# LESSONS LEARNT
# (XMM BACKGROUND MODELING AND MCMC SPECTRAL FITTING)
# FROM THE CHEX-MATE PROJECT


M. Rossetti (INAF IASF-Milano)
D. Eckert, G.Pratt, I. Bartalucci, S. Molendi and the CHEX-MATE Collaboration


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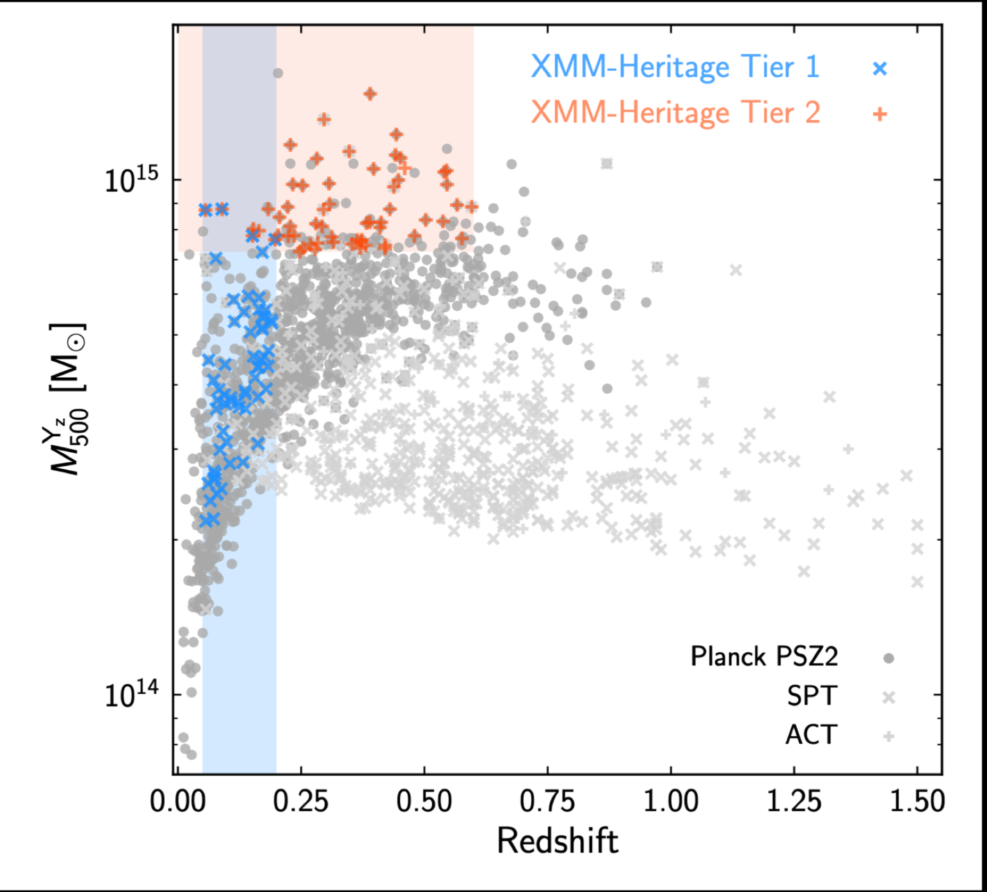
# The Cluster HEritage project with XMM-Newton: Mass Assembly and Thermodynamics at the Endpoint of structure formation




One of the six XMM Heritage program approved since 2017
PIs: S. Ettori (INAF) / G. Pratt (CEA Saclay)

84 new observations (3 Msec) in 2018-2022 + archival data (Total: > 6 Msec)
118 clusters detected by Planck at high S/N

- **Tier 1** a census of the population of clusters at the most recent times
- **Tier 2** the most massive systems to have formed thus far in the Universe

Born as X-ray project but now multi-wavelength: weak lensing, optical spectroscopy, SZ and radio data for most objects

20 accepted papers http://xmm-heritage.oas.inaf.it/

# The Cluster HEritage project with XMM-Newton: Mass Assembly and Thermodynamics at the Endpoint of structure formation

Motivating Questions (Arnaud et al 2021):

- What is the absolute cluster mass scale? How accurately can we measure total masses basing on baryons?
- What are the properties of the «true» cluster population?
- How do the properties of the cluster population change over time?

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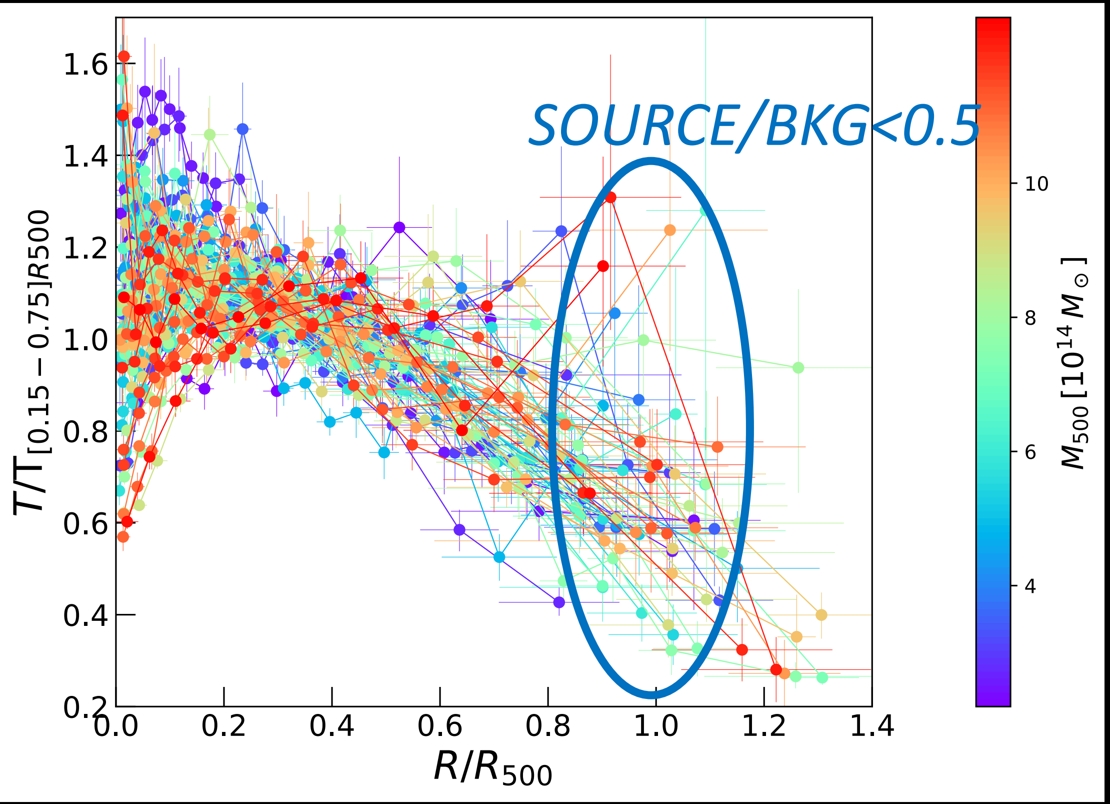


To adress them we need to measure temperature profiles from spectral analysis up to external regions, where the source intensity goes much below the background level

# The CHEX-MATE improved bkg model

Basing on X-COP (Eckert et al 17) and preparatory work for Athena (e.g. Gastaldello et al 22, Marelli et al 21), we built a predictive XMM background model *(MR, D. Eckert et al. 2024)*

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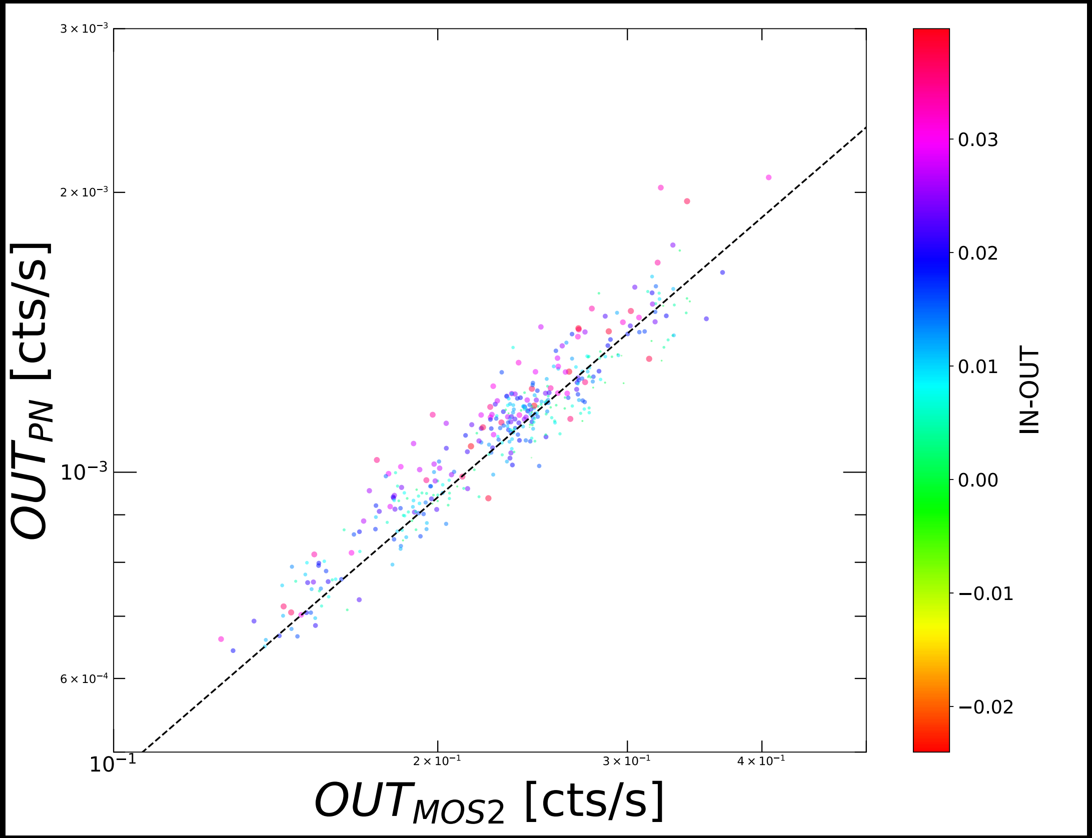


Background induced by Cosmic Ray Particles

- Detector regions unexposed to the sky allow us to monitor the level of CRPB in real time.
- Mature technique for MOS detectors (Snowden et al. 2008, Leccardi & Molendi 2008)
- The pn detector lacks fully unexposed regions, residual contamination from photons and soft protons (Marelli et al 2022).

In CHEX-MATE we calibrated a relation to predict the level of CRPB from the MOS2 background level with a few % intrinsic scatter

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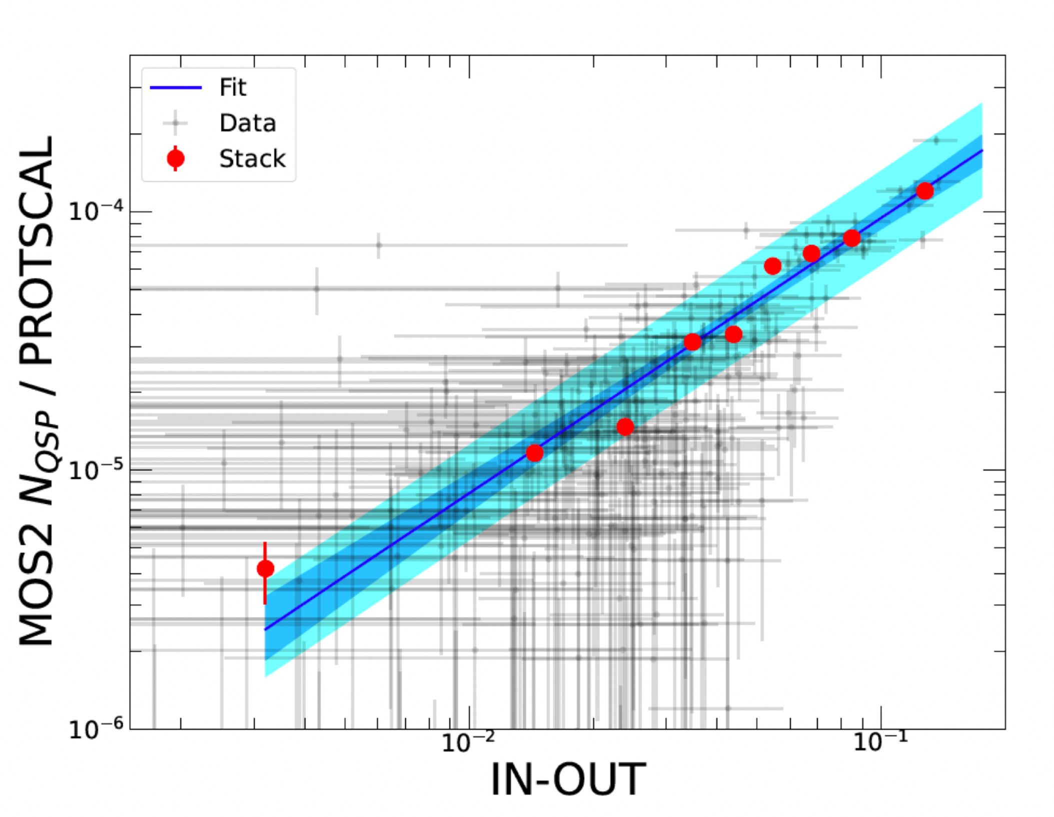
## Residual Focused Component

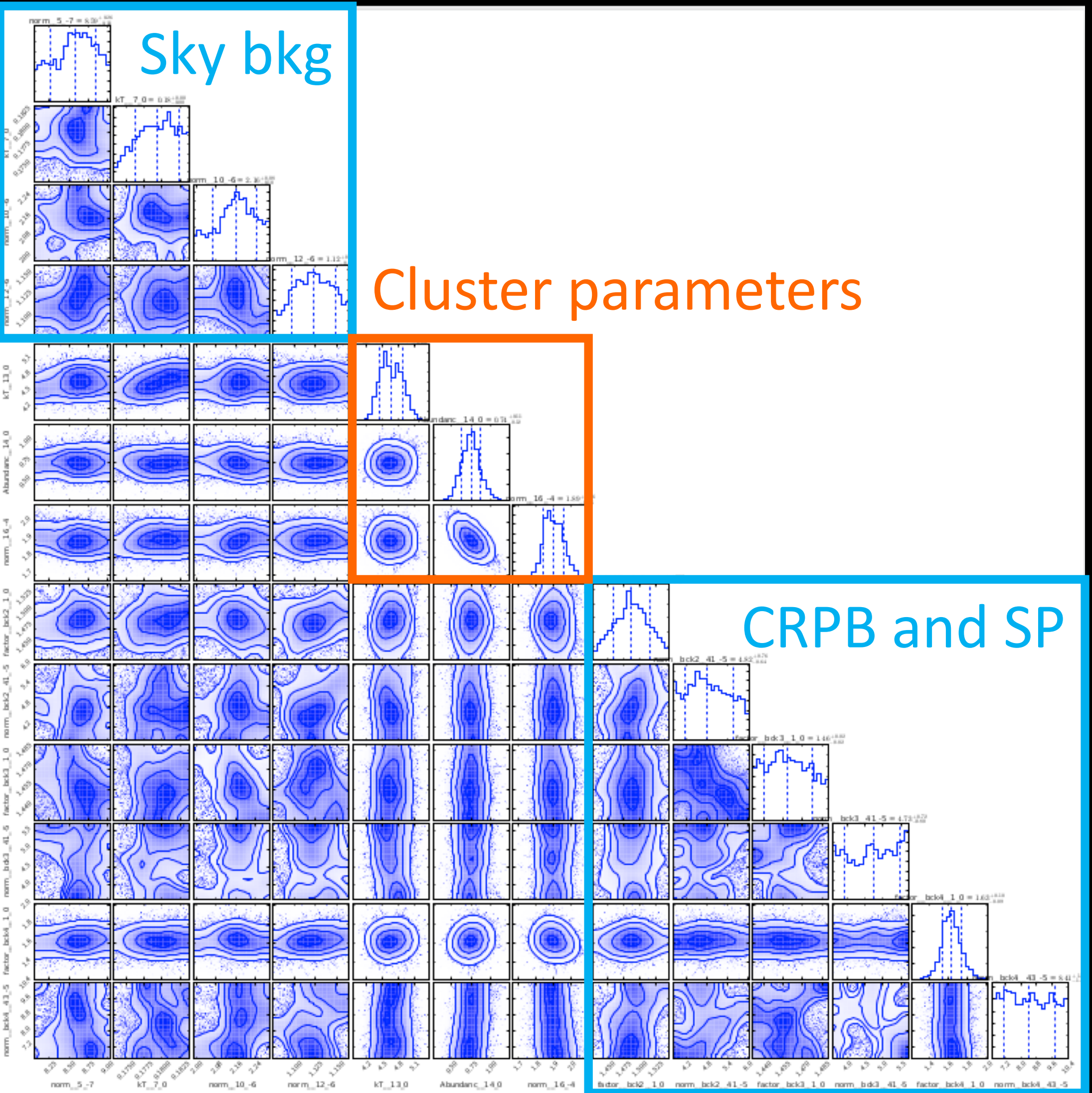
- Even after light curve filtering a residual contamination survives in the FoV (De Luca & Molendi 2004)
- This component has its vignetting curve (Kuntz & Snowden 2008)
- The IN-OUT indicator measure its intensity (Salvetti etal 2017)




We used 500 blanck sky fields (XXL Pierre et al 2016) to spectrally model the residual SP component and calibrate a relation between its normalization and IN-OUT indicator

# The CHEX-MATE MCMC approach

We can now propagate the uncertainty of the bkg model up to the final results thanks to the MCMC fitting within XSPEC (50k burn-in, 50k chains, 2 hours per spectrum)




- We use the predictive background model to build priors on CRPB and SP for each detector
- We also define priors for the sky background

| Parameter | Shape | Central value | Width |
|---|---|---|---|
| CRPB norm. (MOS) | Gaussian | Best Fit of mos-back spectra | 2% intrinsic scatter |
| CRPB norm. (pn) | Gaussian | Best fit of pn-back spectra renormalized by Eq. (2) | 6% intrinsic scatter |
| RFC norm. (MOS) | Uniform | inFOV–outFOV, with Eq. (A.1) | Intrinsic scatter |
| RFC norm. (pn) | Uniform | $inFOV_{PN}$ and $outFOV_{MOS2}$ with Eqs. (A.1) and (A.2) | Intrinsic scatter |
| LHB norm. | Gaussian | Best fit in background region | $1\sigma$ errors |
| GH temp. | Gaussian | Best fit in background region | $1\sigma$ errors |
| GH norm. | Gaussian | Best fit in background region | $1\sigma$ errors |
| CXB norm. | Gaussian | Best fit in background region | $1\sigma$ errors |

*MR et al. 2024*

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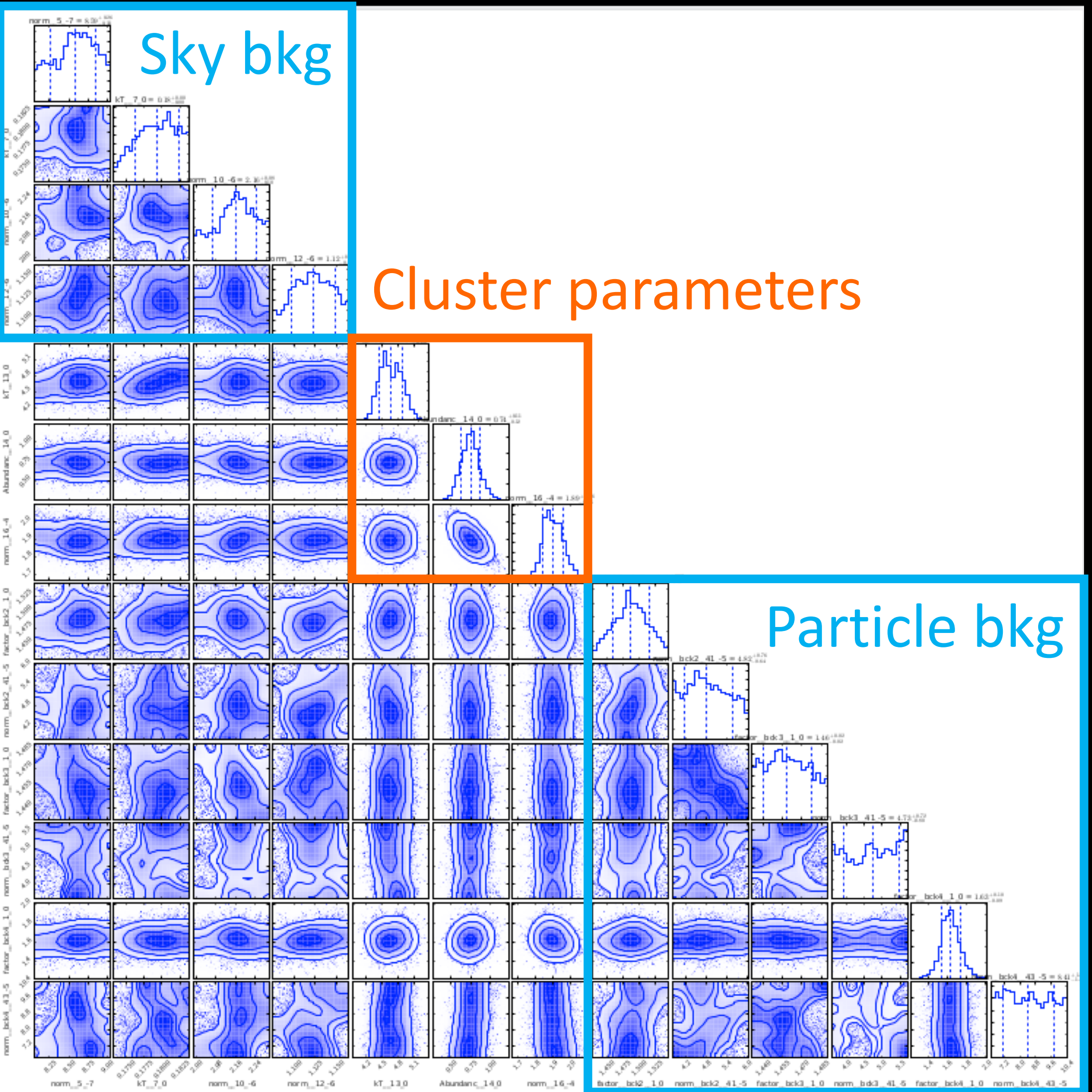


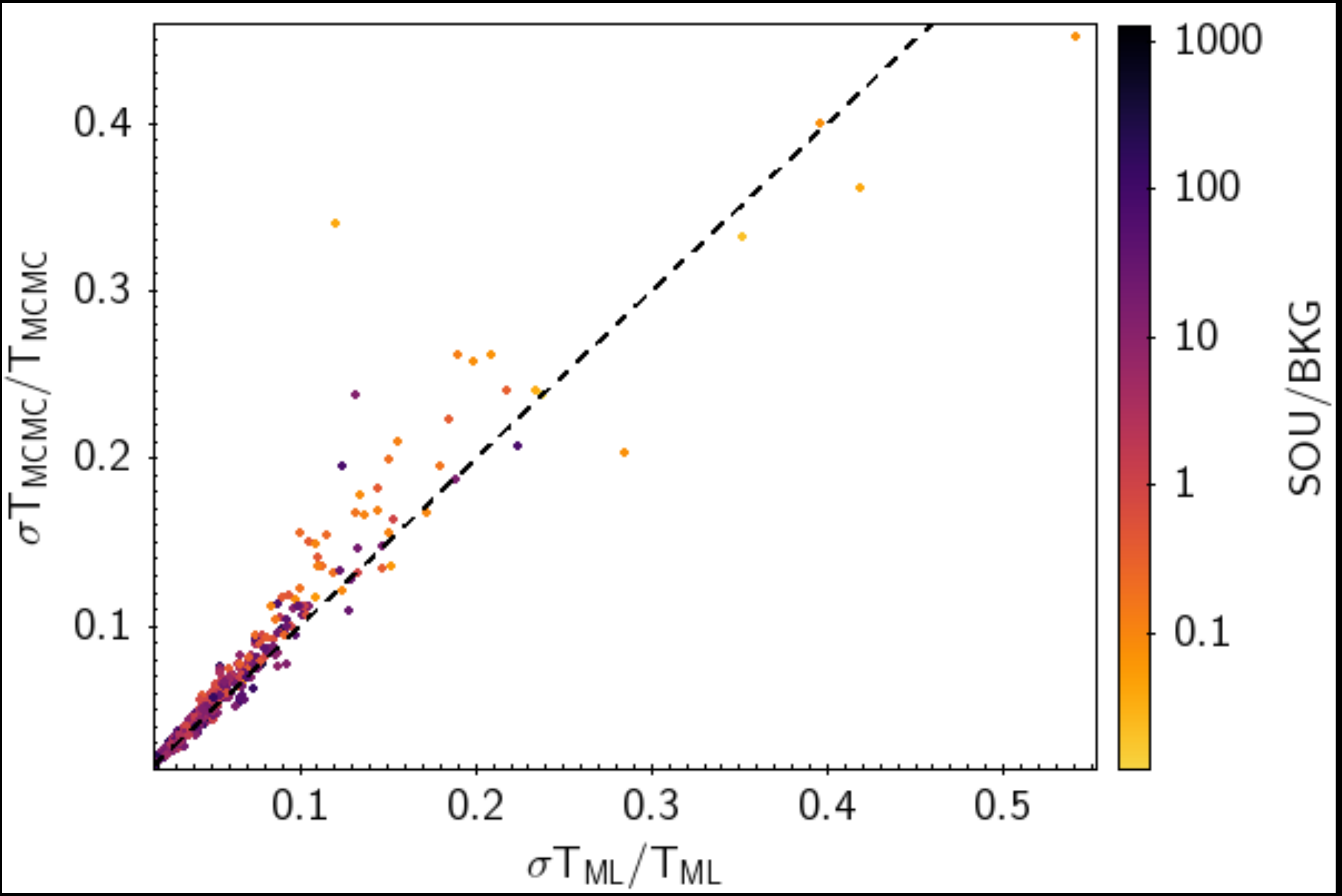


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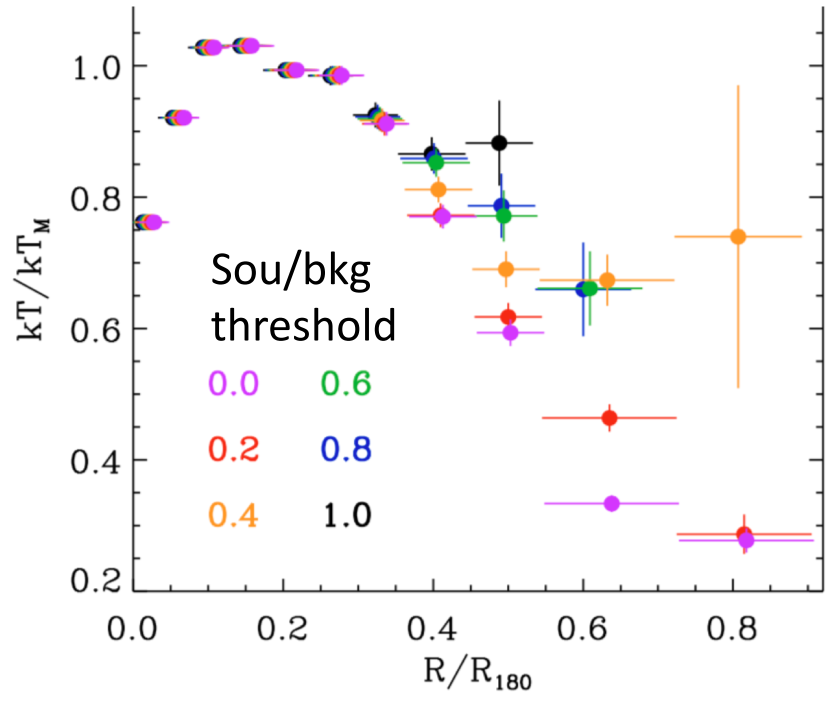
# CHEX-MATE results on T profiles

How does our bkg modeling and methods affect the mean temperature profiles?

Leccardi & Molendi (2008)

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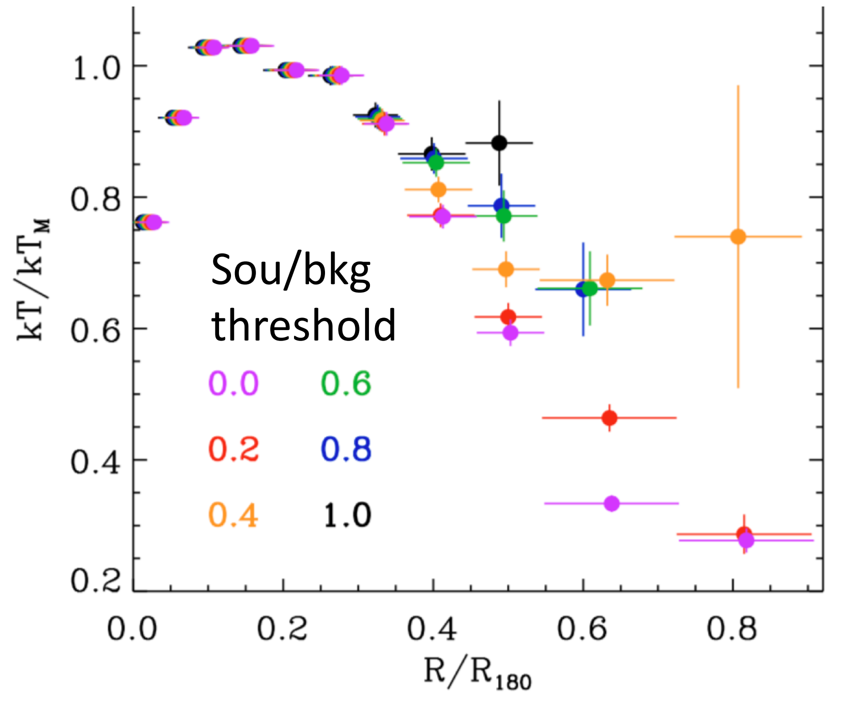


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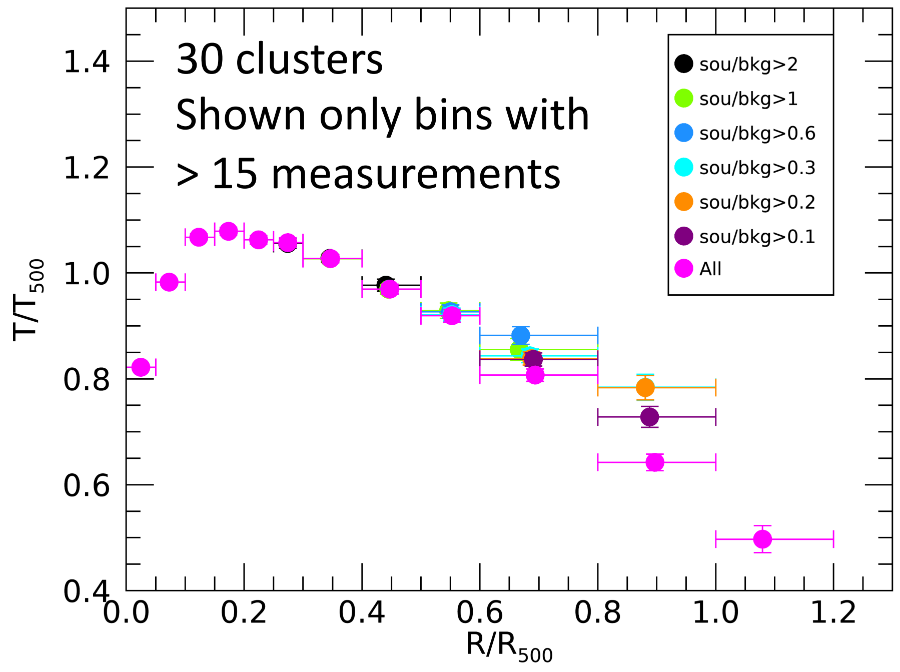
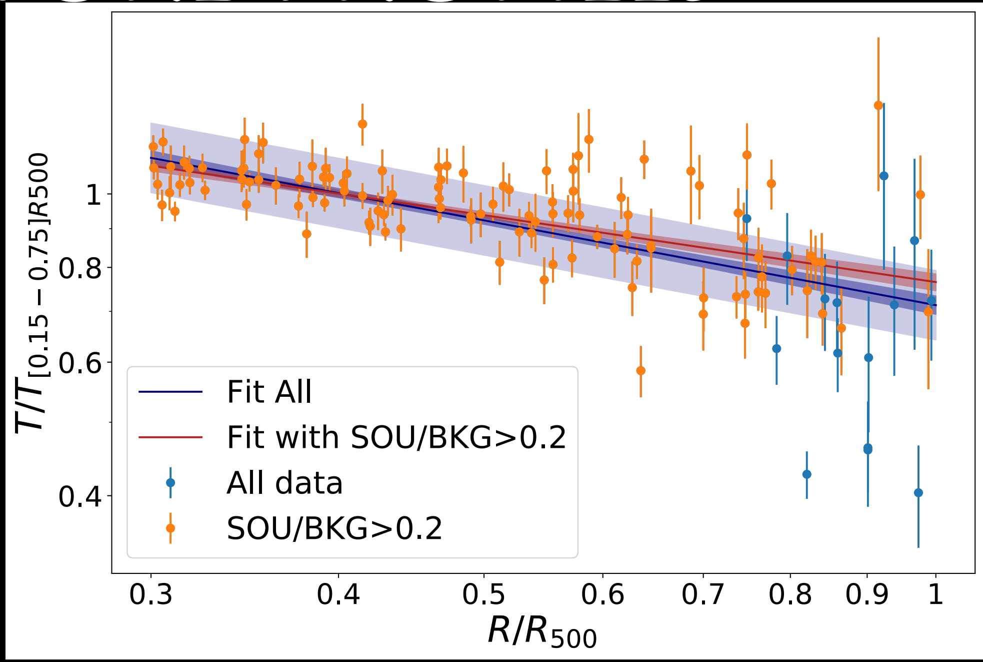



Now, we can go down at least to **sou/bkg > 0.2**

# SYSTEMATICS IN TEMPERATURE PROFILES

Including measurements in regions with SOU/BKG < 0.2 leads to a steepening in the average T profiles, but also moves the barycentre towards lower radii



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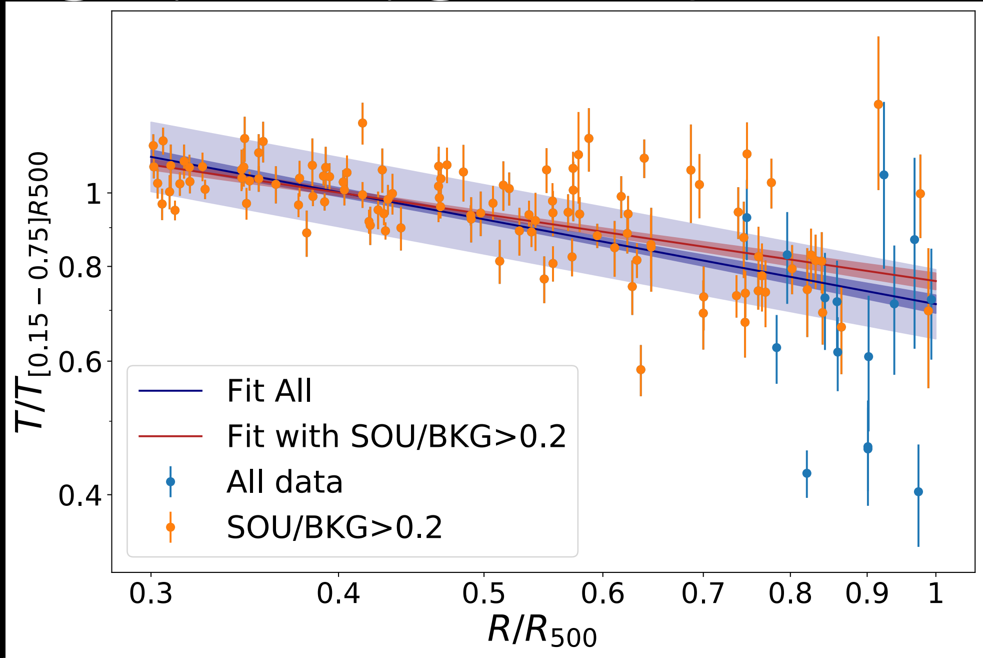


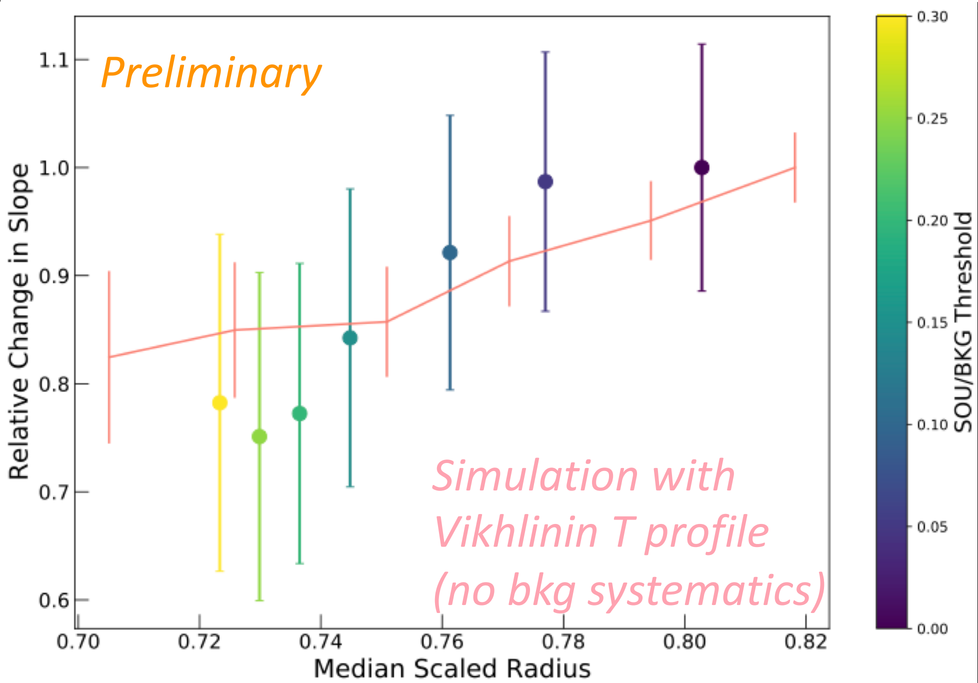

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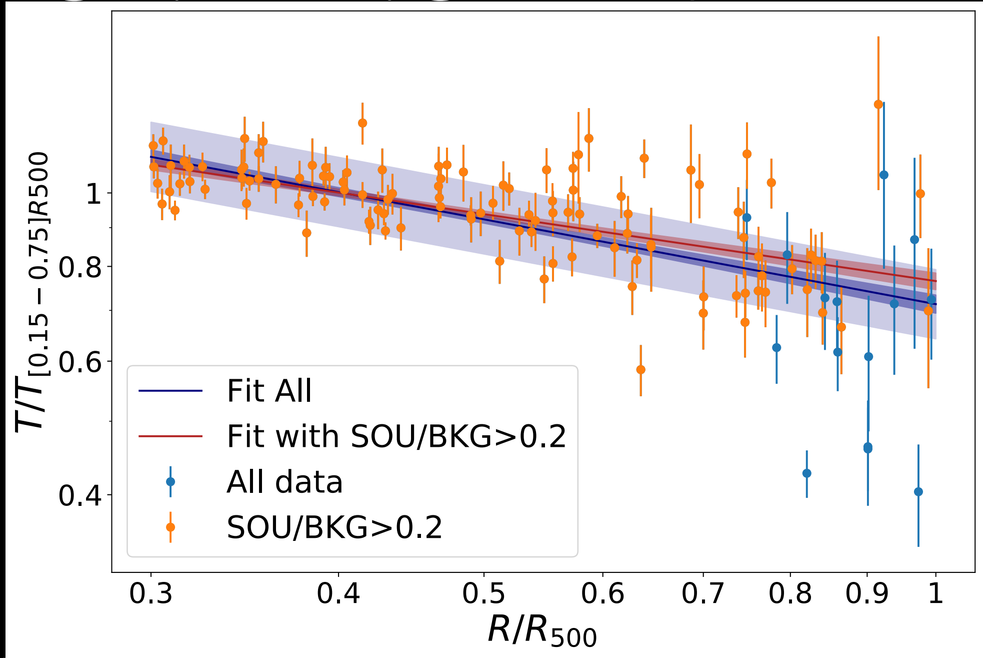
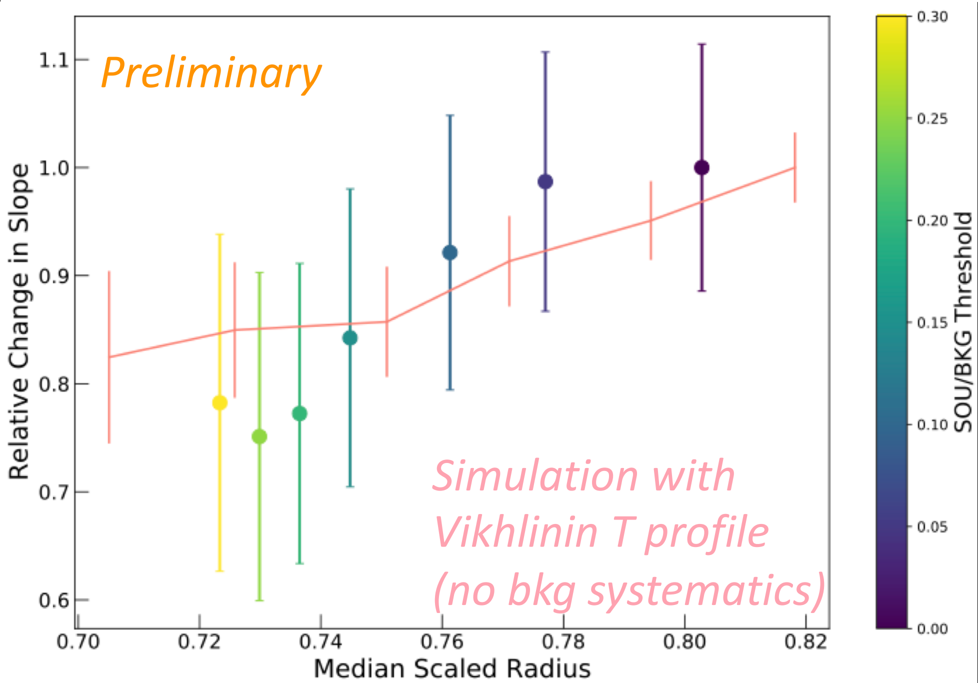
Work in progress: understanding the origin of the steepening and the impact on derived quantities (*SPOILER: <5% on hydrostatic $M_{500}$*)



# TAKE HOME MESSAGES

- We built a predictive and physically-motivated background model for all XMM EPIC detectors and implemented it into a Bayesian MCMC spectral fitting within XSPEC.

- Calibration within a few % became possible thanks to the systematic analysis of archival and blanck sky fields observations (eXTRAS, AREMBES, AHEAD, XXL) and the work of *Background Lovers* at IASF Milano (S.Molendi, F. Gastaldello, I. Bartalucci, M. Marelli, S.Ghizzardi, A. Tiengo, A. De Luca).

- This allowed to push the limits of systematic errors: we can now measure reliable temperatures at least up to regions where source $\gtrsim$ 20% of the background

AHEAD 2020 HIGH ENERGY ASTROPHYSICS
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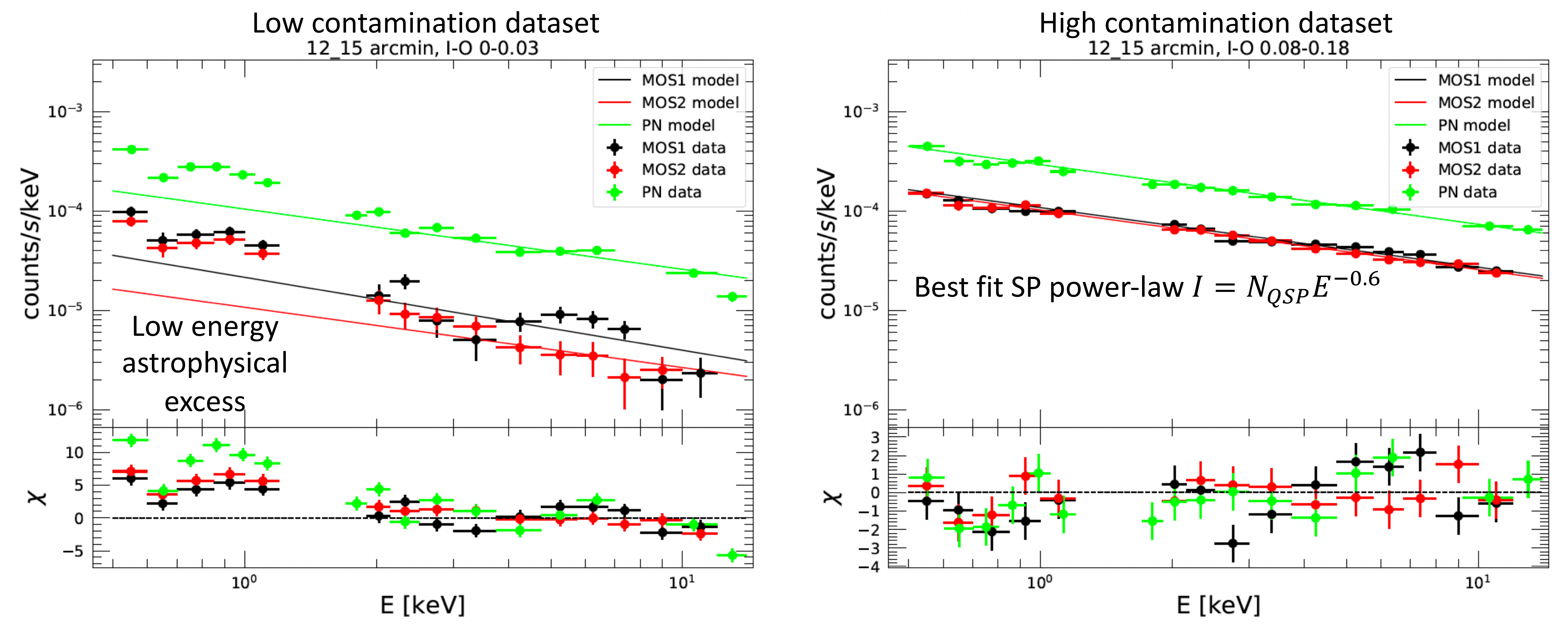
# BACKUP SLIDES

# RESIDUAL FOCUSED COMPONENT

Residual spectra in black-sky fields observations after subtraction of CRPB and sky background



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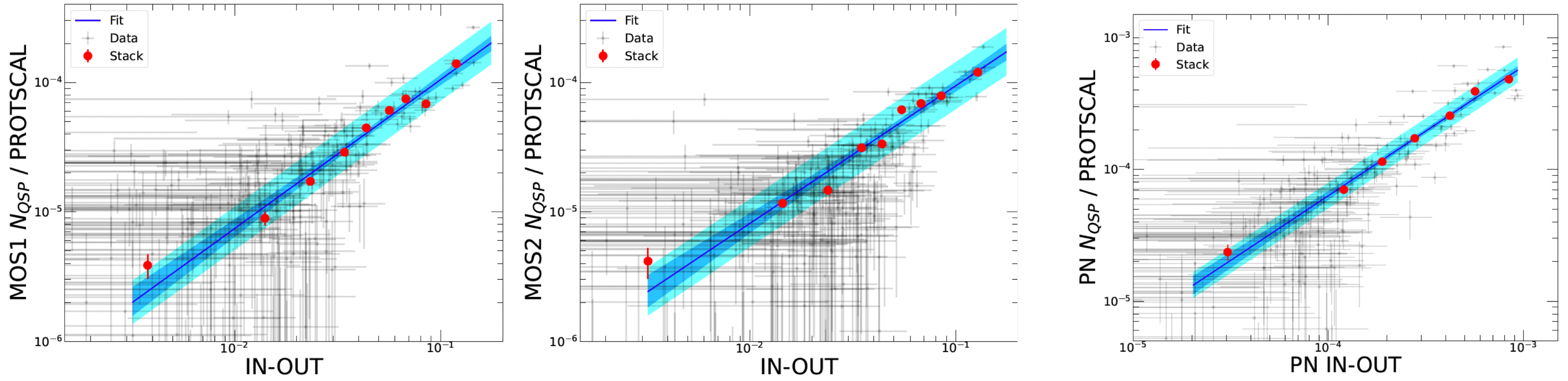
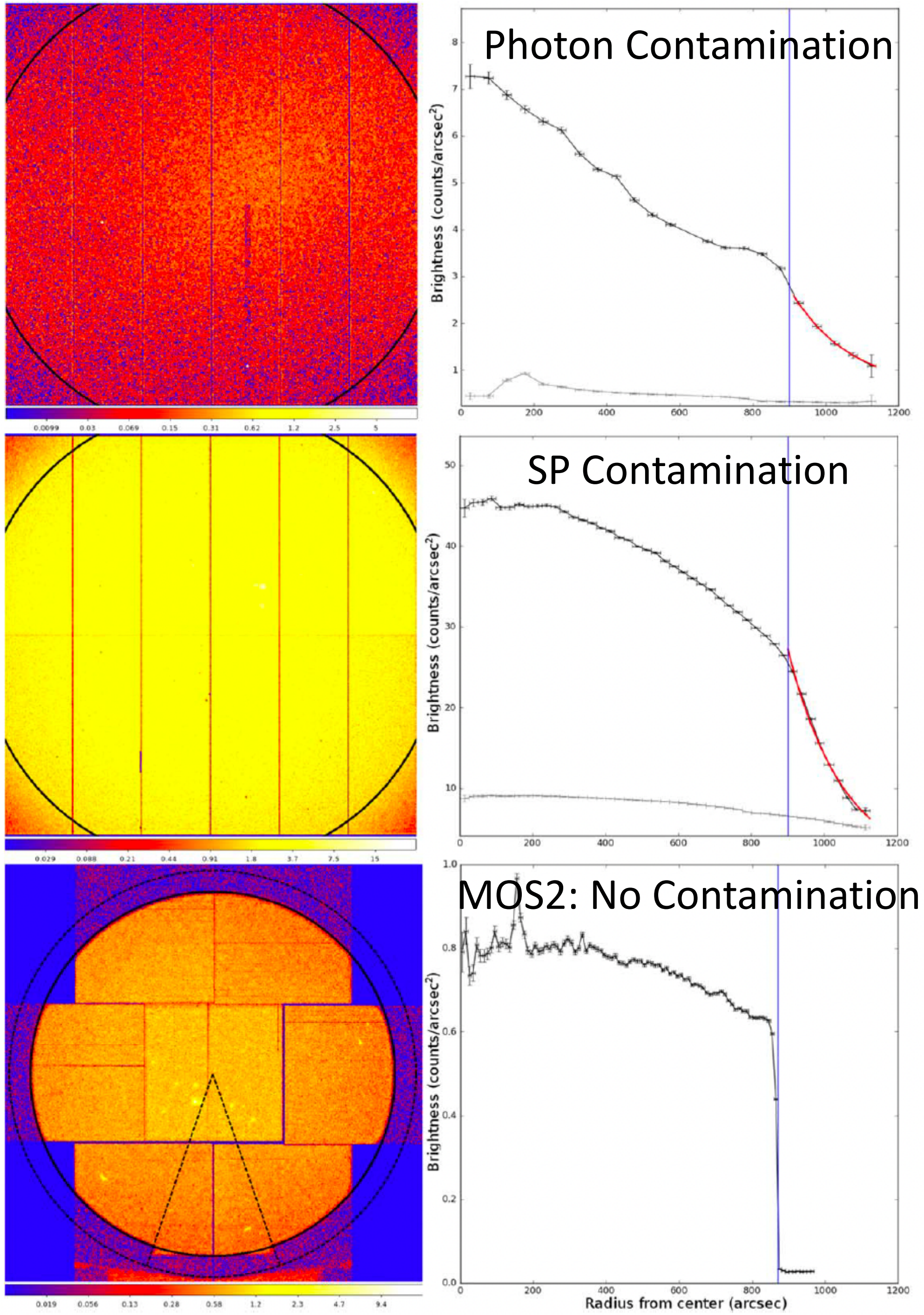



To calibrate the relation for PN we cannot use the MOS IN-OUT but need to define a new indicator because of different GTI selection and contamination of the outFOV region

$$(inFOV - outFOV)_{PN} = CR_{ann} - \mathrm{A}_{\mathrm{CRPB}}\ outFOV_{MOS2}$$




# Contamination in pn OUT

- Marelli et al. (2021) suggest a recipe to minimize the contamation in the pn OUTFOV (region definition, hard band)

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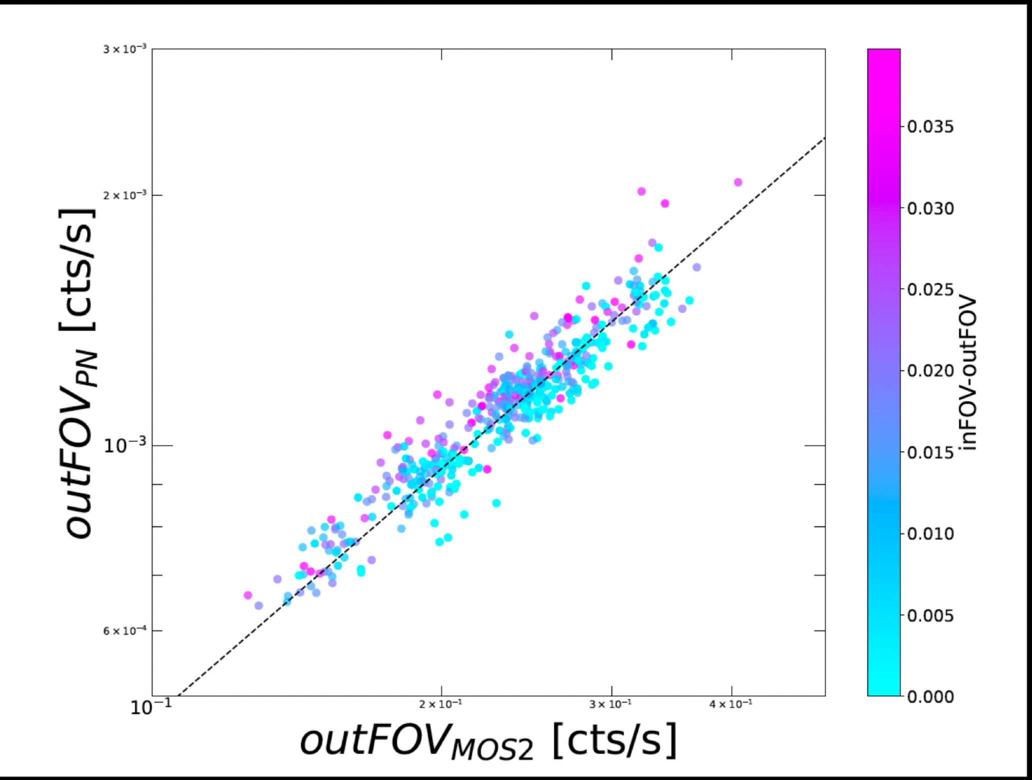
- Marelli et al. (2021) suggest a recipe to minimize the contamation in the pn OUTFOV (region definition, hard band)
- Good correlation with MOS OUTFOV data but scatter depends on residual contamination
- We calibrate a relation, separaring the part due to CRPB and to residual contamination




$$\mathrm{outFOV_{PN}} = A_{\mathrm{CRPB}}\ \mathrm{outFOV_{MOS2}} + A_{\mathrm{SP}}(\mathrm{inFOV} - \mathrm{outFOV}).$$