Lunar Cosmology Dipole Explorer (LCoDE): Measuring the Global 21-cm Signals from the First Stars & Galaxies in the Early Universe

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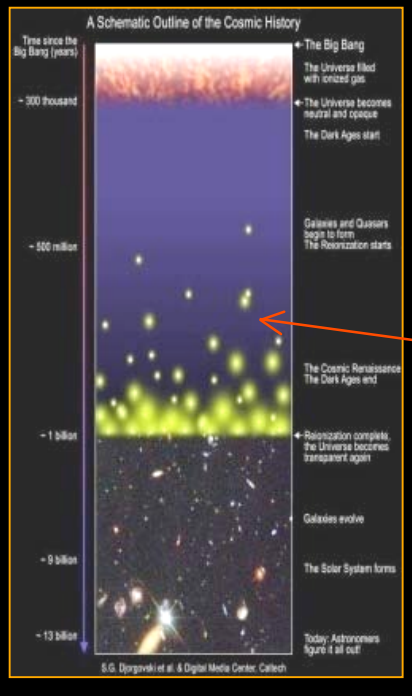
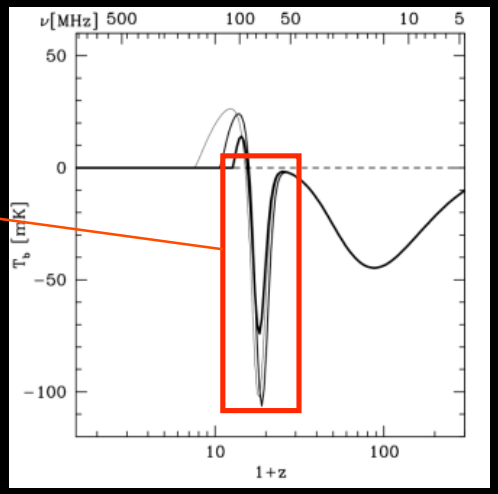
Mission Concept

Lunar Cosmology Dipole Explorer (LCoDE)

- Key Science: Detect (highly redshifted) H I signal from intergalactic medium from the time of the first stars & possibly the Dark Ages at $\nu < 100$ MHz.
- Single (dual-polarization) dipole on orbiting spacecraft.





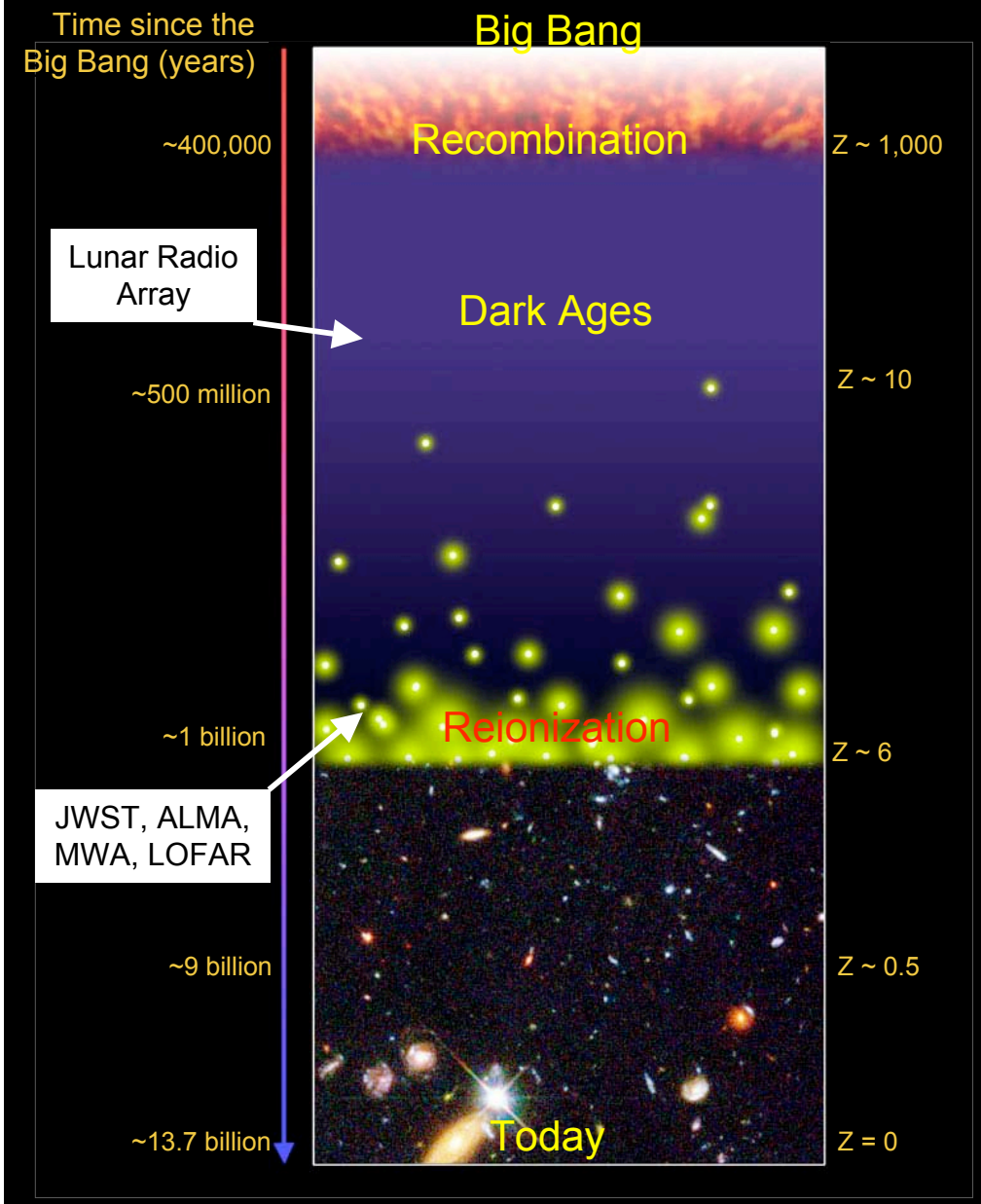
Science Package and Requirements

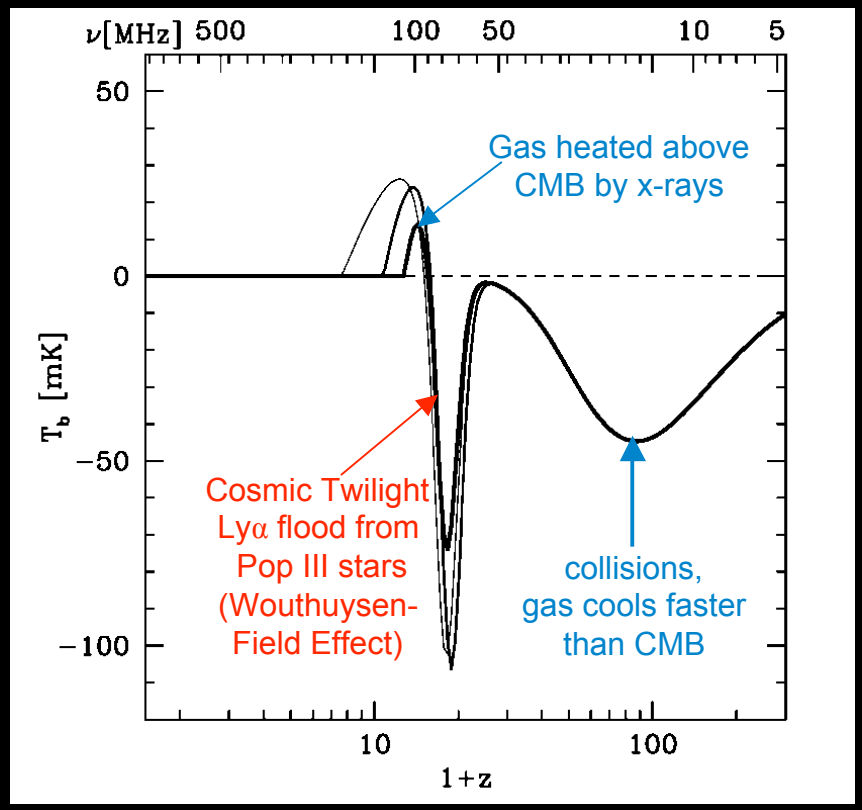
LCoDE

- Orbit with maximal duration behind Moon, in shielded zone.
- Single dual-polarization dipole and receiver.
- Frequency range: ≈20–100 MHz.
- High-speed, low-bit depth sampling.
- High Technical Readiness Level (TRL >6) components.
- <2 kg mass; <2 W power.

Reionization and the Dark Ages

$$\delta T_b(z) \approx 23\,(1+\delta)\; x_{HI}\,(1-T_{CMB}/T_S)\,(50\,\Omega_B\,h^2)\,[(0.15\,\Omega_M^{-1}\,h^{-2})\,((1+z)/10)]^{1/2}\ \mathrm{mK}$$

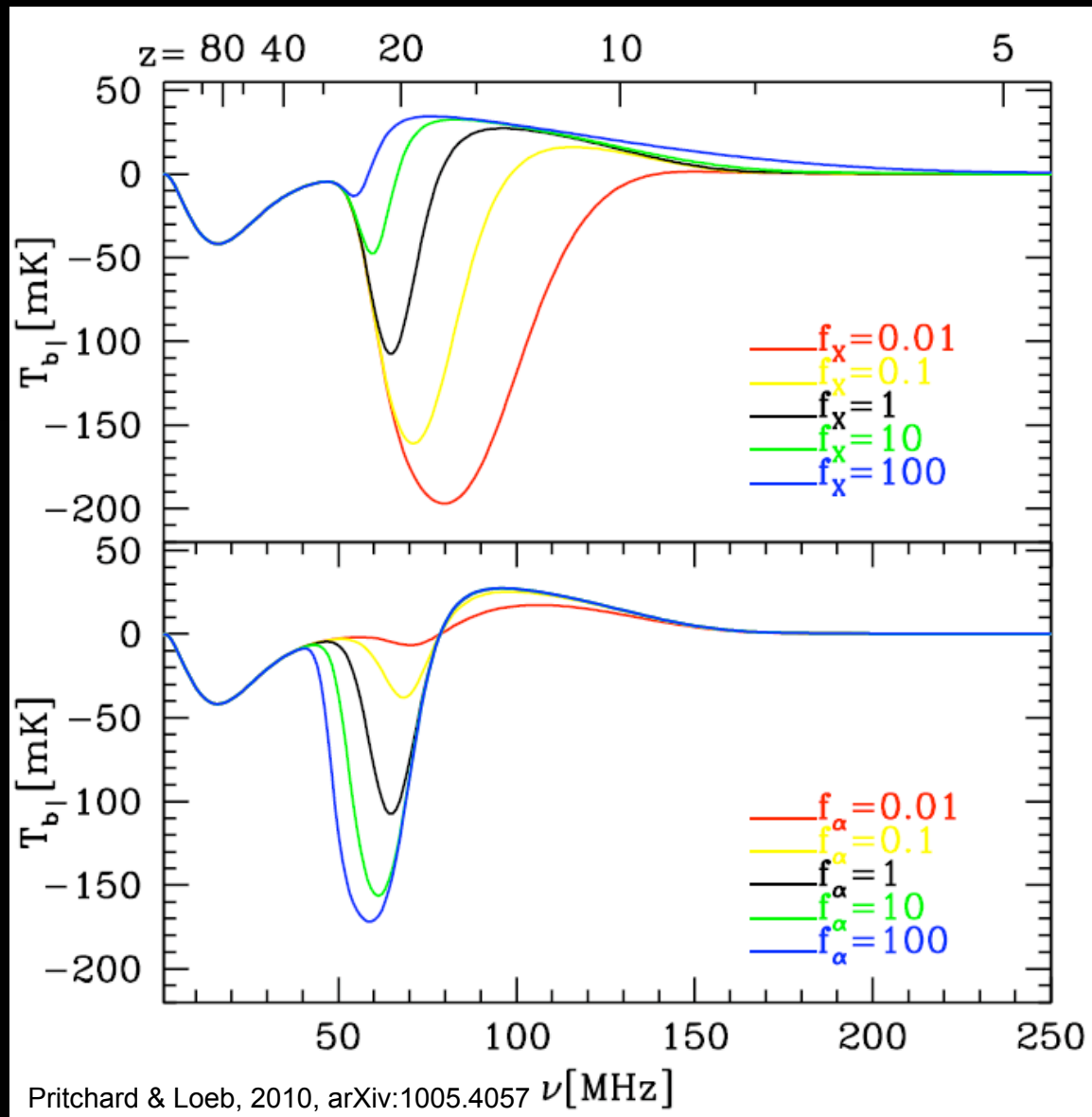




Pritchard & Loeb, 2009, Phys. Rev D, 78, 103511

21 (1+z) cm = 1420/(1+z) MHz
at z=10, λ = 2.3 m (130 MHz)
at z=50, λ = 10.7 m (30 MHz)

The Global (sky-averaged) HI Signal

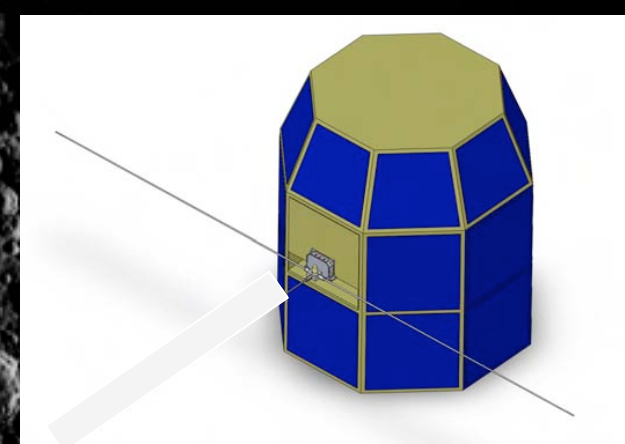


Pritchard & Loeb, 2010, arXiv:1005.4057

Global signal can be detected by single dipole in orbit above lunar farside!

$$\Delta T_{min} = T_{sys}/(\Delta\nu \cdot t)^{1/2}$$

where T_{sys} = sky temperature



Lunar Advantage: No Interference!

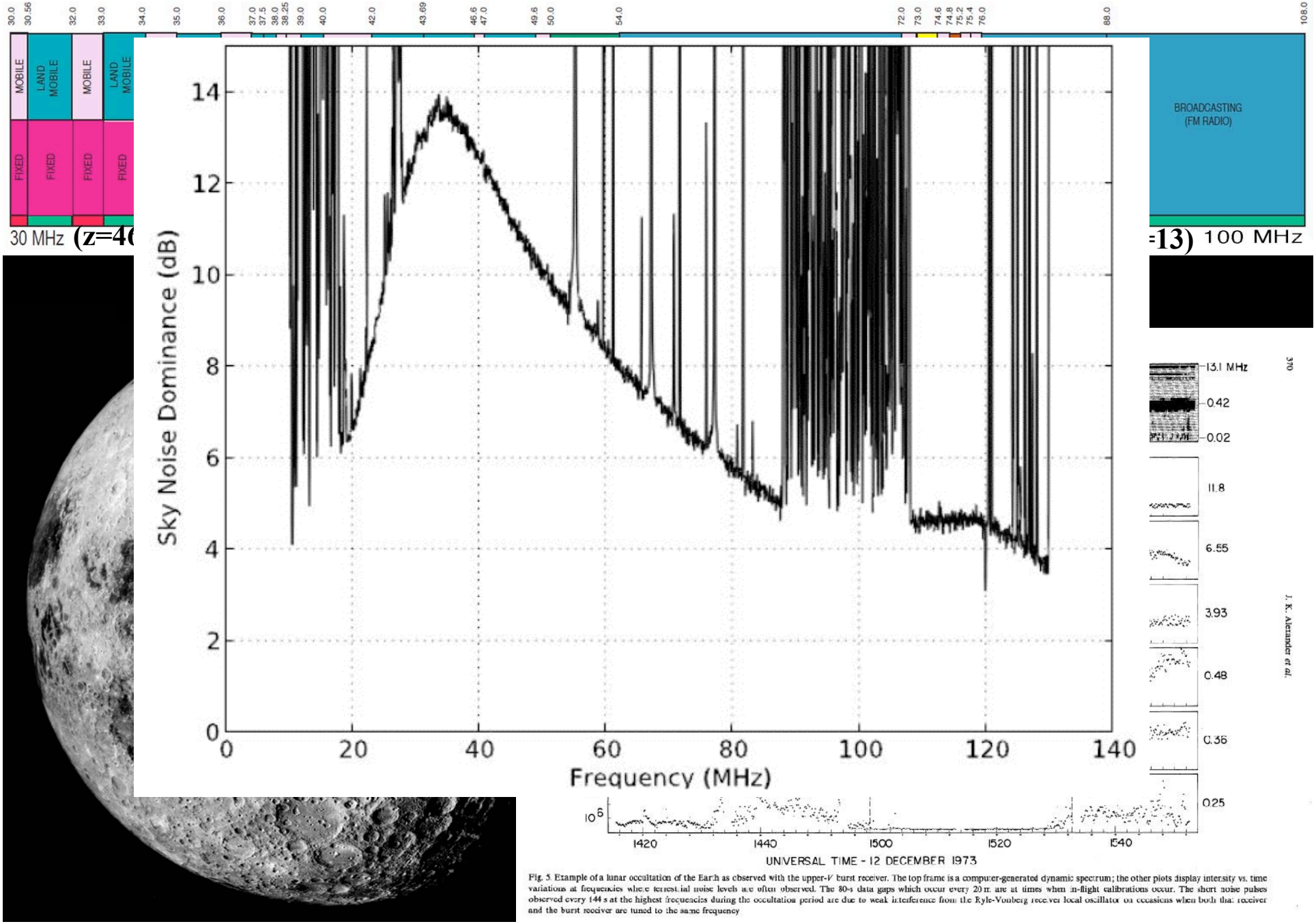


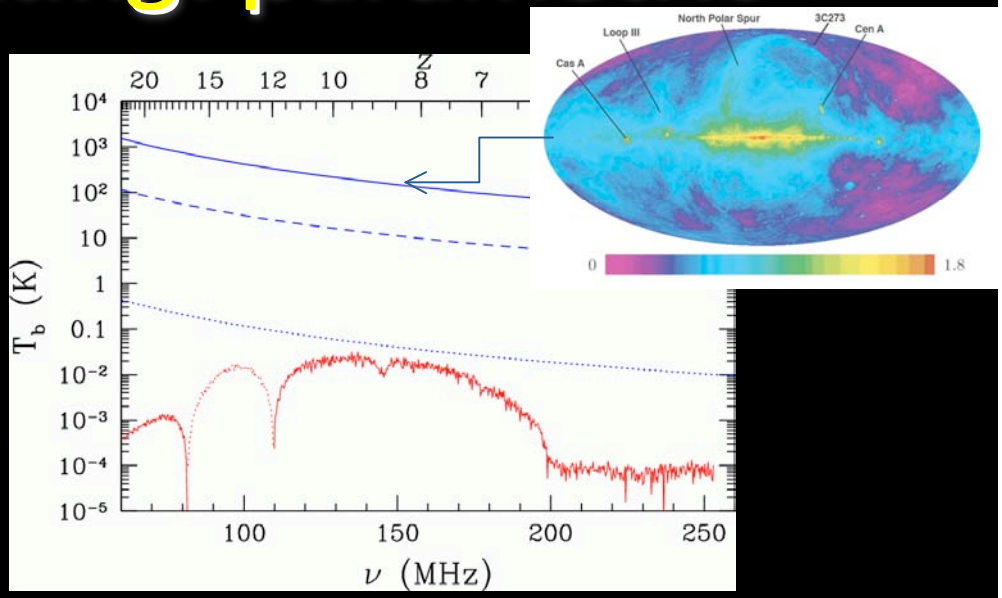
Fig. 5. Example of a lunar occultation of the Earth as observed with the upper-V burst receiver. The top frame is a computer-generated dynamic spectrum; the other plots display intensity vs. time variations at frequencies where terrestrial noise levels are often observed. The 80-s data gaps which occur every 20 m are at times when in-flight calibrations occur. The short noise pulses observed every 144 s at the highest frequencies during the occultation period are due to weak interference from the Ryle-Vonberg receiver local oscillator on occasions when both that receiver and the burst receiver are tuned to the same frequency

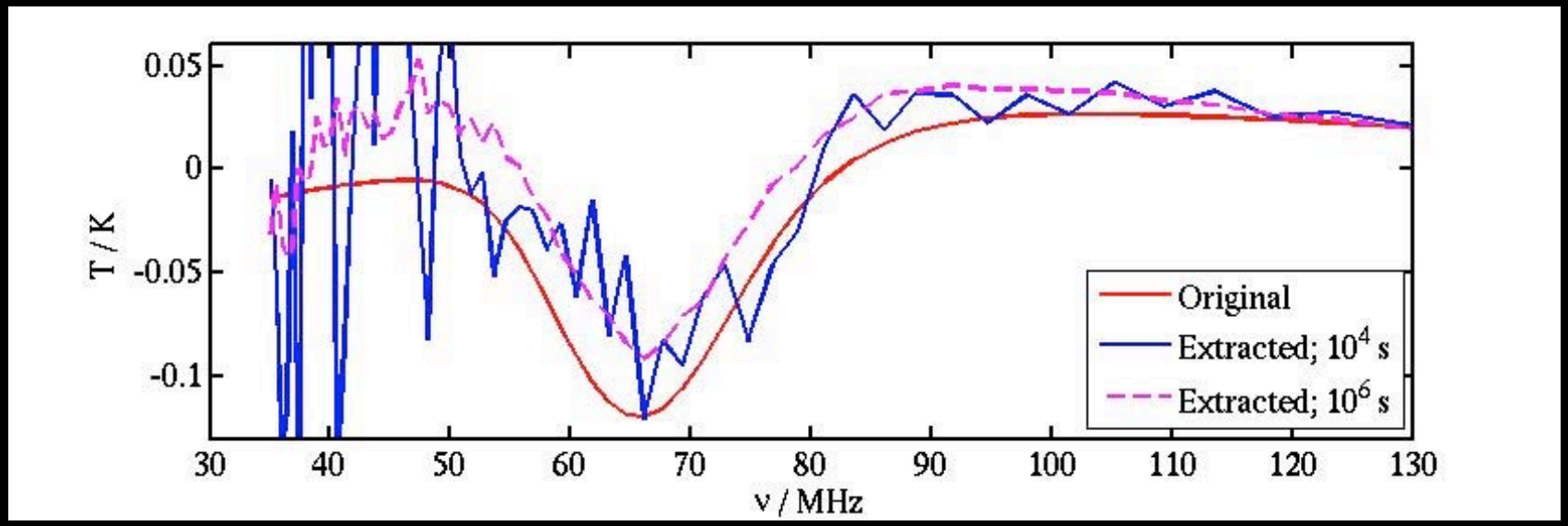
Advantages of the Lunar Farside

- No interference from the Earth.
- Very low density ionosphere ($\nu_p < 1$ MHz).
- Significant times when the Sun, Jupiter, and Galactic Center are occulted.
- The Moon as a calibration source:
  - A limitation of EDGES (ground-based Dipole) is that the dipole's frequency response is uncalibrated.
  - The Moon is a potentially strong calibration source ($T_B \approx 220$ K), which is important in removing foregrounds.

Foreground fitting: parametric

- Detection may be possible in 10^4s; longer times can give position and shape of trough.
- But, expect duty cycle of ≈20%.
- Thermal noise not limiting: may be able to concentrate on cooler areas of sky to improve fitting.



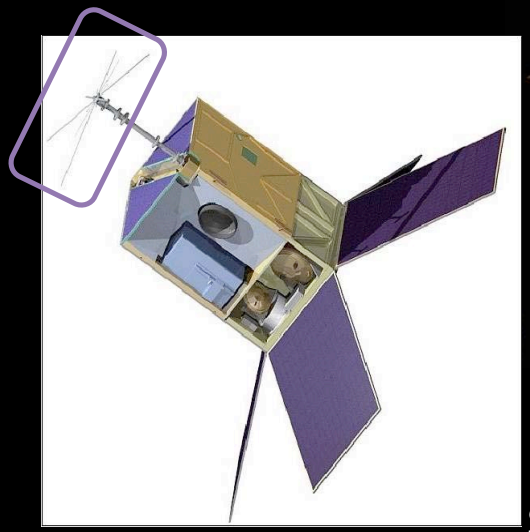


From G. Harker, 2010

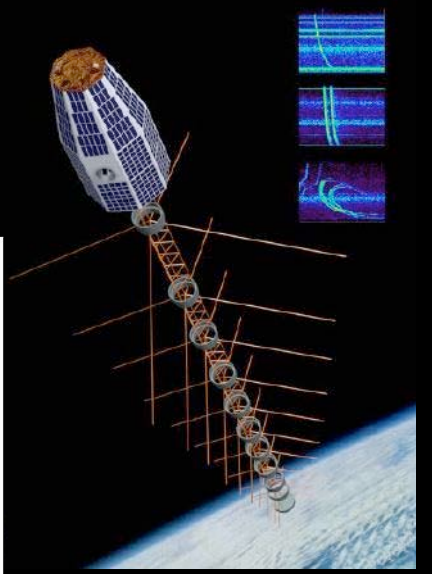
LCoDE Antenna

TRL = 6+

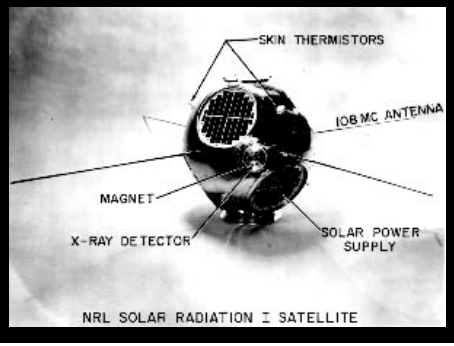
- RF antennas for spacecraft well developed technology
- Many deployed antennas probably *more* complicated than needed



STPSat-1/CITRIS (NRL)



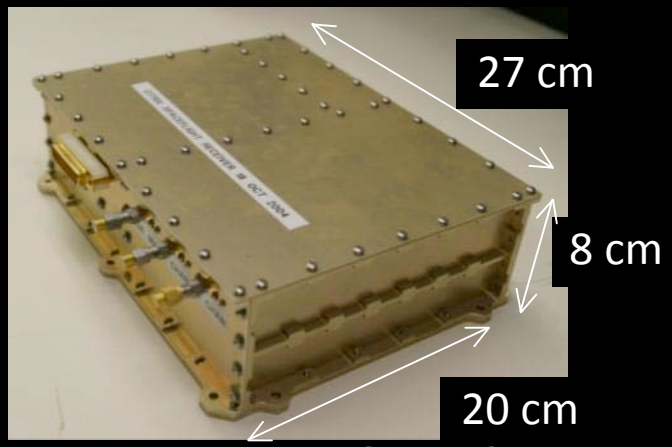
FORTE satellite (LANL)



SOLRAD/GRAB (NRL)

LCoDE Receiver

- TRL = 6+
  - Frequency range: 20–100 MHz
  - Many spacecraft Rx's in this range
- Illustration: NRL CITRIS
  - *4-channel receiver*
  - SWaP reduction possible for single channel system!
- High-speed, low-bit depth sampling



Example: NRL CITRIS Rx

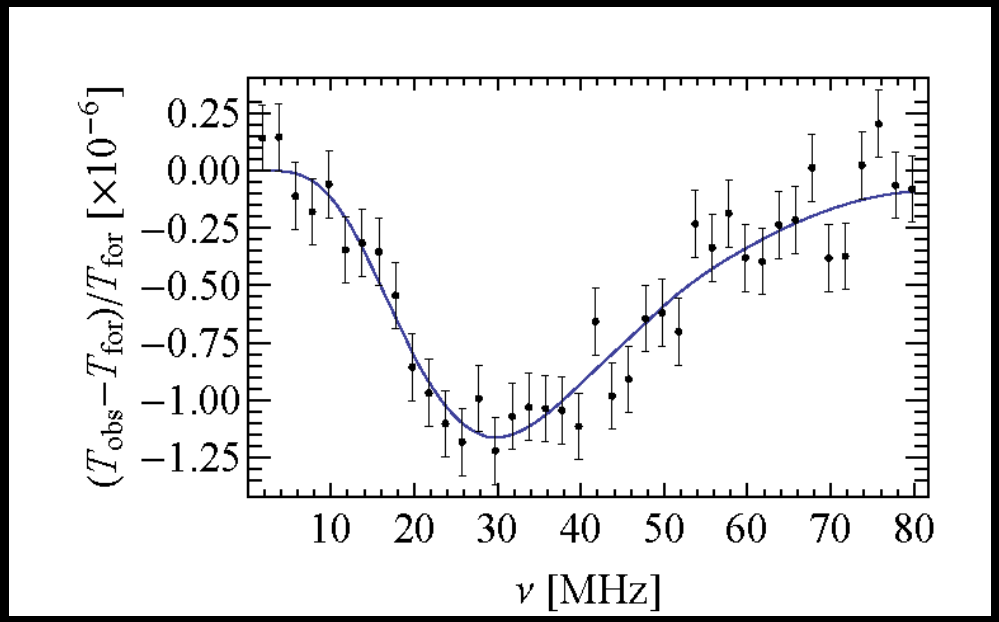
Lunar Cosmology Dipole Explorer Summary

Subsystem*	Mass (kg)	Power (W)	Form	TRL
Antenna/Deploy	1	…	2" × 2" × 2"	6+ (FORTE, CITRIS, THEMIS, STPSat-1, …)
Receiver	1.5	2	12" × 12" × 2"	6+ (FORTE, CITRIS, STPSat-1, …)

*Does not include data storage unit.

Can We Observe the Dark Ages?

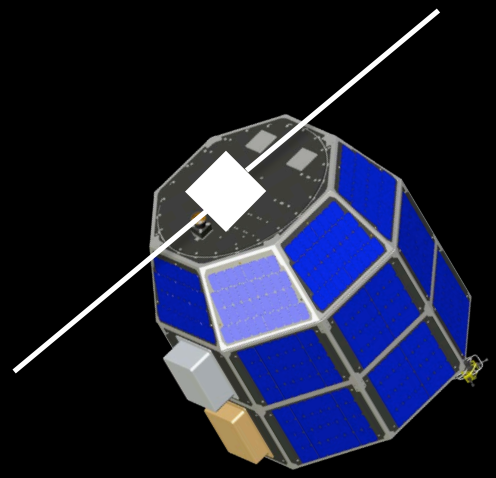
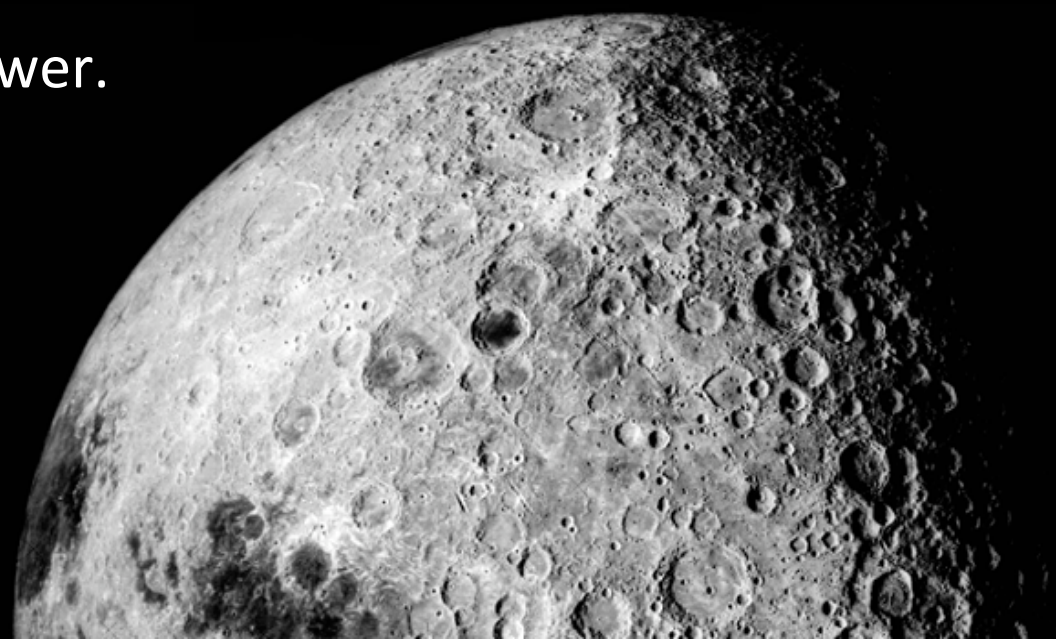
- At z>30, absorption trough is broad & featureless if due only to cosmology.
- However, there may be exotic physics such as Dark Matter decay or evaporating black holes.
- Foregrounds are very large at these frequencies (17,000 K) so superb instrumental calibration will be required.



Jester & Falcke, 2009, ***New Astronomy Reviews***

Summary

Lunar Cosmology Dipole Explorer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