Extended X-ray Emissions from the Radio Galaxies Centaurus B and Fornax A

Makoto Tashiro[1],

Naoki Isobe[2], Masaya Suzuki[1] Kouichi Ito[1], Keiichi Abe[1], and Kazuo Makishima[3]

1:Saitama Univ., 2: ISAS/JAXA, 3:Univ. of Tokyo

1. XMM-Newton observation Centaurus B
2. Summary diagrams of IC-X-ray observation from radio lobes
3. ASCA and Chandra observations of Fornax A

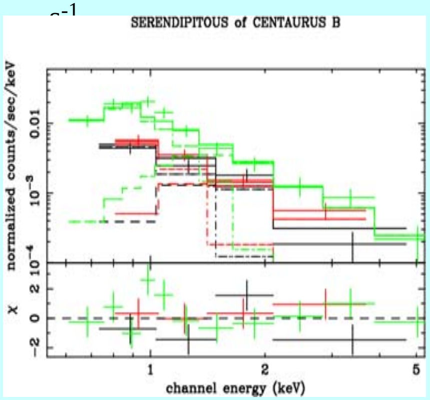
ASCA (ISAS)

1. XMM-Newton observation Centaurus B

(2001, MNRAS, 325, 817)

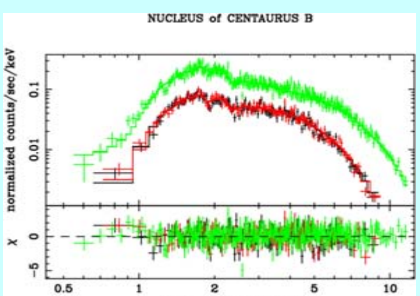
un-ID source ((pow + ray) x Gal. Abs.)

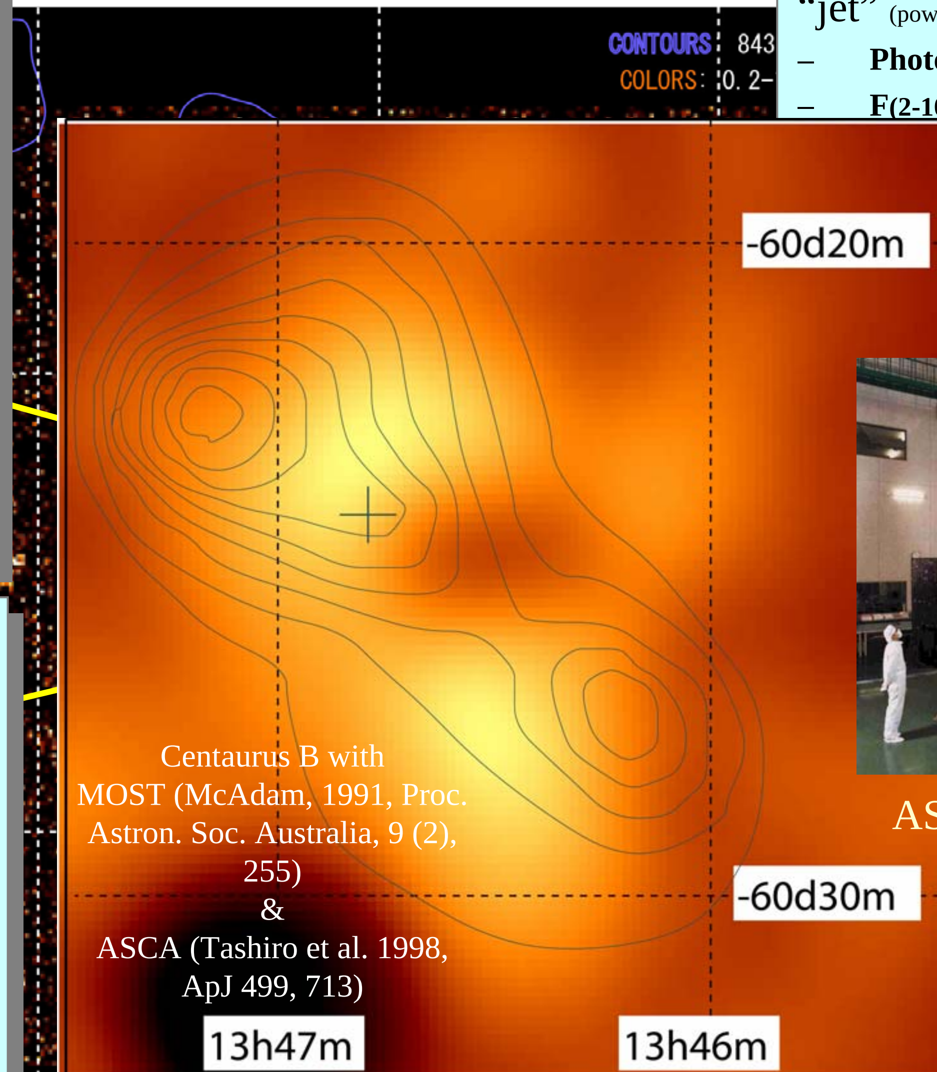
- Photon index: 2.65±0.31
- Temperature: kT = 0.14 keV
- F(2-10keV): 0.3×10^{-13} erg cm^{-2} s^{-1}



AGN (power-law x Abs.)

- Photon index: 1.56±0.02
- F(2-10keV): 5.4E-12 ergcm^{-2} s^{-1}
- L(2-10keV) :1.5E42 erg s^{-1}

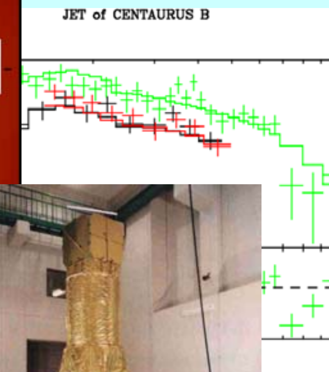


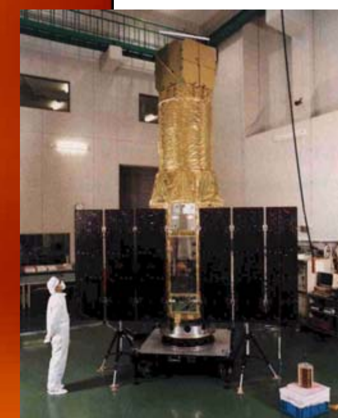


Centaurus B with MOST (McAdam, 1991, Proc. Astron. Soc. Australia, 9 (2), 255) & ASCA (Tashiro et al. 1998, ApJ 499, 713)

"jet" (power-law x Galactic Abs.)

- Photon index: 1.43±0.18
- F(2-10keV): 2.0E-13 erg cm^{-2} s^{-1}
- keV) :5.6E40 erg s^{-1}

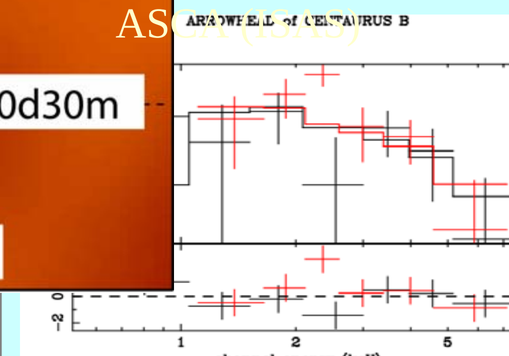


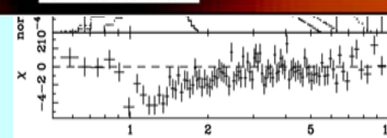


ASCA (ISAS)

lactic Abs.)

m^{-2} s^{-1}



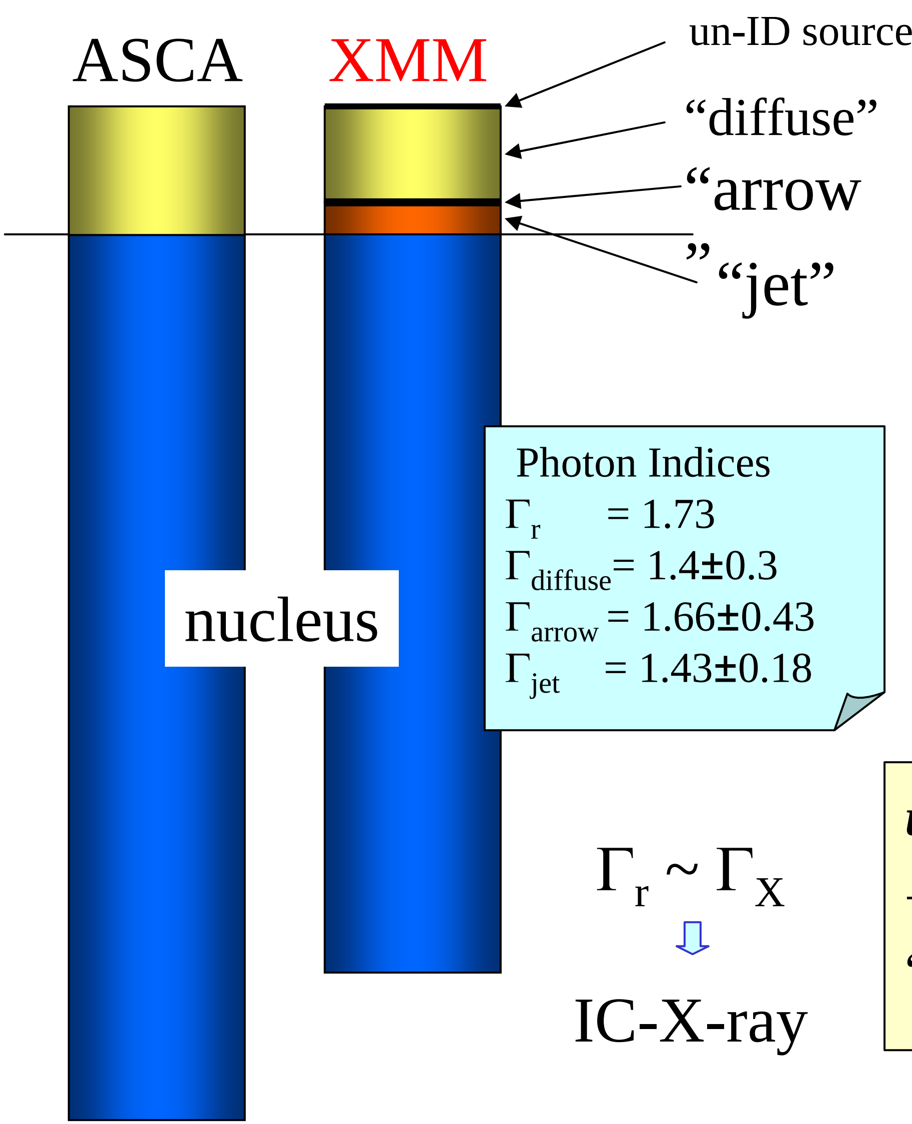


XMM results

in comparison with ASCA results

(Tashiro et al. 1998, ApJ 499, 713)

X-ray flux



Photon Indices

$\Gamma_r = 1.73$

$\Gamma_{diffuse} = 1.4 \pm 0.3$

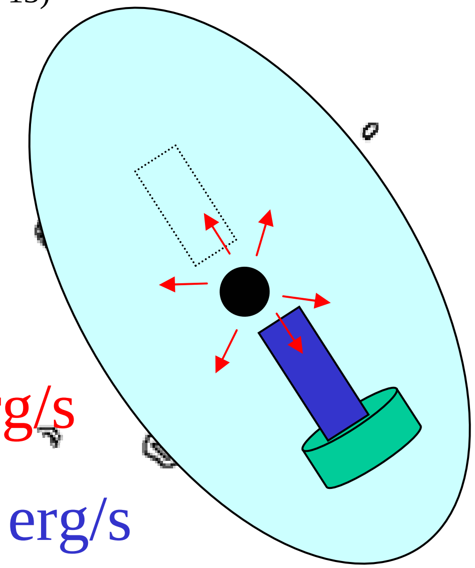
$\Gamma_{arrow} = 1.66 \pm 0.43$

$\Gamma_{jet} = 1.43 \pm 0.18$

$\Gamma_r \sim \Gamma_X$

⇩

IC-X-ray



$L_x^{nuc} = 1.5 \times 10^{42}$ erg/s

$L_x^{jet} = 5.4 \times 10^{40}$ erg/s

$L_x^{arrow} = 1.2 \times 10^{40}$ erg/s

$L_x^{diff} = 1.9 \times 10^{41}$ erg/s

$\boldsymbol{u}_{CMB} > \boldsymbol{u}_{nucleus}$ (d > 3 kpc (0.2’))

→CMB dominates both in the region

“jet” (d~ 7.5 kpc) and “arrow” (d~45 kpc)

Non-thermal radio and X-ray emissions in jets and lobes (e.g. Harris & Grindlay 1979, MNRAS 188, 25)

✓Synchrotron Radio Emission

- flux: $F_{SR} \propto u_e u_m V$
- energy index : α_{SR}

- u_e : energy density of electrons
- u_m : energy density of magnetic fields
- V : Volume of the Lobe

✓Inverse Compton (X-ray) Emission

- flux : $F_{IC} \propto u_e u_{seed} V$
- energy index : $\alpha_{IC} = \alpha_{SR}$

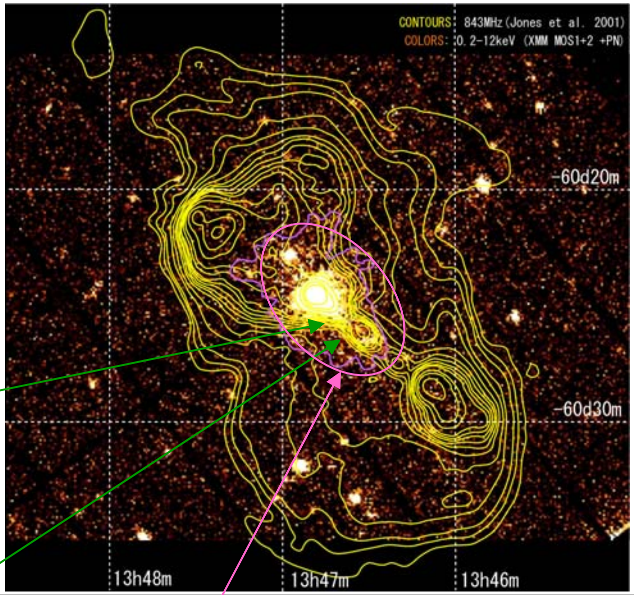
- $u_{eed} = u_{CMB} + u_{sync} + u_{gal} + \ldots$
- u_{CMB} : energy density of CMB
  $4.1 \times 10^{-13} (1 + z)^4$ erg cm^{-3}

in many cases….. $u_{seed} \sim u_{CMB}$

by comparing F_{SR} and F_{IC} → u_e and u_m

Centarusu B: structures and energy densities

- Detected the diffuse X-ray emission and X-ray bright structures ("jet", "arrowhead")
- Derived energy distributions in the "jet" & "arrowhead", considering their expected bulk motions (δ~0.94 (from radio luminosity ratio)), are….



- **"Jet"**
  - $u_m \sim (3.6 \times 10^{-15})(\Gamma/10)^2$
  - $u_e \sim (2.2 \times 10^{-7})(10/\Gamma)^2$
  - □ $(u_e / u_m) \sim 10^8 (10/\Gamma)^4$

    (B ~0.3 μG)
- **"arrowhead"**
  - $u_m \sim (4.2 \times 10^{-15})(\Gamma/10)^2$
  - $u_e \sim (1.0 \times 10^{-10})(10/\Gamma)^2$
  - □ $(u_e / u_m) \sim 10^5 (10/\Gamma)^4$

    (B ~ 0.3 μG)

- **"diffuse"**
  - $u_m \sim (7.3 \times 10^{-14})$

    (B ~ 1.4 μG)
  - $u_e \sim (6.2 \times 10^{-12})$

⇩

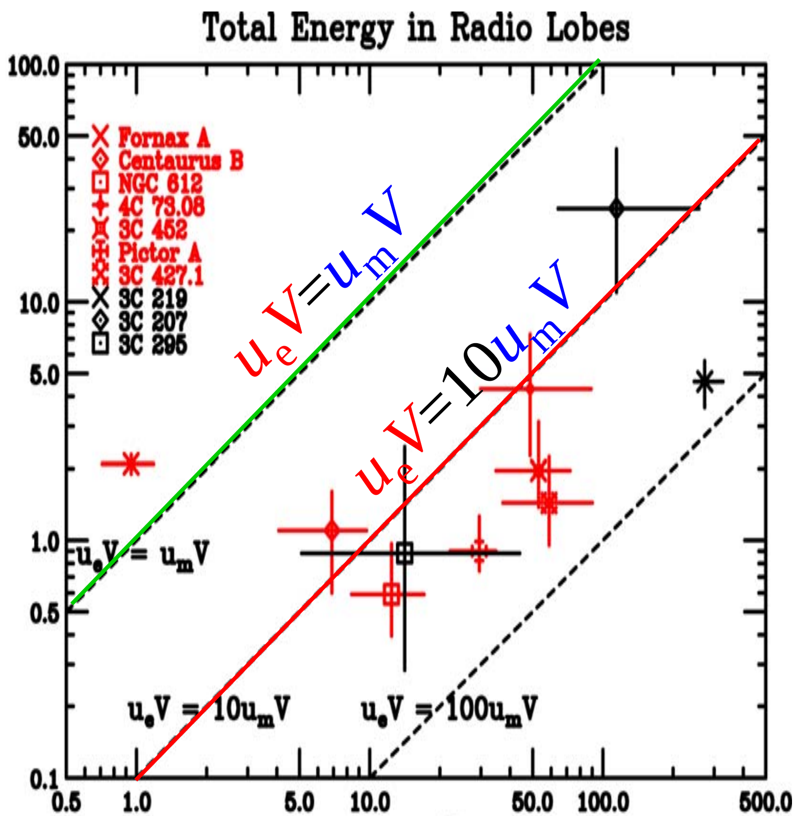
$(u_e / u_m) \sim 100$

(in average of the lobe)

The unit of energy densities are [erg cm^{-3}]

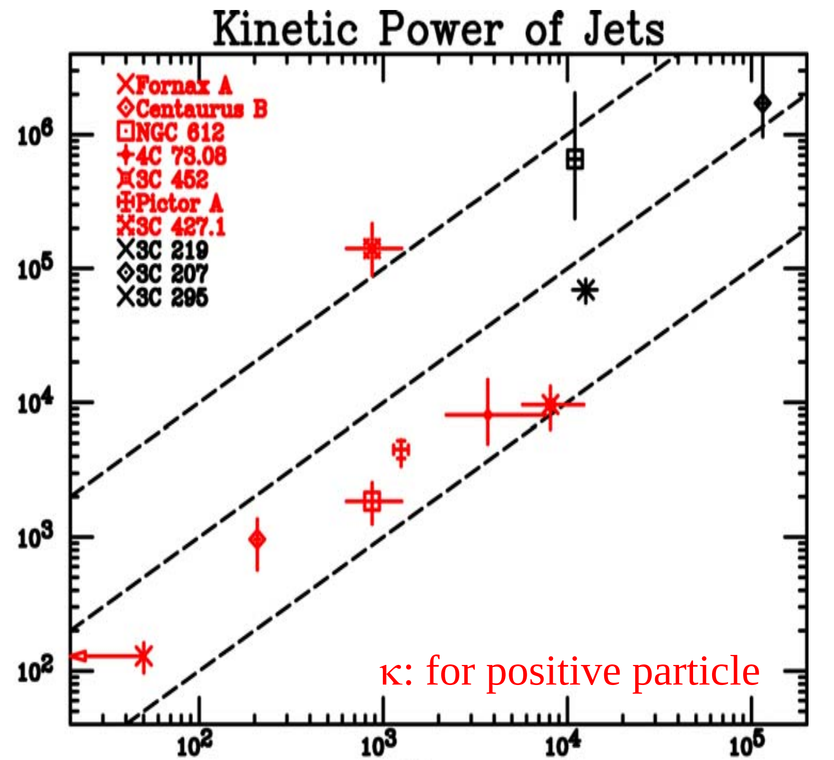
2. Summary diagrams of IC-X-ray observation from radio lobes

$L_{kin}\ \tau_{AGE} \sim u_e V + u_m V$



Magnetic Field Energy $u_m V$ [10^{58} erg]

Electron Energy $u_e V$ [10^{58} erg]



L_{kin} [$(1+\kappa)\ 10^{40}$ erg s^{-1}]

$L_{X(2\text{-}10keV)}$ [10^{40} erg s^{-1}]

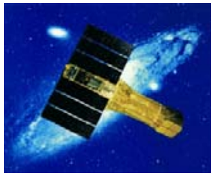
$u_e V > 10\ u_m V$

Isobe 2002
& his poster

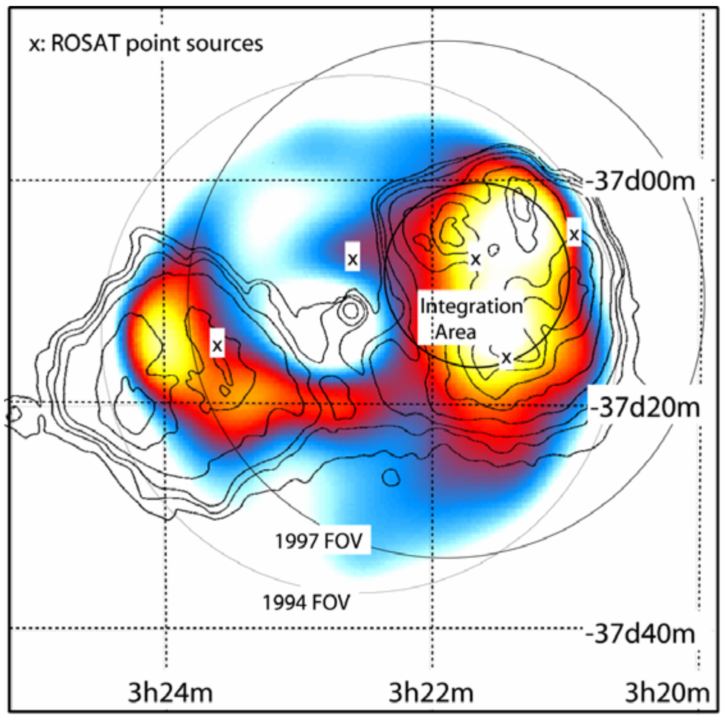
$L_{kin}/(1+\kappa) > L_{X(2\text{-}10keV)}$

3. ASCA and Chandra observations of Fornax A

A possible story of AGN

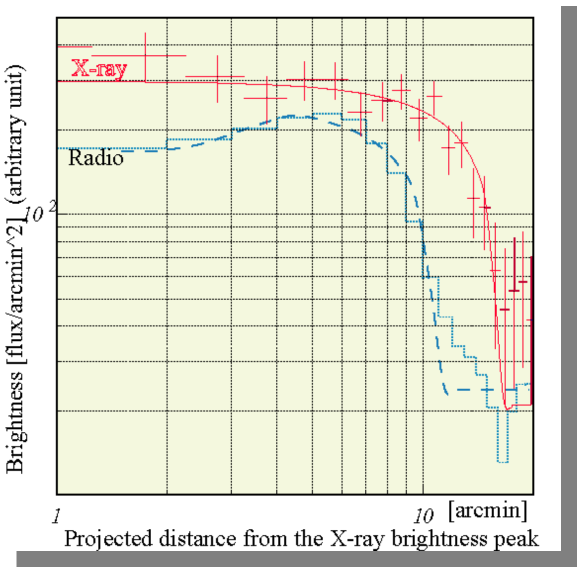


Fornax A : *ASCA*



ASCA image with overlaid VLA image
(Kaneda et al. 1995, ApJ 543, L13;
Ekers et al. 1983, A&A 127, 361
See also Feigelson et al. 1995, ApJ 448, L149)

- Brightness profile of radio ($u_e u_m$) and X-rays (u_e)

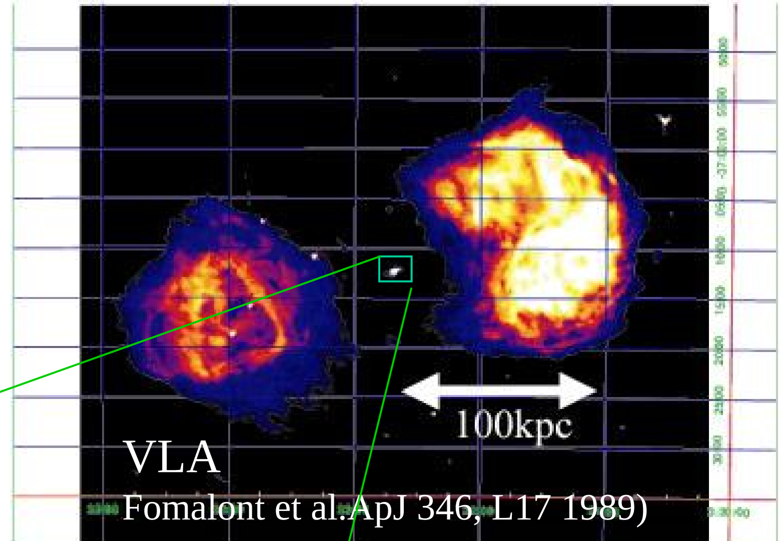


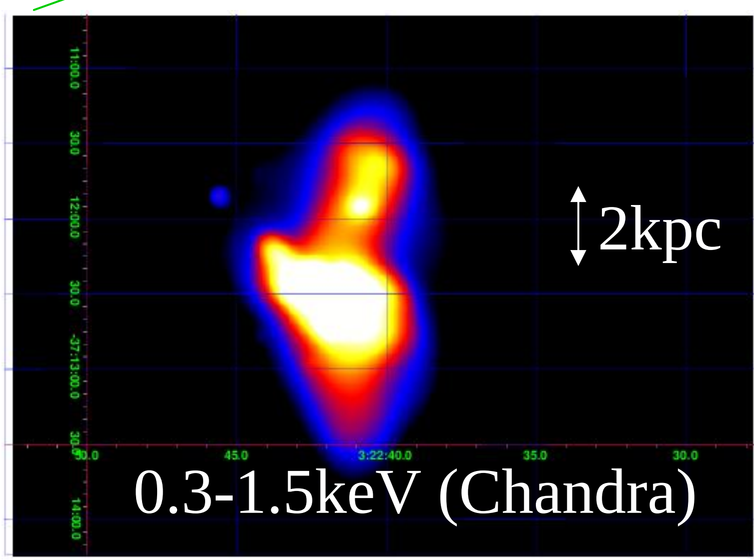
$$\tau_{lobe} = \frac{E_{electron}}{L_{sync} + L_{IC-X}} = 5.6\times10^{8}\,\mathrm{year}$$

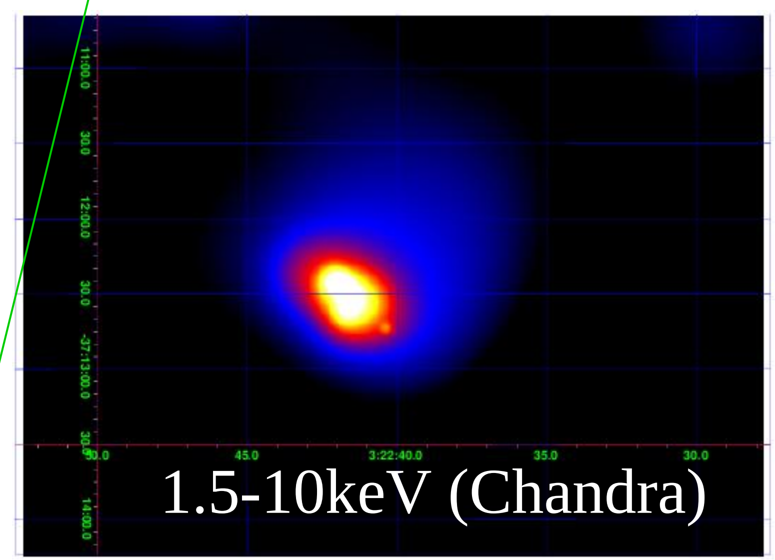
(Tashiro et al. 2001, ApJ 546, L19)

X-ray “blob” (Kim & Fabbiano 2003, ApJ 586, 826)

- An X-ray “blob”
  - 2 kpc from the galaxy
- radiates thermal X-rays
- Independent from jets or lobes
- “merging” is suggested (~ Gyrs. ago?)





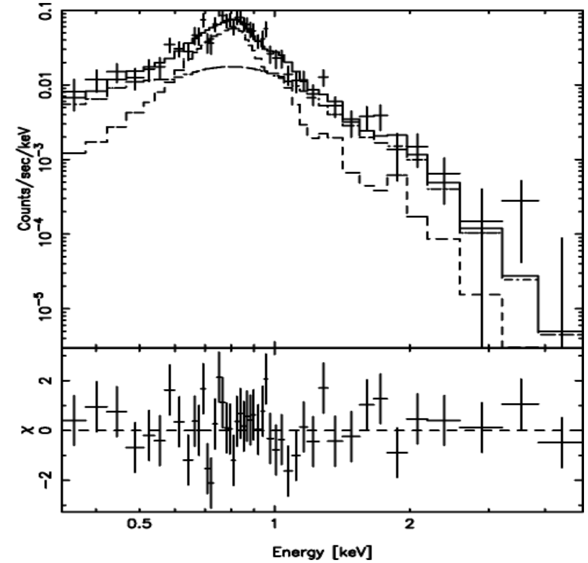


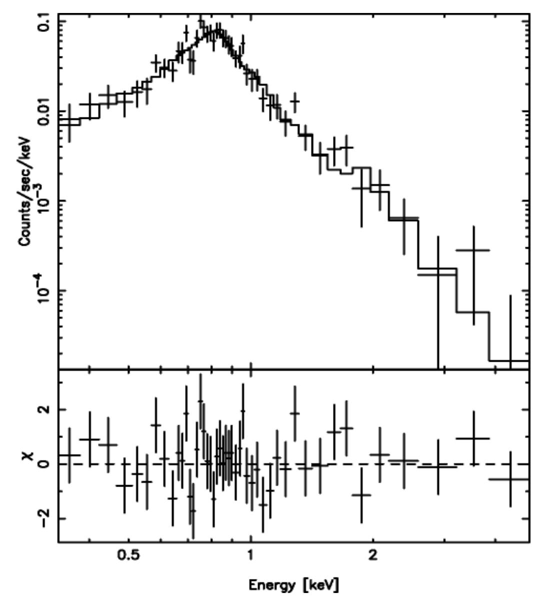
HST: Grillmair et al., 1999, AJ 117, 167

X-ray spectrum from the “blob”

- Two-temperature plasma emission
  - kT = 0.45/ 0.37 keV
- Cooling Flow model
  - kT= 0.19- 0.71 keV
  - z = 0.07

□τ_{cool}= 1-7x10^7year

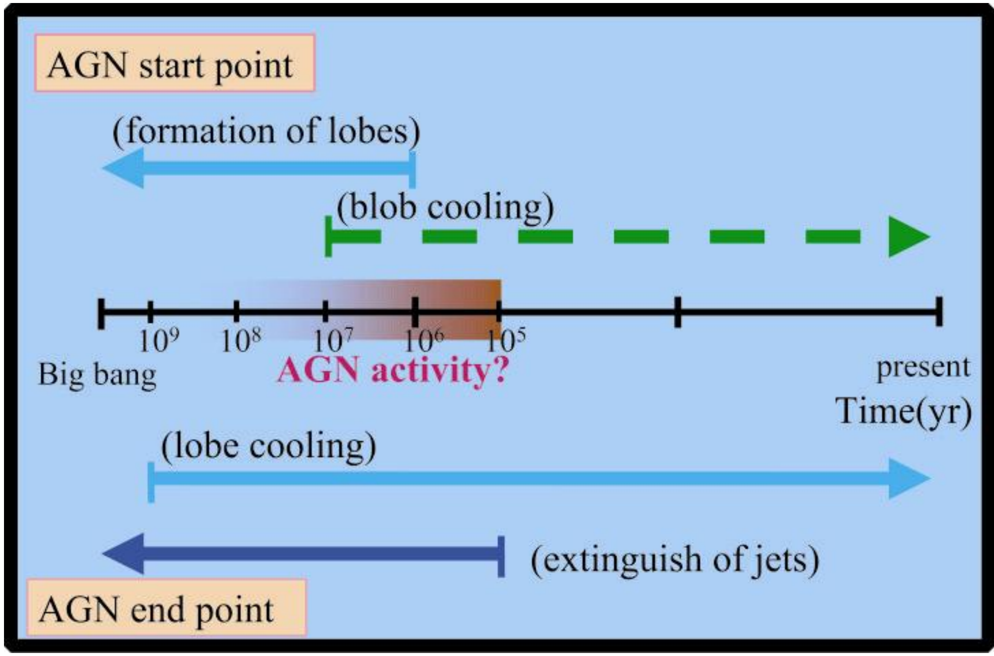




speculation:
Possible History of the nucleus activity

- Activity starts
  - lobe size → before (t-10^6)yr
  - "blob" τ_{cool} → after (t-$10^{7\text{-}8}$)yr

- Activity stops
  - "lobe" τ_{cool} → after (t-10^9)yr
  - No jet → before (t-10^5)yr



(t-10^8)yr < AGN activity < (t-10^5) yr ?

Since the total energy in the lobe ~ 10^{58} erg….,

10^{43} erg/s < L_{kin} < 10^{46} erg/s

again, comparable with the AGN radiation ?

Conclusions

- **With *ASCA*, *Chandra* and *Newton*, CMB boosted IC X-rays are observed from a number of radio lobes.**
- **The derived u_e tends to dominate u_m -- by an order of magnitude.**
- **The electron energy, $u_e V$, seems to be proportional to the nuclear luminosity, although the magnetic energy, $u_m V$ does not dependent on it.**
- **Centaurus B: particle energy u_e dominates the magnetic field u_m, but it dissipates along the "jet".**
- **Fornax A: A possible AGN history is presented.**