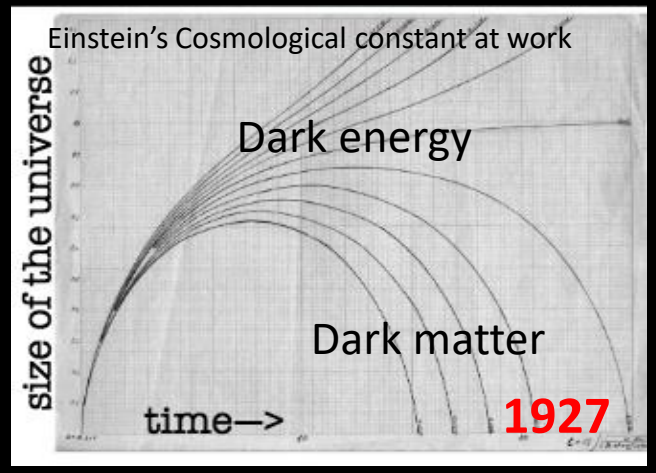
LUNAR COSMOLOGY

Joseph Silk

IAP, JHU, Oxford

The birth of modern cosmology

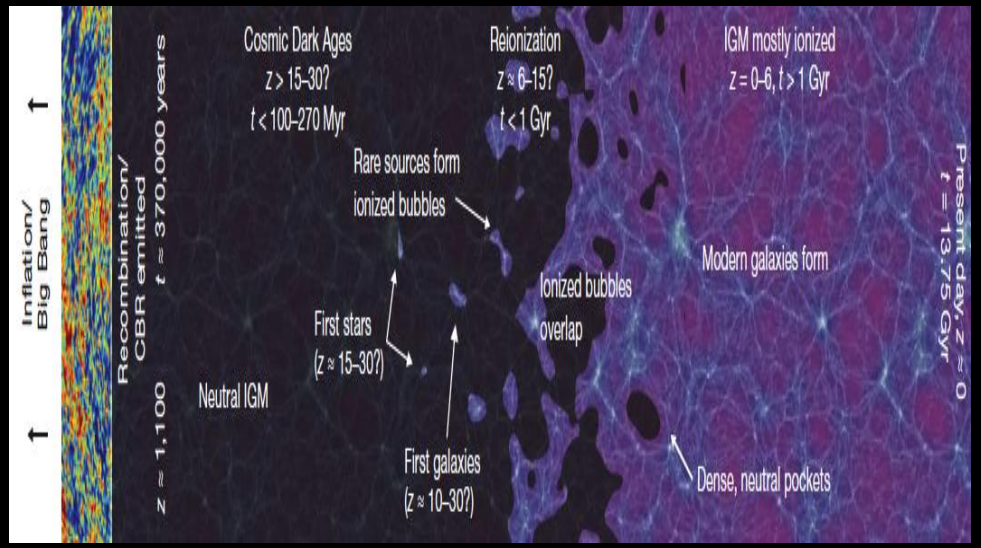

Georges Lemaitre



the energy *in vacuo* would be different from zero. In order that absolute motion, i.e., motion relative to vacuum, may not be detected, we must associate a pressure $p = -\rho c^2$ to the density of energy ρc^2 of vacuum. This is essentially the meaning of the cosmical constant λ which corresponds to a negative density of vacuum ρ_0 according to **1933**

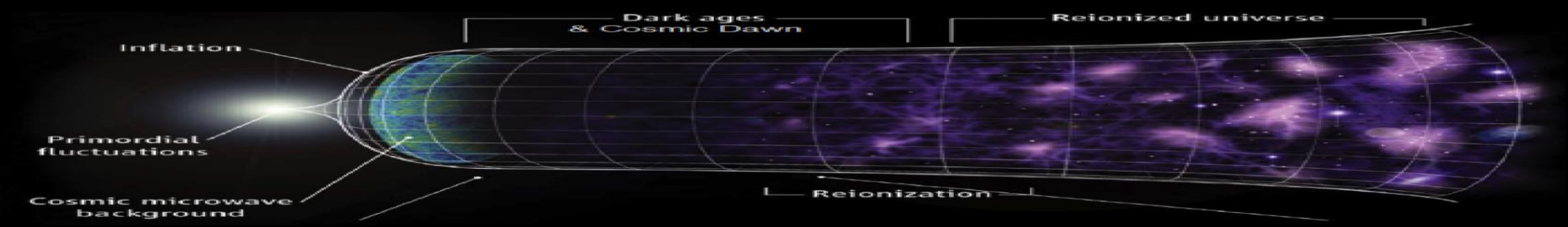
big questions

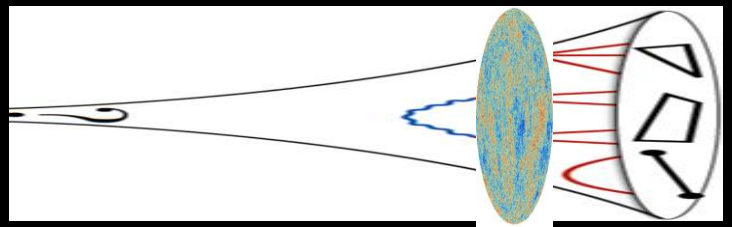
- The new frontier: before the first stars
- how did the big bang begin?
- Is new physics lurking somewhere?



Inflation

Our best theory needs verification

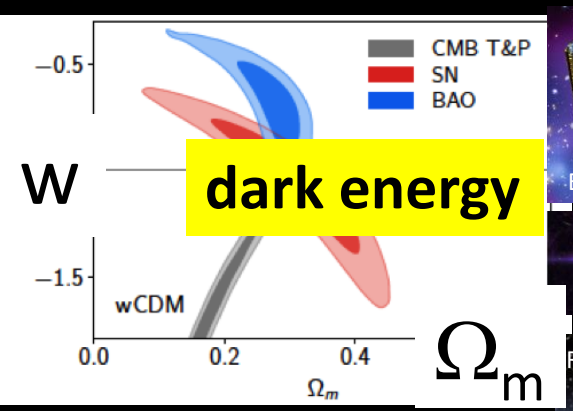


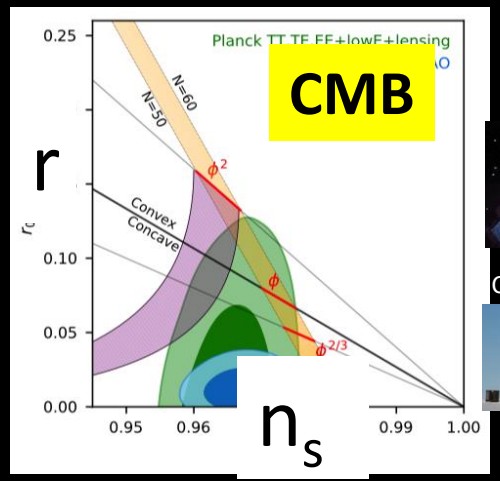


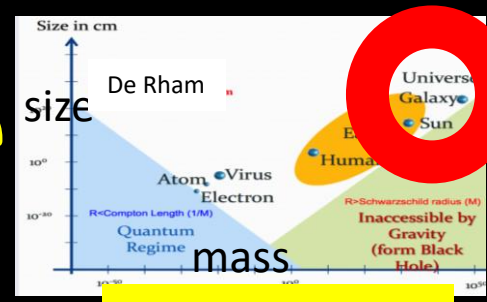
Dark matter? dark energy?
gravity wave background
galaxy formation
primordial correlations

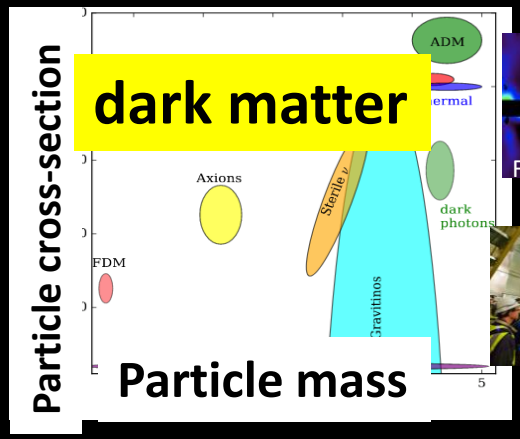
Direct detection
CMB tensor/scalar ratio
CMB spectral distortion

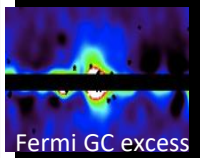
$\delta T/T\ (1+ f_{NL}\ \delta T/T)$



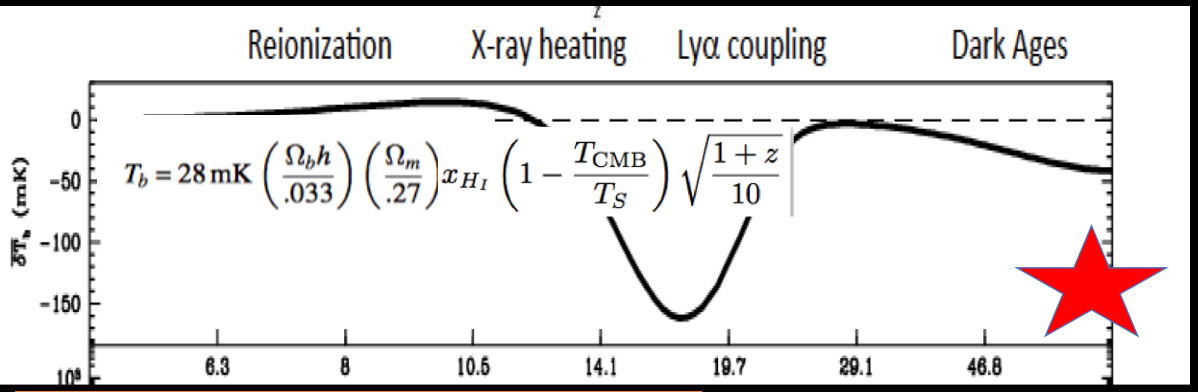




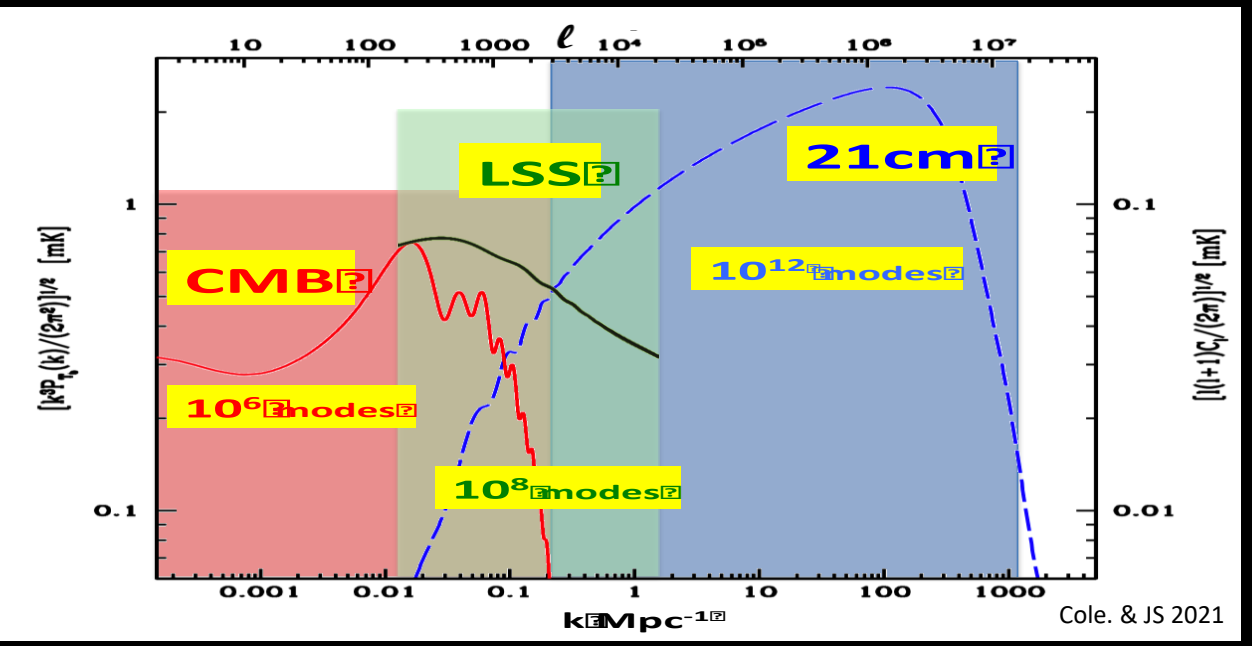




one common feature of all current or planned “cosmology” experiments:
no guaranteed return!



Dark ages in absorption



Cole. & JS 2021

Need compelling science

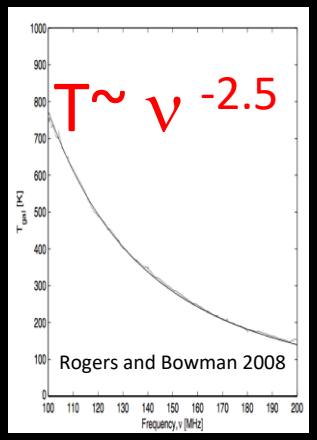
Dark ages is new frontier

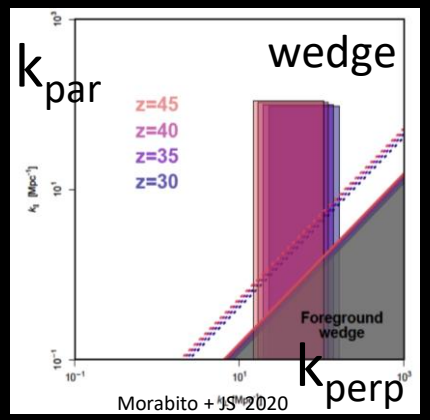
far side of MOON is most radio quiet environment in inner solar system @ 30 MHz no ionosphere

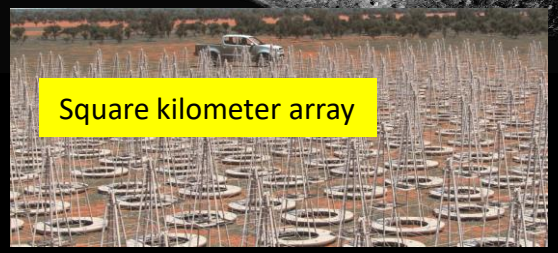
Lunar radio interferometer

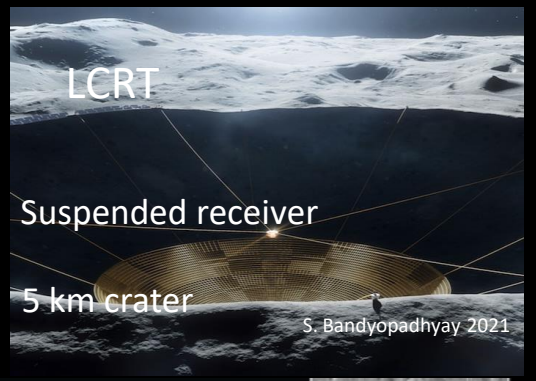
21cm: probe z=50 at λ~ 10 m
100 x CMB resolution $\ell \sim 10^5$ or k~ 10Mpc^{-1}
array $\ell\ \lambda/2\pi$ over D ~100 km + millions of 10 m dipo

only ~ 10mK signal in bright foreground





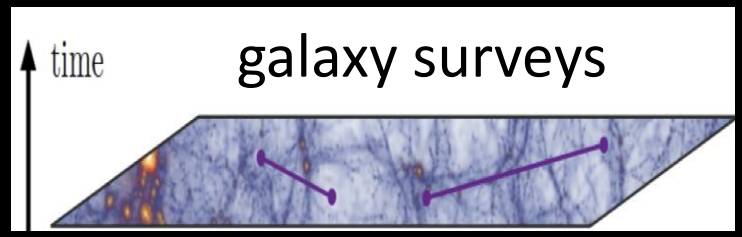




How to explore the dark ages

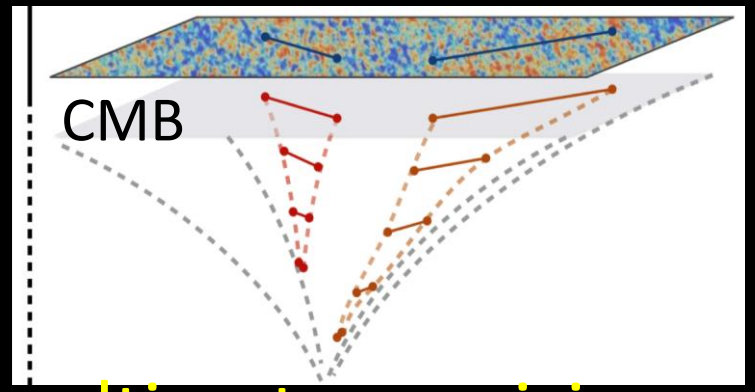
$\delta T/T\,(1+ f_{NL}\,\delta T/T)$ $f_{NL} \sim -5/12\,(n_s-1) \sim 0.01$ $n_s=0.96$ ($9\,\sigma$)

Maldacena 2003, Cabass + 2017; Mattarese + 2021



CMB modes	$N\sim10^6$	$f_{NL}\sim10$
Galaxy surveys	$N\sim10^8$	$f_{NL}\sim1$
21 cm $z \sim 50$	$N\sim10^{12}$	$f_{NL}\sim0.01$

dark ages 21cm



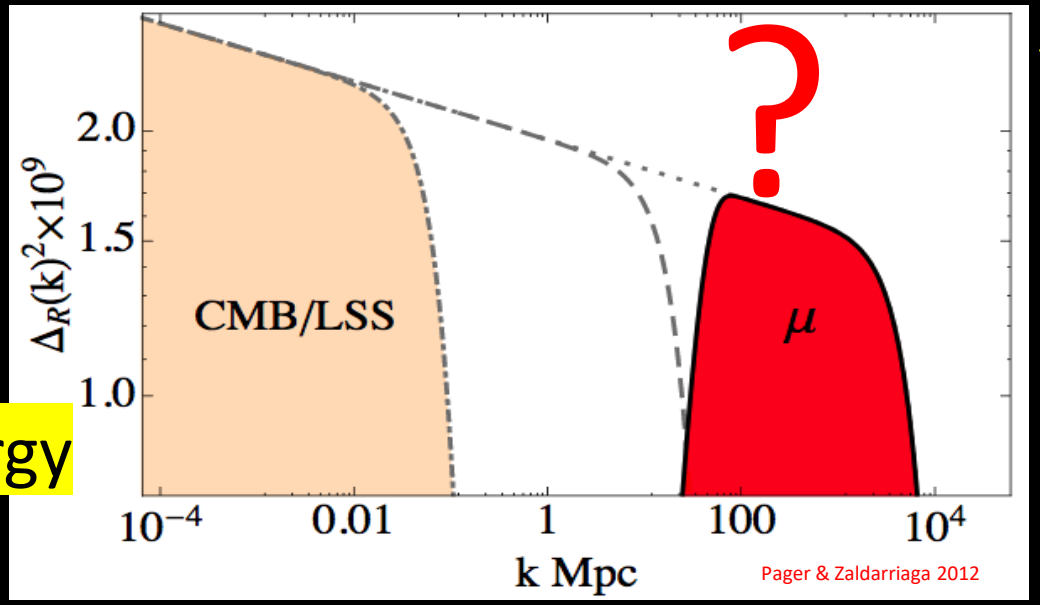
Test inflation via primordial nongaussianity: ultimate precision cosmology

Another frontier: the cosmic blackbody radiation

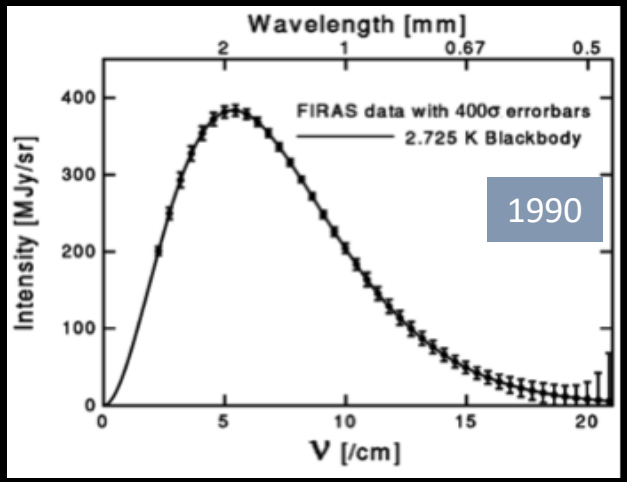
bottom-up formation is fundamental prediction of cold dark matter cosmology

It can't be a perfect blackbody!

The large-scale distribution of clusters and massive galaxies

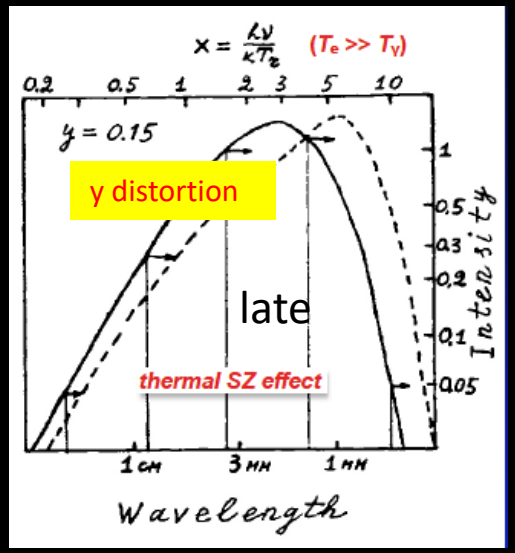


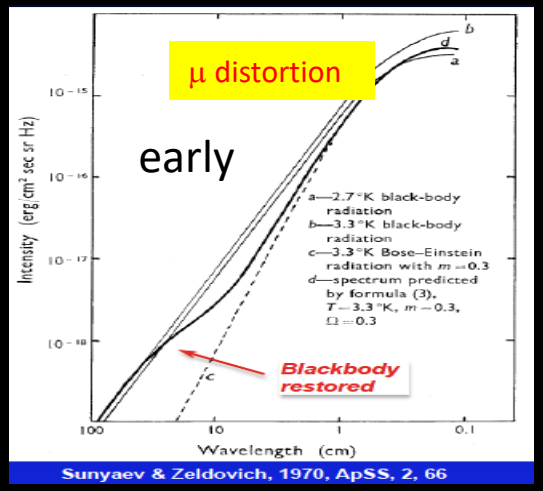
Bottom-up structure formation: the building blocks are dwarfs

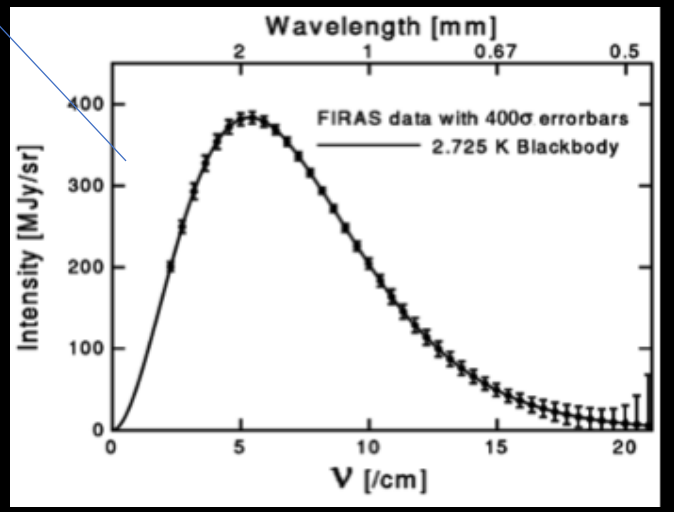


Friction of fluctuations against radiation in first months injects early energy

the most perfect blackbody is in the sky. Trillions of modes from dwarf galaxy precursors injects early energy -> spectral distortions





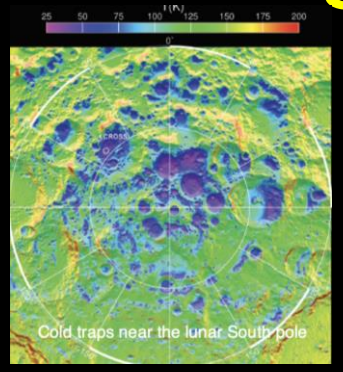


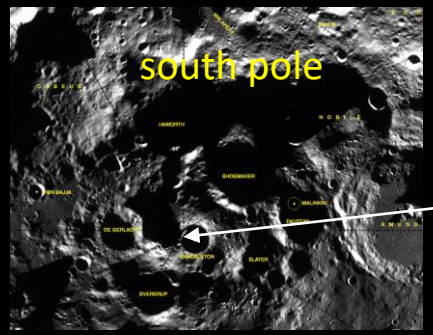
$T_0 = 2.725 \pm 0.001\,\mathrm{K}$

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

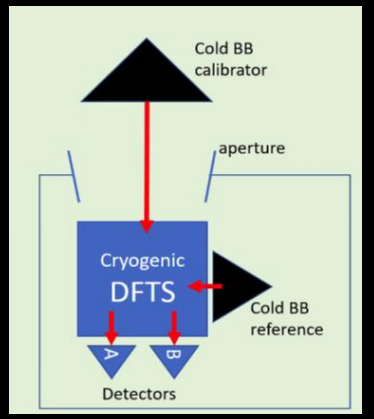
$|\mu| \leq 9\times10^{-5}$

look again with a FIR spectrometer

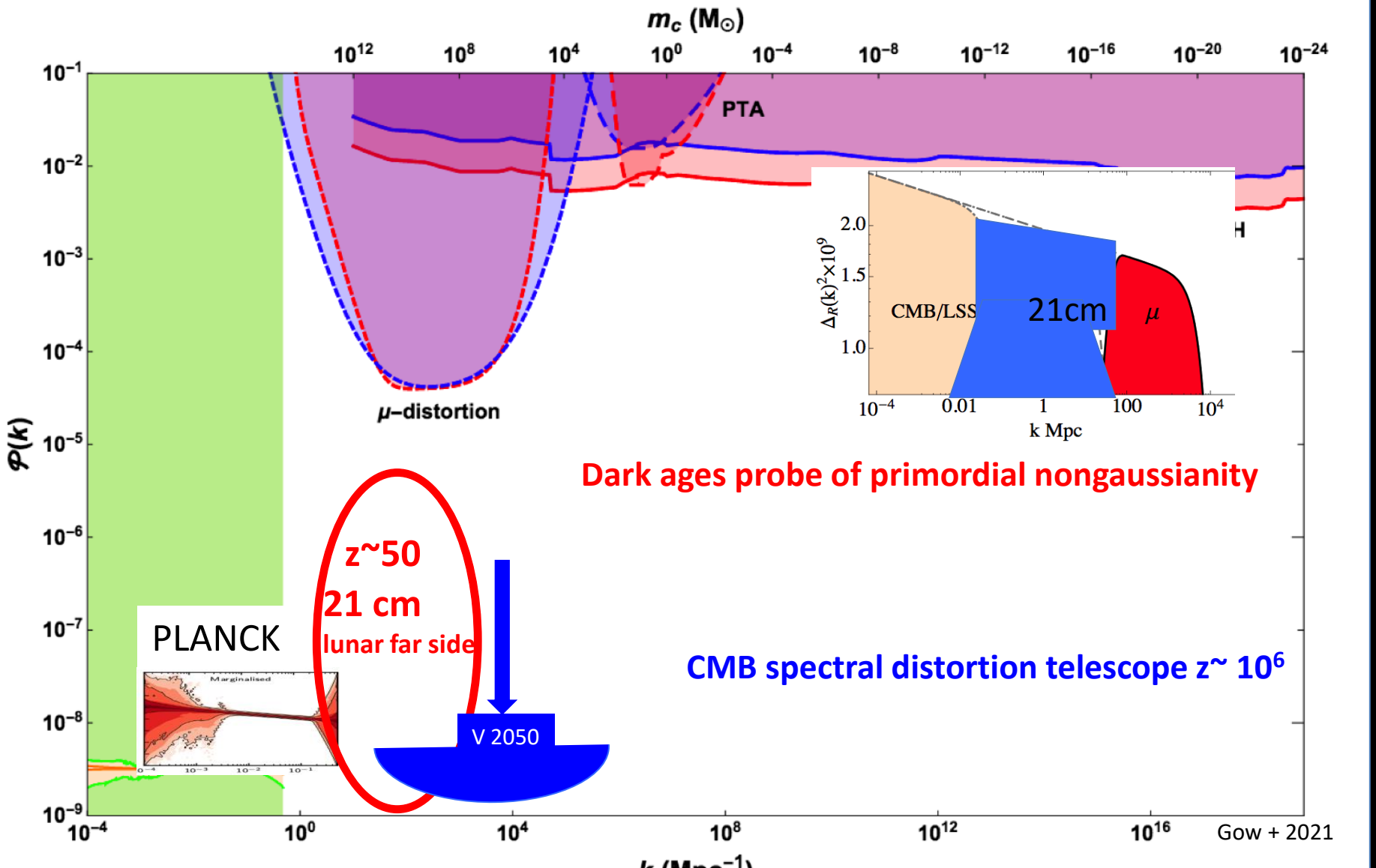




Fourier transform interferometer
90--2000 GHz bolometer array
In a ~30K permanently dark crater
1.5 m telescope cooled to 2.5 K.
Scan sky by lunar rotation
Sunlit rims for solar power



Putting it all together



Gow + 2021

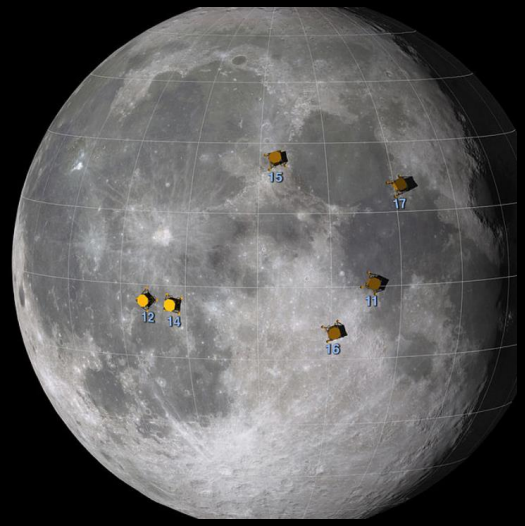
Compelling science

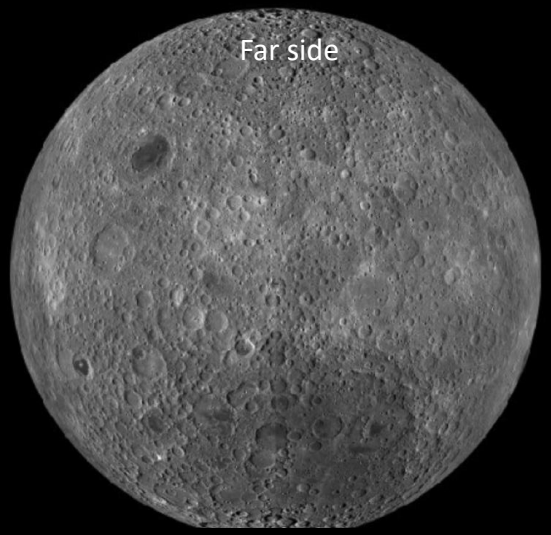
probe dark ages by radio astronomy

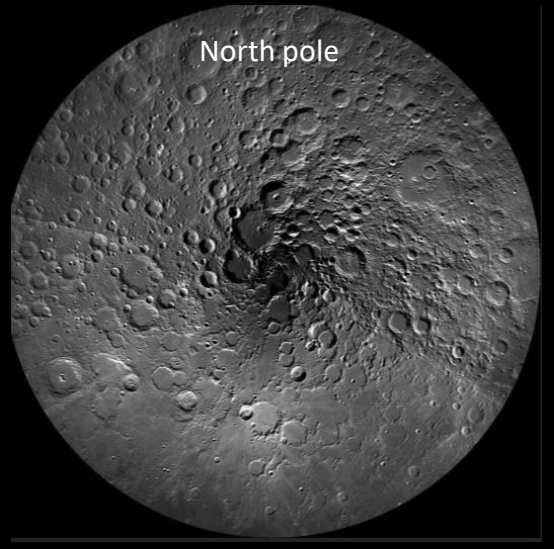
far side of MOON is most radio-quiet environment in inner solar system, no ionosphere

CMB spectral distortions, far infrared astronomy

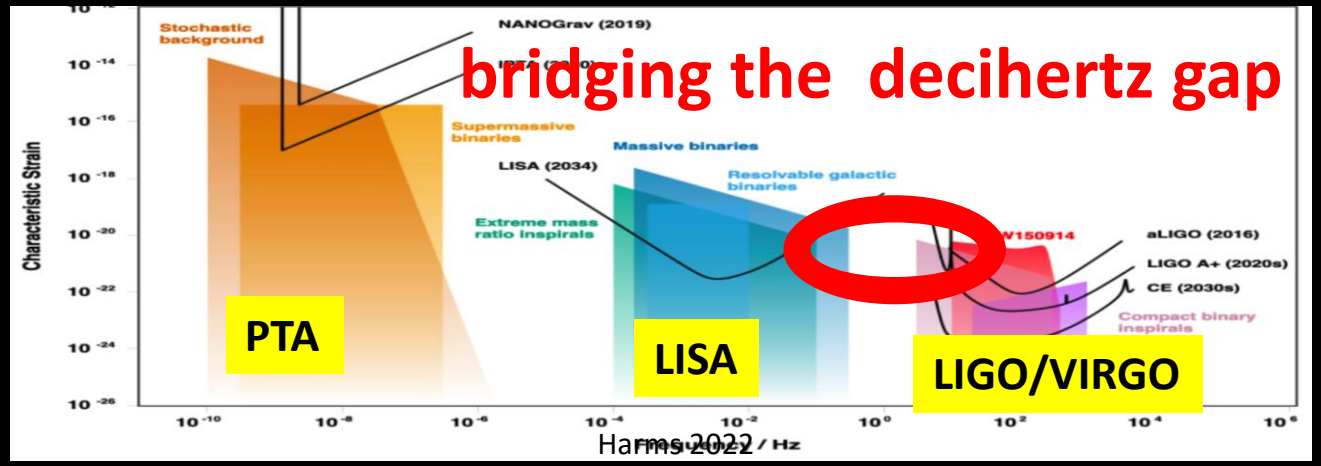
With perpetual solar power availability and permanent cold/darkness, no atmosphere



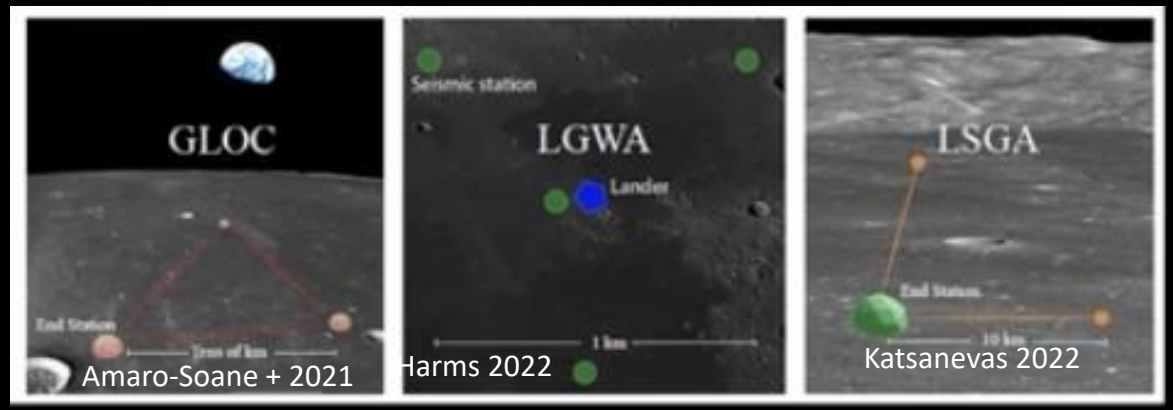




seismologically quiet

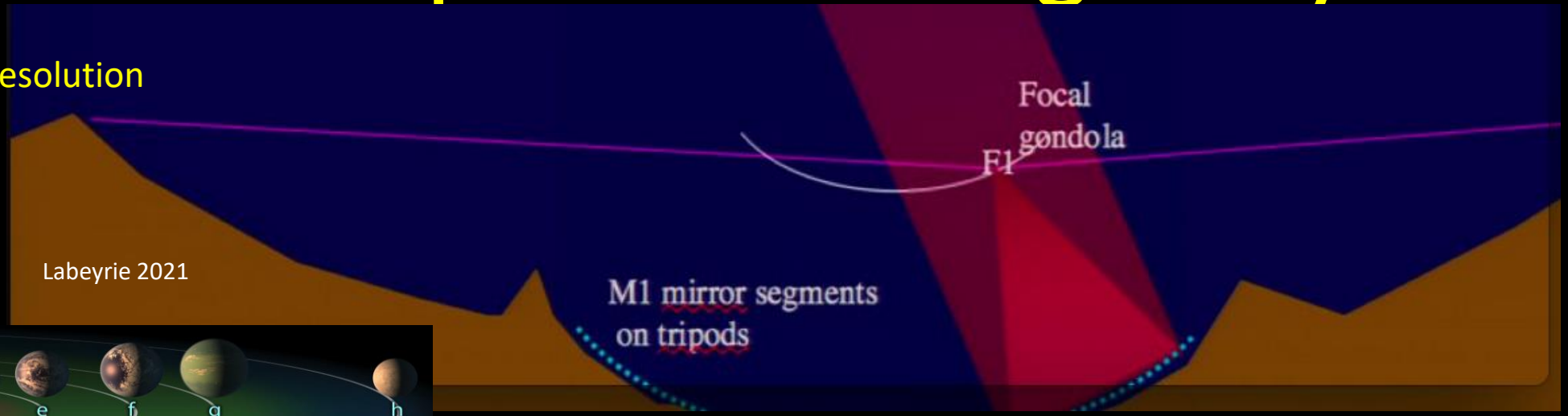


bridging the decihertz gap



no atmosphere + low gravity

telescope size counts
numbers of candidates and resolution



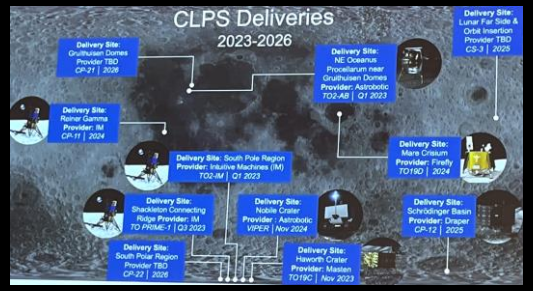
Labeyrie 2021

a current renaissance in lunar science projects

- NASA CLPS

https://www.nasa.gov/content/commercial-lunar-payload-services

3 low frequency radio projects planned by 2028



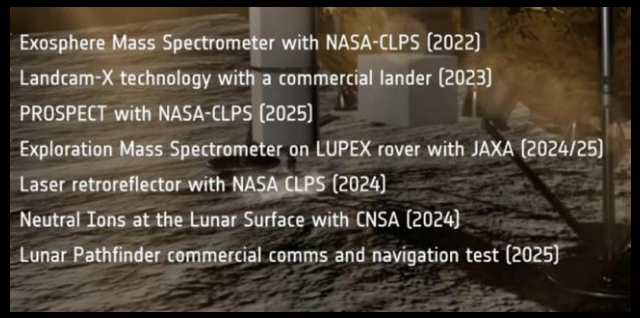
CLPS Providers

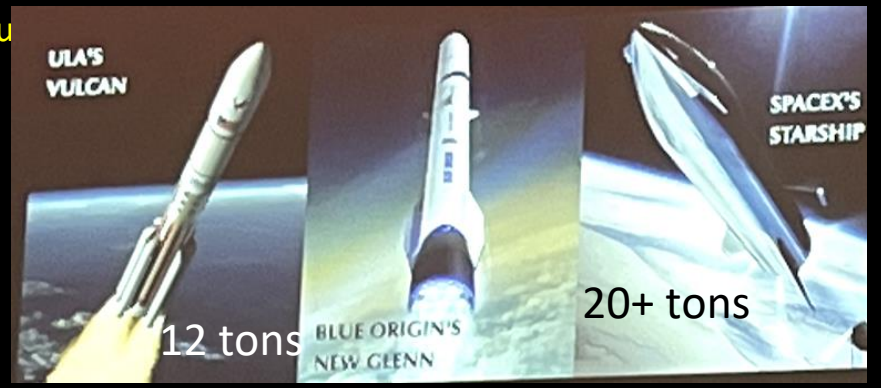
Astrobotic Technology | Blue Origin | Ceres Robotics | Deep Space Systems | Draper | Firefly Aerospace | Intuitive Machines | Lockheed Martin Space | Masten Space Systems | Moon Express | Orbit Beyond | Sierra Nevada Corporation | SpaceX | Tyvak Nano-Satellite Systems

- ESA Argonaut lunar lander/Terrae Novae

https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/Argonaut_Eu

- Launcher Ariane 64
- Launch Site Kourou, French Guiana
- Mass of delivered cargo 1500 kg
- Size 4.5 m in diameter, up to 6 m tall



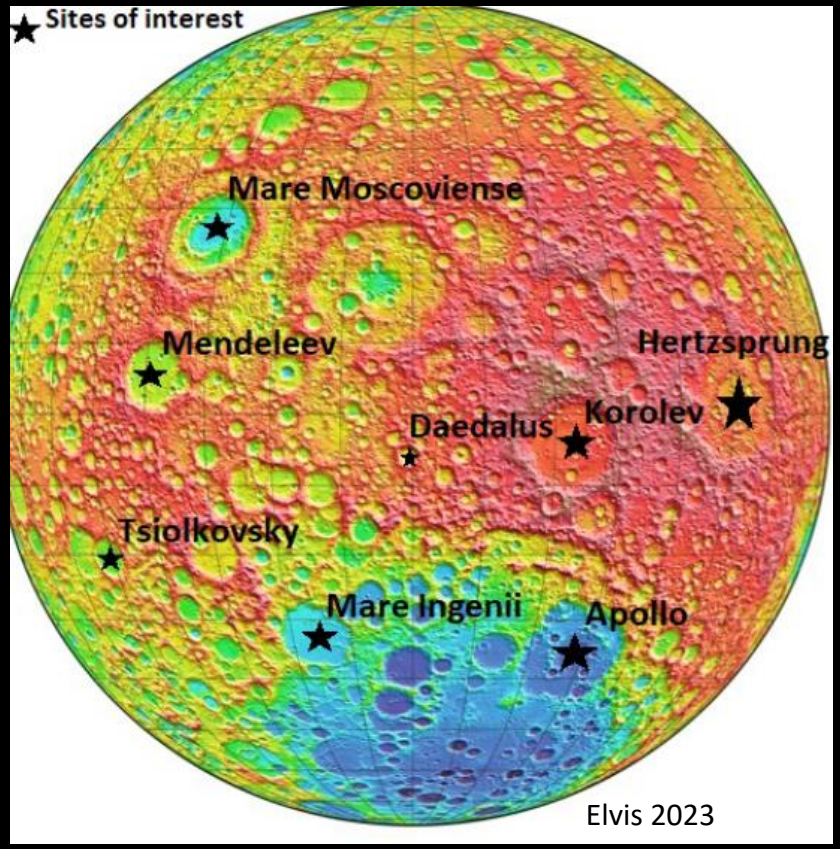


Elon Musk says he's 'highly confident' that SpaceX's Starship rocket launches will cost less than $10 million within 2-3 years

Beware:
the number of suitable sites is limited

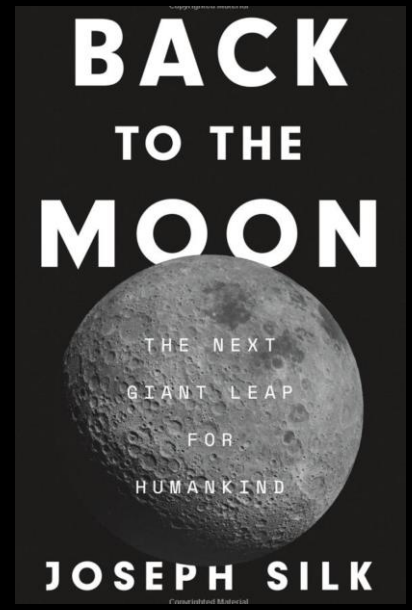
RADIO FAR SIDE
5-50 km scale
smooth
mild slopes
far side for low terrestrial interference

GRAVITY WAVE/FIR
Permanently shadowed polar craters
cold to very cold
low water content
High rims for solar. powe



Back to the Moon!

Lunar renaissance underway



Space-like environment

Radio astronomy at low frequencies
Far infrared at terahertz
Optical/IR at high resolution
Gravity waves at decihertz

Now is the time!

The future of cosmology
The future of astronomy

What were our cosmic origins?

Are we alone?