The Radio Quiet Environment Above the Lunar Farside and its Application to 21-cm Experiments

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and Space Science

University of Colorado
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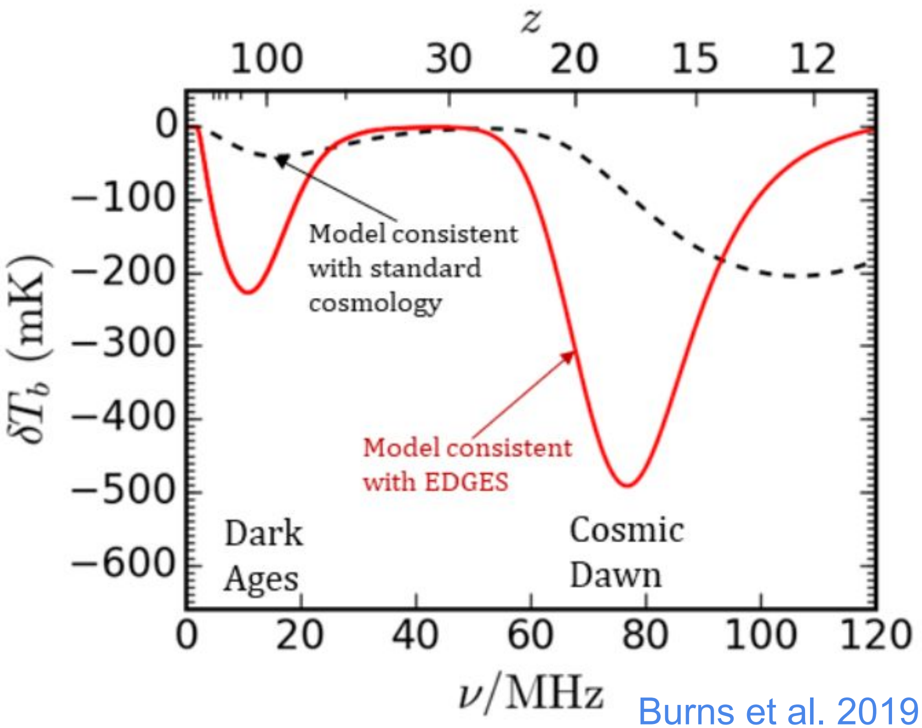
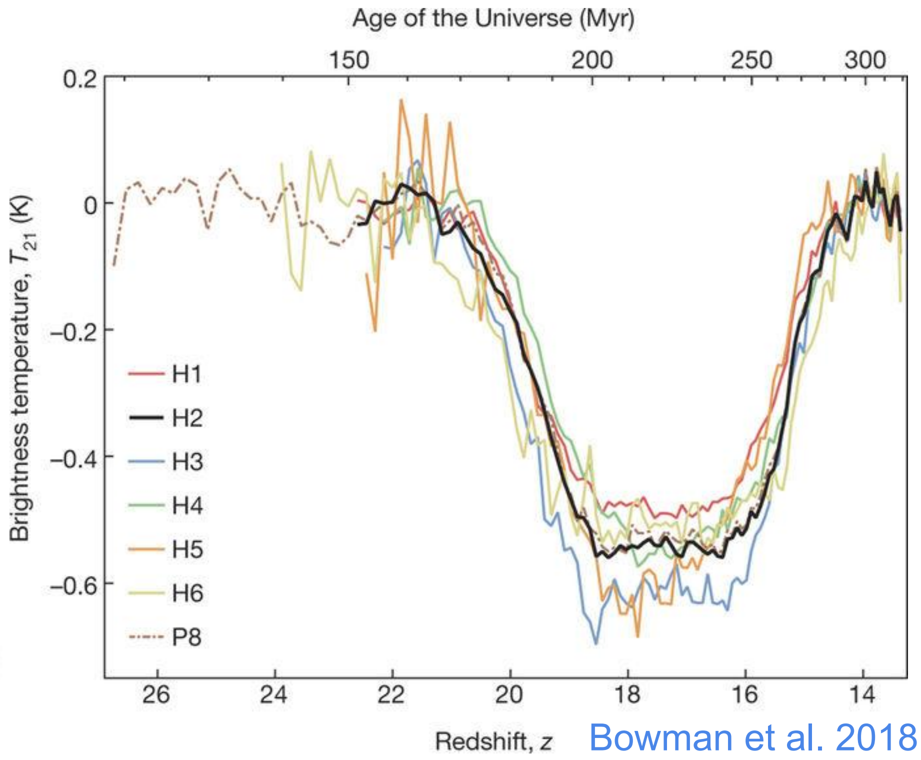
21-cm Hydrogen Cosmology



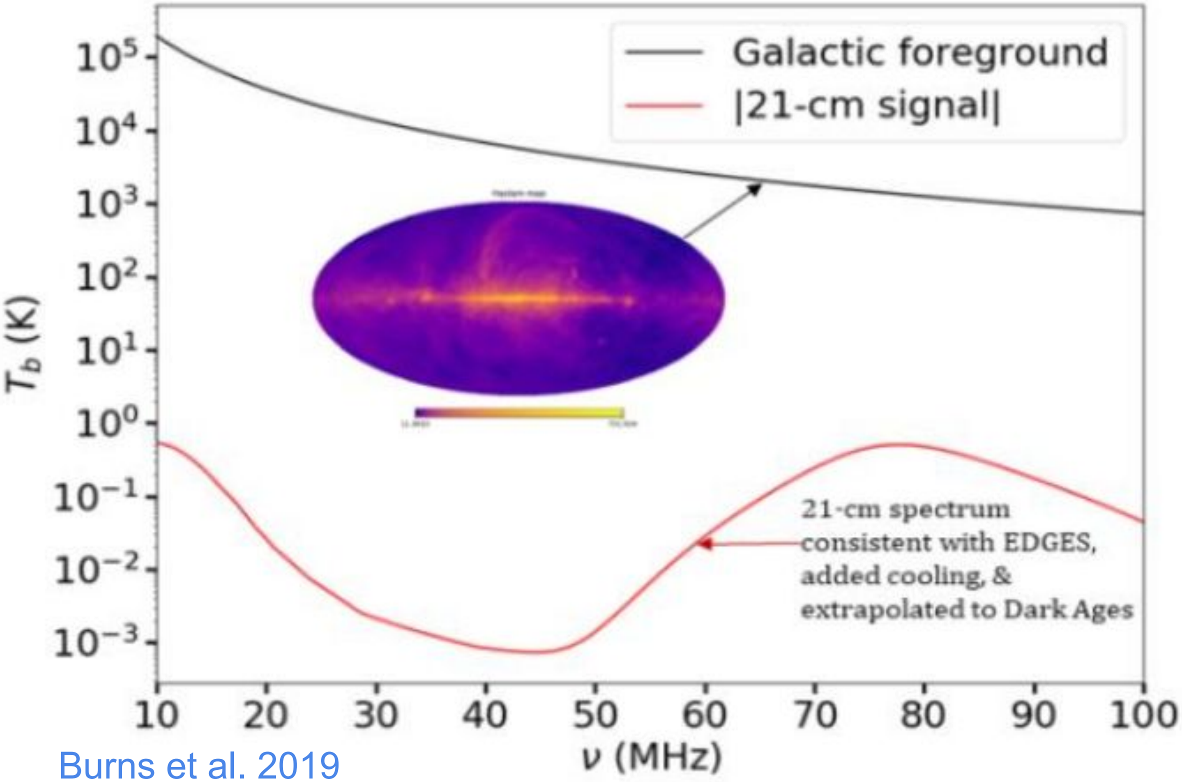
Burns et al. 2019



Bowman et al. 2018

- Left: The redshifted 21-cm spectrum provides information about the universe during the Dark Ages and Cosmic Dawn
- Right: Reported measurement of 21-cm Cosmic Dawn absorption trough centered at 78 MHz reported by EDGES

Observational Difficulties



Burns et al. 2019

Foreground Characteristics

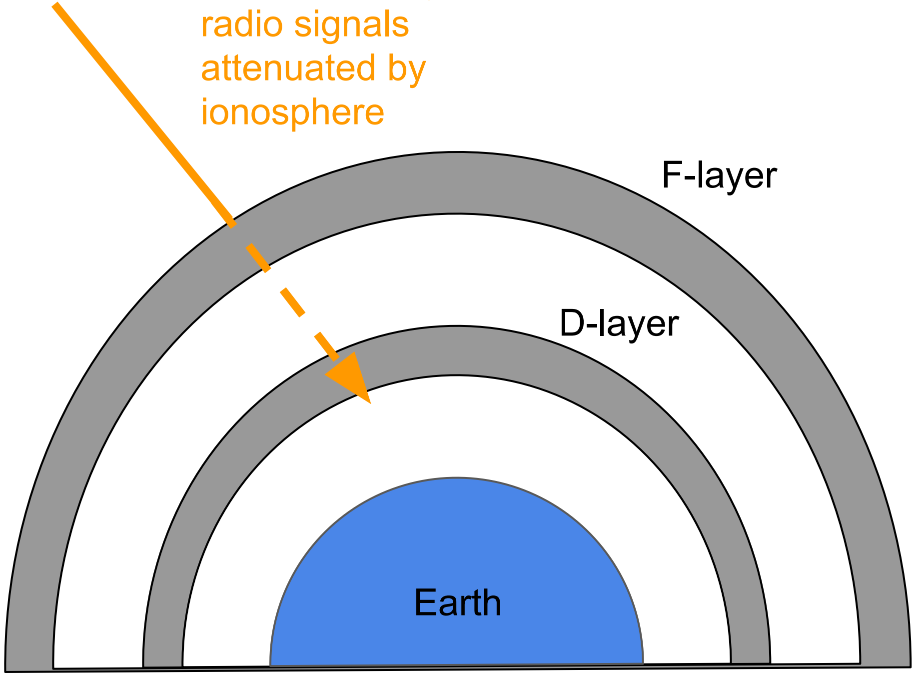
- Spectrally smooth
- Spatial structure
- Polarized

Signal Characteristics

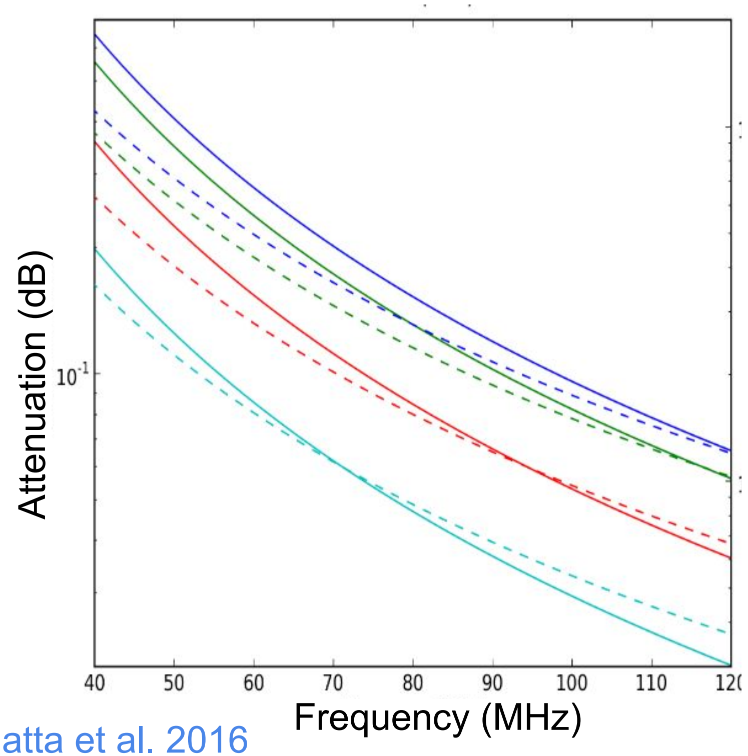
- Spectral structure
- Isotropic
- Unpolarized

- The 21-cm spectrum must be observed through extremely bright foregrounds
- Differences in foreground and 21-cm spectrum can be leveraged to extract cosmological signal

Ionospheric effects



Low frequency radio signals attenuated by ionosphere

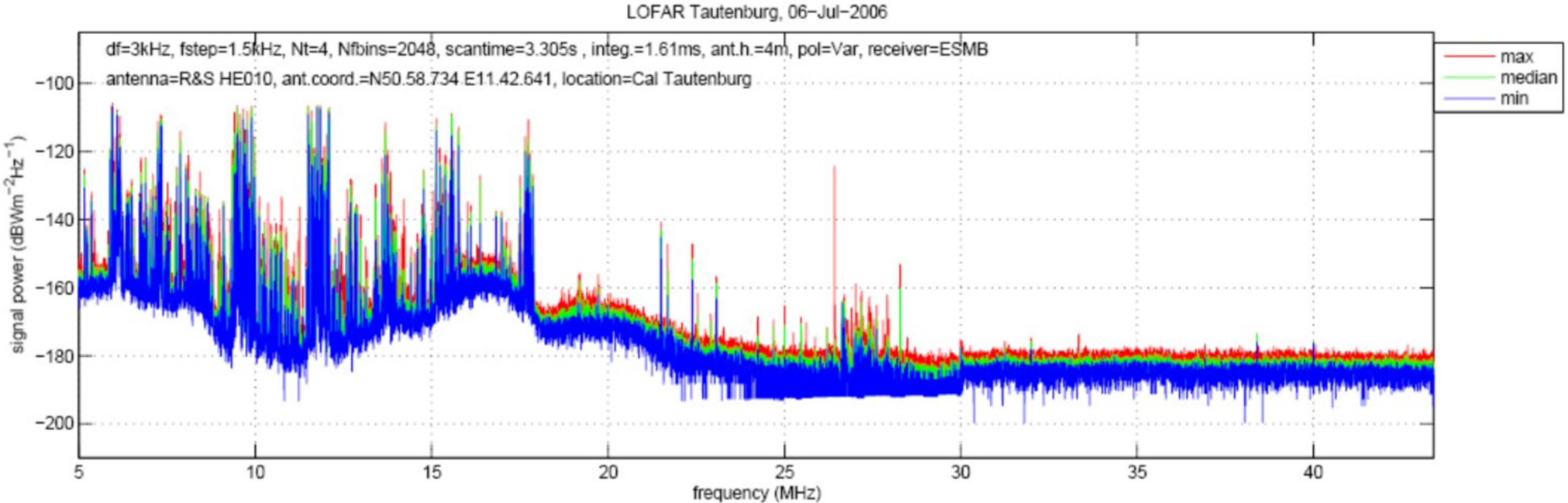


Datta et al. 2016

- Right: Ionospheric attenuation as a function of frequency for four different Total Electron Content (TEC) values

Observations below ~30 MHz must be performed above Earth’s ionosphere to avoid corruption of 21-cm spectrum

Earth-based Radio Frequency Interference (RFI)



Bentum & Boonstra 2011

Even above ionosphere, terrestrial communications may interfere with low frequency measurements

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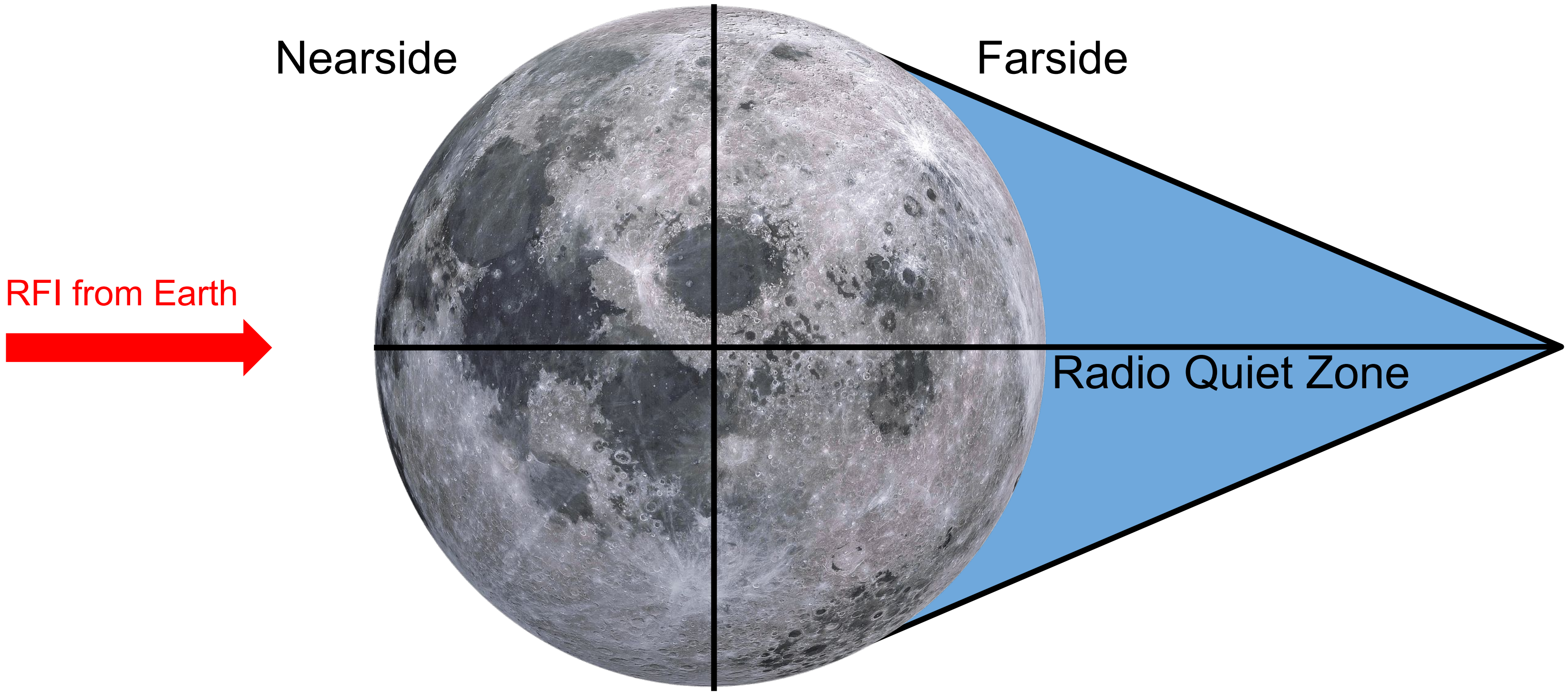
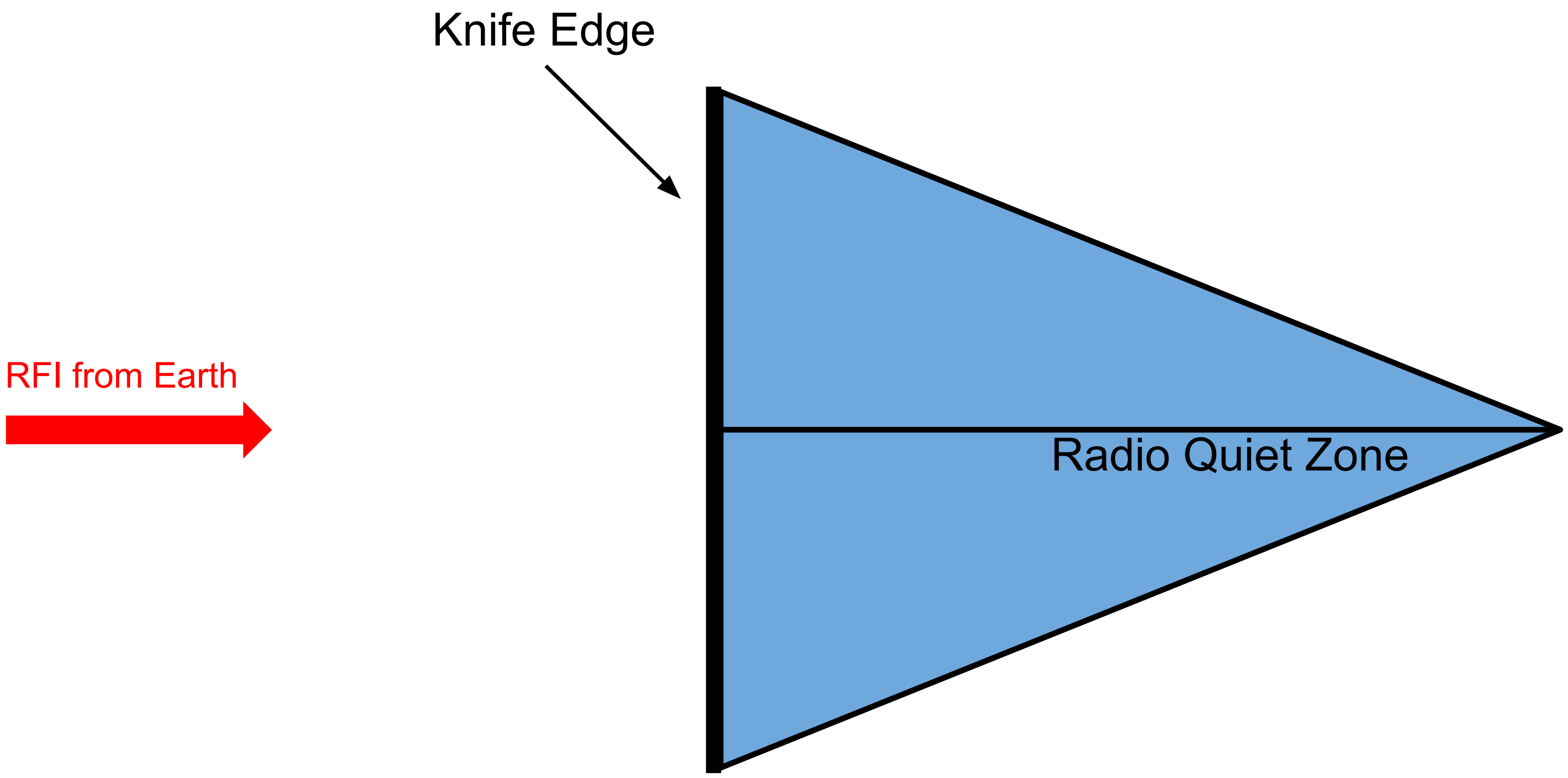
Observations must be performed in a radio quiet environment where Earth-based RFI is mitigated

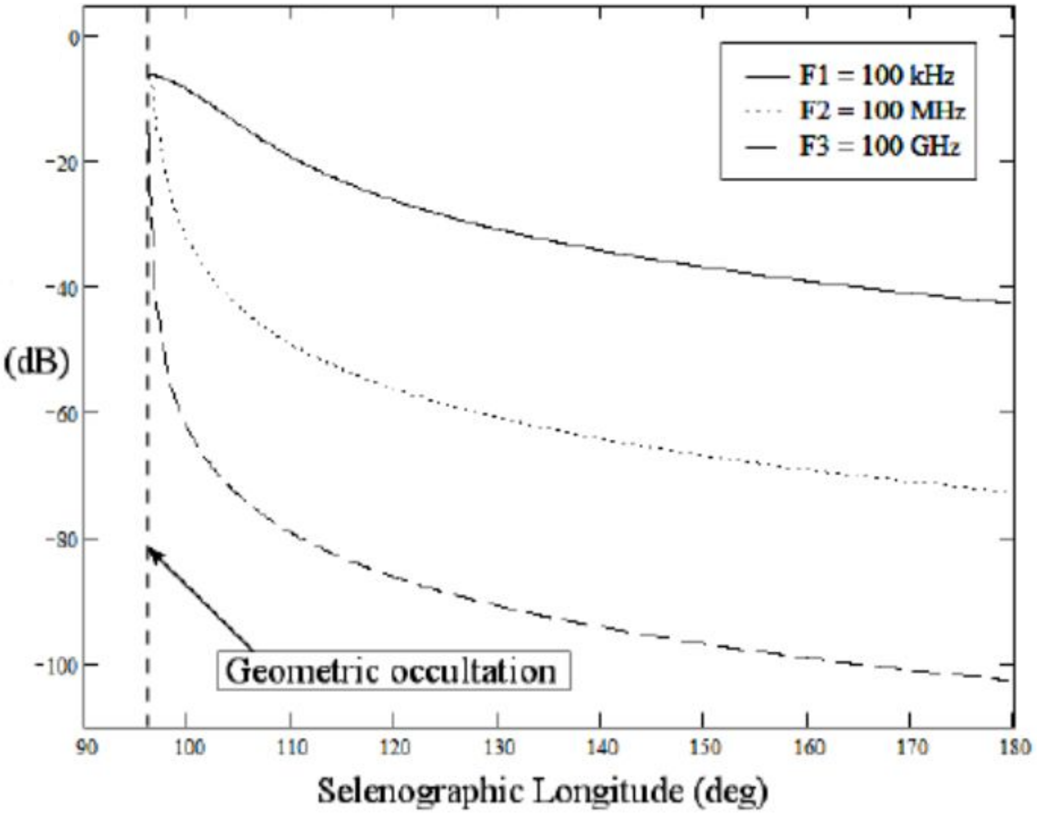
Lunar Radio Environment Geometry



Knife Edge Approximation



Knife Edge Approximation



Pluchino, Antonietti, & Maccone 2007

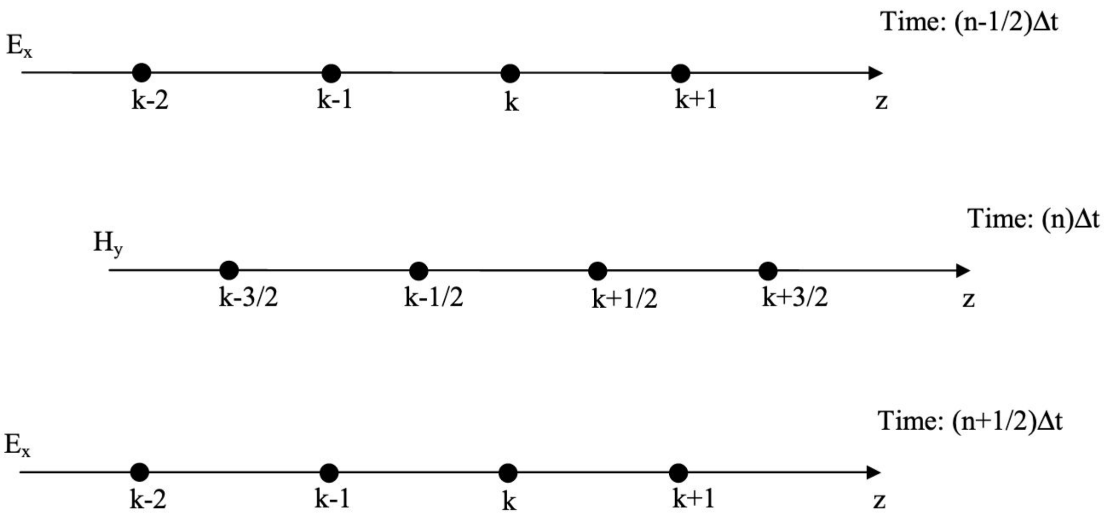
Diffraction around straight edge is analytically solvable, first by Somerfeld in 1896

More accurate treatment requires non-analytic methods, i.e. computer simulations

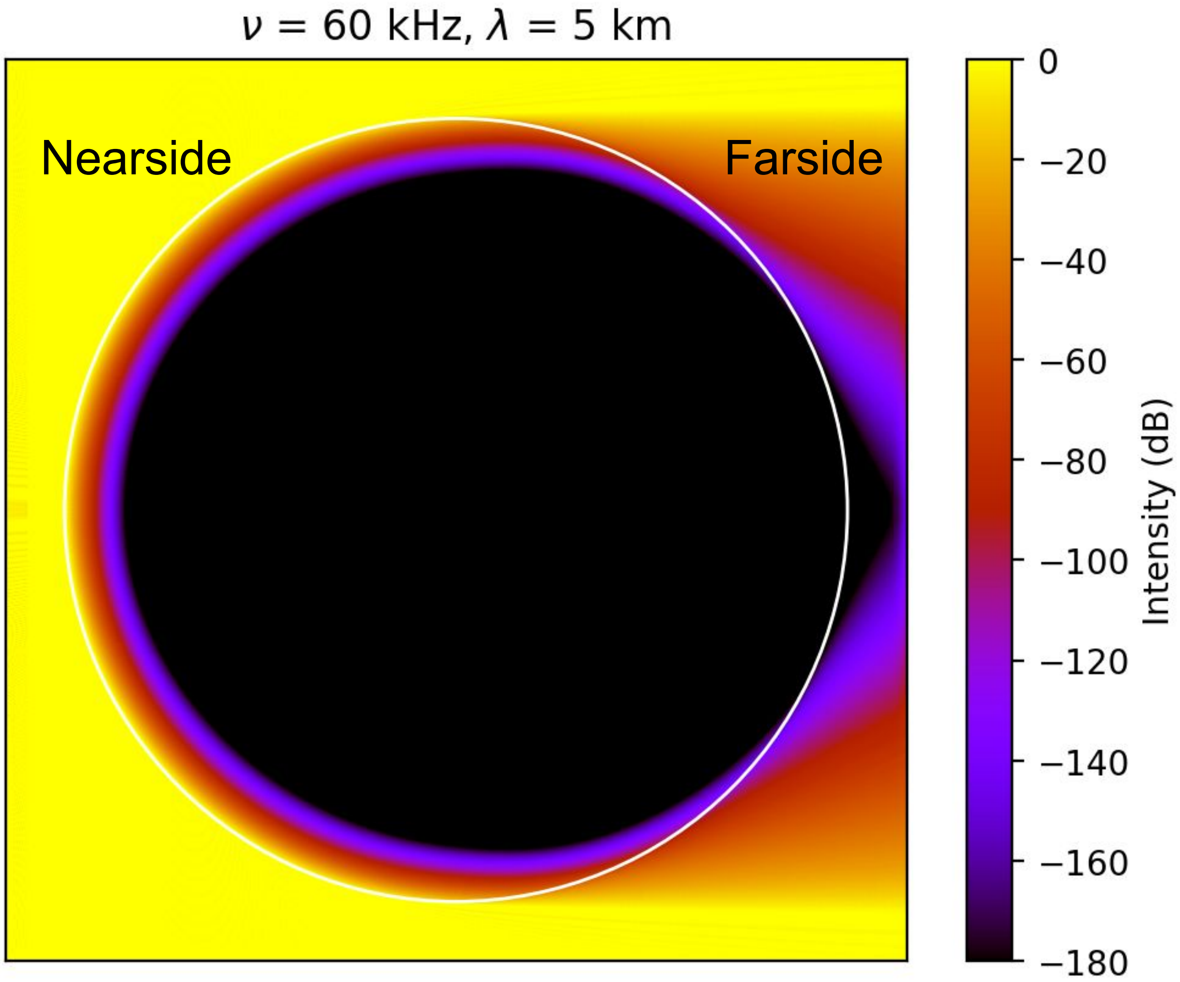
Finite Difference Time Domain (FDTD) Method

$$\frac{\partial E_x}{\partial t} = -\frac{1}{\epsilon_0}\frac{\partial B_y}{\partial z} \longrightarrow \frac{E_x^{n+1/2}(k) - E_x^{n-1/2}(k)}{\Delta t} = -\frac{1}{\mu_0}\frac{B_y^n(k+1/2) - B_y^n(k-1/2)}{\Delta z}$$

$$\frac{\partial B_y}{\partial t} = -\frac{1}{\mu_0}\frac{\partial E_x}{\partial z} \xrightarrow[\text{Yee Grid Discretization}]{} \frac{B_y^{n+1}(k+1/2) - B_y^n(k+1/2)}{\Delta t} = -\frac{1}{\mu_0}\frac{E_x^{n+1/2}(k+1) - E_x^{n+1/2}(k)}{\Delta z}$$



2-dimensional Lunar Simulations



Lunar Electrical Properties:

$$\bar{\rho} = 3.34\ g/cm^3$$

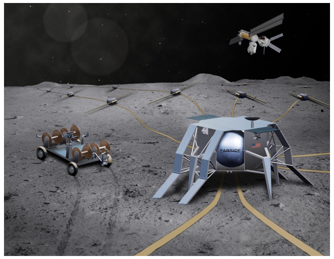
$$\varepsilon = 1.919^{\rho}$$
$$\varepsilon \sim 8.8$$

$$\tan\delta = 10^{(0.44\rho - 2.943)}$$
$$\tan\delta \sim 0.034$$

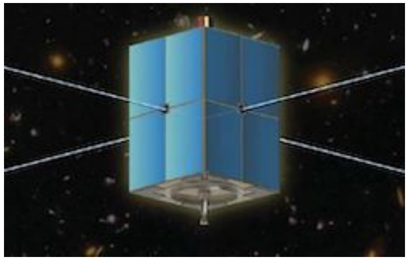
Values from *Lunar Sourcebook*

Simulations performed using MEEP for Python (Oskooi et al. 2010)

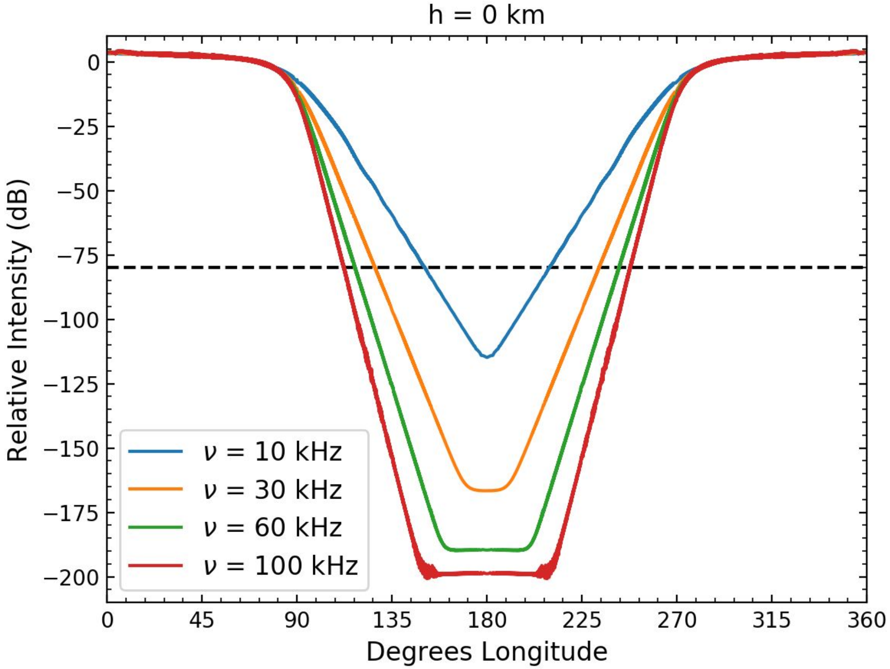
RFI Attenuation

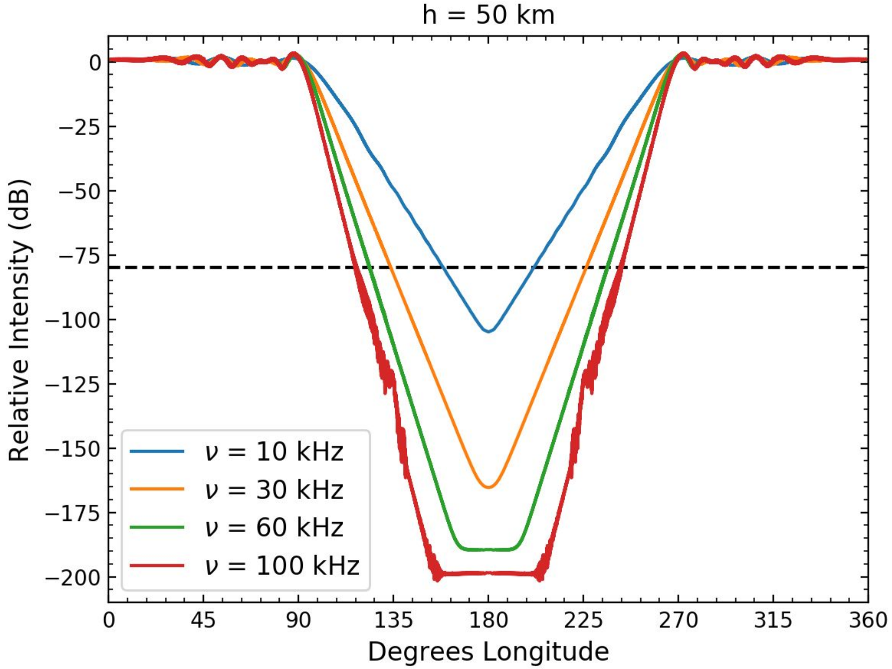


Surface



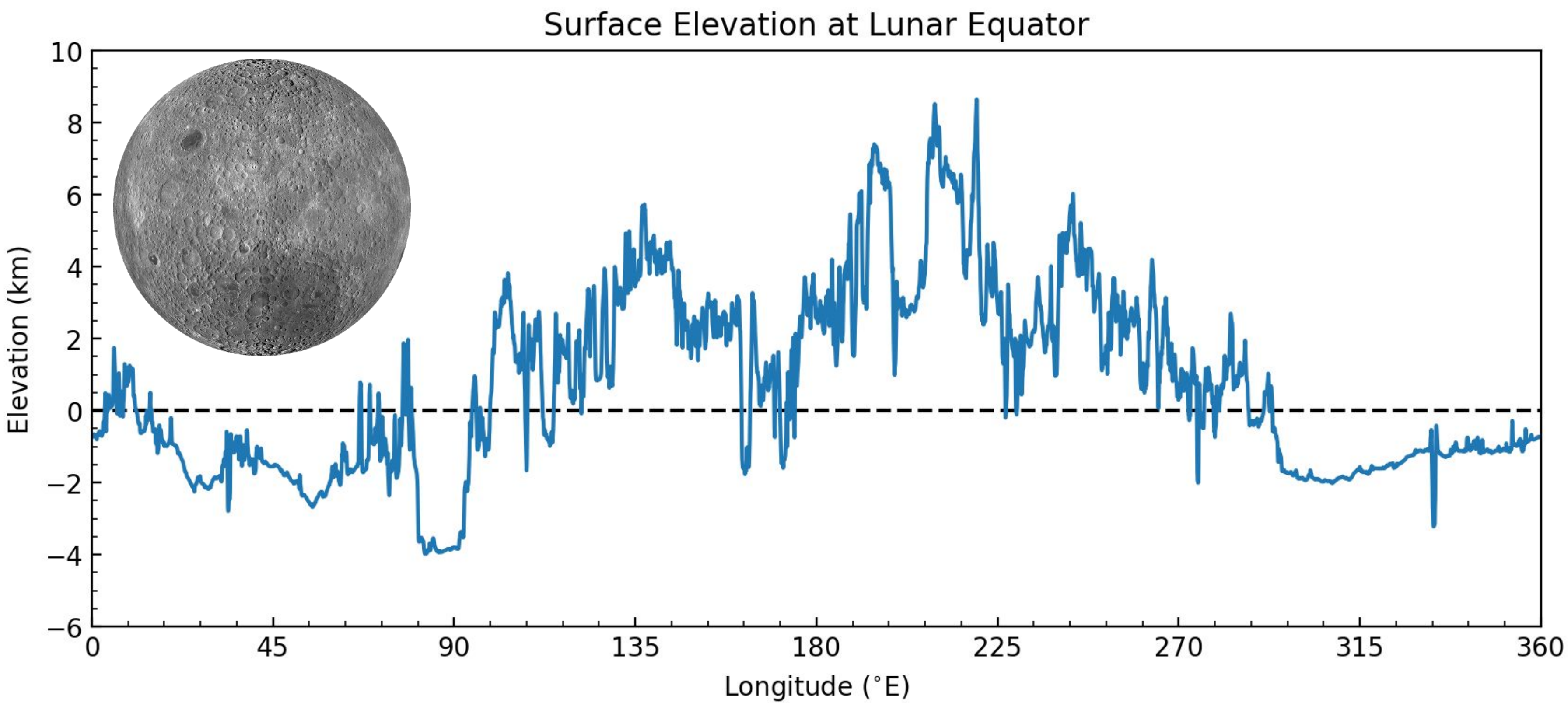
50 km orbit





Science observations are taken in region where RFI is suppressed by at least 80 dB to prevent contamination

Lunar Topography

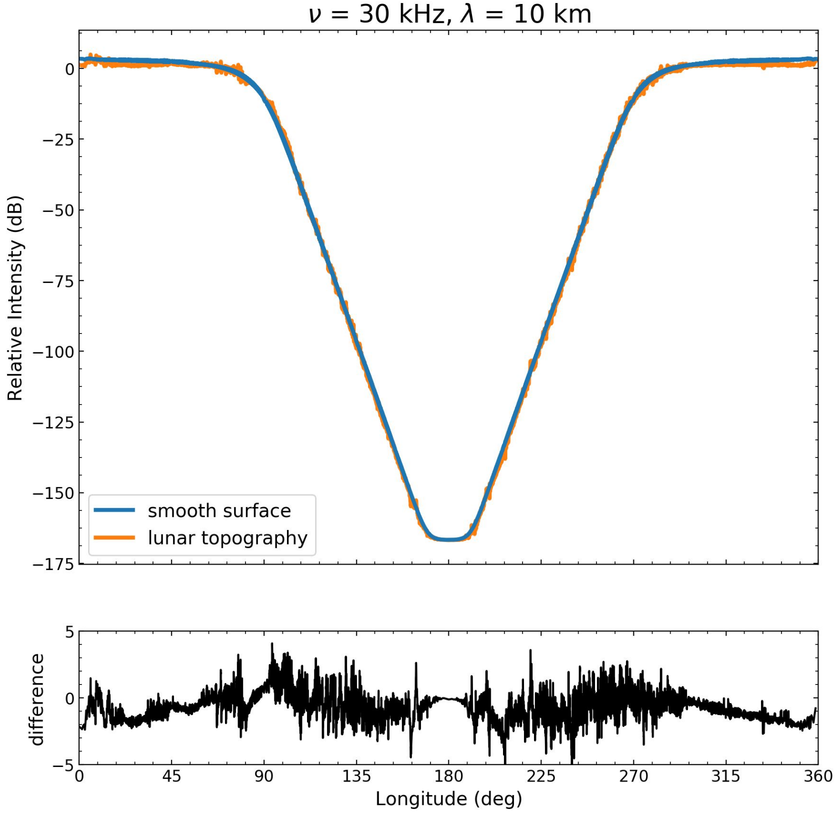


Data from Lunar Orbiter Laser Altimeter (LOLA) instrument on Lunar Reconnaissance Orbiter

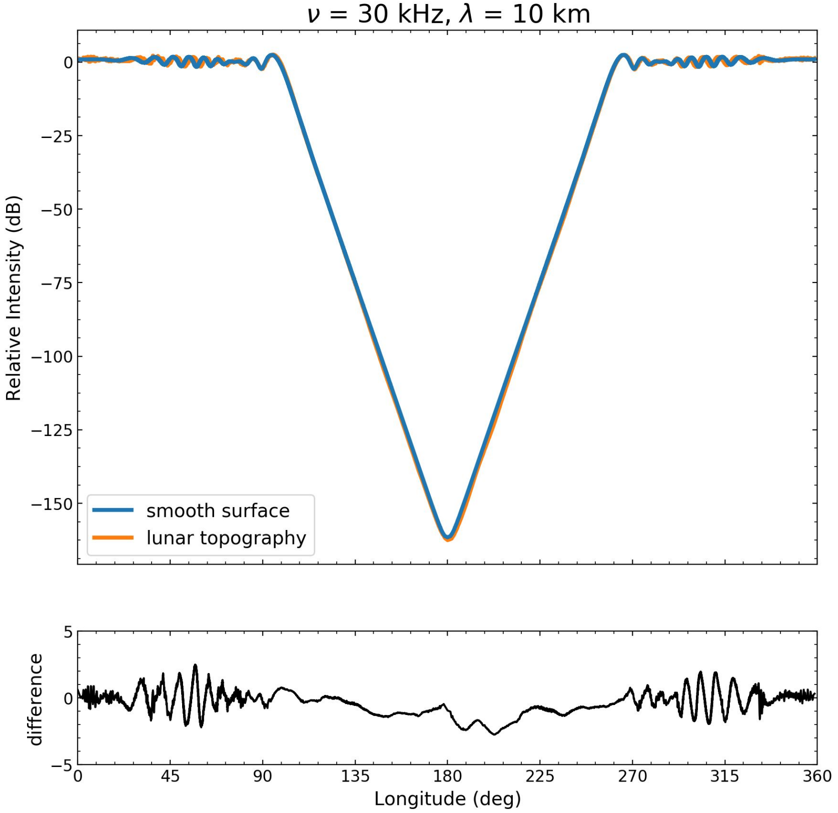
http://pds-geosciences.wustl.edu/lro/lro-l-lola-3-rdr-v1/lrolol_1xxx/DATA/lola_gdr/cylindrical/img/ldem_16.img

Lunar Topography

Surface

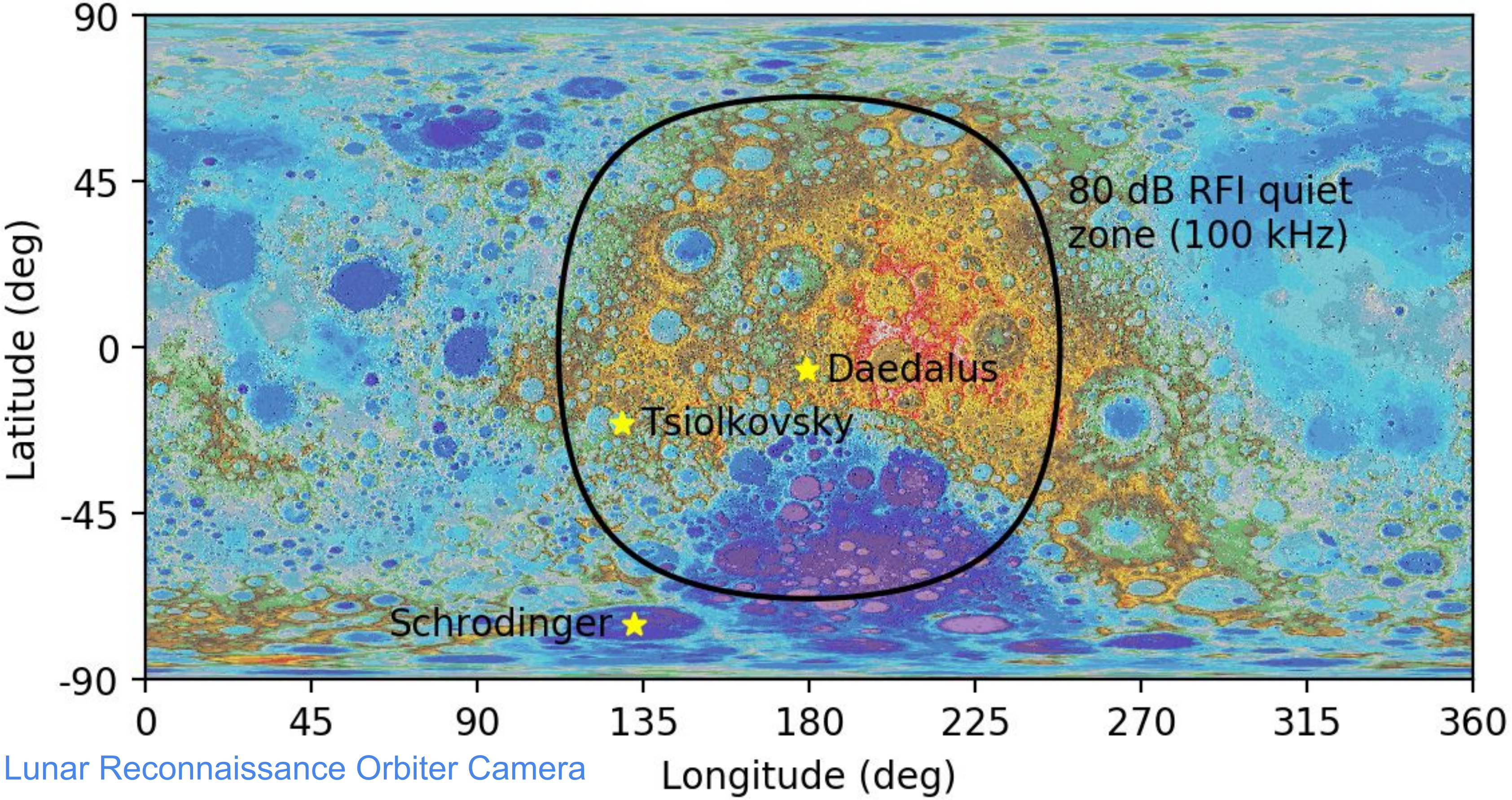


50 km above surface



Lunar topography plays only a small part, but tends to increase attenuation of RFI behind farside, especially above the surface

Possible Surface Locations for Radio Experiments



Lunar Reconnaissance Orbiter Camera

Crater	Latitude	Longitude	RFI (100 kHz)
Schrodinger	75.0° S	132.4° E	-41 dB
Tsiolkovsky	20.4° S	129.1° E	-125 dB
Daedalus	5.9° S	179.4° E	-199 dB

Conclusions

- In order to extract 21-cm spectrum below 30 MHz, observations must be performed in a radio quiet environment above the Earth's ionosphere

- The Moon blocks terrestrial radio signals, providing a unique radio quiet zone behind the lunar farside

- Electromagnetic FDTD simulations show that the suppression of RFI on the farside is sufficient (≥ 80 dB) to perform cosmological 21-cm observations both on the surface and in lunar orbit

- The topography of the Moon does not significantly affect the size of the radio quiet zone

- Sites closer to the lunar limb such as the Schrödinger crater are quiet enough to perform some low frequency astronomical observations