THE SUNYAEV-ZELDOVICH EFFECT

Etienne Pointecouteau

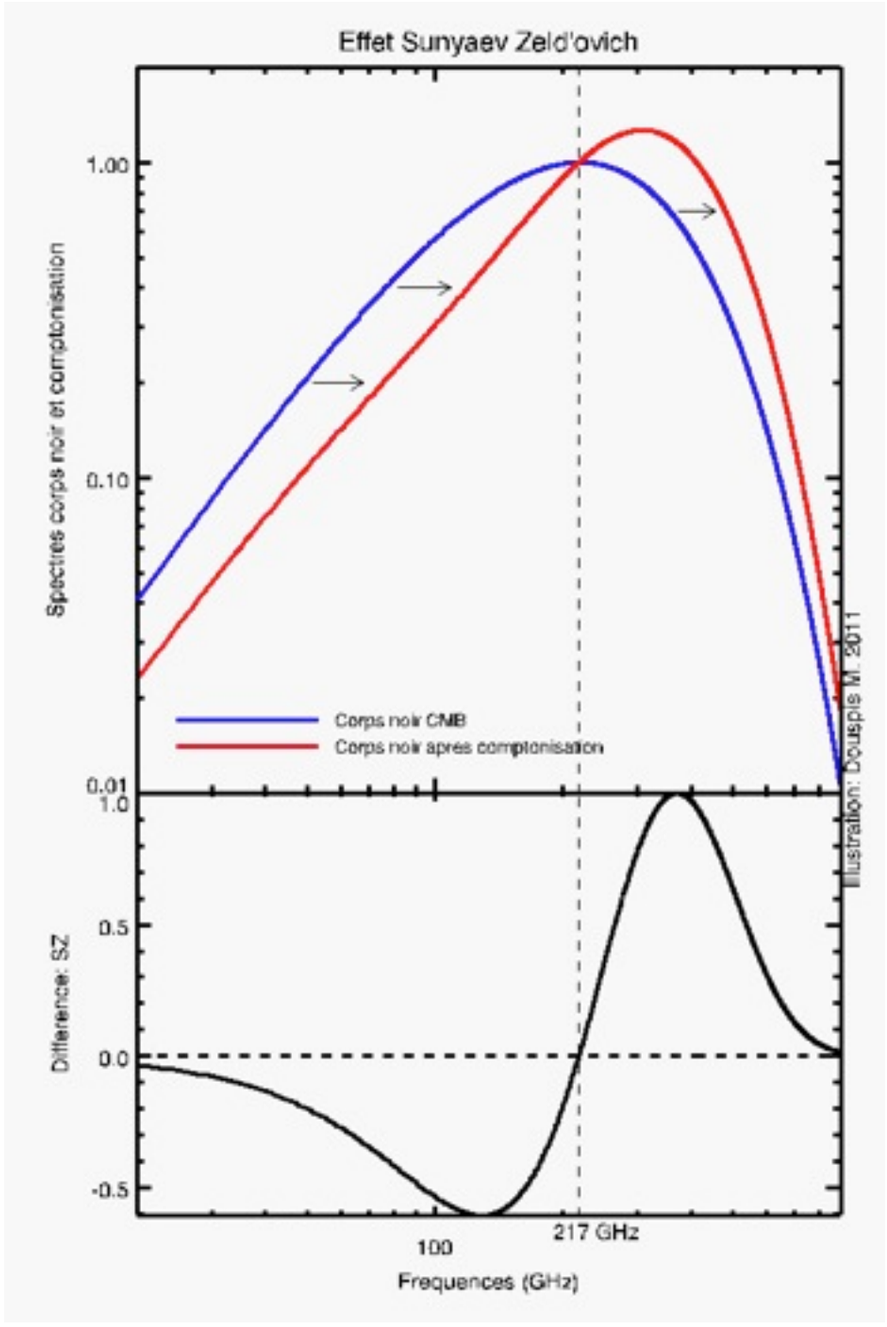
IRAP

(Toulouse, France)

THE SUNYAEV-ZELDOVICH EFFECT

Inverse Compton scattering of CMB photons by intra-cluster electrons

(Sunyaev&Zeldovich+69+72)

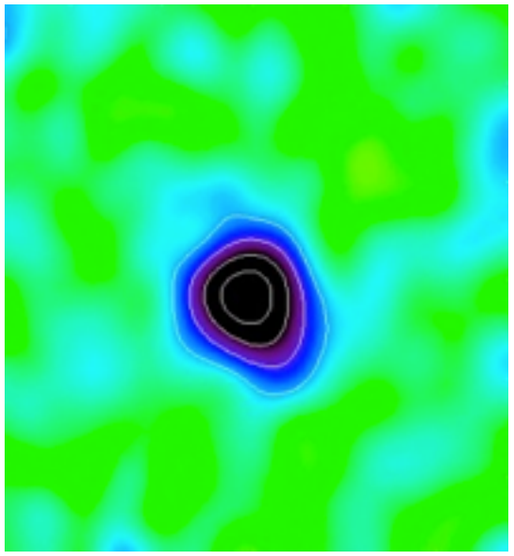


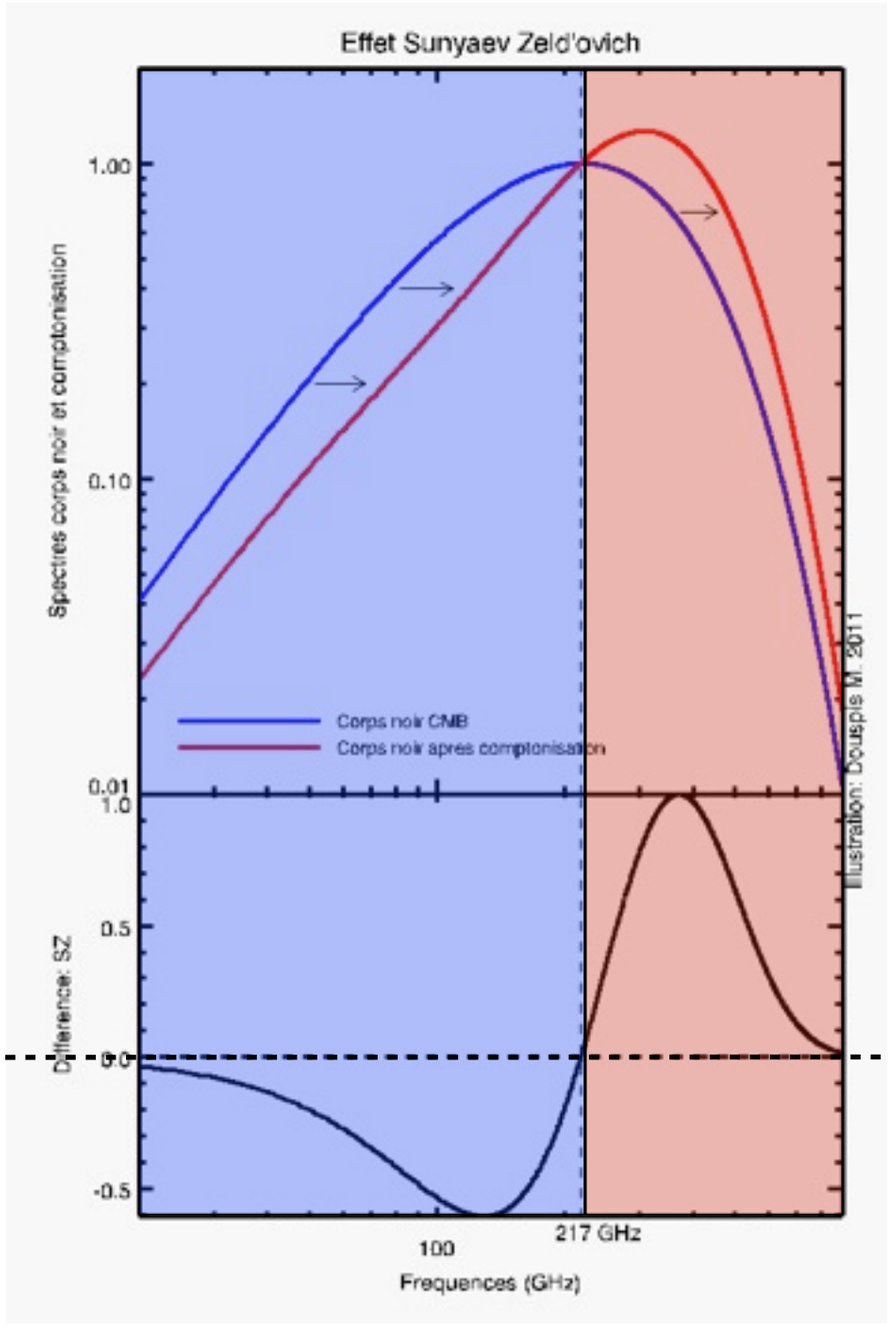
R. A. Sunyaev

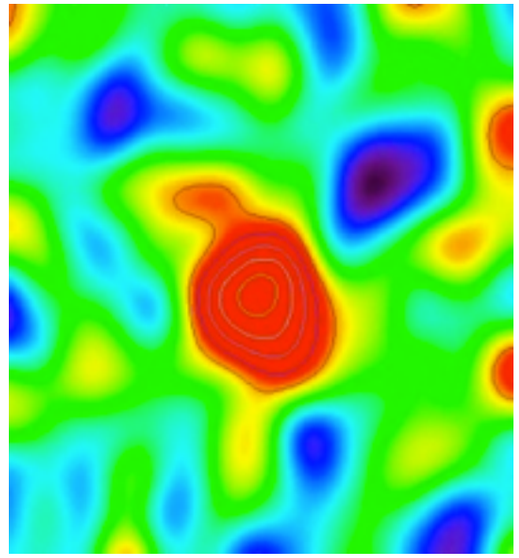
Ya. B. Zeldovich

$$F_\nu^{SZ} \propto Y = \int_\Omega y\, d\Omega = \int_\Omega \int_l (P_{th} = k_B n_e T) dl\, d\Omega$$

THE SUNYAEV-ZELDOVICH EFFECT







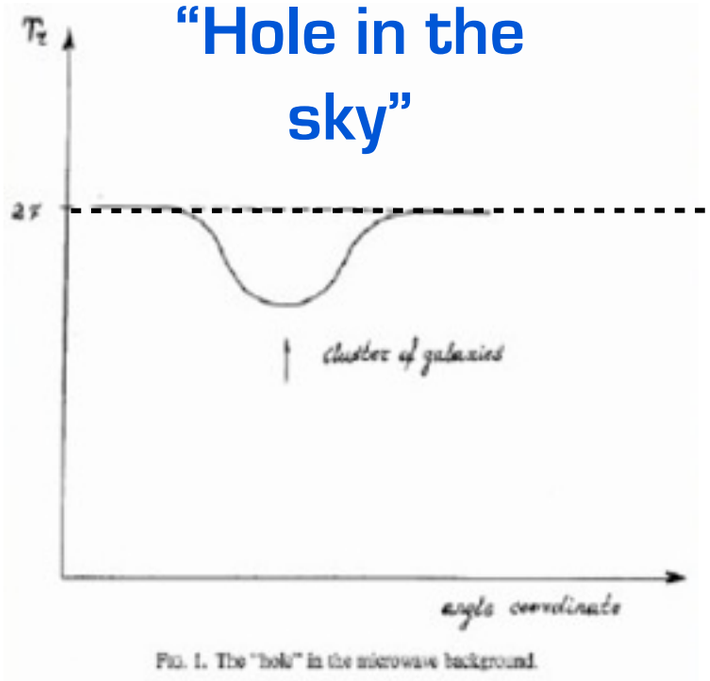
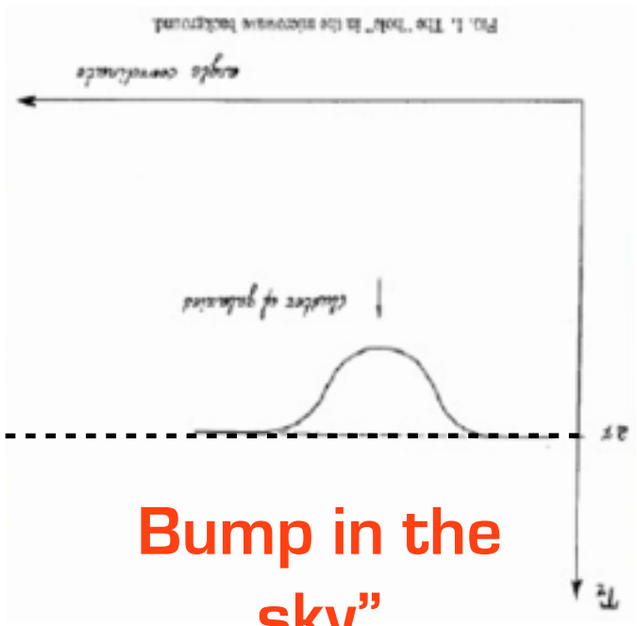


Fig. 1. The "hole" in the microwave background.

"Hole in the sky"



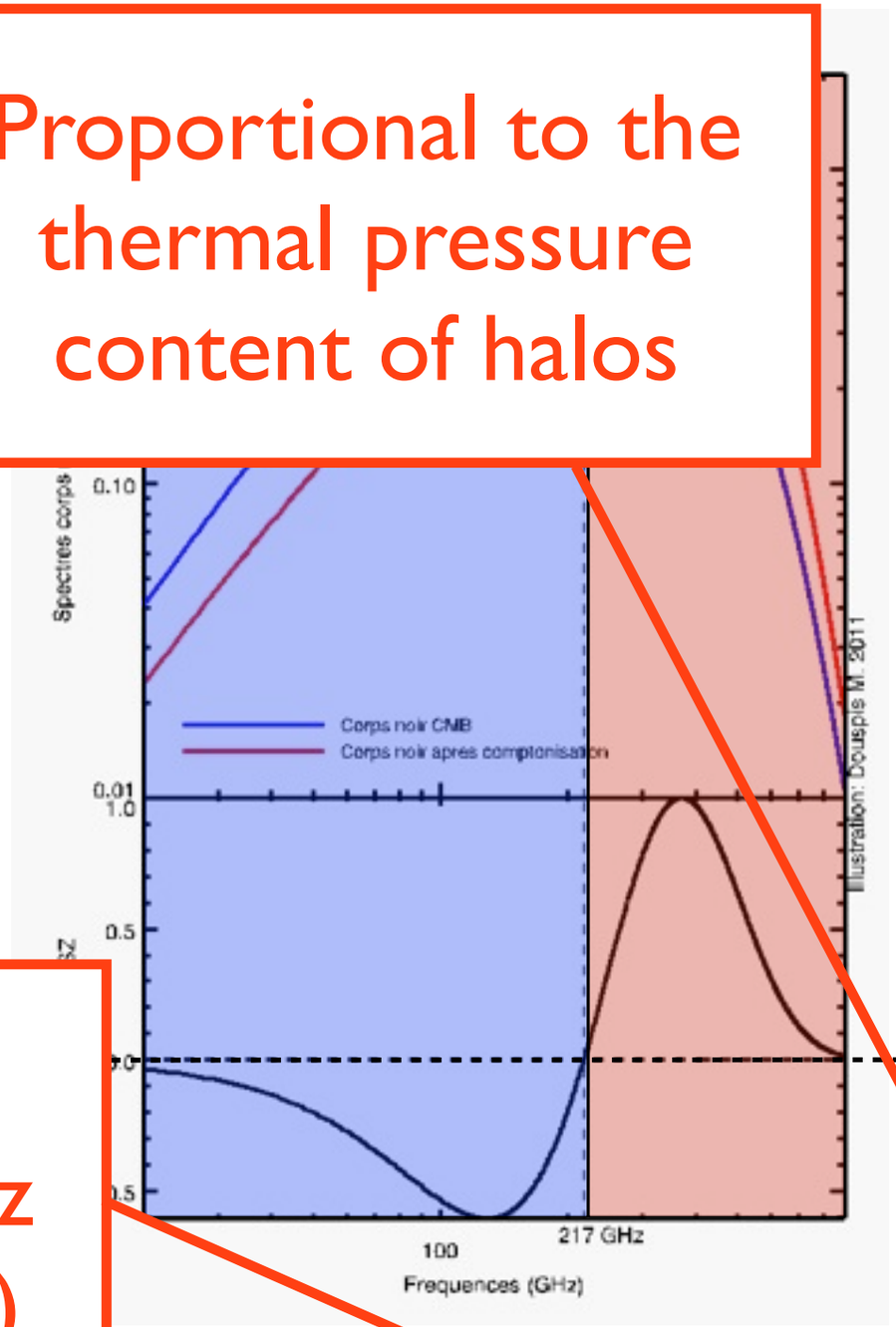
Bump in the sky"

THE SUNYAEV-ZELDOVICH EFFECT

Inverse Compton scattering of CMB photons by intra-cluster electrons

(Sunyaev&Zeldovich+69+72)

Proportional to the thermal pressure content of halos



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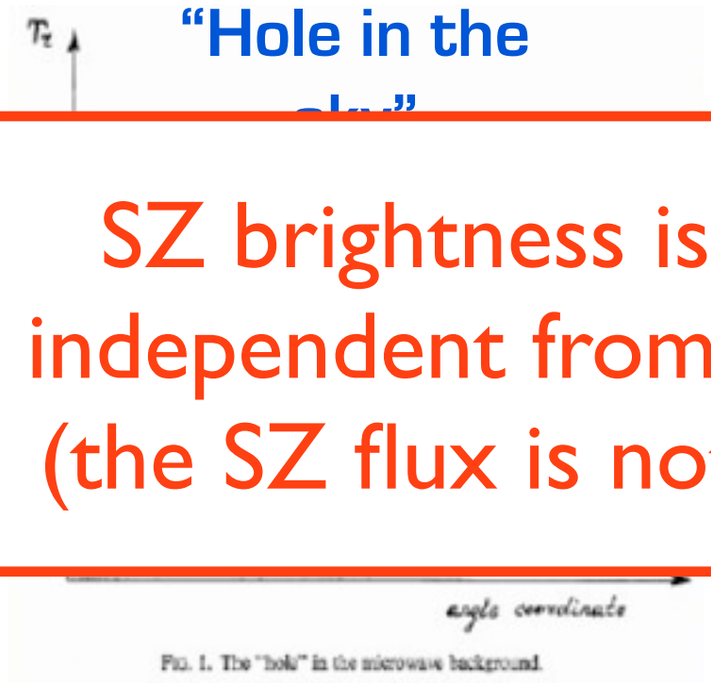
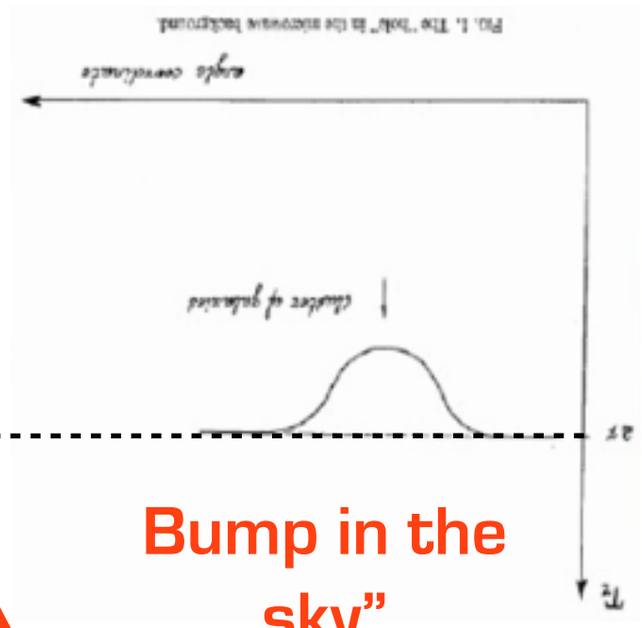


FIG. 1. The "hole" in the microwave background.

"Hole in the sky"

SZ brightness is independent from z (the SZ flux is not)

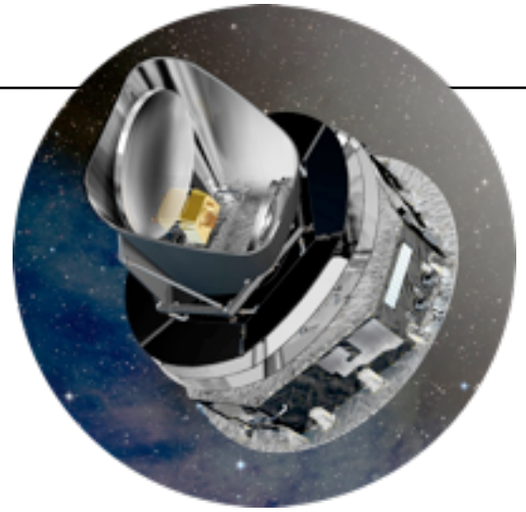


Bump in the sky"

$$F_\nu^{SZ} \propto Y = \int_\Omega y\, d\Omega = \int_\Omega \int_l (P_{th} = k_B n_e T) dl\, d\Omega$$

SZ MACHINES

Planck



Mustang/GBT

SPT

CARMA

Ground-based to space
North to South
10'' to 30'
2cm (15GHz) to 0.3mm (850GHz)
Single dish to interferometers
Bolometers, TES, HEMT

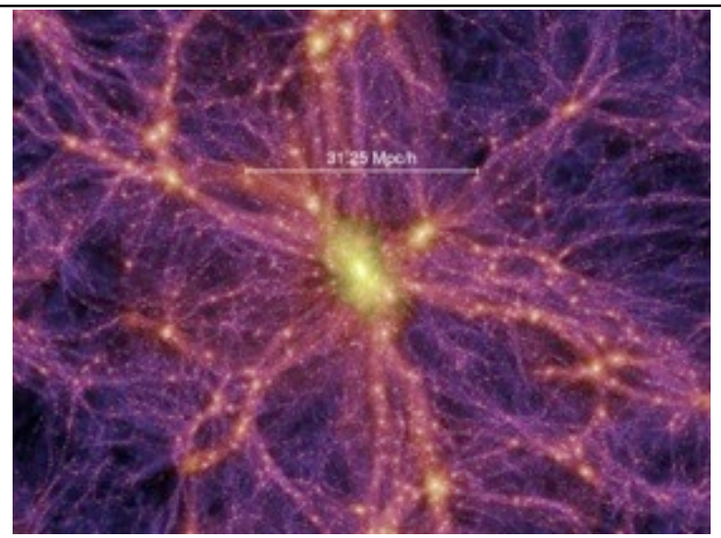
ACT

Amiba

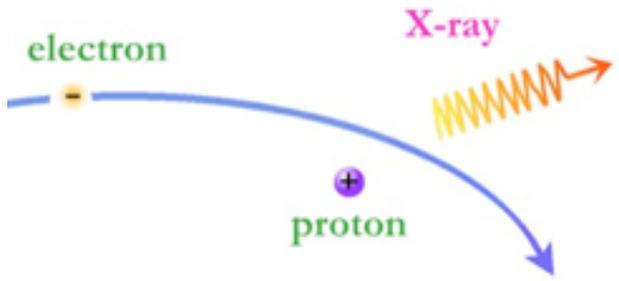
APEX-SZ

AMI

SZ EFFECT AND X-RAYS FROM CLUSTERS



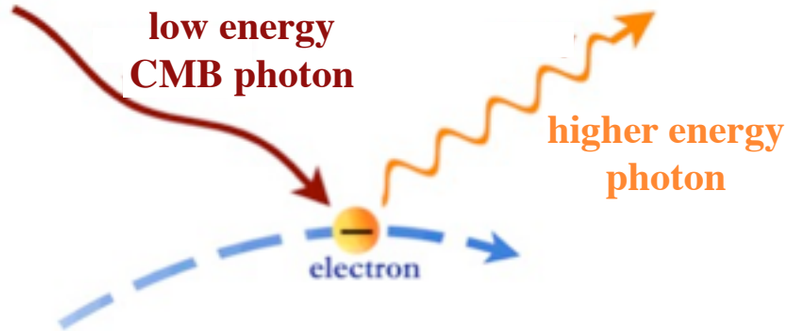
Bremsstrahlung



$$E_X \propto \int_V n_e^2 \Lambda(T) dV$$

→ X-ray emission

Inverse Compton scattering



$$F_\nu \propto Y \propto \int_\Omega (P_{th} = k_B n_e T) d\Omega$$

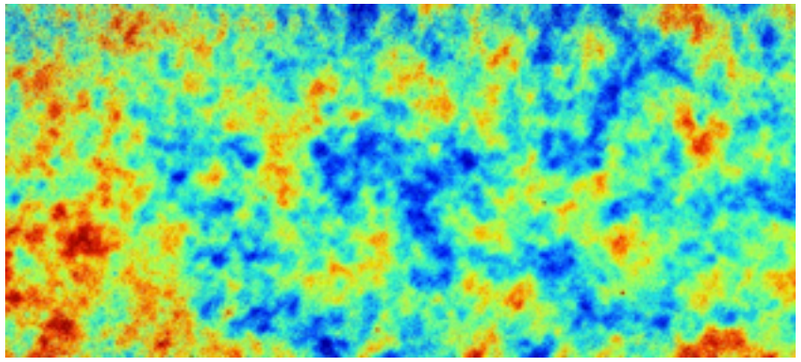
→ Sunyaev-Zeldovich effect

Two independent observables to probe of the same physical component: the intra-cluster gas

DETECTION OF NEW CLUSTERS OF GALAXIES

ETIENNE POINTECOUTEAU, MILANO, OCTOBER 2012

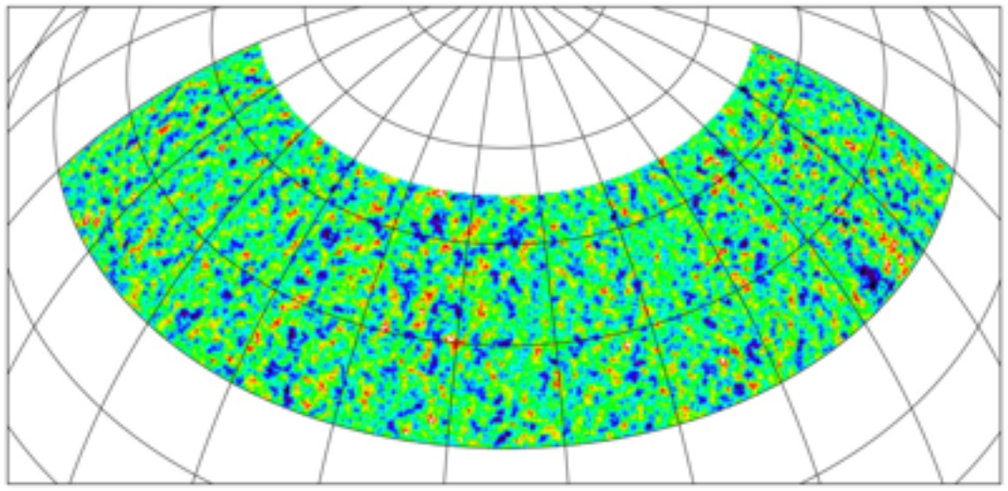
BLIND SZ SURVEYS



ACT

780 deg^2 @ 148 GHz / ~1.5'

(2008 strip)

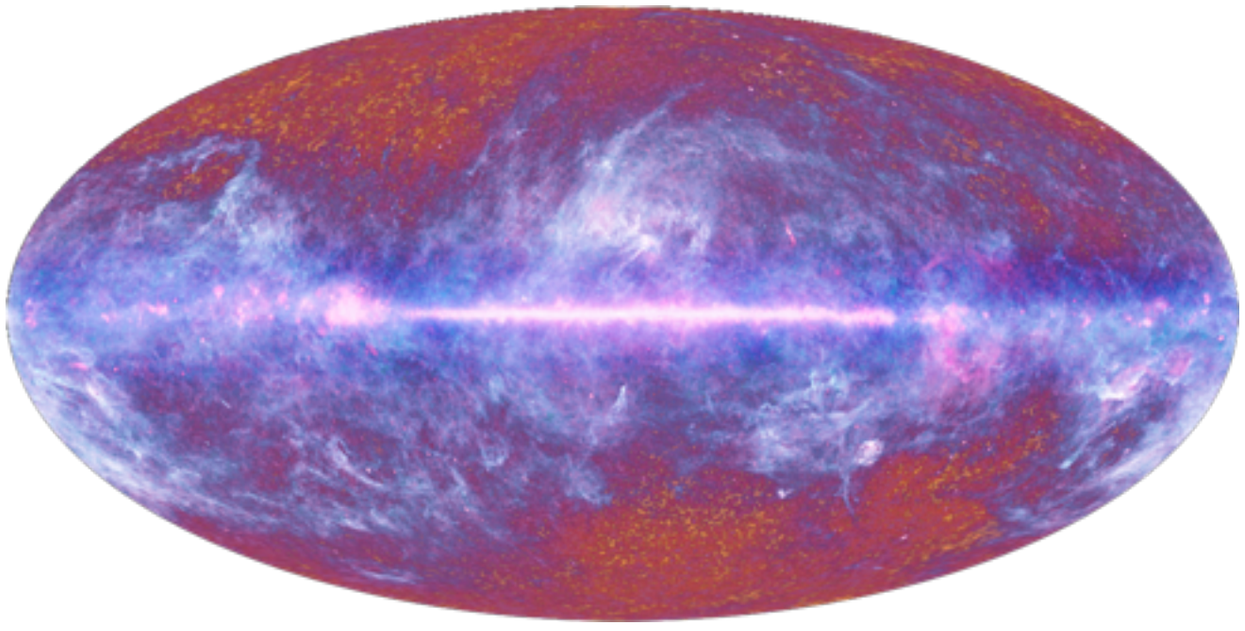


SPT

720 deg^2 @ 150 GHz / ~1.6'

455 deg^2 @ 95 GHz / 1.2'

(2008, 2009 runs)



Planck

41 253 deg^2 (all-sky)

@ 9 channels 30 - 857 GHz /

30 - 5 arcmin s

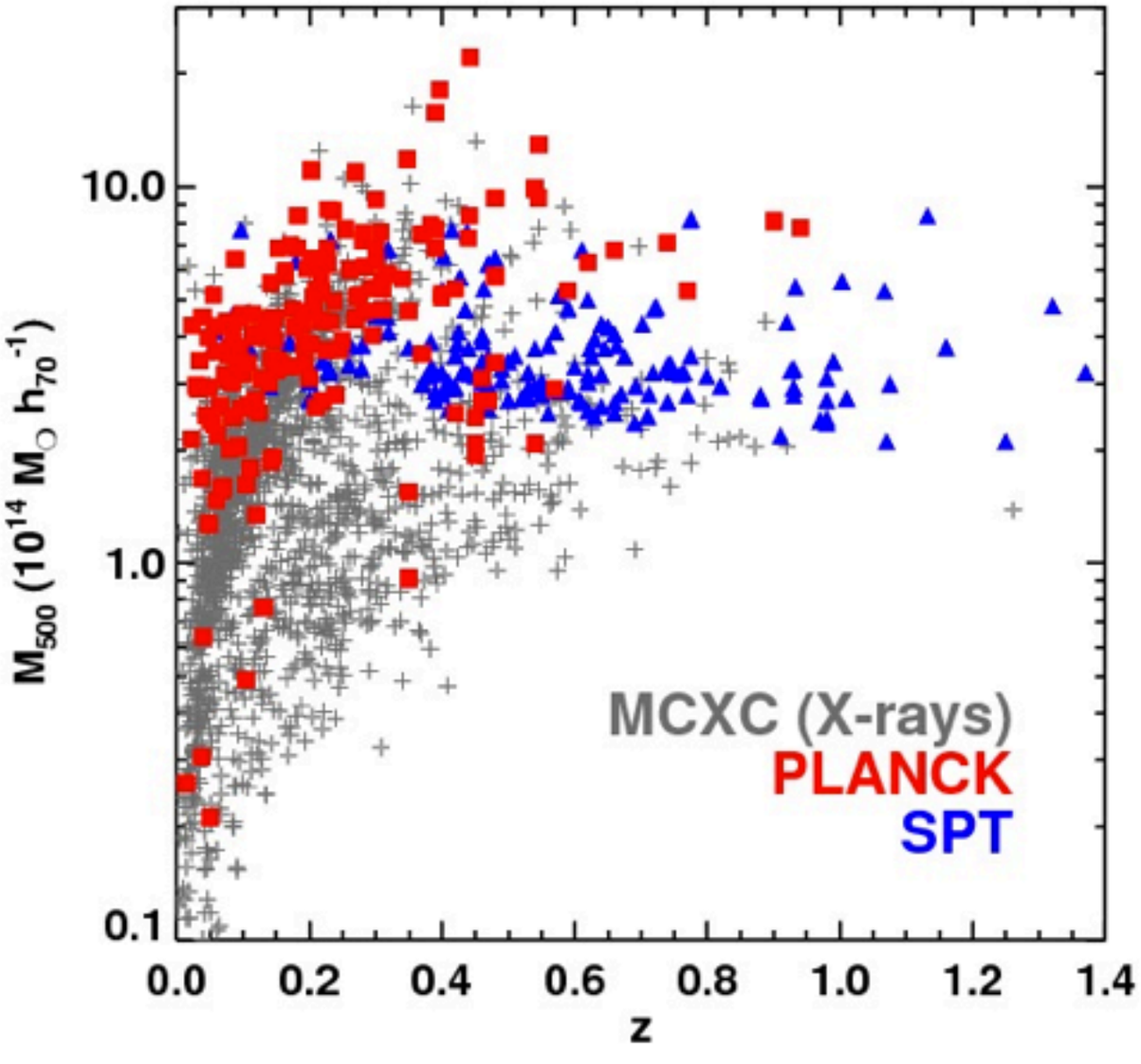
CATALOGUES OF SZ CLUSTERS

- **Catalogue of SZ detected clusters (known + new)**

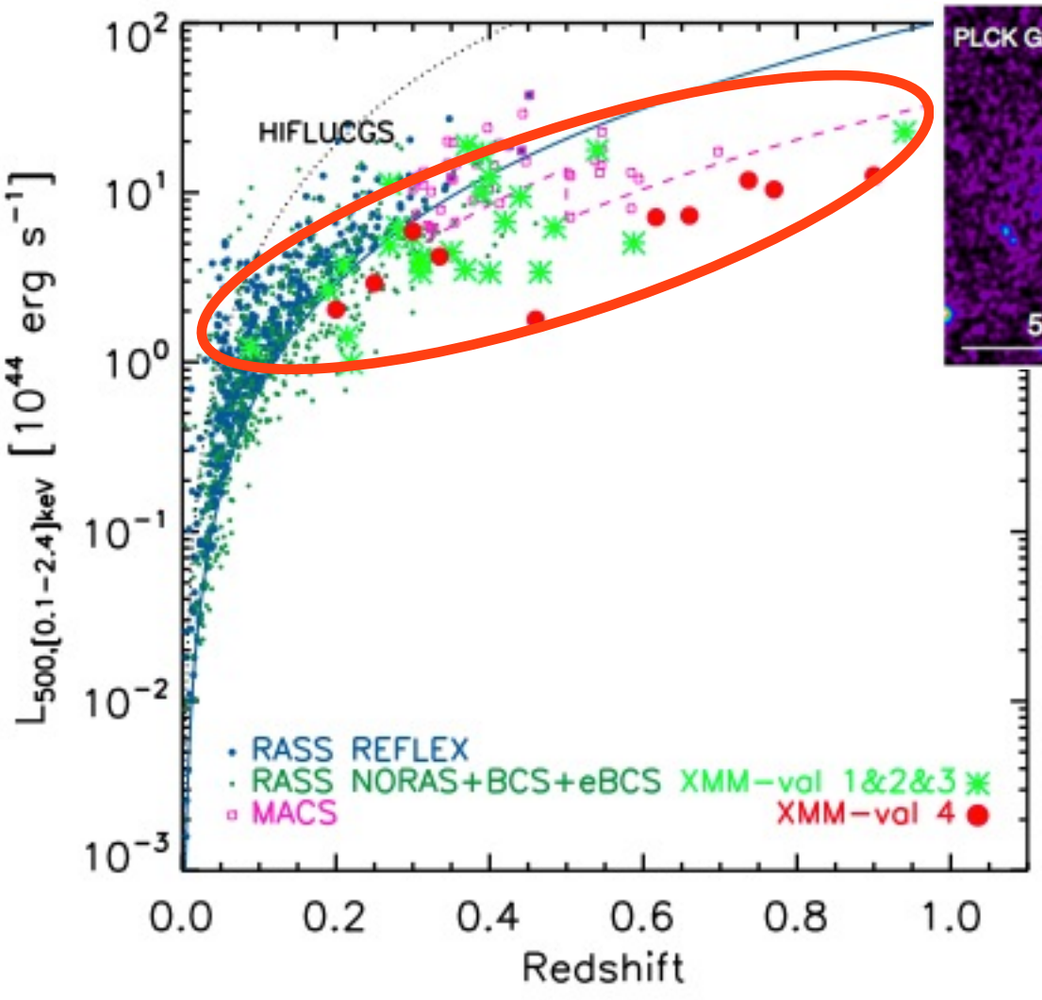
  Planck - 225 clusters (Planck collaboration+11+12)

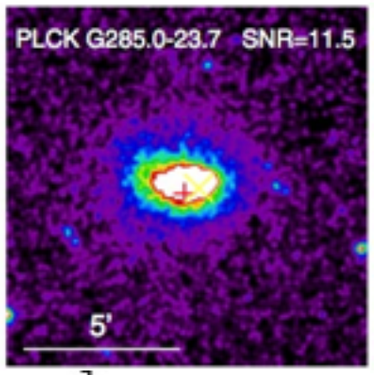
  SPT - 224 clusters (Reichard+12)

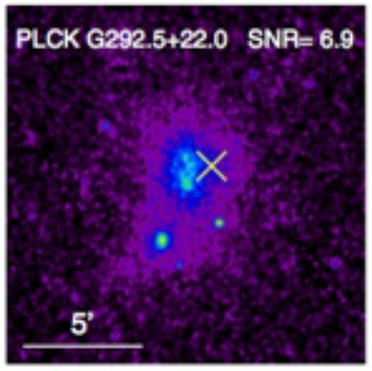
- **New clusters detected in SZ out to 0.1 < z < 1.5**

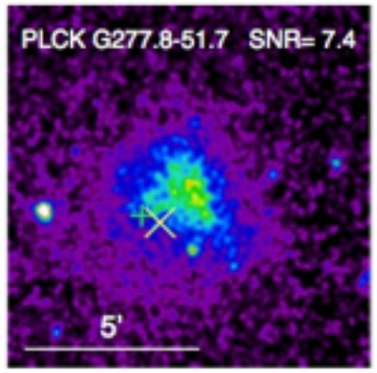


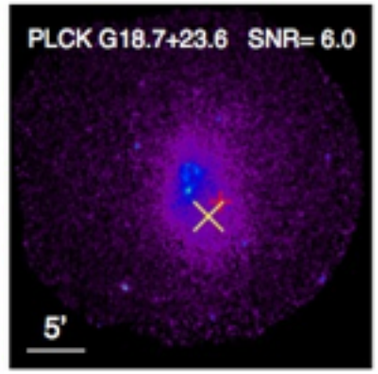
NEW SZ DETECTED CLUSTERS







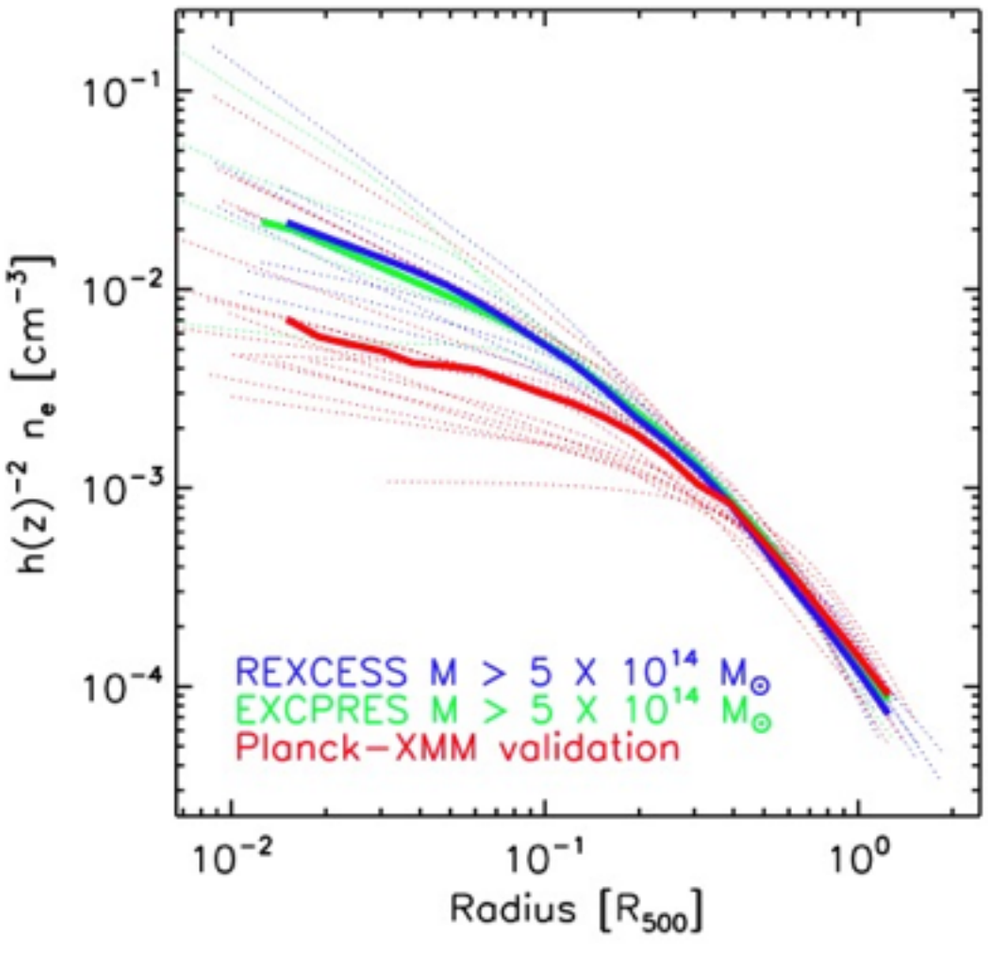




Total of 43 Planck detected clusters confirmed with XMM

- **Morphologically disturbed clusters**
  X-ray selected: ~30% (REXCESS)
  SZ selected: ~70% (PLANCK)

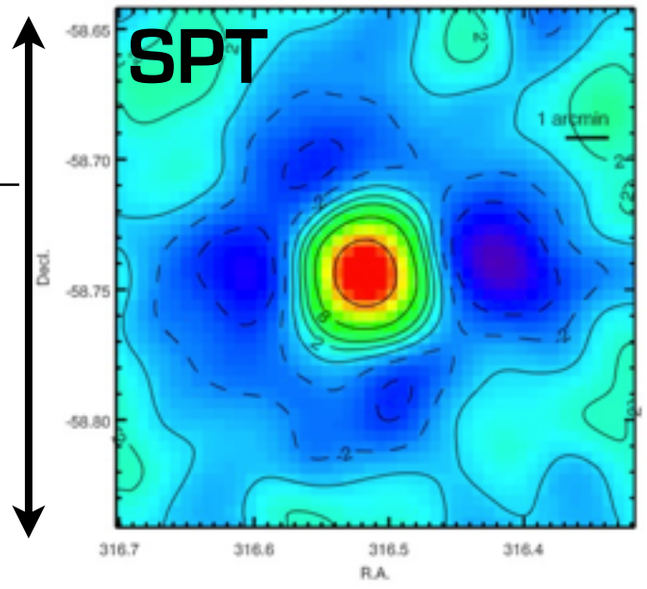
- **Powerful SZ/X-ray synergy**



NEW DISTANT SZ CLUSTERS

- **SPT-CL J2106-5844** (Foley+11) 12’

  z_{spec}=1.13 ; M_{200} = (1.27±0.21)×10^{15} h^{-1} $M_\odot$



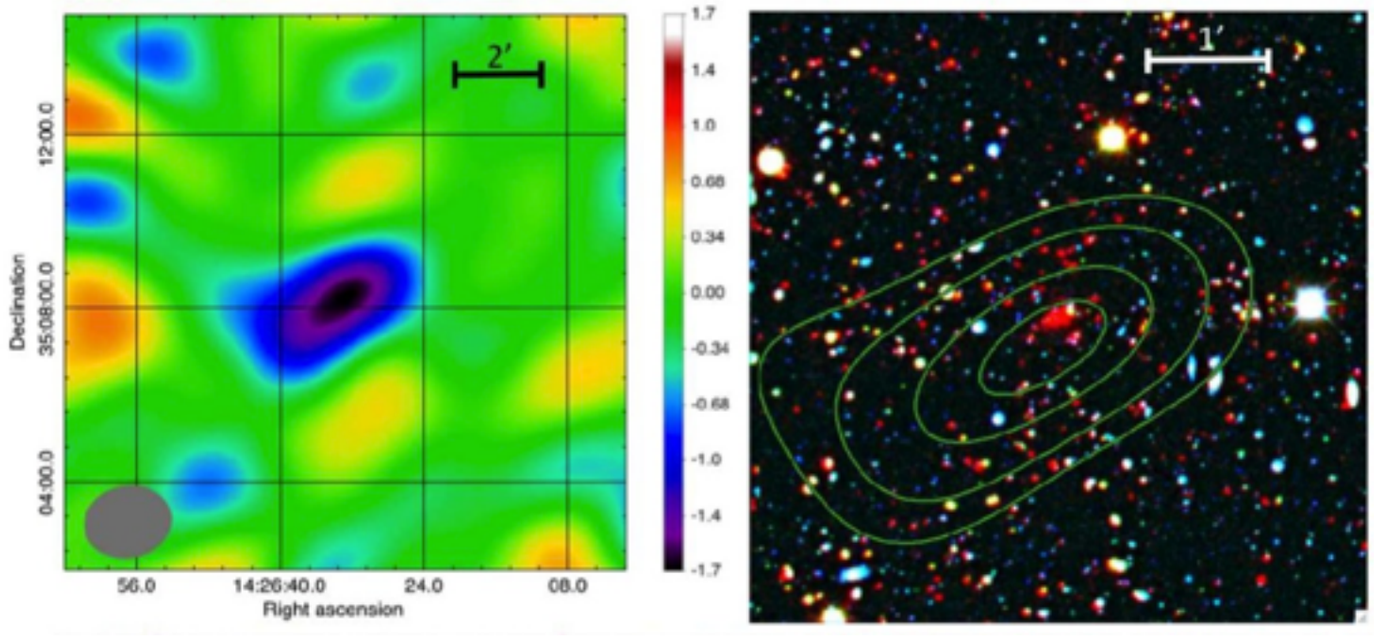
- **IDCS J1426.5+3508**

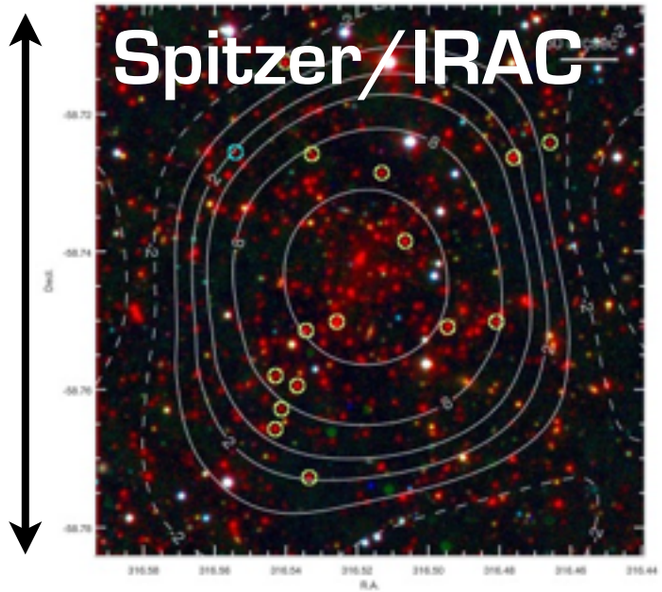
  z_{spec}=1.75 ; M_{200} = (4.3±1.0)×10^{14} h^{-1} $M_\odot$

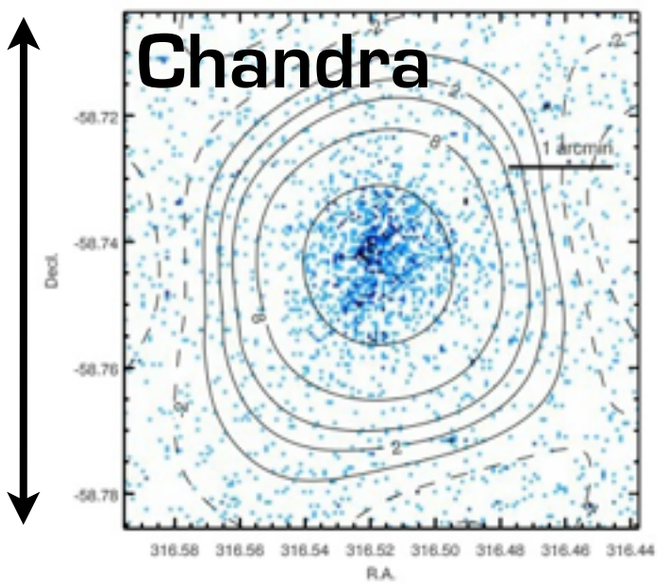
  IR: Detected with Spitzer/IRAC (Stanford+12)

  X-rays: in the Shallow Chandra survey (Murray+05)

  SZ: CARMA measurement at 31 GHz (Brodwin+12)



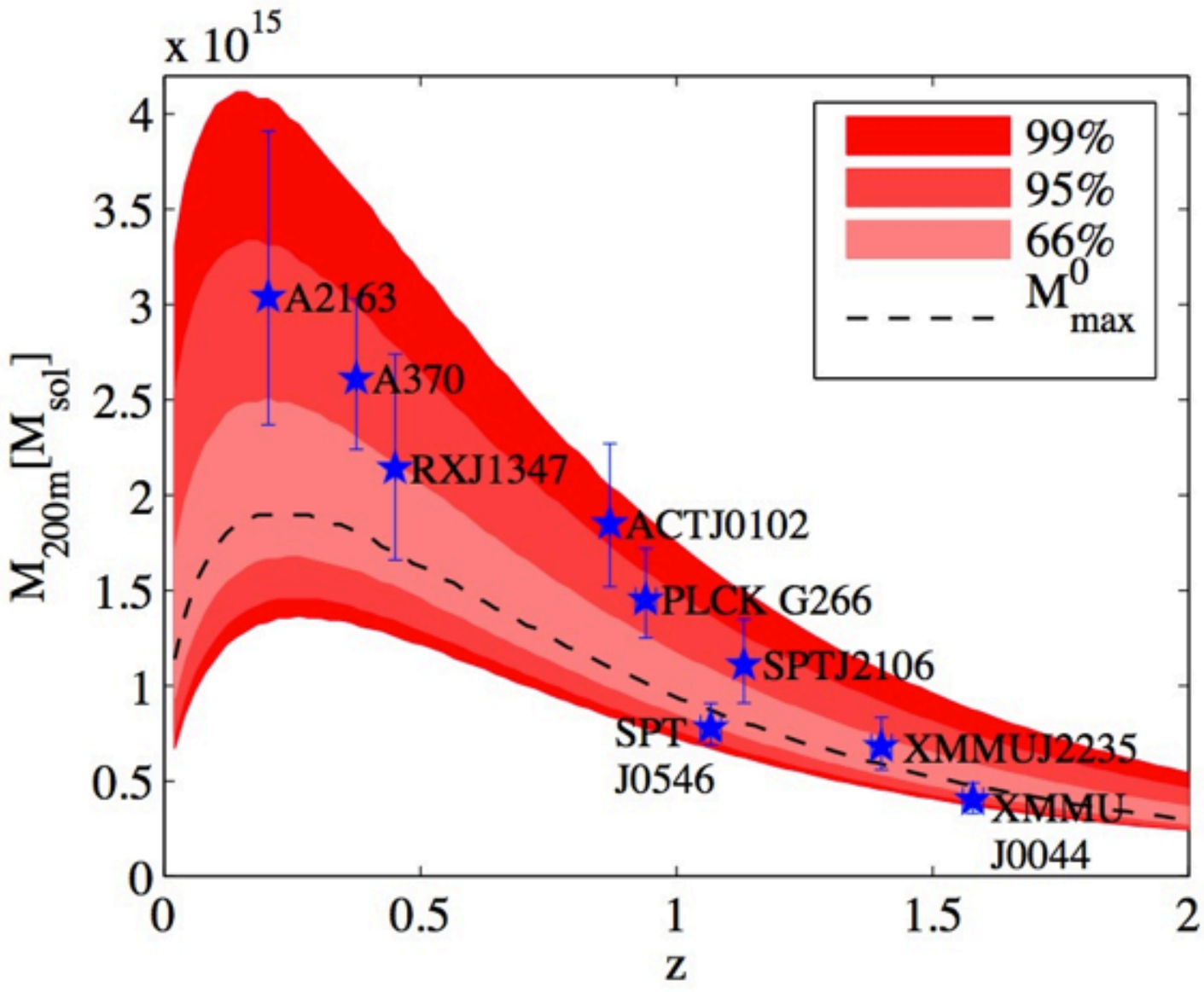




- **Multi-λ synergy (SZ/X-ray/IR/Optical**

CHALLENGING THE STANDARD MODEL?

- A few tenth (to date) SZ clusters with $0.8 < z < 1.5$
- SZ and X-rays have similar redshift reach



(Harrison+12)

COSMOLOGY WITH SZ CLUSTERS

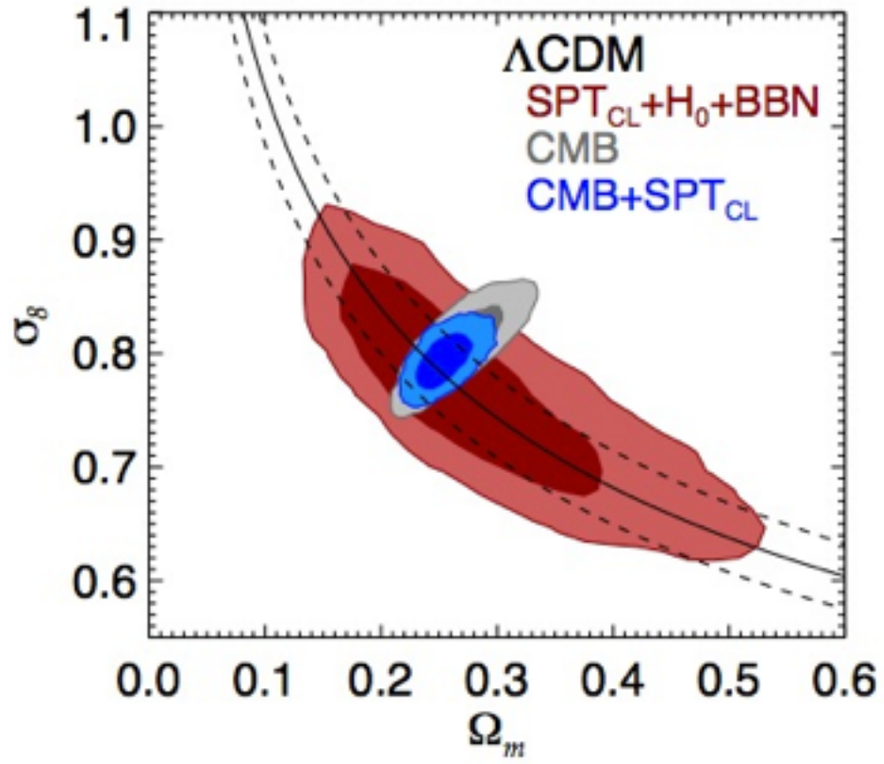
ETIENNE POINTECOUTEAU, MILANO, OCTOBER 2012

SZ CLUSTERS AND COSMOLOGY

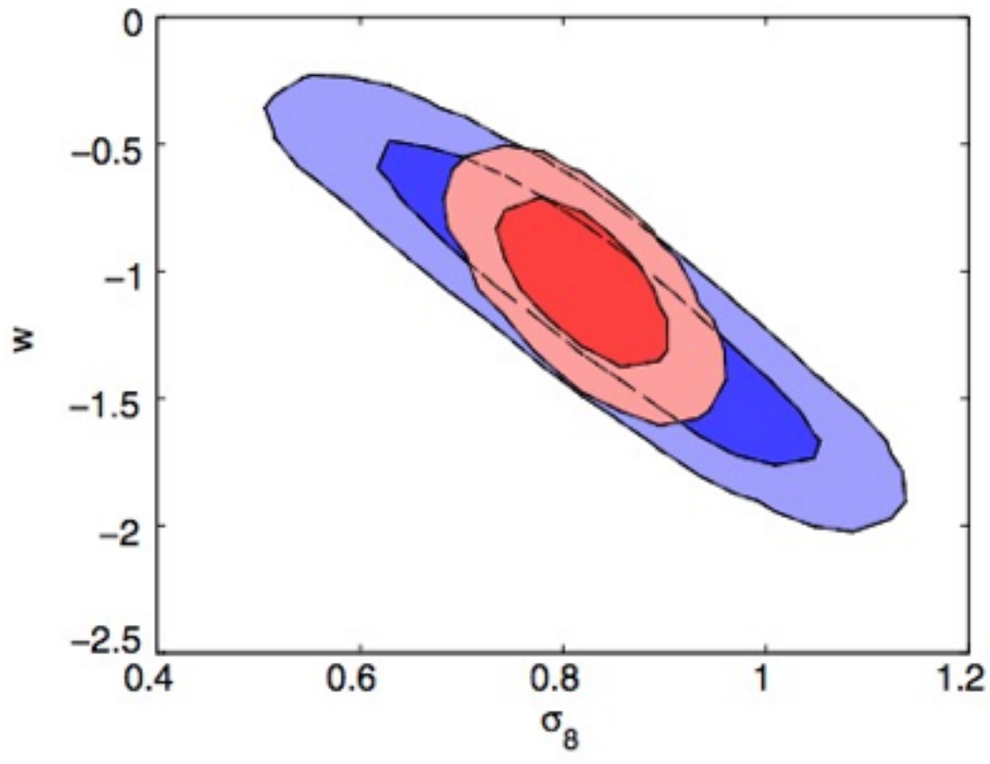
- Clusters are the last structure to form: their mass function is strongly linked to the matter and energy content of the Universe

- SZ samples offer the closest thing to a mass selected sample

- Complementary constraints to CMB, SN, BAO on DM and DE



Reichardt+11 (SPT)

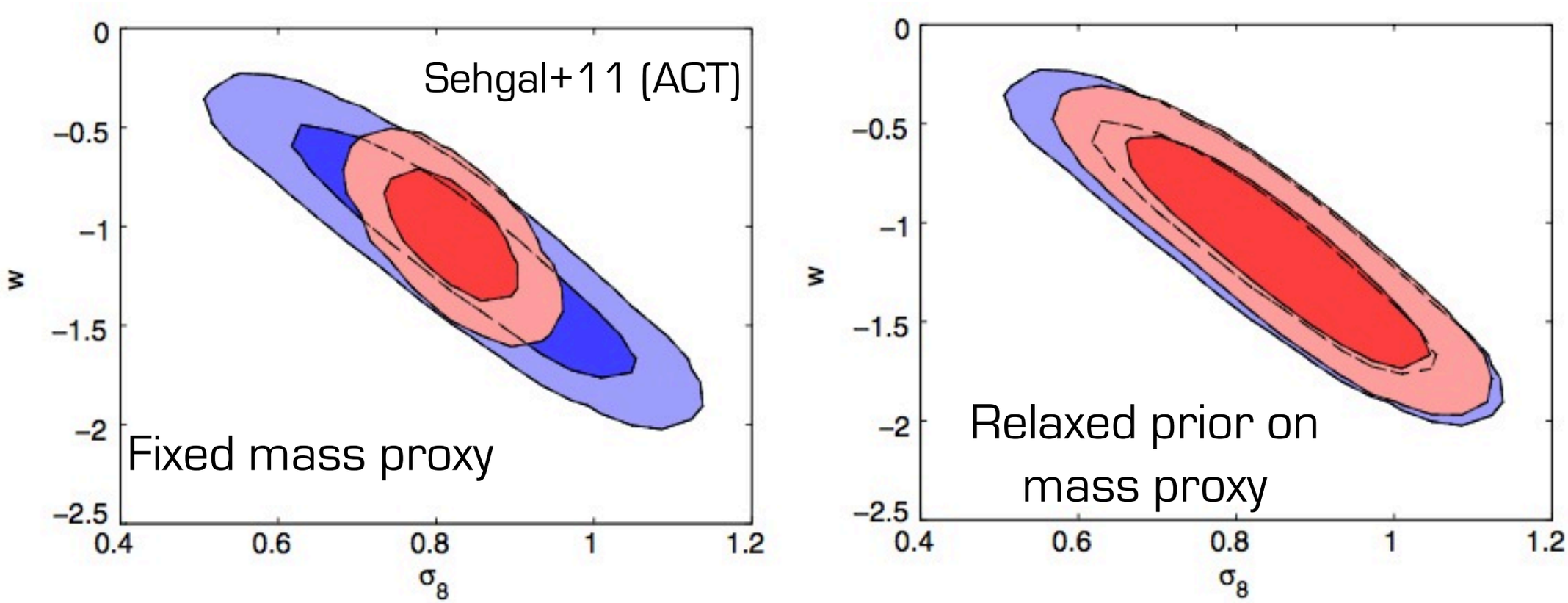


Sehal+11 (ACT)

FROM SZ OBSERVABLE TO MASS

☺ **Clusters are powerful cosmological probe**

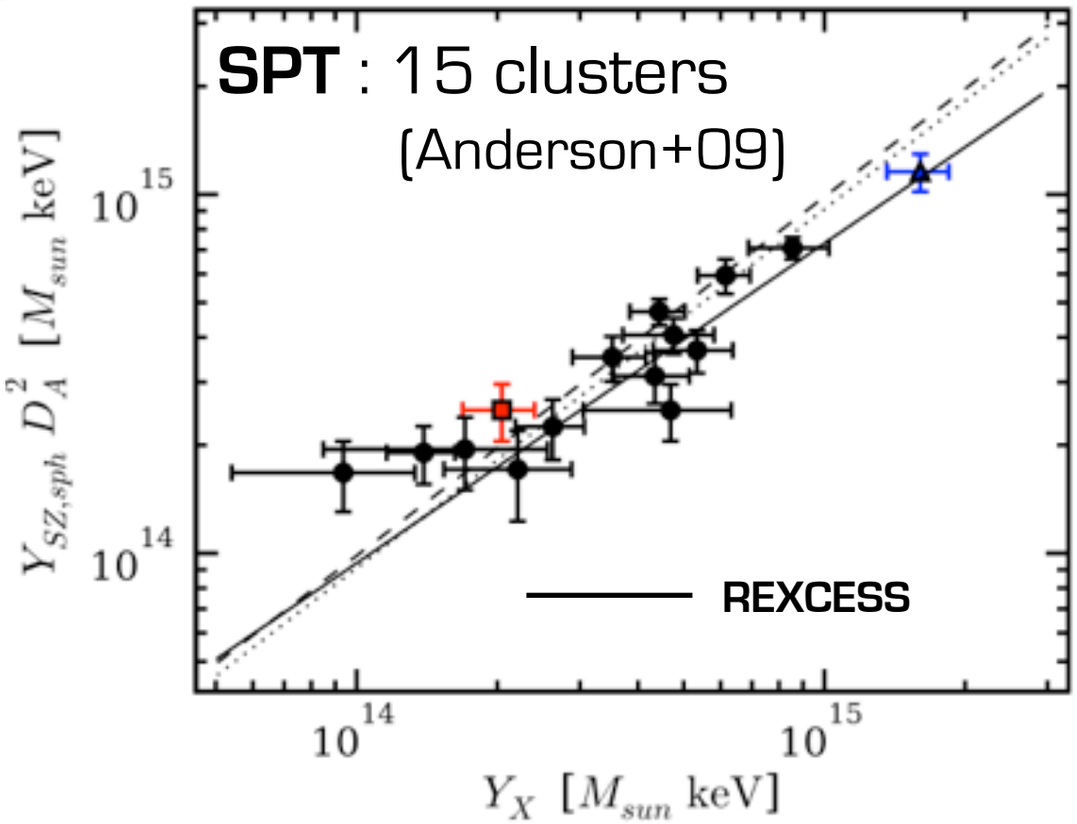
☹ **Cluster cosmology is prone to biases and systematics**

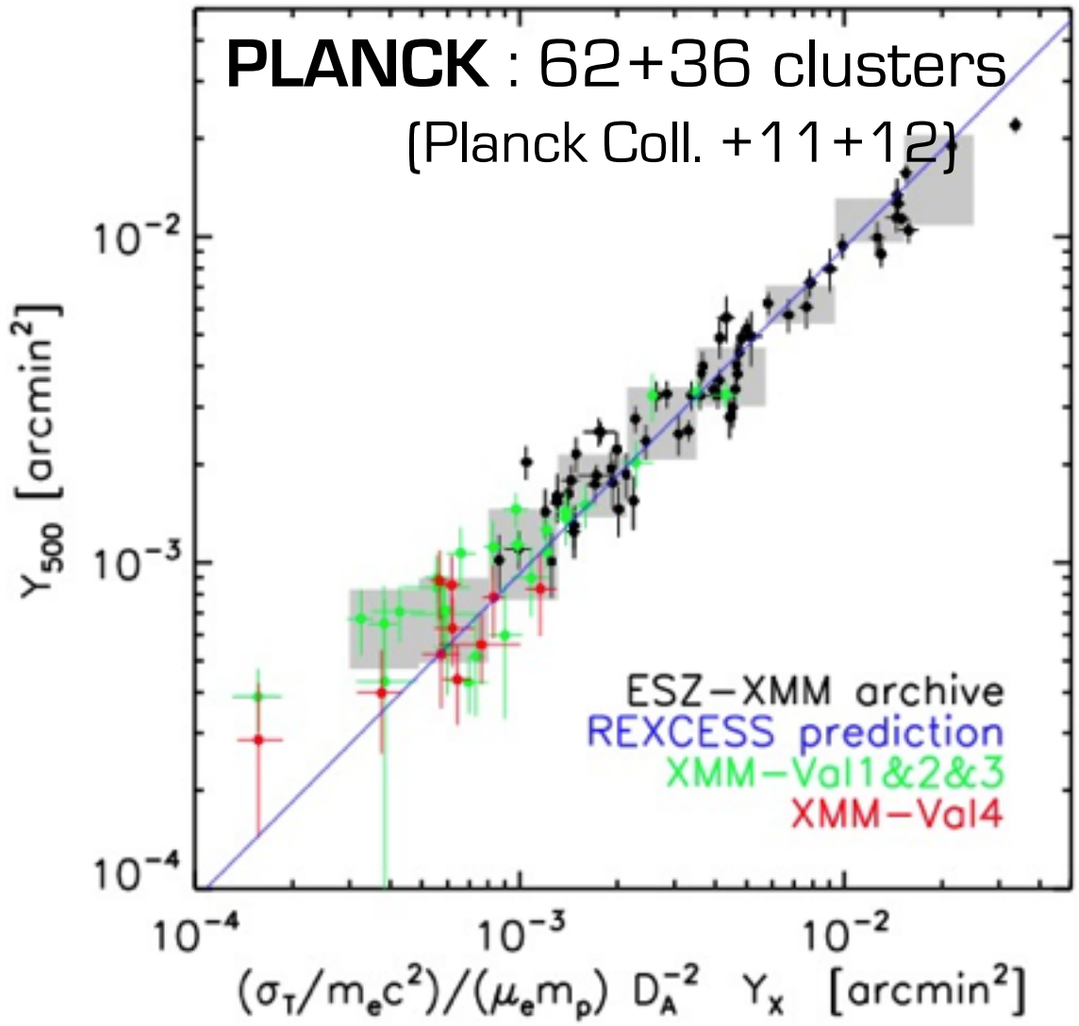


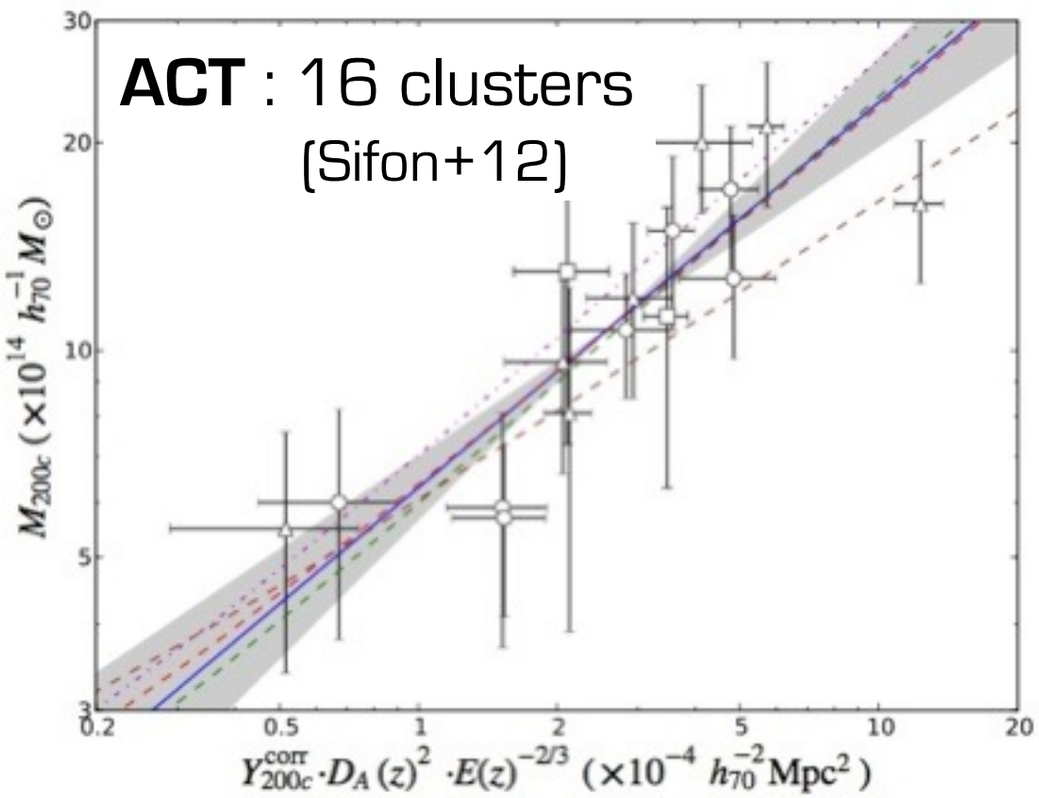
- **Need well understood proxy to link the observable (SZ, X-ray, etc) to the halo mass**

STATISTICAL PROPERTIES OF GALAXY CLUSTERS

SCALING RELATIONS

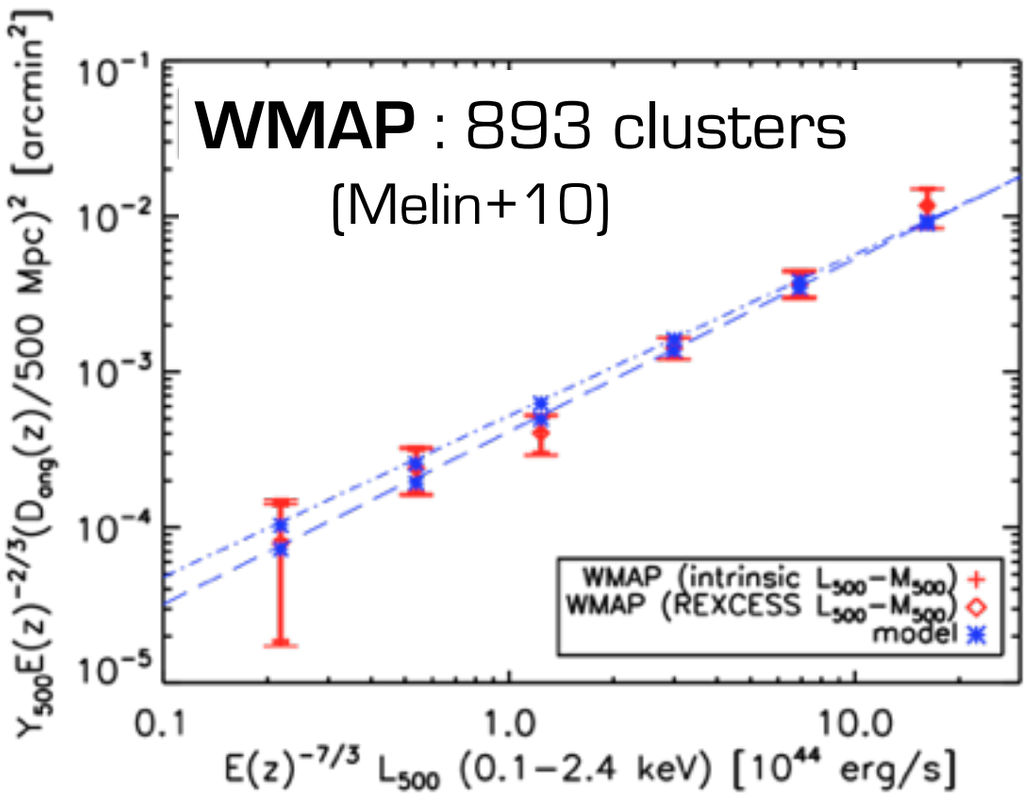


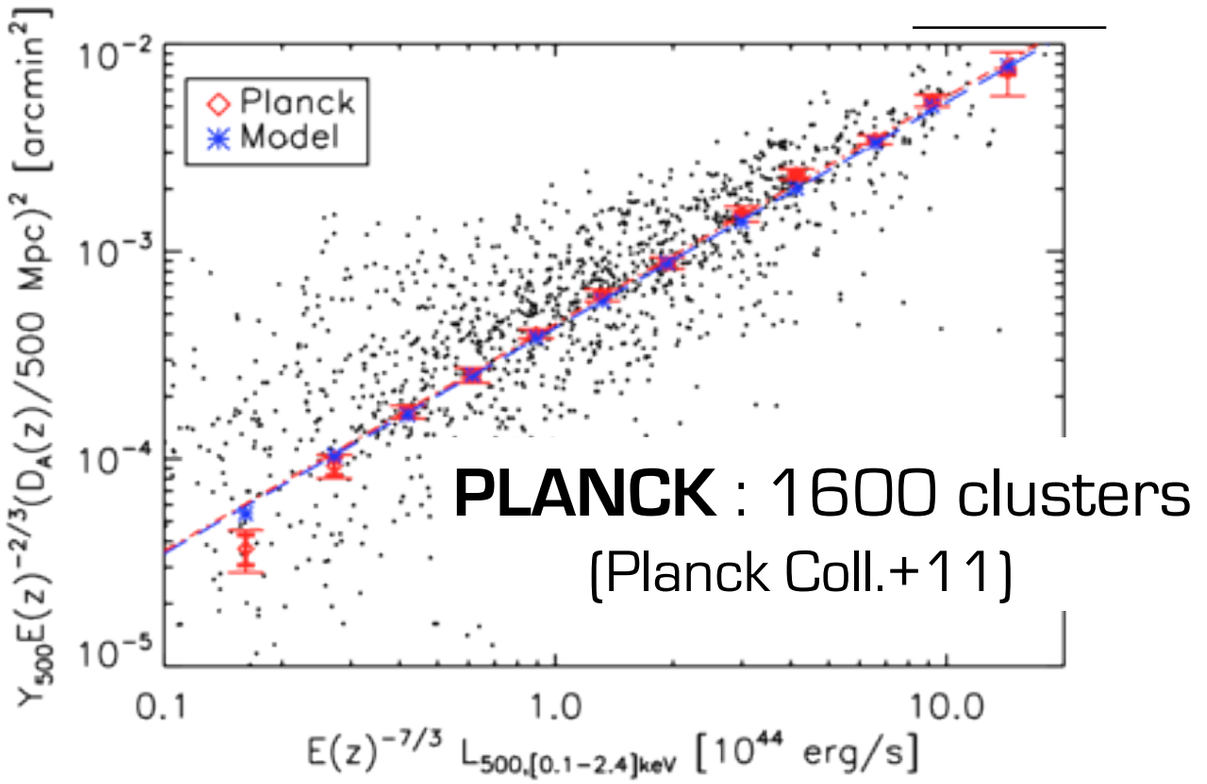




- **SZ selected sample**
- **Consistency between SZ measurements**
- **Excellent agreement between SZ and X-ray data are consistent** (at least within R_{500})

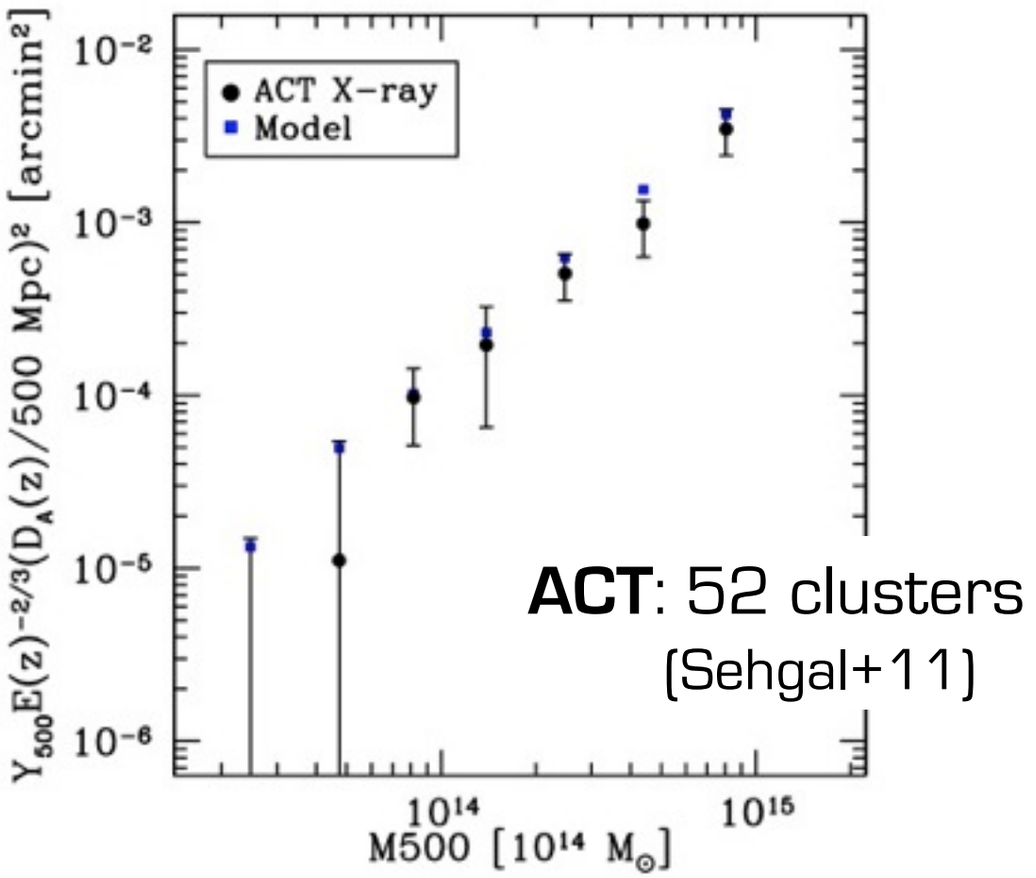
SCALING RELATION FROM STAT ANALYSIS





- **X-ray selected sample**

- **Homogenous results between SZ and X-rays measurements** (at least within R_{500})



ONGOING WORK

- **Precise calibration of SZ/X-ray scaling relations and their evolution**
  For structure formation studies
  For cosmology (quick mass measurement)

- **Consistency with other observables**

- **Ongoing project in CARMA, SPT, Planck collaborations**

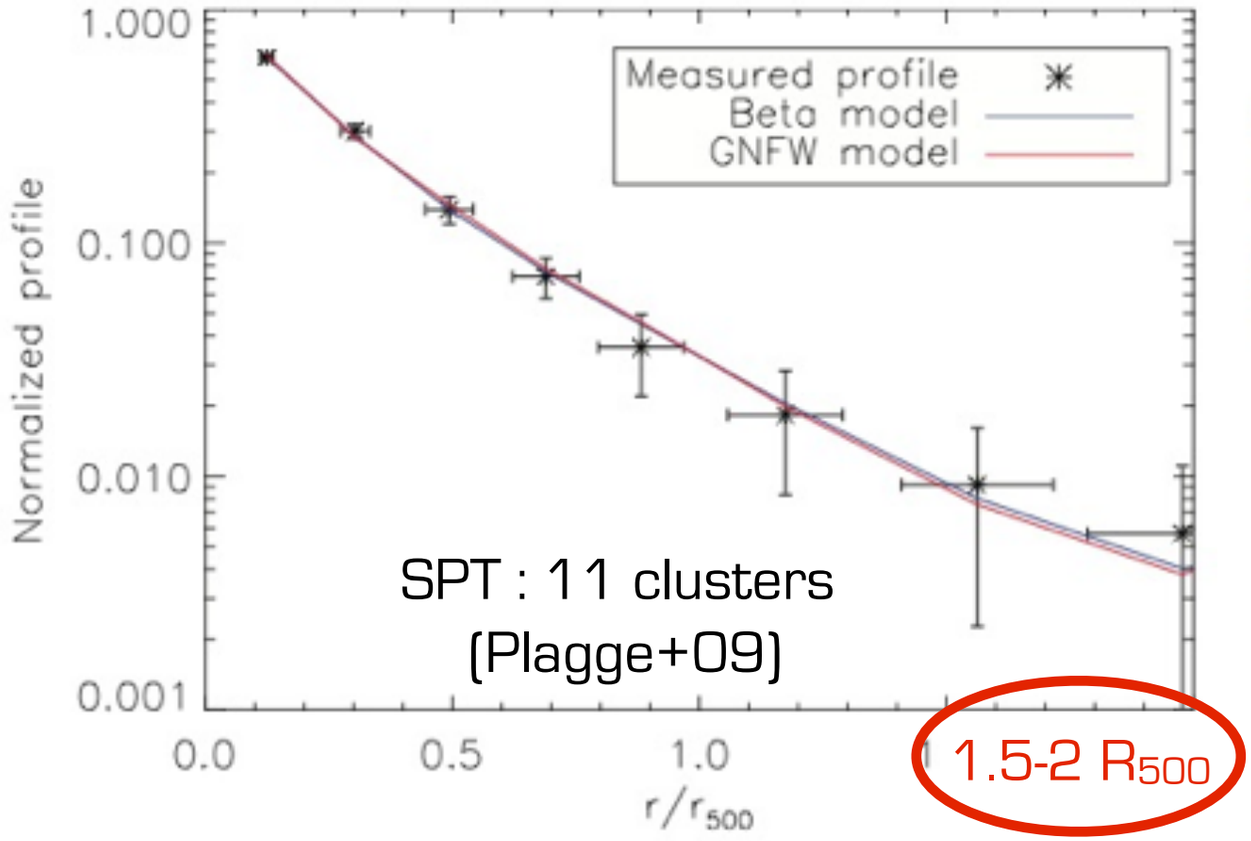
PHYSICS OF GALAXY CLUSTERS

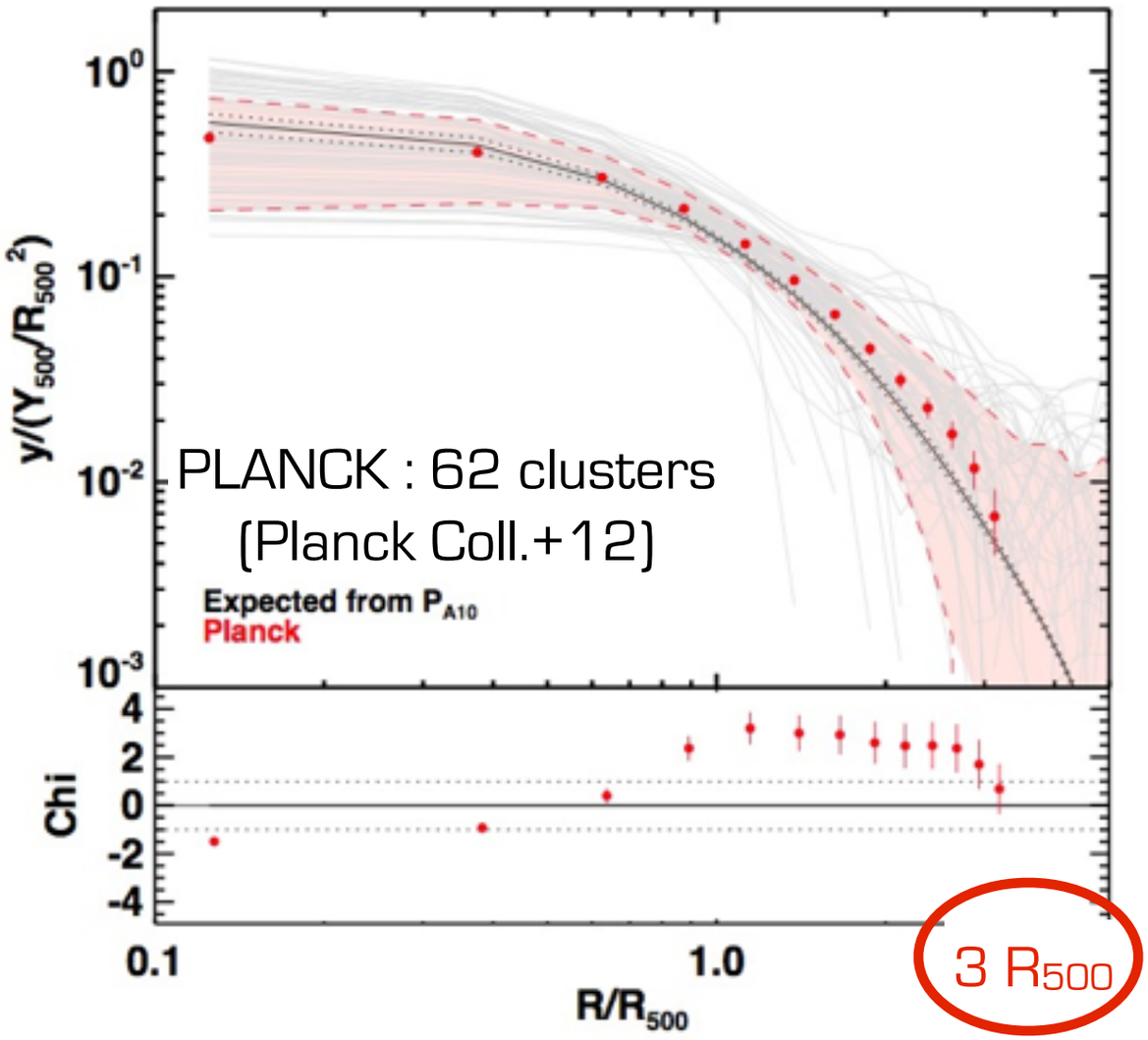
ETIENNE POINTECOUTEAU, MILANO, OCTOBER 2012

irap

CLUSTER STRUCTURE FROM SZ

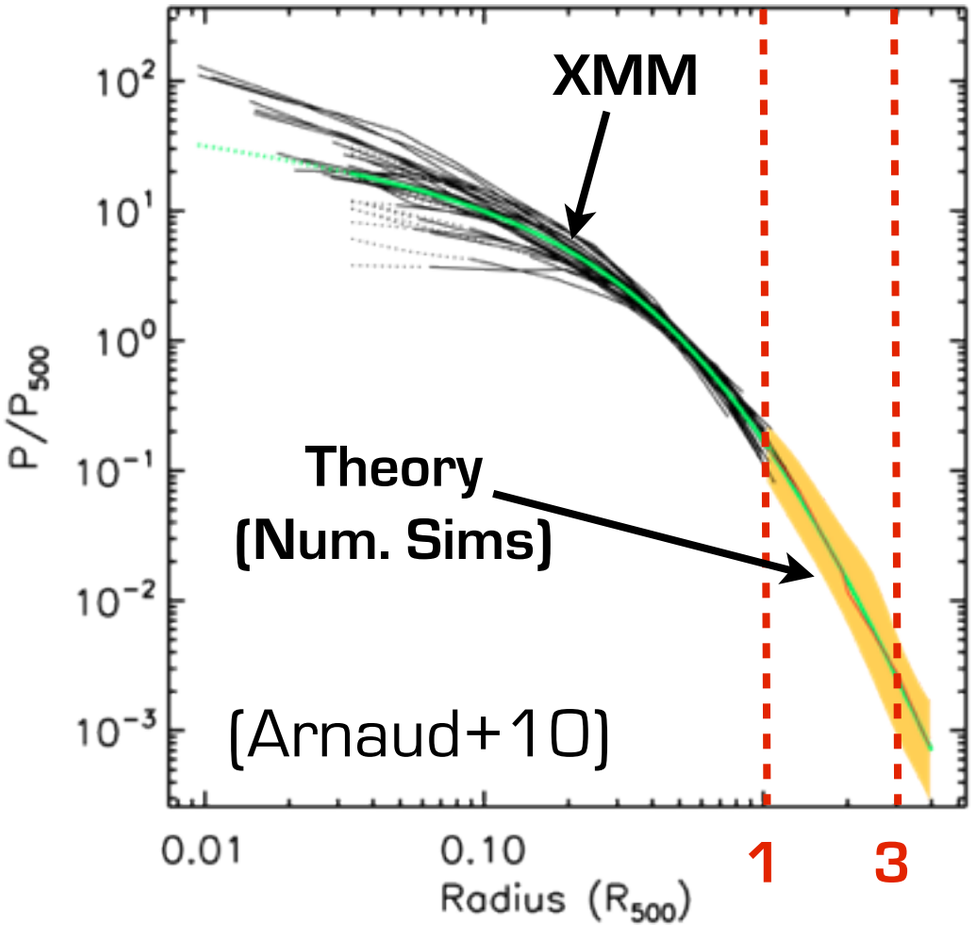
- **SZ signal distribution probing the ICM out to the outskirts of clusters**

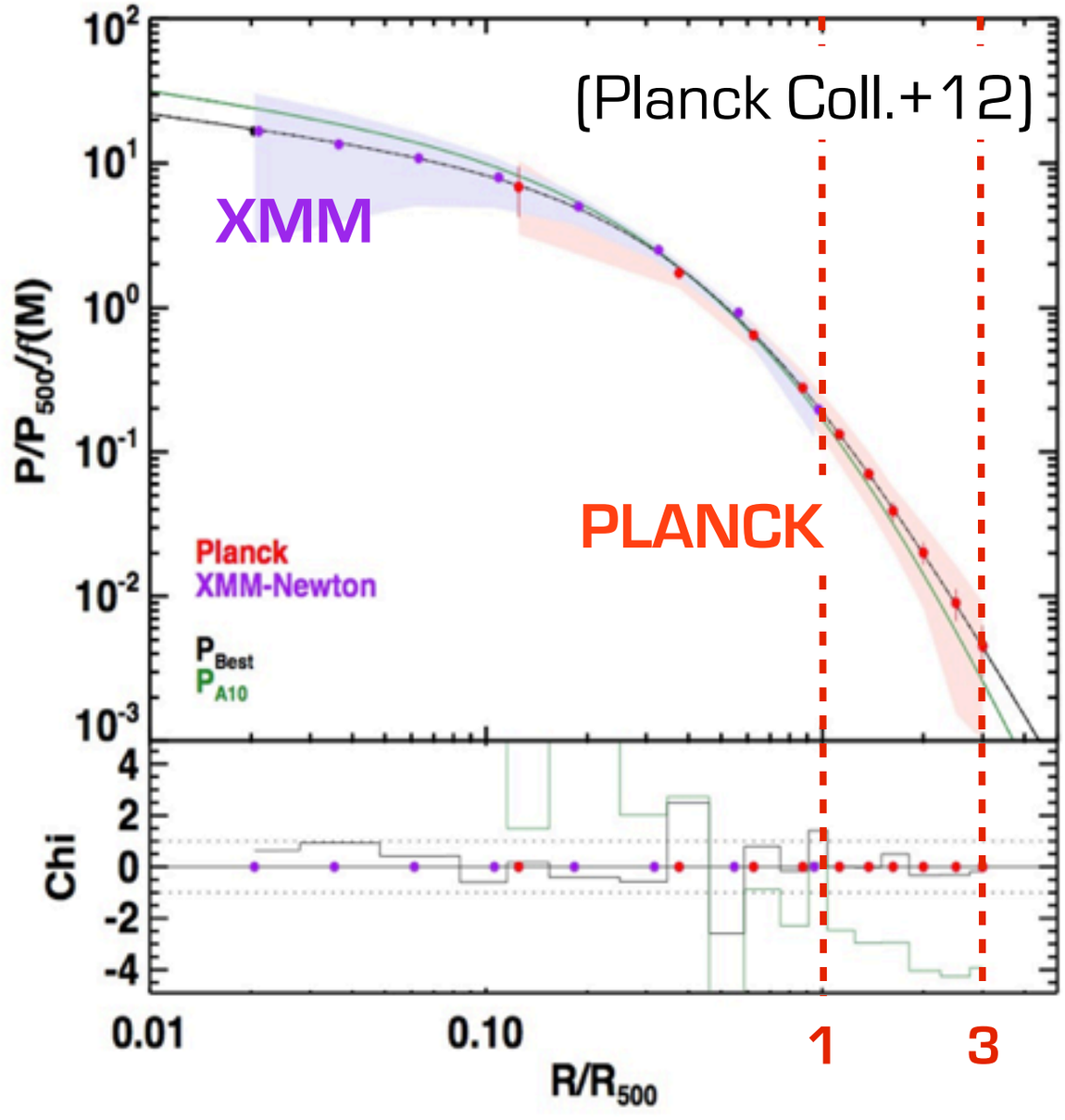




see also Pointecouteau+02, Jia+08, Halverson+09, Nord+09Komatsu+11, Sehgal+11, Bonamente+11

PRESSURE PROFILES





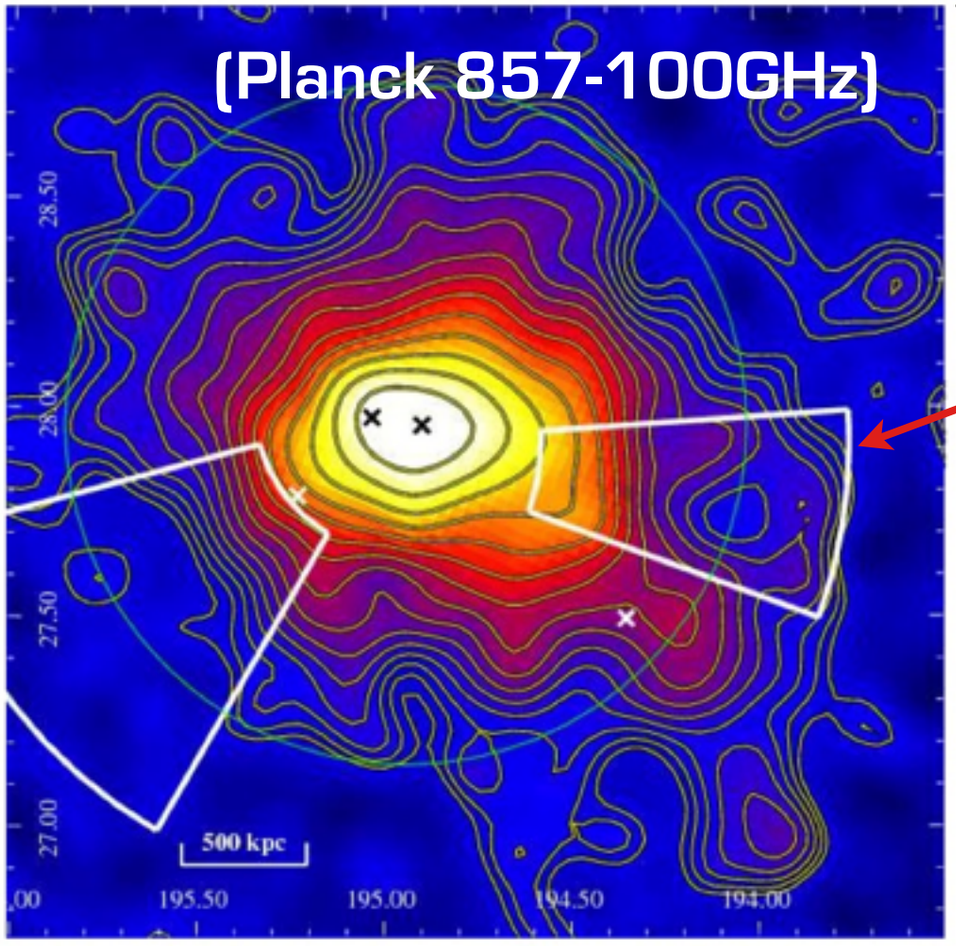
- **Average radial reach of X-rays and SZ measurements**

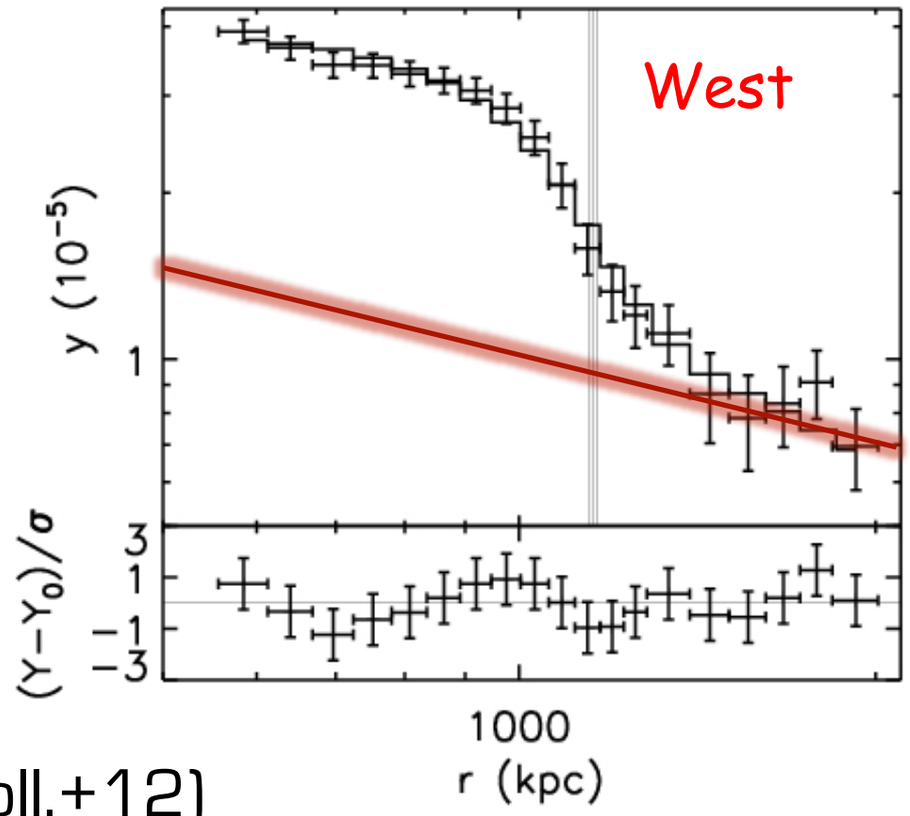
  X-rays → 0.01-1 R_{500} for samples (SXB out to 1-2 R_{500} - e.g. Eckert+12)

  SZ → 0.1-3 R_{500}

- **Agreement of X-ray and SZ profiles over [0.1-1] R_{500}**
- **Joint constraint of the average cluster pressure profile**

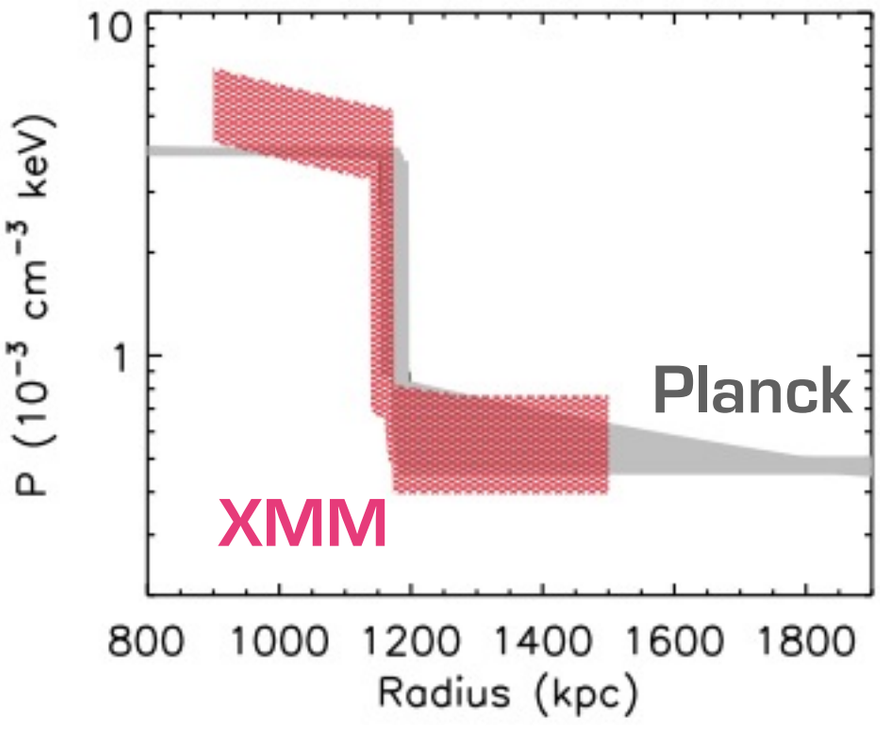
PRESSURE JUMPS IN THE ICM





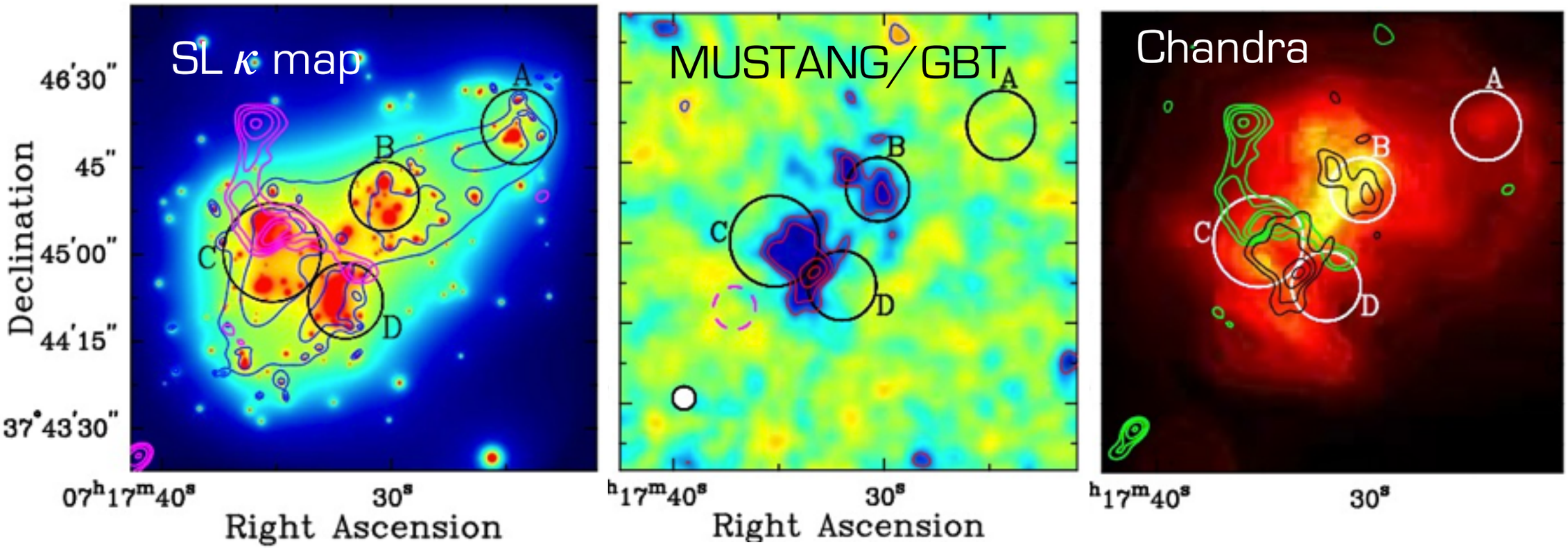
(Planck Coll.+12)

- **Detection and measure of pressure jumps (shocks) in Coma by Planck**
- **Strong constraints on models for the cluster B field and the production of cosmic ray electrons**



2D STRUCTURE: MACS J0717.5+3745

SL (Zitrin+09, Limousin+09) ; Light distribution (Ma+09) ; Radio (van Weeren+09)



- **Shock heated gas in a complex triple merger system**

  Radio emission (GMRT 610 MHz)

  Chandra temprature > 20 keV (Mroczkowski+12)

  Mustang pressure enhancement

- **Dynamics: infalling velocity at the subcluster scale**

  Combine Mustang & Bolocam SZ data + X-rays/Optical

HIGH MASS OR ENHANCED PRESSURE?

- **SZ detection with high significance**

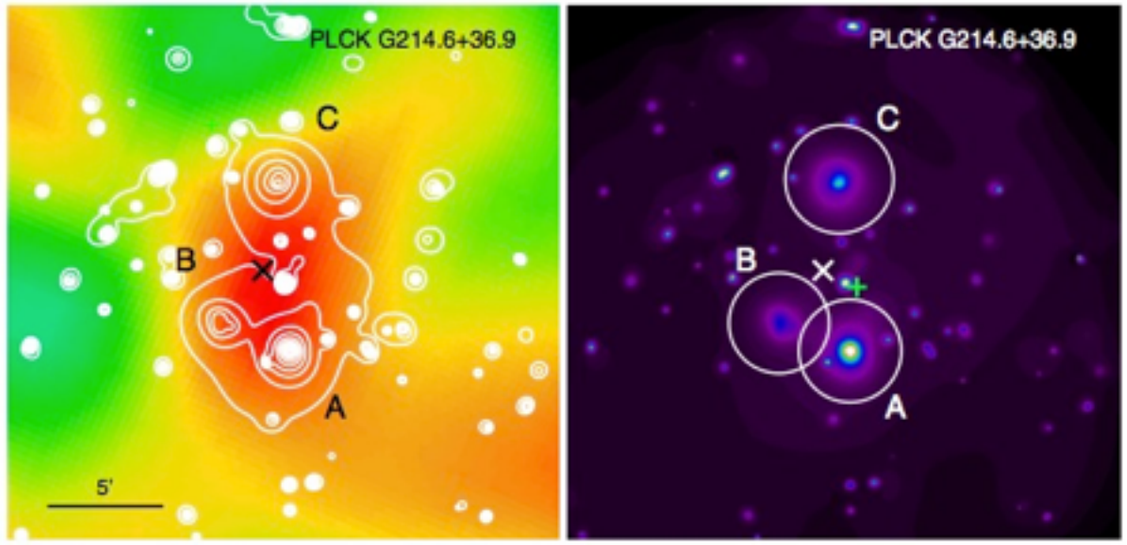
- **Structural details revealed via multi-wavelength follow-up**
  X-rays, Optical, lensing, IR, radio, etc

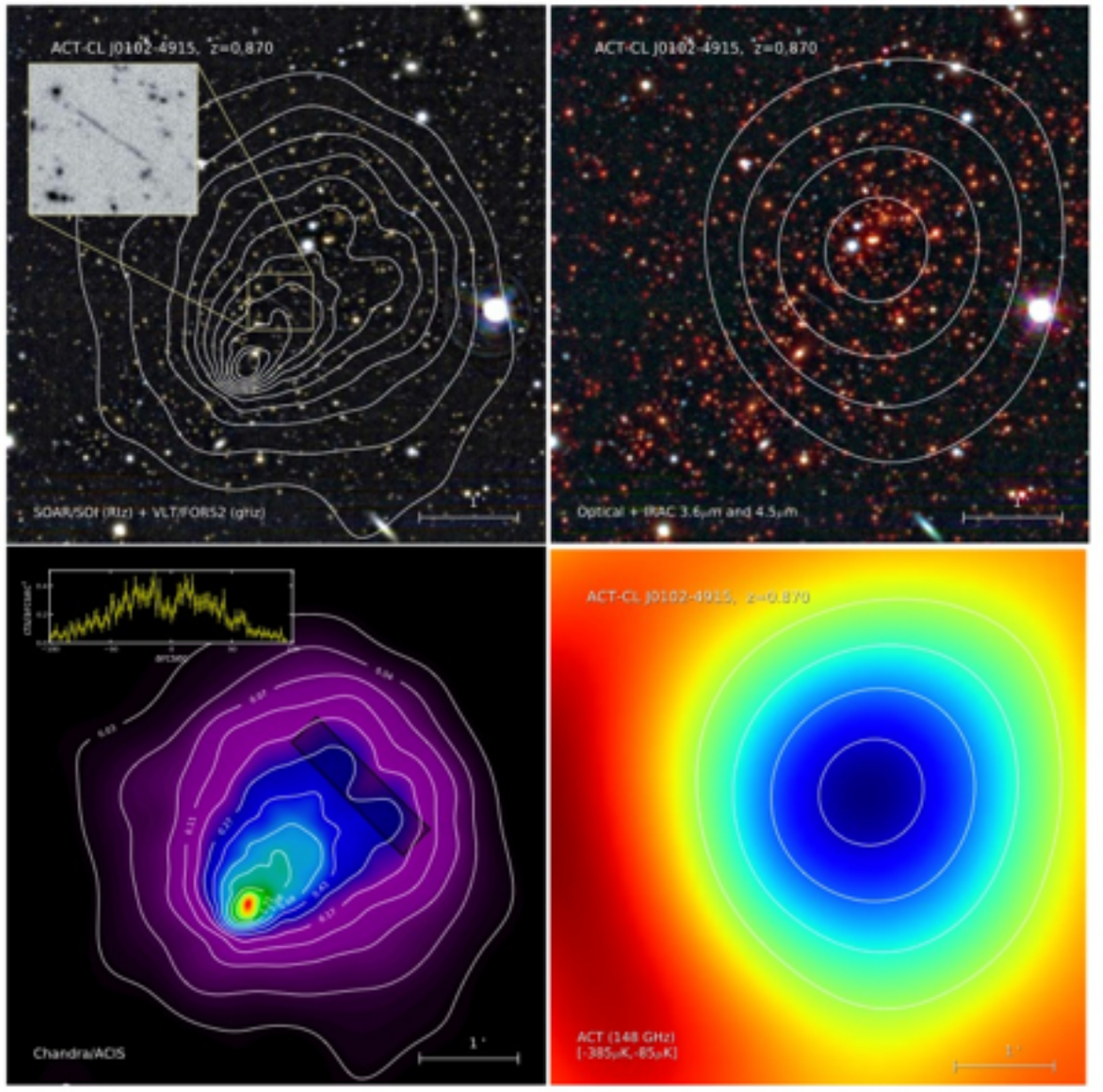
- **Planck supercluster** z=0.45
  (Planck Coll.+11+12)

- **El Gordo (ACT)** z=0.87
  (Menanteau+12)

!!!

SZ signal produced by high mass systems and /or enhanced pressure due to complex dynamics





TAKE HOME MESSAGES

CONCLUSIONS

- **SZ observations**

  Detection of new clusters (since ROSAT and before eROSITA)

  SZ sample are close to mass limited

  Cluster cosmology

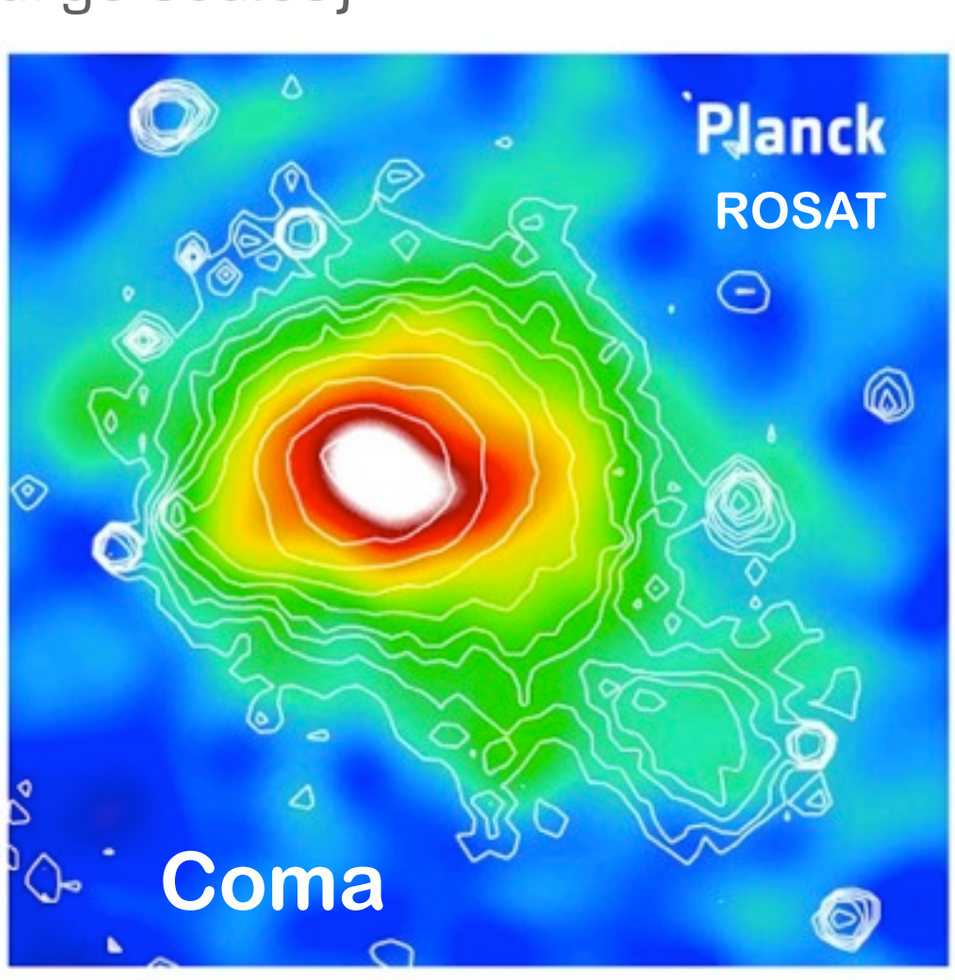
  Formation and evolution of massive halos (statistical properties)

  Physics of the ICM (pressure distribution, dynamics, etc)

  (Signature of the baryons distributed at large scales)

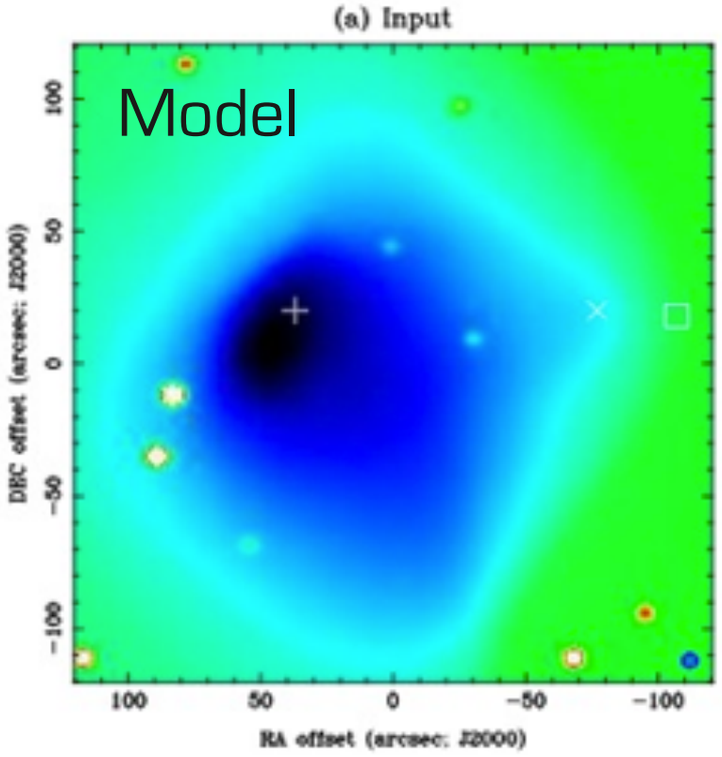
  (Kinetic SZ effect & bulk flows)

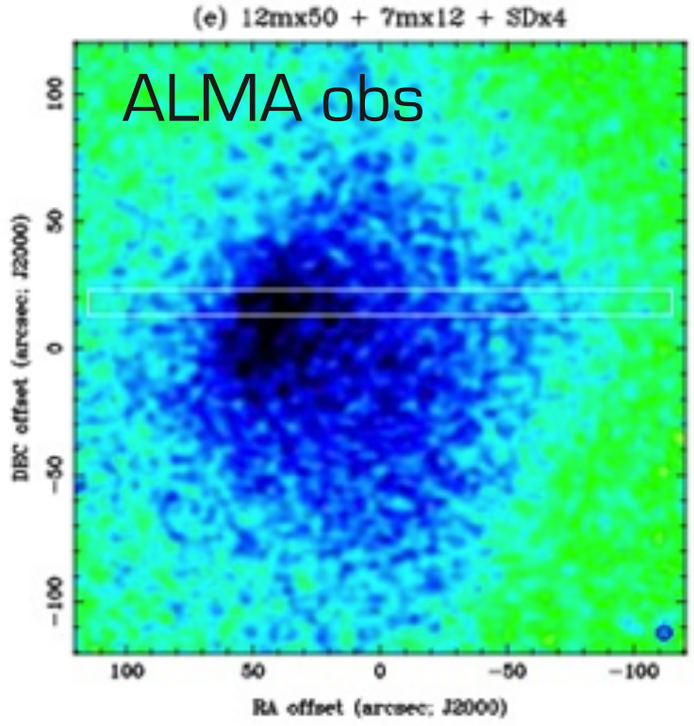
Obvious synergies between SZ and X-rays observations



(NO) FUTURE

ALMA simulation of a bullet like cluster
(Yamada+12)





! Over the whole sky !