The Evolution of Extragalactic Radio Sources

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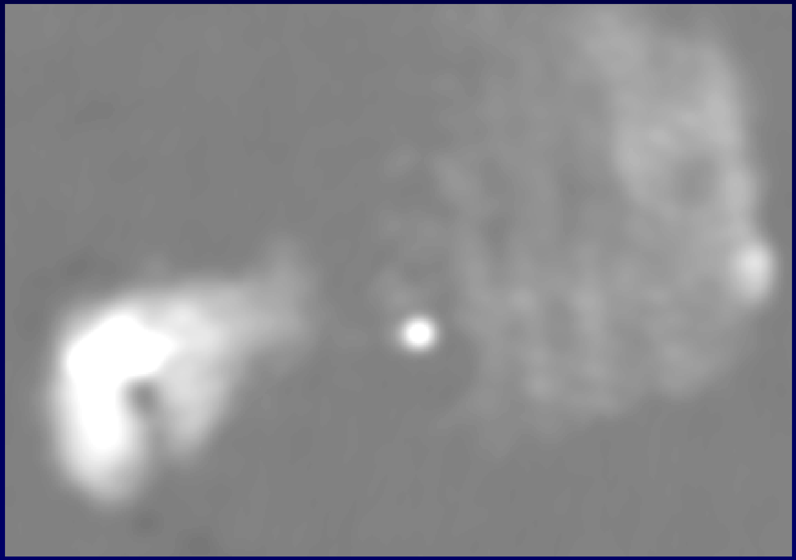
Challenges of Relativistic Jets, Cracow, June 29, 2006

Evolution

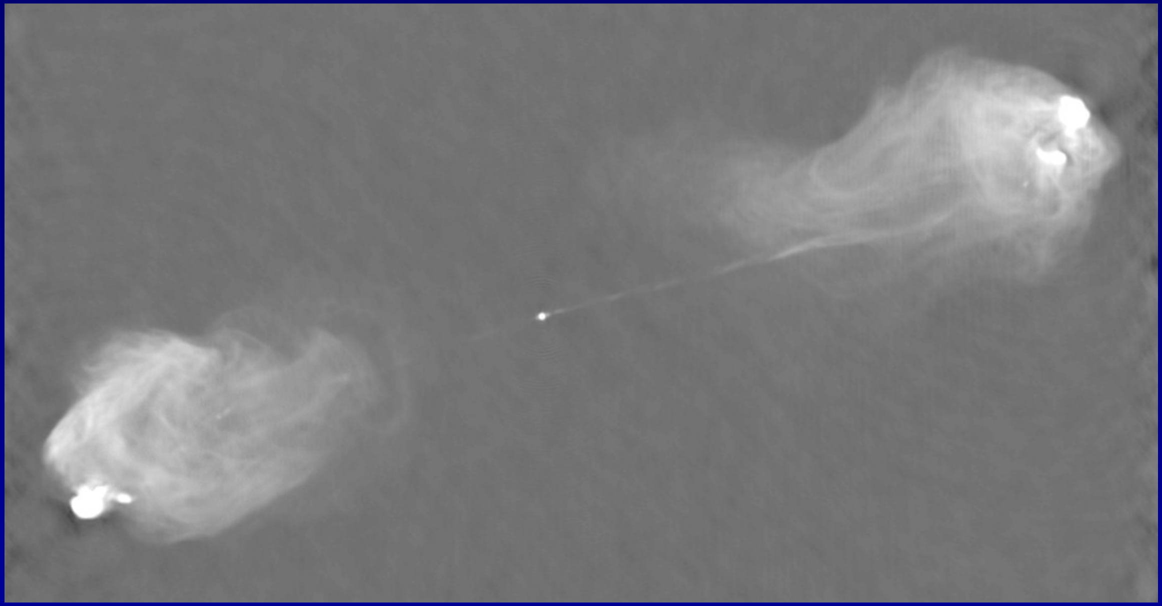
4C31.04



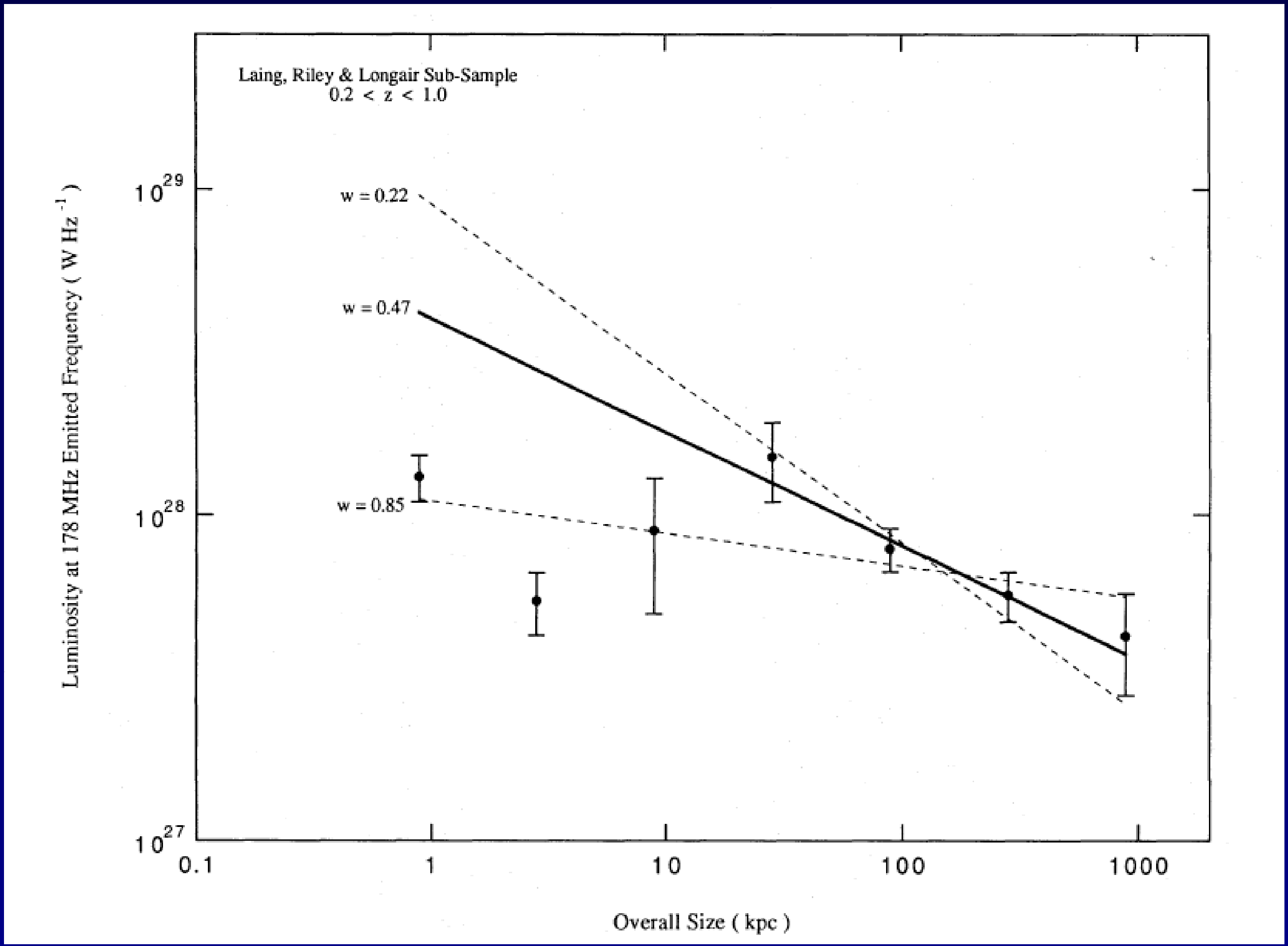
100 pc

↓ ?

Cygnus A



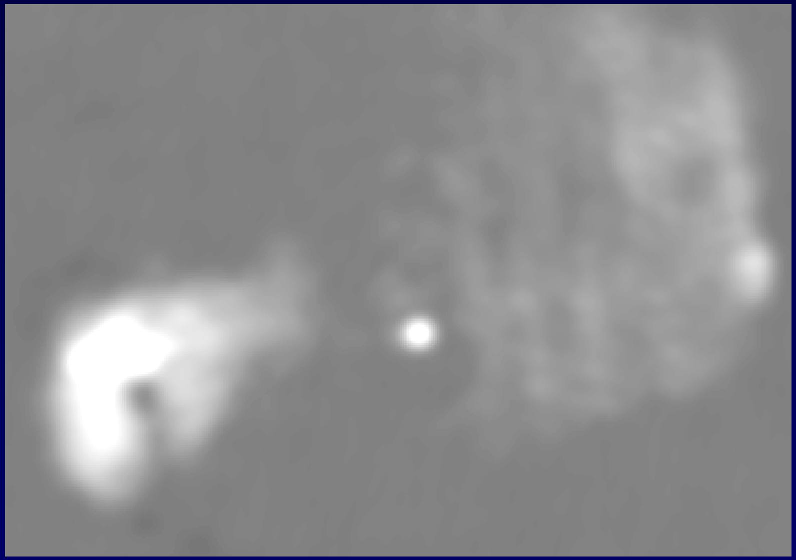
100 kpc



Readhead et al. 1996

Evolution

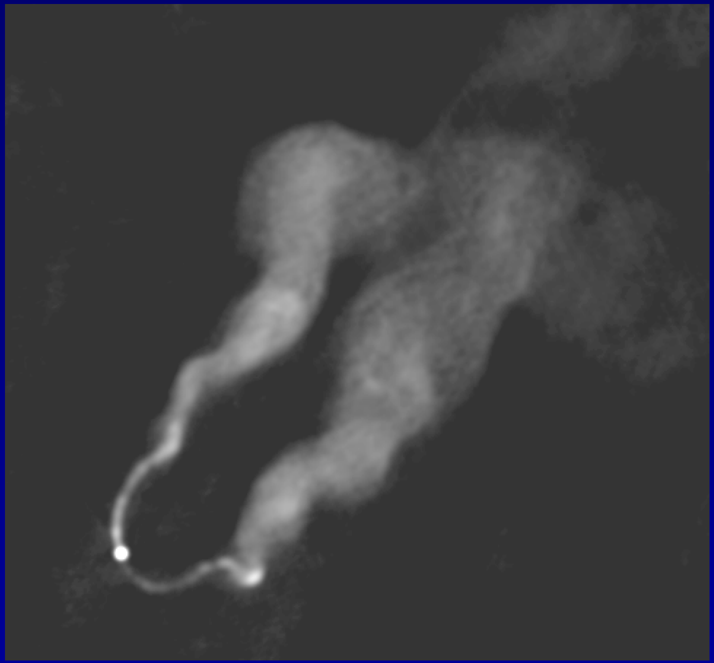
4C31.04



100 pc

↓ ?

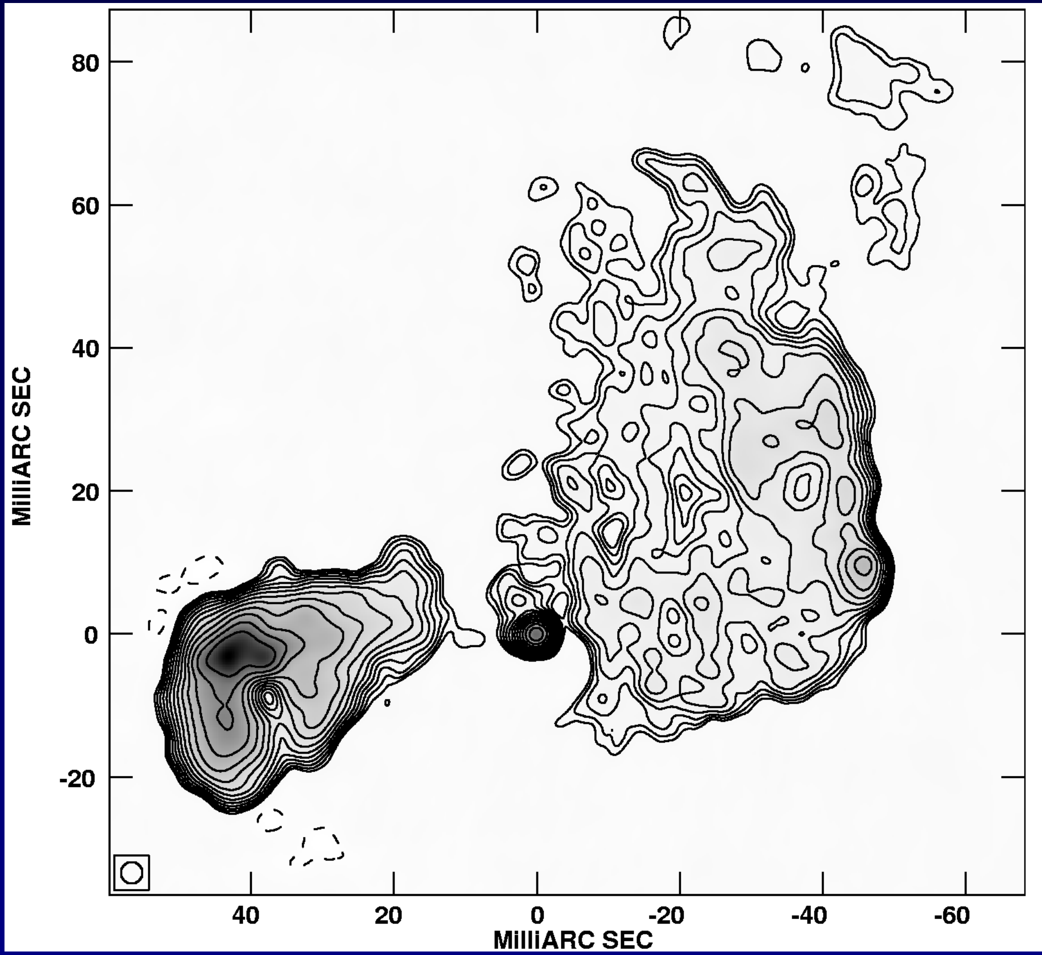
3C129



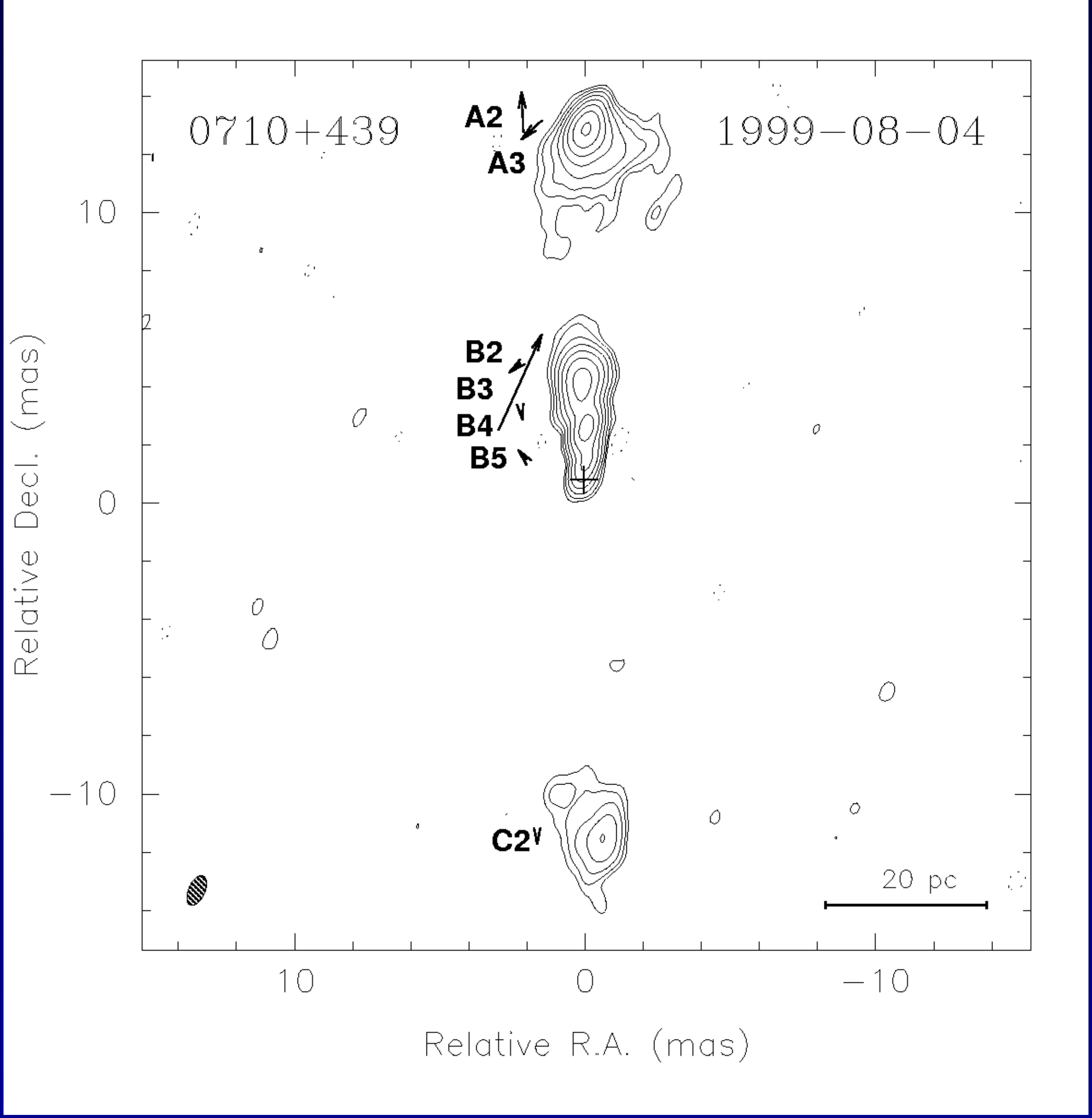
100 kpc

CSO Properties

- size < 1 kpc
- symmetric emission
- hot spots not strongly boosted
- weakly polarized (< 0.1 %)
- usually identified with galaxies
- often (not always) have a GHz Peaked Spectrum (GPS)
- moderately high luminosity $P_{5GHz} = 10^{25}$ W Hz^{-1}
- often have 'S' symmetry
- young (ages ~ 1000 y)
- Elliptical host galaxy



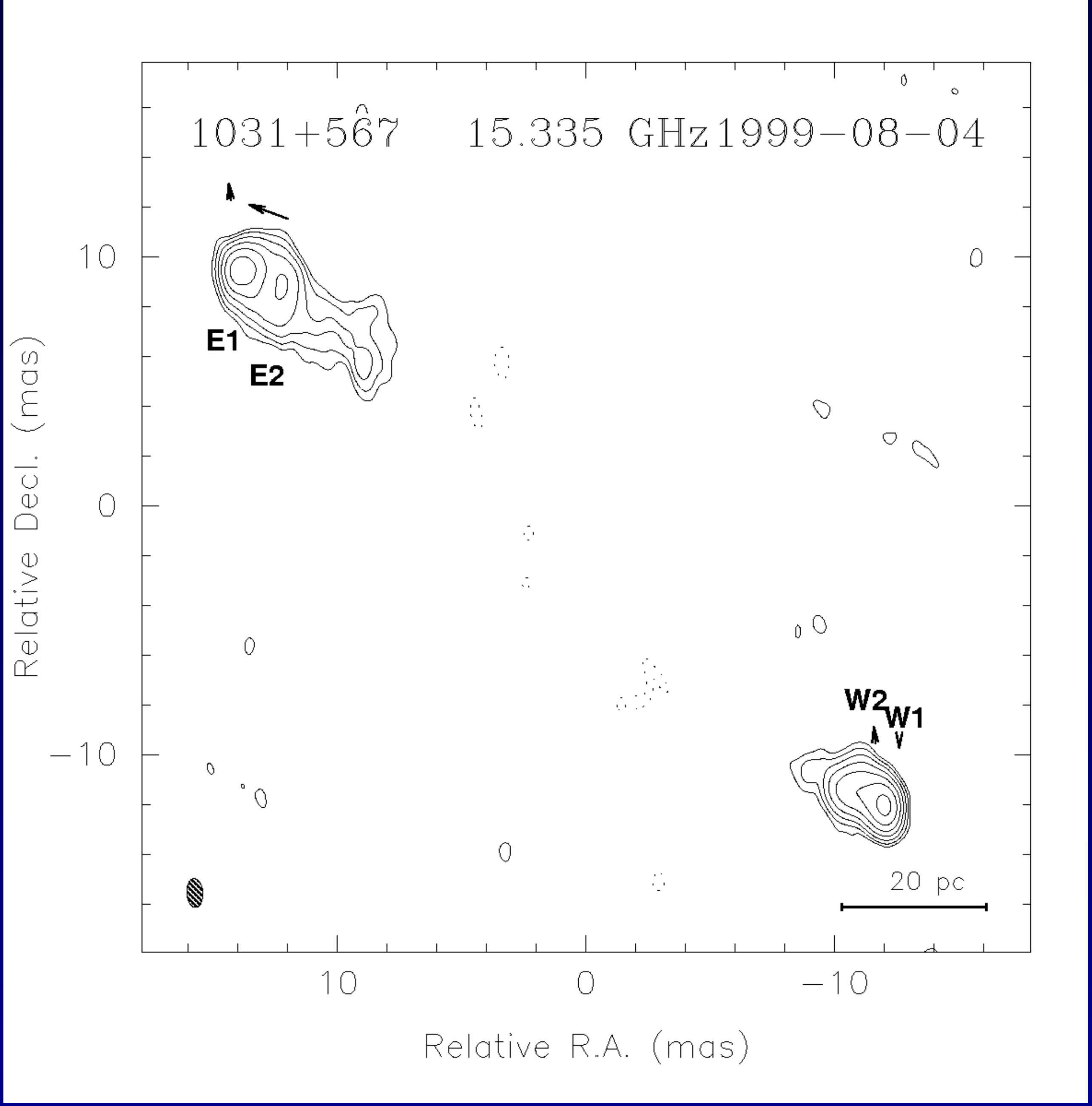
Giroletti et al 2002



Hot Spot Advance speeds:
0.35 c
kinematic age: 550 y

Jet Velocities:
up to 2 c

Owsianik & Conway 1998
Taylor et al. 2000



Hot Spot Advance speeds: 0.41 c

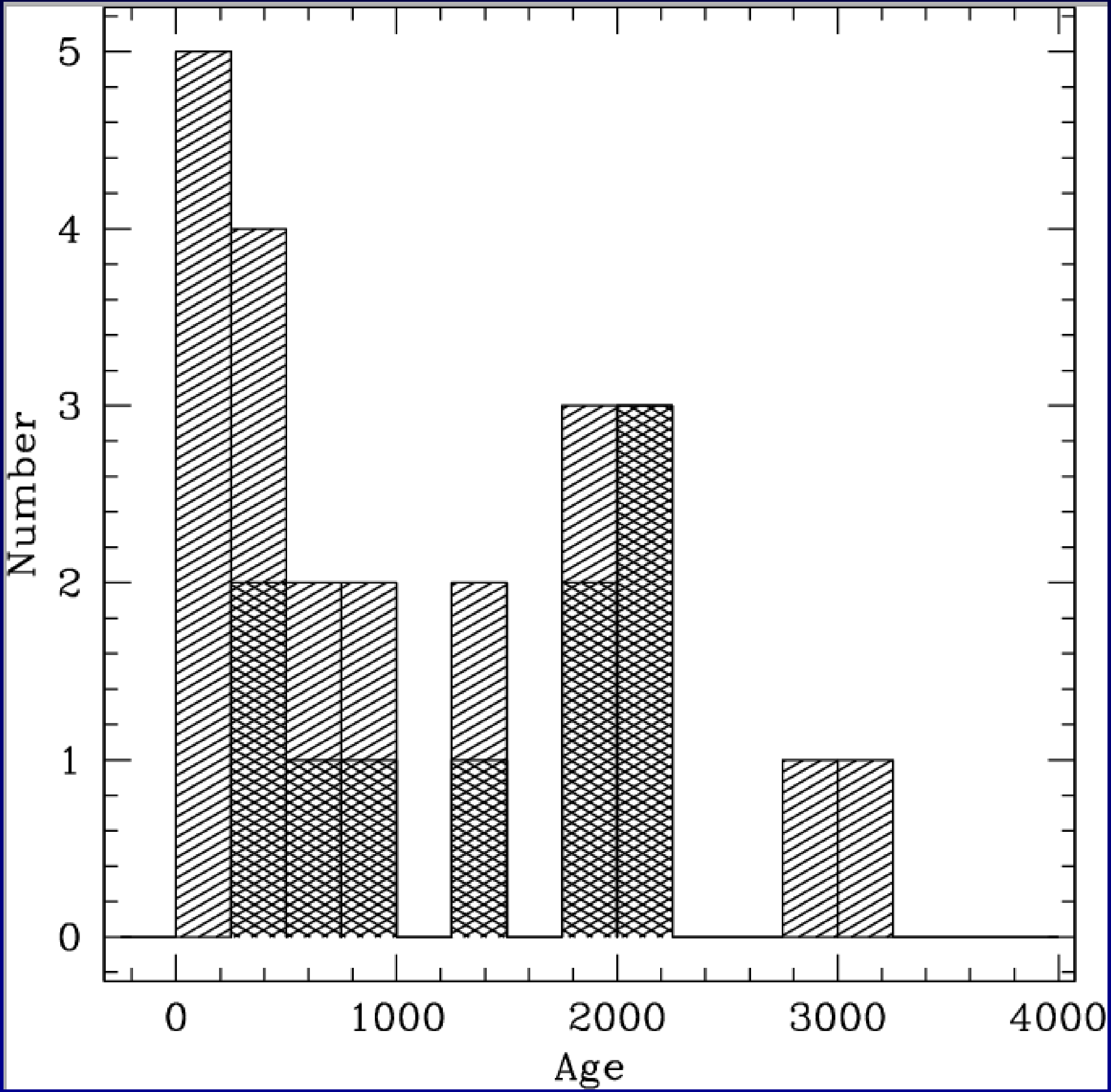
kinematic age: 620 y

Taylor et al. 2000

CSO Ages

Gugliucci et al. 2005

9/23 sources have ages < 500 years



Too many small (young) sources

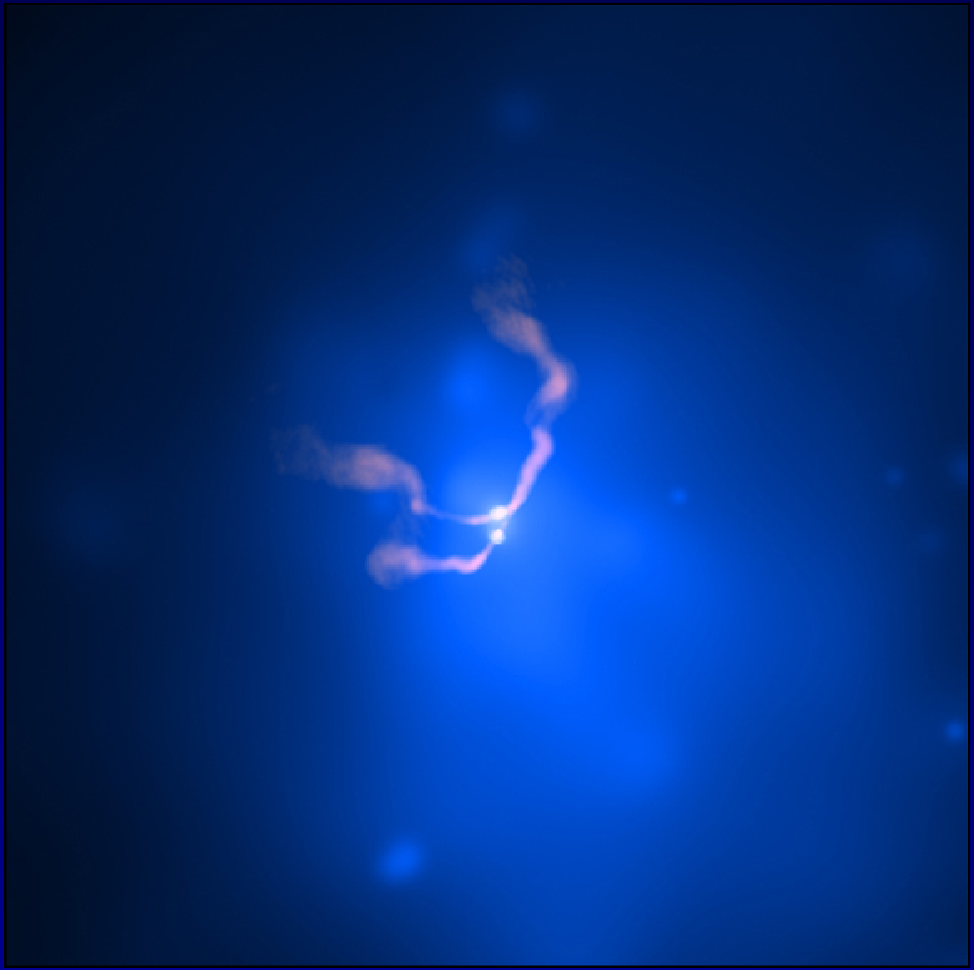
Solutions:
- Confinement
- Many die out (see also poster by Machalski et al.)

Black Hole Mergers (see Merritt & Milosavljević 2005):

1. Galaxies merge. Dynamical friction. Binary system

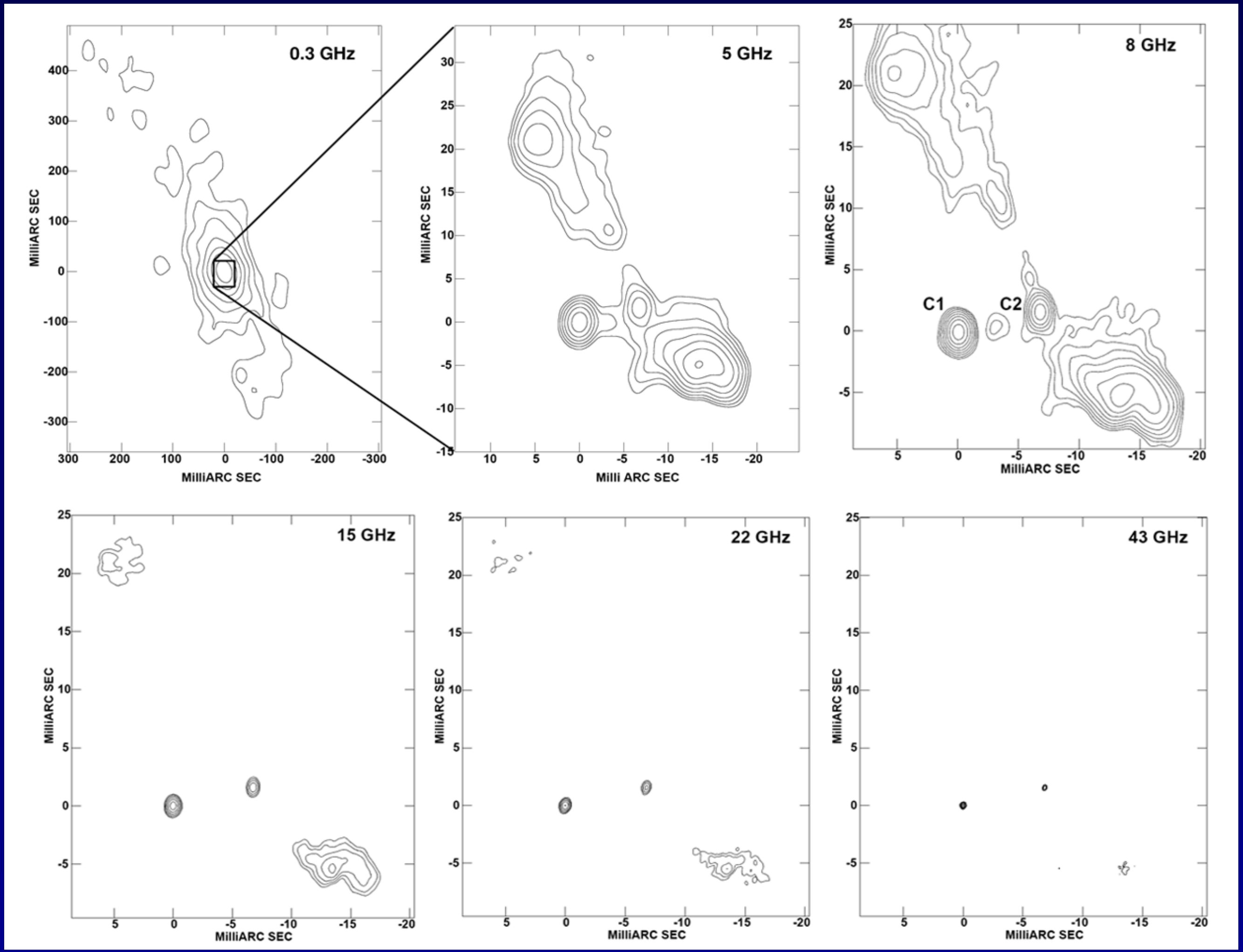
2. Binary continues to decay

3. Gravitational waves become efficient. Supermassive black holes coalesce



X-ray/radio composite image showing the merging of two black holes in Abell 400.

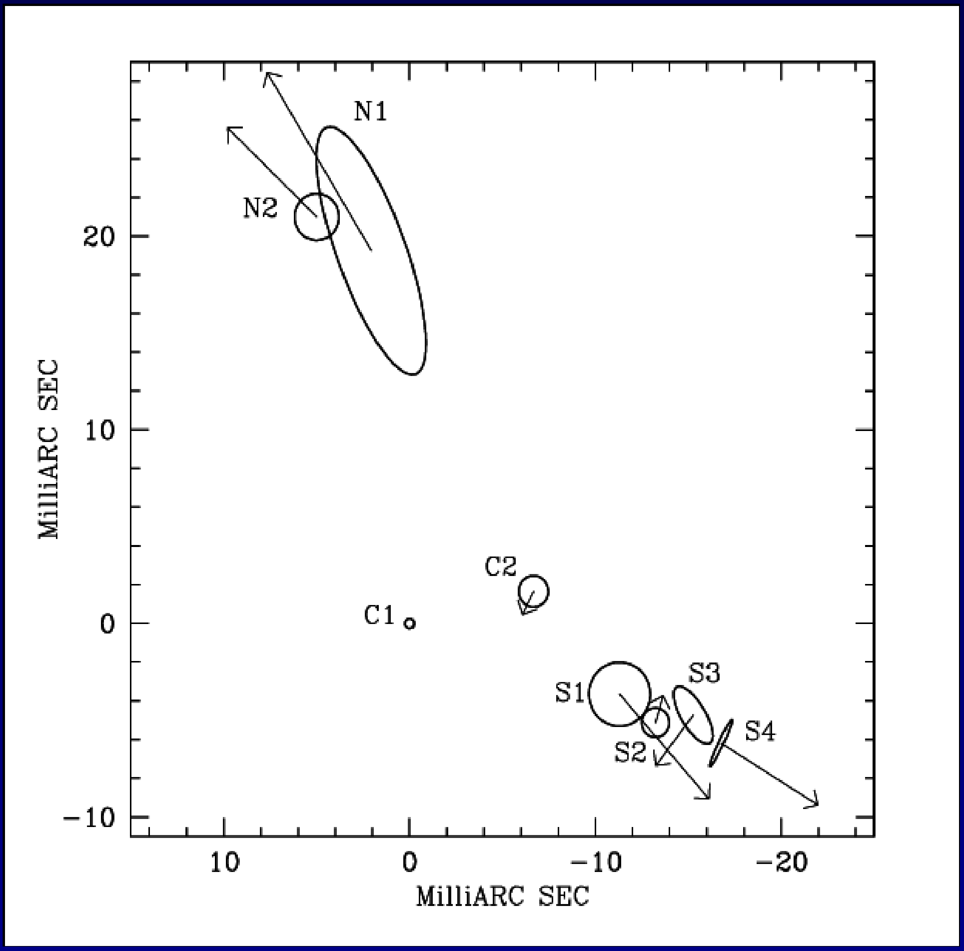
0402+379, a compact Supermassive Binary Black Hole



VLBA - Rodriguez, Taylor et al. 2006

- C1: 0.183 ± 0.048 pc
- C2: 0.124 ± 0.035 pc
- Separation between C1 and C2 equal to 7.3 pc

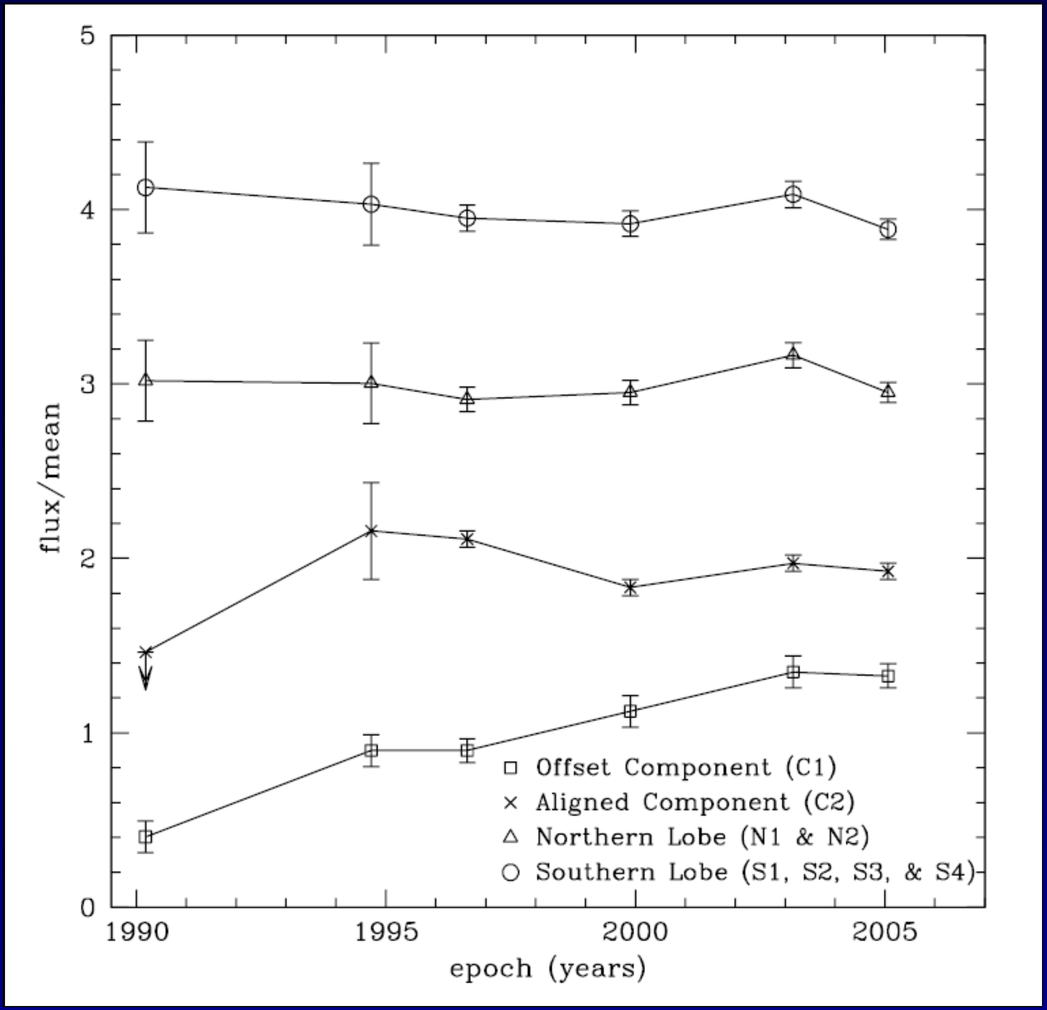
Motions



Model components

- Northern jet is moving away from the two central components to the northeast,
  - N1: (0.185 ± 0.008)c
  - N2: (0.114 ± 0.019)c
- Southern jet is moving away to the southwest, though more slowly,
  - S2: (0.0251 ± 0.0085)c
  - S3: (0.056 ± 0.010)c
- The results obtained for C2 show no significant motion (v < 0.088c)

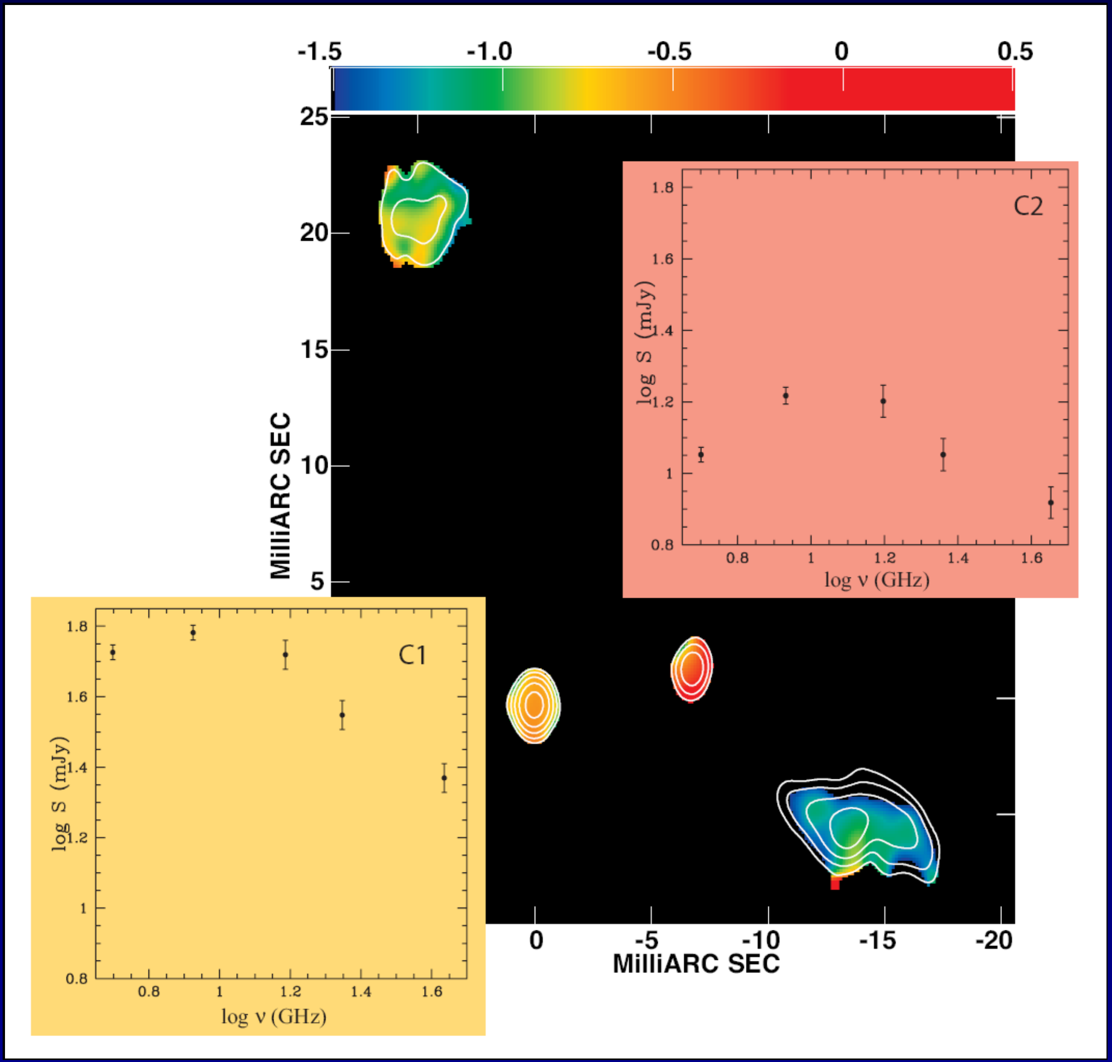
Variability



VLBA Light Curves at 5 GHz

- Component C1 substantially increases in flux over the 15 y baseline.
- Component C2 is also variable.
- For the southern and northern components, there is no substantial variation in the fluxes over the 15 y baseline.

Radio Continuum Spectra



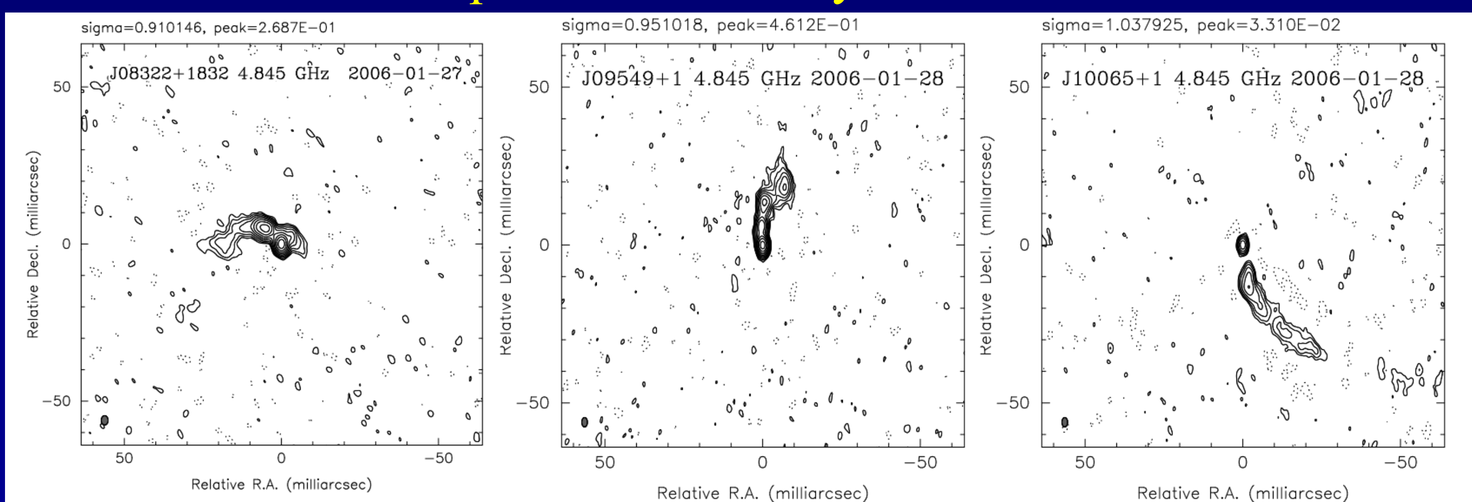
Spectral index between 8 and 22 GHz

- In both hotspots of the source, N2 and S2, a steep spectrum was found.
- In both central components, C1 and C2, the spectrum peaks Between 8 and 15 GHz.

VLBI Imaging of Active Galactic Nuclei

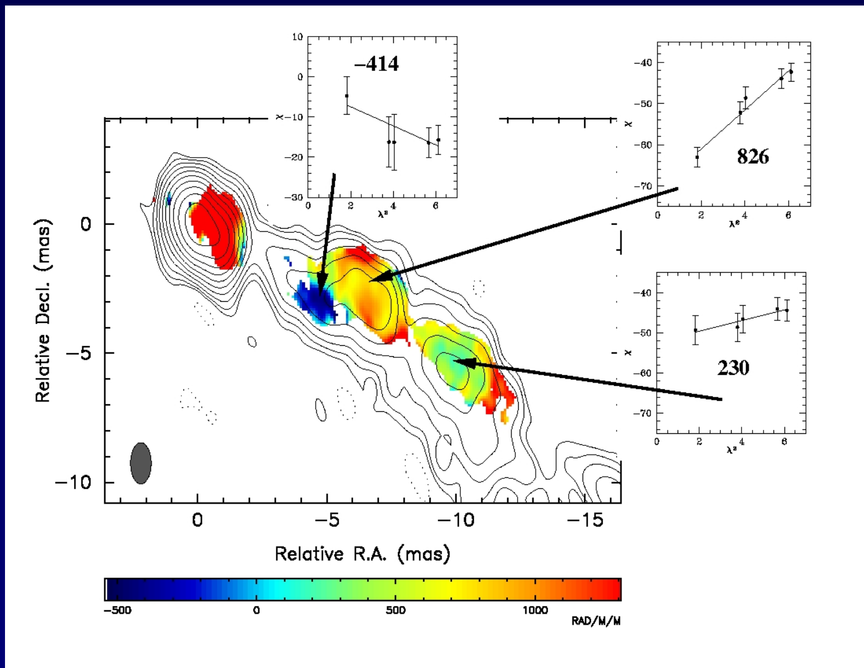
VLBA Imaging Polarimetry Survey (VIPS)

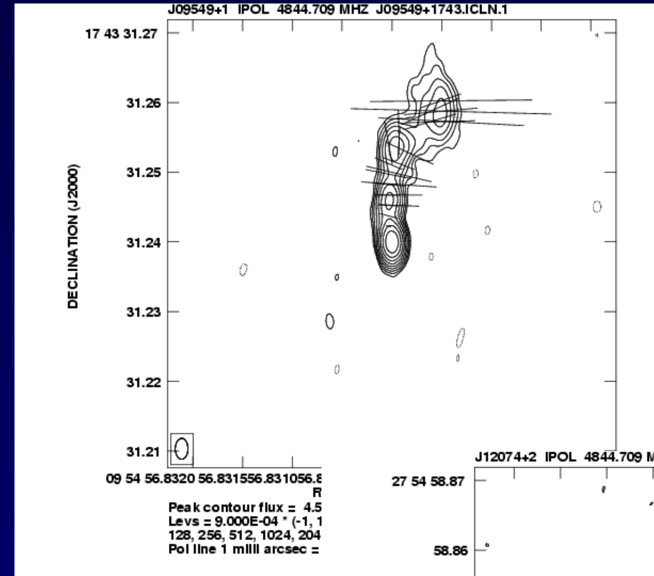
- 1127 sources: S > 85 mJy, 65 > dec > 20, |b|>10 at 5 GHz
  in SDSS northern cap
- First epoch observations on the VLBA in 2006
- Identifications and redshifts from SLOAN, HET, Palomar, …
- Goals:
  - Characterize GLAST (see posters) sources
  - Study Evolution of Radio Sources
  - Study AGN environments
  - Find more supermassive binary black holes

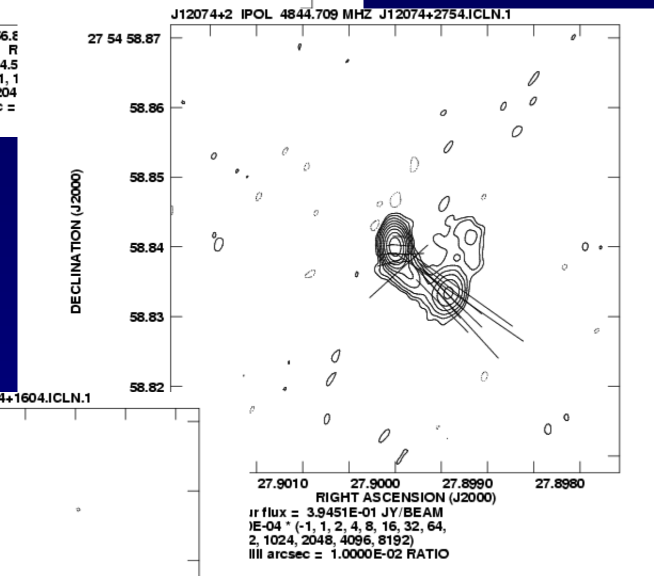


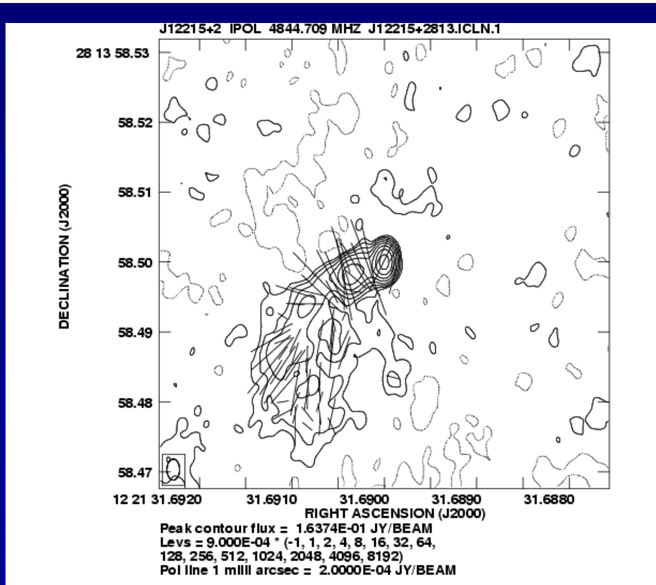
 http://www.phys.unm.edu/~gbtaylor/VIPS/

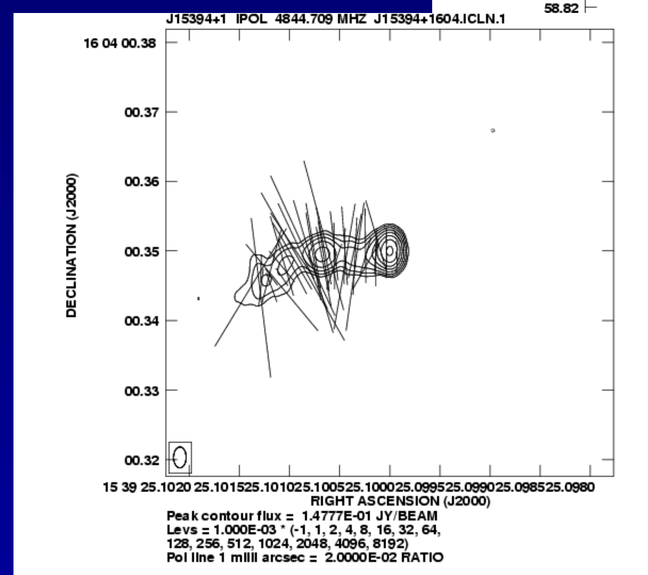
Polarimetry









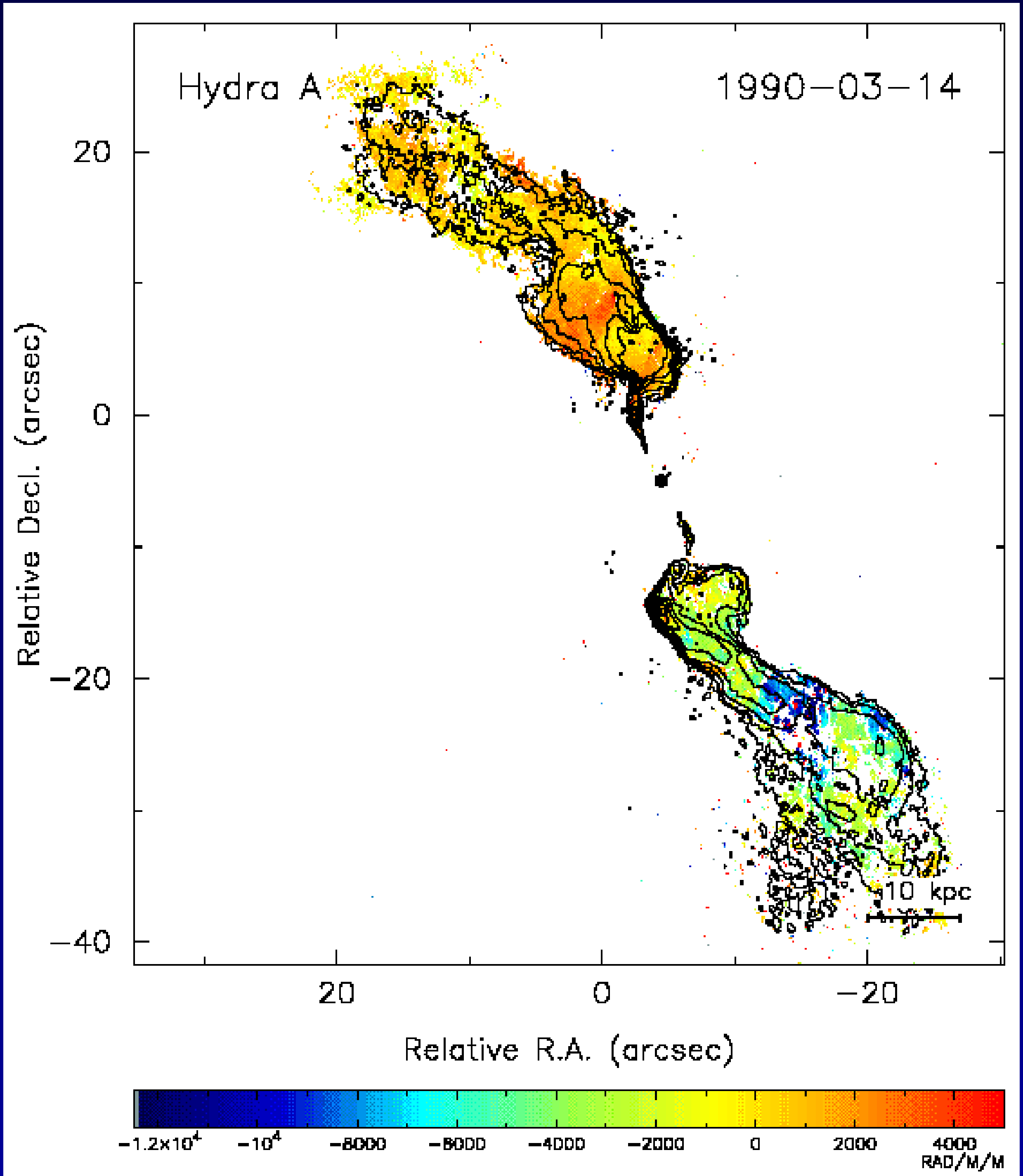


Hydra A

Faraday Rotation Measures

(magnetic fields)

Taylor et al 1991



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

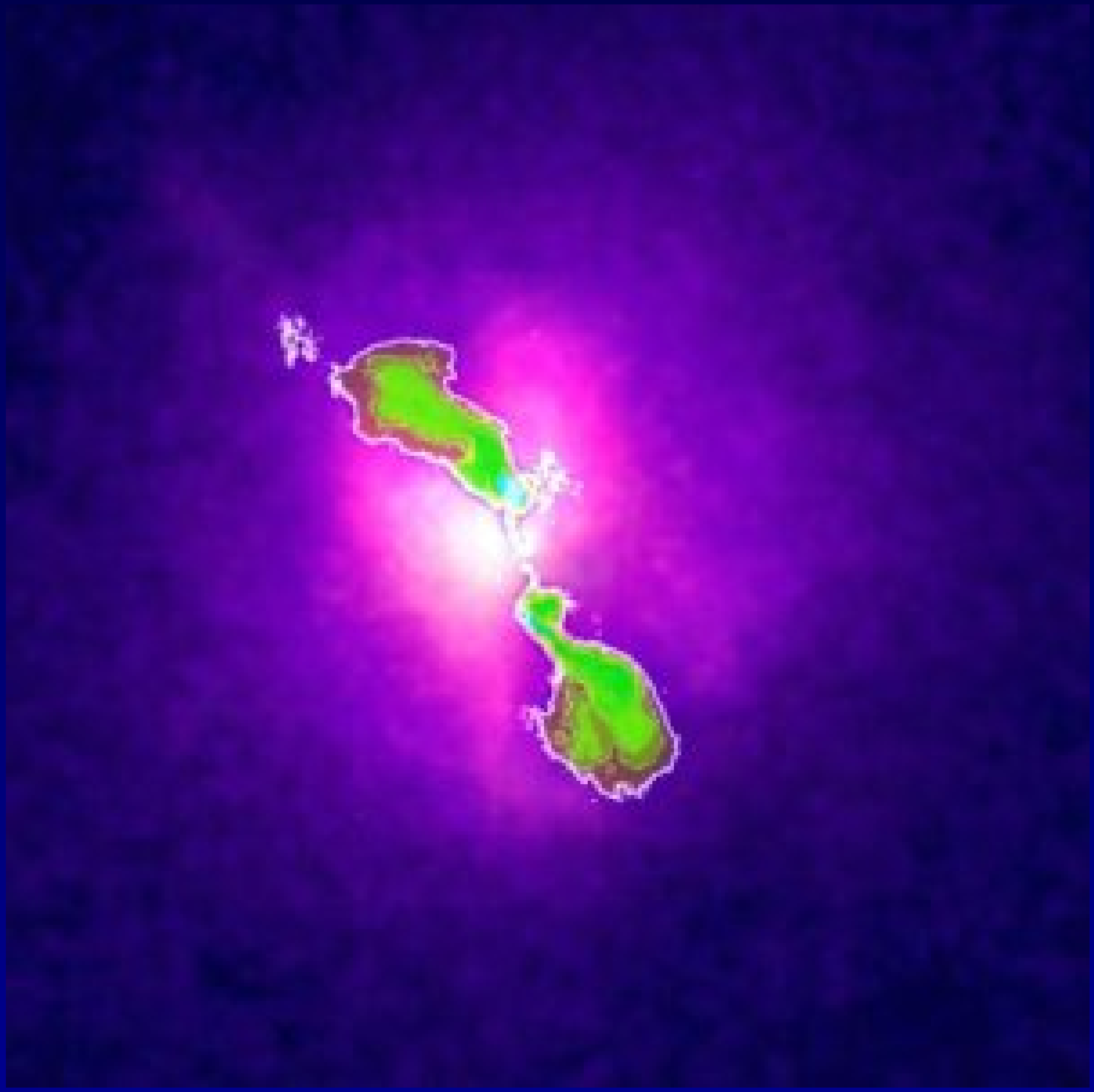
• Could excess energy from AGN go into heating?

• Heater (1 pc), cluster (10^6 pc)

Hydra A
center

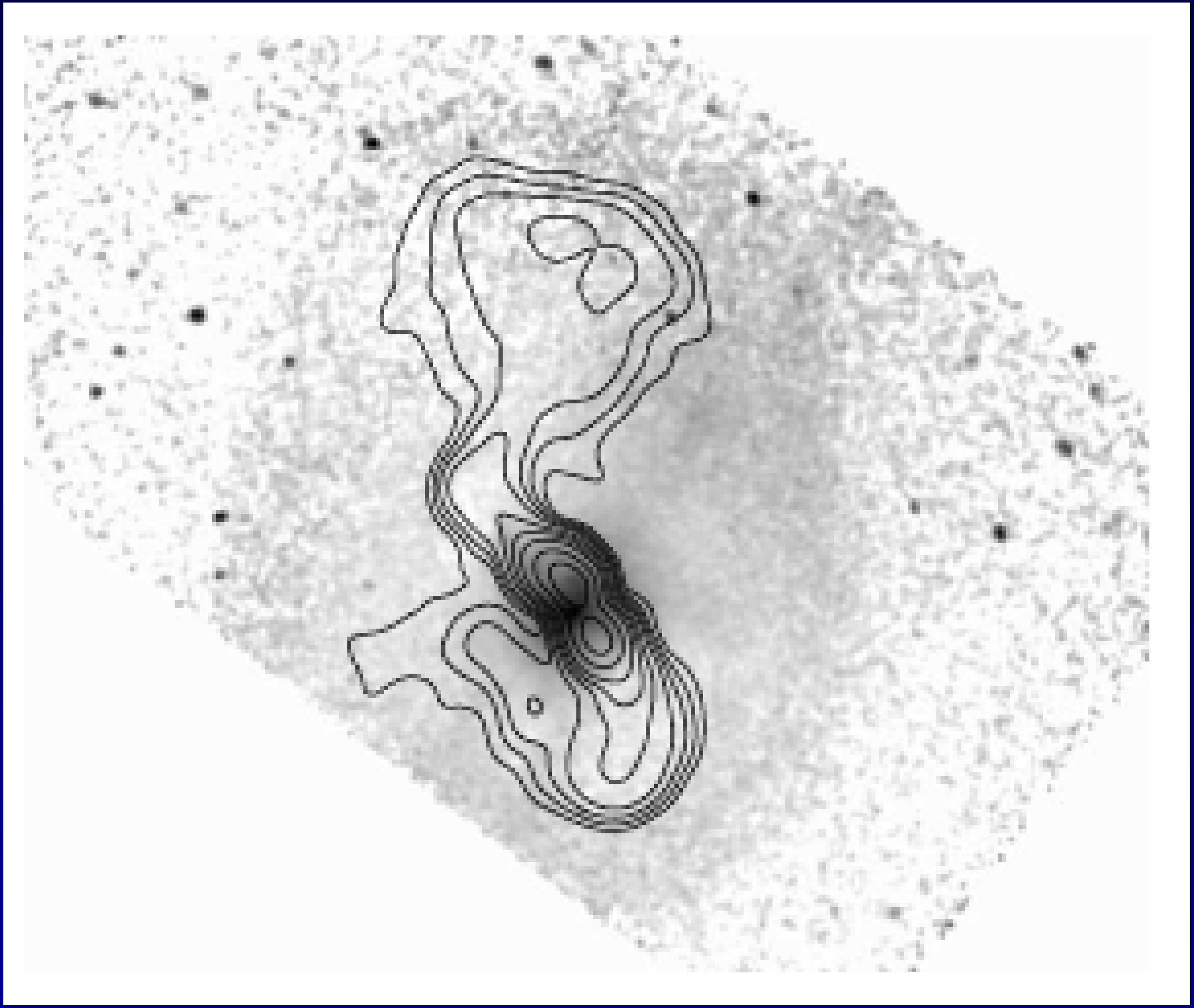
Radio
+
X-rays

McNamara et al.
2000



Hydra A

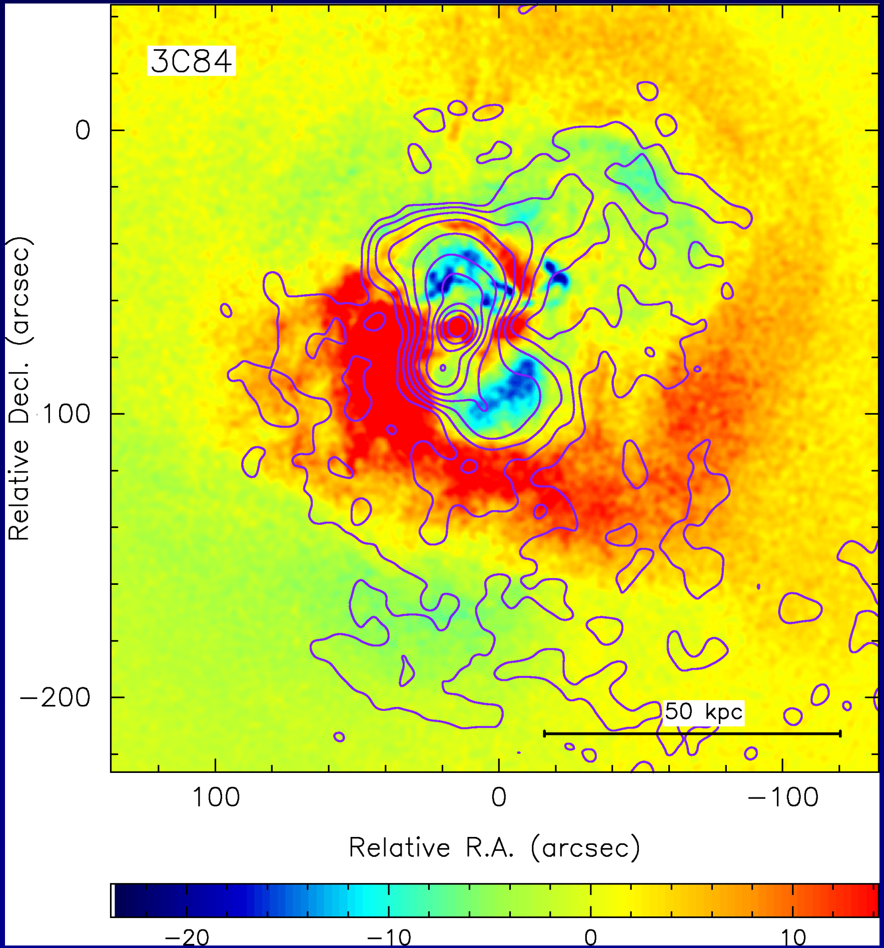
Radio
+
X-rays

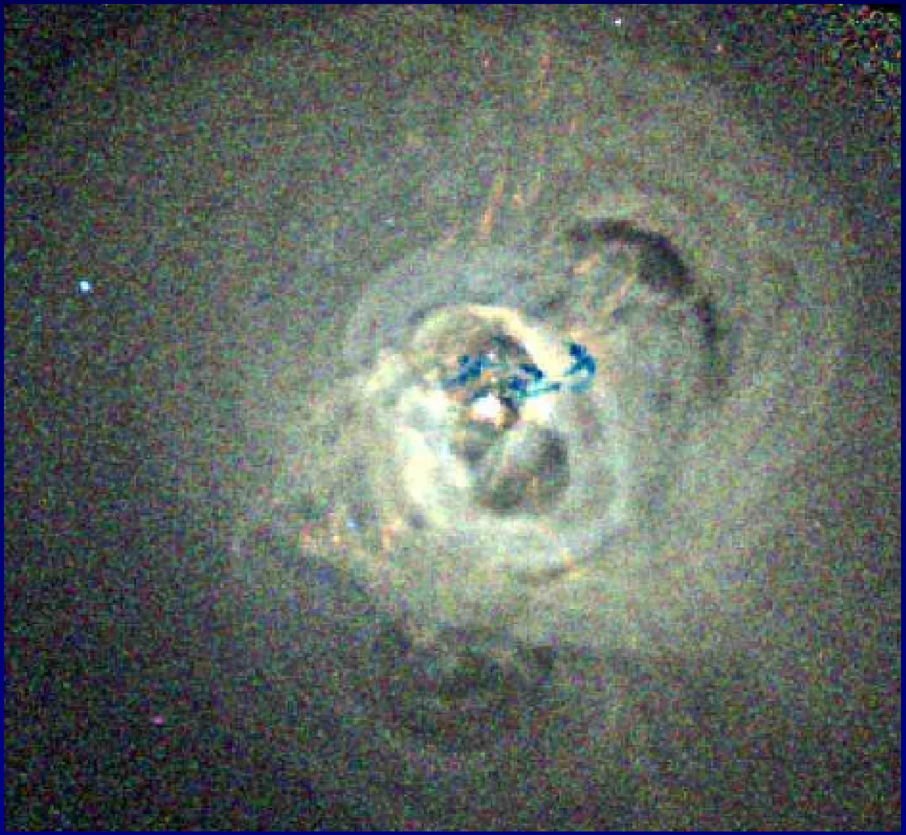


Nulsen et al.
2004

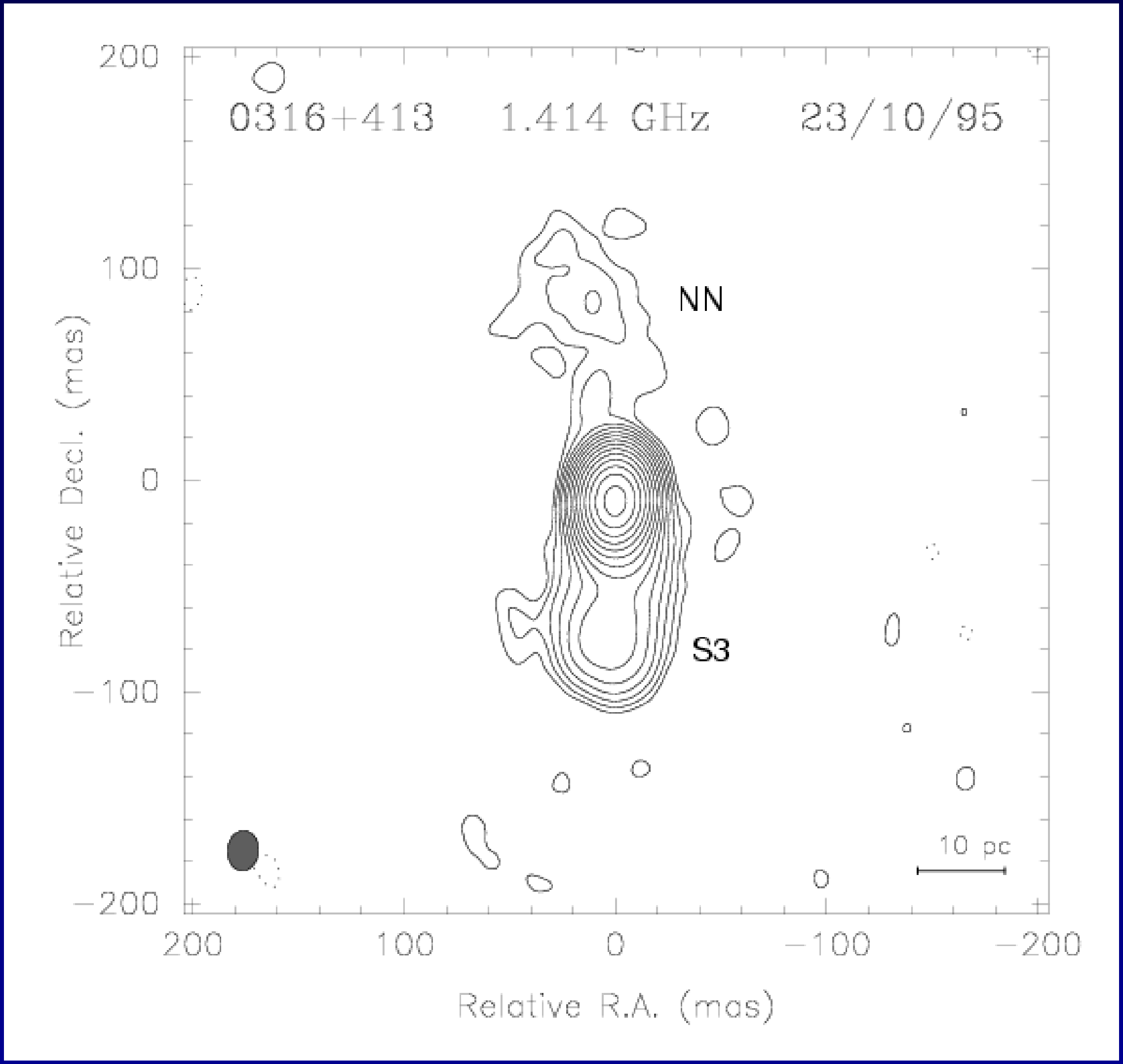
Fabian et al. 2003, 2005

Chandra + VLA



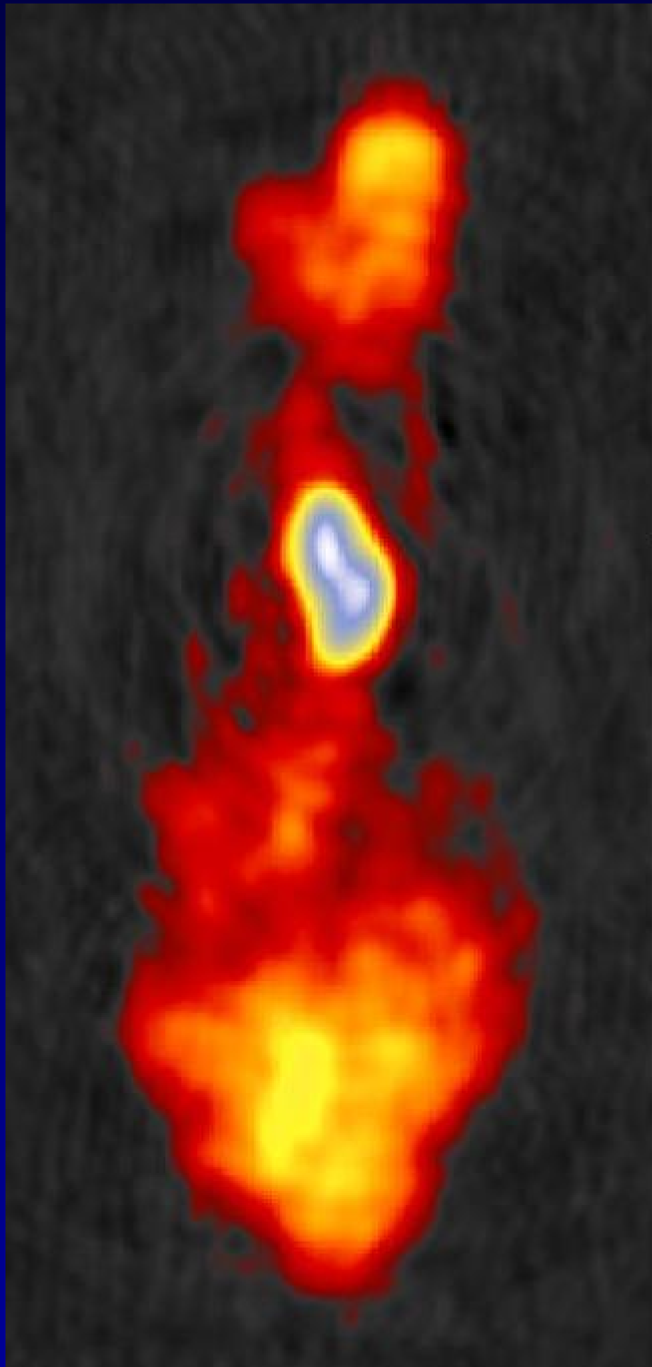


3C 84 at 1.4 GHz



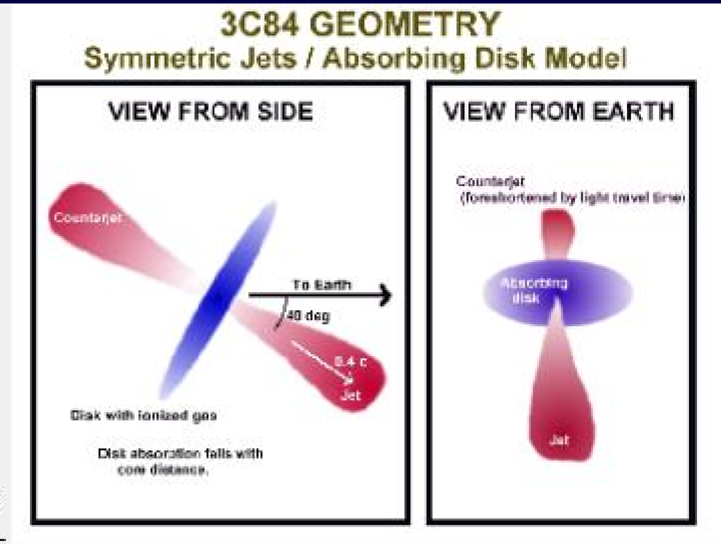
See also poster by Asada et al.

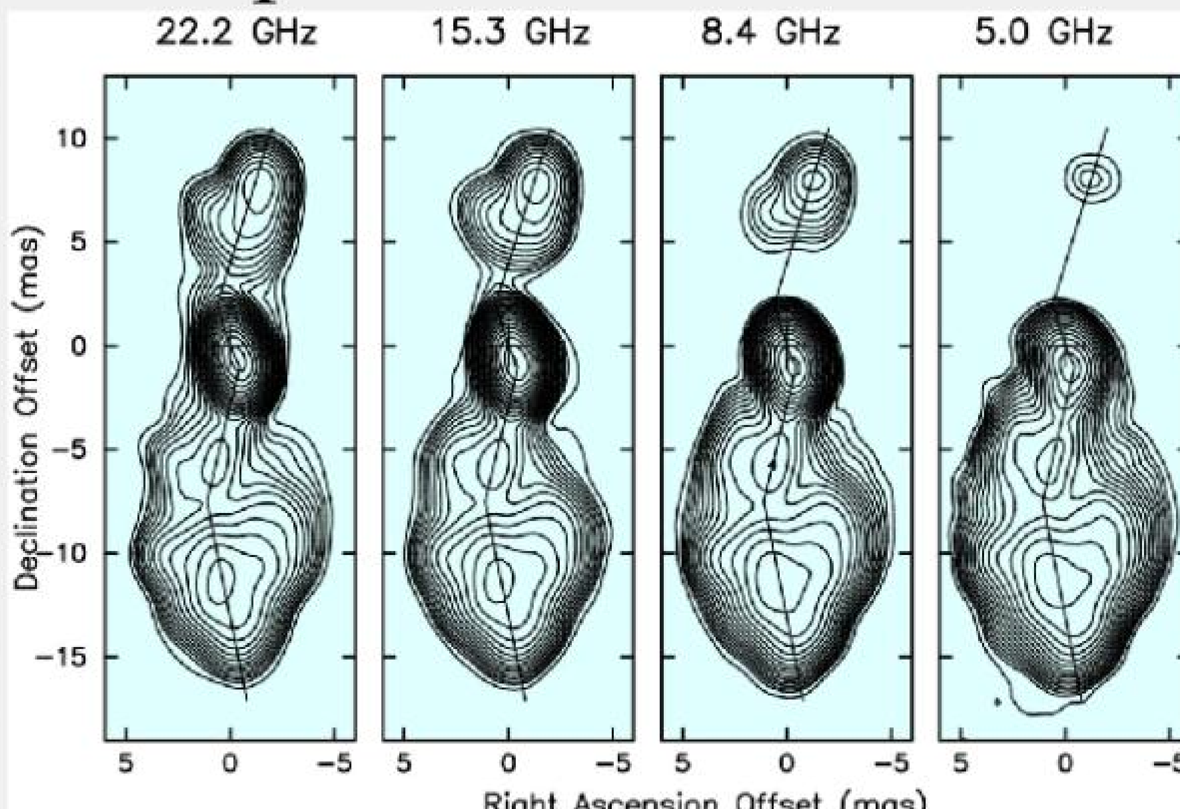
Taylor & Vermeulen 1996



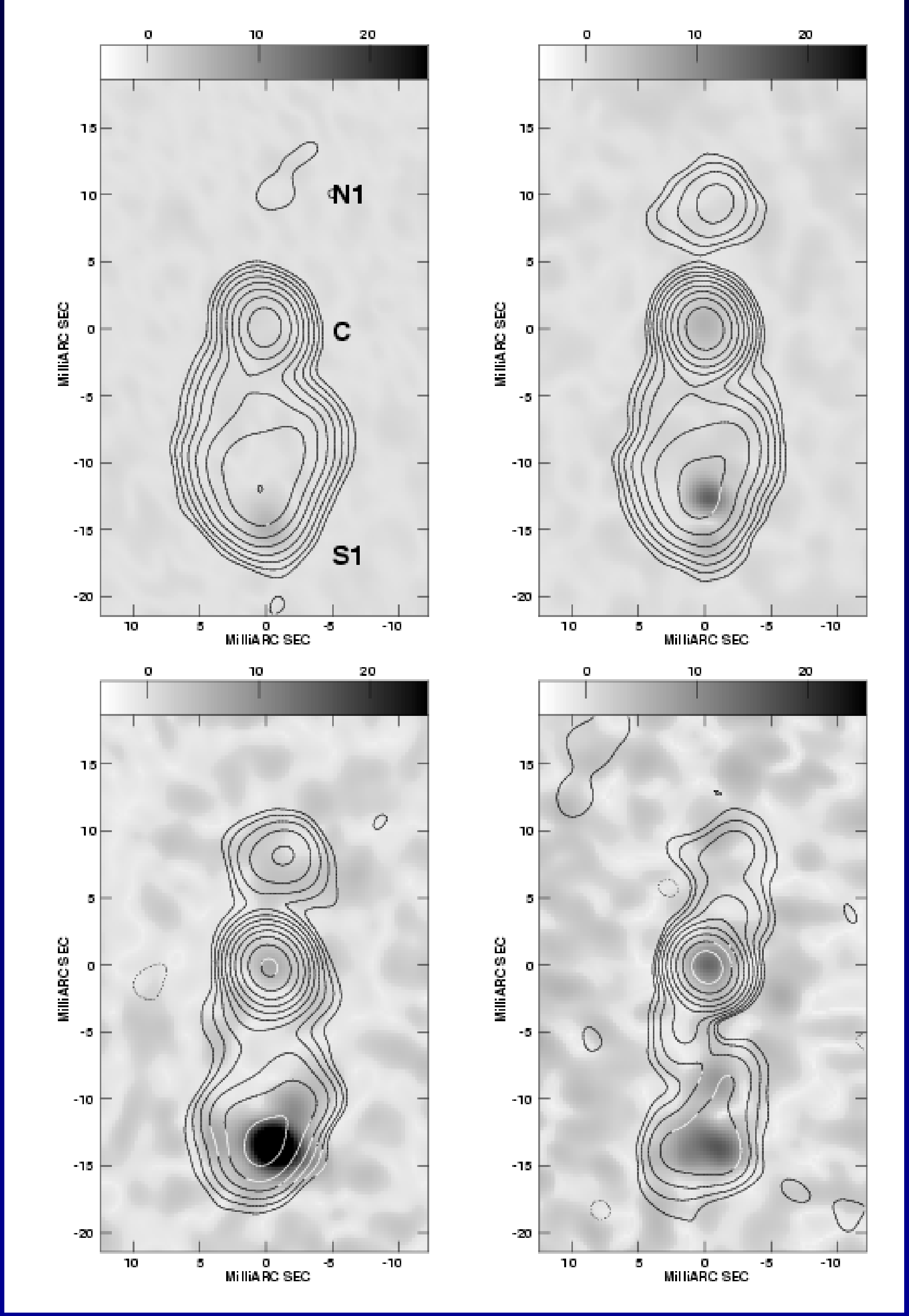
Walker et al. Ap.J. 530, 233

NGC1275 (3C84) Free-free Absorption





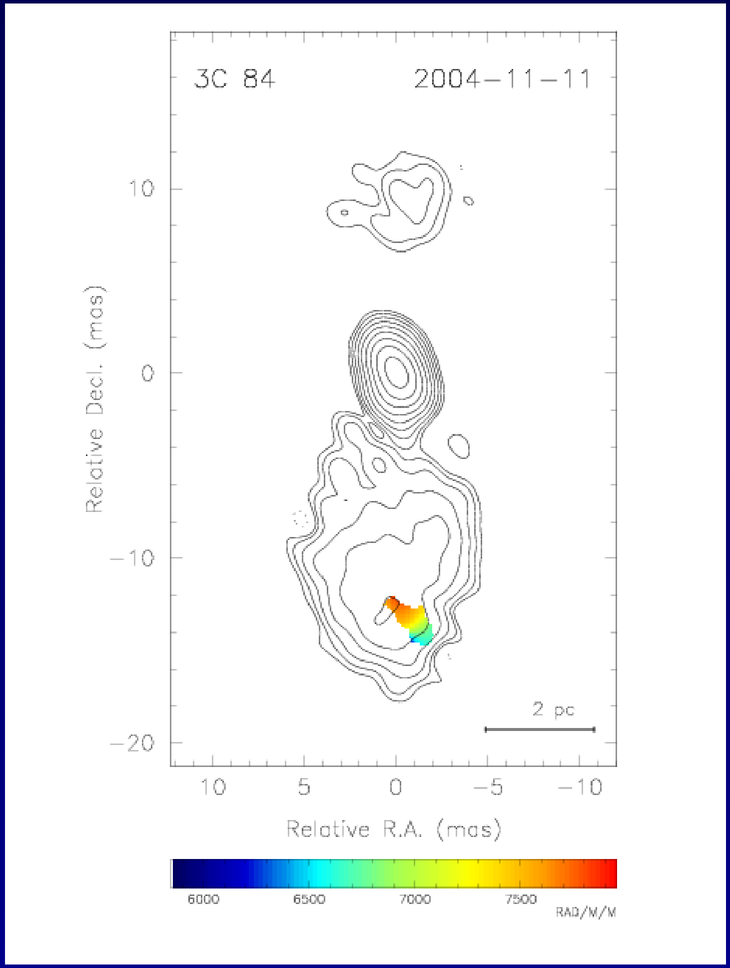
3C84 in Perseus

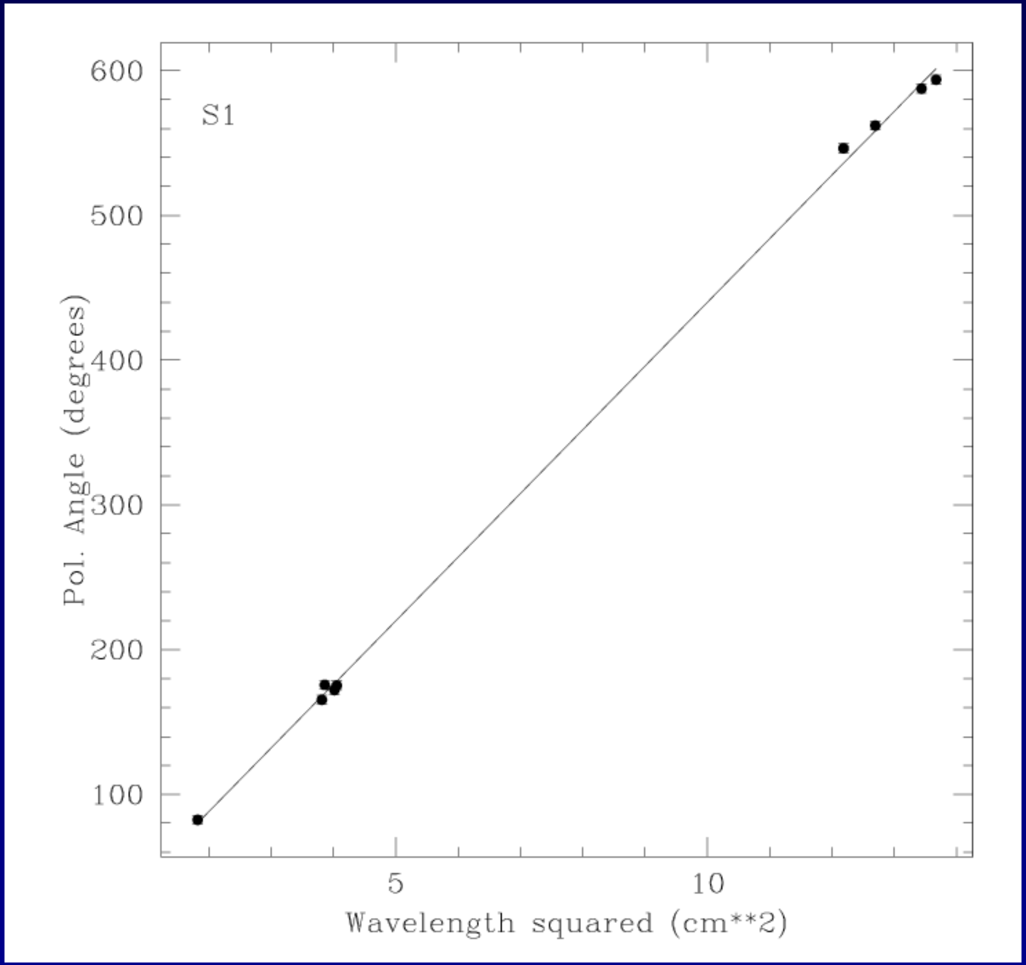


Detection of Linear Polarization

Taylor et al. 2006

3C84 in Perseus

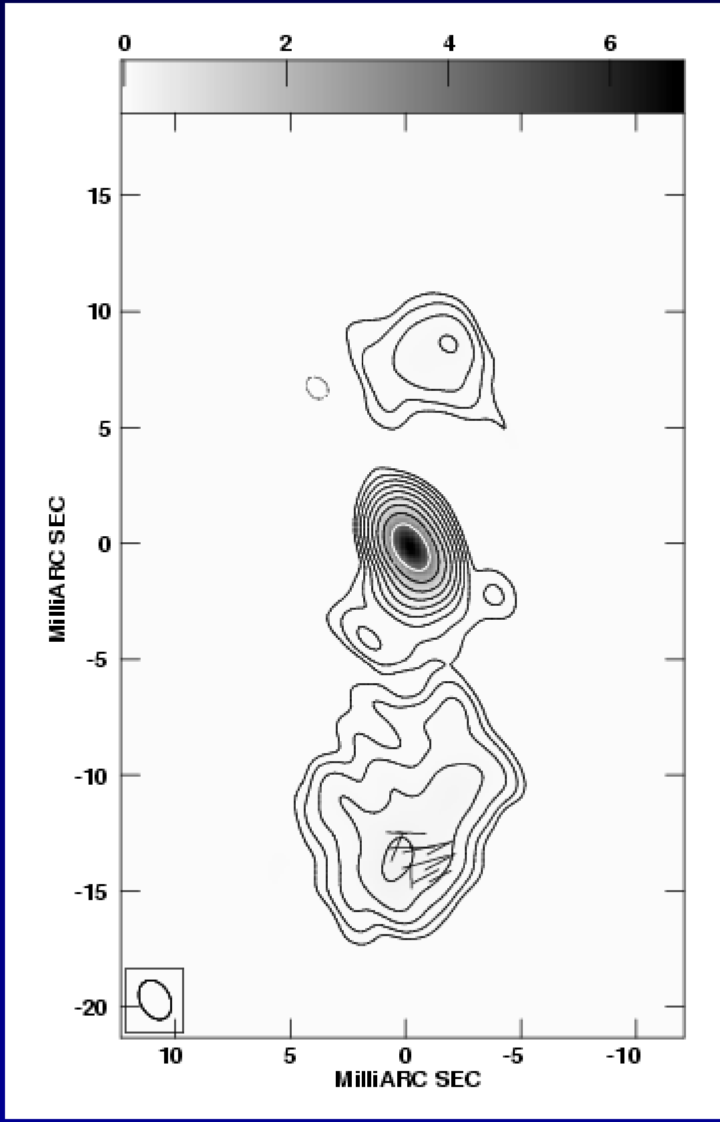




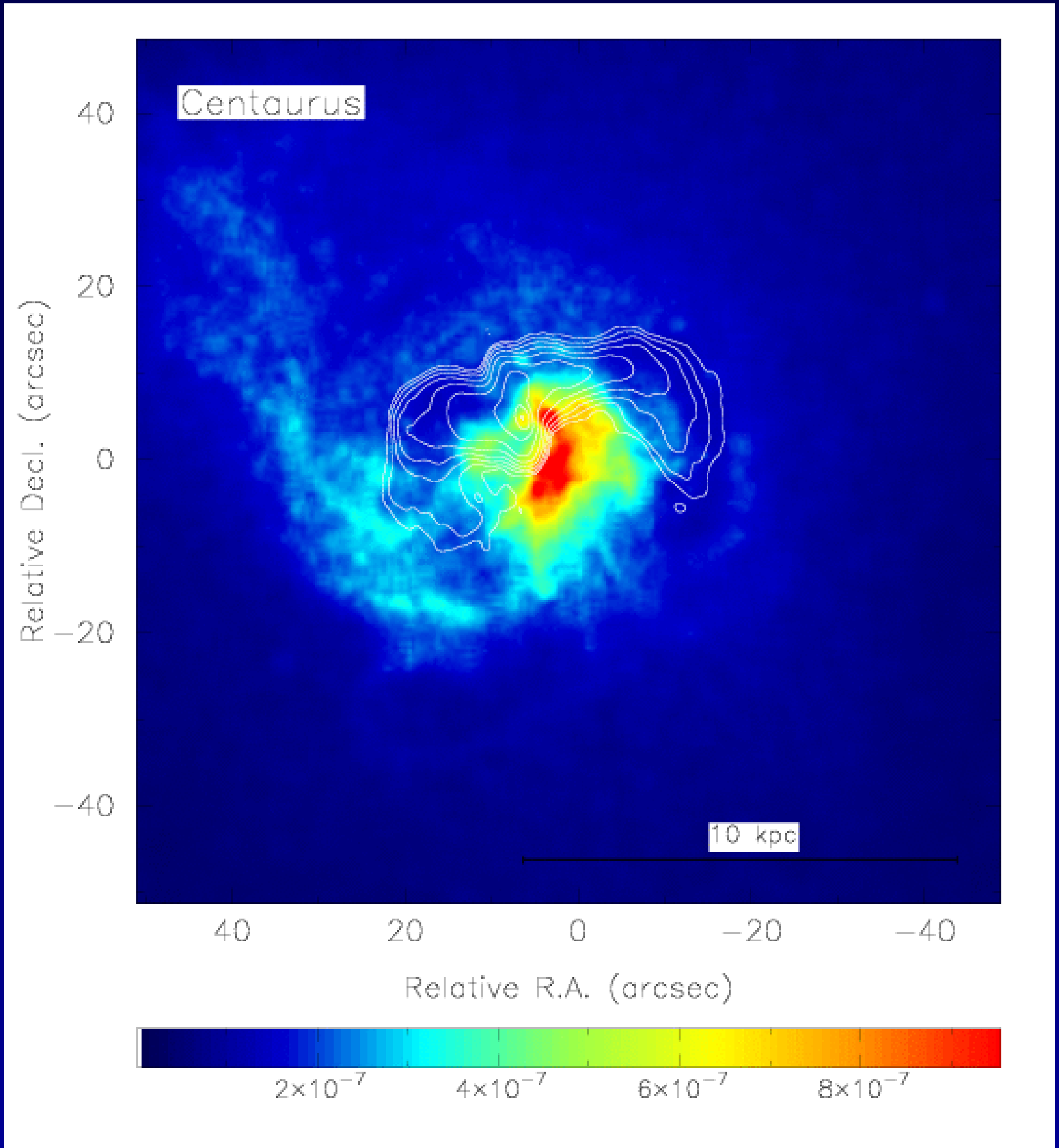
3C84 in Perseus

Summary:

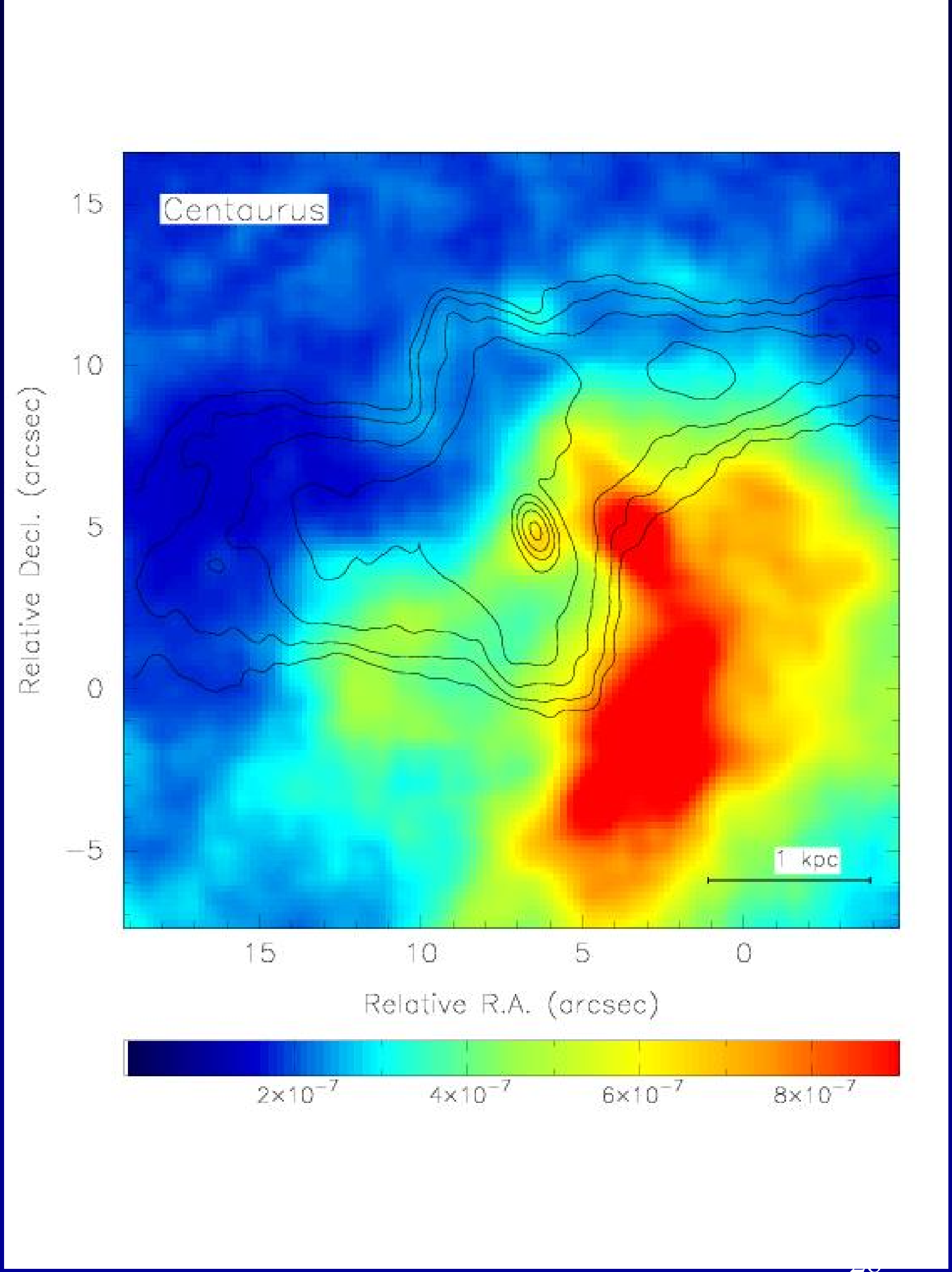
- AGN Feeding is episodic
- Jet components are launched into the intracluster medium (ICM)
- Bubbles drive sound waves
- Bubbles can sweep up ICM



PKS 1246-410 in Centaurus

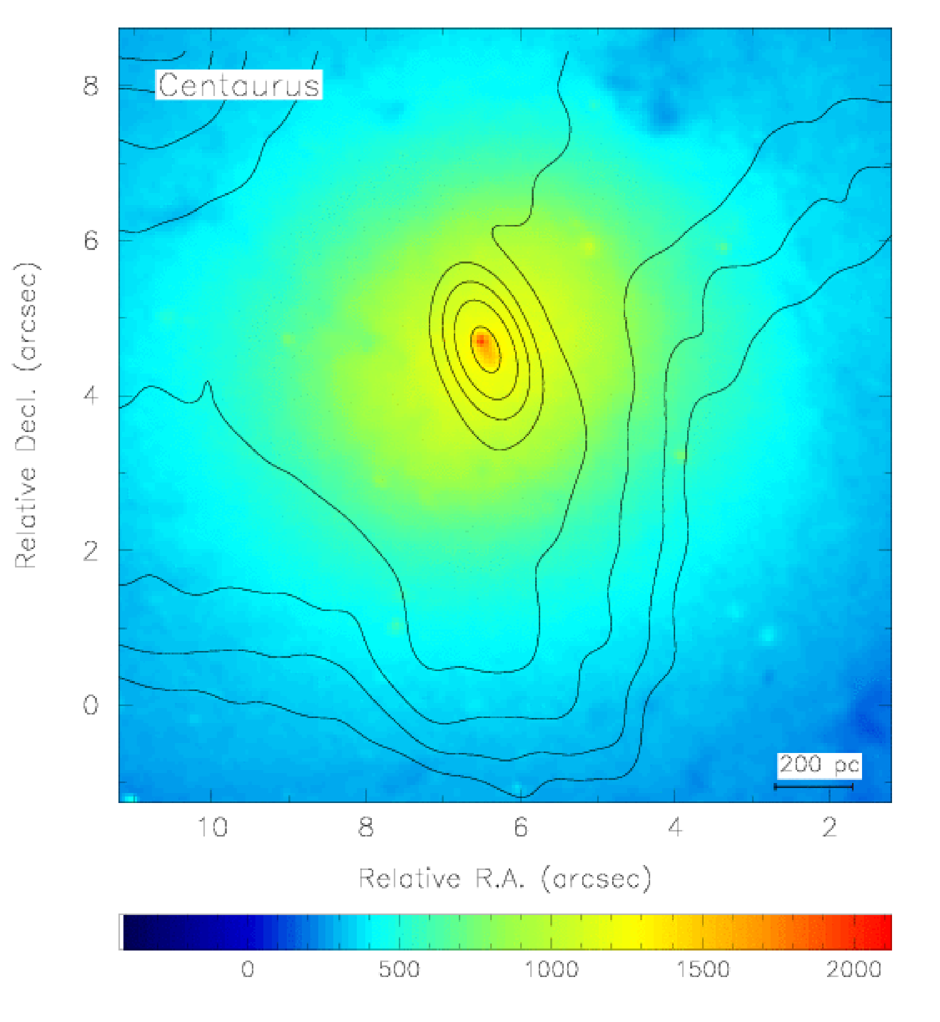


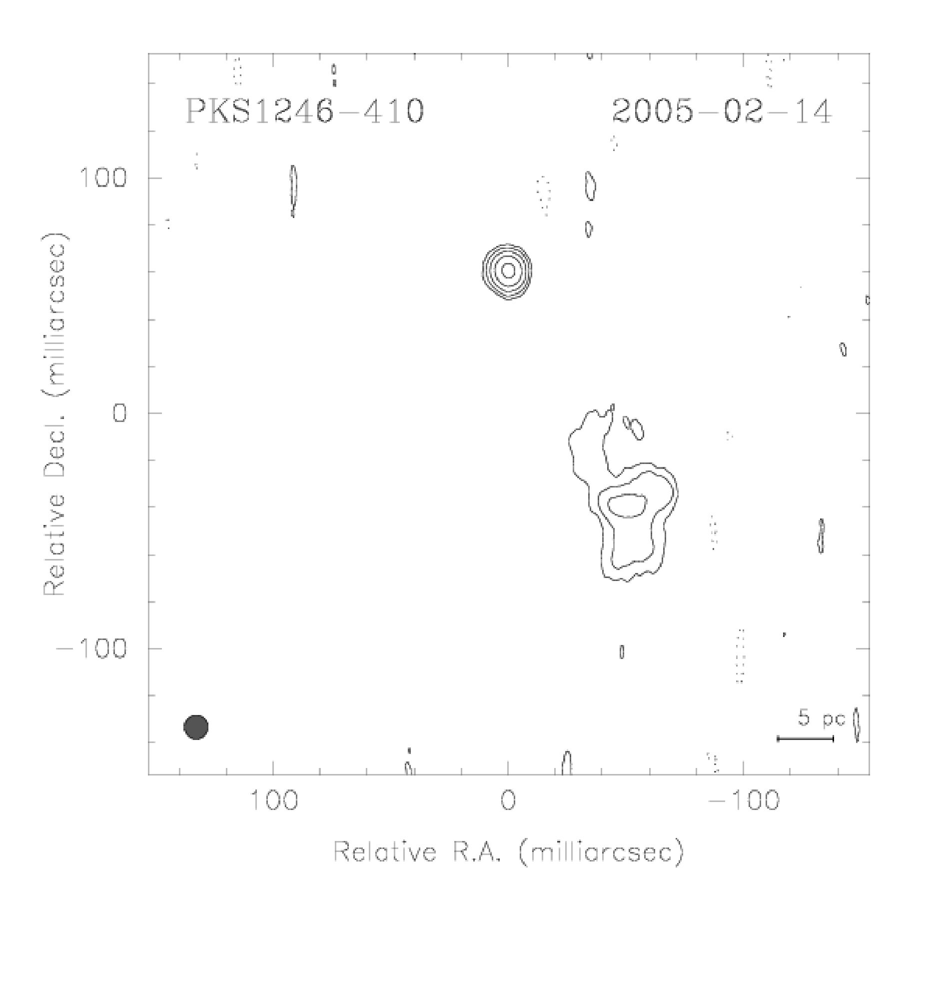
The nucleus of PKS 1246-410



VLA + X-ray

The nucleus of PKS1246-410

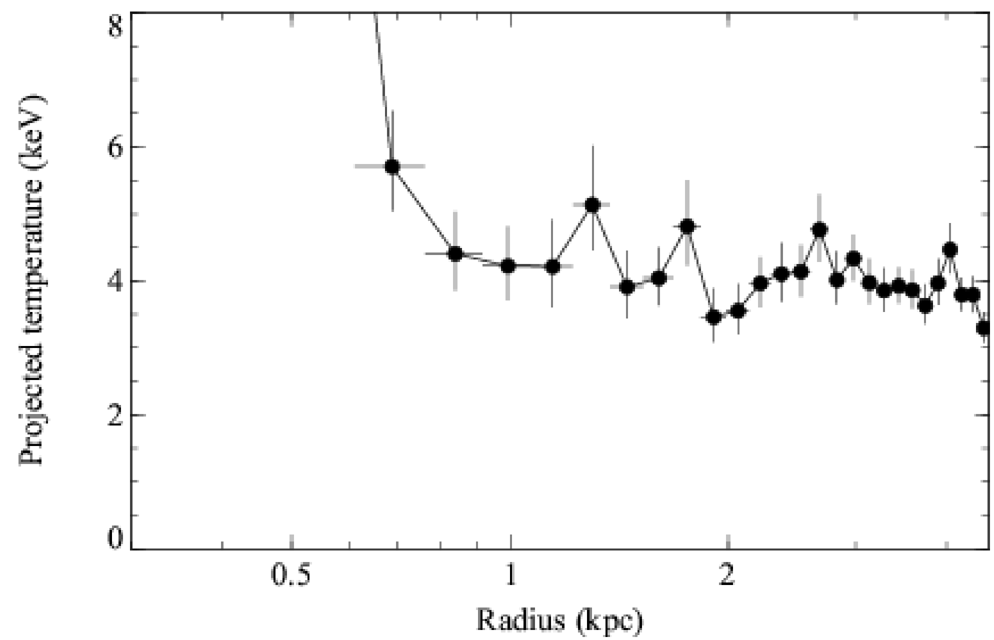




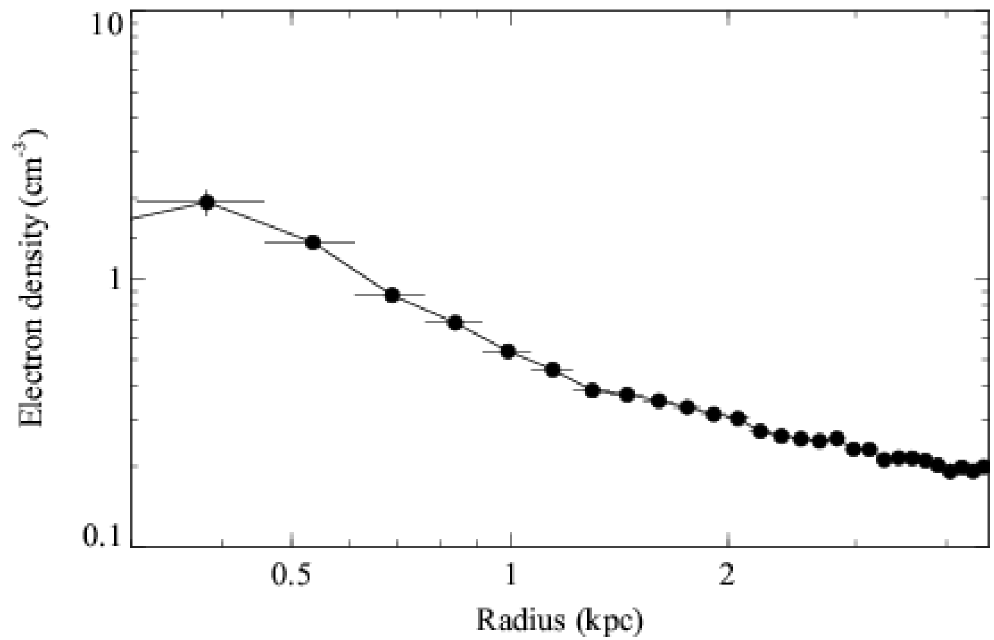
VLA + HST

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 ~ $2GM/c^2$

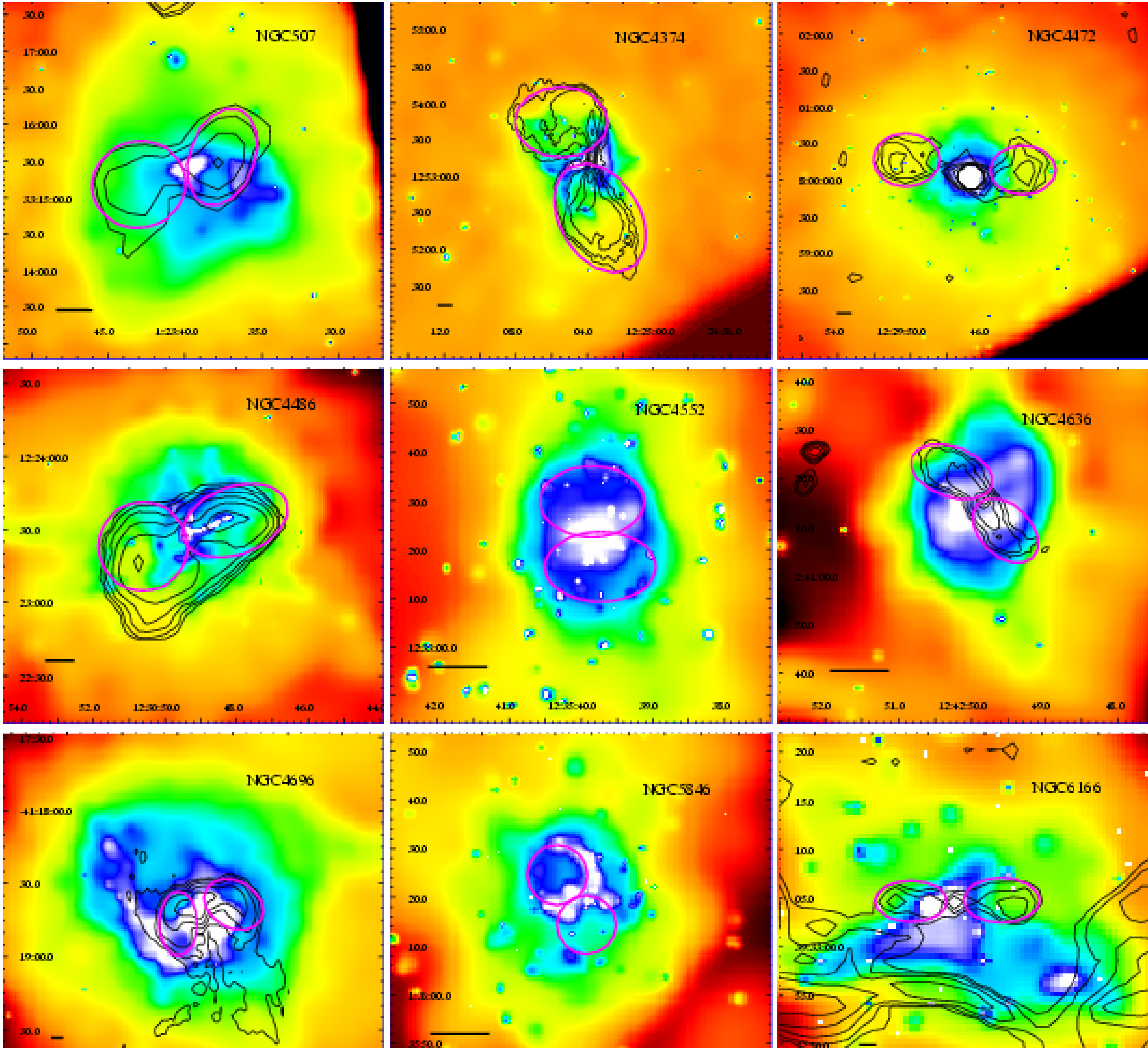
$\dot{M} = 4\pi R_b^{\,2} \rho c_s$

ρ is the density

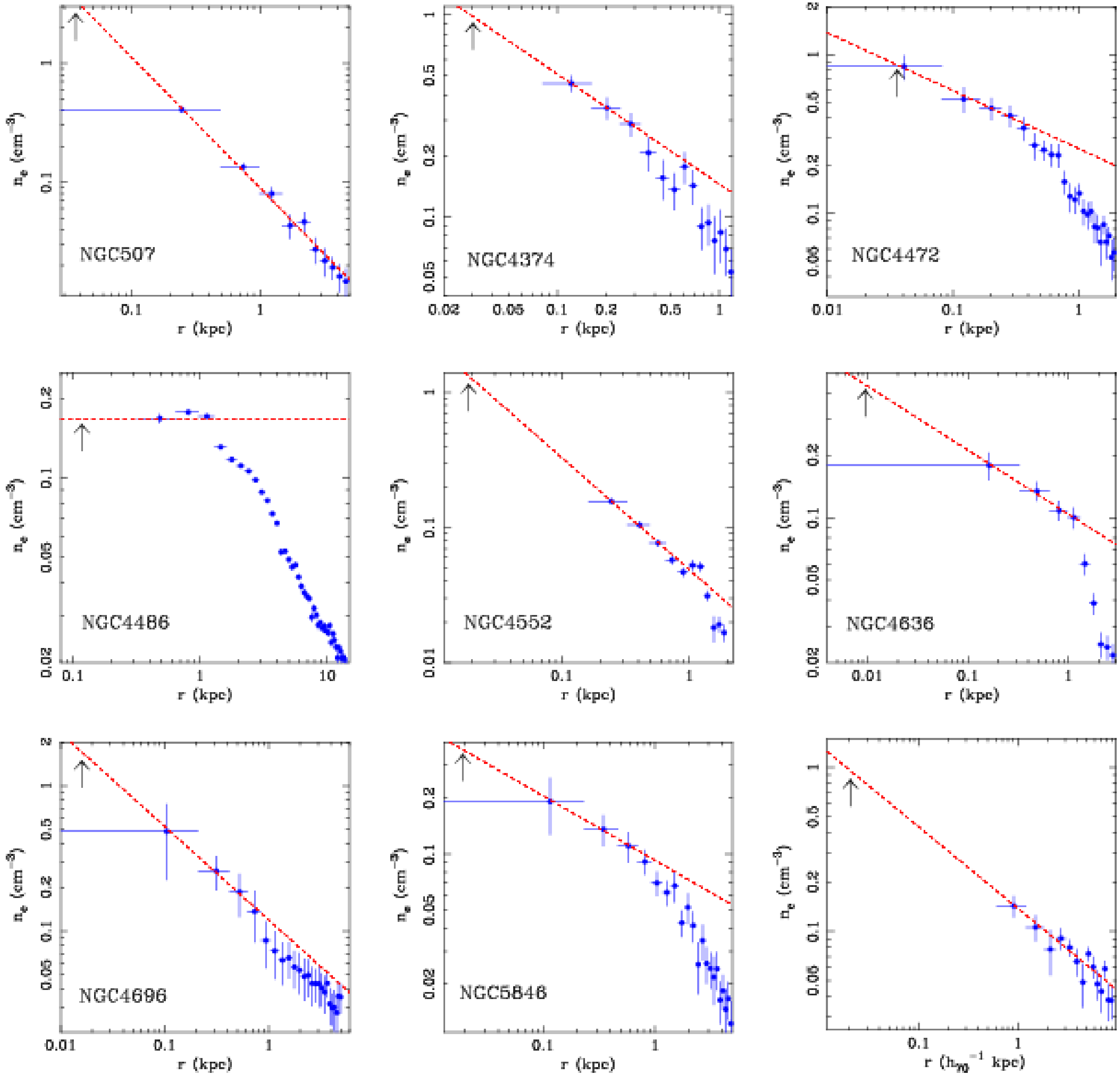
= 0.013 M_{sun}/yr for PKS 1246-410

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

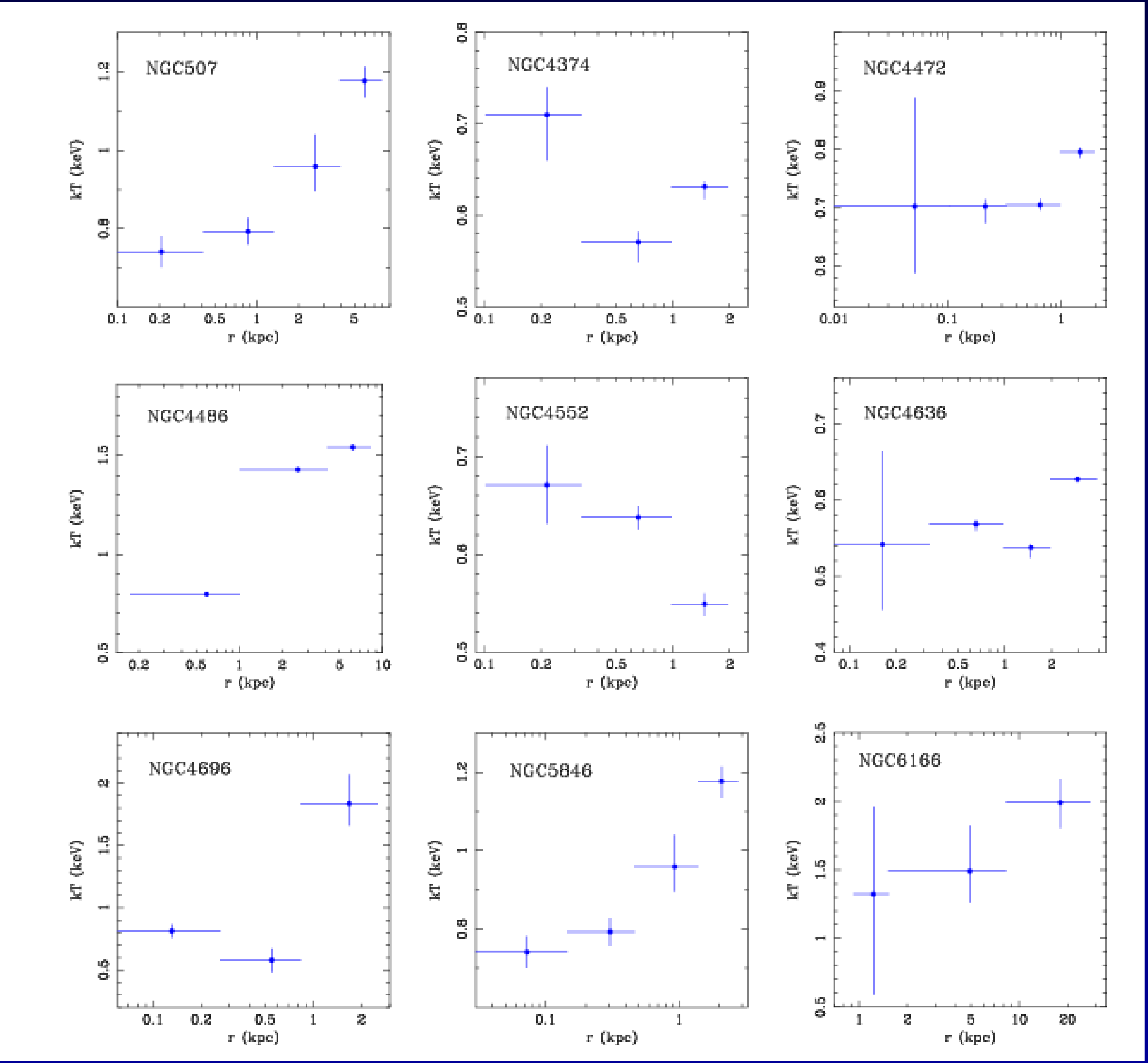
= 8×10^{43} erg/s >> $L_{X\text{-rays}} = 4 \times 10^{39}$ erg/s


NGC507
NGC4374
NGC4472
NGC4486
NGC4552
NGC4636
NGC4696
NGC5846
NGC6166

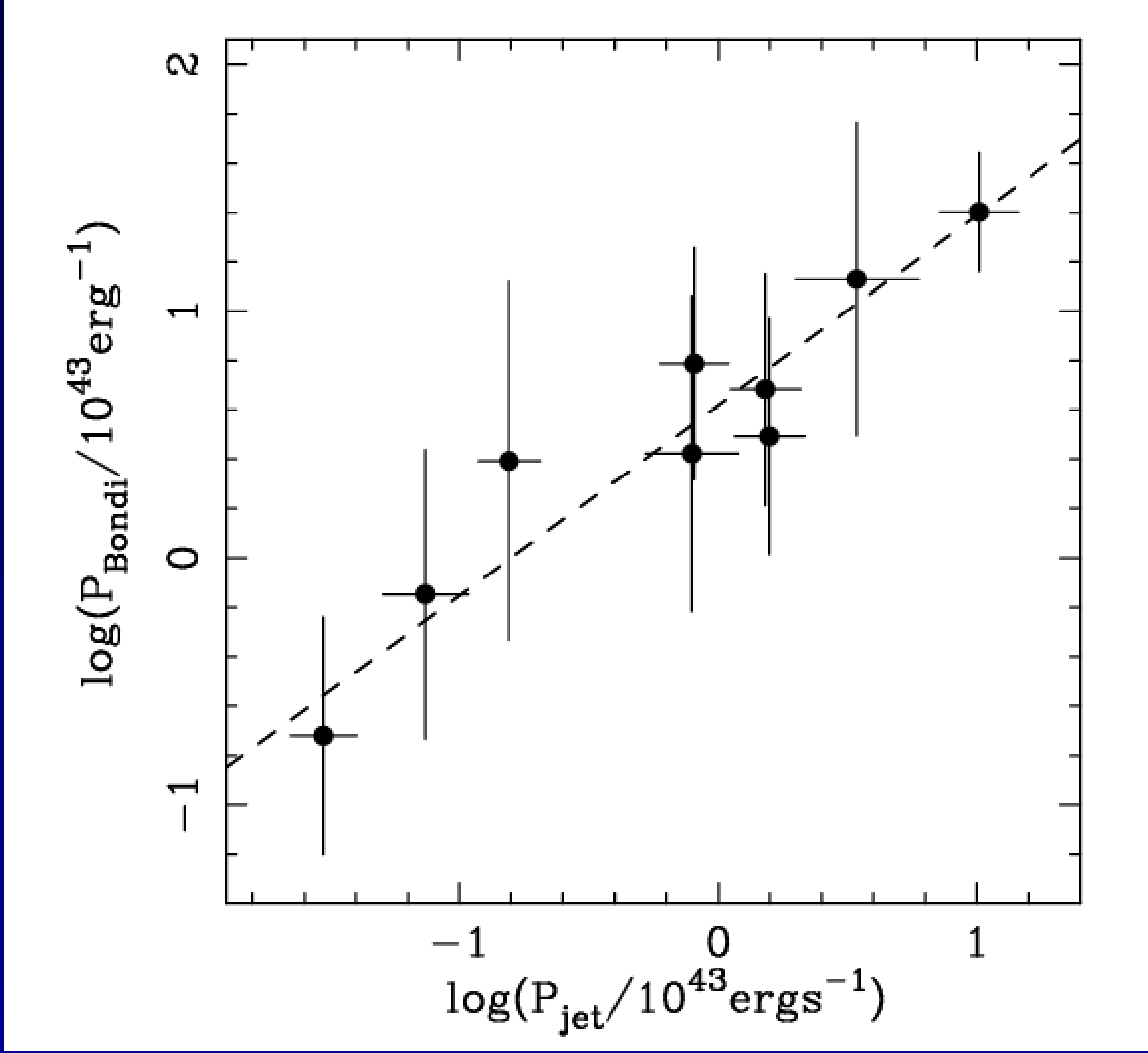
Density profiles



Temperature profiles



Allen et al 2006



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 few million years
- Feedback from the central black holes may be important for shaping the bright end of the galaxy luminosity function (limiting accretion)

SUMMARY

- CSOs can evolve into FR I/II radio galaxies, but many don't make it.
- Compact Supermassive Black Hole Binaries exist
- Radio Galaxies are viable heaters for clusters
- To understand radio galaxies it helps to understand the feedback mechanism that regulates cluster heating
- Future work
  - Use the Long Wavelength Array (LWA) or LOFAR to look for radio emission in "ghost" bubbles
  - Use the LWA or LOFAR to identify 1000s of clusters
  - Obtain more Chandra observations of nearby clusters to test the relation between jet power and accretion efficiency over a greater sample