Inflationary predictions of cosmology

Joseph Silk

IAP/JKHU

19 March 2018

origin of vacuum energy in cosmology

aka the cosmological constant

1933

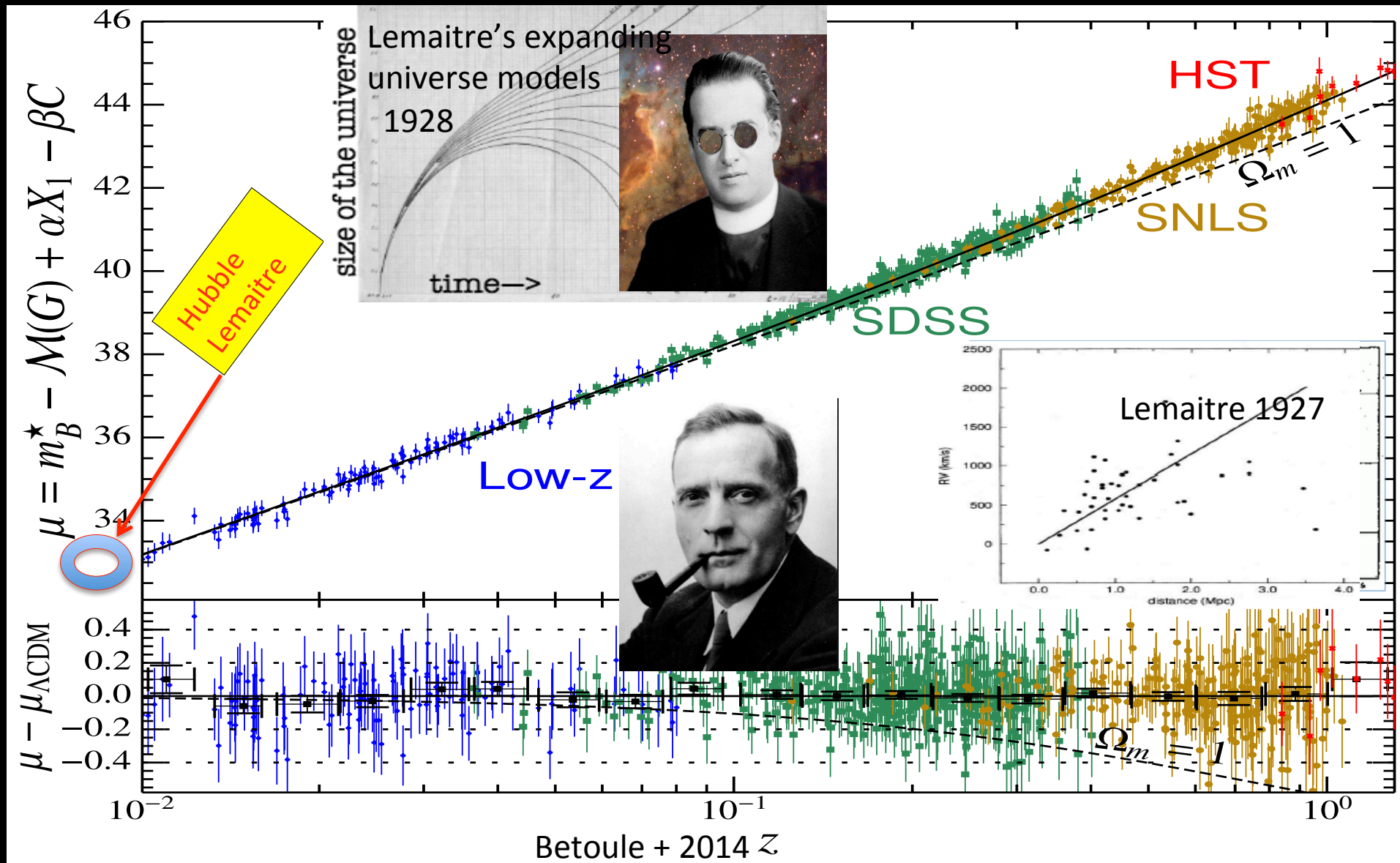
EVOLUTION OF THE EXPANDING UNIVERSE

By G. Lemaitre

University of Louvain

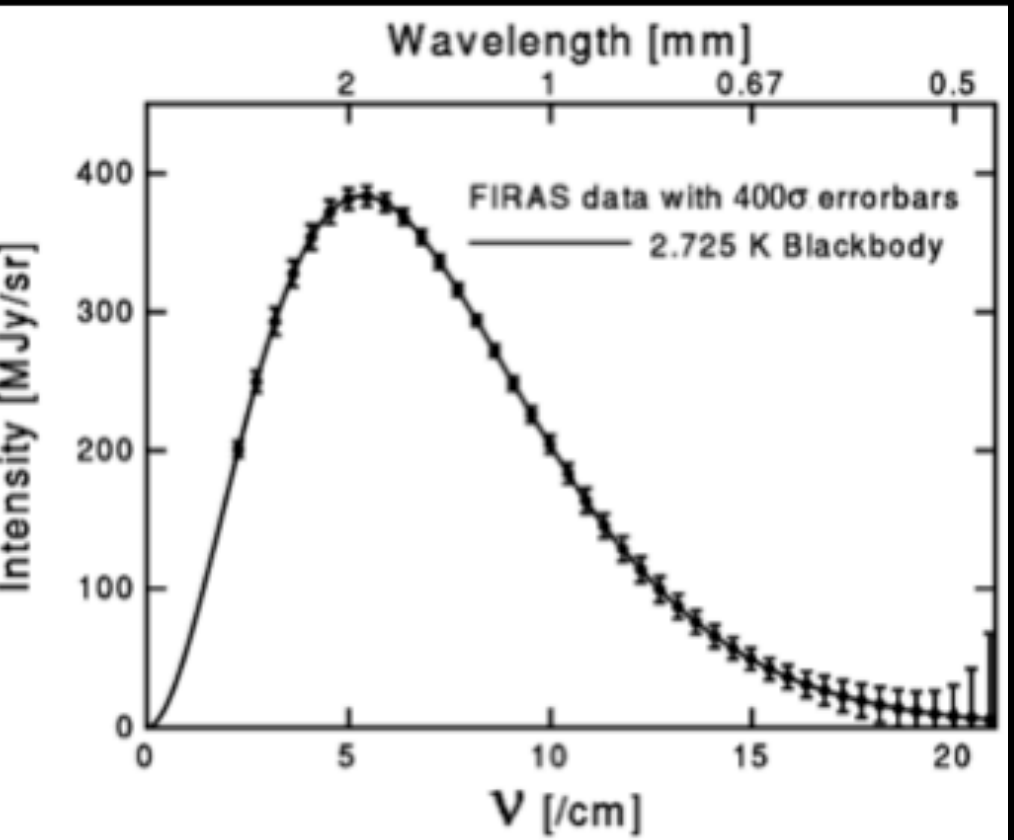
Distant type Ia supernovae are too faint! infer acceleration

ACCELERATION



The cosmic microwave background radiation

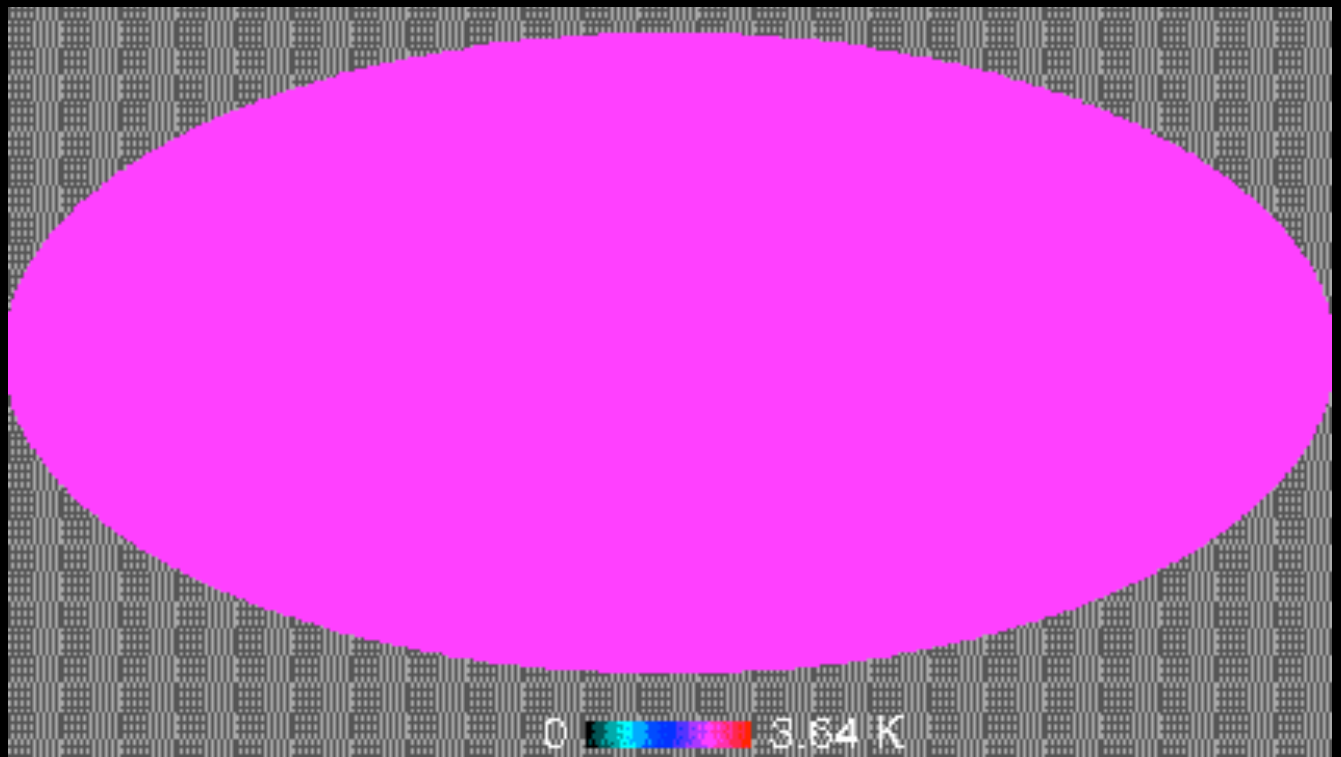
- Fossil glow from the Big Bang
- Cosmic blackbody radiation: perfect furnace



COBE FIRAS 1990

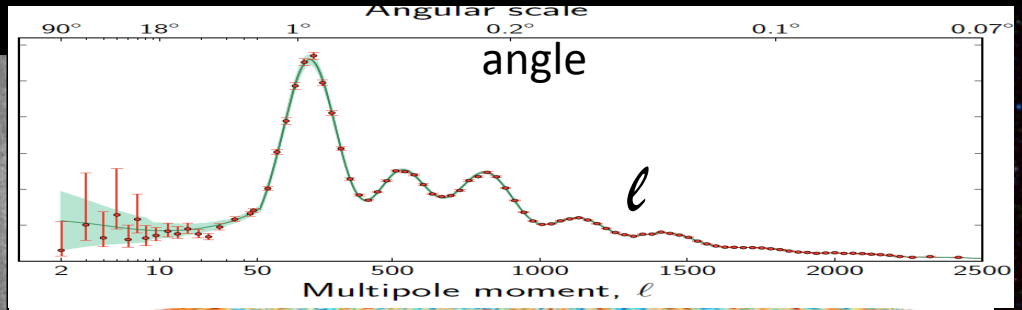
cosmic microwave background radiation

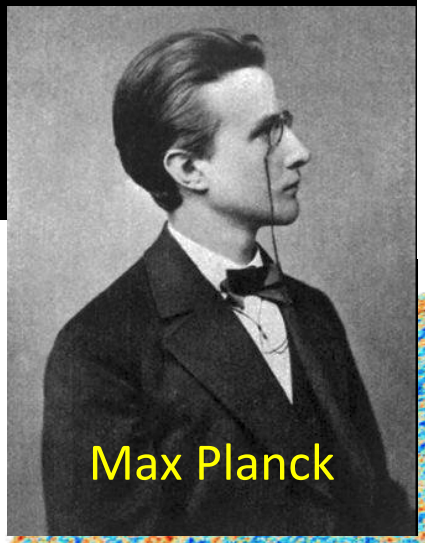
- Fossil glow from the Big Bang
- Cosmic blackbody radiation: perfect furnace
- Temperature fluctuations are seeds of structure
- Galaxies grew by gravity from tiny density fluctuations

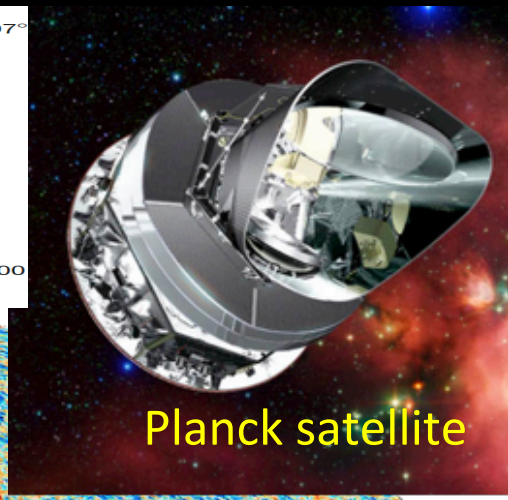


just 2 fundamental numbers + 4 astrophysical parameters describe the temperature fluctuations

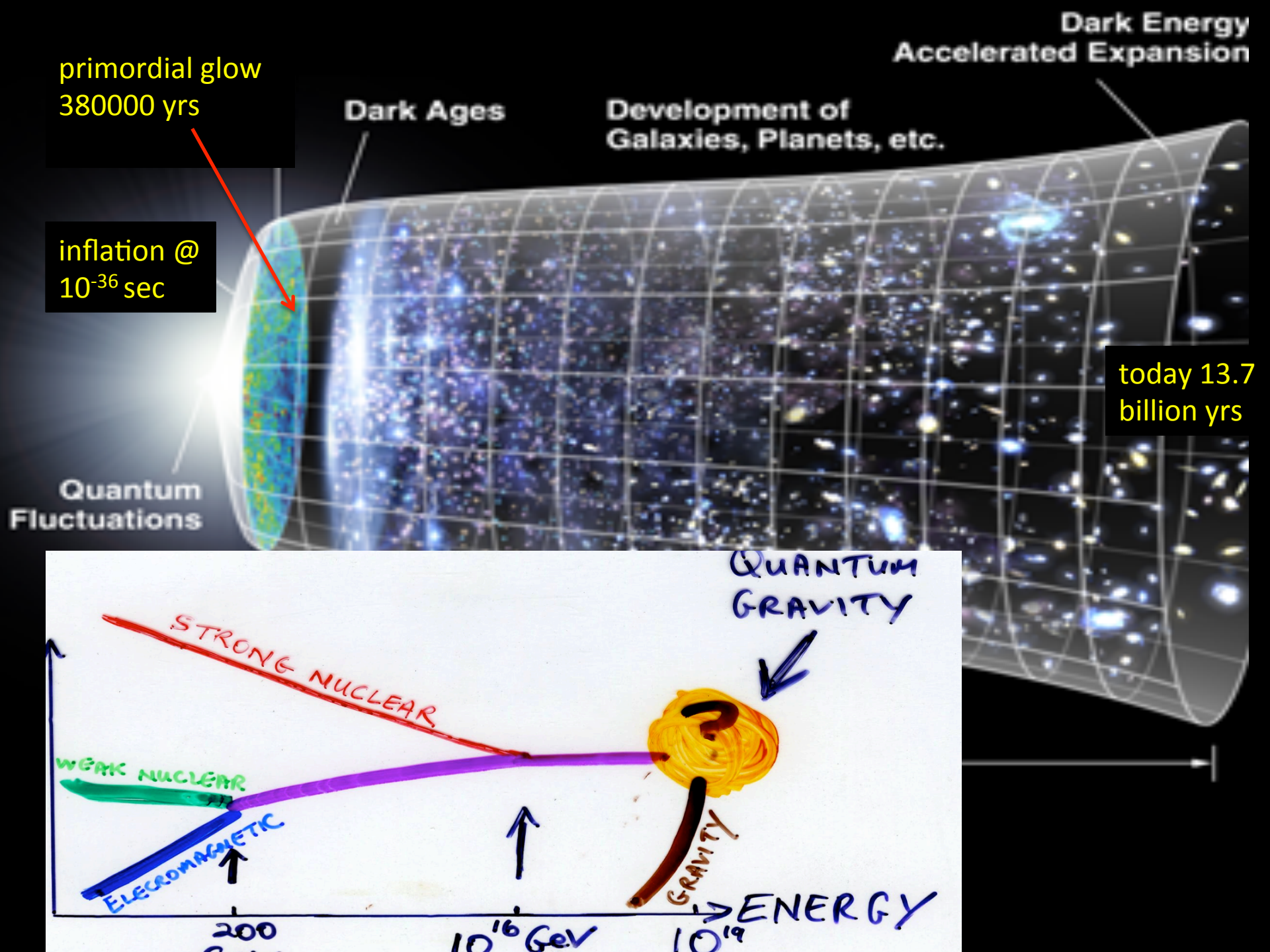
simplest inflation theory predicted one of these




Max Planck


Planck satellite

Temperature fluctuations of a few parts in a million


primordial glow
380000 yrs
Dark Ages
Development of
Galaxies, Planets, etc.
Dark Energy
Accelerated Expansion
inflation @
10^{-36} sec
today 13.7
billion yrs
Quantum
Fluctuations
QUANTUM
GRAVITY
STRONG NUCLEAR
WEAK NUCLEAR
ELECTROMAGNETIC
GRAVITY
ENERGY
200
10^{16} GeV
10^{19}

1980s inflation made 3 predictions

1. flatness of space
2. size of the universe
3. primordial density fluctuations

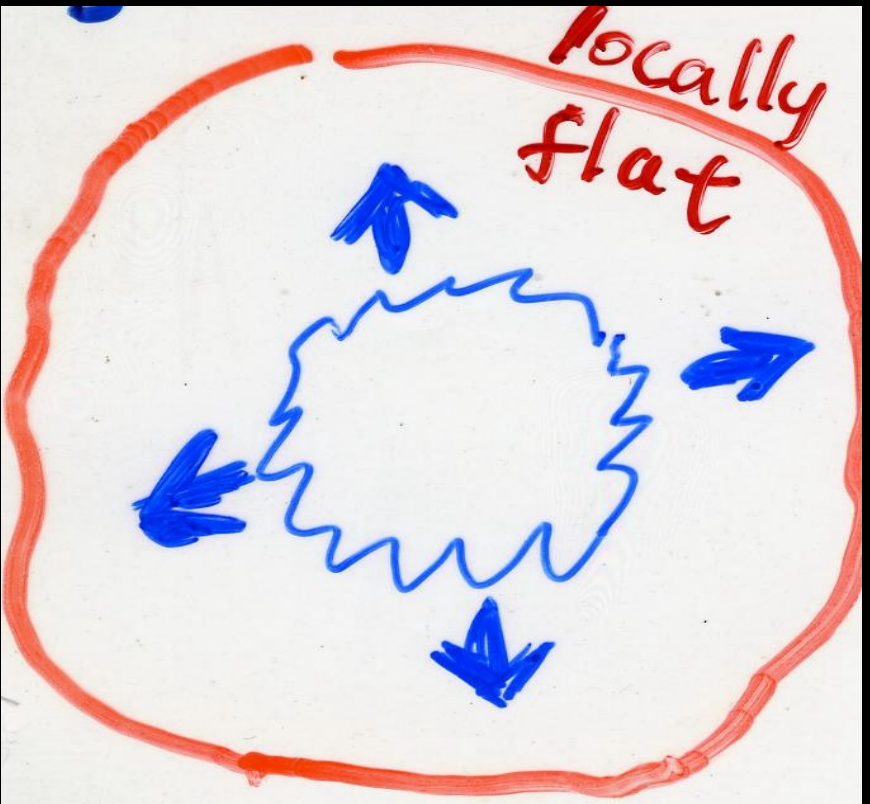

Andrei Linde

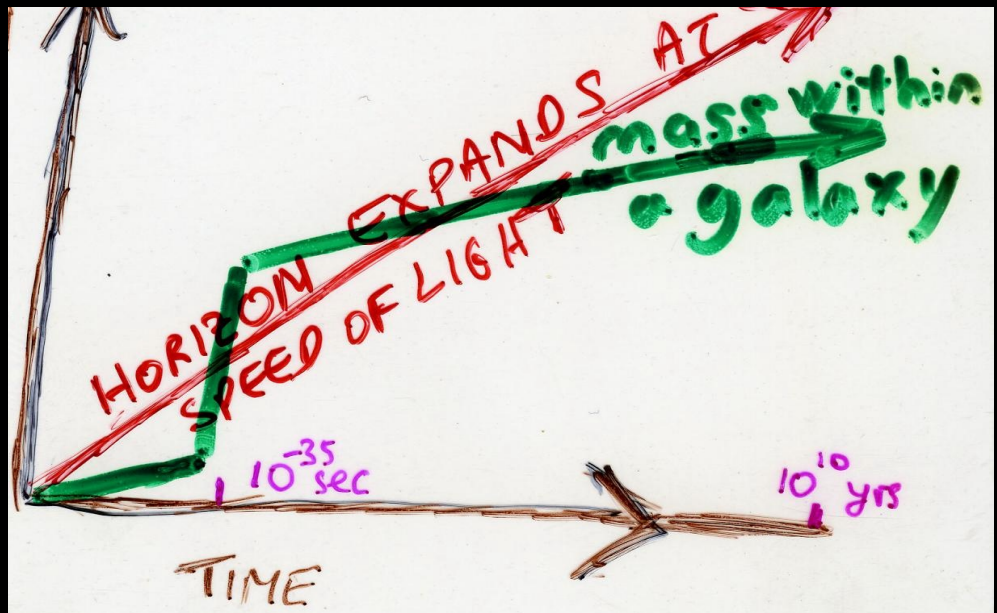

Alan Guth


Paul Steinhardt


Andreas Albrecht

2018: most trust inflation





Some non-generic predictions

Measured

Flatness of space

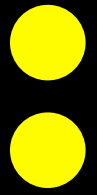
Size of the observed universe

density fluctuations

Predicted

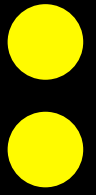
dark matter? **No detection**

dark energy? **No prediction**



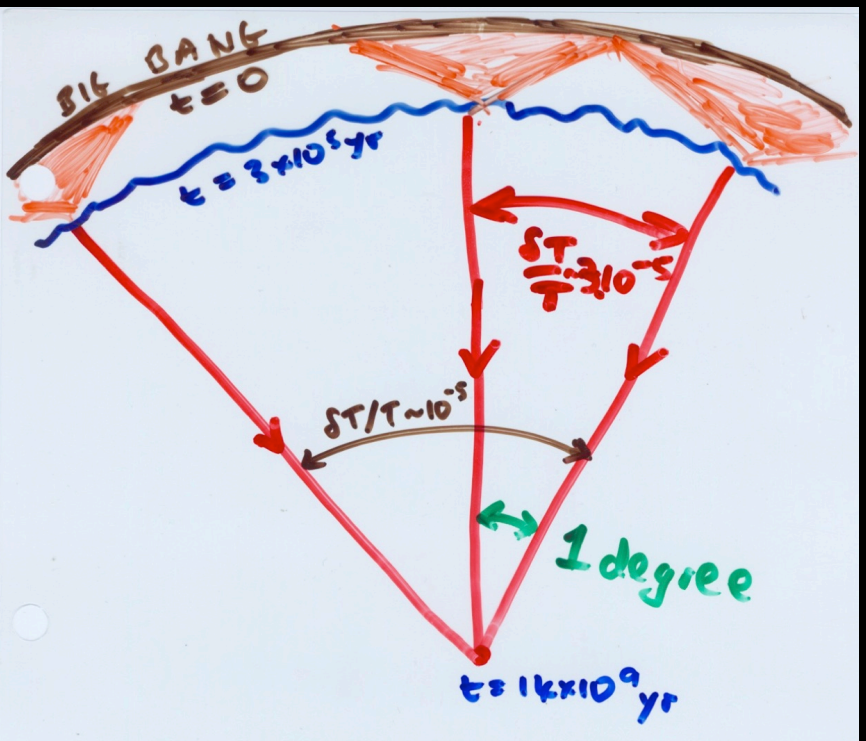
gravity wave background: **upper limit** $T/S < 0.08$

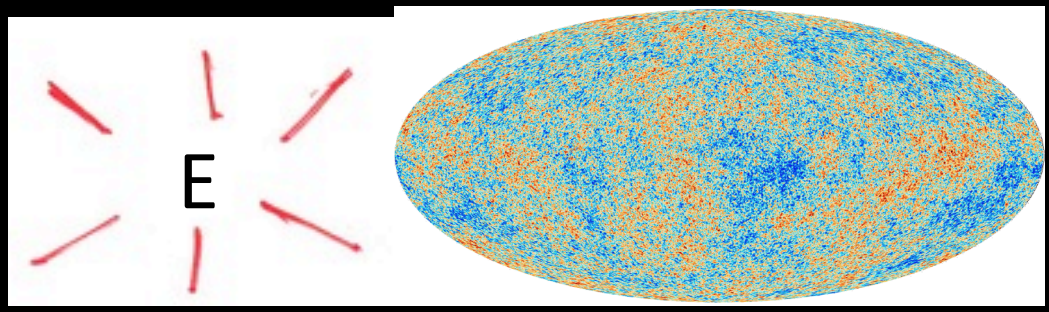
primordial non-gaussianity: **limit** $f_{NL}\,\delta T/T < 0.01\%$



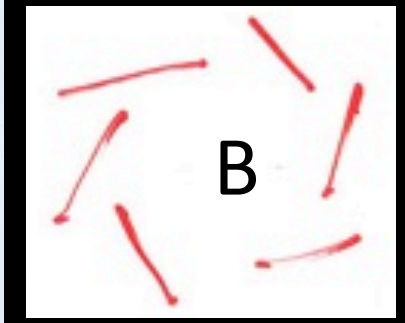
The primordial gravity wave background

- Inflation boosts density fluctuations to large scales
- Inflation shakes space with compressions and twists
- The compressions are the seeds of galaxies
- The twists are gravity waves



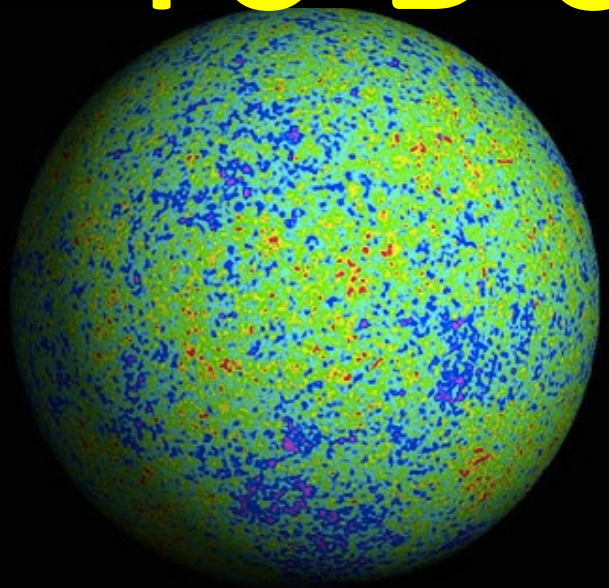


Compression modes are few microKelvins, cf 3K CMB



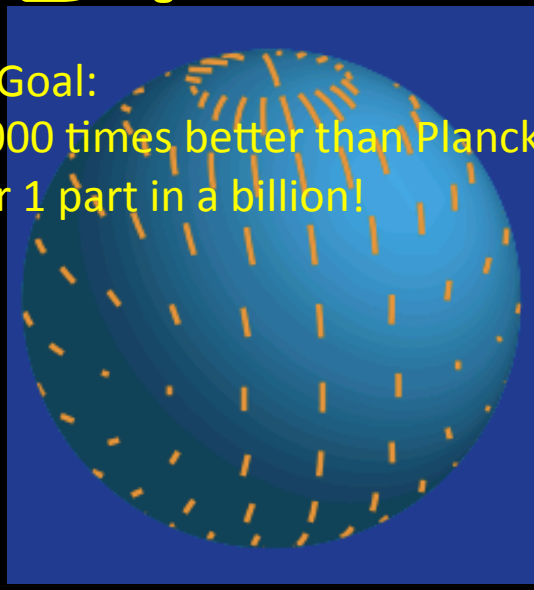
but gravity wave prediction
Is nanoKelvins at most:
a challenge!

To B or not to B?



WMAP: 10 detectors (2003)

PLANCK: 74 detectors (2013)



LiteBIRD 1000 detectors, JAXA launch in 2027?

Simons Observatory 35000 detectors, 2020

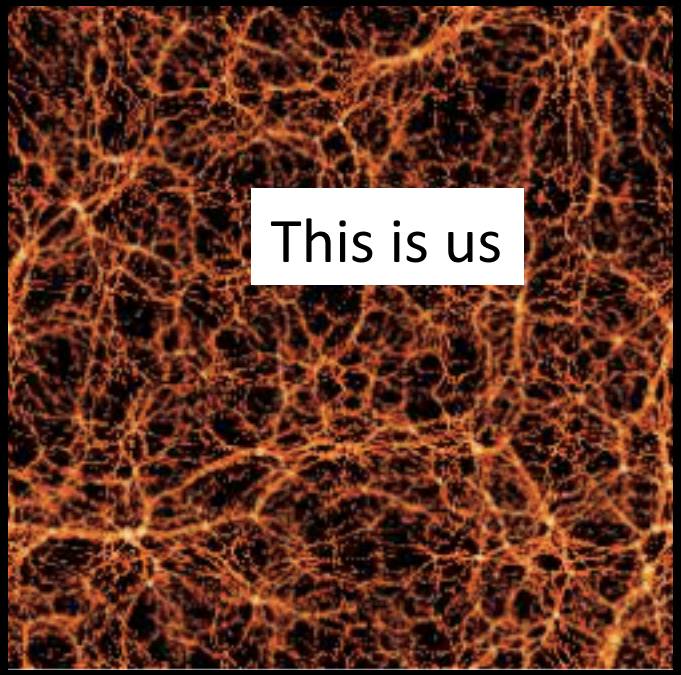
CMB Stage 4: 500,000 detectors, 2025

predicted level 10^{-3} to 10^{-40} (~ T_{Reheat}^{2})

there is no guarantee of a signal!

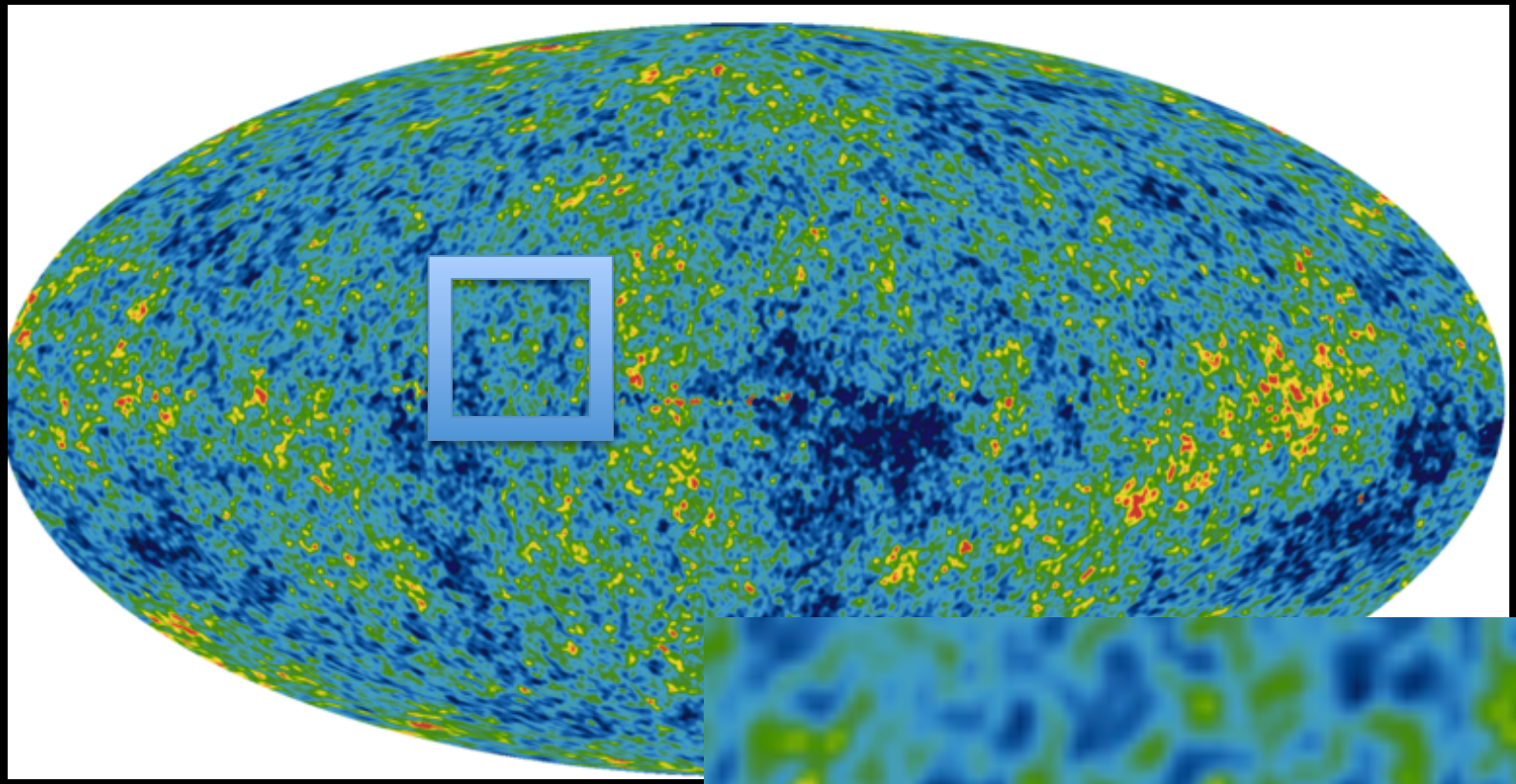
NON-GAUSSIANITY

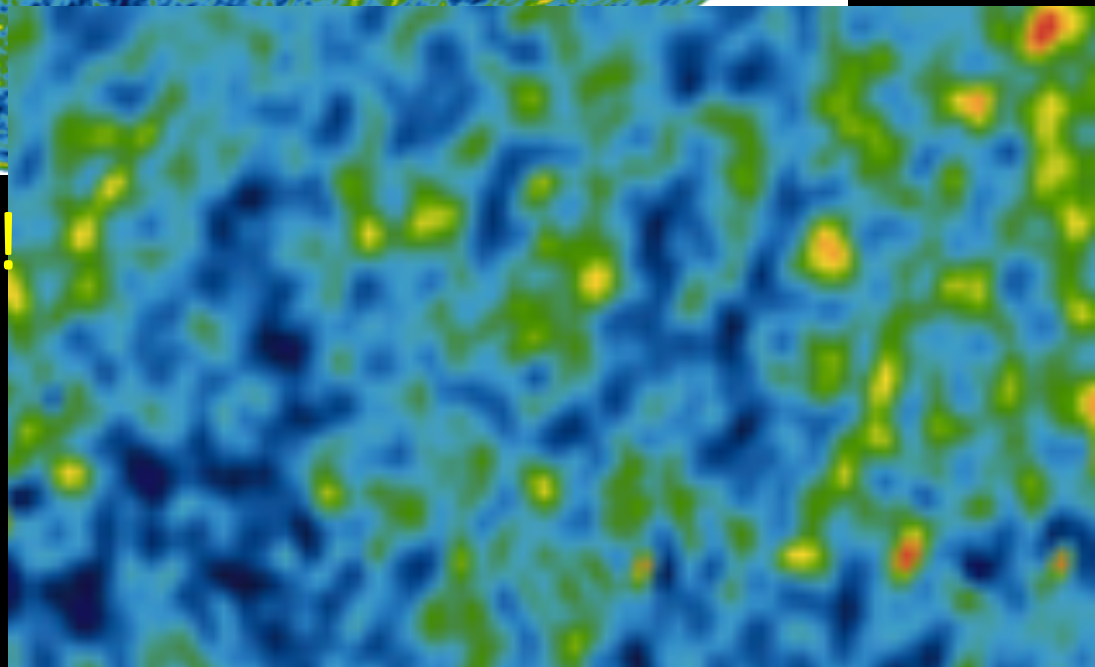
is an essential part of the observed universe



These simulations of galaxy clustering have exactly the same power

Another example of nonprimordial nongaussianity





Beware of foregrounds!

Primordial nongaussianity is predicted generically by inflation

but its very low: $\delta T/T\ (1+ f_{NL}\ \delta T/T)$

Predict: $f_{NL} \sim n_s - 1 \sim 0.03$ n_s is the measured fluctuation spectral index

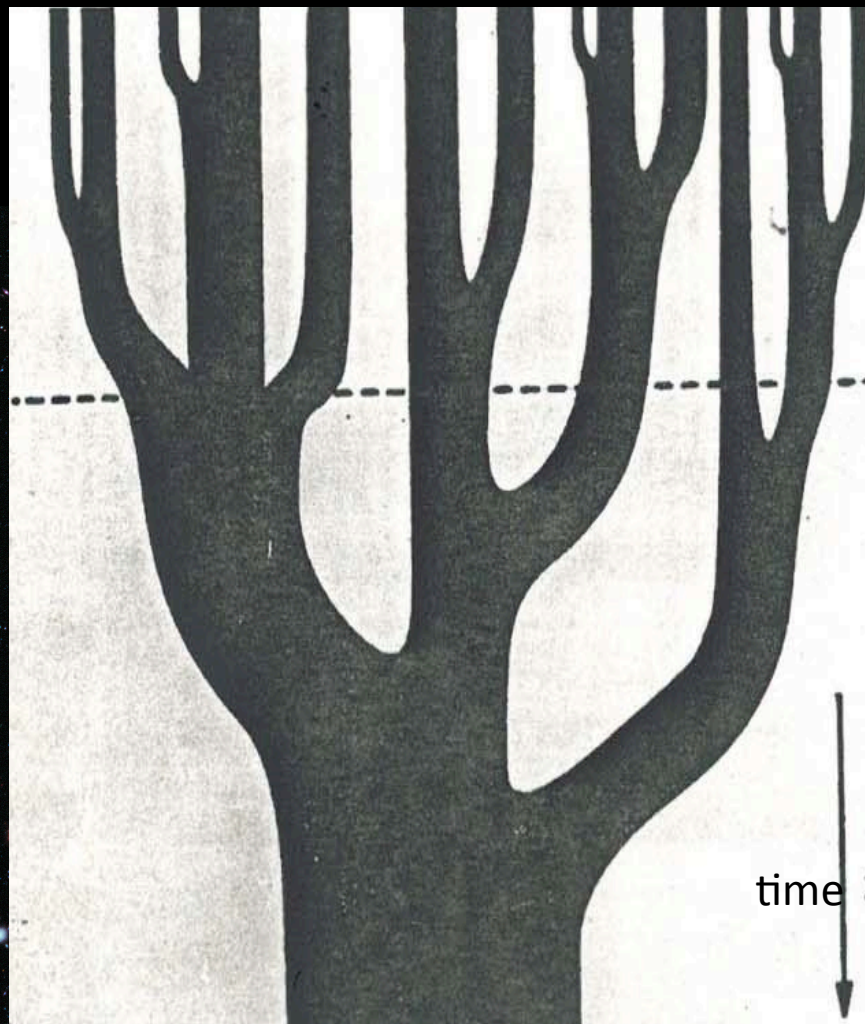
Maldacena 2003 Cabass + 2017: perhaps 0.1 (n_s-1)

Need to improve from $f_{NL}<10$

CMB has a million independent pixels

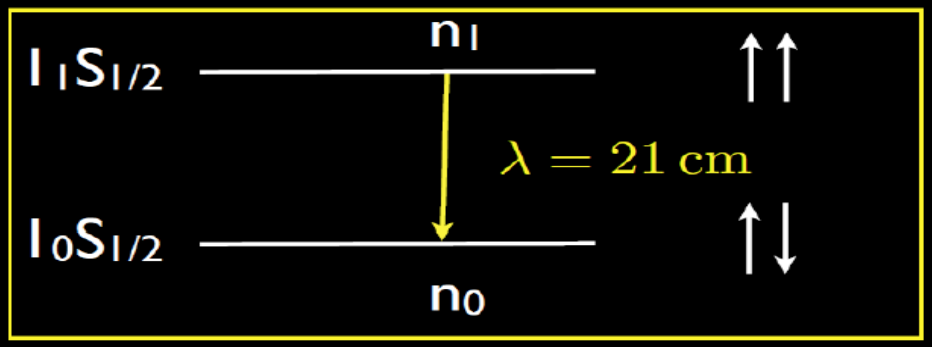
- $N \sim 10^6$ 0.1% CMB 2018
- Use galaxies
- $N \sim 10^8$ 0.01% LSS 2025
- Use 1st clouds
- $N \sim 10^{12}$ 0.0001% 21cm 2040

Precision increases as $N^{-1/2}$

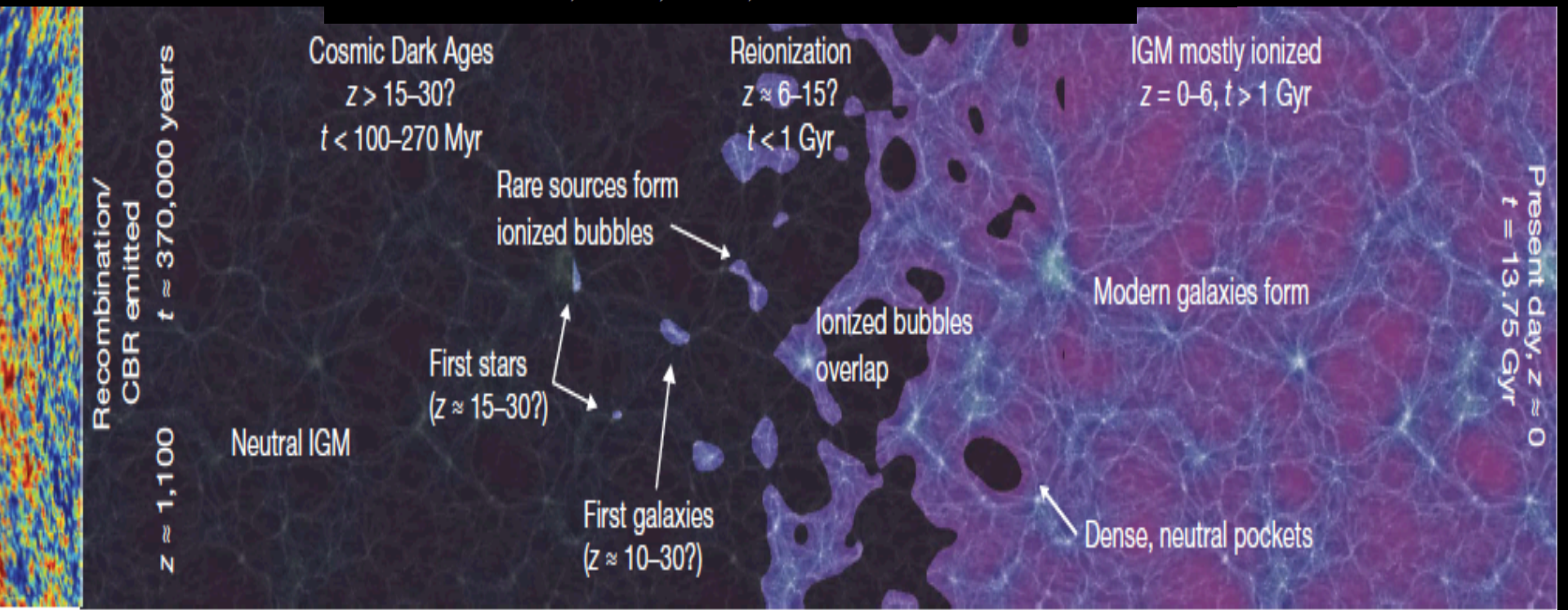


DARK AGES

Hyperfine transition of neutral hydrogen



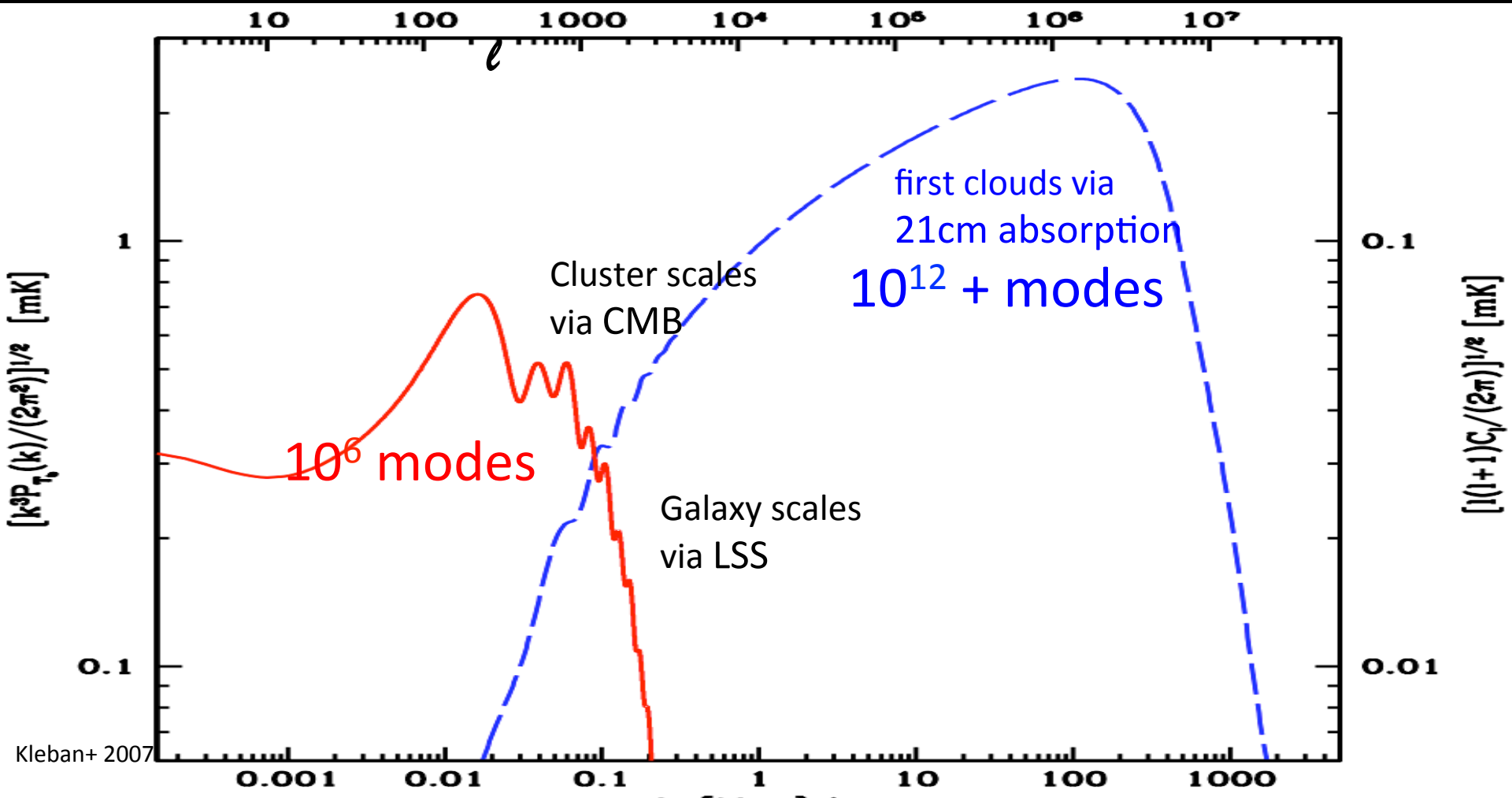
$$\nu_{21cm} = 1,420,405,751.768 \pm 0.001\,\mathrm{Hz}$$



ultimate future: the dark ages

trillions of modes!

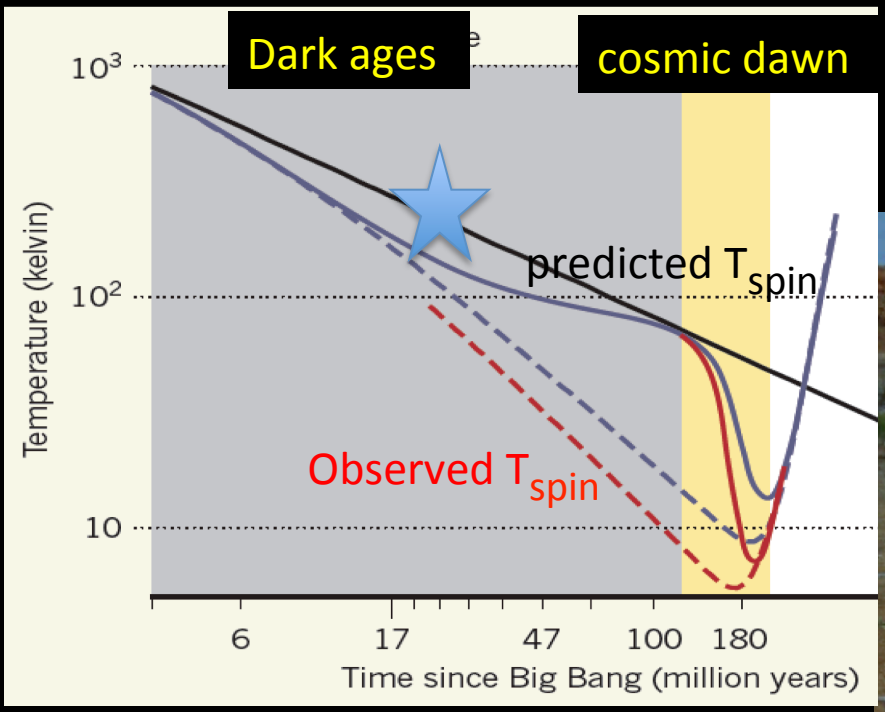
…but it'll be very difficult to remove the foregrounds…

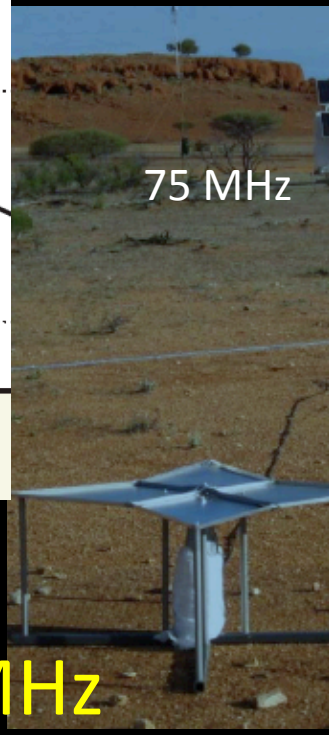


Kleban+ 2007

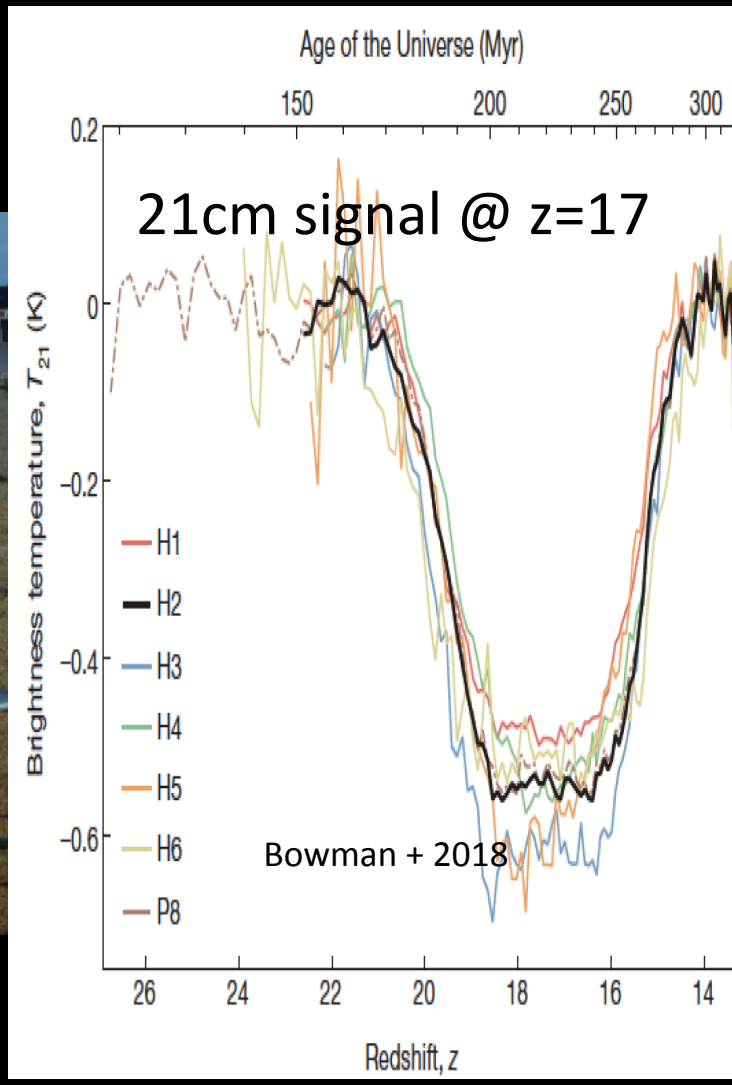
A vision for the ultimate future of cosmology

The journey to the dark ages has begun!





EDGES dipole
W. Australia



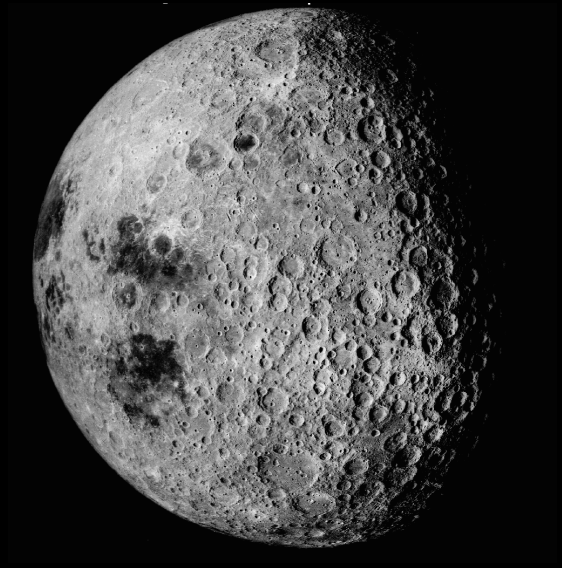
Sweet spot at z ~ 50

Need to observe at 30 MHz

Next step: the Moon!

far side of MOON for low frequency radio astronomy

most radio-quiet environment
in inner solar system



JPL concept

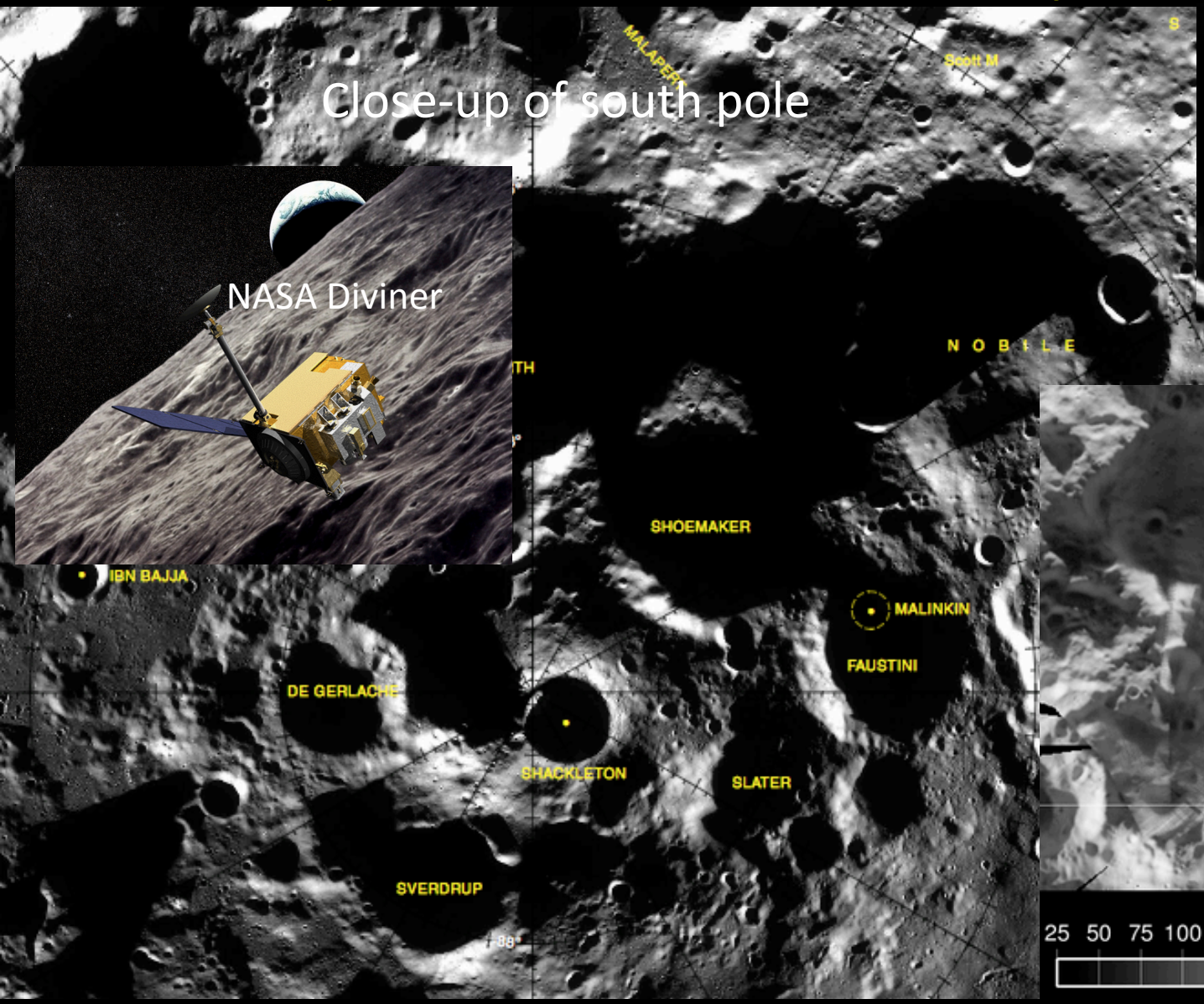
21cm sweet spot: z=50 @ 30 MHz or λ~ 10 m
Need 100 times CMB resolution $\ell \sim 10^5$
Optimal array is $\ell\ \lambda/2\pi$ or D ~100 km

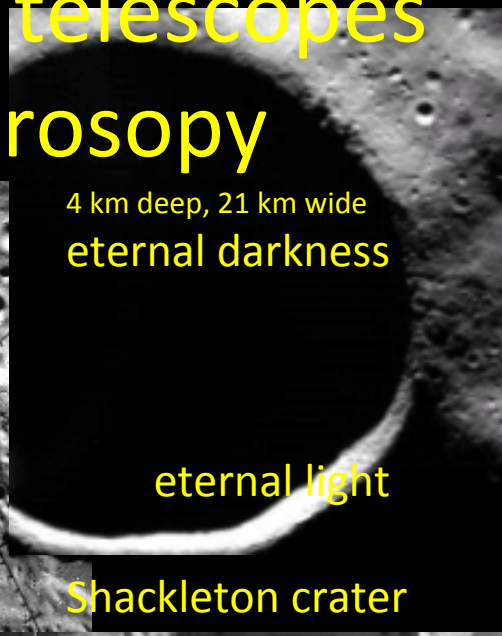
need millions of dipoles: $\frac{D^2}{4\lambda^2}$ ~10^7

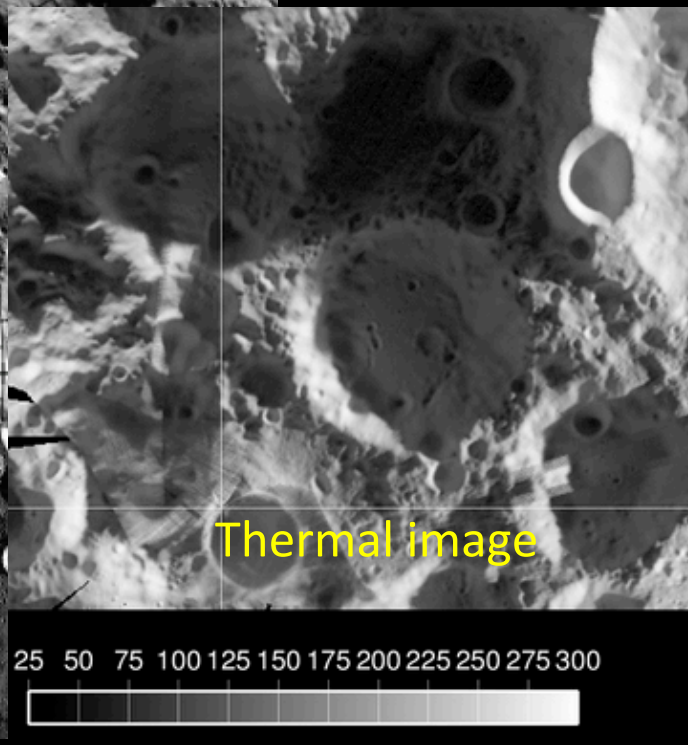
SKA-low 10^5 antennae in 2025

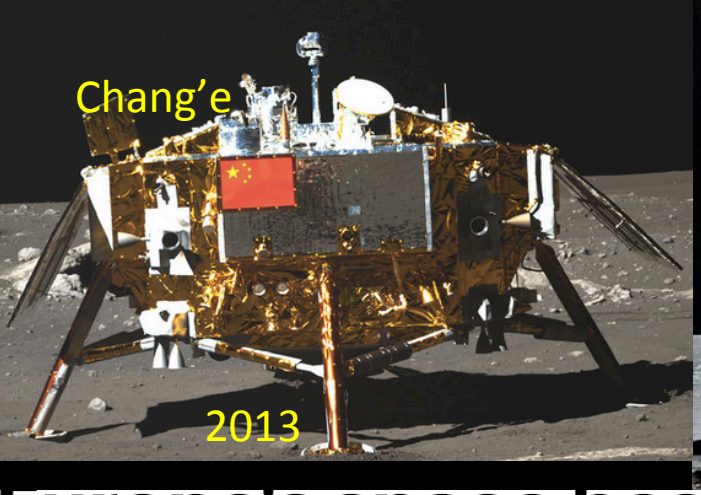
~10mK signal in bright sky foreground T_B~1000K

That's not all! Sites for far infrared telescopes
No atmosphere: ideal for CMB spectrosopy









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 … of the next decade**

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

Trump wants to send U.S astronauts back to moon

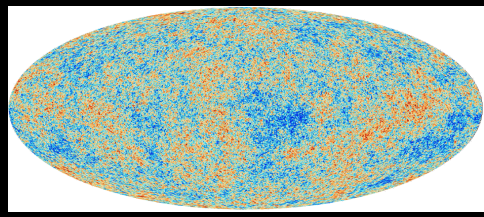
WASHINGTON (Reuters) - At a time when China is working on a ambitious lunar program, President Donald Trump vowed on Monday that the United States will remain the leader in space exploration as he began a process to return Americans to the moo

U.S. President Donald Trump holds a space astronaut toy as he participates in a signing ceremony for Space Policy Directive at the White House in Washington D.C., U.S., December 11, 2017. REUTERS/Carlos Barria

The future of cosmology

$N \sim 10^6$ modes: 0.1% CMB

Precision $N^{-1/.2}$



We must pursue B, we may get lucky!

$N \sim 10^8$

0.01% with galaxies

Much collateral information from deep surveys

$N \sim 10^{12}$

0.0001% with HI in 1st clouds

is in the dark ages