Embedded Spiral Patterns in the massive galaxy cluster Abell 1835

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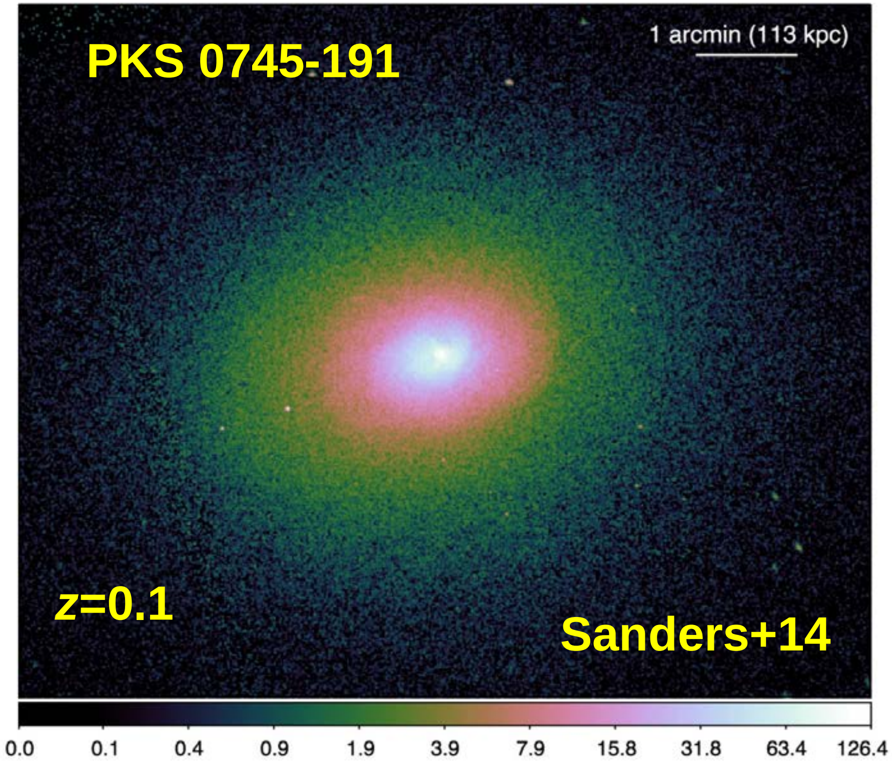
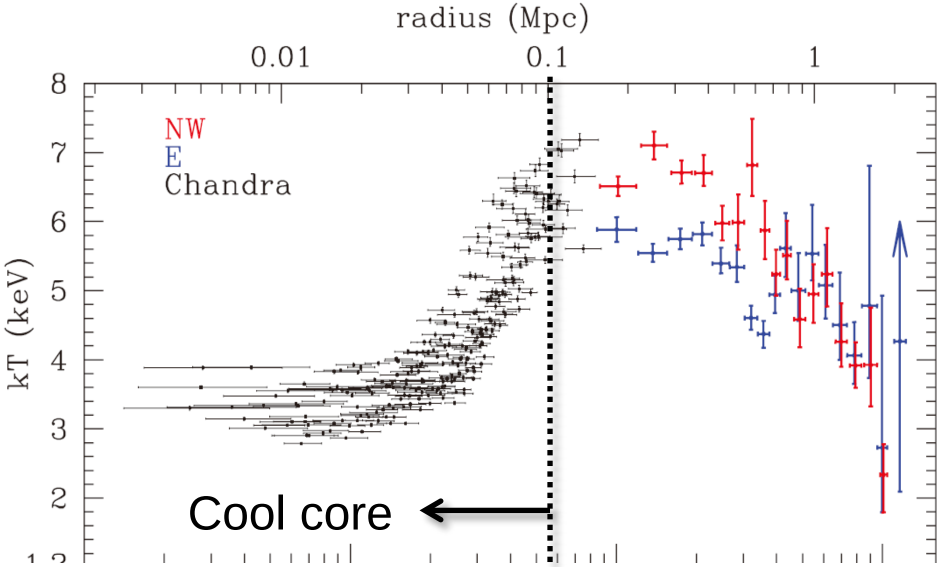
This presentation is based on our recent paper.
(Ueda, Kitayama, & Dotani (2017) ApJ, 837, 34)

What's cool core?
- thermal evolution of X-ray emitting gas -

The ICM temperature in apparent relaxed clusters decreases toward the center, and a region so-called a cool core has been formed.



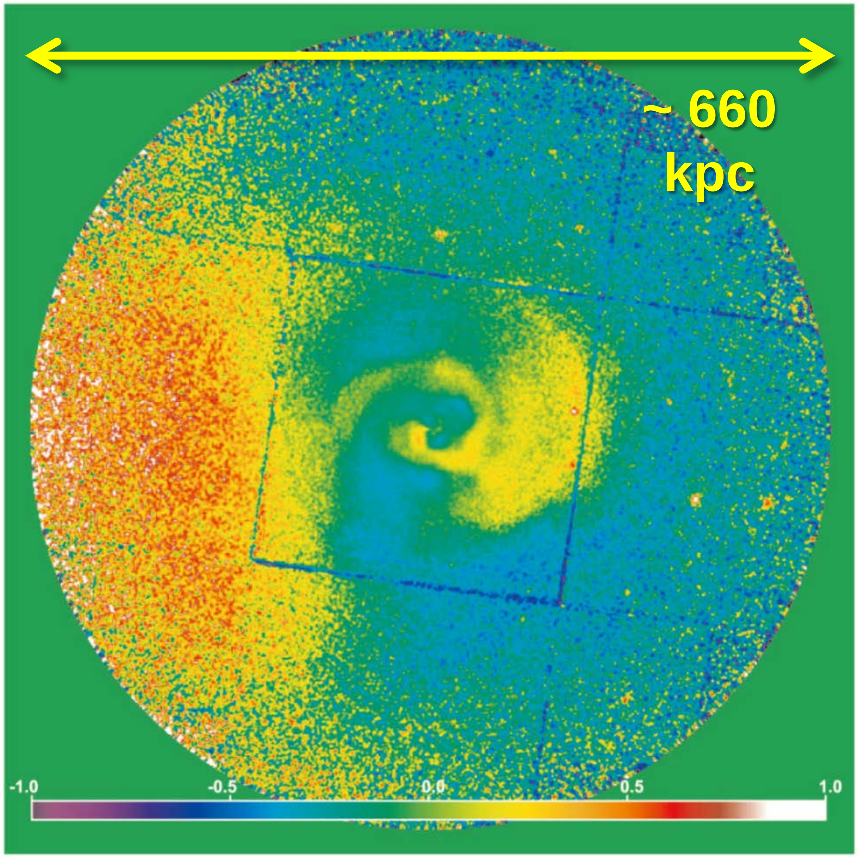


Temperature profile of the ICM in the Perseus cluster (Simionescu+11)

The ICM in the cool core is considered to have lost part of its thermal energy via radiative cooling, however, the exact mechanisms to prevent runaway cooling and to determine the core size are still unclear.

Spiral patterns in the cool core

Spiral patterns are found in the residual image of X-ray surface brightness of some clusters after subtracting its mean profile.



Residual image of the X-ray surface brightness of the Perseus cluster (Churazov+03)

The ICM in such spiral patterns has several common properties (e.g., Blanton+11, Ghizzardi+14).

The ICM in the positive-excess region (bright part of spiral pattern) has

1. higher density
2. lower temperature
3. Higher abundance
4. lower entropy.

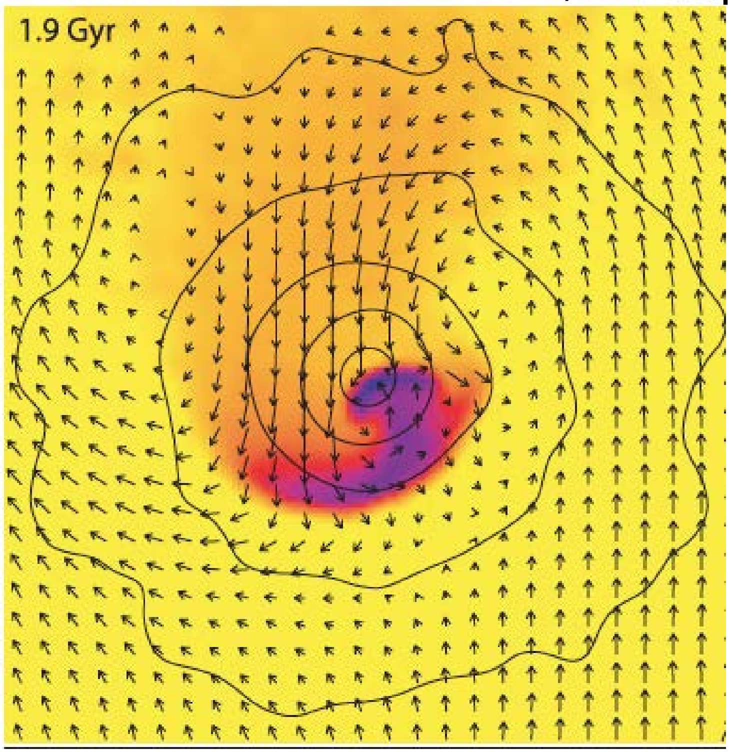
However, the followings are still unclear.

- pressure profile
- size (depends on time?)
- velocity distribution along LOS

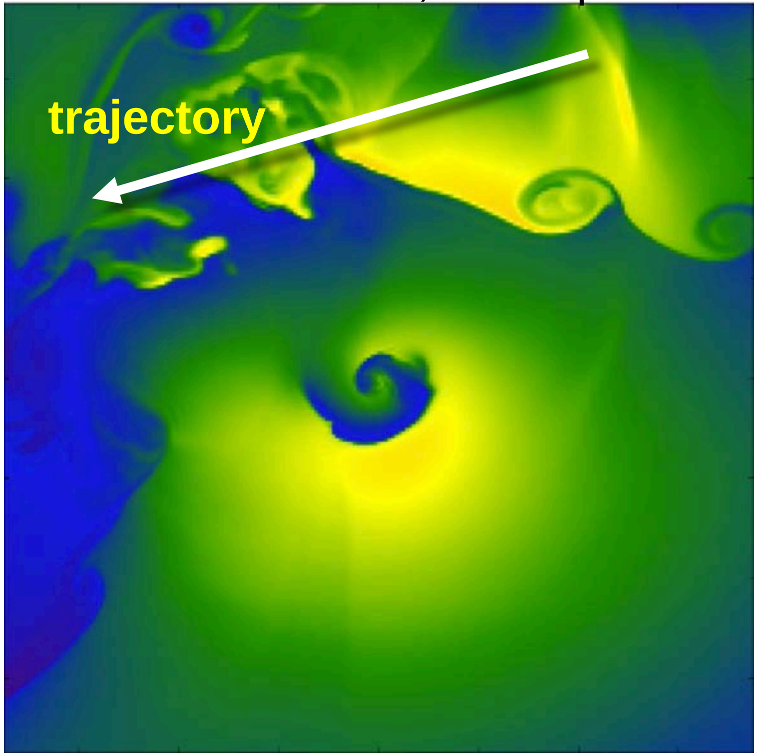
Origin of spiral patterns - minor merger -

Numerical simulations suggest that an off-axis minor merger can produce such spiral patterns in the cluster core (e.g., Ascasibar+06, ZuHone+10).

Ascasibar & Markevitch+06, kT map



Johnson+12, kT map

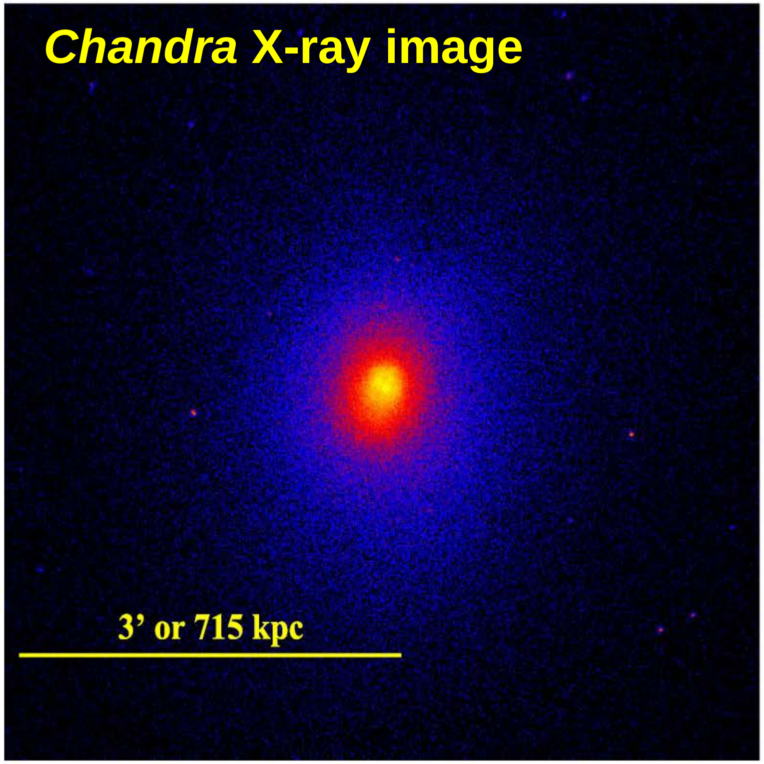


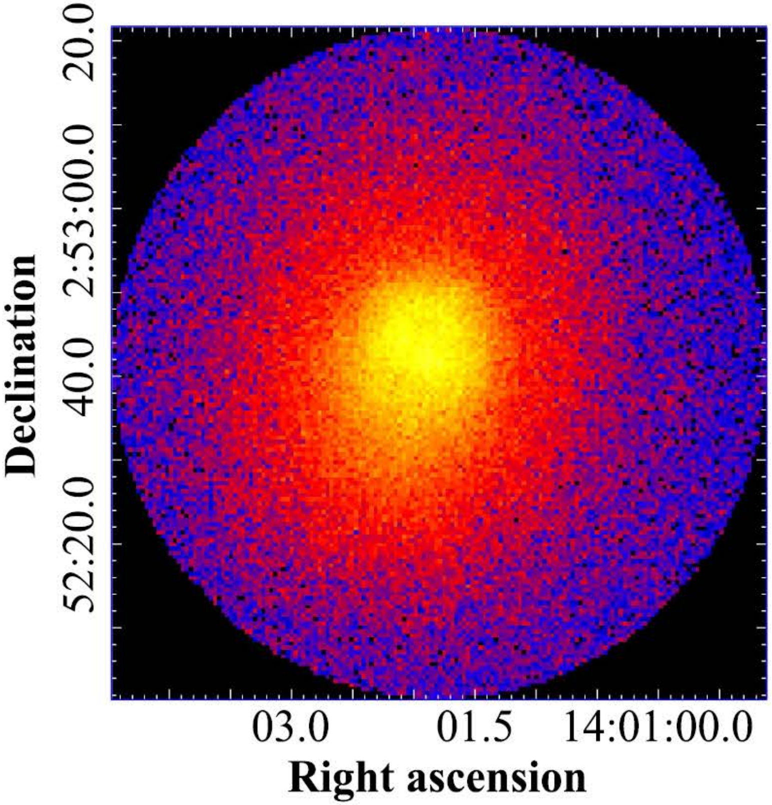
An infalling sub-cluster sloshes the gravitational potential of the cluster.

- The cool, dense, and metal rich ICM is lifted up to the outer region.
- The hotter ICM in the outer region flows to the center.
  - Gas sloshing can give some impacts on the cool core.

Massive relaxed cluster: Abell 1835

- The most luminous cluster in the *ROSAT* Bright Cluster (Ebeling+98)
  - the mass (M_{200}) is estimated to be 1.09 x 10^{15} $M_{\odot}$ (Okabe+10)
- Symmetrical X-ray surface brightness & presence of the cool core
  - no experience of major merger in last Gyrs

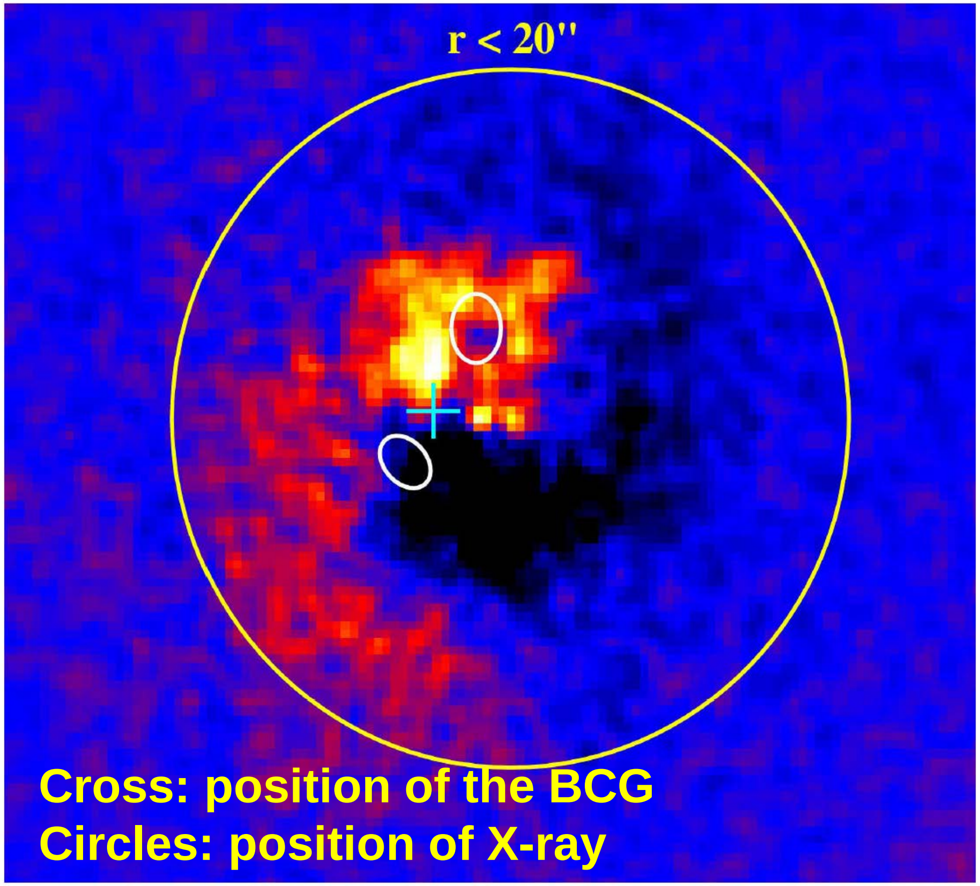


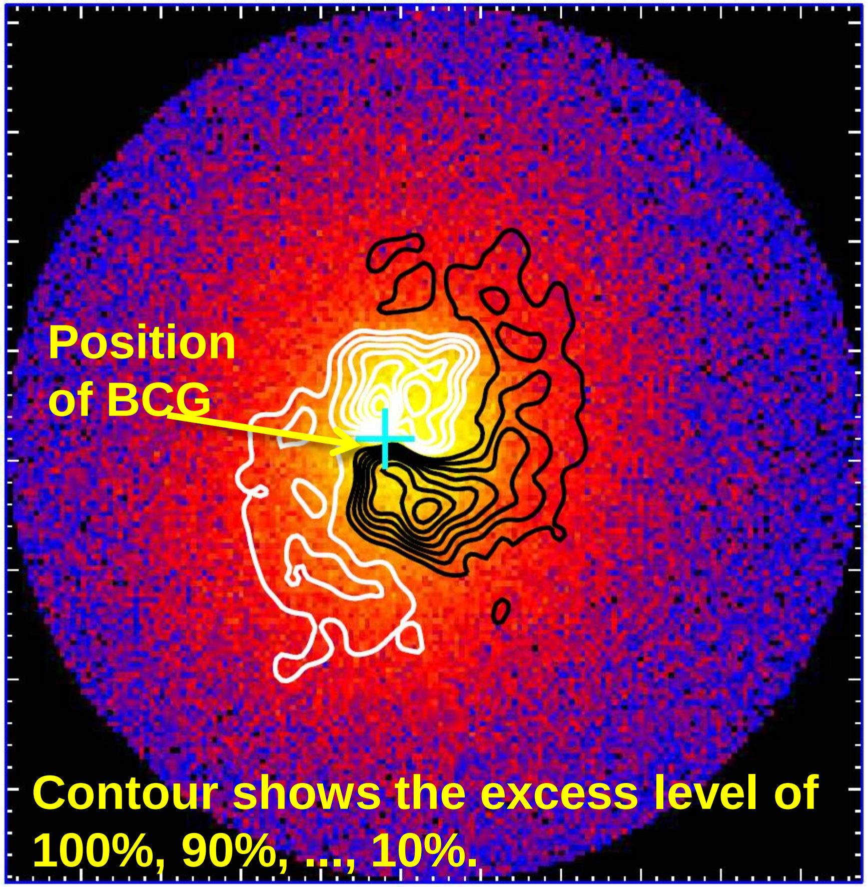


X-ray image (r < 40")

Spiral patterns in the core

We found two arc-like structures in the residual image of X-ray surface brightness using *Chandra* after subtracting its mean profile.



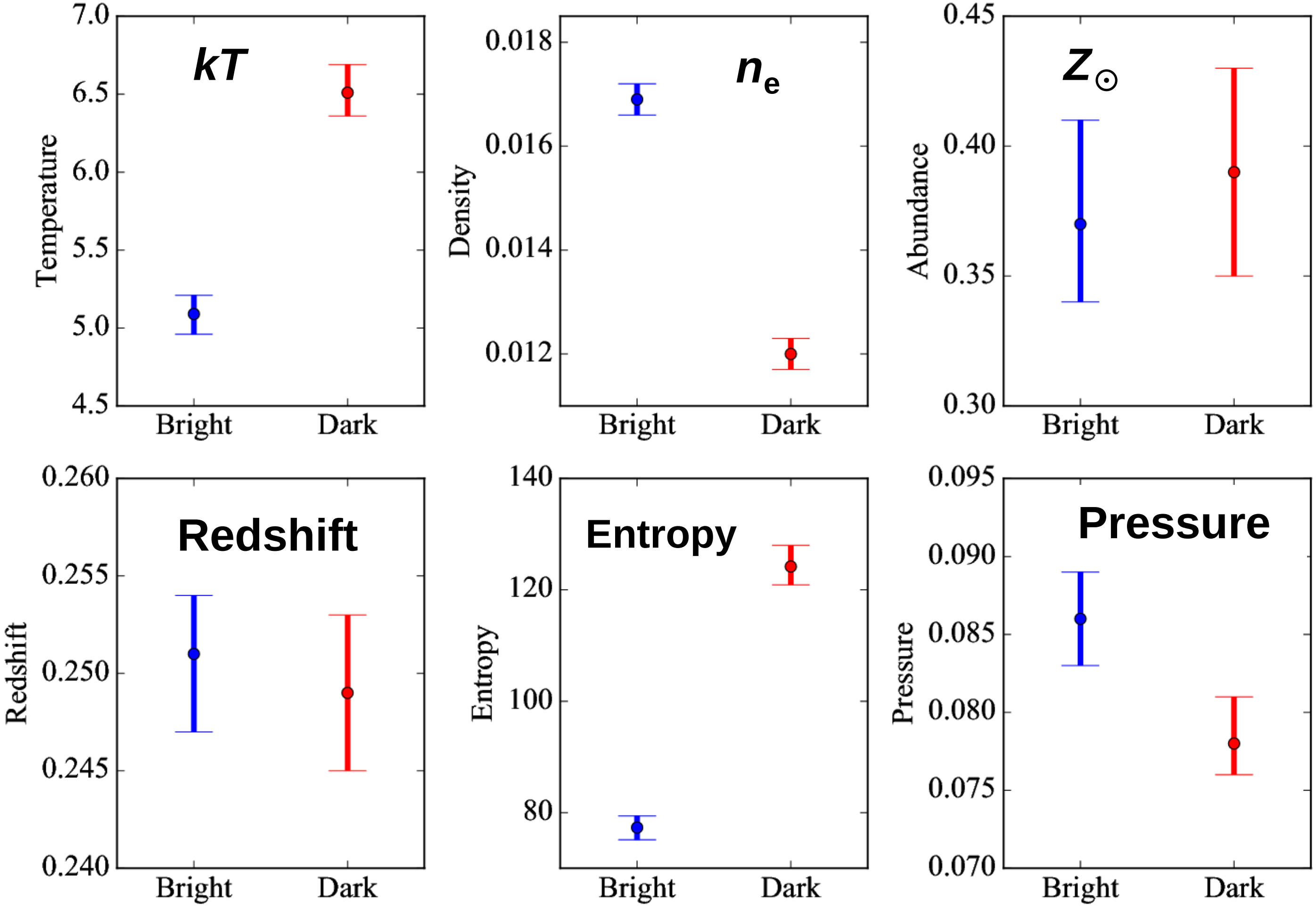


We defined the size of spiral patterns as the distance from the peak position to the farthest tail (10%) of the contour.

⇒ Similar shape and size (~70 kpc) between positive and negative excess regions.

Properties of the ICM toward the spirals

Blue: positive, Red: negative



The ICM in the positive excess region has

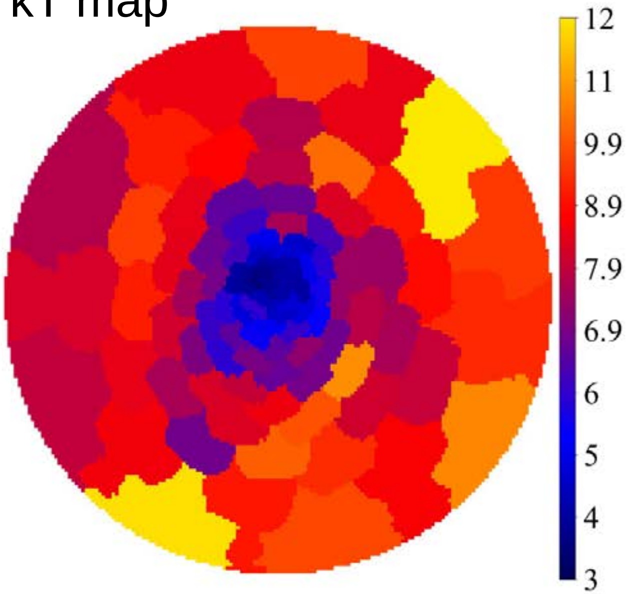
- lower *kT*
- higher n_e
- lower entropy

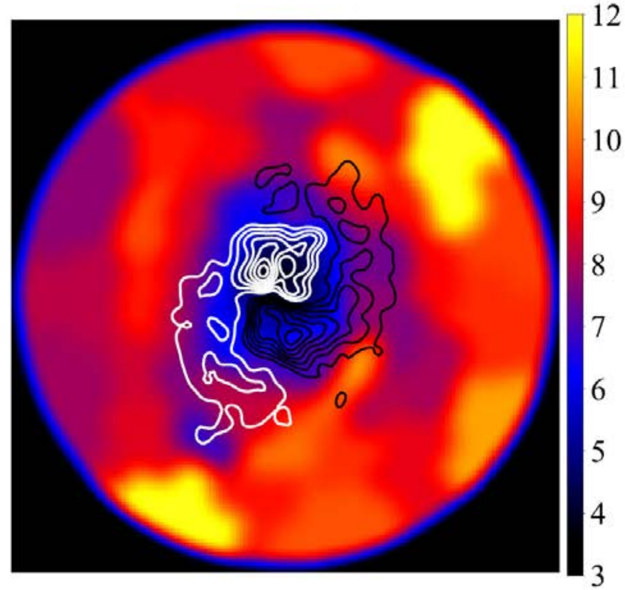
No redshift difference
-> LOS bulk motion is < 600 km/s

The properties are similar to those of other clusters known.
The ICM in the spirals is near or is in pressure equilibrium.

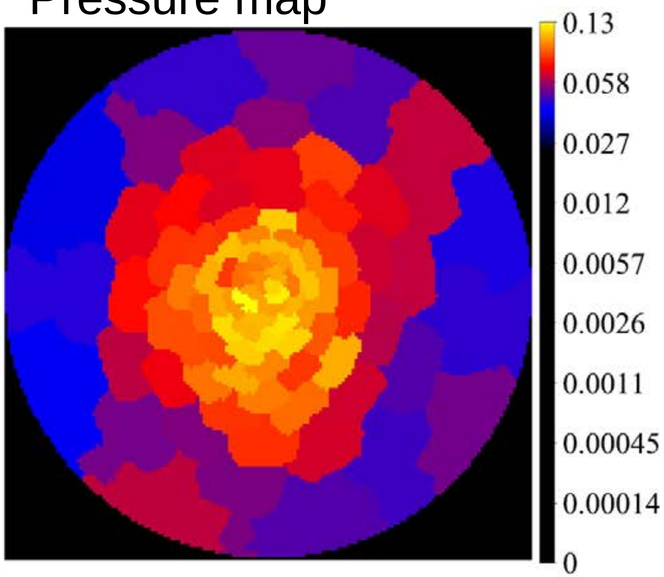
The ICM propertis in the central region

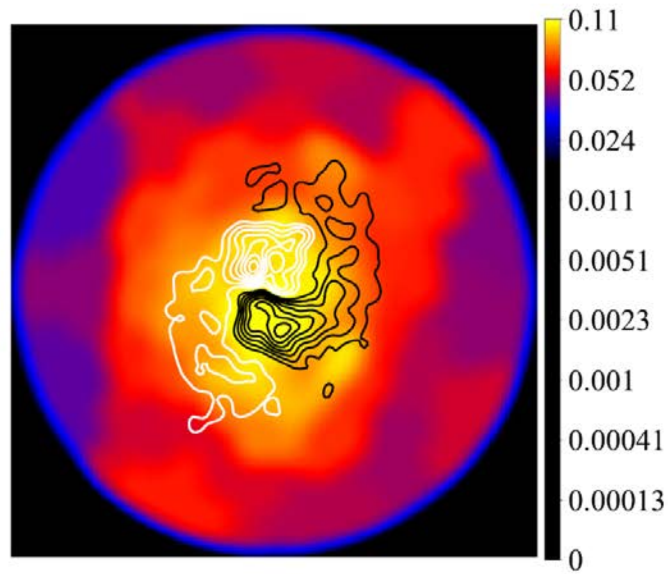
kT map





Pressure map





Using ContBin (Sanders+06), we studied the ICM properties in the central region (*r* < 40”).

The spiral patterns extend from the cool core to the hotter surrounding ICM.

No pressure discontinuity is found in the central region.

Comparison of the size of spirals

We measured the size of spiral patterns in A1835.

- **They are ~ 70 kpc.**

We re-analyzed the data of A496 and A2052, and applied our method to measure their size. We compared the size with the core radius.

	A1835	A496	A2052
Size of spirals	70 kpc	150 kpc	170 kpc
Core radius	31 kpc	15 kpc	18 kpc

The spiral pattern in A1835 is the closest to the core radius in our sample.

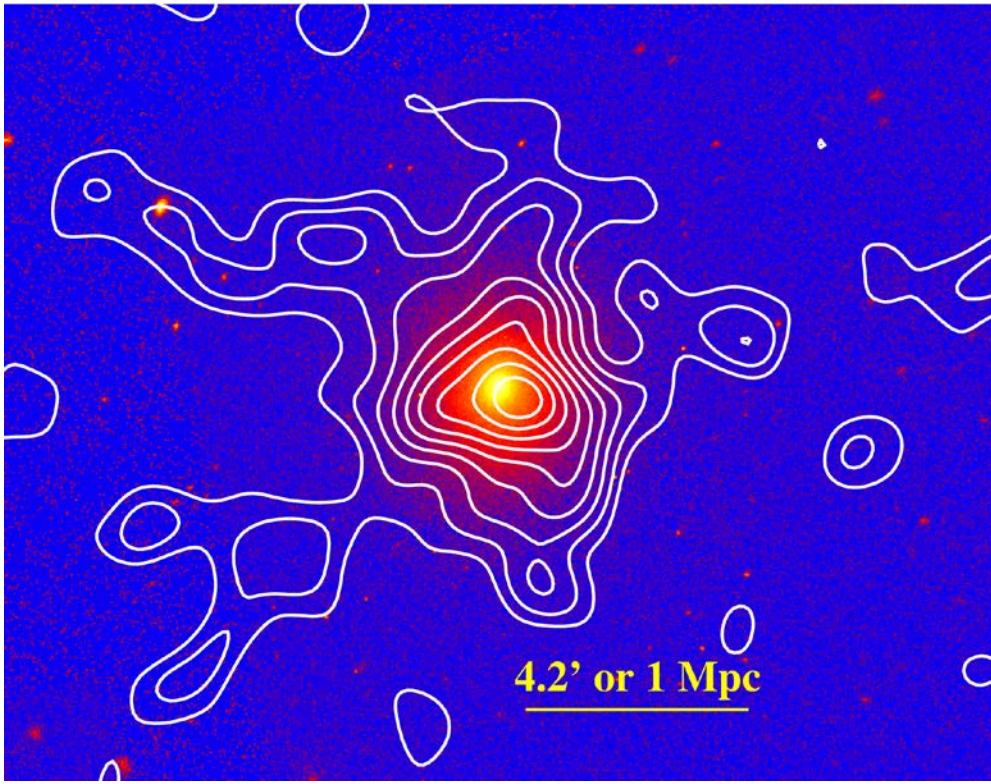
- The size may reflect an evolution history (e.g., ZuHone+10)
  - now experiencing a minor merger??
    - important to compare with the mass map (see next)

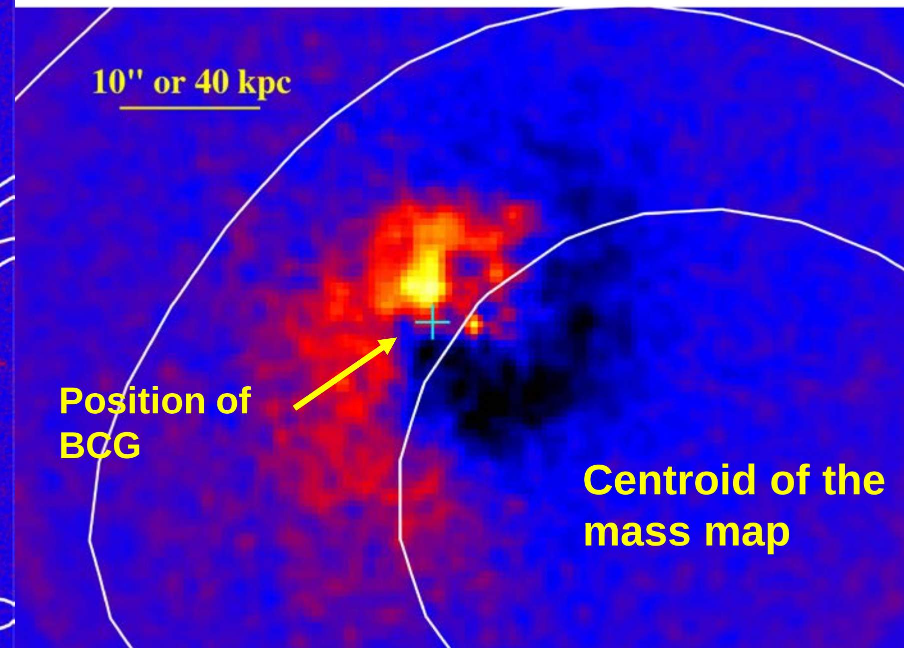
The spiral pattern also extends to the hotter surroundings ICM.

- stirring motion transports a fraction of the cool gas out to larger radii and the hot gas into smaller radii.
  - Such motion might affect a form of the cool core??

Comparison with mass map

Spiral patterns vs. the mass map of A1835 estimated with weak-lensing by Subaru/Suprime-Cam (Okabe+10)





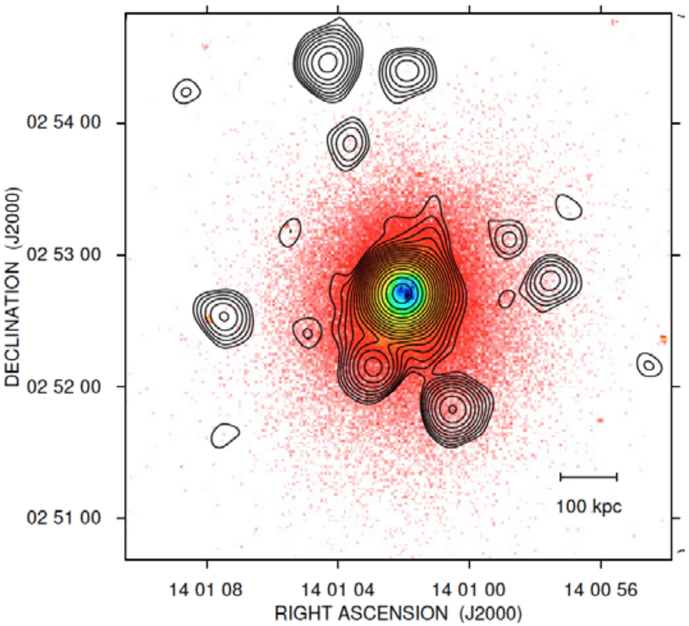
X-ray centroid seems to be not consistent with that of the mass map.

- Gas is sloshing in the potential.
- Strong lensing mass map is needed to compare precise position.

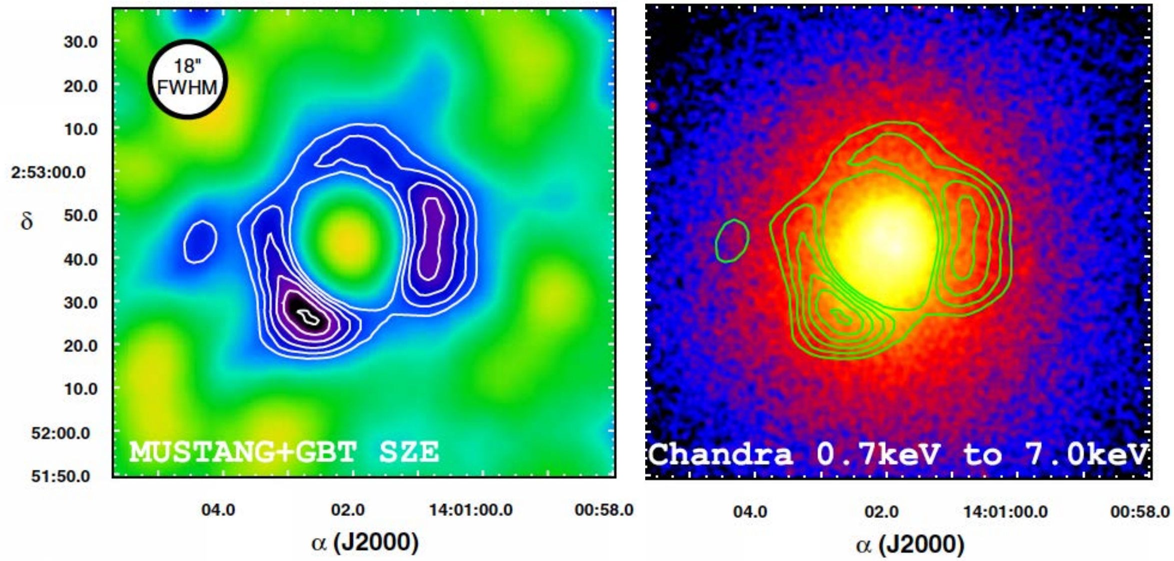
If an early stage minor merger, a substructure travels from north to south west by comparing numerical simulations.

SU+ in prep.

Comparison with SZ effect and radio mini-halo



Radio mini-halo suggested by Govoni+09 with VLA



SZ map obtained with MUSTANG (left) and overlaid on X-ray image (right) (Korngut+11)

- Morphology of radio mini-halo is no apparent signature of disturbance
- SZ map is strongly affected by a contamination of central AGN emission.

To investigate any discrepancies, we need more high angular resolution observations in radio band.

➢ ALMA has a power to measure SZ map with 5” (see Kitayama+16).

Origin and impact of the spiral pattern

The trend of ICM properties in the spiral pattern in A1835 is consistent with that of other clusters known.

- The spiral pattern is likely generated by gas sloshing induced by an off-axis minor merger.

(LOS bulk motion is < 600 km/s, turbulence < 274 km/s (Sanders+10))

- Another possibility is a past energetic activity of central AGN, which created X-ray cavities in the cluster core (McNamara+06)

Pressure equilibrium:

- we found no similar morphology of SZ map due to AGN contamination.
    - ALMA enables us to measure high quality pressure map

Relation to radio mini-halo:

- Govoni+09 suggest a presence of a radio mini-halo
    - Further studies are needed to compare its morphology and that of the spiral patterns.

Summary

Using the *Chandra* observations of A1835, we performed the imaging and spectral analyses, and found the followings.

- Spiral patterns with the size of ~ 70 kpc
  - ➢ smallest size (closest to the core radius) among similar features known so far
- Lower temperature and higher density of the ICM in the positive excess region than those in negative region
  - ➢ Near or in pressure equilibrium
- Spiral patterns extend from the cool core to the hotter surroundings.
  - ➢ Stirring motion may induce inflow and outflow of the ICM
  - ➢ Hot gas from outer region may heat the cool core.
- LOS bulk motion is < 600 km/s, which means the infalling is in the plane of the sky.