The observation strategy for Planck and other Cosmic Microwave Background experiments

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Introduction

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

Cosmic Background 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 one to observe a large area of the sky
- The launching place of the balloon and the 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

Balloon-borne experiments (cont'd)

- 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

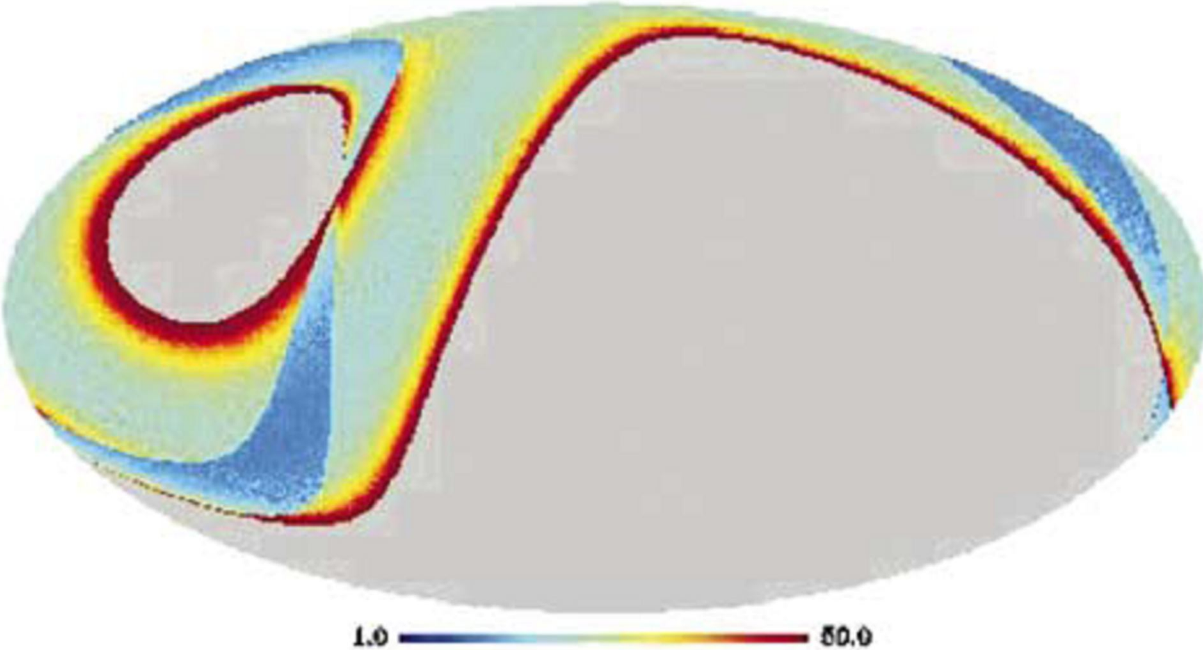
- The factors controlling the observation characteristics are the place and date of launch, the trajectory of the balloon, the flight duration, the elevation angle of scanning above the horizon, the sampling frequency and the rotation speed of the gondola (especially whether it is constant or not)

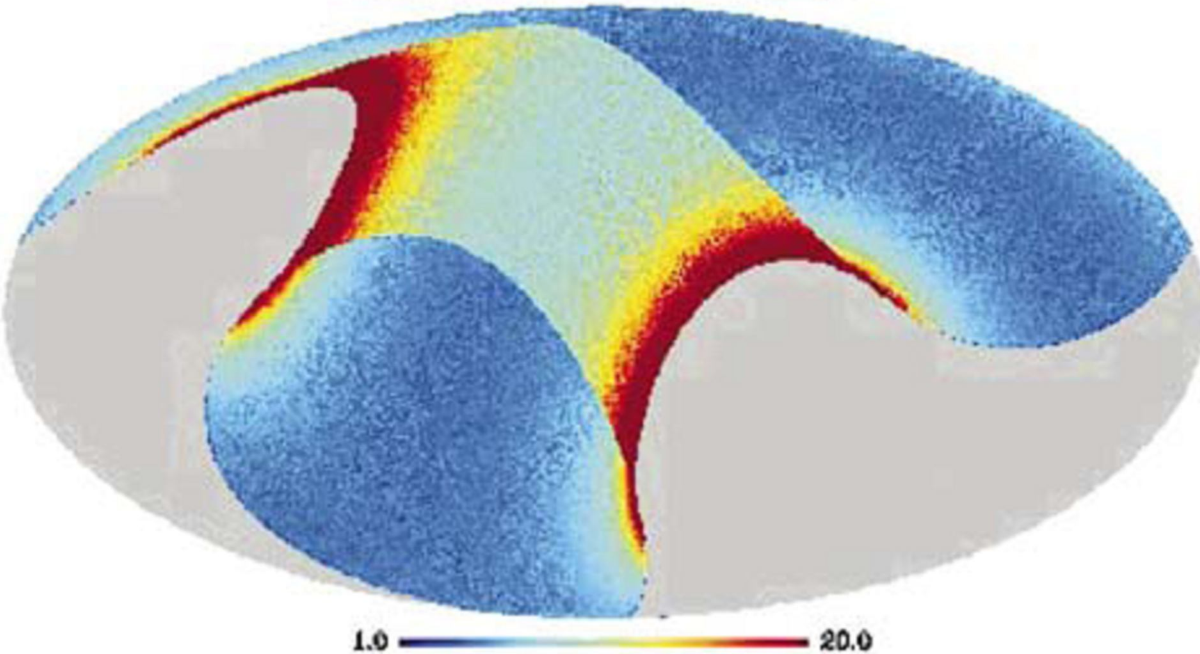
Weight map (integration time) for two possible balloon-borne experiment strategies

Simulation of two balloon-borne experiment time-lines with a constant scanning elevation : one is designed to maximize the redundancy per pixel while covering a large part of the sky: 24-h polar flight from Kiruna, Swedish Lapland. The winter time in this region provides polar nights allowing 24-h flights avoiding contamination from the Sun.

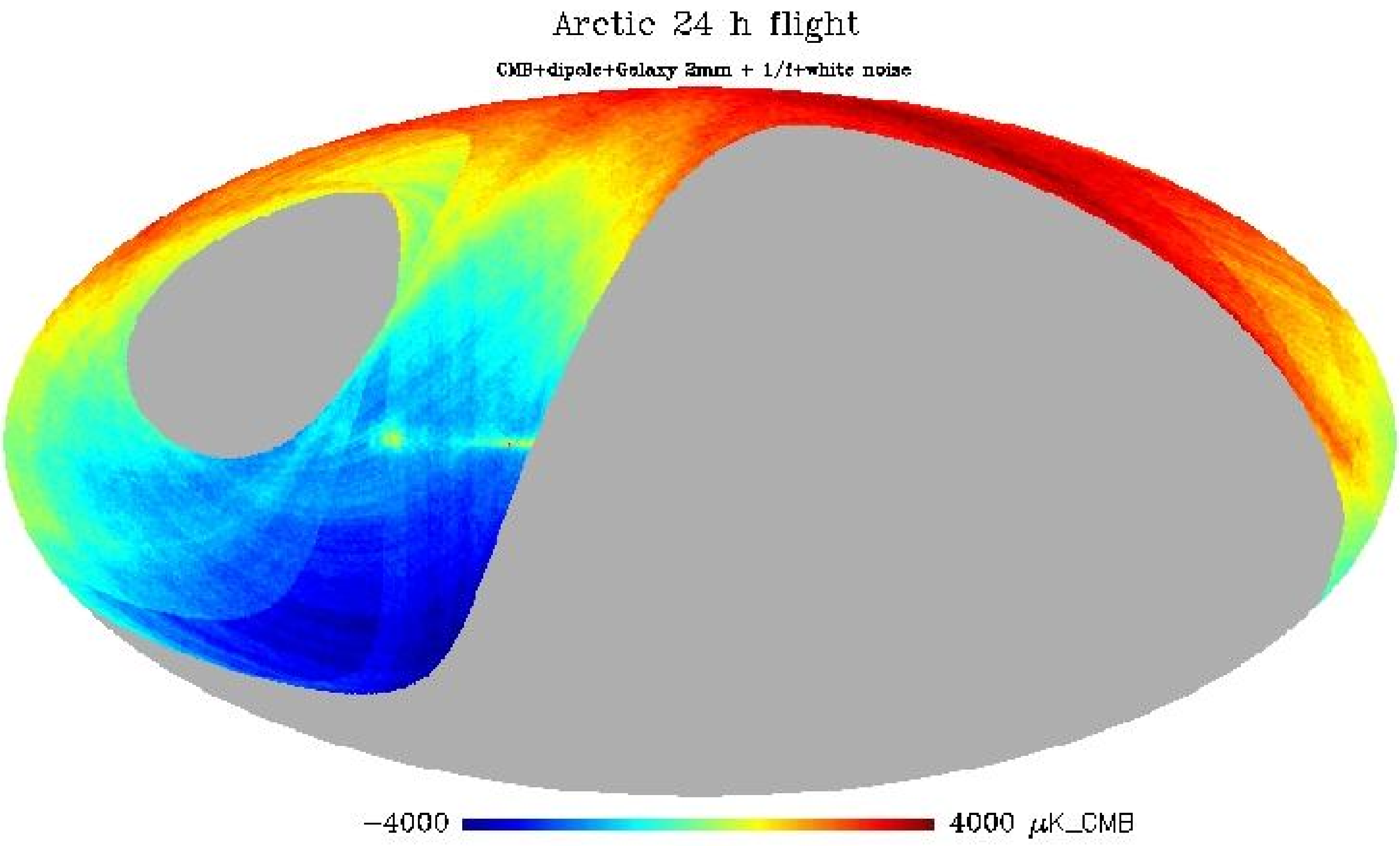
The coverage for this polar flight is 35 % of the sky.

The second simulated experiment is a 12-h equatorial flight. The coverage for this 12-h flight is 61 per cent of the whole sky, and would be 82 per cent for a 24-h flight, or two 12-h flights—one
taking place 6 months after the first one, to avoid sunlight.





Dupac & Giard 2002, MNRAS 330, 497



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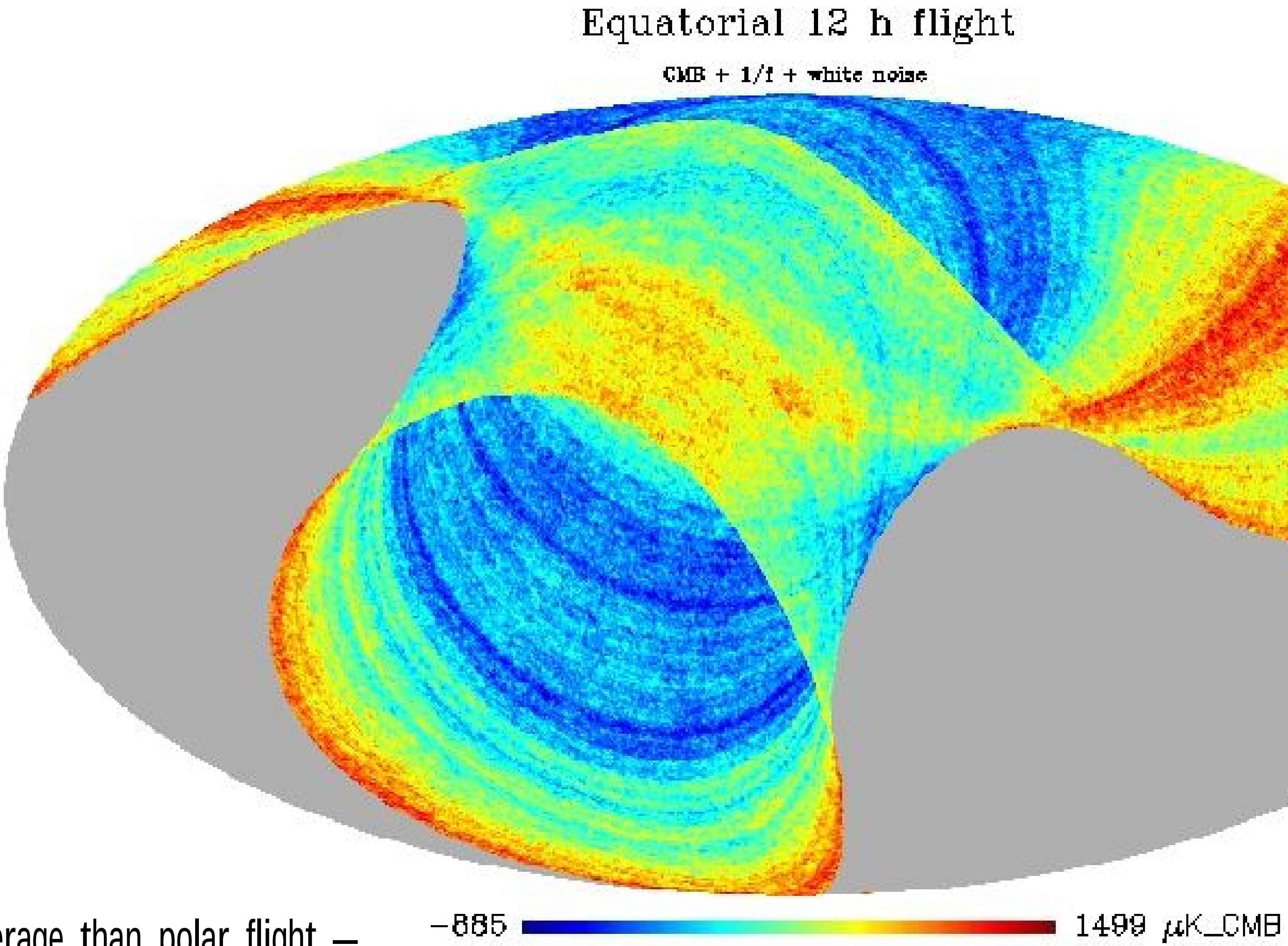
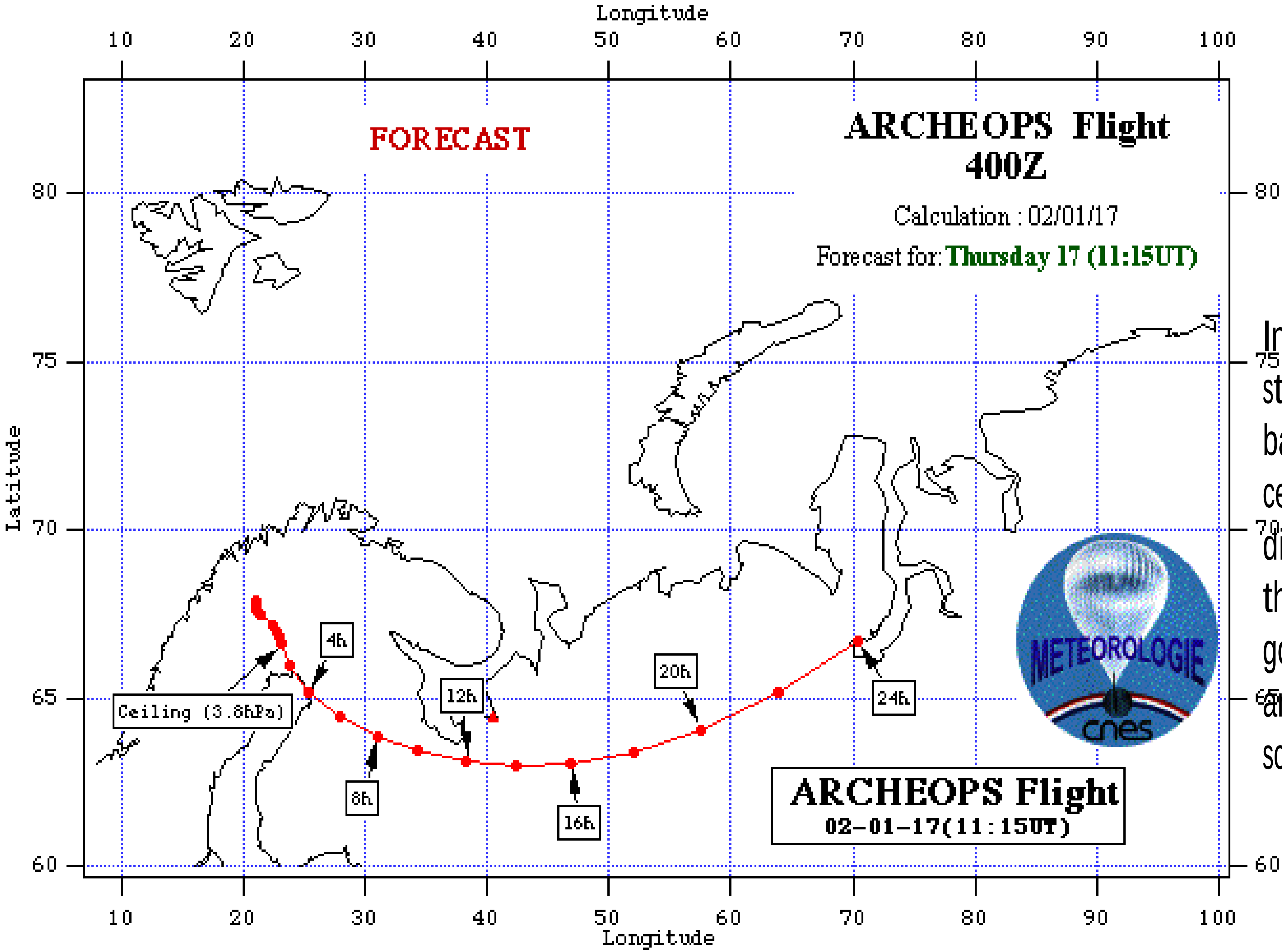


Larger coverage than polar flight – in half the time, due to larger "precession" induced by Earth rotation when the experiment is near the Equator.

Dupac & Giard 2002, MNRAS 330, 497

Case of Archeops : rotation of gondola + Earth rotation + … proper motion above the Earth

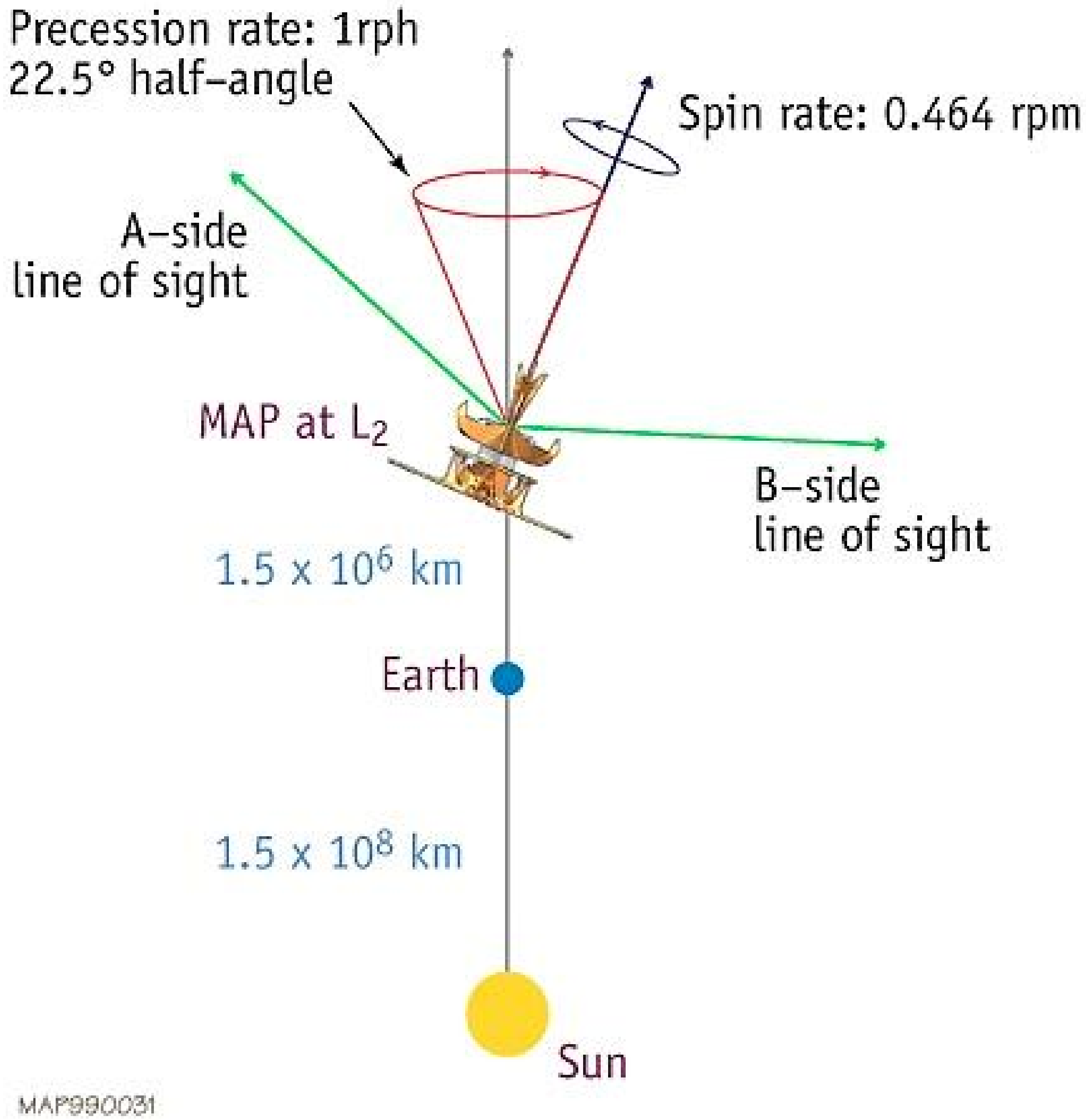


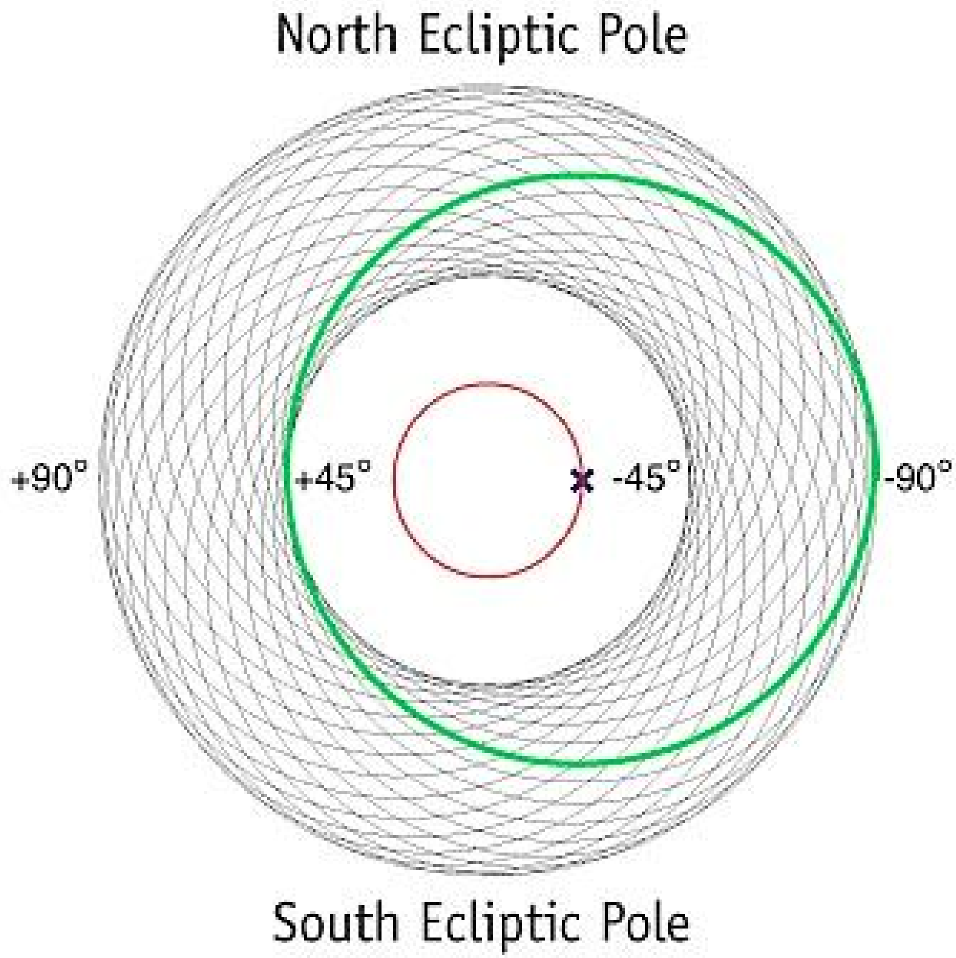
In the case of Archeops, strong winds push the balloon all the way to central Siberia – this adds a different “precession” from that of the Earth rotation – good to maximize complexity and scan crossings in the scanning strategy.

Space-based experiments

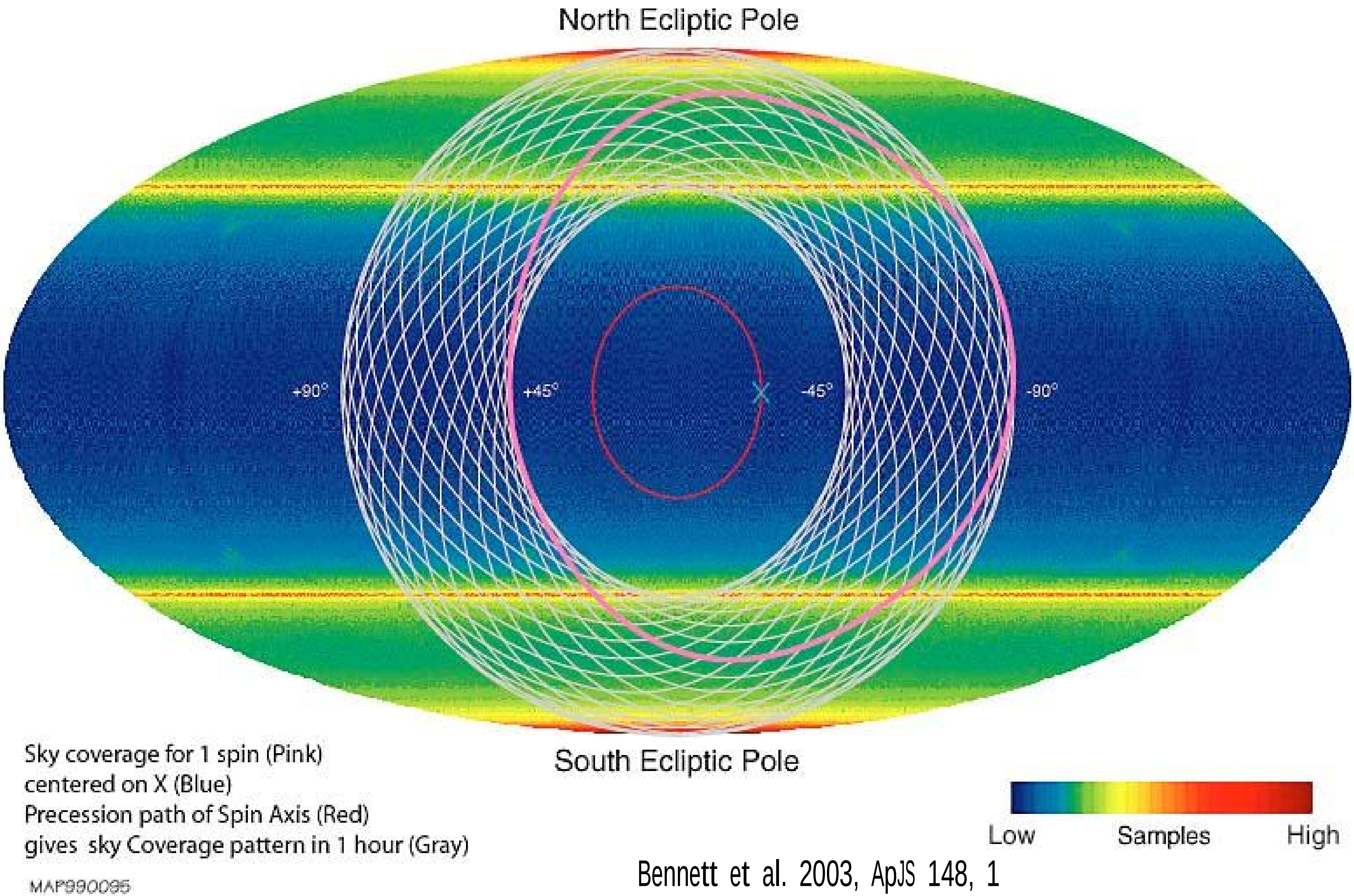
- Space-based CMB experiments are normally of much longer duration than balloons, making it possible to observe the whole sky, several times
- A natural scanning strategy is to sweep the sky in great circles – or near great circles
- for a satellite in a low-Earth orbit, this strategy allows for example 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. 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
- For CMB experiments, it is generally considered better to cross scans in the most intricate way possible, in order to maximize redundancy at all time/angular scales, therefore having a rotating + precessing space-craft

Case of WMAP : fast-precessing strategy





Bennett et al. 2003, ApJS 148, 1



Bennett et al. 2003, ApJS 148, 1

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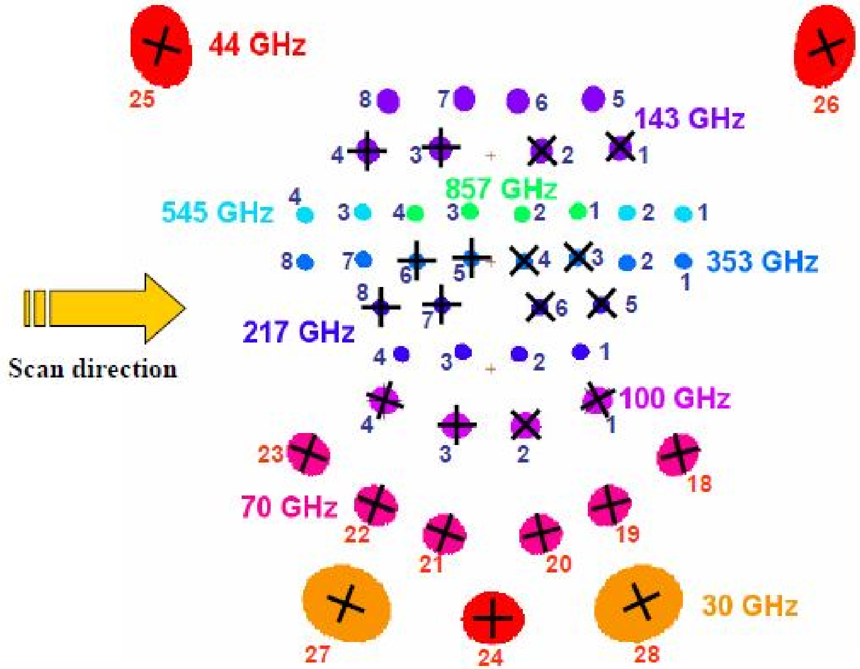
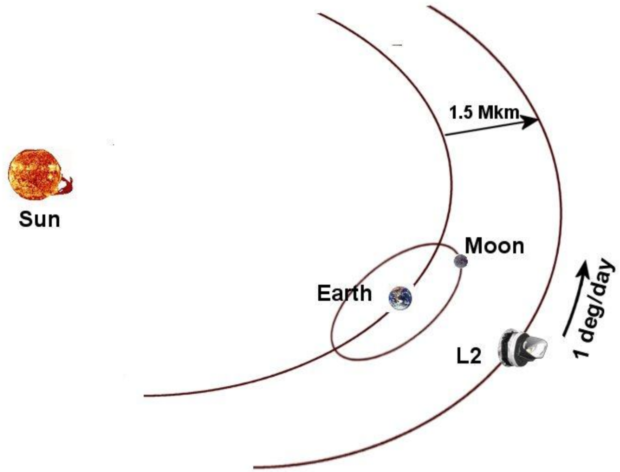
Case of the Planck space telescope

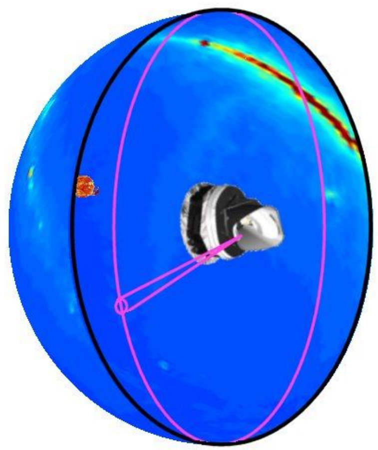


- In the case of Planck, the emphasis is put on stability of the “rings” which means precession is not a feasible option
- Planck is scanning the sky using ~ 85 deg.-boresight small circles
- Since bore-sight is ~ 85 deg. and not 90 deg., Ecliptic meridians strategy does NOT work to cover the whole sky
- Additional motion of the spinning should be added to the normal de pointing along the Ecliptic plane : allows to

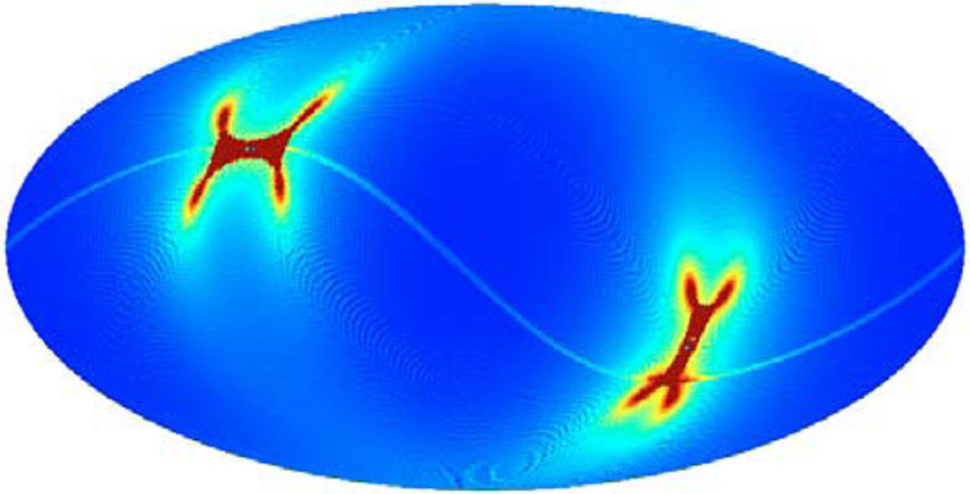
  a) cover the whole sky with all detectors

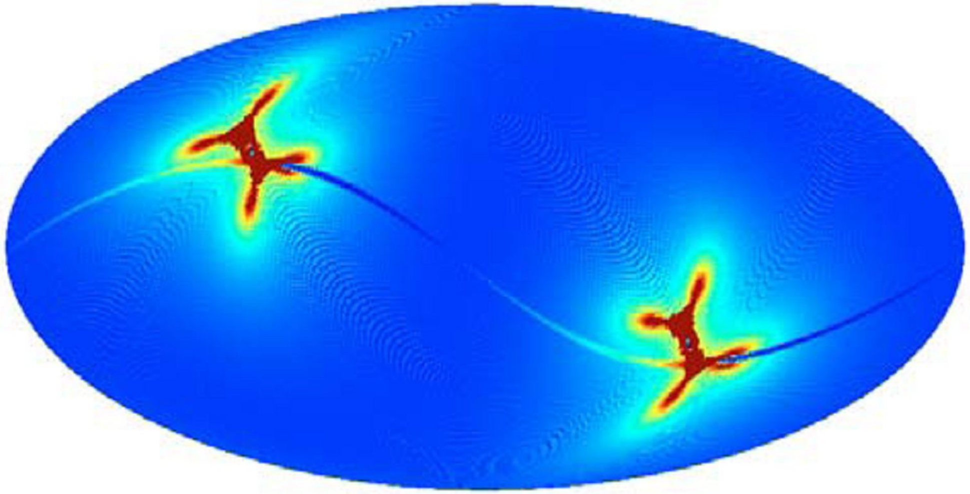
  b) increase crossing redundancy



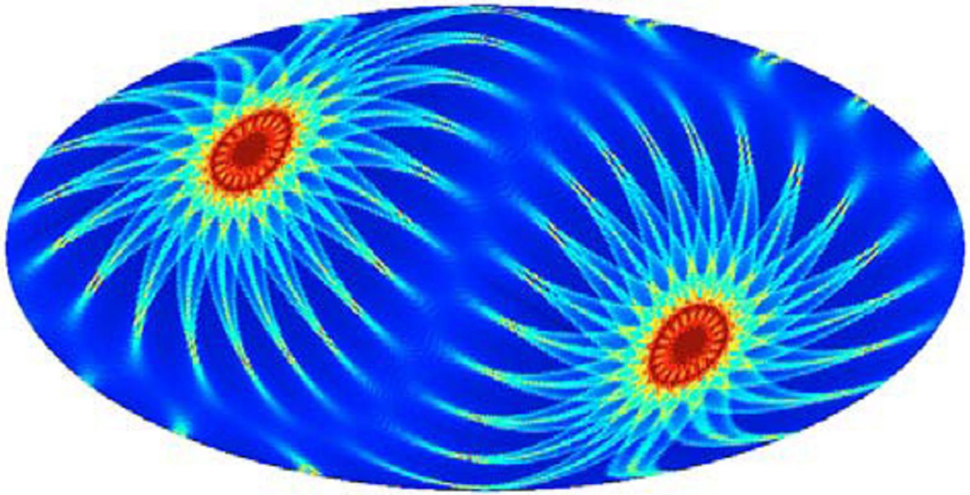


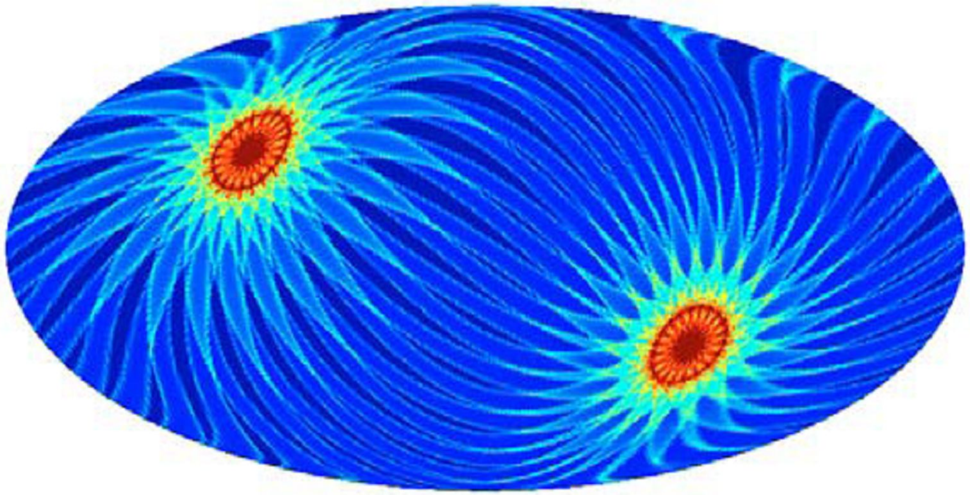
Case of Planck : possible scanning strategies for 1-yr survey





Dupac & Tauber 2005, A&A 430, 363



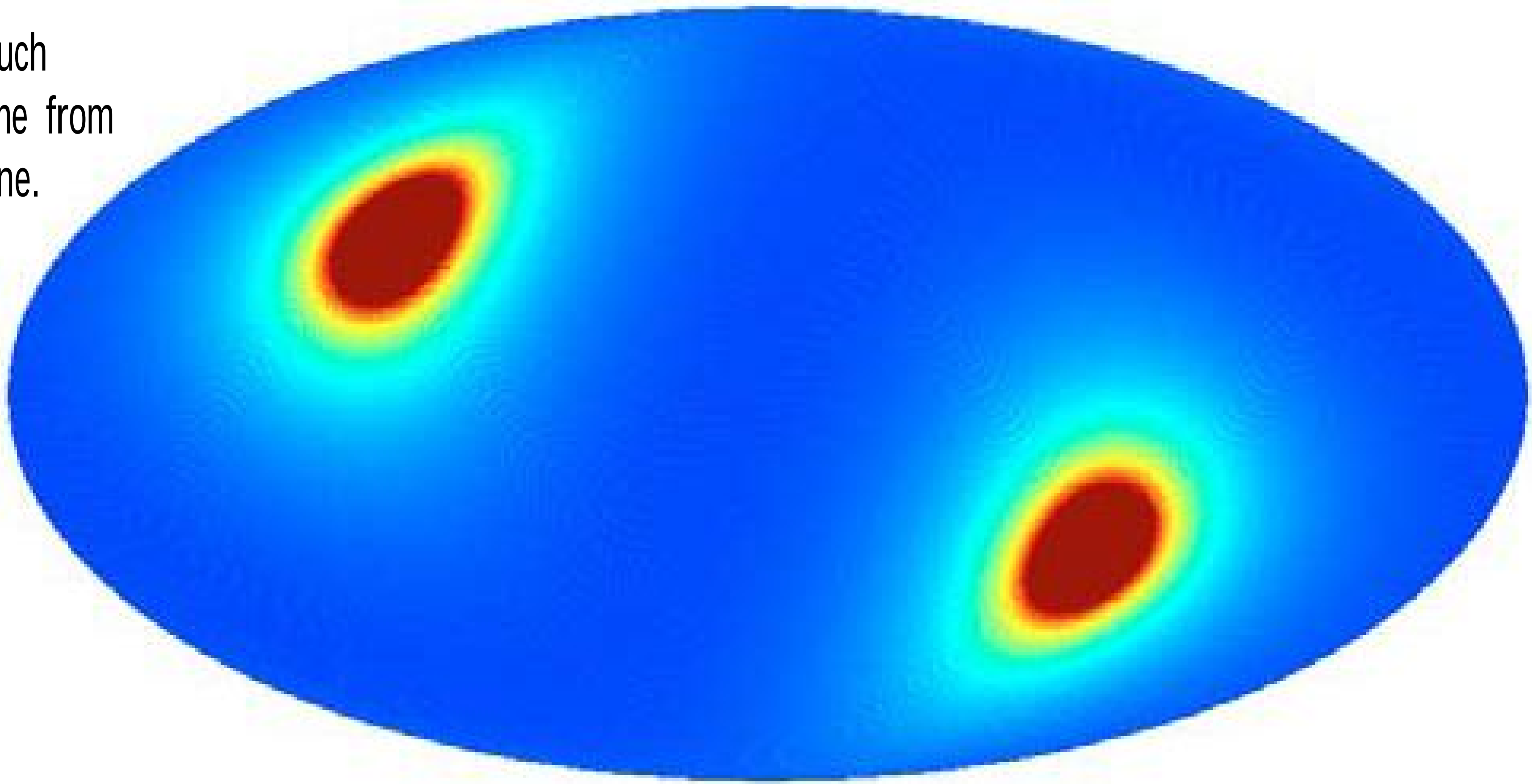


Fast-precessing scanning strategies
Case of a 85 deg.-boresight with Ecliptic orbit (“fast-precessing Planck”)

Dupac & Tauber 2005, A&A 430, 363

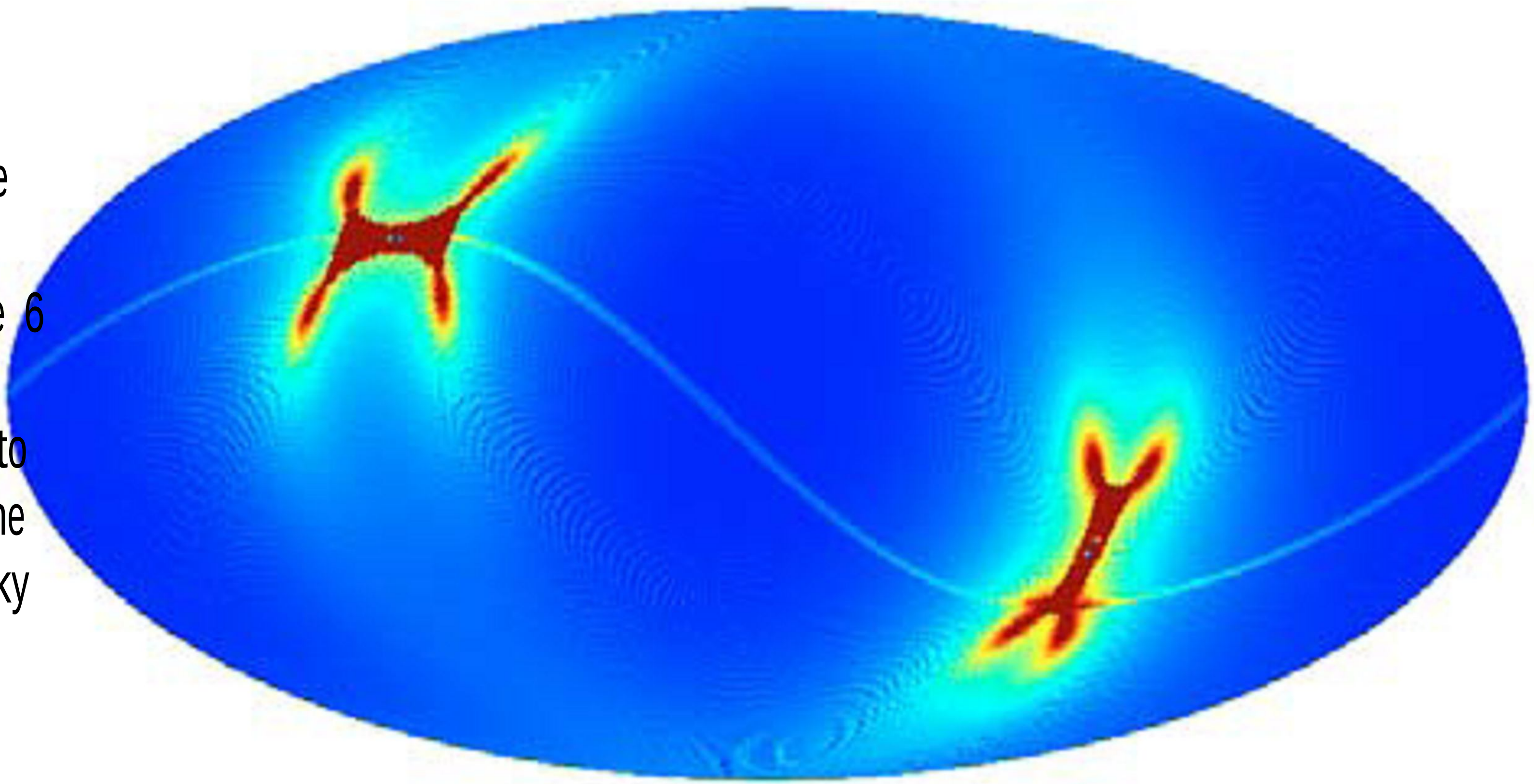
Advantages : great smoothness and homogeneity of the integration-time distribution wrt Ecliptic longitude, lots of crossings

However it does not help much spreading out integration time from Ecliptic poles out to the plane.



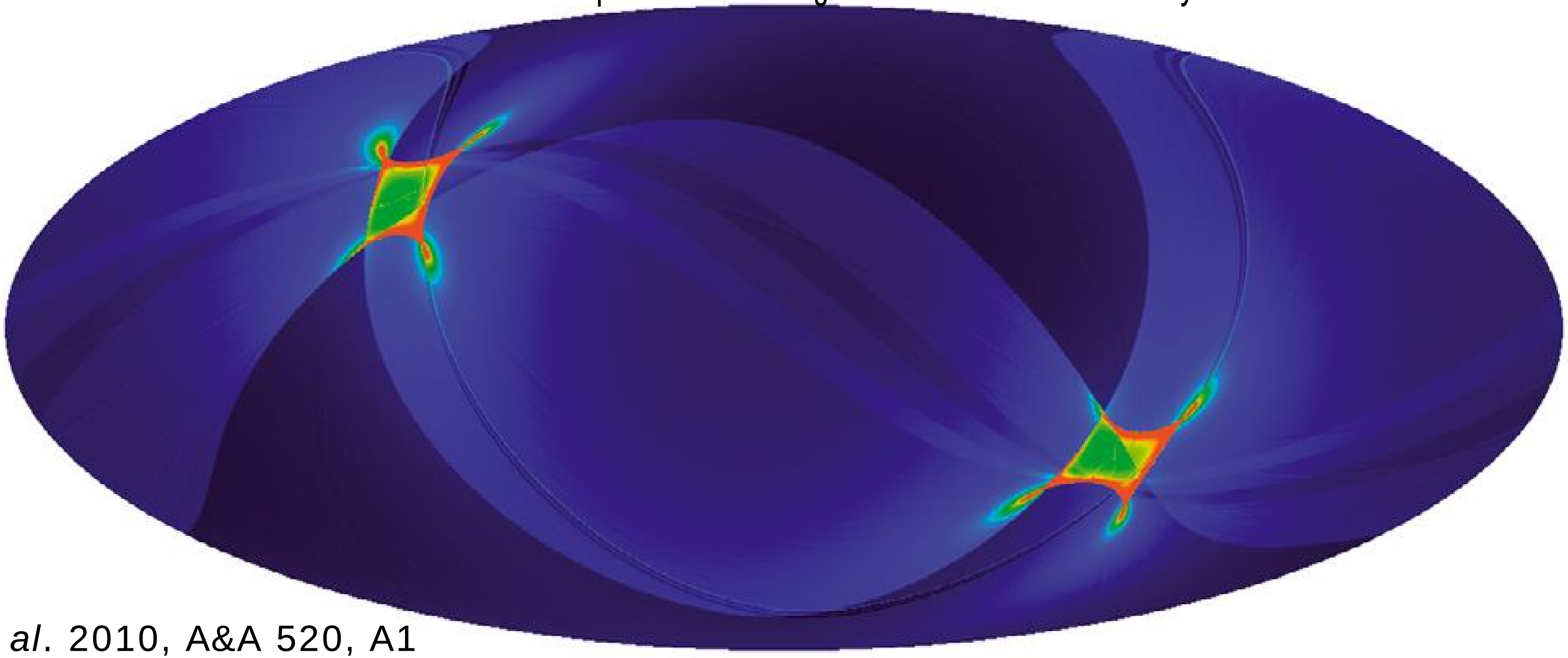
The Planck scanning strategy : simple slow cycloidal precession

Slow cycloidal precession (7.5 deg. wide, 6-month period) 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 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 (almost) all detectors on the focal plane to cover the whole sky in ~ 8 months.



Planck scanning strategy – *in practice*

In practice, a number of modifications happen to the "ideal" cycloidal strategy.
This results in a slightly more "stripy" coverage.
Also, during the LFI-only phase, "deep rings" are performed on essential temperature and polarization 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.

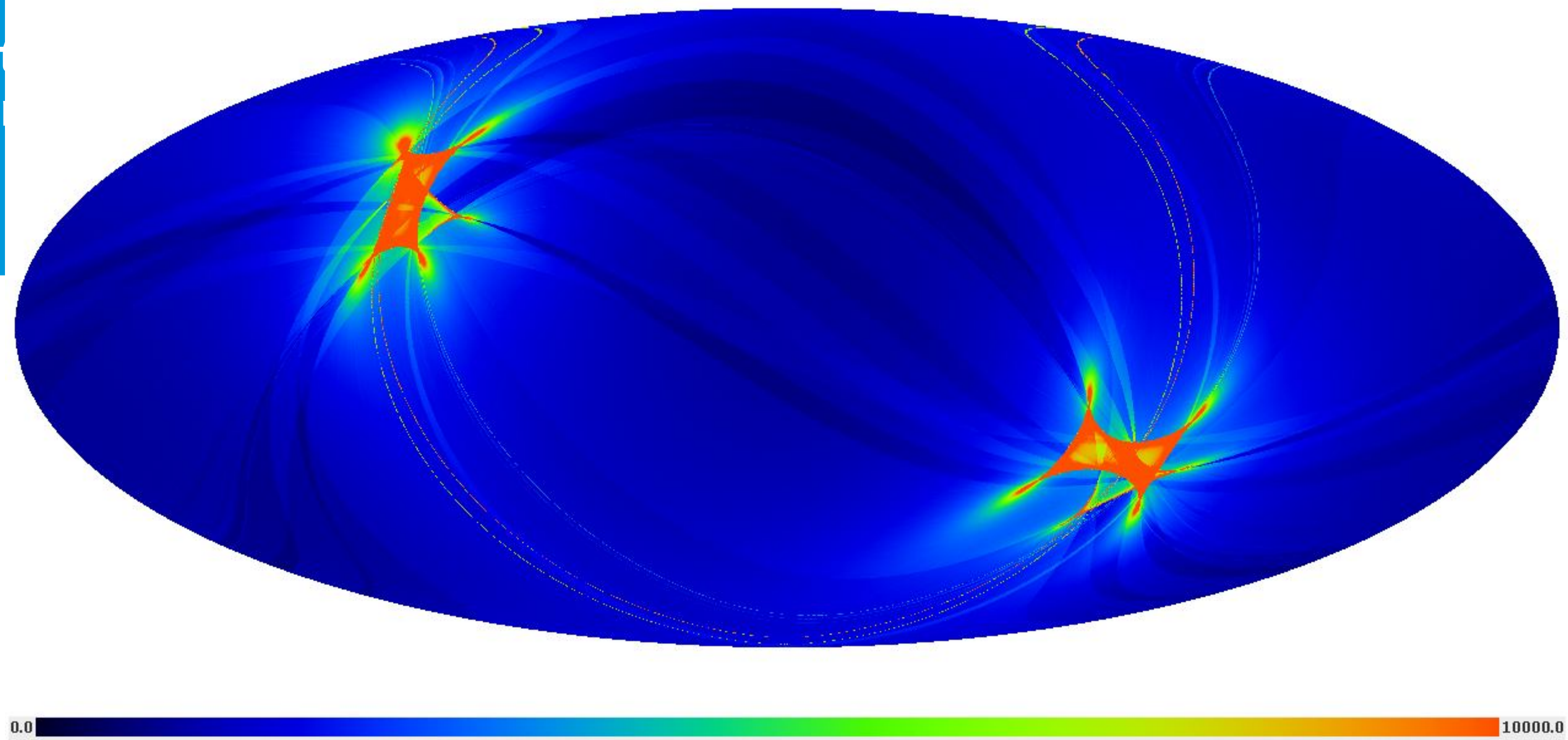


Tauber *et al*. 2010, A&A 520, A1

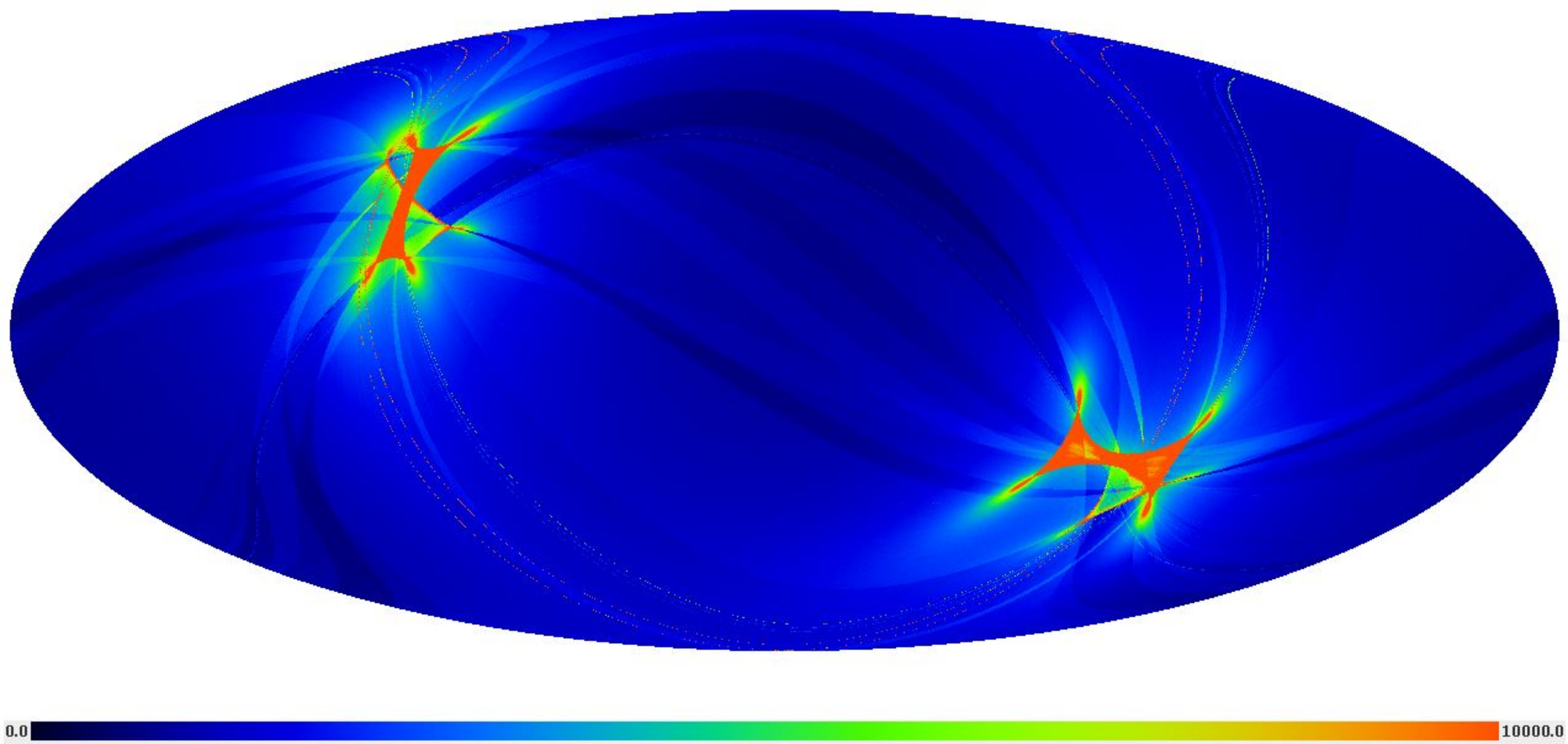
Planck coll. 2011, A&A 536, A1

Planck integration time at the end of the HFI mission - Aug. 14th, 2009 to January 15th, 2012

100 GHz



545 – 857 GHz



Conclusions : *lessons-learned for future CMB experiments ?*

- Cosmic Microwave Background timelines tend to be incredibly 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
- 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 designed together with the other aspects of the experiment (instrumentation, data processing…) rather than *a posteriori*
- Future CMB experiments would benefit from comparing data-processing issues found in ground-based, balloon-borne and space-based CMB experiments whose scanning strategies differ, and drawing conclusions for the design of their own observation strategy