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Anisotropy of the galaxy cluster X-ray L-T relation in eeHIFLUGCS

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+Reiprich, Schellenberger, Pacaud, Lovisari, Ramos-Ceja

COSMOLOGY 2018, DUBROVNIK

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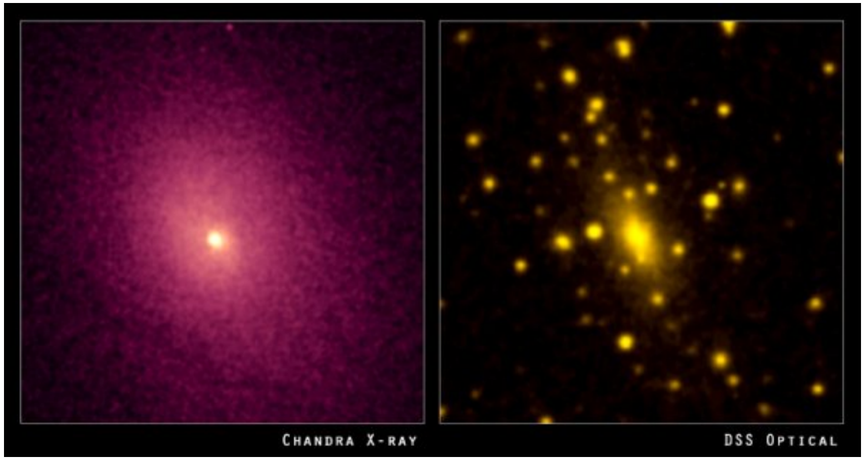
eROSITA

Outline

- Introduction
- Why $L_X - T$?
- Main results from Migkas & Reiprich (2018)
- Our eeHIFLUGCS sample
- First $L_X - T$ results
- Conclusions

Galaxy clusters

They are the largest gravitationally bound systems in the Universe!



X-ray & Optical (http://chandra.si.edu)

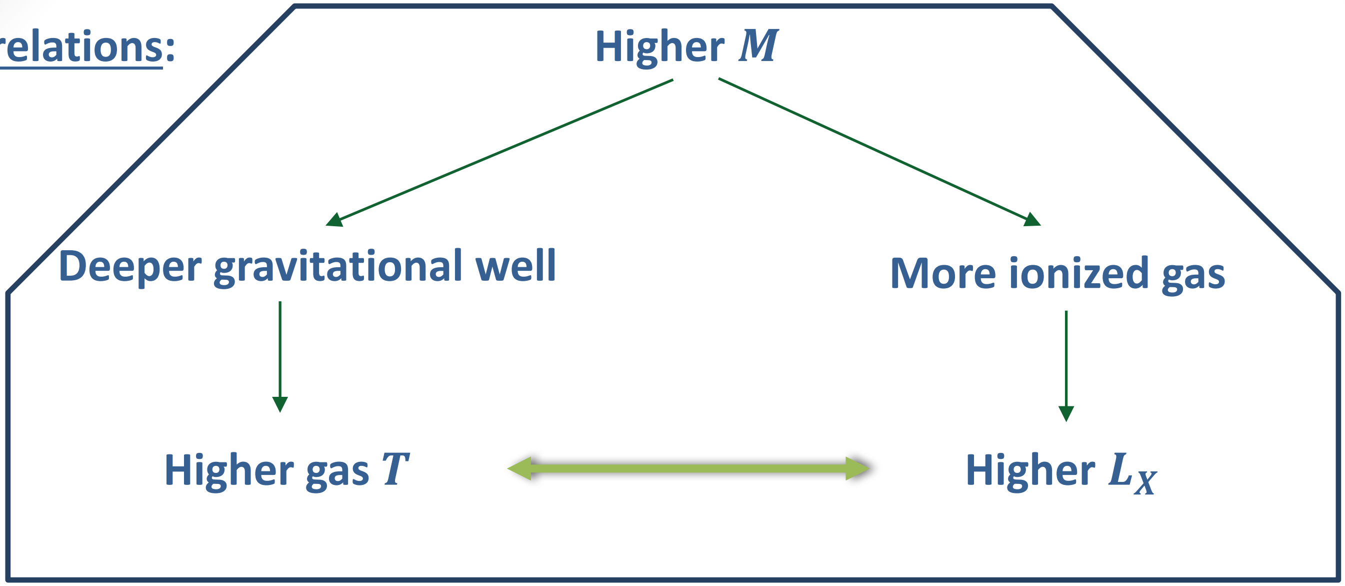
- **30-1000+ galaxies (~3% of total mass)**
- **Dark matter (~85%)**
- **Hot intra-cluster gas with $T \approx 10^7 - 10^8$ K (~12%)**

↓

Strong bremsstrahlung emission (X-rays)

- **Mass: $\sim 10^{14} - 10^{15}\ M_\odot$**
- **Size: $\sim 1 - 10$ Mpc**
- **Up to $z \sim 1.7$**
- **X-ray luminosities: $\sim 10^{42} - 10^{46}$ erg/s**

Correlations:



Theoretical predictions relate physical quantities of clusters!

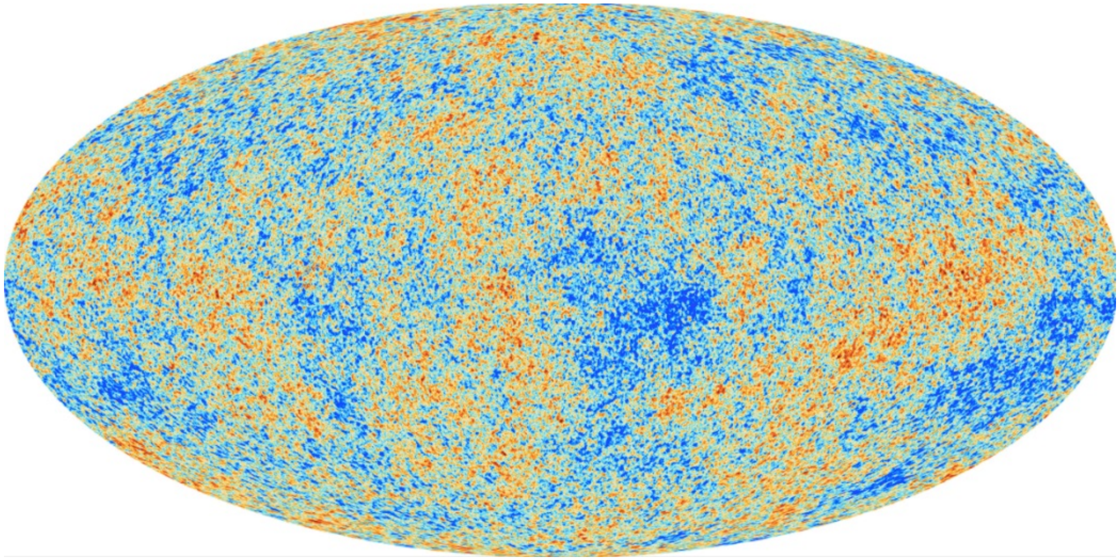
Kaiser (1986):

$$\frac{L_X}{10^{44}\ \mathrm{erg/s}}\, E(z)^{-1} = a \times \left(\frac{T}{4\ \mathrm{keV}}\right)^{b}$$

Cosmological Principle

- **Basis of standard Cosmology → Universe *isotropic & homogeneous***

Isotropy → **Universe has the same *properties* in every sky direction in large scales**



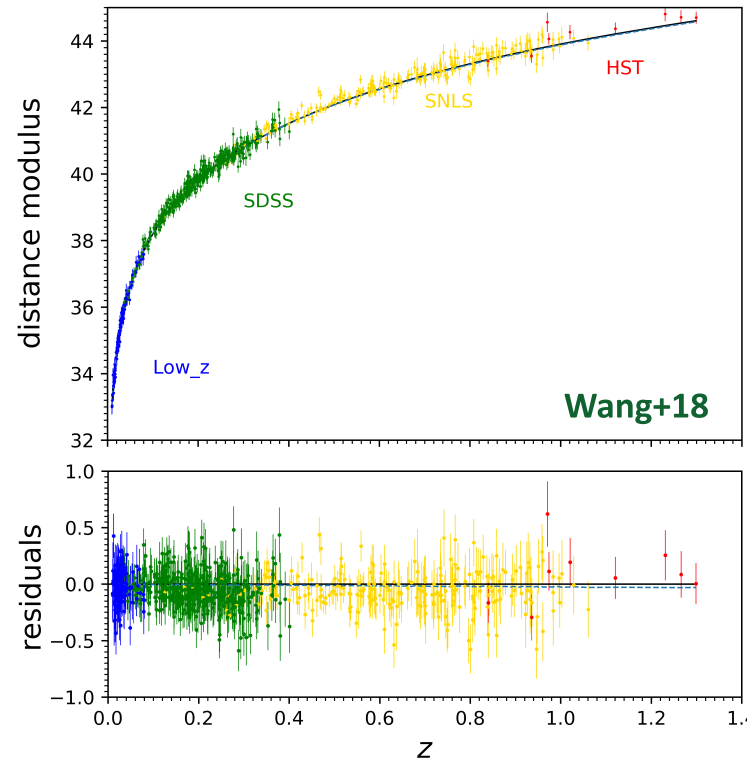
CMB sky (Planck Collaboration 2013)

Several studies using SNIa test D_L:

Mild ~2σ anisotropies for similar sky region → Antoniou+10, Mariano+12, Appleby+15, Javanmardi+15, Migkas+16, Colin+18

No evidence (<1σ) for anisotropy → Kalus+13, Lin+16,Andrade+18, Wang+18

Not full, homogeneous sky coverage!



More D_L/D_A distance tests are needed!

Why (and how to) use $\mathrm{L_X - T}$ for anisotropy studies?

$$\frac{L_X}{10^{44}\ \mathrm{erg/s}} E(z)^{-1} = a \times \left(\frac{T}{4\ \mathrm{keV}}\right)^b$$

Cosmological parameters ($H_0, \Omega_\mathrm{m}, \ldots$)

T determination: cosmology-independent!

Correlate with a

- **Test the isotropy with X-ray galaxy clusters!**
  - **Never been applied before**

Check

↓

Migkas & Reiprich, 2018, A&A, 611, A50

arXiv:1711.02539

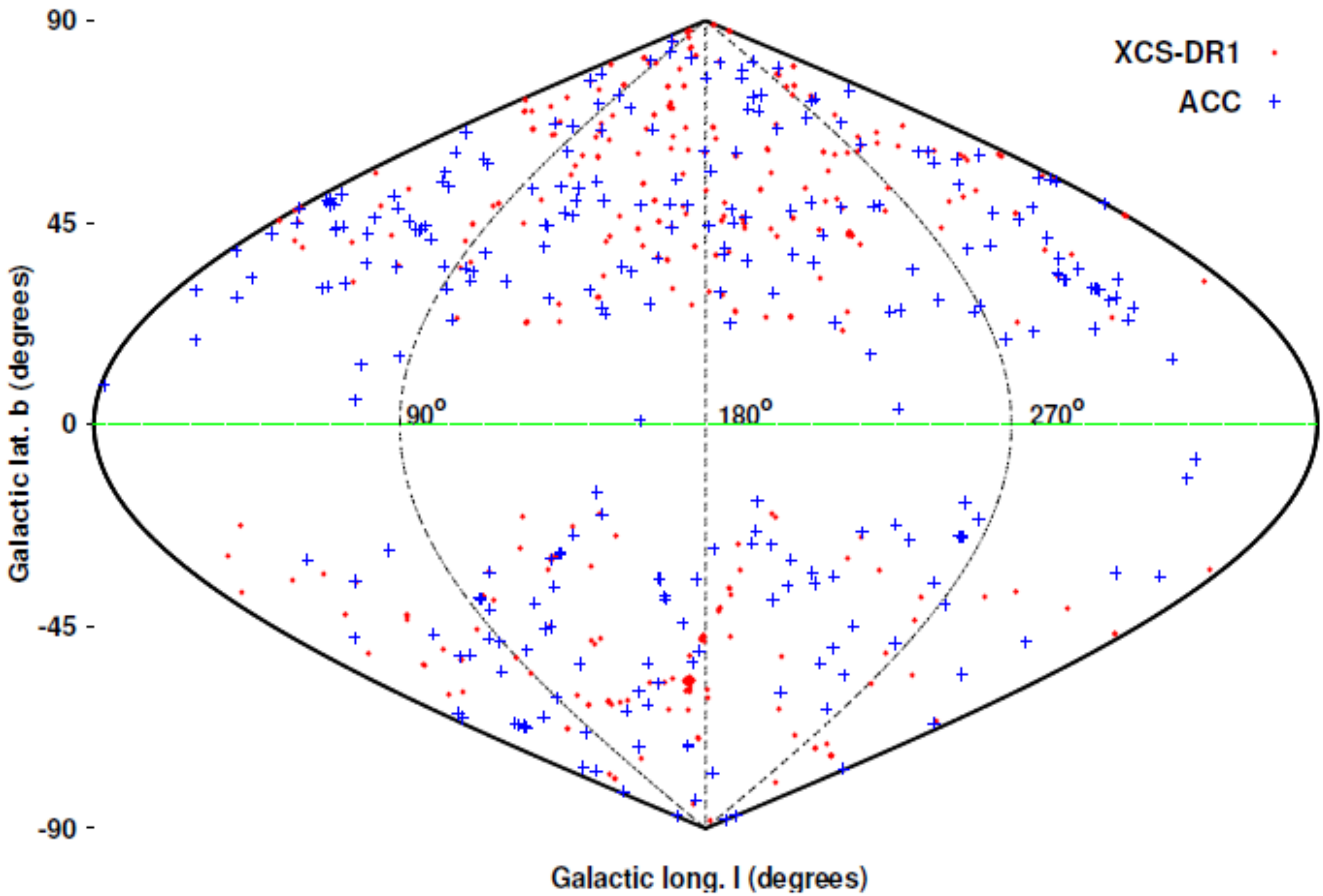
Overview of Migkas+18 results

ACC (273) – Low z

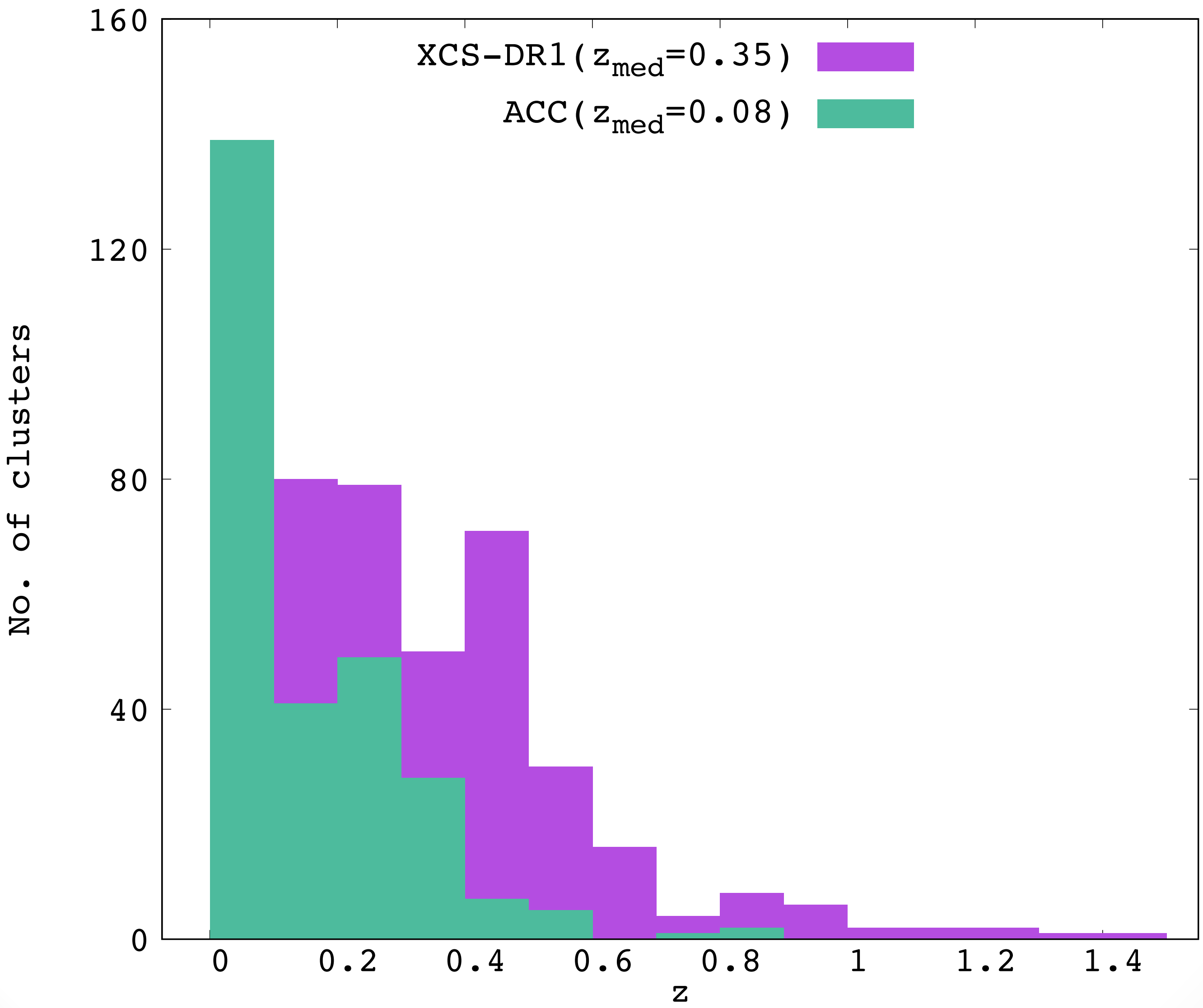
Horner (2001)

XCS-DR1 (364) – High z

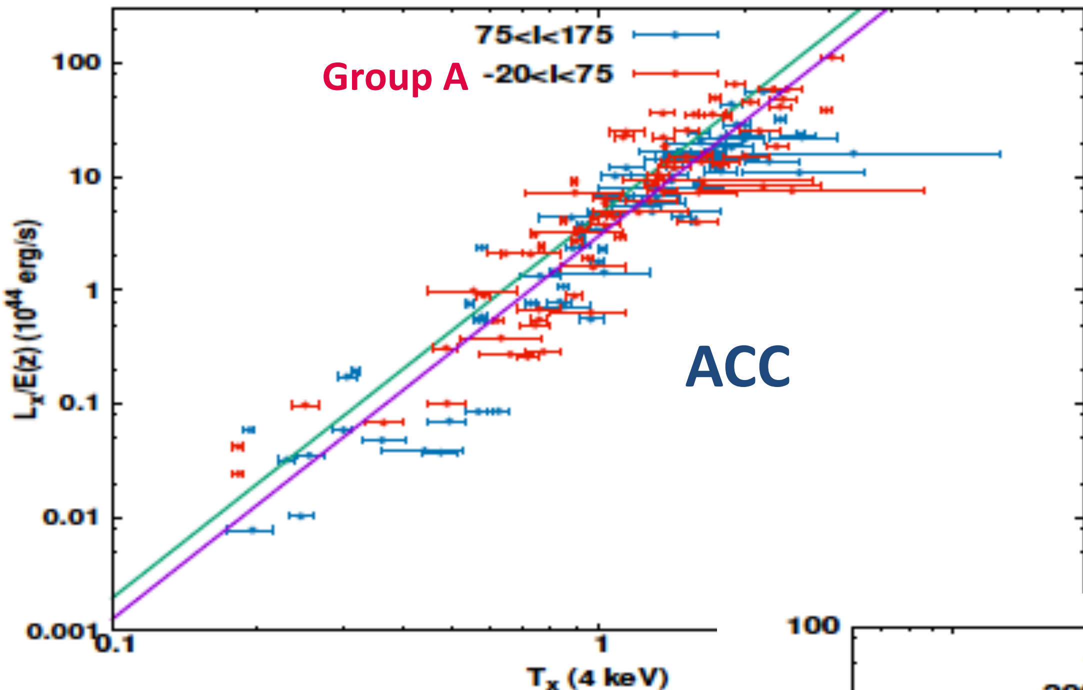
Mehrtens et al. (2012)

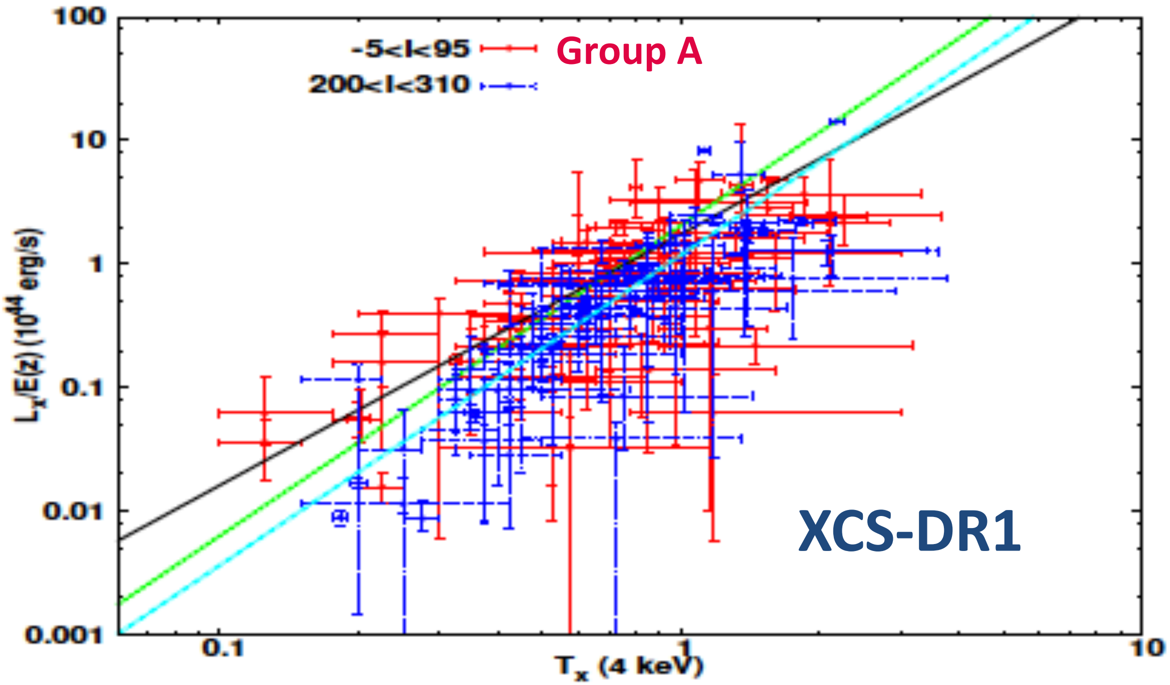


No common clusters between XCS-DR1 & ACC — different properties

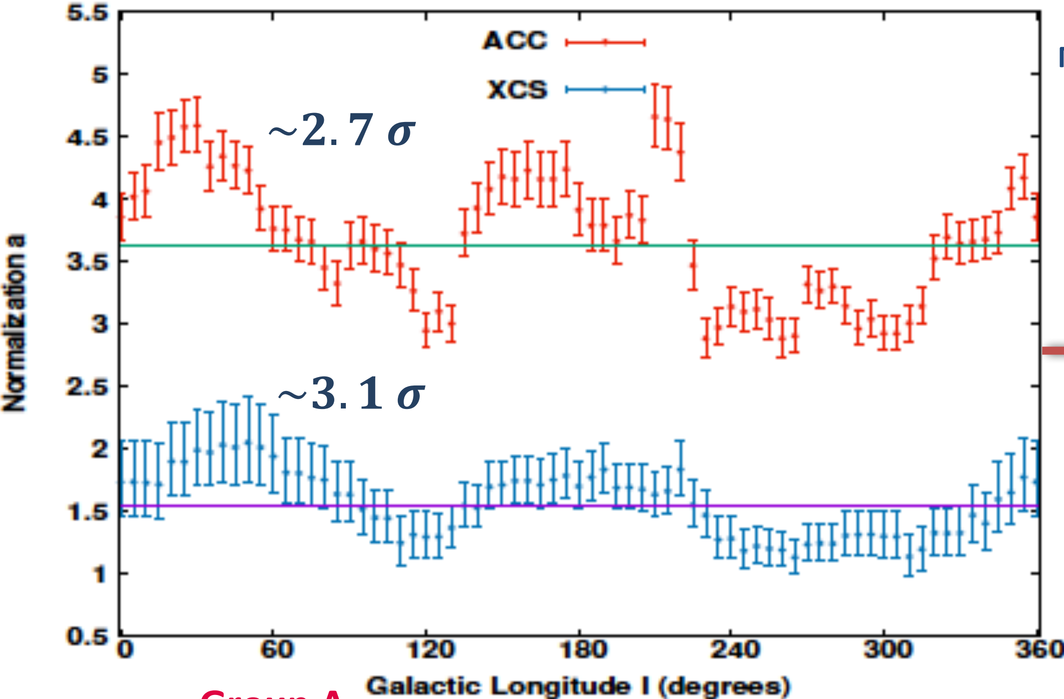


New Method to Test Cosmological Isotropy





$L_X - T$ normalization and H_0 as functions of Galactic l...



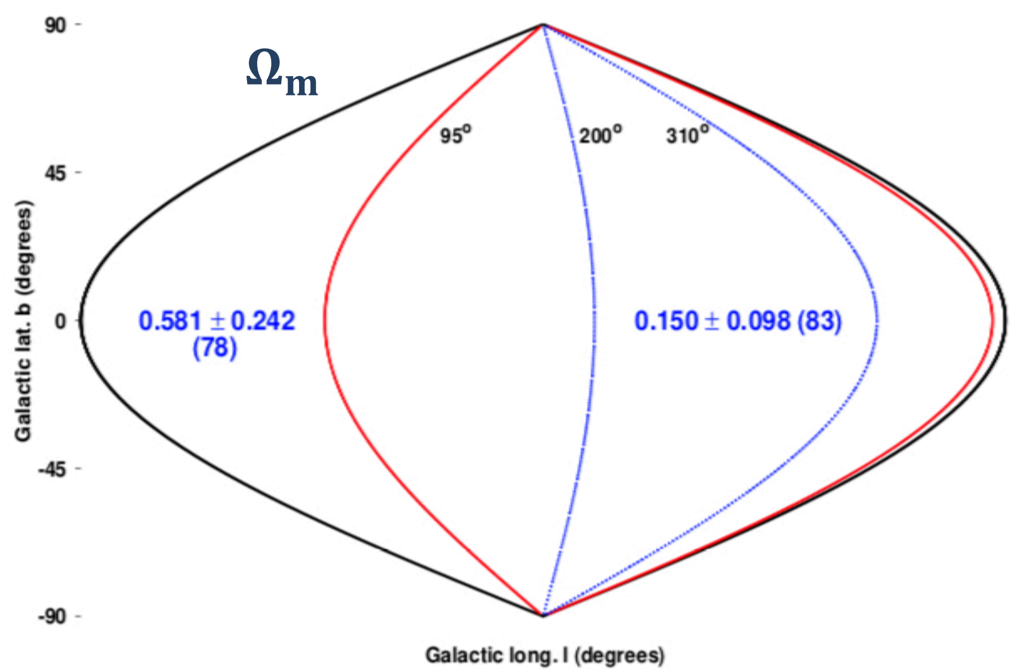
~Group A

Migkas & Reiprich, 2018, A&A, 611, A50

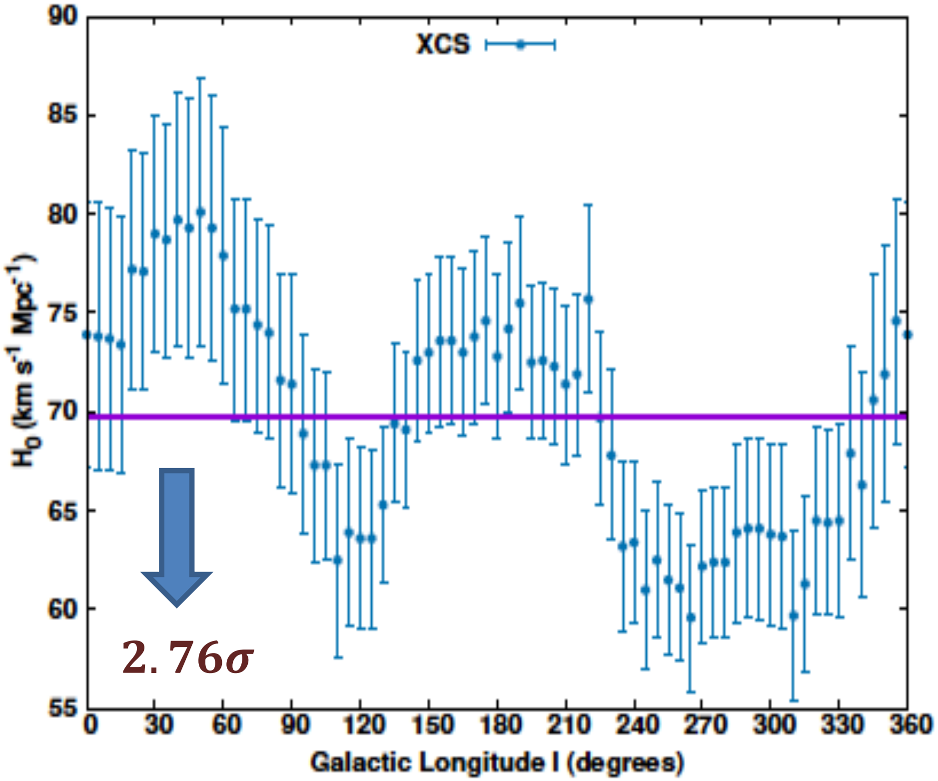
Same fluctuation pattern between ACC and XCS!

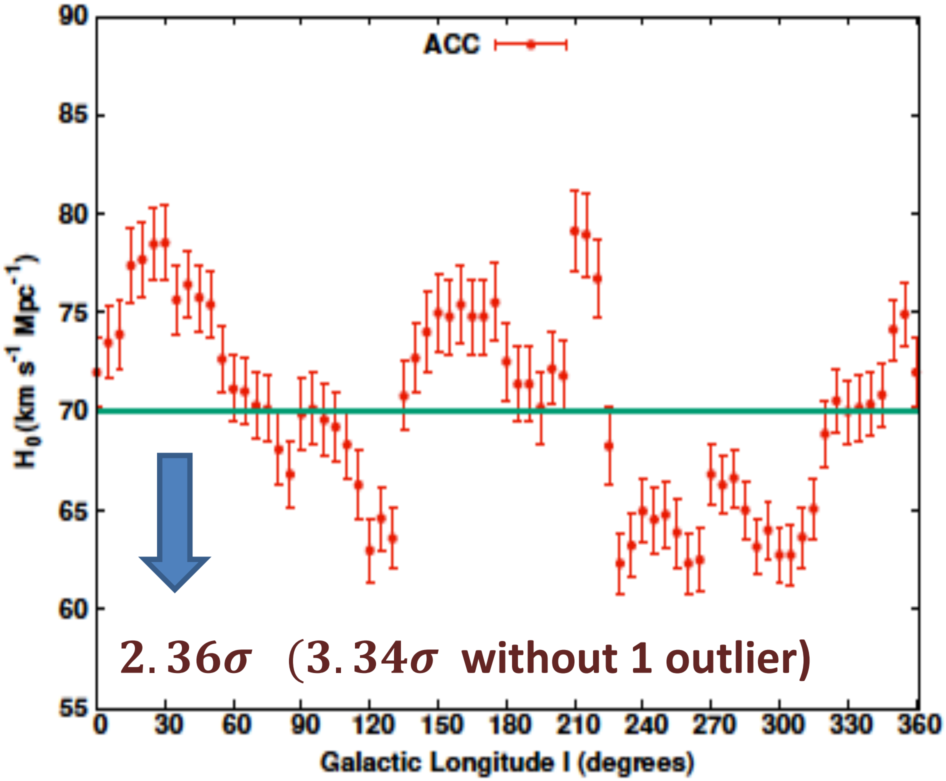
No common clusters between the 2 samples!

?



Different H_0 for different sky directions?





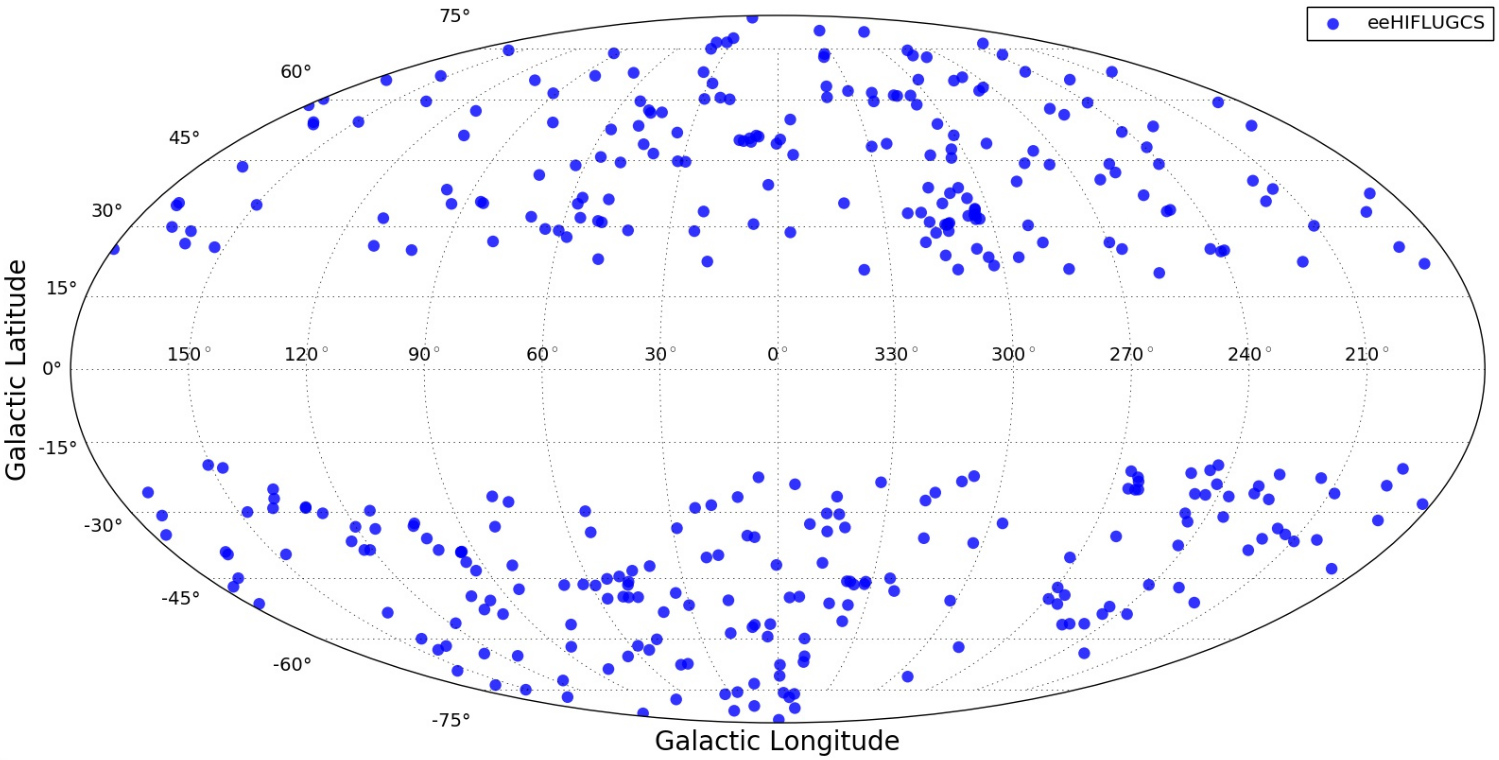
Independent cluster samples!

Many reasons/systematics checked, no explanation up to now...

→ **Migkas & Reiprich, 2018, A&A, 611, A50**

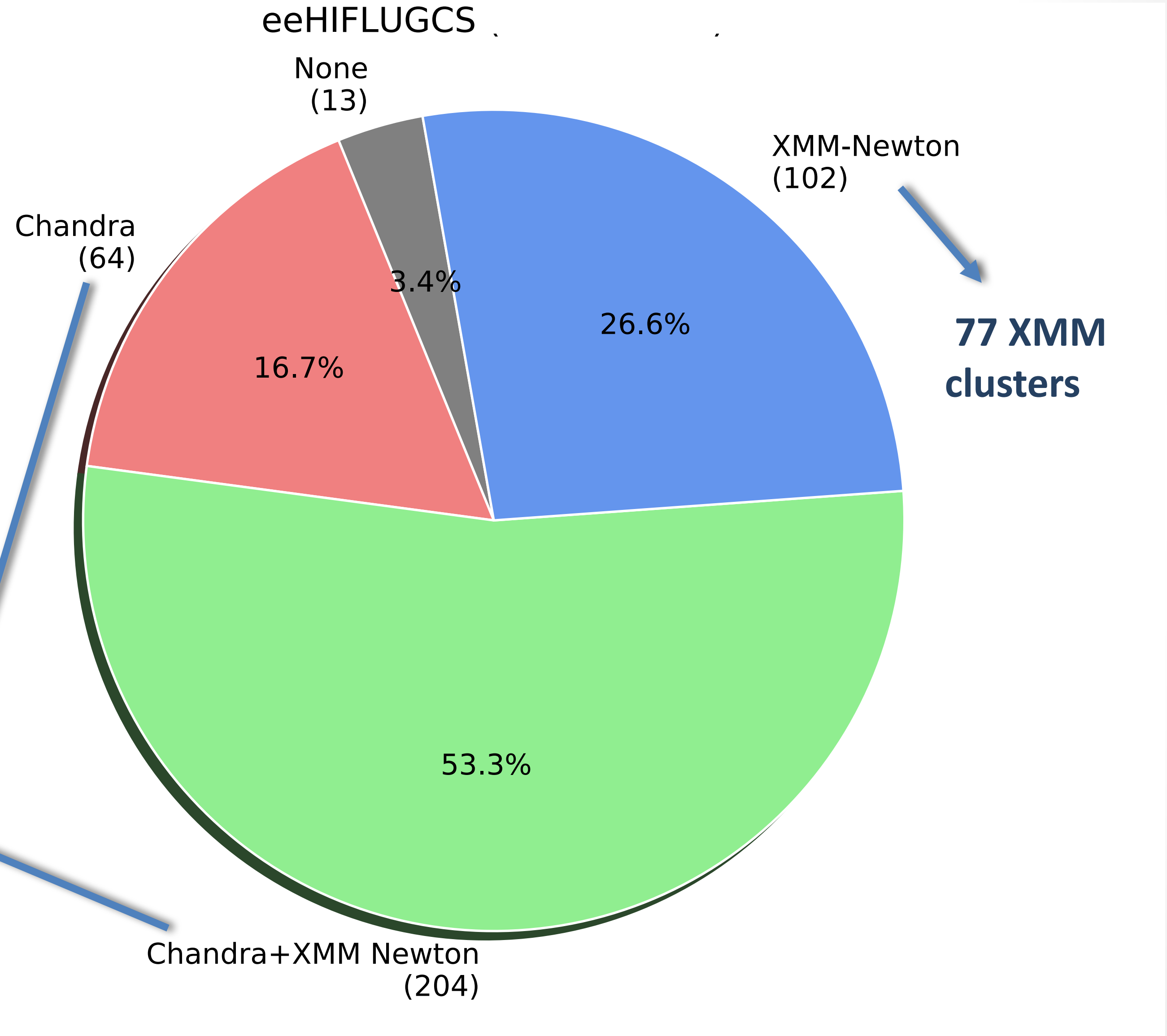
Our *eeHIFLUGCS* sample

- **~400 X-ray brightest clusters in the sky**
- **High quality follow-up with *Chandra* and/or *XMM-Newton* for ~85% of them**



Migkas, Schellenberger, Pacaud, Ramos-Ceja, Lovisari & Reiprich (in prep.)

From where will the temperatures be obtained?



77 XMM clusters

245 Chandra clusters

Raw X-ray observation of a cluster

↓

Full data reduction (solar flares, instrum. bgd, AGNs etc.)

↓

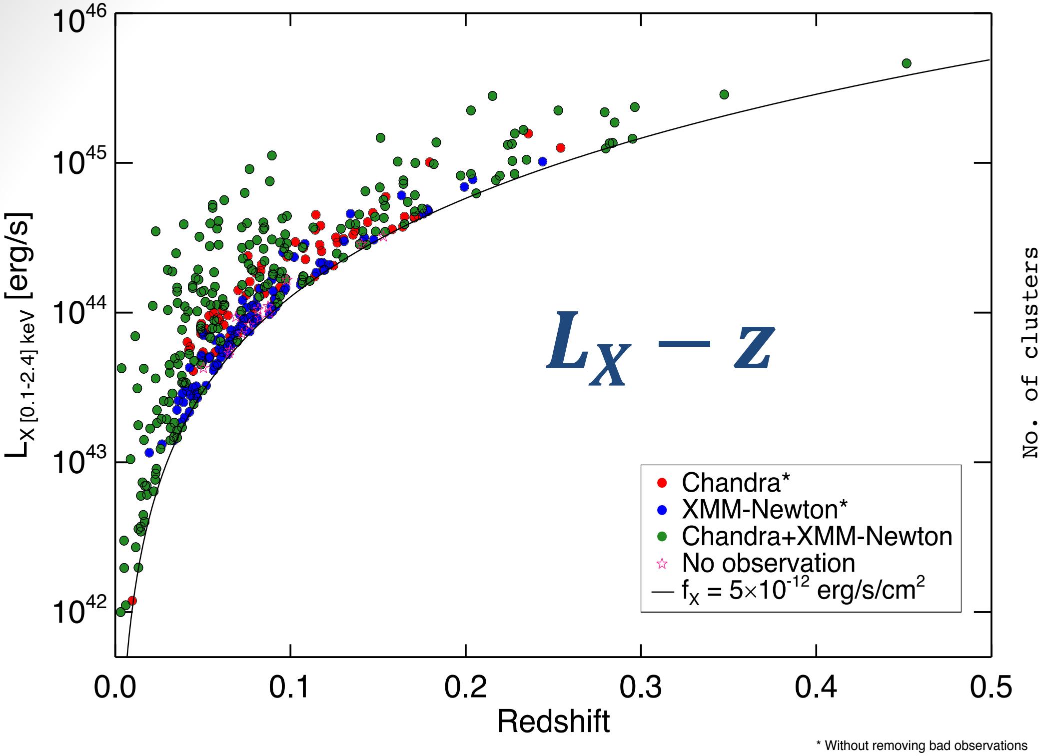
Extraction and fitting of X-ray spectra

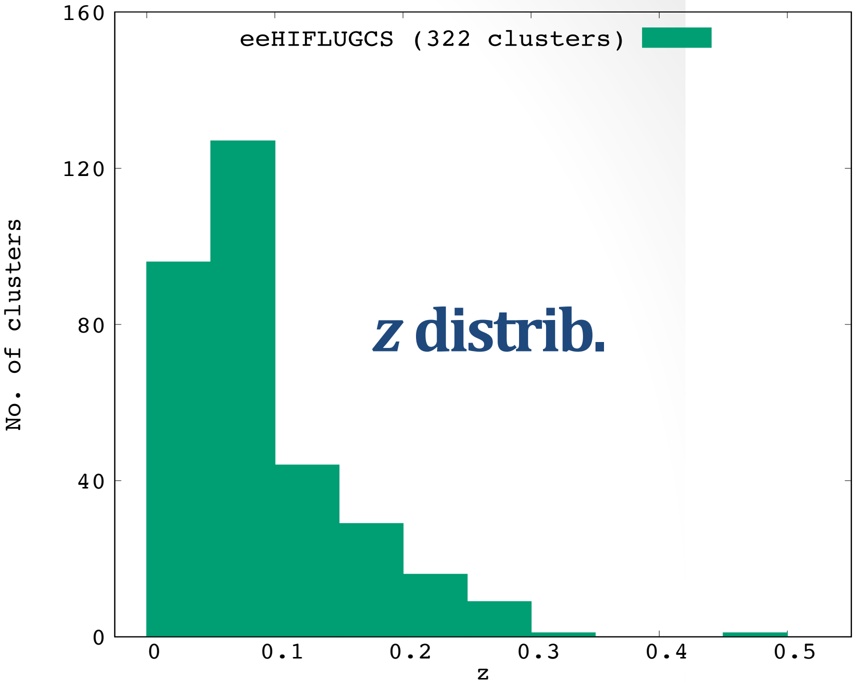
↓

Constrain physical values

↓

Done for 322 clusters (for now)





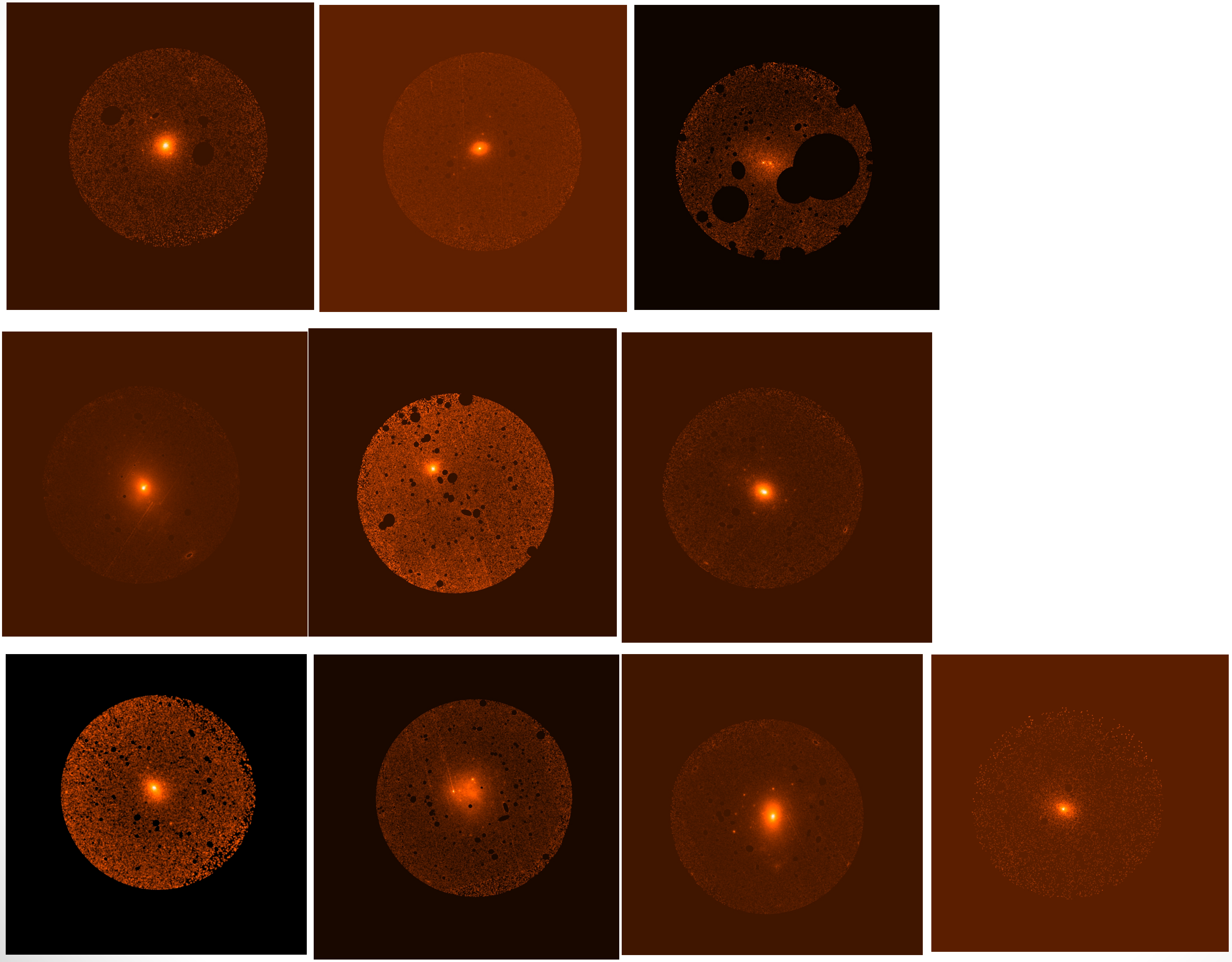
Why eeHIFLUGCS for $L_X - T$?

- Complete sample, many clusters, good observations
- Much better understanding of selection function, systematics etc.
- Brightest clusters → better statistics → low uncertainties $(\sim 3\%)$
- No common clusters with XCS, only 30% common with ACC

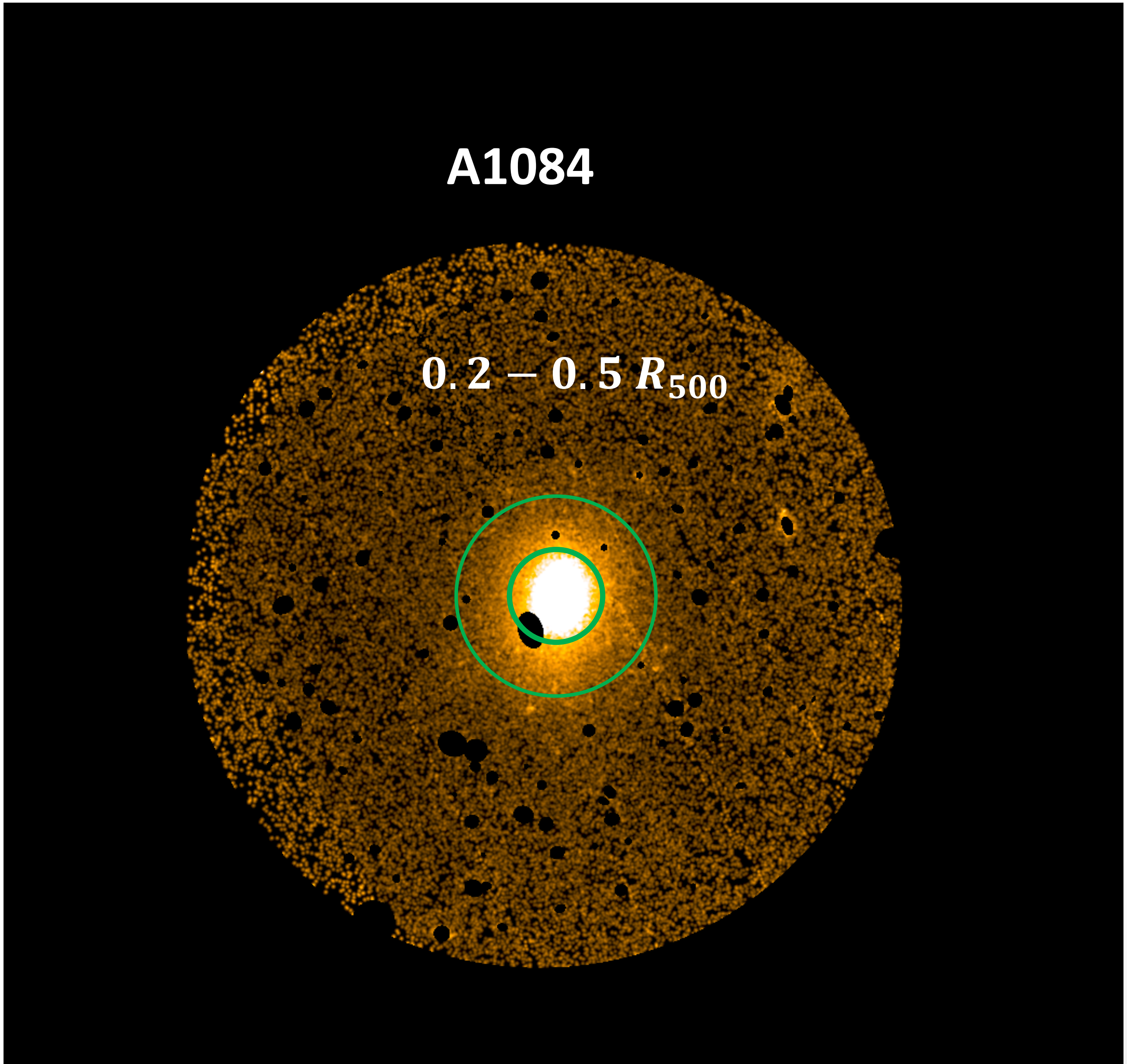
Perfect!

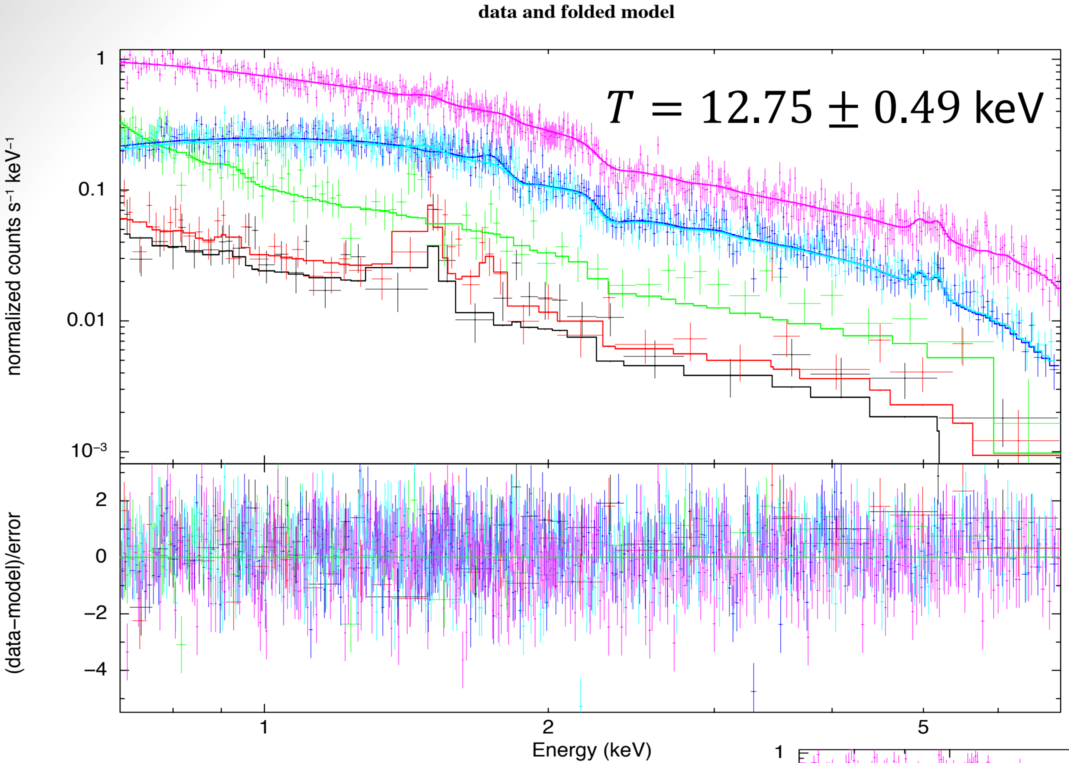
X-ray images of galaxy clusters…

$0.5 - 2$ keV

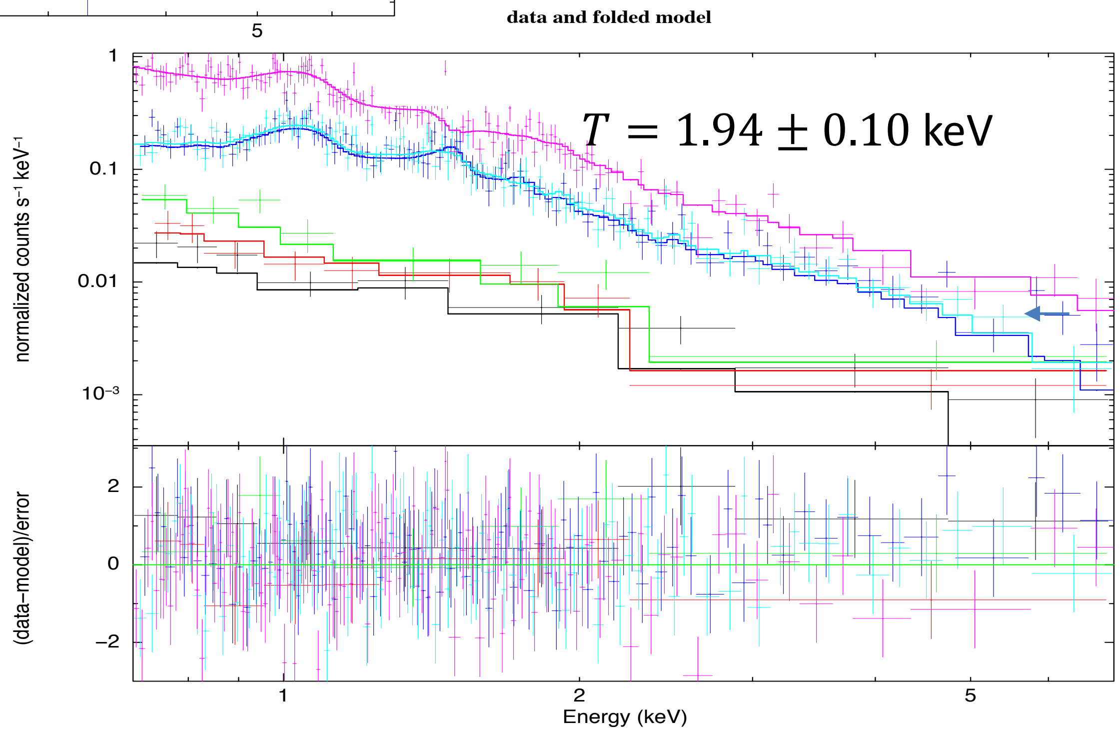


Extract T annulus spectrum $(0.2 - 0.5\ R_{500})$





…fit the X-ray spectra
→ T (& z) constrains

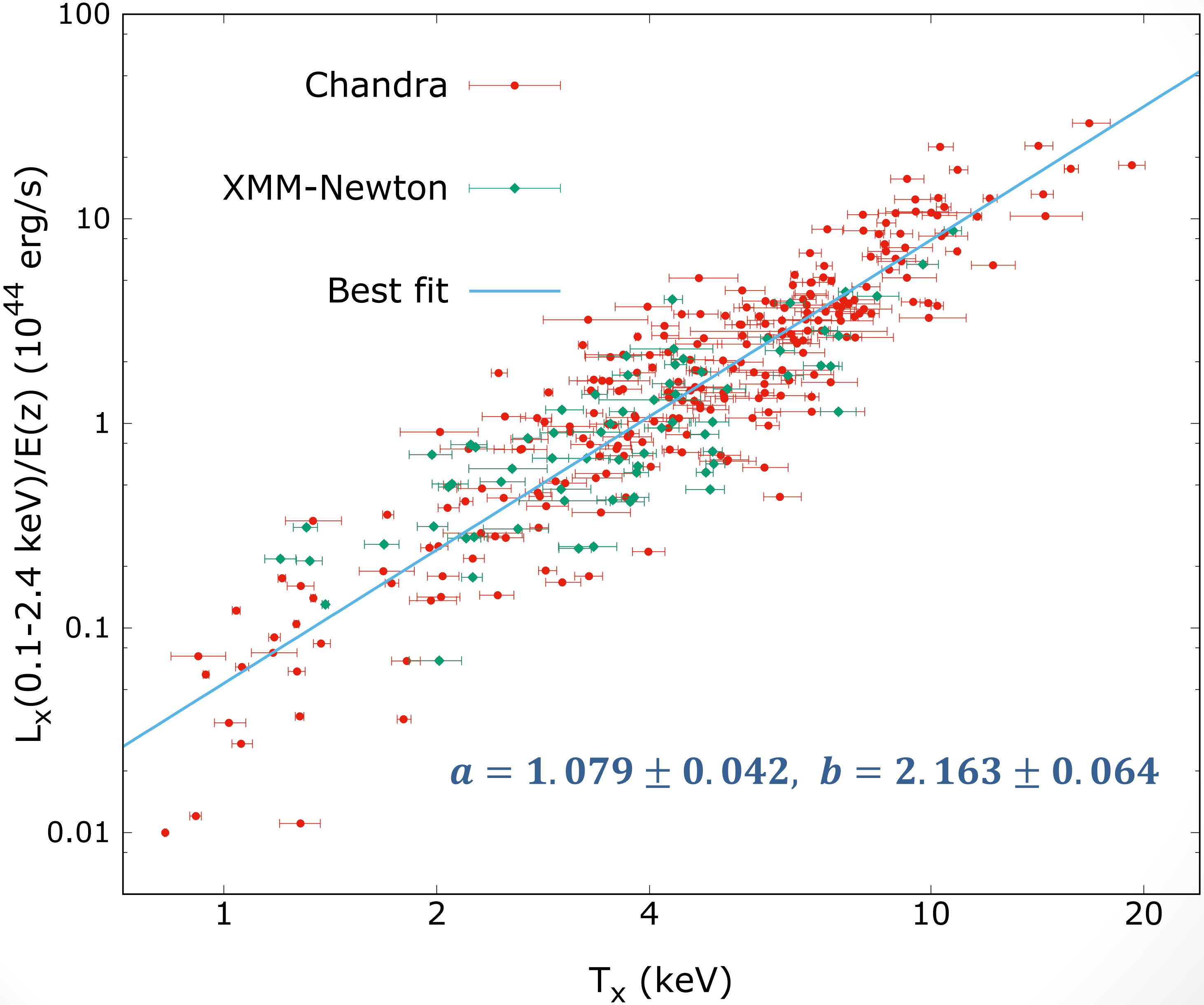


Combine measured T, f_X and z

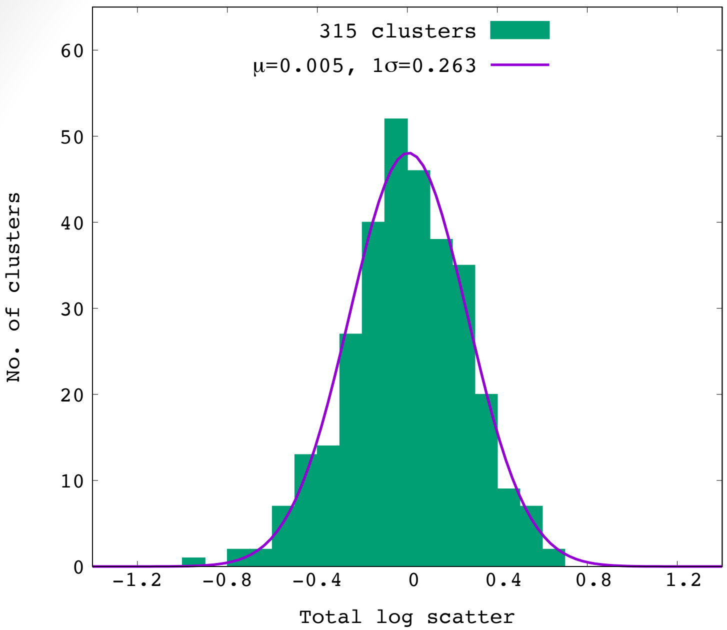
Create $L_X - T$!

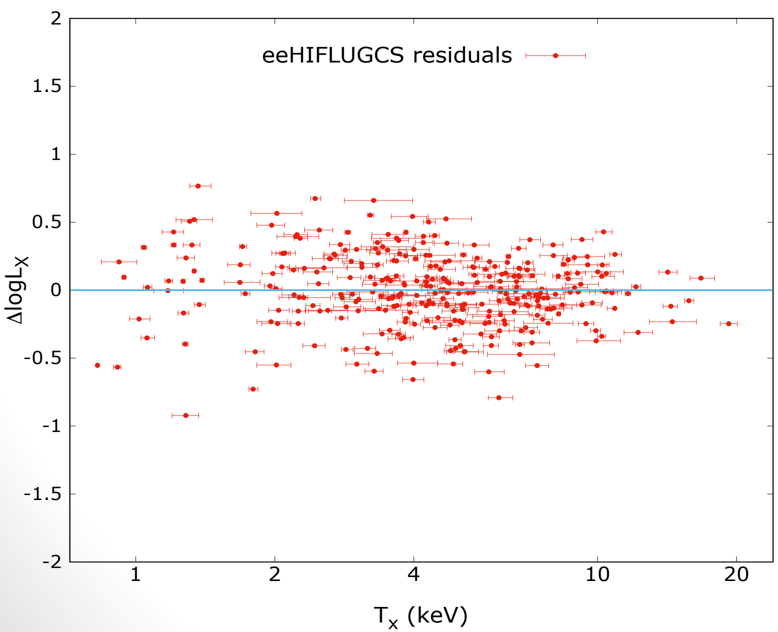
eeHIFLUGCS $L_X - T$ results…

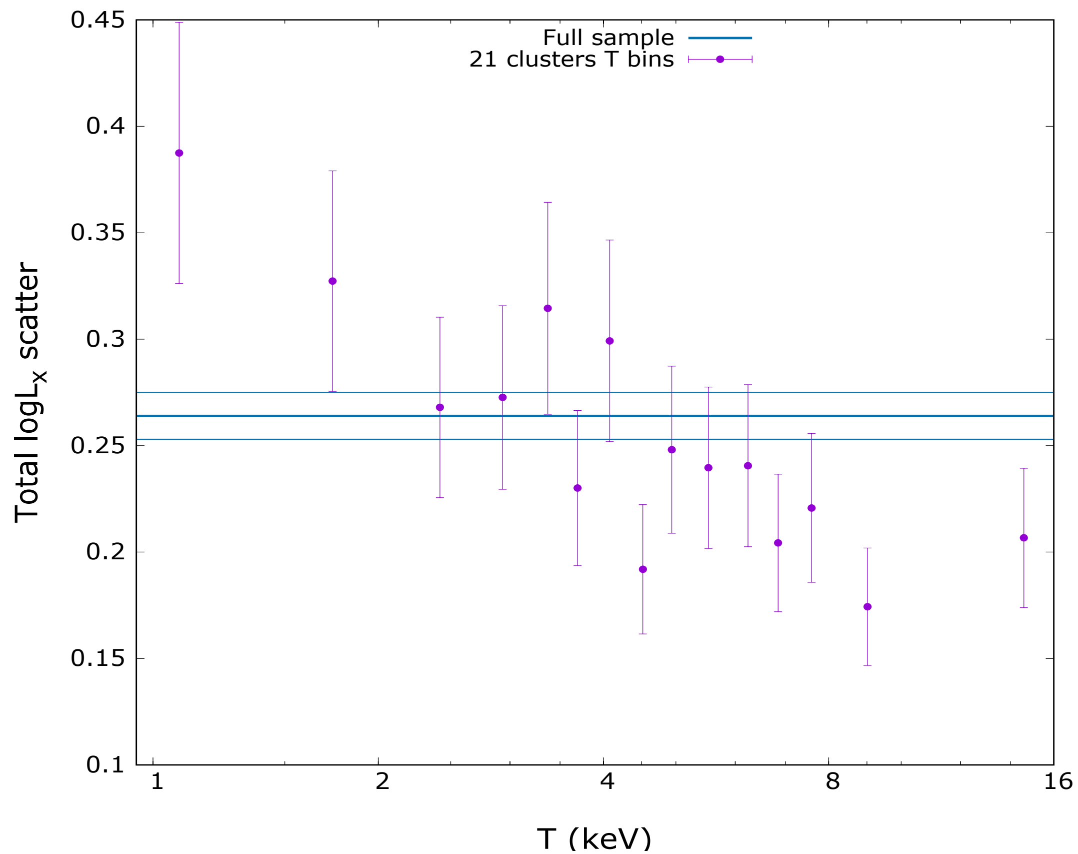
$L_X - T$ plot for *eeHIFLUGCS*



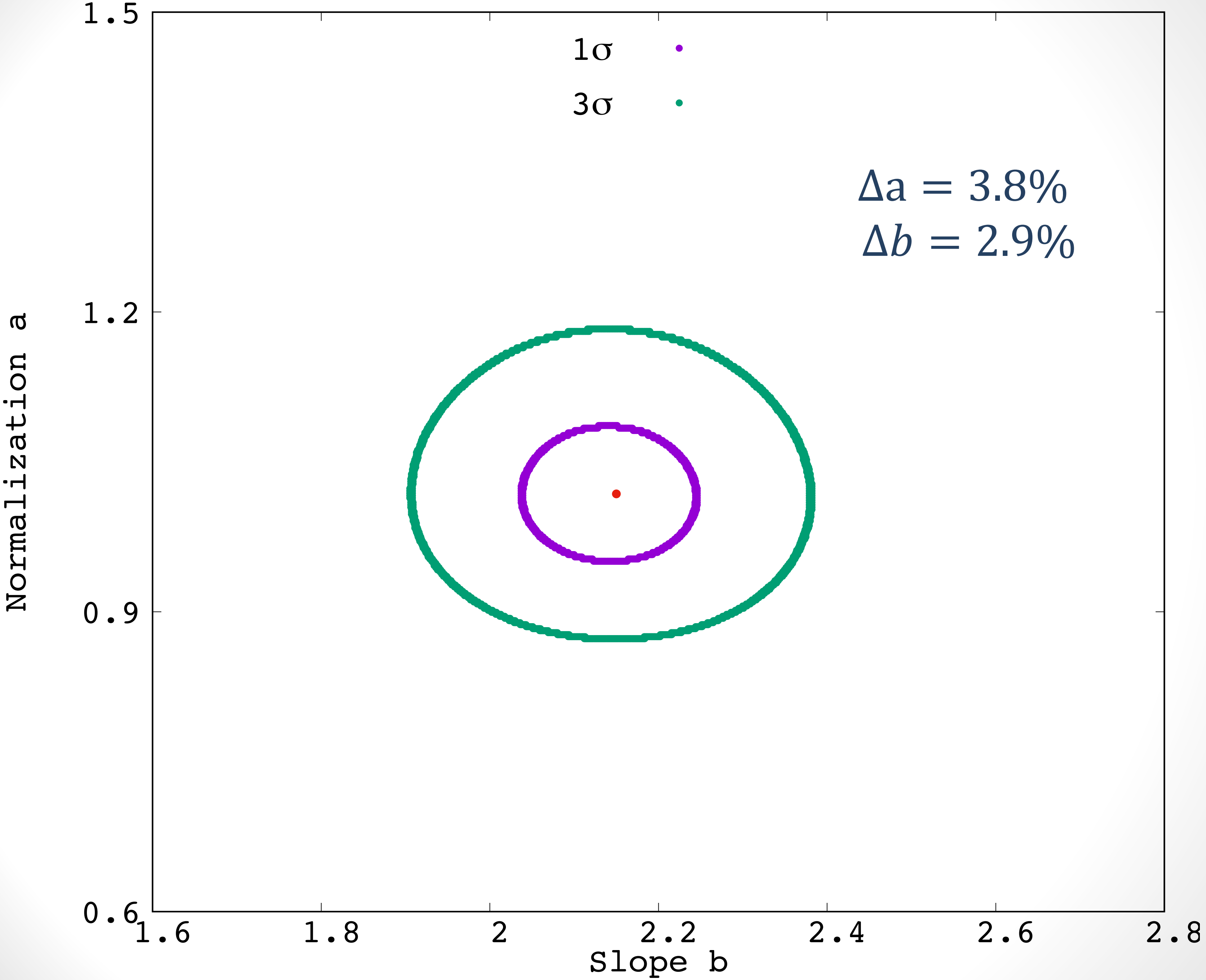
$L_X - T$ scatter







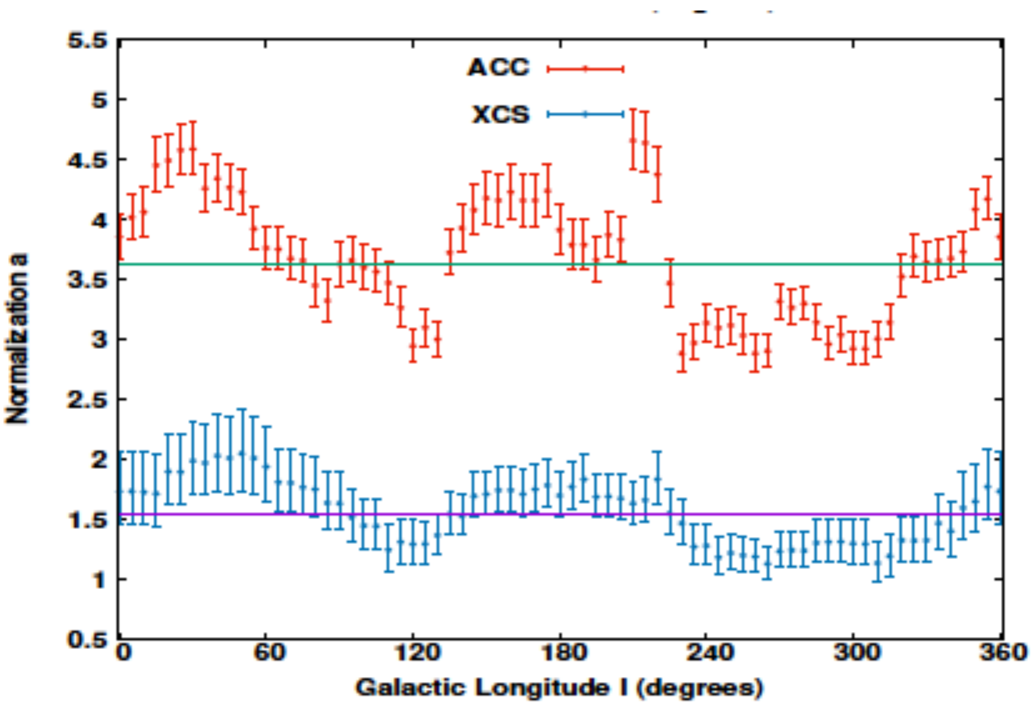
- **Gaussian scatter for full sample**
- **Decreases with increasing *T***



$\Delta a = 3.8\%$
$\Delta b = 2.9\%$

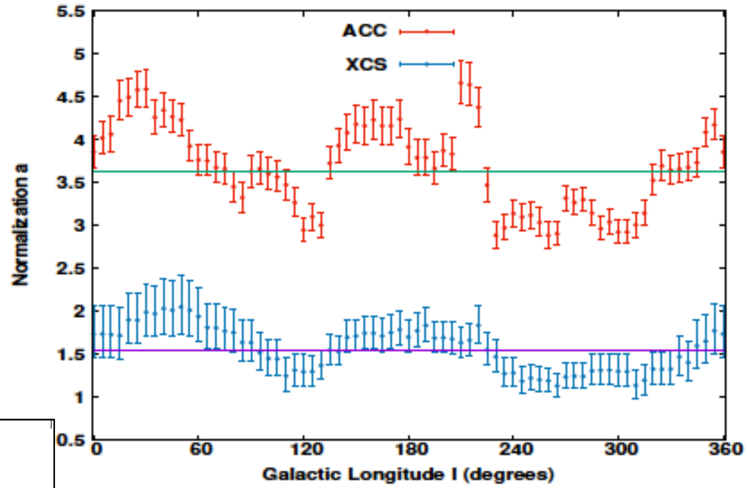
Crucial question:

Will we get the same directional behavior again with eeHIFLUGCS..?

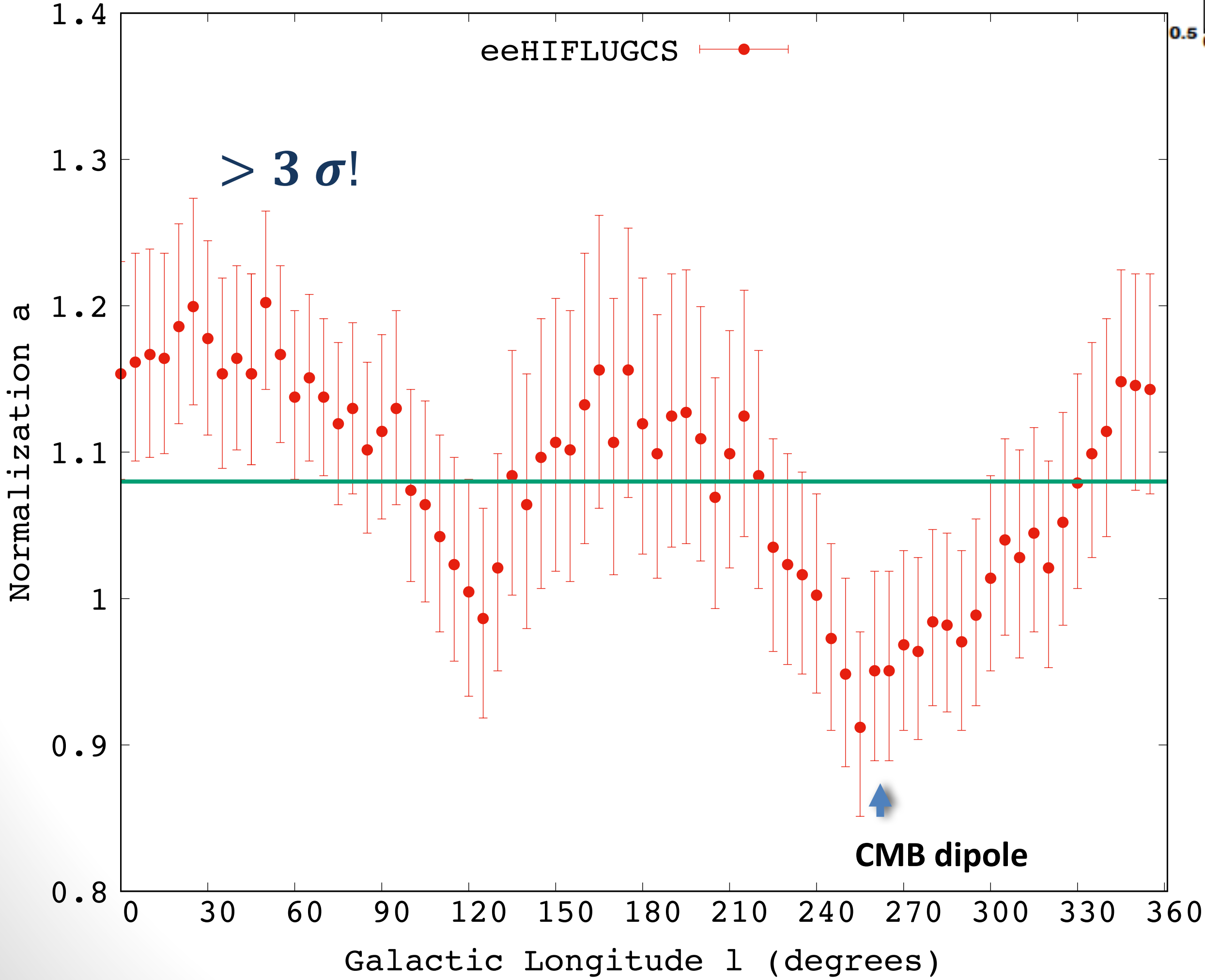


Reminder

Answer: Yes!



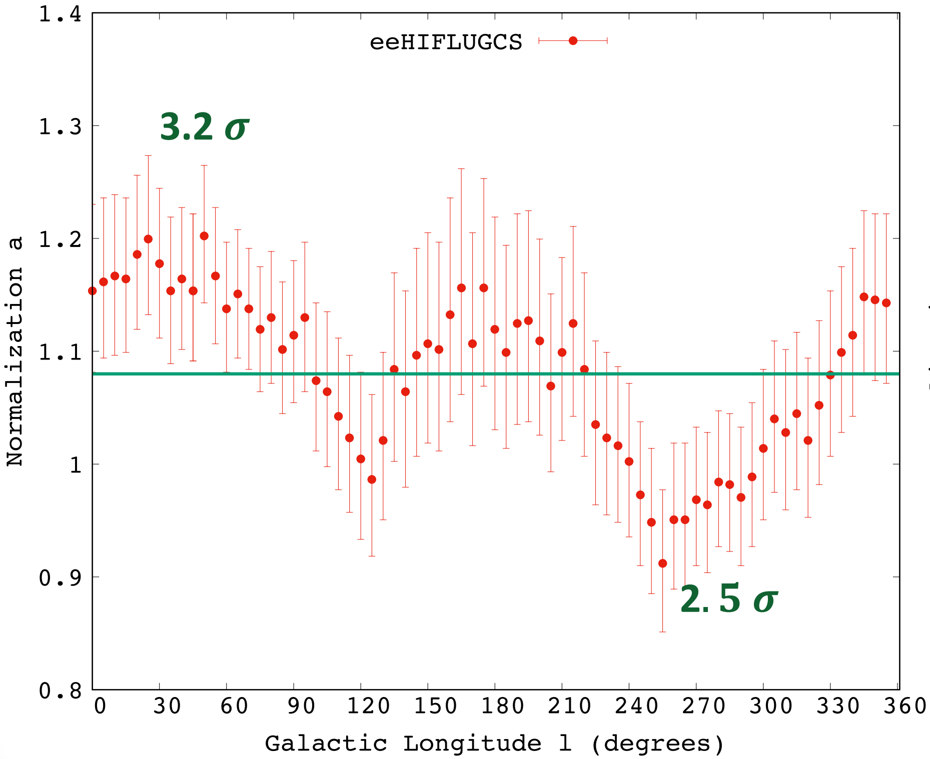
Same pattern shows up again!



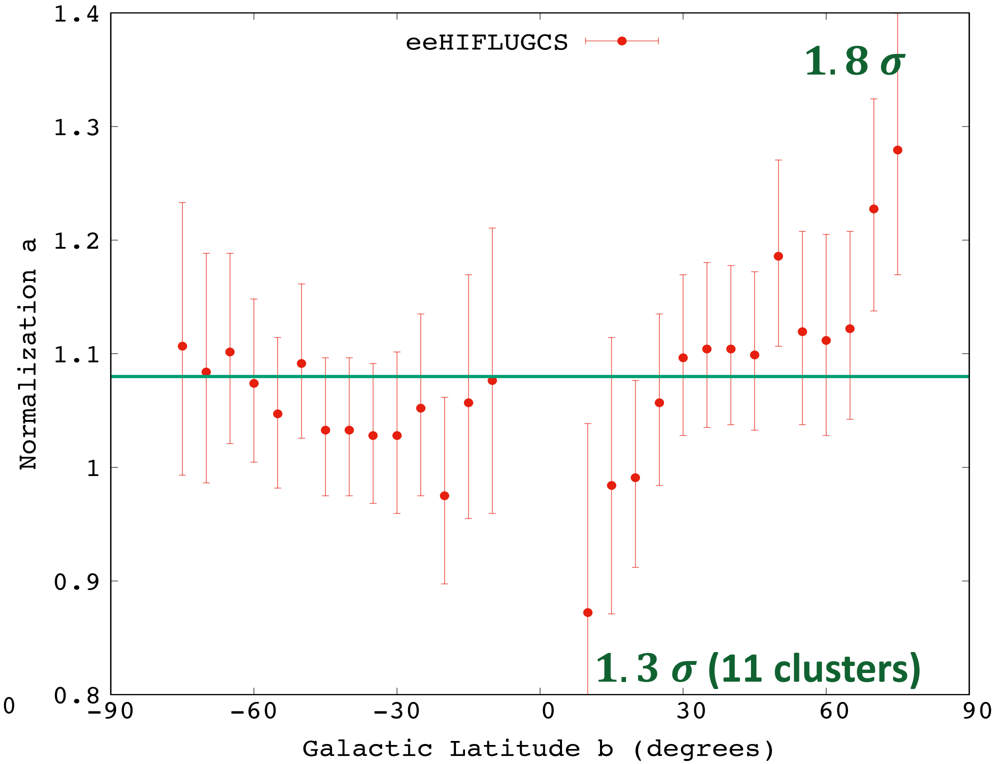
Very exciting…

Full analysis on its way…

$L_X - T$ norm. vs $Glon$



$L_X - T$ norm. vs $Glat$



Scenarios & Consequences:

- **Anisotropy of Universe?→ revisit standard Cosmology. SNIa results match the direction – not the significance**

- ***More likely*: Unidentified factor that affects X-ray photons in a directional-depended way**

↓

- **X-ray astronomy: Conclusions from non-full sky samples → not universal!**

- **X-ray cluster masses from $L_X - M$: Different for every sky patch!**

Summary

- ***Have to be absolutely confident that isotropy (of all kinds) holds!***
- $L_X - T$ varies significantly (3σ) for 2 independent samples, with ***exactly*** the same pattern!
- Essential to identify systematic (or anisotropy?)
- **eeHIFLUGCS**: Great sample for that!
- Same pattern shows up in eeHIFLUGCS!
- Anisotropy or unidentified factor affecting X-ray measurements?

More to come…

THANK YOU FOR YOUR ATTENTION

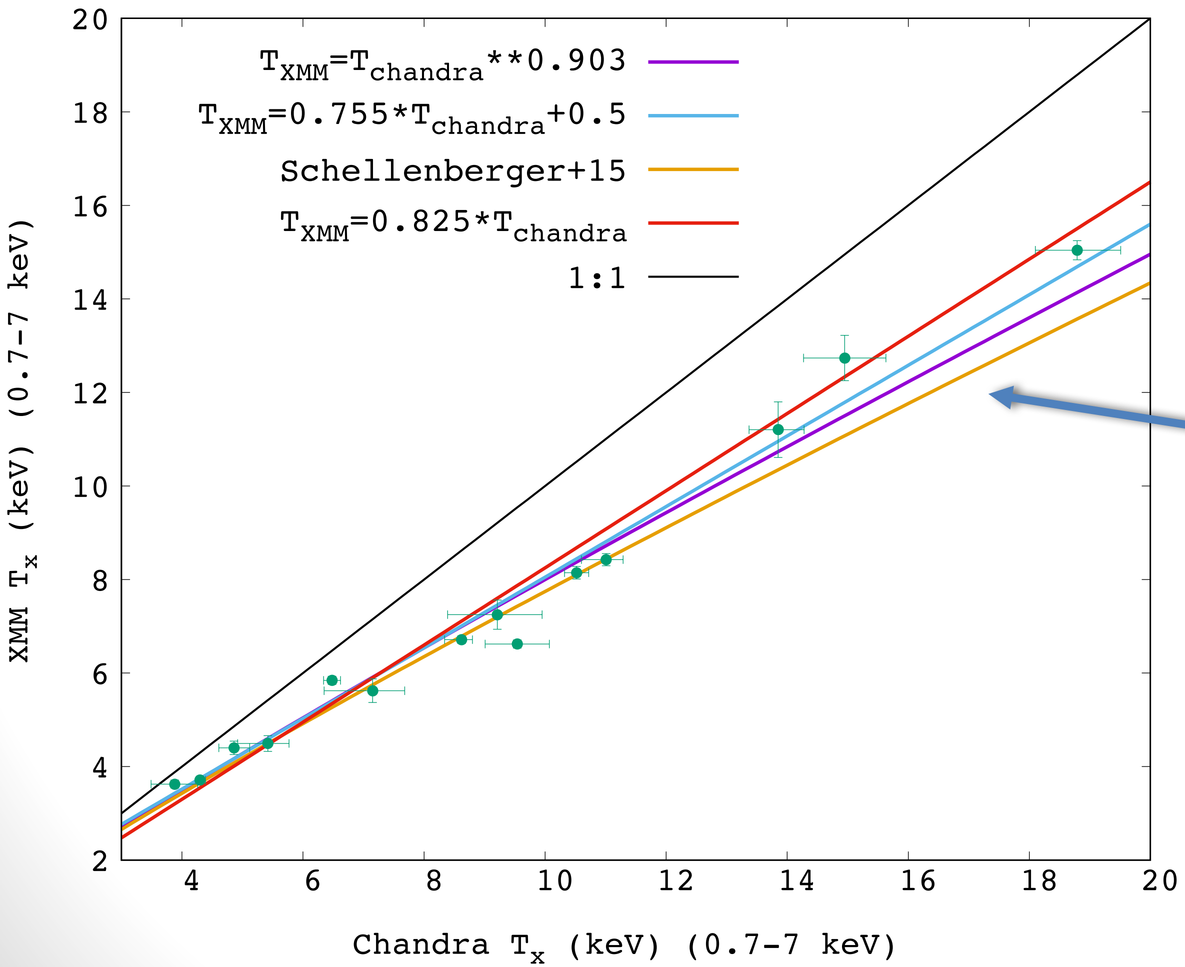
Backup slides

The MCXC meta-catalogue

- **Compilation of catalogues based on the ROSAT All-sky survey (first and only all-sky imaging survey until now) and other serendipitous surveys**
- **Contains 1743 clusters**
- **Brightest clusters in the sky are included**
- **Names, coordinates, L_X, z are given**

- Calibration of XMM/Chandra temperatures is needed…
  - Common XMM+Chandra analysis for 14 clusters to compare T

Using all HIFLUGCS clusters, Schellenberger+15 found: → $T_{XMM} = T_{Chandra}^{0.89}$



Not a good fit for $T_{XMM} \geq 12$ keV

…but…

XMM-only clusters, $T_{XMM} \leq 8.3$ keV

Fitting method

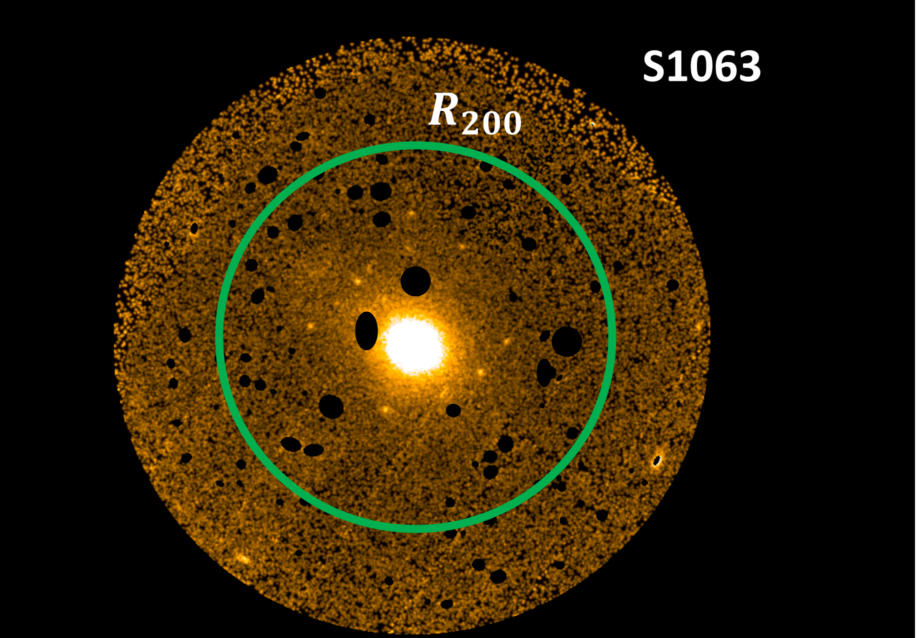
$$\frac{L_X}{10^{44}\ \mathrm{erg/s}}\, E(z)^{-1} = a \times \left(\frac{T}{4\ \mathrm{keV}}\right)^{b}$$

$$\overline{\left(\frac{\sigma_{L_x}}{L_x}\right)} \approx 10\%$$

$$\overline{\left(\frac{\sigma_T}{T}\right)} \approx 3\%$$

$$\chi^2 = \sum_{i=0}^{n} \frac{\left(log\left[L_{i,obs}(H_0, \Omega_\mathrm{m})\right] - a - b\log T_i\right)^2}{\left(\sigma^2_{\log L_i} + b^2\sigma^2_{\log T_i} + \sigma^2_{int}\right)}$$

…+ Bootstrap + Jackknife + MCMC for assessing statistical significance

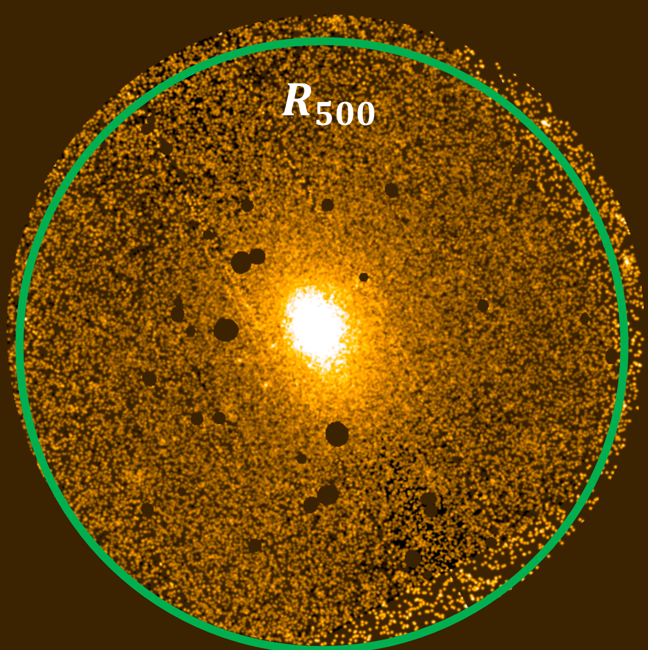


Extract background spectrum:

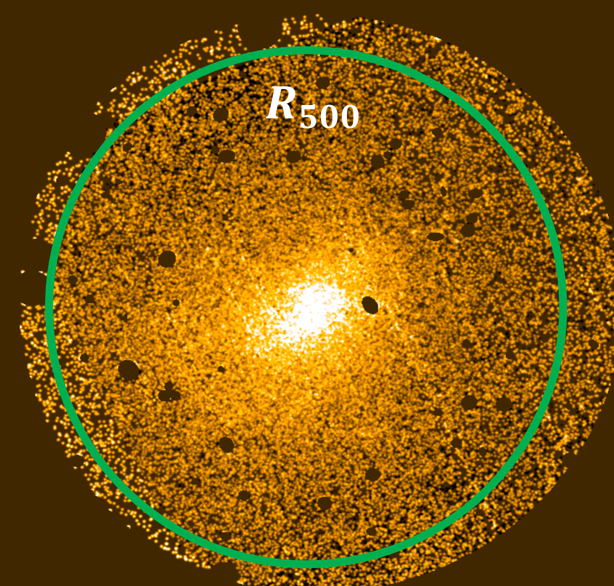
- outside R_{200} preferably
- outside of R_{500}
- small region, as close to R_{500} as possible

0.5 − 2 keV

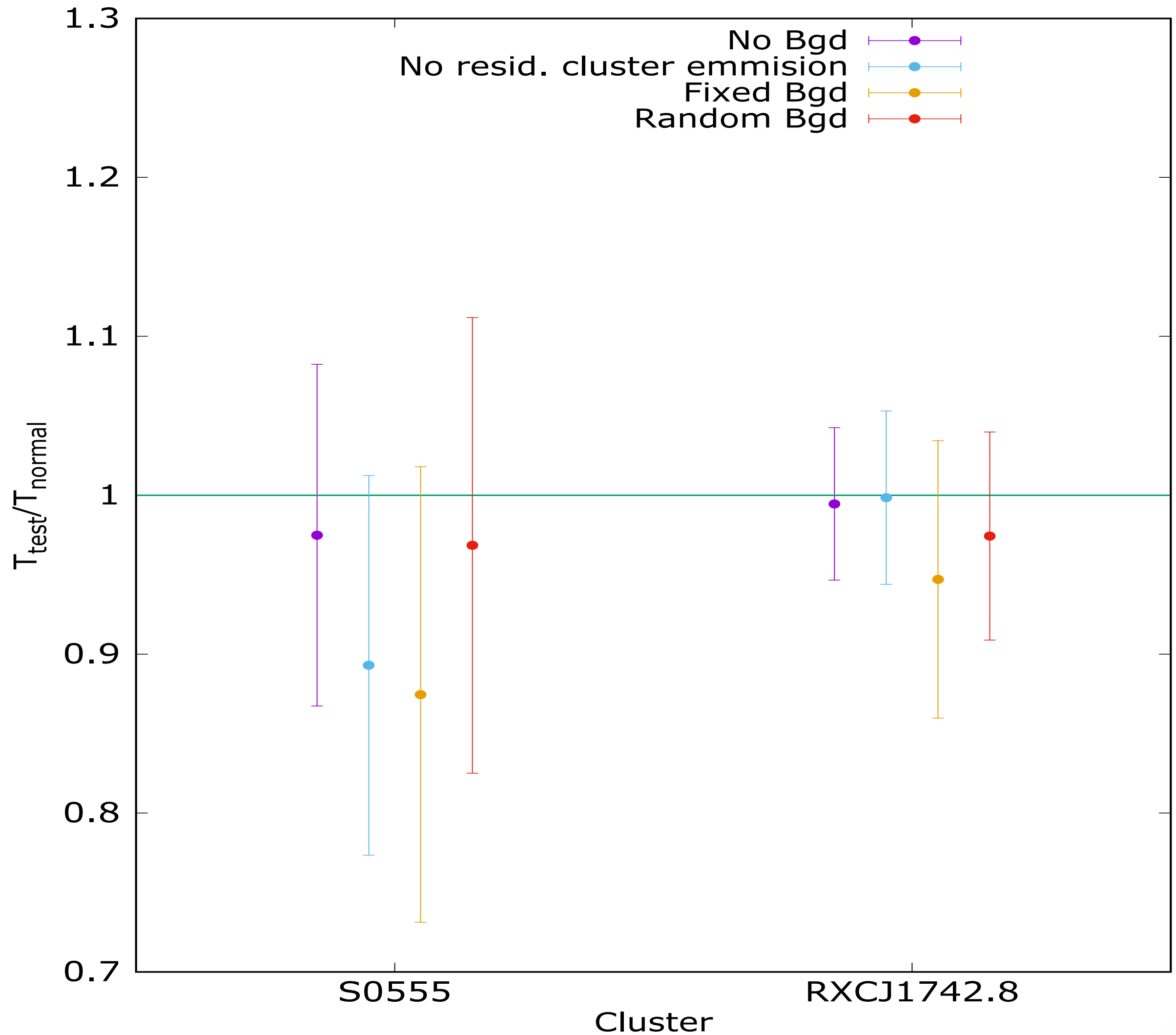
RXCJ1740.5+3539



A3530



No significant differences for different Bgd selections



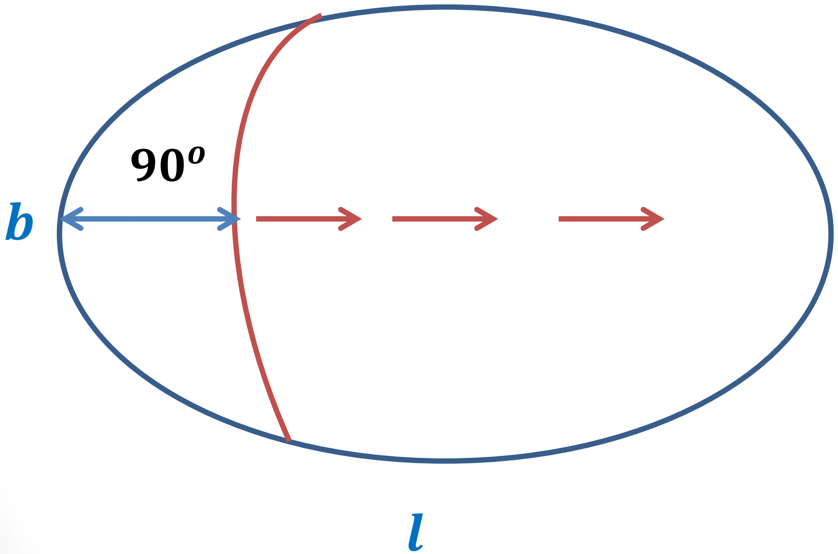
Comparison with previous samples

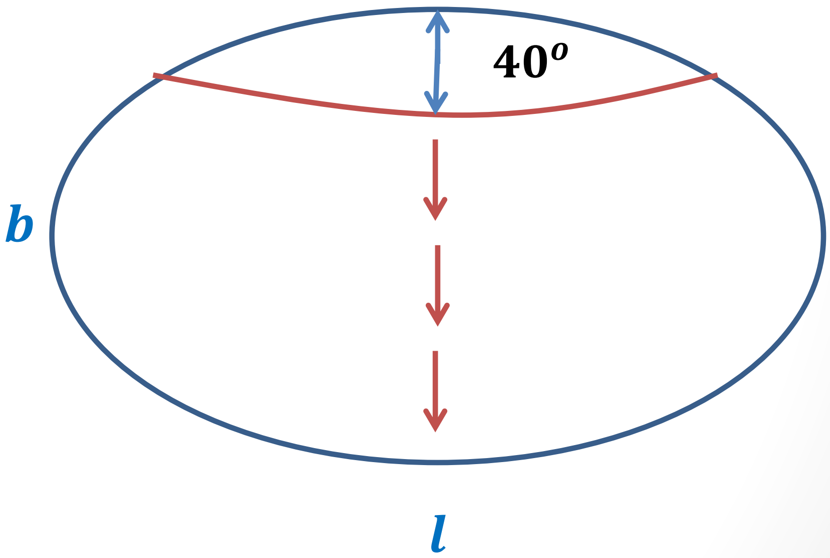
- No. of clusters → XCS-DR1 > eeHIFLUGCS > ACC
- T values → ACC > eeHIFLUGCS $\sim$ XCS-DR1
- z values → XCS-DR1 > eeHIFLUGCS $\sim$ ACC
- Uncertainties → XCS-DR1 $\gg$ ACC $>$ eeHIFLUGCS
- Intrinsic scatter → XCS-DR1 $\gg$ ACC $>$ eeHIFLUGCS

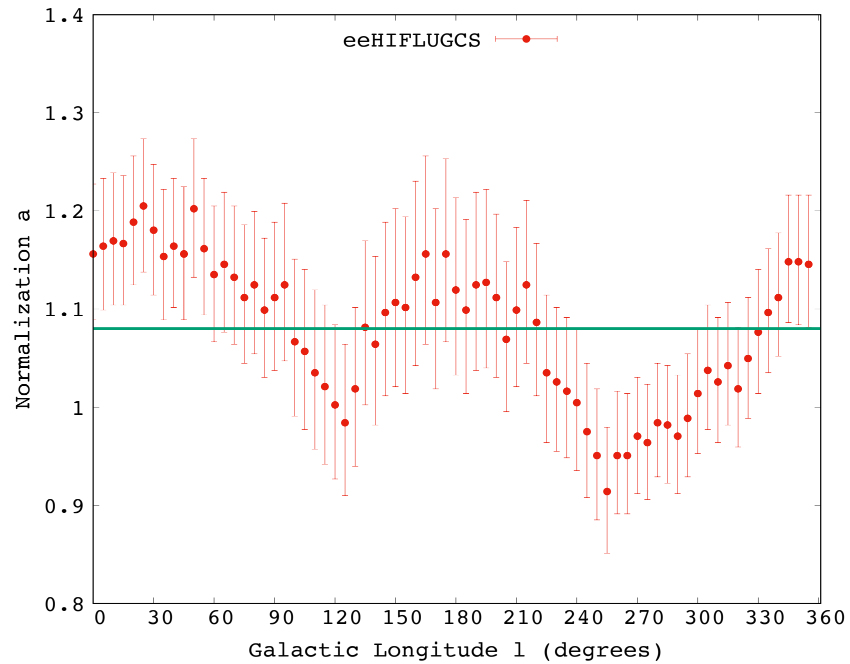
ACC disadvantage: T from entire cluster, not isothermal

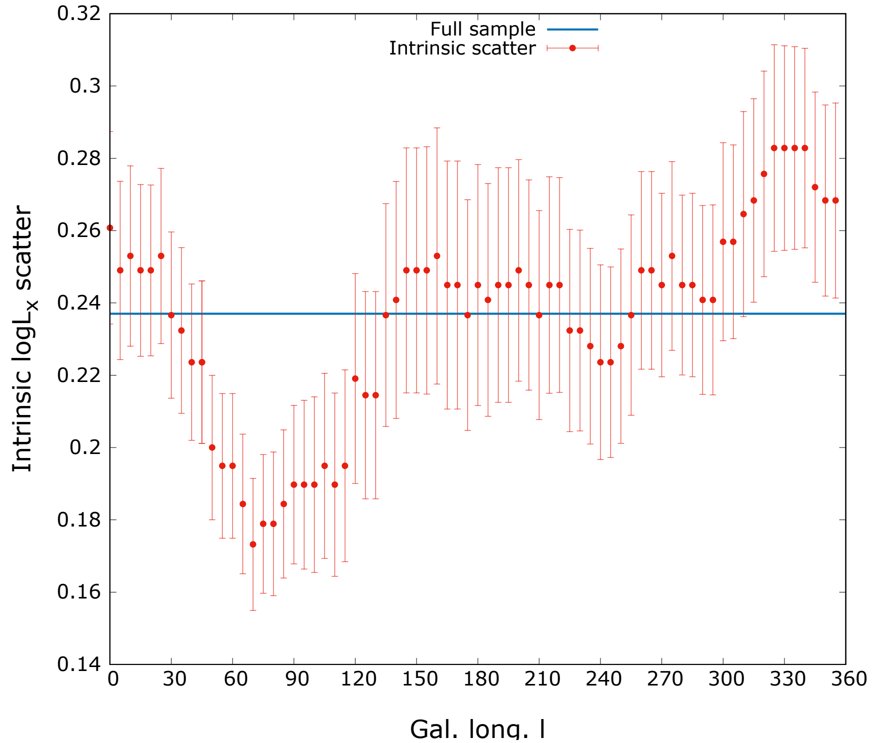
Identification of anisotropies

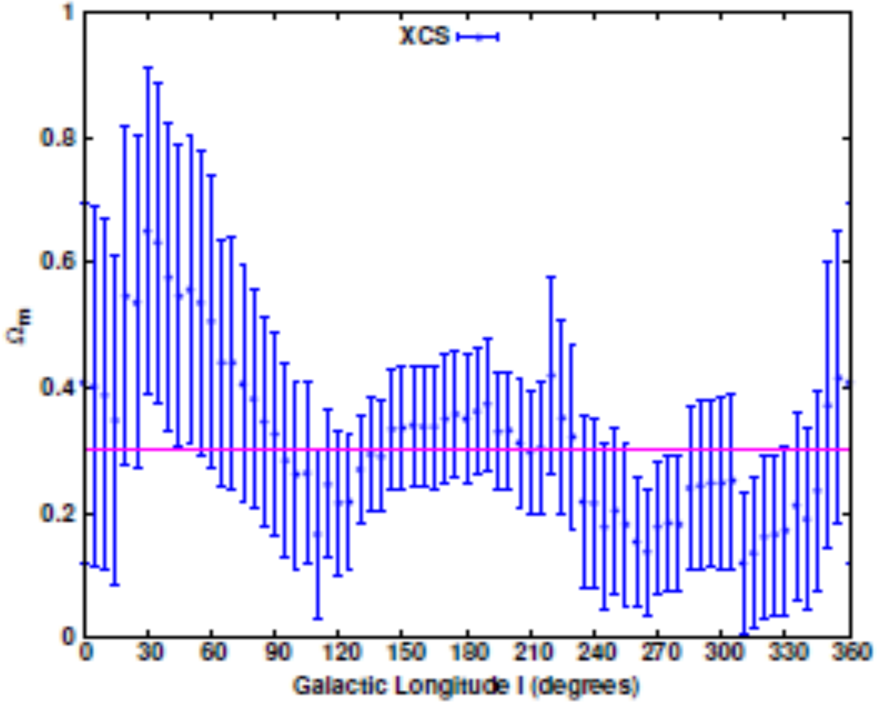
- "Scanning" of the sky → calculate a, H_0, Ω_m everywhere!



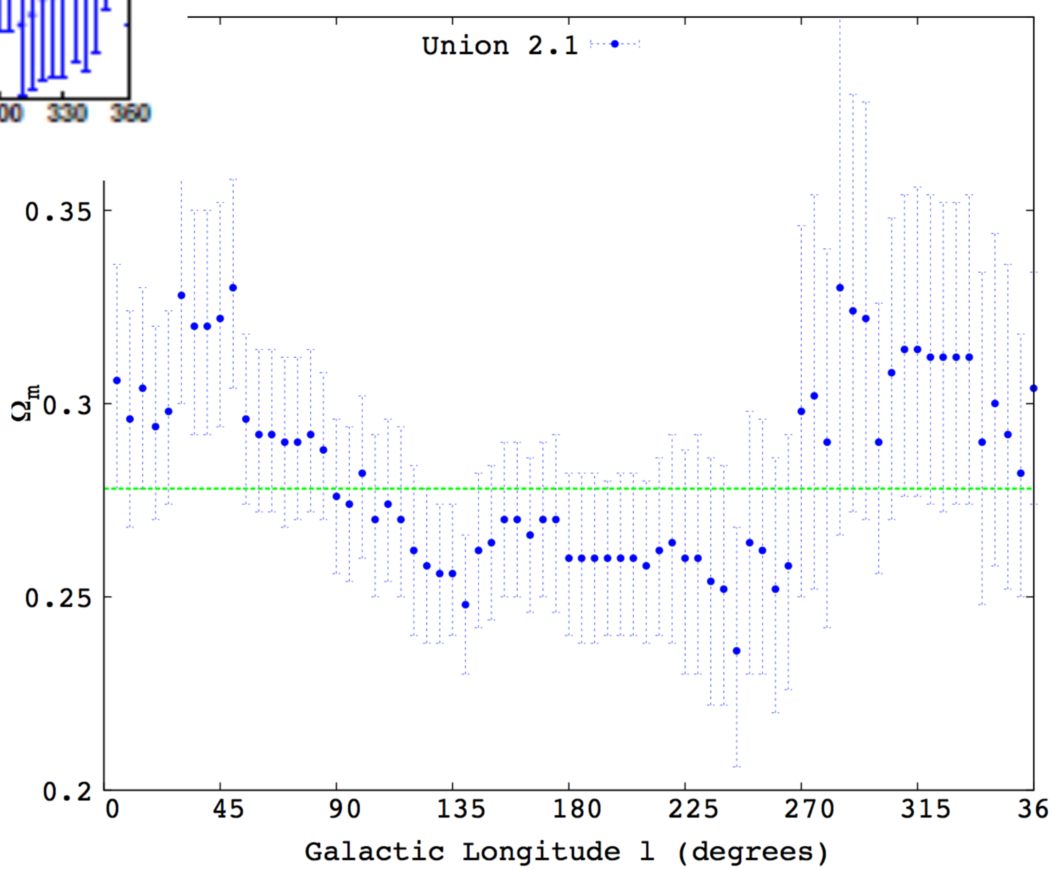



eeHIFLUGCS
Normalization a
Galactic Longitude l (degrees)
1.4
1.3
1.2
1.1
1
0.9
0.8
0
30
60
90
120
150
180
210
240
270
300
330
360

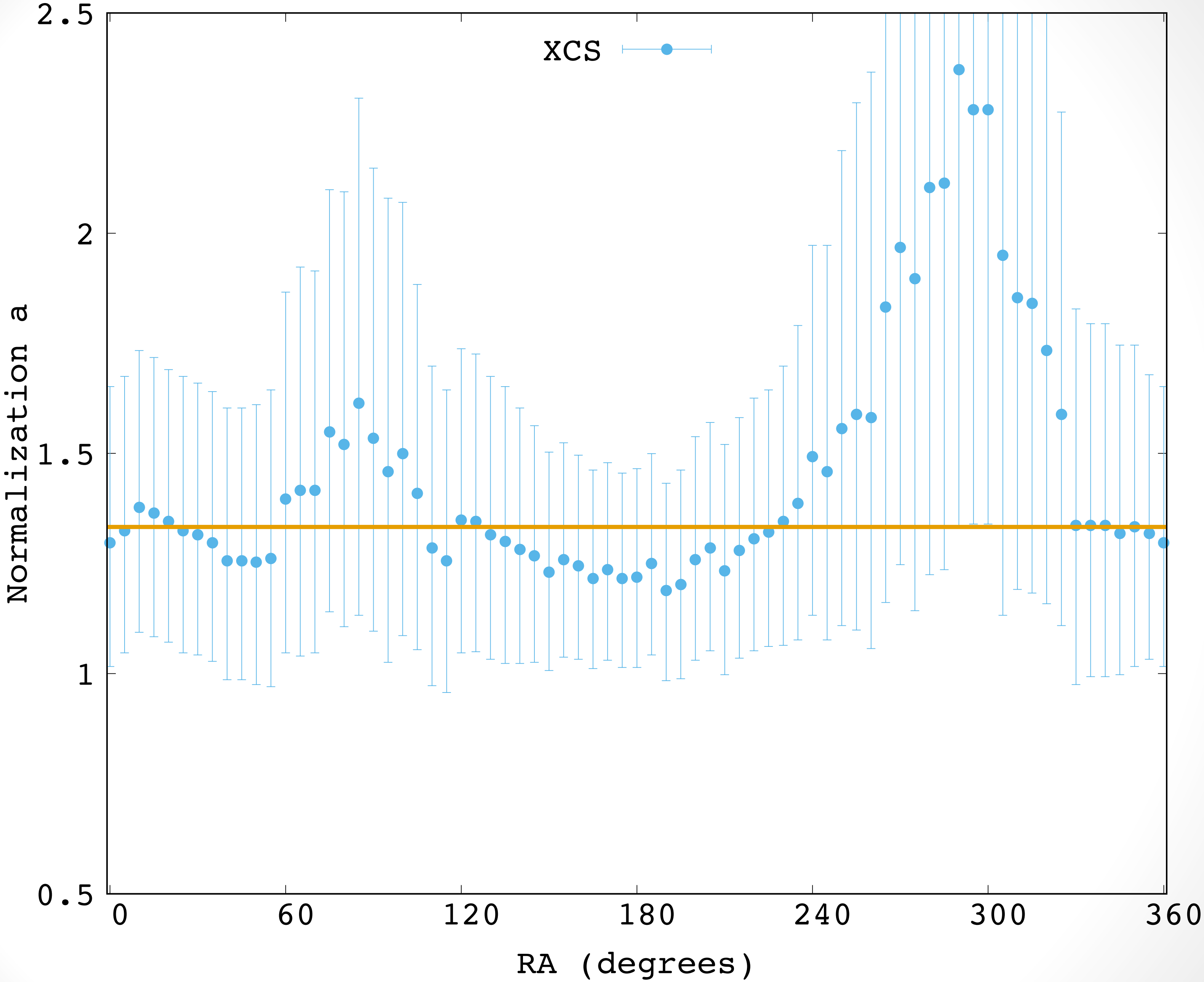

Full sample
Intrinsic scatter
Intrinsic logL_X scatter
Gal. long. l
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0
30
60
90
120
150
180
210
240
270
300
330
360



XCS
Ω_m
0
0.2
0.4
0.6
0.8
1
0 30 60 90 120 150 180 210 240 270 300 330 360
Galactic Longitude l (degrees)



Union 2.1
Ω_m
0.2
0.25
0.3
0.35
0 45 90 135 180 225 270 315 360
Galactic Longitude l (degrees)


XCS
Normalization a
RA (degrees)
2.5
2
1.5
1
0.5
0
60
120
180
240
300
360