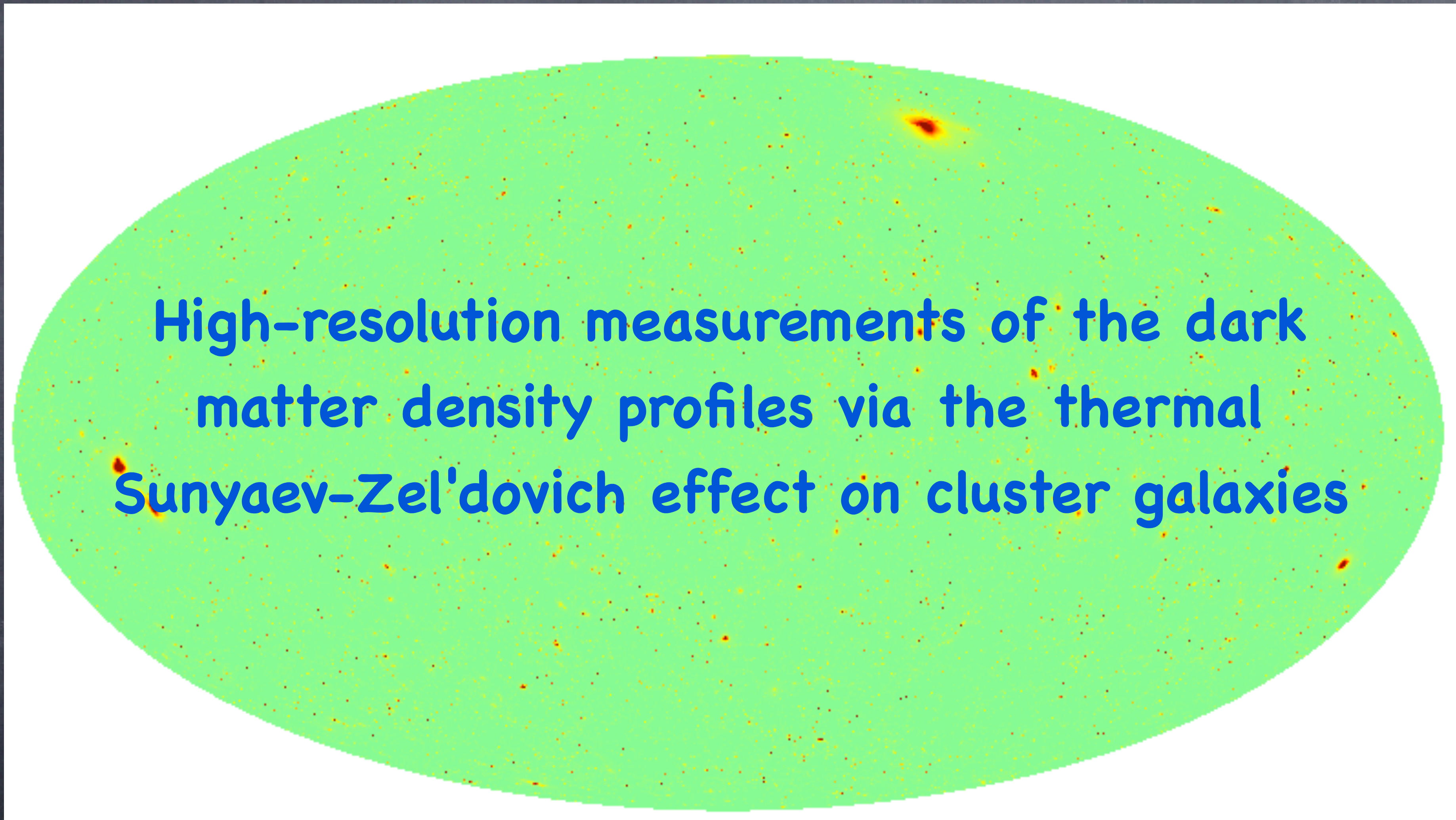
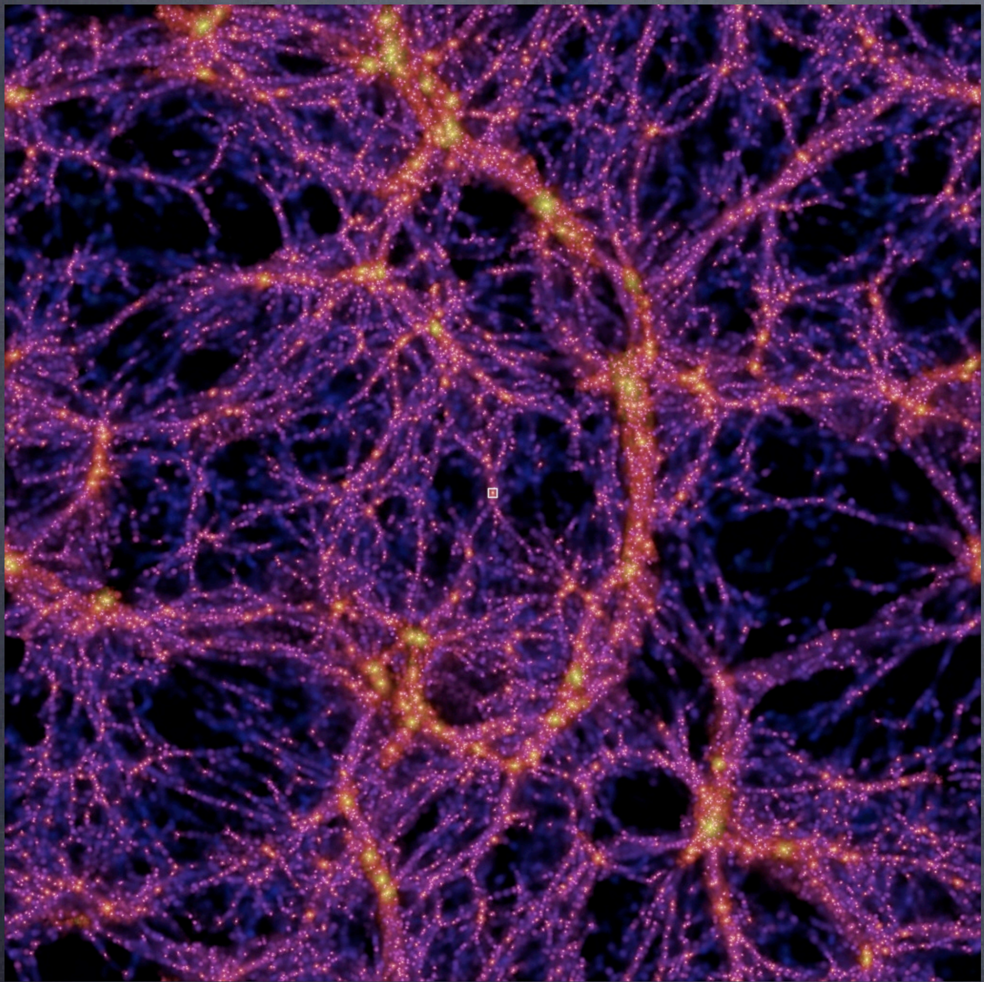


High-resolution measurements of the dark matter density profiles via the thermal Sunyaev-Zel'dovich effect on cluster galaxies

CONTEXT:
Matter distribution in the Universe: a simplistic picture



N-body simulations suggests that:

- dark matter is hierarchically distributed in halos connected by filaments

- the largest halos corresponds to galaxy clusters

- the density profiles in halos are universal and can be scaled with the size of the halo (NFW 1999)

The thermal Sunayev-Zeldovich (tSZ) effect

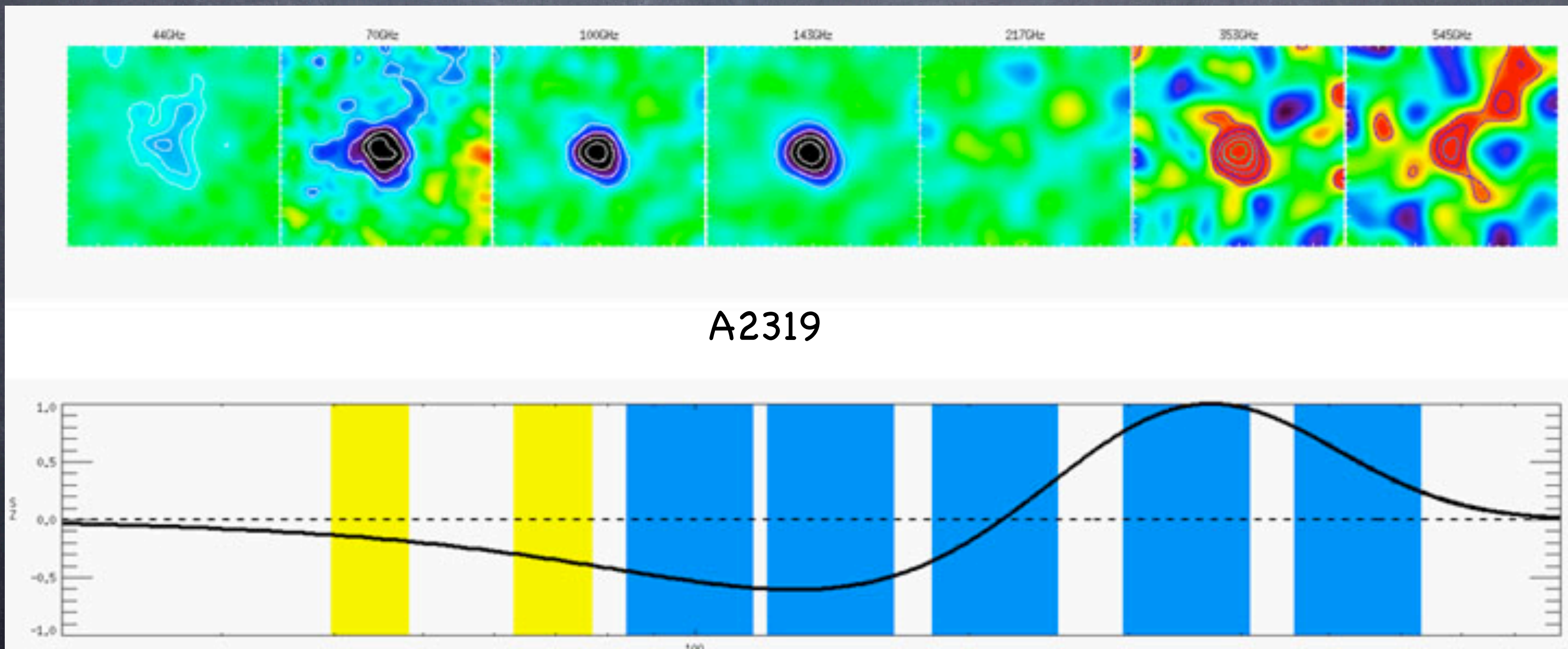
Inverse Compton between CMB photons and hot electrons on cluster of galaxies

$x = h\nu / (k_B T_{CMB})$

$$\frac{\Delta T_{TSZ}}{T_{CMB}} = f(x) y = f(x) \int n_e \frac{K_B T_e}{m_e c^2} \sigma_T d\ell$$

Example of tSZ effect on clusters as measured by Planck:

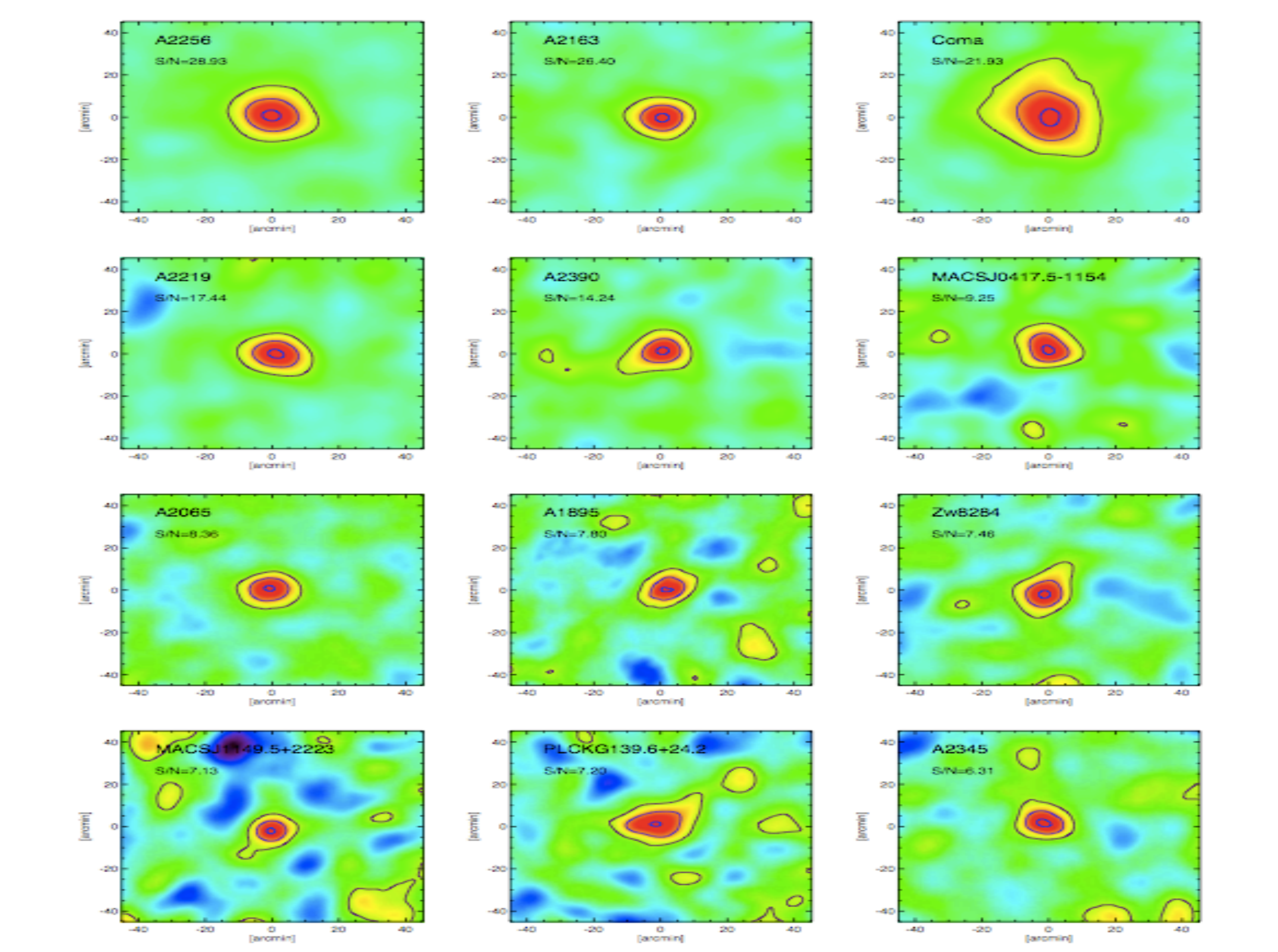
[Planck collaboration 2011]



The all-sky early Sunyaev-Zeldovich (ESZ) cluster sample

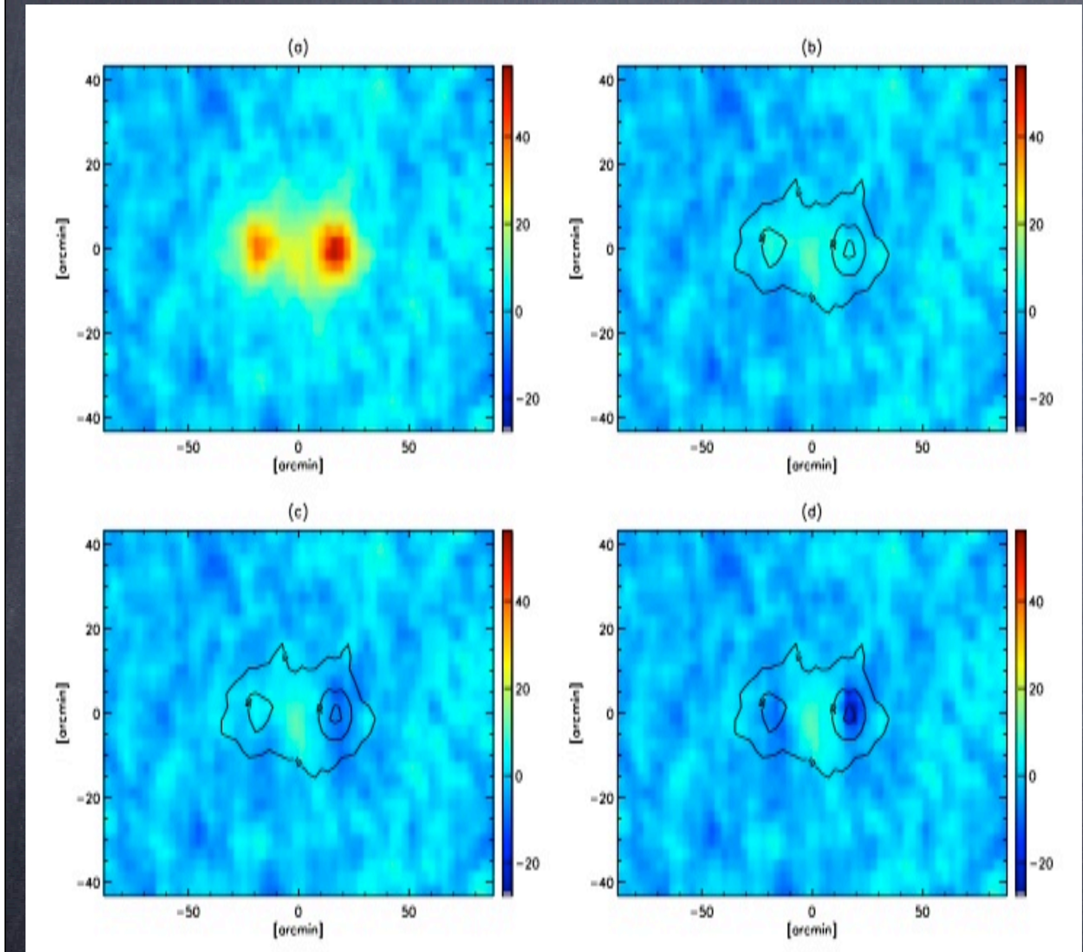
- 169 (already known) + 20 (new) robust cluster detections (S/N > 6)
  + 10 new extra clusters

[Planck collaboration 2011]

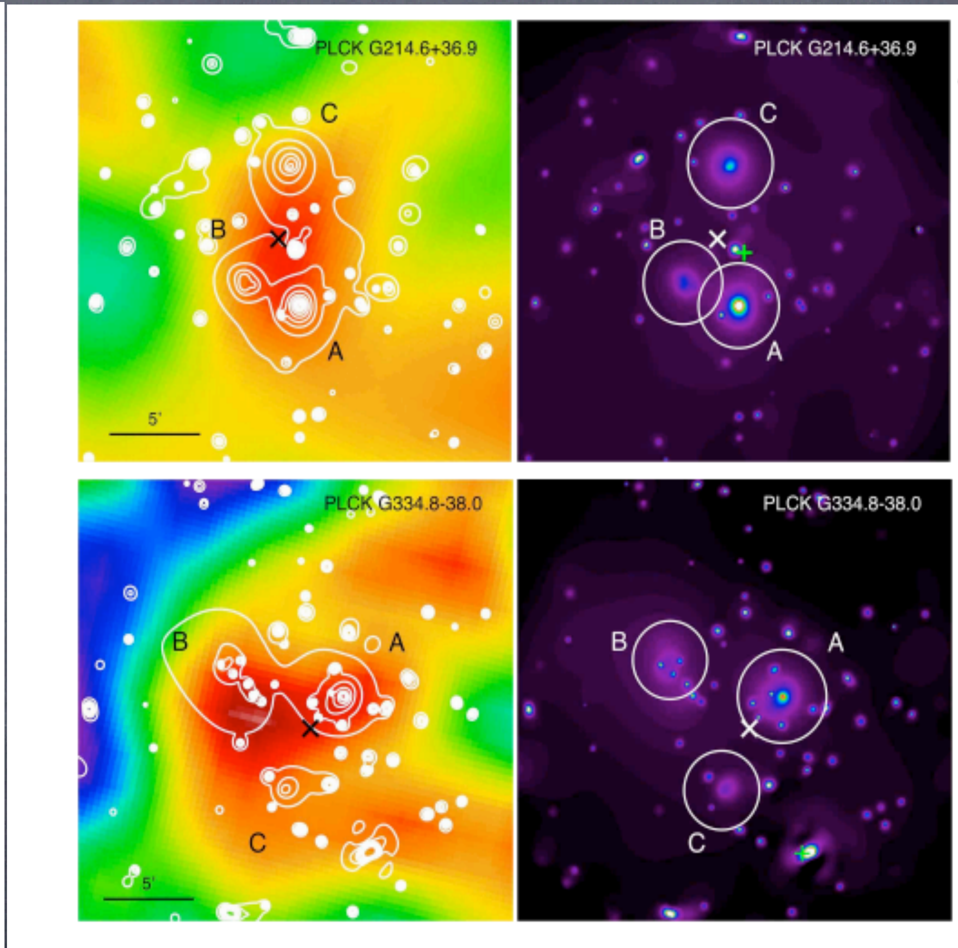


Multiple cluster systems and filaments

Planck resolved systems
A399-A401



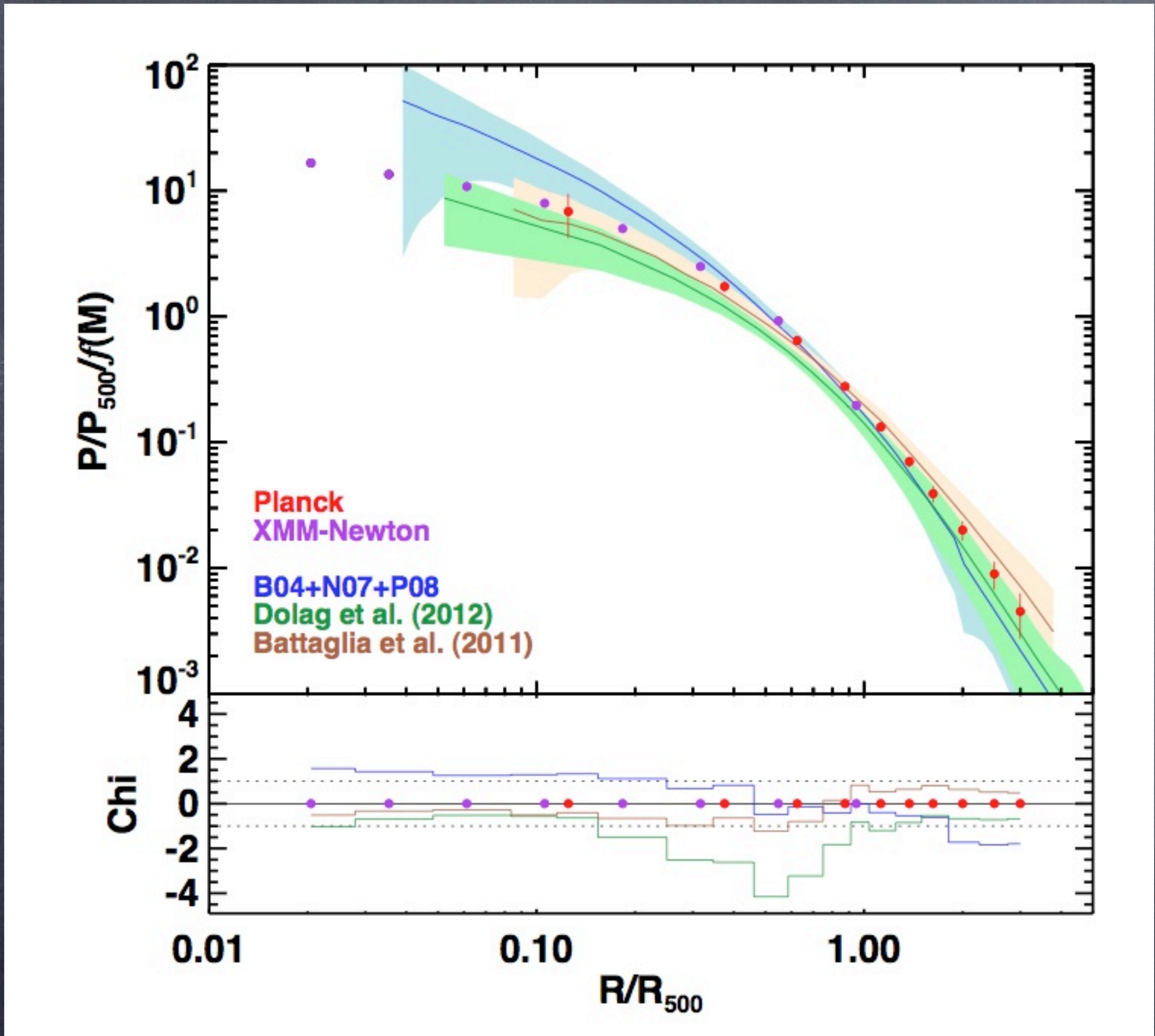
Planck unresolved systems
PLCK G214.6+36.9



[Planck collaboration 2012]

Planck measured galaxy cluster pressure profile

[Planck collaboration 2012]



$$y = \frac{\sigma_T}{m_e c^2} \int P(l) dl,$$

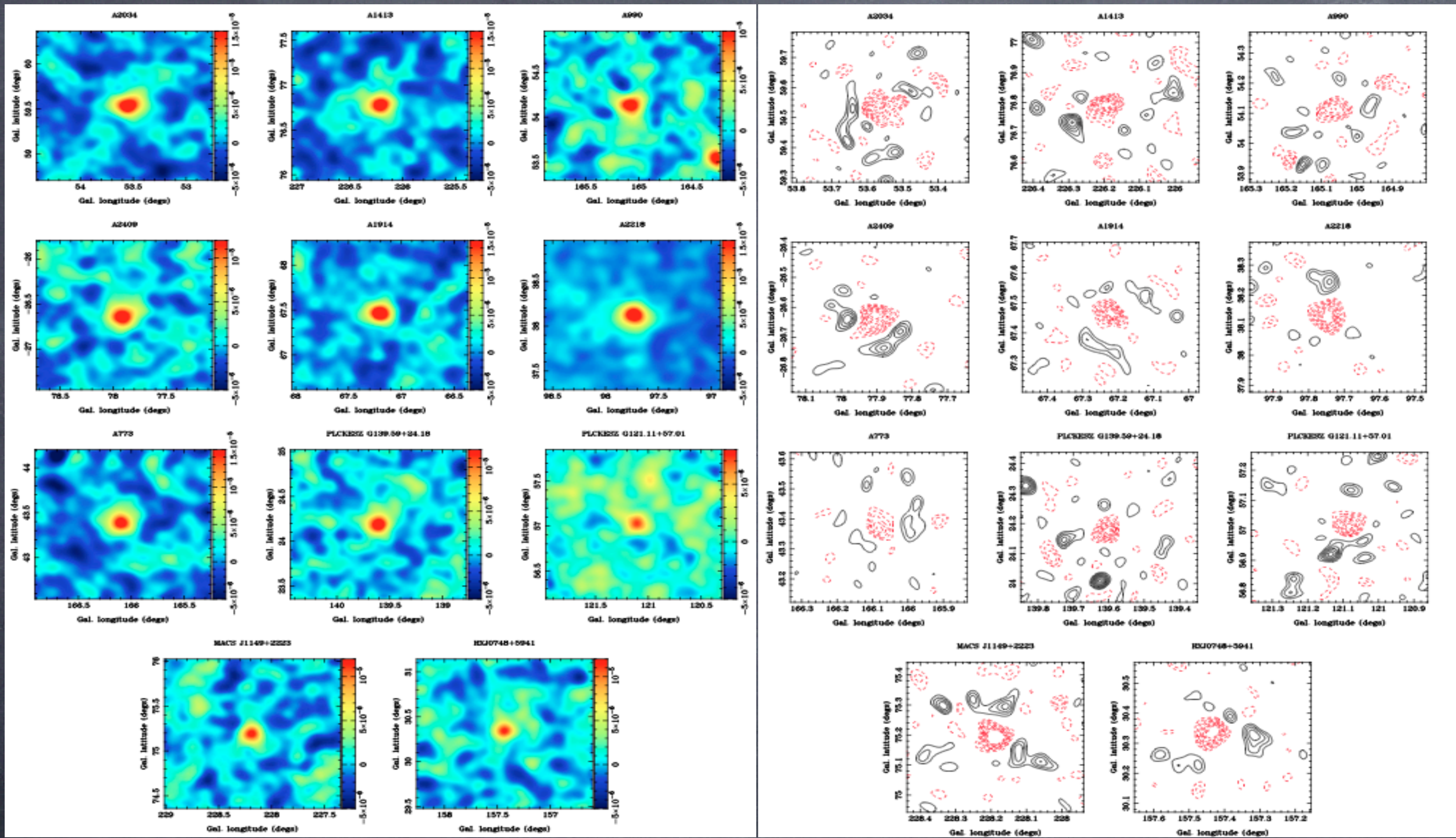
- 62 nearby massive clusters detected at high significance in the 14-month nominal survey

- the measured pressure profiles can be well represented by an universal profile

$$\mathbb{P}(x) = \frac{P_0}{(c_{500}x)^{\gamma}[1 + (c_{500}x)^{\alpha}]^{(\beta-\gamma)/\alpha}},$$

[P0, c500, γ, α, β] = [6.41, 1.81, 0.31, 1.33, 4.13]

Current tSZ high resolution observations with AMI



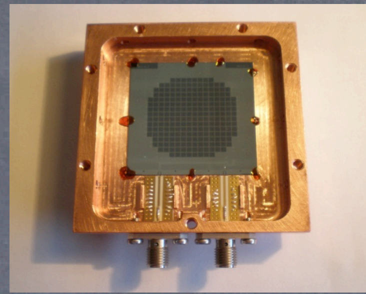
There is NEED for specific very high resolution observations with a dedicated instrument

Monfardini et al. 2010,2011
Bourrion et al. 2011,2012
Calvo et al. 2012

NIKA (New IRAM KIDs Array)

ANR funded

International consortium: Institut Neel, IPAG, LPSC, Cardiff University, SRON, IAS, CEA, APC ?



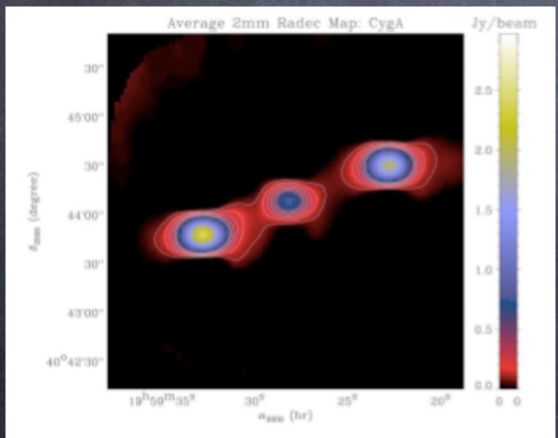
Instrumental design

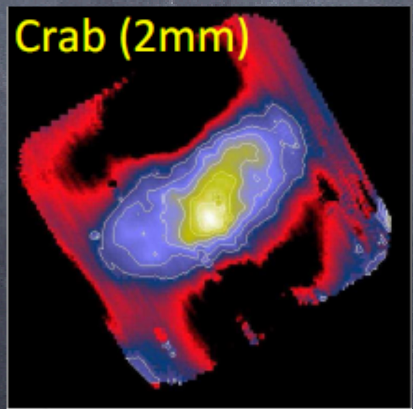
✓Camera for sky observations at mm wavelengths
✓Arrays of KIDs (Kinetic Inductance Detectors)
✓Two bands at 150 and 220 GHz
  144 LEKIDs (prototype) , 2000 MKIDs (camera finale)
Detectors cooled down to 70 mK (pulse-tube dilution cryostat)

Scientific goals

- Dedicated camera for the IRAM 30 m telescope (permanently installed already)
- Array of detectors for the new generation of CMB experiments

✓ 4 successful observational campaigns (2010 -2012)

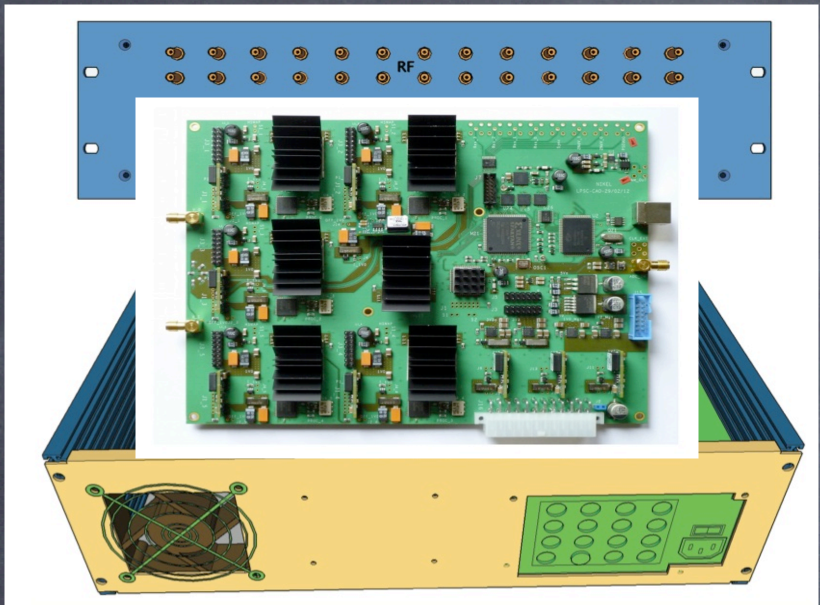


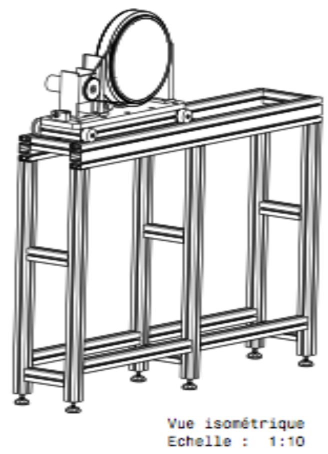


✓ The 2012 observation campaign (November) in preparation

NIKA at LPSC

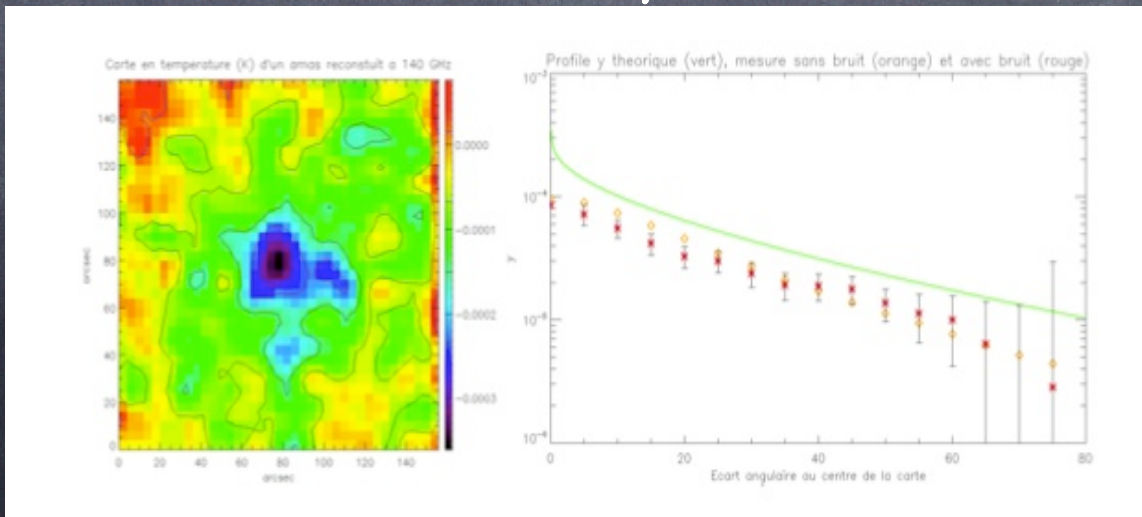
In charge of the readout electronics



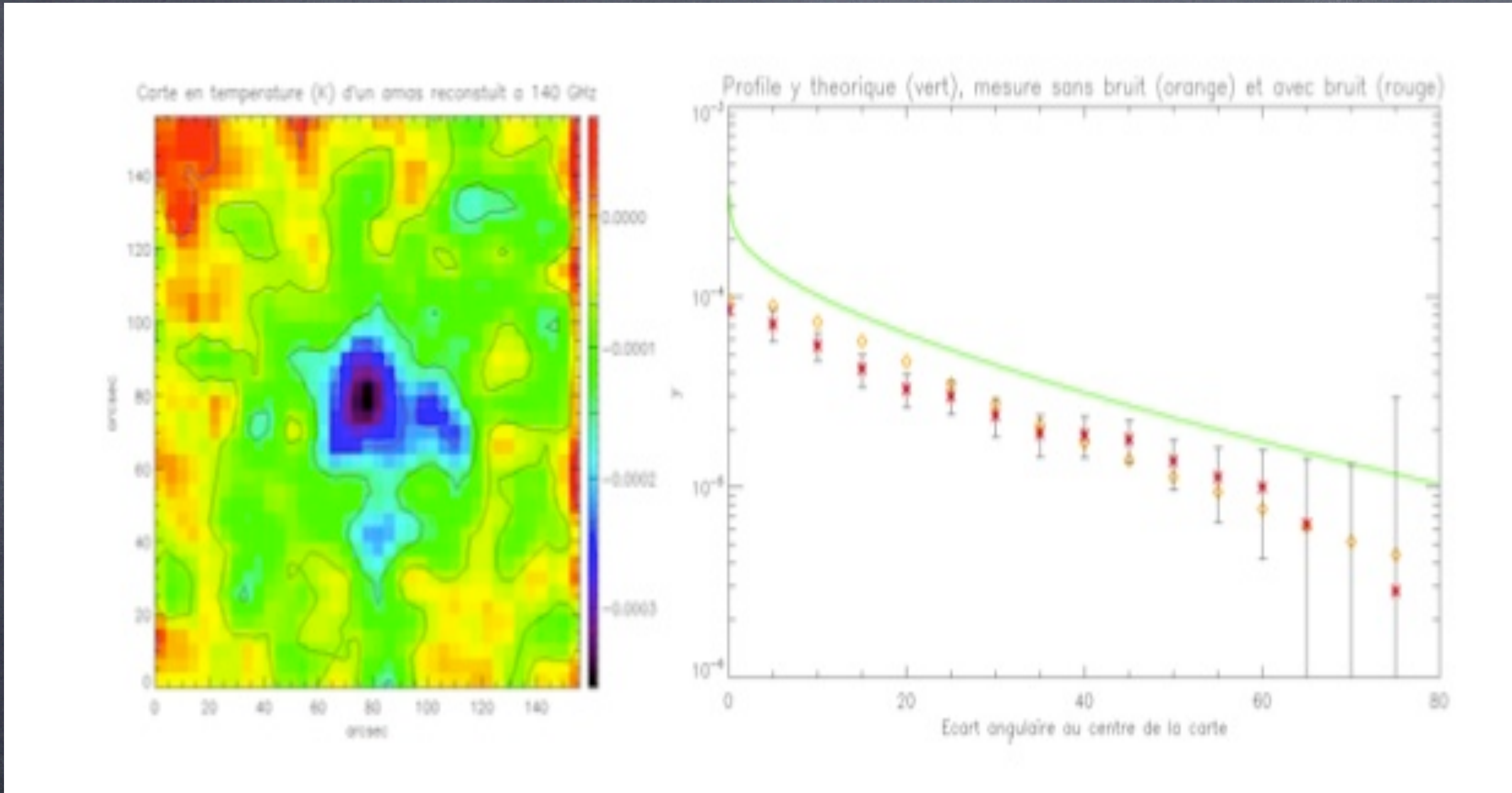


Polarization measurements

Data analysis



NIKA tSZ sensitivity



Detailed reconstruction of the pressure profile even for high redshift clusters

ENIGMASS Postdoc position (3 years)

WHY A POSTDOC ?

- tSZ measurements with Planck and NIKA open a new window for structure formation studies
- Grenoble groups are heavily involved in Planck and NIKA instrumentally wise
- Grenoble groups have played a major role in the interpretation of the current Planck results

SCIENTIFIC GOALS

(I) Obtain tSZ based high resolution pressure profiles of clusters of galaxies
(II) Characterize filamentary structure in supercluster systems

WORK TASKS

✓ Integrate Planck collaboration for selection of most suitable targets
✓ Coordinate Planck galaxy cluster follow-up observations with NIKA
✓ Take in charge the data analysis to obtain galaxy cluster pressure profiles
✓ Animate simulation work for physical interpretation of the results

Conclusions

➡ Recent Planck tSZ measurements have been proved particularly important for understanding structure formation theory with particularly exciting results: more than 200 clusters detected already (800 expected), first discovery of filaments between galaxy clusters, exotic high redshift objects

➡ High-resolution follow-up of Planck clusters of galaxies is needed to understand both the internal structure of clusters and the filaments between clusters of galaxies

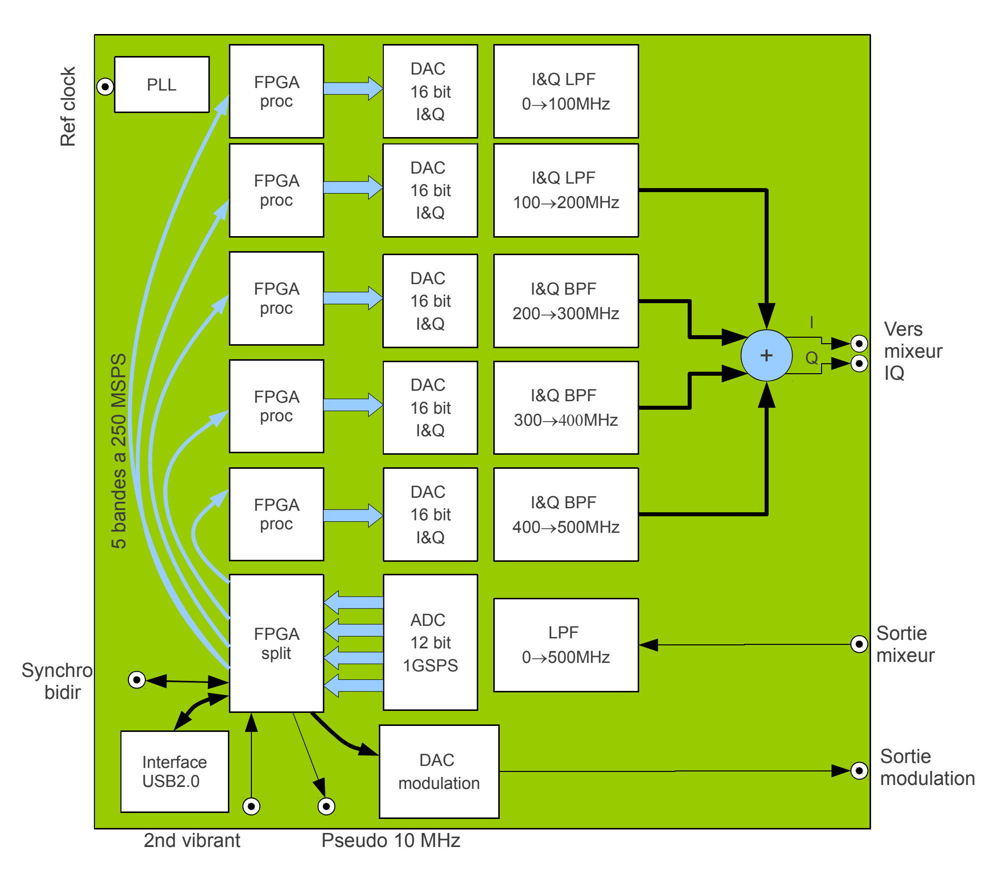
➡ The NIKA camera at the IRAM 30 m telescope is a perfect instrument for such follow-ups: high resolution (12 arcsec) and sensitivity (2000 detectors per channel), large field of view (6 arcmin)

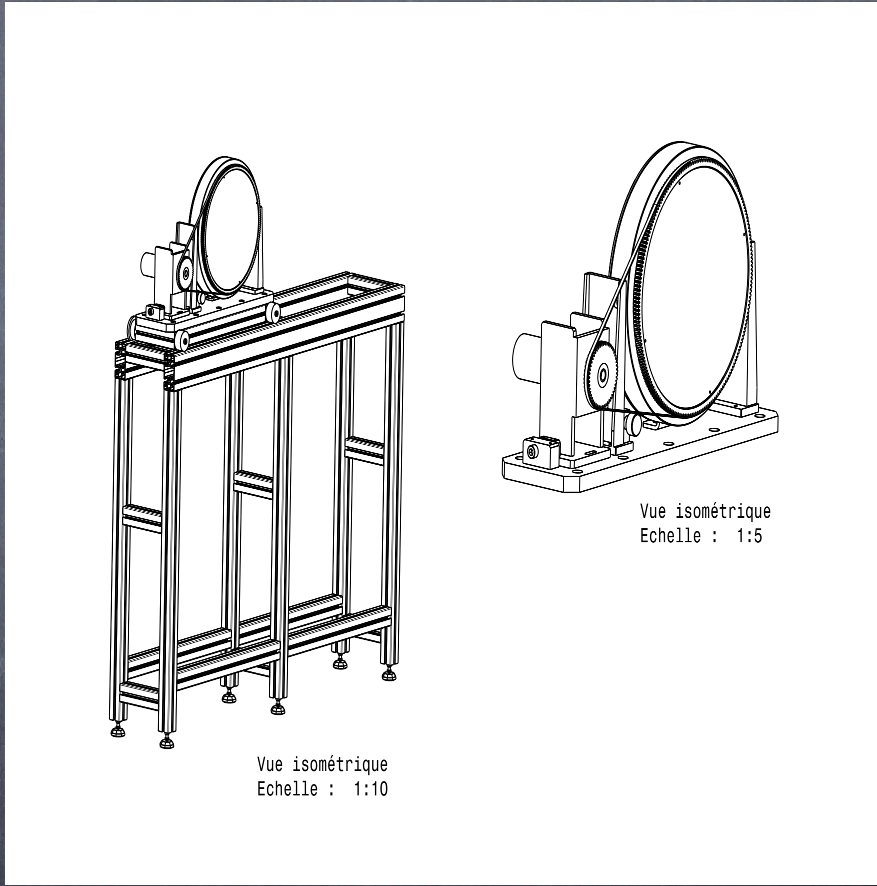
➡An ENIGMAS postdoc will be a major addition for the LPSC group as he/she will allow us to scientifically concretize our instrumental and data analysis efforts in Planck and NIKA

Technical developments for NIKA at LPSC

NIKEL:
electronic board with 500 MHz of bandpass for multiplexing up to 400 detectors

Development and calibration of polarized KIDs arrays: spinning polarizer made of Kapton





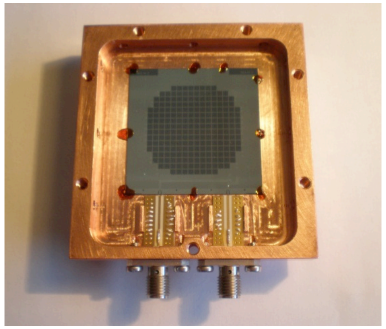
Monfardini et al. 2011
Bourrion et al. 2011

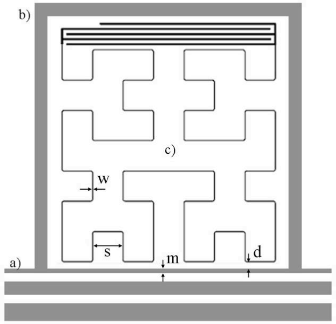
O. Bourrion et C. Vescovi (service électronique)

E. Perbet, J. Pellisier et O. Guillaudin
(service mécanique et instrumentation)

NIKA prototype et résultats

- Prototype installé à l'IRAM : 4 campagnes de mesure 2009-2012
- Deux bandes à 150 (122 détecteurs) et 240 (140 détecteurs) GHz
- Matrices de KIDs fabriquées et vérifiées à Grenoble



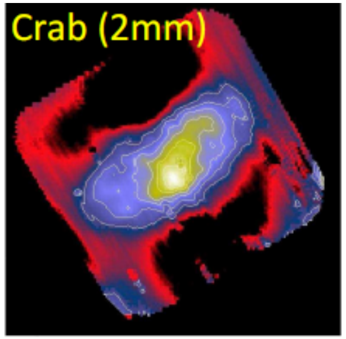


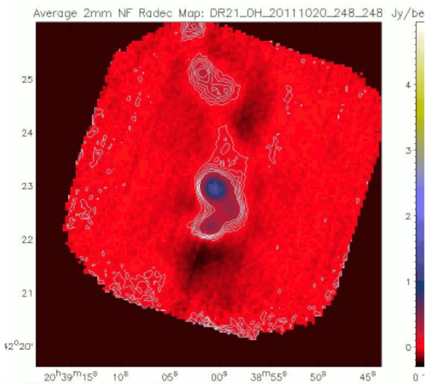
Résultats 2012 très encourageants:

Cryostat pulse tube fonctionne parfaitement

Nouvelle optique améliore les performances

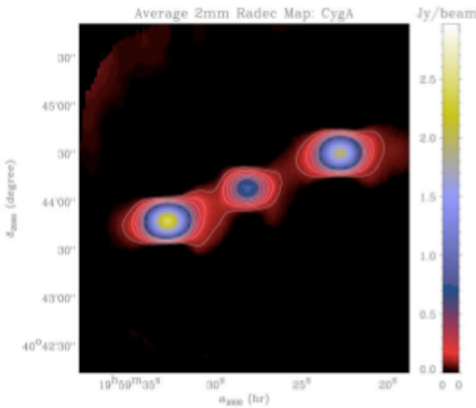
Niveau de bruit: 12 et 22 mJy/ $s^{1/2}$ /beam





DR21(OH) star-forming region

Cas A

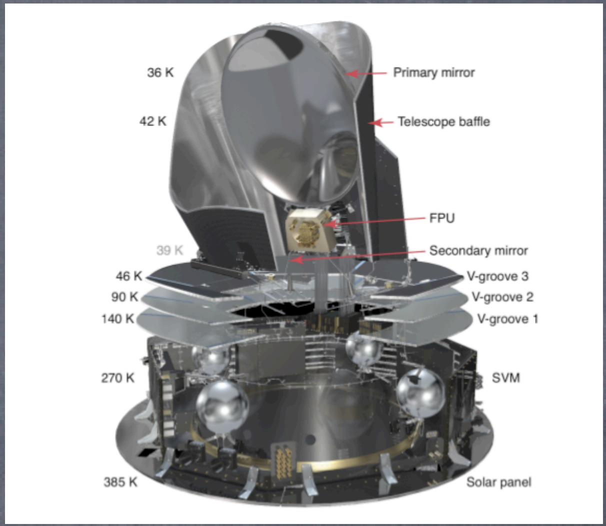


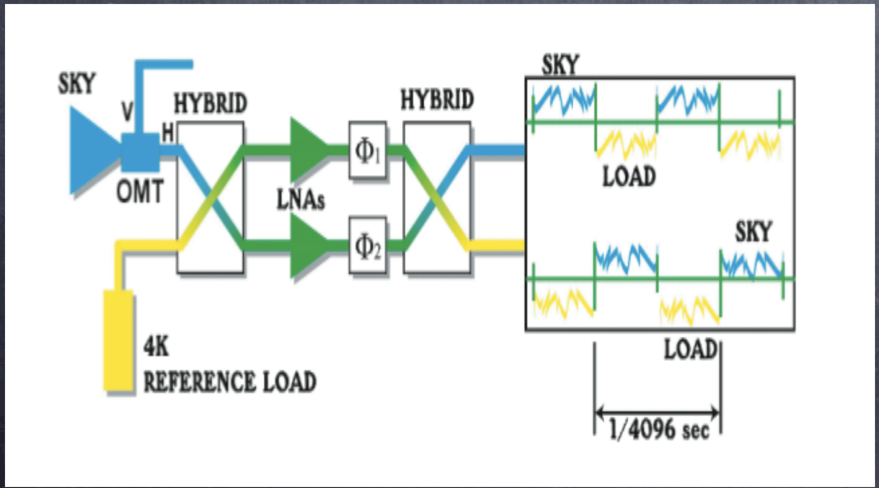
Publications:
Monfardini et al. 2010,2011
Bourrion et al. 2011,2012
Calvo et al. 2012
Roesch et al. 2012

The Planck satellite

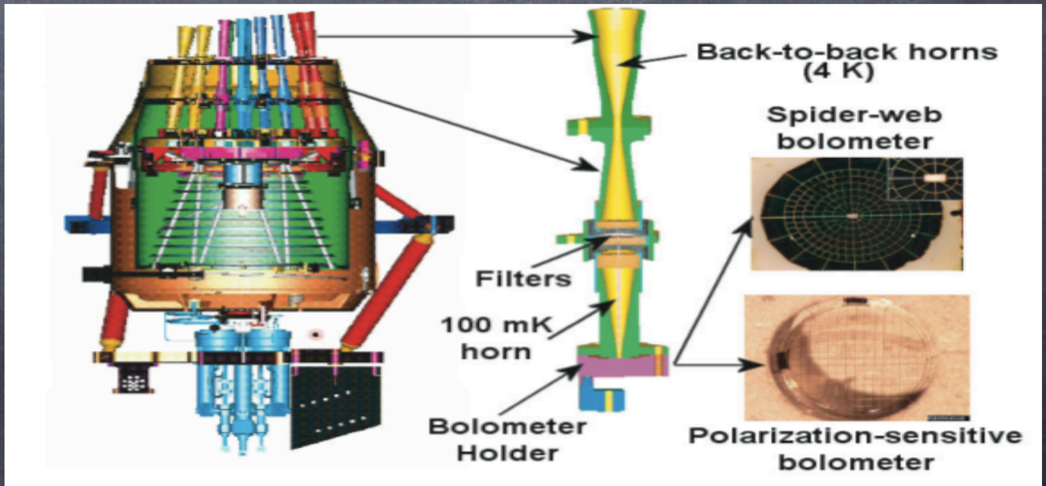
Tauber et al. 2010
Planck collaboration 2011

- 3^{rd} generation of satellite for CMB studies (after COBE and WMAP)
  Launched by ESA 14th May 2009 from the Lagrange L2 point
- Scanning strategy on big circles on the sky (1 rpm, 40 minutes)
  Full-sky coverage in 6-7 months
- 1.5 m hors axis Gregorian telescope
- Stellar sensor for pointing reconstruction
- Observations back to the sun and the earth
- Two instruments:
  LFI : radiometers (OMT) cooled down to 18 K
  30 [4], 40 [6] et 70 [12] GHz
  HFI : bolometers (SW and PSB) cooled down to 100 mK
  100 [8], 143 [8+4], 217 [8+4], 353[8+4], 545 [4] et 857 [4] GHz + 2 Dark
- Complex cryogenic system:
  50 (V-grooves), 18 (H sorption cooler), 4 (JT ^4He), 1.4 et 0.1 K (dilution ^3He-^4He)





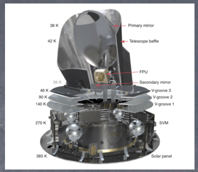
Bersanelli & Mandolesi 2000



Planck HFI Core Team 2011
Lamarre et al. 2003

Tauber et al. 2010
Planck collaboration 2011

The Planck satellite

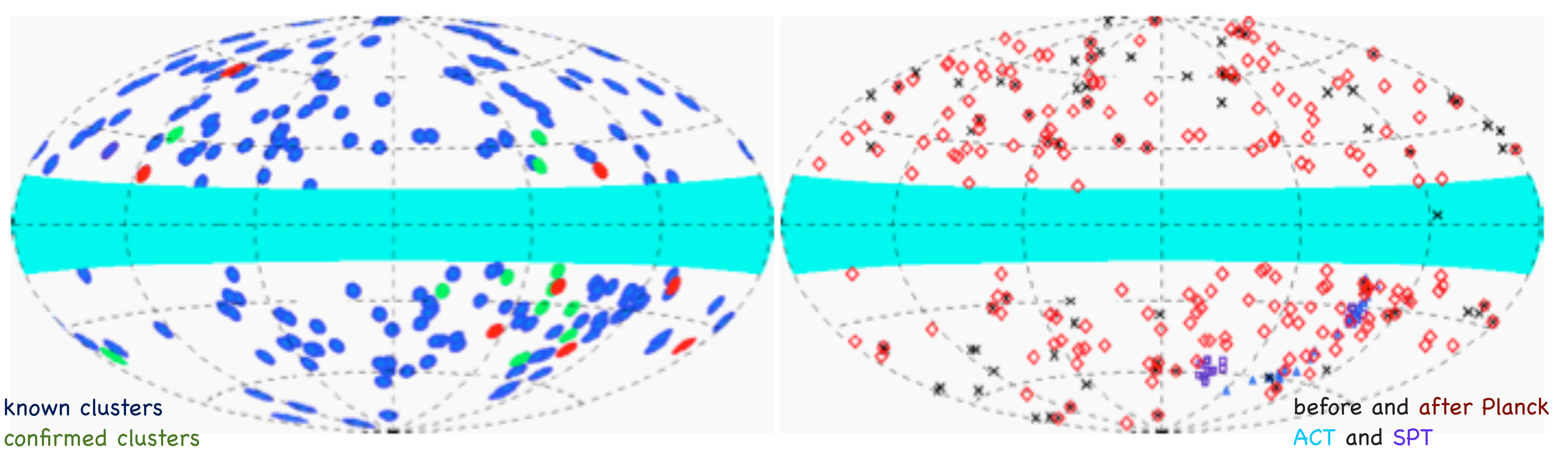


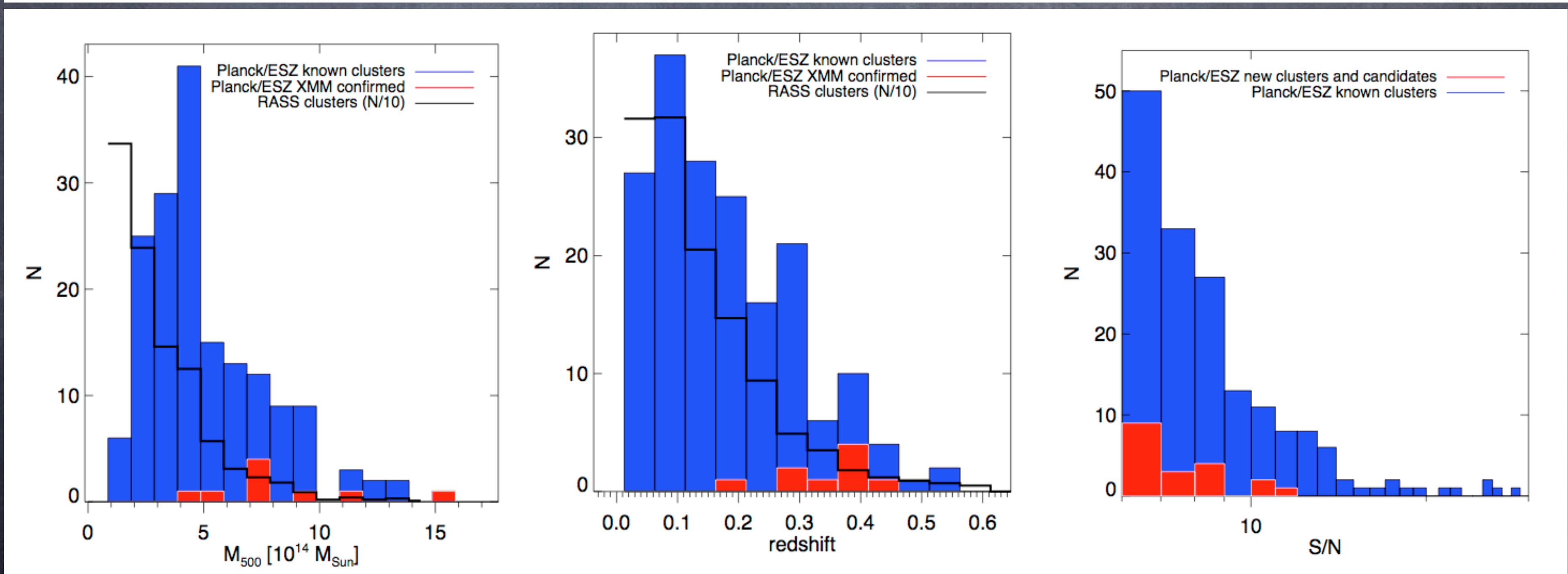
Instrument performances:

	30	44	70	100	143	217	353	545	857
Resolution (arcmin)	32	28	13	9	7	4.7	4.5	3.8	3.6
Sensitivity ($\mu K_{CMB}\ s^{1/2}$)	146	173	152	23	20	28	116	814	23798

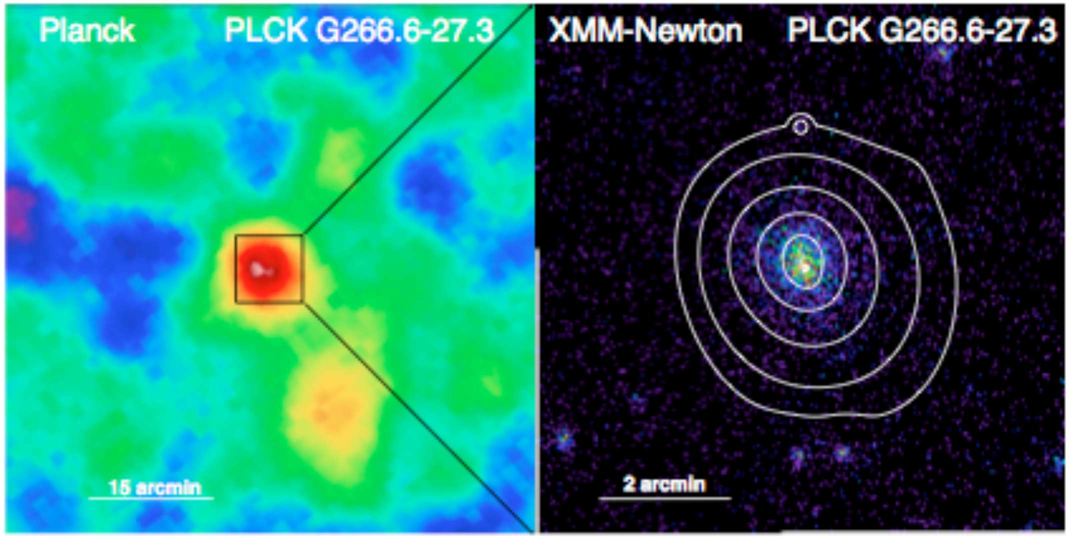
ESZ catalog properties

189 clusters z=0-0.6, M=1-13 10^{14} M_{sun}





PLCK G266.6-27.3 a high redshift cluster



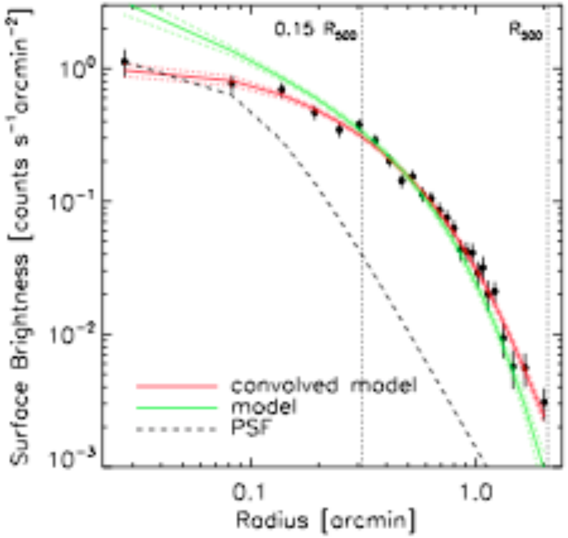


Table 1: Physical properties of PLCK G266.6−27.3 derived from *XMM-Newton* data.

Parameter	Value
z	0.94 ± 0.02
Abundance	0.44 ± 0.17 solar
R_{500}	0.98 ± 0.03 Mpc
M_{500}	$7.8^{+0.8}_{-0.7} \times 10^{14}$ $M_{\odot}$
Y_X	$1.10^{+0.20}_{-0.17} \times 10^{15}$ $M_{\odot}$ keV
T_X	$10.5^{+1.6}_{-1.4}$ keV
$T(< R_{500})$	$11.4^{+1.4}_{-1.2}$ keV
L_{500}([0.5–2.0] keV)	$14.2 \pm 0.5 \times 10^{44}$ erg s^{-1}
L_{500}([0.1–2.4] keV)	$22.7 \pm 0.8 \times 10^{44}$ erg s^{-1}

Table 2: SZ flux derived from *Planck* data with the reference value indicated in boldface.

Method	Definition	Value (10^{-4} arcmin^2)	θ_{500} (arcmin)
MMF blind	Y_{500}	5.6 ± 3.0	3.3 ± 2.8
PWS blind	Y_{500}	6.5 ± 1.8	3.9 ± 1.6
MMF X-ray prior	Y_{500}	$\mathbf{4.1 \pm 0.9}$	fixed
PWS X-ray prior	Y_{500}	5.3 ± 0.9	fixed
MILCA	Y_{tot}	5.9 ± 1.0	. . .

Notes. Uncertainties on the blind values take into account the size uncertainty.

- Very peculiar cluster : very luminous in X and very massive with respect to previously known clusters at z > 0.5

Scaling relations for cluster physics

[Kratsov et al. 2006, Pratt et al. 2009, Arnaud et al. 2010]

- **SELF-SIMILAR evolution: only gravitational processes**

→ ICM: isothermal and hydrostatic equilibrium → $k_B T_e = \mu m_p \frac{G M_{tot}}{r}$ *[Kaiser (1986)]*

$$M_{tot}(r_\Delta) = \frac{4}{3}\pi\rho_c \Delta r_\Delta^3$$

$$r_\Delta \propto \left(\frac{M_{tot}(r_\Delta)}{E(z)^2}\right)^{1/3}$$

$$k_B T_e \propto \frac{G M_{tot}}{r}$$

$$T_e \propto M_{tot}(r_\Delta)^{2/3} E(z)^{2/3}$$

$$\rho_c = \frac{3H_0^2 E(z)^2}{8\pi G} \qquad E(z) = \frac{H(z)}{H_0}$$

$$Y = \int_\Omega y\, d\Omega = \frac{1}{D_A^2}\left(\frac{k_B \sigma_{Th}}{m_e c^2}\right)\int_0^\infty dl \int n_e T_e\, dA$$

$$Y D_A^2 \propto T_e \int n_e\, dV = M_{gas} T_e = f_{gas} M_{tot} T_e$$

$$f_{gas} = M_{gas}/M_{tot}$$

$$Y D_A^2 \propto f_{gas} T_e^{5/2} E(z)^{-1}$$

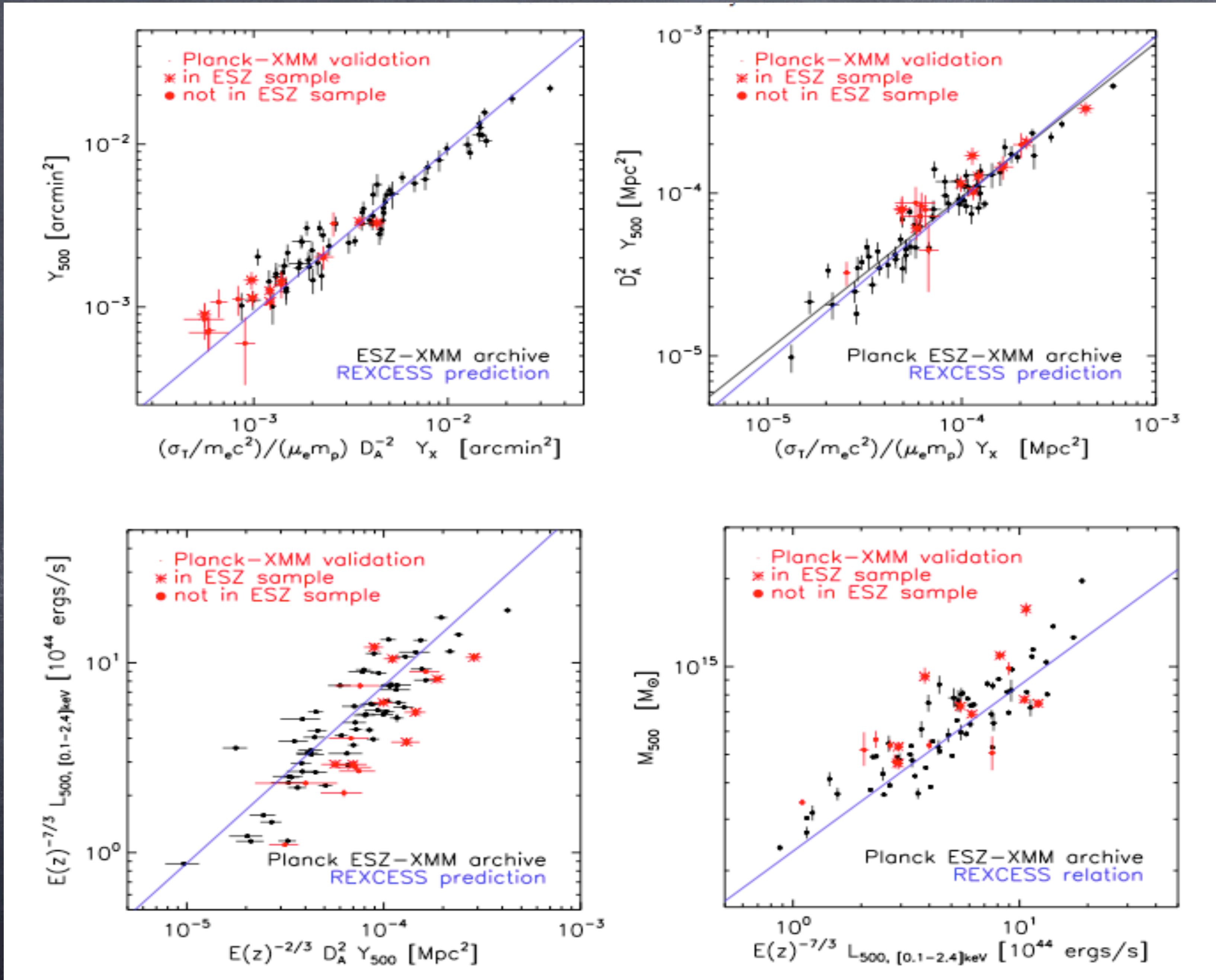
$$Y D_A^2 \propto f_{gas} M_{tot}^{5/3} E(z)^{2/3}$$

$$Y D_A^2 \propto f_{gas}^{-2/3} M_{gas}^{5/3} E(z)^{2/3}$$

$$E(z)^2 = \left(\frac{H(z)}{H_0}\right)^2 = \Omega_M (1+z)^3 + \Omega_\Lambda$$

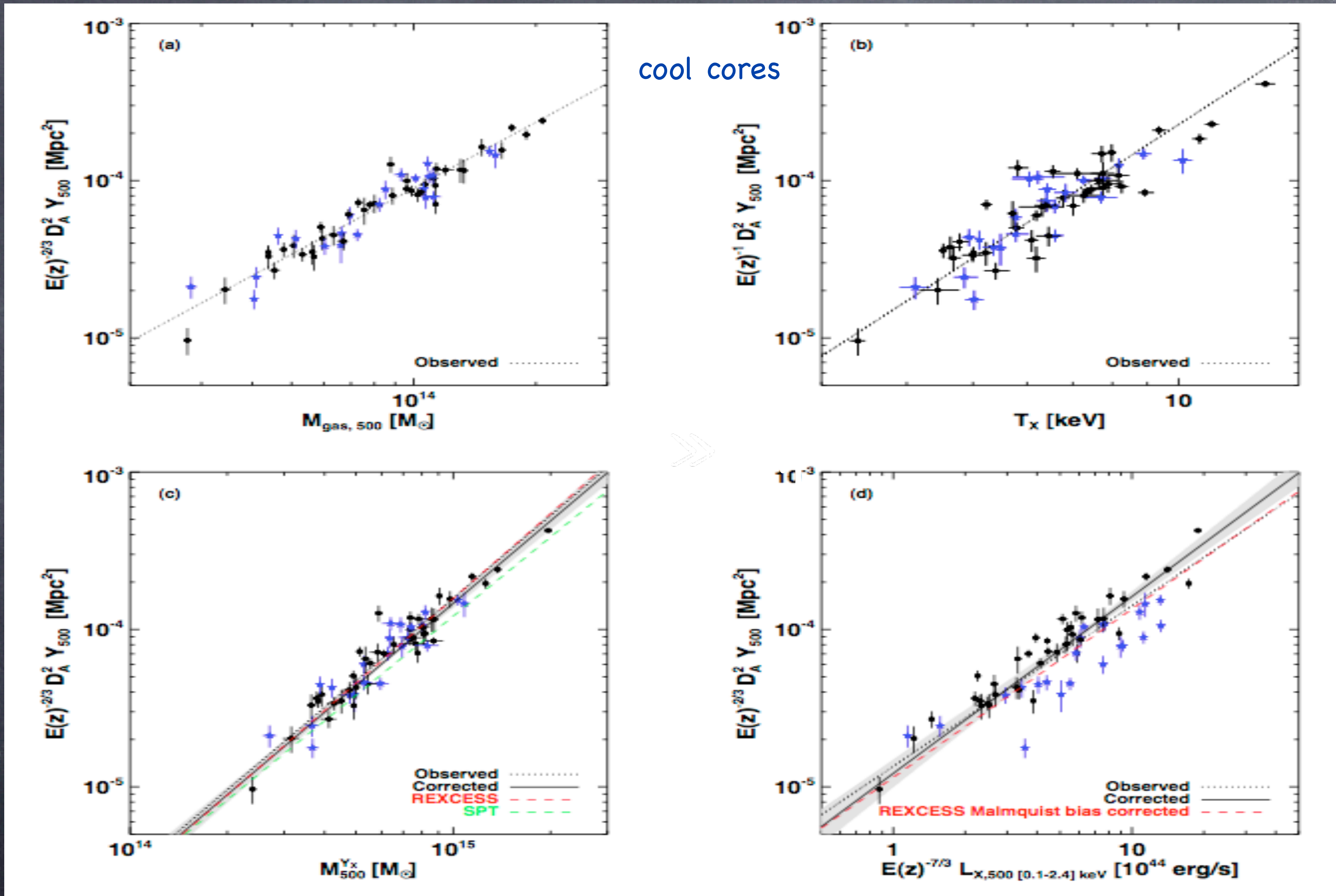
$$\Omega_M = 0.3,\ \Omega_\Lambda = 0.7,\ \Omega_k = 0$$

ESZ clusters scaling relations



Local scaling relations

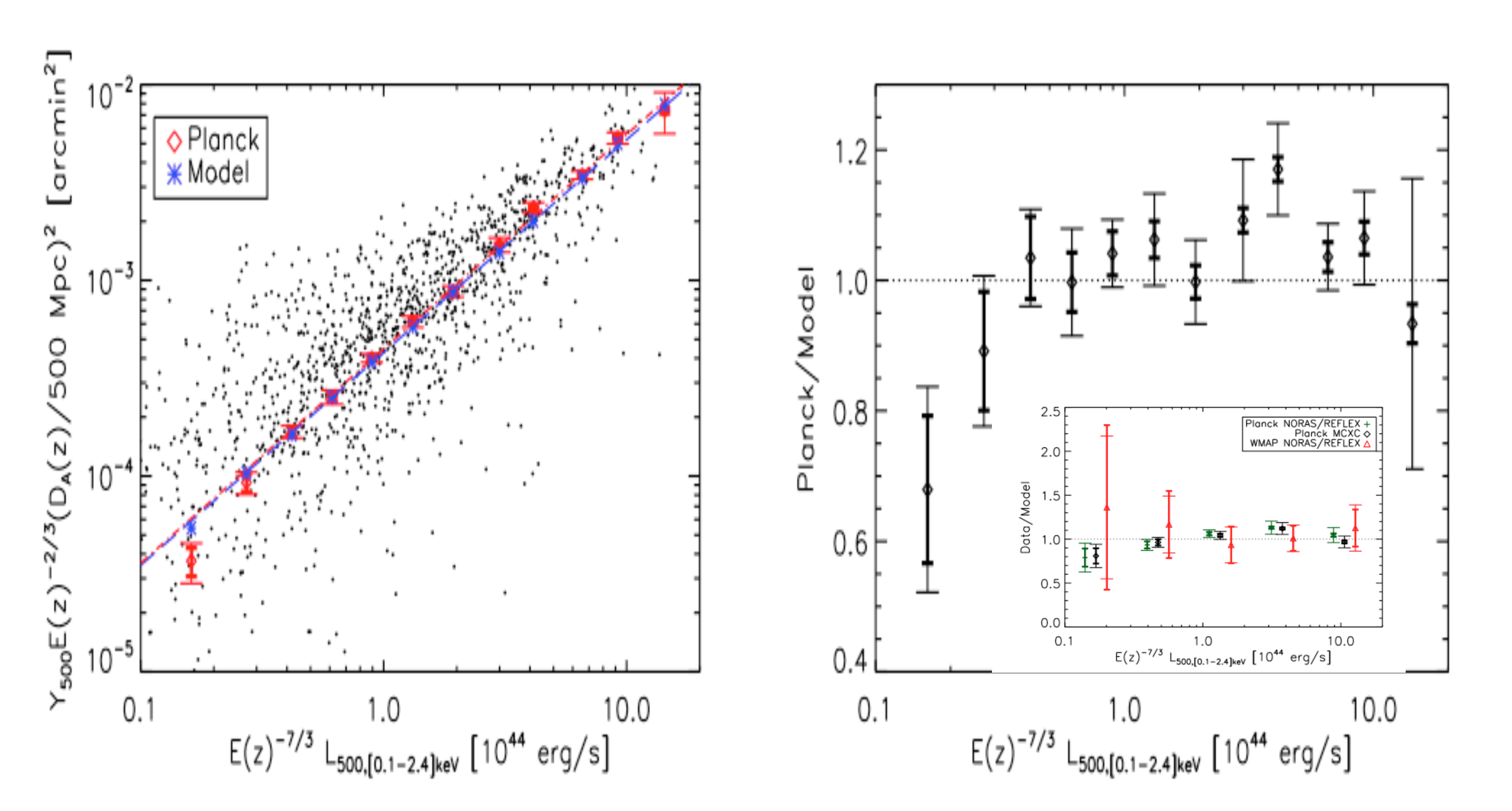
- 62 nearby clusters (Z < 0.5), with total masses from 2×10^{14} M_{sun} to 2×10^{15} M_{sun}



X-ray do not over-predict tSZ flux as previously indicated

Statistical scaling relations

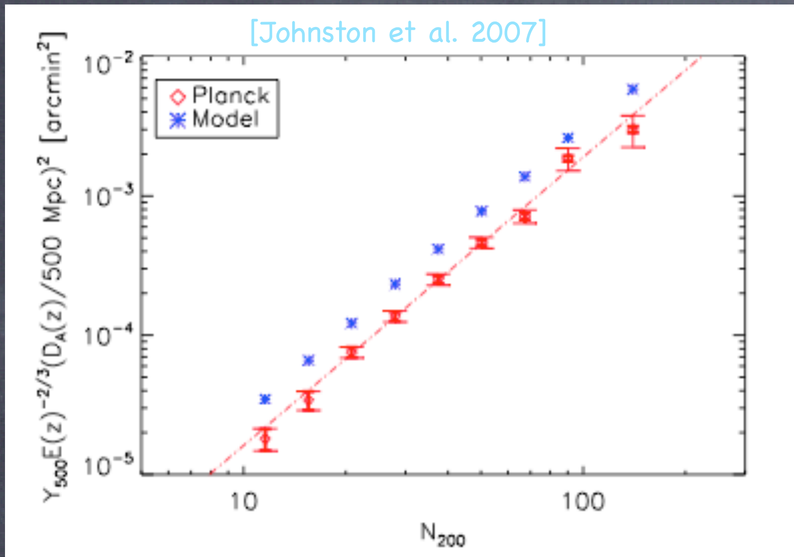
- SZ flux in the direction of 1600 objects from the MCXC (Meta-Catalogue of X-ray detected cluster of galaxies)
- Compute scaling relation on bins of the wanted quantity. [Piffaretti et al. 2011]

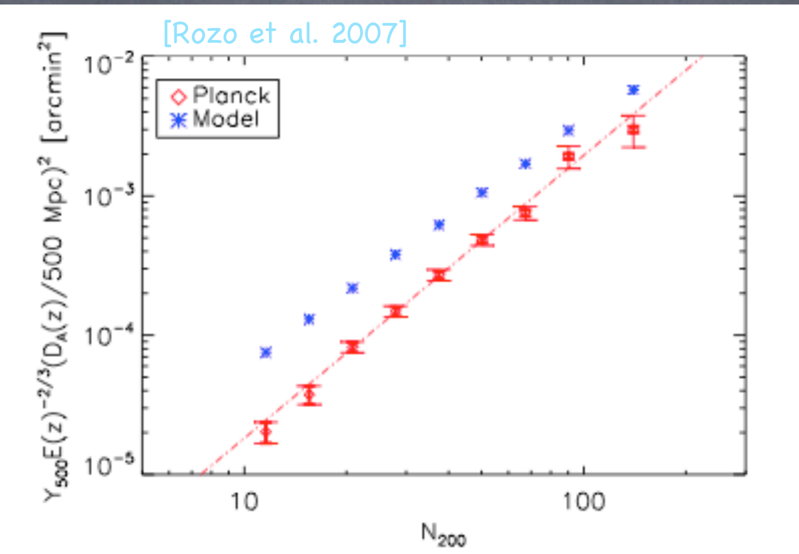


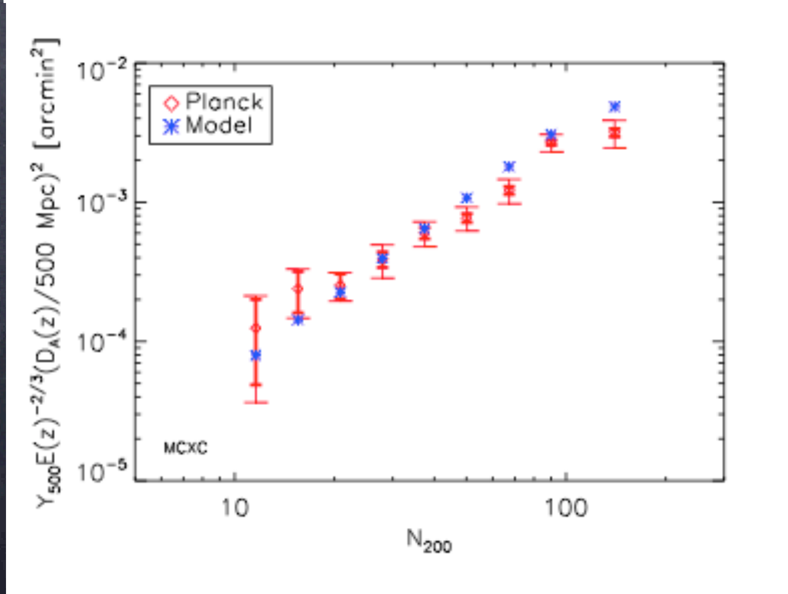
X-ray do not over-predict tSZ flux as previously indicated

Optical scaling relations

- SZ flux in the direction of 13000 objects in the MaxBCG cluster catalogue 0.1 < z < 0.3; 10< N200 <190
- Compute scaling relation on bins of the wanted quantity. [Koester et al. 2009]



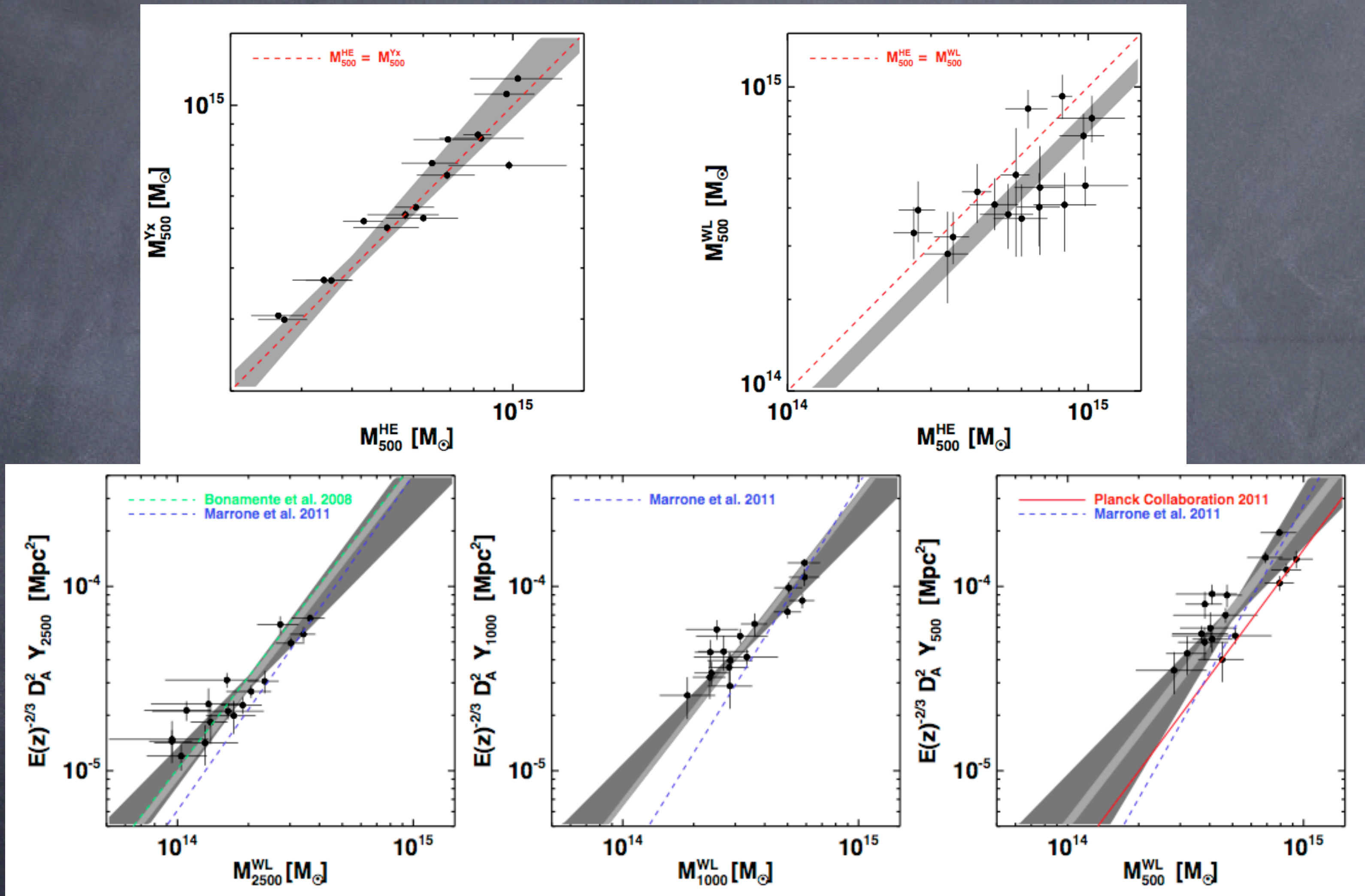




- Clear discrepancy between model and data
- For the MCXC sample the agreement is better
- One possible explanation is the existence of two population of clusters: X-ray under-luminous and X-ray normal
- This might have consequences in structure formation

Mass scaling relations

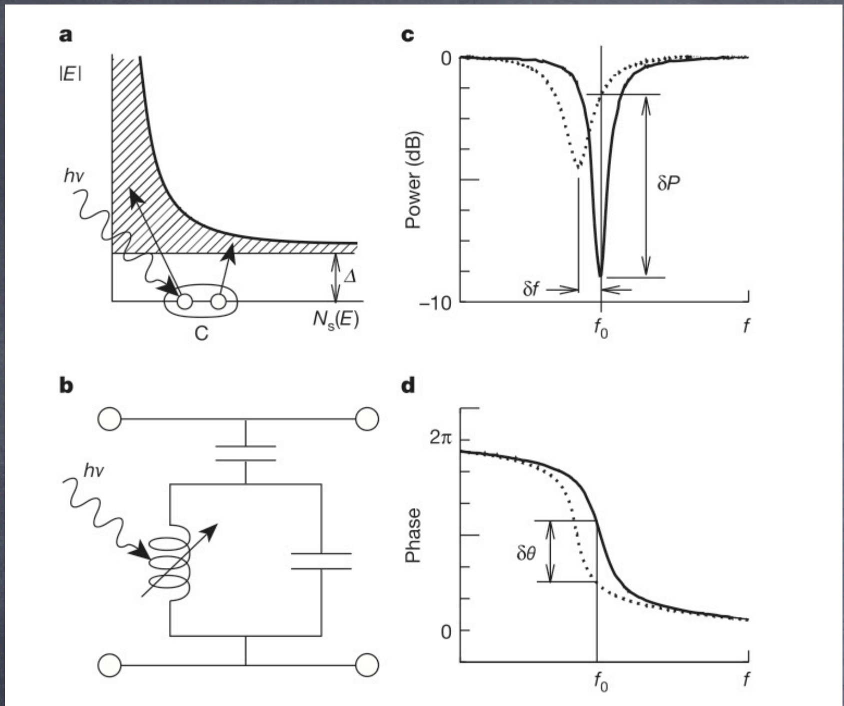
- Use 19 clusters with WL from the LoCuSS sample   Okaku & Umetsu 2008, Okabe et al. 2010]

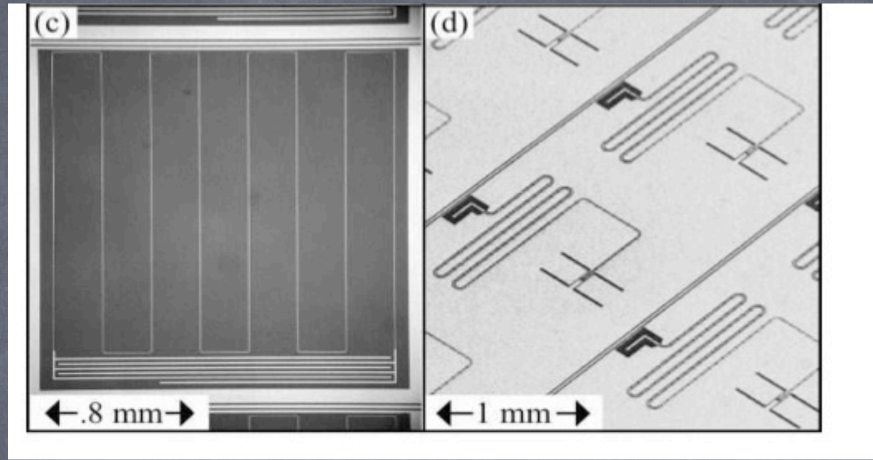


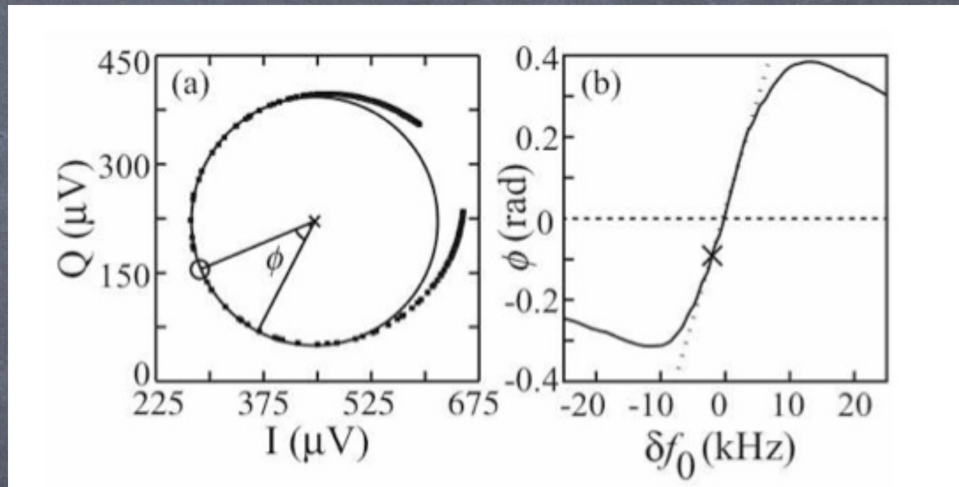
X-ray based masses 22 % larger than WL masses, related to differences in concentration

Using KID arrays for CMB

Microwave resonators coupled to a feed line







KIDs arrays advantages

- ✓ Easy and cheap manufacturing (currently done at Grenoble)
- ✓ Natural multiplexing up to 500 pixels
- ✓ Very sensitive devices (can achieve the Planck bolometer sensitivities)
- ✓ No affected by temperature fluctuations
- ✓ Might find ways to fight against cosmic-rays hits

Mazin et al. 2004
Doyle et al. 2008
Monfardini et al. 2010

1000-pixels matrix

[Planck collaboration 2012]