Evolution of groups and clusters of galaxies with Athena

E. Pointecouteau, S. Allen, N. Ota
on behalf of the Athena SWG-1.1
How does ordinary matter assemble into the large scale structures we see today?

- A hierarchical process, gravitation driven
- Evolution though constant accretion and mergers
- Groups and clusters are the last to form
- Mass of halos: 85% DM, 12% gas, 3% galaxies

➡ Laboratories to test the physics of structure formation (from dark matter and baryons)
Formation of groups and clusters and baryons physics

- Gas dynamics: Markevich & Viklinnin 2007
- AGN feedback: McNamara & Nulsen 2012
- Chemical enrichment: @ NASA
Athena Key questions

How do the mechanisms that govern the physics of hot gas impact the process of the formation and evolution of large scale structures?

— What is the interplay of galaxy, SMBH and the intergalactic medium in groups and clusters of galaxies?

— What are the processes driving the chemical enrichment of the Universe at large scales?

— How and when did form the first galaxy groups binding a hot gaseous atmosphere?
**Evolution of cosmic feedback in clusters and groups**

How and when was the energy contained in the hot intra-cluster medium generated?

Reichert et al. 2011

Hlavacek-Larrondo et al. 2015
Evolution of cosmic feedback in clusters and groups

How and when was the energy contained in the hot intra-cluster medium generated?

Courtesy of B. Maughan
(in Pointecouteau, Reiprich et al., 2013)
Evolution of cosmic feedback in clusters and groups

How and when was the energy contained in the hot intra-cluster medium generated?

EXCPRESS collaboration
(in Planck Collaboration, PEP-IX, 2011)

McDonald et al., 2014
**Athena Simulation**

**Evolution of cosmic feedback in clusters and groups**

How and when was the energy contained in the hot intra-cluster medium generated?

**Entropy profile**
- Pure gravitation
- With AGN and supernova heating

**Courtesy of H. Bourdin, H, Rasia, P. Mazzotta**

(in Pointecouteau, Reiprich et al., 2013)
Evolution of cosmic feedback in clusters and groups

How and when was the energy contained in the hot intra-cluster medium generated?

Athena Simulation

Entropy profile

Pure gravitation

With AGN and supernova heating

z = 2

M = 5 \times 10^{13} M_{\odot}

Courtesy of H. Bourdin, H. Rasia, P. Mazzotta (in Pointecouteau, Reiprich et al., 2013)
Chemical enrichment of the intra-cluster medium

When and how were the largest baryon reservoirs in galaxy clusters chemically enriched?

Iron abundance measurements

Ettori et al. 2015
**Chemical enrichment of the intra-cluster medium**

When and how were the largest baryon reservoirs in galaxy clusters chemically enriched?

Astro-H/SXS 100 ksec

Athena/X-IFU 100 ksec

![Graphs showing chemical enrichment](chart1.png)

Courtesy of J. de Plaa

(in Kitayama et al. 2015)

(in Pointecouteau, Reiprich, et al. 2013)
When and how were the largest baryon reservoirs in galaxy clusters chemically enriched?
Finding the earliest galaxy groups

A few tens of spectroscopically confirmed clusters beyond z=1

X-ray selected

SZ selected

Optical/NIR selected

see also: Stanford+06; Tanaka+10; Llyods-Davies+11; Gobat+11; Mehrtens+12; Fassbender+12, Bayliss+13; Erfanianfar+13; Santos+13+14; Mantz+14, Tuckey+14; Clerc+12 +14
Finding the earliest galaxy groups

Need for a representative sample of the population of groups and clusters

- X-ray selected: e.g., eRosita
  - Borm et al., 2014

- SZ selected: e.g., SPT 3G
  - Benson et al. 2014

- Optical/NIR selected: e.g., Euclid
  - Sartoris et al., 2015
As a way to constrain models of large-scale structure formation, find the first building blocks of the dark matter structure filled with hot gas.

Athena will be able to detect \( M_{500} > 5 \times 10^{13} \, M_{\odot} \) at \( z > 2 \). And measure \( T \) of \( \sim 50\% \) of them.

Courtesy of M. Ramos-Ceja, F. Pacaud (in Pointecouteau, Reiprich et al., 2013)
Conclusions

How does ordinary matter assemble into the large scale structures we see today?

Constraint the processes driving the evolution of the physical properties of dark matter and hot gas in groups and clusters of galaxies.

Characterise the content of the first groups and clusters formed in the Universe and understand how super-massive black holes, galaxies and hot gas co-evolve.

Search for the first collapsed massive halos retaining a hot gaseous atmosphere through their X-ray emission.