# X-ray study of the double radio relic merger cluster Abell 3376 with Suzaku

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## Abstract

We present the X-ray analysis of the nearby double radio relic merger cluster Abell 3376 ($z$ = 0.046), observed with the *Suzaku* XIS instrument. This analysis aims to complete the Akamatsu et al. 2012 [1] results (where clear evidence of western shock front was found) by confirming the presence of an X-ray shock correlated to the eastern radio relic. This study allows us to investigate the spatial differences between radio (non-thermal) and X-ray (thermal) components of the plasma. Their spatial distribution tells us how shocks propagate and heat the intracluster medium (ICM). Moreover, by comparing the properties of the radio and shock heated plasma, we estimate the dynamical age of the shock front, which provides us a better understanding of the evolution of the cluster during a merger.

## Mergers and Shocks

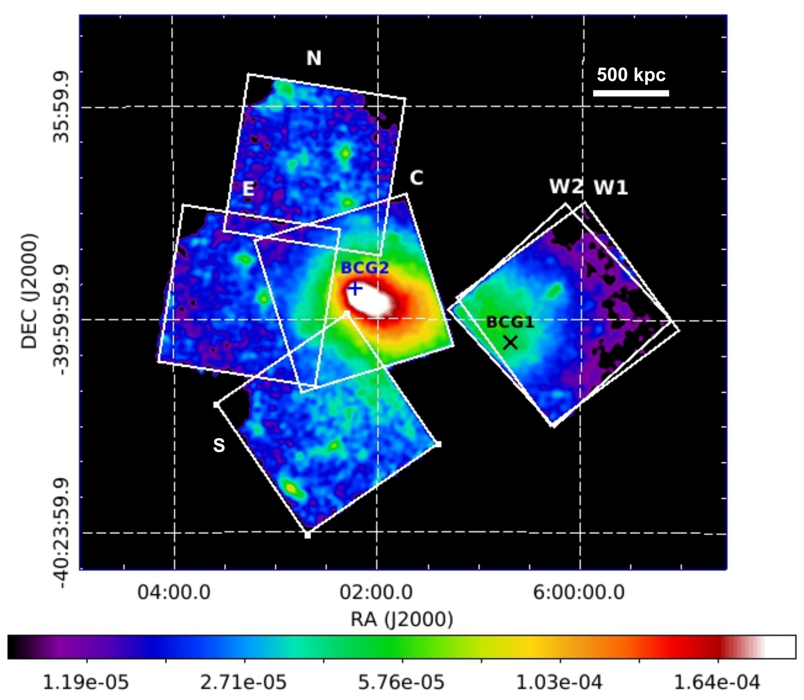
Galaxy clusters are the largest virialised structures in the Universe, which form and grow by accretion and merging with galaxies and sub-clusters. During these processes large-scale shocks with a Mach number peak around $M$~2-4 can be produced, which in some cases are associated with diffuse radio structures known as radio relics. The shocks may accelerate electrons up to relativistic energies by the diffusive shock acceleration (DSA) mechanism which generate radio emission through synchrotron radiation [2].

There are few deep observations of the spatial distribution of shock fronts in X-rays associated to radio relics due to signal-to noise limitation. Suzaku XIS is the most suitable instruments for these observations.

Merger shocks can be observed as **temperature**, **pressure** and **entropy** discontinuities in the ICM; and measurements of the properties of these discontinuities can be used to constrain shocks properties [3].

**Abell 3376** (Courtesy by NASA/CXC/SAO). The Figure shows a multi-wavelength composite image of A3376: X-ray (Gold, ROSAT, by A. Vikhlinin), Optical (RGB, DSS) and Radio (Dark Blue, VLA, by J. Bagchi).

## Abell 3376




**A3376 Suzaku XIS image [8].** The figure shows an X-ray image (0.5-10 keV) with the 6 Suzaku observations (pixel = 8" and Gausssian 2-D smooth σ = 16"). The colorbar represents the counts/s. BCG1 is black x and BCG2 a blue cross.

Abell 3376 is a rich and bright merging cluster of galaxies at redshift $z$ = 0.046. It has two giant arc-like (~Mpc) radio relics in the outskirts, which were discovered by Bagchi et al. 2006 [4]. A3376 contains two Bright Cluster Galaxies (BCG): BCG1 is a cD galaxy and BCG2 is an elliptical bent-jet galaxy [6]. Simulations [7] predict that A3376 has suffered a merger with a mass ratio 6:1 about 0.4-0.5 Gyr ago ([5],[6]).

Recent radio observations ([4], [5], [6]) have estimated a $M$ in the range of 2.2 to 3.3 at the eastern and western relics. Observations in X-rays with XMM-Newton [4] and Suzaku [1] have confirmed an elongated and inhomogeneous merging structure in the east and west outskirt of the cluster center.

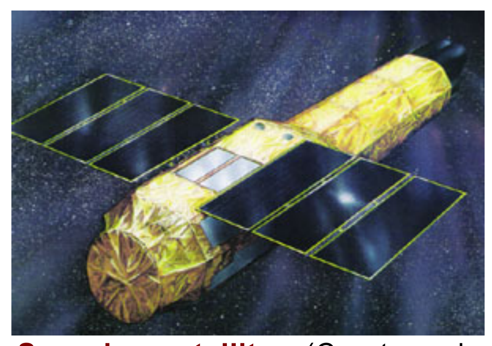
The Suzaku observations (the total obs. time ~500ks and the effective obs. time ~380ks) analyzed in this work are:

- C for merger cluster center
- W1 & W2 associated to western relic
- N, E and S associated to eastern relic

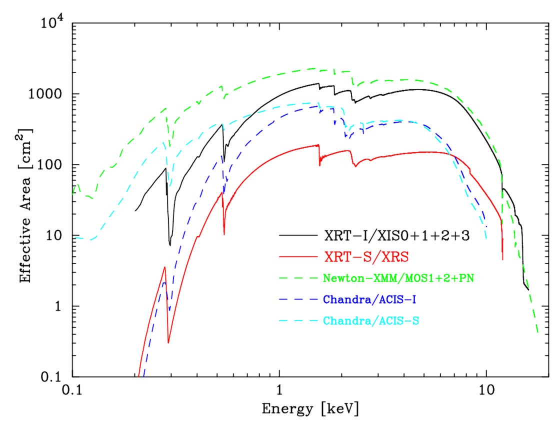
## Why Suzaku?

Suzaku's XIS good performance allows the low surface brightness outskirt to be detected [9]:

- XIS: X-ray CCD camera, E=0.2-12 keV
- Low and stable (3%) non X-ray detector background
- Large effective area, similar to XMM-Newton's EPIC instrument (Fe K)

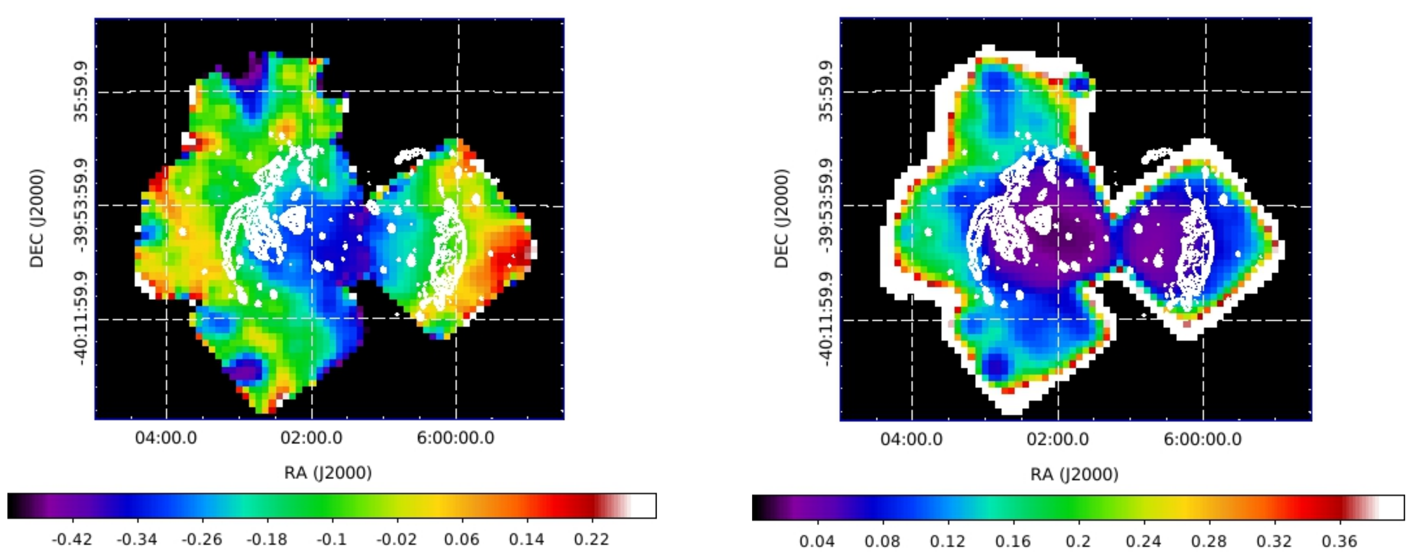


**Suzaku satellite.** (Courtesy by NASA/HEASARC).




**Effective are vs Energy [10].** The figure shows a comparison of the effective area of the main X-ray satellites. The performance of Suzaku XIS (in black) are comparable with XMM-Newton EPIC (in green). Since 2006, XIS 2 was no available, therefore the Aeff was a bit lower.

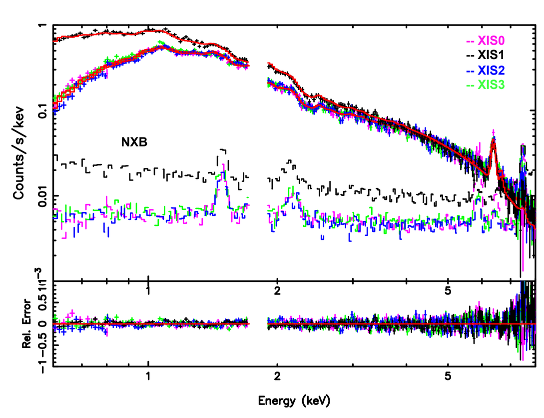
## Hardness Ratio Map

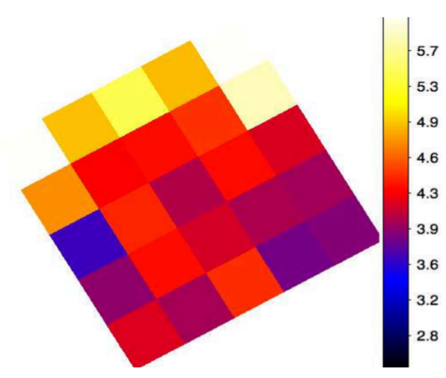



**HR map (left) and statistical error map (right).** The HR map (binned pixel = 1' and Gaussian smoothed with σ = 1') is produced with a soft band (0-5-2.0 keV) and hard energy band (2-7 keV) image. White contours are VLA radio, courtesy by Dr. Kale. Point sources and CXB emission are not subtracted, which implies a bias to the hard energy band (higher values of HR ratio) in the outskirt region beyond the radio contours.

## Spectral Fitting

| Best-fit parameters | Values |
|---|---|
| $kT$ (keV) | 4.71 ± 0.01 |
| norm ($10^{69}$/m$^3$/arcmin$^2$) | 3.7 ± 0.3 |
| Z ($Z_\odot$) | 0.32 ± 0.03 |
| C-stat/d.o.f | 956/773 |




**A3376 Center spectral fitting (left) and temperature map (right).** The sw SPEX v3.01.00 has been used for the fitting and the unique region considered is 18'x18'. The spectral fitting includes the spectrum of XIS 0,1,2 & 3 detectors with Non X-ray Background (NXB) subtraction. The band 1.7-1.9 keV has been excluded due to Si-K edge. We assume a thin thermal emission from ICM. The background components considered are: one, the galactic emission (Local Hubble Bubble and Milky Way Warm Halo), which are modeled as unabsorbed and absorbed *cie* model, respectively; and other, the Cosmic X-ray Background, as a *powerlaw*, so the fitting follows: $cie + absm(cie+pow+cie_{ICM})$.

## References

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