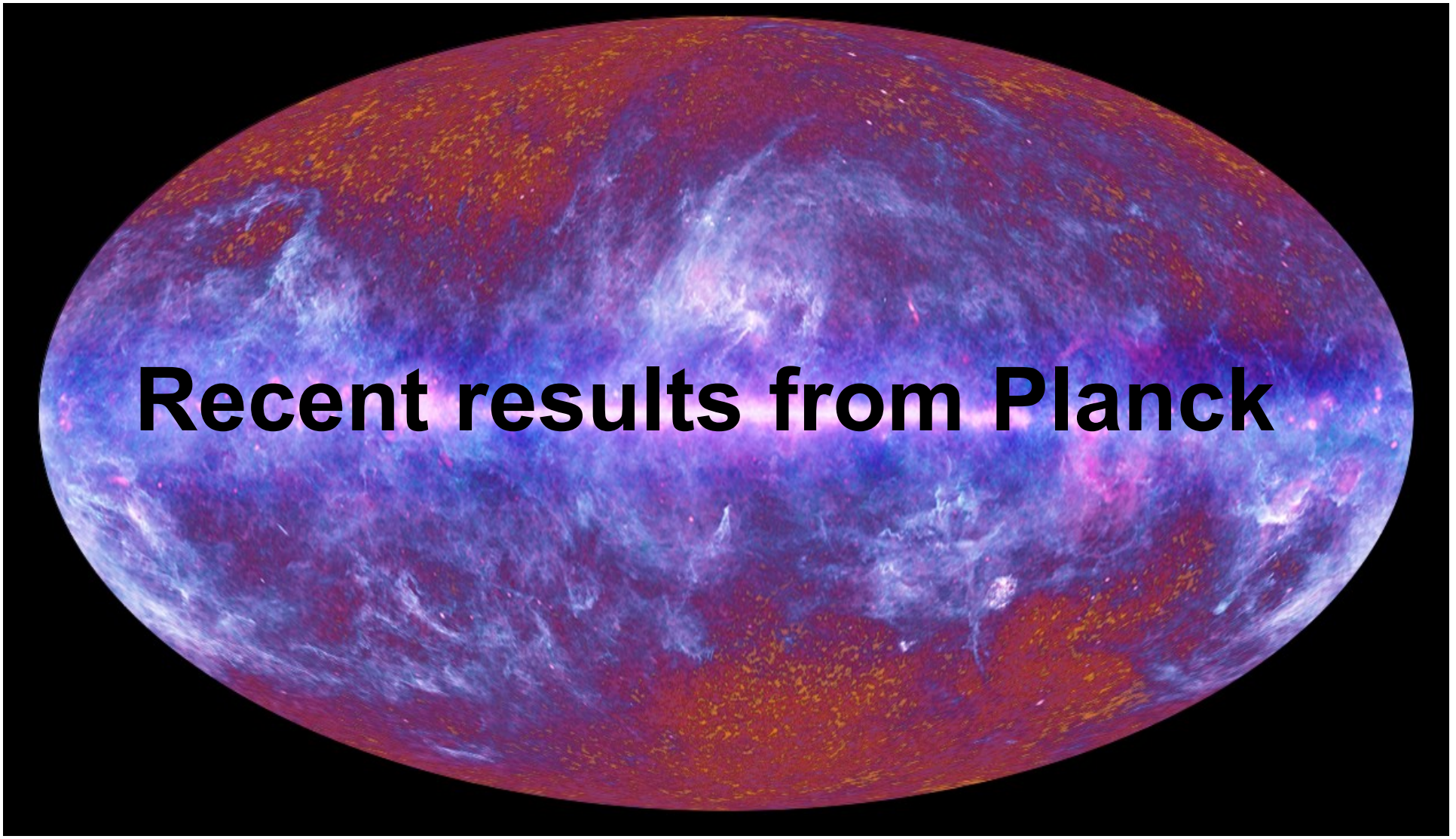


Recent results from Planck

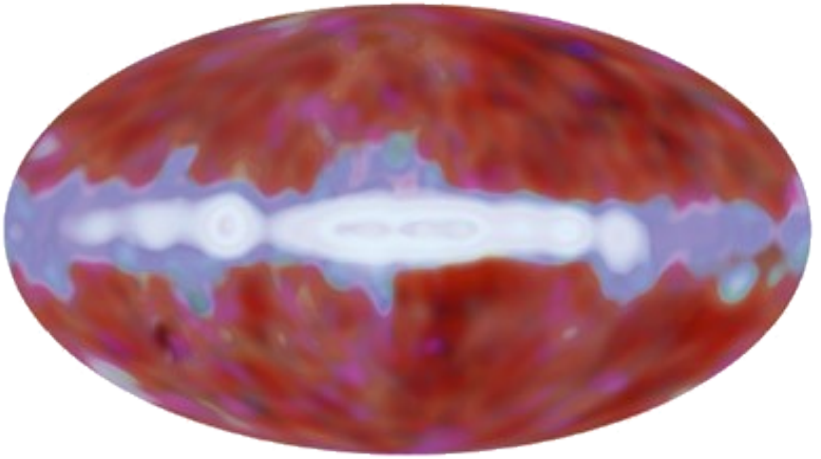
Nabila Aghanim
Institut d'Astrophysique Spatiale, CNRS-Univ. Paris Sud
on behalf of the Planck collaboration


esa
planck
cnes
agenzia spaziale italiana
PLANCK LFI
HFI PLANCK
NASA
cnrs
DTU Space
National Space Institute
INAF ISTITUTO NAZIONALE DI ASTROFISICA
Science & Technology Facilities Council
CSIC
Consejo Superior de Investigaciones Científicas
National Research Council of Italy
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
IAS orsay
IAP
INAF - IASF BO
ISTITUTO NAZIONALE DI ASTROFISICA
ISTITUTO DI ASTROFISICA SPAZIALE E FISICA COSMICA DI BOLOGNA
CSA ASC
DLR
Deutsches Zentrum für Luft- und Raumfahrt e.V.
UK SPACE AGENCY
MAX-PLANCK-GESELLSCHAFT
Aalto University
ioa
KICC
Kavli Institute for Cosmology Cambridge
Cavendish Astrophysics
University of Cambridge
Cardiff University
Prifysgol Caerdydd
irfu
saclay
CESR
CITA–ICAT
cnrs
IN2P3
Les deux infinis
ipac
Infrared Processing and Analysis Center
Helsinki Institute of Physics
IFCA
Instituto de Física de Cantabria
Imperial College London
Università degli Studi di Milano
NÉEL institut
IPAG
Institut de Planétologie et d'Astrophysique de Grenoble
ISDC
Data Centre for Astrophysics
JPL
LAL
Laboratoire de l'Accélérateur Linéaire
l'Observatoire de Paris
LERMA
LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie
The University of Manchester
MilliLab
Max-Planck-Institut für Astrophysik
NUI Maynooth
INAF
Osservatorio Astronomico di Padova
University of Oxford
Dipartimento di Fisica
Sapienza
Università di Roma
Science & Technology Facilities Council
Rutherford Appleton Laboratory
Tor Vergata
Osservatorio Astronomico Trieste
UBC
UC
Universidad de Cantabria
UCSB
SISSA
ALMA
ESO
US
University of Sussex
esa
University of Helsinki
Université de Genève
University of Toronto
Université de Paris-Sud XI
asdc
ASI Science Data Center

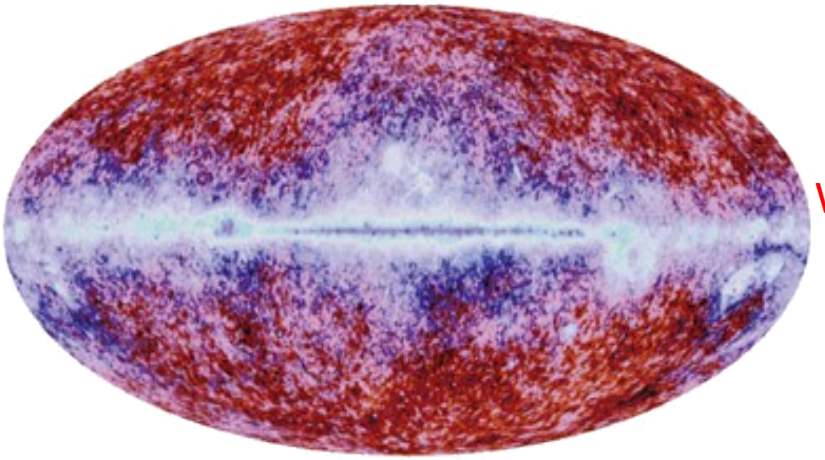
Planck → 3rd generation of CMB space mission

Primary goals → CMB temperature anisotropies to fundamental limits down to 5' & CMB polarisation anisotropies

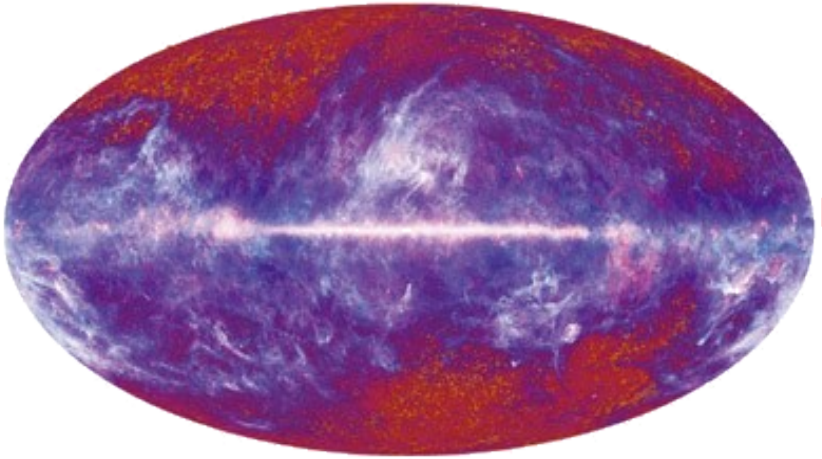
- Separate CMB from foregrounds
- Observe the sky over many frequencies → A lot of ancillary science (subject of Planck early and intermediate results)



COBE ~1993



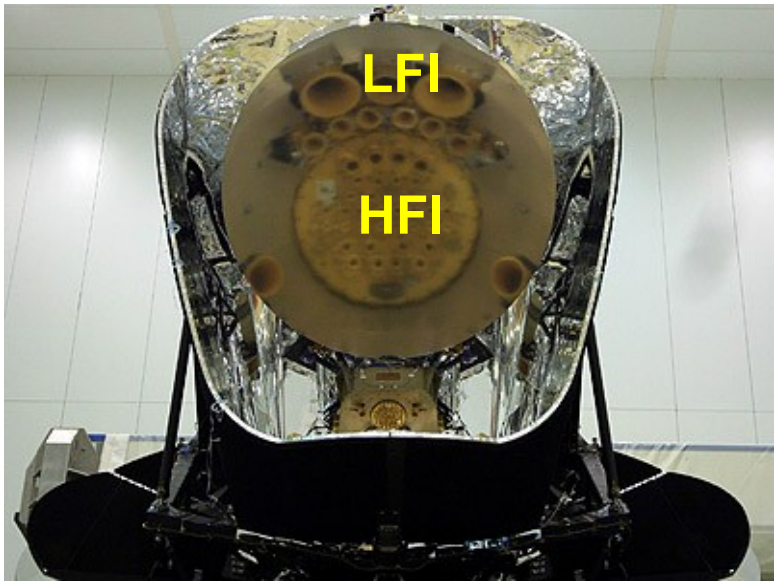
WMAP ~2003

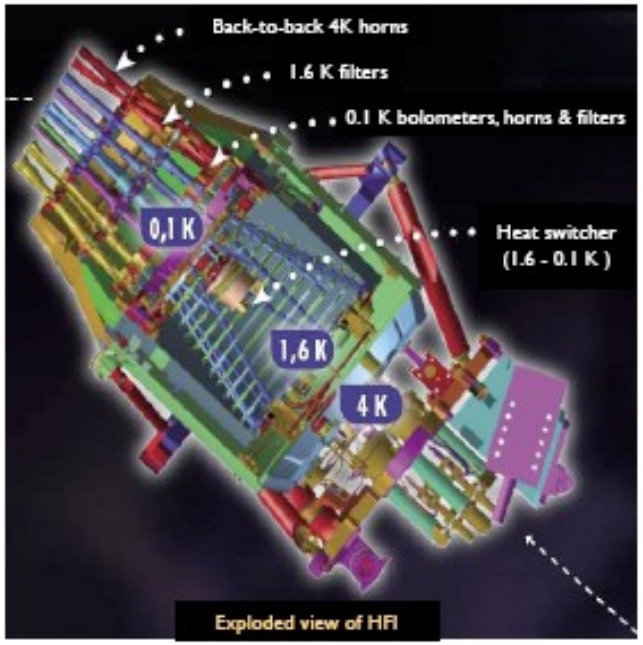


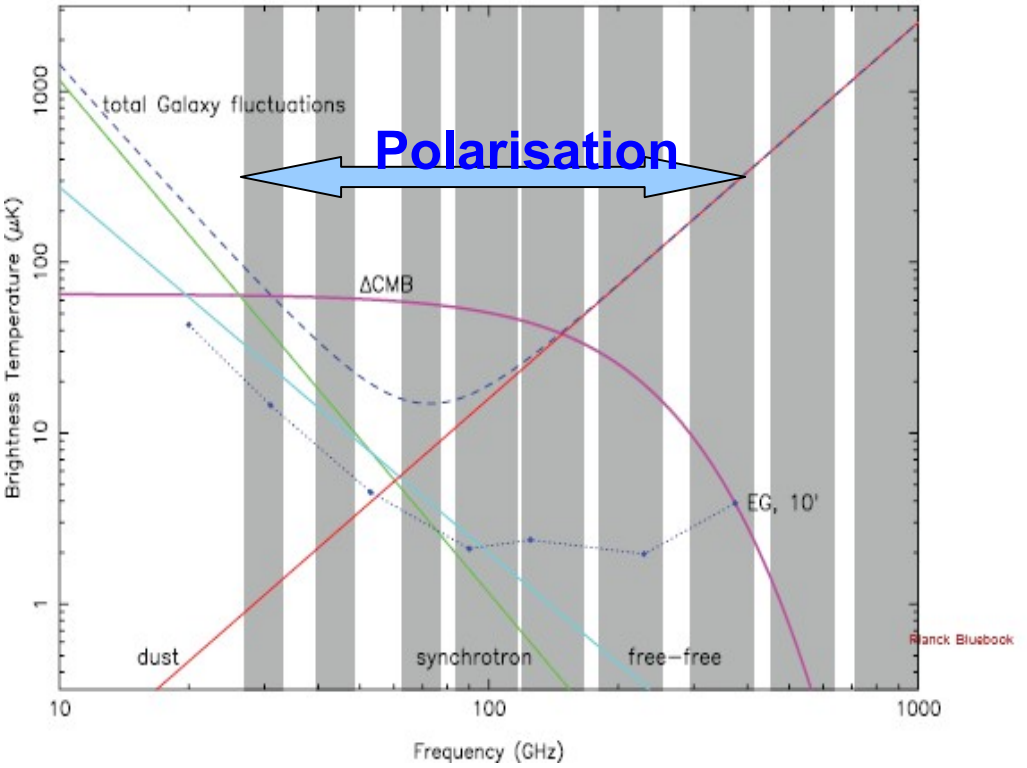
Planck ~2010

Technological achievements

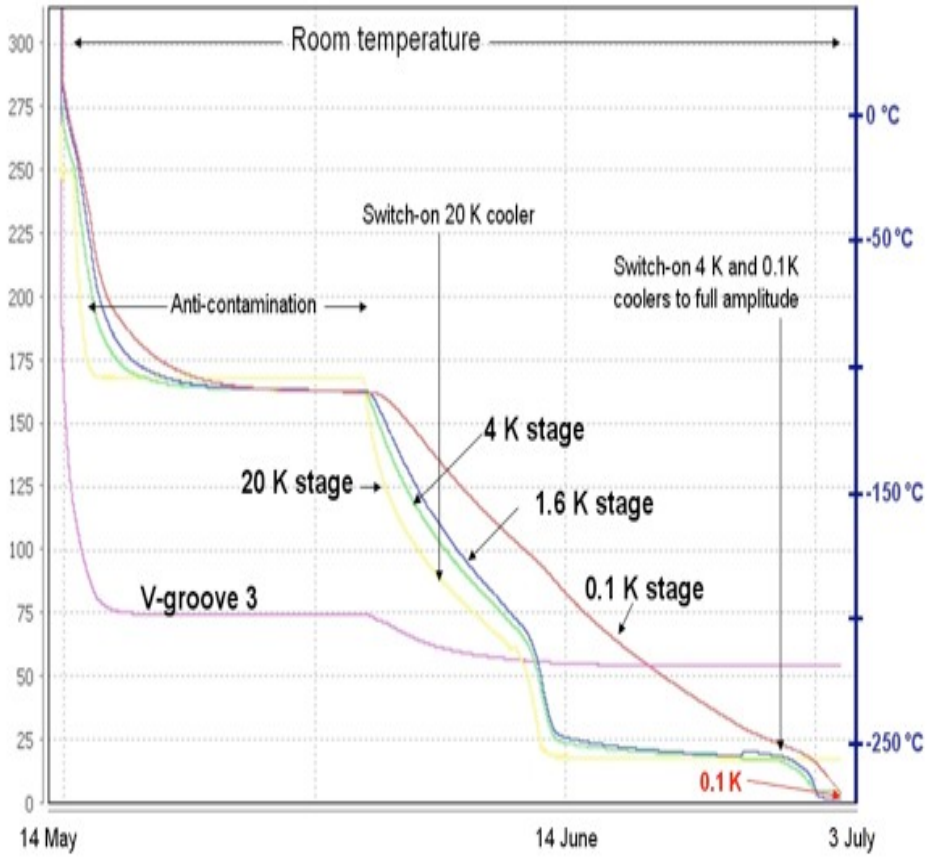
- Intensity in 9 channels, 30- 857GHz with HFI & LFI
- Polarisation from 30 to 353GHz







- Complex cryogenic cooling chain: 5 stages (4 active) including 100mK helium 3 & 4 dilution cooler
- Sensitive and fast bolometers



May 14th 2009 → Launch

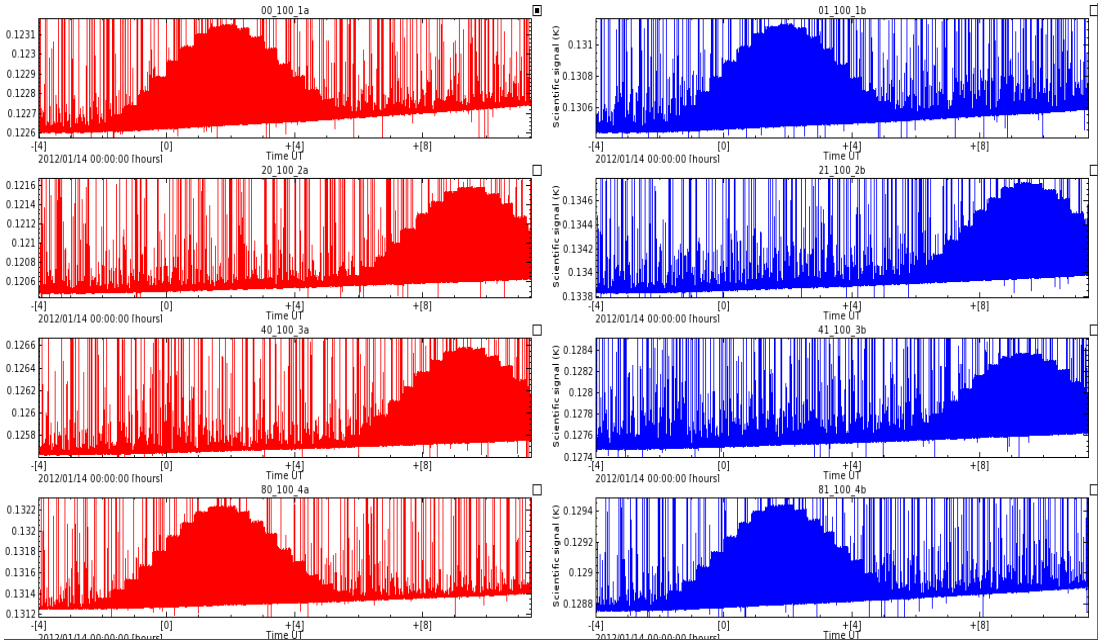
July 2nd 2009 → @L2, 45 days → **Planck-HFI is cool**

August 13th 2009 → Survey starts

December 23rd 2011 → increase pressure in He3 tank → stability of dilution not maintained

→ **Planck-HFI warmed up**

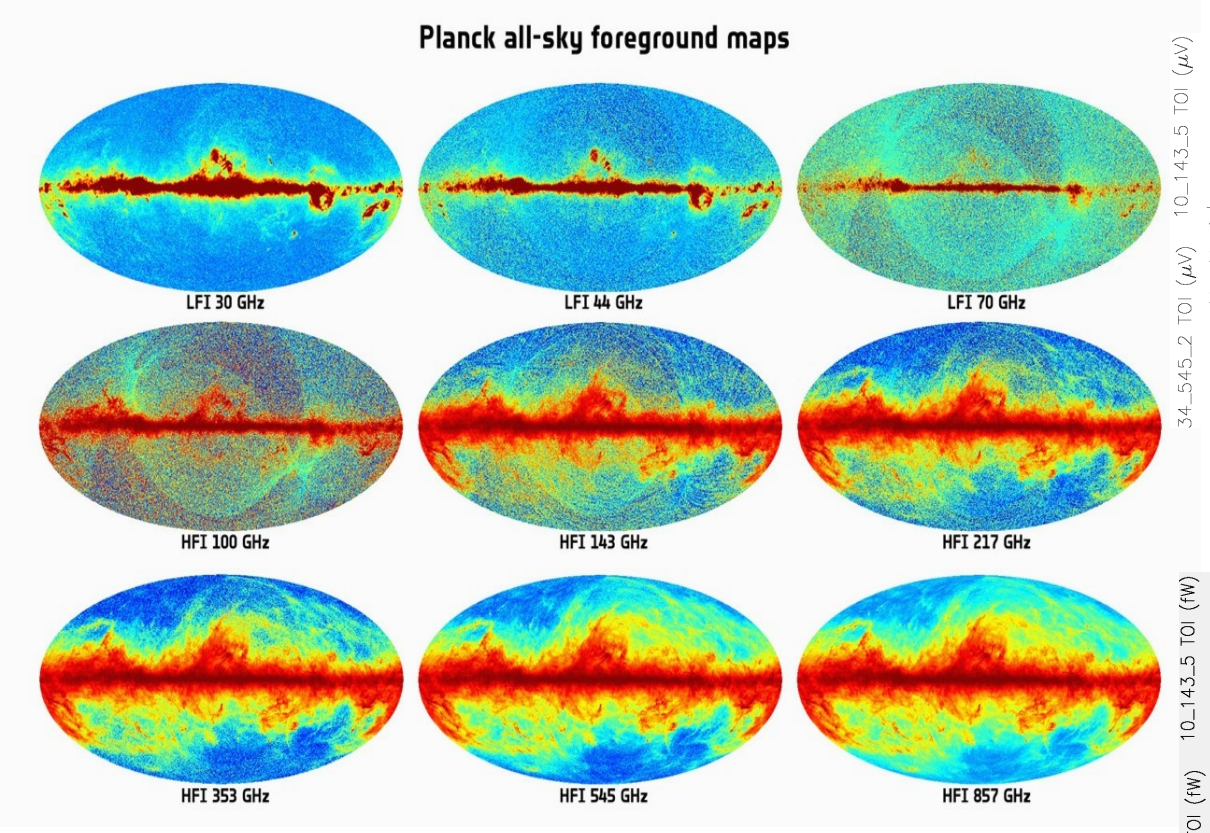
- **Nominal mission** (2 surveys) **achieved November 2010**
- **Extended cryogenic mission** (5 surveys) **achieved ~ mid January 2012**
- **Warm mission ~1 more years**

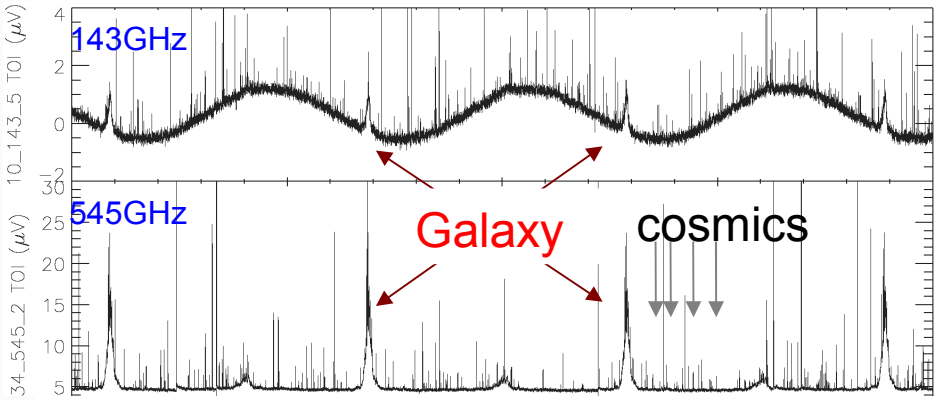


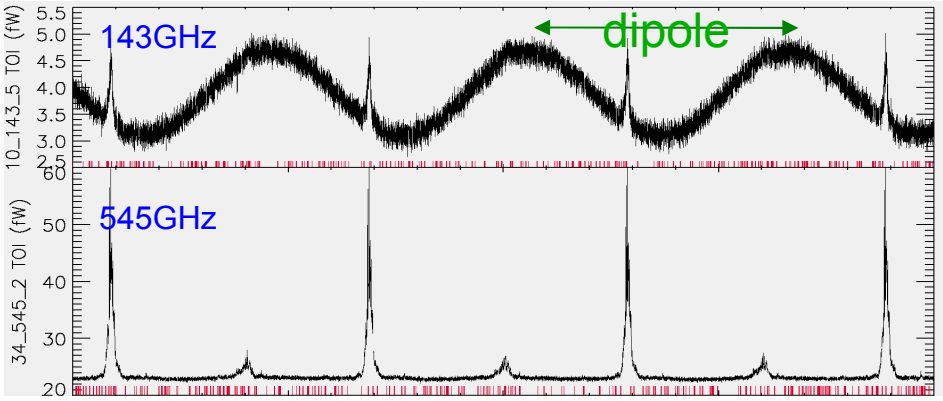
January 14th 2012: last observation in HFI's 5th sky survey: Jupiter

Data analysis challenge

9 channels, 56 bolometers, ~10 billions of samples per bolometer,
~0.5 billions of pixels per map
Not to mention polarisation!







After 10months sensitivity (~0.5 µK.deg) **twice better** than requirements @CMB frequencies
(WMAP ~5.3 µK.deg in 8yrs)

First Planck product

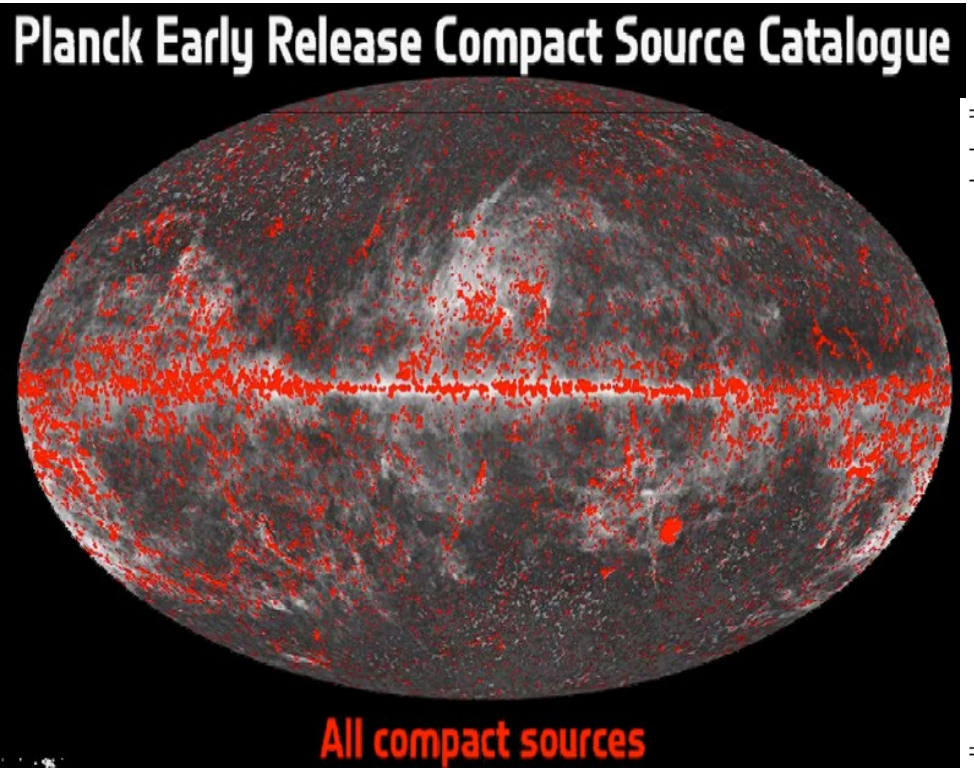
Early Release Compact Source Catalogue (ERCSC)

(Details in arXiv1101.2041)

Released catalogue ~15000 sources

Available from *www.rssd.esa.int/Planck*

- 9 frequency lists 30-857GHz
- 2 multi-channel lists
  - Cold clumps, selected by their temperature (<14K)
  - Clusters selected by Sunyaev-Zeldovich effect



DMR		*WMAP*		*Planck*		*Akari*		*IRAS*		*WISE*	
ν	FWHM	ν	FWHM	ν	FWHM	ν	FWHM	ν	FWHM	ν	FWHM
		23	53								
32	420	33	40	30	32.65						
		41	31	44	27.00						
53	420	61	21	70	13.01						
90	420	94	13	100	9.94						
				143	7.04						
				217	4.66						
				353	4.41						
				545	4.47						
				857	4.23						
						1.9×10^3	0.8				
						2.1×10^3	0.7				
						3.3×10^3	0.45	3×10^3	5.2		
						4.6×10^3	0.32	5×10^3	3.9		
						16.7×10^3	0.09	12×10^3	4.5	13.6×10^3	0.2
						33×10^3	0.05	25×10^3	4.7	25×10^3	0.11
										65×10^3	0.11
										88×10^3	0.1

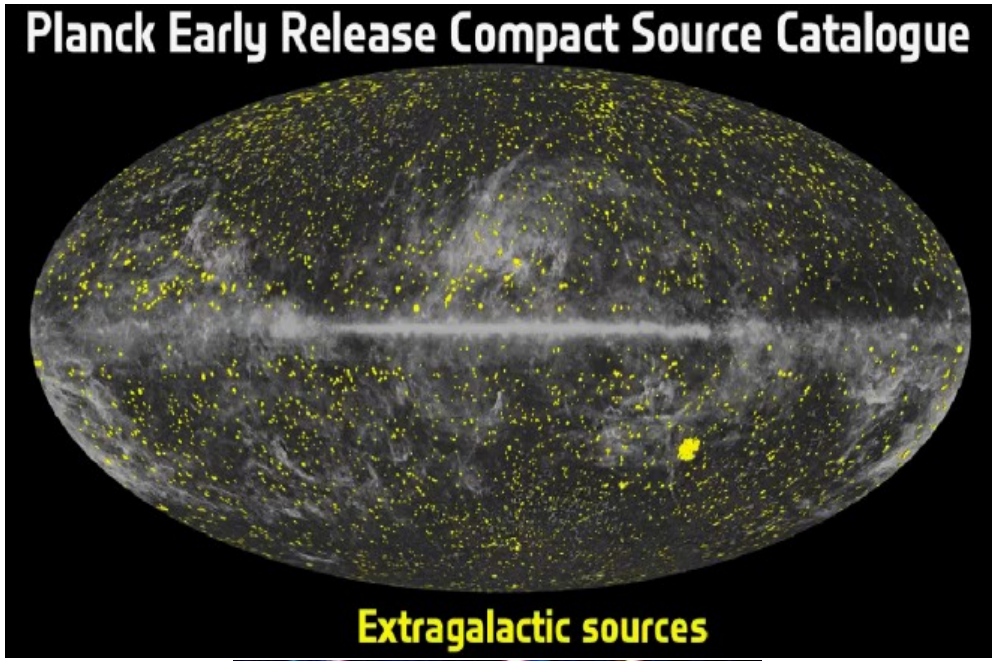
First all-sky catalogue 100- 900GHz

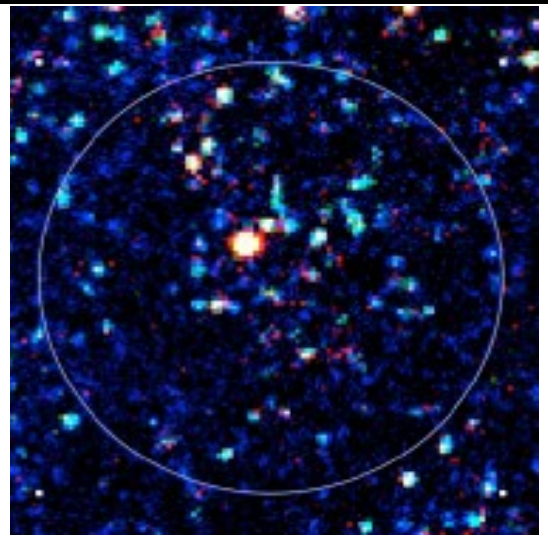
Planck results on point sources: ERCSC

- **IR galaxies & Radio galaxies**
  - Most radio sources have flat spectra
  - Radio galaxies detected down to 353GHz, ~equal number of dusty & synch sources at 353 GHz
  - Model over-predicts bright counts by factor 2

- **Distant sources & proto-clusters?**
  - Color based selection → coldest points
  - Follow-up with Herschel or ground based telescopes for confirmation and redshifts

- **Fluctuations dominated by IR sources (>217GHz)**





250/350/500 microns

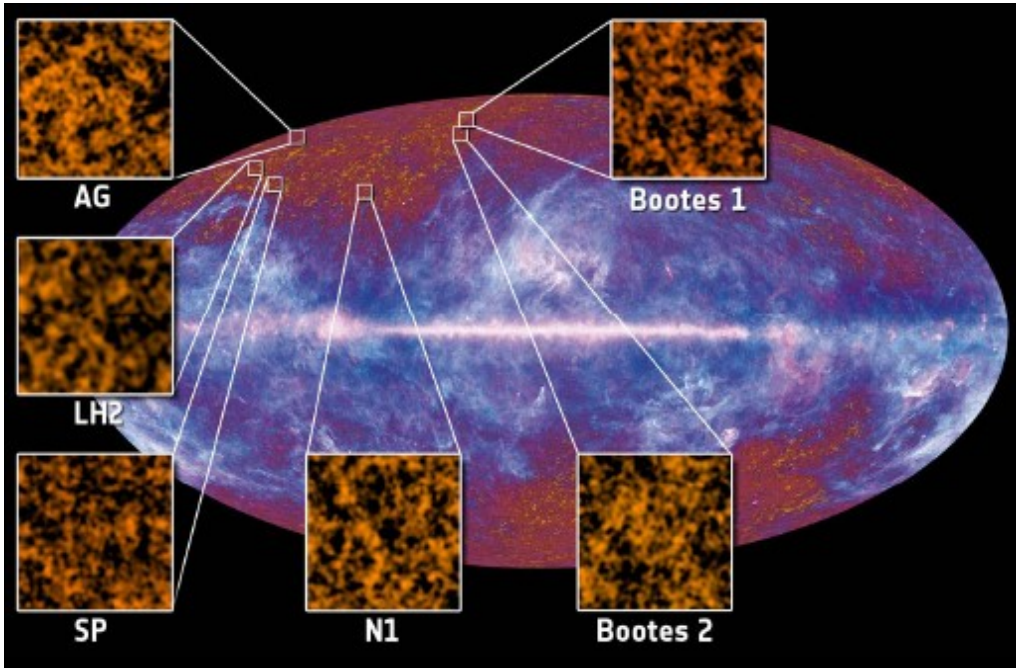
Colours consistent with z~3 → Observed at IRAM z=3.259

Planck results on Cosmic Infra-red Background

CIB → **cumulative IR emission** from reprocessed light in dusty galaxies → probes much of cosmic star formation

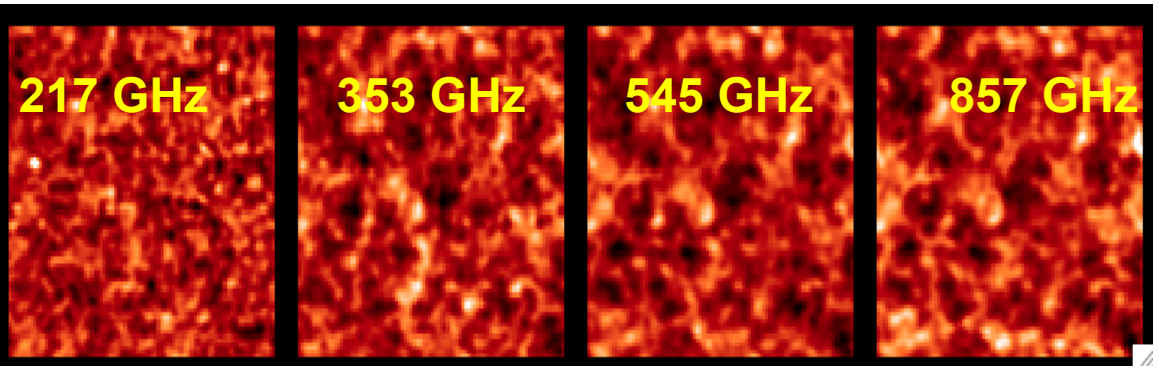
Analysis of 6 cleaned high galactic latitude fields (~40 sq.deg):

- CMB cleaning → Planck 143GHz
- Dust cleaning → HI from GBT tracer of diffuse dust emission



(details in arXiv1101.2028)

- Sub-degree clustered structure at all freq. partially correlated across freq.
- Agrees with other measurements



- Longer wavelengths probe higher z
- CIB by Planck → Forming galaxies @z~2-3

Planck results on galactic foregrounds

Catalogue of galactic cold clumps:

Prospect for the study of the star formation

Confirmation of anomalous emission:

Spinning dust most plausible scenario

“New” regions of anomalous emission

All-sky temperature and dust optical depth from Planck and IRAS:

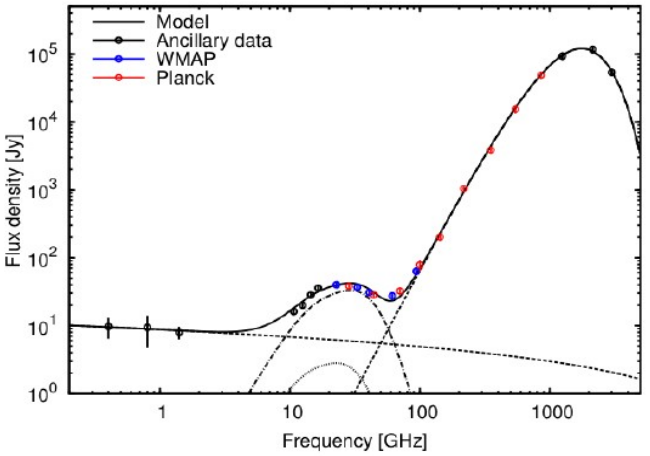
Emission from diffuse molecular hydrogen, “dark gas”

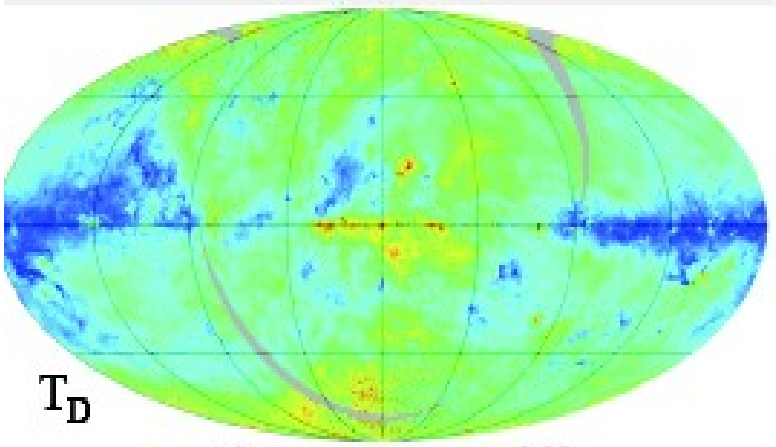
More accurate model for dust evolution

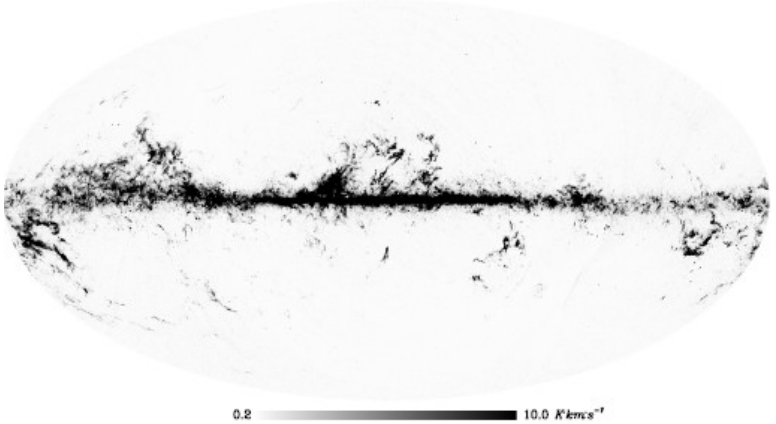
All-sky CO map @100GHz:

New molecular regions away from the plane → role in the star formation

Foreground emission w.r.t. CMB analysis



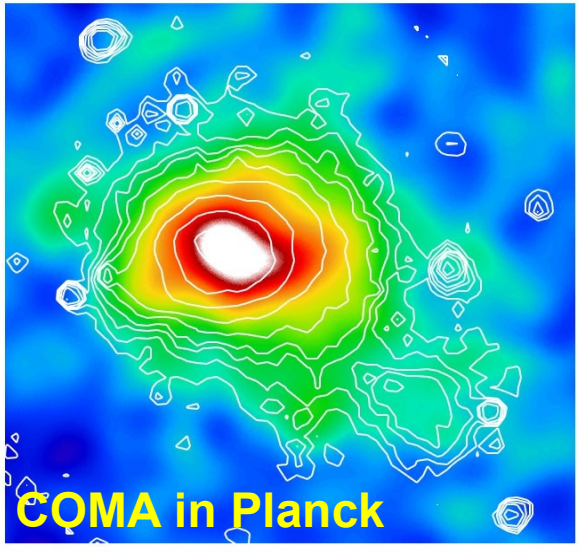


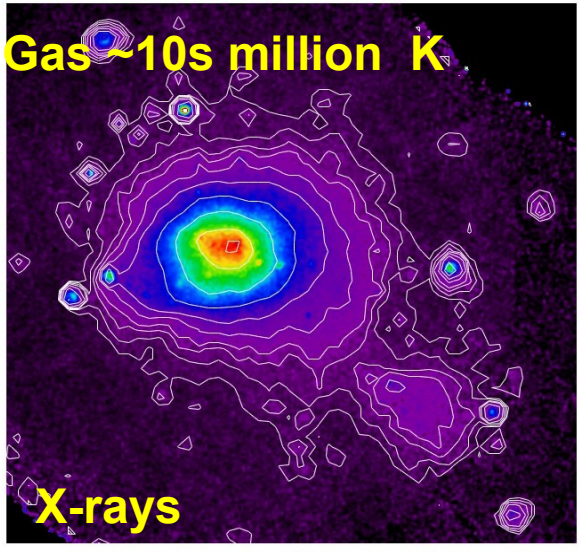


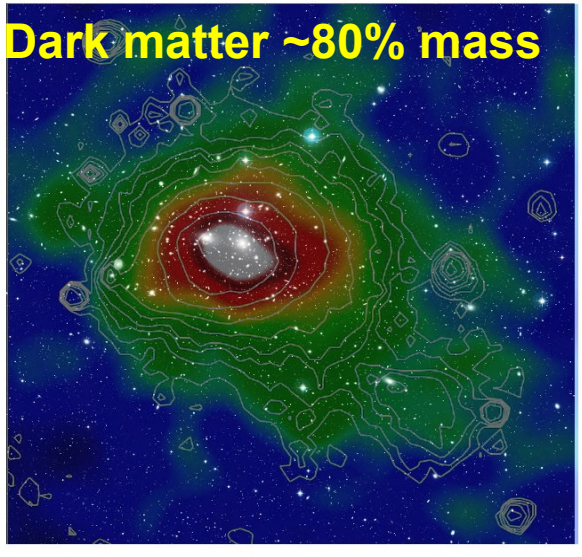
First high-resolution full sky CO emission map

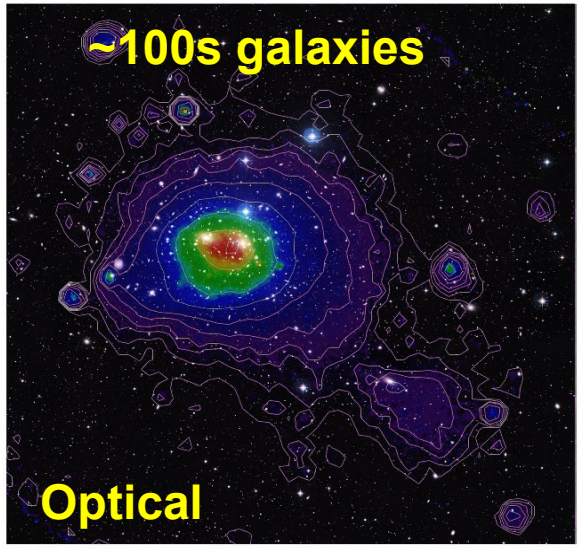
Planck results on galaxy clusters

Clusters = largest formed (gravitationally bound) systems

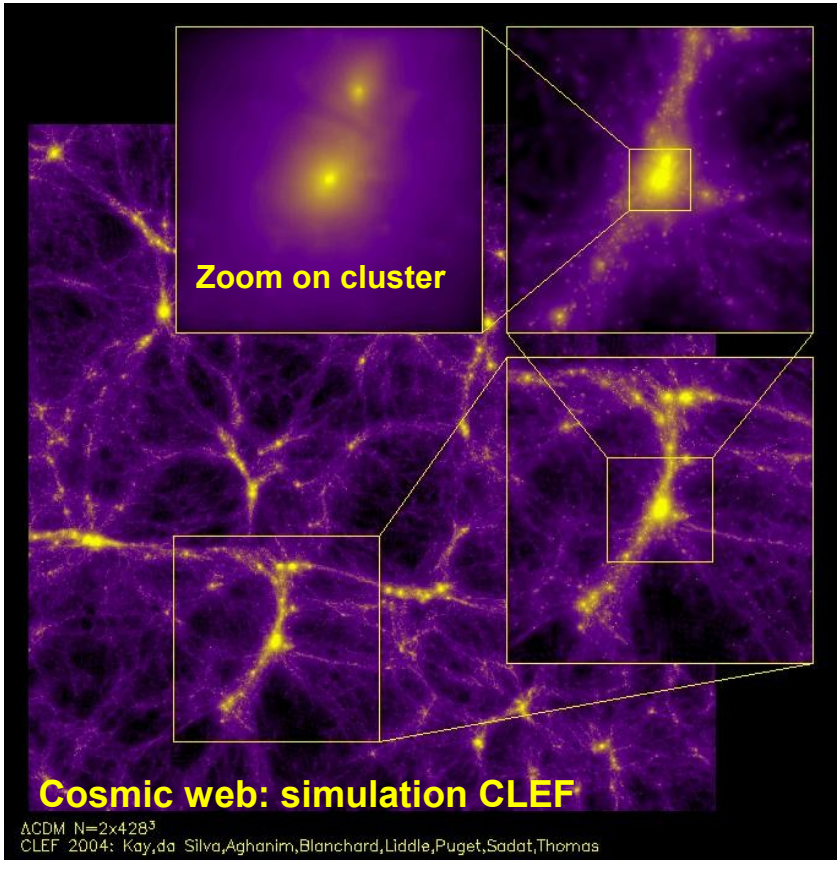








- Witnesses of structure formation history
- Probes of the cosmological model

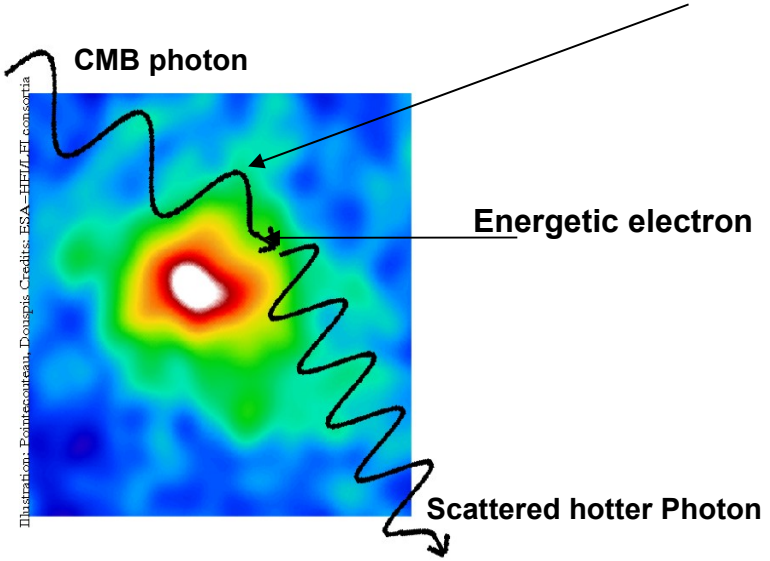


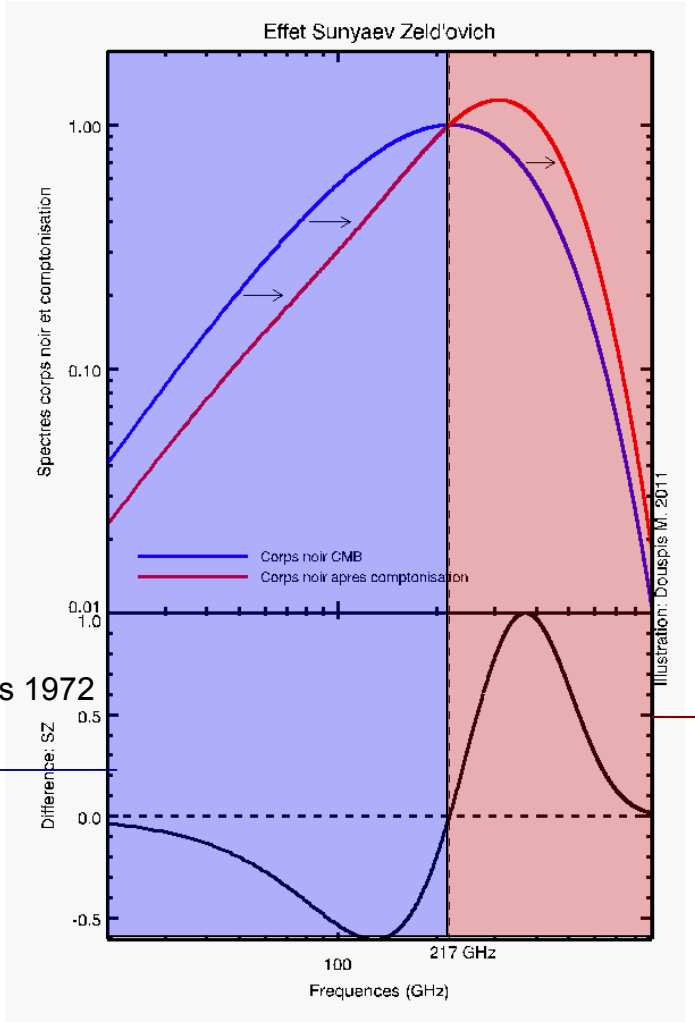
The Sunyaev-Zel'dovich (SZ) effect

R. A. Sunyaev

Ya. B. Zeldovich

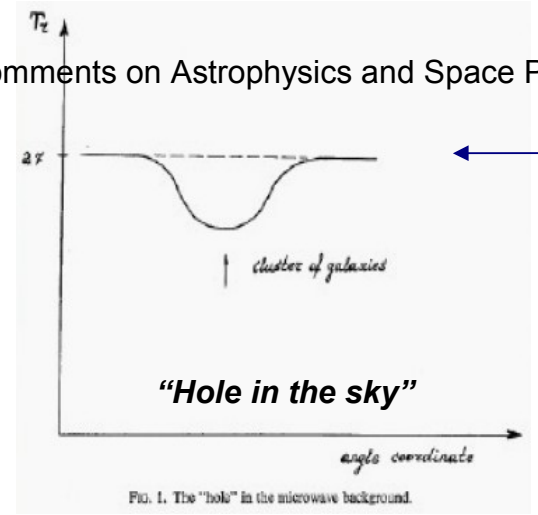
Galaxy cluster = galaxies + hot gas

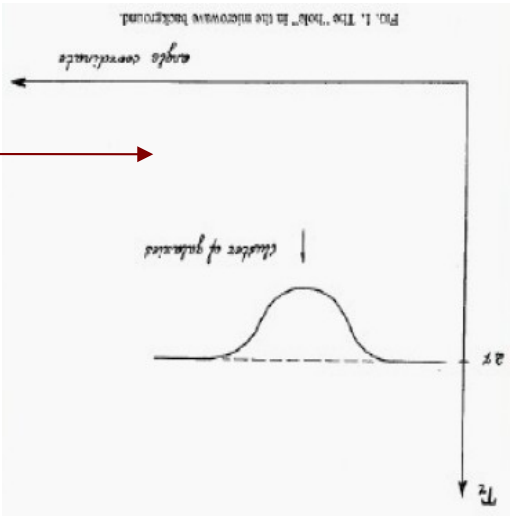




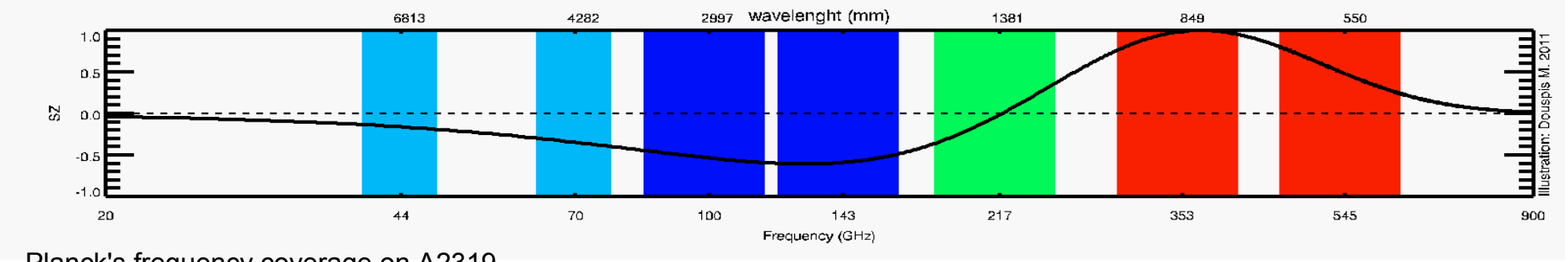
$$y = \int \frac{k_B T_e}{m_e c^2} n_e \sigma_T dl$$

SZ,Comments on Astrophysics and Space Physics 1972

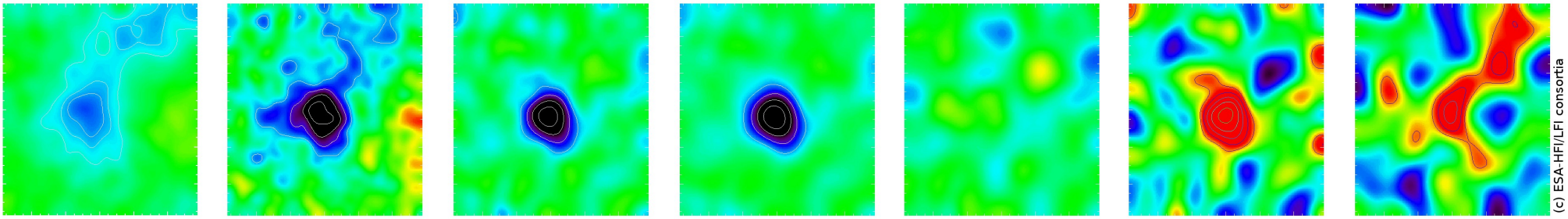




Planck's uniqueness for SZ detection

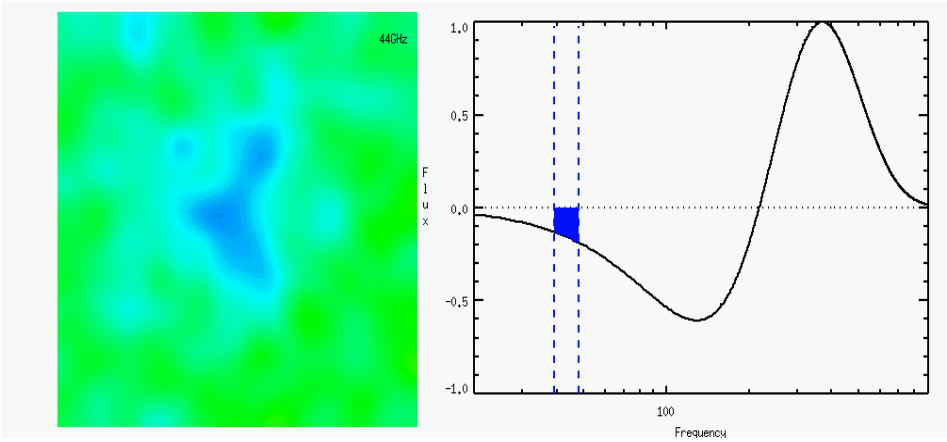


Planck's frequency coverage on A2319



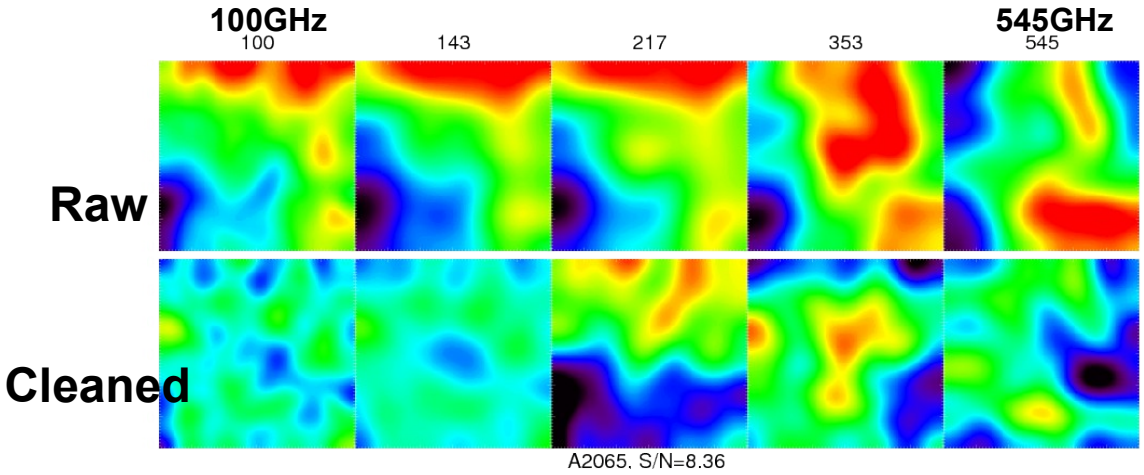
→ Planck, designed from the start to measure SZ

- **All-sky survey**
- **Frequency range from 30 to 857 GHz**
- **Blind and simultaneous measurement of "positive" and "negative" SZ effect**



SZ detection in Planck

Typical clusters → 1-2 sigma in individual cleaned frequency maps

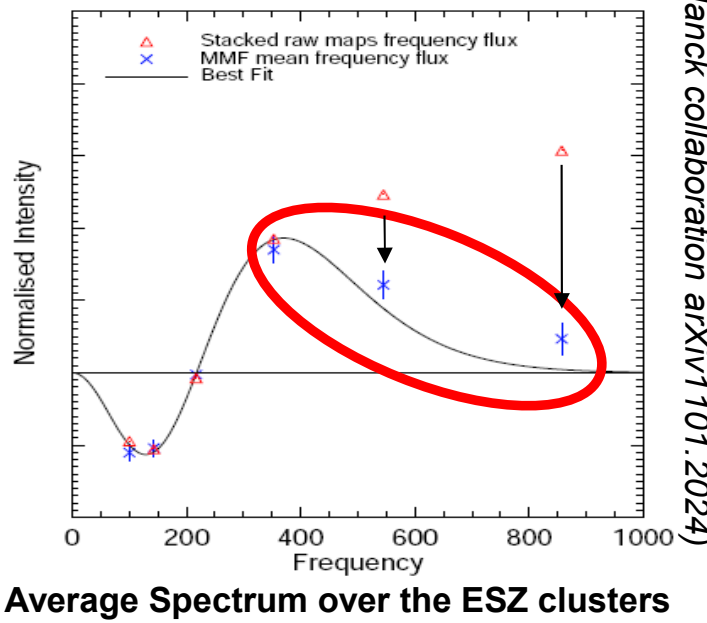


Adapted extraction technique → Matched Multi-Filter*:* F

- known spectrum → non-relativistic SZ
- known cluster shape → Generalised NFW pressure profile *(Arnaud et al. 2010)*

SZ signal enhanced over other components

Validation to insure high reliability



Average Spectrum over the ESZ clusters

(Planck collaboration arXiv1101.2024)

Validation of the SZ sample

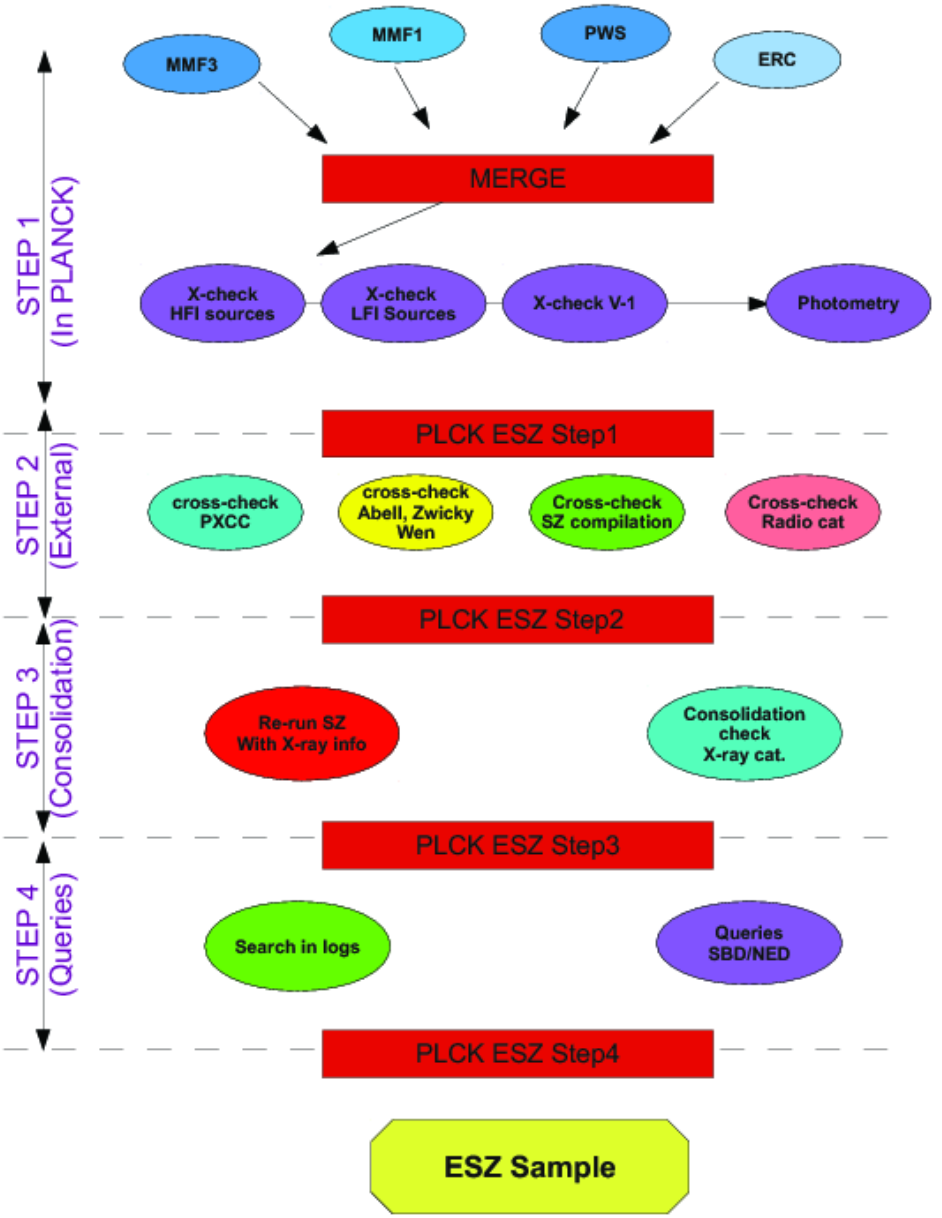
Planck-internal quality assessment

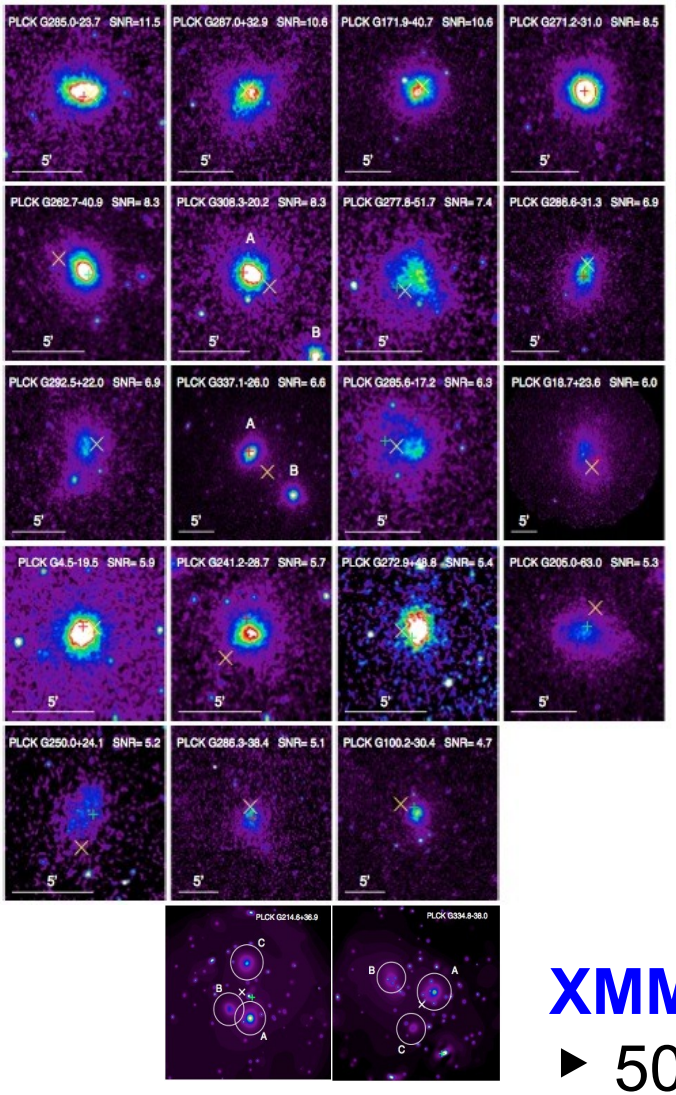
- Redundancy
- Rejection of artifacts, galactic sources

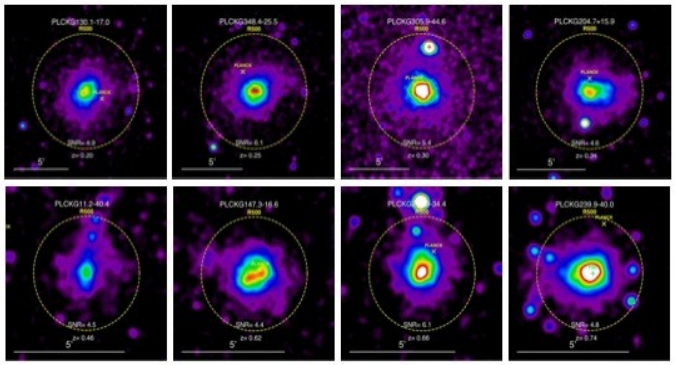
Identification with known clusters from ancillary catalogues (e.g. MCXC, Abell, Zwicky, etc) and search data (e.g. SDSS, RASS)

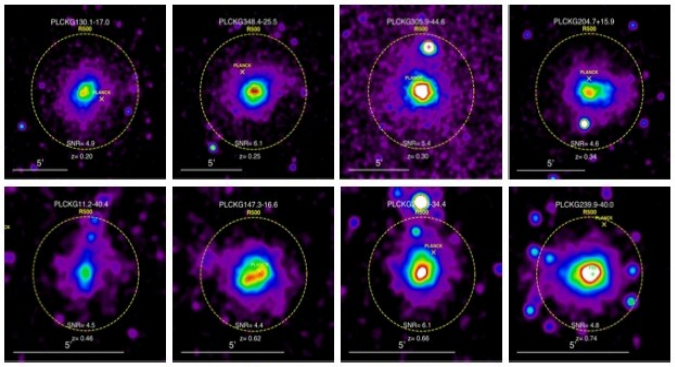
Multi-frequency **follow up programme for confirmation** of SZ candidates (still ongoing)

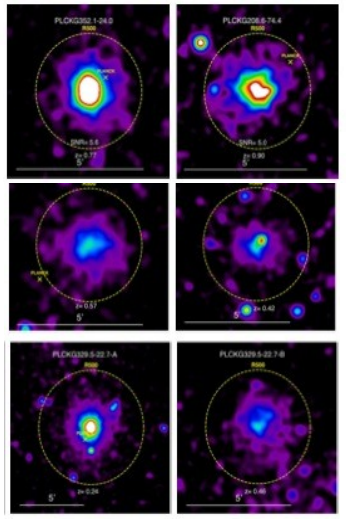
- In optical (ESO, ENO, RTT mainly)
- In SZ (AMI)
- In X-rays with XMM-*Newton* → Backbone of the candidate confirmation of the ESZ sample

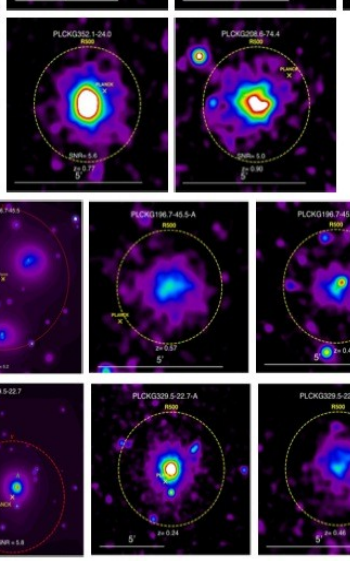












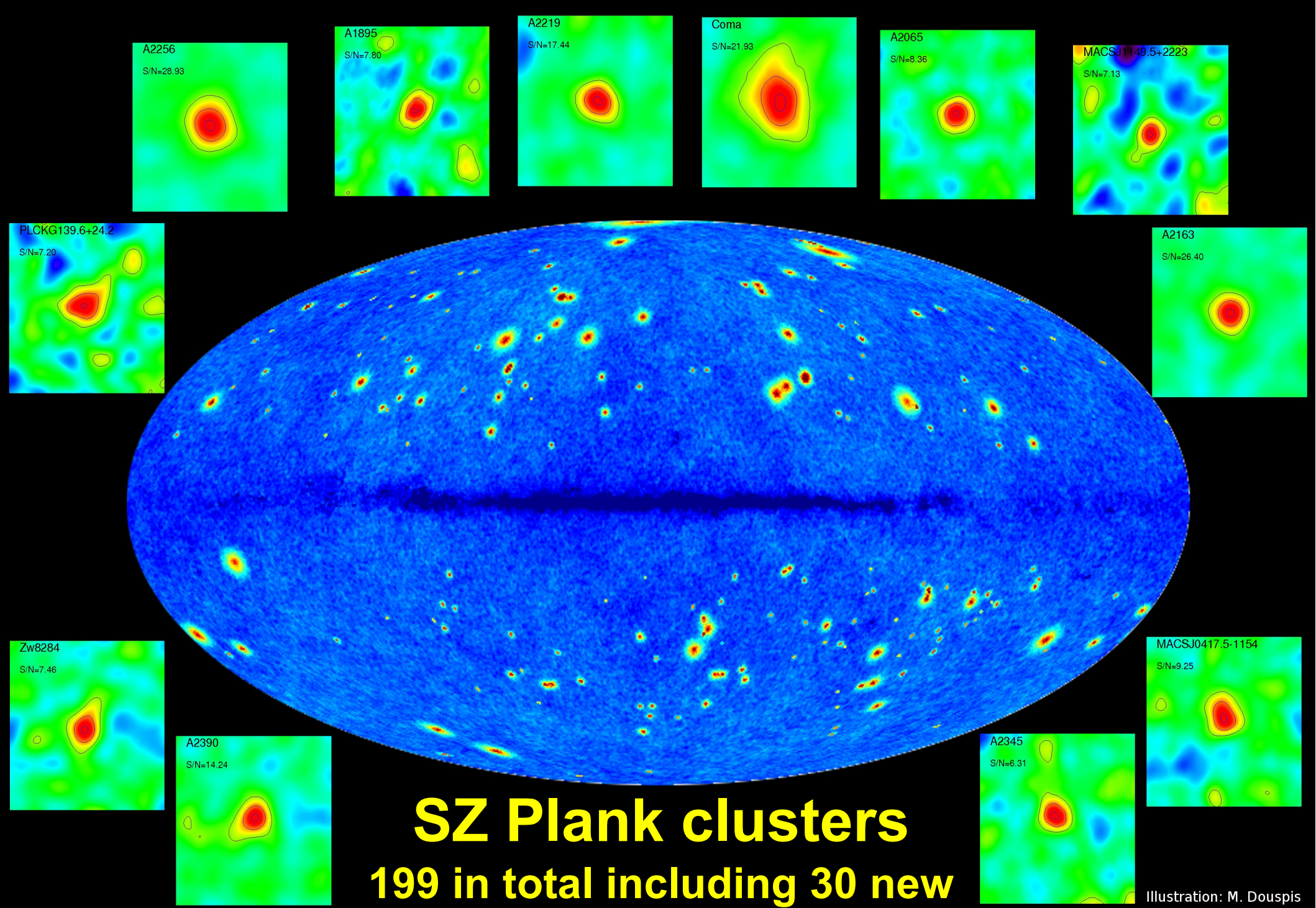
XMM-Newton DDT confirmation program

- 500ks total, short snapshot exposures (10ksec)
- high success rate (>85%)
- 51 new clusters confirmed
- unique capability to unambiguously distinguish between clusters and false detections

Optical follow-up programmes for confirmation

A vigorous optical follow-up effort to confirm Planck candidates and measure redshifts mainly with ESO-MPG, ESO-NTT, ENO and RTT

+ Use of SDSS data, and lately WISE data


A2256
S/N=28.93
A1895
S/N=7.80
A2219
S/N=17.44
Coma
S/N=21.93
A2065
S/N=8.36
MACSJ1149.5+2223
S/N=7.13
PLCKG139.6+24.2
S/N=7.20
A2163
S/N=26.40
Zw8284
S/N=7.46
A2390
S/N=14.24
A2345
S/N=6.31
MACSJ0417.5-1154
S/N=9.25
SZ Plank clusters
199 in total including 30 new
Illustration: M. Douspis

The all-sky Early SZ (ESZ) cluster sample

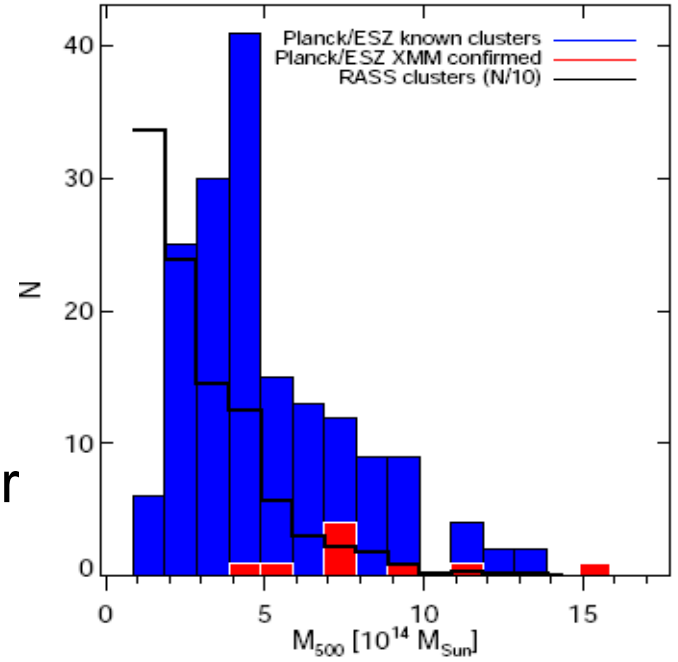
ESZ sample = Unique all-sky cluster sample since RASS
High reliability **S/N>6** & purity **99.5%**

ESZ sample = 189 candidates (S/N> 6)

- 169 identified with known clusters
- 19 confirmed new clusters (including 7 by SPT,SZA, Bolocam, AMI independently from Planck collaboration)
- 1 false detection

Further 10 new clusters (S/N <6)

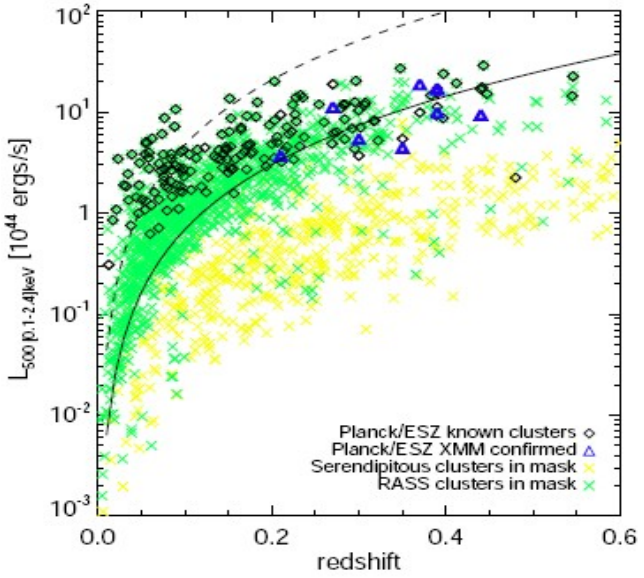
26 more new detections published since ESZ deliver



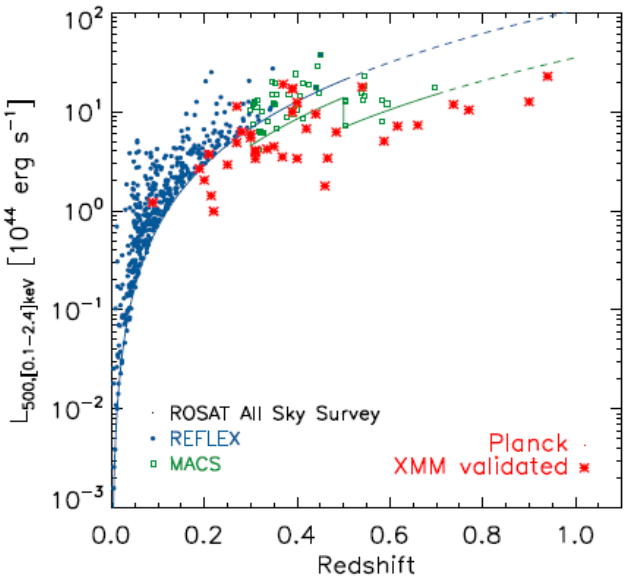
- Largest **homogeneous** SZ sample at moderate redshifts
- First SZ measure for ~80% of the known clusters
- Largest SZ sample of **massive clusters** detected blindly (up to 1.5×10^{15} M_{sol}).

Planck SZ sample vs other surveys

Planck ESZ clusters (black & blue)



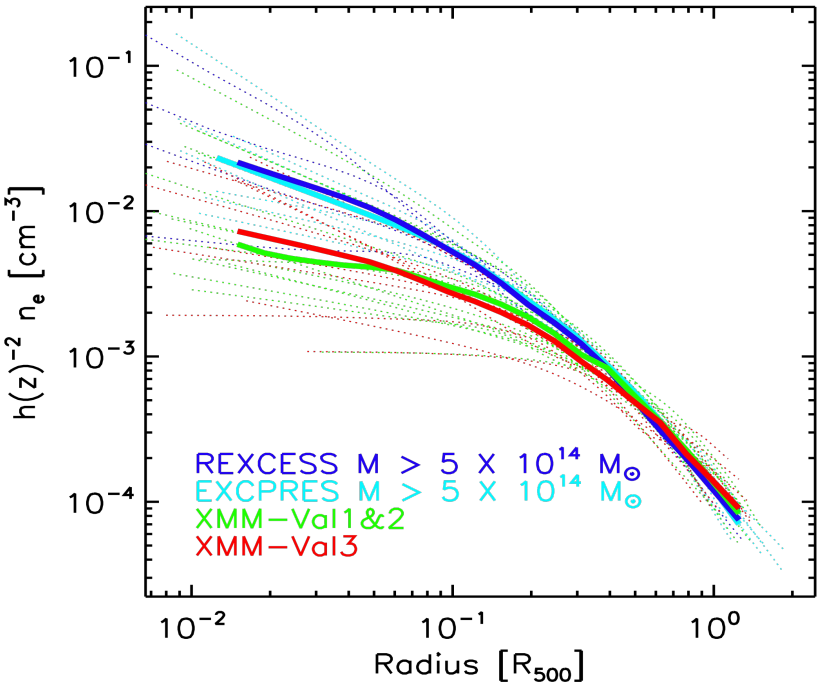
All published new Planck clusters red

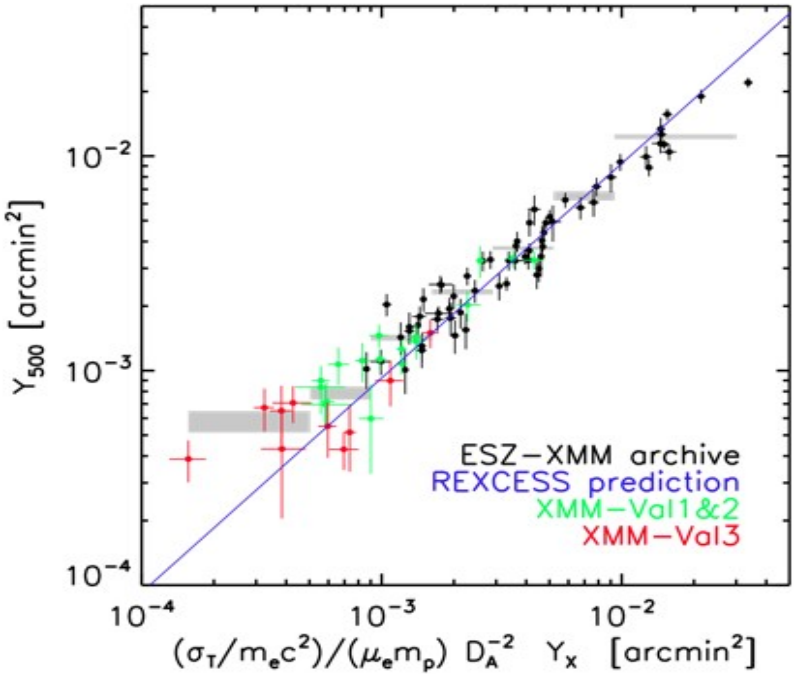


Planck has the unique capability to detect the most massive clusters over the whole sky

- **ESZ provides reference sample for z<0.5 massive clusters**
- Planck SZ detections **complete the high M-z region** sparsely-populated by RASS clusters and other SZ surveys

Preview of new Planck cluster properties from XMM-Newton





- Good agreement between predicted Y_x and measured Y_{sz}
- Density profiles **shallower than X-ray clusters** → under-luminous for their masses
- Large variety of dynamical state → 70% new clusters have **disturbed morphologies** (compared to 30% in X-ray selected clusters e.g. REXCESS) & 14% new detections are **multiple systems** (double or triple)

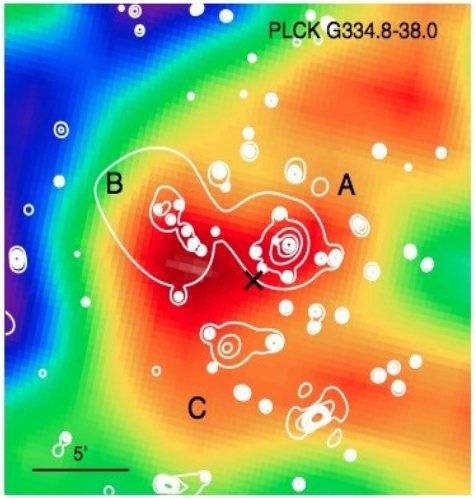
Exploring the cluster content/properties

Search of diffuse SZ emission in multiple systems

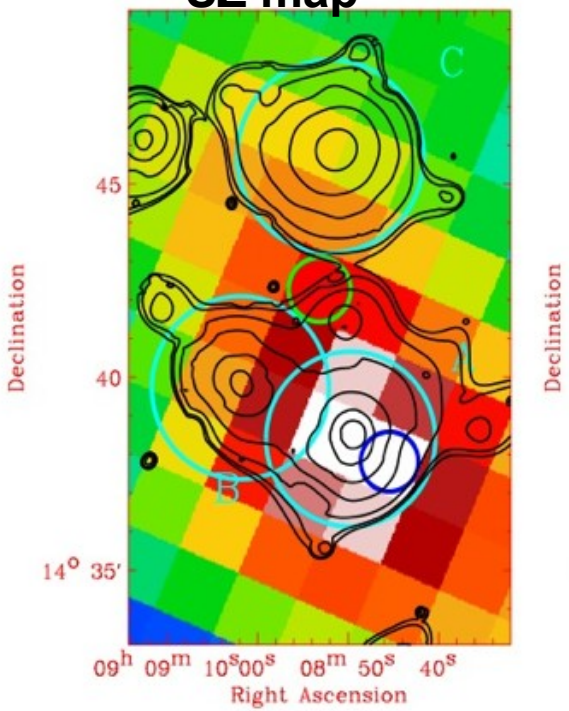
Low S/N Planck detections confirmed as triple systems by XMM-Newton → Studying forming/interacting systems

Dedicated XMM observation (VLT data to be analysed) :

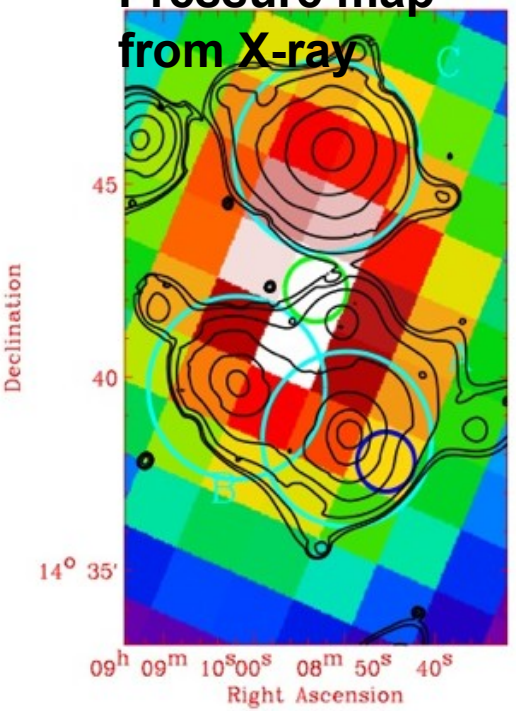
- 3 components A&B z~0.45, C z~0.48 forming structure
- Better agreement with SZ signal from the 3 components

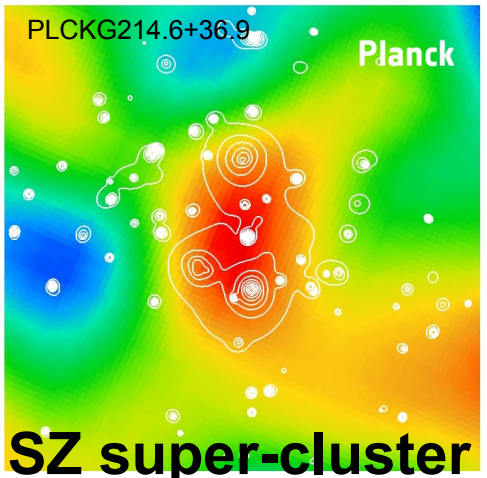


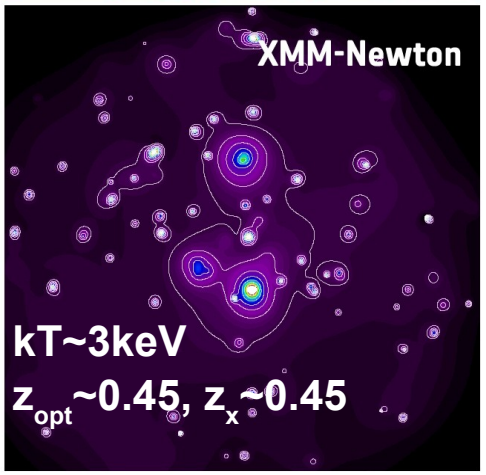
SZ map



Pressure map from X-ray







Cluster pair: A399/A401

Search for warm/hot gas between cluster pairs resolved by Planck

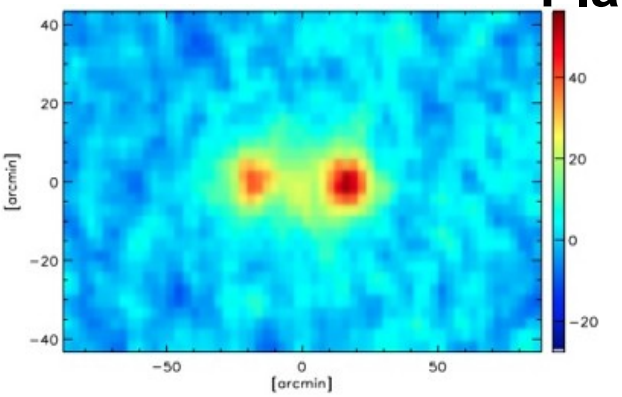
Isothermal filament kT~7keV and $n \sim 3 \times 10^{-4} cm^3$ compatible with XMM data

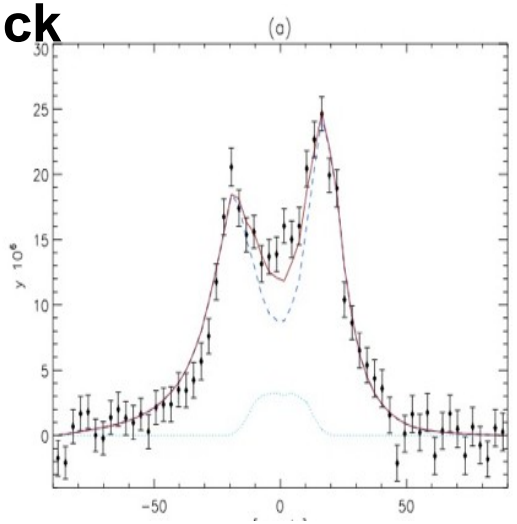
Gravitational interaction → overlapping cluster tails?

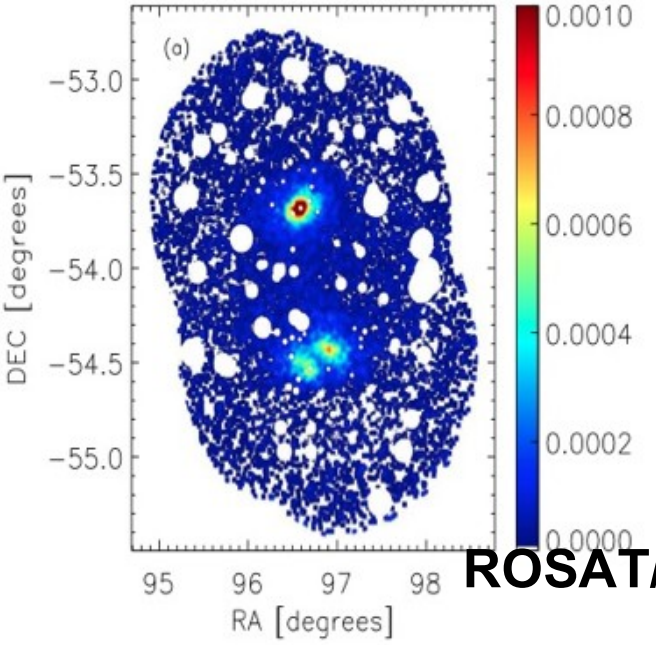
or

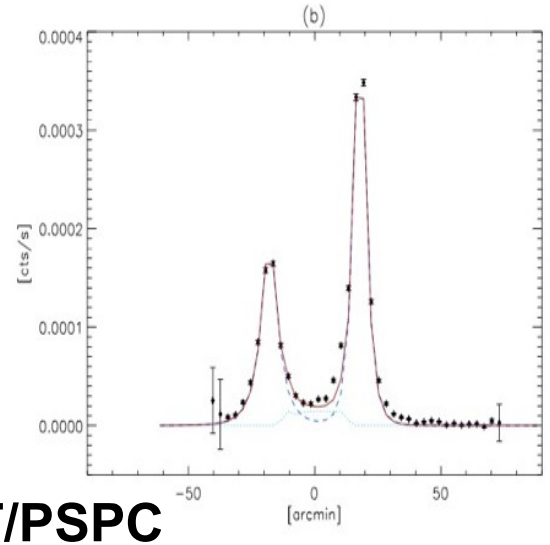
Intercluster filament trapped and compressed?

Planck





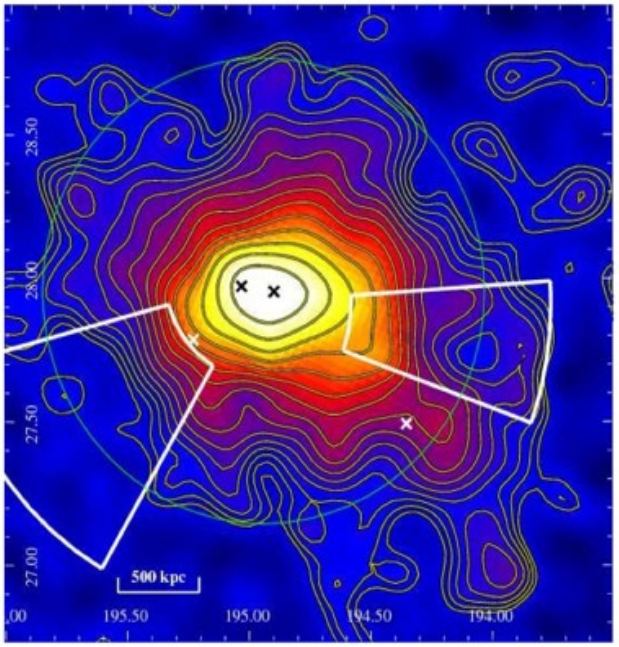


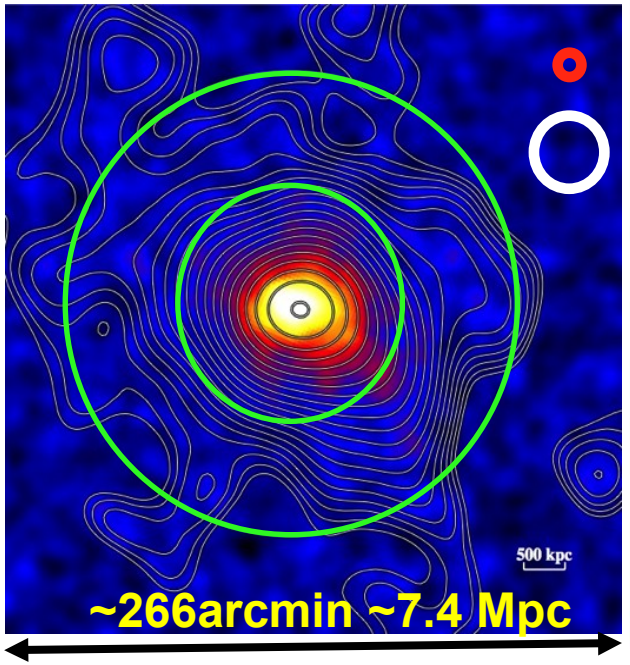


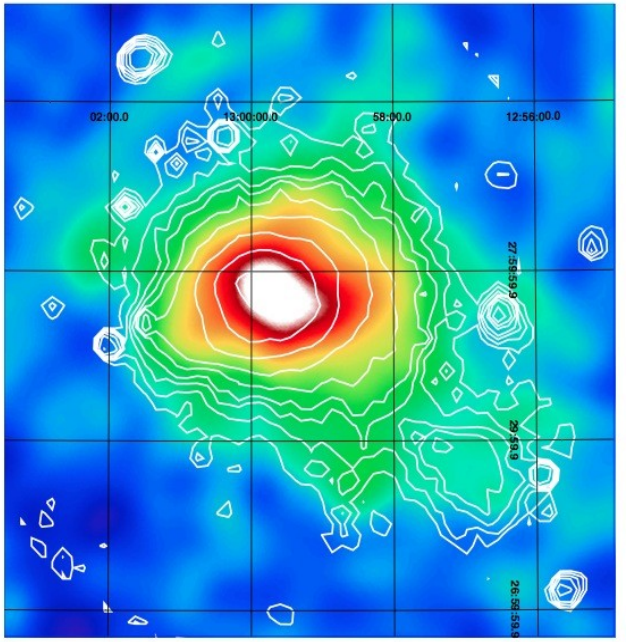
ROSAT/PSPC

Exploring the cluster content/properties

Study of the COMA cluster







Spatially resolved SZ signal from Planck → **Probe the complex cluster physics**

Measured shock fronts, pressure “jump”:

- Independent measure of western jump in Planck & X-rays & radio
- Indication of a new pressure jump in the south-east

Exploring the cluster content/properties

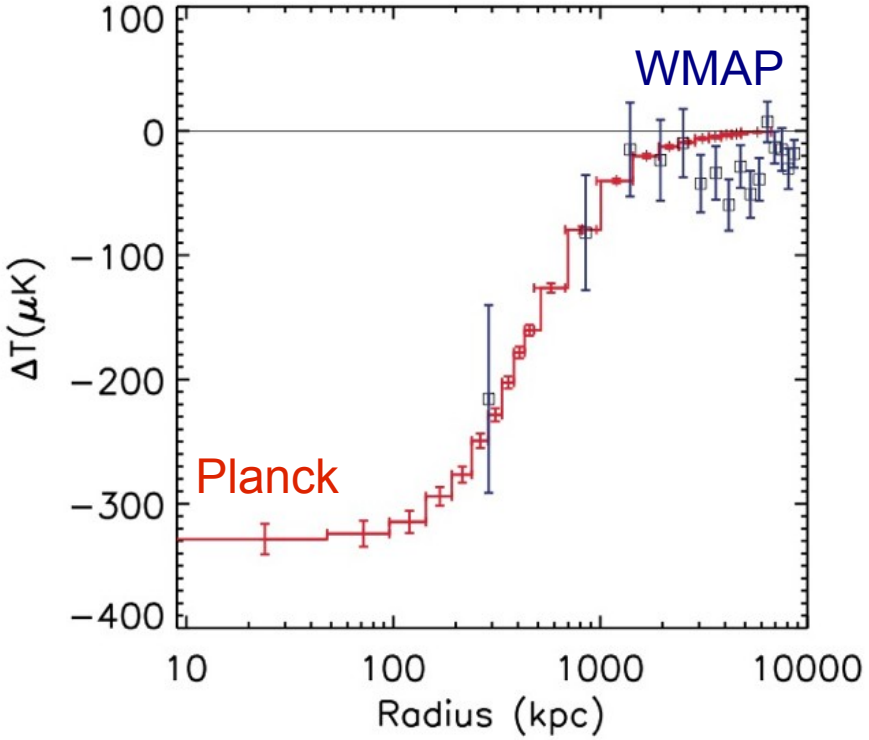
Pressure content of the COMA cluster

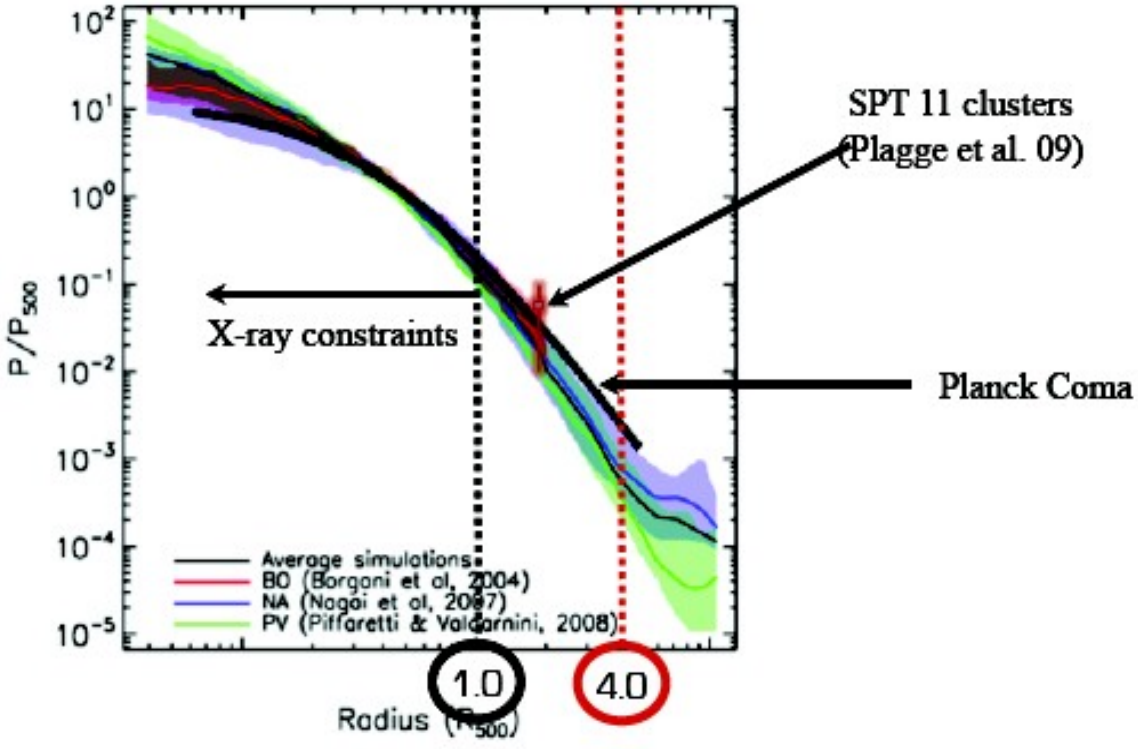
Coma SZ profile detected out to **3-4 R_{500}**

Pressure profile from SZ data "flatter" at large radii than GNFW profile → Sign of non-thermal pressure? Contamination?

Deconvolution & deprojection → from SZ to pressure profile

$$P(r) = \frac{m_e c^2}{\sigma_T} \frac{1}{D_A(z)} y(\theta) \frac{d\theta}{dr}$$

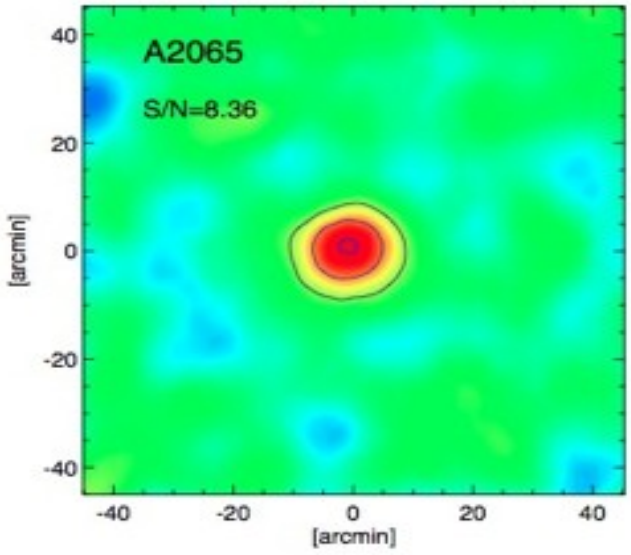


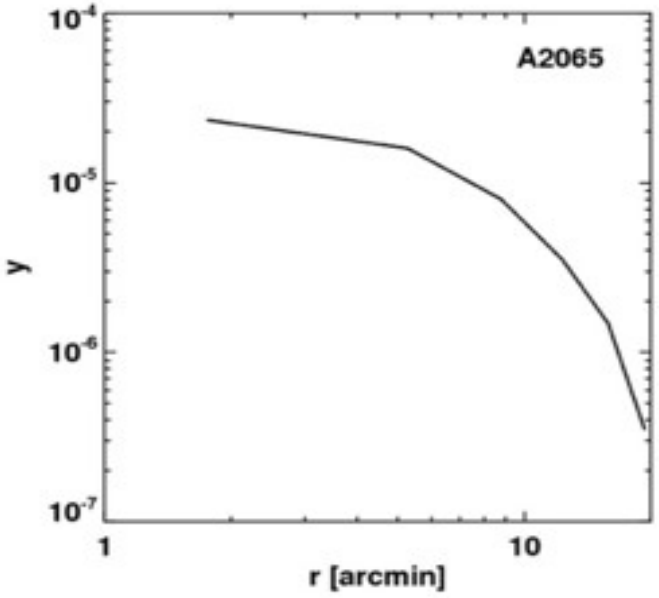


Exploring the cluster content/properties

Pressure from high S/N SZ clusters

Individual signal

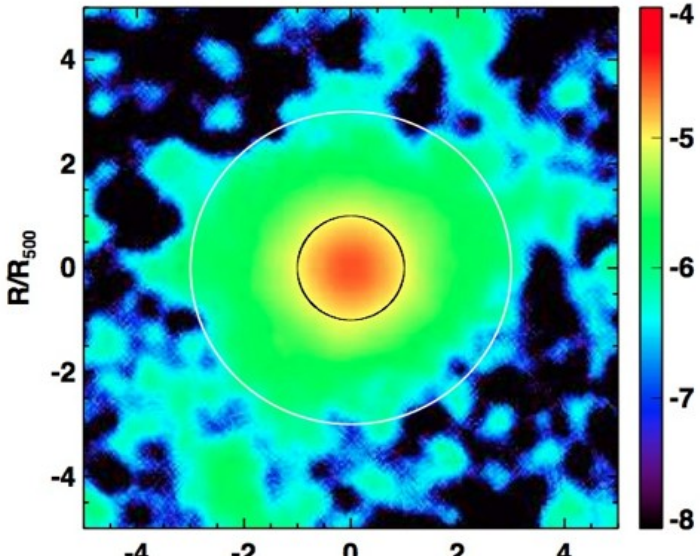


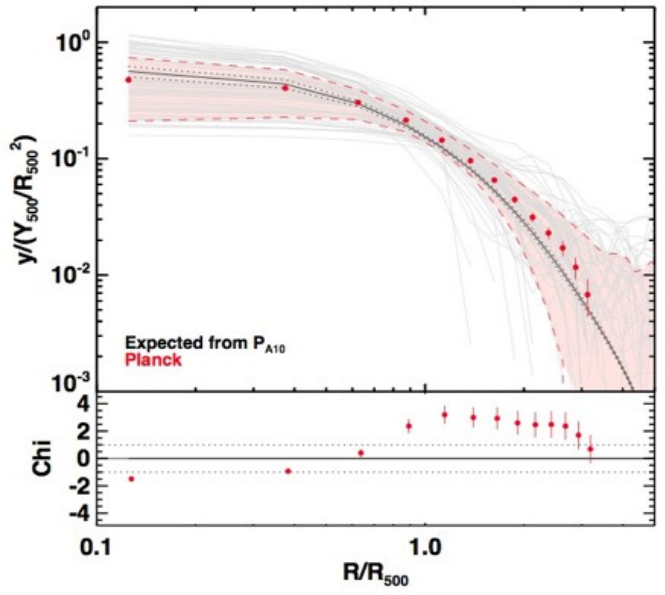


Selection of 62 high S/N clusters from the ESZ sample with high quality X-ray data

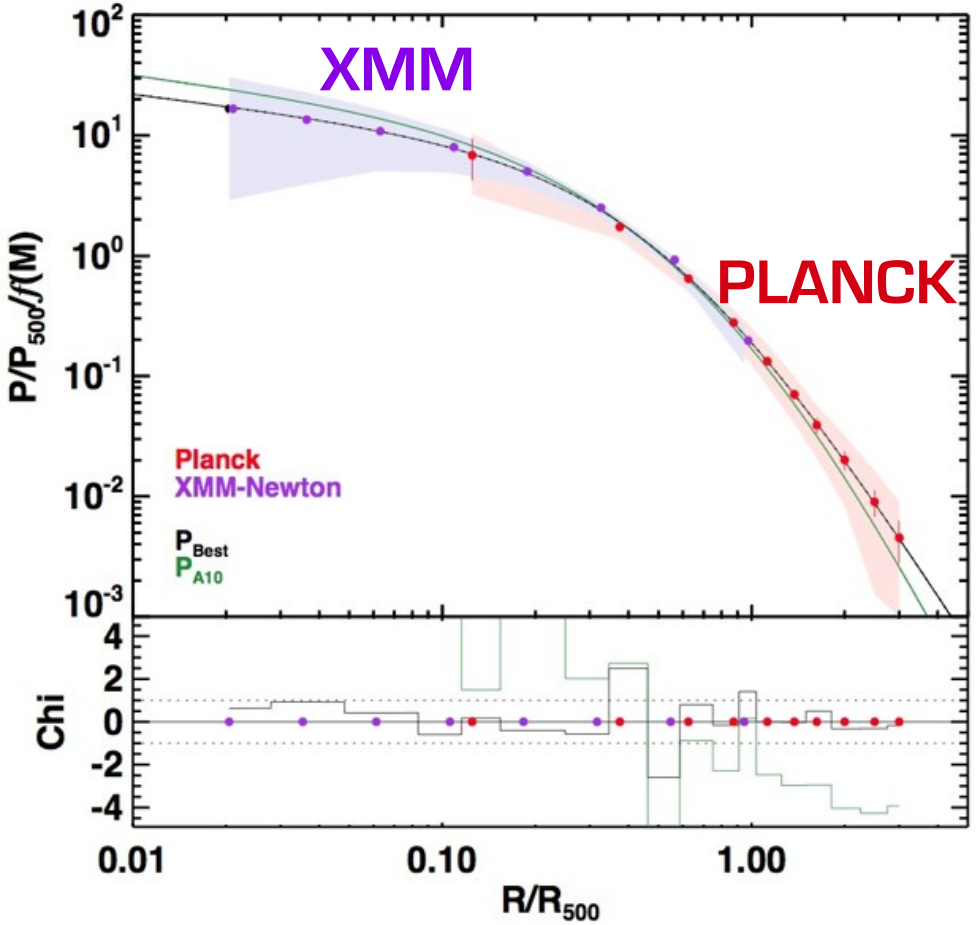
SZ signal detected out to $3R_{500}$

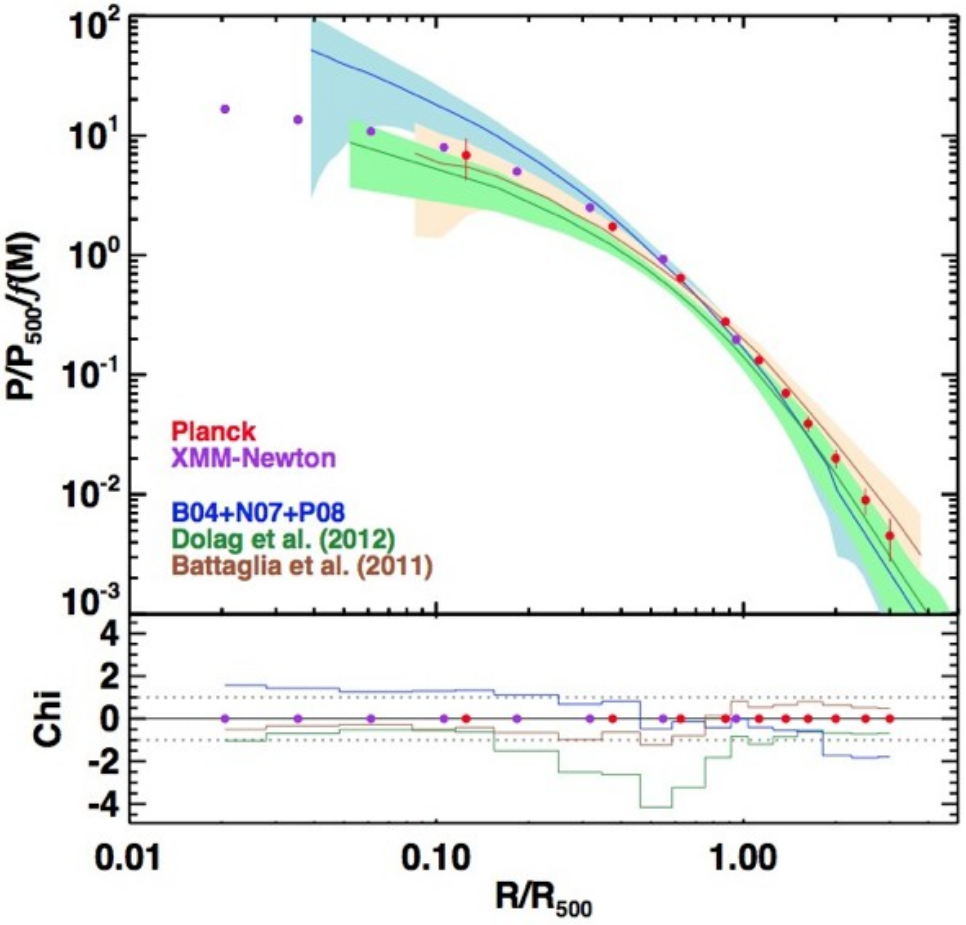
Stacked signal





- Good agreement between GNFW X-ray and SZ pressure profiles within R_{500}
- Combined pressure profile slightly "flatter" than GFNW and than predictions from simulation at large radii





Cluster statistical properties: SZ scaling relations

Relating SZ signal to physical properties, in particular M:
to probe cluster physics
to use cluster counts for cosmological analysis

SZ signal measured 100 to 857 GHz at cluster positions

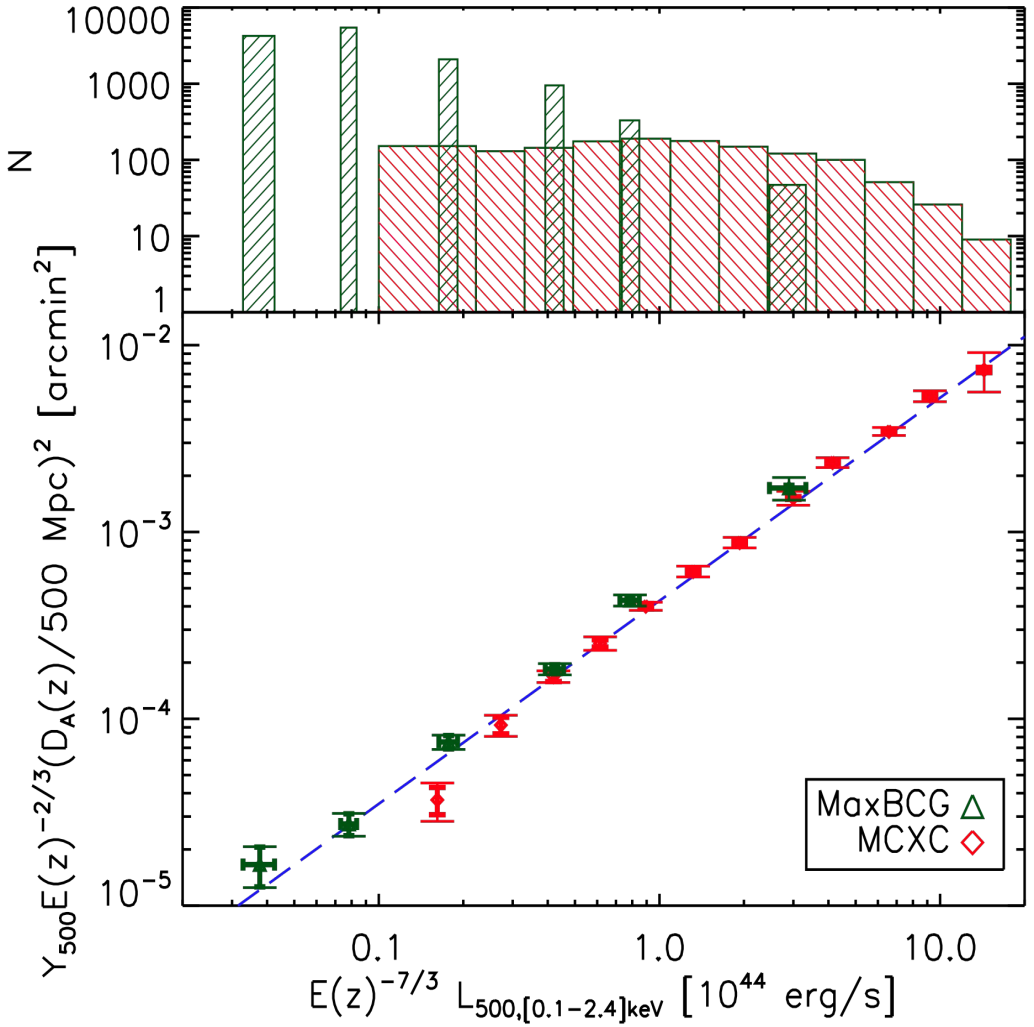
- Statistical analysis of ~1600 **X-ray clusters** from MCXC *(Piffaretti et a. 2010)*
- Analysis of 62 selected clusters with high quality X-ray data from XMM

- Statistical analysis of ~13000 **MaxBCG clusters** from SDSS *(Koester et al. 2007)*
- Statistical analysis of clusters' Central galaxy from SDSS (Planck intermediate result)
- Analysis of sample from LoSuSS

Compare measured and predicted SZ signal Y_{sz} from X-ray & optical properties

SZ signal in Planck data

(from the first 10 months)



Optical and X-ray statistical studies → SZ signal measured coherently in Planck down to ~ 5. 10^{13} M_{sol}

SZ-optical cluster properties

Y_{sz} from weak-lensing calibrated $\mathbf{N_{200}}$-$\mathbf{M_{500}}$ **relations** (e.g. *Rozo et al. 2009*) + gas pressure profile & scaling relations

SZ predicted signal does not agree with measured SZ

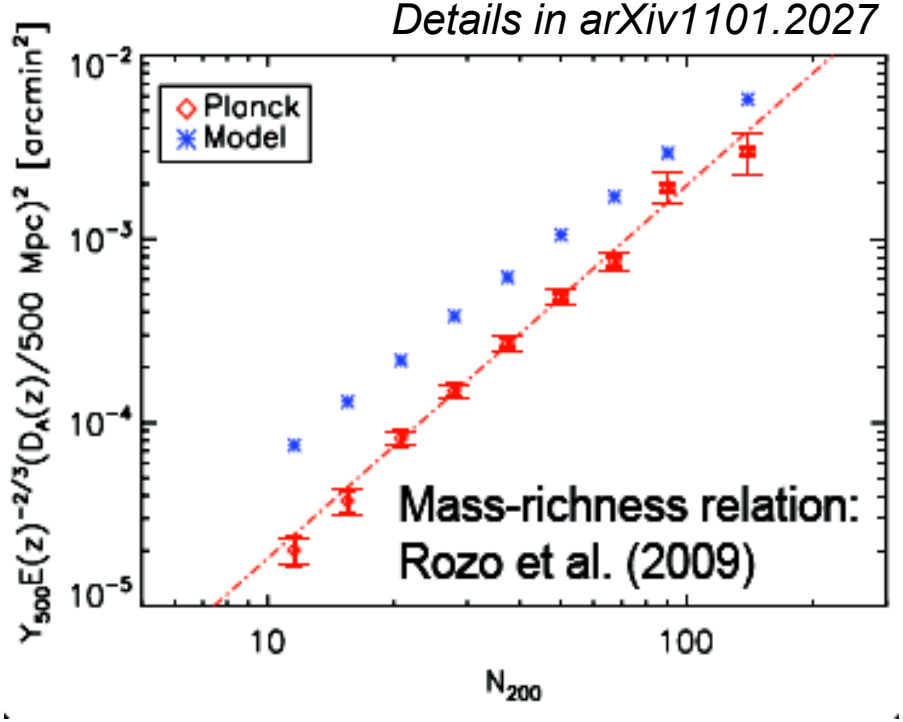
Discrepancy between data and prediction → combination of:

Mass calibration/estimate

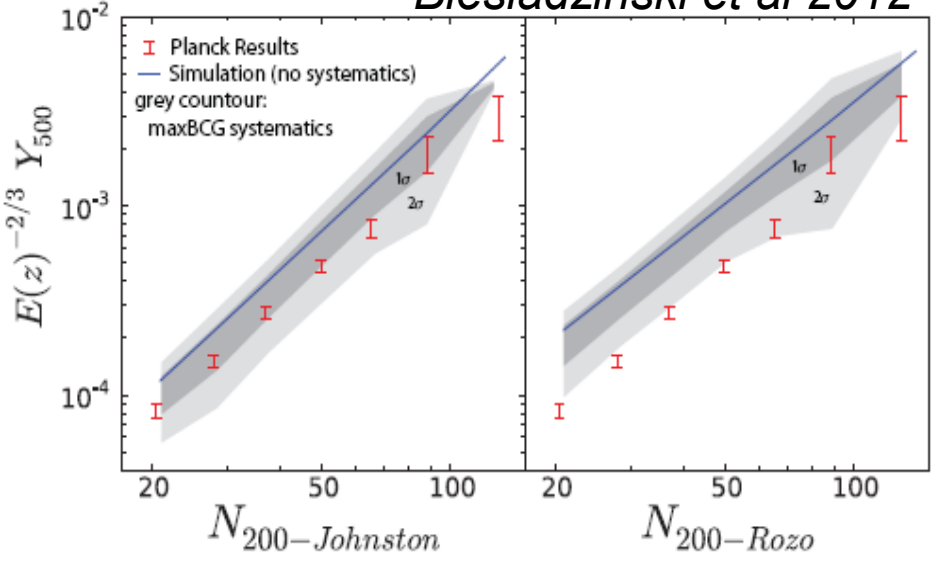
Dispersion in scaling relations, mass scatter

Centering, orientation, volume, purity effects

Details in arXiv1101.2027

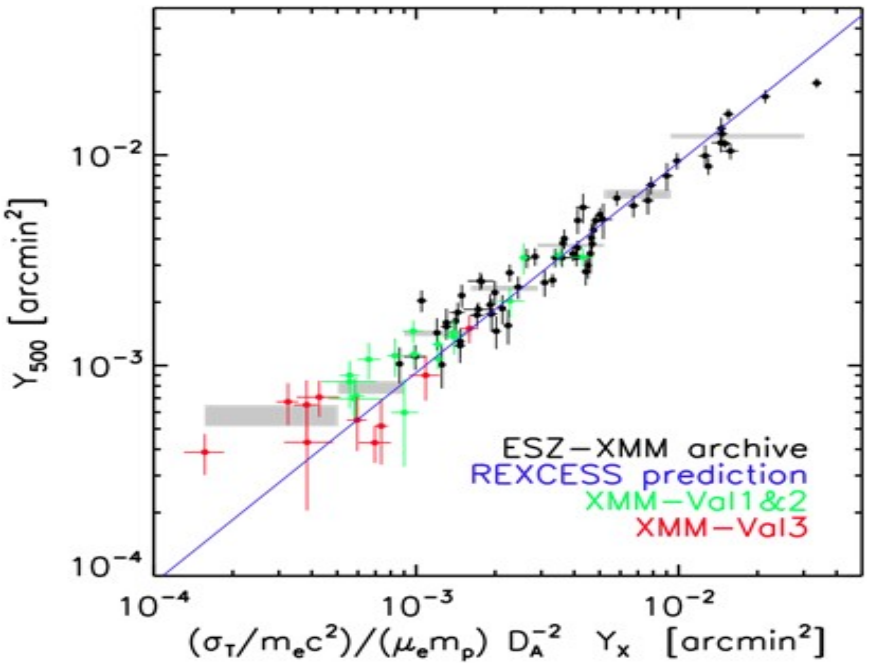


Biesiadzinski et al 2012

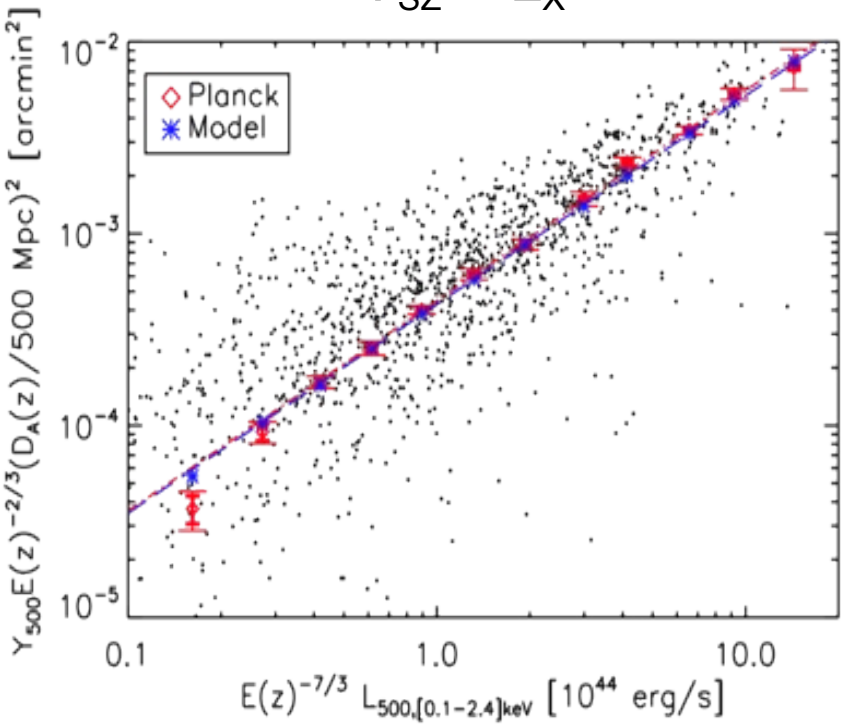


SZ- X-ray properties

Y_{SZ} - Y_X



Y_{SZ} - L_X



- SZ from Planck & X-ray luminosities agree down to lowest luminosity bins
- SZ from Planck & X-ray pressure measurements agree within R_{500}
- **Consistant overall view of ICM** properties from X-rays and SZ

But gives access to HE mass estimate

Summary

- Consistent view of the hot ICM from SZ and X-ray observable
- Open questions as of optical-gas relations
- SZ signal at large radii as an indication of higher gas pressure
- Complex cluster physics probed with SZ signal
- Detection with SZ in Planck of not only « well established » clusters but also dynamically perturbed « forming » clusters

- In the future: Larger catalgue and Planck maps for the community

Conclusions

Planck: CMB experiment with very wide astrophysical capabilities

- Simultaneous observation from 30 to 857GHz
- First survey between 100-900GHz
- Limited resolution (31' to 4') but excellent sensitivity
- All-sky survey

Challenges

→ Control of systematics at the level required for cosmology

→ Control of astrophysical contamination for intensity (high l) & polarisation

Agenda

Jan. 2011 → Early release (10 months of data): Catalogues & results

Early 2013 → First major Planck release (2 sky surveys,nominal mission)

Maps, Catalogues & cosmological results

Early 2014 → Second major Planck release (5 surveys,extended mission)

Maps, Catalogues & cosmological results