

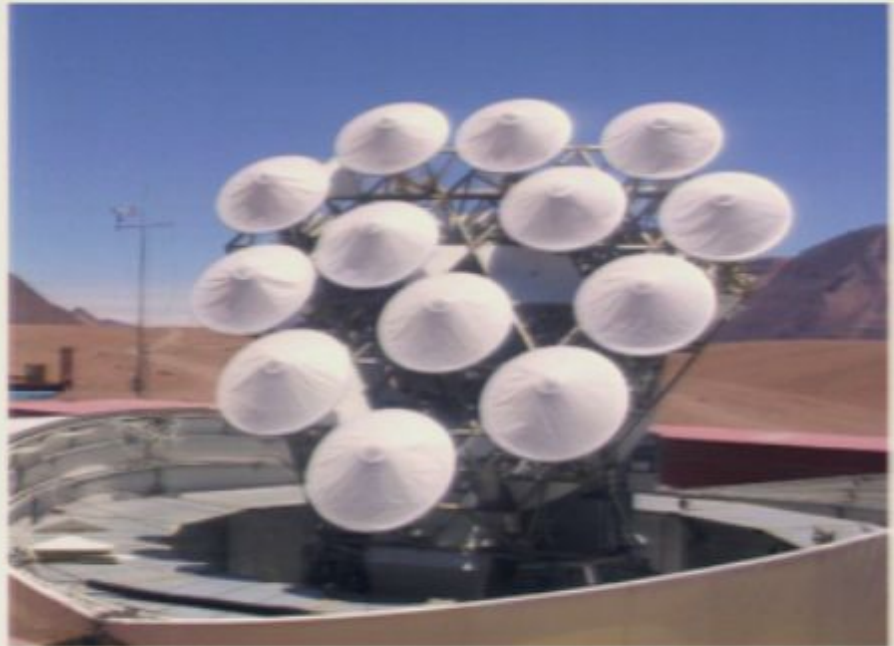
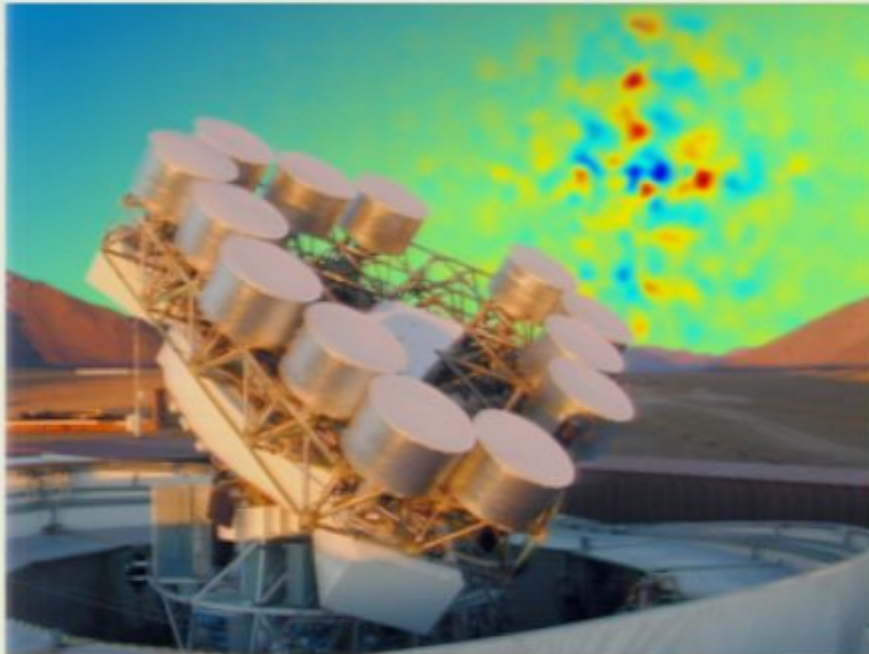
Title: Development of a 200GHz, wide-bandwidth prototype interferometer of SZ - GUBBINS

Date: Apr 29, 2009 02:45 PM

URL: <http://pirsa.org/09040058>

Abstract:

## Observations of the CMB and galaxy clusters using the Cosmic Background Imager 2

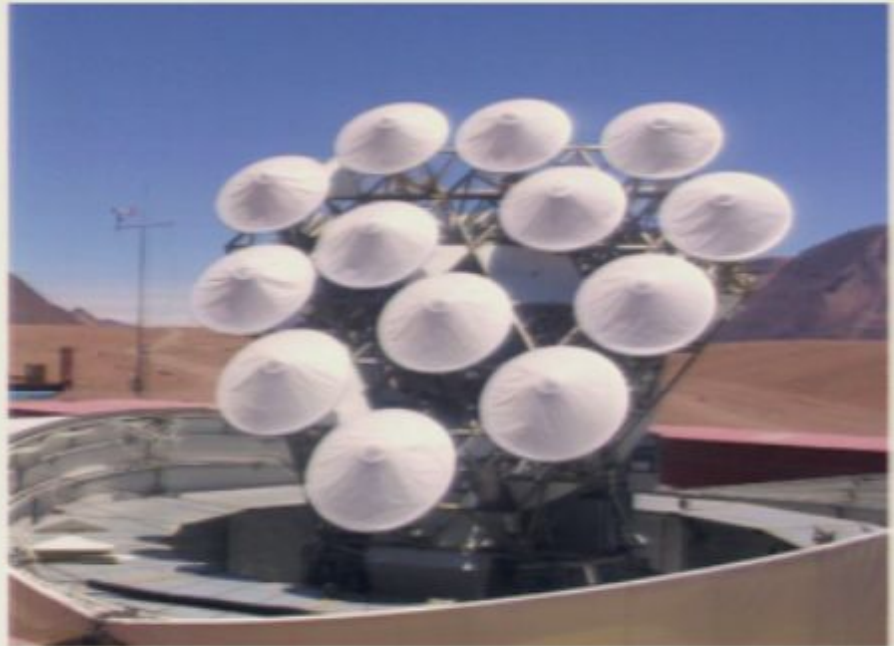
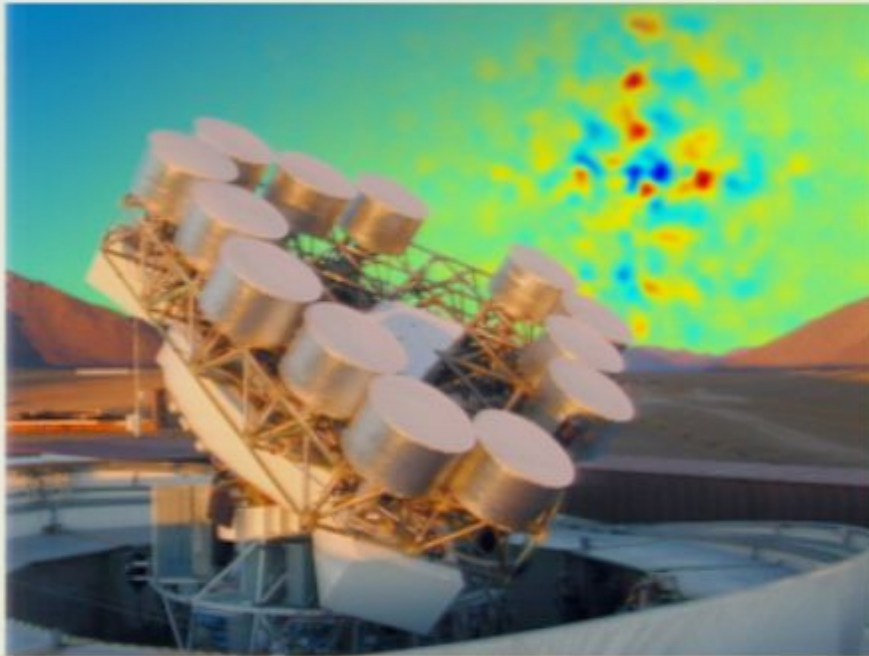


Angela Taylor

University of Oxford

+ CBI Collaboration

## Observations of the CMB and galaxy clusters using the Cosmic Background Imager 2



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## **Caltech/JPL**

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Tim Pearson  
Clive Dickinson  
Joey Richards  
Larry Weintraub  
Kieran Cleary  
Martin Shepherd

## **Oxford**

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Oliver King

## **CITA**

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Dick Bond

## **NRAO**

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## **Universidad de Chile**

Simon Cassasus  
Jorge May  
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## **Manchester University**

Richard Battye  
Scott Kay

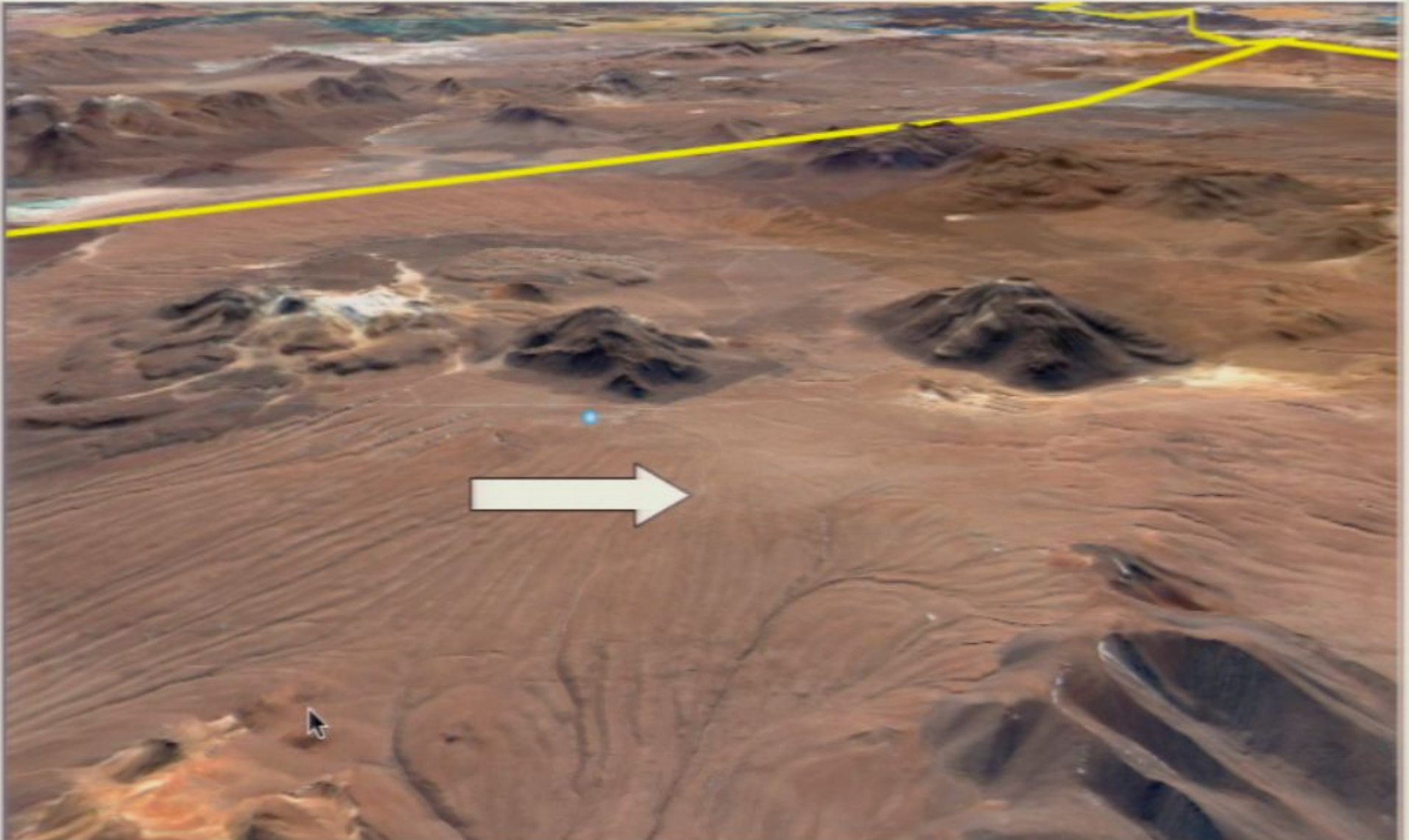
- 13 90-cm Cassegrain antennas
  - » 78 baselines
- 6-meter platform
  - » Baselines 1m – 5.51m
- 10 x 1 GHz channels 26-36 GHz
  - » HEMT amplifiers (NRAO)
  - » Cryogenic 6K,  $T_{\text{sys}}$  20 K
- Full L,R polarization capability
- Field-of-view 44 arcmin
  - » Image noise 4 mJy/bm 900s
- Resolution 4.5 – 10 arcmin
- Sited at 5080m Llano de Chajnantor, Chile



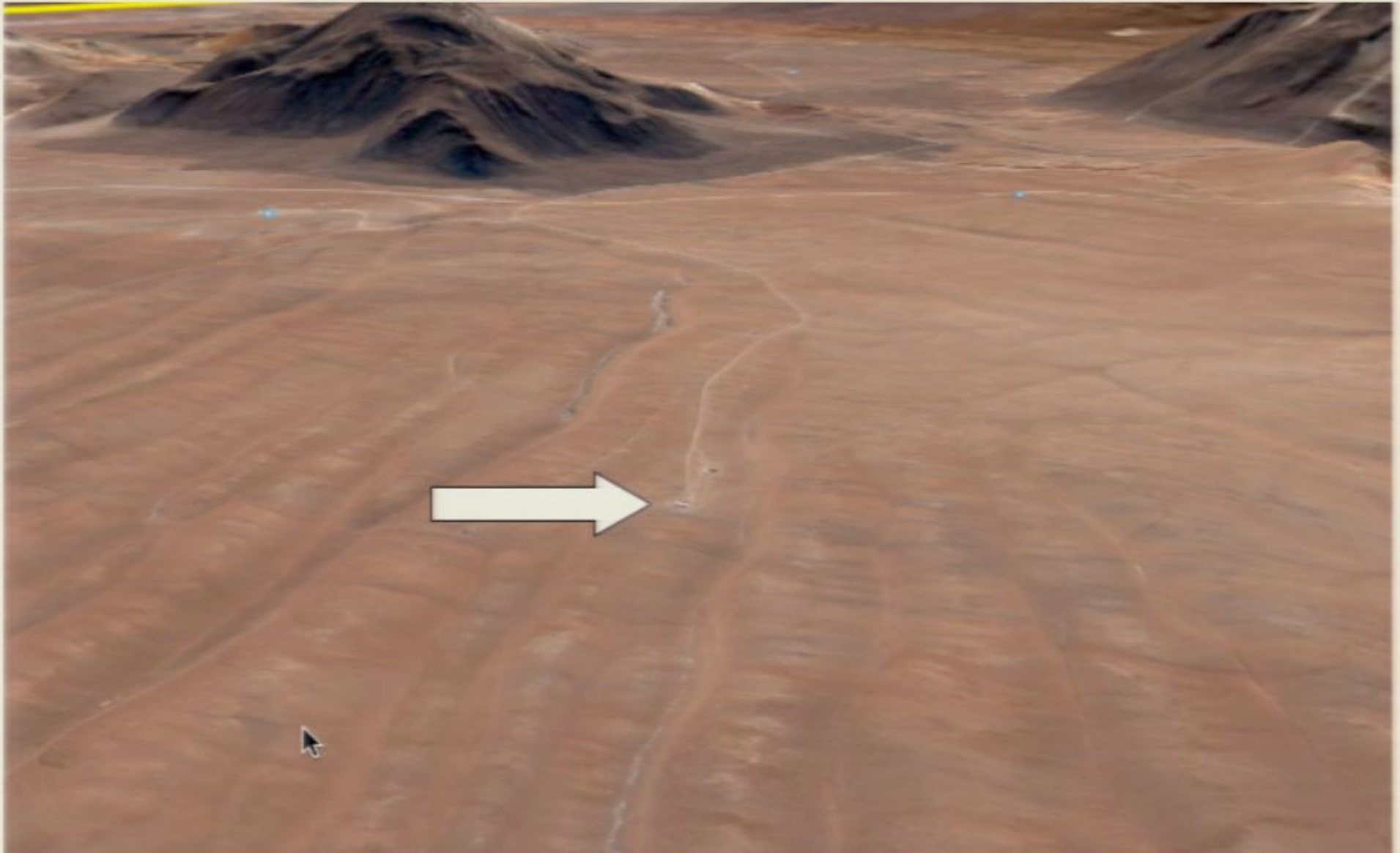
# Chajnantor Observatory









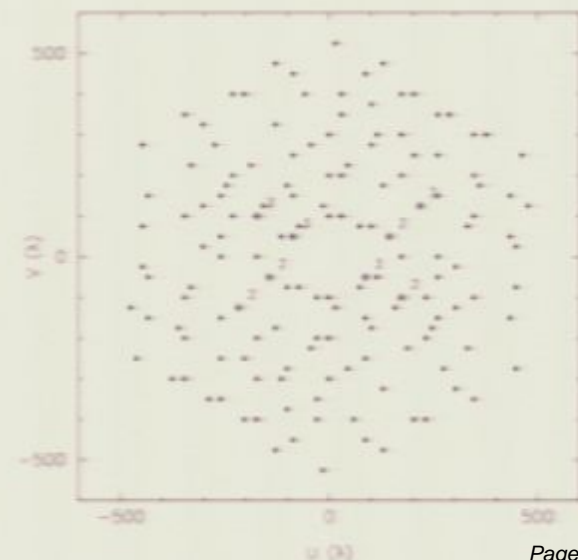
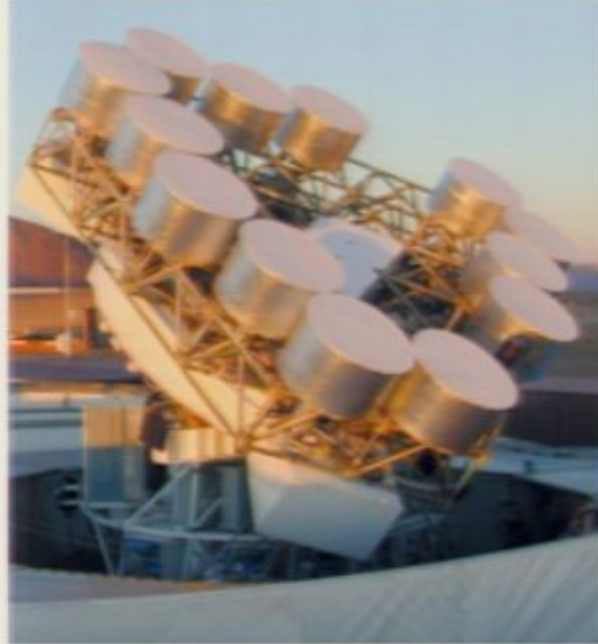




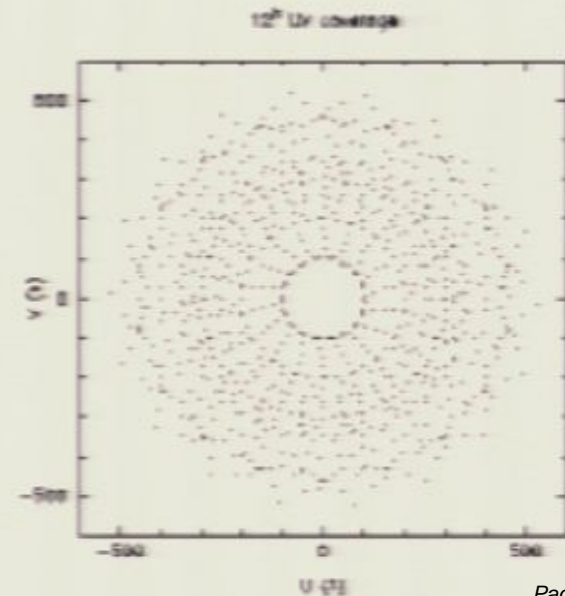


- Altitude 5100m
- Pressure 550 mbar
- Temperature -15 to 0 C
- Latitude 23 S
- PWV 1-2 mm
- Winds 5 – 50 m s<sup>-1</sup>

- CBI tracks source in RA and DEC
  - Mount rotates during the night.
    - » Tracks parallactic angle
- Antennas can be moved around the deck
  - » Long baselines = small angular scales
  - » Short baselines = large angular scales
- Fields observed in pairs or strips at same elevation
  - » allows common mode signals e.g ground pick-up to be removed



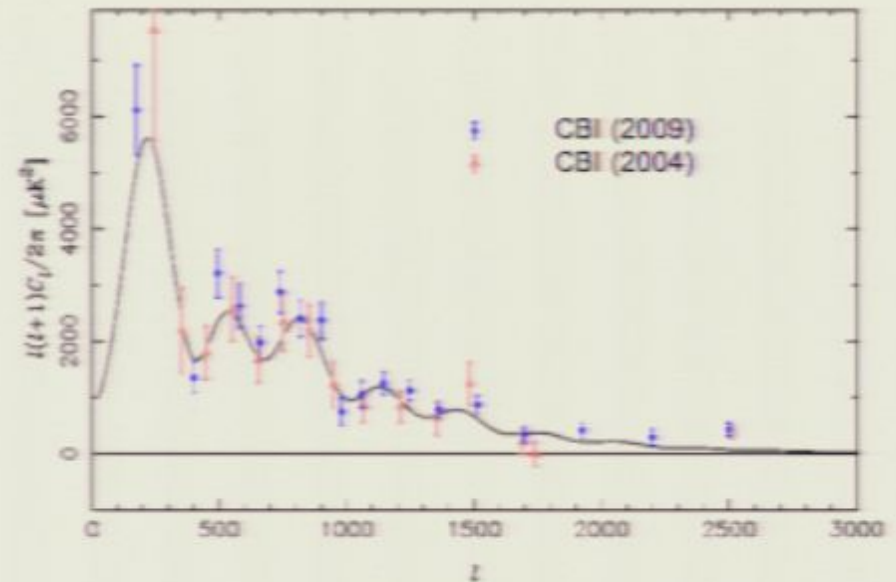
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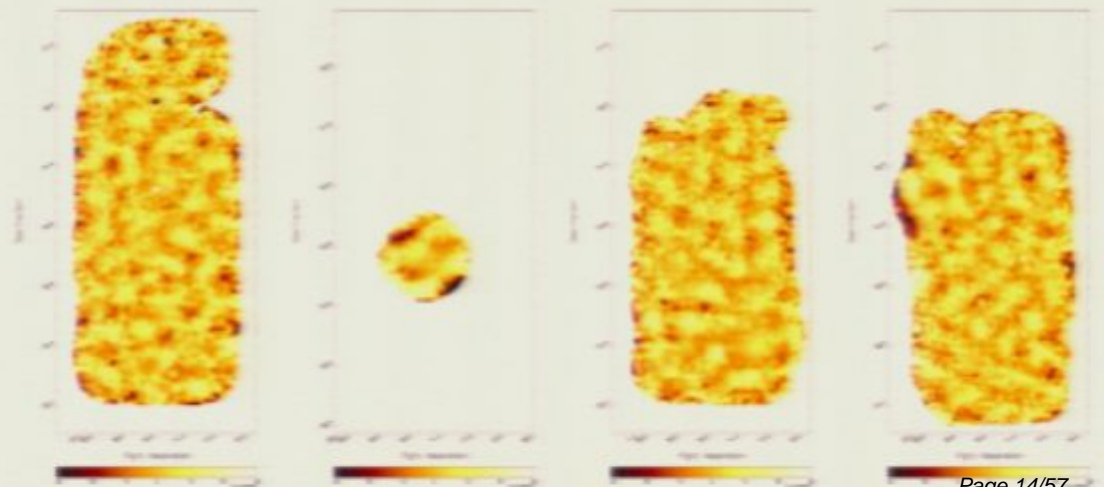
# Measurement of the high- $l$ TT power spectrum



- Data taken 2000 - 2001 (+pol data ->2005)
- 90 deg<sup>2</sup> sky observed including 3 deep pointings.
- CBI detect excess power in the CMB TT power spectrum at high- $l$  ( $l > 2500$ ).



See *Sievers et al. 2009, Readhead et al 2004, Mason et al. 2003*

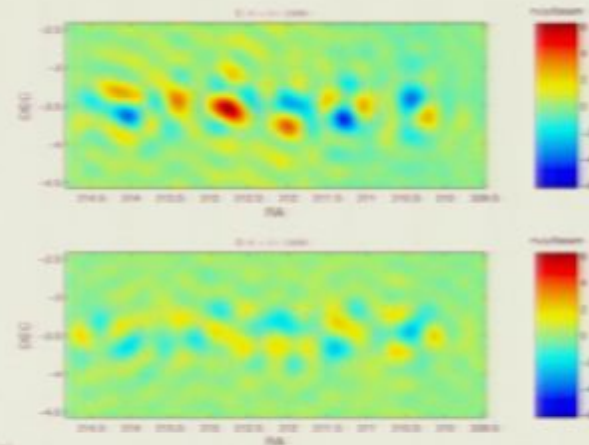
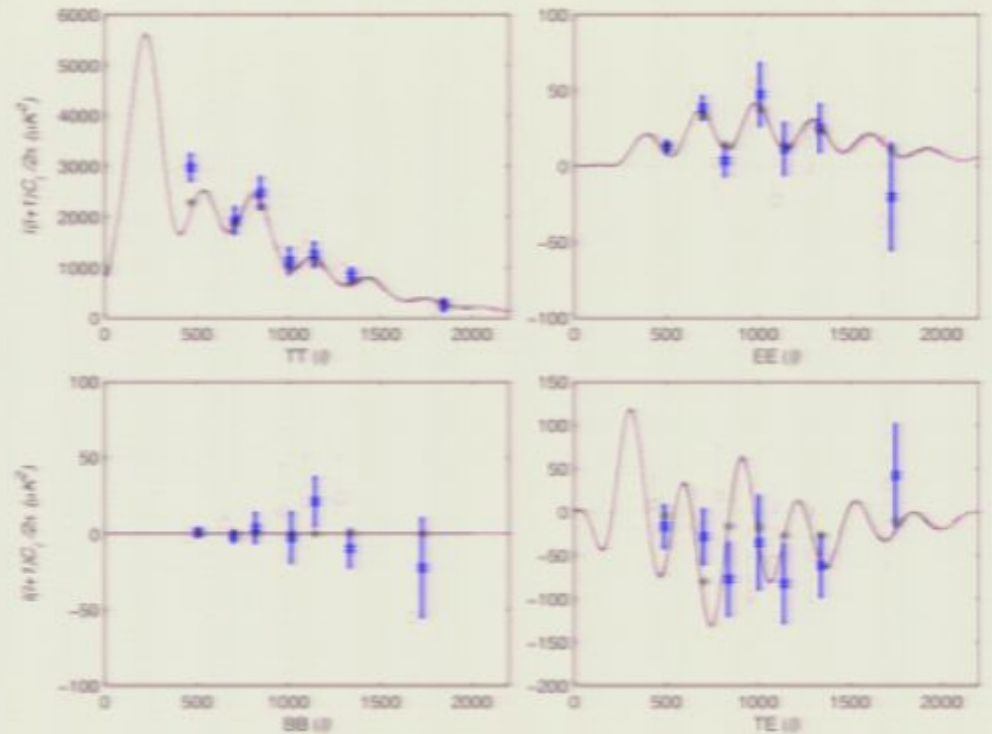
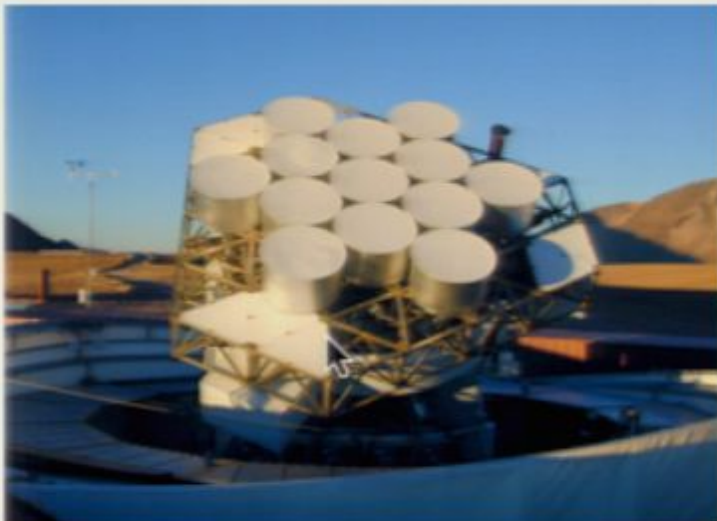


# Measurement of the EE power spectrum

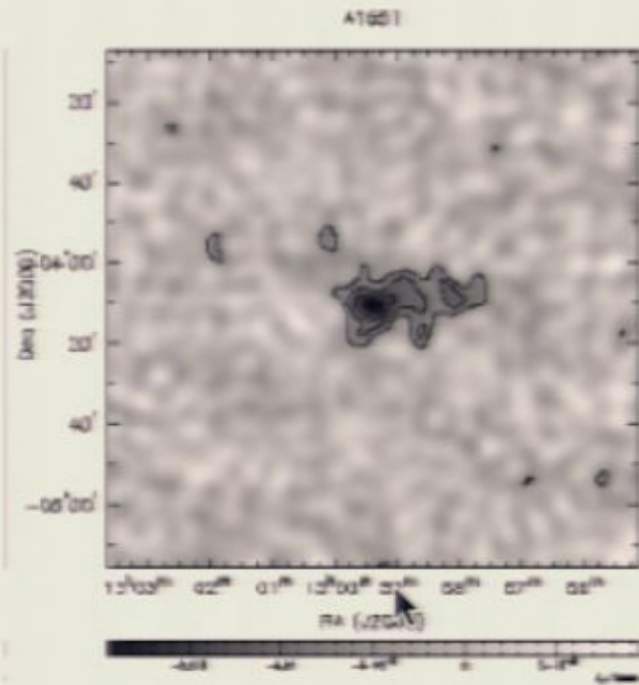


- Data taken Sep 2002 - April 2005
- 4 mosaiced fields  $\sim 64 \text{ deg}^2$  in total
- $11.7\sigma$  detection of EE power spectrum
- $4.2 \sigma$  detection of TE power spectrum
- No detection of BB (3.8uK upper limit)

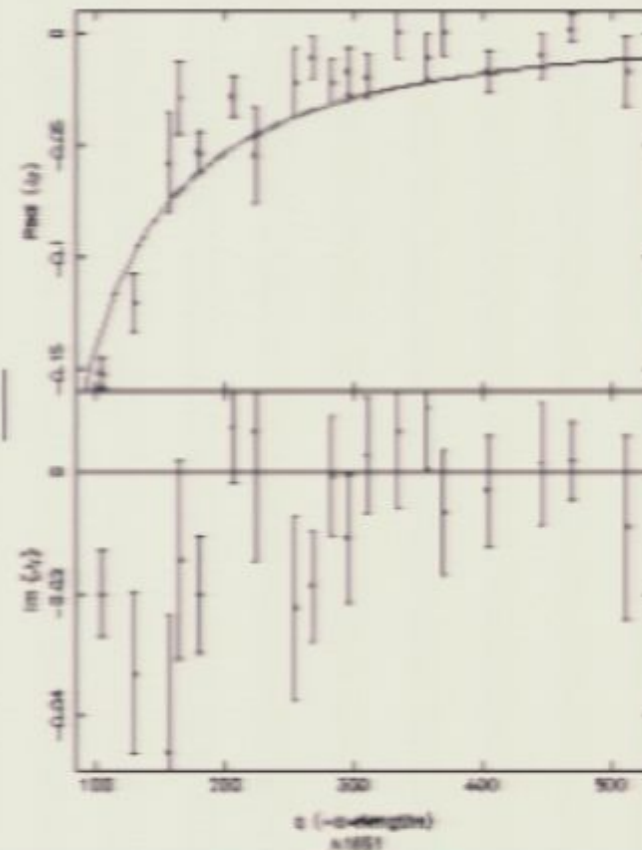
See *Readhead et al. 2004, Sievers et al 2007*



- CBI 1 sample drawn from ROSAT (Ebeling et al. 1996, 1998; de Grandi et al. 1999; Boehringer et al. 2003)
- Initial program of 15 low-redshift clusters ( $z < 0.1$ )
- Sub-sample of 7 published ( see Udomprasert et al, ApJ, 615, 2004)
- Uncertainties dominated by CMB confusion



e.g. A1651 'structure' is CMB



'scatter' in visibilities dominated by CMB





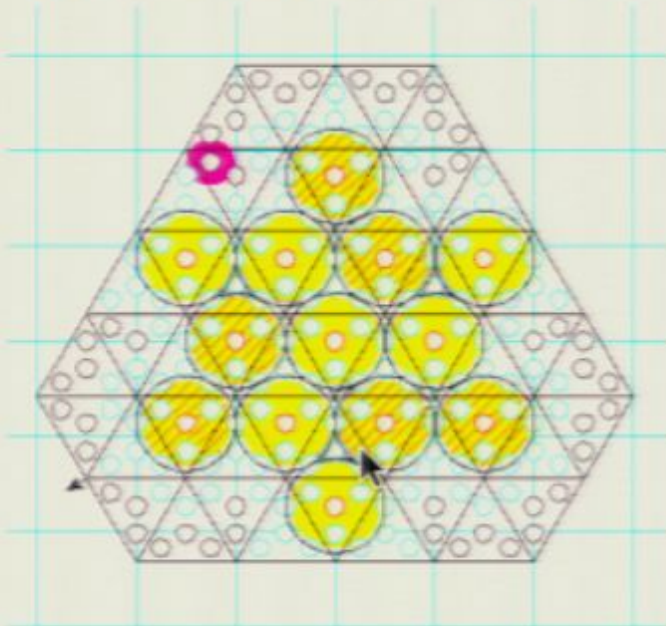
- Small dishes
  - limited filling factor at high- $l$
  - hard to get better sensitivity at  $l \sim 2500$  where the excess is
- CMB contamination of clusters on short baselines
  - exceeds thermal noise limit in short observations

Time for an upgrade.....

- March 2005 CBI 1 was turned off.
- Not the end of the story for CBI.
- Excess power still seems to exist ... possibly SZ

So what next?

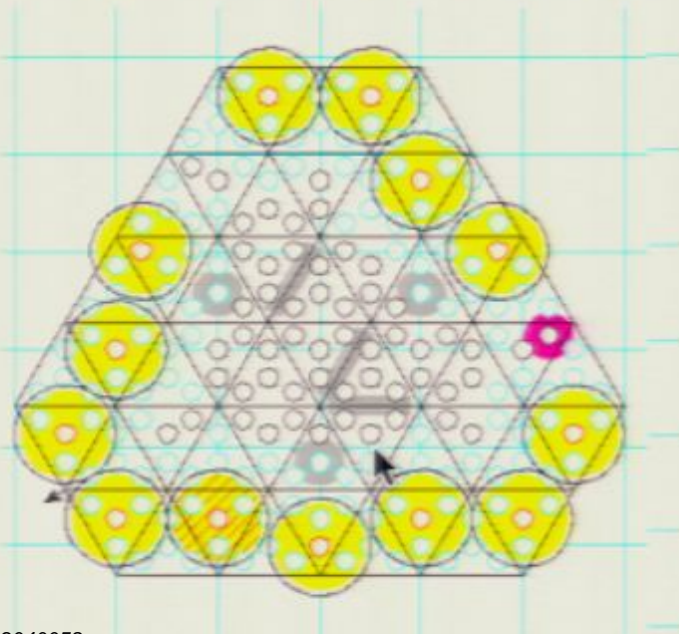
- Lots of space on the CBI deck => increase sensitivity on small angular scales



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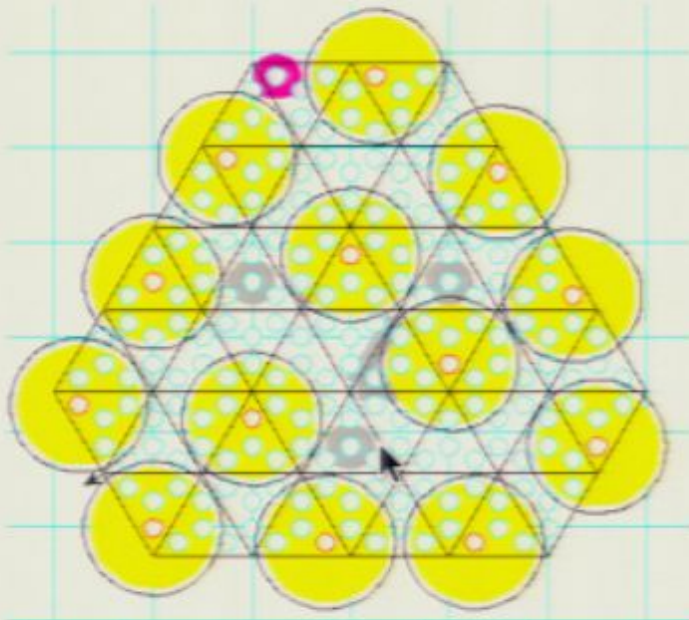


1) Push antennas to edge of table

- August 2005 CBI 1 was turned off.
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- Excess power still seems to exist ... possibly SZ

So what next?

- Lots of space on the CBI deck => increase sensitivity on small angular scales

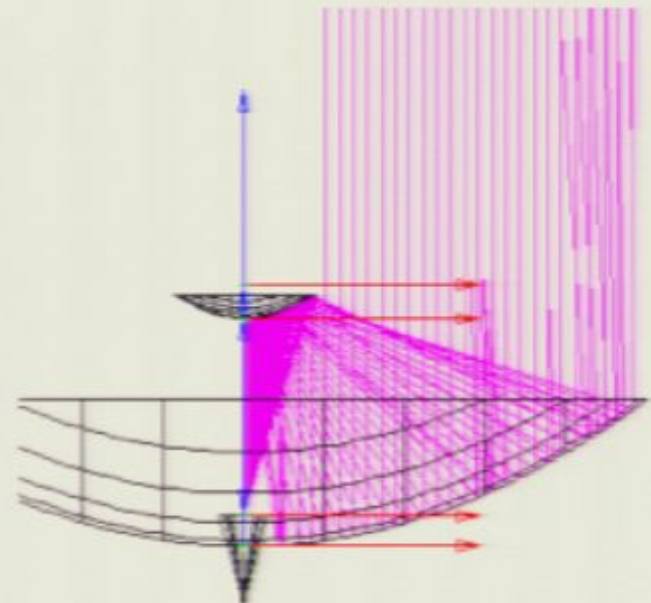
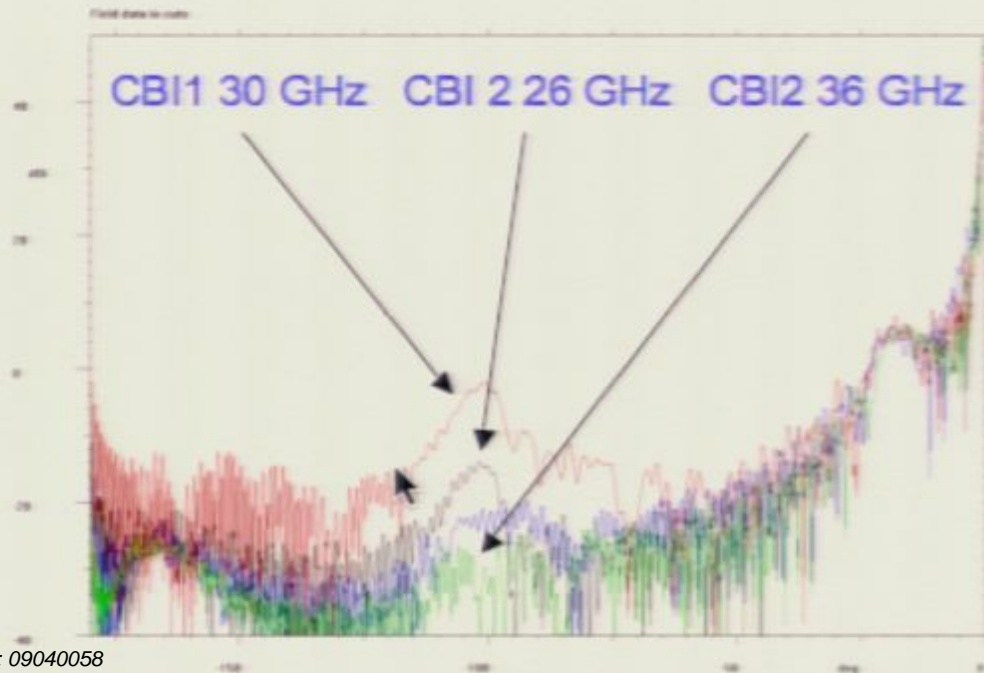


- 1) Push antennas to edge of table
- 2) Install larger antennas

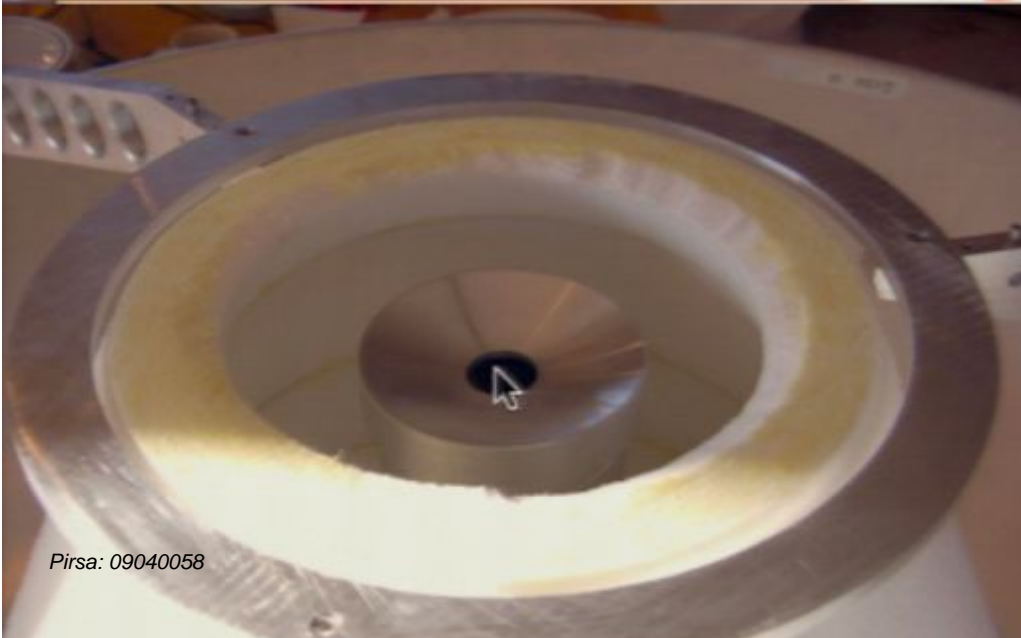
=> Good for high-l CMB

=> Reduce CMB contamination of SZ

- CBI2 – antenna upgrade to CBI
- 13 x 1.4 m antennas
- New low-spillover design
- Factor of 2 more collecting area
- FWHM 30 arcmin

















- Have observed 3 deep CMB regions
- Aim to confirm or otherwise the presence of excess power
- Investigate whether the excess is due to clusters
  - Selected regions of sky with deep data at other wavebands
  - Cross-correlate with deep optical/IR surveys (WFCAM DXS survey + others)
  - radio data (e.g. VLA), weak-lensing, XMM/Chandra

COSMOS field

RA 10h DEC +02

Subaru/XMM-Newton Deep Survey (SXDS) field

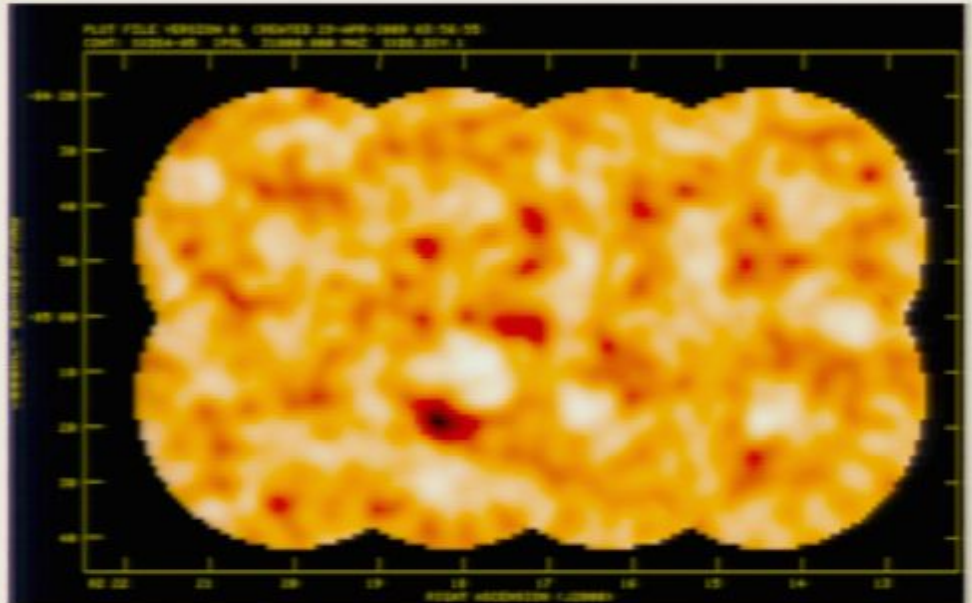
RA 02h DEC -05

VIMOS-VLT Deep Field -

RA 14h DEC +05

- Observed in strips of 4 fields
- Mosaic of 8 deep pointings in SXDF  
=> 2 deg<sup>2</sup>
- Mosaic of 4 deep pointings in VIMOS & COSMOS  
=> 2 x 1 deg<sup>2</sup>
- Data being analysed at present
- Initial analysis showing about 1 mJy/beam

Preliminary CBI2 map of SXDF field



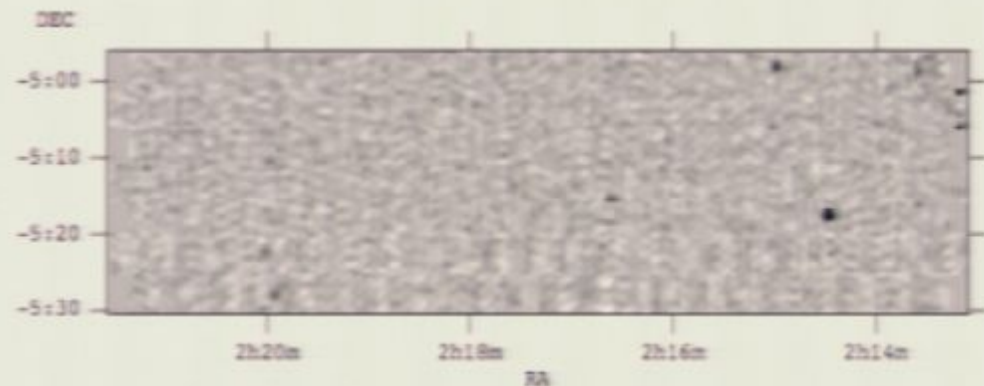
- Already deep radio data in selected fields
- E.g VLA 1.4GHz survey of SXDS field catalogue complete to  $100\mu\text{Jy}$  (Simpson et al., MNRAS, 372, 2006)
- Follow-up at 30GHz using ATCA
- In SXDS fields already have 30GHz:
  - 250 sources @ 1.3 mJy rms
  - 20 sources @  $300\mu\text{Jy}$  rms

**None detected!**

- Also survey fields simultaneously at 4.8 and 8 GHz
- Identify non-NVSS sources and follow-up at 30GHz

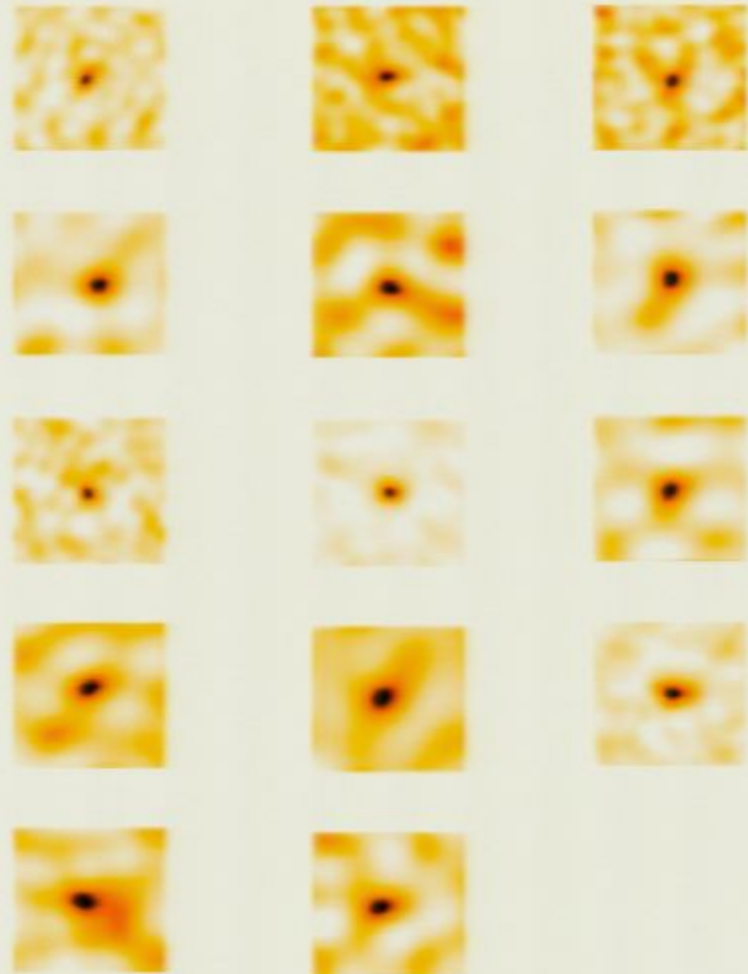


ATCA



8GHz survey of SXDF ( $\sim 600\mu\text{Jy}$  rms)

- Key program to do pointed observations of X-ray selected clusters.
- They will be used to calibrate the scaling relations between SZ and X-ray properties and investigate any evolution with redshift
- CBI2 probes clusters out to  $\sim 15$  arcmin
  - Investigate global cluster physics
  - Recover global properties and radial profiles ( $T_e$ ,  $P$ ,  $M_{\text{tot}}$ ,  $M_{\text{gas}}$ ,  $f_b$ ...)
- In total 40 clusters have been observed with CBI2, some of which are shown in the maps to the right



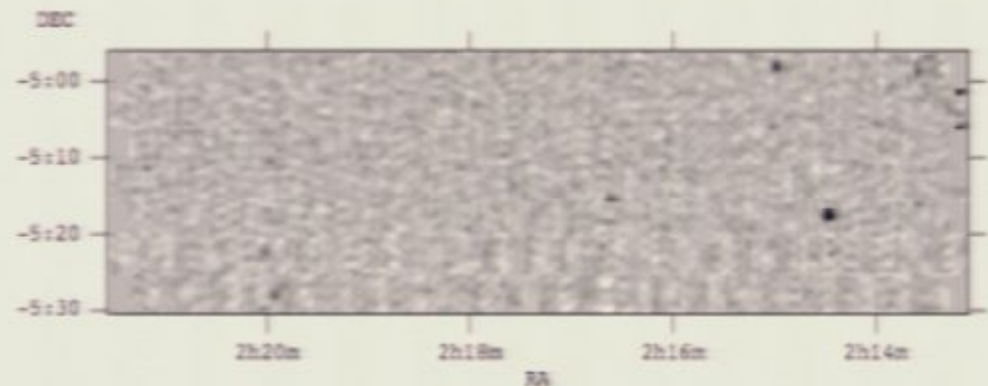
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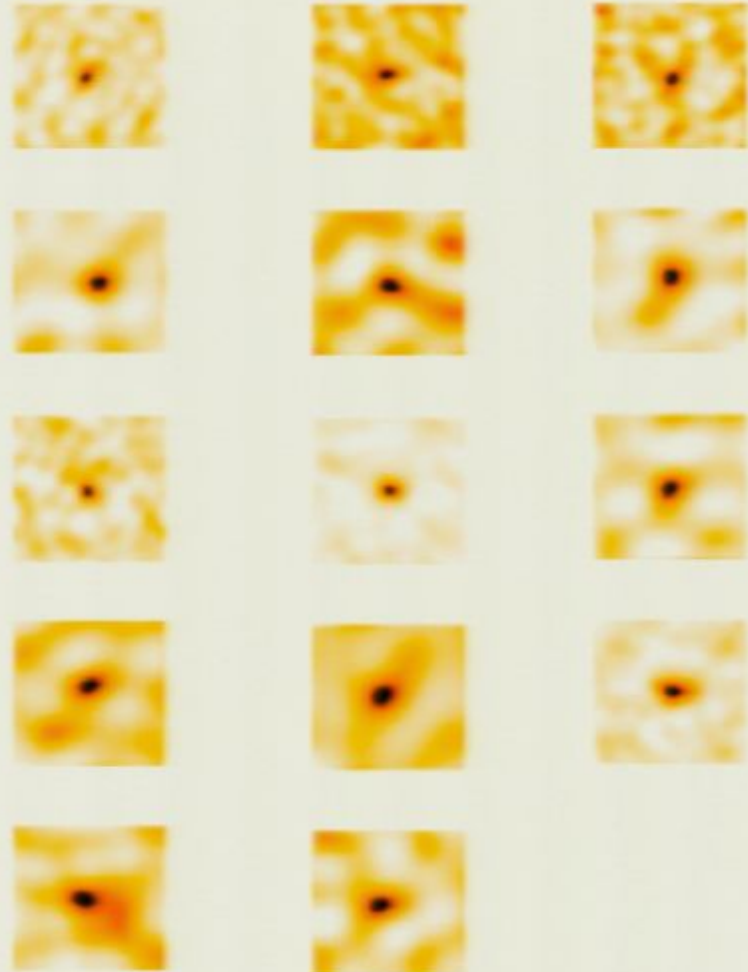


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Name	R.A.	Dec	Redshift	Lx ( $10^{44}$ )
A 1689	13:11:30	-01:20:07.00	0.1832	14.073
RXCJ2014.8-2430	20:14:50	-24:30:30.00	0.16	11.03
A 3888	22:34:31	-37:44:06.00	0.151	7.3814
A 3404	06:45:29	-54:13:08.00	0.1644	7.36
A 0901/2	09:56:26	-10:04:12.00	0.1634	6.077
A 0907	09:58:22	-11:03:35.00	0.1669	5.948
A 1084	10:44:33	-07:04:22.0	0.1342	4.899
A 3364	05:47:38	-31:18:02.00	0.1483	4.667
A 3378	06:05:53	-35:18:02.00	0.1392	4.665
A 3854	22:17:43	-35:43:34.00	0.1486	3.842
A 3856	22:18:40	-38:53:51.00	0.1411	3.781
A 2328	20:48:11	-17:50:37.68	0.1475	3.349
A 22	00:20:43	-25:42:37.00	0.141	3.232

Observed

- Flux limited sample of 33 X-ray clusters
- CBI2 observed brightest 1/3
- Lx range 3 - 14  $\times 10^{44}$  ergs<sup>-1</sup>
- Joint analysis SZ & X-ray
- Scaling relations



Name	R.A.	Dec	Redshift	$L_x$ ( $10^{44}$ )
RXCJ0658.5-5556	06:58:30	-55:57:10.00	0.2965	21.646
RXCJ0516.6-5430	05:16:35	-54:30:36.80	0.2943	13.727
A1300	11:31:56	-19:55:40.50	0.3075	13.27
RXCJ0528.9-3927	05:28:53	-39:28:16.70	0.2839	12.856
A2744	00:14:20	-30:23:15.40	0.3066	12.787
RXCJ2308.3-0211	23:08:23	-02:11:32.10	0.2966	10.174
RXCJ0232.2-4420	02:32:19	-44:20:51.90	0.2836	8.875
RXCJ0437.1+0043	04:37:10	00:43:53.50	0.2842	8.8629
A2631	23:37:38	00:16:15.50	0.2753	7.42
A2813	00:43:24	-20:37:31.20	0.2942	7.387
RXCJ0303.7-7752	03:03:47	-77:52:39.00	0.2742	6.953
A3088	03:07:02	-28:39:55.20	0.2578	6.675
RXCJ0532.9-3701	05:32:56	-37:01:35.50	0.2747	6.525

Observed



- Volume limited subset of REFLEX sample
- CBI2 can observe all but 1 ( dec -77)
- $L_x$  range  $6.5 - 21 \times 10^{44}$  erg  $s^{-1}$  (0.1 – 2 keV)

Name	R.A.	Dec	Redshift	Lx (10 <sup>44</sup> )
RXJ1346.5-1145	13:47:31.0	-11:45:11.00	0.45	54.1
A2390	21:53:37.0	17:41:45.00	0.232	25.2
A2163	16:15:49.4	-06:09:00.00	0.203	23.2
MS0451.6-0305	04:54:10.0	-03:01:07.00	0.537	20.7
A1835	14:01:02.0	02:52:43.00	0.253	16.6
MS0015.9+1609	00:18:33.3	16:26:36.00	0.541	22.8
A520	04:54:19.0	02:56:48.0	0.199	14.5
A1689	13:11:29.5	-01:20:10.00	0.1832	14.1
A2204	16:32:47.0	05:34:33.00	0.152	7.9
ZW3146	10:23:38.8	04:11:20.4	0.29	5.7

- In collaboration with Sarah Church, Stanford
- SuZie observes at 150, 220, 270, 350 GHz
- Combined CBI2/SuZie analysis
- Improve SZ spectra
- Improve peculiar velocities



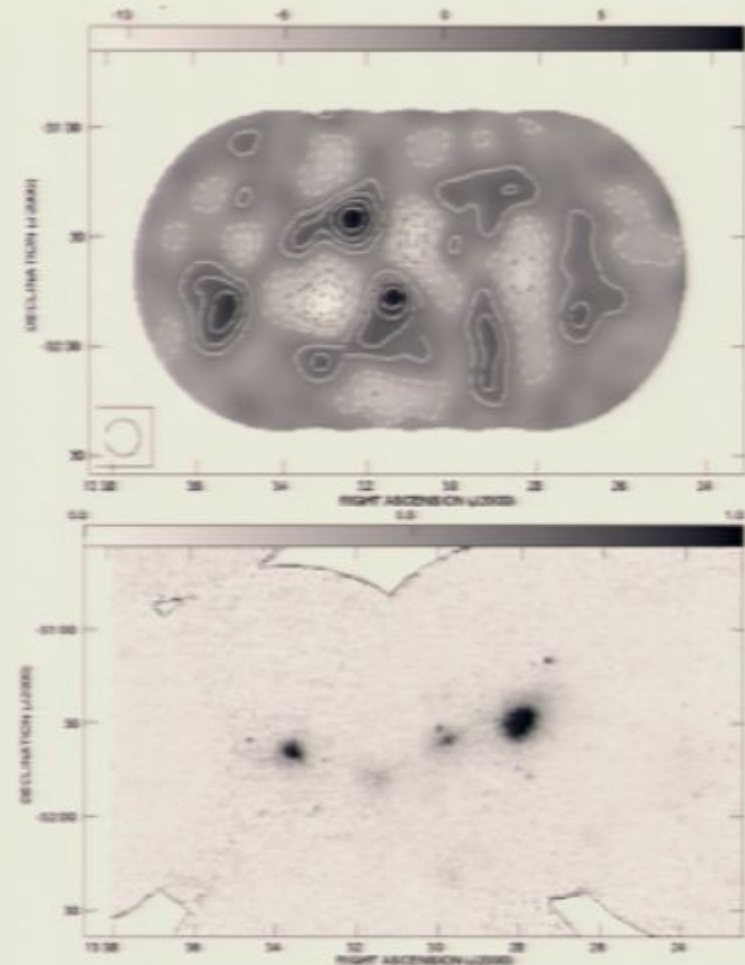
Name	R.A.	Dec	Redshift	$L_x$
RXJ1347-1145	13:47:31	-11:45:11.0	0.4516	54.1
RXJ1206-0848	06:12.5	-08:48:22	0.4414	25.3
RXJ2228.5+2036	22:28:34.0	20:36:47	0.412	25
MS0015.9+1609	00:18:33.3	16:26:36	0.541	22.8
MS0451.6-0305	04:54:10	-03:01:07	0.537	20.7

Observed

- Complete X-ray flux limited sample
- Bright, distant clusters
- $L_x$  range 20 – 55  $\times 10^{44}$  erg  $s^{-1}$  (0.1 – 2 keV)
- Completes redshift range from 0.15 to 0.5

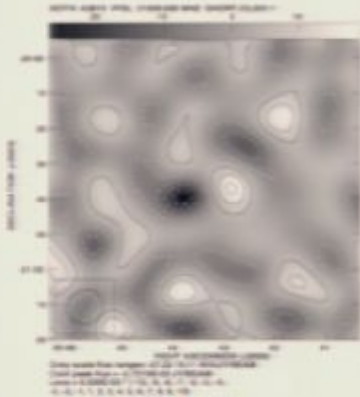


- In addition to the above samples, CBI1 and CBI2 have observed interesting individual SZ candidates
- These include
  - The Shapley supercluster
  - XMMU J2235.2577 ( $z=1.393$ ) high redshift SZ candidate
  - 2df 1435+008, a possible lensed quasar pair
- Aim to combine CBI1 and CBI2 data

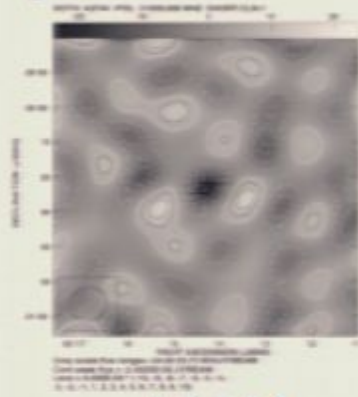


Shapley supercluster  
CBI-SZ (top) and X-ray(bottom)

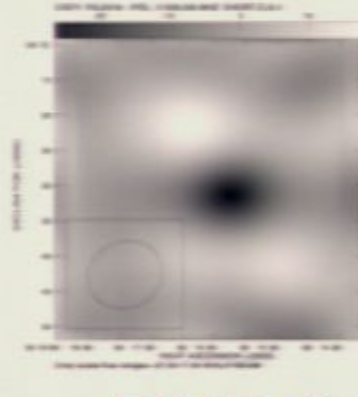
- Starting analysis of 11 clusters from the REFLEX-DXL sample
- Short-baseline maps:



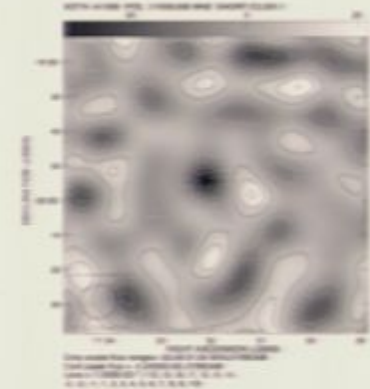
A2813



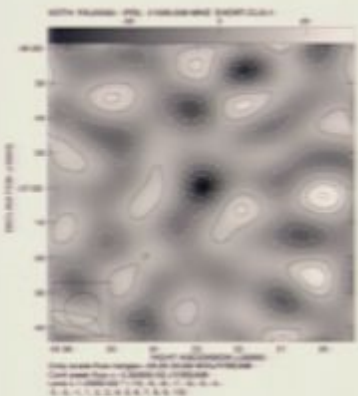
A2744



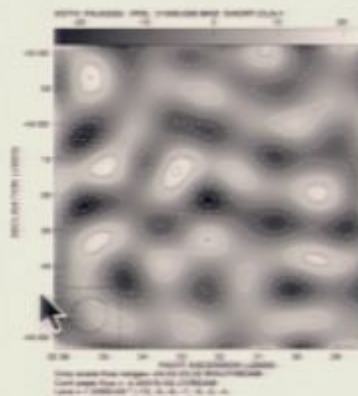
RXJ0516



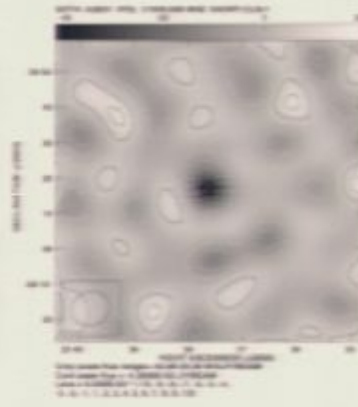
A1300



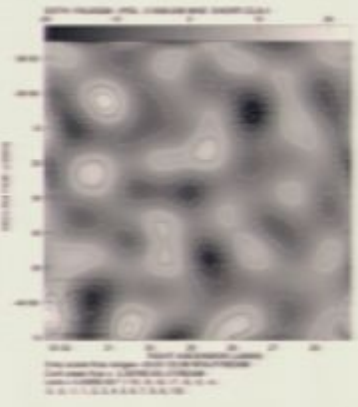
RXJ0532



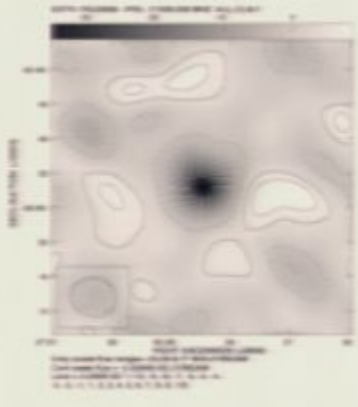
RXJ0232



A2631

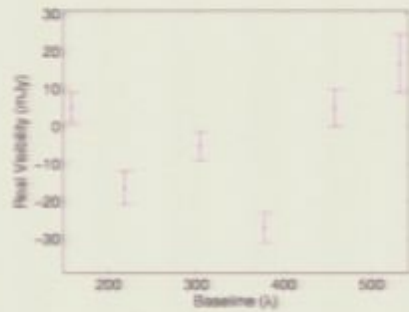


RXJ0528

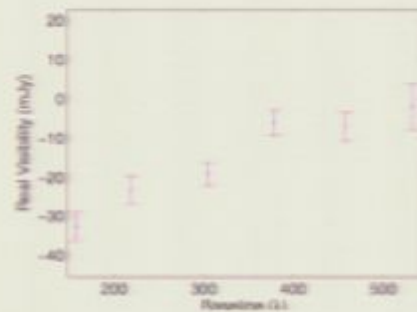


Bullet

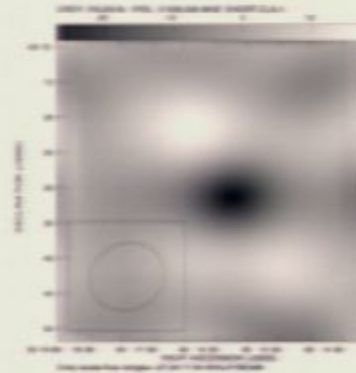
- Visibility profiles for clusters



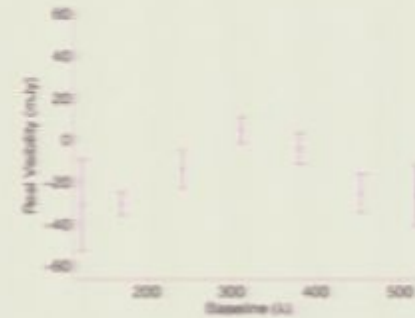
A2813



A2744

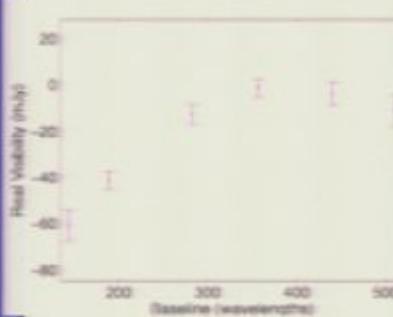


RXJ0516

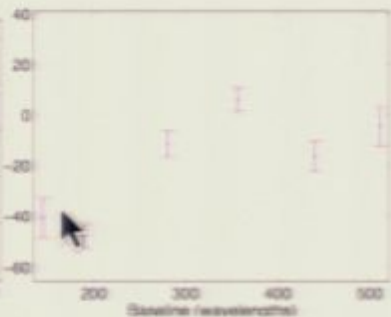


A1300

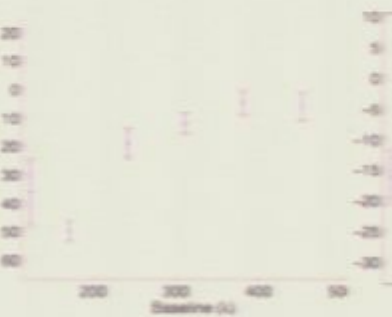
(cluster offset from centre)



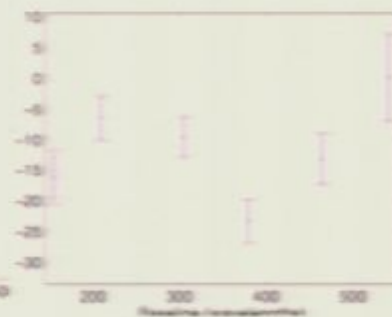
RXJ0532



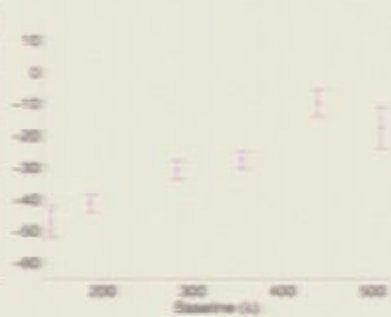
RXJ0232



A2631

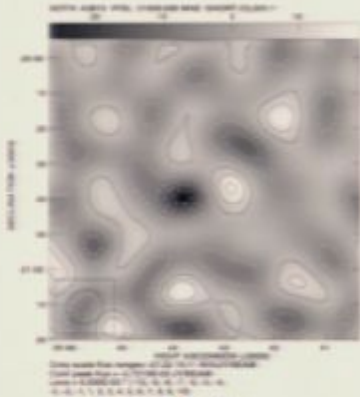


RXJ0528

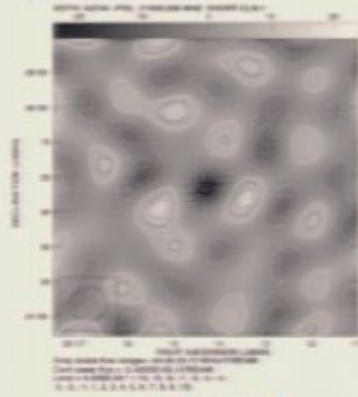


Bullet

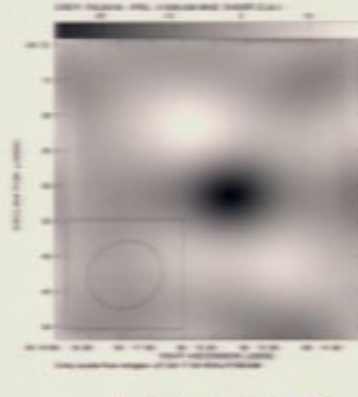
- Starting analysis of 11 clusters from the REFLEX-DXL sample
- Short-baseline maps:



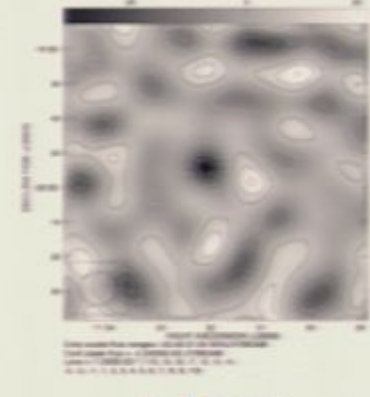
A2813



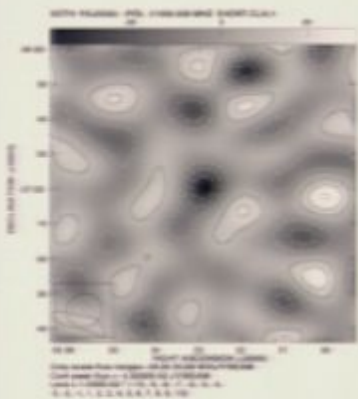
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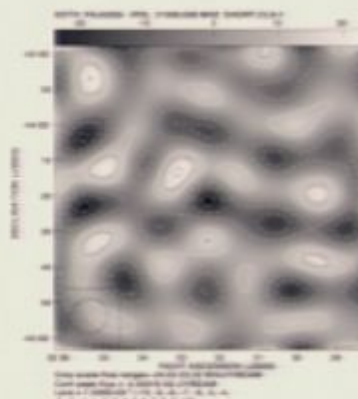
RXJ0516



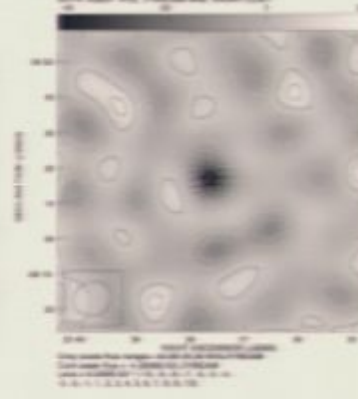
A1300



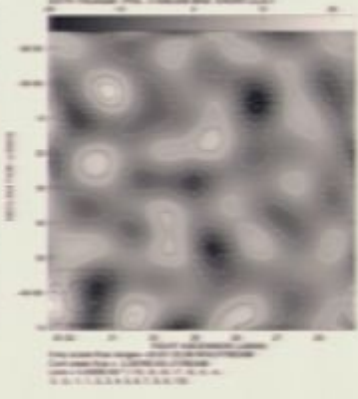
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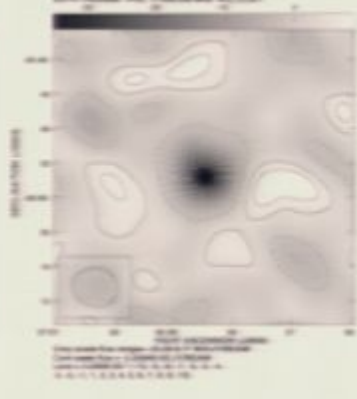
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A2631



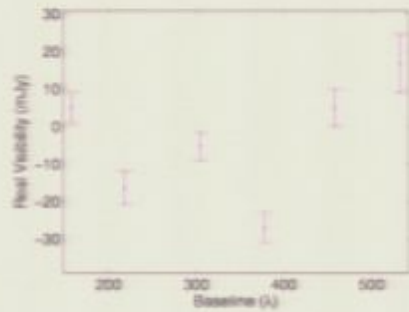
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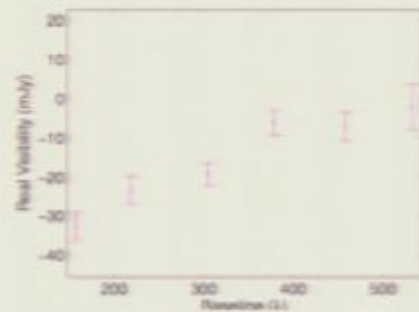
Bullet



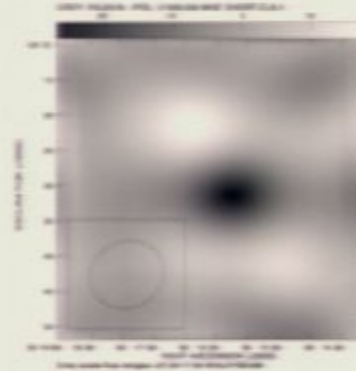
- Visibility profiles for clusters



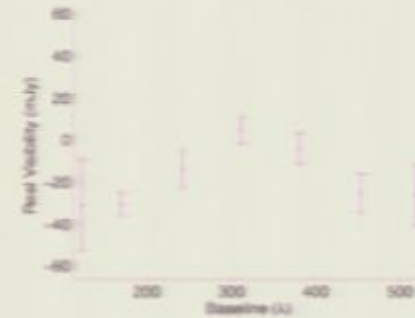
A2813



A2744

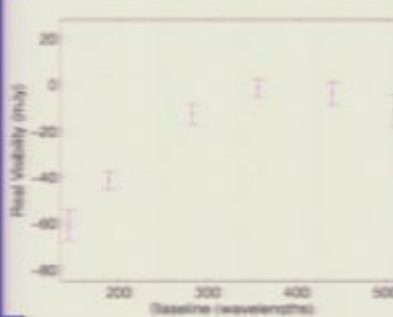


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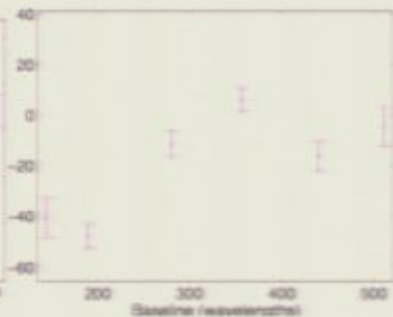


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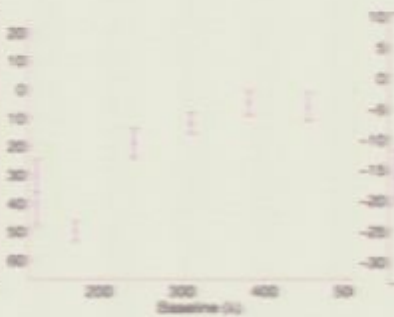
(cluster offset from centre)



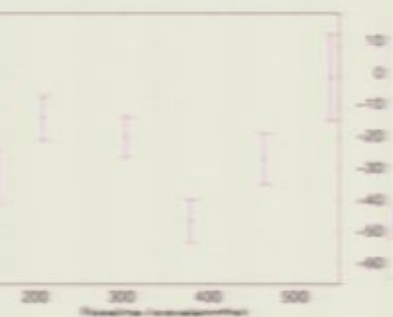
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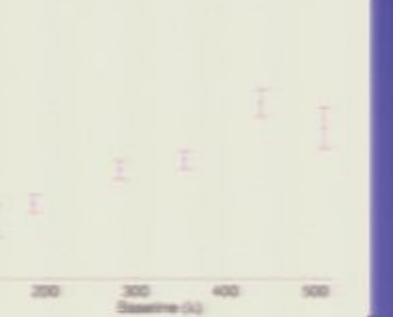
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A2631

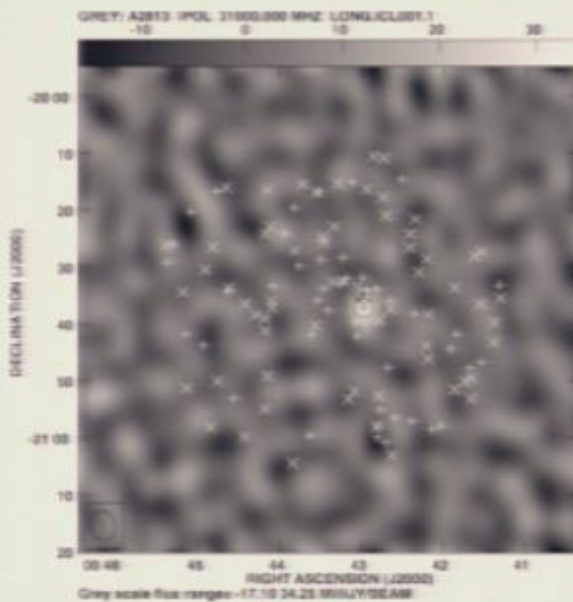


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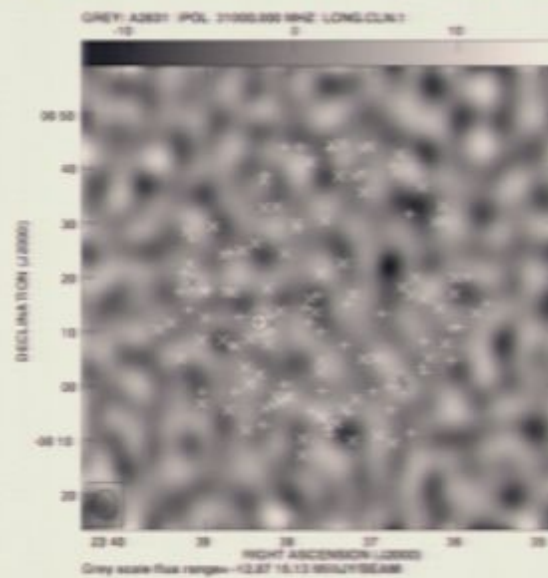


Bullet

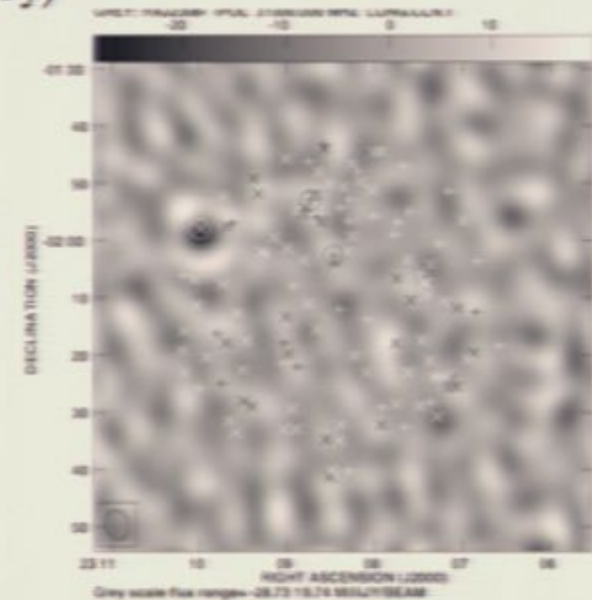
- As for CMB analysis, radio sources can be projected or subtracted during visibility analysis
- Lead-main-trail strategy means we have +ve and -ve sources to deal with.
- Observe all NVSS/SUMSS radio sources within primary beam at 30GHz using ATCA
- Also mosaic field centres at 8GHz and 4GHz (rms~ 600uJy)



A2813



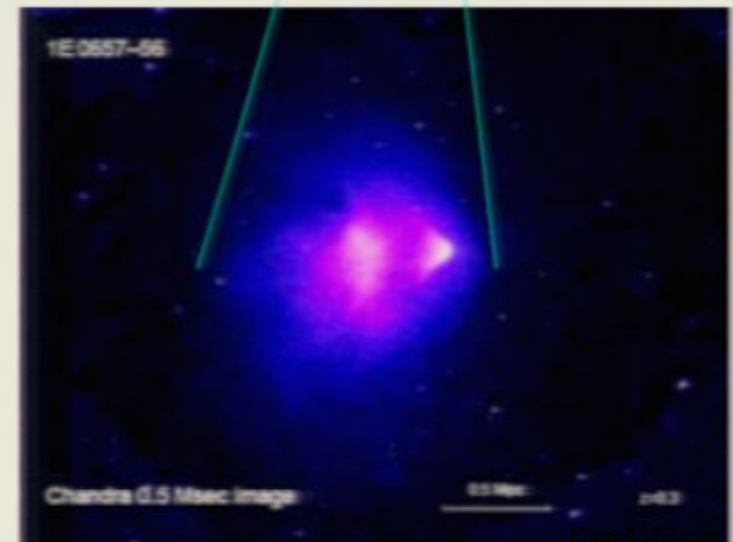
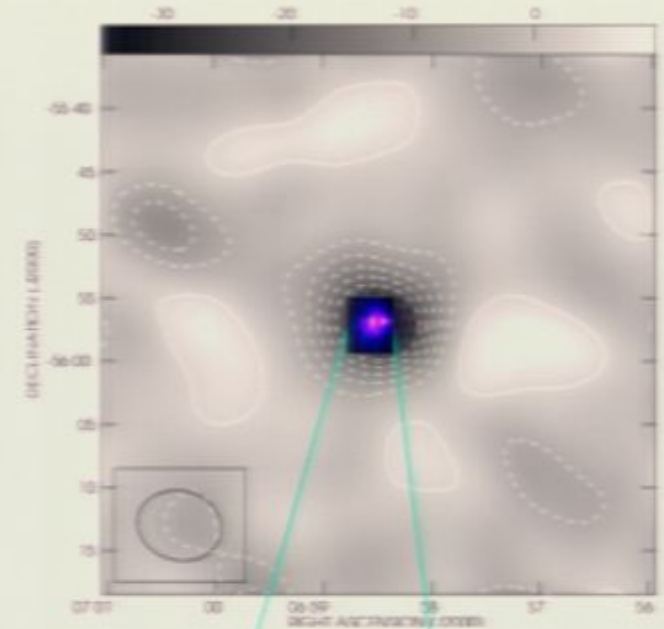
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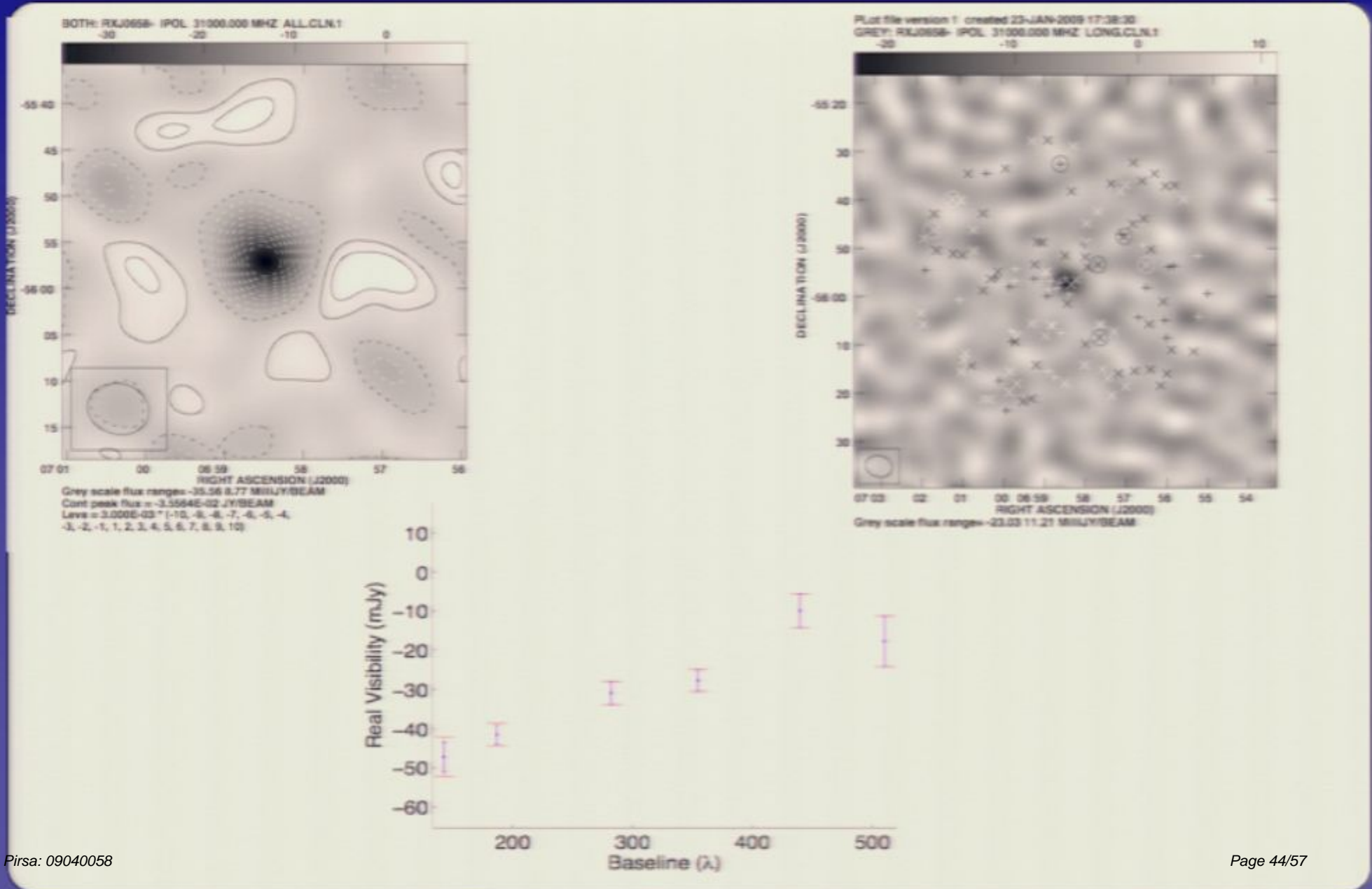


RXJ2308

- + positive source in main field
- X negative source in lead/trail field
- O Detected by ATCA @ 30GHz (rms 1mJy)

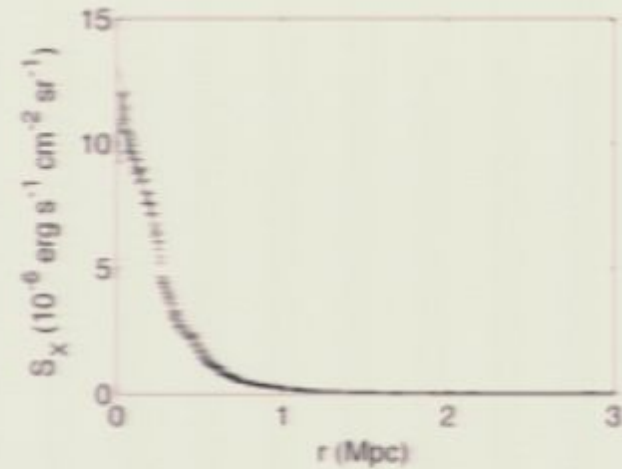
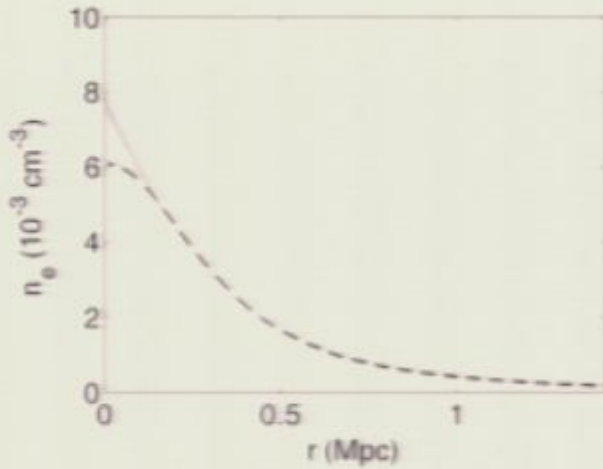
- ‘The Bullet’ – supersonic merger ( $M \sim 3$ )
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- CBI2 sensitive on scales of  $r_{200}$ :
  - »  $2r_{200} \sim 18$  arcmin
- Use model described by James Allison to recover global and radial properties.
- (Preliminary) analysis: SZ plus X-ray:
  - gas in hydrostatic equilibrium
  - dark matter NFW
  - gas entropy power law with core
  - full covariance matrix including CMB, sources for likelihood
  - BayeSys for exploring posterior



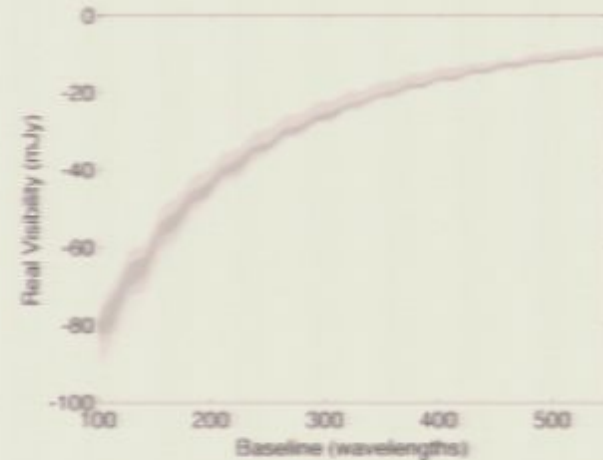
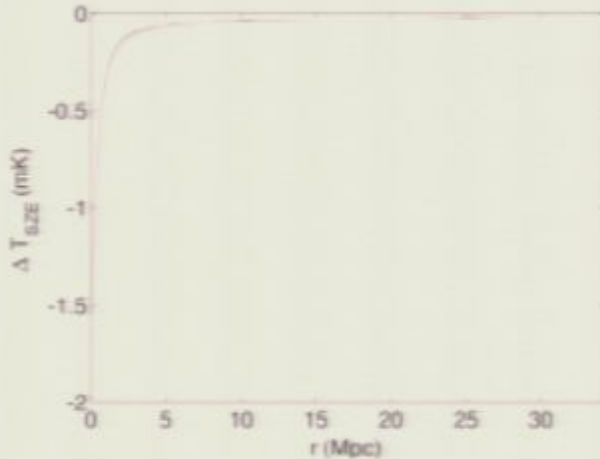


**!! HEALTH WARNING - VERY PRELIMINARY RESULTS !!**

X-Ray



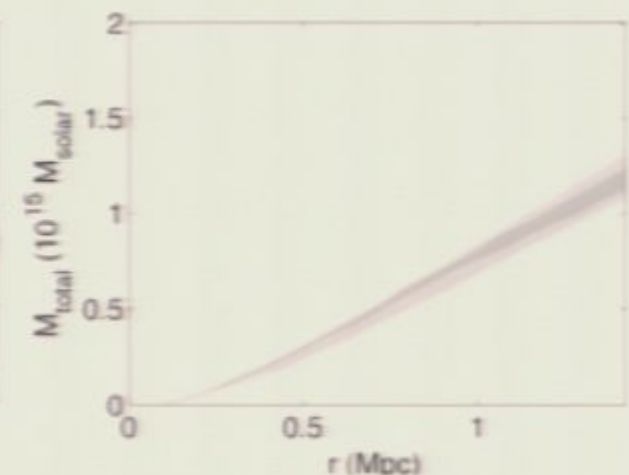
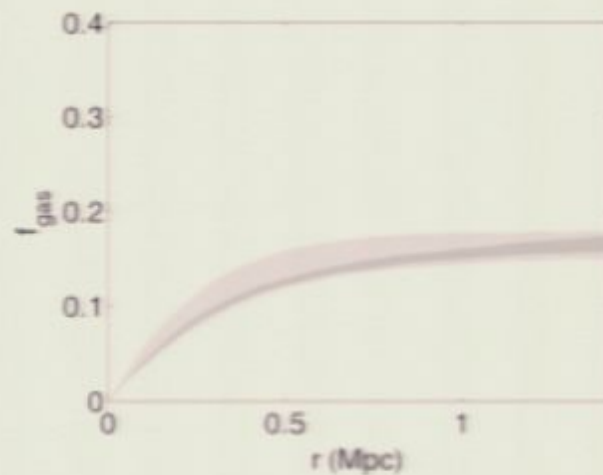
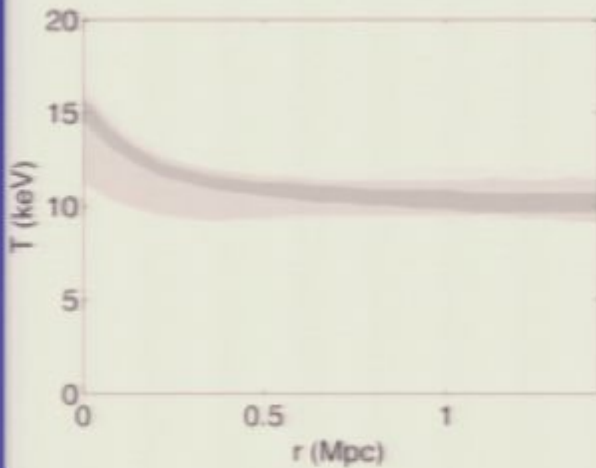
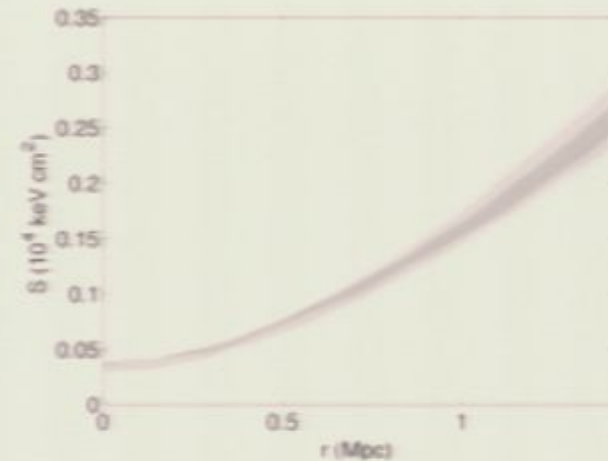
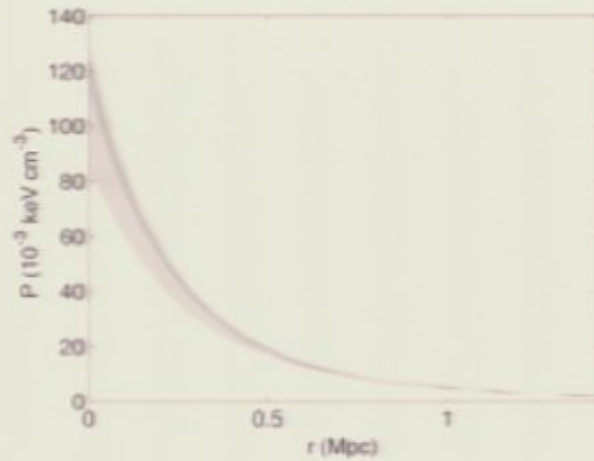
SZ



# Derived cluster properties



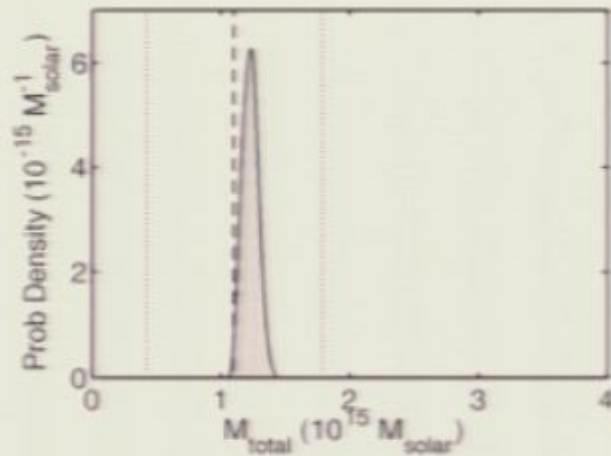
**!! HEALTH WARNING - VERY PRELIMINARY RESULTS !!**



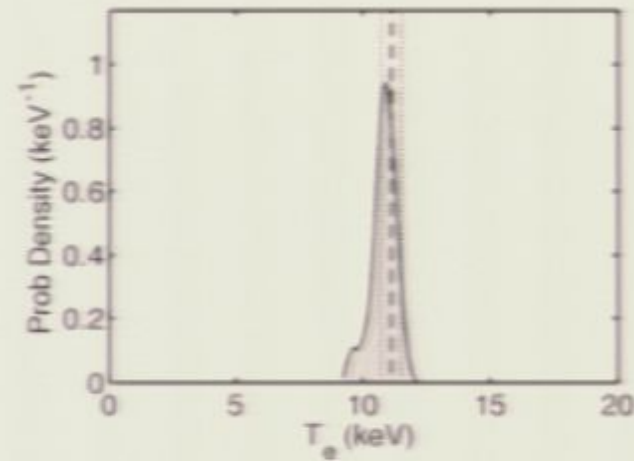
Pirsa: 09040058 Plotted out to 1.5Mpc = r500 (for comparison with Xray)

**!! HEALTH WARNING - VERY PRELIMINARY RESULTS !!**

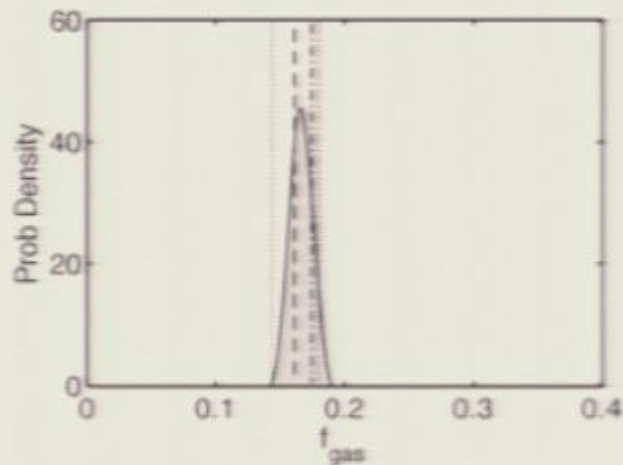
$M_{\text{total}}$



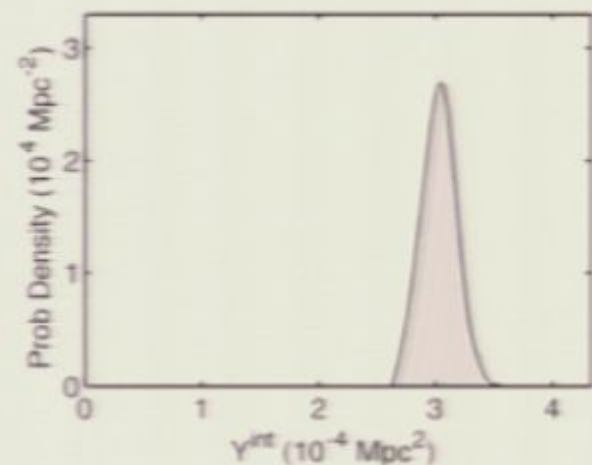
$T_e$



$f_{\text{gas}}$

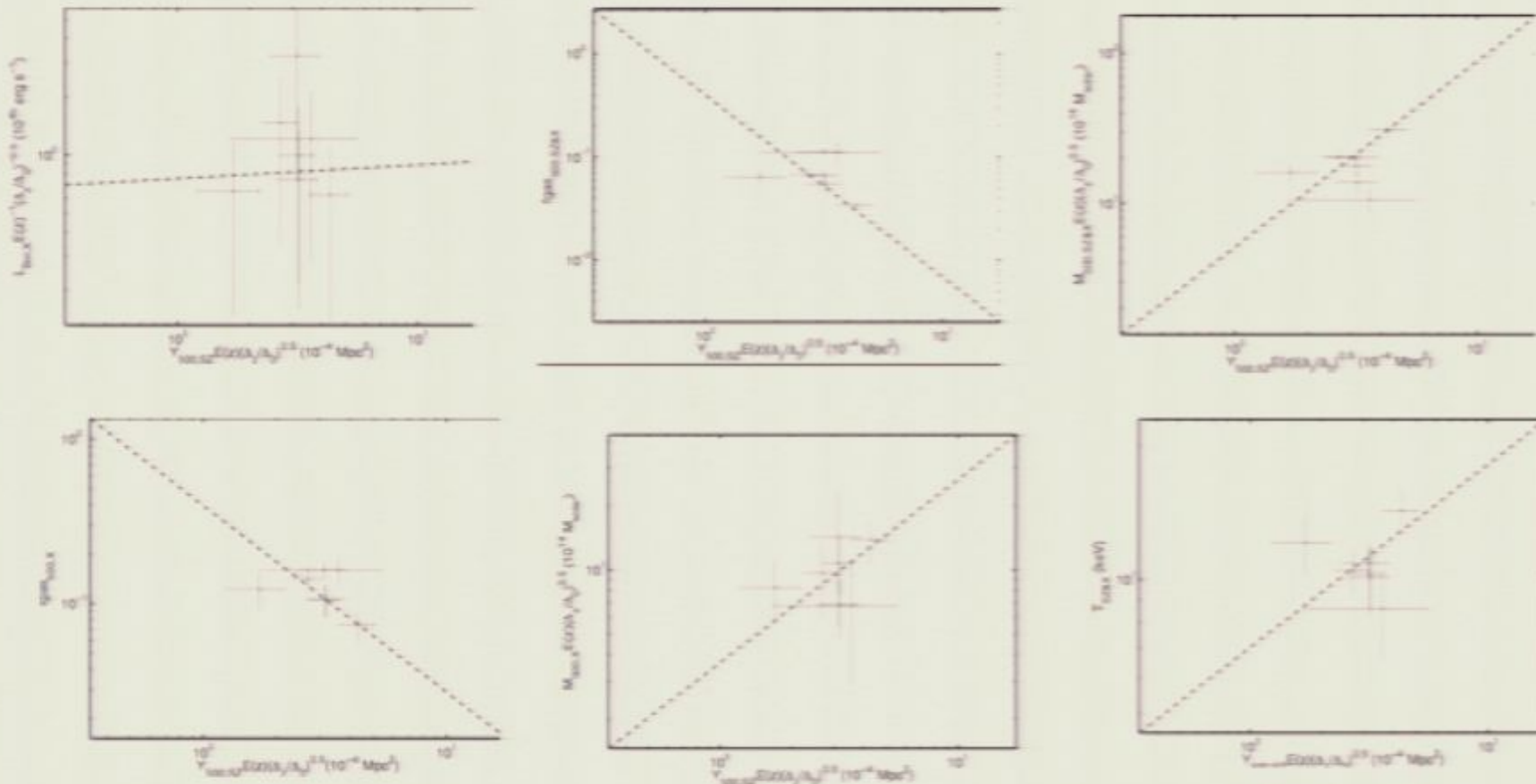


$Y_{\text{int}}$



• Calculated at  $r_{500}$  for comparison with Zhang et al. 2008

- This slide is deliberately small - just to say we have started doing scaling relations!!
- Below only quick run using beta model fitting, need to do properly with full model..... To be continued.....







- CBI2 operated from 2006 - 2008
- *Deep CBI2 CMB data now in hand with follow-up at IR/optical/X-ray*
  - *better constraint on excess (?)*
  - *search for correlation with clusters*
- *CBI2 data on large samples of SZ clusters*
  - *new model to extract large-scale physical properties*
  - *combined analysis with X-ray*
  - *aim to determine global and radial cluster properties out to  $\sim$  virial radius*
- *Use samples to better constrain scaling relations*

*CBI2 now sat in a container on top of the atacama...waiting to be resurrected :-)*

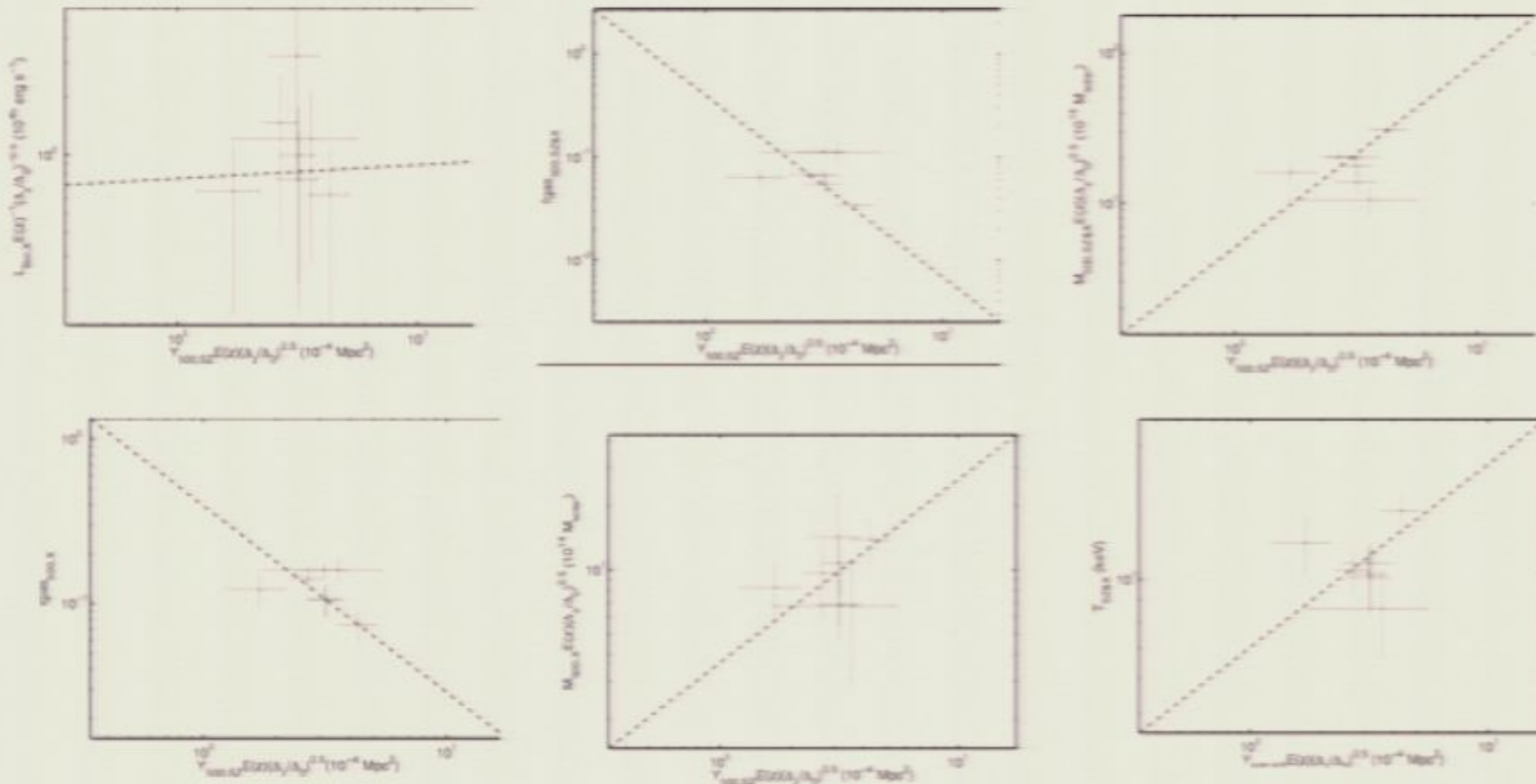


The End

# Yes - we will do scaling relations!

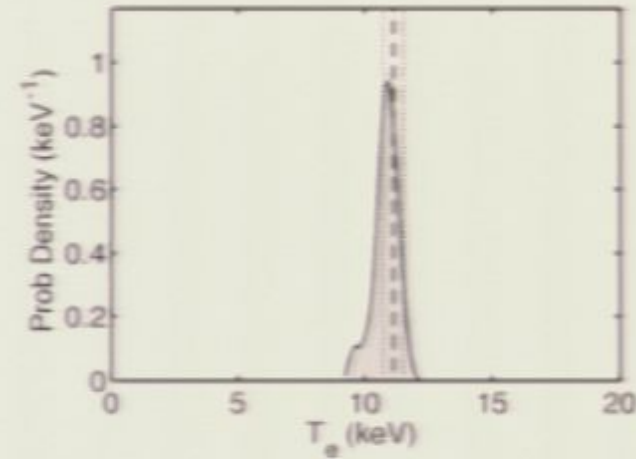
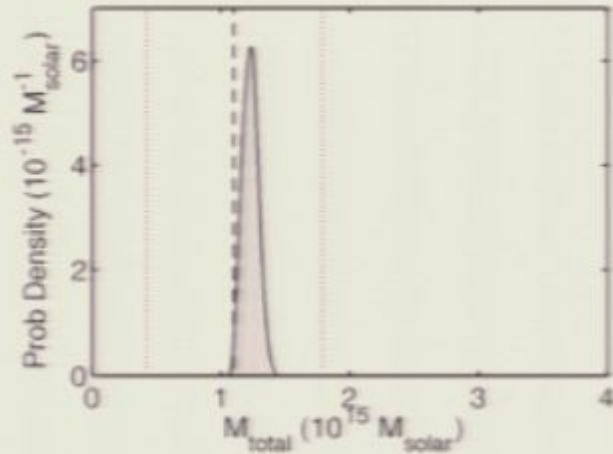


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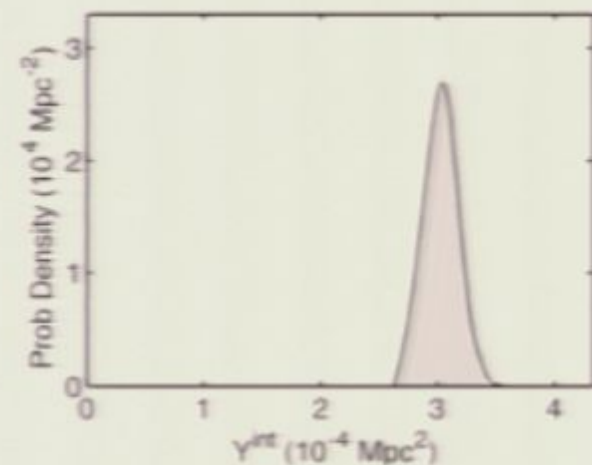
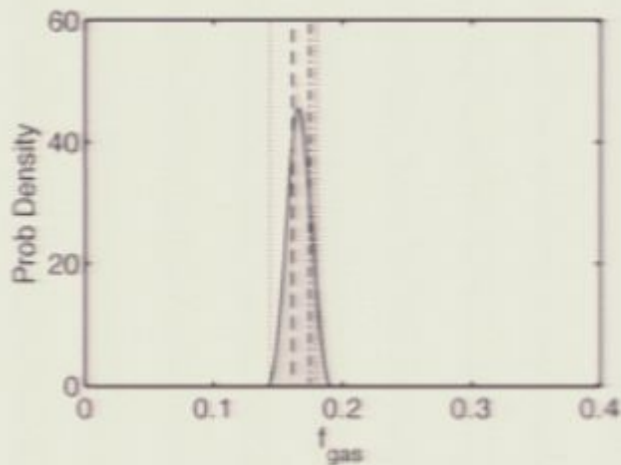
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$M_{\text{total}}$



$T_e$

$f_{\text{gas}}$



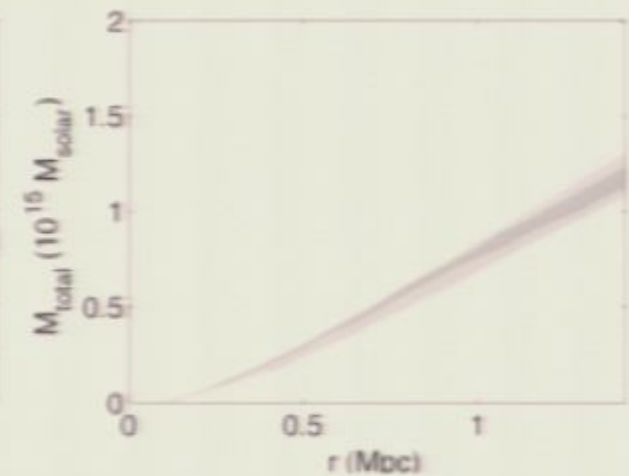
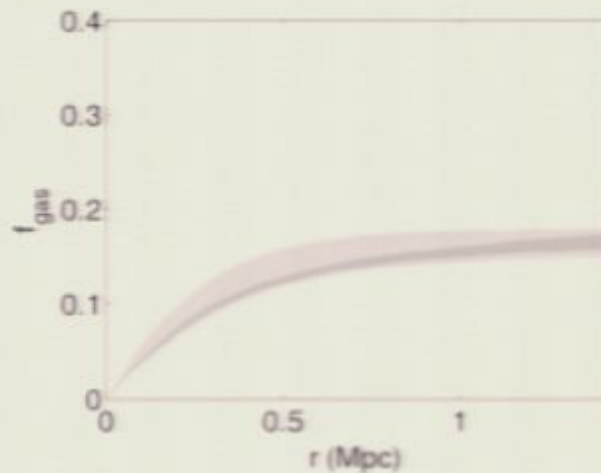
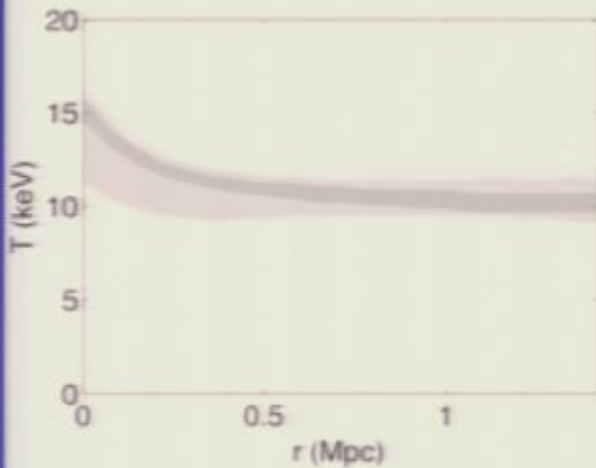
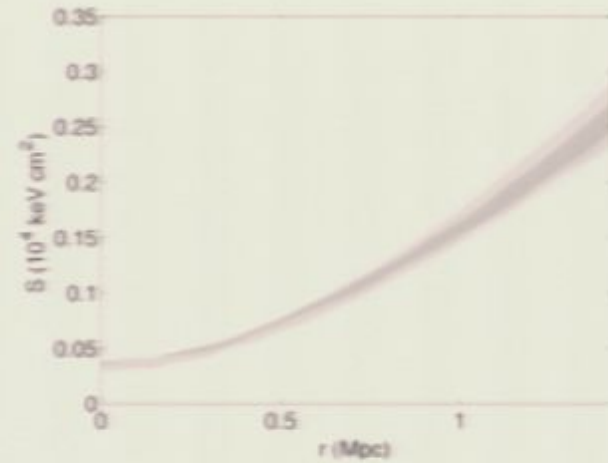
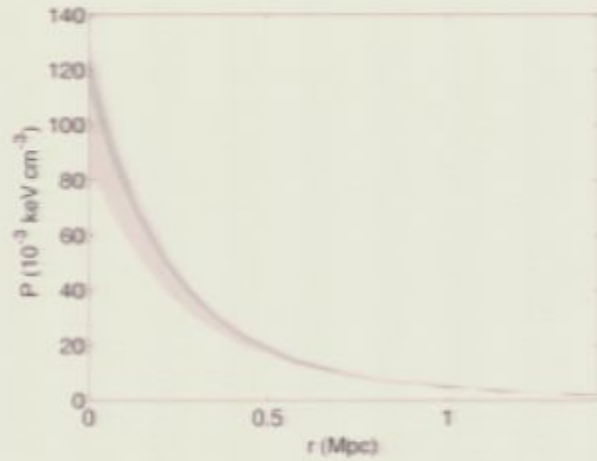
$Y_{\text{int}}$

• Calculated at  $r500$  for comparison with Zhang et al. 2008

# Derived cluster properties

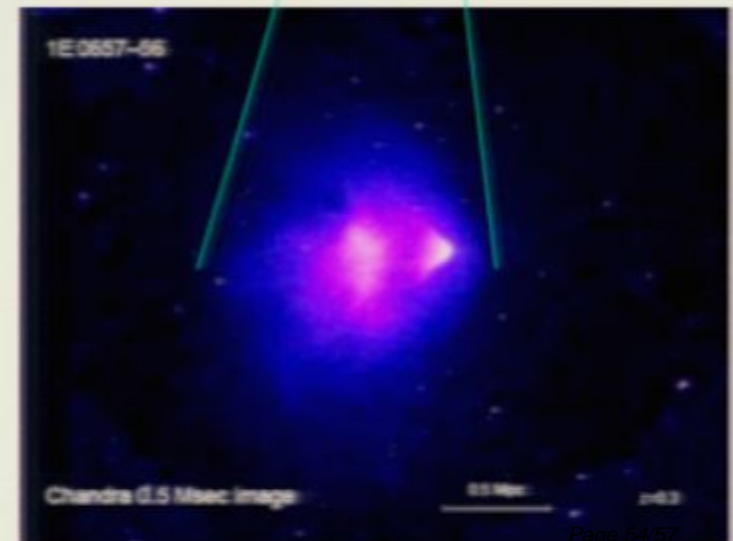
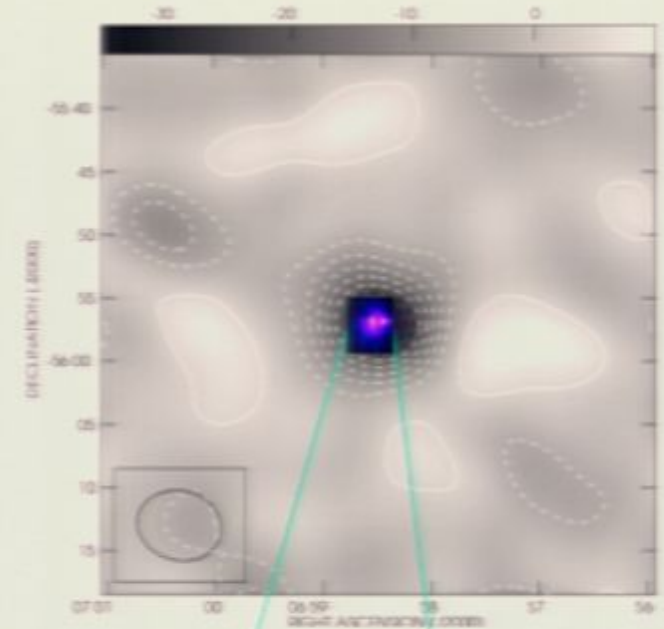


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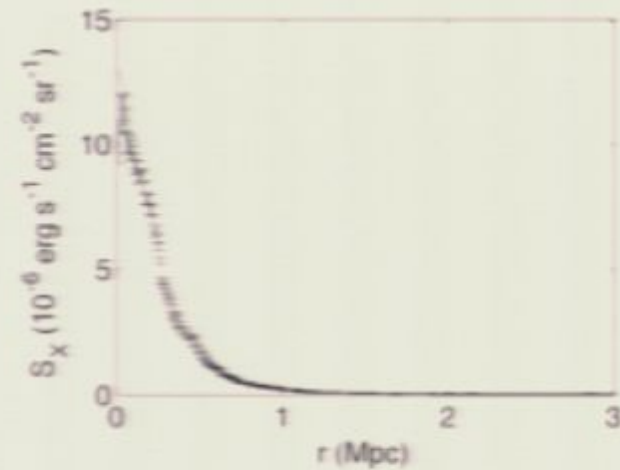
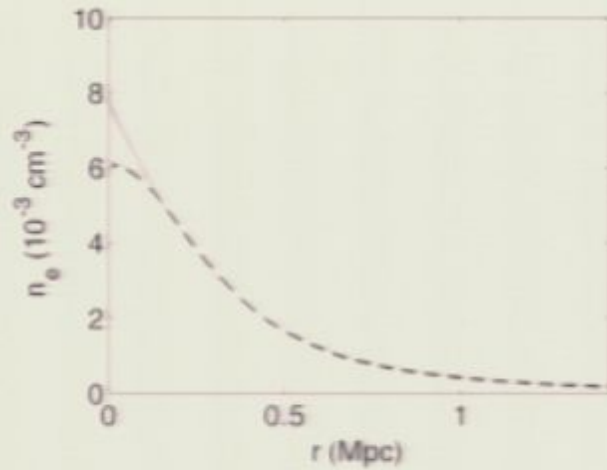
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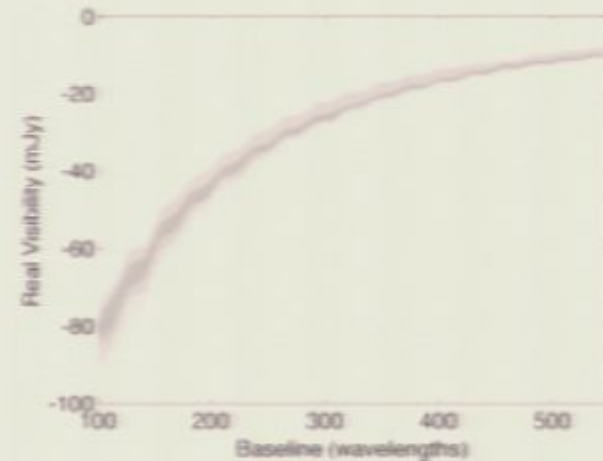
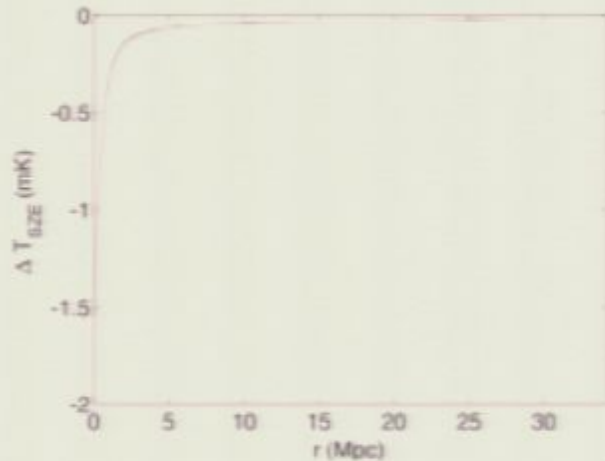


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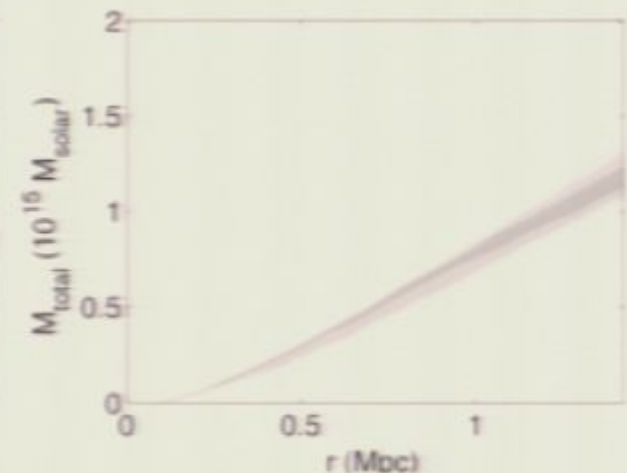
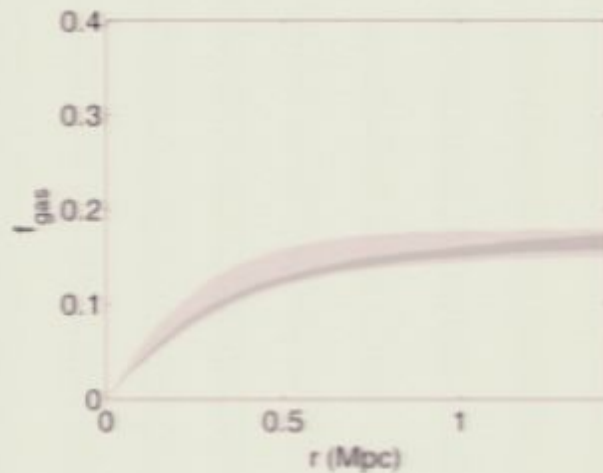
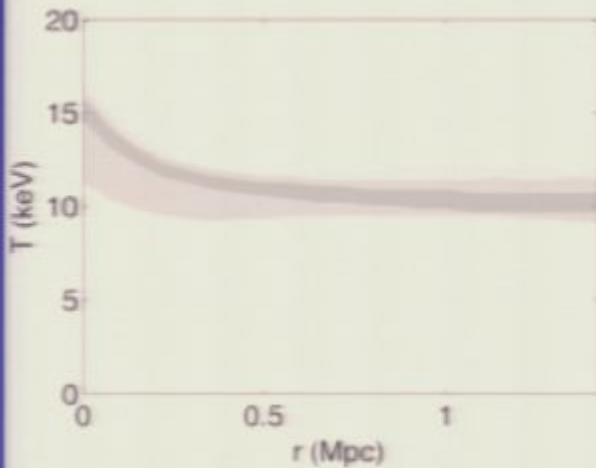
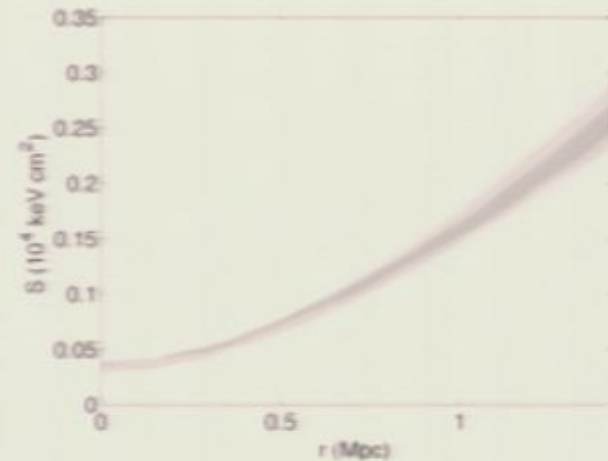
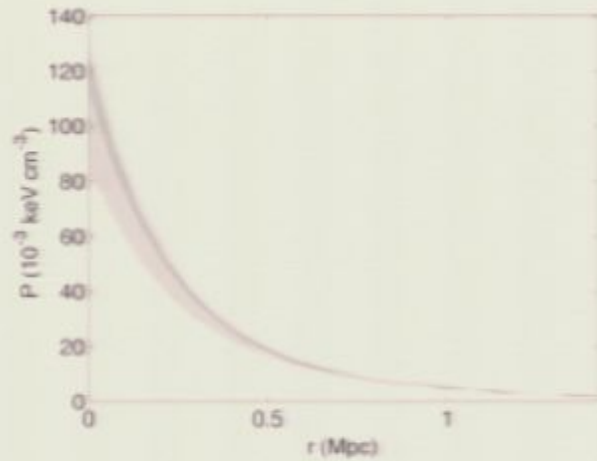
X-Ray



SZ



**!! HEALTH WARNING - VERY PRELIMINARY RESULTS !!**



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**!! HEALTH WARNING - VERY PRELIMINARY RESULTS !!**

