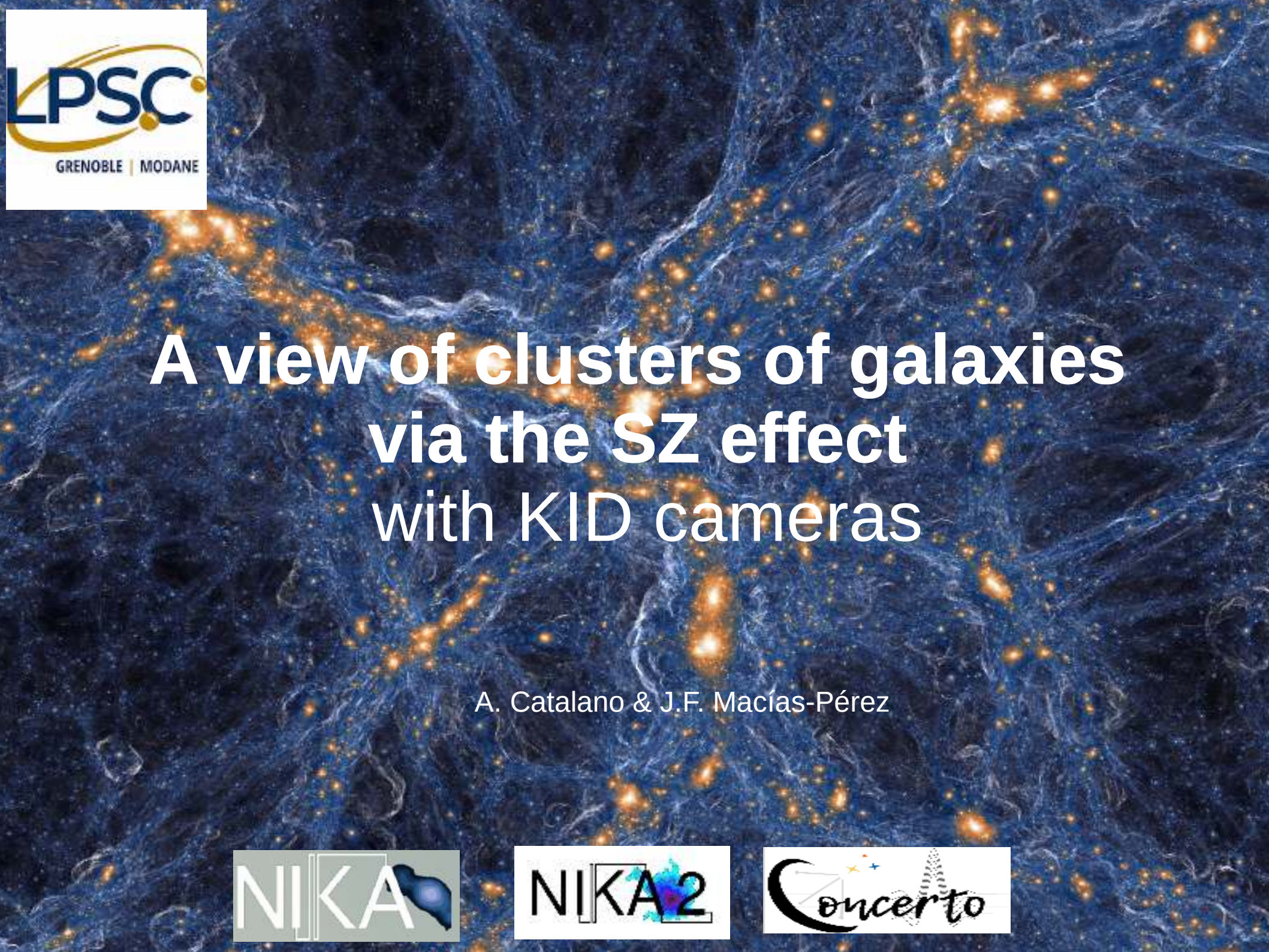


A view of clusters of galaxies via the SZ effect with KID cameras

A. Catalano & J.F. Macías-Pérez

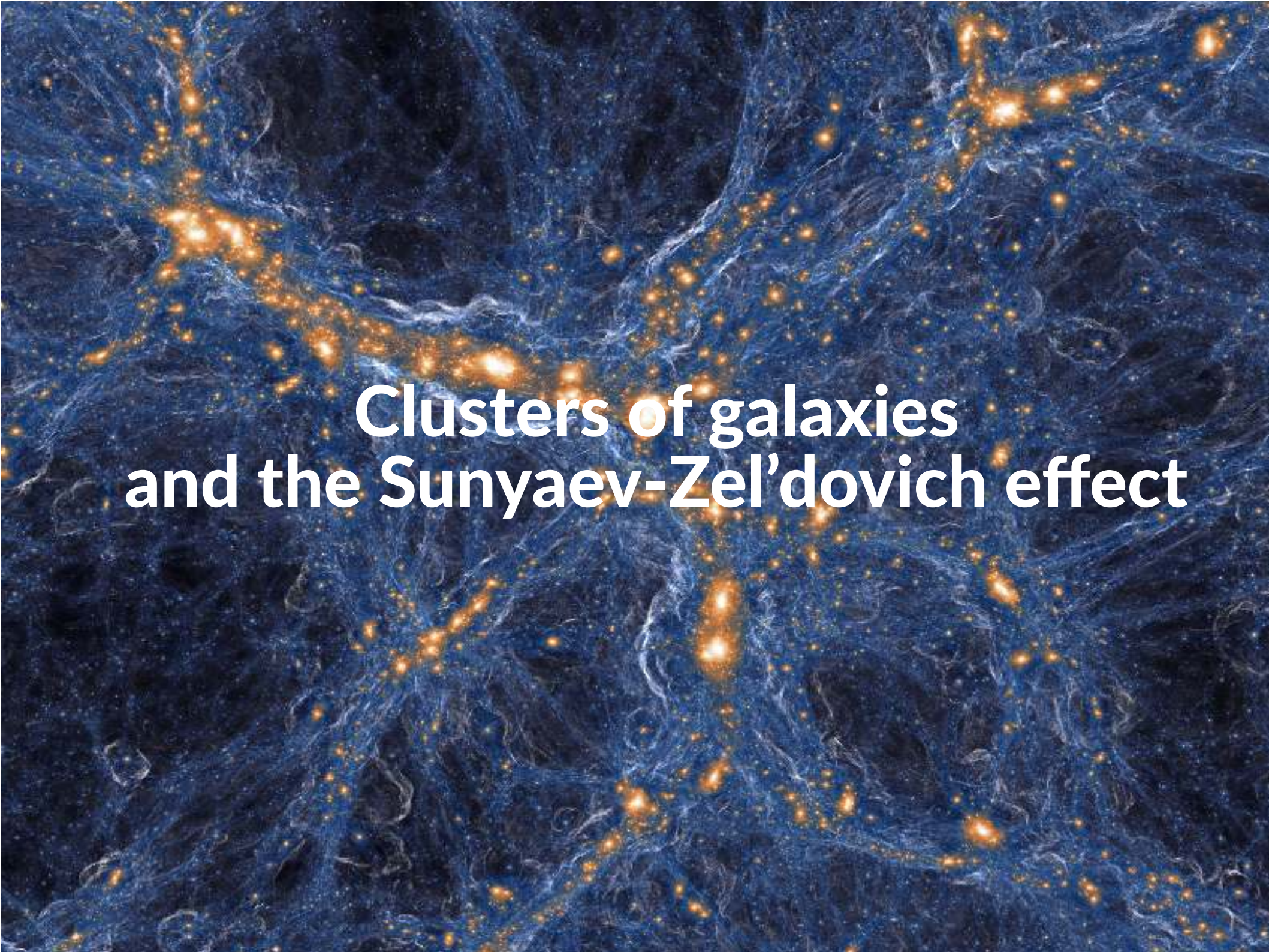
Outline

I. Clusters of galaxies and the Sunyaev-Zeldovich effect

II. KID cameras and spectrometers for SZ

III. SZ with NIKA and NIKA2

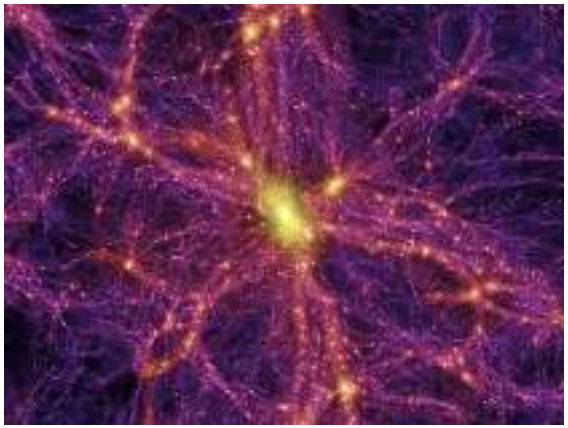
IV. SZ science with CONCERTO



Clusters of galaxies and the Sunyaev-Zel'dovich effect

Clusters of galaxies

- Formed by gravitational collapse at the intersection of cosmic filaments, correspond to massive dark matter halos
  - Self-similar scenario: clusters are scaled copies one of each others
  - However, baryonic physics plays a significant role
- First observed by Zwicky in 1930's who inferred that their total mass was larger than the sum of its luminous components
- Largest gravitationally bound structures in the Universe
  - Dominated by dark matter
  - Most baryonic matter is in the form of gas, the Inter Cluster Medium (ICM)
  - Galaxies count for only 3 % of the total mass
- Total mass 10^{13}- 10^{16} $M_{\odot}$, redshift $0 < z < 3$



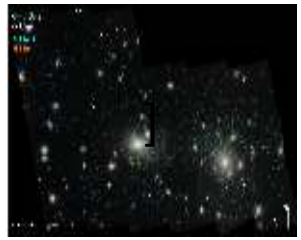
Cluster observables and physics

Cluster observables: detect them and/or measure their physical properties

Visible and IR emission

Light from stars in galaxies

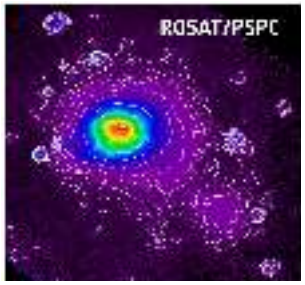
Mass:
- Richness (number of galaxies)
- Luminosity profile
- Velocity dispersion
- Gravitational lensing



X-ray emission

Free-free emission from free electrons in the ICM

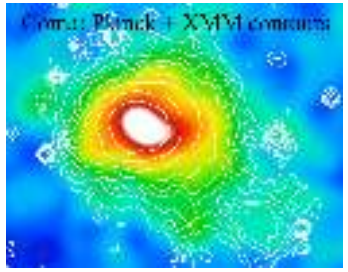
Density, temperature, entropy, mass:
- surface brightness
- spectroscopy



Sunyaev-Zeldovich effect

Interaction of hot electrons in the ICM with CMB photons

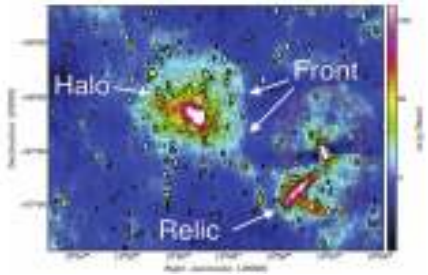
Pressure, mass, shocks:
- Compton parameter



Radio emission

Non thermal emission from accelerated particles

Shocks:
- Surface brightness



Coma cluster

Cluster physics from multi-wavelength observations

Sunyaev-Zel'dovich (SZ) effect

Two main components:

$$\frac{\Delta I_\nu}{I_0} = f_\nu y_{tSZ} + g_\nu y_{kSZ}$$

thermal SZ: CMB spectral distortion induced by inverse Compton interaction of CMB photons with clusters hot electrons

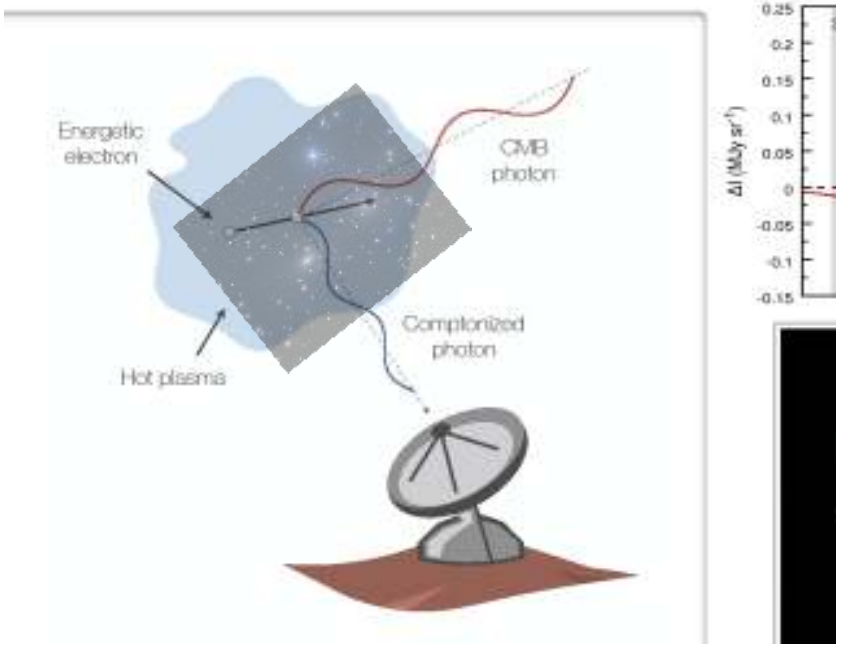
$$y_{tSZ} = \frac{\sigma_T}{m_e c^2} \int P_e d\ell$$

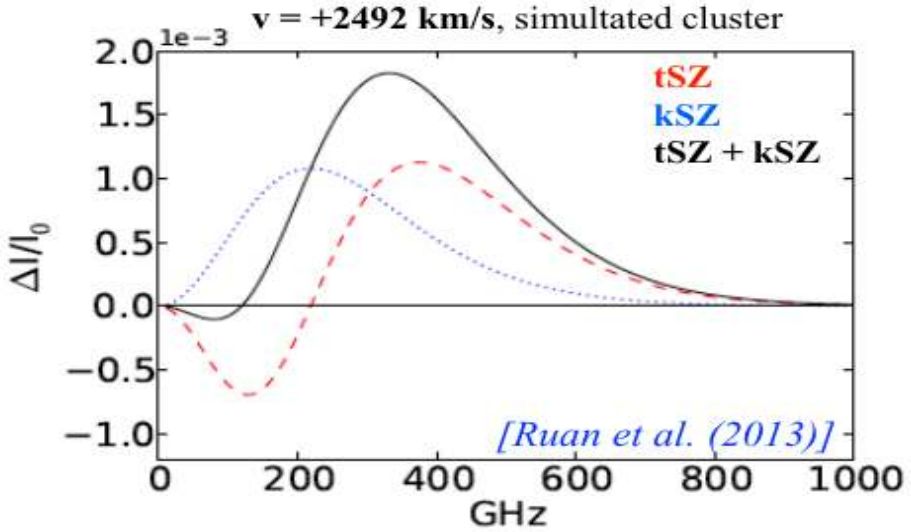
Kinetic SZ: CMB Doppler shift from bulk motion of cluster electrons (about tSZ/10)

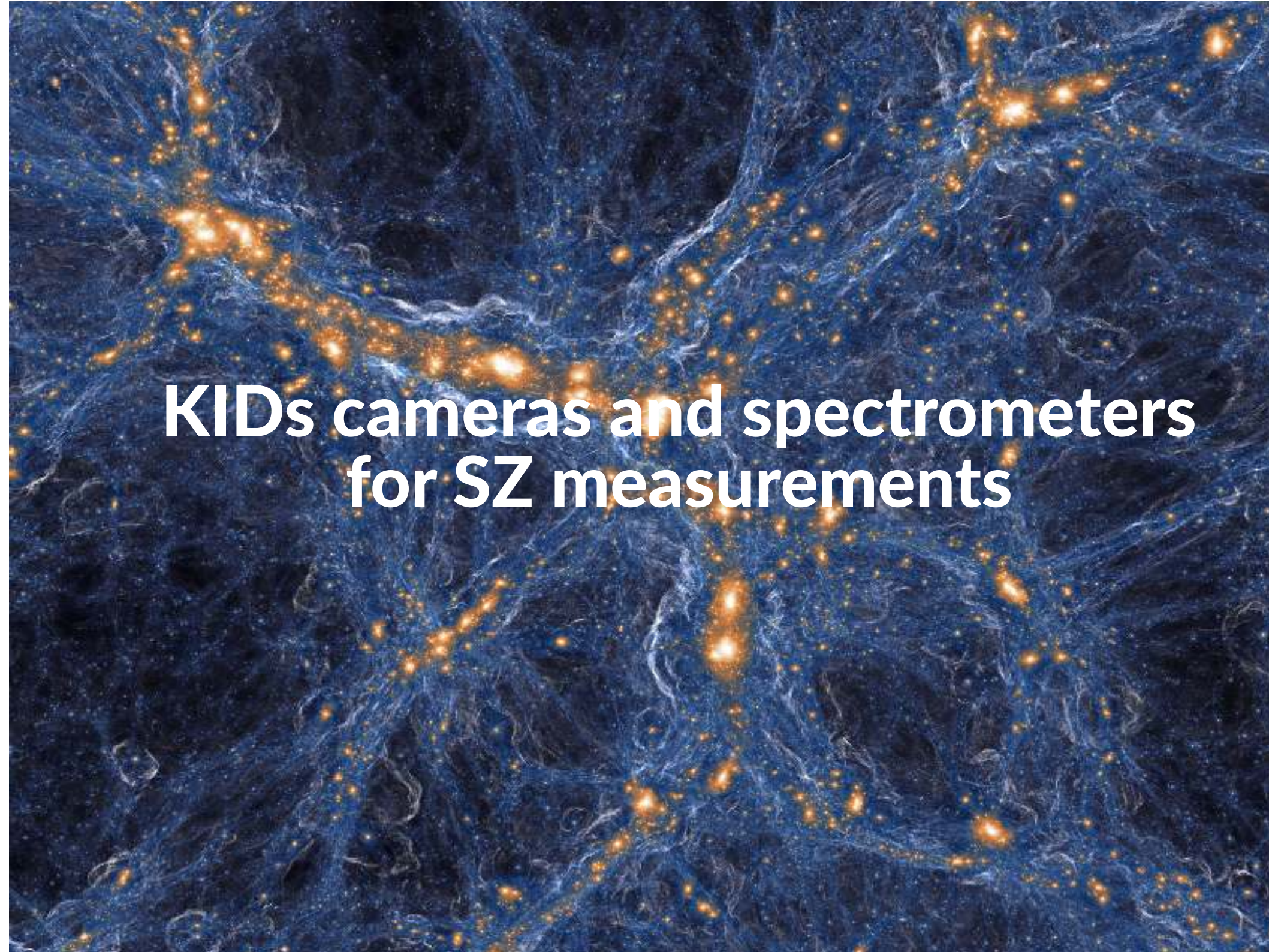
$$y_{kSZ} = \sigma_T \int \frac{-v_z}{c} n_e d\ell$$

No affected by cosmological diming

Probe for intercluster gas, mass and velocity tracer

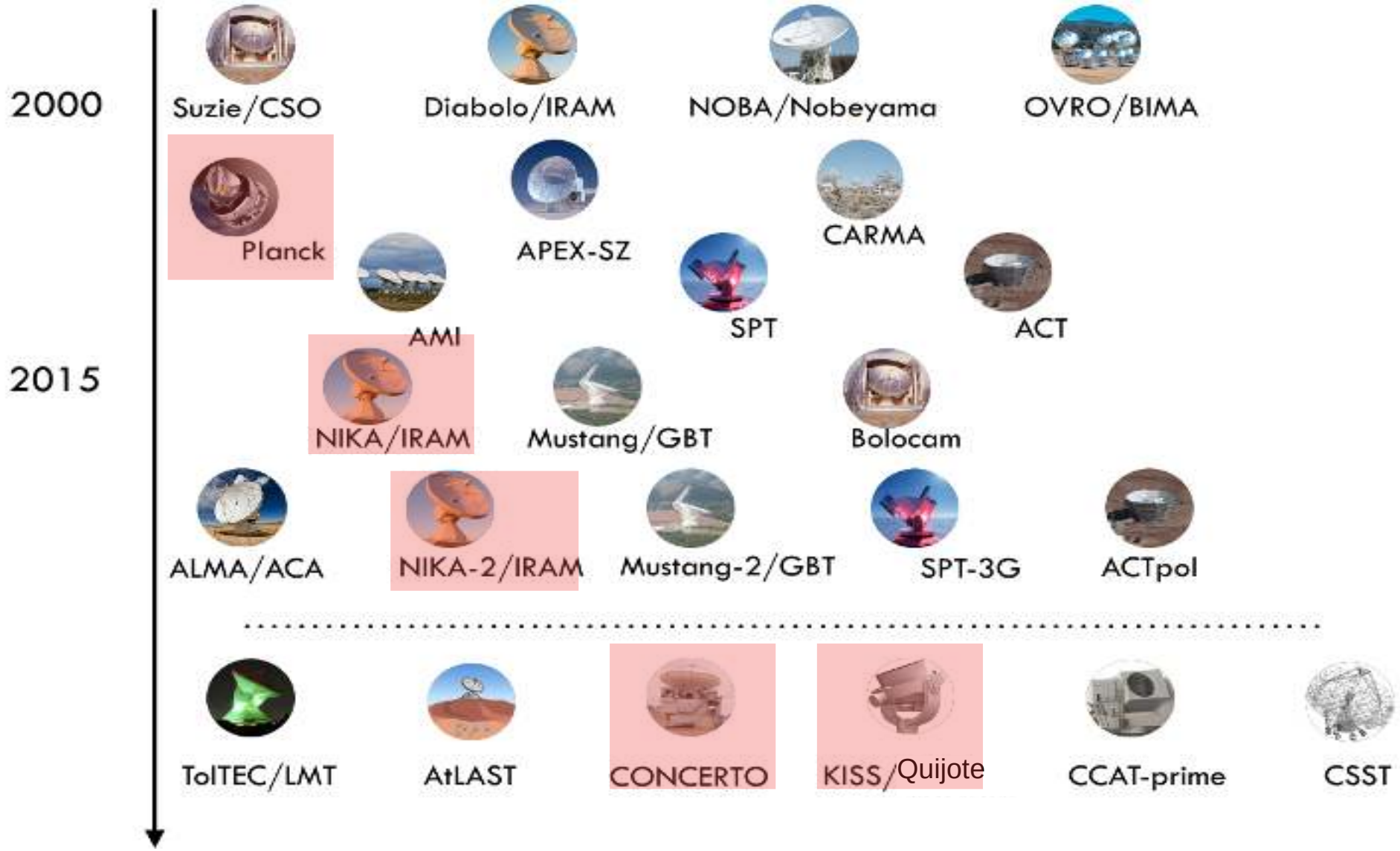






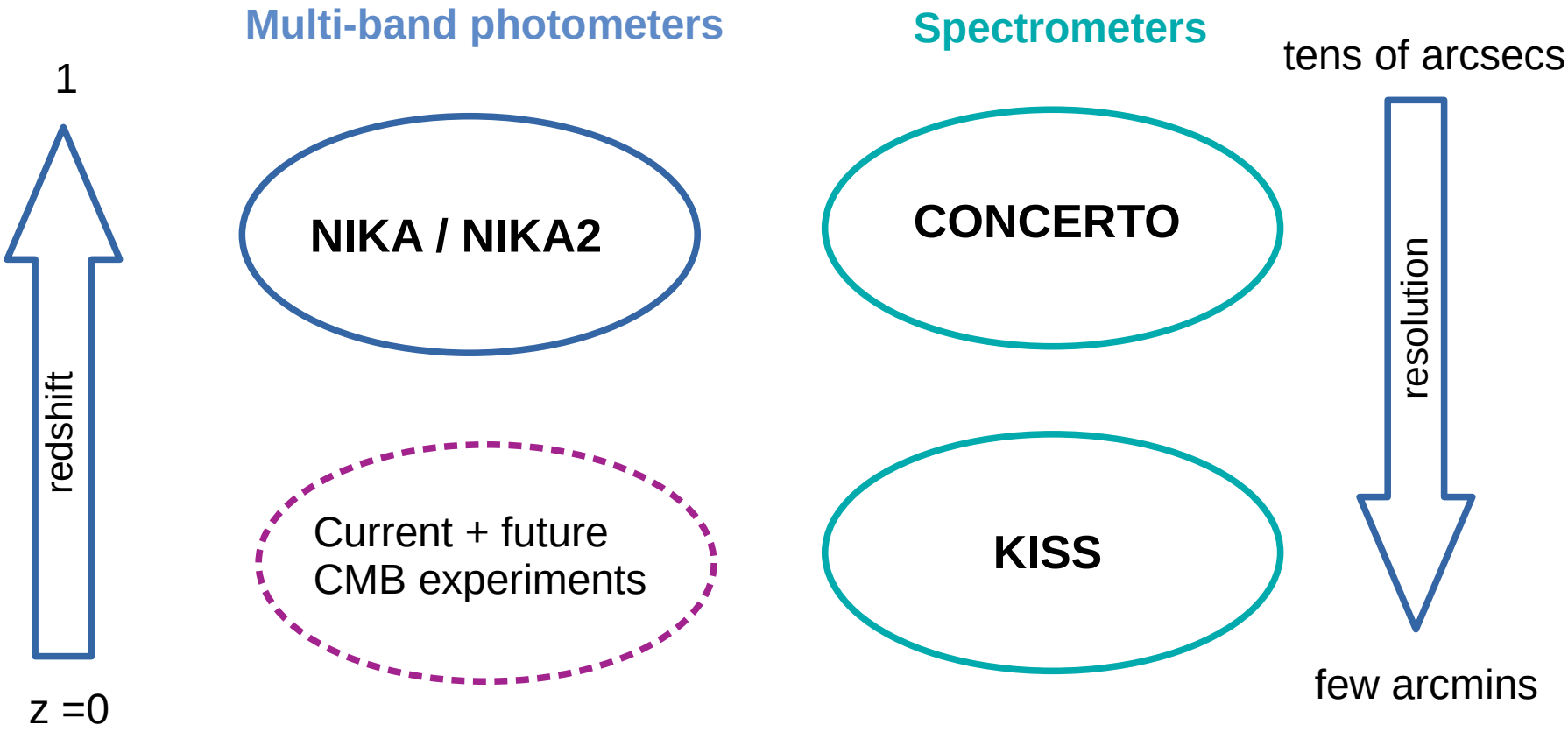
KIDs cameras and spectrometers for SZ measurements

SZ observations ?



Our SZ science approach

Develop new instruments to carry out complementary SZ observations targeting the improvement of cluster physical properties at low and high redshift



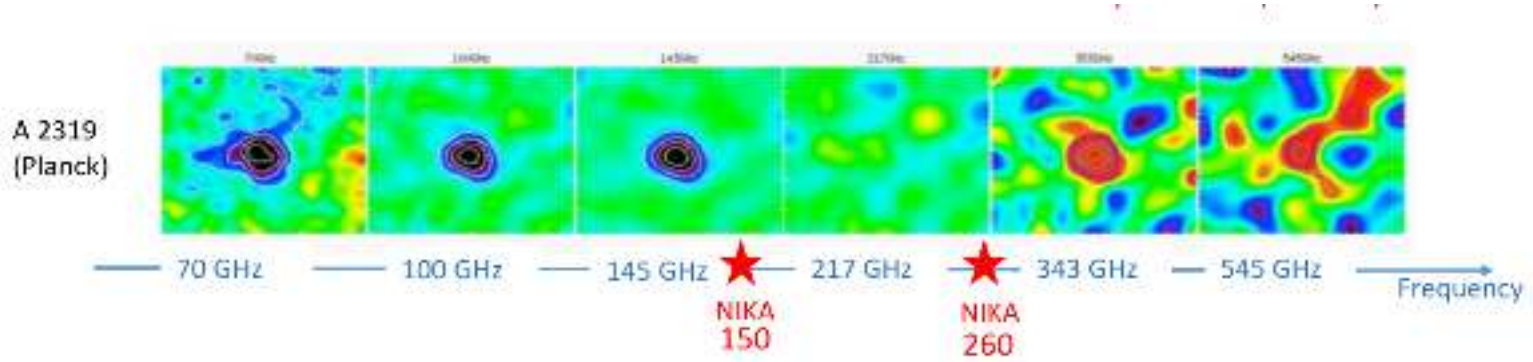
For this we need large arrays of detectors in the millimeter domain

SZ with NIKA/NIKA2

NIKA2 is well adapted for SZ observations of intermediate and high redshift clusters

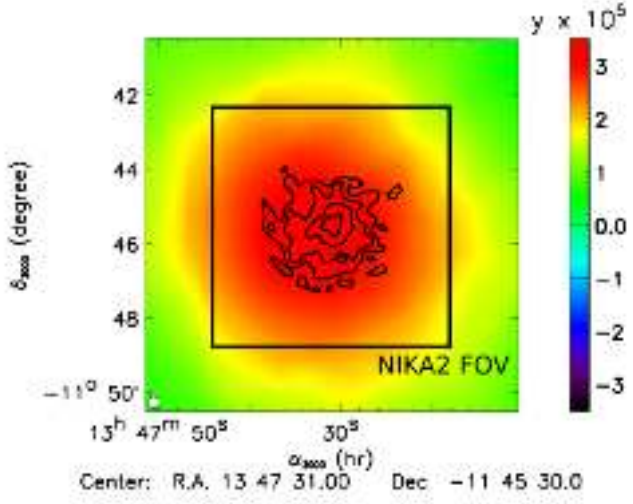
Ideal spectral coverage

Simultaneous mapping of SZ and possible contaminants

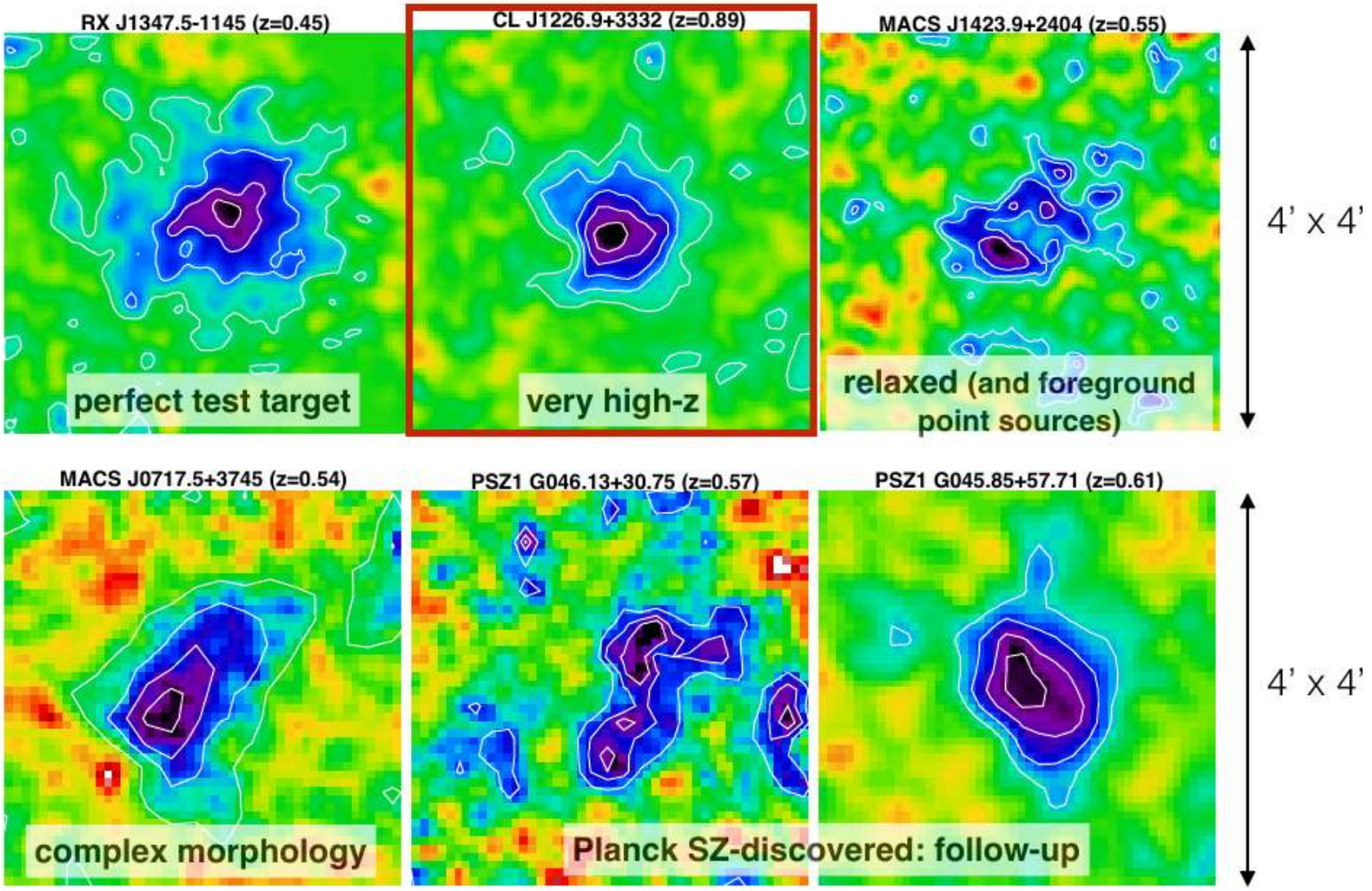


High resolution and large FOV

Can map both cluster inner regions and outskirts



The NIKA cluster sampe

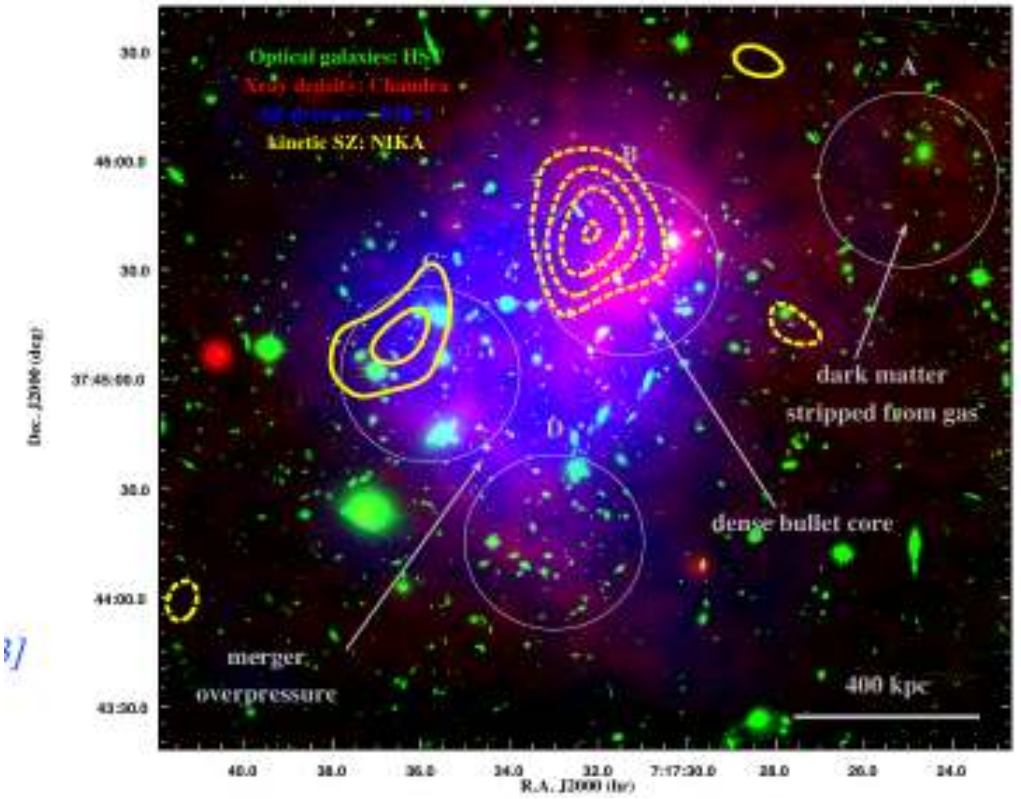


MACS J0717-3745 and kSZ

- High sensitivity NIKA data (12 hours on source)
  + High quality X-ray, optical and IR data
- However, mapping kSZ is very challenging:

  Complex system (5 subclusters
  Foreground emission
  Degeneracy relativistic tSZ and kSZ
- Use the two NIKA channel maps
  + temperature map from X-rays

MACS J0717-3745



$$\frac{\Delta I_\nu}{I_0} = f_\nu \; y_{\rm tSZ} + g_\nu \; y_{\rm kSZ}$$

spectral dependencies

gas pressure

gas velocity and density

kSZ mapping with NIKA

- High sensitivity NIKA data (12 hours on source)
  + High quality X-ray, optical and IR data
- However, mapping kSZ is very challenging:

  Complex system (5 subclusters
  Foreground emission
  Degeneracy relativistic tSZ and kSZ
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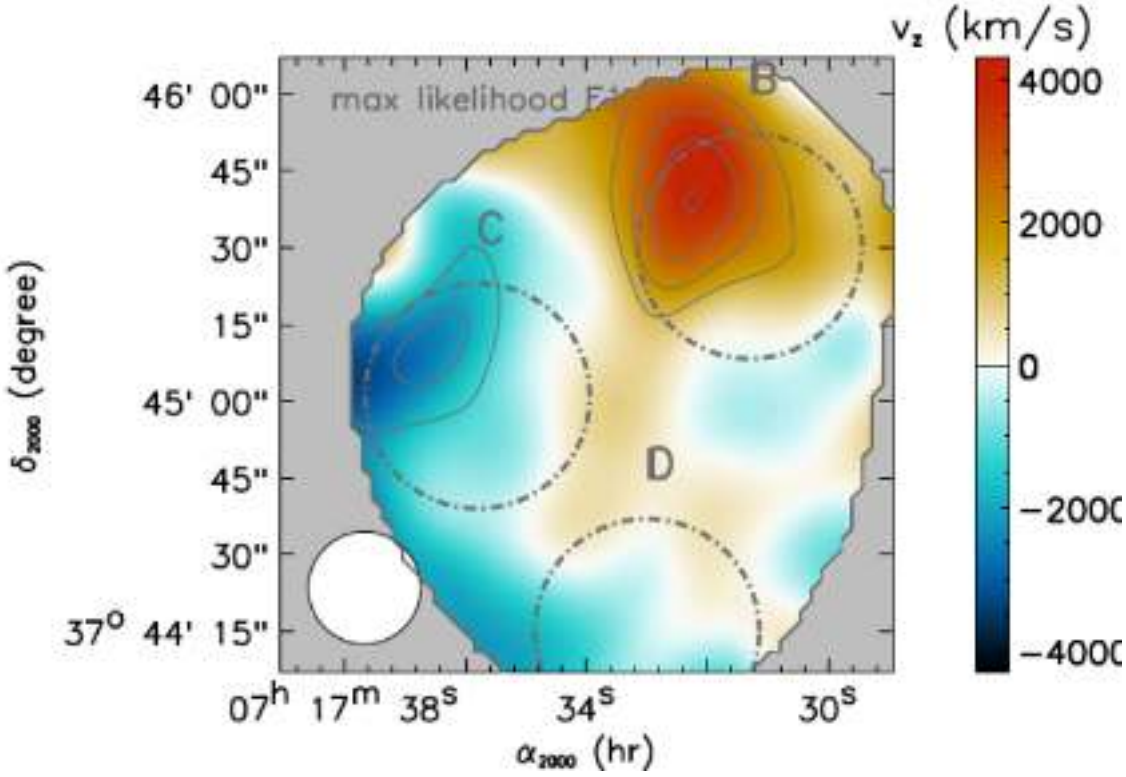
$$\frac{\Delta I_\nu}{I_0} = f_\nu \, y_{\rm tSZ} + g_\nu \, y_{\rm kSZ}$$

spectral dependencies

gas pressure

gas velocity and density

MACS J0717-3745 velocity map

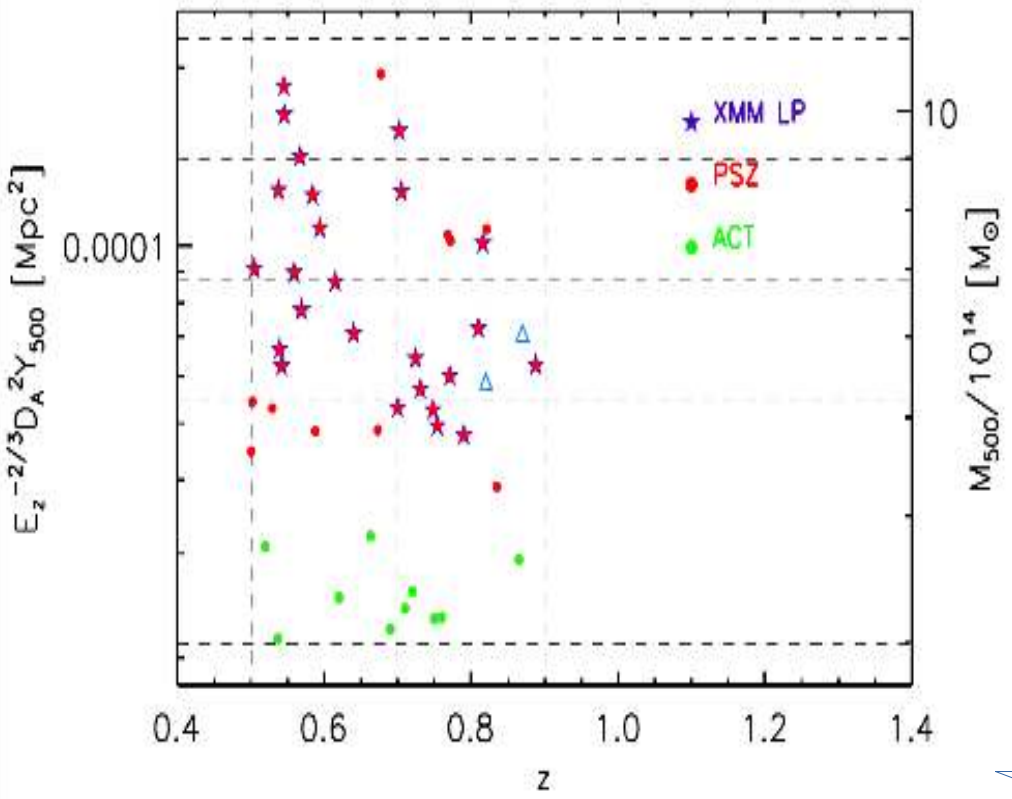


First direct mapping of kSZ emission

[Adam & NIKA collaboration, 2016]

NIKA2 SZ Large program

[Comis+2016, JFMP+2017, Mayet+2020]



One of the 5 NIKA2 LP (1300h in total)

- **300 hours** of tSZ observation
- **45 high redshift clusters 0.5 < z < 0.9**
- tSZ selected clusters from Planck and ACT catalogues

Ancillary data

- X-ray follow-up with XMM
- Optical data using GranTeCan
- MUSIC hydrodynamic simulations

Main goals

- In-depth study of ICM
- Thermodynamic properties: pressure, density, temperature and entropy profiles
- Mass – tSZ flux relationship

Redshift evolution of:

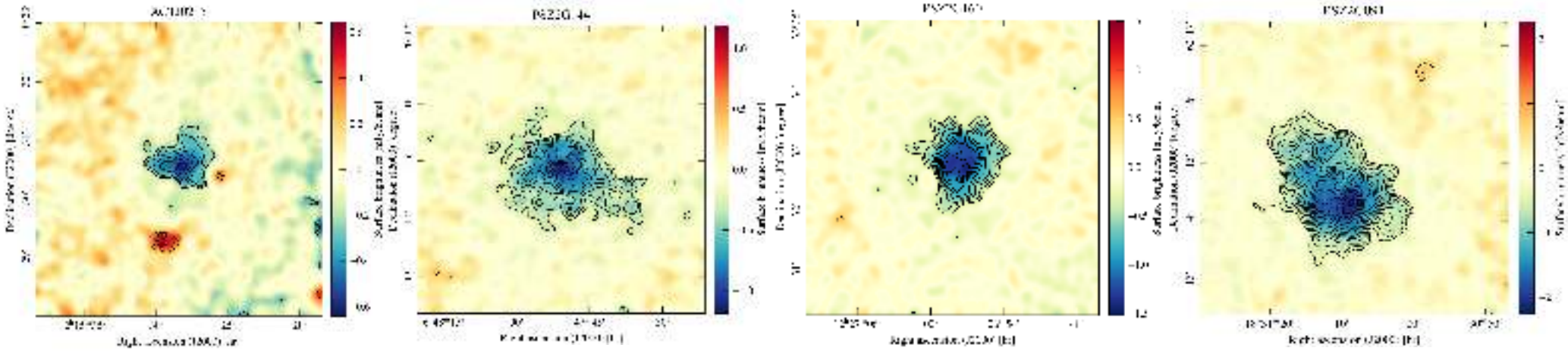
- Thermodynamic quantities profiles
- Scaling laws and hydrostatic bias

Variation of cluster properties with:

- Dynamical state (mergers)
- Morphology (ellipticity)

Observed NIKA2 LP SZ clusters

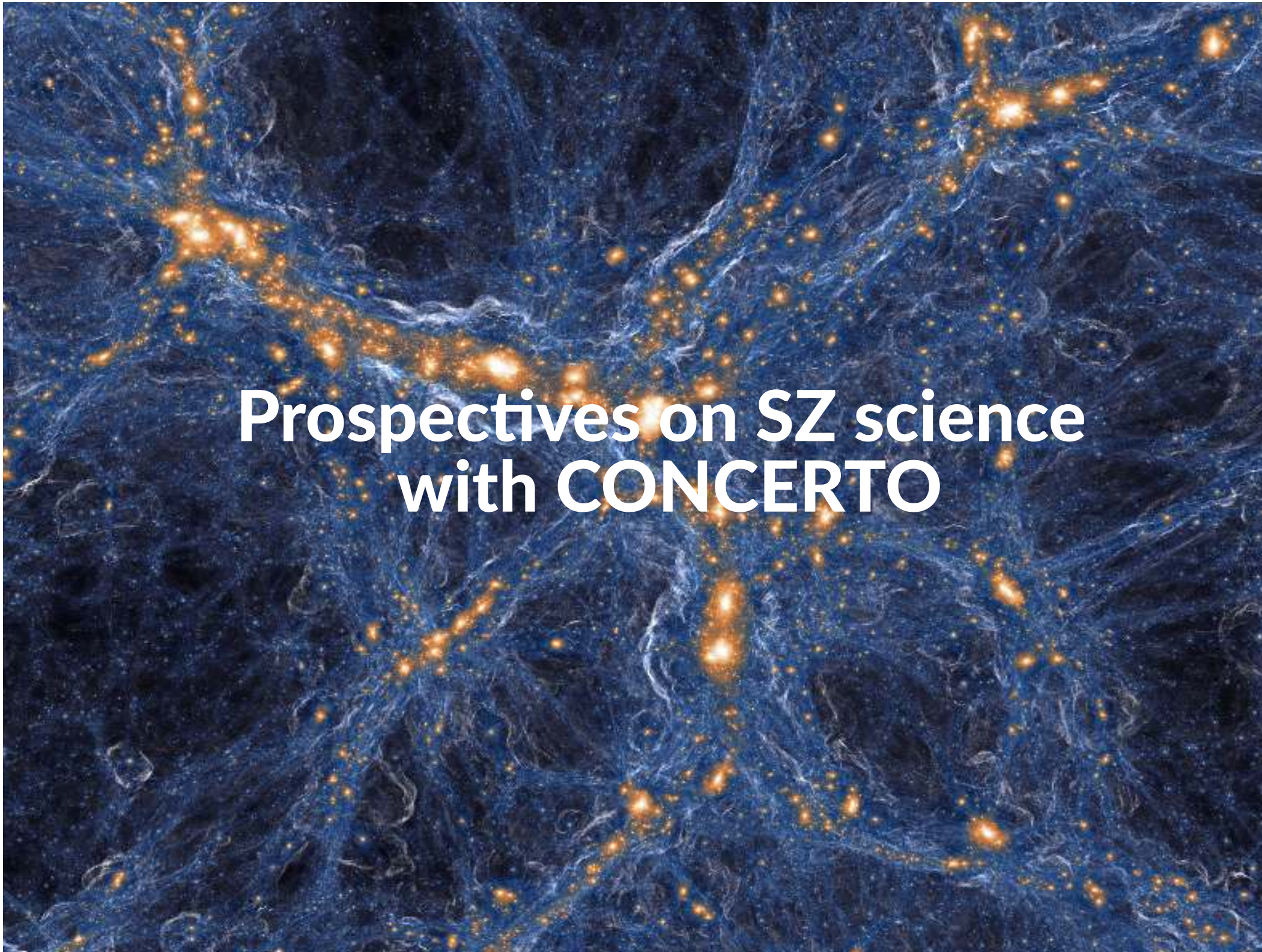
All clusters have been observed and 4 clusters already published individually



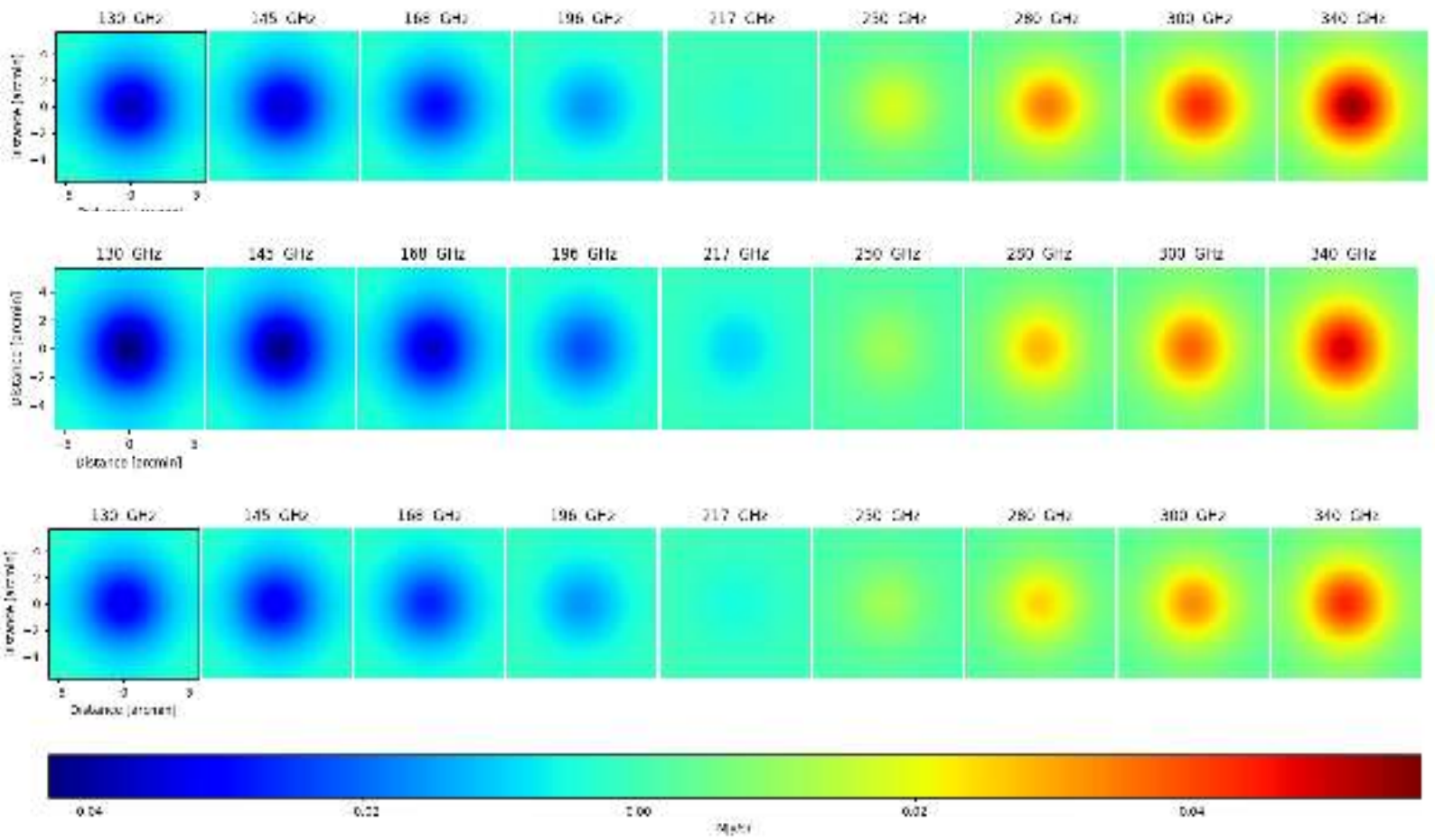
Ruppin+2018, Kéruzoré+2020, Muñoz-Echeverría+2022, Artis+2022

Clusters observations fully completed finished since yesterday !!!

Our PhD students (Miren, Corentin & Alice) will be happy
to come to tell you more about LPSZ and cluster cosmology


Prospectives on SZ science
with CONCERTO

Spectral imaging SZ science

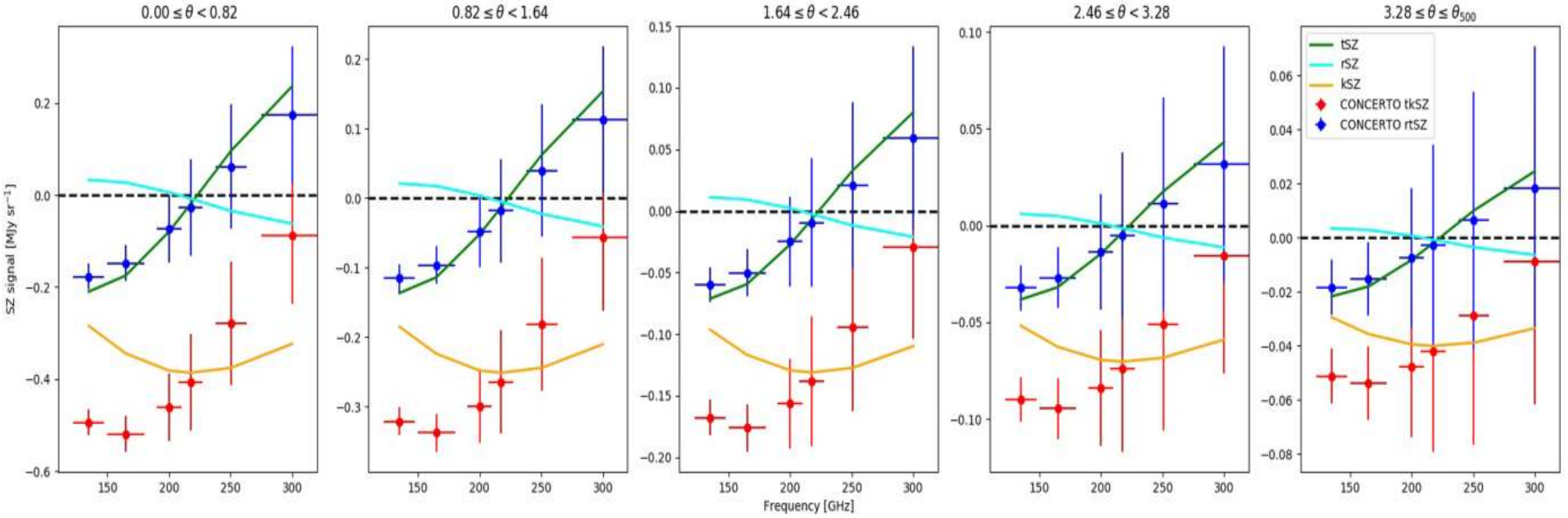


Direct mapping of cluster pressure, temperature and velocity distributions via the tSZ, kSZ and relativistic corrections

CONCERTO SZ performance

SZ effect for a simulated cluster at redshift z = 0.4, with a mass of 10^{15} M_{sun} and a temperature of 20 keV, which is moving at 1000 km/h towards the observer.

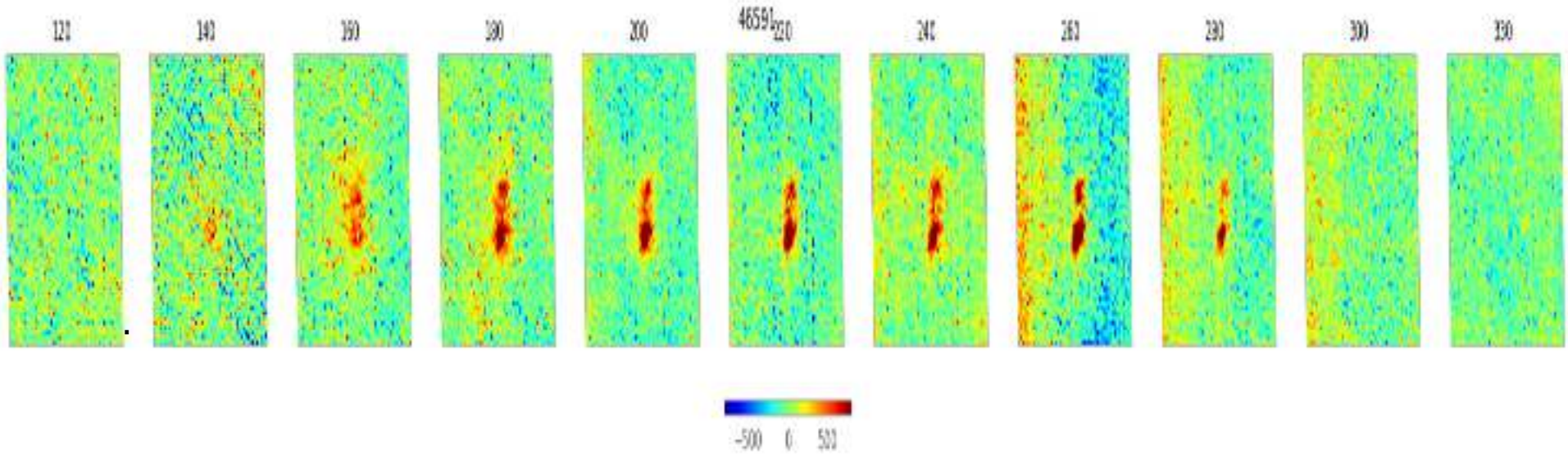
Concerto collaboration+2022.



Four clusters alreday observed with CONCERTO for more than 300 hours

First spectroscopic results with CONCERTO

Un-calibrated single scan (few minutes integration) spectroscopic maps of the Orion Nebula (pilot diffuse emission project)



Sensitivity as expected, need still to work more on data processing pipeline & SZ specific analyses

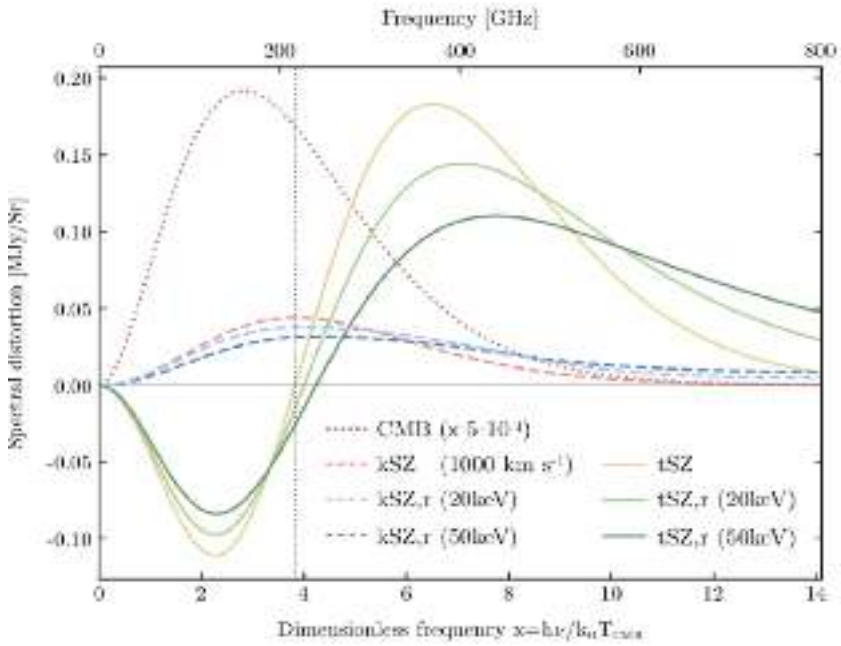
Conclusions

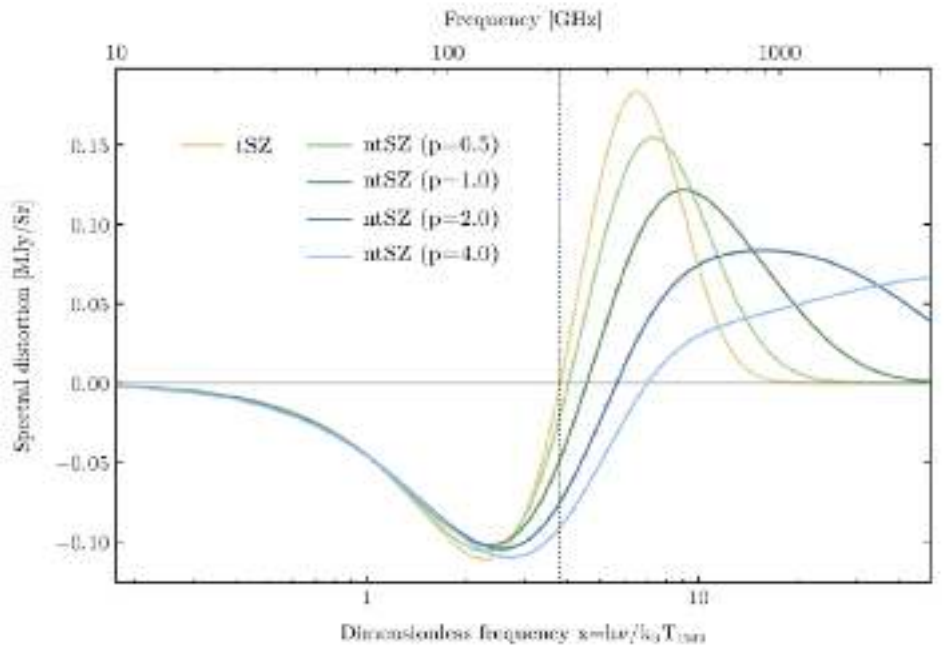
- Current science drivers in mm astronomy and cosmology needs high sensitivity and wide-field multi-color observations with large arrays of detectors
- KIDs have achieved sufficient technical maturity to be a credible option to build those large arrays (tens of thousands pixels) of photon noise limited detectors
- Cluster physics and cosmology via the SZ effect are a target of choice for KID cameras
- NIKA first, and now NIKA2, have demonstrated that KID based mm cameras can achieve state-of-art performance for SZ science
- A new generation ground-based mm spectrometers are possible thanks to KIDs technology: KISS already installed and CONCERTO should come soon
- KID activities in Grenoble are now organized in a GIS (Groupement d'Intérêt Scientifique) to try to tackle new challenges in CMB science

Sunyaev-Zeldovich (SZ) effect

$$\Delta I_\nu^{th} + \Delta I_\nu^{kin} + \Delta I_\nu^{rel} + \Delta I_\nu^{non-th} + \Delta I_\nu^{pol} + \Delta I_\nu^{m-scat}$$

Thermal | Kinetic | Relativistic corrections | Non-thermal | Polarised | Multiple Scattering





Mroczkowski+2019