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Suzaku Observation of the Eastern X-ray Lobe of SS 433

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Abstract

We observed the eastern X-ray robe of SS 433 with Suzaku. The non-thermal component of the X-ray spectrum cannot be described by a simple power-law model, but requires a cutoff around 8 keV. We also found that the cutoff energy decreases as the distance from SS 433 increases. It is probably due to synchrotron cooling of electrons accelerated near SS 433. Based on this, the magnetic field around the lobe B is limited to be weaker than $\sim 75\ \mu$G. The high-energy electrons traveled a distance of $\sim$9.6 pc among 650 yr if B =10 μG. The bulk velocity of the jet, which is 0.26 c near the compact object, keeps $\sim 0.05\ c$ after the jet traveled a distance of $\sim$ 35 pc.

Key words: ISM: jets and outflows — X-rays: individuals:(SS433) — X-rays: individuals:(W50)

1. Introduction

SS 433 is an X-ray binary and its compact object is one of the most famous blackhole candidates. Jets with a velocity of 0.26 c exist near the compact object (Margon 1984). A radio-shell supernova remnant (W50) is associated with SS433. The shell is extended toward the east and west. It is thought that the interaction with the jets caused the extended structure. Diffuse X-ray emission is also associated with the extended radio shell. On the east side, there is a bright structure like a knot (e.g. Yamauchi et al. 1994).

To reveal the detail structure of the X-ray emission, we observed the eastern X-ray lobe for 107 ks with Suzaku XIS whose features are large effective area and a low stable non-X-ray background. The observed position is about 35 arcmin away from SS 433. The X-ray image is shown in figure 1.

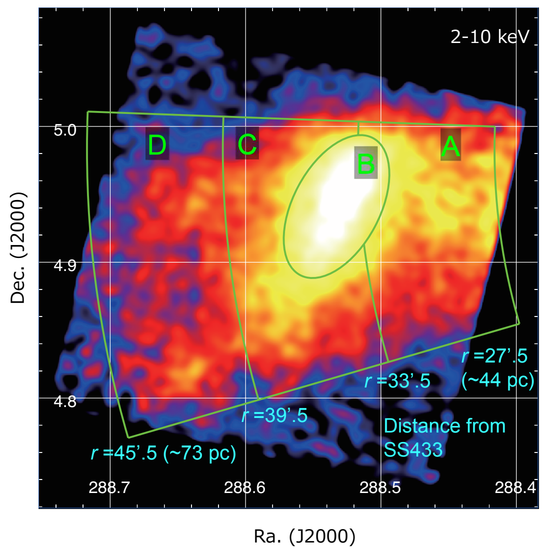

Fig. 1. X-ray Image of the observed region with Suzaku XIS. The regions from which spatially divided spectra are extracted are also shown (see section 3.).

2. Spectrum from the Entire Field of View

We made a spectrum from the entire field of view of XIS. It is shown in figure 2. Models of the Galaxy background (Uchiyama et al. 2013) and the cosmic X-ray background (CXB, Kushino et al. 2002) were added for fitting. As reported by Brinkmann et al. (2007), the spectrum of the X-ray lobe consists of a optically-thin thermal plasma component (APEC, Smith et al. 2001) and a non-thermal component with interstellar absorption.

If we used a simple power law as the non-thermal component, large residual appeared above 3 keV. When the non-thermal component is a cutoff power law with

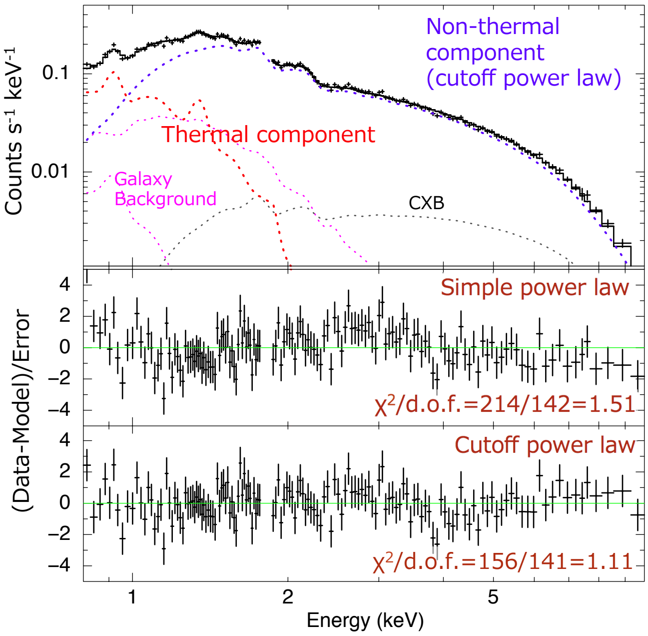

Fig. 2. Spectrum from the entire field of view. The residuals of the fitting with simple or cutoff power-law models for the non-thermal components are also shown.

$h\nu_{cutoff} \sim 8$ keV, the residual disappeared and reduced χ^2 also became much smaller (figure 2). We, for the first time, found that the non-thermal component requires a cutoff.

3. Spatial Profile of the Cutoff Energy

We made spectra from the regions of A, B, C and D shown in figure 1 to study the spatial profile of the cut-off energy $h\nu_{cutoff}$. The regions of A, C and D are annuluses centered at SS 433. The region B corresponds to the bright knot-like structure but its spectrum is not much different from those of the other region. We fitted 4 spectra simultaneously. The temperature of the thermal component, the photon index of the non-thermal component and interstellar absorption were linked for all the regions. The normalizations of the components and $h\nu_{cutoff}$ of determined independently for each region.

The obtained spatial profile of $h\nu_{cutoff}$ is figure 3. The $h\nu_{cutoff}$ decreases as the distance from SS 433 increases. The spatial dependence of photon index was reported by previous studies (Yamauchi et al. 1994, Brinkmann et al. 2007) but we found that it can be explained by the change of $h\nu_{cutoff}$.

4. Discussion

The probable origin of the non-thermal component is synchrotron radiation of high-energy electrons. The cut-off is probably due to the synchrotron cooling of the electrons. The higher the electron energy, the shorter the cooling time. The spatial change of the cutoff $h\nu_{cutoff}$ shows that the electrons accelerated near SS 433 move outward while cooling. Our result suggests that the acceleration occurs outside of the field of view of this Suzaku observation.

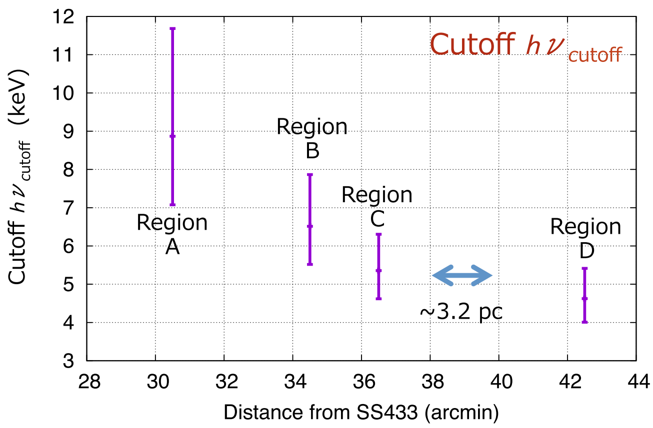

Fig. 3. Spatial profile of $h\nu_{cutoff}$ obtained by simultaneous fitting of spectra from region A–D.

Figure 3 indicates that the electrons traveled the distance between A and C, 9.6 pc (the distance between the Sun and SS 433 is 5.5 kpc, Blundell & Bowler 2004), in the cooling time of electron which radiate photons with the energy of $h\nu_{cutoff} \sim 5.5$ keV typically. The upper limit of the magnetic field B near the eastern X-ray lobe is obtained from the constraint that the speed of electrons is slower than the light velocity. Therefore, B is weaker than 74 μG. A similar calculation between C and D gave a limit of $B < 79\ \mu$G.

Hayashi et al. (2009) reported that the lower limit of the interstellar magnetic field in the western X-ray lobe is 6.8 μG from the TeV γ-ray observation. Considering this and the upper limit obtained above, we assumed that B=10 G. If there is no reacceleration, the electrons are thought to be traveled 9.6 pc during $\sim$ 600 yr (A–C) or $\sim$ 700 yr (C–D). This result shows that the bulk velocity of the jet keeps $\sim 0.05\ c$ after the jet traveled a distance of $\sim$ 35 pc. This is close to a expected velocity after standing shock of the velocity of $0.26\ c$, $0.26/4 = 0.063\ c$.

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