New Detections of Optical Emission from Kiloparsec-scale Quasar Jets

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Abstract

We report initial results from the detection of optical emission in the arcsecond-scale radio jets of two quasars utilizing images from the Hubble Space Telescope archive. The optical emission has a very knotty appearance and is consistent with synchrotron emission from highly relativistic electrons in the jet. Combining these observations with those of previously reported features in other quasars, an emerging trend appears to be that their radio-to-optical spectral indices are steeper than those of similar features in jets of lower power radio sources.

Key words:

1 Motivation

The number of active galaxies observed to have radio-bright kpc-scale relativistic jets emanating from their nuclei has grown to many 100’s over the last several decades (Bridle & Perley, 1984; Liu & Zhang, 2002), but only a handful of them were known to have X-ray counterparts prior to the launch of the Chandra X-ray Observatory. Chandra has in just the last three years netted X-ray detections of jet features in over 30 more radio sources (see Harris & Krawczynski, 2002, and the most recent updates in the associated website – http://hea-www.harvard.edu/XJET/), and many more are being discovered as a result of dedicated searches (see e.g. individual contributions by R. M. Sambruna, H. L. Marshall, and D. A. Schwartz). With the increased interest in the X-rays, studies in the optical/UV regime have also enjoyed a resurgence of activity. This is because the optical is the only other accessible window

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in the electromagnetic spectrum where comparable sub-arcsecond resolution can be readily achieved with the Hubble Space Telescope[1] and bridges the ~6-7 orders of magnitude gap in frequency coverage between radio and X-ray studies of resolved features. It turns out that the optical fluxes and spectra can be a key diagnostic in distinguishing between different X-ray production mechanisms. Specifically, the faintness of the optical knots in the ‘first-light’ X-ray jet detection in the powerful quasar PKS 0637–752 (Chartas et al., 2000; Schwartz et al., 2000) helped to rule out canonical synchrotron and synchrotron self-Compton models, and established the importance of X-rays produced via inverse Compton scattering of CMB photons by synchrotron emitting electrons in the kpc-scale jets (Tavecchio et al., 2000; Celotti, Ghisellini, & Chiaberge, 2001). Also, if the emission mechanism responsible for the optical emission is synchrotron radiation, as is commonly accepted, observations in this waveband probe the physics of the most energetic and short-lived electrons, and are key to studying acceleration processes in the jet.

In the pre-Chandra era, optical jets were predominantly found in low power sources with the HST (e.g., Sparks, Biretta, & Macchetto, 1994; Scarpa & Urry, 2002), and optical counterparts to jets in quasars were difficult to detect with ground based facilities. Only a handful of examples existed, courtesy of the HST (e.g., Ridgway & Stockton, 1997), so optical jets in quasars were thought to be rare. However, Chandra’s successful X-ray detections of quasar jets has forced observers to examine new and archival HST data more carefully, resulting in many new detections in the optical. This resulted in the identifications of a number of bright optical knots coincident with peaks in the radio jets of about ten quasars in a recent Chandra/HST cycle-2 search for such emission (Sambruna et al., 2002, R. Scarpa et al., in prep.). We applied the same techniques employed in this survey and found a bright optical/UV knot in the kpc-scale radio jet of 3C 279 in archival HST data (Cheung, 2002) which encouraged us to search for more such emission in other available archival data.

2 New Detections and Search Strategy

Figures 1 & 2 show two of our first three optical detections in the quasars 3C 454.3 and PKS 1229–021 as a result of our search. The third detection is in the bright radio hotspot in the lobe-dominated quasar 3C 263 which was recently published by Hardcastle et al. (2002) along with the Chandra X-ray detection of the feature. These quasars were known to us to exhibit bright

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1 Based on observations made with the NASA/ESA Hubble Space Telescope, obtained from the data archive at the Space Telescope Science Institute. STScI is operated by the Association of Universities for Research in Astronomy, Inc. under NASA contract NAS 5-26555.
radio jets and were obvious candidates to search for optical counterparts. The optical emission in these and other known kpc-scale quasar jets (Ridgway & Stockton, 1997; Chartas et al., 2000; Sambruna et al., 2002; Cheung, 2002, R. Scarpa et al., in prep.) is compact, match peaks in the radio jets well, and is consistent with synchrotron emission from highly relativistic electrons in the jet.

With the growing number of optical jet detections in radio-loud sources, we can begin to make comparisons between the jet properties of different subclasses. One emerging trend is that the radio-to-optical spectral indices of the jet features in quasars (see above references) appear to be steeper by $\Delta \alpha \sim 0.2$ than those measured in lower power radio sources (see e.g., Sparks, Biretta, & Macchetto, 1994; Scarpa & Urry, 2002).

After these initial detections, we decided on a more systematic approach to mining through the available archival data. We are currently searching the HST archive database for images of radio bright (> 0.5 Jy at 5 GHz) active galaxies obtained after $\sim$1994 (post-COSTAR), mostly concentrating on WFPC2 images which have $\geq 1$ orbit of total exposure time. The resultant list of candidates are being correlated with the compilation of Liu & Zhang (2002) of sources known to exhibit radio jets. As a result of this ongoing effort, we have found optical counterparts to knots in an additional three quasar.
Fig. 2. *HST* WFPC2 F702W grayscale image of PKS 1229–021 (z = 1.045) with an unsharp masked filter applied (as in the right panel of Fig. 1) and a VLA 15 GHz image of the jet (reprocessed from data published in Kronberg et al., 1992) at 0.4″ resolution overlaid. Radio contours are spaced by factors of 2 from 0.3 mJy/beam. We found at least two bright optical knots following the first two peaks in the large-scale radio jet (confirmed also in an archival F450W image).

jets and have already obtained archival multi-frequency MERLIN and VLA data for our analysis. These results will be presented along with the complete analysis of the detections presented here in a forthcoming paper.

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