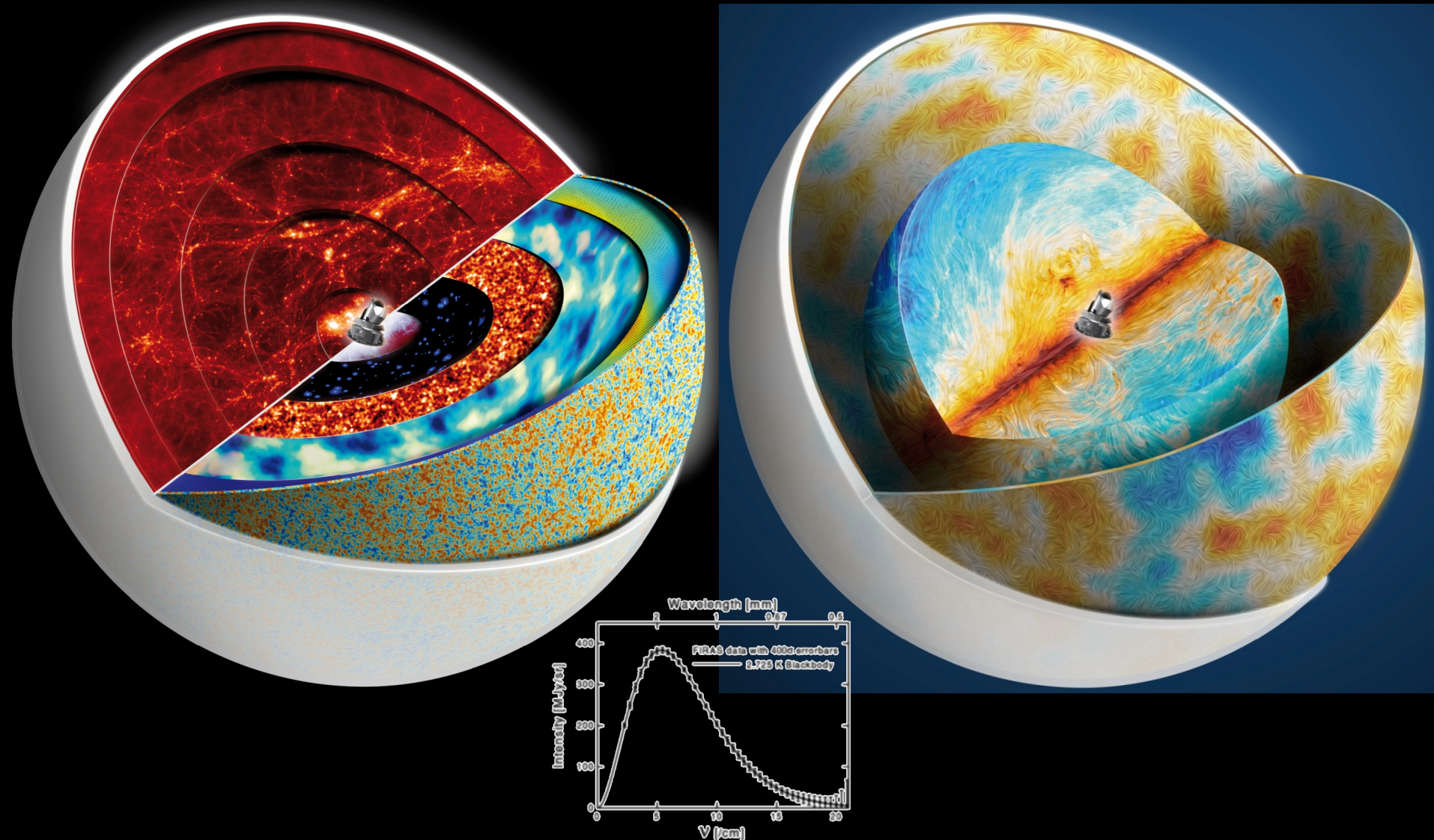
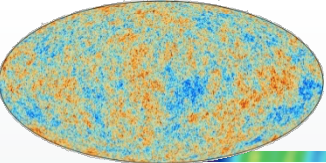


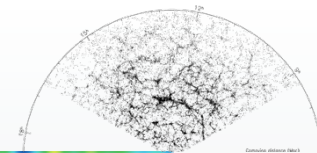
French roadmap for CMB science



François R. Bouchet, Institut d'Astrophysique de Paris, for the roadmapping group

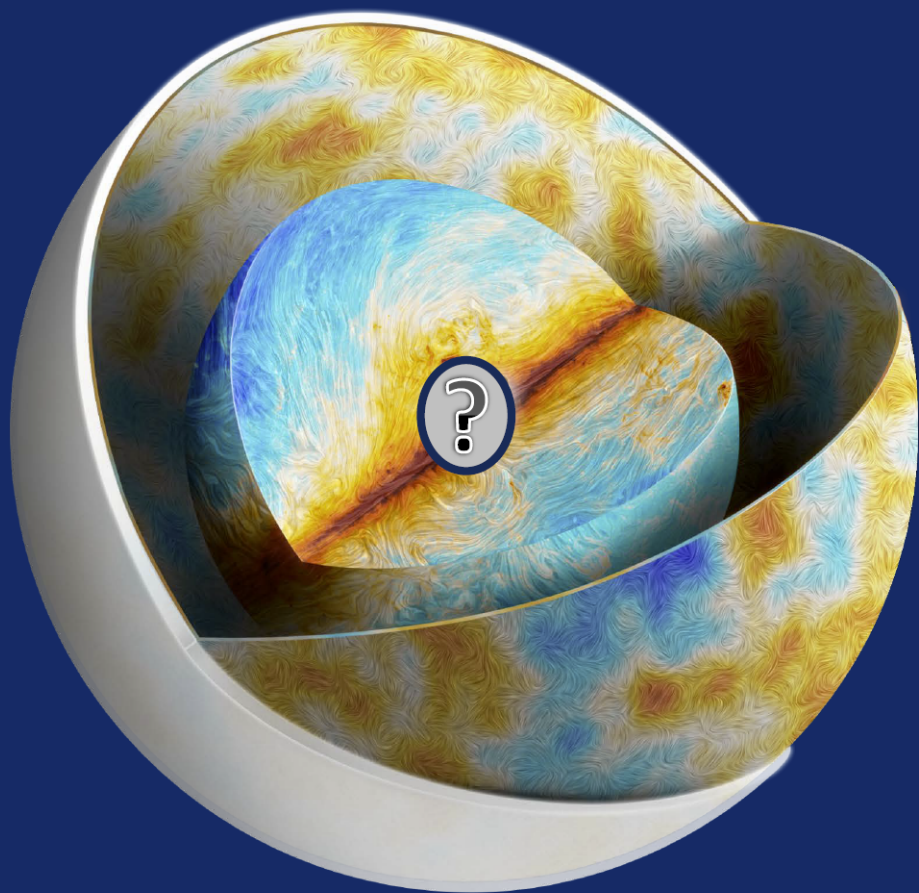


The French exercise



- French governing bodies for fundamental and high energy physics and astrophysics (CNES, INSU, IN2P3 and CEA) called for a joint roadmap on the future of CMB measurements from the ground, balloons, and in space, covering short to long term.
- An ad hoc committee was set up in September 2015 by F. Bouchet & PNCG.
 - ❖ *Membership: François R. Bouchet (Chair), Francis Bernardeau, Anthony Banday, François-Xavier Désert, Marian Douspis, Kenneth Ganga, Guilaine Lagache, Louis Rodriguez, Mathieu Tristram,*
 - ❖ *with ex officio members Monique Arnaud (link to PNCG), Pierre Binetruy (link to CNES-Fundamental Physics group), Cecile Renault (link to CNES-Astronomy group).*
 - ❖ *In the course of the work, Nicolas Ponthieu and François Boulanger were added.*
- The committee organised 4 town hall meetings (slides available at <http://prospective.planck.fr/index.php?n=Main.Meetings>) + 6 closed sessions. Three oral progress reports made on the way (as well as to APPEC at La Sorbonne).
- A preliminary version of the report (in English) was sent to the French community for reactions & further inputs early June. Final version (78p.) made available to agencies end of June 2016: <http://prospective.planck.fr/uploads/Main/2016-06-30-CMBroute.pdf>.
- Representatives of these governing bodies will meet on Oct 5th to discuss follow-up actions. 3-yr plan to be presented in December.

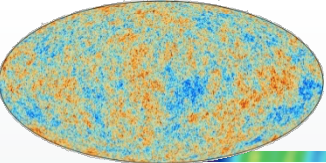
French roadmap for Cosmic Microwave Background science



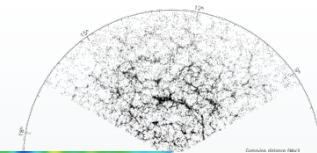
June 2016

Contents

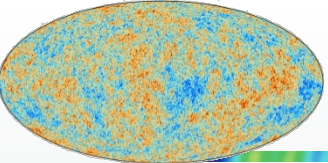
1	Introduction	1
1.1	Current status	3
1.2	The French community	4
2	Scientific potential of CMB measurements	5
2.1	The early universe	5
2.2	The spectral distortions	9
2.3	Constraining the matter content of the universe	12
2.4	Summary	16
3	Foregrounds obstacle	17
3.1	Emission components	17
3.2	Component separation	21
3.3	The foregrounds challenge	23
3.4	Summary	24
4	Science beyond the primary CMB science	24
4.1	Galaxy Cluster and Large-Scale Structure Science	24
4.2	Cosmic Infrared Background	27
4.3	Interstellar Medium	28
4.4	Summary	29
5	Instrumental aspects	29
5.1	Different classes of instruments	30
5.2	Focal Plane Unit	32
5.3	Systematic effects	34
5.4	Spectrometers	36
5.5	Summary	37
6	Data processing and analysis aspects	37
6.1	Types of CMB challenges	37
6.2	Data analysis. From time streams to model constraints	39
6.3	Overcoming the challenges	42
6.4	Summary	43
7	Landscape today	43
7.1	Current Sub-Orbital CMB Experiments	43
7.2	CMB Stage 4	48
7.3	Multiple Telescopes versus Large Focal Planes	49
7.4	Location	50
8	The Future in CMB science	51
8.1	Long-term projects	52
8.2	Mid-term projects	56
9	Outreach	58
10	Conclusions	59
A	French CMB PhD Theses since <i>Planck</i> inception	67
B	Elements on pre-S4 funding in the US	71



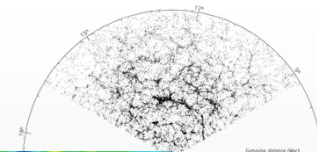
Starting point



- (Science objectives well aligned with US S4 science book).
- Ground
 - S3 ongoing, targeting mainly $T/S=r=10^{-2}$
 - S4 in development, targeting $r=10^{-3}$ + detecting N_{eff} & $\text{mass}\Sigma v$ (+astro)
- Space
 - Pixie/NASA – proposition due dec. 2016, for a 2023 launch
 - Litebird/JAXA – Now in A1, for a 2025 launch
 - M5/Core/ESA(+?) – for a 2026-2030 launch, prop. Due /0510/2016
 - CDF ESA(JAXA) study made early 2016
- ➔ A landscape of widely different capabilities (Sciences/FGs/Systs)
- Very ambitious experimental objectives, with substantial uncertainties on
 - Level of primordial B modes,
 - Astrophysical situation (FG emissions, inc. monopoles),
 - Actual performances of various experimental responses
- And none of the long term decided/funded yet...
- ➔ Necessary complementarity sub-orbital/space
 - Spatial & angular coverage
 - Deployment time & cost



French roadmap rational

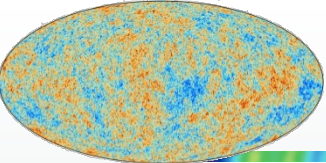


Analysis starts with long term objectives/capabilities (> 10 years timescale):

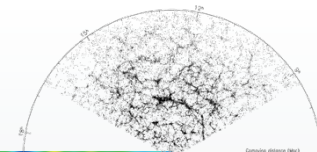
- **M5** at ESA (CORE):
 - the most capable CMB proposal in space,
 - offering the best possibility to play a central role in this science,
 - involving all the community.
 - NB: launch at best between 2026 et 2030.
- **S4**:
 - *Whatever is the fate of the various space proposals*, all new data, science, and lessons learnt (FG/Expnt) will come quasi-exclusively from ground & balloons during at least a decade (or more if neither Litebird nor Pixie are launched).
 - It is therefore **vital** that the national community participates strongly to the suborbital effort building on its strengths.
 - The effort magnitude will of course depend on the fate of the space proposal (both reg. person-power, technology dev^{nt} and money).

➔ French long term priorities (> 2025) must therefore be **M5 + S4**,

- These global priorities allow gauging all other national projects/steps (e.g. Pixie, B-side, QUBIC, AppMath/HPC&processing...)



S4 considerations

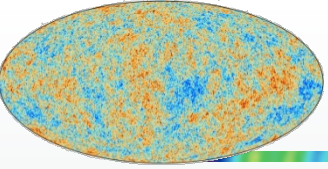


Recognising:

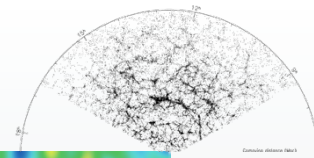
- The magnitude of the needed effort, intellectually, technologically and financially (typically at 50-100 ME consolidated level to be real world players)
 - The existence and competence of the wide Planck community which learnt to work together
 - The fact that US-DoE funds are ear-marked for FP technology, making European influence on FP key technology choices not obvious
- ➔ Seek joint European participation to S4, in synergy/complementarity with US effort, preferably as a full self-standing experiment rather than a series of individual buy-ins in order to allow further developing technical assets, notably regarding kids arrays.

Recognising the lack of Europe-wide host organisation:

- ➔ encourage lead CMB scientists in Europe to urgently set up a scientific consortium whose charge will be to provide a forum for discussions within Europe, undertake discussions with the US S4 stakeholders, investigate **all** funding options, and coordinate all necessary European actions with the help of the European APPEC and Astronet networks of funding agencies in Astroparticle Physics and Astronomy

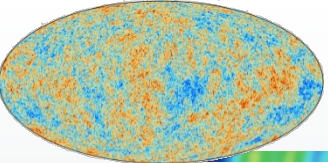


S4 considerations

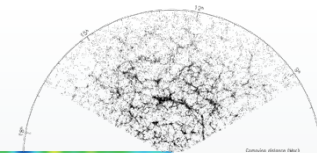


In the event of sufficient convergence on analyses and wills here at Finaly, (some) (interlinked) questions to address together:

- Priority science target(s): low-ell and/or high-ell
 - Noting differing scientific breadth/complementarity with space
 - Experimental concepts (potential, RoM costs...)
 - Organise a call for Ideas? (noting end of Spacekids ITT etc)
 - Site(s): Greenland, Aly, Chajnantor, South pole, Tenerife
 - Assessing site quality, operating costs and infrastructures, synergies, geopolitics...
 - Funding of the different phases/aspects
 - Including people training (EU Marie Curie program), HPC Computing...
 - How to best coordinate with other efforts, noting
 - The interagency committee recently being setup in the US
 - Chinese strong will to develop Aly
 - National idiosyncrasies within Europe
- ➔ Europe needs a telephone number ☺ (or at least a breeding nest/cradle)

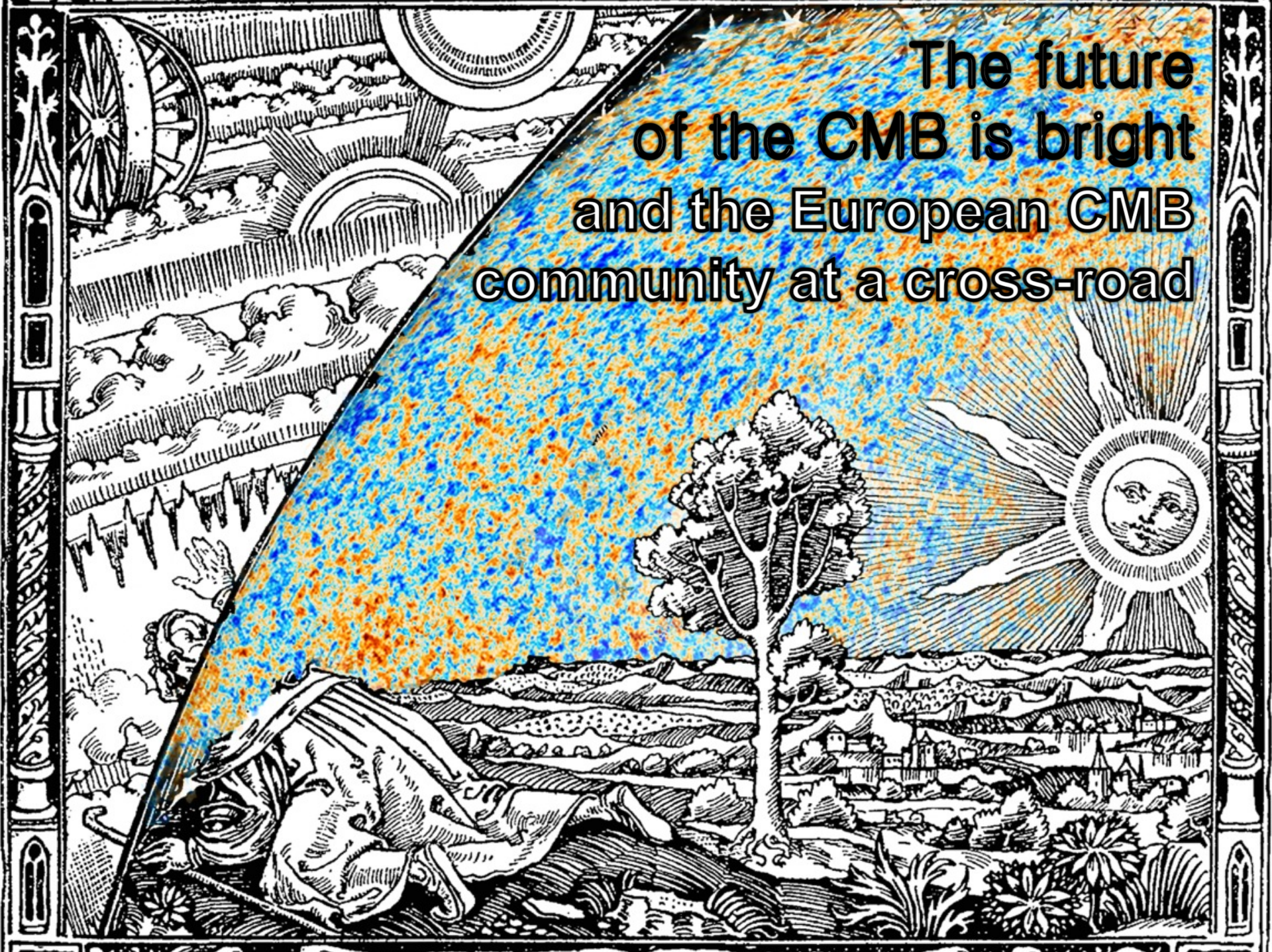


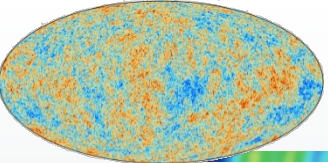
Conclusions



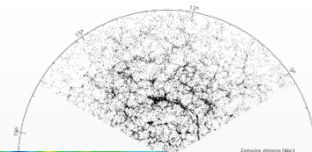
- The experimental situation in the “post-Planck” era is not yet stable, with most projects not fully determined, and even less decided/funded.
- Still, firm recommendations nevertheless emerge.
- Need a long term program.
- M5 & S4 strong participations are the long-term French priorities.
- France should seek joint and substantial European participation to S4 to be involved in all aspects.
- Let us fully contribute to the great next step forward in CMB!

The future
of the CMB is bright
and the European CMB
community at a cross-road





Thoughts on European S4 strategy:



- Which site(s)?
 - *Going alone North is risky (e.g. we do not really know the sites quality)*
 - *Going to the South pole likely too expensive (as a first step)*
 - *Going Chajnantor (Cerro, not plateau) is maybe the best option to start*
 - *Complement with a European coordinated balloon program (if duration!)*
- Which priority?
 - *Large telescopes are needed to do high-ell (n_s , ν 's, some lensing)*
 - *the US already has ACT and SPT. Could we contribute a FP instrument?*
 - *B-modes target is at low-ell → rather meter-class telescopes. A “must” first step? In this case, can we coordinate tiling the sky in synergy with other US deep experiments? it also allows progressive deployment of focal planes.*
- Which coordination?
 - *Charge national reps to urgently propose a consortium (write objectives, structure, propose a plan, etc.?)*

An uncertain multi-dimensionnal space

