
Amas de galaxies et grands relevés en rayons X. *L'apport de eROSITA.*

Nicolas Clerc

IRAP (CNRS/UPS/CNES) – Toulouse

Atelier sondes de l'action Dark Energy

19 Novembre 2019 – Institut Henri Poincaré

Outline

I. Motivation

- *Formation of the large-scale structure and cosmology*

II. The *eROSITA* all-sky survey

- *Collecting large samples with X-ray observations*

III. Population studies in the observable domain

- *A new approach to large cluster samples*
- *Massive confirmation of large cluster samples*

Outline

I. Motivation

- *Formation of the large-scale structure and cosmology*

II. The *eROSITA* all-sky survey

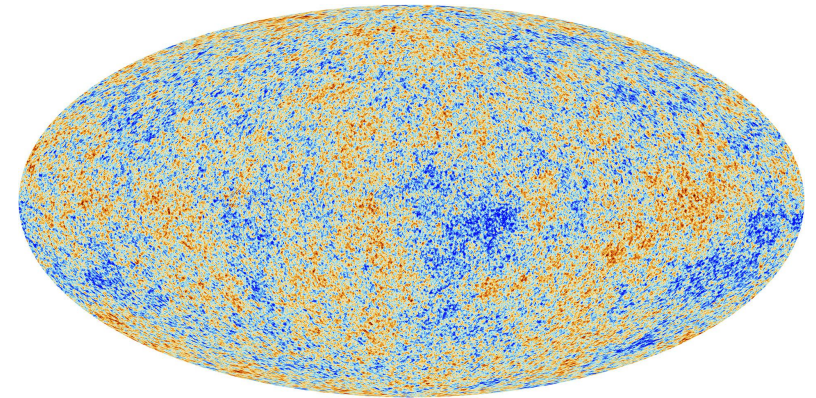
- *Collecting large samples with X-ray observations*

III. Population studies in the observable domain

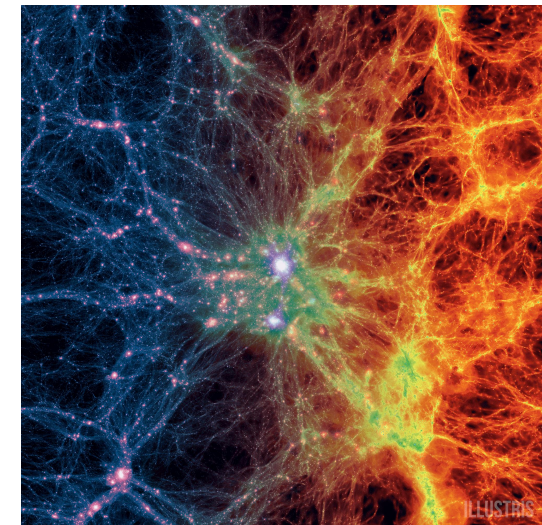
- *A new approach to large cluster samples*
- *Massive confirmation of large cluster samples*

Clusters of galaxies ; large-scale structure

- **Coherent model of structure formation**
- **Primordial fluctuations grow in expanding universe:**
 - Dark matter? Accelerated expansion?
 - Emergence of cosmic web?
- **Clusters of galaxies form last:**
 - Nature, origin of 1st structures?
 - Physical mechanisms entering their formation?

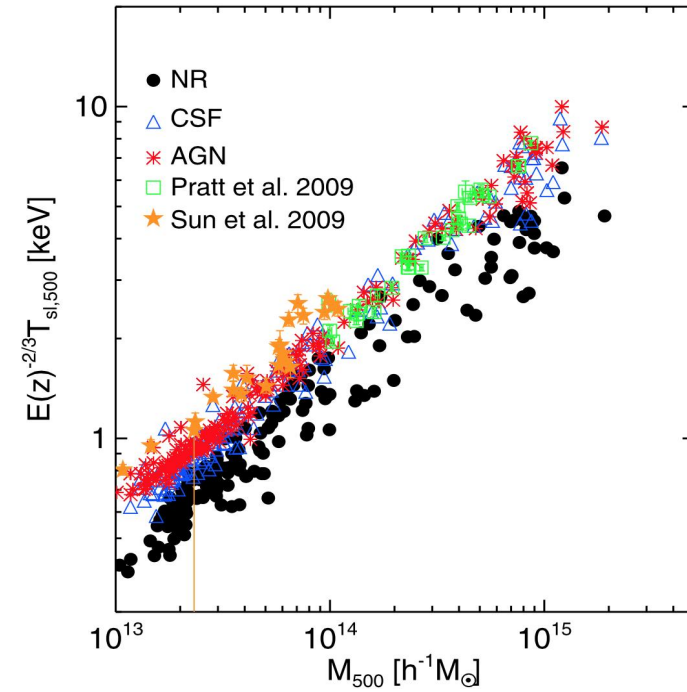
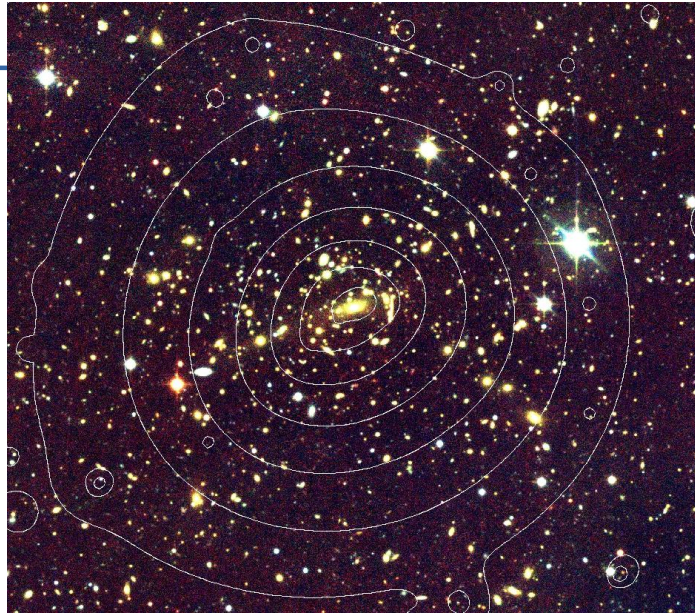


↓ (Planck) CMB =
Primordial fluctuations

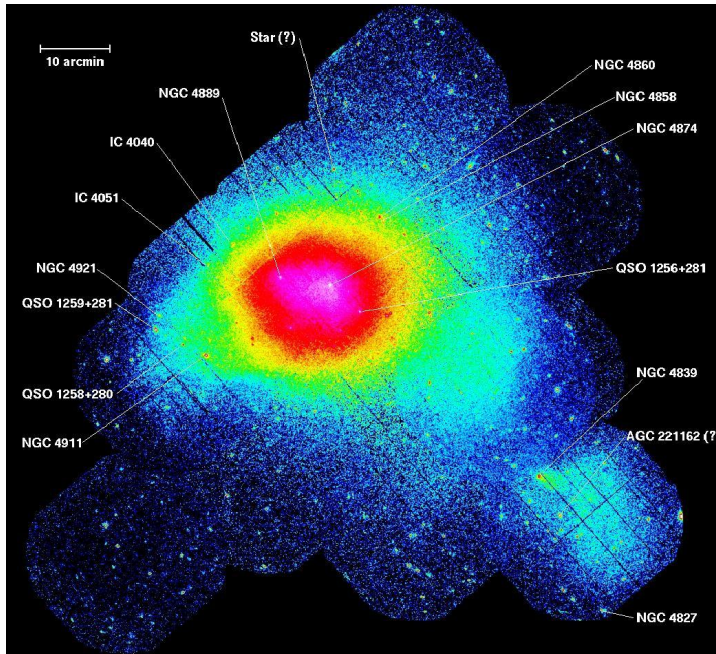


Dark matter ← → Gas density
(simulation $z=0$ "today")

Clusters of galaxies in X-rays

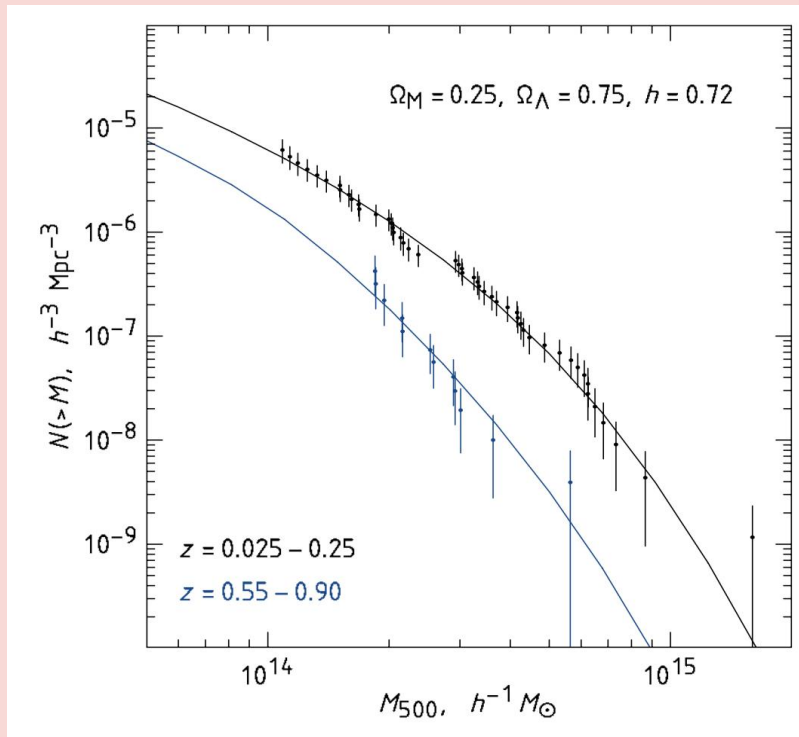


Data: Pratt et al. 2009 (clusters); Sun et al. 2009 (groups)
Simulations: Planelles et al. 2014



- Hot gas = low-density plasma (15%)
 - Highly ionized (e.g. Fe XXV line)
 - Luminous and extended
- **X-ray: clean and efficient selections**
- **Mass-observable link and evolution**

Clusters of galaxies as cosmological probes

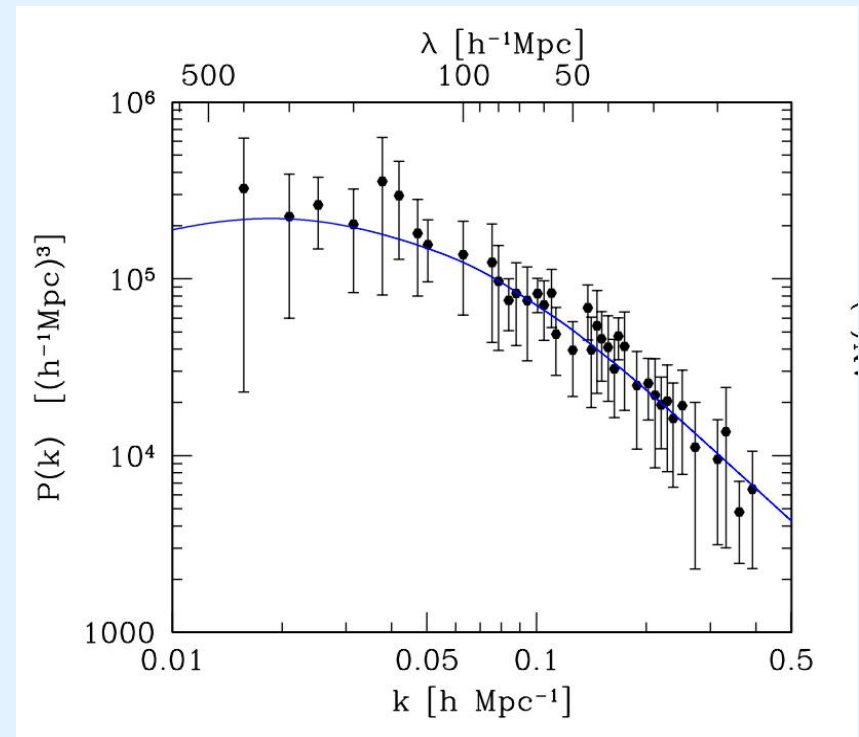


Vikhlinin+09

Growth of structures+expansion history

Halo mass function $n(M, z)$

Physics of X-ray emitting intracluster gas



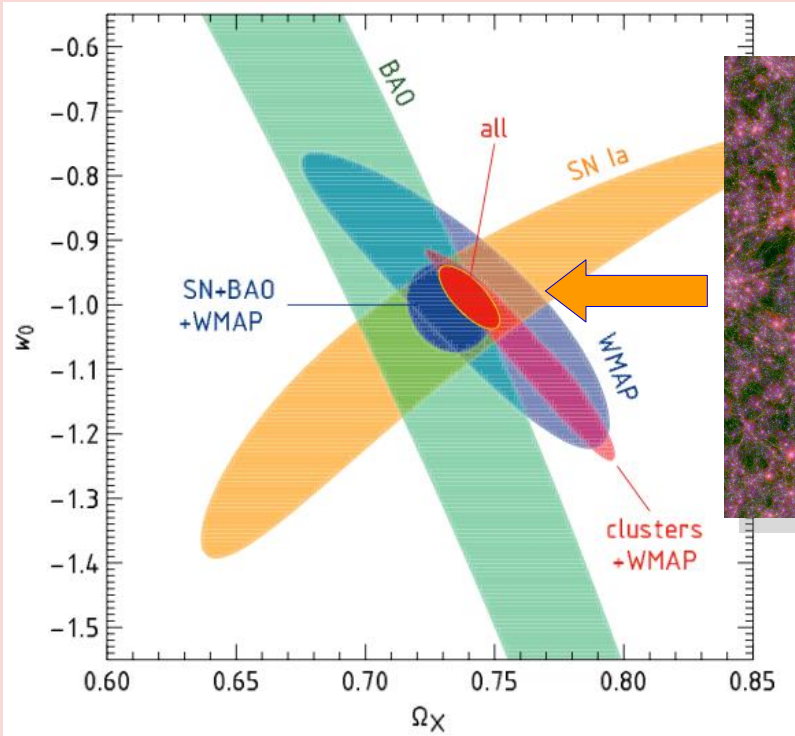
Schueker+03

Large-scale structure

$\xi(s ; z)$ and/or $P(k ; M, z)$

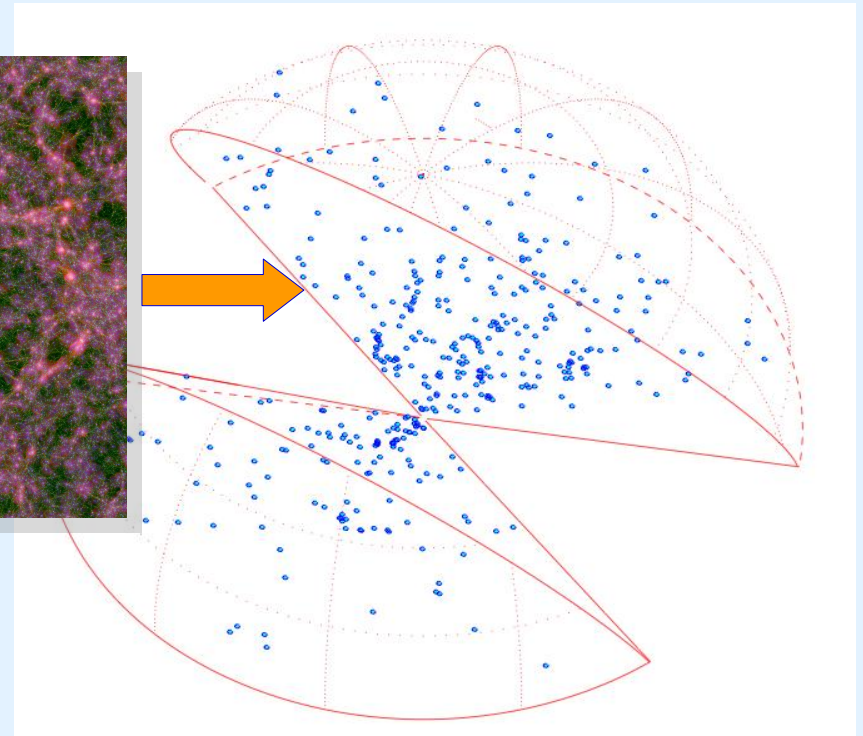
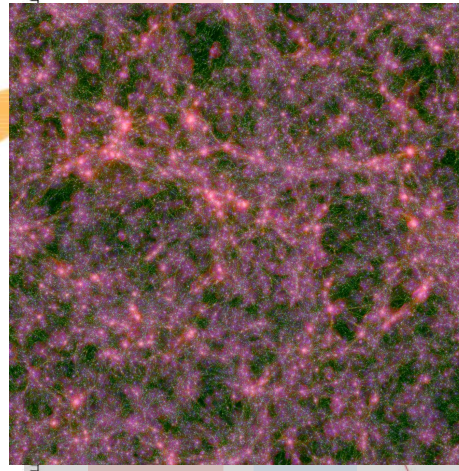
Using clusters as highly biased tracers

Clusters of galaxies as cosmological probes



Vikhlinin+09

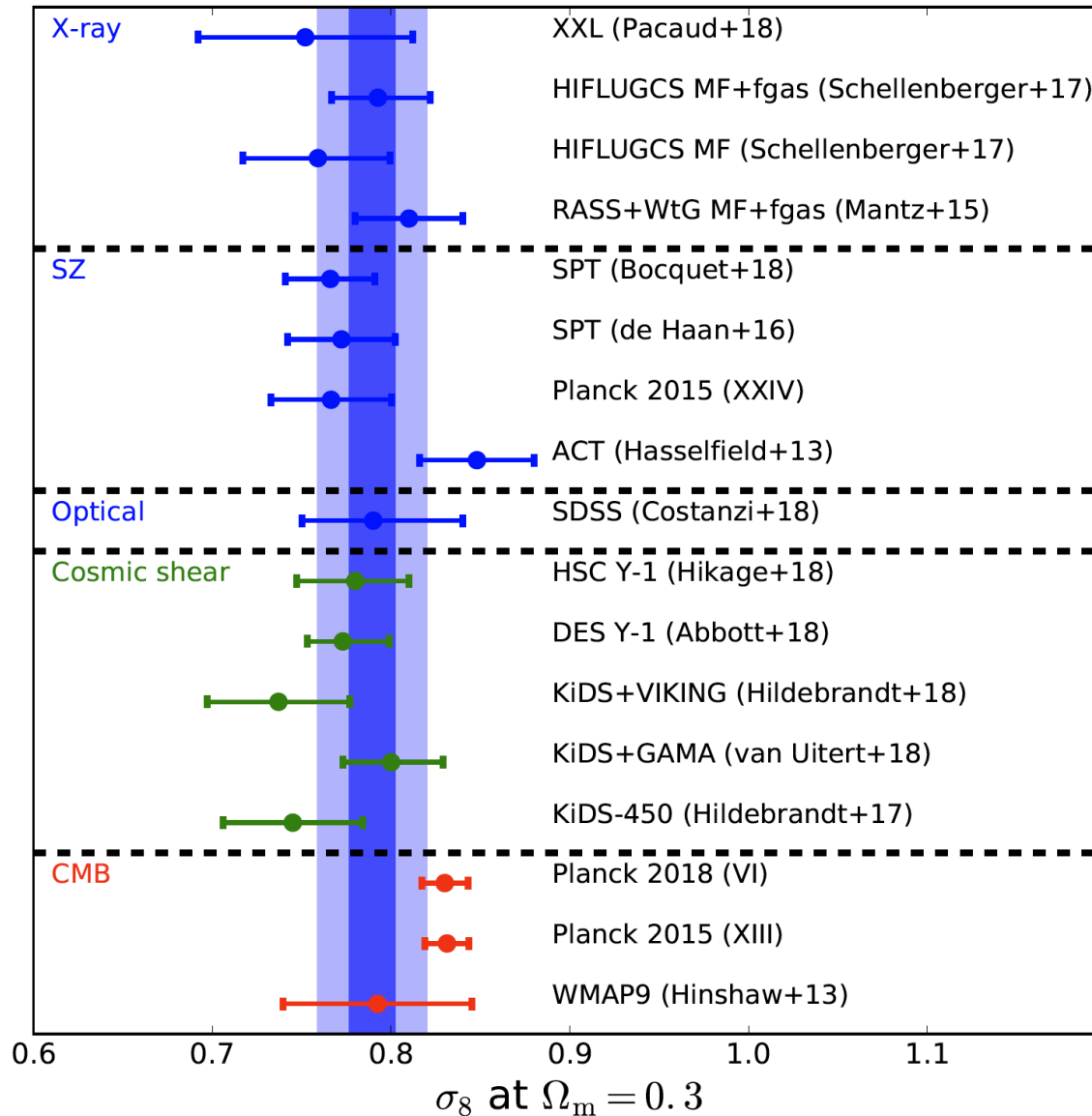
Growth of structures+expansion history
Halo mass function $n(M, z)$
Physics of X-ray emitting intracluster gas



Guzzo+09

Large-scale structure
 $\xi(s ; z)$ and/or $P(k ; M, z)$
Using clusters as highly biased tracers

Clusters of galaxies as cosmological probes



Outline

I. Motivation

- *Formation of the large-scale structure and cosmology*

II. The *eROSITA* all-sky survey

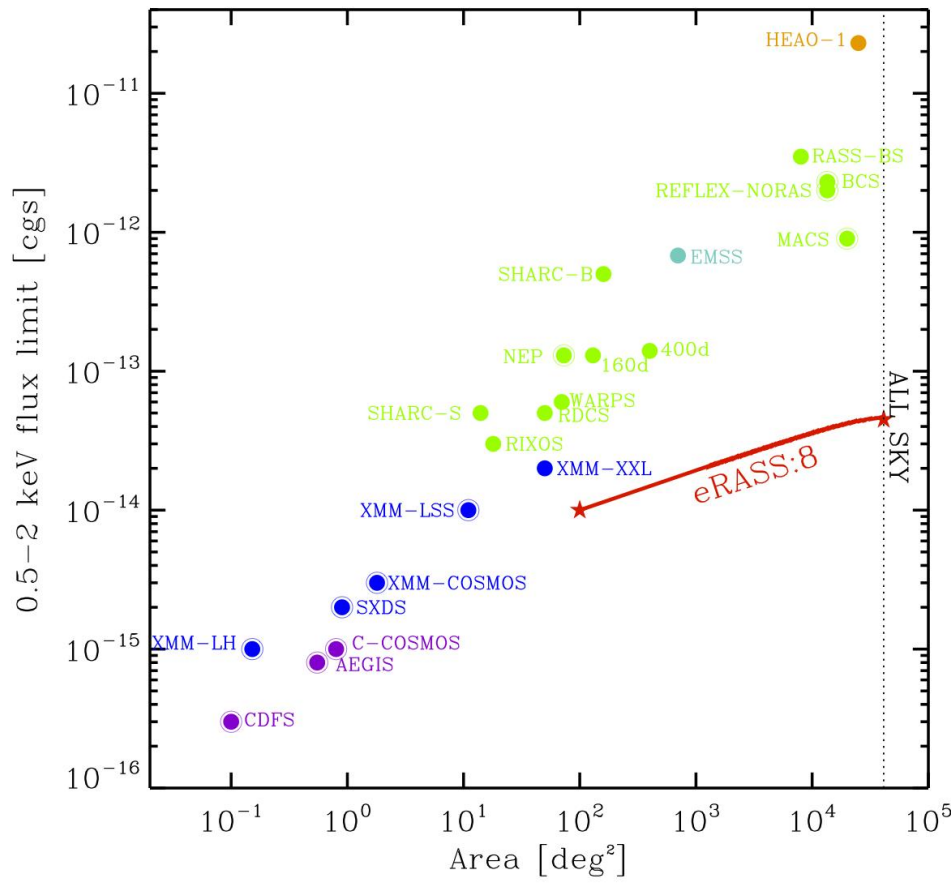
- *Collecting large samples with X-ray observations*

III. Population studies in the observable domain

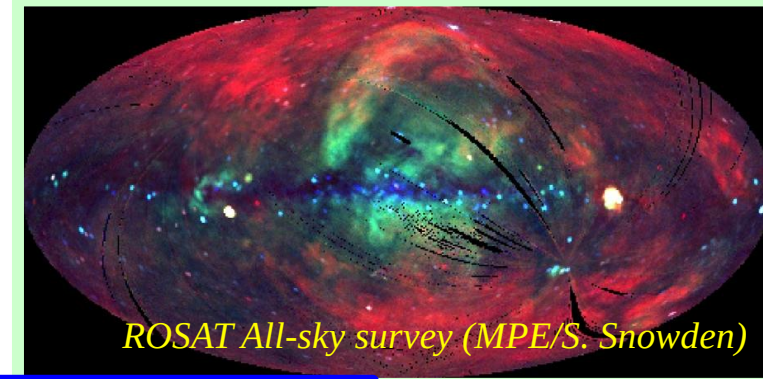
- *A new approach to large cluster samples*
- *Massive confirmation of large cluster samples*

Large galaxy cluster surveys in (soft) X-rays

Atelier sondes DE - 19.11.2019 - N.Clerc

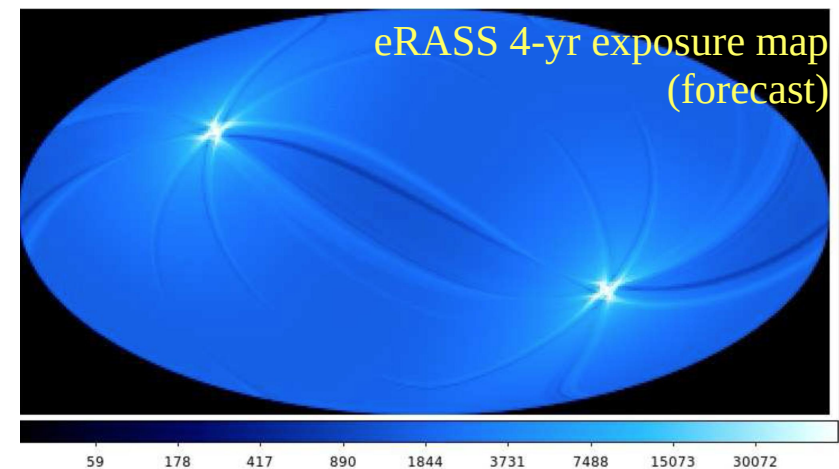
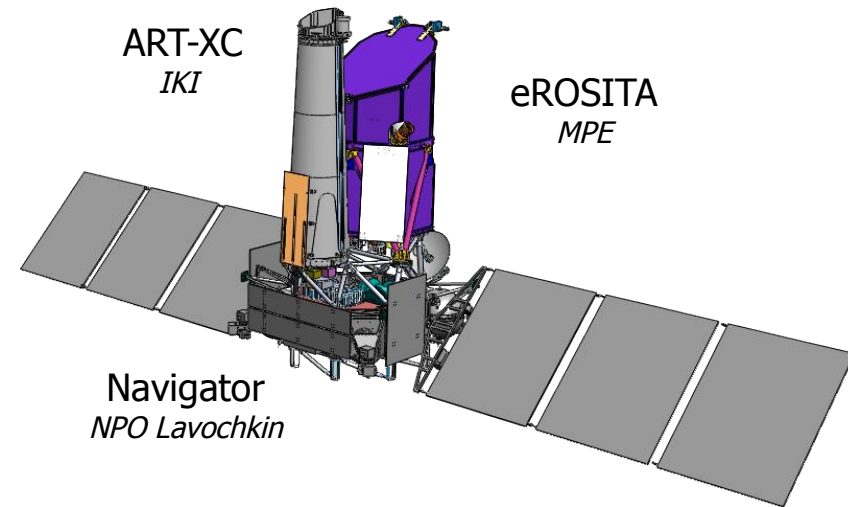


Merloni+12



The *eROSITA* all-sky survey

- **Launched to L2 from Baikonour (July 13th)**
 - 3 months flight to L2: *verification, calibration*
 - 4 yrs survey: 8x *all-sky*
 - 2.5 yrs pointed observations ($\sim 20\%$ GTO)
 - Data shared MPE (DE)/IKI (Ru)
 - PI: P. Predehl, PS: A. Merloni (MPE)
- **More than the successor of ROSAT!**
 - FoV = 0.8 deg^2
 - PSF: 28" (survey-averaged) ; 16.1" (on-axis)
 - $A_{\text{eff}} \sim \text{XMM} @ 1 \text{ keV}$
 - 0.3-10 keV ; $\Delta E/E \sim 20-50$
- ***eROSITA* is now in its Calibration/PV phase**
 - Excellent performance of the 7 telescopes+cameras. First light images public.



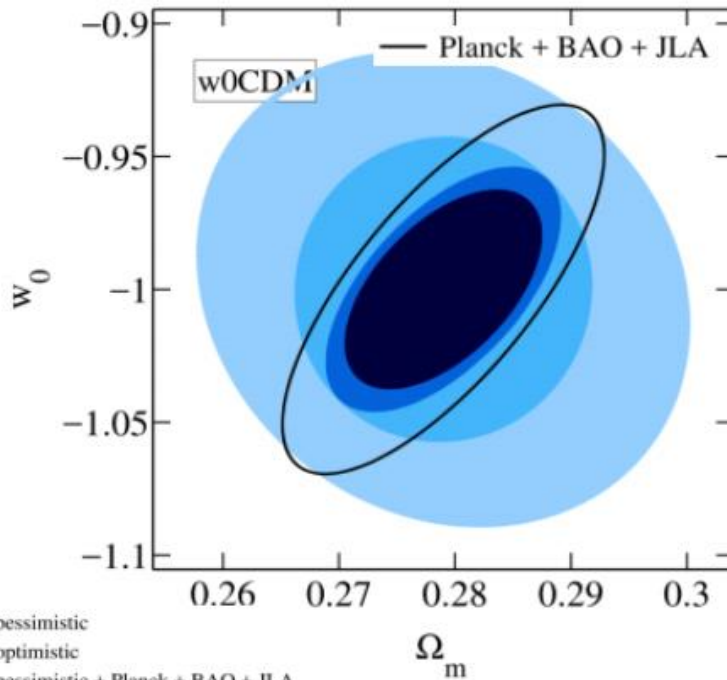
Credit: J. Robrade (Hamburg Obs.)

eROSITA forecasts on wCDM

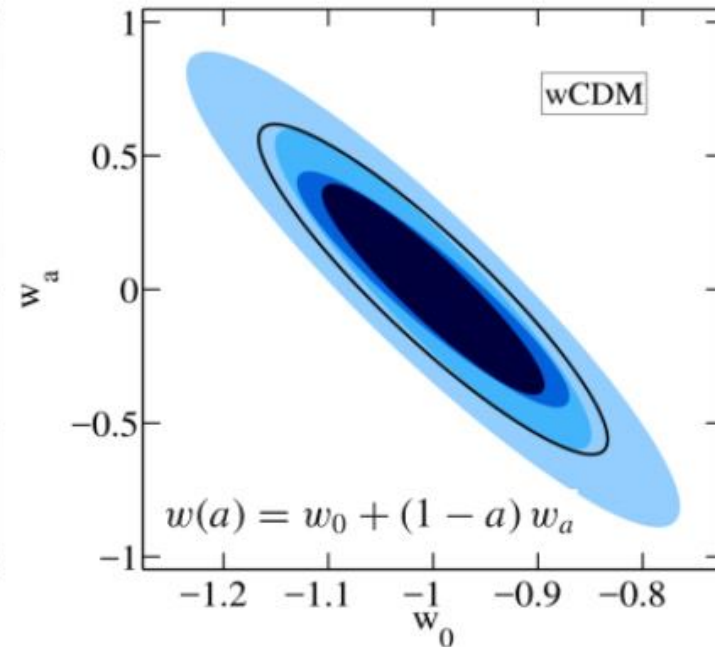
Forecasts on Dark-Energy Models

Pillepich et al. 2018

*e*RASS:8 + H_0 + BBN
 $\Delta w_0 = 4-6\%$



*e*RASS:8 + H_0 + BBN
 $\Delta w_0 = 10-15\%$
 $\Delta w_a = 0.4-0.6$



- eRASS8: pessimistic
- eRASS8: optimistic
- eRASS8: pessimistic + Planck + BAO + JLA
- eRASS8: optimistic + Planck + BAO + JLA

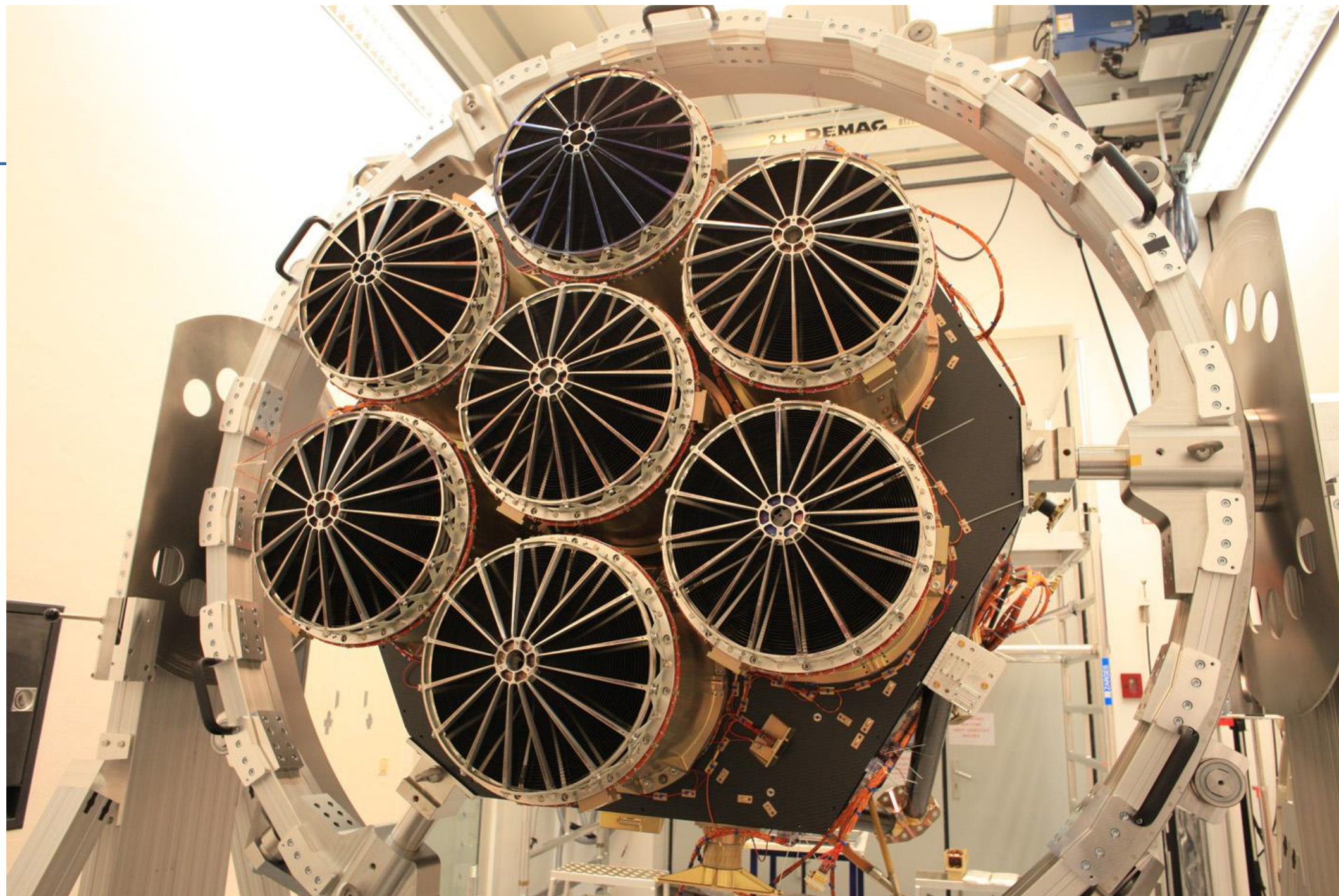
Baikonur, 13.7.2019



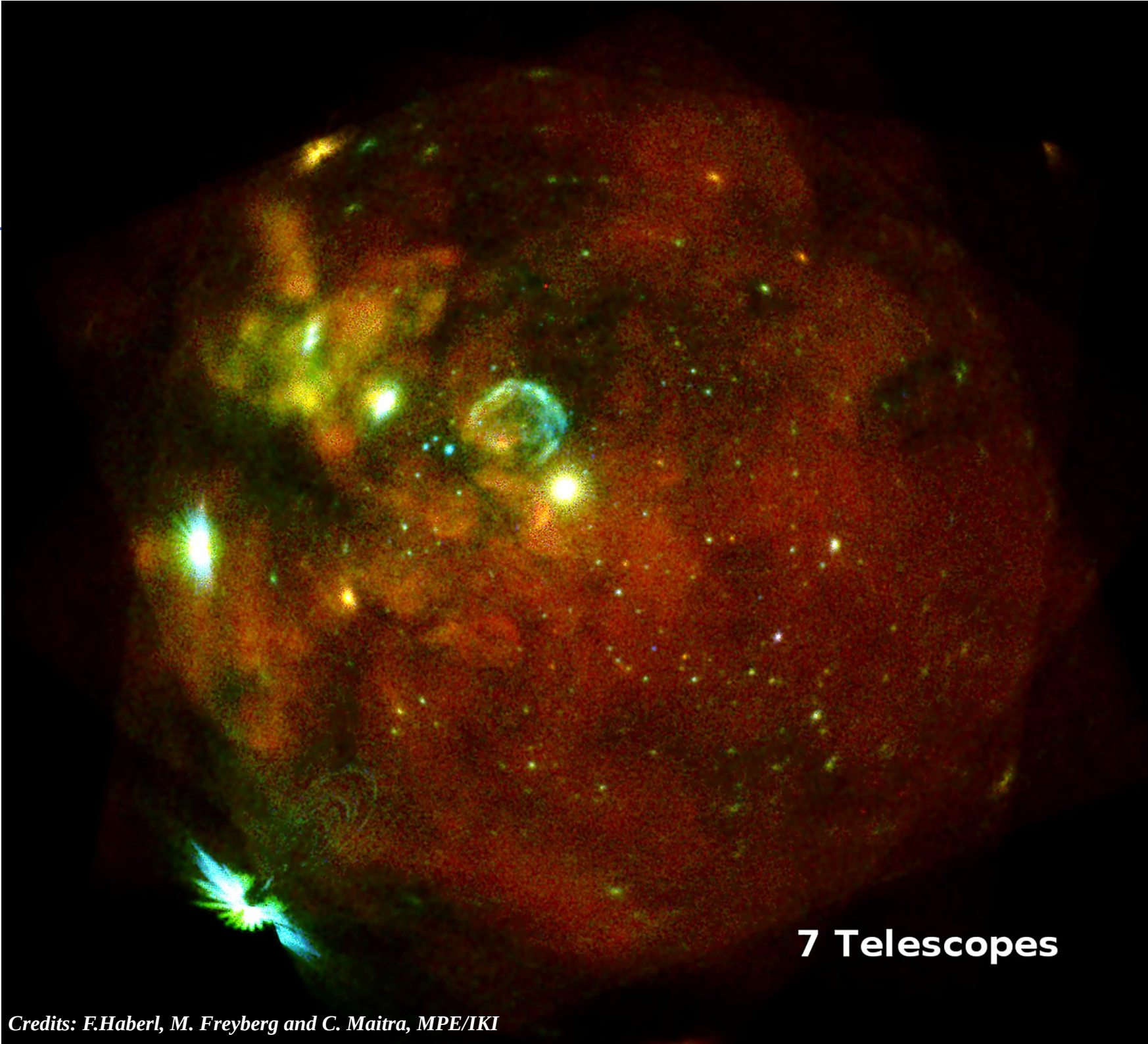
Quelle: Roscosmos

Credits: Roskosmos



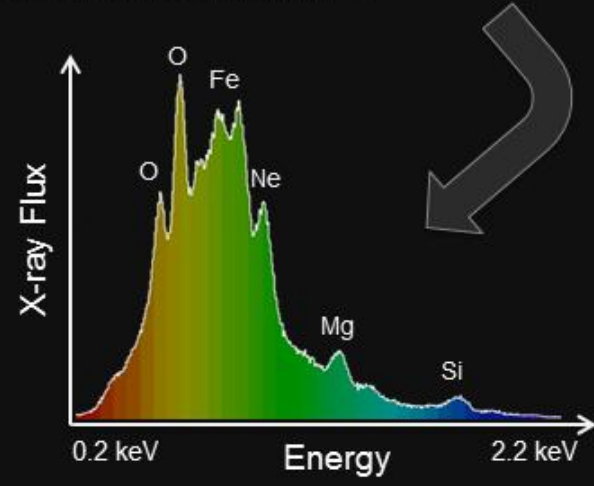
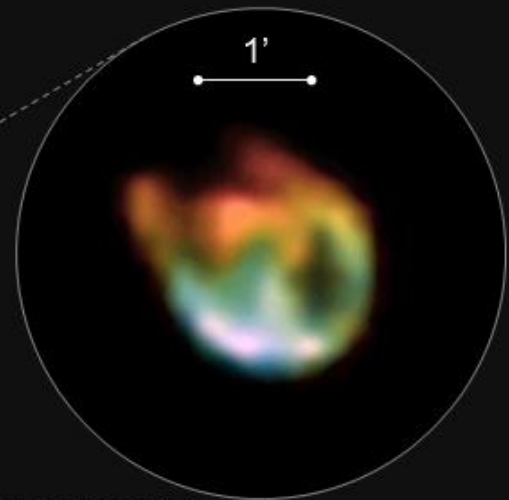
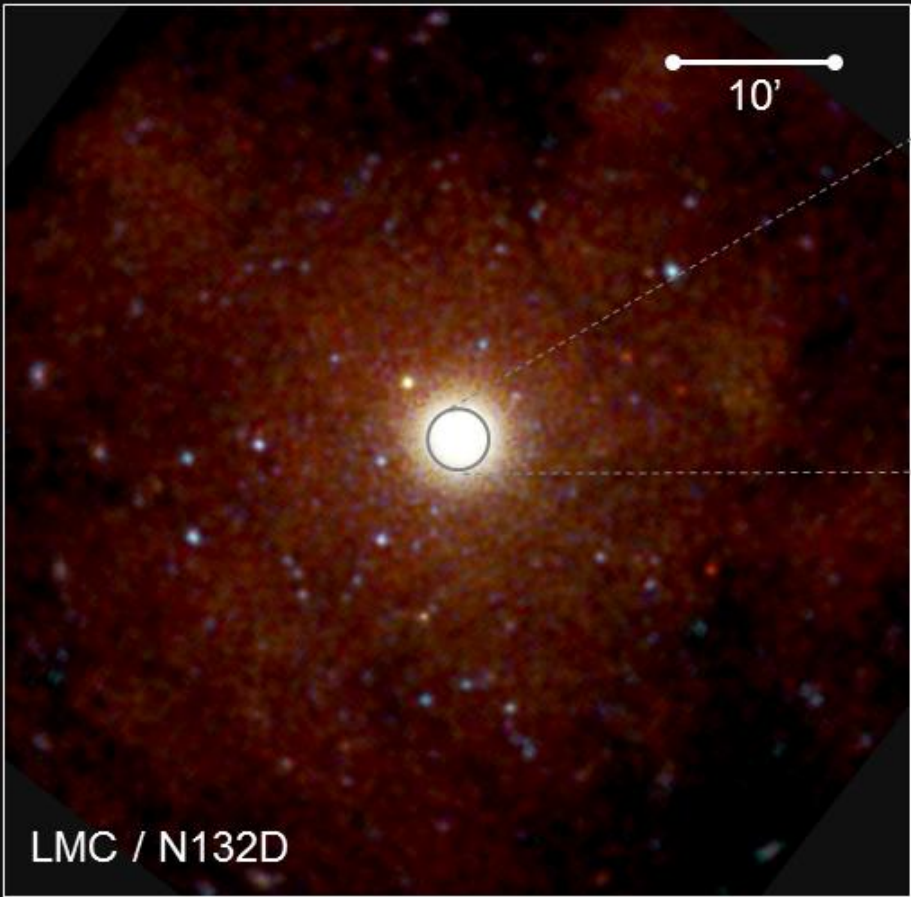


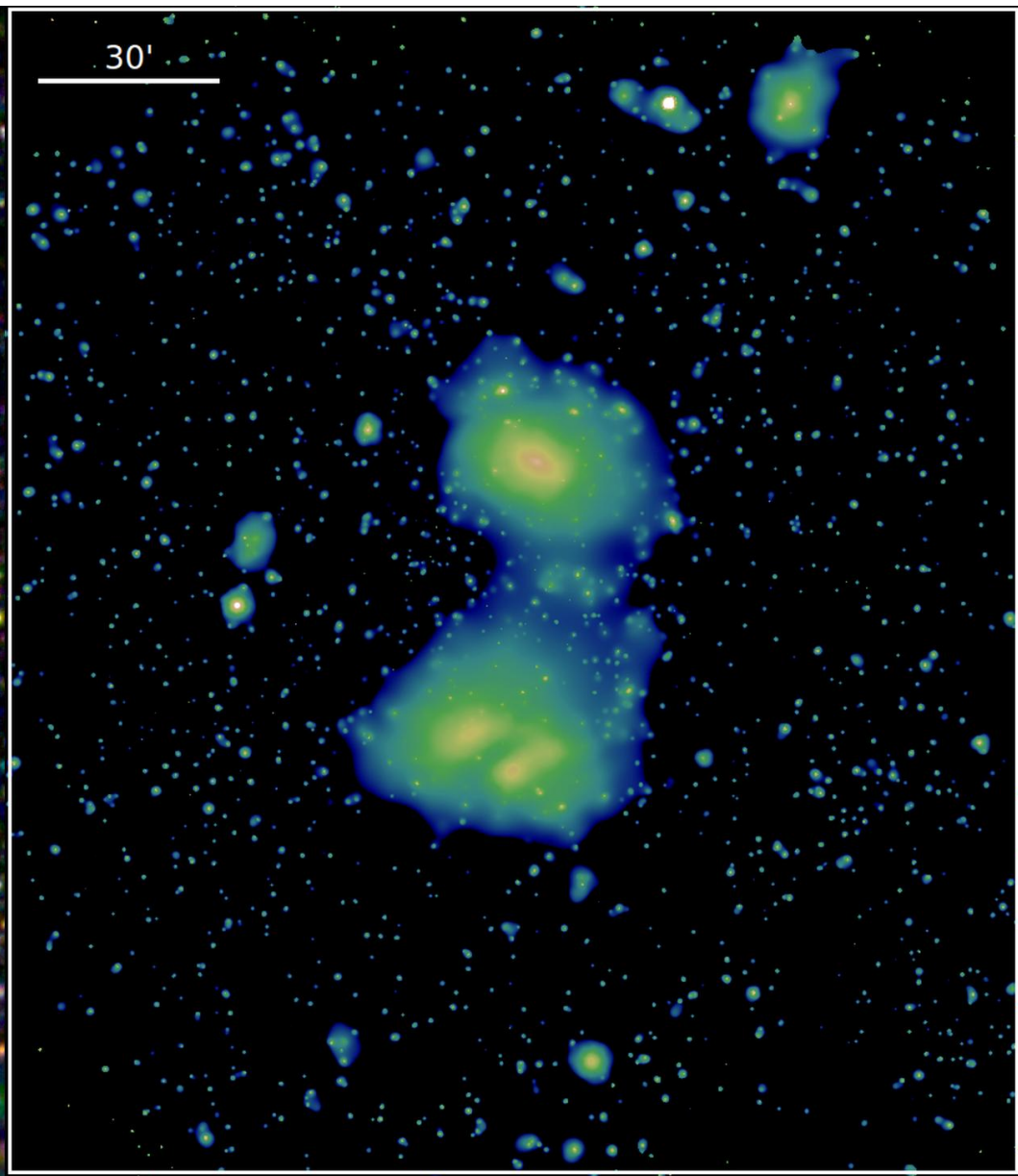
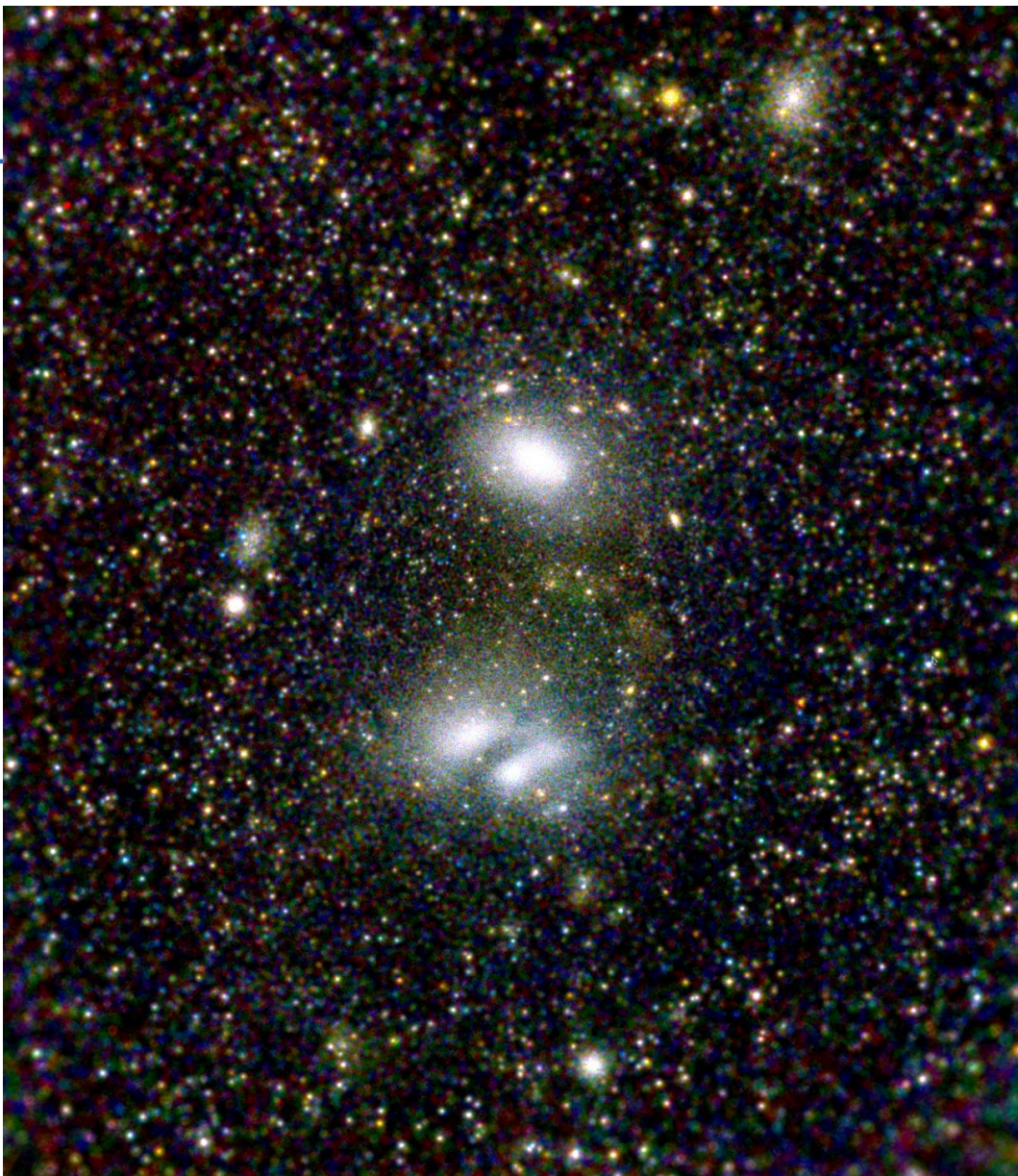
Credits: MPE



7 Telescopes

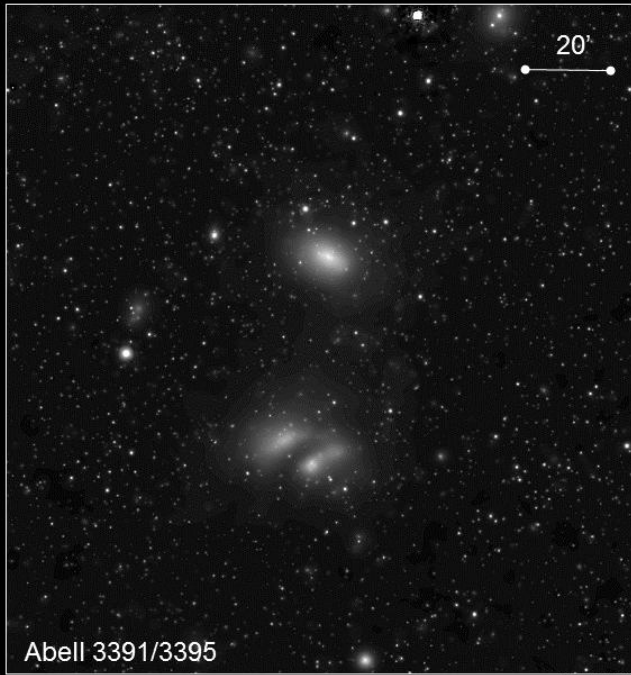
SRG / eROSITA 0.2 - 2.2 keV



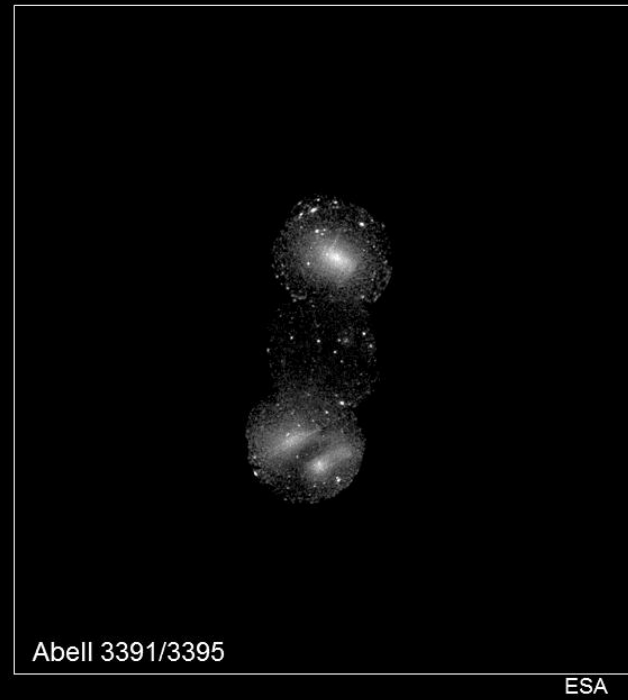


Credits: T. Reiprich (Univ. Bonn), M. Ramos-Ceja (MPE), F. Pacaud (Univ. Bonn), D. Eckert (Univ. Geneva), J. Sanders (MPE), N. Ota (Univ. Bonn), E. Bulbul (MPE), V. Ghirardini (MPE), MPE/IKI

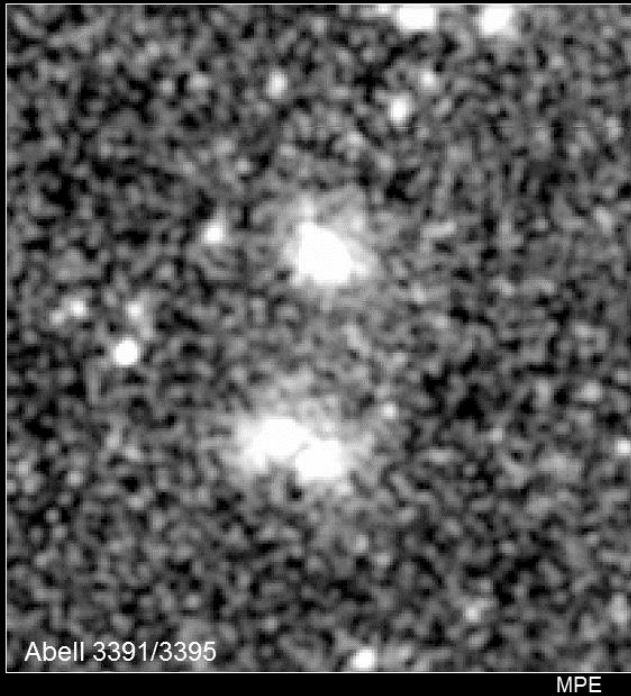
SRG/eROSITA 0.2-2.0 keV



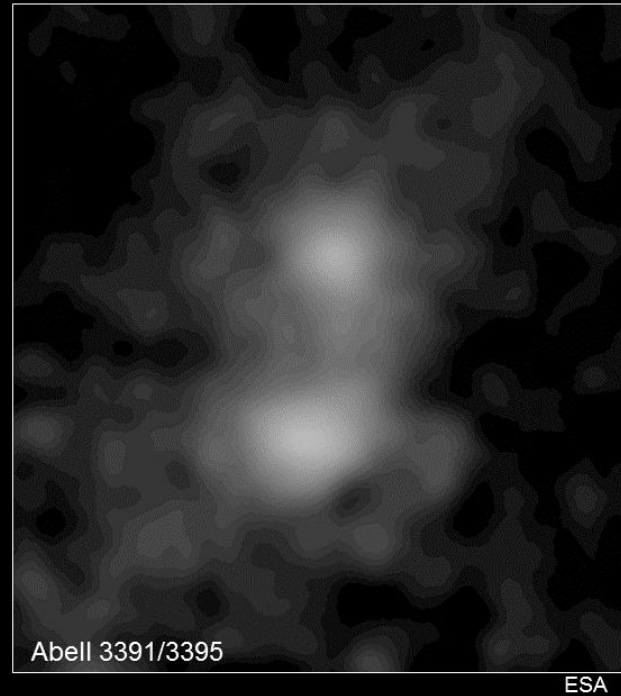
XMM-Newton 0.4-1.25 keV



ROSAT 0.5-2.0 keV



Planck (sub-)mm



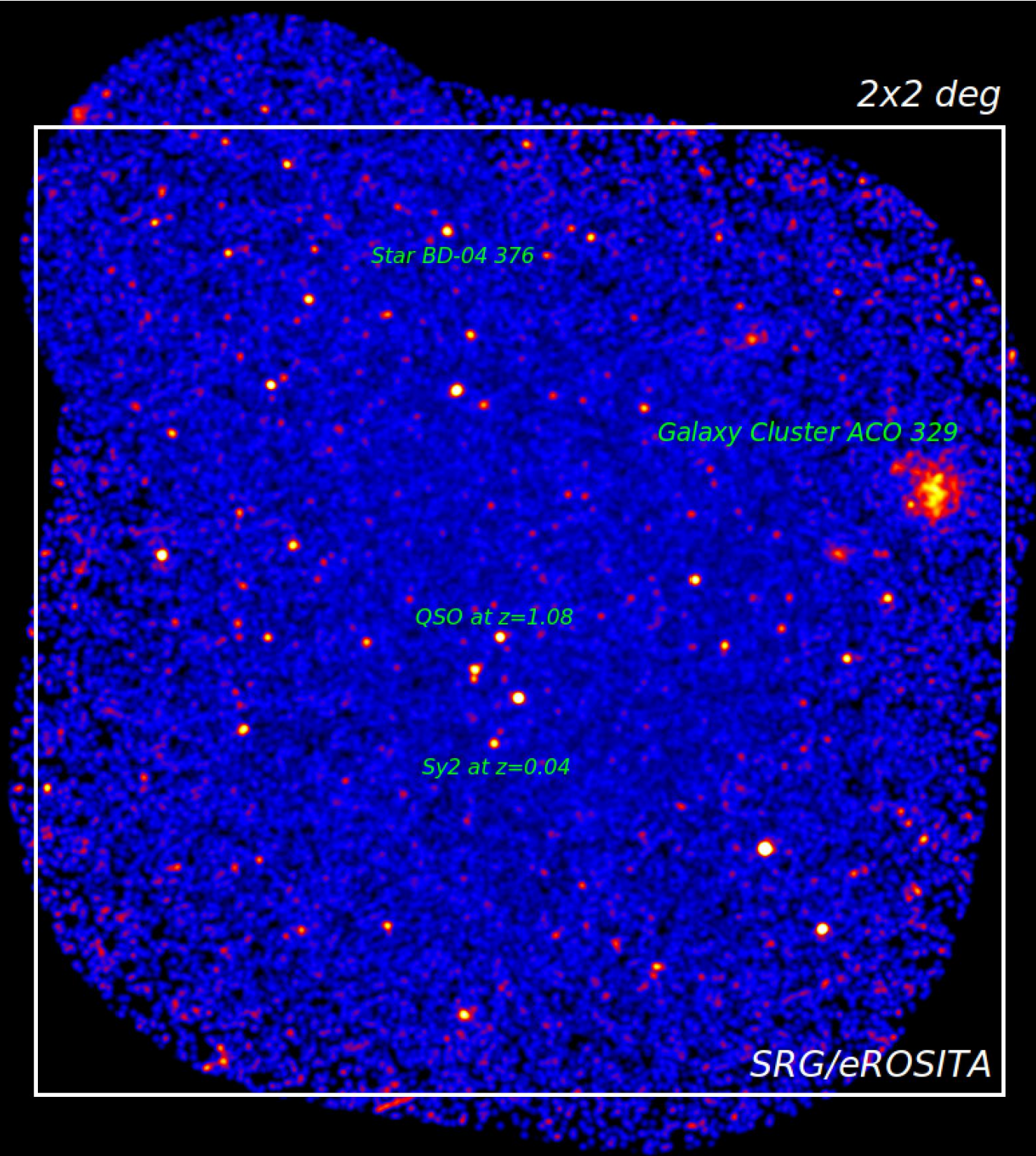
Credits: T. Reiprich (Univ. Bonn), M. Ramos-Ceja (MPE), F. Pacaud (Univ. Bonn), D. Eckert (Univ. Geneva), J. Sanders (MPE), N. Ota (Univ. Bonn), E. Bulbul (MPE), V. Ghirardini (MPE), J. Erler (Univ. Bonn), A. Veronica (Univ. Bonn)

The eROSITA all-sky survey (pre-launch simulations)



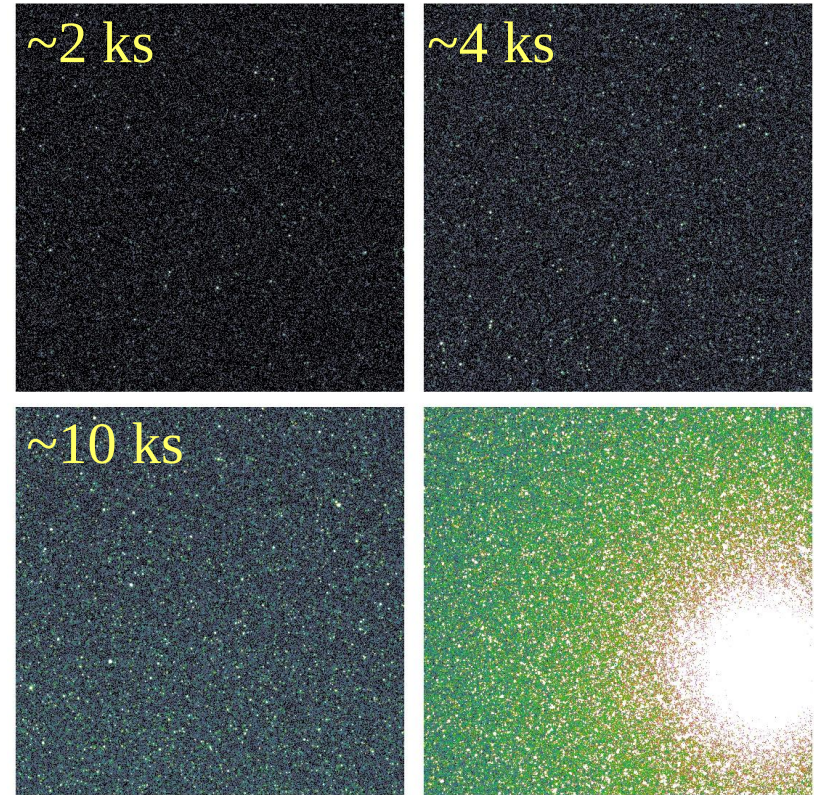
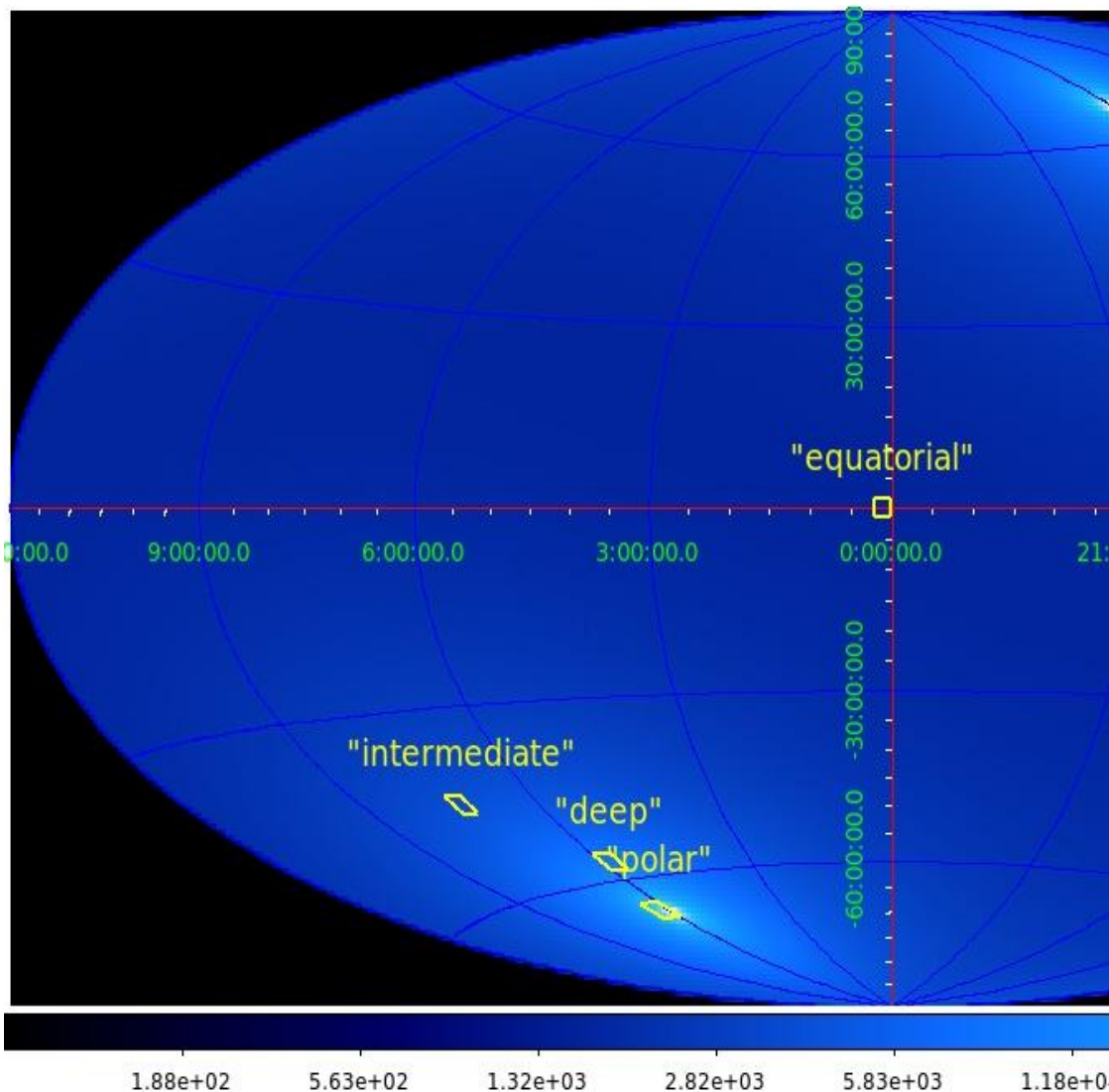
- **Point-source sensitivity:** $\sim 10^{-14}$ (0.5-2 keV) and 2×10^{-13} (2-10 keV) ergs/s/cm²
- **Extended sources sensitivity** $\sim 3-4 \times 10^{-14}$ ergs/s/cm²
- **Wide-area census of galaxy clusters (10^5) and active galactic nuclei (3M) in soft+hard X-rays bands**

Merloni et al. 2012 – Image credits: MPE, eROSITA_DE, XMM-XXL



“Synthetic” simulations

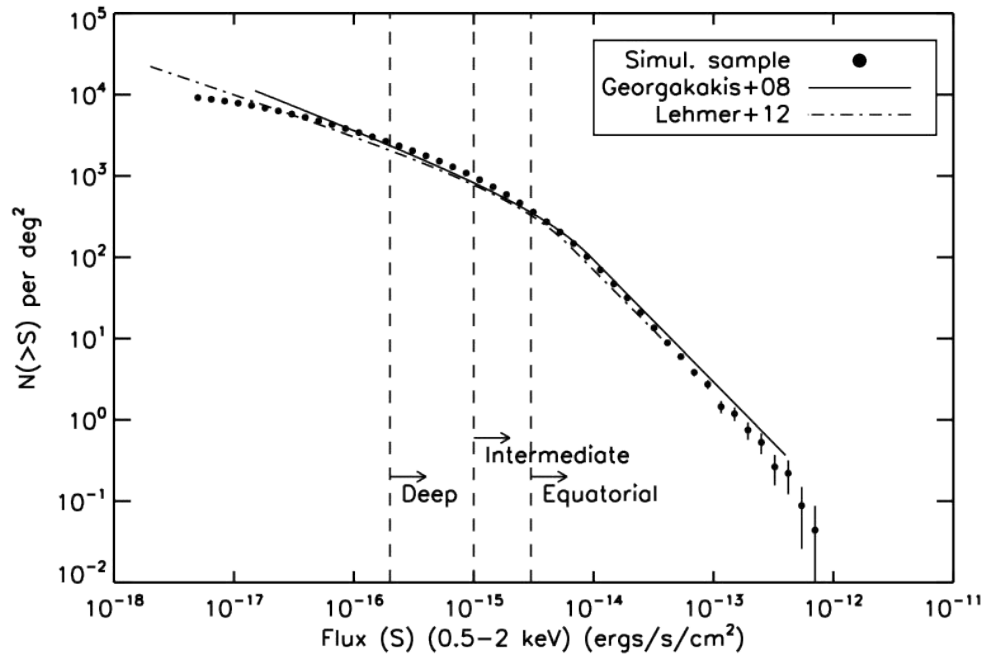
Atelier sondes DE - 19.11.2019 - N.Clerc



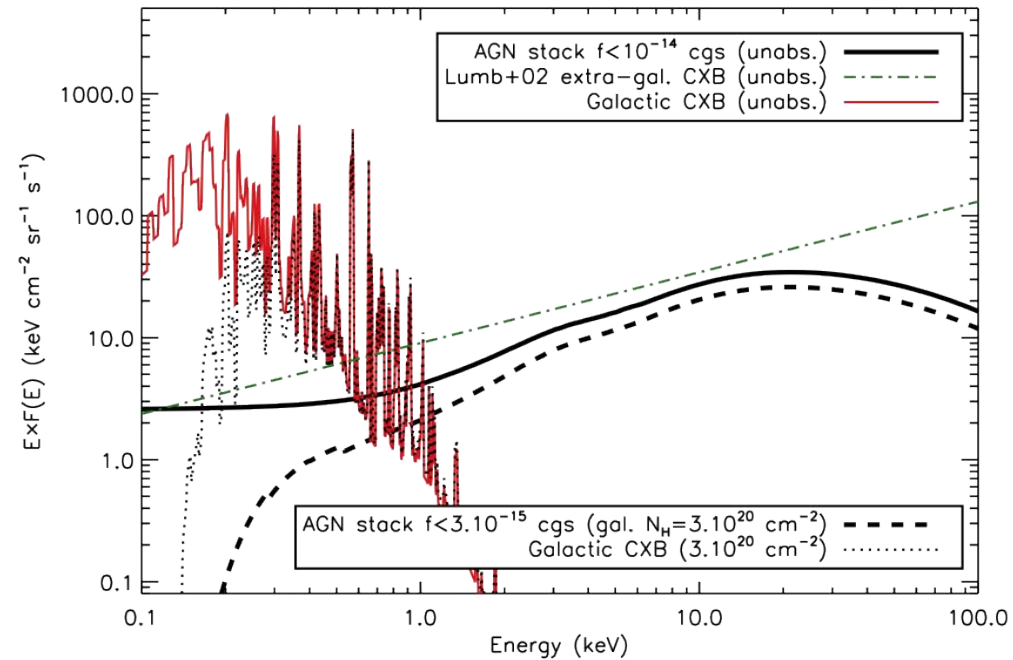
- ✓ Realistic exposure maps
- ✓ Representative backgrounds
- ✓ Ray-tracing PSF/vignetting
- ✓ Photons → Events transform

Realistic AGN populations + backgrounds

Atelier sondes DE - 19.11.2019 - N.Clerc

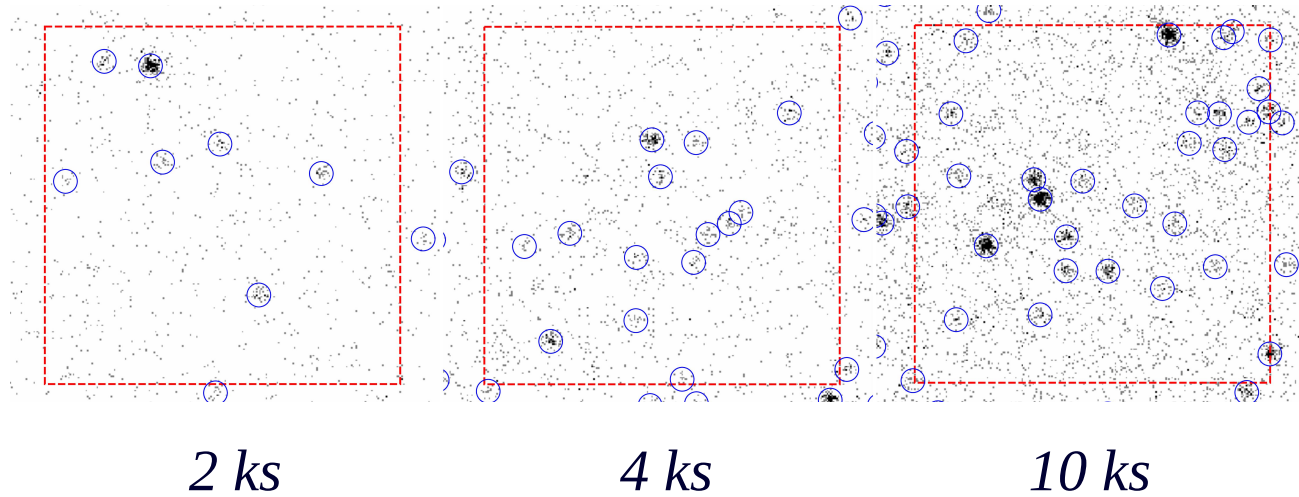
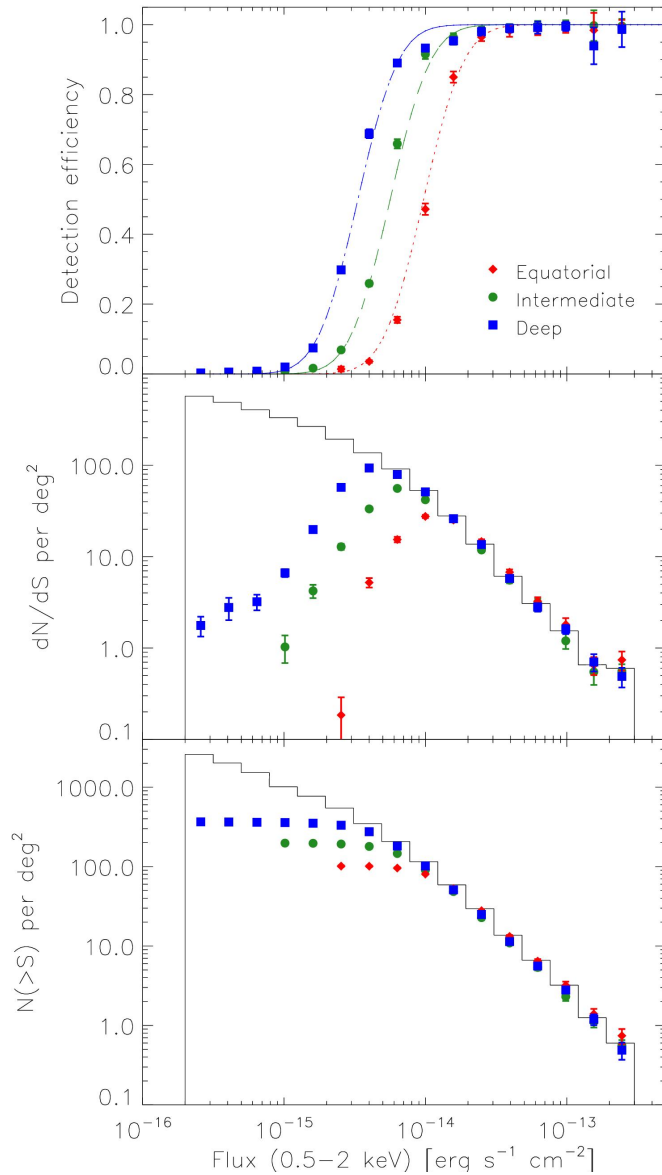


Un- + resolved AGN soft band



Background SEDs

Point-source sensitivities



- ✓ Realistic source detection software (*eSASS*)
- ✓ Sliding box method
- ✓ Joint detection of high off-axis and low off-axis (sharper PSF) events for increased sensitivity and likelihood estimates

Extended source selection & sensitivities

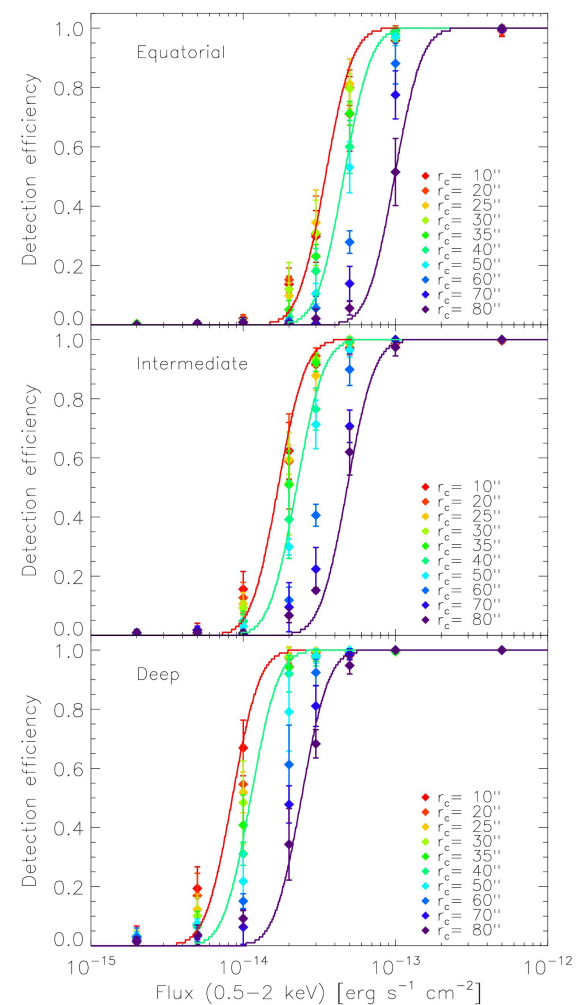
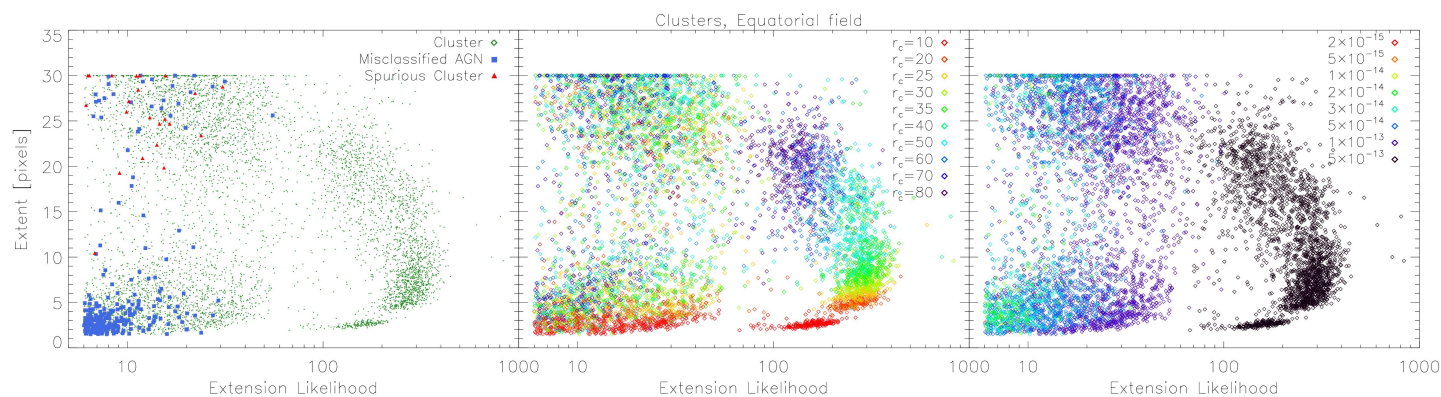
Atelier sondes DE - 19.11.20.

2-parameter β -models

Selected such that:

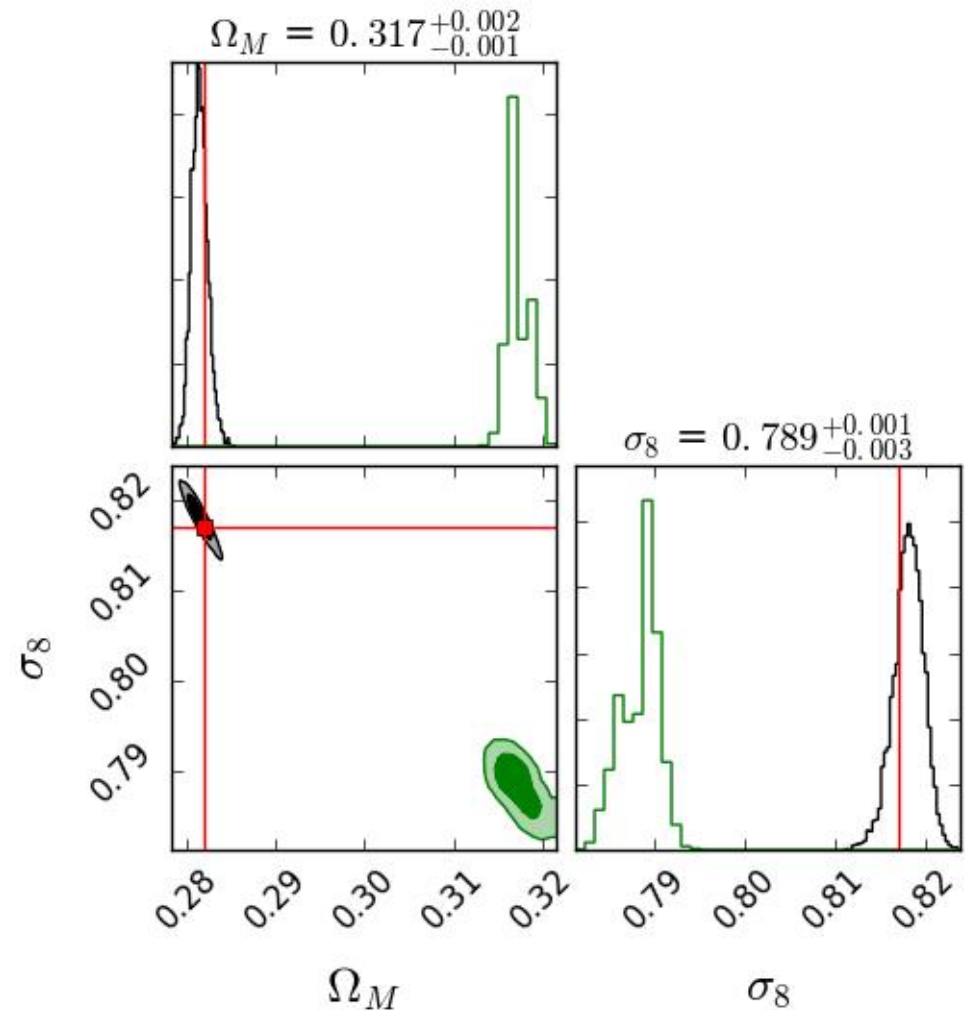
- $\text{Log DET_LH} > 10$
- $\log \text{EXT_LH} > 6$
- $R_c > 6''$

These cuts lead to $\sim 10^5$ clusters over the extra-galactic sky



Relevance of the selection function

- *Toy-model exercise*
- *All other parameters known to 100% accuracy*
- *eROSITA mock catalogue of $\sim 10^5$ clusters, fit with CR-HR observables only*
- **Black:** *assuming complete selection function*
- **Green:** *partial knowledge of selection function (i.e. only one cluster size)*



Outline

I. Motivation

- *Formation of the large-scale structure and cosmology*

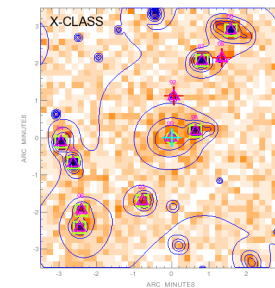
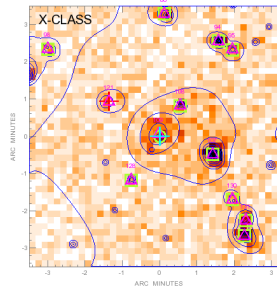
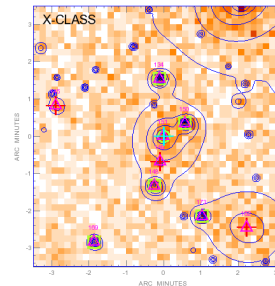
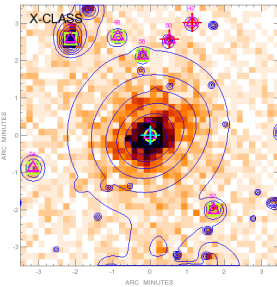
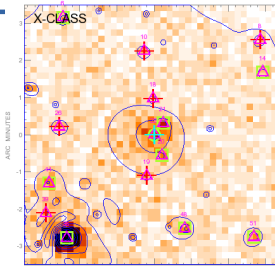
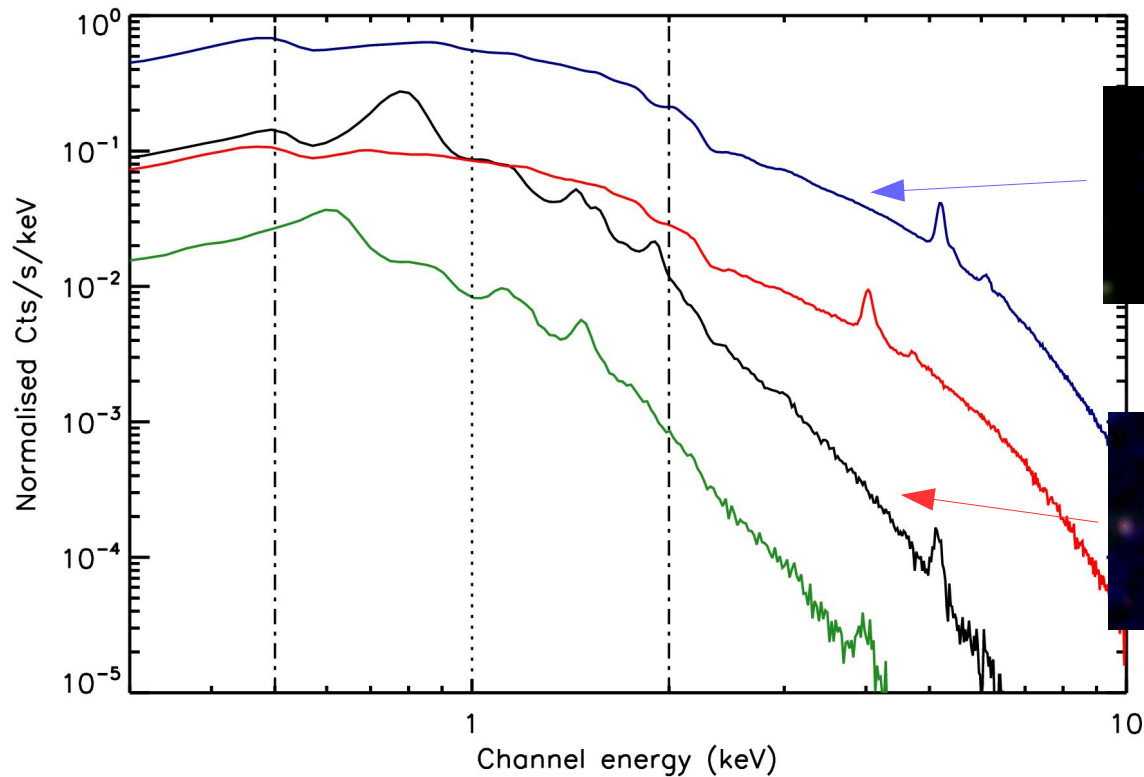
II. The *eROSITA* all-sky survey

- *Collecting large samples with X-ray observations*

III. Population studies in the observable domain

- *A new approach to large cluster samples*
- *Massive confirmation of large cluster samples*

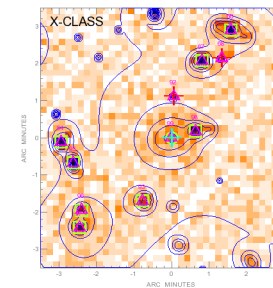
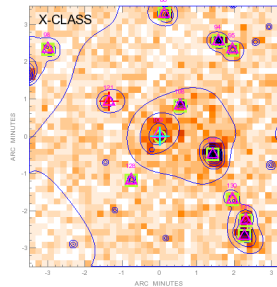
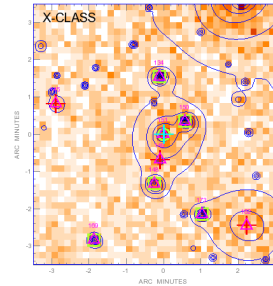
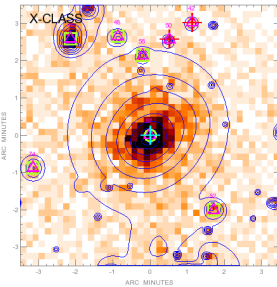
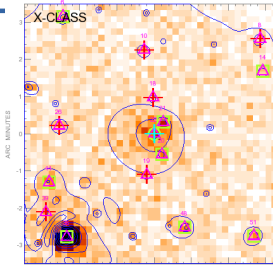
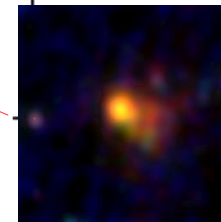
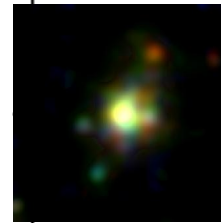
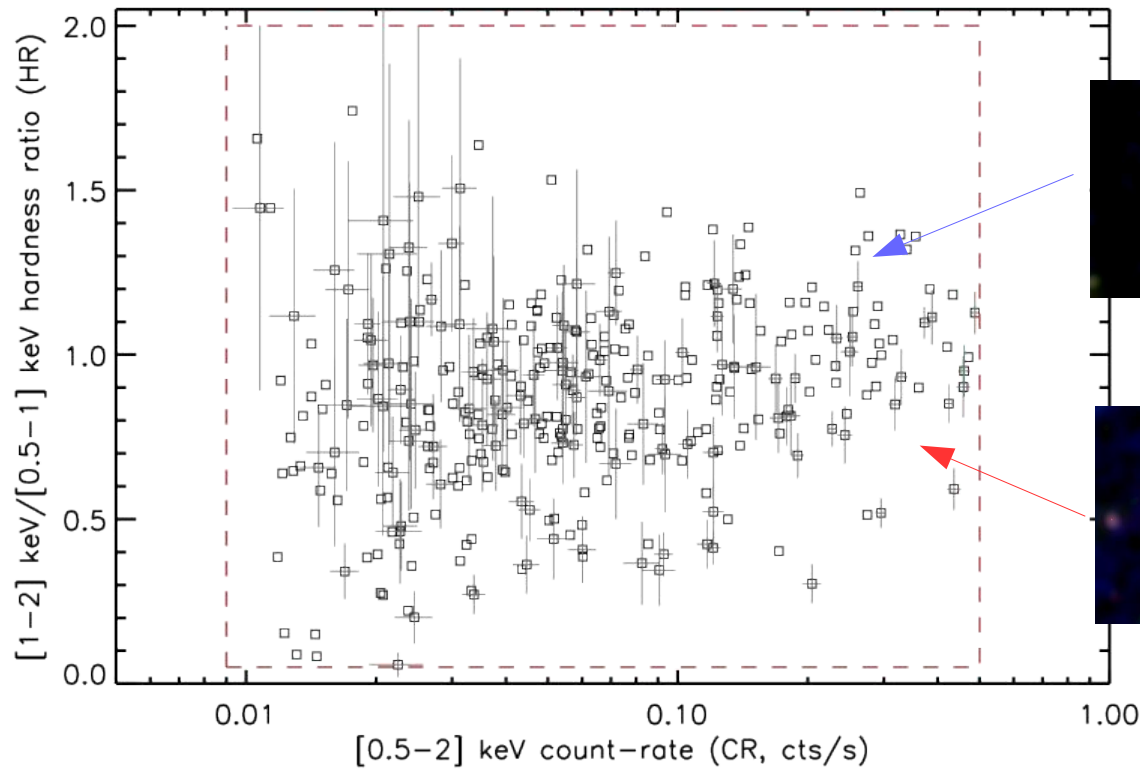
Minimal observables from an X-ray sample



XMM-Newton cluster spectra ($S/N=\infty$)

Minimal observables from an X-ray sample

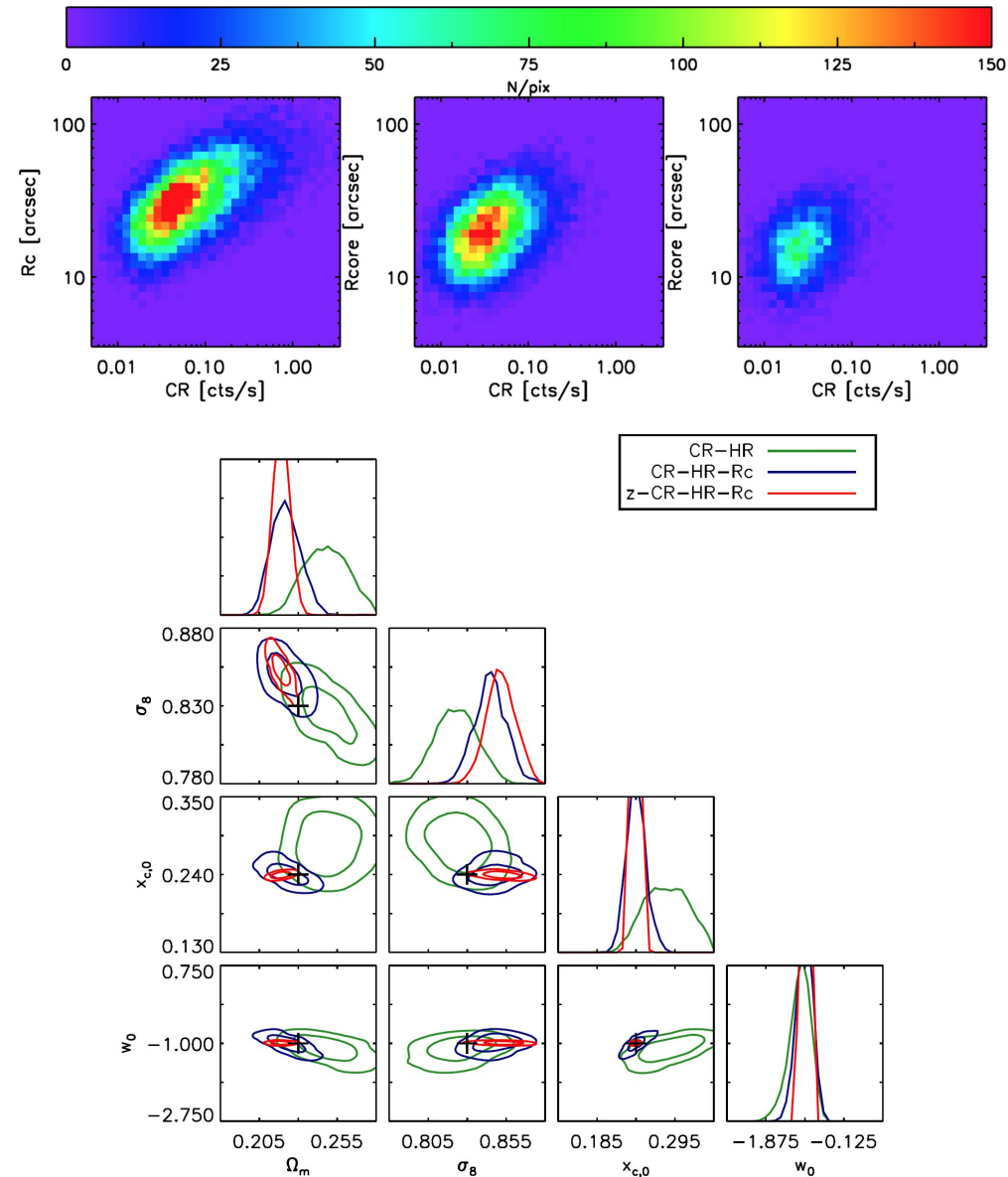
Atelier sondes DE - 19.11.2019 - N.Clerc



XMM-Newton CR-HR ($T_{\text{exp}} = 10 \text{ ks}$)

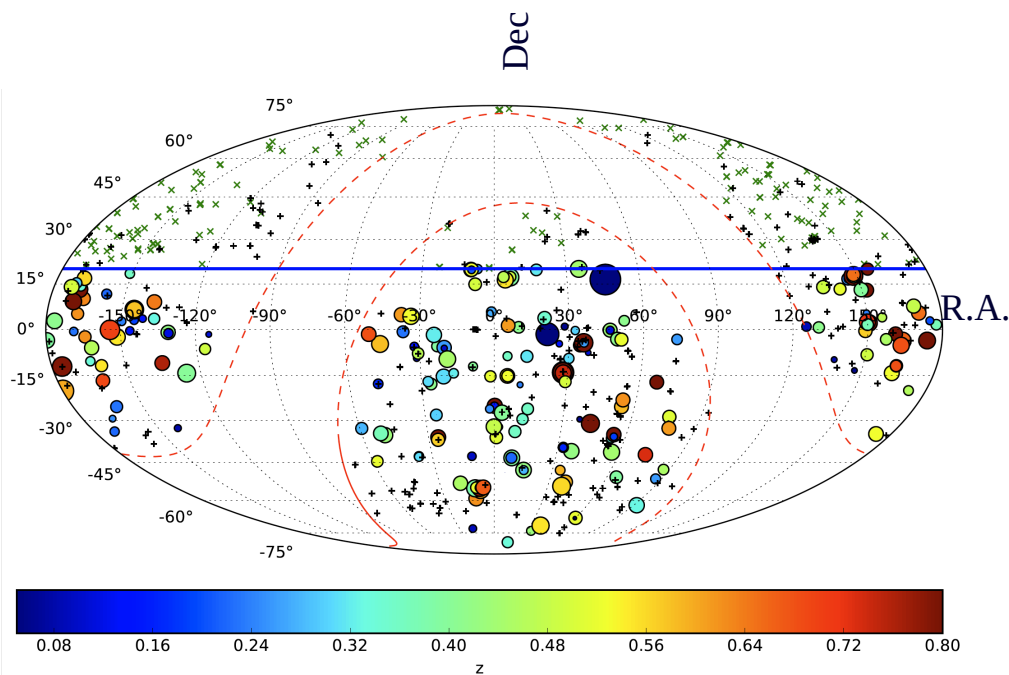
Towards a synthetic observable model

- 4-dimensional observable space (CR, HR, redshift, size)
- Selection function naturally folded in
- Quick likelihood maximization
- Monte-Carlo on mocks to assess uncertainties
- No mass measurements, but [(self-)calibrated] scaling laws
- *Pierre... Pacaud, NC, et al. 2018*
Valotti... Pacaud, NC, et al. 2018



X-CLASS

- XMM CLuster Archive Super Survey
- Cataloguing extended sources in 4000+ pointings selected in the XMM archive
- Based on the XMM-XXL techniques



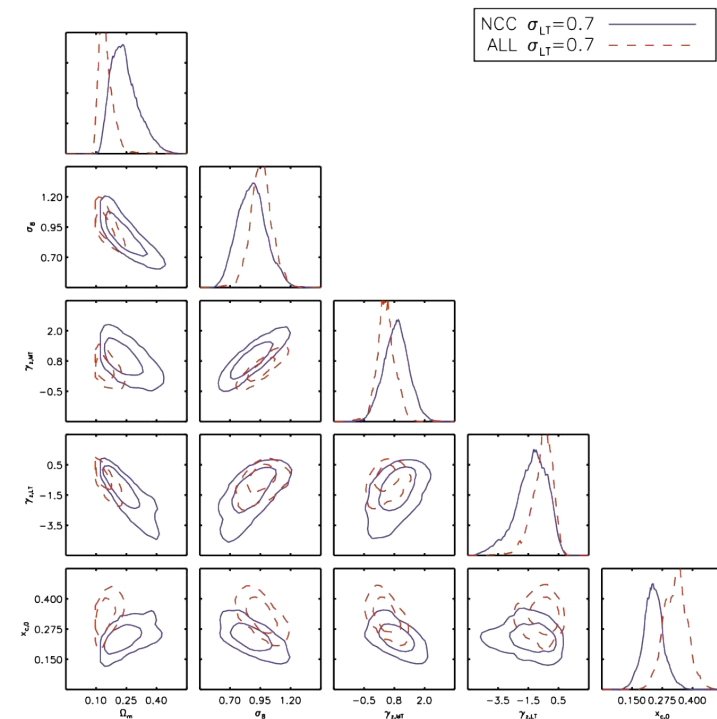
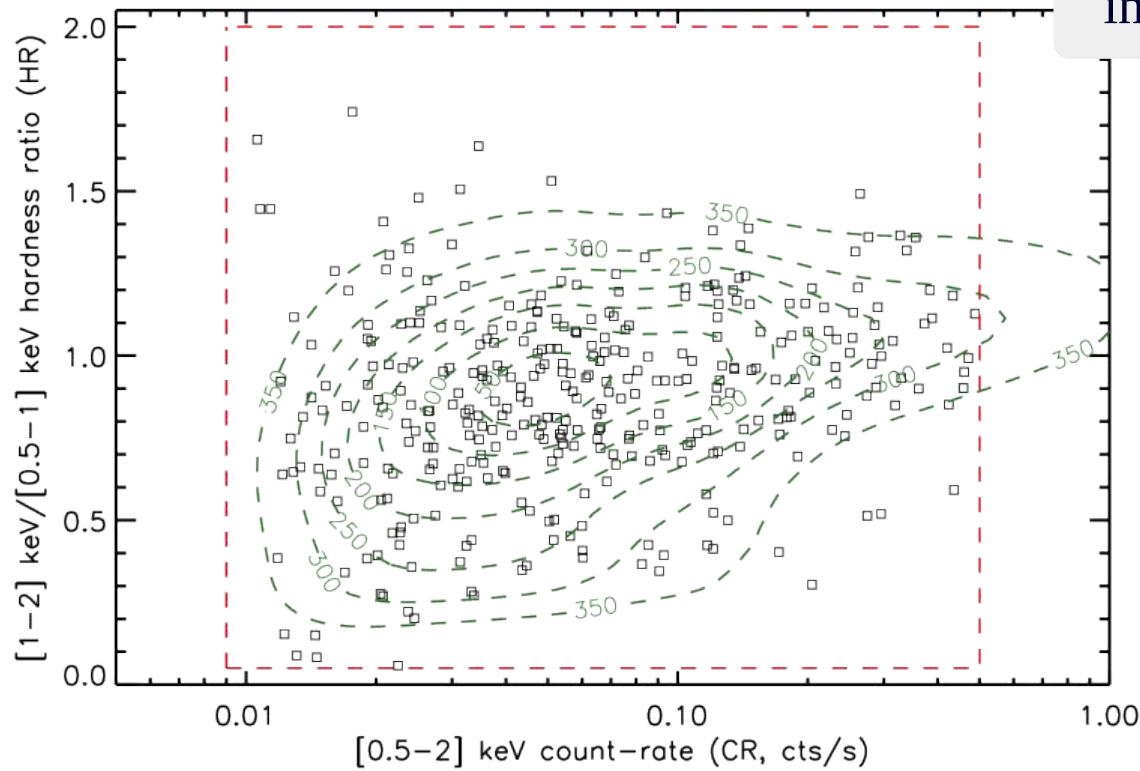
Clerc et al. 2012

Ridl et al. 2017 [photo-z]

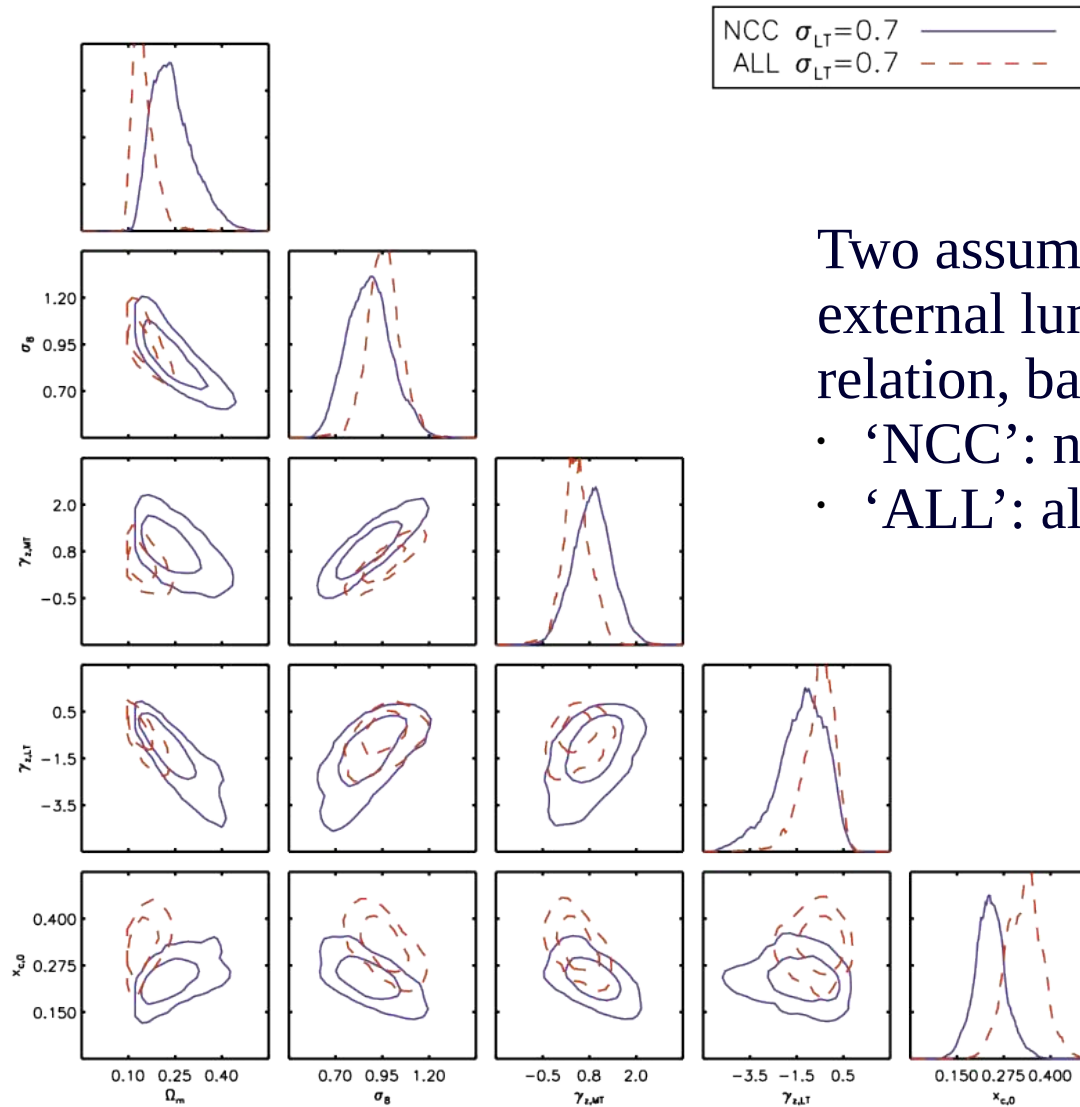
- A survey of extended sources in X-rays. Today: 1600 detections (Clerc+ in prep.)
- Automated and visual characterization of their nature (cluster or other type)
- Spread over entire extragalactic sky
- Known and controlled selection function
– *Each choice of design favors this aspect relative to exhaustivity*
- Powerful dedicated database

X-CLASS-1 analysis: first results

- Extreme forward-modeling in the CR/HR domain
- Constrains a range of model parameters, incl. Ω_m , σ_8 ...



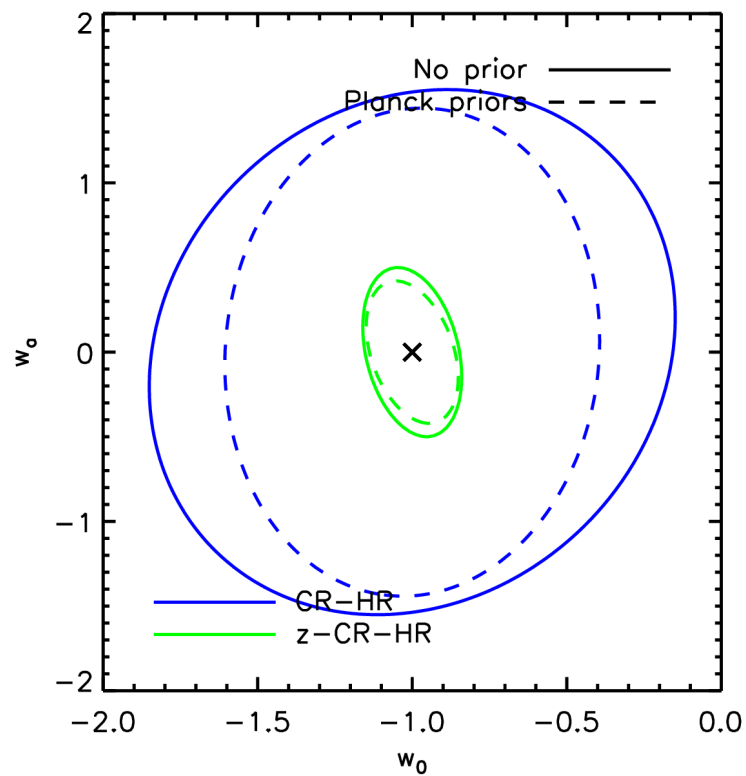
X-CLASS-1 analysis: first results



Two assumptions for the external luminosity-temperature relation, based on Pratt+2009:

- ‘NCC’: non-cool core
- ‘ALL’: all systems

(z)-CR-HR forecasts for eROSITA



	CR-HR		z-CR-HR	
	No prior	<i>Planck</i> priors	No prior	<i>Planck</i> priors
w_0	0.6	0.4	0.1	0.1
w_a	1.0	0.9	0.3	0.3
$\gamma_{z,MT}$	1.3	0.1	0.2	0.05
$\gamma_{z,LT}$	0.8	0.5	0.3	0.1

Outline

I. Motivation

- *Formation of the large-scale structure and cosmology*

II. The *eROSITA* all-sky survey

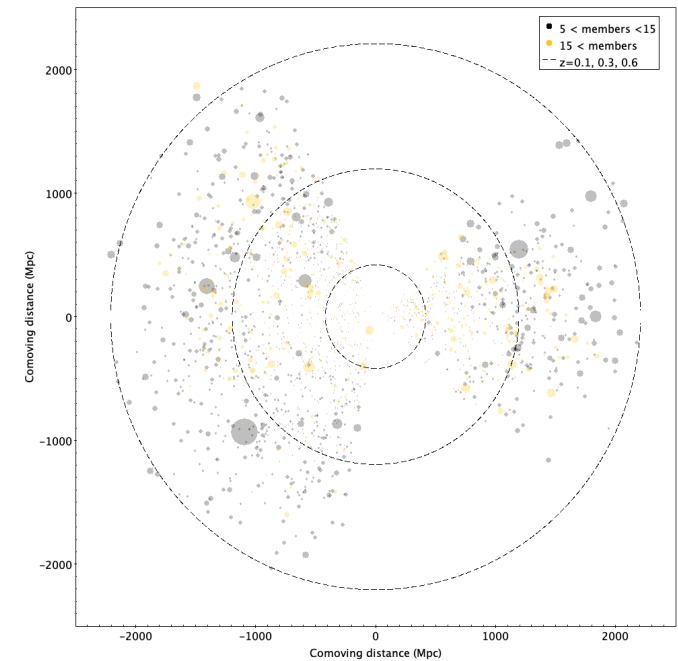
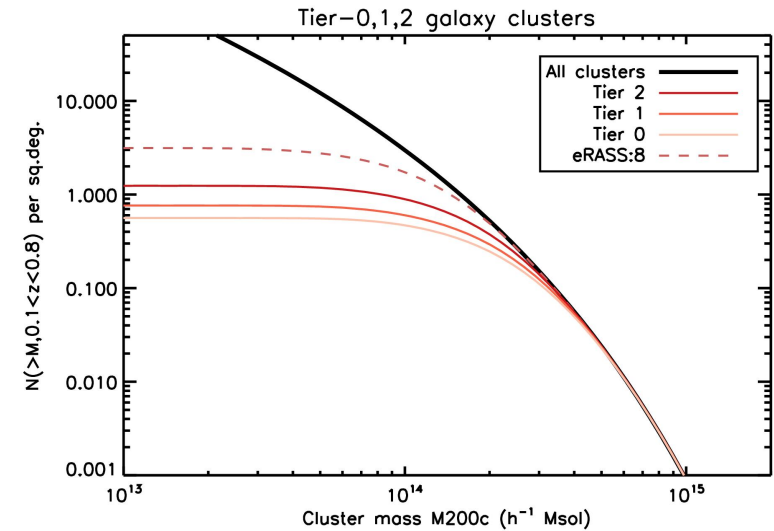
- *Collecting large samples with X-ray observations*

III. Population studies in the observable domain

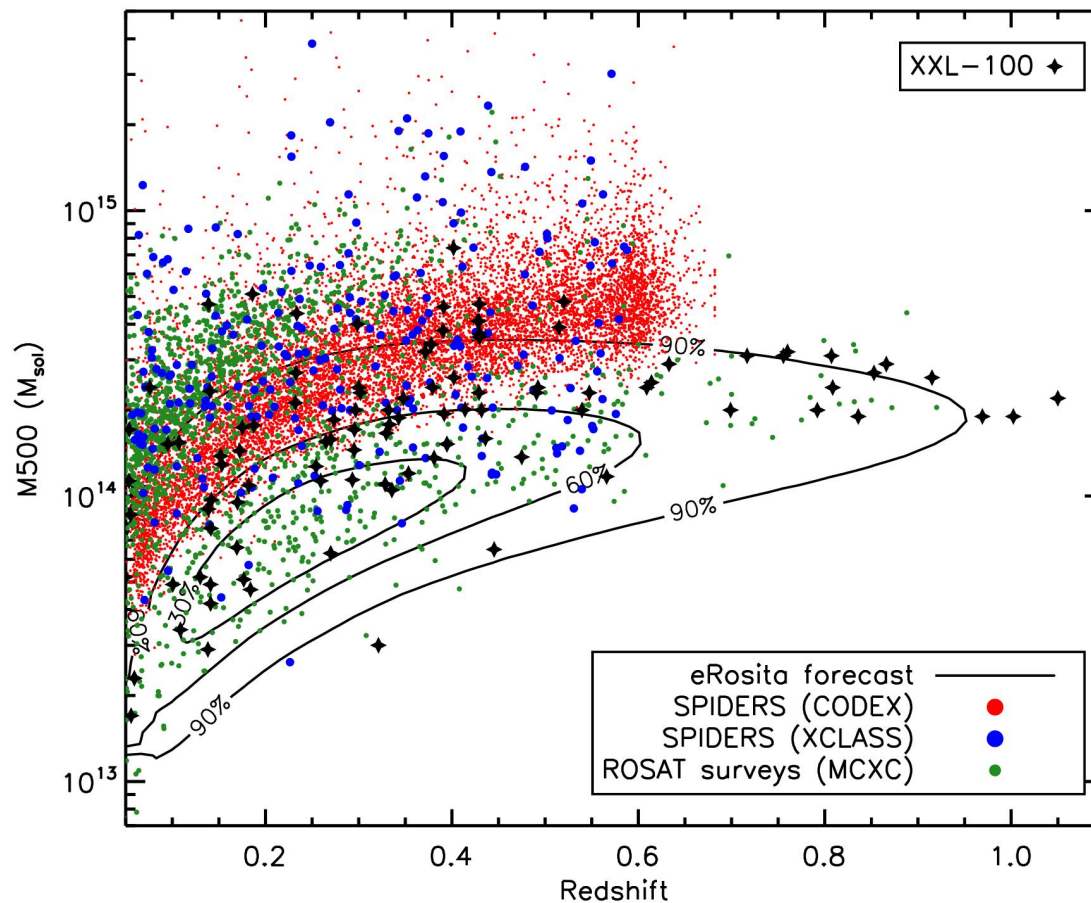
- *A new approach to large cluster samples*
- *Massive confirmation of large cluster samples*

Multi-tiered galaxy cluster optical follow-up

- **Northern hemisphere: SDSS-IV+V**
 - SPIDERS (PI: A. Merloni, K. Nandra)
 - “Tier 0”: RASS and XMM sources (mainly AGN and clusters)
 - “Tier 1”: eRASS:2 follow-up (extended and point-sources)
- **Southern hemisphere: ESO/4MOST(+SDSS-V)**
 - 4-m VISTA telescope
 - AGN and galaxy cluster surveys
 - Operations start 2021



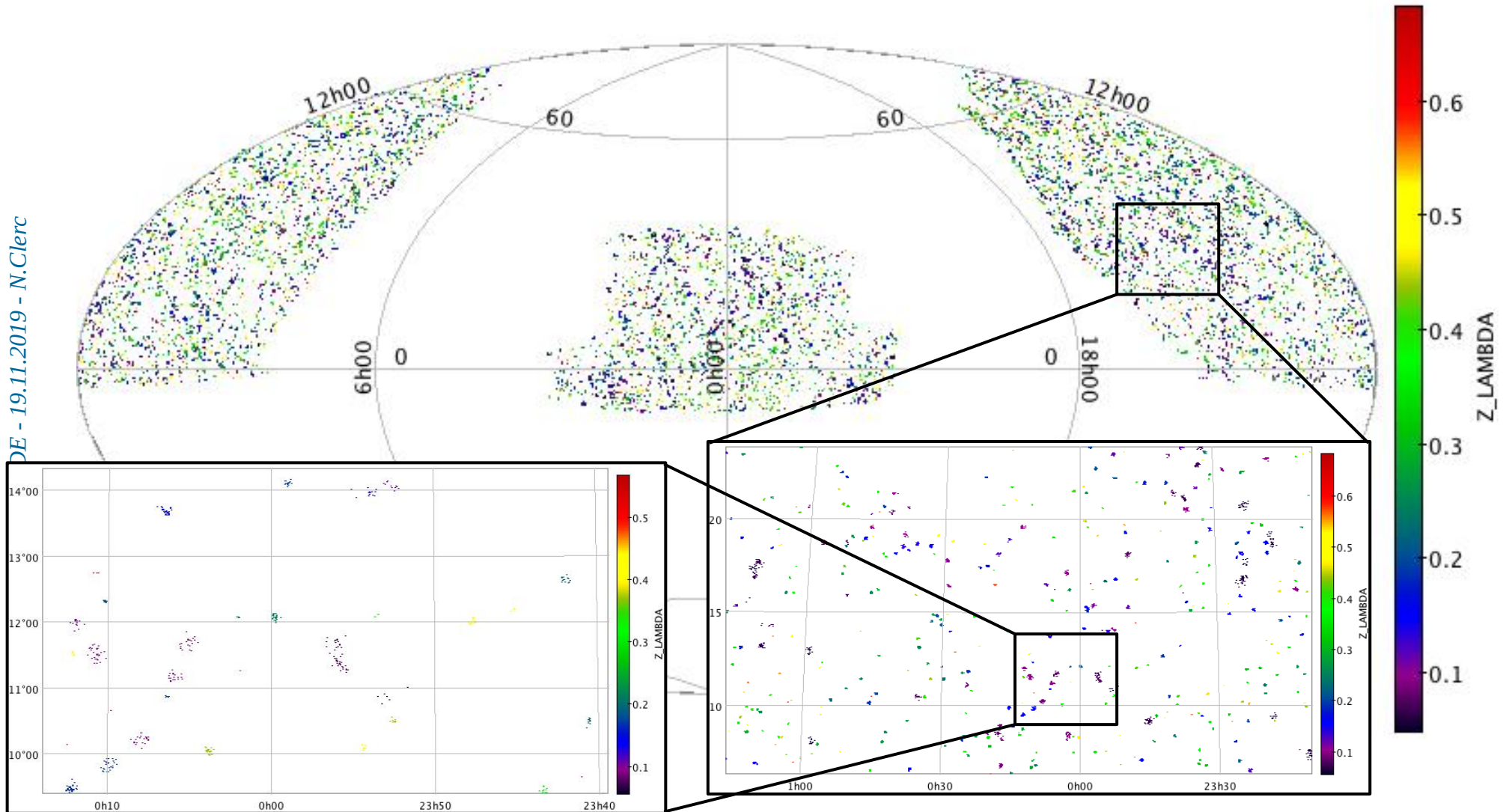
RASS, ROSAT, eRASS, XMM-XXL, SPIDERS



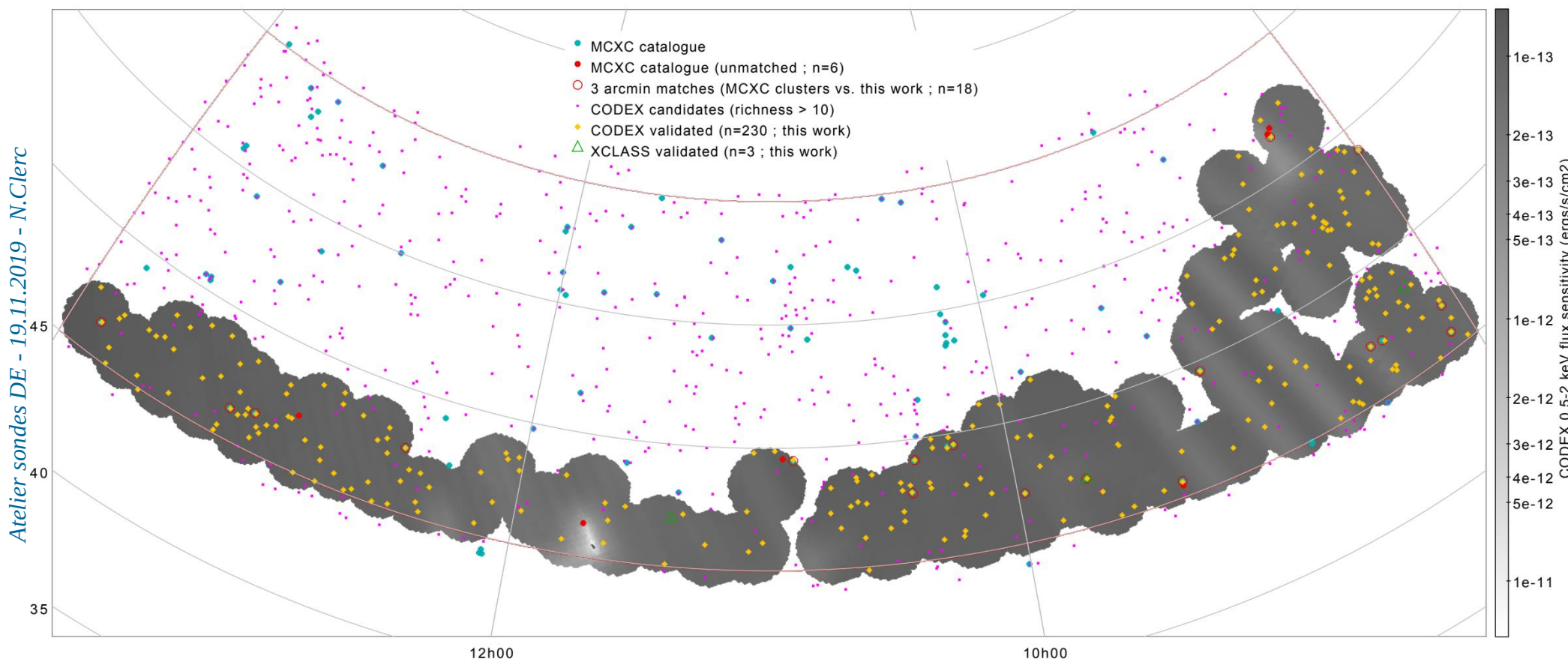
Data points:
Pacaud+2016
Piffaretti+2011
Sadibekova+2014
Finoguenov in prep.
Contours: *NC+2016*

Targeting 50,000 red-sequence galaxies

DE - 19.11.2019 - N.Clerc

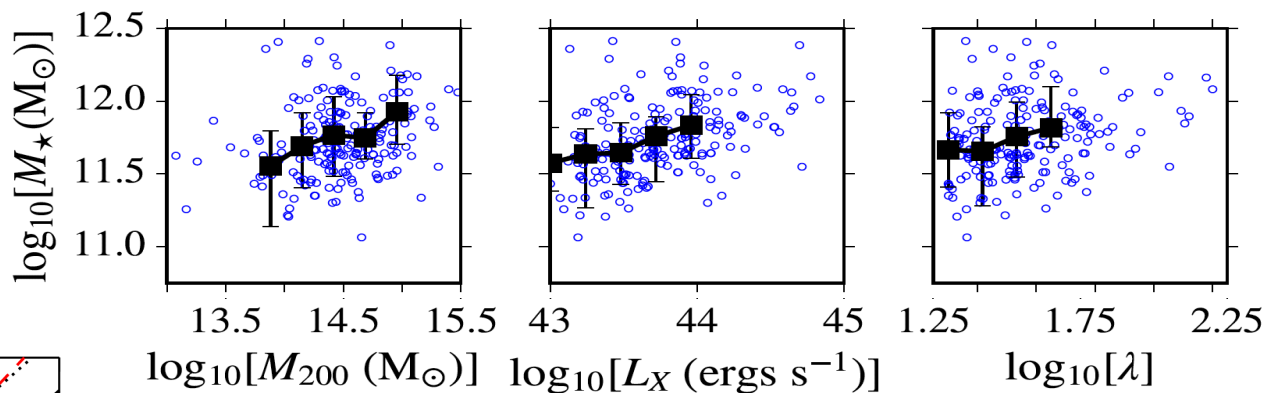


Demonstration sample (300 deg²)

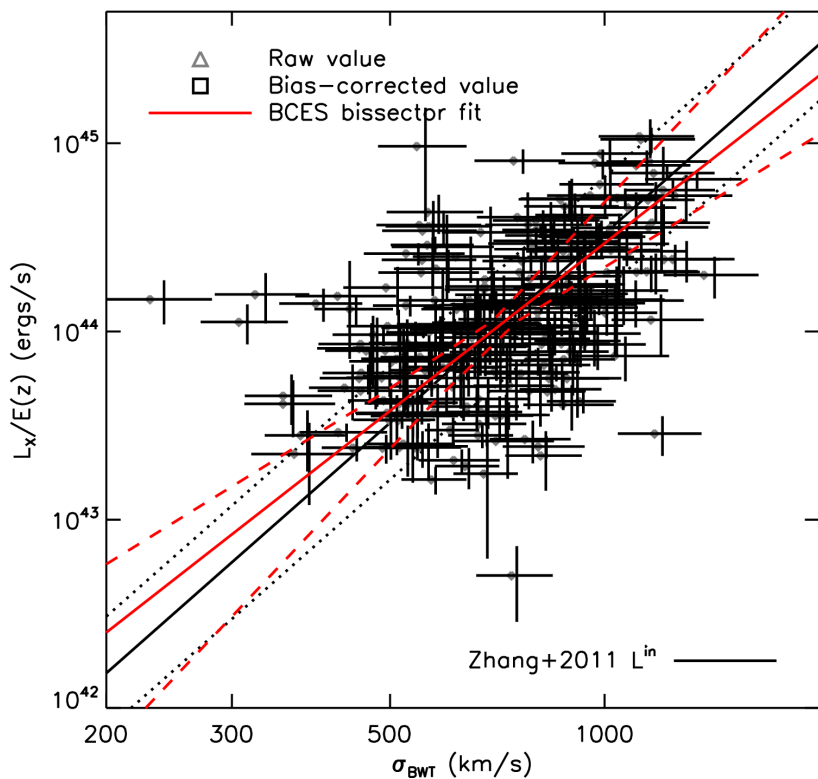


Results from the SPIDERS DR14 catalogue

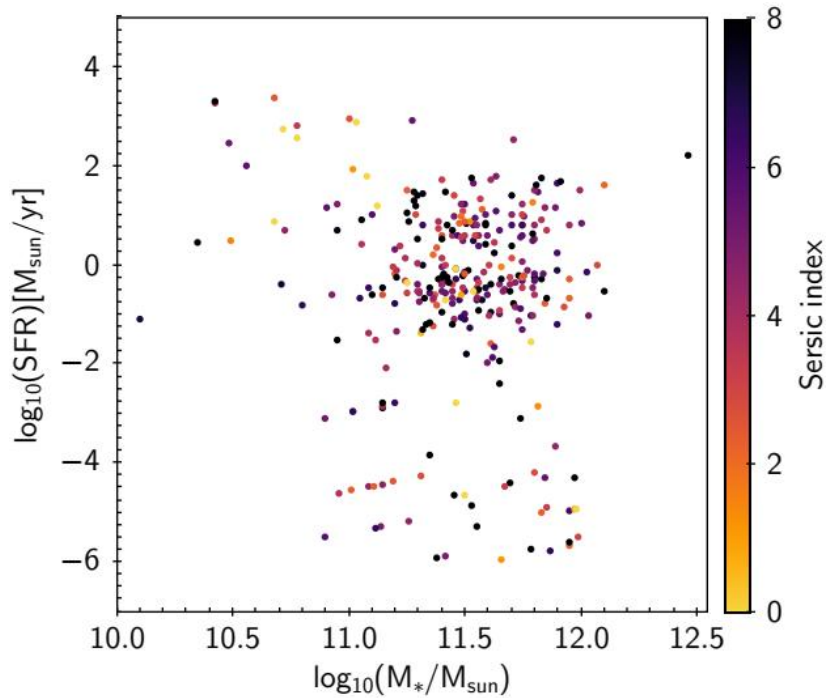
Only systems with > 15 spec-z
 Bias correction and uncertainties on v -disp
 from HIFLUGCS resampling models ↓



↑ adapted from Furnell et al. 2018, A&A



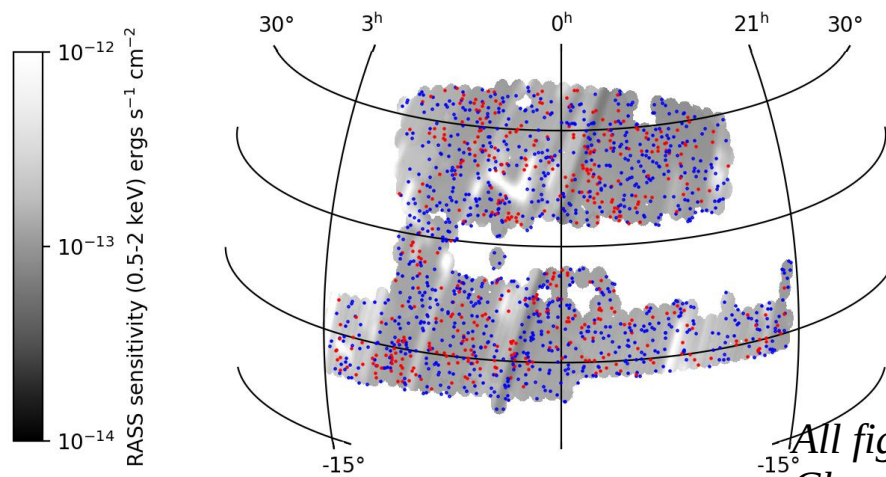
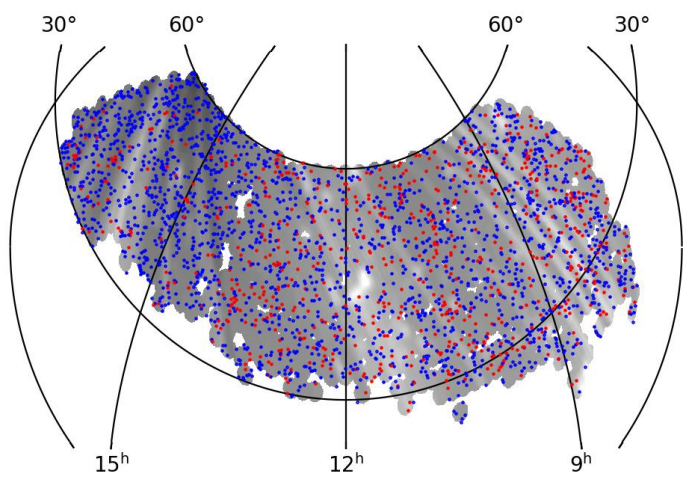
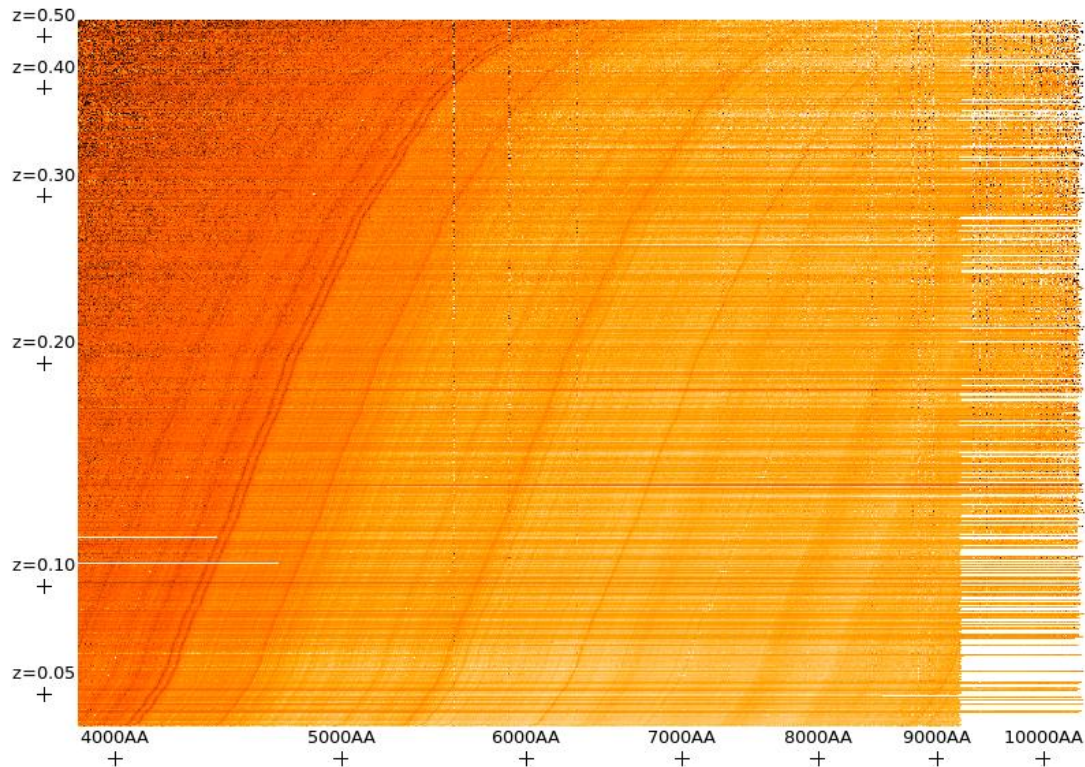
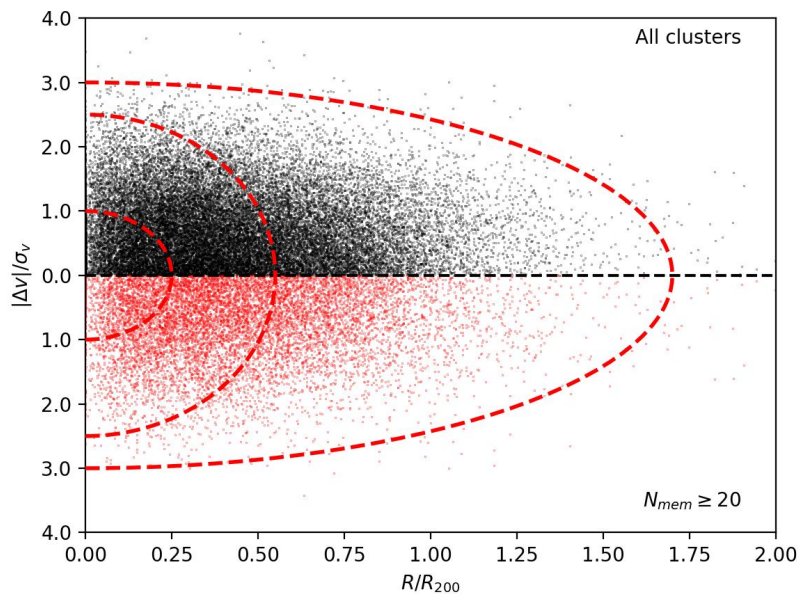
Catalogue presented in
 SDSS Data Release 14 Paper 2018, ApJS 235, 42



← Online catalogue
 of BCG properties
 (Erfanianfar+19)

SPIDERS is finished!

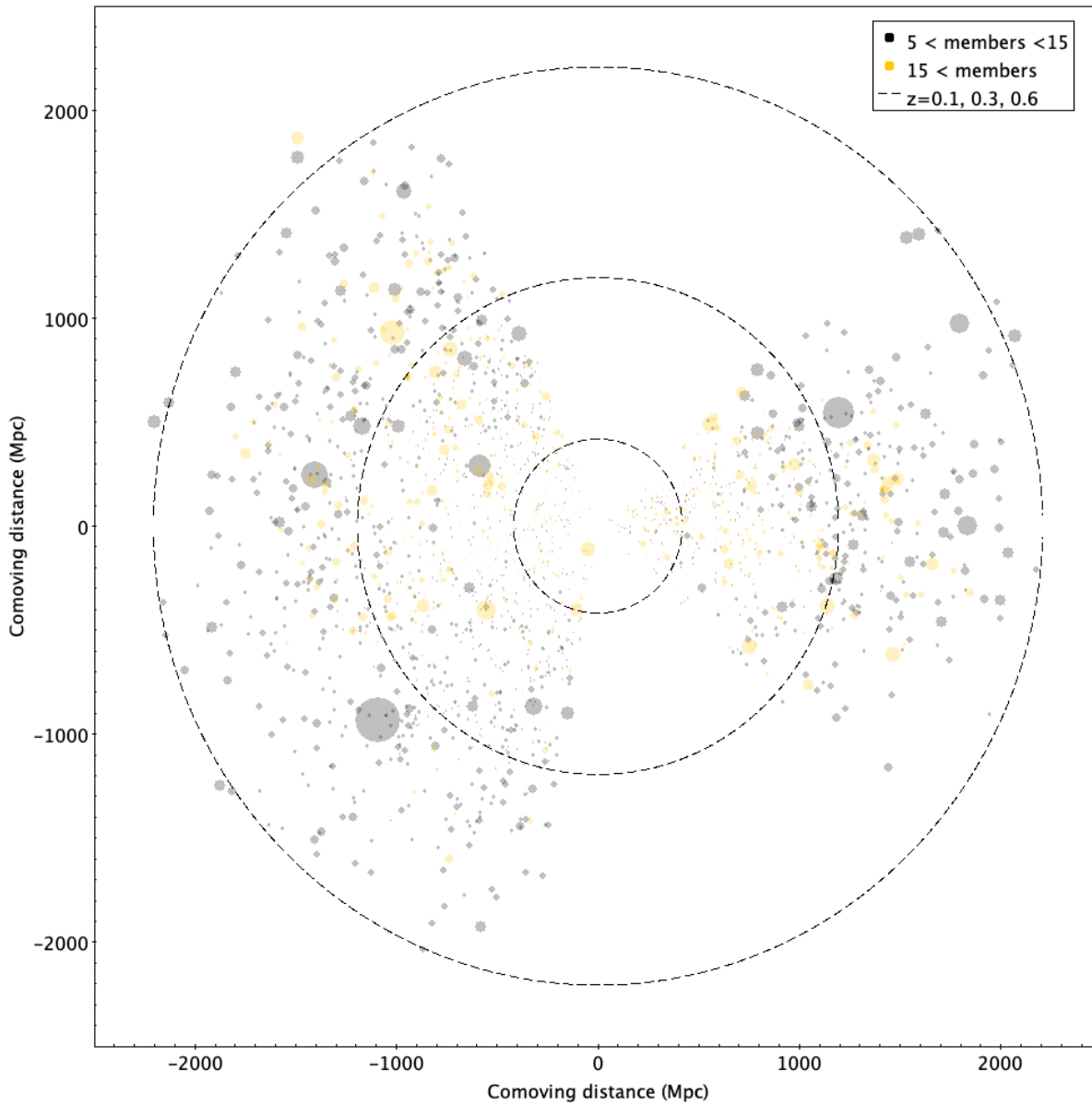
Atelier sondes DE - 19.11.2019 - N.Clerc



All figures:
Clerc et al in prep.

SPIDERS is finished!

Atelier sondes DE - 19.11.2019 - N.Clerc

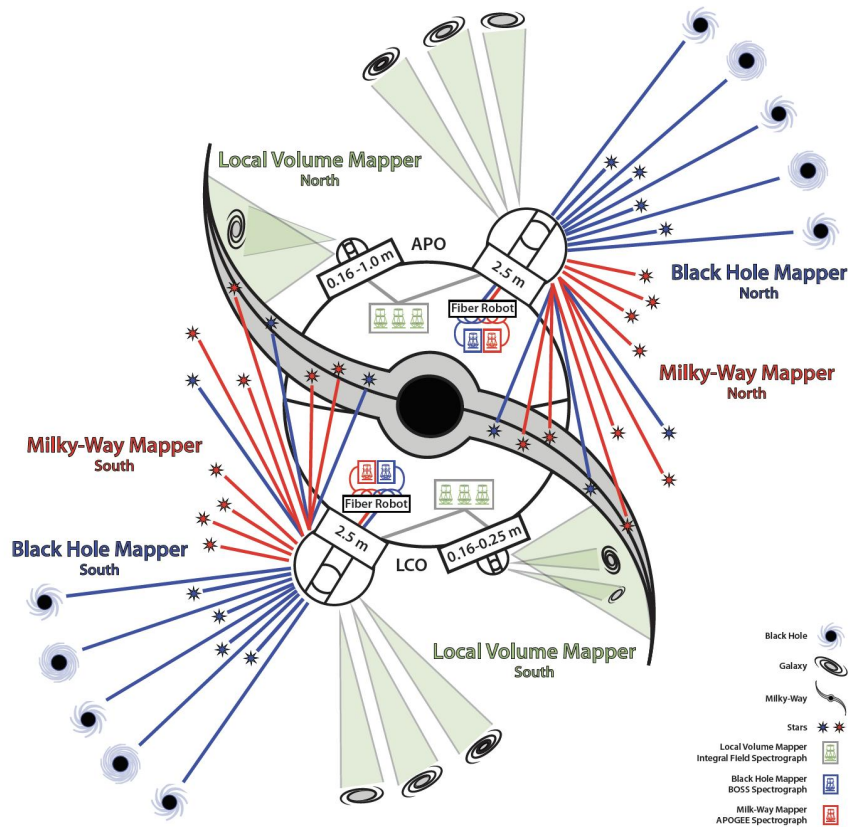


SPIDERS DR16

- 2,740 X-ray clusters up to $z \sim 0.6$
- Spectroscopically confirmed
- >36k members
- >27k new redshifts
- $\sim 5 \text{ cGpc}^3$ surveyed volume

Clerc et al in prep.

SDSS-V: pioneering panoptic spectroscopy



- 5-year program begin mid-2020 in both hemispheres
- 3 science programs
 - *Milky Way Mapper*
 - ***Black Hole Mapper***
 - *Local Volume Mapper*
- SDSS-V is
 - An observing facility
 - A science survey program
 - A consortium & collaboration
 - In particular, 80k spec-z in 10k X-ray clusters
- More info : arXiv 1711.03234 (Kollmeier, et al.)

Conclusions

- Current and upcoming studies are changing our approach to galaxy cluster surveys:
- ✓ **Methodology** – self-consistent modeling of the X-ray cluster/group population in a cosmological framework (*XMM-Newton* samples)
- ✓ **Statistics** – new approach to galaxy cluster samples, drawn from a pool of $\sim 10^5$ objects across the entire extra-galactic sky (*eROSITA*)
- ✓ **Precision measurements** – accurate redshifts enabling precise positions, masses & mapping of the baryonic cosmic web (*SPIDERS*)

Thank you!