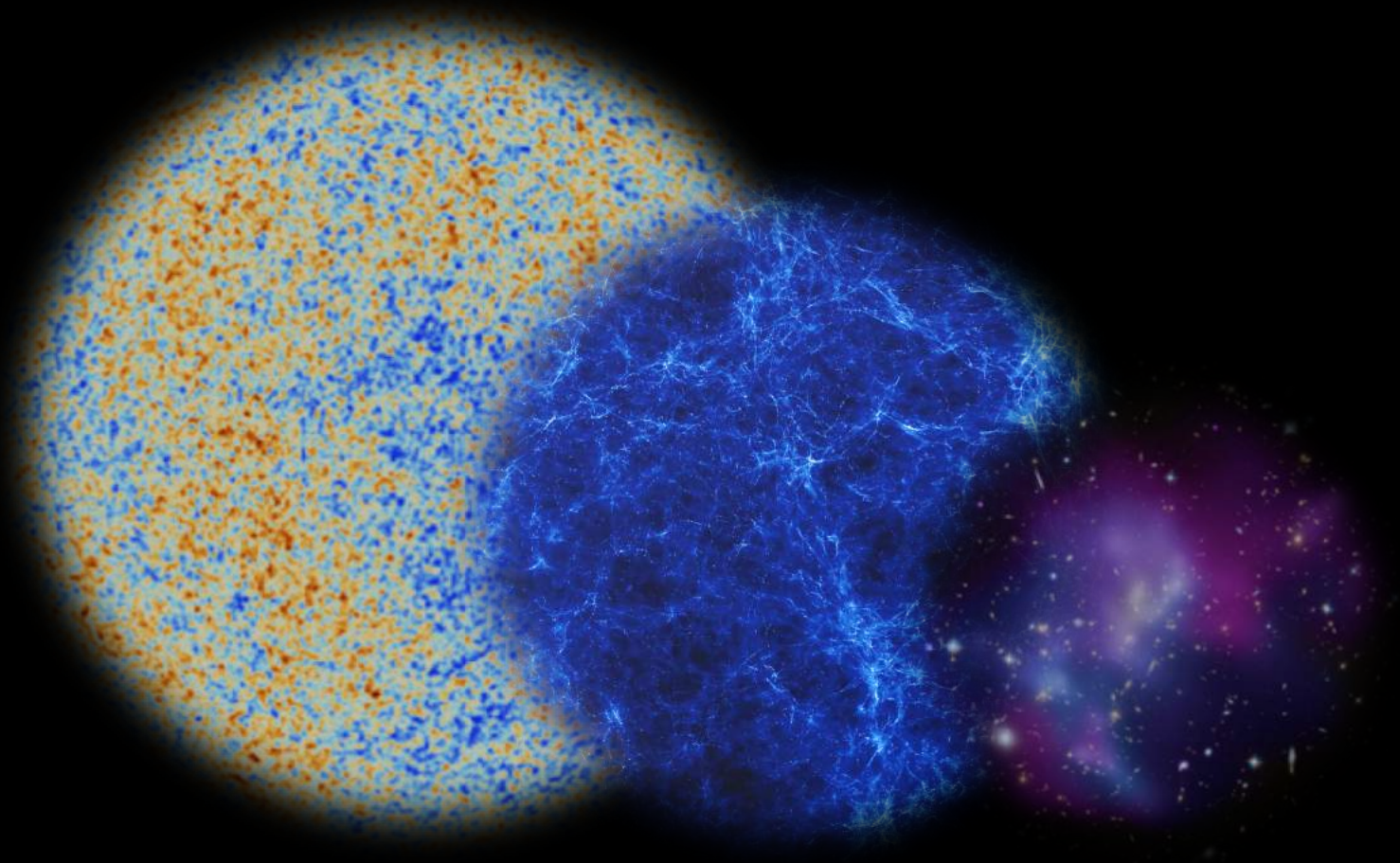


The voyage 2050 ESA prospective and cosmology white papers

Jacques Delabrouille

Laboratoire APC, CNRS/IN2P3, Paris

& IRFU, CEA-Saclay



The context: ESA science in 2035-2050



Voyage 2050 » Ho...

Home
Workshop registration
Workshop programme
Workshop: second announcement
White Papers
Senior Committee
Call for Membership of Topical Teams
Call for White Papers

VOYAGE 2050 LONG-TERM PLANNING OF THE ESA SCIENCE PROGRAMME

*** Registration is open for the Workshop ***
*** See [second announcement](#) and [registration form](#)***

4 March 2019

The Science Programme of the European Space Agency (ESA) relies on long-term planning of its scientific priorities. The first long-term plan, Horizon 2000, was the result of an exercise started in 1983, and it was followed by an extension, Horizon 2000 Plus, that resulted in the initiation of the Gaia and BepiColombo missions. The successive planning exercise, [Cosmic Vision](#), was started in 2004 and is the current basis against which the content of the Science Programme is set.

Cosmic Vision is the result of a bottom-up process that began with a consultation of the broad scientific community. The plan, which comprises a variety of missions and extends up to 2035, defines the wide-ranging and ambitious scientific questions to be addressed by missions in the ESA Science Programme.

DOCUMENTATION

[Letter of Invitation - White Papers \(pdf\)](#)

[Letter of Invitation - Topical Team membership \(pdf\)](#)

[Call for White Papers \(pdf\)](#)

[Call for Membership of Topical Teams \(pdf\)](#)

From Voyage 2050 web site

The context: ESA science in 2035-2050

*This process will
decide what science
will be done by the
three next L-class
missions!*



The Director of Science has appointed the Senior Committee to guide the Voyage 2050 process. This Committee, composed of scientists working in institutions in ESA Member States, is tasked to:

1. Recommend to the Director of Science the three science themes of the three L missions that will be part of the plan.
2. Identify a number of high-impact science themes that could be implemented through an M mission during the plan's time span. The actual M missions will be decided through open calls for missions issued in due time to retain flexibility in the Science Programme. However, the early identification of themes of interest will help the Agency in, e.g., developing key technologies.

*But we are not
asked for mission
proposals!*



White Papers are not proposals for specific missions; they should rather argue why a specific scientific theme should have priority in the Voyage 2050 planning cycle. At the same time, and to ensure realism in the resulting Programme, applicants should briefly illustrate possible mission profiles.

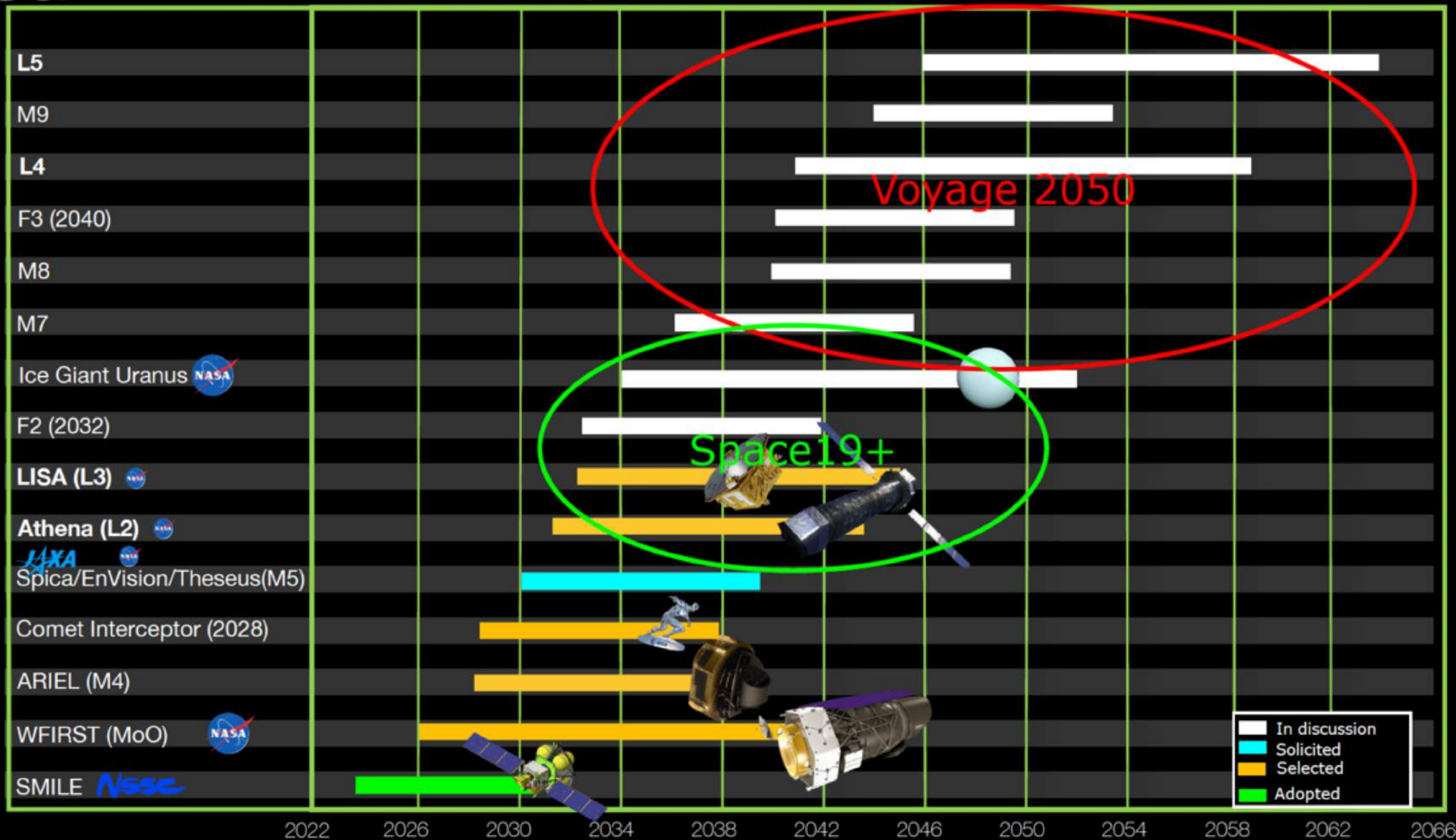
The context: ESA science in 2035-2050

SCHEDULE FOR THIS CALL AND IMPORTANT DATES

Activity	Date
Senior Committee appointed	December 2018
Call for Membership of Topical Teams issued	4 March 2019
Call for White Papers issued	4 March 2019
Deadline for receipt of applications for Topical Team membership	6 May 2019, 12:00 (noon) CEST
Topical Team members appointed	July 2019
Deadline for receipt of White Papers	5 August 2019, 12:00 (noon) CEST
Workshop to present White Papers	29 - 31 October 2019
Topical Teams report to Senior Committee	February 2020
Senior Committee recommendations to Director of Science	Mid-2020

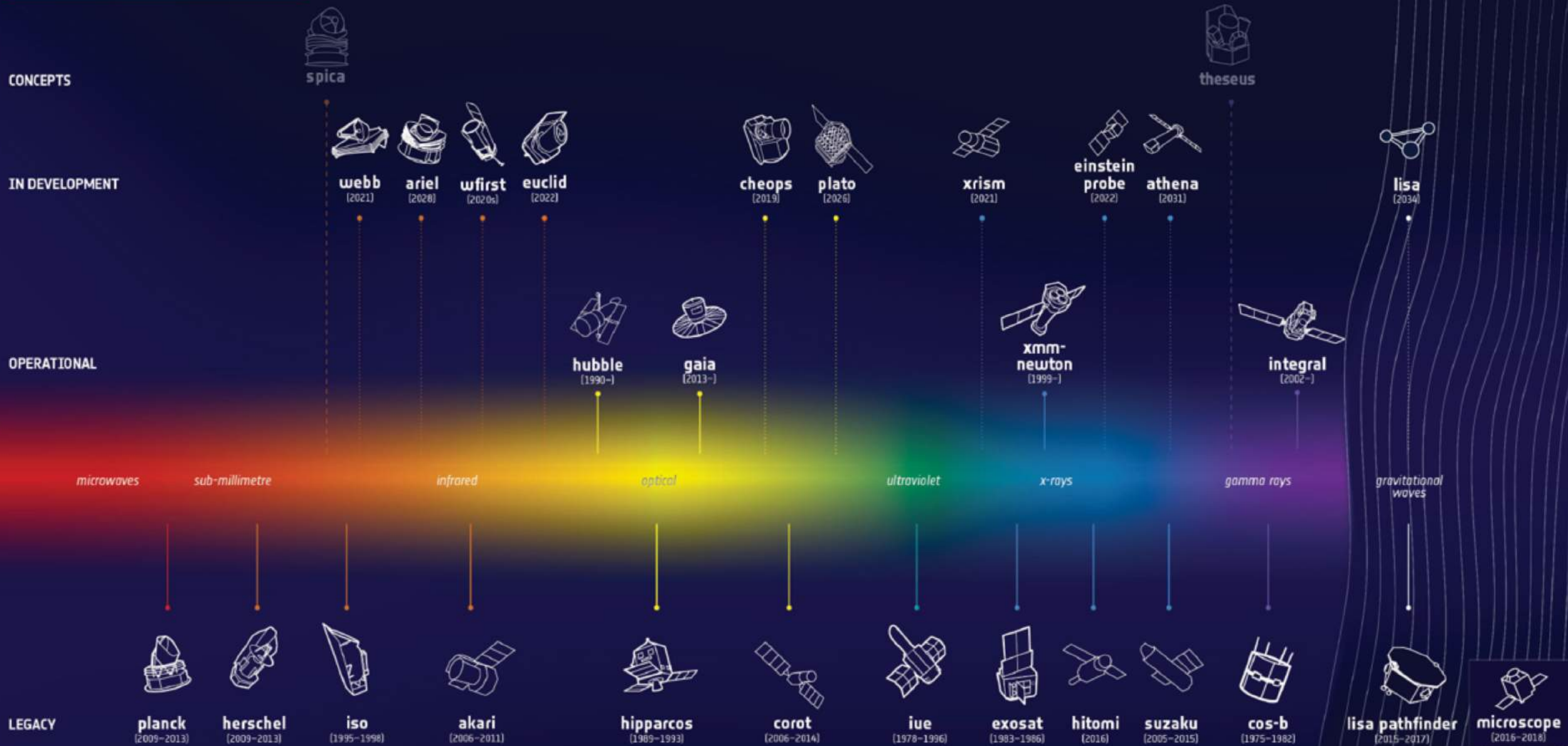
Future ESA Space Science Missions

Slide G. Hasinger



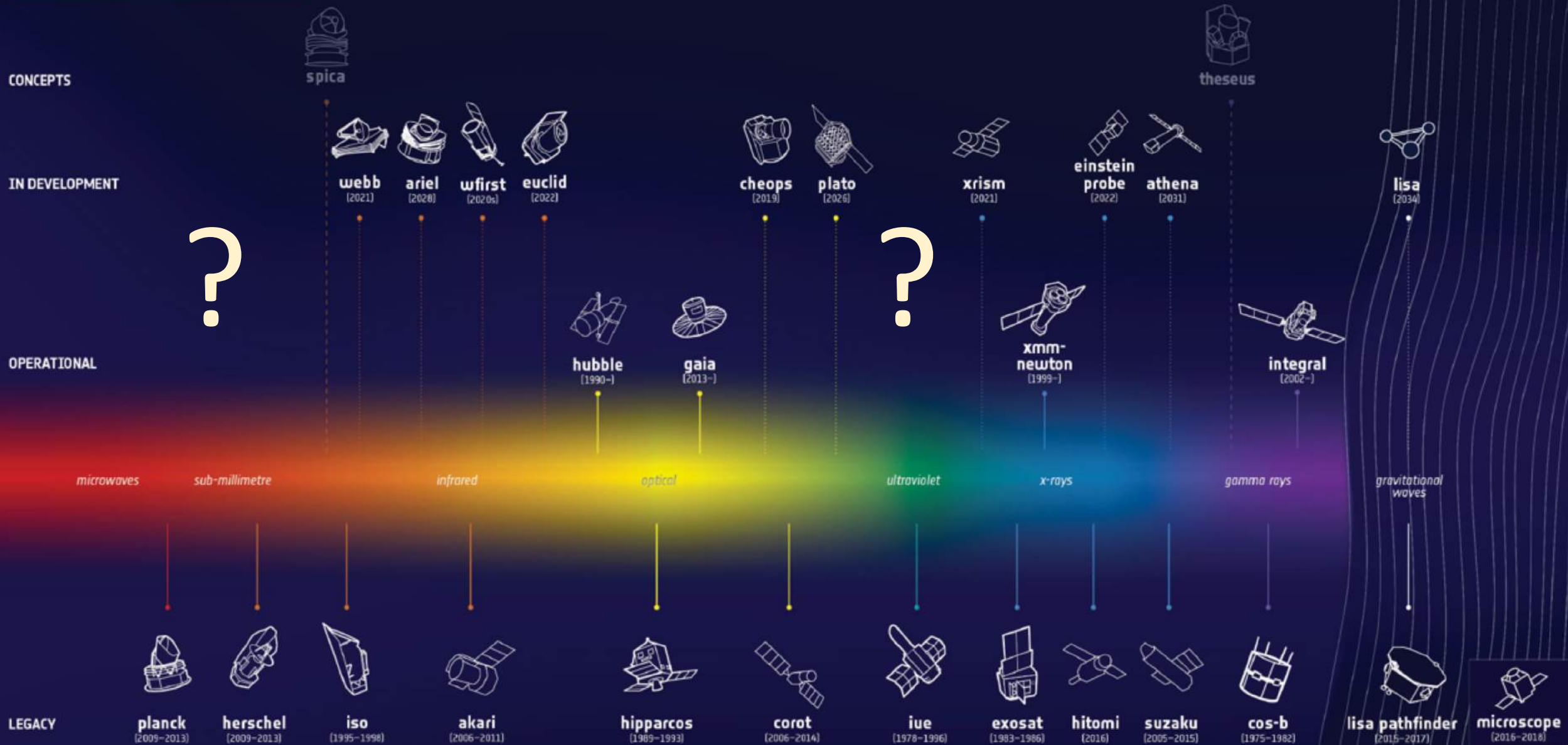
→ COSMIC OBSERVERS

Slide G. Hasinger

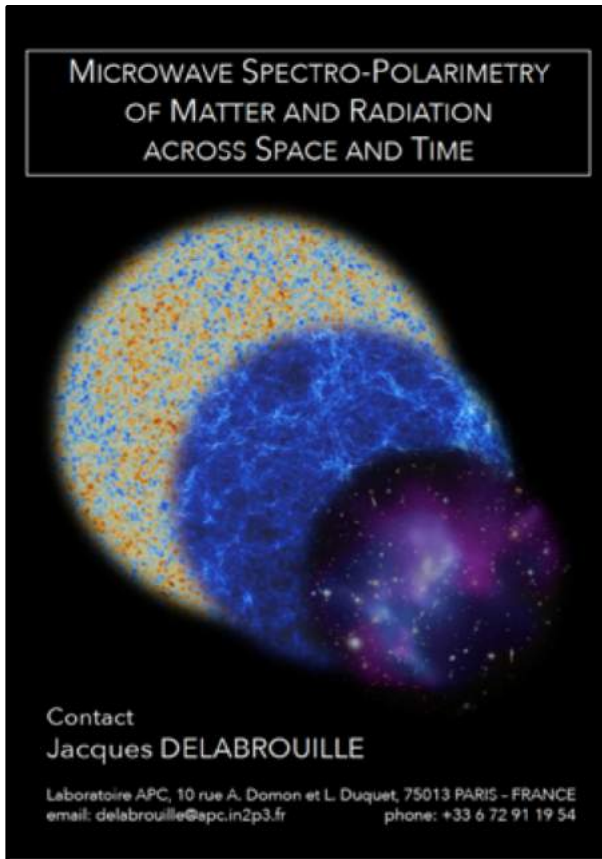


→ COSMIC OBSERVERS

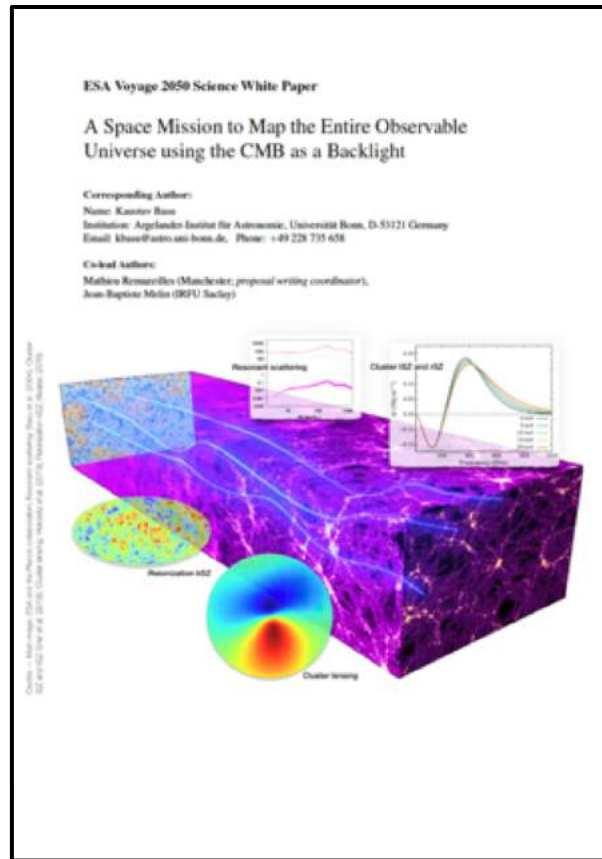
Slide G. Hasinger



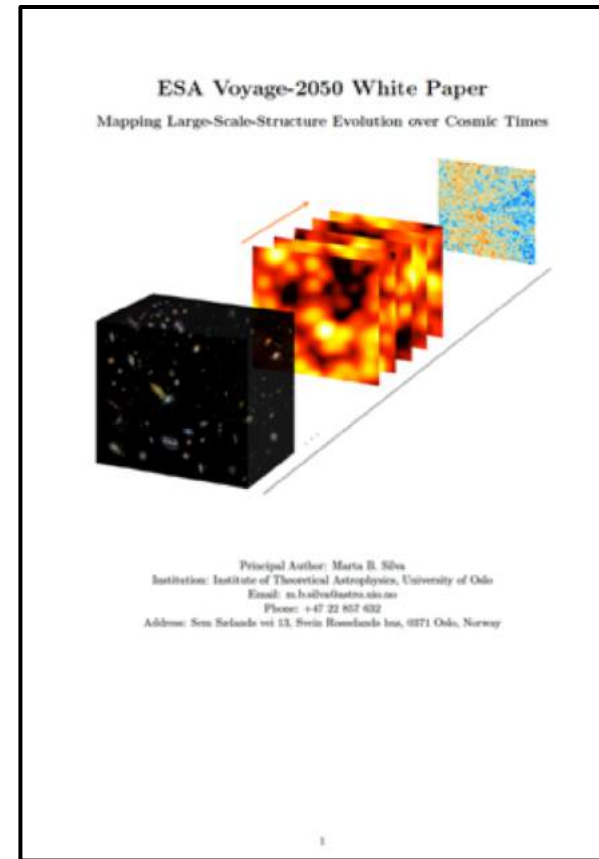
A coordinated microwave observation programme



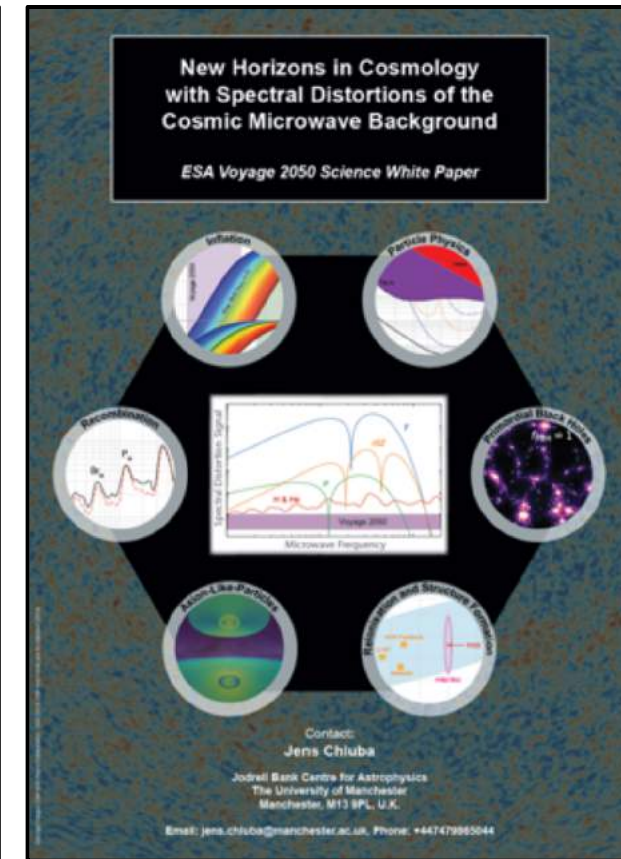
Microwave survey
Jacques Delabrouille et al.



CMB Backlight
Kaustuv Basu et al.



High redshift structures
Marta Silva et al.



Spectral distortions
Jens Chluba et al.

- **How did the Universe begin?**

- What is physics of the early Universe? Has inflation happened?

- **What is the Universe made of?**

- Is Λ CDM right? (What is going on with the “tensions”?)
- What is nature of Dark Matter and Dark Energy?
- What is the mass of neutrinos? Were there extra light particles?

- **How did the structure in the Universe form and evolve?**

- When and how did the first stars form?
- Where are baryons?

Cosmic Microwave Background

- K. Basu, A space mission to map the entire observable Universe using the CMB as a backlight
- J. Chluba, New horizons in cosmology with spectral distortions of the cosmic microwave background
- J. Delabrouille, Microwave spectro-polarimetry of matter and radiation across space and time

Surveying the Universe

- A. Blanchard, Gravitation and the Universe from large-scale structures
- L. Koopmans, Peering into the Dark (Ages) with low-frequency space interferometers
- M.B. Silva, Mapping large-scale-structure evolution over cosmic times

Gravitational Waves

- C.P.L. Berry, The missing link in gravitational-wave astronomy: Discoveries waiting in the decihertz range
- I. Dvorkin, High angular resolution gravitational wave astronomy
- A. Sesana, Unveiling the gravitational Universe at μ -Hz frequencies

Soft X-ray (Structure Formation)

- A. Simionescu, Voyage through the hidden physics of the cosmic web

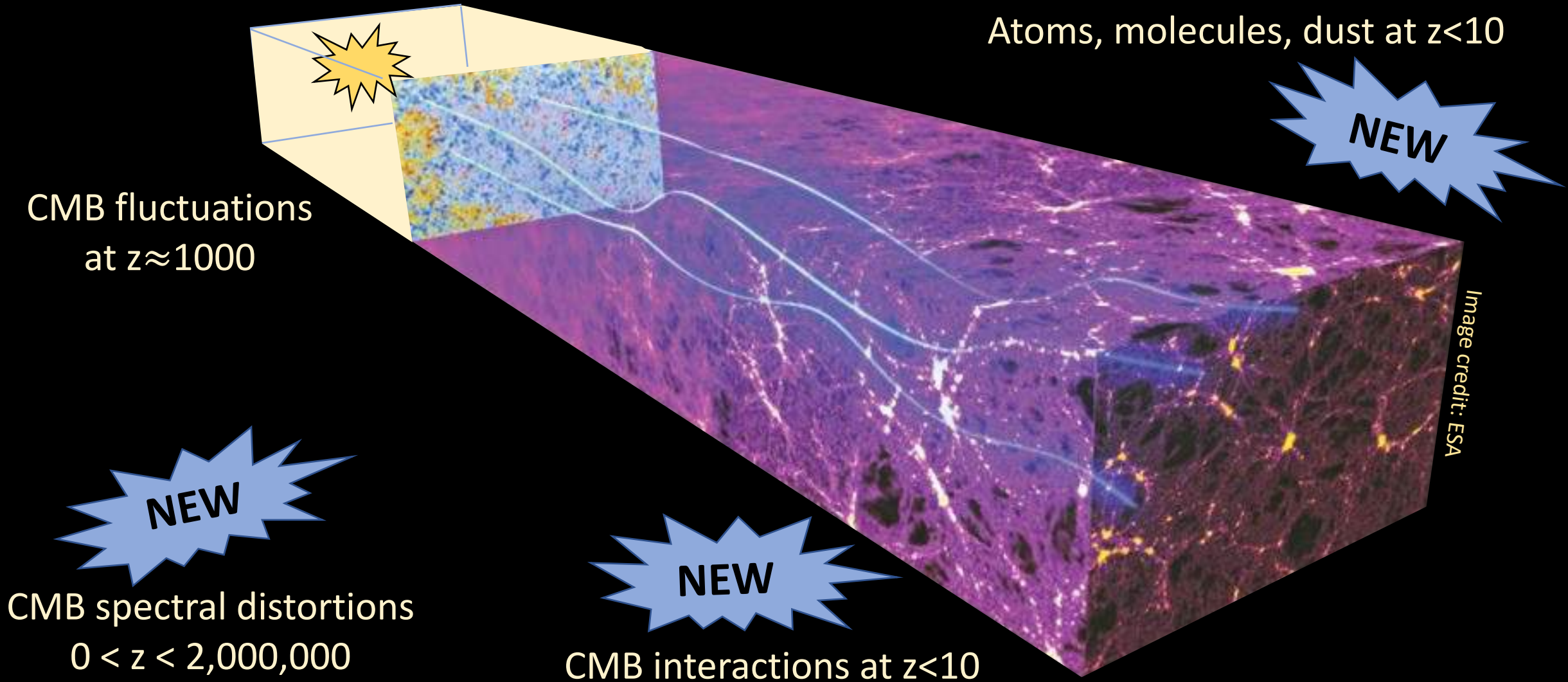
Optical-Near IR Camera (H_0)

- K. Jahnke, The need for a multi-purpose, optical-NIR space facility after HST and JWST

Dark Matter

- A. De Angelis, Gamma-ray astrophysics in the MeV range: The ASTROGAM concept and beyond
- F. Malbet, Faint objects in motion: the new frontier of high precision astrometry
- O. Buchmueller, AEDGE: Atomic experiment for dark matter and gravity exploration

Observe the Universe in the Microwave



Observe the Universe in the Microwave

CMB fluctuations
at $z \approx 1000$

***A microwave spectro-polarimetric
survey to probe matter and radiation
across space, time, and scales in the
entire observable Universe***

Atoms, molecules, dust at $z < 10$

NEW

NEW

CMB spectral distortions
 $0 < z < 2,000,000$

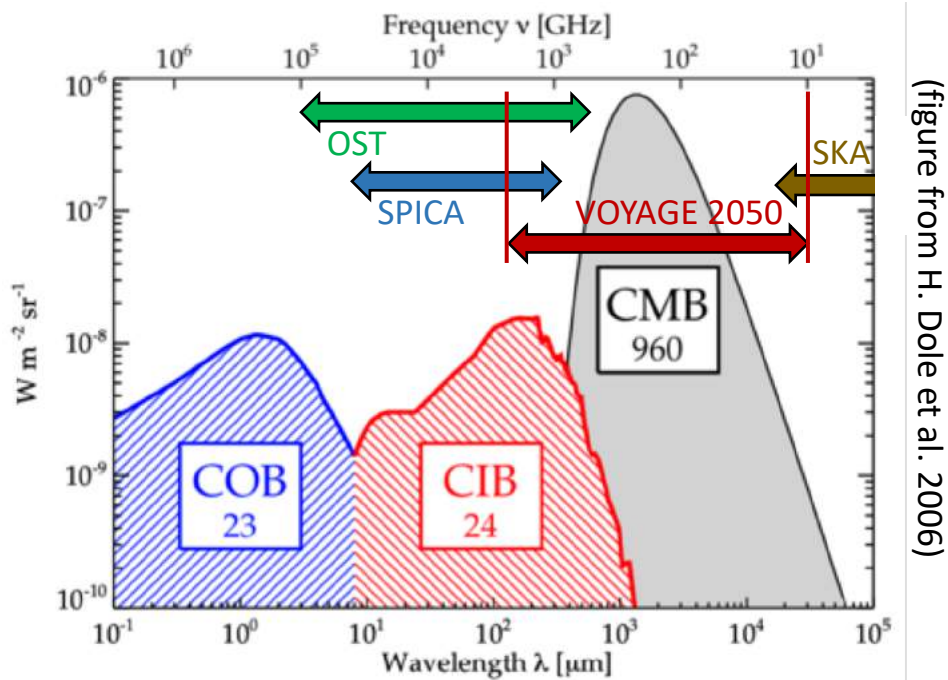
NEW

CMB interactions at $z < 10$

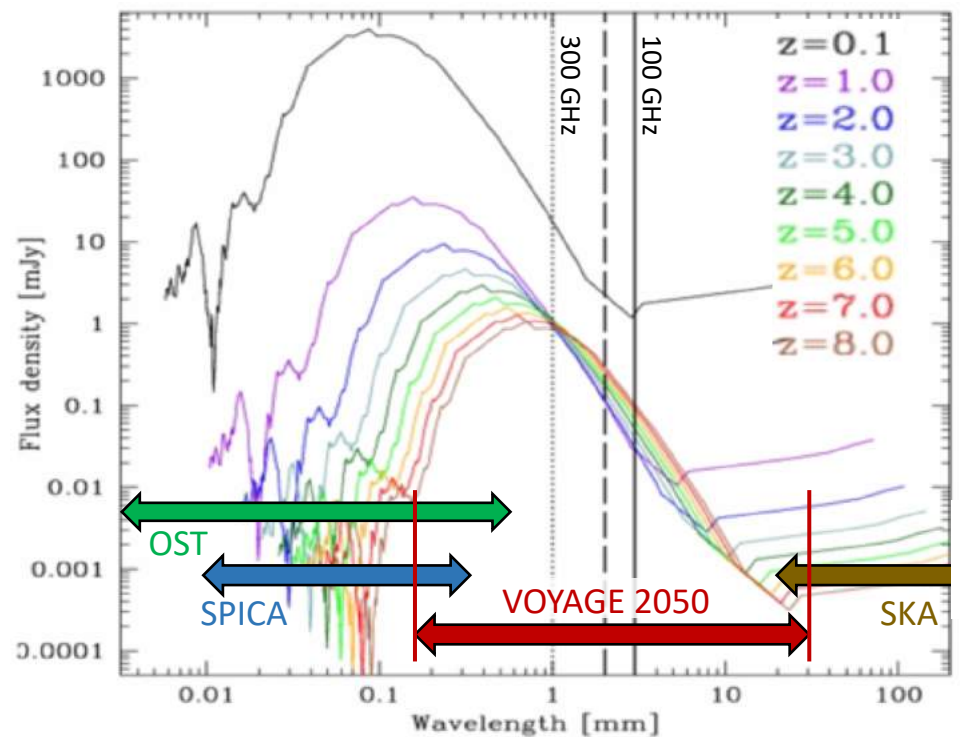
Image credit: ESA

Why microwaves?

1- Most of the radiation in the Universe is in the microwaves!



2- The most distant objects emit in the microwaves



(figure from R. Decarli website)

3- Complement planned observations in the 2030+ time frame

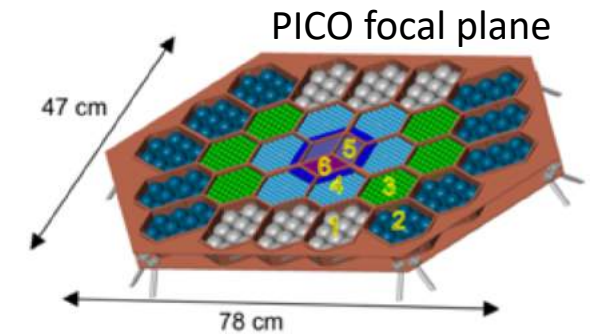
A space telescope / mission with 3 instruments

Microwave Imaging and Spectroscopy Telescope

1. A broad-band, multi-frequency polarised imager

- Reference model: PICO instrument at the focus of 3.5m cold telescope
- 21 bands from ~ 20 to ~ 800 GHz

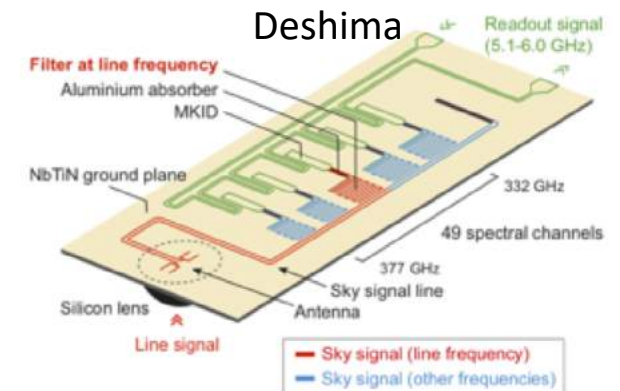
CONTINUUM EMISSION



2. A sensitive spectrometer with $R \approx 300$

- Reference model: Extended Deshima at the focus of the same telescope
- Frequency range ~ 100 -1000 GHz (goal 50-2000 GHz)

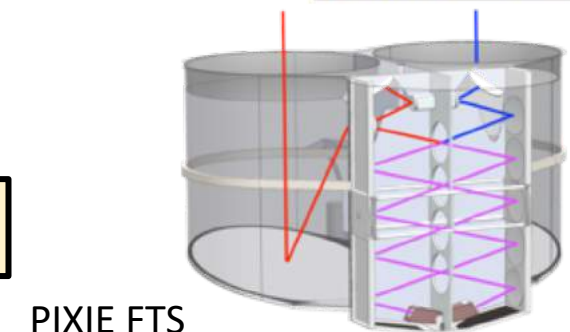
LINE EMISSION



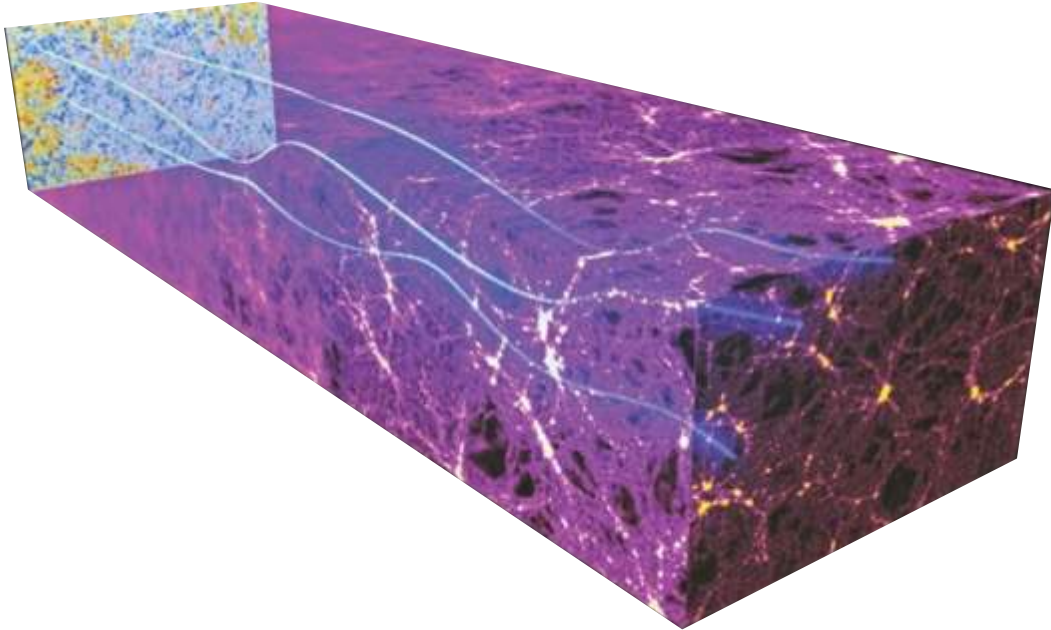
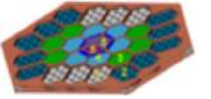
3. An absolutely calibrated FTS

- Reference model: a three-module version of PIXIE / PRISTINE
- Frequency range ~ 10 -2000 GHz

INTEGRATED EMISSION



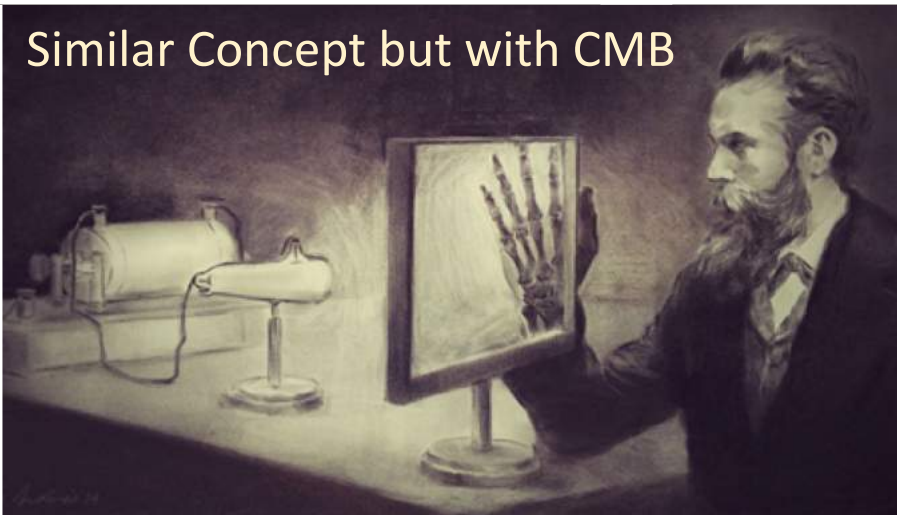
Science highlights : The build-up of structure



CMB "backlight" probes

- Hot gas with thermal Sunyaev-Zeldovich effect ($>10^6$ clusters)
- Gas temperature with relativistic corrections to SZ spectrum
- Velocity flows with kinematic and polarized SZ effects
- Dark matter and halo masses with CMB lensing
- Atoms with Rayleigh and resonant scattering

Similar Concept but with CMB



- **Map entire cosmic web**



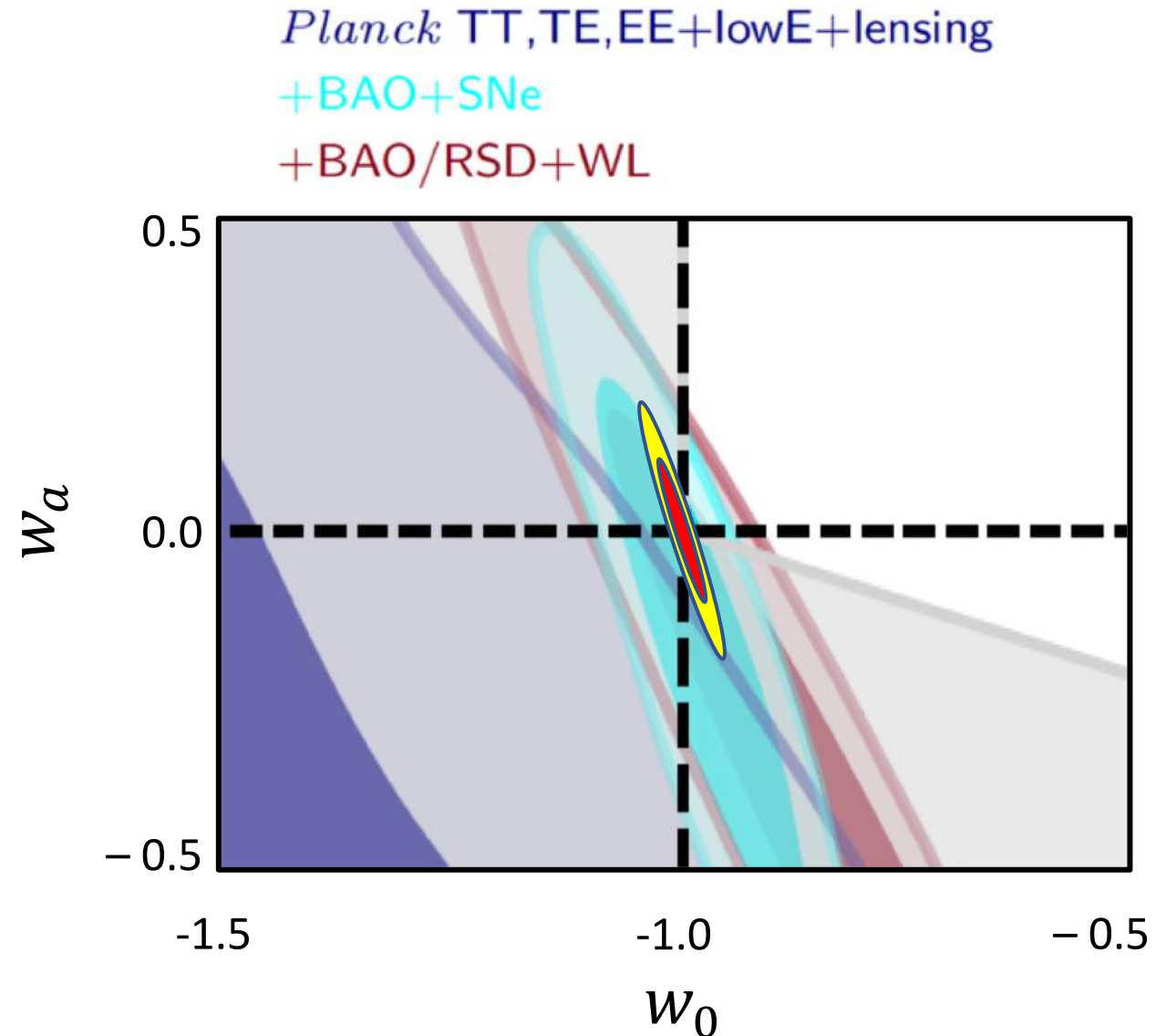
- **Dark Energy**
- **Modified gravity**
- **Distribution of early atoms**
- **Neutrino masses...**

Science highlights : Dark Energy

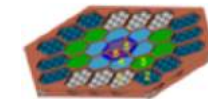
Cosmological exploitation of
 10^6 galaxy clusters

Dark Energy Equation of state:
 $w = w_0 + (1 - a)w_a$

Dark Energy parameters
Dark Energy homogeneity

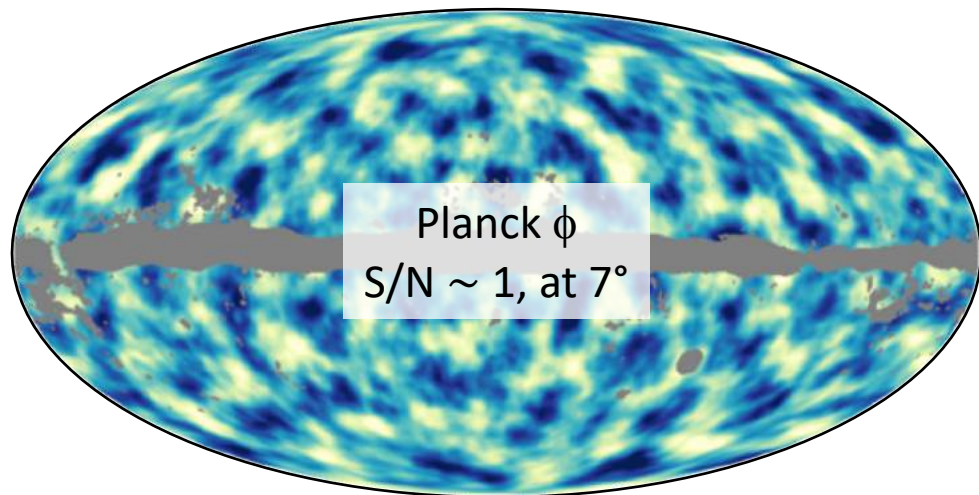


Full sky Dark Matter maps

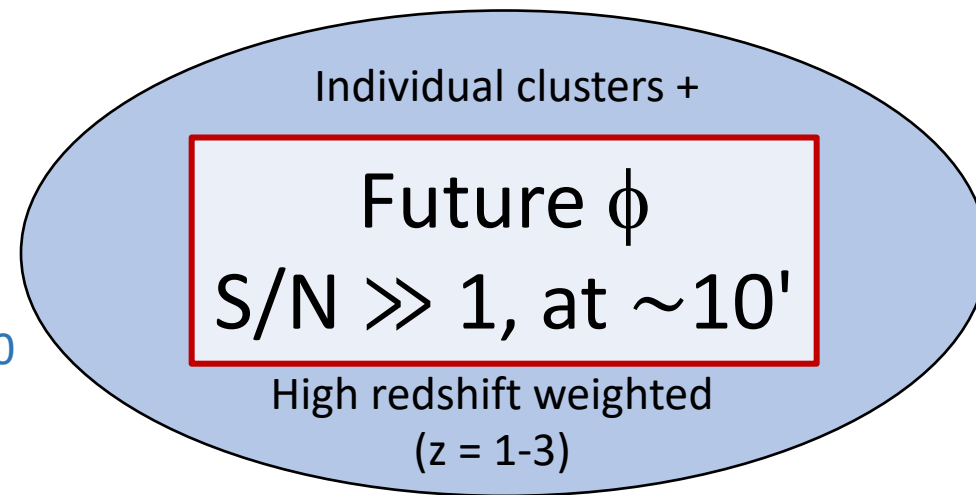


Transformative progress for DM mapping

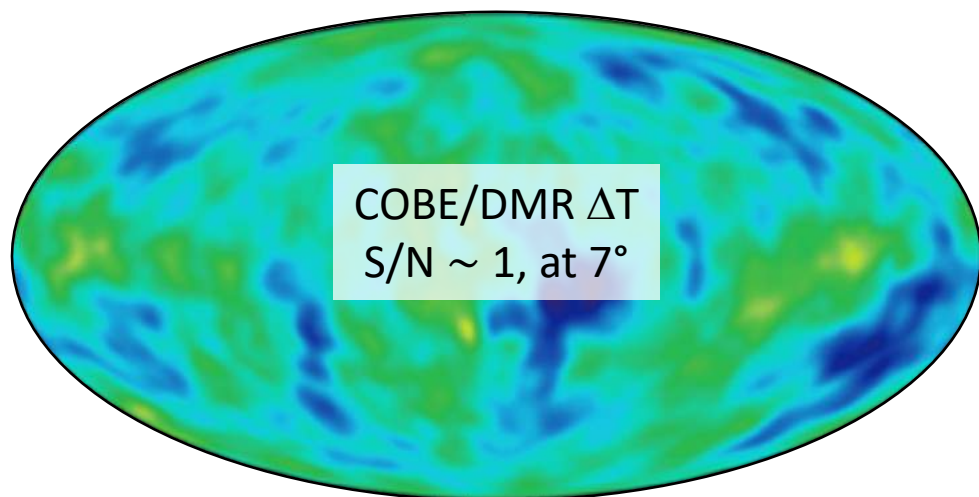
Dark Matter
distribution, $z =$ a few



From
Planck
to
Voyage 2050

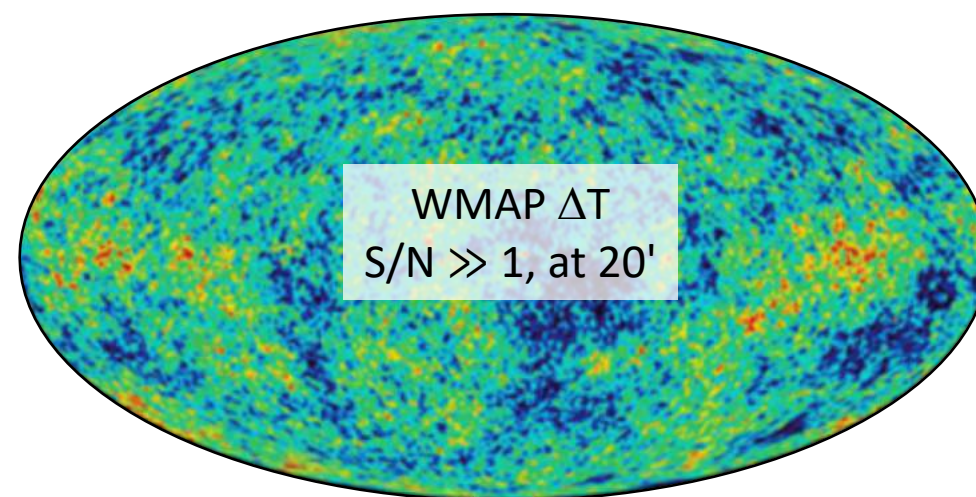


Temperature
fluctuations, $z=1000$

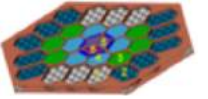


Analogy

From
COBE/DMR
to WMAP



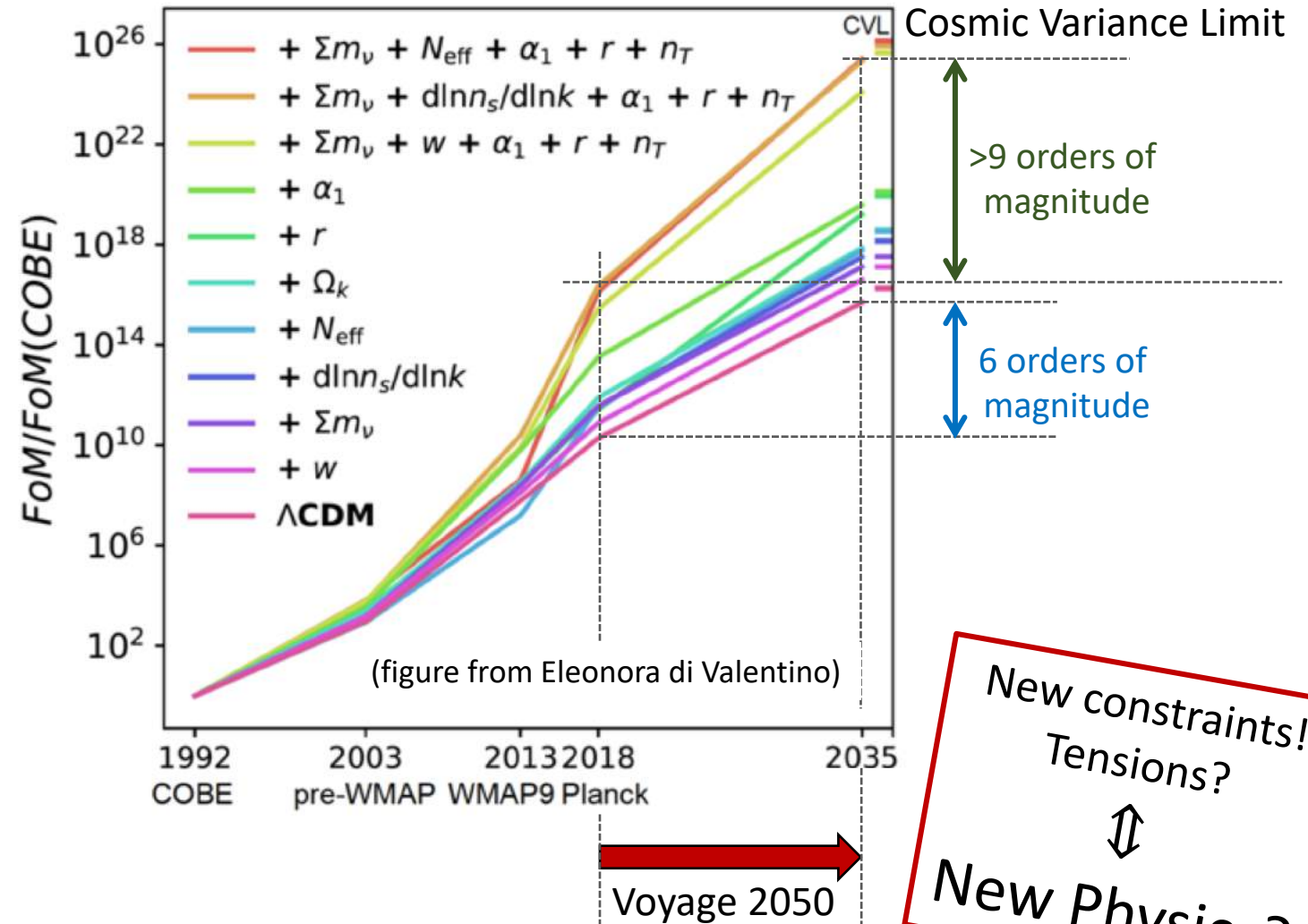
Science highlights : Λ CDM under scrutiny



- ΔT & ΔP CMB sensitivity
 $\approx 5000 \times \text{Planck}$
 $\approx 10 \times \text{CMB-S4 (polar.)}$
- Impressive constraints

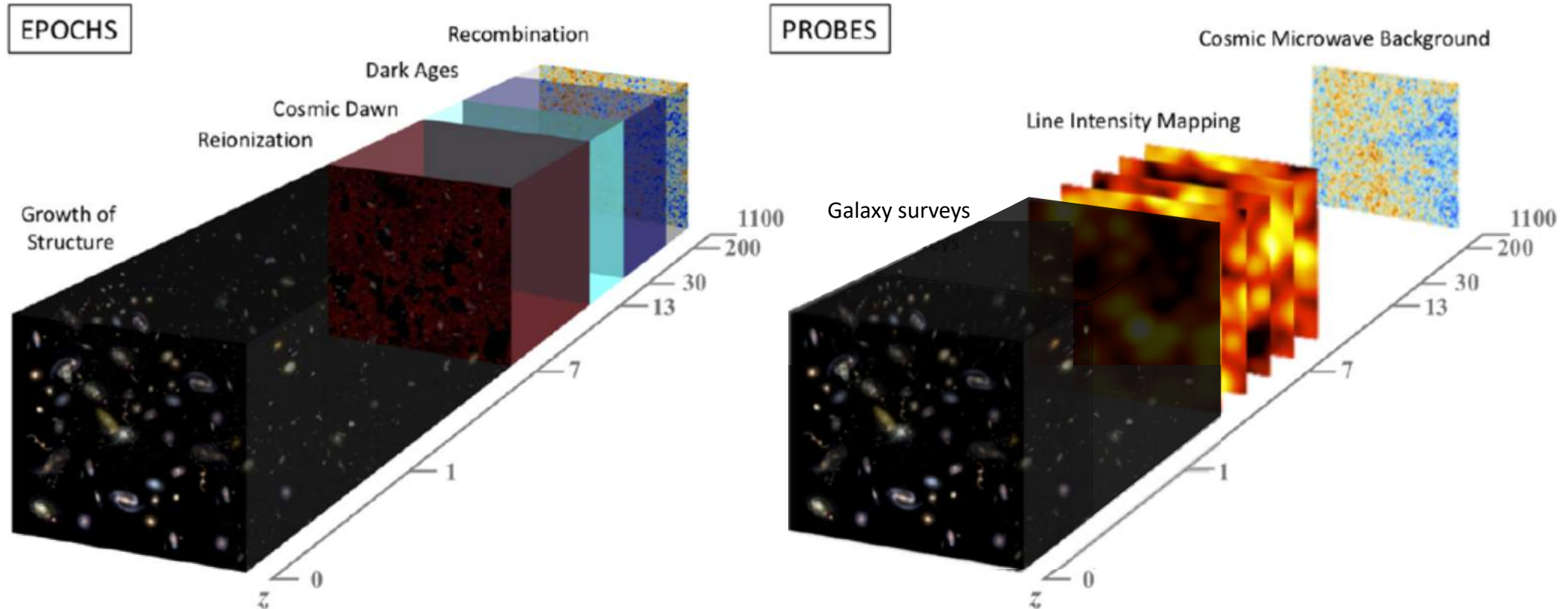
$$\left. \begin{array}{l} \sigma(\Sigma m_\nu) \sim 10^{-2} \\ \sigma(N_{\text{eff}}) \sim 0.016 \end{array} \right\} \text{Neutrinos}$$

$$\left. \begin{array}{l} \sigma(r) \sim 10^{-4} \\ \sigma(n_s) \sim 0.0015 \end{array} \right\} \text{Inflation}$$



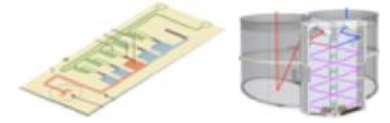
New constraints!
Tensions?
 \Updownarrow
New Physics?

Science highlights : Structure tomography

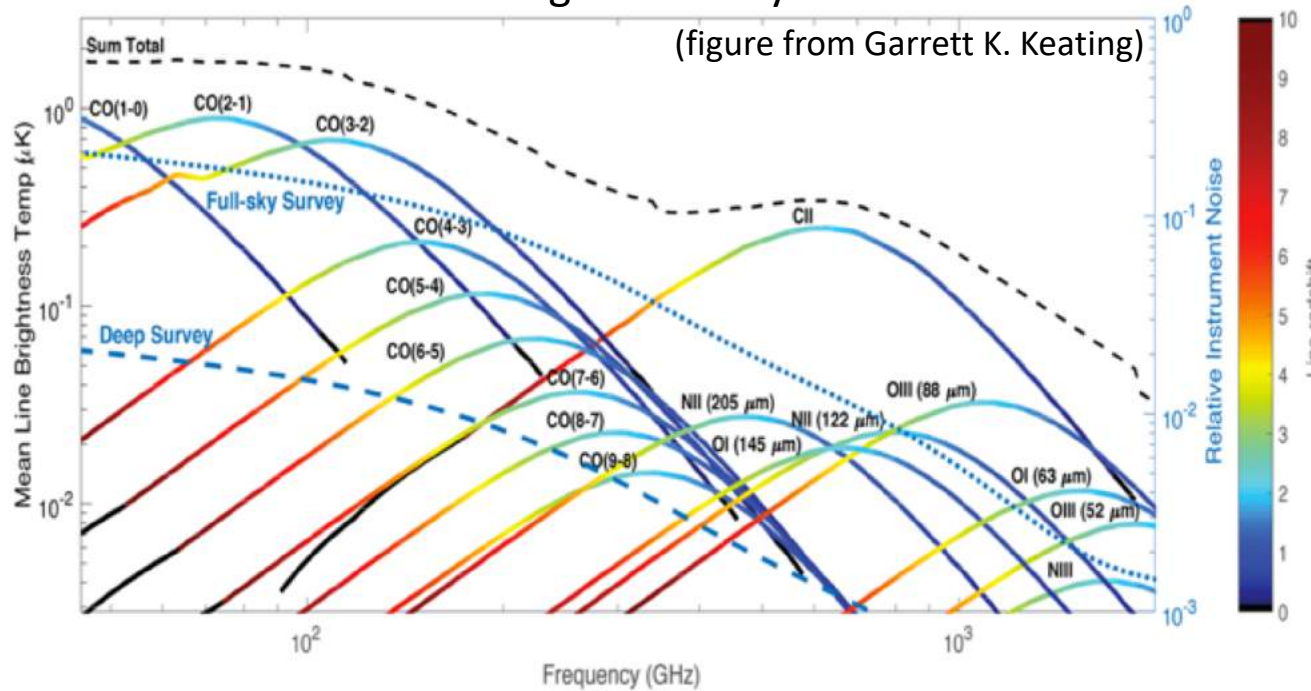


- Matter power spectra;
- Knots in the cosmic web, from protoclusters to clusters;
- Different gas phases in structures;
- History of star formation, molecular gas, dust in structures

Science highlights : Structure tomography

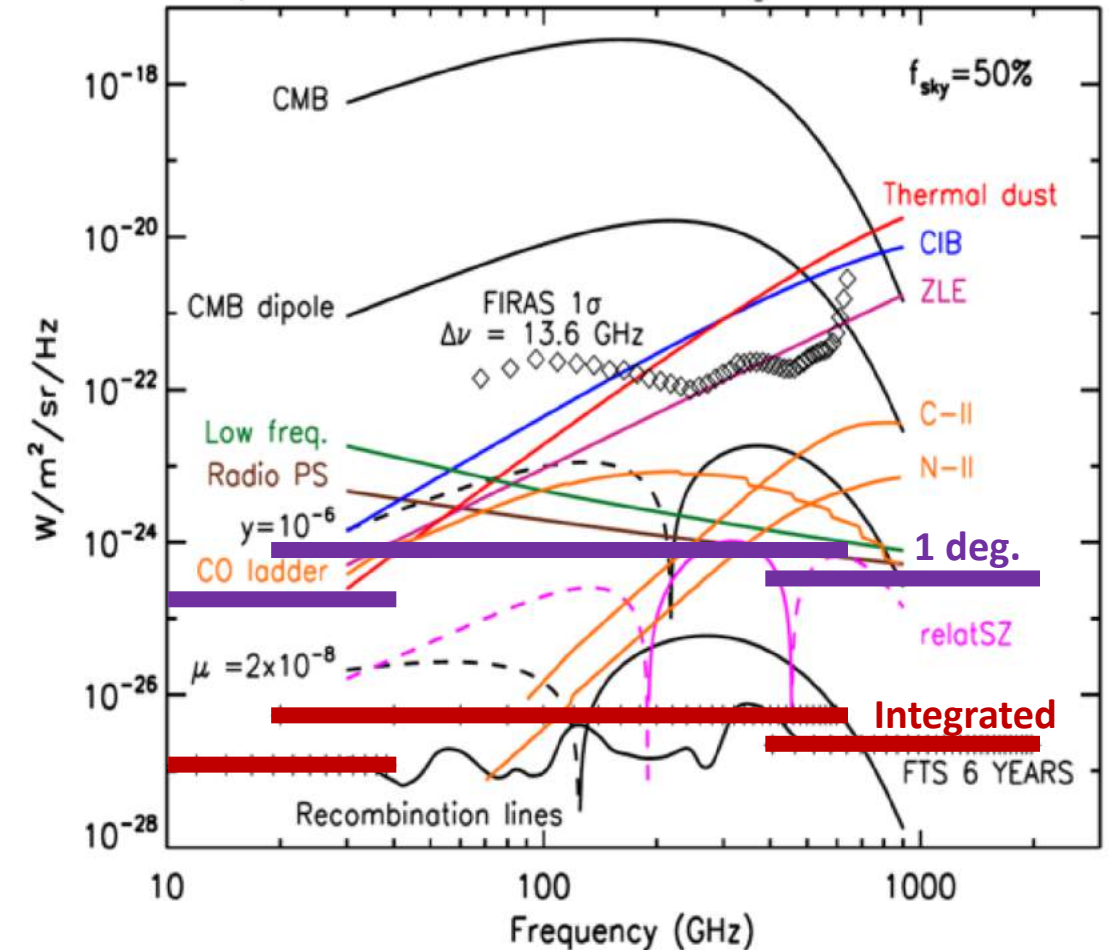


1 deg. sensitivity



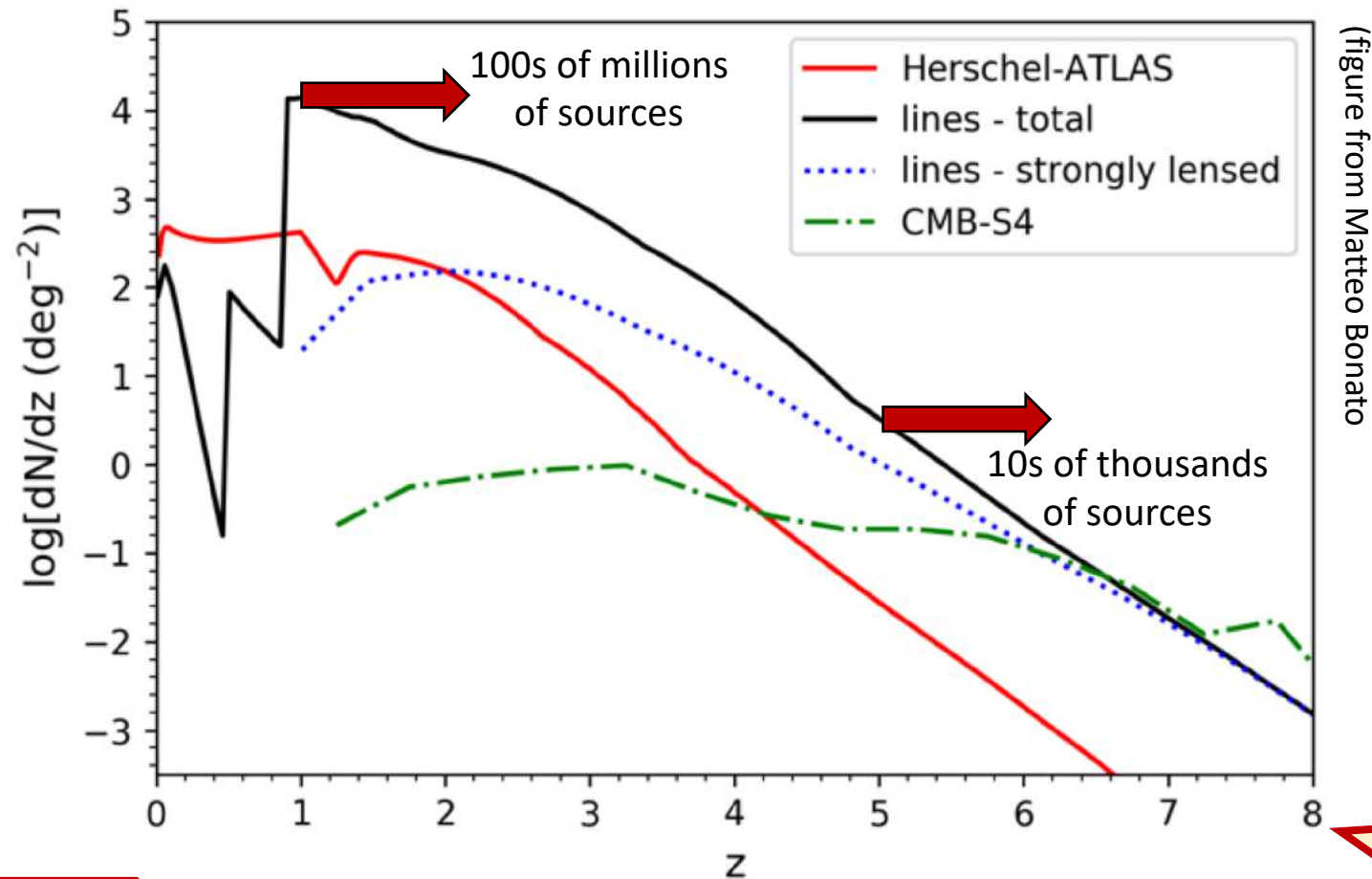
- Integrated emission fluctuations
- Unimpeded frequency coverage

Spectral distortions and foreground emission



Unique in this frequency range!

Science highlights : High-z sources



Individual sources / halos
+ redshift information

Mostly
un-blended !!

And much more!

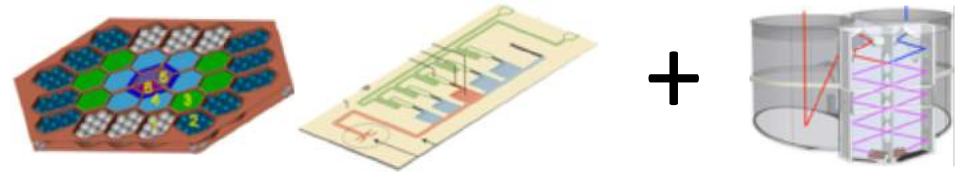
- Inflationary model
- Axion detection in galactic or intra-cluster magnetic fields
- Primordial black holes
- Variations of the constants of physics across spacetime
- Cosmic birefringence
- Primordial magnetic fields
- Cosmic strings
- $>10^8$ sub-mm galaxies up to high redshift, with redshift information
- $>10^5$ high redshift galaxy proto-clusters up to $z=3$ (before hot ICM!)
- $>10^5$ high redshift strongly lensed dusty galaxies (ordinary high- z galaxies!)
- Integrated hot gas in the universe
- Circumgalactic medium
- Cosmic Infrared Background tomography
- Cross correlations between matter tracers
- Isotropy and homogeneity on the largest scales
- Galactic astrophysics – ISM, magnetic field
- Multi-wavelength astronomy ...

Implementation?

- Large cold telescope (req. 2.8m, baseline 3.5m, ~ 8 Kelvin) \Leftrightarrow L-class mission

- Three cryogenic instruments

- Two at the focus of the large telescope
- One separate (could be on another platform)



- Three modes of observation for a ~ 6 -year mission

- Survey 1 – full sky, ~ 2 years
- Survey 2 – deep patches, ~ 2 years
- Observatory – open time, ~ 2 years

Go Broad !
Go Deep !
Be Flexible !

- Builds on previous proposals (with international collaborators)

- PRISM White Paper for L2-L3
- CORE proposal, PICO study (NASA)
- PIXIE (NASA), PRISTINE
- ECHO / CMB-Bharat (ISRO)

**PIs are co-authors of the Voyage 2050
microwave spectro-polarimetry white paper**

Summary

- The Microwave Background remains a key observable to understand the Universe
- In 2035+, an ambitious space mission can harvest a fantastic data set for Cosmology – very rich science case
- Observational objective : sensitive spectro-polarimetric full sky survey in 10-2000 GHz at all scales down to 1'
- Get involved and/or give support !!
- ESA recommendations expected mid-2020

Read the papers (available on arXiv)

2019arXiv190901593C

2019/09



New Horizons in Cosmology with Spectral Distortions of the Cosmic Microwave Background

Chluba, J.; Abitbol, M. H.; Aghanim, N. *and 27 more*

2019arXiv190901592B

2019/09



A Space Mission to Map the Entire Observable Universe using the CMB as a Backlight

Basu, Kaustuv; Remazeilles, Mathieu; Melin, Jean-Baptiste *and 22 more*

2019arXiv190901591D

2019/09



Microwave Spectro-Polarimetry of Matter and Radiation across Space and Time

Delabrouille, Jacques; Abitbol, Maximilian H.; Aghanim, Nabila *and 77 more*

2019arXiv190807533S

2019/08

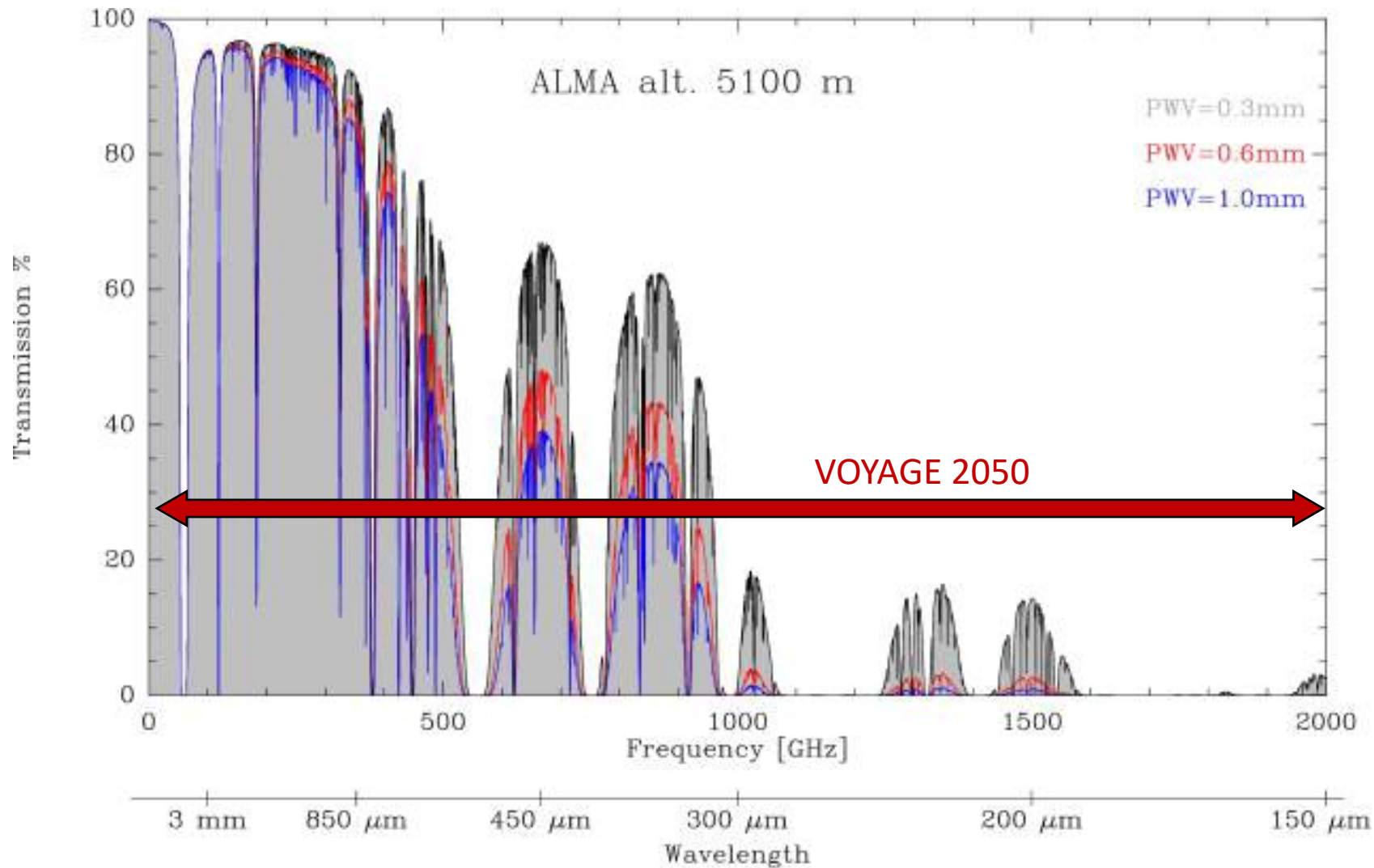


Mapping Large-Scale-Structure Evolution over Cosmic Times

Silva, Marta B.; Kovetz, Ely D.; Keating, Garrett K. *and 6 more*

Backup slides

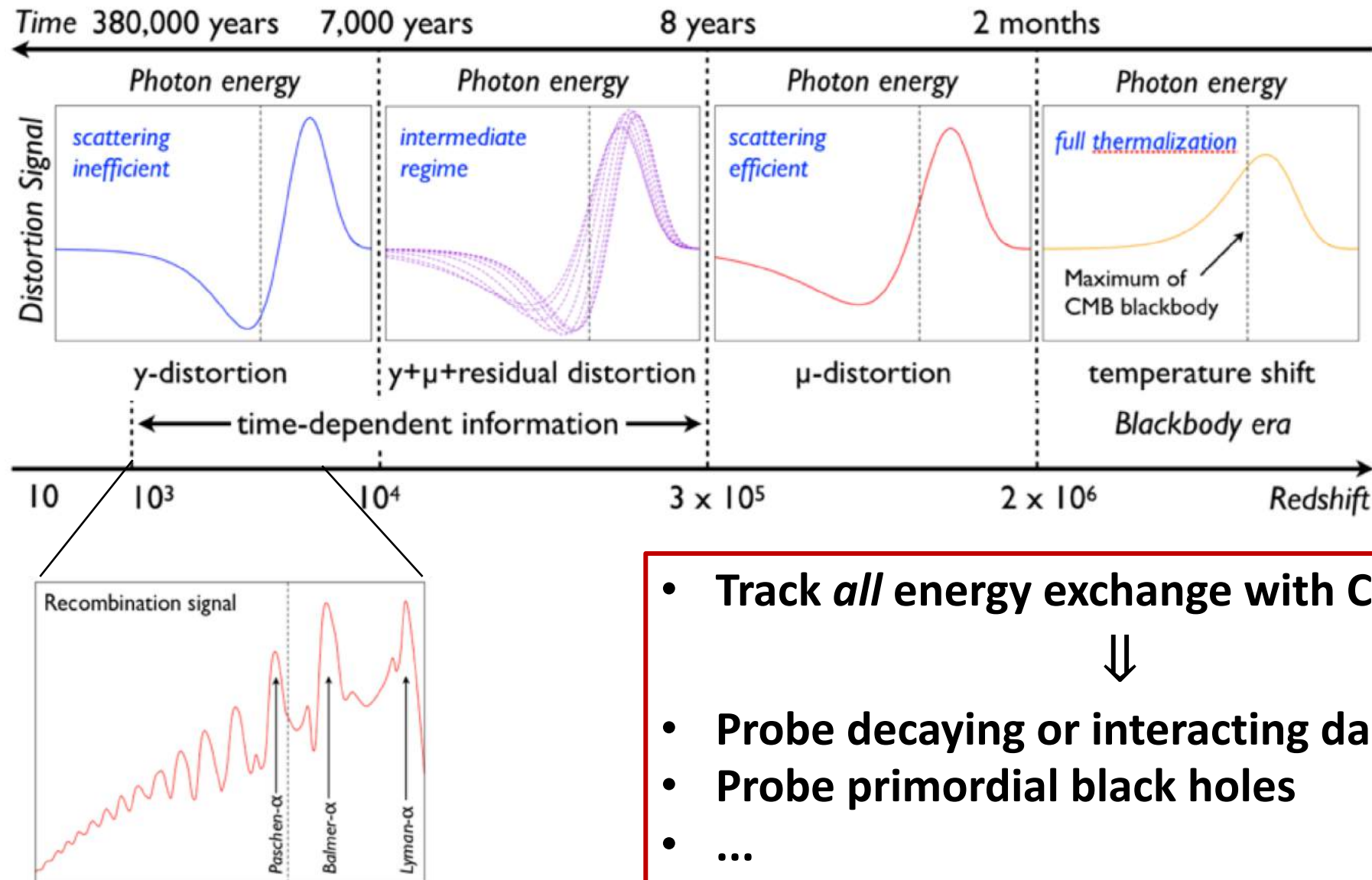
Why from space?



Atmospheric
Transmission
and
Emission !

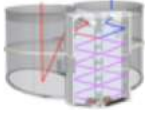
Science highlight 4: Cosmic thermal history

• Track all energy exchange with CMB at $z < 2,000,000$
• Probe decaying or interacting dark matter
• Probe primordial black holes
• ...



- Track *all* energy exchange with CMB at $z < 2,000,000$
- Probe decaying or interacting dark matter
- Probe primordial black holes
- ...

Absolute spectrometry : instrument



One or more small Fourier Transform Spectrometers modules

- For zero-level of intensity maps and CMB spectral distortions
- Can be on a separate platform
- Can be an independent M-class mission, e.g. a revision of PIXIE / PRISTINE

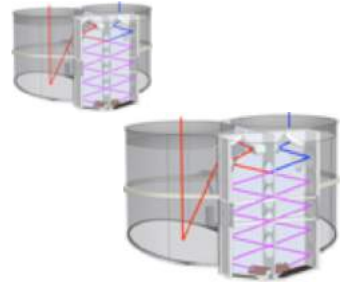
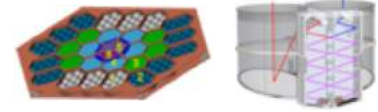


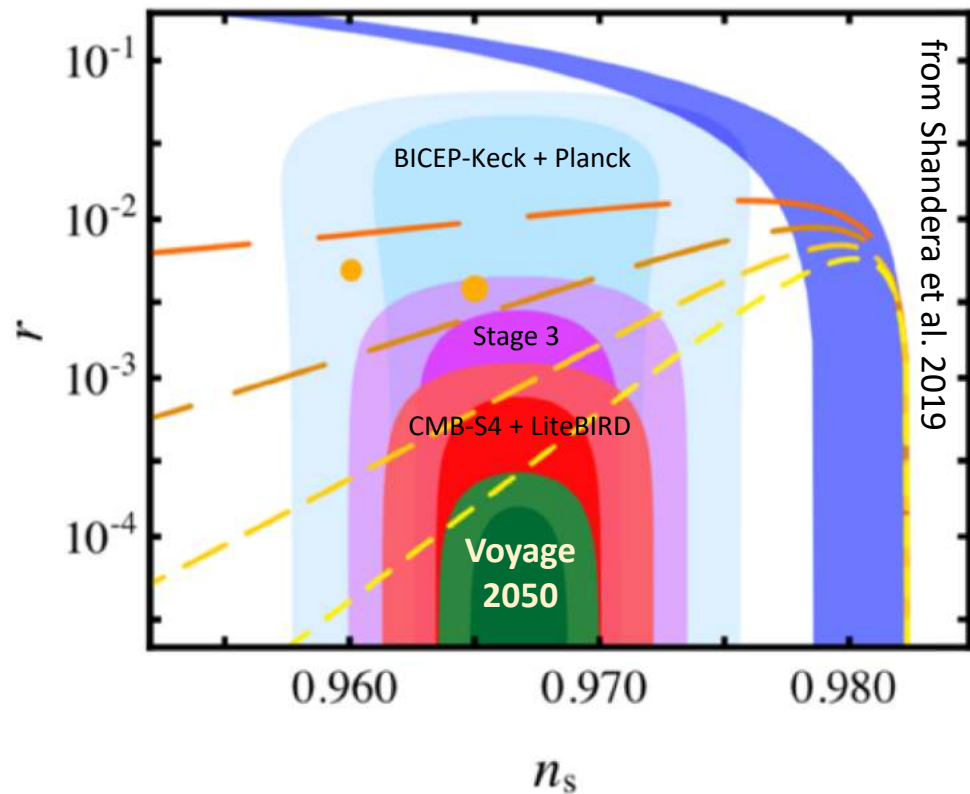
Table II: Multi-module absolute spectrometer; The mission sensitivity in the last column assumes 70% useful data and a 6-year mission.

Module	ν_{\min} (GHz)	ν_{\max} (GHz)	$\Delta\nu$ (GHz)	Sensitivity (Jy. \sqrt{s})	Mission sens. (Jy sr $^{-1}$)
LFM	9.6	38.4	2.4	1435	0.12
MFM	20	600	20	6200	0.54
HFM	406	2000	58	2520	0.22

Science highlight 3 : Inflation



- Energy scale; Stationarity;
- Primordial spectra
- Non gaussianity \Leftrightarrow Multi field ?

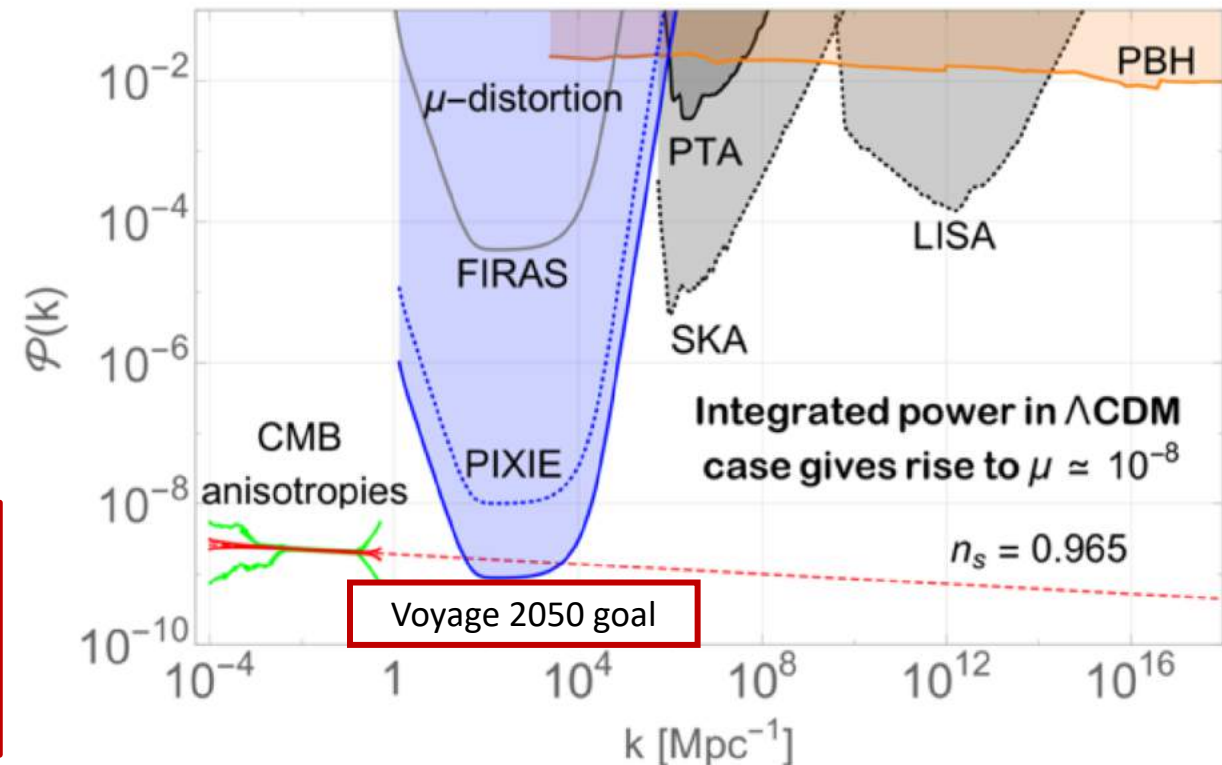


- ϕ^p $47 < \mathcal{N}_* < 57$
- $M = 4M_P$ $\mathcal{N}_* = 57$
- $M = 2M_P$ $\mathcal{N}_* = 57$
- $M = 1M_P$ $\mathcal{N}_* = 57$
- $M = M_P/2$ $\mathcal{N}_* = 57$
- Higgs $\mathcal{N}_* = 57$
- R^2 $\mathcal{N}_* = 50$

CMB Polarization

NG: f_{NL} local from CIB or correlations

CMB spectral distortions



- Energy scale; Stationarity;
- Primordial spectra
- Non gaussianity \Leftrightarrow Multi field ?