What Next?

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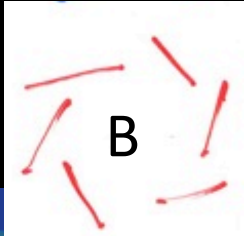
IAP/JHU/Oxford

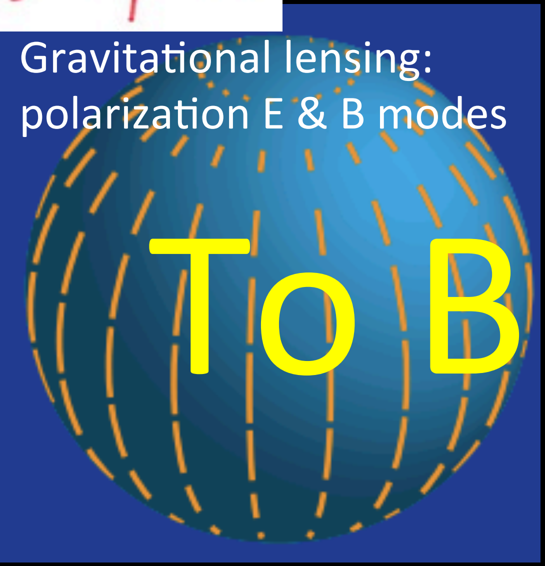
Probing Fundamental physics with CMB Spectral Distortions
CERN 12-16 March 2018

Probing inflation

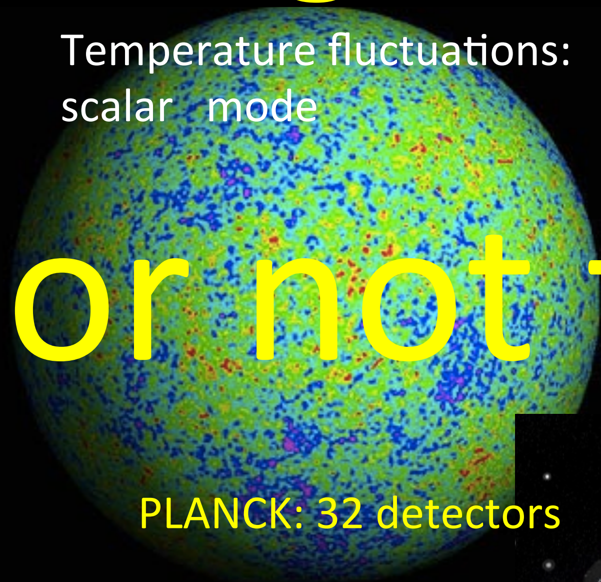
E



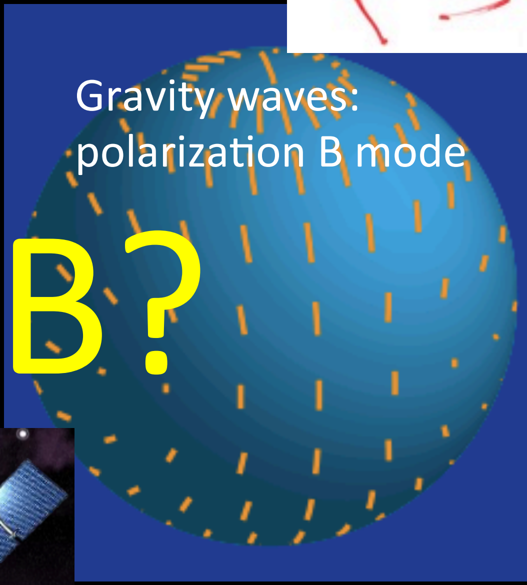
B



Gravitational lensing:
polarization E & B modes



Temperature fluctuations:
scalar mode



Gravity waves:
polarization B mode

To B or not to B?

PLANCK: 32 detectors

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

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

Satellite: LiteBIRD (JAXA launch in 2027?)

Goal: r ~ 0.001

ground/balloon: CMB-S4, c. 2025

South
Pole

Atacama

But so far there is no guarantee of a signal!

Spectral distortions

Need a dedicated spectrometric mission,
no compromise with B mode

Is 1000 x improvement over FIRAS sufficient or
do we need a guaranteed science return?

Probing primordial energy input

μ distortion is our best hope: over z= 5.10^4 to 2.10^6

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

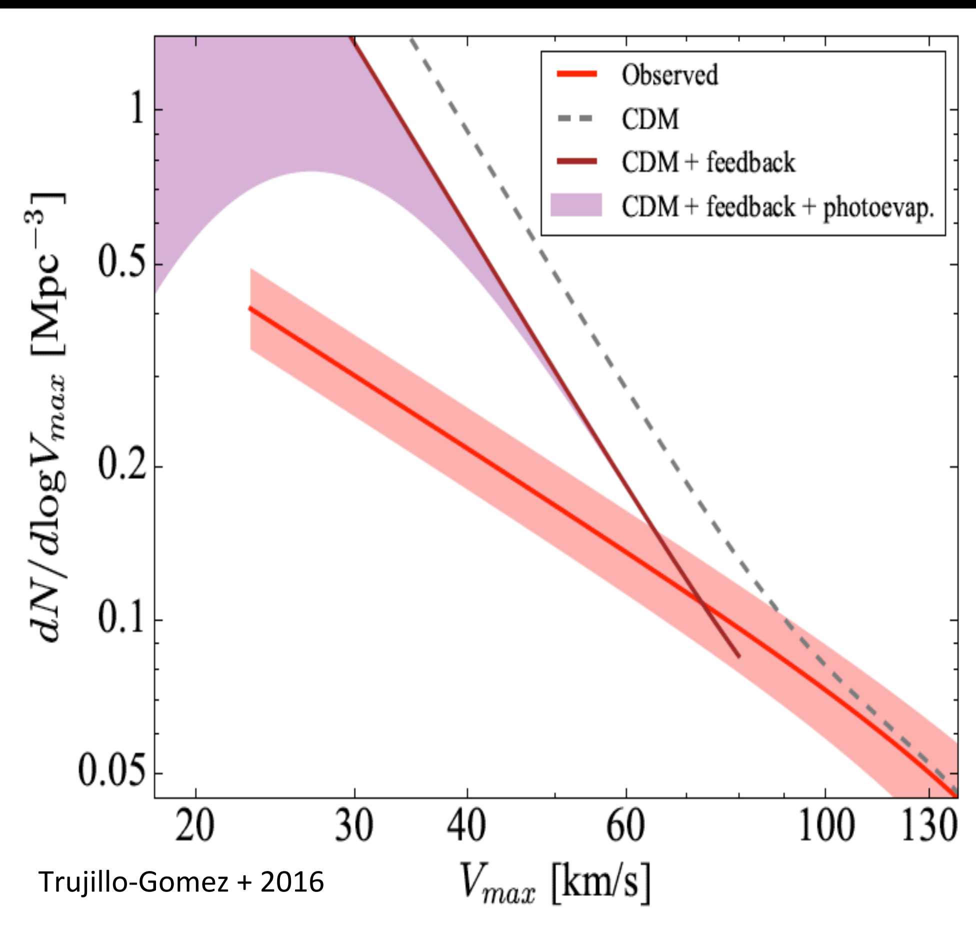
- Many papers on this: eg, decaying particles, primordial black holes…
- No guaranteed signal of exotica

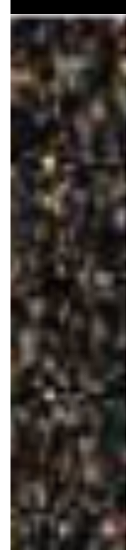
Guaranteed returns to fundamental cosmology

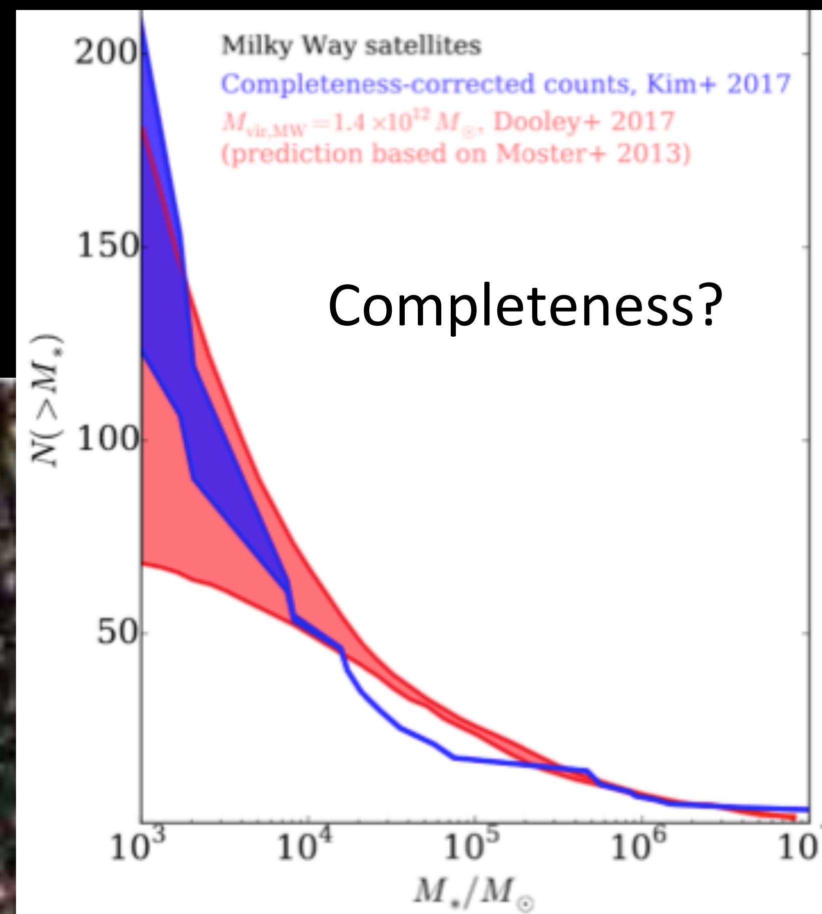
- 1. Damping of dwarf galaxy fluctuations
  $k_D=4z_4^{3/2}$ Mpc^{-1} probes 50-10^4 Mpc^{-1}
- 2. (re)combination spectral lines of hydrogen
  380000 yrs after the Big Bang
- 3. (re)combination spectral lines of helium
  long before the first stars

1. Probing dwarf galaxies

Dwarfs are a challenge to LCDM: too many predicted.
has motivated exotic dark matter, eg WDM, SIDM…





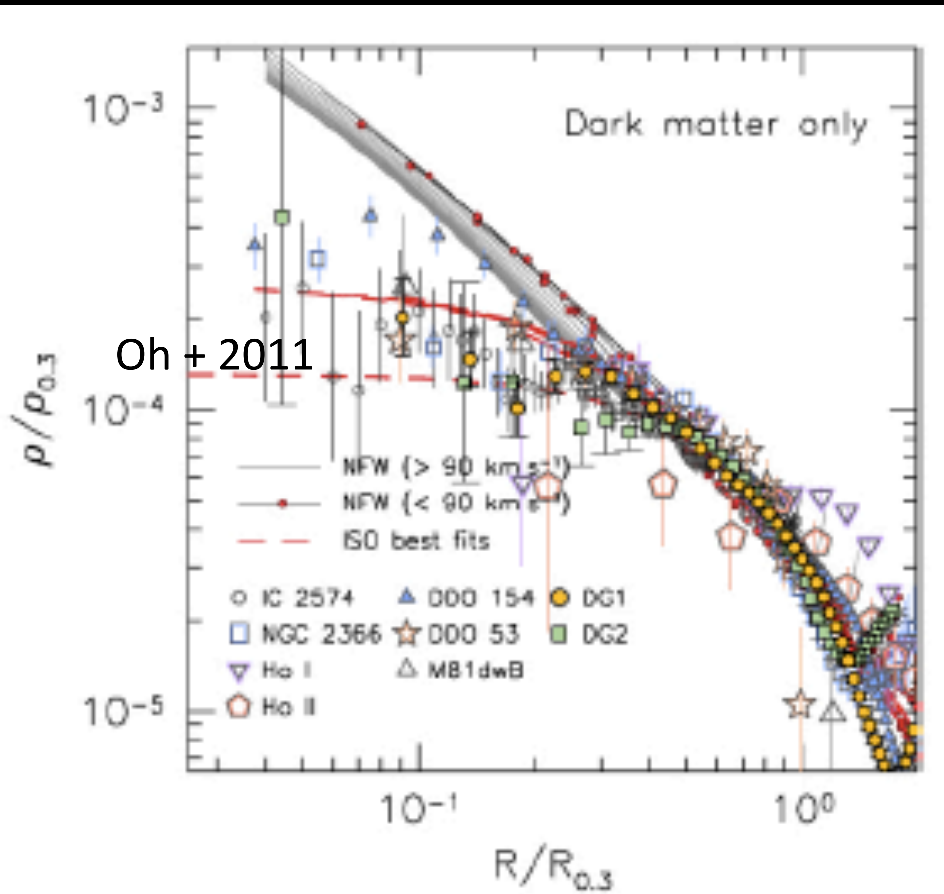


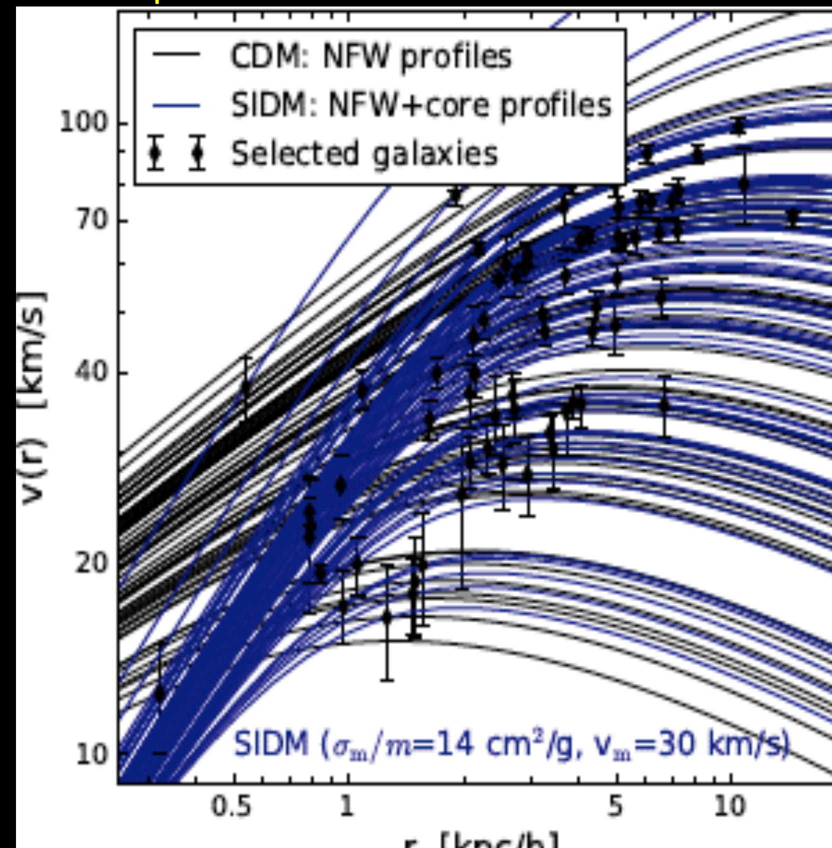
Dwarf galaxies are a continuing challenge

Core/cusp problem

Self-interacting dark matter helps: with $\sigma/m_p \sim 1\ cm^2/gm$ and $\sigma \sim v^{-4}$

Oh + 2011

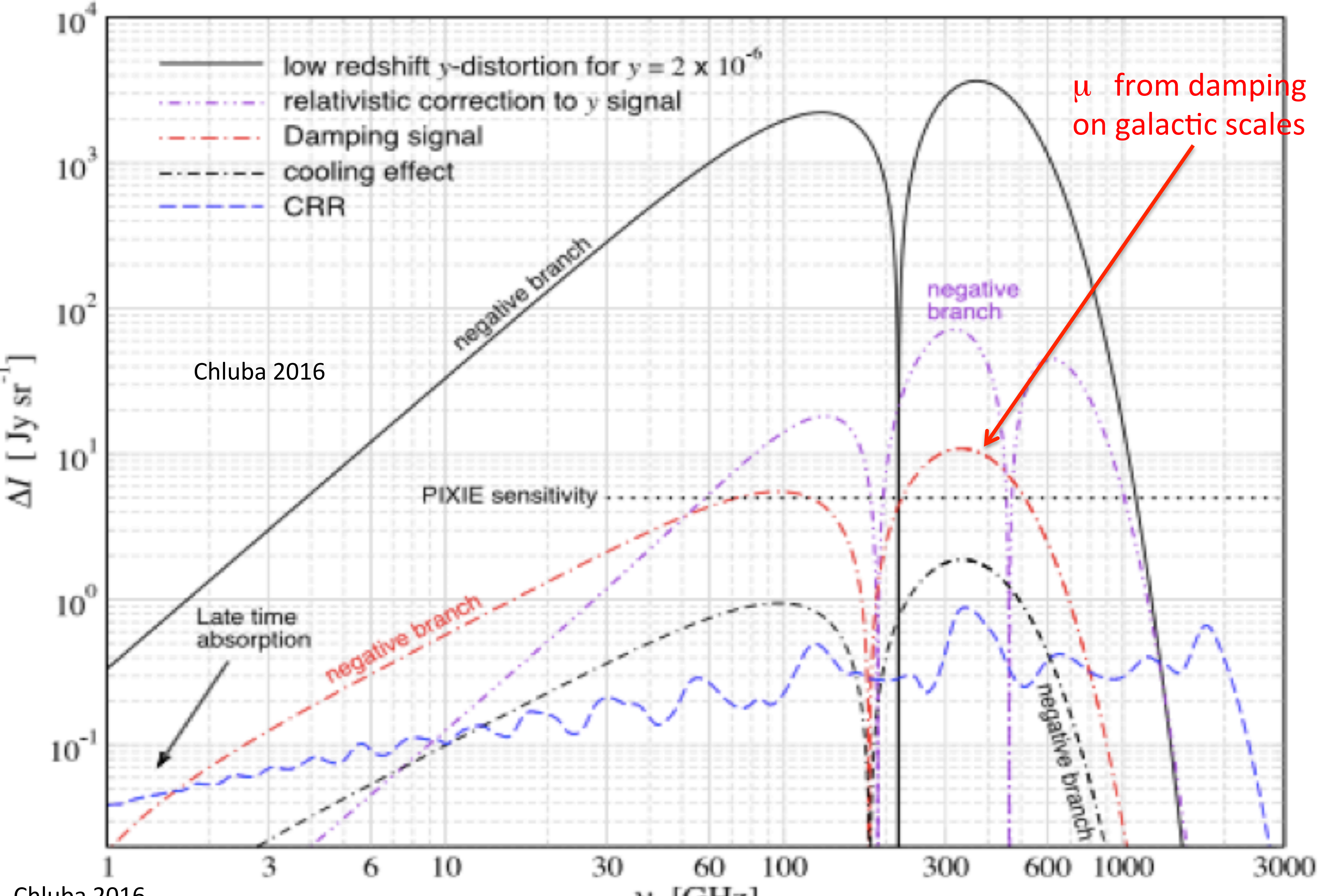




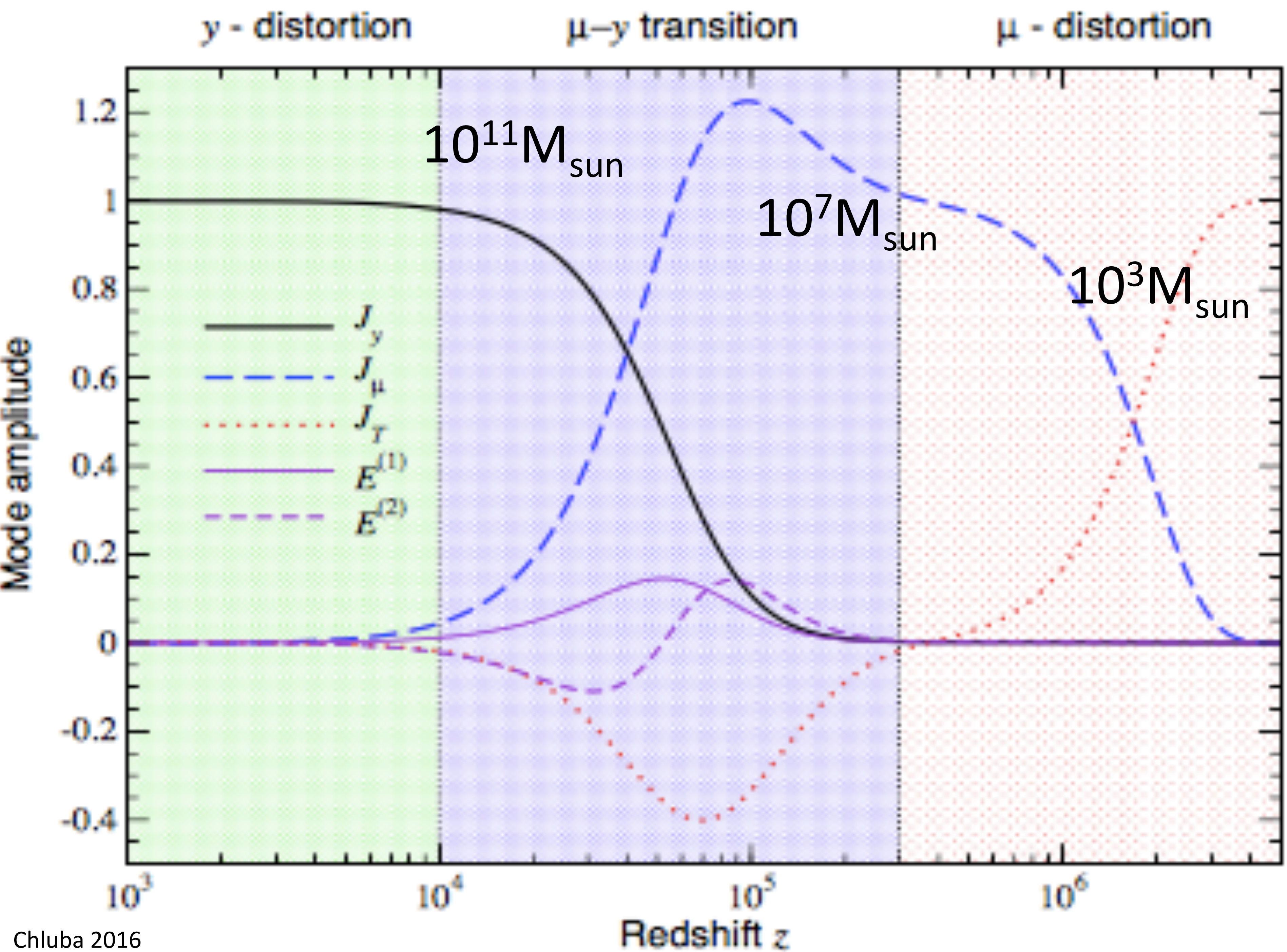
But there are several other dwarf problems to be resolved eg TBF…
Are we in danger inventing one exotic DM hypothesis per problem?

We need a better understanding of dwarfs!

Damping signal from galaxy scales

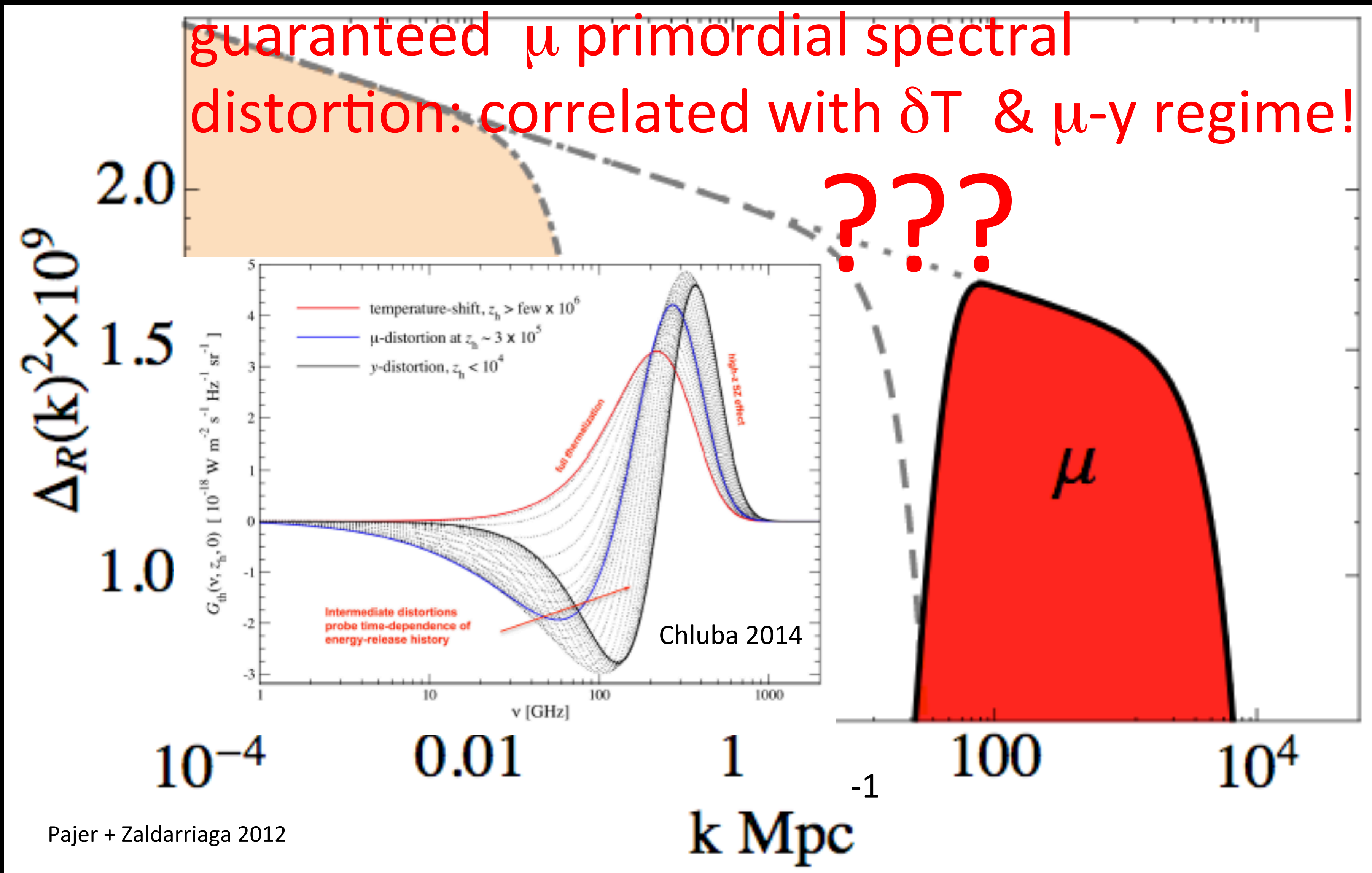


Chluba 2016


y - distortion
μ–y transition
μ - distortion
10¹¹M_sun
10⁷M_sun
10³M_sun
J_y
J_μ
J_T
E^(1)
E^(2)
Mode amplitude
Redshift z
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
10³
10⁴
10⁵
10⁶

Chluba 2016

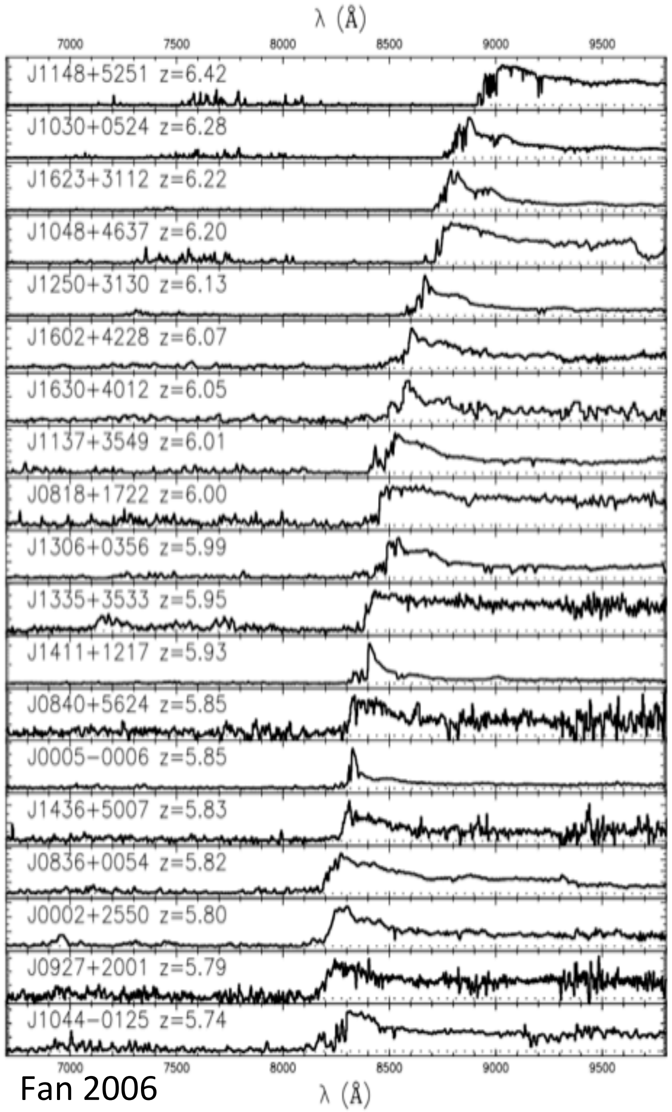
CMB spectral distortions probe fluctuation baryon damping power on dwarf galaxy scales



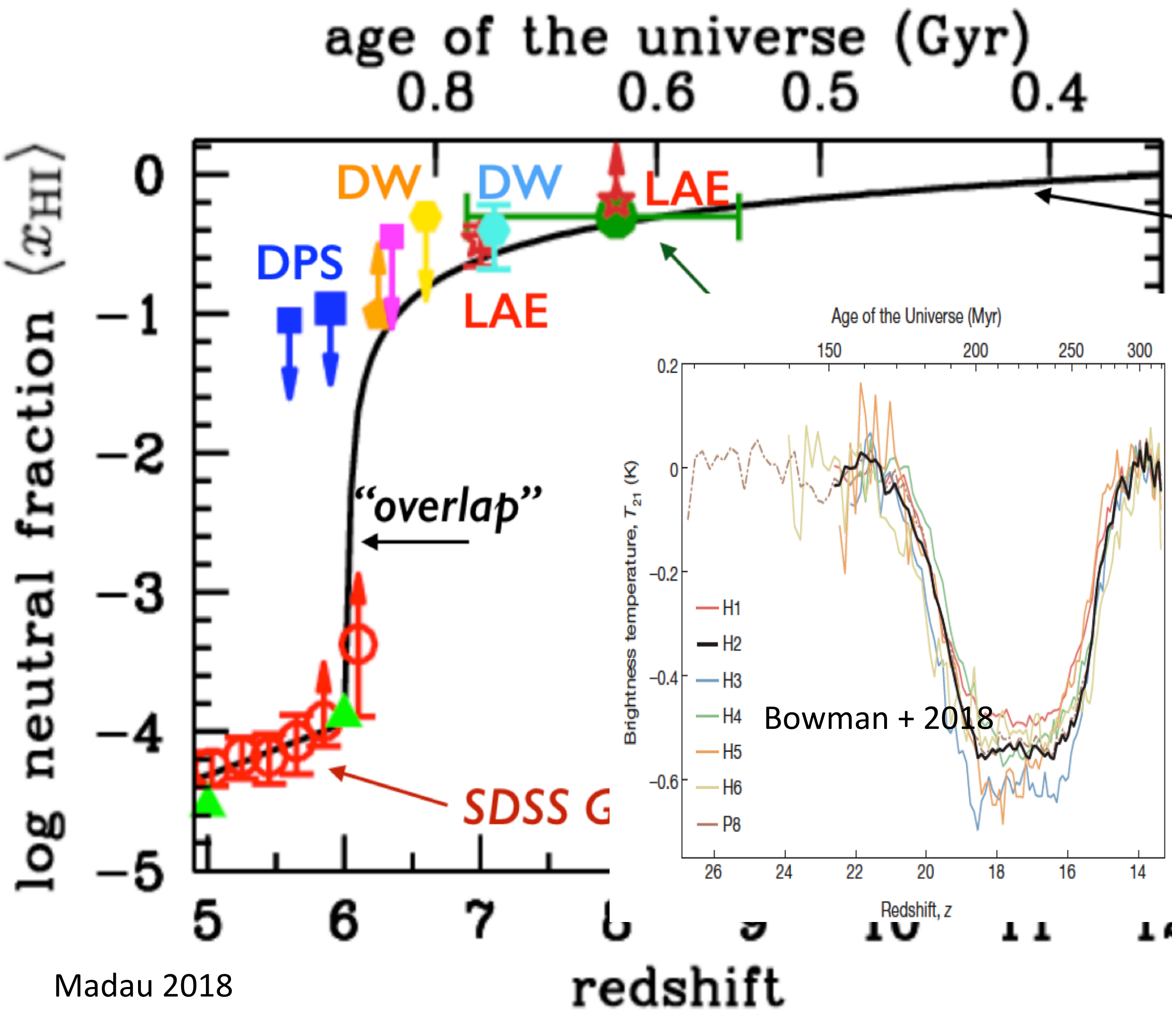
2. Hydrogen recombination lines

We measure atomic hydrogen directly to z ~8

+ 21 cm maybe to z~17

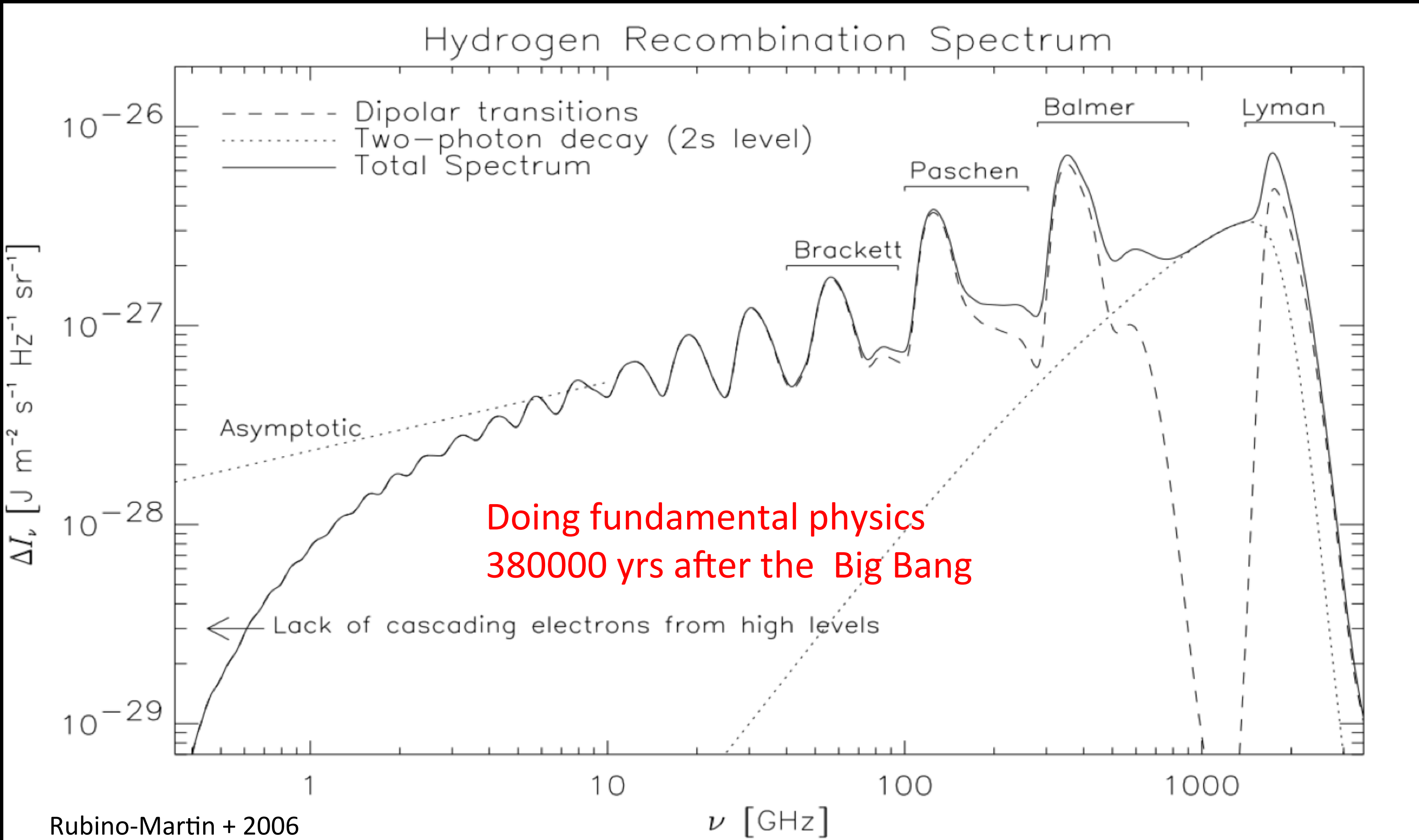


Fan 2006



Madau 2018

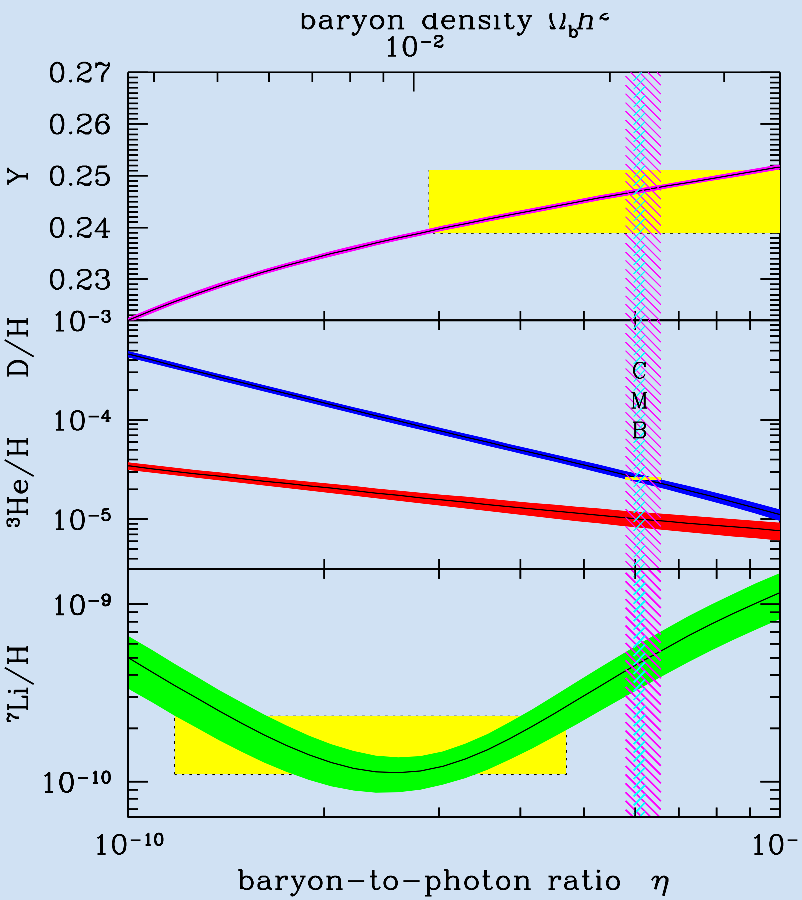
We can measure hydrogen recombination lines at z ~ 1000

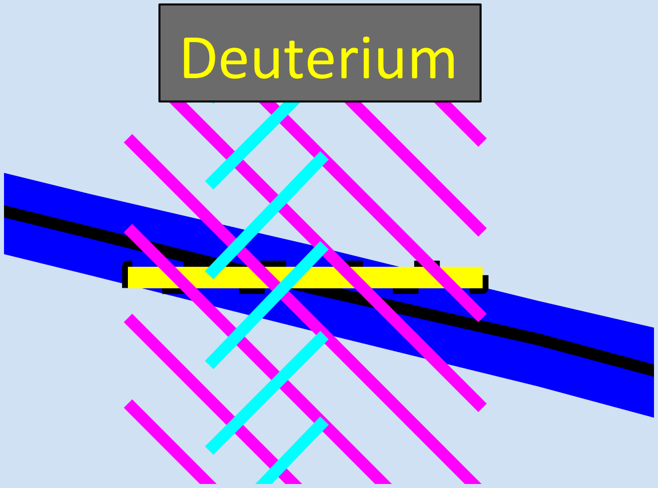


Rubino-Martin + 2006

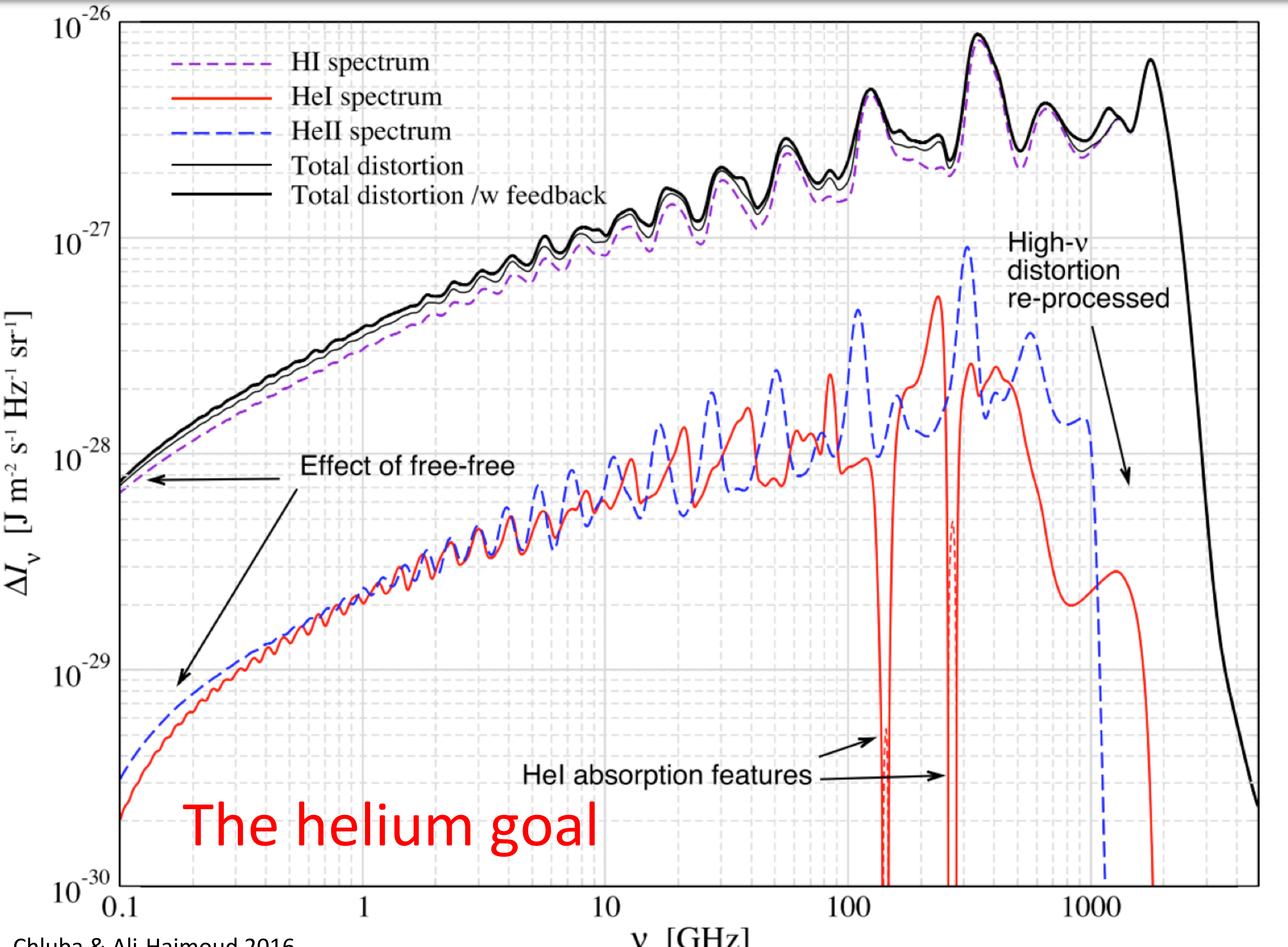
3. Probing primordial helium

- $D/H|_p = 2.569 \pm 0.027 \times 10^{-5}$ (10 determinations)
- $Y_p = 0.245 \pm 0.003$ (0.2446, 0.2449, 0.2551: recent determinations)



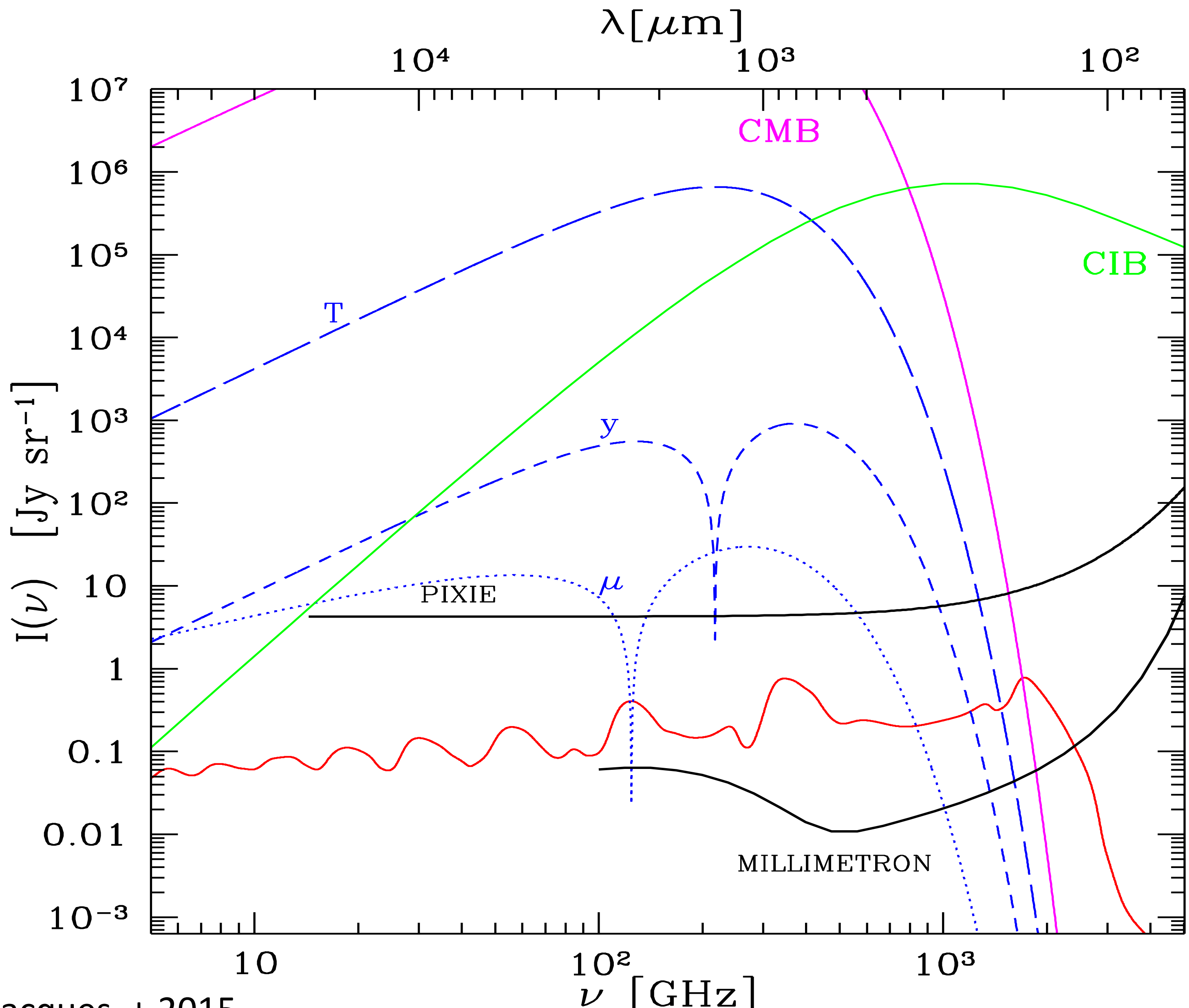


PDG, 2017



Chluba & Ali-Haimoud 2016

spectral distortion challenge to observers



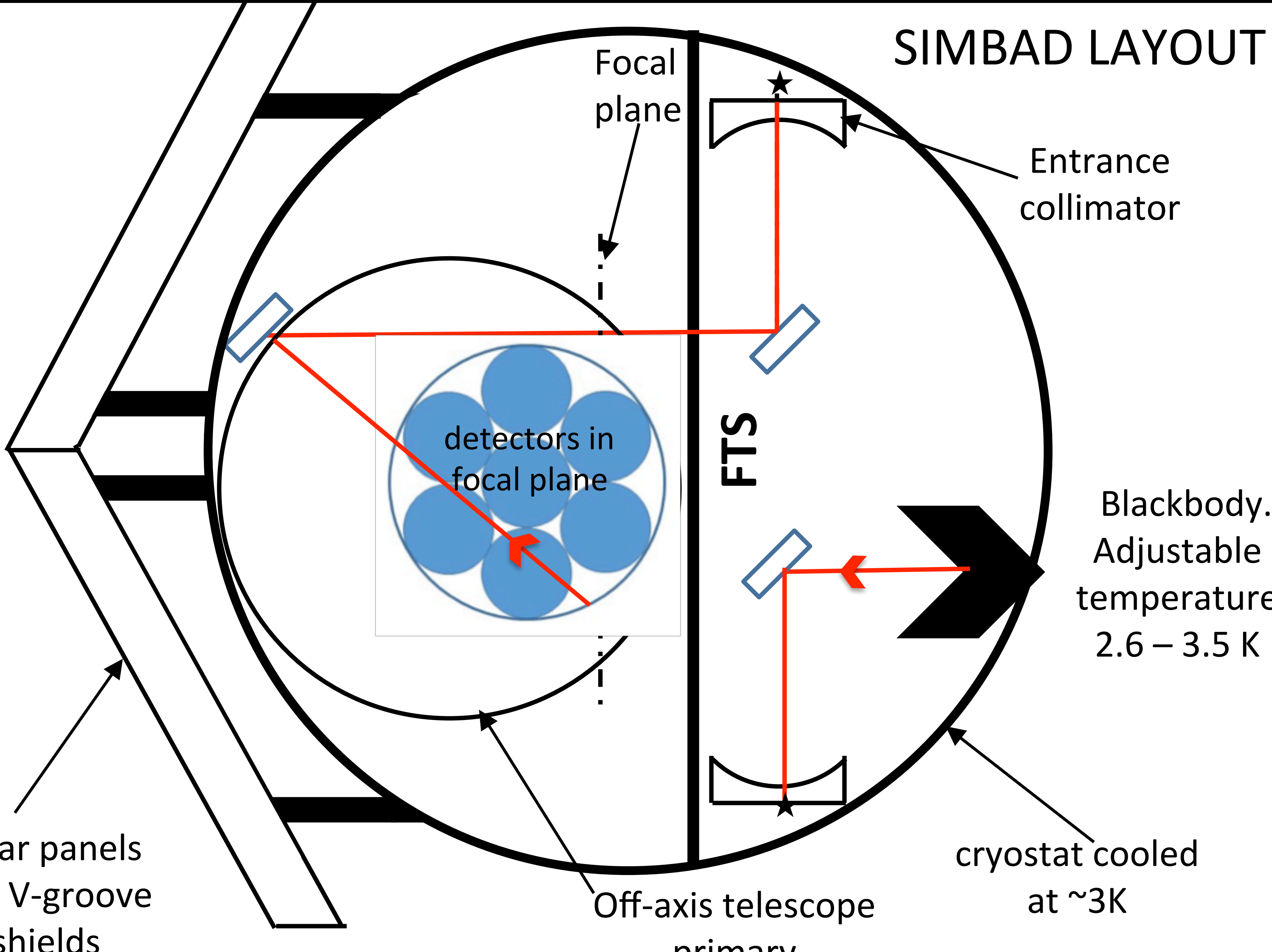
Desjacques + 2015

Let's be ambitious!

- Dedicated to spectral distortions
- Need large improvement on PIXIE sensitivity!
- SIMBAD concept (by J.P. Maillard)

Spectroscopic Imager for Microwave Background Angular Distortions

Spectroscopic Interferometer for Microwave Background Angular Spectral Distortions



J.-P. Maillard 2018

Gain over PIXIE via: larger telescope
many detectors
limited frequency range
single goal

Relative to PIXIE

• Dedicated to spectral distortions	x < 2
• Add detectors: 1 → 16-100	x ~4-10
• Telescope size: (2x) 0.55m → 1x (1 – 5)m	x ~2-10
• Reduce bandwidth → 30GHz-2THz, increase f_{sky}	x < 2

X 100 would guarantee success!

from J.-P.Maillard

Sensitivity Comparison between PIXIE, PRISTINE, SIMBAD

BMS : FTS beam splitter

Nb of detectors	PRISTINE/ PIXIE	SIMBAD/ PRISTINE	SIMBAD/ PIXIE	BMS dia PRISTINE	BMS dia SIMBAD
1	0.57	6.92	5.77	8 cm	12 cm
4	1.15	13.85	11.54	14 cm	22 cm
7	1.52	18.33	15.27	21 cm	33 cm
16	2.30	27.68	23.00	34 cm	54 cm

PROJECT PARAMETERS

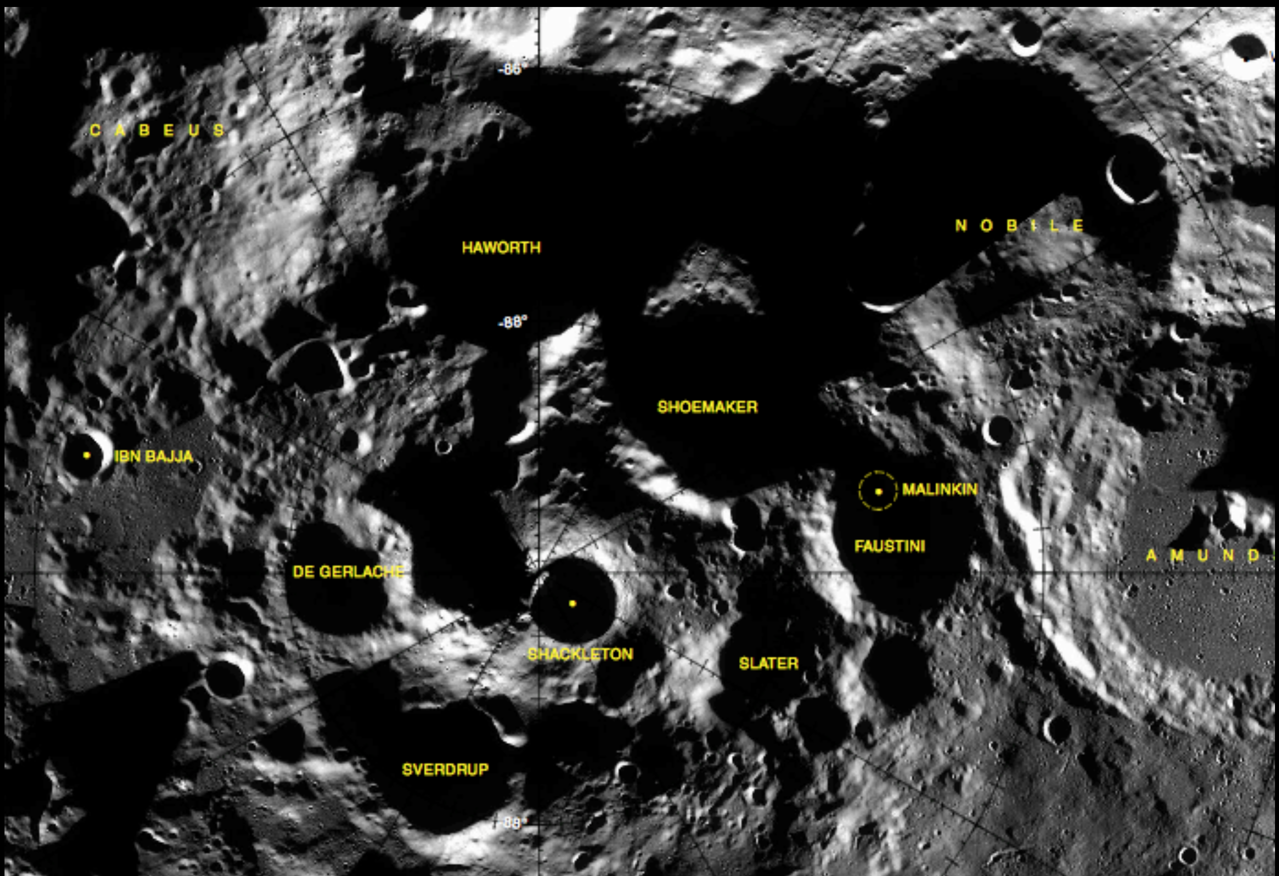
	Tel. dia	Lower freq.	Angular res.	Spectral res.	Program % Distort., Polar.
			)°	15 GHz	30%, 60%
			°	5 GHz	30%, 60%
			)°	15 GHz	90%, 0%

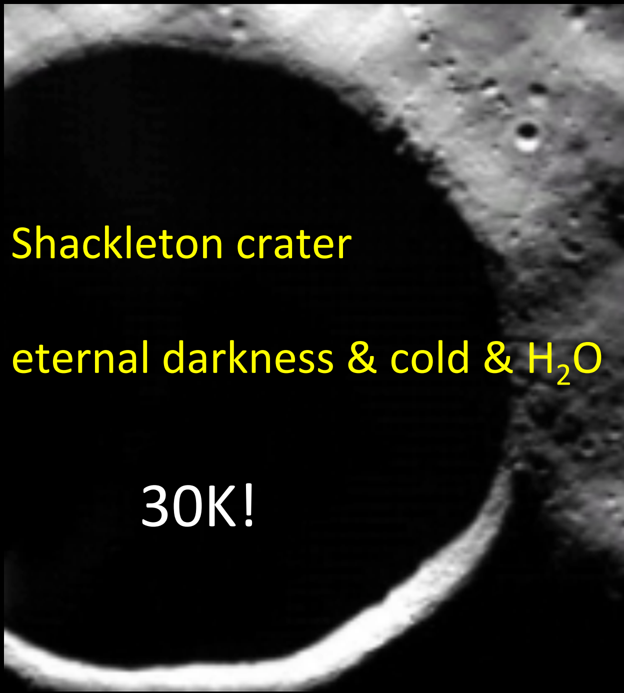
SIMBAD sensitivity compared to PIXIE for 3 telescopes diameter

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

Looking ahead after L2 : the Moon

lunar south pole sites for FIR telescopes





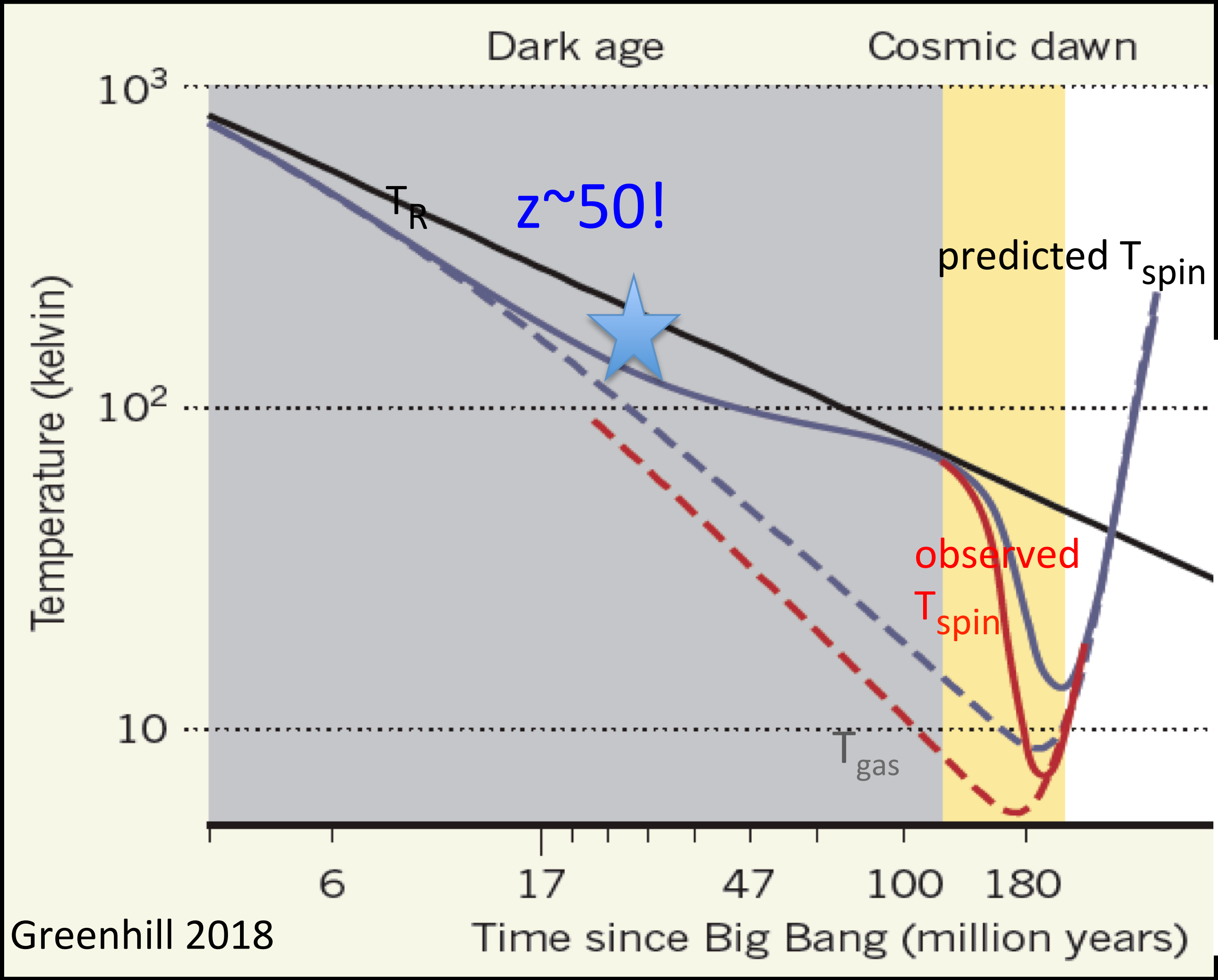
Shackleton crater

eternal darkness & cold & H_2O

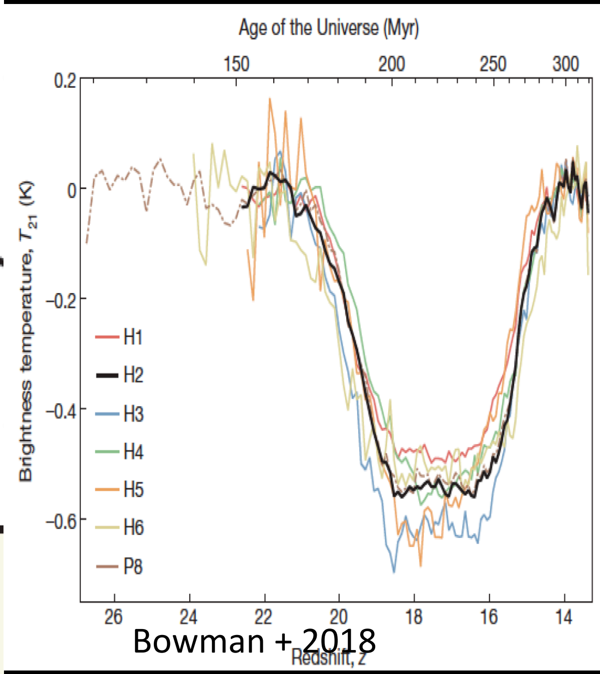
30K!

“la lumiere perpetuelle”
C. Flammarion

What next? Using CMB to probe dark ages



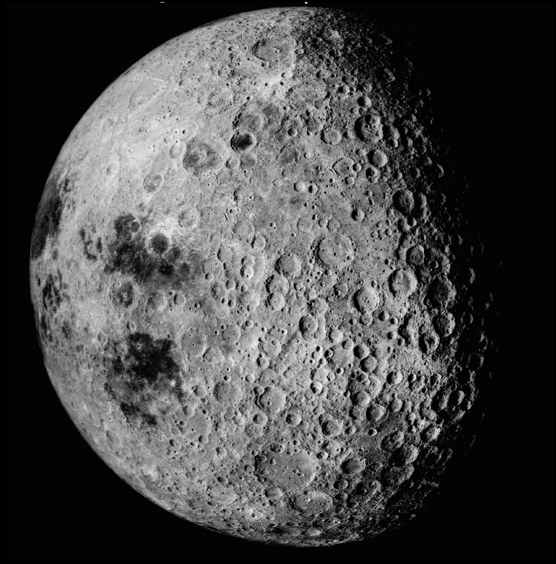
Global signal @ z=17

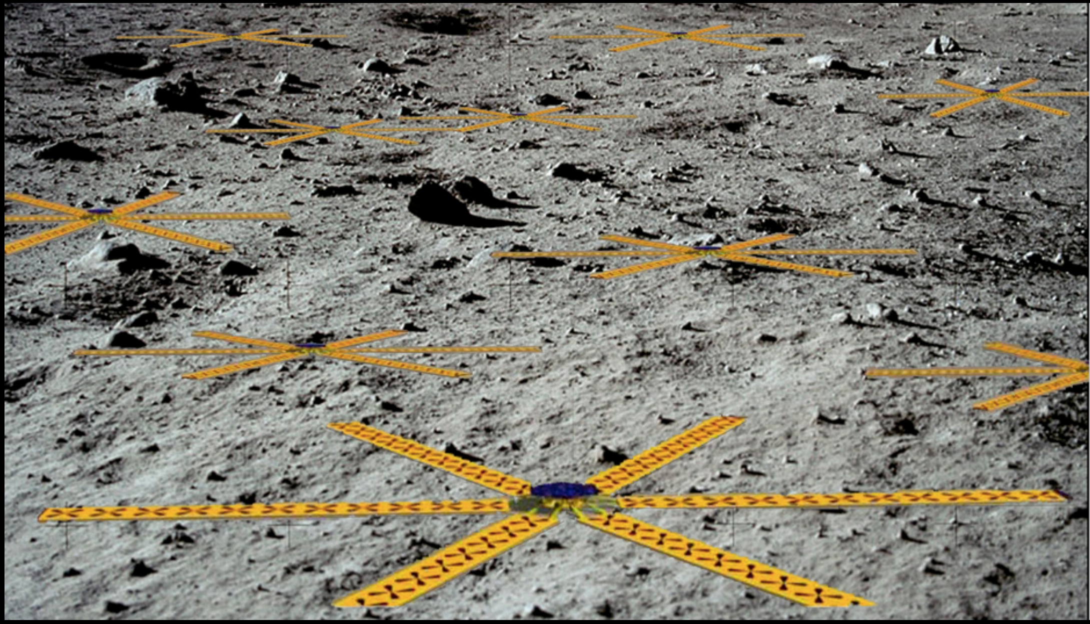


Next step: the dark ages via the Moon!

far side of MOON for low frequency radio astronomy

most radio-quiet environment
in inner solar system





21cm sweet spot: z=50 @ 30 MHz + k~ 100 Mpc^{-1}

Optimal array is $\ell\lambda/2\pi$ or D ~100 km at λ~ 10 m

need millions of dipoles for weak signal: $\frac{D^2}{4\lambda^2}$ ~10^7

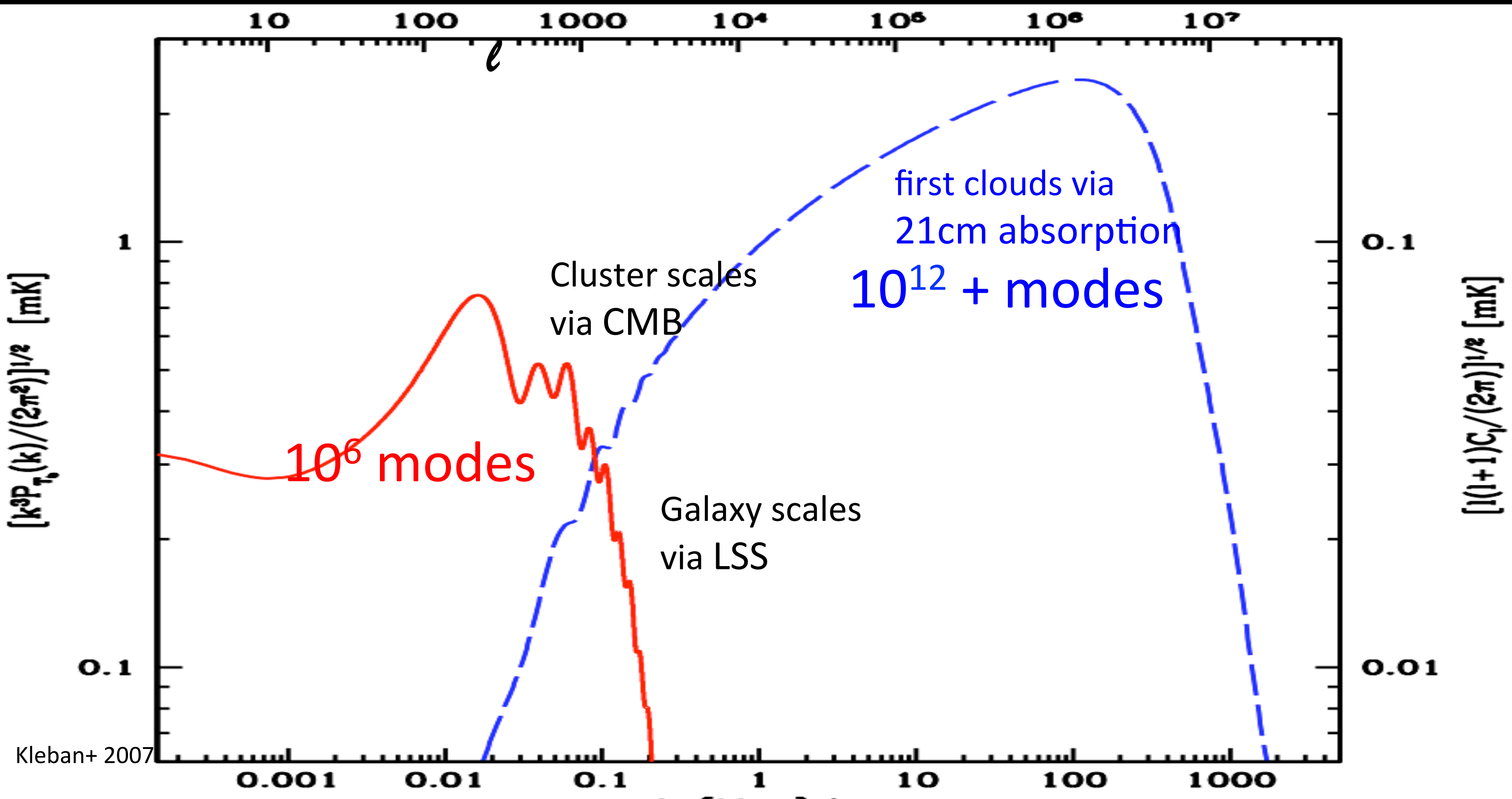
seek ~10mK signal in bright sky foreground T_B~1000K

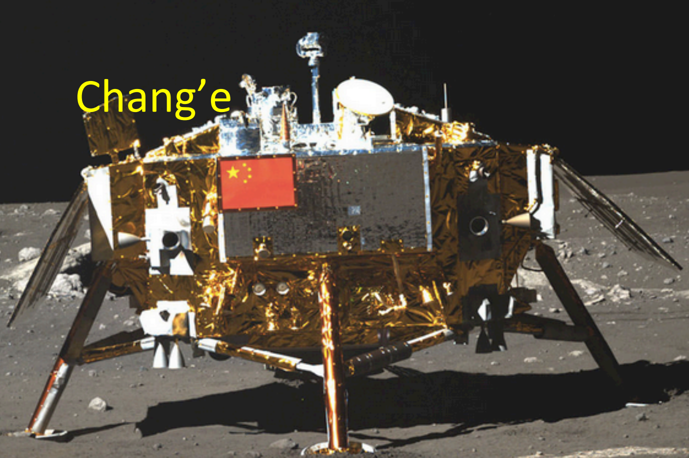
ultimate future: the dark ages

Compare to μ signal:

now can resolve trillions of modes!

…but it'll be very difficult to remove the foregrounds…





When?

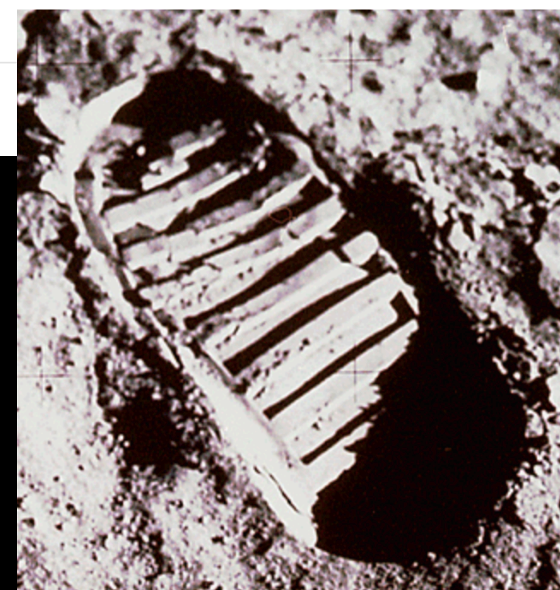
Europe's space boss says 'now is the time to build a moon village' and pledges permanent lunar base by the end of the next decade

- **ESA said the Moon was the 'right place to be' and Mars is 'ultimate destination'**
- **Said immediate goal was to have a permanent presence on the Moon, even if it was just a robot, by the end of the next decade**

By AFP

PUBLISHED: 11:36, 28 September 2017 | **UPDATED:** 18:15, 28 September 2017

Current US presence



Trump wants to send U.S. astronauts back to moon, someday Mars

WASHINGTON (Reuters) - At a time when China is working on an ambitious lunar program, President Donald Trump vowed on Monday that the United States will remain the leader in space exploration as he began a process to return Americans to the moon.