Cosmology with SZ and X-ray cluster surveys

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Workshop on Studies of Dark Energy and Cosmology with X-ray Surveys

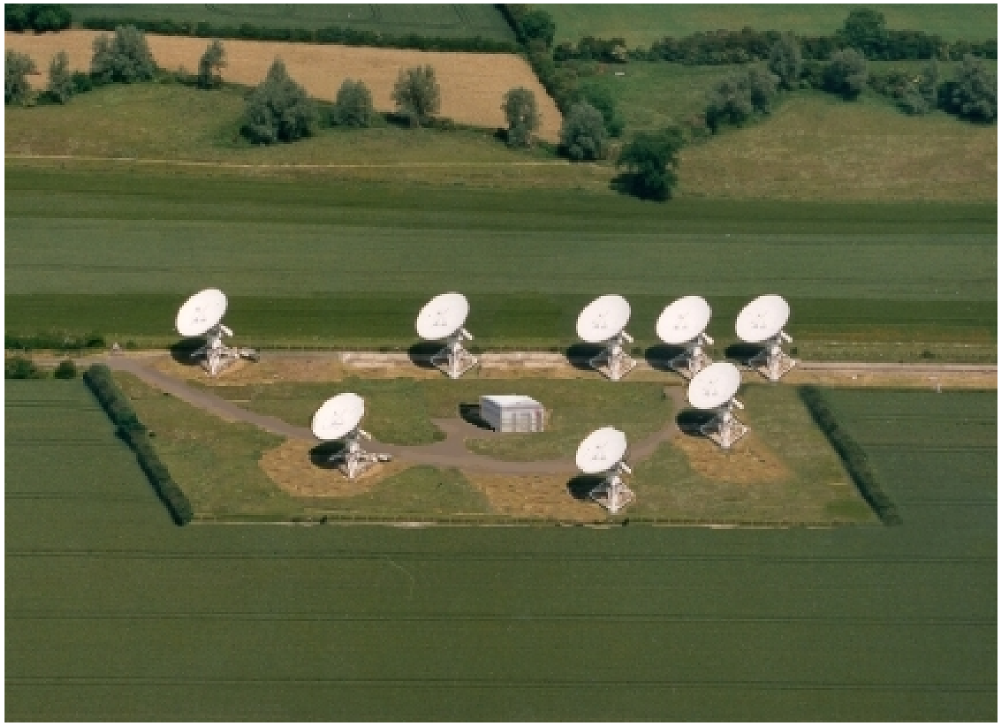
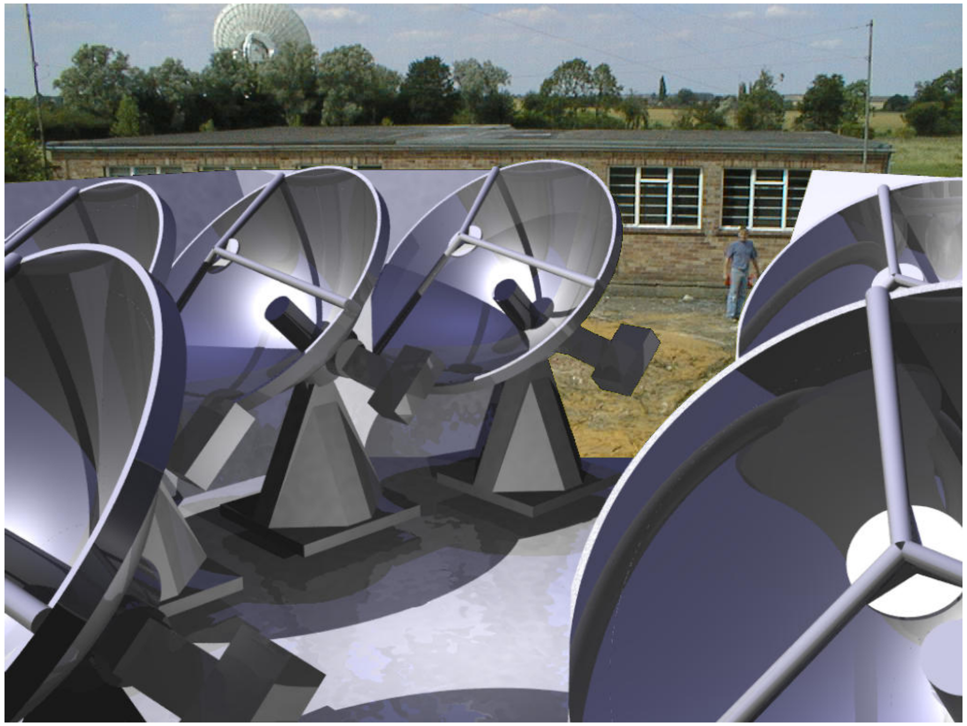
January 15-16 2004, GSFC Maryland

- Arcminute Micro-Kelvin Imager

- Planck Surveyor and X-ray data

- Component separation in X-rays

The Arcminute Micro-Kelvin Imager

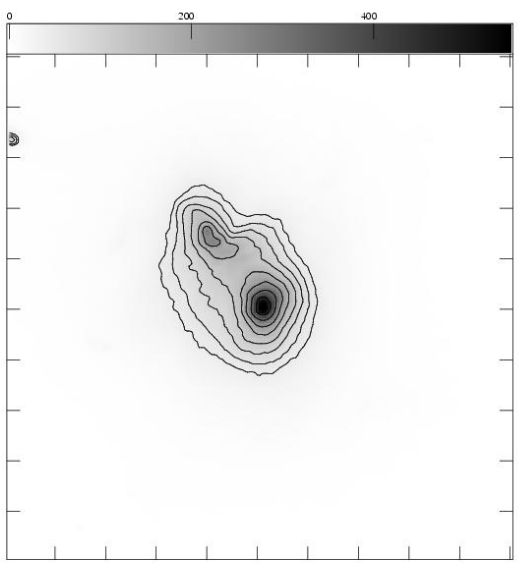
 

Roger Boysen, Tony Brown, Mike Crofts, Tom Culverhouse, Roger Dace, Ken Duggan, Will Flynn, Keith Grainge, Will Grainger, Jörn Geisbüsch, Richard Hills, Christian Holler, Roy Jilley, **Mike Jones**, Tak Kaneko, Rüdiger Kneissl, Anthony Lasenby, Ian Northrop, Guy Pooley, Vic Quy, **Richard Saunders**, Jack Schofield, Paul Scott, Clive Shaw, Angela Taylor, Dave Titterington, Simon West, Brian Wood

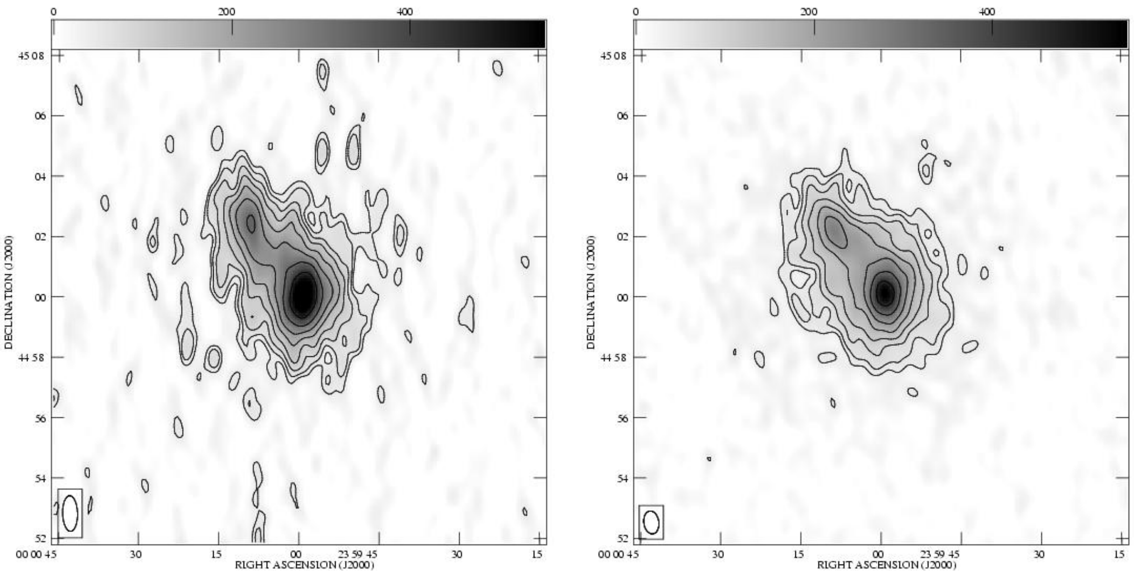
Imaging cluster substructure with AMI

Construction phase 3: Compactifying the Ryle telescope

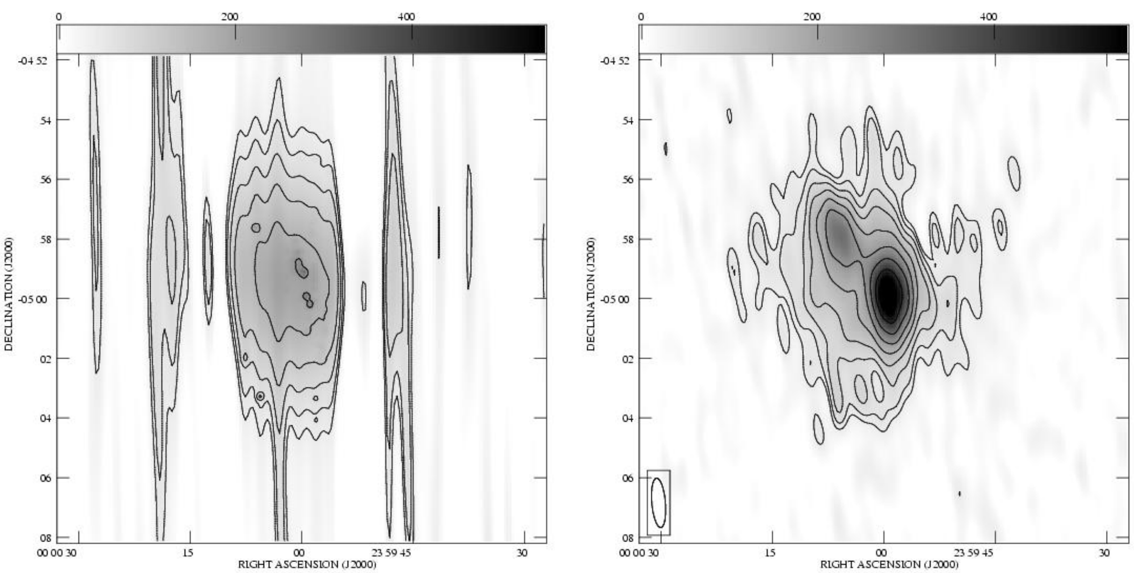
current wide East-West alignment



Hydrosimulation: 5×10^{14} $M_{\odot}$ merging cluster at $z = 0.155$.



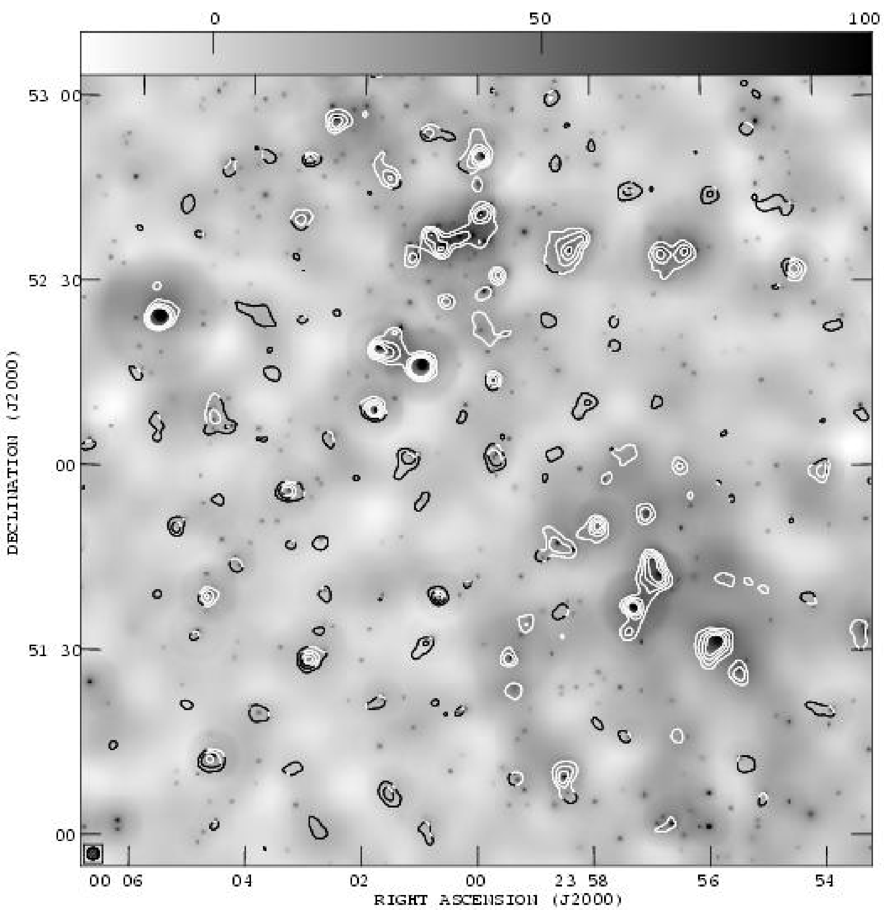
high declination (45 deg)

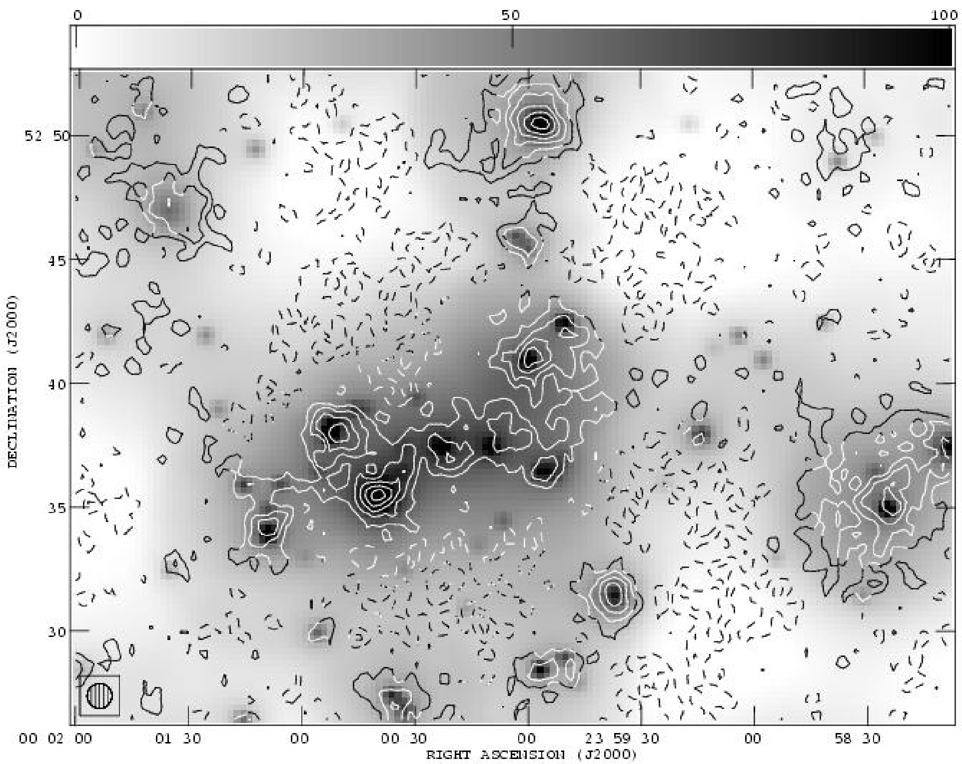


low declination (-5 deg)

more compact array with improved North-South resolution

AMI cluster survey in the presence of primordial CMB





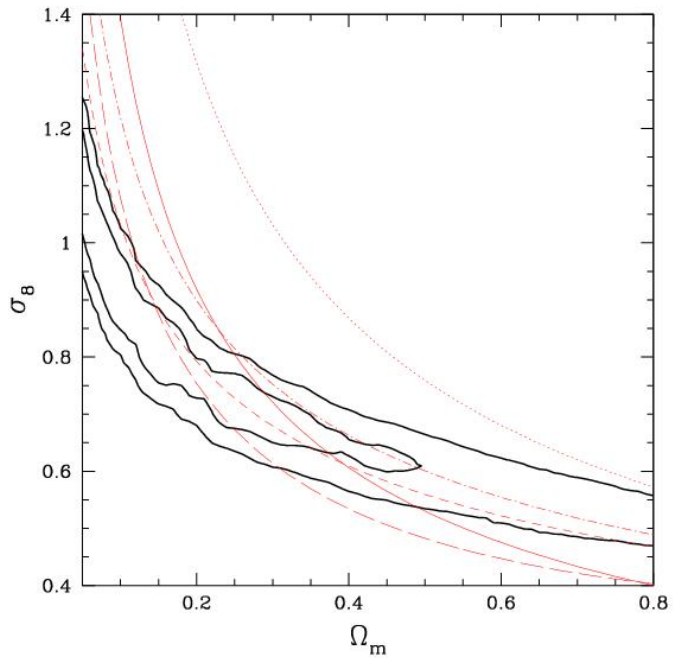
Grayscale image: Virgo cluster positions with scaled β model clusters, plus CMB

Contour overlay: 6 months survey, 2 arcmin resolution. Sources subtracted!

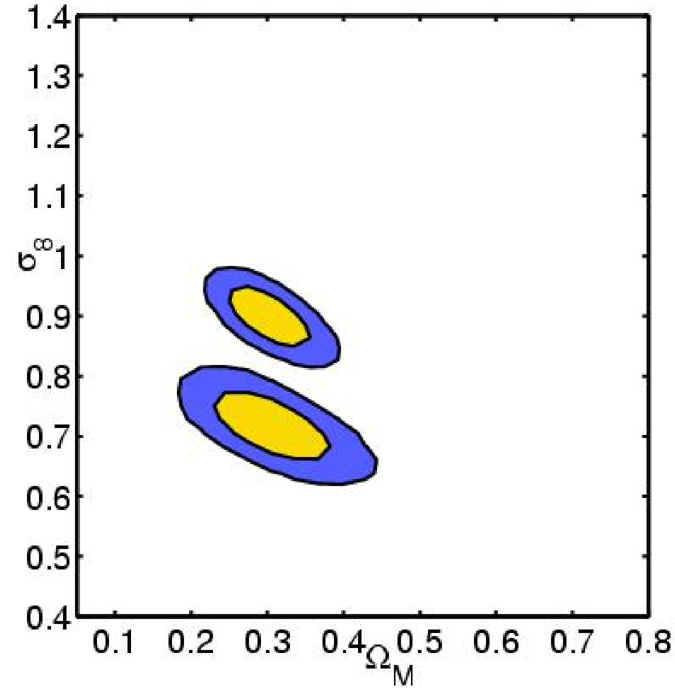
$\sim$ 70 clusters detected

Parameter estimation with AMI

- Two cases considered: $\sigma_8 = 0.9$ and $\sigma_8 = 0.7$ ($\Omega_\mathrm{M} = 0.3$)
- M-T relation is changed consistently with X-ray data
- Size of the error is roughly given by cluster numbers (300 and 150 clusters)
- Other cosmological parameters held fixed (e.g. $h = 0.72$ and $w = -1$)
- Follow-up: redshifts with $\Delta z = 0.1$ out to $z = 2$
- Well-determined cluster scaling relations (e.g. $\Delta f_g \sim 10\%$, $\Delta\beta \sim 10\%$)
- See Weller, Battye, RK (2002) for the method



X-ray cluster abundance (from Allen et al. 2002)

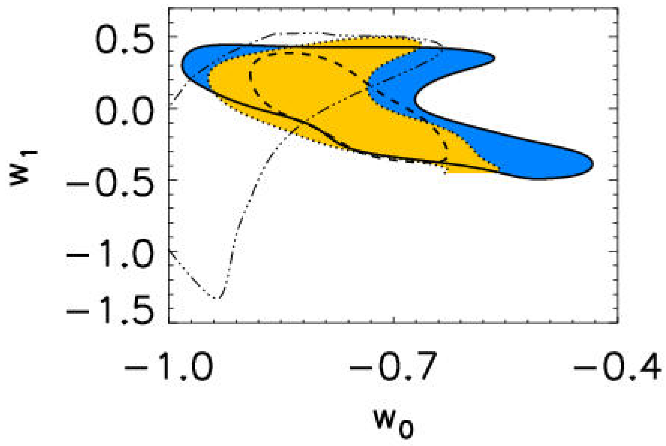


1-year AMI survey of 100 deg^2

Constraining dark energy with SZ clusters

The types of surveys and the number of clusters one would expect to observe in a fiducial cosmology $[h = 0.65, \sigma_8 = 0.925, \Omega_{\rm M} = 0.3, w_0 = -0.8, w_1 = -0.3; p = \rho(w_0 + w_1 z)]$.

	(I)	(II)	(III)	(IV)
$S_{\rm lim}$	0.1	5	≈36	-
ν	15	30	≈100	-
$\Delta\Omega$	10	10^4	20600	4000
$M_{\rm lim}$	1.5	≈ 7.0	≈ 6.0	2.5
$N_{\rm tot}$	≈ 90	≈ 1970	≈ 5200	≈ 13600

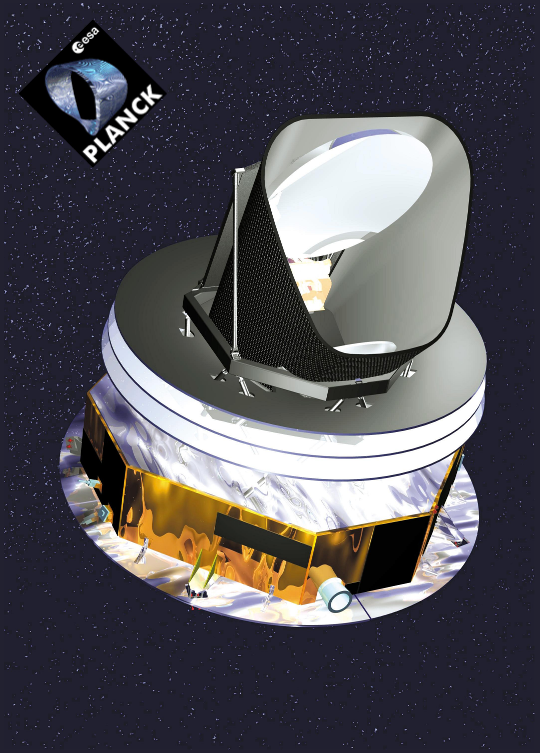


Cluster evolution constraints from survey types II-IV compared with SNAP SNe (from Weller, Battye, RK 2002).

Necessary to take evolution of EoS into account, as expected in most physical models of quintessence.

Dark energy is important for SZ cluster surveys, but no interesting constraints from the first generation of instruments

The Planck Surveyor



Goal Planck instrument characteristics# (TBC)

Telescope	1.3+0.2 m. (projected aperture) Gregorian; shared focal plane; system emissivity 1%									
	Viewing direction offset 80-85° from spin axis.									
Center Frequency (GHz)	30	44	70	100	100	143	217	353	545	857
Detector Technology	HEMT radio receiver arrays				Bolometer arrays					
Detector Temperature	~20 K				0.1 K					
Cooling Requirements	H_2 sorption cooler				H_2 sorption cooler + 4K J-T stage + Dilution system					
Number of Detectors	4	6	12	34	4	12	12	6	8	6
Angular Resolution (')	33	23	14	10	10.7	8.0	5.5	5.0	5.0	5.0
Optical Transmission	1	1	1	1	0.3	0.3	0.3	0.3	0.3	0.3
Bandwidth ($\Delta \nu / \nu$)	0.2	0.2	0.2	0.2	0.25	0.25	0.25	0.25	0.25	0.25
$\Delta T/T$ Sensitivity per res. element (12 months, 1σ, 10^{-6} units)*	1.6 (P)	2.4 (P)	3.6 (P)	4.3 (P)	1.7	2.0 (P3.7)	4.3 (P8.9)	14.4	147.0 (P208)	6670.

Table last updated 11/12/1998
* Sensitivity to polarized signal is marked with a P

PLANCK

Cluster extraction methods for Planck

Maximum Entropy Method (MEM) (eg. Hobson et al. 1998, Stolyarov et al. 2002)

in Fourier / Spherical Harmonic space ($\vec{k}, a_{\ell m}$) (can also be real space $\Delta T(\phi,\theta)$ or wavelets $\psi(L,x)$)

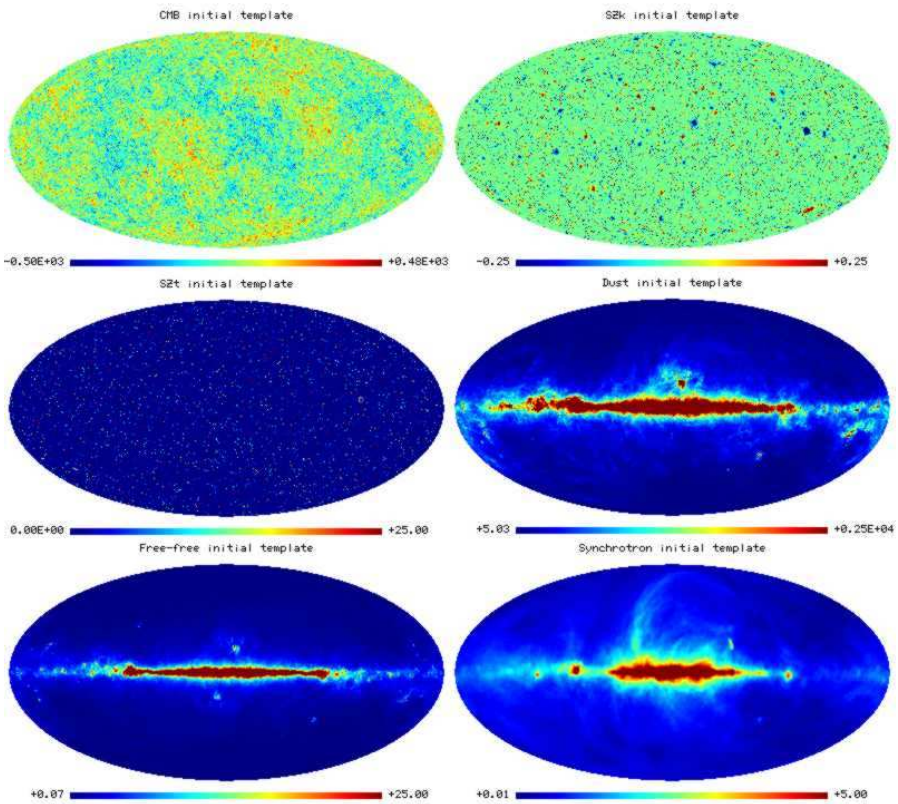
Data model:

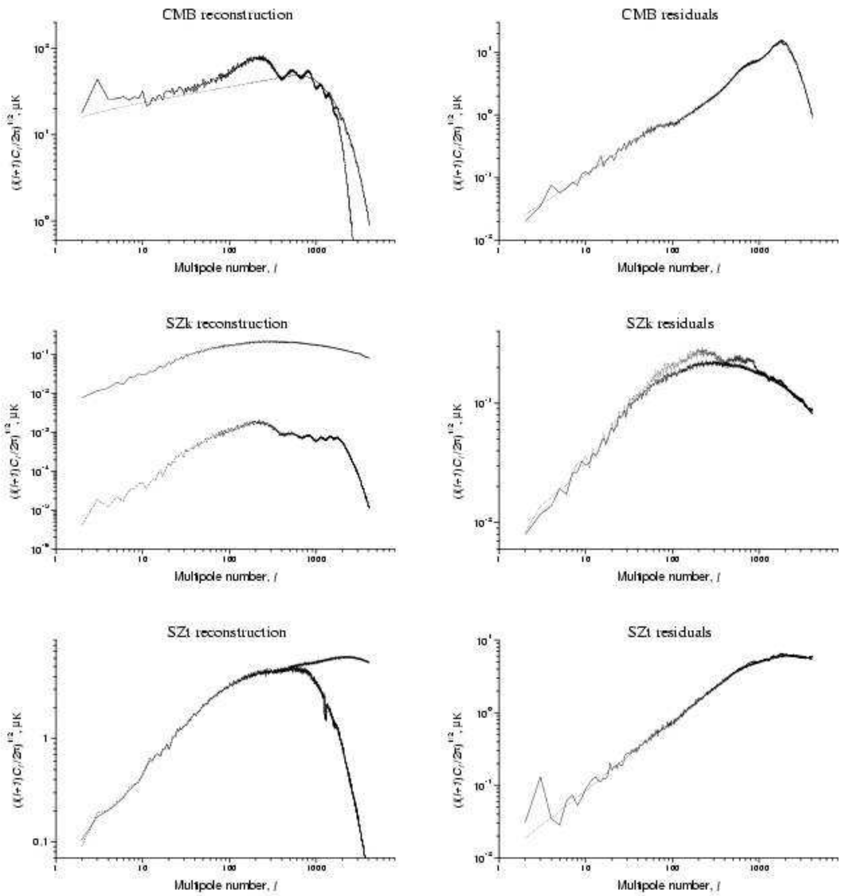
$$\underbrace{\tilde{d}_\nu(\vec{k})}_{\text{data}} = \sum_{p=1}^{n_c} \underbrace{\tilde{P}_\nu(\vec{k}) F_{\nu p}}_{\mathsf{R}_{\nu \mathsf{p}(\tilde{\mathsf{k}})}} \underbrace{\tilde{s}_p(\vec{k})}_{\text{signal}} + \underbrace{\tilde{\epsilon}_\nu(\vec{k})}_{\text{noise}} \leftrightarrow \mathsf{d} = \mathsf{Rs} + \epsilon$$

Bayes' Theorem for inversion, entropic prior (cf. Wiener filter):

$$Pr(s|d) \propto \underbrace{\tilde{\epsilon}_\nu(\vec{k})}_{\exp[-(d-Rs)^{+}N^{-1}(d-Rs)]} Pr(s)$$

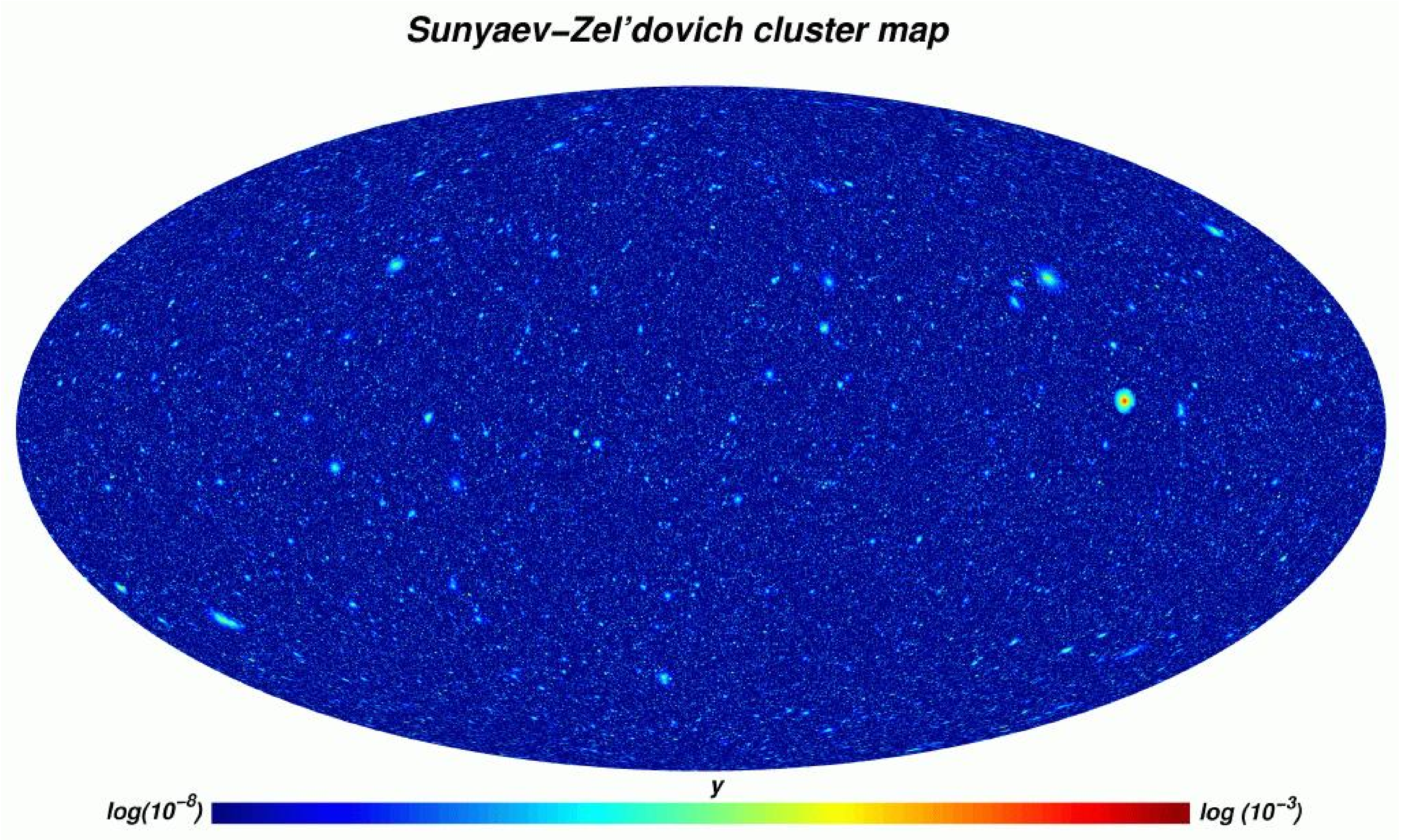
All-sky CMB component separation (Stolyarov et al. 2002)



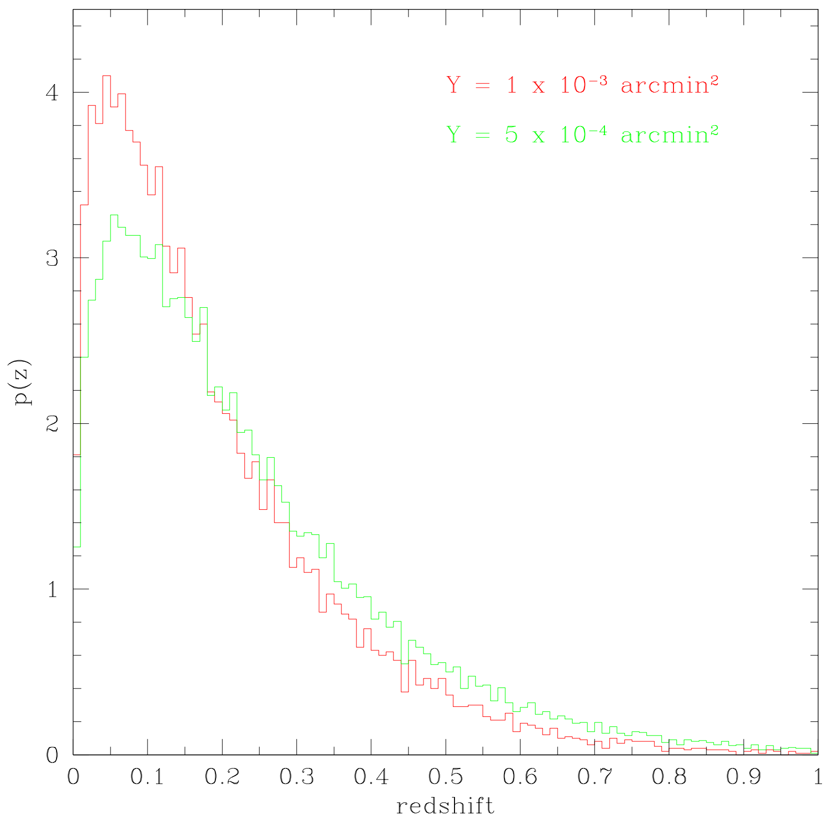


Input component maps

Recovered power spectra

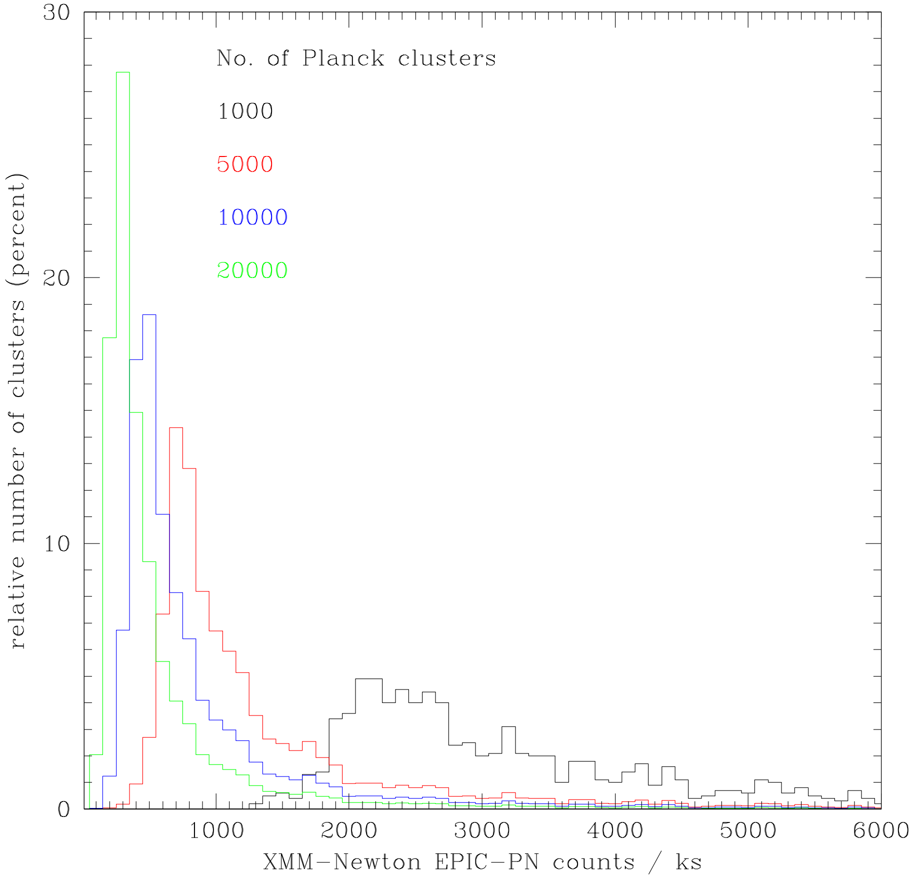

Sunyaev–Zel'dovich cluster map
y
$\log(10^{-8})$
$\log(10^{-3})$

Redshifts of Planck clusters



- Only weak dependence on exact SZ flux limit
- Most ($\sim$ 90%) clusters are at low redshift ($z < 0.5$), and nevertheless mostly unresolved
- Redshift distribution well matched to X-ray selection

Count rates of Planck clusters



- Brightest (~ 1000) SZ clusters already detected by Rosat
- Most Planck clusters too faint for RASS, but “too bright” for XMM/Chandra - snapshots ($t \ll 5$ks) would be required
- Most promising are serendipitous (or slew) surveys, still only ~ 3% percent of Planck clusters will get basic X-ray data
- X-ray information is useful for identification and localisation within the Planck beam; SZ and X-ray combination allows to separate density and temperature/velocity, to test scaling relations and hence to do cosmology
- The large survey area of DUO is ideal for combining with Planck, expect > 1500 clusters in common.

Component Separation for Large X-ray Data Sets

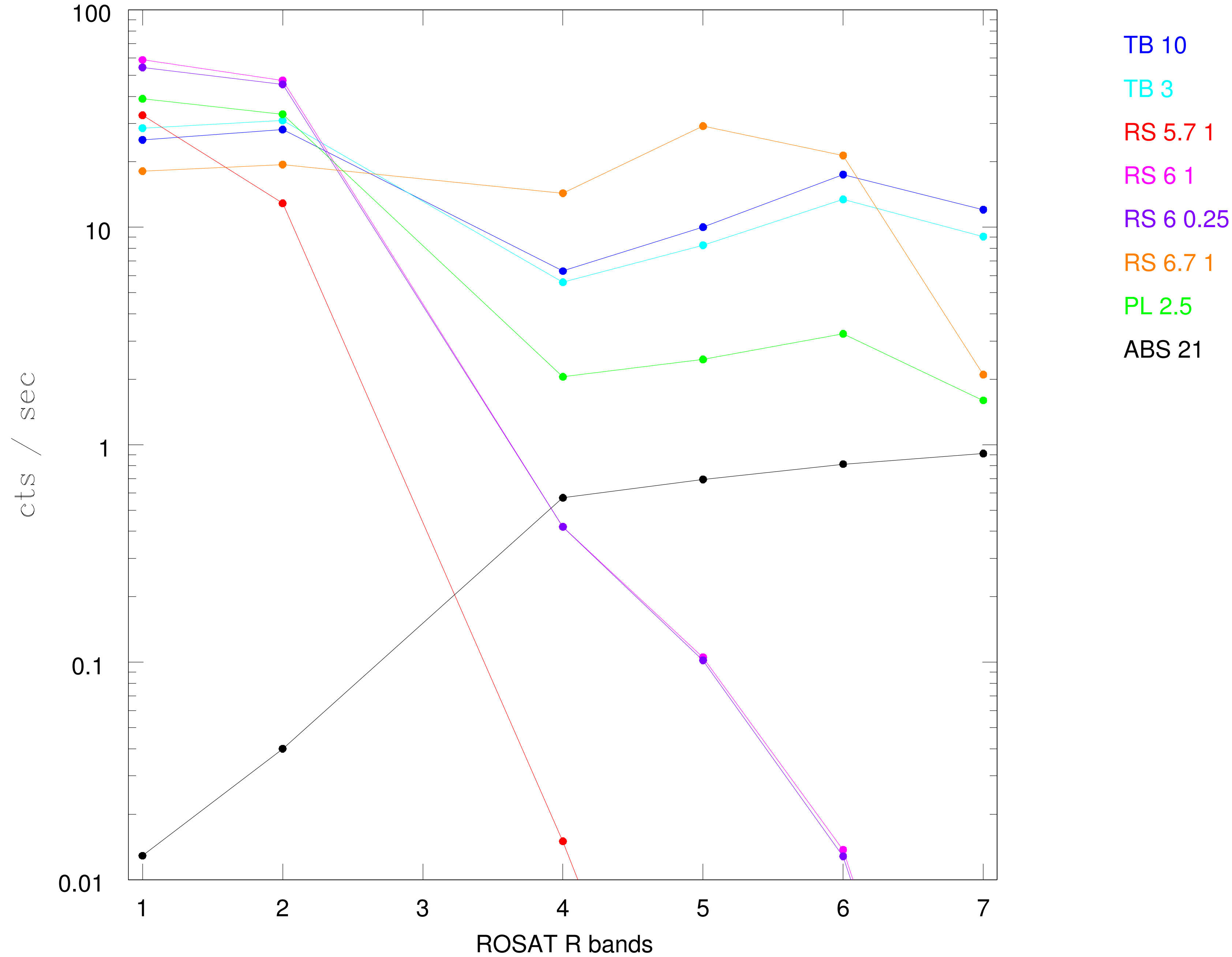
(with M. Ashdown)

- Rosat all-sky survey: R1, R2, R4, R5, R6, R7; diffuse background maps, 12 arcmin resolution

- Healpix pixelisation scheme (equal area, hierarchical, constant latitude),order 9, ’WMAP resolution’

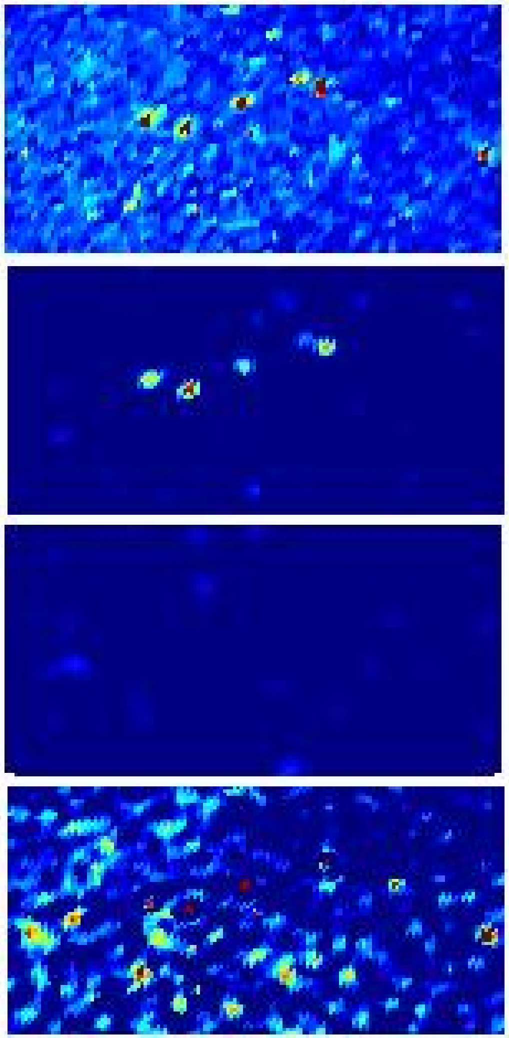
- different spectral models:
  Thermal Bremsstrahlung cluster gas, 10 (3) keV;
  XRB - AGN, power law with $\alpha = 2.5$;
  Raymond-Smith Galactic gas temperatures/metallicities;
  Absorption (Leiden/Dwingeloo, Lockman for HI)

- Maximum Entropy Method (Spherical harmonic and real space):
  - very fast technique ($\sim$ 1 hour on XEON 2.4 GHz for 3×10^6 all-sky pixels), parallelization straightforward
  - wider energy range and higher spectral and spatial resolution computationally not a problem



100
10
1
0.1
0.01
cts / sec
1
2
3
4
5
6
7
ROSAT R bands
TB 10
TB 3
RS 5.7 1
RS 6 1
RS 6 0.25
RS 6.7 1
PL 2.5
ABS 21

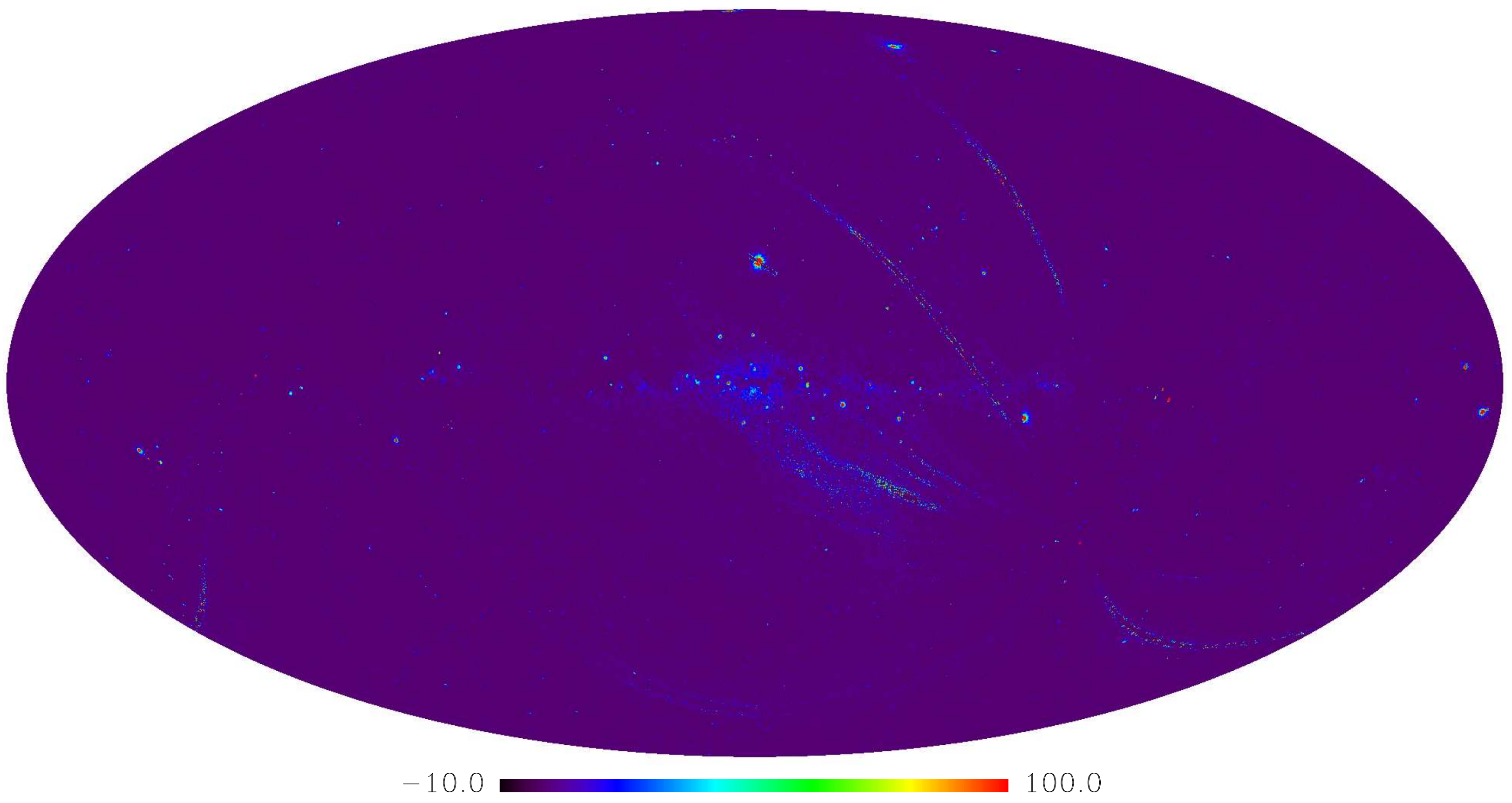
Example field from all-sky map



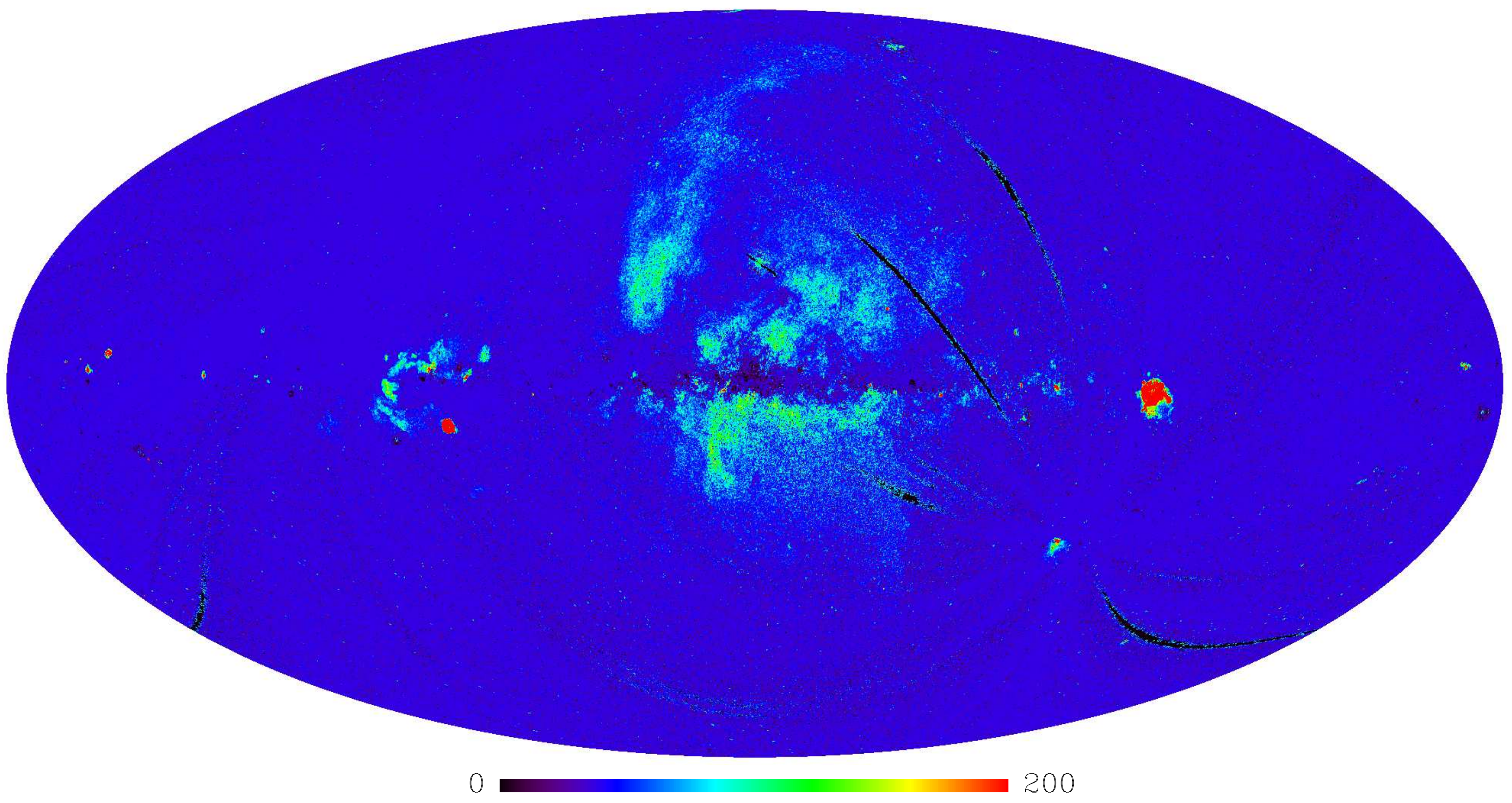
- Rosat R6
- Clusters
- XRB
- Galactic

name	l [deg]	b [deg]	ampl.
ABELL 2063	12.91	49.79	67
RXC J1521.8+0742	11.42	49.53	91
ABELL 2052	9.57	50.14	42
ABELL 2029	6.59	50.67	75
NGC 5846	0.59	48.93	44

Hot ($\sim$ 10 keV) Cluster component



Galactic ($T \sim 10^6$K) gas



Conclusions

- First SZ cluster surveys soon available
- Planck and DUO cluster selection (redshift / sky) well matched
- Combination of X-ray and SZ data beneficial
- New data analysis tools can be useful for DUO