# Chandra Observations of the Extended X−ray Structure of Relativistic Jets

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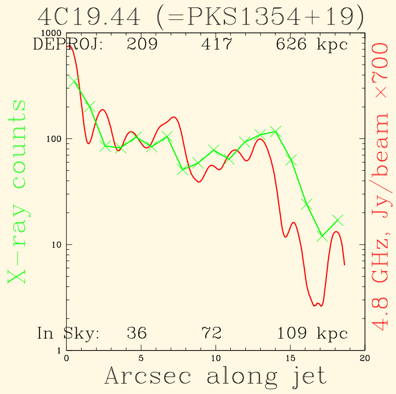
# Challenges of Relativistic Jets:

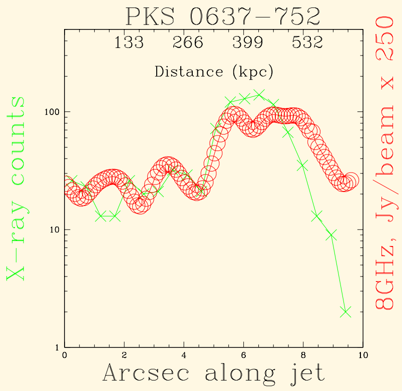
Q: How can the X-ray to Radio flux remain roughly constant over great distances?

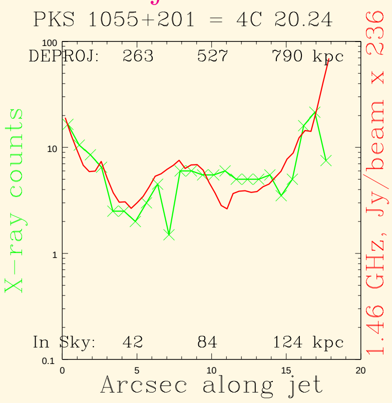
A: Ratio is less sensitive to parameters if X-rays are IC/CMB!

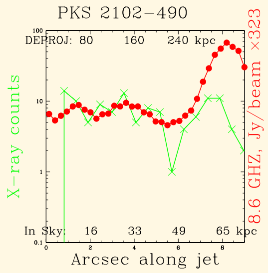
Q: How can the emission decrease over distances shorter than $c \times t_{life}$?

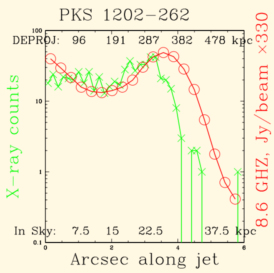
A: Changes in direction have large effects on relativistic jets!

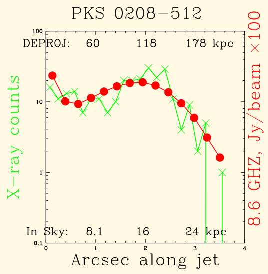


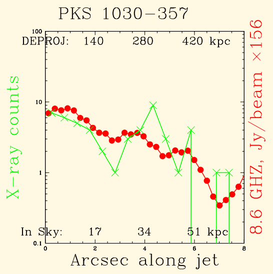




## What do we expect for the X-ray/Radio Relation?

### Emission Mechanisms

$I_{invCompt} \propto R\, T^{1-\alpha}\, \nu^{1-\alpha}\, \rho_{CMB}\, n_0$

$I_{Synch} \propto H_{\perp}^{1+\alpha}\, R\, \nu^{-\alpha}\, n_0$

Non-relativisitic: X-ray and radio synchrotron H$\approx$ 60 to 120 $\mu$G

$\gamma_{radio} \approx 4000$; $\tau_{radio} \approx 10^6$ yrs.

$\gamma_{xray} \approx 2.7\ 10^7$; $\tau_{xray} \approx 150$ yrs.

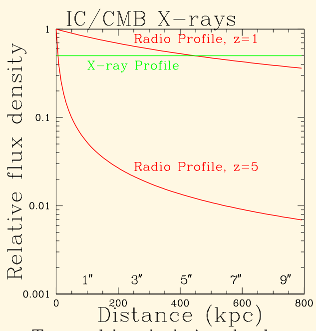
Expect $I_x/I_R \propto \frac{1.\,(2.10^{-8})^{\alpha}\, n_{0x}}{n_{0r}}$ , very sensitive to $\alpha$

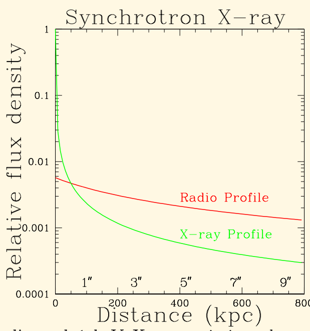
Relativistic: X-ray IC/CMB and radio synchrotron. H$\approx 10\mu$G, $\delta \approx 3$ to 15

$\gamma_{radio} \approx 10^4$; $\tau_{radio} \approx 6 \times 10^6$ yrs.

$\gamma_{xray} \approx 300$; $\tau_{xray} \approx 2 \times 10^8$ yrs.

Expect $I_x/I_R \propto \frac{0.001^{\alpha}\, H^{-1-\alpha}\, \Gamma^2\, ((1+z)\,\delta)^{\alpha}}{\delta}$ , and we estimate $\Gamma \approx \delta$ so ratio is relatively constant for H $\propto \Gamma$ !




Toy models calculating the decrease of 5 GHz radio and 1 keV X-ray emission along a jet, in case all particles are accelerated at distance zero, and either IC/CMB (left panel) or synchrotron (right panel) X-ray emission. Equipartition is assumed. Conversion to angular scale assumes z=1 and that jet is 0.1 radian from our line of sight. Left panel assumes H=10 $\mu$G, and bulk motion with $\Gamma$ = 10. Right panel assumes H=100 $\mu$G, and Doppler factor $\delta$=1. For synchrotron X-rays the lifetime of X-ray emitting electrons is much shorter, and therefore the X-ray profile falls very steeply relative to the radio. IC/CMB, at modest redshifts, can result in a roughly constant ratio.

## Morphology Summary and Interpretation

- Roughly constant $f_x/f_r$ (within ×2).
  X-rays end when radio makes sharp bend.
  IC/CMB: Strong Beaming Dependence
  Examples: PKS 0637-752, PKS 1055+201, PKS 1202-262, PKS 0208-512
- X-ray profile decreases, Radio profile increases, $f_x/f_r$ changes more than ×10.
  Multiple Electron-Population Synchrotron Contributions
  Example: 3C 273 (not shown)
- Roughly constant $f_x/f_r$ (within ×2).
  X-rays persist beyond radio.
  IC/CMB: Longer Lived Low Energy Electrons
  Example: 4C19.44

We acknowledge the support of NASA contract NAS8 39073 to SAO, and CXC grants G02-3151, G04-5107X, and GO5-6116B, and HST grant GO-10352.04-A.