

SUMMARY REMARKS

A future CMB experiment with spectroscopic capabilities

Sub-orbital by 2017

Advanced ACTpol, SPT-3G

PB, SPIDER, CLAS....

Space by 2022

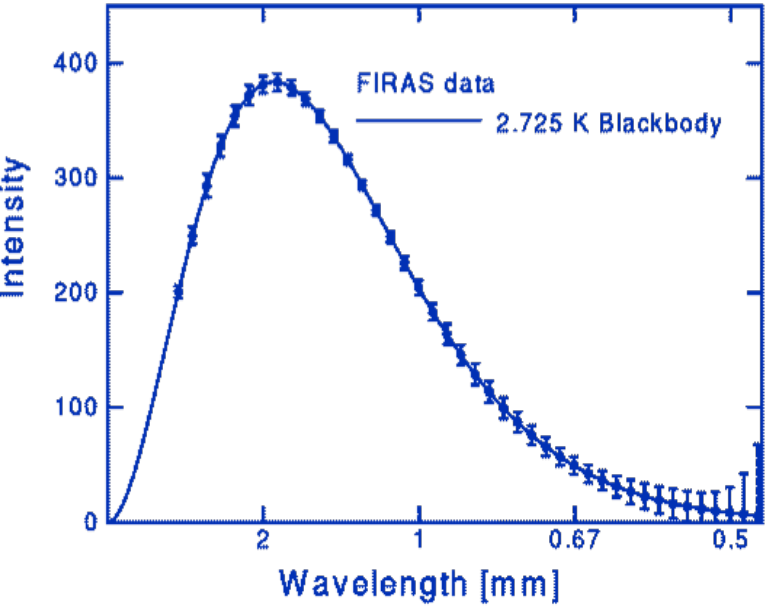
LITEBIRD in 2022, proposed

low l cosmology cosmic variance limited

FUNDAMENTAL PHYSICS CHALLENGES FOR A FUTURE SPACE CMB EXPERIMENT

- Damping tail and m_ν
- Primordial B modes
- Beyond the standard Λ CDM model
- Recombination epoch
- Reionization epoch





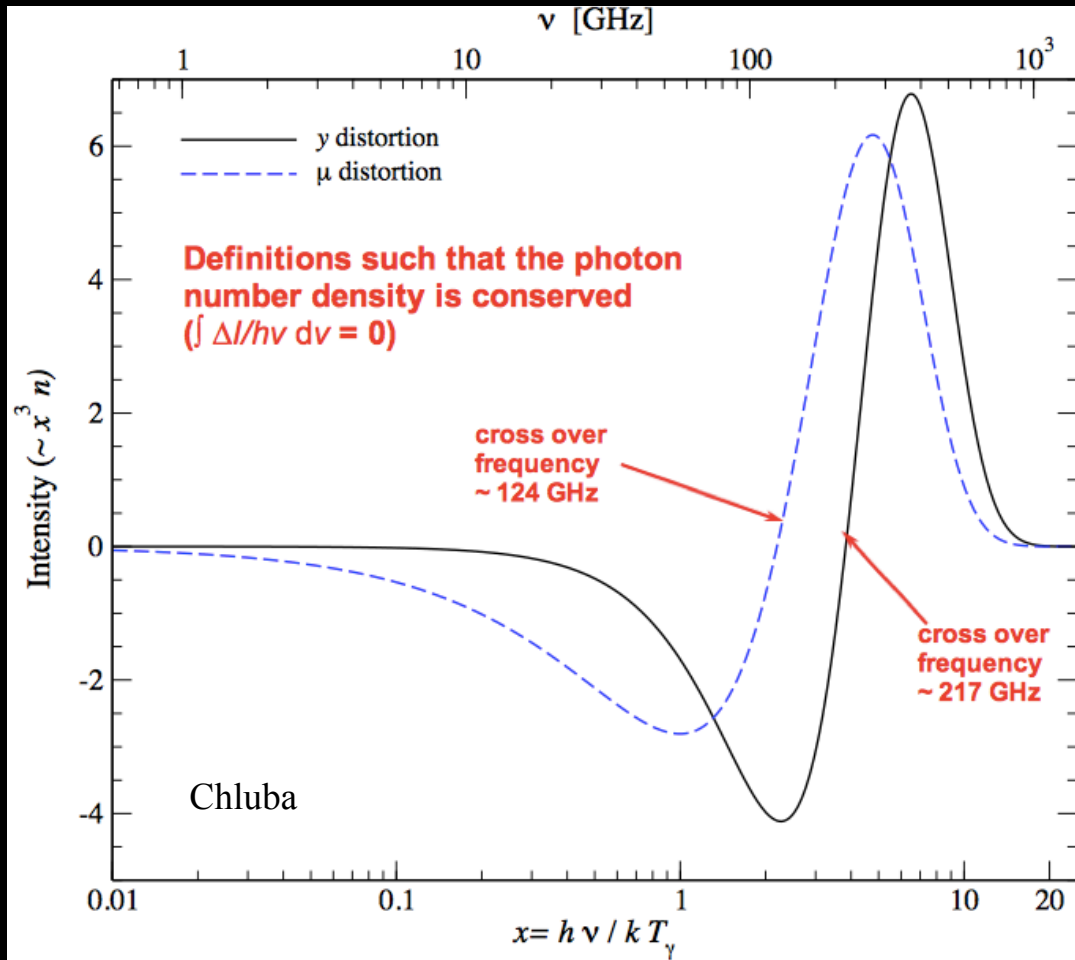
1990

$$T_0 = 2.725 \pm 0.001 \text{ K}$$

$$|y| \leq 1.5 \times 10^{-5}$$

$$|\mu| \leq 9 \times 10^{-5}$$

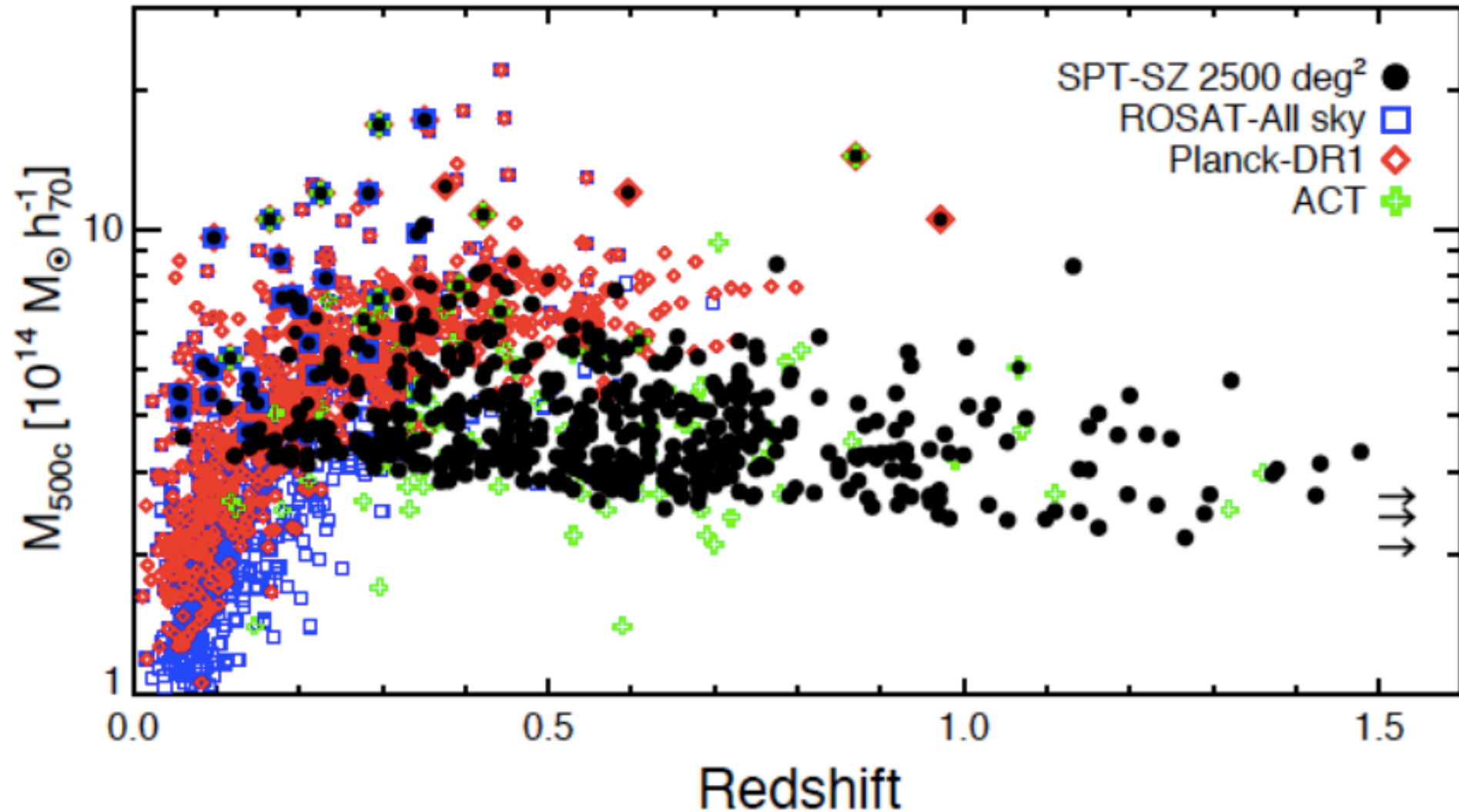
Probe back to $z=2.10^6$:
CMB black body photosphere
whereas visibility function peaks at $z=1080$



Spectral distortions are the next frontier

Guaranteed signals

Sunyaev: $y > 5 \cdot 10^{-8}$ from clusters at $z \sim 1$ $3 \cdot 10^{14} M_{\text{sun}}$



Guaranteed signals

Spergel: $y \sim 10^{-6}$ from groups at $z < 1$ $10^{13}M_{\text{sun}}$
 $dN/dM \sim M^{-2}$ & $T \sim M^{2/3}$, so gain $M^{4/3} \sim 100$

+ T_{groups} from relativistic correction

At least we get 2 numbers!

Also few per sq deg means $\delta y/y \sim 0.3$

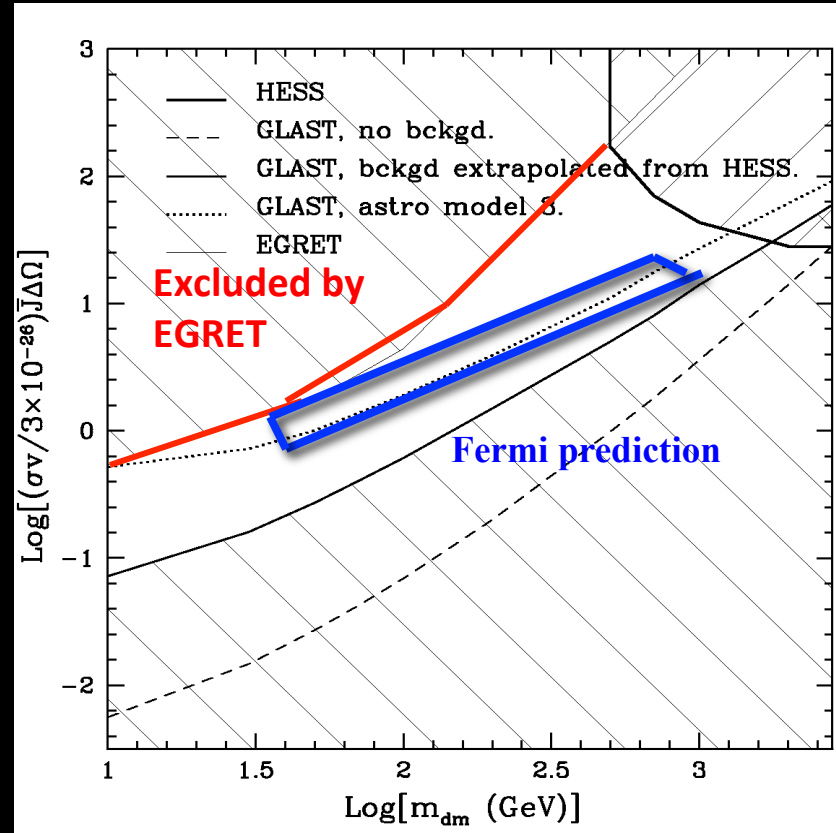
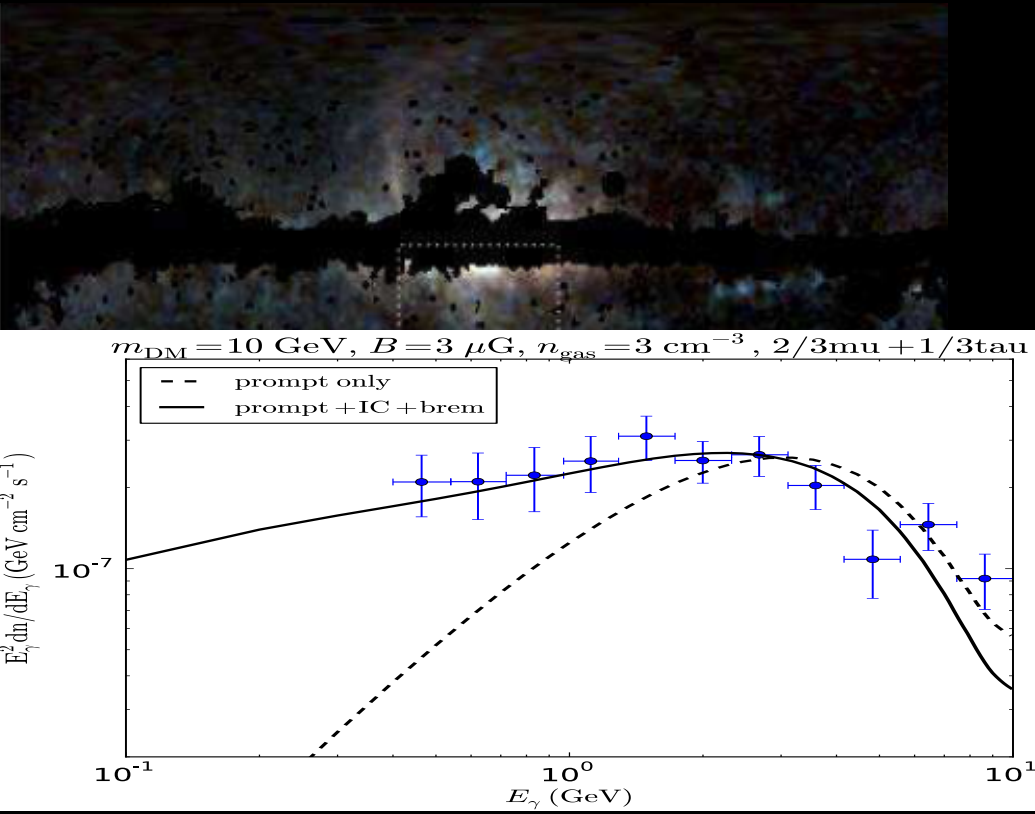
A problem for early universe y ?

foreground: spatial variations in synch spectral index
may affect PIXIE sensitivity to $y \sim 10^{-9}$

Guaranteed signals

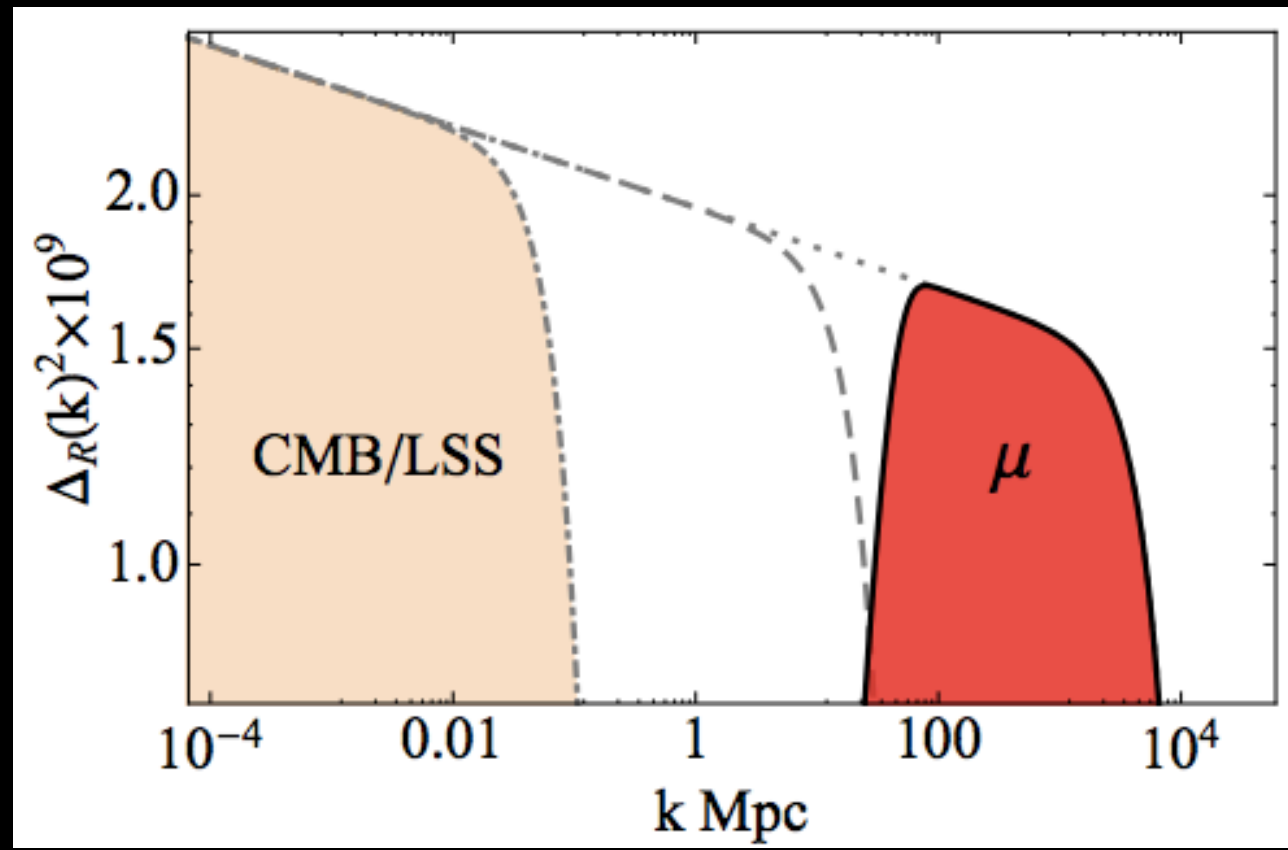
Finkbeiner: 3d dust modelling now good to ~ 0.1 distance
multifrequency improvement 1000 x better [CII], N[II] than COBE/FIRAS

Looking forward: can we use improved ISM modelling to refine the Fermi excess of γ 's
in the central few degrees of the GC: recall the morphology, spectrum, and associated
signals in WMAP/Planck... NB: this was actually predicted from the
excess WMAP 'haze'



Chluba: damping gives $\mu=10^{-8}$

complements CMB power spectrum of acoustic peaks



to $10^{16} M_{\text{sun}}$

the most massive galaxy clusters

$10^7 - 10^4 M_{\text{sun}}$

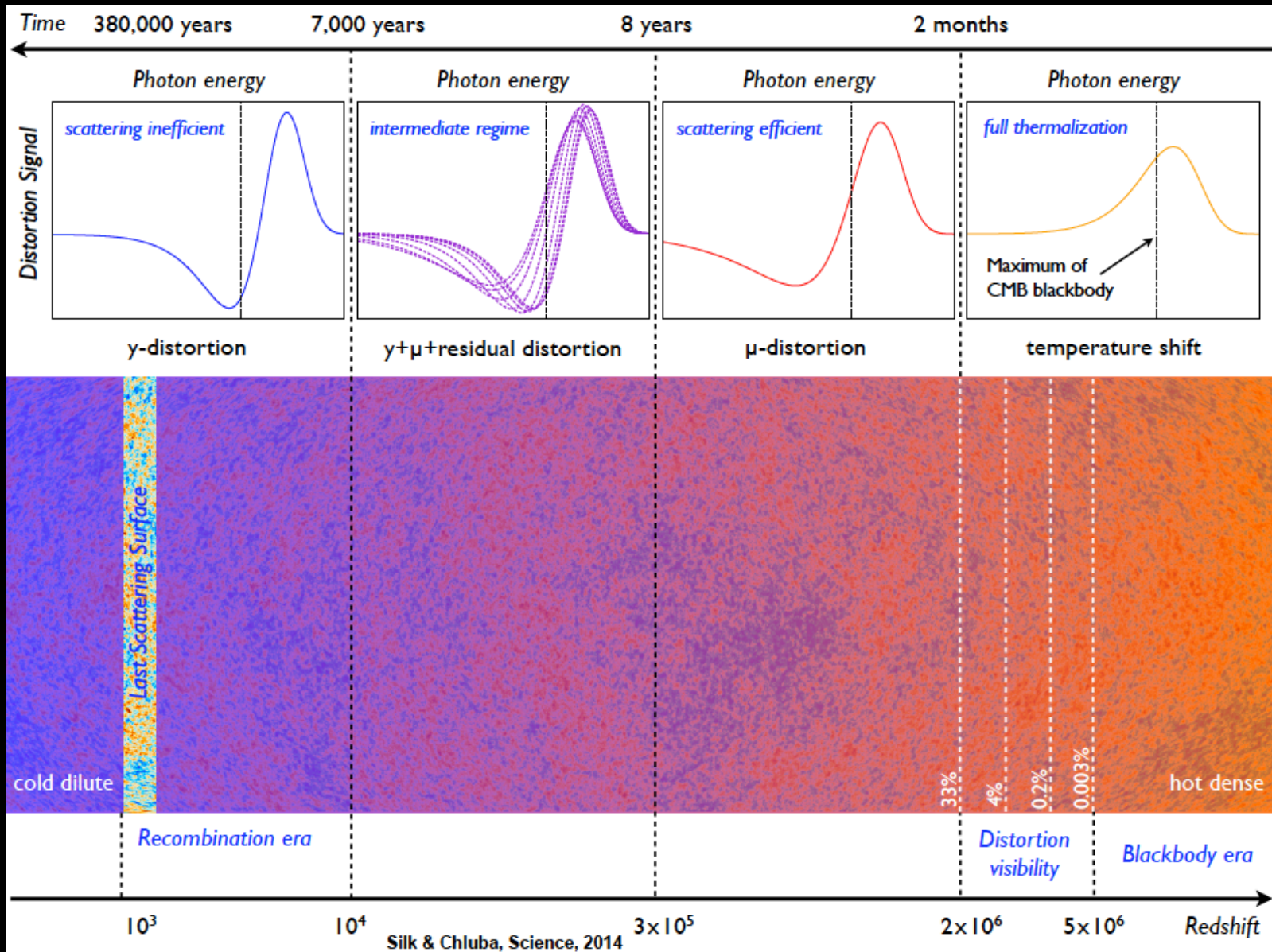
The first star-forming dwarfs

Search for ~ 3 numbers: $\delta T/T = 10^{-8}$

μ

$\mu + y|_{\text{hybrid}}$

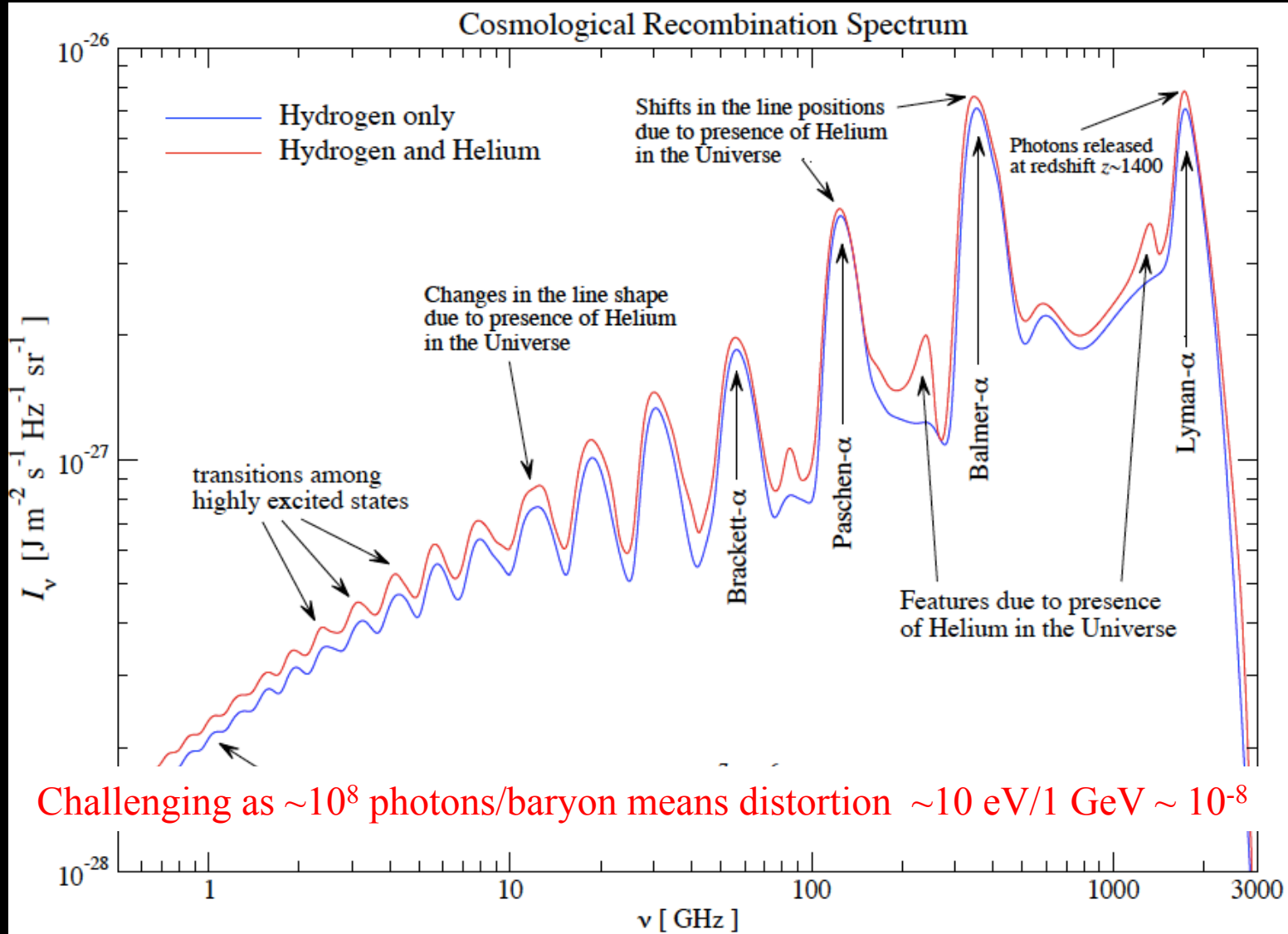
y

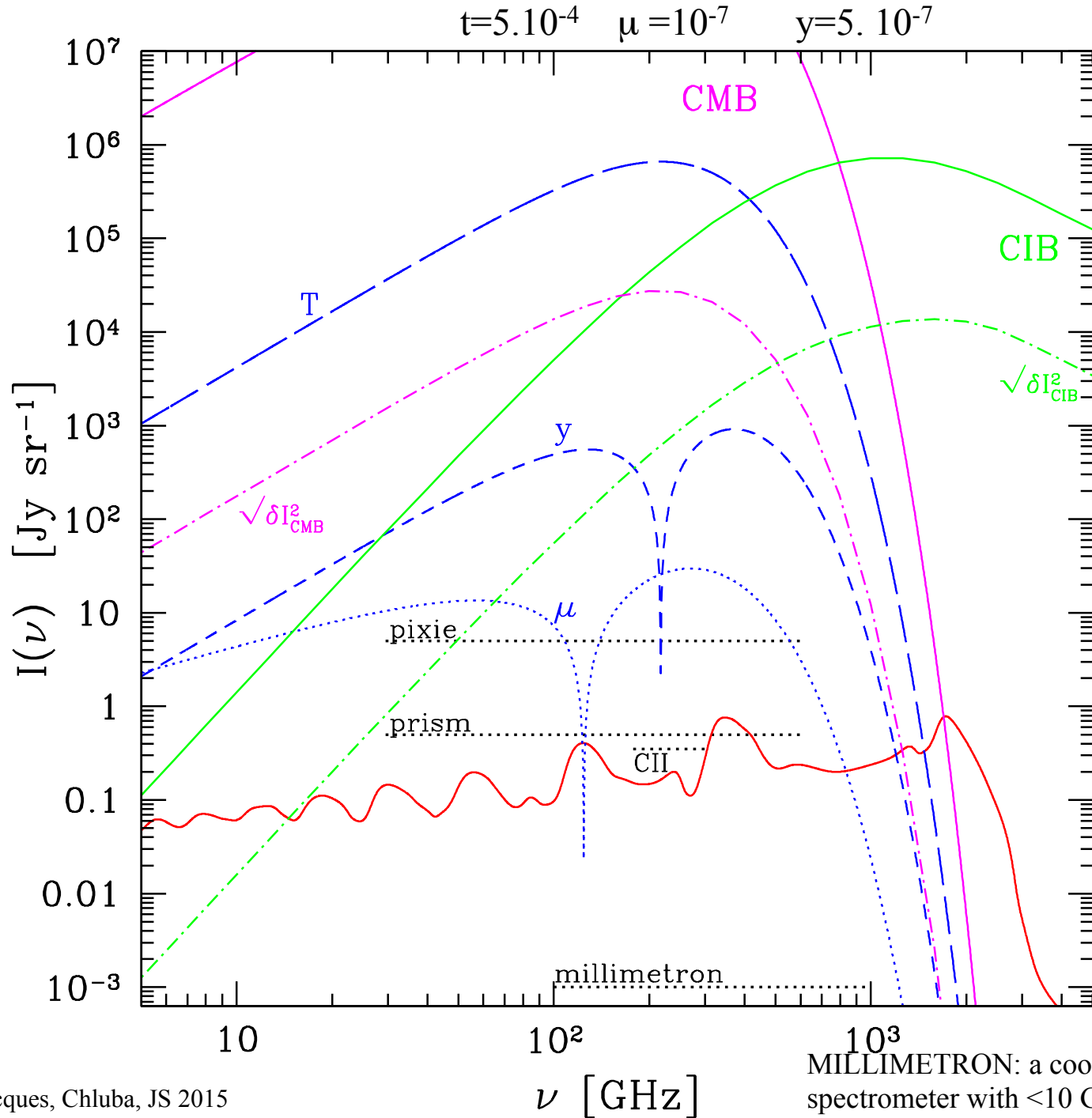


These numbers are integrated over z

Can we do better?

Recombination lines: $\delta T/T=10^{-9}$





MILLIMETRON: a cooled 12m telescope + spectrometer with <10 GHz resolution

CMB spectral distortions open a new window into the early universe
Unexploited for 25 years...ripe for improvement by >3 factors of 10

EARLY ENERGY RELEASE IS A PREDICTION OF THE STANDARD MODEL
This gives integrated information that will be complementary & independent,
eg for damping already measured at $z \sim 1000$, to $z = 2 \cdot 10^6$

+ SOMETHING NEW: exploration of exotic physics

Eg annihilating/decaying dark matter, bubble universe collisions, decaying cosmic strings....

+

+ remarkable T/S $\sim 2 \cdot 10^{-4}$ at 1σ
with marginal
detection of μ at $z \sim 10^6$
and y at $z \sim 1$

early y at $z \sim 10^3$ is 0.01 late y and difficult
to disentangle

PIXIE

A strong case
should be made for B-mode mapping!
NB: LiteBIRD's design goal is 10^{-3}

PIXIE+

With a modest increase x3 in sensitivity, a significant detection of μ is guaranteed

HYPERPIXIE

Theorist's dream:

EXPLORE DECOUPLING at $z = 1080$

Potentially revelatory, eg for directly measuring recombination & for primordial He
BUT need 30x PIXIE sensitivity!

