

# The unique X-ray features of the jet in PKS 1055+201

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Smithsonian Astrophysical Observatory

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**Relativistic Jets: The Common Physics of AGN,  
Microquasars and Gamma-ray Bursts.**

Alumni Center, University of Michigan, Ann Arbor  
14—17 December, 2005

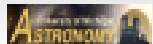
**Scientific Organizing Committee:**

Philip Hughes (UM Astronomy)	Philip Hardee (Alabama)
Joel Bregman (UM Astronomy)	Andrew King (Leicester)
Carl Akerlof (UM Physics)	Georgia Richardson (NSSTC)
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Paul Drake (UM Space Science)	Adam Frank (Rochester)
James Rossmanith (UM Math)	David Meier (JPL)

**Invited Speakers:**

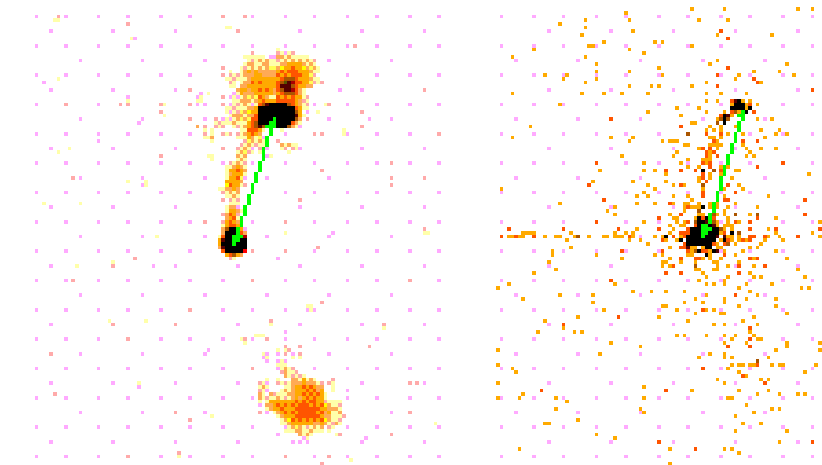
Alan Marscher (Boston)  
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Information: <http://www.astro.lsa.umich.edu/users/mctpwww/>



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## PKS 1055+201=4C 20.24



University of Michigan  
**ASTRONOMY**



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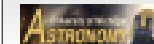
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# Outline

## 1. Context of an X-ray Jet Survey

- Flat Spectrum radio sources
- Extended radio jet longer than 2''
- Predict Detectable X-ray flux in 5ks

## 2. What is Normal About 4C20.24?

## 3. What is Remarkable About 4C20.24?

# Outline

## 1. Context of an X-ray Jet Survey

## 2. What is Normal About 4C20.24?

- X-ray Jet correlates with radio jet
- X-rays modelled as IC/CMB
- Magnetic field strength  $B$  about  $10 \mu\text{G}$ ,
- Doppler factor  $\delta$  about 6

## 3. What is Remarkable About 4C20.24?

# Outline

**1. Context of an X-ray Jet Survey**

**2. What is Normal About 4C20.24?**

**3. What is Remarkable About 4C20.24?**

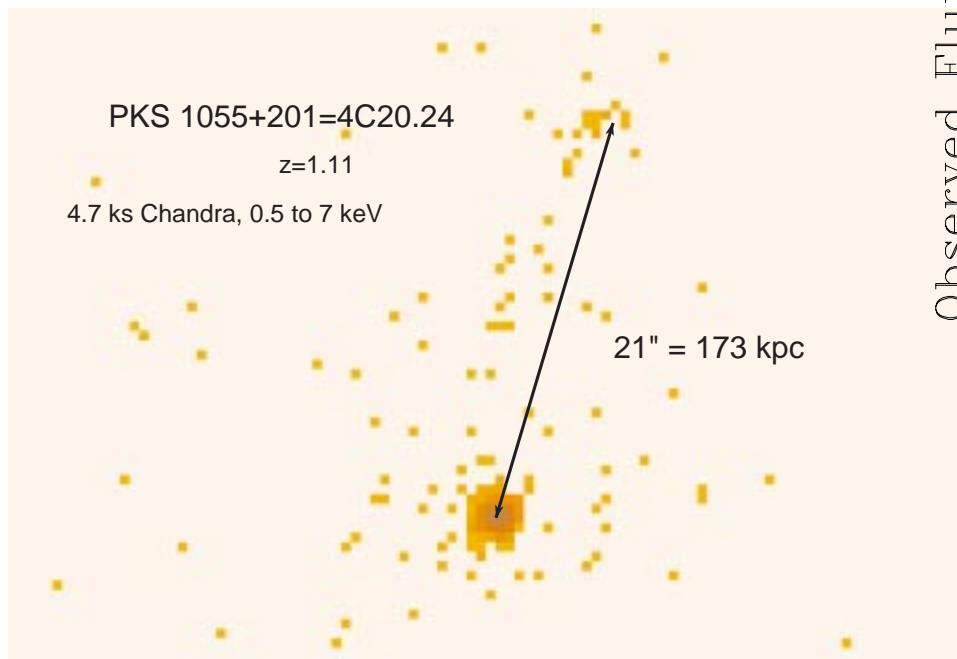
- **Extended X-ray emission symmetric around radio/X-ray jet**
- **Similar extended X-ray emission around unseen counter-jet**
- **Jets appear to be “swept” back from quasar**
- **First case of seeing both the relativistic X-ray jet and its effects on external medium?**

# The Jet Sample

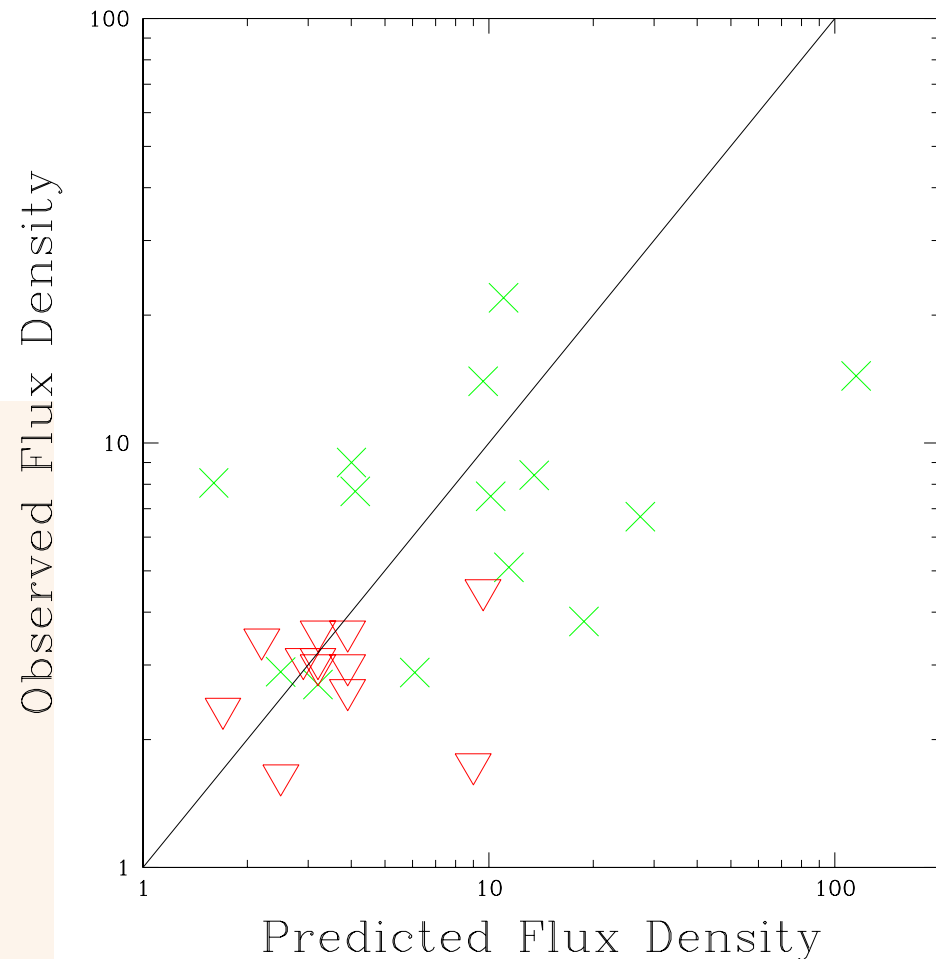
- **Flat Spectrum Quasars. Two Samples:  $S_{5\text{GHz}} > 1\text{Jy}^a$  or  $S_{2.7\text{GHz}} > 0.34\text{Jy}^b$**
- **Radio Maps with  $< 2''$  resolution have jets  $> 2''$  with detection expected by analogy to PKS 0637-752.**
- **Detected 22 of the first 37 Observed.**
- **Deeper *Chandra* Followup of 7**

<sup>a</sup>Murphy, Browne & Perley 1993

<sup>b</sup>Lovell 1997



X-Ray Jet fluxes vs Scaled Predictions



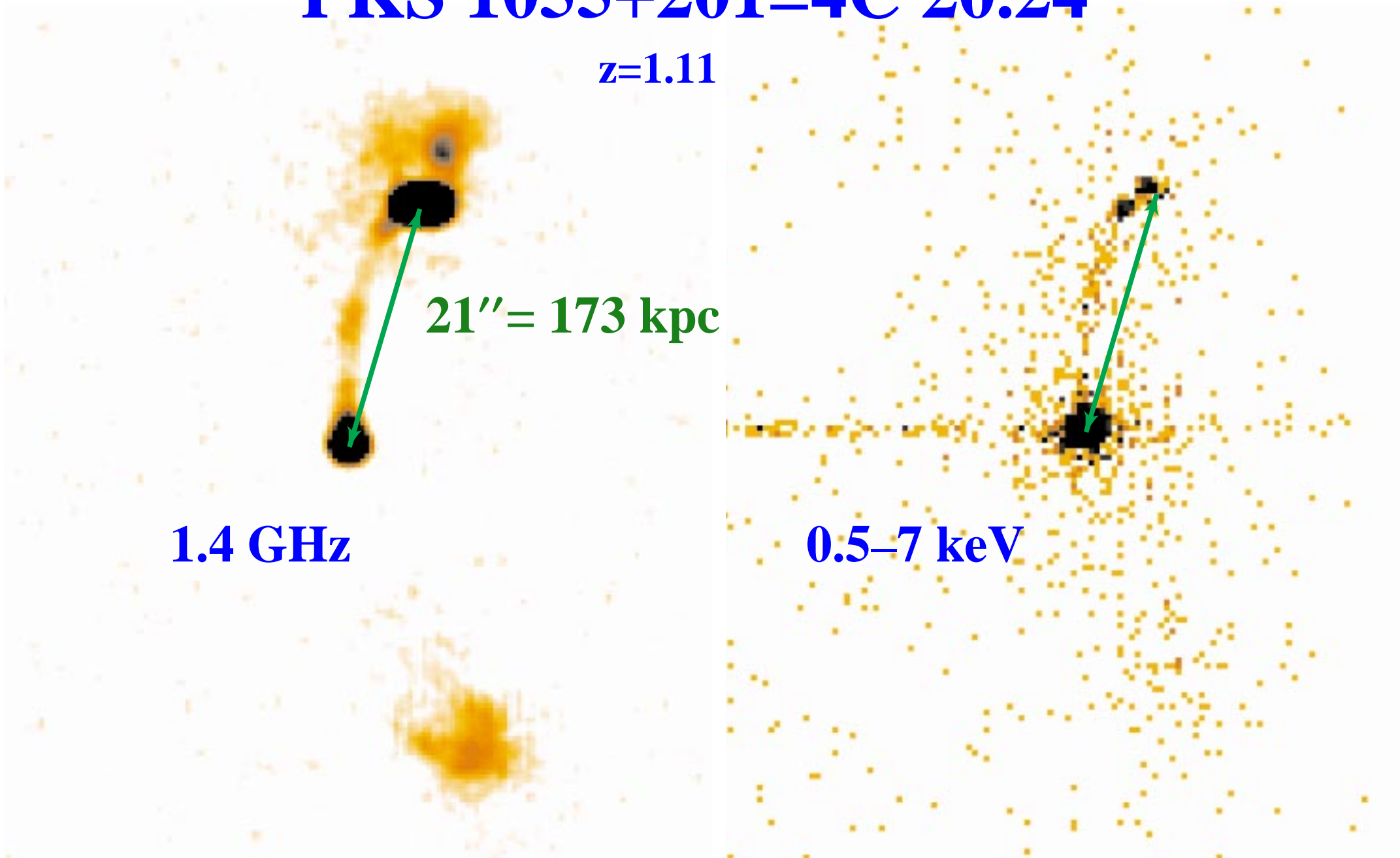
# PKS 1055+201=4C 20.24

$z=1.11$

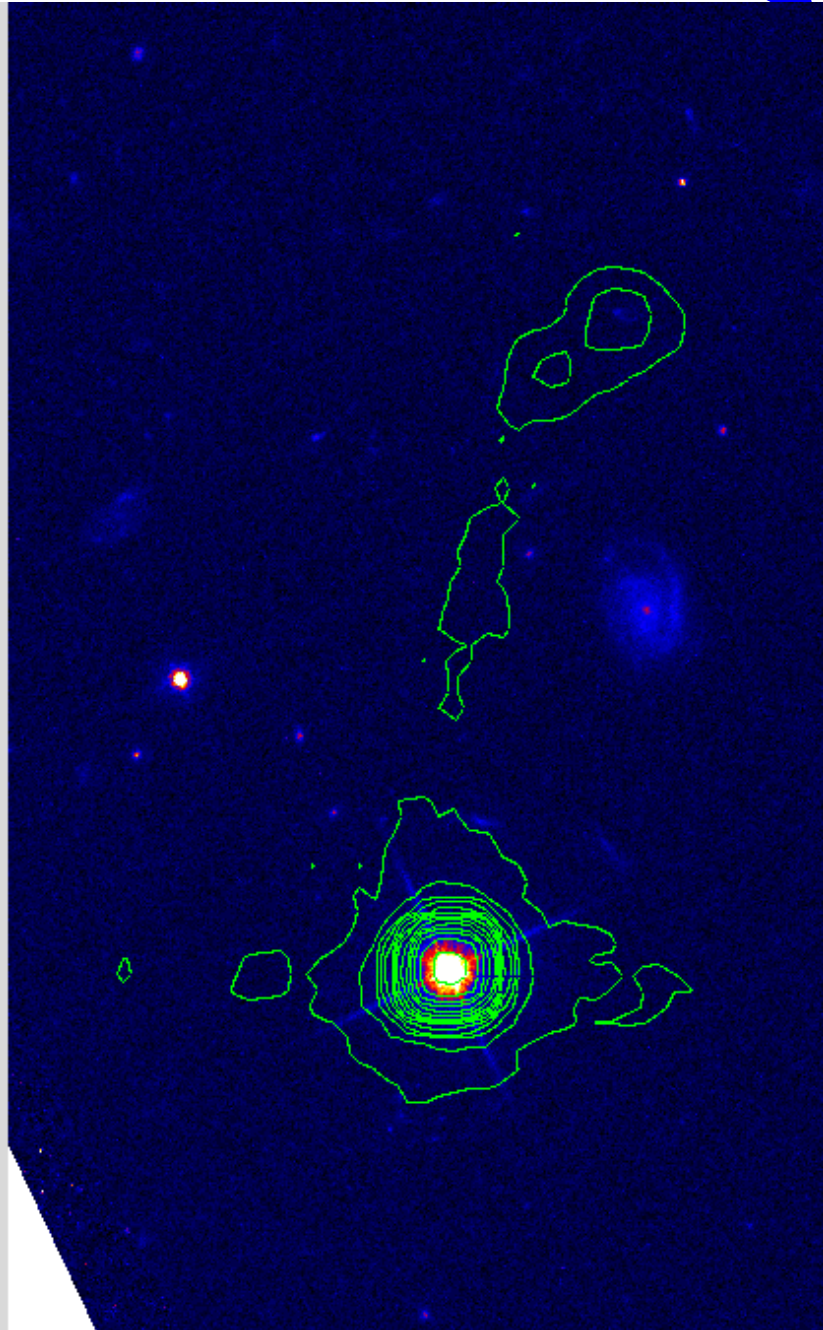
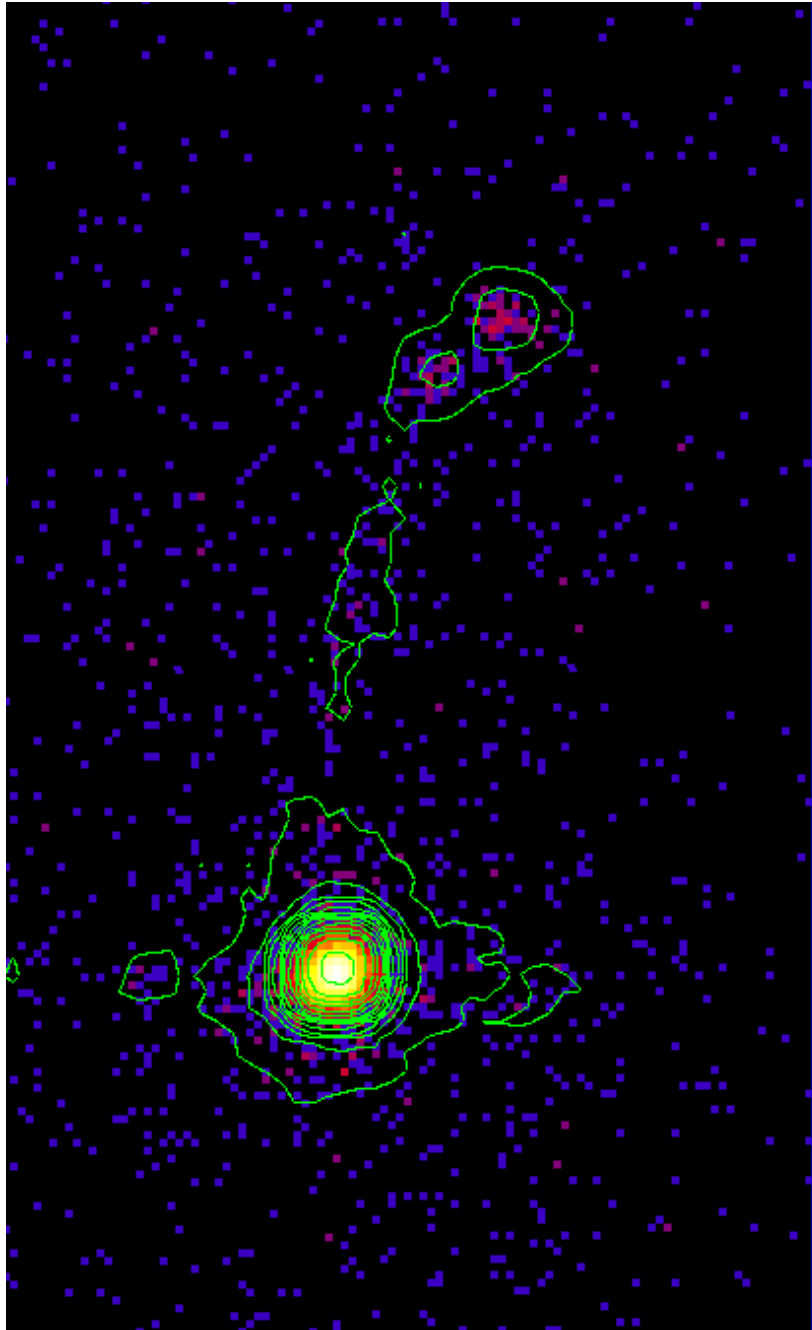
$21'' = 173 \text{ kpc}$

1.4 GHz

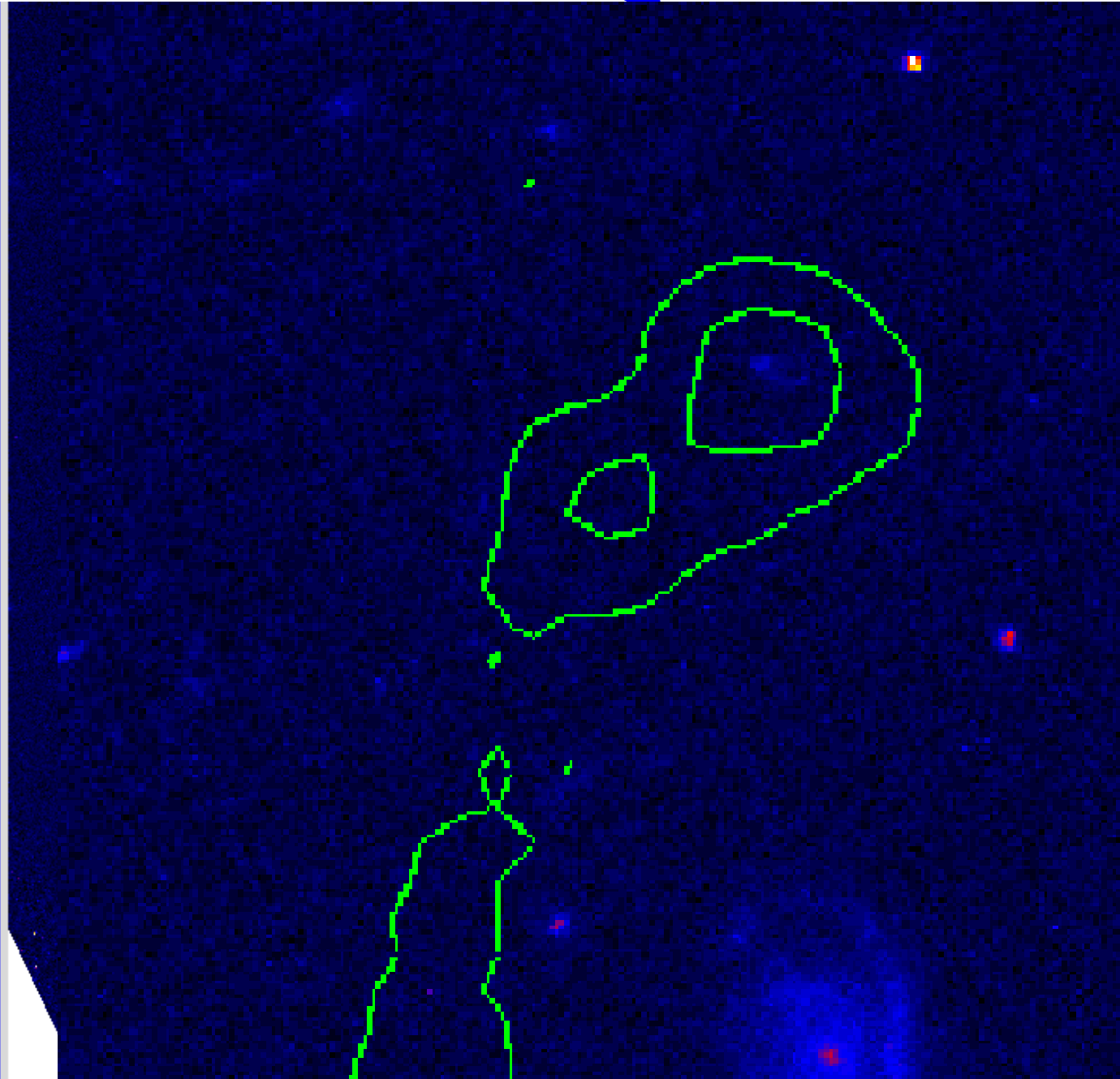
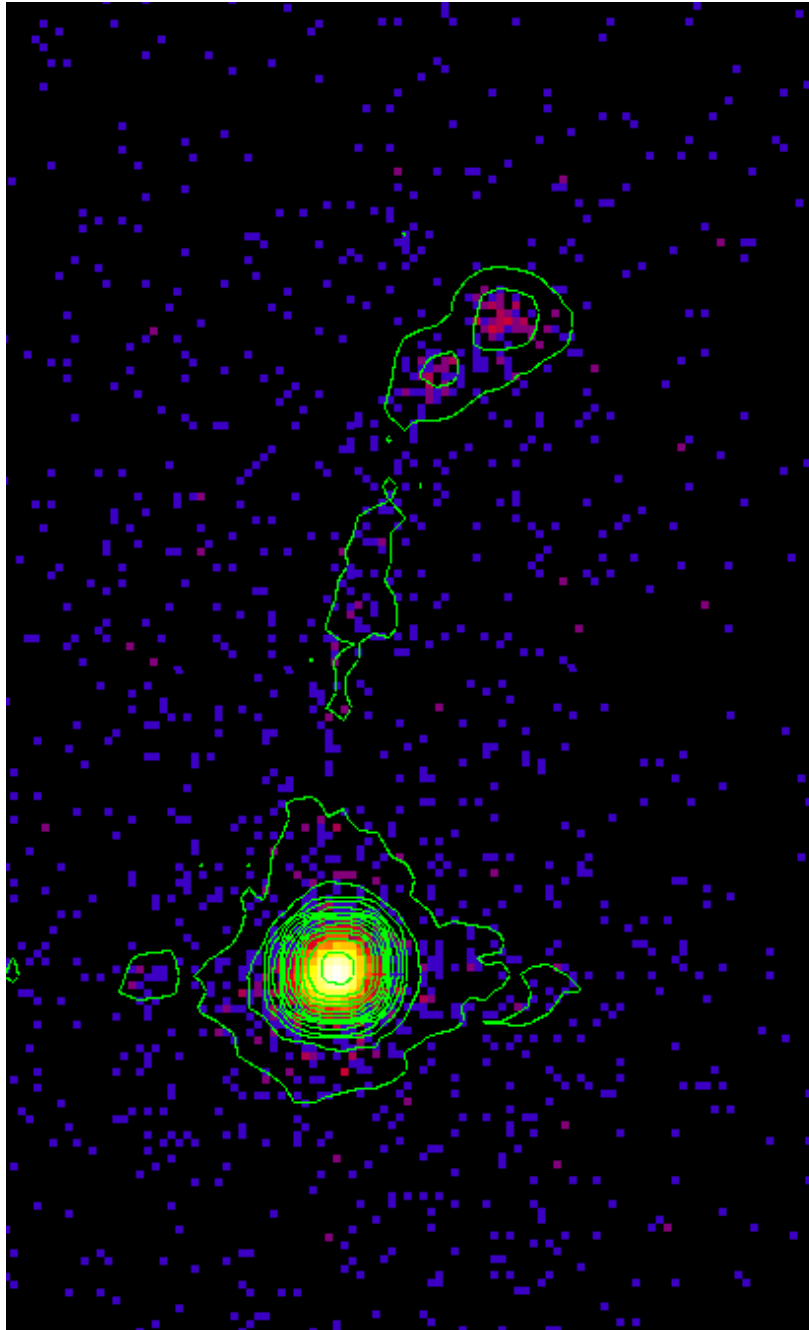
0.5–7 keV



# HST 814 image



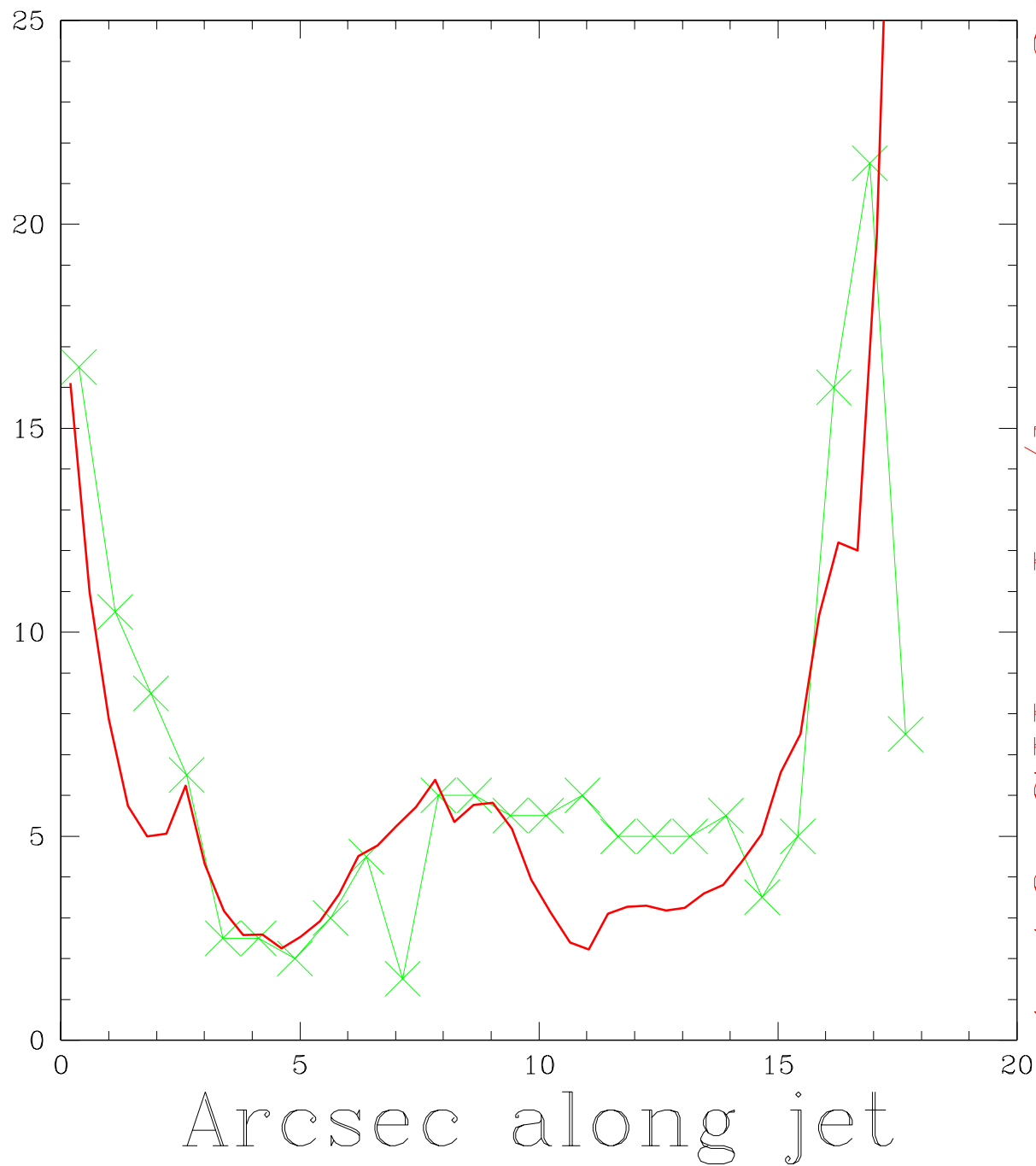
# HST 814 image



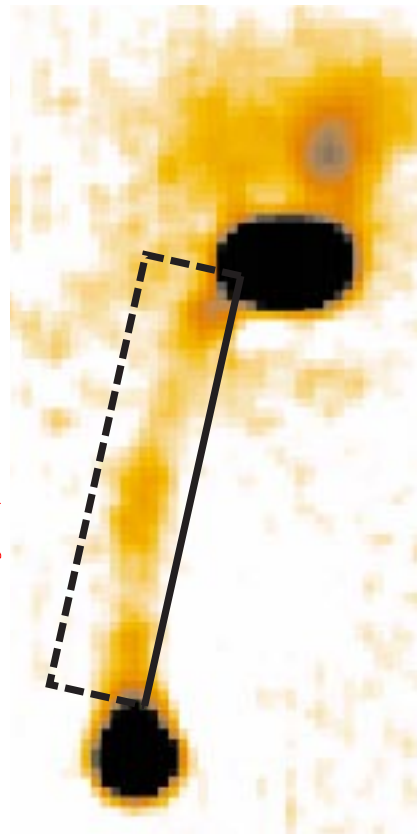
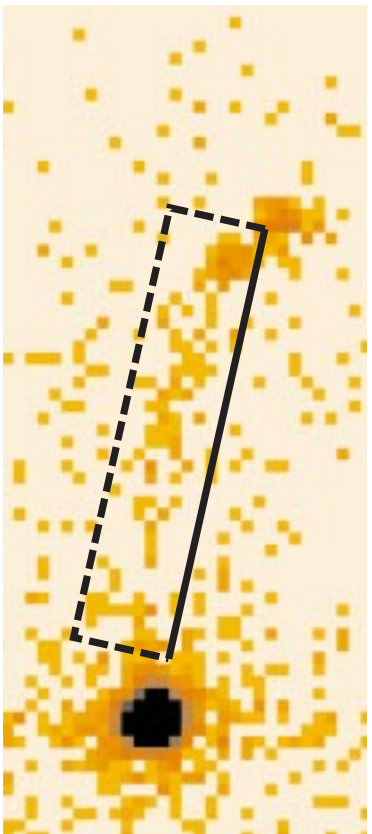


PKS 1055+201 = 4C 20.24

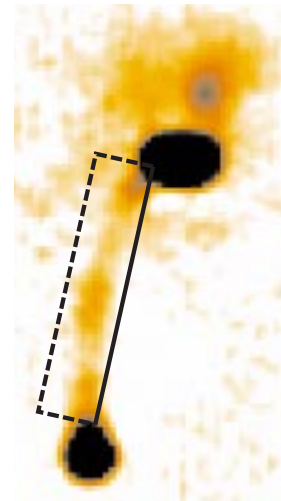
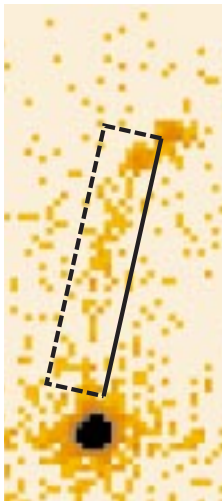
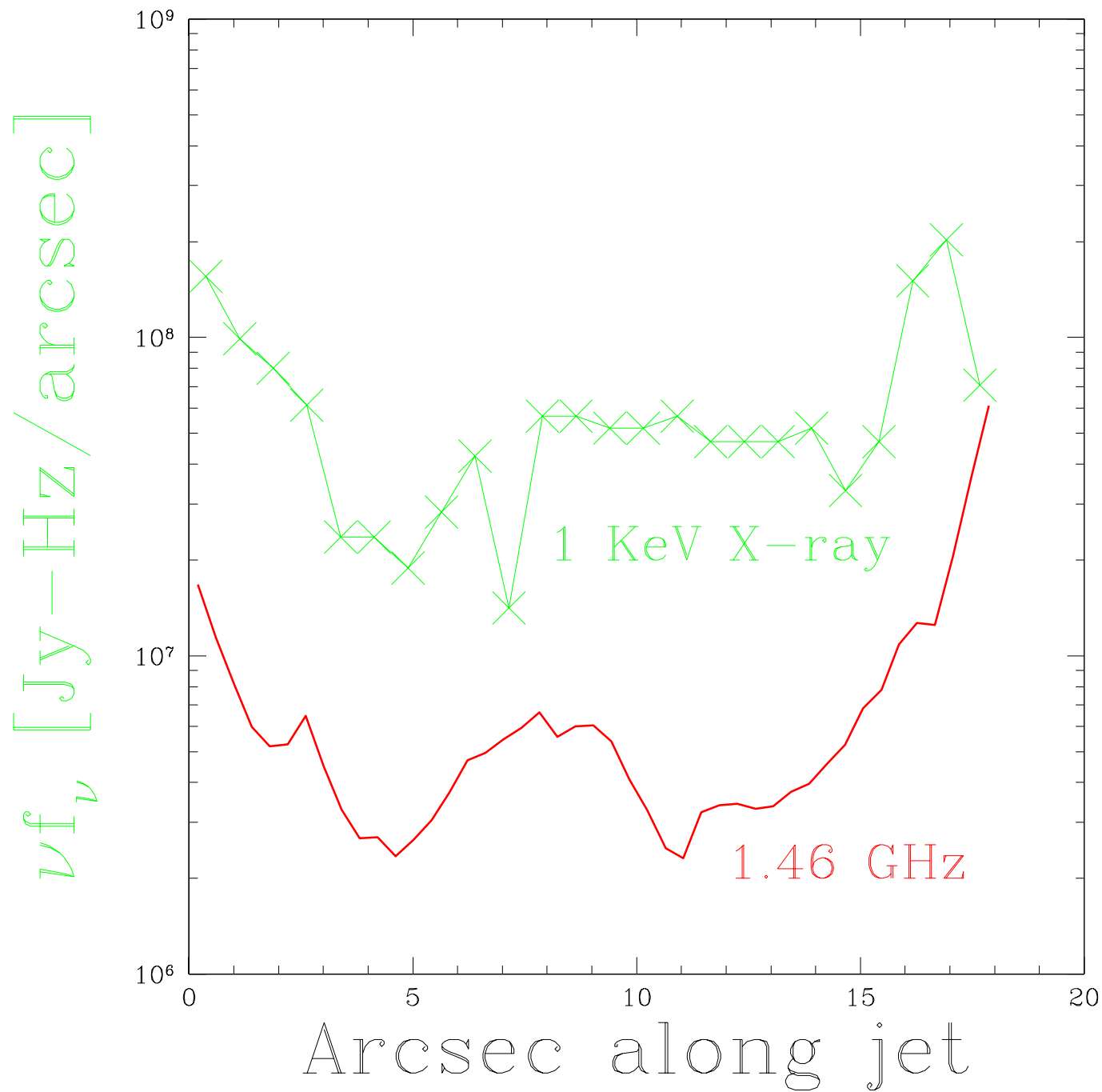
X-ray counts



1.46 GHz, Jy/beam x 200

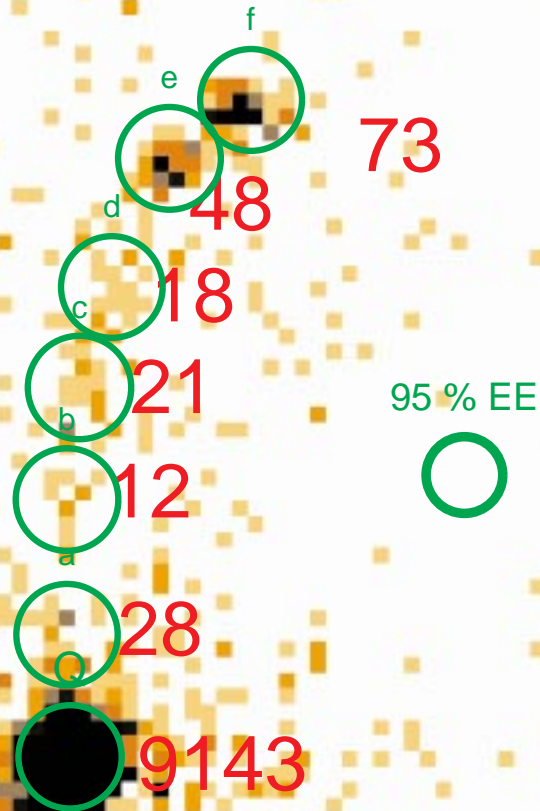


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1.46 GHz

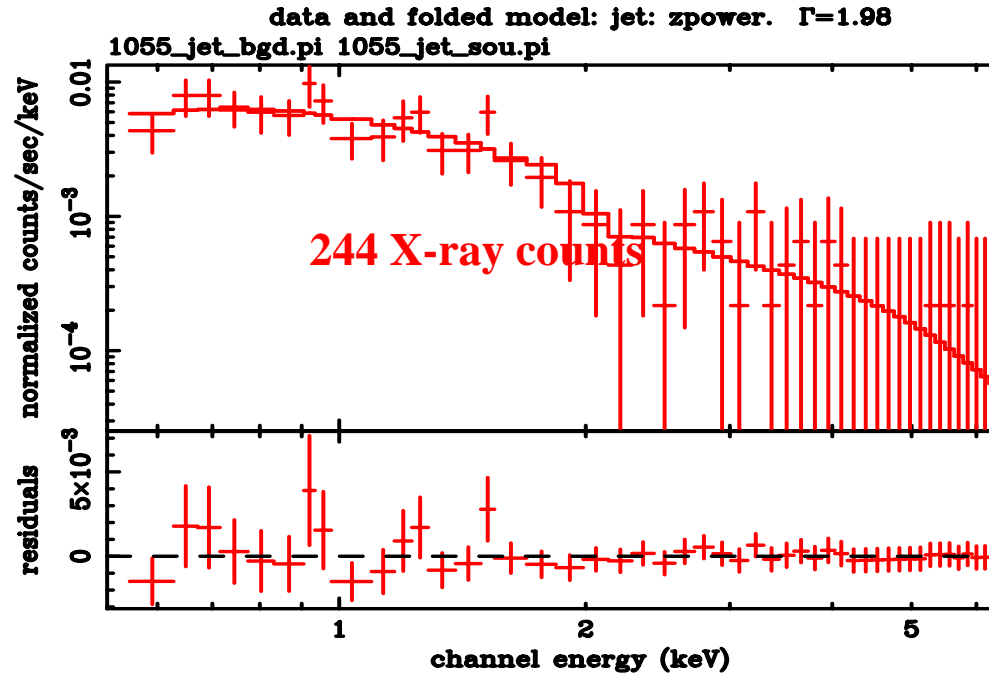
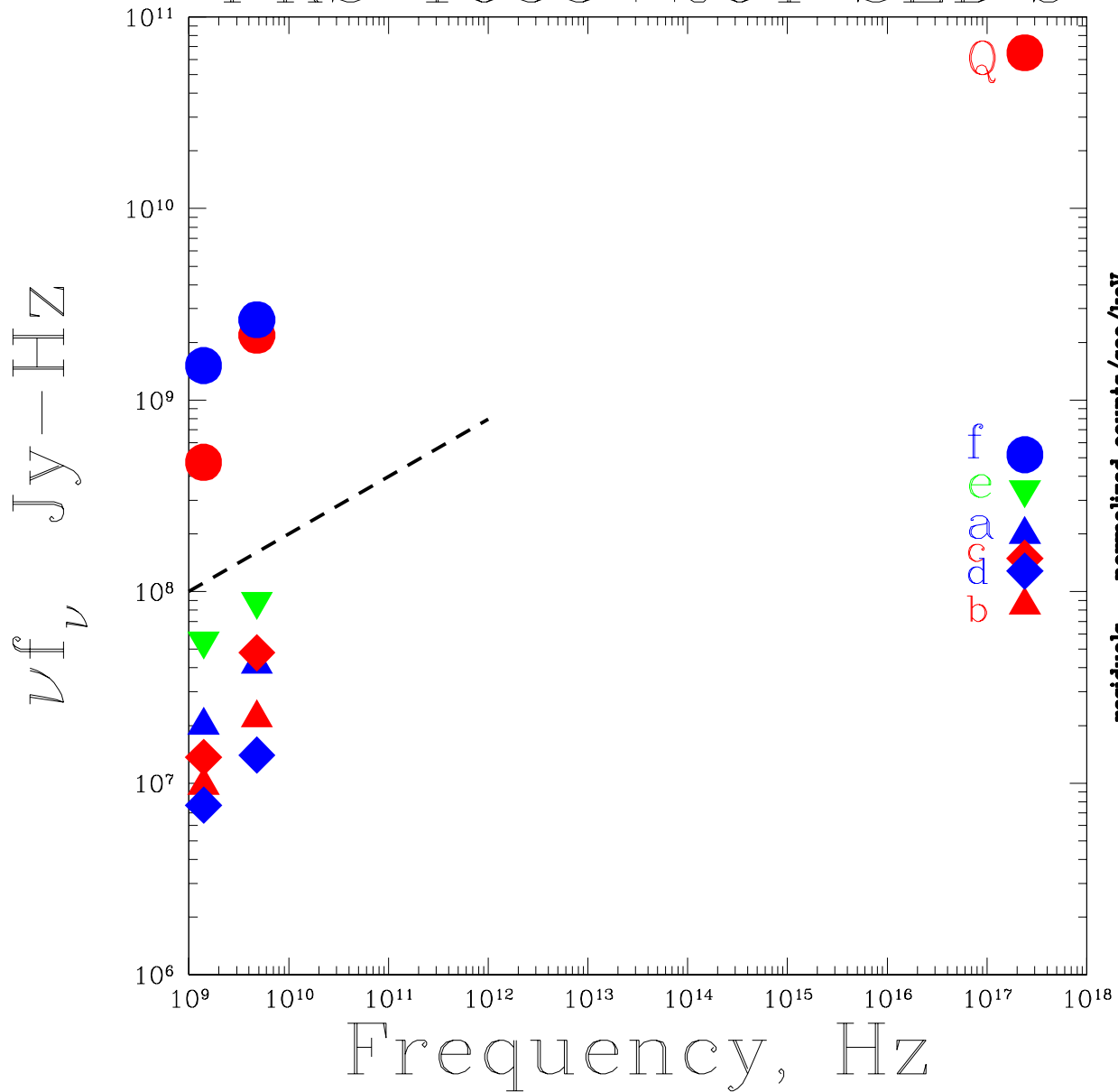
FWHM



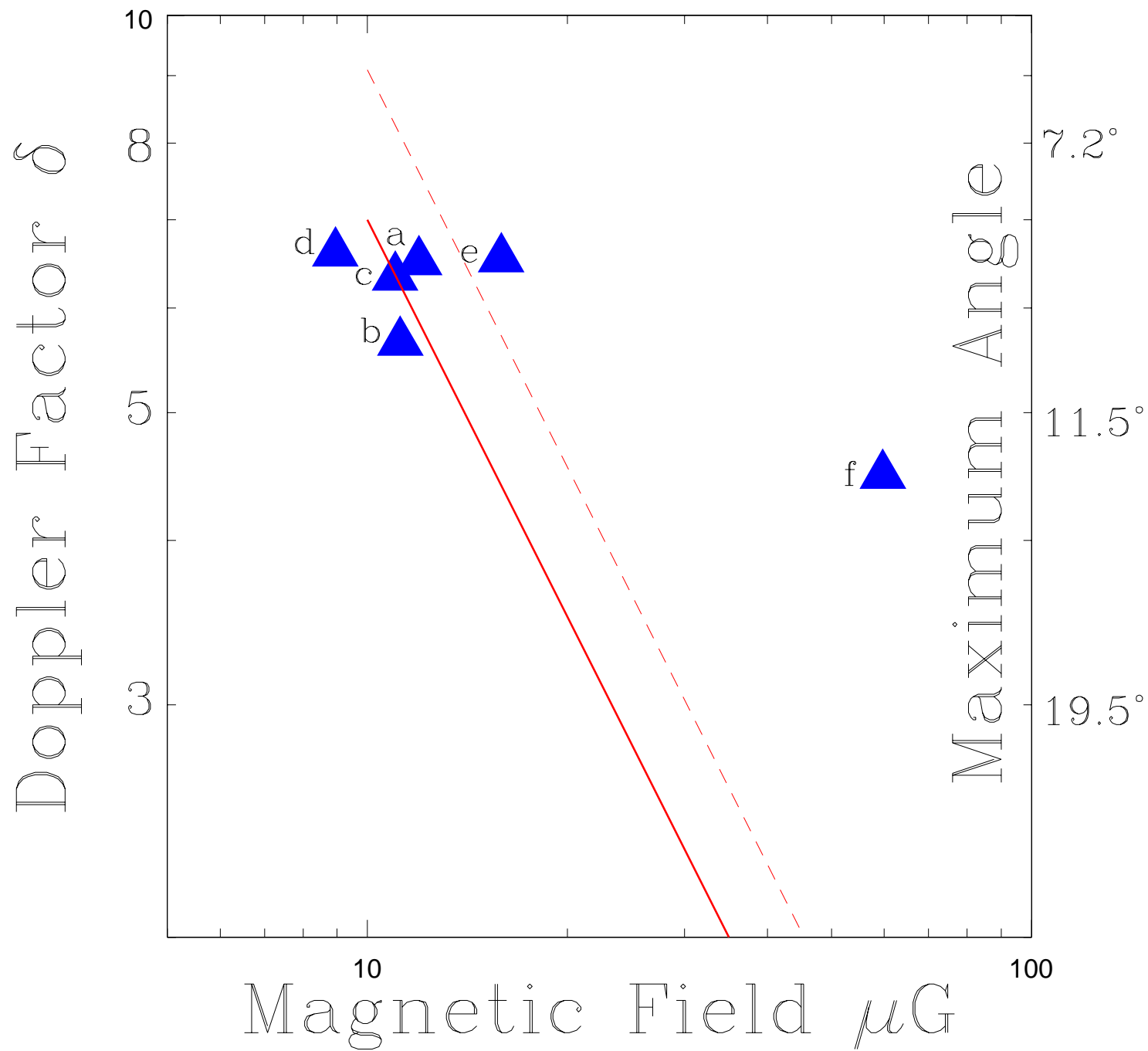
**Regions for spatially distinct SED analysis.**

# Spectral Energy Distribution for the Jet

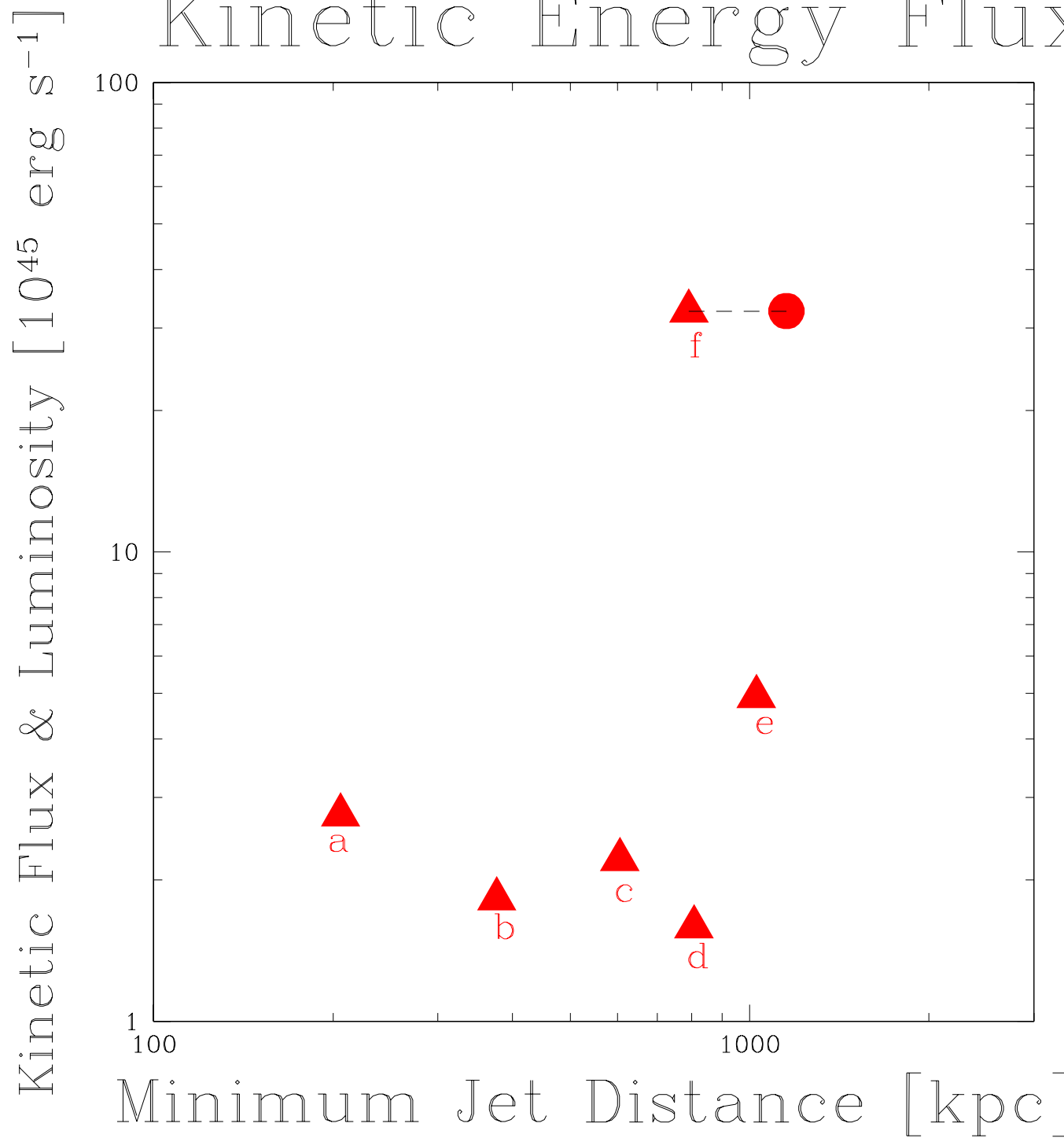
PKS 1055+201 SED's



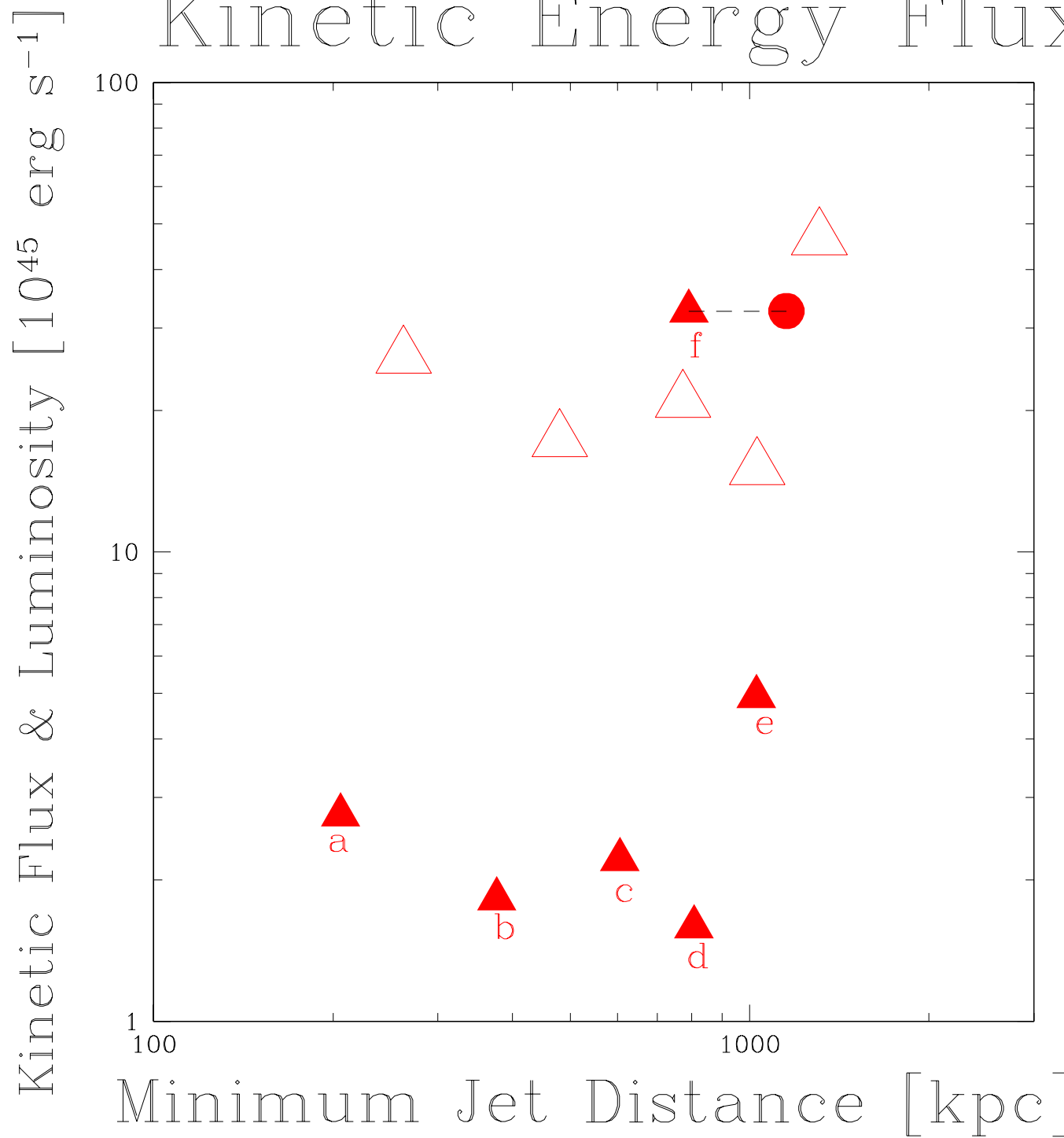
# Structure of 4C 20.24 Jet



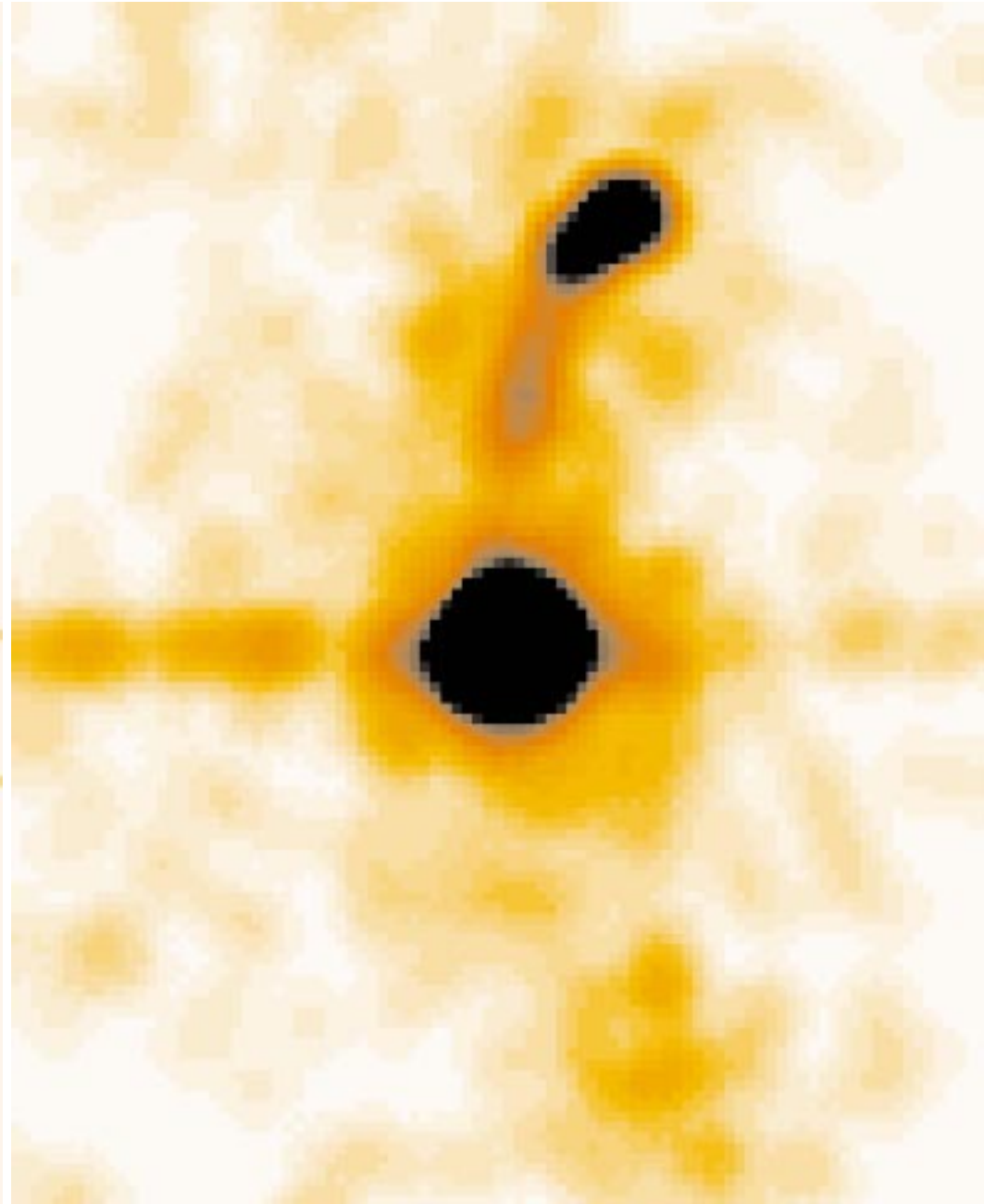
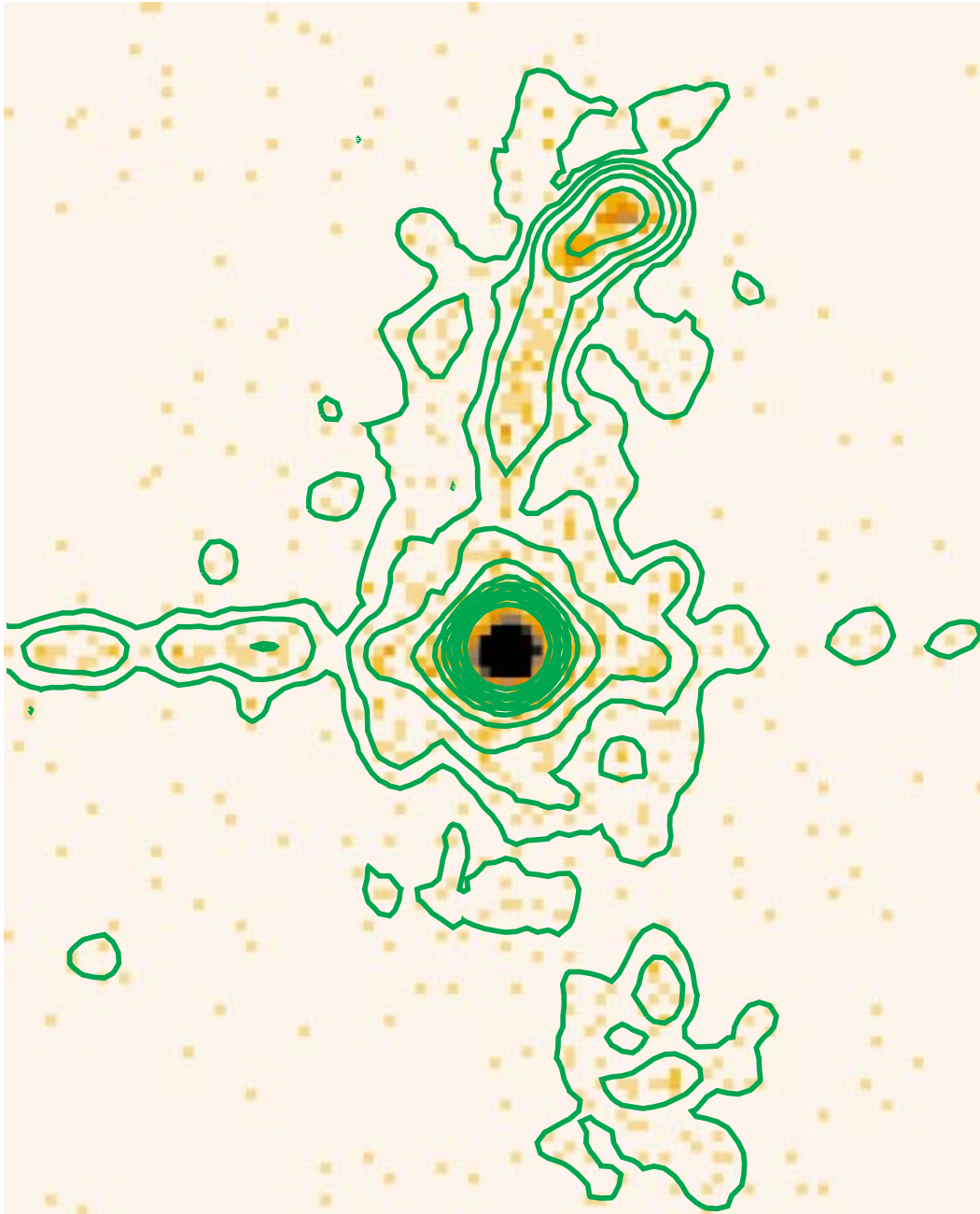
# Kinetic Energy Flux



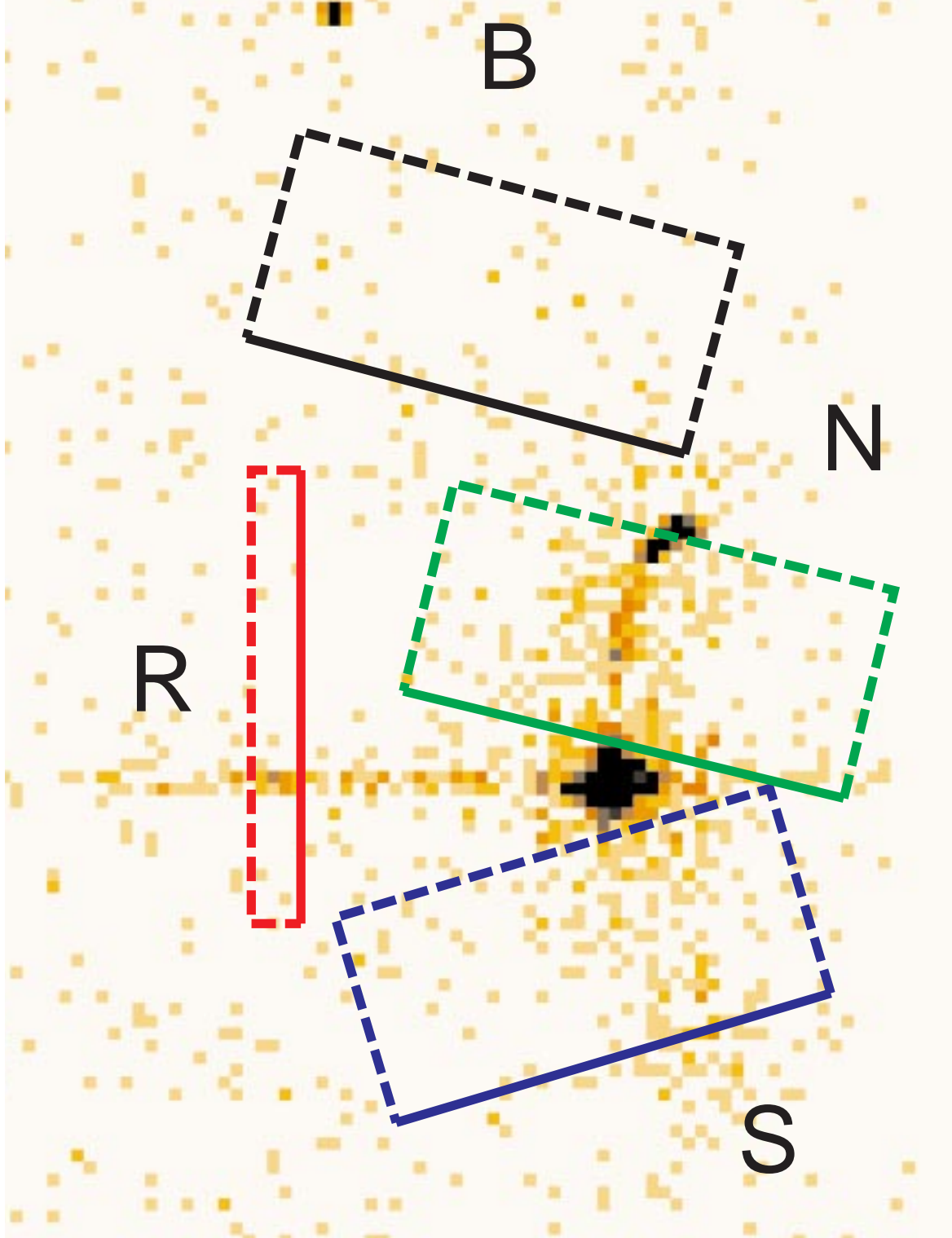
# Kinetic Energy Flux



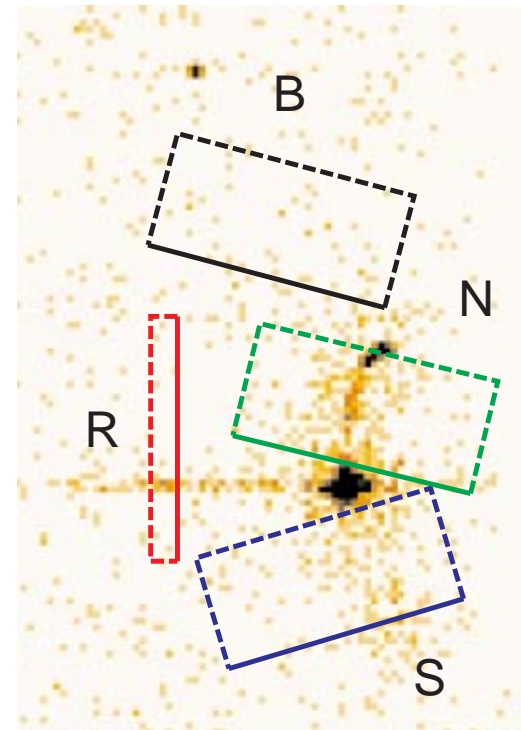
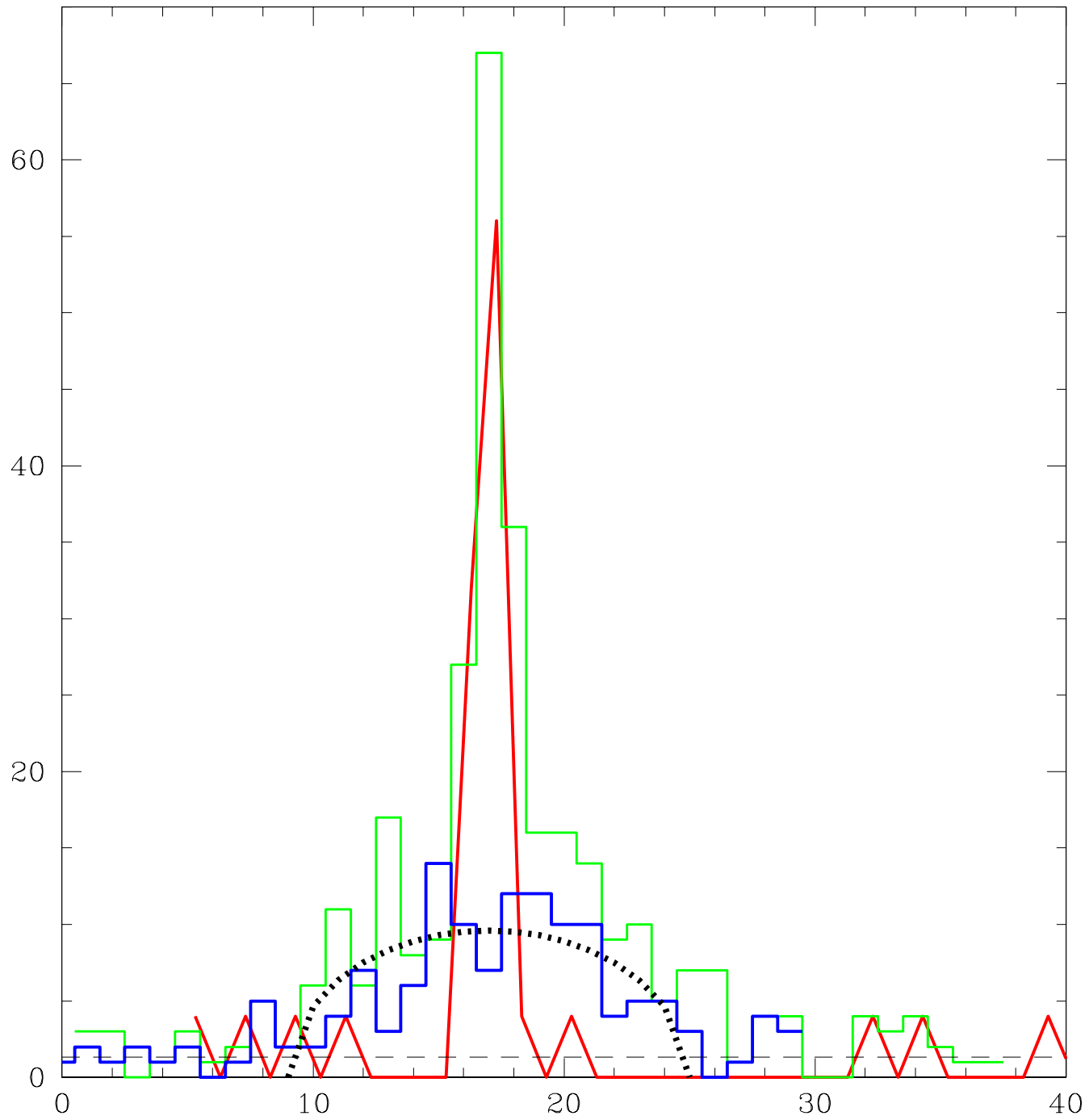
# Broad X-ray Tube Surrounds Jets

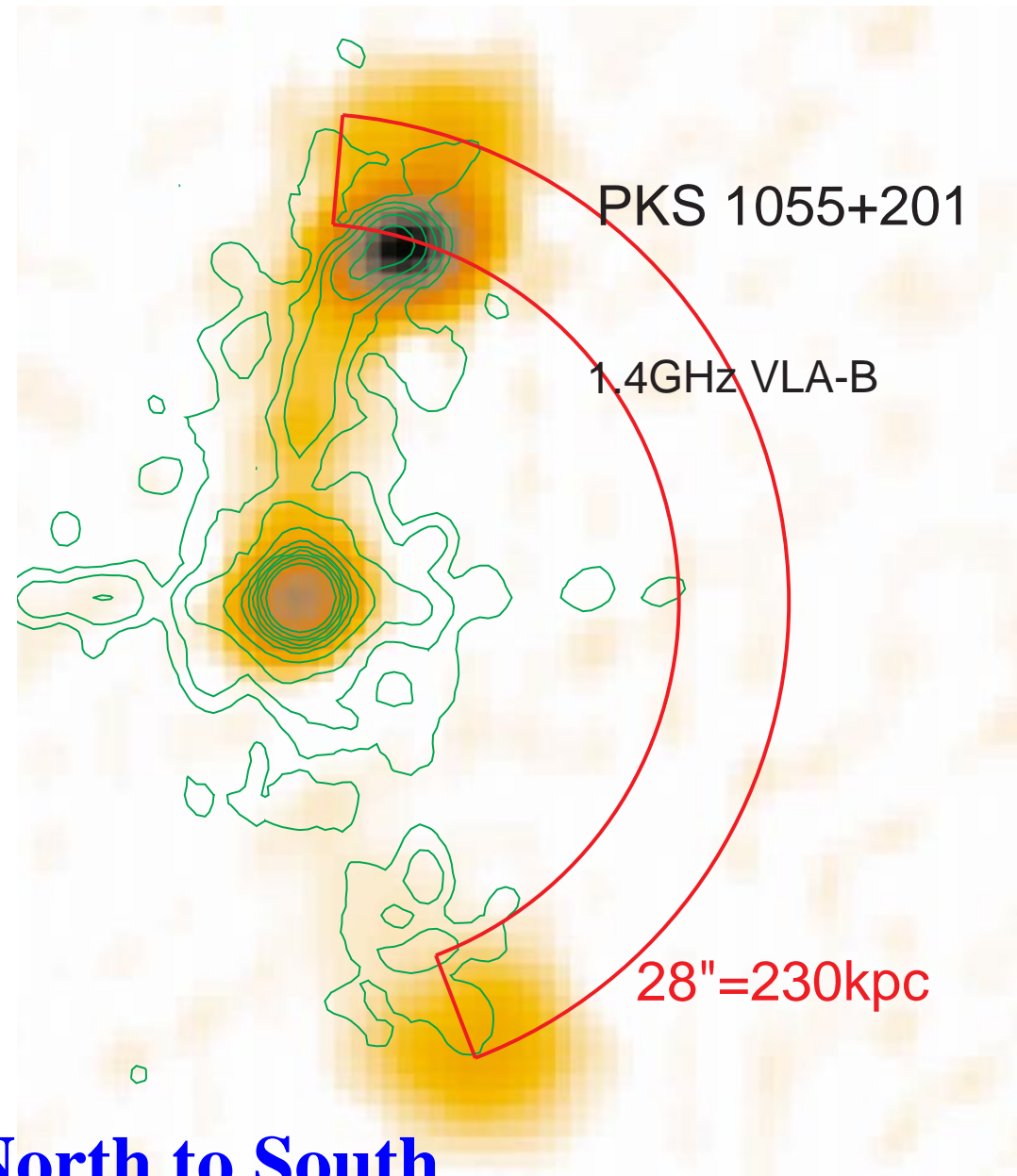
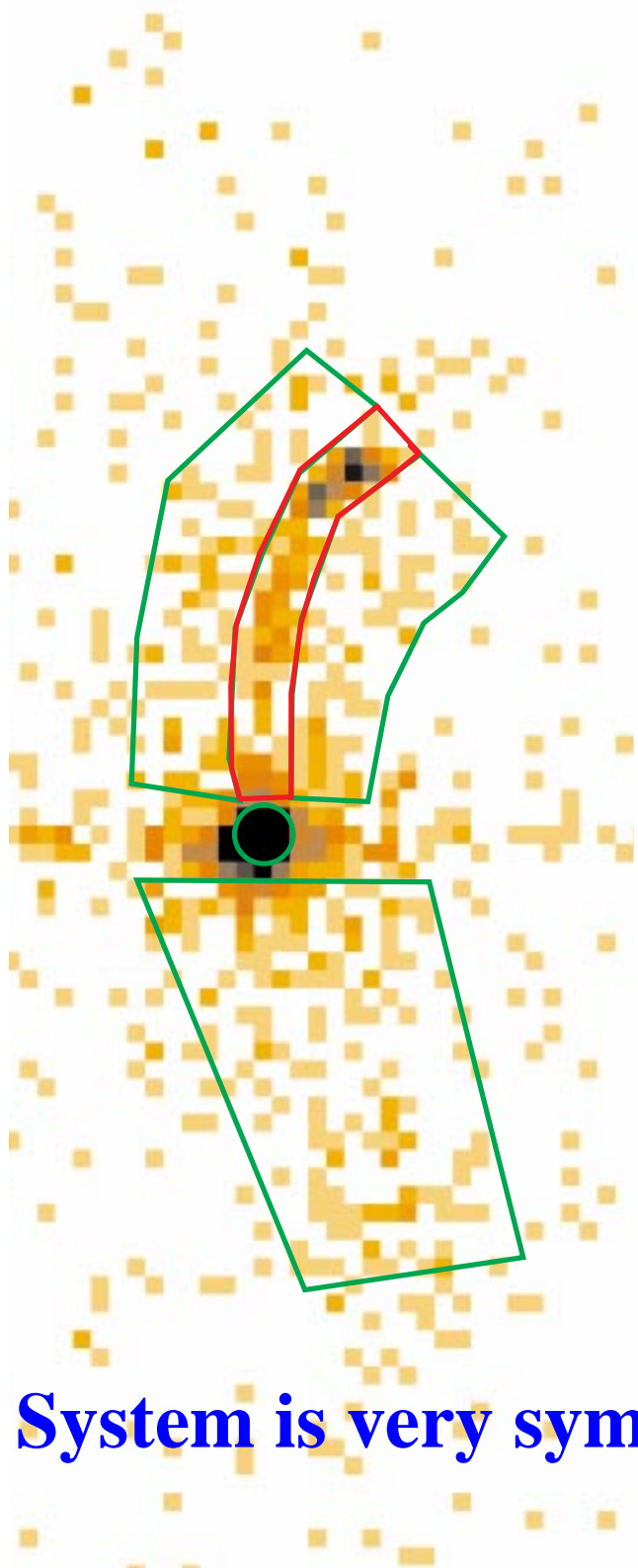






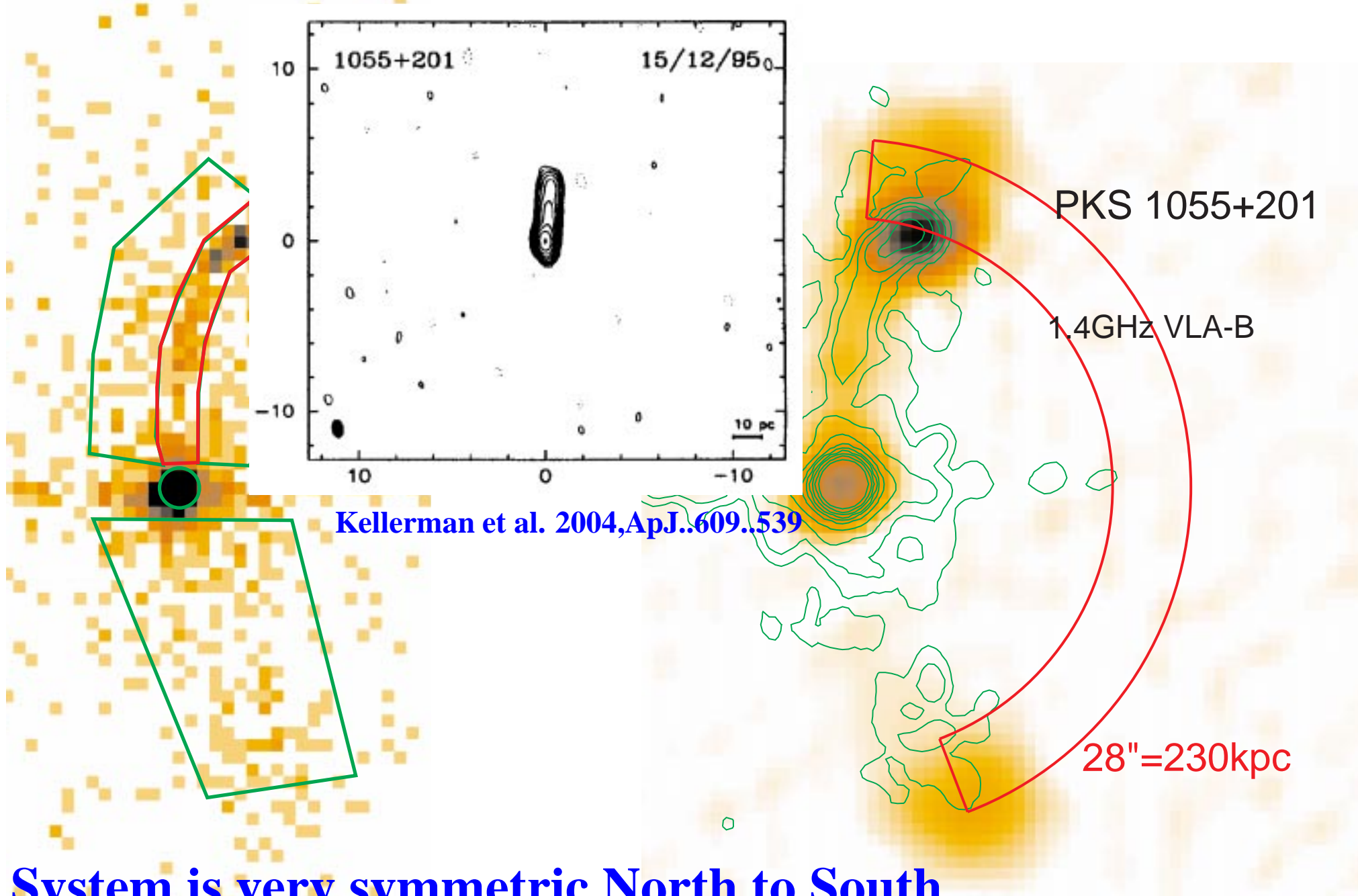
X-ray Counts





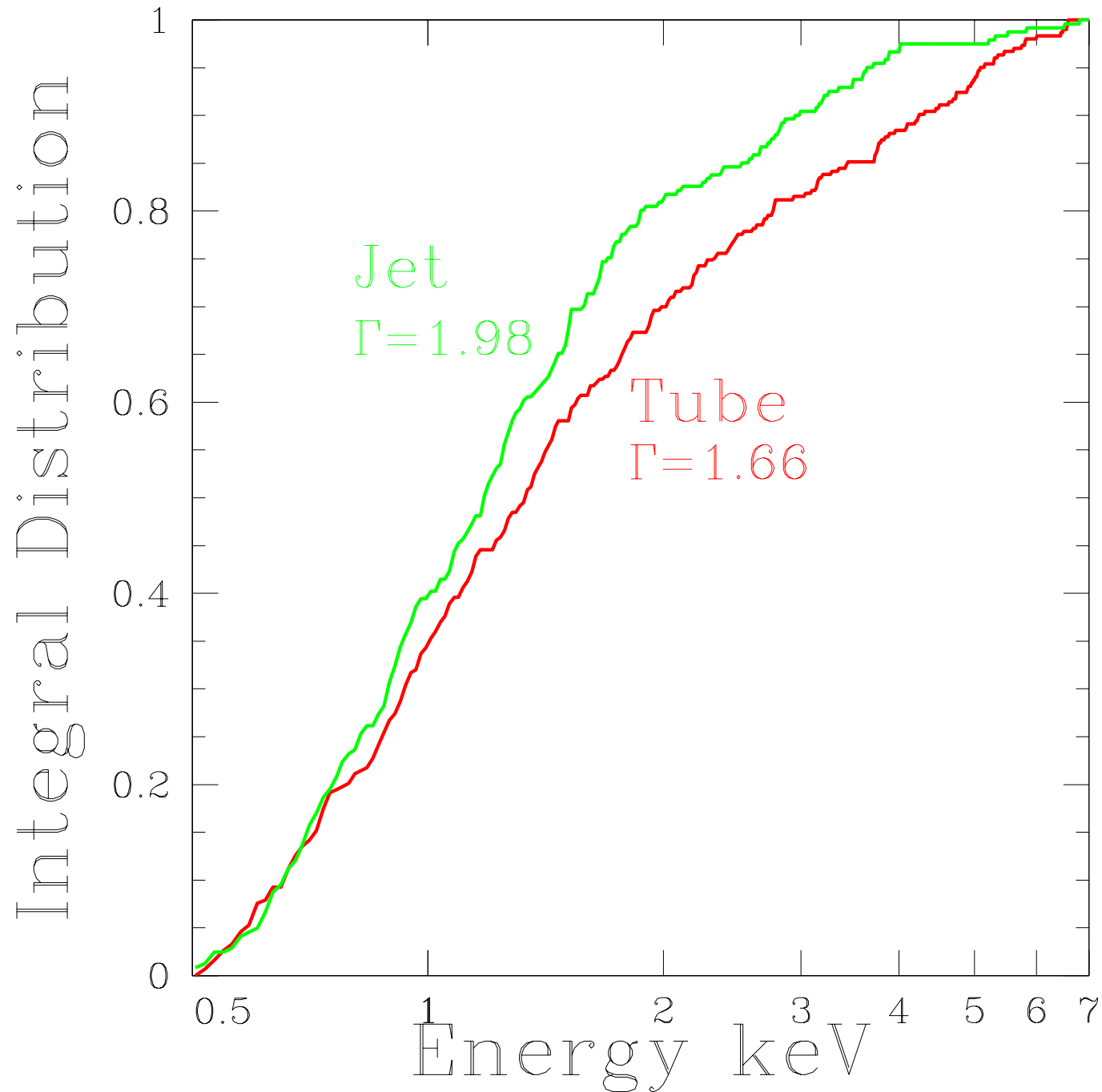
**System is very symmetric North to South**

# Both Jets are swept to West

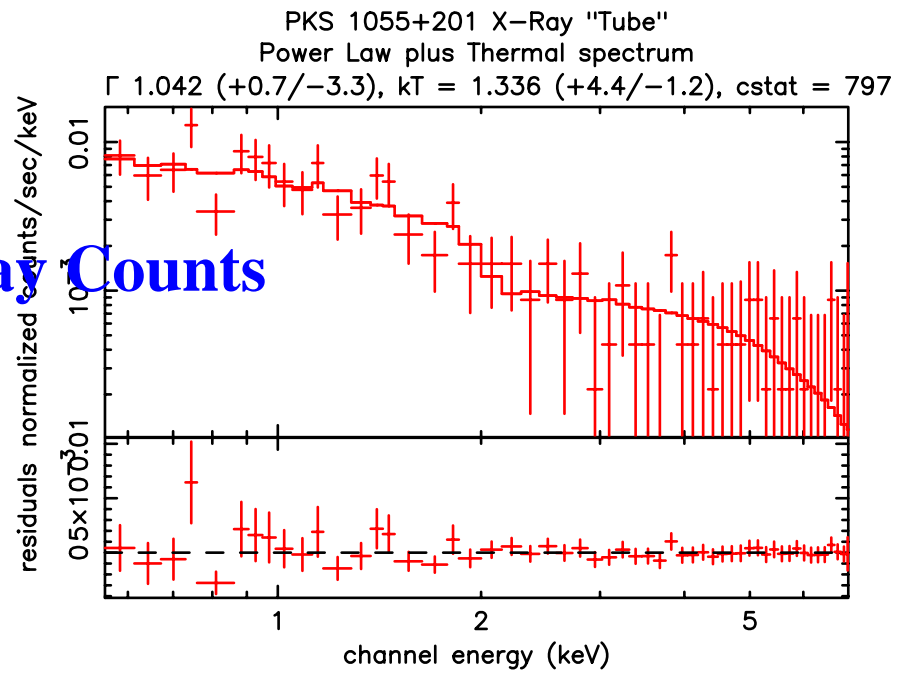
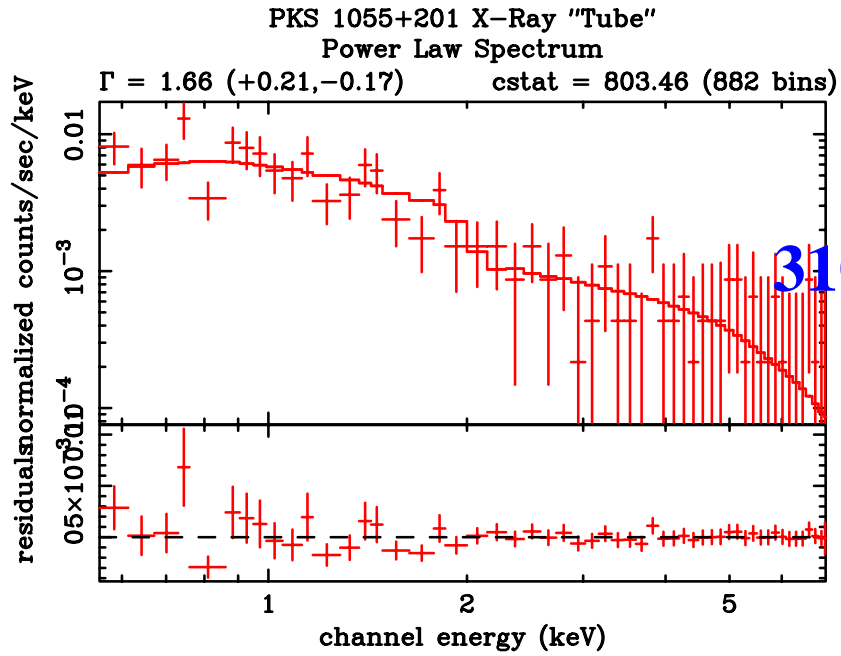


System is very symmetric North to South

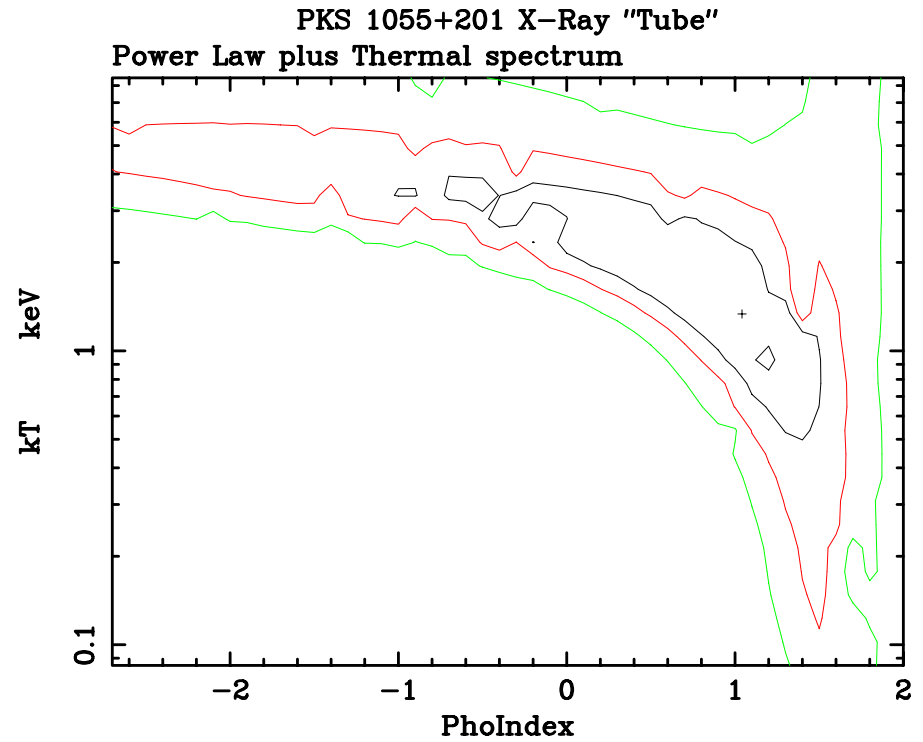
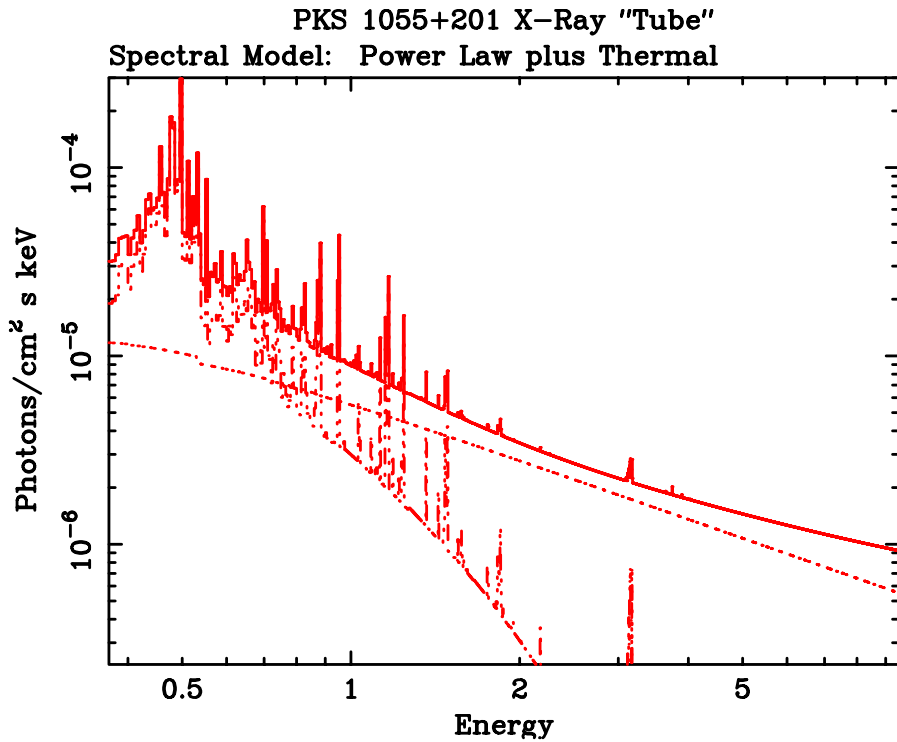
# Jet spectrum is softer than Tube spectrum



# Extended X-ray "Tube"



310 X-ray Counts



# Extended X-ray ‘Tube’

## Thermal Interpretation

$$L_x = 2.5 \cdot 10^{44} \text{ ergs s}^{-1}$$

$$kT = 1.34 \text{ keV}$$

$$n_e = 0.0054 \text{ cm}^{-3}$$

$$t_{\text{gas}} \approx 4 \cdot 10^9 \text{ years}$$

$$P_{\text{gas}} \approx 1.2 \cdot 10^{-11} \text{ dyne cm}^{-2}$$

$$P_{\text{gas}} \approx P_{\text{jet}}$$

$$U_{\text{gas}} \approx 1.5 \cdot 10^{61} \text{ ergs}$$

$$M_{\text{gas}} \approx 2 \cdot 10^{12} M_{\odot}$$

**Predict:**

**Fe Line at 3.2 keV**

**Cooler spectrum away from jet**

## Non-Thermal Interpretation

$$L_x = 5.4 \cdot 10^{44} \text{ ergs s}^{-1}$$

**Model: Electrons diffuse out of jet, into low magnetic field region, and are not in bulk relativistic motion.**

$$n_e \approx 3 \cdot 10^{-8} \text{ cm}^{-3} \approx n_e \text{ in jet}$$

**So  $1/\delta^2 \approx 3\%$  of electrons diffuse out**

**$\tau_e \approx 10^8$  yrs, against CMB**

**Radius of 65 kpc gives  $v_d \approx 300$  km/s**

**Predict:**

**Low frequency radio emission**

**Steeper spectrum away from jet**

# Summary

## 1. Detailed IC/CMB structure of a Mpc scale Jet

- Magnetic fields  $\approx 10 \mu\text{Gauss}$
- Doppler and Lorentz factors  $\approx 6$
- Angle to line of sight  $\leq 9^\circ$
- Kinetic Flux  $2 \times 10^{45} \text{ ergs s}^{-1}$
- Evidence for deceleration at terminal hotspot X-rays

## 2. Extended X-ray emitting “tube” surrounds jet

- $L_x \approx 3.4 \times 10^{44} \text{ ergs s}^{-1}$
- Gas Heated by Jet?
- Entrained material, part of jet or lobe structure?
- Electrons diffusing out of jet?

## 3. Direct Evidence of an unseen counter jet