Confirmation of NIKA2 investigation of the Sunyaev-Zel'dovich effect by using synthetic clusters of galaxies

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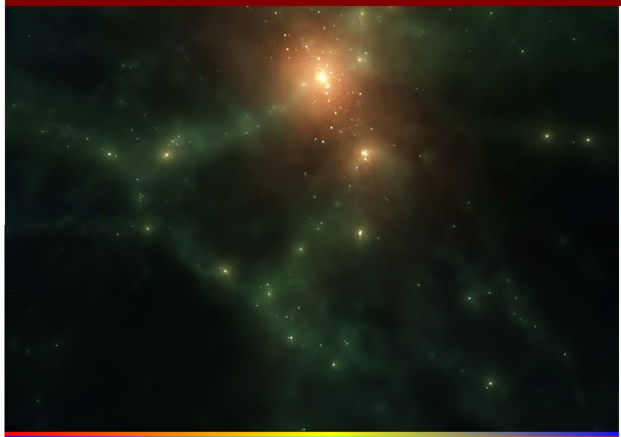


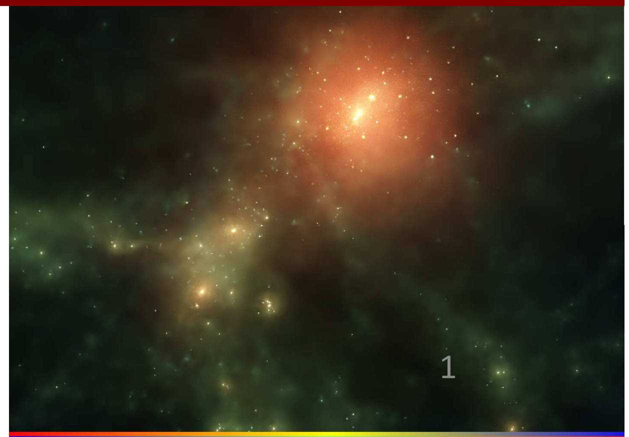

Outline

- NIKA2 tSZ Large Program
- MUSIC-2 dataset
- y-maps morphology and dynamical state
- NIKA2 simulated observations (+Planck)
- Radial gas pressure profiles
- Conclusions

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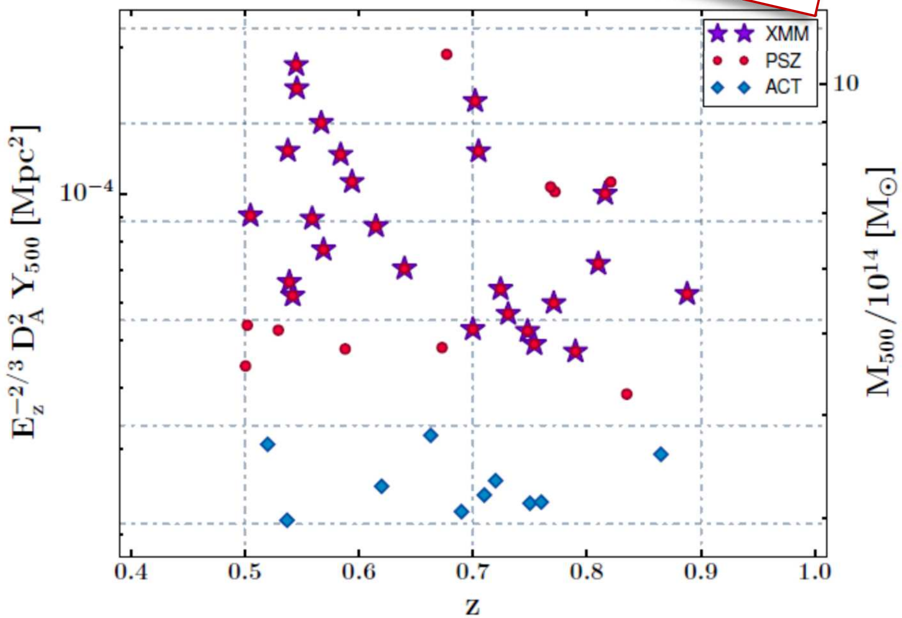
NIKA2 tSZ Large Program

see Frederic's talk

The NIKA2 tSZ Large Program consists in mapping the tSZ signal of a representative sample of **45 galaxy clusters** (selected from Planck & ACT catalogues) in the range **0.5 < z < 0.9** at high angular resolution (<20"). 19 clusters already observed.



… enjoying X-ray data from follow-up observations by the XMM-Newton and optical info

Among the several goals of the NIKA2 SZLP
- characterization of the mean ICM pressure profile properties and of systematic uncertainties associated to departures from a simple model of objects in hydrostatic equilibrium in a high redshift range to possibly ensure

unbiased cosmological results

see Florian_R's talk

Hydrodynamical simulations seem to be a valuable tool as a test-bed for this purpose.

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MUSIC-2 dataset

MUSIC-2 : resimulated clusters from MultiDark Simulation, a Dark-Matter only N-body simulation with 9 billion particles (2048^3 dark matter) in a 1 h^{-1} Gpc cube [Prada et al. 2012]

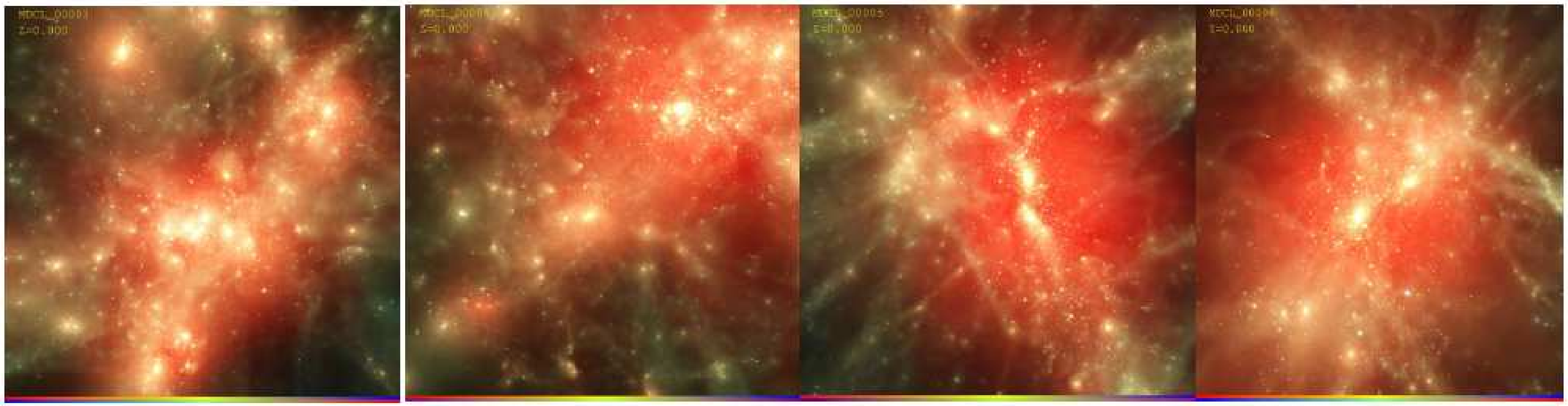
>500 clusters $M>10^{14}h^{-1}M_\odot$

>2000 clusters $M>10^{13}h^{-1}M_\odot$

see Gustavo's talk

MUltidark SImulations of galaxy Clusters

with radiative physics (CSF, *i.e.* with cooling + SFR + UV photoionization + SN feedbacks), non radiative (NR) and AGN.



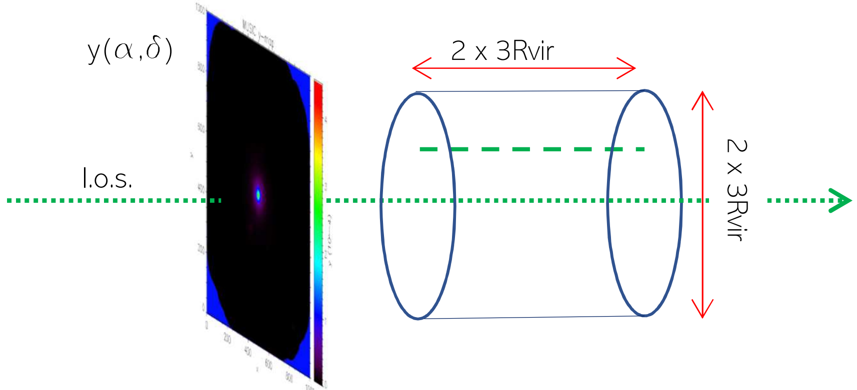
4 clusters with radiative physics (CSF) at z=0

The same object with radiative (CSF) and non radiative (NR) physics at z=0

MUSIC-2 dataset

The steps to generate the NIKA2 SZLP "TWIN SAMPLE"

1) 283 massive (M_{vir}>$10^{15}\,h^{-1}M_{\odot}$ @ z=0) MUSIC-2 clusters at redshifts 0.54 and 0.82 (z-range similar to NIKA2 SZLP)



y-map size ~25x25 arcmin (> NIKA2 FOV 6.5')
pixel resolution 10kpc, *i.e.* 1÷2'' (< NIKA2 150GHz res 18'')

2) Compton parameter maps (y-maps)

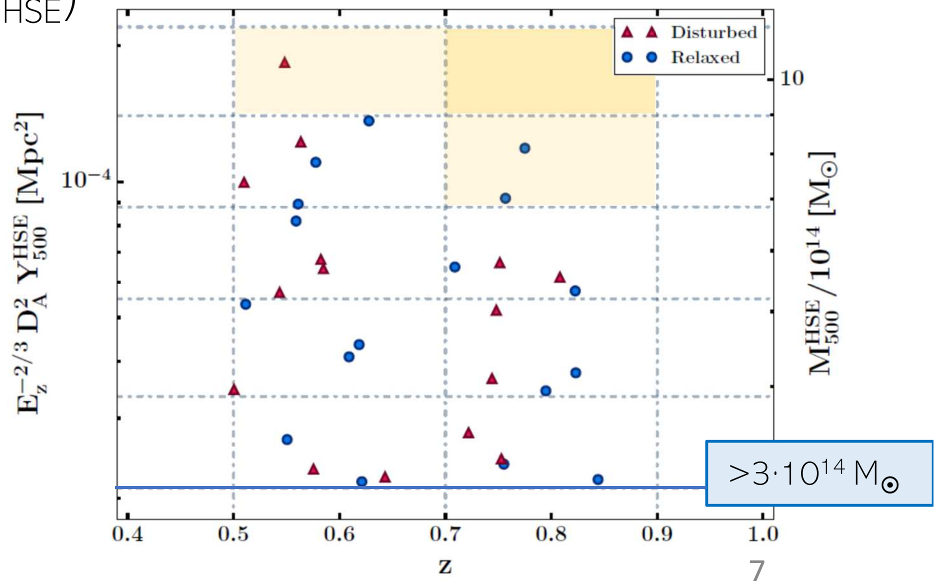
$$y \simeq \frac{k_B \sigma_T}{m_e c^2} \sum_i n_{e,i} T_{e,i} W_p(|\, \boldsymbol{r}_i - \boldsymbol{r}_{com} \,|, h_i)\, \ell_i$$

3) ICM + DM radial profiles

4) Integrated quantities @R_{500} (M, M_{HSE}, Y and Y_{HSE})

5) Selection of 32 MUSIC-2 clusters to populate the NIKA2 SZLP redshift-mass plane (10 bins)
(volume limited sample => a few high z&M objects)

6) MUSIC-2 additional information:
dynamical state objects segregation



[Ruppin et al. sub 2019]

MUSIC-2 dataset: pressure profiles

Pressure radial profiles from sims

$$M_{500}^{\rm true} = \frac{4}{3}\pi R_{500}^3 \times 500\rho_c$$

$$P_{500}^{\rm true} = 1.65 \times 10^{-3}\, E_z^{8/3} \left[\frac{M_{500}^{\rm true}}{3\times 10^{14}\, h_{70}^{-1}\, {\rm M}_\odot}\right]^{2/3} h_{70}^2\ {\rm keV\,cm^{-3}}$$

[Arnaud et al. 2010]

true = derived from total matter density radial profiles

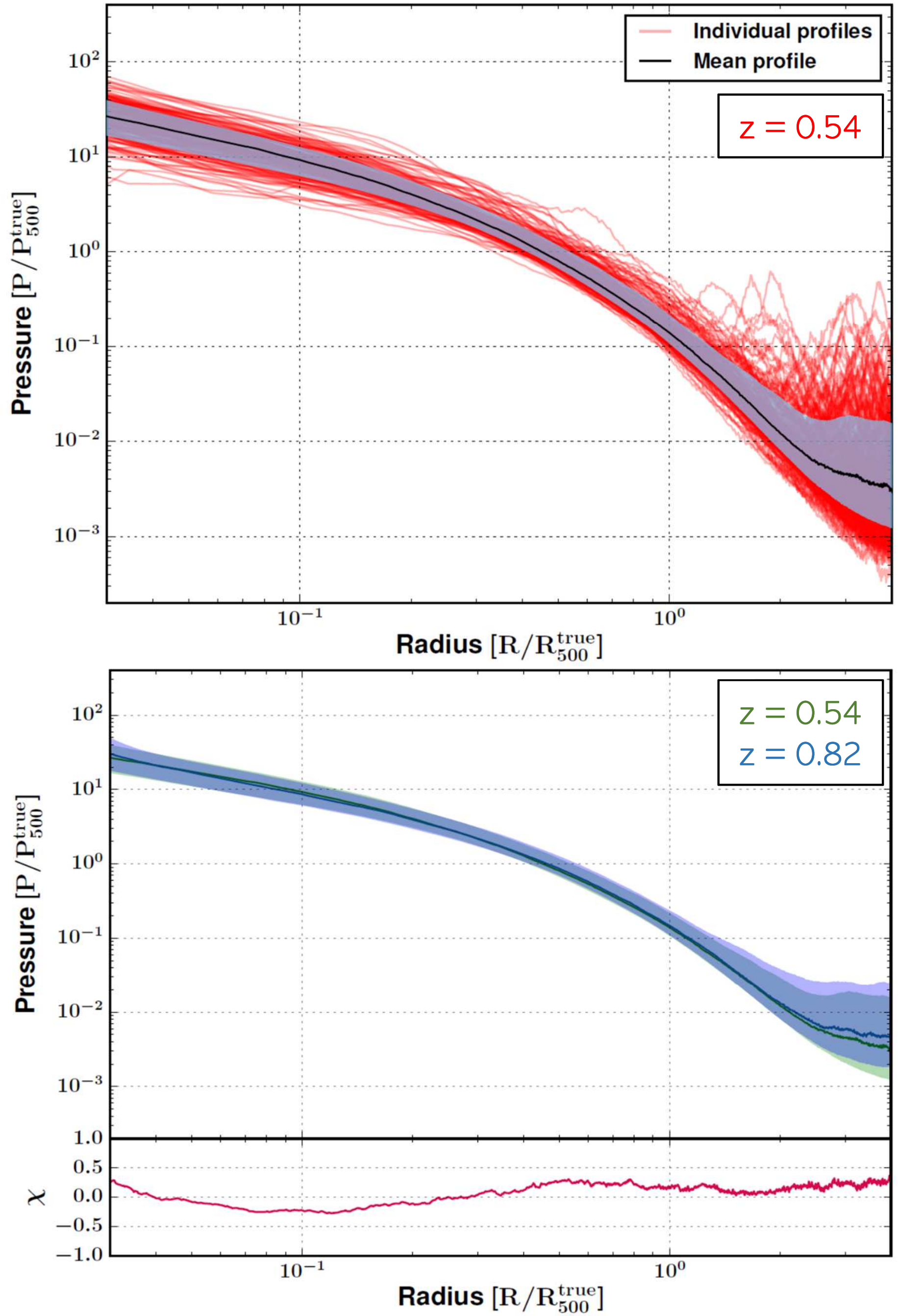
Main features

- Flattening for $R>2R_{500}$ (*splashback radius*)
- Increase of dispersion with radius

Possible explanations

- Deviations from gas dynamic equilibrium
- Accretion of surroundings environment
- Presence of substructures and gas shocks

No relevant differences between the mean pressure profiles at the two redshifts



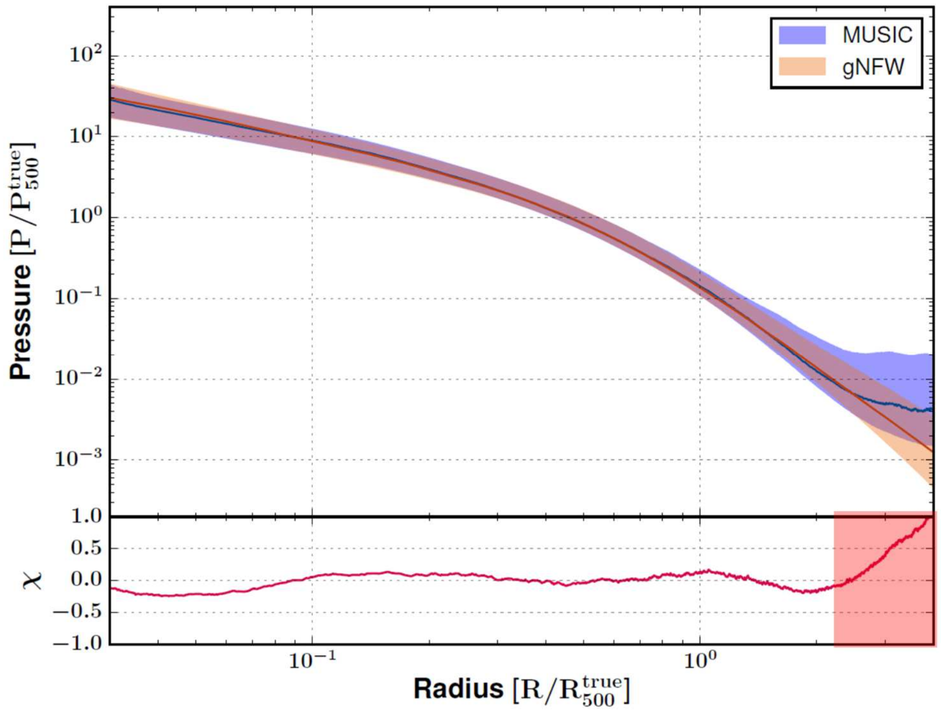
[Ruppin et al. sub 2019]

MUSIC-2 dataset: pressure profiles

gNFW profiles correctly model the pressure distribution of the MUSIC-2 clusters and so are suitable for a combined NIKA2/Planck analysis.

$$P_e(r) = \frac{P_0}{\left(\frac{r}{r_p}\right)^c \left(1 + \left(\frac{r}{r_p}\right)^a\right)^{\frac{b-c}{a}}}$$

The flattening of the pressure profiles at radii greater than $2R_{500}$, results in a systematic bias on the integrated Compton parameter Y_{5R500} of about 6% (lower than the typical relative uncertainty on the integrated tSZ flux measured by Planck).



[Ruppin et al. sub 2019]

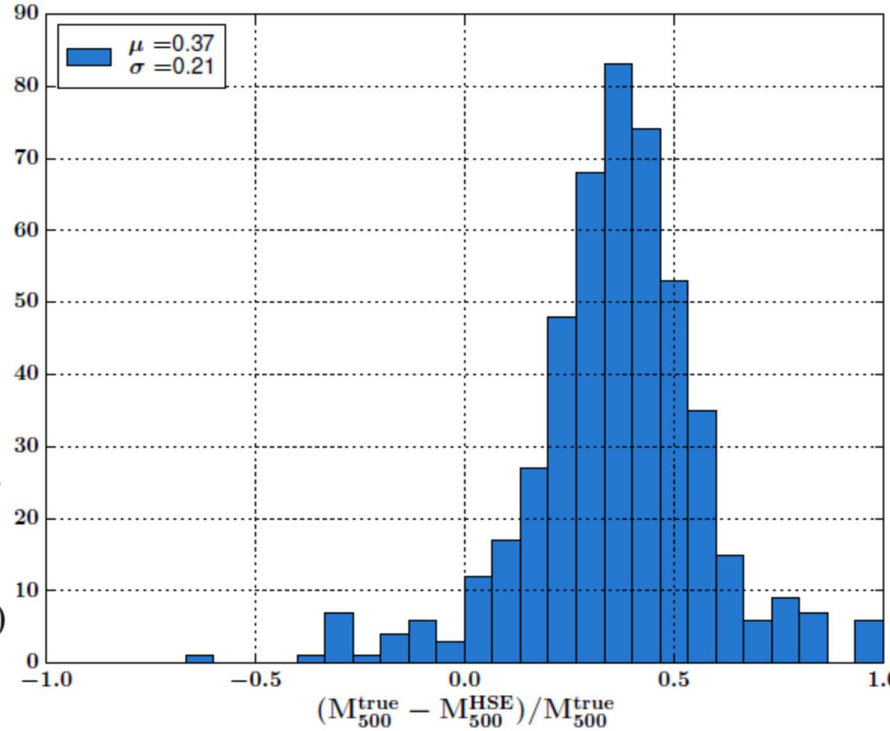
MUSIC-2 dataset: pressure profiles

Cluster total mass profile also derived with an observational approach, assuming the hydrostatic equilibrium (HSE)

$$\mathrm{M}^{\mathrm{HSE}}(r) = -\frac{r^2}{G\mu m_p n_e(r)} \times \frac{d\,P_e(r)}{dr}$$

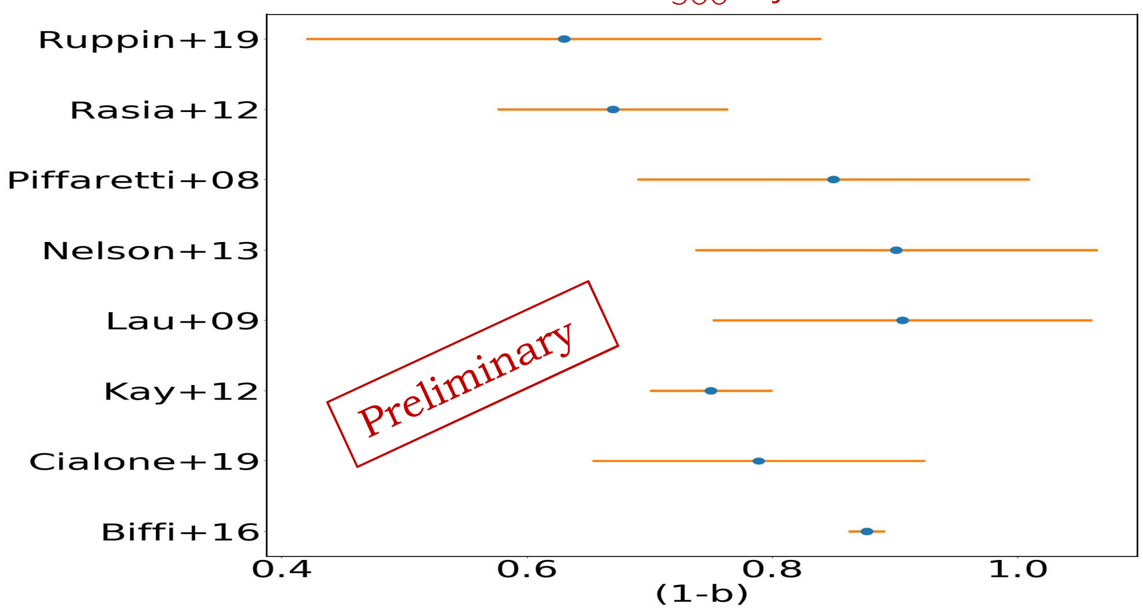
$$R_{500}^{\mathrm{HSE}} \quad M_{500}^{\mathrm{HSE}} \quad b = \frac{M_{500}^{\mathrm{true}} - M_{500}^{\mathrm{HSE}}}{M_{500}^{\mathrm{true}}} \quad M_{500}^{\mathrm{HSE-corr}}$$

$$M_{500}^{\mathrm{HSE}}/(1-\mu_b)$$



[Ruppin et al. sub 2019]

mass bias @R_{500} by sims



[credits G. Gianfagna]

Comparison with mean mass bias values, (1-b), derived from different numerical simulations. The large dispersion of the means could be justified by, among other things:

- Different dynamical state of the sample
- Mass resolution (gas & DM particles)
- Clusters mass range
- Physics included in the sims

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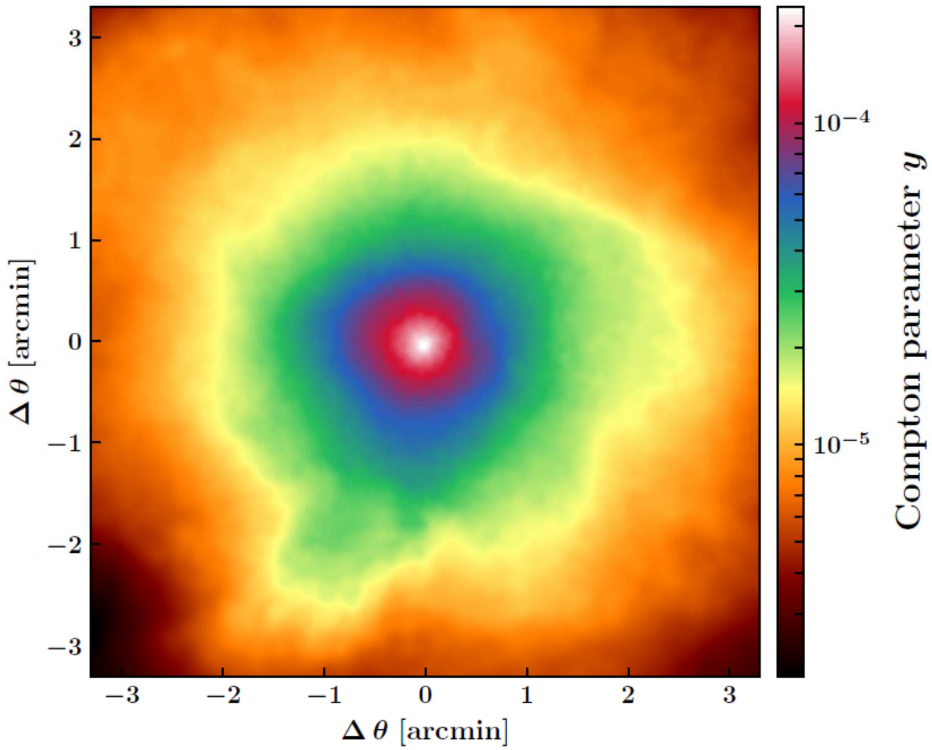
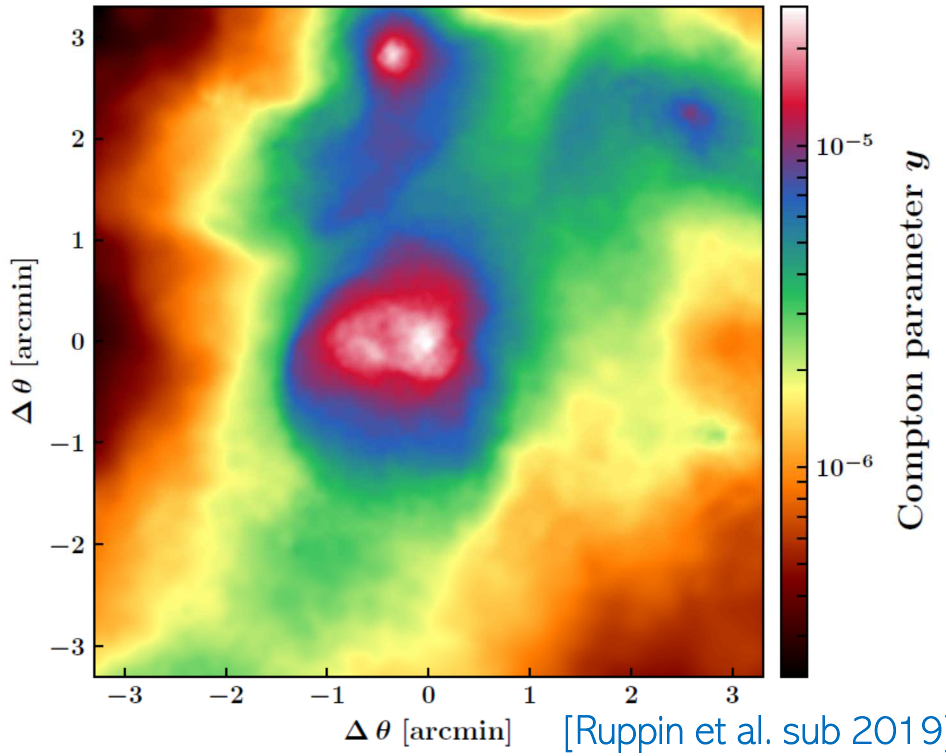
y-maps: morphology and dynamical state

To have a twin sample with a homogeneous dynamical state population, we identify, among the selected 32 clusters, the population of relaxed and disturbed objects applying a morphological approach, already tuned on MUSIC-2 clusters [Cialone et al. 2018]

MUSIC cluster#7 z=0.54
Relaxed



MUSIC cluster#130 z=0.54
Disturbed



[Ruppin et al. sub 2019]

y-maps: morphology and dynamical state

Morphology by 2D y-maps analysis

Six 2D estimators tuned for SZ morphology recovering,

… *a few of them already applied on X-ray maps*

see Iacopo's and MariaChiara's talks

asymmetry parameter

$$A_\theta = \frac{\sum_{r<R_{ap}} |I - R_\theta|}{\sum_{r<R_{ap}} I}$$

light concentration

$$c = \frac{\int_0^{r_1} S(r)\,\mathrm{d}r}{\int_0^{r_2} S(r)\,\mathrm{d}r}$$

third-order power ratio

$$\frac{P_m}{P_0} = \frac{a_m^2 + b_m^2}{2m^2 R_{ap}^2 a_0 \ln(R_{ap})}$$

$$a_m(R_{ap}) = \int_{r\le R_{ap}} S(r,\phi) r^m \cos(m\phi)\,\mathrm{d}r\,\mathrm{d}\phi,$$

$$b_m(R_{ap}) = \int_{r\le R_{ap}} S(r,\phi) r^m \sin(m\phi)\,\mathrm{d}r\,\mathrm{d}\phi,$$

centroid shift

$$w = \frac{1}{R_{ap}} \sqrt{\frac{\sum(\Delta_i - \langle\Delta_i\rangle)^2}{N-1}}$$

strip parameter

$$S = \frac{\sum_{i,j \atop j<i} |S_i(r) - S_j(r)|}{(N(N-1)/2)\max\left[\int_{R_{ap}} S_i(r)\,\mathrm{d}r\right]}$$

gaussian fit parameter

$$G = \frac{\sigma_{min}}{\sigma_{max}}$$

M, the combined parameter

all params (V) togheter but with different weights (W)

$$M = \frac{1}{\sum_i W_i}\left(\sum_i W_i \frac{\log_{10}(V_i^{\alpha_i}) - <\log_{10}(V_i^{\alpha_i})>}{\sigma_{\log_{10}(V_i^{\alpha_i})}}\right)$$

Weights inferred by a Kolmogorov–Smirnov (KS) test on the distributions of the relaxed and disturbed objects populations, as identified from the 3D indicators of the cluster dynamical state.

[Cialone et al. 2018]

y-maps: morphology and dynamical state

Dynamical state of each cluster by 3D data information

Two 3D discriminators (subM and centers-offset)

M_{sub}/M_{vir} ratio between the mass of the largest sub-structure in the cluster and the virial mass

Relaxed clusters < 0.1 < Disturbed clusters

U

$$\Delta_r = \frac{|\mathbf{r}_\delta - \mathbf{r}_{cm}|}{R_{vir}}$$

offset between the position of the peak of the density distribution and the position of the centre of mass of the cluster, normalized to the virial radius

Relaxed clusters < 0.1 < Disturbed clusters

z	CSF relaxed	CSF disturbed	NR relaxed	NR disturbed
0.43	56%	44%	55%	45%
0.54	53%	47%	53%	47%
0.67	56%	44%	55%	45%
0.82	54%	46%	53%	47%

[Cialone et al. 2018]

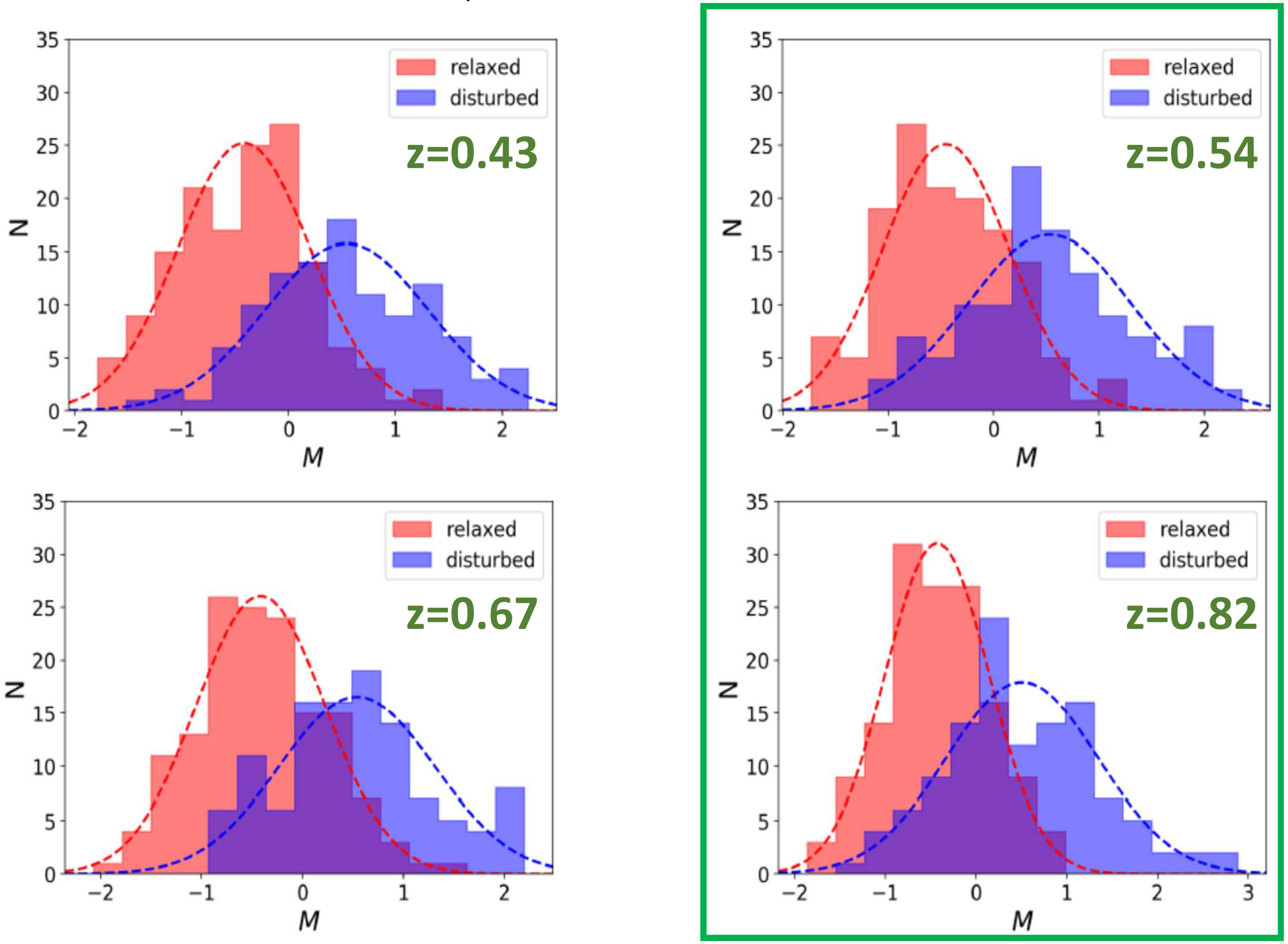
MUSIC-2 clusters

1- no significant differences with z (a small increase of disturbed cluster with z) and flavour;
2- population almost equally distributed among the two dynamical states (*)

(*) N.B. aperture, thresholds & estimators have an impact on the percentages and z evolution, see [De Luca et al. in prep]

y-maps: morphology and dynamical state

Combined parameter, *M* vs 3D selection



[Cialone et al. 2018]

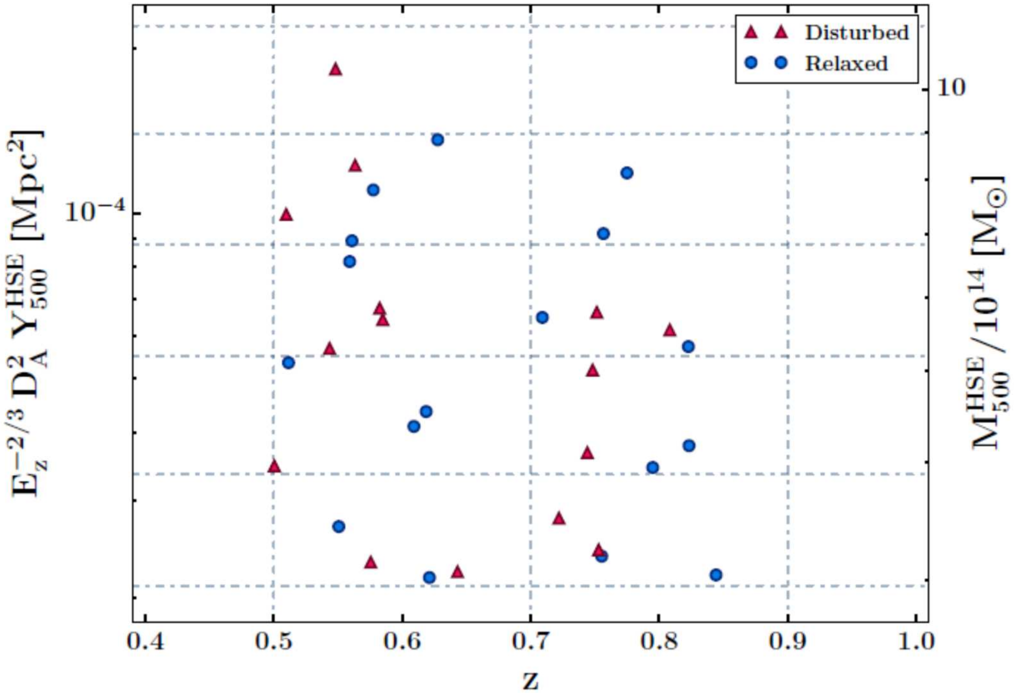
Relaxed clusters < -0.41 < Hybrid clusters < +0.41 < Disturbed clusters

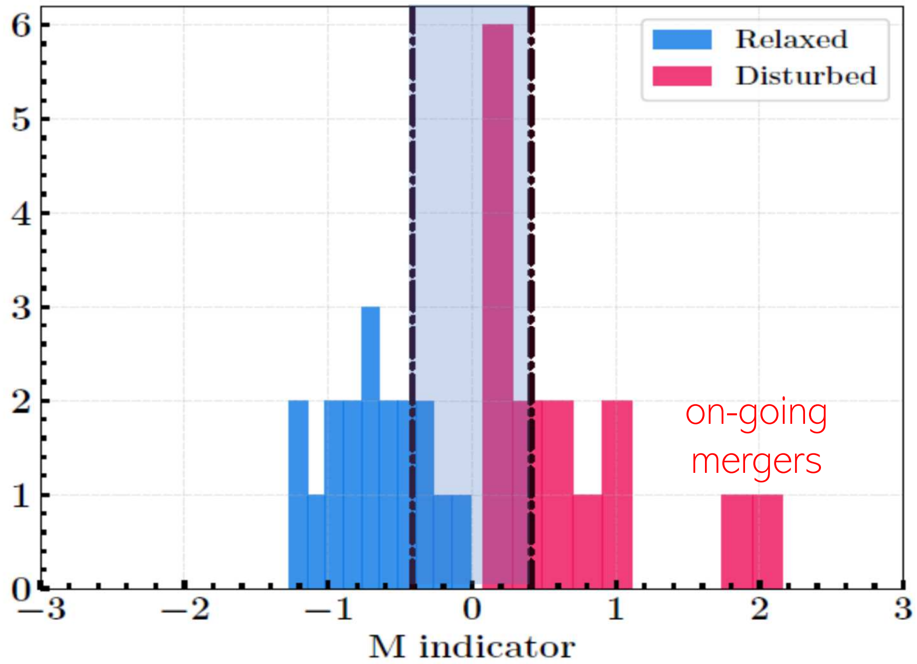
Caveats

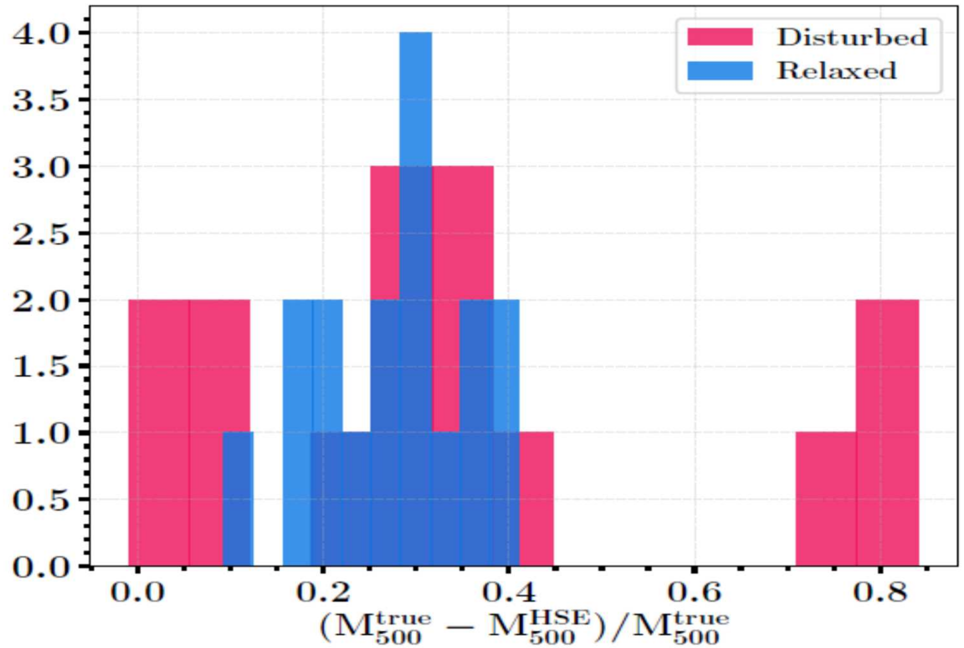
- M parameter is prone to projection effects
- 3D indicator (subM) more focused to detect merging processes

y-maps: morphology and dynamical state

32 MUSIC-2 clusters
18 objects @ z=0.54
14 objects @ z=0.82







Median mass bias @500 around 0.29
(both for disturbed and for relaxed objects)
Larger dispersion for disturbed clusters.

Disturbed outliers:
on-going mergers and pressure shocks
with strong impact on HSE mass profiles

[Ruppin et al. sub 2019]

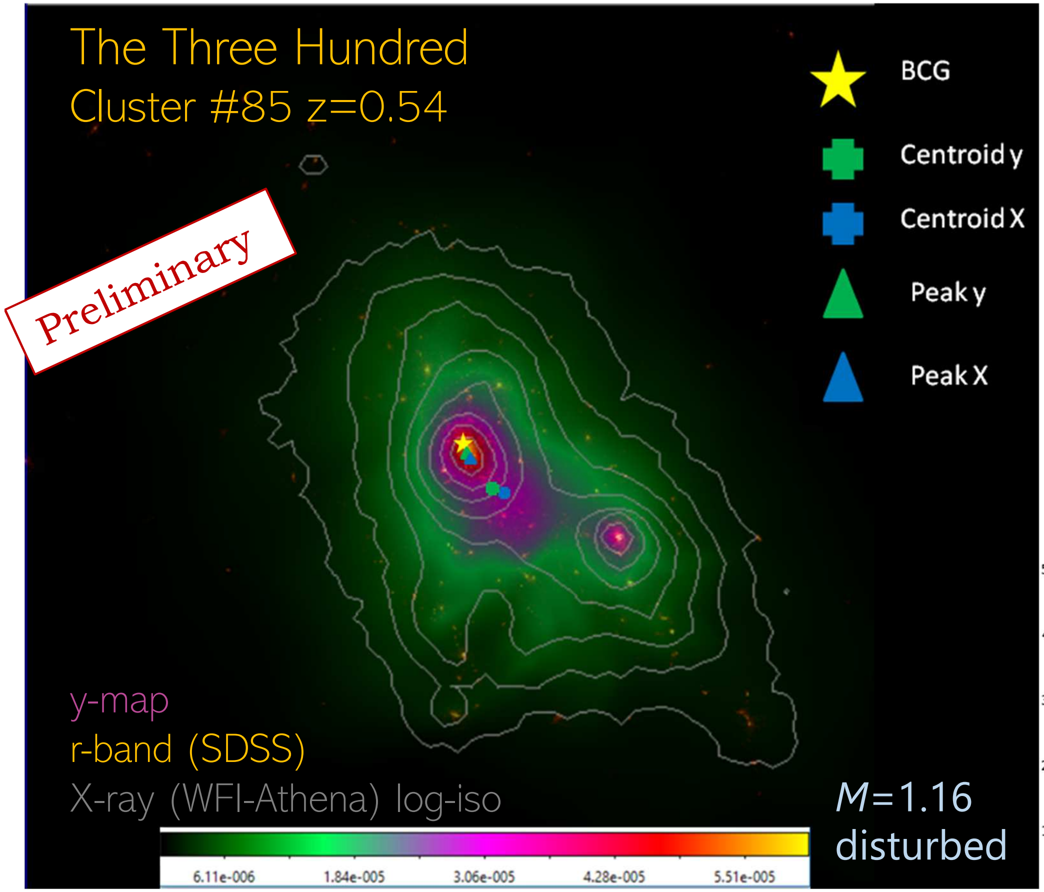
y-maps: morphology and dynamical state

To improve the possibility of inferring the dynamical state through observations, besides the morphological parameter, other estimators are under studying with The Three Hundred dataset

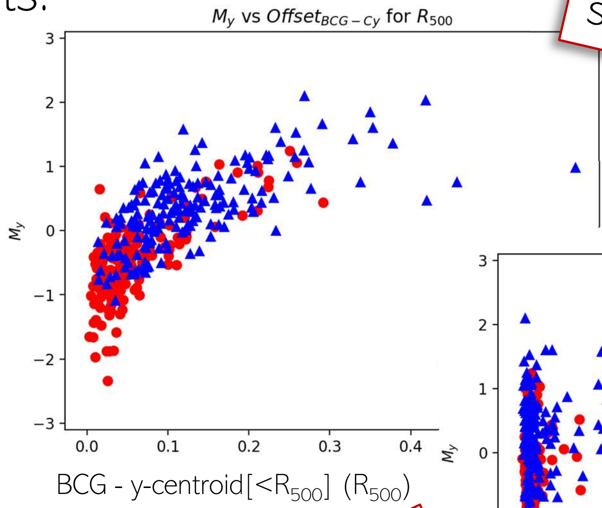
[De Luca et al. in prep] the OFFSETs between 5 points:

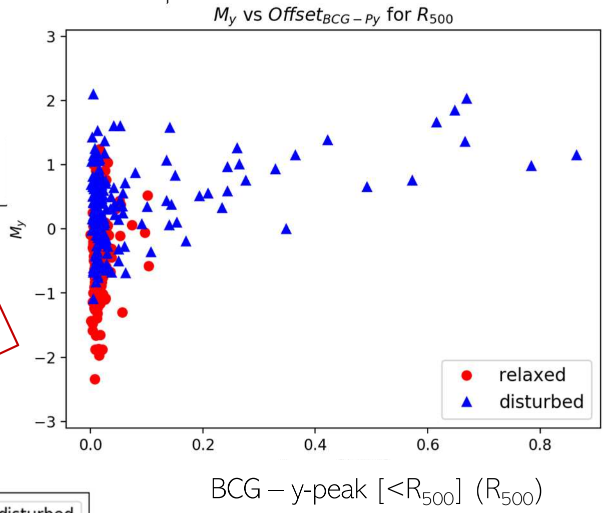
see Gustavo's talk

BCG, X-ray and y maps peaks/centroids ($<R_{500}$) positions

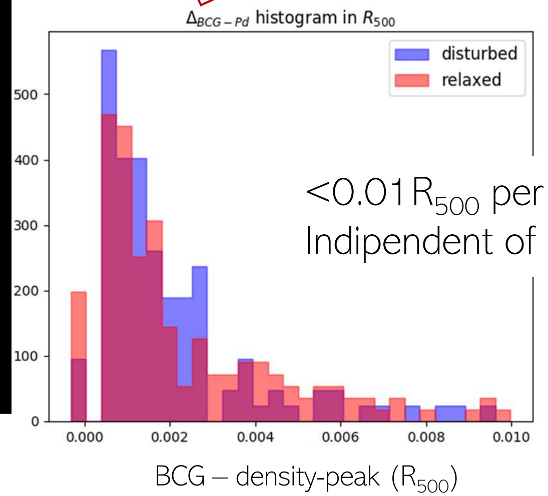


[credits W. Cui & F. De Luca]





Preliminary



$<0.01 R_{500}$ per 85%
Independent of dynamical state

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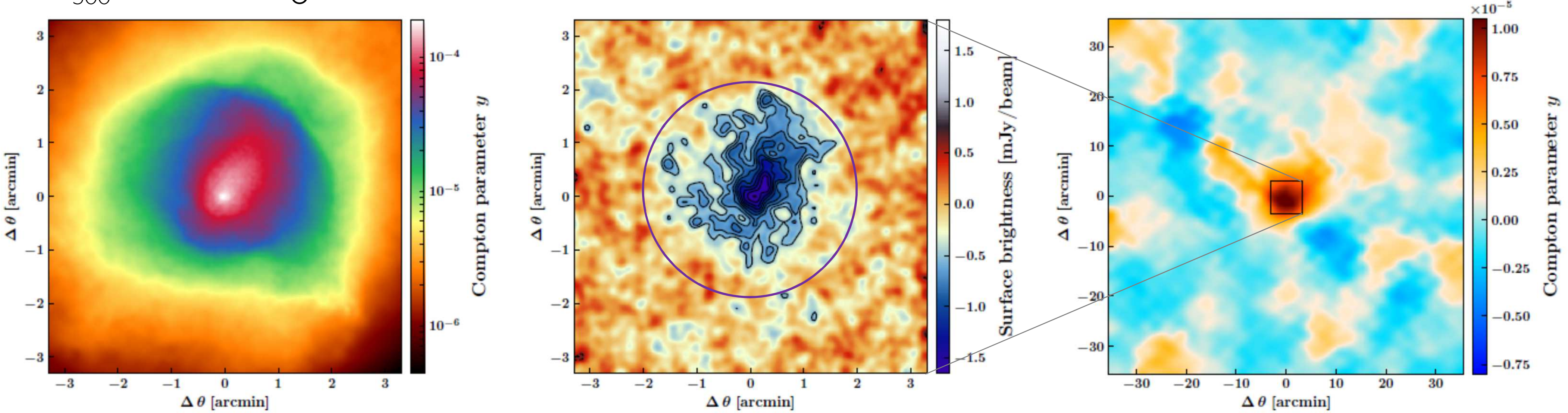
NIKA2 simulated observations (+Planck)

NIKA2 and Planck realistic tSZ observations towards each of the selected clusters that are jointly analysed to infer ICM pressure profiles

MUSIC-2 y-map — M_{500}=5.5·10^{14} $M_{\odot}$ z=0.54

NIKA2 150 GHz map — +17.7" FWHM + transfun

Planck y-map — +10' FWHM + noise



[Ruppin et al. sub 2019]

NIKA2 maps tSZ signal up to 2 arcmin from the peak while Planck put some constraints on Y over larger aperture

Caveats

- CMB negligible at NIKA2 angular scales
- CIB lower than instrumental and atmospheric noises
- No contaminants (radio/submm sources) are included to study the impact of only dynamics on pressure profiles; they increase uncertainties on pressure profiles recovering (see [Adam et al. 2016]).

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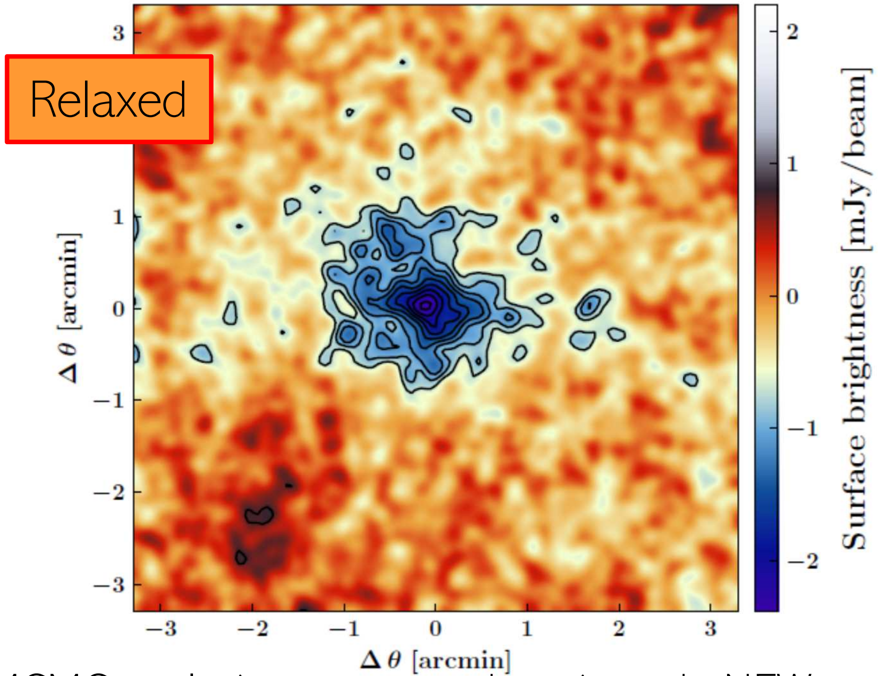
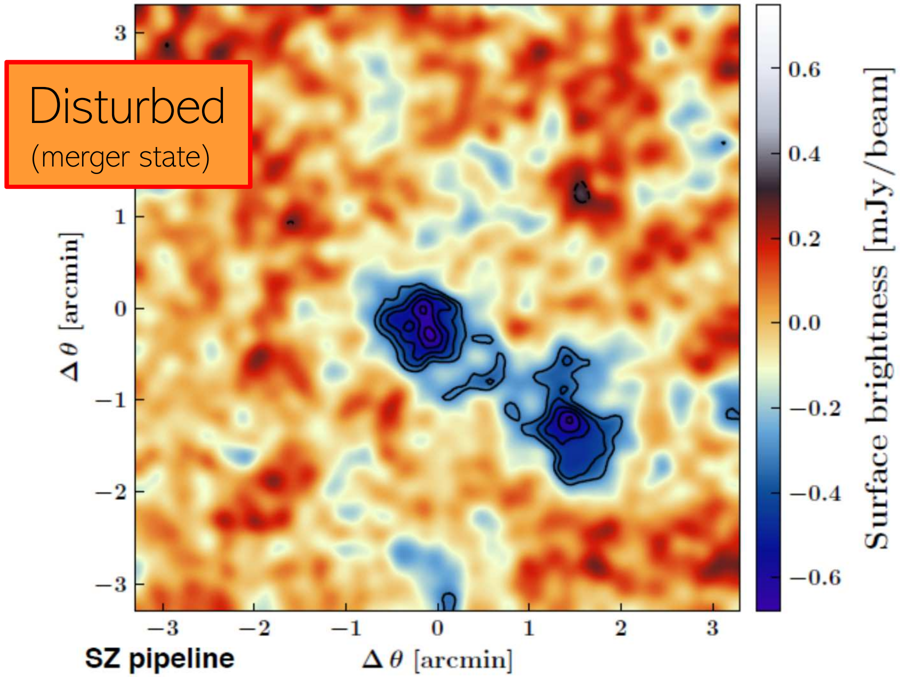
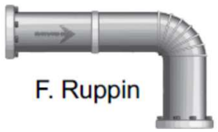
Radial gas pressure profiles



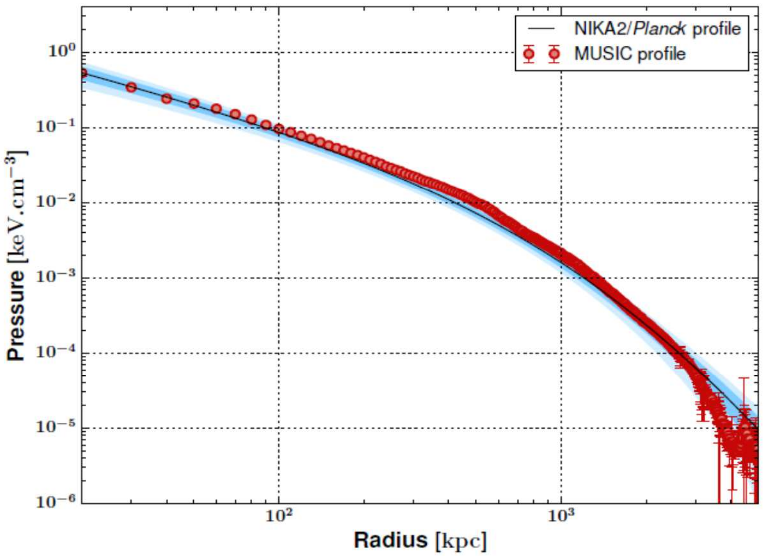


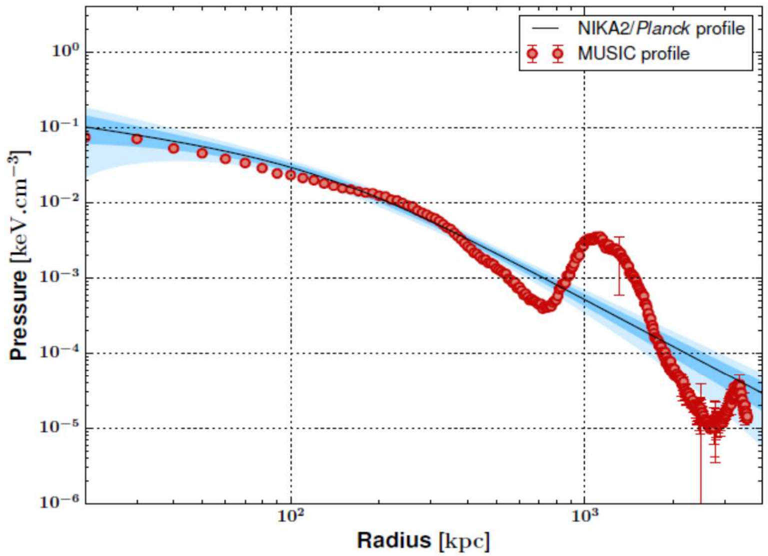
MCMC analysis to recover deprojected gNFW pressure profiles from NIKA2 data plus Y_{5R500} from Planck

SZ pipeline



F. Ruppin





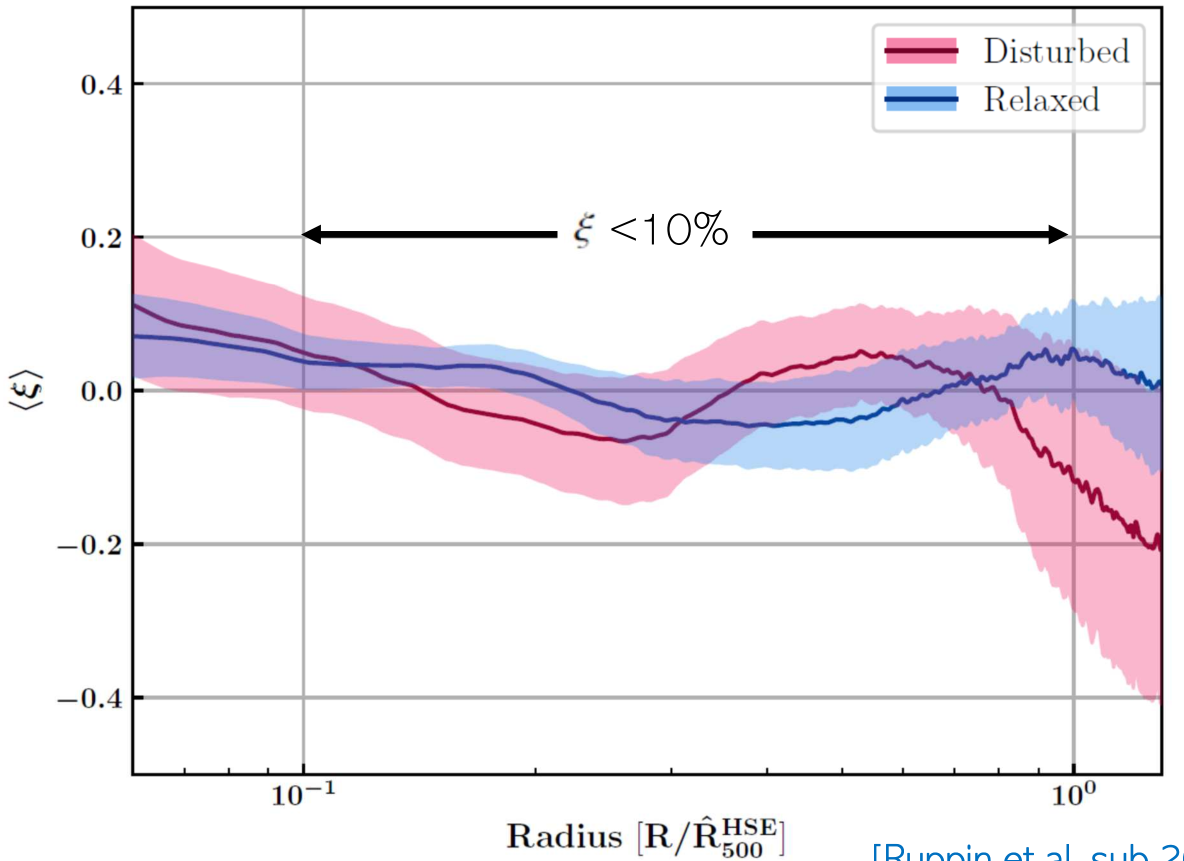
[Ruppin et al. sub 2019]

Radial gas pressure profiles

The NIKA2 tSZ analysis pipeline can be considered valid to estimate the pressure distribution in the case of relaxed clusters, combining complementary data (see Planck).
In presence of a clear merging process, a radial model is no more suitable. In that object, a more appropriate mask-approach on the main substructures is suitable; as already applied on the first NIKA2 SZLP cluster, PSZ2G144 [Ruppin et al. 2018]

Relative difference between MUSIC-2 and recovered deprojected pressure profiles

$$\xi = \frac{P_{\mathrm{MUSIC}} - \tilde{P}}{P_{\mathrm{MUSIC}}}$$



[Ruppin et al. sub 2019]

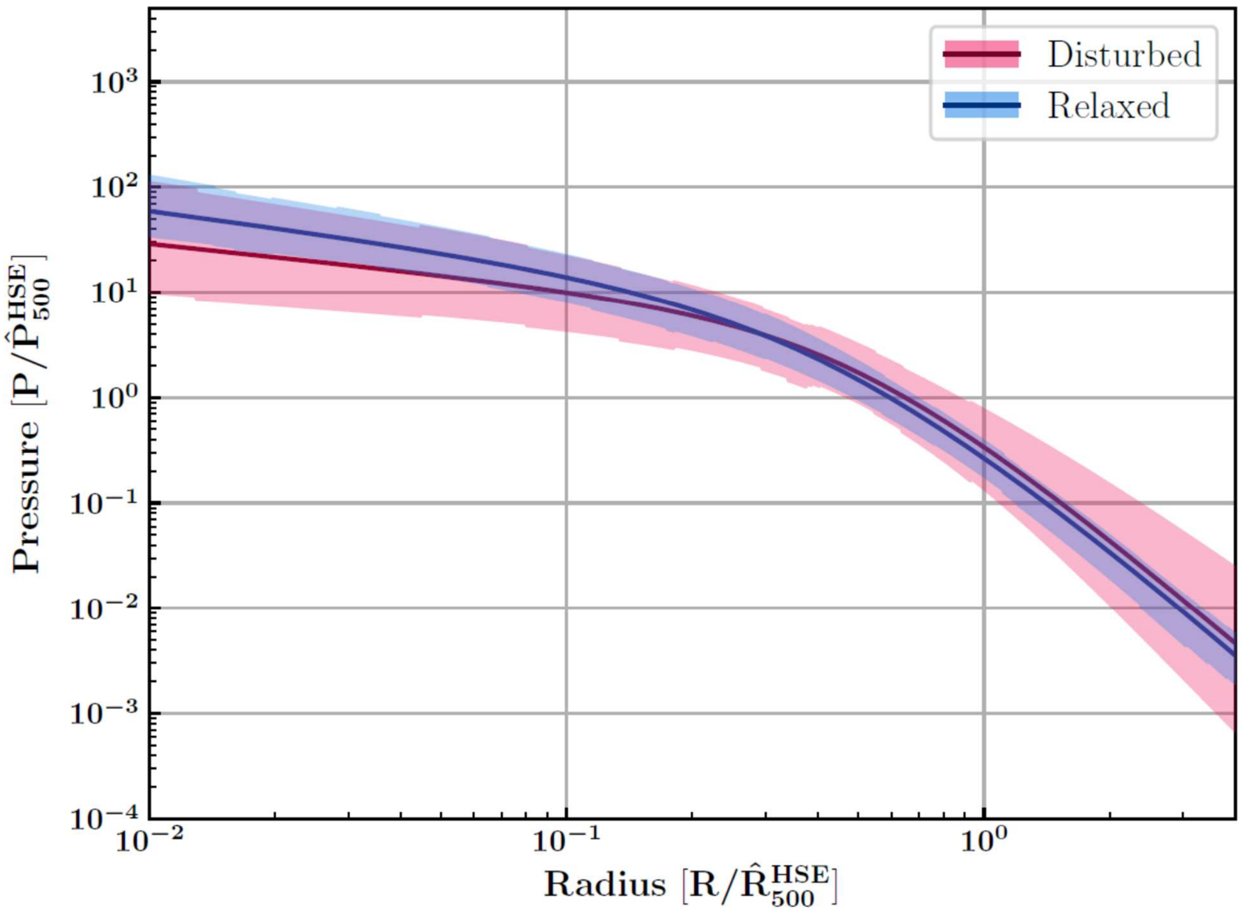
Radial gas pressure profiles

The normalized NIKA2/Planck recovered deprojected pressure profiles for the two populations

Disturbed clusters show a larger scatter in the mean profile than the relaxed one:
65% greater @ R_{500}

What do we learn?

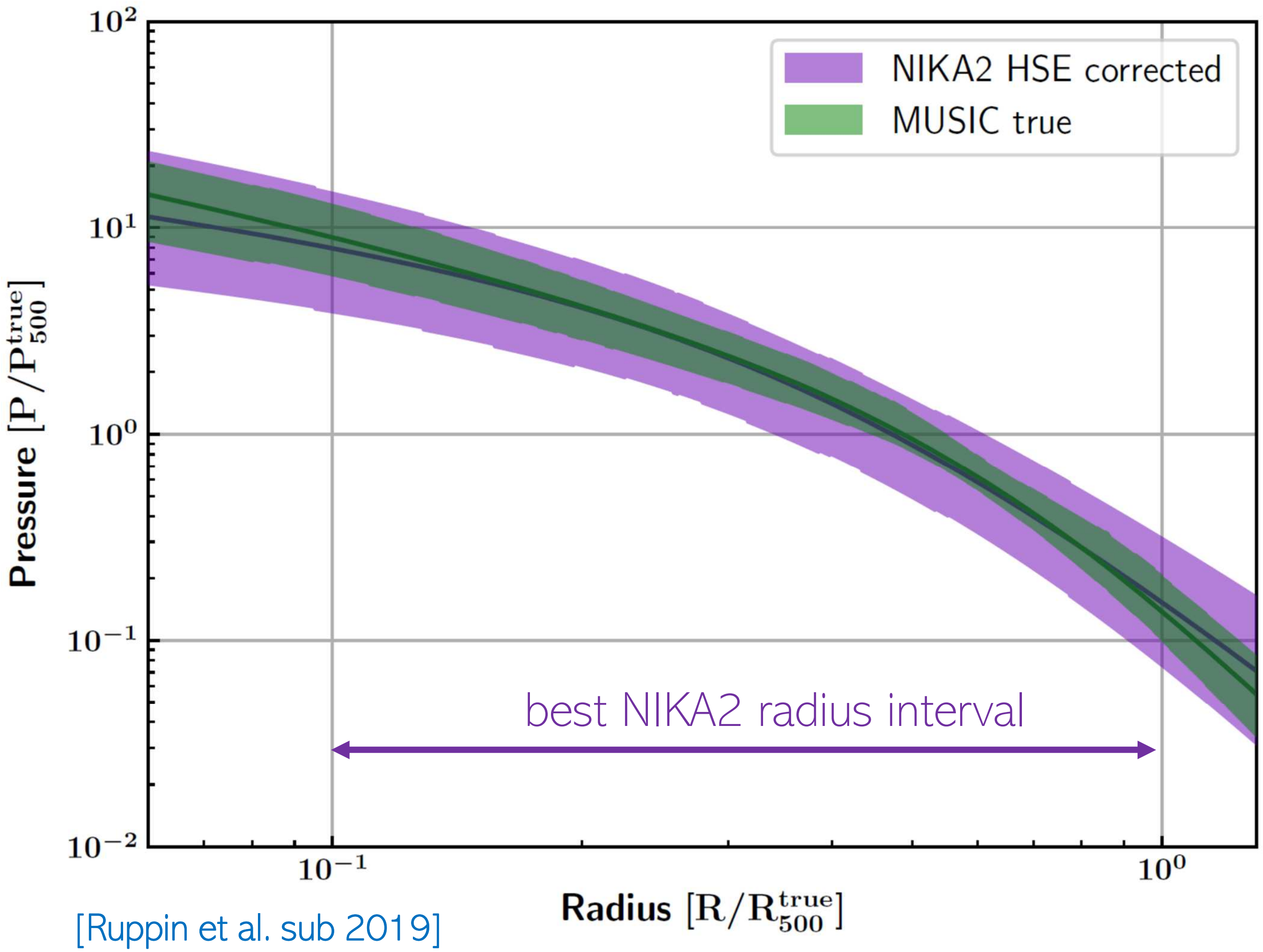
The disturbed clusters population, varying along the redshift, may induce a significant change of the measured intrinsic scatter associated with the distribution of pressure profiles.



[Ruppin et al. sub 2019]

Radial gas pressure profiles

Comparison between the NIKA2 recovered deprojected mean pressure profile of the *twin sample* (normalized with corrected HSE quantities) and the MUSIC-2 radial profiles (normalized with true quantities)



[Ruppin et al. sub 2019]

NIKA2 larger scatter (a factor 2) due to:

- Normalised profiles with integrated and HSE-corrected quantities;
- Simple spherical model not suitable for disturbed objects

Triaxial deprojection approach with NIKA2 and XMM-Newton data could minimize the effect, see e.g. Sereno et al. 2012.

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Conclusions ….. + Addendum

The *twin sample* of the SZLP is composed with different dynamical state synthetic clusters extracted from MUSIC-2 catalogue than it has been "observed" by NIKA2 and Planck to test and to validate:

- the capabilities of NIKA2, as a high angular resolution camera, of detecting the presence of ICM disturbances up to R_{500} at high redshifts and their impact on the HSE approach

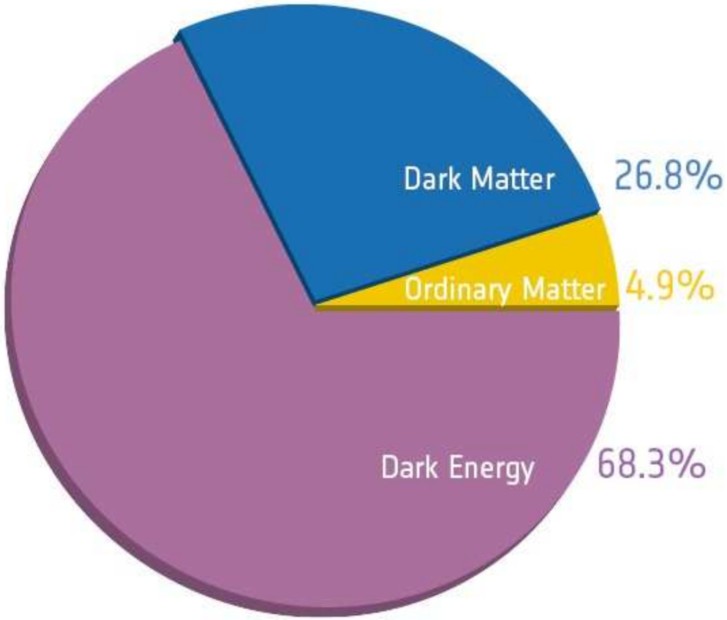
- the NIKA2 pipeline to recover mean pressure profiles different for relaxed and disturbed clusters

- the impact of the dynamical state on the scaling relation, such as tSZ flux, Y, and cluster total mass, M.

NIKA2 SZLP is complemented with X-ray and optical data sets useful to better identify the dynamical state and derive the deprojected radial profiles. Also in these cases, synthetic clusters are employed as a test bed, see new estimators (offsets) tested on The Three Hundred dataset.

Addendum

The composition of the Universe determined from analysis of the Planck mission's cosmic microwave background data © ESA



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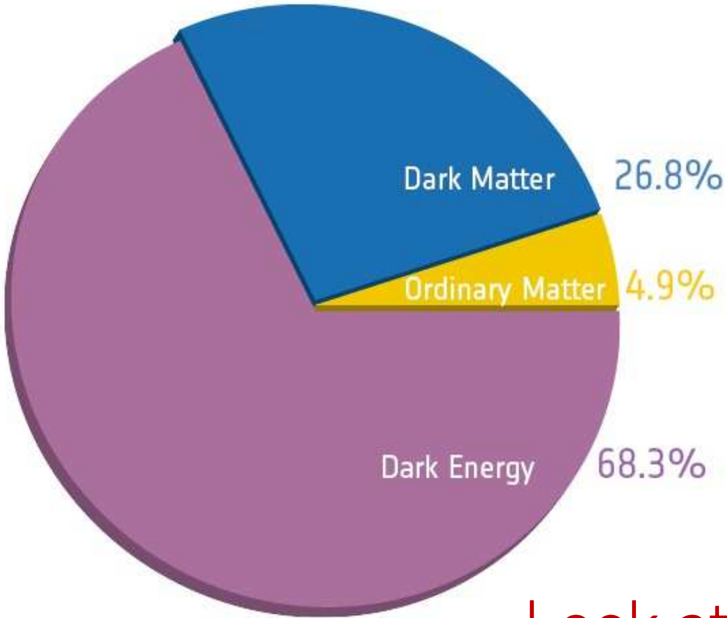
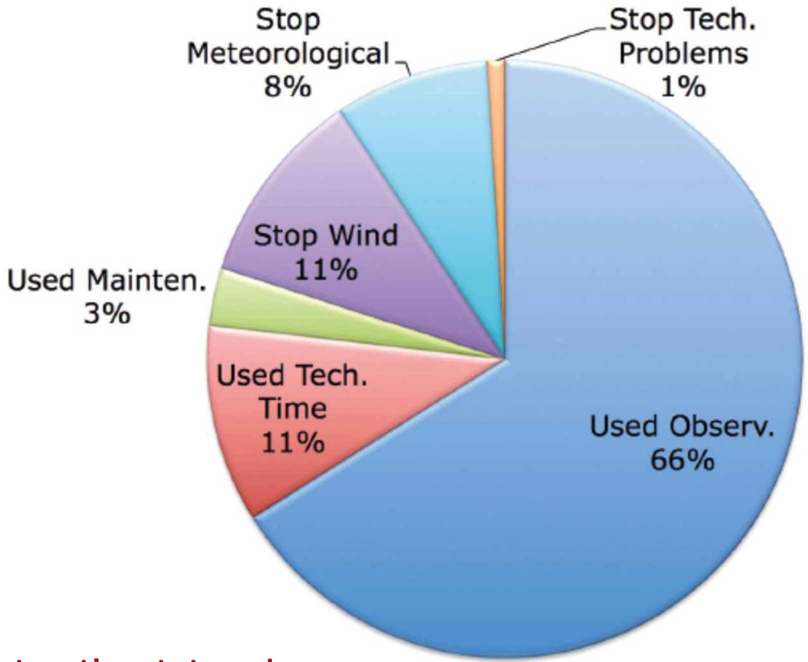


Usage of the total time at the 30-meter Telescope.



Look at some similarities!

[IRAM Annual Report 2017 Published by IRAM © 2018]

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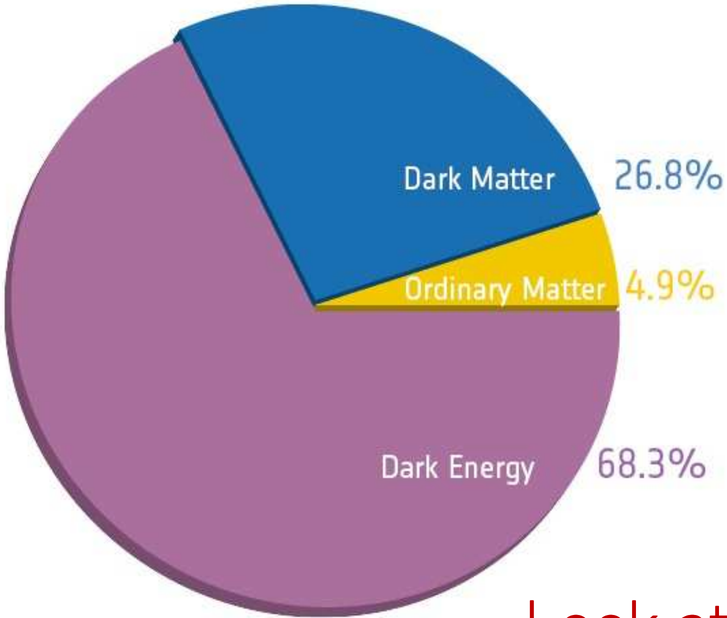

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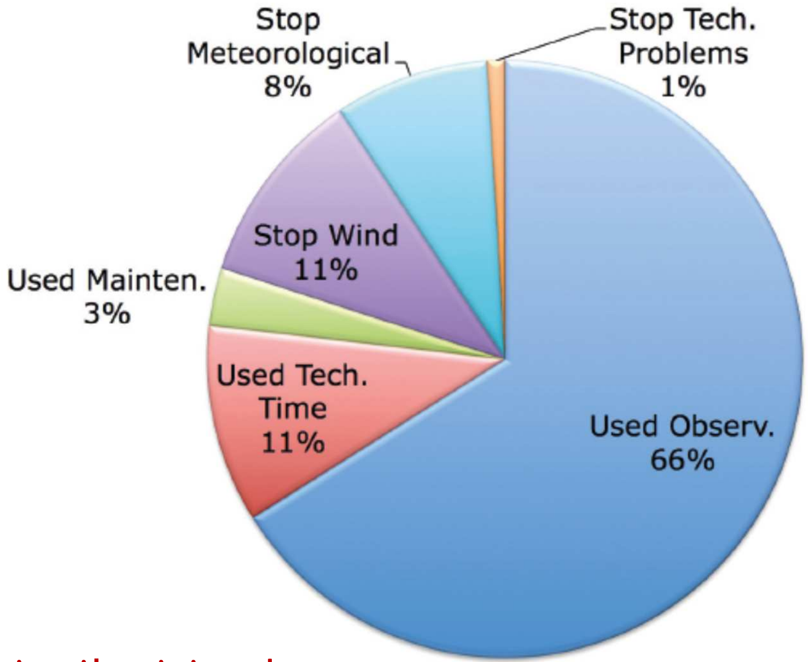

Look at some similarities!

[IRAM Annual Report 2017
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68.3% Dark Energy (to expand the Universe ...) -> 66% Used Observation time (to broaden 30m IRAM visibility ...)

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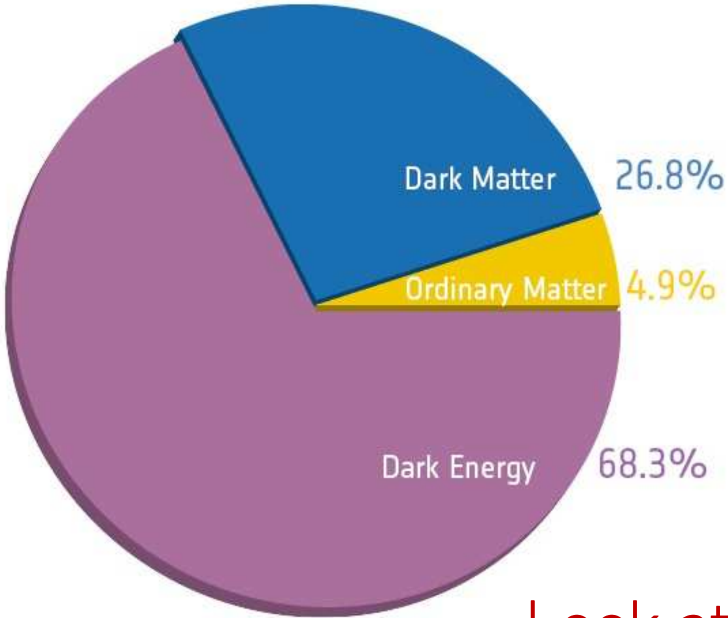

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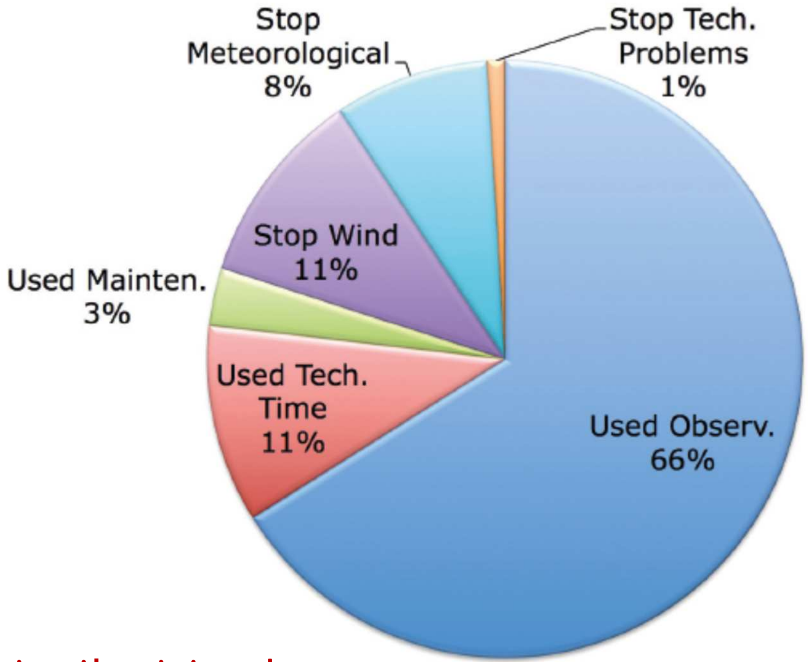

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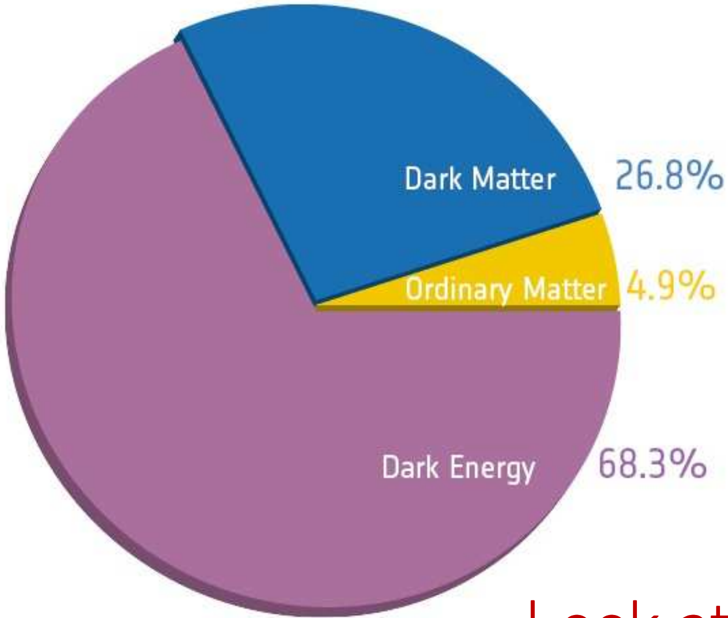
Look at some similarities!

68.3% Dark Energy (to expand the Universe ...) -> 66% Used Observation time (to broaden 30m IRAM visibility ...)

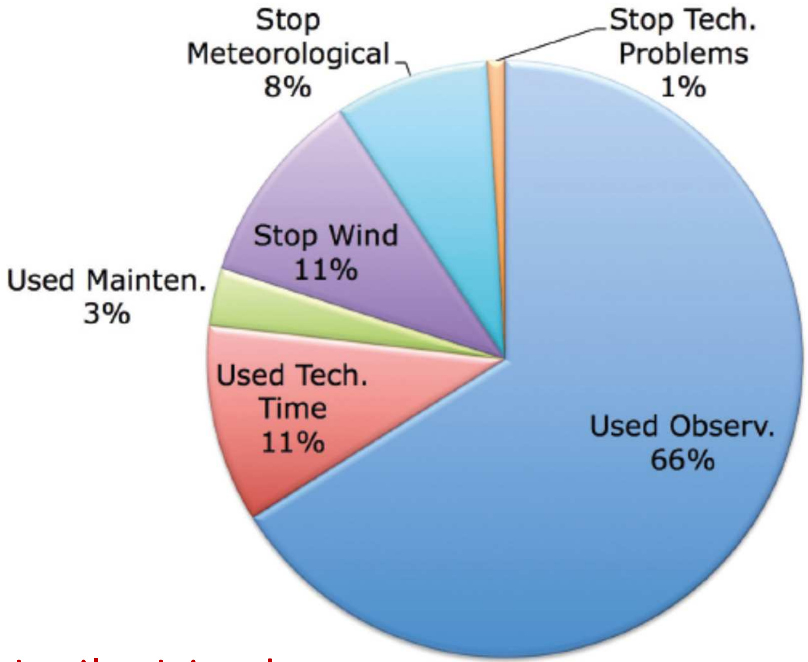
26.8% Dark Matter (unknown composition ...) -> 19% Meteo/wind stop time (unknow weather conditions ...)

Addendum

The composition of the Universe determined from analysis of the Planck mission's cosmic microwave background data © ESA



Usage of the total time at the 30-meter Telescope.



Look at some similarities!

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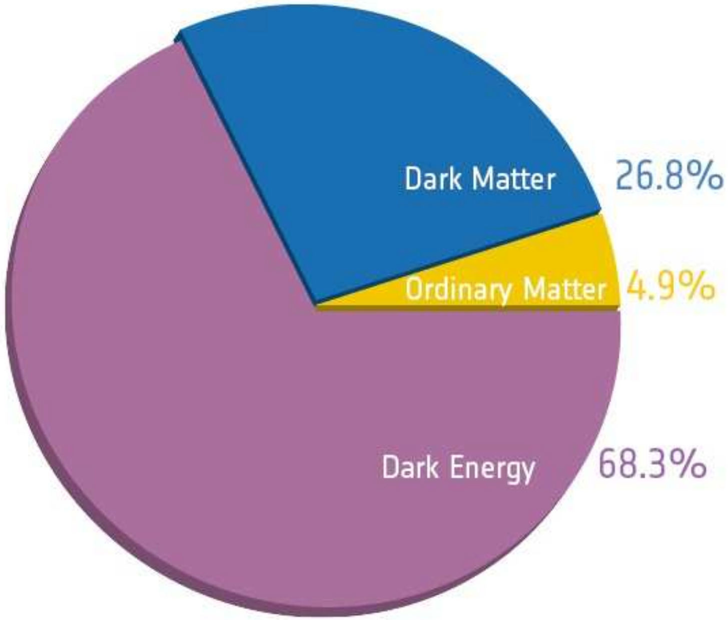
68.3% Dark Energy (to expand the Universe ...) -> 66% Used Observation time (to broaden 30m IRAM visibility ...)

26.8% Dark Matter (unknown composition ...) -> 19% Meteo/wind stop time (unknow weather conditions ...)

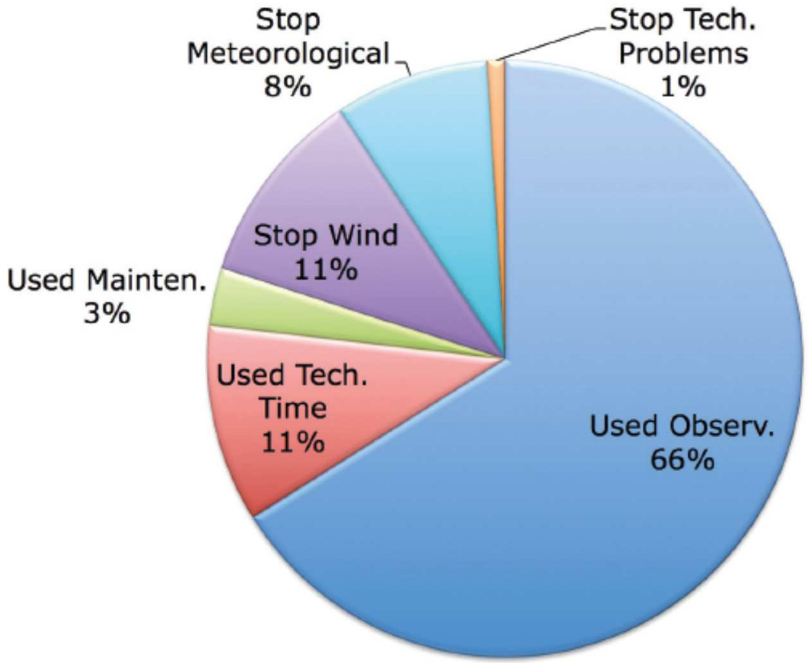
4.9% Ordinary Matter (we touch it ...!) -> 4% Tech, probs and Mainten. stop time (we touch them ...!)

Addendum

The composition of the Universe determined from analysis of the Planck mission's cosmic microwave background data © ESA



Usage of the total time at the 30-meter Telescope.



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Thanks to NIKA2 @ 30-m IRAM!