# Galaxy groups at high redshift (z>2) as seen by ATHENA

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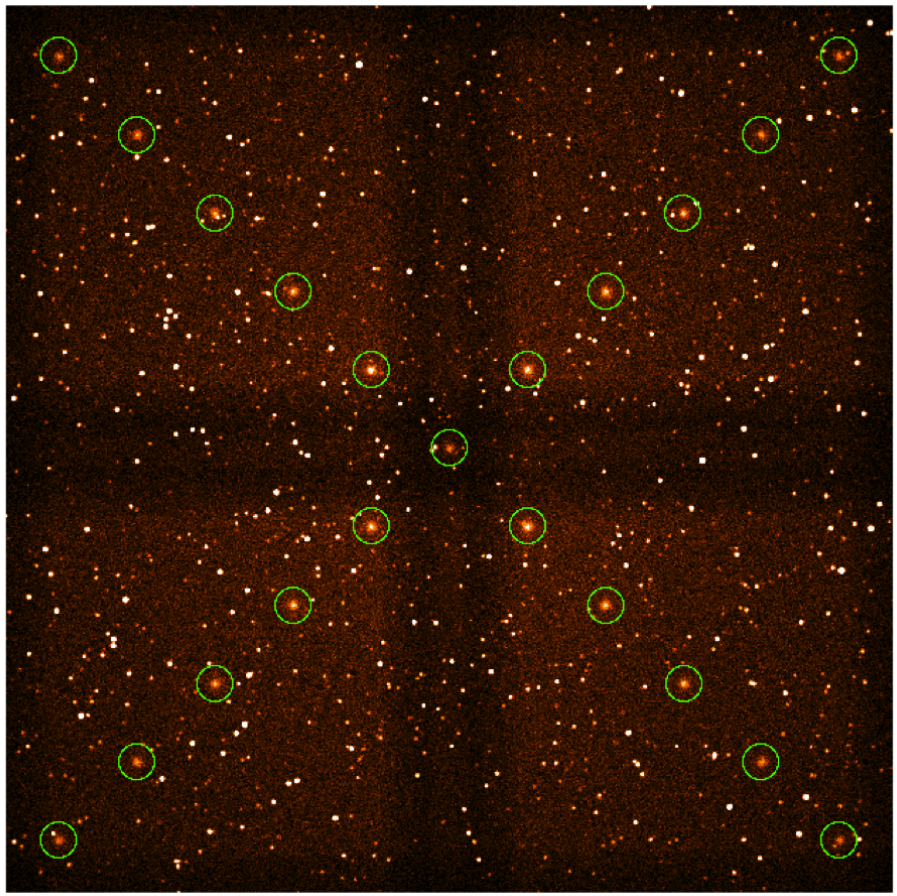
# Introduction

- Galaxy groups are the biggest objects in the Universe, they are crucial to understand the cosmological structure formation.
- Athena will be a unique instrument to perform detailed study of high z groups in X-rays
  1. follow-up high-z groups detected by other instruments e.g. eROSITA, Euclid, LSST and SZ survey (CMB-S4).
  2. characterization of their density and temperature profiles.
- The goal of my project:
  1. use SIXTE simulator to discover the new groups ($z \geq 2.0$ and $M \sim 5 \times 10^{13} M_{\odot}$), and characterize the detection probability with WFI instrument
  2. to constrain the L-T relation by performing the spectrum fitting

# SIXTE simulation setups

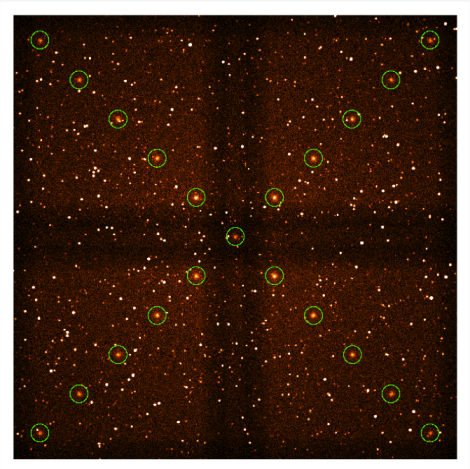
- Simulated Athena image with FoV $40' \times 40'$ at [0.2-2] keV band



- Athena with 15 rows mirror shell.
- Dither mode with exposure time 50, 80 and 100 ks.
- Off axis at $5'$, $10'$, $15'$, $18'$ and $25'$ away from the center.
- AGN population
  1. $Log(N) - Log(S)$ from Lehmer et al. 2012
  2. $[5 \times 10^{-17} - 1 \times 10^{-11}]$ ergs/s/cm$^2$
- Galaxy groups
  1. scaling relation from Reichert et al. 2012
  2. $\beta = \frac{2}{3}$ and $r_c = 0.15 \times r_{500}$
  3. $1 \times 10^{13}$, $5 \times 10^{13}$, $1 \times 10^{14}$ $M_\odot$
  4. $z = 1.0, 1.5, 2.0, 2.5, 3.0, 3.5$ and $4.0$
  5. central AGN contributing 20% of soft-band flux
- Background: $\underbrace{\text{apec}}_{(1)} + \underbrace{\text{wabs}}_{(2)} \times (\underbrace{\text{apec}}_{(3)} + \underbrace{\text{powerlaw}}_{(4)})$
  1. local bubble
  2. galactic absorption
  3. diffuse galactic foreground
  4. unresolved point sources
  5. flat particle background (from SIXTE simulator)

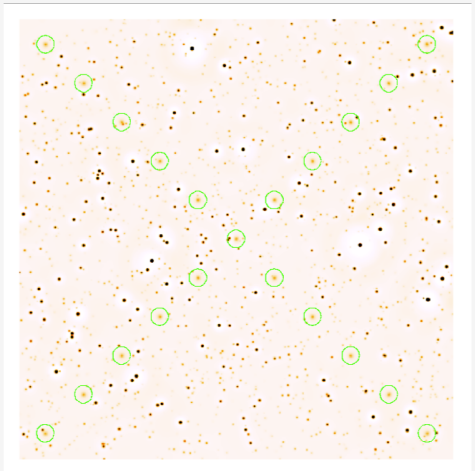
# Detection algorithm

SIXTE image



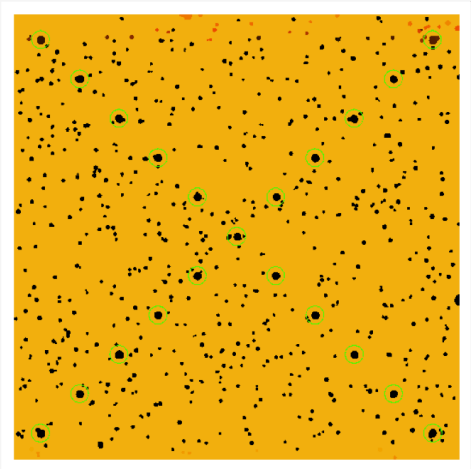
The [0.2-2] keV band images are generated.

Wavelet filtering (à trous algorithm)



Detection method follows the one used in the XXL survey (Pacaud et al. 06,16; Faccioli et al. 18)

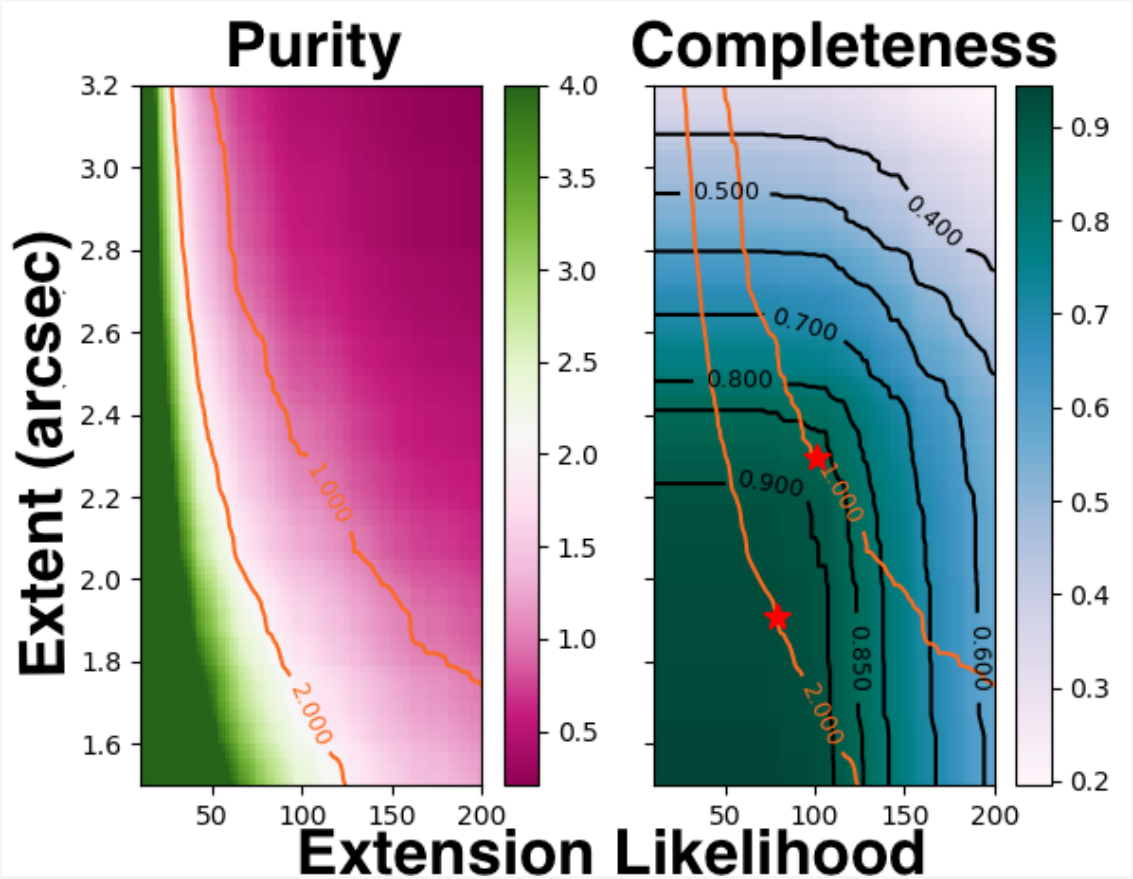
Detection of SExtractor



Both point source and beta profile are modeled.

# Selection criteria

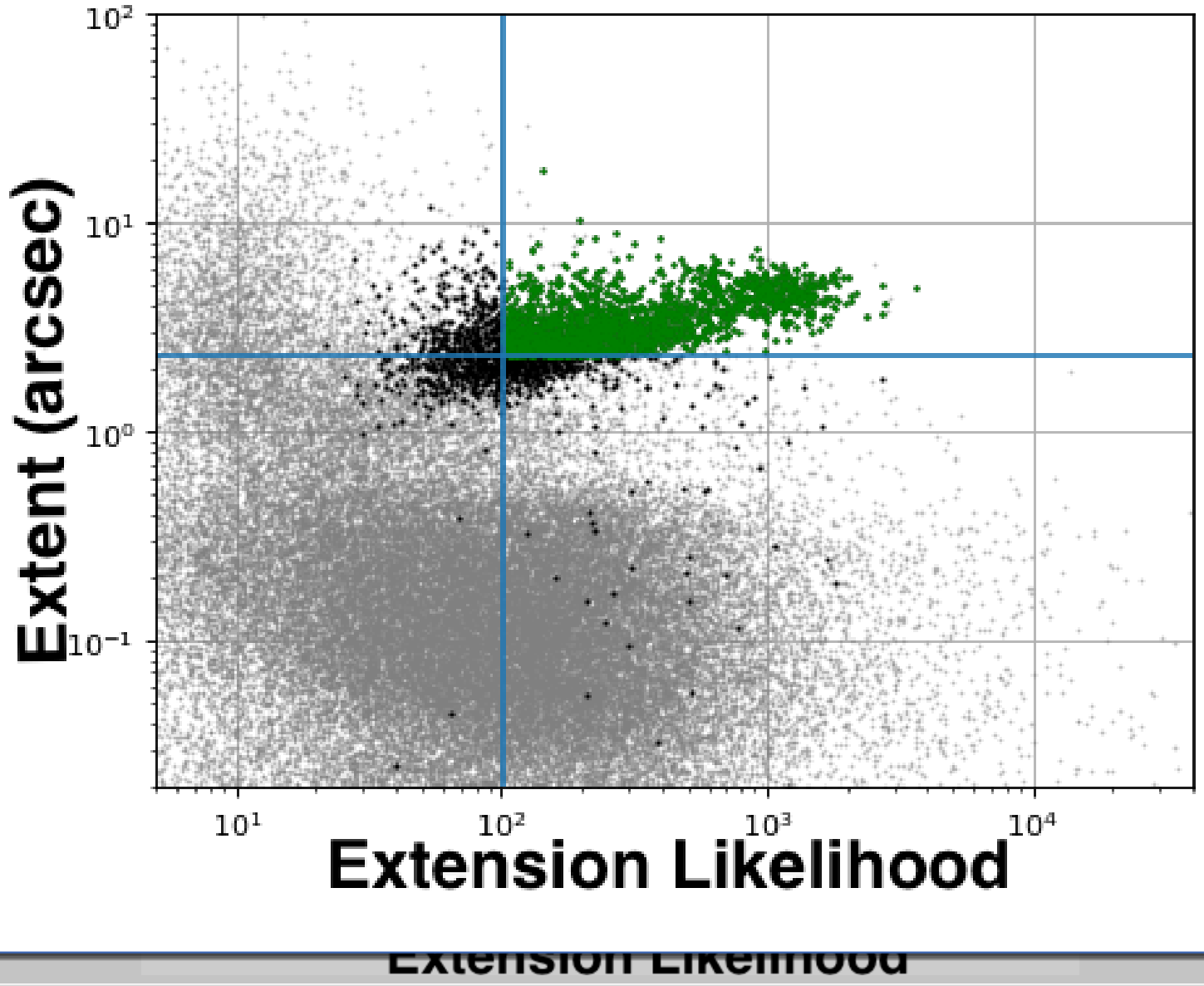
- The selection criteria for galaxy clusters are based on the purity and completeness considerations
- With a maximum contamination requirement of 1 false cluster per image, we set the selection criteria to maximize completeness



# Selection criteria

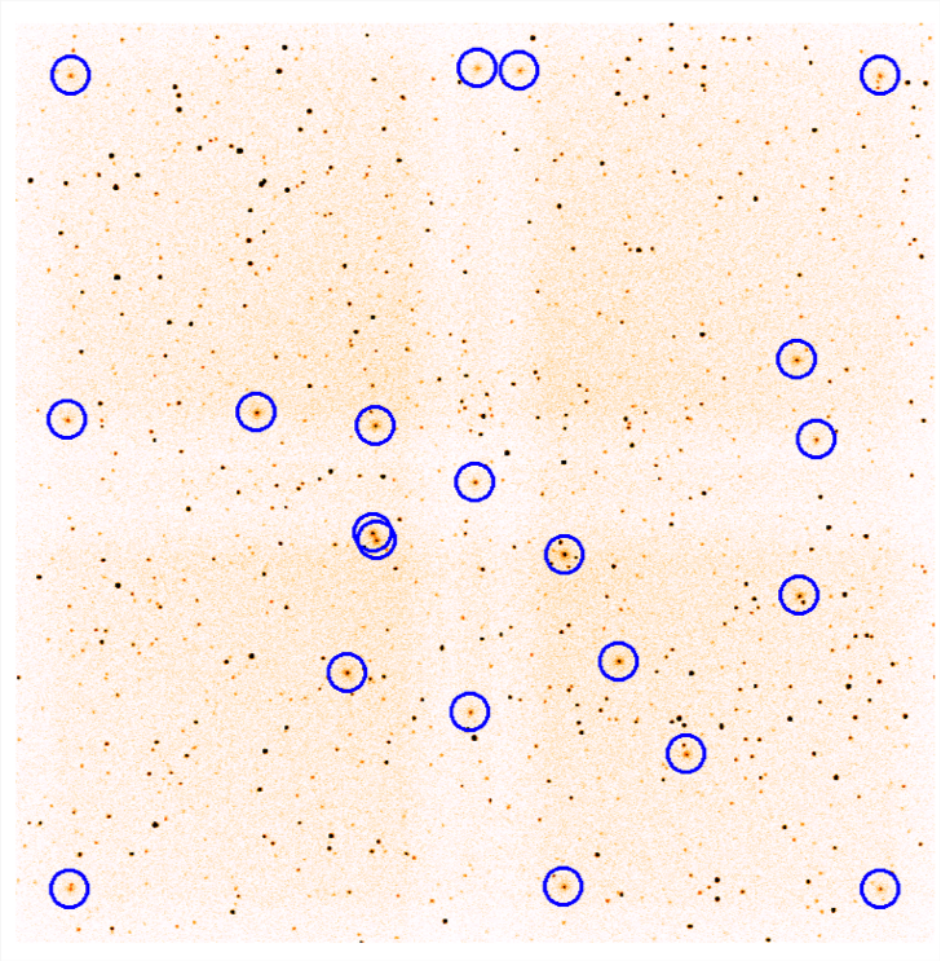
- Th... y and cor...
- Wi... per ima...

## Extent VS extension likelihood in 80 ks

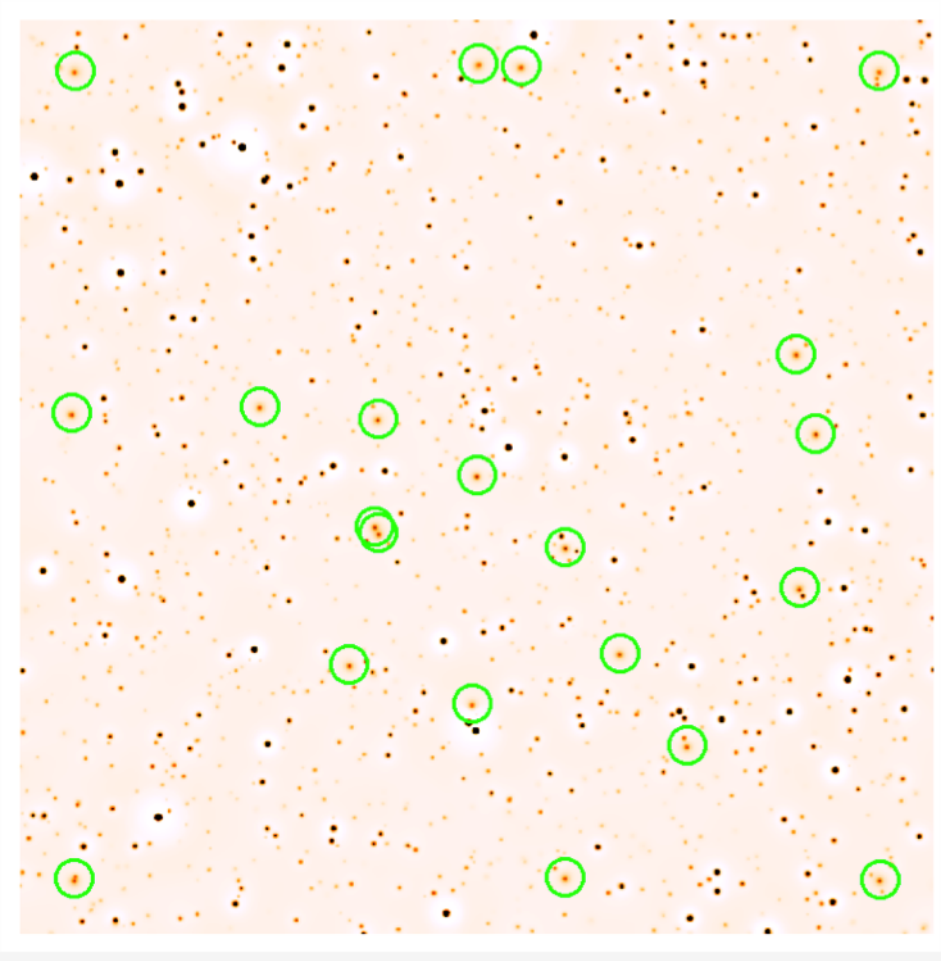


# z=1.0 / 80 ks

- Simulated (raw image)

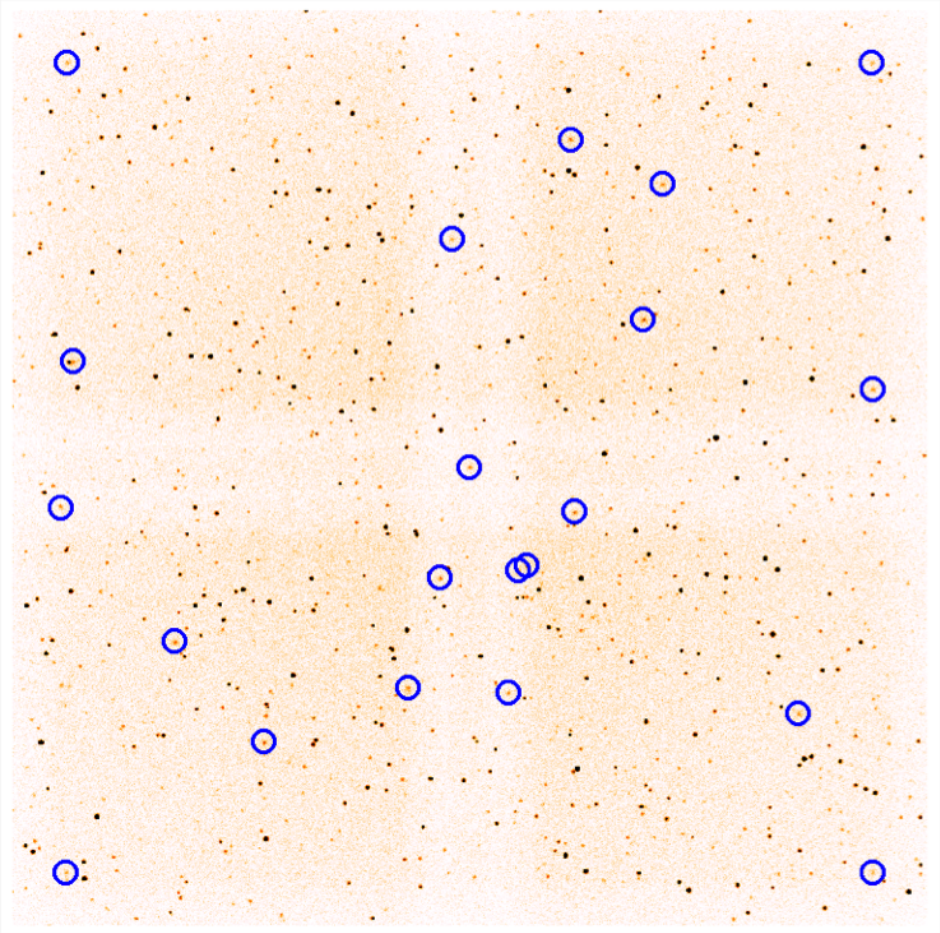


- Detected (filtered image)

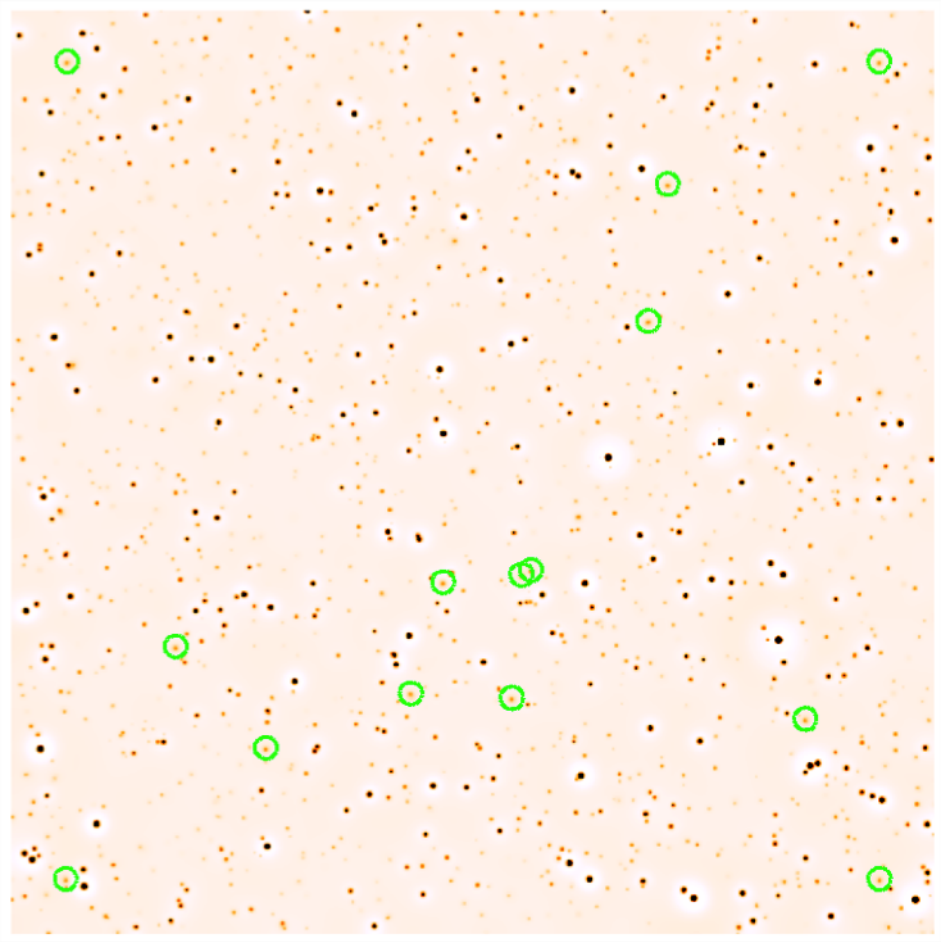


# z=2.5 / 80 ks

- Simulated (raw image)

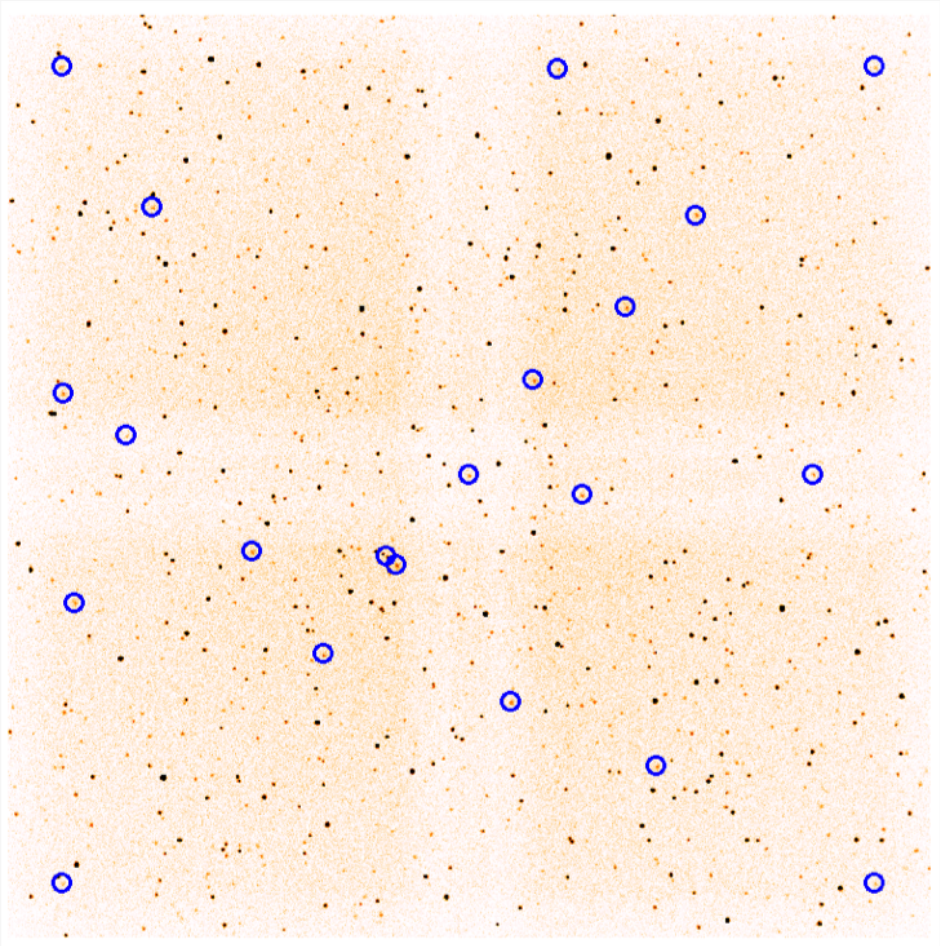


- Detected (filtered image)

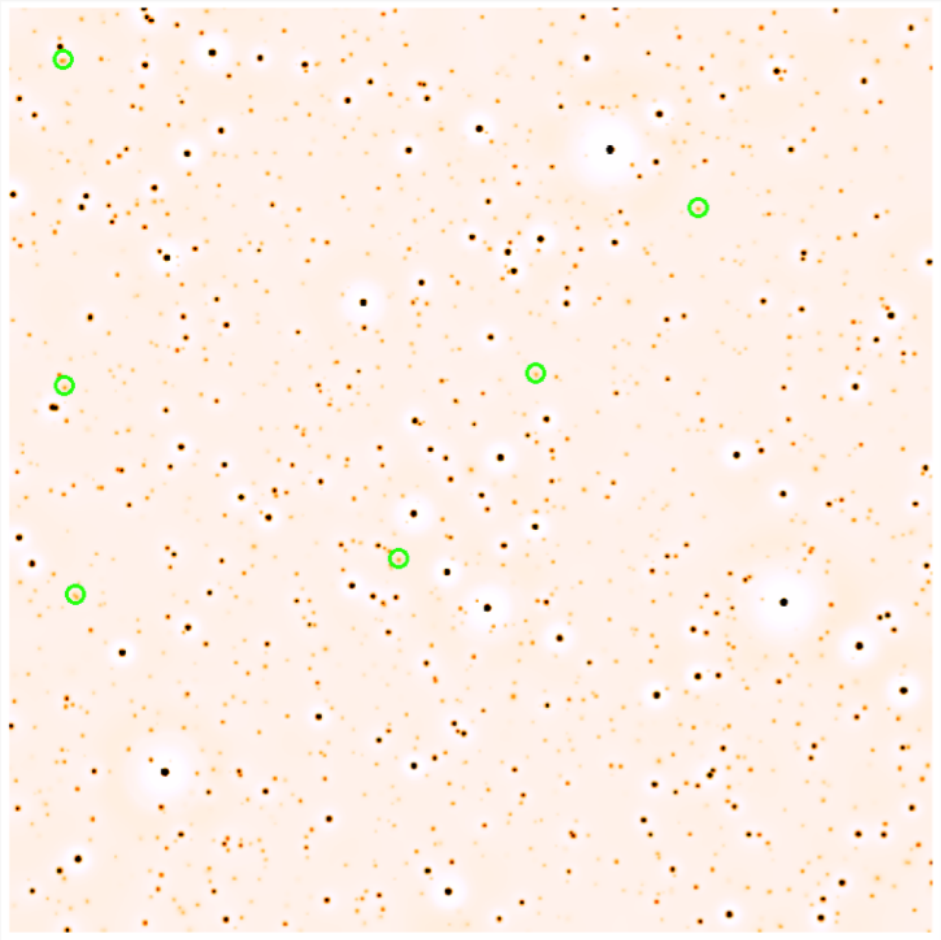


# z=4.0 / 80 ks

- Simulated (raw image)

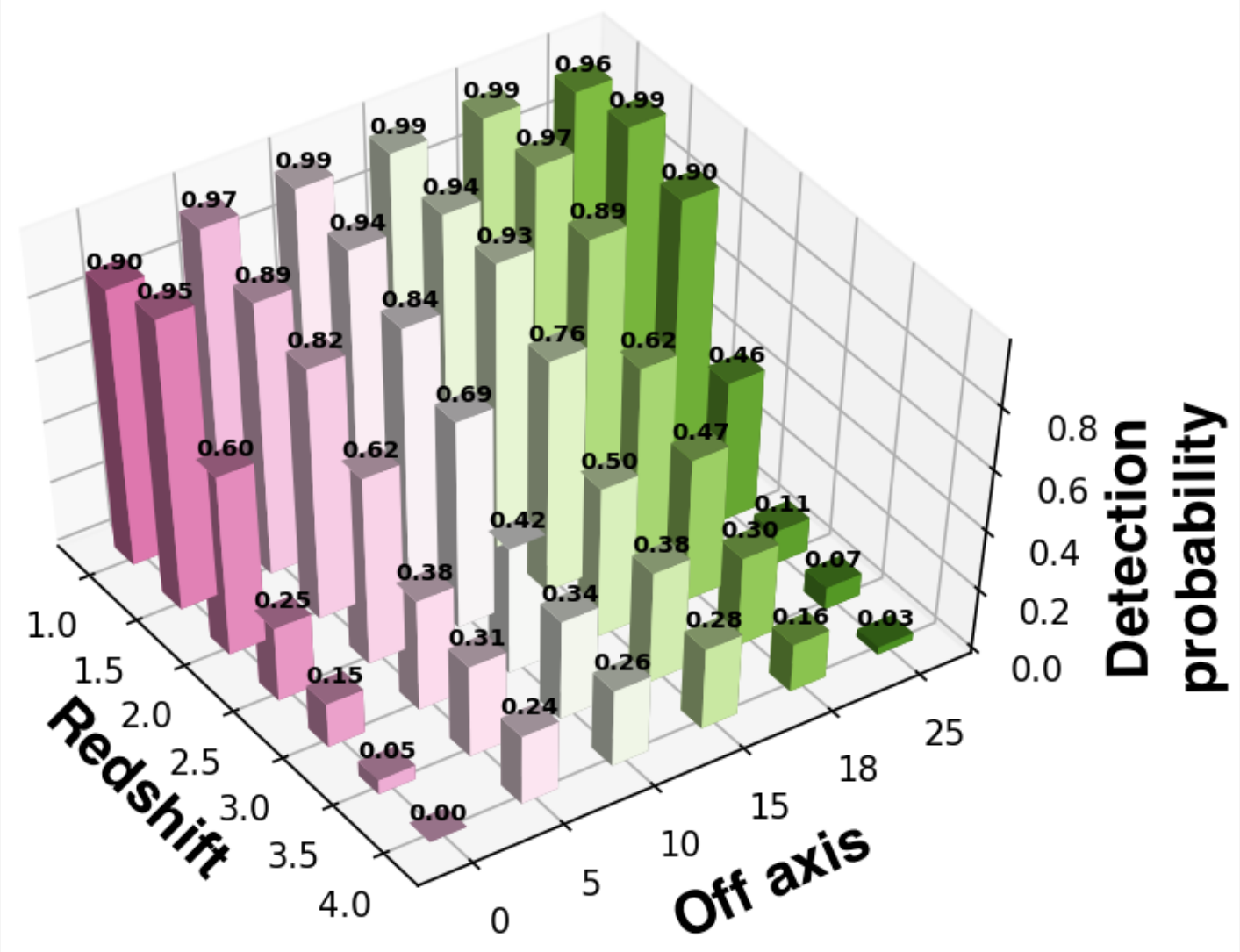


- Detected (filtered image)



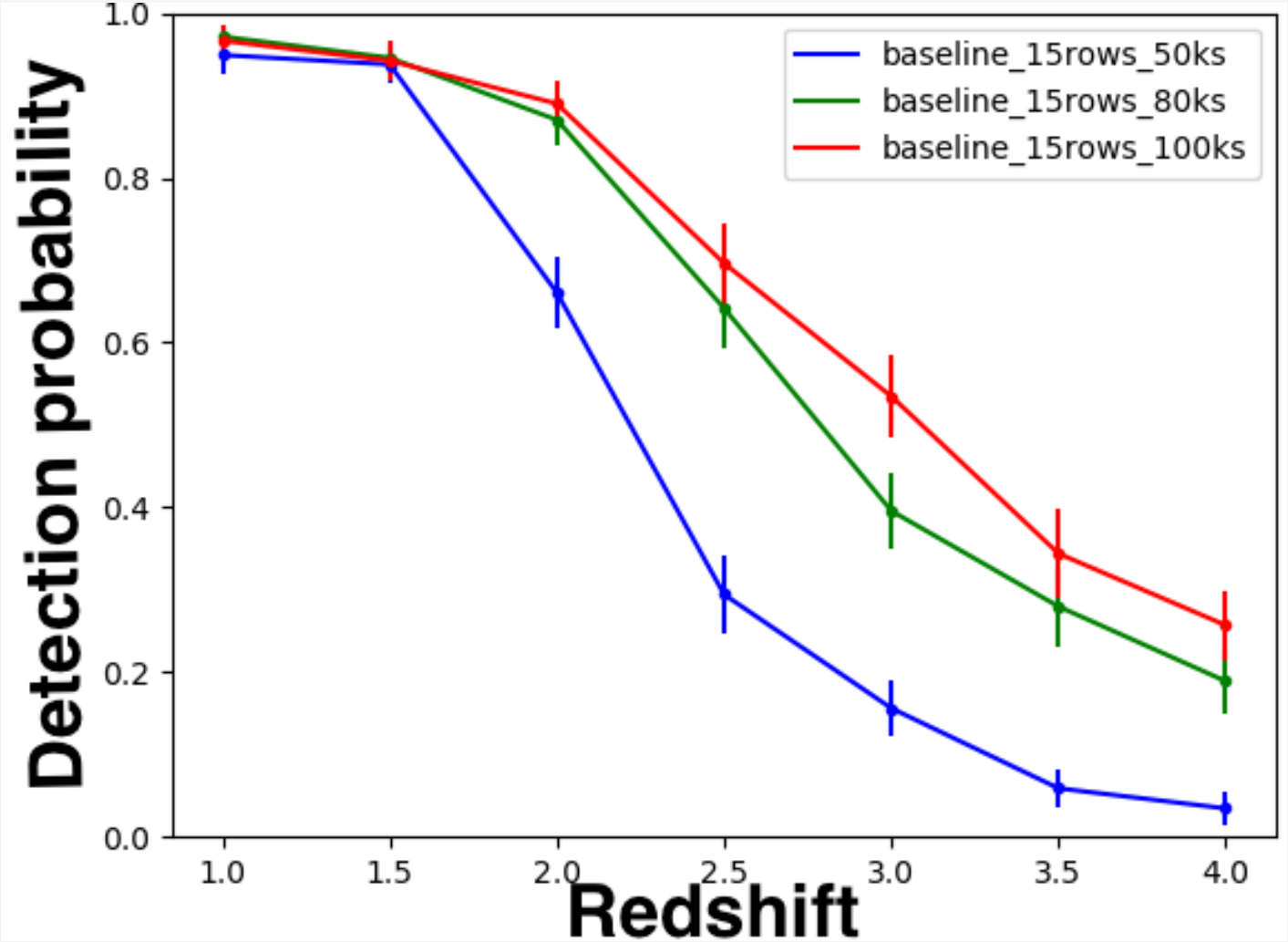
# The 3D detection probability (baseline)

Groups, central AGN, AGN and background with 80 ks

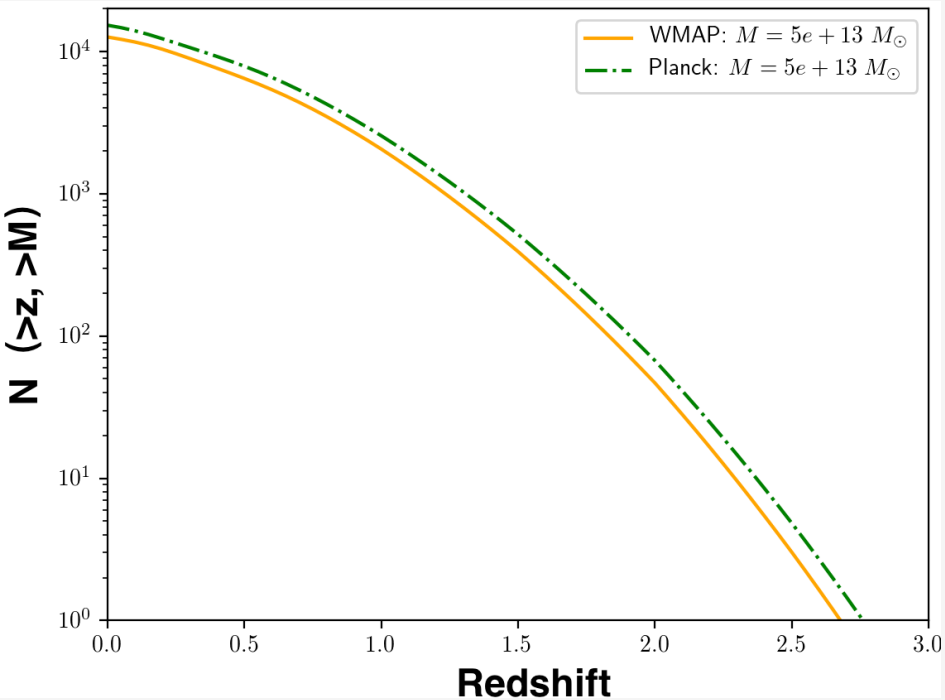


# The detection probability

The 3D detection probability averaged over off axis within the FoV ( simulations with exposure time 50, 80 and 100 ks)



# The number of groups expected by Athena mission

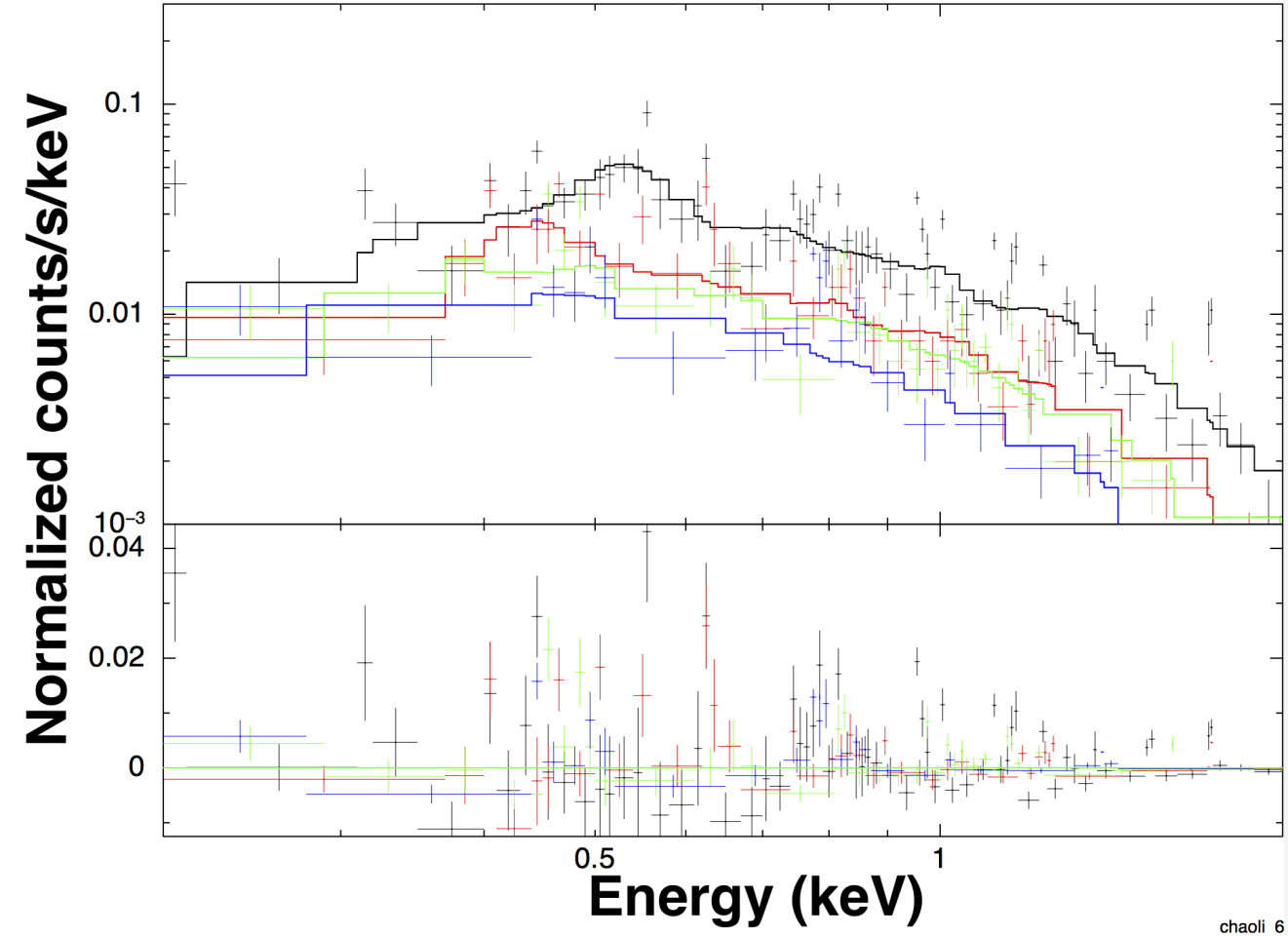



- Cumulative mass function by assuming Tinker et al. (2008) fitting function
- MOP of the WFI survey (v4.0.3): assume the FoV is 0.4 deg$^2$ $\Rightarrow$ a total survey area of 48 deg$^2$
- Detection probability
- The cumulative expected numbers, $N(> 5 \times 10^{13} M_\odot, > z)$

| Redshift | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 |
|---|---|---|---|---|---|---|---|
| WMAP9 | 2059 | 391 | 46 | 3 | 0 | 0 | 0 |
| PLANCK | 2555 | 516 | 67 | 4 | 0 | 0 | 0 |

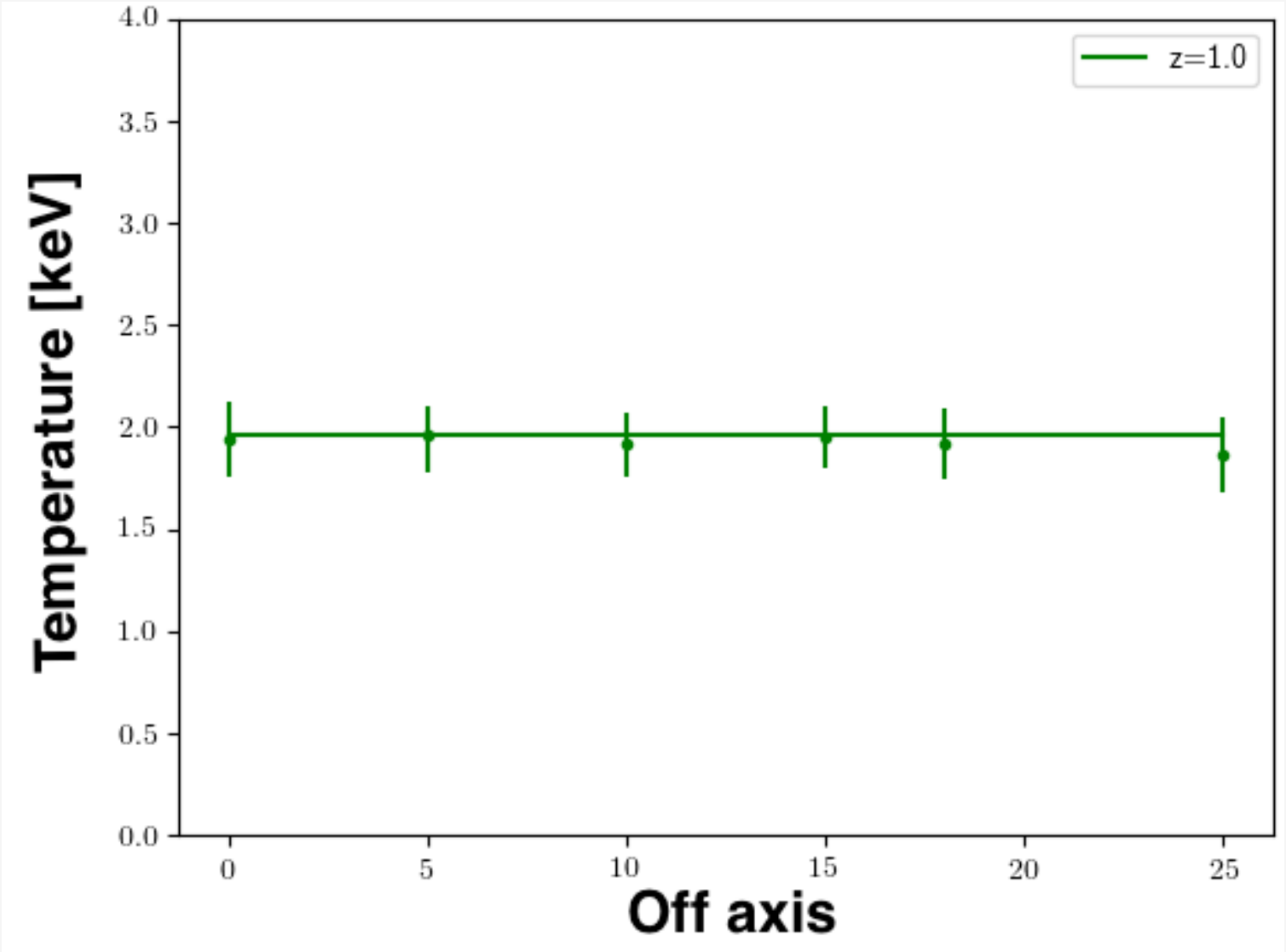
# Spectrum fitting

- Source and background spectra are extracted from the event-lists for $z = 1.0$, 1.5, 2.0, 2.5 at off axis $5'$ with a 80 ks simulation.



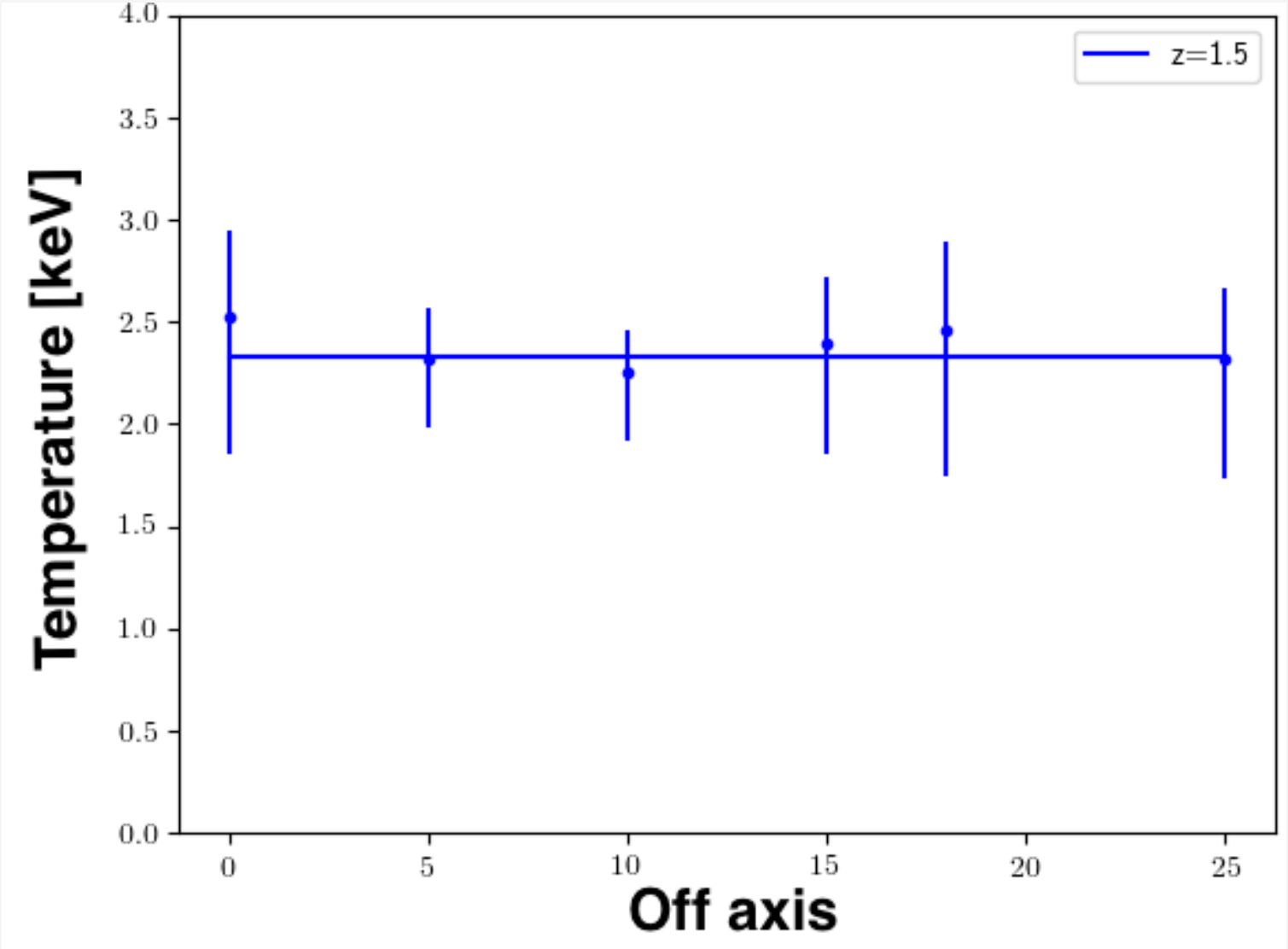
# Temperature result (preliminary)

The temperature fit for $z = 1.0$ with 80 ks.



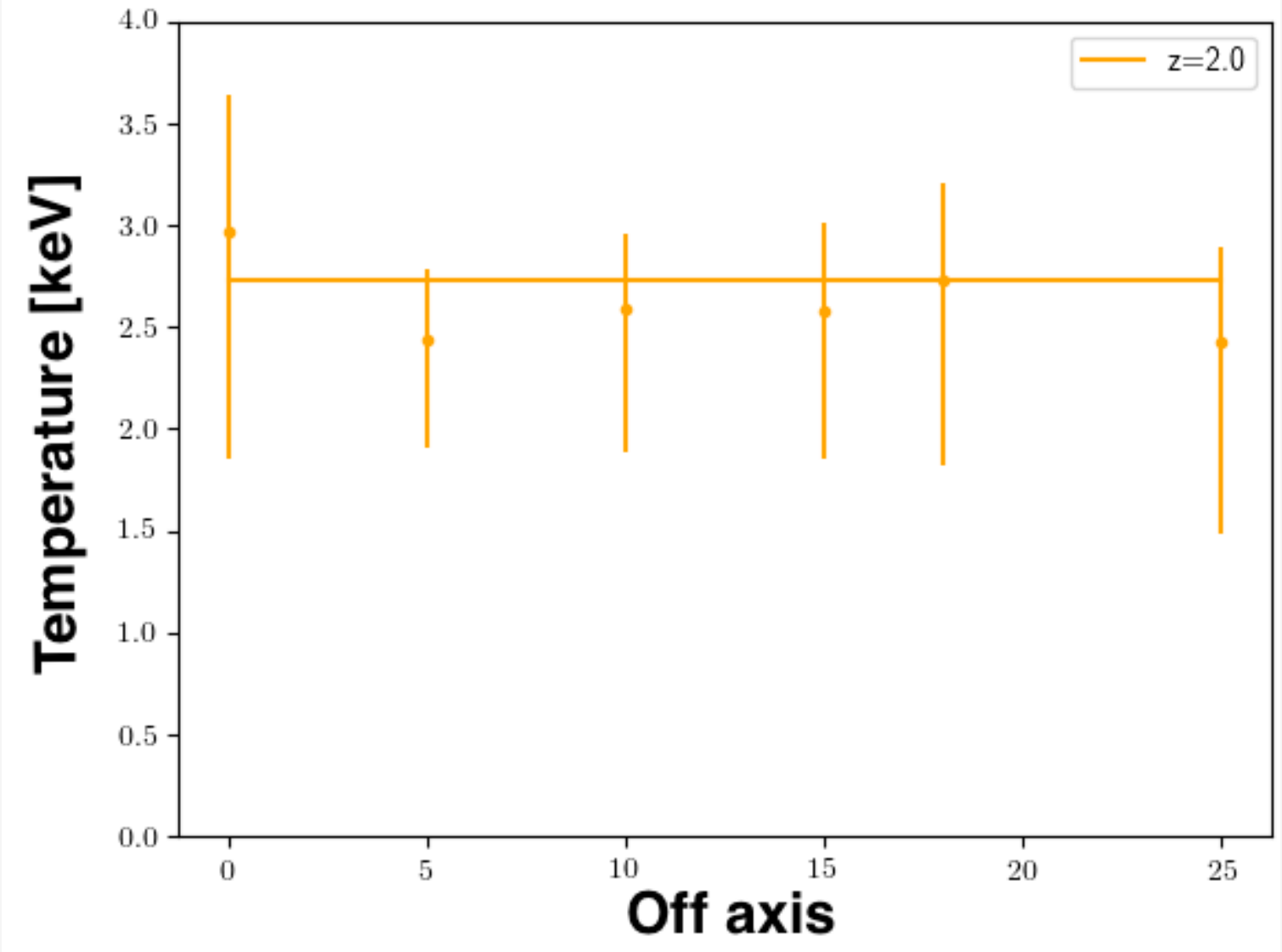
# Temperature result (preliminary)

The temperature fit for $z = 1.5$ with 80 ks.



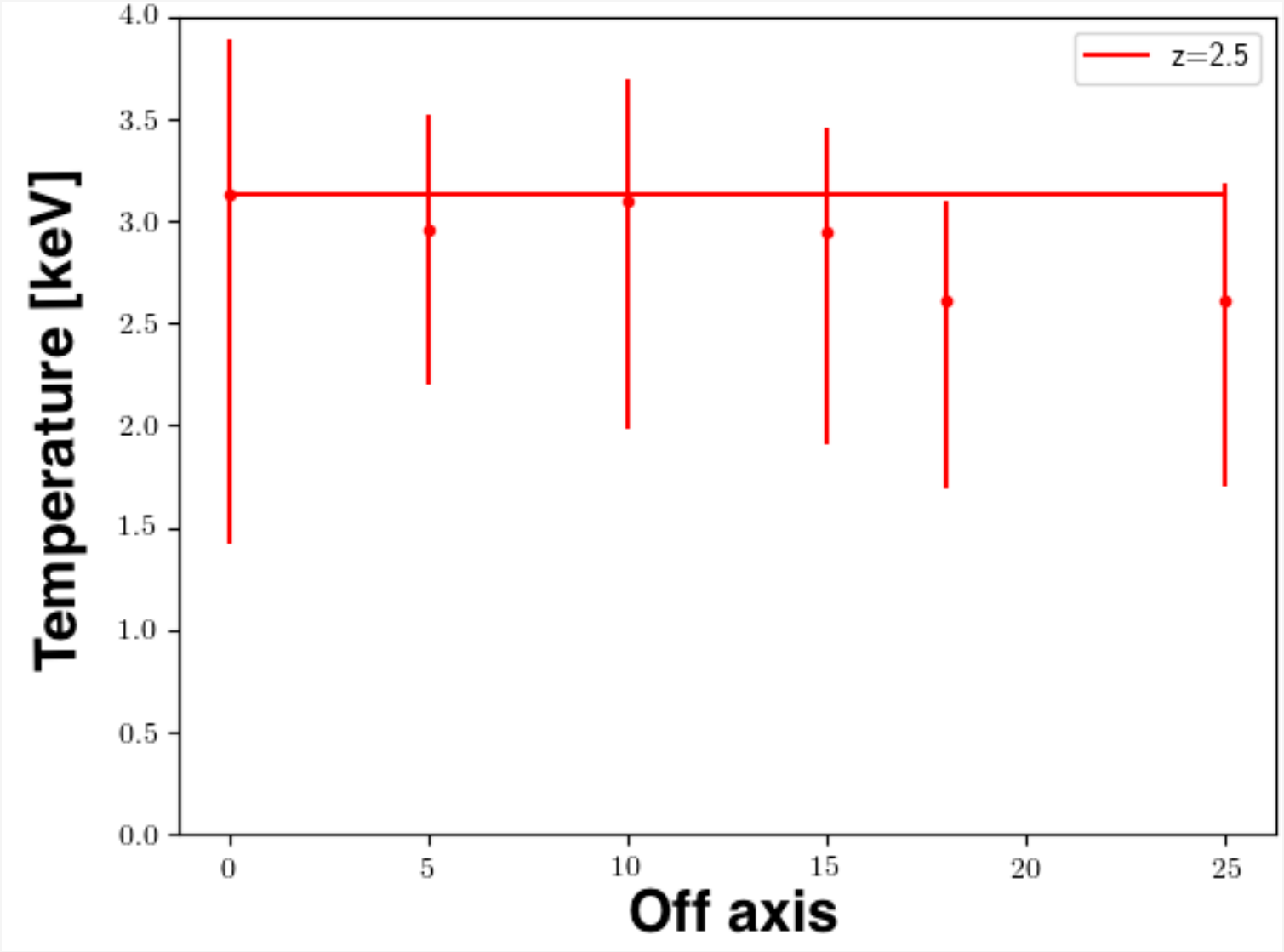
# Temperature result (preliminary)

The temperature fit for $z = 2.0$ with 80 ks.



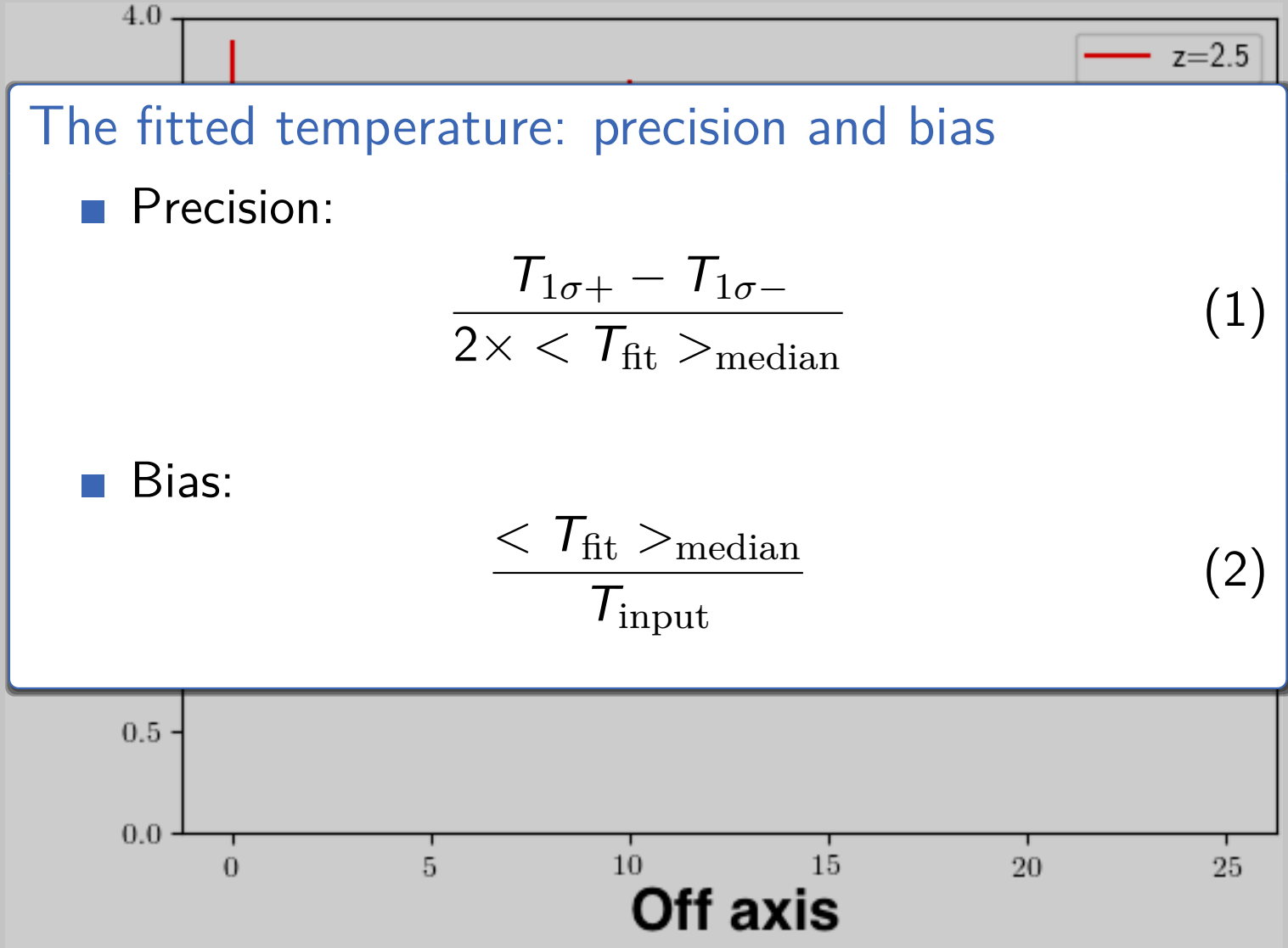
# Temperature result (preliminary)

The temperature fit for $z = 2.5$ with 80 ks.



# Temperature result (preliminary)

The temperature fit for $z = 2.5$ with 80 ks.




## The fitted temperature: precision and bias

- Precision:

$$\frac{T_{1\sigma+} - T_{1\sigma-}}{2\times < T_{\rm fit} >_{\rm median}} \quad (1)$$

- Bias:

$$\frac{< T_{\rm fit} >_{\rm median}}{T_{\rm input}} \quad (2)$$

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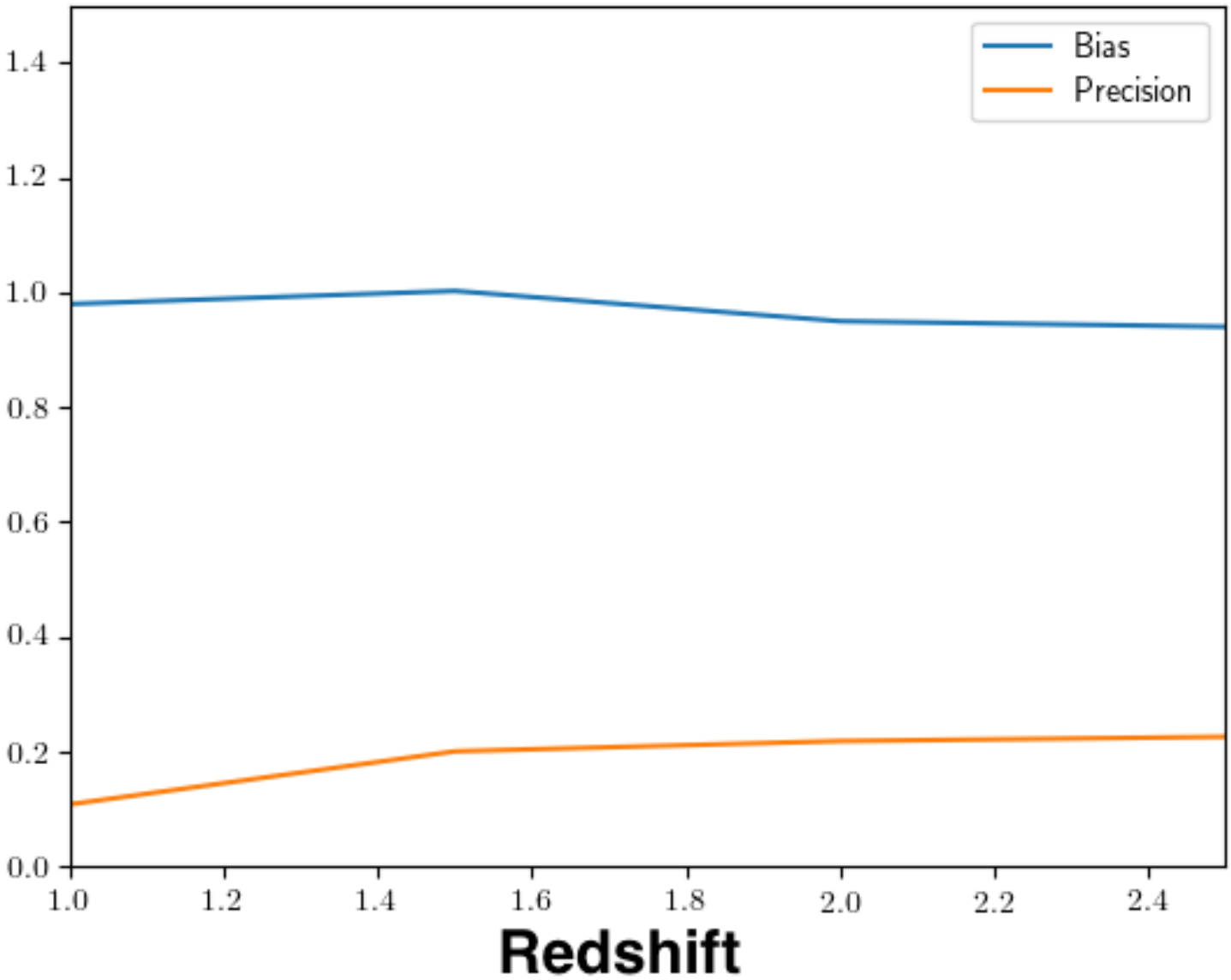
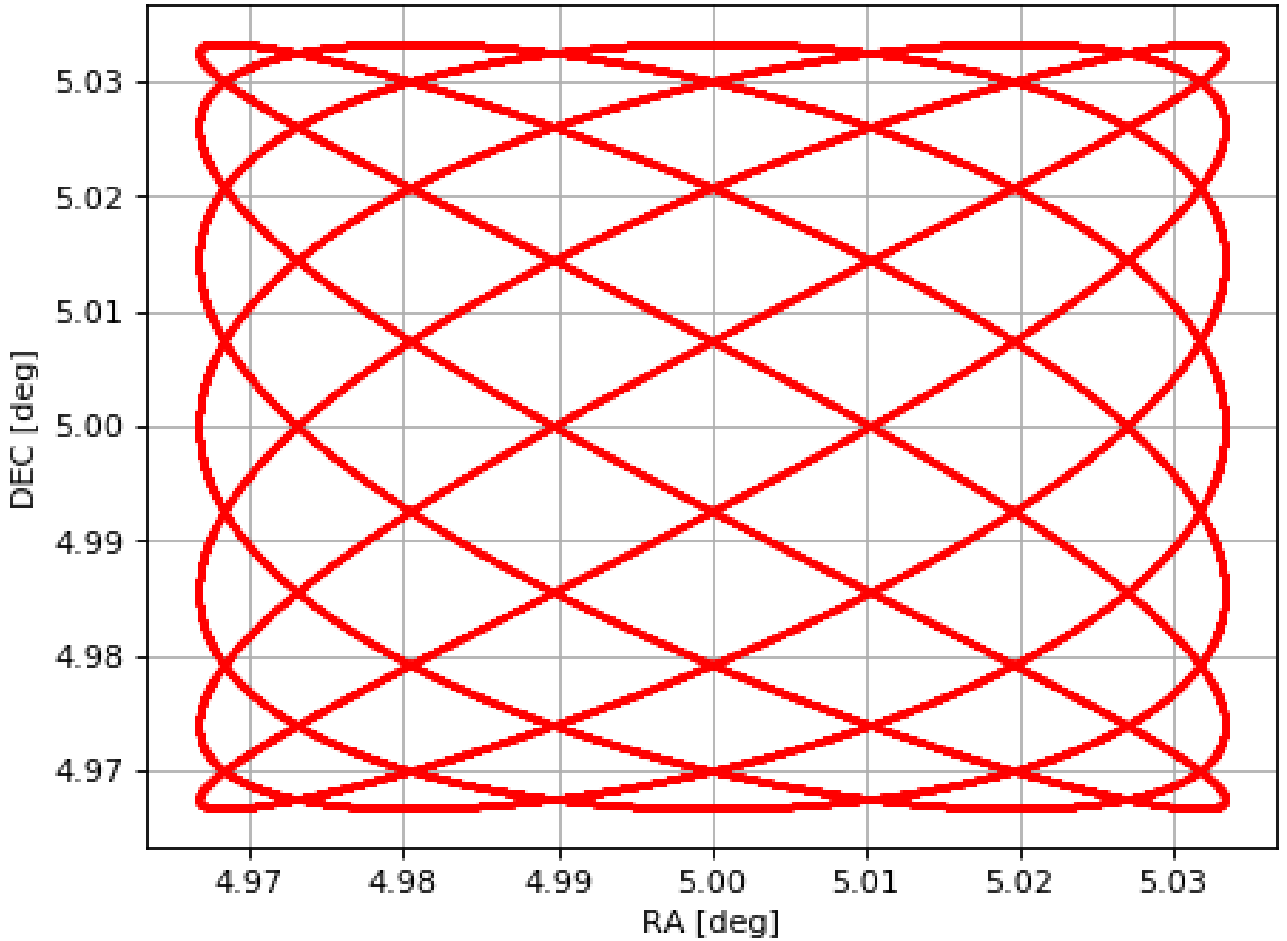
## The fitted temperature: precision and bias



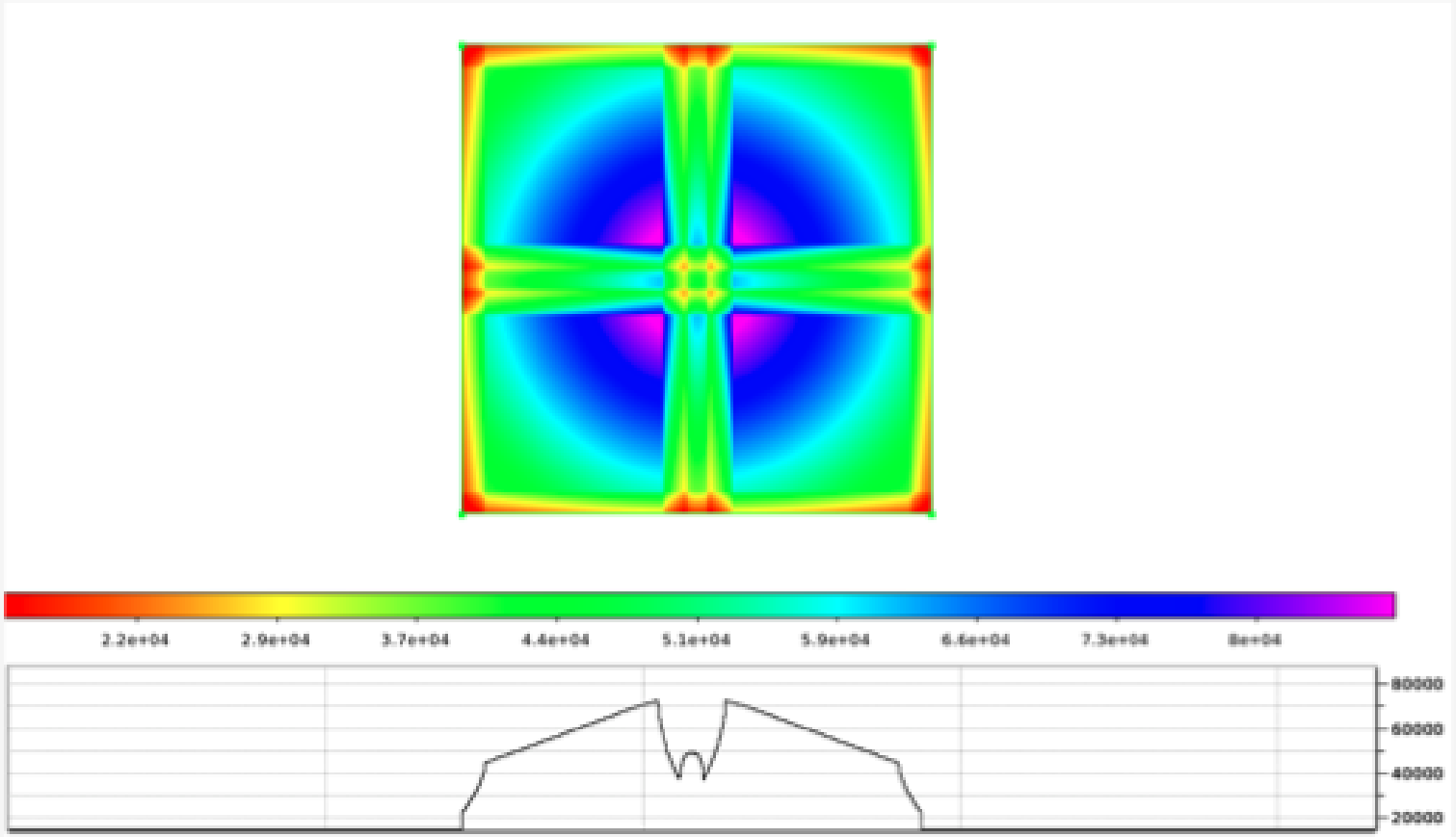
# Conclusion

- We used SIXTE simulator to evaluate the ATHENA capabilities on the detection of high-z galaxy groups through extensive and dedicated image simulations;
- We developed a state-of-the-art source detection and characterisation algorithms for the high-z groups detection including: wavelet filtering, source extraction, maximum likelihood fitting;
- The main results showed that the high-z groups with mass=$5 \times 10^{13}$ $\mathrm{M}_{\odot}$ at $z > 2$ will be detected with high probability (>80%) as extended source by ATHENA
  (temperature extracted from spectrum fitting can recover the input L-T relation, that can help to constrain the scaling relations);
- The Athena survey area will be the main key to detect more groups at high redshift $z > 2.0$.

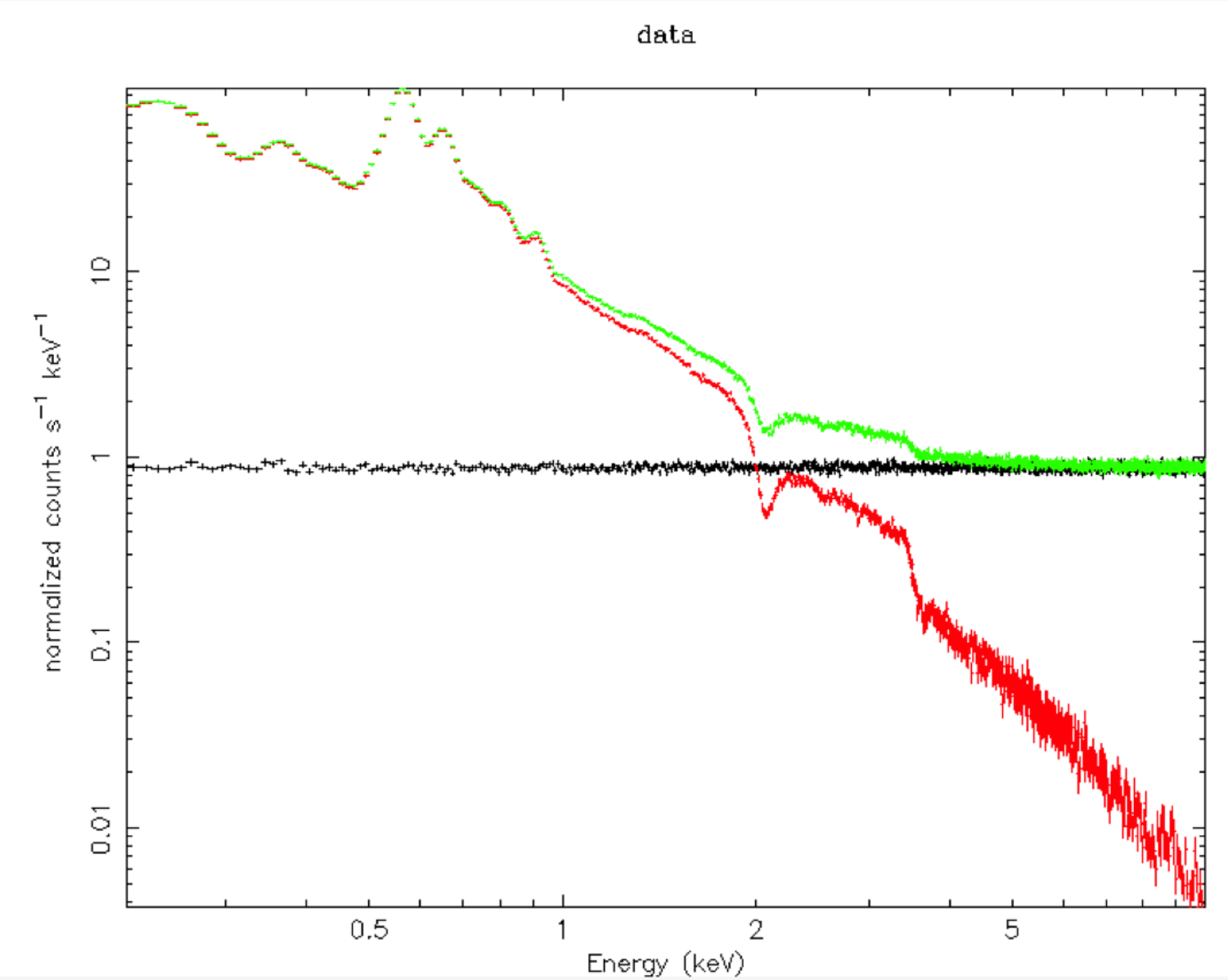
# Lissajous dithering pattern



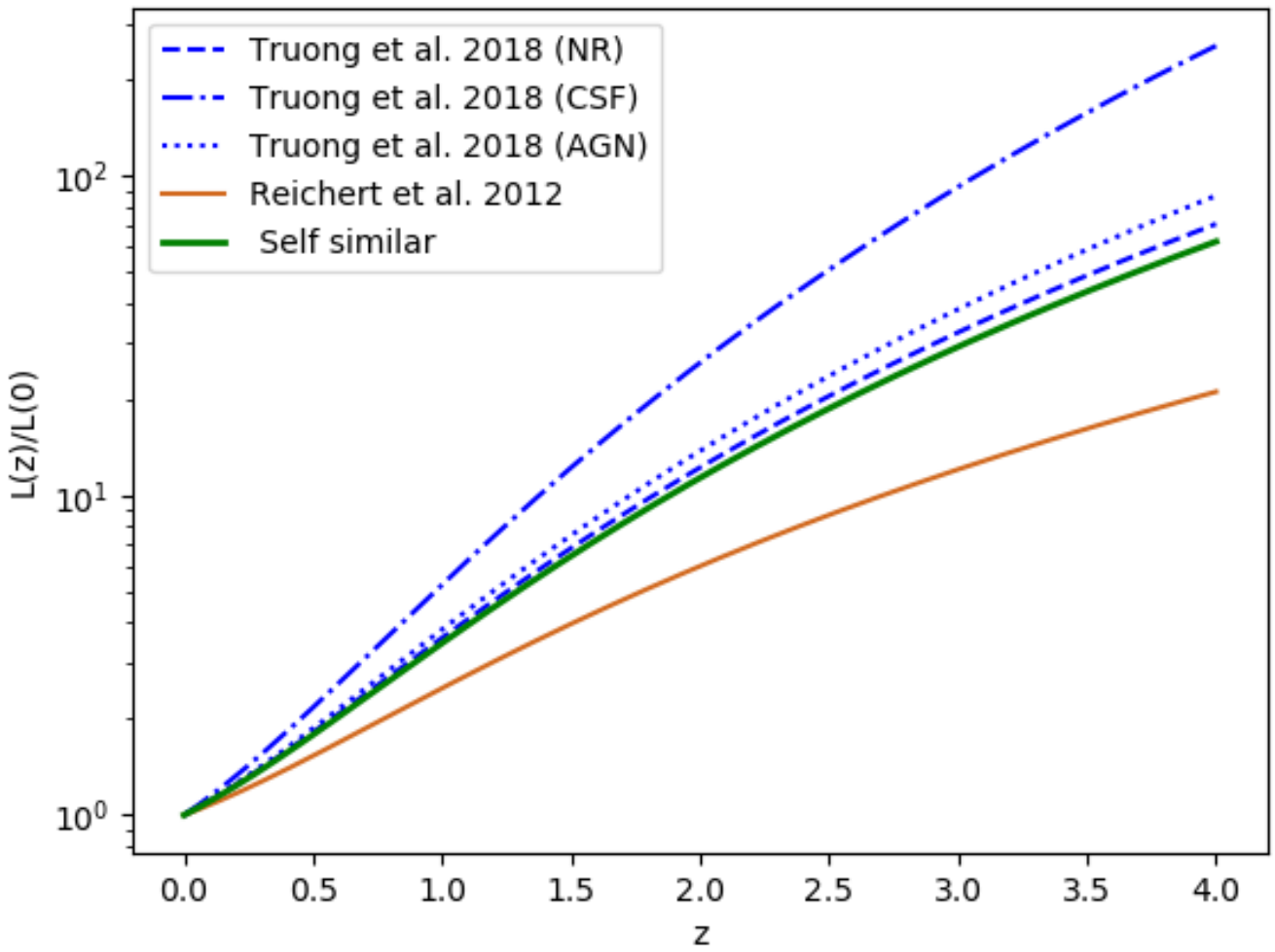
# Exposure map



# Background

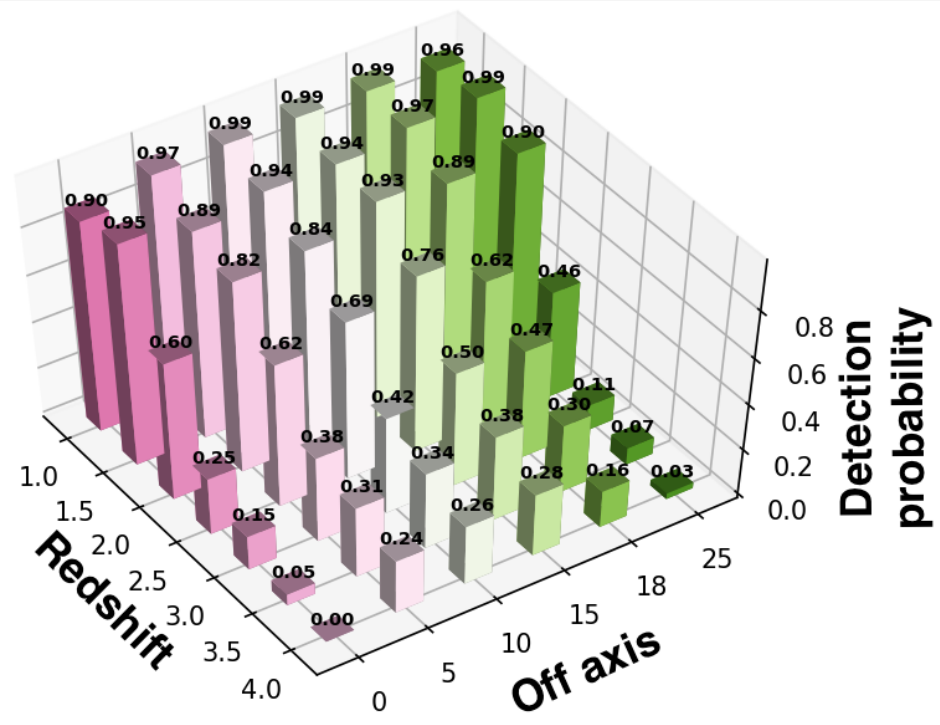


# Scaling relations

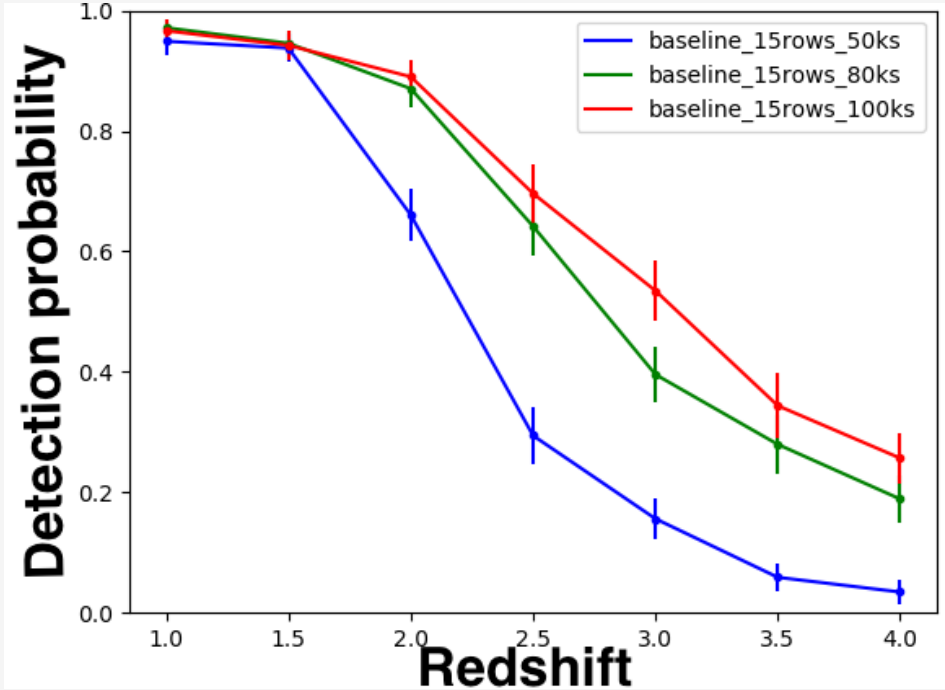


# Baseline

- 3D detection probability, $P(z, \theta)$




- projected detection probability, $P(z)$



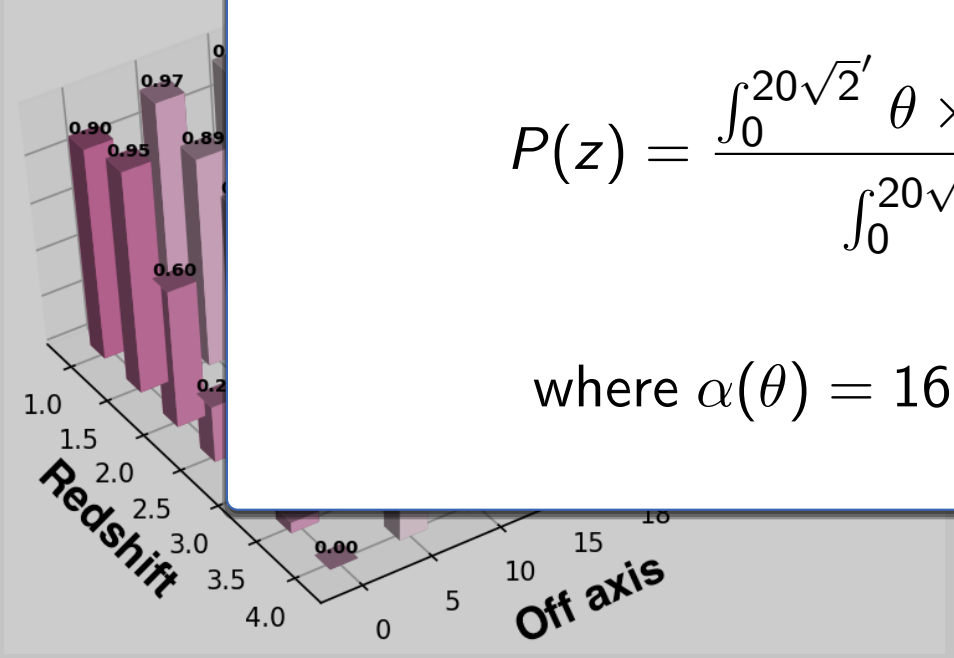
# Baseline

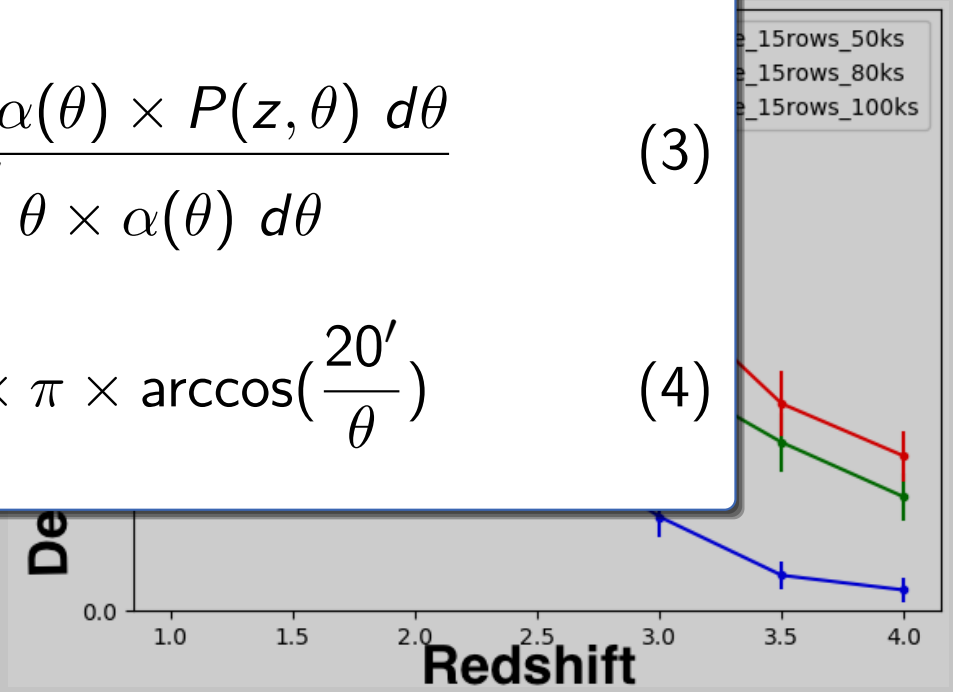
- 3D detection probability, $P(z, \theta)$
- projected detection probability,

## formulation

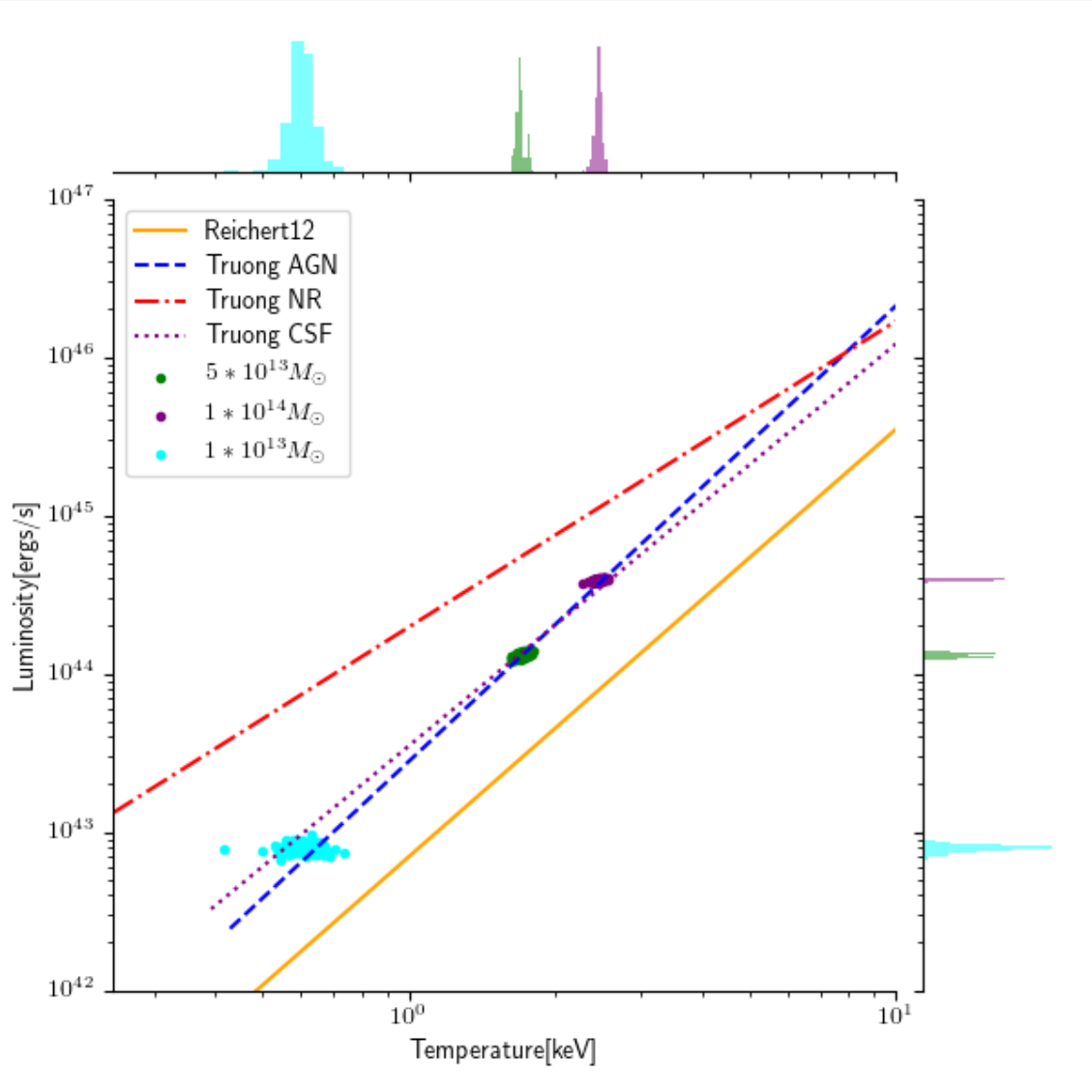
$$P(z) = \frac{\int_0^{20\sqrt{2}'} \theta \times \alpha(\theta) \times P(z, \theta)\ d\theta}{\int_0^{20\sqrt{2}'} \theta \times \alpha(\theta)\ d\theta} \tag{3}$$

$$\text{where } \alpha(\theta) = 16 \times \pi \times \arccos(\frac{20'}{\theta}) \tag{4}$$

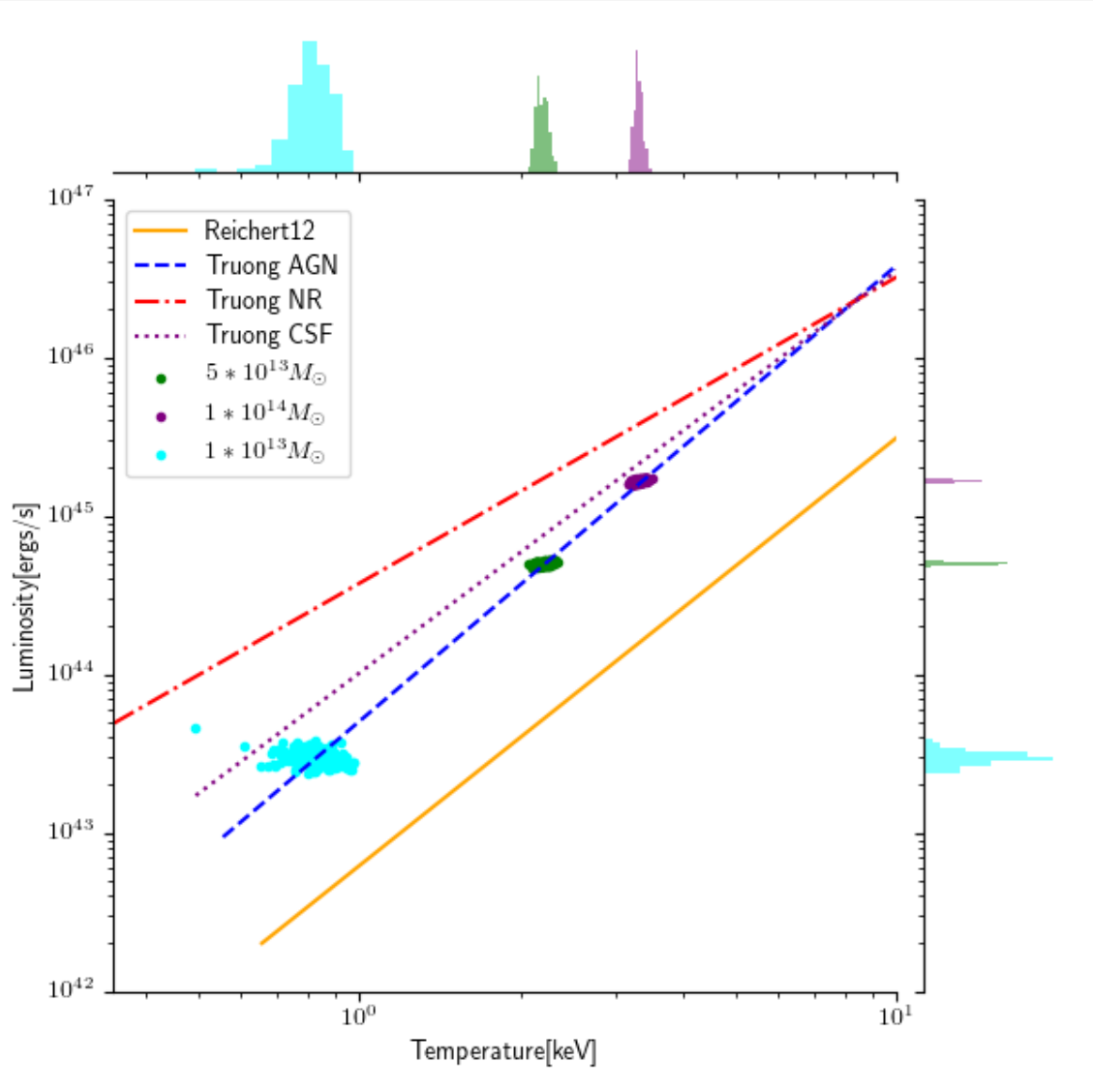


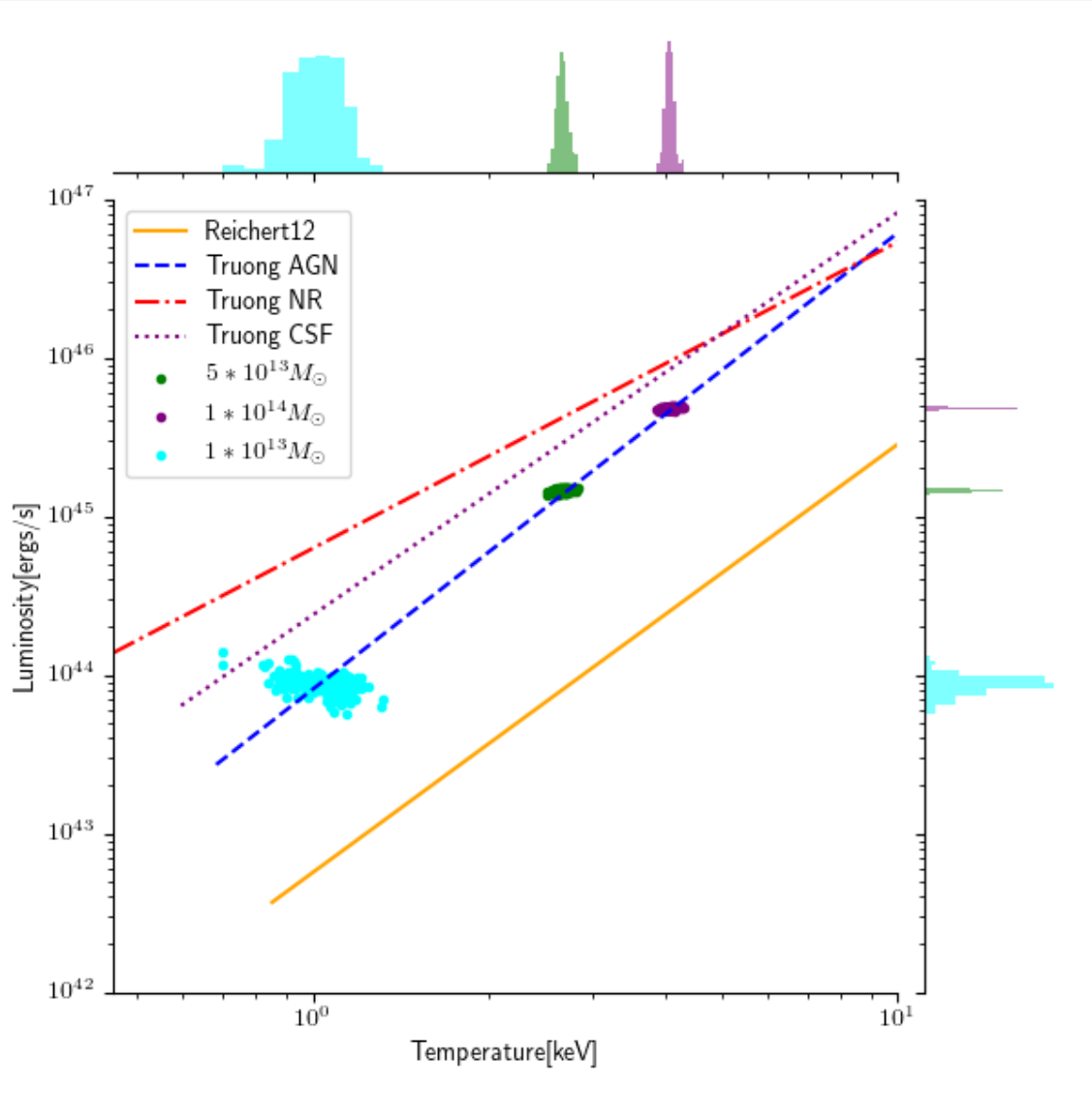
# Luminosity temperature relation $z = 1.0$



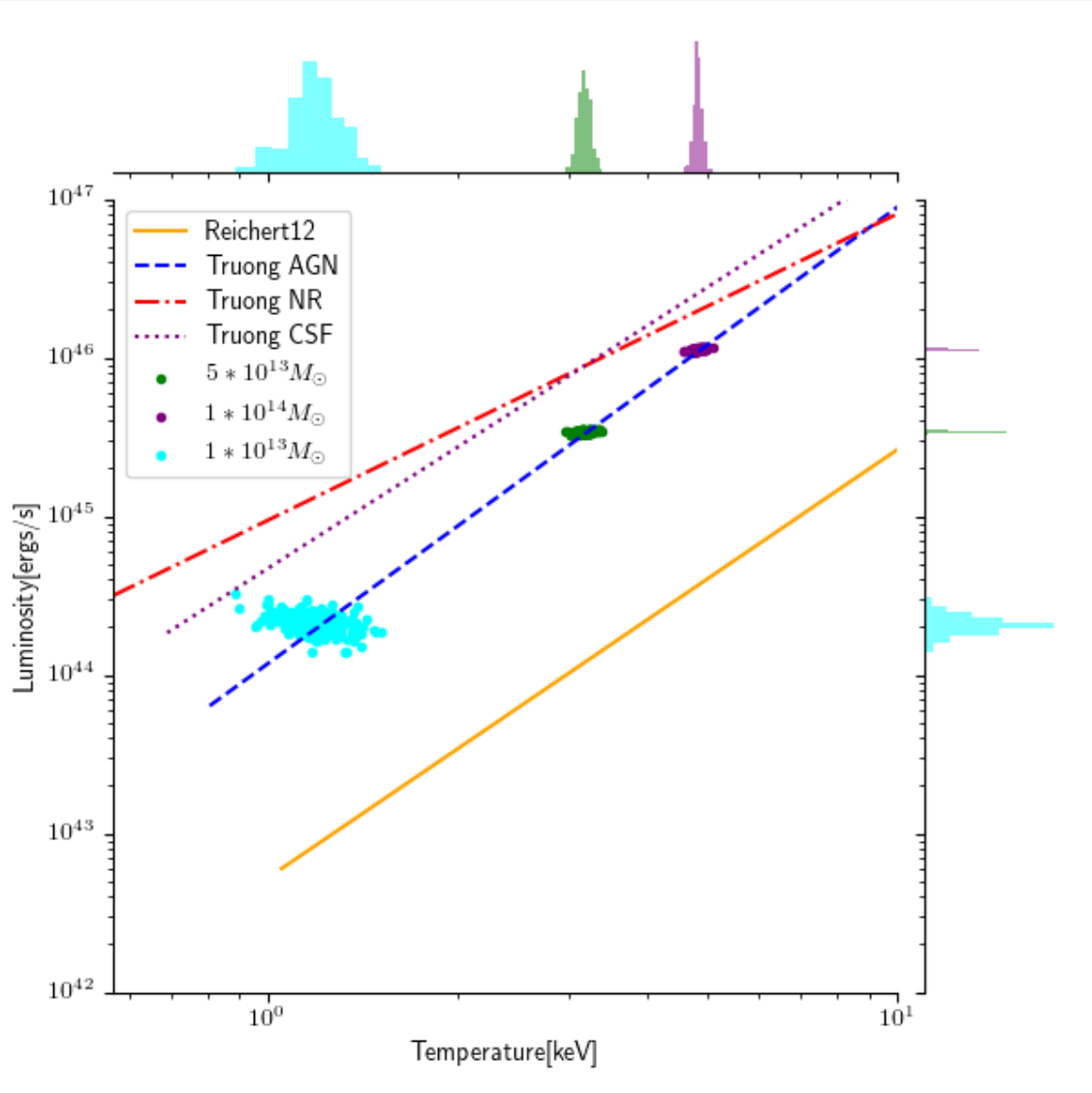
# Luminosity temperature relation $z = 2.0$



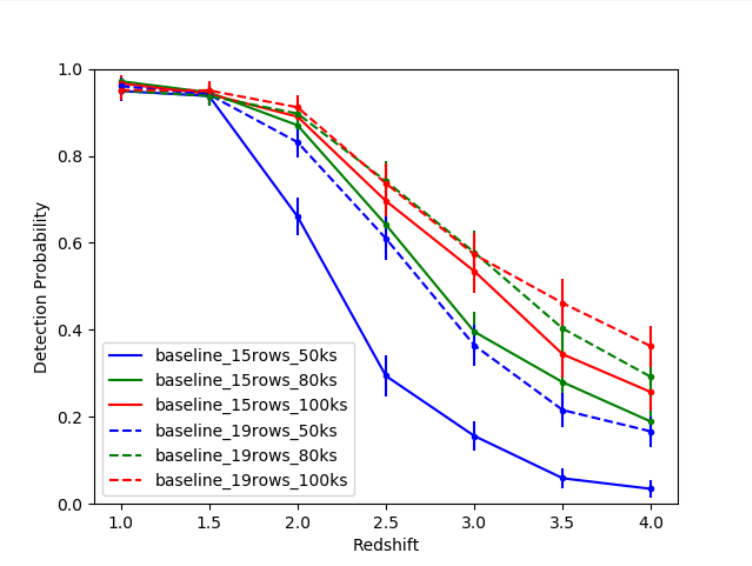
# Luminosity temperature relation $z = 3.0$



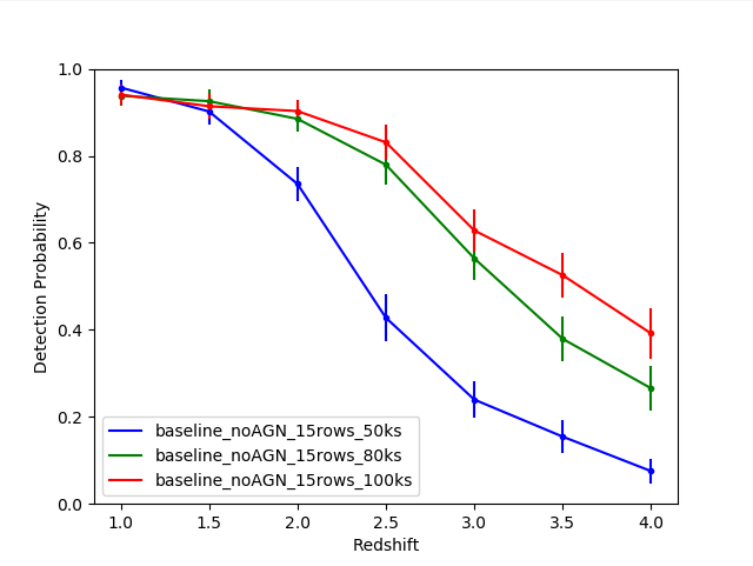
# Luminosity temperature relation $z = 4.0$



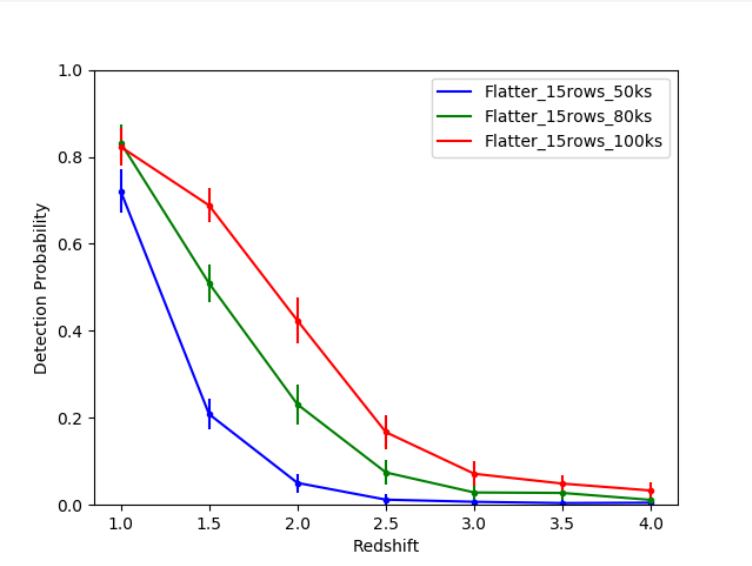
## Baseline model



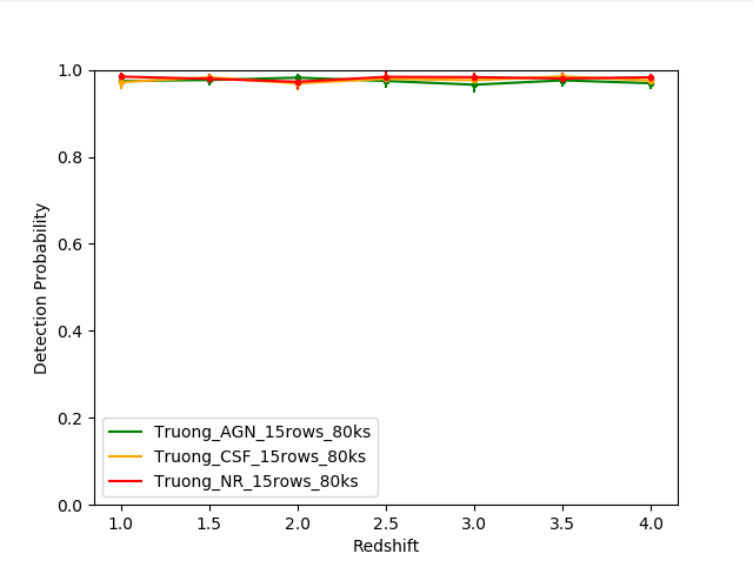

## No central AGNs




## Flatter surface brightness




## Truong scaling relations



# Mass function

$$N(> m, > z) = \int_z^{\infty} n(> m) \times P_z \times V_z \times \Omega_{\text{survey}}\ dz \qquad (5)$$

NOTE: assuming a PLANCK cosmology and a Tinker et al. (2008) mass function.