Astrophysical Phenomena Revealed by Space VLBI
H. Hirabayashi, P.G. Edwards and D.W. Murphy (eds.)

VSOP and ATCA Observations of PKS 0637−752

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Abstract

In August 1999, the Chandra X-Ray Observatory detected an unexpectedly luminous ~ 50 kpc jet in PKS 0637−752, coincident with the arcsecond-scale jet observed at radio wavelengths. Here we describe VSOP and ATCA observations of PKS 0637−752 and the important constraints that they provide for emission models.

1 Introduction

The bright (~ 7 Jy) quasar PKS 0637−752 ($z = 0.651$) was the first celestial object to be observed by the Chandra X-ray Observatory (Marshall et al. 2000) as a calibrator since it was thought to be unresolved. However, the first Chandra images discovered that the quasar hosts the most luminous X-ray jet yet known, at $L_X \approx 3 \times 10^{44}\ \mathrm{erg\,s^{-1}}$ (Schwartz et al. 2000)[1].

[1] $H_0 = 50\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$, $q_0 = 0$

PKS 0637−752 is situated near the south ecliptic pole, making it an excellent target for an on-going VSOP experiment to monitor its milliarcsecond-scale structure (Tingay et al. 2000). Space-VLBI observations of this source were re-scheduled specifically to coincide with the Chandra observations in August 1999. These VLBI observations involved the Australia Telescope Compact Array (ATCA) from which we extracted ATCA-only images at 4.8 and 8.6 GHz. The ATCA at 8.6 GHz has the same resolution as Chandra and so provides a powerful structural comparison. A comparison of the X-ray and radio images is shown in Color Figure 8 on page xviii and reveals a striking coincidence. The arcsecond-scale western radio jet is clearly longer than the X-ray jet, and bends through a projected angle of about 60° at about 12 arcsec from the core. The eastern edges of the brightest knot in the radio and X-ray jets ($\sim 8''$ west of the nucleus) coincide, while the other edge of this knot extends farther west in the radio than in X-rays.

Follow-up ATCA observations were made in September 1999 to obtain linear polarization data at both 4.8 and 8.6 GHz. These data have revealed a strongly polarized jet with fractional polarizations of up to 30%. The polarization E-vectors remain perpendicular to the jet where X-rays are detected (Figure 1), but, as the X-ray flux decreases at the western end of the X-ray jet near the bend in the radio jet, the polarization position angle begins to change so that the E-vectors become parallel to the jet's centre line. Figure 1 and the figure on page X show that both the radio and X-ray jets are well entrained before the bend. The absence of X-ray emission past the bend in the radio jet suggests that whatever causes the bend may also be responsible for quenching the X-rays, or that having the E-field perpendicular to the flow is conducive to generating X-rays.

The lack of detectable rotation measure has been important in ruling out thermal Bremsstrahlung as a mechanism for the jet X-ray emission. The detection of very weak optical components in the jet by the HST is an important constraint on jet emission models. A simple synchrotron model extending from radio through to X-rays is not sufficient as the optical flux is two orders of magnitude weaker than required in such a model. Further, both Inverse-Compton and Synchrotron Self-Compton models have problems providing sufficient X-ray jet flux unless the jet plasma is far out of equipartition or the jet is Doppler boosted with $\delta \sim 0.3$, or the beaming and alignment of the core and kpc-scale jet are finely tuned to provide adequate seed photons from the inner region

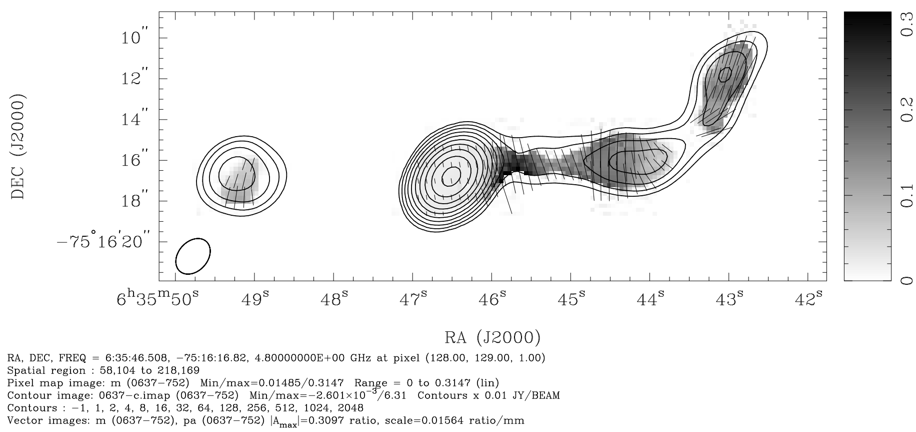

Figure 1: Our 4.8 GHz image of PKS 0637−752 (contours) together with the fractional polarization (greyscale) and polarization E-vectors.

of the source.

The VSOP and ground VLBI data provide key directional information. Analysis shows that the components near the milliarcsecond core are moving in the same projected direction as the arcsec-scale radio/X-ray jet (see figure on page X) at a mean apparent speed of $11.4 \pm 0.6\ c$ (Figure 2) which puts a lower limit on the Lorentz factor of 11.4 and an upper limit on the angle between the jet and the line of sight of 8.9°. If the arcsec-scale jet has a Doppler factor of 0.3, the jet angle to the line of sight would need to increase from $\sim 9°$ to $\sim 45°$ as one goes from the mas-scale to the arcsecond-scale. Under such conditions one would normally expect to see a large apparent bend in the jet which is not observed. The large required bending can only be explained by a geometry in which the mas-scale jet, arcsecond-scale jet and the observer-source line of sight all lie in the same plane which would be an unlikely special case for the first Chandra-observed quasar.

2 Conclusions

The serendipitous discovery of a luminous kpc-scale X-ray jet in PKS 0637−752 has raised many questions concerning its emission mechanism. Observations with VSOP and the ATCA have helped to rule out some models (such as thermal Bremsstrahlung and simple synchrotron models) and provided important constraints to others (such as Inverse-

Compton and Synchrotron Self-Compton models). We are continuing to monitor PKS 0637−752 and are also investigating similar sources to understand how common kpc-scale X-ray/radio jets are and under what conditions they occur.

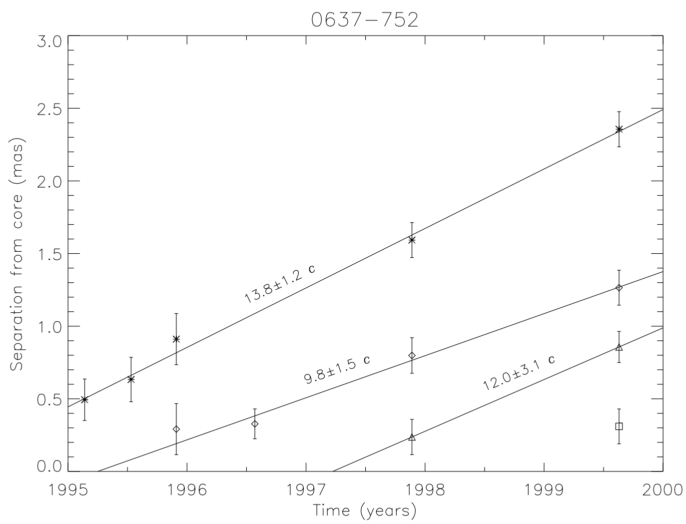

Figure 2: Positions of the milli-arcsecond-scale components as a function of time. The first four epochs are from ground-only VLBI observations and the last two epochs are from VSOP observations. The lines indicate the best fit speeds for each component. Component speeds have been calculated assuming $H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ and $q_0 = 0.15$.

Acknowledgements. We gratefully acknowledge the VSOP Project, which is led by the Japanese Institute of Space and Astronautical Science in cooperation with many organizations and radio telescopes around the world. The Australia Telescope is funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO.

References

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Tingay, S. et al., 2000, *Adv. Sp. Res.*, **26**, 677

Corrections to VSOP Symposium Proceedings
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* In the contents, the author list for the paper starting on page 79
  is incomplete and should read
  "Ignas Snellen, Wolfgang Tschager, Richard Schilizzi et al."

* In the preface, "Orian-KL" should be "Orion-KL"!!!

* The caption to Color Figure 3 refers to the source 1928+734,
  which should be 1928+738.

* In the summary section on page 49 (Murphy et al.), the sentence
  "In that time, we have observed a variety of
   structural changes in the inner jet region near the region."
  should read
  "In that time, we have observed a variety of
   structural changes in the inner jet region near the core."

* In the references on page 175 (Fomalont et al.) and page 182
  (Moellenbrock et al.) "Fomalont et al. 2000" should be updated to
  "Fomalont, E.B., Frey, S., Paragi, Z., Gurvits, L.I., Scott, W.K.,
  Edwards, P.G., Hirabayashi, H., 2000, ApJS, 131, 95"

* On page 217 (Lovell et al), the fourth line of the final paragrpah of
  section 1 should say "(see figure on page xviii)"

* In the references on page 233 (Sambruna) an extraneous "439"
  was introduced during the editing process into the reference
  for Catanese 1999.

* In the First Author List on page 327 (in the Index), the following
  line is missing
  Junor, W.   13