Galaxy clusters: what we are learning from *Planck*

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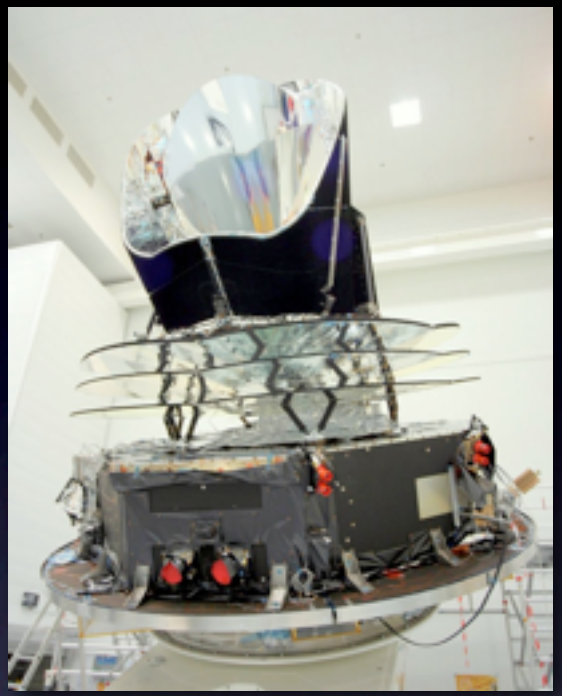
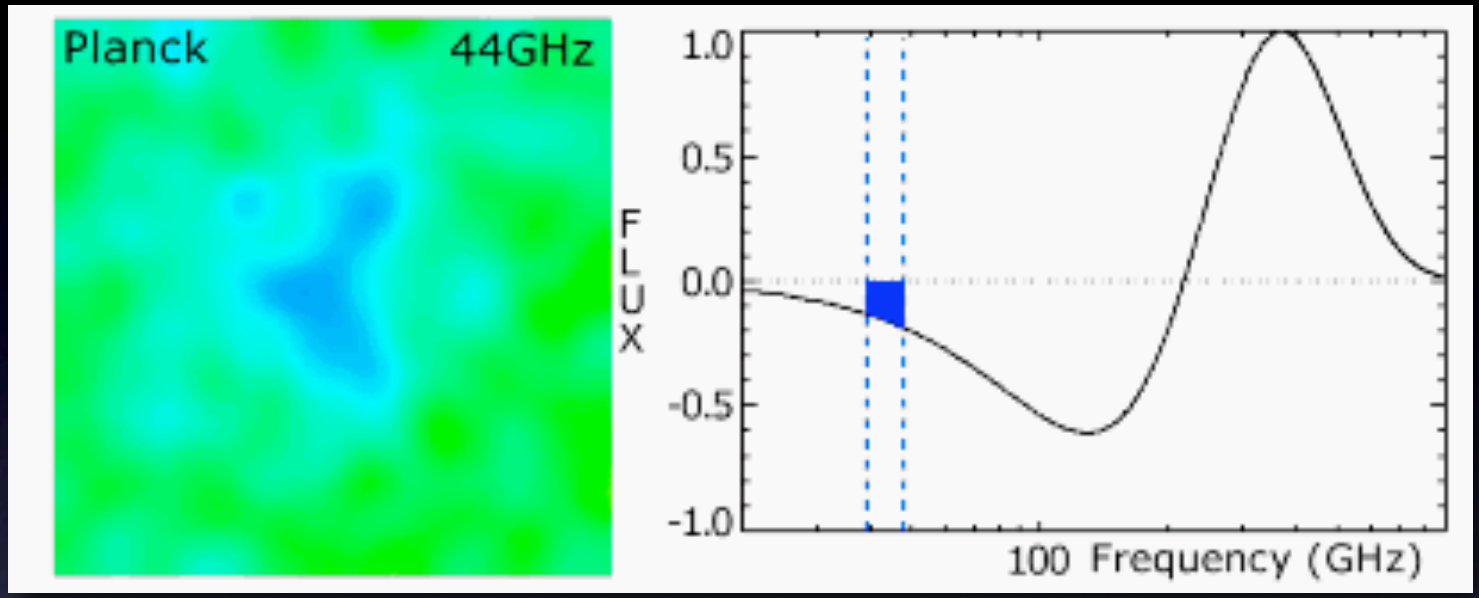
On behalf of the *Planck* Collaboration

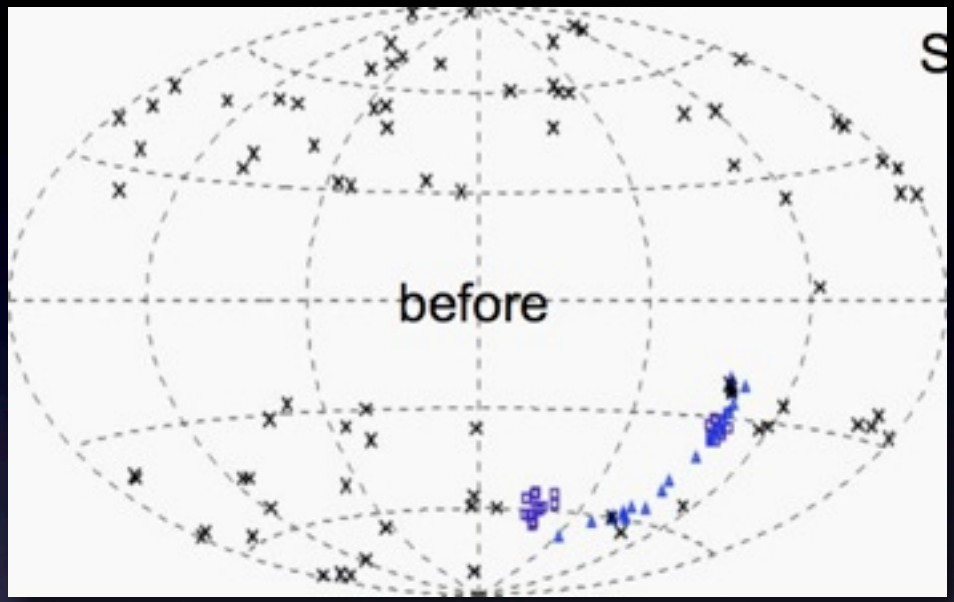
Planck all-sky survey

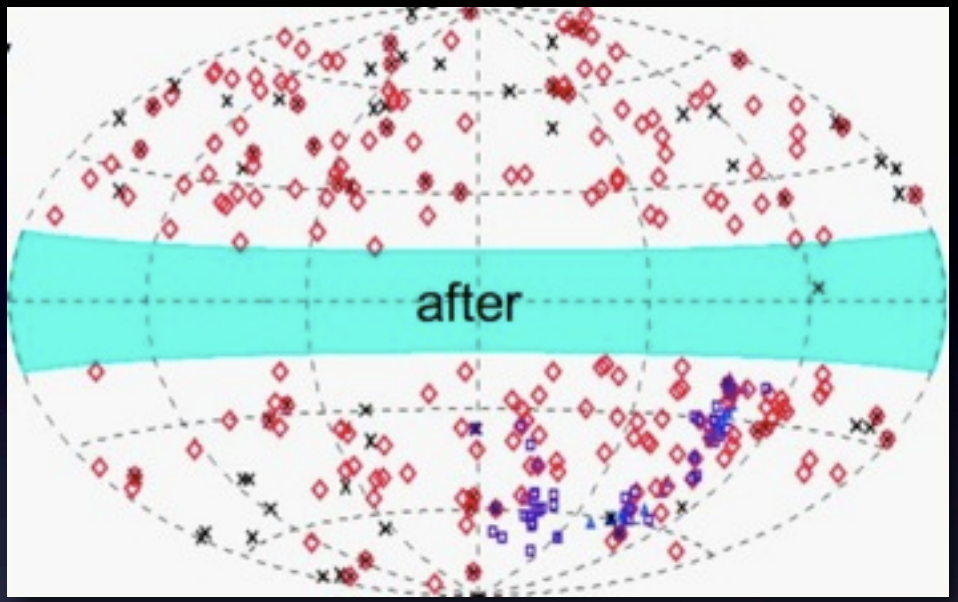




- Nominal survey duration 15 months, extended survey 28 months
- Takes advantage of Planck's unique 9-band coverage
- Search using Multifrequency Matched Filter (MMF; Melin et al. 2006)
  - known spectral shape (tSZ) and spatial distribution (Arnaud et al. 2010)
- First all-sky cluster survey since ROSAT

ESZ - all-sky Early SZ sample



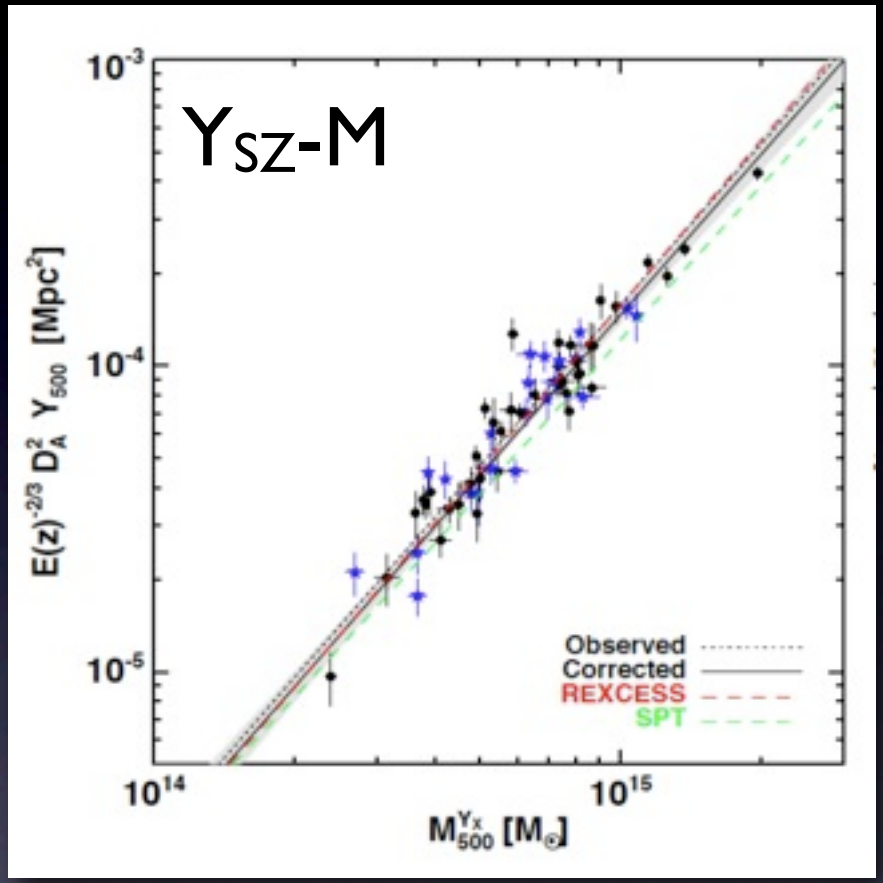


Planck Collaboration VII 2011

- 189 SZ sources with S/N > 6 from first 10 months of survey
- Many known clusters with z < 0.5, but first SZ measure for 80% of these
- 20 new cluster candidates, of which 19 confirmed

- New catalogue out early 2013 using data from nominal 15 month survey

ESZ clusters in XMM archive



Planck Collaboration XI 2011

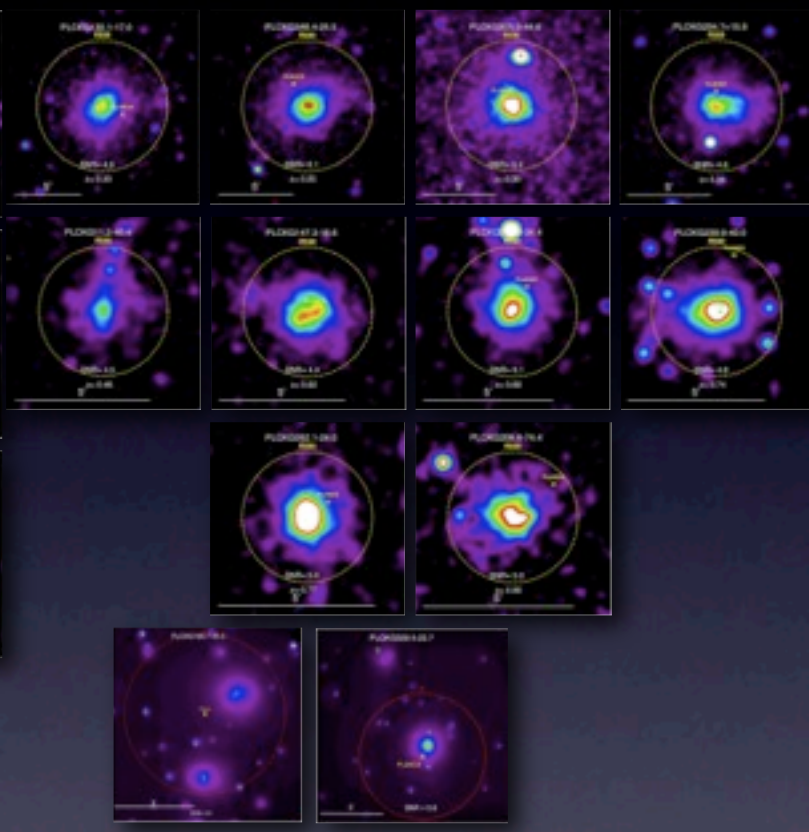
- Tight relation between Y_{SZ} and X-ray estimated mass
- Good agreement with X-ray based predictions

51 newly-discovered Planck clusters

Confirmed with XMM using DDT time

Planck Collaboration IX 2011

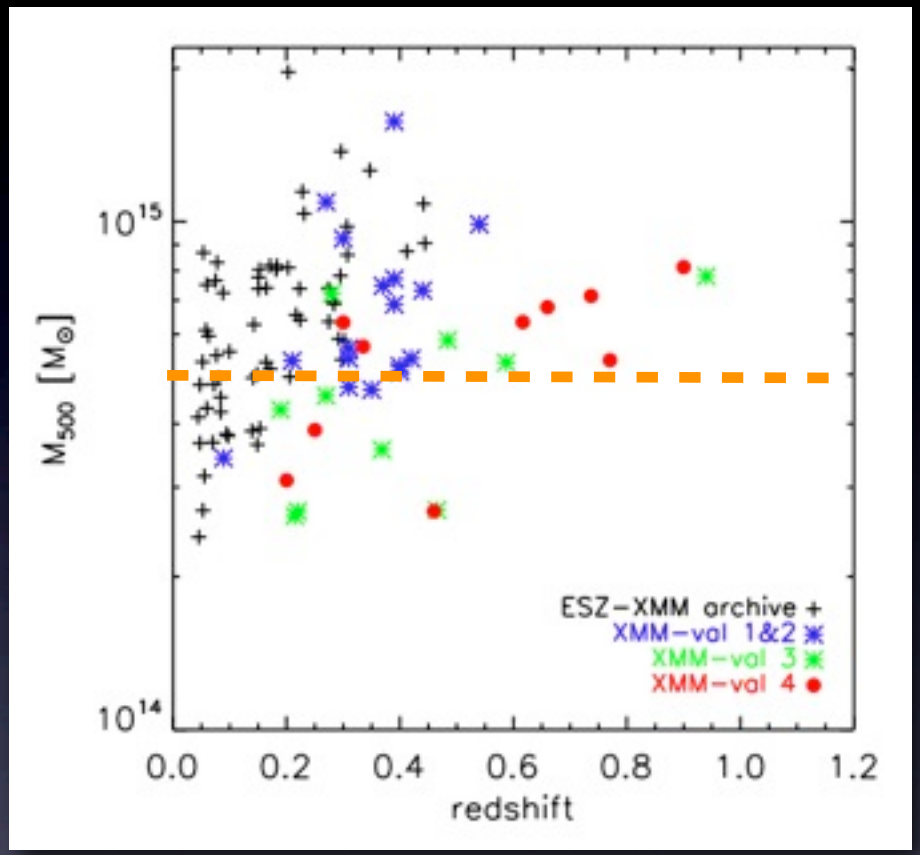
Planck Collaboration I 2012

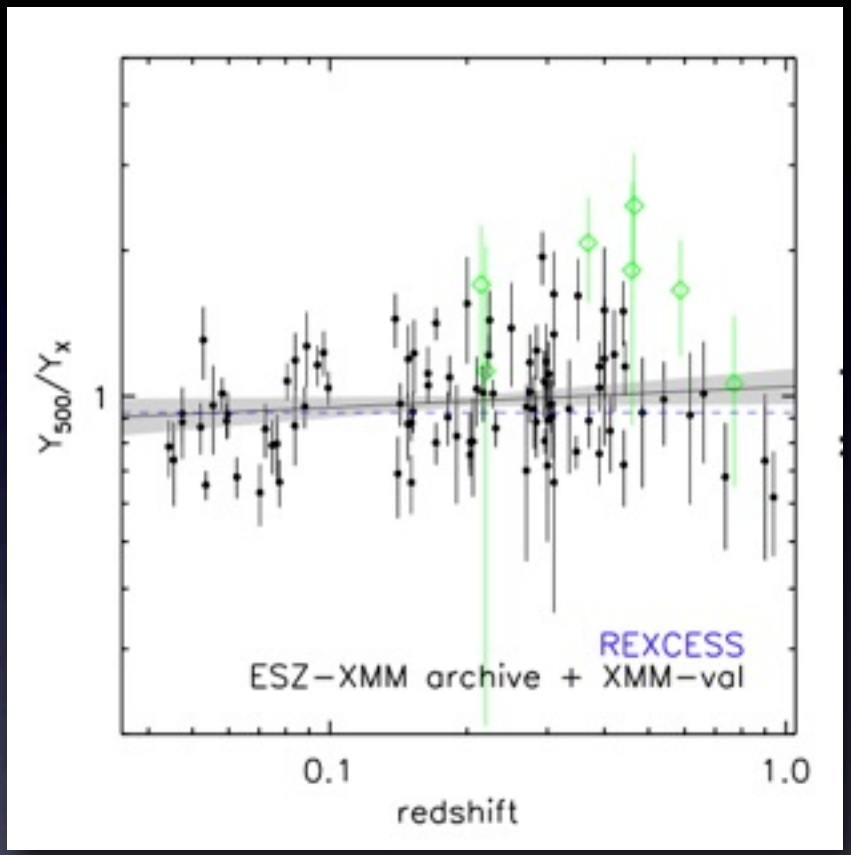


Planck Collaboration IV 2012

NB includes 4 double and 2 triple systems

Newly-discovered Planck clusters

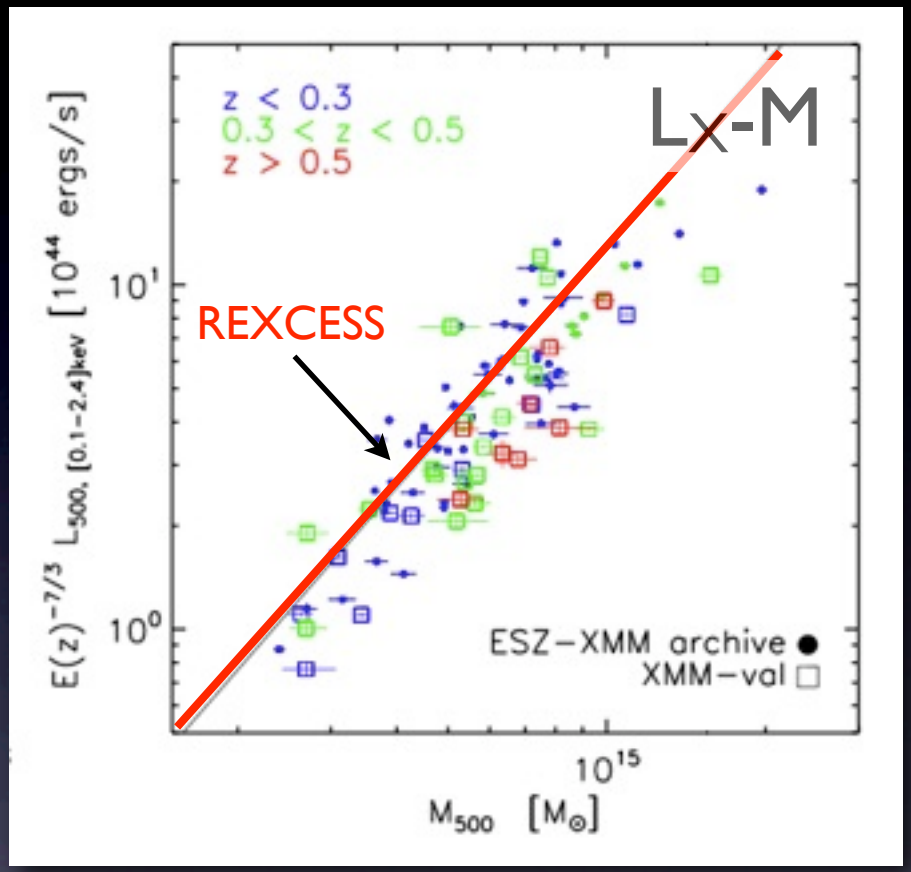




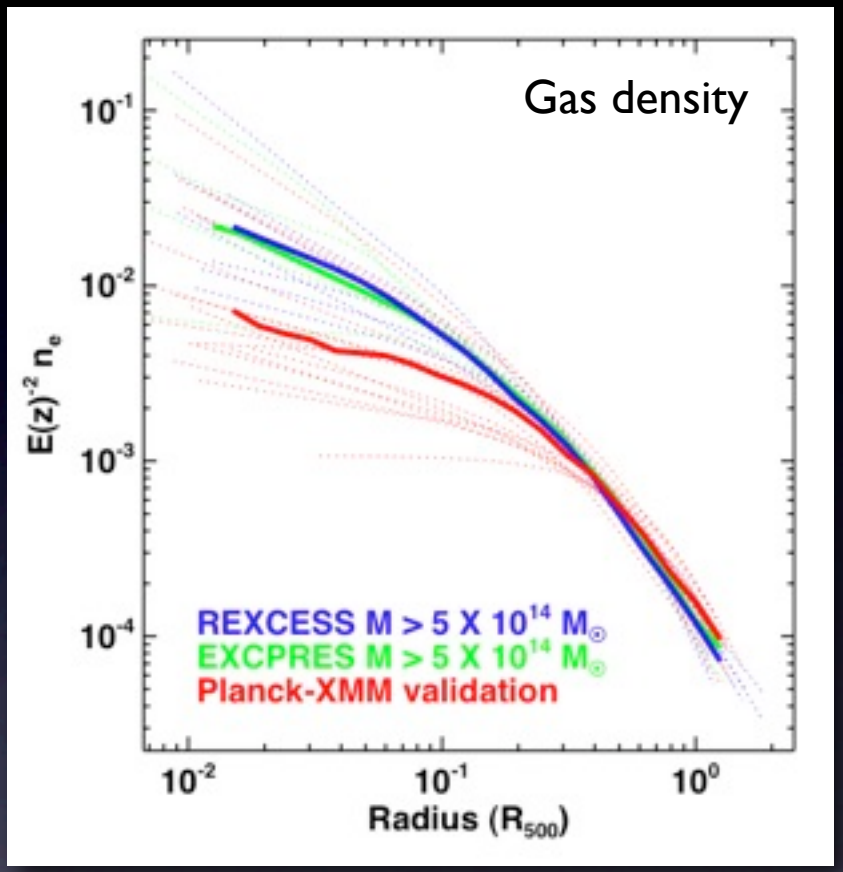
Planck Collaboration IV 2012

- High-mass systems up to z ~ 1
- Good agreement between Y_{SZ} and X-ray based predictions up to z~1

Newly-discovered Planck clusters



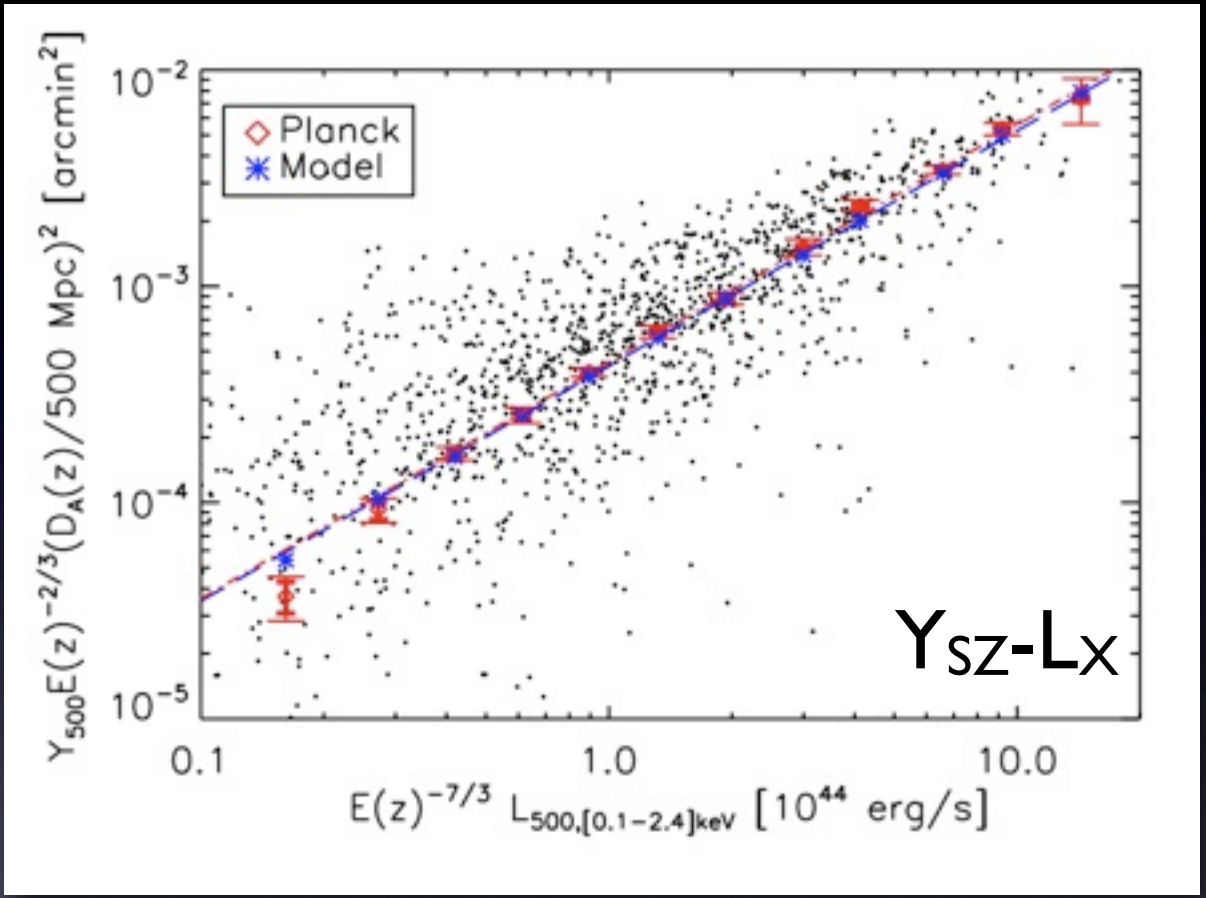
Planck Collaboration IV 2012



Planck Collaboration IX 2011

- Lower X-ray luminosity (on average) for their mass, but high mass
- Generally more morphologically disturbed than X-ray selected clusters

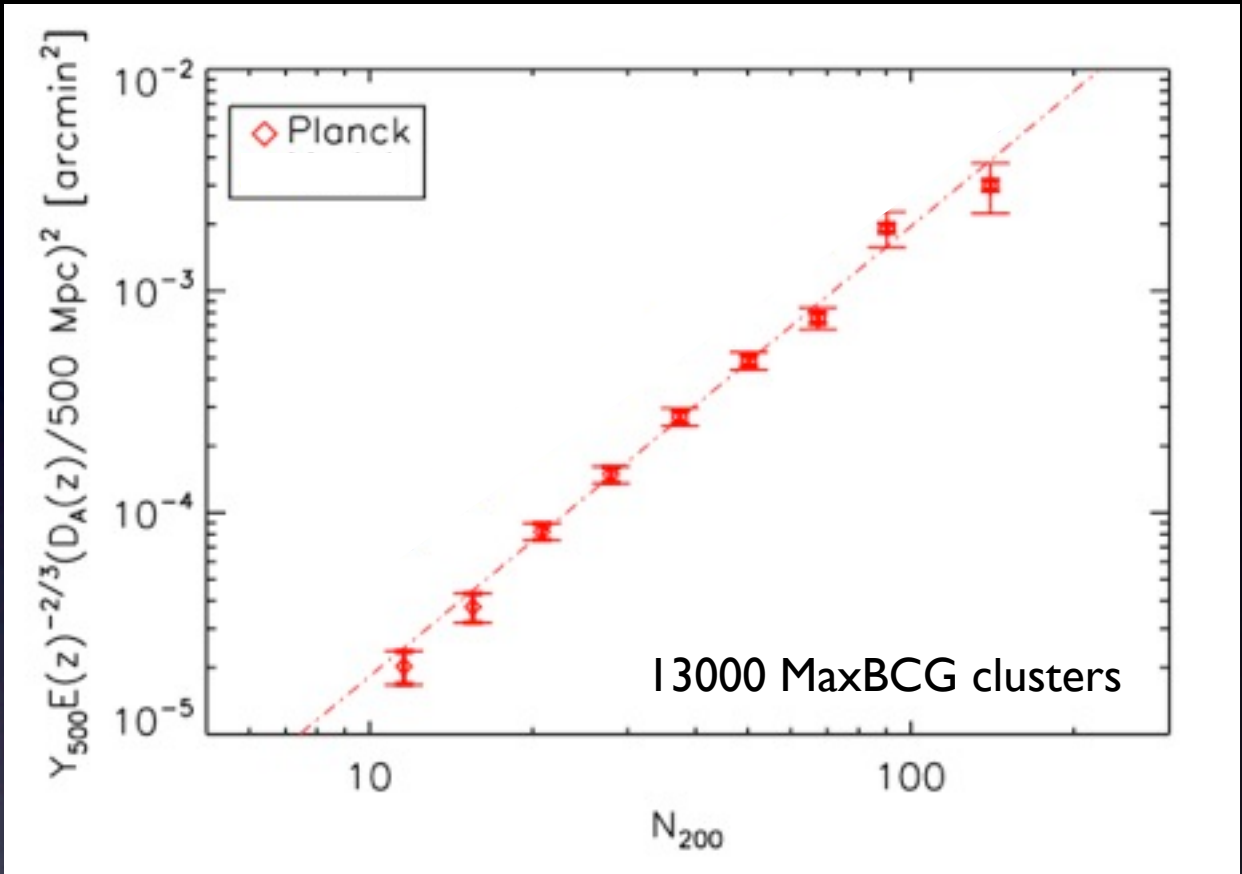
X-ray selected clusters



Planck Collaboration X 2011

- 1700 MCXC X-ray selected clusters
- Stacking via $L_X \rightarrow M \rightarrow Y_{SZ}$ is good match to X-ray expectations

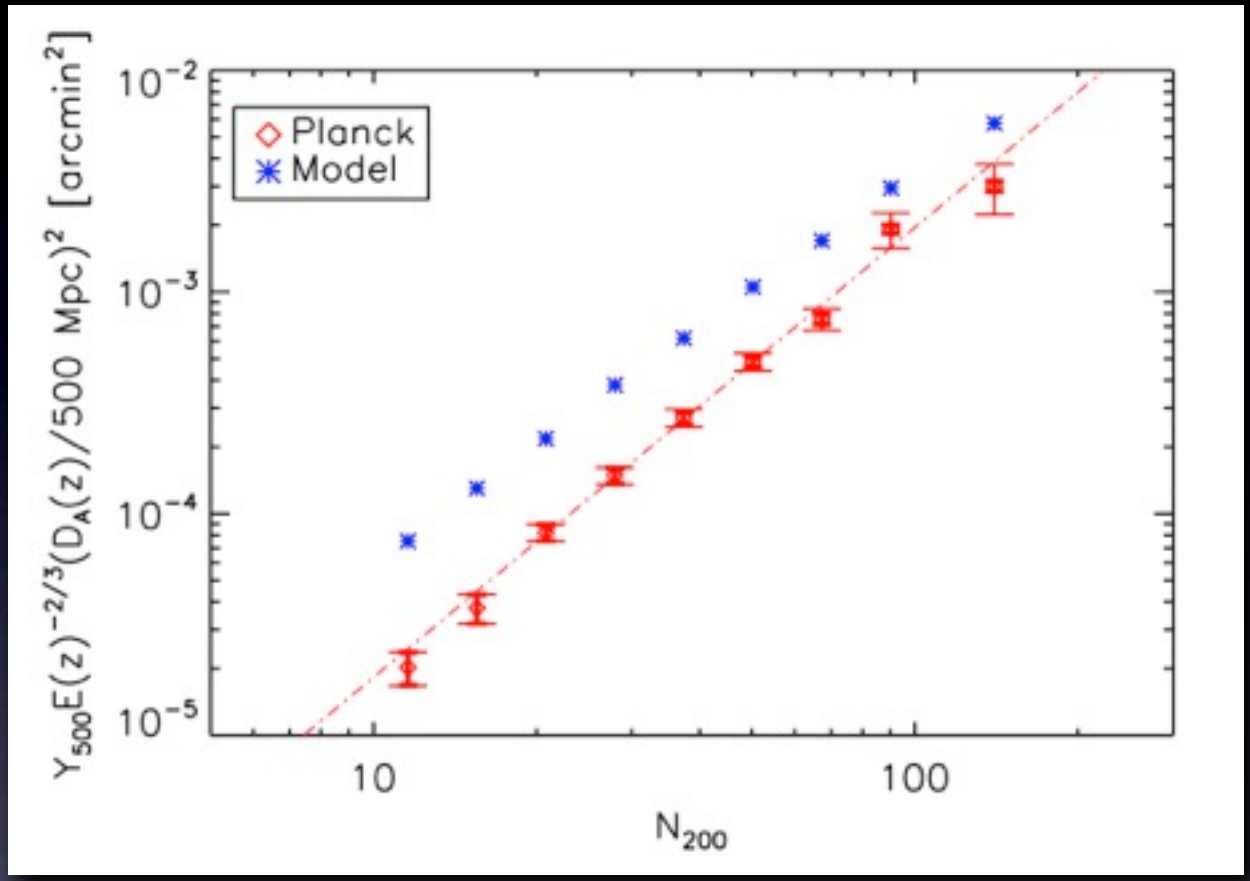
Optically-selected clusters



Planck Collaboration XII 2011

- Power-law relation between Y_{SZ} and clusters stacked on optically-estimated mass N_{200}

Optically-selected clusters

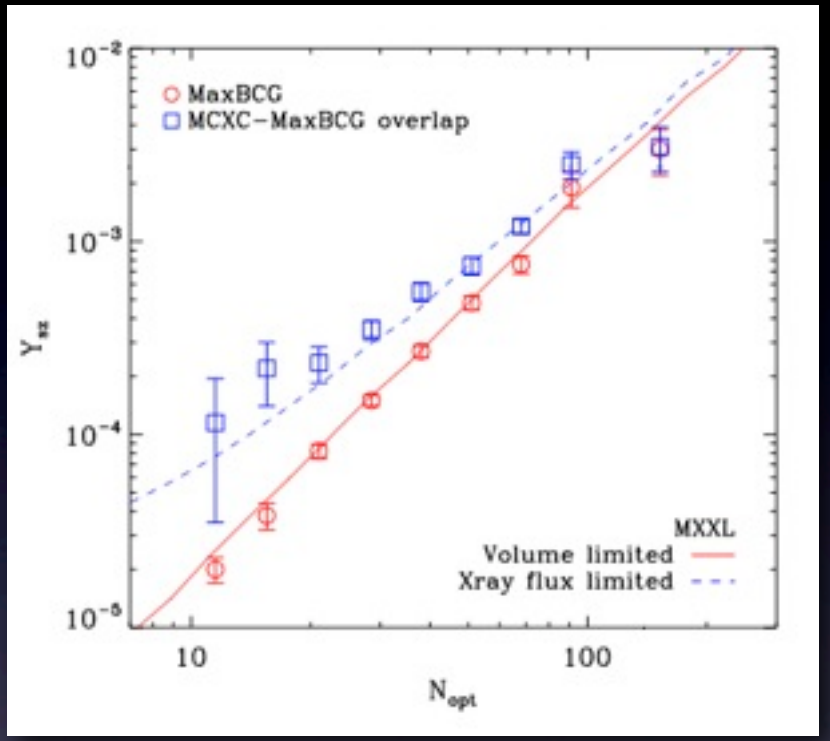


Planck Collaboration XII 2011

- Power-law relation between Y_{SZ} and clusters stacked on optically-estimated mass N_{200}
- But stacking via $N_{200} \rightarrow M \rightarrow Y_{SZ}$ is bad match to X-ray model

Comparing optically- & X-ray-selected clusters

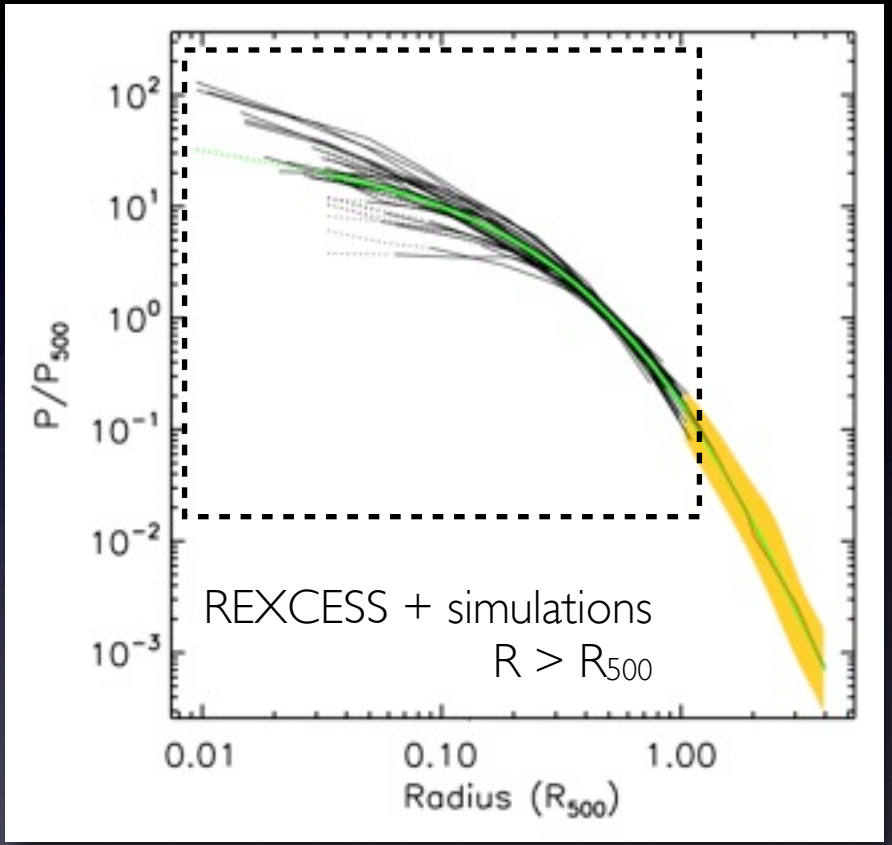
- **Survey biases** (e.g., Angulo et al. 2012)
  - Malmquist bias: affects flux-limited samples (X-rays) more than volume limited samples (optical)
- **Observable biases** (e.g., Rozo et al. 2012)
  - Covariance: At fixed M, correlated scatter between quantities due to e.g., orientation, internal structure, etc
  - Either the X-ray or the weak lensing mass calibration (or both) is incorrect
- **Further progress**
  - Better account for sample selection
  - Better mass calibration



Angulo et al. 2012

Pressure profiles

$$\Delta i_\nu \propto y \propto \int_{\rm los} n_e T\,(\equiv P)\,dl \quad \Rightarrow \text{pressure is the fundamental SZ quantity}$$

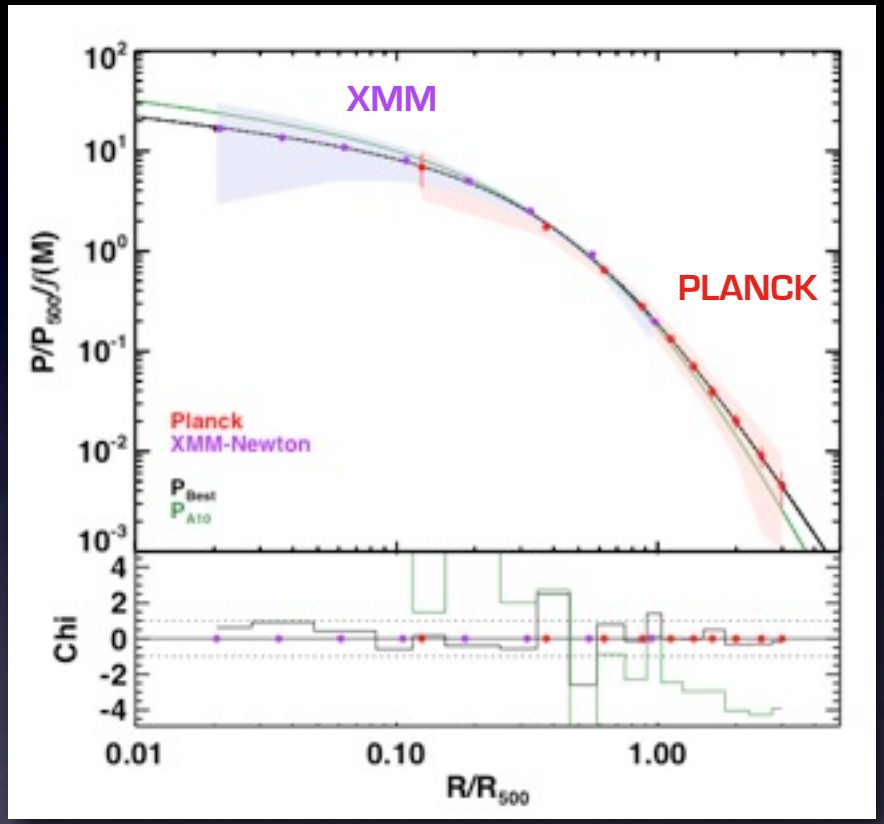


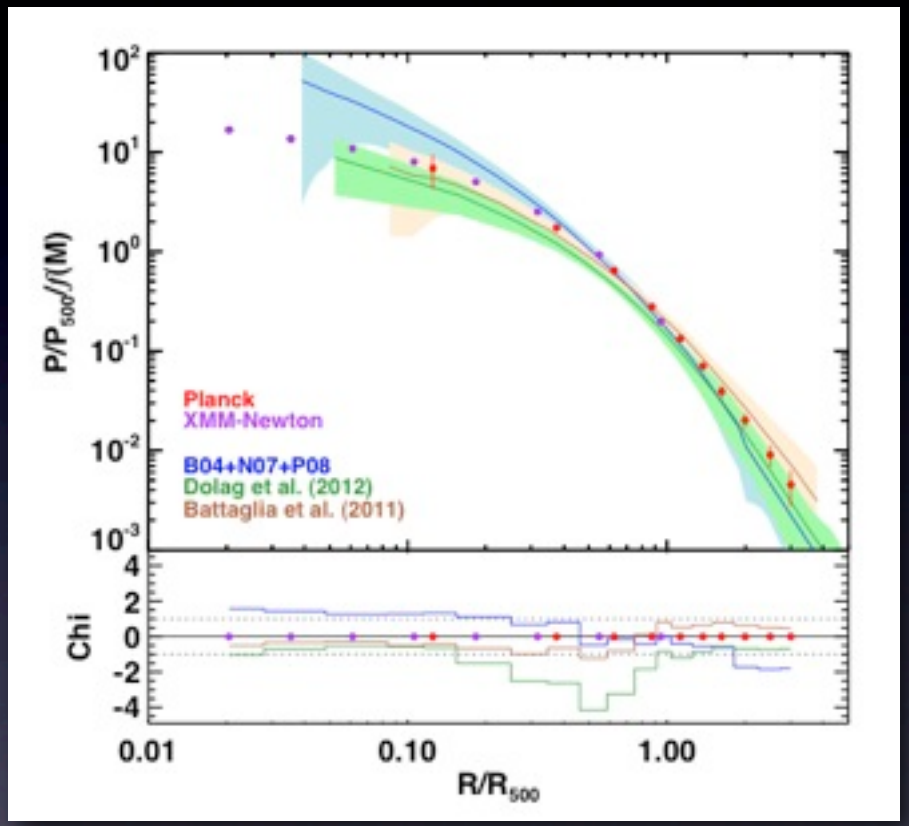
Arnaud et al. 2010

- 'Universal' profile derived from XMM observations
- No X-ray constraints beyond R_{500} so simulations used instead

Pressure profiles from *Planck*

Stacked pressure profile from 62 ESZ systems

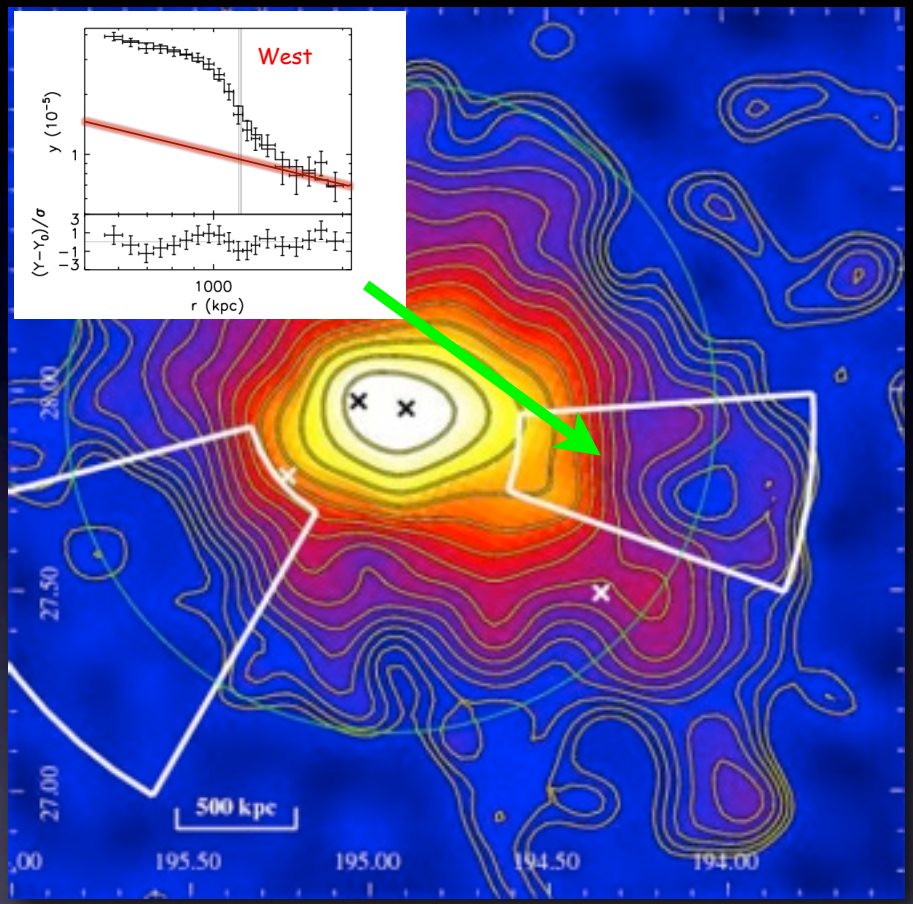




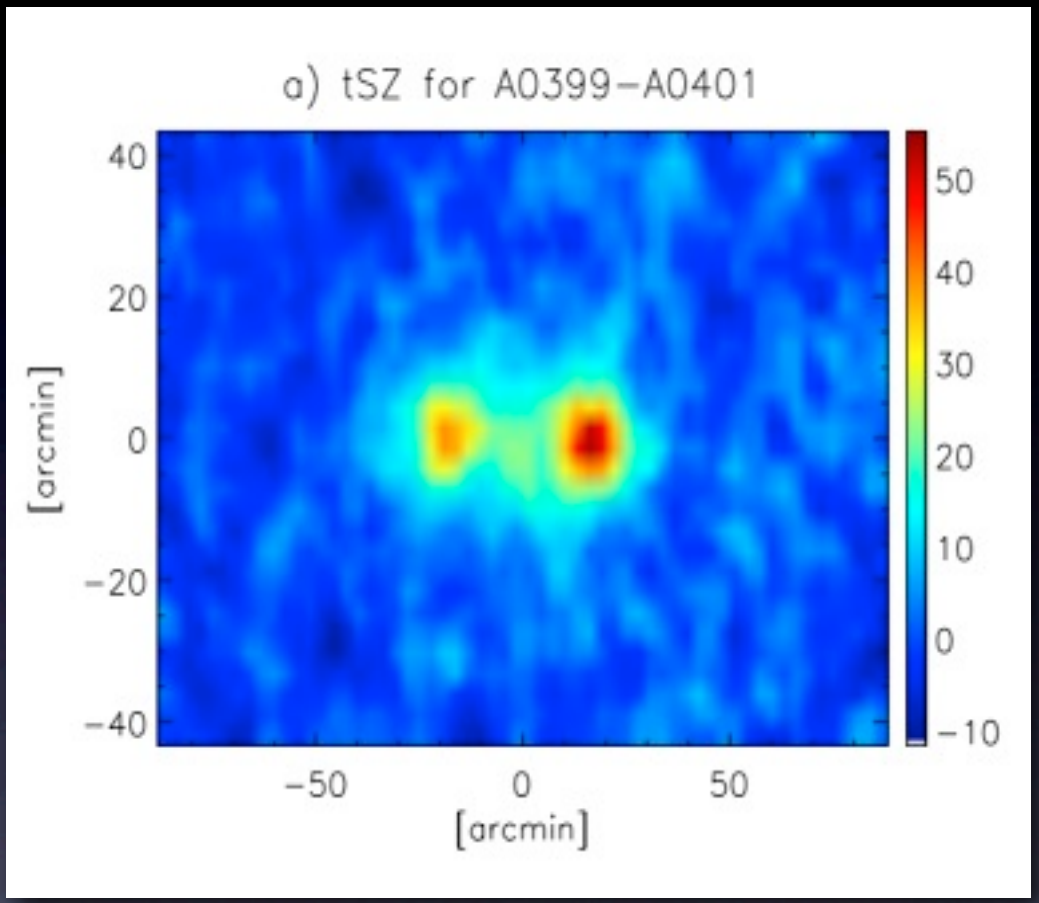
Planck Collaboration V 2012

- Excellent agreement with X-ray measurements within R_{500}
- First-ever constraints out to $3R_{500}$
- Slightly more pressure in outskirts than predicted from simulations

Other recent highlights



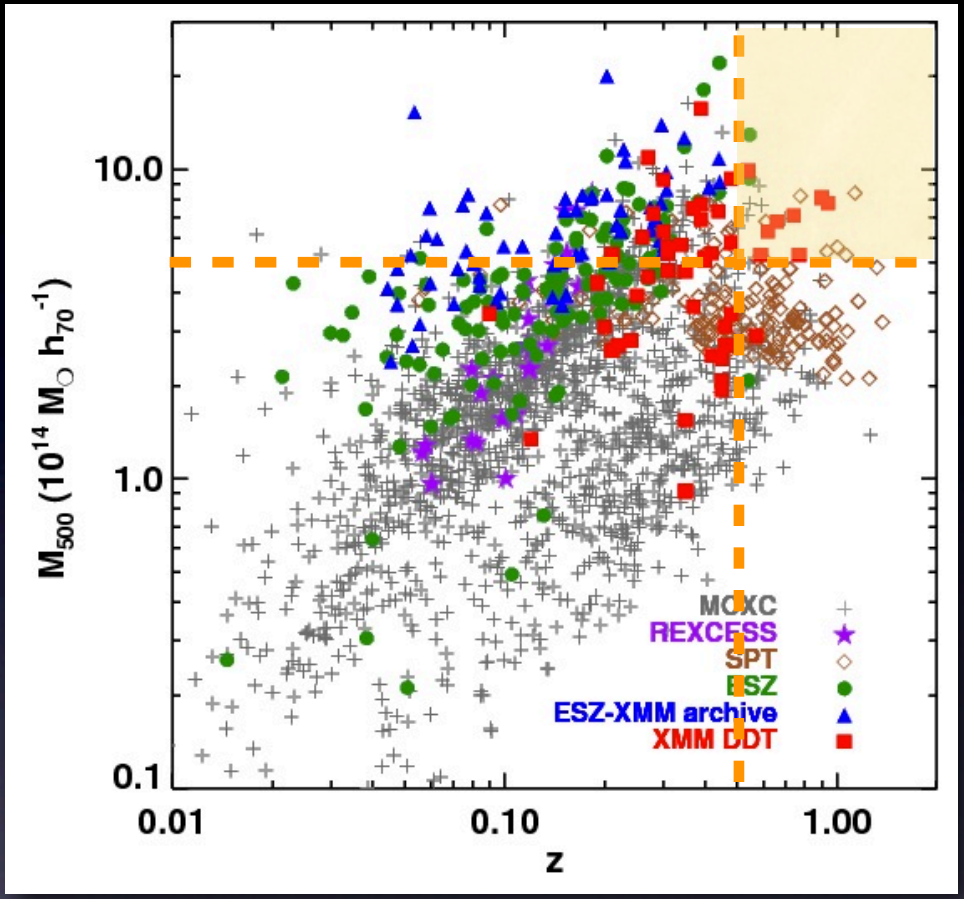
Planck Collaboration X 2012

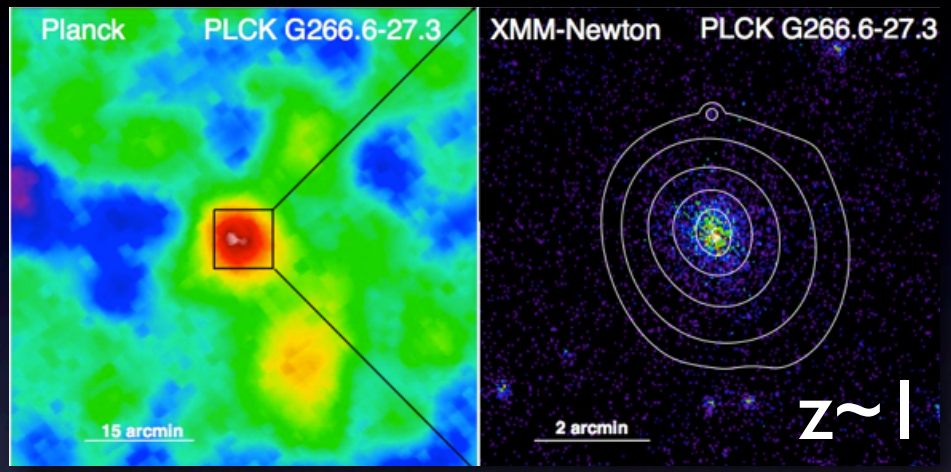


Planck Collaboration VIII 2012

- Large-scale high resolution map of Coma; detection of pressure jumps
- Strong detection of heated region between A399-A401 in SZ

The high redshift connection





PLCK G266.6-27.3;
Planck Collaboration XXVI 2011

- Planck survey represents unique discovery space (all-sky, $M_{500} > 5 \times 10^{14} M_\odot$, $z > 0.5$)
- Some high mass, high redshift clusters already discovered
- Understanding of lower-z systems essential to understand evolution

Conclusions

- Many new, interesting, clusters being discovered up to z~1
- Power-law relations between global quantities over several decades in mass
  - Clusters are regular objects
  - But sample selection effects have large bearing on interpretation
- First-ever constraints on pressure profiles up to $3R_{500}$
  - Robust, consistent view of ICM in X-ray and SZ
- Interesting new physics
  - Pressure jumps in SZ, heated regions between clusters, etc
- Unique discovery space
  - Now pushing to all sky survey at $z > 0.5$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