EMISSION-MECHANISM CLUES FROM THE RESOLVED HIGH-REDSHIFT QUASAR JET PKS J1421-0643

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Chandra has revolutionized the X-ray study of resolved quasar jets but, even after 20 years, important issues remain unsettled. Despite the fact that kpc-scale inverse-Compton scattering of cosmic microwave background photons into the X-ray band (iC-CMB) is mandated, proof of detection in individual sources is often insecure. High redshift provides favourable conditions and constrains the known synchrotron-emitting electron spectrum at high energies. We present results for the resolved jet in the $z = 3.69$ quasar PKS J1421-0643 that argue in favour of the detection of inverse-Compton X-rays for modest magnetic field strength, Doppler factor, and viewing angle.

Context

Electron energy losses via iC-CMB dominate those to synchrotron radiation if

$$B < 0.32\ \Gamma\ (1+z)^2 \quad \mathrm{nT}$$

where Γ is the jet's bulk Lorentz factor and B its magnetic field strength. At low z, B would need to be abnormally low to meet this condition for modest Γ. Not so at the z of PKS J1421-0643 where, e.g., for $\Gamma = 4$, $B < 28$ nT satisfies the condition.

Figure 1 shows the redshift histogram of quasars at $z > 0.2$ from which kpc-scale jets are detected with *Chandra*, using results of the main quasar jet surveys together with 21 objects from other publications. Observations of high-z jets favouring the detection of iC-CMB are sparse. Here we report findings for PKS J1421-0643 at $z = 3.69$ with *Chandra*, *HST* and the *VLA*.

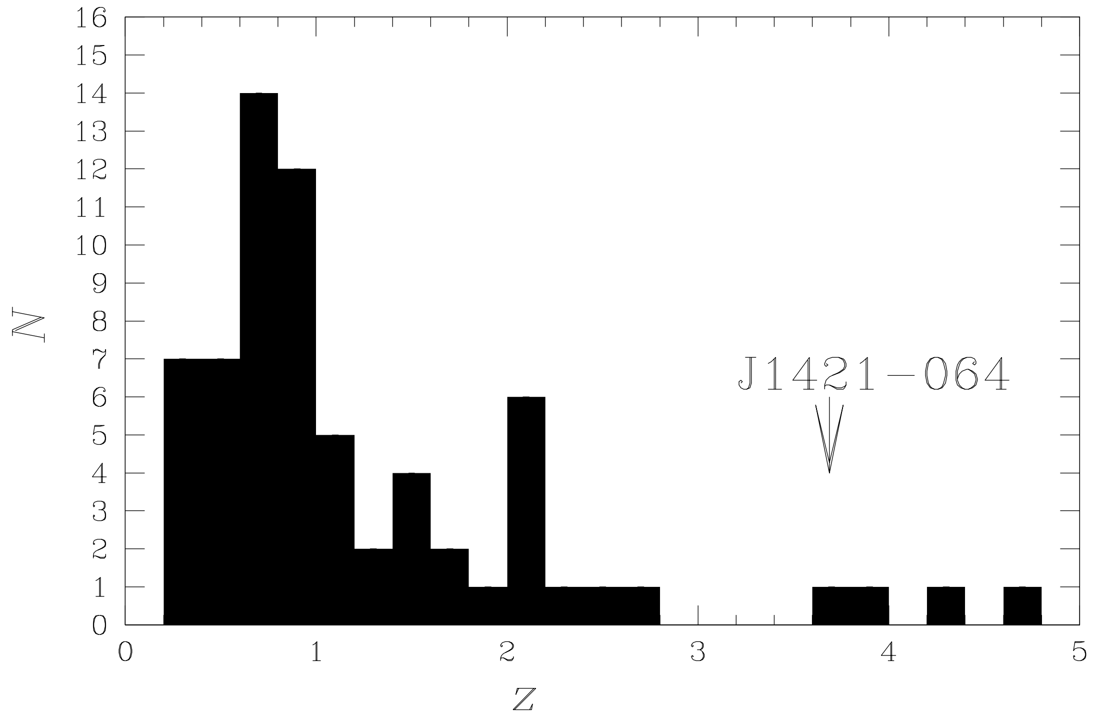

Figure 1. Redshift distribution of 67 quasars at $z > 0.2$ for which detected kpc-scale X-ray jets are reported.

Morphology and Spectrum

Chandra detects a continuous jet extending $5''$ NNE of the quasar core whose brightest deconvolved features trace modest bending (Fig 2). The jet X-ray spectrum is consistent with $\alpha_{\rm x} \approx 0.65$ throughout.

One of the most notable results is that the radio spectra in all jet regions are so steep that they match emission from within the synchrotron exponential tail of an electron spectrum with a maximum cut-off Lorentz factor, $\gamma_{\rm max}$. The core spectrum is normal.

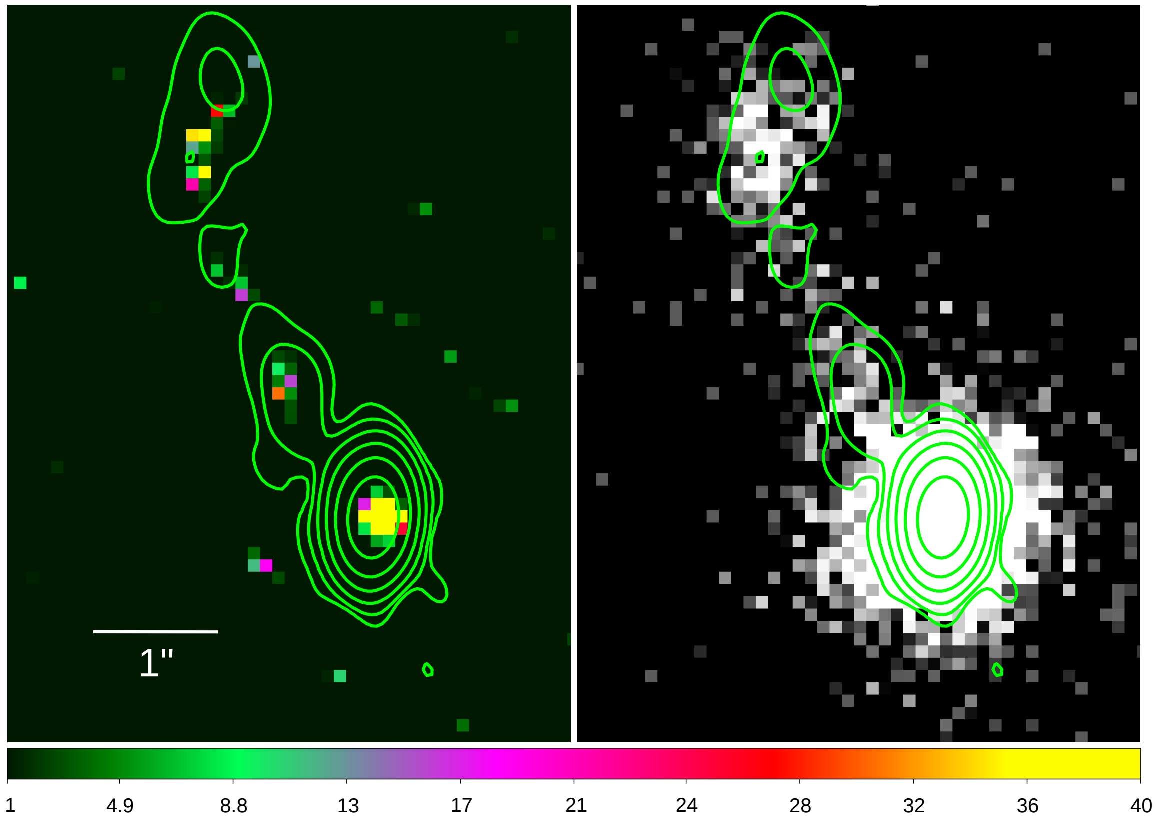

Figure 2. 0.5–5-keV *Chandra* images in $0.0984''$ pixels with contours from 5.13-GHz *VLA* map of restoring beam $0.48'' \times 0.28''$. $1'' = 7.2$ kpc projected length. Left: after PSF deconvolution showing the core and bent jet. Colour bar is linear in units of counts. Right: Unsmoothed *Chandra* data.

Jet Modelling

The steep radio spectrum renders X-ray synchrotron emission improbable. The X-ray spectrum is characteristic of that expected for electrons undergoing continuous particle acceleration. We therefore use equations in the form given by Worrall (2009 A&ARv, 17, 1) to model the X-rays as iC-CMB from an electron spectrum extending to $\gamma_{\rm max}$. We adopt a minimum-energy magnetic field as found to be broadly appropriate for the lobe plasma of powerful radio galaxies (Croston et al 2005, ApJ 626, 733) and commonly used for quasar jet modelling.

Results for all four jet regions of Fig. 3 are similar in key features. Examples are shown in Fig. 4 of the multiwavelength spectrum and model fit and in Fig. 5 of the acceptable values of Γ and angle to line of sight, θ.

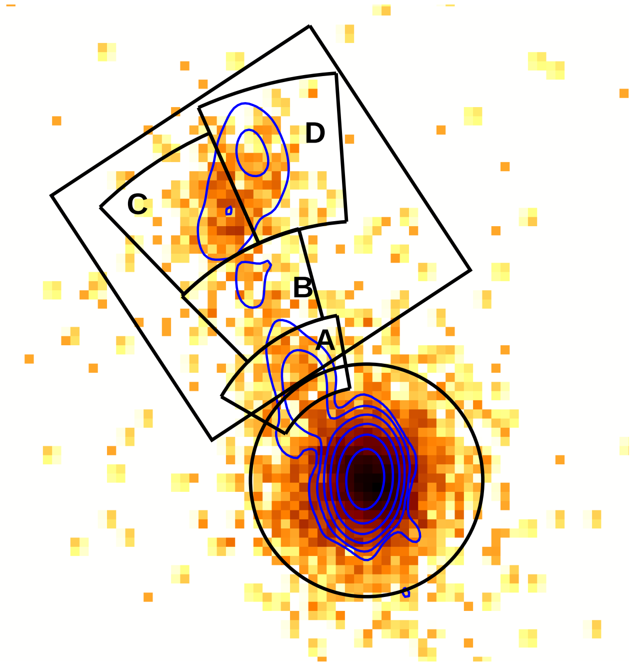

Figure 3. Data of Fig. 2 showing regions used for data modelling.

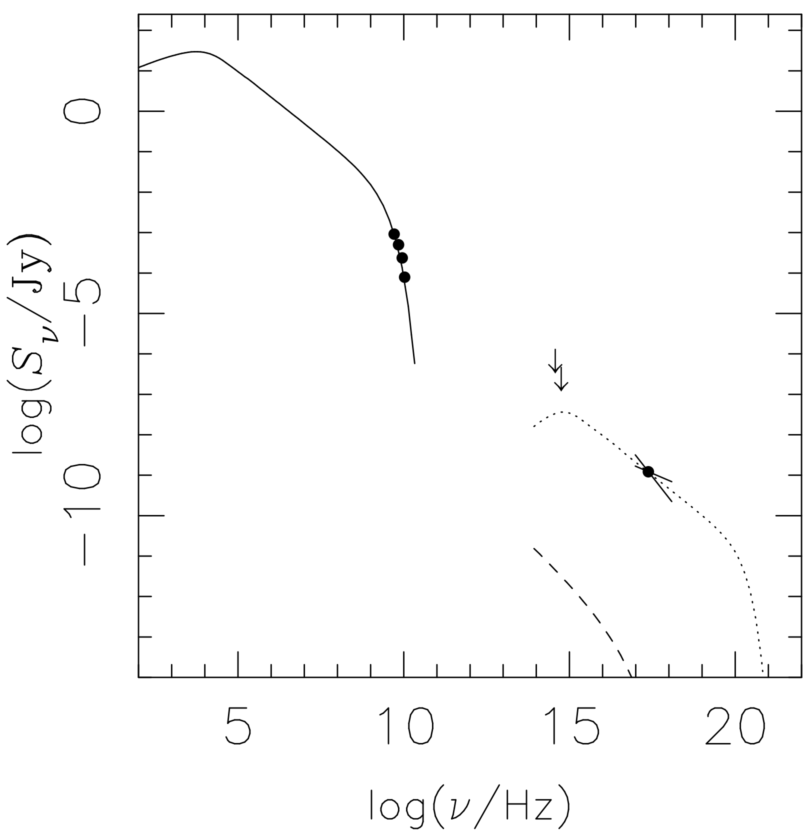

Figure 4. Spectrum of region D of the jet modelled with an equivalent spherical radius $r = 0.78''$. Plots for regions A, B, C are similar in their key features. Continuous line shows synchrotron emission, with the radio data falling on the high-energy exponential tail. The dotted line is iC-CMB modelled to give the X-ray emission using a minimum-energy B field of 3 nT, $\Gamma = 4$, $\theta = 14.5°$ (weak scaling with r). Dashed line is the synchrotron self-Compton prediction. iC-CMB plummets in the *Fermi* γ-ray band. The energy-loss lifetime of electrons emitting at $\gamma_{\rm max} = 5000$ is $\approx 6.3 \times 10^4$ yr and those emitting the X-rays is $\approx 10^6$ yr.

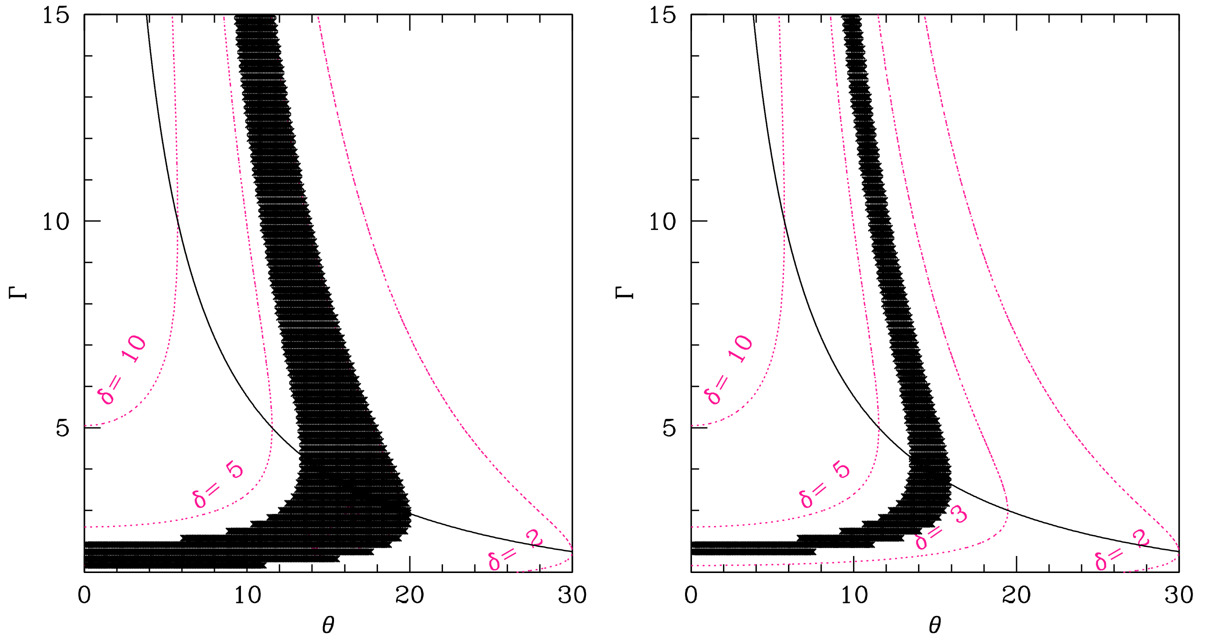

Figure 5. Shaded regions show values for Γ and θ within statistical uncertainties for jet regions A and D. B and C give similar results. Black line shows $\Gamma = \delta$. Modest $\Gamma \approx 4$ and $\theta \approx 15°$ are most likely.

Main Results

- Jet X-ray emission of total luminosity $\approx 3 \times 10^{45}$ erg s^{-1} (2-20 keV rest frame) extends to $5''$ (36 kpc projected, ≈ 140 kpc intrinsic).
- Small changes in jet position angle are seen.
- The jet radio spectra are abnormally steep $\Longrightarrow \gamma_{\rm max} \approx 5000$. Electrons are not being accelerated to the much higher energies measured in closer and less powerful jets.
- The iC-CMB model best explains the X-rays ($\Gamma \approx 4, \theta \approx 15°, B \approx 3$ nT), with values that confirm the domination of inverse-Compton over synchrotron losses for the electrons.
- γ-ray detection is not expected with *Fermi*.