Planck results on inflation: The future

Martin BUCHER, Laboratoire Astroparticles & Cosmologie,
Université Paris 7 (Denis-Diderot)

for the PLANCK Collaboration

18 June 2013, CERN Institute "Cosmology and Fundamental Physics with Planck"

Underlying question: conventional parameterization

What is the primordial power spectrum?

- For lack of a fundamental theory, expand in powers of $\ln(k)$

$$
\begin{aligned}
\ln\left(\mathcal{P}(\ln k)\right) &= \mathcal{P}_0\left(\ \ln(k/k_{piv})\right)^0 + \mathcal{P}_1\left(\ \ln(k/k_{piv})\right)^1 + \mathcal{P}_2\left(\ \ln(k/k_{piv})\right)^2 + \ldots \\
\mathcal{P}(k) &= A(k/k_{piv})^{(n_s-1)} \\
&\text{or} \\
\mathcal{P}(k) &= A(k/k_{piv})^{(n_s-1)+\alpha\ln(k/k_{piv})+\ldots}
\end{aligned}
$$

- *Planck* seems to be telling us that the first two terms suffice, and using just the first term can be ruled out at a respectable statistical significance. $n_S \neq 1$ implies exact scale invariance needs to be downgraded to an approximate symmetry. No statistically significant evidence for running of the spectral index.

Underlying question: searching for features

- Two approaches
  - Parameterized approaches : make Ansätze with a small number of extra parameters and compare quality of fit to simpler model to determine whether extra parameters are justified by the data (Aikake Information Criterion, Bayesian Information Criterion, Bayesian Evidence, . . .). (Approach followed in Planck paper XXII, section 8)
  - Non-parameterized approaches: penalized likelihoods,.... [Details of approach followed in Planck XXII paper follow: Gauthier, Christopher; Bucher, Martin; Reconstructing the primordial power spectrum from the CMB, JCAP 10, 050 (2012) (arXiv:1209.2147) (Approach followed in Planck paper XXII, section 7)

Penalized likelihood

Let $\mathcal{P}_0(k) = A_\mathrm{s}(k/k_*)^{n_\mathrm{s}-1}$ be the best fit power spectrum of the six parameter model. We define a general Ansatz for the power spectrum in terms of a fractional variation, $f(k)$, relative to this fiducial model, so that

$$\mathcal{P}_\mathcal{R}(k) = \mathcal{P}_0(k)\Big[1 + f(k)\Big]. \tag{1}$$

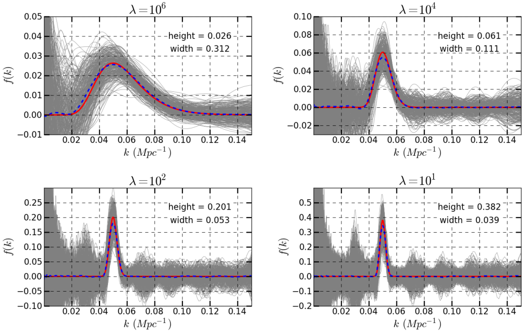
Any features are then described in terms of $f(k)$.

In this analysis we use the Planck+WP likelihood supplemented by the following prior, which is added to $-2\ln\mathcal{L}$:

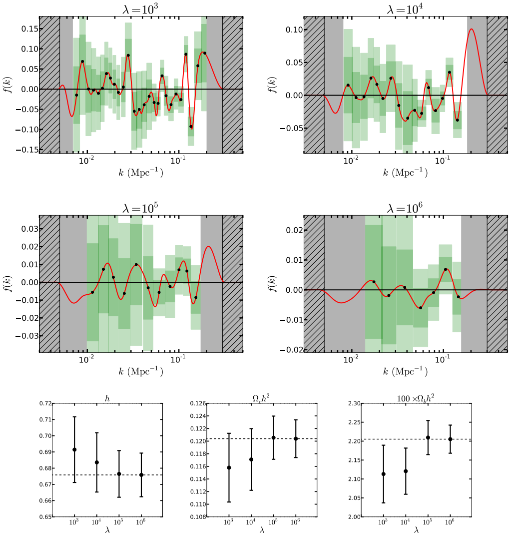
$$\begin{aligned}\mathbf{f}^T\mathbf{R}(\lambda,\alpha)\mathbf{f} = \lambda\int \mathrm{d}\kappa\ \left(\frac{\partial^2 f(\kappa)}{\partial\kappa^2}\right)^2 \\ + \alpha\int_{-\infty}^{\kappa_\mathrm{min}} \mathrm{d}\kappa\ f^2(\kappa) + \alpha\int_{\kappa_\mathrm{max}}^{+\infty} \mathrm{d}\kappa\ f^2(\kappa).\end{aligned} \tag{2}$$

where $\kappa = \ln k$.

Validation of method

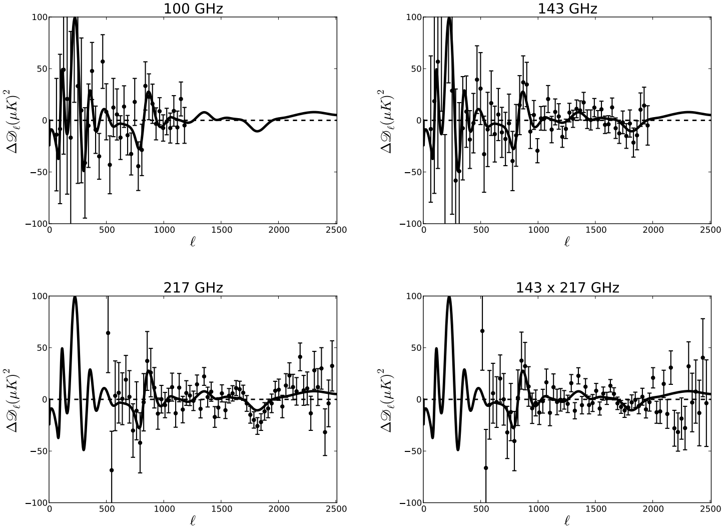


Results on Planck “Nominal mission" likeklihood

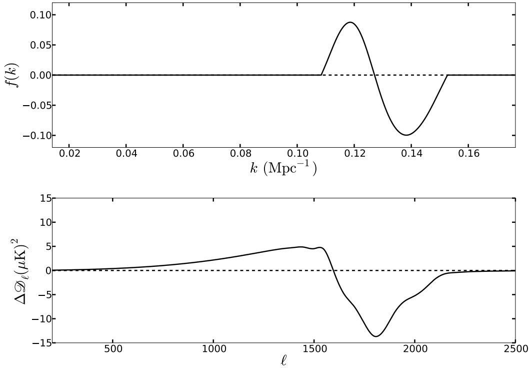


Maximum excursions locally 3.2σ and 3.9σ for $\lambda = 10^4$ and 10^3, respectively. After look-elsewhere-effect translates into $p = 1.74\%$ and $p = 0.21\%$, or 2.4σ and 3.1σ.

Where does this come from in the CMB multipole power spectrum?



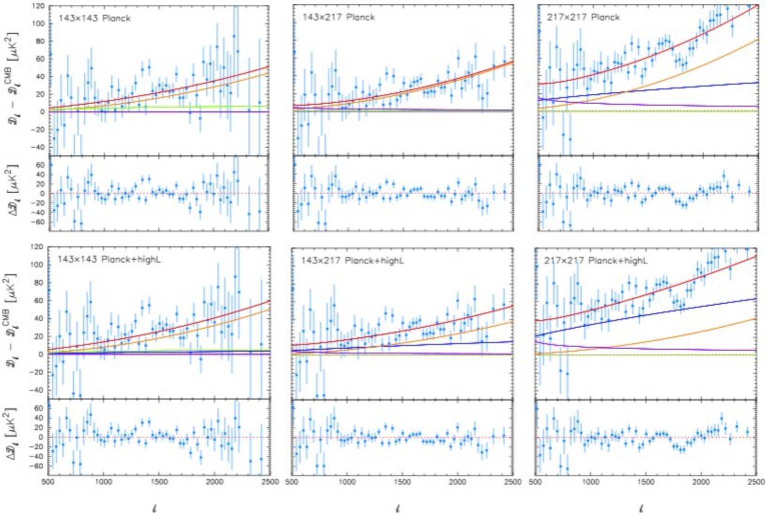
Proof that signal is from around $\ell \approx 1800$



(Extract from parameters paper)

To the extremely high accuracy afforded by the Planck data, the power spectrum at high multipoles is compatible with the predictions of the base six parameter ΛCDM cosmology. This is the main result of this paper. Fig. 1 does, however, suggest that the power spectrum of the best-fit base ΛCDM cosmology has a higher amplitude than the observed power spectrum at multipoles $\ell \lesssim 30$. We will return to this point in Sect. 7.

(Extract from parameters paper)



(Extract from parameters paper)

Table 6. Goodness-of-fit tests for the *Planck* spectra. The $\Delta\chi^2 = \chi^2 - N_\ell$ is the difference from the mean assuming the model is correct, and the last column expresses $\Delta\chi^2$ in units of the dispersion $\sqrt{2N_\ell}$.

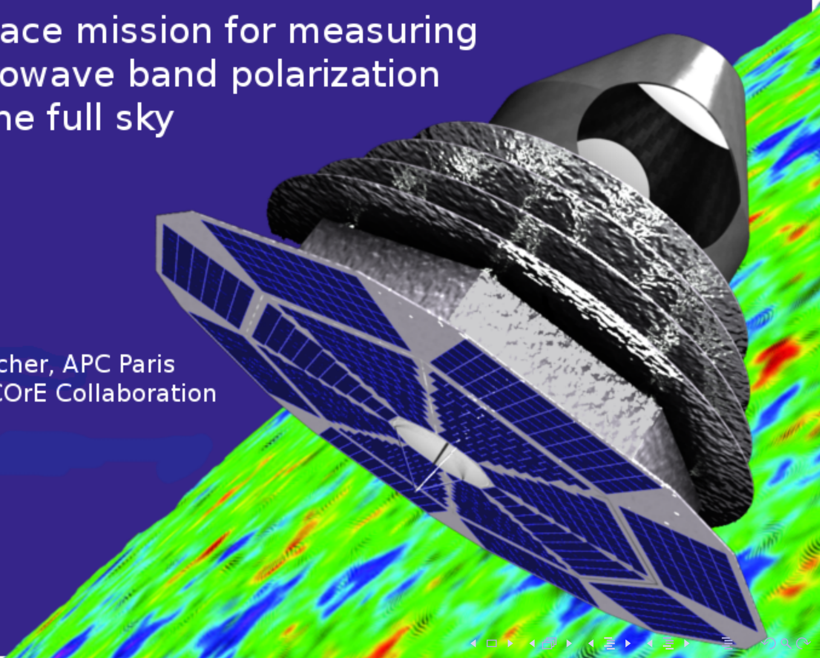
Spectrum	$\ell_{\rm min}$	$\ell_{\rm max}$	χ^2	χ^2/N_ℓ	$\Delta\chi^2/\sqrt{2N_\ell}$
100×100	50	1200	1158	1.01	0.14
143×143	50	2000	1883	0.97	-1.09
217×217	500	2500	2079	1.04	1.23
143×217	500	2500	1930	0.96	-1.13
All	50	2500	2564	1.05	1.62

Conclusions:

- While low-ℓ power spectrum anomaly is at about 2σ, the high ℓ anomaly is at 3.1σ.
- Global χ^2 is not a good statistical method to test for residuals because expected signal is concentrated in a small number of degrees of freedom and any possible signal becomes drowned in the noise. Good for proving concordance and testing understanding of noise model, but poor for detecting new physics.
- We must wait for a more detailed analysis using the full mission data.

COrE : Cosmic Origins Explorer

A space mission for measuring microwave band polarization on the full sky

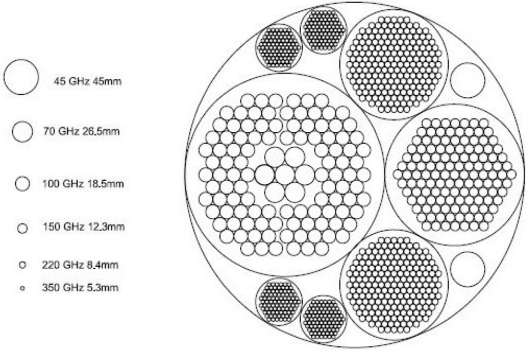


Martin Bucher, APC Paris
for the COrE Collaboration

History–European polarization satellites

- (circa 2006) CNES SAMPAN study - a refracting telescope - Conclusion : too expensive for France to do it alone, should explore mission in a European context
- (2006 - 2007) B-Pol defined (main partners: France, Germany, Italy, Spain, United Kingdom with a expression of interest from several US groups) proposal submitted in 2007 to ESA as a class M mission. Judged not technologically not ready, bets too much on a single and uncertain scientific objective, (i.e., B modes). Design: several telescopes for the various frequencies)
- (Jun 2010) Announcement of an M3 slot in the framework of ESA Cosmic Vision, remobilization of European collaboration, attempt to improve performance within the budget, to expand the science case, documents available at (www.core-mission.net). COrE was not selected but ranked 4th by the AWG, 3 projects were forwarded by the AWG to the SSAC. Disappointing but not bad !!

B-Pol (2007)


45 GHz 45mm
70 GHz 26.5mm
100 GHz 18.5mm
150 GHz 12.3mm
220 GHz 8.4mm
350 GHz 5.3mm

COrE: Cosmic Origins Explorer

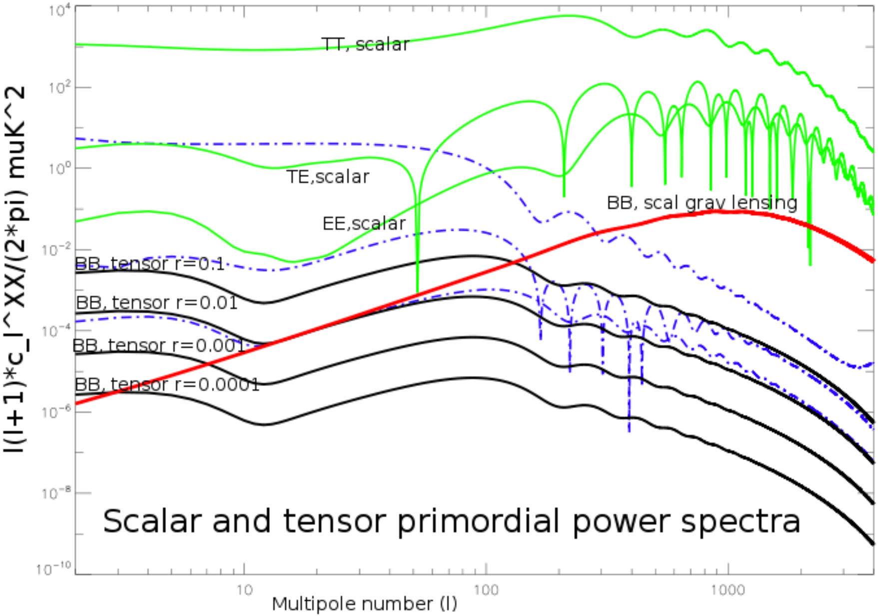
Proposed to ESA in December 2012 as a Cosmic Vision M3 Mission for ≈ 2020
http://www.core-mission.org
White paper available (90 pages) (astro-ph/1102.2181)
Answers to AWG Questions (available on website)

Mission and programmatics working group: F. R. Bouchet, P. de Bernardis, B. Maffei, P. Natoli, M. Piat, N. Ponthieu, R. Stompor

Instrument working group: B. Maffei, M. Bersanelli, P. Bielewicz, P. Camus, P. de Bernardis, M. De Petris, P. Mauskopf, S. Masi, F. Nati, T. Peacocke, F. Piacentini, L. Piccirillo, M. Piat, G. Pisano, M. Salatino, R. Stompor, S. Withington,

Science working group: M. Bucher, M. Avilles, D. Barbosa, N. Bartolo, R. Battye, J.-P. Bernard, F. Boulanger, A. Challinor, S. Chongchitnan, S. Colafrancesco, T. Ensslin, J. Fergusson, P. Ferreira, K. Ferriere, F. Finelli, J. Garcia-Bellido, S. Galli, C. Gauthier, M. Haverkorn, M. Hindmarsh, A. Jaffe, M. Kunz, J. Lesgourgues, A. Liddle, M. Liguori, P. Marchegiani, S. Matarrese, A. Melchiorri, P. Mukherjee, L. Pagano, D. Paoletti, H. Peiris, L. Perroto, C. Rath, J. Rubino Martin, C. Rath, P. Shellard, J. Urrestilla, B. Van Tent, L. Verde, B. Wandelt

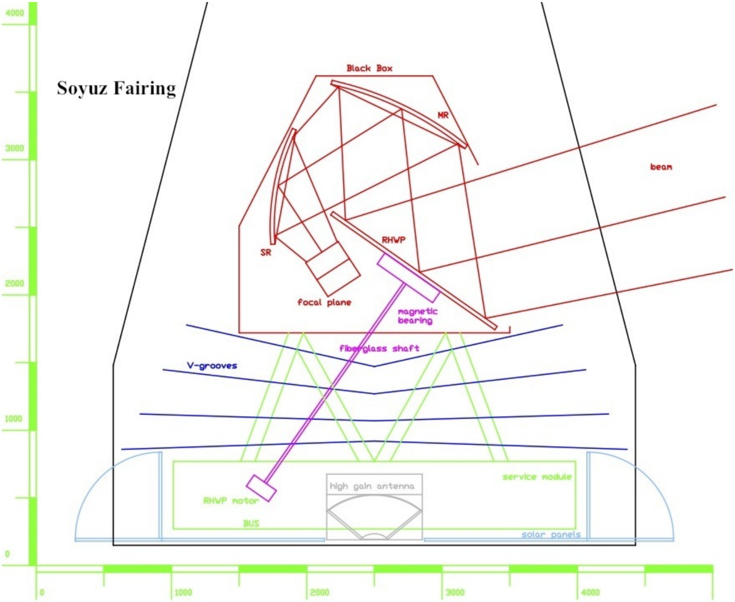
Foregrounds working group: C. Burigana, J. Delabrouille, C. Armitage-Caplan, A. Banday, S. Basak, A. Bonaldi, D. Clements, G. De Zotti, C. Dickinson, J. Dunkley, M. Lopez-Caniego, E. Martinez-Gonzalez, M. Negrello, S. Ricciardi, L. Toffolatti

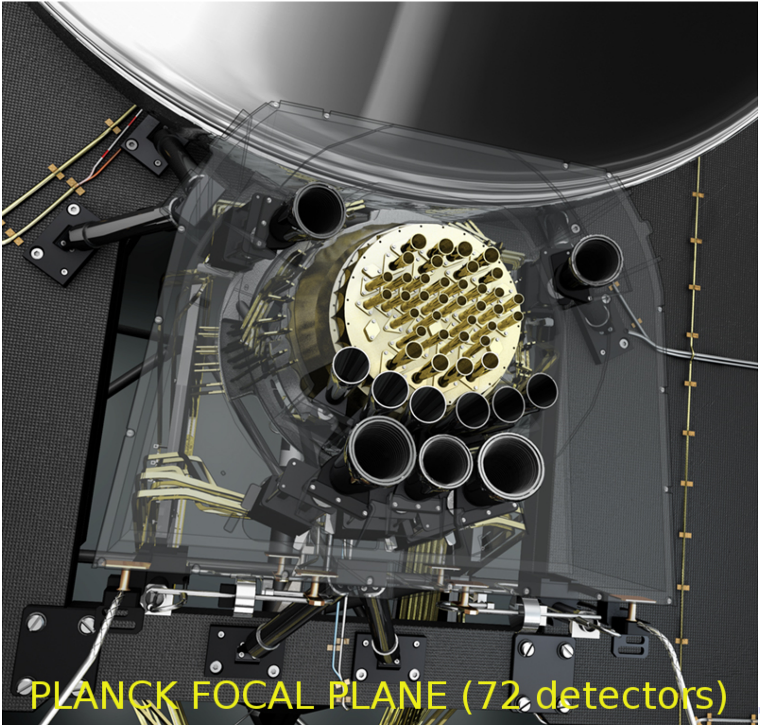


TT, scalar
TE,scalar
EE,scalar
BB, scal grav lensing
BB, tensor r=0.1
BB, tensor r=0.01
BB, tensor r=0.001
BB, tensor r=0.0001
Scalar and tensor primordial power spectra
l(l+1)*c_l^XX/(2*pi) muK^2
Multipole number (l)
10
100
1000
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}

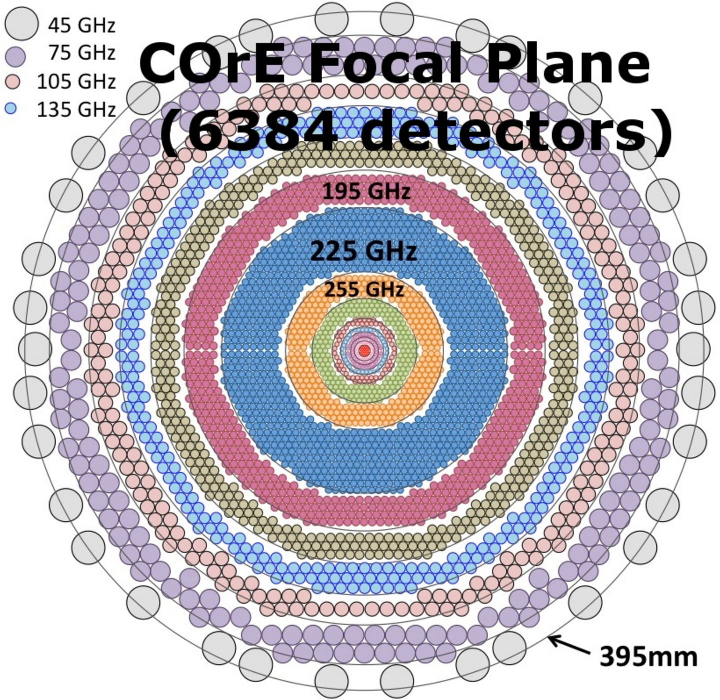
CAD realization of COrE design

COrE schematic




PLANCK FOCAL PLANE (72 detectors)

COrE Focal Plane (6384 detectors)



Photon shot noise

For a single mode:

$$\langle N \rangle = \Big(\exp(x) - 1\Big)^{-1}, \qquad x = \left(\frac{h\nu}{k_B T_{CMB}}\right) = \left(\frac{\nu}{57\ GHz}\right)$$

$$\langle N^2 \rangle = 2\langle N \rangle^2 + \langle N \rangle, \qquad \langle (\delta N)^2 \rangle = \langle N \rangle^2 + \langle N \rangle = N^2 + N$$

$$\left(\frac{\delta N}{N}\right) = \sqrt{1 + N^{-1}}$$

For $x \gg 1$, pure Poissonian noise, almost. For $x \ll 1$, photon bunching (Hanbury Brown and Twiss) photons arrive roughly in bunches of N, these correlations augment noise relative to Poisson distribution.

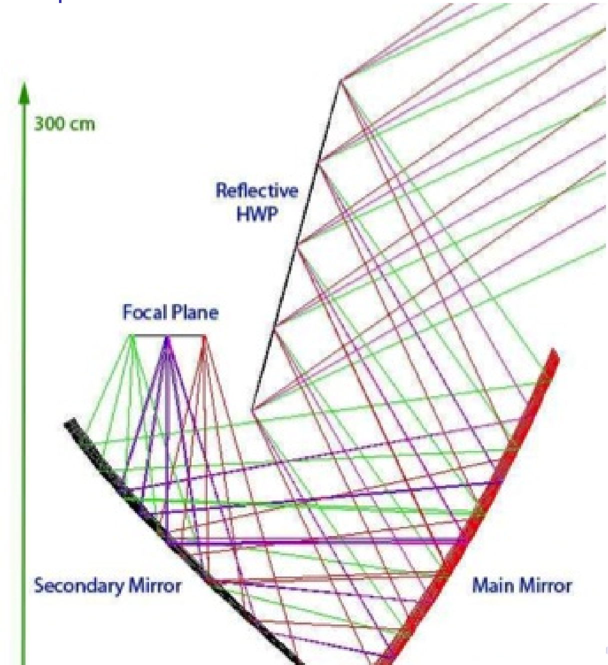
Radio astronomers' formula (quantum corrected)

$$\left(\frac{\delta I}{I}\right) = \frac{1}{\sqrt{N_{det}}} \left(\frac{T_{sky} + \epsilon_{tel} T_{tel}}{T_{sky}}\right) \frac{1}{\sqrt{(\Delta\nu) t_{obs}}} \sqrt{e^{-1} + n_{occ}^{-1}}$$

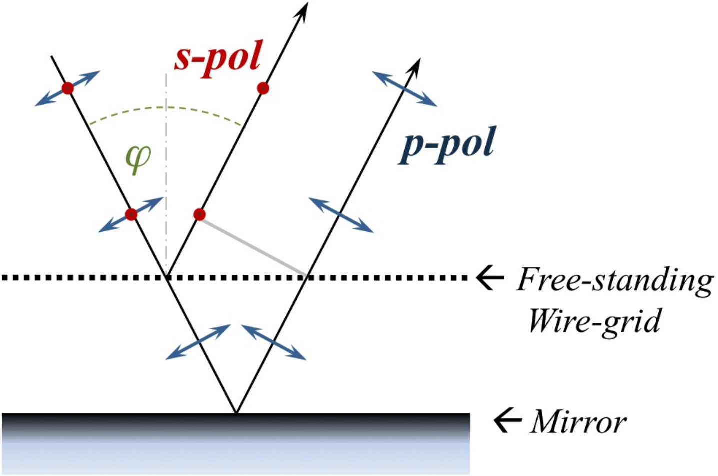
$e = (\text{quantum efficiency}) = (\text{prob. } \gamma \text{ is absorbed}), \qquad T_{sky} \approx T_{CMB}$

$\epsilon_{tel} = (\text{telescope emissivity})$

Core Optics


300 cm
Reflective
HWP
Focal Plane
Secondary Mirror
Main Mirror

Polarization Modulation—Rotating Half-Wave Plate



Polarization modulation with a rotating half-wave plate

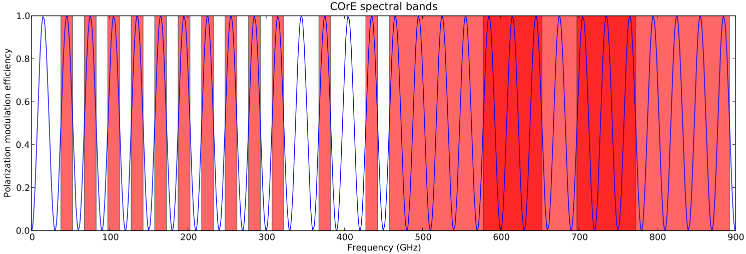
$$\begin{pmatrix} E_x^{(tel)} \\ E_y^{(tel)} \end{pmatrix} = \begin{pmatrix} \cos\Omega t & \sin\Omega t \\ -\sin\Omega t & \cos\Omega t \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \begin{pmatrix} \cos\Omega t & -\sin\Omega t \\ \sin\Omega t & \cos\Omega t \end{pmatrix} \begin{pmatrix} E_x^{(sky)} \\ E_y^{(sky)} \end{pmatrix}$$

$$\left\langle (E_x^{tel})^2 \right\rangle = I + Q\cos 4\Omega + U \sin 4\Omega t$$

$$\left\langle (E_x^{tel})^2 \right\rangle = I - Q\cos 4\Omega - U \sin 4\Omega t$$

- For measuring polarization, all harmonics —in particular those at $0\Omega t$, $2\Omega t$—are rejected except those at $4\Omega t$ are rejected.
- Stray light that becomes polarized from within telescope is thus rejected. $T_{tel} \to B\ mode$
- One is not subtracting two measurements with different beamsizes, aliasing T anisotropy into B mode
- Still has to know detector and telescope geometry very accurate; otherwise, E mode masquerades as B mode

COrE's 15 Spectral Bands



Note that 3 highest bands overlap

- In order to carry out foreground subtraction and provide redundancy for cross-checks 15 bands are required, minus a few. [3 synchrotron-amp.+spect-ind+running, 1 CMB, 2 free-free, 6 dust (2 BBs A+temp+emmis. index)+1 th.sz=13+2(safety)]

ν GHz	n_{unpol}	n_{pol}	θ_{fwhm} arcmin	Temp (I) $\mu K \cdot$arcmin RJ	CMB	Pol (Q,U) $\mu K \cdot$arcmin RJ	CMB
30	4	4	32.7	198.5	203.2	280.7	287.4
44	6	6	27.9	228.0	239.6	322.4	338.9
70	12	12	13.0	186.5	211.2	263.7	298.7
100	8	8	9.9	23.9	31.3	33.9	44.2
143	11	8	7.2	11.9	20.1	19.7	33.3
217	12	8	4.9	9.4	28.5	16.3	49.4
353	12	8	4.7	7.6	107.0	13.2	185.3
545	3	0	4.7	6.8	1.1×10^3	—	—
857	3	0	4.4	2.9	8.3×10^4	—	—

PLANCK (30 month mission)

ν *GHz*	$(\Delta\nu)$ *GHz*	n_{det}	θ_{fwhm} arcmin	Temp (I) $\mu K \cdot$arcmin RJ	CMB	Pol (Q,U) $\mu K \cdot$arcmin RJ	CMB
45	15	64	23.3	4.98	5.25	8.61	9.07
75	15	300	14.0	2.36	2.73	4.09	4.72
105	15	400	10.0	2.03	2.68	3.50	4.63
135	15	550	7.8	1.68	2.63	2.90	4.55
165	15	750	6.4	1.38	2.67	2.38	4.61
195	15	1150	5.4	1.07	2.63	1.84	4.54
225	15	1800	4.7	0.82	2.64	1.42	4.57
255	15	575	4.1	1.40	6.08	2.43	10.5
285	15	375	3.7	1.70	10.1	2.94	17.4
315	15	100	3.3	3.25	26.9	5.62	46.6
375	15	64	2.8	4.05	68.6	7.01	119
435	15	64	2.4	4.12	149	7.12	258
555	195	64	1.9	1.23	227	3.39	626
675	195	64	1.6	1.28	1320	3.52	3640
795	195	64	1.3	1.31	8070	3.60	22200

COrE summary (4 year mission)

Table: **COrE performance compared to WMAP and PLANCK.**

Broadening HF Bands

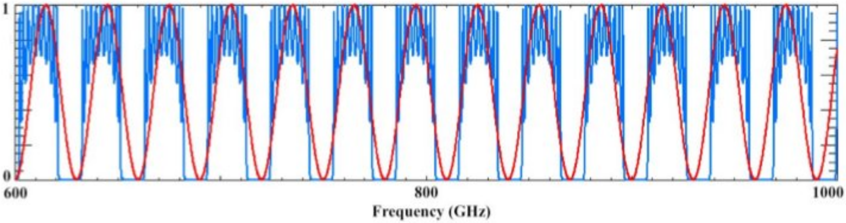
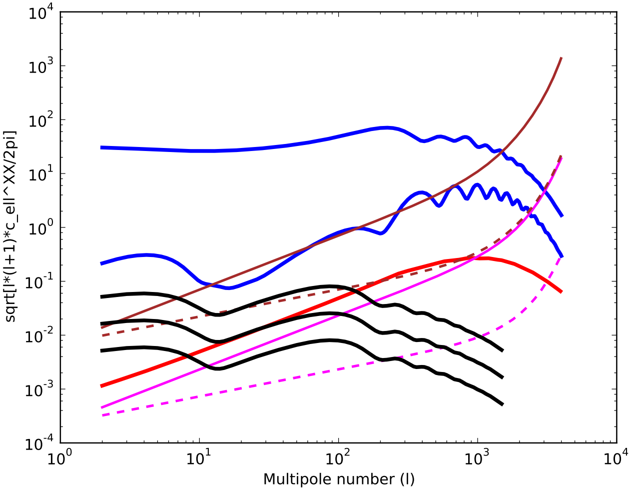


Figure 30: Sub-band filtering: Filter transmission (blue) and RHWP efficiency (red).

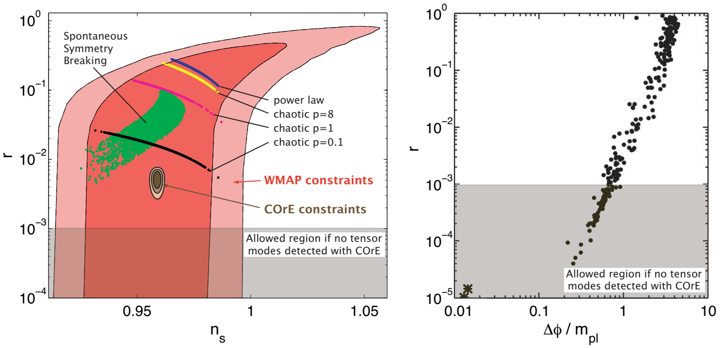
Science with COrE

COrE Planck Sensitivities vs. Expected signal



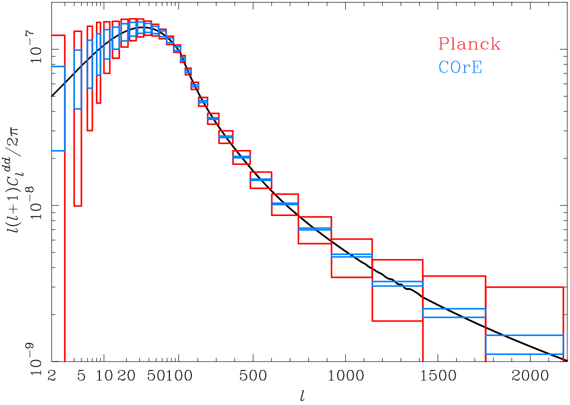
brown=planck; magenta=COrE; dashed = broad binning $\Delta\ell \approx \ell$, black=BB, ten for $r = 10^{-1}$, $r = 10^{-2}$, and $r = 10^{-3}$

Constraining inflation with COrE

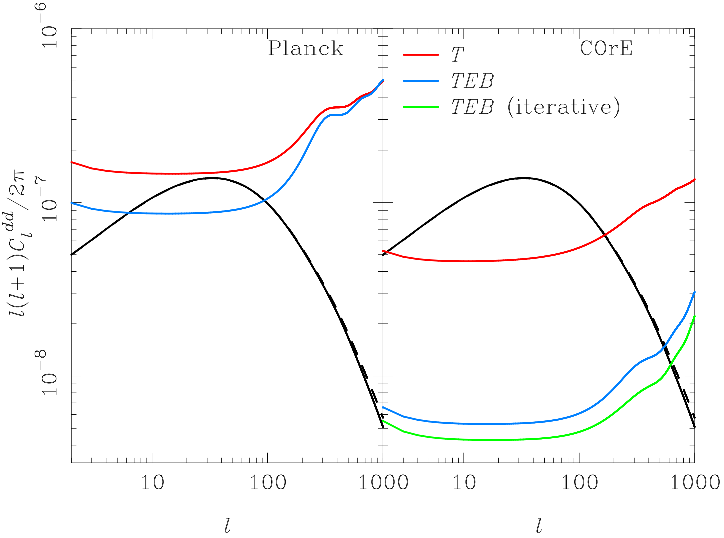


$r = 10^{-3}$ at 3σ at least.

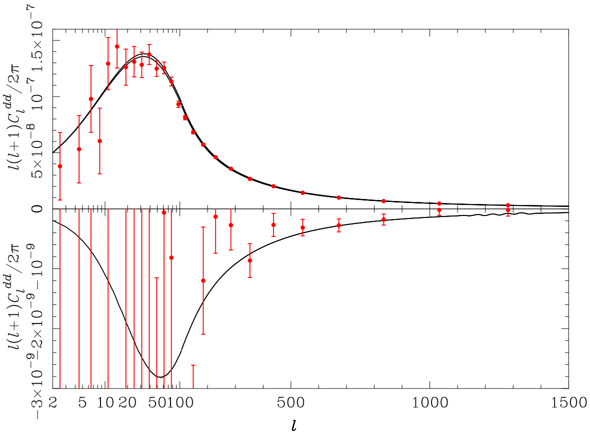
Lensing science with COrE—Measuring the Lensing Deflection Power Spectrum



Lensing reconstruction noise: PLANCK vs COrE



Detecting inverted absolute neutrino mass hierarchy



Here we plot $m_\nu^i = 0$ vs. $m_1 = m_2 = 0.05$ eV, $m_3 = 0$

$\sigma(\sum m_\nu^i)$=0.03 eV (COrE with all parameters other parameters determined by COrE), 0.012 eV (with other parameters fixed)
For comparison, KATRIN projection is $\sigma \approx 0.1 eV$ on electron neutrino mass.

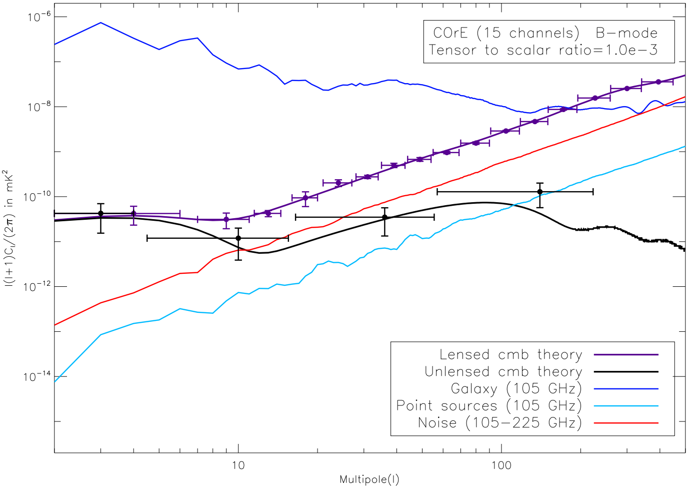
Galactic science with COrE

- The low-frequency data (especially the 45 GHz map) will be 30 times more sensitive than PLANCK LFI and will provide a full-sky view of the synchrotron polarization virtually free of Faraday rotation, which in conjunction with lower frequency data from the ground (eg QUIJOTE ....) can be used to map the galactic magnetic field.
- Above 353 GHz PLANCK has no polarization sensitive bolometers and the resolution is not diffraction limited (4.4 arcmin vs 1.3 arcmin) in highest frequency channel. This will allow high-resolution mapping of the polarized dust emission in diffuse regions not accessible and allow mapping the magnetic field in regions of star formation.
- Numerous new point sources (both polarized and unpolarized) will be discovered across the full sky.

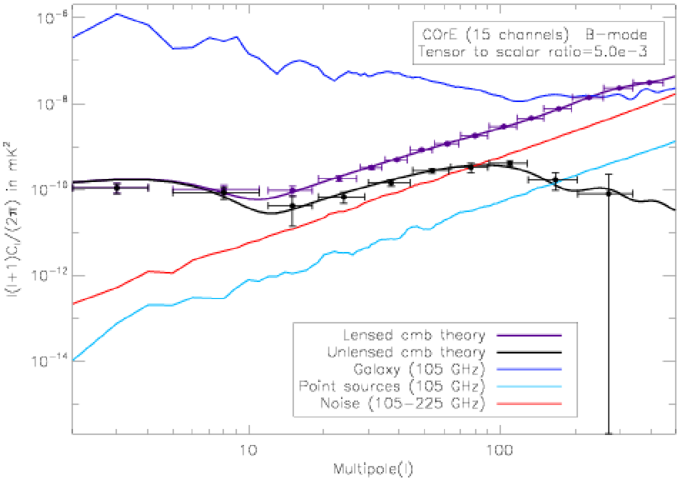
Foregrounds and component separation

- **Synchrotron emission** (cosmic rays spiralling in galactic magnetic field) $T_{sync,RJ} \propto \nu^{\alpha}$ where $\alpha \approx 3$ but varies spatially. Spectrum smooth in ν. Observed by WMAP to be highly polarized.
- **Free-free emission** bremsstrahlung of electrons in HI regions, For I H_{α} maps serve as faithful tracer. At most slightly polarized.
- **Spinning dust** (aka anomalous dust emission) regions of low frequency emission correlated with dust emission at high-frequencies. Attributed to rapidly (supra-thermally) spinning dust grains. Polarization properties uncertain.
- **Thermal dust emission.** At present best model has two components with separate amplitudes, emissivity indices, and temperatures. Model could become more complicated as data improves.
- **Zodiacal light.** Hotter dust from our solar system. Thermal emission and scattering. Most visible in 25μ maps, does not lend itself well to traditional component separation methods.
- **Sunyaev-Zeldovich (thermal and kinetic).**
- **Radio and infrared point sources.** Each have a different spectrum. Mask brightest and model unresolved.

Linear component separation model.
$T_f^{sky}(\Omega) = M_{fc} X_c(\Omega)$
Simulations and forecasts for COrE: Basak, Bonaldi, Delabrouille, Peiris, Ricciardi, Verde



Basak & Delabrouille; similar results from Bonaldi & Ricciardi



Basak & Delabrouille; similar results from Bonaldi & Ricciardi

ν	$\Delta\nu$	n_{det}	θ_{fwhm}^{arcmin}	(ΔP)/arcmin			Pixel sensitivity		$(\Delta P)_{A(V)=1}^{forecast}$	$(S/N)_{pol}^{pix}$
				$(\mu\mathrm{K})_{thermo}$	$(\mu\mathrm{K})_{RJ}$	MJy/st	$(\mu\mathrm{K})_{RJ}$	MJy/st	MJy/st	
255	15	575	4.10	1.05×10^1	2.43	4.85×10^{-3}	0.59	1.18×10^{-3}	6.30×10^{-3}	5.33
285	15	375	3.70	1.74×10^1	2.94	7.33×10^{-3}	0.79	1.98×10^{-3}	8.20×10^{-3}	4.13
315	15	100	3.30	4.66×10^1	5.62	1.71×10^{-2}	1.70	5.19×10^{-3}	1.13×10^{-2}	2.20
375	15	64	2.80	1.19×10^2	7.01	3.03×10^{-2}	2.50	1.08×10^{-2}	2.12×10^{-2}	2.00
435	15	64	2.40	2.58×10^2	7.12	4.14×10^{-2}	2.97	1.72×10^{-2}	3.82×10^{-2}	2.20
555	185	64	1.90	6.26×10^2	3.39	3.21×10^{-2}	1.78	1.69×10^{-2}	7.53×10^{-2}	4.47
675	185	64	1.60	3.64×10^3	3.52	4.92×10^{-2}	2.20	3.08×10^{-2}	1.28×10^{-1}	4.13
795	185	64	1.30	2.22×10^4	3.60	6.99×10^{-2}	2.77	5.38×10^{-2}	1.65×10^{-1}	3.07
795**	185	64	1.30	1.00×10^4	1.61	3.13×10^{-2}	1.24	2.41×10^{-2}	1.65×10^{-1}	6.86

** represents the new modified baseline with the number of detectors in the 795 GHz channel increased by a factor of five as discussed in the main text.

Table 4: ***COrE* performance for mapping polarized dust in the highest frequency channels.** For the eight highest frequency channels for the baseline defined in Table 1, we indicate in three different ways the sensitivities scaled to an arcmin square pixel for the polarization (Q, U) anisotropies, first as a thermodynamic temperature fluctuation relative to $T_{CMB} = 2.73K$—that is, as a fluctuation in ΔT_{CMB}, then as a Rayleigh-Jeans temperature fluctuation, and finally in terms of radiance units—that is, megaJansky per steradian. The polarization sensitivity is then given for a square pixel of dimension θ_{fwhm} on a side, as well as the prediction of the rms signal in Q and U in a pixel expected in a region with $A_V = 1$. Finally the resulting signal-to-noise within a pixel with unit magnitude visual extinction is indicated.

COrE

Answers to questions from the AWG

10 February 2011

Question 1

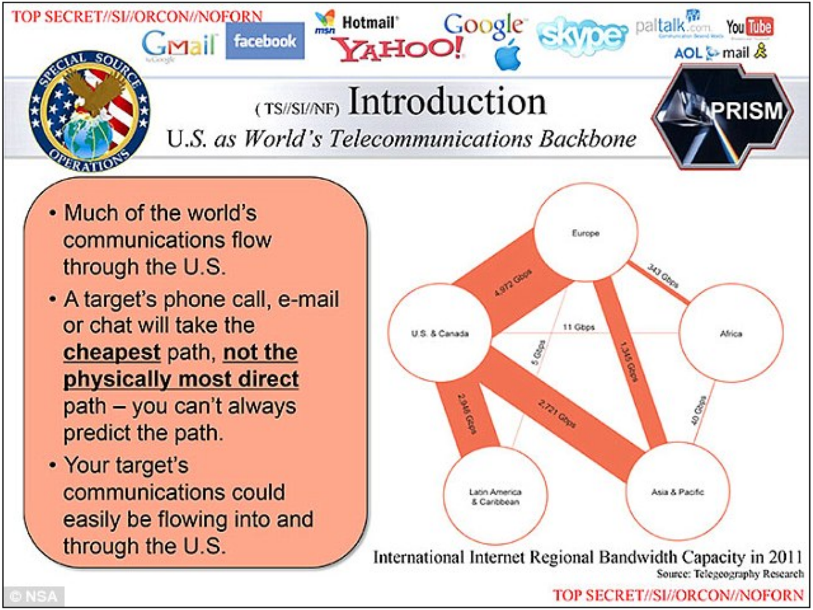
Full assessment of the COrE scientific potential will need knowledge of Planck results. While Planck seems to be performing well, its CMB results will not be known until 2013. In that situation, the proposers should provide a clear description of the potential and specific role of COrE assuming main branches of possible Planck outcome, in particular for the two cases of a detection or nondetection of polarization B modes by Planck.

Question 2

Making COrE a reality on the M3 timescale implies filling a large focal plane with complex sensitive TES detector systems. The AWG would like to get a status of the preparatory activities within the proposing consortium, and of the performances reached.

Question 3

The proposal (section 2.1) refers to a baseline design based on 6 frequency channels (75-225 GHz). The actual instrument design is based on 15 frequency channels (40-800 GHz), with a significant increase in size and complexity (overall frequency range to be covered by the optics, focal plane dimensions, number of pixels, heat load. etc.). What is the minimum number of frequency channels (and the corresponding frequency range) compatible with the COrE science objectives? A reduction in frequency range would enable a considerable simplification, potentially allowing to consider a smaller size, transmissive HWP.



Key source: PRISM has been described by NSA officials 'as the most prolific contributor to the president's Daily Brief,' providing analysts with a wealth of 'raw material'

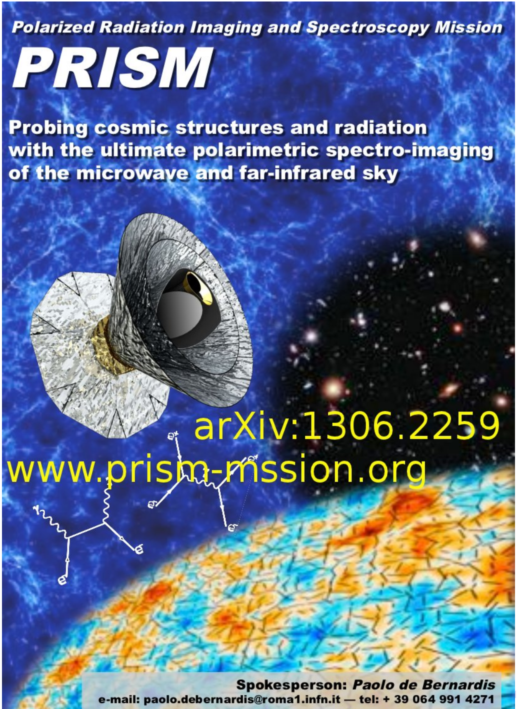
European support for NSA PRISM

UK gathering secret intelligence via covert NSA operation

Exclusive: UK security agency GCHQ gaining information from world's biggest internet firms through US-run Prism programme

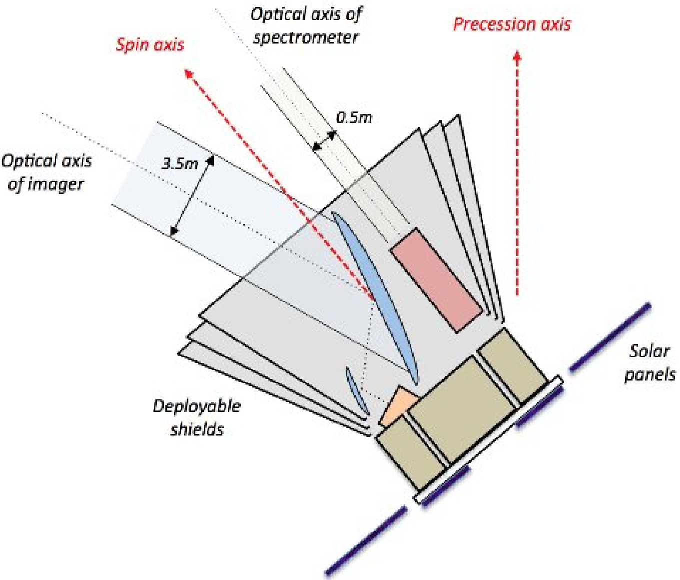
Nick Hopkins
guardian.co.uk, Friday 7 June 2013 14.27 BST

Documents show GCHQ (above) has had access to the NSA's Prism programme since at least June 2010. Photograph: David Goddard/Getty Images



Polarized Radiation Imaging and Spectroscopy Mission
PRISM
Probing cosmic structures and radiation
with the ultimate polarimetric spectro-imaging
of the microwave and far-infrared sky
arXiv:1306.2259
www.prism-mssion.org
Spokesperson: *Paolo de Bernardis*
e-mail: paolo.debernardis@roma1.infn.it — tel: + 39 064 991 4271

PRISM “Strawman" instrument concept



PRISM spacecraft with its two instru-

PRISM instrument highlights

Two instruments working in tandem:

1. A Polarimeteric Imager
   - 3.5 mirror (cooled to $\approx 4K$) (to be compared with Planck mirror 1.5m not including underilumination)
   - Approximately 7000 detectors deployed at frequencies ranging from 30 GHz to 6 THz (details to be optimized). A small number of detectors with split bands for enhanced spectral sensitivity and targetting galactic emission lines.
   - Elaborate scanning strategy mitigates systematic effects
2. FTS (Fourier Transform Spectrometer)
   - Basic idea is to measure the absolute spectrum with an Martin-Pupplet FTS instrument (like COBE FIRAS but over three orders of magnitude better and similar to PIXIE)
   - Splitting bands with dichroics increases sensitivity
   - Combining with imager (having high angular resolution) provides important synergies

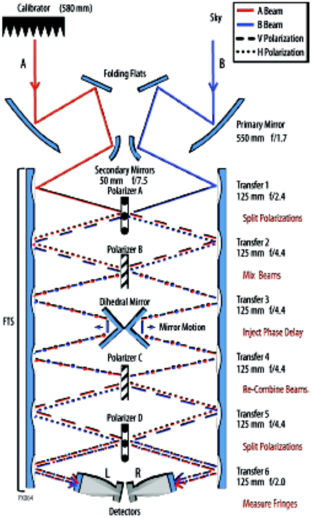
Polarimetric imager—CMBchannels

ν_0 GHz	Range GHz	$\Delta\nu/\nu$	n_{det}	$\theta_{\rm fwhm}$	σ_I per det 1 arcmin μK_{RJ}	σ_I per det 1 arcmin μK_{CMB}	$\sigma_{(Q,U)}$ per det 1 arcmin μK_{RJ}	$\sigma_{(Q,U)}$ per det 1 arcmin μK_{CMB}	Main molec. & atomic lines
30	26-34	.25	50	17'	61.9	63.4	87.6	89.7	
36	31-41	.25	100	14'	57.8	59.7	81.7	84.5	
43	38-48	.25	100	12'	53.9	56.5	76.2	79.9	
51	45-59	.25	150	10'	50.2	53.7	71.0	75.9	
62	54-70	.25	150	8.2'	46.1	50.8	65.2	71.9	
75	65-85	.25	150	6.8'	42.0	48.5	59.4	68.6	
90	78-100	.25	200	5.7'	38.0	46.7	53.8	66.0	HCN & HCO^+ at 89 GHz
105	95-120	.25	250	4.8'	34.5	45.6	48.8	64.4	CO at 110-115 GHz
135	120-150	.25	300	3.8'	28.6	44.9	40.4	63.4	
160	135-175	.25	350	3.2'	24.4	45.5	34.5	64.3	
185	165-210	.25	350	2.8'	20.8	47.1	29.4	66.6	HCN & HCO^+ at 177 GHz
200	180-220	.20	350	2.5'	18.9	48.5	26.7	68.6	
220	195-250	.25	350	2.3'	16.5	50.9	23.4	71.9	CO at 220-230 GHz
265	235-300	.25	350	1.9'	12.2	58.5	17.3	82.8	HCN & HCO^+ at 266 GHz
300	270-330	.20	350	1.7'	9.6	67.1	13.6	94.9	
320	280-360	.25	350	1.6'	8.4	73.2	11.8	103	CO, HCN & HCO^+
395	360-435	.20	350	1.3'	4.9	107	7.0	151	
460	405-520	.25	350	1.1'	3.1	156	4.4	221	CO, HCN & HCO^+
555	485-625	.25	300	55"	1.6	297	2.3	420	C-I, HCN, HCO^+, H_2O, CO
660	580-750	.25	300	46"	0.85	700	1.2	990	CO, HCN & HCO^+

Polarimetric imager—high-frequency channels

					nK_{RJ}	kJy/sr	nK_{RJ}	kJy/sr	
800	700-900	.25	200	38”	483	9.5	683	13.4	
960	840-1080	.25	200	32”	390	11.0	552	15.6	
1150	1000-1300	.25	200	27”	361	14.6	510	20.7	
1380	1200-1550	.25	200	22”	331	19.4	468	27.4	N-II at 1461 GHz
1660	1470-1860	.25	200	18”	290	24.5	410	34.7	
1990	1740-2240	.25	200	15”	241	29.3	341	41.5	C-II at 1900 GHz
2400	2100-2700	.25	200	13”	188	33.3	266	47.1	N-II at 2460 GHz
2850	2500-3200	.25	200	11”	146	36.4	206	51.4	
3450	3000-3900	.25	200	8.8”	113	41.4	160	58.5	O-III at 3393 GHz
4100	3600-4600	.25	200	7.4”	98	50.8	139	71.8	
5000	4350-5550	.25	200	6.1”	91	70.1	129	99.1	O-I at 4765 GHz
6000	5200-6800	.25	200	5.1”	87	96.7	124	136	O-III at 5786 GHz

Martin-Pupplet FTS spectrometer–basic concept



Courtesy of PIXIE collaboration–arXiv:1105.2044

FTS spectrometer performances–several options

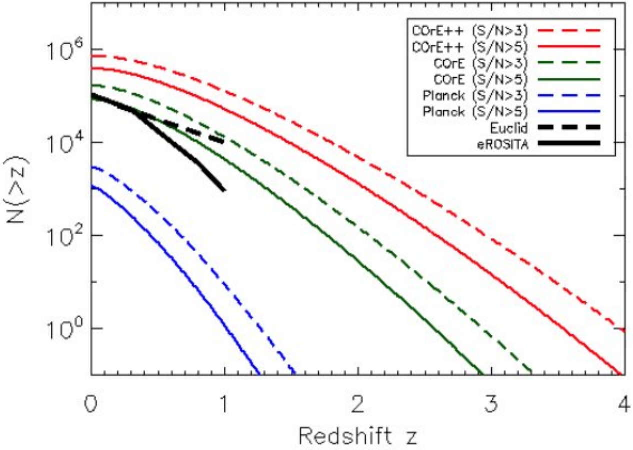
Band (GHz)	Resolution (GHz)	$A\Omega$ ($cm^2 sr$)	Background (pW)	NEPν ($W/m^2/sr/Hz\times\sqrt{s}$)	Global 4-yr mission sensitivity ($W/m^2/sr/Hz$)
30-6000	15	1	150	1.8×10^{-22}	1.8×10^{-26}
30-500	15	1	97	7.0×10^{-23}	7.2×10^{-27}
500 - 6000	15	1	70	1.7×10^{-22}	1.7×10^{-26}
30-180	15	1	42	3.5×10^{-23}	3.6×10^{-27}
180-600	15	1	57	6.3×10^{-23}	6.5×10^{-27}
600-3000	15	1	20	7.4×10^{-23}	7.6×10^{-27}
3000-6000	15	1	28	1.6×10^{-22}	1.6×10^{-26}

Qualitatively new science made possible by PRISM

- The ultimate cluster survey 10^6 clusters including many at $z > 1$ Significantly surpasses eRosita, which will be the state-of-the-art when PRISM flies. Temperature will be measured based on relativistic corrections to the SZ spectral template and peculiar velocities from kSZ.
- Understanding the origin of the CIB (dusty IR galaxies) where most of the star formation in the universe took place
- Detect distortions to the perfect blackbody spectrum (cannot be done with convential CMB experiments that are sensitive only to angular variations and lack an absolute calibration)
- Map the galactic magnetic field both in the hot gas and the diffuse cold regions where star formation takes place.
- Probe B modes from primordial gravitational wave generated during inflation much better than any other experiment even if foregrounds are very messy and probe gravitational lensing.

Expected cluster counts

(Plot courtesy of Jean-Baptiste MELIN)



Physical mechanisms that lead to release of energy

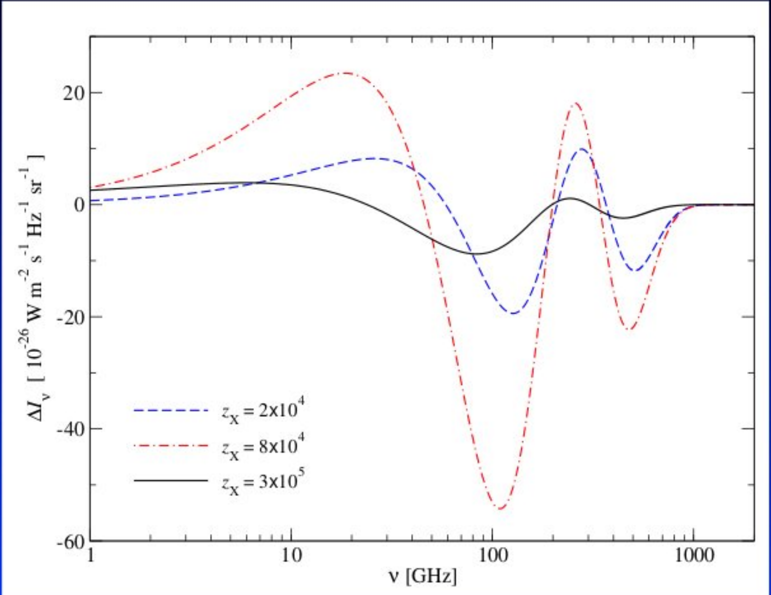
- *Cooling by adiabatically expanding ordinary matter*: $T_\gamma \sim (1+z) \leftrightarrow T_m \sim (1+z)^2$
  (JC, 2005; JC & Sunyaev 2011; Khatri, Sunyaev & JC, 2011)
  - continuous *cooling* of photons until redshift $z \sim 150$ via Compton scattering
  - due to huge heat capacity of photon field distortion very small ($\Delta\rho/\rho \sim 10^{-10}$-$10^{-9}$)
- Heating by *decaying* or *annihilating* relic particles
  - How is energy transferred to the medium?
  - lifetimes, decay channels, neutrino fraction, (at low redshifts: environments), ...
- *Evaporation of primordial black holes & superconducting strings*
  (Carr et al. 2010; Ostriker & Thompson, 1987; Tashiro et al. 2012)
  - rather fast, quasi-instantaneous energy release
- *Dissipation of primordial acoustic modes & magnetic fields*
  (Sunyaev & Zeldovich, 1970; Daly 1991; Hu et al. 1994; Jedamzik et al. 2000)
- *Cosmological recombination*

„high" redshifts

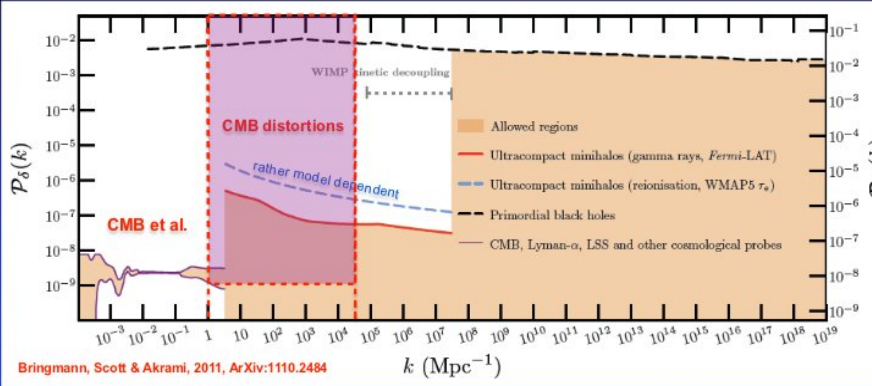
„low" redshifts

- Signatures due to first supernovae and their remnants
  (Oh, Cooray & Kamionkowski, 2003)
- Shock waves arising due to large-scale structure formation
  (Sunyaev & Zeldovich, 1972; Cen & Ostriker, 1999)
- SZ-effect from clusters; effects of reionization (Heating of medium by X-Rays, Cosmic Rays, etc)

Decaying particle scenarios (information in residual)

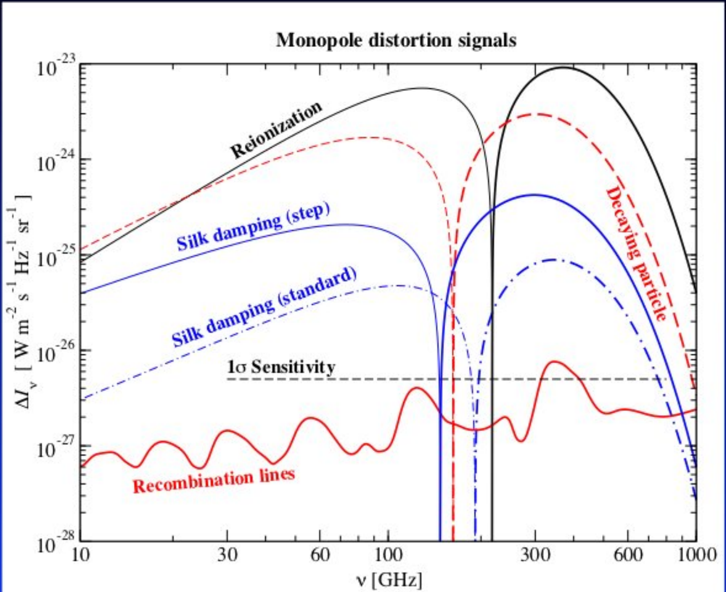


Power spectrum constraints



- Amplitude of power spectrum rather uncertain at $k > 3$ Mpc^{-1}
- improving limits at smaller scales would constrain inflationary models
- CMB spectral distortions could allow extending our lever arm to $k \sim 10^4$ M

Average CMB spectral distortions



NSA PRISM vs ESA PRISM

James Clapper, PI NSA Prism

Paolo de Bernardis, ESA Prism Spokeperson

- The NSA wants wants to find out everything about you.
- We want to find out everything about the Universe between 30GHz and 6THz capturing all available signals.

Conclusion:

Help us find out everything there is to know about the universe with PRISM.

Please sign up as a supporter:

www.prism-mission.org

and sign up on email list to receive updates

http://listserv.in2p3.fr/cgi-bin/wa?A0=BPOL-ALL-L