X-ray properties of Centaurus A (NGC 5128)

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Abstract. We have observed the nearby radio galaxy Centaurus A (NGC 5128) with the ROSAT HRI. With a distance of about 3 Mpc, this object contains the closest of the three extragalactic Jets which have been studied in x-rays. We confirm the existence of separate knots of X-ray emission which are coincident with the radio-knots. The angular scale of 15 pc arcsec^{-1} now permits us to resolve the jet laterally even in the X-ray domain and to study the morphology of the jet in detail. We do not detect a counter-jet, but the HRI images reveal an X-ray filament which is associated with the shock front of the southern inner radio lobe (on the counter-jet side). This filament probably traces shock-heated gas.

In addition we detect diffuse emission from the host galaxy of the AGN which is partially absorbed by the cold matter of the prominent absorption band on the line of sight towards the nucleus of NGC 5128.

1. Introduction

Cen A is a large, prototypical radio-galaxy, which has been studied in great detail. It is the closest active galaxy to the Milky Way and permits studies of unsurpassed spatial resolution in many frequency bands. Unfortunately, the central part of this object is hidden behind a prominent dust band. This prohibits any investigation of the nucleus at optical and UV wavelengths and still severely affects studies in the adjacent IR and X-ray regimes.

Cen A does not only contain the closest extragalactic jet, but also one of the very few jets which have been detected at X-ray energies. The radio-emission on scales of tens of parsecs to kiloparsecs has been studied extensively (see e.g. Clarke et al., 1986, 1992). They have resolved many of the knots found in earlier investigations into complex substructures with steep spatial gradients of the radio spectral indices. This complex morphology suggests that the radio jet is hollow with most radio emission being emitted from filaments. The flow seems to have some helical components. It is collimated out to the prominent knot B, downflow of which it expands in a linear fashion until it hits knot G where the jet is disrupted and the plasma enters the northern 'inner' radio lobe. While a symmetrically placed southern 'inner' radio lobe has comparable luminosity, there is no radio counter-jet.

Optical investigations found no direct emission from the synchrotron jet. At large distances from the nucleus, however, Morganti et al. (1992) discovered gas which is photoionized by a hard continuum. They suggest that this gas actually intercepts the jet and is photoionized by the unabsorbed (and probably beamed) nuclear radiation, indicating that Cen A is a misdirected blazar.

Near-IR studies by Joy et al. (1991) found an elongated feature which is spatially coincident with the radio-jet and conclude that the IR emission is thermal in nature.

The most elaborate X-ray studies published up to now have been carried out by Feigelson et al. (1981) using EINSTEIN HRI data. They showed that the X-ray emission is mostly due to a small number of knots which are often spatially coincident with radio knots. The much higher sensitivity of ROSAT and the better resolution of its HRI detector now allows a more detailed investigation of the X-ray properties and shows that the X-ray knots are spatially extended with diameters larger than 50 pc. We present some of the results of our ROSAT HRI observations. A full discussion is given in Döbereiner et al. (in prep.) and Wagner et al. (in prep.).

2. Diffuse Emission

The well-defined X-ray jet (Sect. 3), about 40 point-sources and the X-ray filament (Sect. 4) are superposed of a diffuse component, centered on the nucleus of the galaxy. This diffuse emission is intercepted by bands running perpendicular to the jet orientation. They perfectly trace the well-known absorption bands which are very prominent in optical images of NGC 5128. The absorption in the central parts prohibits the derivation of the radial luminosity profile of the diffuse emission. We cannot compare the X-rays directly with the optical light. The surface brightness of the diffuse emission outside the absorption bands is consistent with the hypothesis that the diffuse emission is due to the underlying stellar population of this giant radio-galaxy. We cannot exclude, however, that a fraction as high as 40 % may be due to additional interstellar X-ray gas. The scale length of the diffuse emission suggests, that most of it lies within the dust band. We can therefore use the small-scale modulation of the X-ray intensity parallel to the X-ray jet (which is caused by the "foreground" absorption of the dust band) to constrain the amount of small-scale modulation along the ridge line of the jet which is due to this absorption rather than substructure of the X-ray emissivity of the jet.

3. The X-ray Jet

The jet is the most prominent feature in the X-ray image of Cen A which is shown in contours in Fig. 1. The morphology of the observed jet is subject to photoelectric absorption by the dust belt. In order to study the true spatial variations we subtracted a smooth background component and corrected for small-scale variation of the foreground absorption as mentioned in Sect. 2. Uncertainties in this procedure may result in errors of the corrected images by about 15 % with a safe upper limit of 40 %. It is obvious that the separation of the X-ray jet into individual knots is not due to modulations of foreground extinction. Apart from the nucleus, knots A and B are the most prominent, knots E, F, and G are clearly visible. The reality of knots C and D is subject to details of the correction for foreground absorption. They are not significant in our analysis. All of the knots are extended along the jet, knots B, E, and F are clearly extended perpendicular to the jet. Their X-ray morphology is similar to the structure in the 6 cm radio map of Clarke et al., 1992.

The nucleus has a spatial profile which is consistent with the PSF. In addition to the (resolved) knots we detect smooth X-ray emission along the jet with some indication for emission even beyond knot G. The HRI data do not constrain the X-ray spectrum of the jet. In spite of differences in the flux densities of the knots between our data and those of Feigelson et al. (1981), we confirm their conclusion that the X-ray emission may be due to synchrotron radiation.

4. The Southern Filament

We do not detect a counter-jet in the X-ray image. On the counter-jet side, however, we detect a filament which is extended perpendicular to the jet direction at a distance of 5.5 arcmin to the nucleus. This filament is 90" long and unresolved along its short axis. The reality of the feature has been confirmed by lower S/N detection in archival PSPC and EINSTEIN HRI data. The bright point source 5.5 arcmin southwest of the nucleus is spatially coincident with a distant early-type galaxy and most likely unrelated to the filament. This superposition makes it impossible, however, to determine constraints of the X-ray spectrum of the filament from the PSPC data. As can be seen from Fig. 1, the filament traces the front end of the southern inner radio lobe. Clarke et al. (1992) used radio data to detect depolarization and Faraday rotation in the inner part of this southern lobe and concluded that the southern lobe is on the far side of the galaxy. The front end of the lobe has a large projected distance from the core and is not affected very much from the depolarization which is related both to the absorption band and to halo gas. As shown by Clarke et al. (1992; see their figure 5), the magnetic field is enhanced and oriented along the front. This clearly demonstrates that the magnetic field in this region is compressed. The compression is likely to be caused by shocks from the inner radio lobe propagating into the external medium. The close association of the X-ray filament with this regime of compressed gas suggests that the X-ray filament is due to shock heated gas (Wagner et al., in preparation).

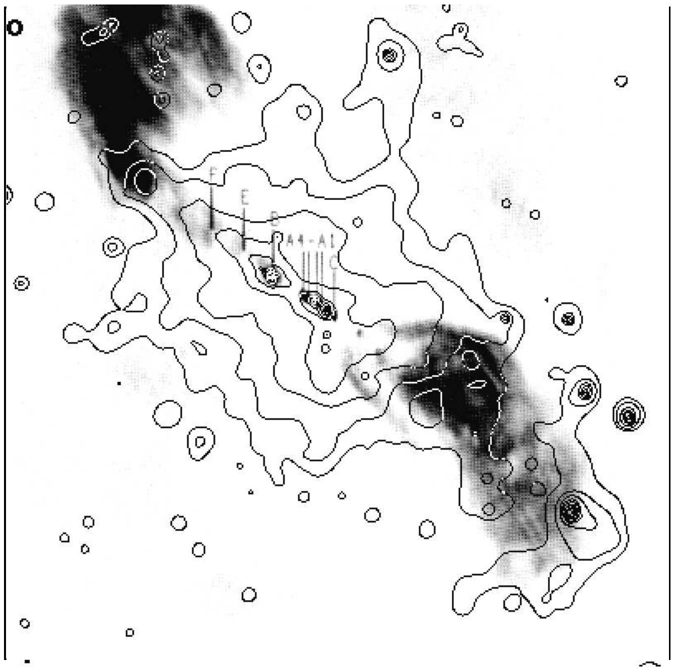

Fig. 1. X-ray emission from HRI observations of NGC 5128 (contours) superposed on a 18 cm radio map (greyscale; see Clarke et al., 1992). The knotted X-ray jet, the diffuse emission, intercepted by absorption bands running perpendicular to the jet orientation, and a tangential X-ray filament at the front-end of the southern radio lobe are clearly visible.

Acknowledgements. SW acknowledges support from the Deutsche Forschungsgemeinschaft (SFB 328).

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