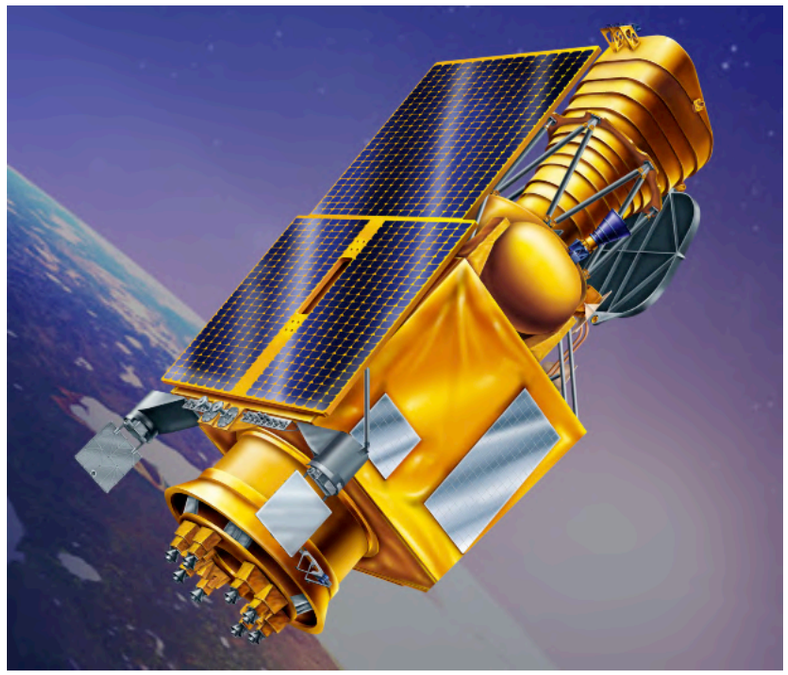
ULTRASAT as a powerful cosmology* probe

*Generalized to: applications of the reference all-sky intensity fluctuations map

Ely D. Kovetz & Sarah Libanore

Ben-Gurion University



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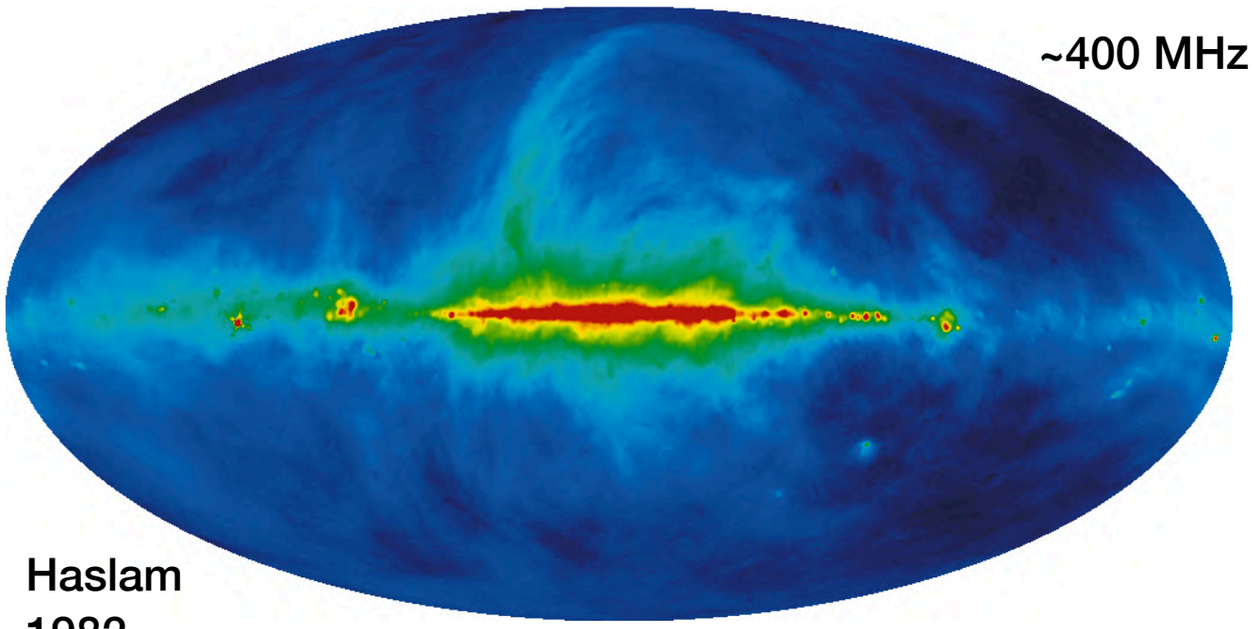

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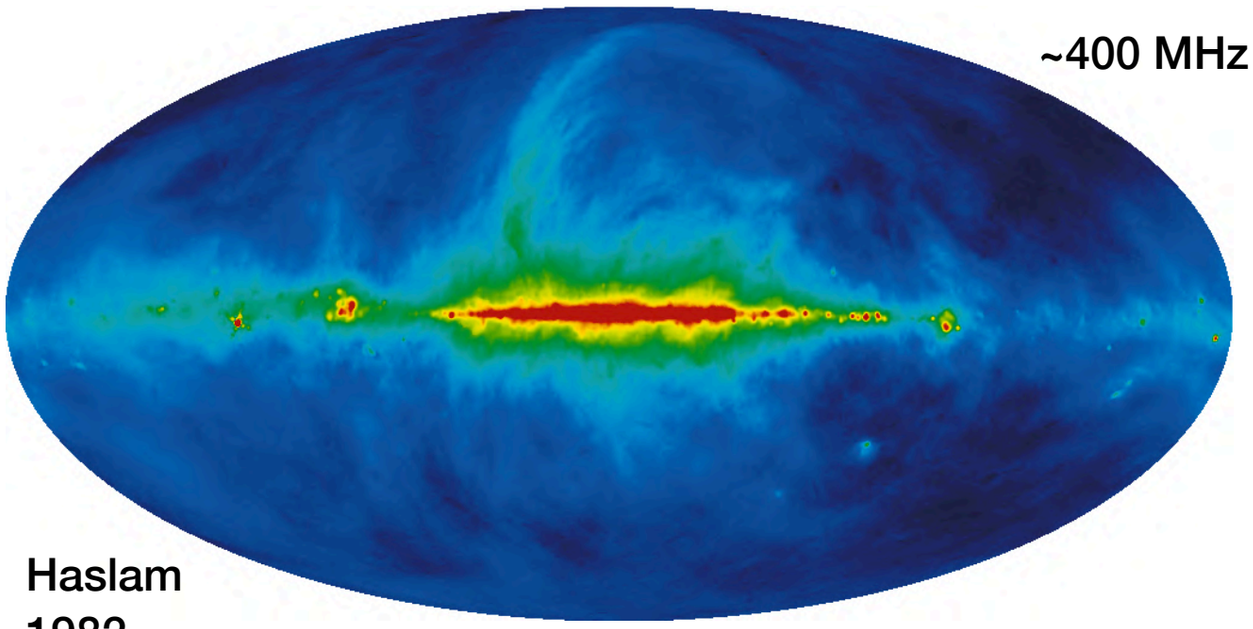

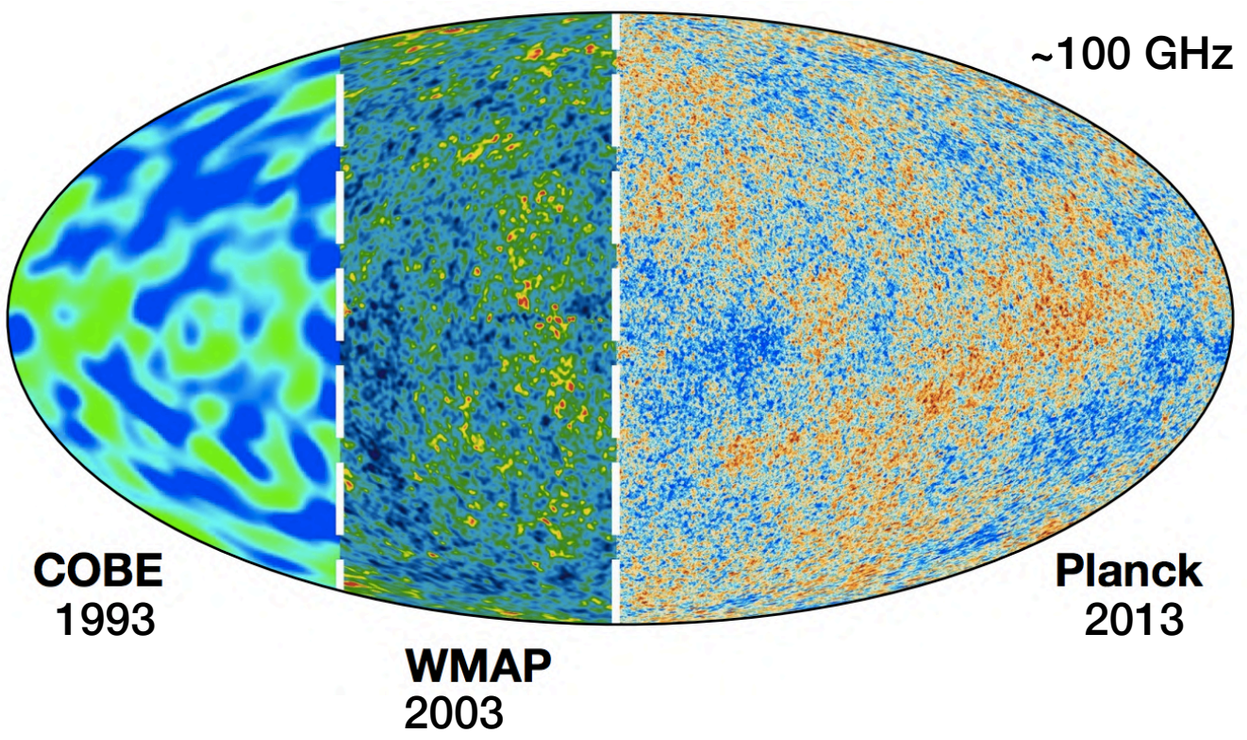

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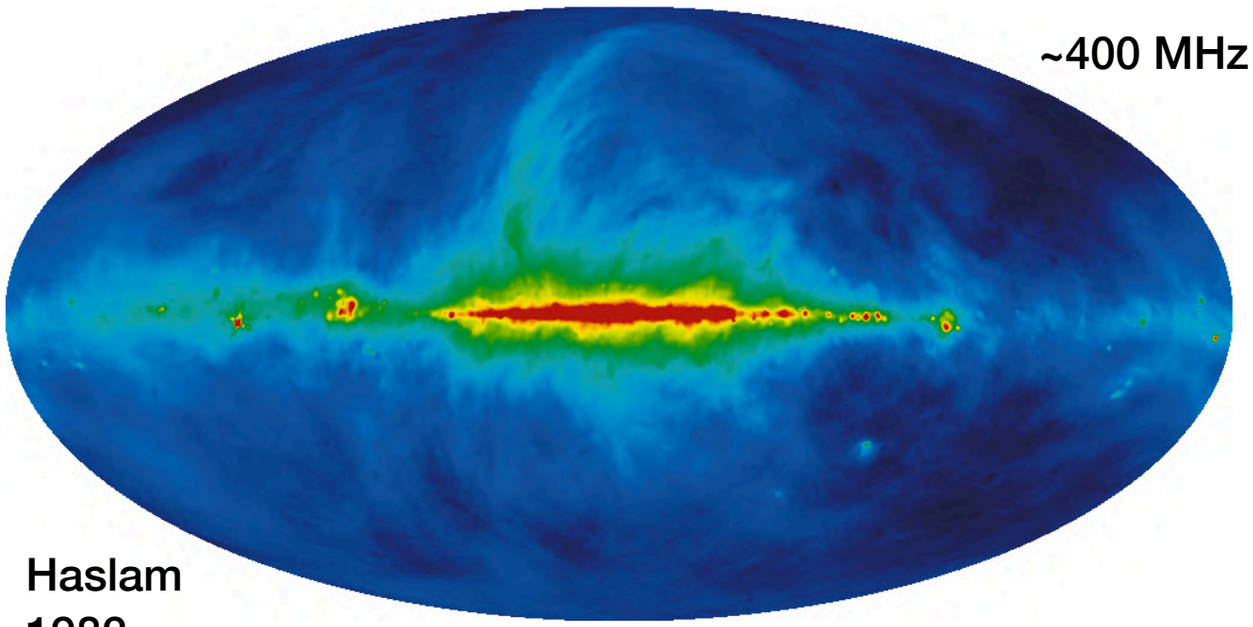

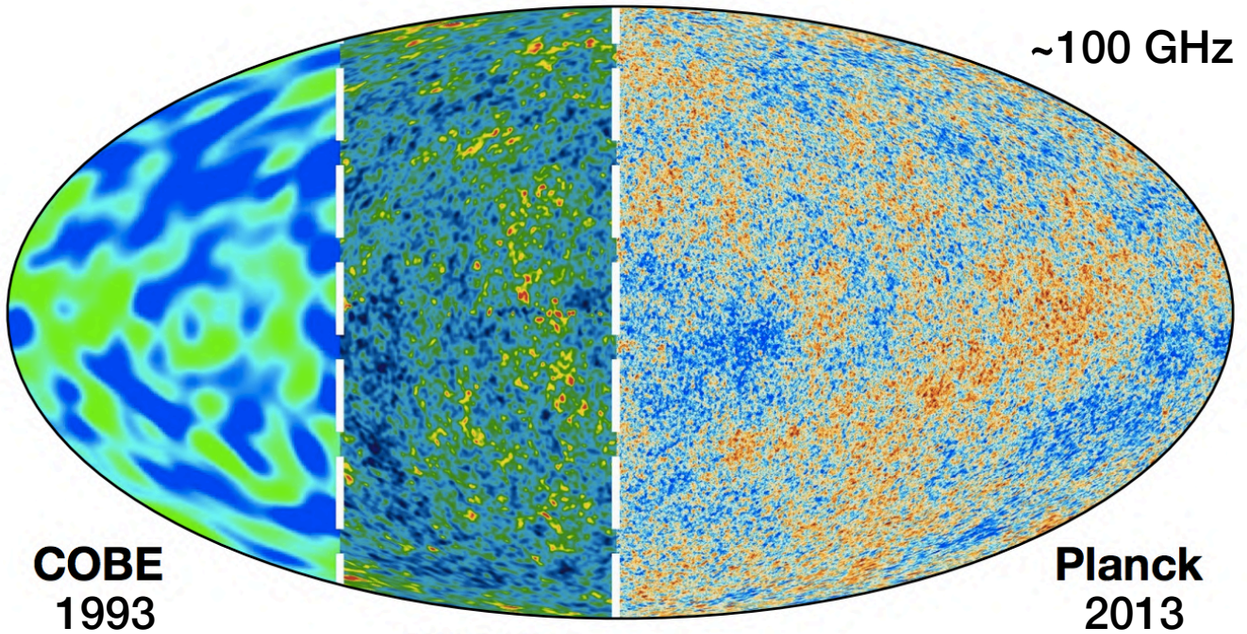

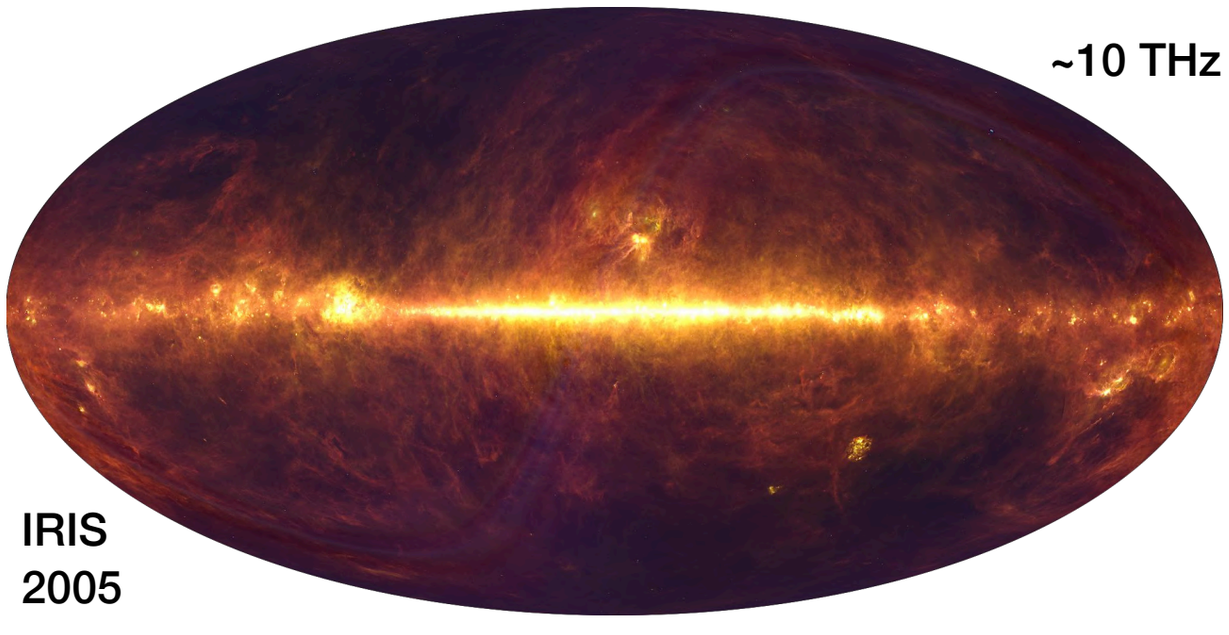

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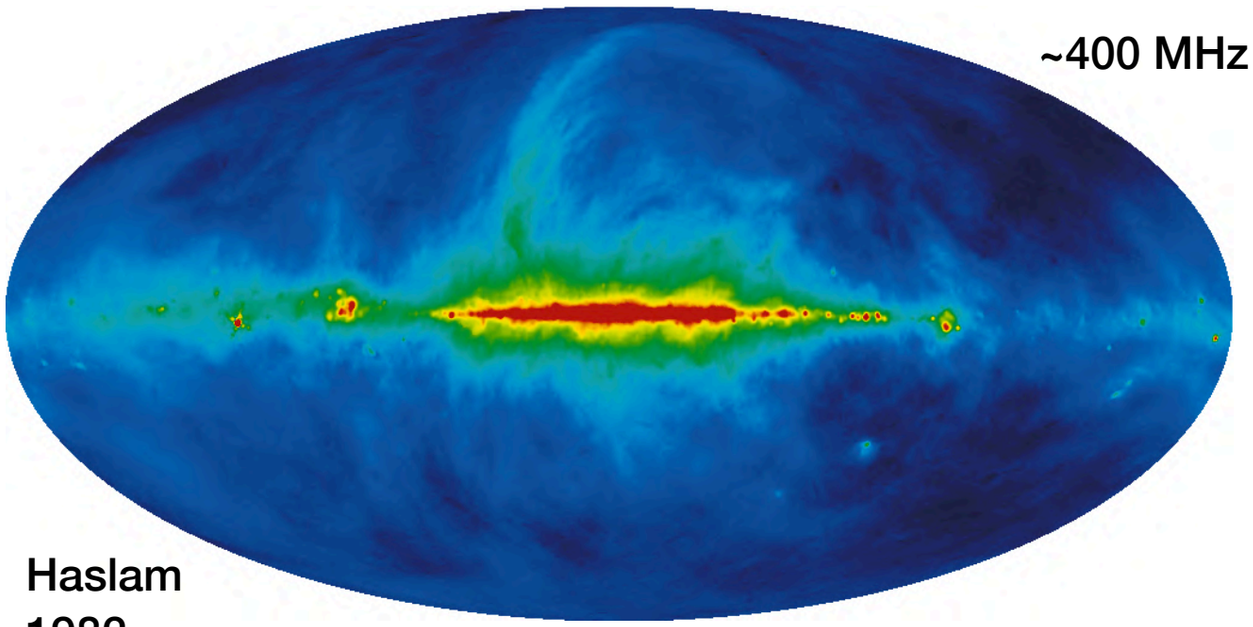

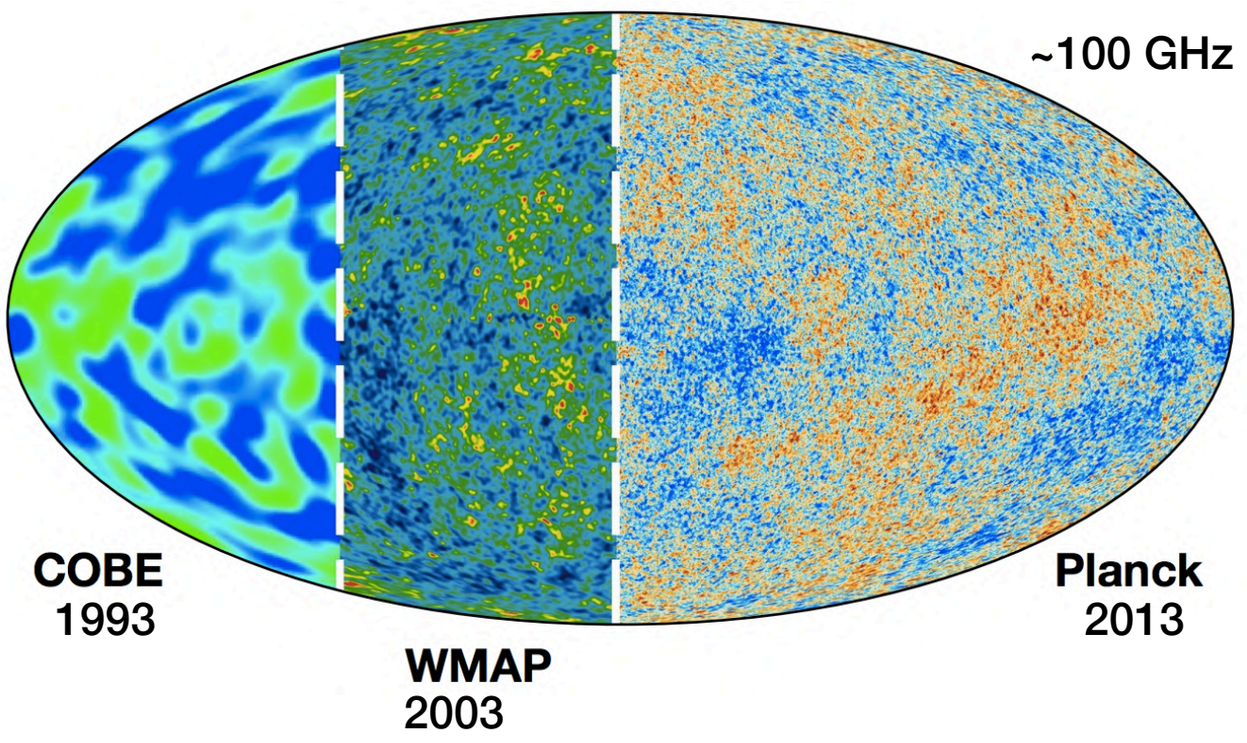

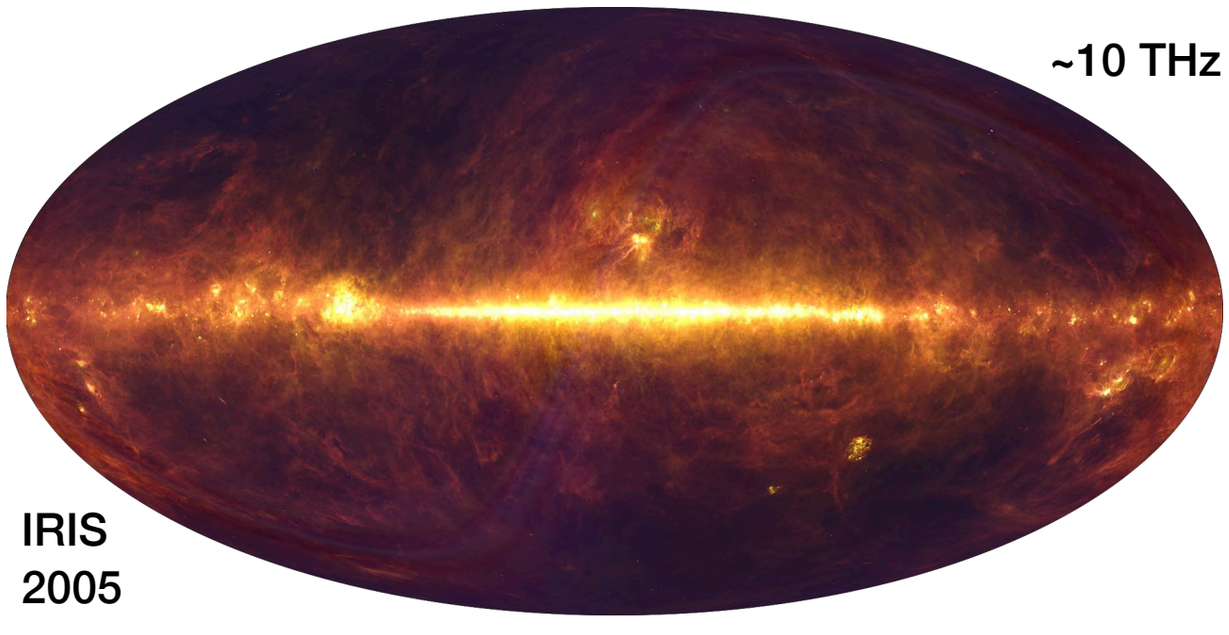

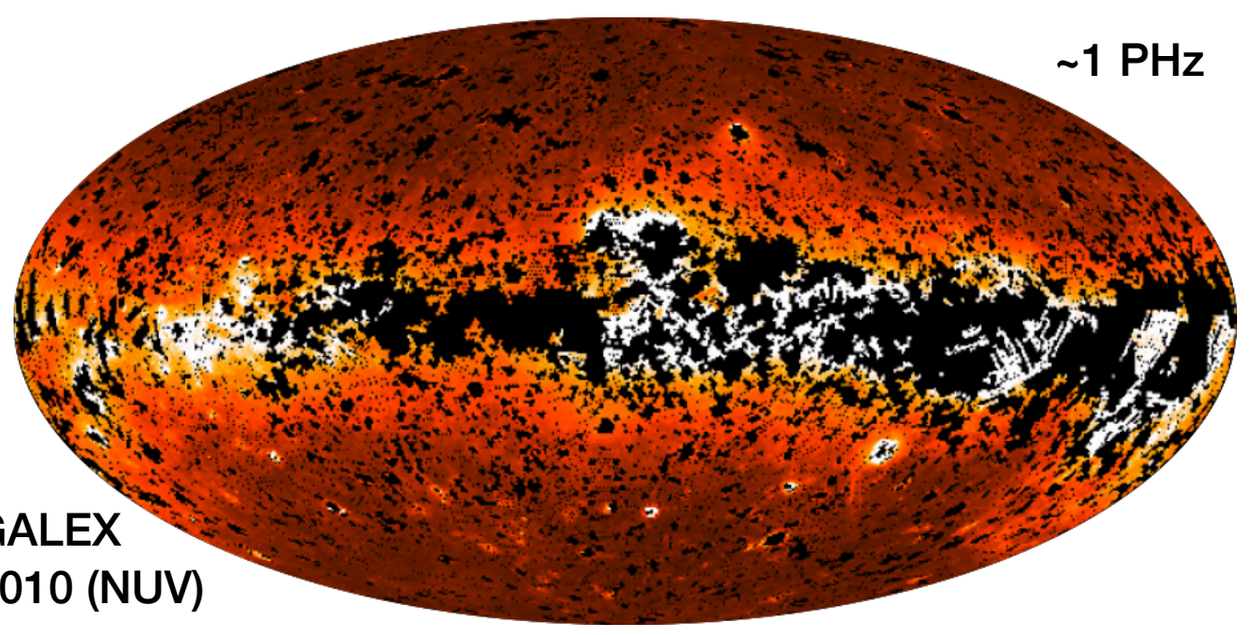

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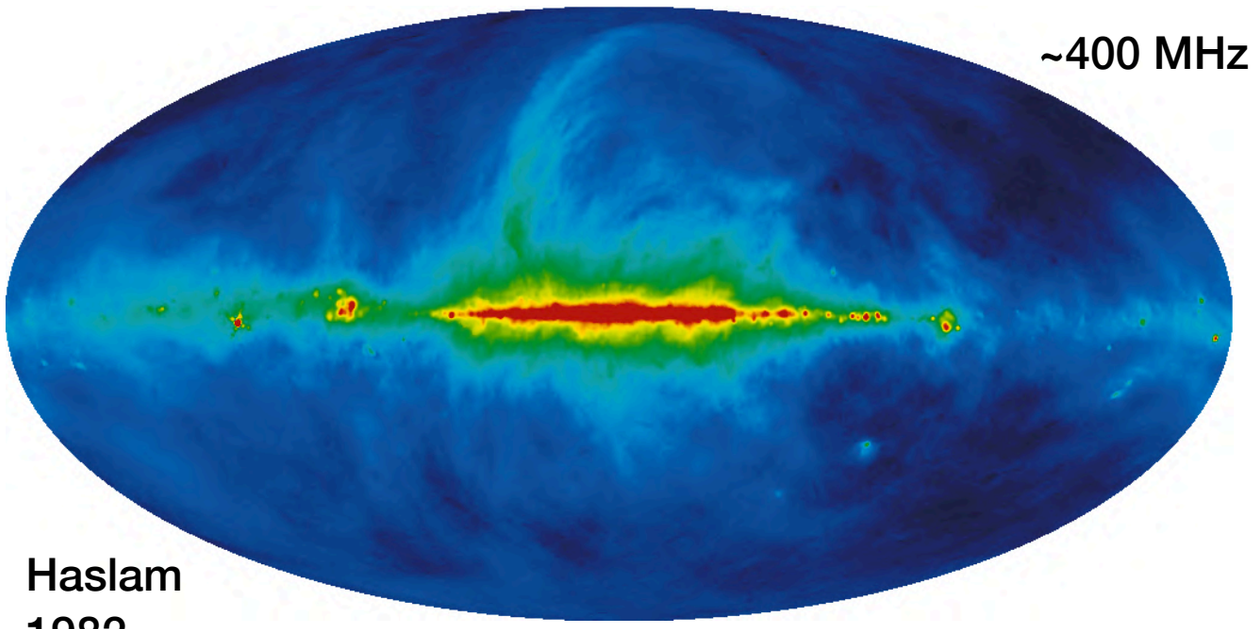

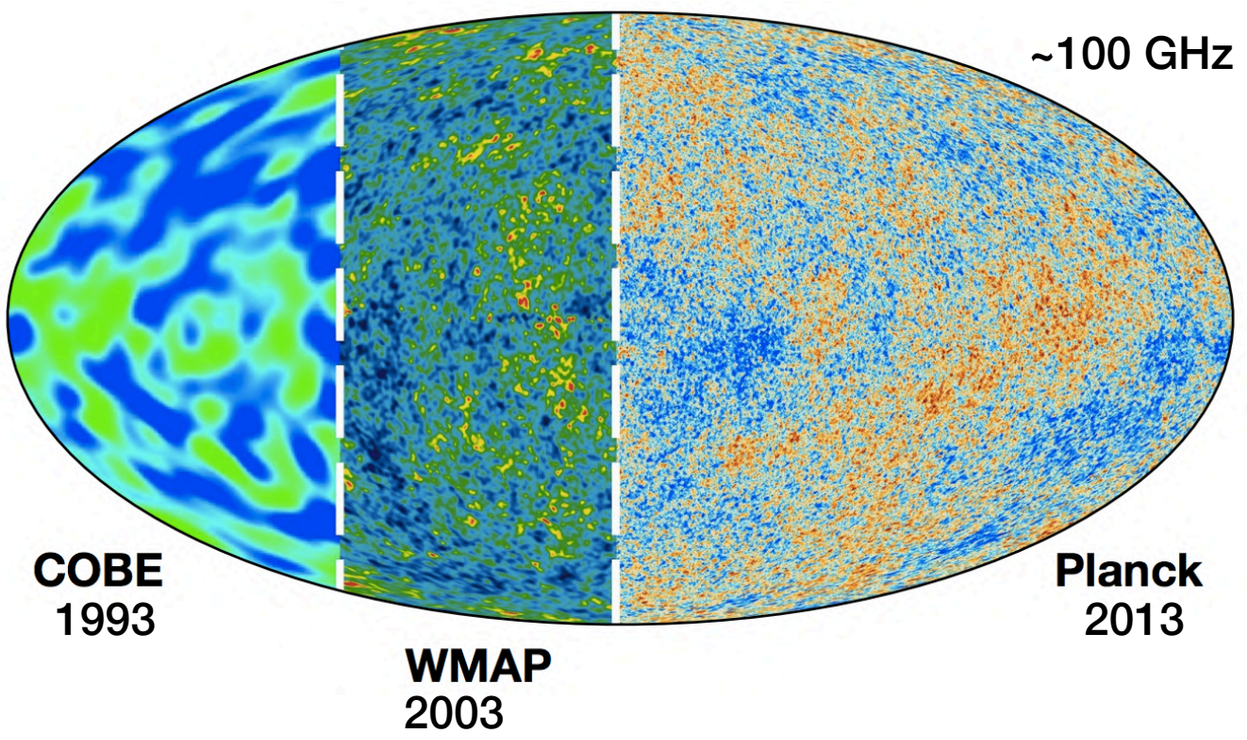

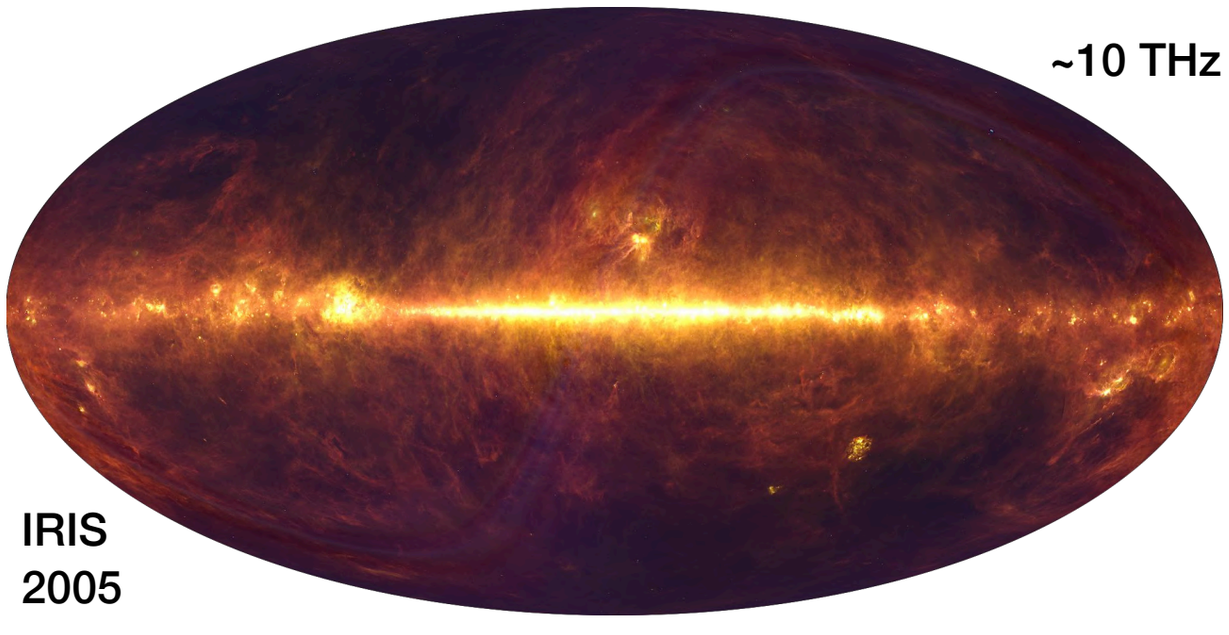

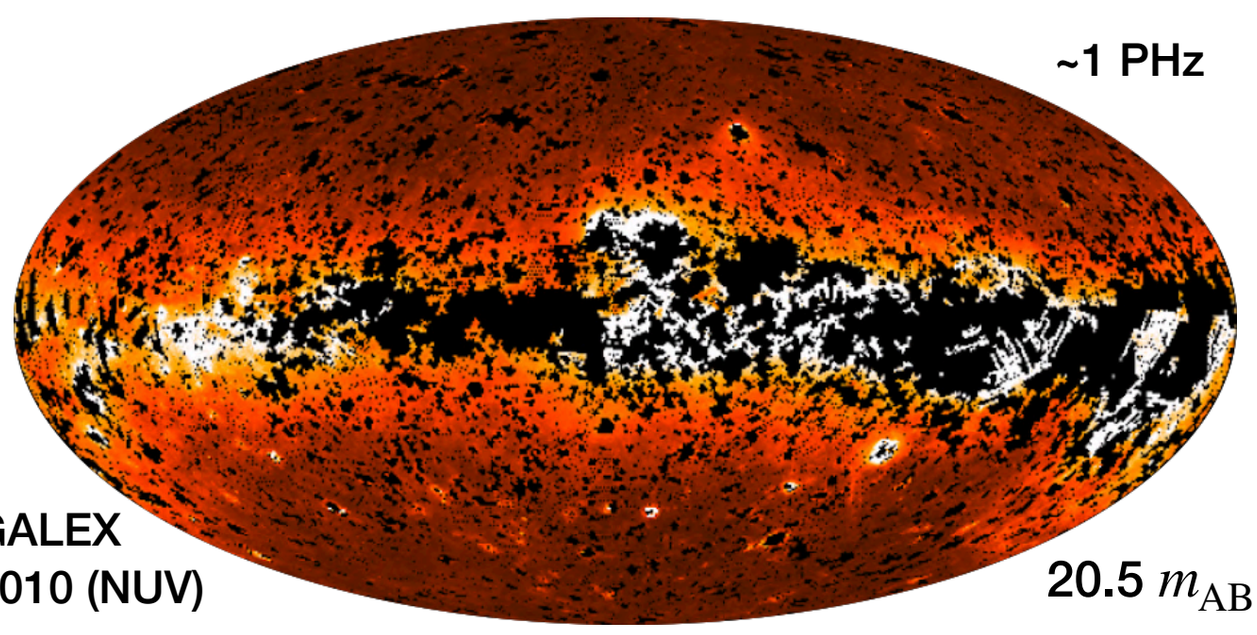

Line-Intensity Mapping: Introduction

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Intensity mapping: 3D mapping of the specific intensity due to line emission.

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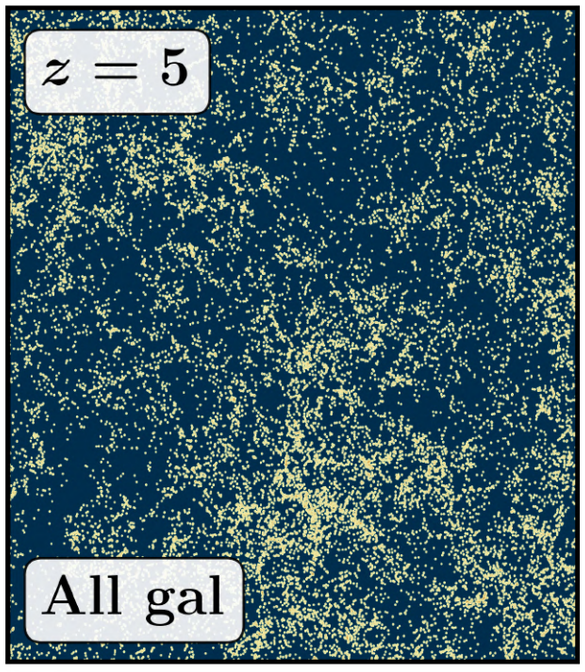

Bernal and Kovetz, arXiv:2206.15377, Astronomy and Astrophysics Review

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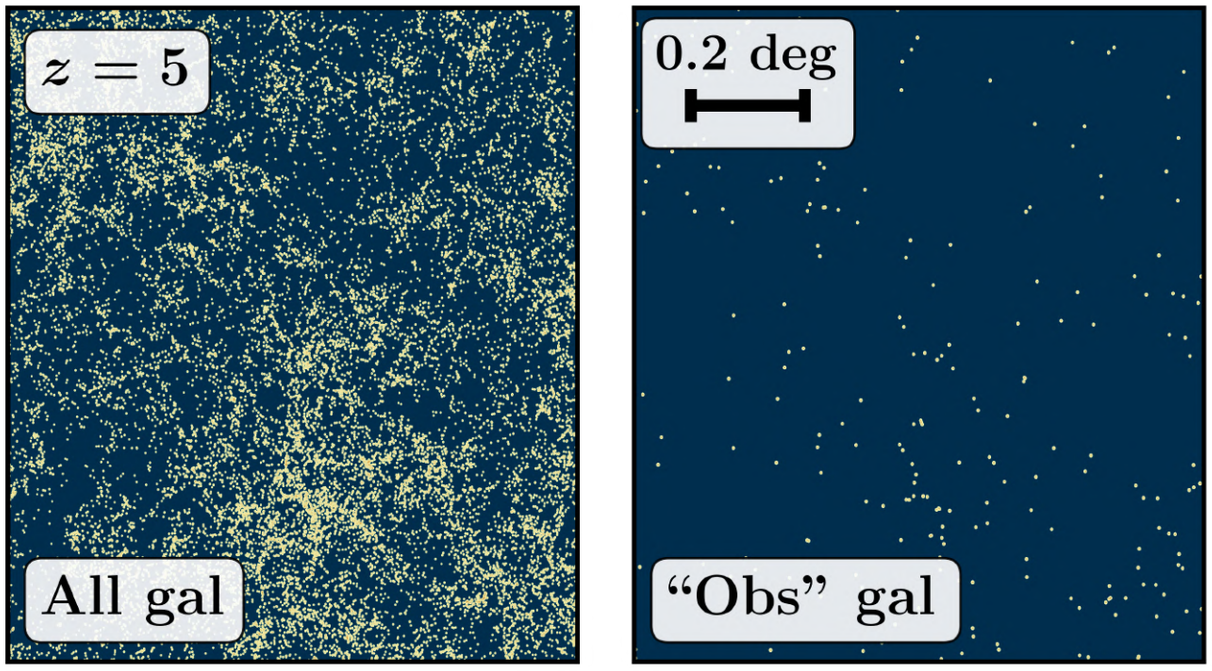

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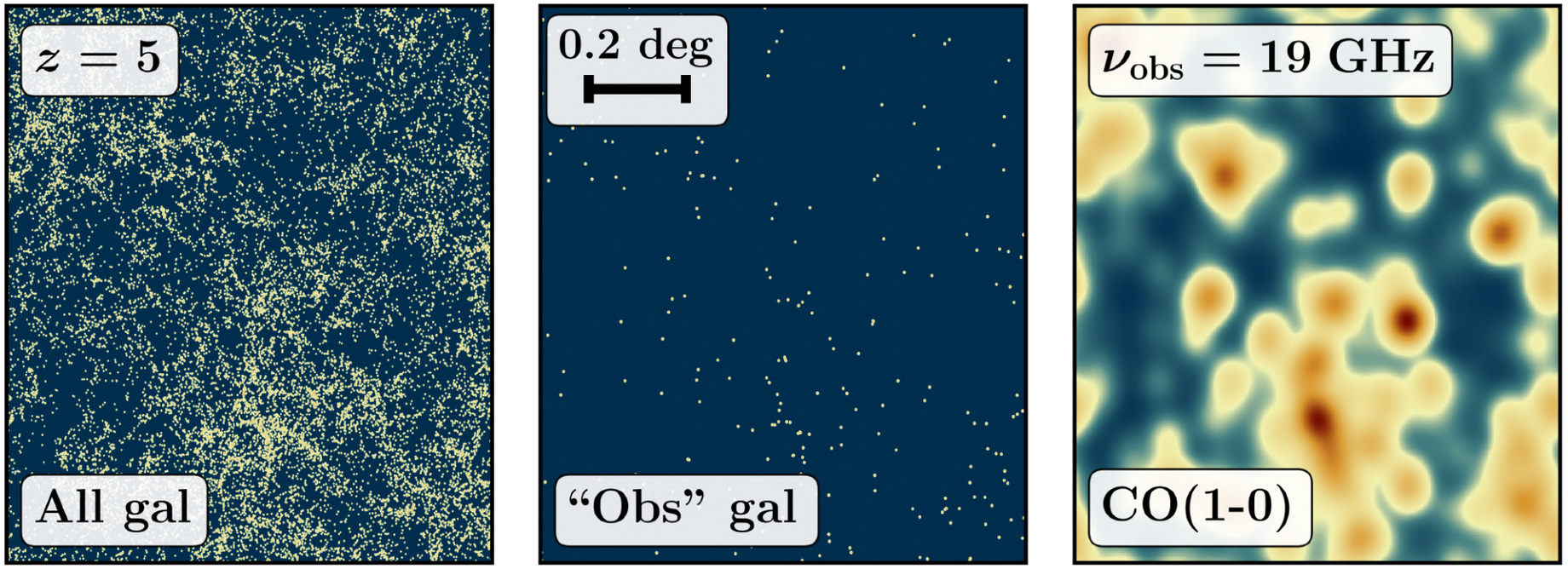

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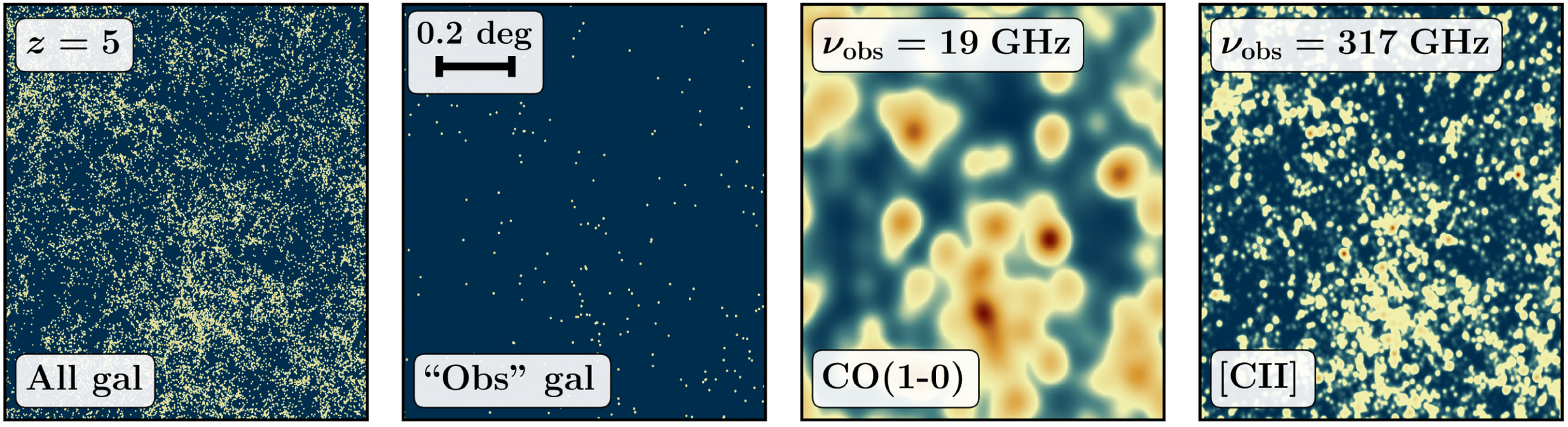

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Line-Intensity Mapping: Ultimate Cosmology Probe

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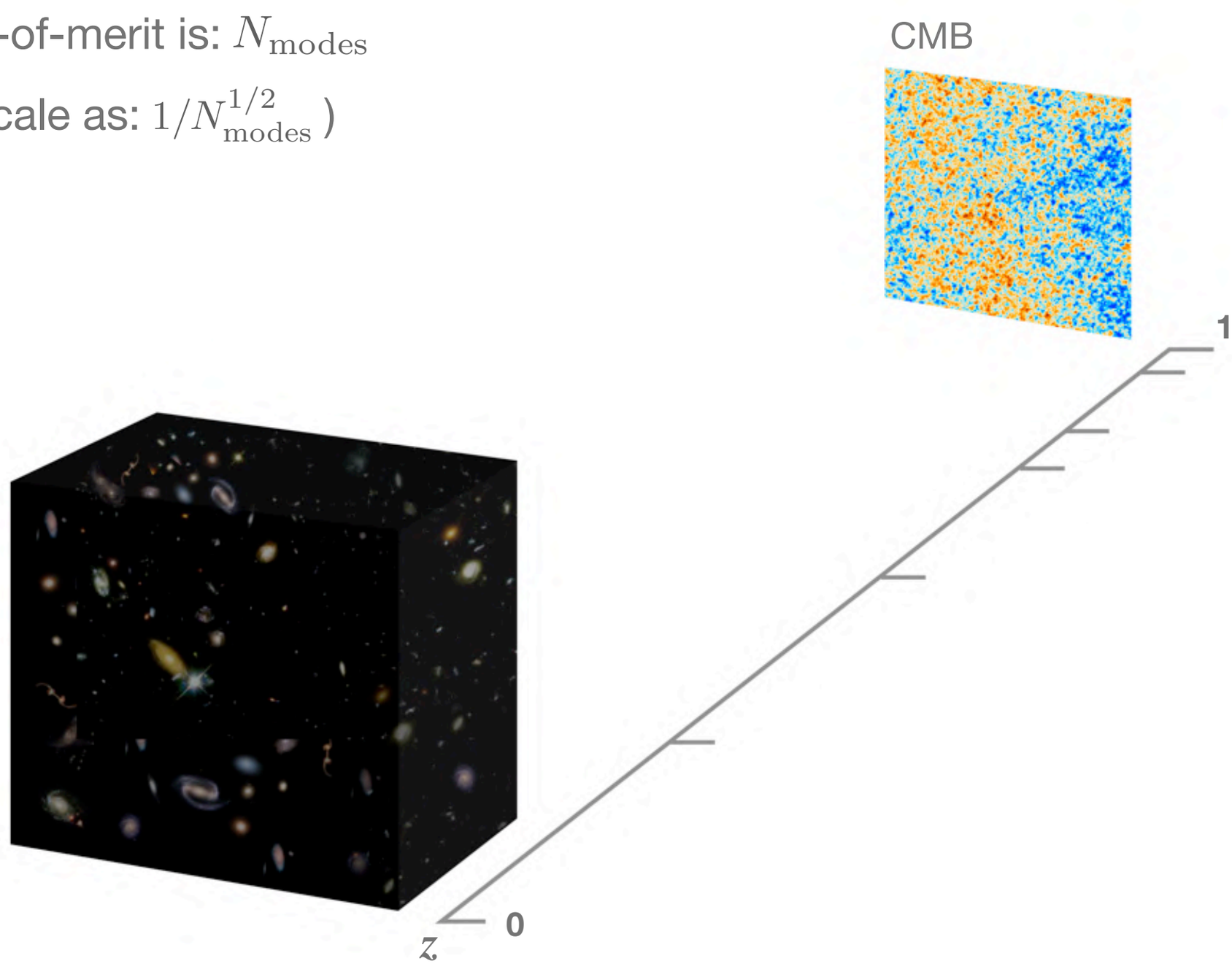

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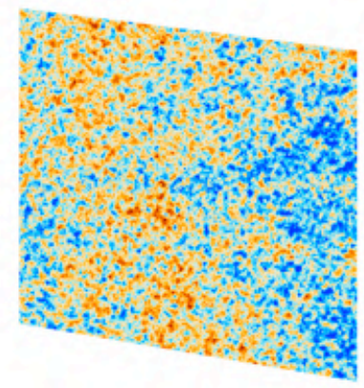

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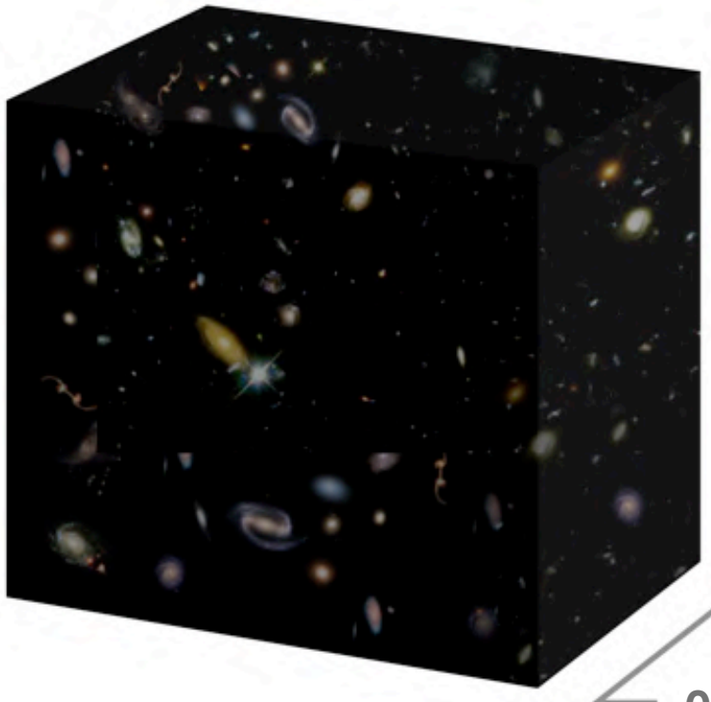
Galaxy Surveys



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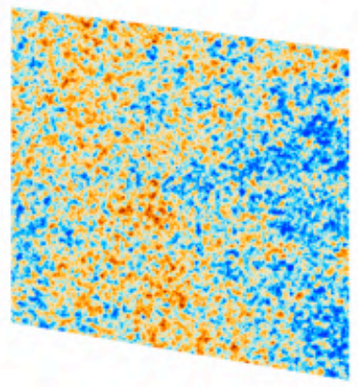

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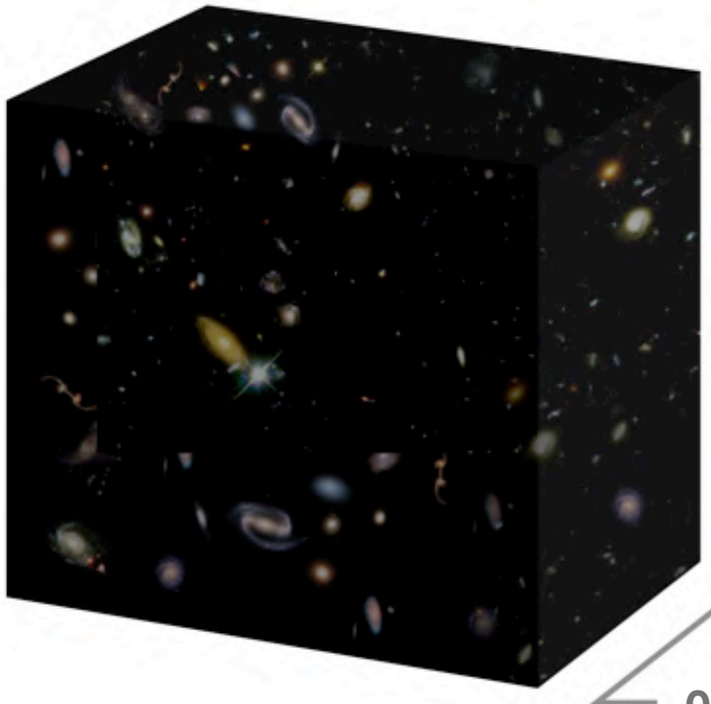

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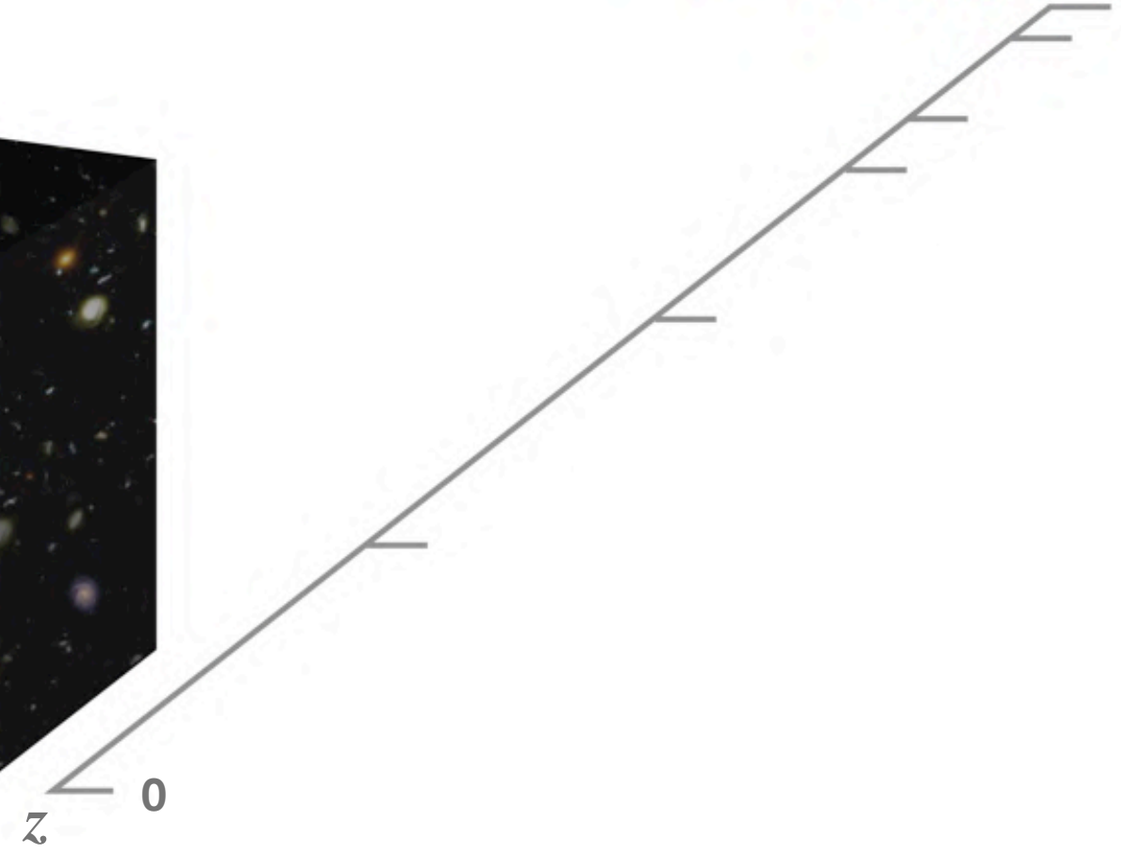
$\longrightarrow N_{\rm sources} > 10^8$ (Euclid, LSST?)



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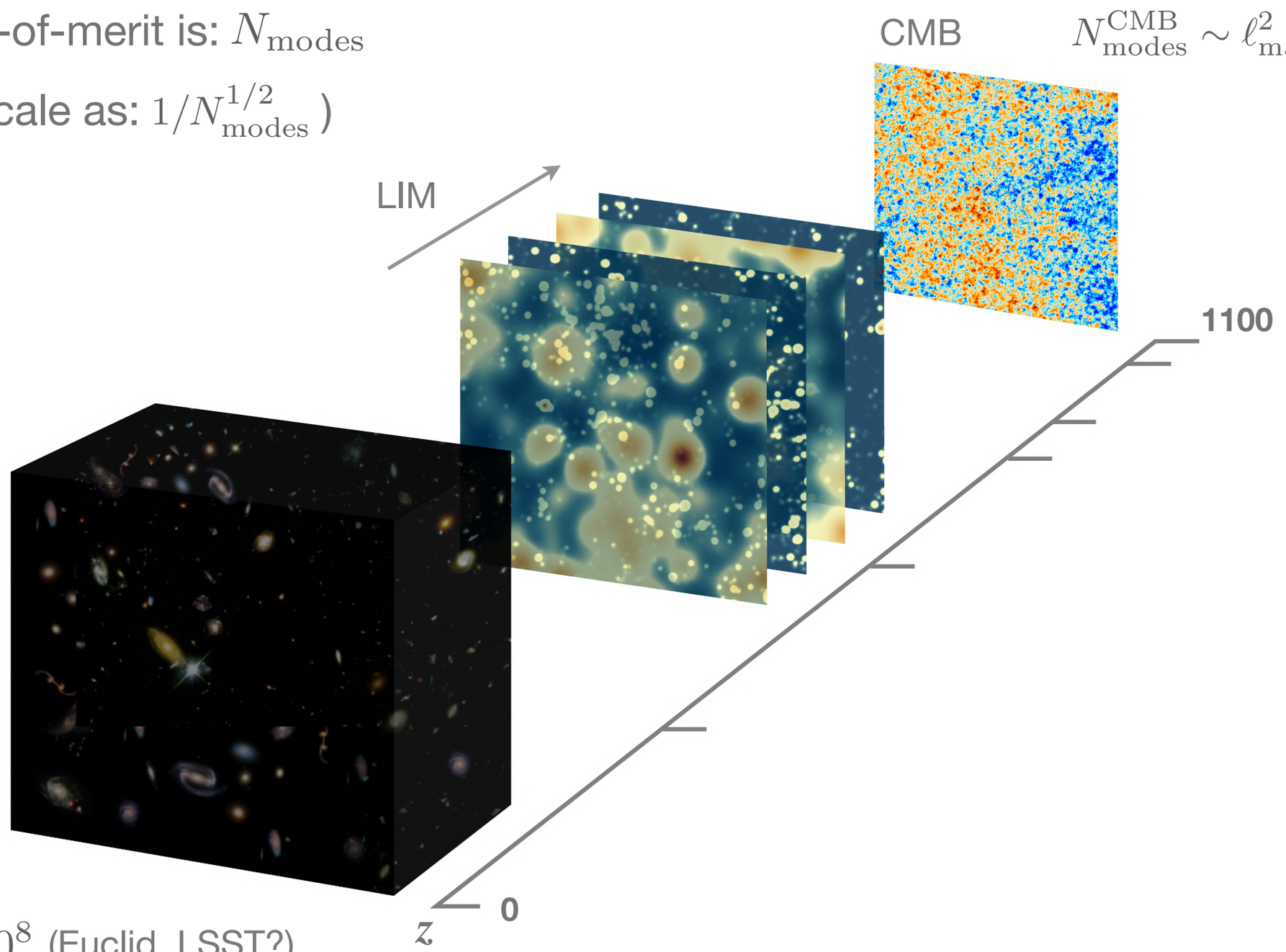

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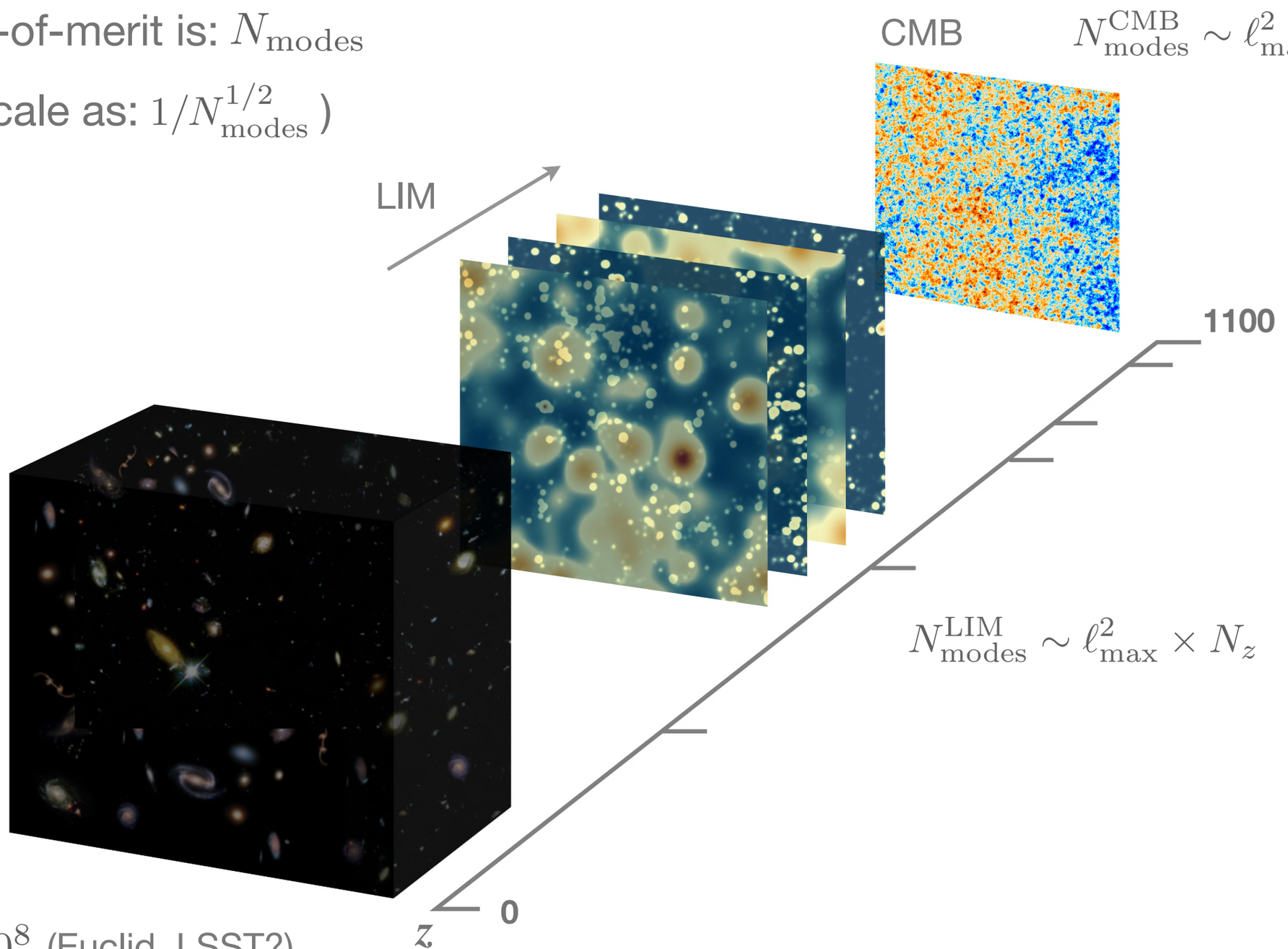

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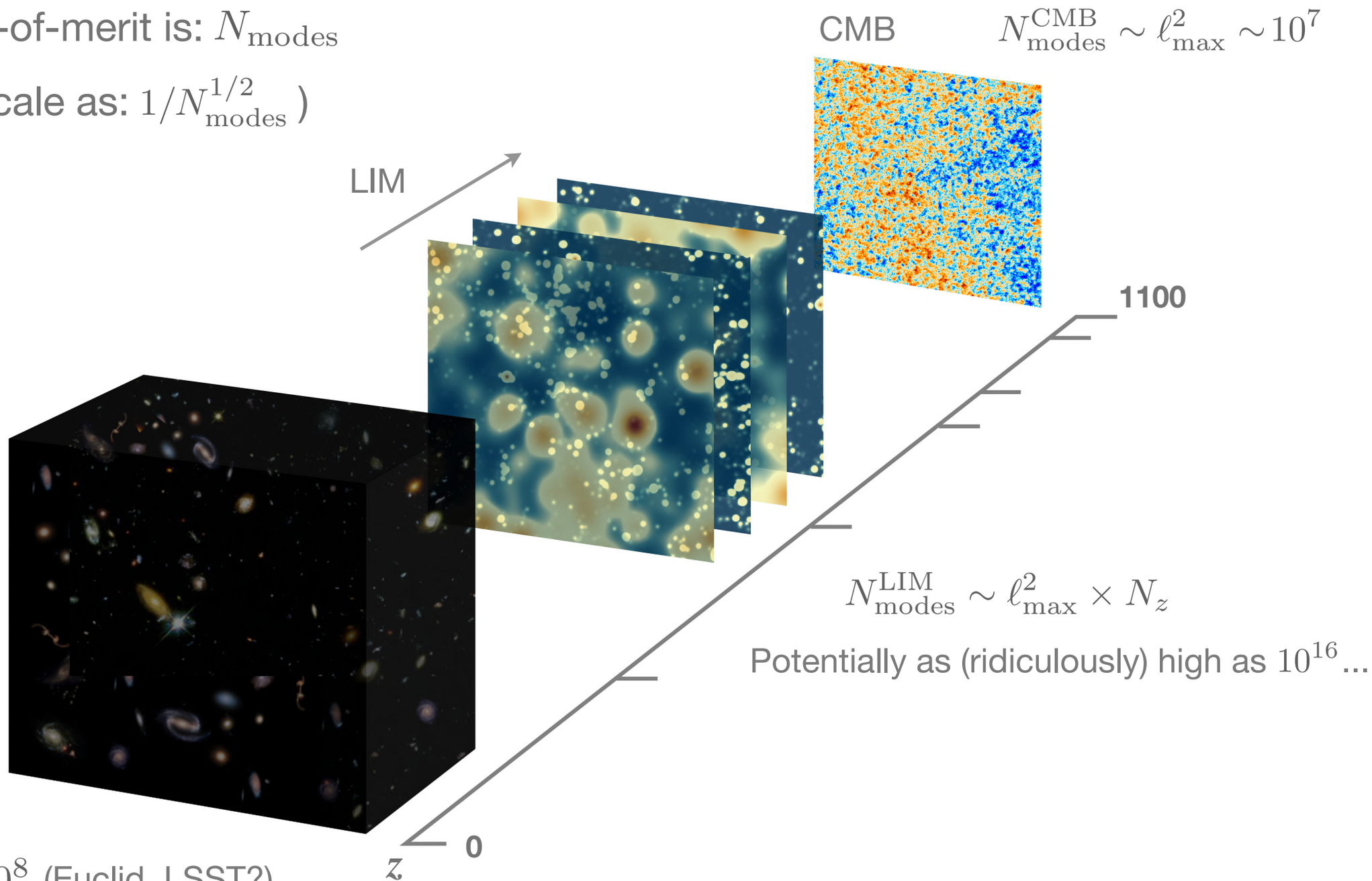

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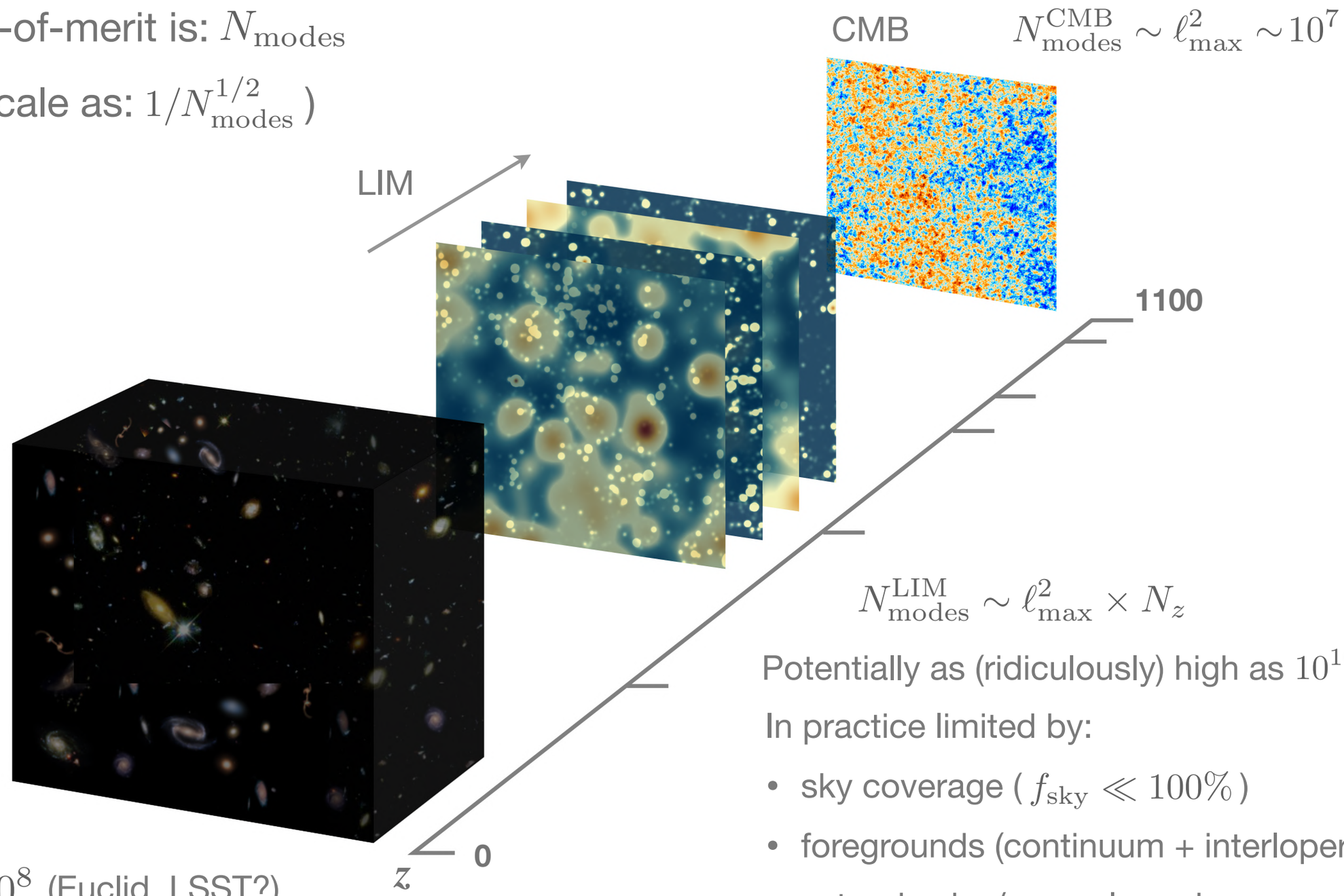

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Potentially as (ridiculously) high as 10^{16}...

In practice limited by:

- sky coverage ($f_{\rm sky} \ll 100\%$)
- foregrounds (continuum + interlopers)
- astrophysics/cosmology degeneracy

Galactic Emission Lines

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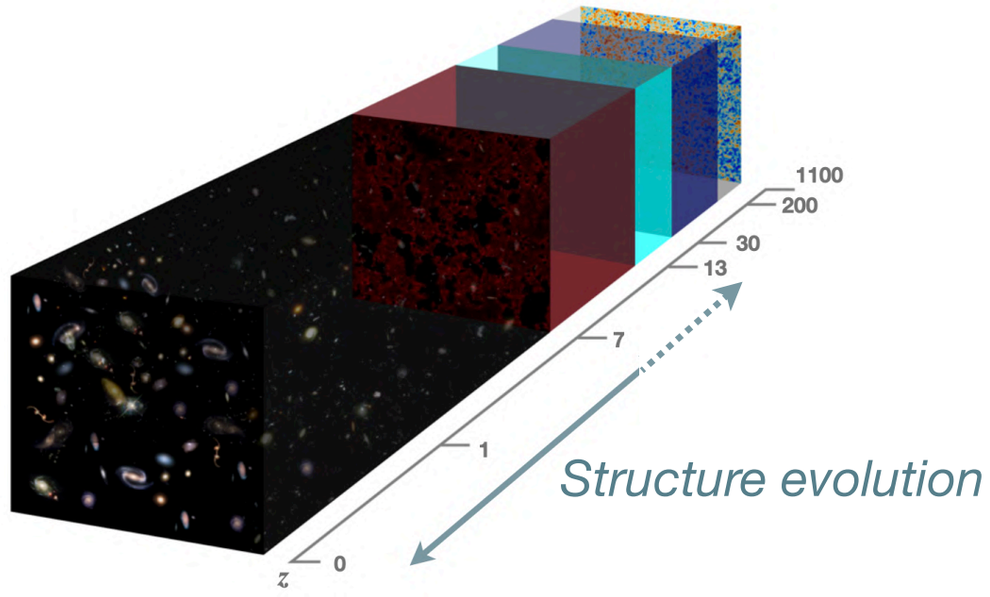

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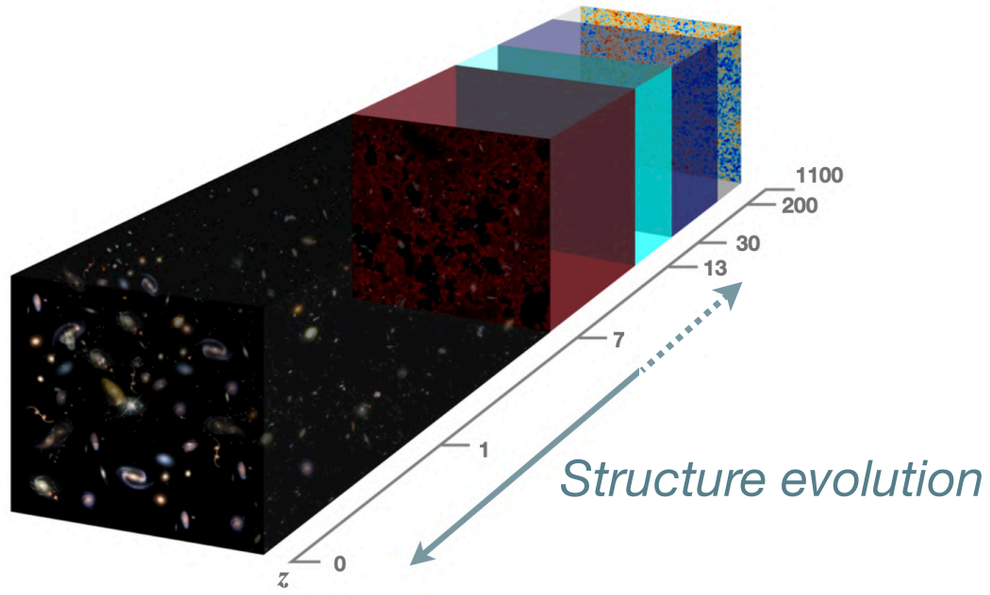
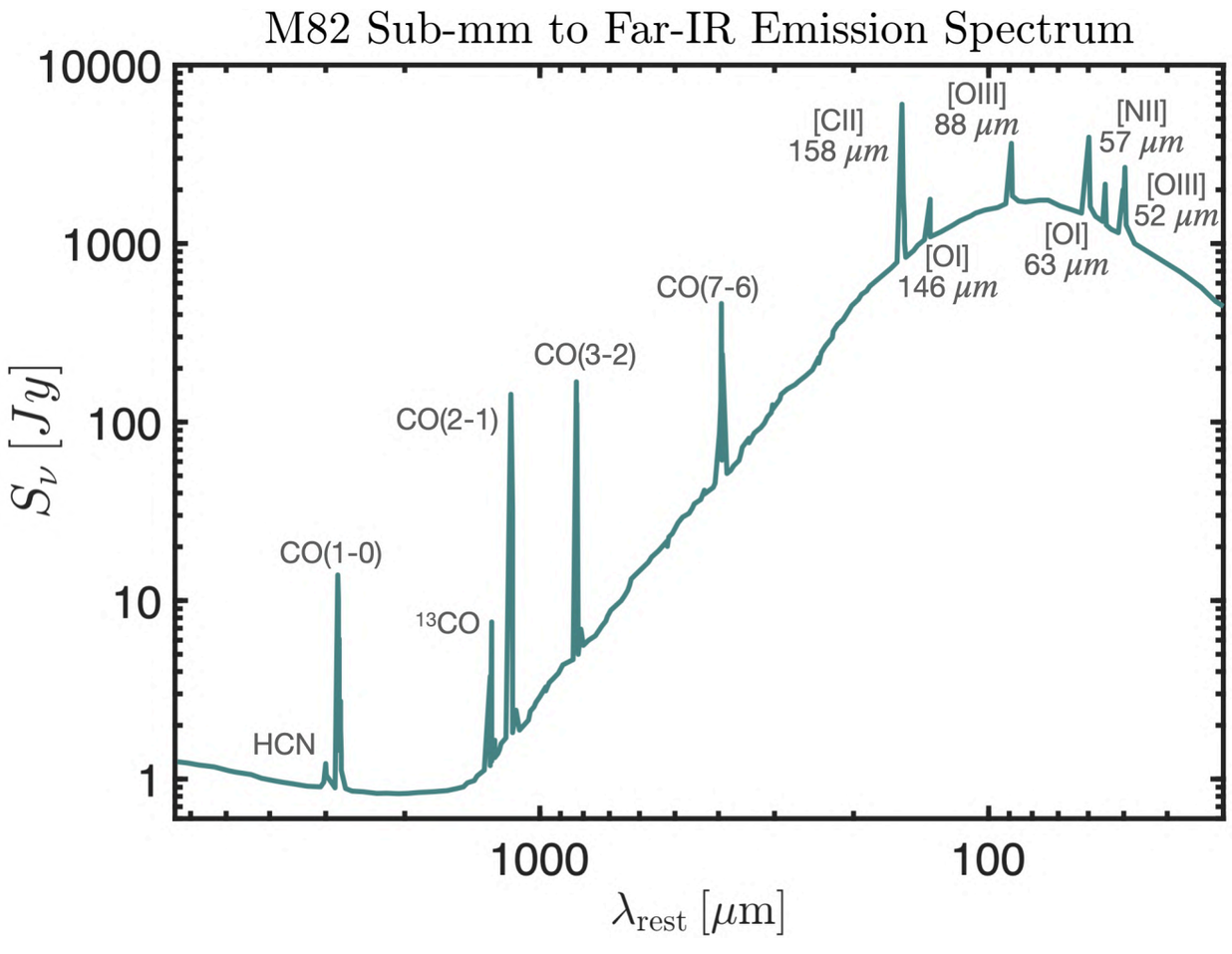
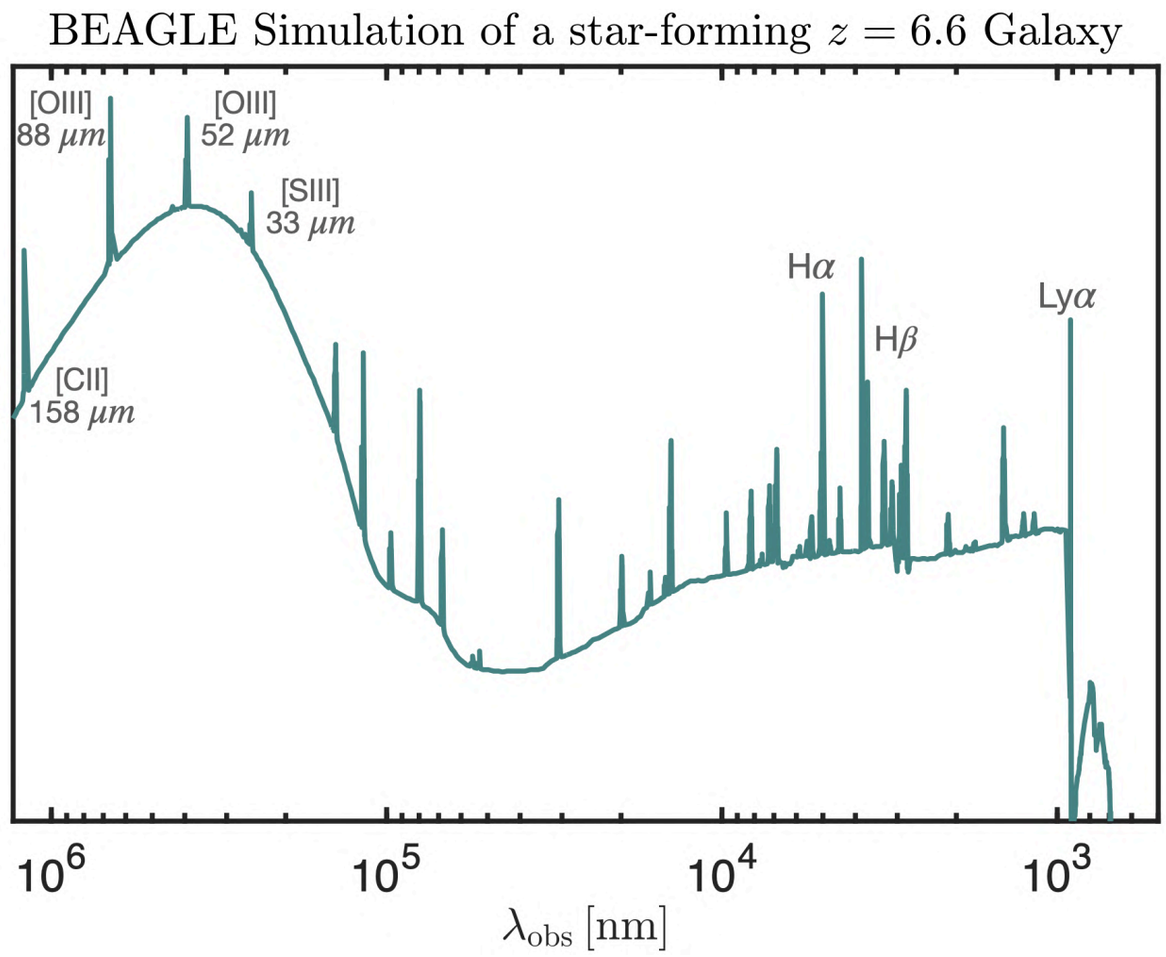


Spectrum of a typical galaxy:

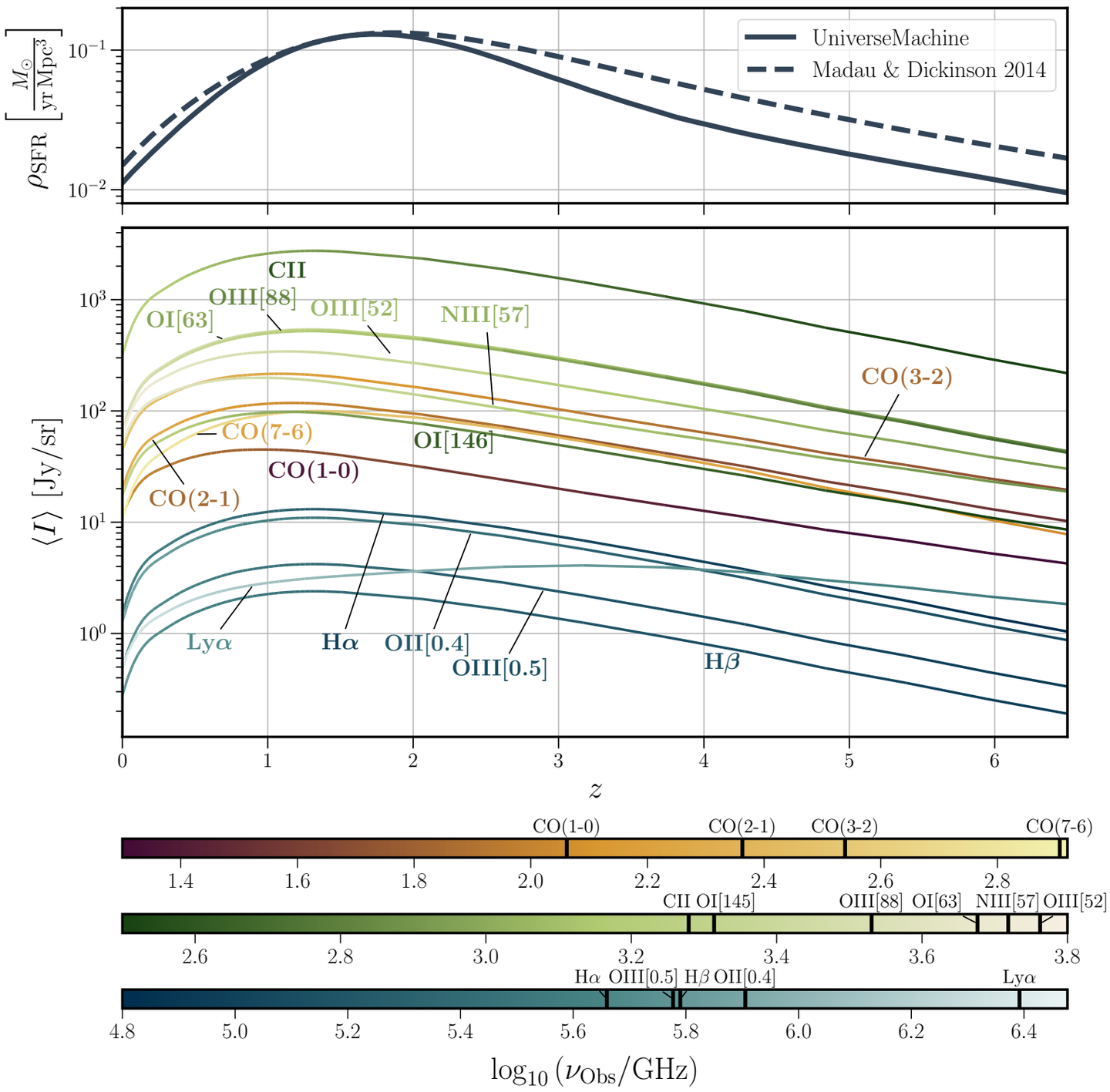


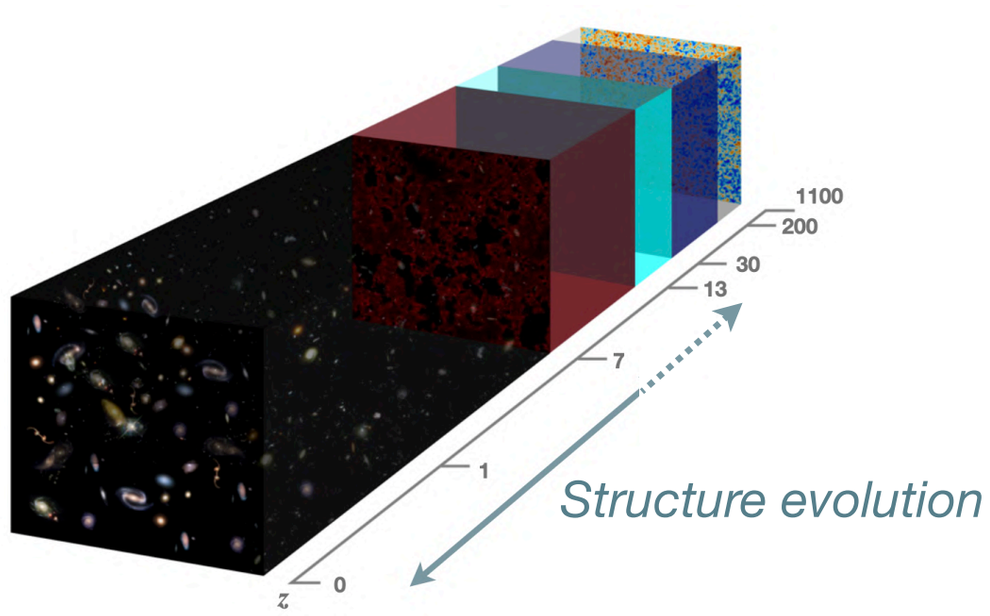


Bernal and Kovetz, arXiv:2206.15377, The Astronomy and Astrophysics Review

Galactic Emission Lines

Tracers of the star-formation rate:





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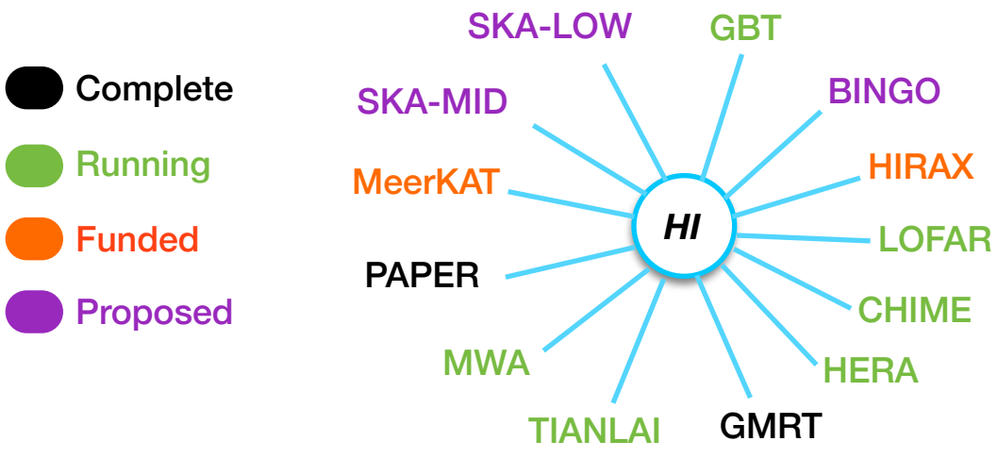

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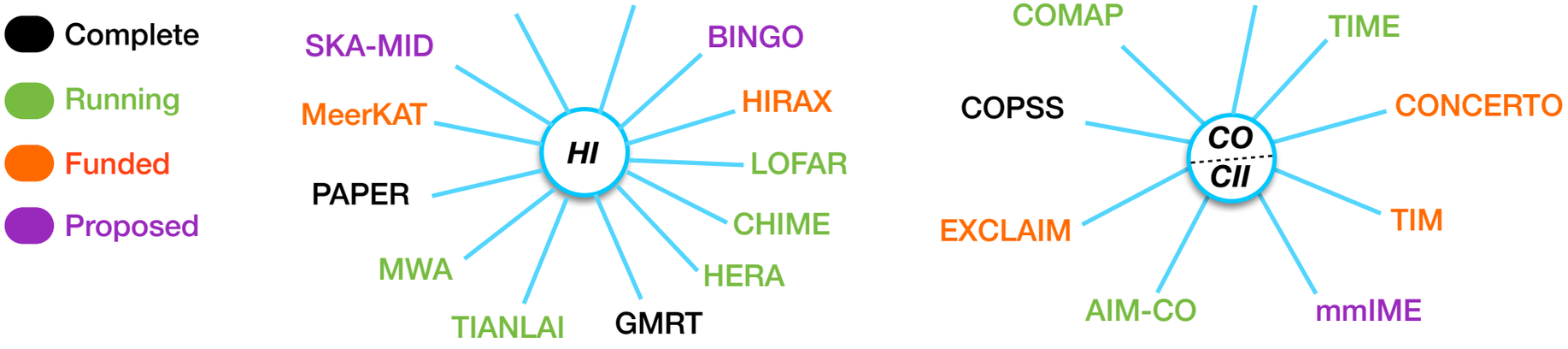

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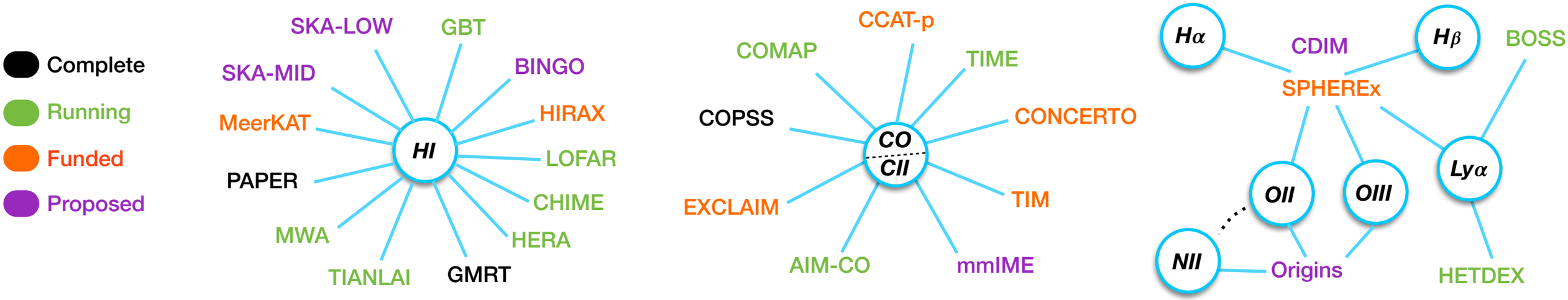

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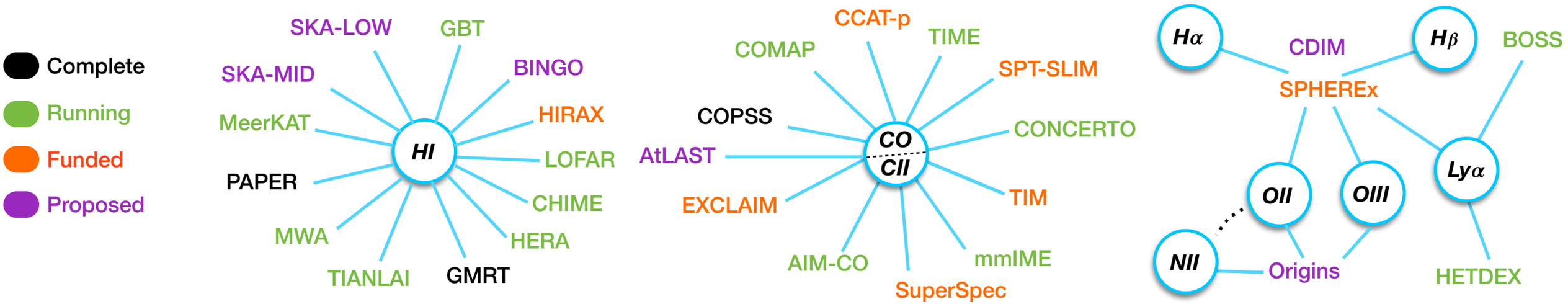

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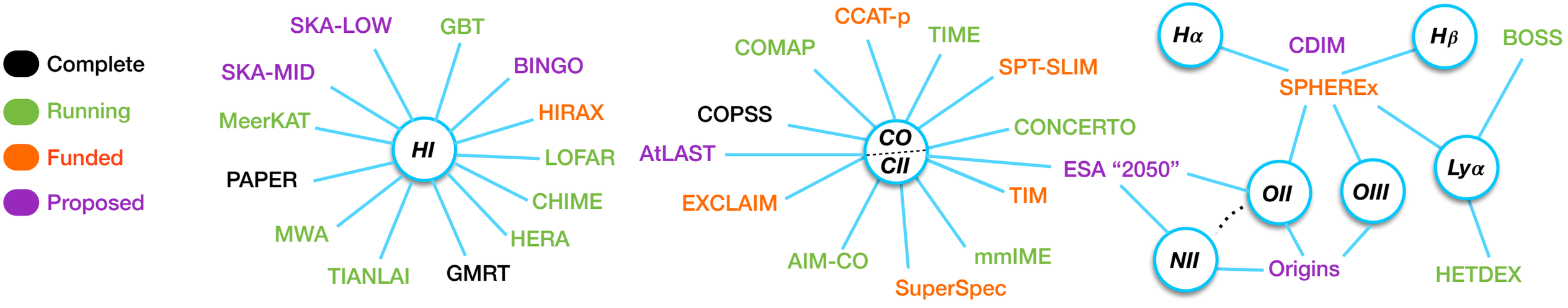

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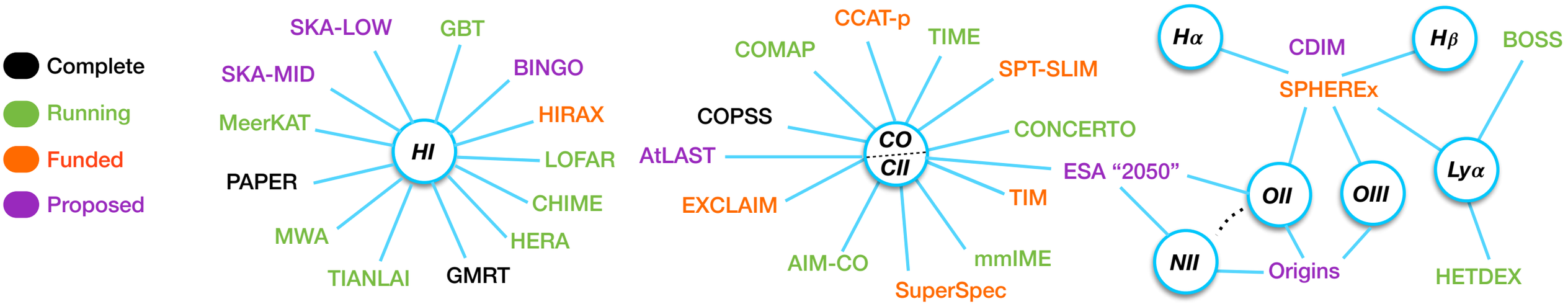

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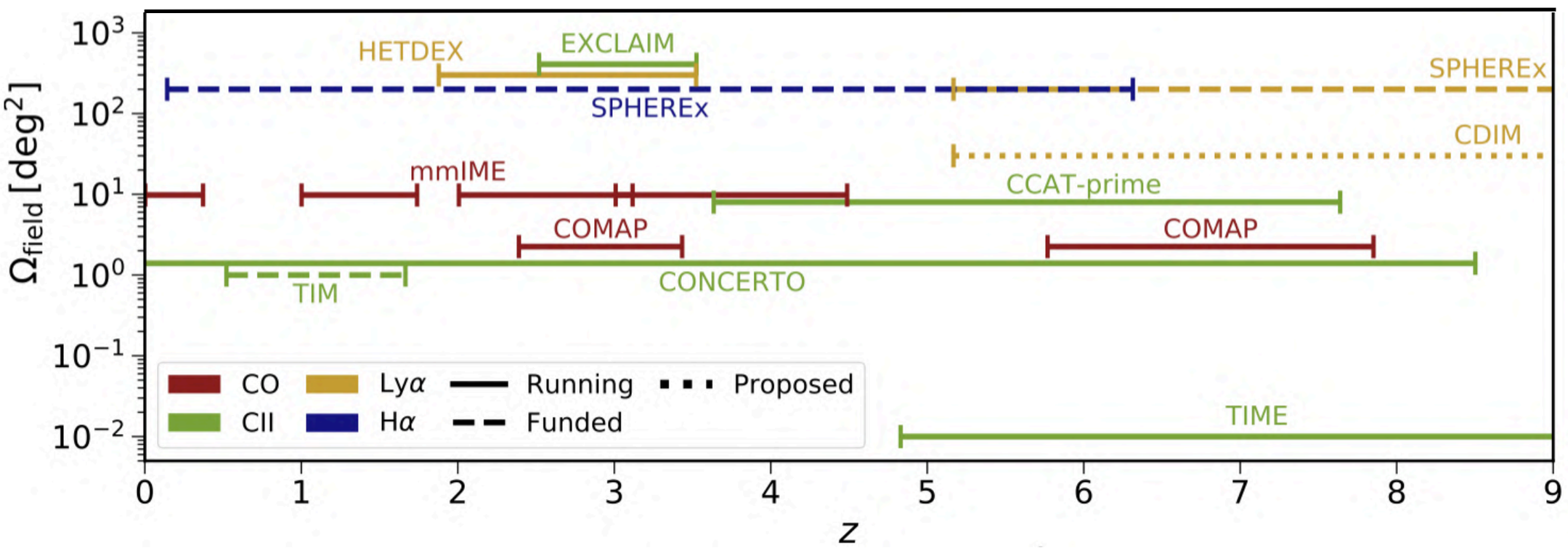

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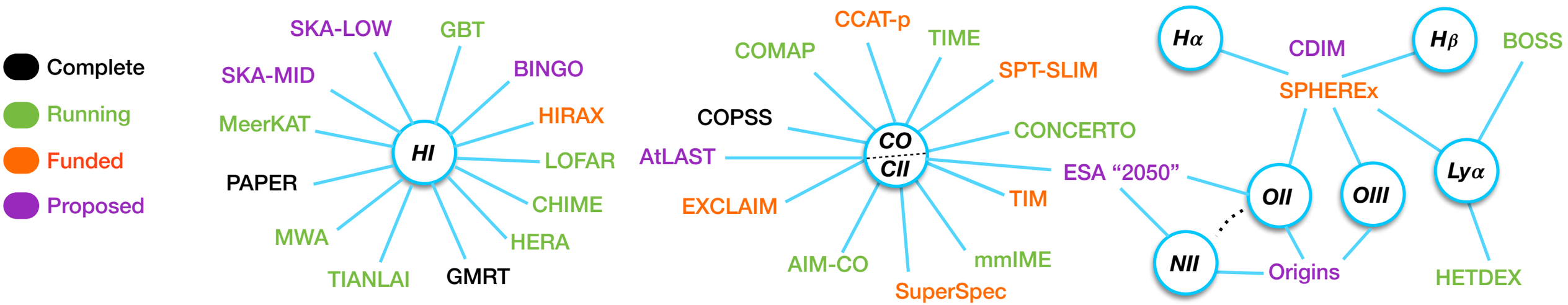

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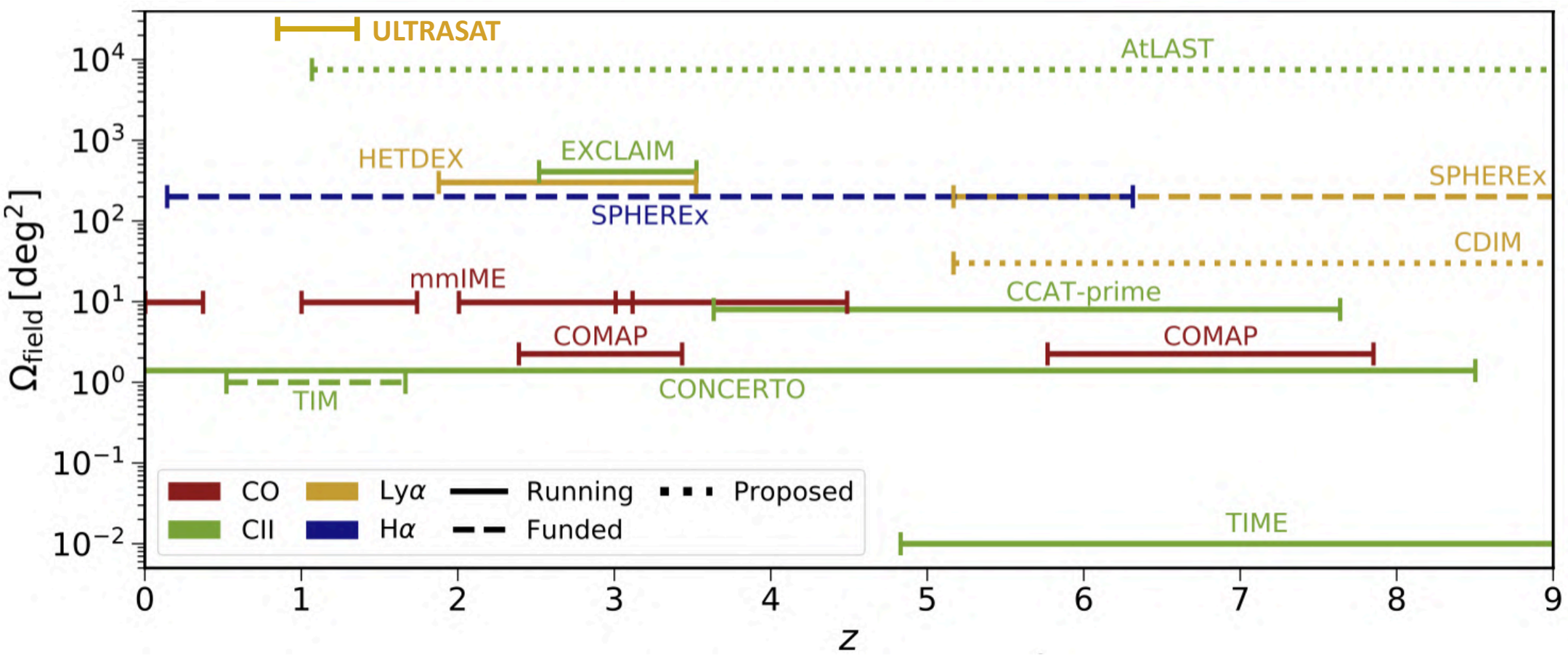

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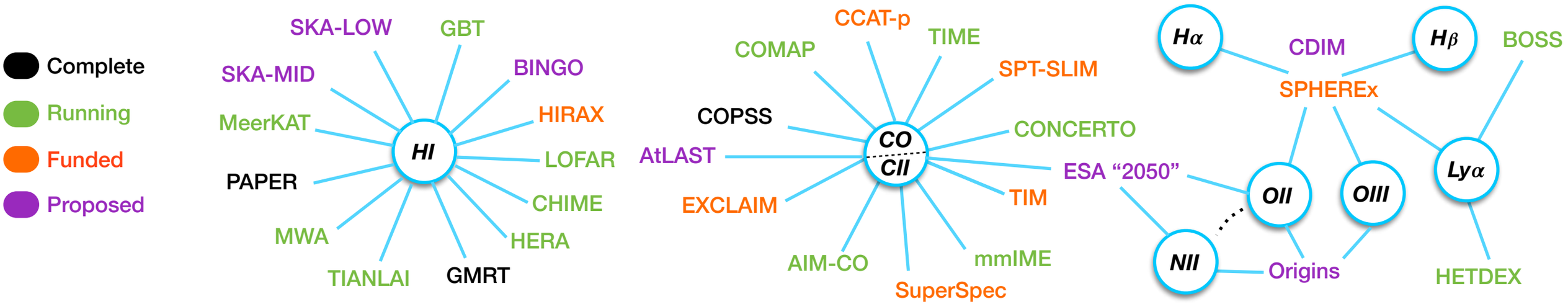

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	ULTRASAT	GALEX	SPHEREx	HETDEX
$\bar{\lambda}_{\rm obs}$ [nm]	260	$\{155, 230\}$	$\{820, 1190\}$	$\{370, 520\}$
$\Delta\lambda$ [nm]	60	$\{40, 110\}$	$\{150, 300\}$	$\{40, 60\}$
$z^{\rm Ly\alpha}$	$[0.9, 1.4]$	$[0.1, 0.5], [0.4, 1.3]$	$[4.7, 7.3], [6.8, 12]$	$[1.7, 2.4], [2.8, 3.8]$
$\Omega_{\rm field}$ [deg^2]	$\sim 20\,000$	$\sim 20\,000$	200	$300 + 150$
$\sigma_{\rm FWHM}$ [arcsec]	8.3	~ 5	6.2	5.47
$\sigma_{N,1\,\rm vox}$ [Jy/sr]	656	7797	$\{981, 1006\}$	57

Line-Intensity Mapping: Science Goals

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From various recent LIM white papers and reviews:

Reviews: Kovetz et al., arXiv:1709.09066; Bernal and Kovetz, TAAR, arXiv:2206.15377

WPs: *Astro2020*: Kovetz et al., 1903.04496; *ESA2050*: Silva, Kovetz et al., 1908.07533; *Snowmass2021*: Karkare et al., 2203.07258

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Astrophysics:

- Reionization: bubble sizes, ionized fraction, duration
- Star formation rate (history, peak rise/fall, Pop III stars)
- Metallicity history
- AGN feedback
- Molecular gas density
- IGM density, evolution, clustering
- Faint end of luminosity function
- …
- …

Line-Intensity Mapping: Science Goals

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Reviews: Kovetz et al., arXiv:1709.09066; Bernal and Kovetz, TAAR, arXiv:2206.15377

WPs: *Astro2020*: Kovetz et al., 1903.04496; *ESA2050*: Silva, Kovetz et al., 1908.07533; *Snowmass2021*: Karkare et al., 2203.07258

Astrophysics:

- Reionization: bubble sizes, ionized fraction, duration
- Star formation rate (history, peak rise/fall, Pop III stars)
- Metallicity history
- AGN feedback
- Molecular gas density
- IGM density, evolution, clustering
- Faint end of luminosity function
- …
- …

Cosmology:

- Inflation (running, non-gaussianity, oscillations, CIP, etc.)
- Dark matter (clustering, decaying, annihilating, interacting)
- Expansion rate history (BAO, VAO)
- Dark energy (c.c. or dynamical? wa/w0, etc.)
- Neutrinos (sum of masses, hierarchy, decay)
- Optical depth to Reionization (SFR, degeneracies, etc.)
- Modified gravity
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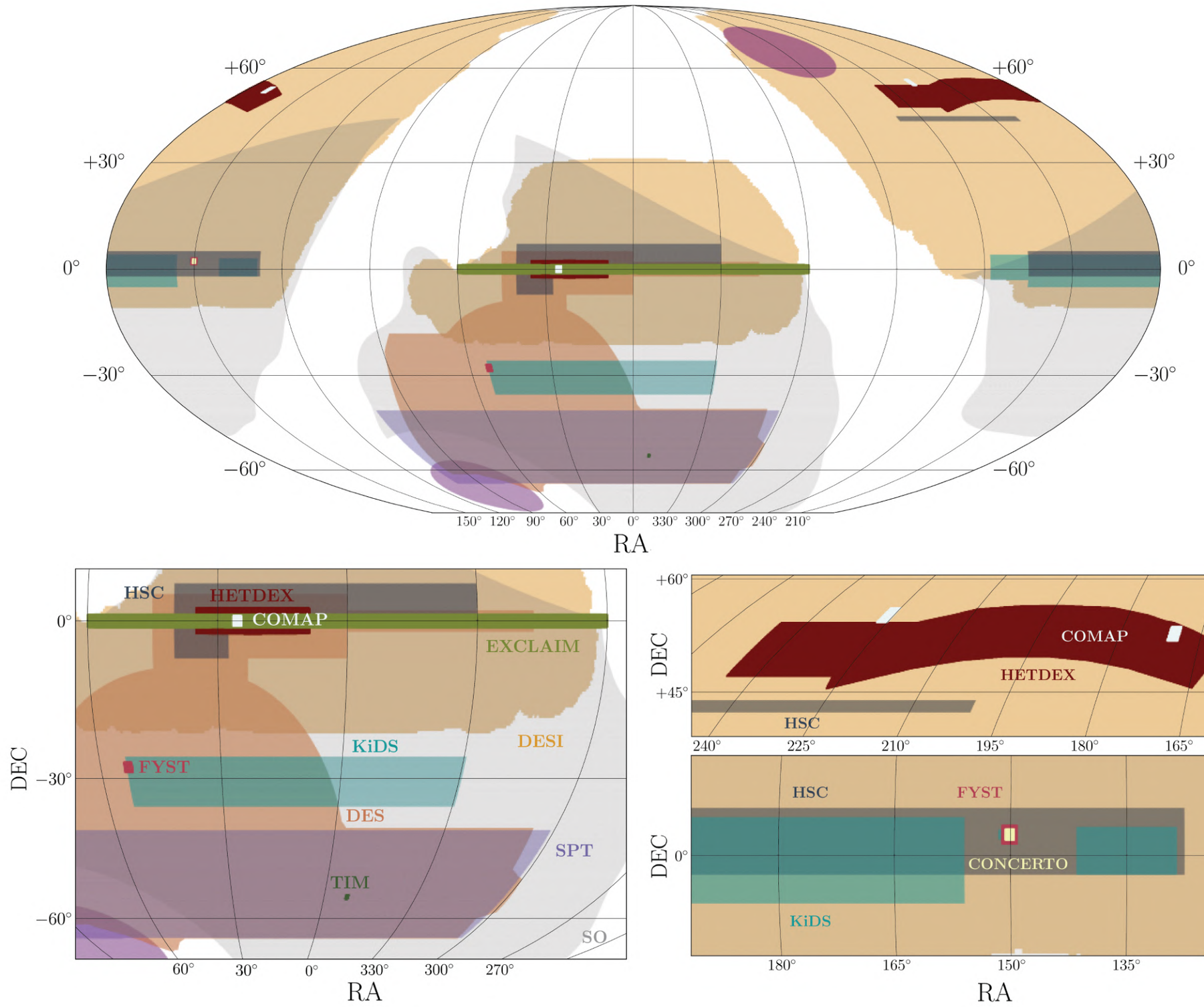
One’s signal is another’s foreground

Line-Intensity Mapping: Cross-Correlations!

(Bernal and Kovetz, arXiv:2206.15377, The Astronomy and Astrophysics Review)



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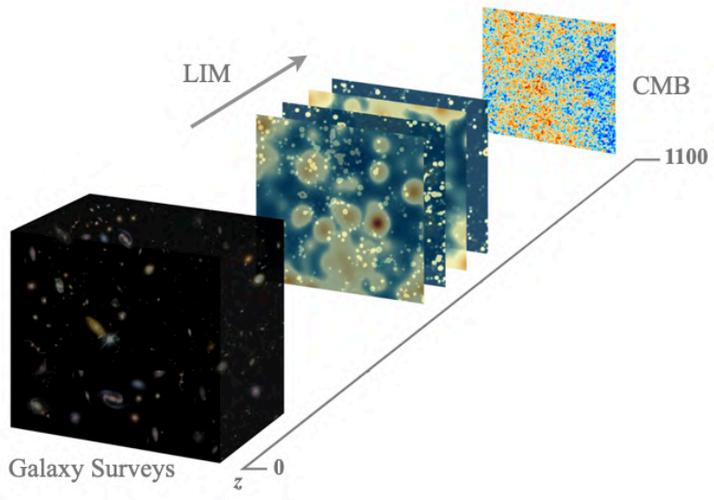
Overlap with galaxy surveys:



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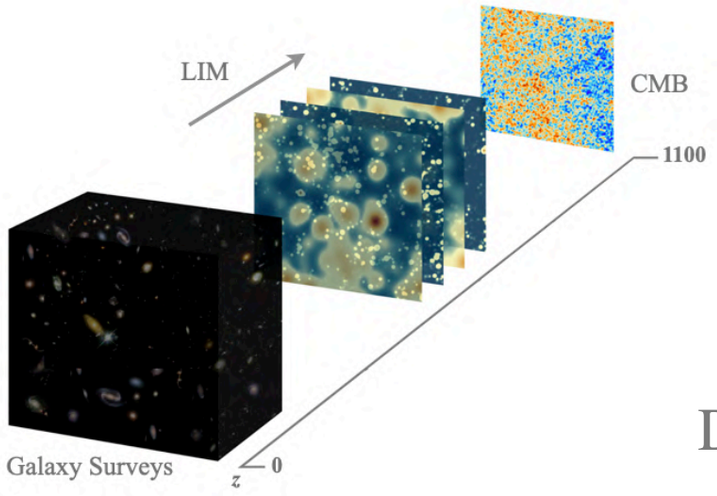
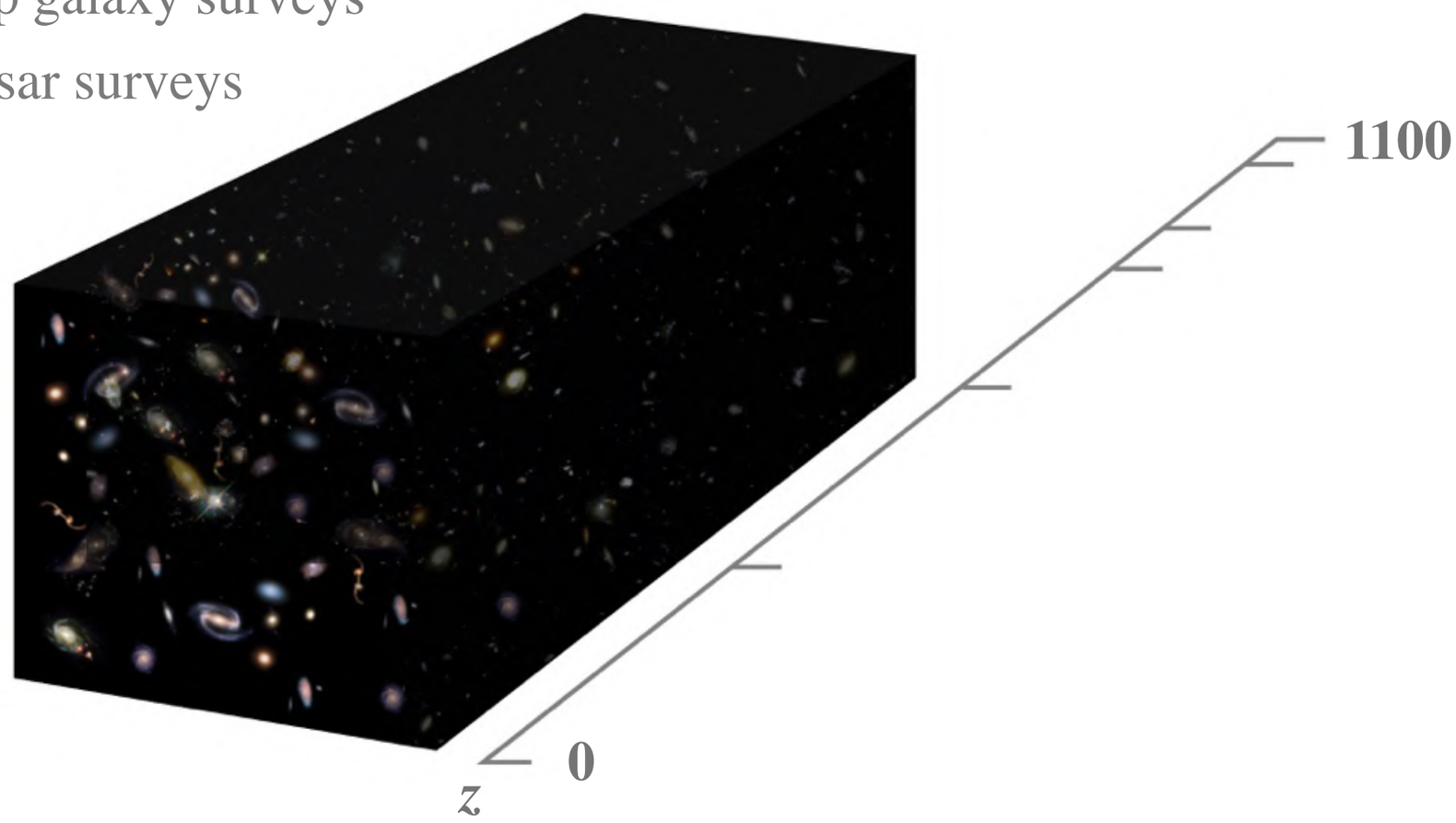


Deep galaxy surveys

Quasar surveys

…



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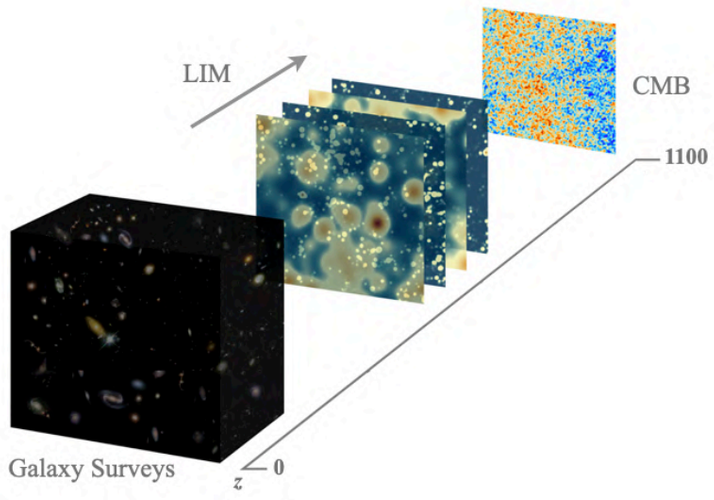
Overlap with CMB secondary anisotropies:



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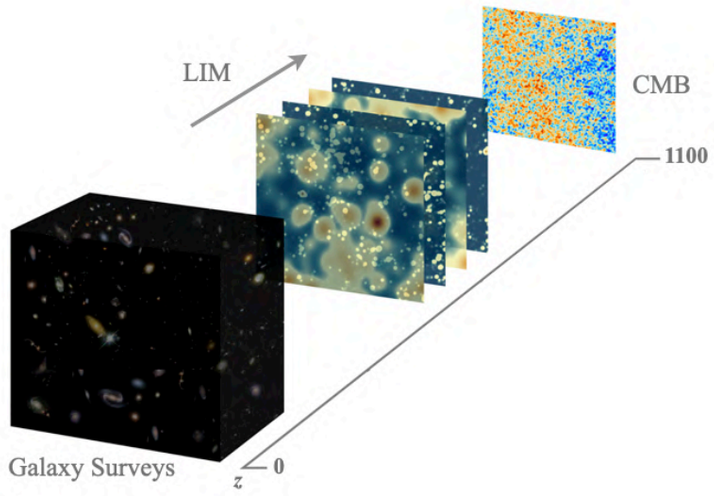

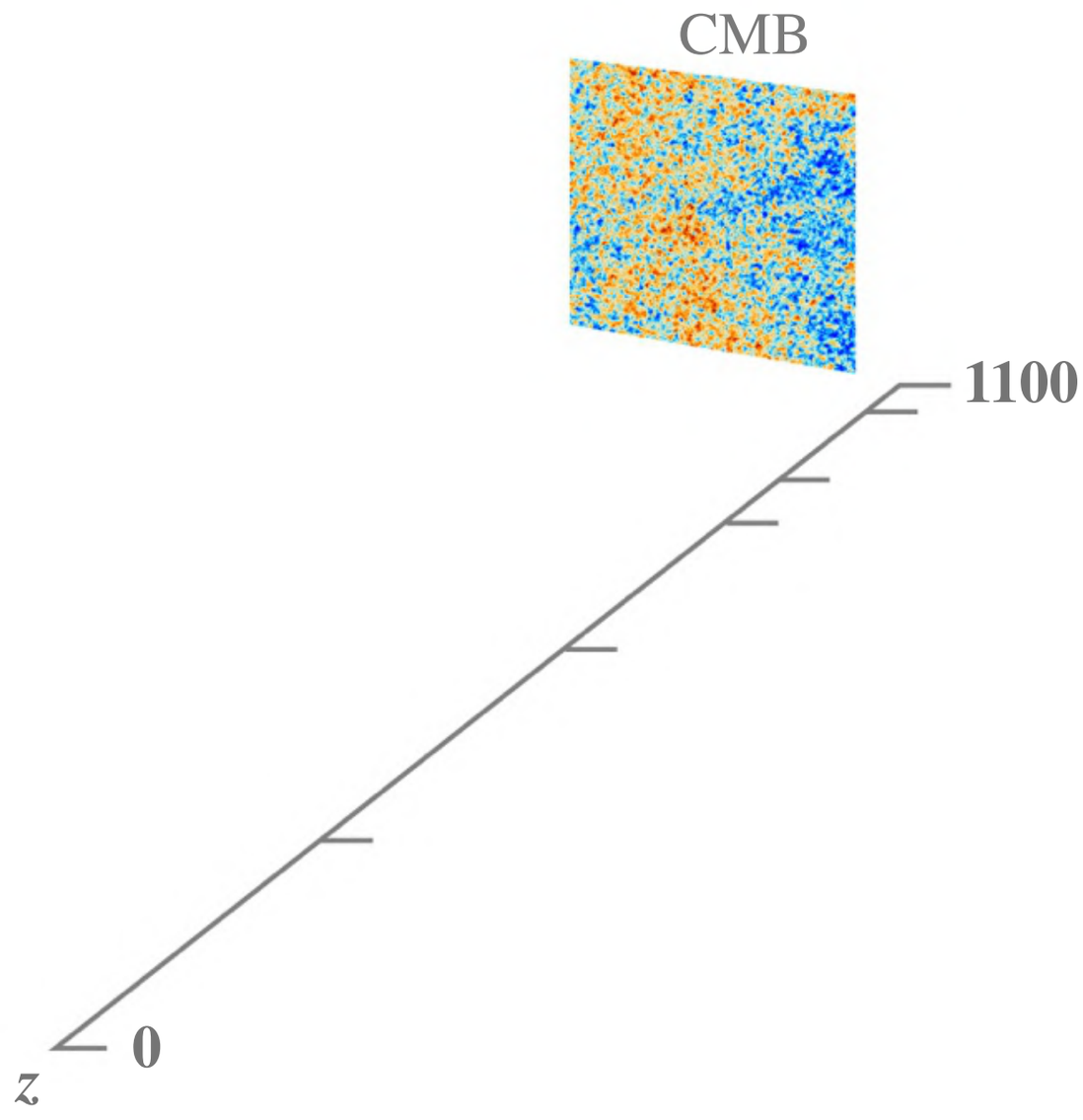

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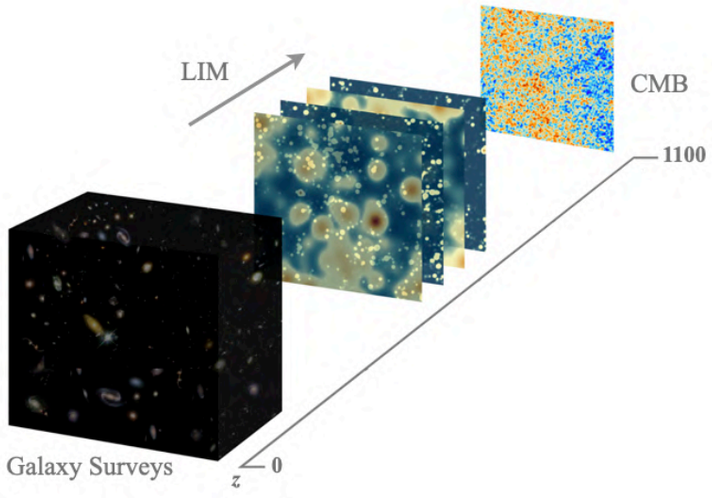

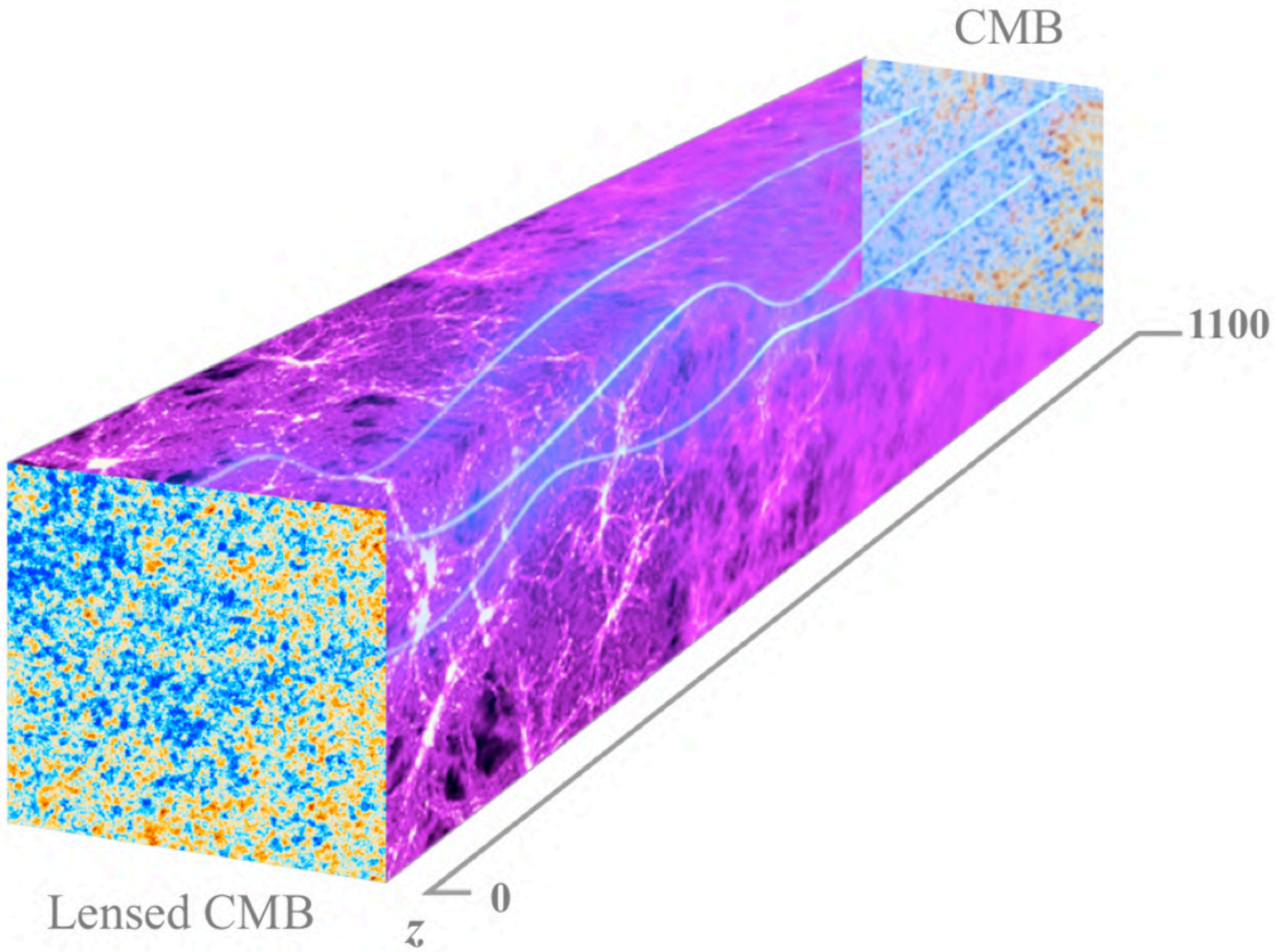

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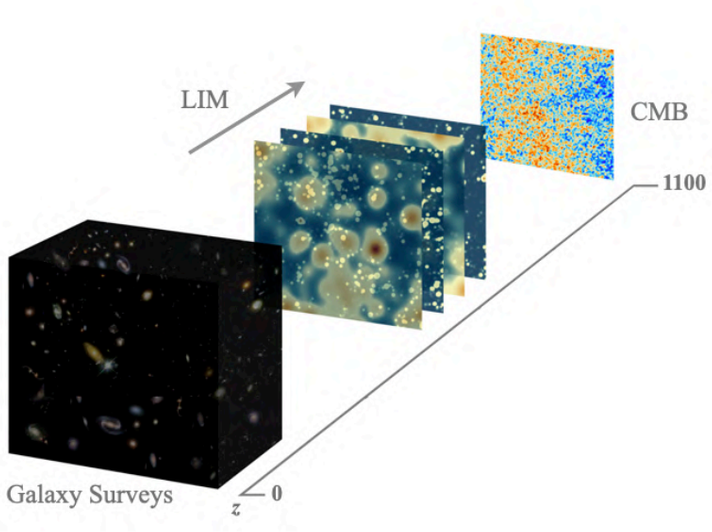

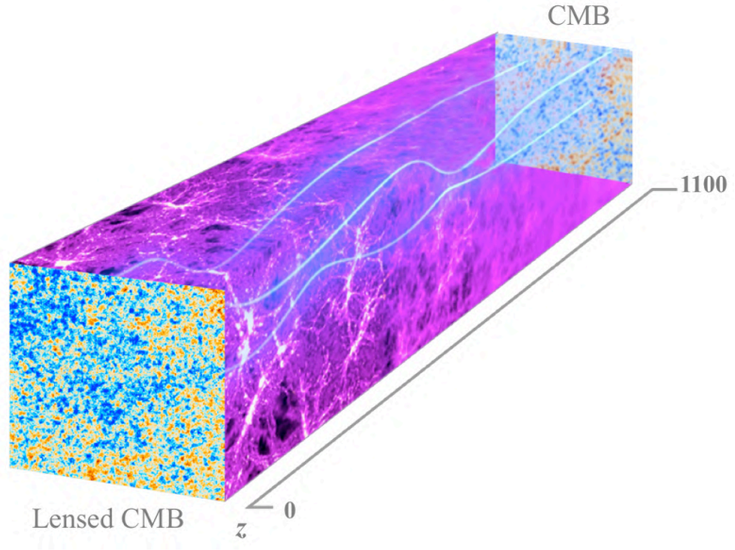

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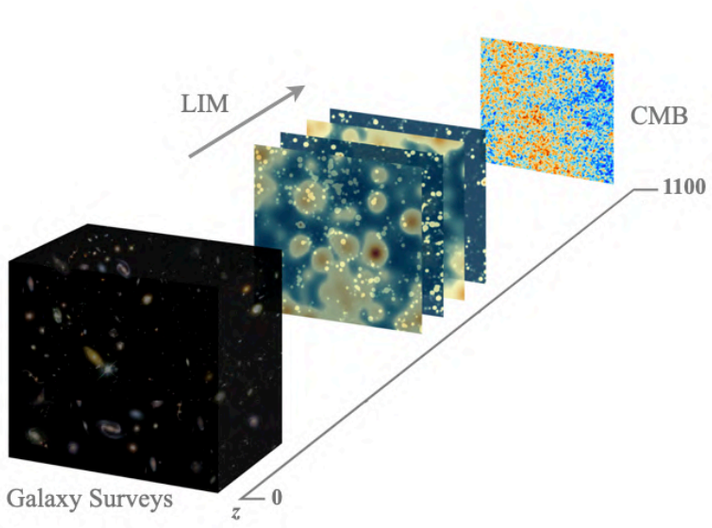

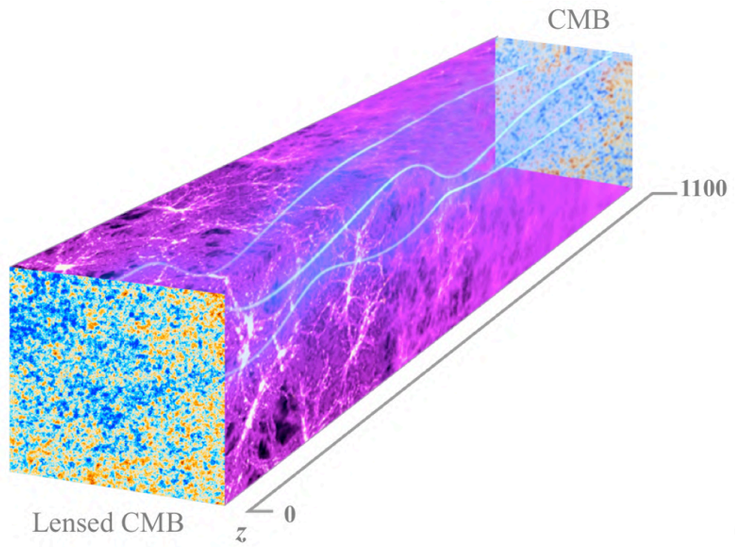

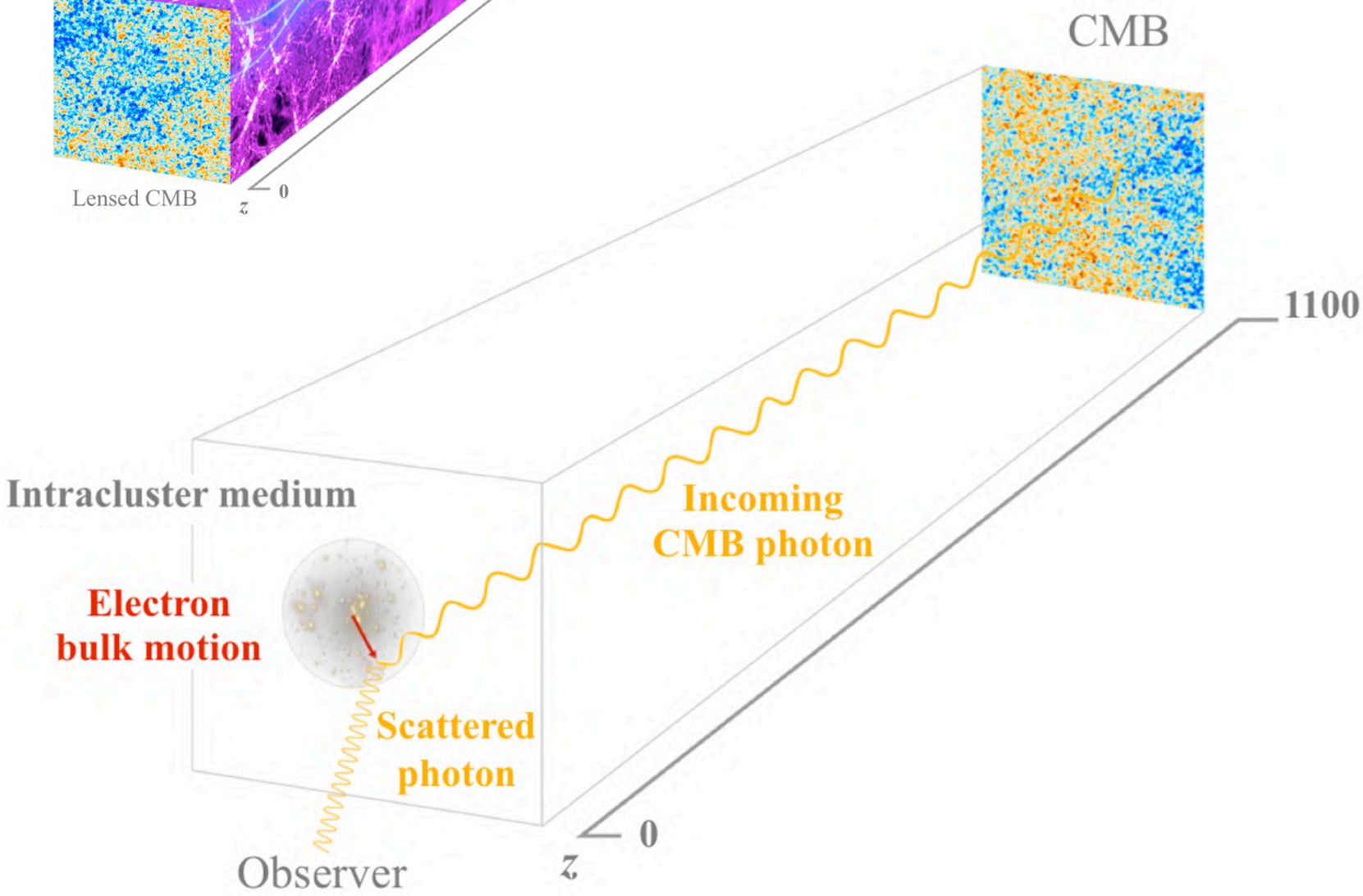

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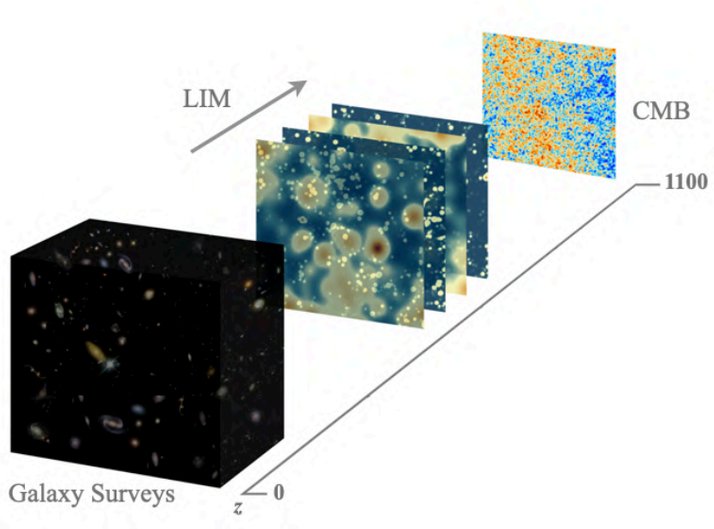

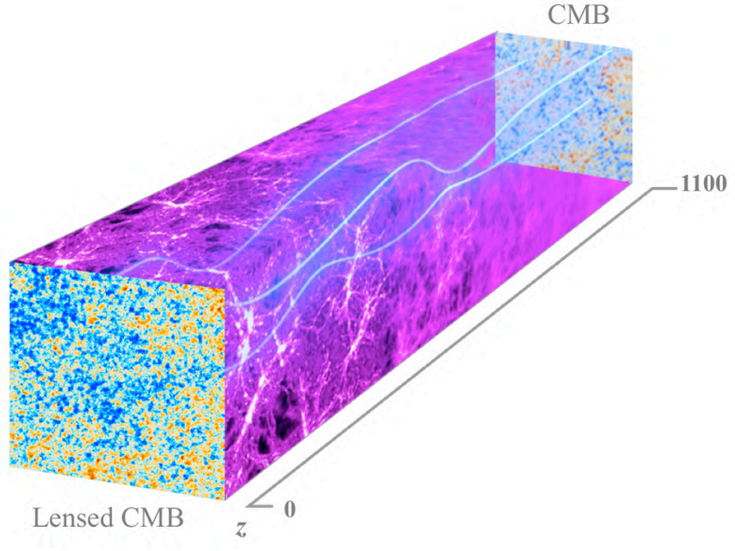

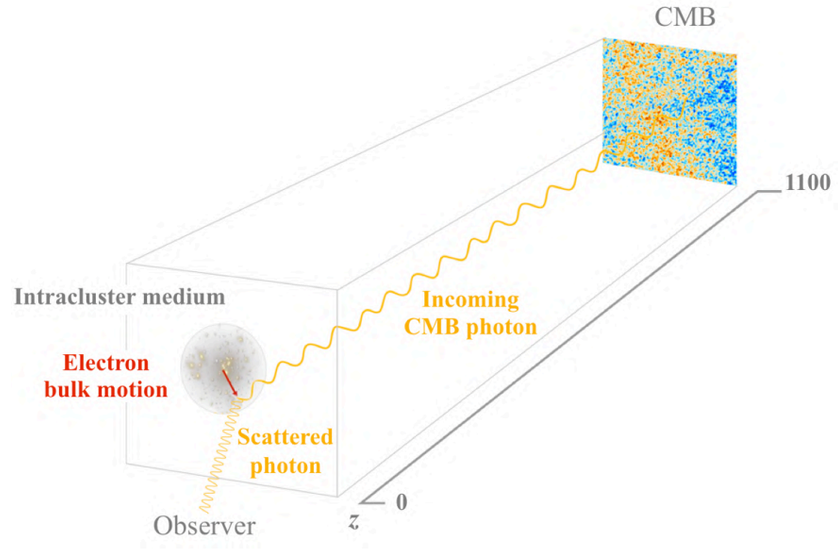

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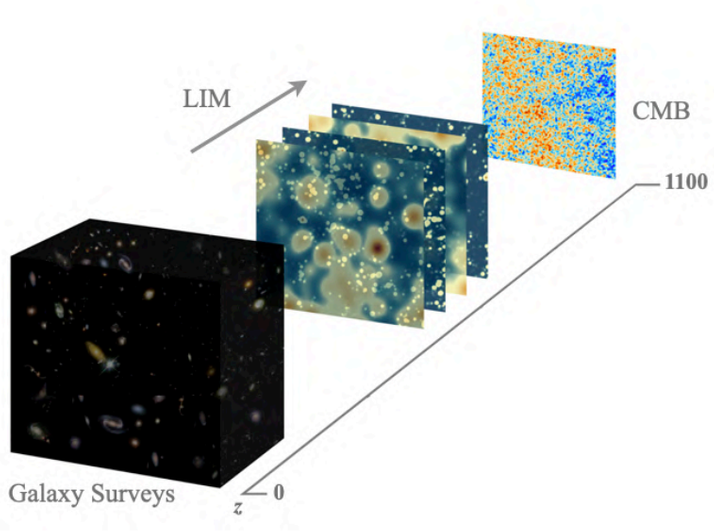

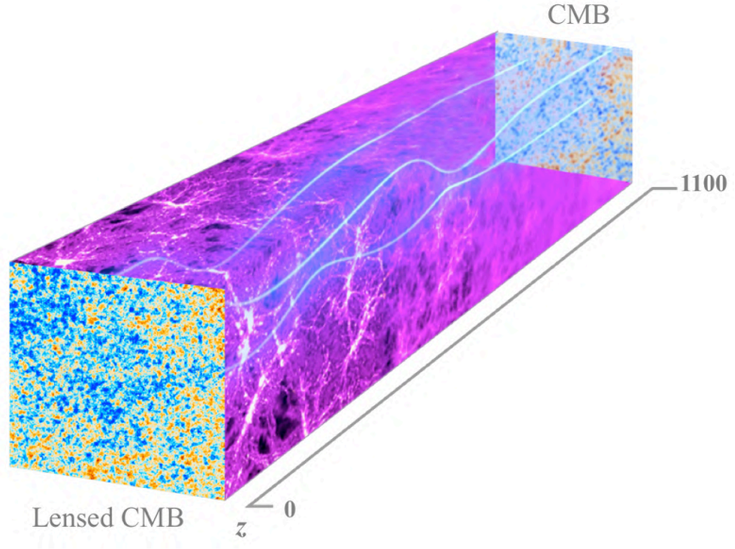

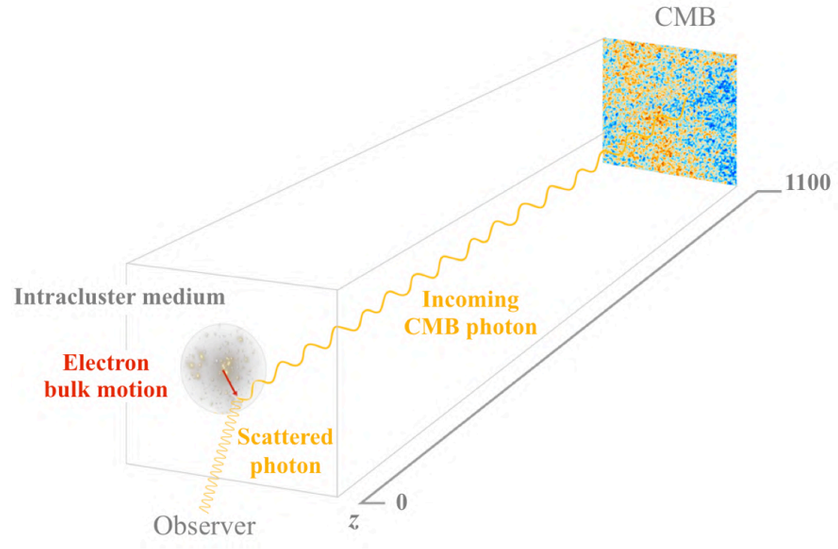

Coming in 2029!

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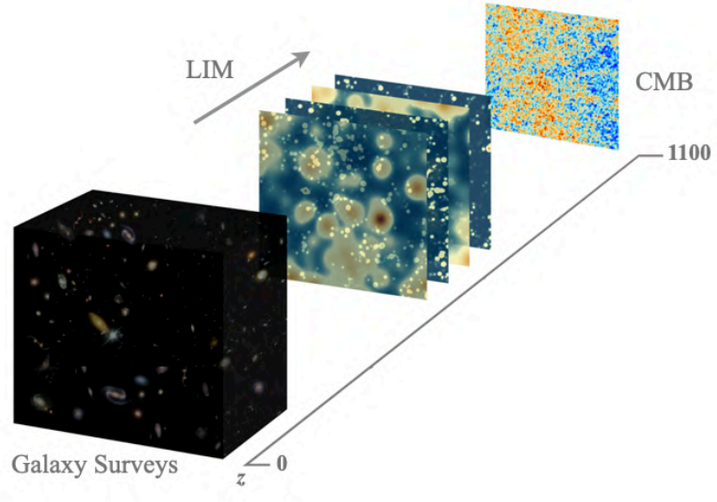

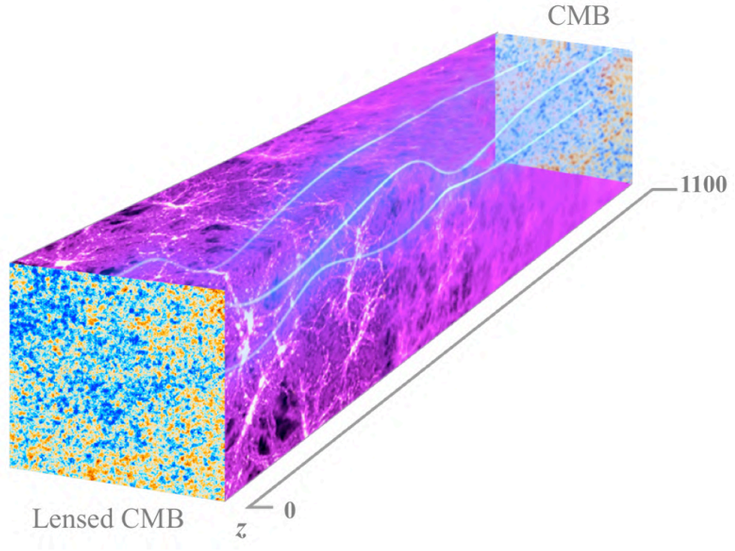

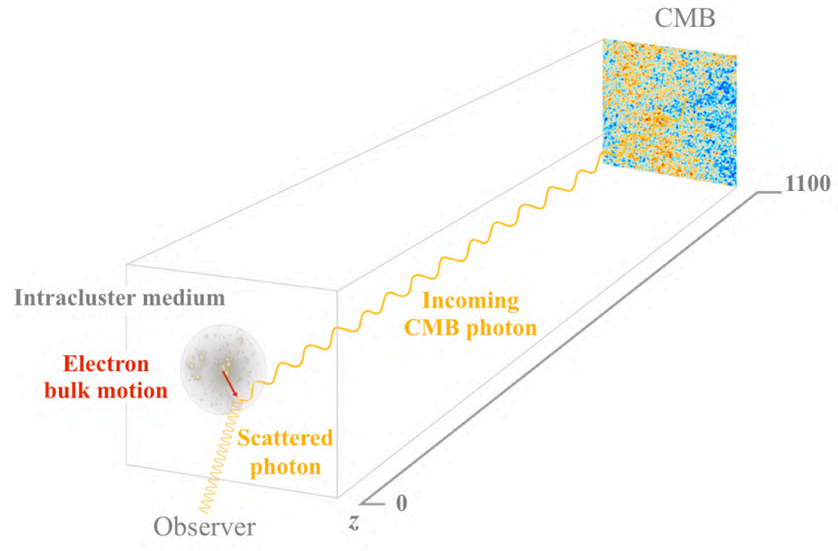

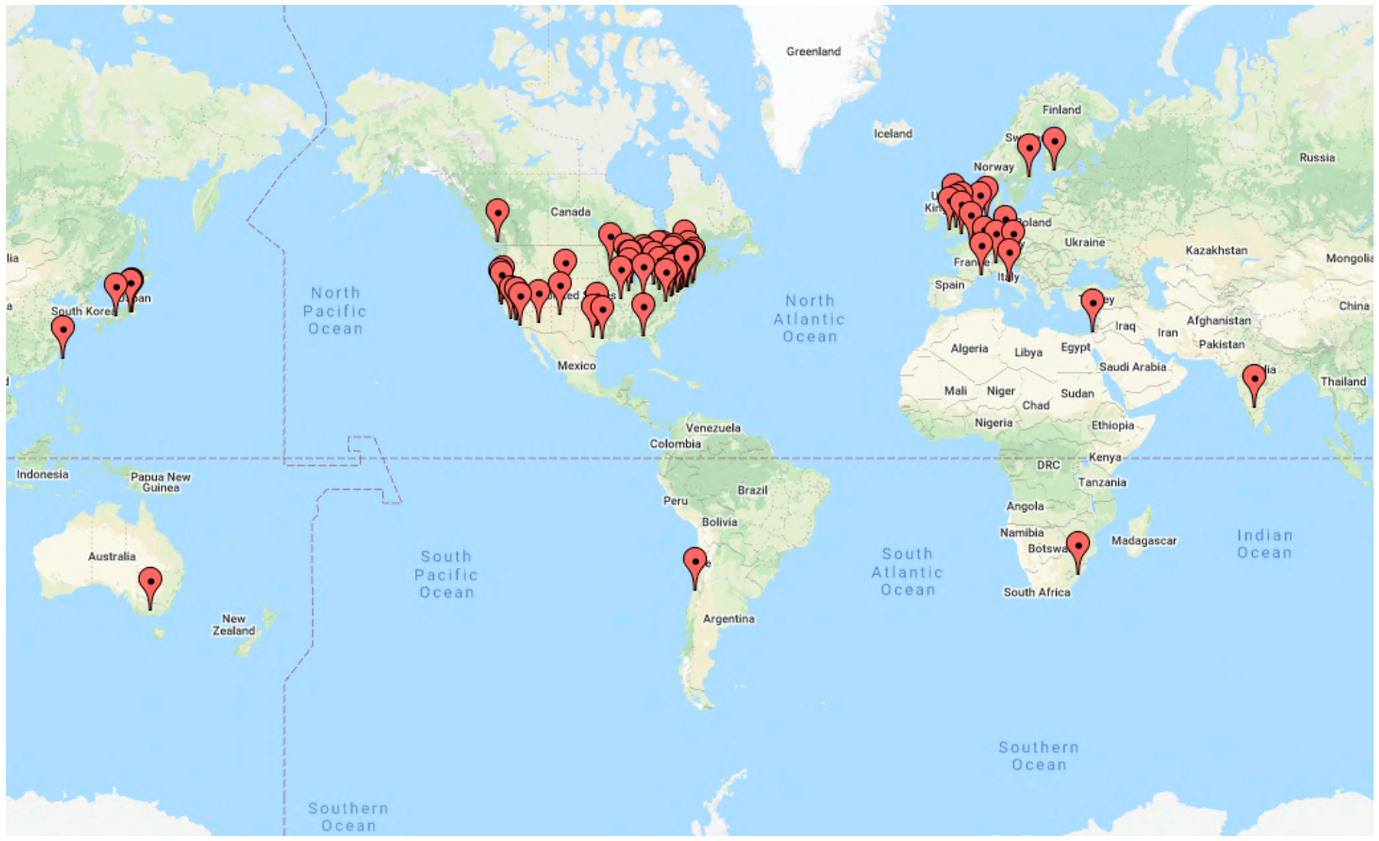

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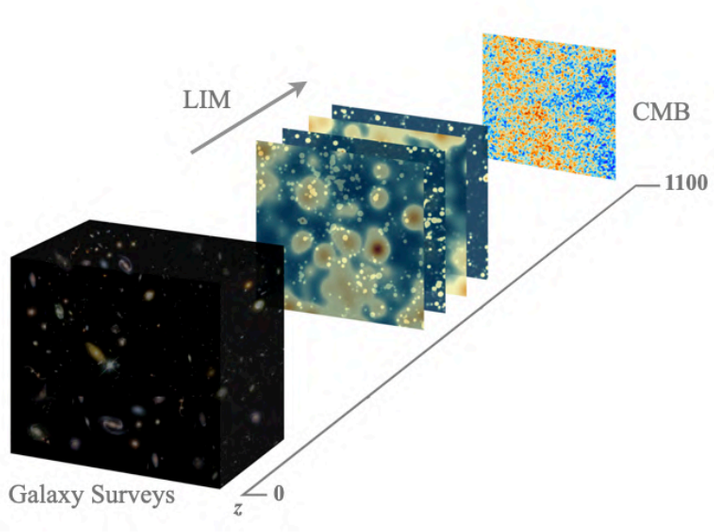

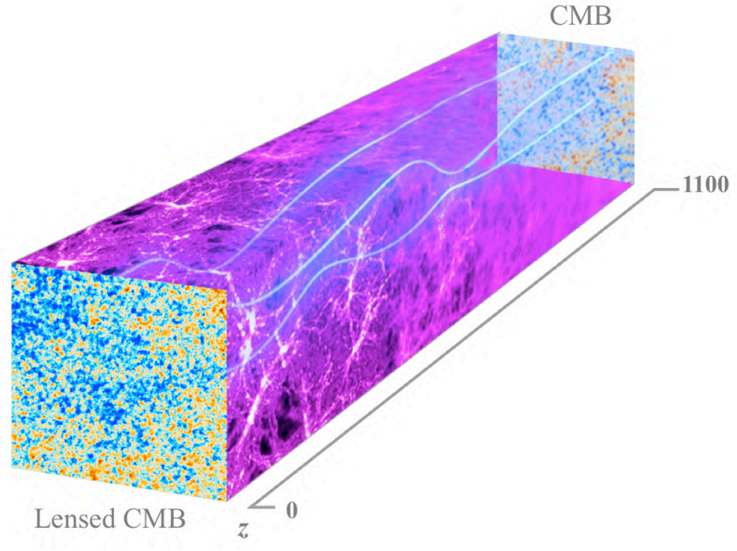

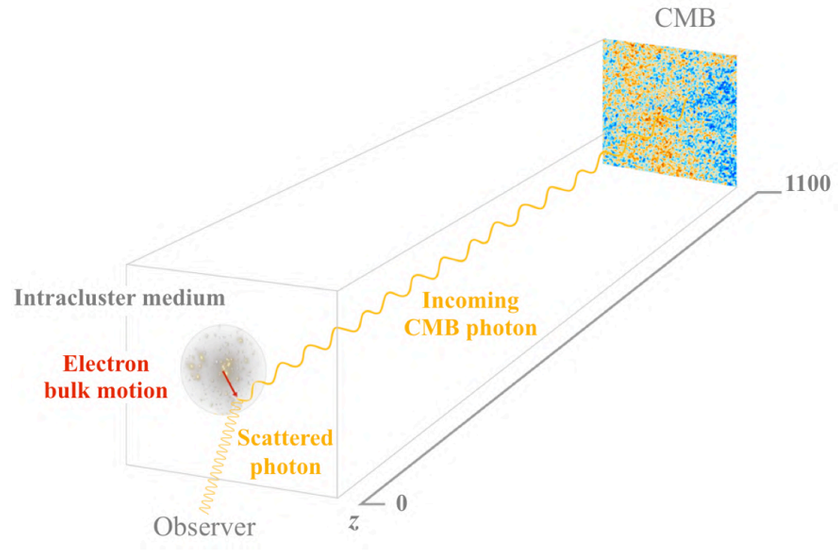

Overlap with astrophysical transients:

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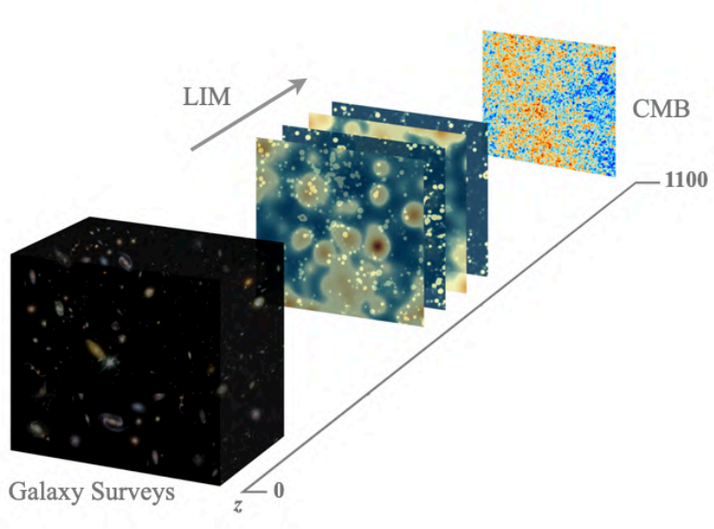

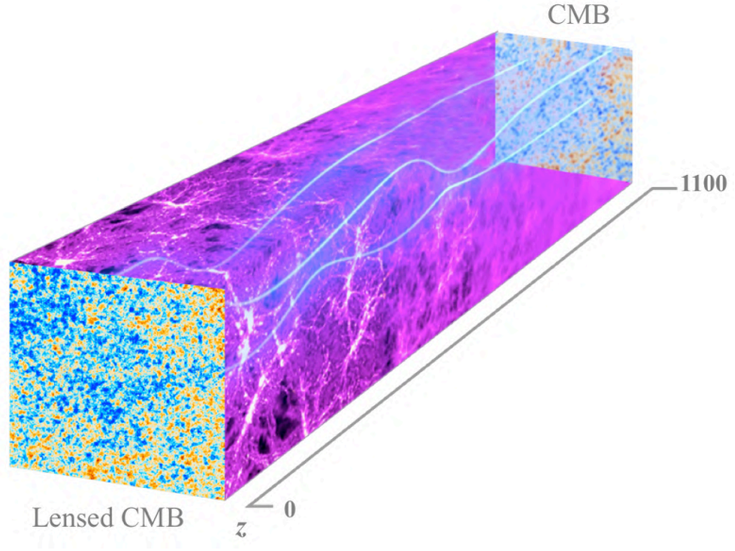

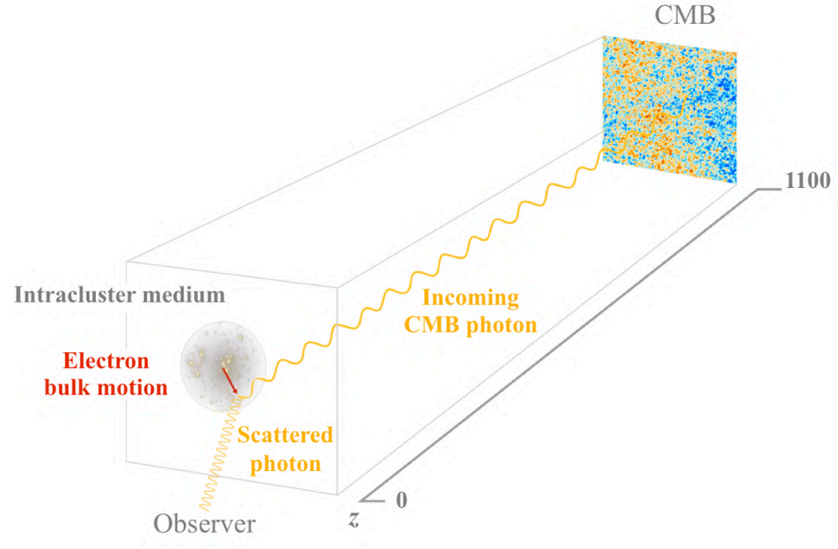

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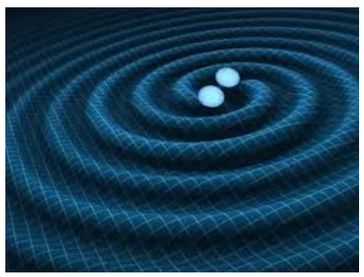

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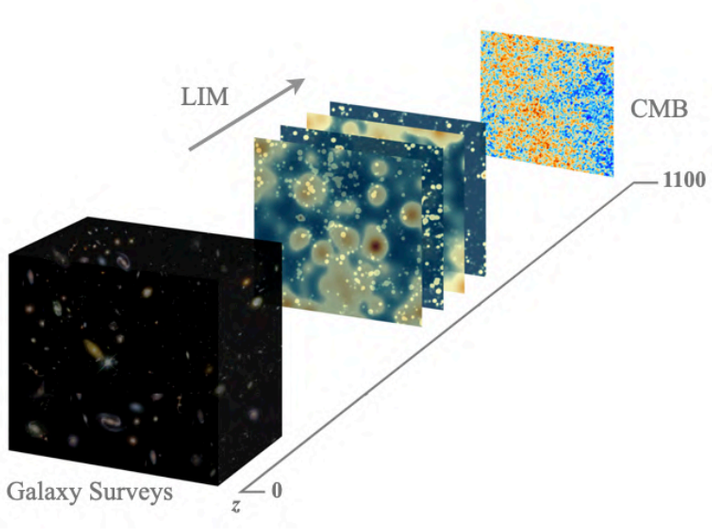

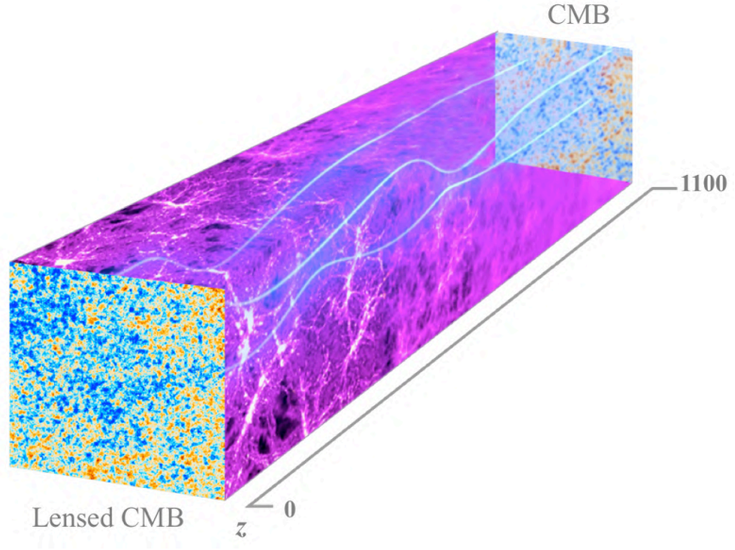

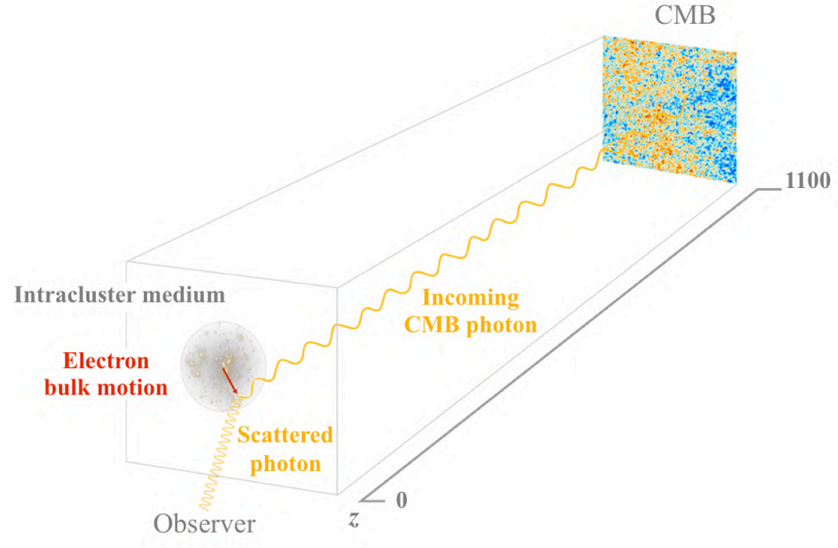

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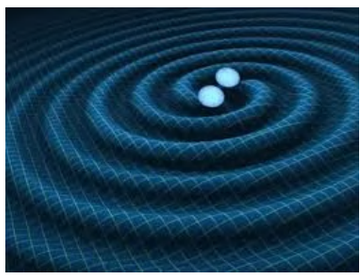

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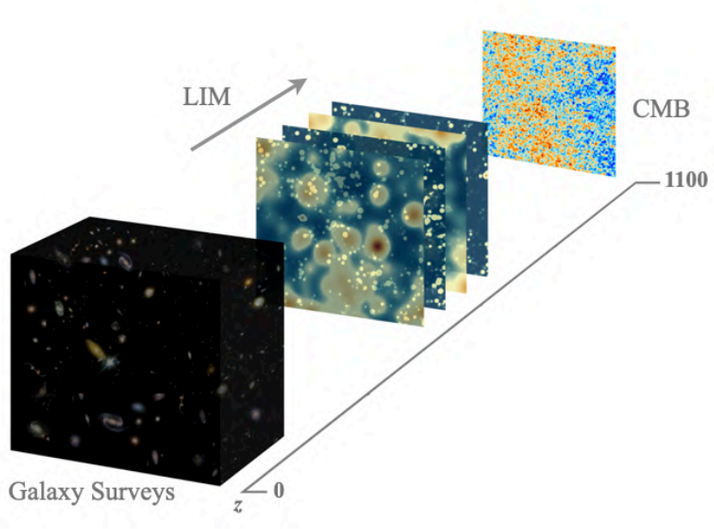

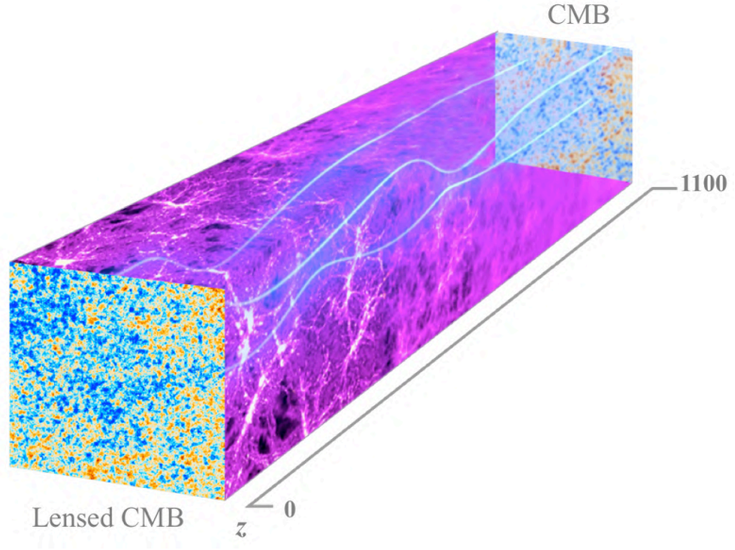

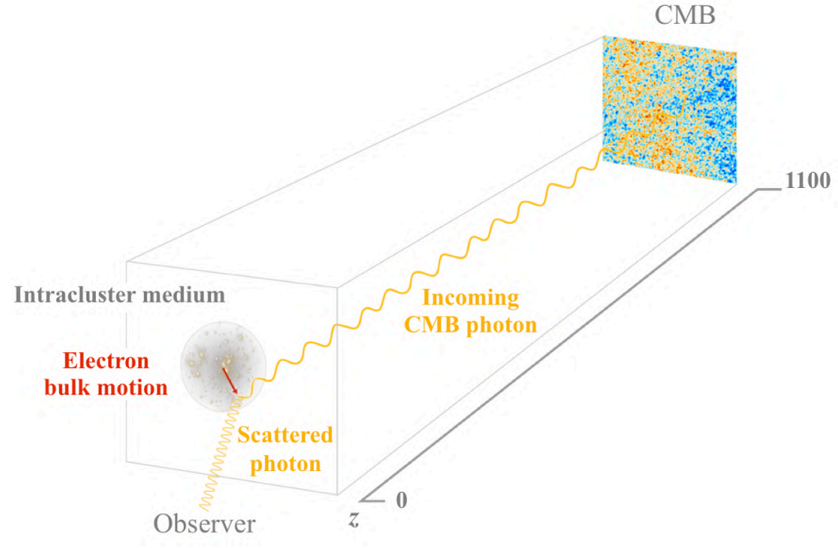

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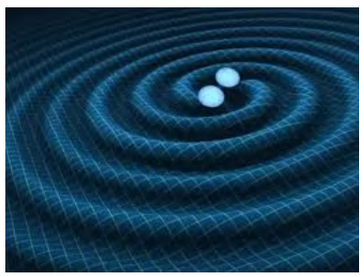

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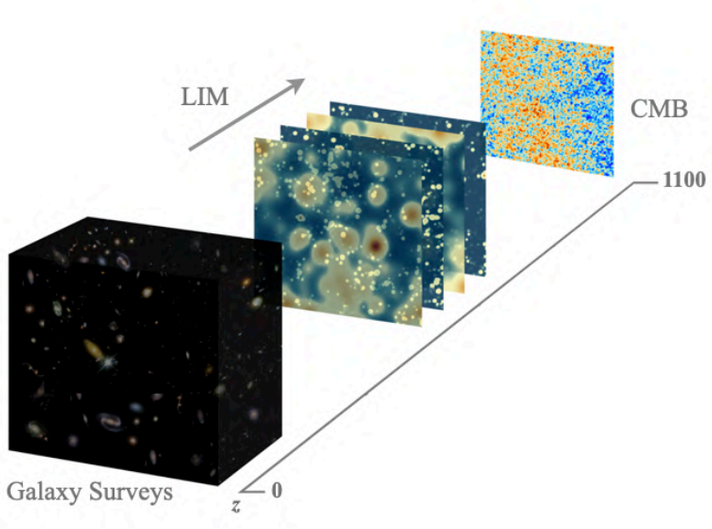

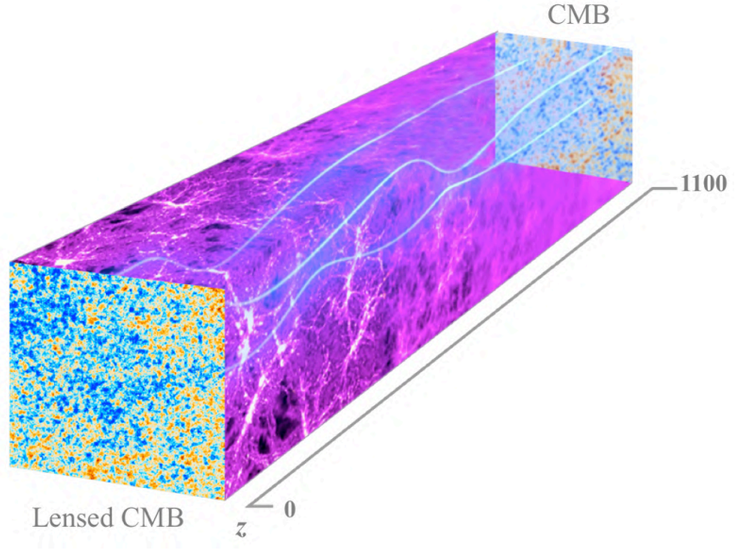

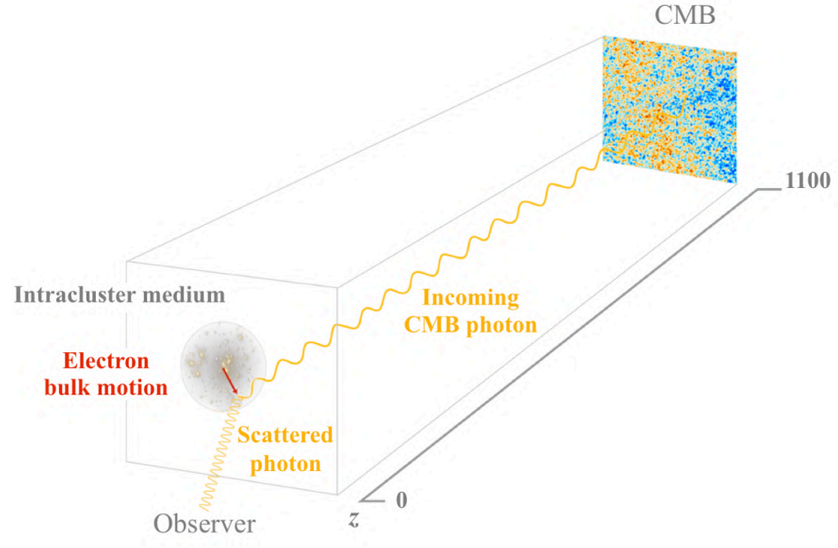

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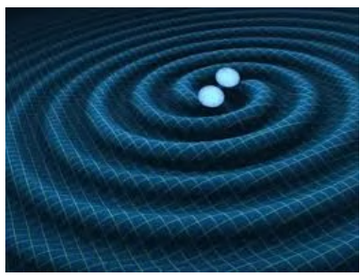

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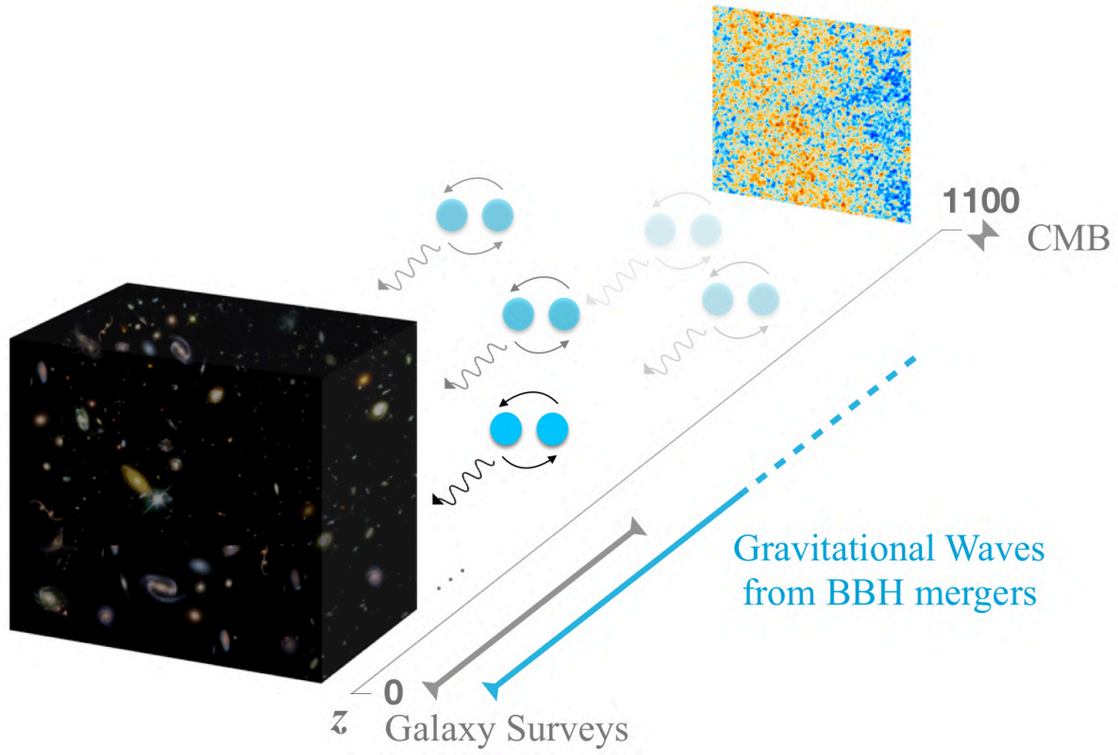

Broadband Line-Intensity Mapping: Tomography

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Clustering-based redshifts:

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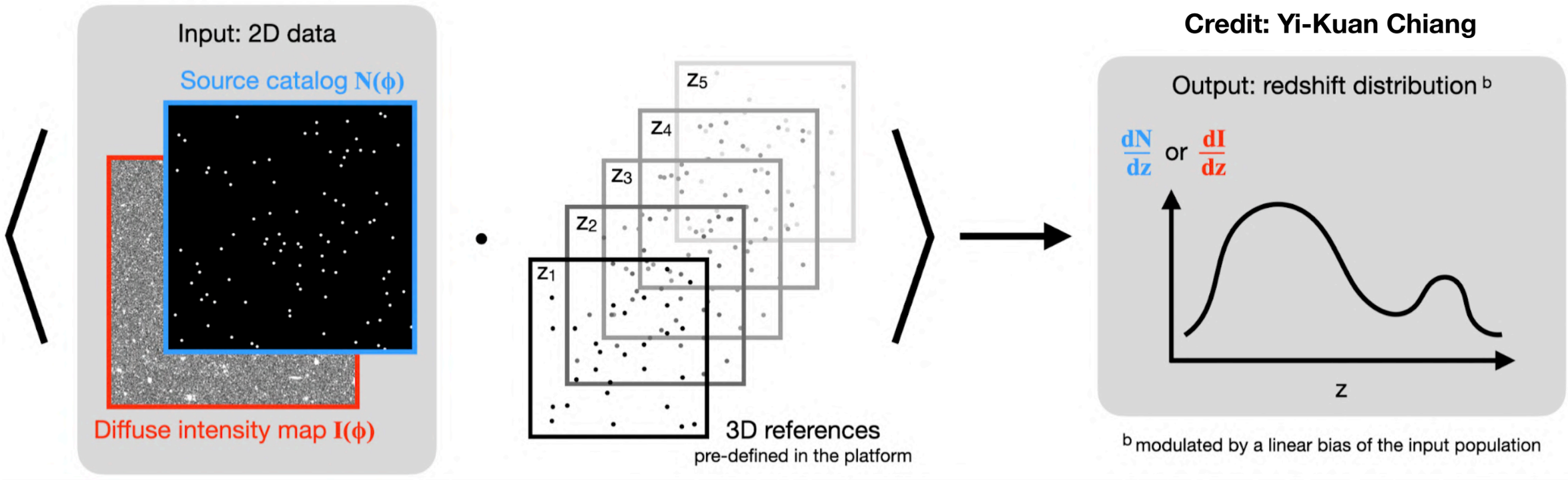

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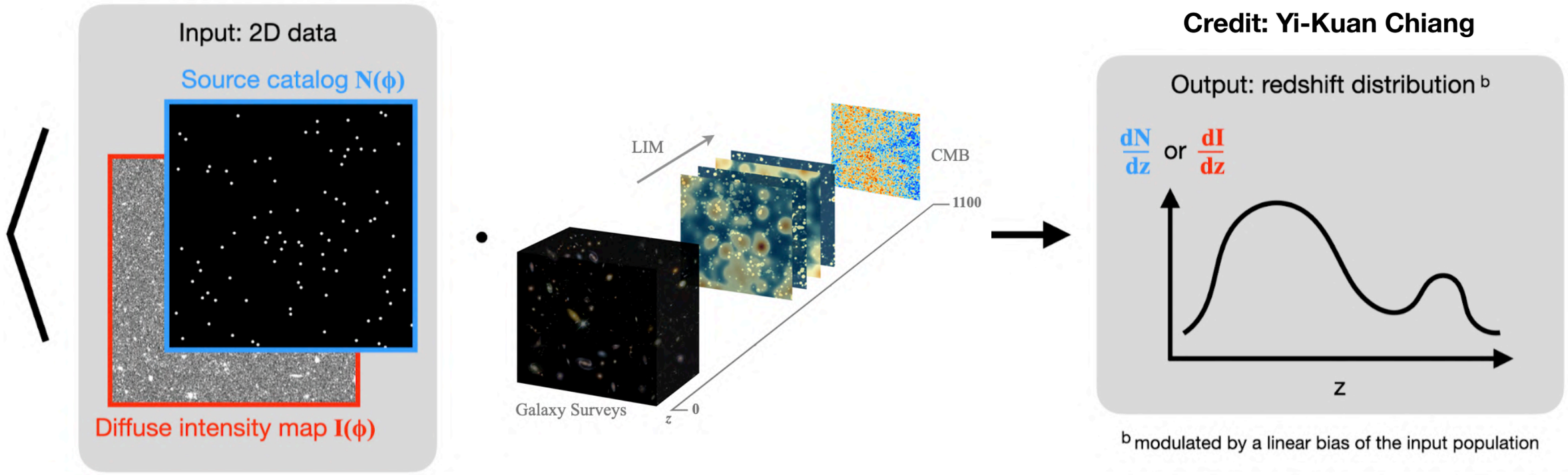

[b] modulated by a linear bias of the input population

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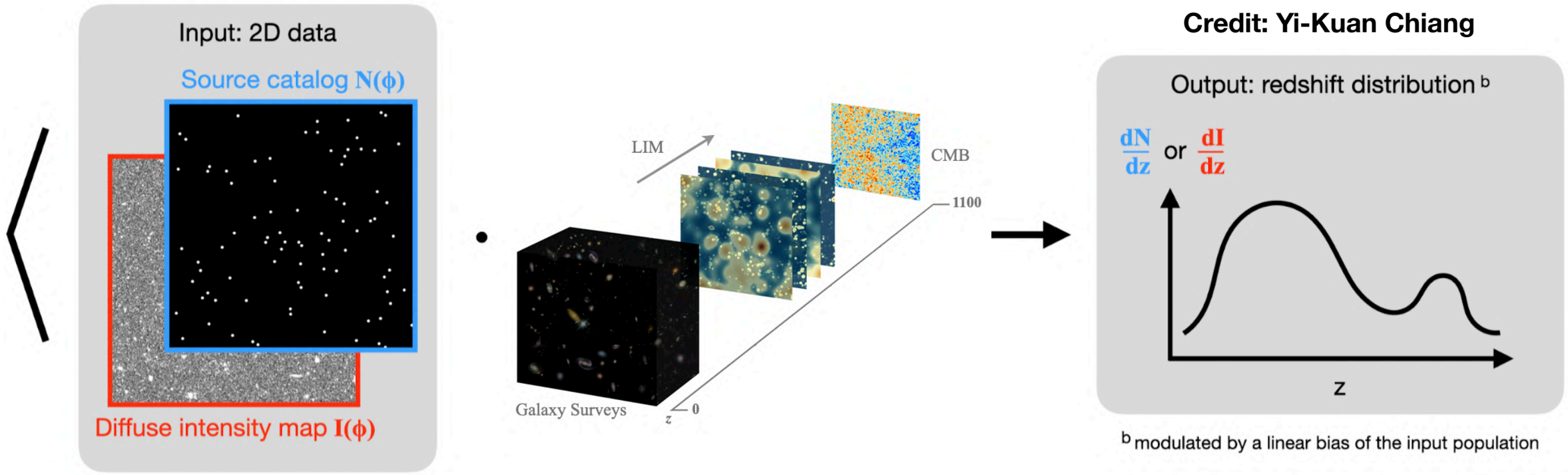

Binning improves constraints, e.g.:

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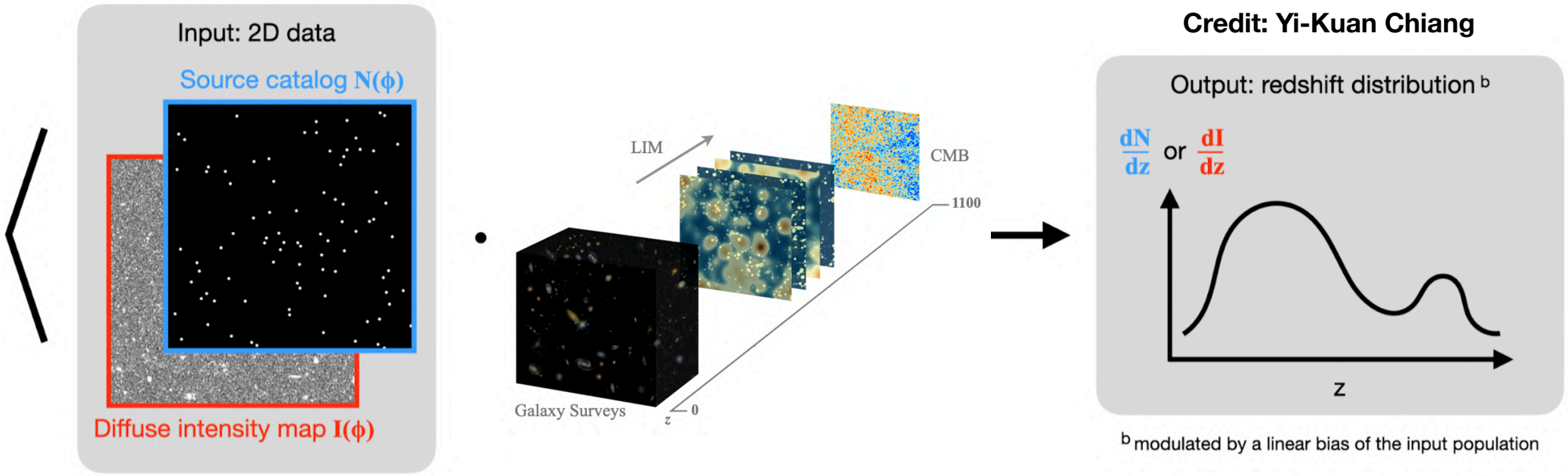

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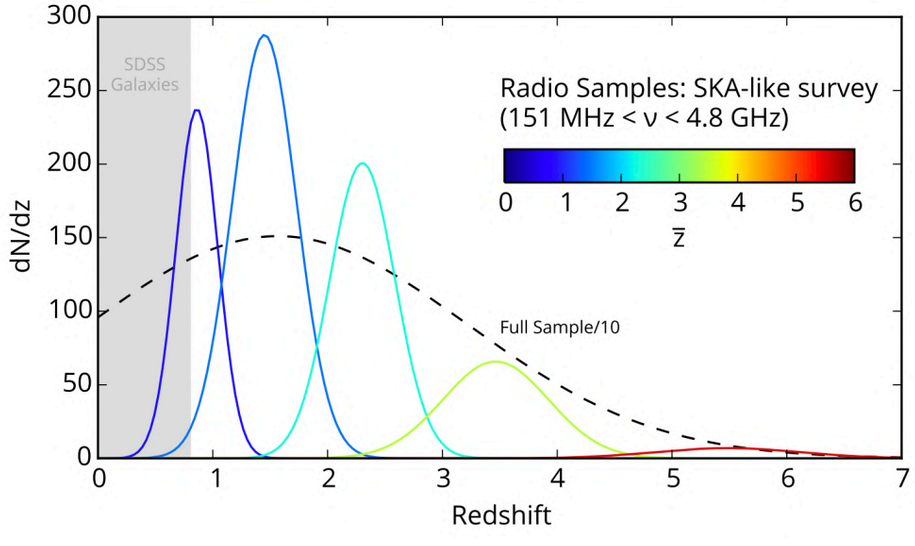

With SKA galaxies:

$$\sigma(f_{\rm NL}) \lesssim \mathcal{O}(1)$$

Kovetz, Rahman and Raccanelli, MNRAS 468 (2017)

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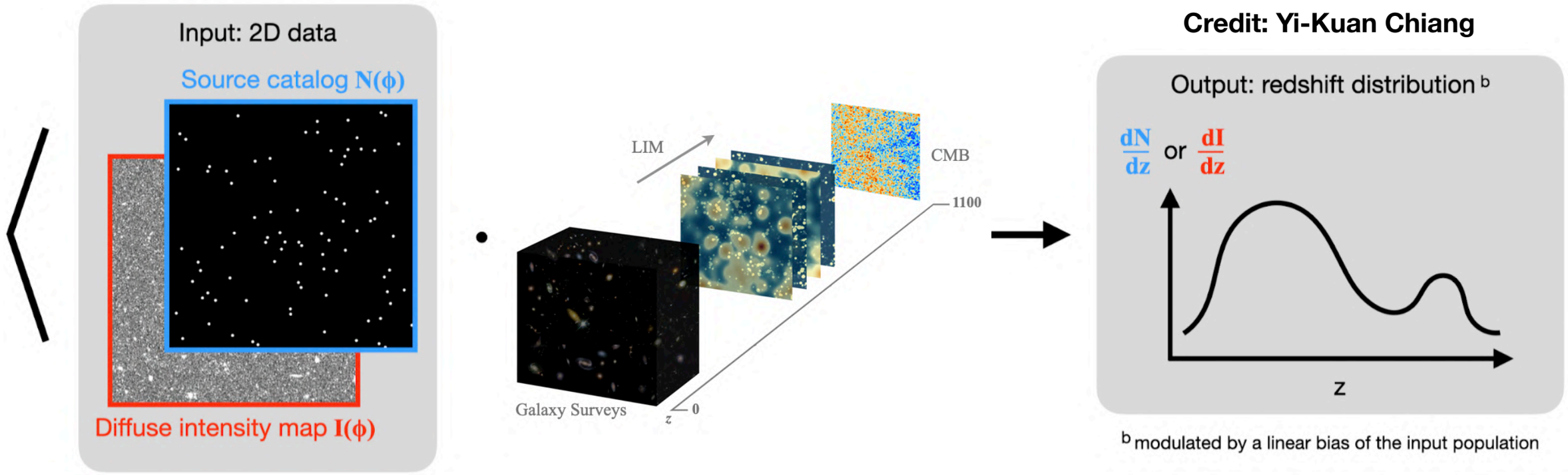

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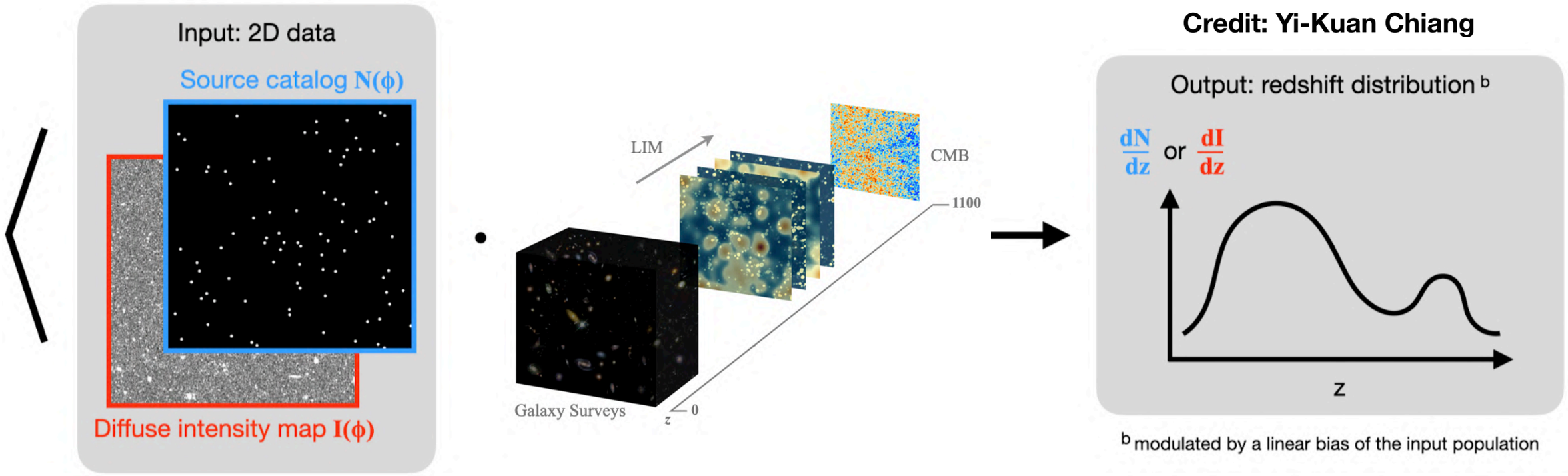

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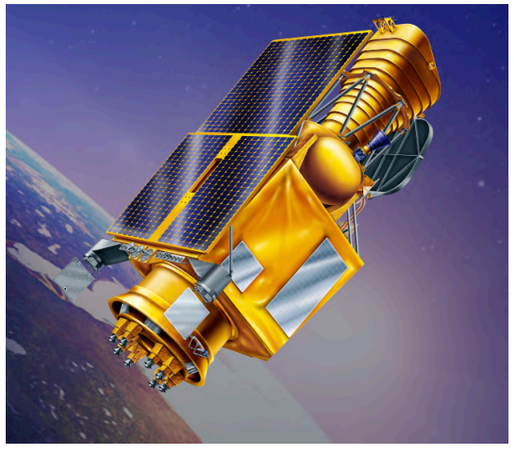
ULTRASAT?



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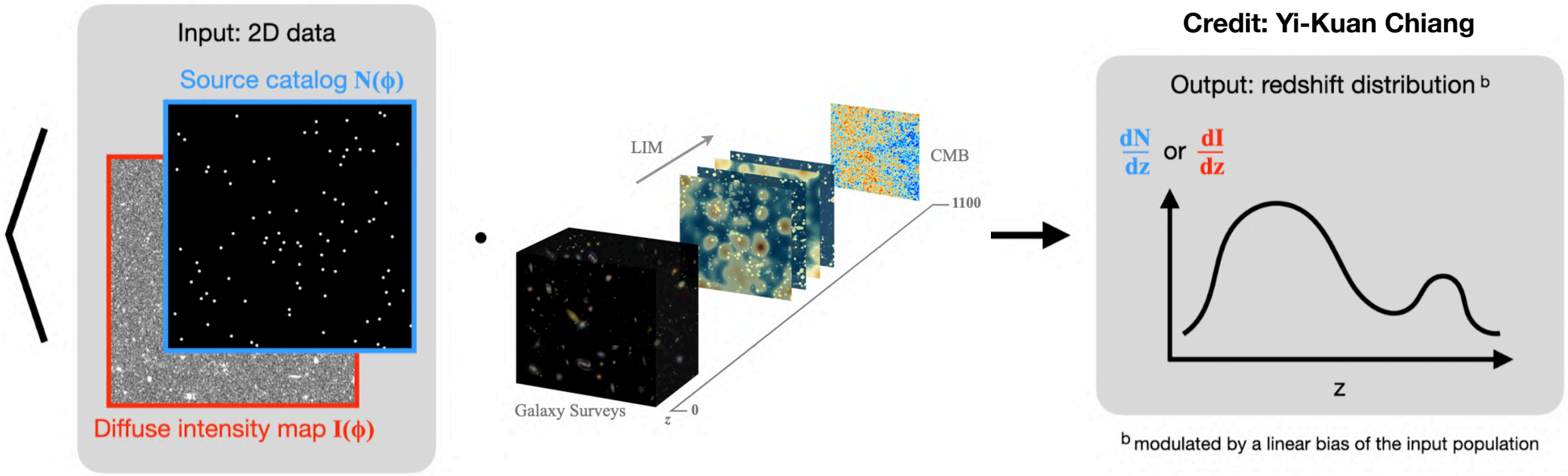

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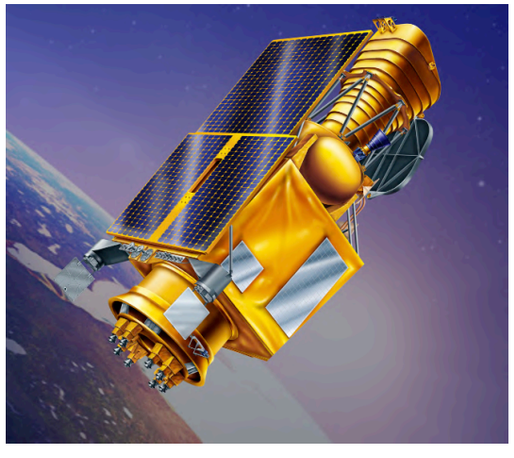

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Broadband Line-Intensity Mapping: Tomography

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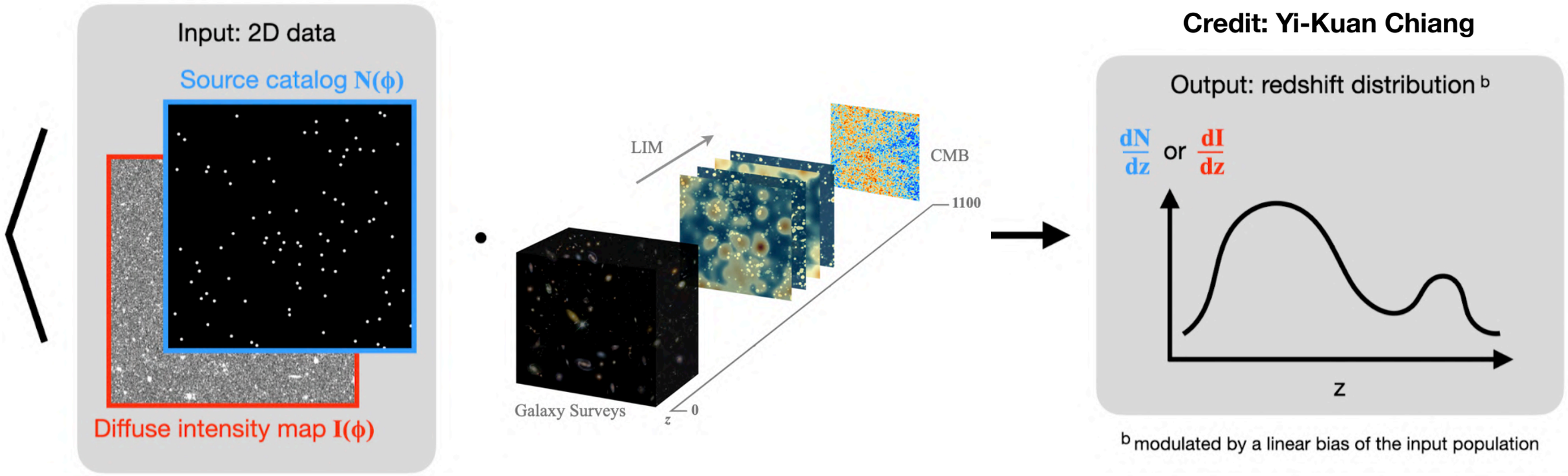

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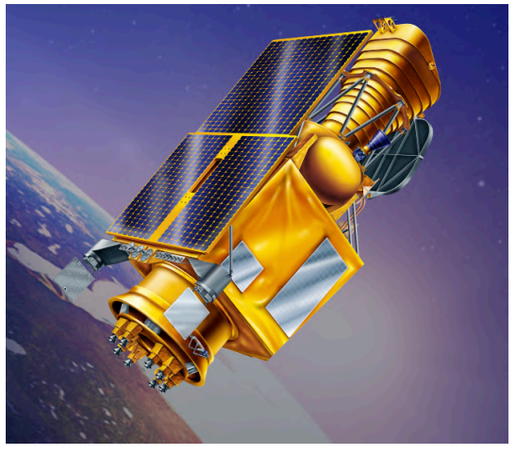

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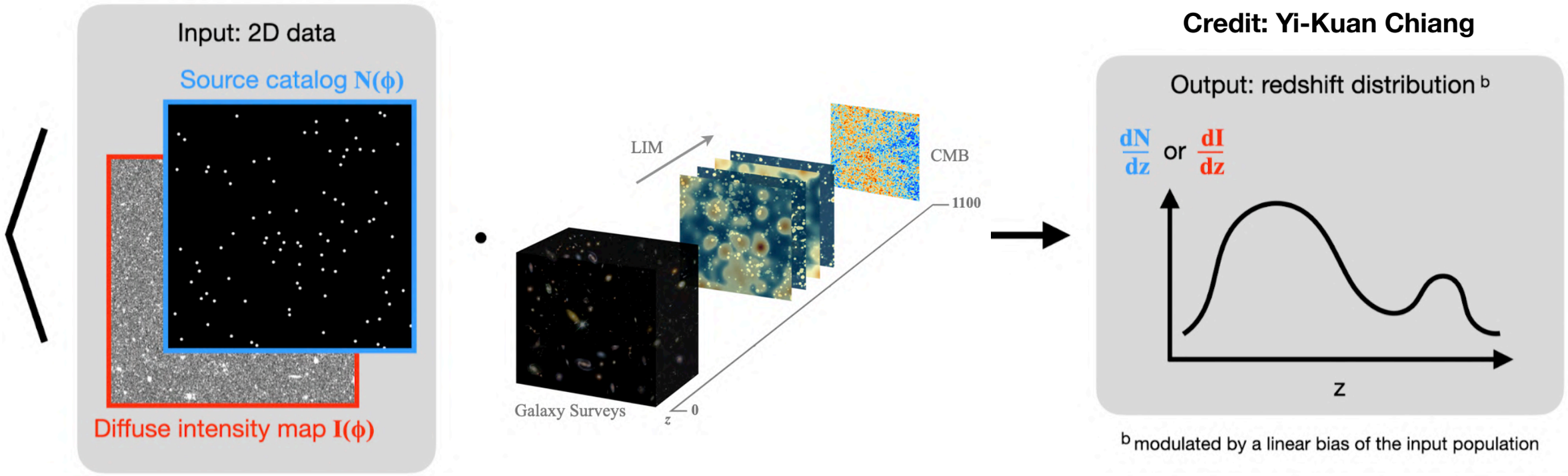

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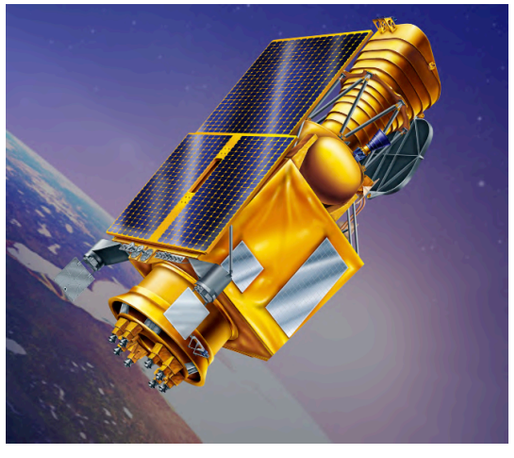

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For very preliminary estimates, see:
Libanore and Kovetz, ULTRASAT WG4 White Paper

Line-Intensity Mapping: the Line Power Spectrum

Basic formalism: power spectrum of line-intensity fluctuations

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Emitters trace the underlying dark matter density field

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$$P_{\rm line}(k,z) = b^2(z) P_m(k,z)$$

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$$P_{\rm line}(k,z) = \langle I_{\rm line}(z)\rangle^2 b^2(z) P_m(k,z)$$

↑

Convert from
galaxy spectrum
to line spectrum

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$$P_{\rm line}(k,z) = \langle I_{\rm line}(z)\rangle^2 b^2(z) P_m(k,z) + P_{\rm shot}(z)$$

We measure emission from discrete sources

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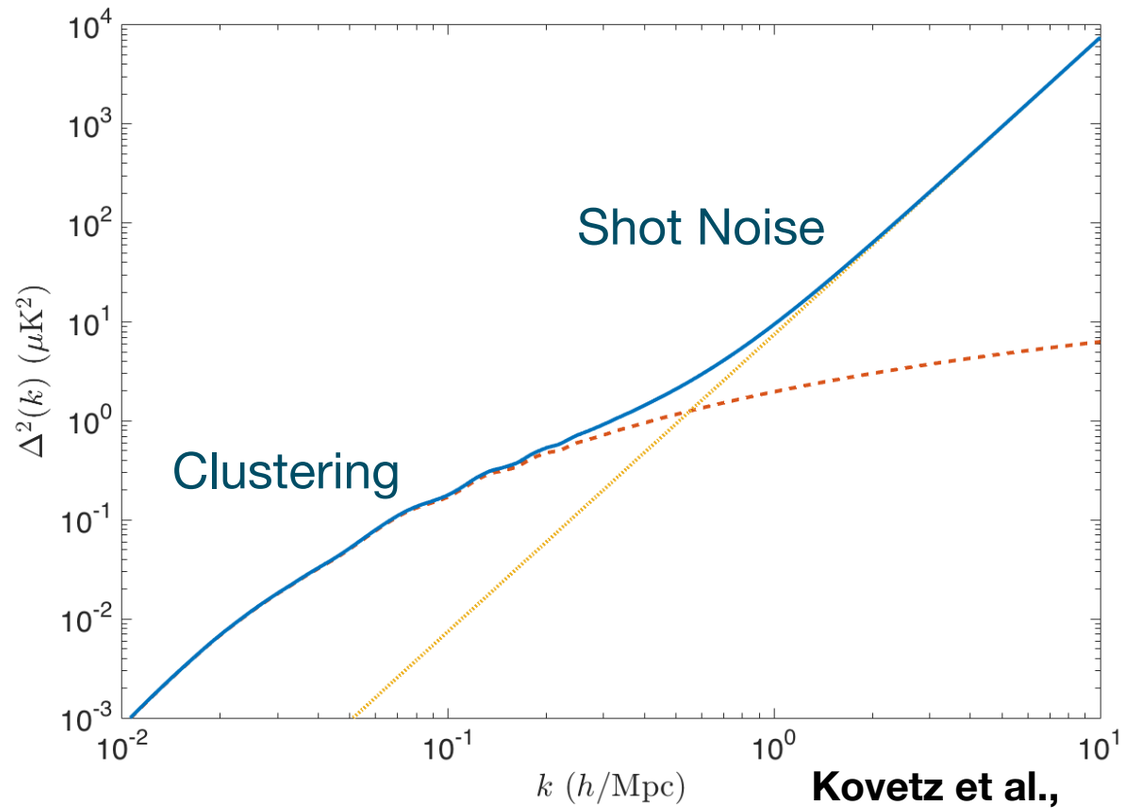

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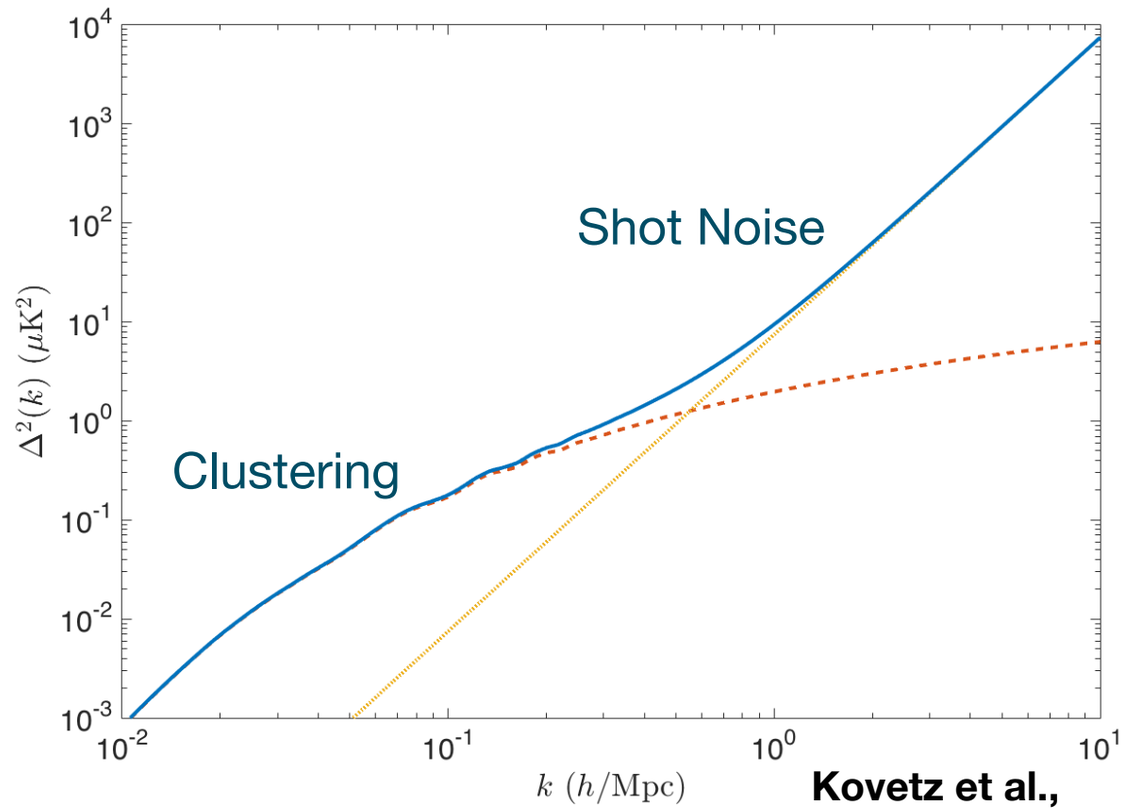

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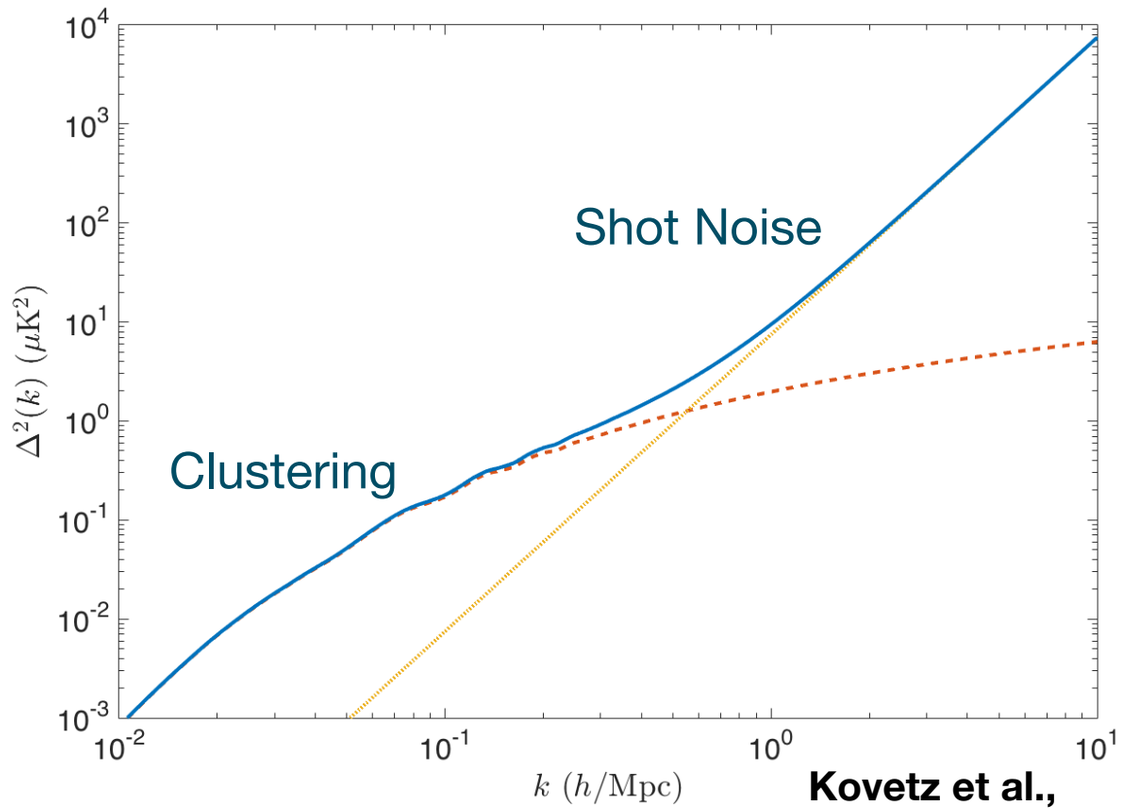

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Line-Intensity Mapping: Beyond Power Spectrum

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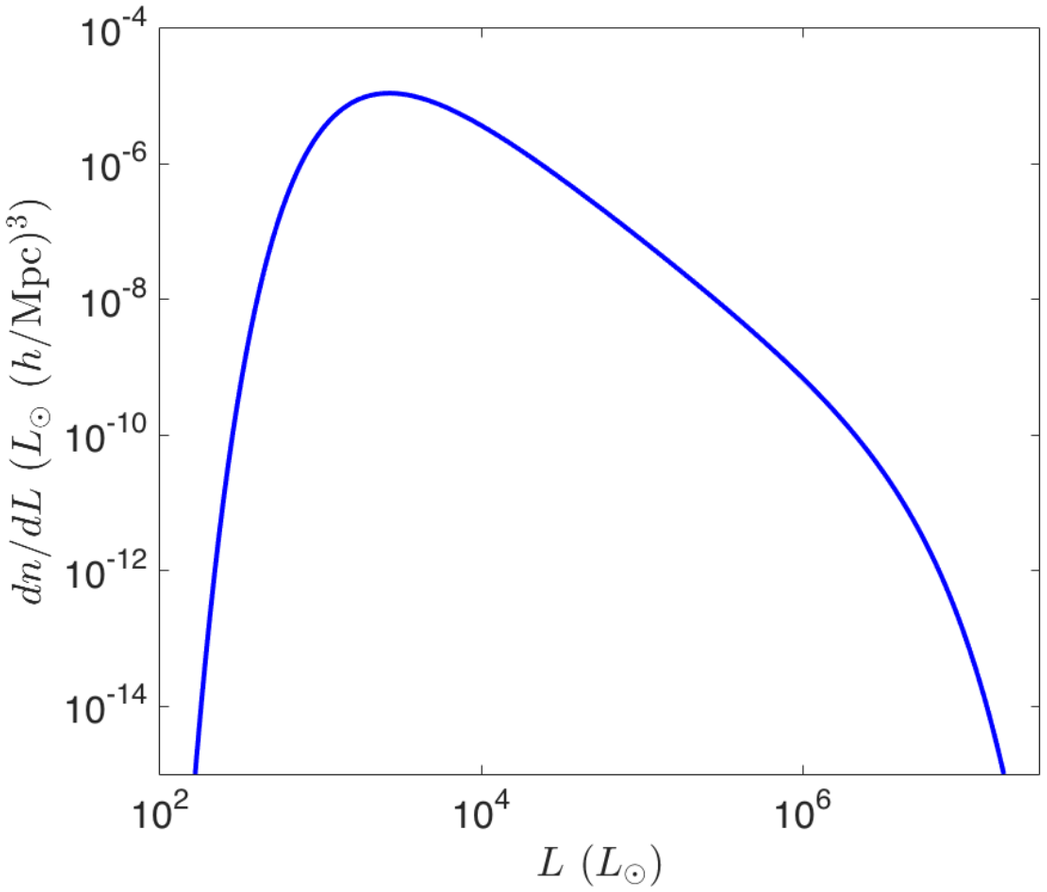

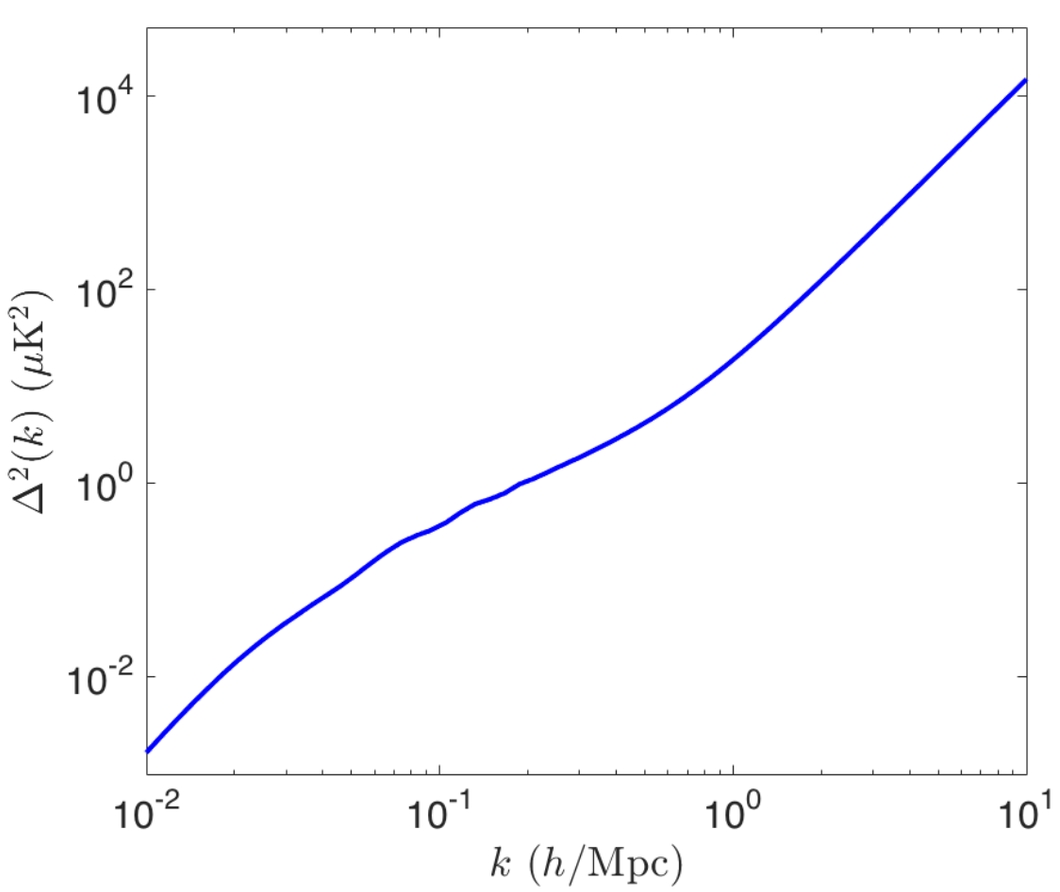

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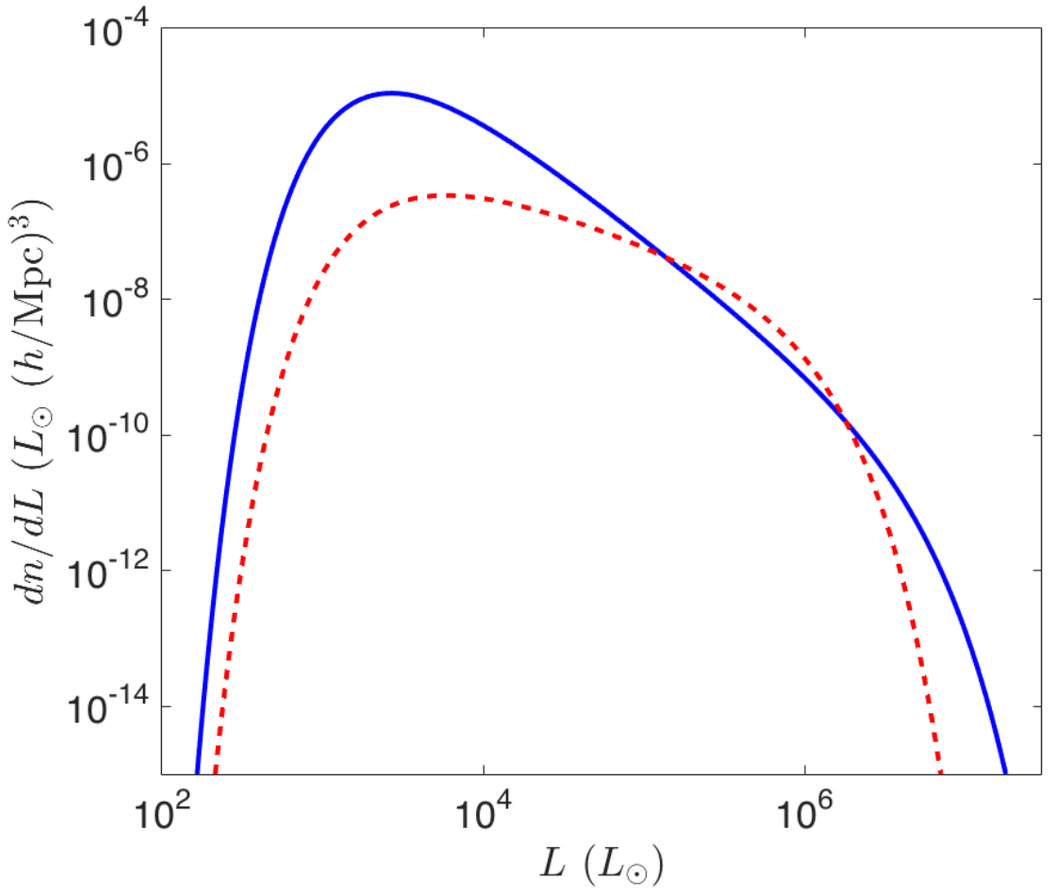

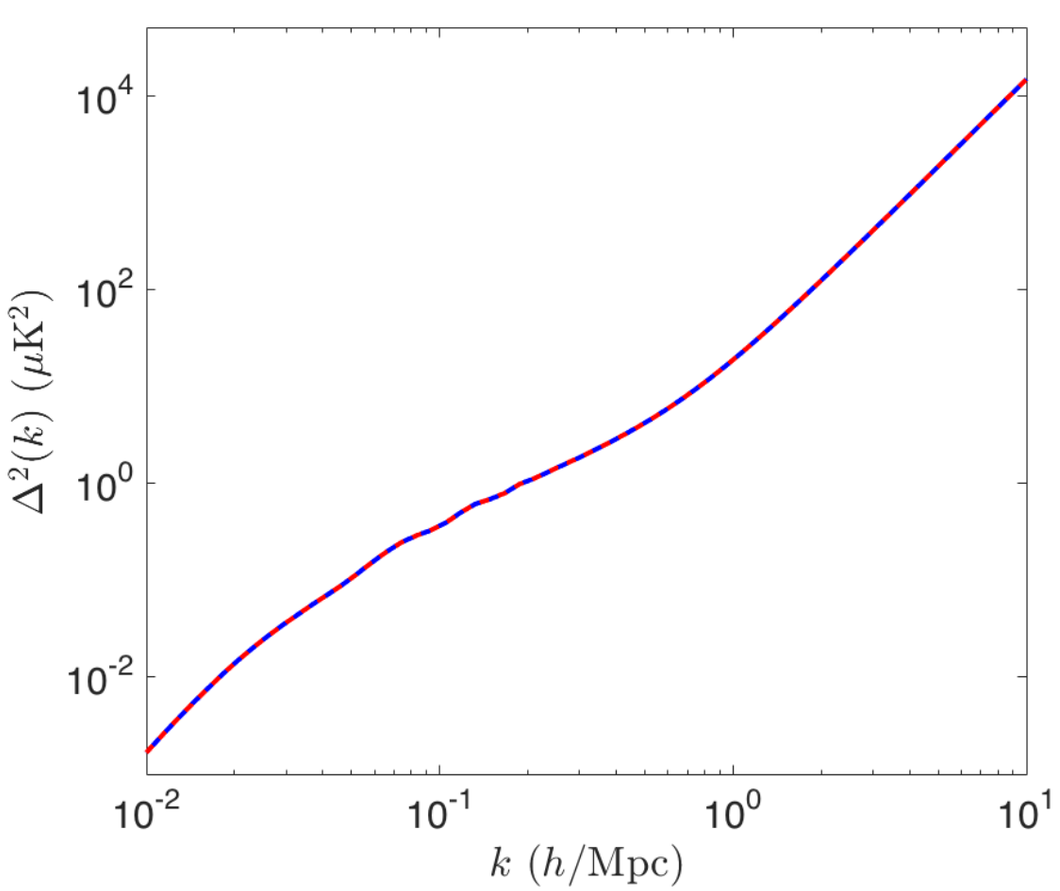

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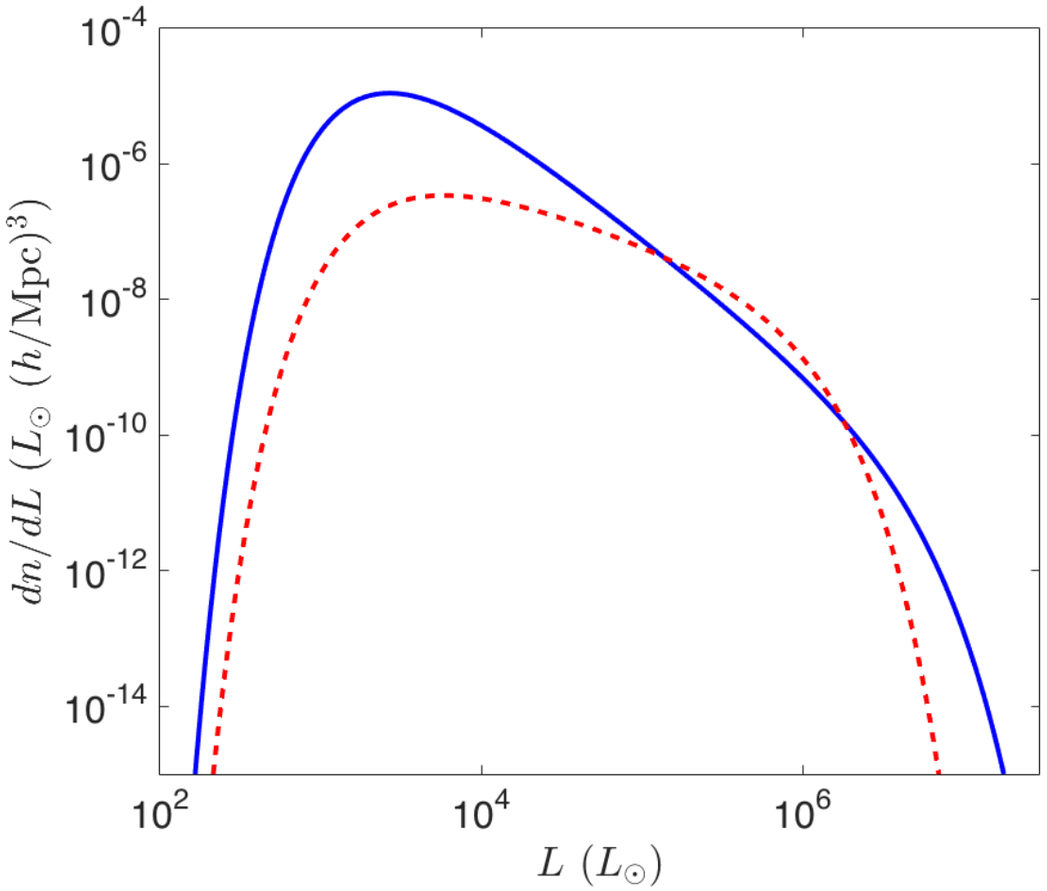

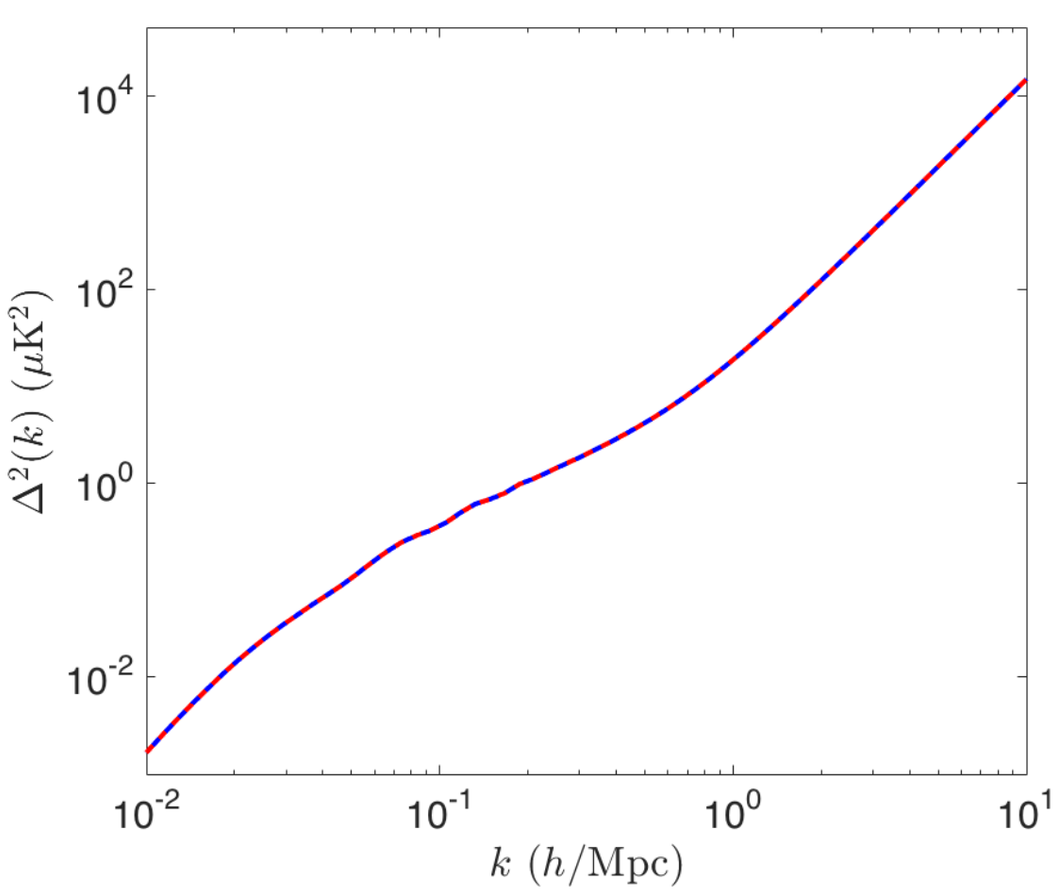

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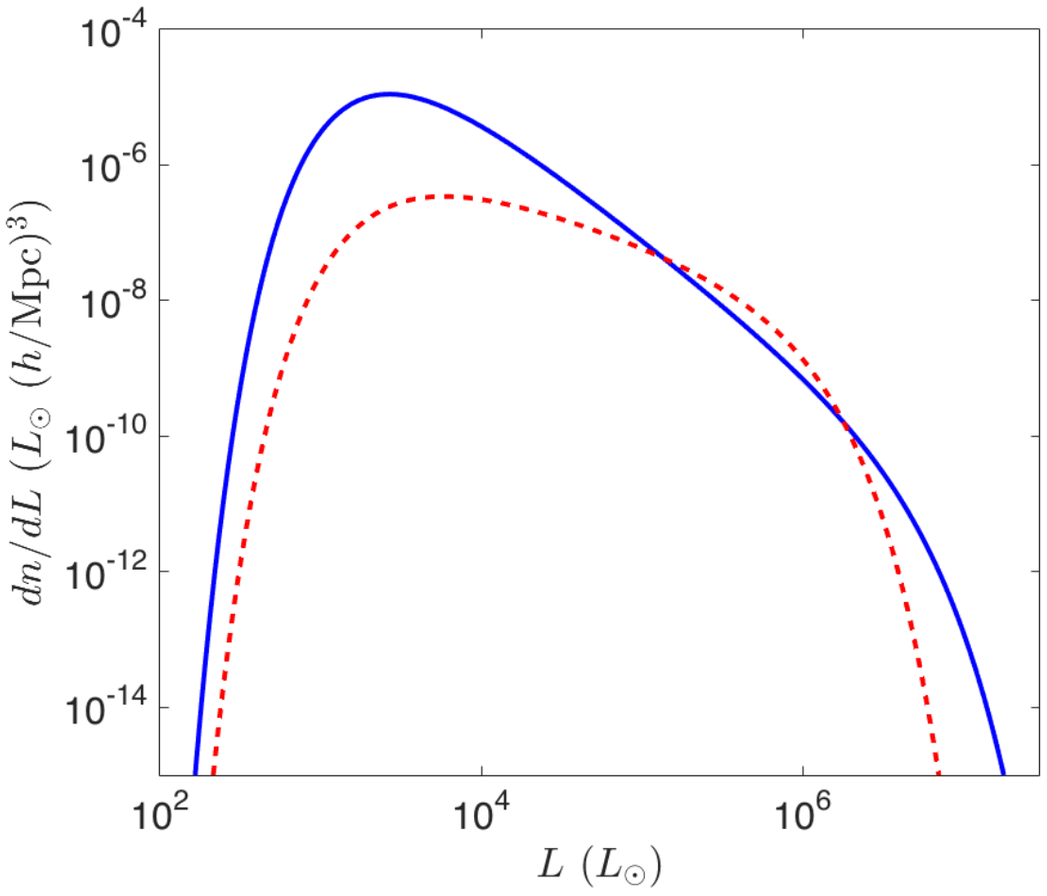

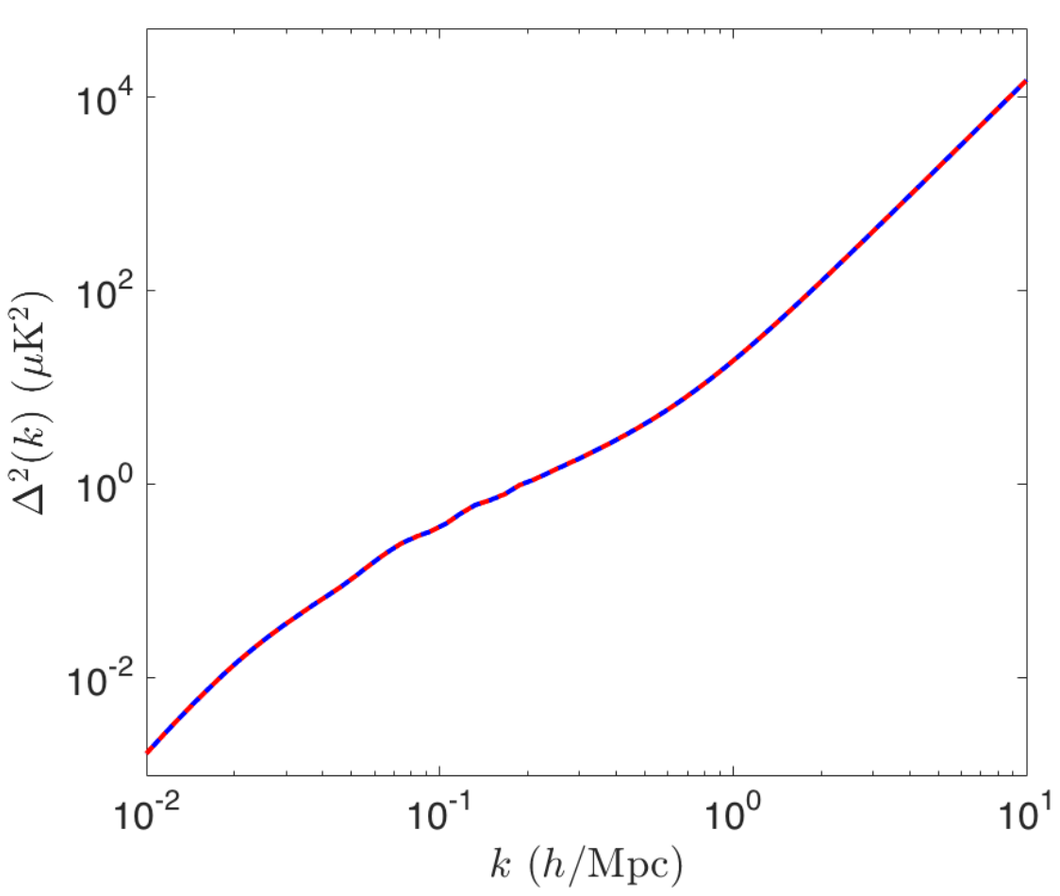

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Voxel Intensity Distribution gives full luminosity function, integrals over clustering.

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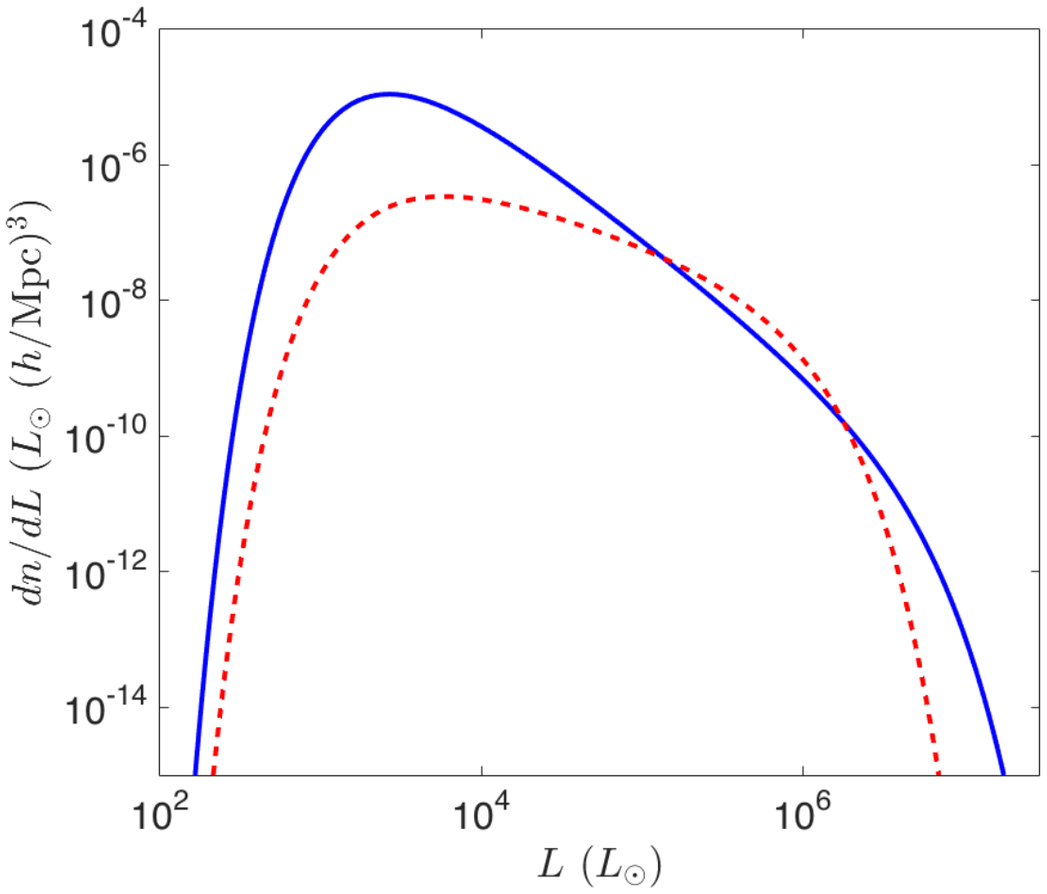

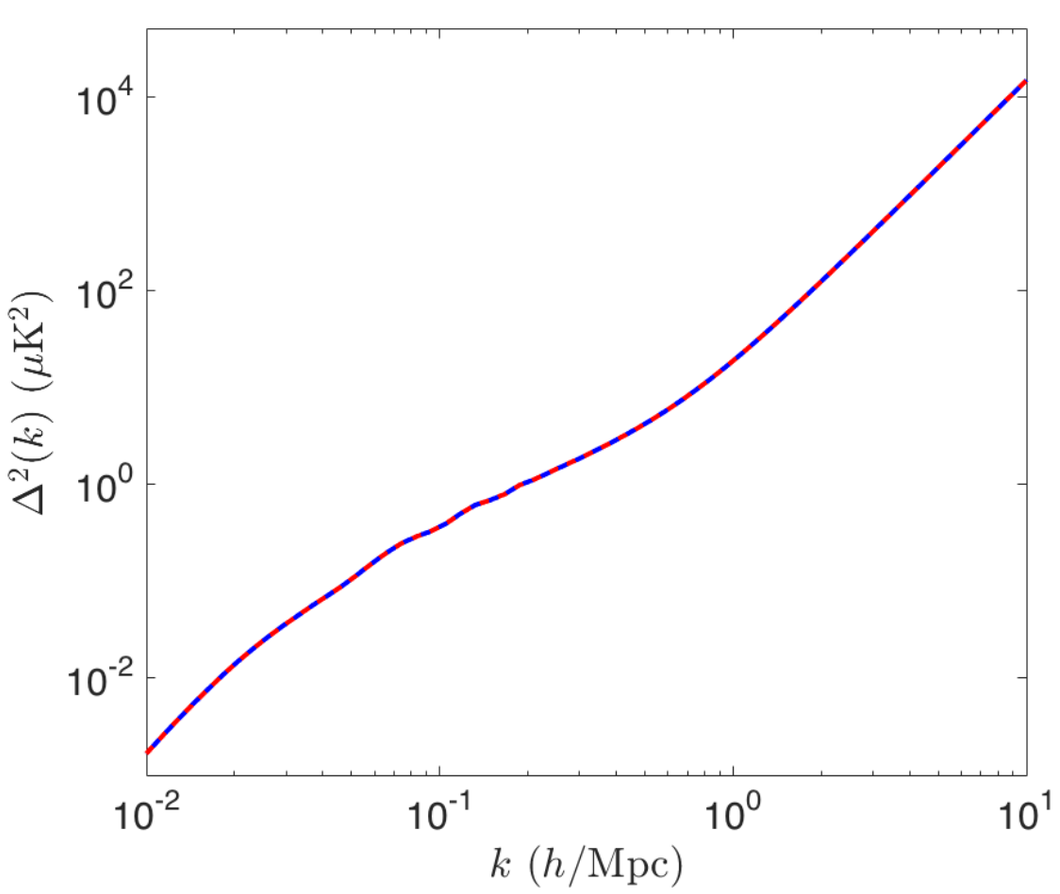

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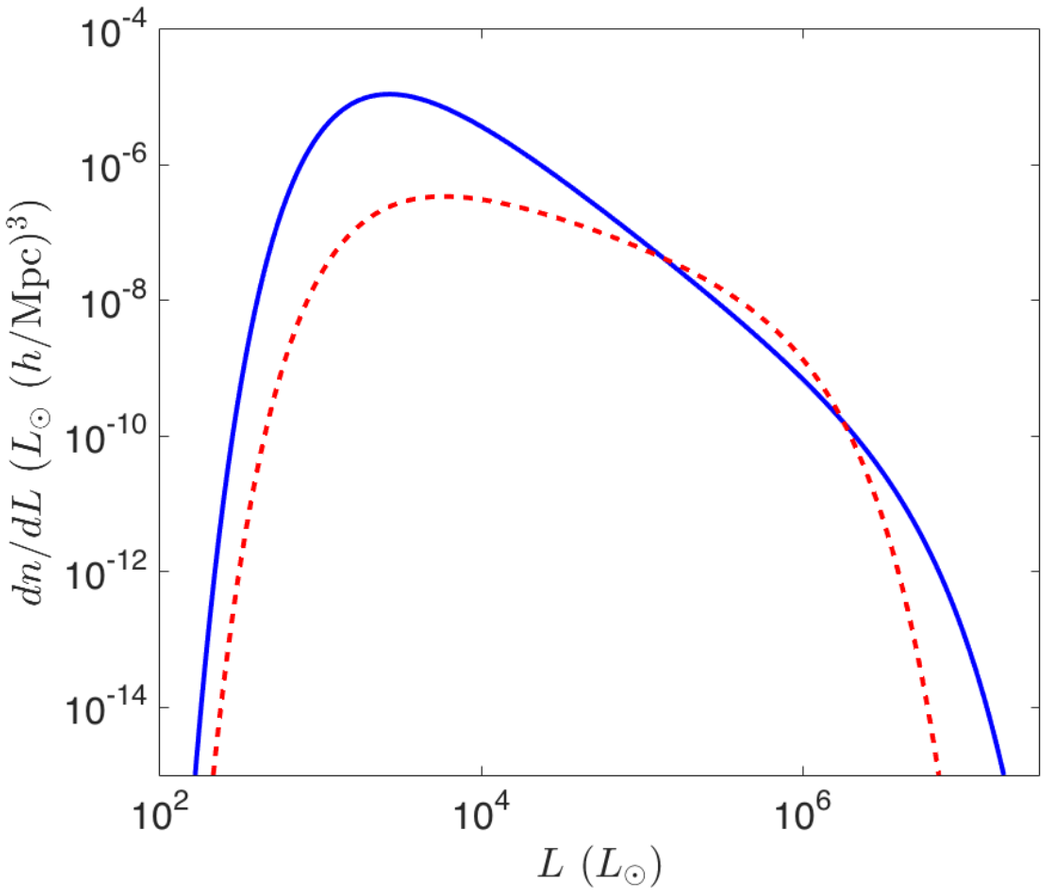

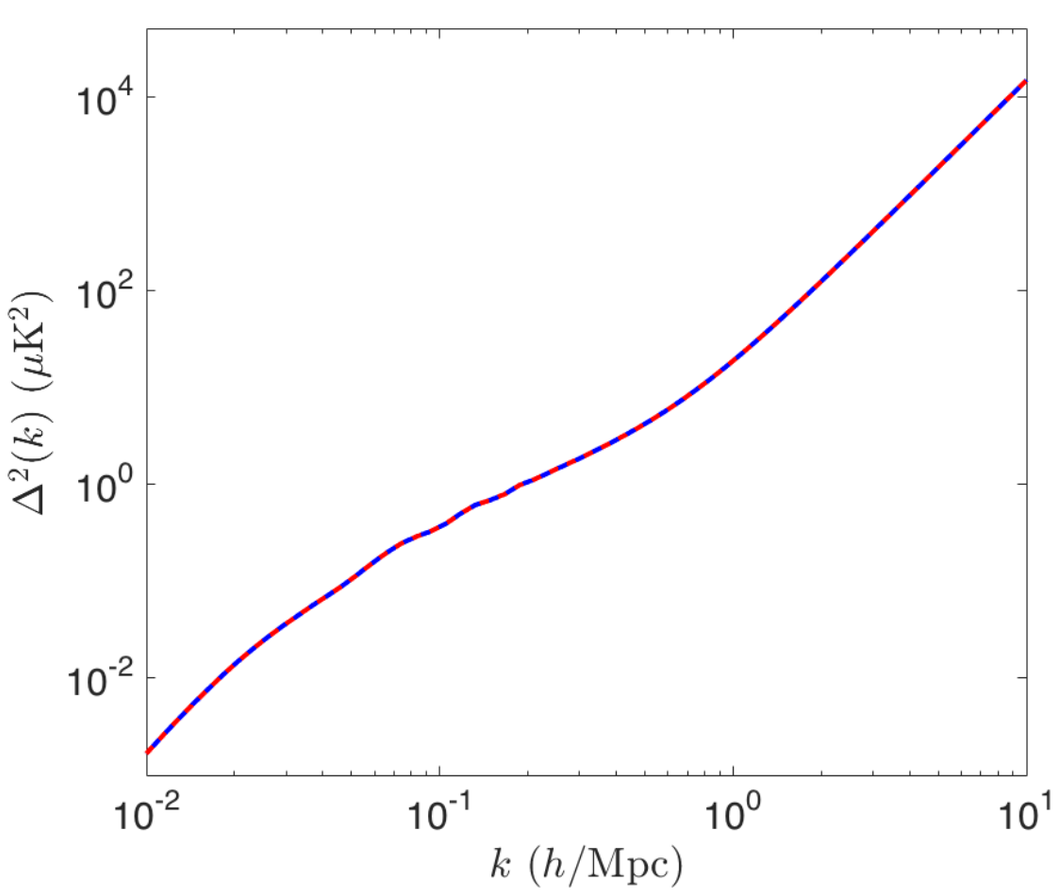

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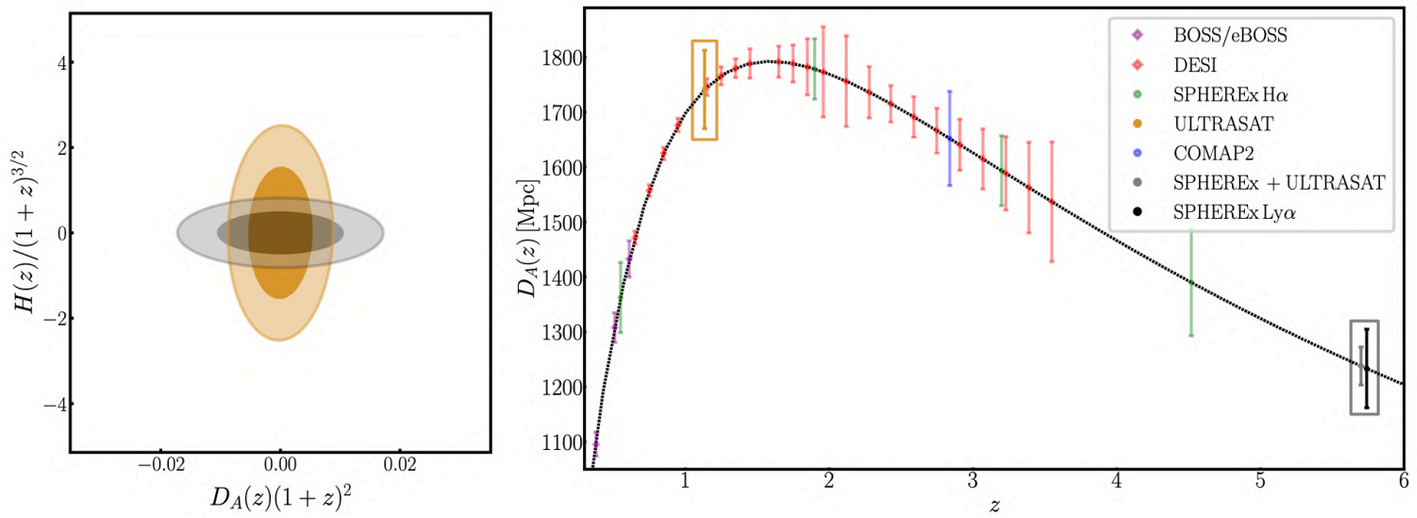
Power spectrum probes only large scales (determined by experimental resolution).
VID sensitive to small scales (through integrated signal from all the faint sources).

ULTRASAT Full-Sky Map: Specific Applications

Cosmic expansion history:



Dark energy equation of state:

$$w(a) = w_0 + w_a(1-a)$$

	$f_{\rm sky}$	$N_{\rm bins}$	CBR	σ_{w_0}	σ_{w_a}
$P_{\rm Ly\alpha}(k,z)$	1	1	×	0.27	0.78
$P_g(k,z)$	1/3	5	×	1.21	3.83
$P_g(k,z)$	1	5	×	0.70	1.92
$P_{g,{\rm Ly\alpha}}(k,z)$	1/3	5	✓	0.26	0.83
$P_{g,{\rm Ly\alpha}}(k,z)$	1	5	✓	0.15	0.48

Local non-gaussianity:

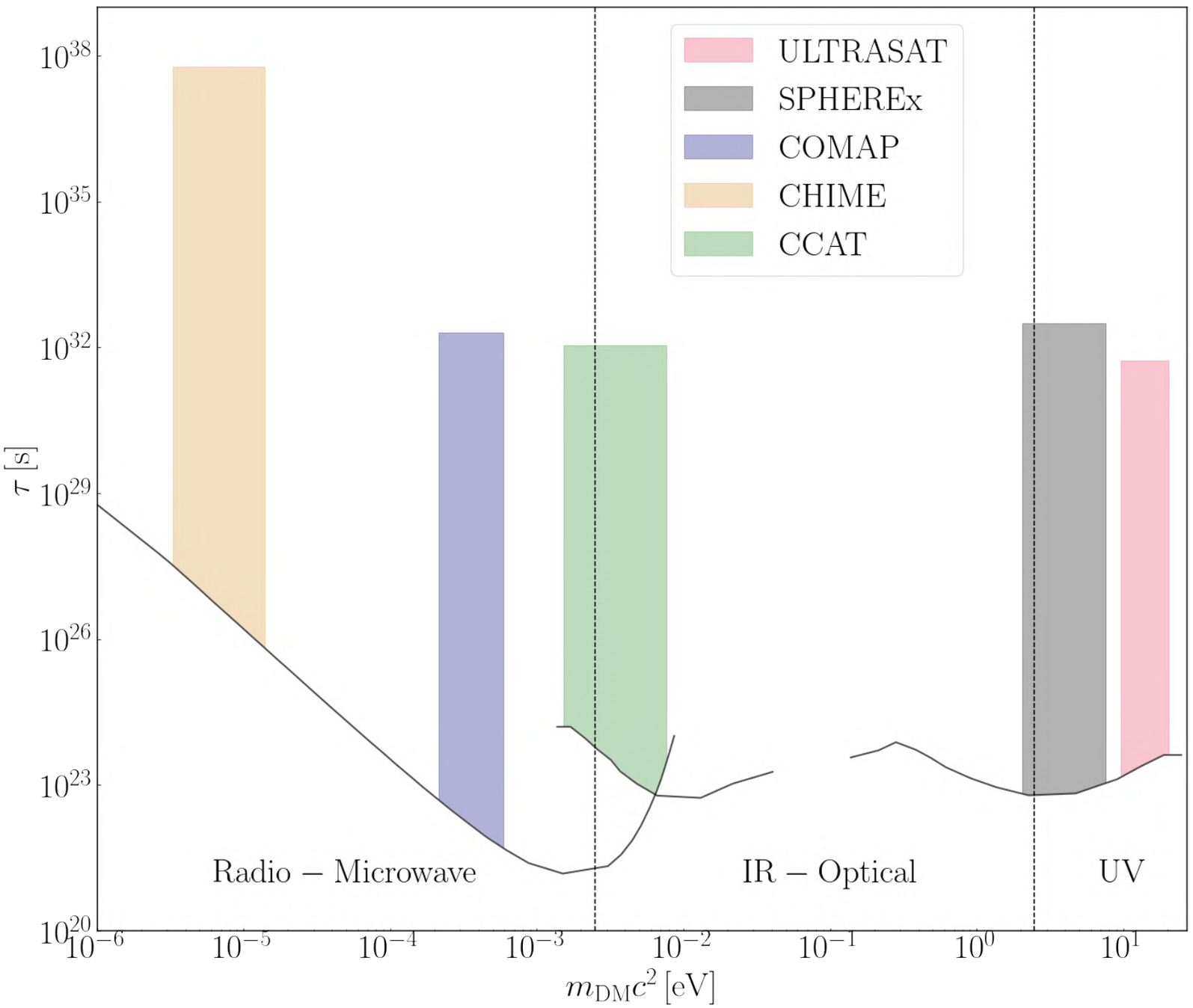
$\sigma_{f_{\rm NL}}$ from VID			$\sigma_{f_{\rm NL}}$ from Power spectrum		
Optimistic	Pessimistic	Gaussian prior	Optimistic	Pessimistic	Gaussian prior
$\mathcal{O}(10)$	$\mathcal{O}(1000)$	$\mathcal{O}(100)$	$\mathcal{O}(1)$	$\mathcal{O}(100)$	$\mathcal{O}(10)$

ULTRASAT Full-Sky Map: Specific Applications

Dark matter decay:

$$\chi \longrightarrow \gamma\gamma$$

$$\nu_\chi = \frac{m_\chi c^2}{2h}$$



ULTRASAT Full-Sky Map: Specific Applications

Target: Lyα emissivity

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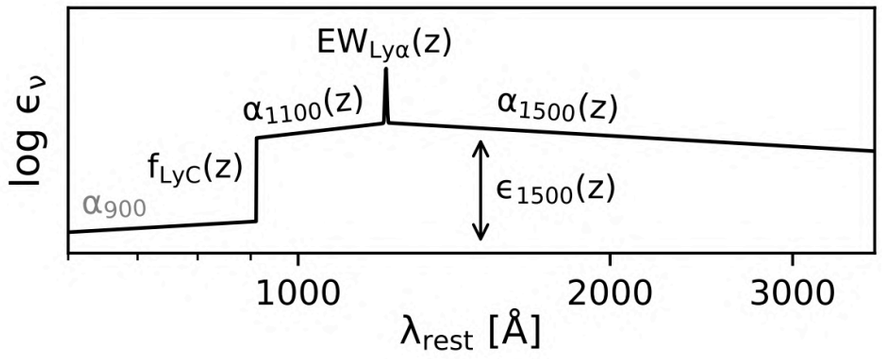
Chiang and Menard, PRD 2018



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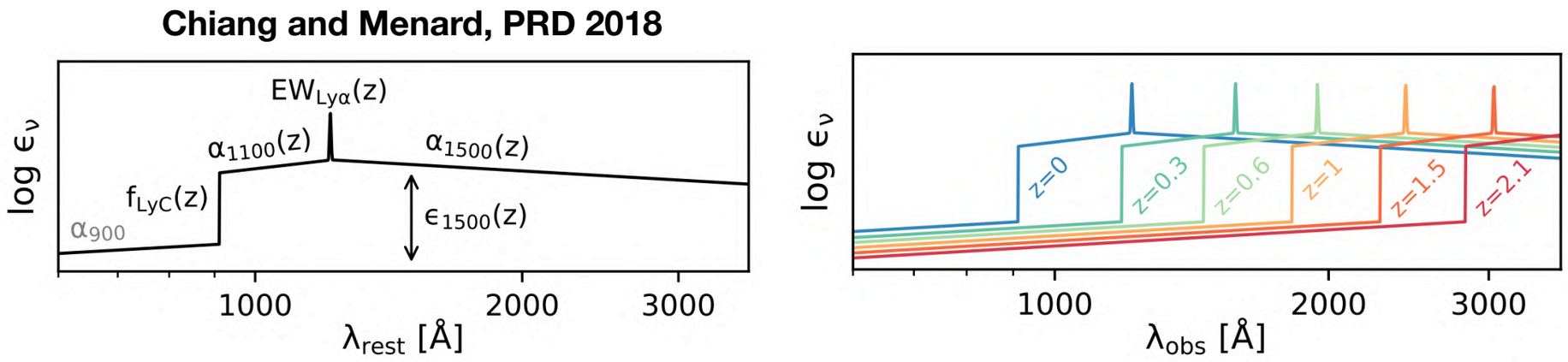

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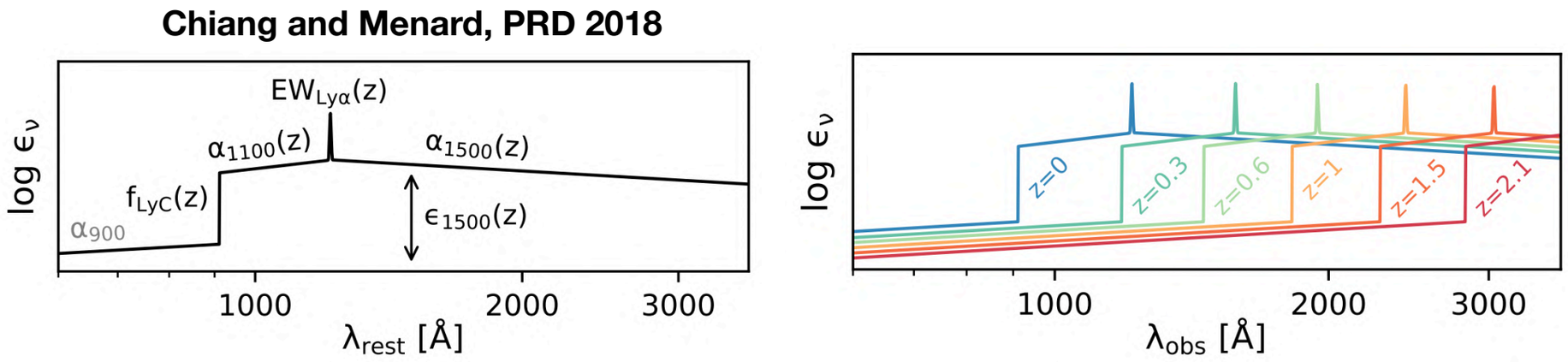

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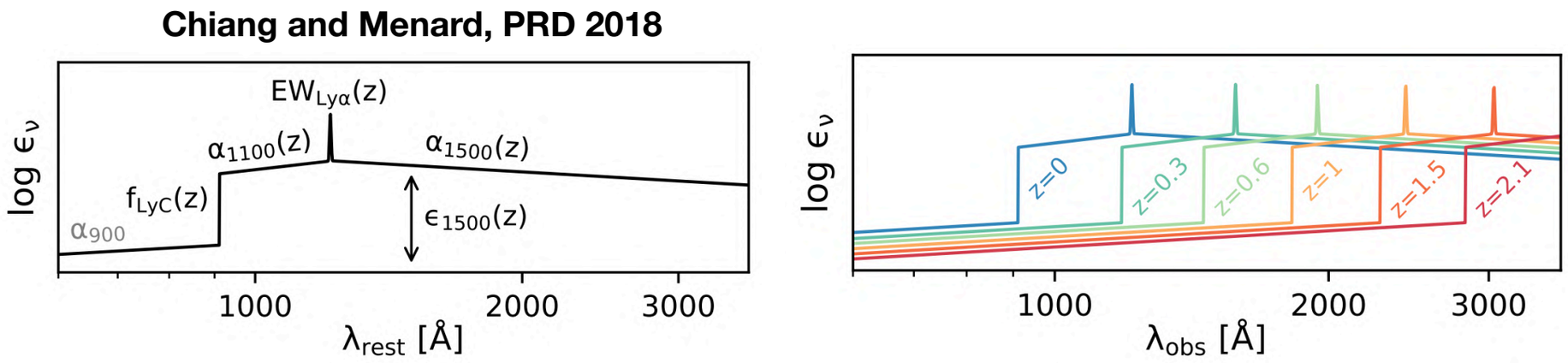

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$$\frac{dJ_{\nu_{\rm obs}}}{dz}(z) = \frac{c}{4\pi H(z)(1+z)} \int \frac{d\nu_{\rm obs}}{\nu_{\rm obs}} R(\nu_{\rm obs}) \epsilon_\nu(\nu, z) e^{-\tau}$$

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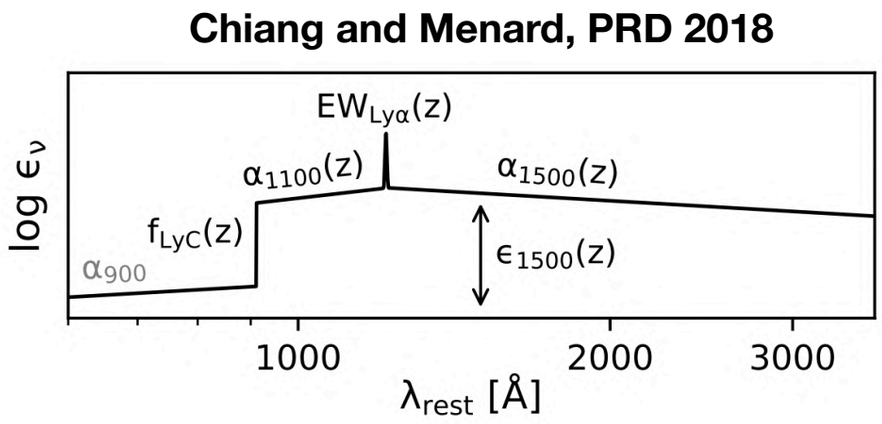

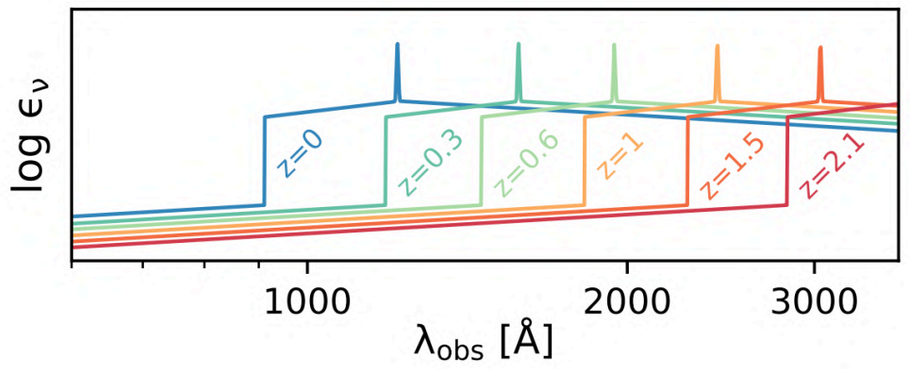

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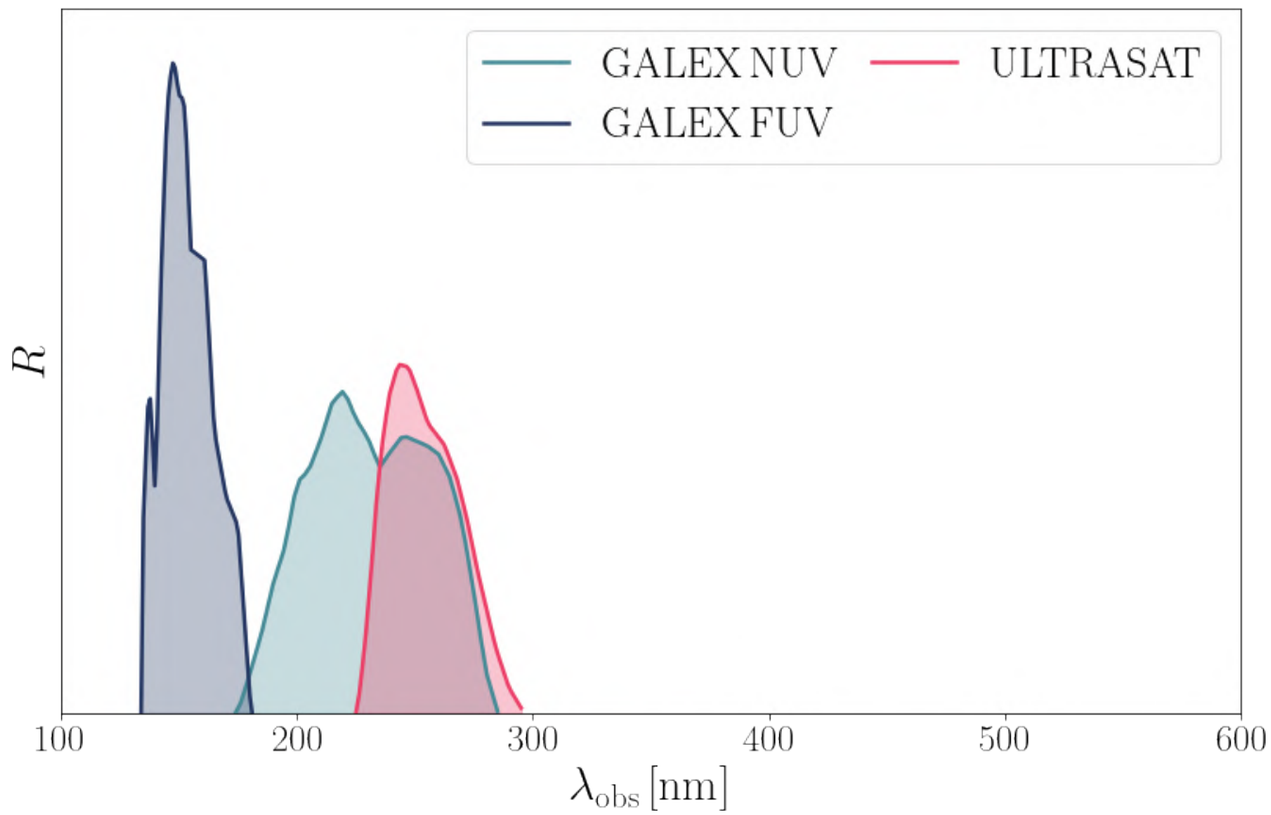

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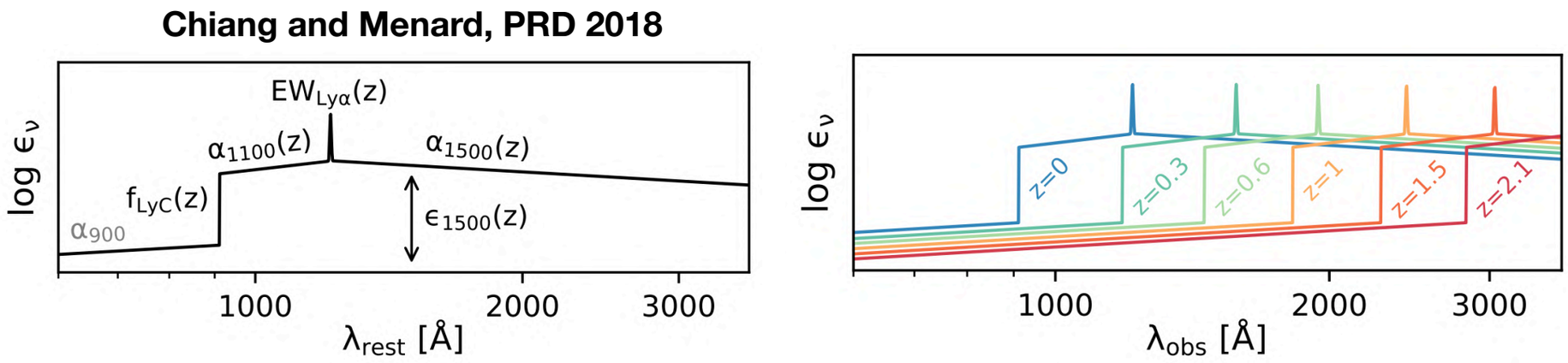

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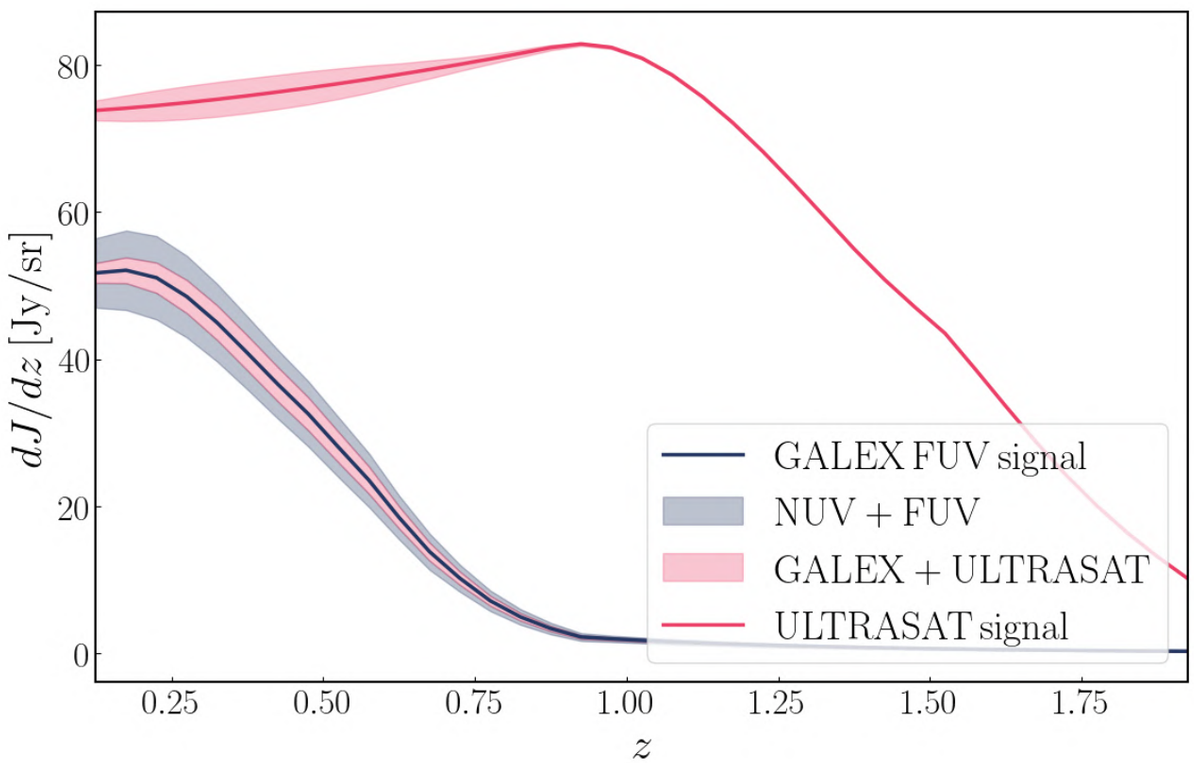

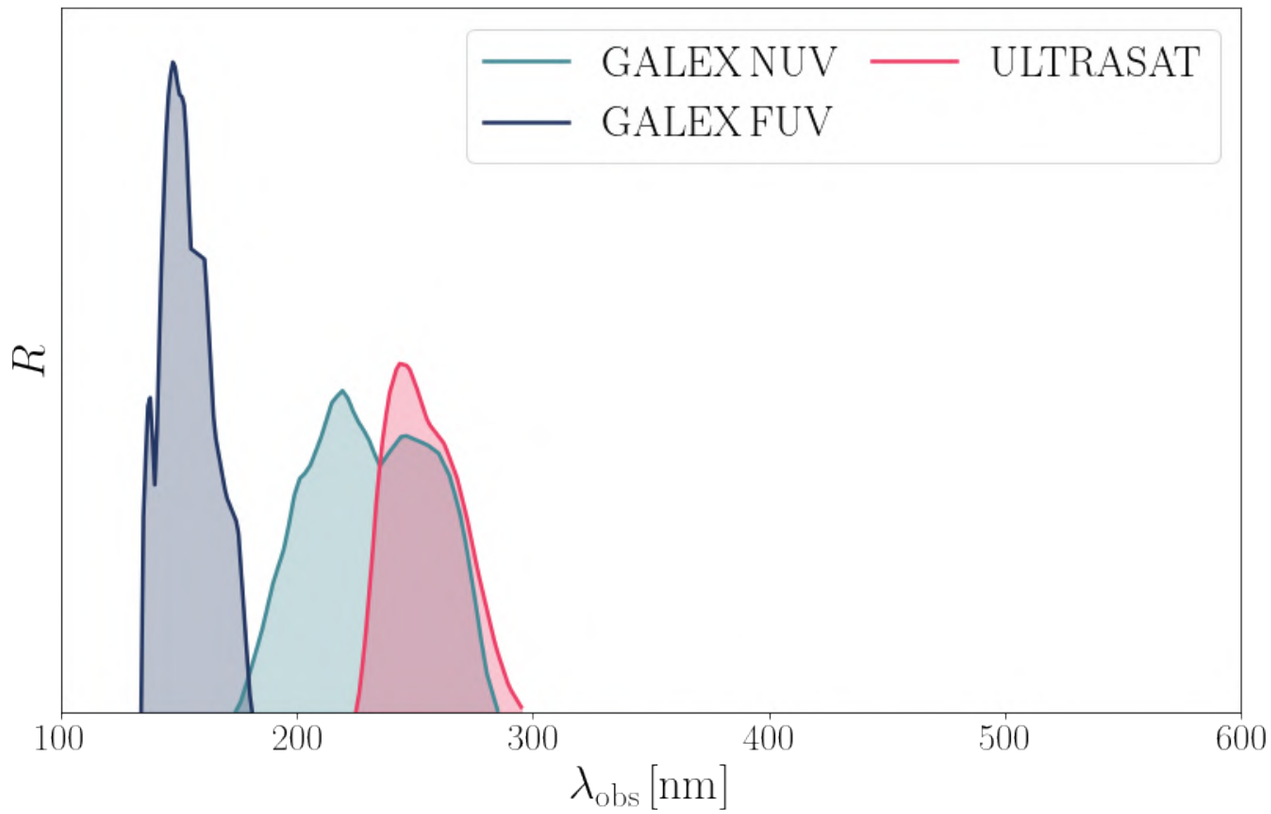

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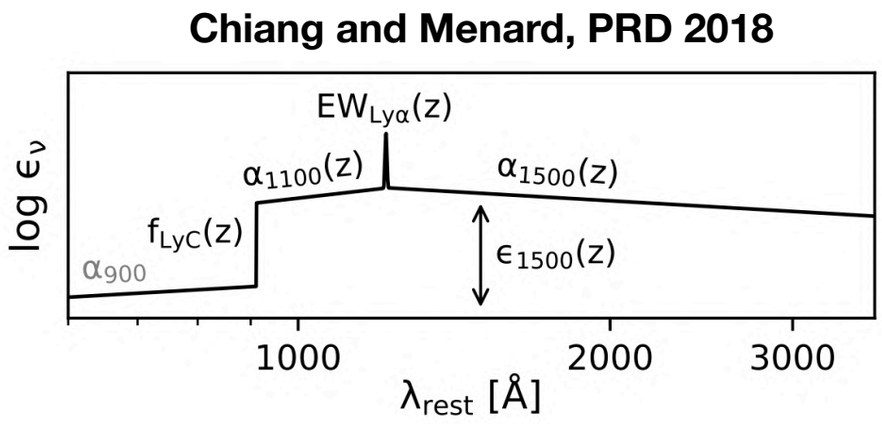

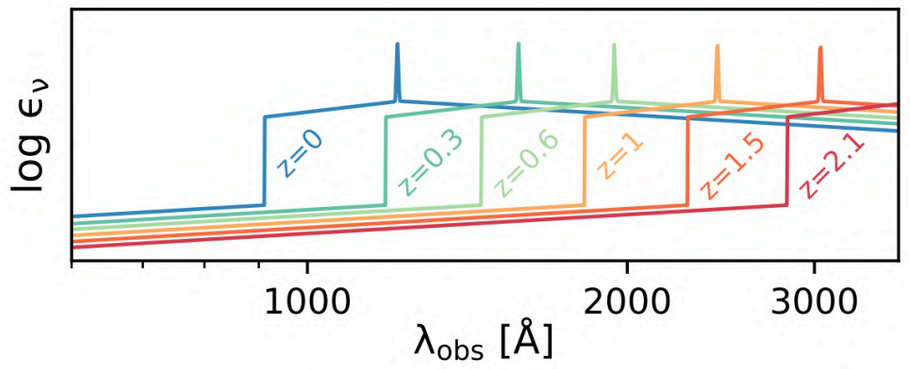

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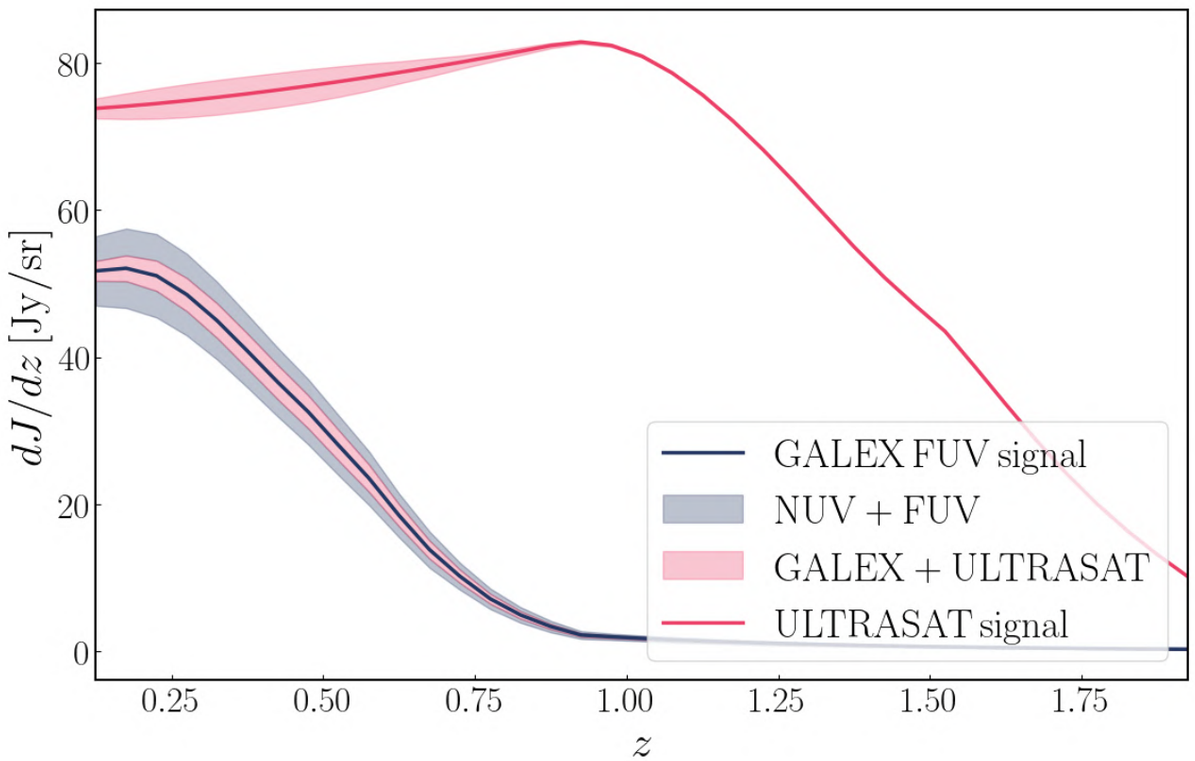

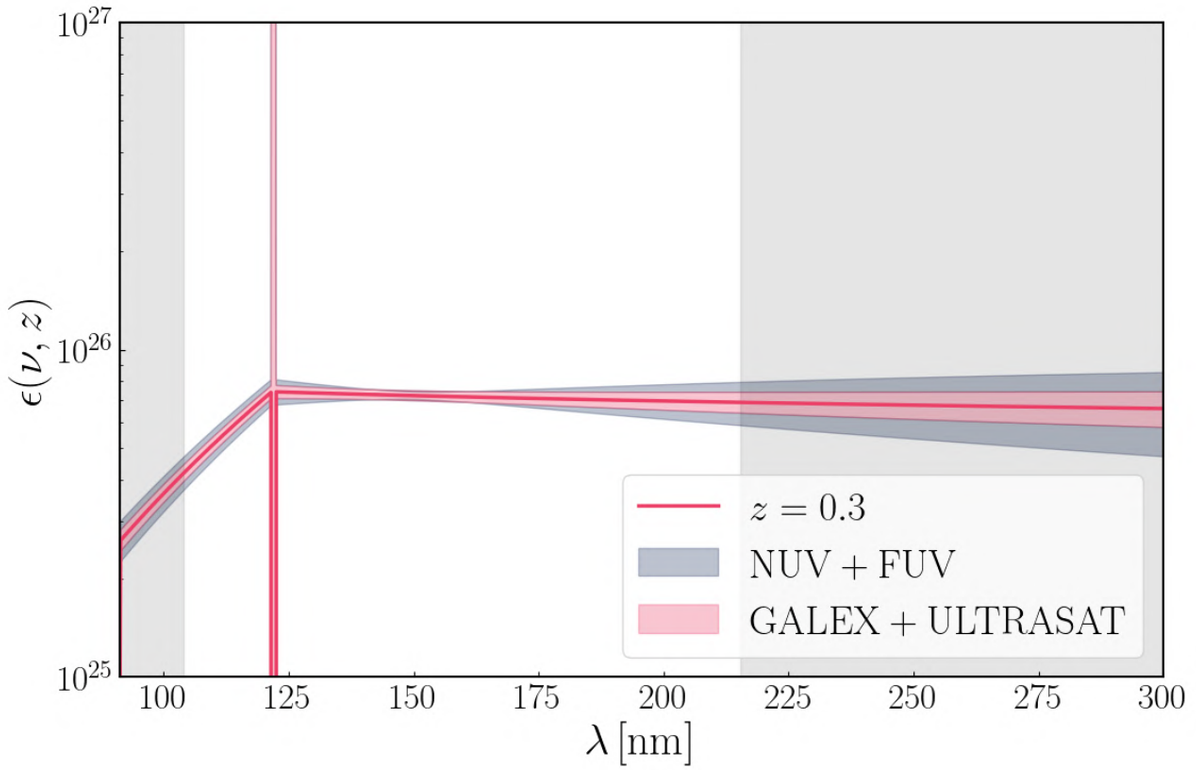

Questions? Ideas?

Ely D. Kovetz & Sarah Libanore

Ben-Gurion University