The Merger Dynamics of the Cygnus A Cluster

Direct Detection of the Subcluster Infall Velocity

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Abstract

The radio galaxy Cygnus A lies in a cooling core cluster which is currently undergoing a major merger with a particularly simple geometry mainly along the line of sight. The radial velocity distribution of member galaxies can be separated into two subgroups (Ledlow et al. 2005) separated by a velocity difference of about 2000 km/s, which is consistent with the expectation from the ASCA temperature map (Markevitch et al. 1999) showing a shocked region between the two subclusters. Here, we present a recent 43 ks *Suzaku* XIS observation of these merging subclusters. The redshifts of the Fe-Kα and Kβ lines monotonically increase from Cygnus A towards the other subcluster, and we find a radial velocity difference between them of 2650 ± 900 km/s, consistent with the sense and magnitude of the galaxy velocities. Also, we confirm the temperatures measured with ASCA for the Cygnus A cluster, the merger region, and the subcluster of $kT = 4.8 \pm 0.1$, 9.0 ± 0.8, and 6.4 ± 0.4 keV, respectively.

Key words: workshop: proceedings — galaxies: clusters: individual (Cygnus A) — galaxies: kinematics and dynamics — X-rays: galaxies: clusters

1. Introduction

Cygnus A, the archetypal FR II radio galaxy, is the brightest extragalactic object in the sky at radio frequencies. It lies at the center of a cool core in a massive ($\sim 10^{14}$ $M_{\odot}$), hot (~ 7 keV) and nearby (240 Mpc) cluster first discovered in X-rays with Uhuru (Giacconi et al. 1972) due to its proximity to the Galactic Plane, which makes the galaxy population difficult to observe despite its low redshift. An extension at lower surface brightness to the NW was first observed with Einstein (Arnaud et al. 1984) and confirmed by ROSAT. Markevitch, Sarazin, & Vikhlinin (1999) created large-scale temperature maps from ASCA data and found a hot region (~ 8 keV) in between the peaks of emission surrounding Cygnus A (hereafter referred to as A, see labels in Fig. 2) and the emission to the NW (B), which were interpreted as approximately equal mass subclusters in the early stages of a head-on collision, with approach velocity 2200 km/s. While no surface brightness jumps are observed between subclusters A and B from *XMM-Newton* and *Chandra* observations, such a jump would not be detected if the merger is occurring along the line of sight. An analysis of 118 galaxies spectroscopically identified as cluster members (Ledlow, Owen, & Miller 2005) reveal a bimodal radial velocity distribution with Cygnus A below the mean of the total distribution by ~ 1300 km/s, suggesting that an approximately equal mass merger along our line of sight is indeed underway.

Thus far, the detection of velocity differences in the ICM of clusters has been hampered by poor CCD spectral resolution and instrumental gain variations. Several claimed detections have been made with *XMM-Newton* and *Chandra* in, e.g., Centaurus (Dupke & Bregman, 2006) and A576 (Dupke et al. 2007), though no velocity difference was seen in Centaurus with *Suzaku* (Ota et al. 2007). In this work, we take advantage of *Suzaku*'s superior CCD spectral resolution and stable gain to investigate the merger state of the Cygnus A cluster.

2. Observations

The Cygnus A cluster was observed for 44.6 ks on 15-16 Nov. 2008 by the *Suzaku* X-ray Observatory. In this analysis, we combine spectra extracted from the X-ray Imaging Spectrometer (XIS) front-illuminated detectors, XIS0 and XIS3, using the cleaned events files produced by the processing pipeline and the standard selection criteria. Background events are taken from observations of the night Earth for a total accumulation of 370 ks. In Figure 1, we present a background-subtracted, exposure/vignetting-corrected image from the XIS0 detector, smoothed by a Gaussian of width 2 pixels and displayed in histogram-equalized grayscale. Logarithmically-spaced contours from the ROSAT PSPC observation are overlaid in black and show excellent

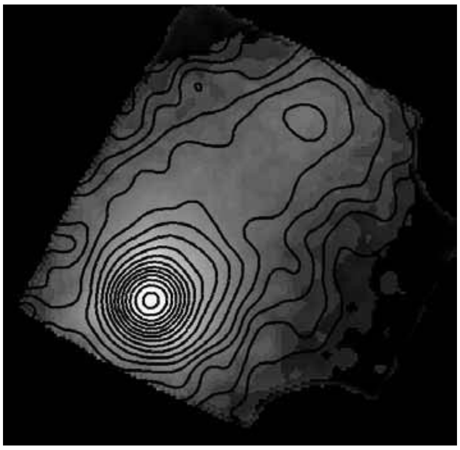

Fig. 1. Background-subtracted, exposure/vignetting-corrected image from the XIS0 detector. Contours from the ROSAT PSPC observation are overlaid for comparison.

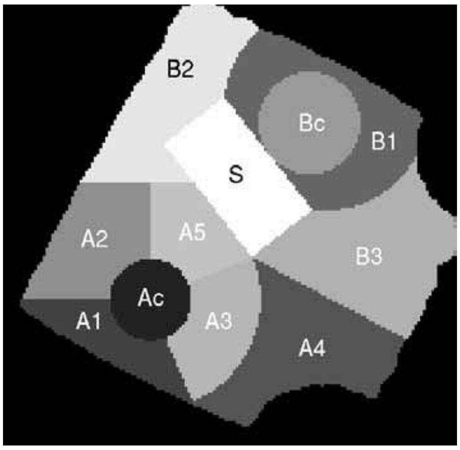

Fig. 2. Large-scale temperature map of the merging subclusters A and B (see Fig. 3 for kT values and errors). 'Ac' and 'Bc' correspond to the centers of each subcluster, which have significantly cooler temperatures than the shocked region 'S'.

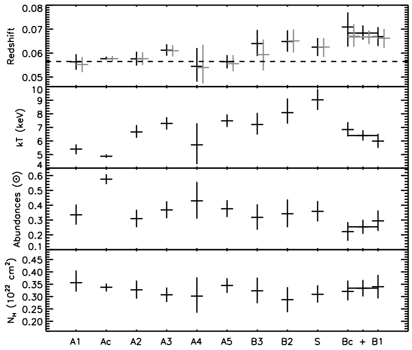

Fig. 3. Parameters for single temperature APEC fits (1 keV$< E < 12$ keV) and 90% error bars. The regions are specified in Fig. 2; region '$+$' between 'Bc' and 'B1' refers to a region containing both 'Bc' and 'B1'. In the top panel, gray crosses are redshifts derived from Gaussian fits to the Fe lines.

agreement. In addition to a thermal (APEC) model for the ICM, fits include a thermal model for Galactic emission and a power law point-source for the Cygnus A X-ray AGN.

3. Results

We confirm the general ASCA merger scenario, in which two subclusters are in the early stages of a major merger with a shocked region of higher temperature gas between them (labelled 'S' in Fig. 2 and Fig. 3). The subclusters are approaching for the first time, and neither the cooling core nor the radio source have been disrupted. The impact parameter of the merger appears to be slightly off-axis, based on the XIS and ROSAT isophotes. The redshift of subcluster B is greater than the redshift of subcluster A (see Fig. 3), and the detection of the velocity difference is significant at the 3σ level, including a systematic uncertainty of 900 km/s due to possible spatial and/or temporal variations in the gain. This is the first direct detection of a velocity difference in the ICM of a cluster with *Suzaku*. Subcluster B is cooler (ignoring the cooling core at the center of A) and has a lower abundance than subcluster A, indicating that it is slightly less massive than A. Using the Rankine-Hugoniot jump conditions for a one-dimensional shock and pre- and post-shock temperatures of 3-4 keV and 9 keV respectively, we estimate a collision velocity of 2400-3000 km/s. Combining our measured radial velocity of 2650 ± 900 km/s (90% statistical) with the total merger velocity yields an angle $\theta < 54°$ (90% confidence) between our line-of-sight and the merger axis.

In the near future, following Ota et al. (2007), we will look for variations in the gain in time and across the detectors. We will also include the contributions of all point sources detected in a previous *XMM* observation, as well as compare these results with a large suite of binary merger simulations (Chatzikos et al. 2009) to better constrain the merger dynamics.

References

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