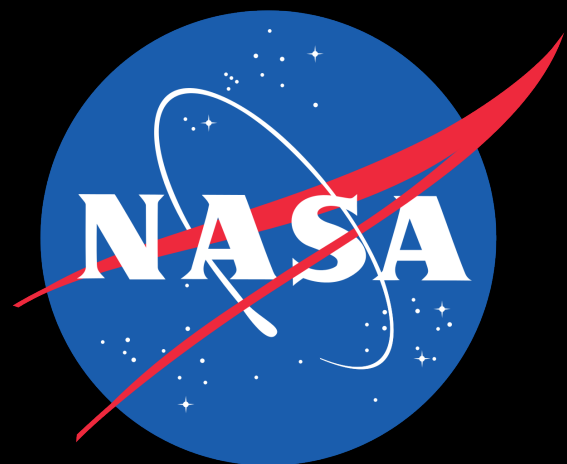
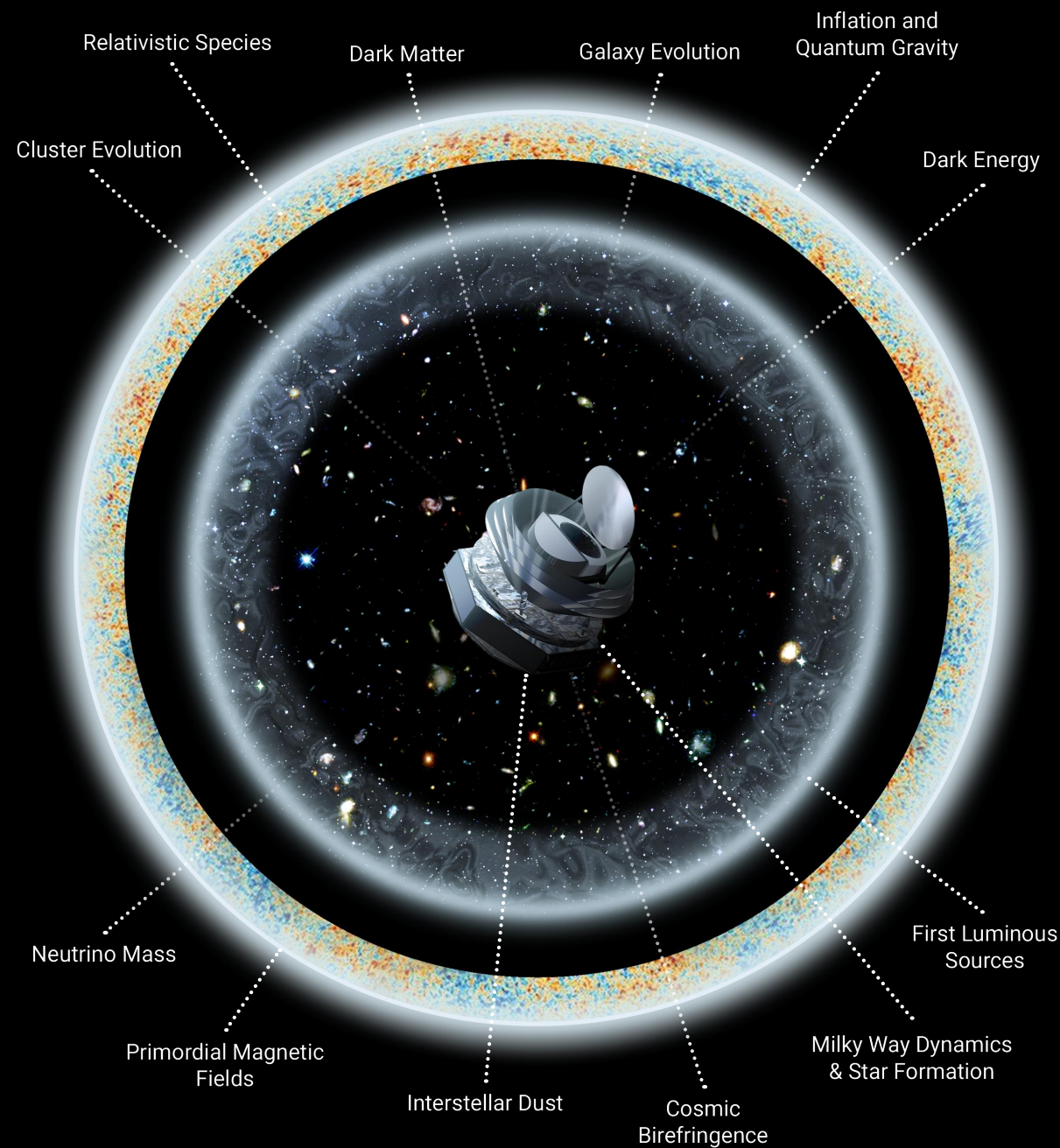


The Extragalactic Millimeter Sky with CMB Probe+: A Census of Cosmic Structure and Obscured Star Formation



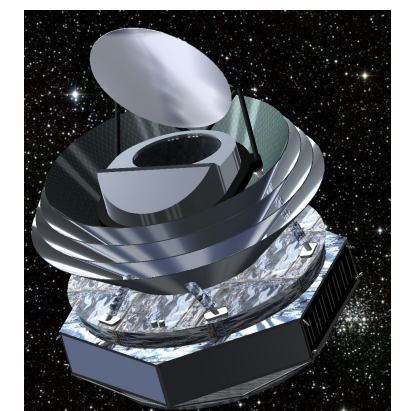
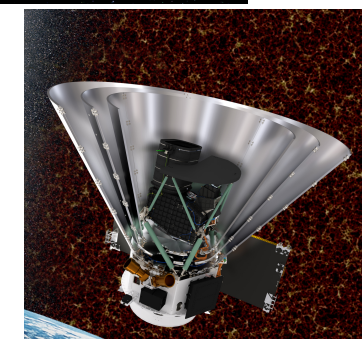
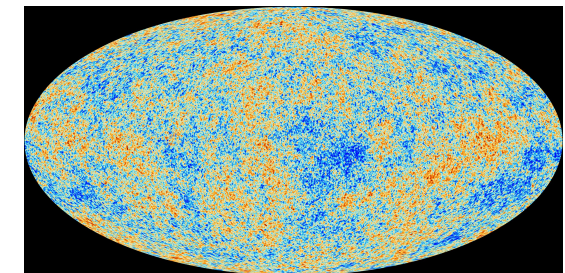
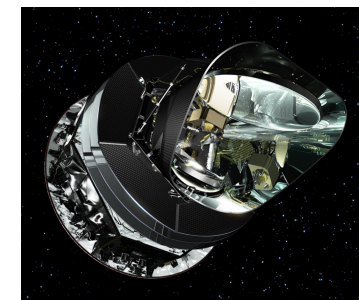
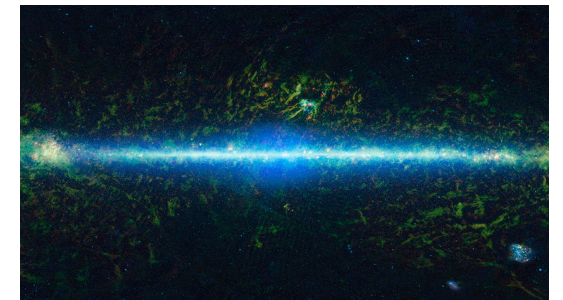
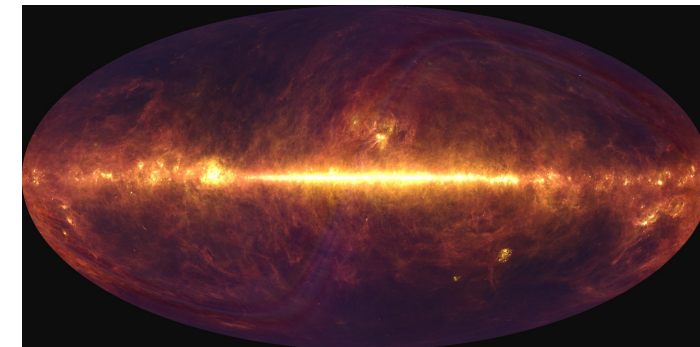
Joaquin Vieira

I ILLINOIS

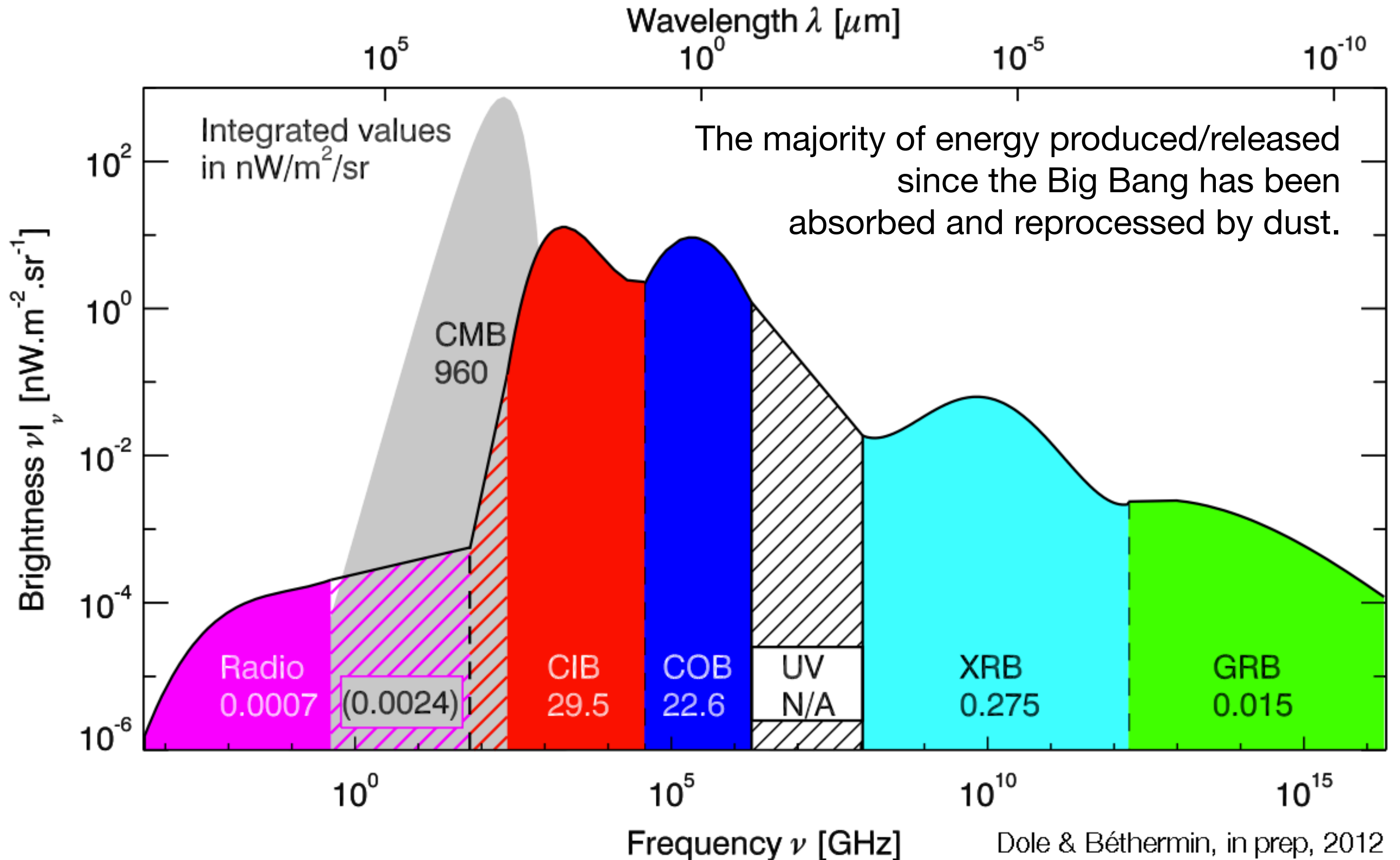
01 Sept 2026

All-sky FIR surveys have played an important role in our understanding of the Universe

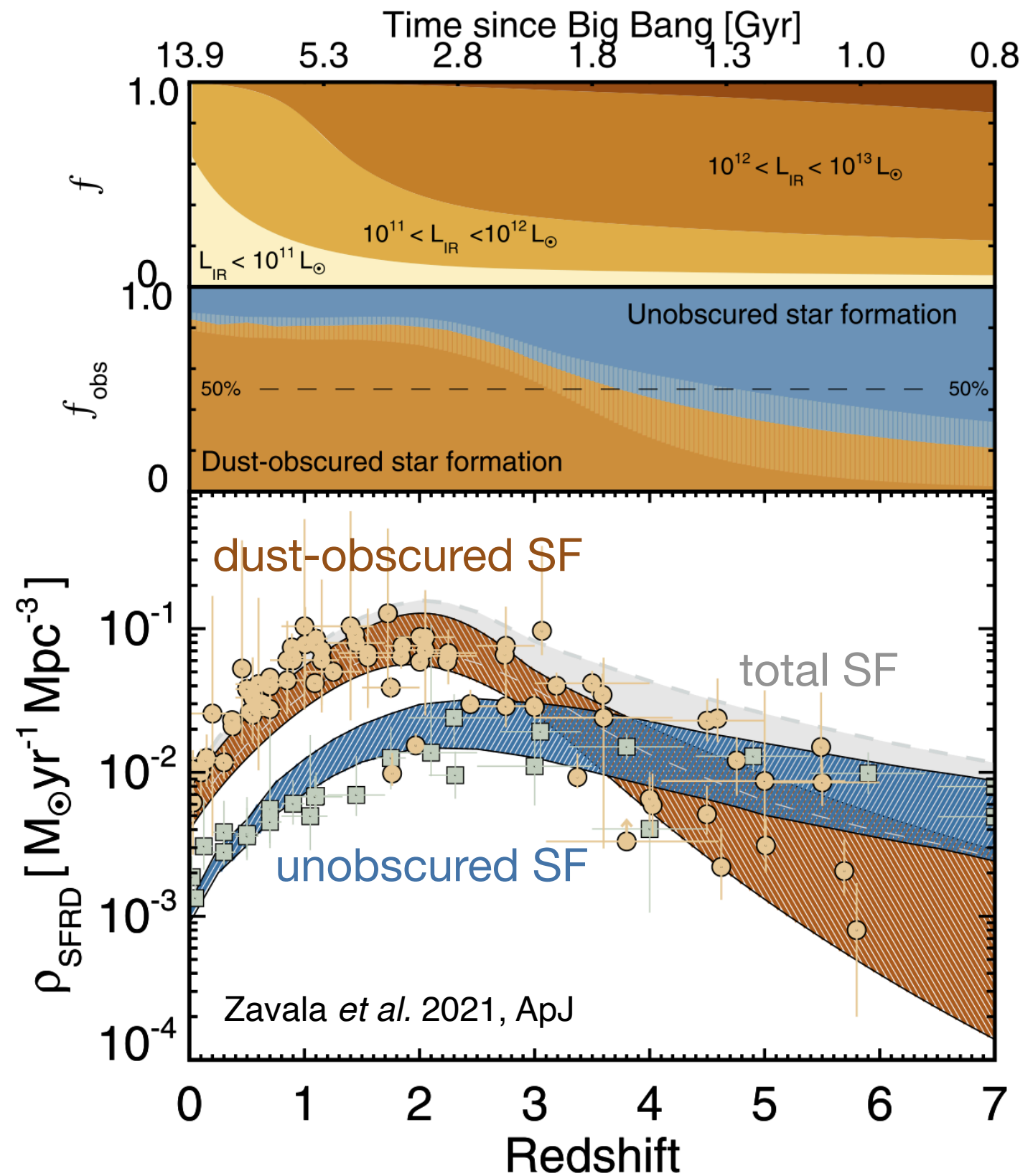
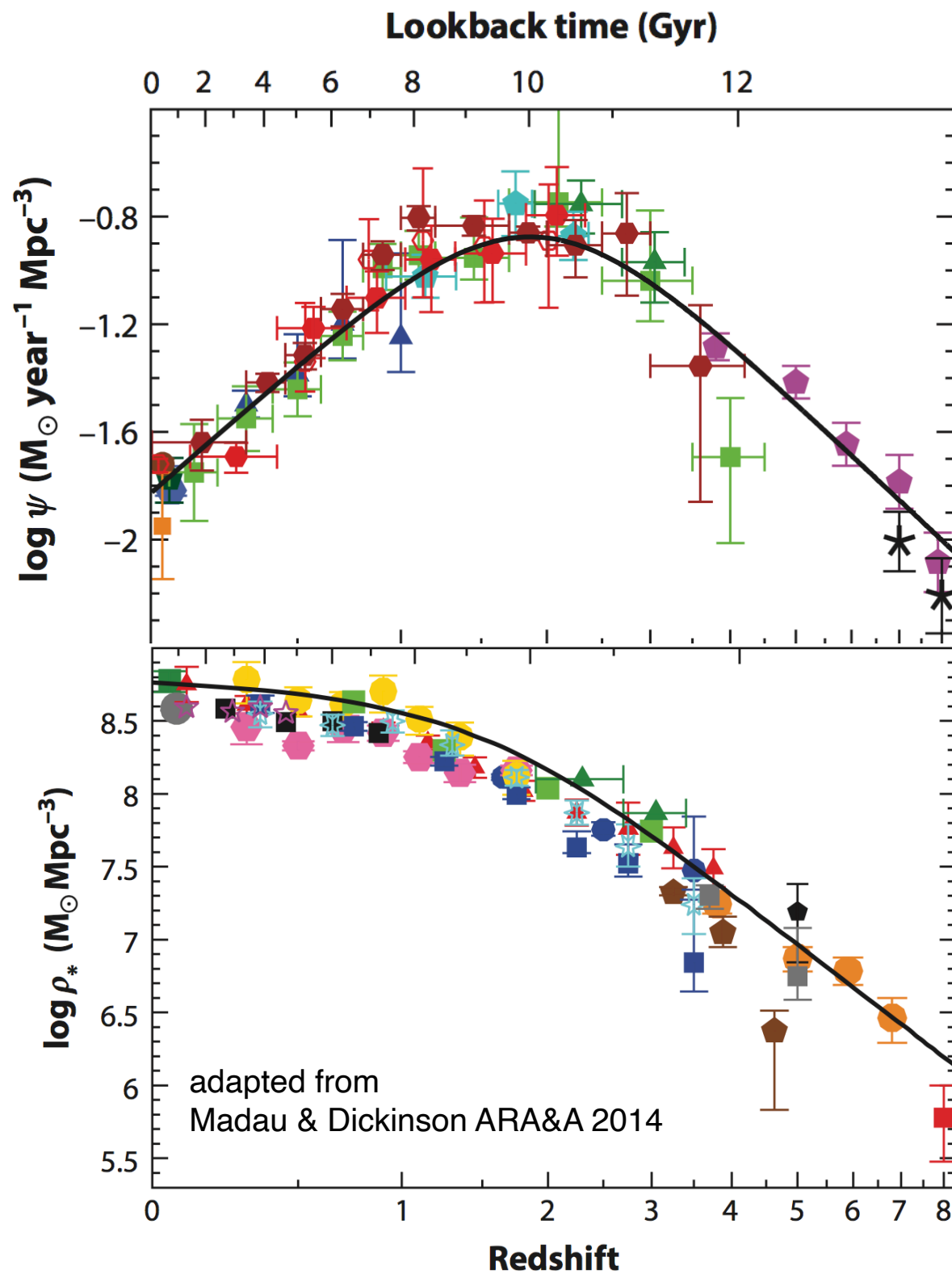
Mission	launch	λ [μm]	FWHM	discovery
IRAS	1983	12–100	$\sim 1'$	ULIRGS, debris disks
WISE	2009	3.4–22	$\sim 6''$	cold brown dwarfs, asteroids, obscured AGN
Planck	2009	350–1000	$\sim 2.5'$	LCDM, CMB lensing, Milky Way dust and polarization
SPHEREx	2025	0.75–5	$\sim 5''$	???
CMB Probe	~ 2040	365–1000	$\sim 2'$	???



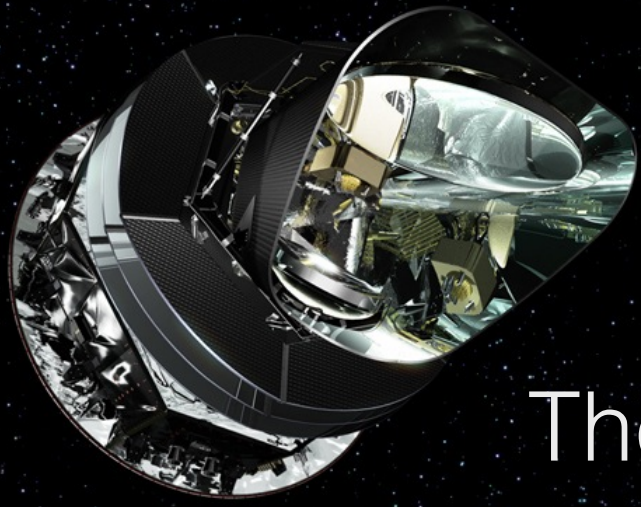
Spectrum of the Cosmic Background



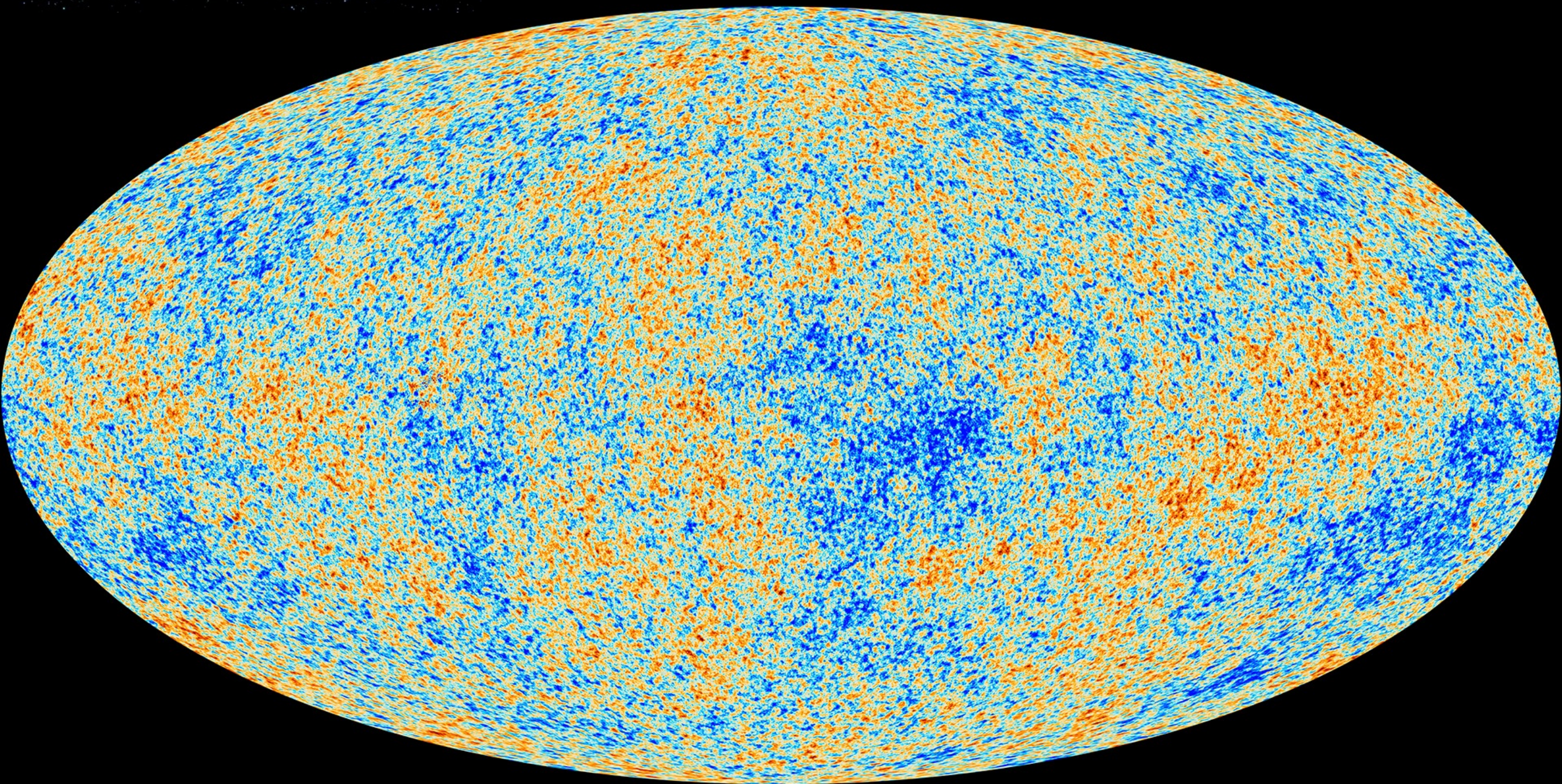
The History of Cosmic Star Formation



ESA *Planck* Satellite



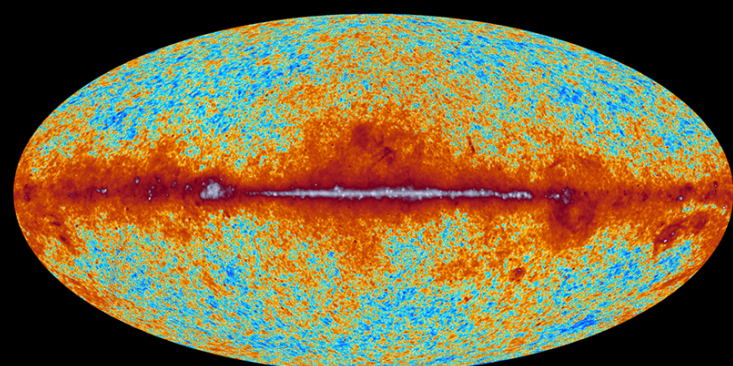
The Cosmic Microwave Background (CMB)



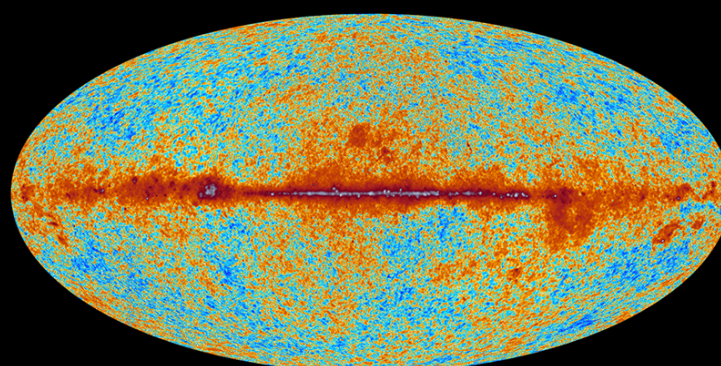


planck

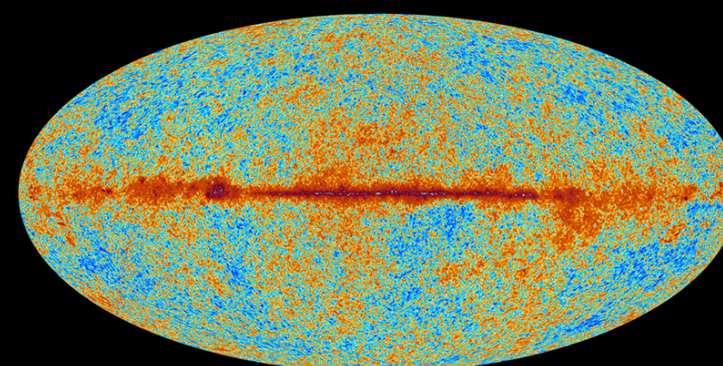
The sky as seen by Planck



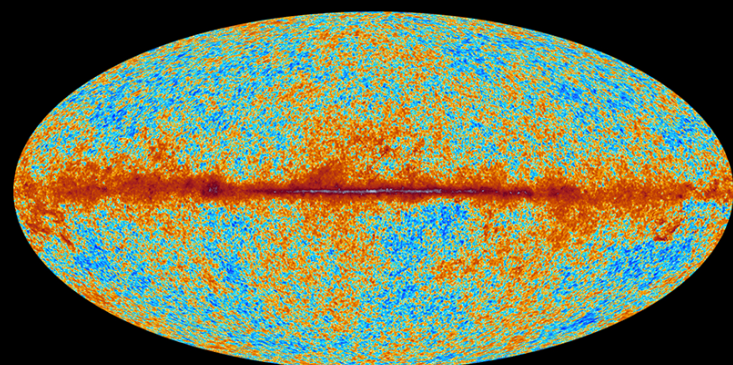
30 GHz



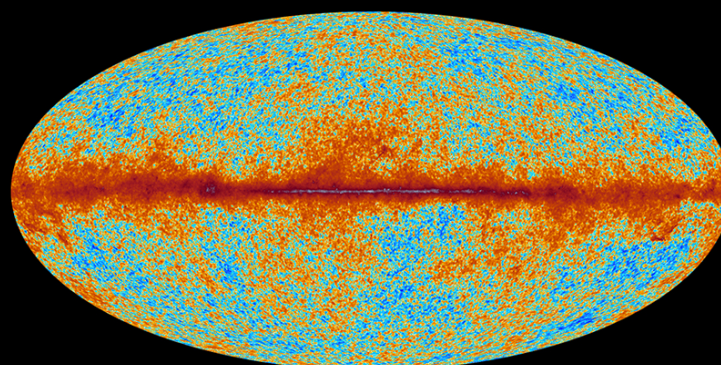
44 GHz



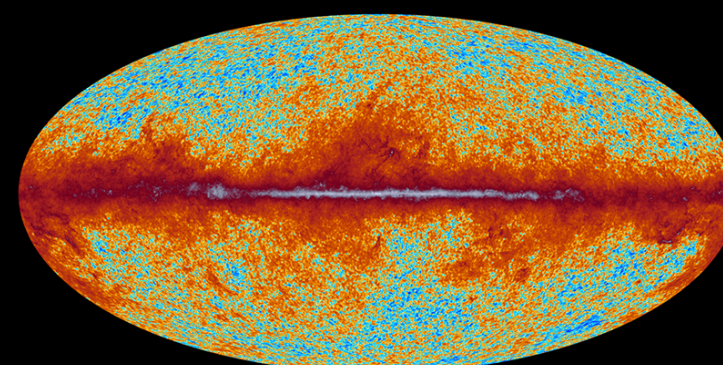
70 GHz



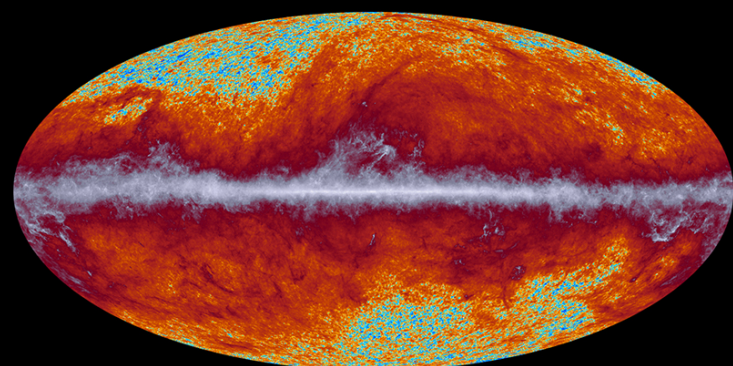
100 GHz



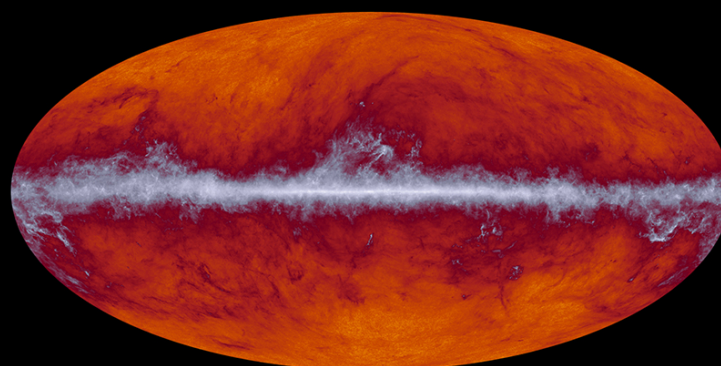
143 GHz



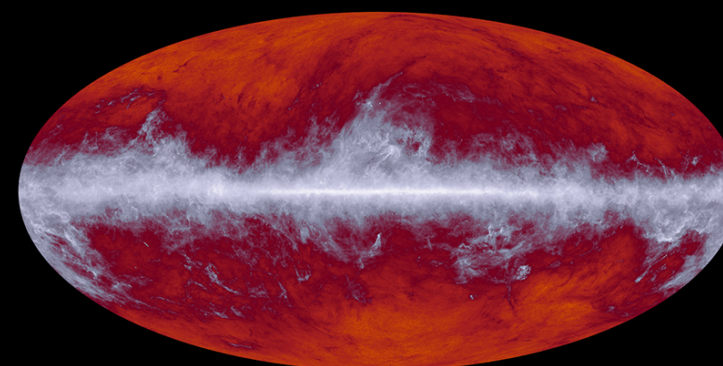
217 GHz



353 GHz



545 GHz

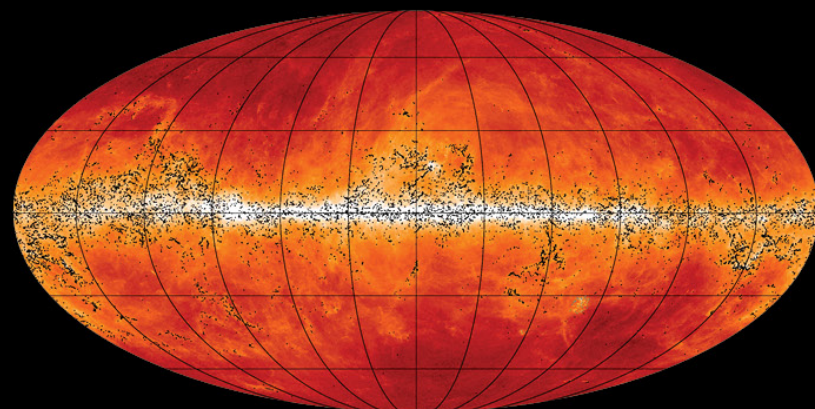


857 GHz

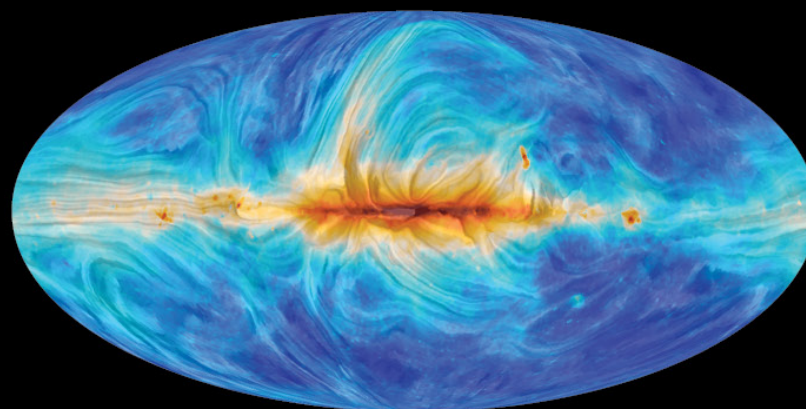


planck

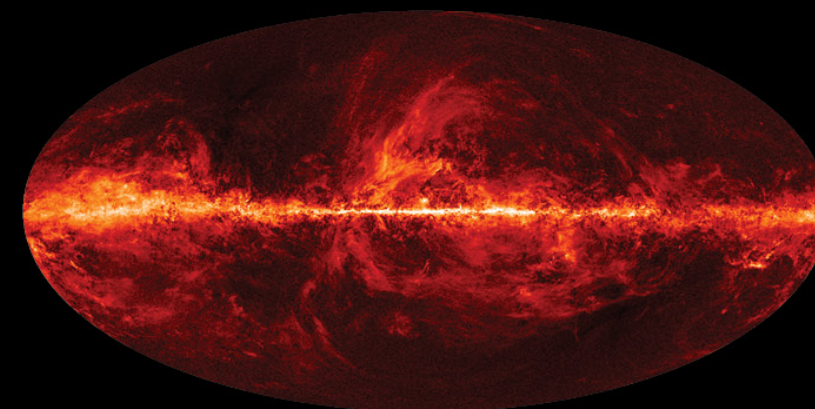
The sky as seen by Planck



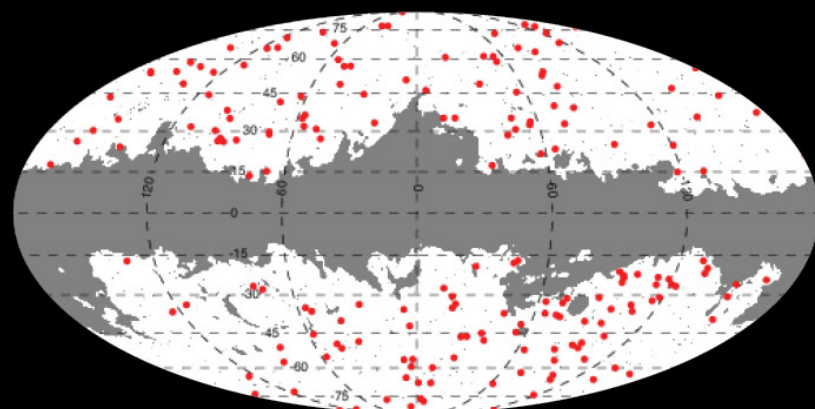
Galactic cold clumps



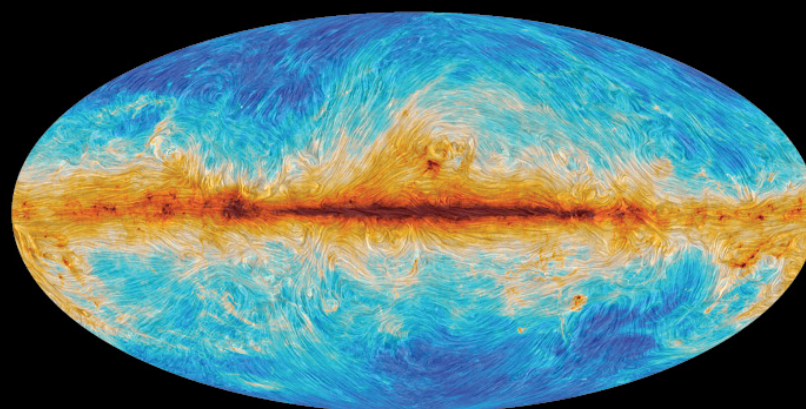
Magnetic field lines traced
by synchrotron radiation at 30 GHz



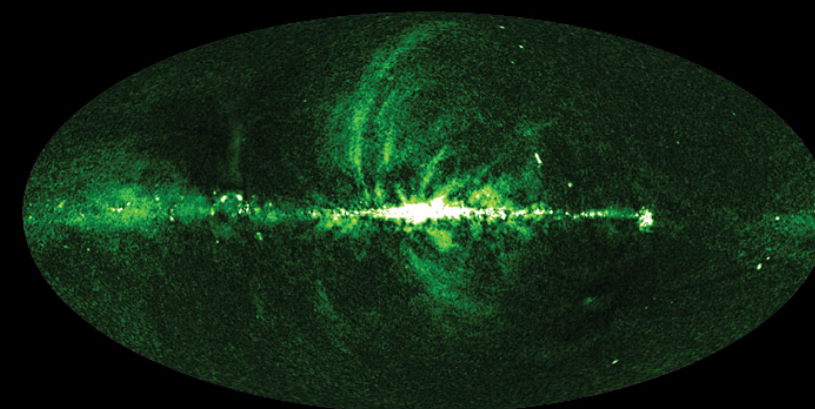
Polarised dust emission



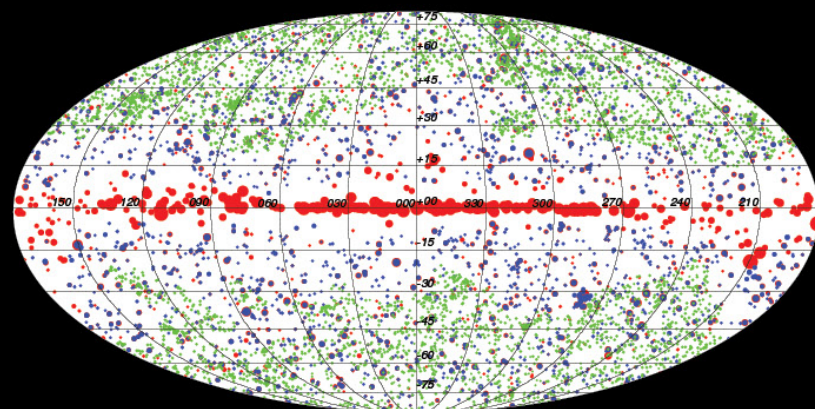
Galaxy clusters detected by
the Sunyaev-Zeldovich effect



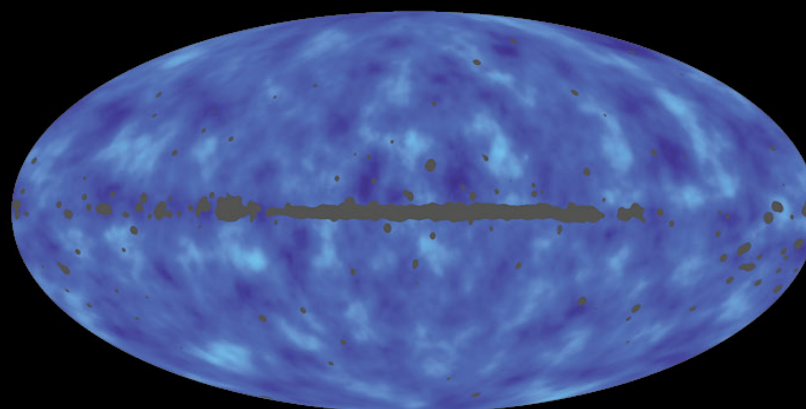
Magnetic field lines traced
by dust emission at 353 GHz



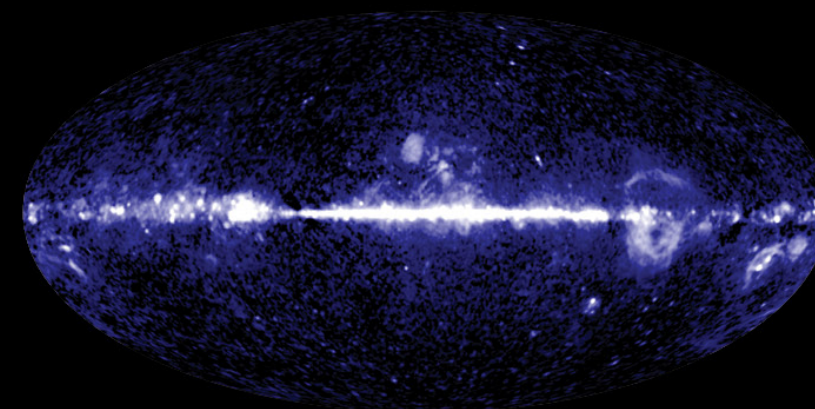
Polarised synchrotron emission



Compact sources

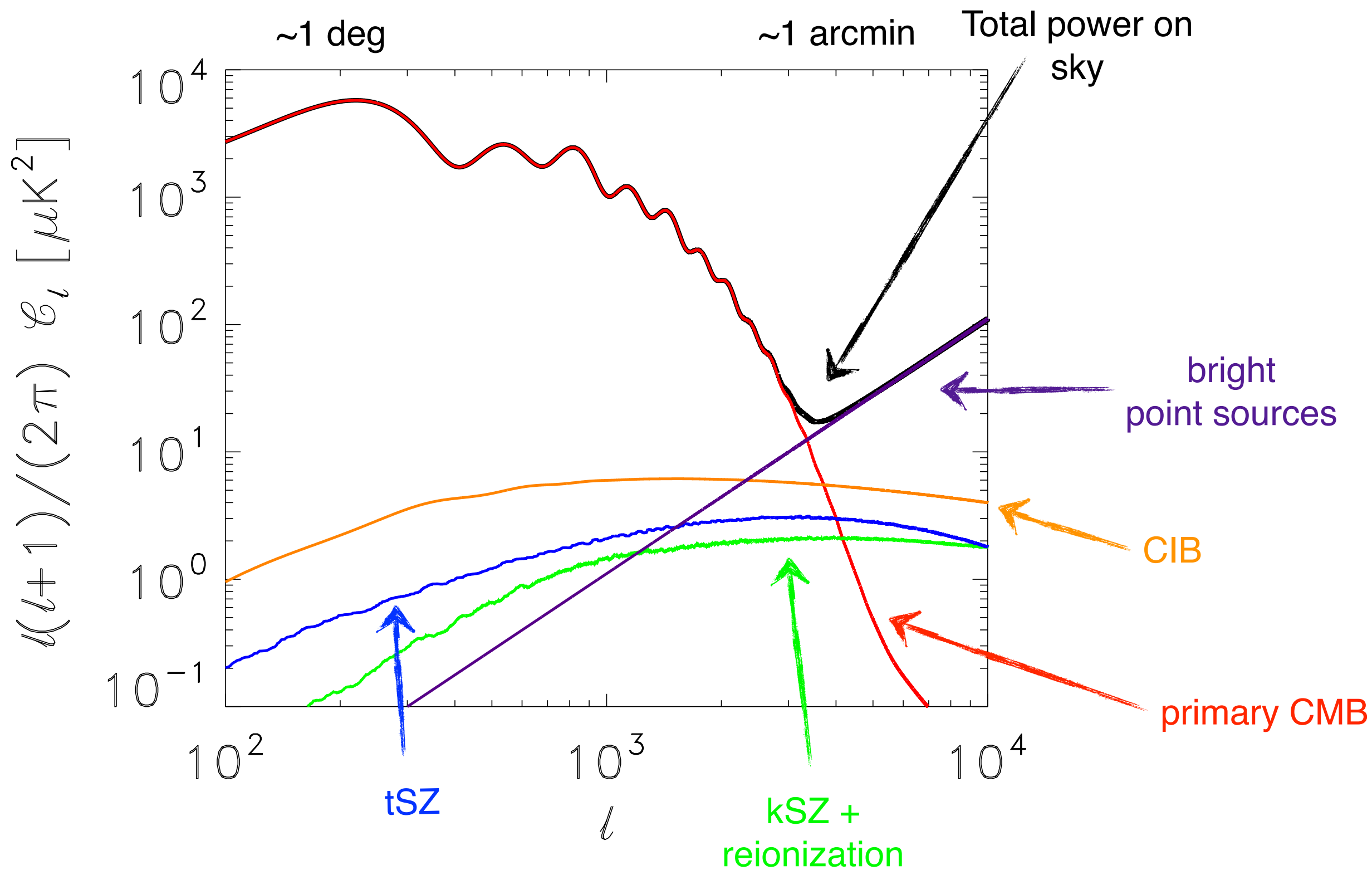


Gravitational-lensing potential —
a tracer of dark matter structures

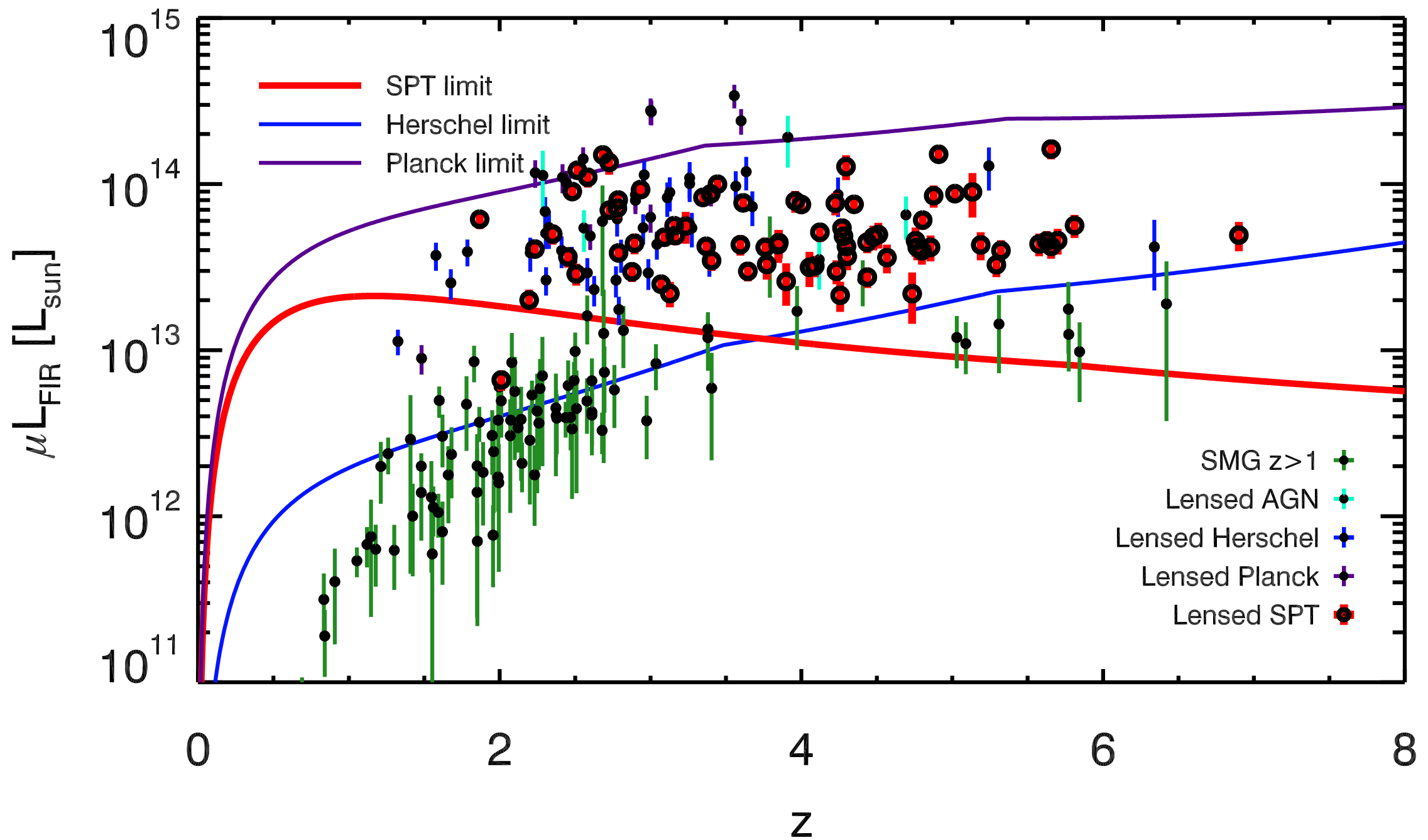


Line radiation from carbon monoxide gas

Fluctuations in the mm Sky

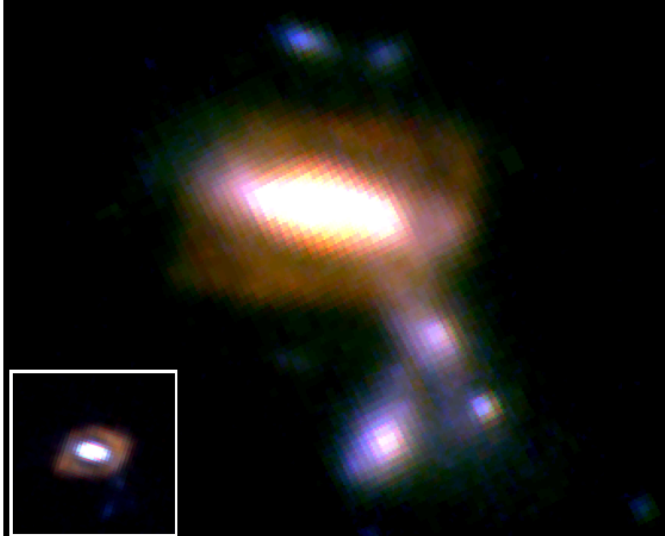


Bright sources detected in the FIR and mm

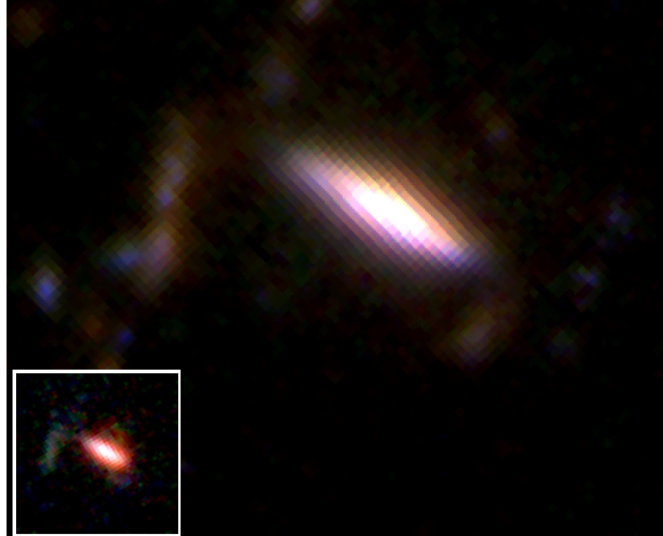


see Reuter *et al.* 2020

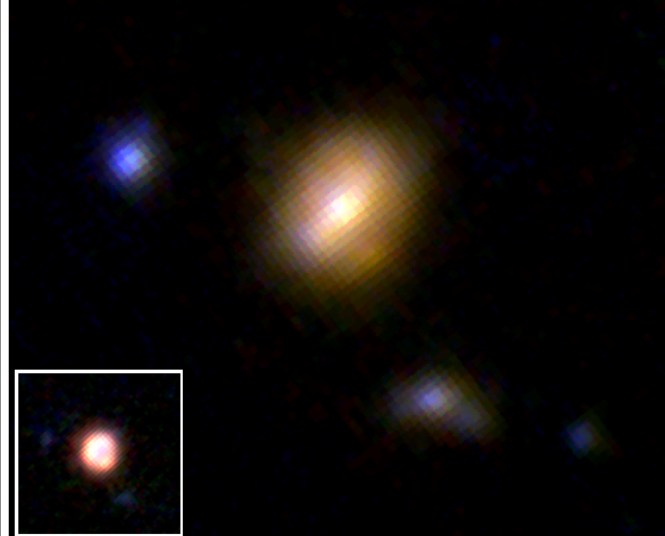
SPT0202-61
 $z = 5.018$



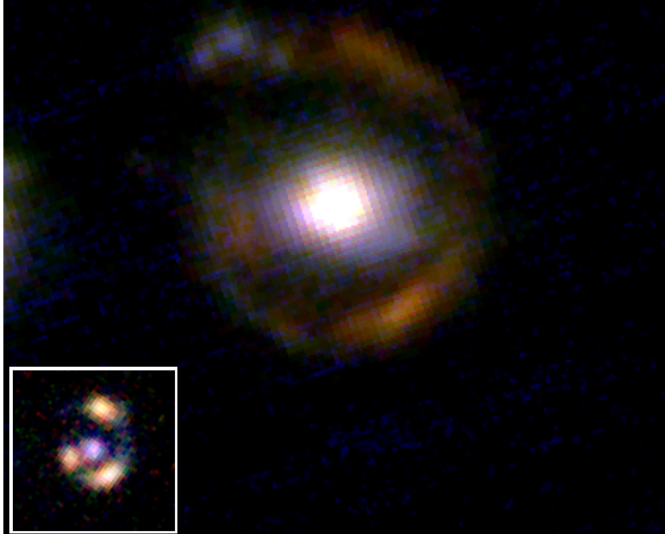
SPT0311-58
 $z = 6.901$



SPT0345-47
 $z = 4.296$



SPT0346-52
 $z = 5.655$



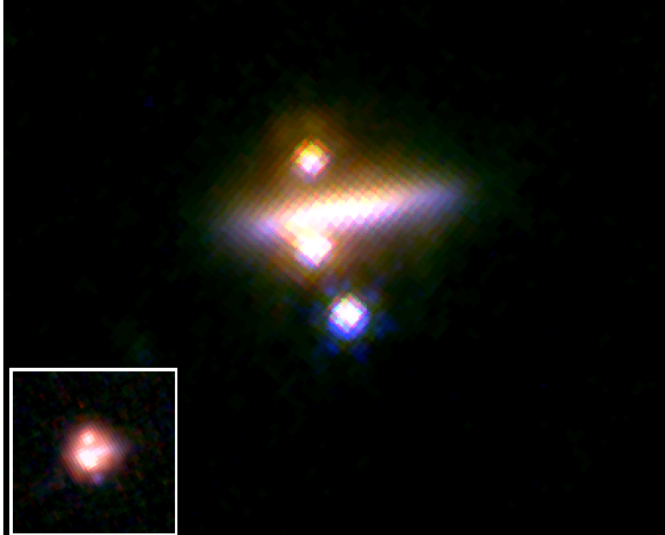
SPT0418-47
 $z = 4.225$



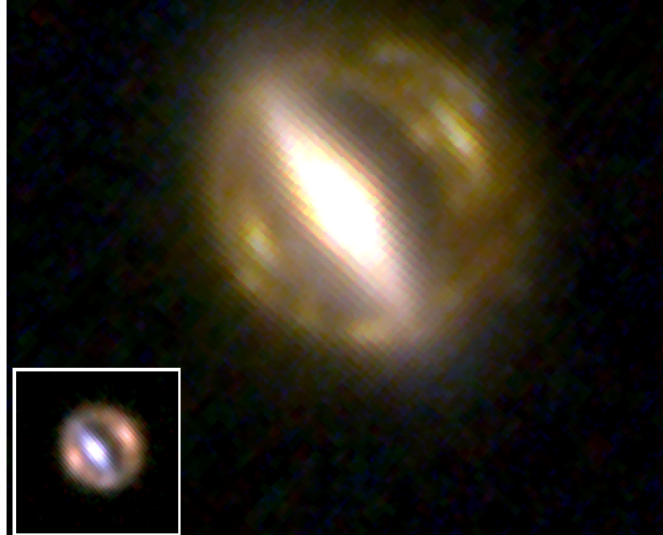
SPT0441-46
 $z = 4.480$



SPT2132-58
 $z = 4.768$



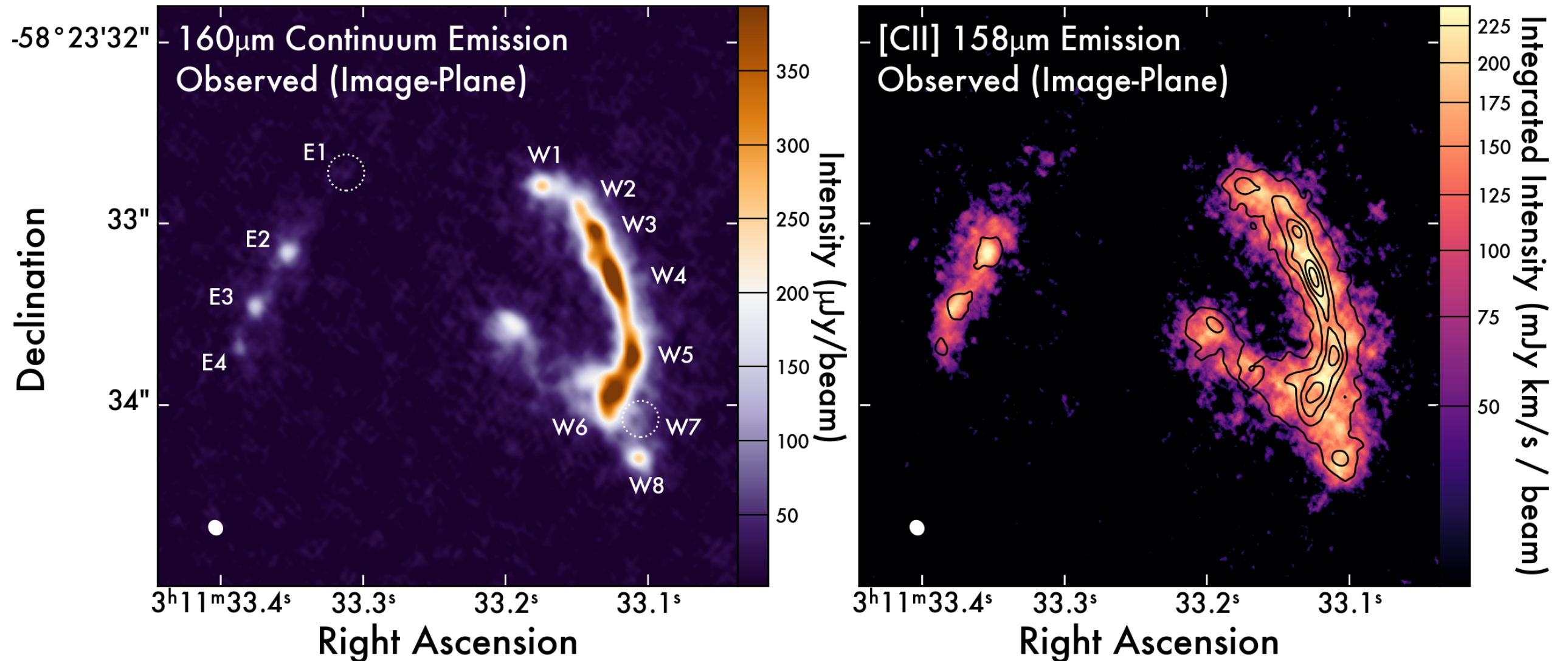
SPT2146-55
 $z = 4.567$



SPT2147-50
 $z = 3.760$



ALMA image of SPT0311-58 @ $z=6.9$



**This is the most detailed look at the
redshift ~ 7 Universe**

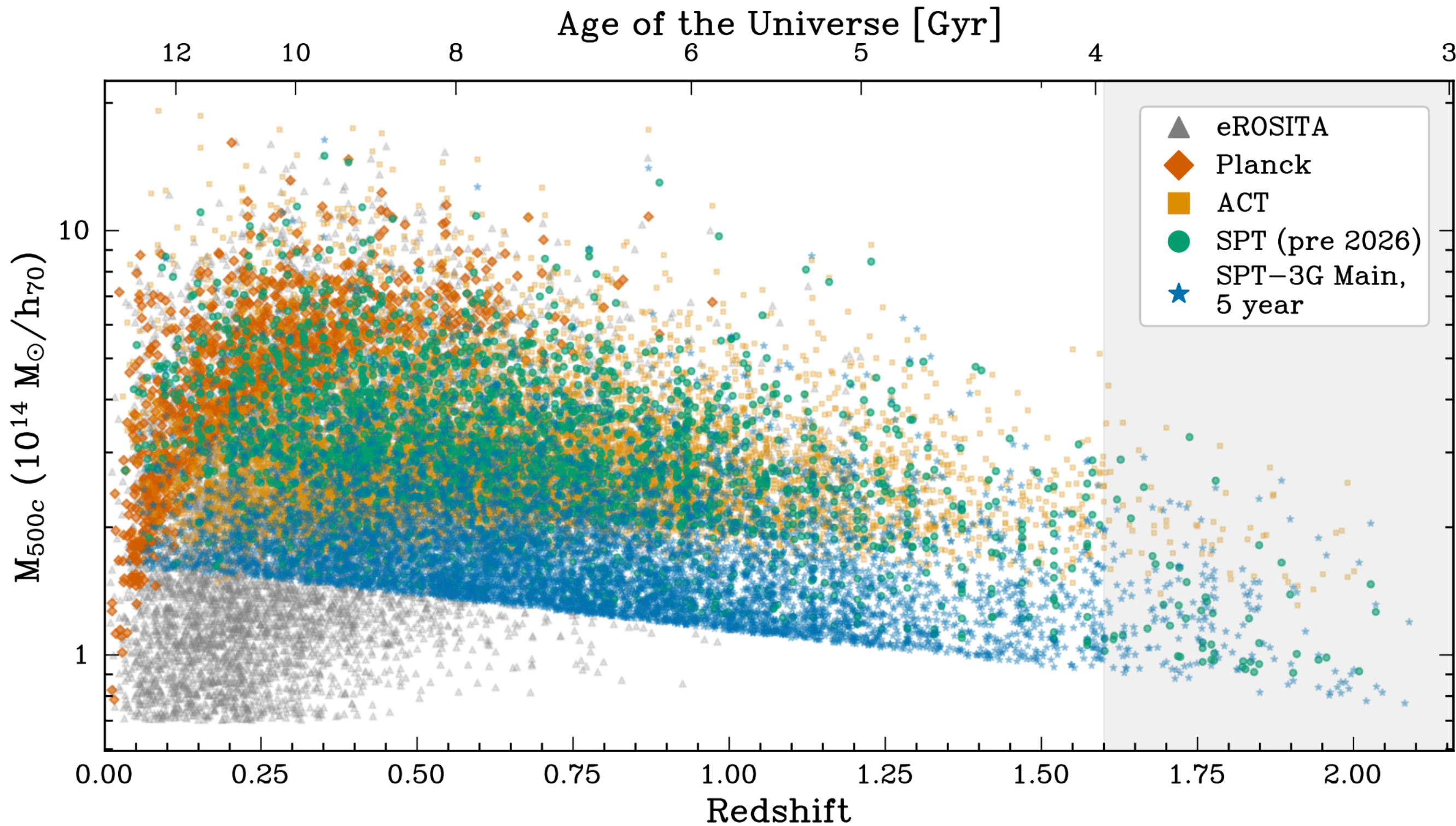
Just 800M years after the Big Bang

This is what ALMA was MADE to do

See also:

Strandet, *et al.* 2017, ApJ
Marrone, *et al.* 2018, Nature
Jarugula, *et al.* 2021, ApJ
Spilker, *et al.* 2022, ApJ

Clusters of Galaxies detected via the SZ



Bleem *et al.* 2026

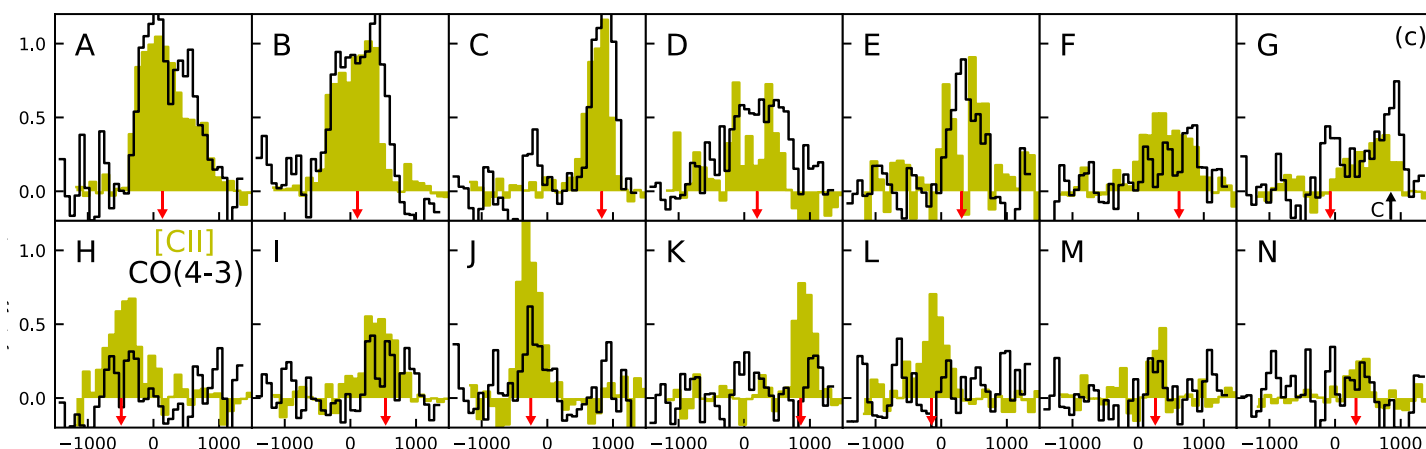
A massive core for a cluster of galaxies at a redshift of 4.3

T. B. Miller^{1,2*}, S. C. Chapman^{1,3,4}, M. Aravena⁵, M. L. N. Ashby⁶, C. C. Hayward^{6,7}, J. D. Vieira⁸, A. Weiß⁹, A. Babul¹⁰, M. Béthermin¹¹, C. M. Bradford^{12,13}, M. Brodwin¹⁴, J. E. Carlstrom^{15,16,17,18}, Chian-Chou Chen¹⁹, D. J. M. Cunningham^{1,20}, C. De Breuck¹⁹, A. H. Gonzalez²¹, T. R. Greve²², J. Harnett²³, Y. Hezaveh²⁴, K. Lacaille^{1,25}, K. C. Litke²⁶, J. Ma²¹, M. Malkan²⁷, D. P. Marrone²⁶, W. Morningstar²⁴, E. J. Murphy²⁸, D. Narayanan²¹, E. Pass^{1,29}, R. Perry¹, K. A. Phadke⁸, D. Rennehan¹⁰, K. M. Rotermund¹, J. Simpson^{30,31}, J. S. Spilker²⁶, J. Sreevani⁸, A. A. Stark⁶, M. L. Strandet^{9,32} & A. L. Strom³³

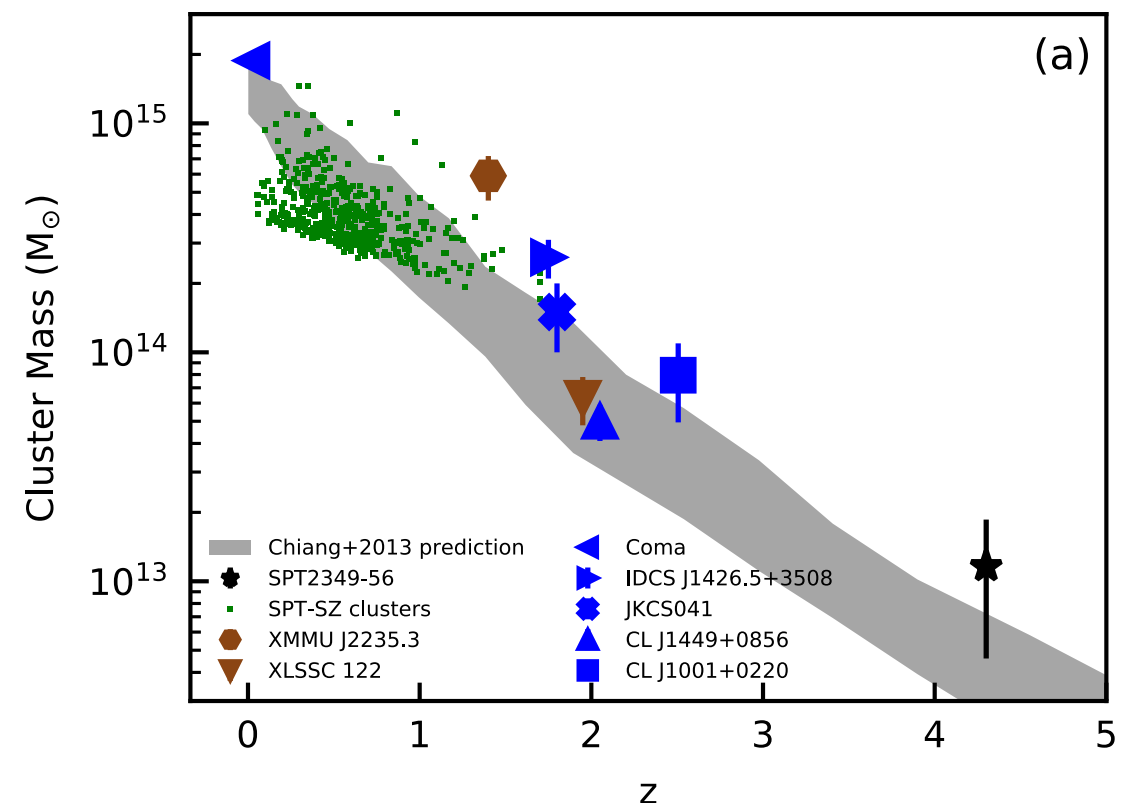
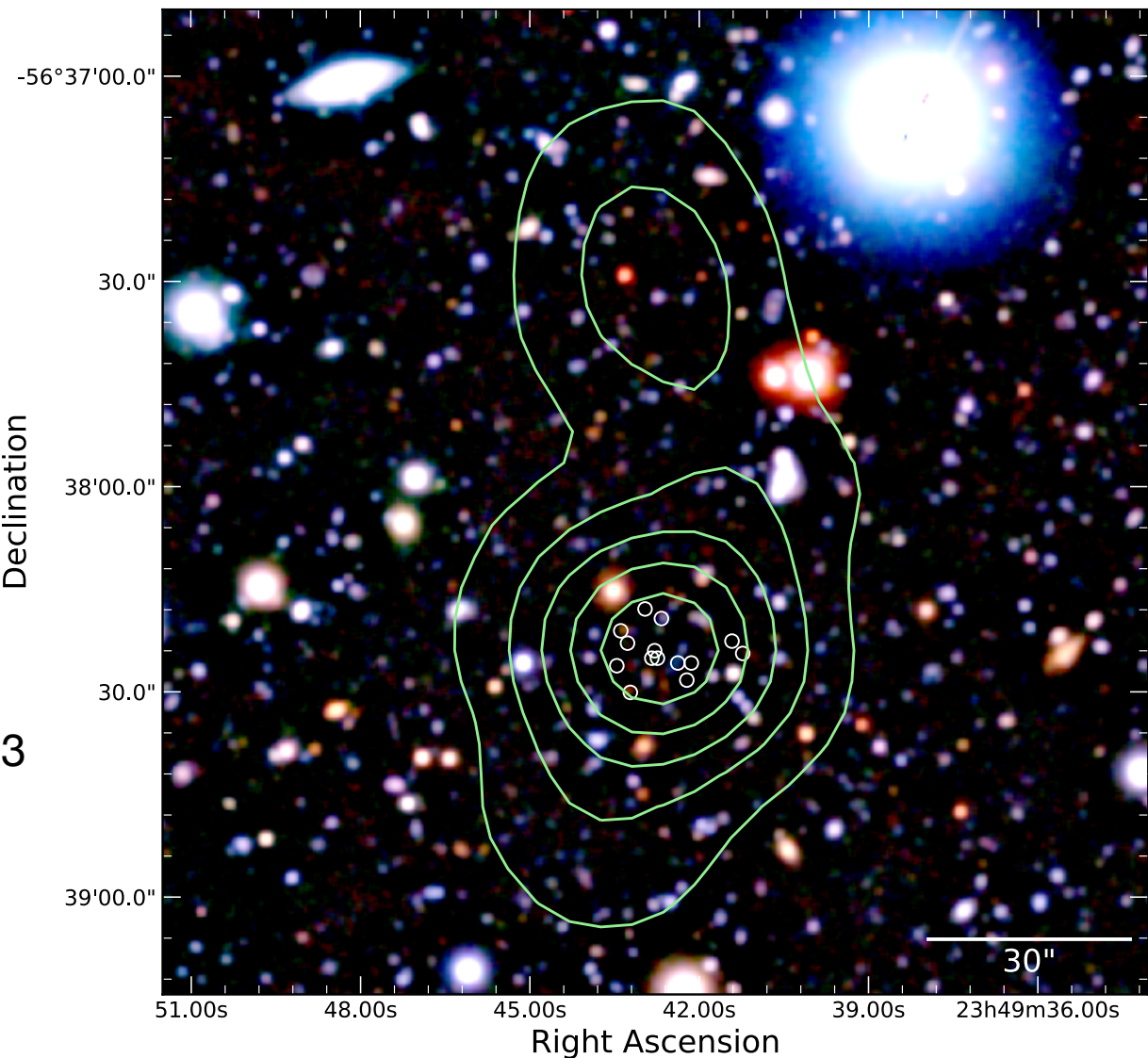
SPT2349-56: massive & rich *unlensed* protocluster at $z=4.3$

- 15+ members with individual SFR $\sim 1,000 M_{\odot}/\text{yr}$ in brightest 3
- Total SFR of protocluster up to $\sim 20,000 M_{\odot}/\text{yr}$
- Most massive & luminous protocluster discovered to date.
- Comparable in rarity to the most extreme and massive clusters ever discovered.
- Interesting environment to investigate relation of SMGs to LBGs, AGN, etc.

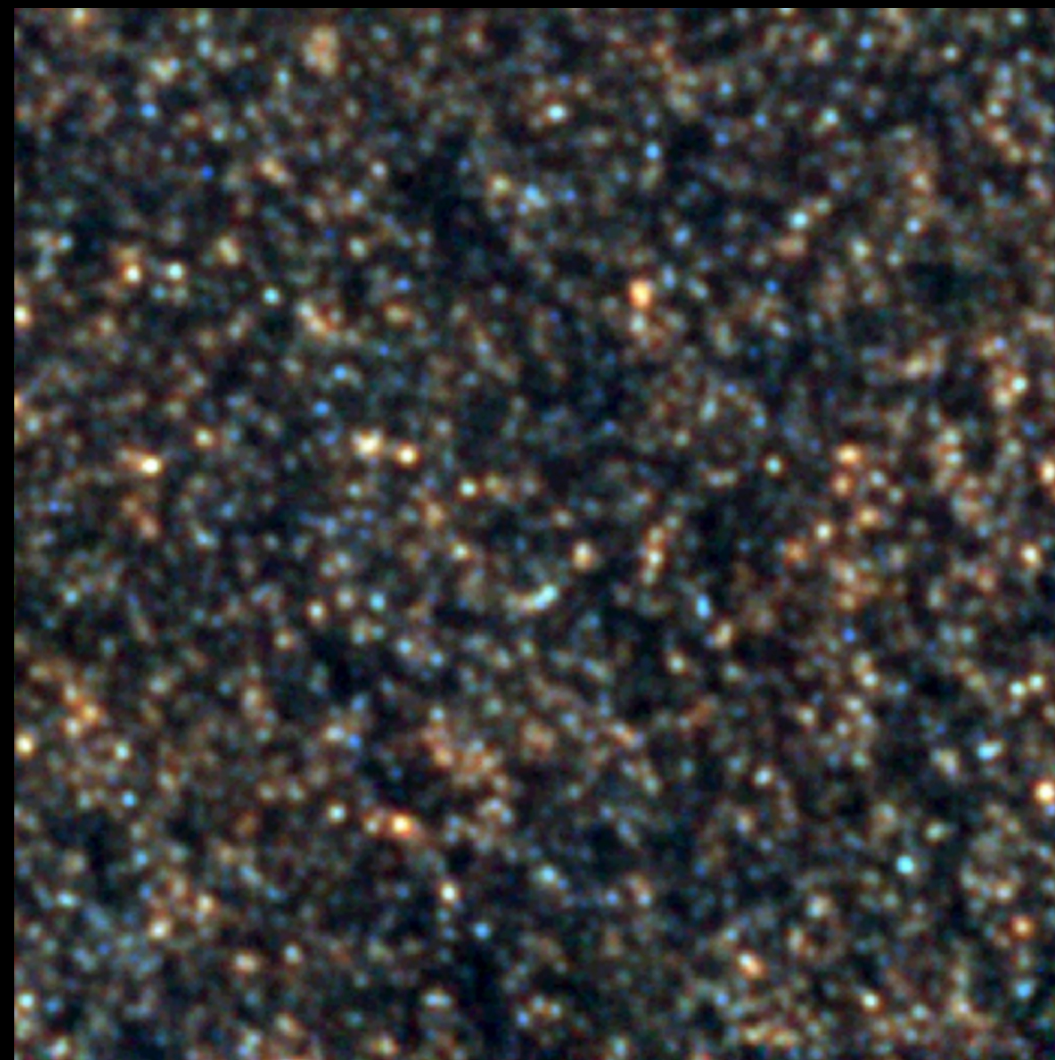
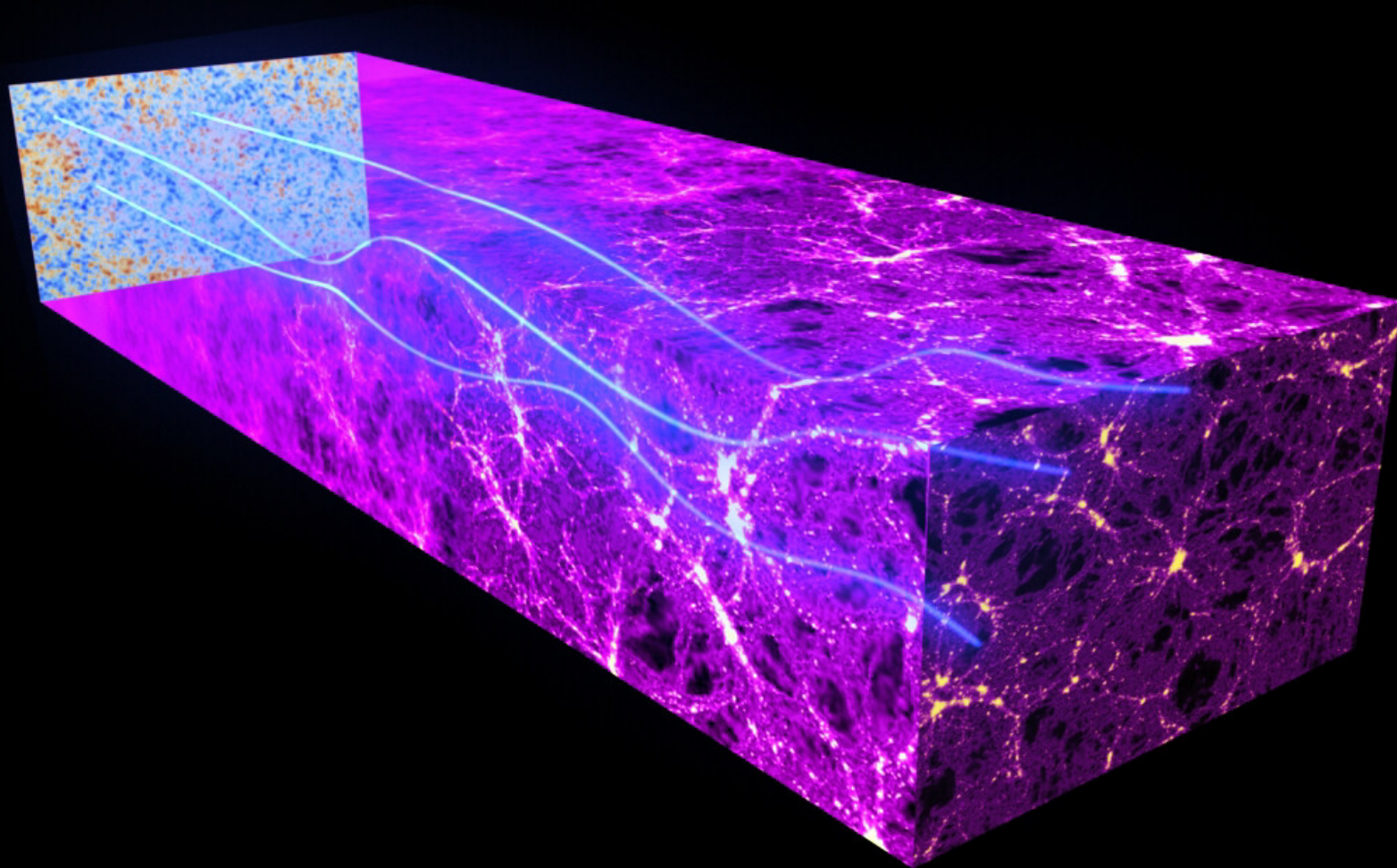
ALMA B7 [CII] spectra:



Declination



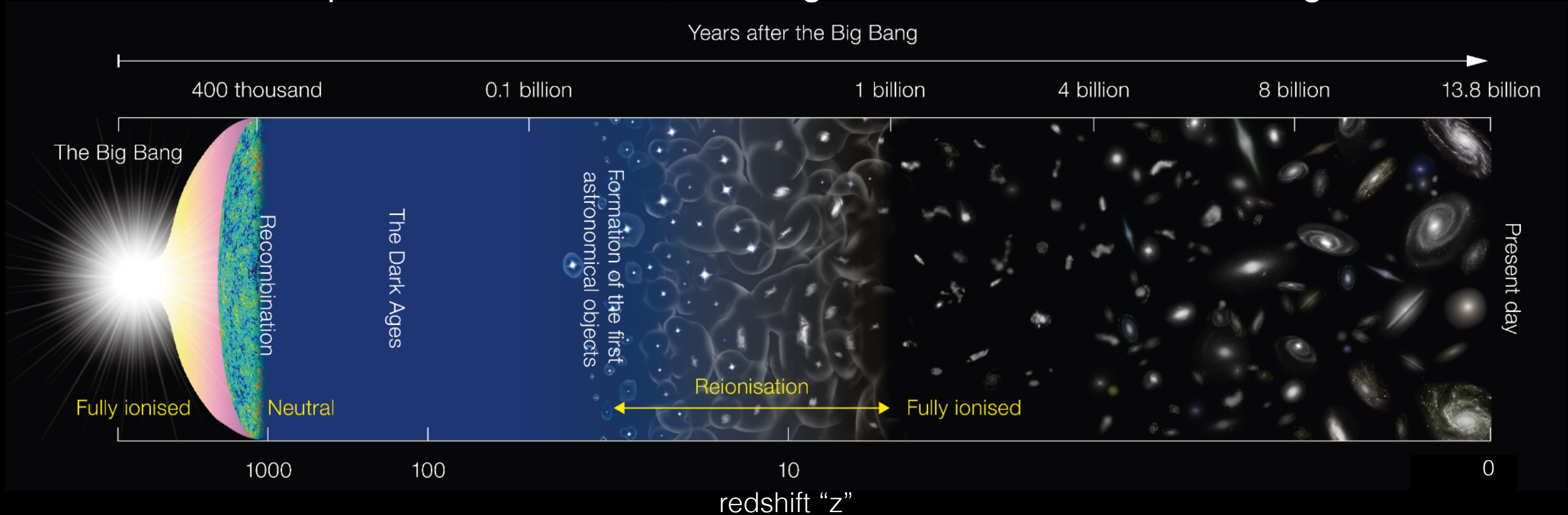
CMB lensing × CIB



- The CIB traces the integrated history of obscured star formation
- Cross correlating with the CMB lensing map provides insight into the connection between star formation and the underlying dark matter halos
- In a decade, there will be many more data sets to cross correlate with: Euclid, Rubin, Roman, SPHEREx, etc

Brief History of the Universe

A telescope is a time machine, allowing us to observe our cosmic origins



The epoch of **inflation** is the first 10^{-36} s after the beginning when the Universe underwent a period of extreme expansion and quantum mechanical fluctuations were stretched and seeded the structure we see in the universe today.

The **cosmic microwave background (CMB)** radiation is the oldest light in the universe. It originated from when the universe initially expanded and cooled and neutral hydrogen formed and the universe became neutral at ~400k yrs ($z \sim 1100$) after the beginning.

The **epoch of reionization** occurred around 0.5 Gyr ($z \sim 20$) when the first stars formed and emitted UV photons, which reionized the universe.

The peak of **cosmic star formation** and galaxy evolution occurred when the Universe was half of its current age ($z \sim 1-2$).

Currently we are in the age of accelerated expansion, where structure is defined by the distribution of **dark matter**, but space is dominated by **dark energy**.

Extragalactic Astrophysical Legacy of a CMB Probe

- A Cosmic Microwave Background (CMB) Probe, surveying the millimeter and sub-millimeter full sky with arc-minute resolution and the equivalent sensitivity of more than 6,000 Planck missions, would be transformative for extragalactic science.
- A CMB Probe would produce un-precedented measurements of the Cosmic Infrared Background (CIB), dusty star-forming galaxies, active galactic nuclei (AGN), galaxy clusters, and other compact sources.
- Cross correlations will provide insights into the connection of baryons and star formation to the underlying dark matter halos.

