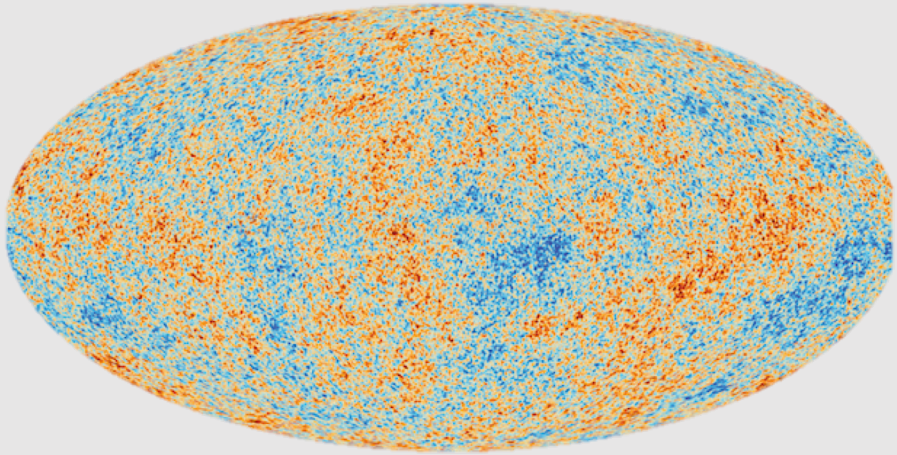
Challenging the isotropy of the local Universe with galaxy clusters

Konstantinos Migkas + eROSITA collaboration

Tensions in Cosmology – Corfu, Sept 2022

Cosmological Principle

Evidence for isotropy? Mostly Cosmic Microwave Background (CMB)



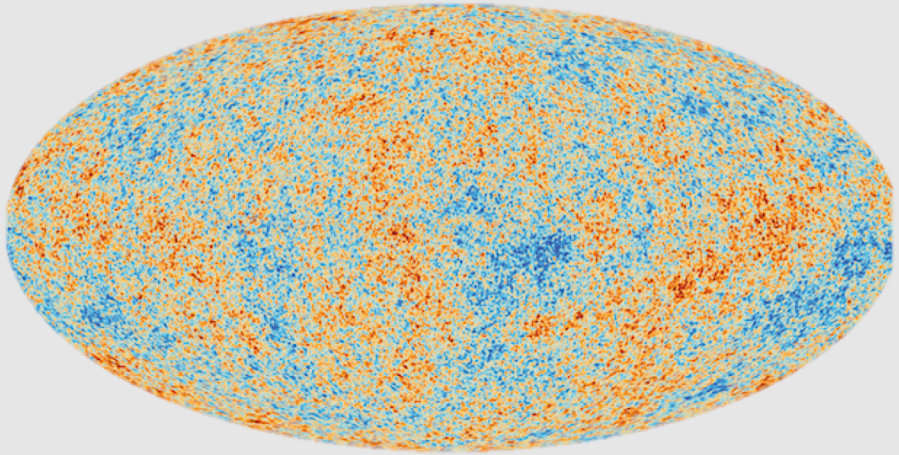
Planck Collaboration 2013

Defines CMB (radiation) rest frame in early Universe!

Is this the late-Universe matter rest frame..?

Cosmological Principle

Evidence for isotropy? Mostly Cosmic Microwave Background (CMB)



Planck Collaboration 2013

We should test observationally!

Galaxy Clusters

Cosmo-dependent cluster measurements

	Luminosity	Gas mass	isophotal radius
X-ray:	$L_{\rm X} \propto H_0^{-2}$	$M_{\rm gas} \propto H_0^{-1}$	$R_{50\%} \propto H_0^{-1}$

Total gas thermal energy

Microwave: $Y_{\rm SZ} \propto H_0^{-2}$

Biggest galaxy luminosity

Infrared: $L_{\rm gal} \propto H_0^{-2}$

Observable + redshift → assume $\rm H_0$, etc. to get distance → **Cluster property**

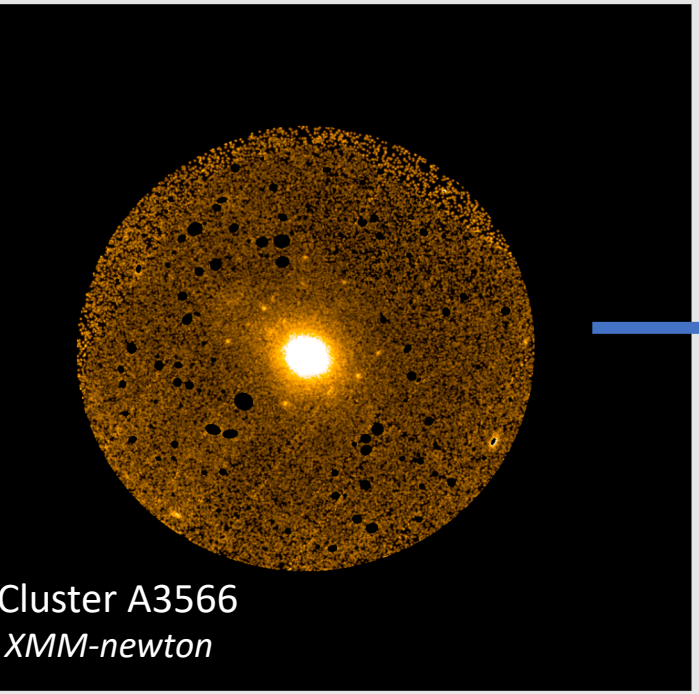
Cosmology-dependent!

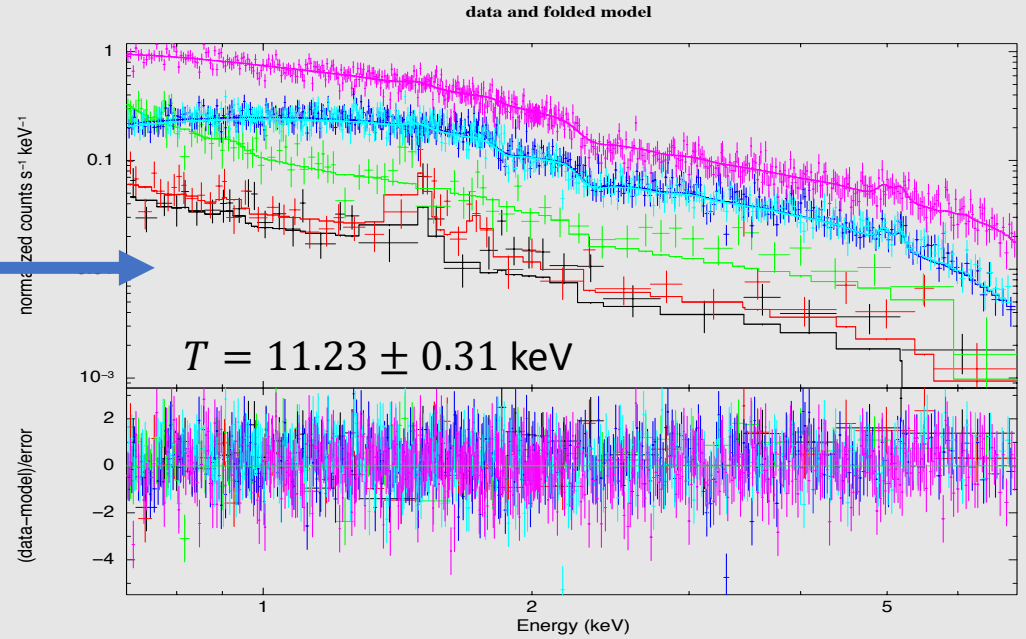
Cluster X-ray **temperature**

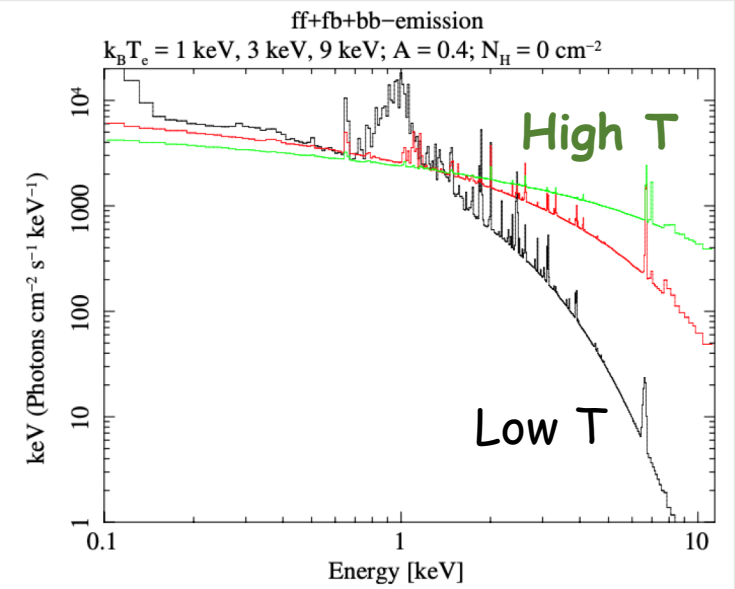
is the **key measurement**

for testing cosmic isotropy!

Galaxy clusters in X-rays

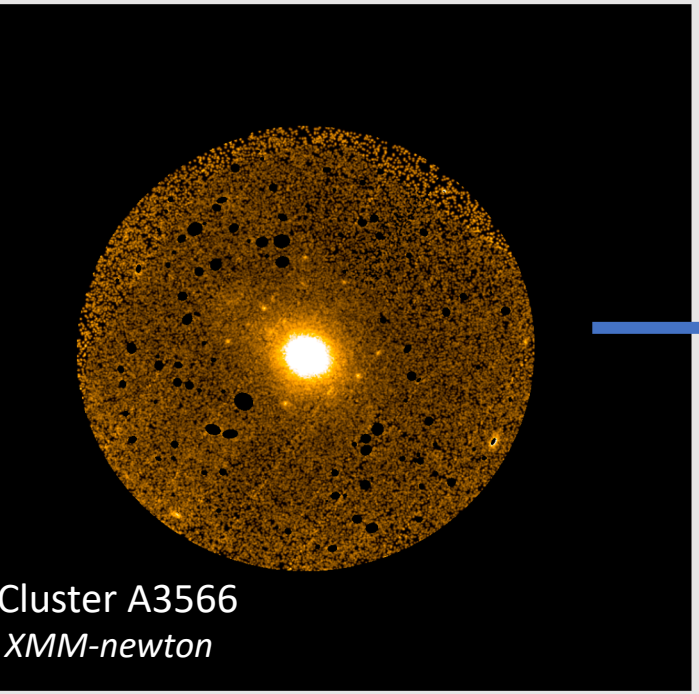


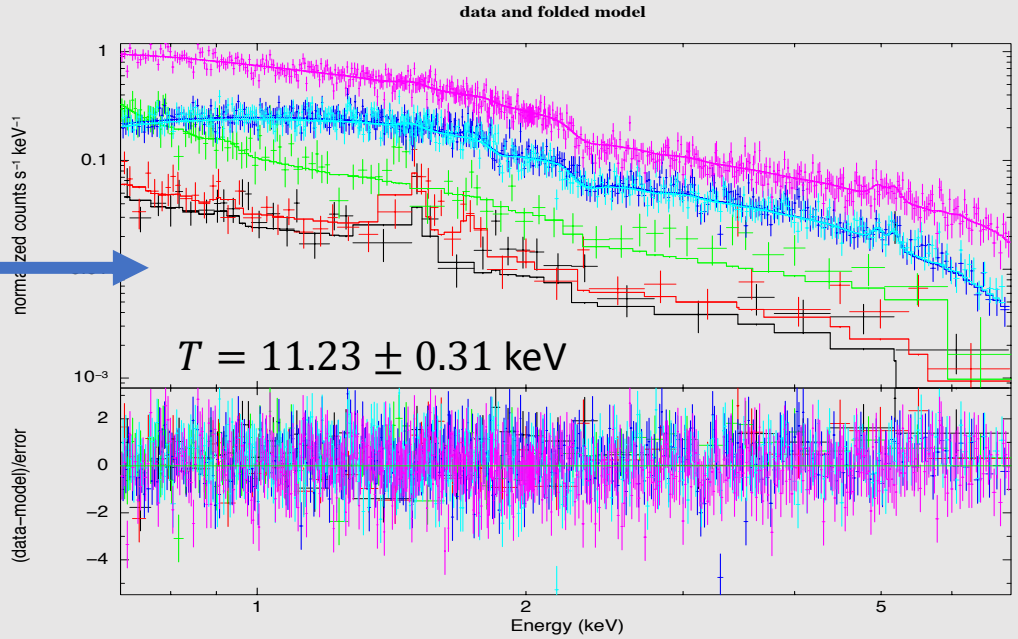




- Extract spectrum of cluster
- **Measure temperature** via fitted models

Galaxy clusters in X-rays





T determination: cosmology-independent!

Constrain isotropy with scaling relation

$$L_{\rm X} E(z)^{-1} \propto T^{B_{LT}}$$

$$Y_{\rm SZ} E(z) \propto T^{B_{YT}}$$

$$\propto \mathrm{distance}(H_0, z)^2$$

Strong cosmology and bulk flow dependence!

Measure T → Predict left part

cosmology-independent!

Constrain isotropy with scaling relation

$$L_{\rm X} E(z)^{-1} \propto T^{B_{LT}}$$

$$Y_{\rm SZ} E(z) \propto T^{B_{YT}}$$

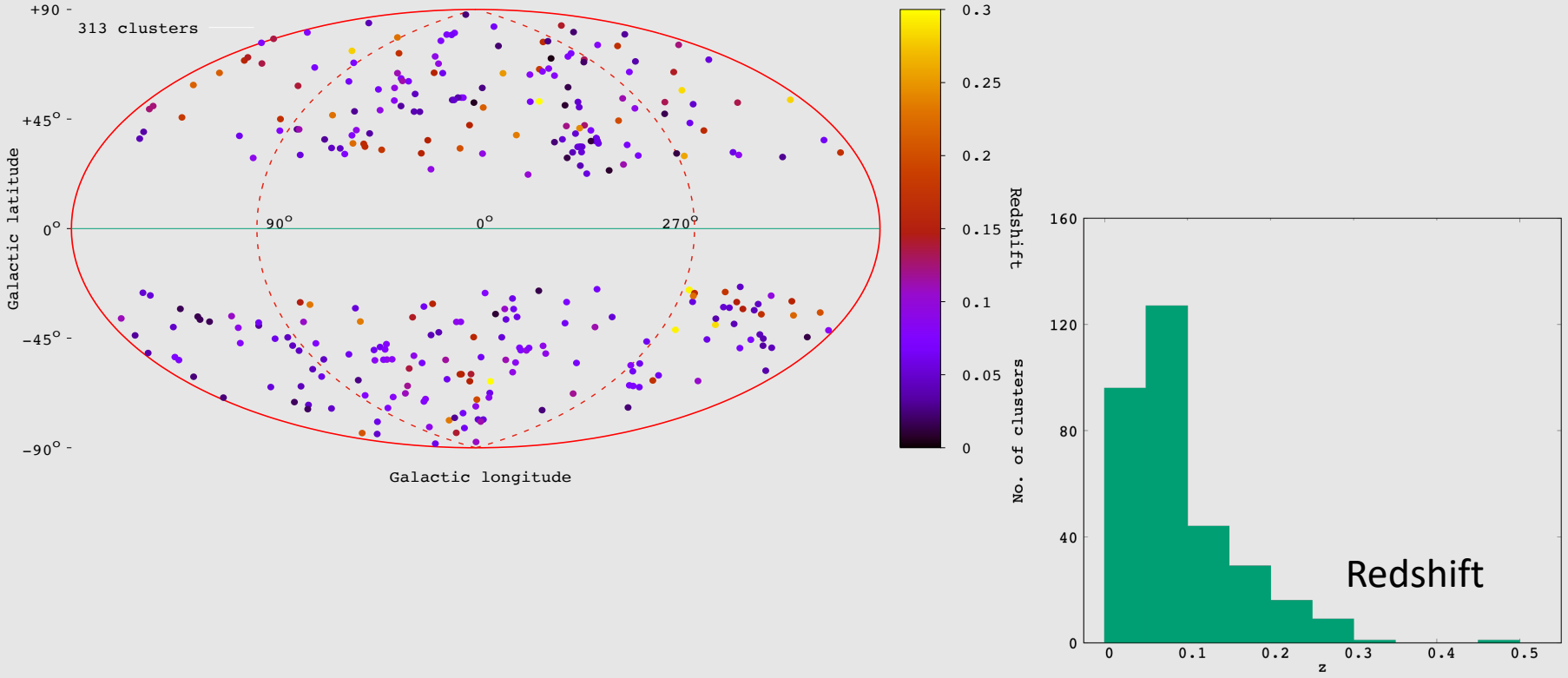
cosmology!

no cosmology!

- Scan the sky with a cone, constrain relations for each cone separately → all-sky color map

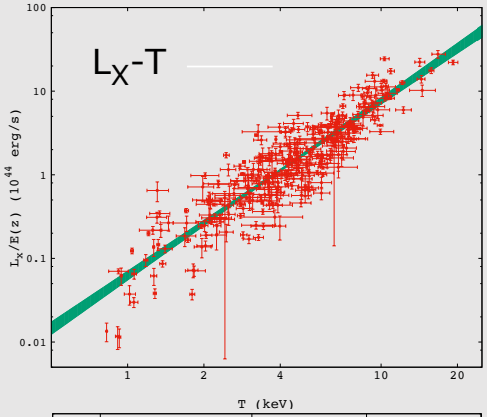
- **Quantify apparent H_0 variation and bulk flows**

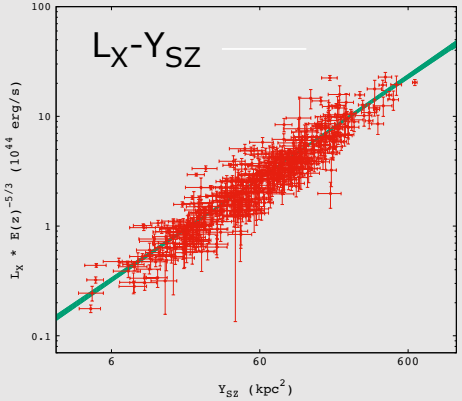
eeHIFLUGCS sample (Migkas+20;21)

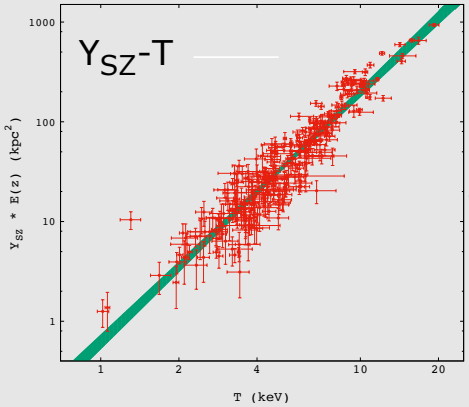


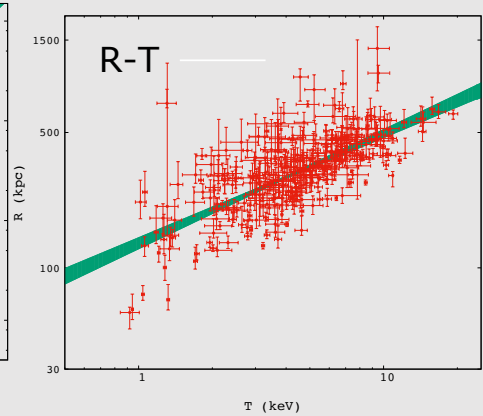
- Homogeneously selected, **~400** brightest **X-ray clusters**, mostly $z < 0.25$
- Measure **X-ray L_X**, **T** and **$R_{50\%}$** **(XMM, Chandra, Rosat)**
- Measure **microwave Y_{SZ} (Planck)** and **infrared L_{BCG} (2MASS)**

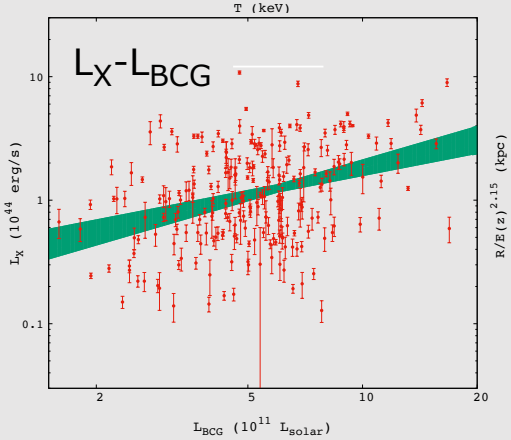
10 multiwavelength cluster scaling relations!

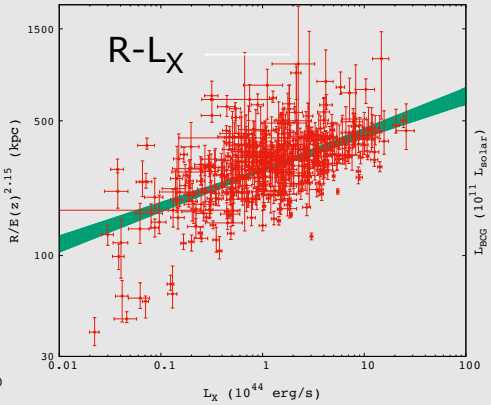


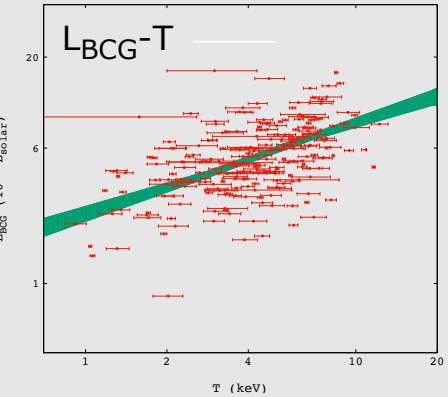


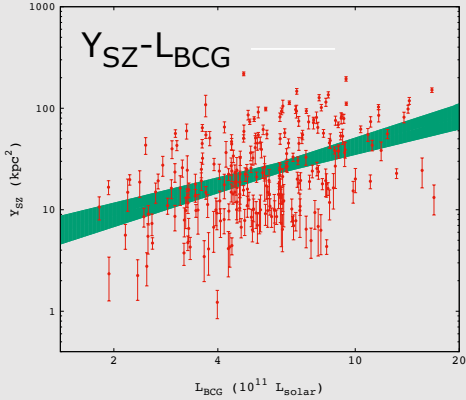


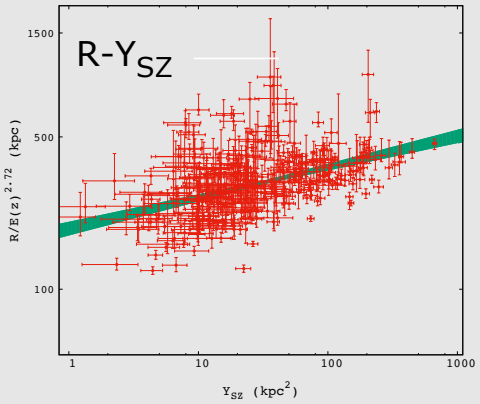


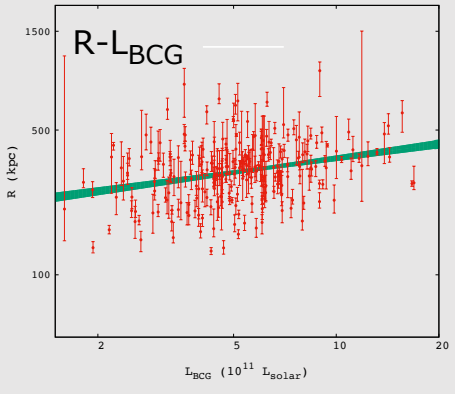








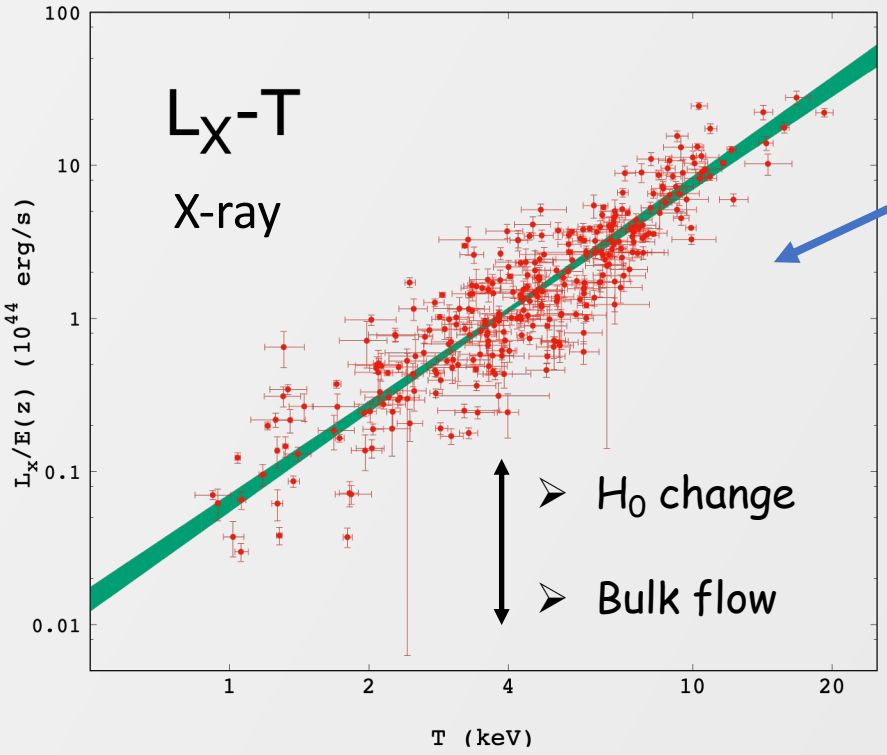




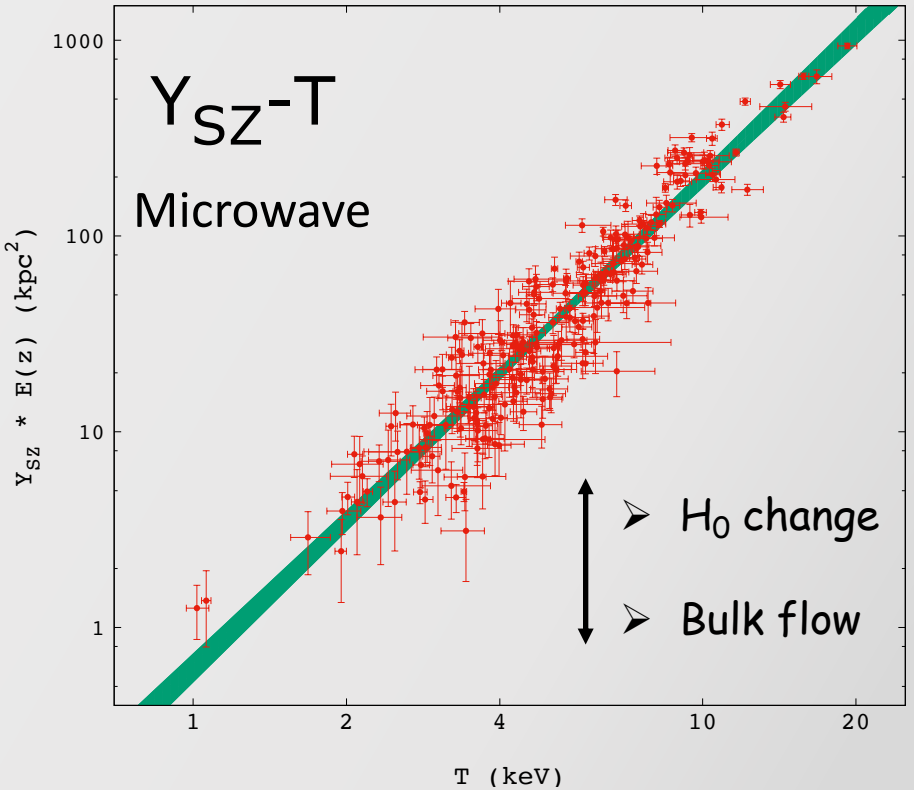
- Information for cosmology, systematics, cluster physics

Migkas+21

The $L_X - T$ and $Y_{SZ} - T$ relations…

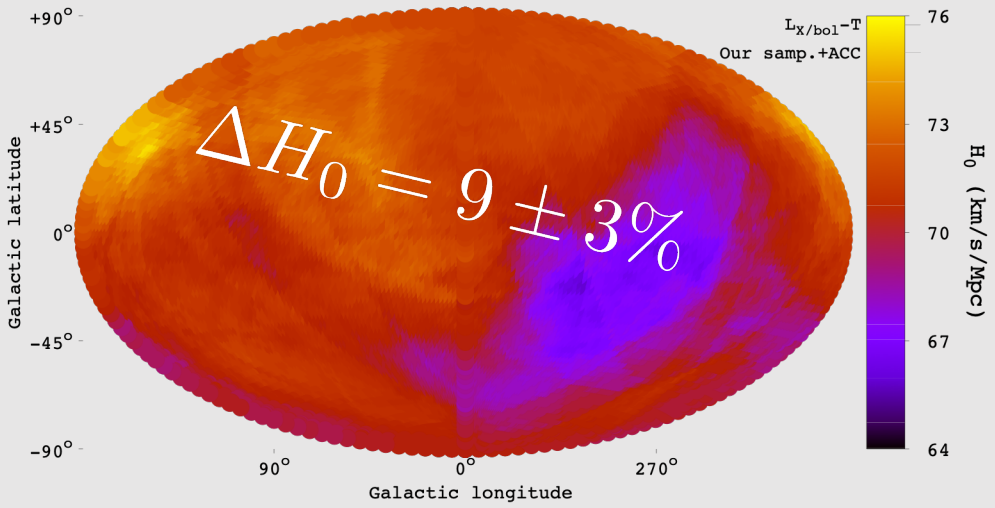


"Tully-Fisher" of clusters



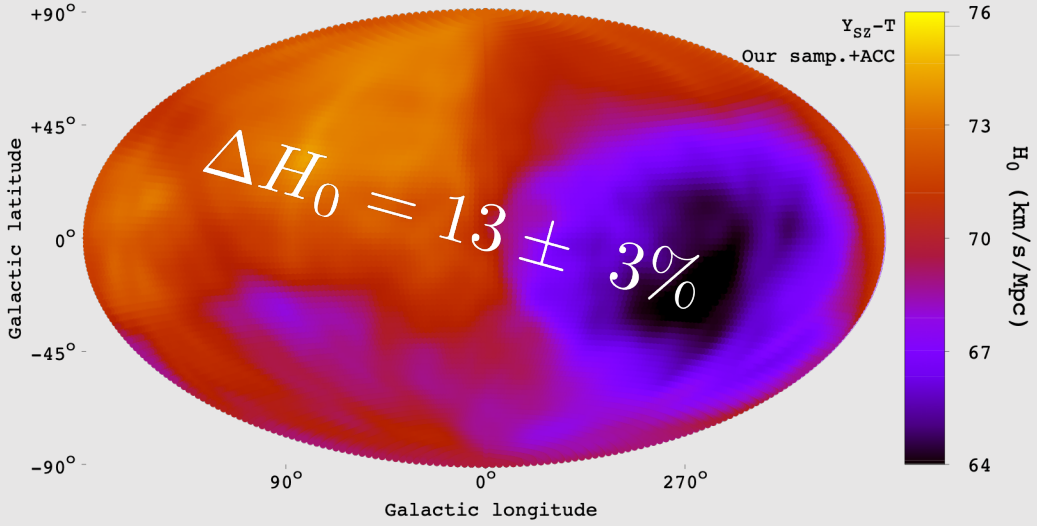
Apparent H_0 variation

$L_X - T$ 3σ



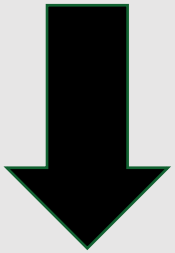
Jointly analyzing all available, all-sky, independent cluster samples at z<0.3

$Y_{SZ} - T$ 4.3σ



Nearly independent results..! (X-ray and microwave)

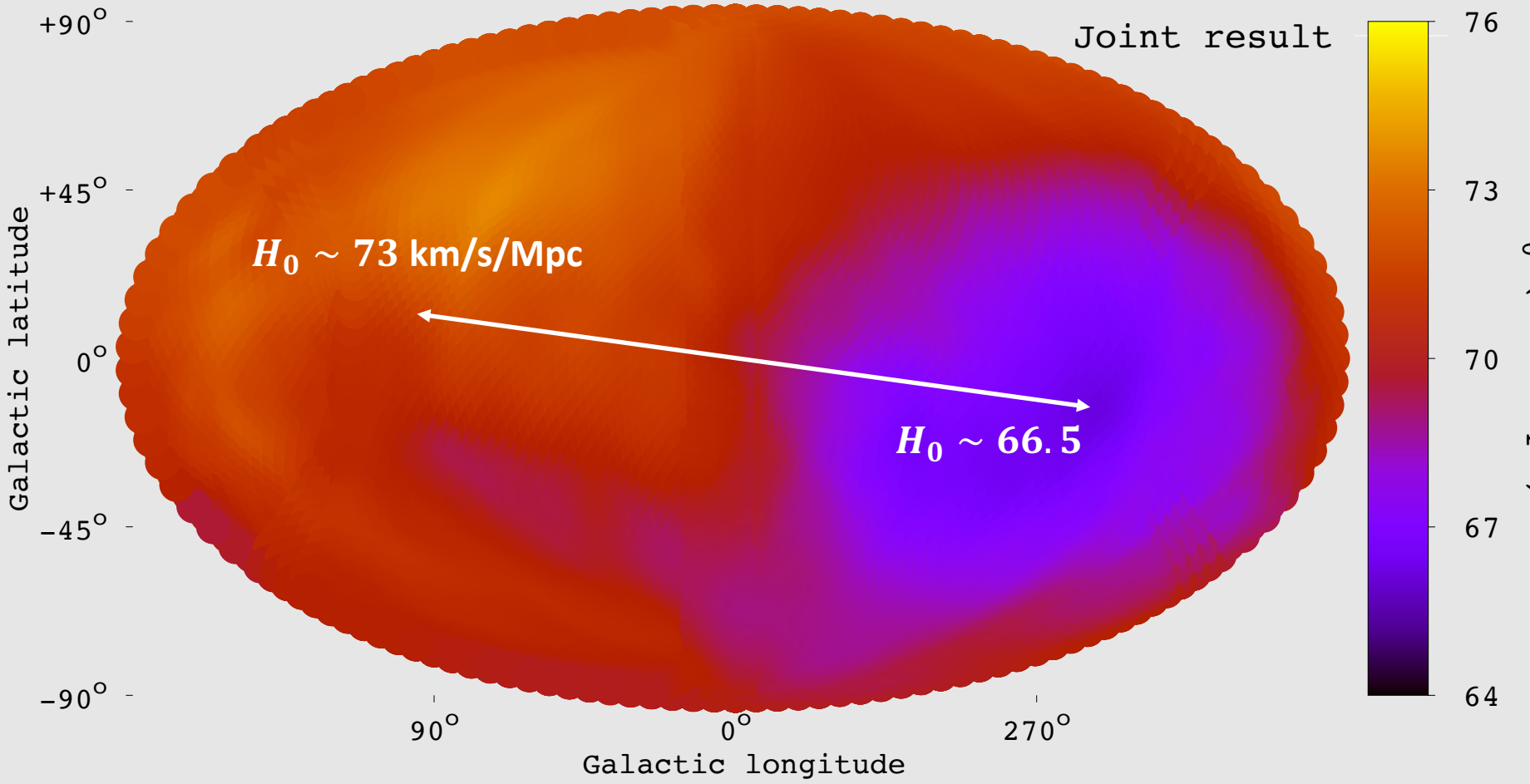
Combining all X-ray, microwave, and infrared cluster info with in-depth, exhaustive analysis…



First-ever multiwavelength H_0 anisotropy map!

Overall result: 5.4σ! (from Monte Carlo)

Migkas et al. 2021, A&A, 649, A151



Most robust detection of late-Universe anisotropy ever!

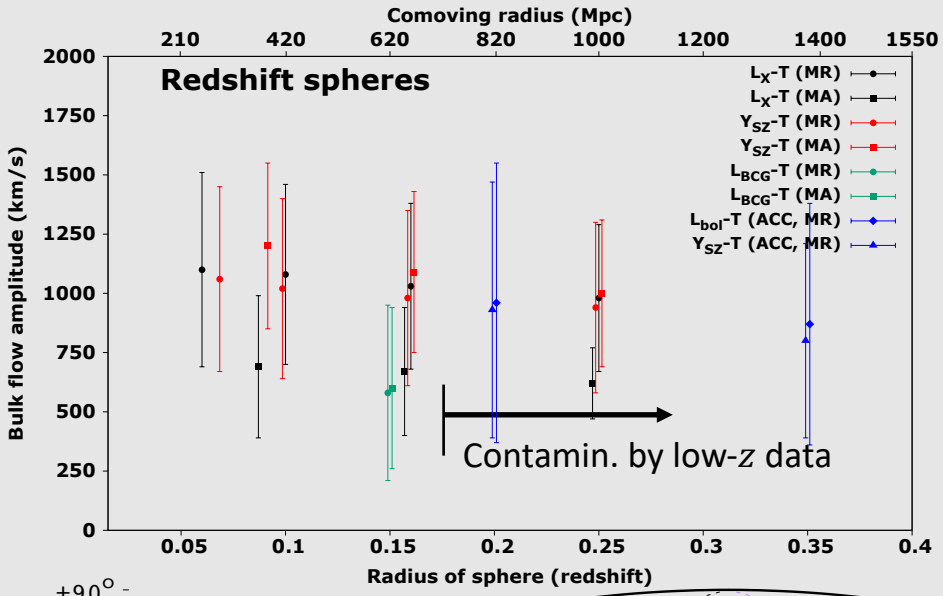
$$(l, b) = (273^{\circ}{}^{+42^{\circ}}_{-38^{\circ}}, -11^{\circ}{}^{+27^{\circ}}_{-27^{\circ}})$$

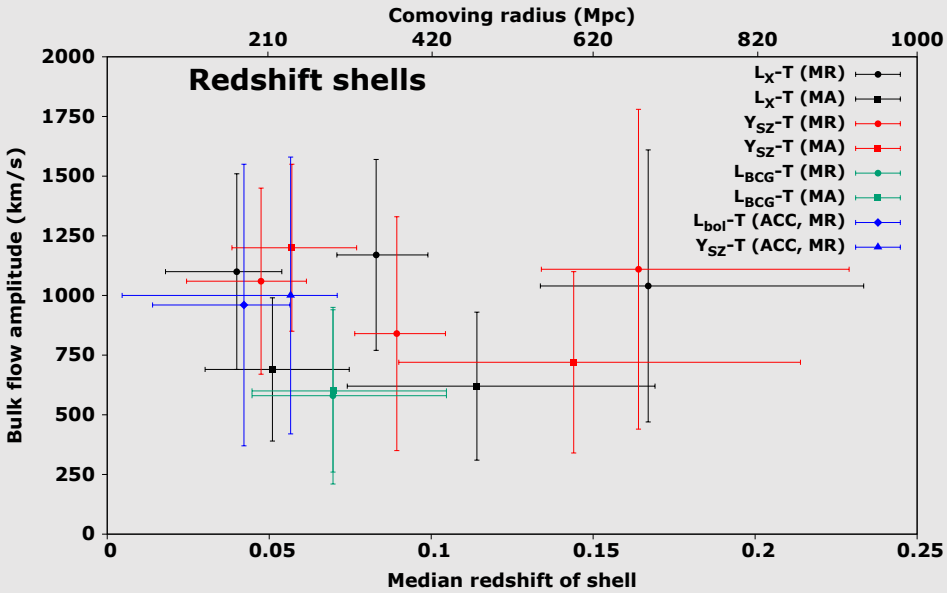
What if true H_0 = isotropic?

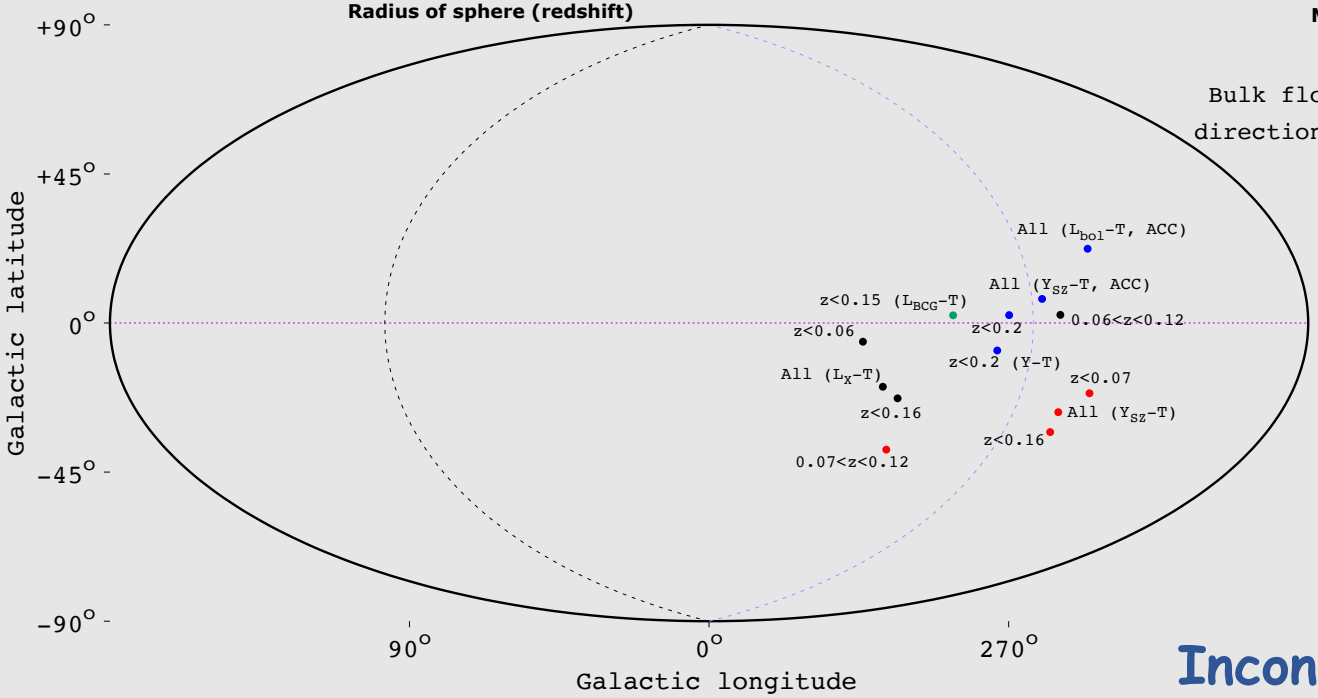
Then, we need a large bulk flow...

First-ever bulk flow constraints from cluster scaling relation..!

Cluster bulk flows







~ 900 km/s BF

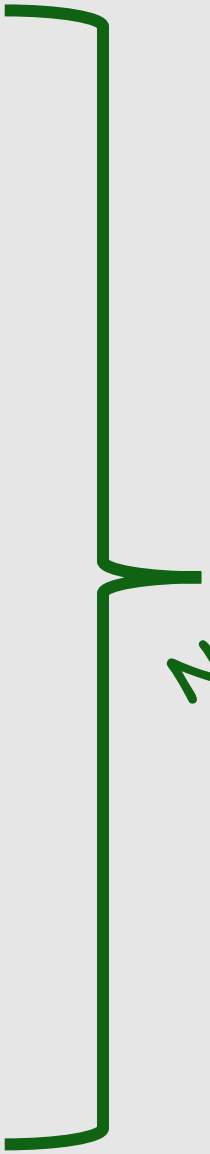
up to 500 Mpc

$(z \sim 0.12)$

Inconsistent with ΛCDM!

Numerous tested systematics

- Cluster morphology effects
- Malmquist bias
- Zone of Avoidance bias
- Different selection cuts
- Scatter correlation of $L_{\rm X}, Y_{\rm SZ}$
- MCMC for any cluster properties correlation
- X-ray temperature calibration
- Redshift evolution
- Several other tests



No explanation for the anisotropies!

Finally, eROSITA..!

Credit: MPE, Garching

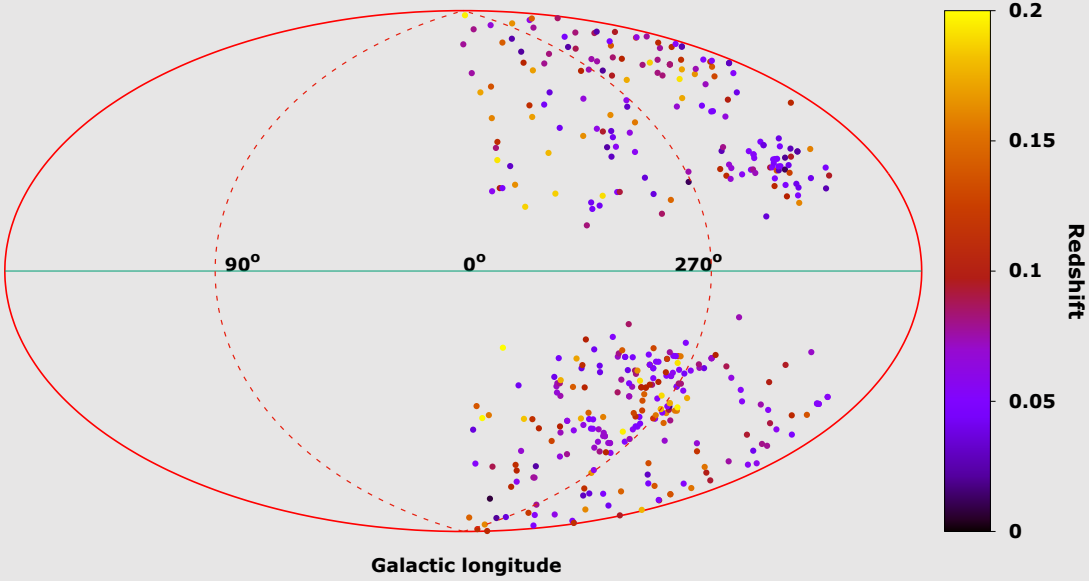
- First X-ray all-sky survey in 30 years
- $\sim 10^4$ of new galaxy clusters eventually!
- One sky half for Germany, one for Russia
- eRASS1 data ($1/8^{th}$ of final data) fully available

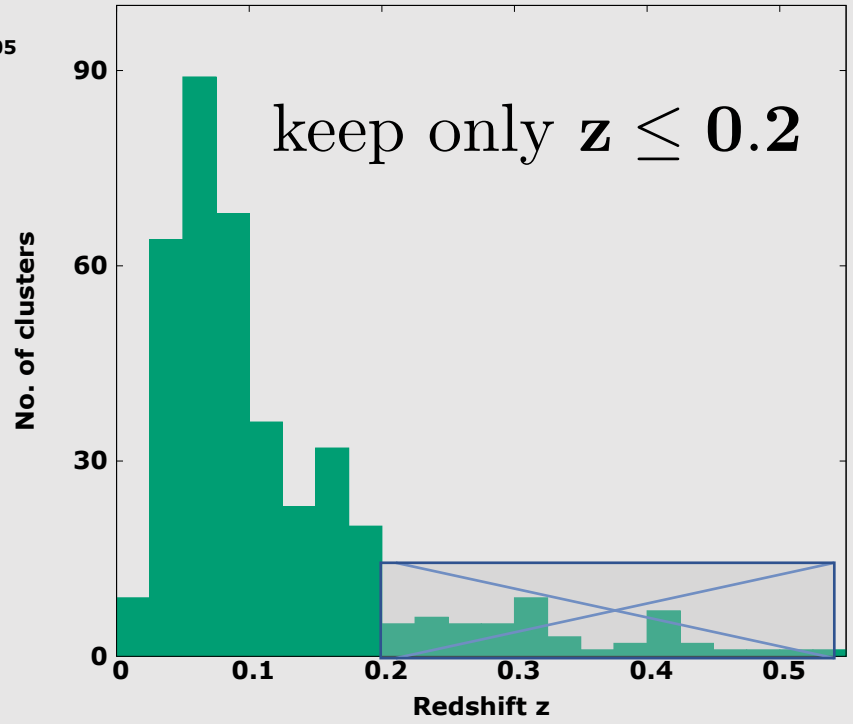
Merloni+12, Predehl+21

First-ever results on isotropy from eROSITA...

eROSITA

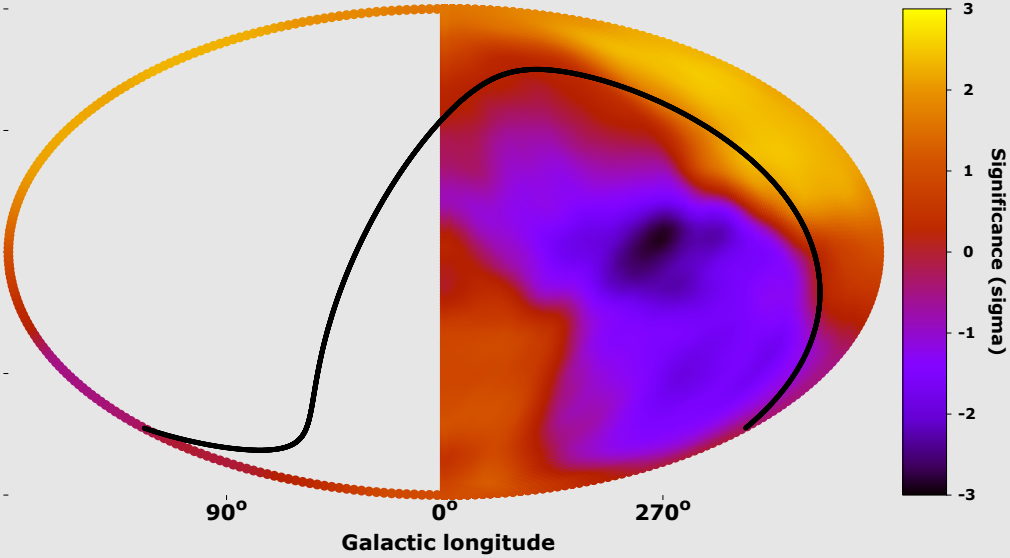
- **341 clusters at z<0.2** with spec-z and reliable T





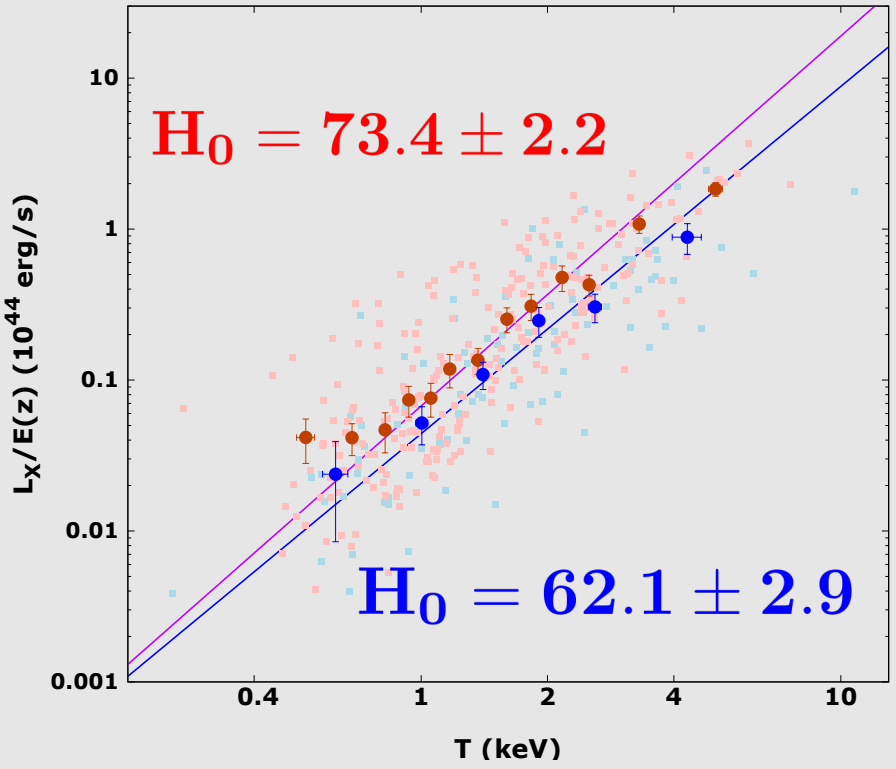
eROSITA: L_X-T + M_{gas}-T

- Same anisotropy direction as in eeHIFLUGCS at z<0.2!
- Slightly stronger variation (16.1 ± 6.4% instead of 9.0 ± 1.7%)



3.1σ

$(l, b) \sim (274°, +6°)$



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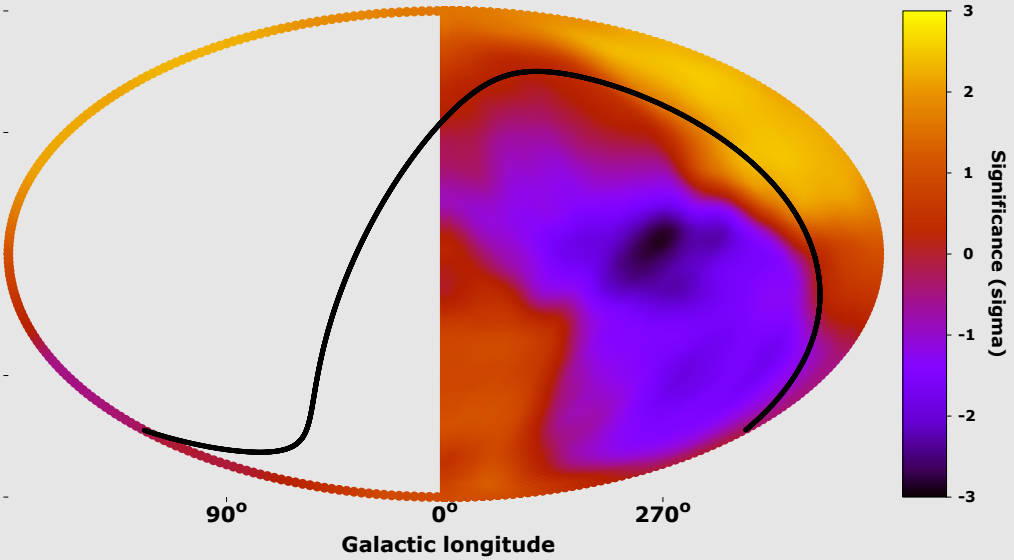


3.1σ

$(l, b) \sim (274^\circ, +6^\circ)$

Or, similar bulk flow as before!

970 ± 310 km/s

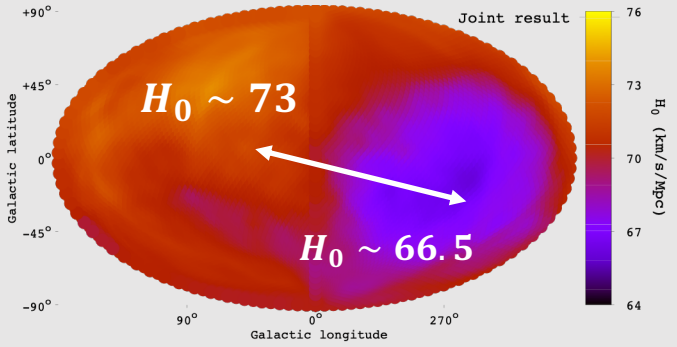
up to z<0.15..!

Take-home message

The cluster anisotropies are there at z<0.2….

- A completely unknown new systematic affecting all cluster samples and multiwavelength relations…?

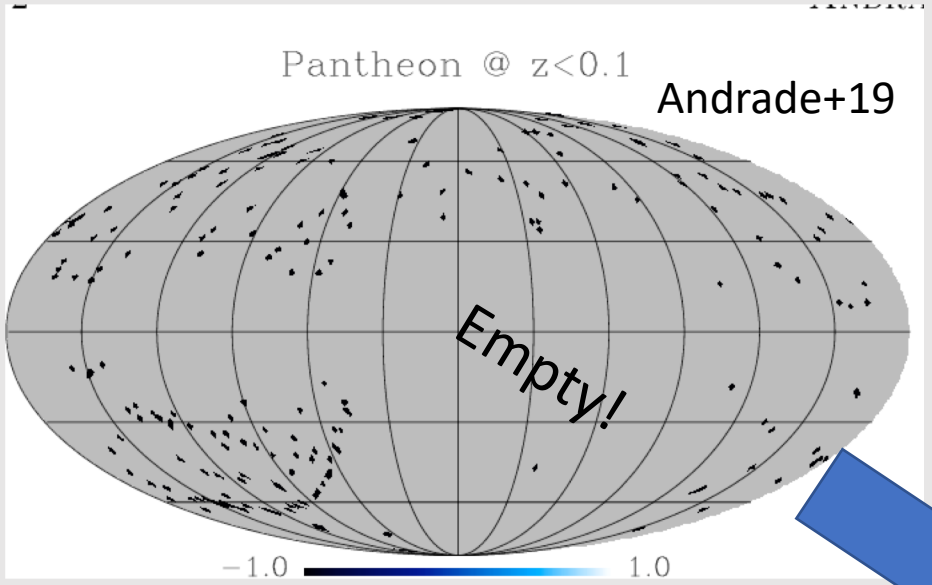
- … or is the **local Universe more complicated** that we thought up to now, with **huge implications for low-z cosmology..?**

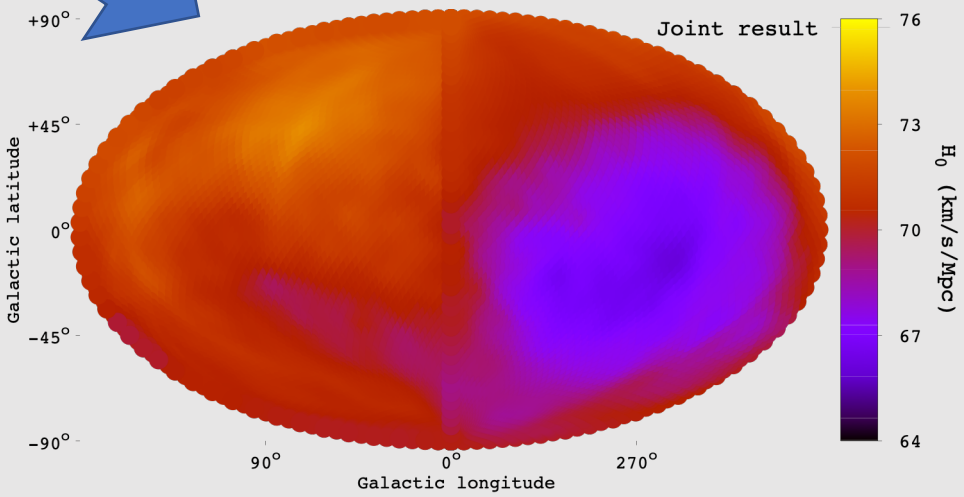


Thank you!

Back up slides

Non-uniform SNIa sky distribution





Publications about this project

➢ **Migkas et al. 2020, A&A, 636, A15**

A&A 636, A15 (2020)
https://doi.org/10.1051/0004-6361/201936602

Astronomy & Astrophysics

Probing cosmic isotropy with a new X-ray galaxy cluster sample through the L_X–T scaling relation

K. Migkas[1], G. Schellenberger[2], T. H. Reiprich[1], F. Pacaud[1], M. E. Ramos-Ceja[1], and L. Lovisari[2]

\+ Work in progress

➢ **Migkas et al. 2021, A&A, 649, A151**

A&A 649, A151 (2021)
https://doi.org/10.1051/0004-6361/202140296

Astronomy & Astrophysics

Cosmological implications of the anisotropy of ten galaxy cluster scaling relations

K. Migkas[1], F. Pacaud[1], G. Schellenberger[2], J. Erler[1,3], N. T. Nguyen-Dang[4], T. H. Reiprich[1], M. E. Ramos-Ceja[5], and L. Lovisari[2,6]

Other late-Universe probes also point to a dipole anisotropy (eg Secrest+22, Singal+21, etc)

The evidence to be reviewed here is that the dipole anisotropy in the distribution of objects at distances comparable to the Hubble length is about in the direction expected from the kinematic effect if the dipole anisotropy in the CMB is due to our motion relative to the rest frame defined by the mean mass distribution, but the dipole amplitude is at least twice the prediction. This anomaly is about as well established as the Hubble Tension, yet the literature on the kinematic effect is much smaller than the 344 papers with the phrase "Hubble Tension" in the abstract in the SAO/NASA Astrophysics Data System. (I expect the difference is an inevitable consequence of the way we behave.) To illustrate this difference I offer my attempt at

Peebles (2022)