Future Cosmic Microwave observations from Space: A European perspective

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Outline

- Context and overview
- Science case
  - Cosmology and fundamental physics from the CMB
  - The CMB as a backlight to probe the Hubble volume
  - Microwave observations of large scale structure
  - CMB spectral distortions
- Mission

The Context : ESA science in 2035-2050

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voyage 2050

esa

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

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

DOCUMENTATION

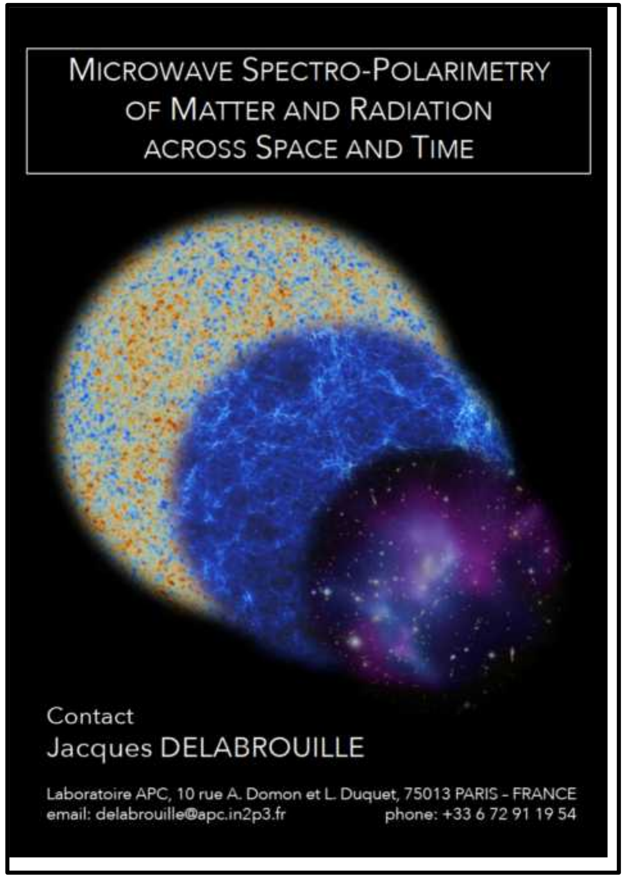
Letter of Invitation - White Papers (pdf)

Letter of Invitation - Topical Team membership (pdf)

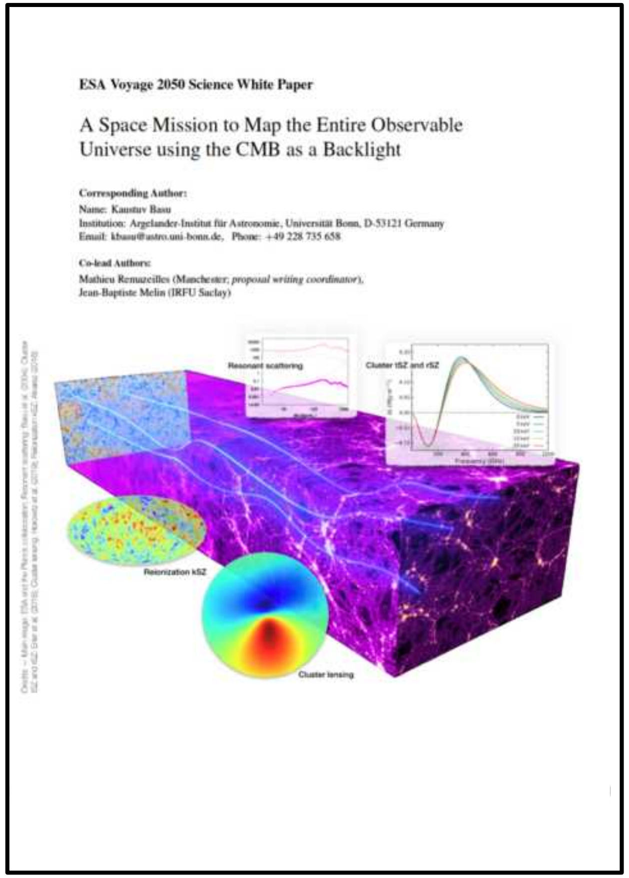
Call for White Papers (pdf)

Call for Membership of Topical Teams (pdf)

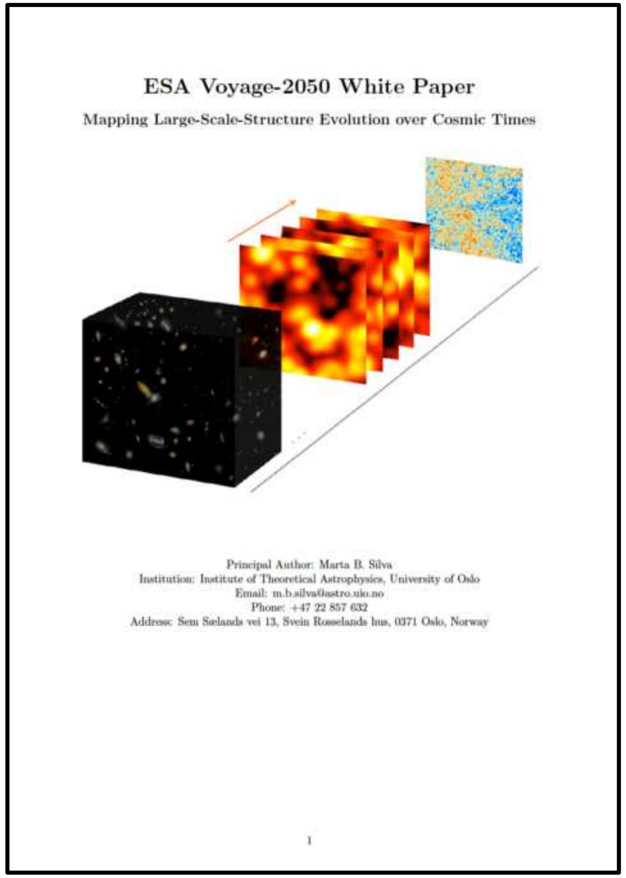
Four coordinated "CMB" white papers



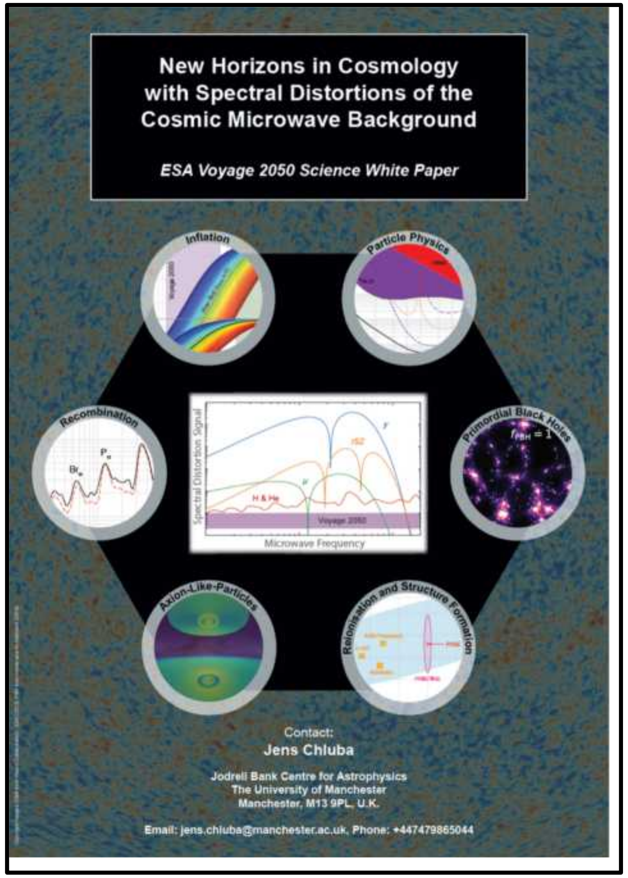
Microwave survey
Jacques Delabrouille et al.



CMB Backlight
Kaustuv Basu et al.



High redshift LSS
Marta Silva et al.



Spectral distortions
Jens Chluba et al.

Key Observables: microwave backgrounds

1- CMB polarization survey

- E and B-modes: Inflation (r, n_s, NG, ...)
- TEB on all scales: extend ΛCDM (FOM x 10^9)
- Lensing: Dark matter structures

2- SZ survey of ionised gas

- Galaxy cluster counts: extend ΛCDM
- Cosmic web, galaxies and clusters
- Velocity flows: gravitation

3- CIB and line intensity mapping

- Map structures across redshift
- First objects: stars, galaxies, clusters

4- CMB spectral distortions

- Inflation (n_s, ...)
- Reionization, Clusters (diffuse gas)
- Dark Matter interactions or decay
- Recombination lines

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Finelli, Lesgourgues, Di Valentino, ...

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Basu, Melin, Remazeilles, ...

Silva, Kovetz, ... Dannerbauer, De Zotti, ...

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Chluba, ...

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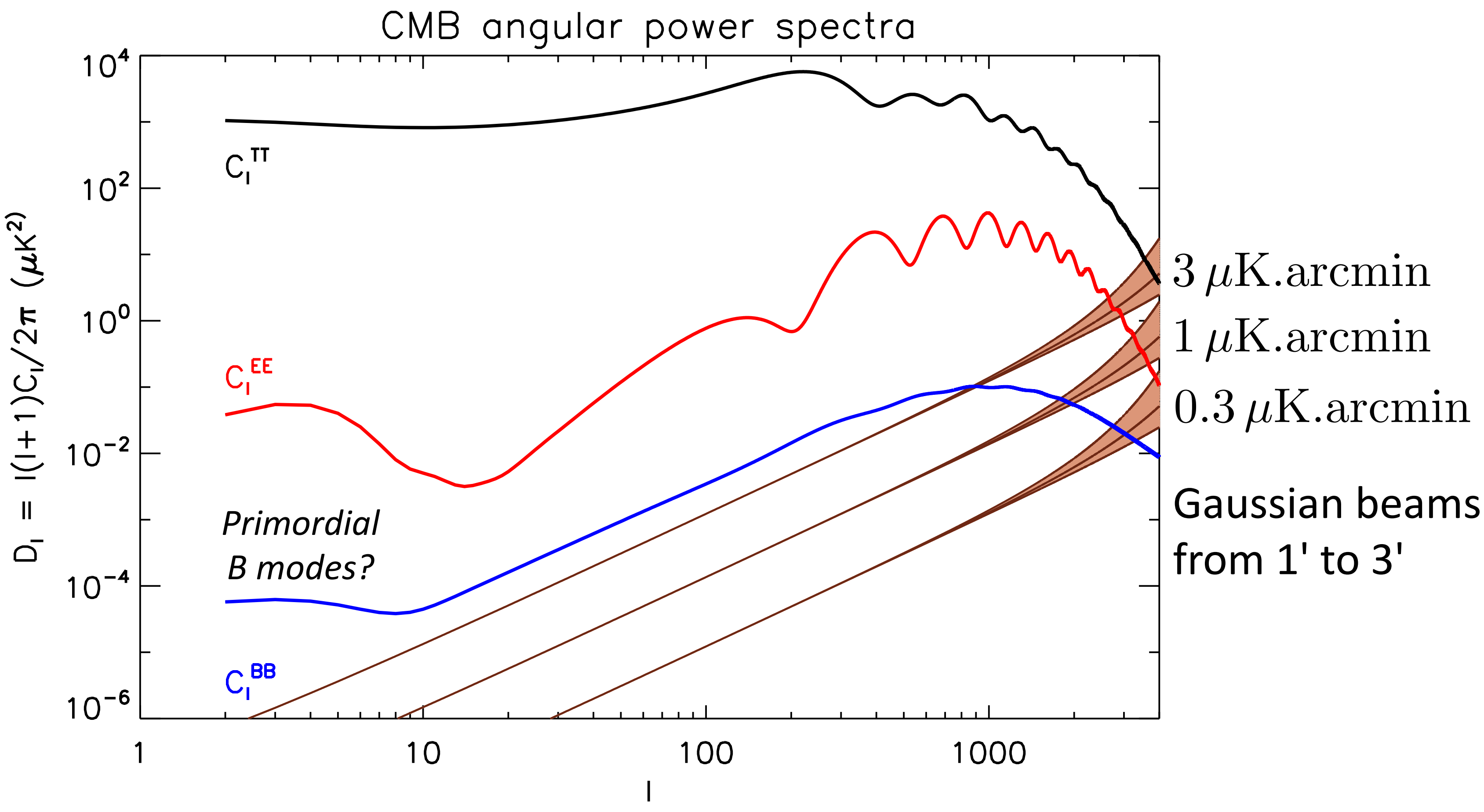
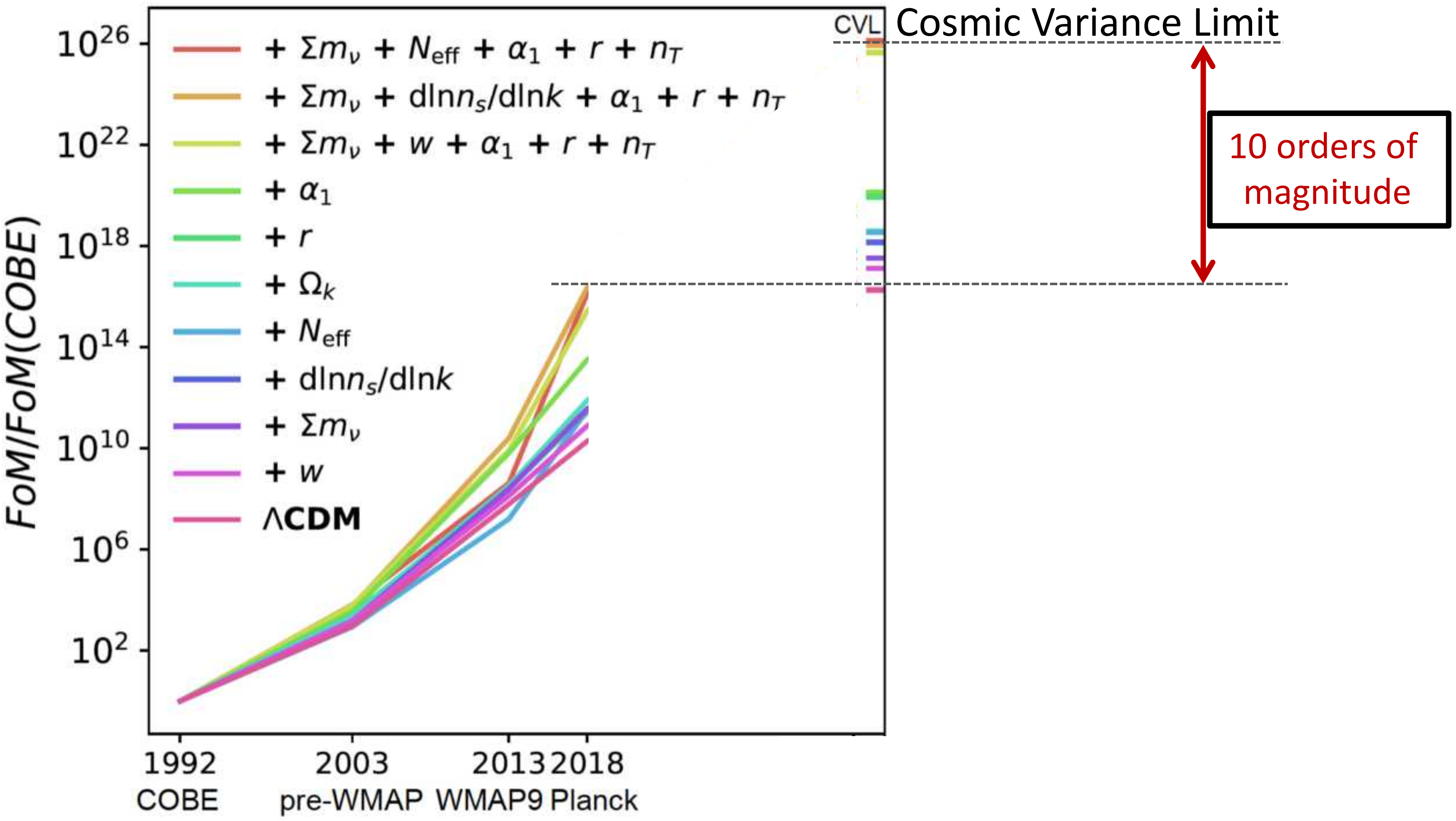
CMB Spectra



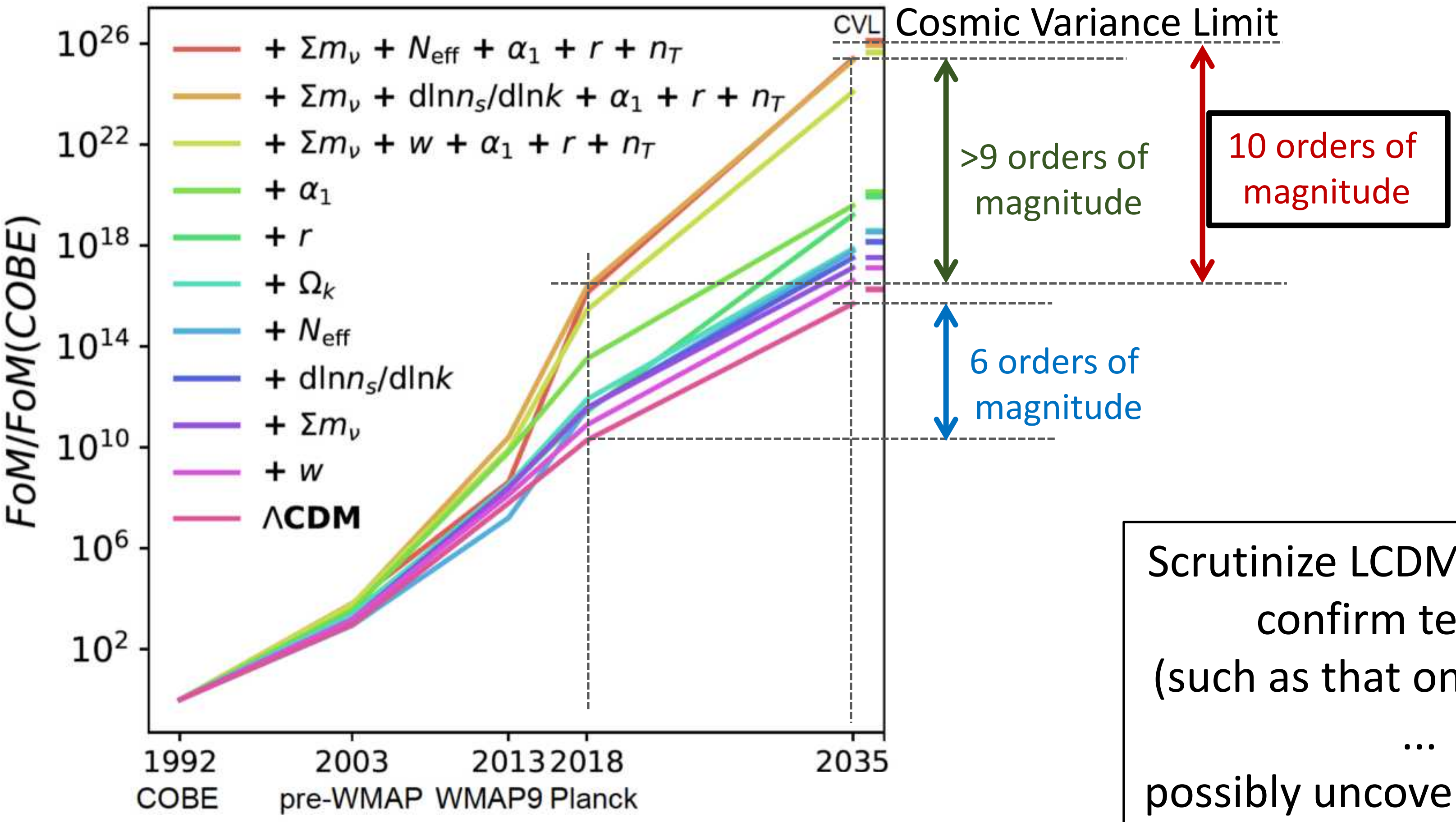
Gaussian beams from 1' to 3'

Constraints on extended ΛCDM



Delabrouille et al., Voyage 2050 White Paper

Constraints on extended ΛCDM



Scrutinize LCDM to solve or confirm tensions (such as that on Hubble H_0)

...

possibly uncover new ones !

(figure from E. di Valentino)

Delabrouille et al., Voyage 2050 White Paper

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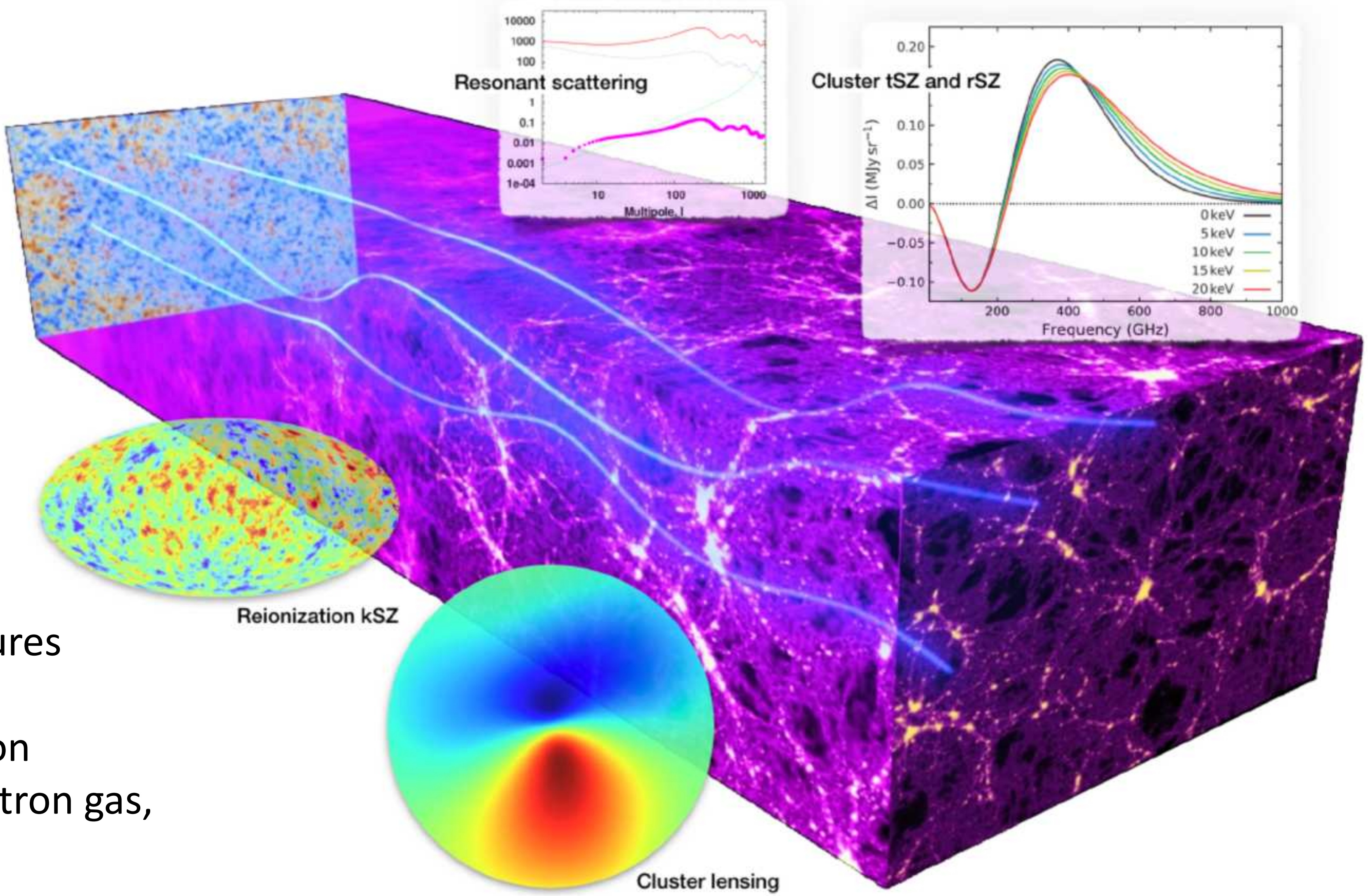
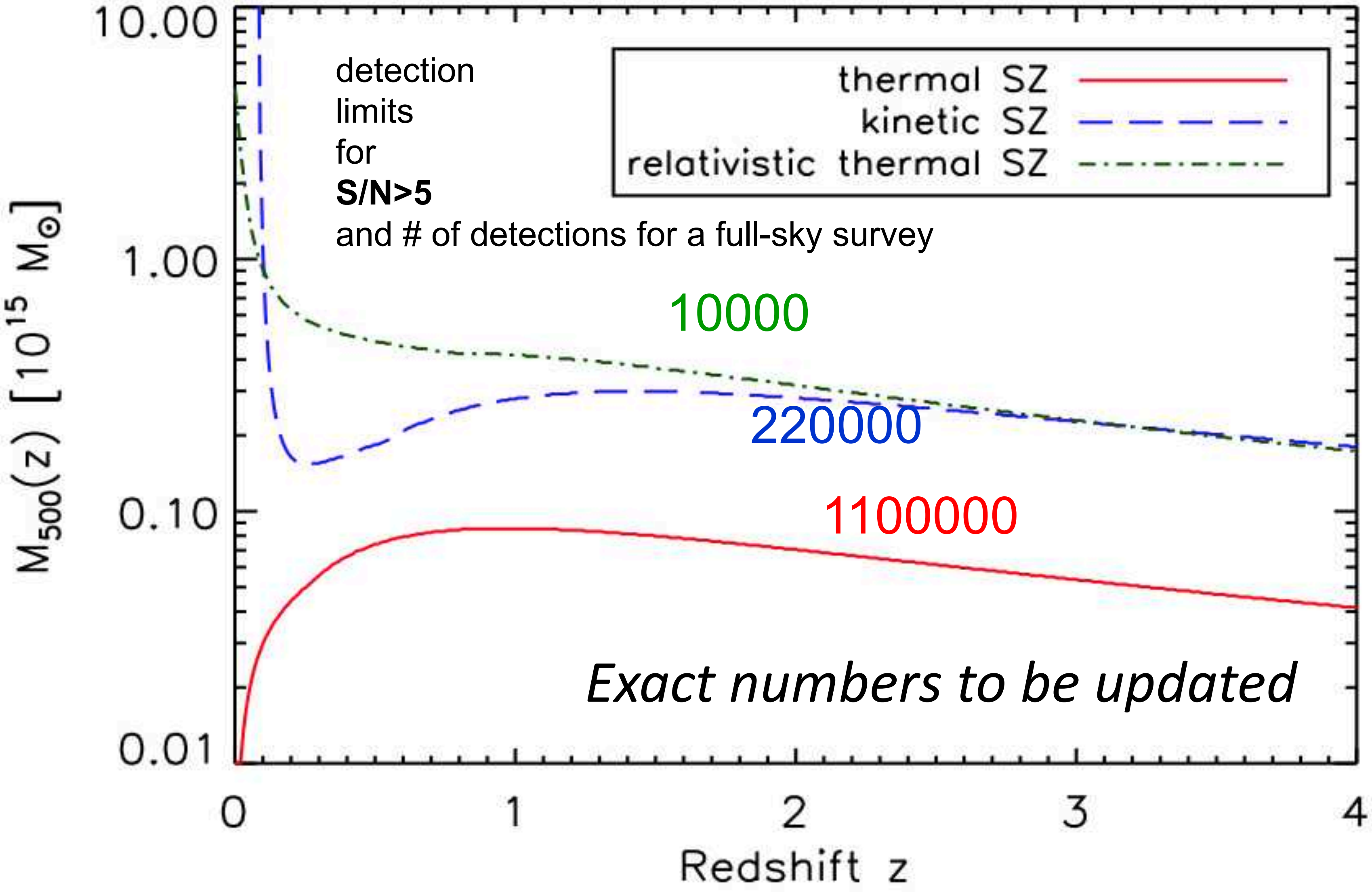
Backlight



The CMB is a backlight
that interacts with structures
in many different ways,
and probes the distribution
of mass, of atoms, of electron gas,
and of velocity flows
in the full Hubble volume.

Basu et al., Voyage 2050 White Paper

Cluster catalog and cluster counts (PRISM 2013)



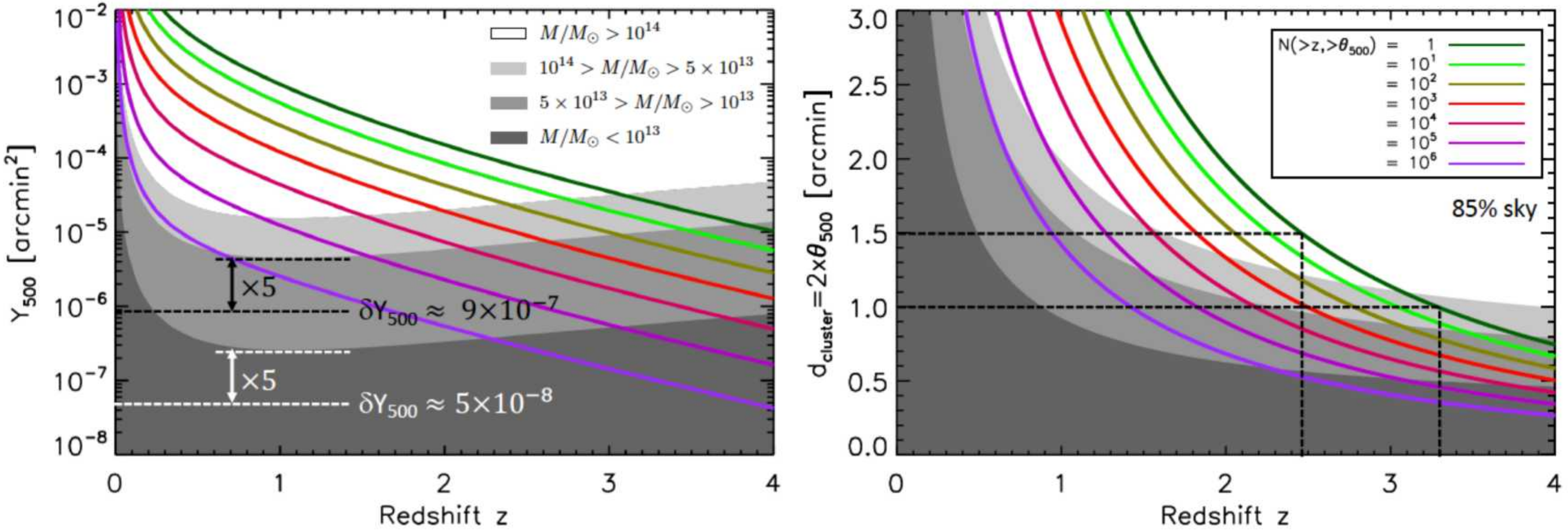
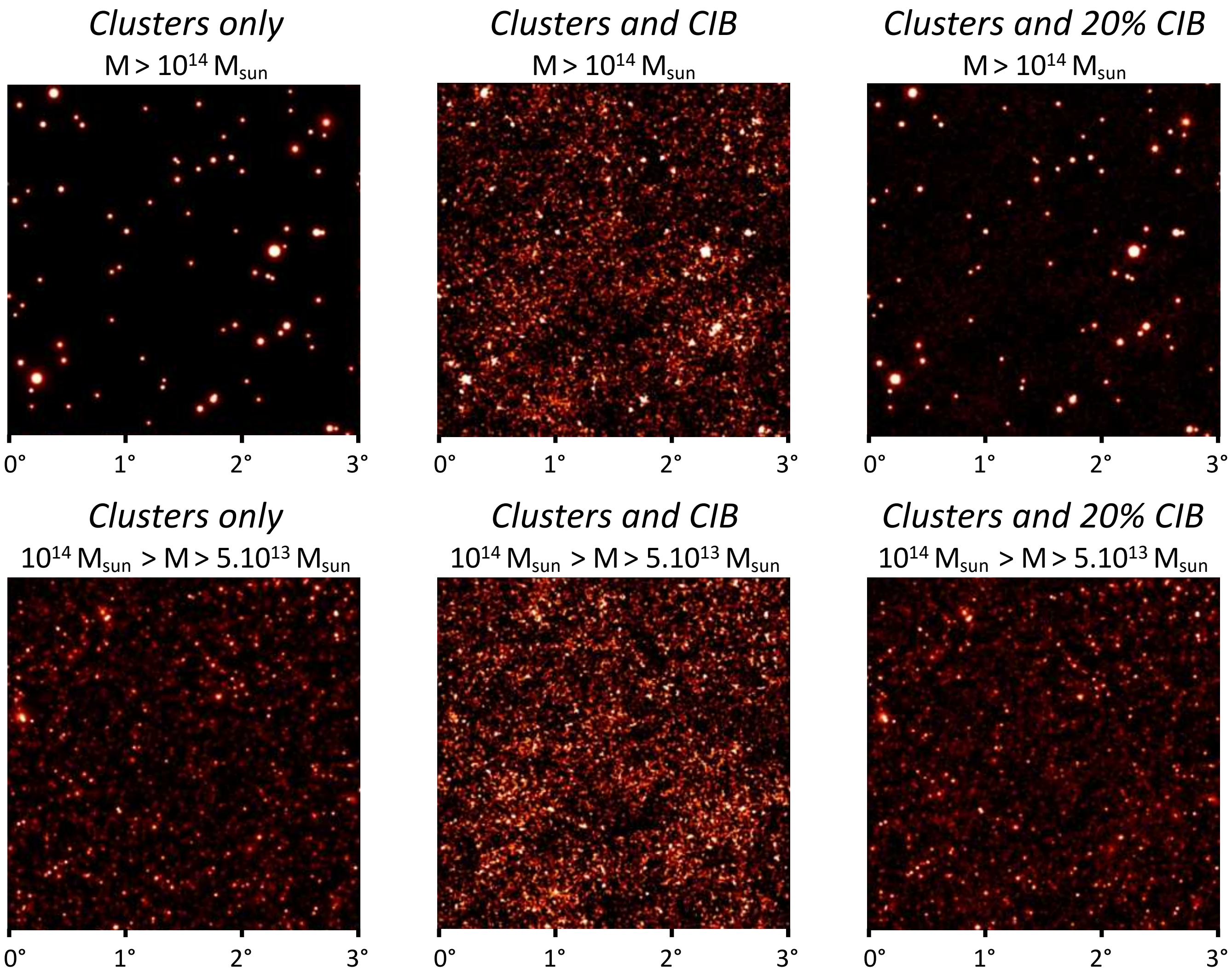


Figure 2: *Left*: Distribution of clusters for various mass ranges as a function of redshift and integrated Compton parameter (white and gray areas of various shades), modeled following the self-similar model of [22]. A survey with tSZ flux error $\delta Y_{500} \simeq 9 \times 10^{-7}$ would detect all clusters of mass $M > 5 \times 10^{13} M_\odot$ (about 1.5 million objects), while $\delta Y_{500} \simeq 5 \times 10^{-8}$ would be sufficient to even detect groups of $\simeq 10^{13} M_\odot$. Colored lines show, as a function of z and cluster-integrated Compton parameter Y_{500}, the expected number of clusters that have both larger tSZ signal, and are located at higher redshift. *Right*: Distribution of clusters as a function of redshift and angular size, with the same white and gray color code. All clusters of mass $M > 10^{14} M_\odot$ (white) have an angular size larger than $\simeq 1'$, and clusters $> 5 \times 10^{13} M_\odot$ (white and light gray) larger than $\simeq 0.8'$. Colored lines show, as a function of z and cluster angular diameter $d_{cluster}$, the expected number of clusters that have both larger angular diameter, and are located at higher z. Dashed lines show that the highest redshift clusters with angular sizes $1.5'$ are at $z \simeq 2.5$, and with size $1'$ at $z \simeq 3.3$.

SZ and CIB confusion (even at 150 GHz)



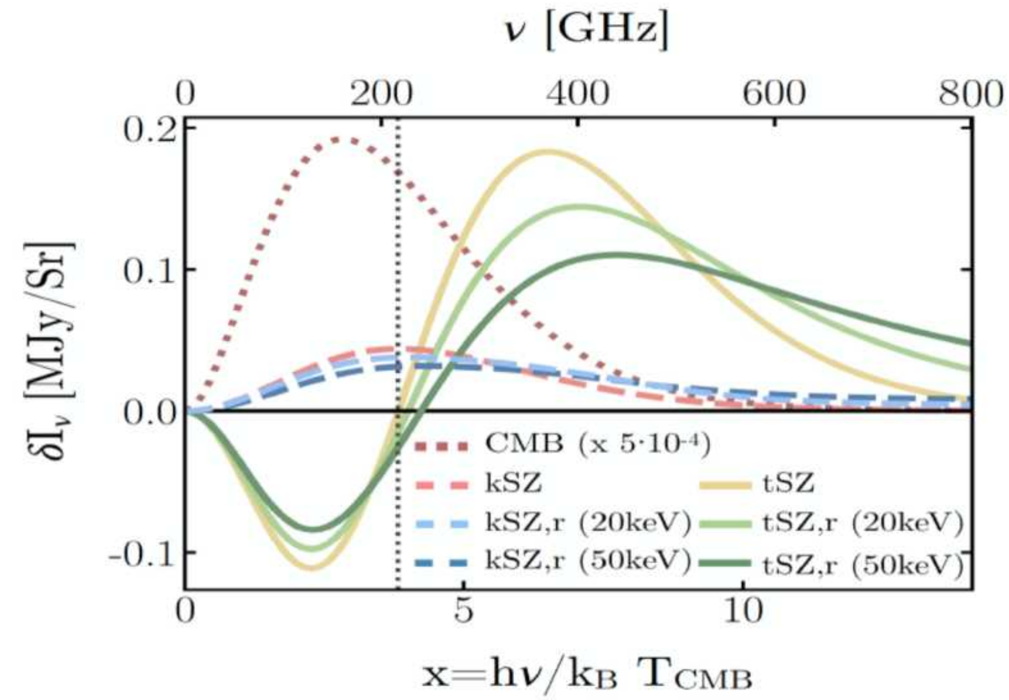
If one can reduce the level of CIB contamination to 20% of its original level at 150 GHz, thermal SZ emission dominates.

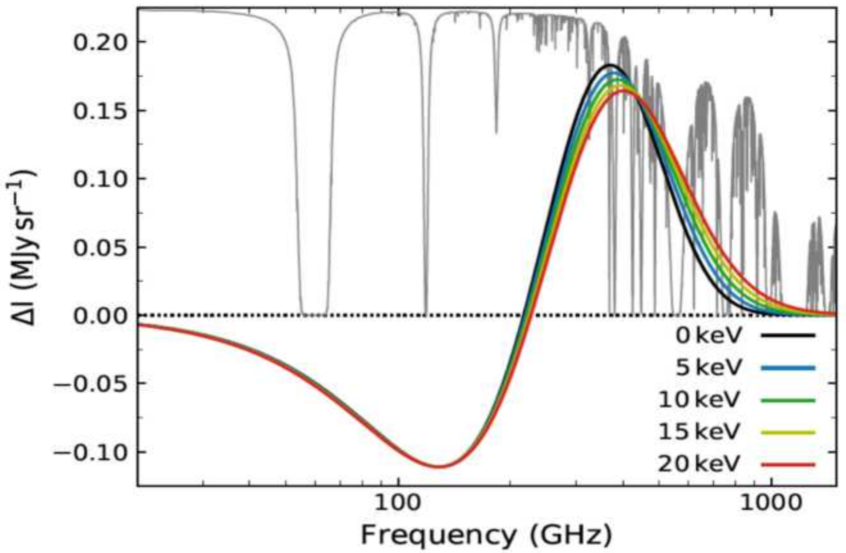
However, better decontamination will be required for kinematic SZ and for measuring relativistic corrections (cluster temperatures).

This requires channels above 300 GHz.

For a large sky parch, this can be realistically done only from space.

Cluster spectroscopy





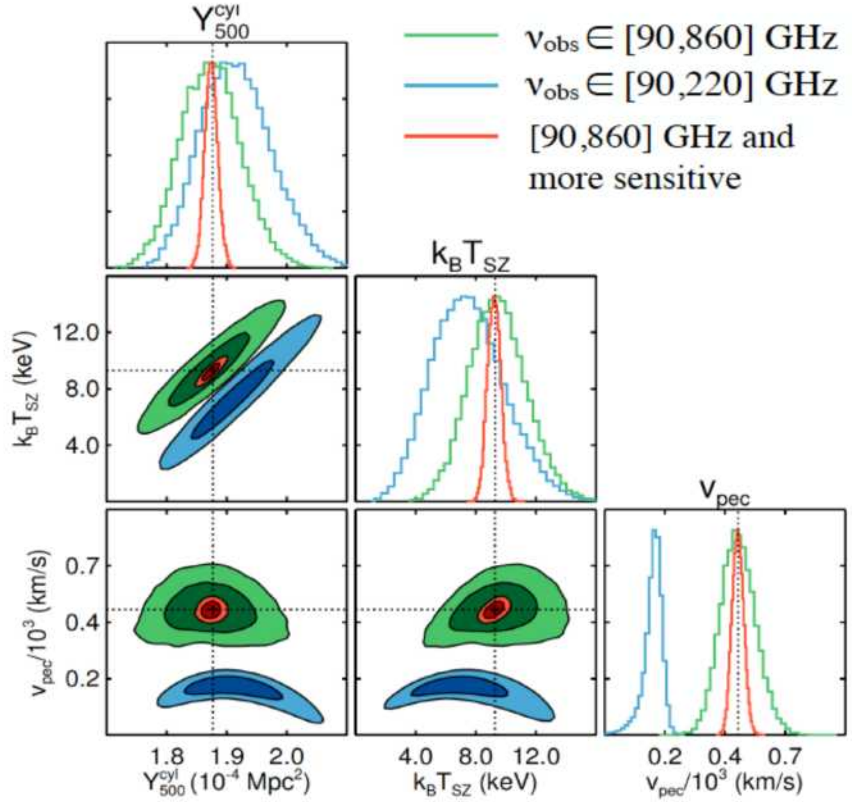
Basu et al., Astro2020 White Paper

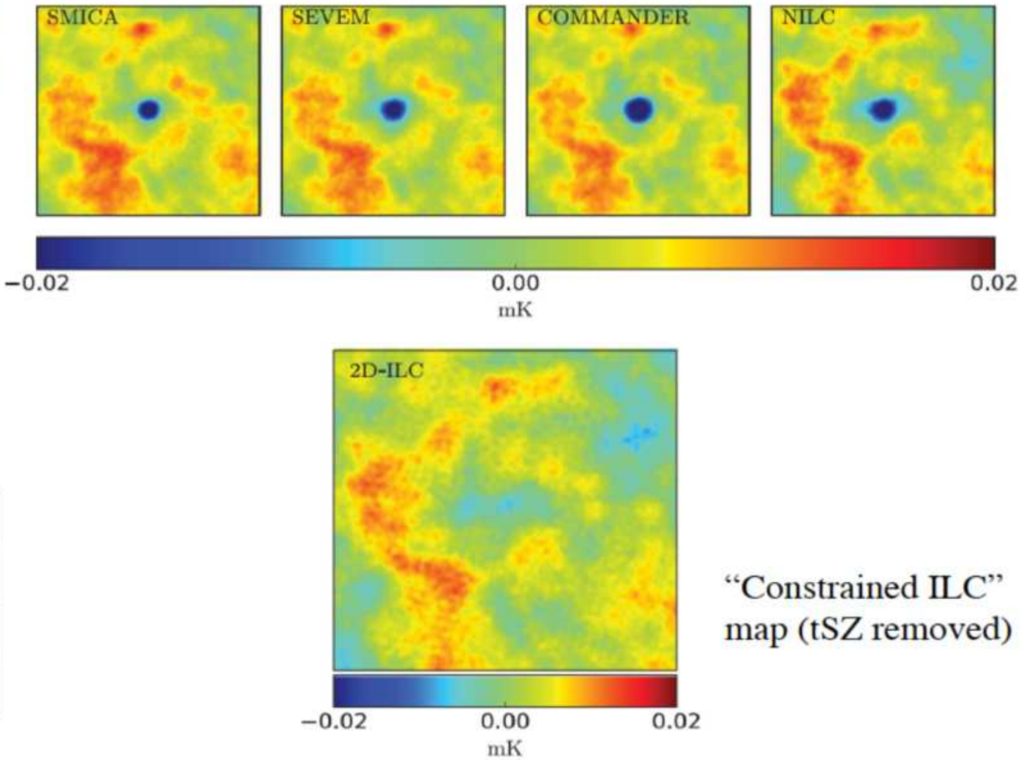
Basu et al., Voyage 2050 White Paper

A precise measurement of cluster spectra across frequencies allows to recover

- thermal SZ effect (gas pressure), non thermal SZ effect
- relativistic corrections (cluster temperature)
- kinematic SZ effect (cluster flows)
- contamination by radio and IR sources, early clusters in the FIR
- modeling uncertainties

Cluster spectroscopy: avoiding biases

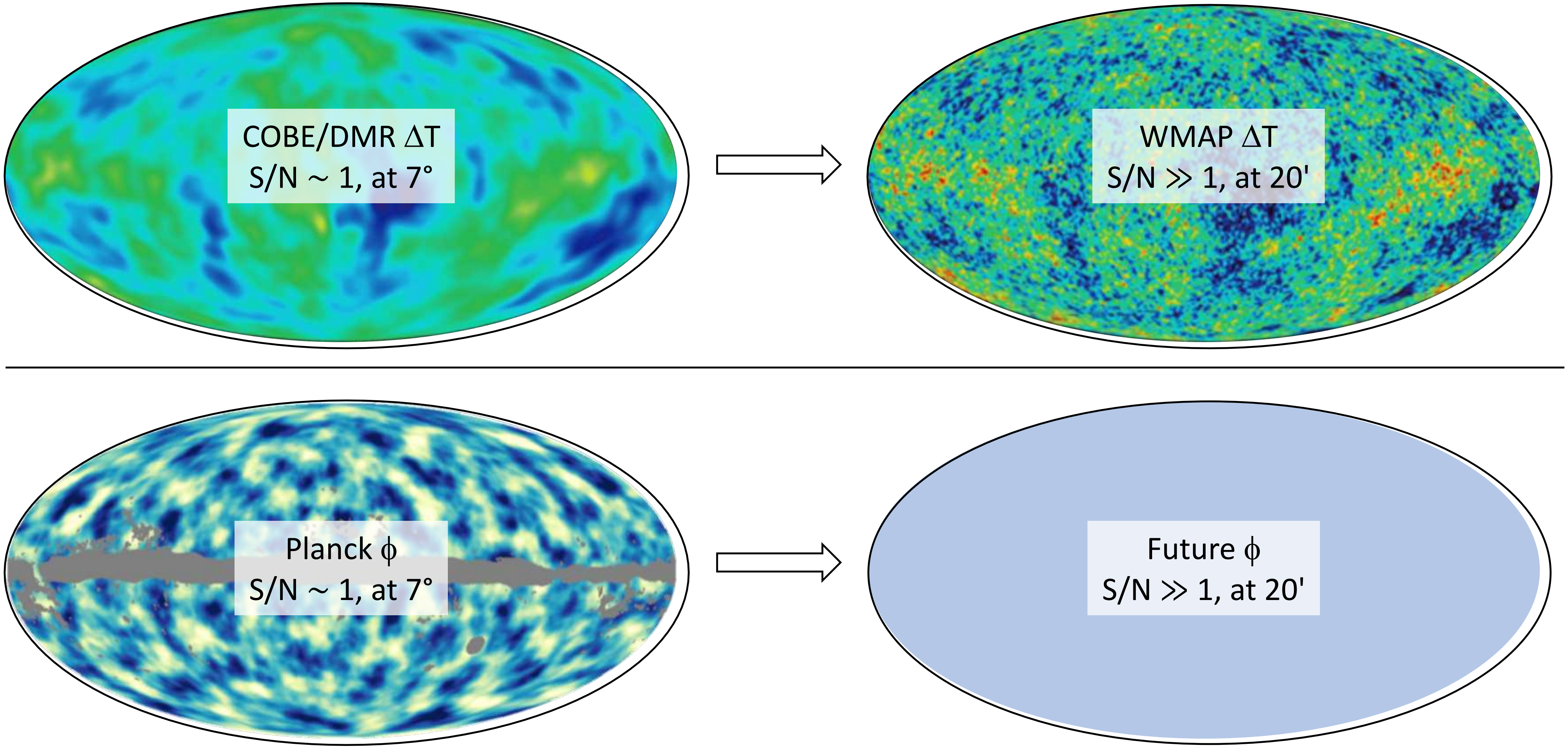




Basu et al., Astro2020 White Paper
Chen, Remazeilles & Dickinson, 2018

Biases from inaccurate estimates using only limited available frequencies;
Spectroscopy allows estimation of IR and line emission through stacking.
Combination with CMB lensing for cluster masses.

Mapping the Dark Matter



Measuring cluster velocities and masses

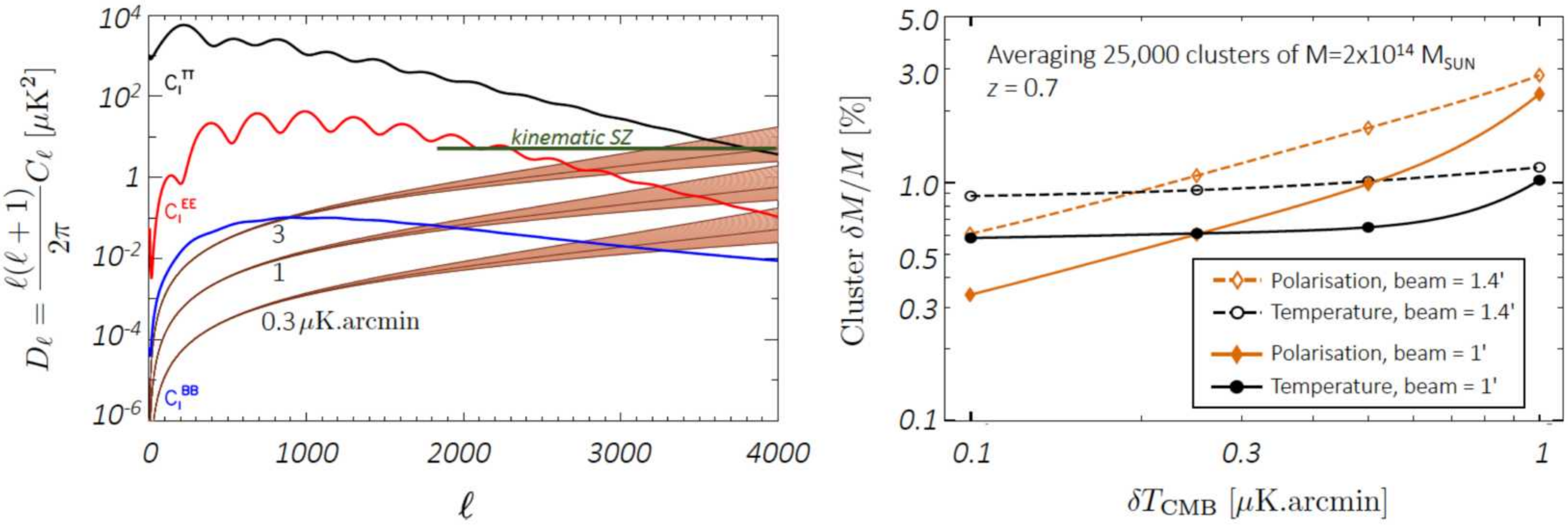


Figure 3: *Left*: CMB TT, EE, and lensing BB spectra. The light brown bands correspond to noise at the level of 3, 1, and 0.3 μK.arcmin, and angular resolution ranging from 1 to 3 arcmin. The dark green horizontal line shows the approximate level of the kSZ effect on small scales ($\ell > 2000$, [25]). *Right*: Accuracy of cluster mass calibration achieved by averaging 25,000 clusters at redshift 0.7, both from temperature and from polarization measurements, for resolutions of $1.4'$ and $1'$.

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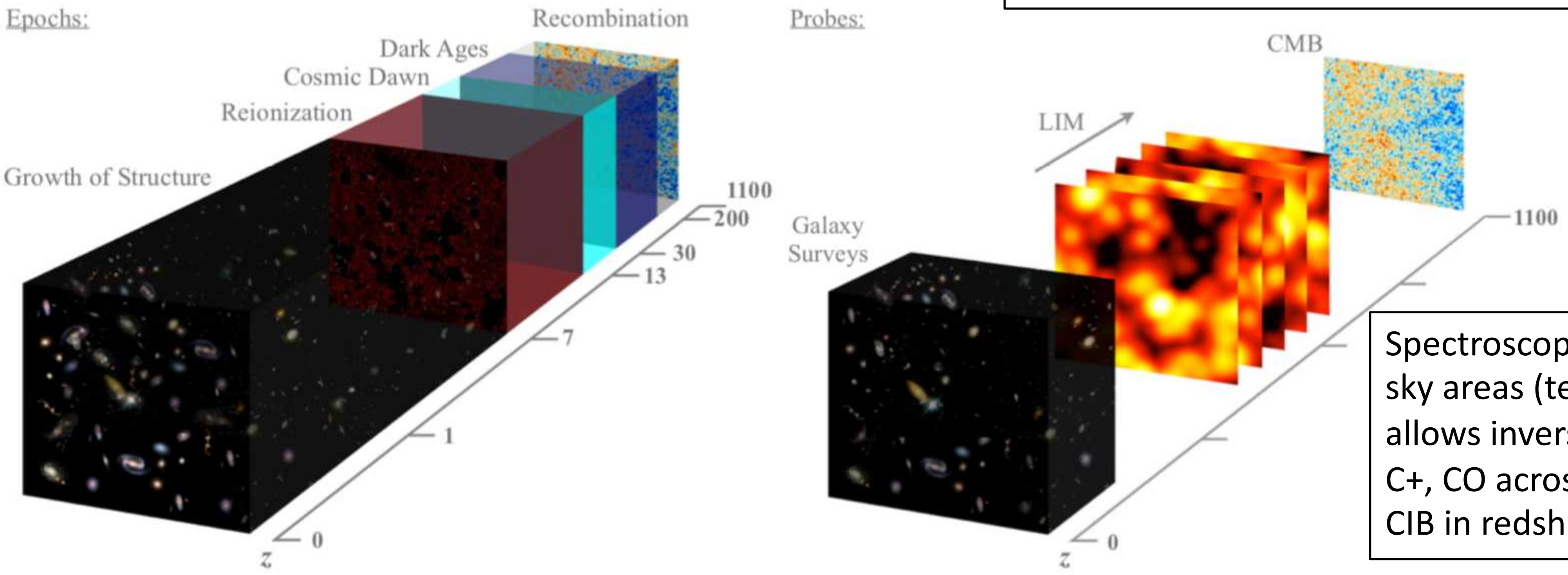
3- CIB tomography, Line Intensity Mapping

LIM gives access to "emission shells" for cosmological constraints across cosmic time.
(e.g. handle on cosmic expansion at high redshift)

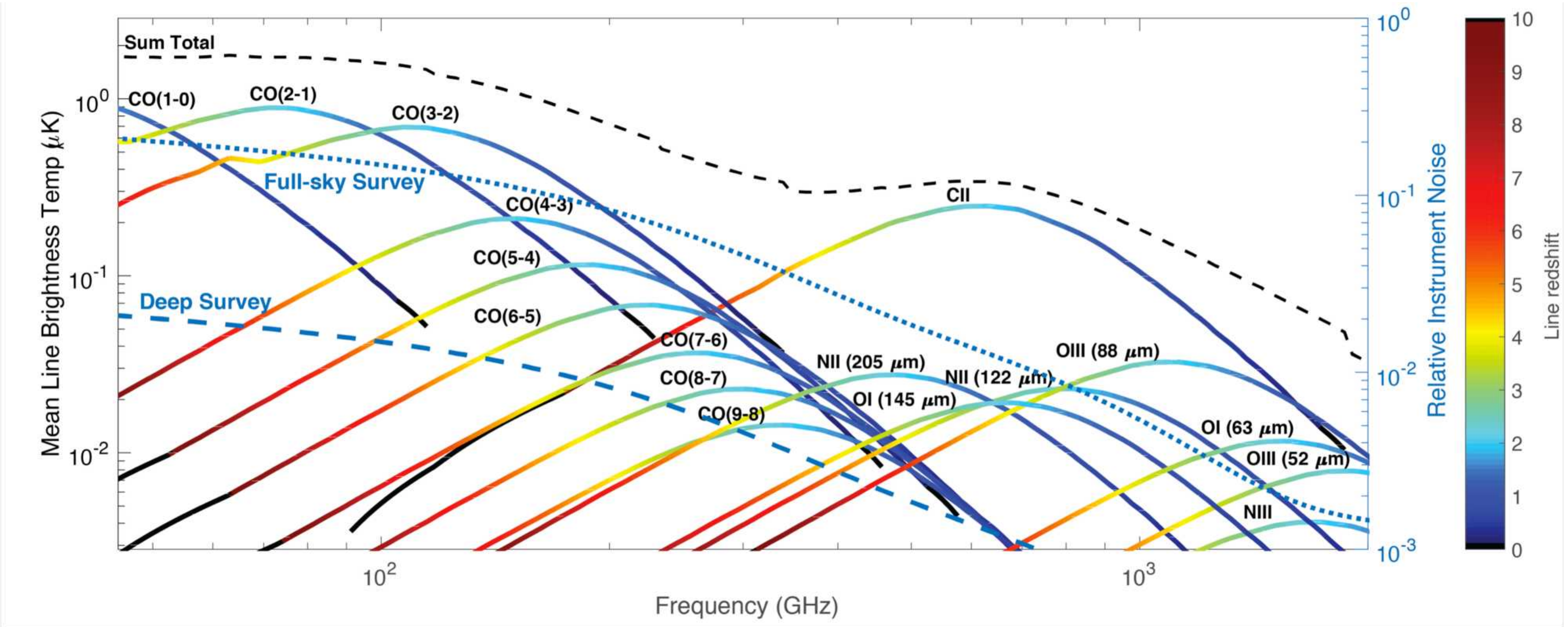


Spectroscopy on large sky areas (tens of %) allows inversion $\nu \rightarrow z$
C+, CO across cosmic time
CIB in redshift shells

FIG. 1: Line-Intensity Mapping can access the uncharted $\gtrsim$80% volume of the observable Universe.

Kovetz et al., Astro2020 White Paper

CIB tomography, Line Intensity Mapping



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Spectral distortions

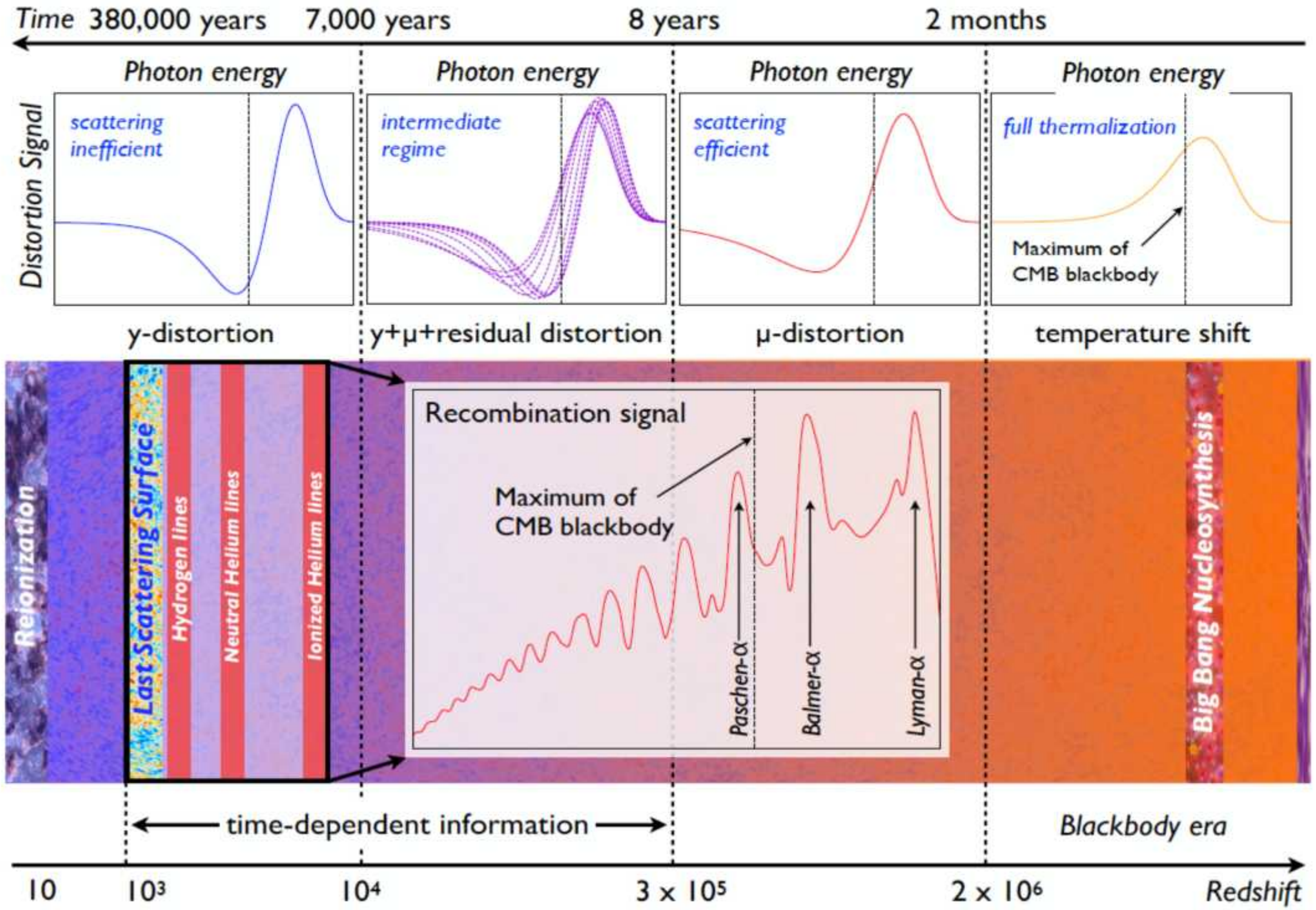
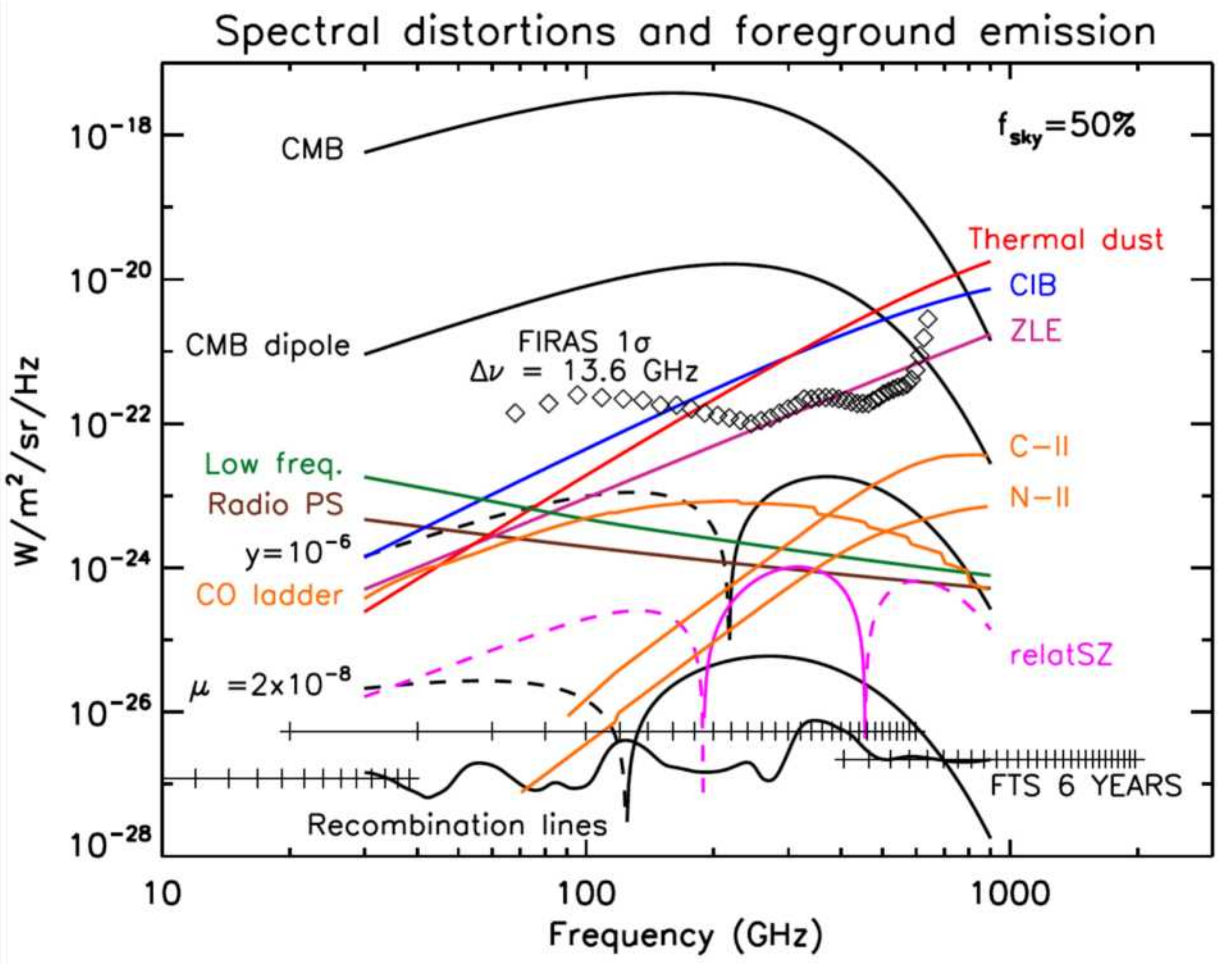


FIG. 1: Evolution of spectral distortions across time. Distortions probe the thermal history over long periods deep into the primordial Universe that are inaccessible by other means. The distortion shape contains valuable epoch-dependent information that allows distinguishing different sources of distortions.

see Chluba et al., Voyage 2050 White Paper

Spectral distortions



Constrain / observe

Inflation (small scale spectrum)
Total amount of hot gas in clusters
Average group/cluster gas temperature
Lines from primordial atoms

Foreground emissions

see Chluba et al., Voyage 2050 White Paper

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Concept inspired from PRISM

Full-sky spectro-polarimetric survey in the microwave

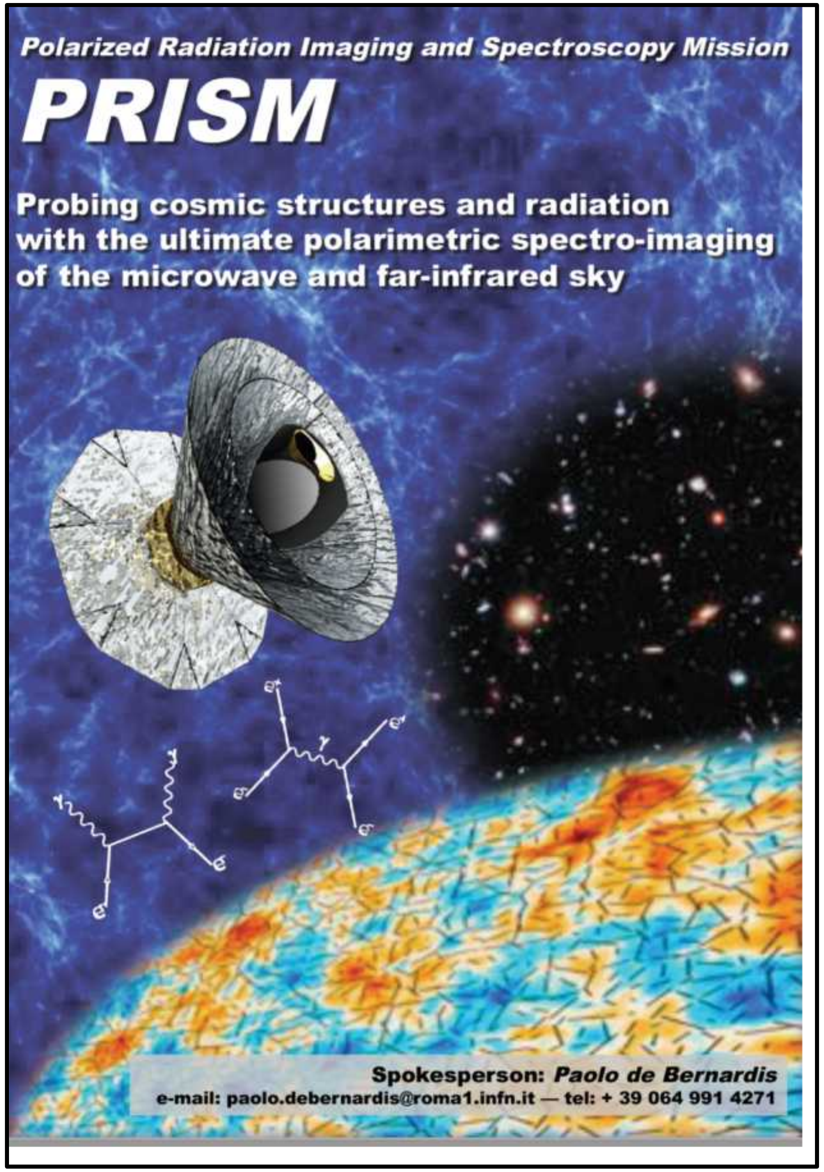
Submitted to ESA for L2-L3 in 3013,

with Paolo de Bernardis (lead), François Bouchet, Martin Bucher, ...

- Rich science case
  - Galaxy clusters
  - CMB polarization
  - CMB spectral distortions
  - High redshift galaxies and CIB
  - Dusty magnetised ISM
- Rich legacy value
- Main instruments
  - a polarised imager and a spectro-imager with a 3.5m telescope
  - a Fourier Transform Spectrometer (similar to PIXIE)

Good feedback in 2013 (among 5 audited)

but not selected (lost the competition to Athena and LISA)



Possible L-class mission

Large (2-3m) cold telescope with 2 focal plane instruments

- A polarised imager (for CMB polarisation and lensing, cluster science), e.g. CORE, PICO
  - Resolution for CMB ranging from 5' at 100 GHz to 2' at 250 GHz
  - 20 bands within 15-1500 GHz (TBD), resolution from 30' to 20" depending on frequency
- A spectrometer (for mapping line emission, both galactic and extragalactic)
  - R = 300 (TBD)
  - Frequency range within 50-2000 GHz, angular resolution at the arcminute scale
- Possibility of an additional guest instrument?
- Must be an L-class mission (or M-class contribution to international L-class mission)

	CMB sensitivity (μK.arcmin)	SZ sensitivity (*y*.arcmin)
full-sky 2 years	0.66	1.7×10^{-7}
5% sky 6 months	0.29	7.7×10^{-8}

Absolute spectrometer modules

One or more small Fourier Transform Spectrometers modules

- For zero-level of intensity maps and CMB spectral distortions
  - Coarse resolution, typically degree-scale to few degree scale (TBC)
  - Frequency range within 10 GHz – 2000 GHz
- Can be a separate 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	$\nu_{\rm min}$ (GHz)	$\nu_{\rm max}$ (GHz)	$\Delta\nu$ (GHz)	Sensitivity (Jy.$\sqrt{\rm s}$)	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

Observation modes

Optimize the spread of observing time

- Full sky survey for ~ 25% of the mission lifetime
- Deeper observation of selected wide areas
  - possibly 'clean' sky at high galactic latitude
  - observed ~25% of the time
- Deep observation on selected patches (galactic or extragalactic)
  - possibility of 'observatory mode' for ~50% of the mission lifetime

Summary

- The Cosmic 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'
- ESA recommendations expected mid-2020

Thank you for your attention !