X-GAP: Mocking the selection of galaxy groups within the Large Scale Structure of the Universe

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Outline

- ***Intro: X-GAP and motivation***

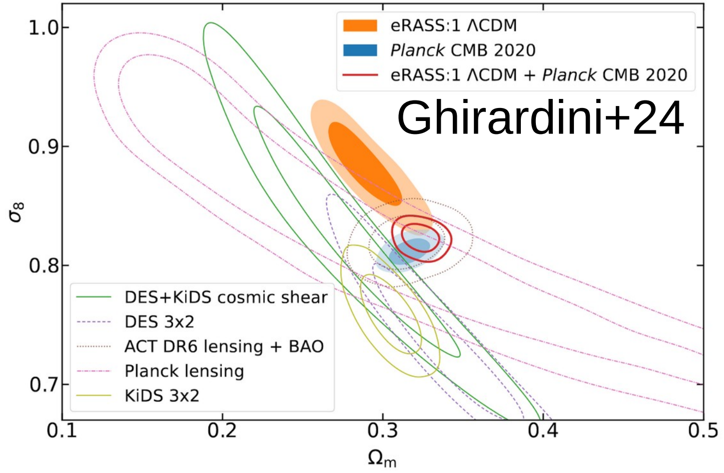
- ***Simulation strategy***

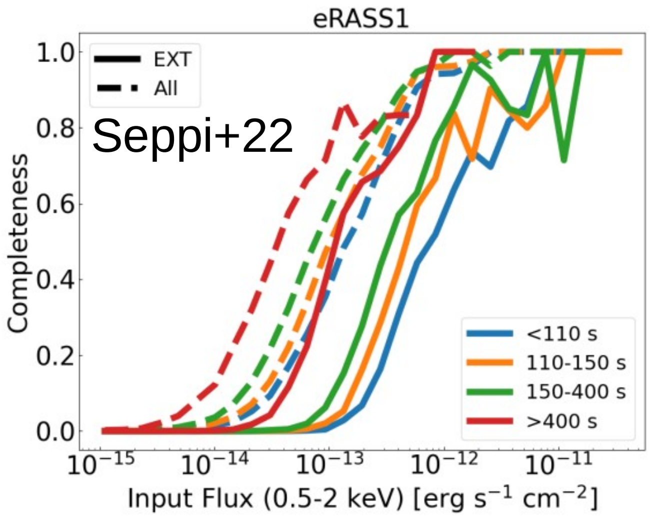
- ***Models for galaxies, clusters & groups (NEW)***

- ***Current status of the Mocks (Xray+optical)***

Why simulations?

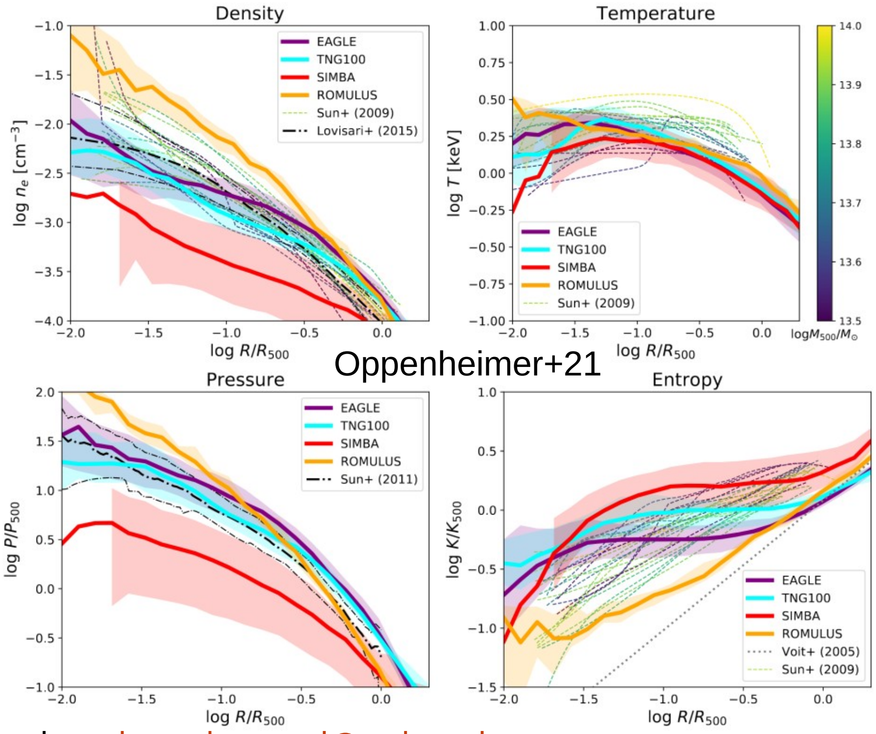
- Understand survey source catalogue
- Key for population and cosmology studies
- Test detection/X-ray pipelines



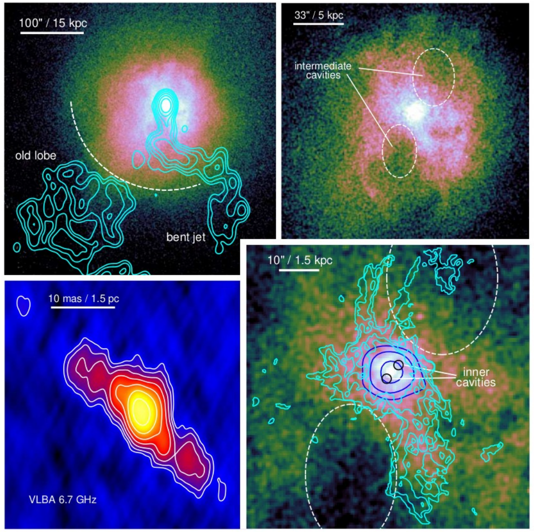


Context

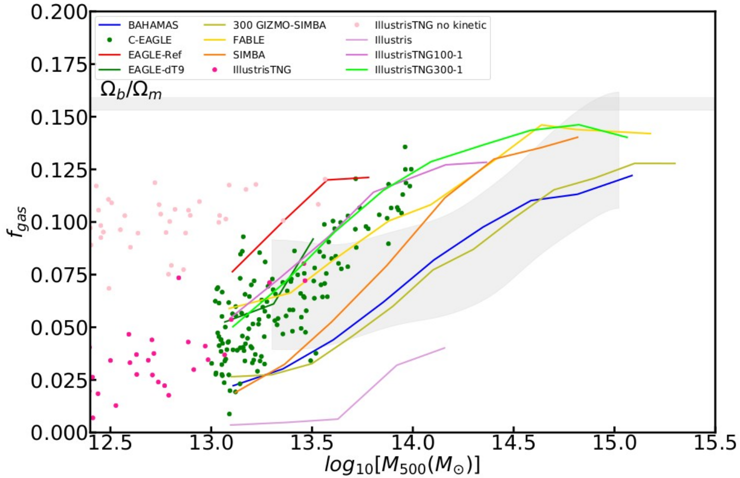
- Feedback processes are pivotal FEG ingredients (regulate SF, quenching, stellar mass function…)
- Galaxy groups: log(Mhalo)~13-14, ~10 galaxies
- Galaxy groups are very sensitive to AGN feedback



Oppenheimer+21



Eckert+21

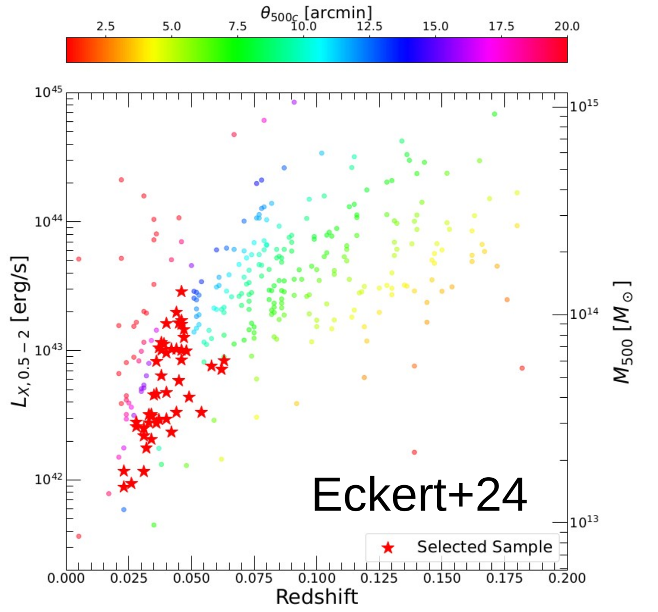


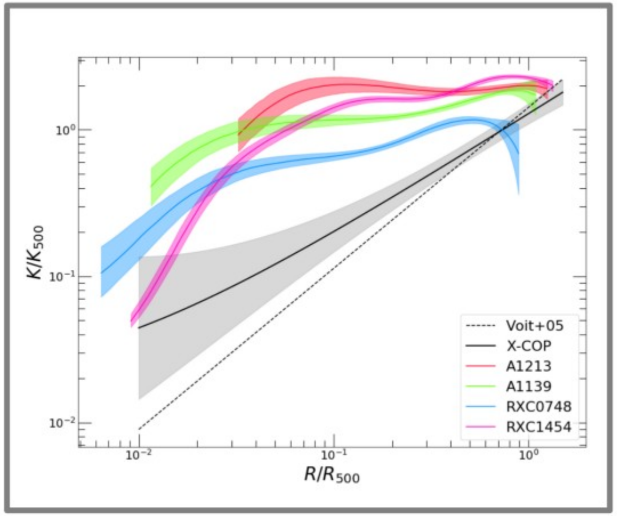
X-GAP

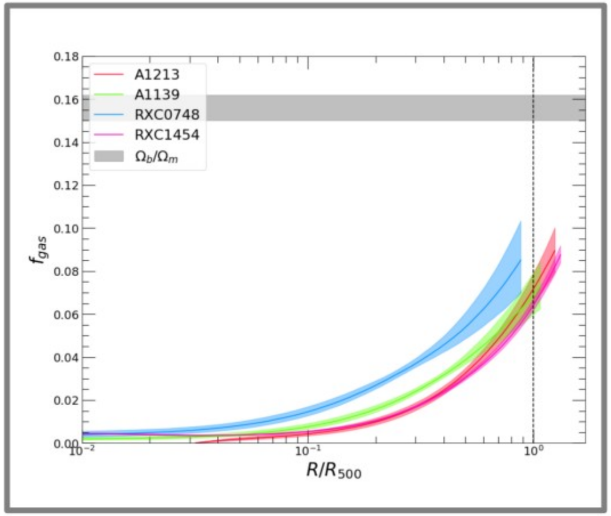
- XMM Newton Group AGN Project (D. Eckert):

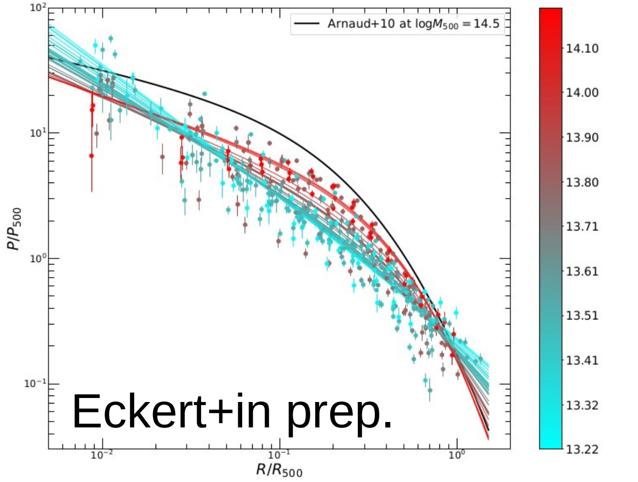
  ROSAT All Sky Survey (X-ray) + SDSS FoF (optical) selection: Thermodynamic properties of 49 groups to be compared to simulations

- KEY: understand group selection (with mocks!)

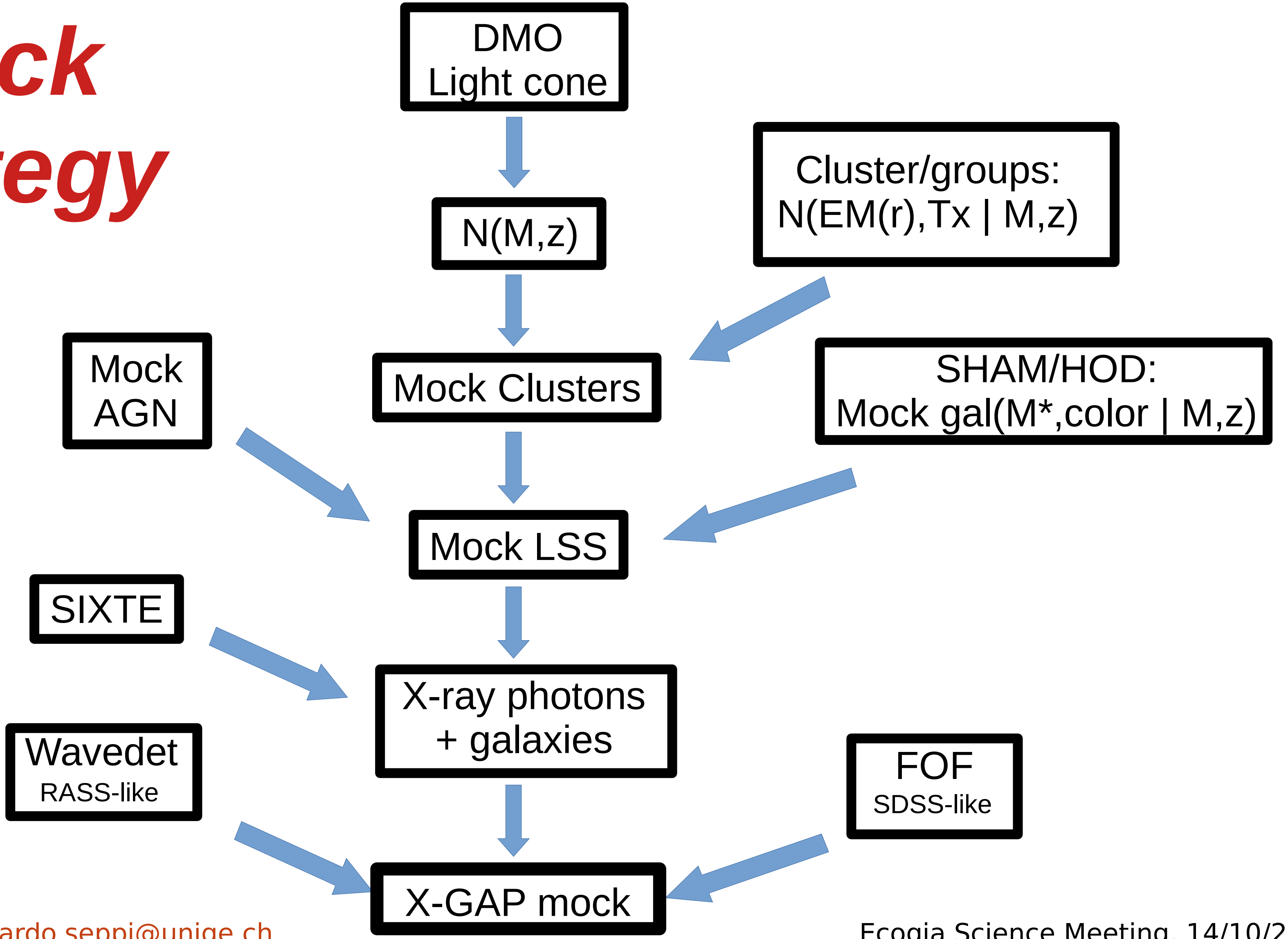








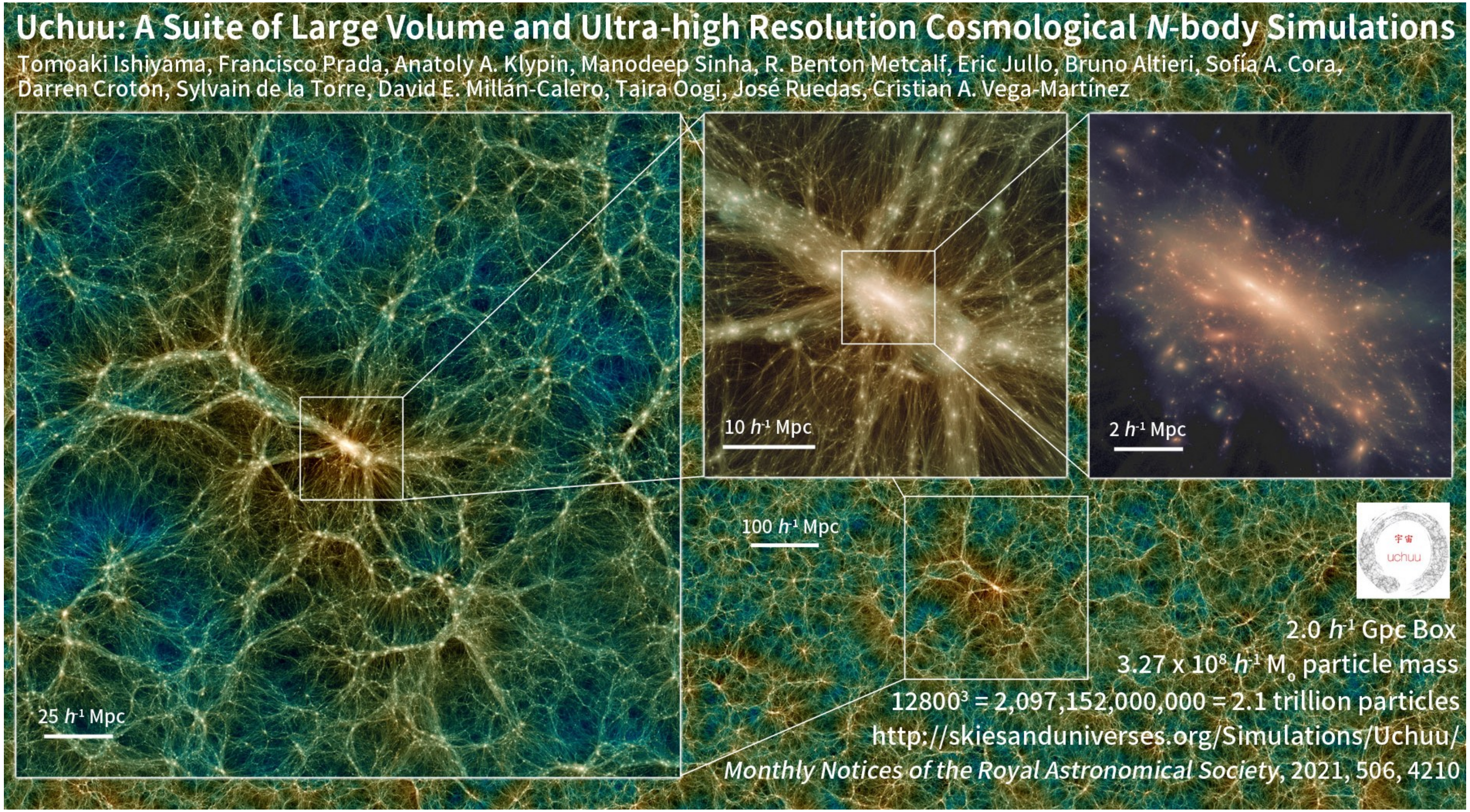
Mock strategy



Uchuu

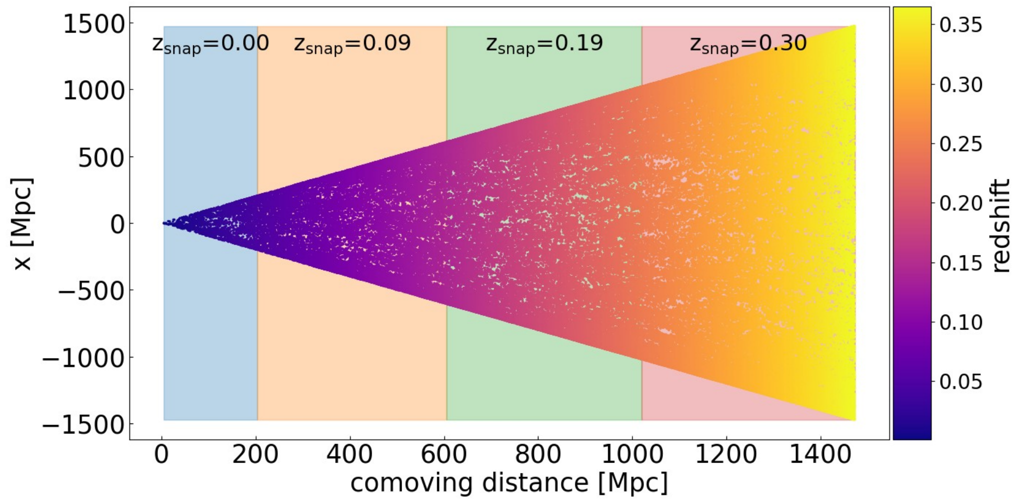
Dark Matter light cone: great for haloes hosting clusters, AGN, galaxies

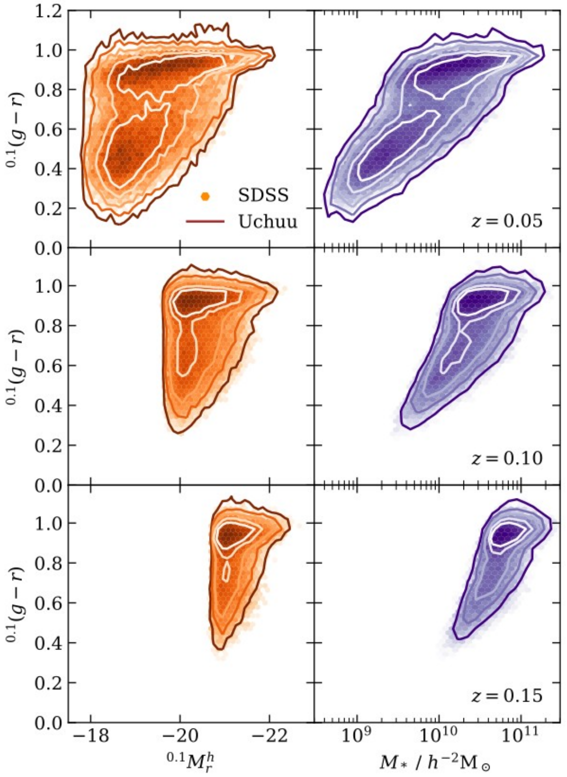
Allows measurement of velocity dispersion (Ishiyama+21)

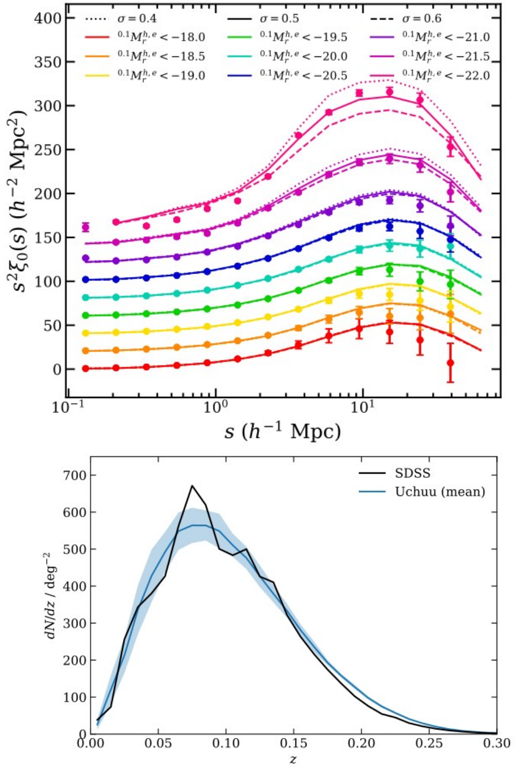


Uchuu light cones

- Concatenate individual snapshots (Seppi+in prep.)
- Mock galaxies: UchuuSDSS (Dong-Paez+22): SHAM Uchuu + SDSS mag

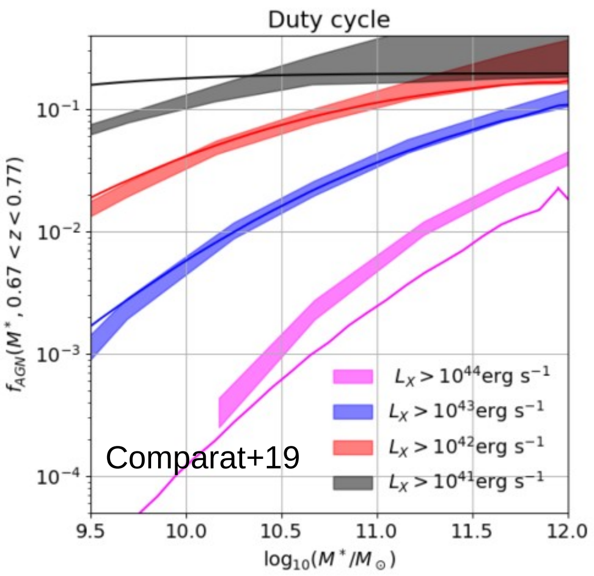


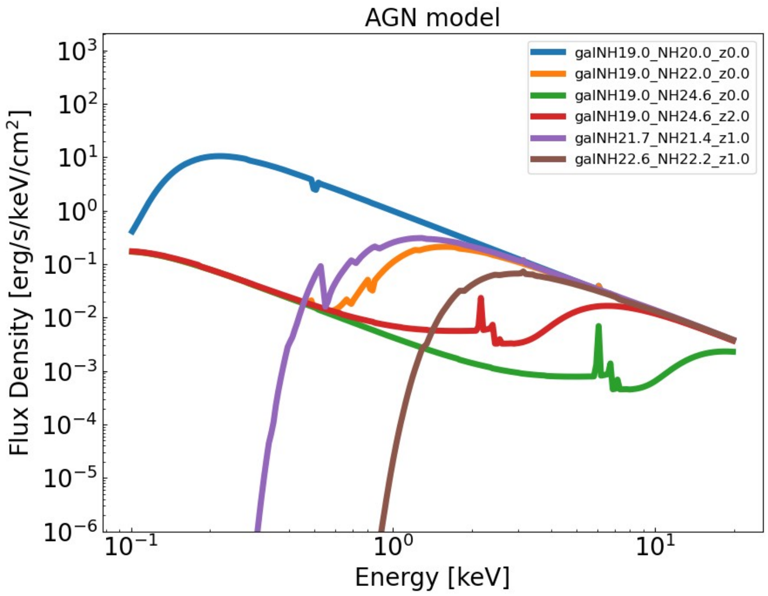




Mock AGN

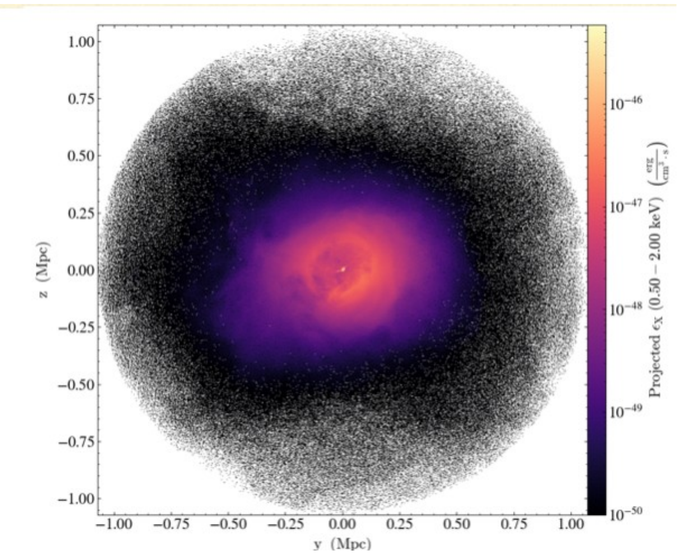
- SHAM model (Comparat+19): AGN assigned with duty cycle-z-stellar mass
- Hard Lx drawn from luminosity function and assigned with Lx-stellar mass
- Spectral library(galnH, nH, z): abs power-law+SE, reflection+emission lines

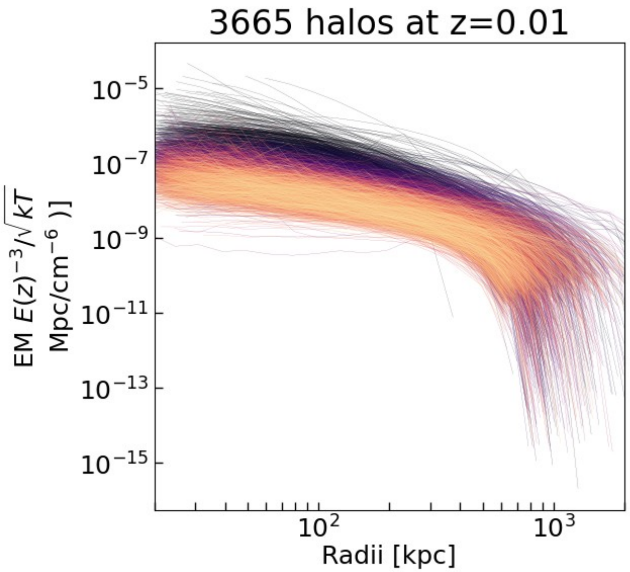


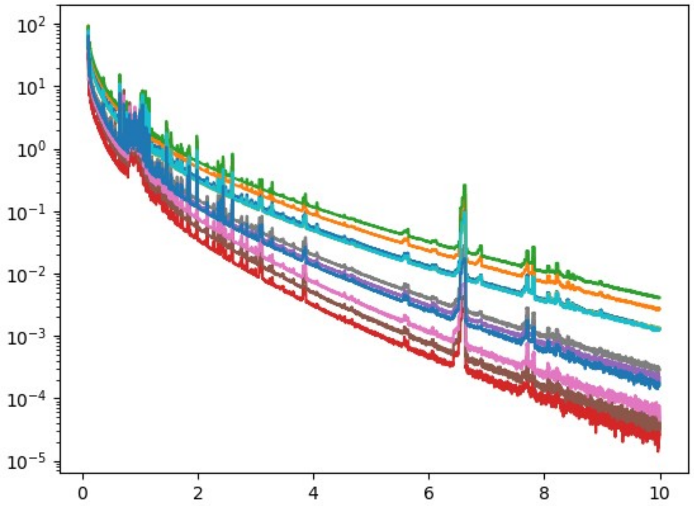


Mock Clusters & Groups

- Build model from groups in simulations (TNG)
- Extraction of EM profiles with pyxsim (see Shreeram+24)
- Tx from fitting ideal mock X-ray spectra
- Generate variety with ML (or pick nearest neighbor in M,z)



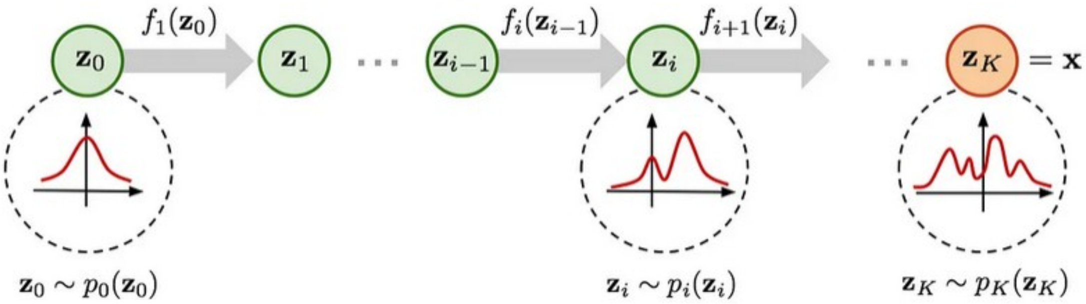


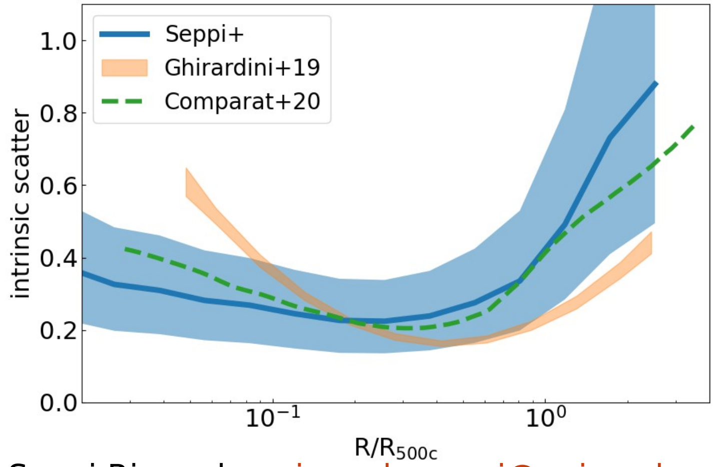


Mock Clusters & Groups

- New model with Normalizing Flows: build complex distribution from simple ones

(e.g. Glow – OpenAI)

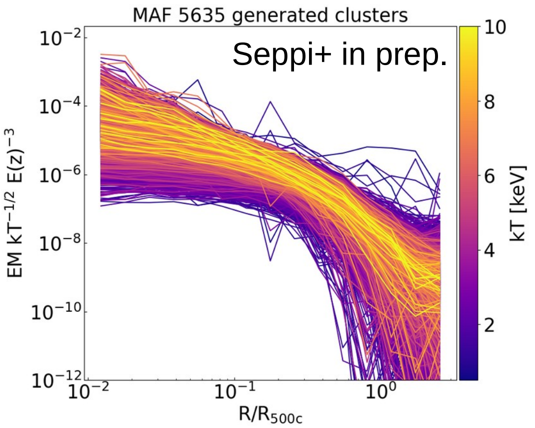




Build P(EM,kT | M,z)

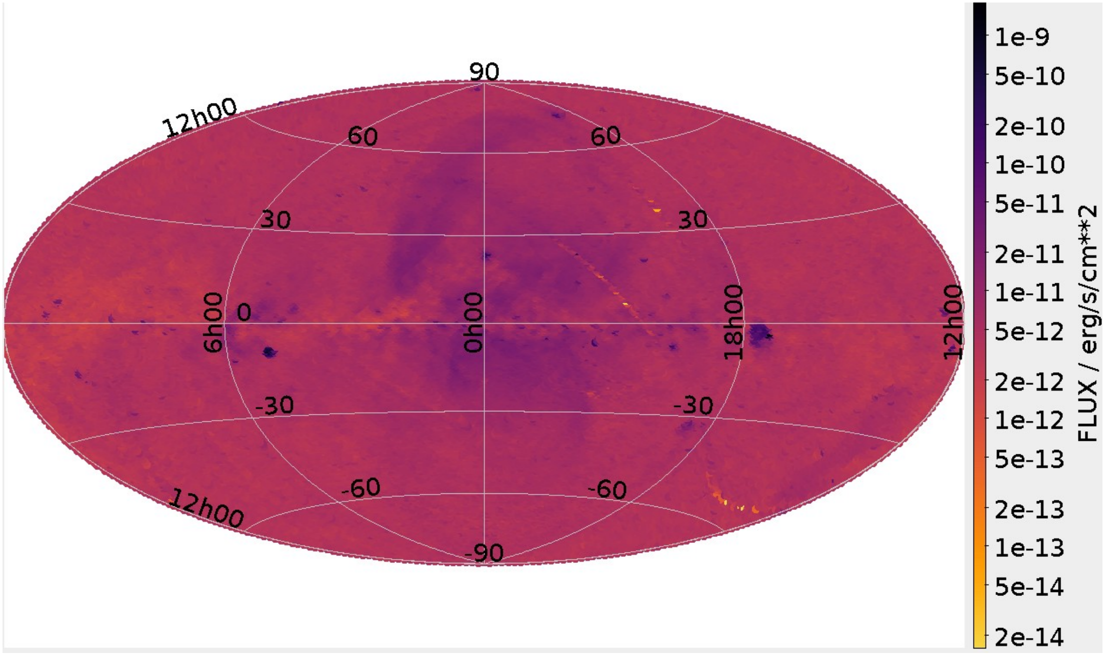
Halo assignment

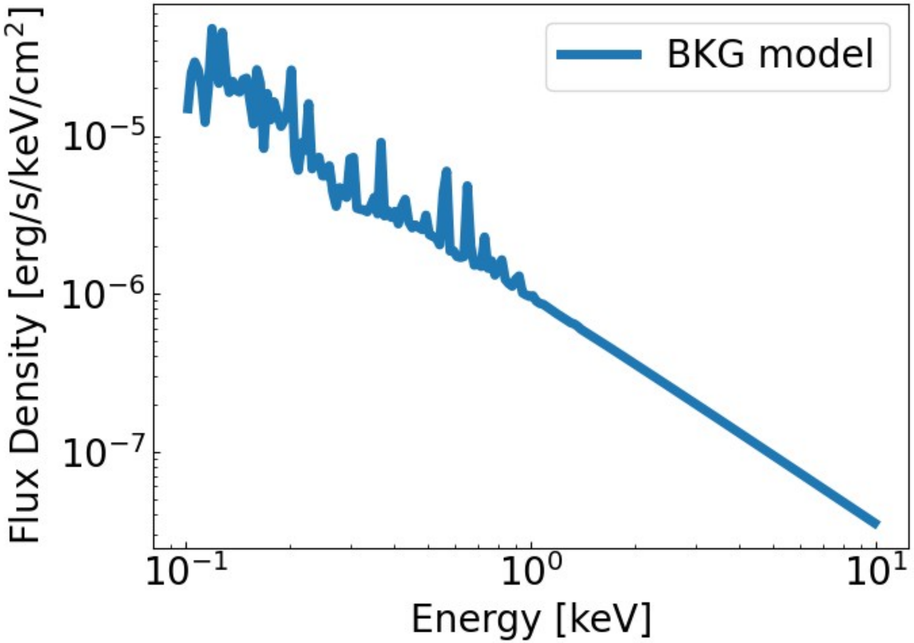
Validate model (scaling relations, profile shape)



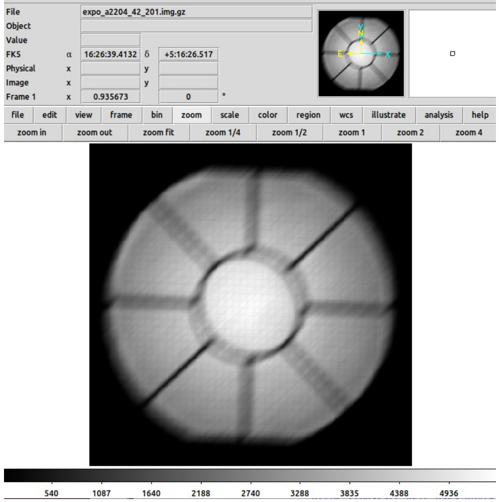
Mock Background

- Simulated as individual component: trace spatial variations
- Merge RASS BKG maps 4-7: 0.44-2.51 keV
- Spectrum with LHB, GH, CXRB

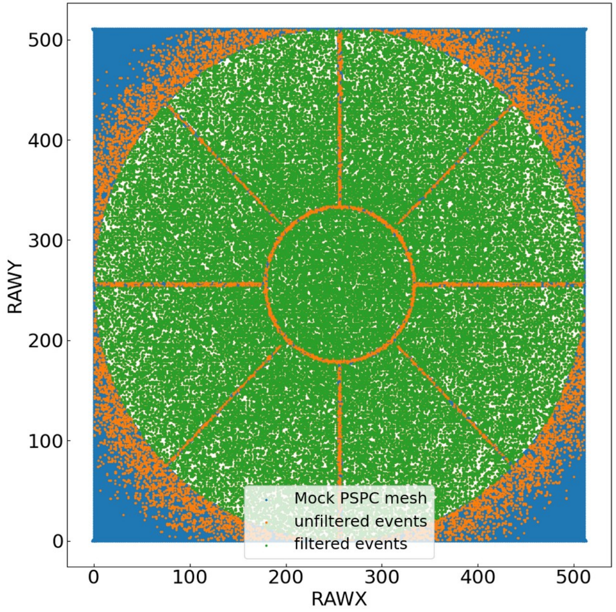


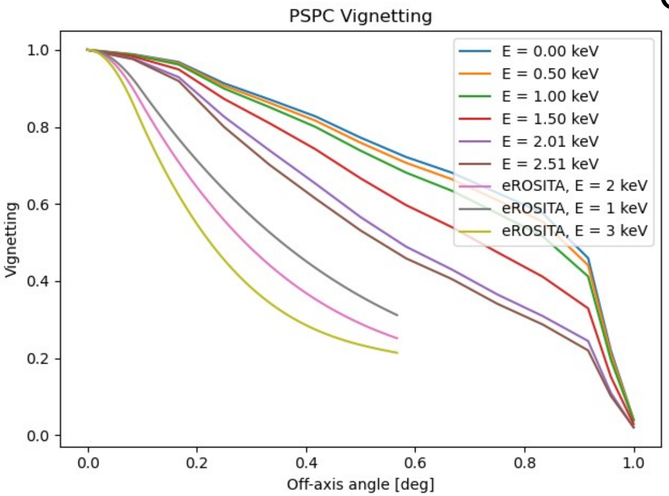


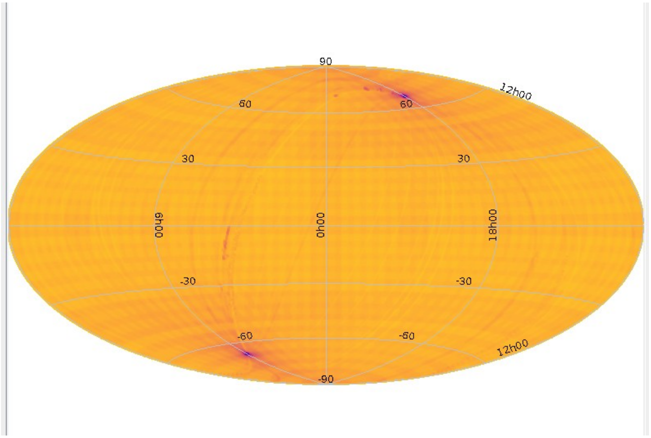
Mock PSPC

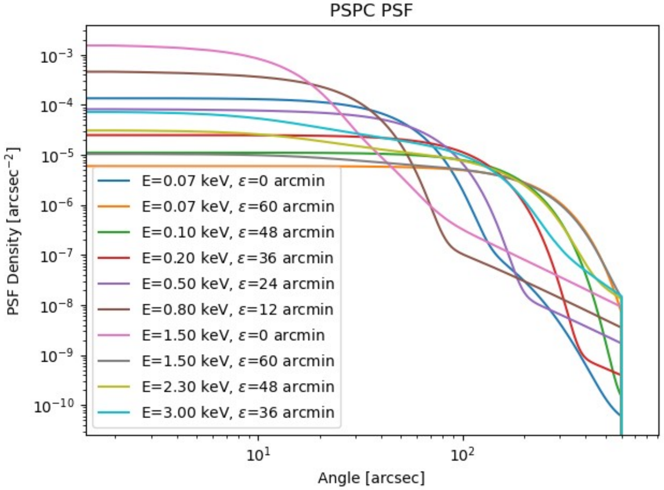


- Mock PSPC with large pixels, fast readout in SIXTE (Dauser+19)
- Mock optics structure masking X,Y
- Vignetting from M. Freyberg
- PSF model from Boese+00
- ARF, RMF: SIXTE PSPC module (M. Lorenz, J. Wilms – K.Remeis Obs. Bamberg)
- Concatenate individual RASS pointings



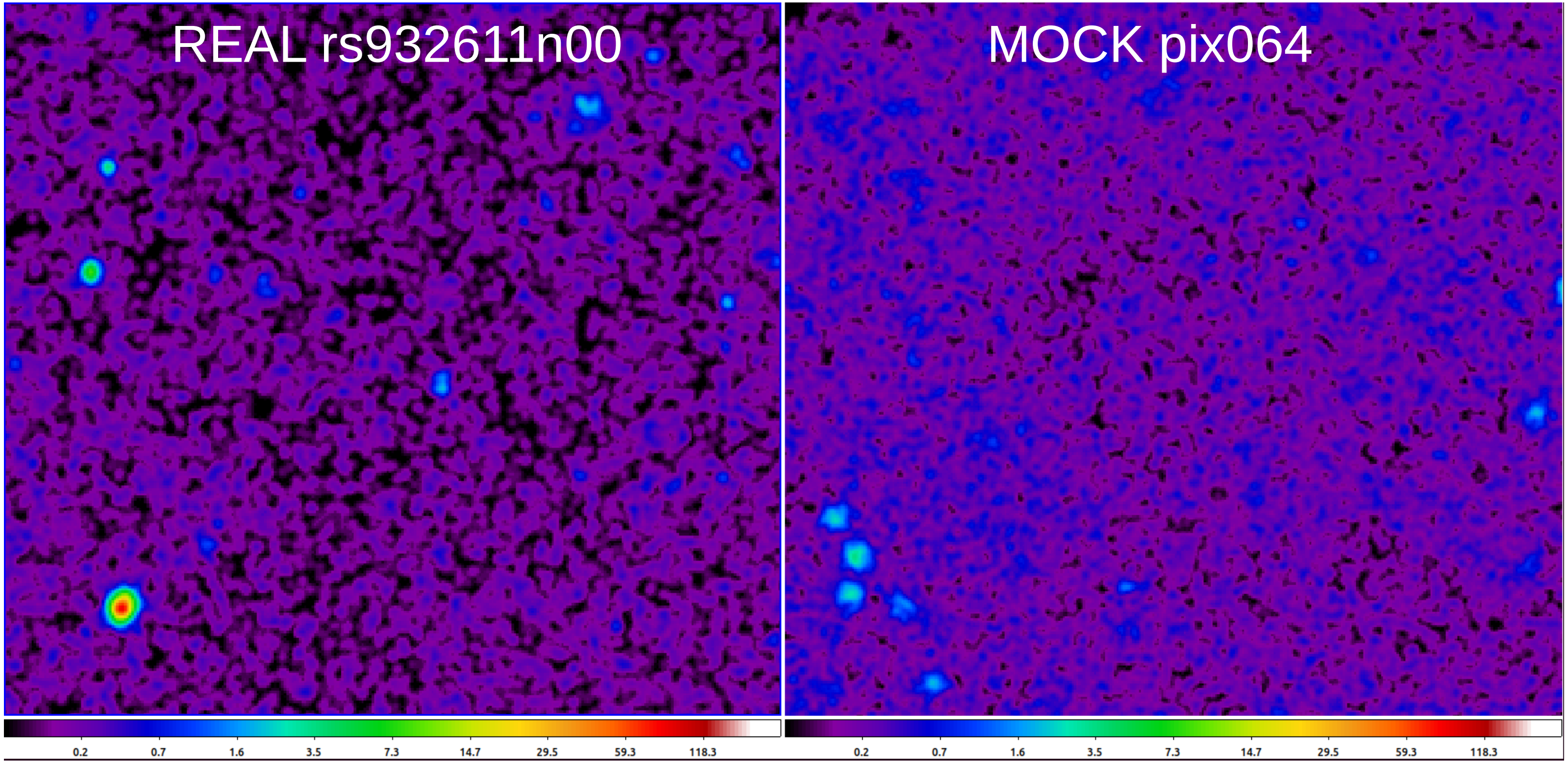






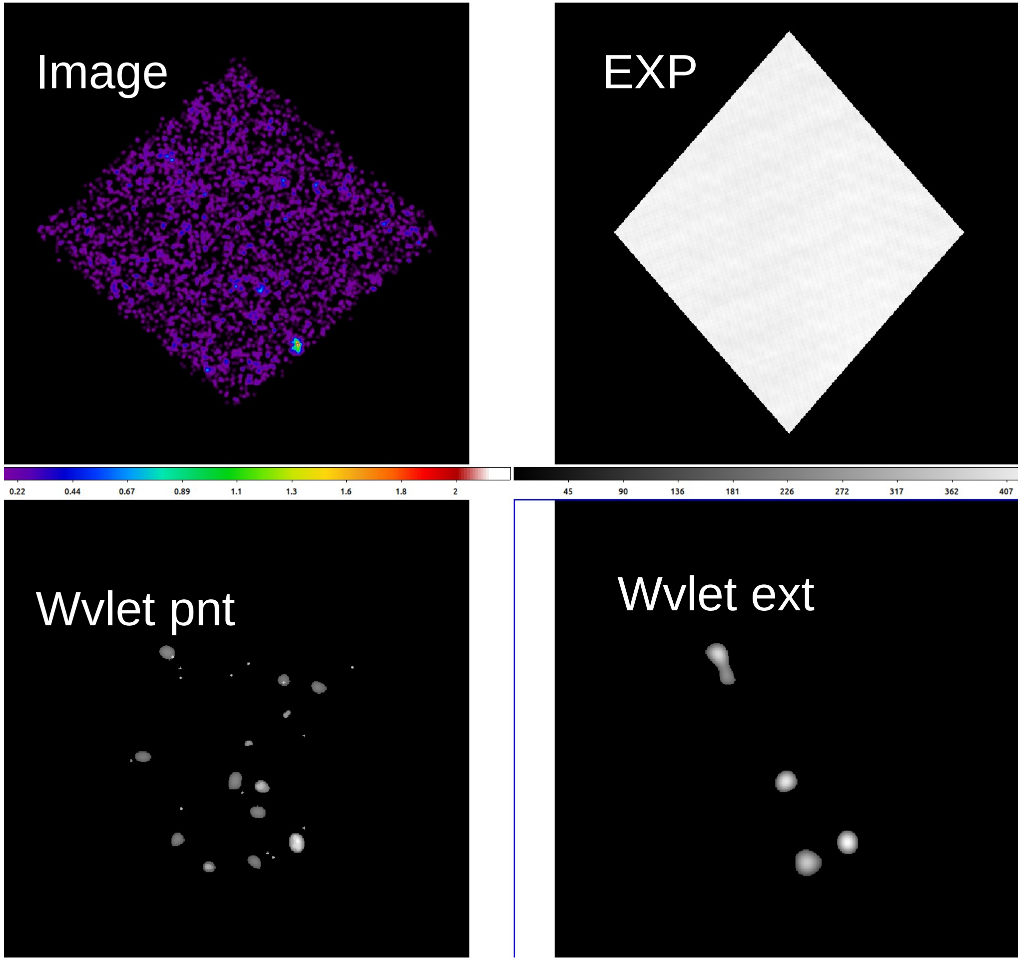
RASS mocks

- X-ray simulator provides event files
- Generate images of the mock RASS sky



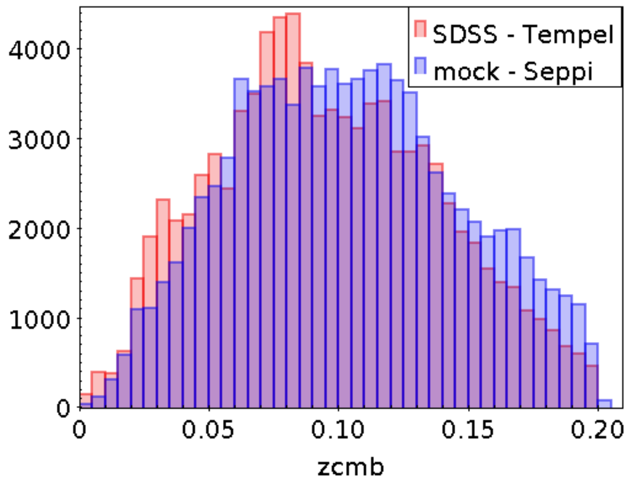
X-GAP mocks – X-ray selection

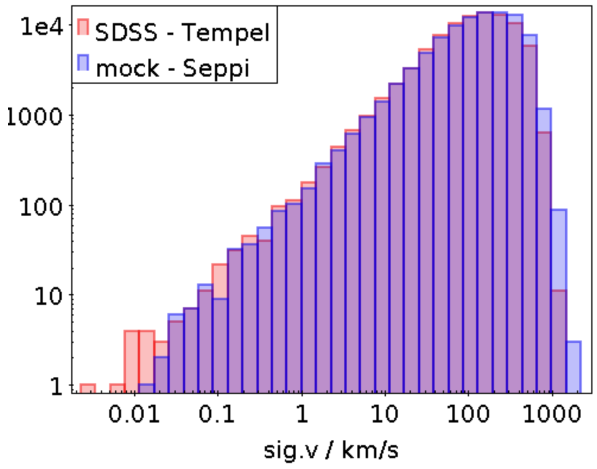
- Wavelet filtering (1 pix=45”)
- Pnt:2-4, Ext: 5-6 (Damsted+24)
- EXT detection with sextractor

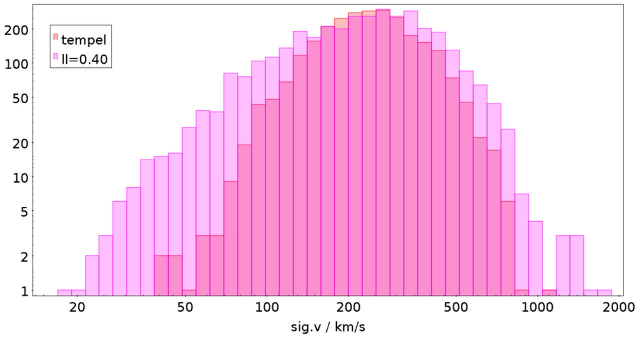


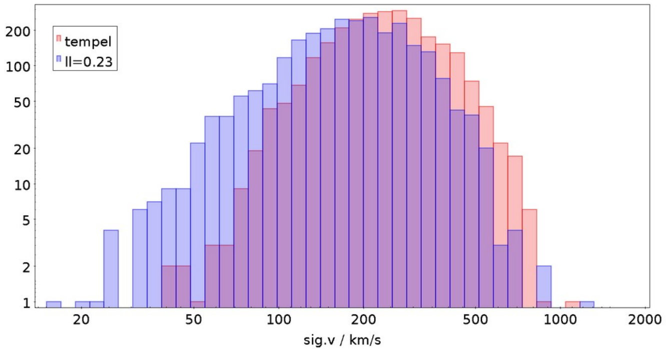
X-GAP mocks – optical selection

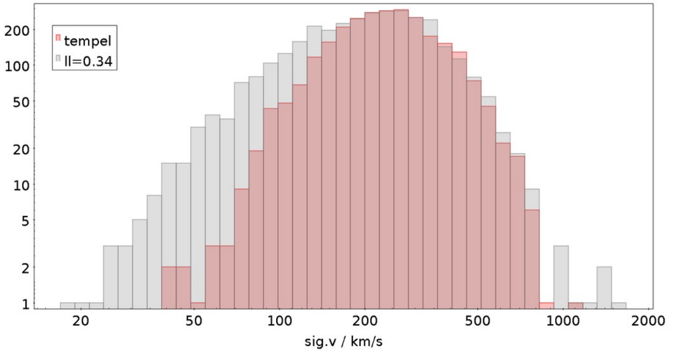
- Friends-of-Friends group finder (SDSS, Tempel+17)
- Output catalogue strongly depends on input parameters
- Good old little-h issues











X-GAP mocks

Development of interactive Mock Sky View

X-GAP Mock Sky View

RA Center: 142.17

DEC Center: 51.49

Radius (arcmin): 60

Update Region

Clusters Summary

4 clusters found

ID	RA	DEC	M500c	R500 (arcmin)	Redshift	veldisp	RA_X	DEC_X
618569754484.0	142.18	51.49	6.51e+14	14.62	0.077	896.58	142.20	51.50
14980931784356.0	142.90	50.60	5.68e+13	3.76	0.139	342.40	0.00	0.00
618569767798.0	142.75	50.86	3.86e+13	5.53	0.079	393.37	0.00	0.00
618569752047.0	142.70	51.90	2.83e+13	5.13	0.077	635.11	0.00	0.00

Cluster ID = 618569754484 has an X-ray detection with offset: 0.94 arcmin

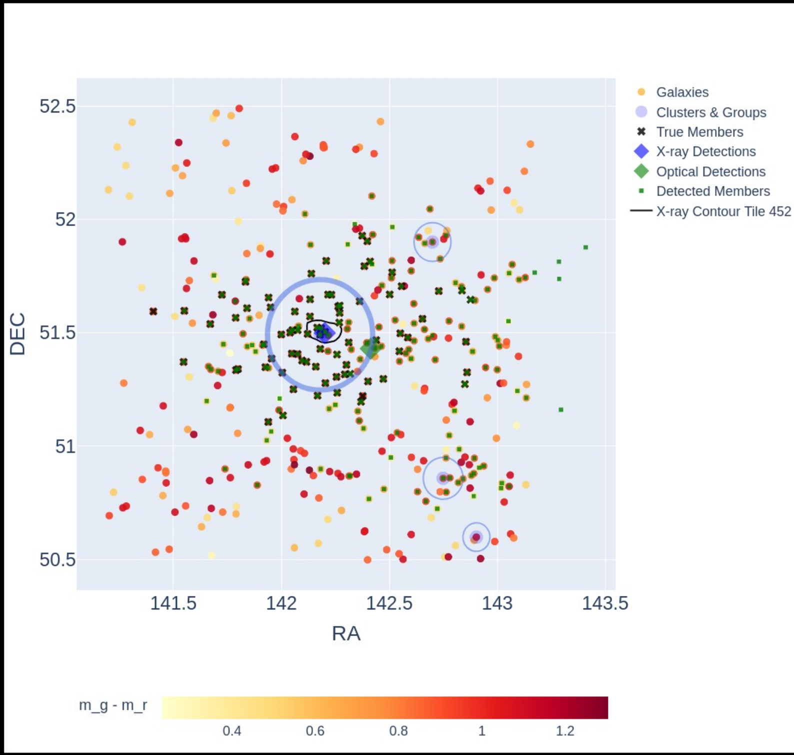
Cluster ID = 618569754484 has an optical detection with offset: 9.54 arcmin and Pmatch: 0.92389

77 cluster members for cluster ID=618569754484

RA	DEC	z_obs	m_r	m_g	m_z
142.18	51.49	0.076	14.78	15.63	14.13
142.59	51.48	0.080	14.90	15.84	14.23
142.17	51.52	0.078	15.16	15.88	14.63

195 detected FoF members for group ID=[711.]

RA	DEC	z	mag
143.07	51.80	0.079	14.69
142.18	51.49	0.076	14.78
142.70	51.90	0.078	14.86
142.59	51.48	0.080	14.90
142.75	50.86	0.075	15.12
142.17	51.52	0.078	15.16
142.38	51.79	0.075	15.16



X-ray Input-output
using photonID (Seppi+22, Liu+22)

Optical Input-output
with probabilistic approach

$$r = \frac{d_{3D}}{R_{500c}}$$

$$P_{\rm dist}(r) = \frac{1}{1+r^2}$$

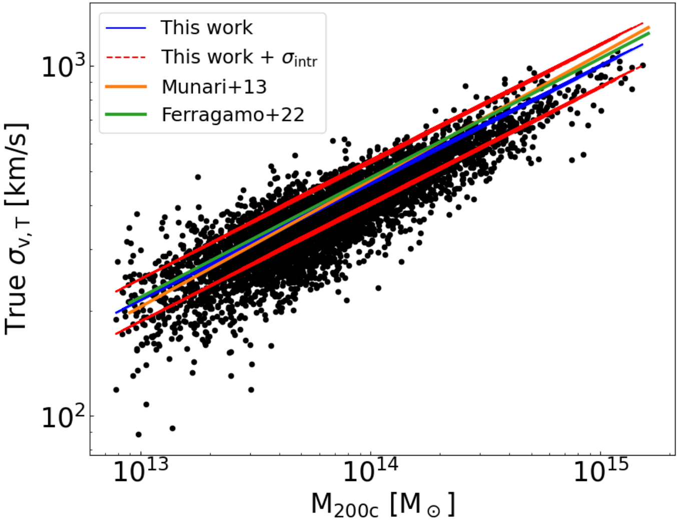
$$\mathcal{I} = \int_0^{100} P_{\rm dist}(r)dr$$

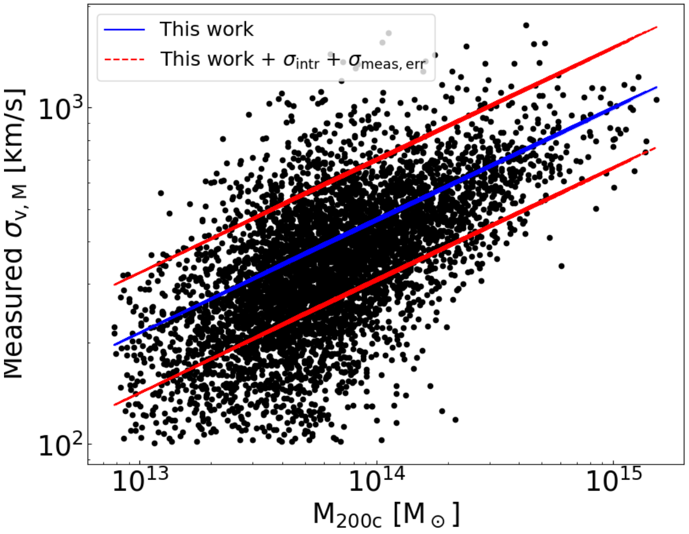
$$P_{\rm match}(\sigma_{\rm v,M}, \sigma_{\rm v,T}, r) = \mathcal{LN}(\sigma_{\rm v,M}|\sigma_{\rm v,T}) \times \frac{P_{\rm dist}(r)}{\mathcal{I}}$$

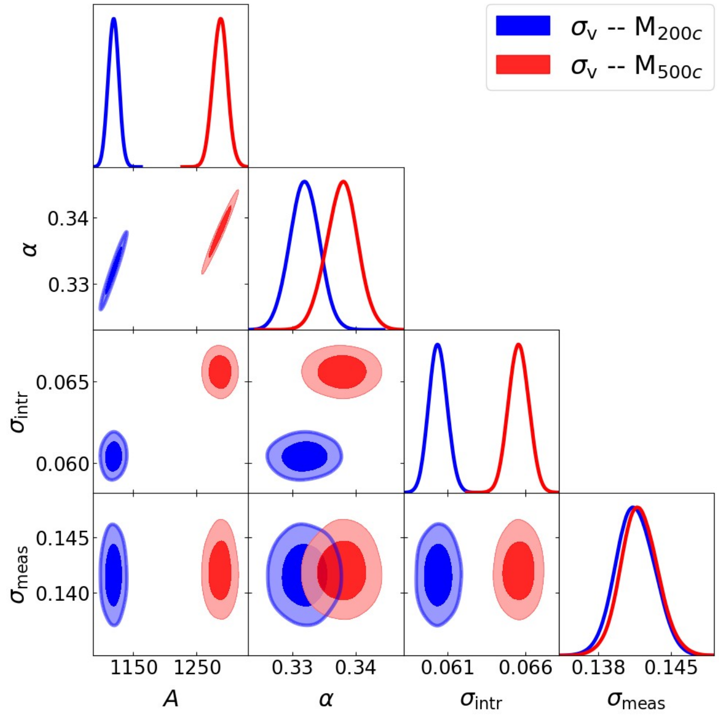
X-GAP mock: velocity dispersion

- Velocity dispersion from subhalo velocities
- Calibration of the scaling relation between with halo mass
- Model accounting for:

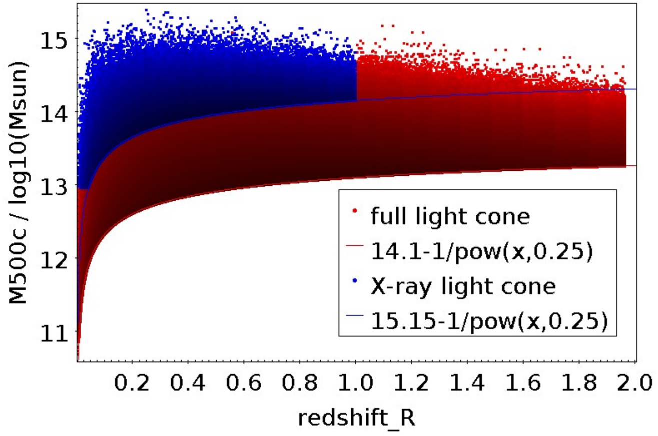
Power law SR + intrinsic scatter + measurement scatter

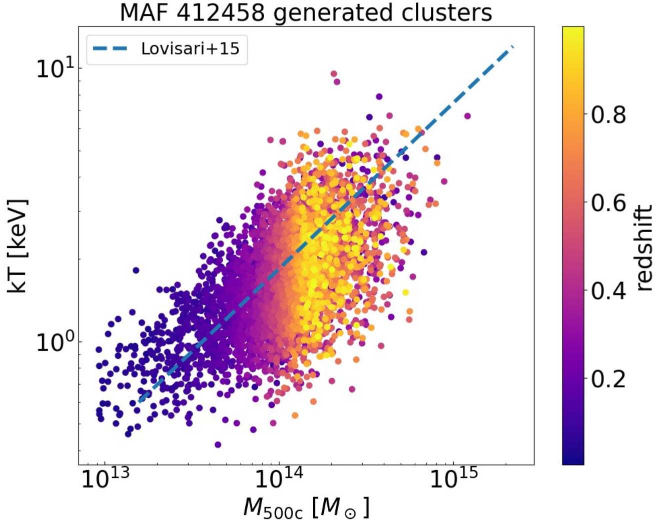




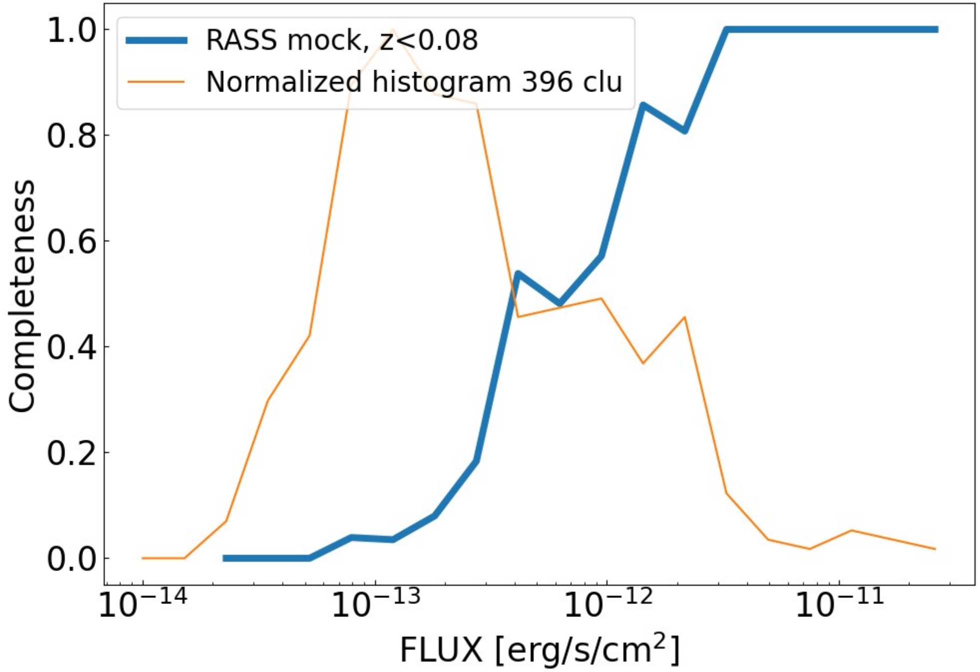


X-GAP mocks – X-ray selection





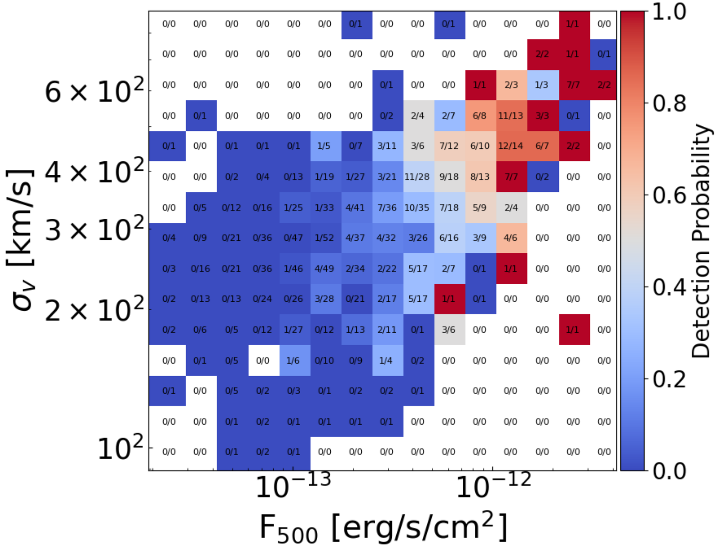
- The cluster model is PRELIMINARY
  - Flux distribution to be improved



X-GAP selection function

- To model accounting for observables:
Flux (XMM-Newton), velocity dispersion, (z?)

- Key component in comparison to hydrosims



OUTLOOK

- Finalize and validate cluster model
- Polish optical selection (linking length, n_members)
- Increase statistic with light cones in different orientations (3x on the way)
- Model the selection function and its uncertainty

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Summary

Swiss National Science Foundation

- End goal: inform AGN feedback models using galaxy groups
- Comparison to hydro-sims, baryonic models (e.g. Arico'+21)
- Selection modeling with end-to-end mocks
- New X-ray model for groups/clusters
- Pdet(Fx, vel_disp, z)
- Calibration of Mhalo-vel_disp

X-GAP: simulations and selection function

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ABSTRACT

Context. Context
Aims. Aims
Methods. Method
Results. Results
Conclusions. Conclusions

Key words. X-rays: galaxies: clusters - Galaxies: clusters: intracluster medium - Surveys - Cosmology: large-scale structure of Universe - Methods: data analysis

1. Introduction

RS: large scale structure The large scale structure (LSS) of the Universe evolves under the action of gravity following a bottom-up scenario (Springel et al. 2005). The massive dark matter haloes we observe nowadays in the nodes of the LSS are the end result of a process of merging and accretion from smaller haloes formed in the early Universe after collapsing initial perturbations in the density field. The behaviour of baryonic components such as gas and stars within the distribution of dark matter has been a key scientific puzzle for the last few decades. The feedback from active galactic nuclei (AGN, Padovani et al. 2017) came up as a solution to a variety of questions, such as the suppression of cooling flows towards the center of galaxy clusters (Gitti et al. 2012), the suppression of star formation to explain the shape of the stellar mass function (Silk & Rees 1998; Pillepich et al. 2018), or the origin of scaling relations between galaxy properties and supermassive black hole (SMBH) mass (Magorrian et al. 1998; Kauffmann & Haehnelt 2000).

RS: groups Galaxy groups play a key role in this context, because their gravitational binding energy is comparable to the output energy of the central AGN. Therefore, galaxy groups are very sensitive to the physics of AGN feedback. They are located at the peak of the mass density at the current epoch (see e.g. Fig. 5 in Tinker et al. 2008). Groups of galaxies were historically first detected and studied in the optical and infrared bands, as collection of their member galaxies identified as overdensities in angular and redshit distributions (Abell 1958; Zwicky et al. 1963; Huchra & Geller 1982; Geller & Huchra 1983; Beers et al. 1990). Since then, various works presented similar methods to identify groups from galaxy surveys, including phase space methods (Mamon et al. 2013), the identification of red sequence galaxies (Gladders & Yee 2000; Saro et al. 2013; Rykoff et al. 2014; Licitra et al. 2016), and Friends-of-Friends (FoF) algorithms (Trevese et al. 2007; Muñoz-Cuartas & Müller 2012; Wen et al. 2012; Tempel et al. 2012). Groups are often characterized in terms of velocity dispersion of their galaxy members (Mamon et al. 2010). We refer the reader to Old et al. (2014, 2015) for a comprehensive description and review about optical detection and mass estimate of galaxy groups. Galaxy groups are also often identified in X-rays thanks to thermal bremsstrahlung and line emission from the hot gas filling their potential wells (e.g., Böhringer et al. 2000; Rosati et al. 2002), reaching temperatures between 10^6 and 10^7 K (Sanders 2023). Surveys in the X-ray, such as ROSAT (Truemper 1982) and eROSITA (Merloni et al. 2012; Predehl et al. 2021), are therefore suitable to detect these objects. X-ray observations show prominent features such as cavities in the intra-group medium (IGrM) produced by massive outflows related to SMBH activity (Bîrzan et al. 2008; Gastaldello et al. 2009; Randall et al. 2015). If the outburst is supersonic, shock waves propagating perpendicular to the outflow become visible (Liu et al. 2019). The behaviour of the gaseous atmosphere is therefore strongly connected with both gravitational and non gravitational processes.

RS: simulations Currently, hydrodynamical cosmological simulations include the implementation of AGN feedback in various forms and recepies. Some simulations, such as cosmo-OWLS (Le Brun et al. 2014), EAGLE (Schaye et al. 2015) and BAHAMAS (McCarthy et al. 2017) rely on an isotropic and thermal response to gas accretion onto the SMBH (see e.g. Booth & Schaye 2009). The gas surrounding the central black hole is heated when the AGN turns on, which suppresses gas cooling and hence star formation. Other works, including Illustris (Vogelsberger et al. 2014), HorizonAGN (Dubois et al. 2016), MAGNETICUM (Dolag et al. 2016), IllustrisTNG (Pillepich

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