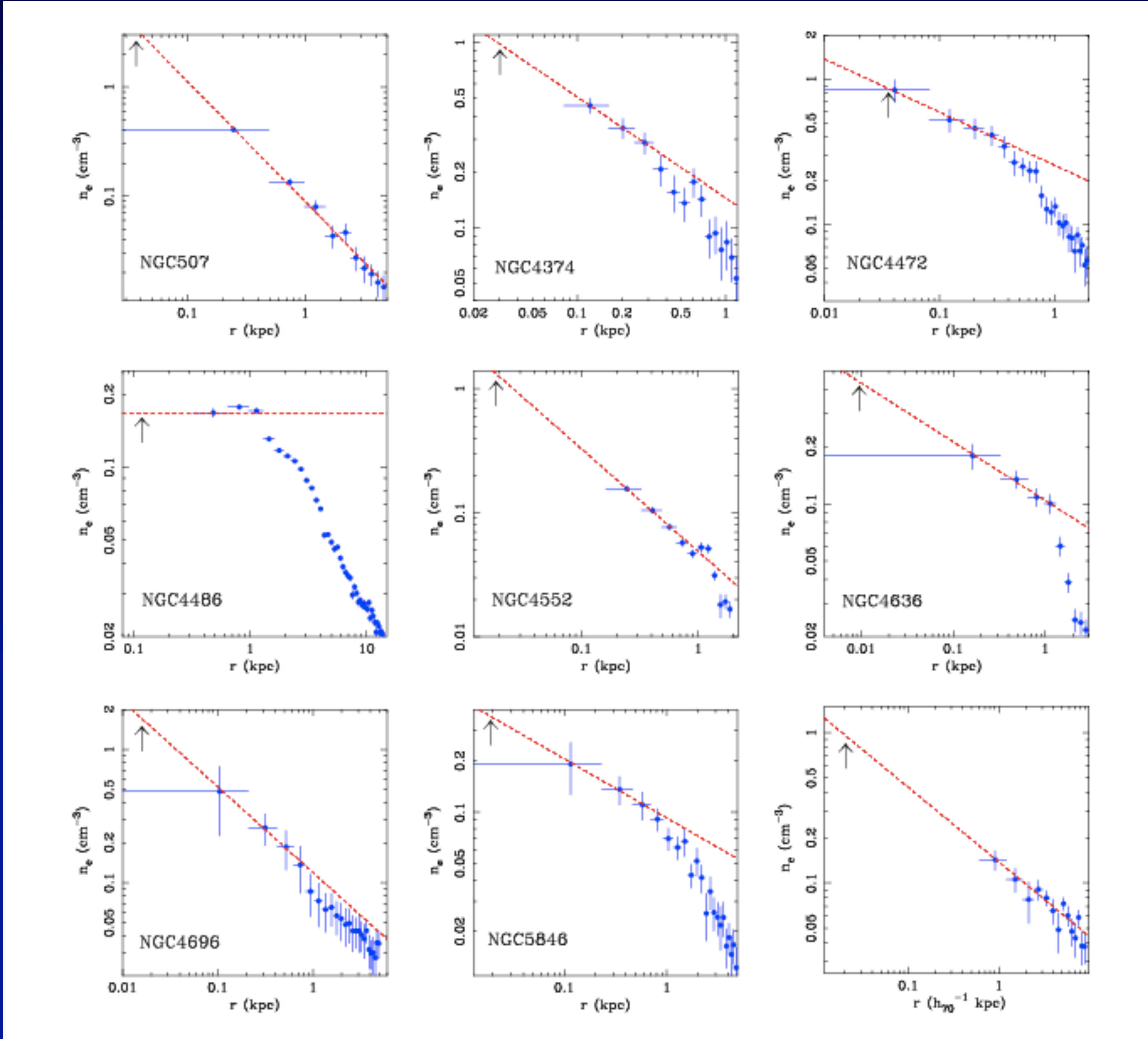
$= 8 \times 10^{43}$ erg/s >> $L_{X\text{-}rays} = 4 \times 10^{39}$ erg/s

Allen et al
2006

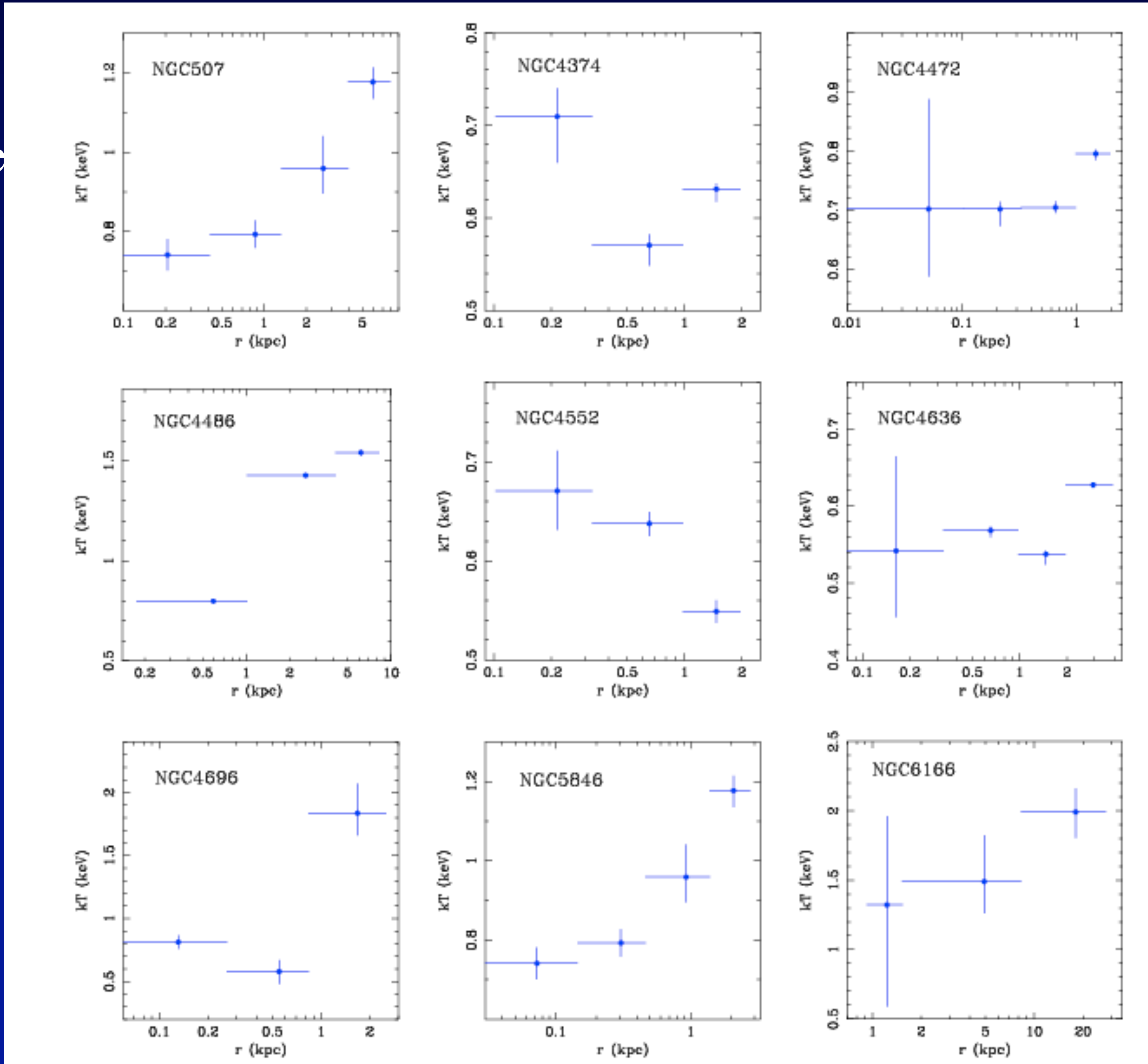



NGC507
NGC4374
NGC4472
NGC4486
NGC4552
NGC4636
NGC4696
NGC5846
NGC6166

Density profiles



Temperature profiles



Journal Class

- **Observational Evidence of AGN Feedback**
- Fabian 2012

Discussion leader: **Sarah Stamer**

Note: To encourage discussion everybody must pose at least one question during the group discussion

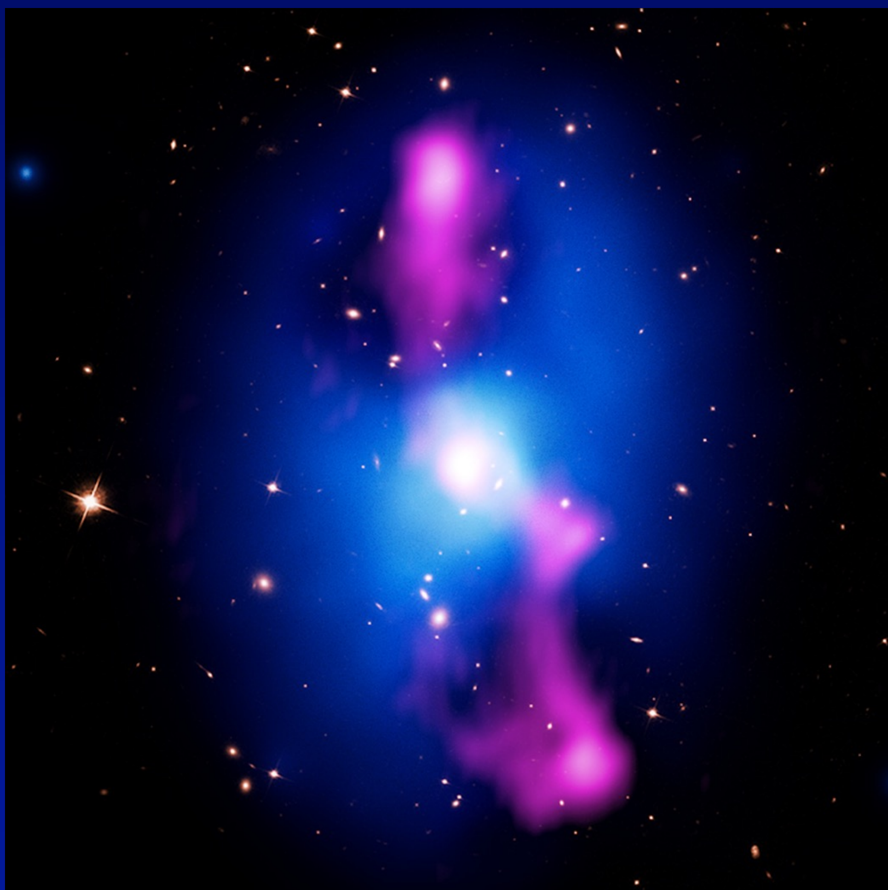
Journal Class

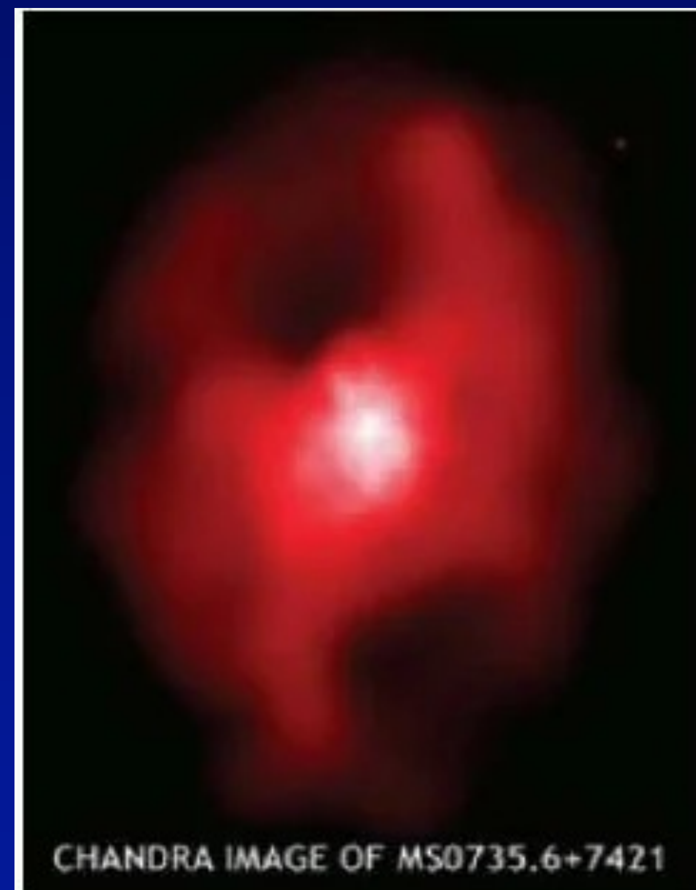
- **The Bullet cluster at its best: weighing stars, gas, and dark matter**
- Paraficz et al. 2016

Discussion leader: **Izabela Pavel**

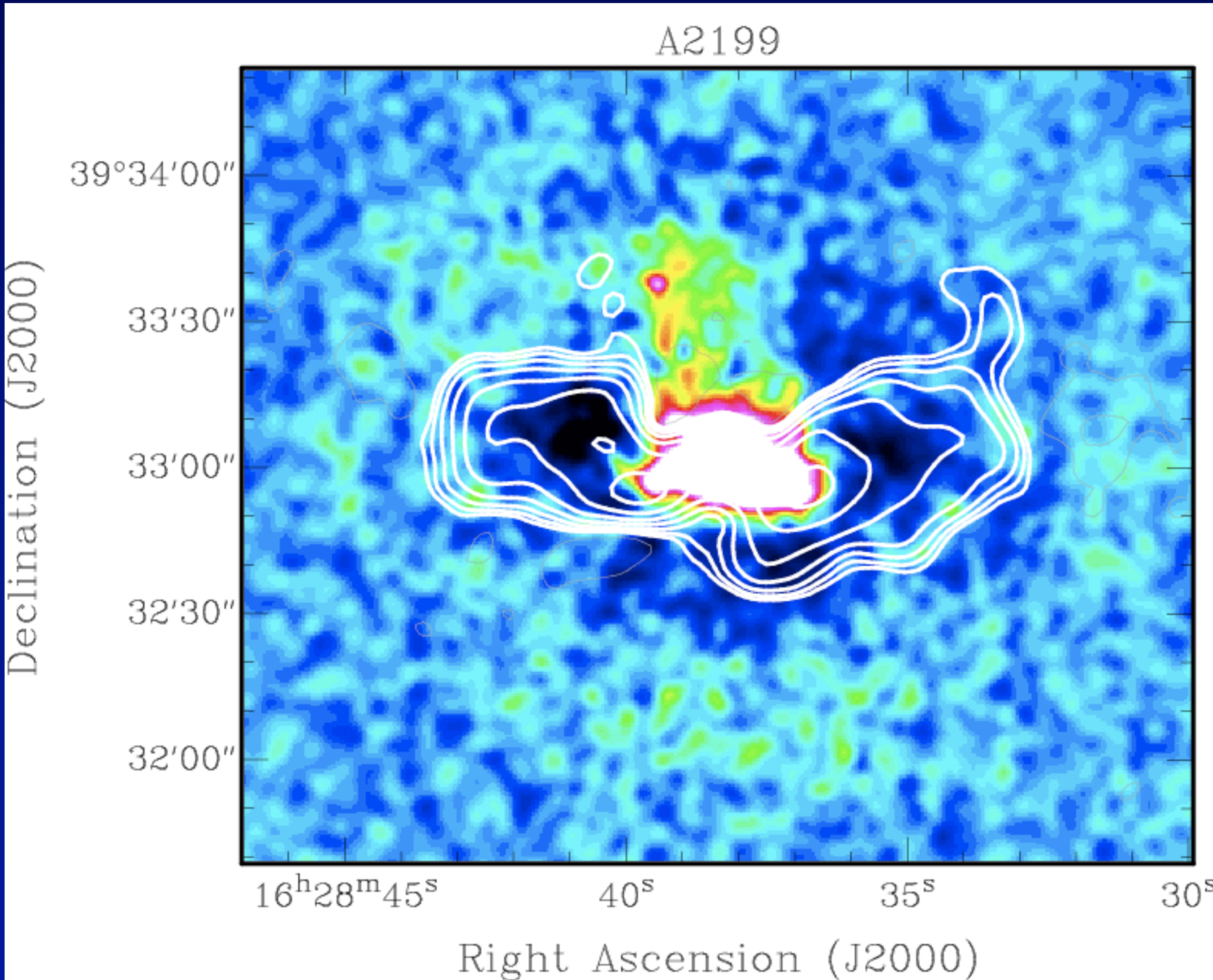
Note: To encourage discussion everybody must pose at least one question during the group discussion

MS0735.6+7421 Galaxy Cluster





Outer lobes of A2199



Sanders & Fabian 2006

Gentile et al. in prep

Implications

- Bondi formalism provides a reasonable description despite the presence of magnetic fields and angular momentum
- Accretion flows must be stable over the bubble inflation times of a 1-100 million years
- Efficiencies required are ~10%
- Feedback from the central black holes may be important for shaping the bright end of the galaxy luminosity function (limiting accretion)

SUMMARY

- Radio Galaxies are viable heaters for clusters
- Future work
  - Obtain more Chandra observations of nearby clusters (and Es) to test the relation between jet power and accretion efficiency
  - Use the Long Wavelength Array (LWA) to look for radio emission in "ghost" bubbles
  - Use the LWA to identify 1000s of clusters from their low frequency halos