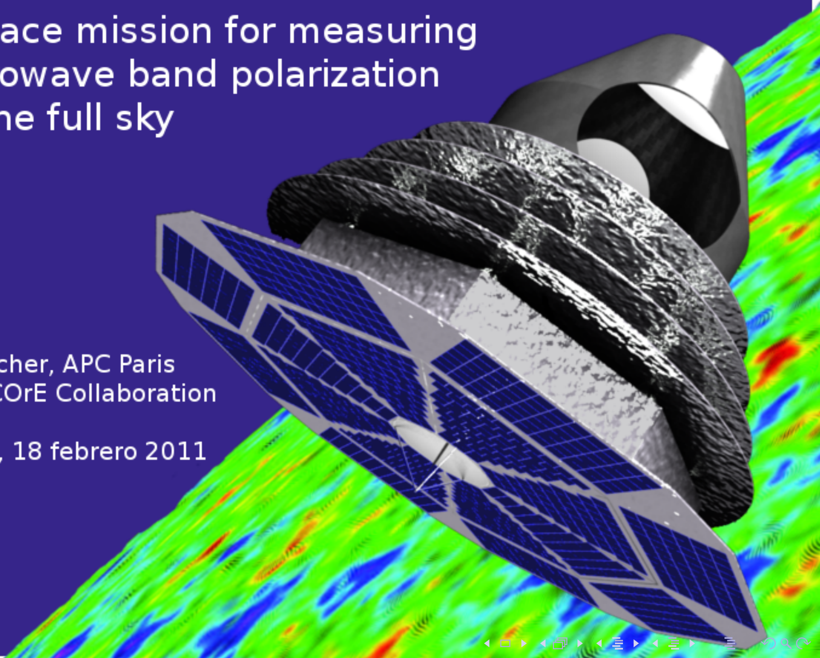
COrE : Cosmic Origins Explorer

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



Martin Bucher, APC Paris
for the COrE Collaboration

Benasque, 18 febrero 2011

COrE : Cosmic Origins Explorer

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

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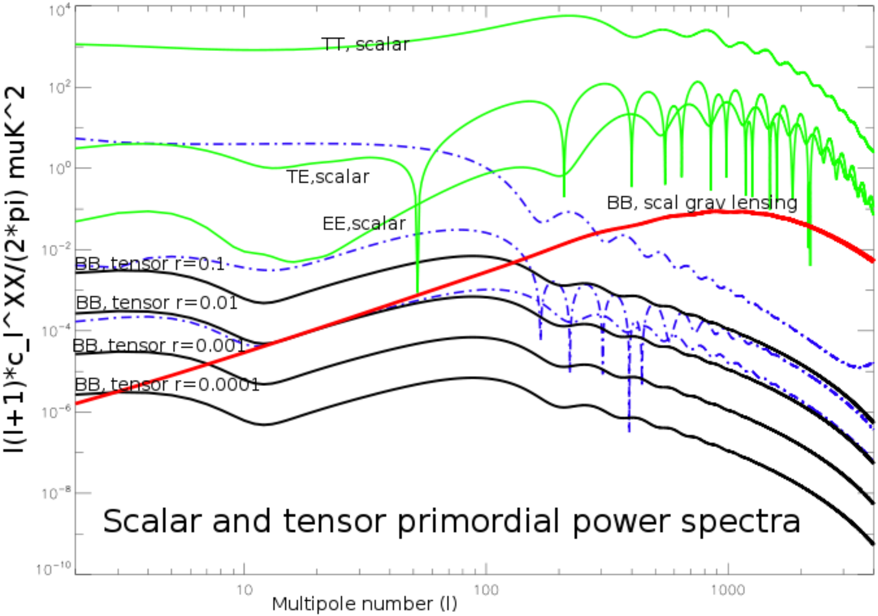
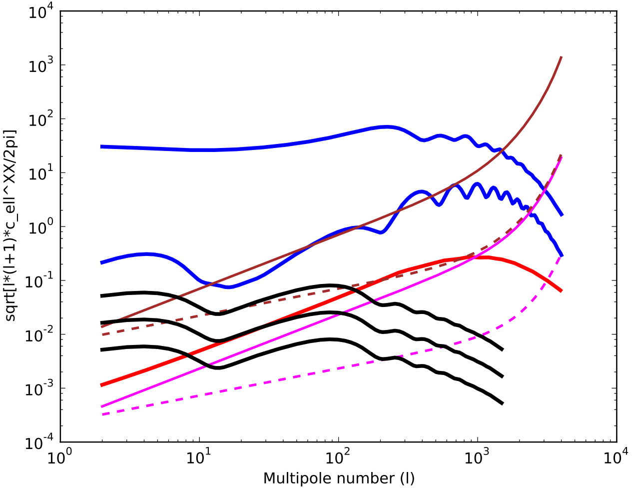
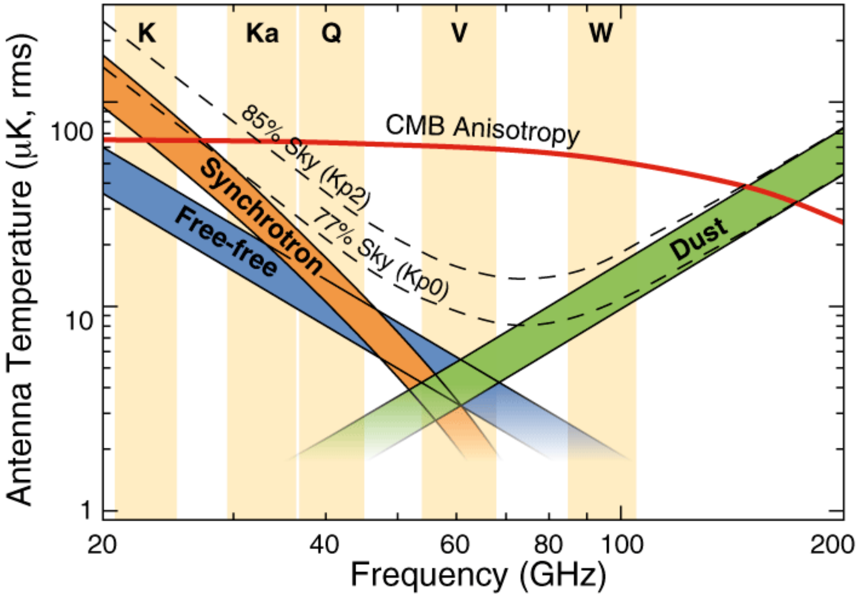


TT, scalar
TE,scalar
EE,scalar
BB, scal grav lensing
BB, tensor r=0.1
BB, tensor r=0.01
BB, tensor r=0.001
BB, tensor r=0.0001
Scalar and tensor primordial power spectra
l(l+1)*c_l^XX/(2*pi) muK^2
Multipole number (l)
10
100
1000
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}

COrE Planck Sensitivities vs. Expected signal

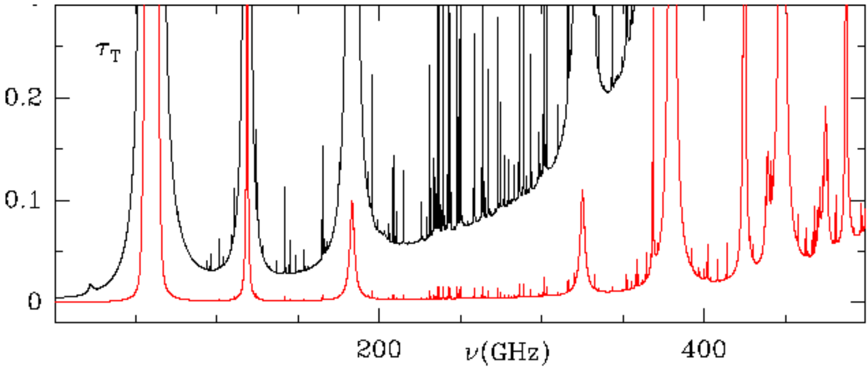


brown=planck ; magenta=COrE ; dashed = broad binning $\Delta\ell \approx \ell$, black=BB, ten for $r = 10^{-1}$, $r = 10^{-2}$, and $r = 10^{-3}$



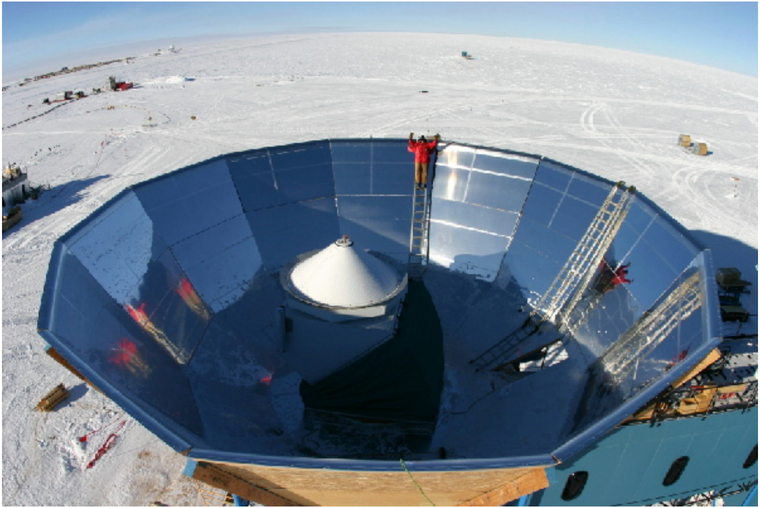
K
Ka
Q
V
W
CMB Anisotropy
85% Sky (Kp2)
77% Sky (Kp0)
Synchrotron
Free-free
Dust
Antenna Temperature (μK, rms)
100
10
1
20
40
60
80
100
200
Frequency (GHz)

Atmospheric optical depth vs. ν (GHz)



Red=South pole, black=stratospheric balloon

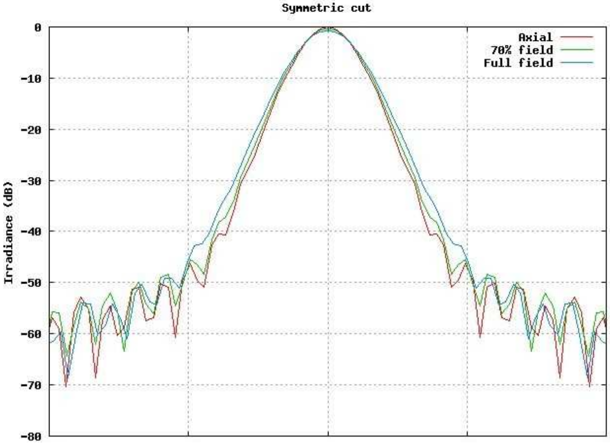
Earth and balloon based experiments need ground shields



Horns define a clean beam with highly suppressed sidelobes

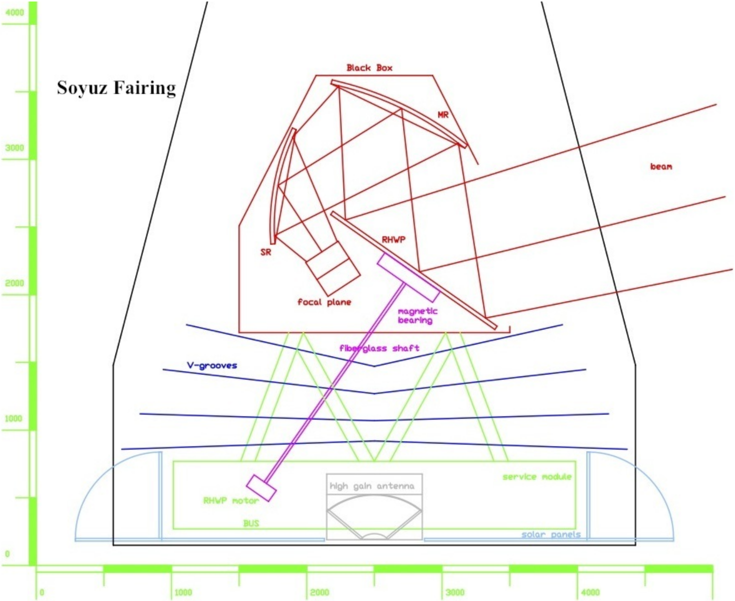
Horns from ACBAR

Far side lobes

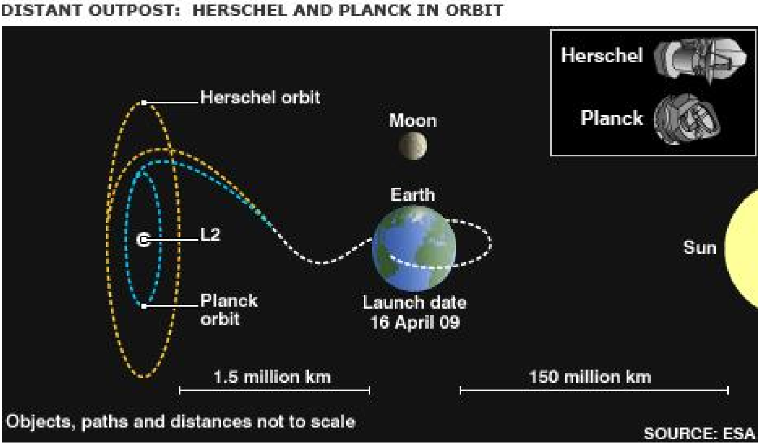


CAD realization of COrE design

COrE schematic



At L2 all hot objects can be kept far below 'horizon'



Photon shot noise

For a single mode :

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

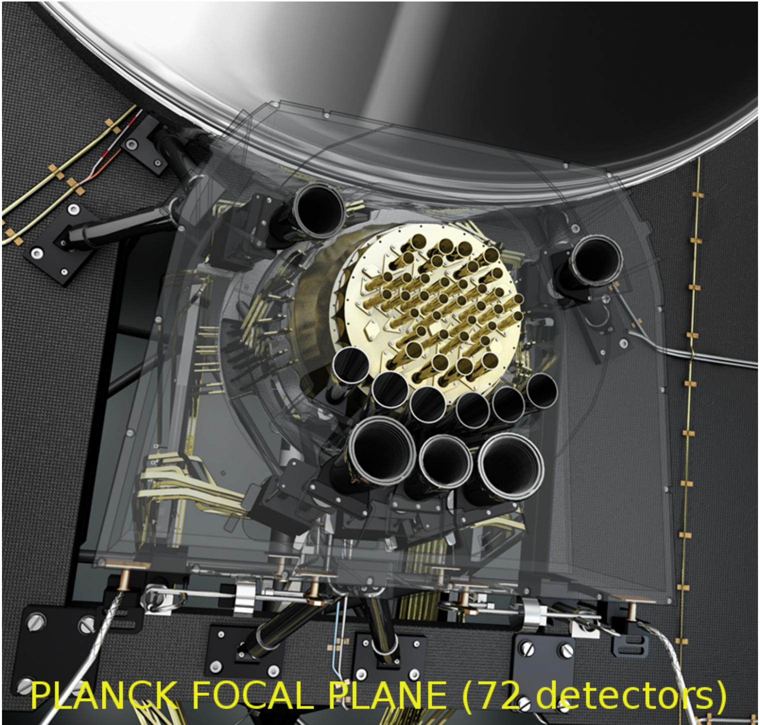
$$\langle N^2 \rangle = 2\langle N \rangle^2 + \langle N \rangle, \qquad \langle (\delta N)^2 \rangle = \langle N \rangle^2 + \langle N \rangle = N^2 + N$$

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

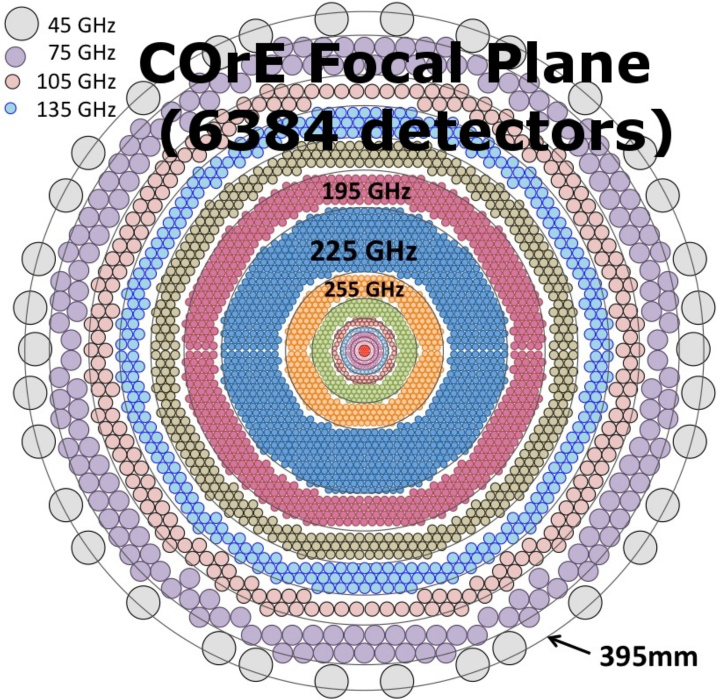
For $x \gg 1$, pure Poissonian noise, almost. For $x \ll 1$, photon bunching (Hanbury Brown and Twiss) photons arrive roughly in bunches of N, these correlations augment noise relative to Poisson distribution.
Radio astronomers' formula (quantum corrected)

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

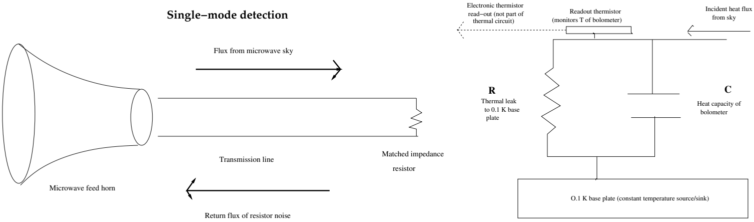
$e =$ (quantum efficiency) $=$ (prob. γ is absorbed), $\qquad T_{sky} \approx T_{CMB}$
$\epsilon_{tel} =$ (telescope emissivity)


PLANCK FOCAL PLANE (72 detectors)

COrE Focal Plane (6384 detectors)



Single-mode bolometric detection



ν GHz	n_{unpol}	n_{pol}	θ_{fwhm} arcmin	Temp (I) $\mu K \cdot$arcmin RJ	Temp (I) $\mu K \cdot$arcmin CMB	Pol (Q,U) $\mu K \cdot$arcmin RJ	Pol (Q,U) $\mu K \cdot$arcmin 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	—	—

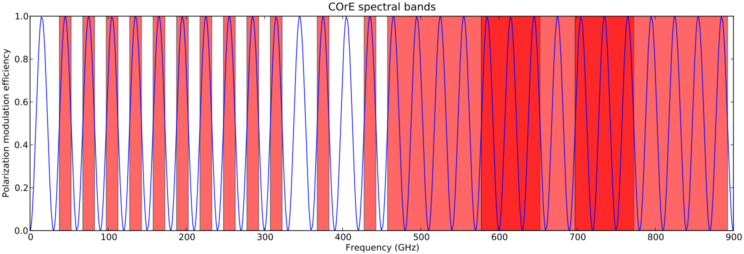
PLANCK (30 month mission)

ν *GHz*	$(\Delta\nu)$ *GHz*	n_{det}	θ_{fwhm} arcmin	Temp (I) $\mu K \cdot$arcmin RJ	Temp (I) $\mu K \cdot$arcmin CMB	Pol (Q,U) $\mu K \cdot$arcmin RJ	Pol (Q,U) $\mu K \cdot$arcmin 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)

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

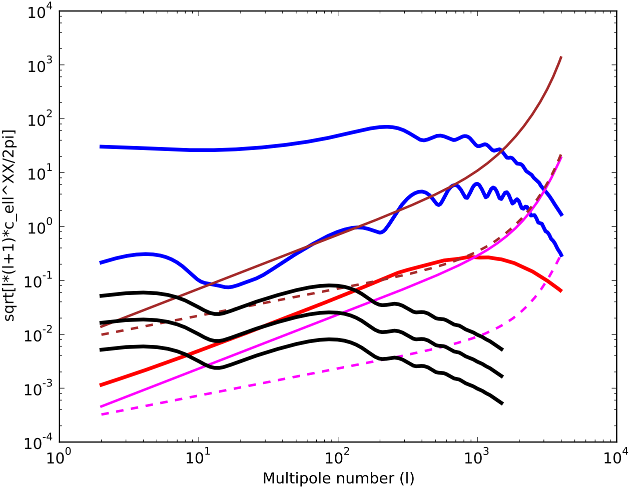
COrE's 15 Spectral Bands



Note that 3 highest bands overlap

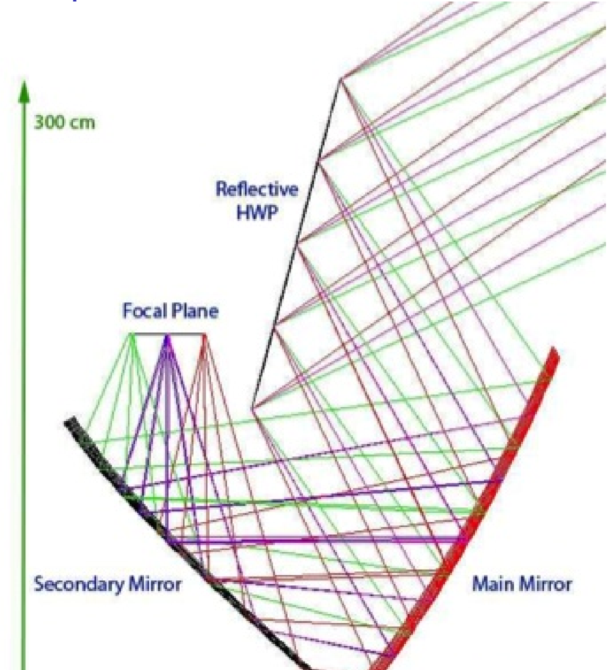
- In order to carry out foreground subtraction and provide redundancy for cross-checks 15 bands are required, minus a few. [3 synchrotron-amp.+spect-ind+running, 1 CMB, 2 free-free, 6 dust (2 BBs A+temp+emmis. index)+1 th.sz=13+2(safety)]

COrE Planck Sensitivities vs. Expected signal



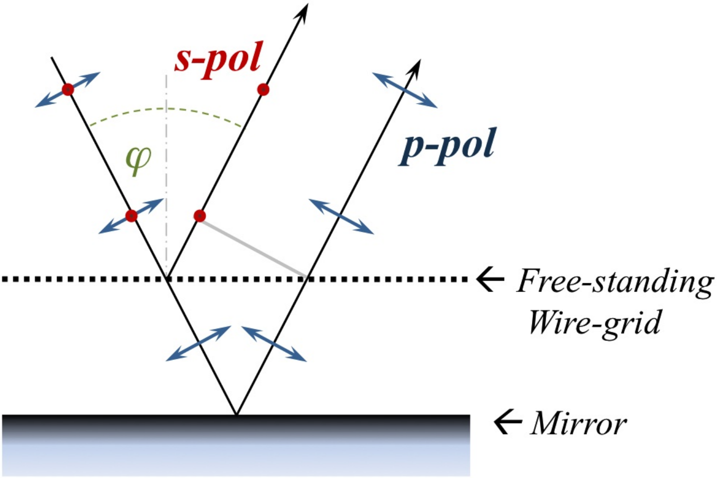
brown=planck ; magenta=COrE ; dashed = broad binning $\Delta\ell \approx \ell$, black=BB, ten for $r = 10^{-1}$, $r = 10^{-2}$, and $r = 10^{-3}$

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

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

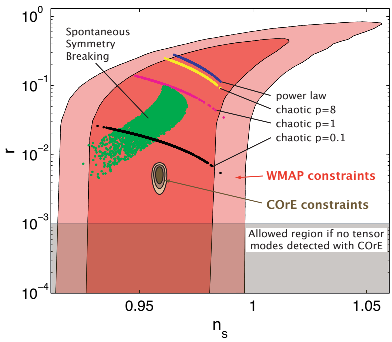
$$\left\langle (E_x^{tel})^2 \right\rangle = I + Q\cos 4\Omega + U\sin 4\Omega t$$

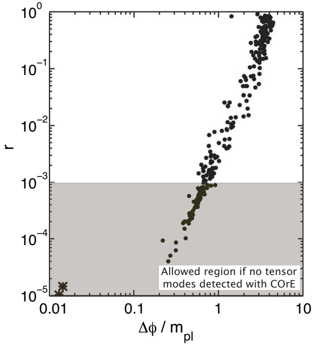
$$\left\langle (E_x^{tel})^2 \right\rangle = I - Q\cos 4\Omega - U\sin 4\Omega t$$

- 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

Science with COrE

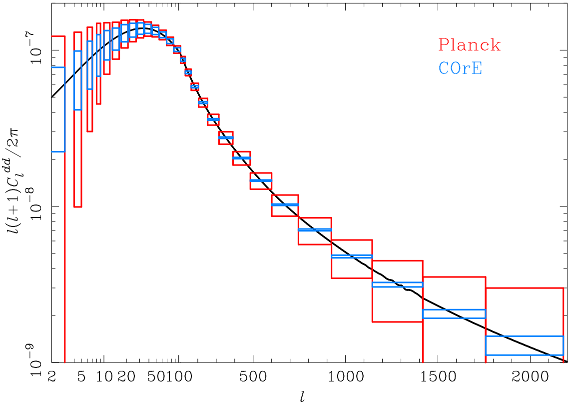
Constraining inflation with COrE



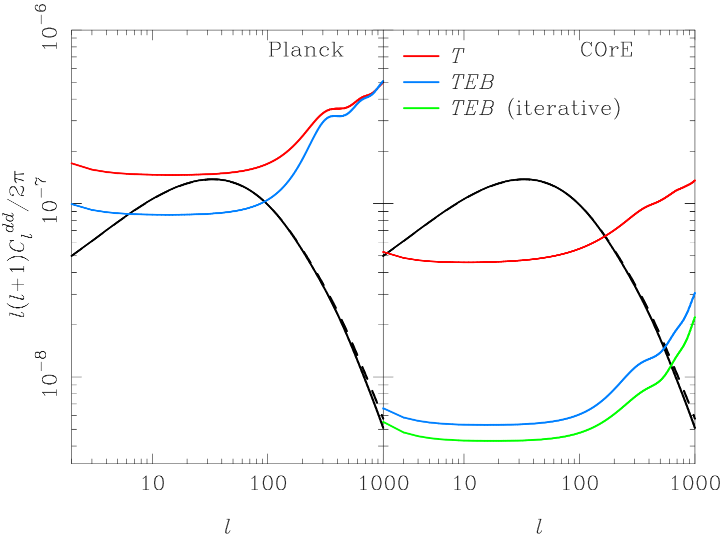


$r = 10^{-3}$ at 3σ at least.

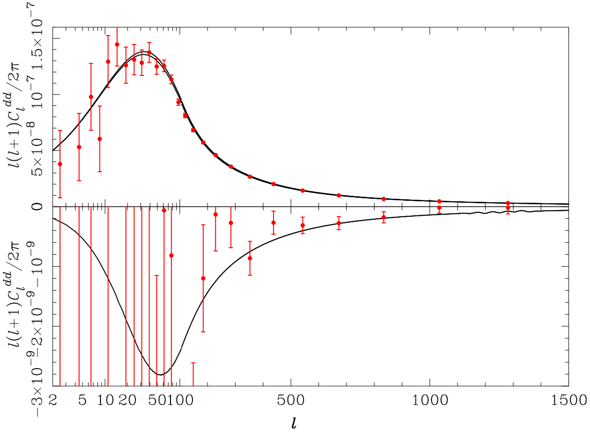
Lensing science with COrE—Measuring the Lensing Deflection Power Spectrum



Lensing reconstruction noise : PLANCK vs COrE



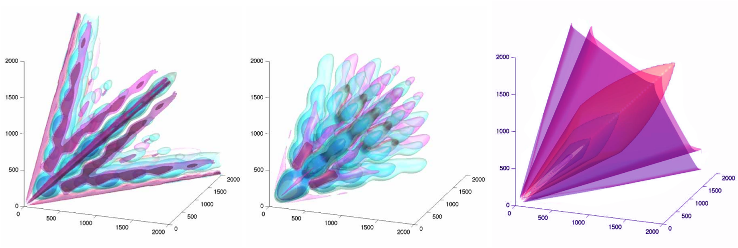
Detecting inverted absolute neutrino mass hierarchy



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.

Probing Primordial Bispectral Non-Gaussianity



Three shapes of primordial non-Gaussianity (local, equilateral, cosmic strings). $f_{NL}^{local} < 2.5$

Factor 2.5 improvement relative to PLANCK.

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.

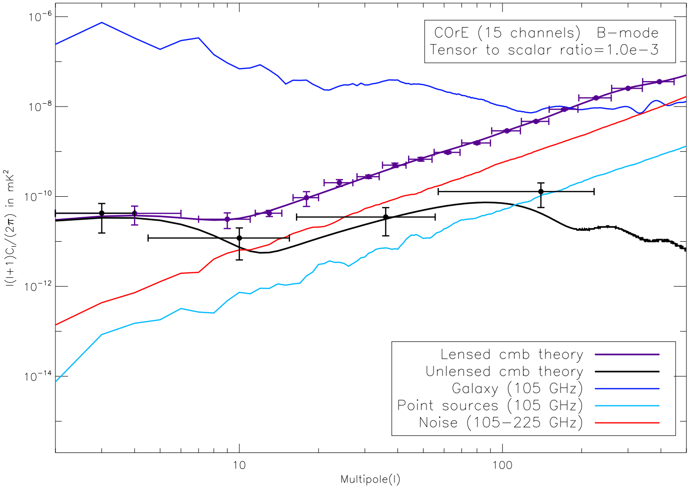
Foregrounds and component separation

- **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.

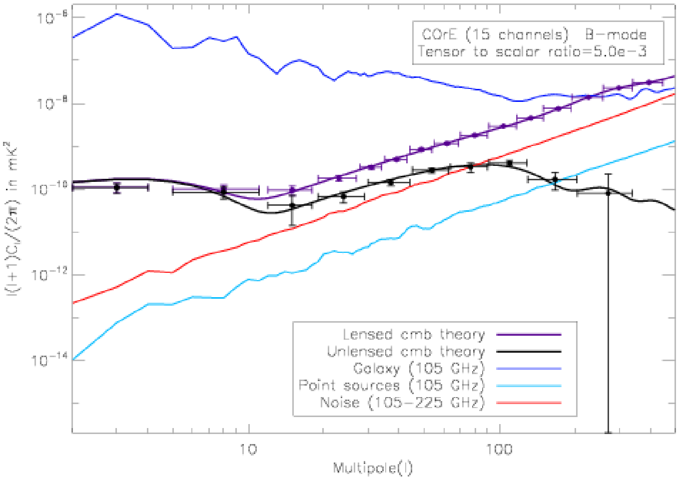
Linear component separation model.

$T_f^{sky}(\Omega) = M_{fc} X_c(\Omega)$

Simulations and forecasts for COrE : Basak, Bonaldi, Delabrouille, Peiris, Ricciardi, Verde



Basak & Delabrouille ; similar results from Bonaldi & Ricciardi



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