The Remarkable X-ray Jet Structures in the Quasar 4C 20.24

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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?
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 $10 \, \mu G$
   - 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 X-ray jet and the gas it is heating?
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

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$^a$Murphy, Browne & Perley 1993  
$^b$Lovell 1997

PKS 1055+201 = 4C20.24

$z=1.11$

4.7 ks *Chandra*, 0.5 to 7 keV

21'' = 173 kpc
PKS 1055+201 = 4C20.24

- 1.4 GHz
- 15 GHz

Murphy et al. 1994, MNRAS 264, 298

PKS 1055+201 = 4C20.24

1.4 GHz

Murphy et al. 1994, MNRAS..264..298

15 GHz


β = 10

mas

year
PKS 1055+201 = 4C20.24

1.4 GHz

15 GHz

-5°

mas

year


4C 20.24, Across Jet

X-ray Counts

Arcsec

North
South
Readout Streak
PKS 1055+201

$z=1.11$

1.46 GHz

FWHM

$28''=230$ kpc

1.4GHz VLA-B

PKS 1055+201
Regions for spatially distinct SED analysis.
Spectral Energy Distribution

PKS 1055+201 SED’s

Frequency, Hz

244 X-ray counts
Structure of 4C 20.24 Jet

Doppler Factor $\delta$

Magnetic Field $\mu$G
Kinetic Energy Flux

- $K = \pi r^2 \beta c \Gamma^2 (H - \rho_0 c^2 / \Gamma)$
- $H$ is enthalpy density, $H_B + H_e + H_p$
- For equipartition,
  $H = \frac{B^2}{8\pi} (2 + \frac{4}{3} (1+k))$
- NOTE: $K$ constant $\Rightarrow (B \Gamma)^2 = \text{constant}$
Kinetic Energy Flux

- \( K \approx \pi r^2 \beta c \Gamma^2 H \)
- We take \( \Gamma \approx \delta \)
  \[
  \delta = (\Gamma(1 - \beta \cos(\theta)))^{-1}
  \]
- \( \cos(\theta_{\text{max}}) = \frac{\delta - 1/\delta}{\sqrt{\delta^2 - 1}} \)
Kinetic Energy Flux

We take:

\[ K \approx \pi r^2 \beta c \Gamma^2 H, \]

\[ U_p = U_e \]
4C20.24 Extended X-ray Emission

$L_x = 3.4 \times 10^{44}$ ergs s$^{-1}$

$kT = 2$ keV

$n_e = 0.01$ cm$^{-3}$

$t_{gas} \approx 4 \times 10^8$ years

$P_{gas} \approx 10^{-10}$ dyne cm$^{-2}$

$P_{gas} \approx 10 \times P_{jet}$

310 X-ray Counts
Summary

1. Detailed IC/CMB structure of a Mpc scale Jet
   - Magnetic fields $\approx 10 \, \mu$Gauss
   - Doppler and Lorentz factors $\approx 6$
   - Angle to line of sight $\approx 9^\circ$

2. Extended X-ray emitting region
   - $L_x \approx 3.4 \times 10^{44} \, \text{ergs s}^{-1}$
   - Gas Heated by Jet?
   - Entrained material, part of jet structure?

3. Direct Evidence of an unseen counter jet