THE ENIGMATIC X-RAY JET OF 3C120

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Abstract

Our poster focuses on the emission process(es) responsible for the X-rays from 'k25', a knot in the jet of 3C120. We argue that models using thermal, synchrotron self-Compton, and inverse-Compton/cosmic microwave background processes encounter difficulties, and that the X-rays from the k25 knot most likely come from synchrotron emission. Since the two brightest parts of k25 appear to have flat X-ray spectra, we suggest that either the shocks on the two edges of the radio knot produce a power law distribution of relativistic electrons ($N(E) \propto E^{-p}$) characterized by $p < 2$, or that for high electron energies, there is a significant departure from the power law defined by the radio data.

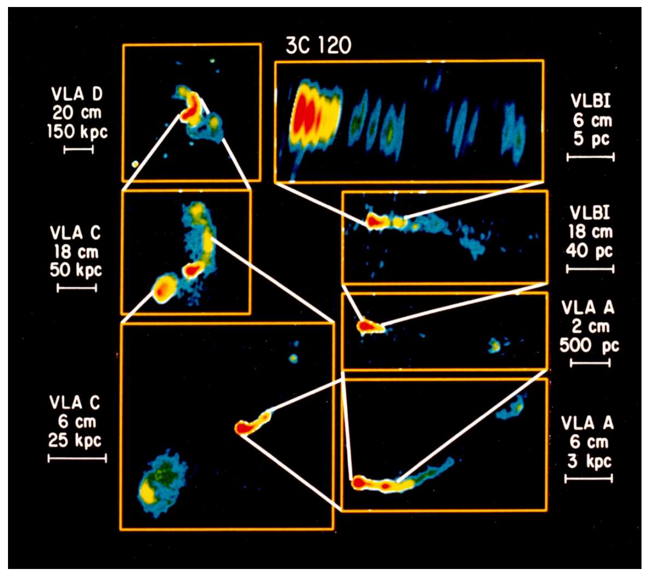

Figure 1: The radio emission at many scales.

1 Introduction

This contribution is meant to closely resemble the poster presented at the meeting. A full length article will be submitted to the ApJ.

3C120 is a nearby ($z = 0.033$) radio galaxy often described as a Seyfert optically, but with a complex radio structure on many scales (Fig. 1). The inner jet, of interest to us, is one sided and exhibits superluminal motions at Very Long Baseline Interferometry scales. For a luminosity distance of 140 Mpc, $1''$ corresponds to 0.64 kpc. We follow the usual convention for spectral index: flux density, $S_\nu \propto \nu^{-\alpha}$.

Our primary focus here is to evaluate the emission process(es) for the X-rays coming from various features of the radio jet. By way of introduction, we show an *HST* image (Fig. 2), a *Chandra* image (Fig. 3), and an enlarged view of the primary knot of interest, 'k25' which is resolved and lies approximately $25''$ from the core (Fig. 4). The radio contours used in these figures come from data reported in Walker (1997).

1.1 Spectra of knots k4 and k25

The X-ray photometry relies on flux maps generated from an archival *Chandra* observation of the zero order image from data taken with the high energy transmission grating. Four energy bands were used and flux densities are plotted together with optical and radio values in Fig. 5 (knot k4) and 6 (the 3 parts of k25, showing only the X-ray spectra).

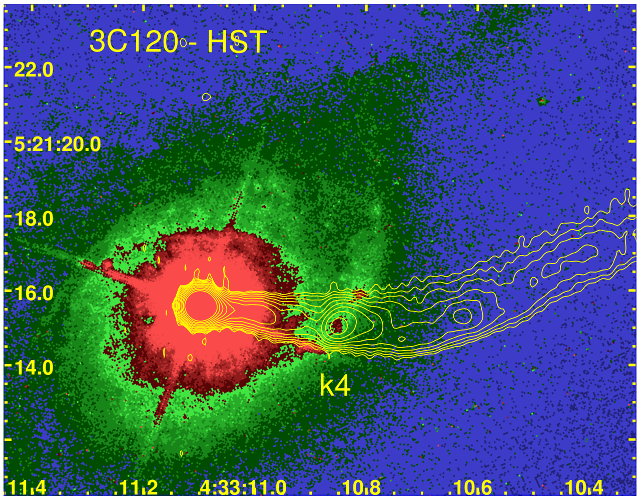

Figure 2: An *HST* image of 3C120 with radio contours overlaid. Knot 'k4' in the jet is labeled.

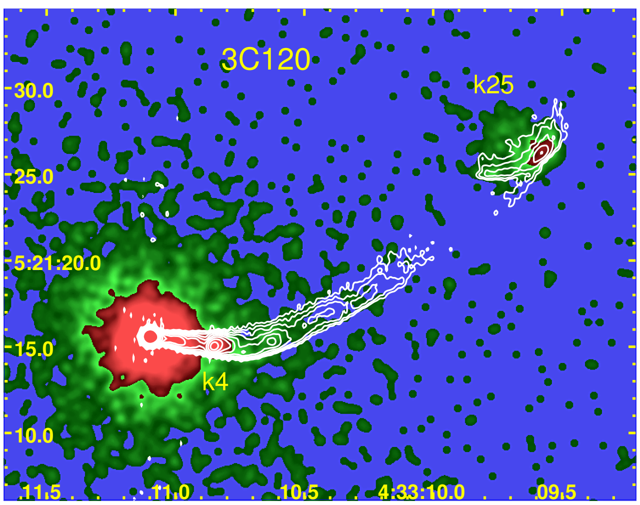

Figure 3: A *Chandra* image with radio contours.

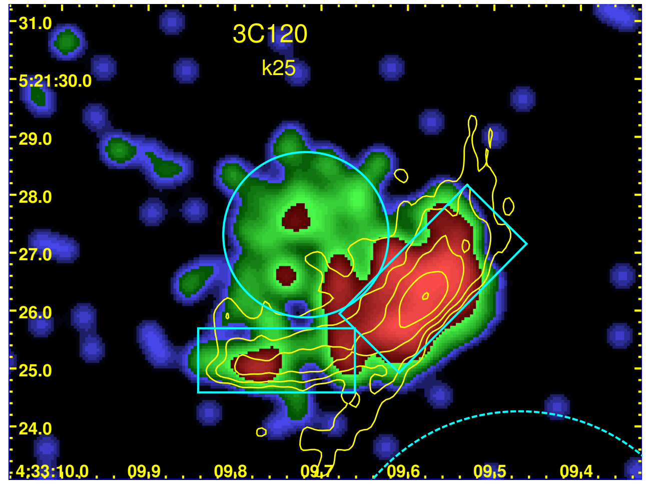

Figure 4: Knot 'k25'. The image is from *Chandra* (smoothed with a Gaussian of FWHM = $0.5''$) with radio contours overlaid. Also shown are the three regions used for photometry: The lower rectangle is the 'inner' part of the knot (facing upstream); the rectangle to the right is the 'outer' region; and the circle is the 'new' part. Also shown with a dashed line is a segment of the background circle.

2 Synchrotron parameters

The basic parameters for no beaming are given in the first 6 columns of Table 1. These are followed by the jet frame luminosity and half-life (observer's frame) of electrons responsible for the observed 2 keV emission, for representative values of δ: 3 and 6.

All these parameters appear to be reasonable and fail to define any problems with synchrotron models.

3 Thermal bremsstrahlung parameters

The standard arguments against the thermal bremsstrahlung emission process include

- if the X-ray emission occupies the same volume as the radio emission, there would be a departure from the λ^2 law for the radio polarization position angle;
- if the thermal region surrounds the emitting region, the predicted large rotation measures are not seen; and
- the thermal pressure of the emitting region generally exceeds the estimate of the ambient gas pressure.

For the inner jet, the observed Faraday rotation measures (RM's) are small (0 to -10 radians m^{-2}, Walker et al. 1987) and although the radio polarization for k25 has a low signal-to-noise ratio, the observed position angles suggest that RM(k25) < 100. Thus the large predicted RM's (Table 2) would appear to preclude thermal X-ray emission.

4 Inverse Compton parameters

Inverse Compton (IC) emission from scattering on cosmic microwave background (CMB) photons by jet features with relativistic beaming has been suggested as a method to increase the energy produced via the IC channel relative to that in the synchrotron channel

Table 1: Synchrotron parameters

Region	B(1) (μG)	α_r	α_{rx}	logL$_s$ (erg s^{-1})	$\tau_{\frac{1}{2}}$ (years)	$\delta = 3$ logL$_s$ (erg s^{-1})	$\delta = 3$ $\tau_{\frac{1}{2}}$ (years)	$\delta = 6$ logL$_s$ (erg s^{-1})	$\delta = 6$ $\tau_{\frac{1}{2}}$ (years)
k4	116	0.74	0.9	41.829	23	39.921	56	38.716	27
k25inner	36	0.74	0.82	41.142	131	39.233	108	38.029	18
k25outer	27	0.66	0.81	41.448	195	39.539	105	38.335	16
k25new	9	...	0.70	41.241	669	39.332	74	38.128	9

δ is the beaming factor

B(1) is the equipartition magnetic field strength for the case $\delta = 1$. For other values of δ, it is B(1)/δ (Harris & Krawczynski, 2002).

α_r is the radio spectral index.

α_{rx} is the spectral index connecting the radio to the X-ray bands.

$\tau_{\frac{1}{2}}$ is the half-life, as observed at the earth, for the electrons responsible for the observed 2 keV emission (Eq. B7 of Harris & Krawczynski, 2002, assuming $\Gamma = \delta$).

The emission spectrum is assumed to cover the range 10^6 to 5×10^{18} Hz in the observed frame.

Table 2: Thermal bremsstrahlung parameters

Region	n$_e$ (cm^{-3})	τ_c (years)	Mass ($M_\odot$)	Pressure (dyne cm^{-2})	RM (m^{-2})
k4	6.6	1.5×10^5	6.3×10^6	2.0×10^{-8}	22,450
k25inner	1.7	5.6×10^5	8.0×10^6	5.6×10^{-9}	5,780
k25outer	1.9	5.2×10^5	2.4×10^7	5.6×10^{-9}	11,450
k25new	0.5	1.9×10^6	4.0×10^7	1.5×10^{-9}	7,520

τ_c is the cooling time.

The electron density is that necessary for a uniform plasma with the volume estimated from the highest resolution radio data.

The pressure values assume a temperature of 1 keV.

RM gives the predicted rotation measure for a field of 10 μG and a path-length corresponding to the depth of the emitting volume. RM(rad m^{-2}) = 810 $\times$ B(μG) $\times$ dL(kpc) $\times n_e$(cm^{-3}).

Table 3: IC/CMB parameters

Region	α	B(1) μG	R(1)	δ Γ	θ (deg)	R'	DfC (kpc)
k4	0.74	116	0.0917	16	3.5	65	42
k25in	0.74	36	0.3967	13	4.5	352	184
k25out	0.66	27	0.1939	18	3.2	1840	269
k25new	0.70	10	1.3454	14	4.1	5060	215

α is the spectral index for both the IC and synchrotron spectra. For both k25in and k25out, the actual X-ray spectrum is significantly flatter than the radio spectrum, so that is another problem for the IC/CMB beaming model.

B(1) is the equipartition magnetic field strength for no beaming.

R(1) is the ratio of amplitudes of the IC to synchrotron (observed) spectra.

The δ/Γ column gives their values for $\Gamma = \delta$, and the relevant angle to the line of sight is θ.

R' is the ratio of E^2 losses in the jet frame (IC/synchrotron).

DfC is the de-projected distance from the core for the particular feature (projected distance/sinθ).

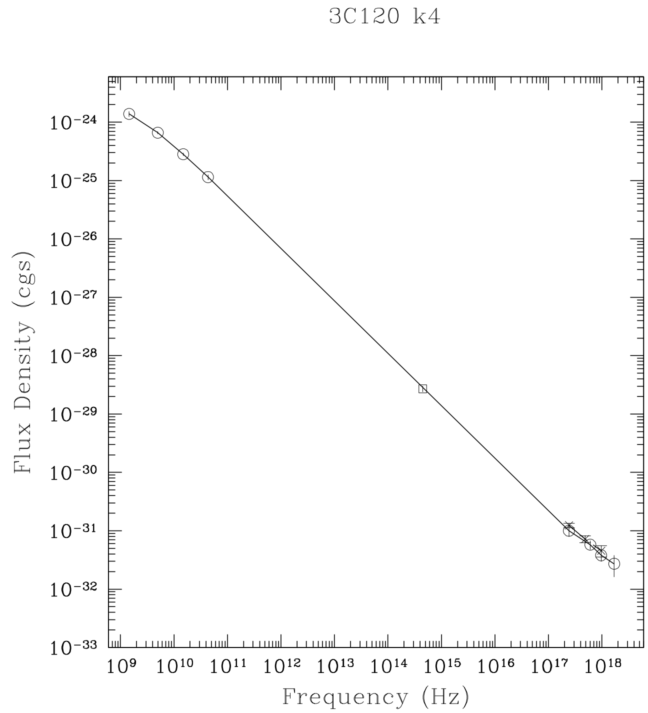

Figure 5: The radio-optical-X-ray spectrum of k4.

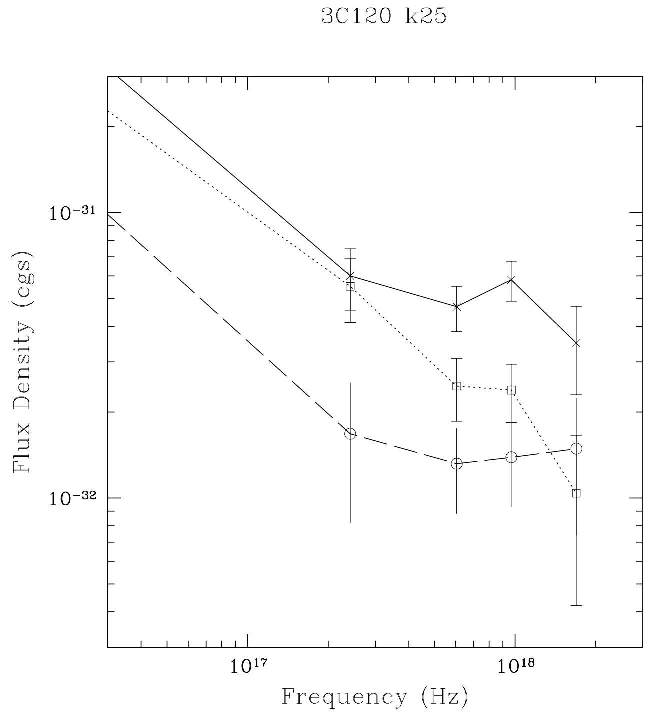

Figure 6: The X-ray spectra for 3 parts of k25. The lines leading off to the left connect to the radio data. The dashed line is for the 'inner' region; the solid line for the 'outer' region; and the dotted line for the 'new' region.

(Celotti et al. 2001, Tavechhio et al. 2000). The beaming parameters given in Table 3 are not entirely unreasonable if the Γ of the jet does not decrease significantly out to k25. However, as noted in the table, for several features the spectral index observed in the X-ray band disagrees with that expected from the radio spectrum. Additionally, the small angles of the jet to the line of sight (of order 5°) for most of the knots also leads one to infer a large projection effect so that the physical size of the jet becomes uncomfortably long. Furthermore, the beaming parameters required (Γ, δ, θ) are more extreme than those generally applied to the pc scale jet (Gomez et al.; Walker et al. 1987). For these reasons, we disfavor the IC/CMB emission model.

5 Conclusions

For k25, synchrotron self-Compton emission is untenable because the energy density of the magnetic field is always 10 to 1000 times greater than that of the synchrotron photons. Relying on bulk relativistic velocities to increase the effective energy density of the CMB requires small angles to the line of sight and unreasonably large values of the beaming factors (see Atoyan & Dermer, 2004, for general problems for IC/CMB models). Although thermal bremsstrahlung is a tempting explanation of the flat spectra associated with the outer and inner edges of k25, the rotation measures thereby expected are not observed.

If the flat X-ray spectra of the inner and outer edges is synchrotron emission, then either the power law for the electron distribution defined by the lower frequencies suffers a 'pileup' at the high energy end (see, e.g., Dermer & Atoyan, 2002) or there is a separate spectral component which is flatter than that produced by the conventional shock acceleration theories (N(E) $\propto E^{-\mathrm{p}}$ with p ≥ 2). Although the X-ray emission from 'k25new' appears to have a more normal spectrum, both the radio and X-ray emission from this region have very low brightnesses, making it difficult to measure the region's properties well enough to draw convincing conclusions.

Acknowledgments

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References

Atoyan, A., Dermer, C. D. 2004, astro-ph/0402647
Celotti, A., Ghisellini, G., Chiaberge, M. 2001, MNRAS, 321, L1
Dermer, C. D., Atoyan, A. M. 2002, ApJ, 568, L81
Gomez, J. L., Marscher, A. P., Alberdi, A., Jorstad, S. G., Garcia-Miró, C. 2000, *Science*, 289, p.. 2317
Harris, D. E., Krawczynski, H. 2002, ApJ, 565, 244
Tavecchio, F., Maraschi, L., Sambruna, R. M., Urry, C. M. 2000, ApJL, 544, L23
Walker, R. C., Benson, J. M., Unwin, S. C. 1987, ApJ, 316, 546
Walker, R. C. 1997, ApJ, 488, 675