ISTITUTO NAZIONALE DI ASTROFISICA
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Group-size Accretion at Large Radii on Massive Clusters of Galaxies

Sabrina De Grandi

Collaborators:
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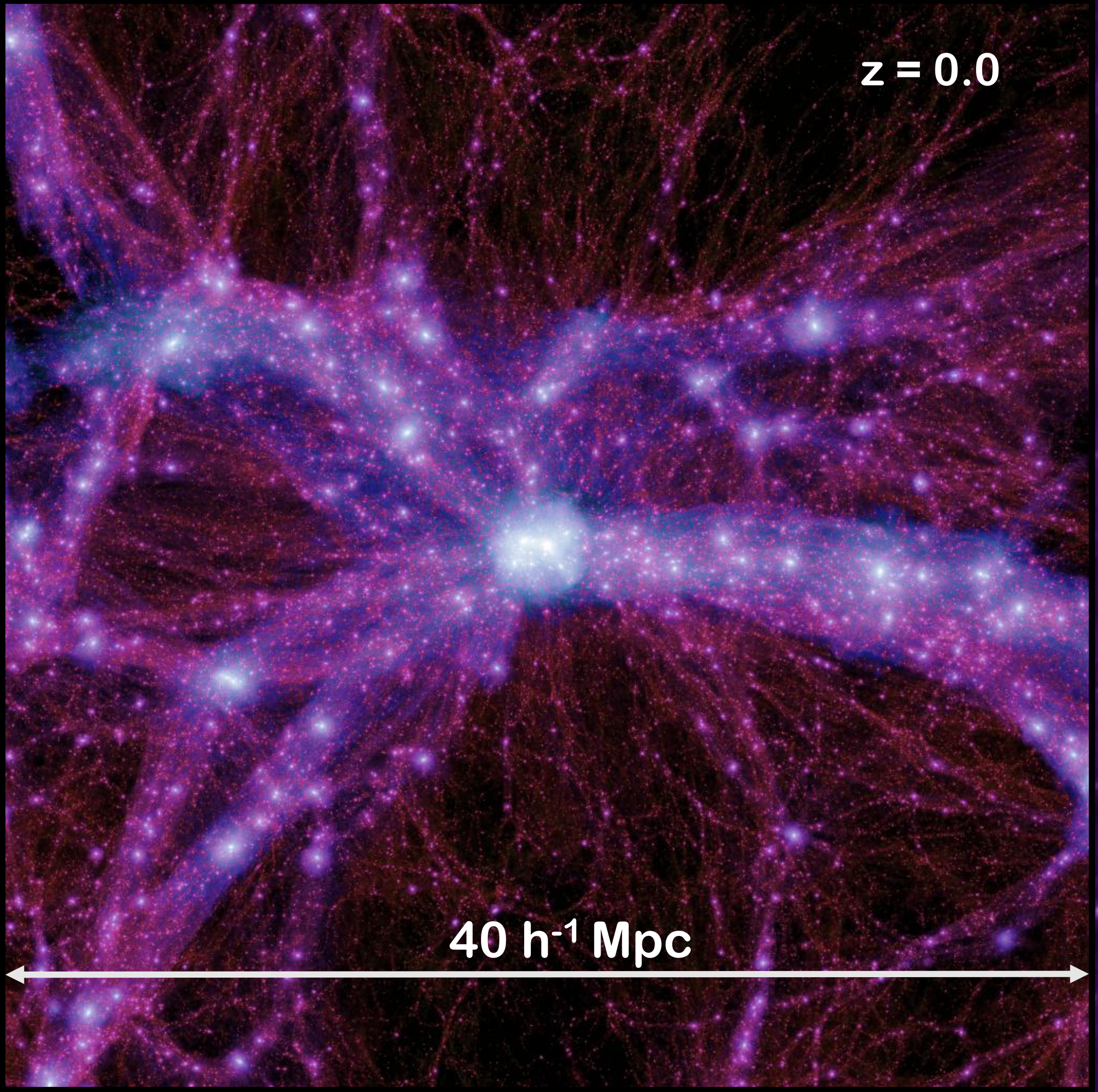
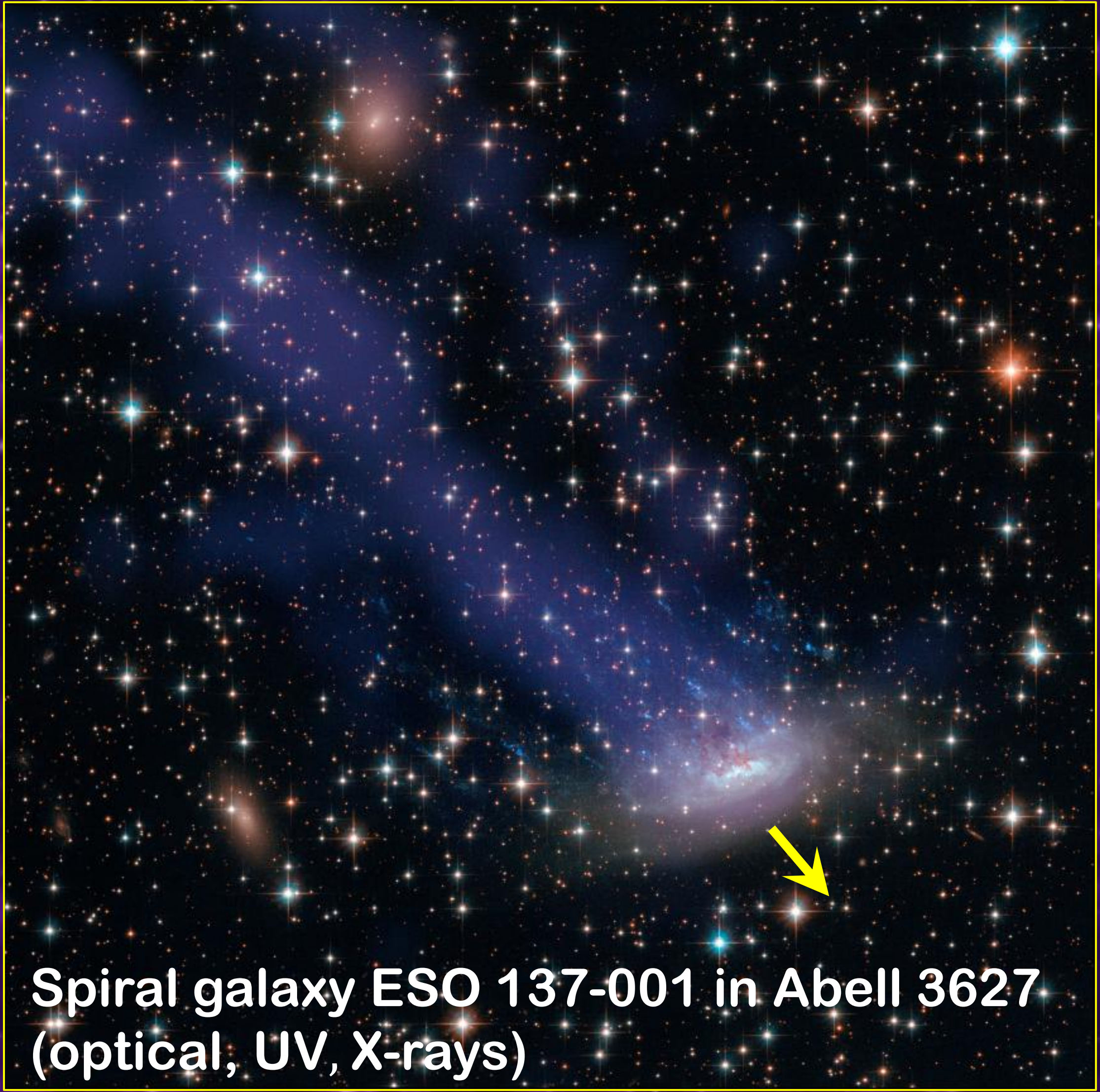
Galaxy Clusters are the nodes of the cosmic web

- In the hierarchical scenario of structure formation, clusters are still forming through:
  - merging of several massive entities,
  - accretion of smaller structures (galaxies and galaxy groups) from the cosmic filaments.
- While major mergers carry a lot of mass but are rare, most of the cluster mass (~ 80%) accumulates through accretion of small structures (galaxies and galaxy groups)
- Signatures of accretion processes should be found in the outskirts of clusters where they are connected to filaments



- On the smallest scales, a few disturbed in-falling galaxies have been observed in the optical and in X-rays in nearby clusters (e.g. Virgo, Coma, A3627)
- The ram-pressure stripping is expected to be the key to the evolution of the cluster galaxy population by quenching rapidly the star formation in galaxies that fall into clusters.
- Observations at larger, groups and clusters, scales started more recently

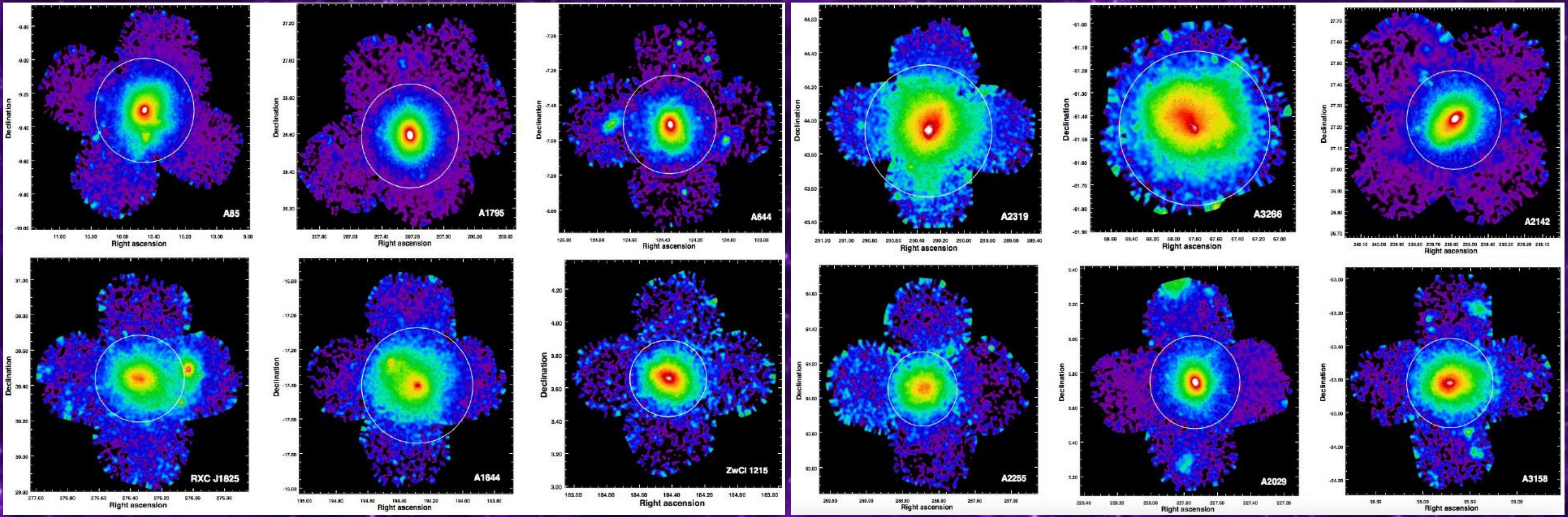


Spiral galaxy ESO 137-001 in Abell 3627 (optical, UV, X-rays)

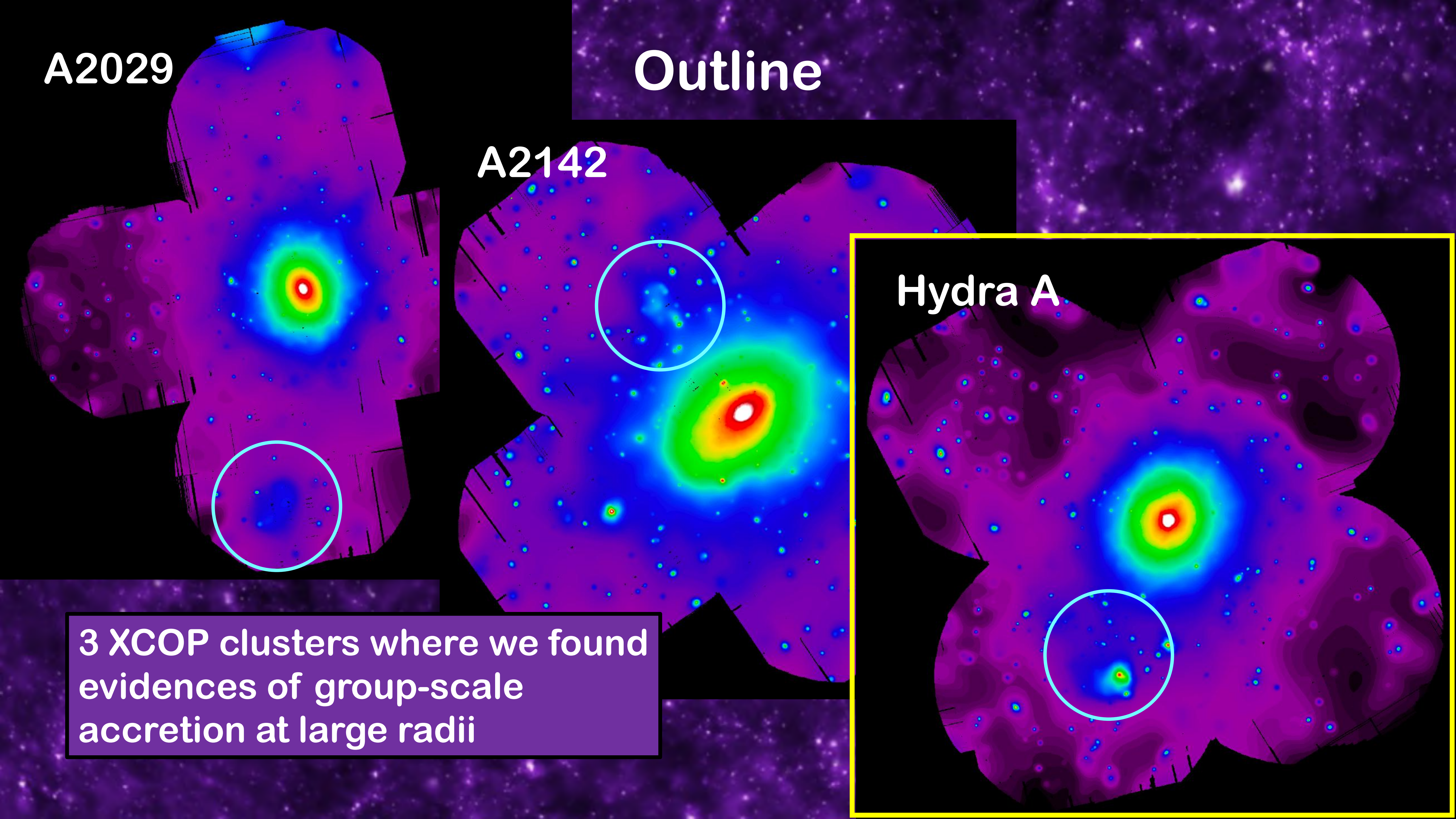
The XMM Cluster Outskirts Project (PI D. Eckert, VLP 1.2Ms)

Targets are the outer regions of a sample of 13 clusters: $M_{500} > 3\times10^{14}\ M_{\odot}$ @ $z<0.1$

- Main GOALS (details on sample selection in Eckert+17):
  - measure the distribution of entropy and thermal energy
  - asses the presence of non-thermal pressure support in cluster outskirts
  - study the occurrence and mass distribution of in-falling gas clumps



Outline



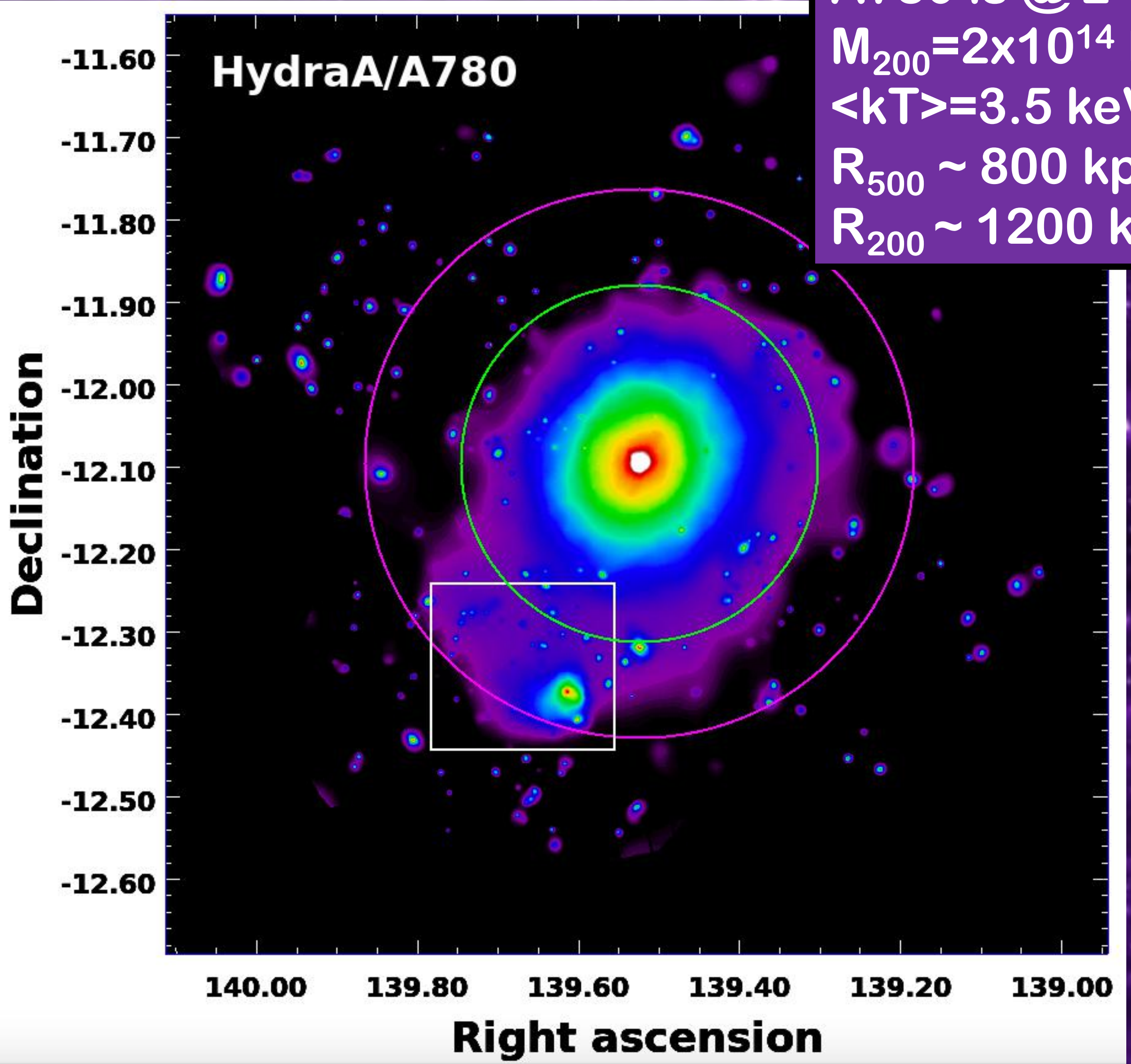
3 XCOP clusters where we found evidences of group-scale accretion at large radii

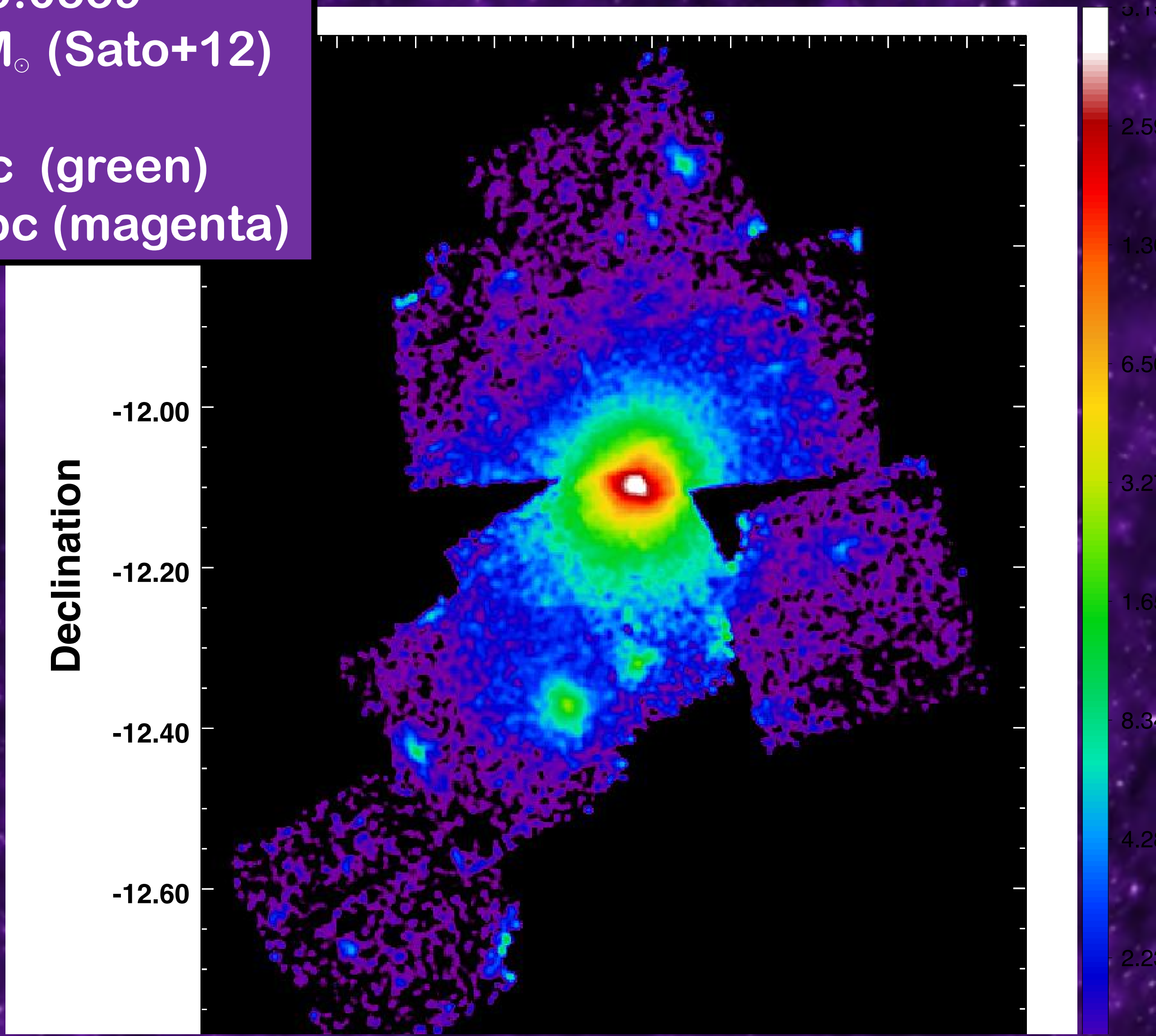
Accreting group in Hydra-A (A780)

XMM (>300 ks)

SUZAKU (250 ks)

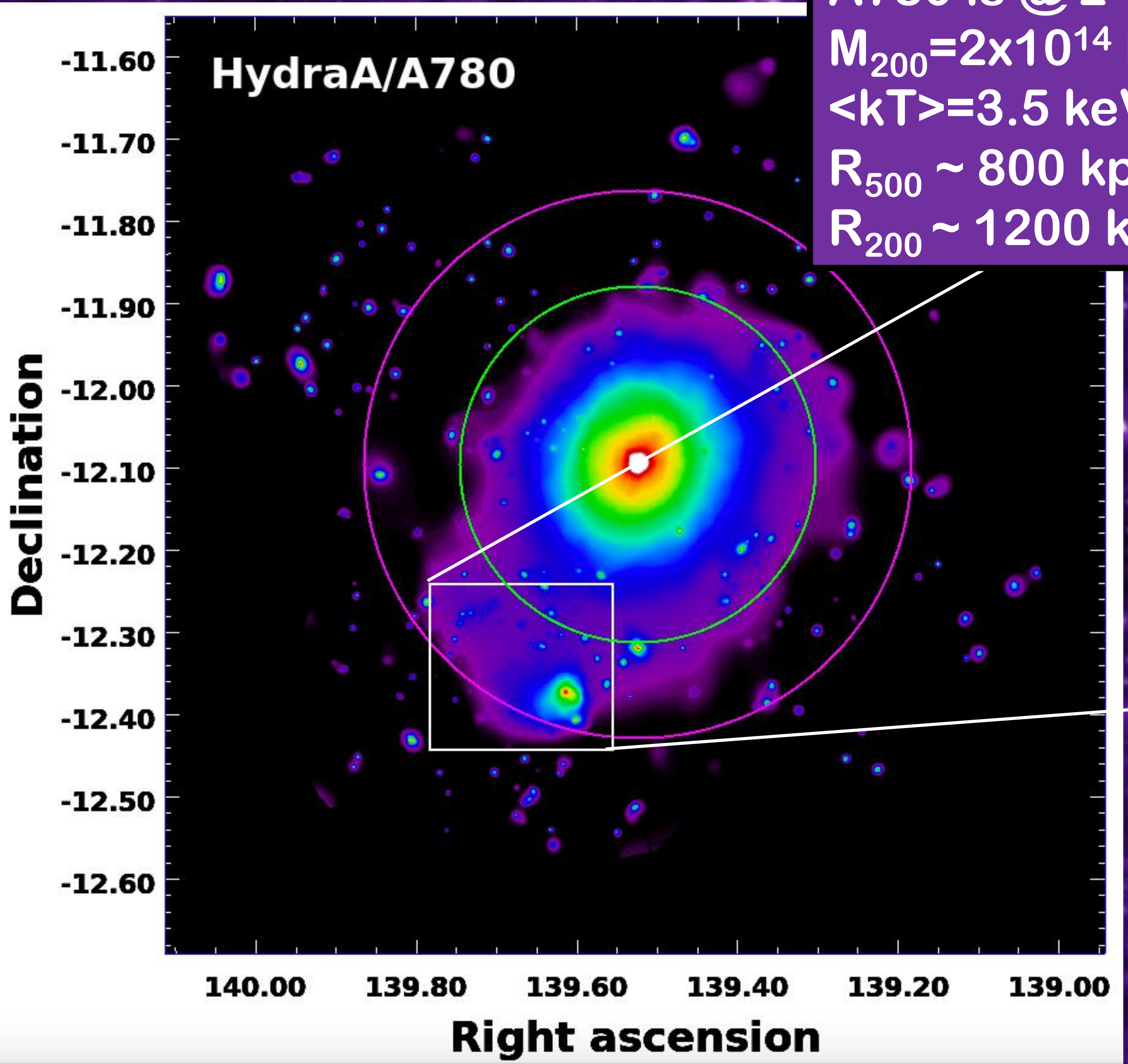
A780 is @ z=0.0539
M_{200}=2x10^{14} $M_{\odot}$ (Sato+12)
<kT>=3.5 keV
R_{500} ~ 800 kpc (green)
R_{200} ~ 1200 kpc (magenta)





Accreting group in Hydra-A (A780)

XMM (>300 ks)



A780 is @ z=0.0539
M_{200}=2x10^{14} $M_{\odot}$ (Sato+12)
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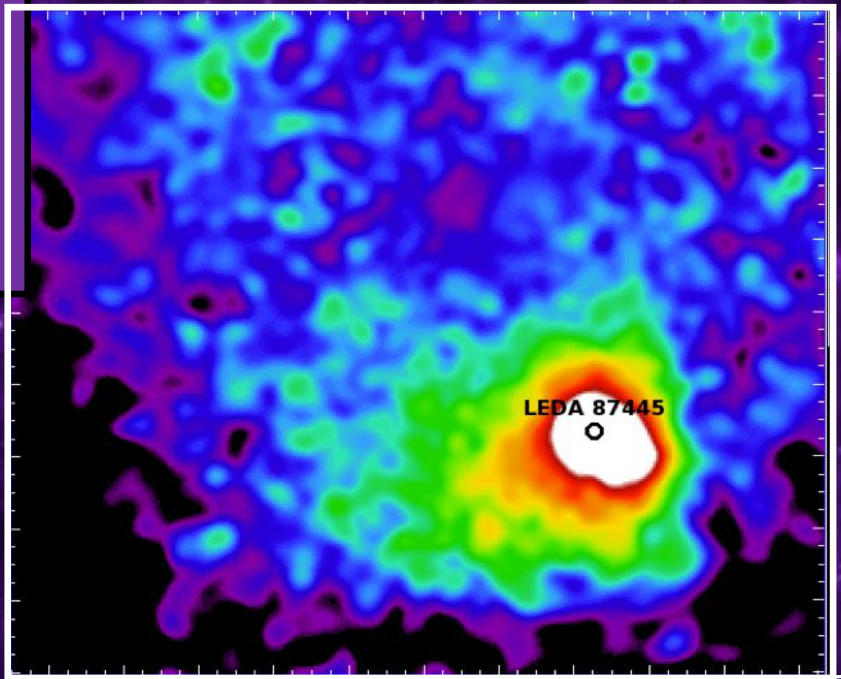
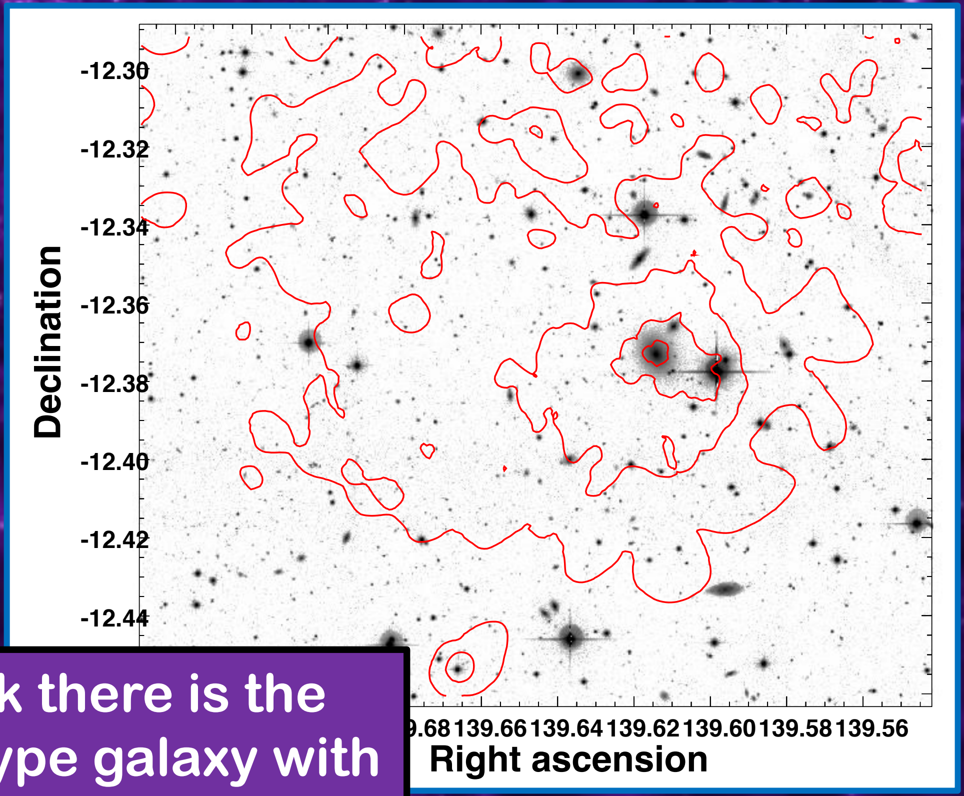
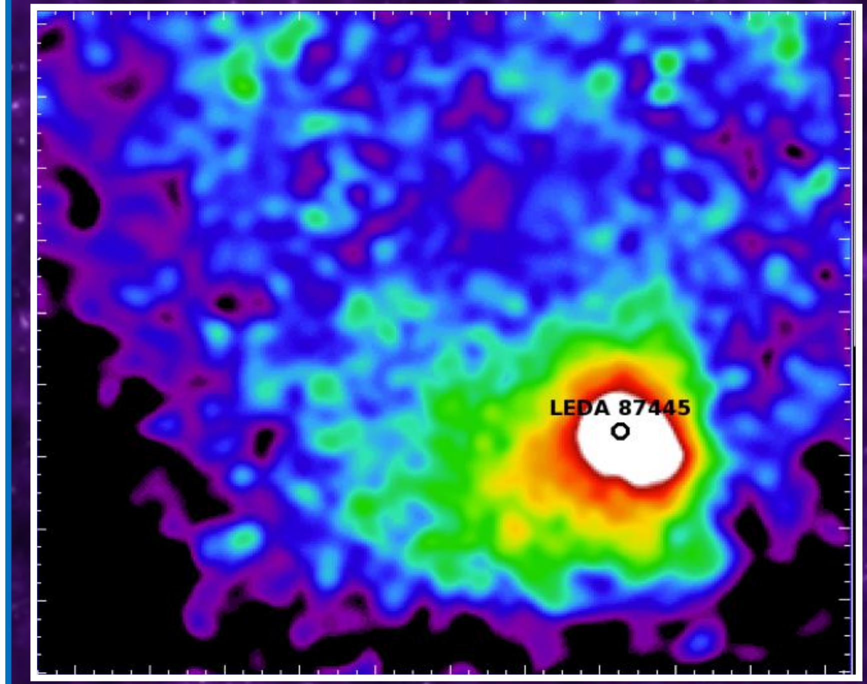


We discovered an accreting structure at 1.1 Mpc South of the cluster core with a very extended faint "tail" (~760 kpc)
(De Grandi et al. 2016)

Accreting group in Hydra-A (A780)

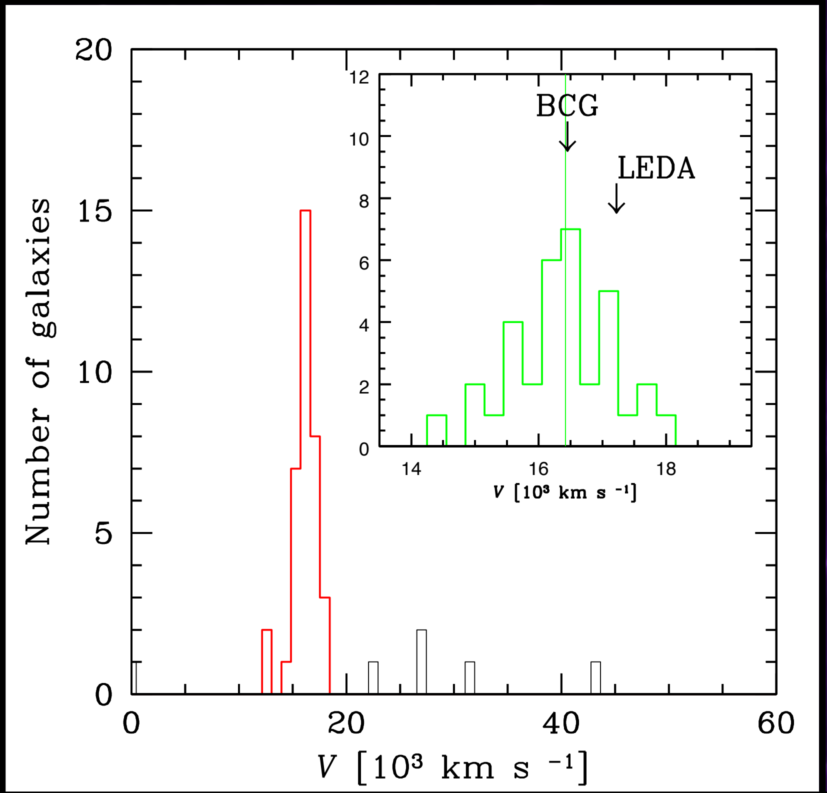


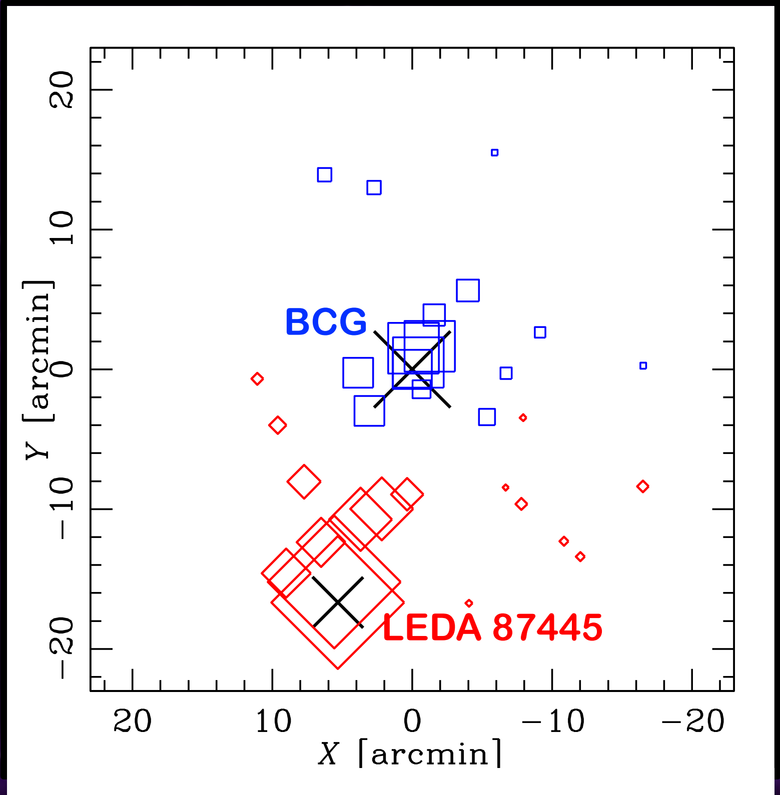


CFHT/Megacam r-band image

- ❖ At the X-ray peak there is the LEDA 87445 E-type galaxy with z=0.0575 (z_{HydraA}=0.0539)
- ❖ 42 galaxies with published Line-of-Sight velocities (Smith+04)

The LEDA 87445 group: kinematical analysis

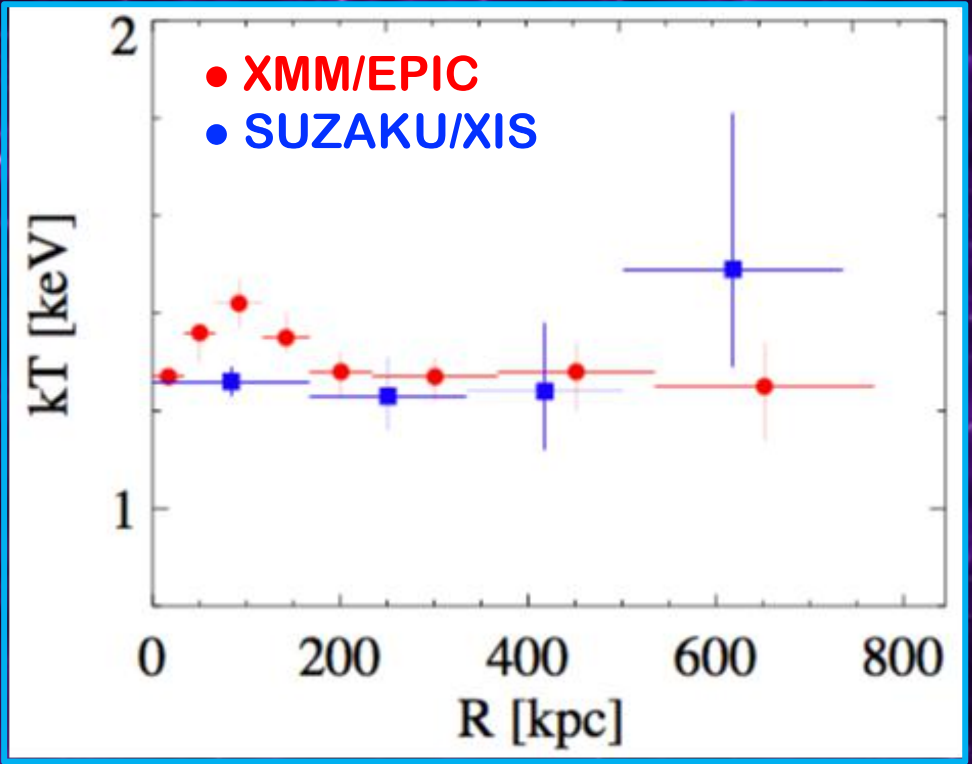


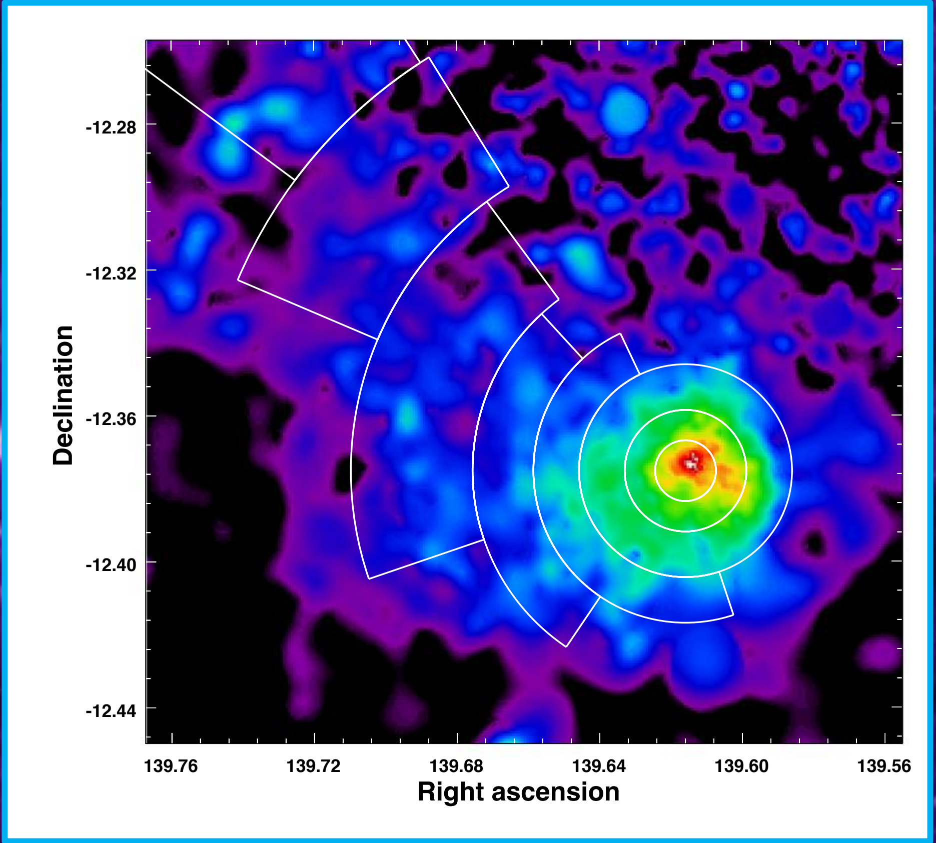


- Line-of-Sight velocity distribution of the galaxies with z_{spec}
  (DEDICA method by Girardi+98)

- Red: distribution of galaxies assigned to HydraA.
- Green: distribution of 33 fiducial members.

DS-test based on the mean velocity of 33 fiducial members detected a substructure around LEDA 87445 with a c.l. larger than 99%.

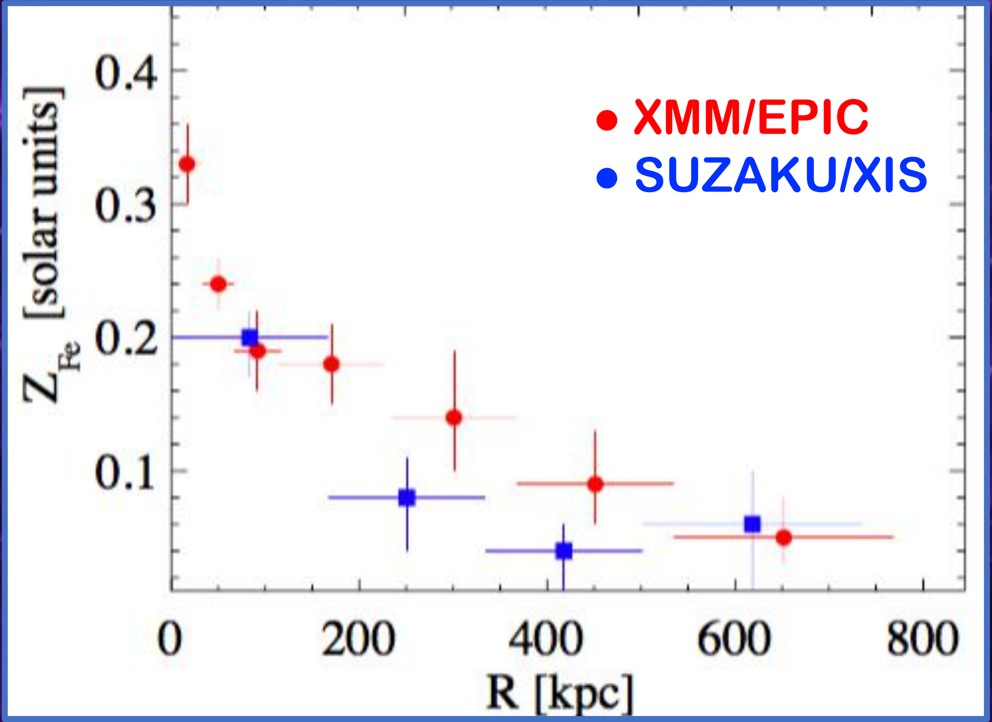


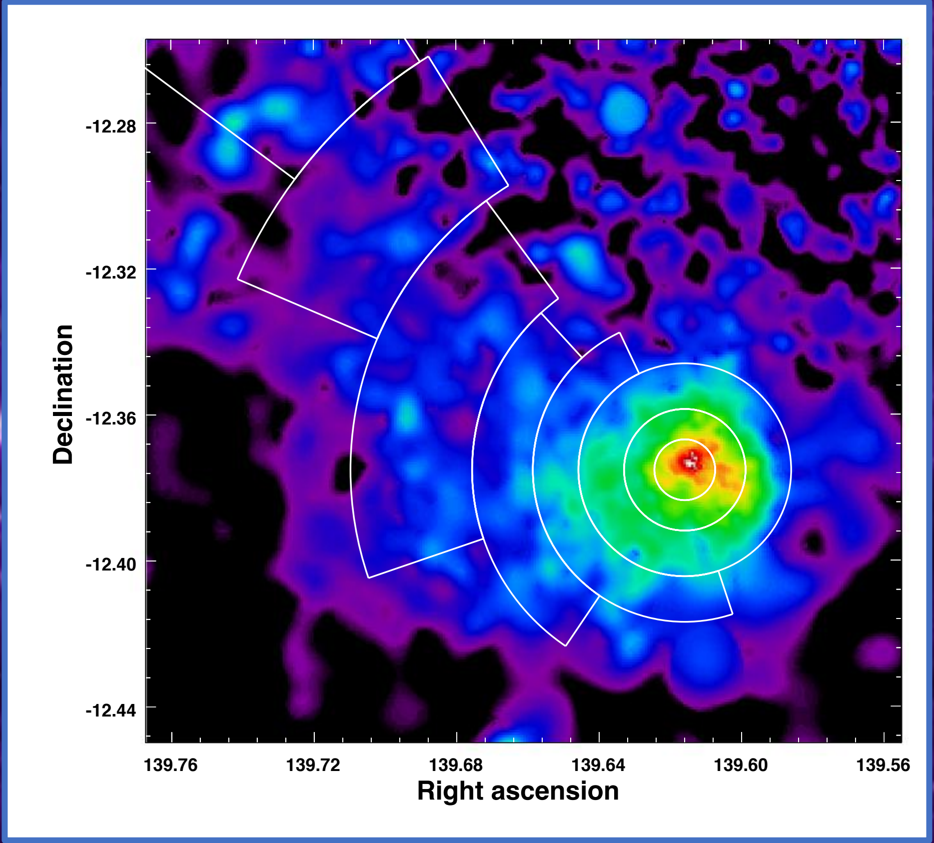


The temperature of the group is 1.3 keV, ~ 2 times smaller than in the surrounding ICM (~2.5 keV)

Regions selected for spectral analysis.

This temperature is typical of a galaxy group with total mass of a few $10^{13} M_{\odot}$.



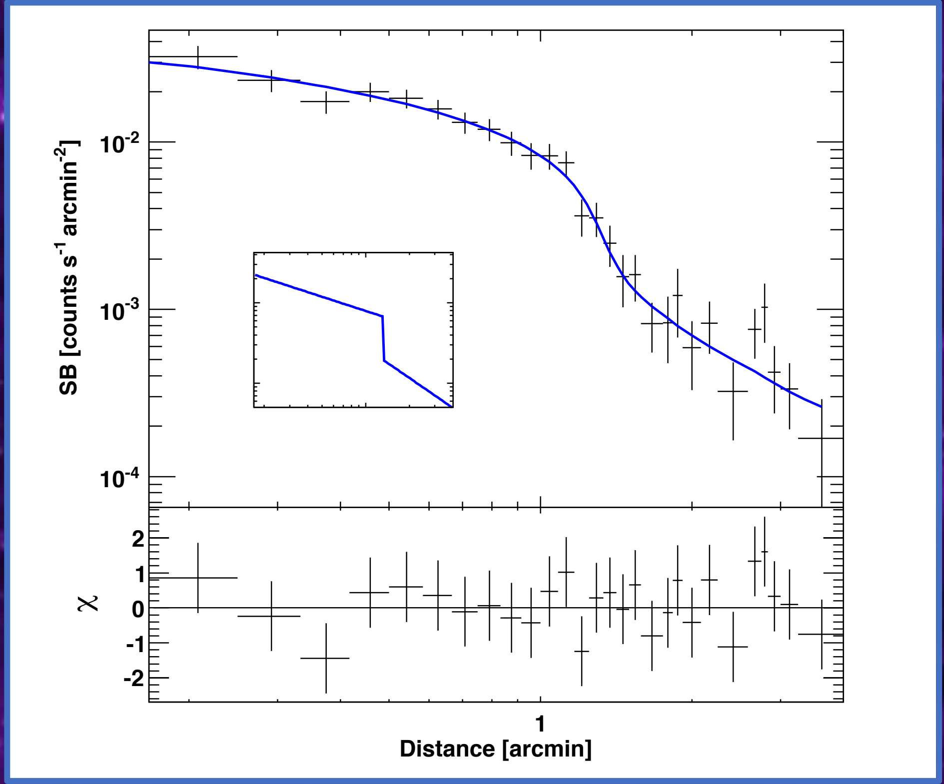


The metallicity is peaked on the LEDA galaxy and decreases along the tail.

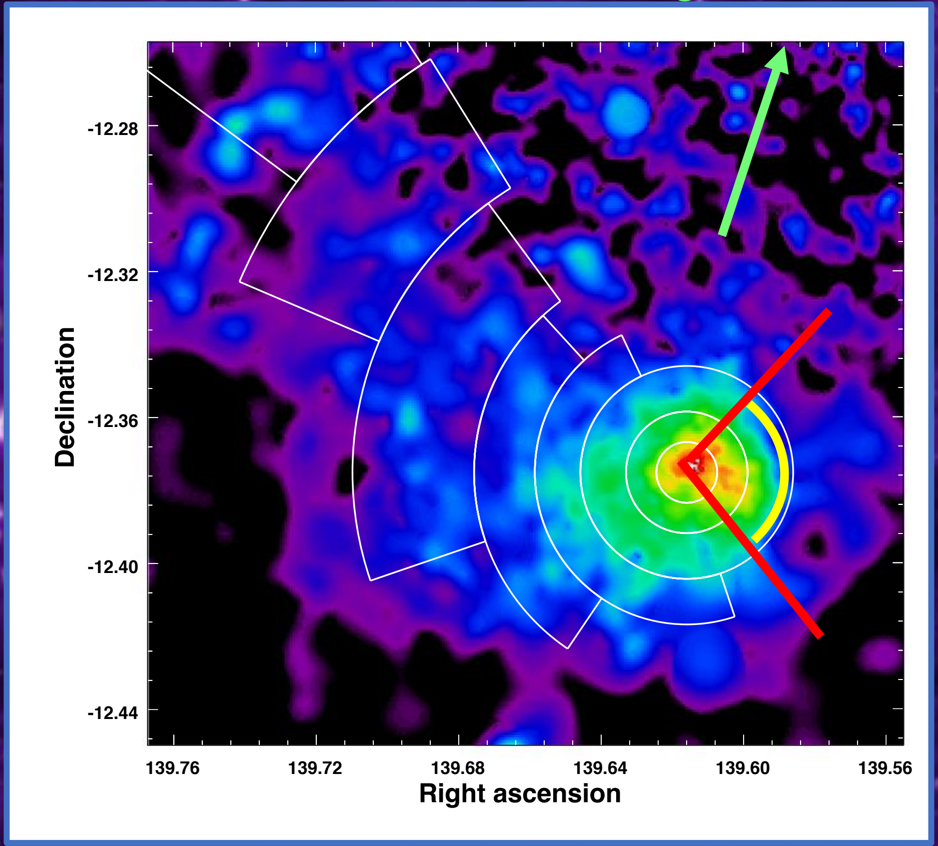
The abundance peak indicates a previously evolved group.

The low Z_{Fe} in the tail could be due to Fe-bias due to presence of multiphase gas (here analyzed with a 1T-model)

EPIC/XMM SB profile in a narrow sector



HydraA/A780



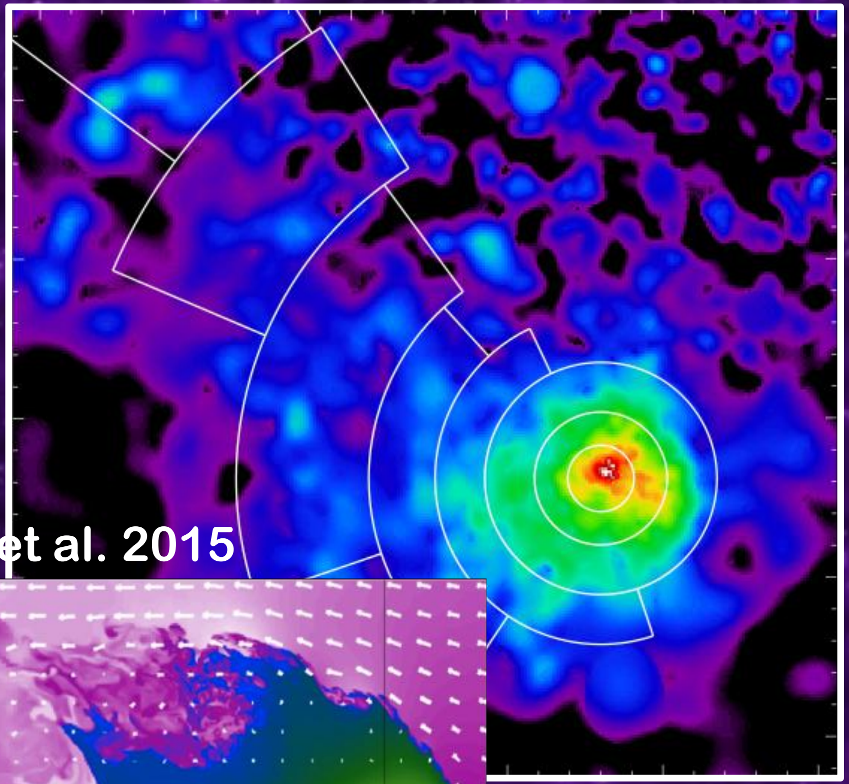
The SB drop at ~100 kpc west indicates the presence of a contact density discontinuity. Since we measure $n_{in} > n_{out}$ and $T_{in} < T_{out}$ this discontinuity is a Cold Front.

Note: The Cold Front is not pointing towards the main cluster core

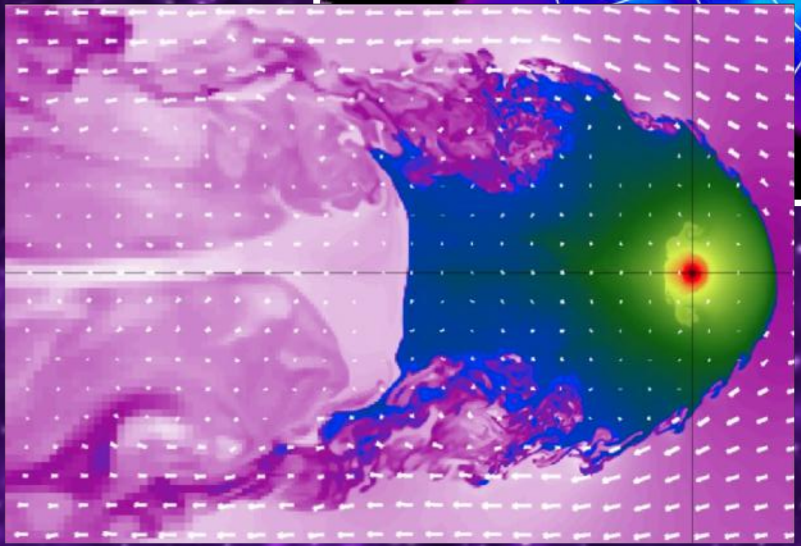
Ram Pressure Stripping properties

Interesting features:

- the cold front at the peak with the KH rolls on the side,
- the remnant tail (still bound to the galaxy) in the blue low-velocity area, and
- the stripped wake trailing behind.



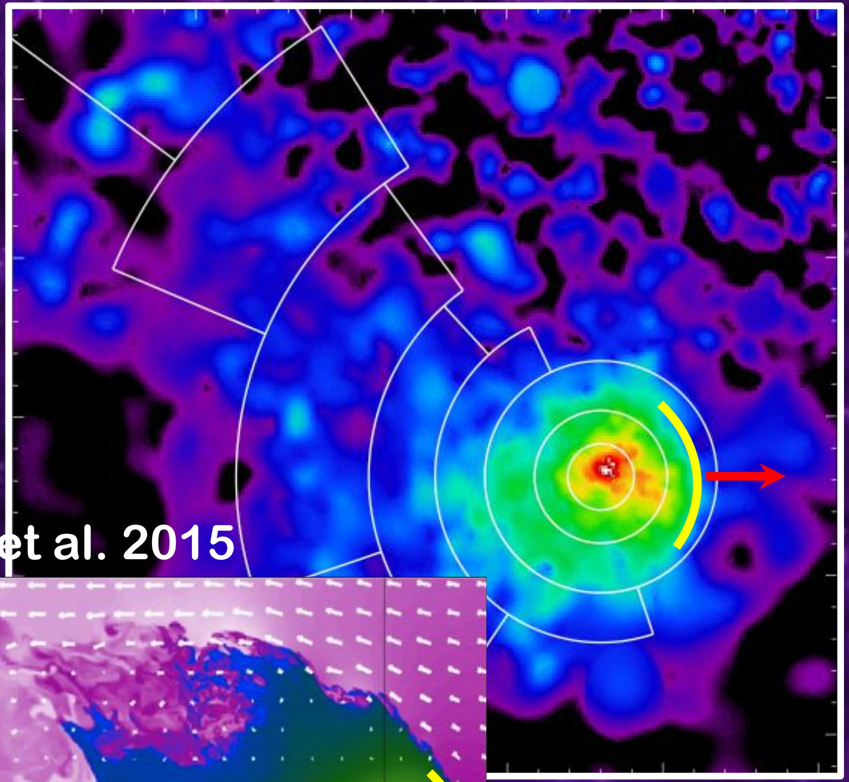
Roediger et al. 2015



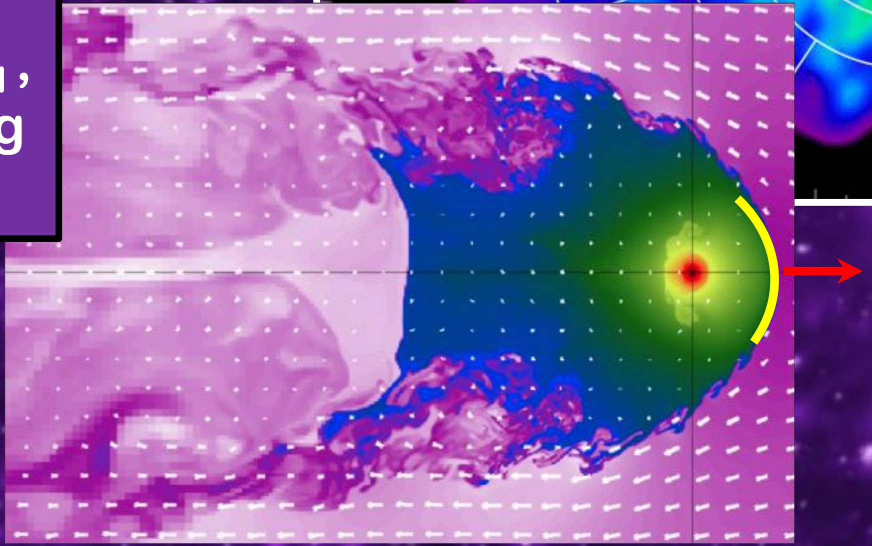
Ram Pressure Stripping properties

- From the "stagnation point" analysis at Cold Front (Vikhlinin et al. 01) ☛ $\mathcal{M} = 1.1^{+0.3}_{-0.4}$ ☛ group velocity of 965^{+270}_{-370} km/s ($\approx c_{sound}$)
- If v_{group} ~ const, the gas in the outermost tail's region was stripped ~ 0.8-1 Gyr ago.
- For groups of $M_{tot}=3\times10^{13}$ $M_\odot$ the gas mass is ~ 5% M_{tot} (Sun+09) ☛ $M_{gas,group}$ ~$1.5\times10^{12} M_\odot$
- We estimated the gas mass in the tail, $M_{gas,tail}$, from the measured gas density and assuming a simple geometry of the tail

➡ $\sim$50% of the group gas has been stripped



Roediger et al. 2015



Thermal conduction constraints

Thermal conduction quickly transfers heat between hot and cold gas phases erasing in-homogeneities.

The thermal conduction timescale in the plasma is

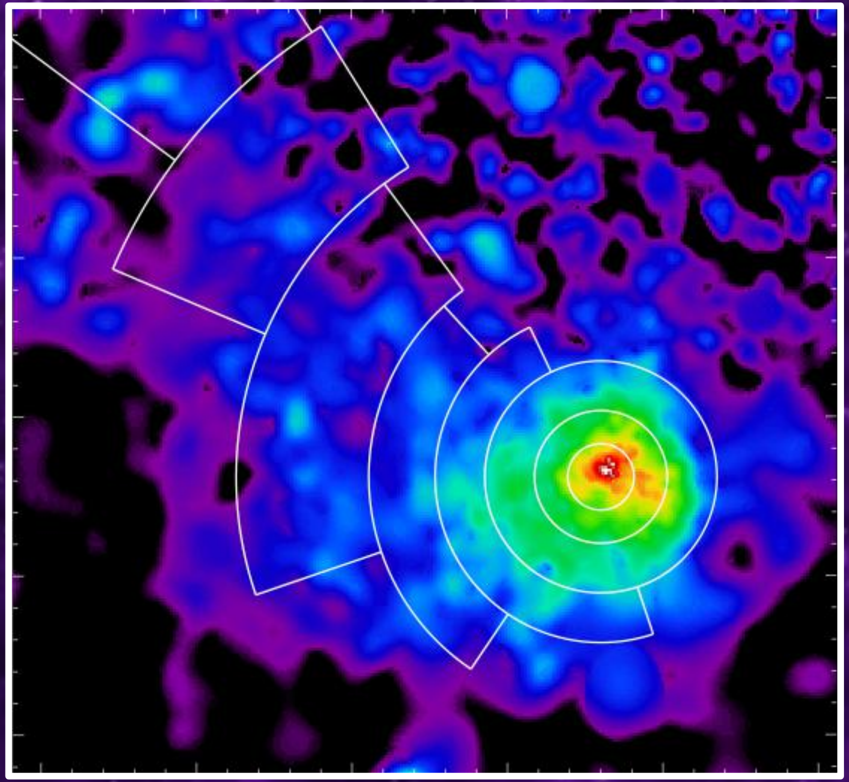
$$t_{cond} \sim \frac{l^2}{D_{cond}} \propto T^{5/2} \sim 16 \text{ Myr}$$

By comparing this timescale with the "age" of the tail

$$t_{age\ tail} \approx \frac{l_{tail}}{v_{group}} \sim 800\text{-}1000 \text{ Myr}$$

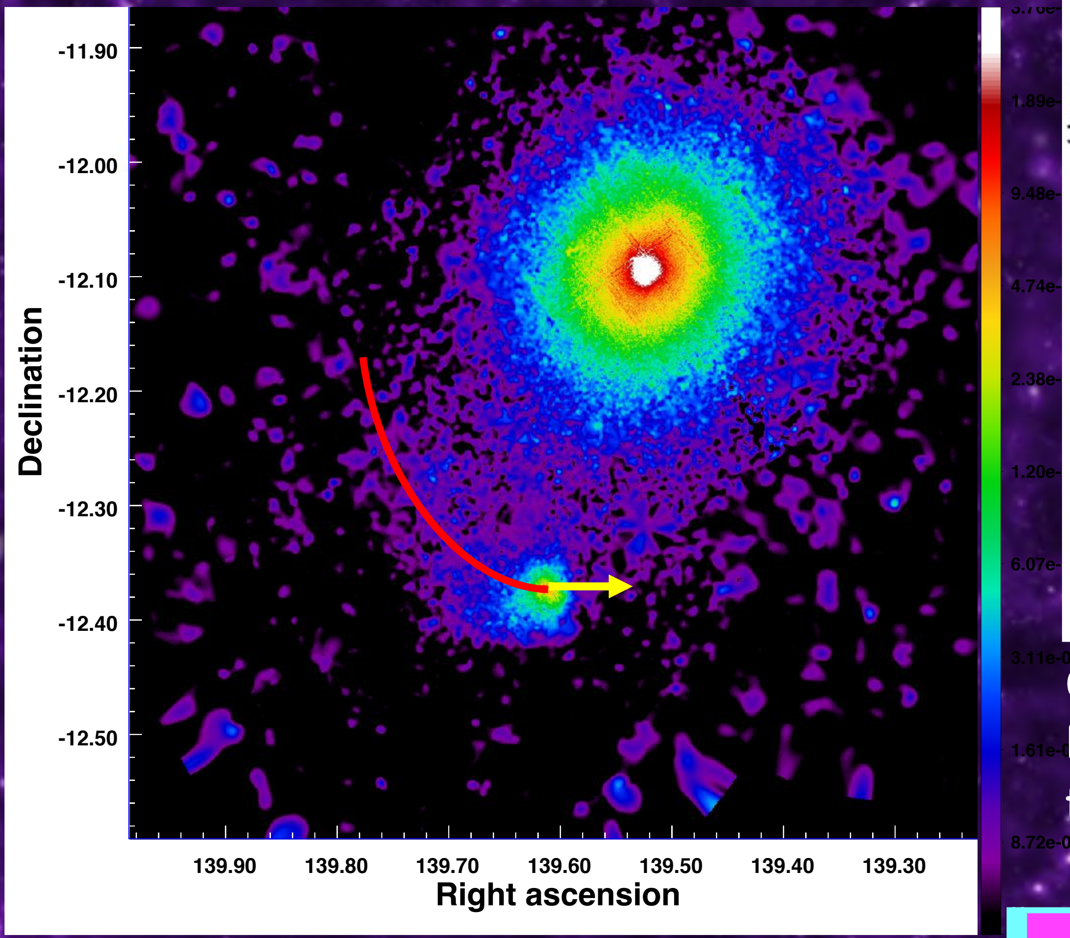
We find that:

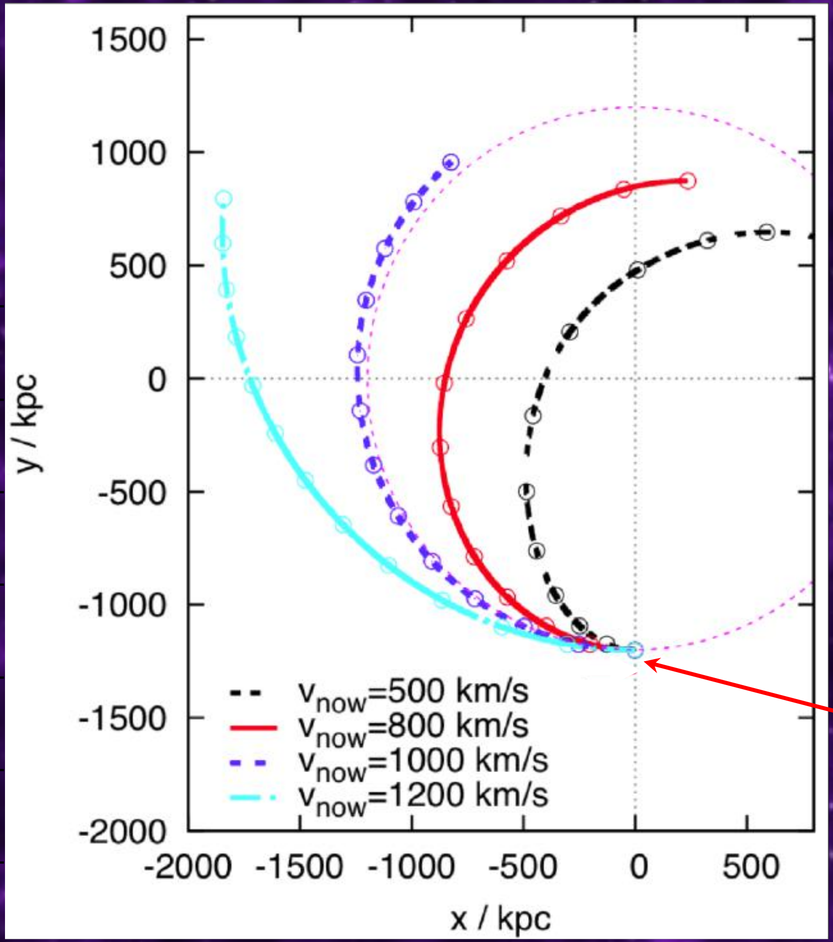
$$t_{age\ tail}/t_{cond} \geq 50$$



the thermal conduction in the ICM is highly inhibited (direct confirmations outside the cluster core)

We roughly estimated the orbit of the group from its X-ray morphology





Dashed red circle is the Keplerian orbit: smaller orbits are bound with the main cluster

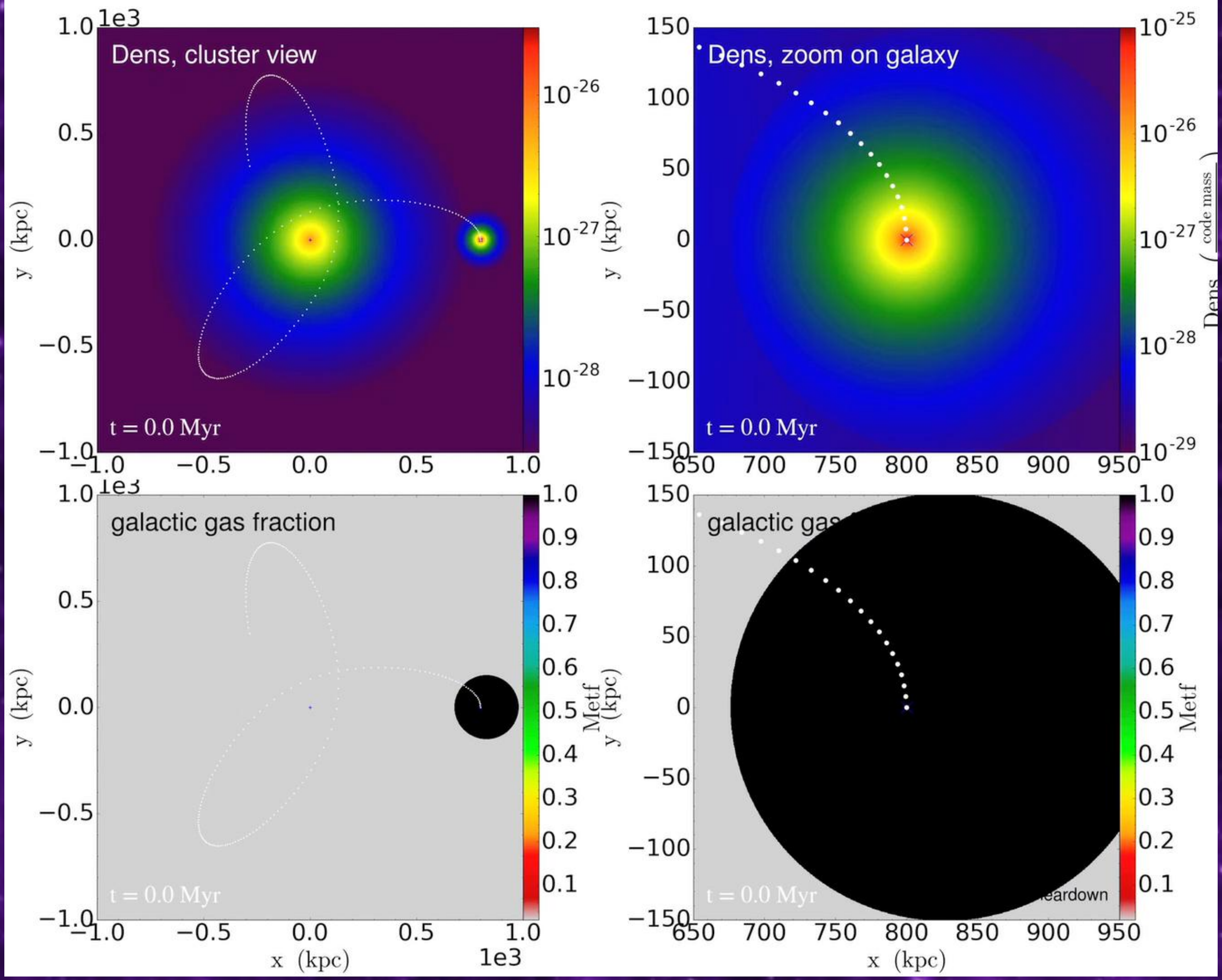
current position of LEDA @1.1Mpc

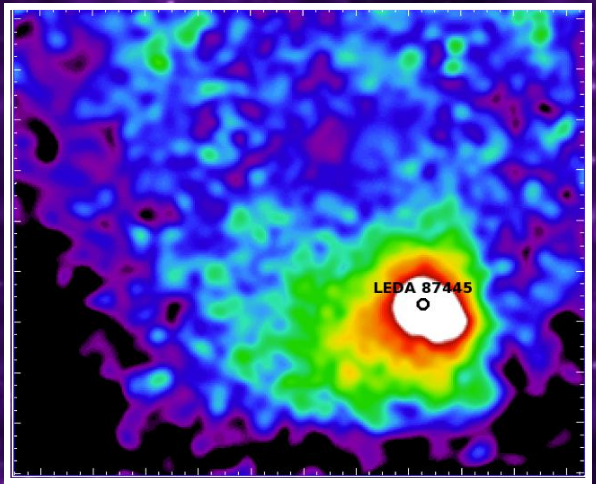
Orbits of a test particle in the potential well of HydraA moving with different velocities (pure tangential velocity, dynamical friction neglected)

Probably Group at first passage
(large impact parameter, 50% still gas retained)

Reconstructing the orbit with hydro-simulations

E. Roediger et al. (in prep.)





Work in Progress

Hydro-dynamical simulations (E. Roediger et al., in prep.)

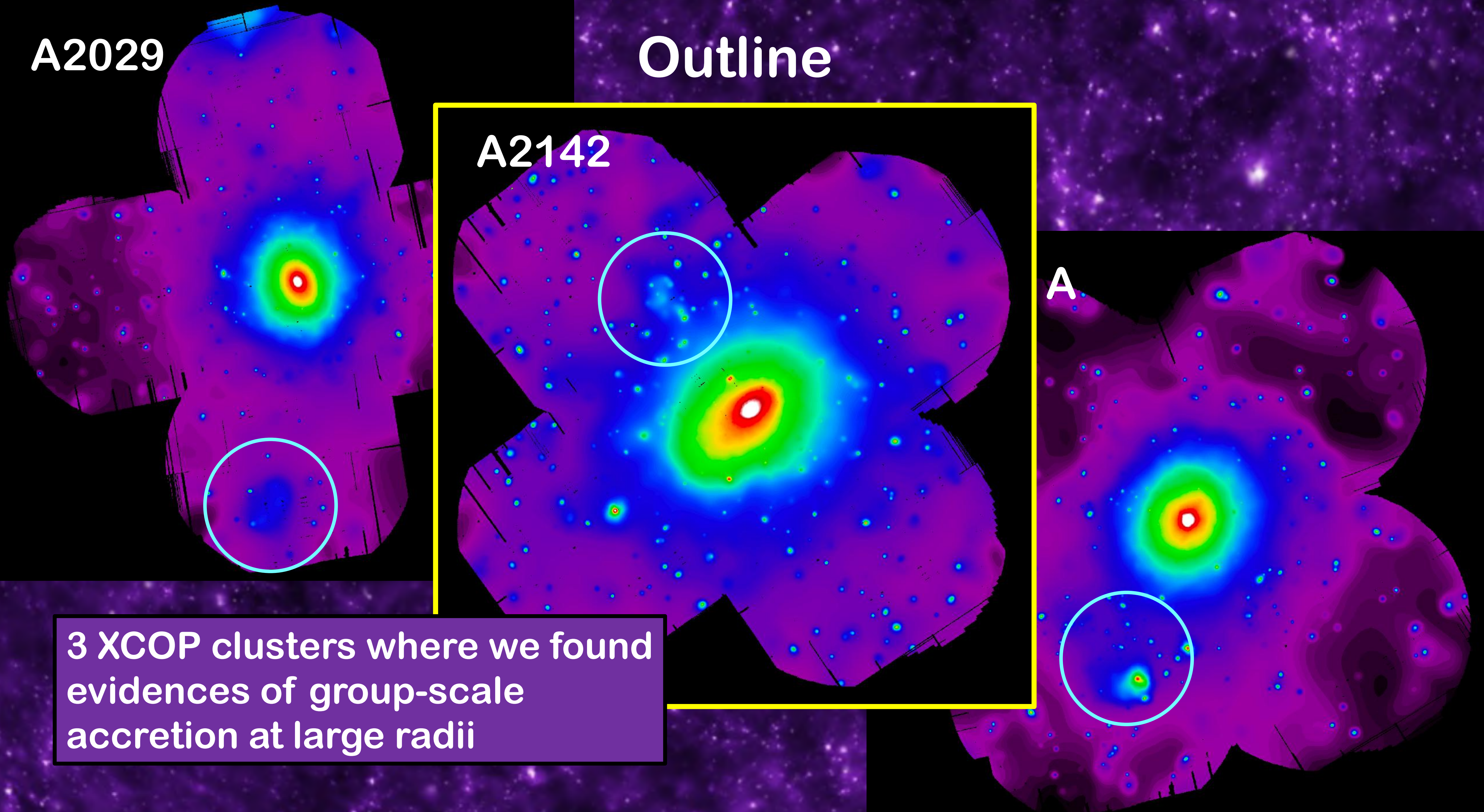
+

200 ks Chandra obs of LEDA (PI De Grandi, first 100ks obs Feb17)

+

DOLORES-TNG/VIMOS-VLT spectroscopy of galaxies (PI Girardi, in prep.)

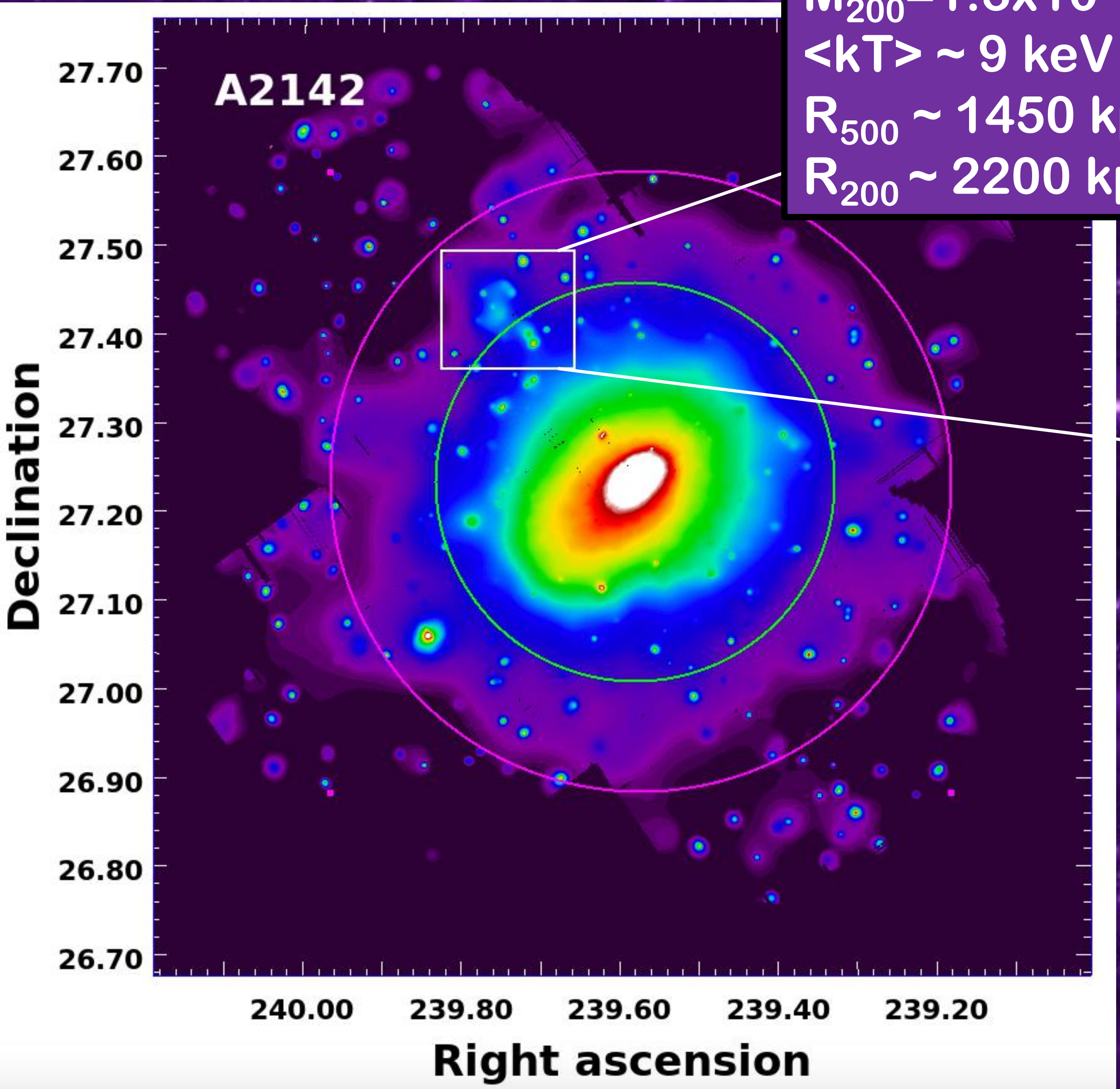
Outline



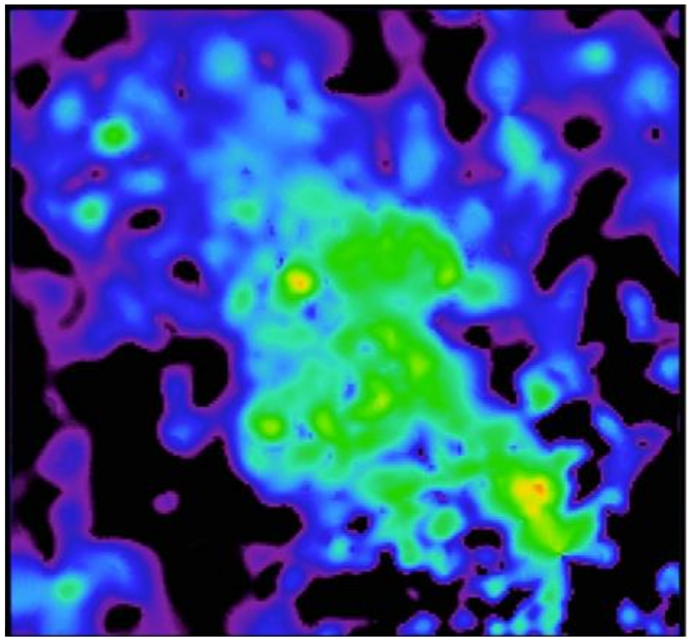
3 XCOP clusters where we found evidences of group-scale accretion at large radii

Accreting group in A2142

XMM (250 ks)



A2142 is @ z=0.09
M_{200}=1.3x10^{15} $M_{\odot}$ (Munari+14)
<kT> ~ 9 keV (De Grandi+02)
R_{500} ~ 1450 kpc (green)
R_{200} ~ 2200 kpc (magenta)

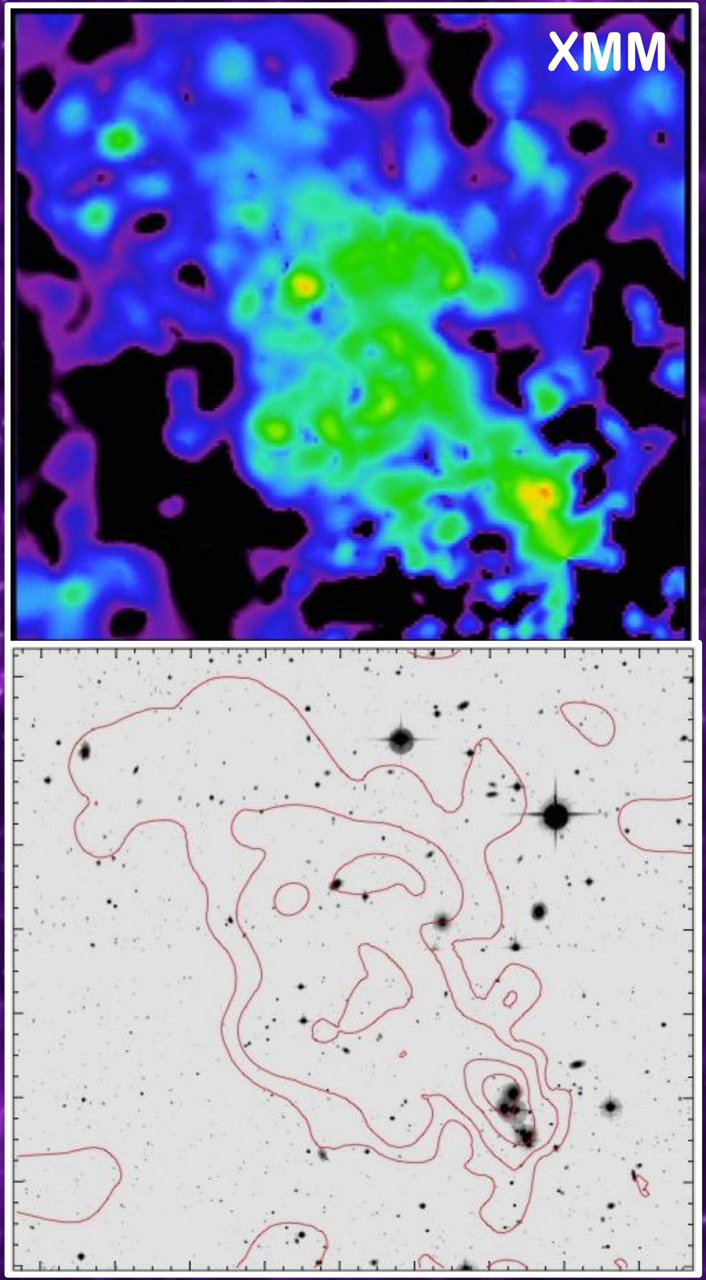


We discovered a group with irregular, elongated morphology moving radially towards the cluster center @ 1.5 Mpc.
(Eckert et al. 2014)

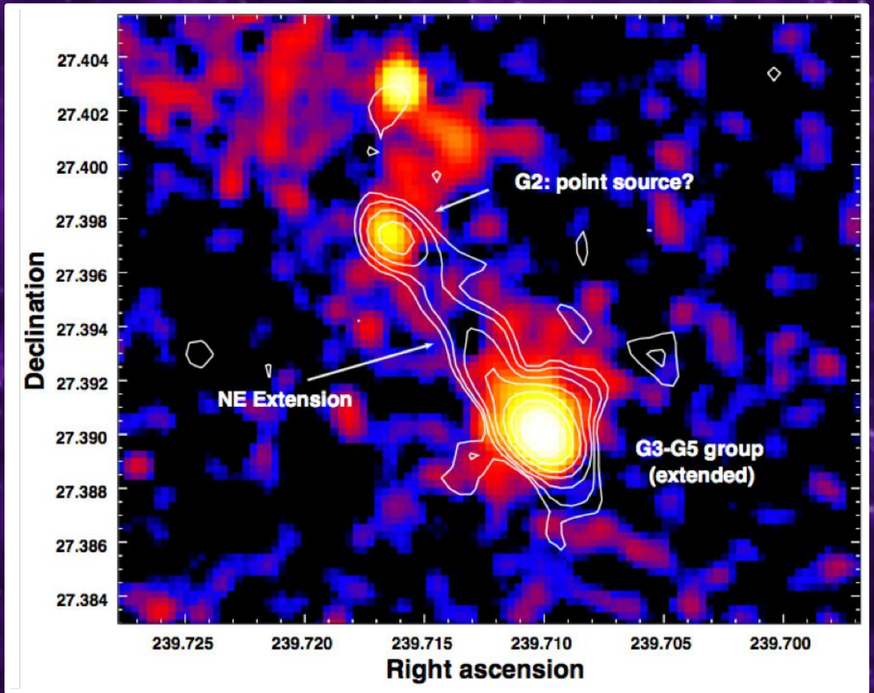
- The tip is associated with a galaxy group (at least 5 with z_{spec} confirmed members).
- The bulk of the gas is lagging behind the tip in the long fainter tail
- The tail is the most extended observed so far ~ 800 kpc

Disruption of an in-falling group onto A2142

- The emission behind the group (tail) comes from the intra-group gas that has been stripped by the ram-pressure of the ambient ICM
- The tip of the emission is the remaining unperturbed gas lying at the center of the group.

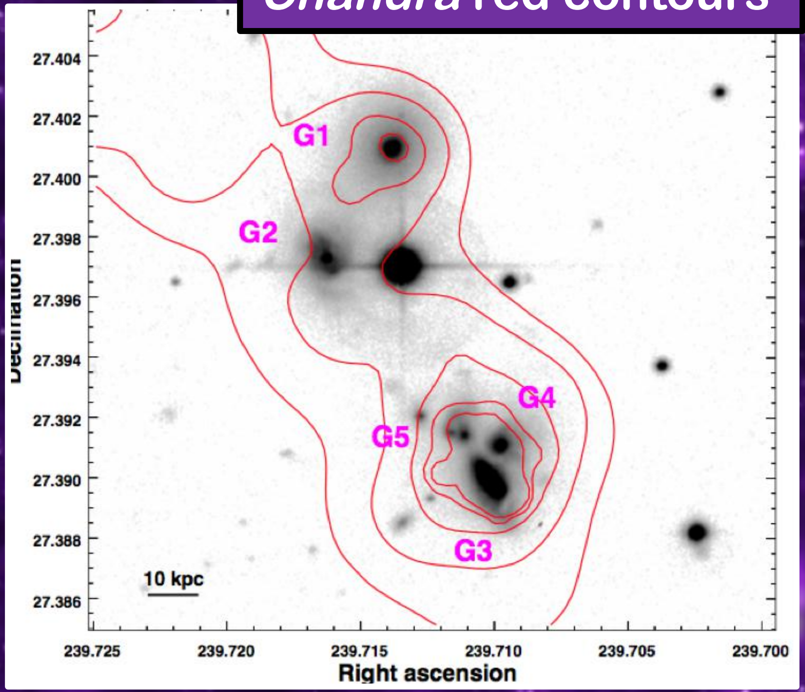


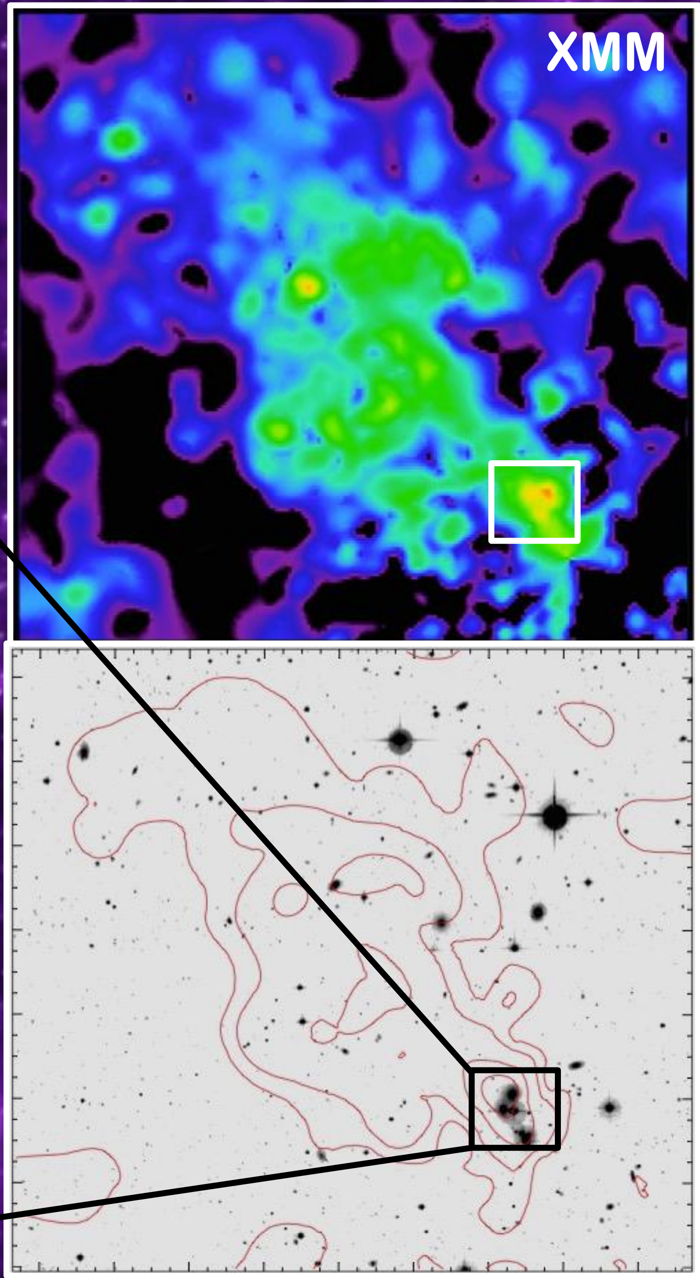
Chandra data - Eckert et al. 2017



GMRT radio contours at 610 MHz overlayed (Venturi et al. subm.) on *Chandra*

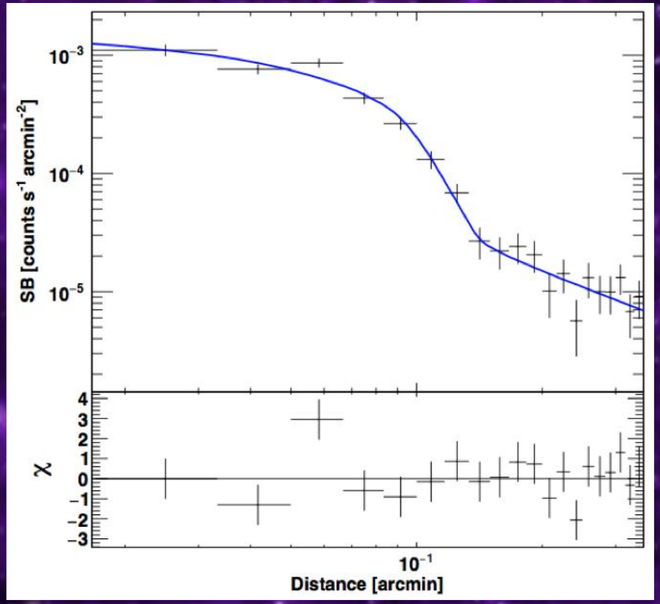
CFHT *g*-band image of the region with *Chandra* red contours



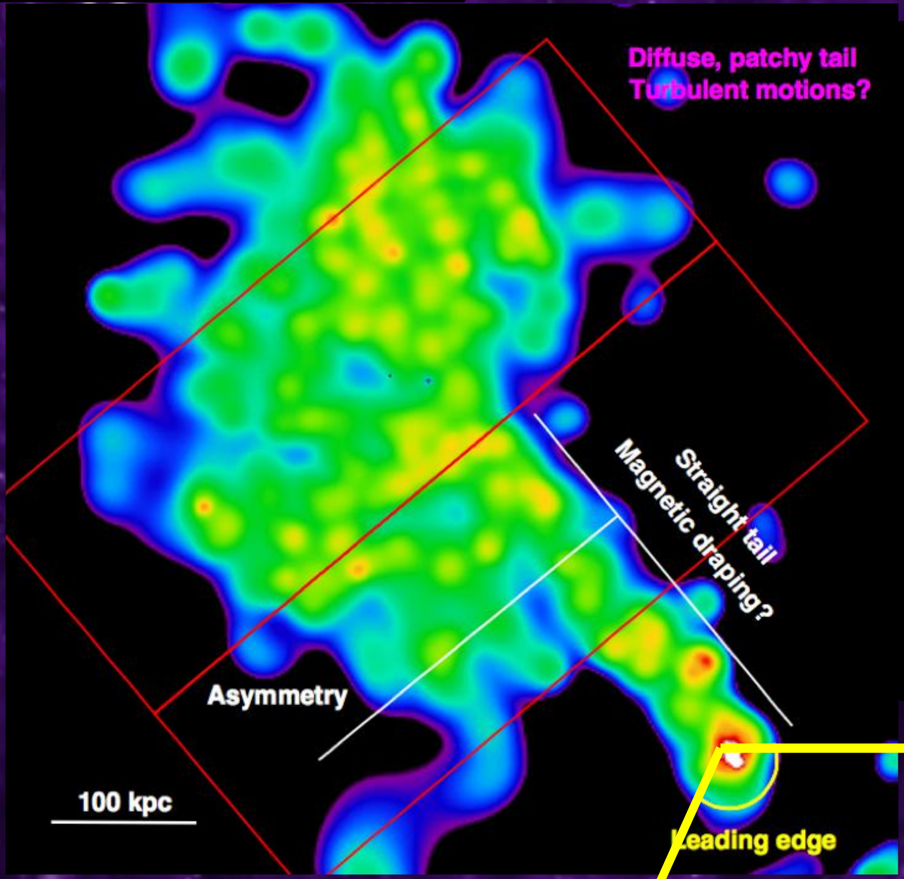


Complex structure of the tip:
G3-G5 brightest X-ray structure with extended radio emission (NE head-tail morphology) consistent with group moving toward SW

200 ks Chandra data Eckert et al. 2017

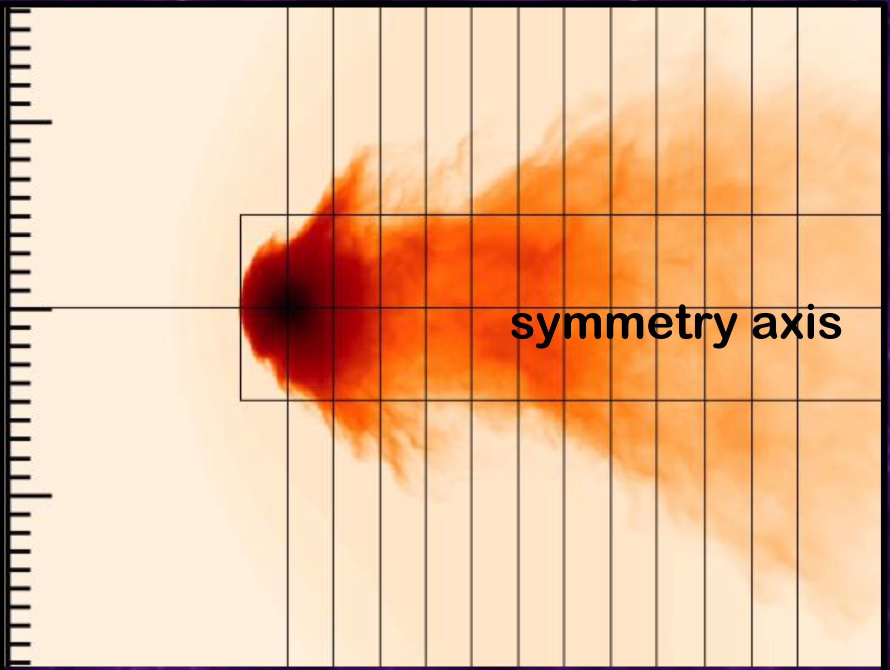


Density jump at the tip (leading edge) indicates a Cold Front



Chandra SB map shows complex geometry:

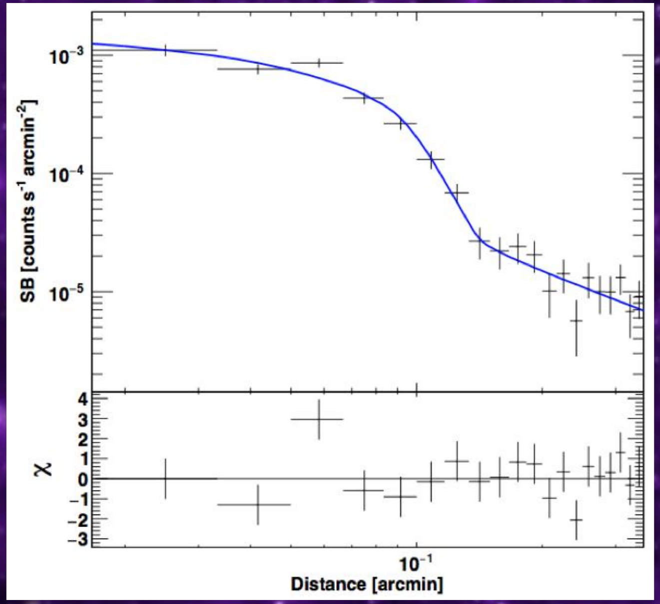
- straight narrow tail (~250 kpc)
- asymmetric, patchy region

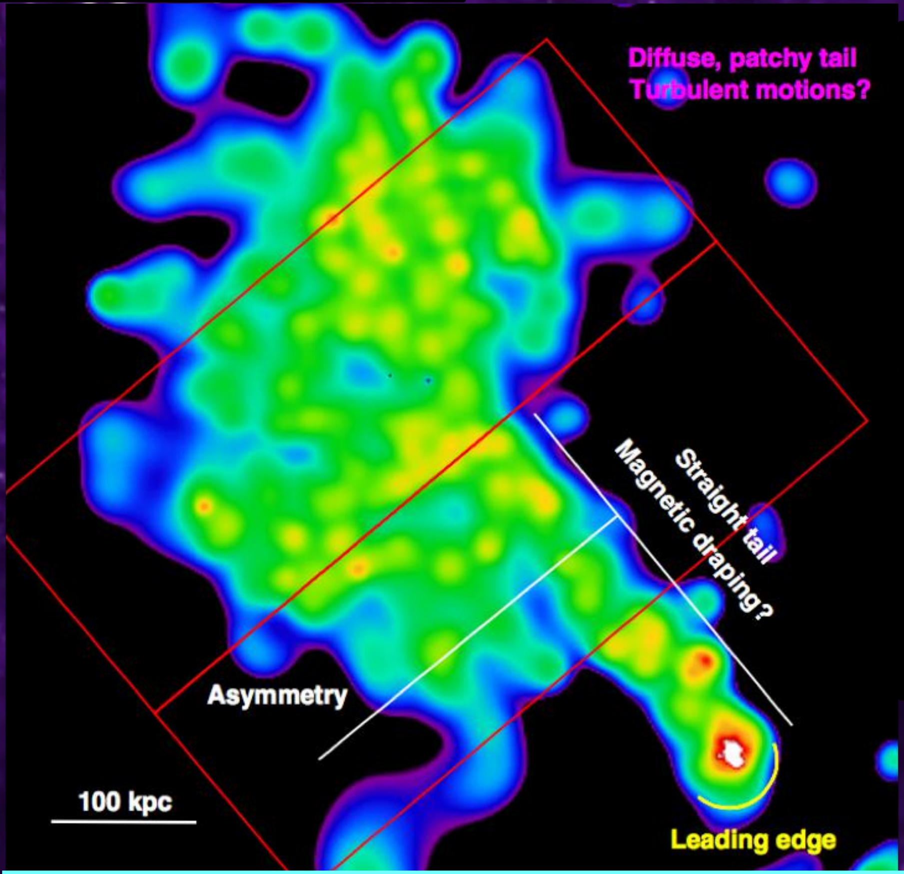


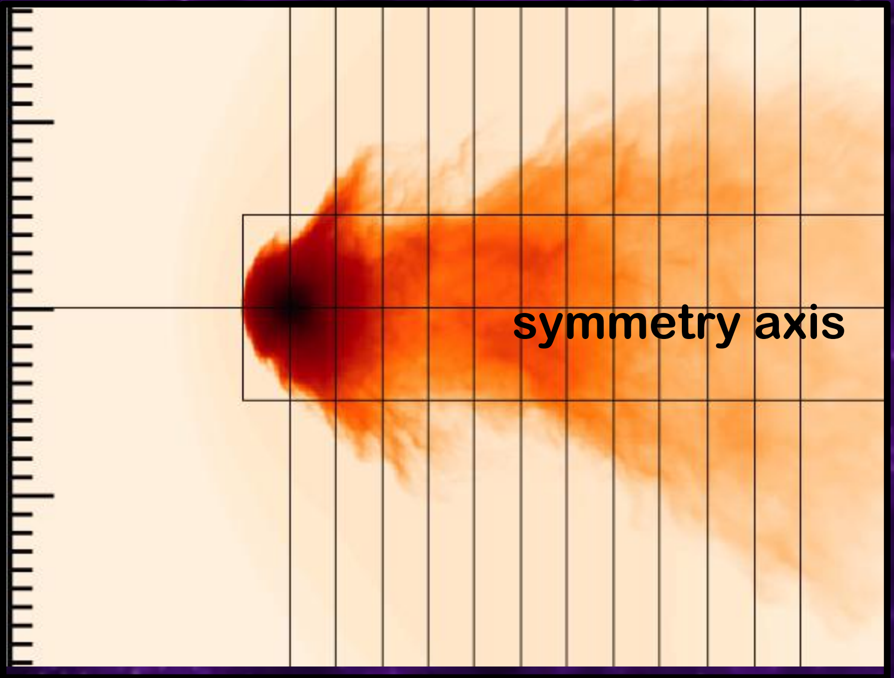
Disturbance in the gas distribution of the group can be either due to:

- gas sloshing in the group or
- expanding AGN outflows (e.g. Roediger in prep)

200 ks Chandra data Eckert et al. 2017







Density jump at the tip (leading edge) indicates a Cold Front

Chandra measurements are consistent with a mild level of turbulence in the stripped gas with a Mach number in the range 0.1-0.25.

- The galaxy group is moving radially at infall velocity $v_{group} \sim 1200$ km/s

- The gas is significantly cooler (~1-2 keV) than the ambient ICM (~5 keV, Tchernin+16), typical of a group with $M_{tot} \sim$ a few 10^{13} $M_\odot$

- Comparing the gas mass in the tail with total gas mass of the group we find that

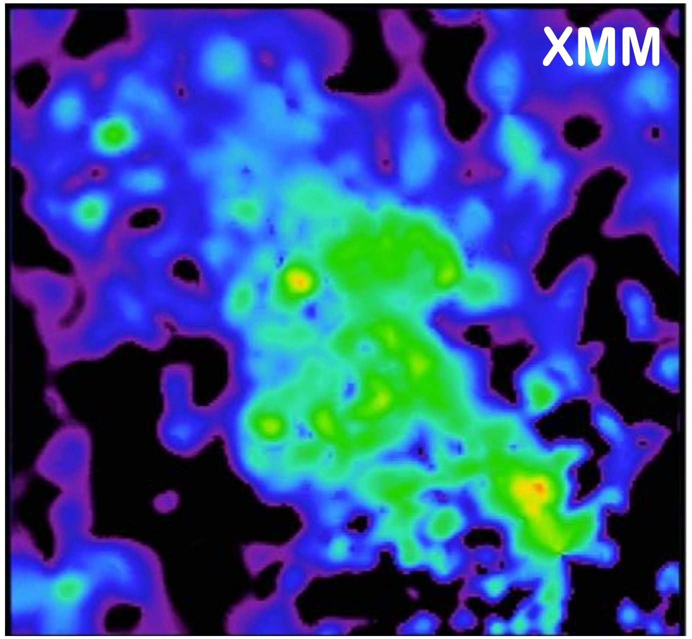
$$M_{gas,tail} \sim 90\% \ M_{gas,group}$$

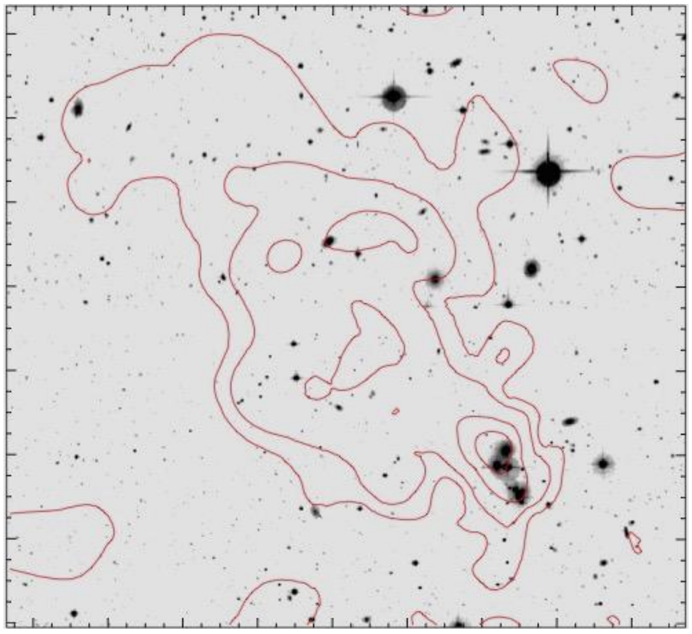
This group is in an advanced state of disruption

- We find that

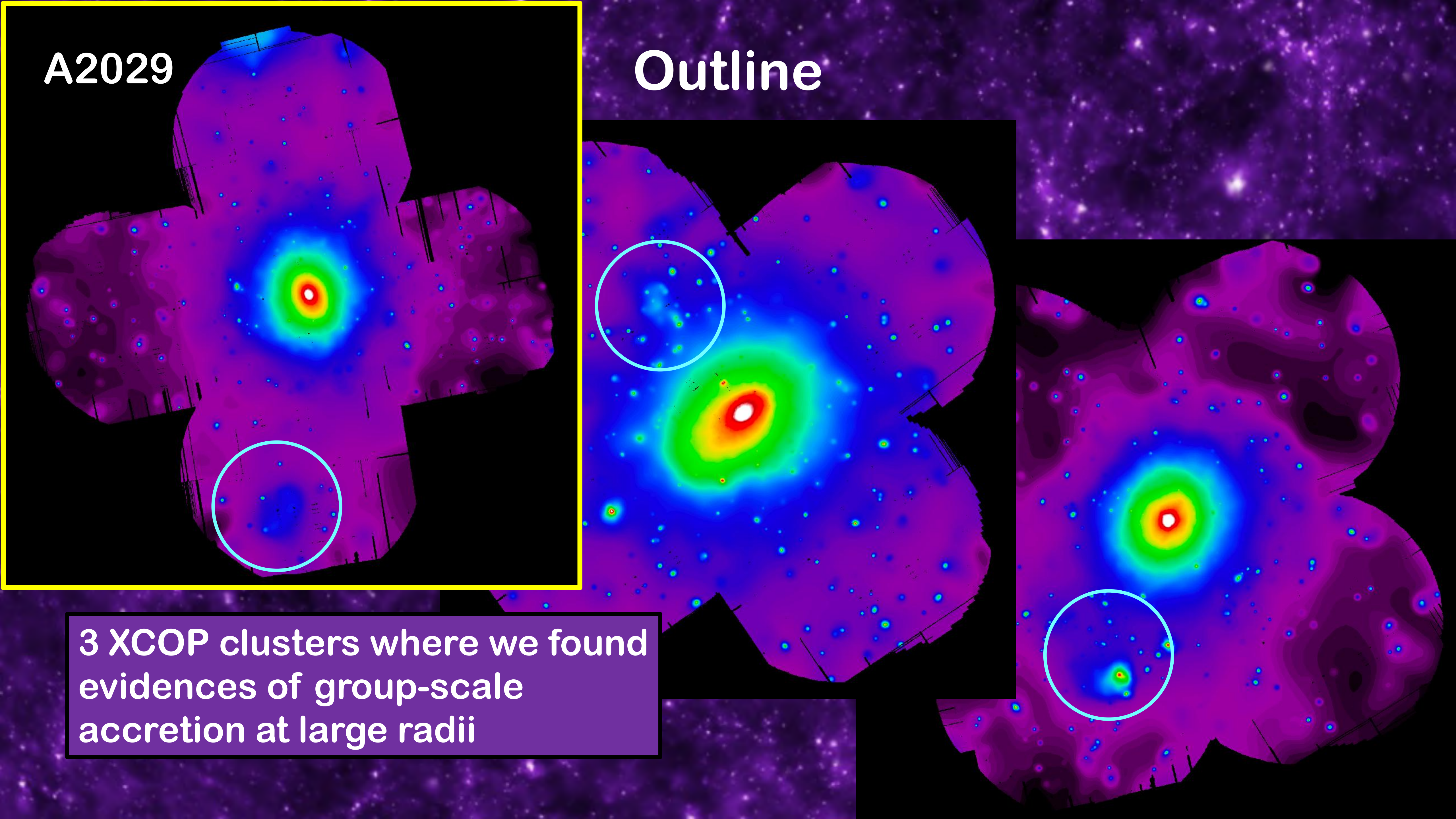
$$t_{age\ tail}/t_{cond} \geq 400$$

Thermal conduction in the ICM is strongly suppressed





Outline

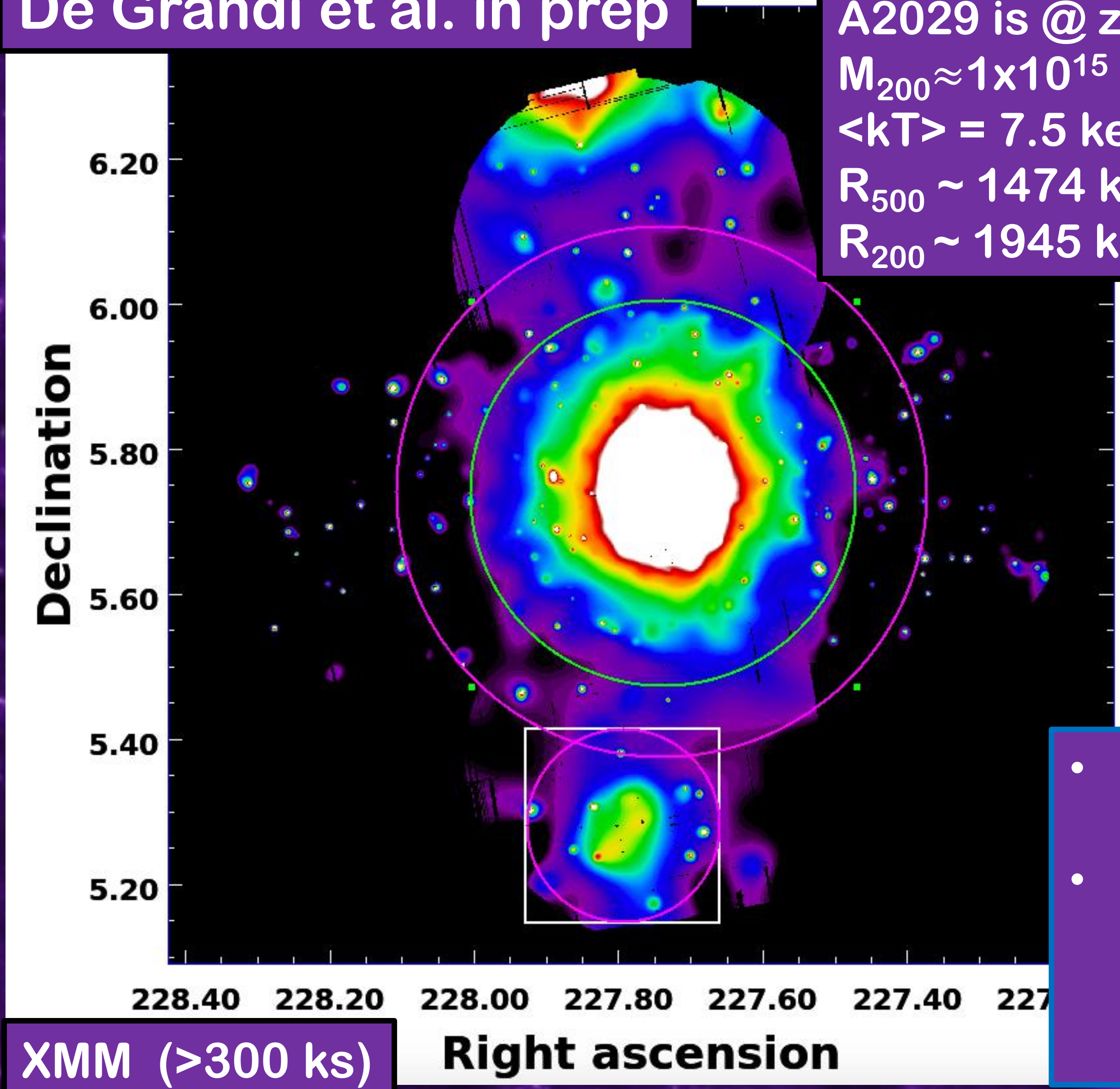


3 XCOP clusters where we found evidences of group-scale accretion at large radii

Accreting group in A2029

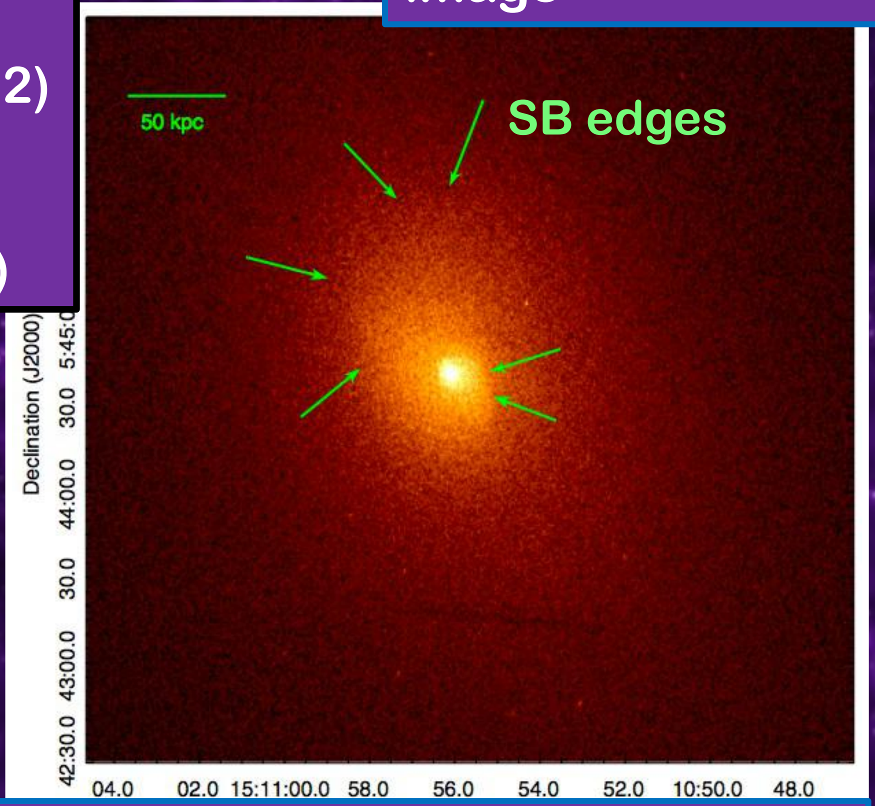
De Grandi et al. in prep

A2029 is @ z=0.077
$M_{200} \approx 1 \times 10^{15}\ M_\odot$ (Walker+12)
<kT> = 7.5 keV
R_{500} ~ 1474 kpc (green)
R_{200} ~ 1945 kpc (magenta)



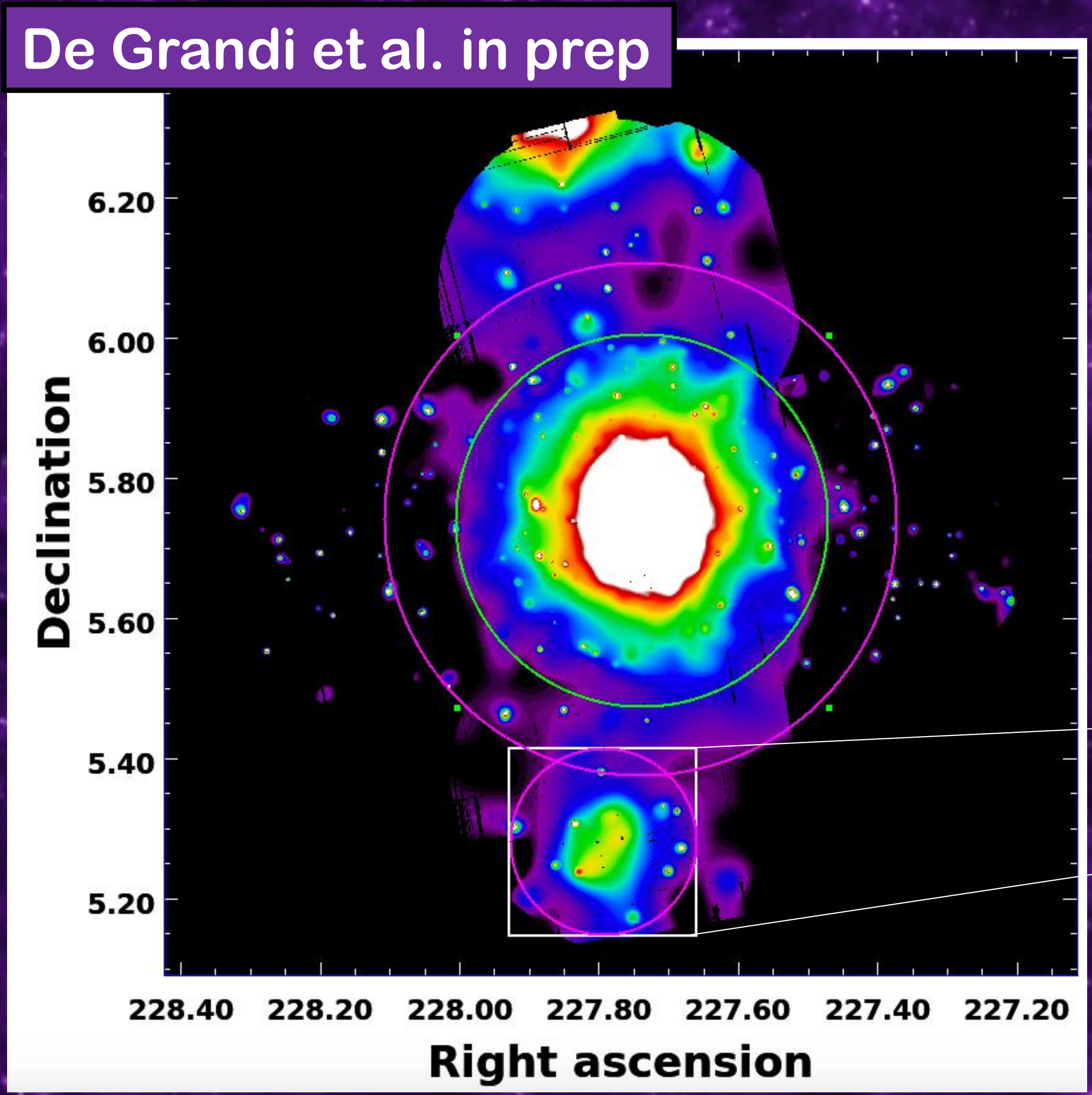
XMM (>300 ks)

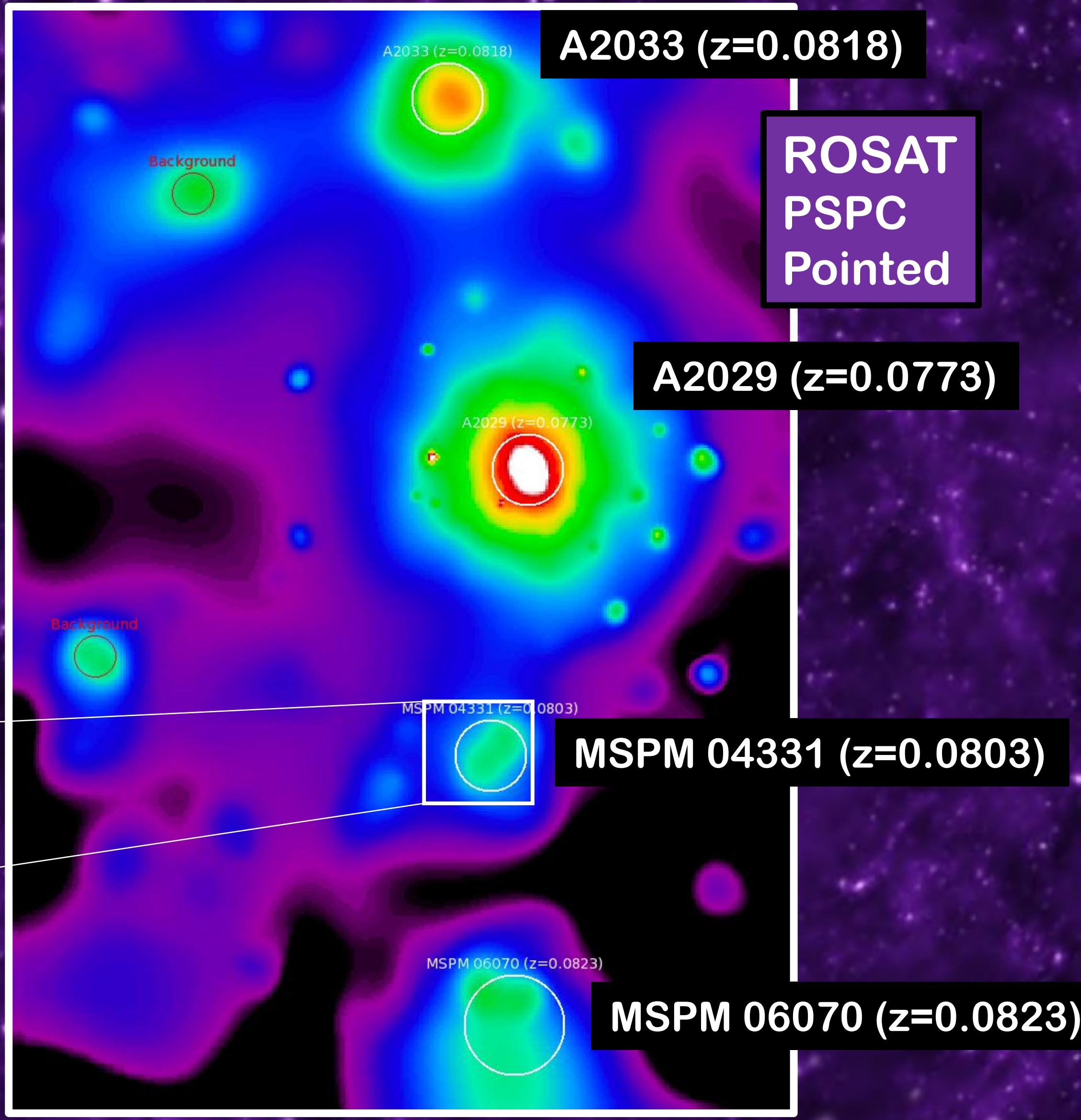
Chandra SB image



- *Chandra* data show a sloshing spiral extending from the cluster core outward to ~400 kpc
- Gas sloshing occurs in cool core clusters that have been disturbed by an off-axis merger with a sub-cluster or group (Paterno-Mahler et al. 2013)

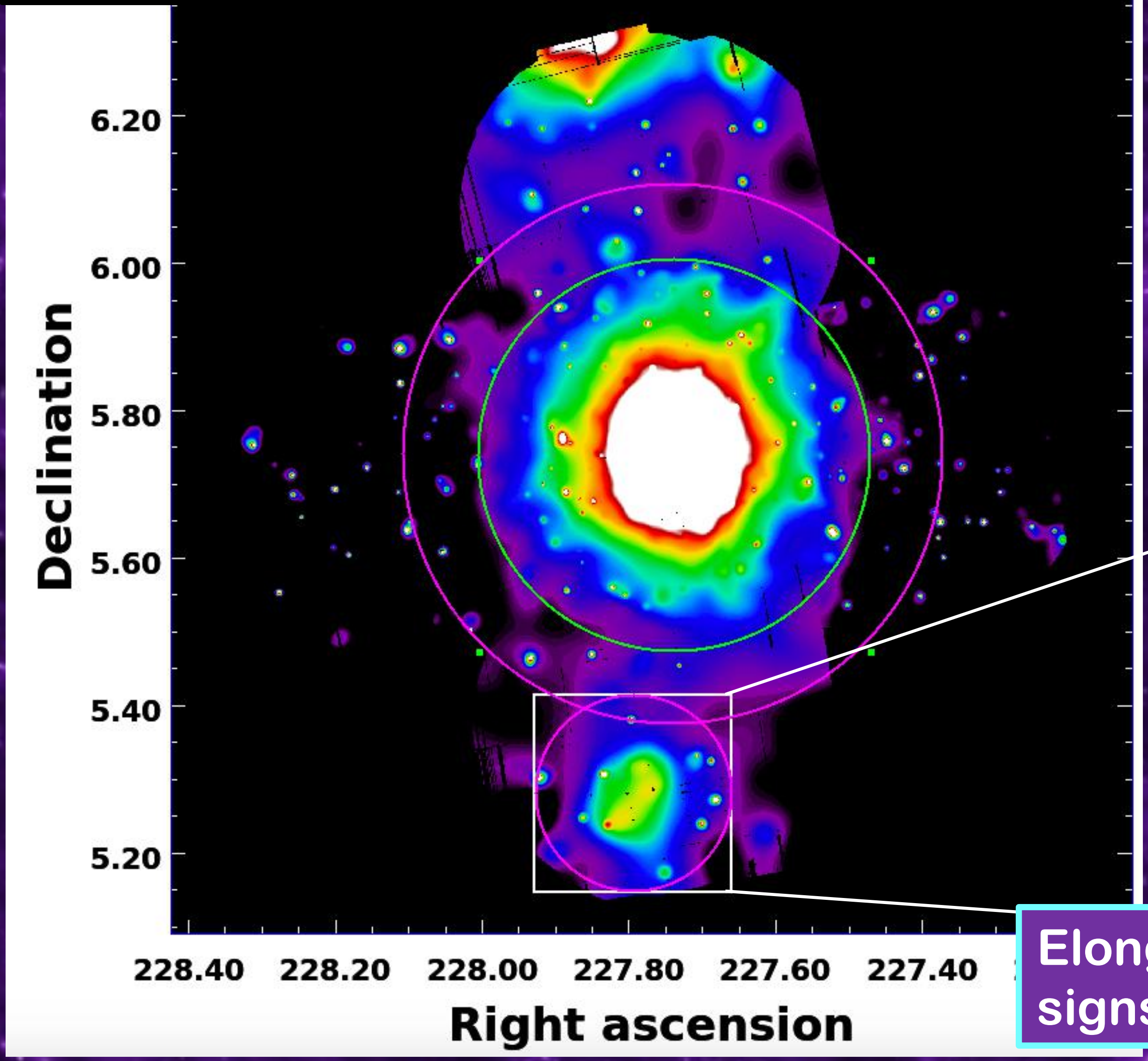
Accreting group in A2029

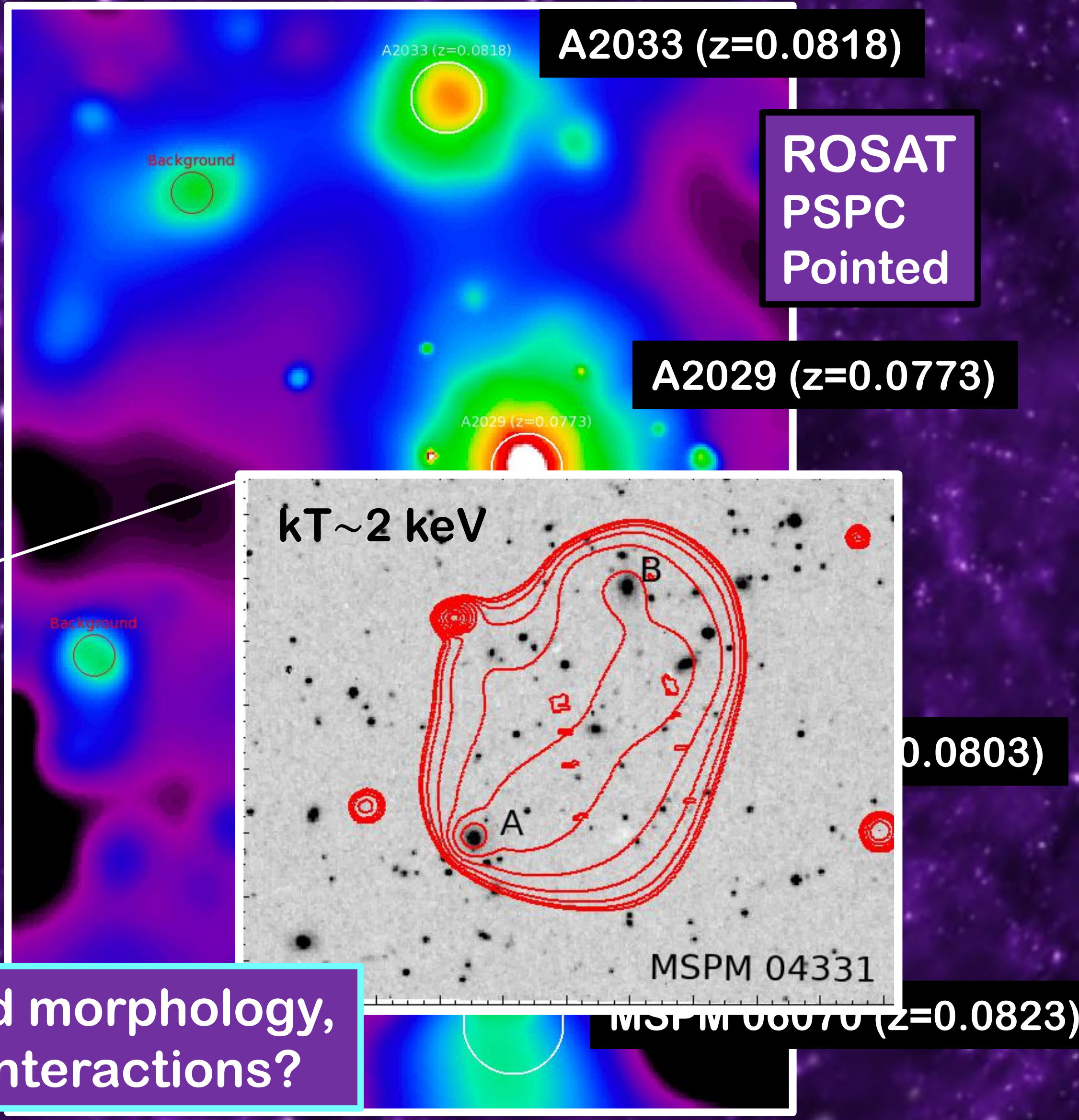




Accreting group in A2029

De Grandi et al. in prep

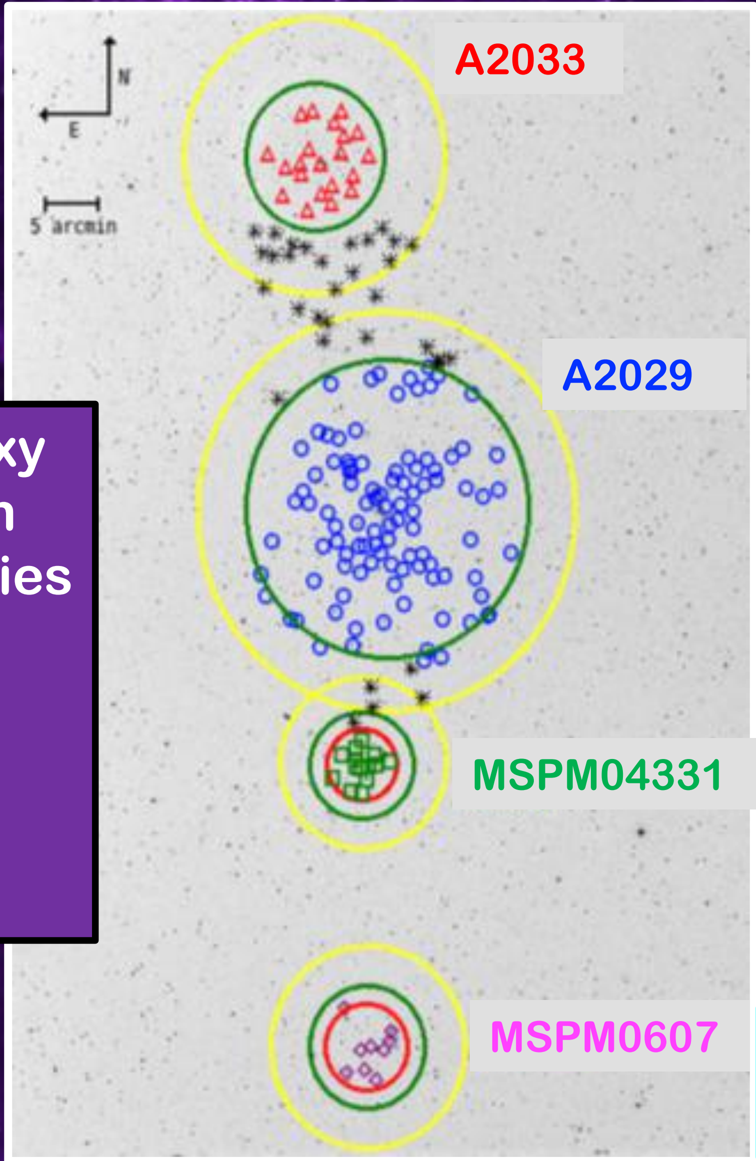




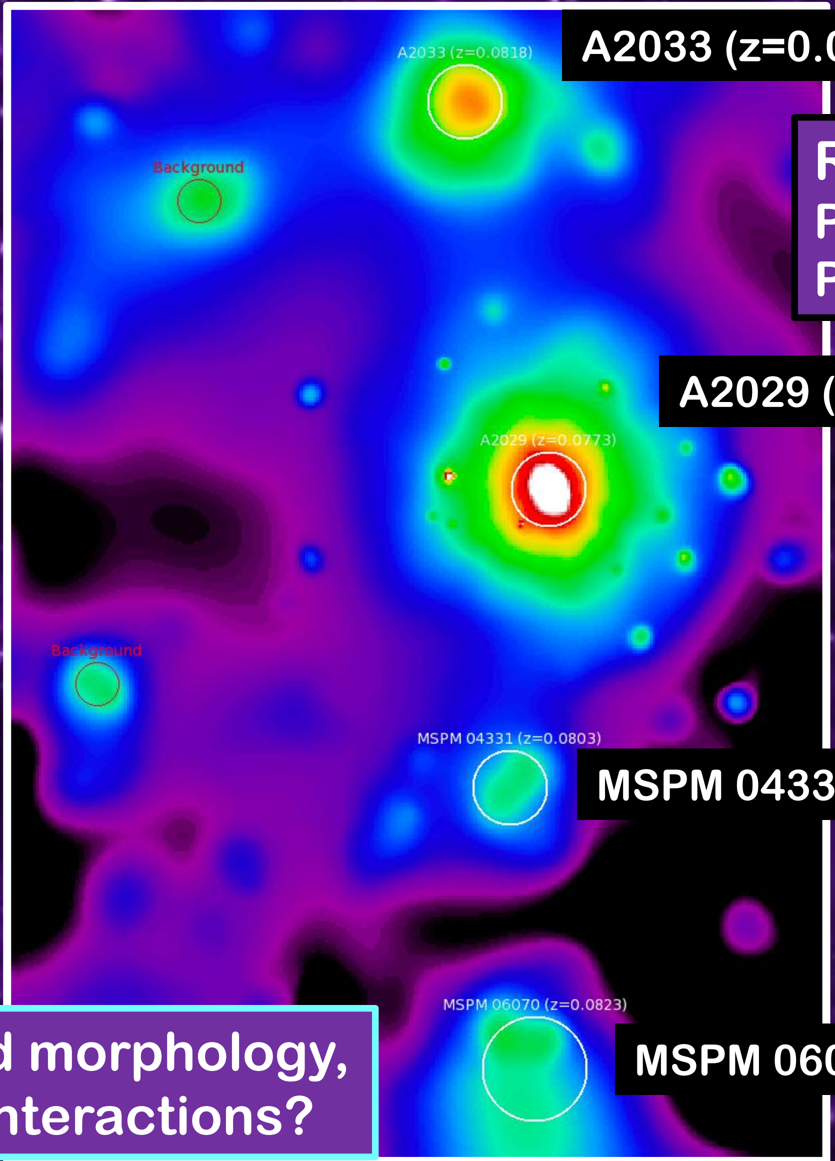
Elongated morphology, signs of interactions?

SDSS galaxy distribution (only galaxies with z_{spec})

R1500
R500
R200



ROSAT PSPC Pointed



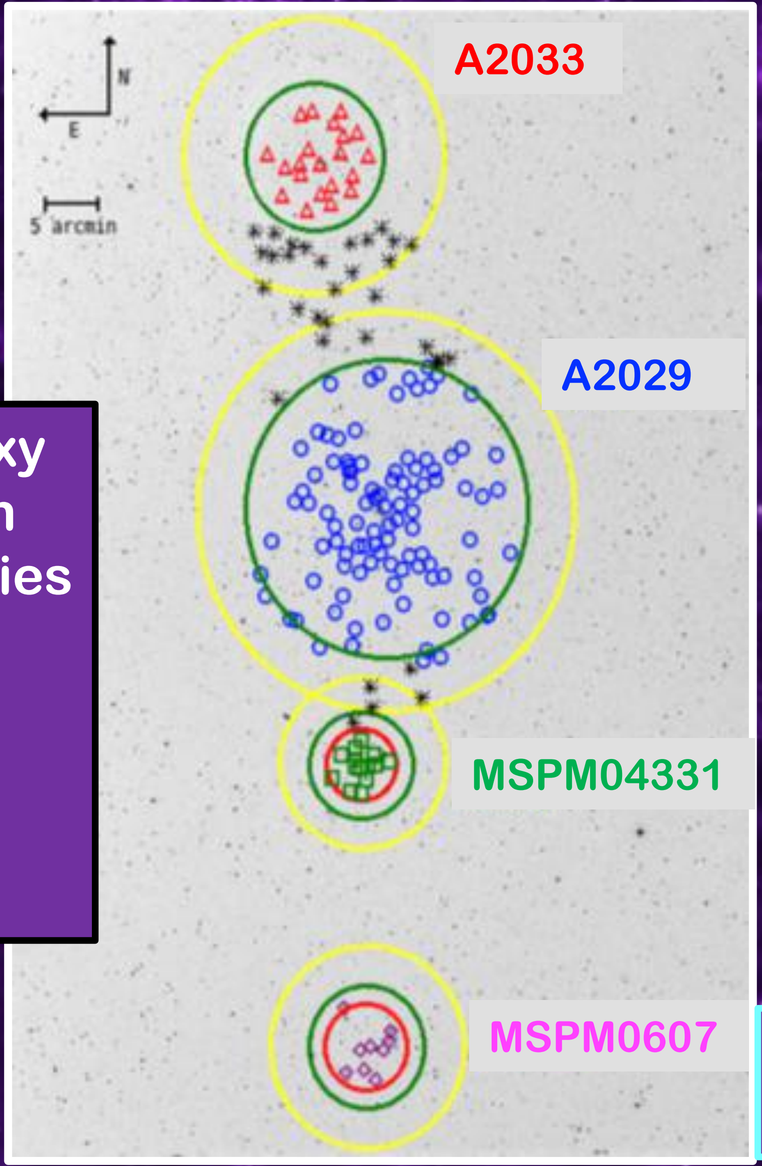
Elongated morphology, signs of interactions?

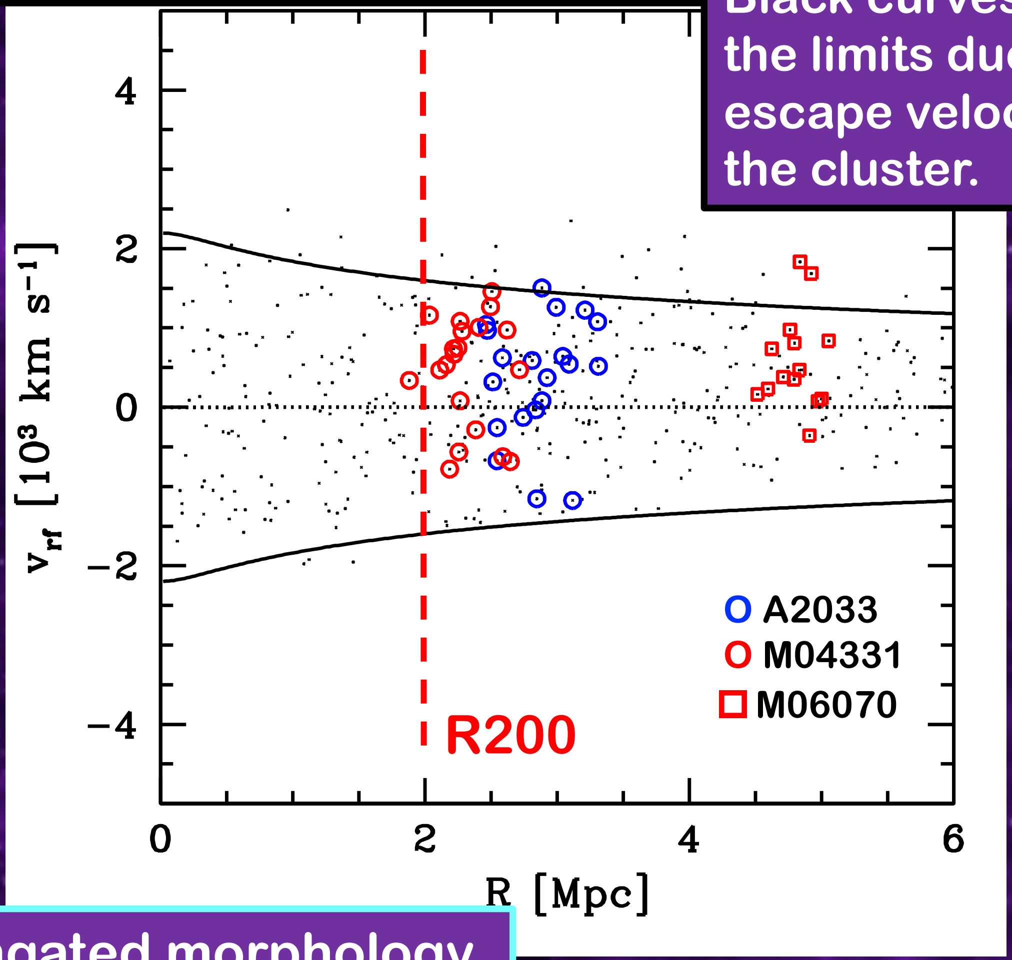
Rest-frame LOS velocity vs. projected distance from the center of A2029 of the spectroscopic 685 members of the cluster complex.

Black curves show the limits due to the escape velocity in the cluster.

SDSS galaxy distribution (only galaxies with z_{spec})

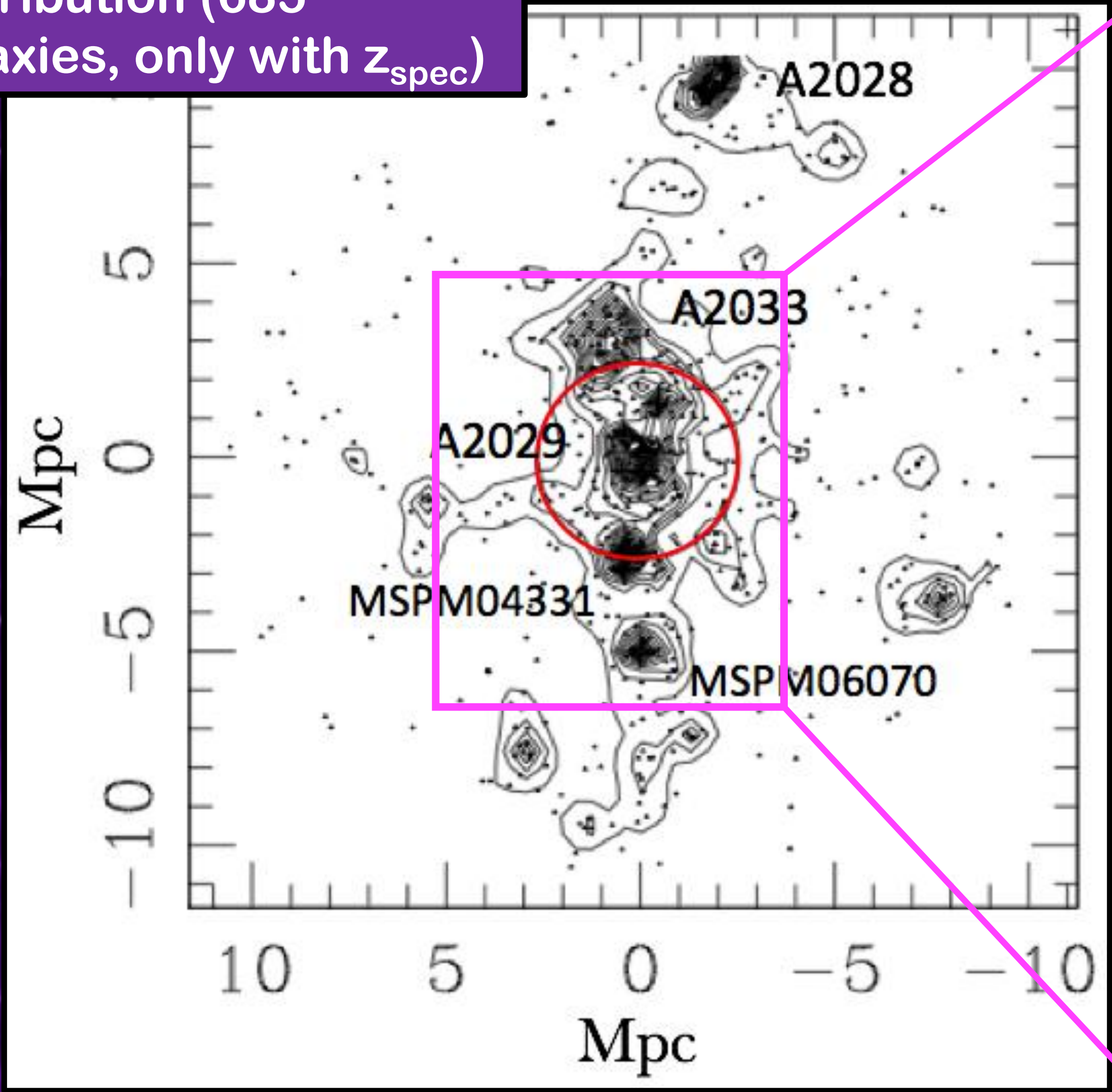
R1500
R500
R200

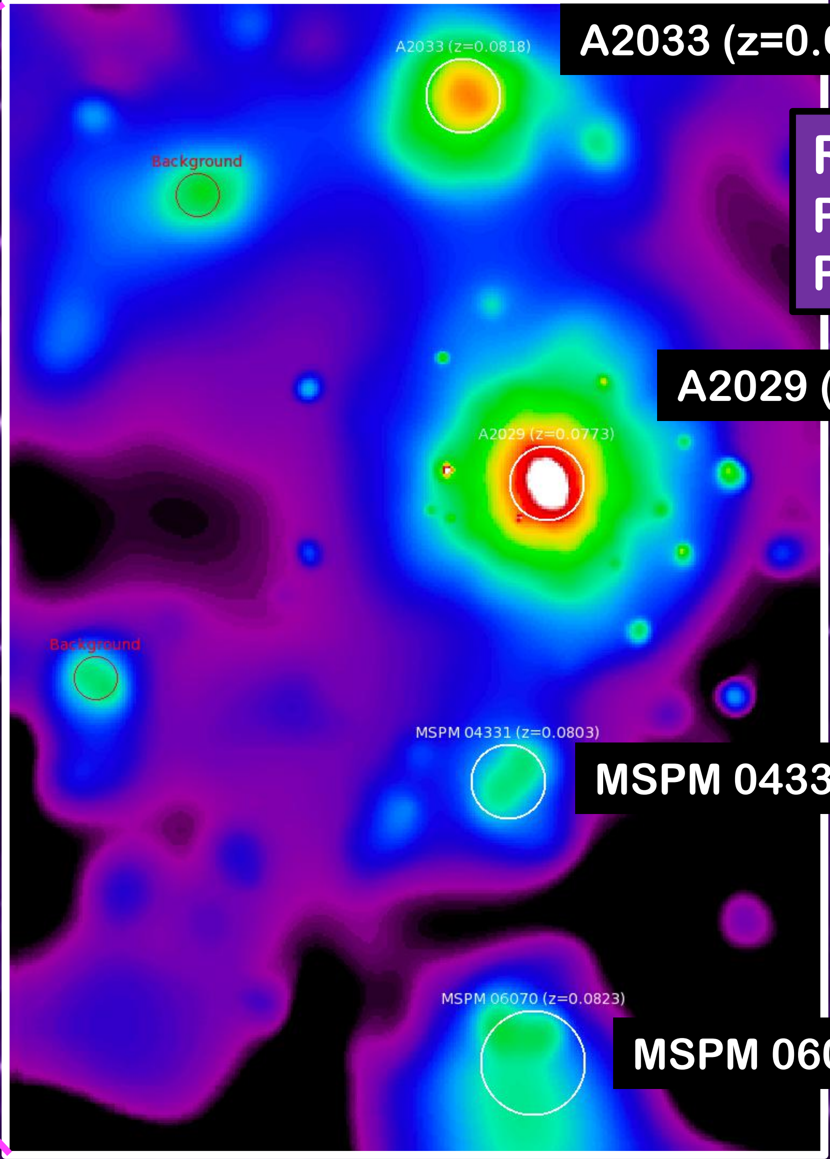




Elongated morphology, signs of interactions?

SDSS galaxy density distribution (685 galaxies, only with z_{spec})





ROSAT PSPC Pointed

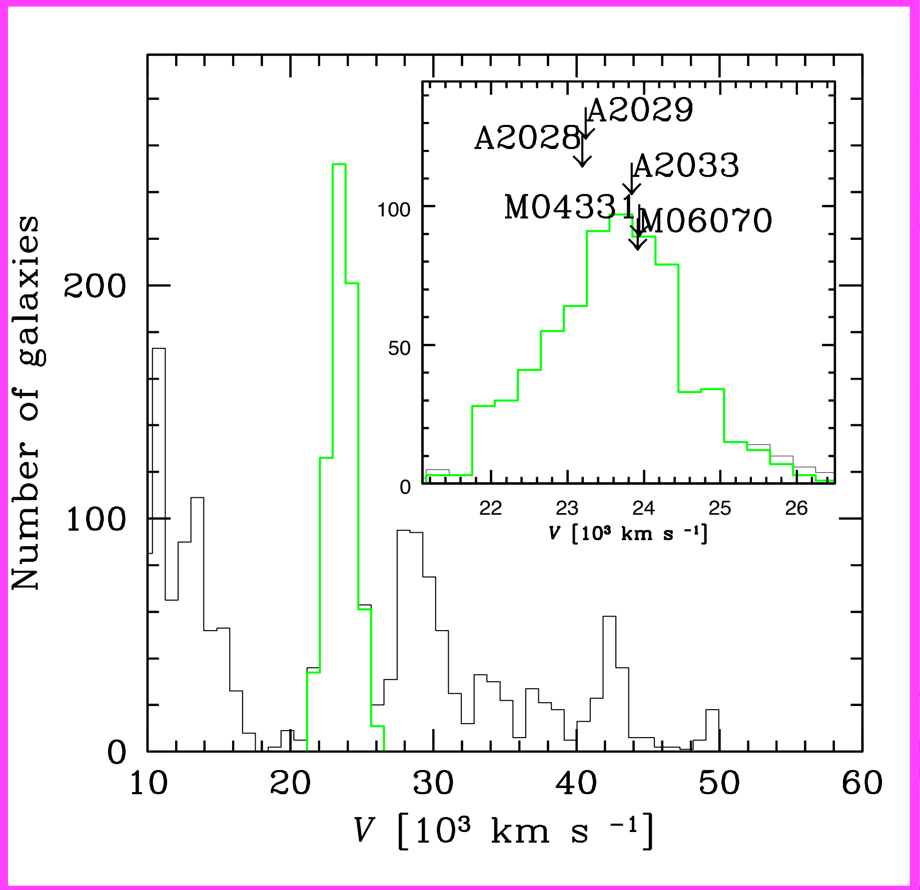
A2033 (z=0.0818)

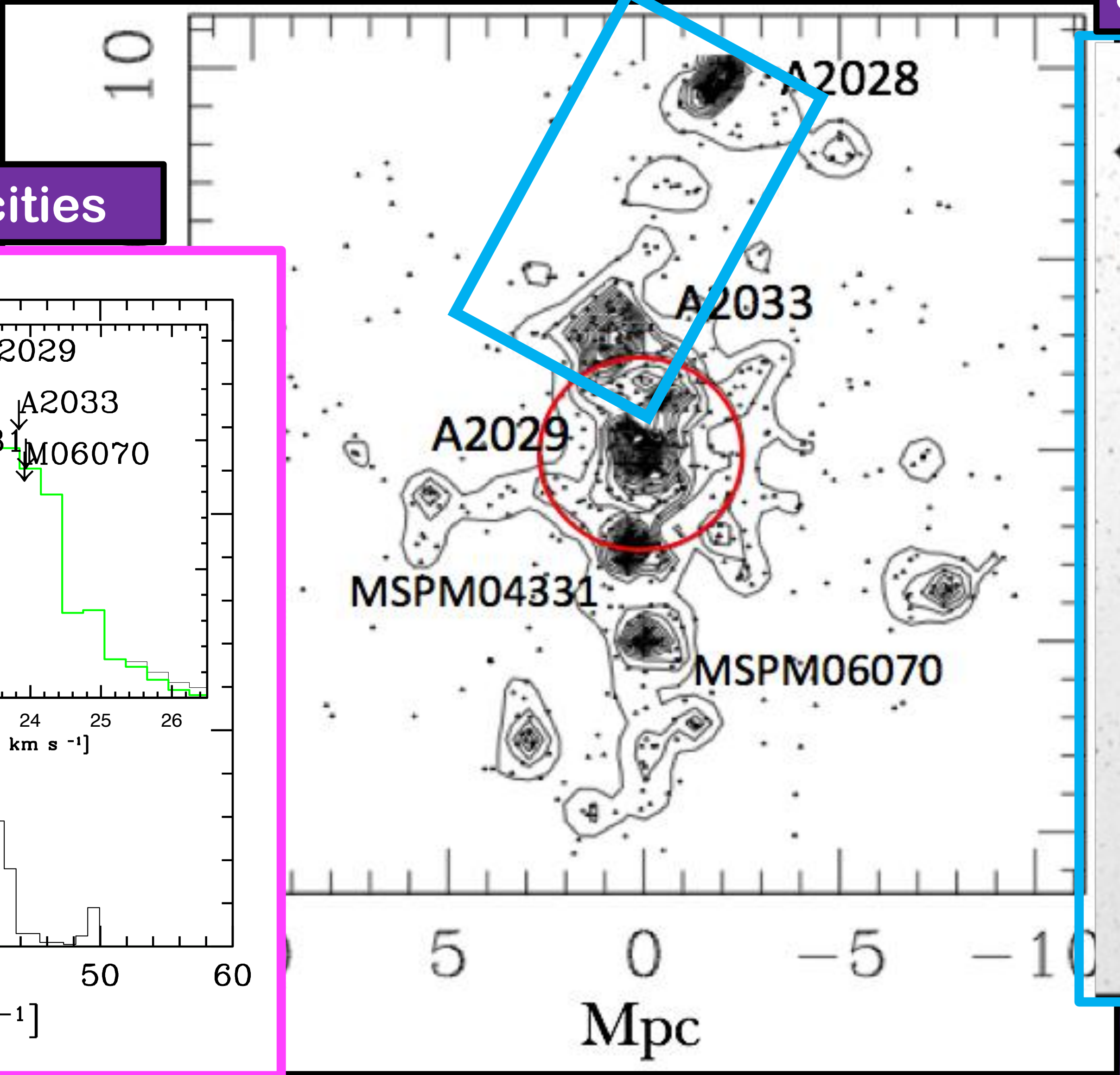
A2029 (z=0.0773)

MSPM 04331 (z=0.0803)

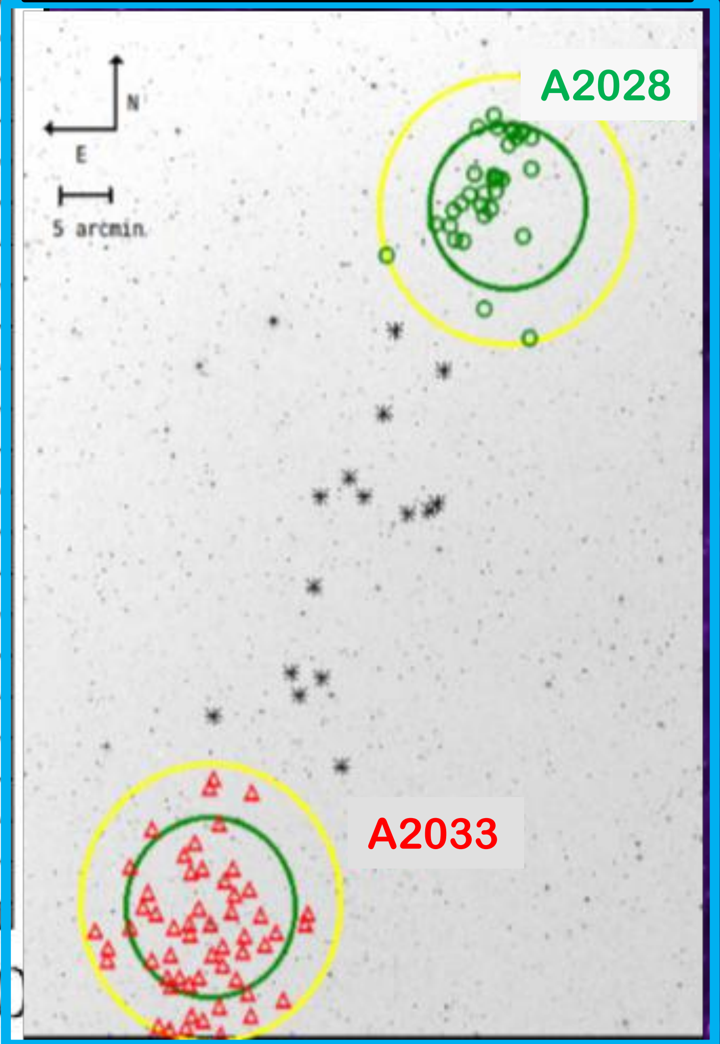
MSPM 06070 (z=0.0823)

SDSS galaxy LOS velocities





SDSS galaxies with z_{spec}

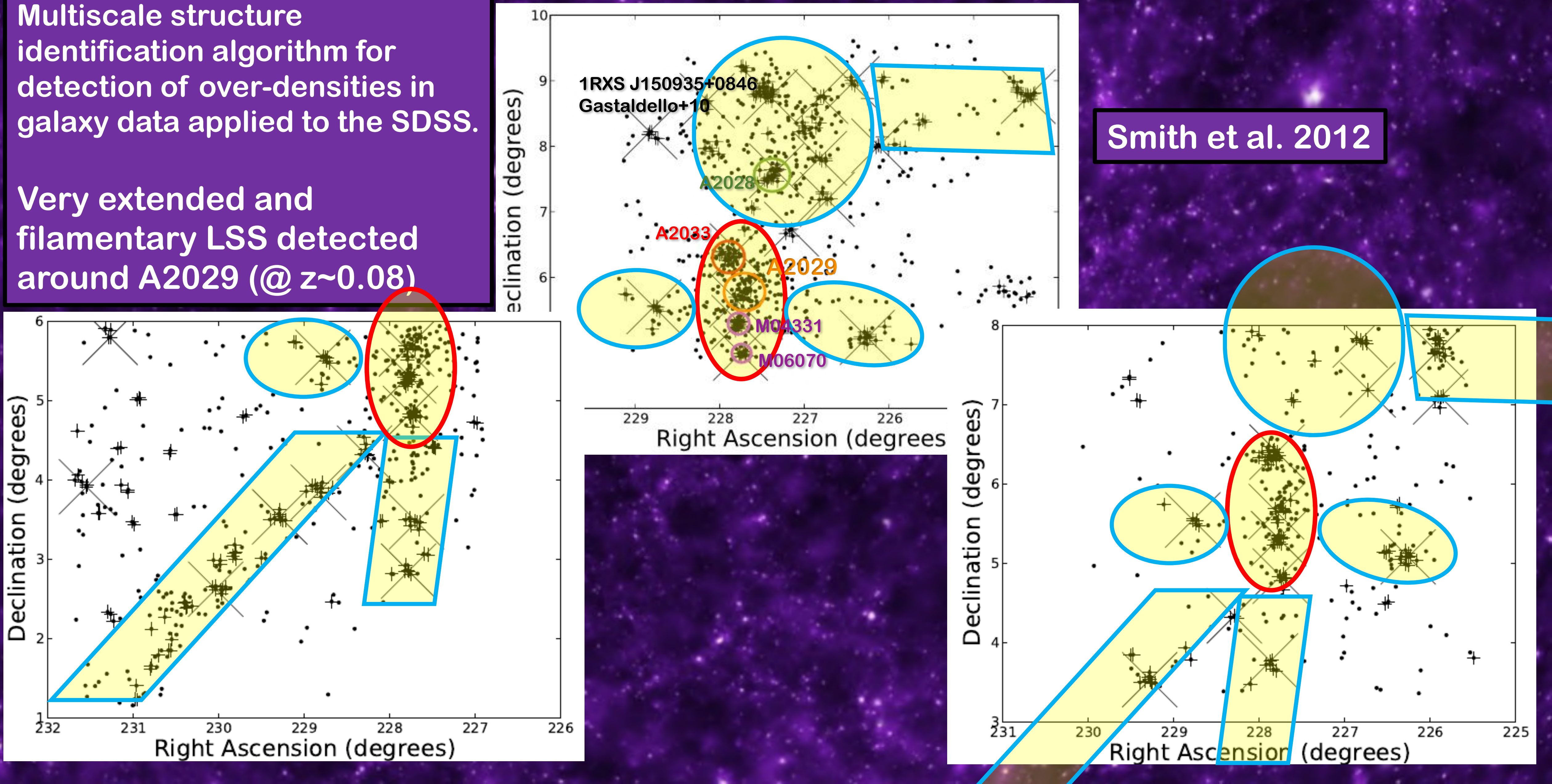


The A2029 Supercluster

Multiscale structure identification algorithm for detection of over-densities in galaxy data applied to the SDSS.

Very extended and filamentary LSS detected around A2029 (@ z~0.08)

Smith et al. 2012



Summary

- We found spectacular evidences of accreting structures in the outskirts of A2142 and Hydra A (A2029 in prep).
- The X-ray structures are associated with infalling galaxy groups with M_{tot} of a few 10^{13} $M_\odot$
- The X-ray gas trails behind the core of the structures because of ram-pressure stripping over ~ Mpc scales
- Ram-pressure stripping is efficient already at large distance from the cluster core
- The long survival of the tails brings direct evidence that thermal conduction is strongly suppressed at these radii
- Group-size accretion is a frequent phenomenon (3/13, but we have other candidates, work in progress)
- Stay tuned! More is coming soon from a statistical analysis of the accretion at large radii from the whole X-COP sample.