

# Evolution of galaxy clusters and groups with Athena

# ATHENA

**Edoardo Cucchetti (IRAP Toulouse)**  
**(also on behalf of Pasquale Mazzotta - Università di Roma Tor Vergata)**

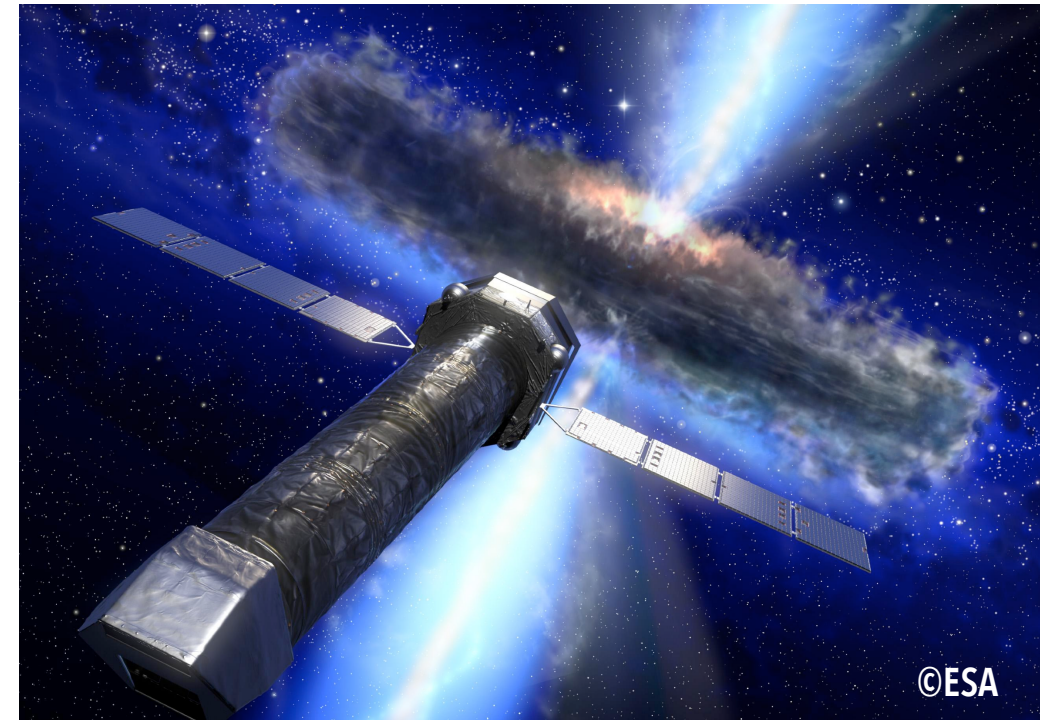


Athena Palermo Conference 25/09/2018

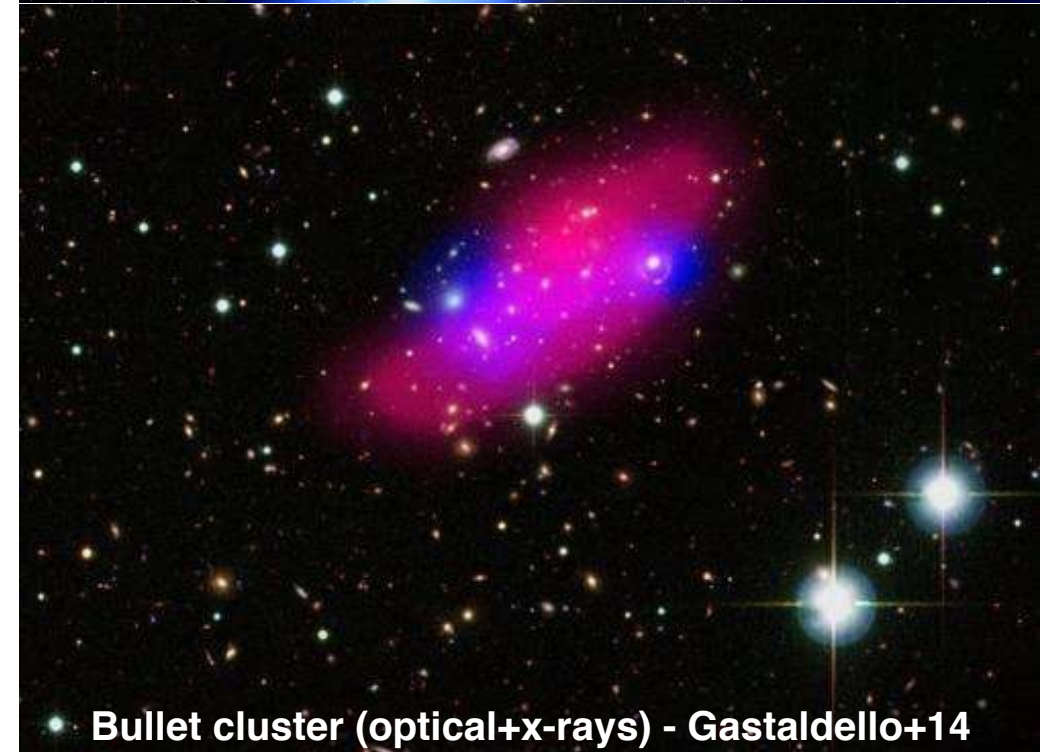




- Clusters of galaxies are a key science objective of *Athena*:
  - X-ray emission of clusters of galaxies provides insight on (thermo-) dynamical and chemical state
  - Driver of the main performances of the mission
- Relatively young and bound objects
  - Pristine laboratories to test our knowledge of the physics (turbulence, feedback, chemical enrichment)
  - Evolution of clusters is tightly correlated to the evolution of our Universe
  - Measuring evolution through **entropy, bulk motion, temperature, chemical content...**



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# Implications of the Athena downsizing to the “Evolution of Galaxy Groups” Science Case

**Pasquale Mazzotta**  
**Università di Roma Tor Vergata**

**Collaborators: H. Bourdin, E. Rasia**

**Athena Palermo Conference 25/09/2018**



## The Evolution of Galaxy Groups and Clusters with Athena (Pointecouteau, Reiprich et al., 13)

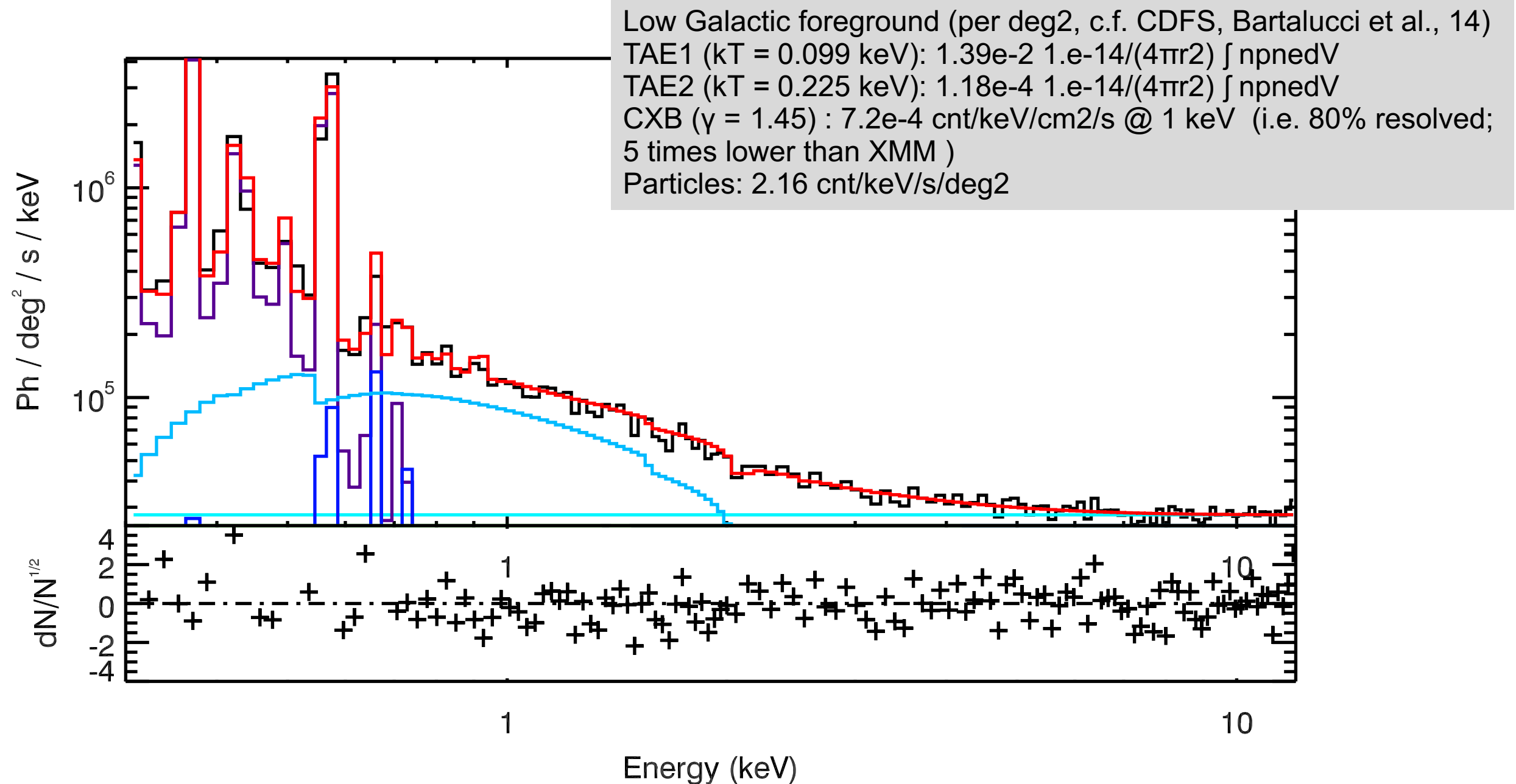
The paper addresses a number of unanswered questions... and states:

Answering these questions requires the full physical characterisation of the thermo-dynamical state and chemical composition of the hot intra-group/-cluster medium (ICM) around the time of their formation, i.e., within the redshift range  $0.5 < z < 2.5$ .



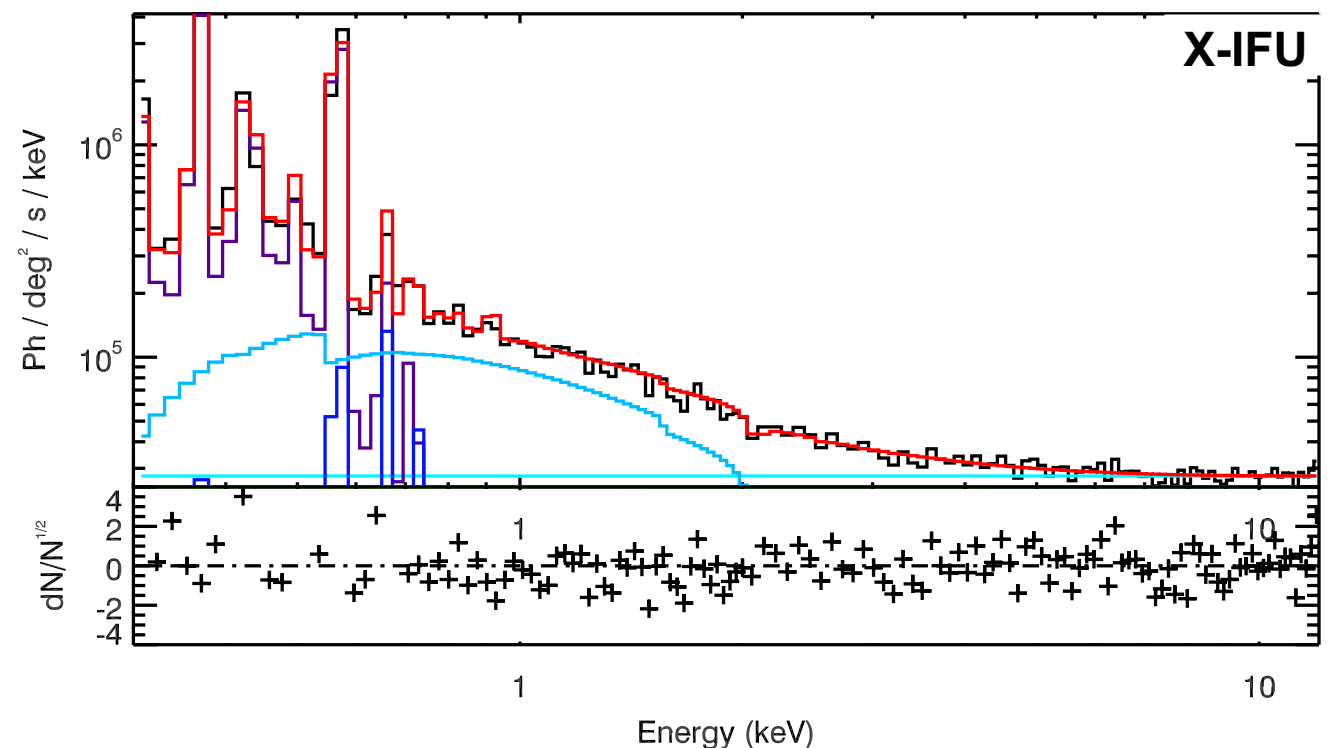
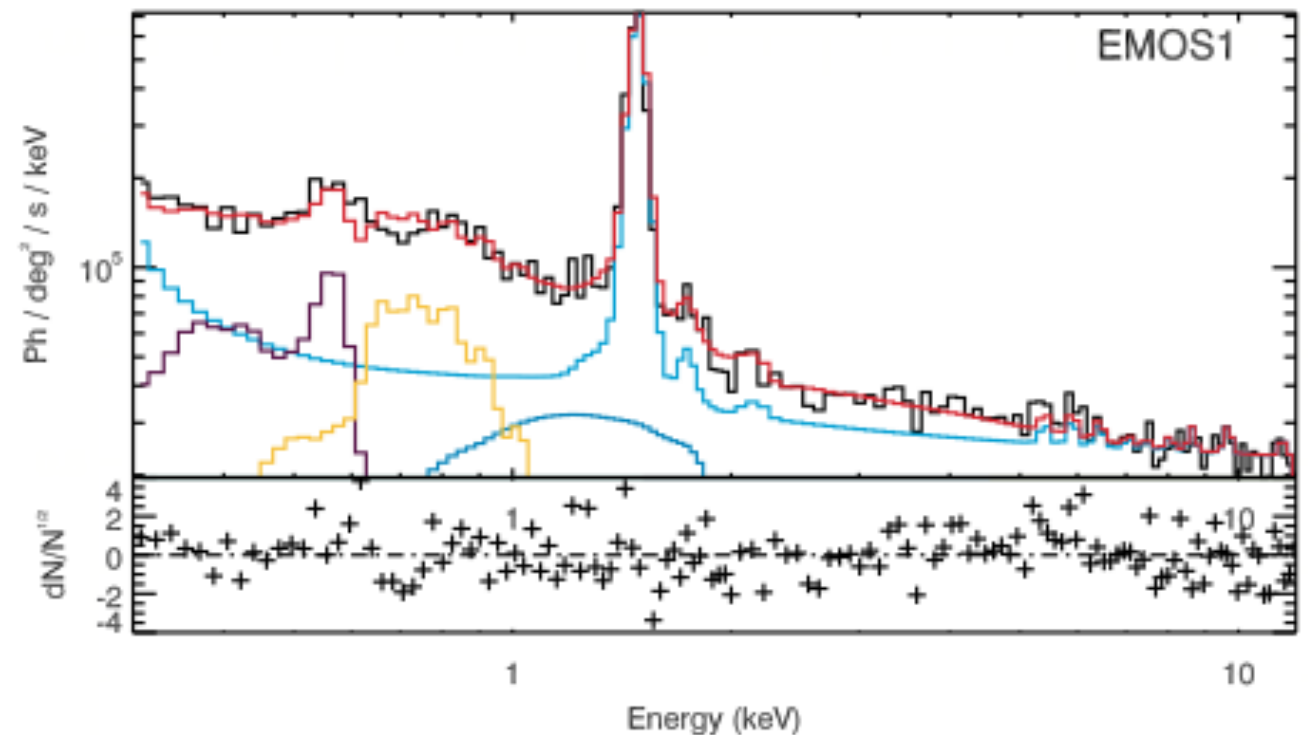
# X-IFU/WFI Total background noise

ATHENA



# Total background: XMM vs. Athena (extreme conditions) ATHENA

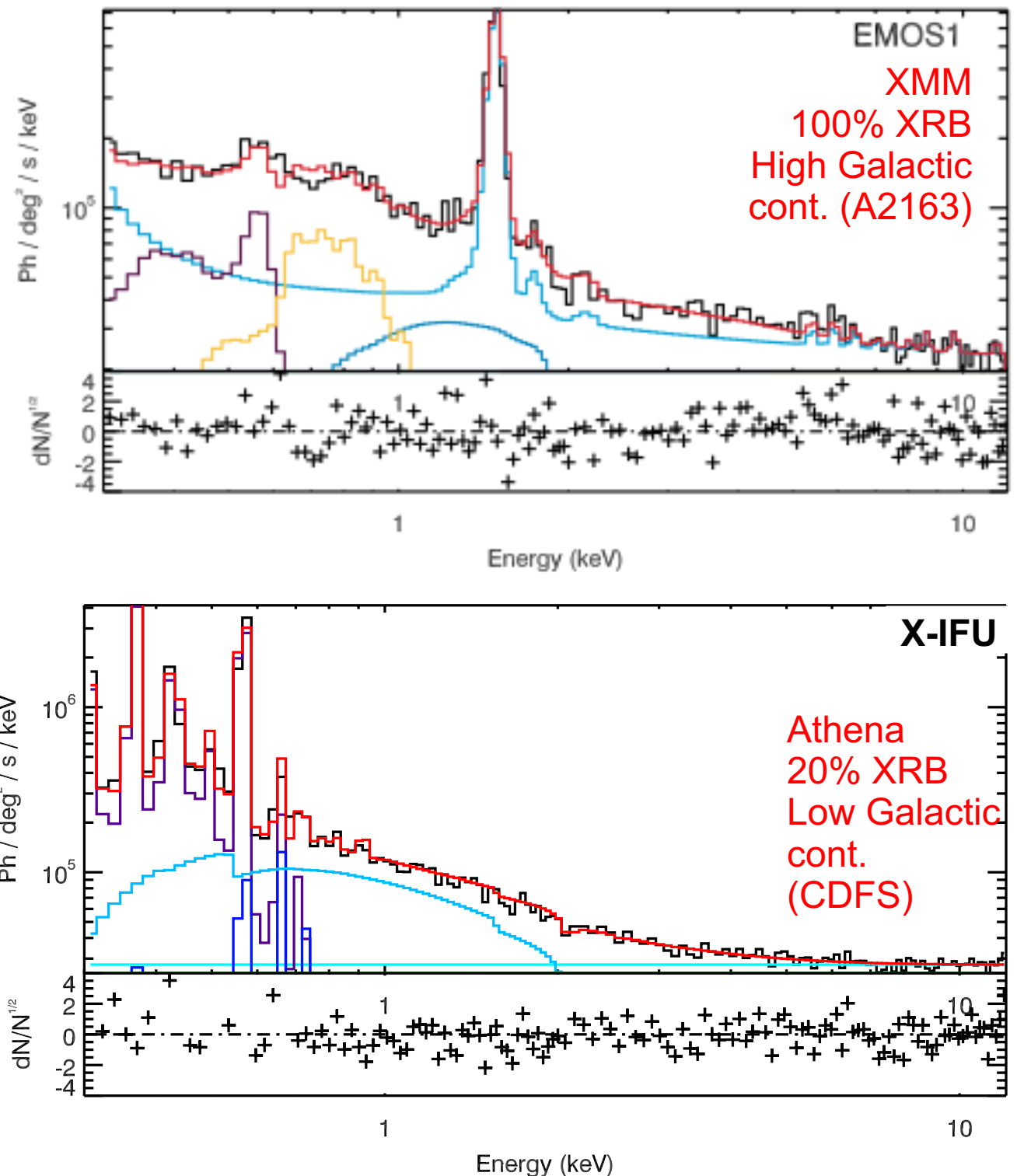
- **XMM:** Even in the case of a high Galactic foreground (e.g., NPS, A2163), the total background noise is **dominated by particles**
- **Athena:**
  - **Dominated by sky components** (CXB+Galaxy) in the soft band
  - Even assuming a low Galactic foreground, sky background is the major source of systematics in the flux measurements and spectroscopic estimates





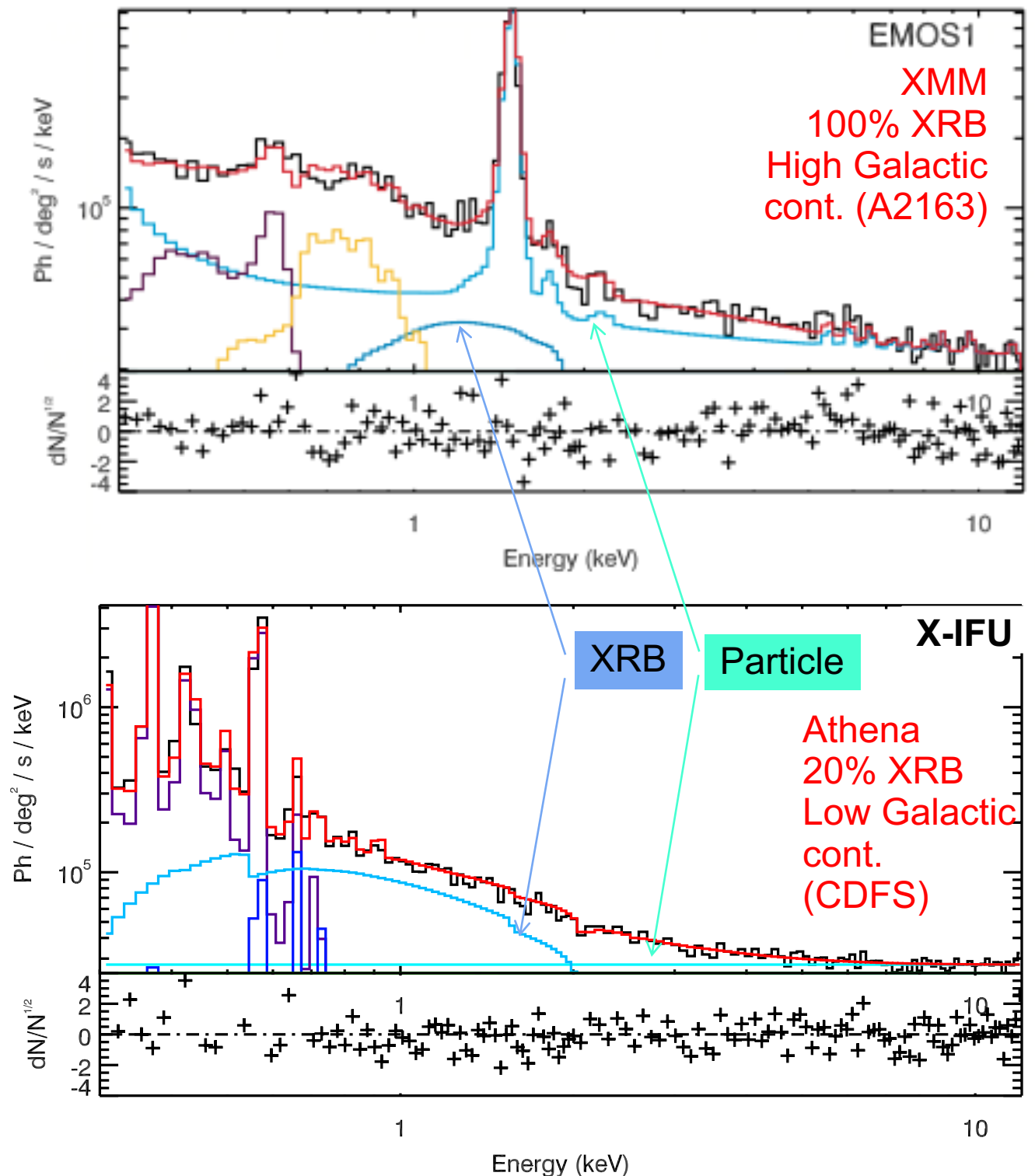
# Total background: XMM vs. Athena (extreme conditions) ATHENA

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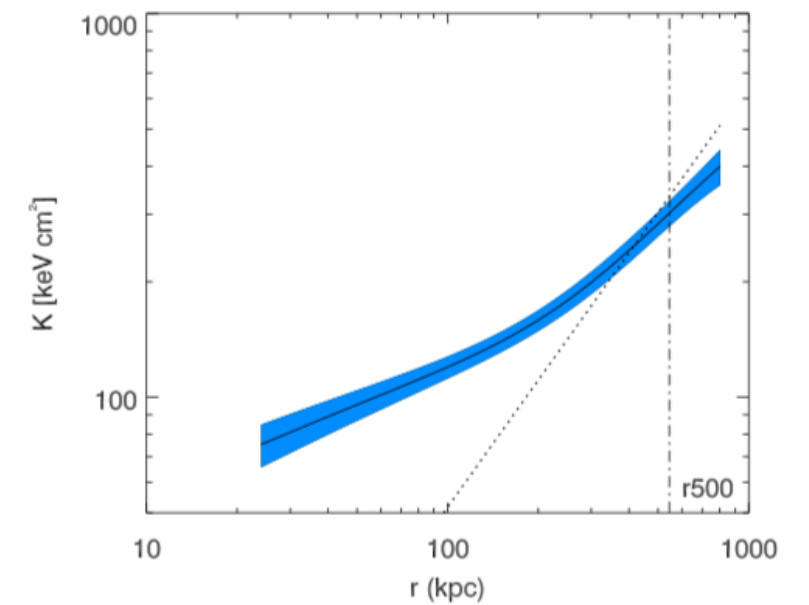
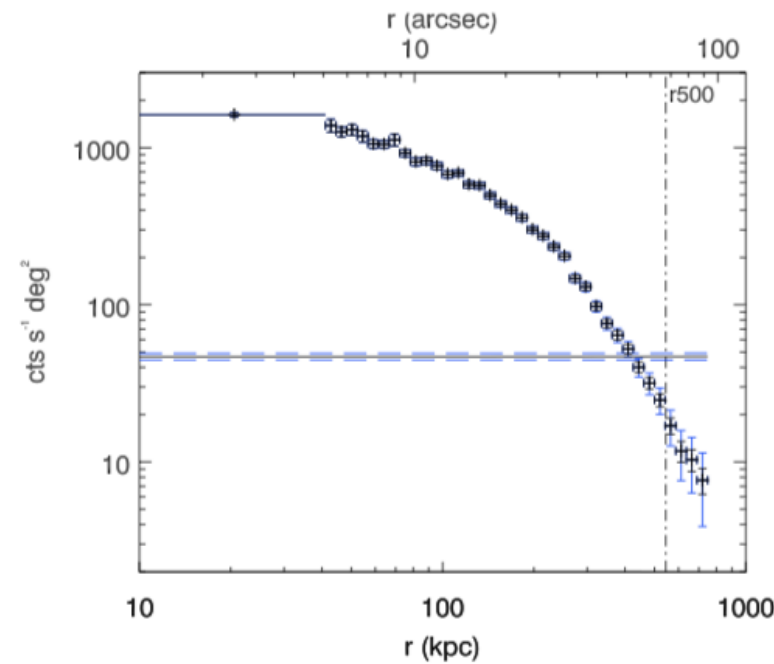
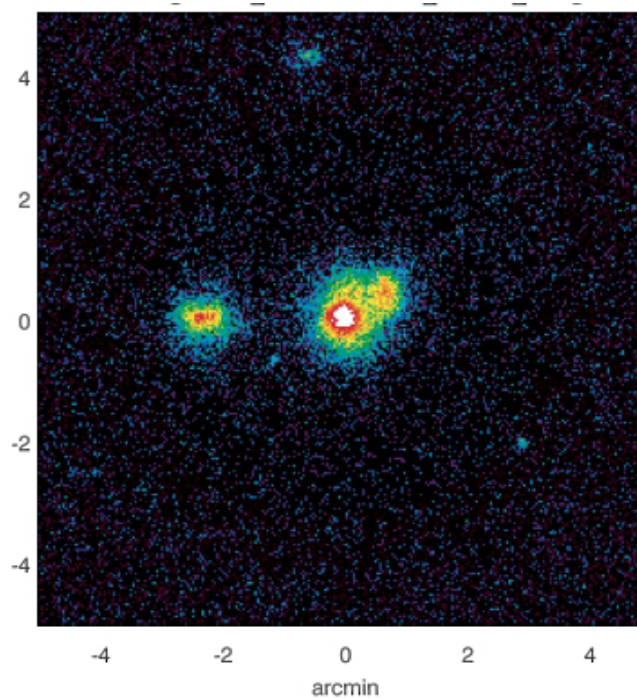
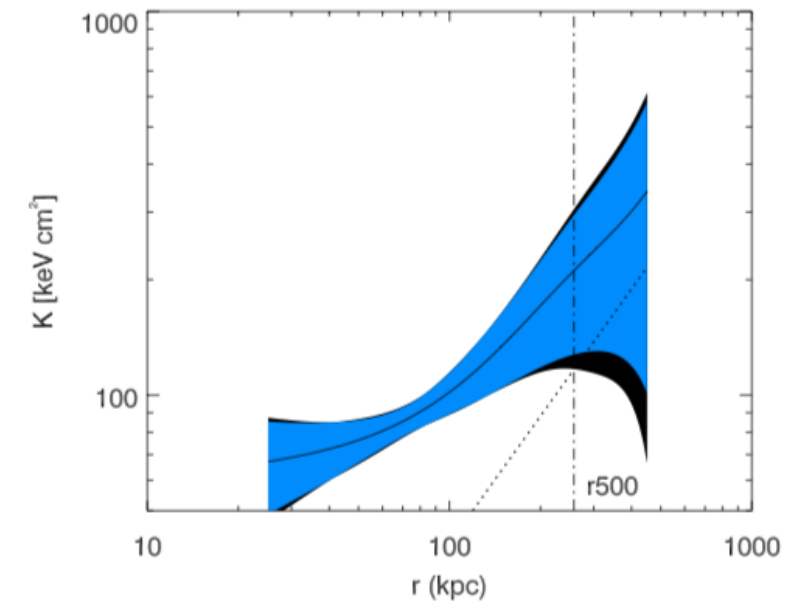
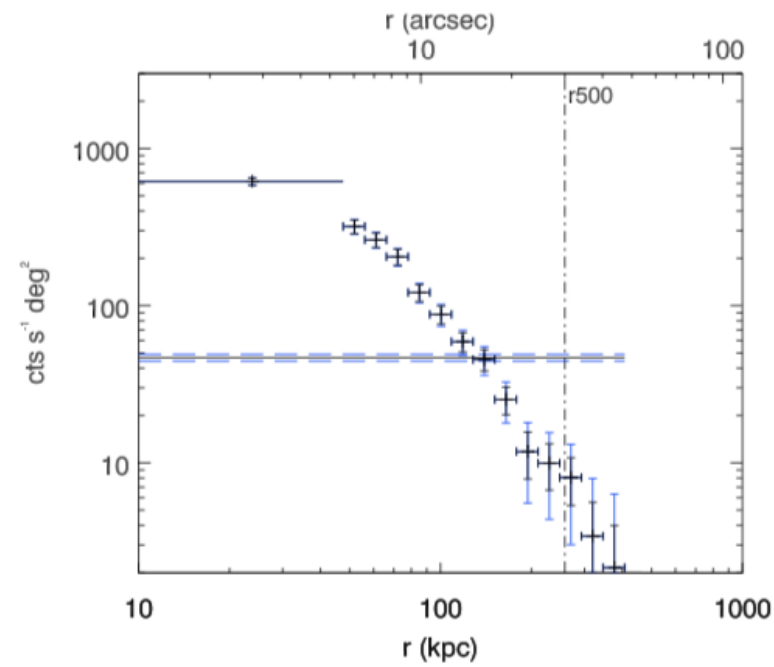
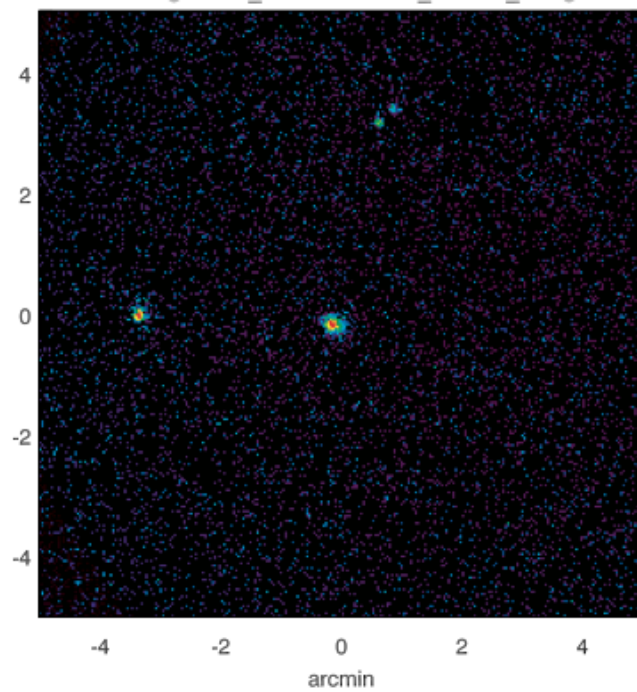


**19 v.s. 15 Mirror Area**

**Clusters and groups will be observed with  
X-IFU rather than WFI**

# Original WFI pointings

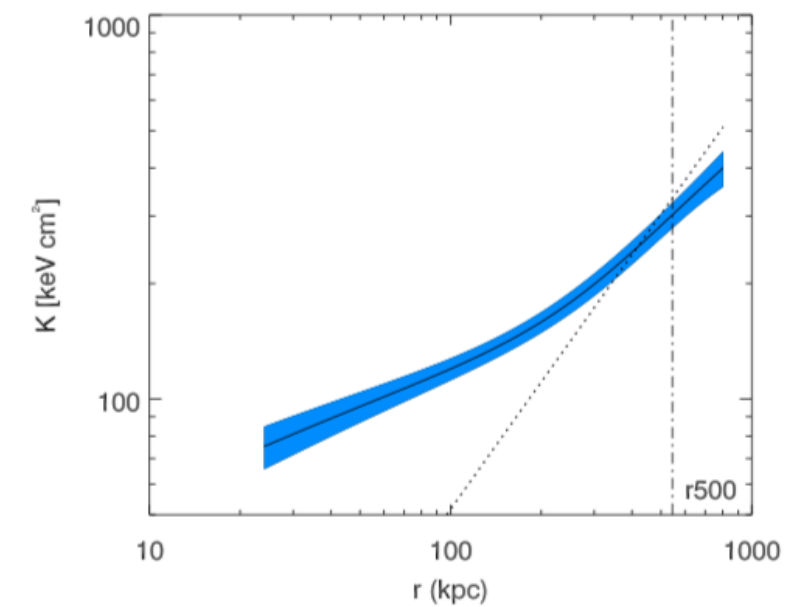
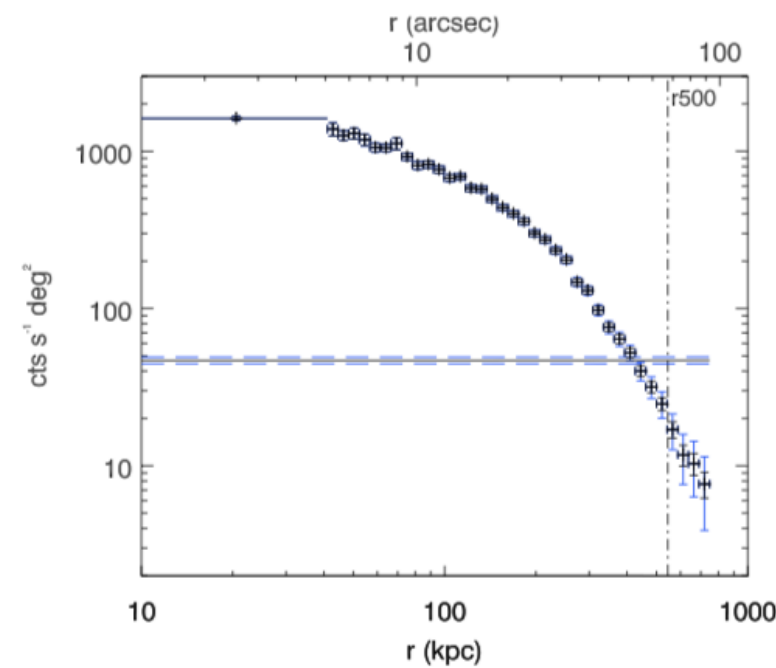
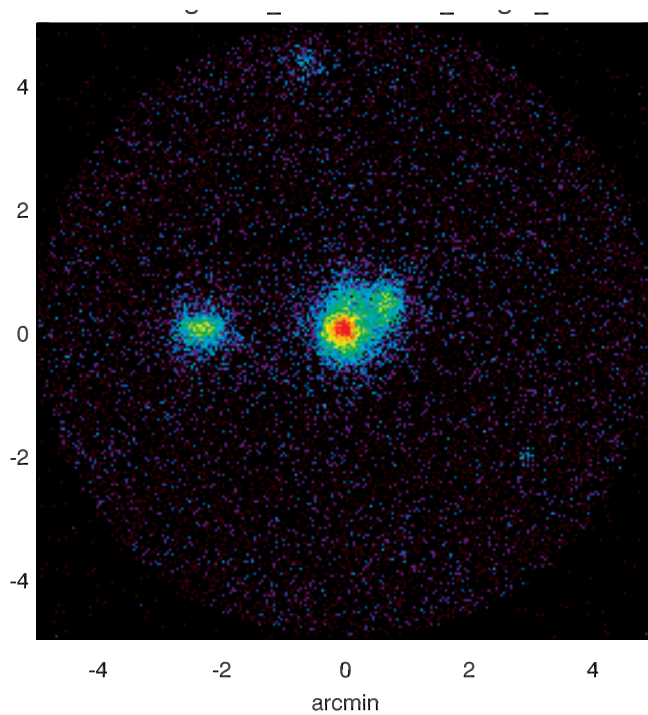
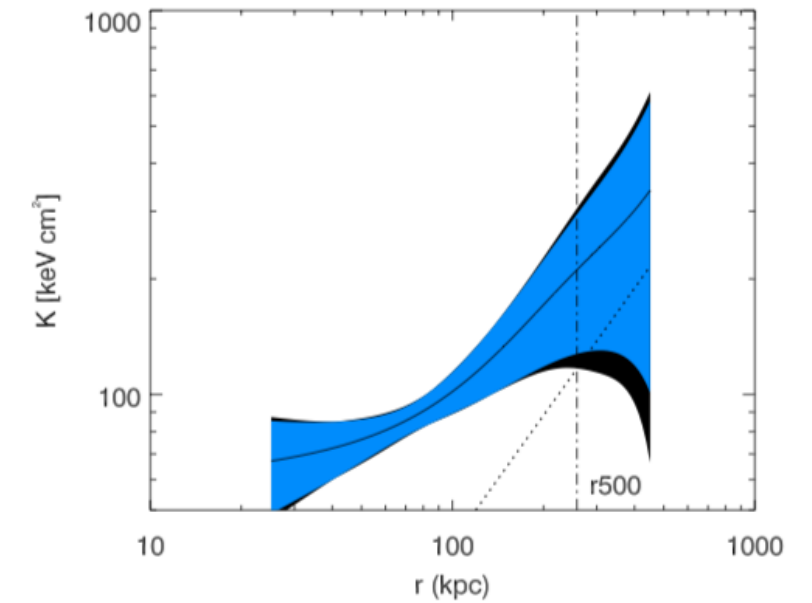
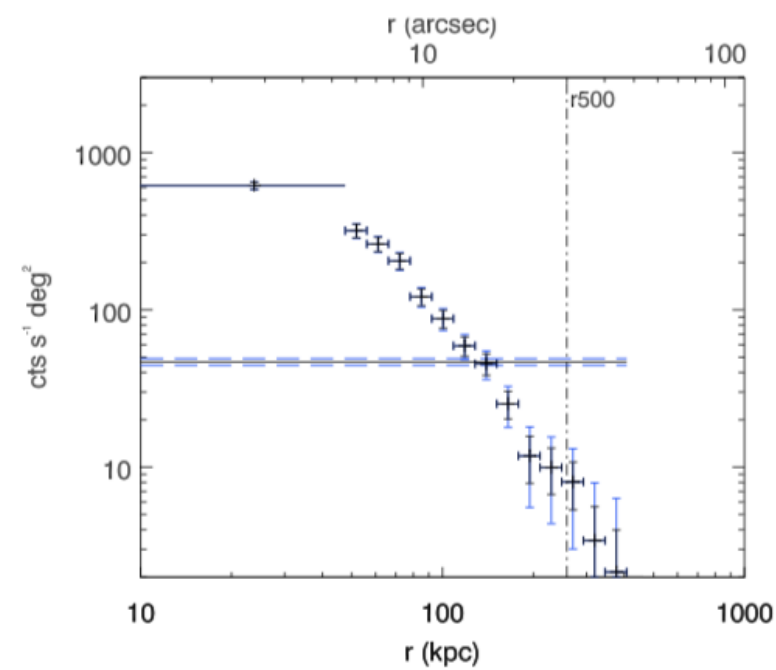
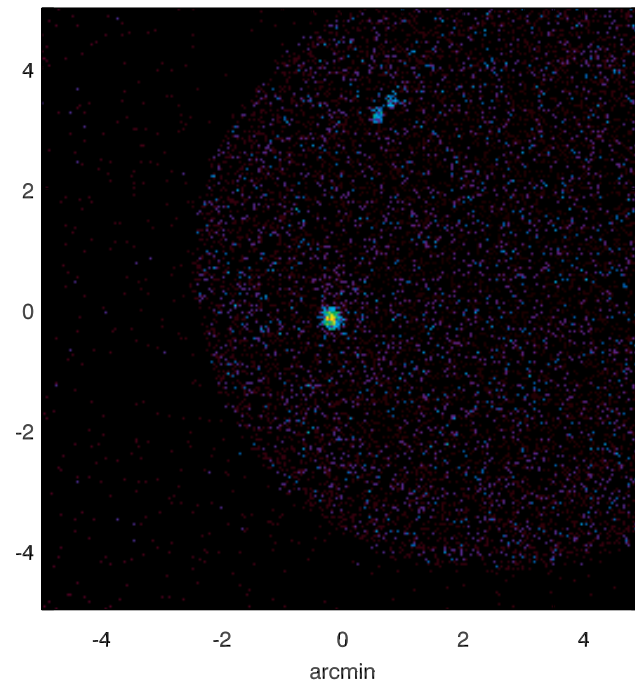
Groups of galaxies evolving from  $z=2$  to  $z=1$ , 100ks (Pointecouteau, Reiprich, 2013)



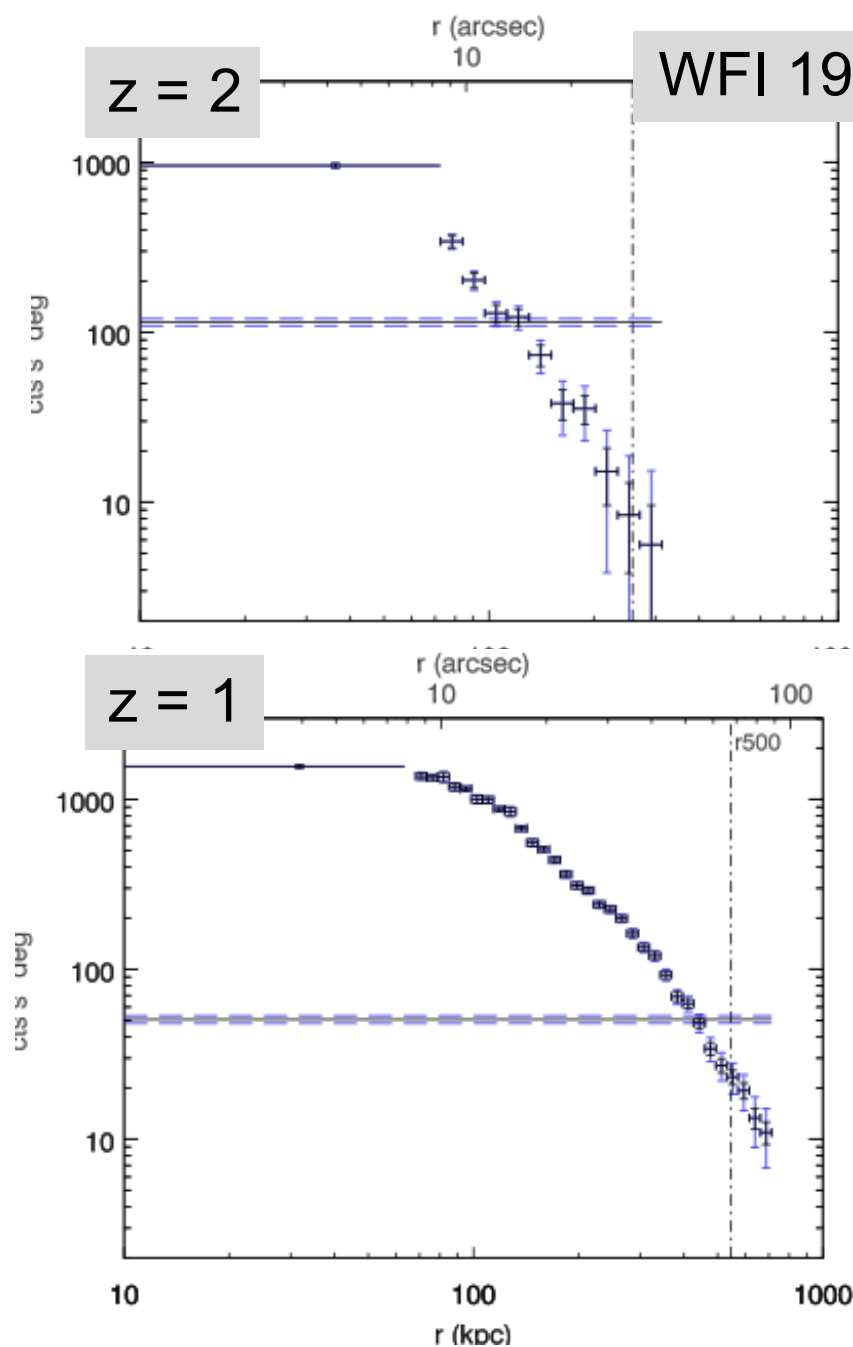


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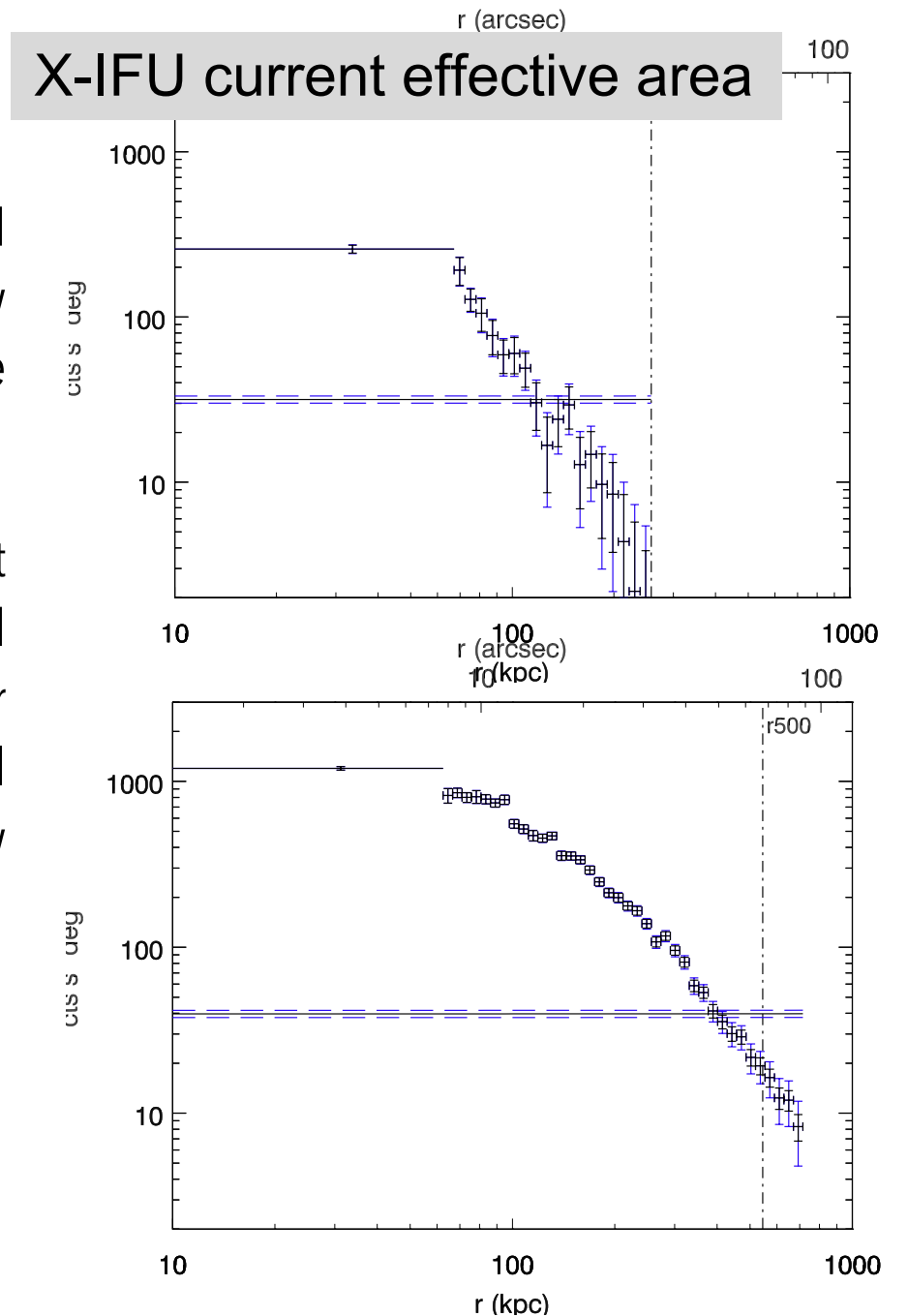
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Groups of galaxies evolving from  $z=2$  to  $z=1$ , X-IFU 100ks (Pointecouteau, Reiprich, 2013)

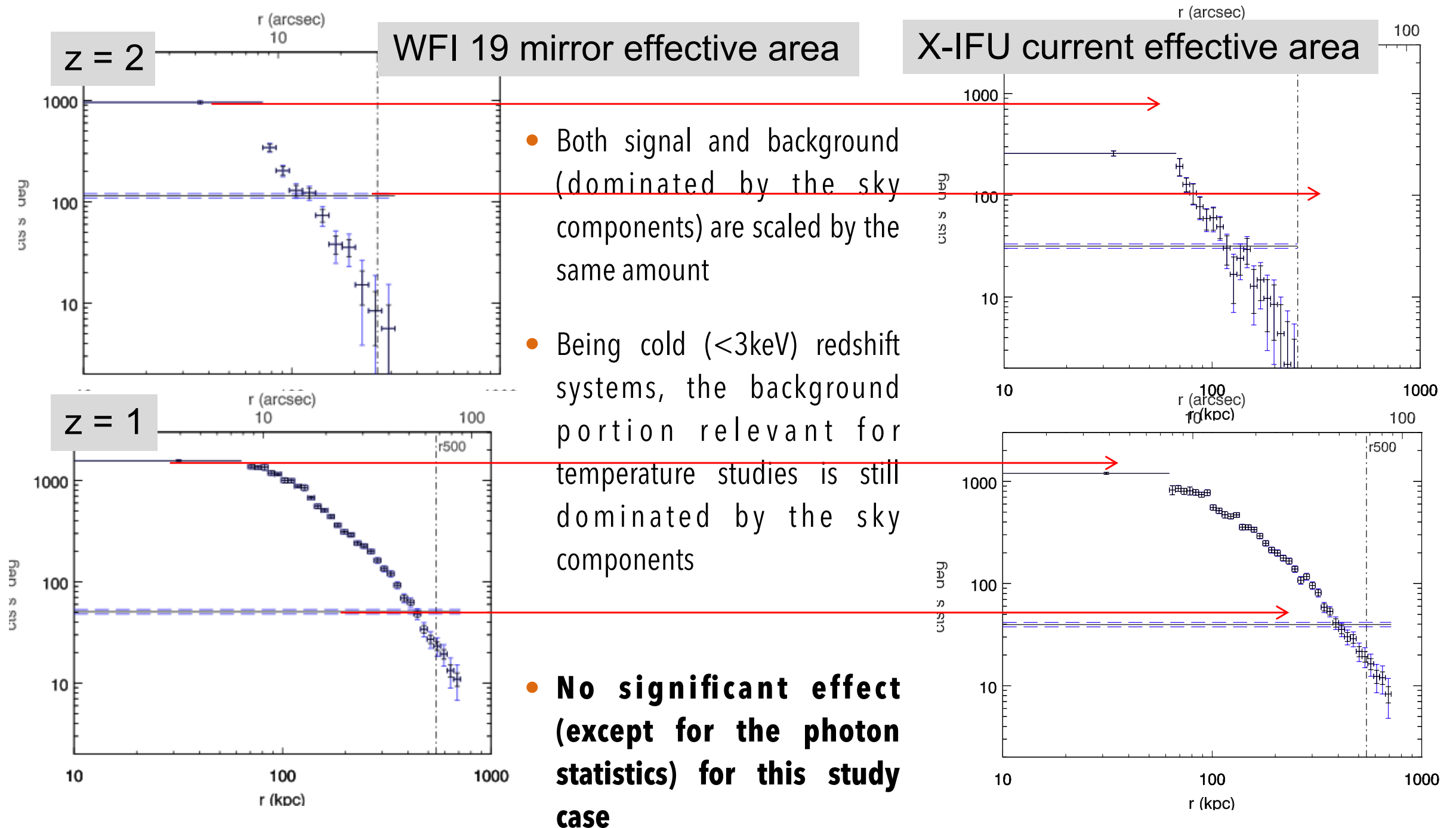


- Both signal and background (dominated by the sky components) are scaled by the same amount
- Being cold ( $<3\text{keV}$ ) redshift systems, the background portion relevant for temperature studies is still dominated by the sky components





Groups of galaxies evolving from  $z=2$  to  $z=1$ , X-IFU 100ks (Pointecouteau, Reiprich, 2013)



- Assuming the target particle background level the sky background ( i.e. background+ foreground emission) dominates the noise level @  $E < 2\text{keV}$
- This energy range is particularly relevant for  $z > 1$  cluster science (but also for outskirts of intermediate redshift clusters)
- Expect for the photon statistics the evolution of galaxy groups science case will be not significantly affected by the downsizing
- It will be important to have an accurate (spectral and spatial) model of the sky background



# Probing the evolution of the chemical enrichment of clusters with the X-IFU



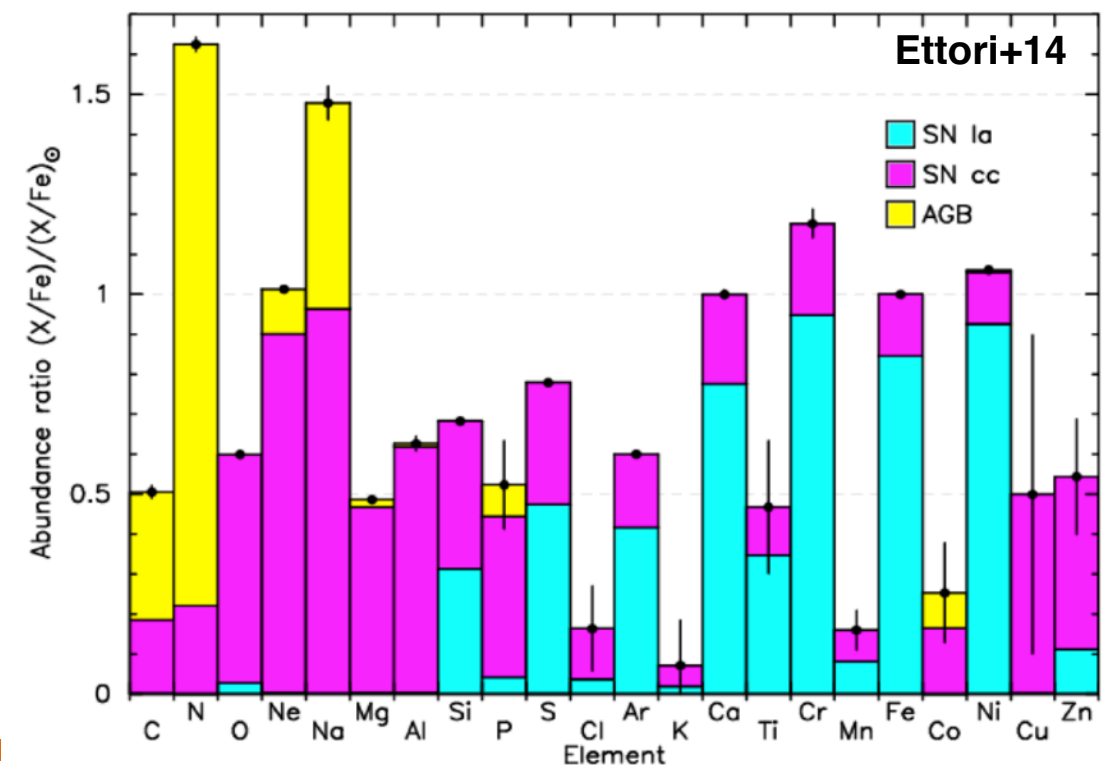
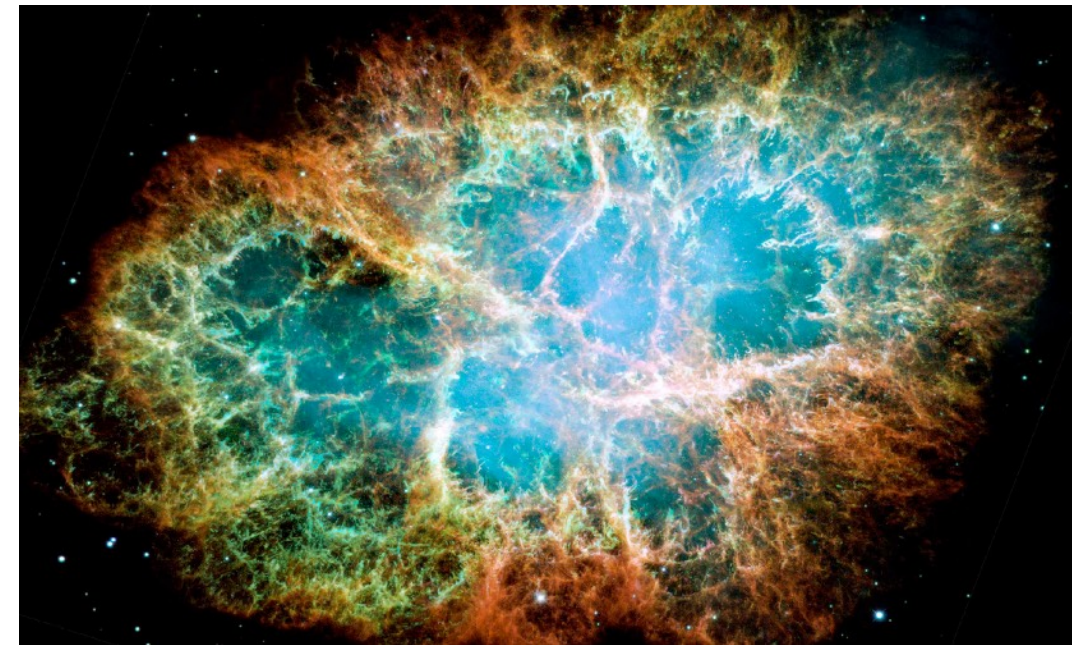
**Edoardo Cucchetti (IRAP Toulouse),**

E. Pointecouteau, P. Peille, N. Clerc, E. Rasia, V. Biffi, S. Borgani, L. Tornatore, K. Dolag,  
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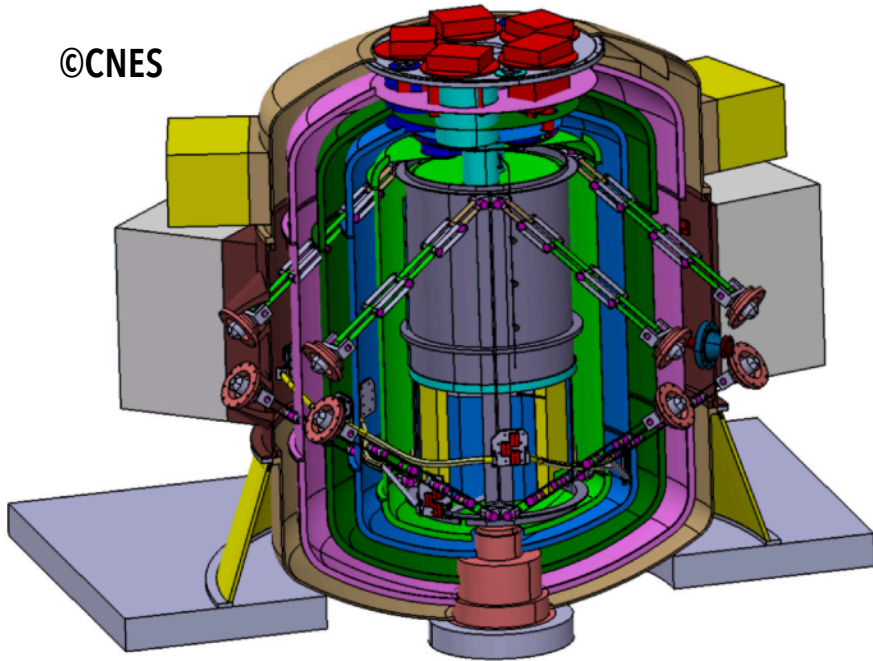


- The origins of the chemical enrichment
  - Stars! Metals are created mainly by supernovae or stellar winds
  - Single stellar studies yield great results, but nearby SN are rare events
  - Clusters contain billions of stars within their galaxies  $\Rightarrow$  chemical enrichment of the ICM
- Investigating the ICM
  - Self-similar behaviour assumed between clusters
  - Metallic content is trapped in the ICM
  - Study of clusters at different  $z \Rightarrow$  evolution of stellar mechanisms through time



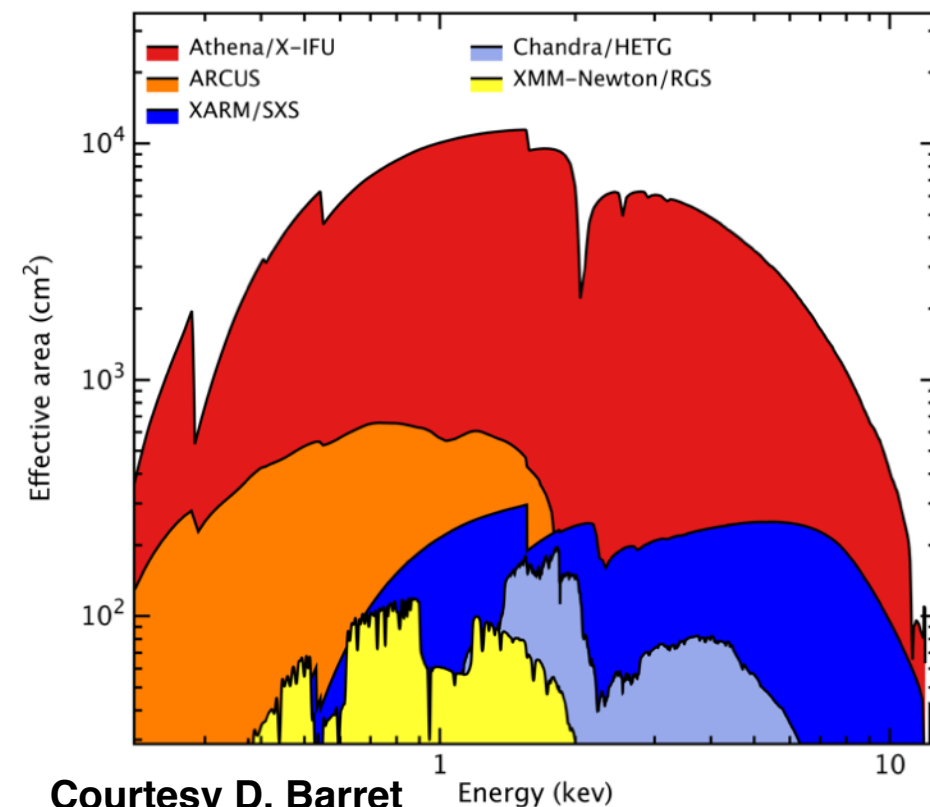


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- Metal content is traced through spectroscopic studies
  - Need to couple spatial information with high spectral resolution  $\Rightarrow$  micro-calorimeters
  - Breakthroughs with *Hitomi*, more expected with *XRISM*
- Challenge of cluster observations
  - Faint sources  $\Rightarrow$  exposure time, effective area
  - Complex spatial and spectral information
  - Background (instrumental and sky)
  - High-resolution spectroscopy
- Athena will be the leap forward in this area!

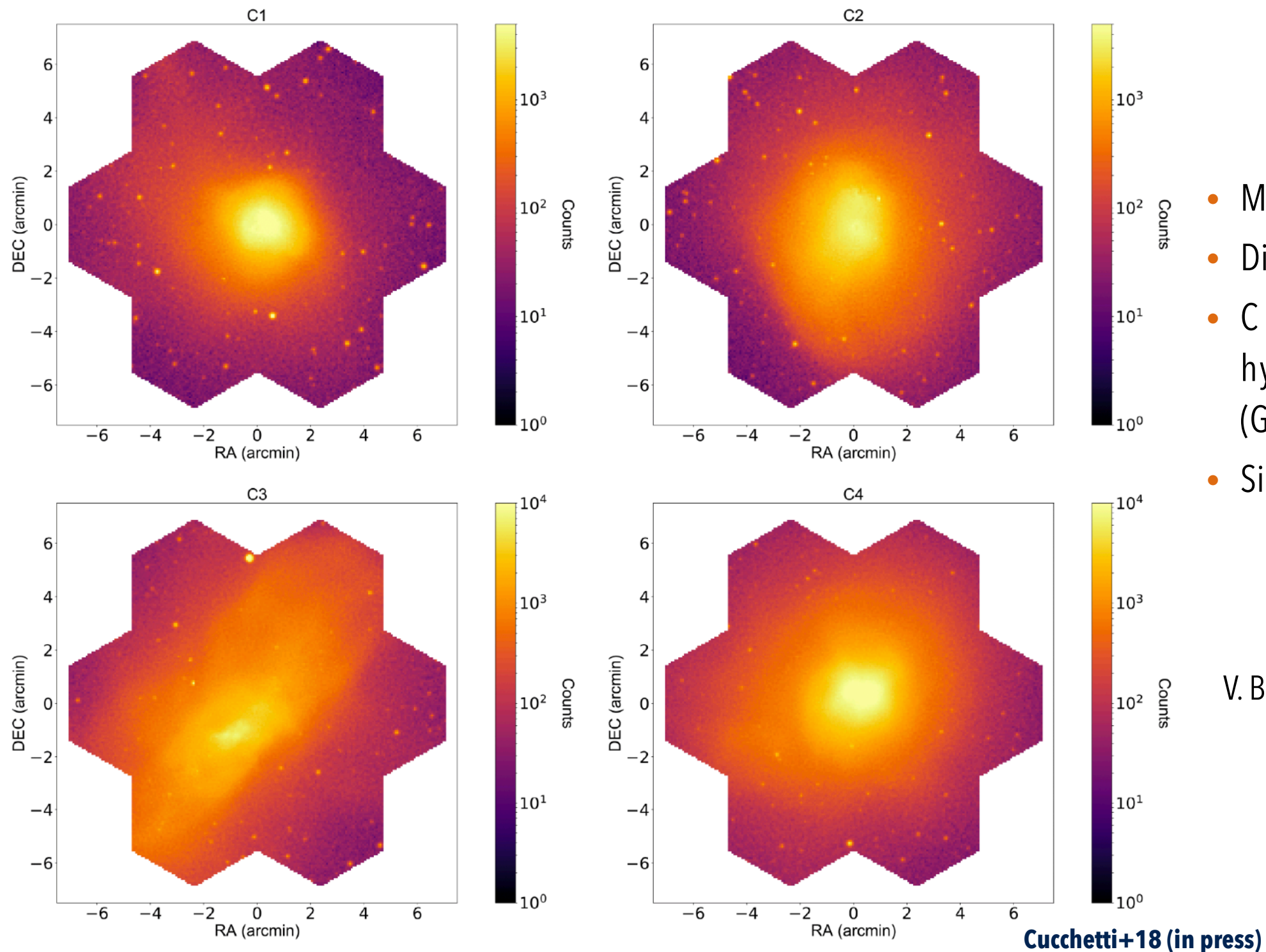
**Feasibility need to be tested beforehand**



Courtesy D. Barret

# Simulating the performance of the instrument

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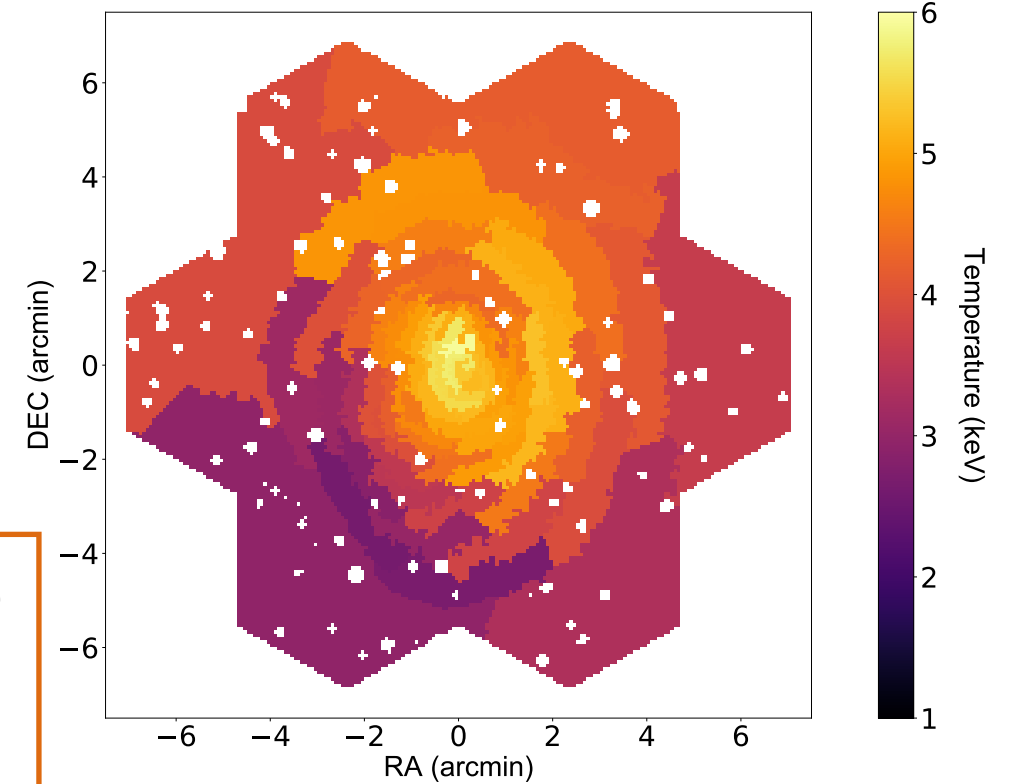
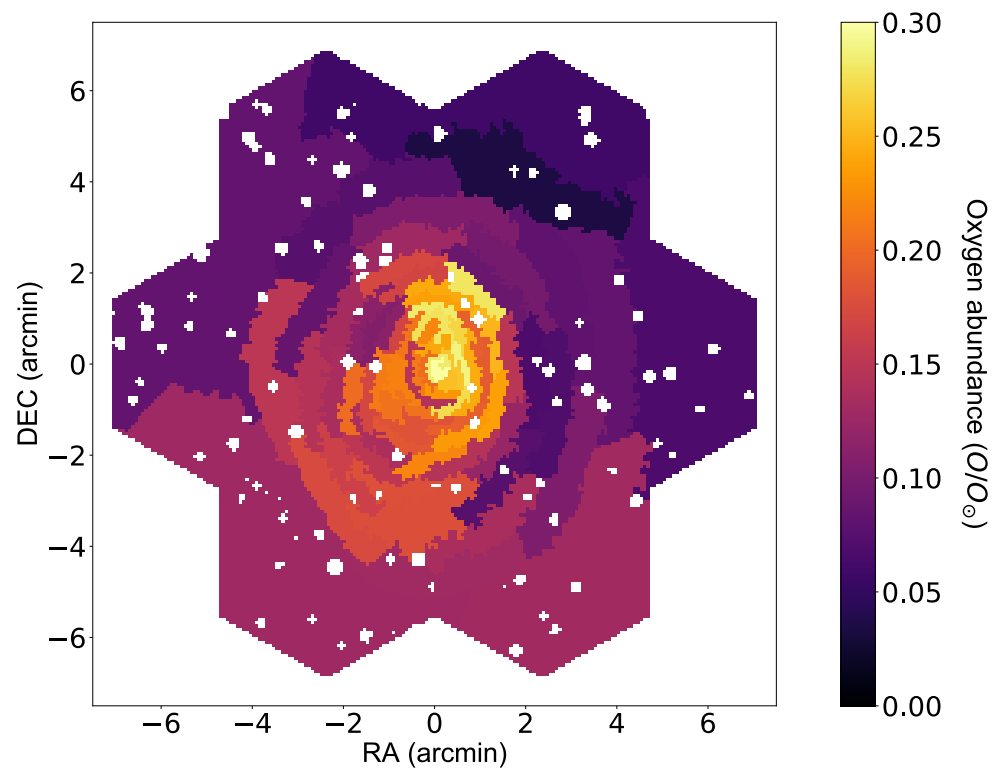
- Massive clusters ( $>2 \cdot 10^{14} M_{\text{sun}}$ )
- Different redshifts ( $0.1 < z < 2$ )
- Clusters extracted from hydrodynamical simulations (GADGET-3)
- Simulations with SIXTE

Numerical simulations:  
V. Biffi, S. Borgani, K. Dolag, E. Rasia,  
L. Tornatore.  
(see Rasia+15, Biffi+17)

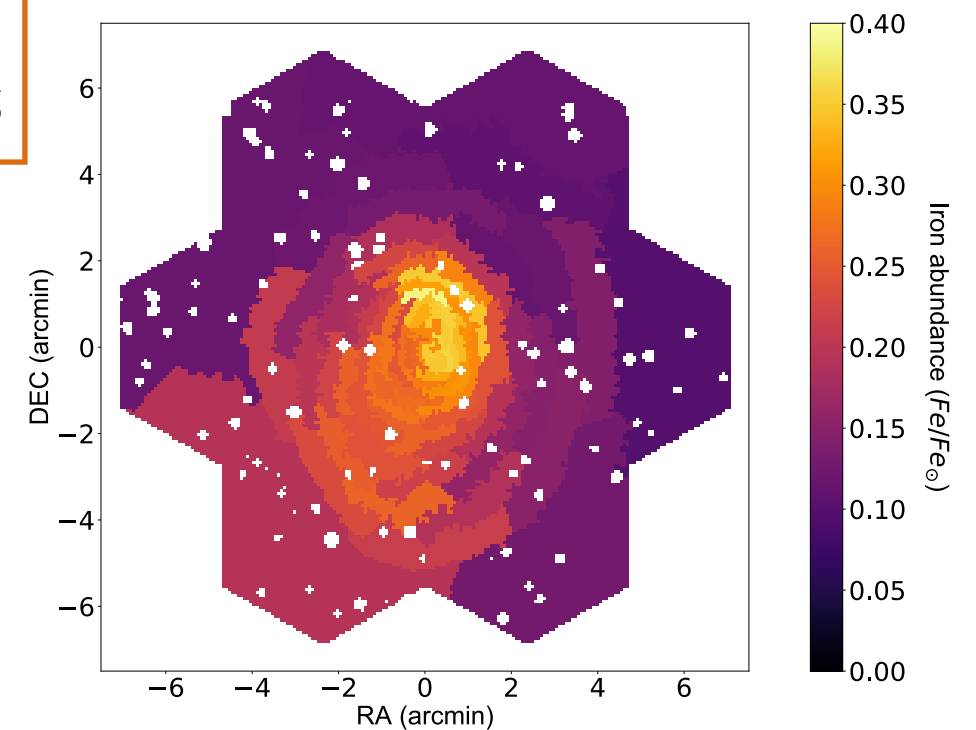
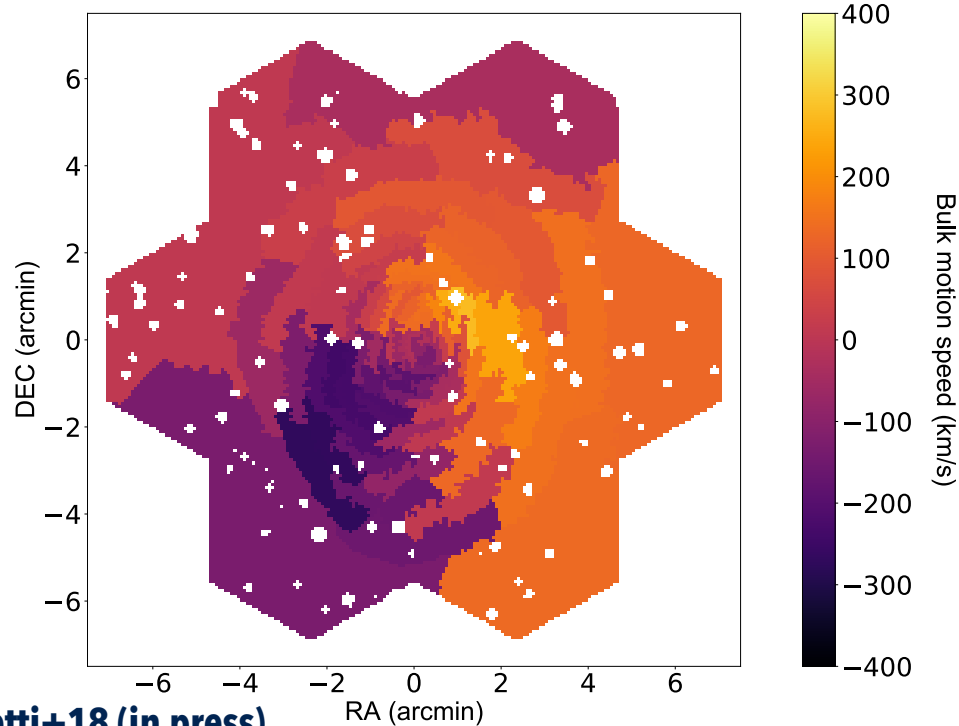


# Probing the ICM in the local Universe...

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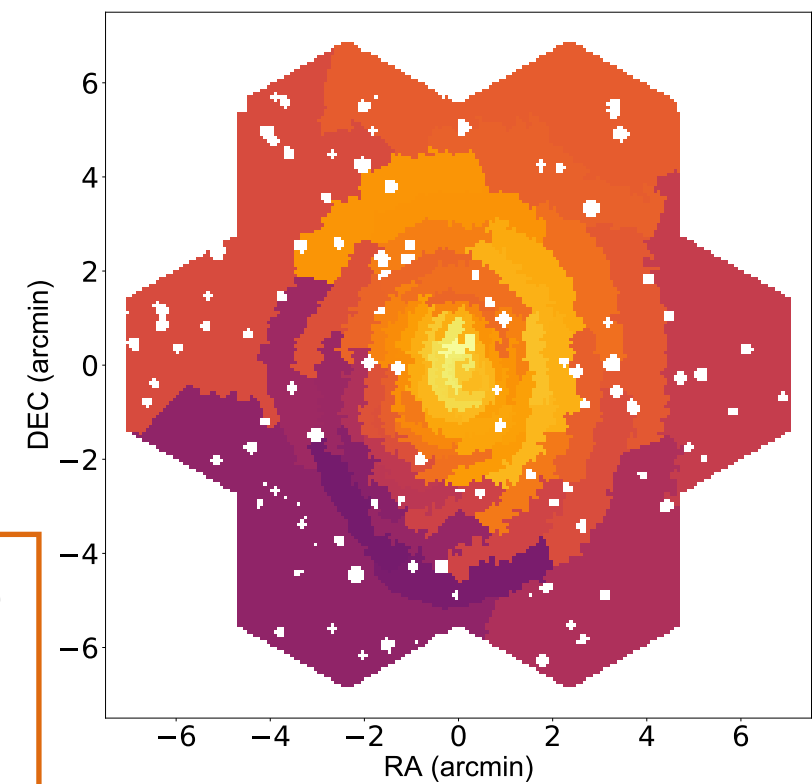
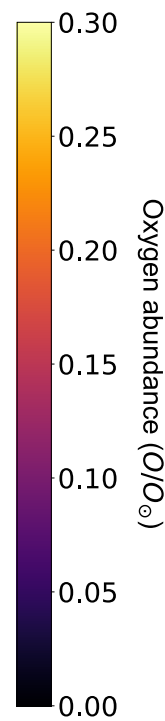
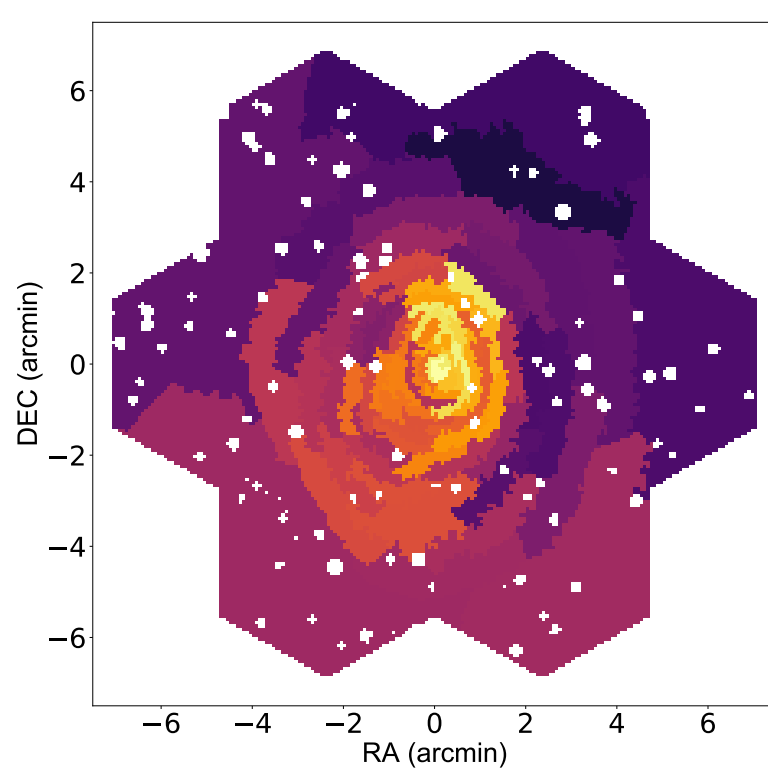
Reconstructing the  
spatial distribution  
of the cluster  
physical parameters



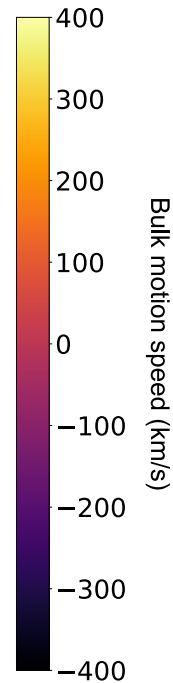
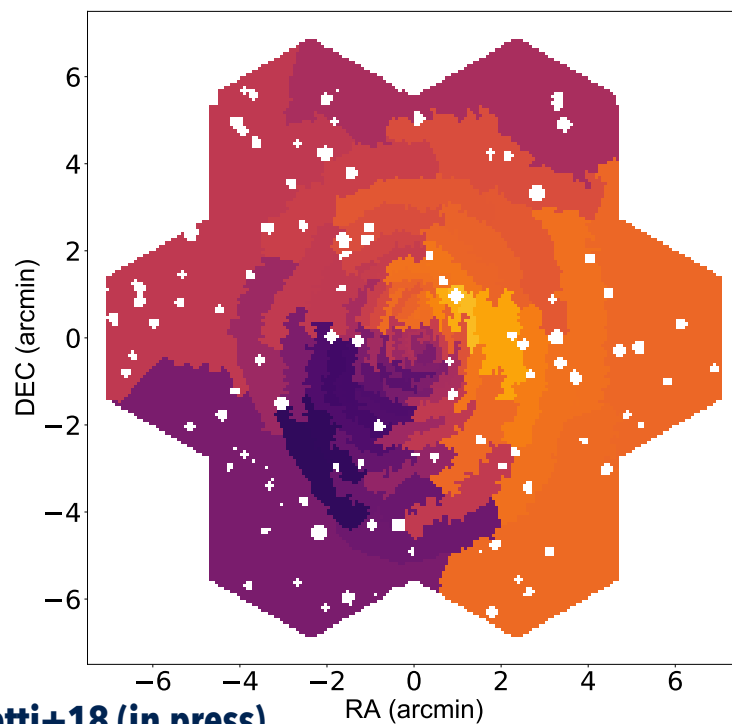
Cucchetti+18 (in press)

# Probing the ICM in the local Universe...

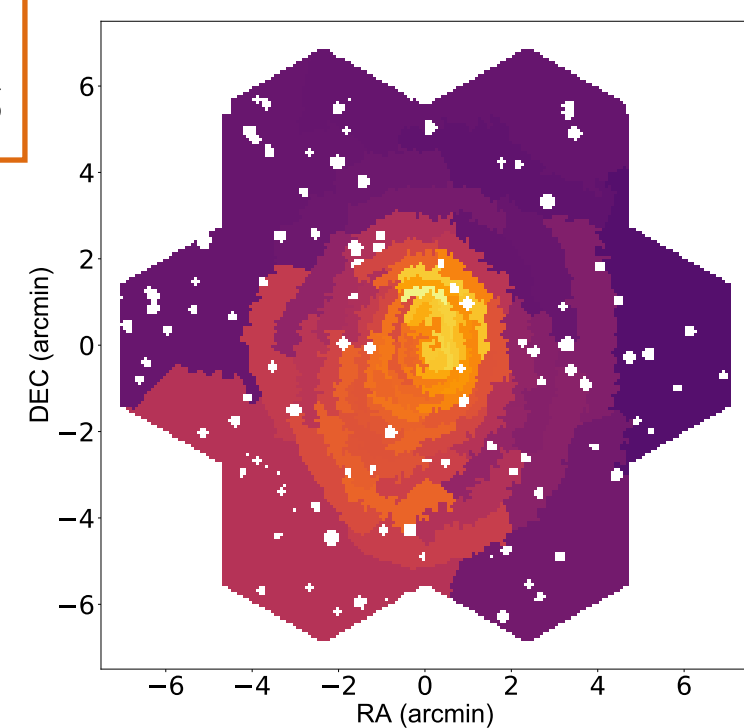
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Reconstructing the  
spatial distribution  
of the cluster  
physical parameters



For a study of  
turbulence, see  
Roncarelli+18



Cucchetti+18 (in press)



# Probing the ICM in the local Universe...

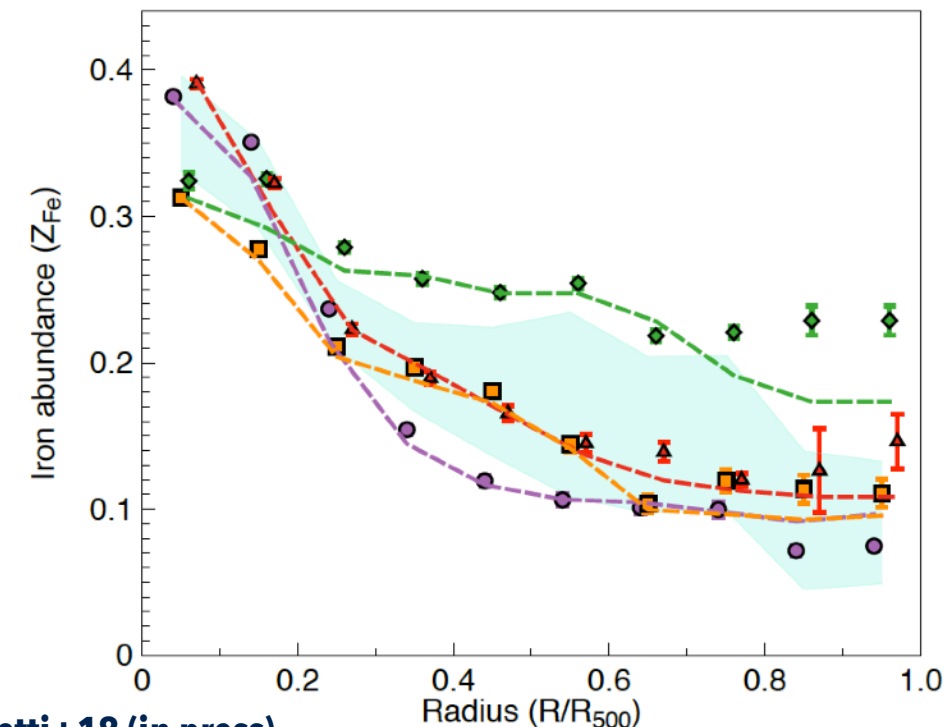
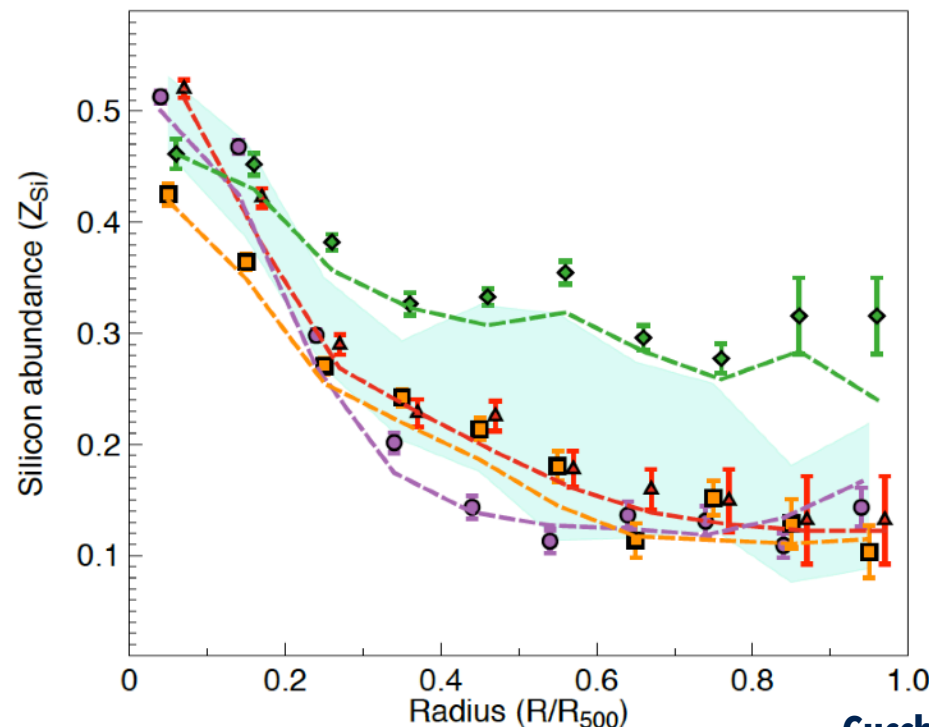
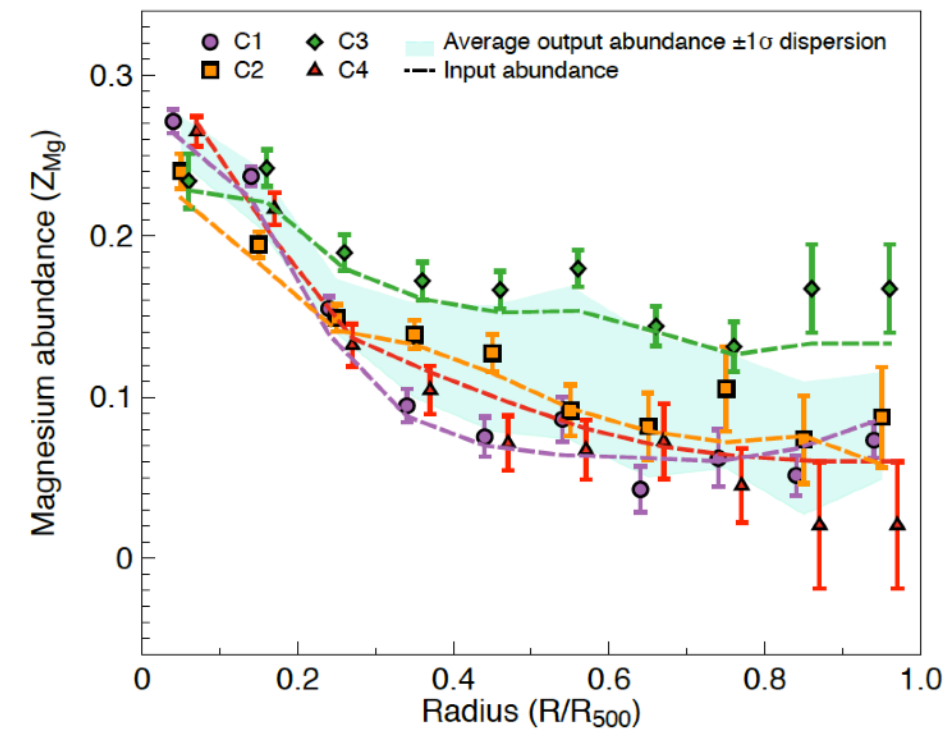
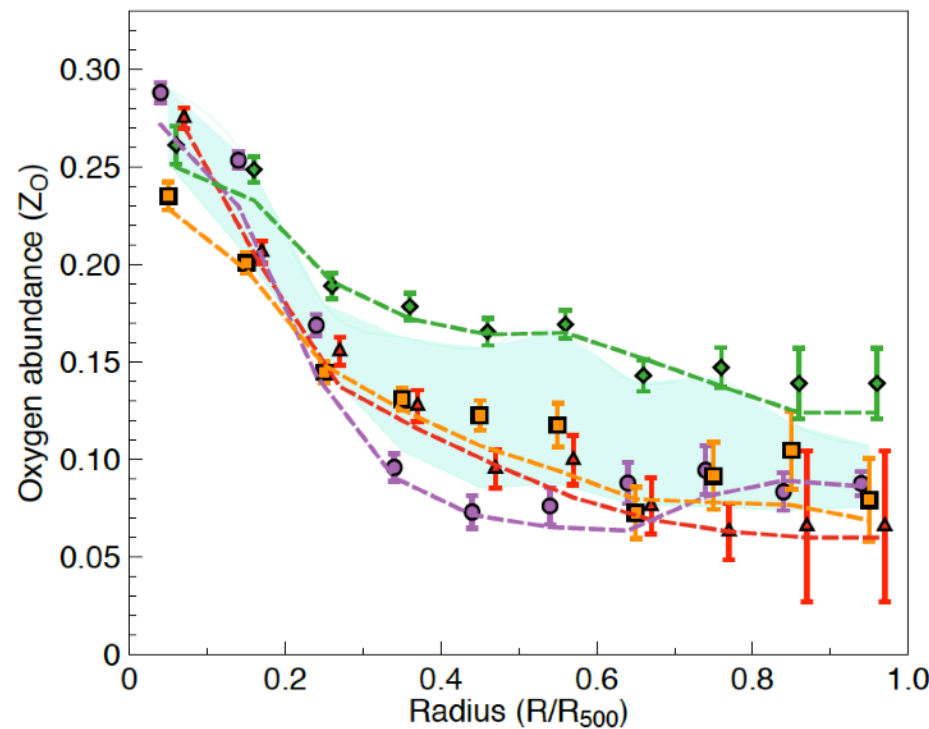
ATHENA

- Radial profiles of metallicity (100ks)

- Excellent accuracy between input and the recovered metallicities
- Access to accurate information on the metallicity out to R500
- Strong constraints on the scatters with X-IFU
- Cluster dynamics visible

- Sample analysis

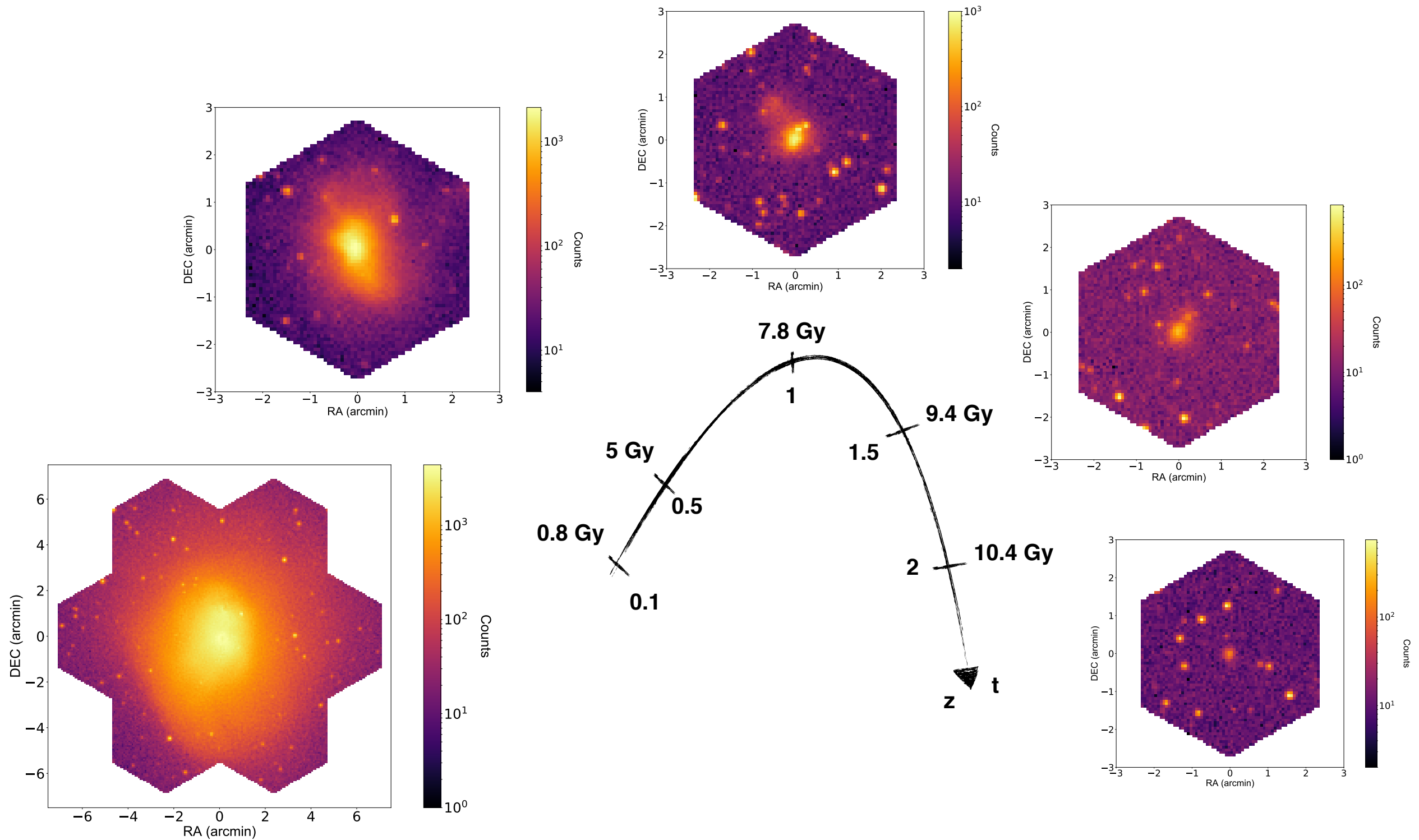
- Self-similarity?
- Cosmic variance? (see N. Clerc poster)



Cucchetti+18 (in press)

# ... and through time!

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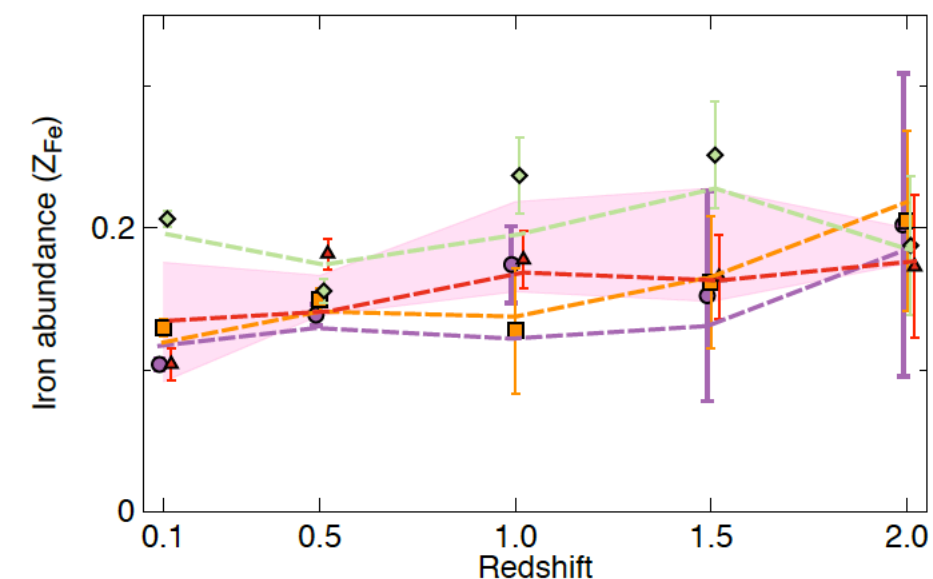
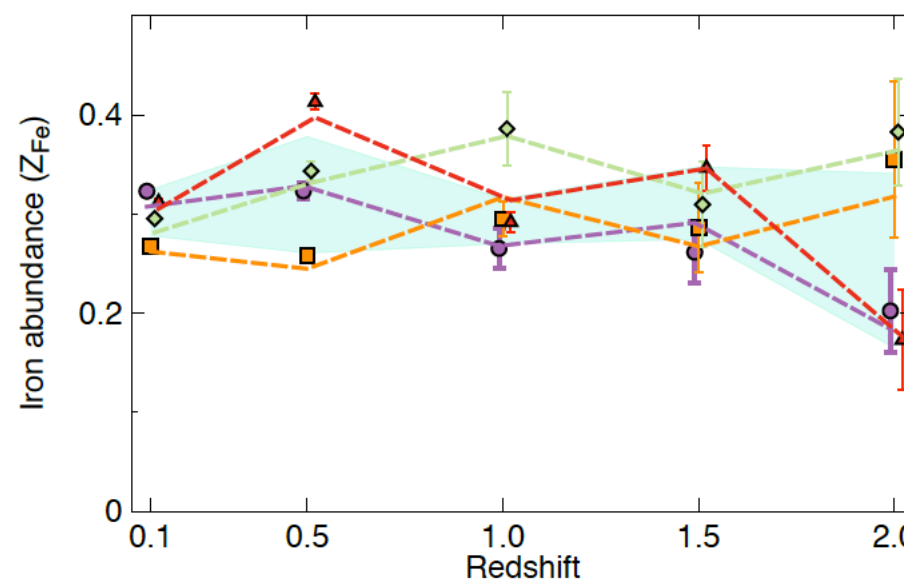
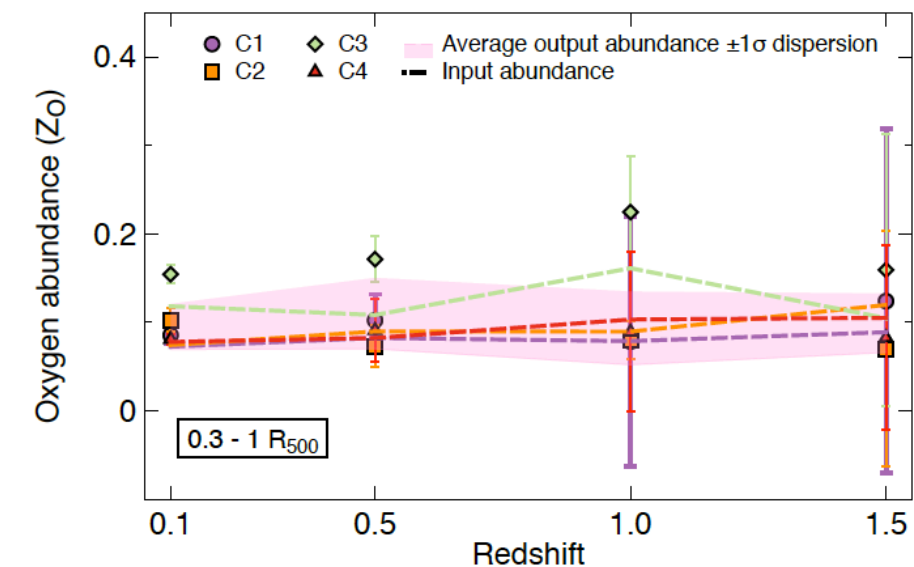
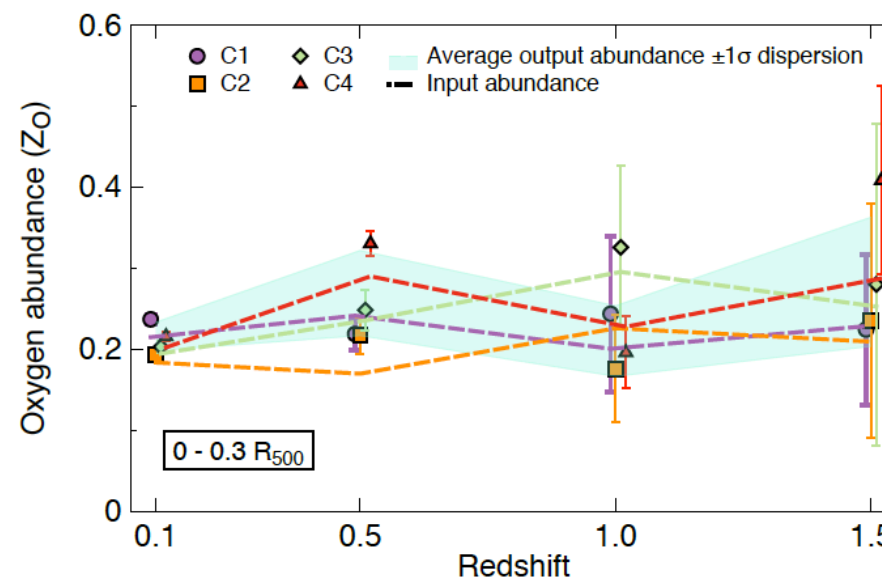


- Evolution of the metallicity (100ks)

- X-IFU can access metallicities in and outside the cluster's core
- Metals can be traced out to high redshift
- Background becomes the limiting factor

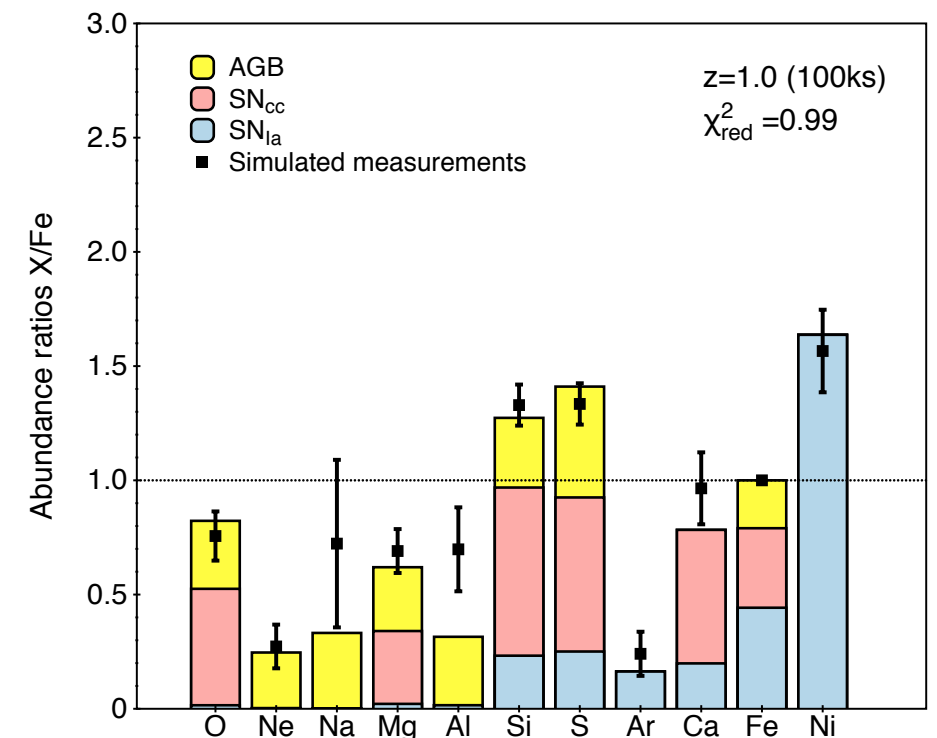
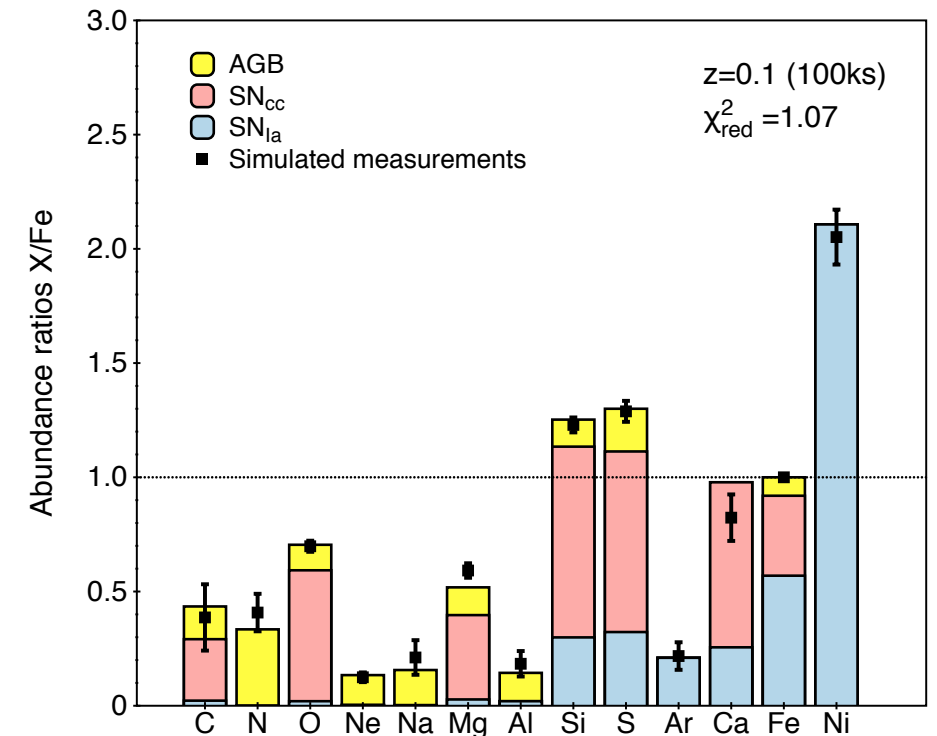
- Routine study of the evolution of metals in the ICM

- Important information on the chemical enrichment
- Validation of current pre-enrichment models



Cucchetti+18 (in press)

- The X-IFU will give access to abundance ratios with unprecedented accuracy
  - Main and rarer elements are accurately recovered
  - Investigations of abundance ratios with typical exposure times of the X-IFU
  - Abundance ratios can be found out to at least  $z=1$  for main elements
- Testing the enrichment models through time
  - Yields are recovered with good accuracy in both cases (self-consistency with the model)
  - Slight changes in the yields through time  $\implies$  key to understanding evolution in future data.
  - The X-IFU will allow deeper tests of enrichment schemes





- Athena will provide breakthrough observations of galaxy clusters and groups
  - High spatial resolution and unprecedented spectral resolution observations
  - Faint lines will be resolved for the first time, glimpse already given by *Hitomi*
- Probing the evolution of clusters of galaxies
  - In depth thermo-dynamics of clusters (bulk motions and turbulence, entropy, temperature,...)
  - High-quality information on the cluster physical properties with typical exposures
  - Insight on the chemical enrichment of the Universe both locally and across time
  - Possibility to test pre-enrichment models and ultimately enrichment schemes

**Plenty of breakthrough science ahead!**

# Probing the chemical enrichment of clusters of galaxies with the X-IFU



**Edoardo Cucchetti (IRAP Toulouse),**

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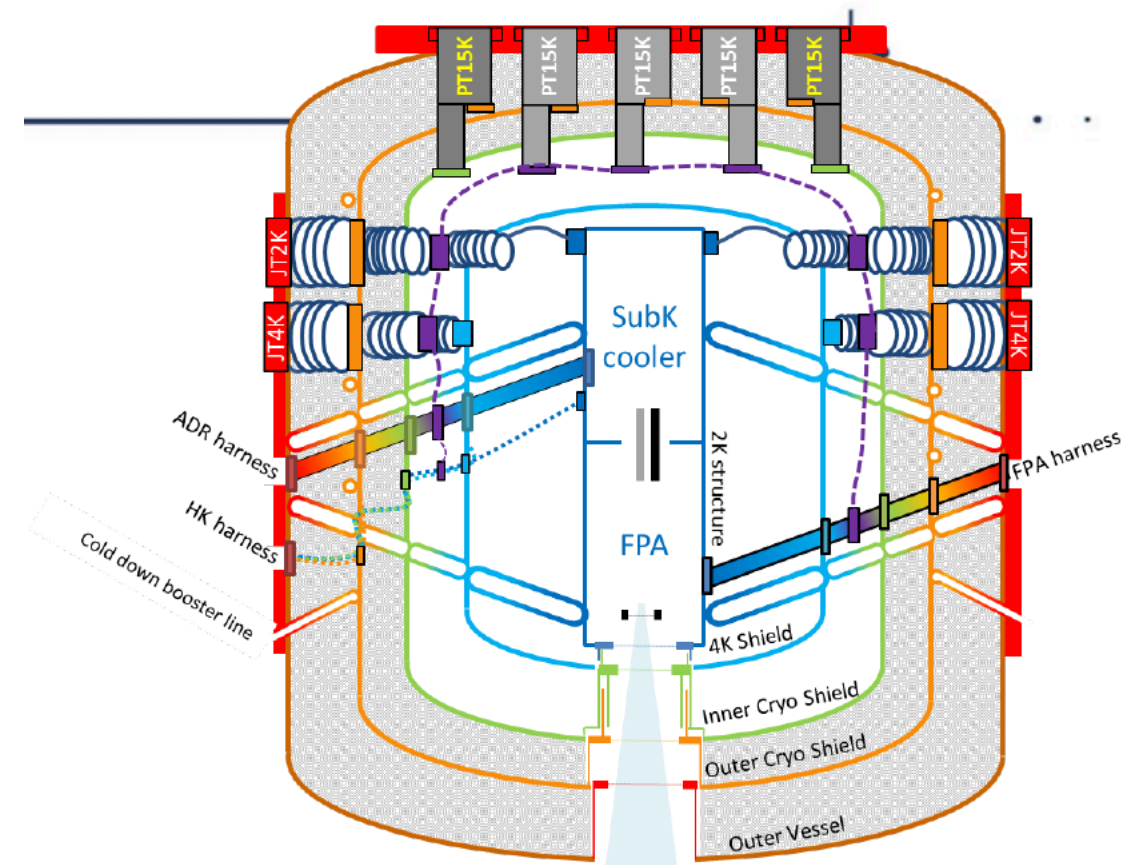
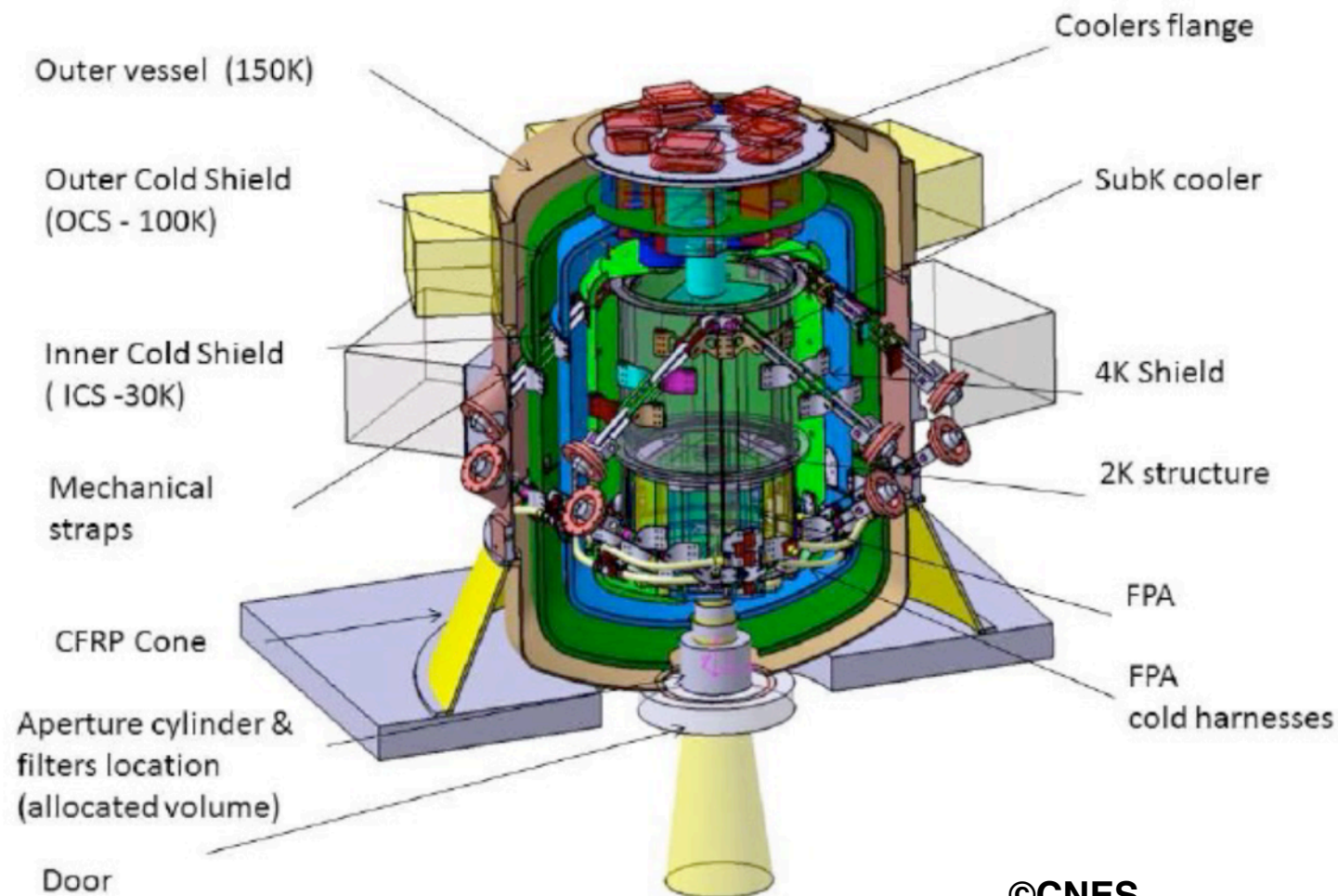
Athena Palermo Conference 26/09/2018



# The X-ray Integral Field Unit

ATHENA

- Cryogenic instrument @50mK
- ~800kg of total mass

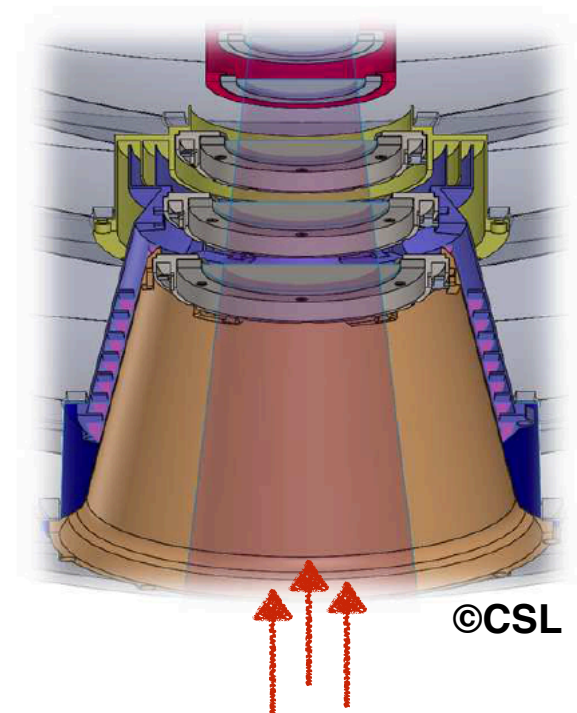
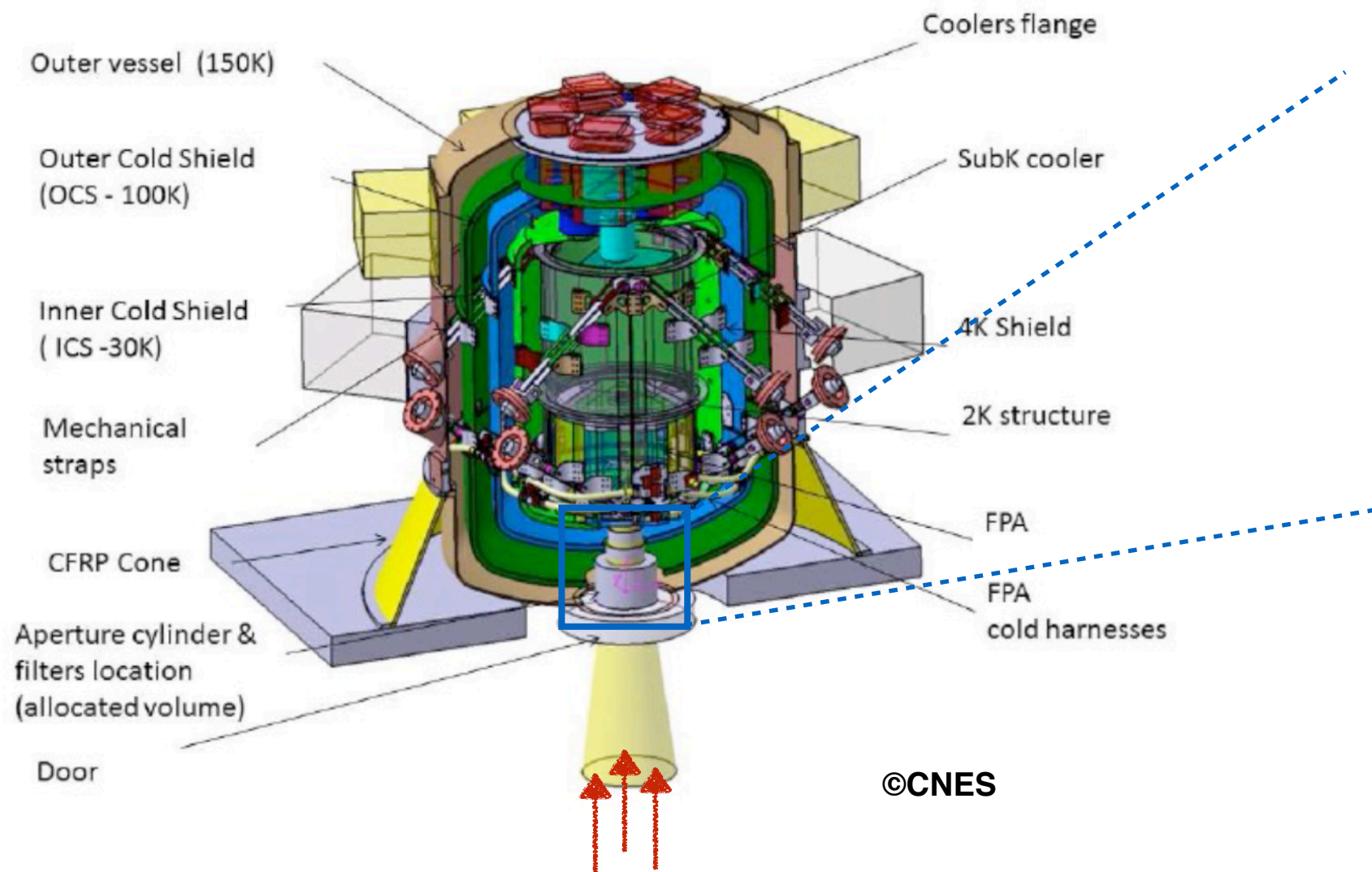




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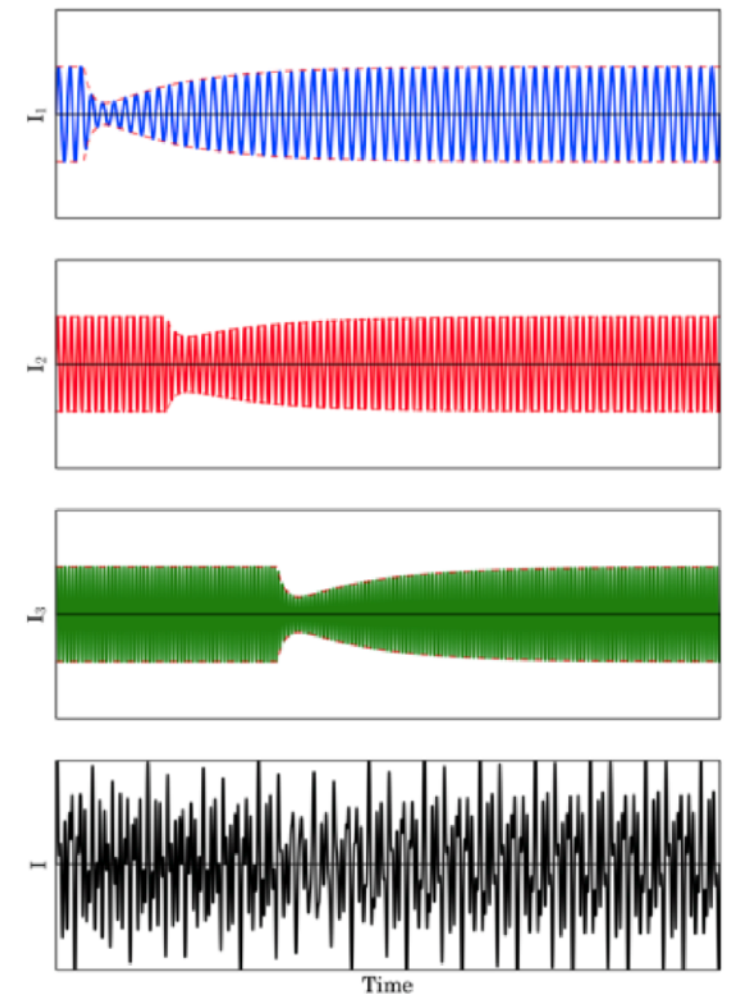
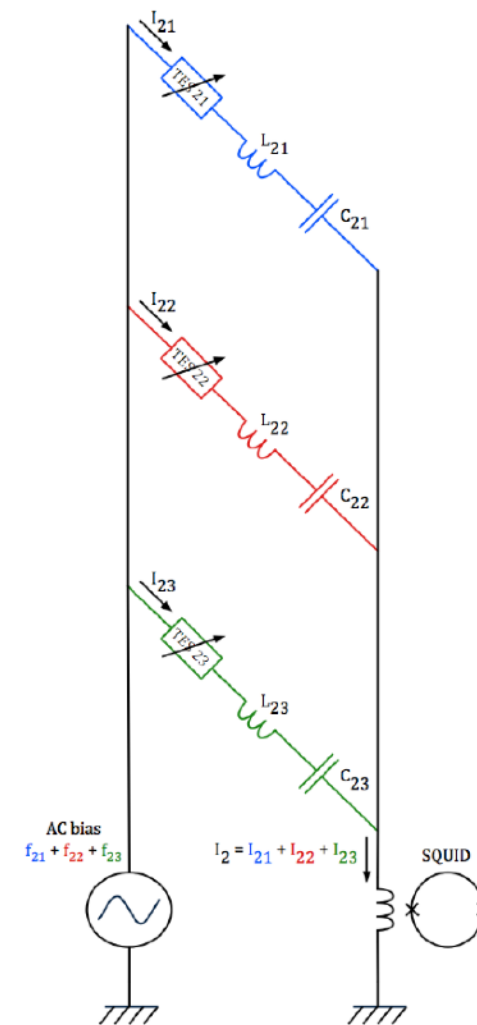
ATHENA

- Aperture cylinder focuses the light into the instrument
- 5 filters to cut IR/visible light
- Low-energy cut of the instrument



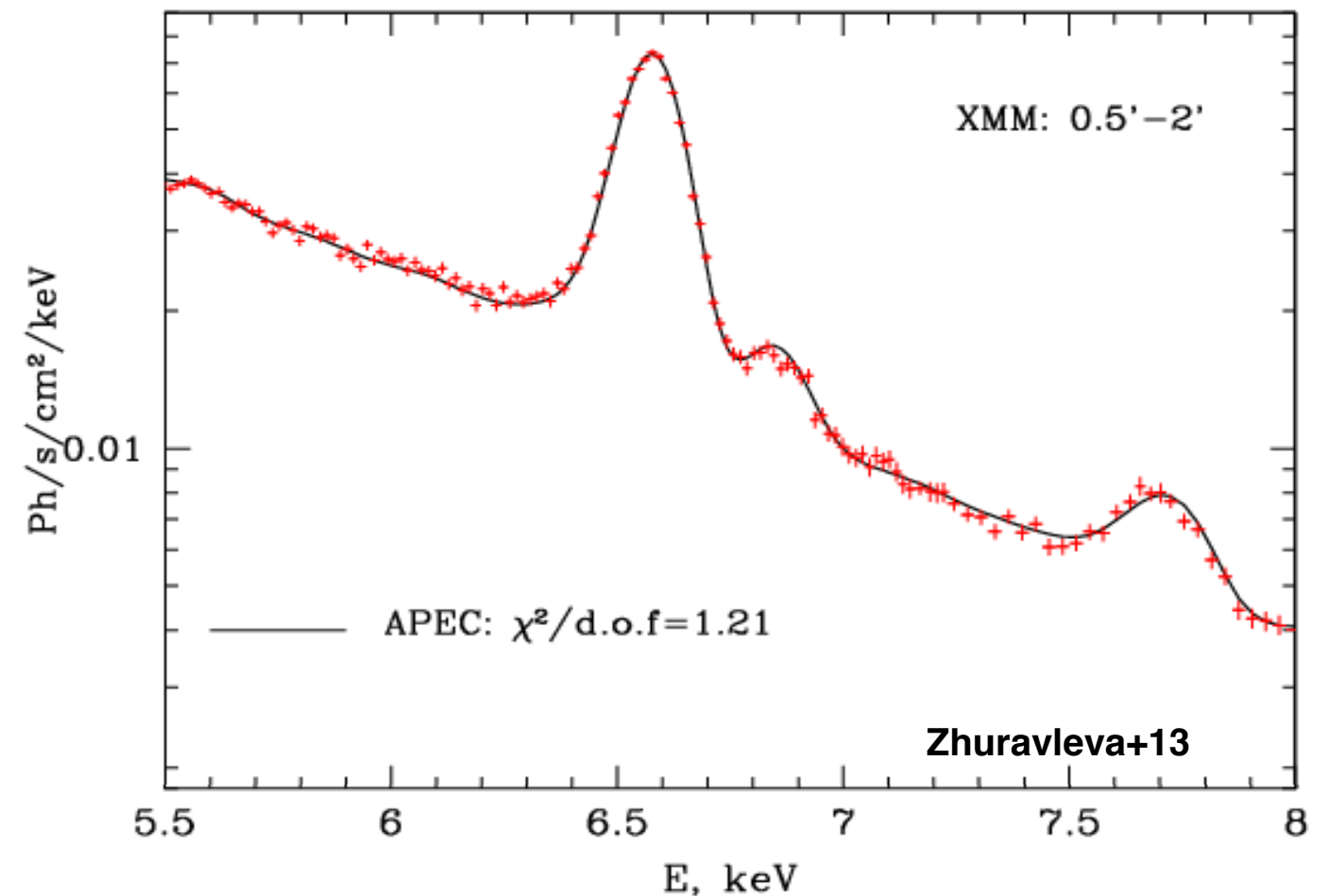
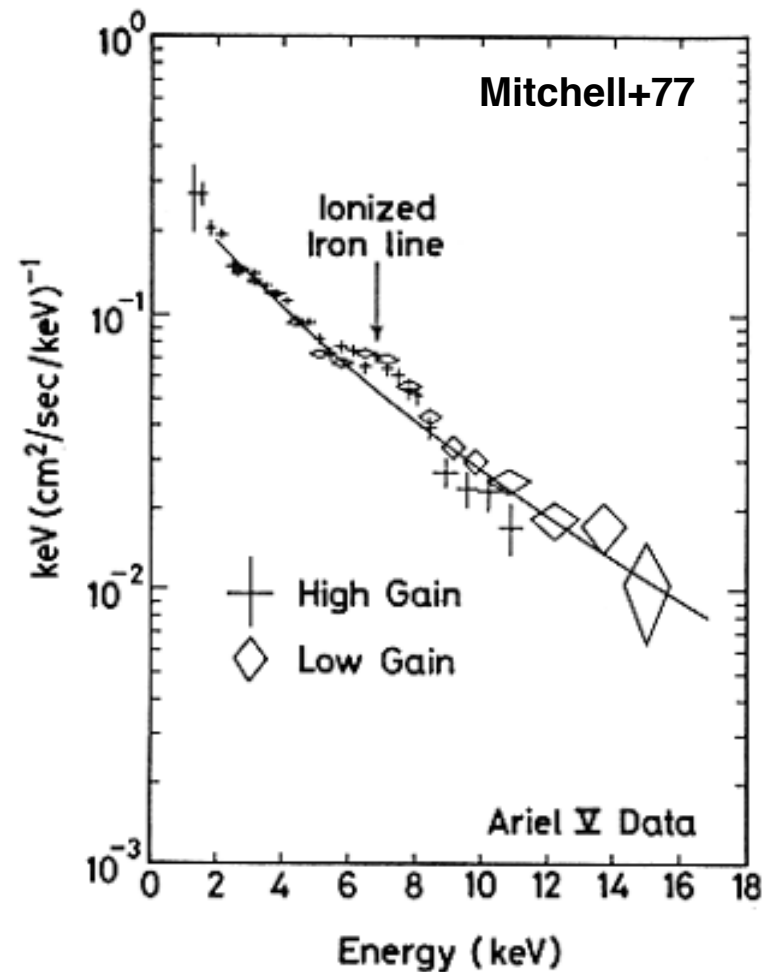


- Each TES is AC-biased
- Readout scheme:  
Frequency Domain Multiplexing (FDM)
- One frequency carrier per pixel ([1-5] MHz)
- 96 channels of 40 pixels
- Pulse processing and grading
- Obtain the "Pulse-Height" of the event



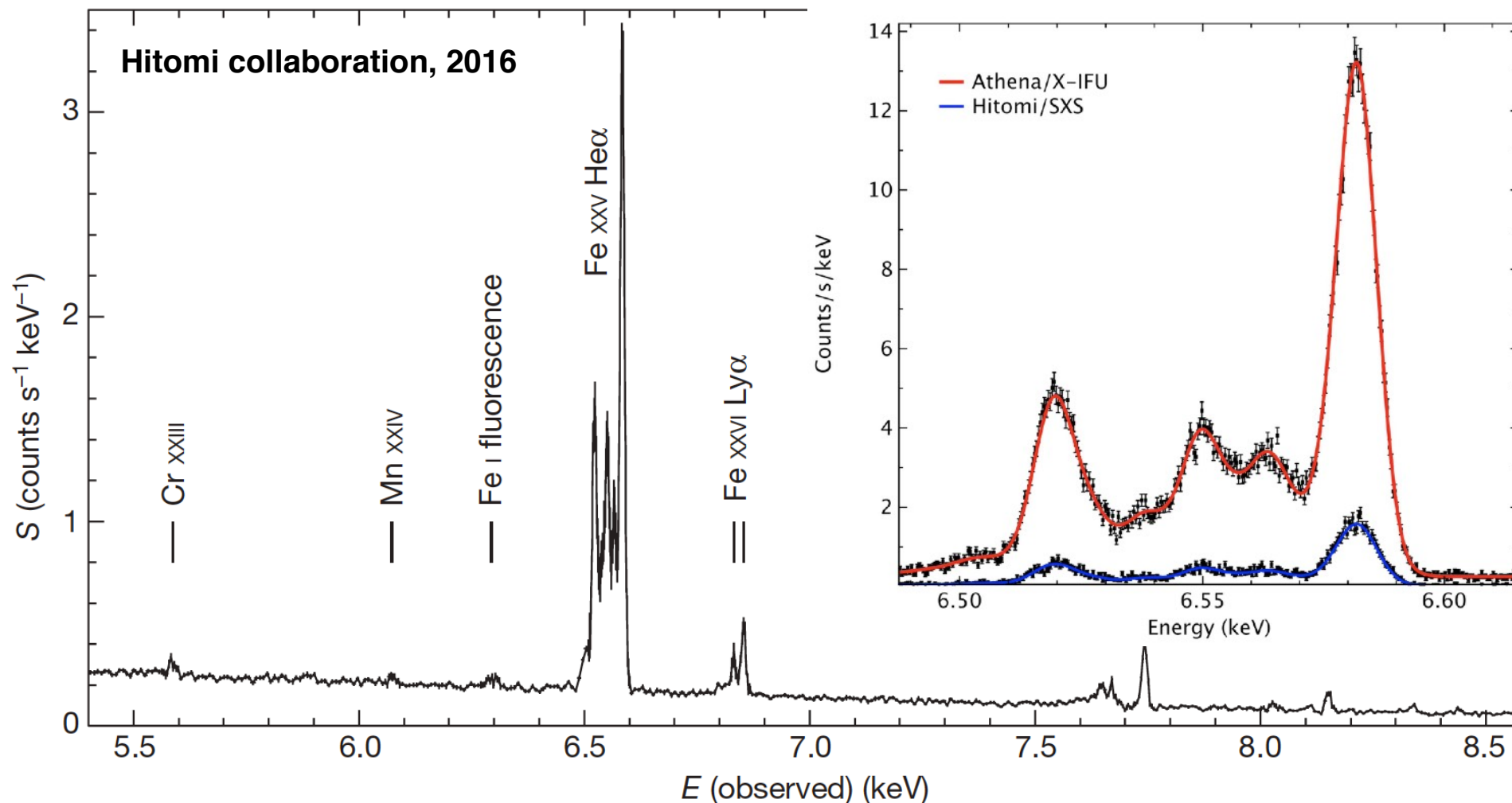
Ravera+14

# The need for high resolution spectroscopy



- Metal content is traced through spectroscopic studies of the clusters
  - Spatially-resolved line with CCD resolution, high-resolution lines through gratings (no spatial information)
  - Enrichment studies need to couple spatial information with high spectral resolution
  - Breakthroughs with *Hitomi*, more expected with *XRISM*





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