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High angular resolution observations of synthetic clusters of galaxies

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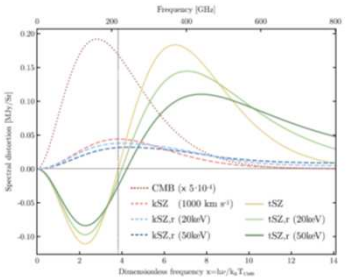
Abstract The observational capabilities of the Millimetron Space Observatory will allow to explore the high frequency spectral window (>300 GHz), challenging from the ground, with a spatial resolution (20" @ 1mm) able to exploit clusters of galaxies science by the Sunyeav-Zel'dovich effect (SZ). SZ is the distortion of the CMB blackbody spectrum due to Compton scattering of CMB photons on high-energy IntraCluster Medium (ICM) electrons.. Low frequency observations (<300 GHz) of the SZ are under investigation with a few arcseconds resolution by ground-based large single dishes (NIKA2 @ 30m-IRAM, Mustang2 @ GBT and AzTEC @ LMT) or by arrays of telescopes (ALMA compact configuration). Hydrodynamical N-body simulations enable validating the observational approaches by SZ and the methods that are normally used in order to estimate the ICM properties, and more generally the galaxy clusters physics, by comparing the results obtained by mock observations of synthetic clusters to properties that can be directly extracted from the three dimensional cube of the simulation.

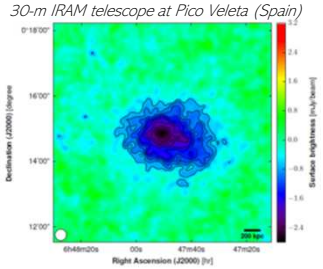
Scientific topic Clusters of galaxies science is a powerful way to provide useful cosmological information. The abundance of these objects in the Universe, as function of total mass and redshift, is strictly related to the mean matter density, Ω_m, and the amplitude of matter perturbations at a scale of 8 h^{-1}Mpc, σ_8. For this reason, the total mass of these objects must be inferred with high accuracy without systematics even along the redshift. The thermal component of SZ (tSZ) is a suitable probe to map ICM pressure distribution in clusters even at high redshifts. Thereafter the cluster mass is derived, under the assumption of hydrostatic equilibrium, by adding X-ray data. Alternatively the overall cluster mass is directly inferred from the integrated tSZ flux over a solid angle being proportional to the thermal energy content of the galaxy clusters, under the assumption of self-similarity among clusters. Remarkable, the kinematic component (kSZ), is useful to investigate ICM motions. High resolution tSZ observations allow us to carefully map ICM inhomogeneous distribution and to detect point-like sources as contaminants. Moreover, high spectral resolution observations (extended to the high frequency coverage) can discriminate SZ components (tSZ, kSZ or relativistic corrections) and foreground contaminants.



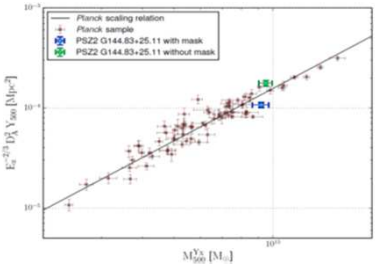
tSZ (solid) and kSZ (dashed) SZ spectra, plus relativistic corrections for various temperatures [3].

High angular tSZ observations NIKA2 camera [4] observes the sky at 150 and 260 GHz at 30-m IRAM telescope focal plane reaching an angular resolution of 20" and 13", respectively. A tSZ Large Program (300h of GT) is on-going to observe 50 clusters selected from Planck and ACT catalogs. The relevance of the resolution has already been highlighted with the analysis of the first observed cluster, PSZ2 G144.83+25.11 [5]. A significant difference between the pressure profiles obtained *with* and *without* masking an over-pressure region is evident. This ICM disturbance also has an impact on the integrated quantities used for the calibration of the tSZ-mass scaling relation.

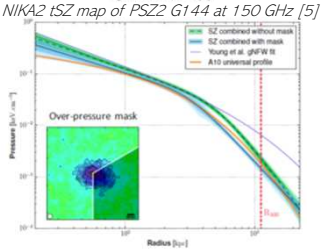
30-m IRAM telescope at Pico Veleta (Spain)



NIKA2 tSZ map of PSZ2 G144 at 150 GHz [5]



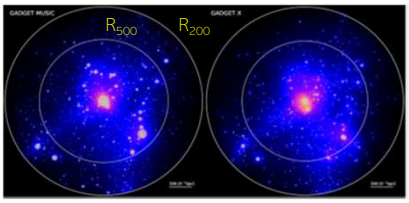
The two estimates of Y_{500} (with and without mask) together with Planck Y_{500}-M_{500} scaling relation (black line) [5].



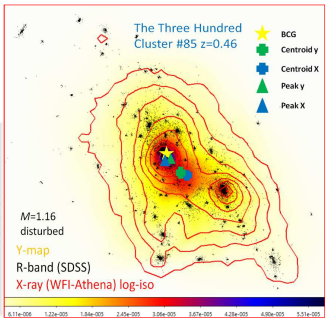
Radial pressure profile of PSZ2 G144 with and without the mask [5].

Hydrodynamical simulations Marenostrum MUltidark SImulations of galaxy Clusters (MUSIC) [1] and The Three Hundred Project (300s) [2] are two datasets of synthetic clusters fully available to cosmological and astrophysical applications, such as for Millimetron science. The 300s Project consists in zoomed regions of 15 h^{-1}Mpc radius around the 324 most massive clusters of the MultiDark-Planck simulation (~4000^3 resolution) formed at z=0 with $8x10^{14} < M_{vir} < 3.2x10^{15}\ h^{-1}M_\odot$. Multi-wavelength mock observations are available:

a) X-ray (Chandra, ATHENA),
b) tSZ (y-maps),
c) CCD (SDSS bands) and
d) lensing maps.

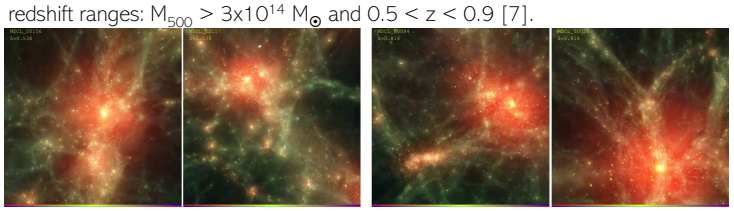


DM density map (blue-red) plus galaxies distribution of the most massive cluster of 300s [2].



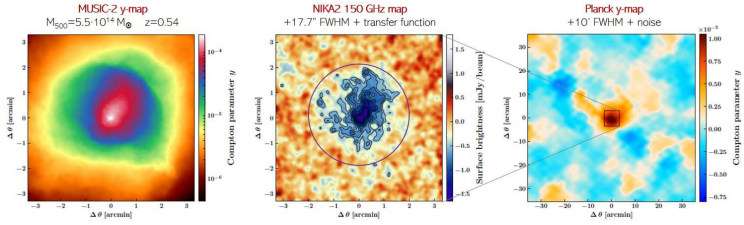
Cluster #85 observed in r-band; overplotted y-map and X-ray contours in log scale.

Hydro sims + observations To exploit the capabilities of high angular resolution experiments, such as NIKA2, MUSIC synthetic clusters have been selected to generate a *twin sample* of the NIKA2 tSZ LP spanning the same mass and redshift ranges: $M_{500} > 3x10^{14}\ M_\odot$ and $0.5 < z < 0.9$ [7].



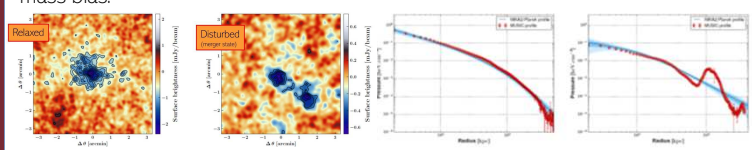
Gas distribution in 4 MUSIC clusters at z=0.54 (left) and z=0.82 (right) simulated with radiative physics.

NIKA2 and Planck tSZ realistic observations are generated for each synthetic cluster, classified according to its dynamical state by 3D simulation data and by 2D morphological analysis [8].



Left: MUSIC Compton parameter map of a selected disturbed cluster at z=0.54. Middle: simulated NIKA2 tSZ surface brightness map at 150 GHz. Right: simulated Planck Compton parameter map [7].

Through the NIKA2 tSZ pipeline and a joint NIKA2-Planck MCMC analysis, the radial pressure profiles are recovered under the hypothesis of hydrostatic equilibrium. The possibility to map ICM disturbances allows control of their impact on the profiles and so on the hydrostatic mass estimate minimizing the mass bias.



Left: Simulated NIKA2 tSZ surface brightness maps at 150 GHz for a relaxed and a disturbed cluster. Right: Pressure profiles estimated at the maximum likelihood from the MCMC analysis [7].

The same approach could be applied for studying Millimetron observational capabilities to explore medium/high redshift clusters of galaxies.

References

[1] Sembolini F. et al, MNRAS, 429, 323 (2013)
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[6] Planck Collaboration XX, A&A, A20, 571 (2014)
[7] Ruppin F. et al. accepted A&A (2019)
[8] Cialone G. et al, MNRAS, 477 (2018)

Useful websites

MUSIC
music.ft.uam.es
The Three Hundred
www.nottingham.ac.uk/~ppzfrp/The300
NIKA2 Project
ipag.osug.fr/nika2