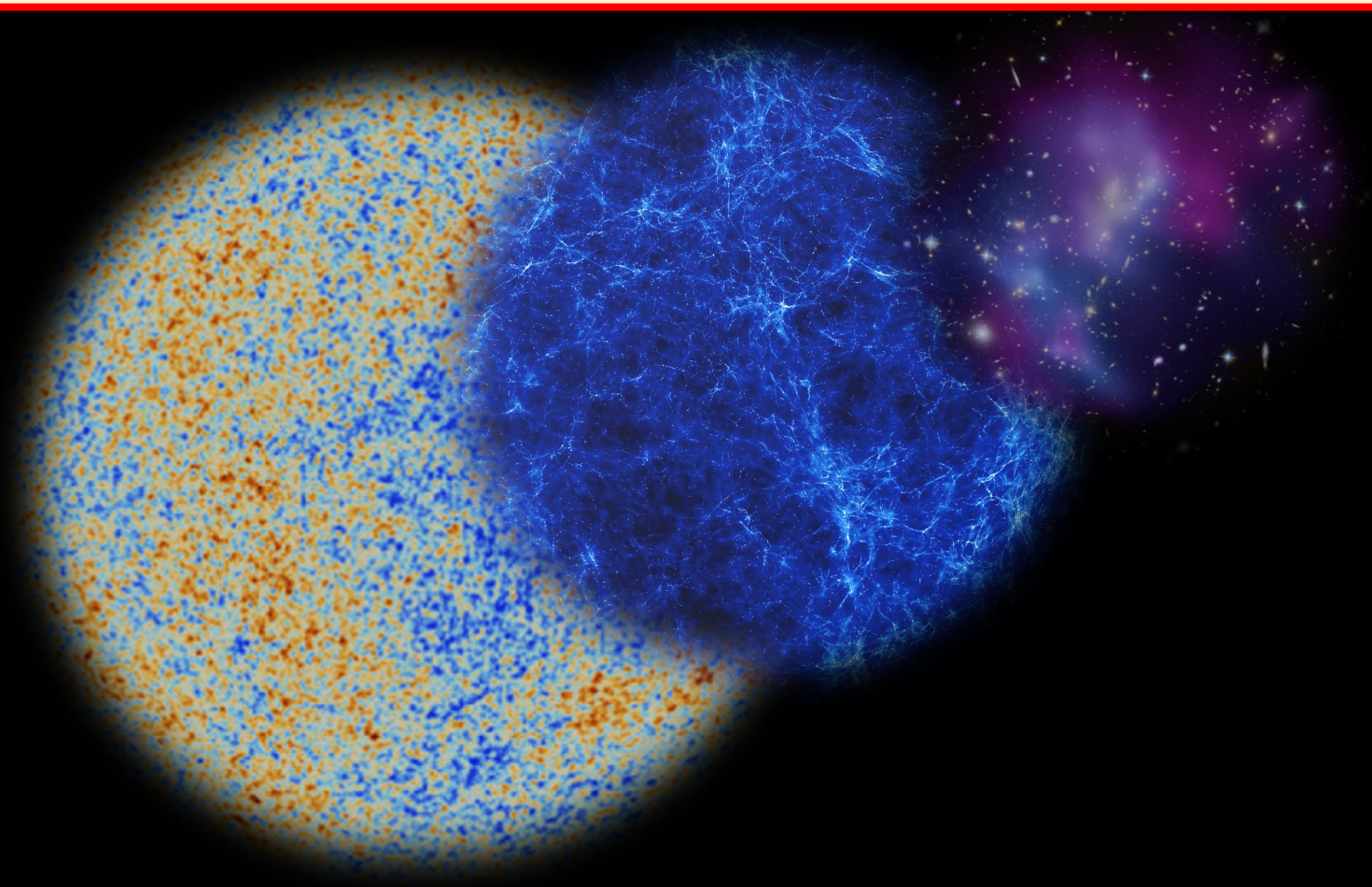
Future CMB observations from space

CORE, PRISM and "Voyage 2050"



Jacques Delabrouille

Centre Pierre Binétruy CNRS-Berkeley

and LBNL, Berkeley

(Glorious) Past of microwave observations from space

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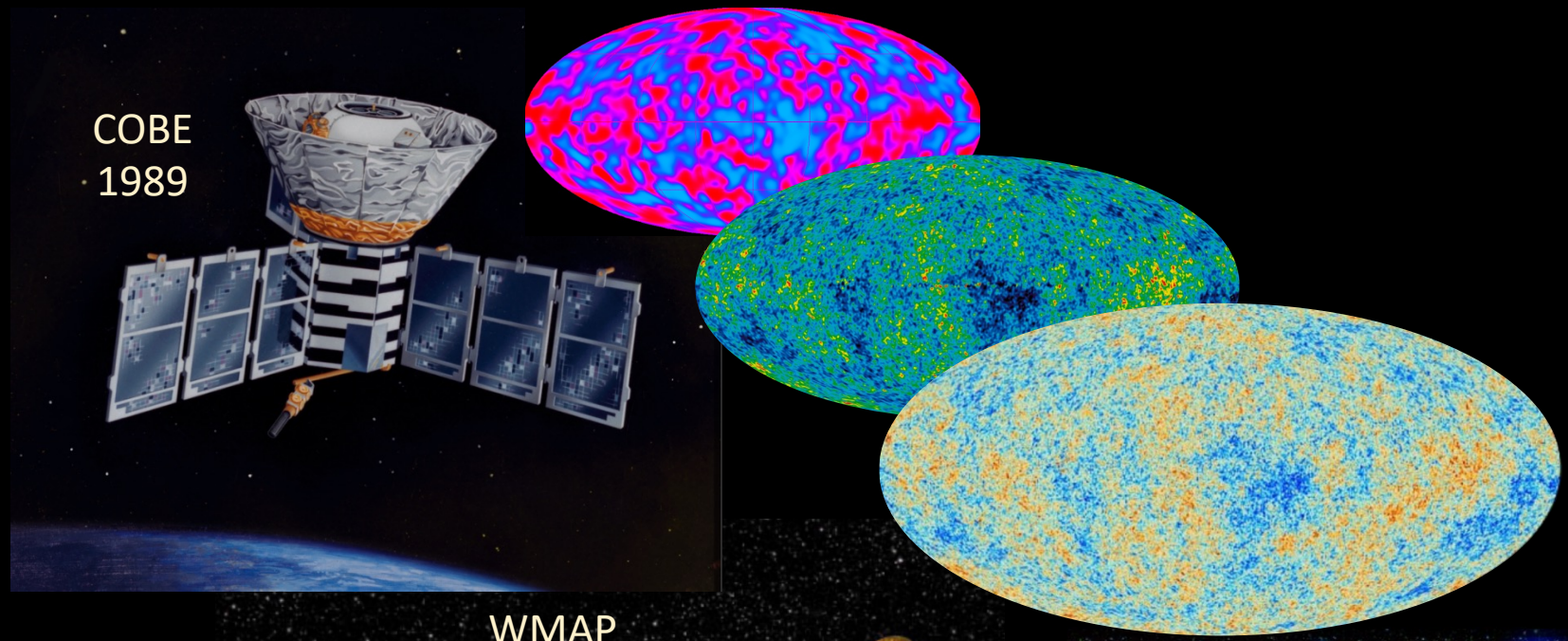
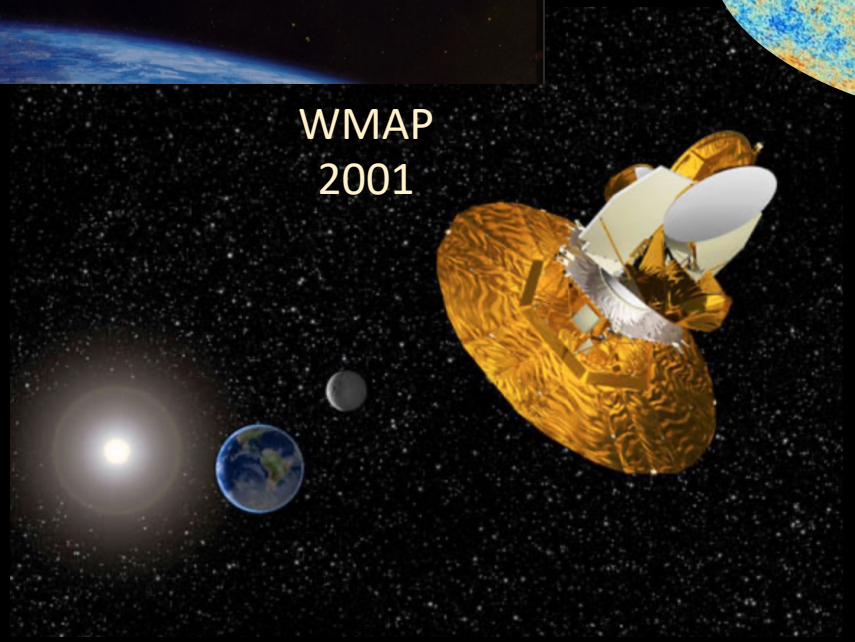
COBE
1989

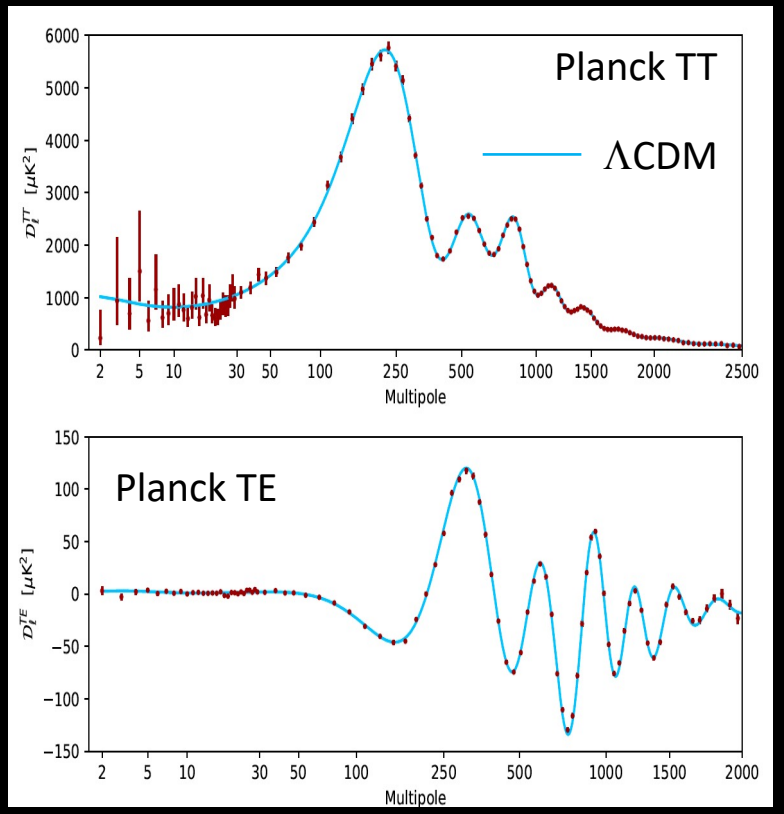


WMAP
2001

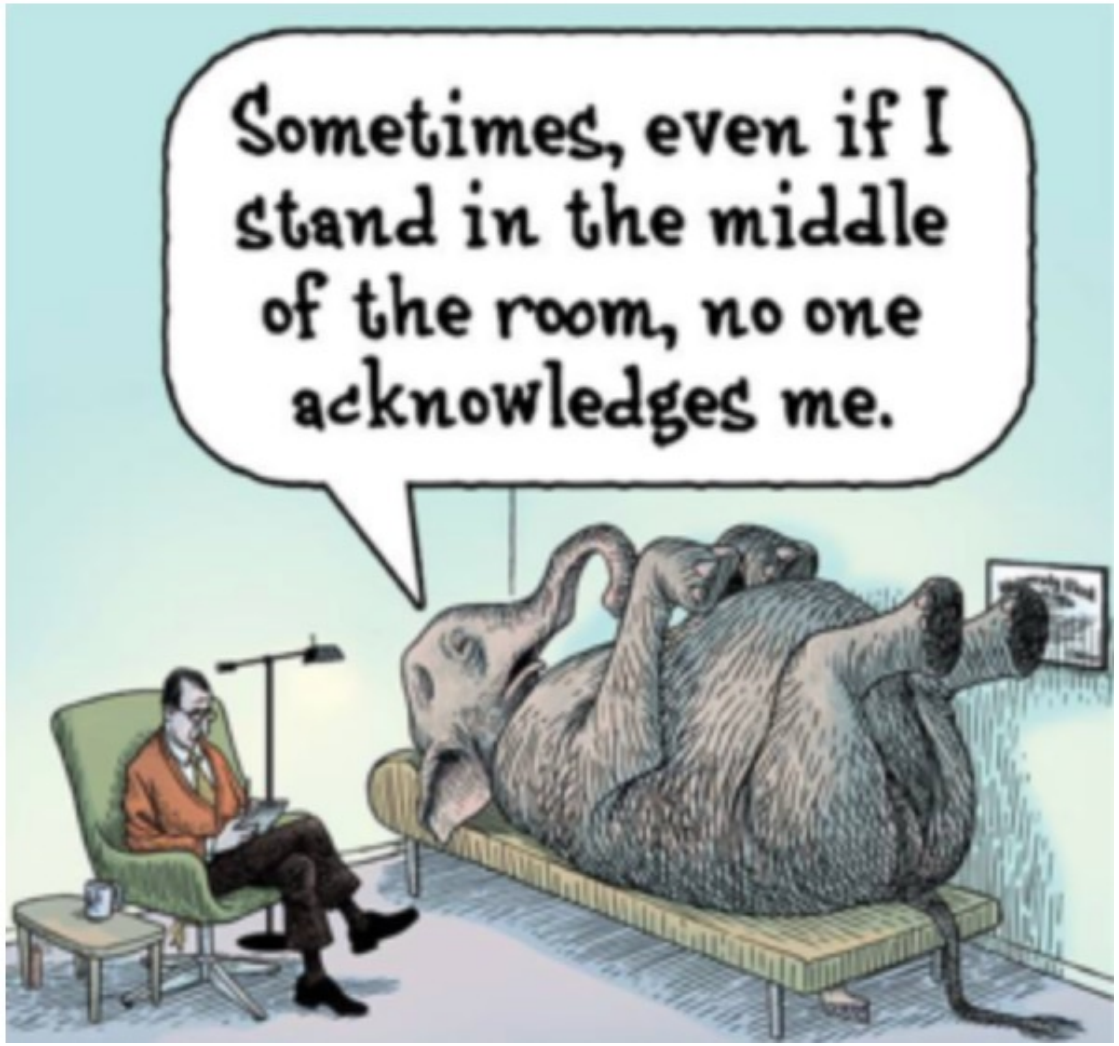


Planck
2009

Planck 2018 results



Are we done?


Sometimes, even if I stand in the middle of the room, no one acknowledges me.

Are we done?

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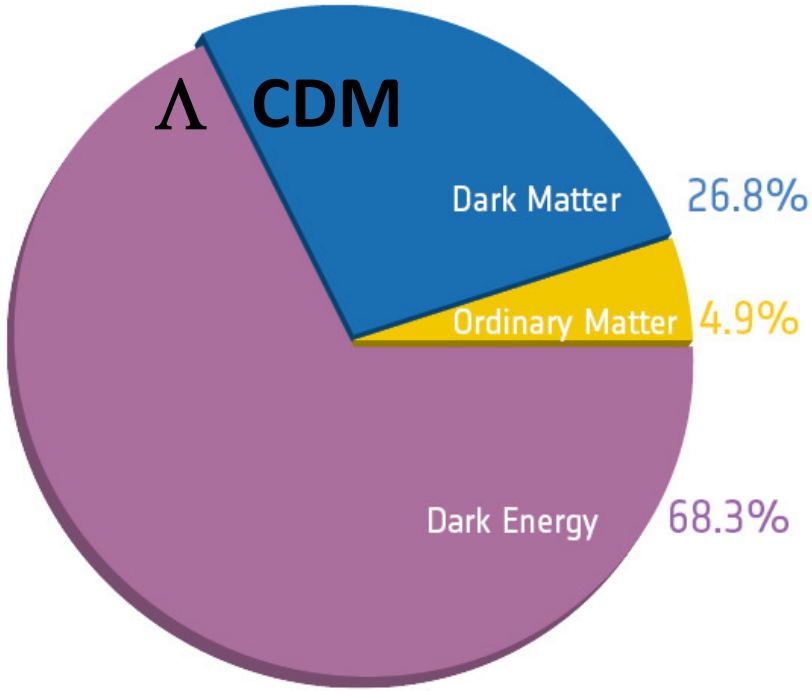
- Inflationary ΛCDM
  - ***impressively successful***

But

- **incomplete** theoretical foundation
- **anomalies and tensions** ⟹ cracks in the model?
- **fundamental questions** remain unanswered



1. ***Dark sector?***
2. ***Inflation?***
3. ***Gravitation?***

Are we done?

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Centre Pierre Binétruy

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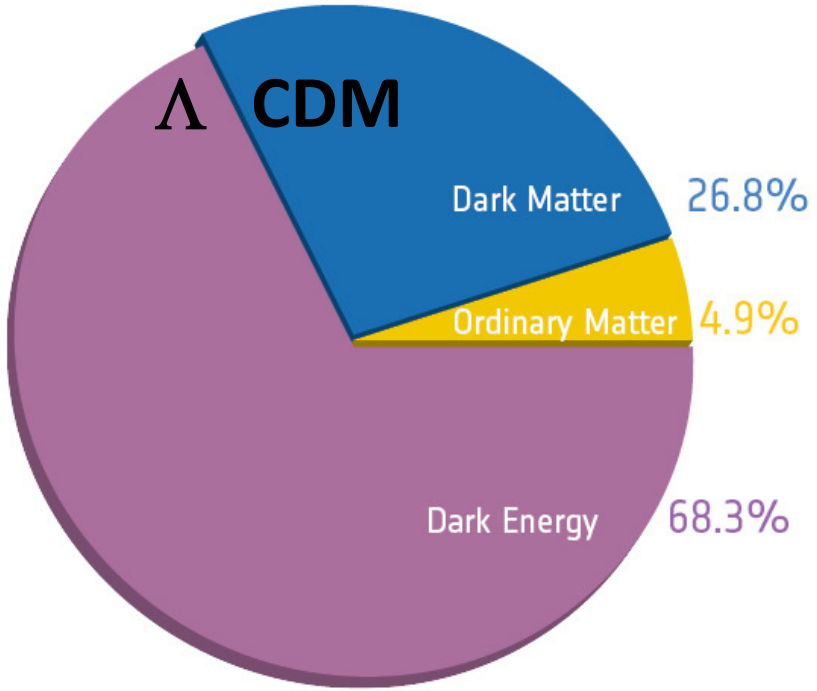

1. ***Dark sector?***
2. ***Inflation?***
3. ***Gravitation?***

The distribution of matter and energy across space, time and scales encodes answers to these questions

Map the entire observable Universe in the microwave

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CMB fluctuations
at z≈1000

Atoms, molecules, dust
in the Hubble volume

CMB spectrum
0 < z < 2,000,000

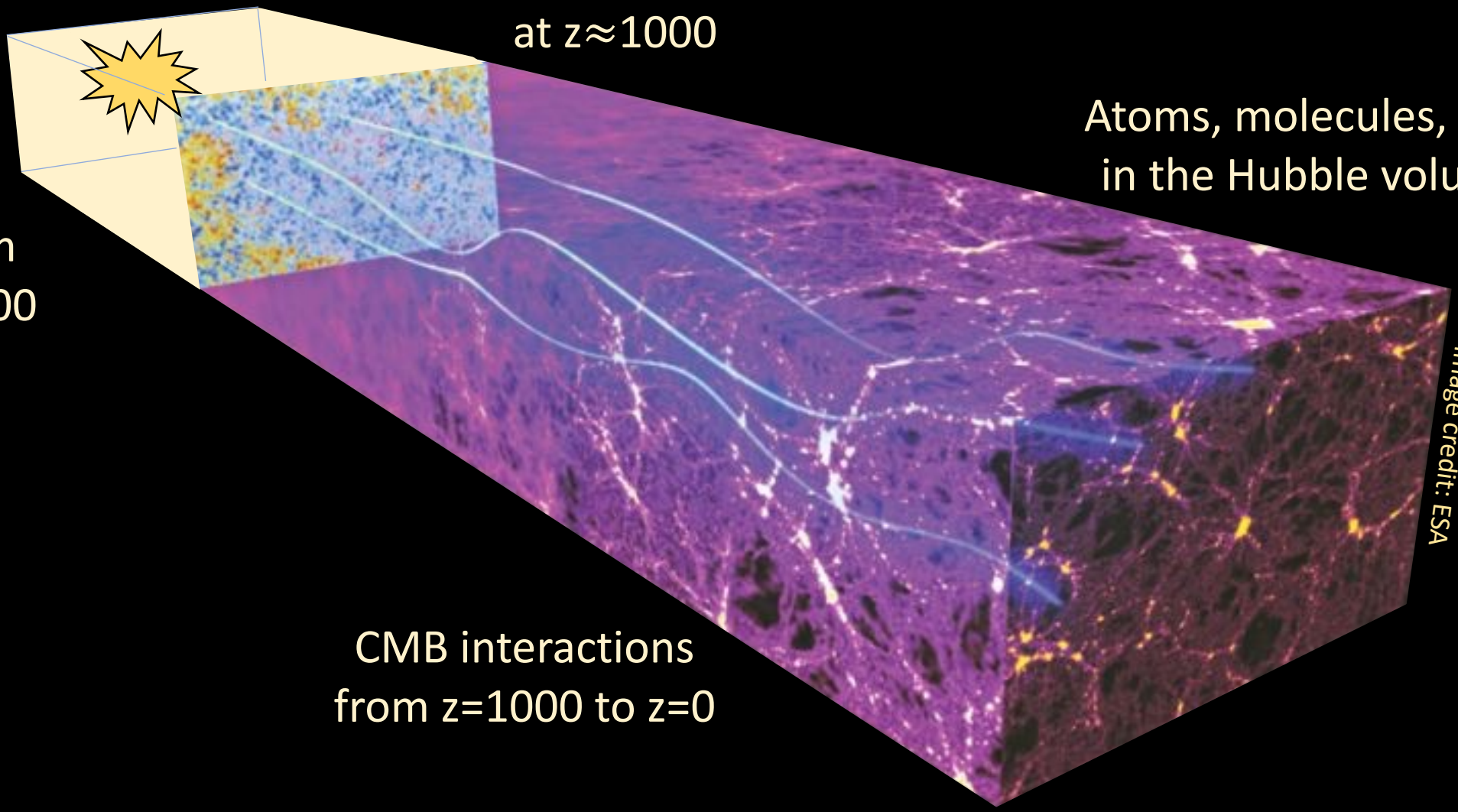

Image credit: ESA

CMB interactions
from z=1000 to z=0

Why microwaves ?

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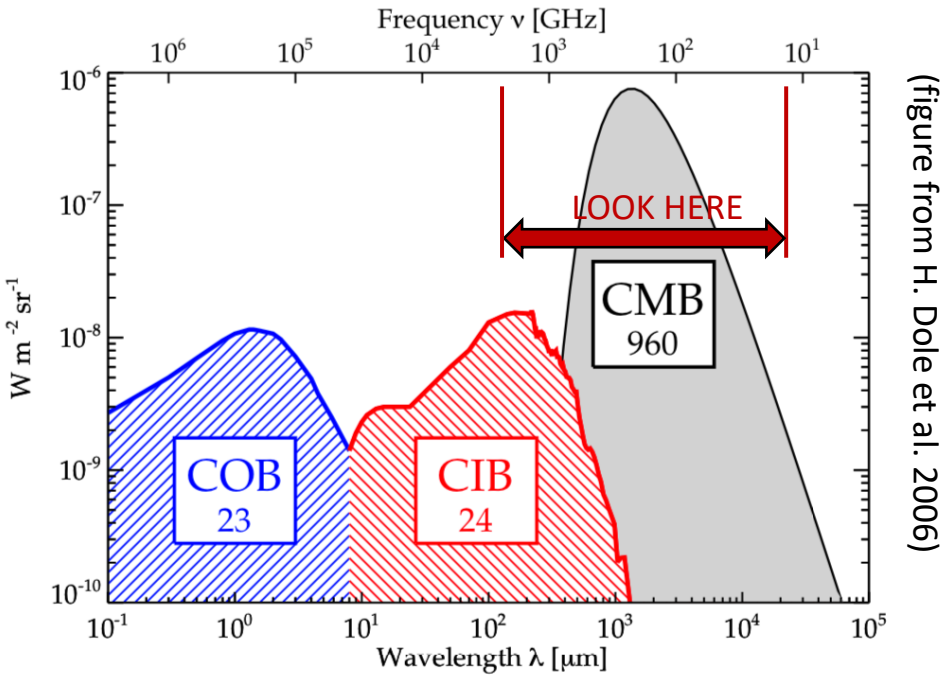
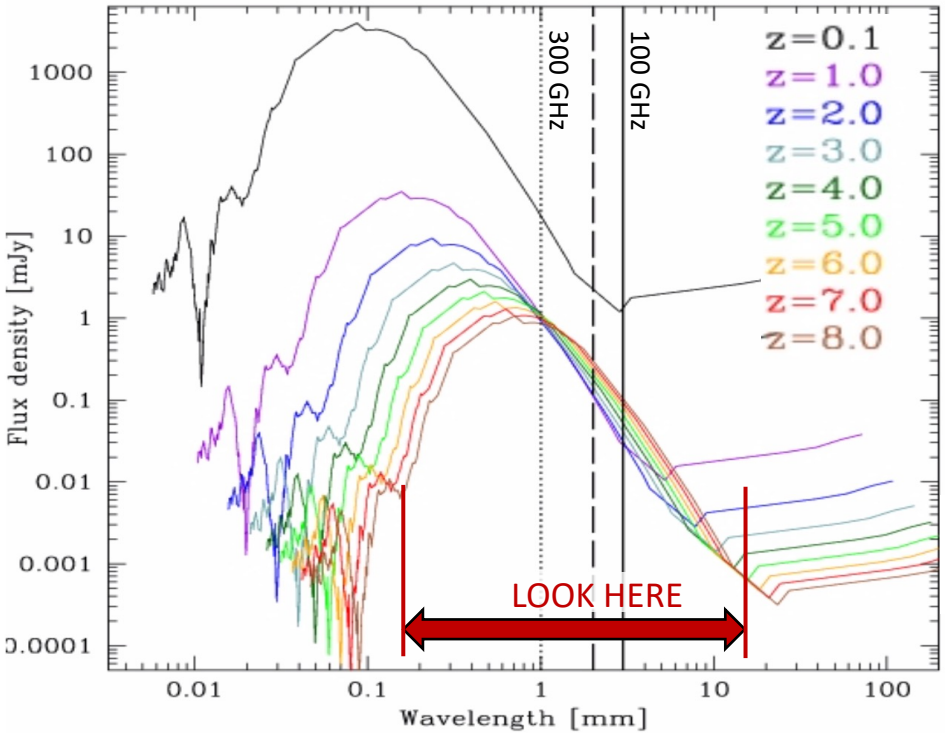
1- Most of the radiation in the Universe is in the microwaves!



(figure from H. Dole et al. 2006)

2- The most distant objects emit in the microwaves



(figure from R. Decarli website)

Three paths in microwave observations

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- Broad-band polarized imaging
  15-20 bands → *CMB anisotropies (inflation? ΛCDM?)*
- Absolute spectroscopy
  R ≈ 20+ (≈ 100 frequency bands) → *CMB spectrum (energy exchange?)*
- Moderate resolution spectroscopy
  R ≈ 500-1000 → *Atoms and molecules (3D structure tomography)*

Most useful frequency range
≈ 20-2000 GHz

Broad-band polarized imaging: ΛCDM under scrutiny...

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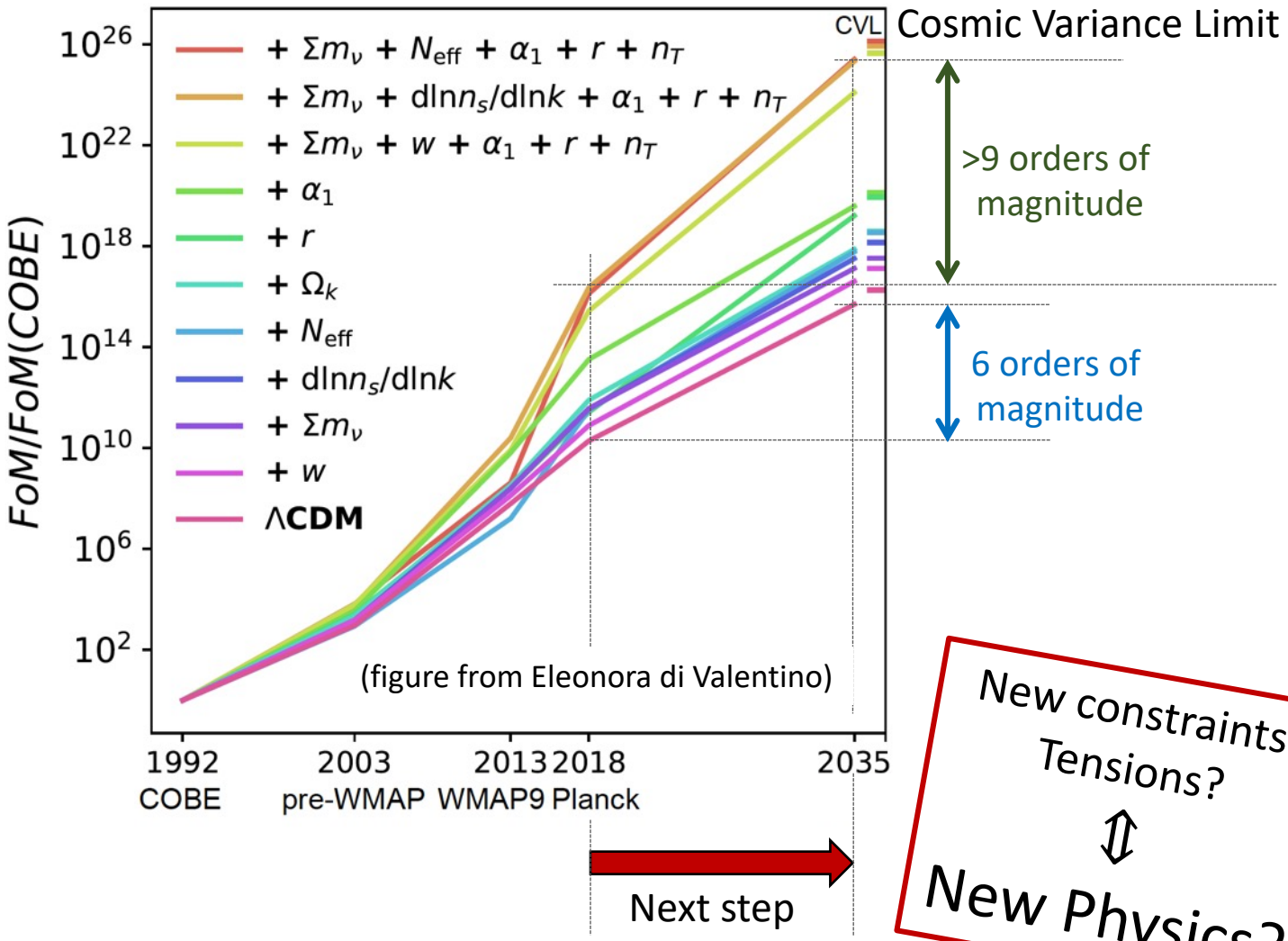
The ultimate CMB space mission

- ΔT & ΔP CMB sensitivity
  ≈ 10000 × Planck
  ≈ 10 × CMB-S4 (polarization)

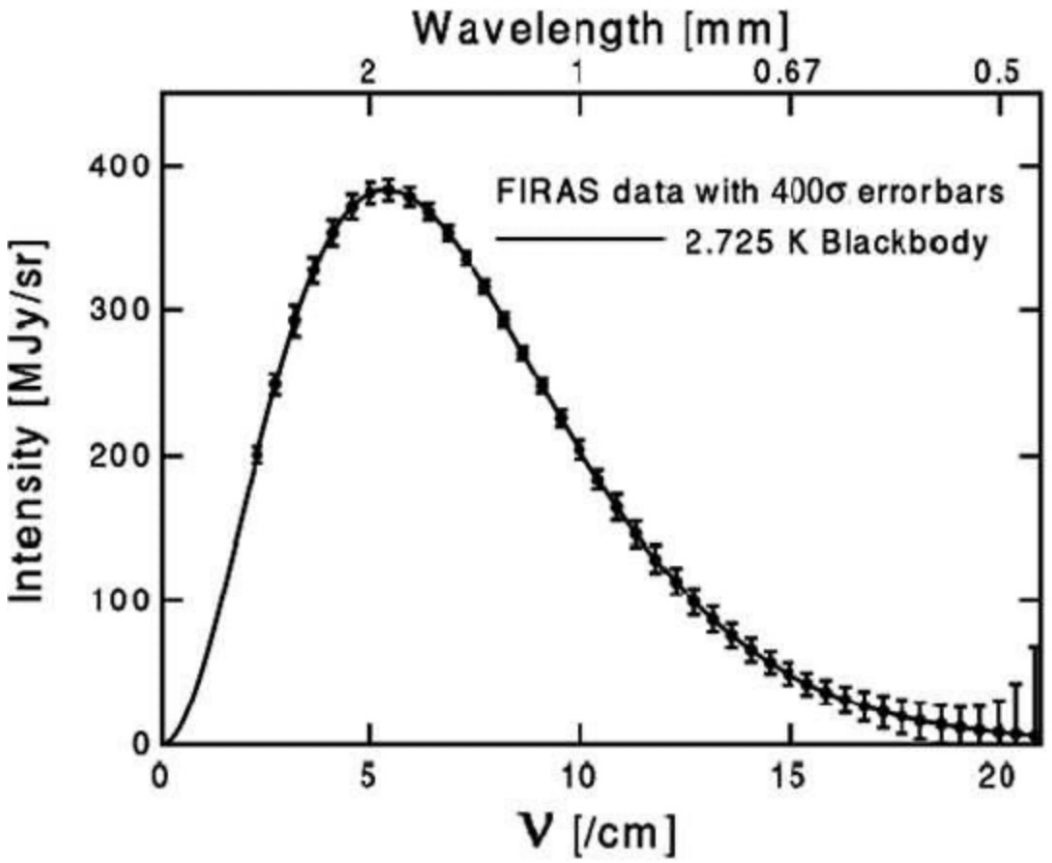
$$\left.\begin{aligned}\sigma(\Sigma m_\nu) &\sim 10^{-2}\\ \sigma(N_{\rm eff}) &\sim 0.016\end{aligned}\right\}\ \text{Neutrinos}$$

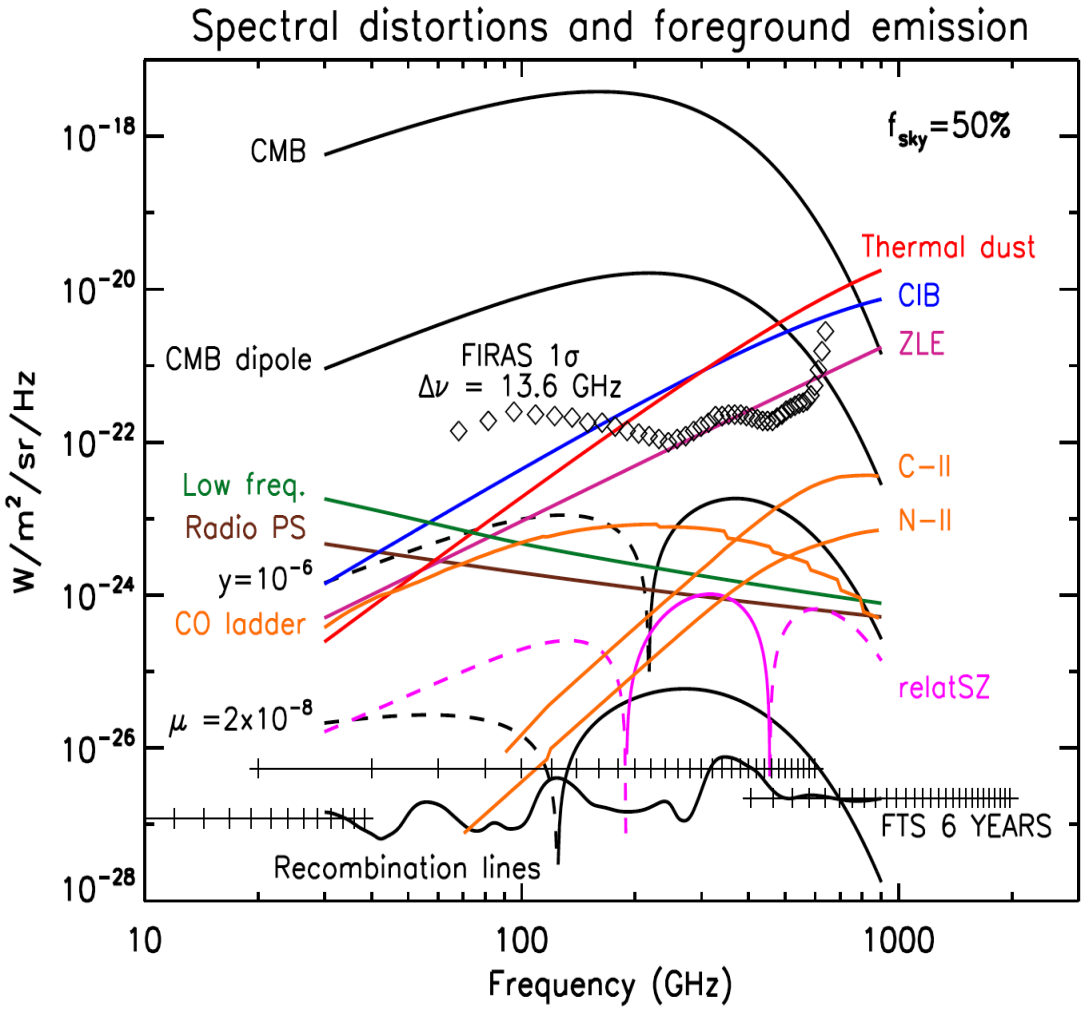
$$\left.\begin{aligned}\sigma(r) &\sim 10^{-4}\\ \sigma(n_s) &\sim 0.0015\end{aligned}\right\}\ \text{Inflation}$$



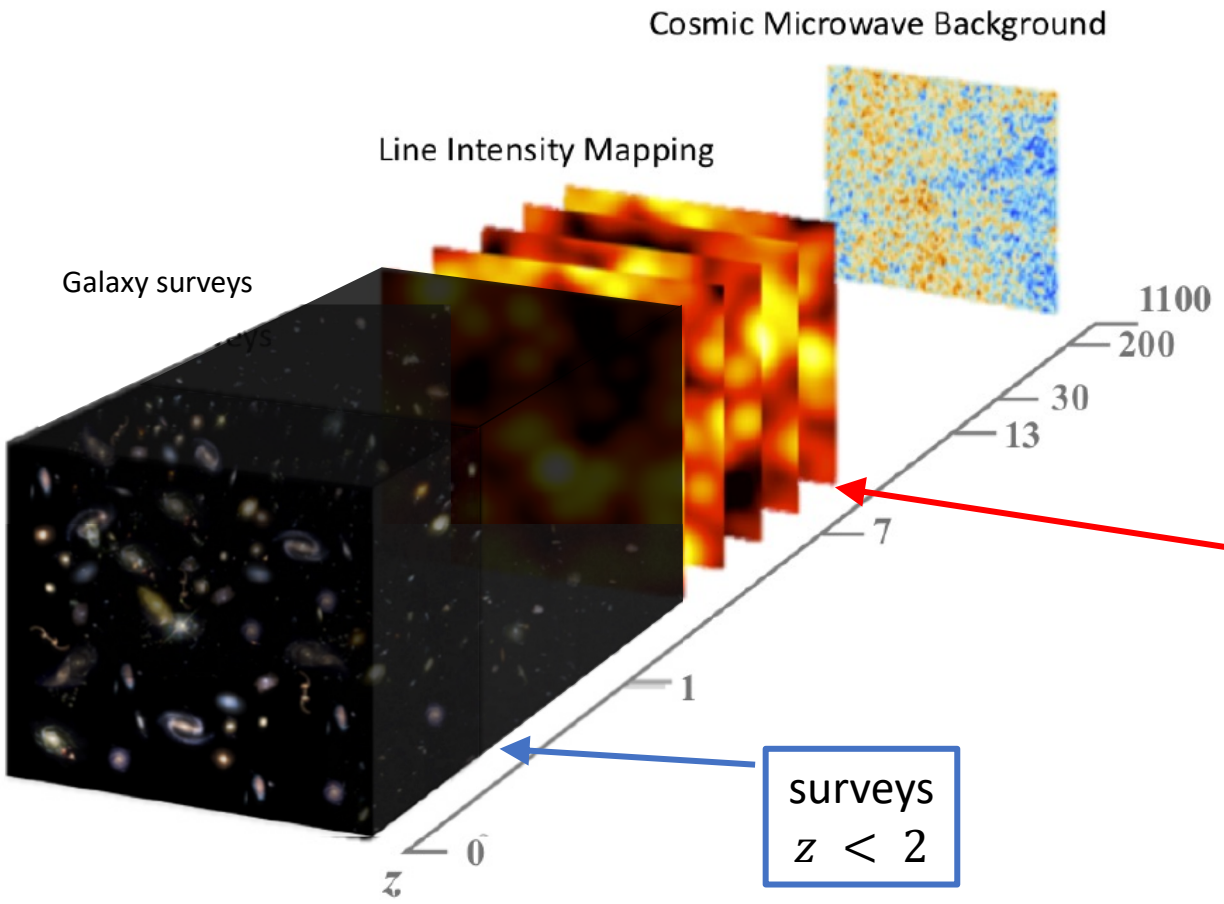
New constraints!
Tensions?
⇕
New Physics?

Absolute spectroscopy: Energy exchange with the CMB

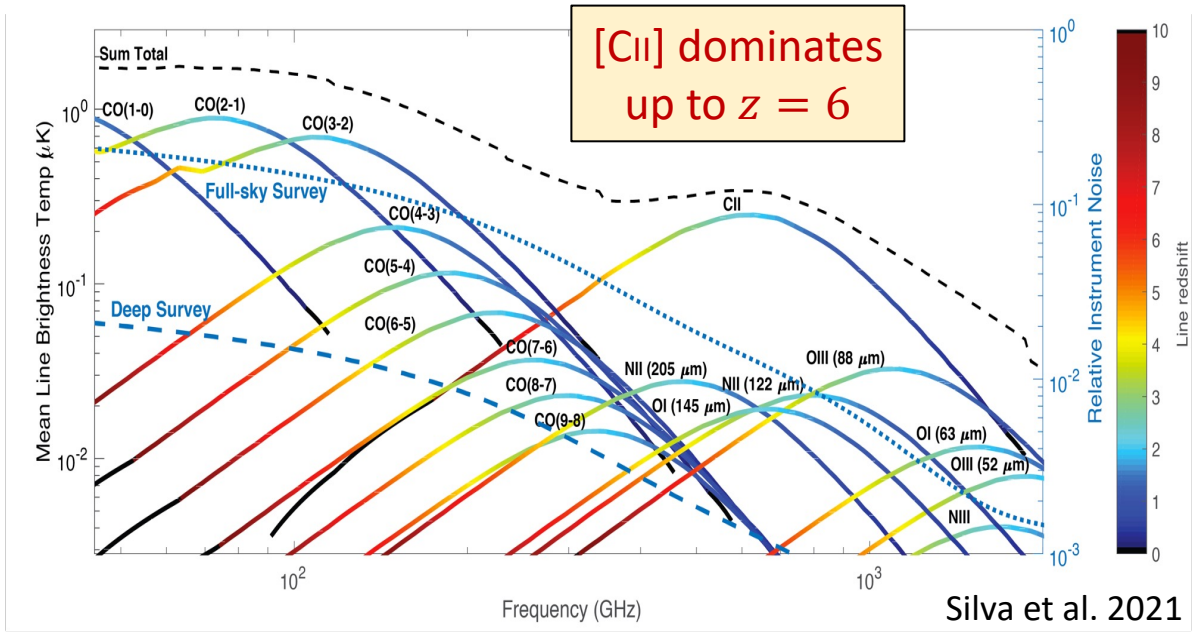




Moderate resolution spectroscopy: LIM



Kovetz et al., Astro 2020 white paper



Silva et al. 2021

Line Intensity Mapping: the high-redshift Universe in 3D

European proposals: CORE and PRISM

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- **CORE (Cosmic ORigins Experiment)**
  - The "ultimate" M-class CMB space mission
  - Submitted several times at ESA (M3: 2011; M4: 2015; M5: 2018)

No success, in spite of strong community and national agency support.

10 publications in a special issue of JCAP: JCAP Volume 2018, Number 4

- **PRISM (Primordial Radiation Imaging and Spectroscopy Mission)**
  - More capable than CORE: larger dish, imaging + spectroscopy
  - Submitted as an L-class ESA mission (L2-L3: 2013)

Made it to the top-5, but lost competition to LISA and Athena.

PRISM white paper, André et al., JCAP, 2014 (arXiv:1310.2554)

Voyage 2050: Four coordinated science topics

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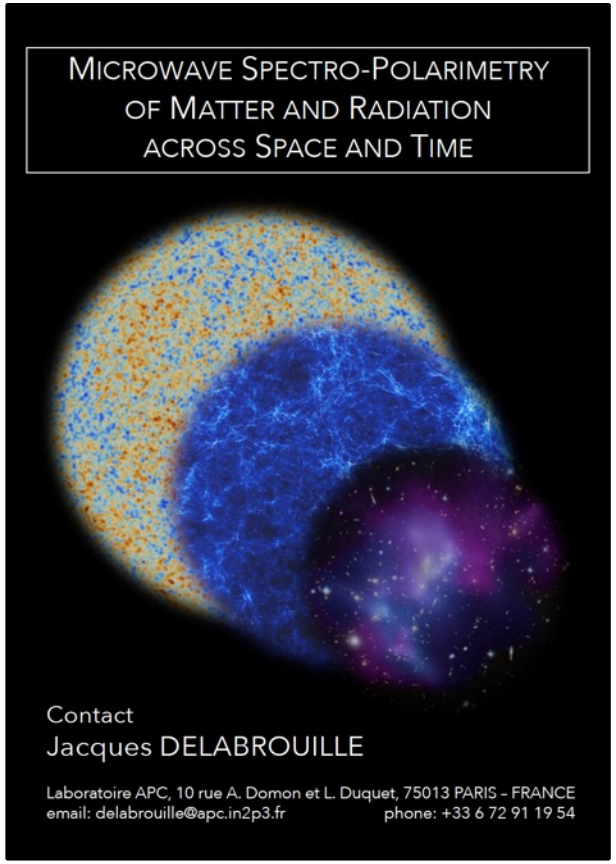
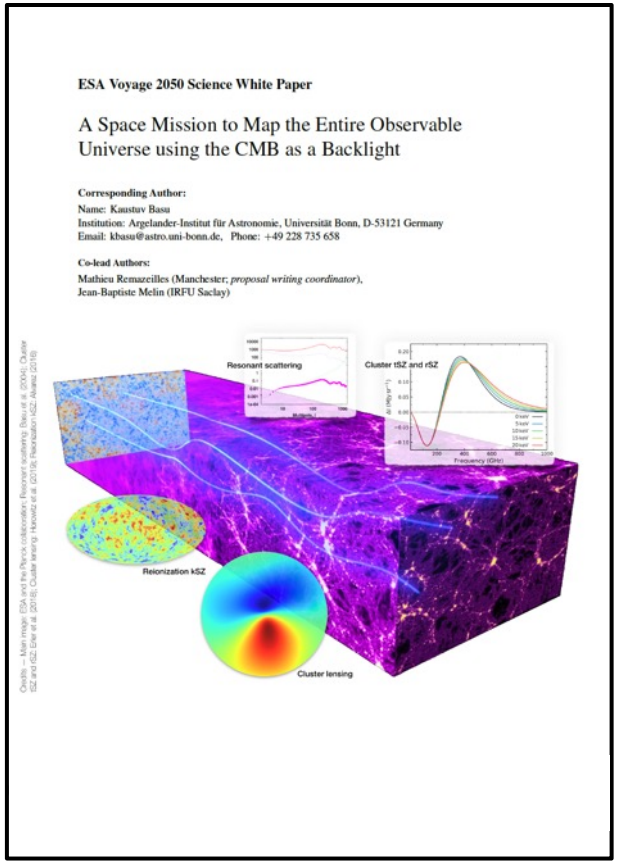
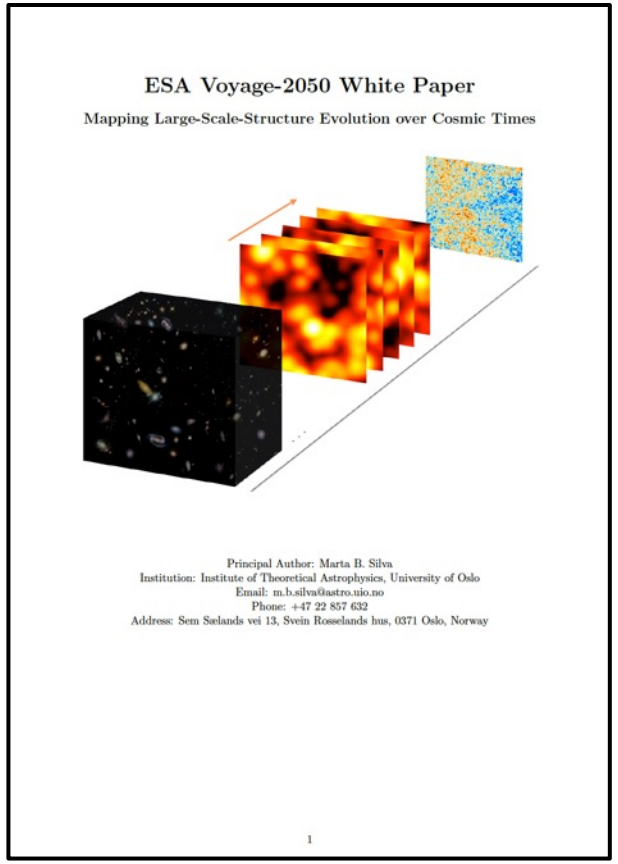


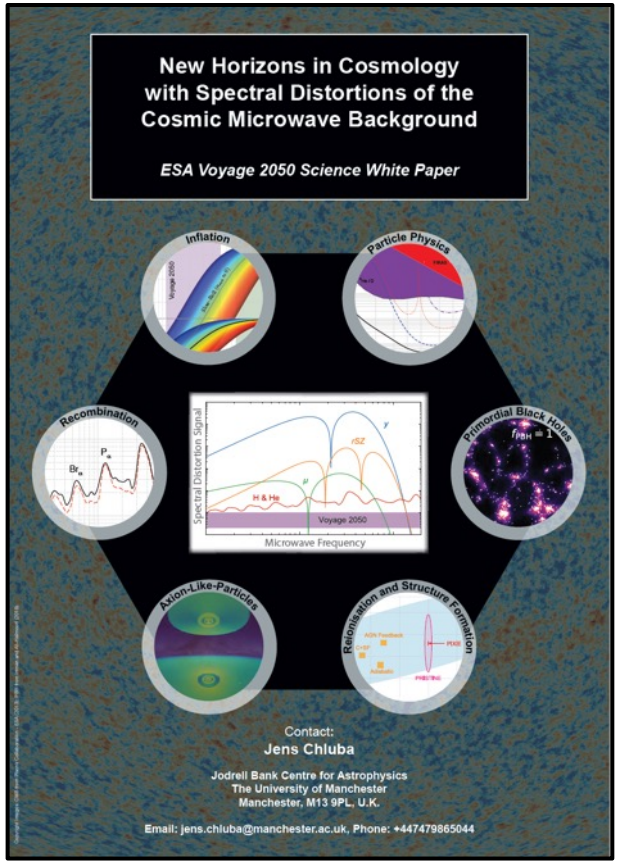
Microwave survey
Jacques Delabrouille et al.



CMB Backlight
Kaustuv Basu et al.

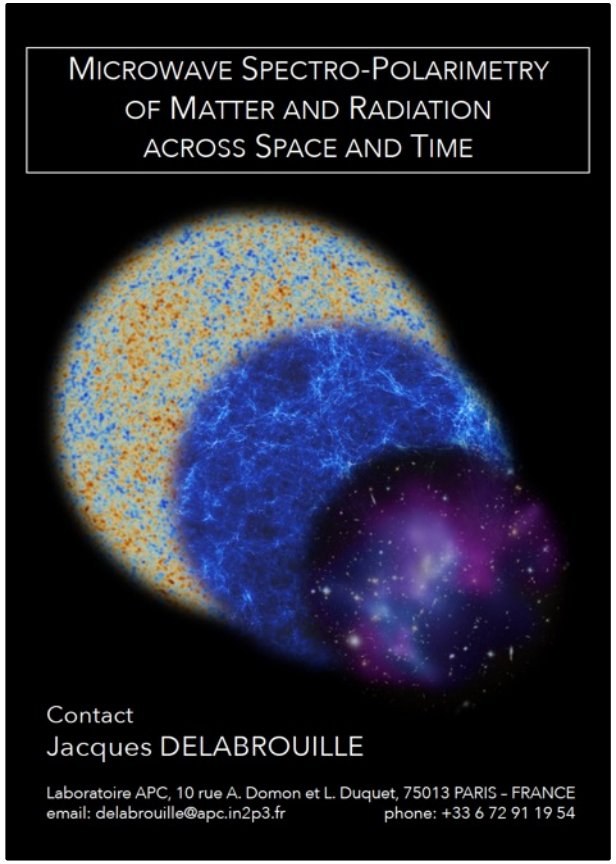


High redshift structures
Marta Silva et al.



Spectral distortions
Jens Chluba et al.

Voyage 2050: Four coordinated science topics



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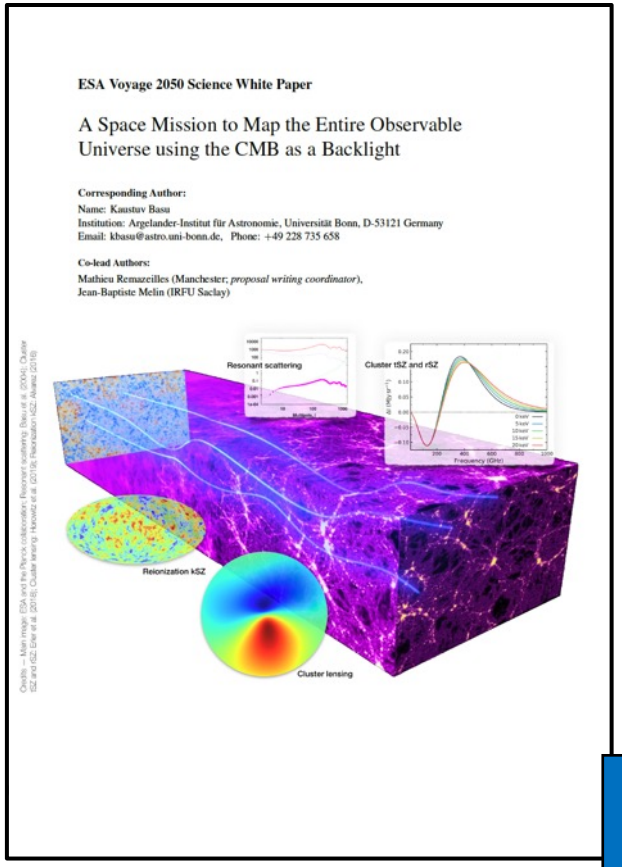

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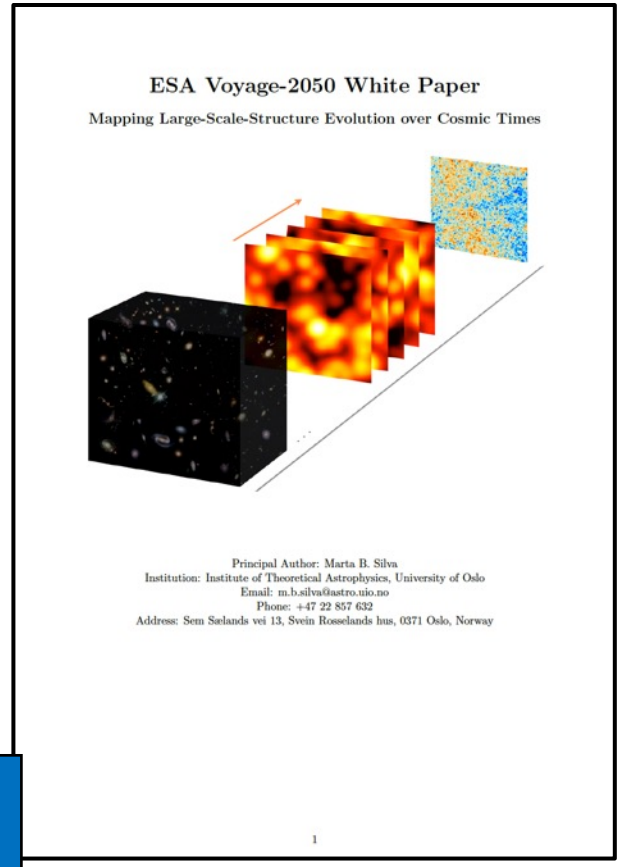

High redshift structures
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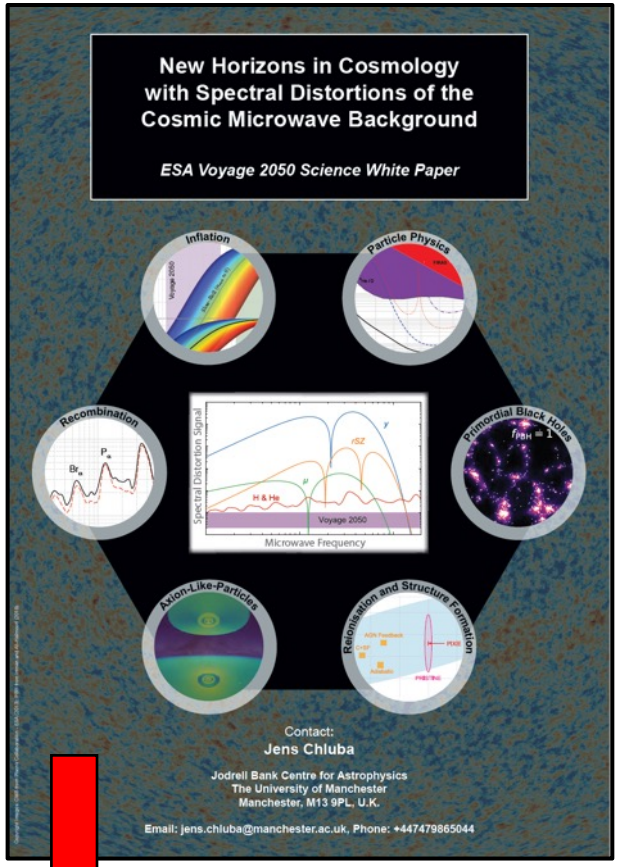

Spectral distortions
Jens Chluba et al.

Potential science themes for an M-CLASS MISSION

Candidate for an L-CLASS MISSION

Why from space ?

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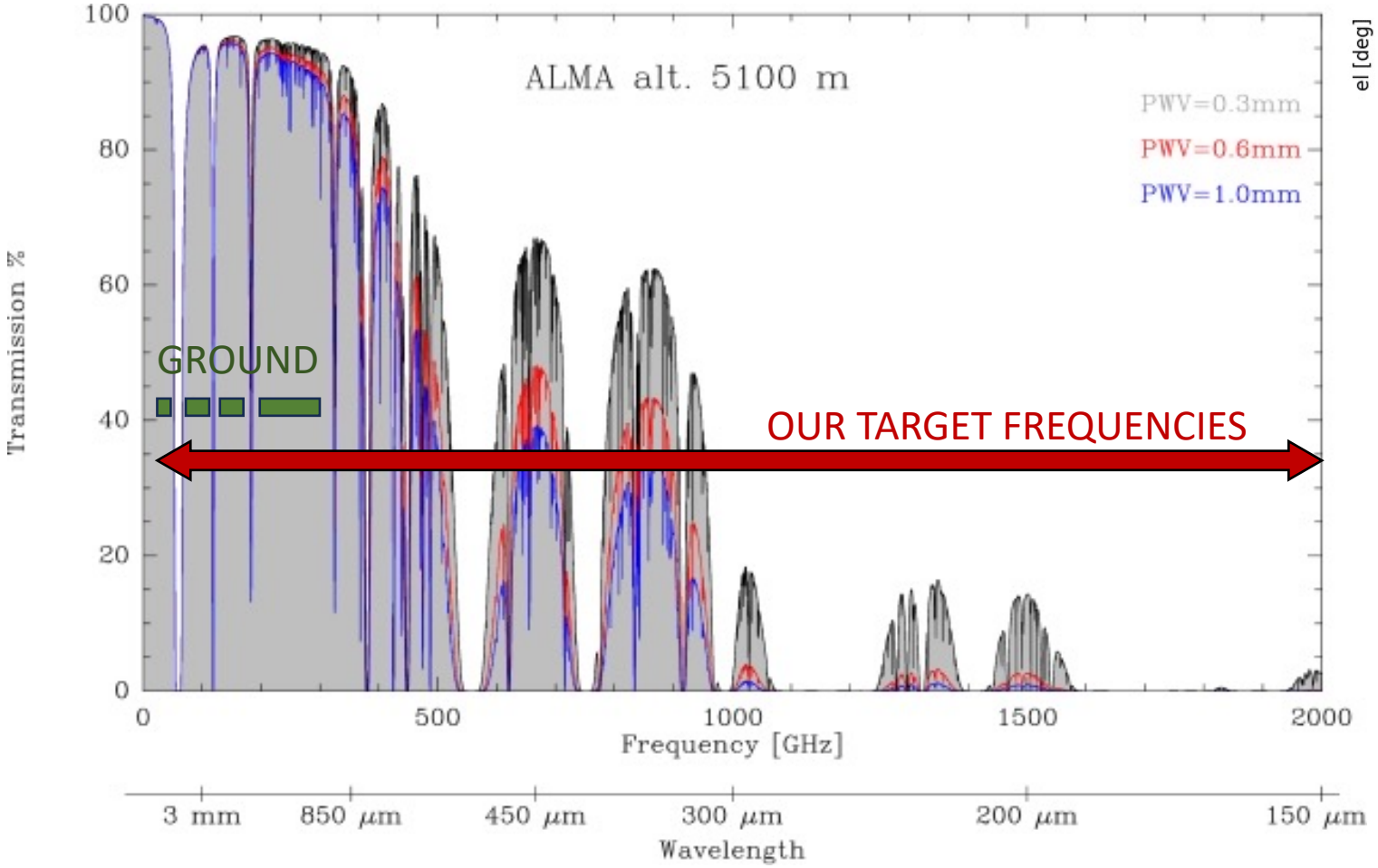
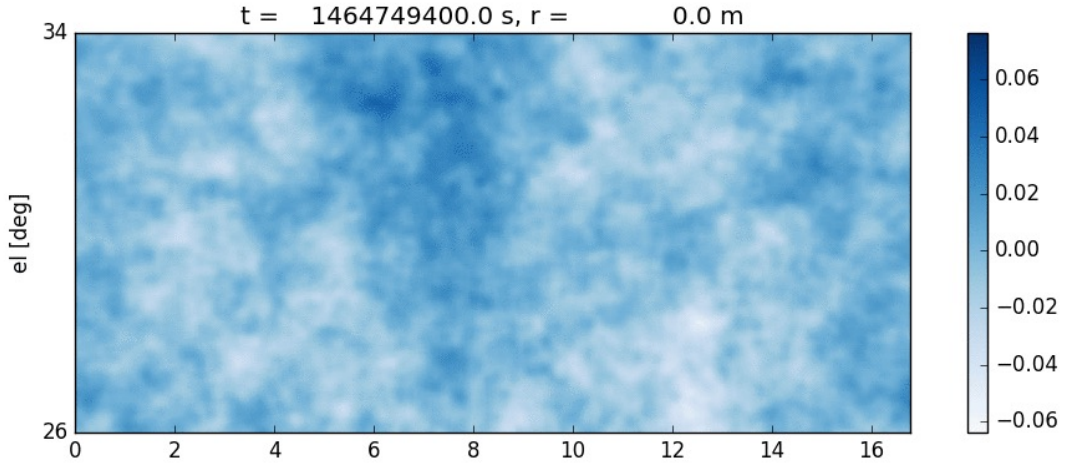
Chile (Atacama)





Simulation Reijo Keskitalo / LBNL C3-CMB

Atmospheric
Transmission and Emission !

1 detector in space
=
100-1000+ ground-based detectors

Summary

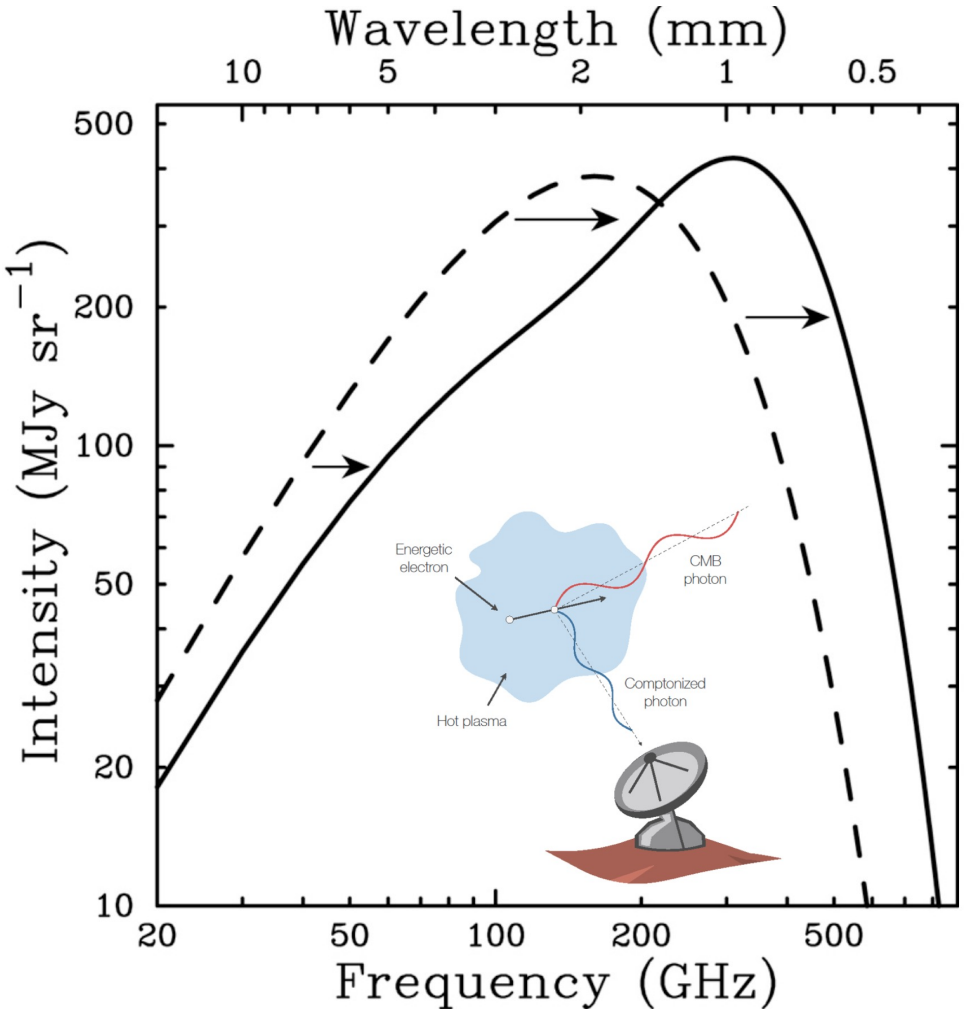
- **Very rich science case for microwave polarimetric spectro-imaging**
  - From space for full science return
  - Ultimate CMB science
  - Unique opportunity to explore the universe on the largest scales

- **An option at ESA for a future L-Class mission**
  - Prepare for a CMB spectroscopy L-class mission bid in 2030-2040
  - TRL increase is key: balloons, other missions
  - Science: build on upcoming ground-based observations (CMB-S4, CCAT/FYST)

- **In the US**
  - Prepare for a probe-class mission bid in the next decade

Thank you for your attention

Map the entire Universe using CMB as a backlight



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