# Millimetron & CMB spectral distortions

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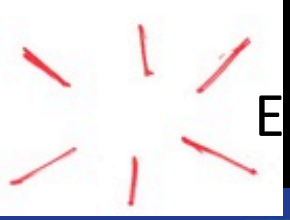
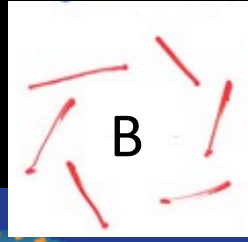
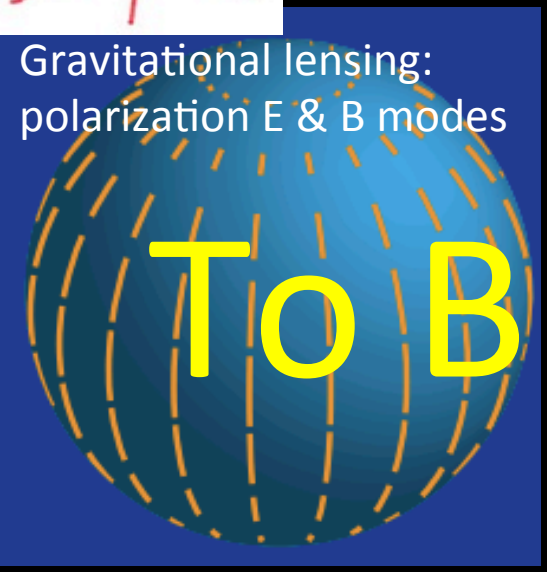


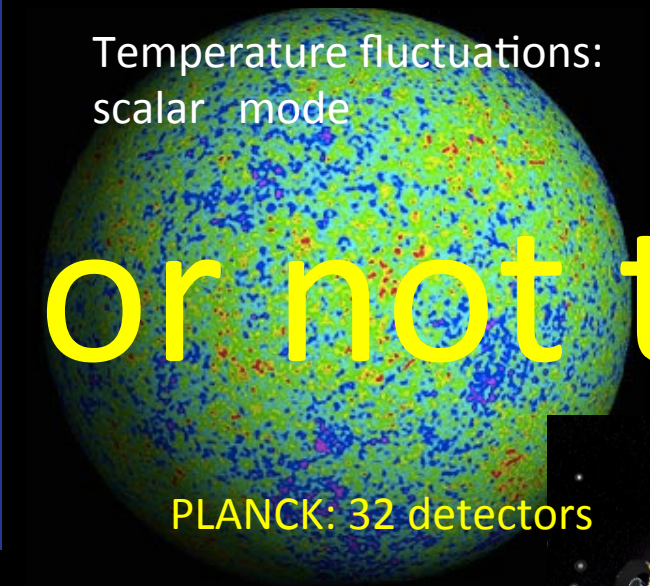

# What next?



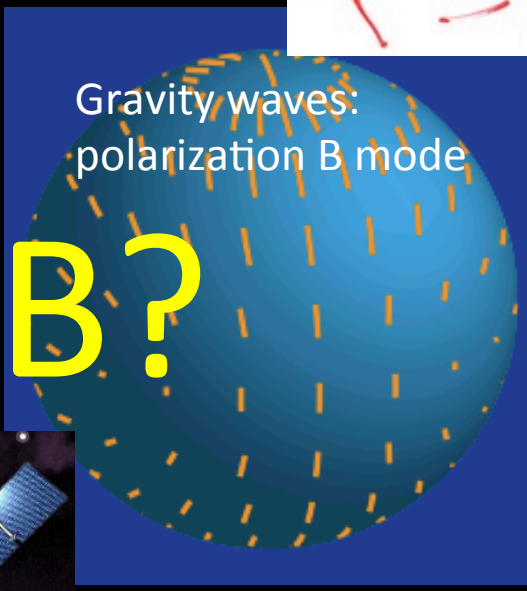

Gravitational lensing:
polarization E & B modes



Temperature fluctuations:
scalar mode

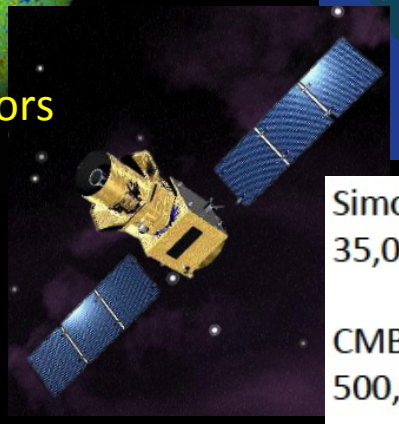


Gravity waves:
polarization B mode



# To B or not to B?

PLANCK: 32 detectors



Satellite: LiteBIRD (JAXA launch in 2027?)

Goal: r ~ 0.001

Simons Observatory:
35,000 Detectors – 2TB/day

CMB S4:
500,000 Detectors – 140 TB/day

ground/balloon: CMB-S4, c. 2025



But so far there is no guarantee of a signal!

# Something different

# CMB spectral distortions

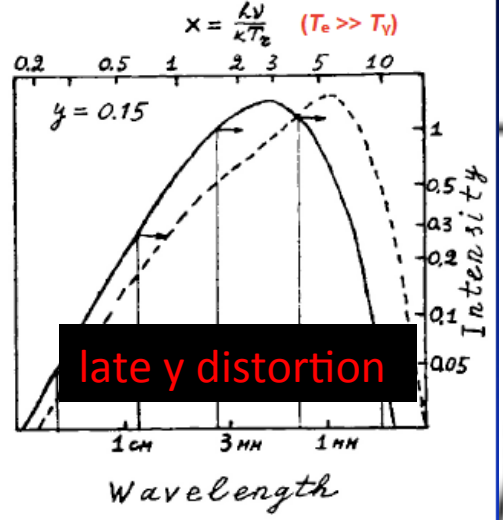
Probes early energy input into the universe

Ultimate goal: recombination of the universe

# Its all about sensitivity

- Need to improve on FIRAS by 5 orders of magnitude
- But that was in 1980

# Spectral distortions: new frontier




late y distortion




Bose-Einstein limit

$$T_0 = 2.725 \pm 0.001\,\mathrm{K}$$

$$|y| \le 1.5\times10^{-5}$$

$$|\mu| \le 9\times10^{-5}$$




early μ distortion

Sunyaev & Zeldovich, 1970, ApSS, 2, 66

# Probing primordial energy input

$\mu$ distortion is our best hope: over $z = 5.10^4$ to $2.10^6$

- $z > 2.10^6$: bremsstrahlung +double Compton creates blackbody photons
- $\mu = 1.4\ \delta E_{injection}$ due to Compton scattering
- adds energy, conserving photon number, over $2.10^6 > z > 5.10^4$ : $\mu$
- $5.10^4 > z$: Thompson transfers energy : y spectral distortion

- Many papers on this: eg, decaying particles, primordial black holes…
- No guaranteed signal of exotica

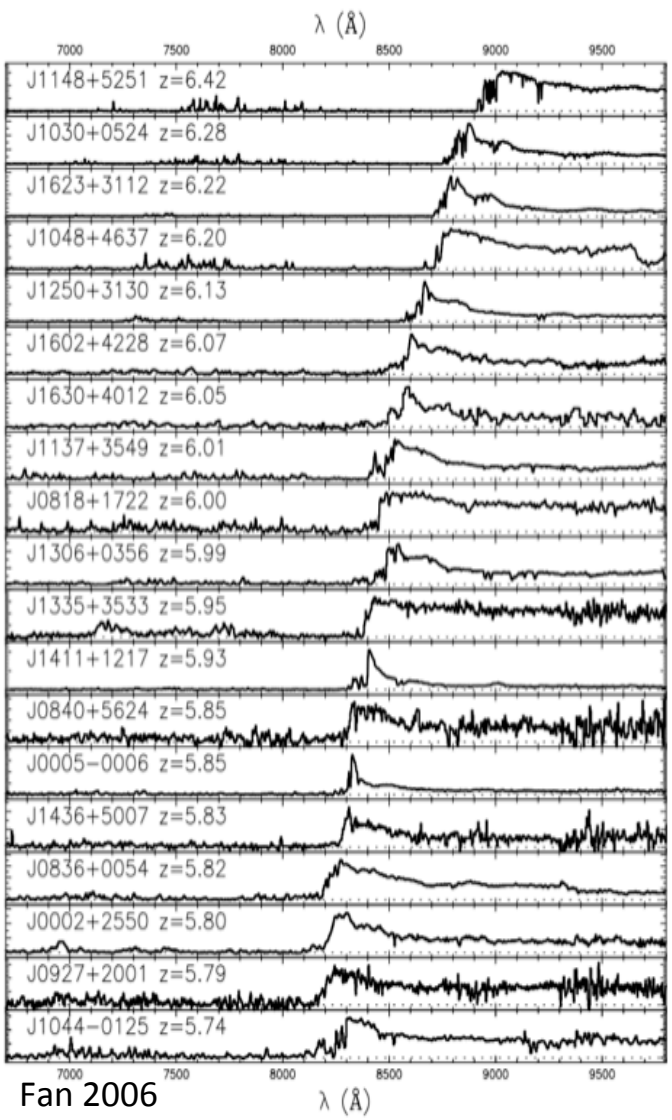
# Guaranteed returns to fundamental cosmology

- 1. Damping of dwarf galaxy fluctuations
  $k_D = 4 z_4^{3/2}$ Mpc$^{-1}$ probes 50-$10^4$ Mpc$^{-1}$
- 2. (re)combination spectral lines of hydrogen
  380000 yrs after the Big Bang
- 3. (re)combination spectral lines of helium
  200000 yrs after the Big Bang
  long before the first stars

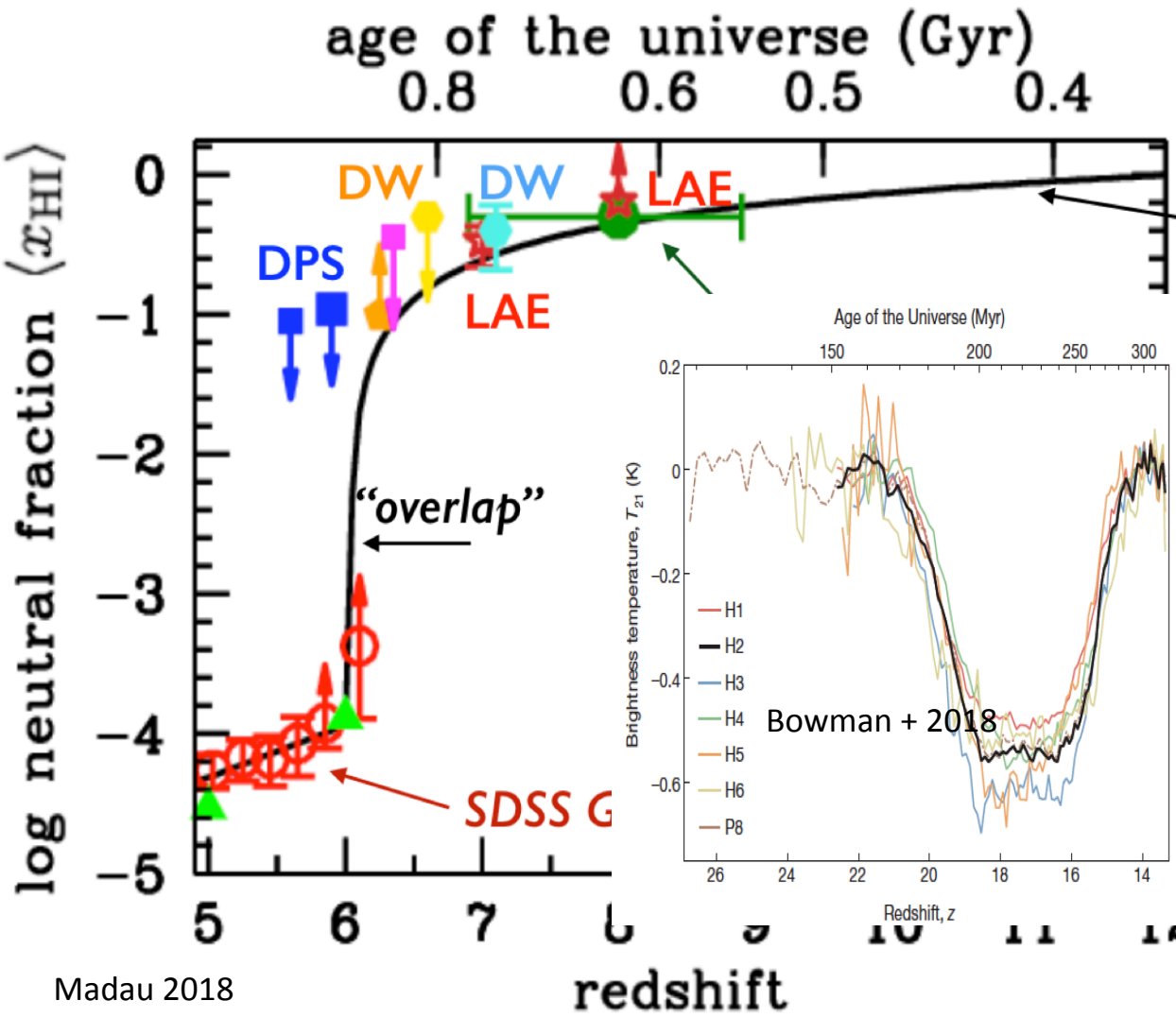
# Hydrogen recombination lines

We measure atomic hydrogen directly to z ~8

+ 21 cm maybe to z~17

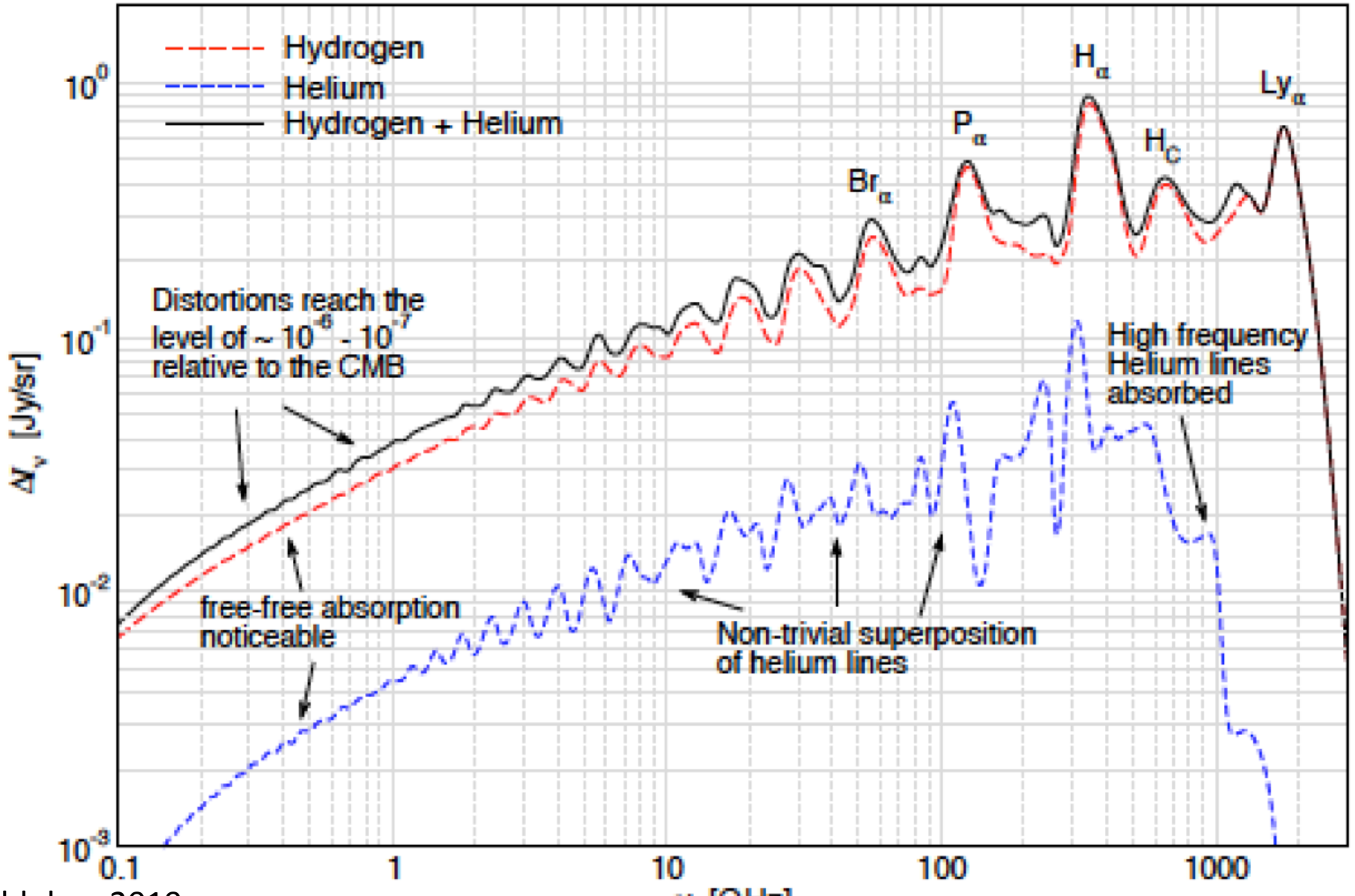



Fan 2006

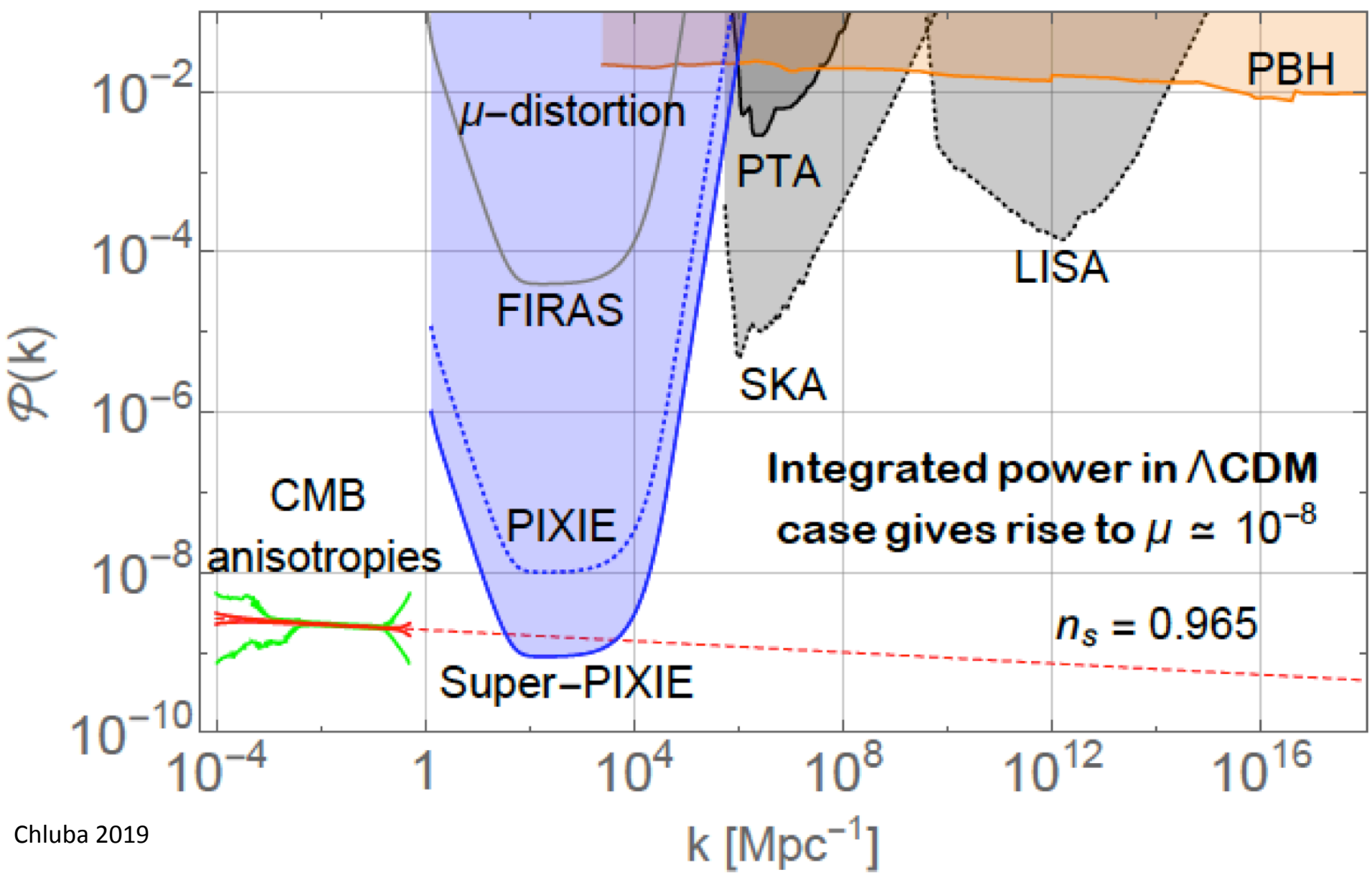



Madau 2018

# Going for primordial helium

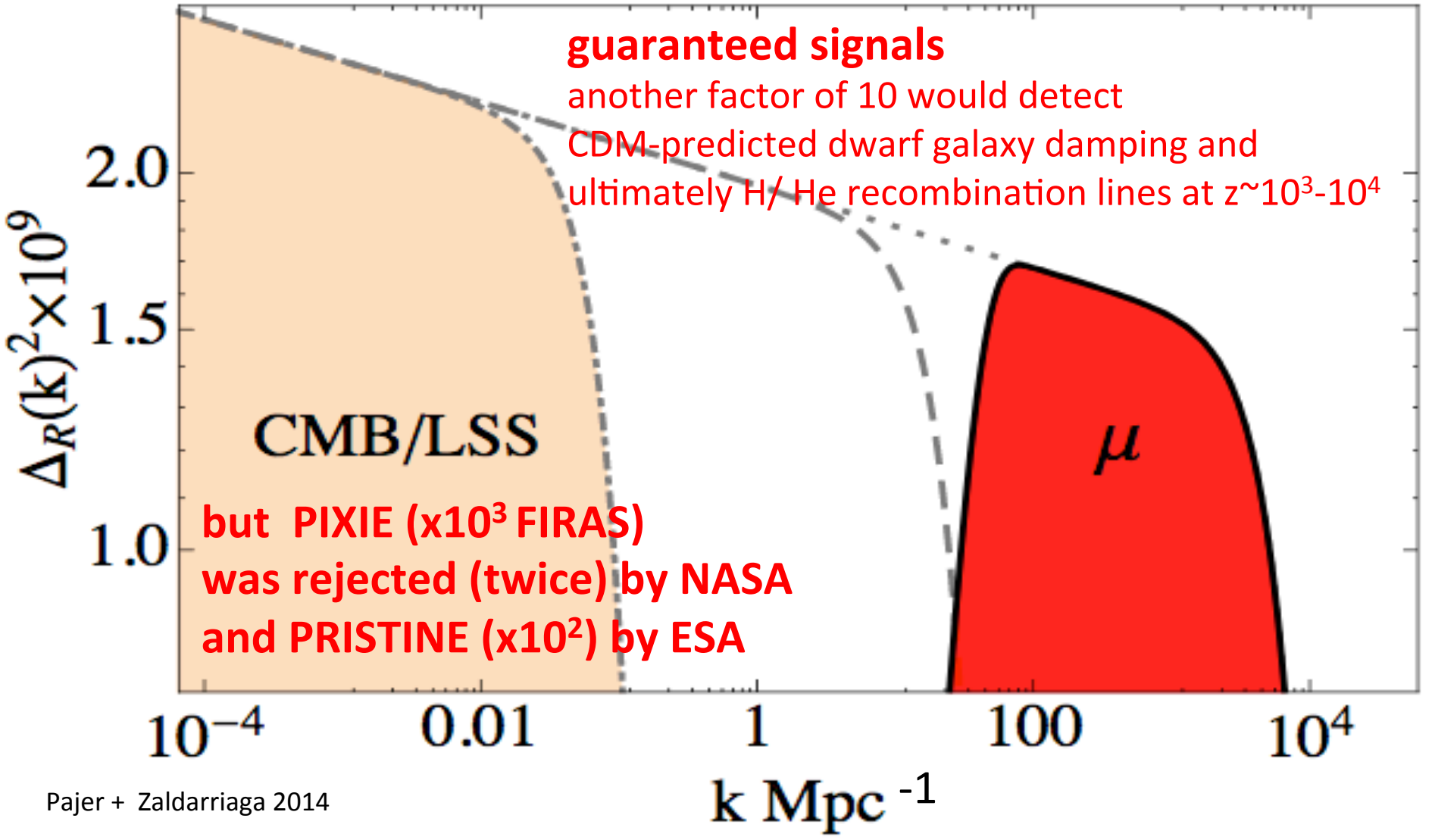


# Sensitivity needed for a guaranteed signal




Chluba 2019

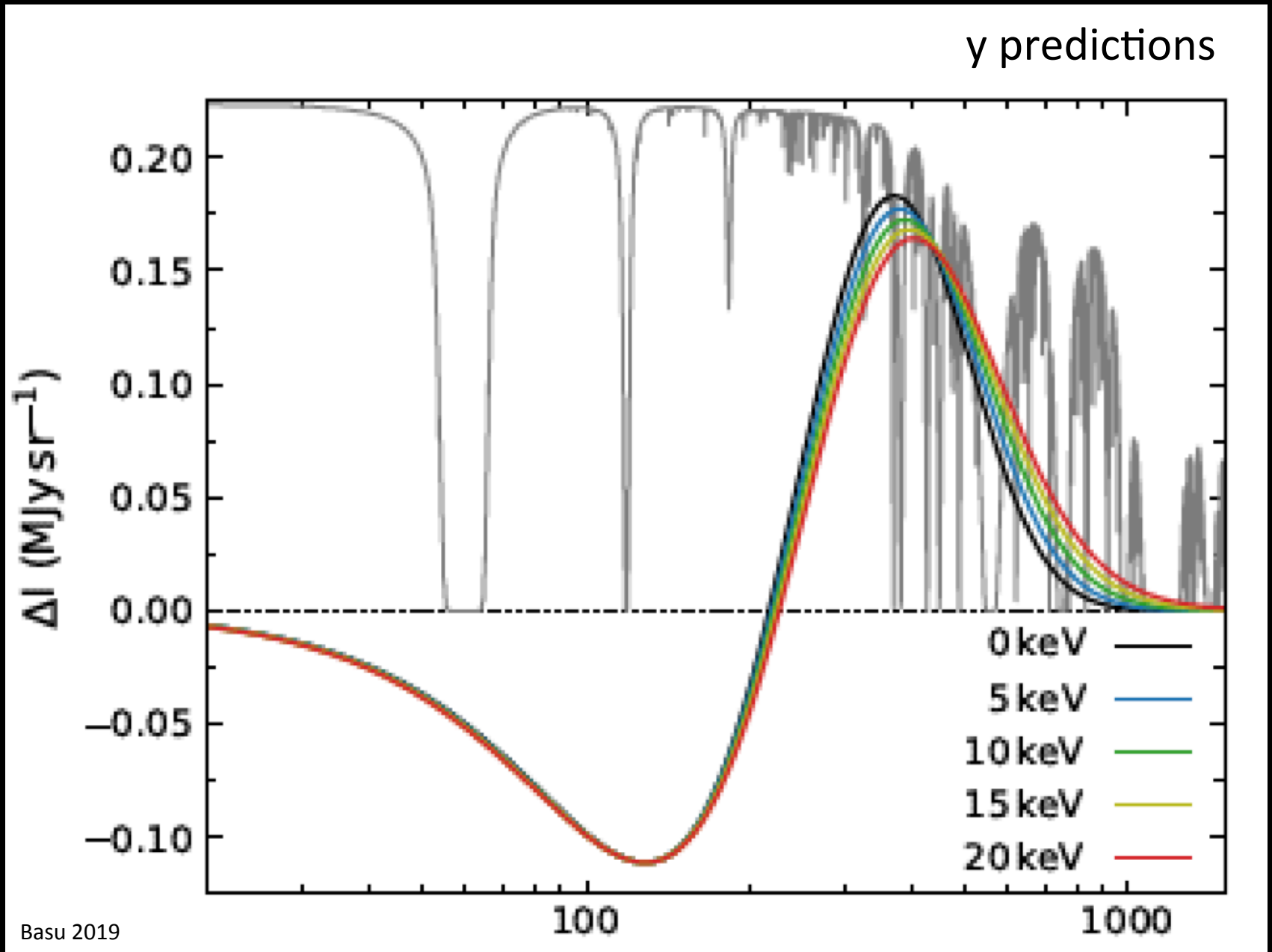
# The μ goal




Pajer + Zaldarriaga 2014

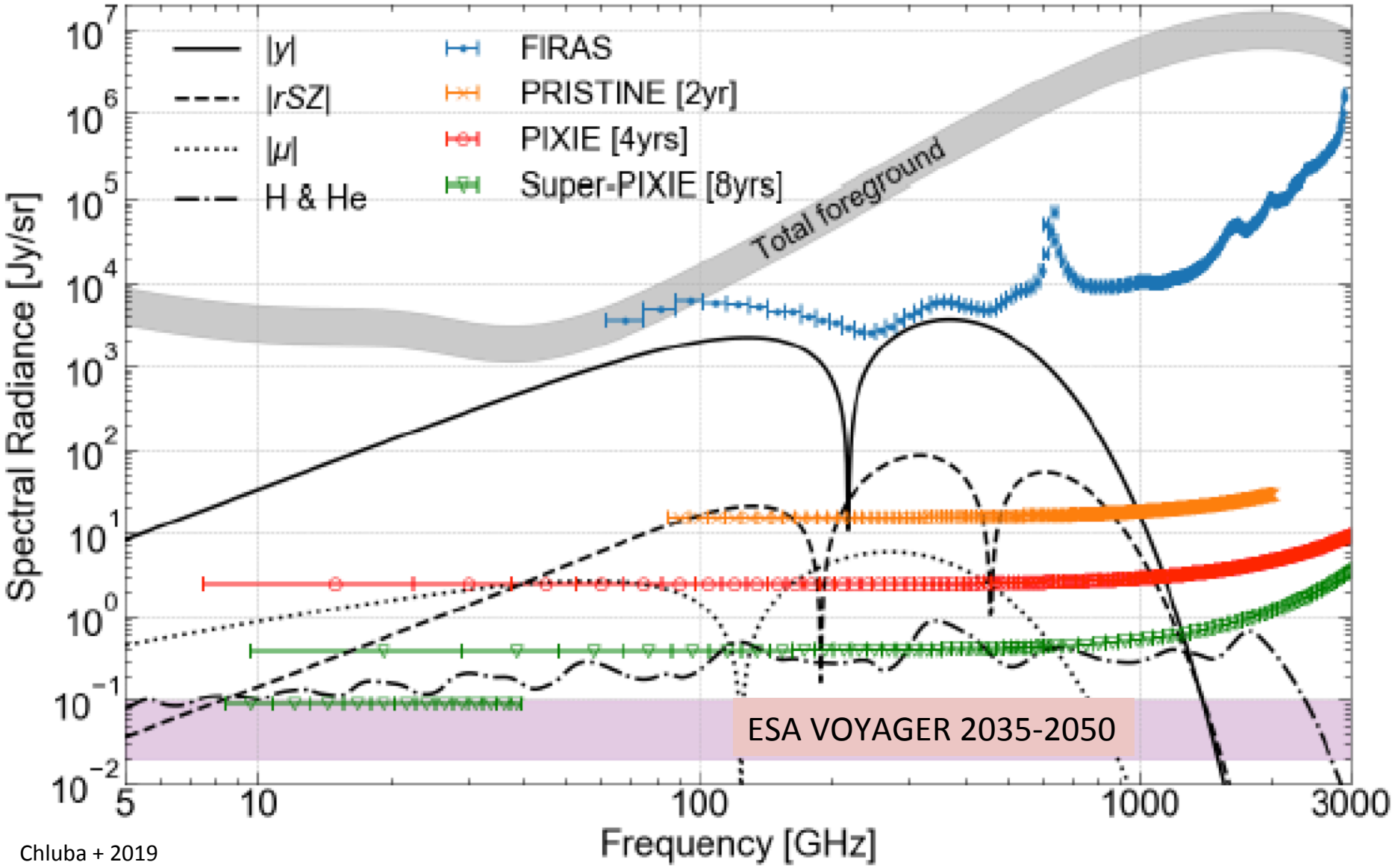
probe baryon damping power on dwarf galaxy scales via trillions of modes

# Advantages of space




Basu 2019

# planning for a CMB spectral distortion mission



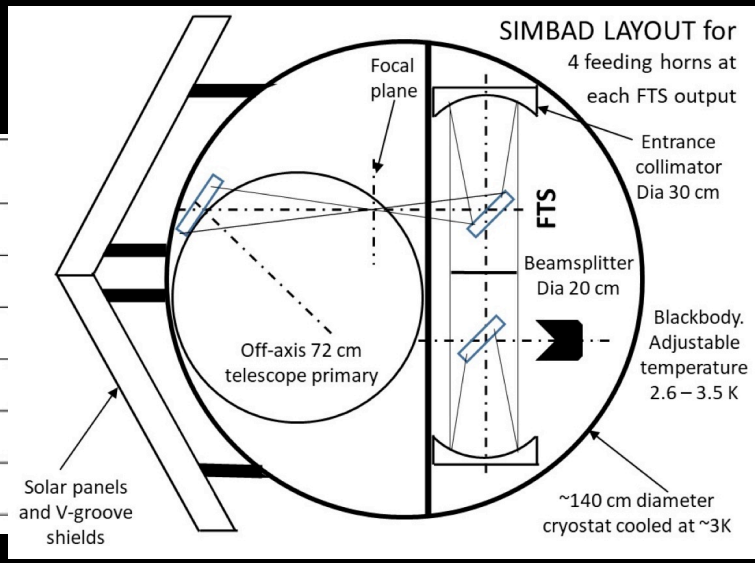

Chluba + 2019

# Fourier transform spectrometer

## sensitivity needed compared to PIXIE

J-P Maillard 2019

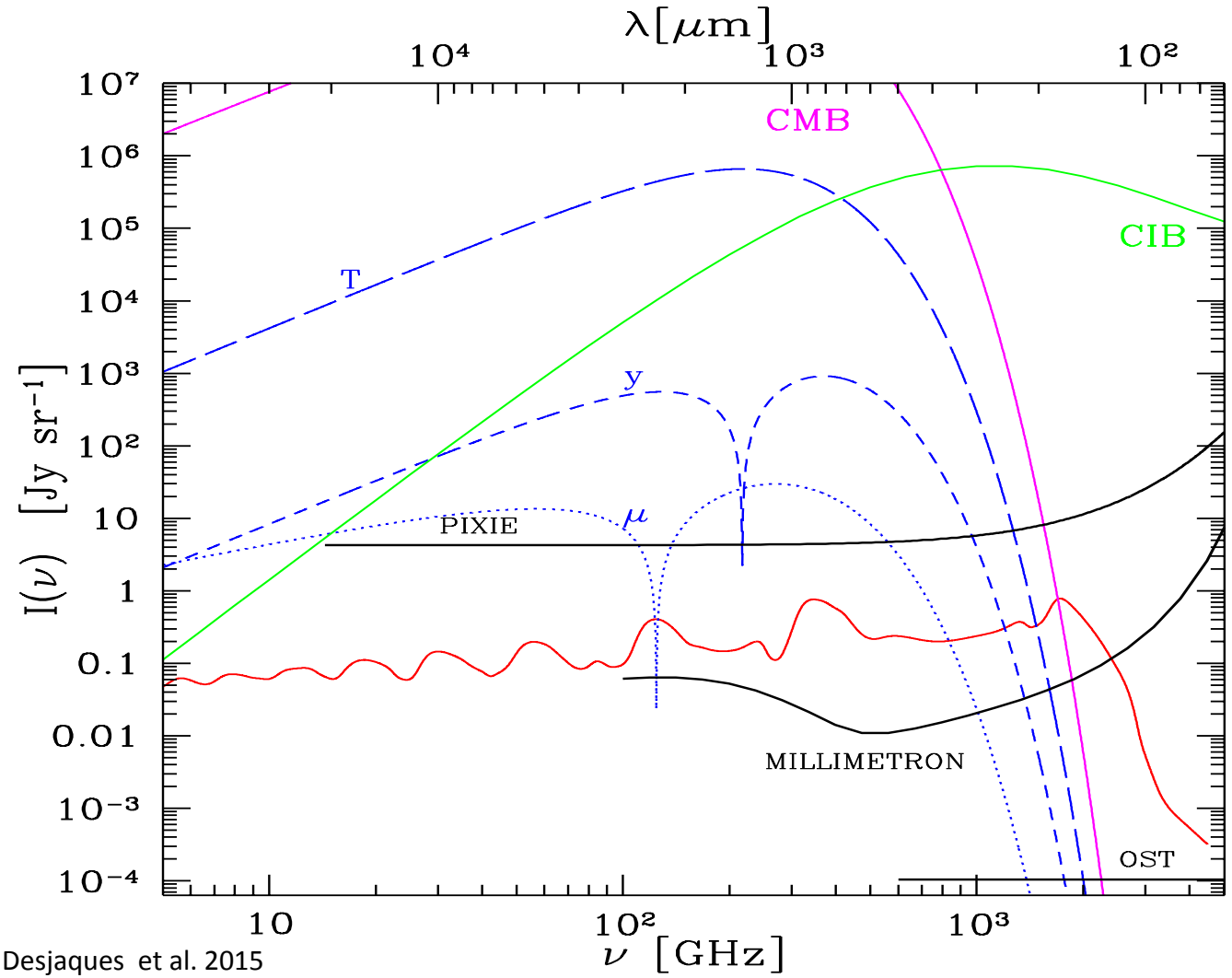
| Telescope diameter | | 1.4 m | 5.0 m | 10.0 m |
|---|---|---|---|---|
| 1 detector | BMS dia | 17 cm | 47 cm | 88 cm |
| | SIMBAD/PIXIE | 7.35 | 26.24 | 52.49 |
| 4 detectors | BMS dia | 33 cm | 93 cm | 176 cm |
| | SIMBAD/PIXIE | 14.70 | 52.49 | 105.00 |
| 7 detectors | BMS dia | 49 cm | 139 cm | 263 cm |
| | SIMBAD/PIXIE | 19.44 | 69.43 | 138.86 |




$\mu \sim 10^{-9}$ achievable with ~ 10 detectors + 10m telescope

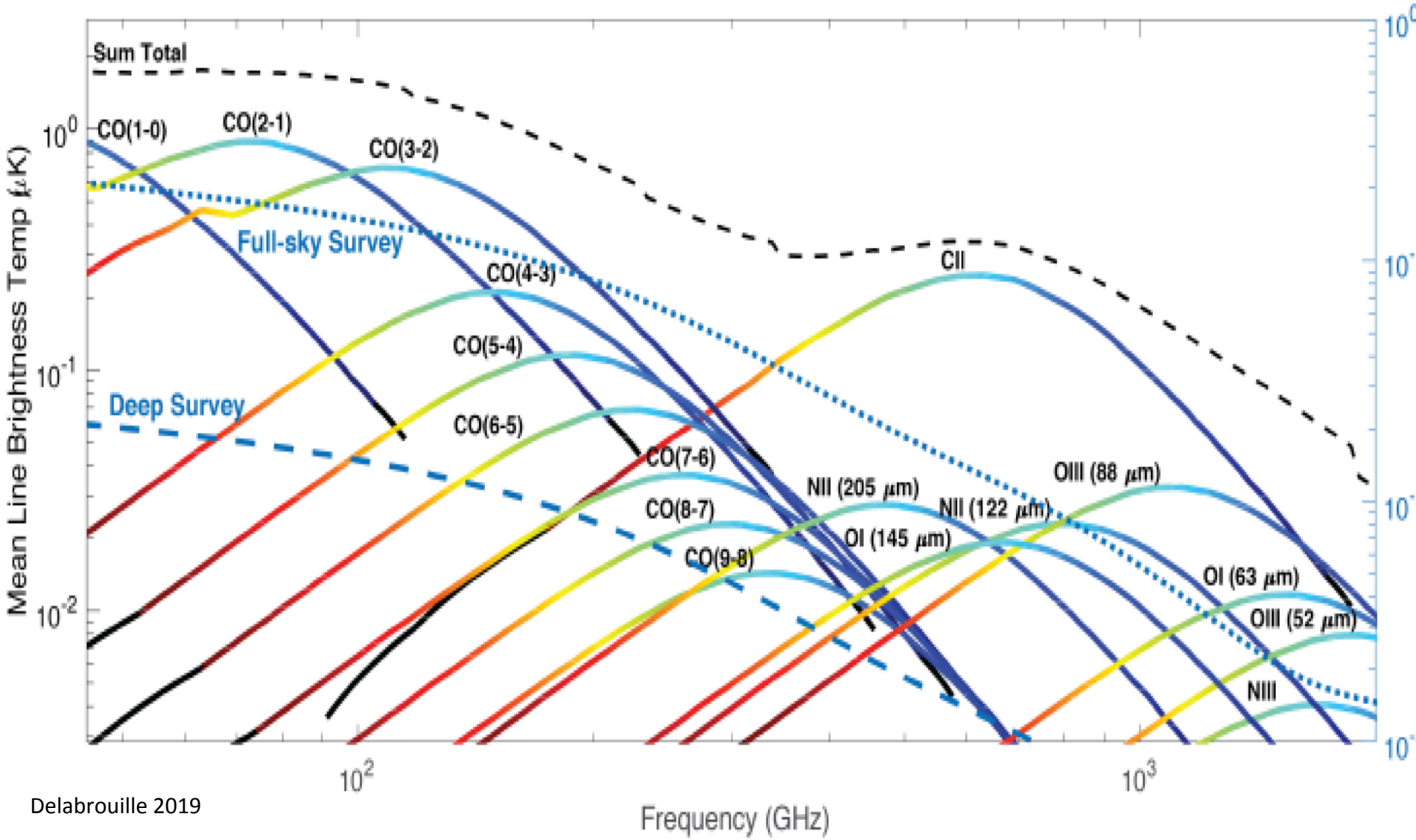
another approach that would do complementary science

# Target for MILLIMETRON



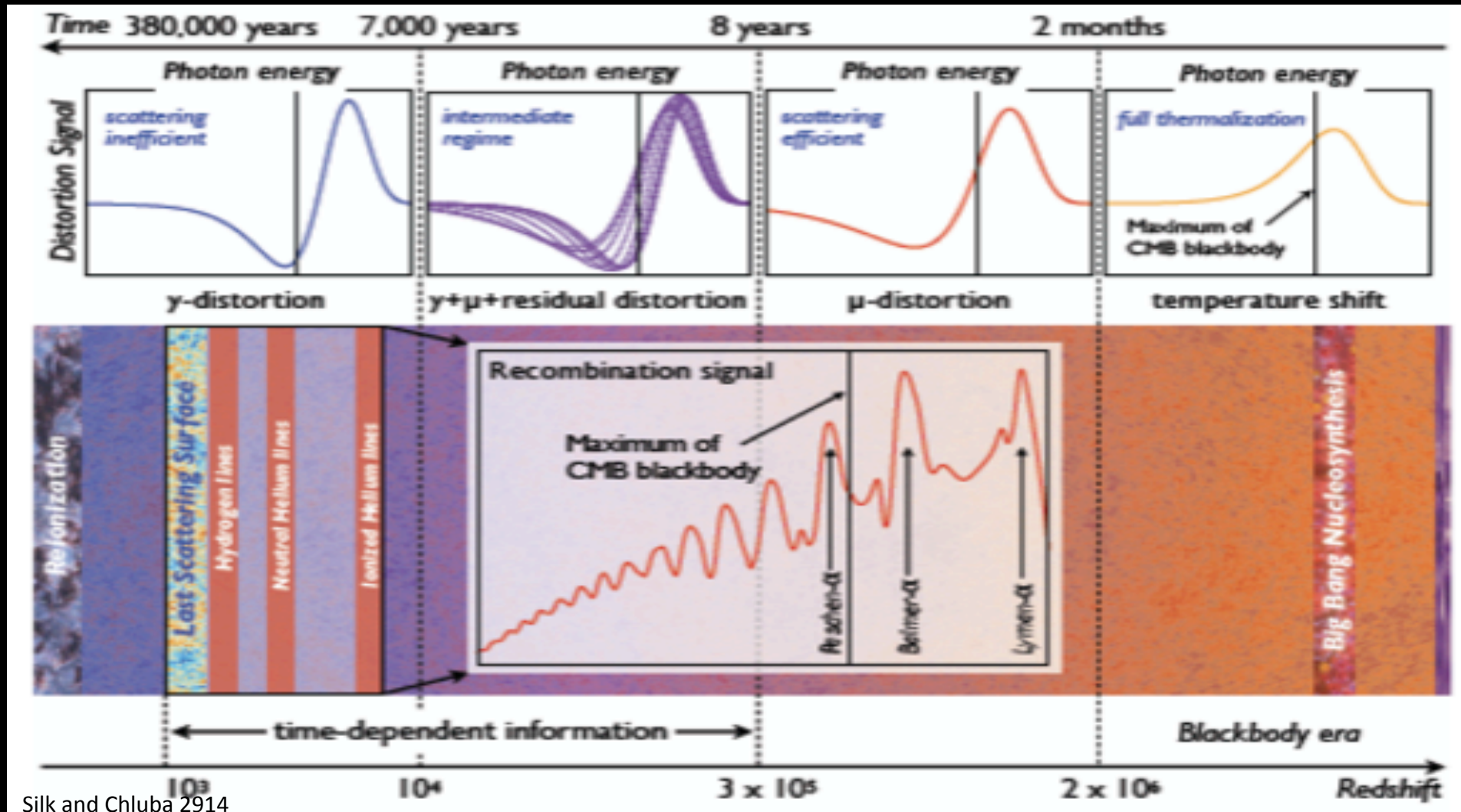

Adapted from Desjaques et al. 2015

# Foregrounds from galaxies & IGM




Delabrouille 2019

# The big picture




Silk and Chluba 2914

# Opening up a new epoch for cosmological exploration