CMB Observations and the Standard Model:
A Status Report

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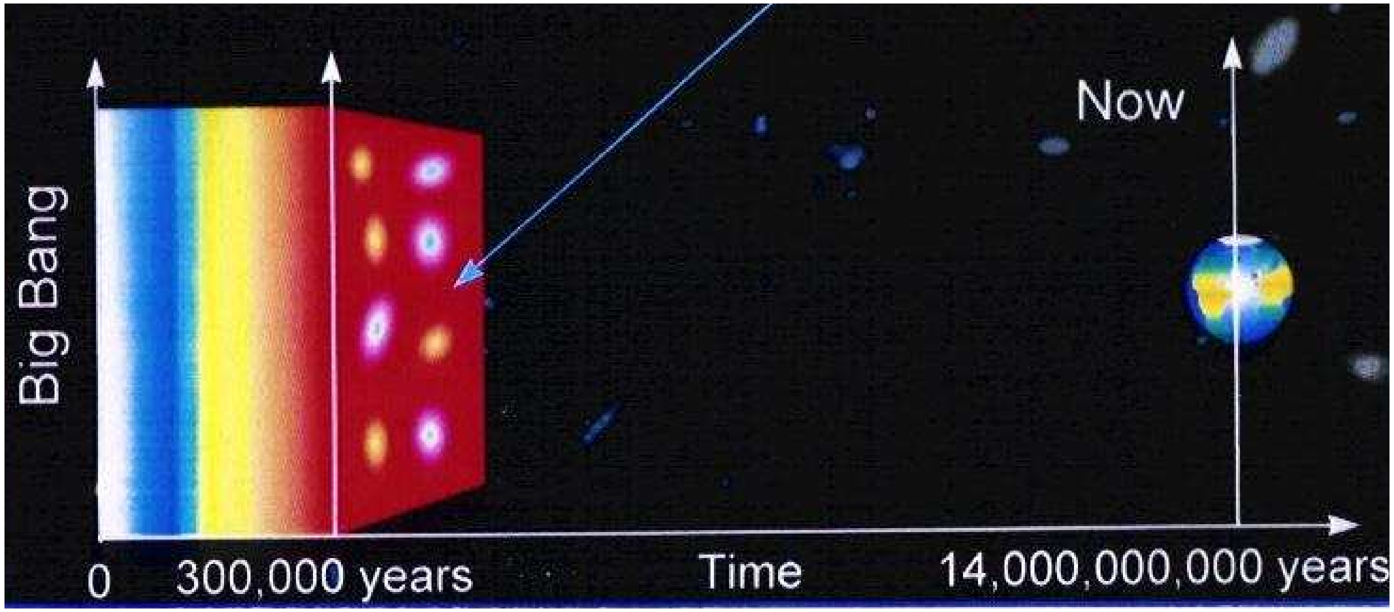
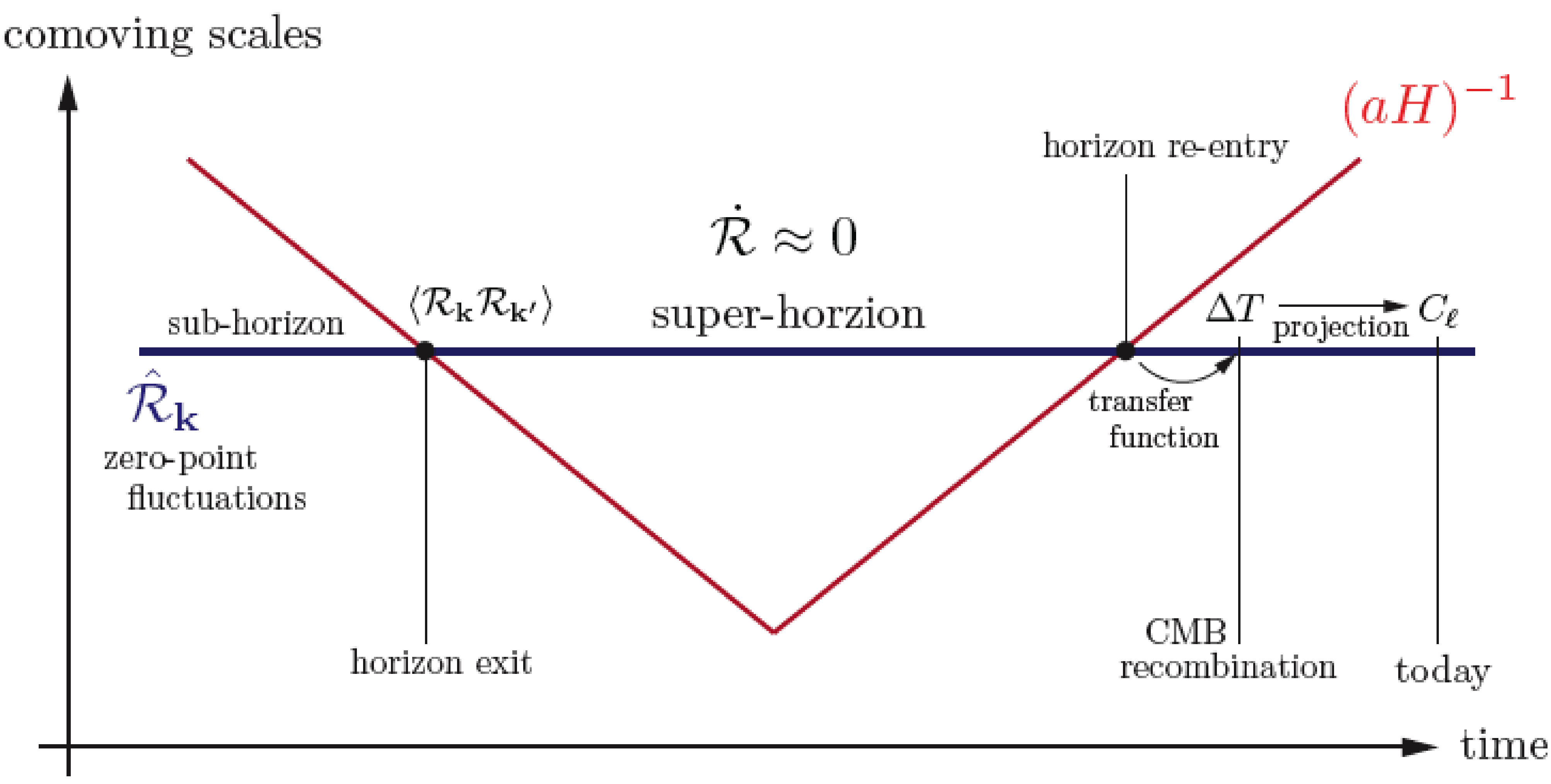
The cosmic microwave background



- The Cosmic Microwave Background (CMB) was emitted at about 300,000 years after the big bang and has been propagating to us ever since
- Think about 90% of the photons make it straight to us, telling us about the physics at the time of recombination
- Rest carry imprints of what has happened on the way
- But when emitted also has encoded in it information dating from about 10^{-36} seconds after the big bang

How the perturbations from inflation reach us



(From lecture notes by George Efstathiou)

THE PHOTON/BARYON FLUID

- In terms of conformal time $\eta = \int \frac{dt}{a(t)}$, then using the continuity and Euler equations for the coupled photon/baryon fluid, we find, with $\delta = \delta\rho_\gamma/\rho_\gamma$

$$\frac{1}{4}\ddot{\delta} + \frac{1}{4}\frac{HR}{1+R}\dot{\delta} + \frac{1}{4}k^2 c_s^2 \delta = F(\eta)$$

with a driving term $F(\eta)$ (itself oscillatory) and

$$c_s^2 = \frac{P}{\rho} \approx \frac{P_\gamma}{\rho_\gamma + \rho_B} = \frac{1}{3(1+R(\eta))} = \quad \text{squared sound speed}$$

where $R \equiv 3\rho_B/(4\rho_\gamma)$

- Can see second term is basically Hubble drag
- So have a damped, forced, harmonic oscillator
- The forcing term itself will oscillate, due to the gravitational potential responding to the oscillations of the photon/baryon fluid, and we can attempt a WKB solution in terms of the slowly varying frequency $kc_s(\eta)$

THE PHOTON/BARYON FLUID

- We find

$$\frac{1}{4}\delta_\gamma(\eta) = A(\eta) + B(\eta)\cos(kr_s(\eta)) + C(\eta)\sin(kr_s(\eta))$$

where the coefficients A, B and C are meant to vary only slowly, and $r_s(\eta)$ is called the sound horizon, and is meant to show the distance a disturbance in the fluid could have traveled since some early time:

$$r_s(\eta) = \int_0^\eta c_s(\eta)d\eta$$

- The initial condition linking δ and the Newtonian gravitational potential at early times is

$$\delta(0) = -2\Phi(0)$$

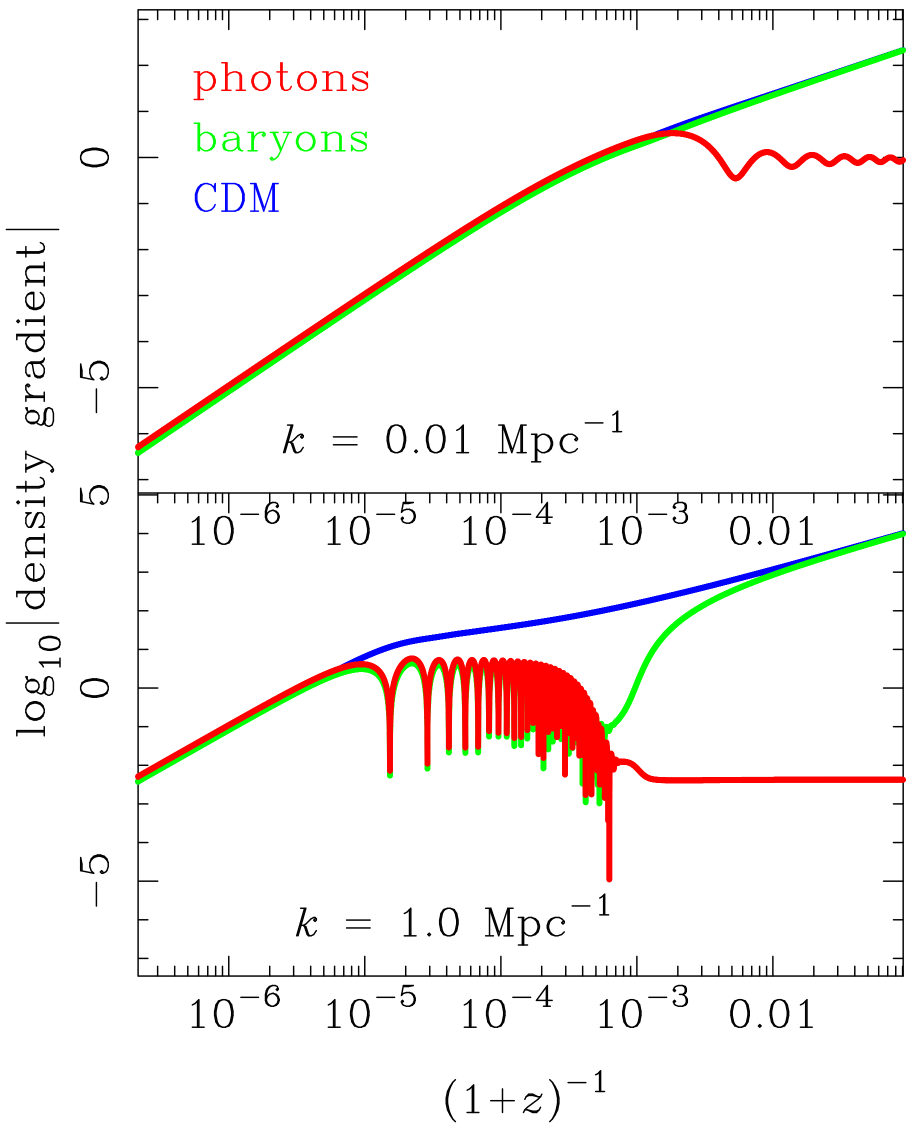
and δ remains roughly constant until horizon crossing

- So we see that it is the cosine term that is picked out and excited by the initial conditions

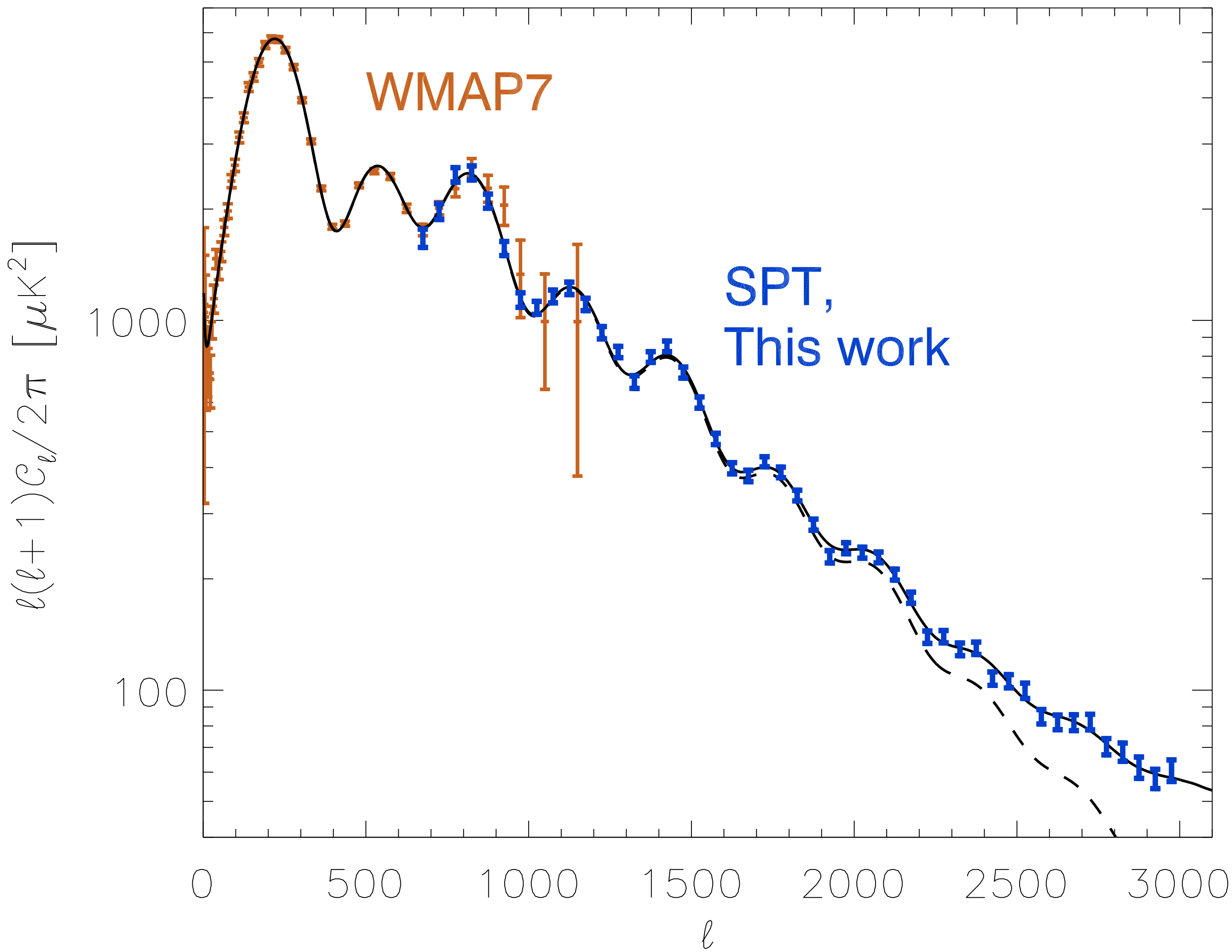
- This is what phases things up

THE RESULTS

- $\delta_\gamma/4$ ($\equiv \Delta T/T$) starts out constant $\Rightarrow$ cosine oscillation about equilibrium point
- Modes with $k\int_0^{\eta_*} c_s\, d\eta = n\pi$ are at extrema at last scattering $\Rightarrow$ acoustic peaks in power spectrum
- As soon as decoupling of the photon/baryon fluid occurs, baryons fall into the potential wells created by the CDM
- Can calculate r_s at last scattering in standard model and find $r_s(\eta_*) = 150\,\mathrm{Mpc}$
- What does this picture lead to?

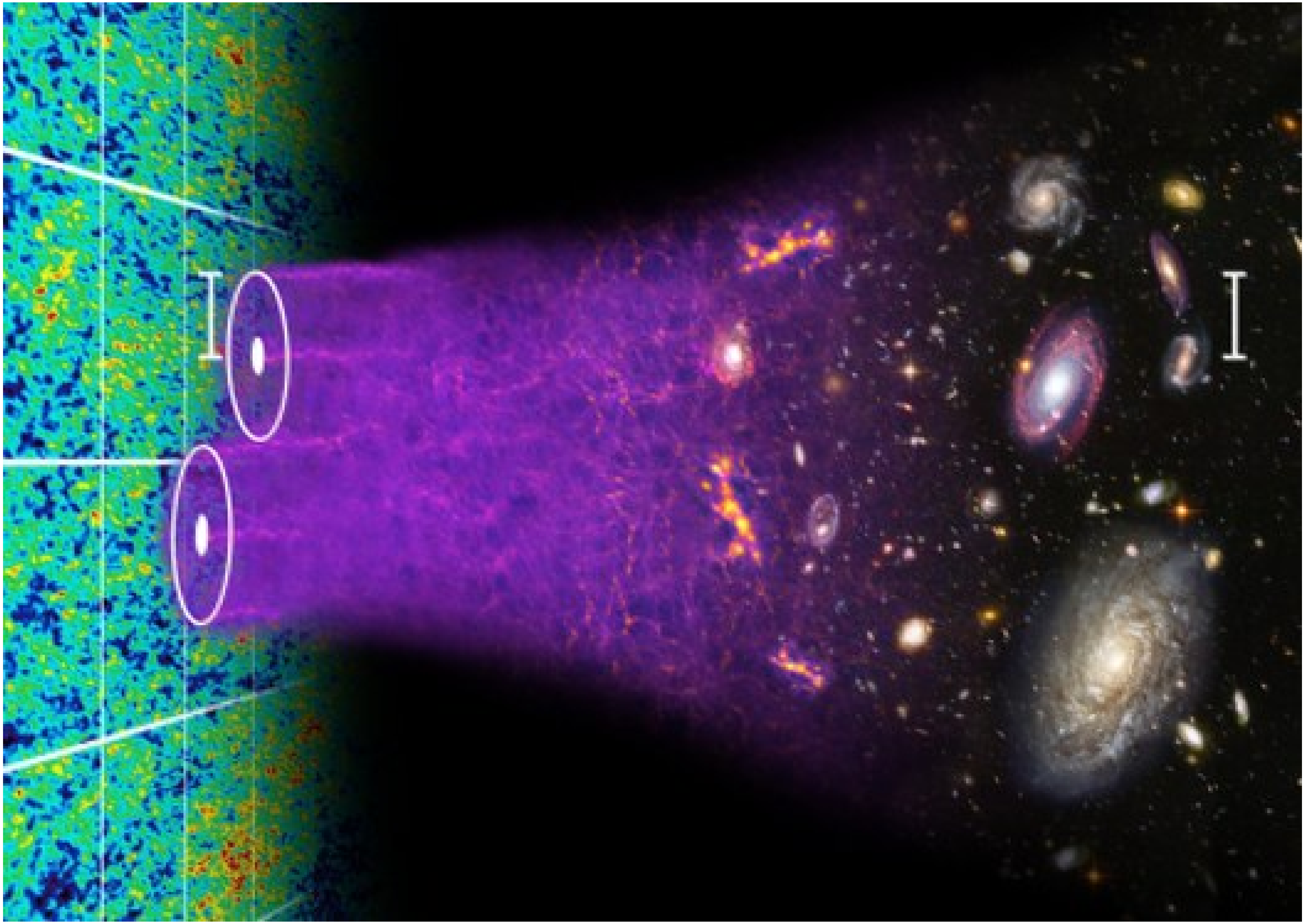


LAST YEAR'S SPT POWER SPECTRUM RESULT



Keisler et al (arXiv:1105.318)

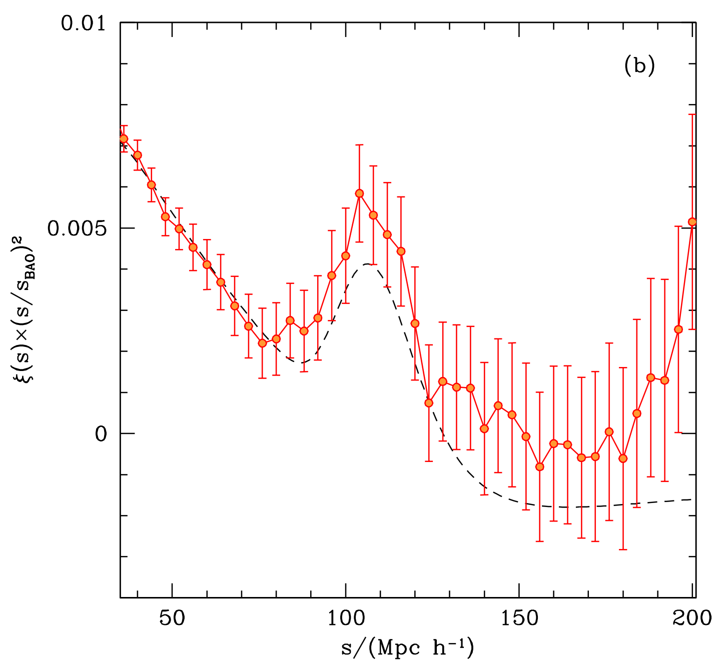
- Think one could now reasonably claim that 9 peaks have been measured in the CMB power spectrum!
- For the matter:

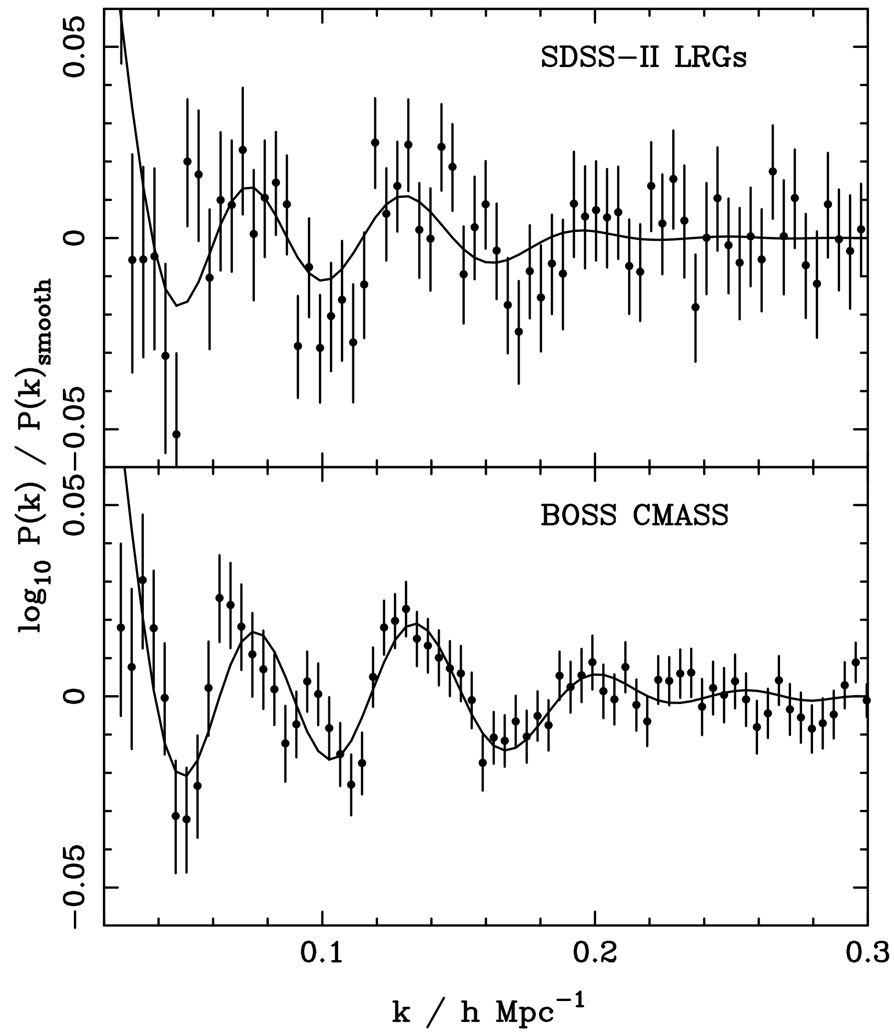


http://www.sdss3.org/surveys/boss.php (Chris Blake and Sam Moorfield)

BAO RESULTS

- The baryon acoustic oscillations are getting quite spectacular in themselves
- At right are oscillations in the power spectrum of galaxy clustering from SDSSII and then SDSIII from Anderson et al. (arXiv:1203.6954)
- Below shows two-point correlation function (essentially F.T. of power spectrum) of same data from (Sanchez et al arXiv:1203.6616)





- Note $150\,\mathrm{Mpc} \approx 105\,h^{-1}\,\mathrm{Mpc}$

GRAVITY WAVES

- Other important aspect for CMB is polarization and gravity waves
- Express the amplitude of these coming from inflation, relative to scalar modes from inflation, via their ratio r at some fiducial comoving wavenumber (typically low, e.g. $k = 0.001\,\mathrm{Mpc}^{-1}$)
- Key point is that if we decompose CMB polarization vector field on sky into a potential part E and curl part B (both of which are rotationally invariant, unlike Q and U Stokes parameters), the only primordial source of B are gravity waves!
- What would a detection of primordial gravity waves tell us?
- Strong evidence that inflation happened
- Find

$$r = 0.008 \left(\frac{E_{\mathrm{inf}}}{10^{16}\,\mathrm{GeV}} \right)^4$$

- Thus detectable gravity waves ($r > 0.01$ say) would mean inflation occurred at the GUT scale
- We would then be accessing particle physics at a scale about at least 10^{12} higher than those achievable at LHC

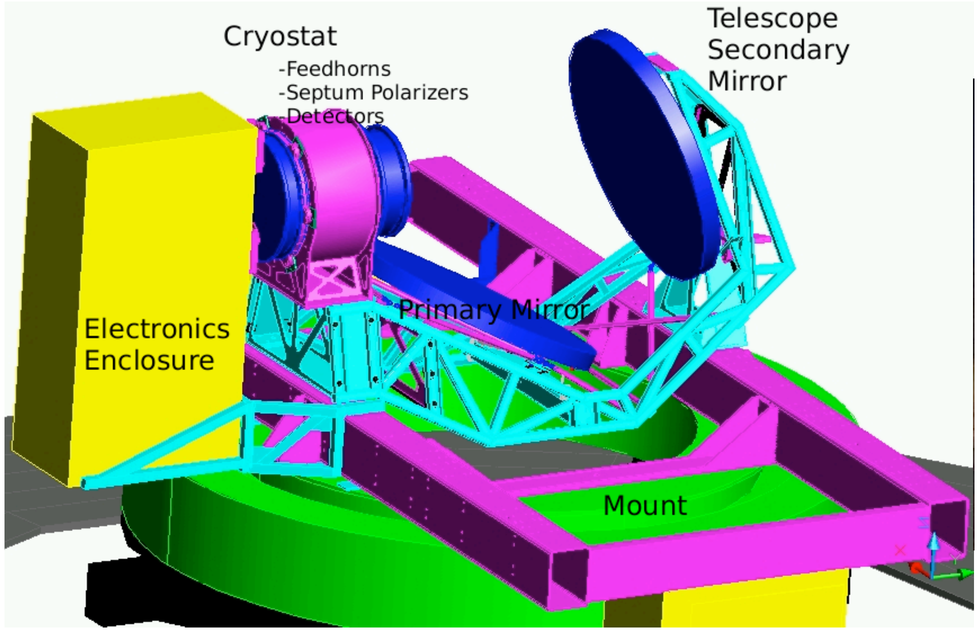
Some Current/Future CMB Polarisation Experiments

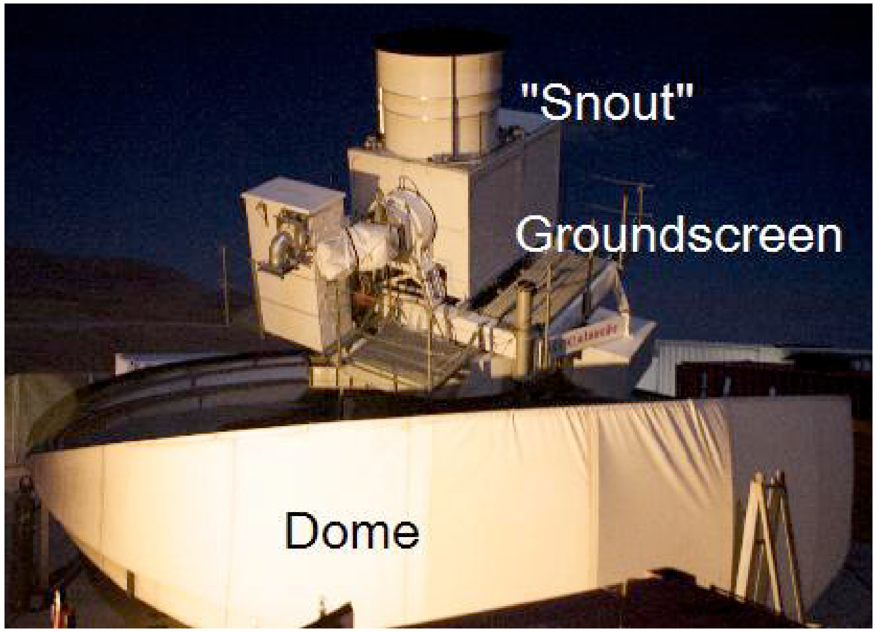
Name	Type	Detectors	ℓ range	r target	First Obs.
QUAD	ground	bolometer	$200 < \ell < 3000$		completed
BICEP	ground	bolometer	$50 < \ell < 300$	0.1	2007
BICEP2	ground	bolometer	$50 < \ell < 300$	0.05	2009
QUIET	ground	MMIC	$\ell < 1000$	0.05	2008
CLOVER	ground	bolometer	$20 < \ell < 600$	0.01	Cancelled
EBEX	balloon	bolometer	$20 < \ell < 1000$	0.03	2012
SPIDER	balloon	bolometer	$\ell < 100$	0.025	2013
CORE	space	bolometer	$\ell < 2000$	1–5 $\times 10^{-3}$	??
QUIJOTE	ground	MMIC	$\ell < 80$	0.1/0.05	2012
POLARBEAR	ground	bolometer	$20 < \ell < 2000$	0.05	?

Note:

- Paper on BICEP2 results expected imminently
- SPIDER — Spider delayed a year — first flight expected next year (Australia)
- EBEX — First southern hemisphere flight later this year(?) — some excitement recently when it was stolen in transit to the Palestine Texas balloon launch site!

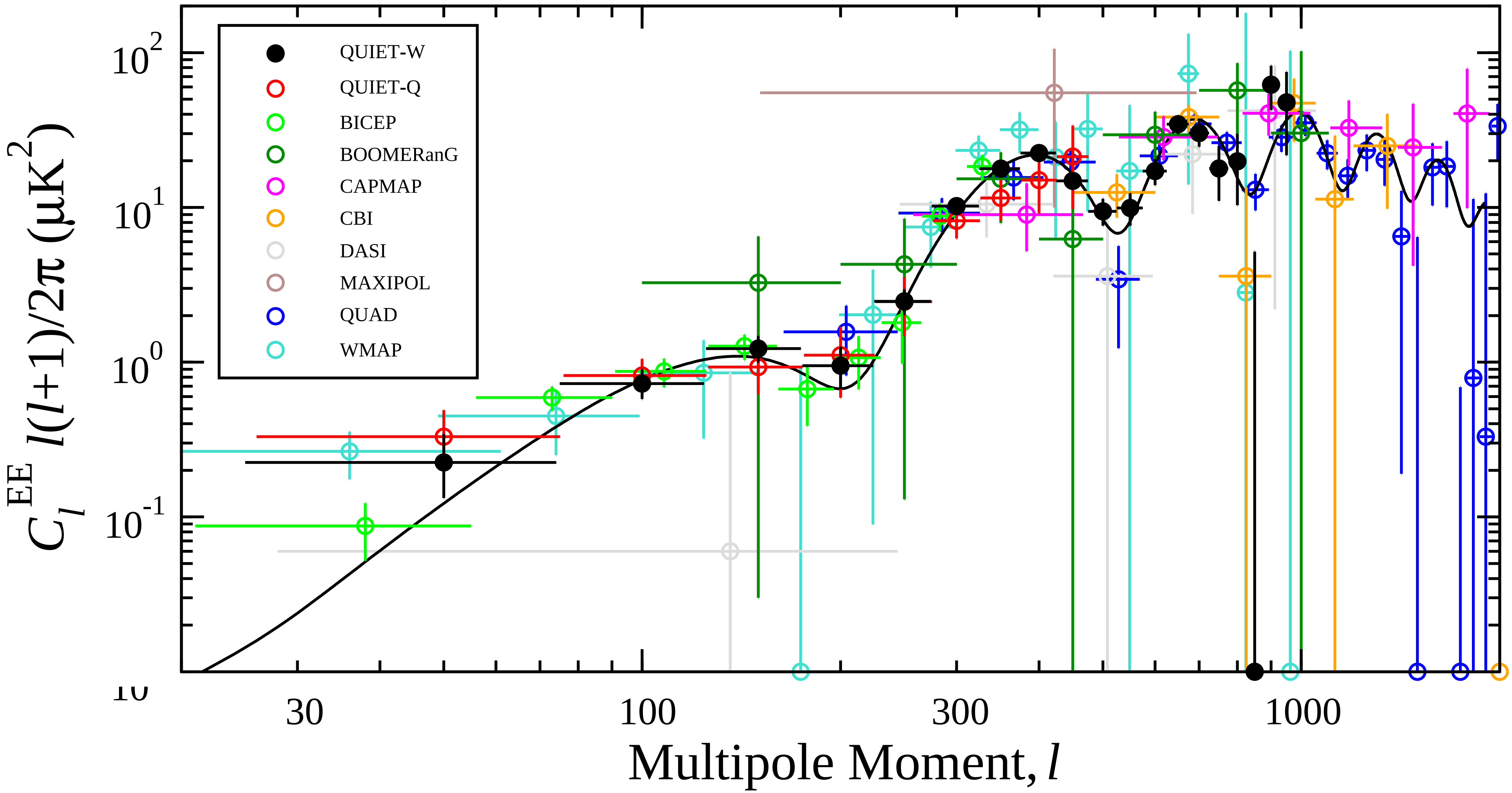
QUIET





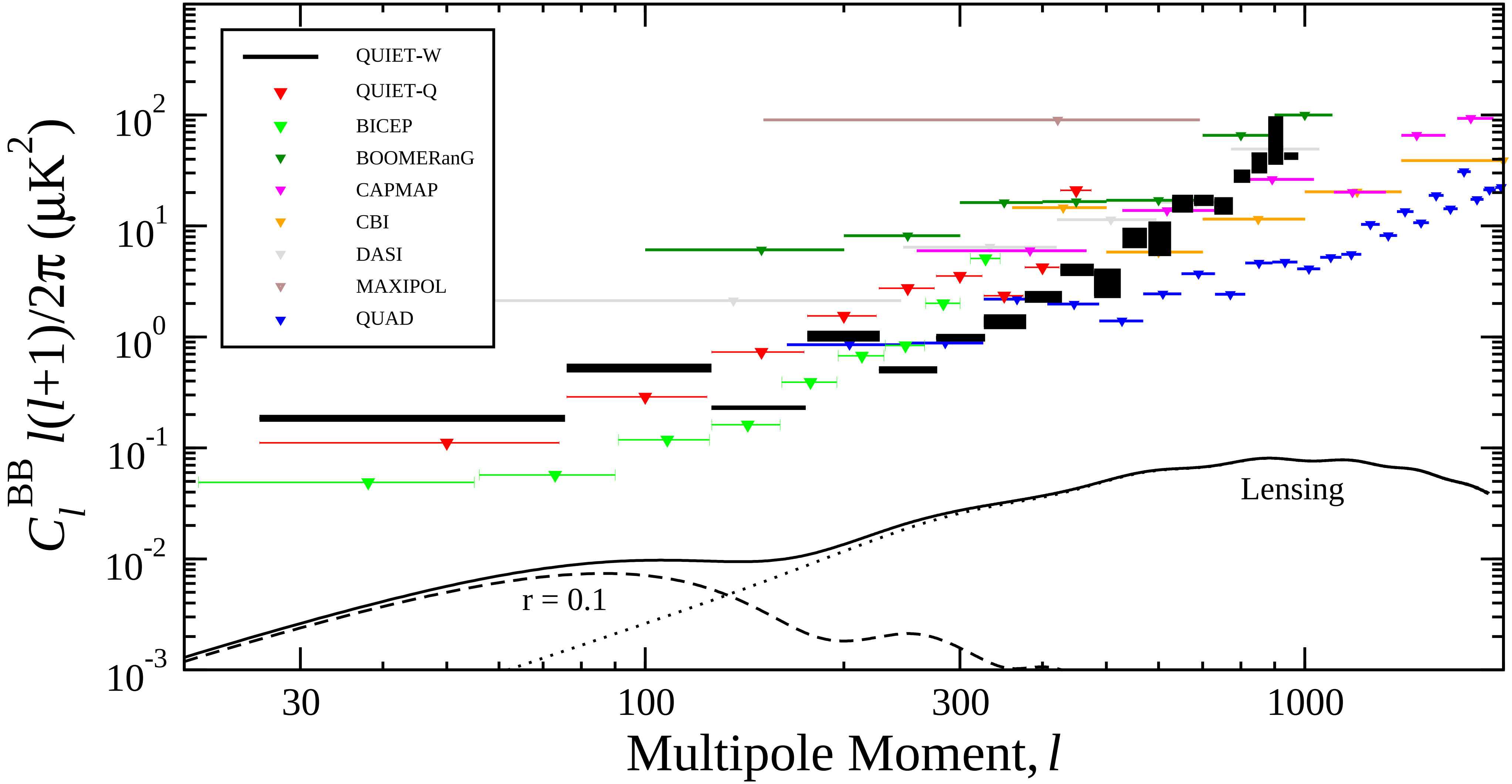
- Unlike most other current experiments uses coherent rather than bolometric techniques
- Feeds look at a 1.4 m primary — whole is mounted on old CBI mount in Chile
- Most of the visible exterior consists of groundscreens
- Last year (arXiv:1012.3191, Bischoff et al.) reported polarization results at 43 GHz (Q-band)
- Paper came out yesterday reporting on 95 GHz (W-band) results! (Hear more from Ingunn Wehus.)

QUIET EE RESULTS AT 90 GHz



From QUIET Collaboration arXiv:1207.5034

QUIET BB results at 90 GHz

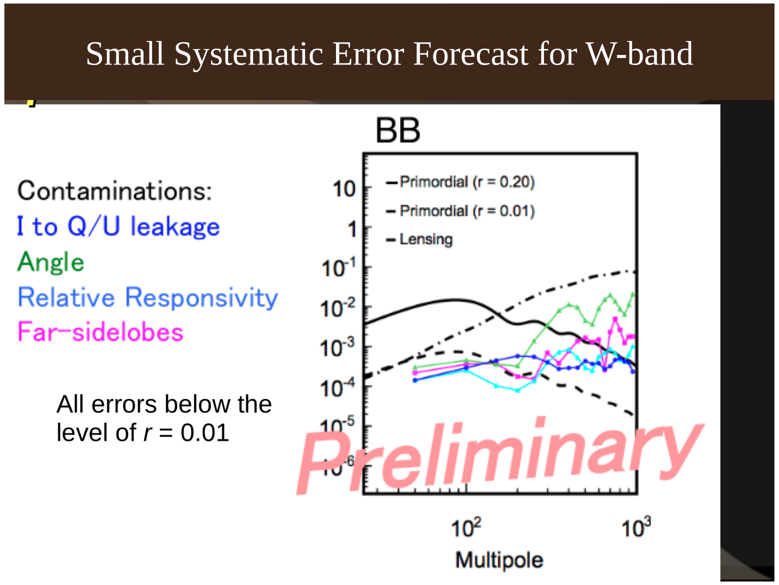


From QUIET Collaboration arXiv:1207.5034

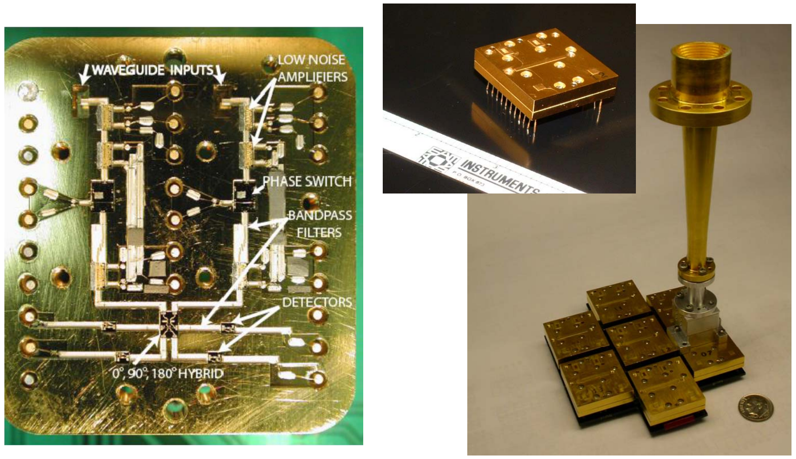
Direct r constraints are $r \lesssim 2.7$ at 95% confidence.

QUIET FUTURE

- Part of interest of results lies in quite different systematics expected for bolometer versus coherent detectors
- QUIET team believe they have the best control of these systematics in B-mode data, even if so far published constraints for r (previous one from Bischoff et al was < 0.9) is not lower than from BICEP (< 0.73) (Chiang et al 2010)
- Another part of interest lies in use of MMIC (Monolithic microwave integrated circuit) technology
- Prototype for QUIET Phase II proposal
- Plans are for a 499-element 85-105 GHz Array, coupled with 10-element 33-40 GHz Array and 3-element 26.5-33 GHz Array to remove synchrotron



Radiometer on a chip

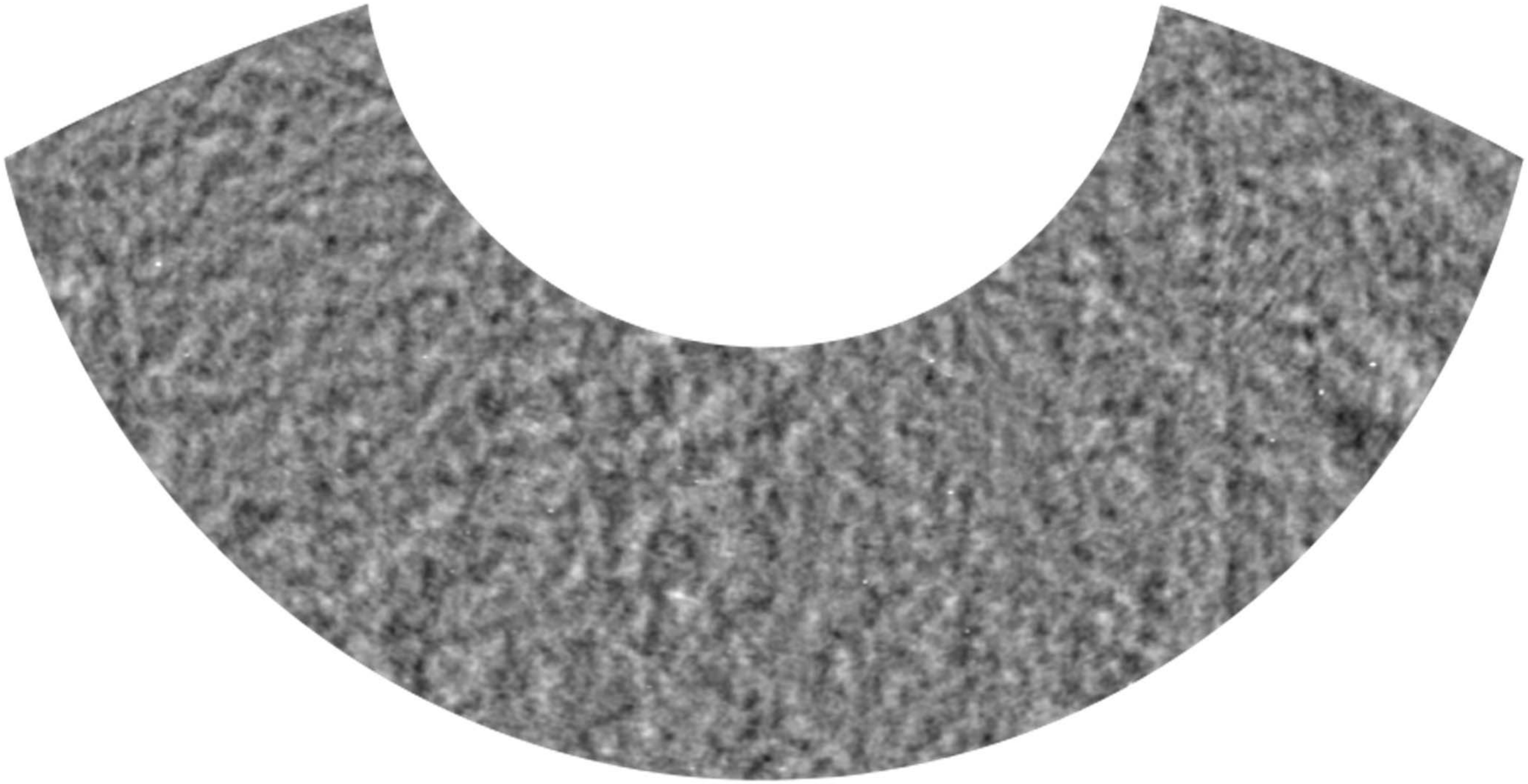


Pictures courtesy Tony Readhead

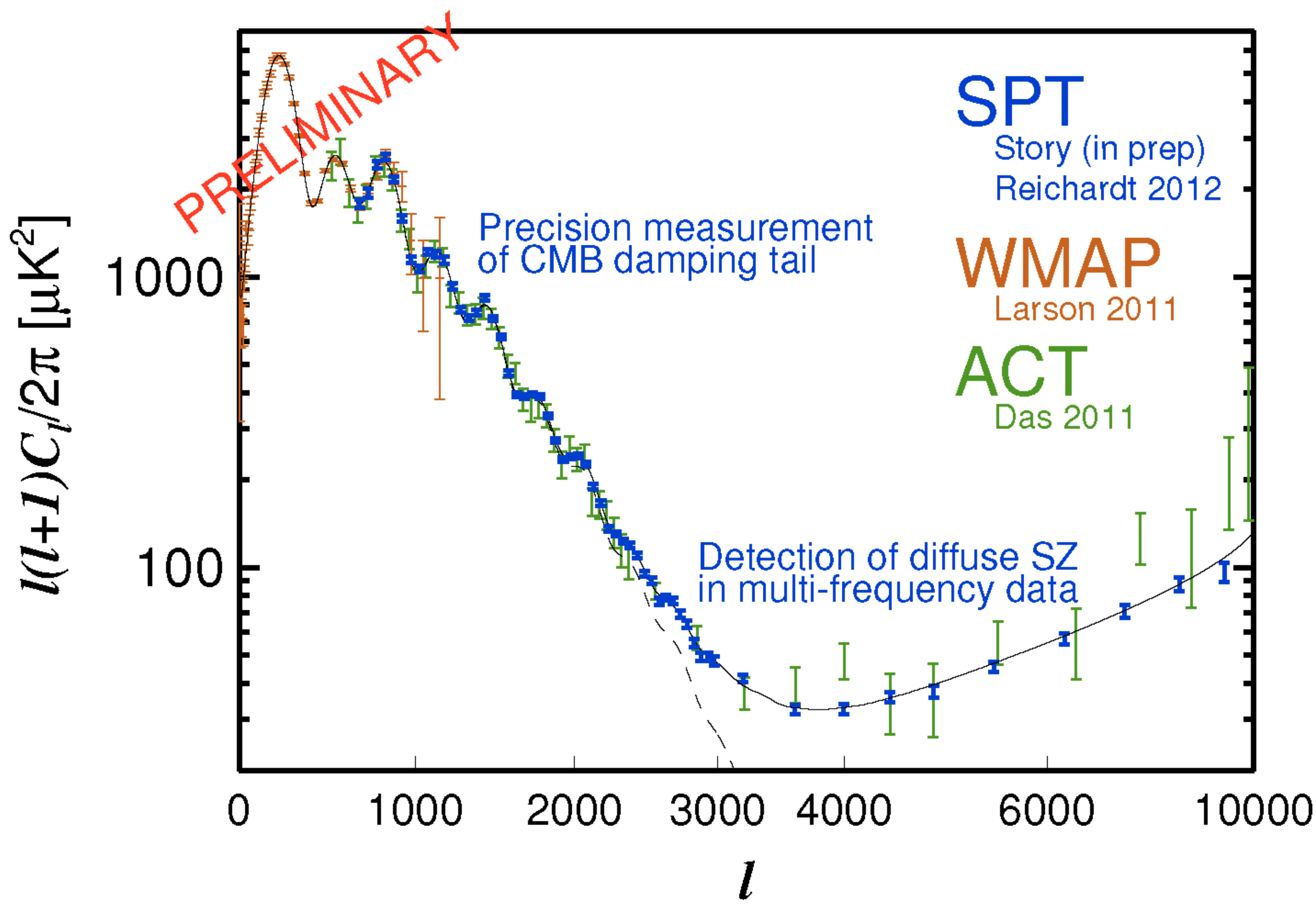
THE SOUTH POLE TELESCOPE

- A stream of wonderful results at high ℓ for both primordials and secondaries has been coming out from the South Pole Telescope (SPT) and Atacama Cosmology Telescope (ACT) over the last year
- Lyman Page will be talking about ACT results, so I'll concentrate here on the South Pole Telescope results
- Very impressive paper from Keisler et al (arXiv:1105.318) last year on high-ℓ power spectrum
- Used 790 square degrees of sky measured at 150 GHz

The SPT 5-year, 2500 deg² survey is now complete



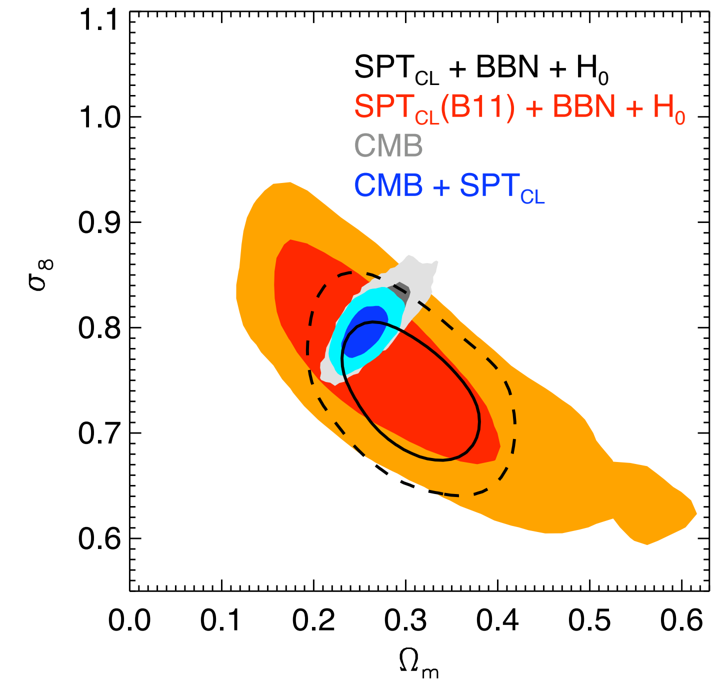
Picture courtesy John Carlstrom and Bill Holzapfel

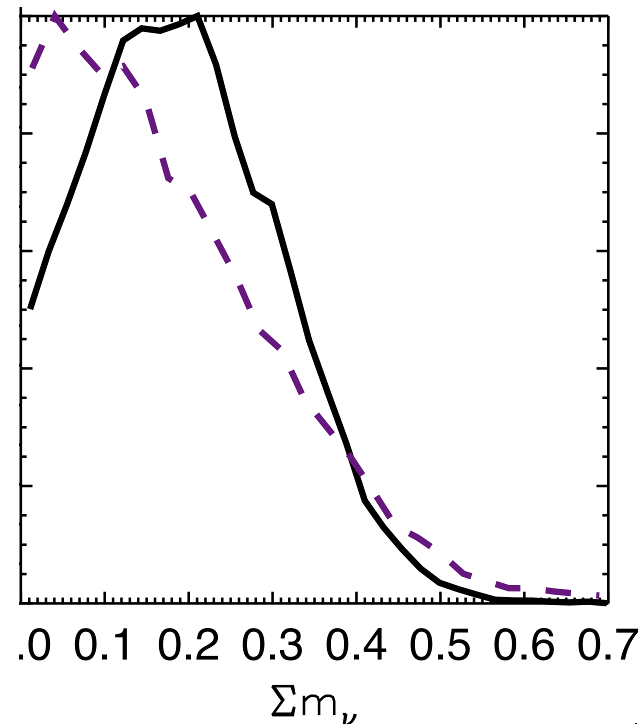


Picture courtesy John Carlstrom and Bill Holzapfel

Cosmological Constraints from SPT Clusters

- Reichardt et al (arXiv:1203.5775) have presented a catalogue of 224 clusters from Sunyaev-Zeldovich effect measurements in the first 720 deg^2 survey (mainly at 150 GHz — subset also mapped at 90 GHz)
- 117 previously unknown clusters reported
- 100 clusters at high S/N used for cosmological constraints
- Interesting (and a common theme currently) that real problem is the cluster mass calibration
- This is what limits ability to constrain parameters — not current survey size or noise
- Neutrino result gives a $\sim 1\sigma$ offset from zero: $\Sigma m_\nu = 0.17 \pm 0.13\,\text{eV}$





SPT Lensing Results

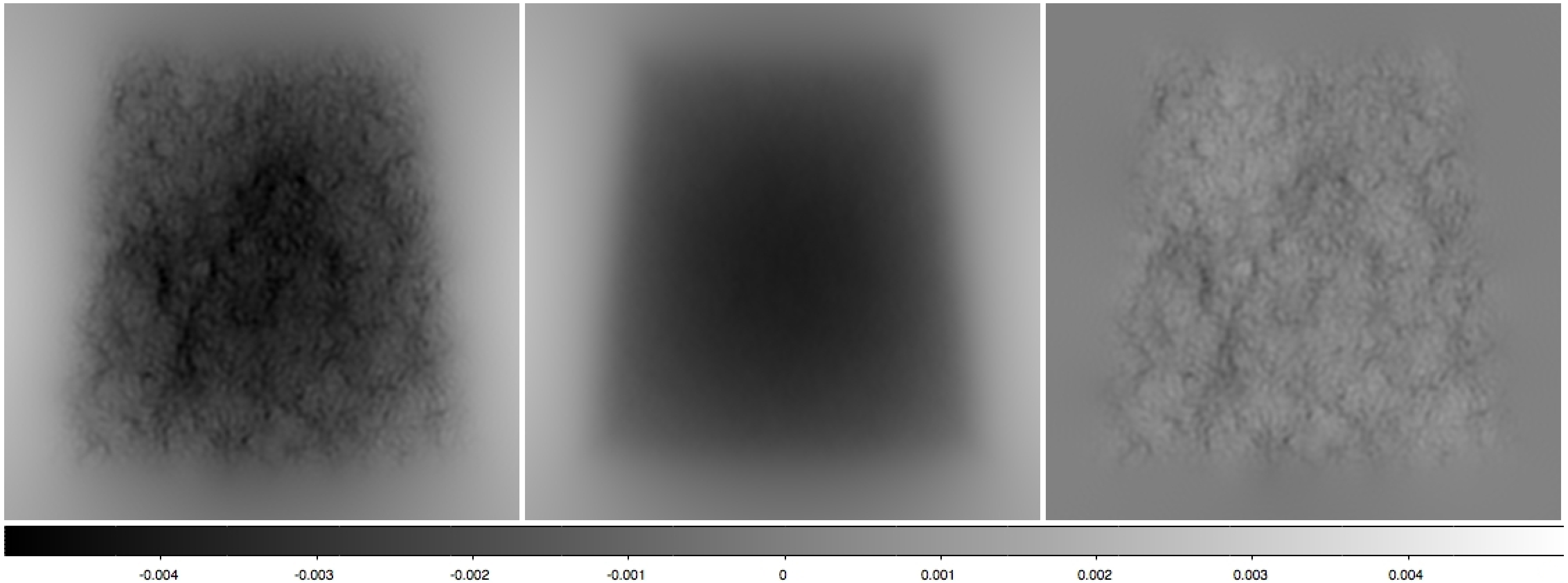
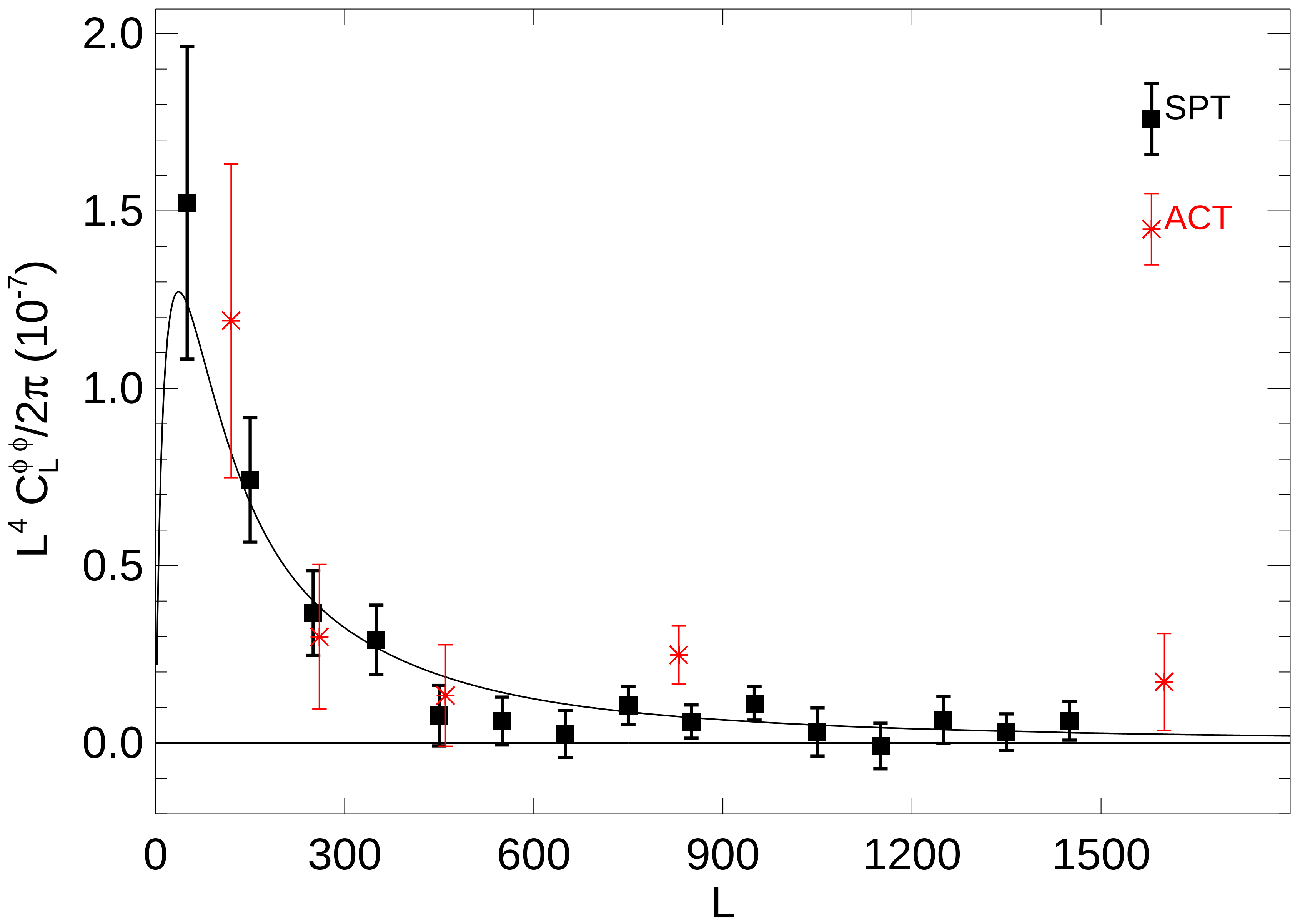


FIG. 1.— Impact of apodization: (left) reconstruction of lensing deflection for one of the SPT fields (RA5H30DEC-55); (middle) mean estimated deflection for 100 simulations, indicating the mean apodization feature; (right) resulting estimate of the deflection in the SPT field after subtracting the estimated apodization feature. All maps have the same greyscale (±0.005).

From van Engelen et al, arXiV:1202.0546

- SPT can now make maps of reconstructed lensing deflection
- Previous results (e.g. Keisler et al, arXiv:1105.3182) worked from effects on the peaks in primary CMB power spectrum (lensing tends to smooth these out)
- Here, one forms the power spectrum of lensing itself

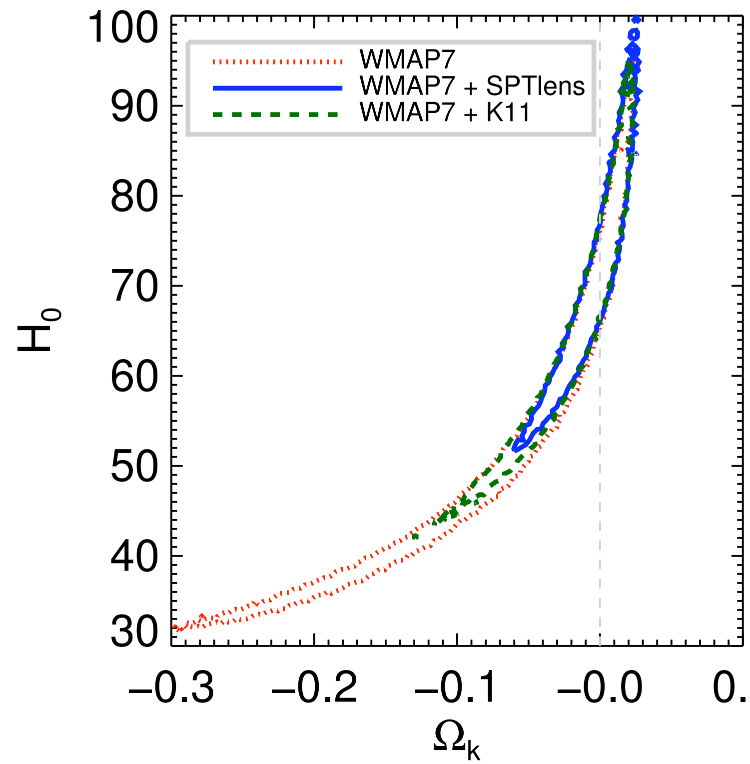
LENSING BANDPOWER RESULTS (VAN ENGELEN ET AL, ARXIV:1202.0546)



- The solid black line is not a fit but the prediction in a fiducial ΛCDM cosmology
- ACT points from Das et al (arXiv:1103.2124)

Cosmological Constraints from Lensing

- Clear that lensing power estimate is coming out in region it should (first ones from ACBAR were too high??)
- Most dramatic effect of including lensing data comes from effect on curvature
- The Ω_Λ-Ω_k angular diameter distance degeneracy in standard CMB is broken by the fact the lensing data introduces information at a different distance (the late times where lensing is taking place)
- Error on 1d marginalised result on Ω_k using CMB data alone is reduced by a factor 3.9 over WMAP7 alone
- WMAP7 (no extra data) gives $\Omega_k = -0.0545 \pm 0.0670$; WMAP7 + SPT lensing result gives $\Omega_k = -0.0014 \pm 0.0172$



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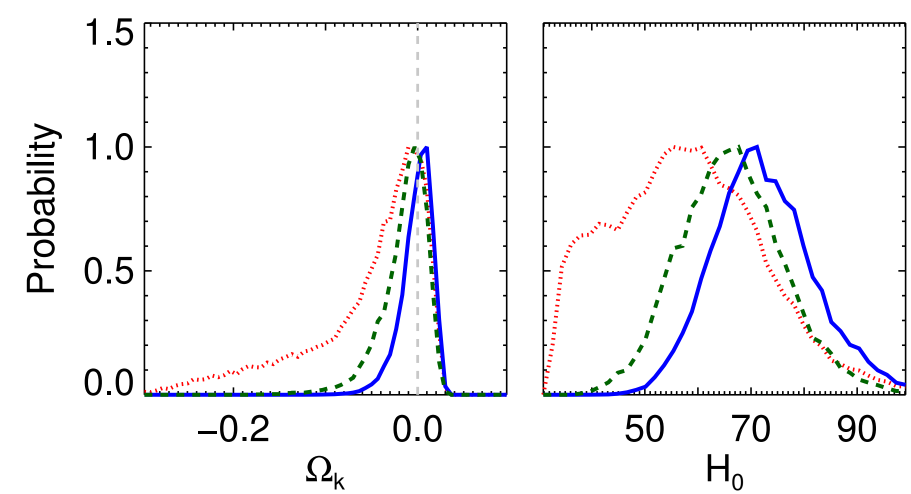


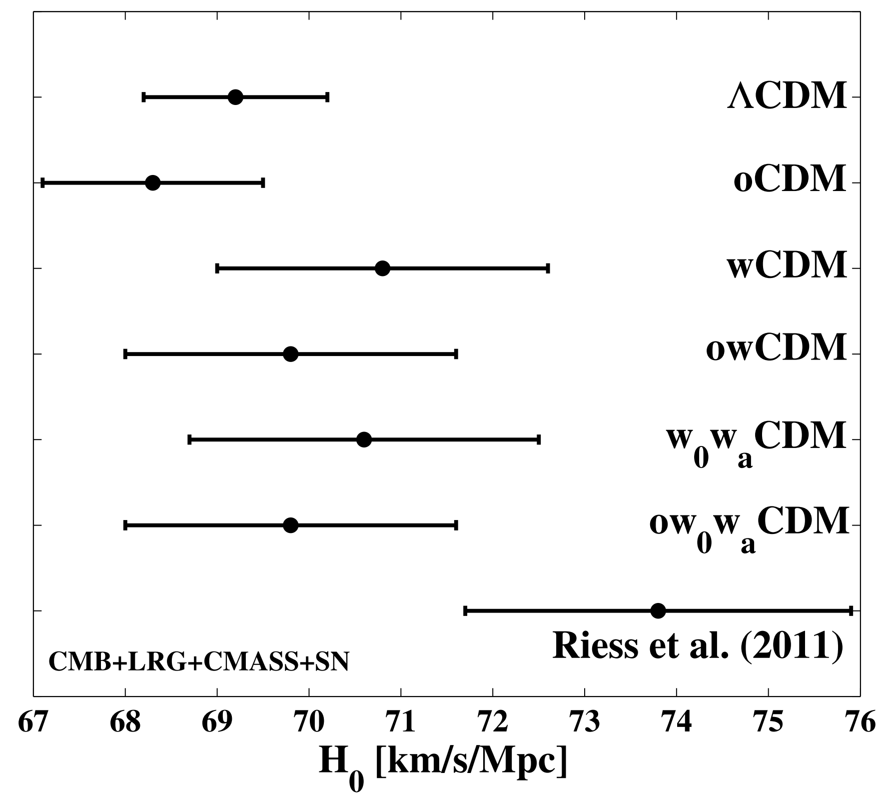
TENSION BUILDING UP AS REGARDS H_0?

- Last year, Riess et al. (arXiv:1103.2976) gave an improved determination of the Hubble constant using the HST (Key project value of $72 \pm 8\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ was in Freedman et al 2001.)

- This uses the Wide Field Camera 3 to improve the local distance ladder measurements of Cepheids and their cross-calibration with SNe IA

- Riess et al value is $73.8 \pm 2.4\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$

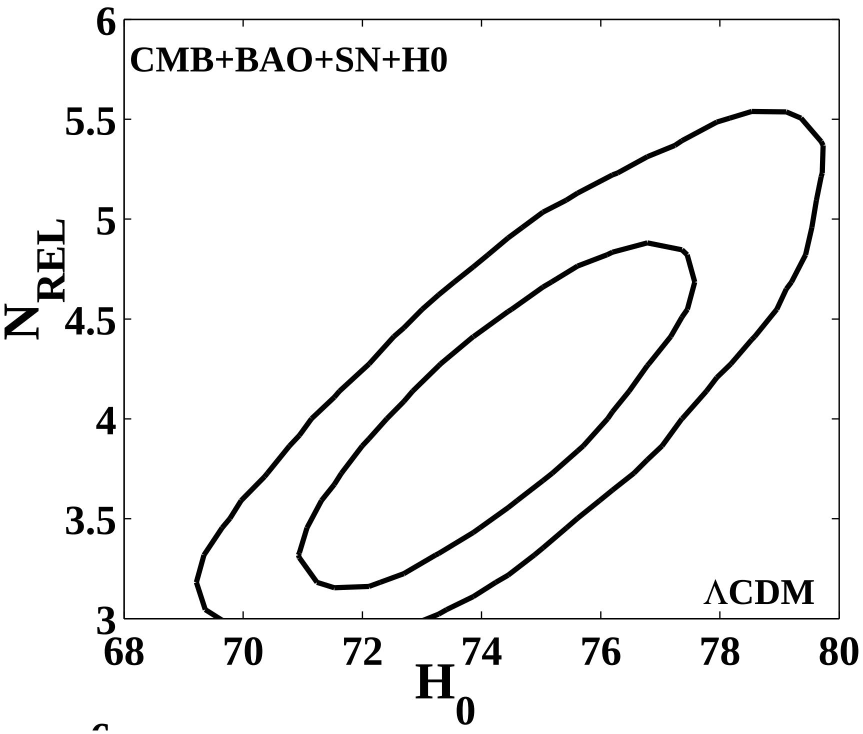
- BOSS values for different types of cosmological model are shown right



From Anderson et al (arXiv:1203.6954)

TENSION BUILDING UP AS REGARDS H_0?

- They suggest the best way to bring the two into agreement is with a greater number of neutrino species ($N_\nu = 4.26 \pm 0.56$)



From Mehta et al (arXiv:1202.0092)

The Primordial Power Spectrum

- Inflation produces a primordial power spectrum expressed in terms of the local 3-space curvature: $\mathcal{P}_{\mathcal{R}}(k)$ ($\mathcal{R}$ here is the same as the ζ often used for curvature perturbations), which is constant after horizon exit (hence so convenient)
- This is then reprocessed after horizon entry and during recombination to give the $C(\ell)$s and baryon features we measure toady
- Can we work back from the latter to get primordial spectrum?
- Have developed some new methods in Cambridge

- The structure of the primordial spectrum $\mathcal{P}_{\mathcal{R}}(k)$ is determined using an optimal model-free reconstruction
- The reconstruction process is essentially the same as *binning*, however here we allow the data to decide the level of complexity of the model – the number of nodes and their optimum position – via the Bayesian evidence

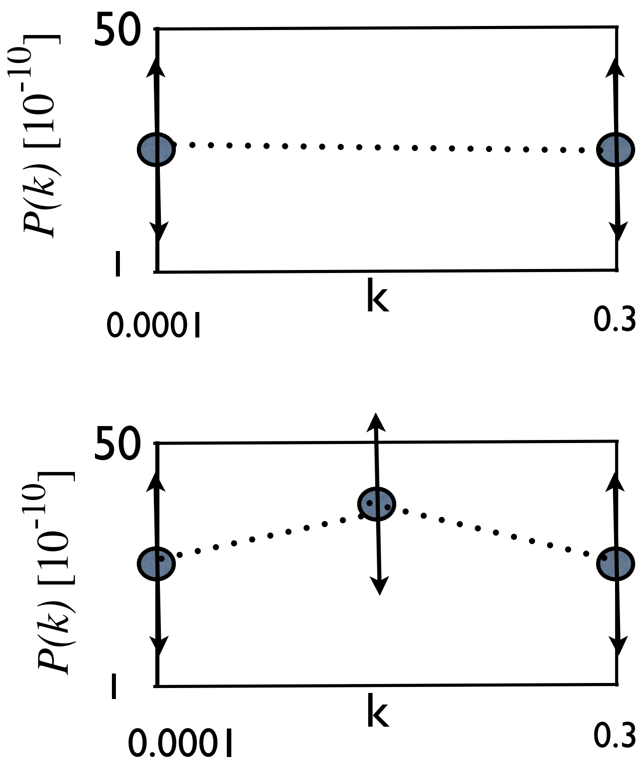
We parameterise $\mathcal{P}_{\mathcal{R}}(k)$ with a specific number of bins, logarithmically spaced in k, and varying only each amplitude A_{s,k_i}.

The form of the power spectrum is described by

$$\mathcal{P}_{\mathcal{R}}(k) = \begin{cases} A_{s,k_{min}} & k \le k_{min} \\ A_{s,k_i} & k \in \{k_i\} \\ A_{s,k_{max}} & k \ge k_{max} \end{cases}$$

and with linear interpolation for

$$k_{min} \le k_i < k < k_{i+1} \le k_{max}.$$

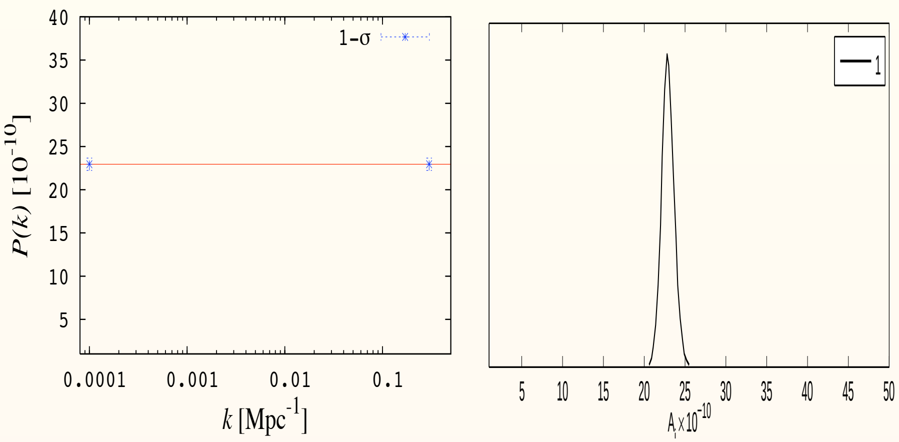


- This work carried out in Vazquez, Bridges, Hobson & Lasenby, JCAP, **06** (2012), 006 (arXiv:1203.1252)
- Uses WMAP7, ACT, Supernovae (SCP), LRG power spectrum from SDSS DR7 and Riess et al. (2009) HST H_0 prior
- Bayesian evidence calculated accurately using MULTINEST algorithm (Feroz, Hobson & Bridges, arXiv:0809.3437)
- Evidence is essentially the average of the likelihood w.r.t. the prior, and automatically incorporates Occam's razor into Bayesian reasoning
- Can interpret directly as probability of a given model j relative to a base model i (normally take ln of this ratio, and call this $\mathcal{B}_{j,i}$)
- Jefferies said:

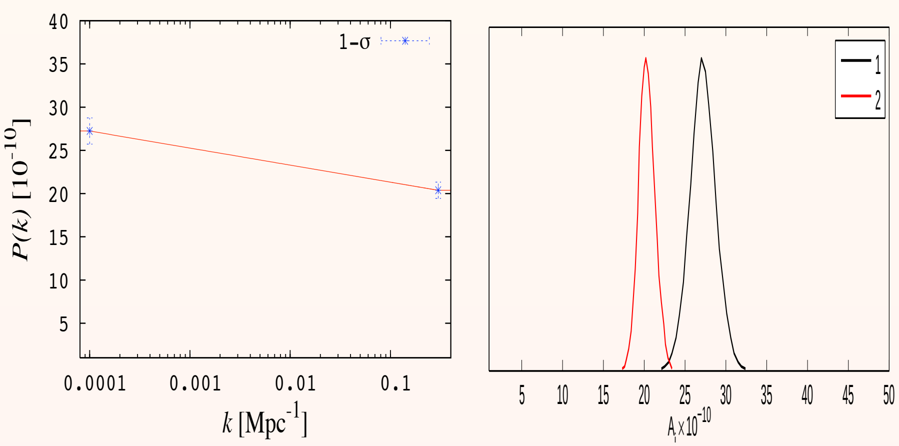
$\lvert\mathcal{B}_{i,j}\rvert$	Probability	Strength
< 1.0	< 0.750	Inconclusive
1.0-2.5	0.923	Significant
2.5-5.0	0.993	Strong
> 5.0	> 0.993	Decisive

RESULTS FOR HORIZONTALLY FIXED NODES

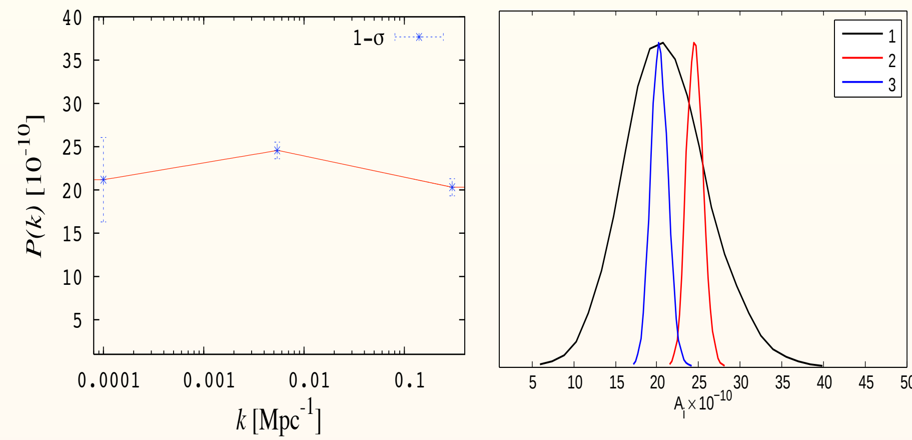
$(a)\ \mathcal{B}_{1,1} = 0.00 \pm 0.30$



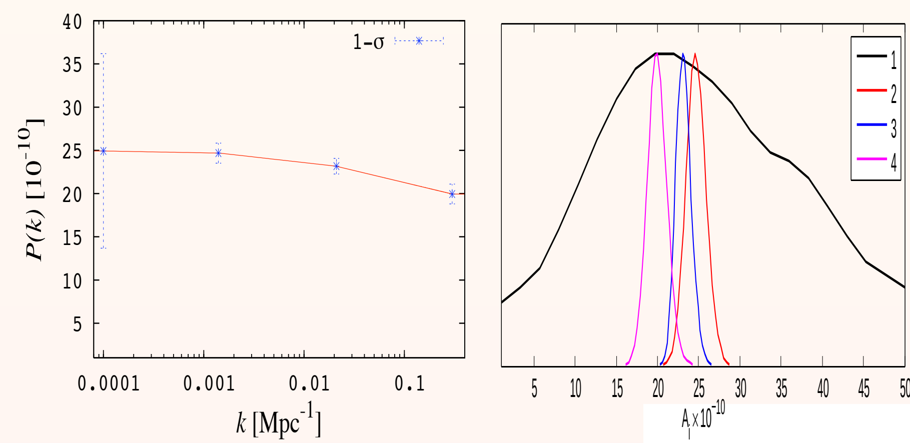
$(b)\ \mathcal{B}_{2,1} = +2.93 \pm 0.30$



$(c)\ \mathcal{B}_{3,1} = +2.75 \pm 0.30$



$(d)\ \mathcal{B}_{4,1} = +0.67 \pm 0.30$



So here, simple slope (corresponding to an $n_s \approx 0.95$) has highest evidence.

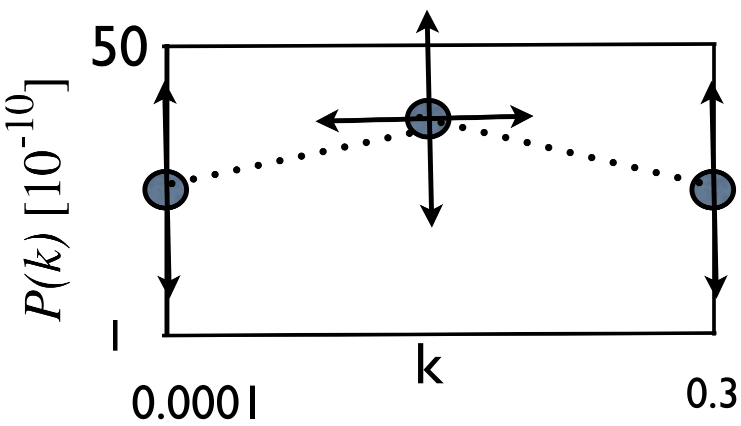
(Harrison-Zeldovich model strongly rejected.)

- To localise features in k-space, we may consider moving either back or forth the internal k-nodes until we find their optimal position
- Place internal additional 'nodes' with the freedom to move around in both position k_i and amplitude A_{s,k_i}

The spectrum is then described by

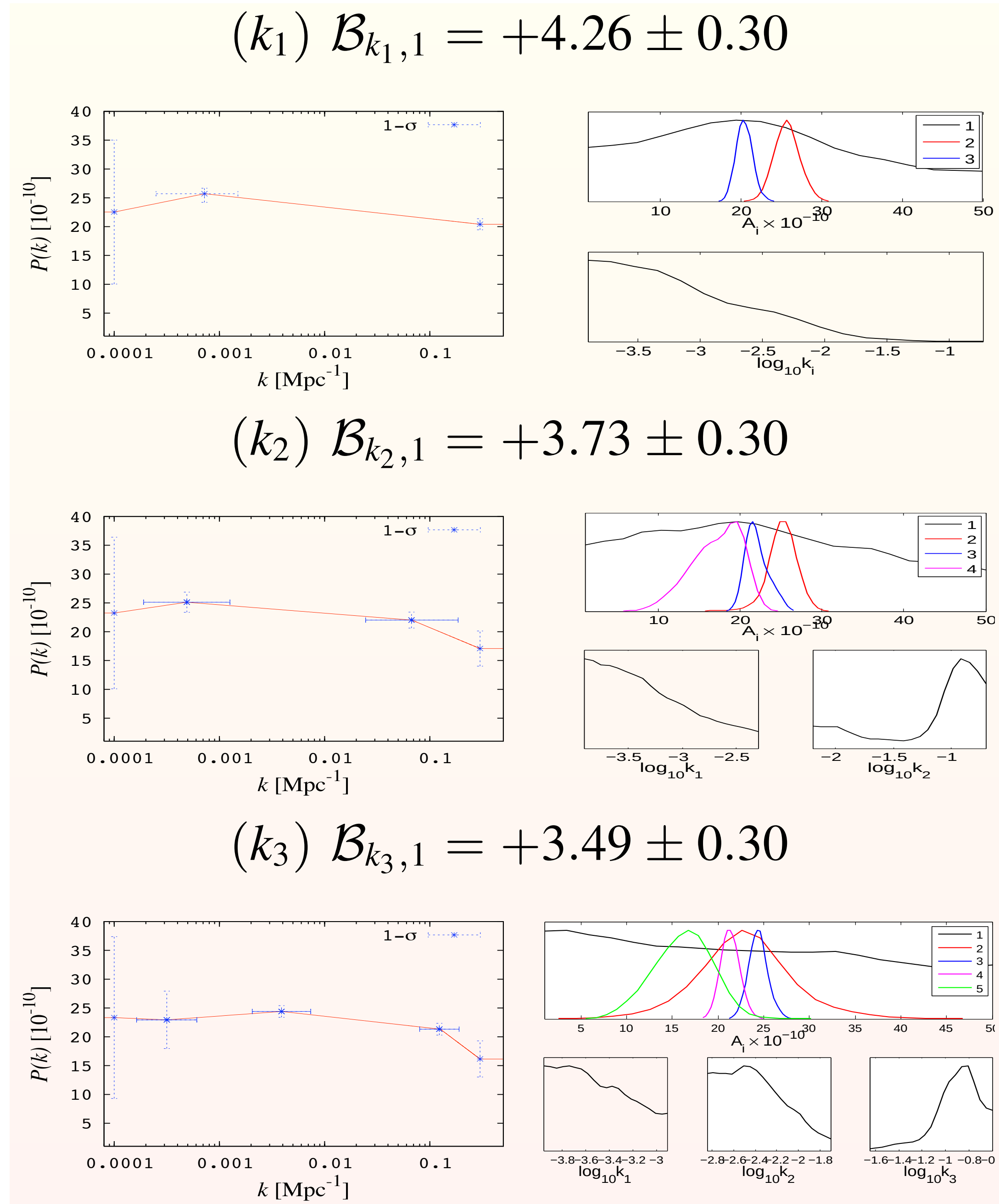
$$\mathcal{P}_{\mathcal{R}}(k) = \begin{cases} A_{\mathrm{s},k_{\mathrm{min}}} & k \leq k_{\mathrm{min}} \\ A_{\mathrm{s},k_i} & k_{\mathrm{min}} < k_i < k_{i+1} < k_{\mathrm{max}} \\ A_{\mathrm{s},k_{\mathrm{max}}} & k \geq k_{\mathrm{max}} \end{cases} \tag{1}$$

and with linear interpolation for $k_{\mathrm{min}} \leq k_i \leq k_{\mathrm{max}}$.



RESULTS FOR FREE PLACEMENT OF INTERNAL NODES

- Here, one internal node (and two fixed external nodes) is optimal
- Evidence ratio says this this model has a probability $\exp(4.26) = 71$ times more likely than Harrison-Zeldovich, and $\exp(4.26 - 2.93) = 3.8$ times more likely than two-node parametrisation (so significant on Jefferies scale)



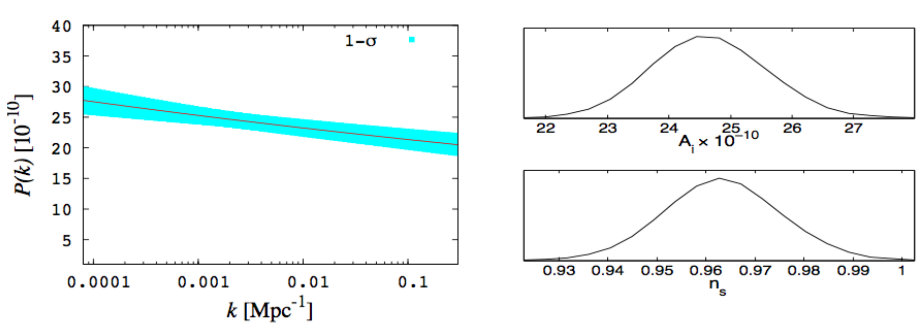
Results for Power-law and running spectra

... for comparison

The standard approach assumes a power-law parameterisation in terms of a spectral amplitude A_s and a spectral index or tilt parameter n_s:

$$\mathcal{P}_\mathcal{R}(k) = A_\mathrm{s}\left(\frac{k}{k_0}\right)^{n_\mathrm{s}-1},$$

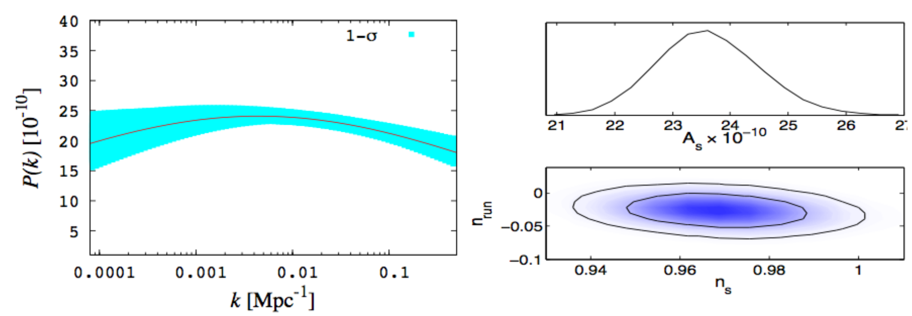
(n_s) $\mathcal{B}_{n_\mathrm{s},1} = +3.25 \pm 0.30$



Consider possible deviations from power-law by allowing the spectral index to vary as a function of scale $n_\mathrm{s}(k)$:

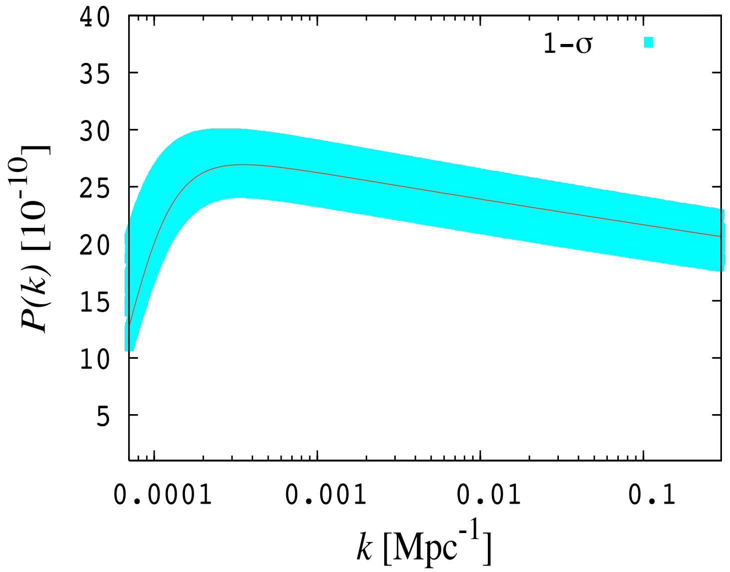
$$\mathcal{P}_\mathcal{R}(k) = A_\mathrm{s}\left(\frac{k}{k_0}\right)^{n_\mathrm{s}-1+\frac{1}{2}\ln\left(\frac{k}{k_0}\right)n_\mathrm{run}},$$

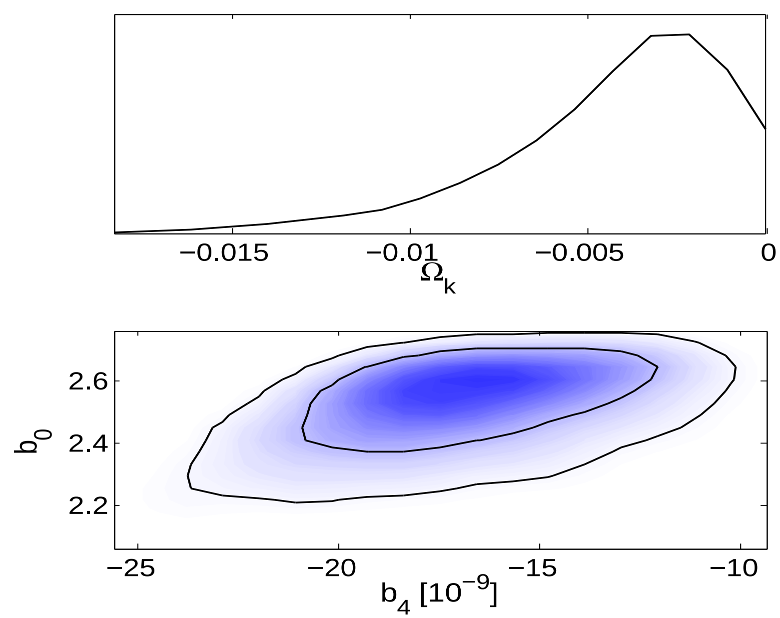
(n_run) $\mathcal{B}_{n_\mathrm{run},1} = +2.06 \pm 0.30$



- The LD model is based on the restriction of the total conformal time available in the entire history of a closed Universe. $\mathcal{P}_{\mathcal{R}}(k)$ depends upon $\{b_0, b_4\}$
- Naturally incorporates an exponential cut-off on large scales $\rightarrow$ possible explanation for the lower-than-expected CMB spectrum at low multipoles.
- On small scales, $\mathcal{P}_{\mathcal{R}}^{1/2}(k)$ and ln k is linear, $\rightarrow$ predicting a reduced power at large k as compared to a simple tilted spectrum (ln $\mathcal{P}_{\mathcal{R}}^{1/2}(k)$ vs ln k is linear).

$$\mathcal{B}_{\mathrm{LD},1} = +4.94 \pm 0.30$$



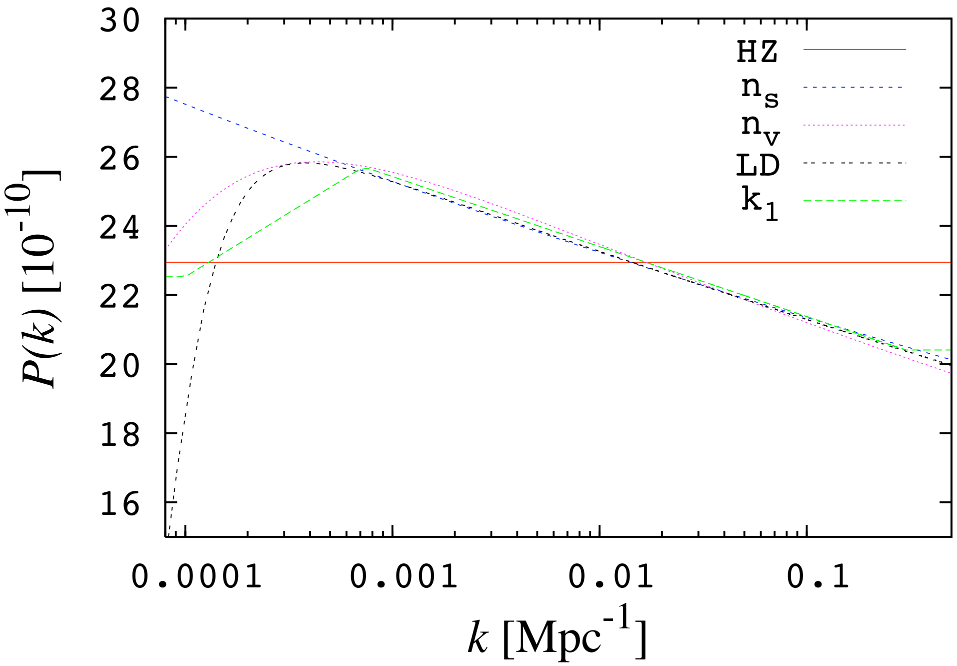


For further details see *A. Lasenby, C. Doran Phys.Rev.D.,* ***71****, 063502 (2005) and Vazquez, Lasenby, Bridges & Hobson (2011) (arXiv:1103.4619)*

CONCLUSIONS ON $\mathcal{P}_{\mathcal{R}}(k)$

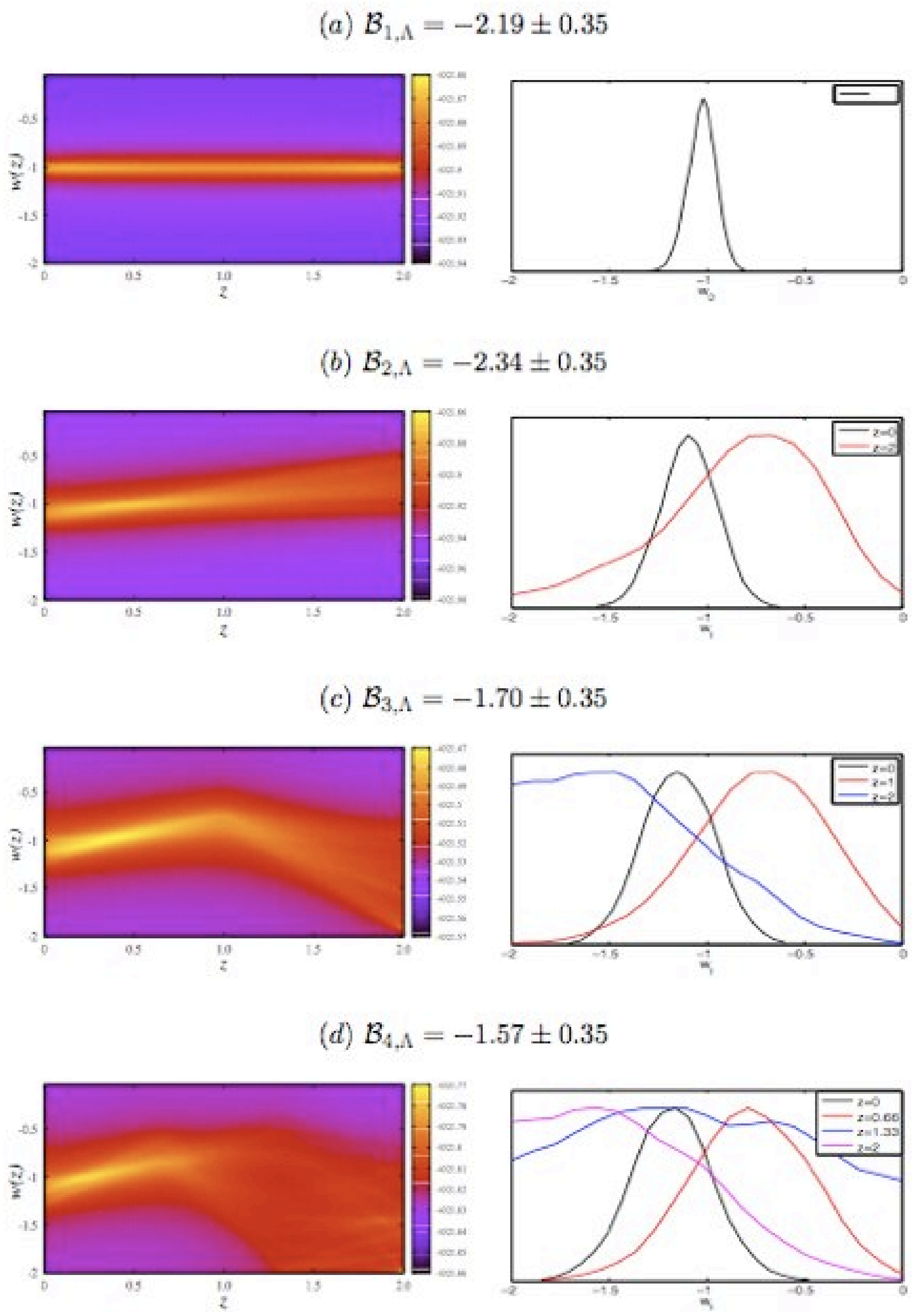
We fit an optimal degree of structure for the primordial spectrum using Bayesian model selection as our discriminating criterion.

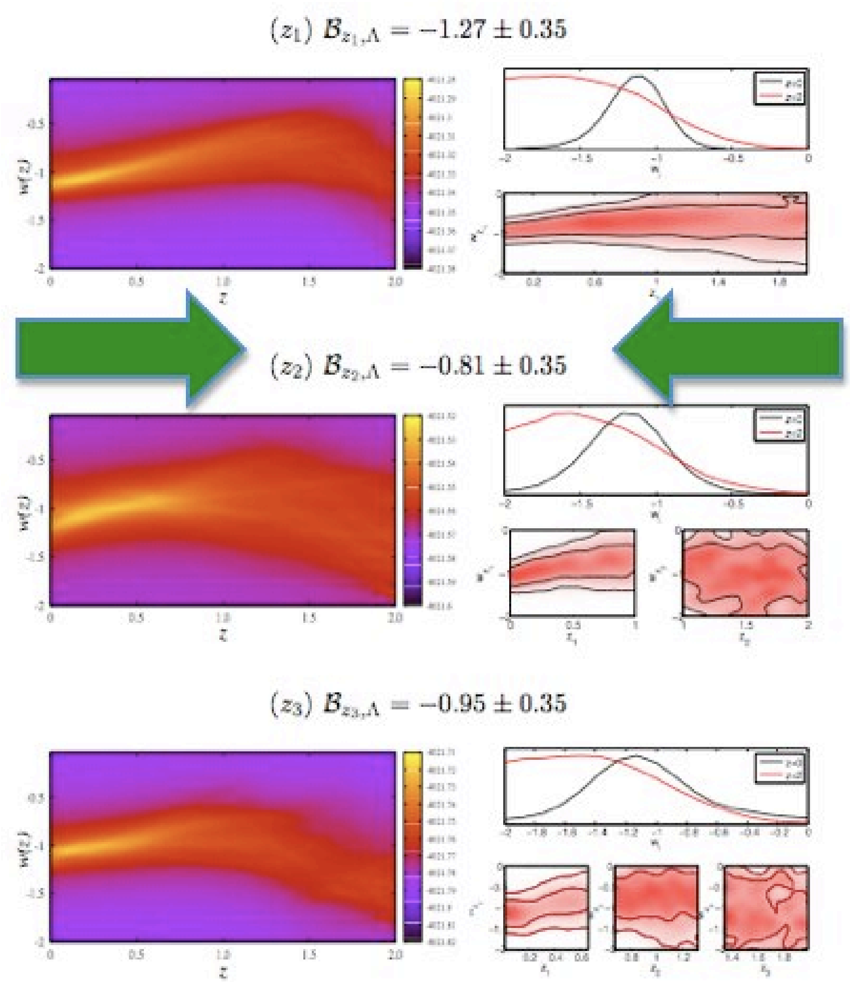
Model	N_{par}	χ^2_{min}	Bayes factor
HZ	8	0.0	$+0.0 \pm 0.3$
n_S	9	-8.6	$+3.3 \pm 0.3$
LD	10	-9.4	$+4.9 \pm 0.3$
k_1	11	-9.1	$+4.3 \pm 0.3$



- The presence of a turn-over at large scales and the reduced power at small scales are important in the selection of the best-fit model through its Bayesian evidence
- Note turnover on large scales happens not just in the L+D closed universe model, but anywhere we have initial kinetic dominance (e.g. several works by Sanchez, de Vega and Destri)
- We believe we have shown here that the data argues for this in a model independent way

Application of the same techniques to dark energy $w(z)$



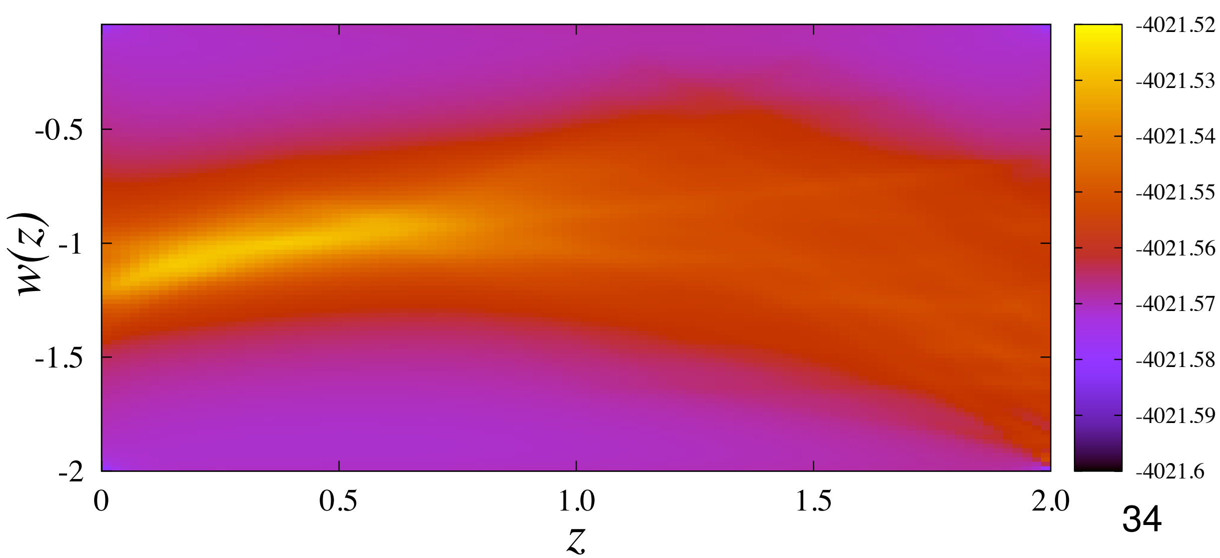


$\lvert\mathcal{B}_{i,j}\rvert$	Probability	Strength
< 1.0	< 0.750	Inconclusive
1.0-2.5	0.923	Significant
2.5-5.0	0.993	Strong
> 5.0	> 0.993	Decisive

CONCLUSIONS FOR $w(z)$ RECONSTRUCTION

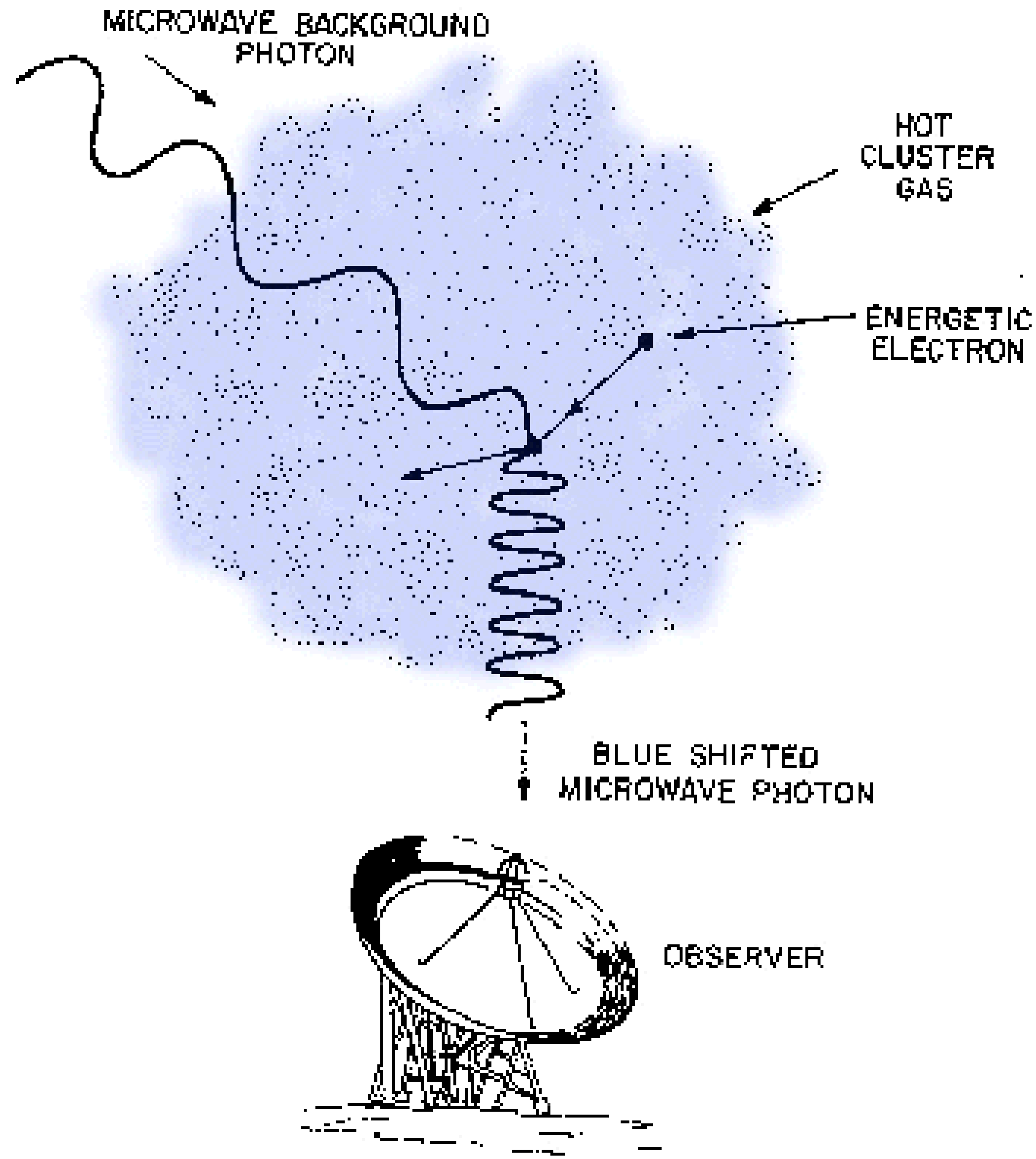
- Work reported here is in Vazquez, Bridges, Hobson & Lasenby (arXiv:1205.0847)
- Preferred model in terms of evidence is plain Λ, i.e. $w = -1 = \text{const.}$
- All solutions seem to exhibit a preferred temporal evolution, however (at lower evidence)
- Besides Λ, the preferred $w(z)$ has $w \lesssim -1$ at the present time and a small bump located at $z \sim 0.6 - 1.0$
- Data is quite well constrained near $z \sim 0.3$ but poorly constrained from $z \gtrsim 1$
- Some well-known parameterizations are disfavoured (CPL = Chevallier-Polarski-Linder parameterisation $w(z) = w_0 + w_a z/(1+z)$; JBP = Jassal-Bagla-Padmanabhan parameterisation $w(z) = w_0 + w_a z/(1+z)^2$)

Model	N_{par}	$\mathcal{B}_{i,\Lambda}$
Λ	-	0.0 ± 0.3
CPL	+2	-2.8 ± 0.3
JBP	+2	-2.8 ± 0.3
(d)	+4	-1.6 ± 0.3
z_2	+6	-0.8 ± 0.3



PROGRESS WITH THE SUNYAEV-ZELDOVICH EFFECT

- There's been a great deal of progress made on the SZ effect over the past year, both external to Planck, and in papers from Planck
- E.g. in first category, SPT catalogue already discussed, and also new aspects of the SZ effect itself
- Will discuss one of those here, then move on to Planck. So much material overall that will basically only be able to give a few highlights! (See also talk by Carlo Burigana)



(From astro.uchicago.edu.)

First detection of the Kinetic SZ effect

- The Kinetic SZ effect is proportional to $v_{\text{pec}}\tau$, where τ is the optical depth through the cluster, $\int n_e \sigma_T dl$

- Meanwhile the thermal effect is proportional to the line integral of pressure through the cluster $\int n_e \sigma_T (k_B T_e / m_e c^2) dl$

- So if we estimate the temperature from the virial theorem, i.e. $k_B T_e \sim m_p GM/R$, we find that the ratio of Kinetic to Thermal SZ effect is

$$\frac{\text{kSZ}}{\text{tSZ}} \approx \frac{m_e c^2}{m_p} \frac{(v_{\text{pec}}/c)}{GM/R}$$

- So assuming v_{pec} is set by Lambda CDM, and typically $200\,\text{km}\,\text{s}^{-1}$, we can see that the ratio is going to be smaller for clusters which have a large potential well, i.e. for more massive clusters, and biggest for small potential wells (e.g. groups of galaxies)

- So (putting numbers on this), for a cluster mass $\sim 8 \times 10^{14} M_\odot$, $\text{kSZ}/\text{tSZ} \sim v_{\text{pec}}/3500\,\text{km}\,\text{s}^{-1} \approx$ 6%, while for a ‘cluster’ mass $10^{13} M_\odot$, expect effects about comparable

FIRST DETECTION OF THE KINETIC SZ EFFECT

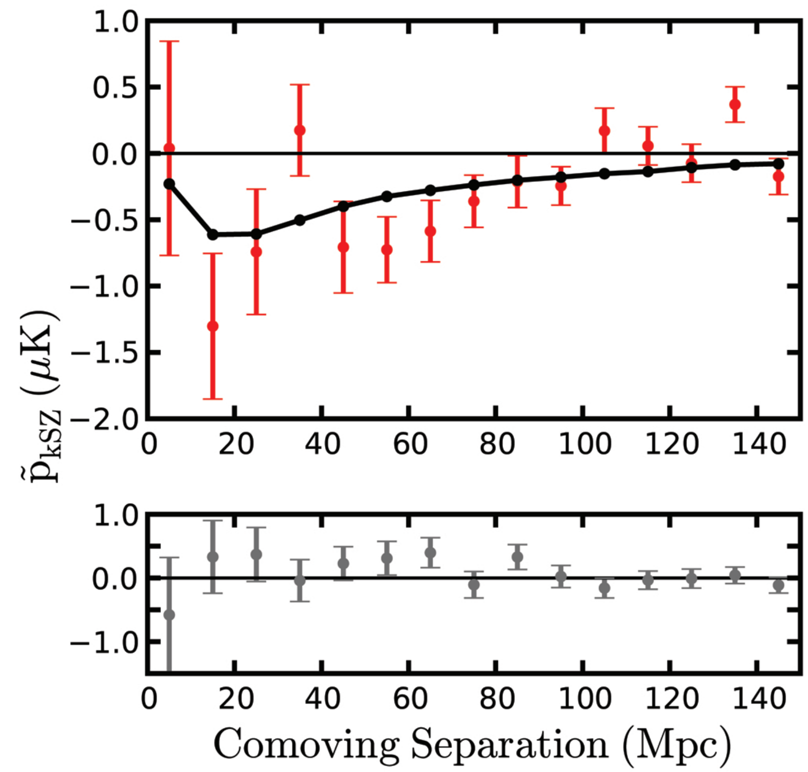
- So up to now, with observations concentrating on largest clusters, effect has never been seen
- Recently ACT (in Hand et al, arXiv:1203.4219) have made first detection of the effect statistically, by looking at pairwise momentum statistic at positions of a sample of galaxies in BOSS Data Release 9
- Statistic (if had 3d information) is

$$p_{\mathsf{pair}}(r) = \langle (\mathsf{p}_i - \mathsf{p}_j) \cdot \widehat{\mathsf{r}}_{ij} \rangle$$

- This should show an effect, since on average, under gravitational instability motions, clusters should show a mean motion towards each other

First detection of the Kinetic SZ effect

- ‘Momentum’ is measured by the kSZ and the thermal SZ automatically cancels out!
- So can just use the ‘bare’ ACT 148 GHz data at the cluster positions, without needing to separate out the two contributions
- So effect appears to be seen, at approx 3.8σ, and is in line with expectations for Lambda CDM universes: $\sim 2.2\,\mu\mathrm{K}$ for masses about $10^{14} M_\odot$ and $\sim 0.9\,\mu\mathrm{K}$ for masses about $10^{13} M_\odot$, if $v_{\rm pec} \sim 200\,\mathrm{km\,s}^{-1}$



From Hand et al, arXiv:1203.4219. Bottom panel shows same constructed with randomized positions

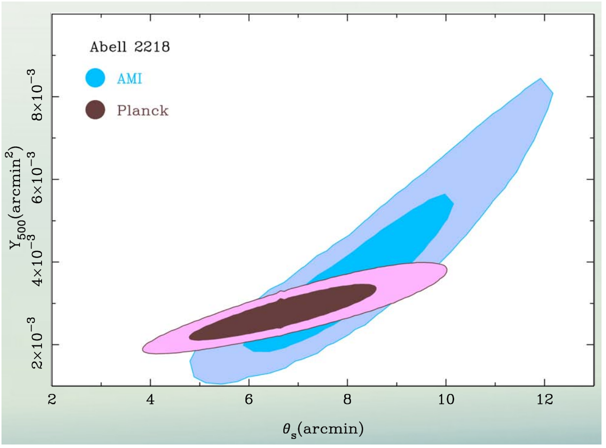
The scientific results presented today are a product of the Planck Collaboration, including individuals from more than 50 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency -- ESA -- with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

AMI and Planck observations of Clusters

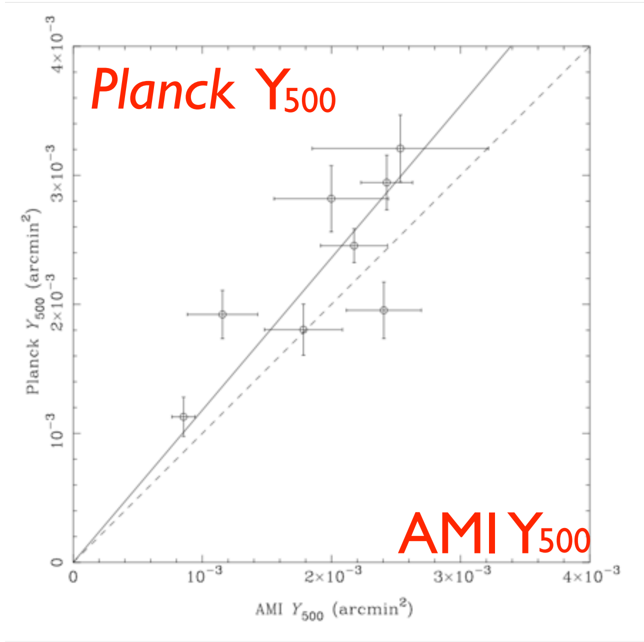
- AMI (The Arcminute MicroKelvin Imager) is a telescope for observing the Sunyaev-Zeldovich effect in clusters of galaxies
- Consists of two arrays (the Large and Small arrays) sited at Lord's Bridge near Cambridge, working at 15 GHz
- Planck SZ constraints exhibit a degeneracy between derived SZ Compton-Y parameter and cluster size
- AMI's higher resolution can provide more accurate cluster positions & size estimates, and thus break this degeneracy
- Also being used for verification of new candidate detections from Planck

THE AMI SMALL ARRAY

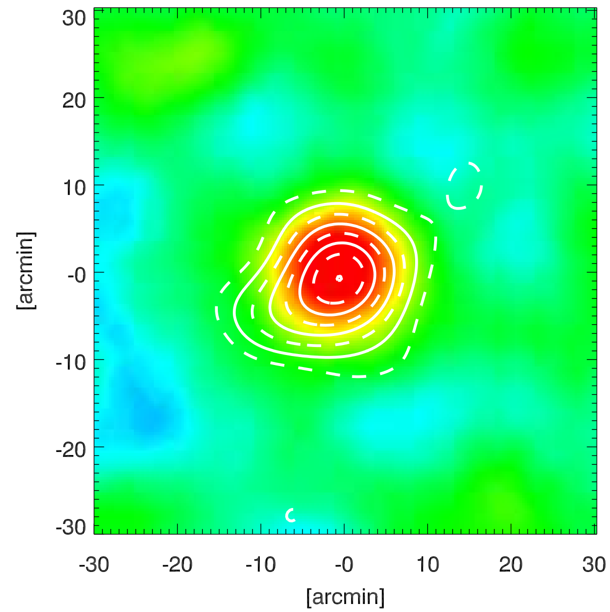


COMPARISON OF PLANCK AND AMI DATA FOR A KNOWN CLUSTER — A2218

- We have recently submitted a joint study of 11 clusters observed by both AMI and Planck (arXiv:1204.1318)
- Sample includes two cool-core clusters, two newly-discovered Planck clusters, and has a fairly large spread in redshift ($0.11 < z < 0.55$)
- Good agreement on many individual clusters but on average, AMI finds clusters to be fainter and smaller than Planck. Currently investigating whether changing assumed form of radial pressure profile is key to understanding this
- (AMI also doing many other SZ observations, and also galactic object science, particular for spinning dust where AMI's frequency and resolution fills a unique niche.)

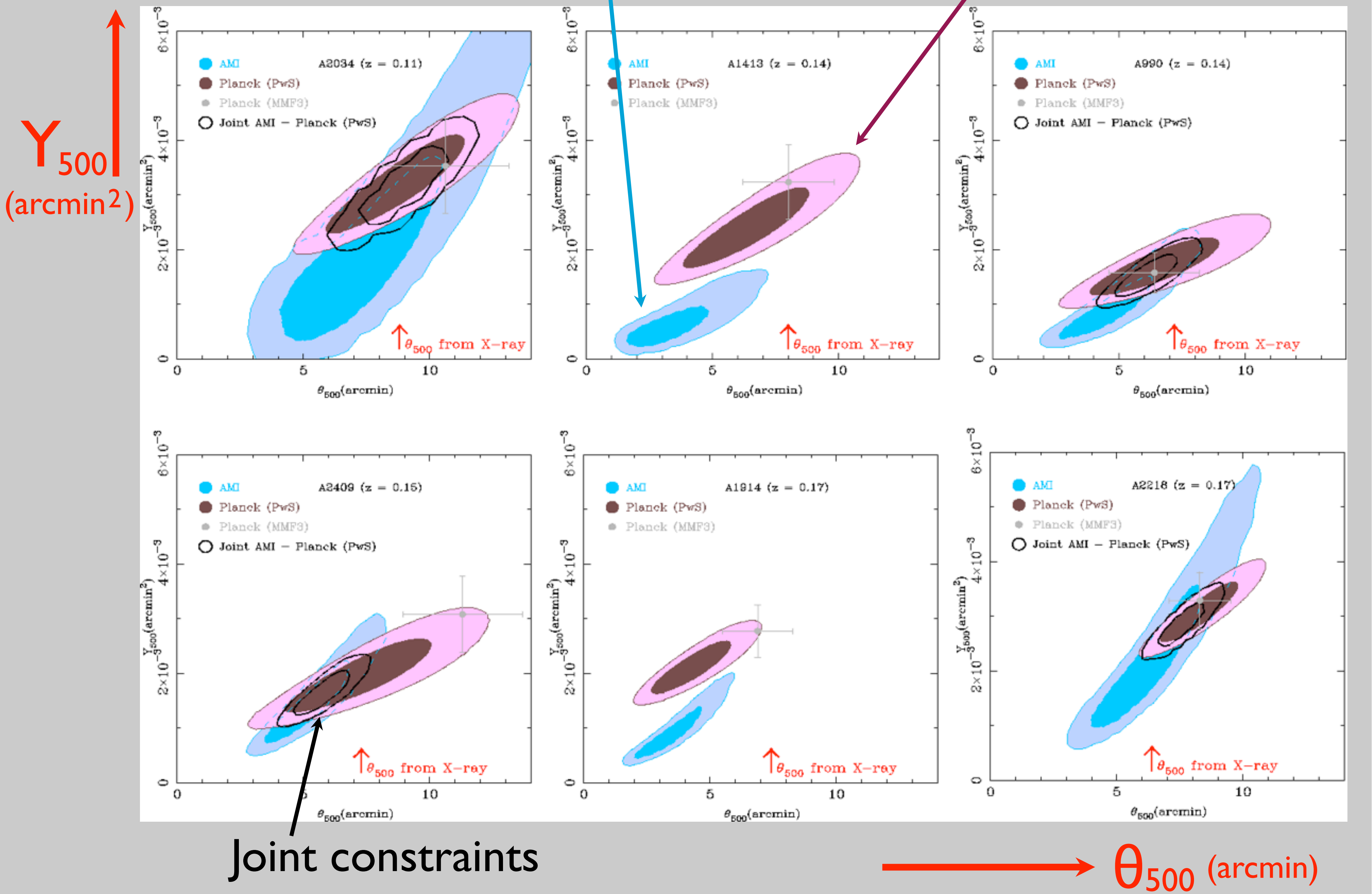


Comparison of Planck and AMI SZ amplitudes

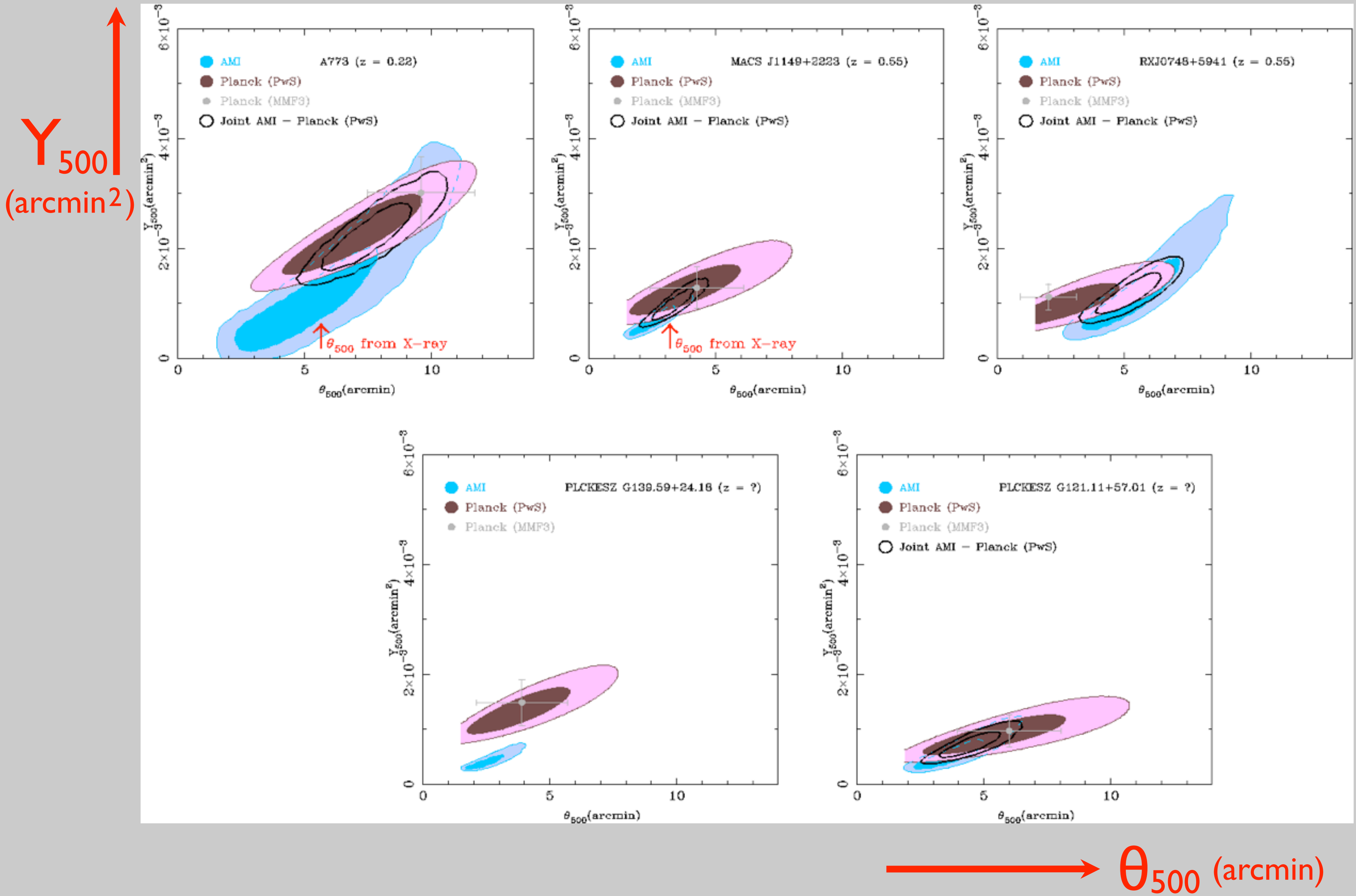


AMI observations of the new Planck cluster PLCKESZ G139.59+24.19. Contours = AMI, Colour = Planck

Results:


AMI constraints
Planck constraints
Y_{500} ($arcmin^2$)
Joint constraints
θ_{500} (arcmin)
AMI
Planck (PwS)
Planck (MMF3)
Joint AMI – Planck (PwS)
A2034 (z = 0.11)
A1413 (z = 0.14)
A990 (z = 0.14)
A2409 (z = 0.15)
A1914 (z = 0.17)
A2218 (z = 0.17)
θ_{500} from X-ray
θ_{500}(arcmin)
Y_{500}($arcmin^2$)

Results: AMI constraints *Planck* constraints



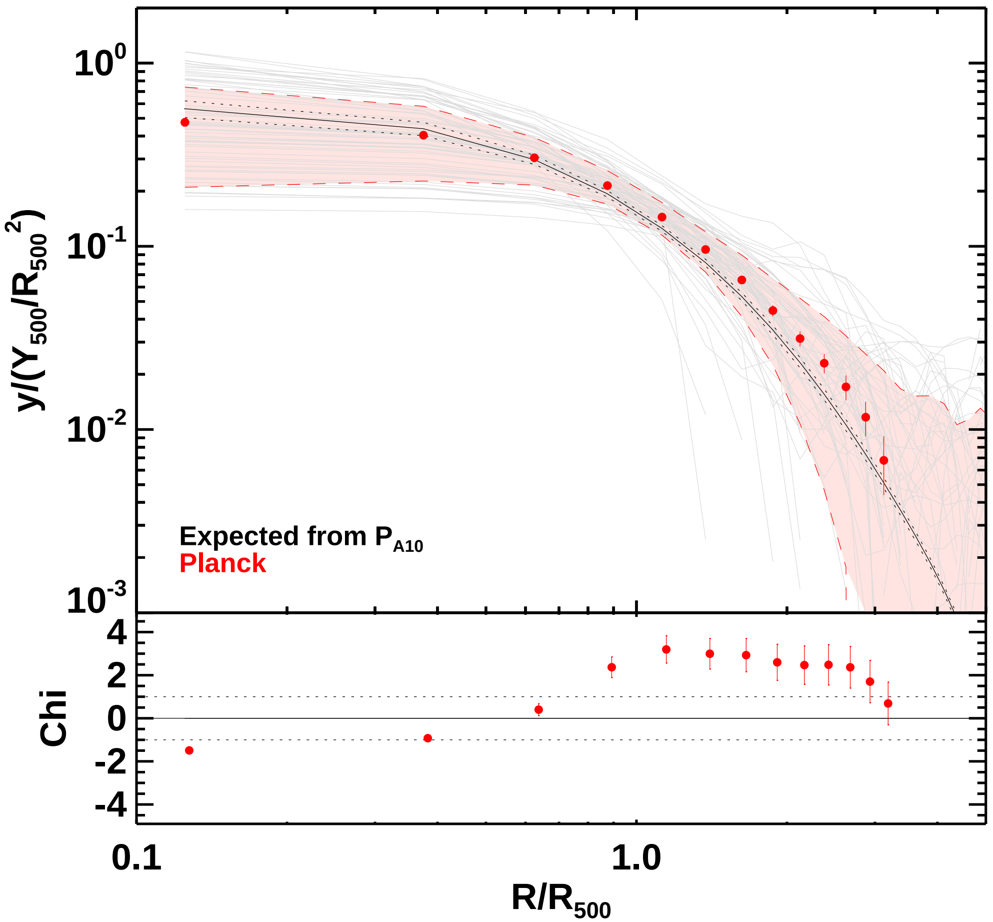
Direct results on pressure profiles from Planck

- The pressure profile used in Planck analysis (matched in AMI analysis) so far has been the Universal Pressure Profile of Arnaud et al, (A&A, **517**, A92,(2010)) a GNFW profile derived from X-ray observations and numerical simulations

$$P(r) = P_{500}\left(\frac{M_{500}}{3\times 10^{14} M_\odot}\right)^{\alpha_{\rm P}} \frac{P_0}{(c_{500}x)^\gamma \left(1+(c_{500}x)^\alpha\right)^{\frac{\beta-\gamma}{\alpha}}}$$

- A particular set of the concentration and shape parameters $c_{500}, \alpha, \beta, \gamma$ etc., was derived by Arnaud et al.

- The evidence now from Planck and X-ray observations of 62 nearby clusters is that this profile underpredicts SZ effect in outer regions (main effect from β being too large)
- This would also potentially tie in with AMI results — Planck more sensitive to extended emission than AMI, so if UPP (used in the common analysis) is not the right profile, AMI would be thought to be giving on average too small results
- Work now proceeding on a larger sample of common clusters
- Many other wonderful Planck results on clusters, see e.g. http://www.iasfbo.inaf.it/events/planck-2012/talks/pip for several publically available talks



From Planck Intermediate Paper V: 'Pressure profiles of galaxy clusters from the Sunyaev-Zeldovich effect' arXiv:1207.4061

CONCLUSIONS

- B-mode searches still ongoing — some way to bridge gap to even largest values of r expected (~ 0.1)
- Temperature power spectrum at small angular scales proving very interesting — also tie in with BAO — questions developing about H_0 and number of neutrino species
- Secondaries (inc. SZ effect) rapidly developing — large SZ cluster catalogues, and larger to come (e.g. Planck at start of next year)
- Some new information about outer regions of clusters, and detailed astrophysics internally