Galaxy cluster cosmology in Enigmass

Marina Ricci (postdoc @ LAPP)
on behalf on the Rubin, NIKA2 and Euclid members at LAPP & LPSC
Thank you to all the contributors: C. Combet, J. F. Macías-Pérez, F. Mayet, L. Perotto

Première Assemblée Générale Enigmass2

The Bullet cluster
Credits : Markevitch, Clowe et al
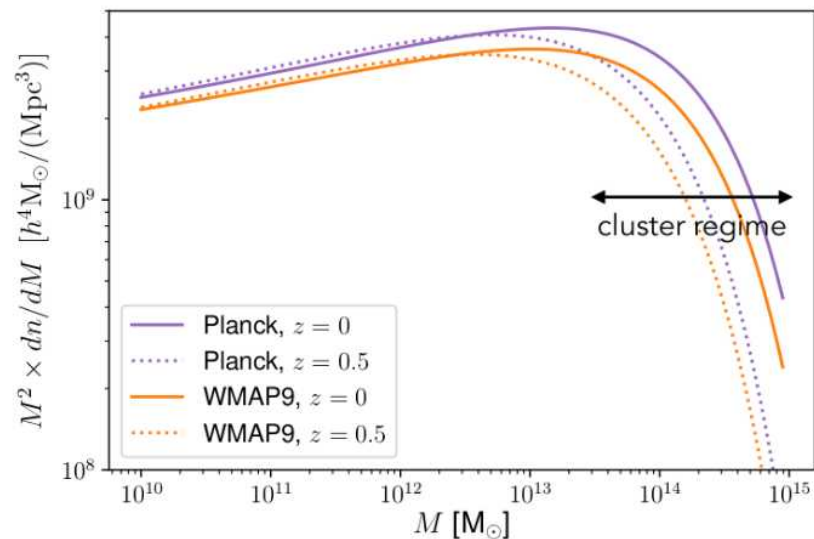
Galaxy clusters as powerful cosmological probes

Clusters **trace the matter** density field

> **Most massive objects that collapsed under their own gravity**
> Typical mass : ~10^{14-15} M_{sun} and size : ~1 Mpc

Credits : Angulo & White
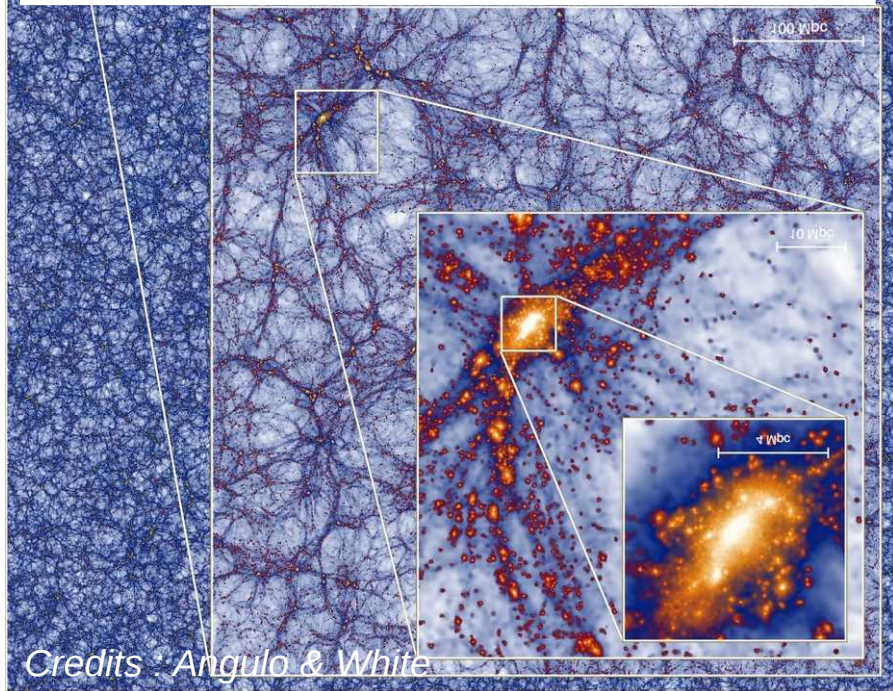
their number as a function of mass and z can be used to **constrain cosmology**
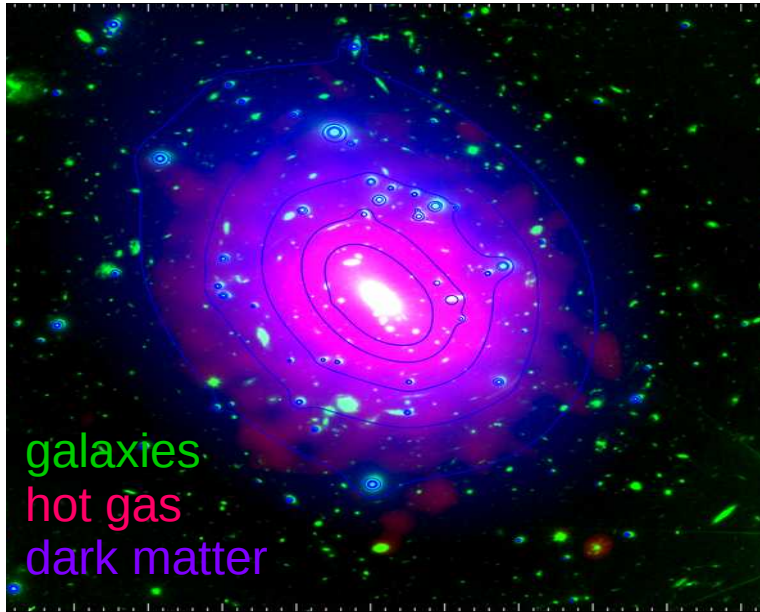

- Growth of structures
- Gravitation law
- Dark energy e.o.s
- Sum of neutrino masses

also DM properties, expansion rate, structure formation scenario...

Galaxy clusters as rich astrophysics laboratories

Clusters are multi-wavelengths objects

galaxies
hot gas
dark matter

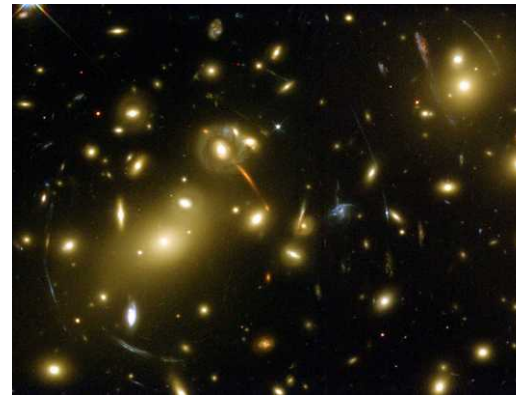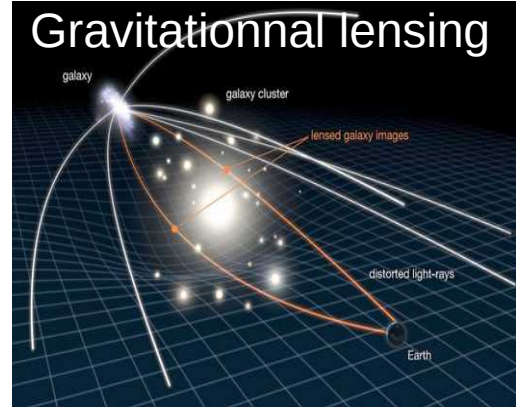*[Adapted from Adam et al 2016]*

~ **5 % of galaxies**

- **Optical/IR : stellar light emission**

- (+ FIR to mm & Radio/X-ray)

~ **15 % of hot gas**

- **mm : Sunyaev-Zel'dovich effect**

- X-ray : thermal bremsstrahlung
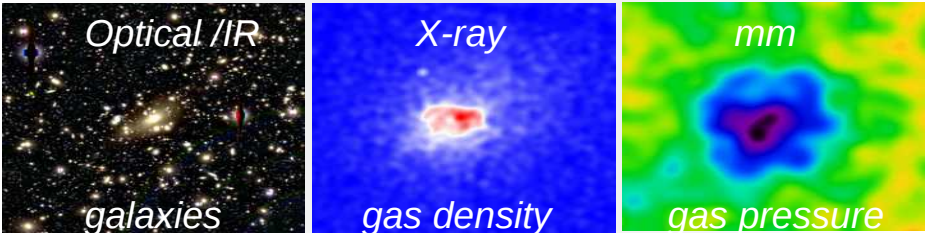
~ **80 % of dark Matter**

- Distribution indirectly accessible from **gravitational lensing**

Gravitationnal lensing

Using clusters for cosmology requires to model the connection between the dark matter, gas and galaxies

Constructing a cosmological cluster sample

Detection from survey

Optical /IR — galaxies

X-ray — gas density

mm — gas pressure

Selection function

Representativity of detected clusters wrt the underlying population

Cluster catalogue

Mass determination

Observable : e.g. richness, SZ signal

Calibration from sub-samples with mass measured via e.g. gravitational lensing

true relation

bias+scatter

log(observable)

log(mass)

Scaling relation
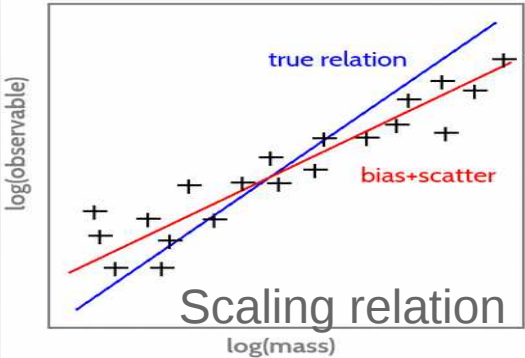
Redshift determination

possible internally (in optical/IR) or via spectro follow-ups

The selection function and the mass determination are critical aspects

Status & future of cluster cosmology

- **Observed deficit in clusters counts** wrt expectations from early Universe probe : b**reakdown** of our cosmological model or **mismodelling of cluster physics** ?
- Combine info from complementary instruments : ≠ cluster components, with ≠ systematics

Future large cluster survey

Vera C. Rubin Obs. optical
LAPP/LPSC
Credits : Todd Mason/LSST

Euclid NIR
LPSC
Credits : ESA

+ eROSITA in X-ray, CMB-S4 in mm (SZ)...

Current follow-up instruments

NIKA2 @ IRAM-30m mm (SZ)
LPSC

+ XMM & Chandra in X-ray, spectro...

Control detection, mass/z determination & selection function in the optical/NIR, mm & X-ray

Clusters in the optical: the Vera Rubin Observatory

> Cosmological analyses in the *Dark Energy Science Collaboration* (DESC)
> Clusters : one of the 5 main probes for DESC **(> 300k detection expected at z<1.2)**
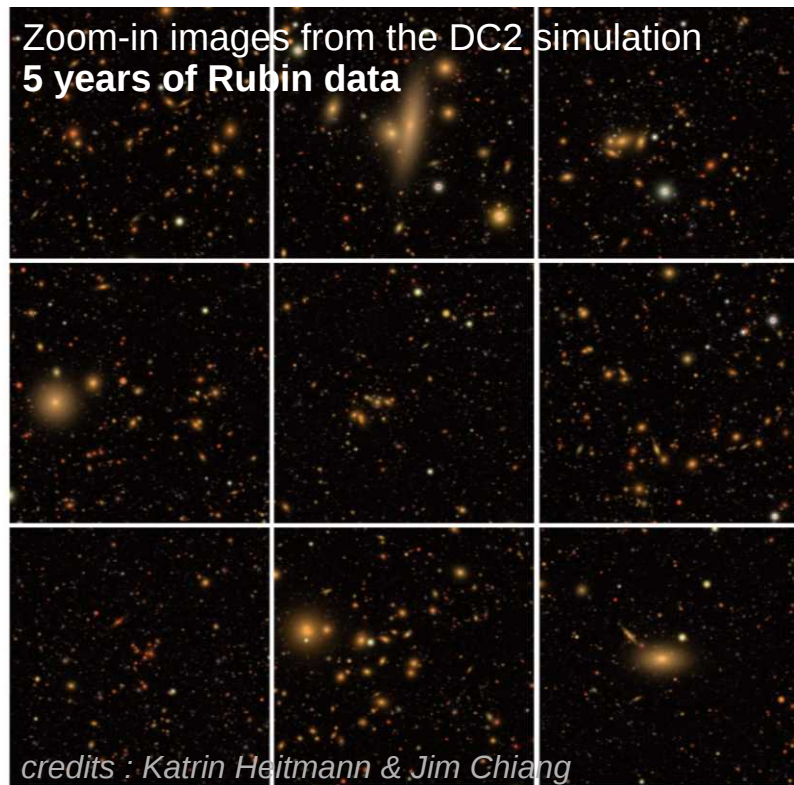> Need to **control all the steps from raw images to cosmological constraints**

Main activities at LAPP & LPSC (4 axes):

1) Robust galaxy catalogs from multi-band photometry

- **test Rubin image processing** in cluster fields *[D. Boutigny, N. Chotard]*

- build-up and validation of the **DC2 DESC simulation** *[DESC et al. 2020]*

2) Cluster detection and sample selection function

- **performances of the redMaPPer** detection algorithm in DC2 *[M. Ricci]*

- detection with **alternative algorithm** in DC2 *[M. Aguena]*

Zoom-in images from the DC2 simulation
5 years of Rubin data

credits : Katrin Heitmann & Jim Chiang

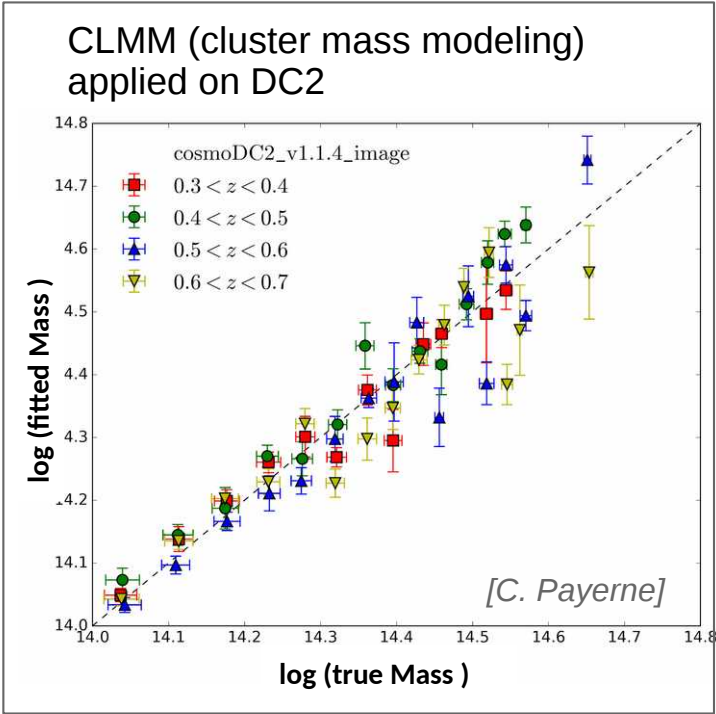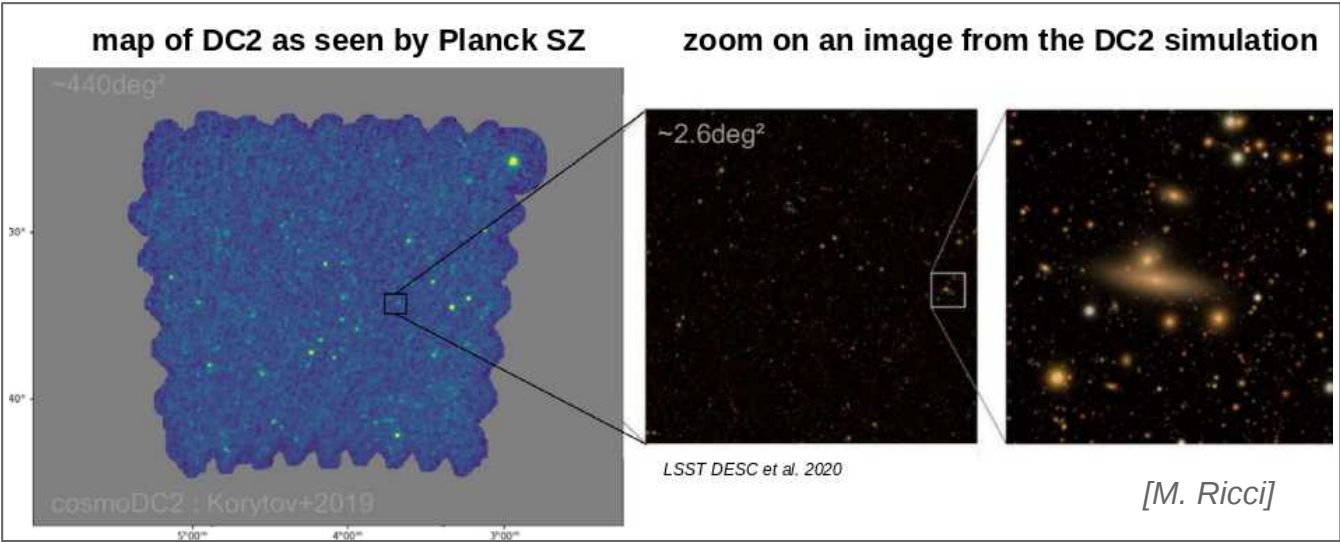# Clusters in the optical: the Vera Rubin Observatory

Main activities of the teams (4 axes):

3) Cluster mass measurement from gravitationnal lensing

- codes to model and derive masses : **CLMM** *[M.A, C.P, M. P, M. R, co-led by C. Combet]* and *NumCosmo [M. Penna Lima]*
- application on DC2 using **shear** *[C. Payerne PhD]* and **magnification** *[M. Ricci]*

4) Developpment of multi-wavelenghts analyses

- physics of observed high z clusters *[Ricci et al. 2020]*
- creation and analyses of **X-ray + SZ counterparts of DC2** *[M.R]*

map of DC2 as seen by Planck SZ

~440deg²

30°

40°

cosmoDC2 : Korytov+2019

5ʰ00ᵐ 4ʰ00ᵐ 3ʰ00ᵐ

zoom on an image from the DC2 simulation

~2.6deg²

LSST DESC et al. 2020

[M. Ricci]

CLMM (cluster mass modeling) applied on DC2

cosmoDC2_v1.1.4_image
- $0.3 < z < 0.4$
- $0.4 < z < 0.5$
- $0.5 < z < 0.6$
- $0.6 < z < 0.7$

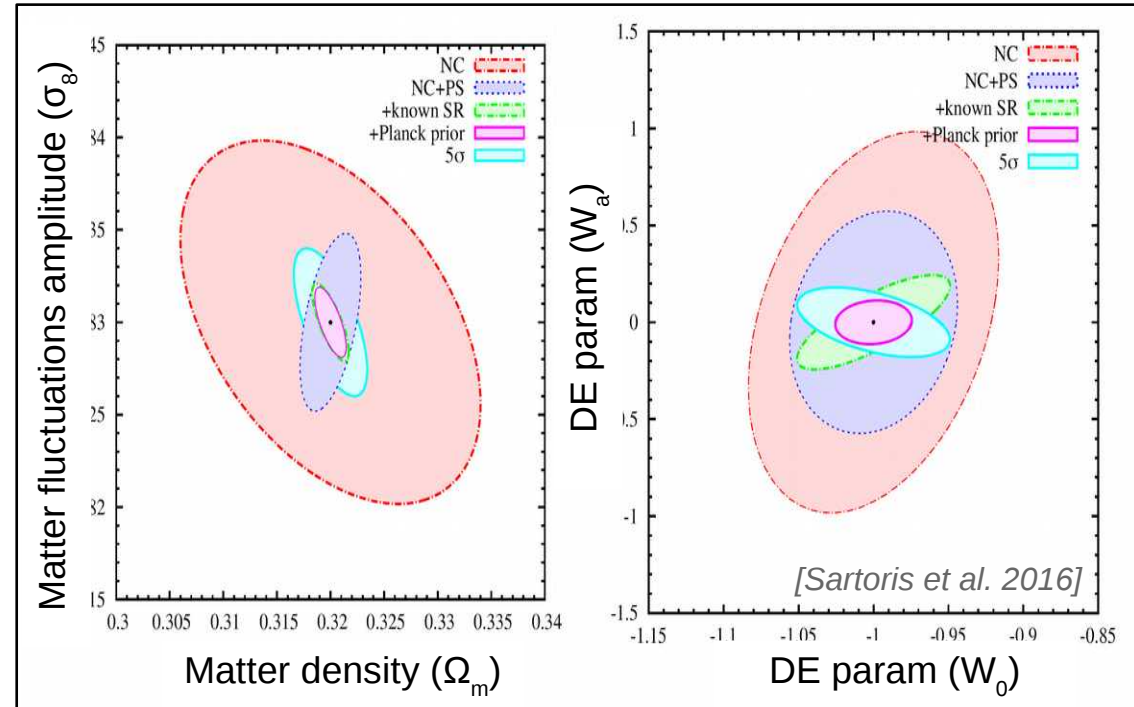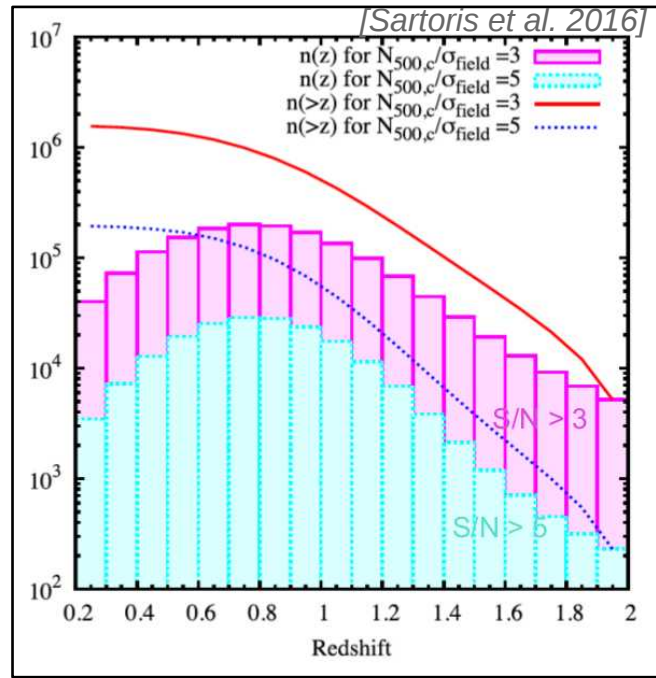log (fitted Mass)

log (true Mass)

[C. Payerne]

Clusters in the optical & infrared: EUCLID

Perfect instrument for high redshift cluster

- Large sky coverage: north and south
- Strong synergy with other satellite missions (e.g. Planck, e-Rosita) and ground based telescope (e.g. Rubin Obs.)
- Detection of > **200k clusters** at 0.2<z<2

- Mass estimates from lensing + velocity dispersion
- Cosmo constraints from cluster number counts & spatial distribution
- **Tight constraints** expected on **structure formation** and **dark energy** equation of state

[Sartoris et al. 2016]

n(z) for $N_{500,c}/\sigma_{field}$ =3
n(z) for $N_{500,c}/\sigma_{field}$ =5
n(>z) for $N_{500,c}/\sigma_{field}$ =3
n(>z) for $N_{500,c}/\sigma_{field}$ =5

S/N >3

S/N> 5

Redshift

Matter fluctuations amplitude (σ_8)

NC
NC+PS
+known SR
+Planck prior
5σ

Matter density (Ω_m)

DE param (W_a)

NC
NC+PS
+known SR
+Planck prior
5σ

DE param (W_0)

[Sartoris et al. 2016]
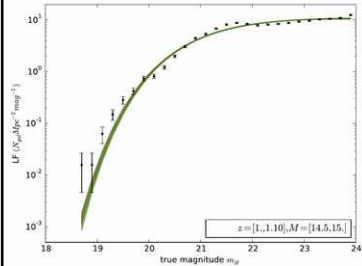
Clusters in the optical & infrared: EUCLID

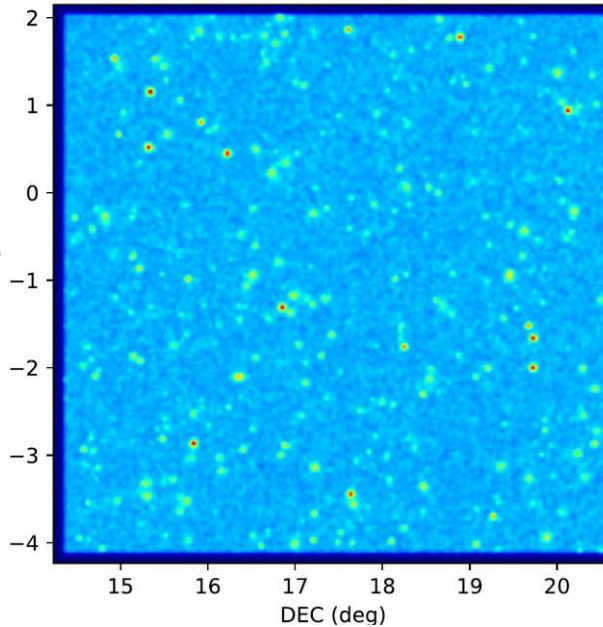**Two main axis of current work @ LPSC** (A. Jiménez-Muñoz PhD)

1. Cluster injection for selection function:
   produce simulation on clusters based on EUCLID measured cluster properties
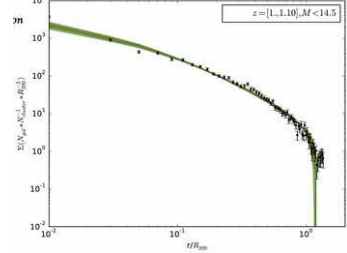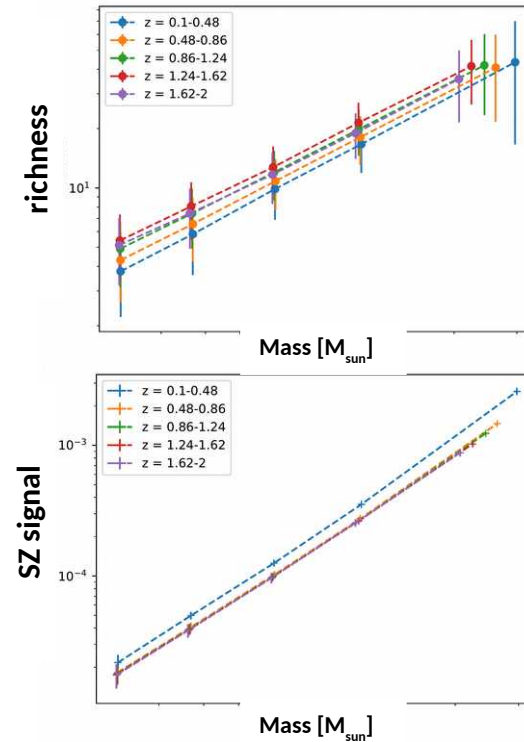
   Luminosity function

   3D galaxy distribution

2. Cluster mass estimation using SZ signal:
   produce scaling relation relating SZ signal to richness, needed for very high redshift clusters
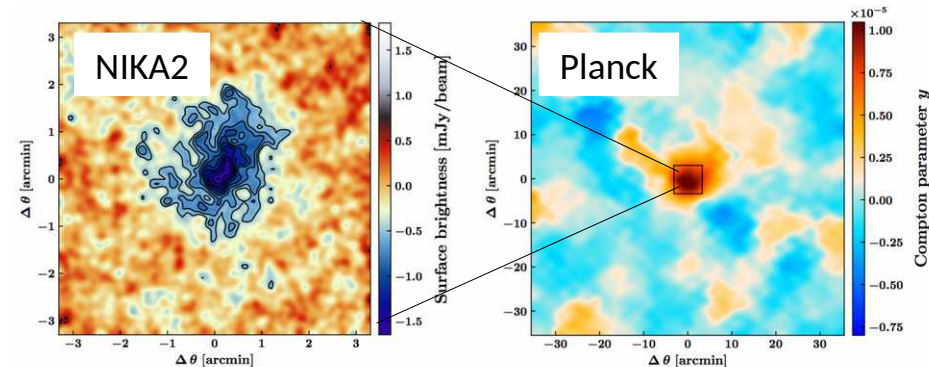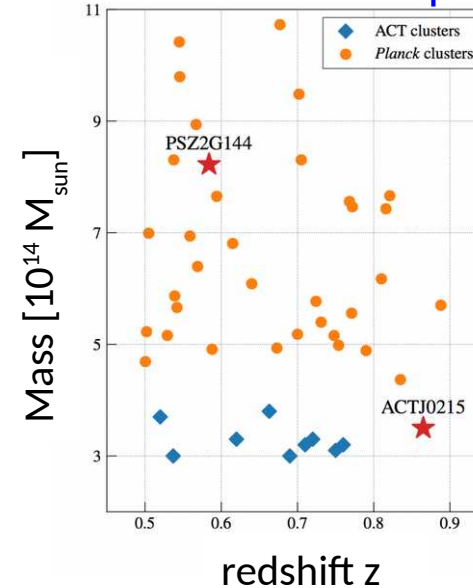
Cluster cosmology with the NIKA2 camera

LPSZ : SZ Large program

- 300 hours of guaranteed time for SZ effect observations
- A sample of 45 clusters selected in SZ from Planck & ACT catalogs
  (20 already observed - end of the program in 2024)
- Complementary X-ray data and hydro simulation in hands

Main Goals :

- Measure mass and redshift evolution of :
  - Mass - SZ signal scaling relation
  - mean pressure profile and scatter
  - Thermodynamic properties (P,T, ne, K)
- Assess the impact of the dynamical state of clusters
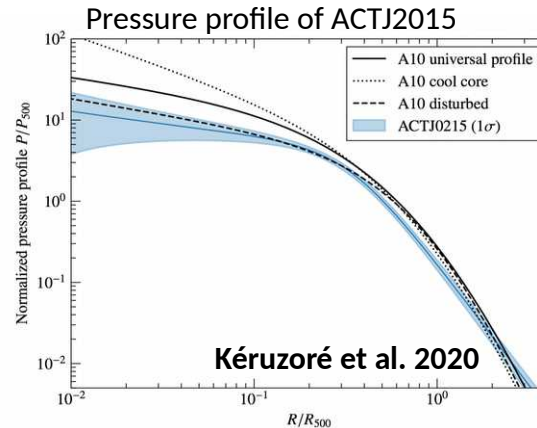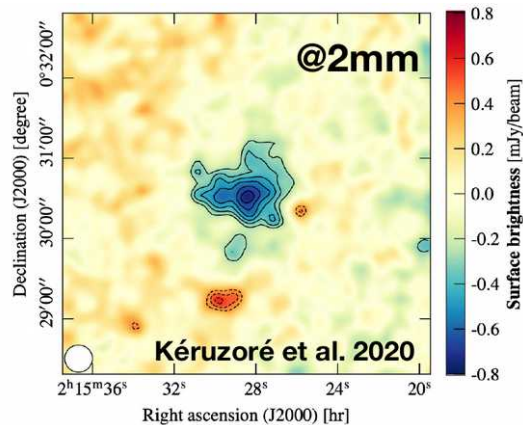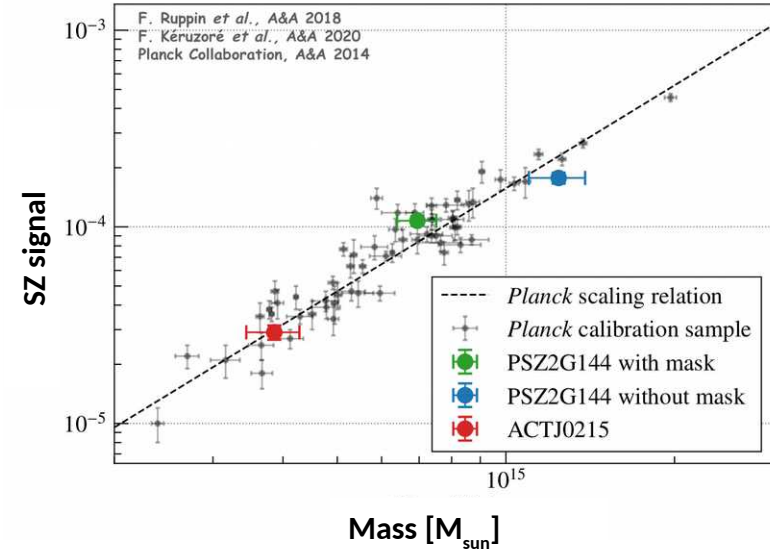
LPSZ Cluster sample

Disturbed cluster (MUSIC simulation) as seen by Planck & NIKA2 : high-resolution needed !
F. Ruppin et al., A&A 2019

Cluster cosmology with the NIKA2 camera

LPSZ : very promising recent results

- Detailed instrumental characterization

  => sensitivity better than expected [*L. Perotto et al. 2020*]

- **Mass determination for two extreme clusters**

  PSZ2G144 [*F. Ruppin et al. 2018*] & ACTJ2105 [*F. Kéruzoré et al. 2020*]

  => study induced systematics

- Full **SZ analysis pipeline ready** [*F. Kéruzoré PhD*]

- Fruitful external collaborations [*~10 papers in 2020*]

- Successful '*mm Universe with NIKA2*' conference at LPSC in 2019

F. Ruppin *et al.*, A&A 2018
F. Kéruzoré *et al.*, A&A 2020
Planck Collaboration, A&A 2014

- - - *Planck* scaling relation
- *Planck* calibration sample
- PSZ2G144 with mask
- PSZ2G144 without mask
- ACTJ0215

SZ signal / Mass [M_sun]

@2mm — Kéruzoré et al. 2020

Pressure profile of ACTJ2015

- A10 universal profile
- A10 cool core
- A10 disturbed
- ACTJ0215 (1σ)

Kéruzoré et al. 2020

Small departure from the Universal Pressure Profile

=> disturbed cluster

=> need more clusters to draw conclusion

Summary and take home messages

Galaxy clusters

- Clusters : powerful tools to **test cosmological models**

- **Rich laboratories** to understand the **complex physics of the dark matter, gas and galaxy connection**

- Cosmo analyses **affected by systematics** from astro processes : **combining data and sims at different wavelenghts & scales** is key
  [Combet et al. for the in3p3 2020 prospectives]

LAPP/LPSC

LPSC

LPSC

Involvement of the Enigmass teams in two main cosmological suveys and a state-of-the art follow-up instrument :

complementary approach and high potential for synergies