Future CMB/far-infrared space missions

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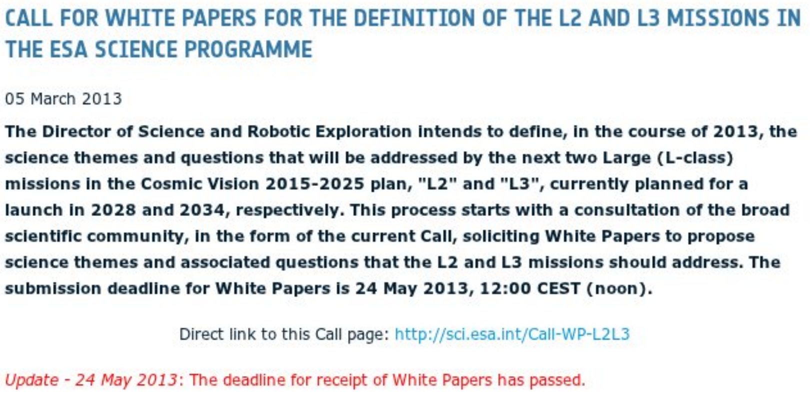
for the PRISM Collaboration

25 June 2013, Santander Planck Conference

ESA Call for Large Mission Themes



CALL FOR WHITE PAPERS FOR THE DEFINITION OF THE L2 AND L3 MISSIONS IN THE ESA SCIENCE PROGRAMME

05 March 2013

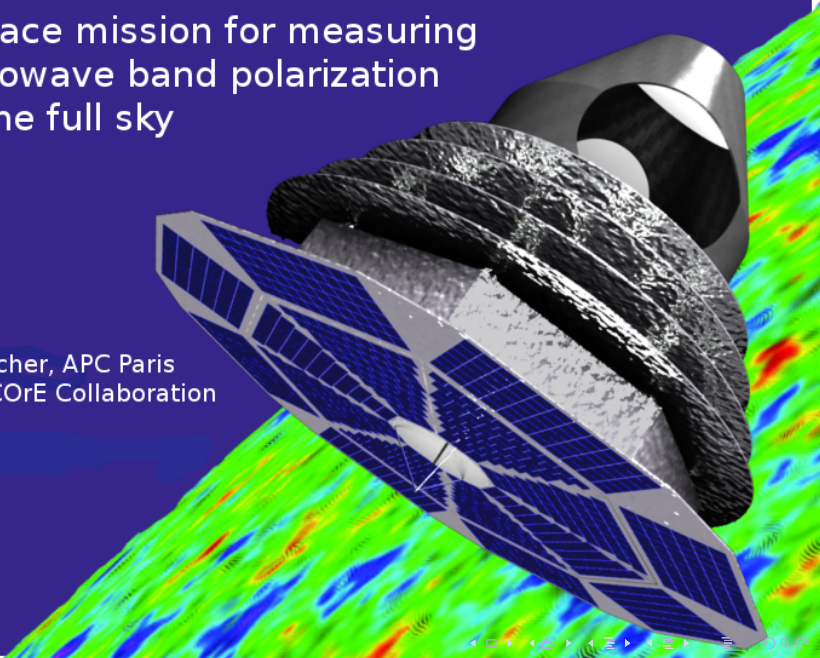
The Director of Science and Robotic Exploration intends to define, in the course of 2013, the science themes and questions that will be addressed by the next two Large (L-class) missions in the Cosmic Vision 2015-2025 plan, "L2" and "L3", currently planned for a launch in 2028 and 2034, respectively. This process starts with a consultation of the broad scientific community, in the form of the current Call, soliciting White Papers to propose science themes and associated questions that the L2 and L3 missions should address. The submission deadline for White Papers is 24 May 2013, 12:00 CEST (noon).

Direct link to this Call page: http://sci.esa.int/Call-WP-L2L3

Update - 24 May 2013: The deadline for receipt of White Papers has passed.

COrE : Cosmic Origins Explorer

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

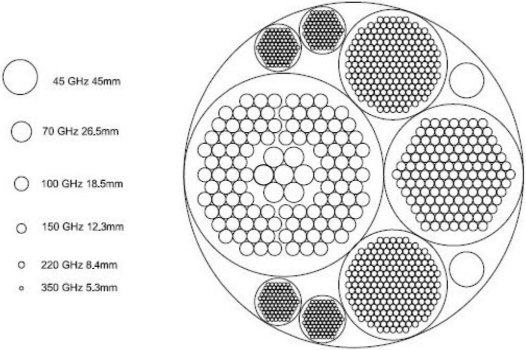


Martin Bucher, APC Paris
for the COrE Collaboration

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

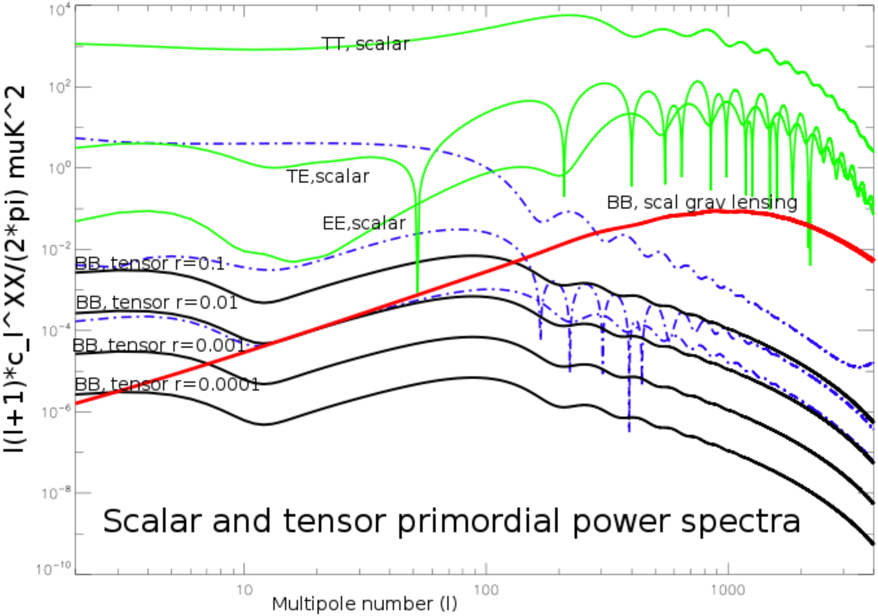
Proposed to ESA in December 2012 as a Cosmic Vision M3 Mission for ≈ 2020
http://www.core-mission.org
White paper available (90 pages) (astro-ph/1102.2181)
Answers to AWG Questions (available on website)

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

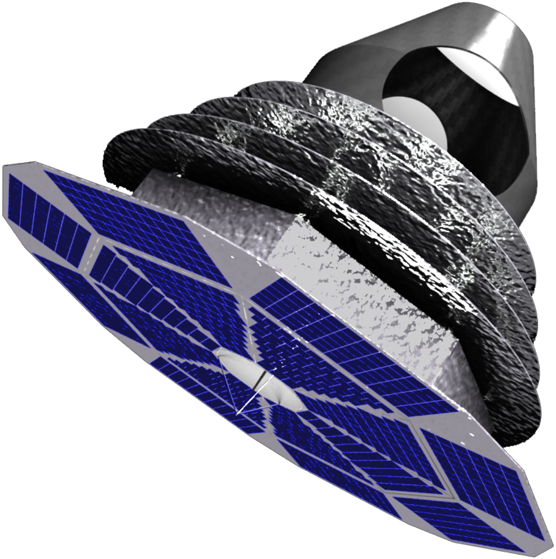
Instrument working group: B. Maffei, M. Bersanelli, P. Bielewicz, P. Camus, P. de Bernardis, M. De Petris, P. Mauskopf, S. Masi, F. Nati, T. Peacocke, F. Piacentini, L. Piccirillo, M. Piat, G. Pisano, M. Salatino, R. Stompor, S. Withington,

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

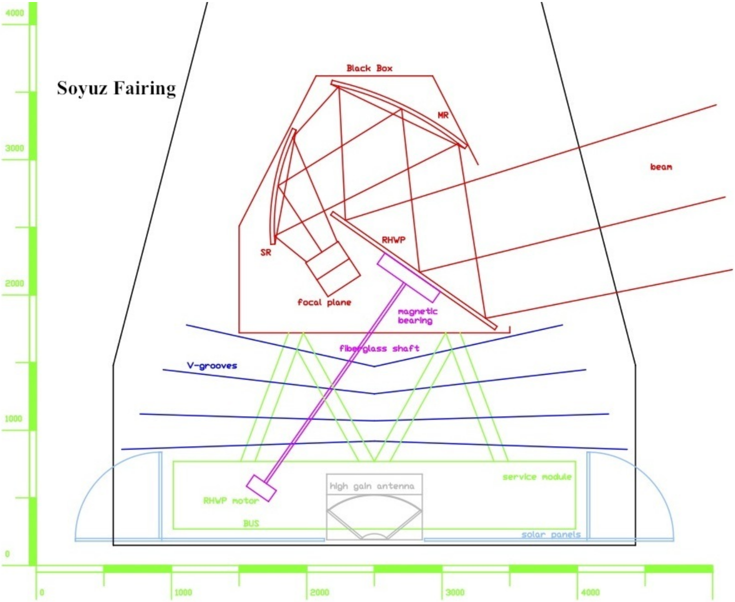
Foregrounds working group: C. Burigana, J. Delabrouille, C. Armitage-Caplan, A. Banday, S. Basak, A. Bonaldi, D. Clements, G. De Zotti, C. Dickinson, J. Dunkley, M. Lopez-Caniego, E. Martinez-Gonzalez, M. Negrello, S. Ricciardi, L. Toffolatti

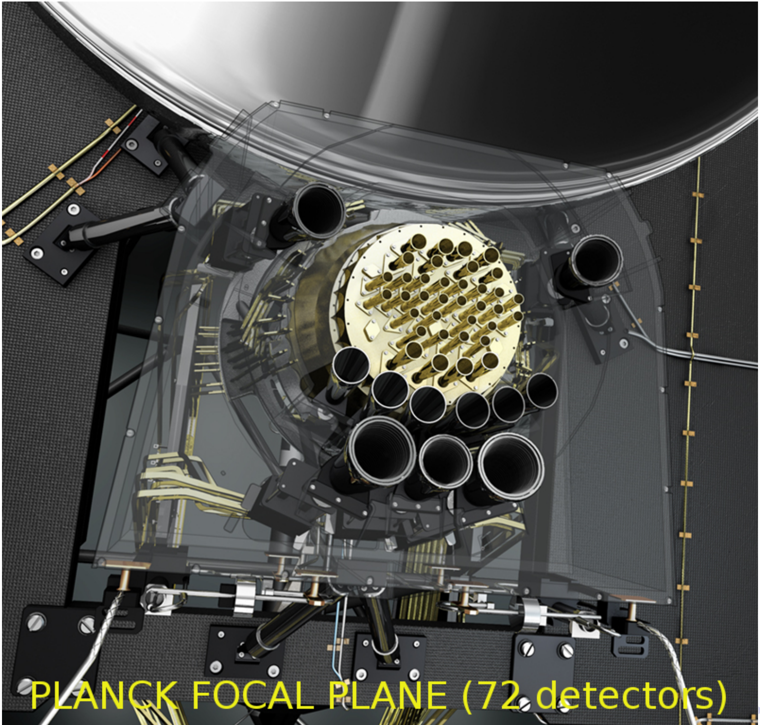

TT, scalar
TE,scalar
EE,scalar
BB, scal grav lensing
BB, tensor r=0.1
BB, tensor r=0.01
BB, tensor r=0.001
BB, tensor r=0.0001
Scalar and tensor primordial power spectra
l(l+1)*c_l^XX/(2*pi) muK^2
Multipole number (l)
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10
100
1000

CAD realization of COrE design



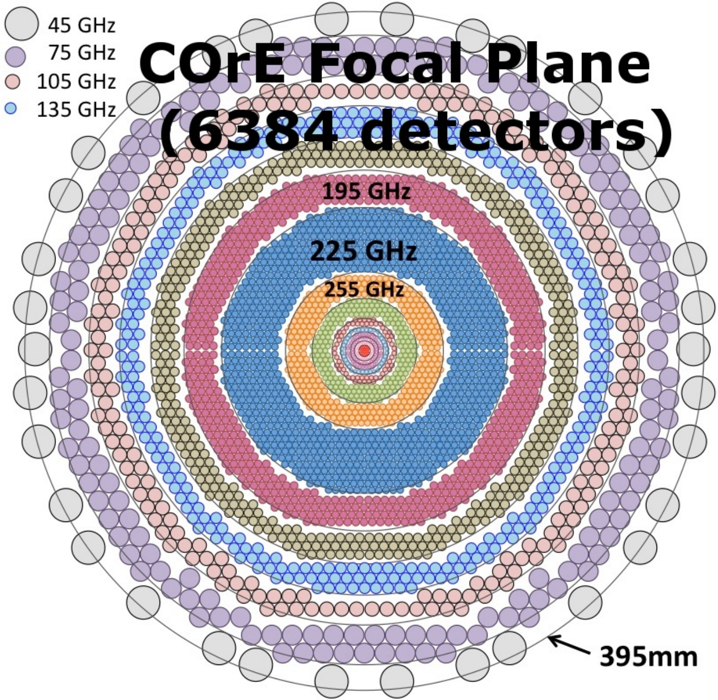
COrE schematic





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.

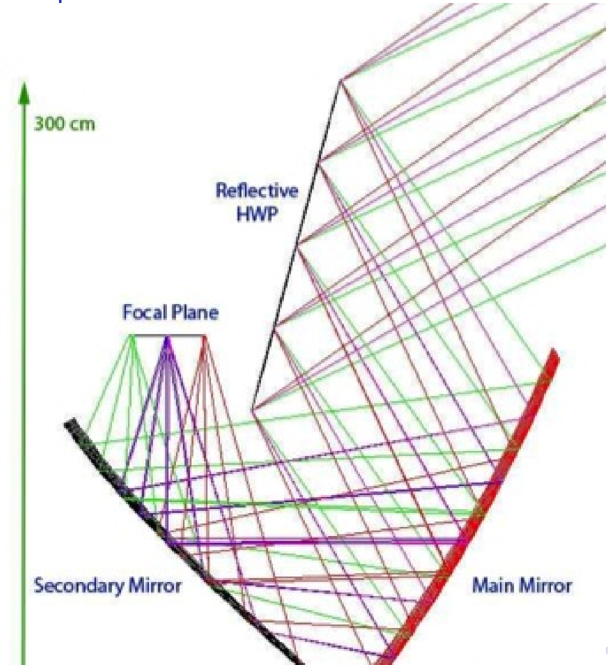
Radio astronomers' formula (quantum corrected)

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

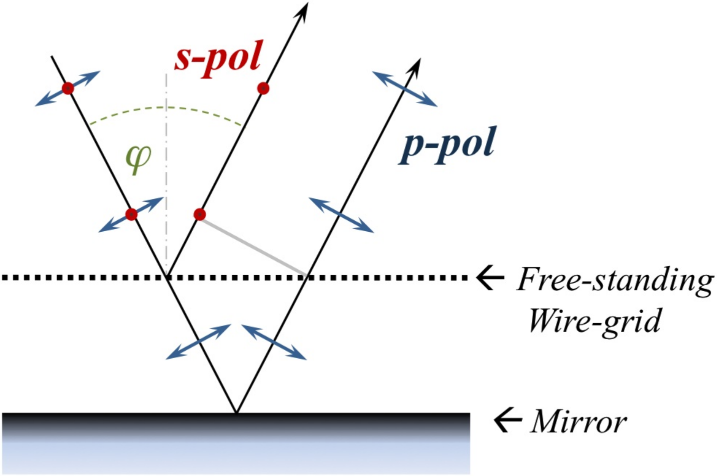
$e = \text{(quantum efficiency)} = \text{(prob. } \gamma \text{ is absorbed)}, \qquad T_{sky} \approx T_{CMB}$

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

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

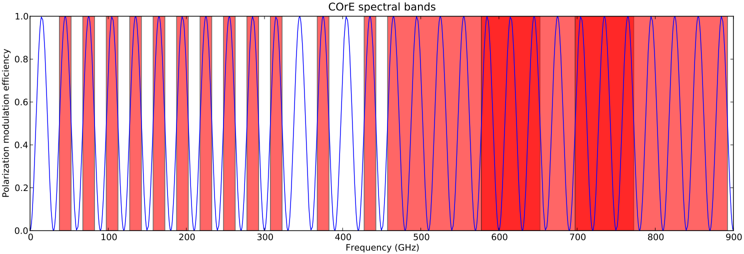
$$\begin{pmatrix} E_x^{(tel)} \\ E_y^{(tel)} \end{pmatrix} = \begin{pmatrix} \cos\Omega t & \sin\Omega t \\ -\sin\Omega t & \cos\Omega t \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \begin{pmatrix} \cos\Omega t & -\sin\Omega t \\ \sin\Omega t & \cos\Omega t \end{pmatrix} \begin{pmatrix}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

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

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

- 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. $T_{tel} \rightarrow B\ mode$
- 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	n_{unpol}	n_{pol}	θ_{fwhm}	Temp (I) $\mu K \cdot$arcmin		Pol (Q,U) $\mu K \cdot$arcmin	
GHz			arcmin	RJ	CMB	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	$(\Delta\nu)$	n_{det}	θ_{fwhm}	Temp (I) $\mu K \cdot$arcmin		Pol (Q,U) $\mu K \cdot$arcmin	
GHz	*GHz*		arcmin	RJ	CMB	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

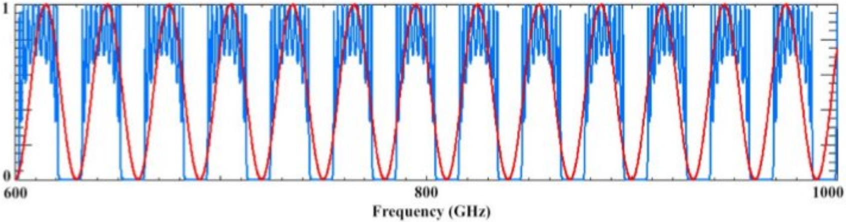
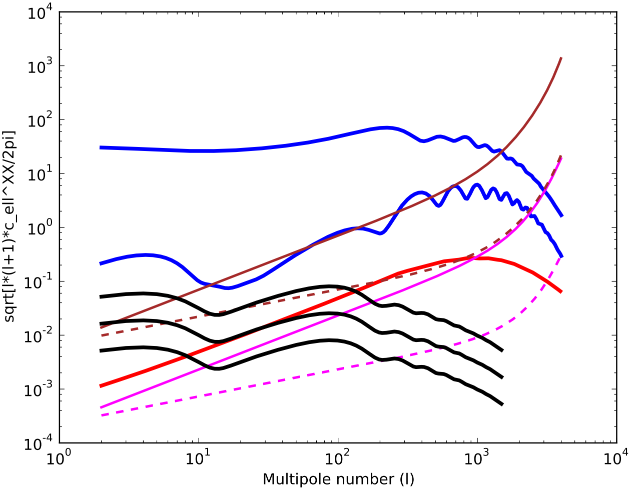


Figure 30: Sub-band filtering: Filter transmission (blue) and RHWP efficiency (red).

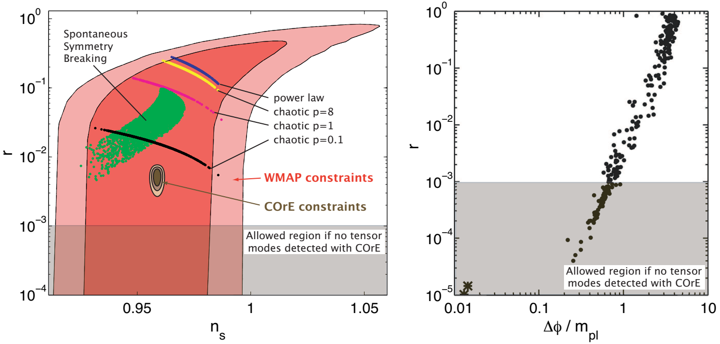
Science with COrE

COrE Planck Sensitivities vs. Expected signal



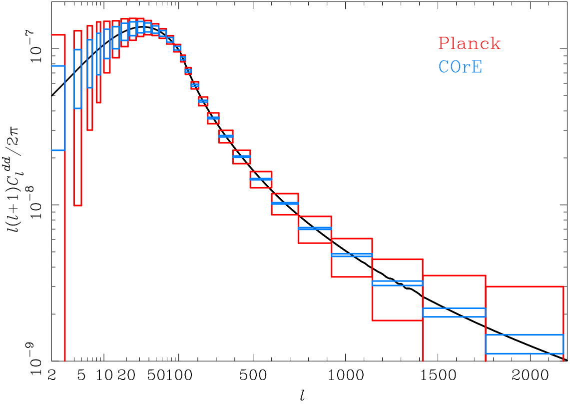
brown=planck; magenta=COrE; dashed = broad binning $\Delta\ell \approx \ell$, black=BB, ten for $r = 10^{-1}$, $r = 10^{-2}$, and $r = 10^{-3}$

Constraining inflation with COrE

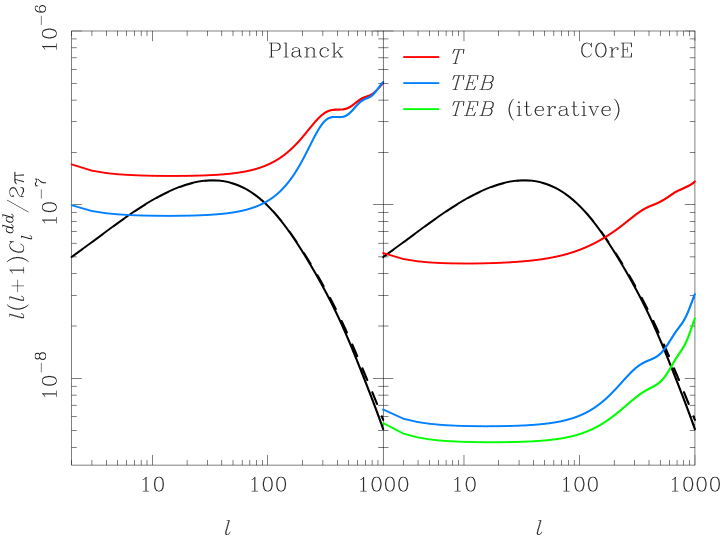


$r = 10^{-3}$ at 3σ at least.

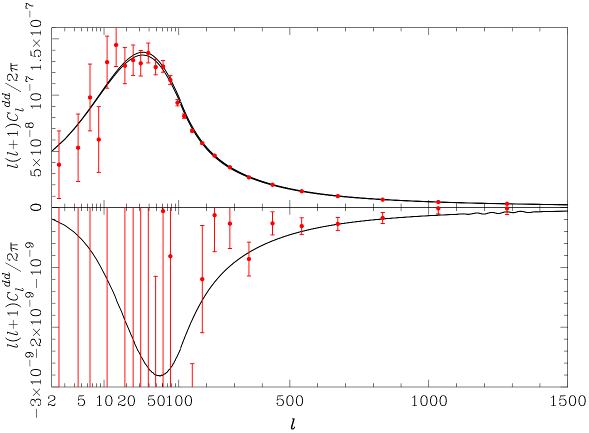
Lensing science with COrE—Measuring the Lensing Deflection Power Spectrum



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.

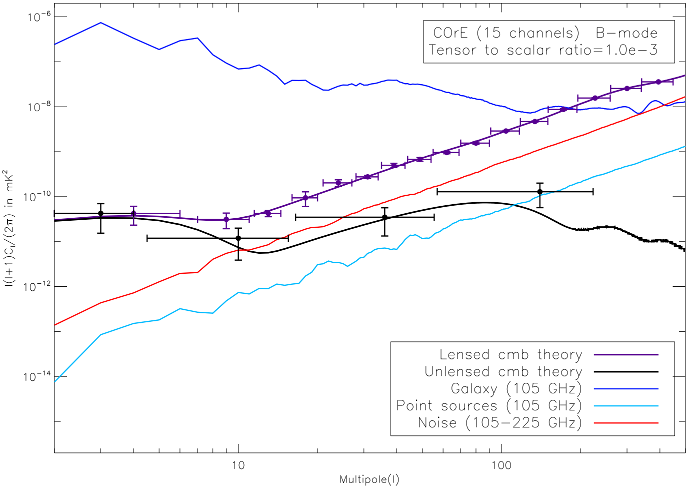
Galactic science with COrE

- 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.

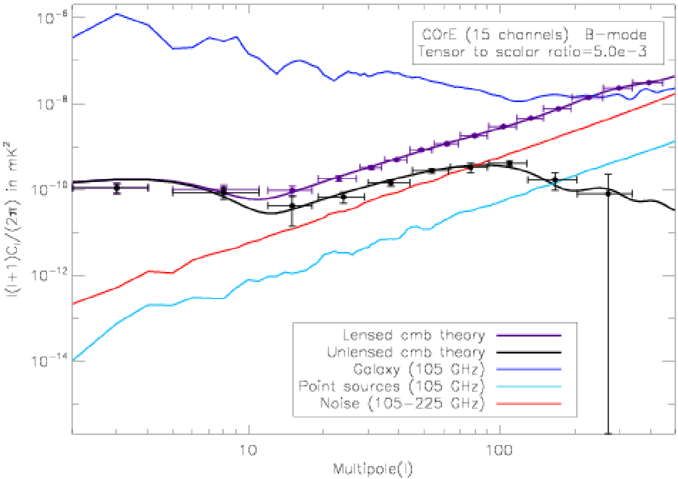
Foregrounds and component separation

- **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

				(ΔP)/arcmin			Pixel sensitivity		$(\Delta P)^{forecast}_{A(V)=1}$	
ν	$\Delta\nu$	n_{det}	θ^{arcmin}_{fwhm}	$(\mu\text{K})_{thermo}$	$(\mu\text{K})_{RJ}$	MJy/st	$(\mu\text{K})_{RJ}$	MJy/st	MJy/st	$(S/N)^{pix}_{pol}$
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

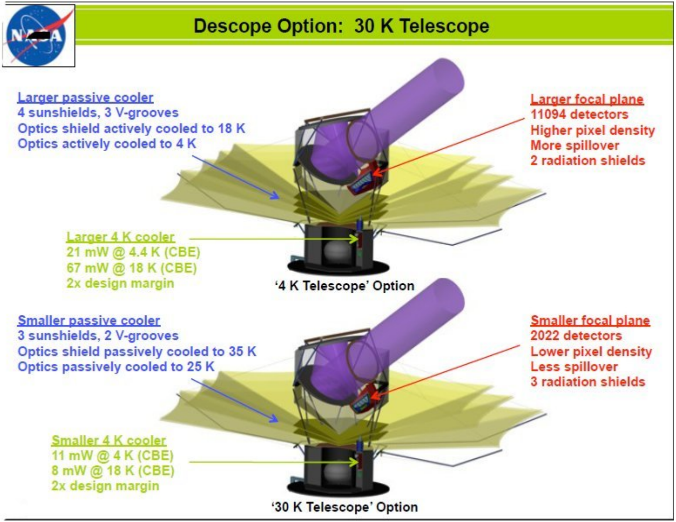
Making COrE a reality on the M3 timescale implies filling a large focal plane with complex sensitive TES detector systems. The AWG would like to get a status of the preparatory activities within the proposing consortium, and of the performances reached.

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.

NON-EUROPEAN INITIATIVES

US Proposal: EPIC



Descope Option: 30 K Telescope

Larger passive cooler
4 sunshields, 3 V-grooves
Optics shield actively cooled to 18 K
Optics actively cooled to 4 K

Larger focal plane
11094 detectors
Higher pixel density
More spillover
2 radiation shields

Larger 4 K cooler
21 mW @ 4.4 K (CBE)
67 mW @ 18 K (CBE)
2x design margin

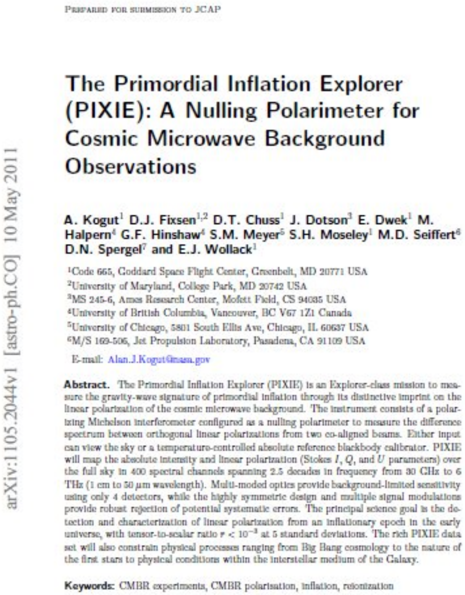
‘4 K Telescope’ Option

Smaller passive cooler
3 sunshields, 2 V-grooves
Optics shield passively cooled to 35 K
Optics passively cooled to 25 K

Smaller focal plane
2022 detectors
Lower pixel density
Less spillover
3 radiation shields

Smaller 4 K cooler
11 mW @ 4 K (CBE)
8 mW @ 18 K (CBE)
2x design margin

‘30 K Telescope’ Option



PREPARED FOR SUBMISSION TO JCAP

The Primordial Inflation Explorer (PIXIE): A Nulling Polarimeter for Cosmic Microwave Background Observations

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Abstract. The Primordial Inflation Explorer (PIXIE) is an Explorer-class mission to measure the gravity-wave signature of primordial inflation through its distinctive imprint on the linear polarization of the cosmic microwave background. The instrument consists of a polarizing Michelson interferometer configured as a nulling polarimeter to measure the difference spectrum between orthogonal linear polarizations from two co-aligned beams. Either input can view the sky or a temperature-controlled absolute reference blackbody calibrator. PIXIE will map the absolute intensity and linear polarization (Stokes I, Q, and U parameters) over the full sky in 400 spectral channels spanning 2.5 decades in frequency from 30 GHz to 6 THz (1 cm to 50 μm wavelength). Multi-moded optics provide background-limited sensitivity using only 4 detectors, while the highly symmetric design and multiple signal modulations provide robust rejection of potential systematic errors. The principal science goal is the detection and characterization of linear polarization from an inflationary epoch in the early universe, with tensor-to-scalar ratio $r < 10^{-3}$ at 5 standard deviations. The rich PIXIE data set will also constrain physical processes ranging from Big Bang cosmology to the nature of the first stars to physical conditions within the interstellar medium of the Galaxy.

Keywords: CMBR experiments, CMBR polarisation, inflation, reionization

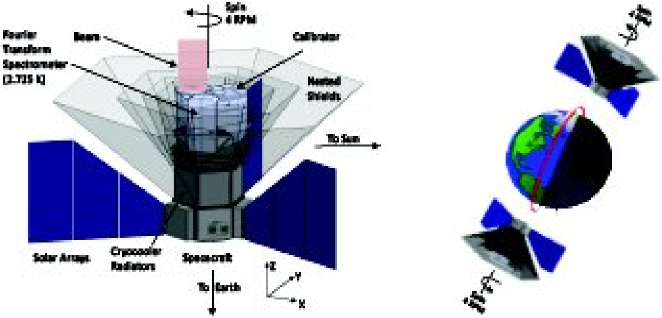
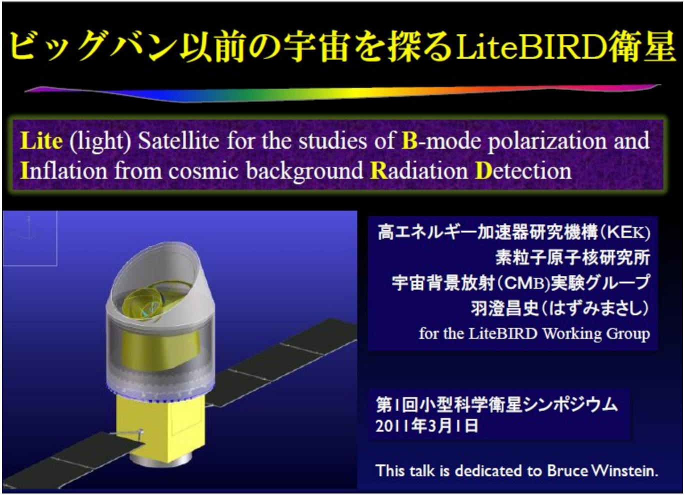


Figure 4. PIXIE observatory and mission concept. The instrument is maintained at 2.725 K and is surrounded by shields to block radiation from the Sun or Earth. It observes from a 660 km polar sun-synchronous terminator orbit. The rapid spin and interferometer stroke efficiently separate Stokes I, Q, and U parameters independently within each pixel to provide a nearly diagonal covariance matrix.



ビッグバン以前の宇宙を探るLiteBIRD衛星

Lite (light) Satellite for the studies of **B**-mode polarization and **I**nflation from cosmic background **R**adiation **D**etection

高エネルギー加速器研究機構(KEK)
素粒子原子核研究所
宇宙背景放射(CMB)実験グループ
羽澄昌史(はずみまさし)
for the LiteBIRD Working Group

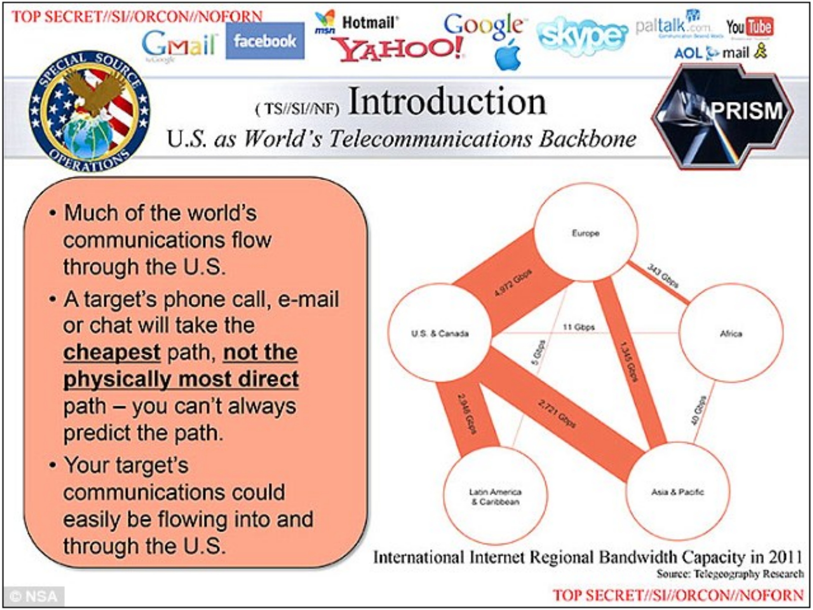
第1回小型科学衛星シンポジウム
2011年3月1日

This talk is dedicated to Bruce Winstein.

LiteBird Detectors/Resolution

Band	Beam size [degs]	Pixel size[cm]	Edge Taper [dB]	Aperture efficiency	The # of bolometers	uK arcmin for 2 K mirror/ baffle
60	1.7	2.0	4.5	0.65	312	6.35
80	1.3	2.0	7.8	0.84	156	6.53
100	1	2.0	<-10	0.94	156	6.06
Sub total					624	
100	1	1.2	-4.5	0.65	434	4.16
150	0.7	1.2	-10	0.91	434	3.02
220	0.47	1.2	<-10	0.99	434	3.02
Sub total					1302	
Total					1926	1.7

PRISM



TOP SECRET//SI//ORCON//NOFORN

(TS//SI//NF) Introduction

U.S. as World's Telecommunications Backbone

- Much of the world's communications flow through the U.S.
- A target's phone call, e-mail or chat will take the **cheapest** path, **not the physically most direct** path – you can't always predict the path.
- Your target's communications could easily be flowing into and through the U.S.

International Internet Regional Bandwidth Capacity in 2011

Source: Telegeography Research

TOP SECRET//SI//ORCON//NOFORN

© NSA

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

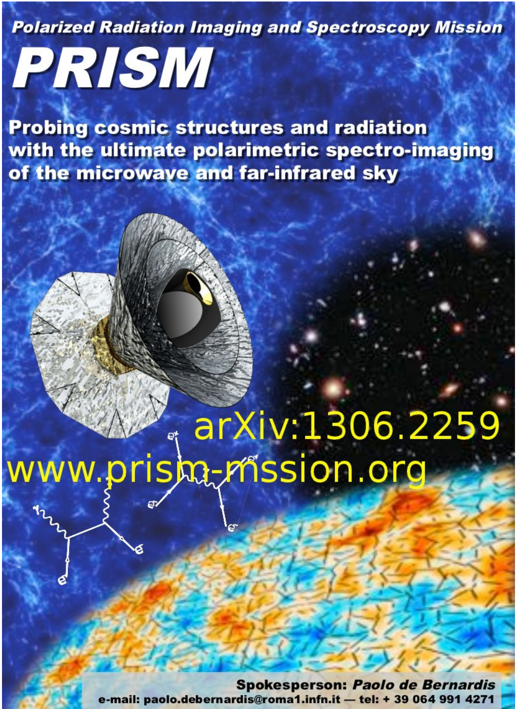
UK gathering secret intelligence via covert NSA operation

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

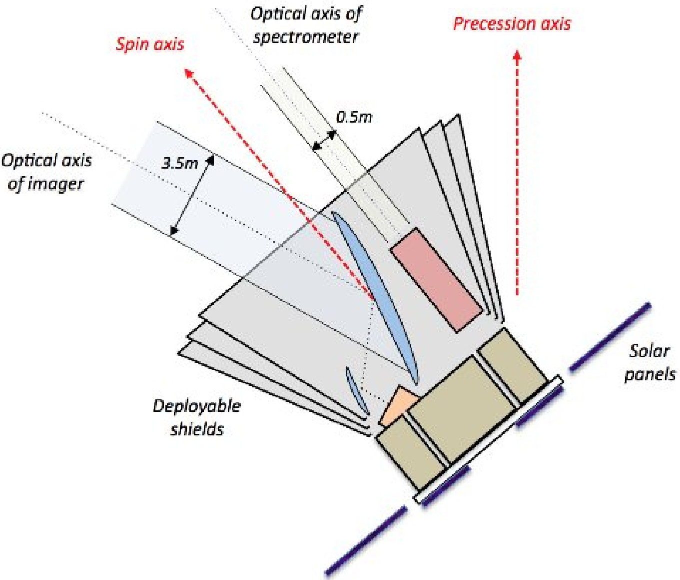
**Probing cosmic structures and radiation
with the ultimate polarimetric spectro-imaging
of the microwave and far-infrared sky**

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



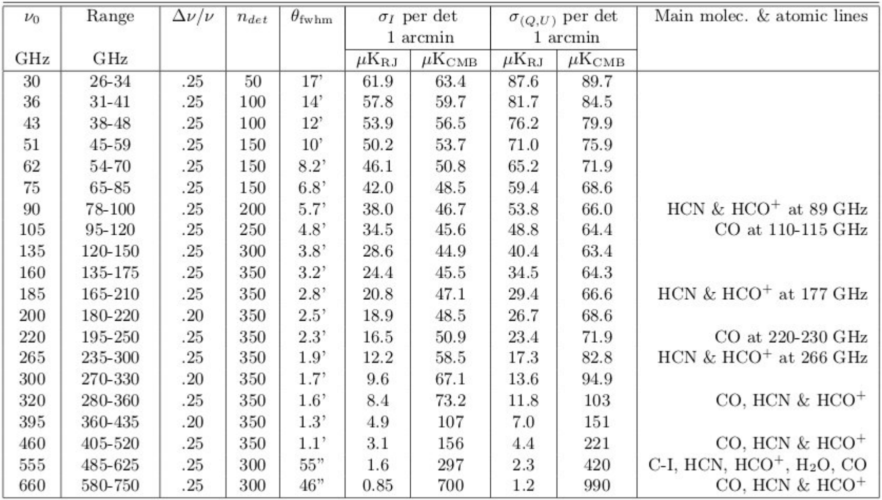
PRISM spacecraft with its two instru-

PRISM instrument highlights

Two instruments working in tandem:

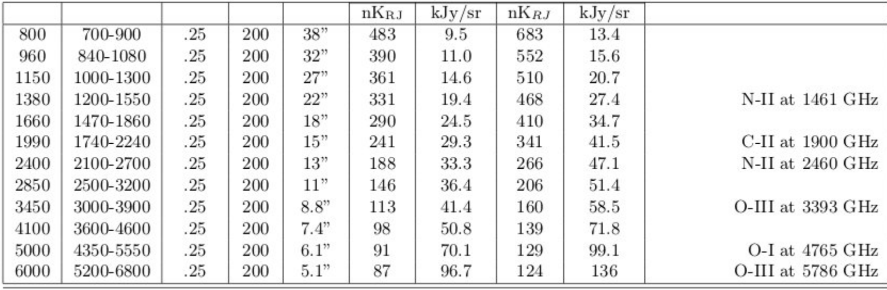
1. A Polarimeteric Imager
   - 3.5 mirror (cooled to $\approx 4K$) (to be compared with Planck mirror 1.5m not including underilumination)
   - Approximately 7000 detectors deployed at frequencies ranging from 30 GHz to 6 THz (details to be optimized). A small number of detectors with split bands for 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



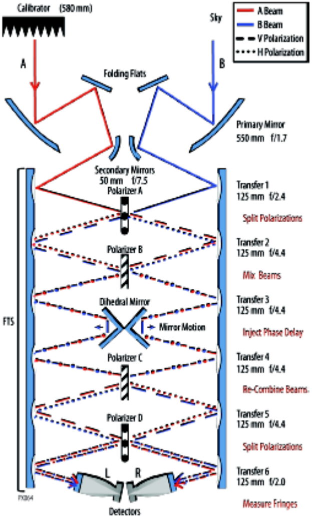
ν_0 GHz	Range GHz	$\Delta\nu/\nu$	n_{det}	$\theta_{\rm fwhm}$	σ_I per det 1 arcmin		$\sigma_{(Q,U)}$ per det 1 arcmin		Main molec. & atomic lines
					$\mu K_{\rm RJ}$	$\mu K_{\rm CMB}$	$\mu K_{\rm RJ}$	$\mu K_{\rm CMB}$	
30	26-34	.25	50	17’	61.9	63.4	87.6	89.7	
36	31-41	.25	100	14’	57.8	59.7	81.7	84.5	
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



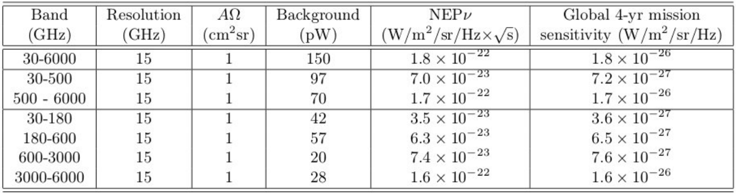
					nK$_{RJ}$	kJy/sr	nK$_{RJ}$	kJy/sr	
800	700-900	.25	200	38”	483	9.5	683	13.4	
960	840-1080	.25	200	32”	390	11.0	552	15.6	
1150	1000-1300	.25	200	27”	361	14.6	510	20.7	
1380	1200-1550	.25	200	22”	331	19.4	468	27.4	N-II at 1461 GHz
1660	1470-1860	.25	200	18”	290	24.5	410	34.7	
1990	1740-2240	.25	200	15”	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



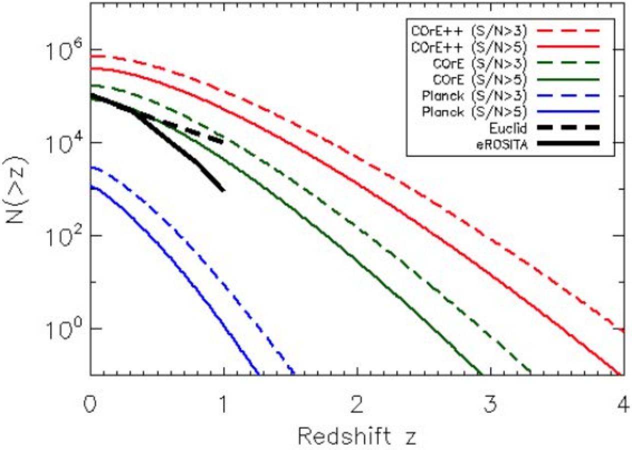
Band (GHz)	Resolution (GHz)	$A\Omega$ ($\mathrm{cm}^2\mathrm{sr}$)	Background (pW)	NEPν ($\mathrm{W/m^2/sr/Hz}\times\sqrt{\mathrm{s}}$)	Global 4-yr mission sensitivity ($\mathrm{W/m^2/sr/Hz}$)
30-6000	15	1	150	1.8×10^{-22}	1.8×10^{-26}
30-500	15	1	97	7.0×10^{-23}	7.2×10^{-27}
500 - 6000	15	1	70	1.7×10^{-22}	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)



Relativistic Sunyaev-Zeldovich Effect

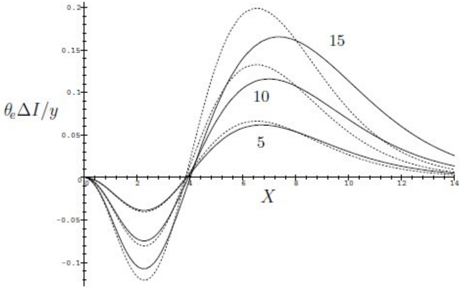


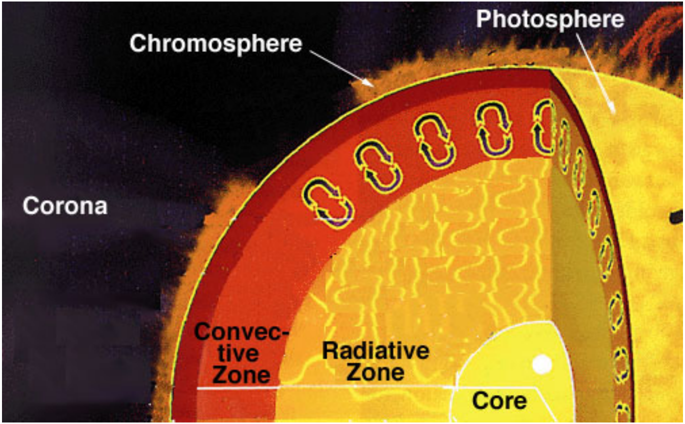
Fig. 1.— *The intensity change* $\theta_e \Delta I/y$ *(in units of* $2(k_B T_0)^3/(hc)^2$*) plotted against* X *for three values of* $k_B T_e$ *(in* keV*). The solid curves are calculated using the first-order correction to the Kompaneets equation, while the dashed lines are calculated from the usual Kompaneets expression.*

Allows independent measurement of gas temperature

(From Challinor and Lasenby, astro-ph/9711161)

NEW SCIENCE WITH ABSOLUTE SPECTROSCOPY

What is the depth of the CMB “photosphere”?



Defined in the same way as for the Sun. How deep can you see?

What is the depth of the CMB “photosphere”?

Answer: For temperature and polarization anisotropies, $z_{photo} \approx 10^3$, BUT Thomson scattering does not change the number of photons. So if the number of photons is wrong this is corrected only before $z \gtrsim 10^6$. Energy injected soon thereafter generates so-called μ distortion. For energy injection much later the spectral distortion is more complicated.

Physical mechanisms that lead to release of energy

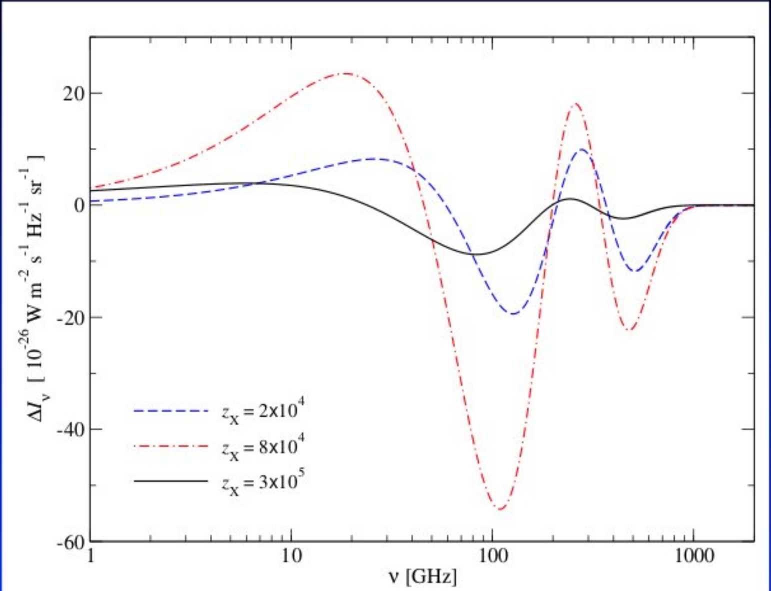
- *Cooling by adiabatically expanding ordinary matter*: $T_\gamma \sim (1+z) \leftrightarrow T_m \sim (1+z)^2$
  (JC, 2005; JC & Sunyaev 2011; Khatri, Sunyaev & JC, 2011)
  - continuous *cooling* of photons until redshift $z \sim 150$ via Compton scattering
  - due to huge heat capacity of photon field 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

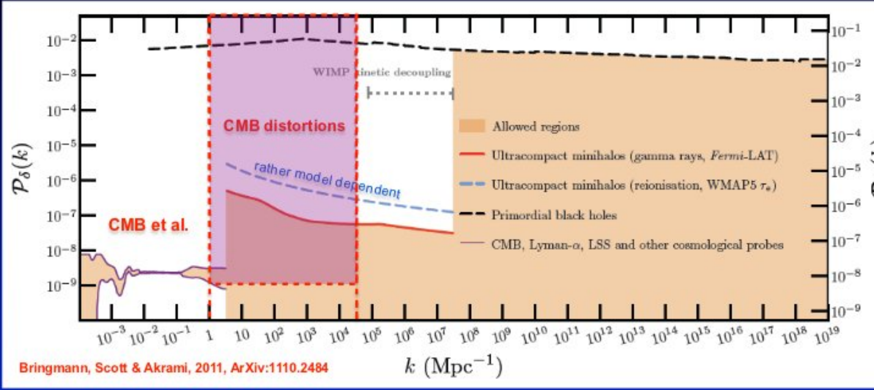
„low“ redshifts

- 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)



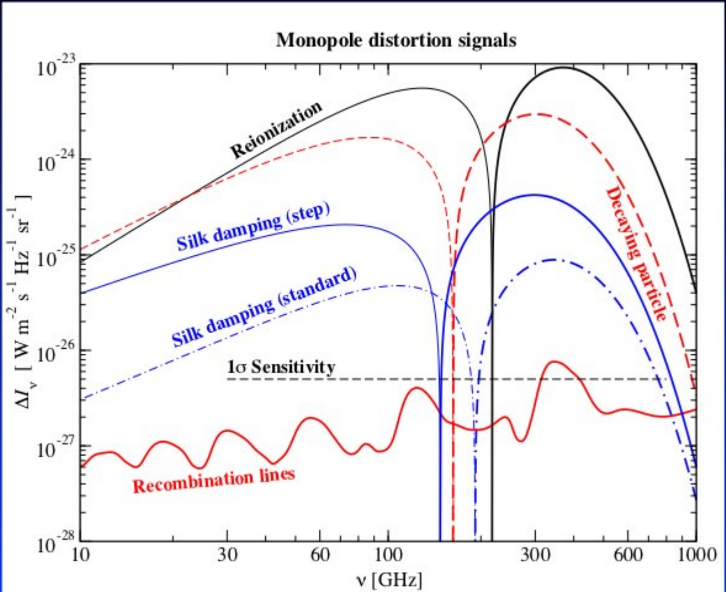
Power spectrum constraints



Bringmann, Scott & Akrami, 2011, ArXiv:1110.2484

- 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