Observation strategy for Planck and other Cosmic Microwave Background experiments

X. Dupac

European Space Agency – ESAC

Villanueva de la Cañada, Madrid, Spain

xdupac@sciops.esa.int

We present possible and actual observation strategies for Cosmic Microwave Background experiments. Such experiments largely aim at covering the whole sky or a significant part of it, with the challenges associated to this. In particular, orbital constraints (for space experiments) or geographical constraints (for ground-based or balloon-borne experiments) make it difficult to observe the sky in a smooth and uniform way. Additionally, depending on the instrument characteristics, noise and systematic effects control may demand some particular types of observation strategies. We shortly describe the WMAP and Planck scanning strategies as well as those used for some CMB balloon-borne experiments, and possible conclusions for future experiments.

CMB balloon-borne experiments

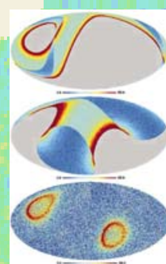
Scanning strategies for balloon-borne experiments can make good use of the daily rotation of the Earth and the proper motion of the balloon over the Earth while the observations take place.

In most cases, CMB balloon-borne experiments scan the sky through constant elevation circles at a constant rotation speed, as Archeops and TopHat did for example.

This allows to observe a large area of the sky.

The launch place and flight duration have a crucial influence on the sky coverage and the redundancy in the map pixels.

Experiments using this constant elevation scanning strategy have to balance between coverage and redundancy. Maximum redundancy is obtained with high elevation angles and high-latitude launch sites. In contrast, the best coverage / flight time ratio is obtained at near-equatorial sites and with low elevation angles.

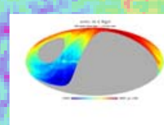


The factors controlling the observation characteristics are the place and date of launch, the trajectory of the balloon, the flight duration, the elevation angle of scanning above the horizon, (the sampling frequency and the rotation speed of the gondola).

Fast-scanning of a large part of the sky often leads to difficult map-making challenges due to the nature of the noise (1/f, systematic effects).

Maximizing number of crossings and redundancy in pixels is important to process properly the noise during map-making.

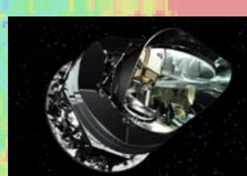
Elevation angle of scanning and/or launch site latitude are crucial for this. Reference: (3)



Space-based CMB experiments

Space-based CMB experiments (COBE (7), WMAP (1), Planck (5)) are normally of much longer duration than balloons, making it possible to observe the whole sky, several times.

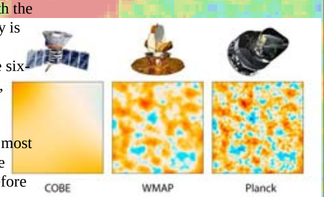
A natural scanning strategy is to sweep the sky in great circles – or near great circles. For a satellite in a low-Earth orbit, this strategy allows for example to always point towards the zenith, in order to avoid light contamination from the Earth.



This kind of strategy also works for a space-craft at L2, such as Planck (5,6). In this case the strategy can be as simple as a constant great circle in the Ecliptic meridian perpendicular to the Sun–Earth axis, which slowly shifts with the revolution of the Earth. A whole-sky survey is therefore completed in six months.

In case the bore-sight angle is < 90 deg, the six month survey leaves a hole in the coverage, which can be mitigated using slightly more complicated strategies.

Some CMB experiments cross scans in the most intricate way possible, in order to maximize redundancy at all time/angular scales, therefore have a rotating + precessing spacecraft.



Conclusions

Cosmic Microwave Background time-ordered datasets tend to be remarkably complex and difficult to process properly, taking into account noise statistical properties, signal properties, systematic effects, beam shape issues, etc. In order to help with the data-processing challenges, an optimal scanning strategy is a great asset – for polarization data, the issue is even more critical since the CMB signal is tinier and foreground signals no less annoying.

An "optimal" scanning strategy may be defined as one which maximizes redundancy at all possible time and angular scales, in order to have redundant information in pixels at different times and with various scanning directions. An obvious example are the "stripes" in large sky maps : these are usually efficiently reduced when using a fast-precessing scan-crossing strategy.

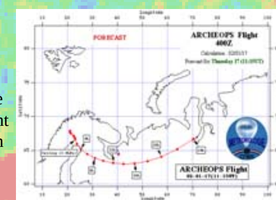
Observation strategy is an essential part of the design of a CMB experiment, which should be defined together with the other aspects of the experiment (instrumentation, data processing…) rather than a posteriori.

Future Cosmic Microwave Background experiments would benefit from comparing data-processing issues found in past ground-based, balloon-borne and space-based experiments whose scanning strategies differ, and drawing conclusions for the design of their own observation strategy.

Case of Archeops

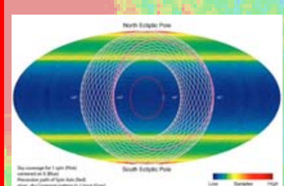
Rotation of gondola + Earth rotation + proper motion above the Earth !

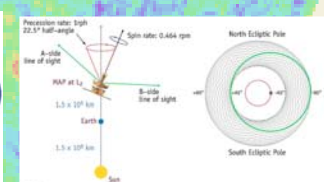
In the case of Archeops (2), strong stratospheric winds push the balloon all the way to central Siberia – this adds a different "precession" from that of the Earth rotation – good to maximize complexity and scan crossings in the scanning strategy (3).



Case of WMAP

The Wilkinson Microwave Anisotropy Probe (1) makes use of a rotating and precessing spacecraft. The resulting integration time is inhomogeneous over the sky but the intricate pattern of scans allows efficient systematic effects removal to take place.





The Planck scanning strategy

Slow cycloid precession

In the case of Planck (5,6,8), the emphasis is put on stability of the "rings" which means precession of the spacecraft is not a feasible option. Planck is scanning the sky using ~ 85 deg.-boresight small circles. Since the bore-sight angle is ~ 85 deg. and not 90 deg., a simple Ecliptic meridian strategy does not work to cover the whole sky.

An additional motion of the spin axis should be added to the normal de-pointing along the Ecliptic plane (4) : this allows to

a) cover the whole sky with all detectors

b) increase crossing redundancy – for measuring polarizer angles and helping keep systematic effects under control.

Slow cycloid precession (7.5 deg. wide, 6-month period, see central panel, top map) around the anti-Sun direction : allows to cover the whole sky, while maintaining the Sun aspect angle constant – thought to be important for thermal perturbation control.

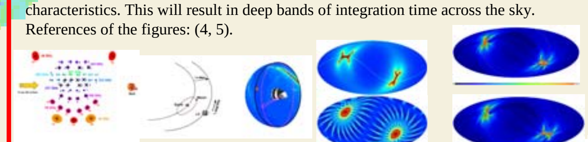
Other strategies yielding more crossings were considered (see central panel, bottom map) but the thermal aspects were considered essential, hence the choice of the 6 month-precession strategy. The value of 7.5 deg. is chosen to allow all detectors on the focal plane (left figure) to cover the whole sky in ~ 8 months.

In practice, a number of modifications happen to the "ideal" cycloid strategy.

This results in a slightly more "stripy" coverage (right panel maps).

During the LFI-only phase, "deep rings" are performed on essential calibrators (Jupiter, Crab Nebula) in order to maximize knowledge of beams and polarized detector characteristics. This will result in deep bands of integration time across the sky.

References of the figures: (4, 5).



References and acknowledgements

(1) Bennett et al. 2003, ApJS 148, 1
(2) Benoît et al. 2003, A&A 399, L25
(3) Dupac & Giard 2002, MNRAS 330, 497
(4) Dupac & Tauber 2005, A&A, 430, 363
(5) Planck coll. 2011, A&A 536, A1
(6) Planck coll. 2013, A&A, subm. "I. Overview of products and scientific results"
(7) Smoot et al. 1992, ApJ, 396, L1
(8) Tauber et al. 2010, A&A 520, A1

The development of Planck has been supported by: ESA; CNES and CNRS/INSU-IN2P3-INP (France); ASI, CNR, and INAF (Italy); NASA and DoE (USA); STFC and UKSA (UK); CSIC, MICINN and JA (Spain); Tekes, AoF and CSC (Finland); DLR and MPG (Germany); CSA (Canada); DTU Space (Denmark); SER/SSO (Switzerland); RCN (Norway); SFI (Ireland); FCT/MCTES (Portugal); and PRACE (EU).