Chandra's X-ray guide to Centaurus A

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Abstract

Centaurus A is the closest radio-loud active galactic nucleus (AGN). At a distance of 3.8 Mpc, the angular resolution of 0.5 arcsec of *Chandra*/ACIS translates to $\sim$ 10 pc. This gives us the unique opportunity to disentangle the X-ray emission from different components. We analyze archival data (2000-2013) and study timing and spectral properties of the core region and the diffuse gas in Cen A. Using the soft X-ray emission lines, we study the nature of this diffuse material. The core region of Cen A emits time- and spectrally-variable hard X-rays. We report that a circumnuclear "halo" (up to 0.2 kpc away from the core) also emits an Fe Kα line, and we investigate the nature of this emission.

The Core

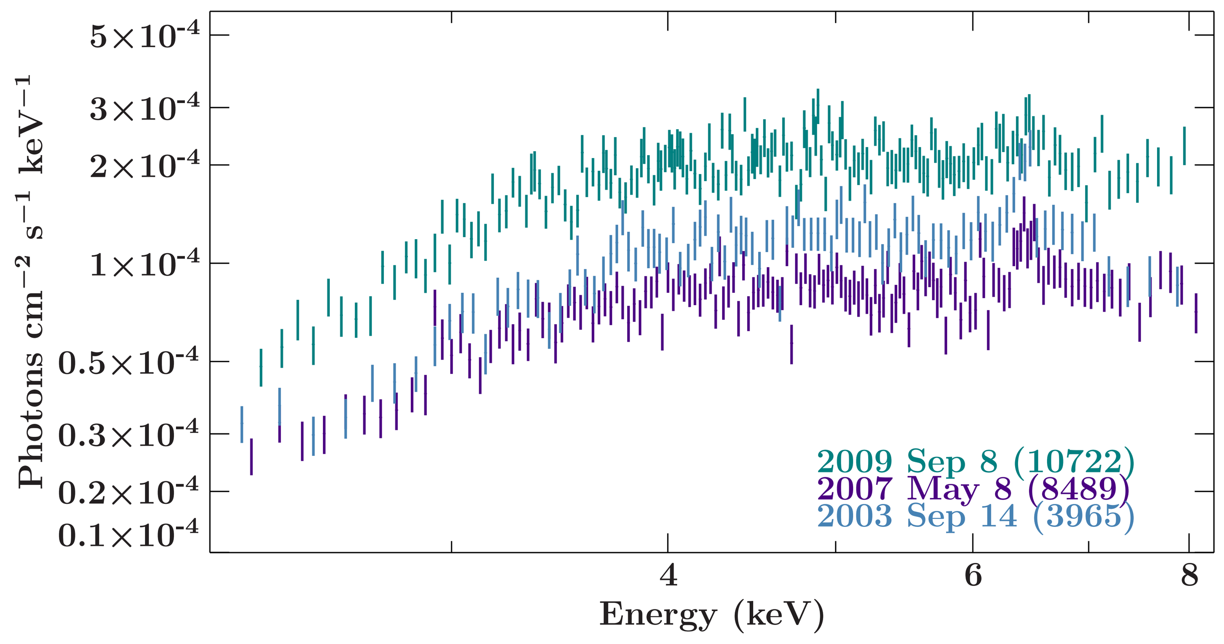

Fig. 1. Spectra of the core emission.

The core emits a strongly absorbed power law continuum with a prominent Fe Kα line (Evans et al., 2004, and references therein). Not only does the core show short- and long-term flux variability (see Fig. 1), but also the strength of the fluorescent Iron Kα line seems to vary (see also Fig. 8 and Table 1). The absorption column $\left(N_H \sim 10^{23}\,\mathrm{cm}^{-2}\right)$ has also been found to be variable, probably due to a clumpy torus (Rivers et al., 2011).

The Soft X-Rays

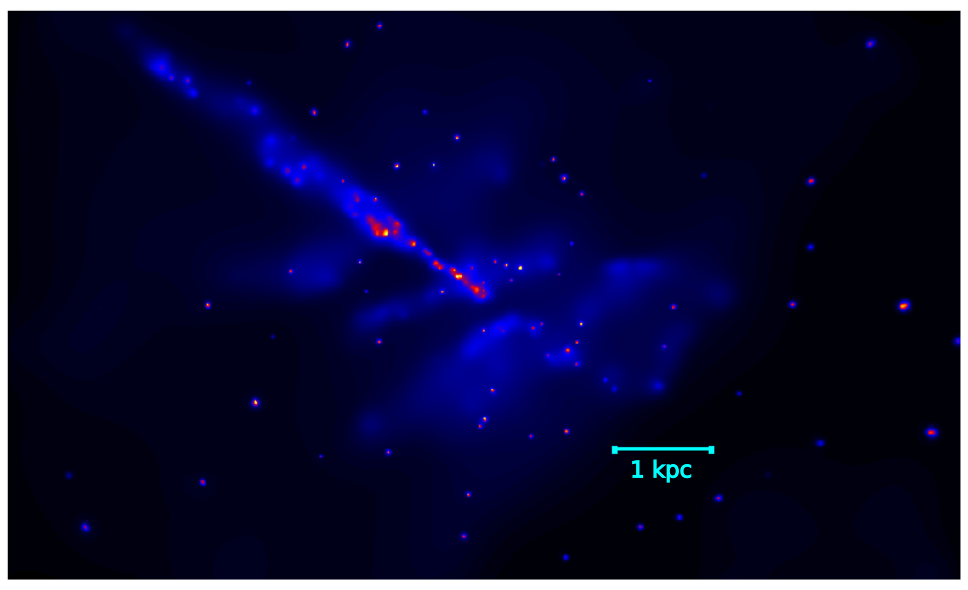

Fig. 2. Soft X-ray emission of Centaurus A (E $\leq$ 2 keV).

Fig. 2 shows the soft X-ray emission at energies below 2 keV. The dust lane (see Fig. 6) is clearly visible as most soft X-ray photons are absorbed (Karovska et al., 2002). The jet is very bright and barely absorbed. Surprisingly the soft emission surrounding the core is extended (5-6 kpc) and not confined to a small region but encompasses the whole galaxy and is also present at high latitudes (Karovska et al., 2002). This soft emission has been known for a long time, but not studied in detail (Markowitz et al., 2007). We have forthcoming *Chandra*/LETGS observations of the diffuse emission to study the emission lines seen below 2 keV in detail. Line diagnostics using the He-like triplets allow us to constrain temperature and density of the emitting medium. We will therefore be able to probe AGN "feedback" in Cen A – the impact of radiative output from the central engine on nearby diffuse gas.

The Jet

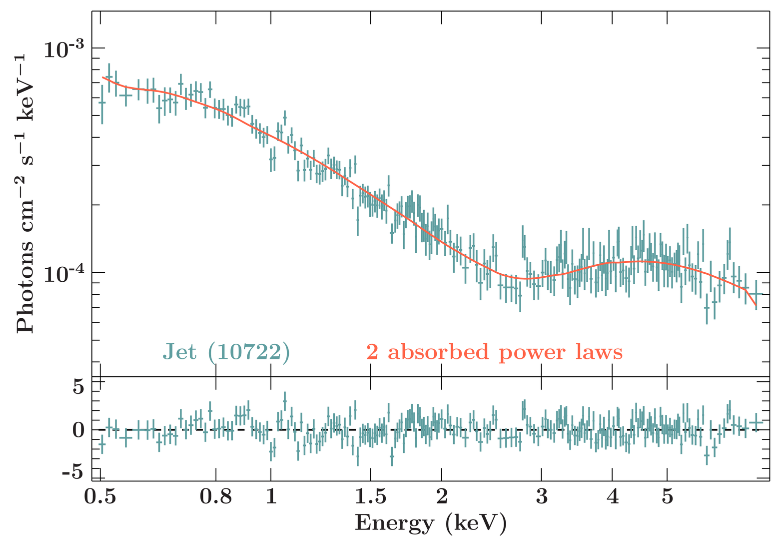

Fig. 4 The inner jet emits a barely-absorbed power law. Above $\sim$ 3 keV, a separate component, likely the core, dominates.

The jet's X-ray emission is unabsorbed and spectrally steep: surprisingly, it is not visible above $\sim 5-6$ keV (Fig. 4). We have been investigating links between jet radio production, as probed by the TANAMI program, and integrated hard X-ray emission from the inner jet (see Müller et al., 2014).

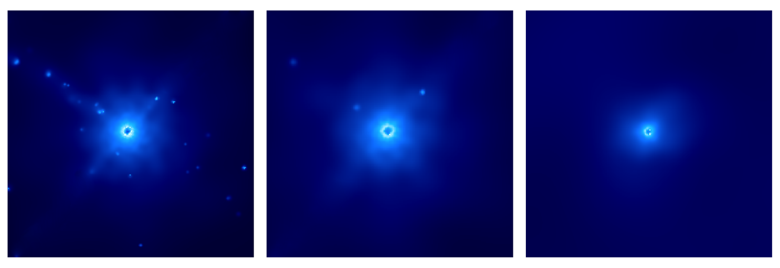

Fig. 5. The jet vanishes at higher energies (*left*: E $\geq$ 3 keV, *center*: E $\geq$ 5 keV, *right*: E $\geq$ 7 keV).

Fig. 3. X-ray emission of Centaurus A. *Credit: R. Kraft (SAO) et al., CXC, NASA*

Centaurus A

Fig. 6. Composite image of Centaurus A. Clearly visible are the large dust lane, the radio lobes and the strong jet emission (*Credit: CXC*).

Centaurus A has been the object of various studies across the entire EM spectrum and is a key object within the scope of the TANAMI multiwavelength program to observe active galaxies (Ojha et al. 2010). Here, we take advantage of *Chandra*'s spatial resolution to separate the various X-ray emission regions: the core, the extended jet, and the diffuse region around the central engine (Fig. 7).

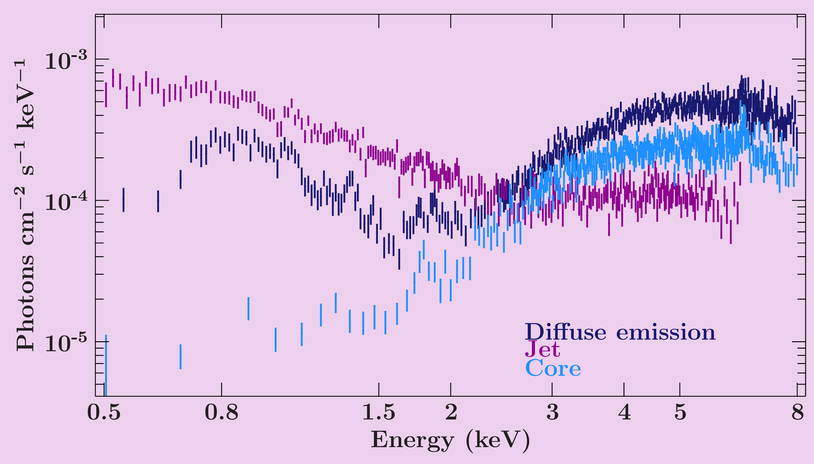

Fig. 7. Spectra of Cen A's emission regions.

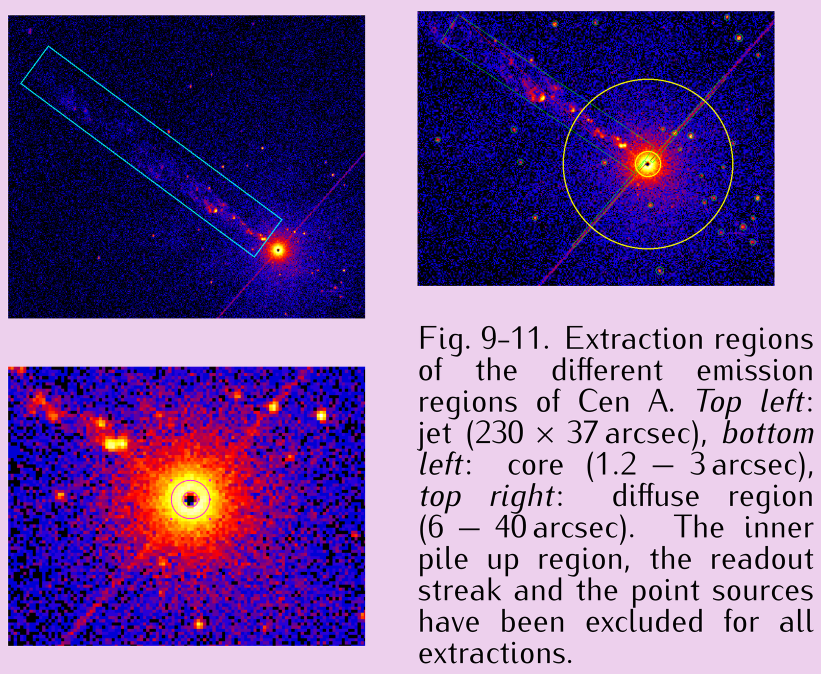

Fig. 9-11. Extraction regions of the different emission regions of Cen A. *Top left*: jet (230 $\times$ 37 arcsec), *bottom left*: core (1.2 – 3 arcsec), *top right*: diffuse region (6 – 40 arcsec). The inner pile up region, the readout streak and the point sources have been excluded for all extractions.

The Iron Kα Emission

Table 1. Equivalent width of the Fe Kα line in annulus regions around the center of Centaurus A.

ObsID & Date	Equivalent width of Fe Kα line						
	r=1″-2″ [10^2 eV]	r=2″-3″ [10^2 eV]	r=3″-4″ [10^2 eV]	r=4″-5″ [10^2 eV]	r=5″-6″ [10^2 eV]	r=6″-7″ [10^2 eV]	r=7″-8″ [10^2 eV]
10722, 2009 Sep 8	0.5 ± 0.6	1.3 ± 0.5	$1.0^{+0.6}_{-0.5}$	$1.8^{+0.8}_{-0.7}$	1.5 ± 0.8	$1.0^{+0.8}_{-0.7}$	$1.3^{+0.9}_{-0.8}$
8489, 2007 May 8	$1.3^{+1.2}_{-0.9}$	2.6 ± 0.8	$2.9^{+1.1}_{-1.0}$	2.3 ± 1.0	$3.0^{+1.3}_{-1.2}$	$2.0^{+1.3}_{-1.2}$	$1.0^{+1.1}_{-1.0}$
7797, 2007 Mar 22	-0.4 ± 0.6	$1.2^{+0.8}_{-0.7}$	1.3 ± 0.8	$2.0^{+1.0}_{-0.9}$	$1.7^{+1.1}_{-1.0}$	$2.3^{+1.3}_{-1.1}$	$0.8^{+0.11}_{-0.10}$
3965, 2003 Sep 14	1.3 ± 0.7	$1.9^{+0.8}_{-0.7}$	$3.9^{+1.3}_{-1.1}$	$3.1^{+1.3}_{-1.2}$	$1.3^{+1.2}_{-1.1}$	$1.3^{+1.4}_{-1.3}$	$1.0^{+1.3}_{-1.1}$
2978, 2002 Sep 3	$2.1^{+0.8}_{-0.7}$	$2.3^{+0.9}_{-0.8}$	$3.2^{+1.3}_{-1.2}$	$2.0^{+1.3}_{-1.1}$	$1.3^{+1.4}_{-1.3}$	$2.5^{+1.8}_{-1.6}$	$2.5^{+1.9}_{-1.7}$

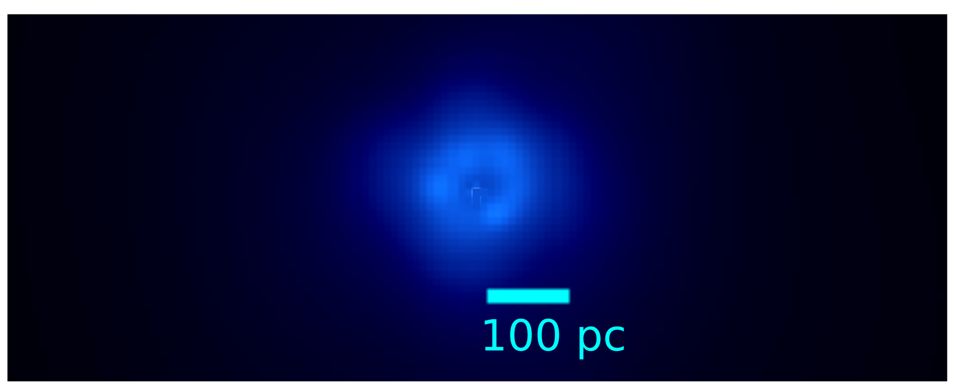

Fig. 8. Extended iron emission (6.3 keV $\leq$ E$\leq$ 6.6 kev).

Circumnuclear gas around AGN (accretion disks, torus) usually show Fe Kα emission at 6.4 keV. For Cen A, we report for the first time an *extended* Fe Kα emitting region. We show that the Fe Kα emission is not only emitted by the core, but also by a "halo" surrounding the center and extending up to at least 0.2 kpc. We find time- and spatially-variable Fe Kα emission flux (see Table 1 and Fig. 8), and are currently investigating the roles of variable point sources (LMXBs and transient BH XRBs; e.g., Burke et al., 2013).

Conclusion and Outlook

- ⋆ *Chandra* images reveal the extended emission at soft X-rays
- ⋆ Extended Fe Kα emission: Scattering off surrounding medium? Jet-plasma interaction? Point sources?
- ⋆ The jet is not visible at energies above $\sim$ 5 keV
- → *Chandra*/LETGS observations will allow us to study soft diffuse emission in detail
- → Further investigation of the origin of the hard X-ray emission and a possible link to the iron-line variability

References

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