Chandra observations of the merging cluster Abell 578 and its central radio galaxy 4C +67.13

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1. Introduction

Relativistic jets in AGN are thought to play a major role in the co-evolution of supermassive black holes and galaxies via the feedback processes. However, most of the jetted AGN found in the centers of nearby clusters are "low-power" FR I-type radio sources (e.g., Zirbel 1997).

Abell 578 is an unusual cluster, whose brightest cluster galaxy hosts the "powerful" FR II-type radio source, 4C +67.13. This cluster is not fully relaxed and consists of two merging sub-systems. Here, we report the results of radio (VLA), optical (WHT) and X-ray (Chandra) analysis of Abell 578 and its central radio galaxy.

2. Radio and optical data

Radio data

For the purpose of studying the jet activity of the central radio galaxy 4C +67.13, archival VLA data at 4.7 GHz and 1.5 GHz were analyzed.

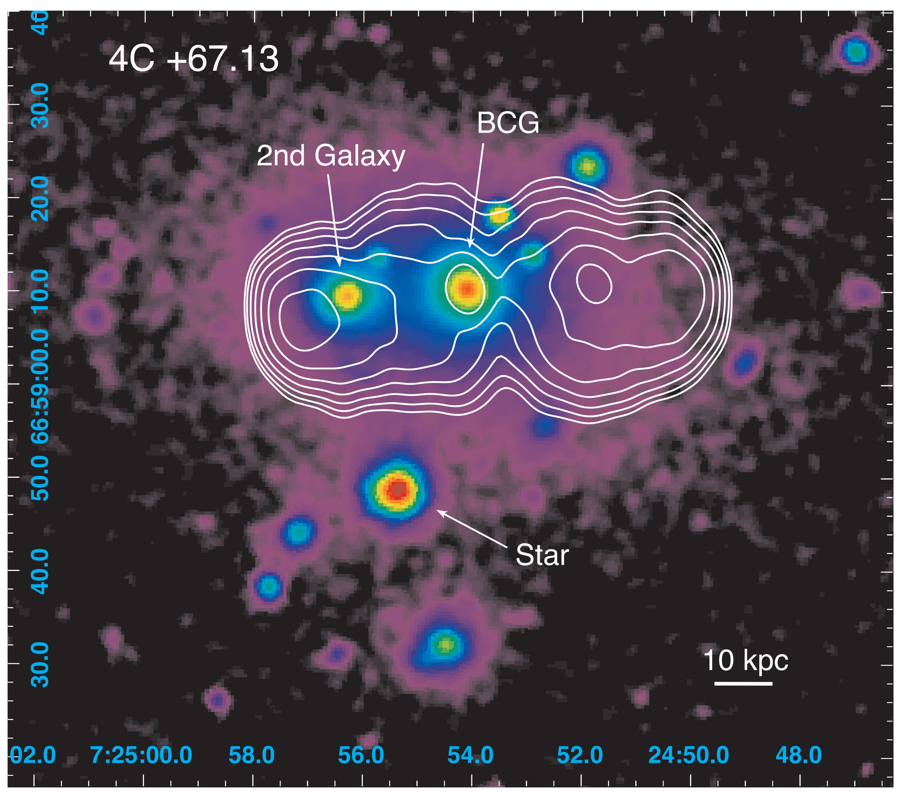


Fig. 2 VLA 4.7 GHz contours of 4C +67.13 superimposed on the smoothed optical SDSS i-band image.

- Total linear size: 47''≃75 kpc
- Axial ratio: ≃2
- Volume of the lobes: $V_f \simeq 1.6\times10^{69}$ cm
- Spectral index for both lobes: 0.84±0.12
- Radio power of the lobes: $\mathbf{L_{1.5GHz} \simeq 1.8\times10^{41}}$ **erg s^{-1}**

Typical for FR IIs
But, **no hot spots**

Optical data

To investigate the accretion activity, 4C +67.13 was observed by the WHT on 2010 April 21.

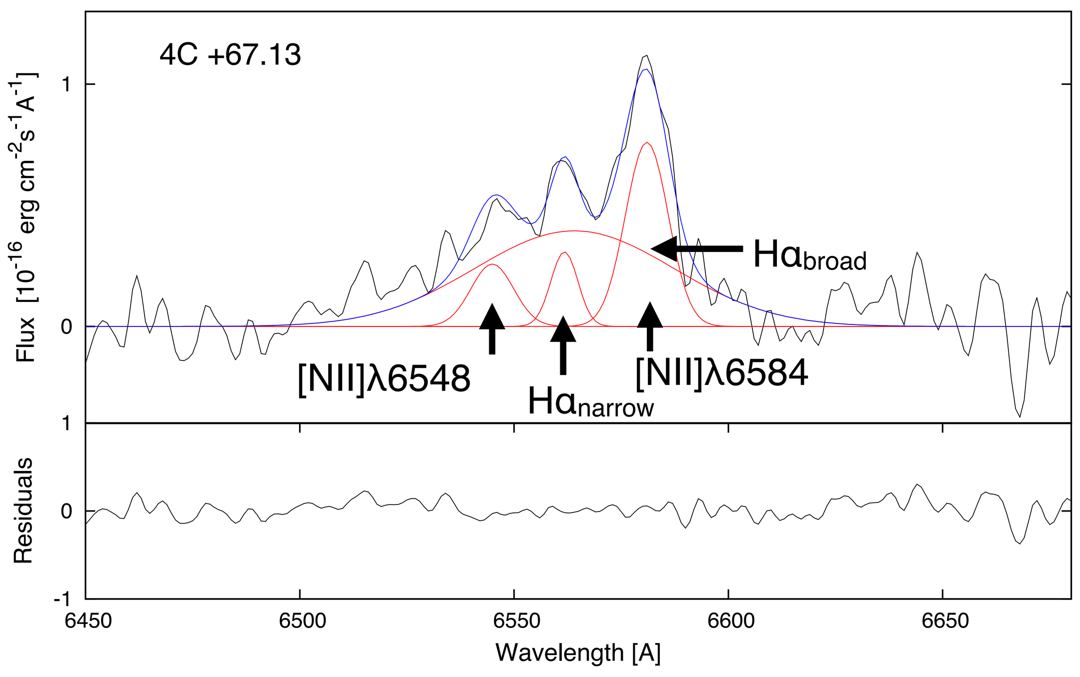


Fig. 1 Observed emission lines of 4C +67.13 (black), with Gaussian profiles fitted to the emission lines (red). Some of Gaussian profiles are plotted by blue.

- Stellar population: No traces of young (≲Gyr) populations
- Black hole mass: $\mathbf{M_{BH} \sim 10^9 M_\odot}$
- AGN activity: **LINER type**
- Bolometric accretion-related luminosity: $\mathbf{L_{nuc} \simeq 10^{43}}$ **erg s^{-1}**, or in the Eddington units $\mathbf{\Lambda \simeq 10^{-4}}$

3. X-ray data

Chandra observations of Abell 578 were performed on 2010 May 29 (obsid=11749) and July 23 (obsid=12225) using the ACIS-S detector. A total exposure time is 39.3 ks.

Image analysis

To estimate the cluster center and to extract the general characteristics of the cluster large-scale morphology, we fit the 0.5-7.0 keV image with the isotropic/elliptical 2-D β model.

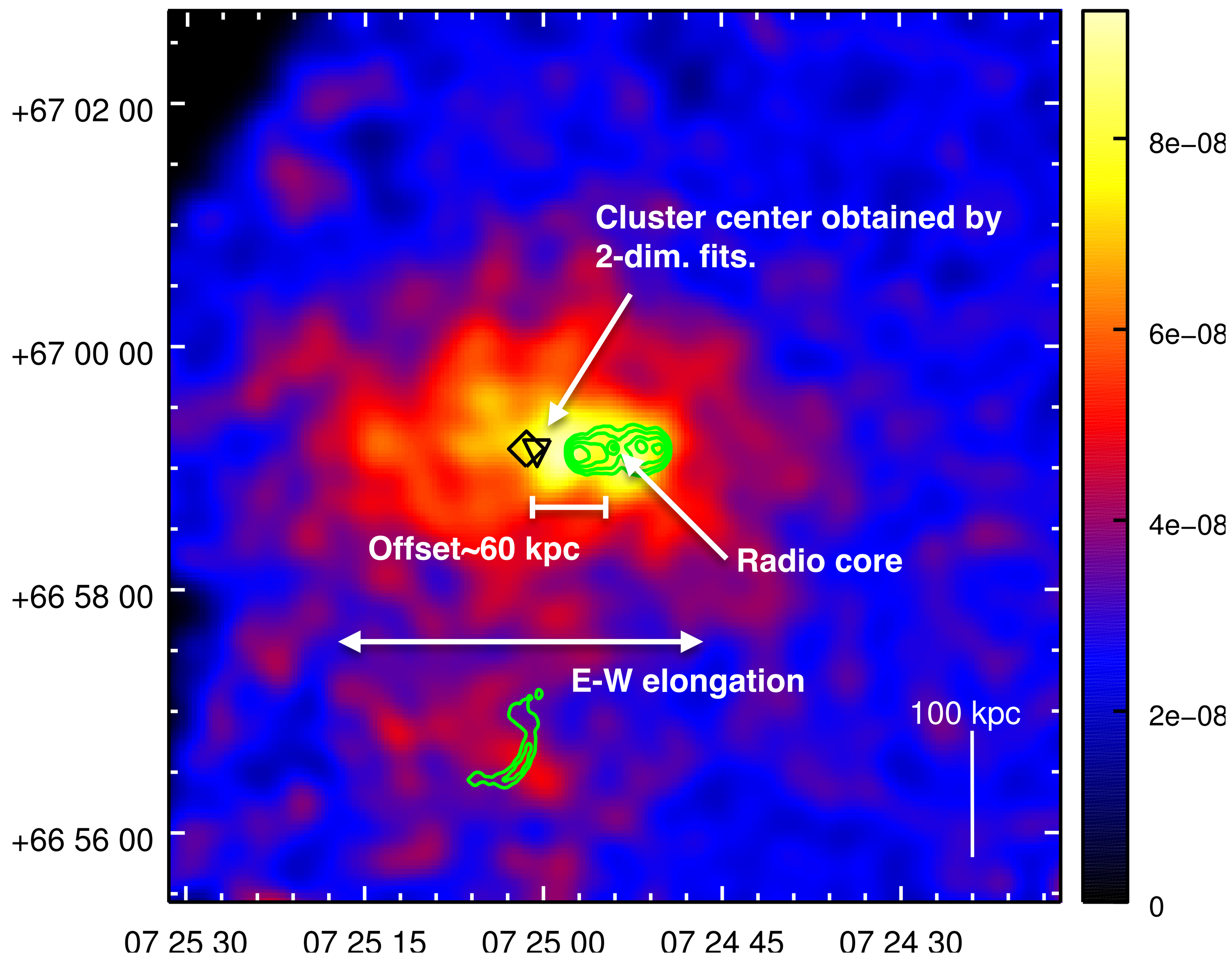


Fig. 3 The exposure-corrected Chandra 0.5-7.0 keV image of Abell 578 with the VLA 4.7 GHz contours superimposed. Open black triangle and square denote the position of the cluster center obtained from the 2-dimensional fitting with elliptical and isotropic 2-D β models, respectively.

- **Elongation**
  The elliptical model gives a better fit than the isotropic model. It indicates the cluster is elongated with the ellipticity parameters of $\varepsilon=0.32_{-0.05}^{+0.04}$ and $\theta=-3.2°_{-4.2}^{+4.3}$ (E-W direction).
- **Offset between the position of BCG and the cluster center**
  The positions of cluster center obtained by both models are consistent. This position is clearly offset from the position of the 4C +67.13 core. The offset in projection is $\mathbf{r_x \simeq 38''}$, corresponding to **61 kpc**.

Spectral analysis

In order to investigate in more detail the impact of the radio source on the cluster environment, spectra are extracted from the **north**, **south**, **east** and **west** regions.

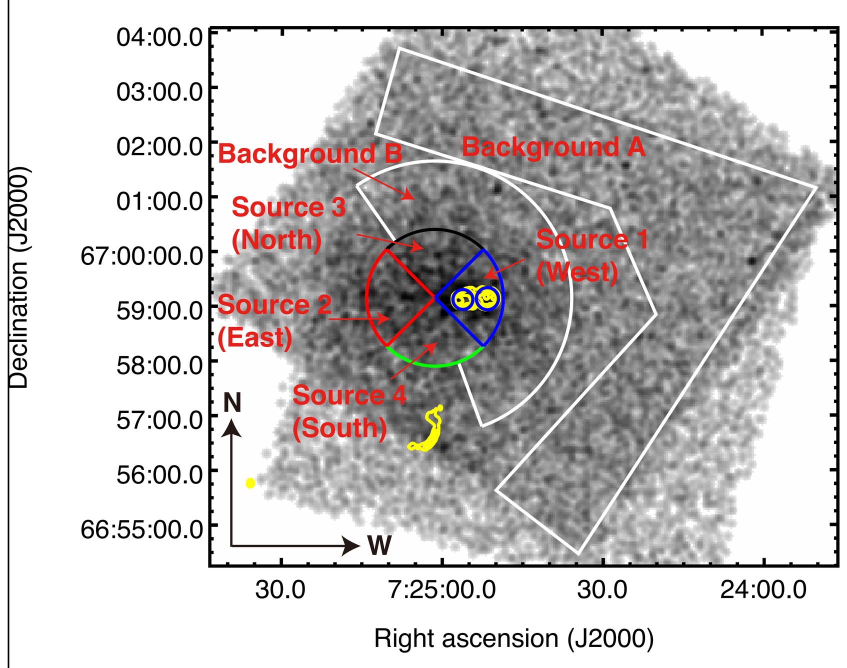


Fig. 4 Regions selected for the cluster spectral analysis. The north, south, east, west regions are plotted in black, red, green and

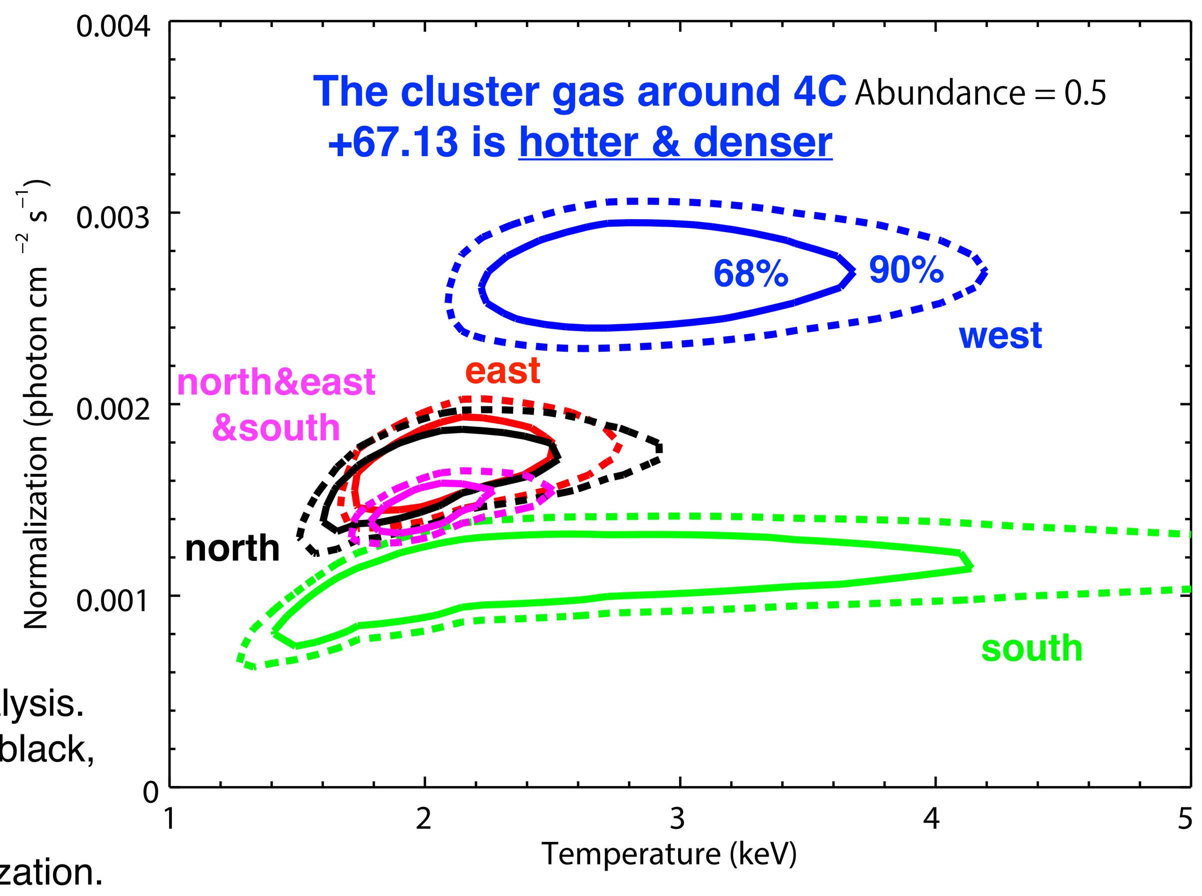


Fig. 5 Contour plots of temperature versus normalization.

- The temperature ratio: $1.37_{-0.18}^{+0.30} \rightarrow \mathcal{M}_{sh} \simeq \mathbf{1.38}$ (Shock Mach number)
- The density ratio: $1.36_{-0.06}^{+0.06} \rightarrow \mathcal{M}_{sh} \simeq \mathbf{1.24}$

This implies the presence of a weak shock.

4. Discussion and Conclusions

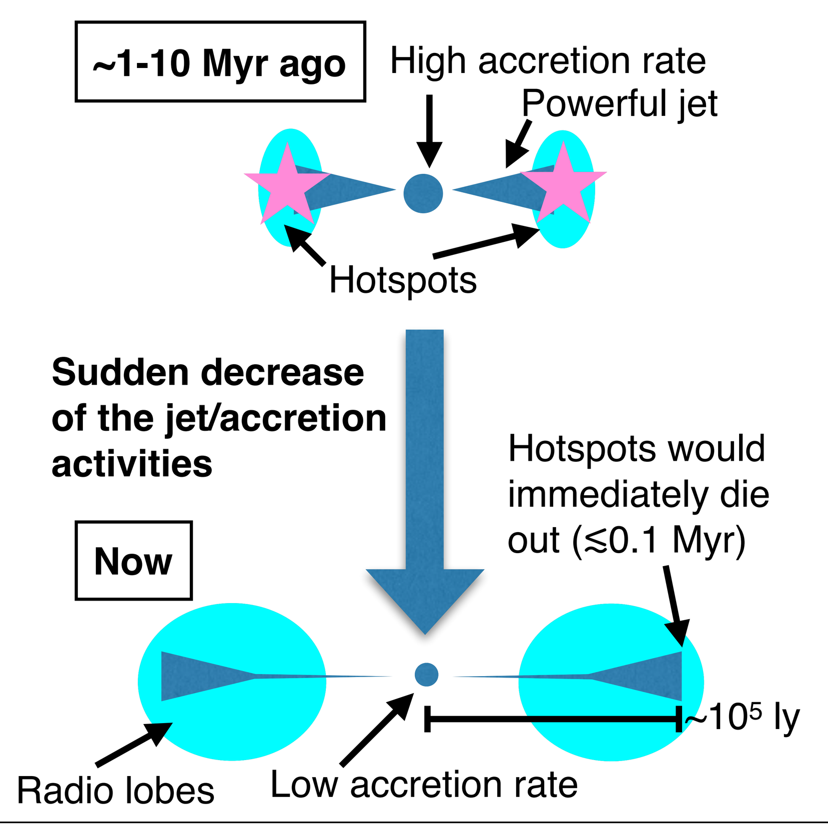
Cluster formation processes

We found that the Abell 578 system has interesting properties:

- E-W elongation of the cluster
- Offset between cluster center and BCG
- Heating/compression of the cluster gas

These imply deviations from the dynamical equilibrium during the cluster formation. Therefore, our results provide an interesting insight into the widely debated cluster formation processes.

Highly modulated duty cycle of the jet



According to the optical data of 4C +67.13, the accretion rate is very low. However, **despite such a limited accretion rate, this AGN is able to launch luminous jets**. Its jet kinetic power is estimated as $L_{j/(rad)} \sim (2\text{-}7)\times10^{44}$ erg s^{-1} by using the relation between the jet power and the lobe luminosity on the assumption of a slow (sonic) expansion of the jet cocoons.

In this source, this assumption is not justified because of the possible presence of a shock. This requires **the jet kinetic power is much higher than $\mathbf{L_{j/(rad)}}$**, implying **a highly modulated jet/accretion activity** in the system. Such a sudden drop of the nuclear accretion rate is also indicated by the observational fact that **the prominent hotspots are absent** at the edge of the radio lobes.