ICM in Cluster Outskirts Affected by Large Scale Structure Discovered in A1689

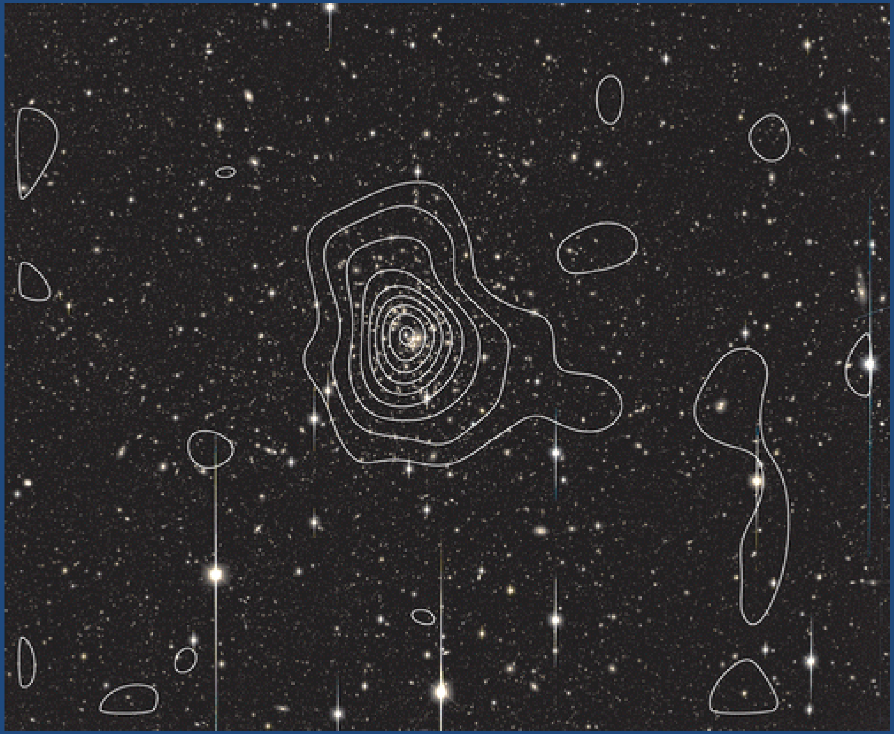
M. Kawaharada (ISAS/JAXA), N. Okabe (ASIAA),
K. Umetsu (ASIAA), M. Takizawa (Yamagata U.),
K. Matsushita (Tokyo Science U.), Y. Fukazawa (Hiroshima U.),
T. Hamana (NAOJ), S. Miyazaki (NAOJ),
K. Nakazawa (U. Tokyo), T. Ohashi (Tokyo Metro. U.)

This presentation is based on Kawaharada, Okabe, et al. 2010, ApJ 714, 423
Email: kawahard@astro.isas.jaxa.jp
X-ray Universe 2011 @Berlin, 2011/Jun/29

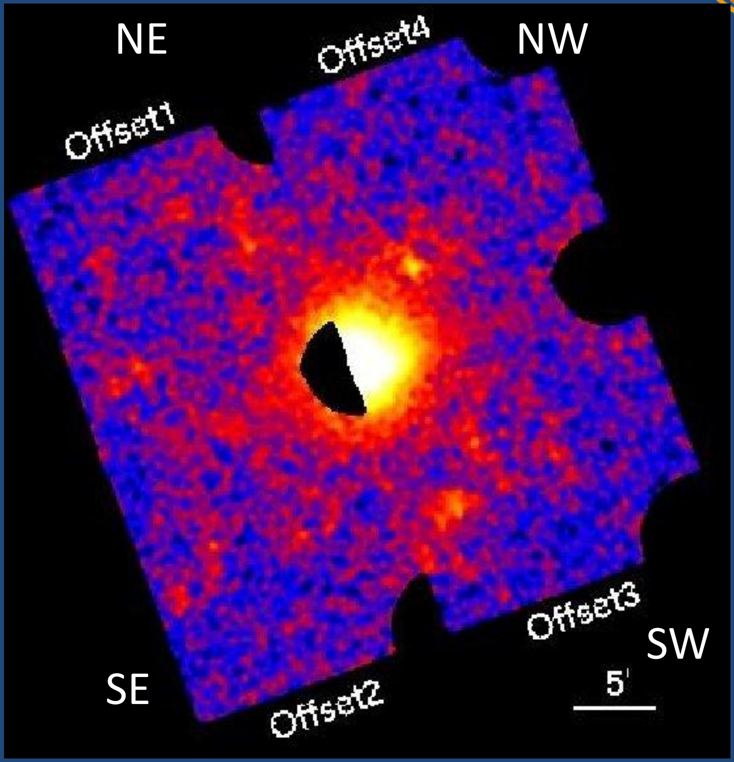
Background of the study

- A collaboration between X-ray and weak-lensing Japanese researchers has been organized. The study of A1689 is one of the first results in this collaboration.
- The collaboration aims at observationally revealing physical processes in growth of clusters by mass accretion from the surrounding large scale structure (e.g. Nagai & Kravtsov 03).
- Physical properties of the ICM in cluster outskirts should be affected by the mass accretion.
- Observe the ICM toward the virial radius with Suzaku.
- Compare the ICM properties with mass distribution from weak lensing analysis (e.g. Okabe+08) .

Suzaku observations of A1689



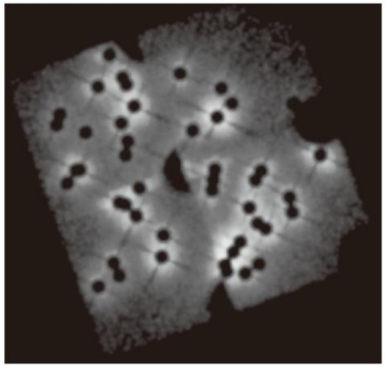
30’x 25’ mass density contour
(Umetsu & Broadhurst 08)



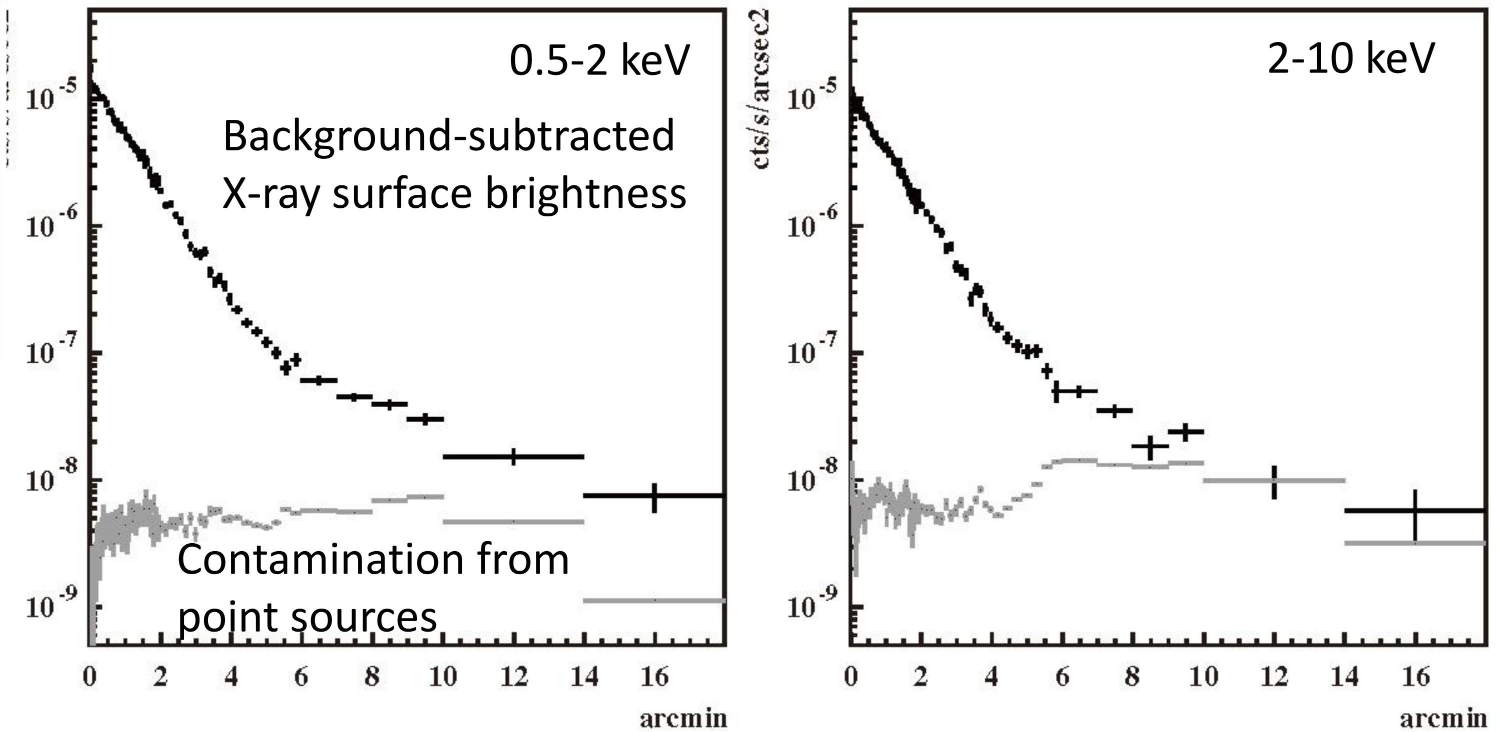
Suzaku X-ray CCD mosaic image.
(Kawaharada+10)

- Mass distribution of A1689 has been precisely known from lensing analysis (e.g. Umetsu & Broadhurst 08)
- Four pointing observations of Suzaku cover an entire cluster region up to the virial radius

X-ray surface brightness profile

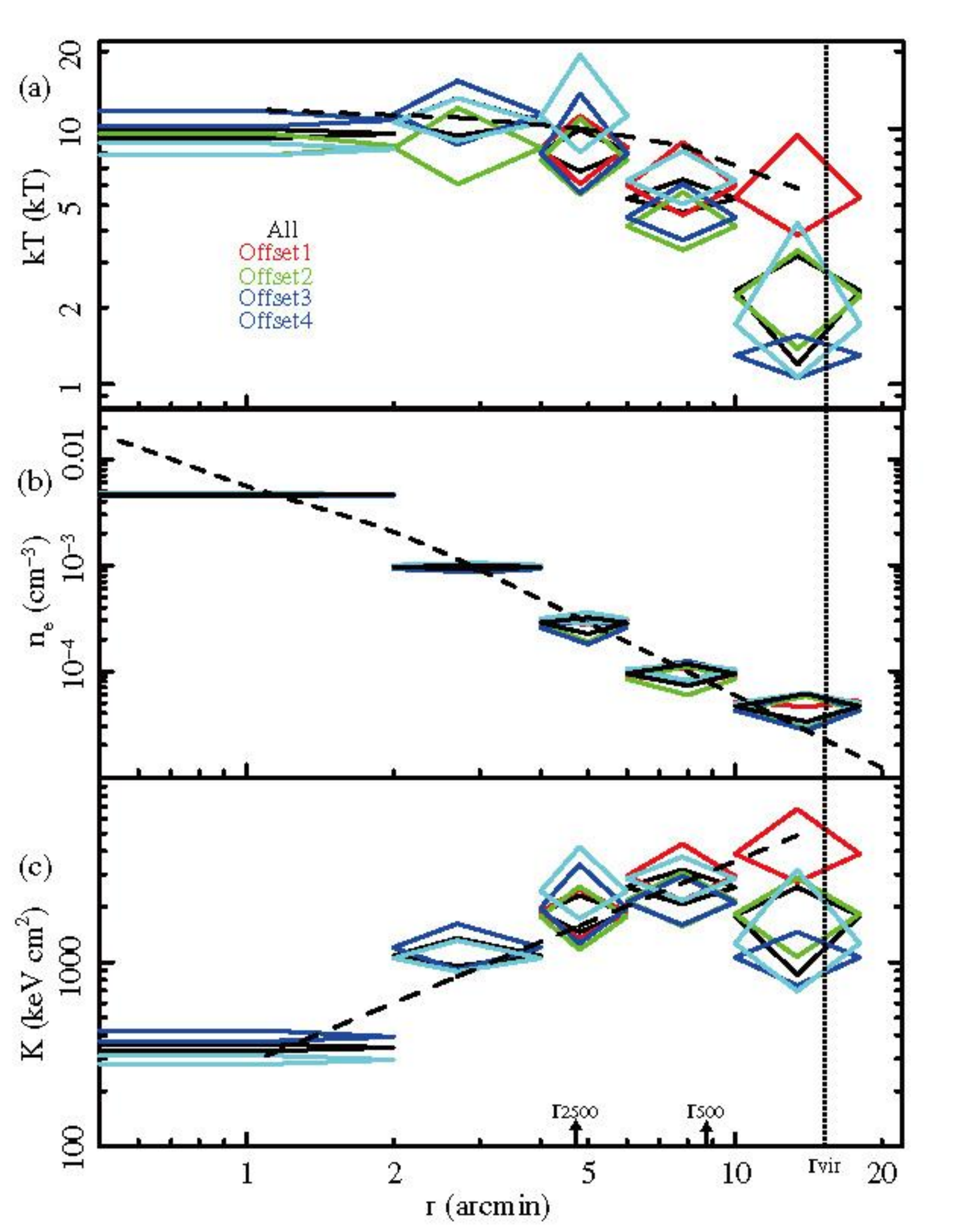


Simulated map of contamination from point sources



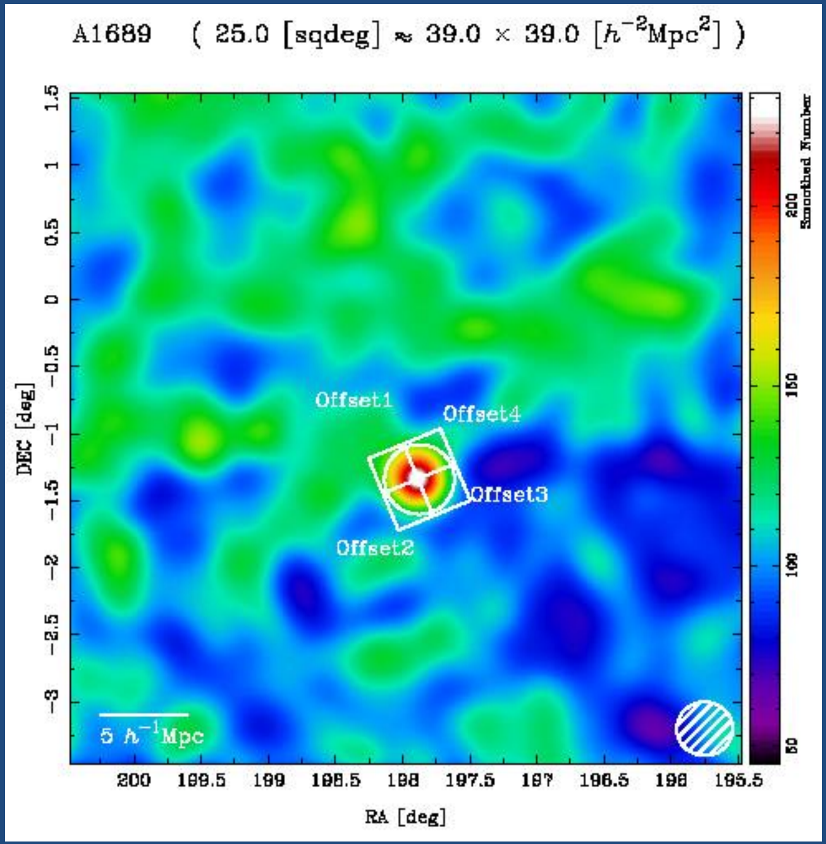
- ➢Background-subtracted X-ray surface brightness was derived.
- ➢Stray signal from removed point sources was simulated.
- ➢ICM signal is detected out to the virial radius at 4.0σ level in 0.5-2 keV energy range.

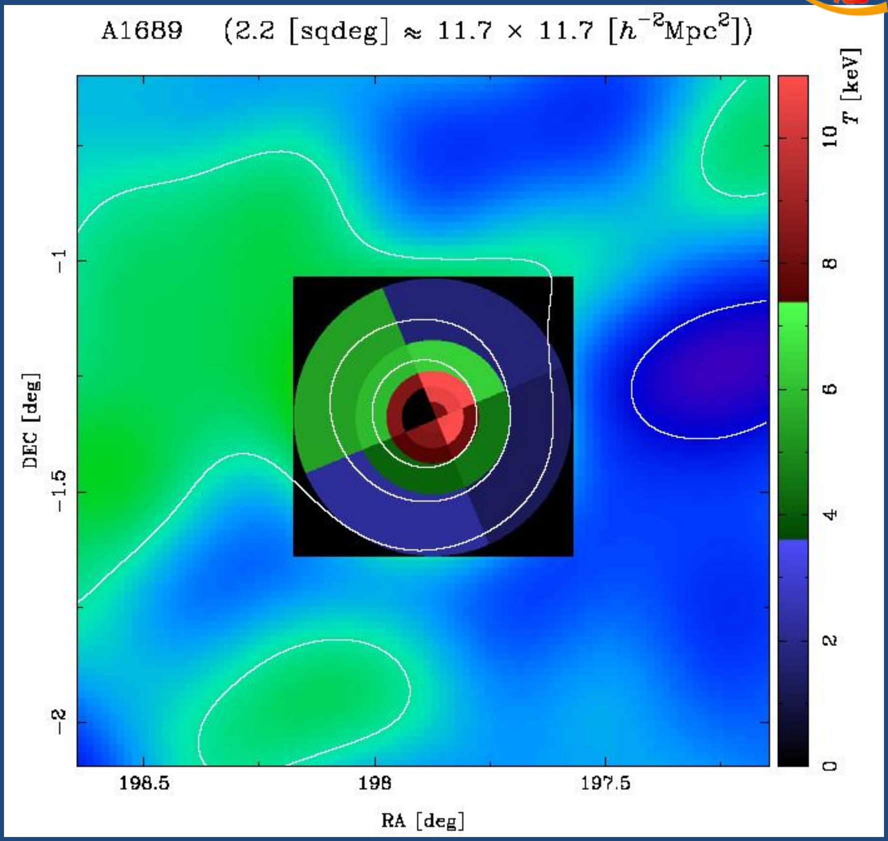
Gas parameter Profiles



- ➢ 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 (-1.8) 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.

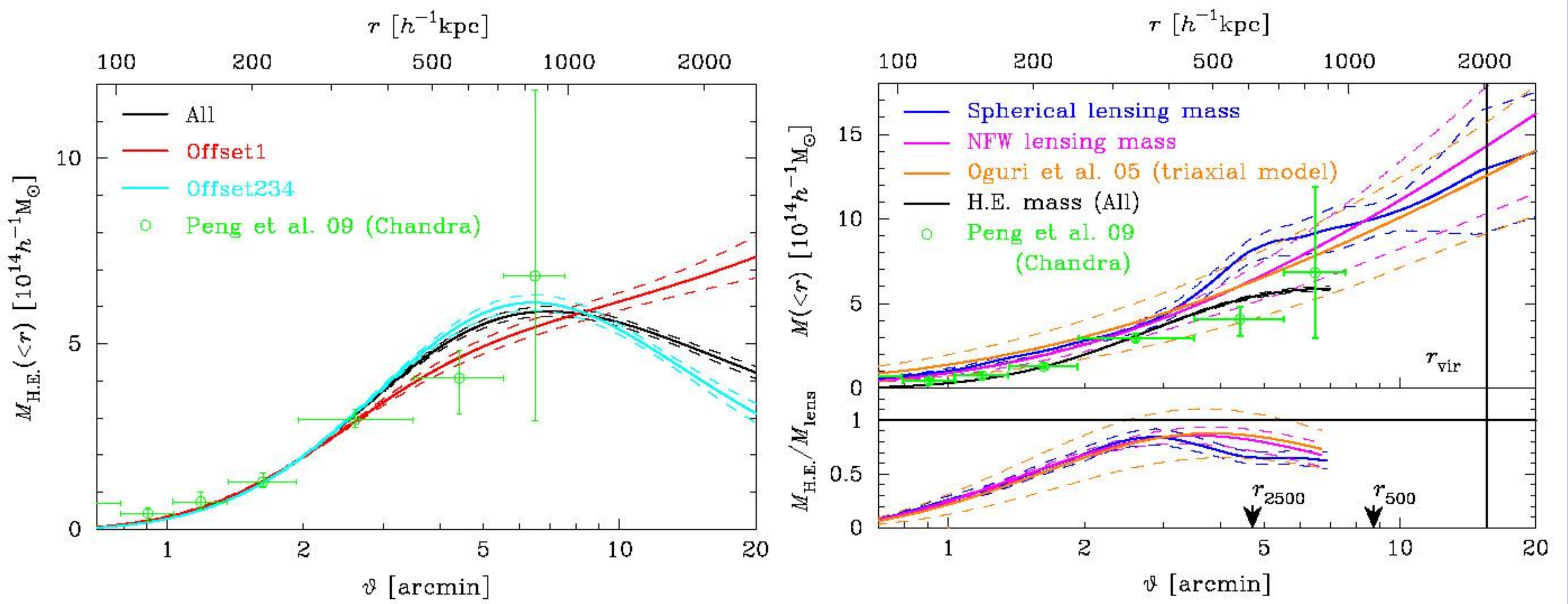
SDSS galaxy map





- ➢ 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 facilitates thermalization process of the ICM in the ourskirts.

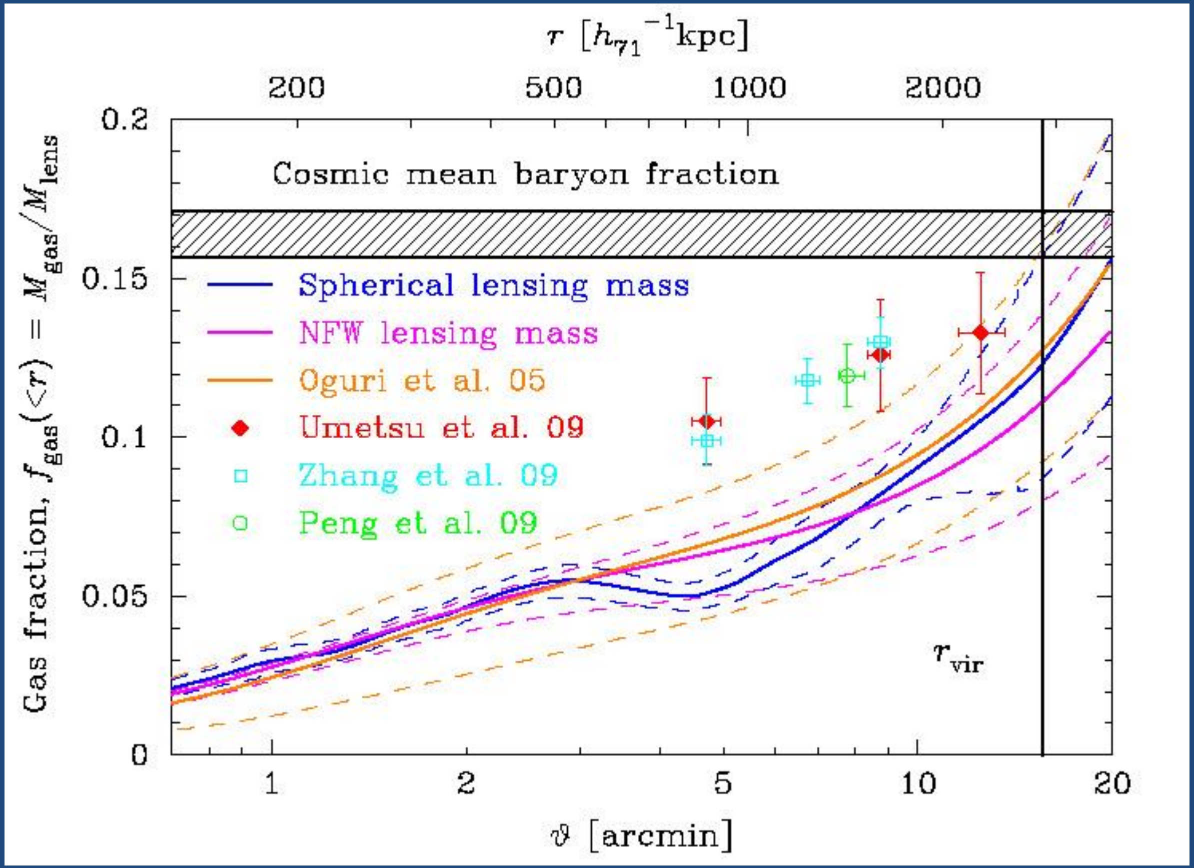
Mass comparison



➢ 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. Additional source(s) of gas pressure is required there.

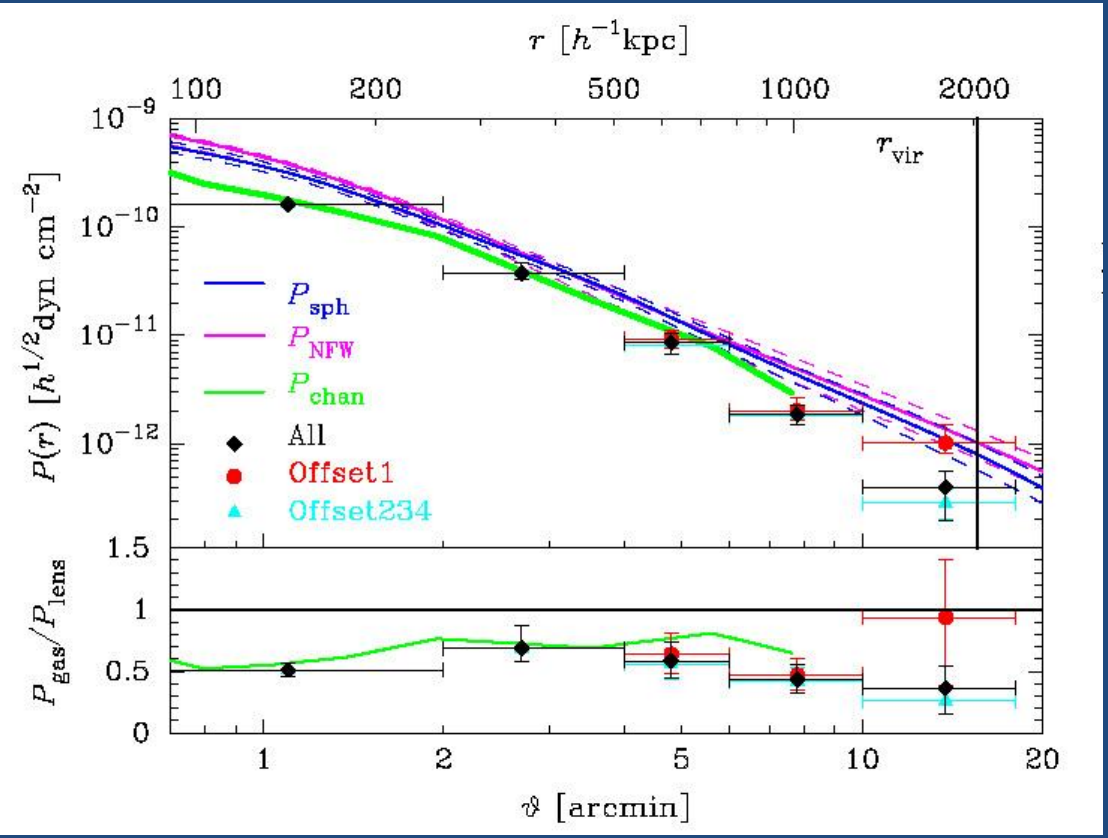
Gas fraction



➢The gas fraction increases toward the viral radius, but does not reach the cosmic mean baryon fraction (WMAP5; Komatsu+09) at the virial radius.

➢In some models (e.g. Bode+09), the gas fraction reaches the cosmic value at 1.2 r_{vir} because of gas expansion. Our result is roughly in agreement with the model. The electron density profile also qualitatively supports this model .

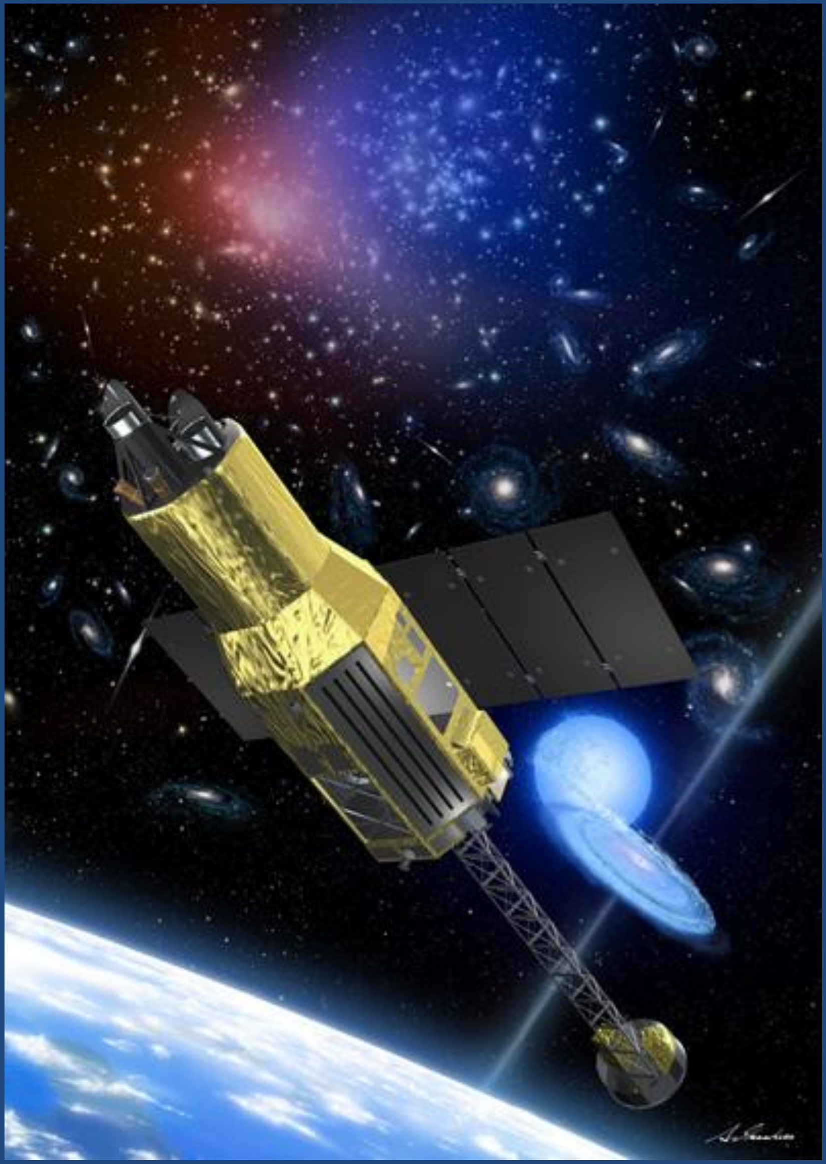
Gas pressure



- ➢ Thermal gas pressure is 40%-60% of the total pressure predicted by the spherical lensing mass model, except the outermost NE direction.
- ➢These values are lower limits if triaxiality is taken into account, but these small values suggest additional pressure support(s), such as bulk motion and/or turbulent.
- ➢In particular, gas pressure in the outermost Offset2,3,4 regions would be insufficient, because gas entropy is also low.

Prospects for 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.
- Understanding of nonthermal pressure in the ICM will be greatly advanced with ASTRO-H.



Summary

- ➢ A strong collaboration of the X-ray and optical researchers was organized on the A1689 study.
- ➢Suzaku revealed anisotropic gas temperature and entropy distributions in NE direction.
- ➢ Using SDSS, a filamentary structure was found, connected to the NE high temperature gas region.
- ➢The large-scale structure would play an important role in thermalization process of the ICM at cluster ourskirts.
- ➢Combined with the lensing analysis, non-hydrostatic equilibrium and additional pressure support such as bulk motion and/or turbulent are suggested in the ICM, except the outermost NE direction.
- ➢Understanding of nonthermal pressure in the ICM will be greatly advanced with ASTRO-H.

Backup slides

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 ~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 (plasma frequency)^(-1), which is significantly shorter than the dynamical timescale of a cluster.

・Definition of virial radius in this study. Within the virial radius, mean interior density is 110 times the critical mass density $\rho_c(Z)$.
Δvir = 110 (Nakamura & Suto 1997)