Unveiling the Dark Ages

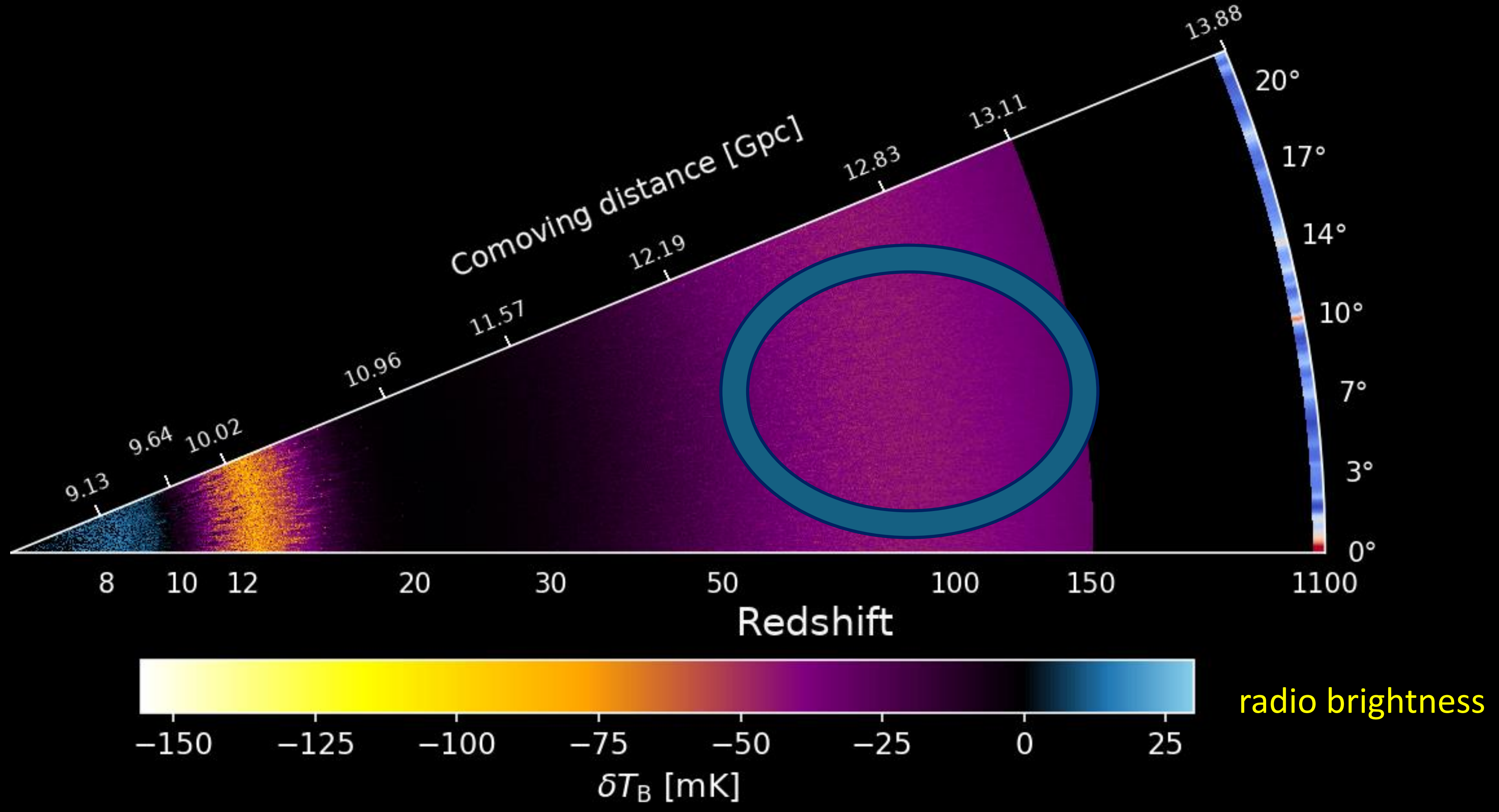
Particle Physics and the Early Universe

Paris & Orsay 14-18 September 2026

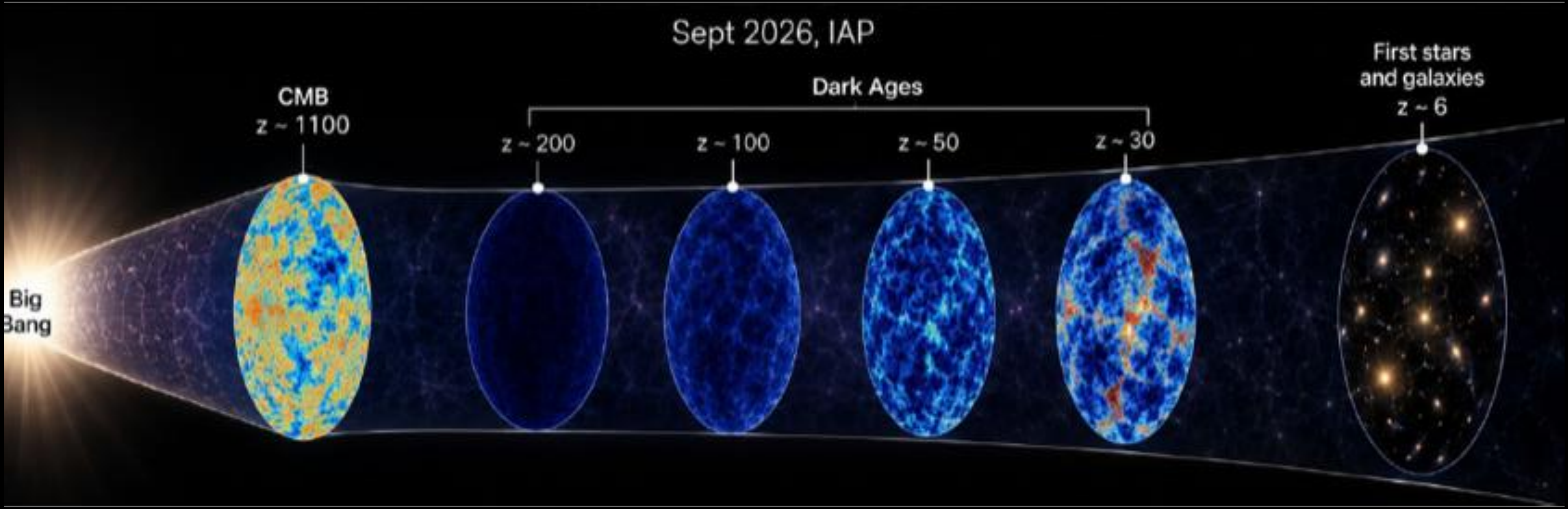
Joseph Silk (IAP,JHU)

with Josh Hibbard (UCB/IAP)

From dark matter to dark ages



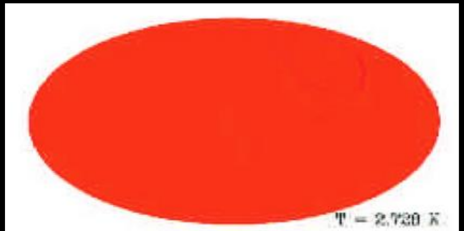
From CMB last scattering to 21cm dark ages

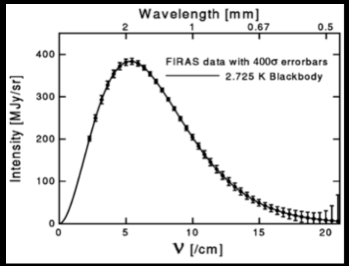


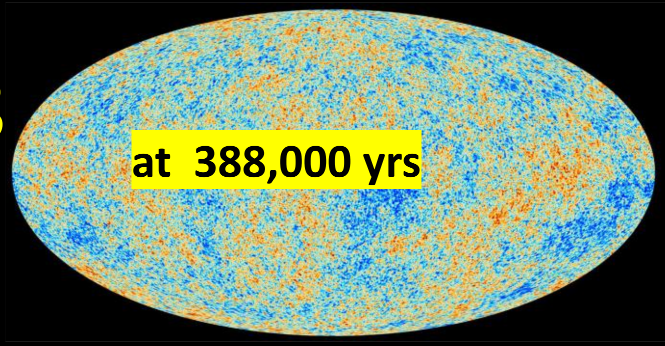
J. Hibbard 2026

Analogy with the CMB → precision cosmology

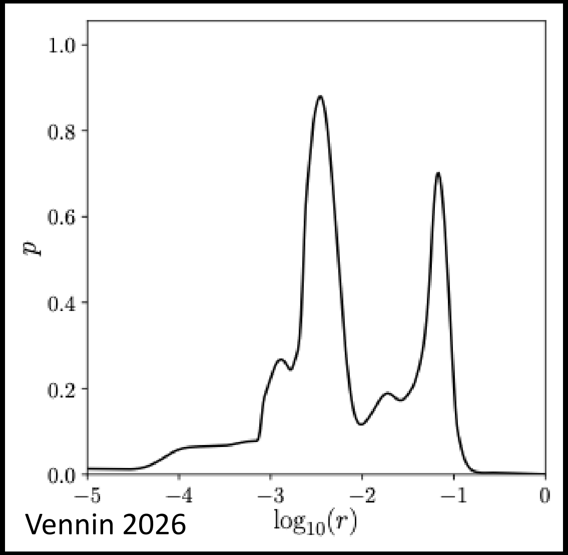
First: the CMB monopole, spectrum and fluctuations

1964 

1990 

2018 

Next: the polarized fluctuations



Probe inflation by tensor mode detection

T/S aim (2035) ~0.001 SO, SPO, LiteBIRD

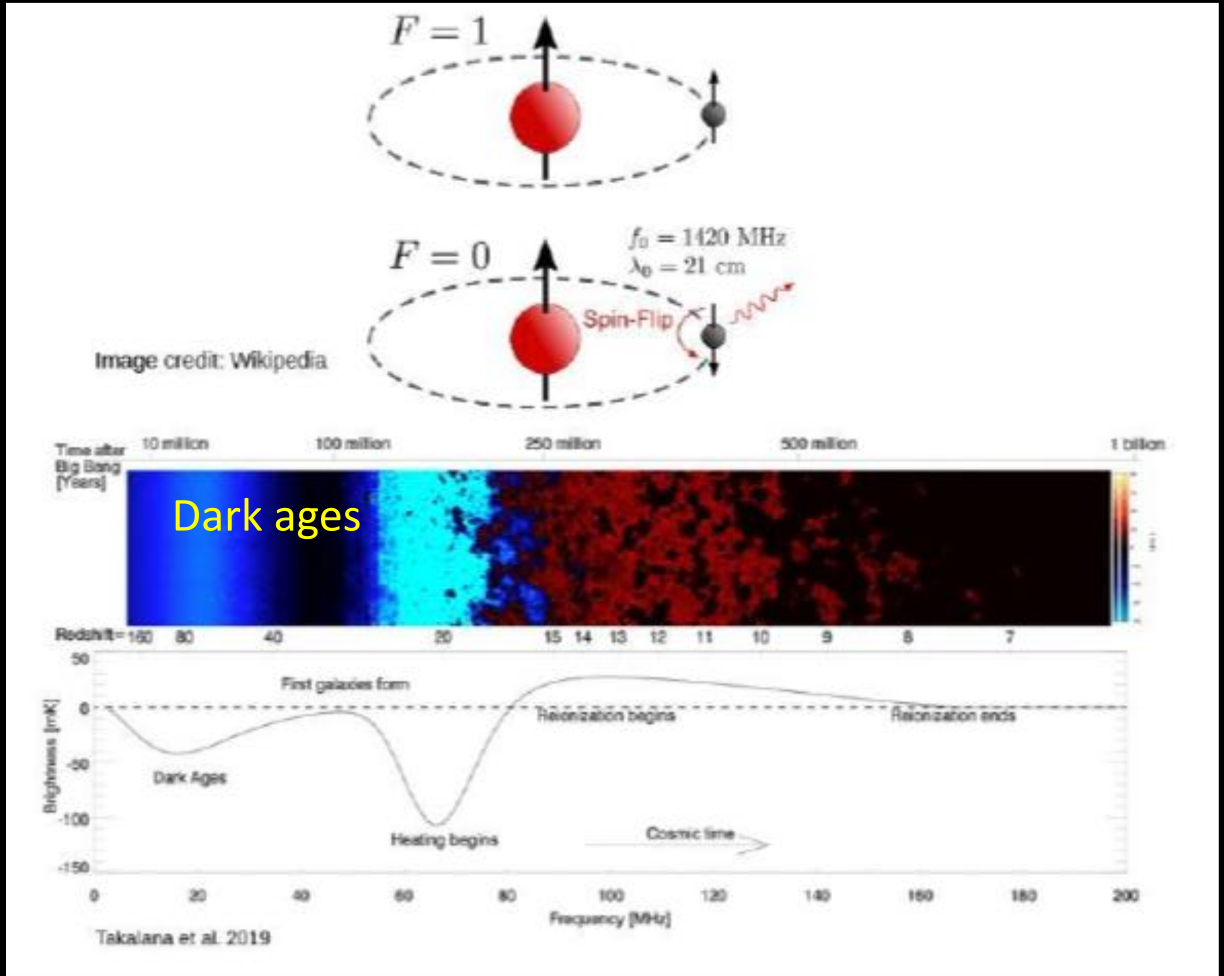
but robust goal is ~ 3.10^{-5} for single field inflation

Let's consider a complementary approach

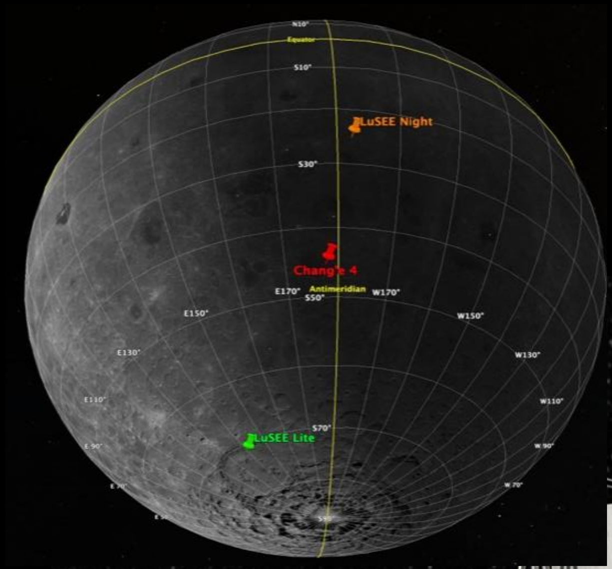
21cm at z~50-100 → ultraprecision cosmology

First: hydrogen shadow of the dark ages in absorption against the CMB

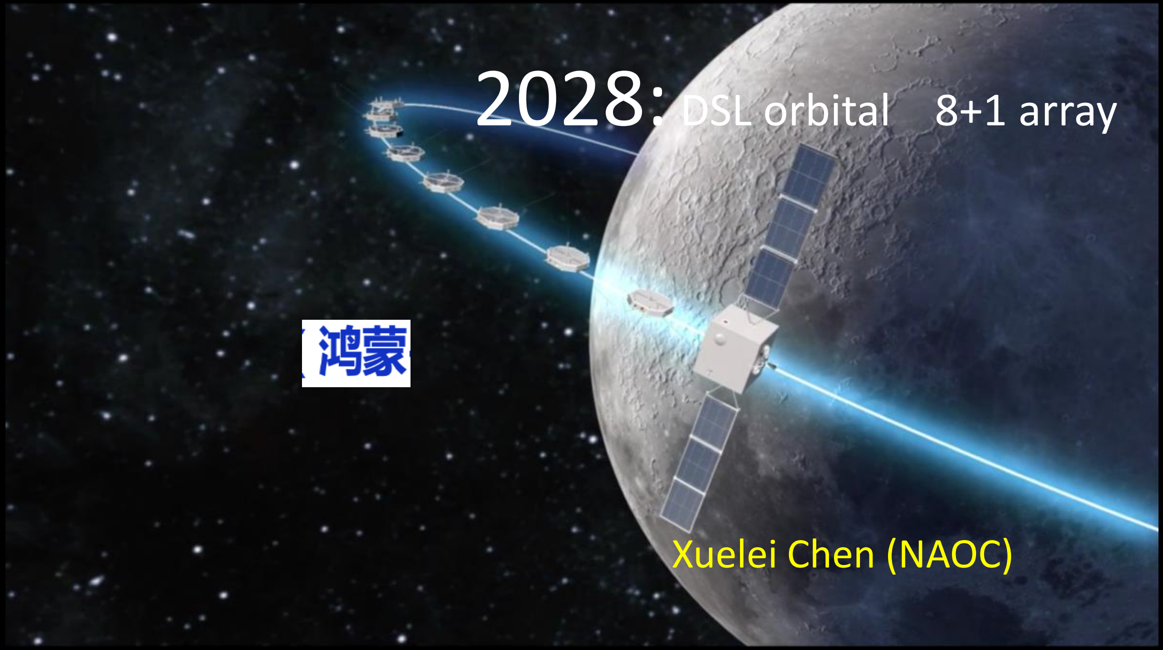
Next: the fluctuations, power spectrum and bispectrum



only from the far side of the Moon



its beginning!

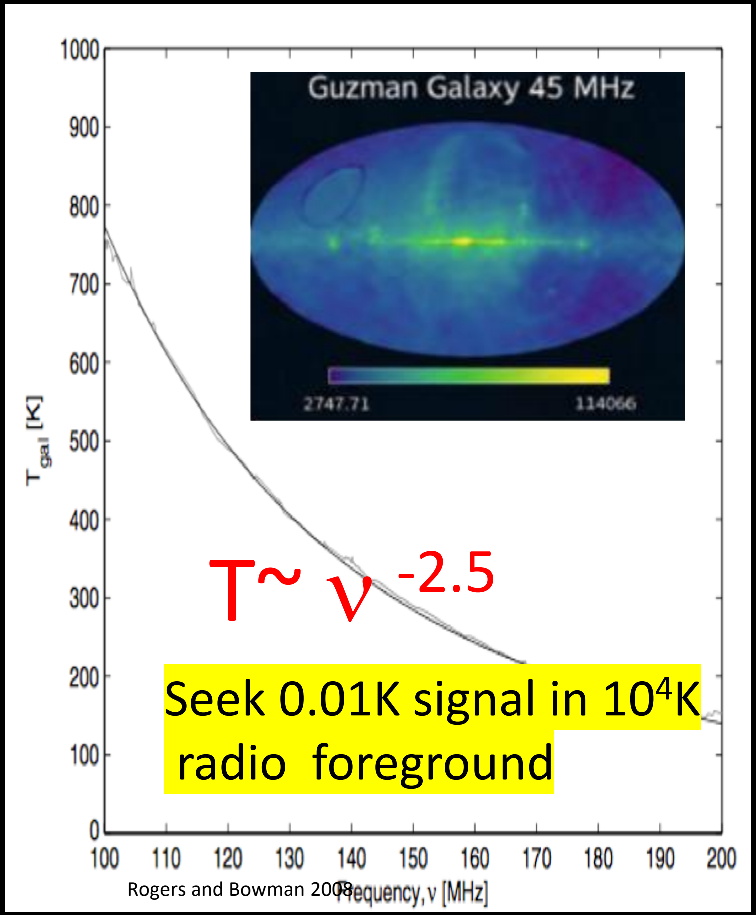


far side of MOON for low frequency radio astronomy
No ionosphere, no terrestrial radio interference
Most radio quiet environment in inner solar system

Not easy as low frequency radio foregrounds are ferocious

If we succeed, attack ultimate probe of inflation

primordial non-gaussianity f_{nl}

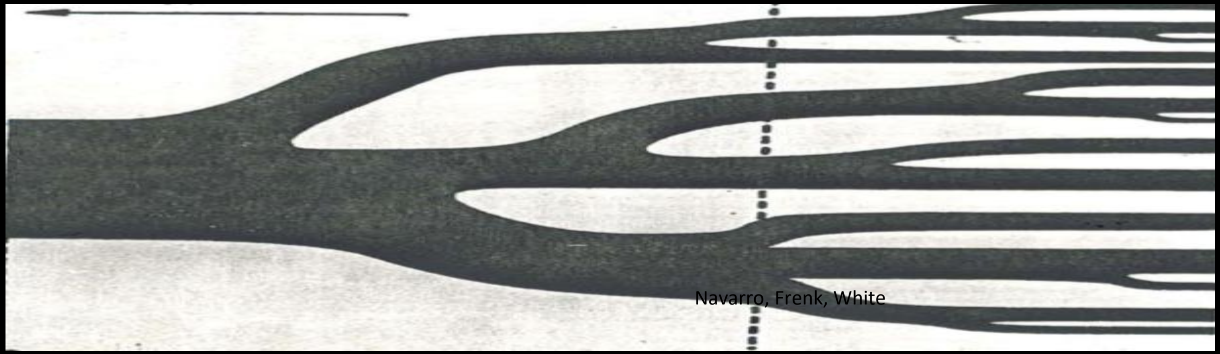


generically predict f_{nl} ~ 0.01

whereas CMB f_{nl}~10 or LSS f_{nl}~1

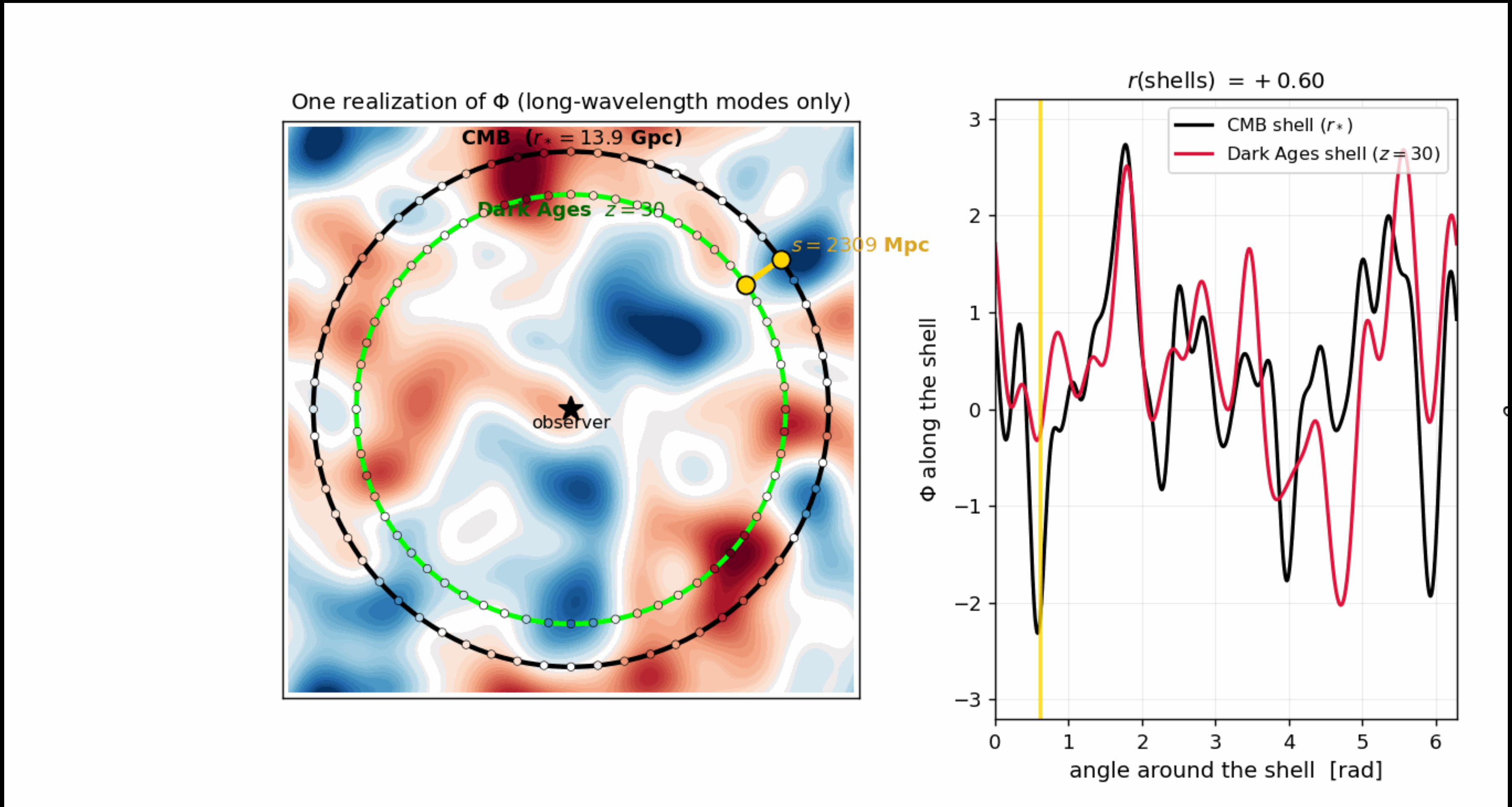
dark ages are key

CMB ~ 10^6 CMB pixels LSS ~ 10^9 galaxies DA > 10^{12} HI clouds



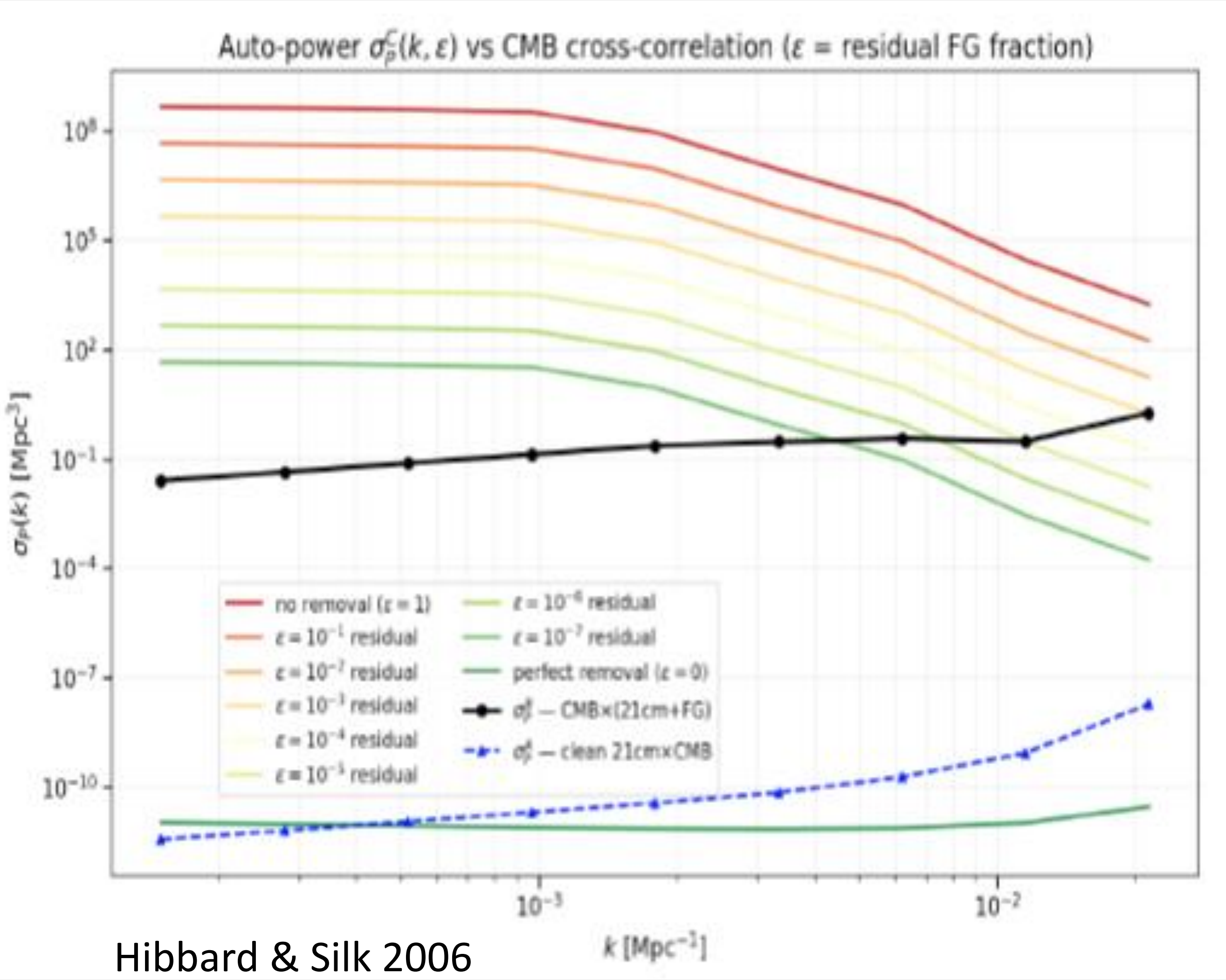
Use 21cm building blocks of the galaxies

CMB and 21cm are correlated



How to tackle foregrounds

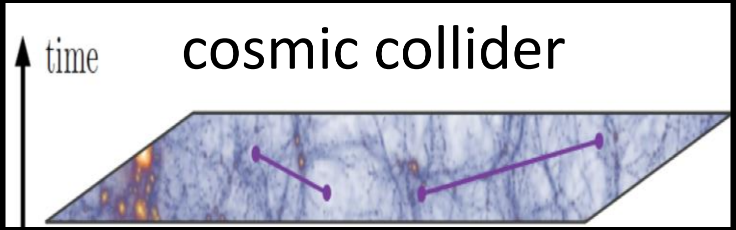
tomography is key + cross-correlate with CMB



Hibbard & Silk 2006

The way forward in cosmology

need low frequency radio interferometers



21cm: probe z=50 at λ~ 10 m or 30MHz

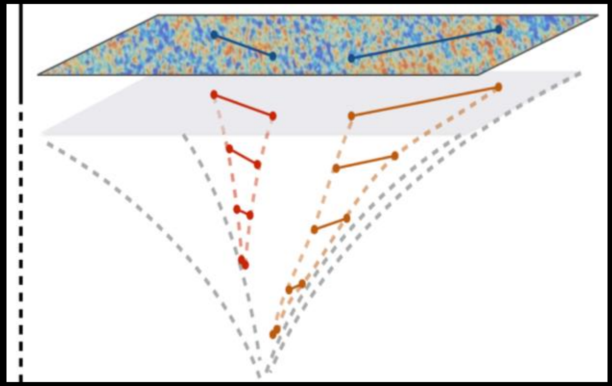
100 x CMB resolution $\ell \sim 10^5$ or k~ $10 Mpc^{-1}$

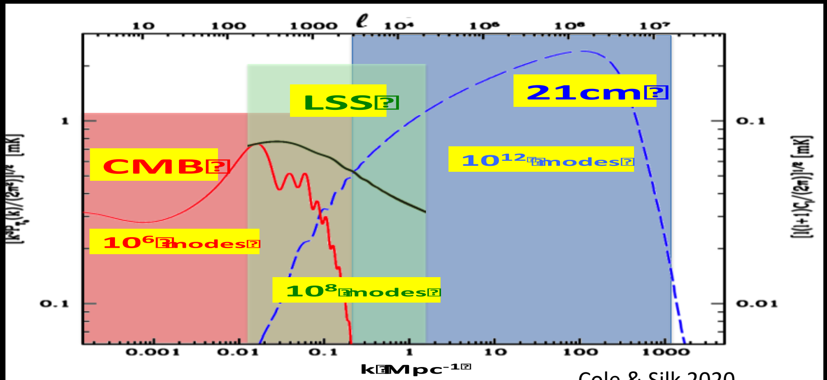
Optimal array ℓ $\lambda/2\pi$ or D~100 km

Sensitivity: millions of dipoles: ~10^6

$$\frac{D^2}{4\lambda^2}$$

dark ages 21cm





Cole & Silk 2020

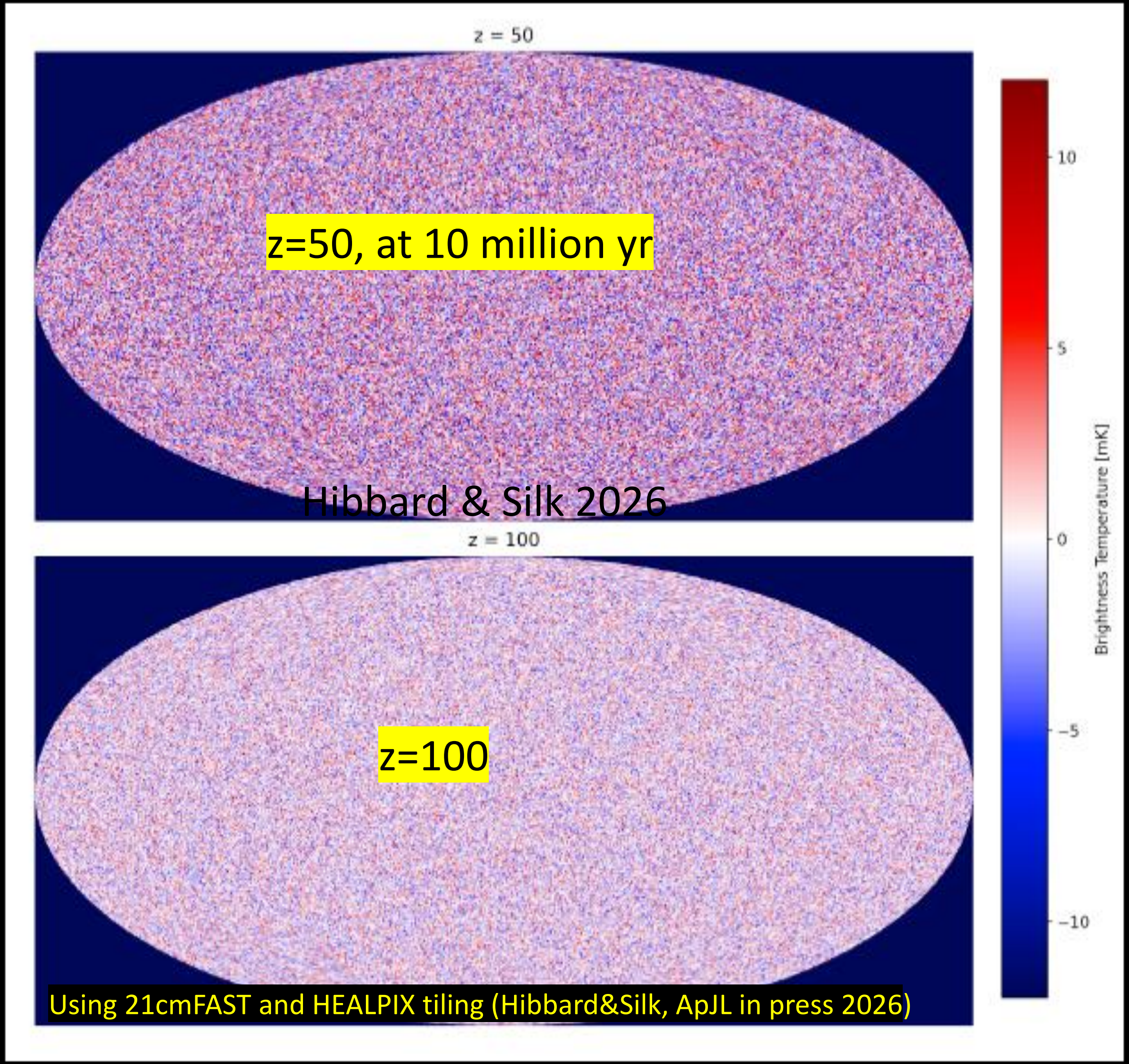
ultraprecision cosmology, a robust probe of inflation

Lunar dreams @ 21cm

(potentially) > 100 x S/N of CMB

- FAR SIDE OF THE MOON: no ionosphere
- no terrestrial radio interference
- most radio quiet environment in inner solar system

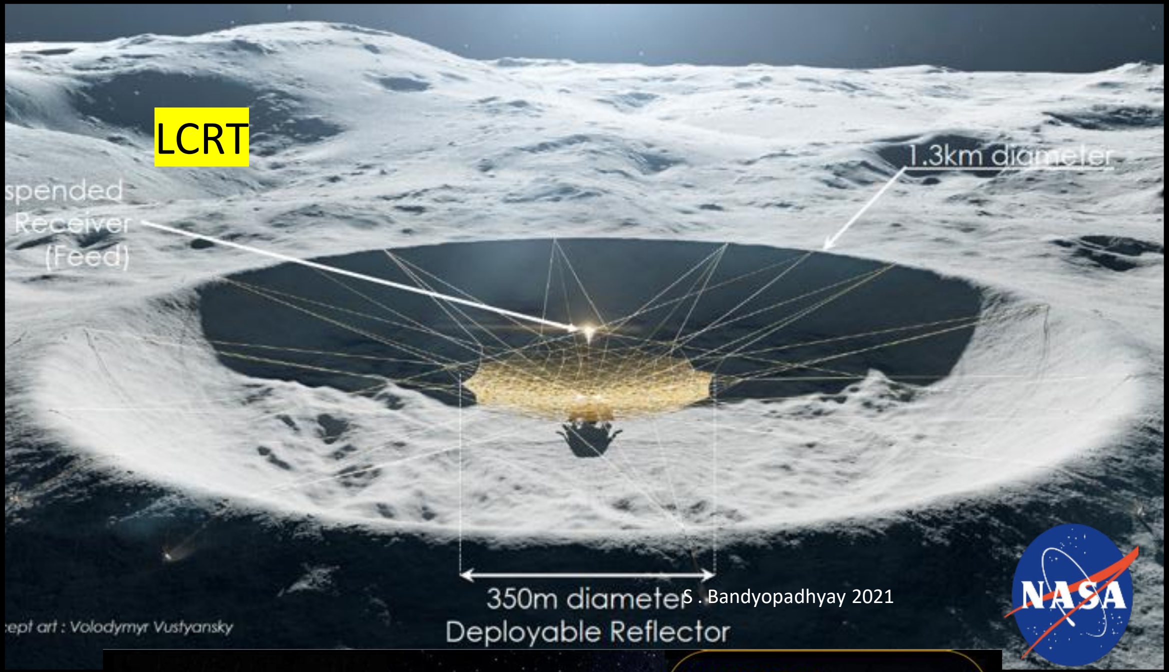
Pathway to ultrahigh precision cosmology
Future: beyond CMB, galaxy surveys

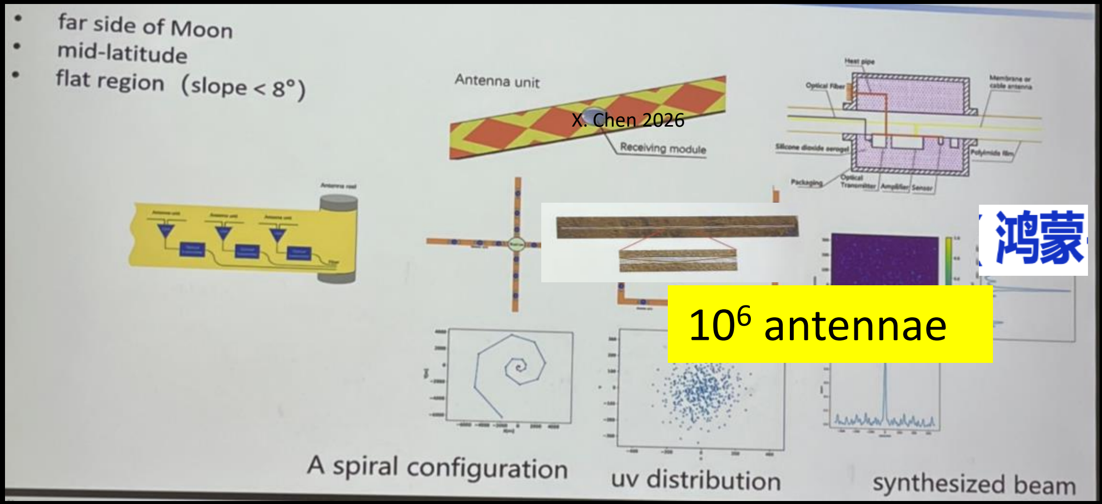


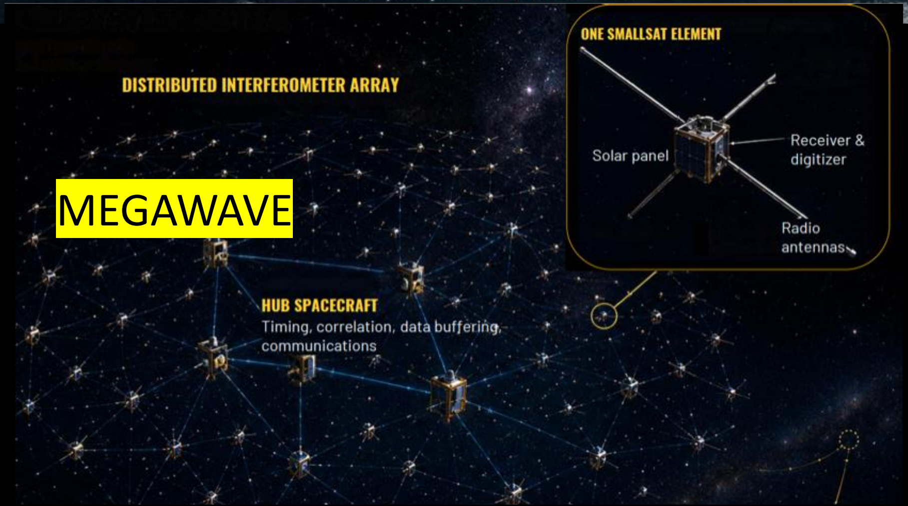
2040+: giant lunar radio telescopes

We have mastered the technology!

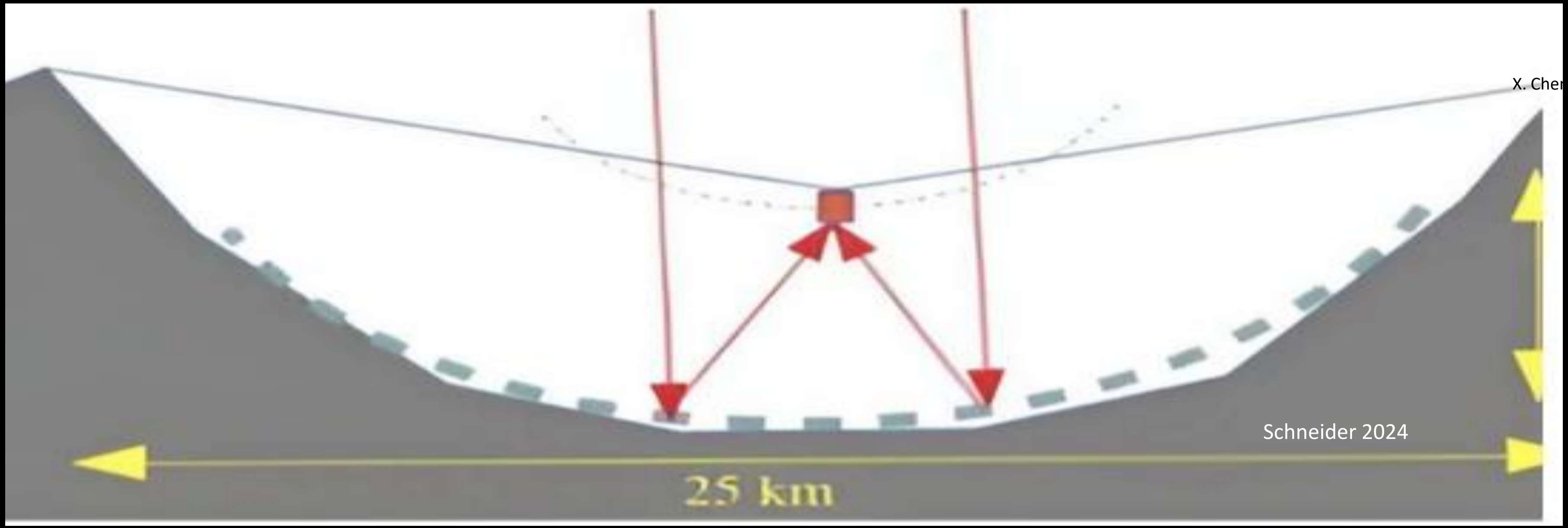
2040+: giant lunar radio telescopes







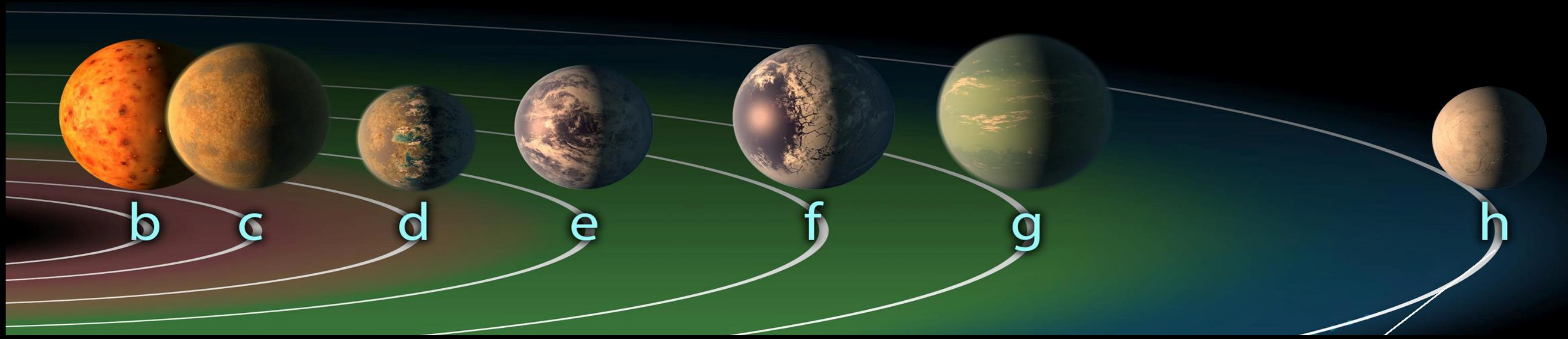
2040+: giant lunar optical telescopes



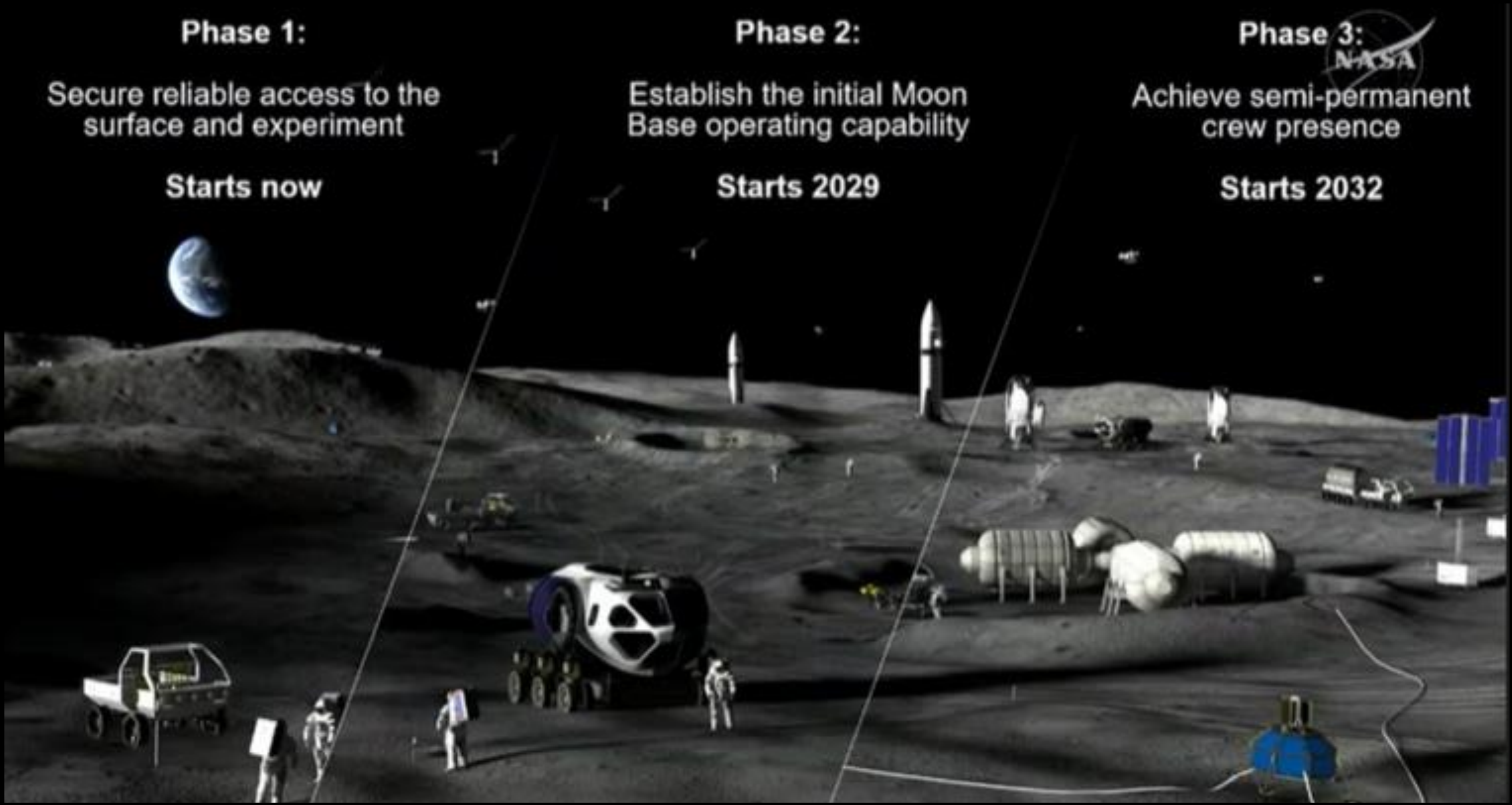
WHY?

μsec resolution

eg. Trappist-1 system at 12.5 pc



NASA 's road map



Why are dark ages so powerful a probe ?

generic prediction of inflation $\delta T/T\,(1+ f_{nl}\,\delta T/T)$

$f_{nl} \sim -5/12\,(n_s-1) \sim 0.01$ $n_s=0.96\ (9\,\sigma)$

Maldacena 2003, Cabass + 2017; Mattarese + 2021

Only the dark ages

$N \sim 10^6$ CMB pixels → $f_{nl}\sim 10$

$N\sim 10^9$ galaxies → $f_{nl}\sim 1$

$N\sim 10^{12}$ hydrogen clouds → $f_{nl} \sim 0.01$

next generation of flagship space missions

current planning

cosmology : SO, SPO, LiteBIRD, NASA probe 2035+
exoplanets : beyond Habitable Worlds Observatory 2040s

new initiatives

ESA 2075 NASA 2050 CERN:FCC 2050

Similar timescales for lunar telescopes---we can piggyback on the lunar base

with telescopes on the Moon,
we will answer humanity’s biggest questions:
it’s for the young generation!