X-RAY RELIC COUNTERJET OF CYGNUS A

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Abstract

We present a deep 200 ks co-added ACIS-I image of Cygnus A. The only linear bright X-ray feature, which does not trace the current counterjet, is identified with a relic counterjet; visible in X-rays due to inverse-Compton scattering of the microwave background (ICCMB) radiation. No relic jet is observed in the western, i.e. nearer lobe. The nearer and further lobes are separated by 10s of kpc and therefore by 10s of thousands of years in light-travel time, giving us temporal resolution as well as spatial resolution. From the lack of relic jet emission on the near side, we constrain the timescale between successive episodes of jet activity to be $\sim 10^6$ years.

1 Introduction

Cygnus A was observed 10 times with at least an exposure time of 5 ks, 8 of which use the ACIS-I detector, 2 which use the ACIS-S detectors and for which we only use the spectra. Fig. 1 shows the X-ray image of Cygnus A, with the linear feature in the counterlobe. From its position, i.e. on the line between the hotspots in the lobe and counterlobe and the nucleus, this is likely a jet feature.

Detection of X-ray photons that arise from inverse Compton up-scattered Cosmic Microwave Background (ICCMB) photons mandate the presence of relativistic particles with Lorentz factors of order 10^3 [Harris & Grindlay 1979]. Such particles have lower Lorentz factors than ambient synchrotron-emitting particles radiating at the typically-observed radio wavelengths, assuming the magnetic field strengths in the lobes of radio galaxies are nT in size or lower. Thus, co-spatial X-rays can reveal information about the lower-energy population, possibly present as a relic (that is previously, but no longer detectably synchrotron emitting) plasma (e.g. [Erlund et al. 2008], and [Blundell et al. 2006]). The spectrum (see Fig. 2) shows that the X-ray relic counterjet cannot be fit with a thermal plasma model, and that most of the emission is non-thermal. All, the other bright X-ray features in the image are well fit with a thermal plasma model [Wilson, Smith & Young 2006].

For a redshift of 0.05607 [Owen et al. 1997] the physical size, not correcting for possible line of sight angle, of Cygnus A is 130 kpc. Therefore, the light-travel time between opposite lobes exceeds $\cos\theta \times 4 \times 10^5$ years, where θ is the angle between the axis of the radio source and our line-of-sight. Since the light we observe from opposite lobes is received at the same telescope time, this means that an observer on Earth sees the nearer lobe at a more recent epoch than the further lobe, which is seen at an earlier time in the radio galaxy's history. The implications of the light-travel time on the observed luminosity are shown in Fig. 3.

Figure 1: The 0.2−10 keV ACIS-I image, with a transfer function clearly showing the linear counterjet-like feature delineated by the green box and the non-detection of anything corresponding to this on the jet side.

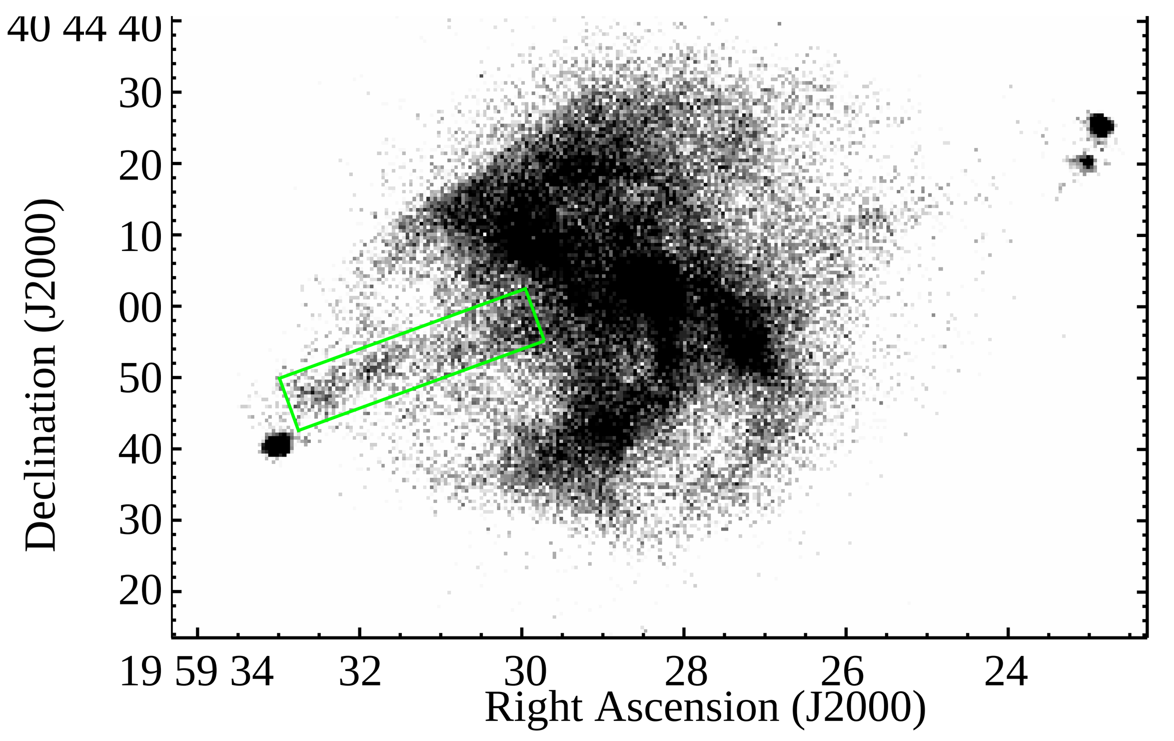


Figure 2: Flux spectrum for the energy interval $0.5 - 7$ keV from the 10 different observations for the X-ray counterjet within the eastern lobe. The best fit power-law plus thermal model in red, the blue curve indicates the best fit thermal model. Note that the 6.4 Fe Kα line is severely over-predicted in the latter fit. The slight excess around 6.4 keV is due to the thermal emission from the cluster surrounding Cygnus A. The small difference between the fits at shorter wavelengths is a direct result of the different calibrations for the different set-ups of the instruments used.

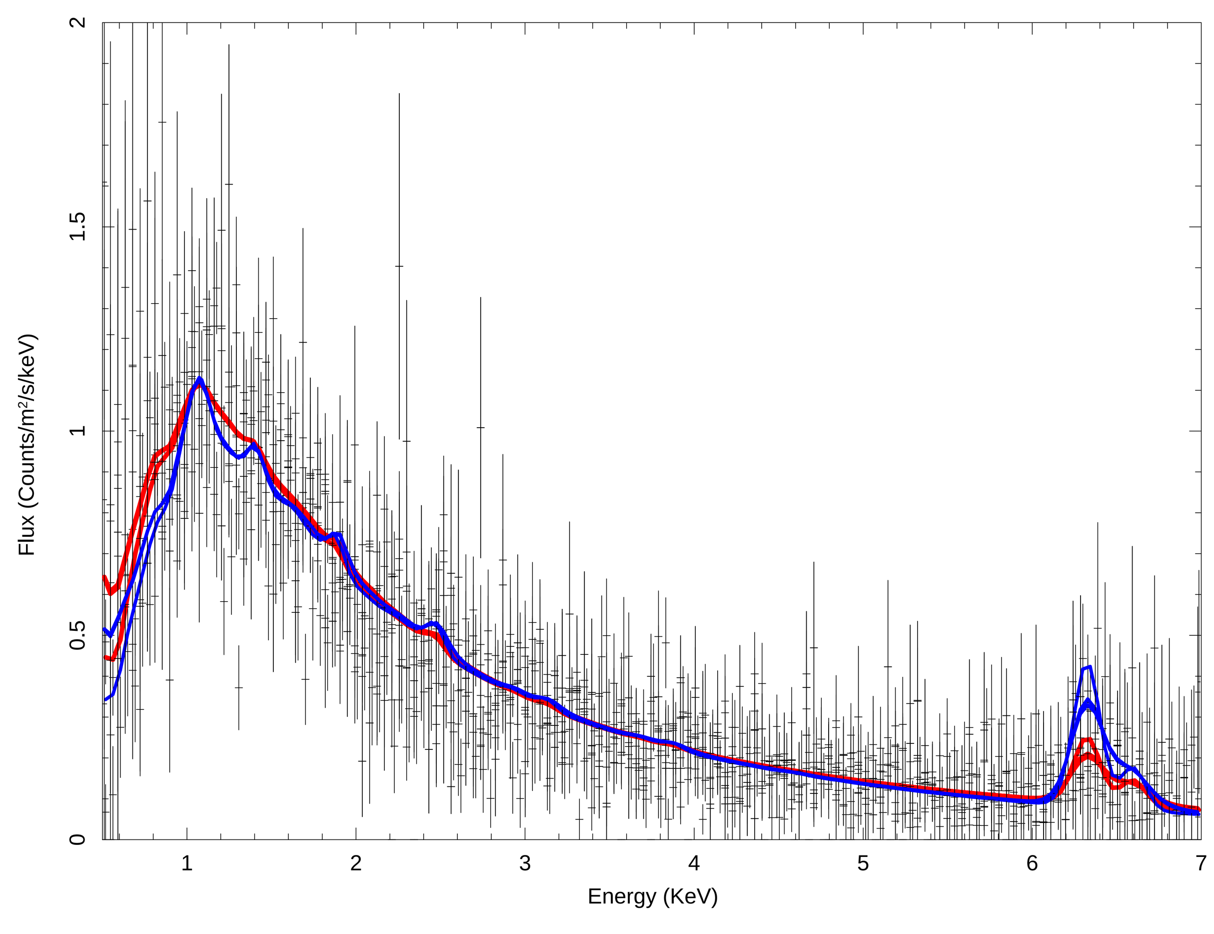
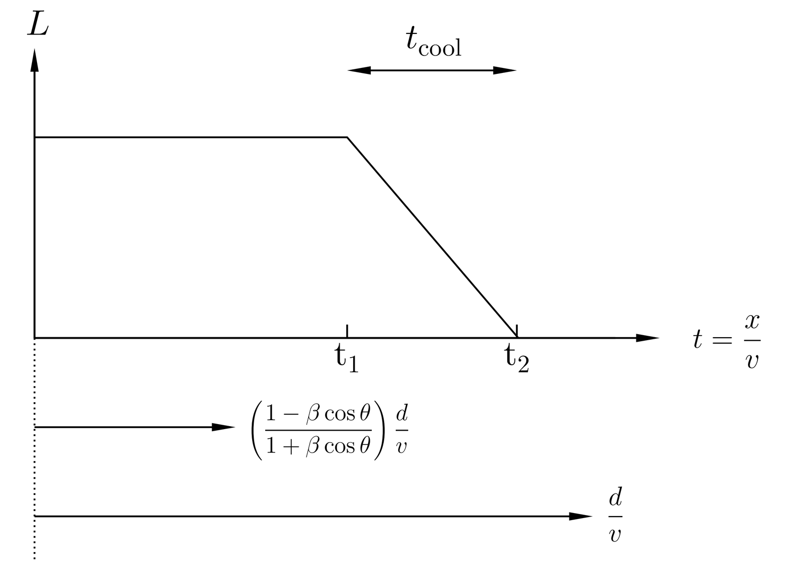
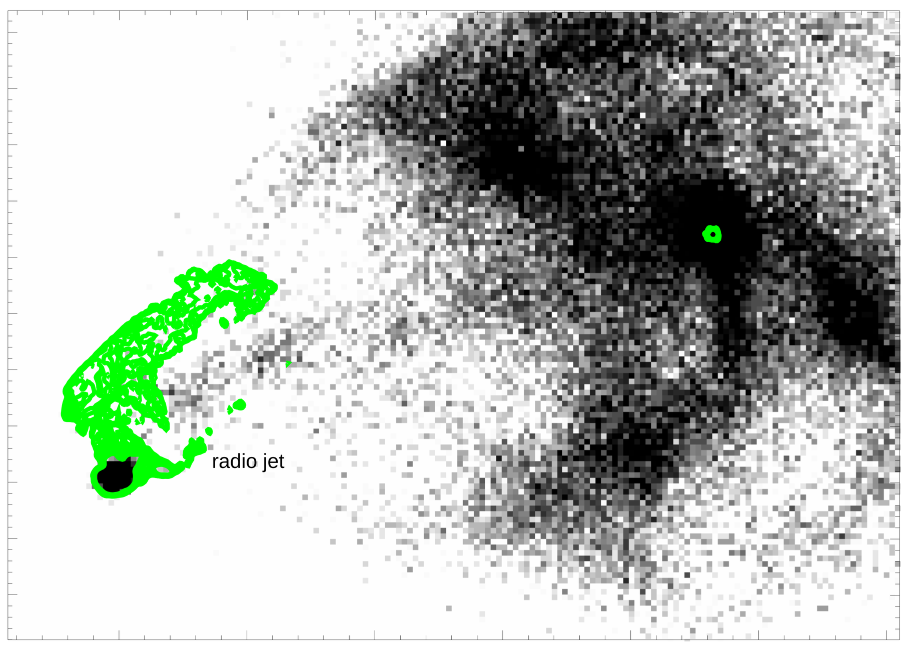


Figure 3: *Upper:* This is a schematic lightcurve for a fading jet. The timescales below indicate what we expect to see at the telescope for the counterlobe (i.e. the side furthest away from us) and the nearer lobe due to light-travel time effects. *Lower:* This illustrates the possible combinations of on/off states for a fading jet and counterjet. The squares coloured black are not formally possible, because of light-travel time effects while those in grey are formally possible but excluded for this object by observation. The squares labelled "poss" and "obs" are allowed solutions. For the square labelled "obs" it is possible to calculate magnetic field strength of the relic counterjet.



app \ rec	on	fading	off
on	(grey)	poss	obs
fading	(black)	poss	poss
off	(black)	(black)	(grey)

Figure 4: Detail of the ACIS-I image with a transfer function optimised to show the relic X-ray counterjet. The contours are from the 15 GHz image, indicating the flux between 0.008 and 0.05 Jy. Note how the transversely extended X-ray counterjet goes through a low luminosity radio region, seemingly pushing radio lobe plasma north. Furthermore, note that the radio counterjet, shown in green contours, is detected to the south of the X-ray counterjet.



2 Discussion

From the light-travel time and an assumed hotspot advance speed of 0.1c one can calculate that the last episode of jet activity was $\sim 10^6$ years ago, which is also the age of the current jet. This short timescale can plausibly be explained by adiabatic expansion causing the jet to cool and thereby fade in the X-rays. The upper limit for observed radio emission due to the relic counterjet allows us to deduce an upper limit for the magnetic field strength within it; this is well below the equipartition value.

Its power-law spectrum, with photon index of 1.7, indicates that the feature is due to emission from jet plasma having spectral index 0.7. Comparing the X-ray detected relic counterjet with the observed radio counterjet in the 15-GHz radio image (Fig. 4), we conclude that the counterjet detected in X-rays does not overlay the counterjet detected in radio images. Instead, it forces the current jet to bend over by an angle of about 27° and pushes the lobe plasma northwards, creating a very radio luminous thick lobe edge.

We conclude that the X-ray counterjet is a relic from the following observations: (i) the curvature of the outer parts of the X-ray counterjet is significantly different from that of the current radio counterjet; (ii) this feature lacks any directly associated radio emission implying a lack of high energy synchrotron particles; and (iii) the width of the X-ray counterjet is significantly broader than the radio jet or counterjet implying expansion.

References

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For further details see arXiv:0805.2169 and arXiv:0805.2172.