The X-ray emission in the radio jet of 3C 17 and 3C 78

F. Massaro[1], D. E. Harris[1], M. Chiaberge[2], P. Grandi[3], F. D. Macchetto[2], A. Capetti[4], S. A. Baum[5], and C. P. O'Dea[6]

[1] *Harvard, Smithsonian Astrophysical Observatory, MA*
[2] *Space Telescope Science Institute, MD*
[3] *INAF-IASF - Istituto di Astrofisica Spaziale e fisica cosmica di Bologna, Italy*
[4] *INAF - Osservatorio Astronomico di Torino, Italy*
[5] *Carlson Center for Imaging Science 76-3144, NY*
[6] *Dept of Physics, Rochester Institute of Technology, NY*

Abstract

The X-ray radiation observed from radio jets is generally interpreted to be from non-thermal processes, even if its nature is still unclear for any particular jet. It could be described in terms of synchrotron emission or in terms of several varieties of inverse Compton radiation. In this work, we investigated the X-ray emission of the radio jets in 3C 17 and in 3C 78 to understand the nature of their radiation. These two sources belong to the *Chandra* snapshot program started last year to complete the sample of X-ray observations of the 3CR radio galaxies at redshift lower than 0.3. We compare the X-rays emission of 3C 17 and 3C 78 with the radio maps in the VLA and in the MERLIN archives and with the optical-IR archival images of the Hubble Space Telescope derived during the HST snapshot program of the 3CR sample. We found an X-ray detection of both radio jets in our two sources, both with optical-IR counterparts. We derived the spectral energy distribution for the nuclear emission and for the knots in the jets. We give source parameters required for the various X-ray emission models.

1 3C 17.0

3C 17.0 is a radio galaxy ($z \sim 0.22$) (Schmidt et al. 1965) with a peculiar radio structure as investigated by Morganti et al. (1993) and subsequently confirmed by the same authors in 1999. As reported in Fig. 1 the radio structure of the VLA map shows a very bent jet on the south-east side of the nucleus (Morganti et al. 1999). This jet has a very bright knot at 3.7 arcsec while the curved part lies at about 11 arcsec from the nucleus. The VLBA map of this source reports the detection of an easternside jet in the same position angle of the first bright knot (Venturi et al. 2000). Its Hα emission has a strong broad component and both the [O II] λ3727 and [O III] λ5007 emission lines are extended (Dickson 1997). This source shows also a significant optical polarization in its nucleus (Tadhunter et al. 1997), and its first detection in X-rays has been reported by Siebert et al. (1996) using the ROSAT All Sky survey data. It was also originally classified as a FRII BLRG.

1.1 Jet knots

The source 3C 17.0 represents the best example in our sample of an X-ray jet detection. An X-ray counterpart for two radio knots has been found as shown in Fig. 1. The first knot lies at about 3.7" (12.8 kpc) from the nucleus while the other detected knot is about 11.3" (39.5 kpc) away. An optical and UV counterpart has been detected for both knots (Fig. 3 and Fig. 4a)

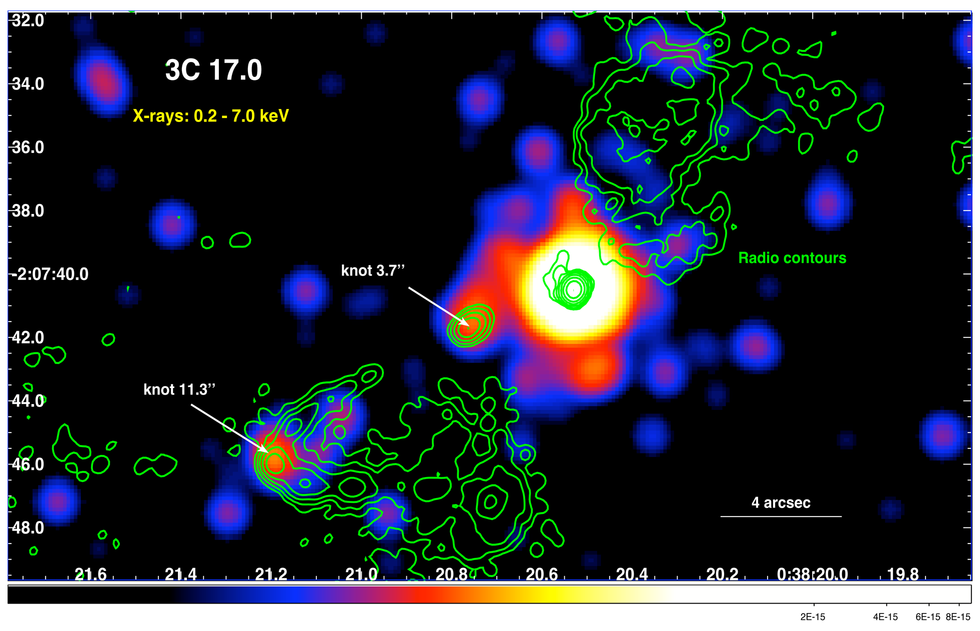

Figure 1: The X-ray image in comparison with the radio map at 5 GHz (green contours), where the detection of two knots is shown.

We tried several models to describe the emitted spectrum of both knots in 3C 17.0. We argue that the best description is given in terms of synchrotron emission for the whole spectrum from the radio band to the X-rays. We performed our calculations assuming the following hypothesis: 1.) the distribution of emitting electrons is a power-law, 2.) the volume of the accelerating region is the same of the emitting one, and correspond to that you can measure using the radio map, 3.) the magnetic field is in equipartition with electrons. Solution reported in Fig. 2 has the beaming factor fixed to 1.

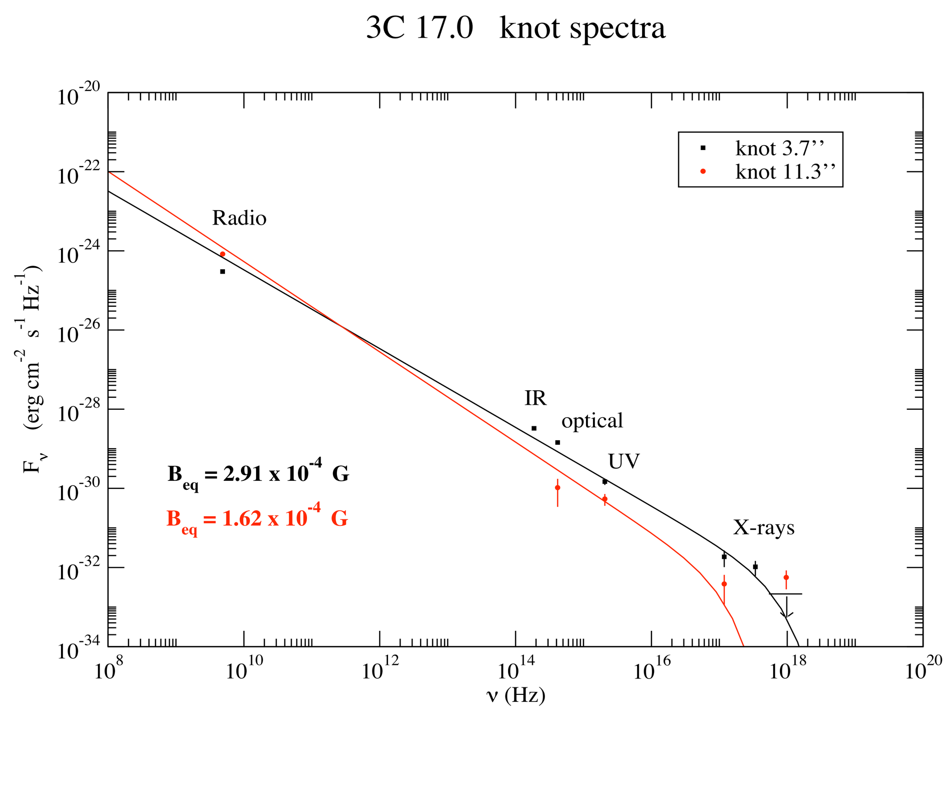

Figure 2: The spectrum of the knot at 3.7" (black) and the other at 11.3" (red). The lines refer to the synchrotron calculations done under the assumptions described in Sect. 1.1.

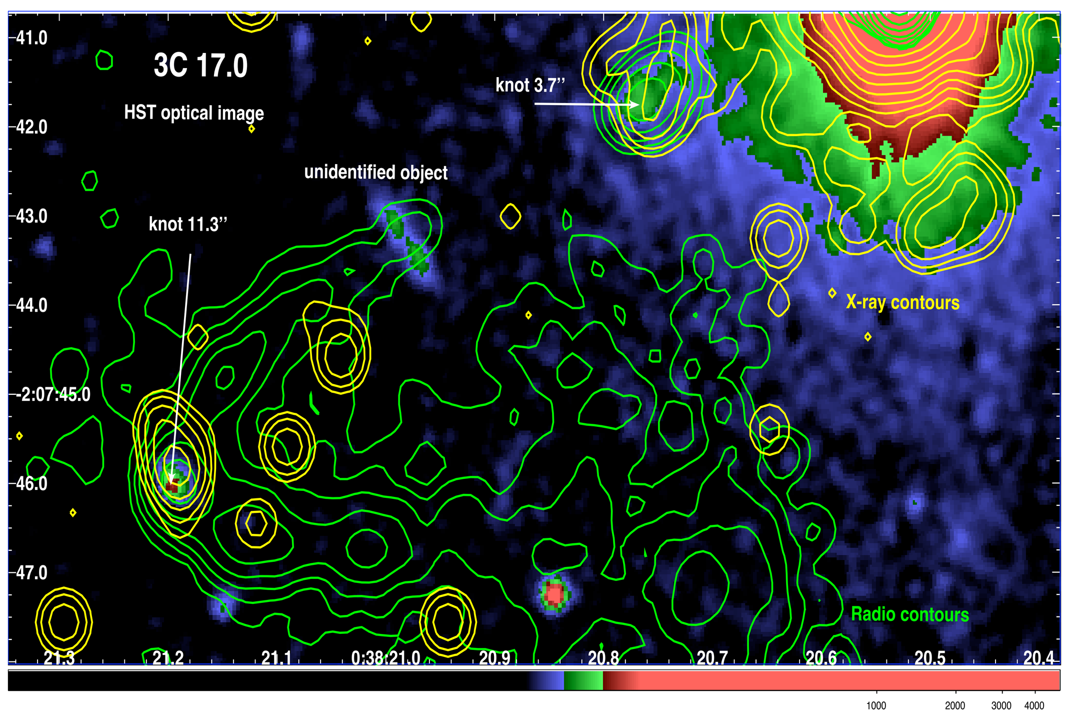

Figure 3: HST optical image of 3C 17.0. The overlaid green contours refer to the radio emission, while the yellow ones to the X-rays. Here, the radio knots at 3.7" and 11.3" show an optical counterpart. An unidentified object, that lies at about 7.4" from the nucleus and perpendicular to the radio jet, is here indicated (see Sect. 1.2 for details).

1.2 Unidentified object

We report the detection of an unidentified object in the HST optical image (see Fig. 3) with an IR counterpart (see Fig. 4b). We consider 4 'types' of possibile explanations for this object:

- The object is a foreground or background object (e.g. edge on spiral) and has nothing whatsoever to do with the jet. A rough estimate of the probability of the jet crossing a random background source within the 0.2″ nuclear region (defined by the lowered brightness center at 7216Å) is 0.2/360=5.5×10^{-4}. We don't know how to estimate the probability that the (upstream) invisible jet just happens to start converting some of its power into relativistic electrons and B field at this location, but we believe the total probability is so small that the 'chance coincidence' hypothesis is not a serious contendor for being the correct explanation.
- The emitting region arises from the interaction of the jet and some pre-existing entity (e.g. a large HI cloud, only a part of which gets ionized and produces free-free emission).

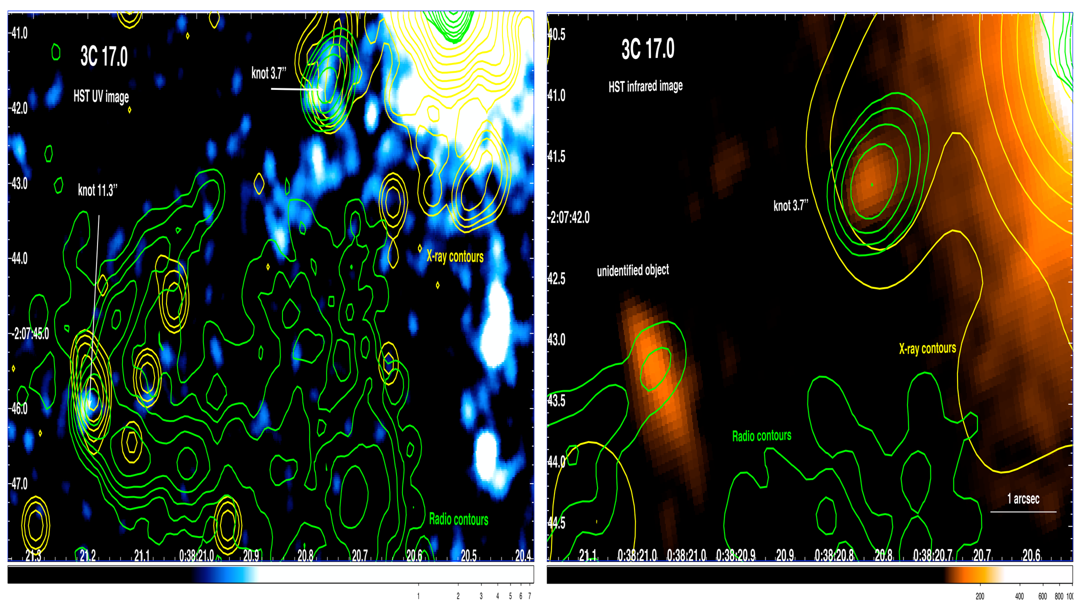

Figure 4: a) HST UV image with radio (green) and X-ray (yellow) contours overlaid, both knots are here detected. b) HST IR image at 1.6 μm with radio (green) and X-ray (yellow) contours overlaid, the knot at 11.3" is out of the NICMOS FOV.

- The emitting region comes from an as yet unknown property of the jet. Something like an instability where angular momentum is dumped and B field and relativistic electrons are spun out the sides.
- The object is indeed an edge on spiral and is a close companion of 3C17 (25 kpc in projection). The jet pierces the center of this galaxy and that is why the jet begins to be visible at this location. This jet, like all one sided jets, is coming 'mostly' towards us: perhaps 5° - 15° to the l.o.s. The edge on spiral's plane is perpendicular to the plane of the sky. Therefore, the actual impacting jet will be close to hitting the plane of the galaxy edge-on, not coming in at the pole, as it appears in the projected view. In any event the probability of hitting an object whose's center subtends 1 kpc^2 (as seen from the SMBH of 3C17) by chance is $\frac{1}{4\pi R^2} \leq 1.3 \times 10^{-4}$.

2 3C 78.0

The case of 3C 78 was used as an good example of a possible X-ray detection of jets during the preparation of the *Chandra* 3C sources snapshot proposal, and in the *Chandra* archive this source has two observations (Birkinshaw et al. 2002). This source, also known as NGC 1218, is a nearby ($z \sim 0.03$) S0 galaxy (Schmidt et al. 1965) with a prominent optical synchrotron jet detected with the WFPC2 on board on HST during the 3CR snapshot survey program and reported by Sparks et al. (1995), and associated with the radio emission detected by Unger et al. (1984) in the MERLIN observation and in that of the VLA (Morganti et al. 1993).

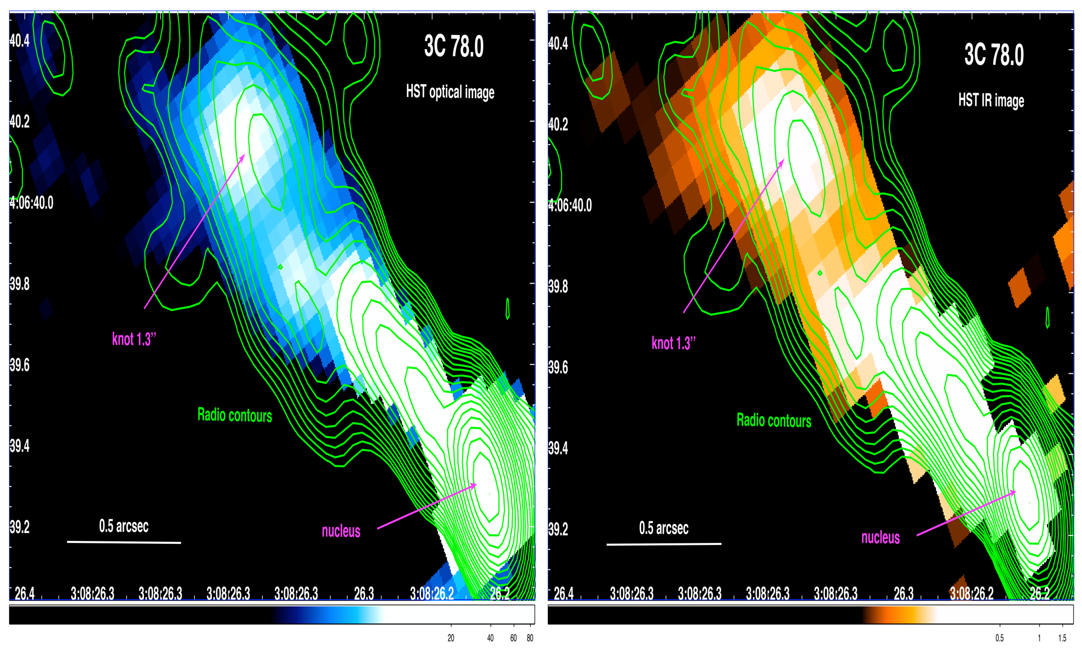

Figure 5: a) HST optical image performed with WFPC2 with radio (green). b) HST IR image at 1.6 μm with radio (green) contours overlaid.

The X-ray emission detected for the knot 1.3" (0.73 kpc) is equal to 6.69×10^{-14} erg cm^{-2} s^{-1} in the 0.2 – 7.0 keV. Fig. 6 reports the multiwavelength of the knot spectrum for 3C 78.0.

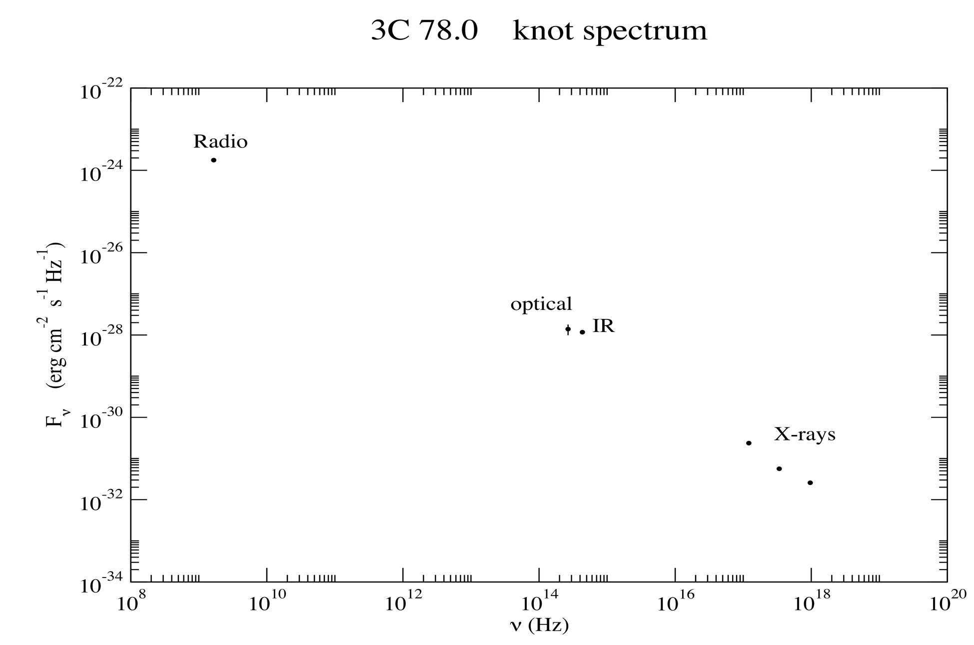

Figure 6: The knot spectrum of 3C 78.0 from radio to X-rays

Note: For the numerical results we used cgs units, unless stated otherwise. We assume a flat cosmology with $H_0 = 72$ km/(s Mpc), $\Omega_M = 0.27$ and $\Omega_\Lambda = 0.73$ (see Spergel et al., 2007). So 1 arcsec is equivalent to 3.467 kpc for 3C 17 and to 0.559 kpc for 3C 78.0.

Acknowledgments: We thank A. Siemiginowska and J. McDowell for their help in the use of the *Chandra* CIAO data reduction analysis software. We are grateful to R. Morganti for the archival radio map of 3C 17.0 and to the MERLIN archive for the map of 3C 78.0.
MERLIN is a National Facility operated by the University of Manchester at Jodrell Bank Observatory on behalf of STFC.
This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.
This work is supported by NASA-GRANT GO8-9114A.