Joint X-ray, Lensing and Optical Study of Abell 1689: Anisotropic Gas Temperature and Entropy Distributions Associated with the Large-Scale Structure


This presentation is based on Kawaharada, Okabe, et al. 2010, ApJ 714, 423
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The joint study on A1689

- Suzaku can reach the ICM in an unexplored 80% outer cluster volume, thanks to its low and stable background.
- Detecting the ICM up to the virial radius (15.8 = 2.9 Mpc).
- Obtaining radial profiles of gas temperature, density, and entropy.
- Studying the connection between the ICM outskirts and the large-scale structure, using SDSS data.
- Comparing these profiles with those obtained by lensing analysis.
ICM detection out to the virial radius

- Background-subtracted X-ray surface brightness was derived.
- Stray signal from removed point sources was simulated.
- ICM signal was detected out to the virial radius at 4.0σ level in 0.5-2 keV energy range.
Profiles obtained by Suzaku

- Temperature profile gradually decreases from 10 keV to 2 keV, that is lower than the scaled temperature profile (Pratt+07) at the virial radius, except NE direction.
- The temperature at the virial radius in NE direction is 5 keV, significantly higher than those of the other directions.
- Electron density profile is isotropic, and its slope around the virial radius is shallower (-1.2) than the NFW profile (-3).
- Entropy profile of NE direction is consistent with the prediction of accretion shock heating models (Tozzi & Norman 01; Ponman+03), while those of the other directions are lower than the model prediction at the virial radius.
Galaxy number density map in a slice around the cluster redshift (z=0.18320±0.00004±0.00035).

A filamentary structure is connected to the high temperature NE region.

The large-scale structure would play an important role in thermalization process of the ICM in the ourskirts.
The cumulative hydrostatic mass *unphysically* decreases outside 9’ except the NE direction, indicating the ICM (except NE direction) is not in hydrostatic equilibrium. The hydrostatic to spherical-lensing mass ratio at 3’ < r < 7’ is 60%–90%. Using the triaxial halo model, the mass ratio in the same annulus becomes consistent with unity within errors. However, the mass ratio within 2’ is < 60%, significantly biased low.
Gas pressure and entropy

- Thermal gas pressure is 40%-60% of the total pressure predicted by the spherical lensing mass model, except the outermost NE direction.
- Although these values give lower limit taking into account the triaxial halo model, the thermal pressure would be insufficient to balance the total gravity of the cluster, requiring additional pressure support(s), such as bulk motion and/or turbulent.
- The slopes of the entropy profiles match those predicted by lensing spherical masses with the hydrostatic equilibrium assumption from the core to $r_{500}$. In NE direction, this is also the case at the virial radius.
Summary

- A strong collaboration of the X-ray and optical researchers was teamed up on the A1689 study.
- Suzaku revealed anisotropic gas temperature and entropy distributions in NE direction.
- Using SDSS, a filamentary structure was found, connecting to the NE high temperature gas region.
- Combined with the intensive lensing analyses, non-hydrostatic equilibrium and additional pressure support such as bulk motion and/or turbulent are suggested in the ICM at cluster outskirts, except the NE direction.
- The large-scale structure would play an important role in thermalization process of the ICM at cluster outskirts.
- Understanding the nonthermal pressure(s) in the ICM and accurately measuring cluster masses will lead to derive a robust cluster mass function, combined with forthcoming multi-wavelength surveys, such as Subaru/Hyper-Suprime-Cam, eROSITA and ACT.
Why don’t you collaborate with ASTRO-H?

- **X-ray microcalorimeter (ΔE<6 eV):** ICM bulk motion and turbulent.
- **Hard X-ray imager (up to 80 keV):** non-thermal emission in the ICM.
- **Wide field X-ray CCD (35’x35’):** ICM physics in cluster outskirts.
- Collaborations with next generation missions/telescopes are always welcome. They will greatly enhance sciences on galaxy clusters.
Other possible causes for the non-hydrostatic equilibrium than ICM bulk motion or turbulence.

1. Convective instability
We investigated the possibility of convective instability in the radial direction.
The convective motion in Offset234 is unstable outside \( \sim 9.0 \), but the timescale of the growing mode is comparable to the age of the universe at cluster redshift \( z = 0.1832 \).

2. Higher temperature of ions
We computed the thermal equilibration time between electrons and ions through the Coulomb interaction. In the cluster outskirts of A1689, the timescale is given by \( t_{ei} \sim 0.4 \) Gyr (e.g., Spitzer 1962; Takizawa 1999; Akahori & Yoshikawa 2009). The Coulomb interaction would provide us with the maximum timescale of thermal equilibrium, because there might be other processes, such as plasma instability, to facilitate the interaction between electrons and ions.
Thermalization process in the cluster outskirts

In the low-temperature (2 keV) outskirts regions, $(1/2) m_e v^2, (1/2) m_p v^2$ $(v_e=v_p=v)$. Kinetic energy of ions is likely to give the additional pressure.

When the gas is thermalized by shocks, kinetic energies of ions and electrons are converted to thermal energy, resulting in temperatures $T_p > T_e$.

These different temperatures are relaxed to one temperature by plasma instabilities, such as beam instability and two-fluid instability, in a time scale of $(\text{plasma frequency})^{-1}$, which is significantly shorter than the dynamical timescale of a cluster.