Measurements of the Cosmic Microwave Background

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DESY
29/09/2004

Plan of the talk

- CMB Observables
- Experimental Problems:
  - Foregrounds
  - Detector sensitivity
  - Systematics
- Current/Planned Experiments
- Hot CMB topics / measurements:
  - Polarization E, B
  - Sunyaev-Zeldovich in Clusters

Summary of CMB observables:

Increasing Difficulty

- CMB spectrum — $\langle T \rangle = 2.725K$
- CMB anisotropy angular power spectrum — $\Delta T_{rms} = 80\mu K$
- CMB polarization angular power spectra:
  - E-modes — $\Delta T_{E,rms} = 2\mu K$
  - B-modes — $\Delta T_{B,rms} < 0.1\mu K$

We heard from Ruth's talk why it is so important for cosmology and fundamental physics to measure each of these observables.

Fundamental sensitivity limit: Radiation Noise

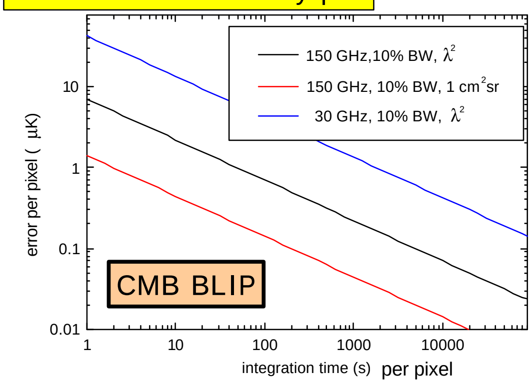
- CMB anisotropy (or polarization) measurement, integration time t, limited only by radiation noise (noiseless detector, no foregrounds !)

$$\Delta B(n,T) = \frac{\Delta T}{T}\int_{x_1}^{x_2}\frac{xe^x}{e^x-1}B(x,T)\,dx$$

$$\sigma\left(\frac{\Delta T}{T}\right) = \frac{\sigma(\Delta B)}{\int_{x_1}^{x_2}\frac{xe^x}{e^x-1}B(x,T)\,dx}$$

$$\sigma\left(\frac{\Delta T}{T}\right) = \frac{\sqrt{\frac{4k^5T^5}{c^2h^3}A\Omega\int_{x_1}^{x_2}\frac{x^4e^x}{(e^x-1)^2}dx}}{\frac{2k^4T^4}{c^2h^3}A\Omega\int_{x_1}^{x_2}\frac{x^4e^x}{(e^x-1)^2}dx}\sqrt{\frac{1}{t}}$$

The ultimate sensitivity plot



1) How can we make any other radiation negligible wrt CMB ?

- 1.1) Atmosphere
- 1.2) Astrophysical Foregrounds

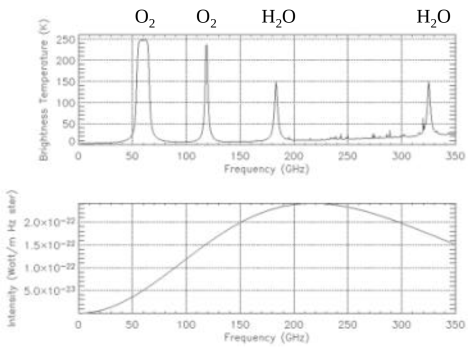
2) How do current detectors compare to CMB radiation noise ?

- 2.1) coherent detectors
- 2.2) bolometers
- 2.3) progress in large format arrays

Atmospheric Foreground

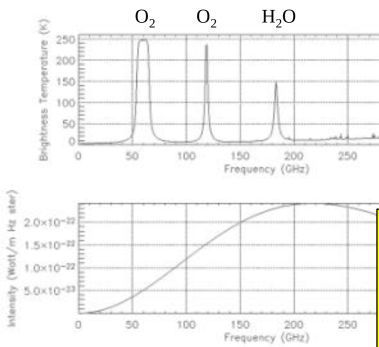
- The Earth atmosphere is a strong emitter of mm radiation.
- The instrument must operate in an atmospheric window, or carried outside the Earth atmosphere using a space carrier.
- In the first case, high altitude, cold and dry sites are selected.
- In the second case, stratospheric balloons (40 km), sounding rockets (400 km) or satellites (400 km to 10^6 km..) have been heavily used for CMB research.

Atmosphere vs CMB



from astro-ph/0307052

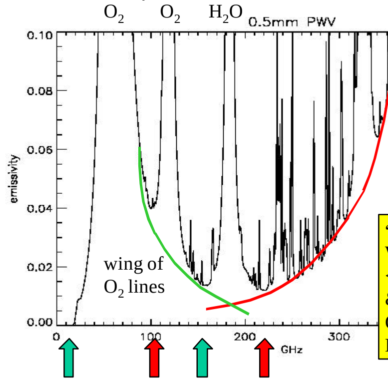
Atmosphere vs CMB



Windows:
< 30 GHz
90 GHz
150 GHz
230 GHz
..

from astro-ph/0307052

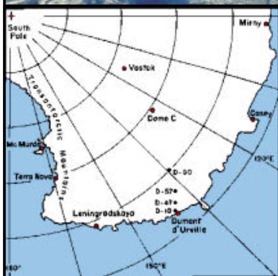
Best Atmosphere – Dome-C

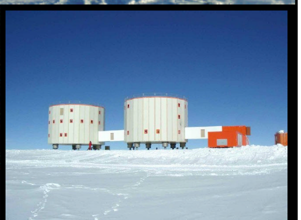


"Best"
Windows:
< 30 GHz
& 150 GHz :
O_2 in the 90 GHz
H_2O in the 230 GHz

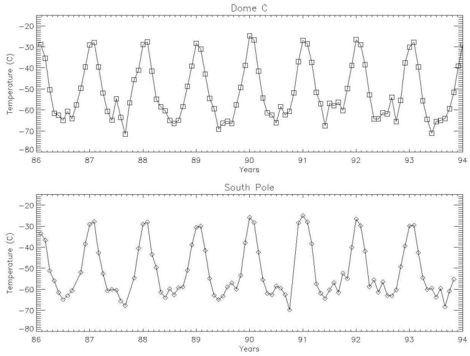
Dome-C

75° 06' 25" S 123° 20' 44" E
Altitude 3280 m osl

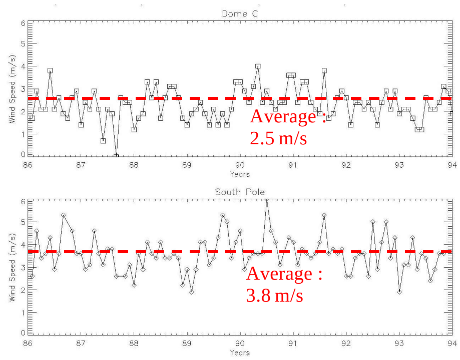




The Italian-French CONCORDIA station
Starting winter operations this year



Temperature monthly averages, from Dall'Oglio&Valenziano PASA



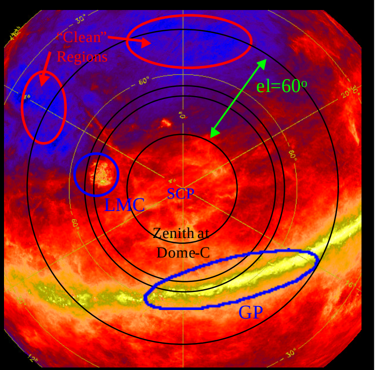
Comparison of wind speed, from Dall'Oglio&Valenziano, PASA

From Dome C:

At zenital angle 10º the instrument can survey the LMC & SMC, the Galactic plane and many cirrus clouds

At zenital angle 30º the instrument can access the "clean" regions (including the BOOMERanG one)

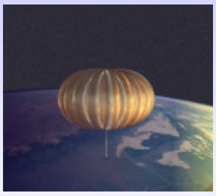
Interstellar dust map (Finkbeiner)

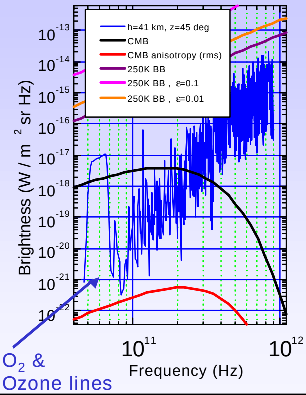


Ground based experiments are limited in frequency and sky coverage.

Wider frequency coverage, expecially at high frequency, can be obtained only from space. This is essential to monitor/remove foregrounds.

At balloon altitude (41km):



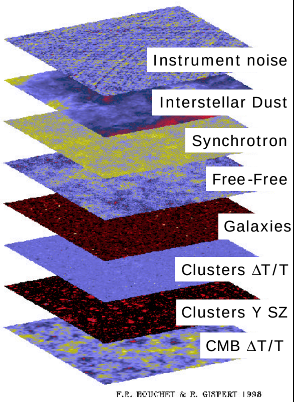


At 90 and 150 GHz balloon observations can be CMB-noise limited

Satellite observations are limited only by the astrophysical foregrounds:

Astrophysical Foregrounds

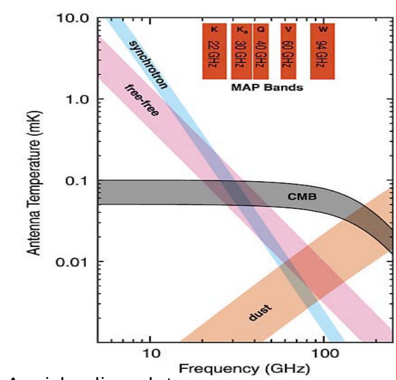
- From our location inside the Galaxy, we see the Early Universe through several layers of “local” matter, absorbing CMB photons and emitting other photons.
- Most of these layers are “thin” (optical depth <<1)



Looking outside

- The key to optimally observe the CMB (and in general any extragalactic radiation) is mainly to work at a frequency ν where the interstellar t_n is small.

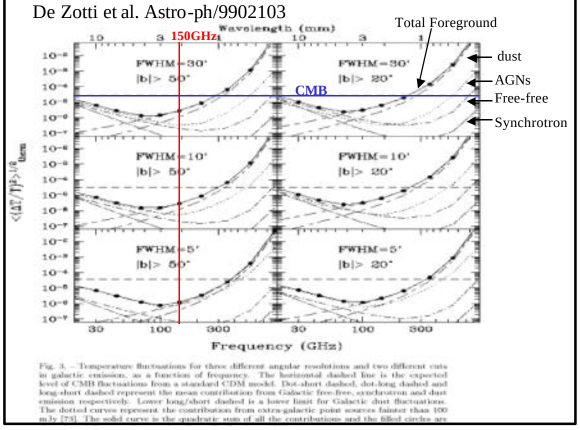
- When this is not enough, the different spectral characteristics of the galactic and extragalactic signals must be exploited to separate the two (components separation).



A misleading plot

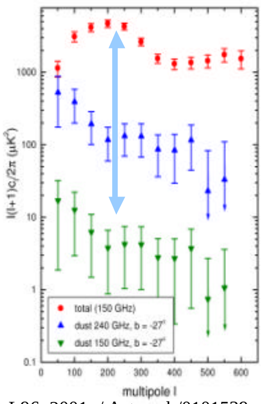
Anisotropy of different foregrounds From the WMAP web page. From this plot it looks like CMB anis. and dust anis. have similar levels 150 GHz. **Not true at high galactic latitudes!** Dust is much dimmer than CMB anisotropy

De Zotti et al. Astro-ph/9902103

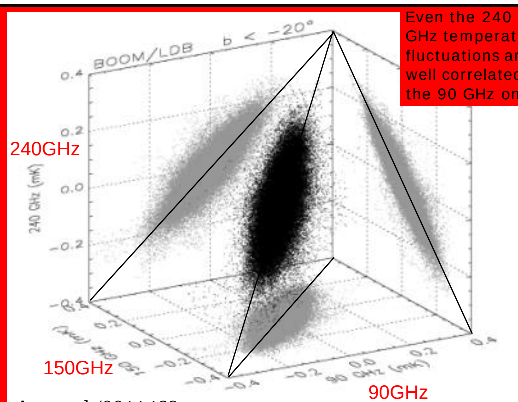


Dust fluctuations at CMB wavelengths

- In the BOOMERanG region we have measured cirrus dust fluctuations at 150 GHz.
- Their power spectrum is 2 orders of magnitude smaller than CMB anisotropy at multipoles > 100.



Masi et al. Ap.J.Letters, **553**, L93-L96, 2001 / Astro-ph/0101539



Even the 240 GHz temperature fluctuations are well correlated to the 90 GHz ones!

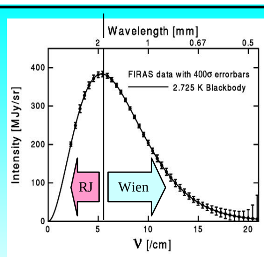
Astro-ph/0011469

The situation is not as bad as in the WMAP figure, and 150 GHz seems to be an optimal frequency for bolometer surveys. (see e.g. Baccigalupi et al., Maino et al., Tegmark, Herranz et al., Delabrouille et al., Cardoso et al., Patanchon et al.…)

However, we are basically ignorant about the polarized foreground (see e.g. Prunet et al.).

Measurements are needed !

- **Techniques ?**



$\nu \le \nu_{max} = 100\,GHz \Rightarrow$ coherent detectors $(A\Omega = \lambda^2)$

$\nu \ge \nu_{max} = 100\,GHz \Rightarrow$ bolometers $(A\Omega \ge \lambda^2)$

$\nu \approx \nu_{max} = 100\,GHz \Rightarrow$ hybrid techniques

Current detectors are approaching the CMB BLIP.

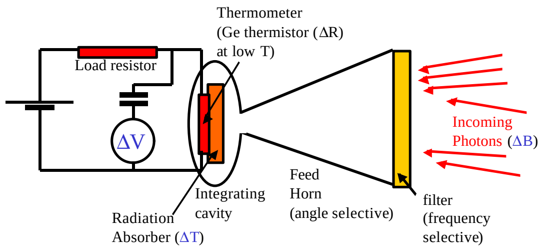
Once that is reached, the only way to improve is to use large format arrays of detectors, boosting the mapping speed.

Detectors

- Coherent detectors measure amplitude and phase of the em wave
- Thermal detectors measure the energy of the em wave
- On both sides, astrophysical and CMB research drove the development of new devices:
  - Cryogenic, ultra-low noise HEMT amplifiers (coherent)
  - Cryogenic “Spider Web” and “Polarization Sensitive” Bolometers (thermal)
  - Low sidelobe corrugated antennas …..
- Also, the two worlds are progressively mixed: for example waveguides and striplines are now used with cryogenic bolometers

Cryogenic Bolometers

- The CMB spectrum is continuum and bolometers are wide band detectors. That's why they are so sensitive.



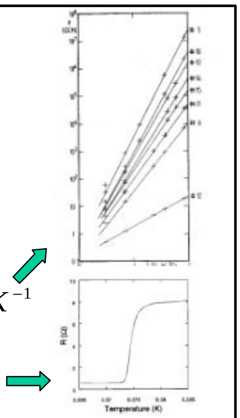
- Fundamental noise sources are Johnson noise in the thermistor ($<\Delta V^2> = 4kTR\Delta f$), temperature fluctuations in the thermistor (($<\Delta W^2> = 4kGT^2\Delta f$), background radiation noise ($T_{bkg}{}^5$) → need to reduce the temperature of the detector and the radiative background.

Cryogenic Bolometers

$$\alpha = \frac{1}{R(T)}\frac{dR(T)}{dT}$$

$$\Re = \frac{i\alpha R}{G_{eff}\sqrt{1+\tau^2\omega^2}}$$

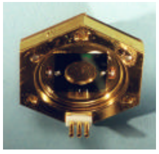
- A large α is important for high responsivity.
- Ge thermistors: $\alpha \approx -10\,K^{-1}$
- Superconducting transition edge thermistors: $\alpha \approx 1000\,K^{-1}$

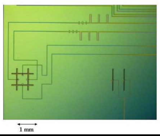


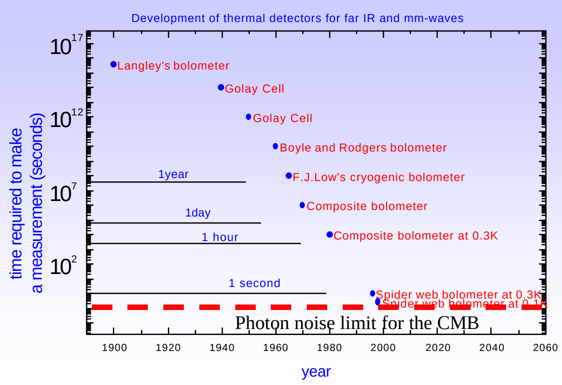
S.F. Lee et al. Appl.Opt. 37 3391 (1998)

Cryogenic Bolometers

- Ge thermistor bolometers have been used in many CMB experiments:
  - COBE-FIRAS, ARGO, MAX, BOOMERanG, MAXIMA, ARCHEOPS
- Ge thermistor bolometers are extremely sensitive, but slow: the typical time constant C/G is of the order of 10 ms @ 300mK
- Transition Edge Superconductor (TES) thermistors can do much better using electro-thermal feedback (100 µs) – Recent development (Hear Paul Richards ..)







Spider-Web Bolometers

- The absorber is micro machined as a web of metallized Si_3N_4 wires, 2 µm thick, with 0.1 mm pitch.
- This is a good absorber for mm-wave photons and features a very low cross section for cosmic rays. Also, the heat capacity is reduced by a large factor with respect to the solid absorber.
- NEP ~ 2 10^{-17} W/Hz$^{0.5}$ is achieved @0.3K
- 150µK_{CMB} in 1 s
- Mauskopf *et al.* Appl.Opt. **36**, 765-771, (1997)

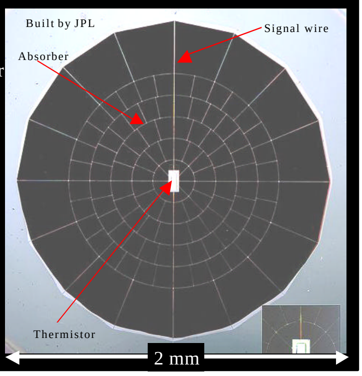


Table 5. In-flight bolometer performance

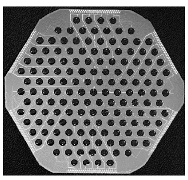
ν_0 (GHz)	τ (ms)	η_{opt}	G (pW K^{-1})	R (MΩ)	NEP (1 Hz) (10^{-17} W/$\sqrt{Hz}$)	NET_{CMB} ($\mu K\sqrt{s}$)
90	22	0.30	82	5.5	3.2	140
150sm	12.1	0.16	85	5.9	4.2	140
150mm	15.7	0.10	88	5.5	4.0	190
240	8.9	0.07	190	5.7	5.7	210
410	5.7	0.07	445	5.4	12.1	2700

Note. — In-flight bolometer performance. The 150 GHz channels are divided into single mode (150sm) and multimode(150mm). The optical efficiency of the channels decreased significantly from the measured efficiency of each feed structure due to truncation by the Lyot stop. The NEP is that measured in flight, and includes contributions from detector noise, amplifier noise, and photon shot noise.

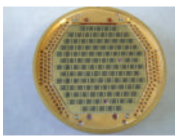
Crill et al., 2003 – BOOMERanG 1998 bolometers, 300 mK

Bolometer Arrays

- Once bolometers reach BLIP conditions (CMB BLIP), the mapping speed can only be increased by creating large bolometer arrays.
- BOLOCAM and MAMBO are examples of large arrays with hybrid components (Si wafer + Ge sensors)
- Techniques to build fully litographed arrays for the CMB are being developed.
- TES offer the natural sensors. (A. Lee, D. Benford, A. Golding ..hear Richards..)

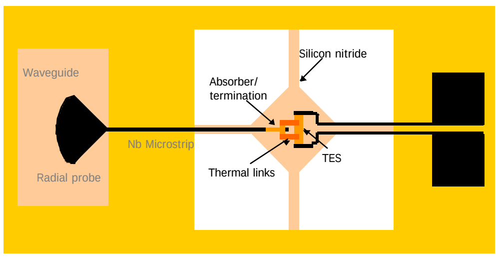


Bolocam Wafer (CSO)



MAMBO (MPIfR for IRAM)

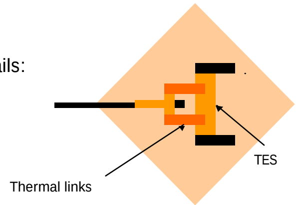
PROTOTYPE FULLY LITOGRAPHED SINGLE PIXEL - 150 GHz (Mauskopf)



Similar to JPL design, Hunt, et al., 2002 but with waveguide coupled antenna

PROTOTYPE FULLY LITOGRAPHED
SINGLE PIXEL - 150 GHz (Mauskopf)

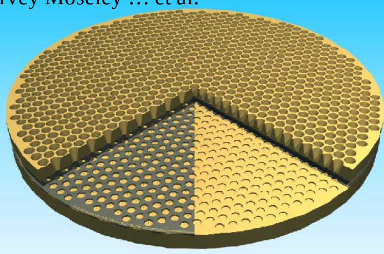
Details:



Absorber - Ti/Au: 0.5 Ω/square - t = 20 nm
Need total R = 5-10 Ω
w = 5 μm → d = 50 μm
Microstrip line: h = 0.3 μm, ε = 4.5 → Z ~ 5 Ω

TES arrays

- Are the future of this field. See recent reviews from Paul Richards, Adrian Lee, Jamie Bock, Harvey Moseley … et al.

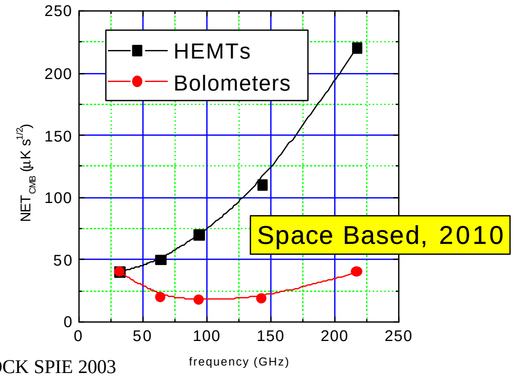


- In Proc. of the Far-IR, sub-mm and mm detector technology workshop, Monterey 2002.

Coherent Detectors

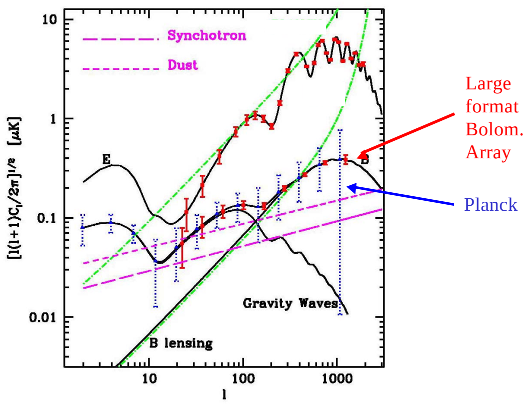
- Here the CMB em waves interact with an antenna, and a selected mode is propagated in a waveguide to a probe, where a voltage proportional to the incoming field is generated.
- The voltage is amplified by means of a fast, low noise amplifier (direct receivers)
- Very low noise HEMT amplifiers, cooled at 20K have been developed (NRAO).
- They have been used in many CMB experiments: TOCO, DASI, CBI, WMAP and will be used in Planck-LFI.
- There is no cheap way to replicate HEMT amplifiers to build a large format array (> 500$/pixel ?); moreover, due to the longer wavelength, the focal plane is larger.

SINGLE HORN POLARIMETER SENSITIVITY



J. BOCK SPIE 2003

- Imagine to have several hundred pixels observing simultaneously at 150 GHz, plus other observing at higher frequencies for foreground subtraction.
- This can be done only on a balloon (atmospheric noise/trasparency does not allow to work at f>150 GHz even from Dome-C) or on a satellite (Inflation-Probe).



Systematics

Systematics ARE there.

- Knox's formula assumes simple white gaussian noise.
- In the real world noise is not gaussian and we have drifts, spikes, events of different kind in the raw data.
- Detectors characteristics (responsivity, noise) can change with time during the survey.
- Moreover, low-level local emission can contaminate the sky signal in a non gaussian way.
- Evident features are easily identified and rejected.
- Features smaller than the noise cannot be removed, and contaminate the results.

Systematics ARE there.

- The experiment needs to have internal redundancy in order to make tests for the presence of systematics.
  A. Several detectors at the same frequency
  B. Several different frequencies
- The experimental conditions must be changed, to check the reliability of the result
  C. Experiment different scan speeds
  D. Experiment different sidelobes conditions
  E. Experiment different locations of sun, moon, strong sources.
  F. Results must be compared to results of similar, independent experiments.
- Calibration should be carried out several times during the survey
- All these tests have been passed by BOOMERanG.

Current/planned CMB experiments:

ACBAR, ACT, AMI, AMiBA, APEX, Archeops, BICEP, BOOMERanG, B-POL, BRAIN, CAPMAP, CBI, CG, ClOVER, COMPASS, DASI, MAXIPOL, MBI, MINT, OLIMPO, PLANCK, POLAR, Polatron, SPT, SuZIE, SZA, TopHat, VSA, WMAP, ...

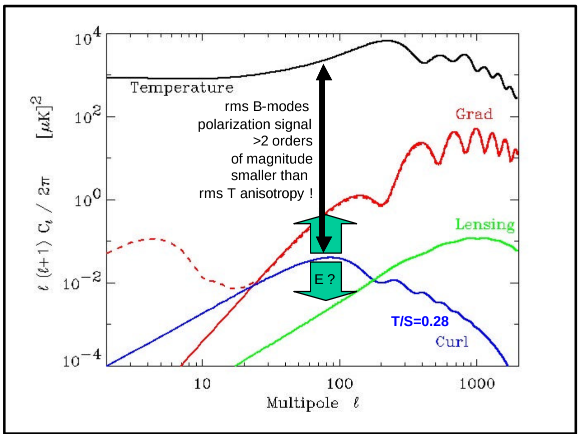
so many that it is impossible to review all. I'll focus on two hot topics / experiments:

a) Measurements of CMB polarization. B-modes are generated during inflation and are not generated at recombination. Test of inflation.
Long way to go: B2K is a first step. ClOVER will be an advanced step.

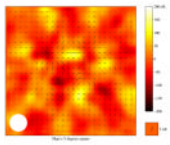
b) Measurement of SZ effect in distant clusters of Galaxies. Test of expansion rate / dark energy. OLIMPO is our way to approach the problem.

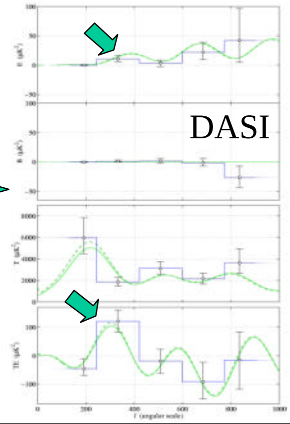
The B-modes signal is extremely weak

- Nobody really knows how to detect it.
  – Pathfinder experiments are needed
- Whatever smart, ambitious experiment we design to detect the B-modes:
  – It needs to be extremely sensitive
  – It needs an extremely careful control of systematic effects
  – It needs careful control of foregrounds
  – It will need independent experiments with orthogonal systematics.
- There is still a long way to go: ...

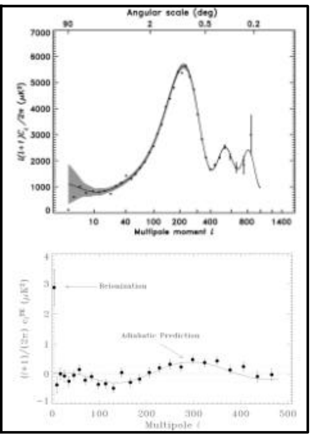


- The Degree Angular Scale Interferometer DASI at the south pole has recently detected for the first time the linear polarization of the CMB
- astro-ph/0209478
- astro-ph/0209476
- astro-ph/0409357
- at a level **consistent with the concordance model**.





- 2003: First results from WMAP, the CMB anisotropy mission of NASA, working from L2.
- The TT power spectrum, limited by cosmic variance up to l=350
- The power spectrum of TE (correlation between anisotropy and gradient polarization) in agreement with the acoustic oscillations scenario, and featuring an excess at low l.



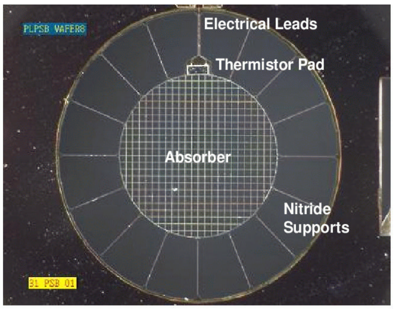
Universita' di Roma, La Sapienza: P. de Bernardis, S. Masi, F. Piacentini, A. Iacoangeli, A. Melchiorri, G. Polenta, G. de Troia, S. Ricciardi, F. Nati
Case Western Reserve University: J. Ruhl, T. Kisner, E. Torbet, T. Montroy
Caltech/JPL: A. Lange, J. Bock, W. Jones, V. Hristov
University of Toronto: B. Netterfield, C. MacTavish, E. Pascale
Cardiff University: P. Ade, P. Mauskopf
IROE: A. Boscaleri
ING: G. Romeo, G. di Stefano
CSU, Dominguez Hills: B. Crill
IPAC: K. Ganga, E. Hivon
CITA: D. Bond, C. Contaldi
LBNL, UC Berkeley: J. Borrill
Imperial College: A. Jaffe
Institut d' Astrophysique: S. Prunet
University of Alberta: D. Pogosyan
U. Penn.: M. Tegmark, A. de Oliveira-Costa
Universita' di Roma, Tor Vergata: N. Vittorio, G. de Gasperis, P. Natoli, A. Balbi, P. Cabella

B2K = BOOMERanG 2003

Polarization-sensitive bolometers JPL-Caltech

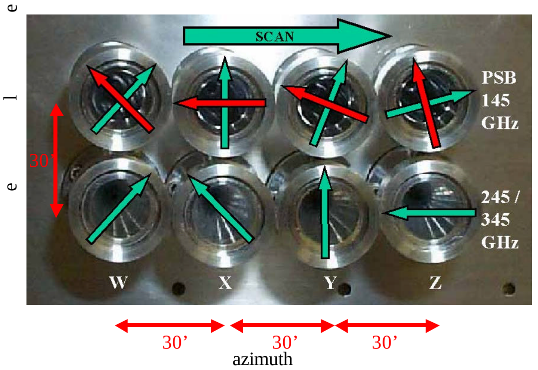
3 µm thick wire grids, Separated by 60 µm, in the same groove of a circular corrugated waveguide

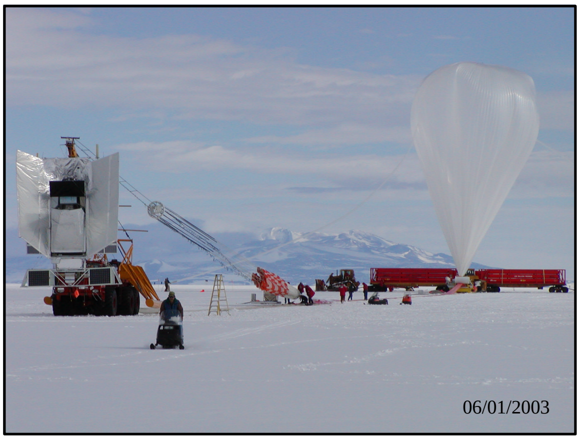
Planck-HFI testbed



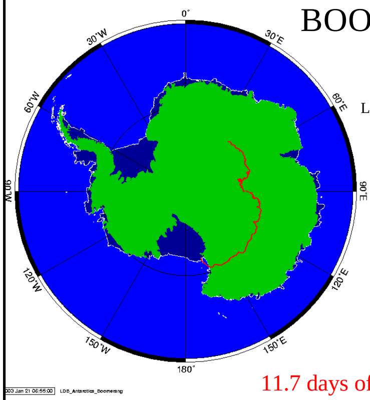
B.Jones et al. Astro-ph/0209132

B2K Focal Plane





BOOM03 Flight



Launched:

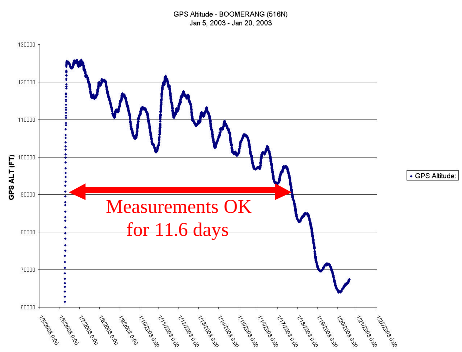
January 6, 2003

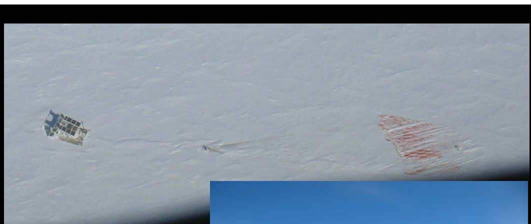
From:

McMurdo Station,

Antarctica

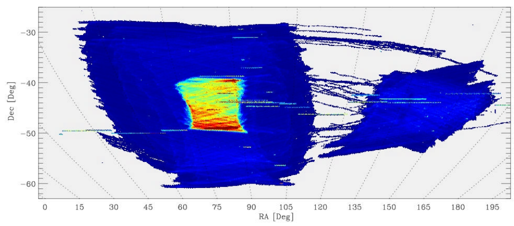
11.7 days of good data



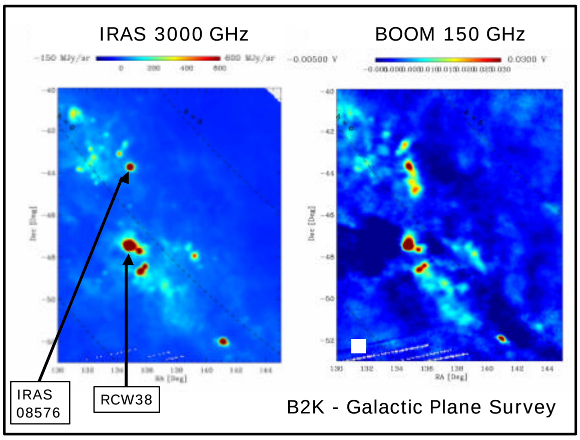


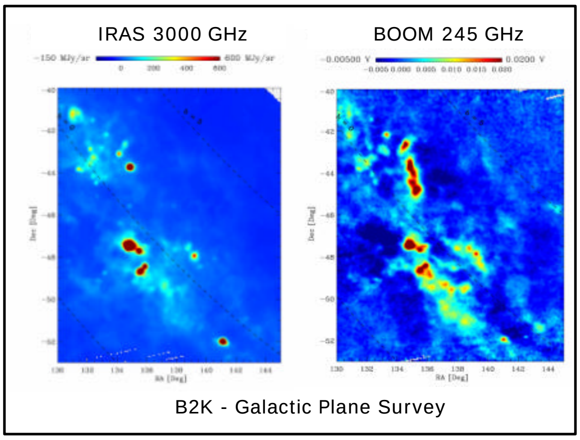
BOOMERanG landed near Dome Fuji (h=3700m) after 14 days of flight. The data have been recovered immediately . The payload has been recovered in Jan 2004.

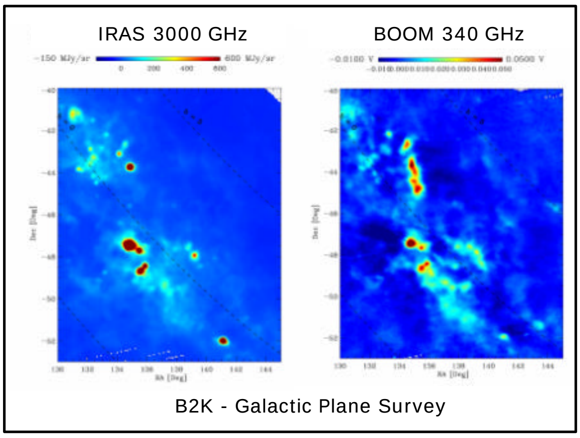
Survey Strategy

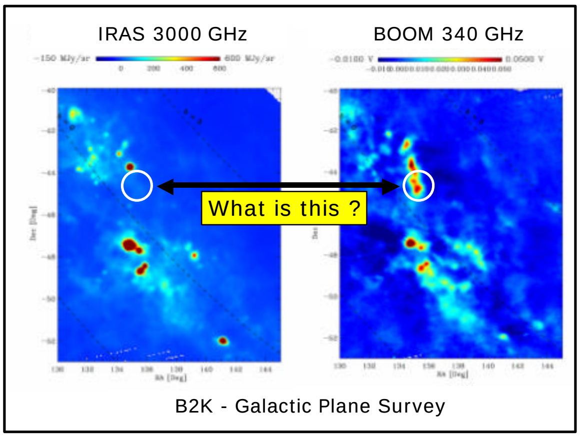


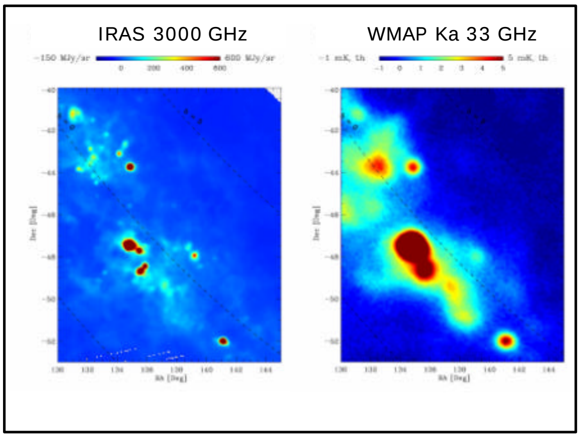
Region	Size (sq deg)	Goal	Time per 7' pixel
Deep CMB	115	<EE>	60 sec
Shallow CMB	1130	<TE> and <TT>	3.3 sec
Galactic Plane	390	Polarized Foregrounds	4.7 sec

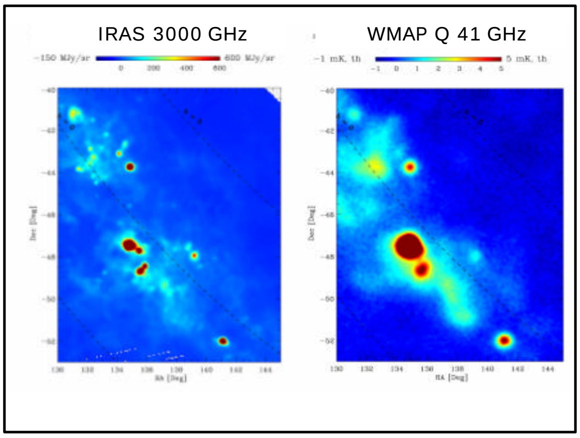

IRAS 3000 GHz
BOOM 150 GHz
IRAS
08576
RCW38
B2K - Galactic Plane Survey

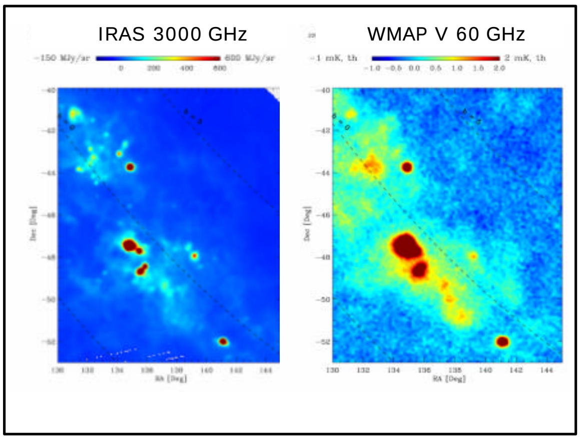

IRAS 3000 GHz
BOOM 245 GHz
B2K - Galactic Plane Survey

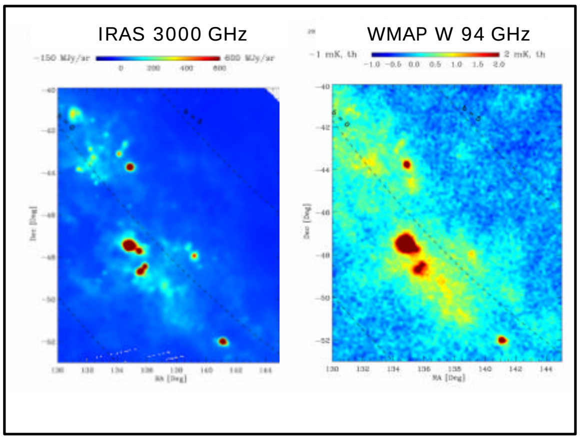

IRAS 3000 GHz
BOOM 340 GHz
B2K - Galactic Plane Survey

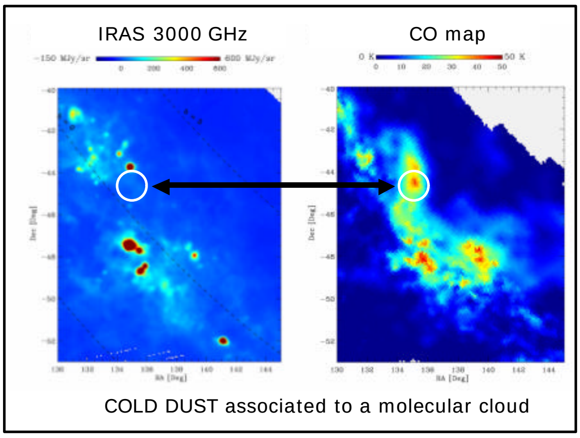

IRAS 3000 GHz
BOOM 340 GHz
What is this ?
B2K - Galactic Plane Survey

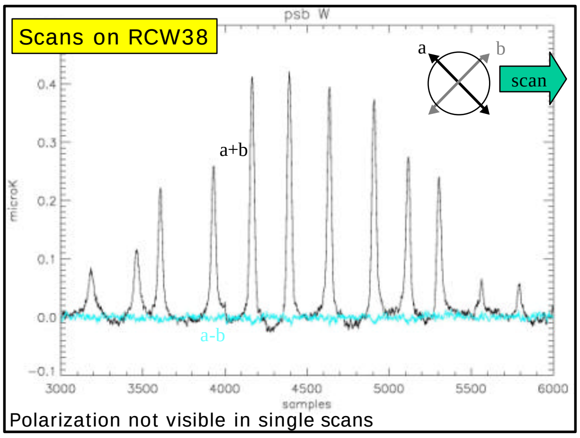

IRAS 3000 GHz
WMAP Ka 33 GHz

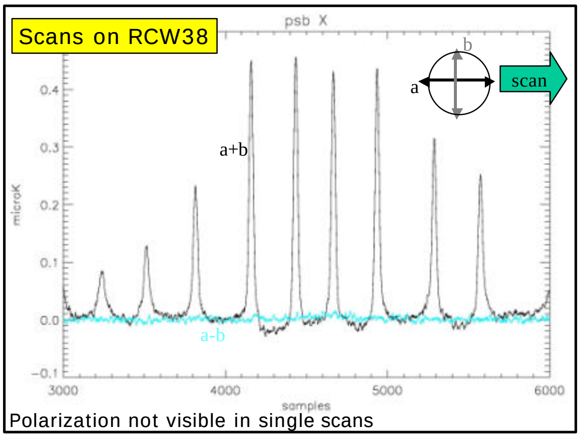

IRAS 3000 GHz
WMAP Q 41 GHz

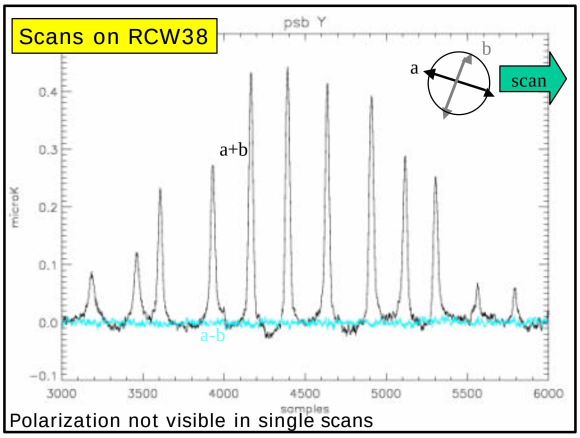

IRAS 3000 GHz
WMAP V 60 GHz

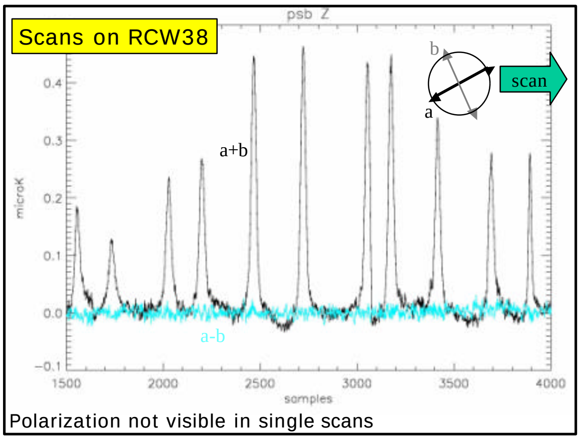

IRAS 3000 GHz
WMAP W 94 GHz

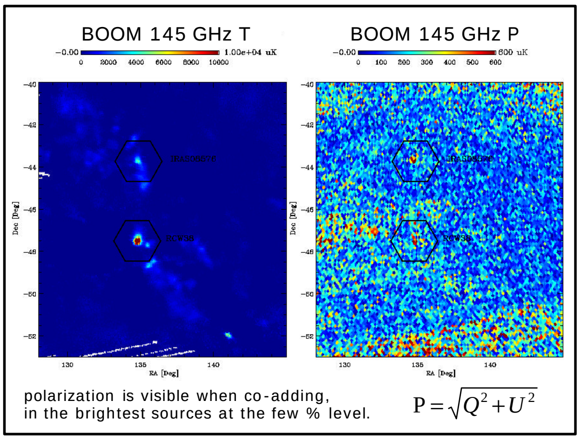

IRAS 3000 GHz
CO map
COLD DUST associated to a molecular cloud

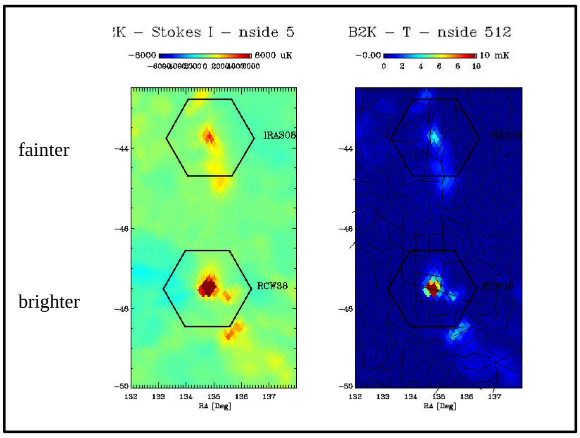

Scans on RCW38
psb W
a
b
scan
a+b
a-b
microK
samples
Polarization not visible in single scans

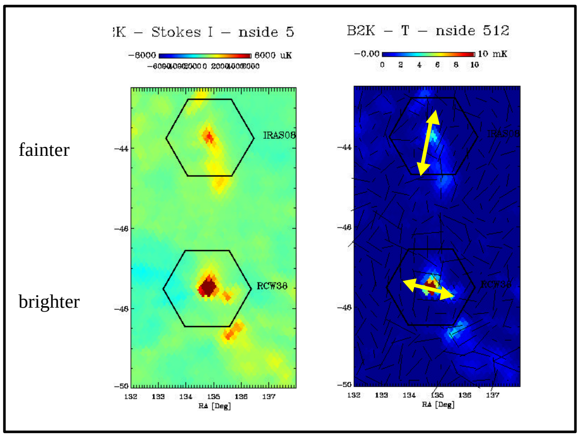

Scans on RCW38
psb X
a
b
scan
a+b
a-b
microK
samples
Polarization not visible in single scans

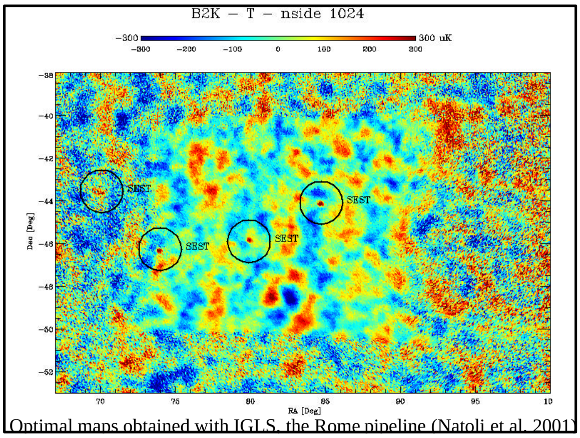

Scans on RCW38
psb Y
a
b
scan
a+b
a-b
microK
samples
Polarization not visible in single scans

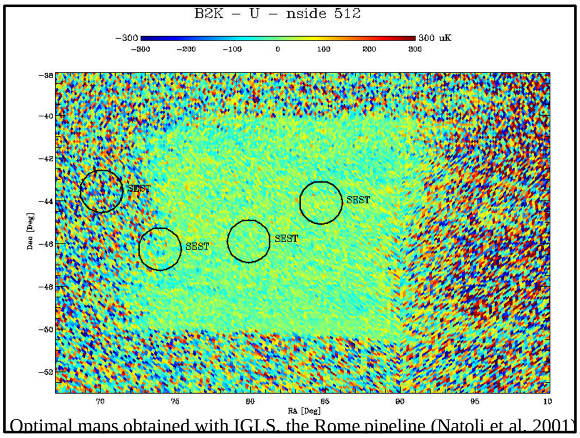

Scans on RCW38
psb Z
a+b
a-b
b
a
scan
microK
samples
Polarization not visible in single scans

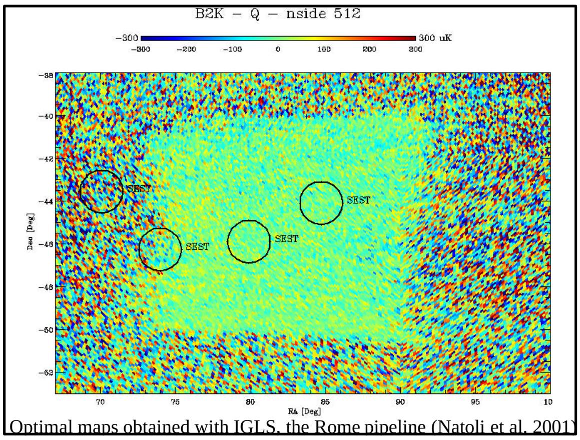

BOOM 145 GHz T
BOOM 145 GHz P
polarization is visible when co-adding,
in the brightest sources at the few % level.
$P = \sqrt{Q^2 + U^2}$


K – Stokes I – nside 5
B2K – T – nside 512
fainter
brighter
IRAS08
RCW38
RA [Deg]


K – Stokes I – nside 5
B2K – T – nside 512
fainter
brighter
IRAS08
RCW38
RA [Deg]


B2K – T – nside 1024
SEST
RA [Deg]
Dec [Deg]
Optimal maps obtained with IGLS, the Rome pipeline (Natoli et al. 2001)


B2K – U – nside 512
SEST
RA [Deg]
Dec [Deg]
Optimal maps obtained with IGLS, the Rome pipeline (Natoli et al. 2001)



Optimal maps obtained with IGLS, the Rome pipeline (Natoli et al. 2001)

Is there any signal in the Q,U maps ?

- Likelihood to measure the observed signals in the i=1..N pixels. For gaussian correlated signal and noise:

$$L(\sigma^k_{sky}) = \prod_i \frac{1}{\sqrt{2\pi\left|C_{ij}(\sigma^k_{sky})\right|}} \exp\left[-X_i C^{-1}_{ij}(\sigma^k_{sky}) X_j\right]$$

$$k = \begin{cases} T \\ Q \\ U \end{cases} ;\ X = \begin{cases} T_i \\ Q_i \\ U_i \end{cases} ;\ C_{ij}(\sigma^k_{sky}) = (\sigma^k_{sky})^2 R^k(\theta_{ij}) + (N^k_{ij})^2$$

Normalized Sky covariance

Pixel Noise covariance

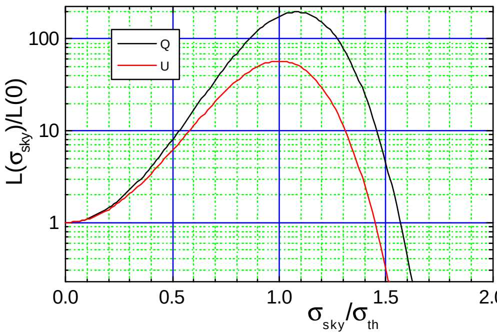
Is there any signal in the Q,U maps ?

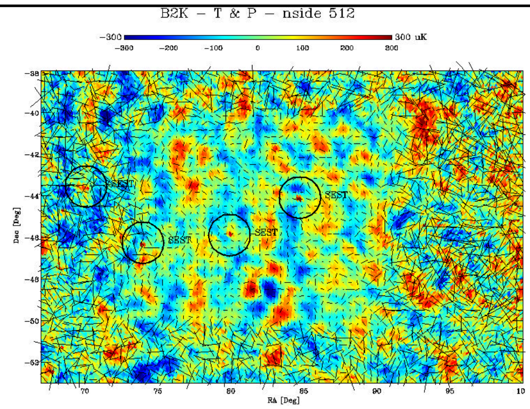
- For a rough estimate, we can neglect the correlations:

$$L(\sigma^k_{sky}) = \prod_i \frac{1}{\sqrt{2\pi(\sigma_i^2 + \sigma_{sky}^2)}} \exp\left[-\frac{1}{2}\frac{X_i^2}{\sigma_i^2 + \sigma_{sky}^2}\right]$$

$$k = \begin{cases} T \\ Q \\ U \end{cases} ;\quad X = \begin{cases} T_i \\ Q_i \\ U_i \end{cases}$$

- In the deep region we have N=5137 pixels (7' side).
- Average noise = (20,28,28 μK) per pixel (T,Q,U).
- Expected CMB rms: (100, 2, 2 μK) for (T,Q,U).



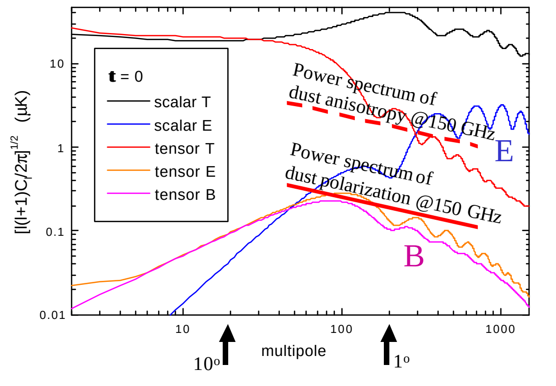


Data Analysis

- Is underway. We have now two pipelines (one in the USA, one in Italy) converging to optimal maps of T, Q, U.
- Optimal Spectral estimation is also underway.

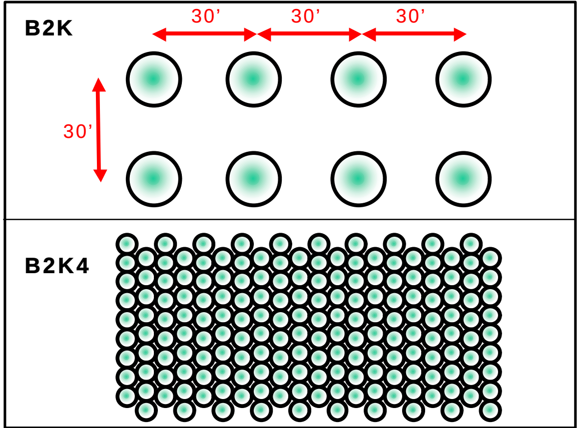
The future of BOOMERanG

- Diffuse Dust emission is polarized at 10% in the plane of the Galaxy. See **astro-ph/0306222** "First Detection of Polarization of the Submillimetre Diffuse Galactic Dust Emission by Archeops".
- Its polarization will have both E-modes and B-modes.
- We know that **at 150 GHz** at high latitudes the PS of dust emission is about 1% of the PS of CMB anisotropy (Masi et al. **Ap.J. 553,** L93-L96, 2001)
- So **we naively expect B-modes from dust polarization PS at a level of 10^{-4} of the anisotropy**.
- This is an important foreground for B-modes of CMB, whose level is also about 10^{-4} of anisotropy !
- These are only rough estimates. We know very little about the configuration and distribution of the magnetic fields aligning the dust grains.



B2K5

- We plan to re-fly B2K with an upgraded forcal plane, to go after foreground cirrus dust polarization.
- This information is **essential** for all the planned B-modes experiments (e.g. BICEP, Dome-C etc.) and is very difficult to measure from ground.
- The BOOMERanG optics can host an array of >100 PSB at >350 GHz.



(http://oberon.roma1.infn.it/olimpo)

OLIMPO

An arcmin-resolution survey of the sky at mm and sub-mm wavelengths

Silvia Masi
Dipartimento di Fisica
La Sapienza, Roma

and

the OLIMPO team

(http://oberon.roma1.infn.it/olimpo)

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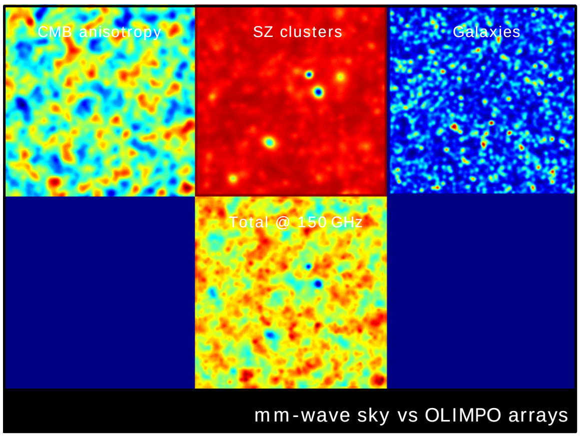
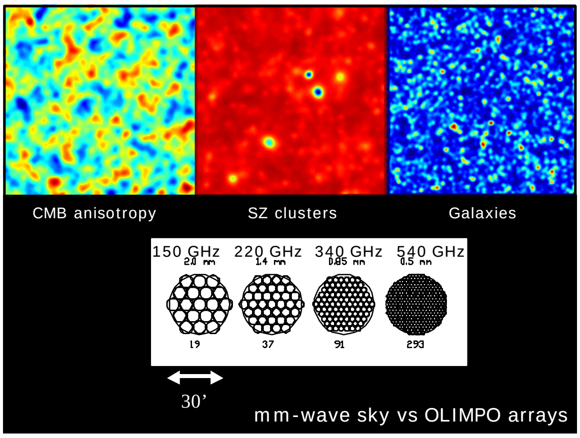
OLIMPO: the Team

- Dipartimento di Fisica, La Sapienza, Roma
  - S. Masi, M. Calvo, L. Conversi, P. de Bernardis, M. De Petris, F. Melchiorri, F. Nati, L. Nati, F. Piacentini, G. Polenta, S. Ricciardi
- IFAC-CNR, Firenze
  - A. Boscaleri
- INGV, Roma
  - G. Romeo
- Univ. of Cardiff, Astronomy
  - P.A.R. Ade, P. Mauskopf, A. Orlando
- CEA Saclay
  - D. Yvon
- Univ. Of San Diego
  - Y. Rephaeli

OLIMPO

- Is the combination of
  - A large (2.6m diameter) mm/sub-mm telescope with scanning capabilities
  - A multifrequency array of bolometers
  - A precision attitude control system
  - A long duration balloon flight
- The results will be high resolution (arcmin) sensitive maps of the mm/sub-mm sky, with optimal frequency coverage (150, 220, 340, 540 GHz) for SZ detection, Determination of Cluster parameters and control of foreground/background contamination.



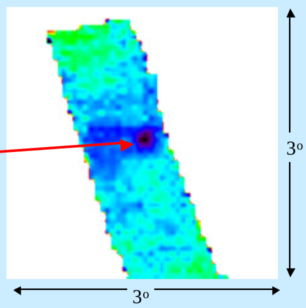


Olimpo: list of Science Goals

- Sunyaev-Zeldovich effect
  - Measurement of H_o from rich clusters
  - Cluster counts and detection of early clusters -> parameters (Λ)
- Distant Galaxies – Far IR background
  - Anisotropy of the FIRB
  - Cosmic star formation history
- CMB anisotropy at high multipoles
  - The damping tail in the power spectrum
  - Complement interferometers at high frequency
- Cold dust in the ISM
  - Pre-stellar objects
  - Temperature of the Cirrus / Diffuse component

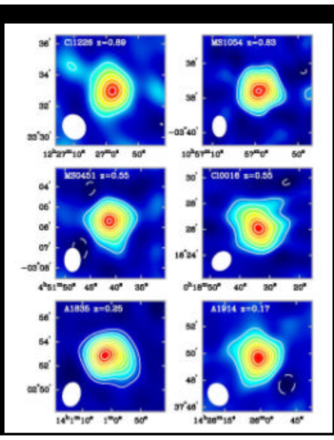
OLIMPO observations of a SZ Cluster

- Simulated observation of a SZ cluster at 2 mm with the Olimpo array.
- The large scale signals are CMB anisotropy.
- The cluster is the dark spot evident in the middle of the figure.
- Parameters of this observation: scans at 1°/s, amplitude of the scans 3°p-p, detector noise 150 mK s$^{1/2}$, 1/f knee = 0.1 Hz, total observing time = 4 hours, comptonization parameter for the cluster y=10^{-4}.

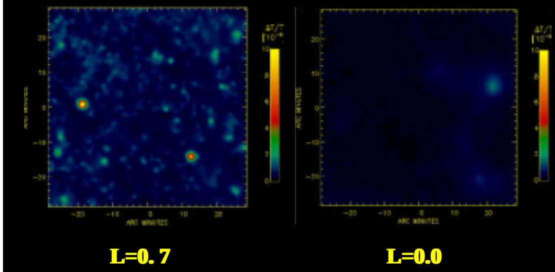


Carlstrom J., et al. Astro-ph/0208192 ARAA 2002

The SZ signal from the clusters does not depend on redshift.



Simulations show that the background from unresolved SZ clusters is very sensitive to **L** (see e.g. Da Silva et al. astro-ph/0011187)

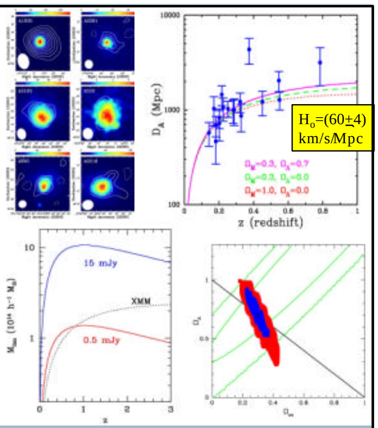


S-Z

SZ and X brightness measurements can be combined to measure D_A. (Cavaliere 1978)
Doing this for a sample of clusters with known z, it is possible to derive H_0 (see e.g. Reese et al. Astro-ph/0205350)

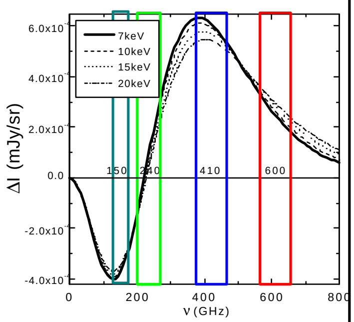
Deep surveys of SZ clusters can give independent estimates of Λ and Ω_M through the measurement of SZ clusters counts.

See e.g. Carlstrom et al. Astro-ph/0103480



The uniqueness of OLIMPO

- OLIMPO measures in 4 frequency bands simultaneously. These bands optimally sample the spectrum of the SZ effect.
- This allows us to clean the signal from any dust and CMB contamination, and even to measure T_e by means of the relativistic corrections.



Simulations show that:

- For a
  - $Y=10^{-5}$ cluster,
  - in a dust optical depth of 10^{-5} @ 1 mm,
  - In presence of a 100 μK CMB anisotropy
- In 2 hours of integration over 1 square degree of sky centered on the cluster
  - Y can be determined to $\pm 10^{-6}$,
  - ΔT_{CMB} can be measured to $\pm 10\mu K$
  - T_e can be measured to ± 3keV
- Many clusters (order 100) can be observed in a long duration flight

Clusters sample

- We have selected 40 nearby rich clusters to be measured in a single long duration flight.
- For all these clusters high quality data are (or will be) available from XMM/Chandra

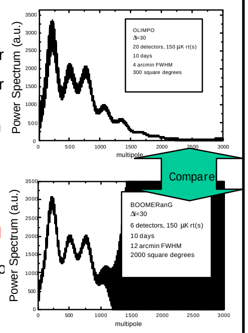
Number	Cluster	z	Number	Cluster	z
1	A168	0.0452	11	A1317	0.0695
2	A400	0.0232	12	A1367	0.0215
3	A426	0.0183	13	A1656	0.0232
4	A539	0.0205	14	A1775	0.0696
5	A576	0.0381	15	A1795	0.0616
6	A754	0.0528	16	A2151	0.0371
7	A1060	0.0114	17	A2199	0.0303
8	A1185	0.0304	18	A2256	0.0601
9	A1215	0.0494	19	A2319	0.0564
10	A1254	0.0628	20	A2634	0.0312

Serendipitous Clusters

- Distant clusters produce the same SZ as nearby ones.
- OLIMPO is able to detect clusters never seen in the X-rays.
- The number density of these clusters strongly depends on the expansion history, i.e. on Λ.
- The higher resolution and sensitivity wrt Planck will allow deeper observations.
- The multifrequency observation will allow a cleaner removal of high frequency foregrounds (wrt SP, APEX etc.).

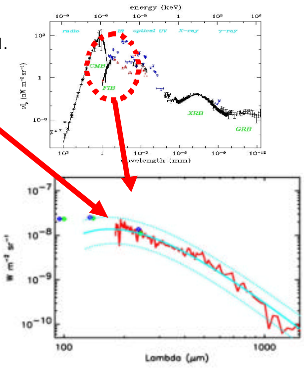
Olimpo: CMB anisotropy

- Taking advantage of its high angular resolution, and concentrating on a limited area of the sky, OLIMPO will be able to measure the angular power spectrum (PS) of the CMB up to multipoles l ≈3000, significantly higher than BOOMERanG, MAP and Planck.
- In this way it will complement at high frequencies the interferometers surveys, producing essential independent information, in a wide frequency interval, and free from systematics like sources subtraction.
- The measurement of the damping tail of the PS is an excellent way to map the dark matter distribution (4) and to measure $\Omega_{darkmatter}$ (5).



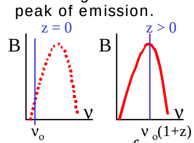
mm/sub-mm backgrounds

- Diffuse cosmological emission in the mm/sub-mm is largely unexplored.
- A cosmic far IR background (FIRB) has been discovered by COBE-FIRAS (Puget, Hauser, Fixsen)
- It is believed to be produced by ultra-luminous early galaxies (Blain astroph/0202228)
- Strong, negative k-correction at mm and sub-mm wavelengths enhances the detection rate of these early galaxies at high redshift.

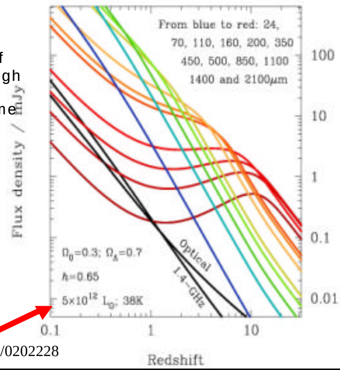


mm/sub-mm galaxies

- In the sub-mm we are in the steeply rising part of the emission spectrum: if the galaxy is moved at high redshift we will see emission from a rest-frame wavelength closer to the peak of emission.



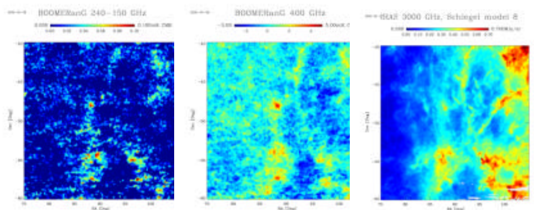
$$S_n = \frac{1+z}{4\pi D_L^2} L \frac{f_{n(1+z)}}{\int f_n \, dn'}$$



Blain, astro-ph/0202228

Olimpo: Cold Cirrus Dust

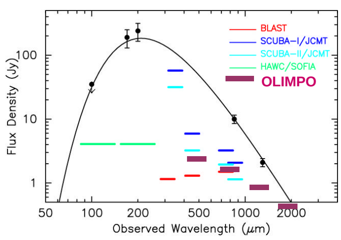
- Sub-mm observations of cirrus clouds in our Galaxy are very effective in measuring the temperature and mass of the dust clouds.



- See Masi et al. Ap.J. **553**, L93-L96, 2001; and Masi et al. *"Interstellar dust in the BOOMERanG maps"*, in "BC2K1", De Petris and Gervasi editors, AIP 616, 2001.

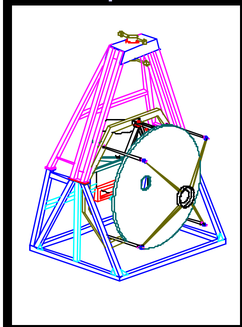
OLIMPO can be used to survey the galactic plane for pre-stellar objects

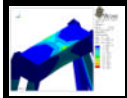
M16 - In the constellation Serpens

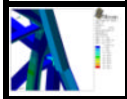


The SED of L1544 with 10σ 1 second sensitivities

Olimpo: The Payload







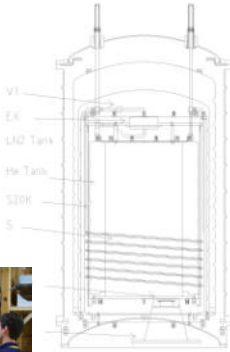
The inner frame can point from 0° to 60° of elevation.

Olimpo: The Primary mirror

- The primary mirror (2.6m) has been built and verified.
- It is the largest mirror ever flown on a stratospheric balloon.
- It is slowly wobbled to scan the sky.

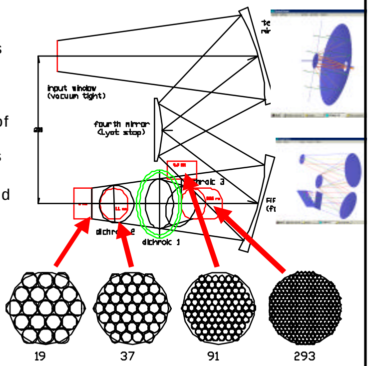
Olimpo: technical solutions

- The **dewar** is being developed in Rome. It is based on the same successfull design of the BOOMERanG dewar (6,7)
- 25 days at 290 mK.



Olimpo: reimaging optics

- The **cryogenic reimaging optics** is being developed in Rome.
- It is mounted in the experiment section of the cryostat, at 2K, while the bolometers are cooled at 0.3K.
- Extensive baffling and a cold Lyot stop reduce significantly straylight and sidelobes.



OLIMPO will be flown as a trans-Mediterranean flight (24 hours) from Sicily to Spain in July 2005 (ASI)

The long duration flight (300 hours) will be in 2006 from Svalbard or from Antarctica.