Characterizing the Radio Quiet Region Behind the Lunar Farside for Low Radio Frequency Experiments

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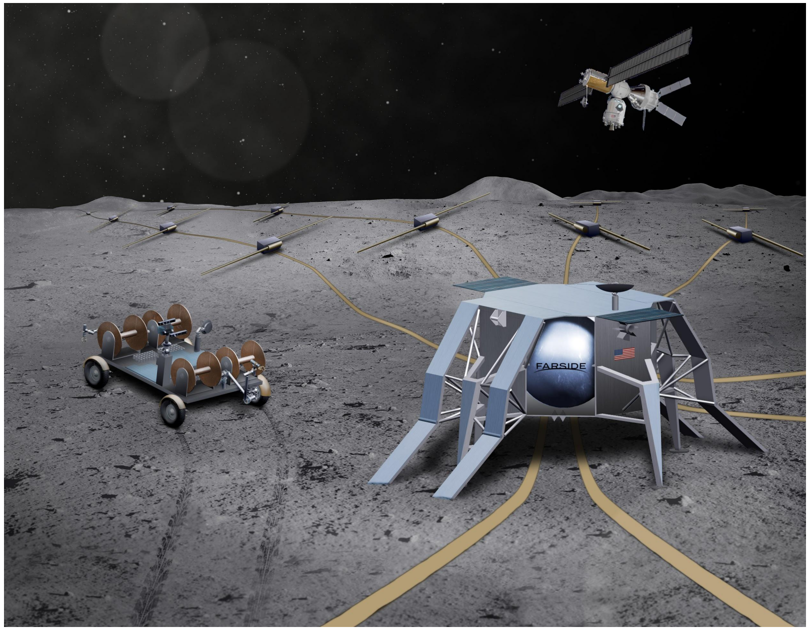
NESS
Network for Exploration and Space Science

University of Colorado Boulder

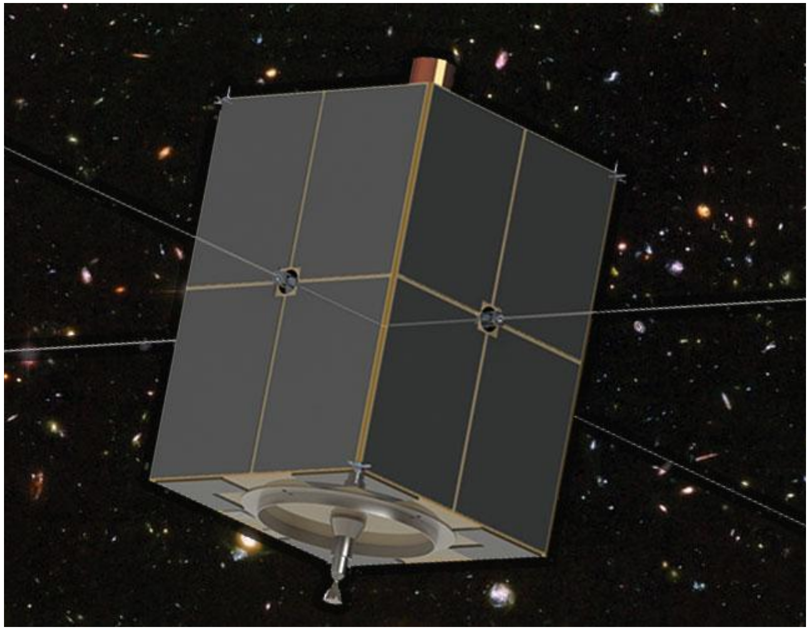
Motivation

Farside Array for Radio Science Investigations of the Dark ages and Exoplanets (FARSIDE)



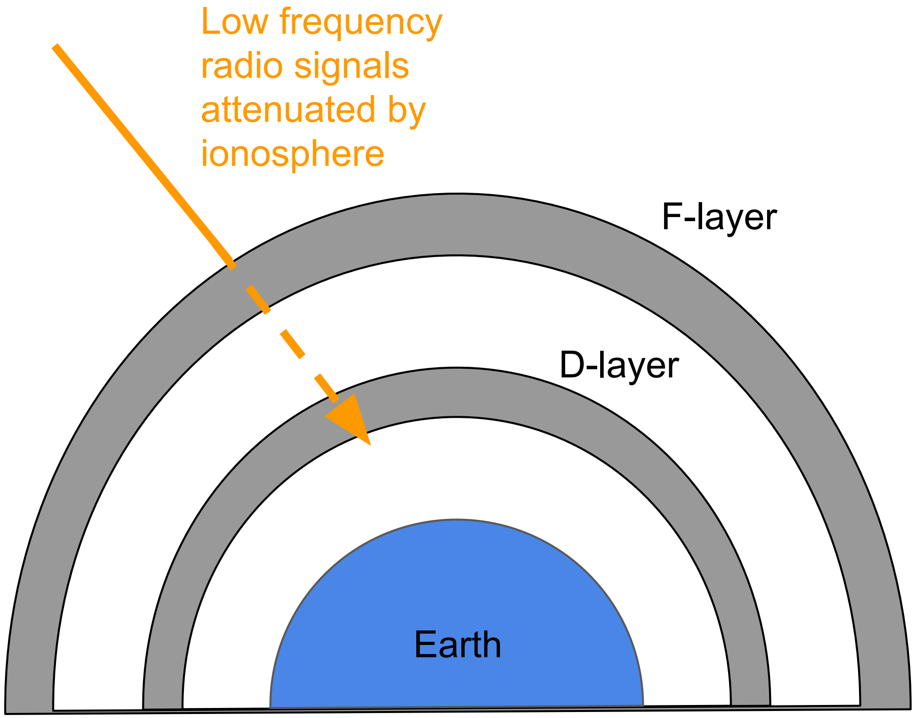
- 200 kHz - 40 MHz
- Interferometric array of 128 antennas directly on lunar surface
- 21-cm power spectrum, direct imaging of exoplanet magnetospheres

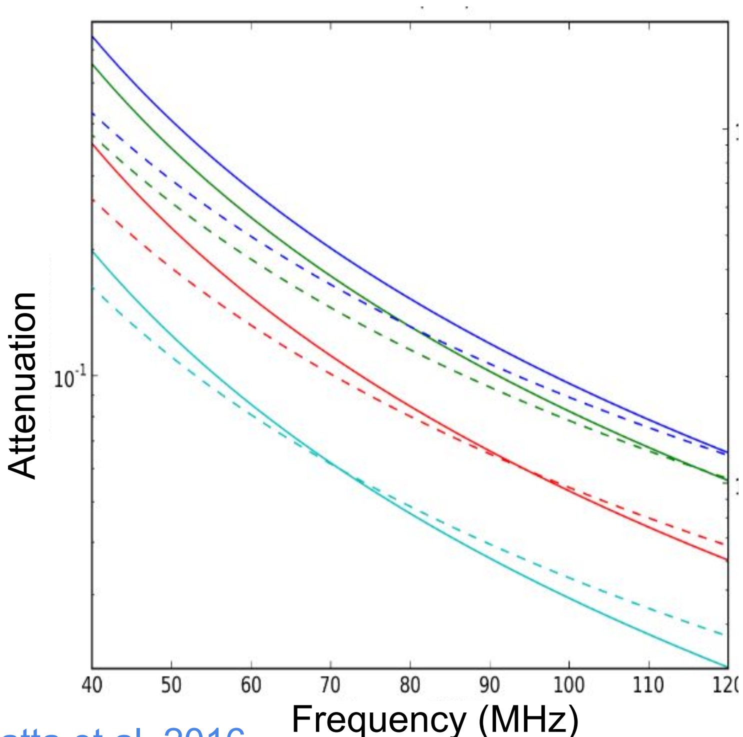
Dark Ages Polarimeter PathfindER (DAPPER)



- 17 - 107 MHz
- Single Antenna in 50x125 km orbit of the Moon
- 21-cm global signal measurement

Ionospheric effects



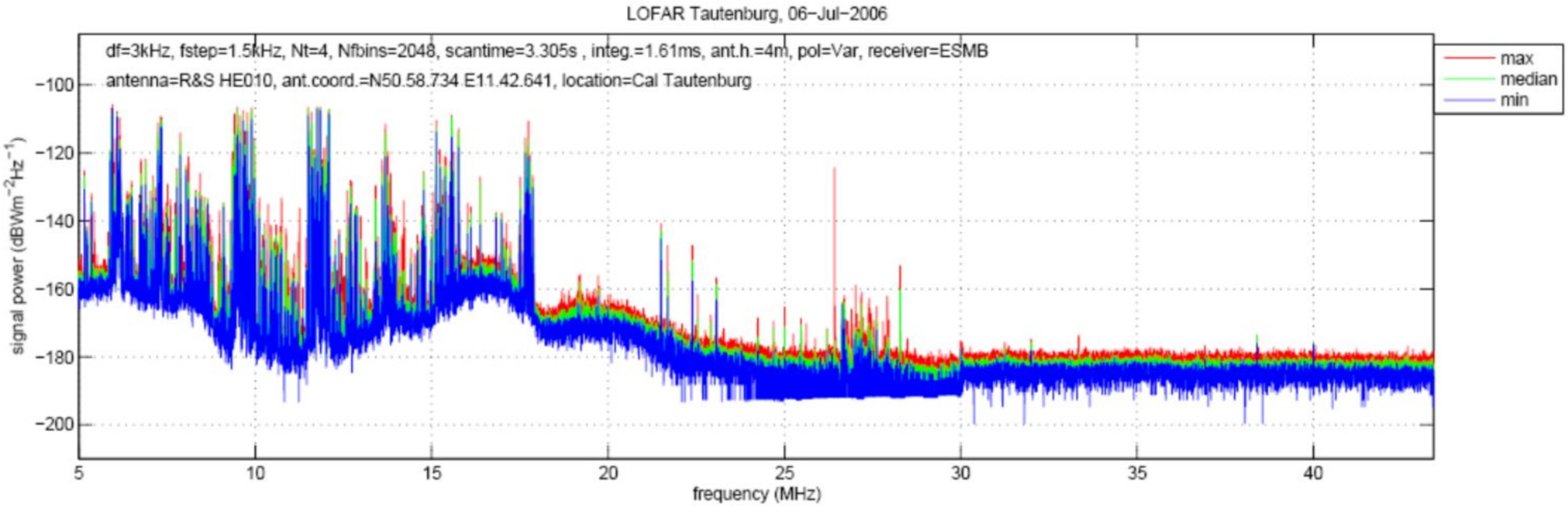


Datta et al. 2016

- 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

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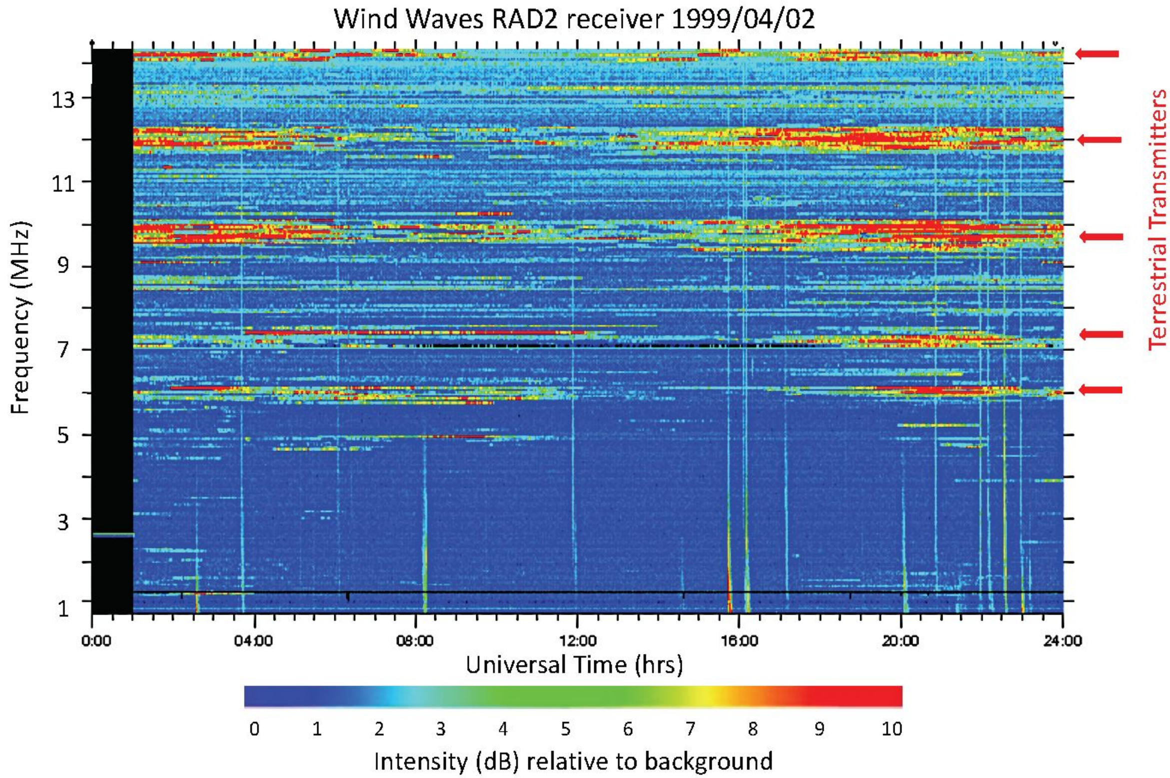

Even above ionosphere, terrestrial communications may interfere with low frequency measurements

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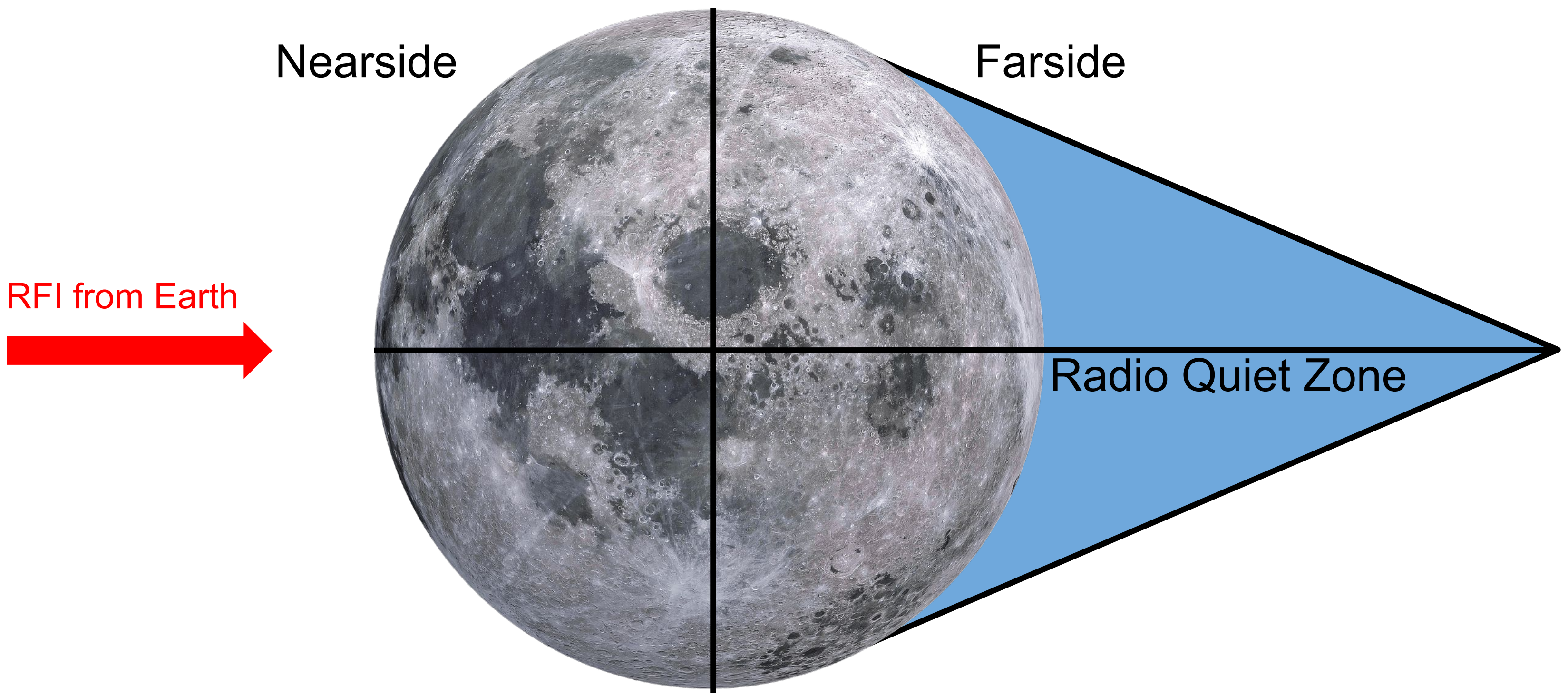
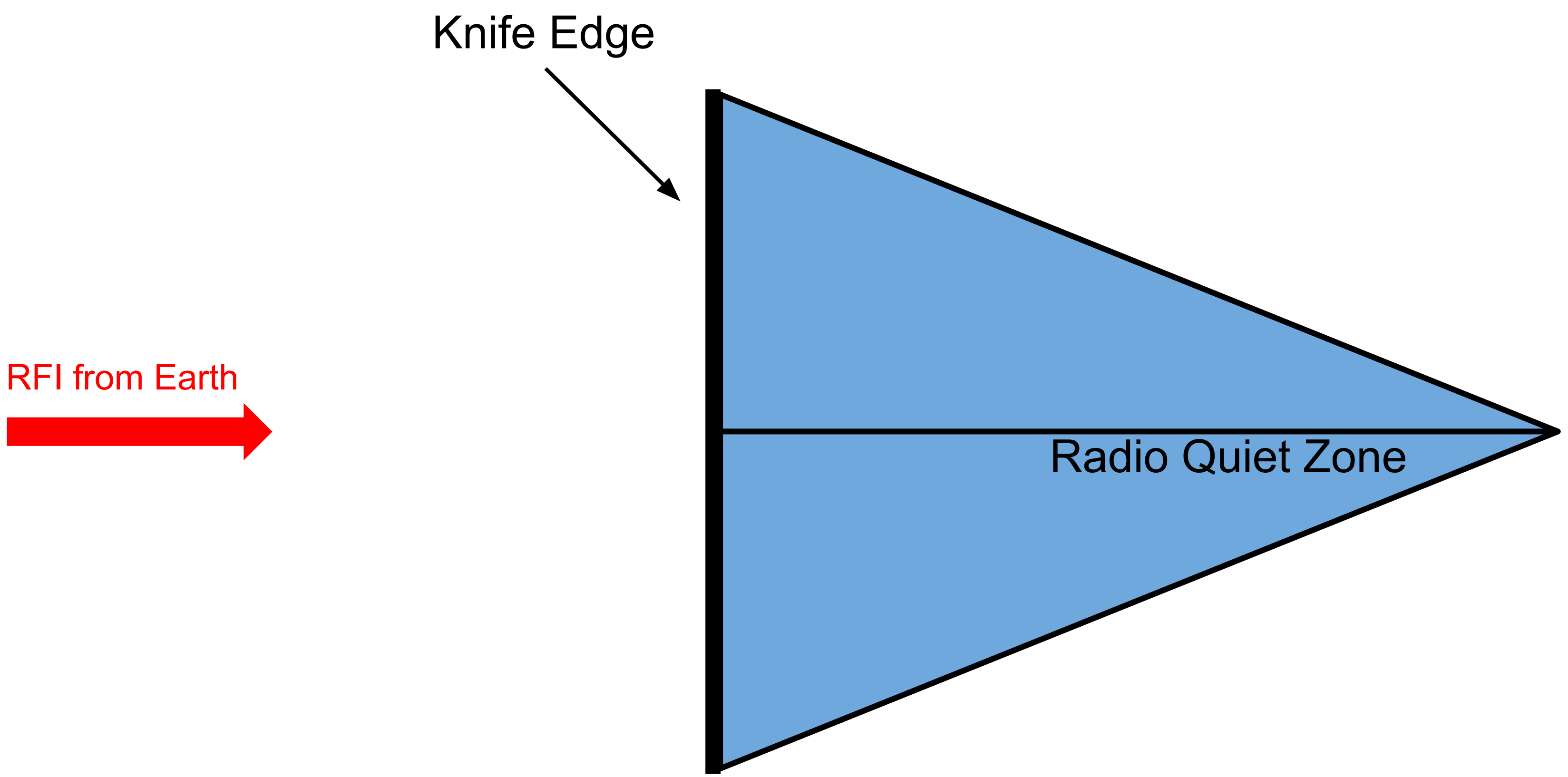
Observations must be performed in a radio quiet environment where Earth-based RFI is mitigated

Lunar Radio Environment Geometry



Knife Edge Approximation



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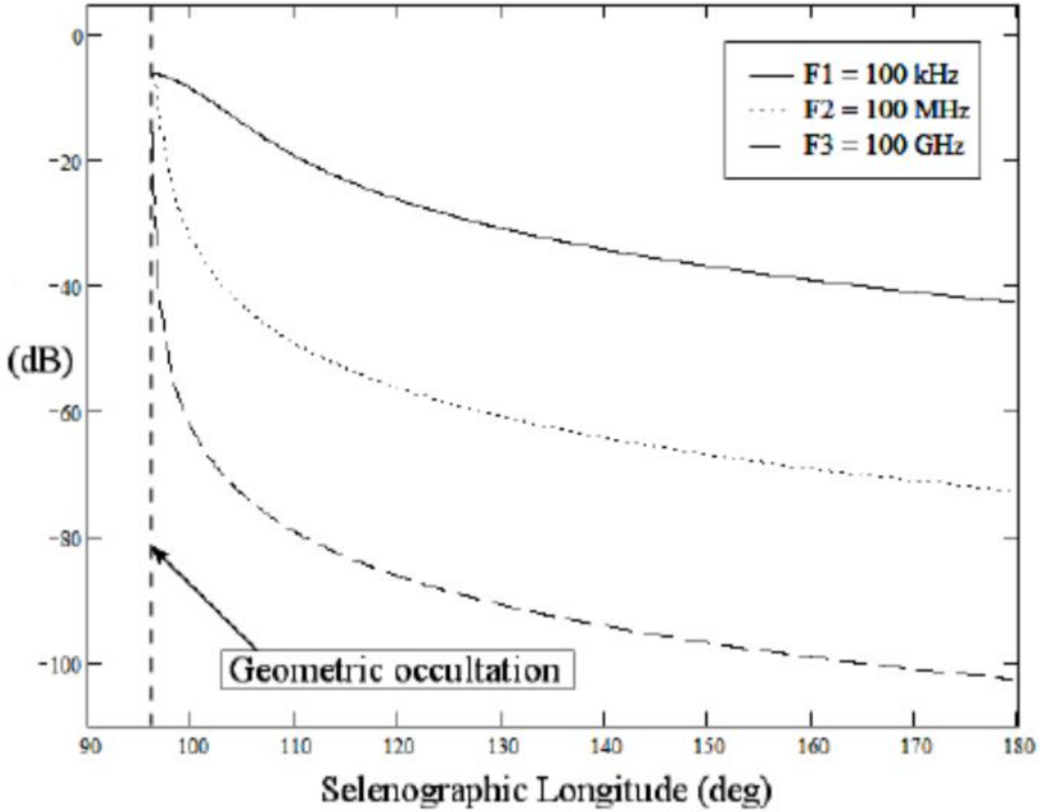


Pluchino, Antonietti, & Maccone 2007

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

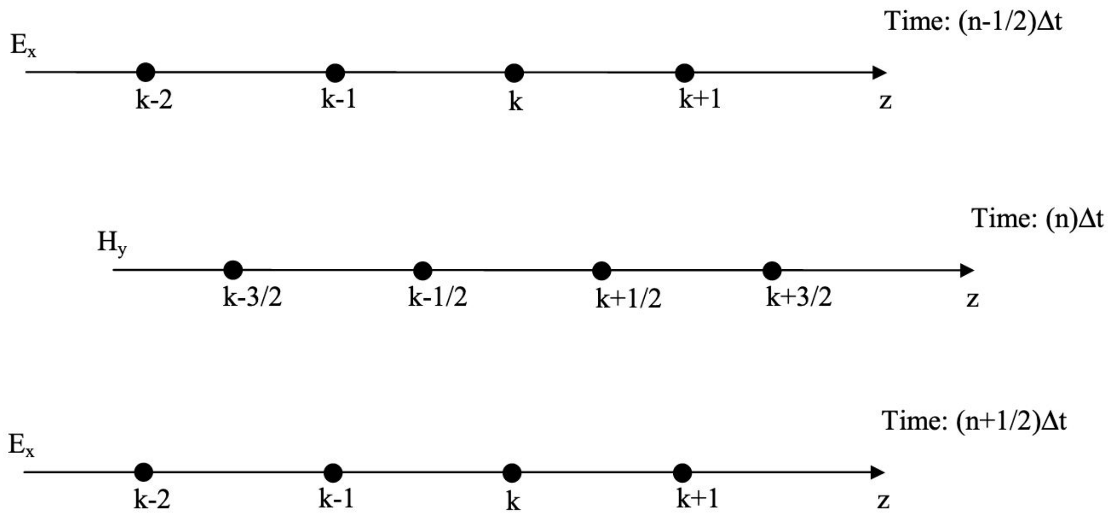
More accurate treatment requires non-analytic methods, i.e. computer simulations

Finite Difference Time Domain (FDTD) Method

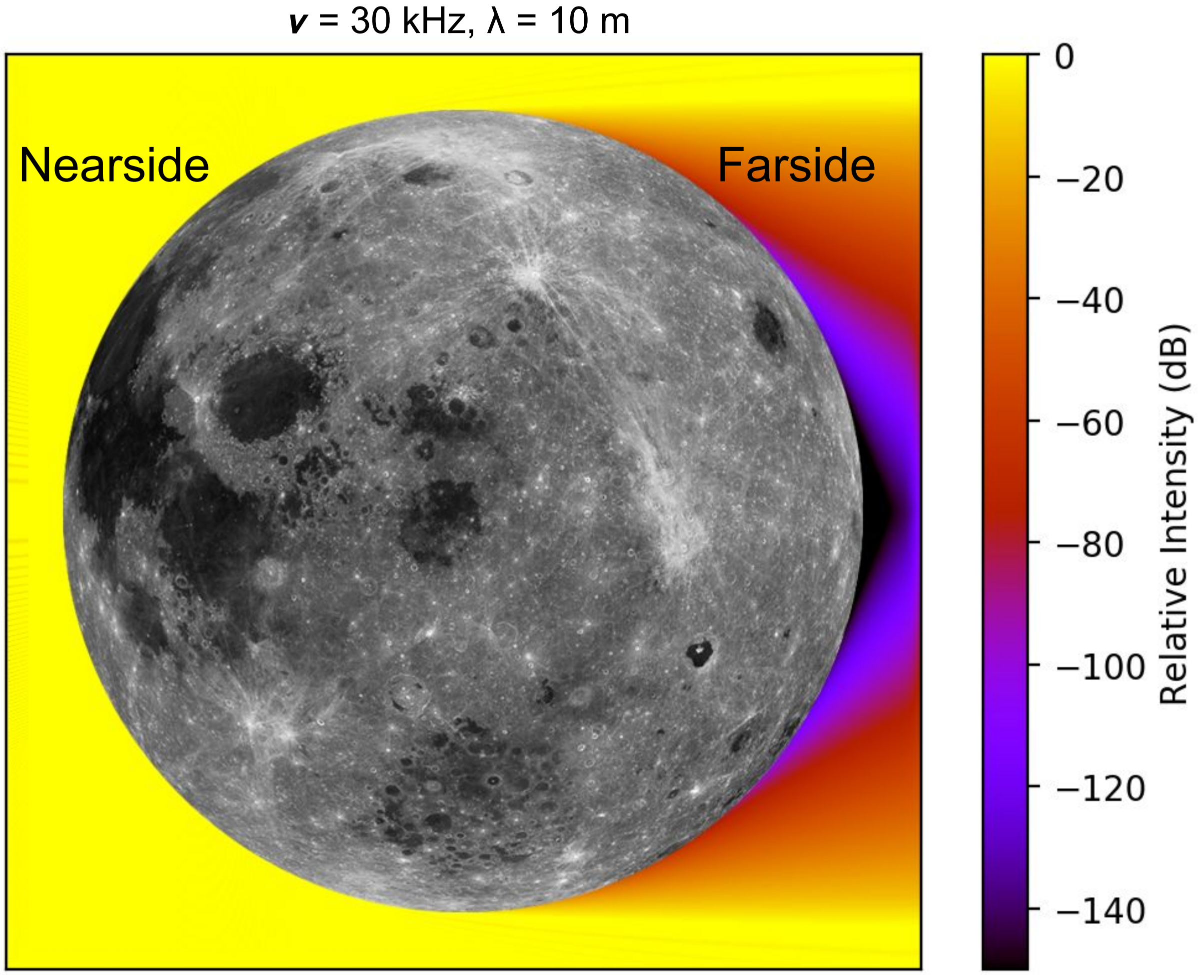
$$\frac{\partial E_x}{\partial t} = -\frac{1}{\epsilon_0}\frac{\partial B_y}{\partial z} \quad \longrightarrow \quad \frac{E_x^{n+1/2}(k) - E_x^{n-1/2}(k)}{\Delta t} = -\frac{1}{\mu_0}\frac{B_y^n(k+1/2) - B_y^n(k-1/2)}{\Delta z}$$

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

Yee Grid Discretization



2-dimensional Lunar Simulations



Lunar Electrical Properties:

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

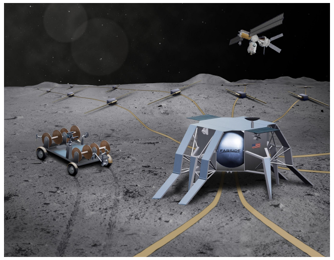
$$\varepsilon = 1.919^{\rho}$$
$$\varepsilon \sim 8.8$$

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

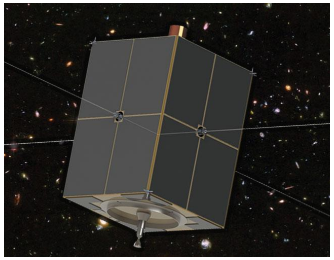
Values from *Lunar Sourcebook*

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

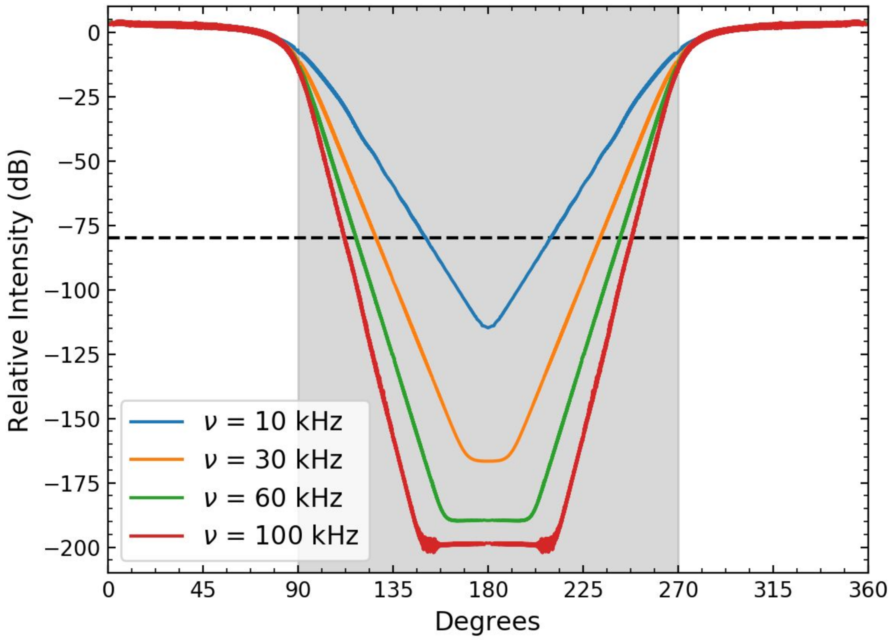
RFI Attenuation

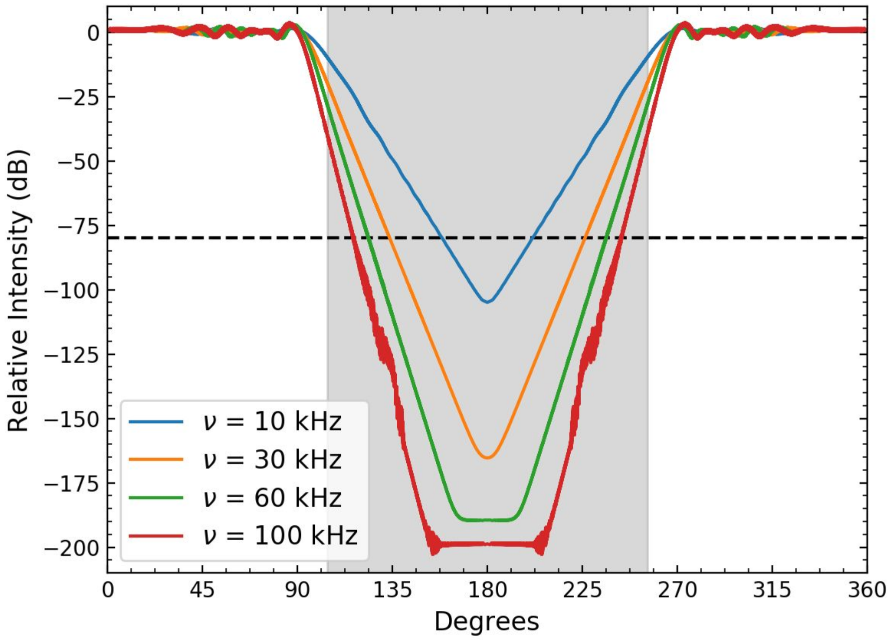


Surface (FARSIDE)



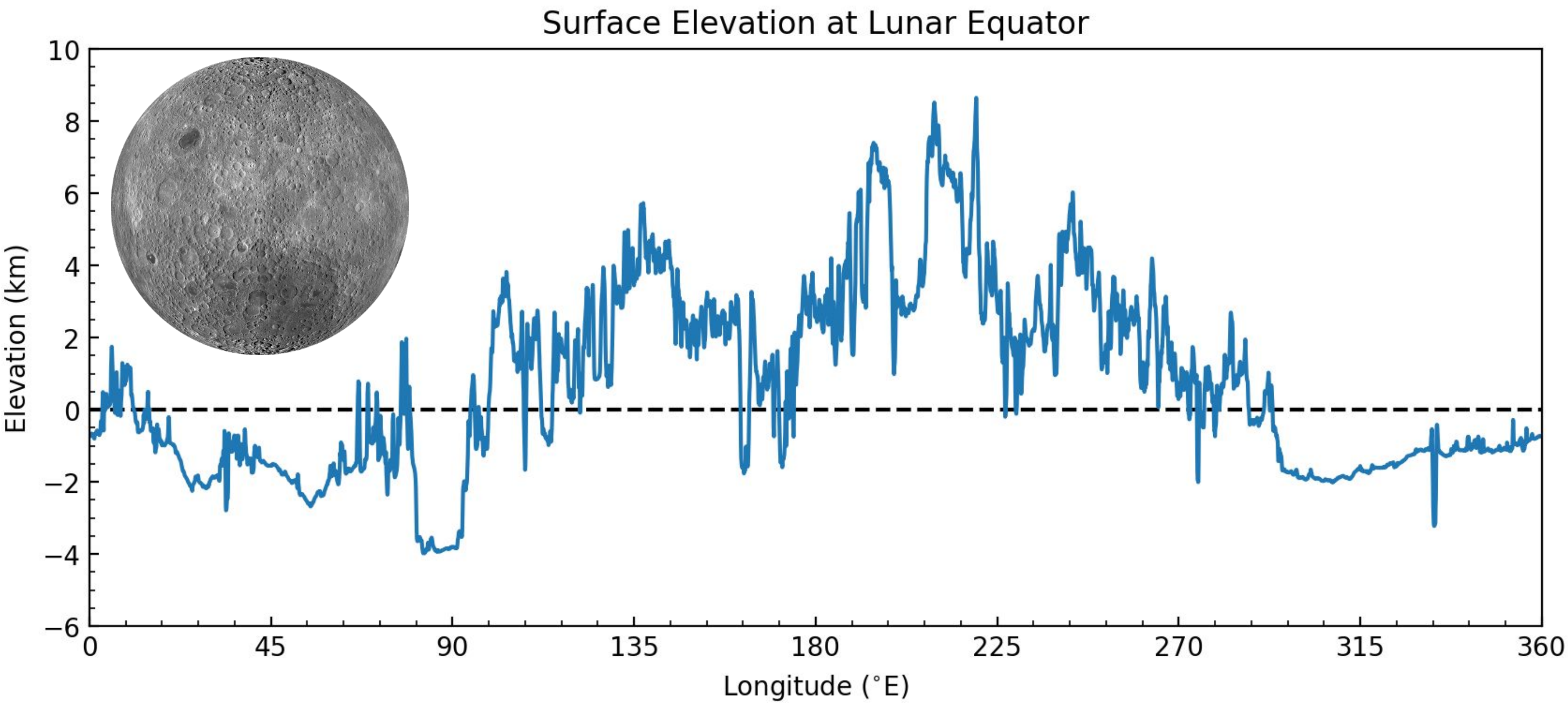
50 km orbit (DAPPER)





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

Lunar Topography

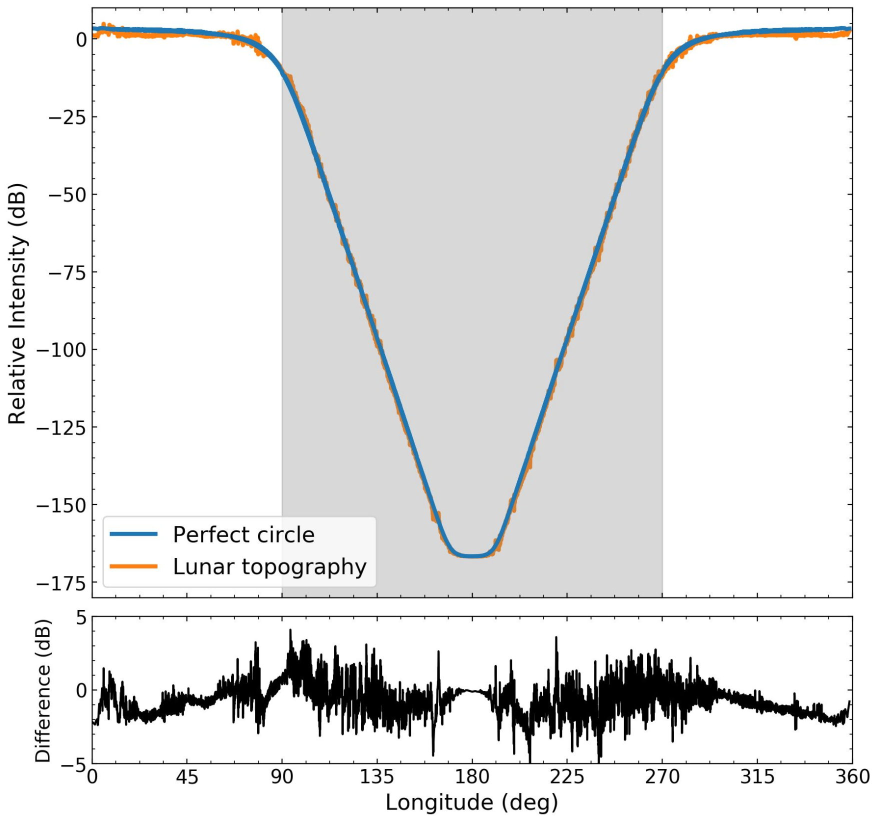


Data from Lunar Orbiter Laser Altimeter (LOLA) instrument on Lunar Reconnaissance Orbiter

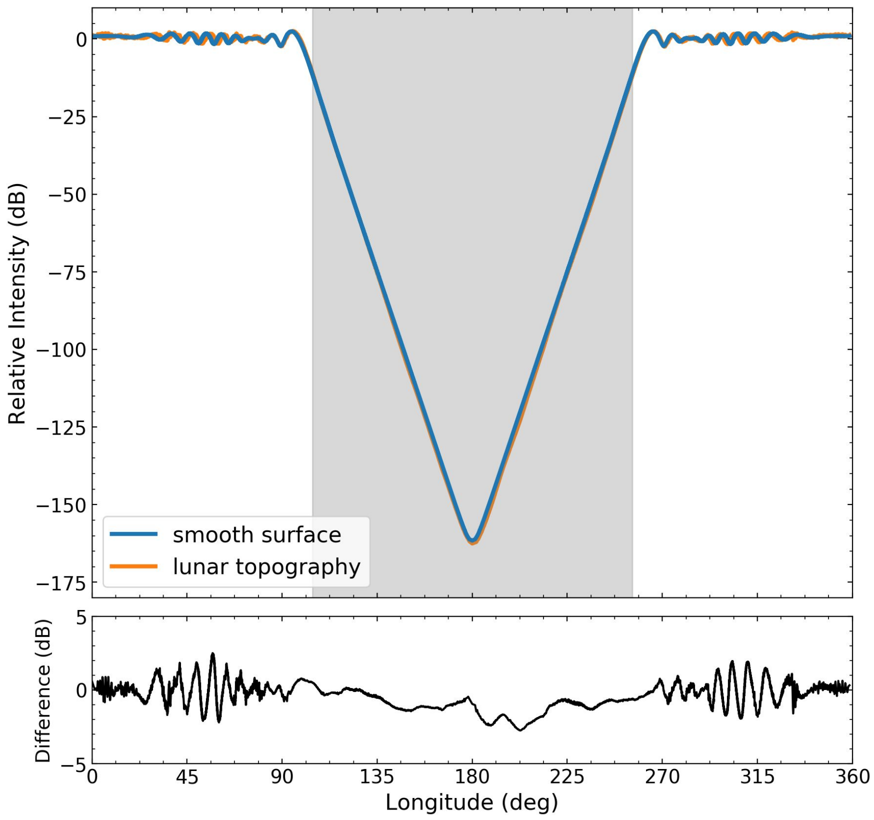
http://pds-geosciences.wustl.edu/lro/lro-l-lola-3-rdr-v1/lrolol_1xxx/DATA/lola_gdr/cylindrical/img/ldem_16.img

Lunar Topography

Surface

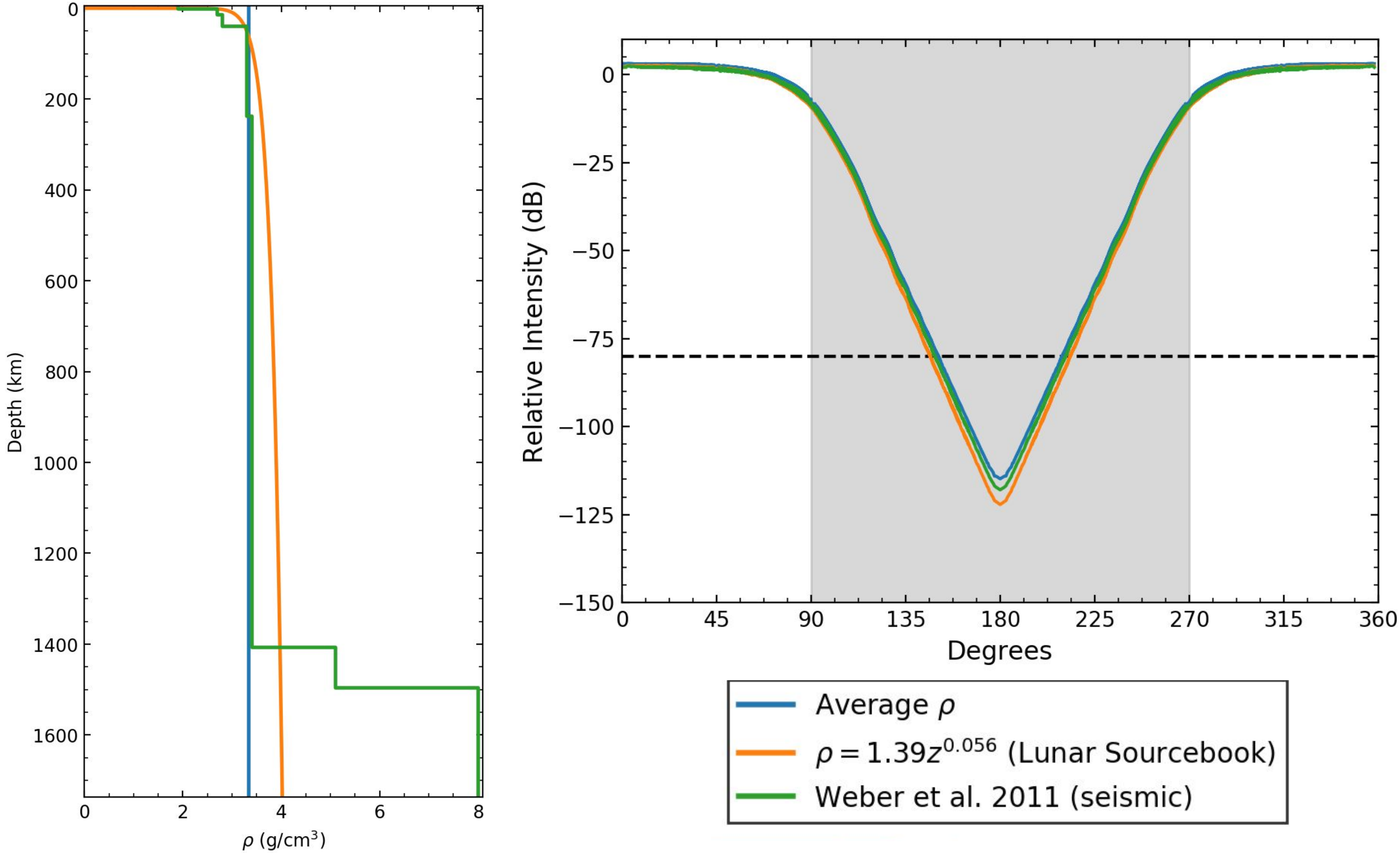


50 km above surface



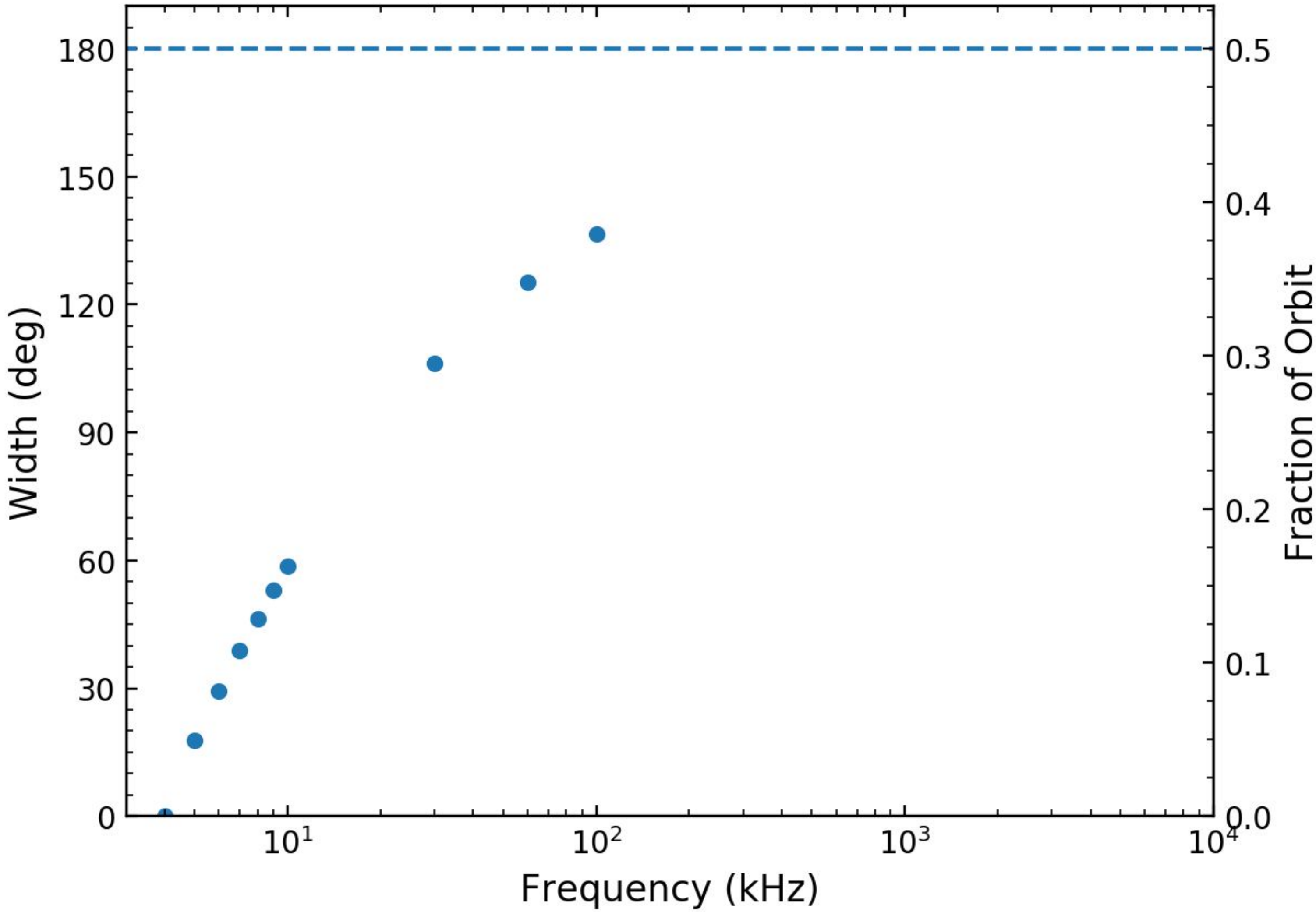
Lunar topography plays only a small part, but tends to increase attenuation of RFI behind farside, especially above the surface

Lunar Density Profiles



Constant average density profile provides lower limit on size of quiet region

Extrapolating to Higher Frequencies



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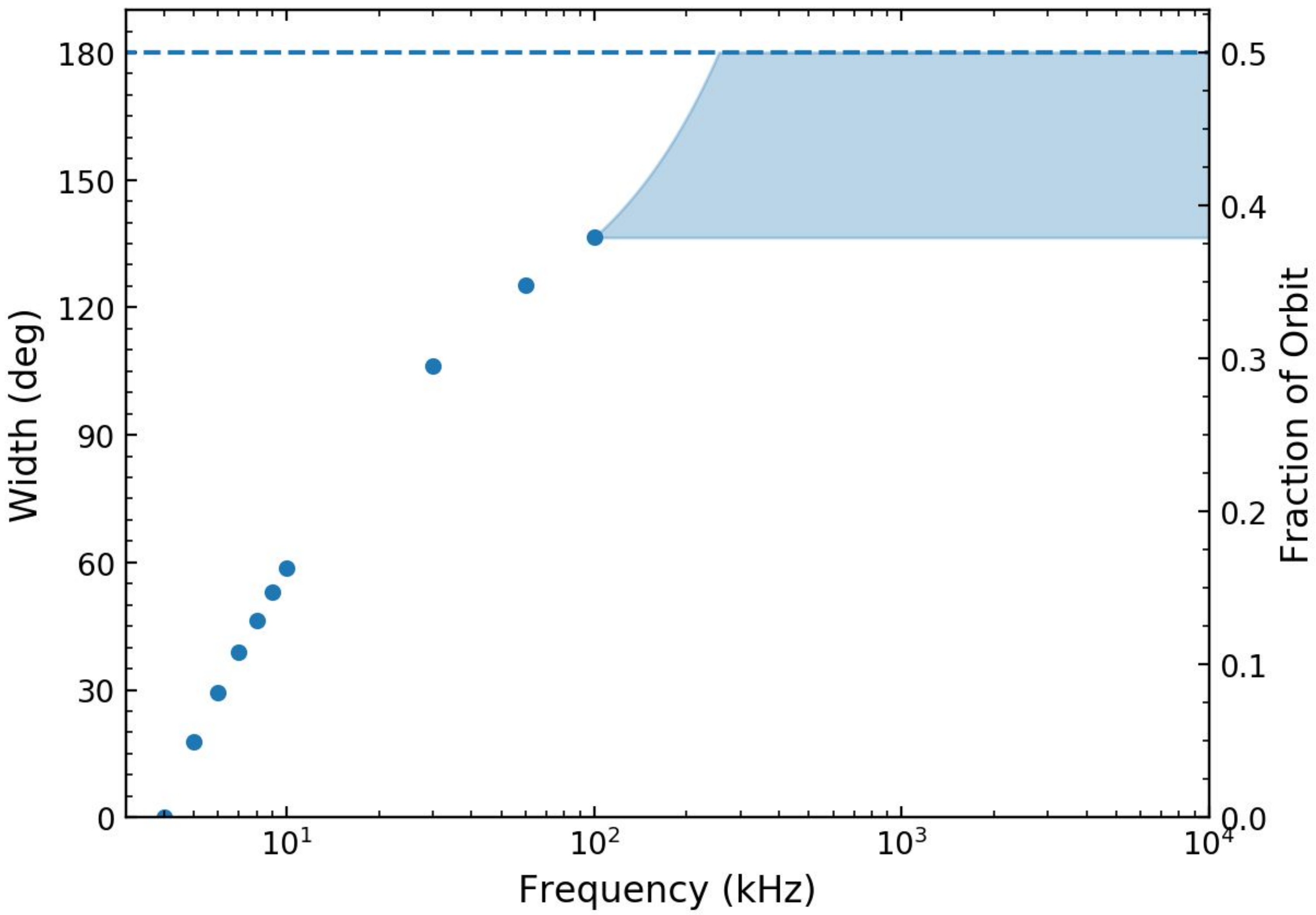

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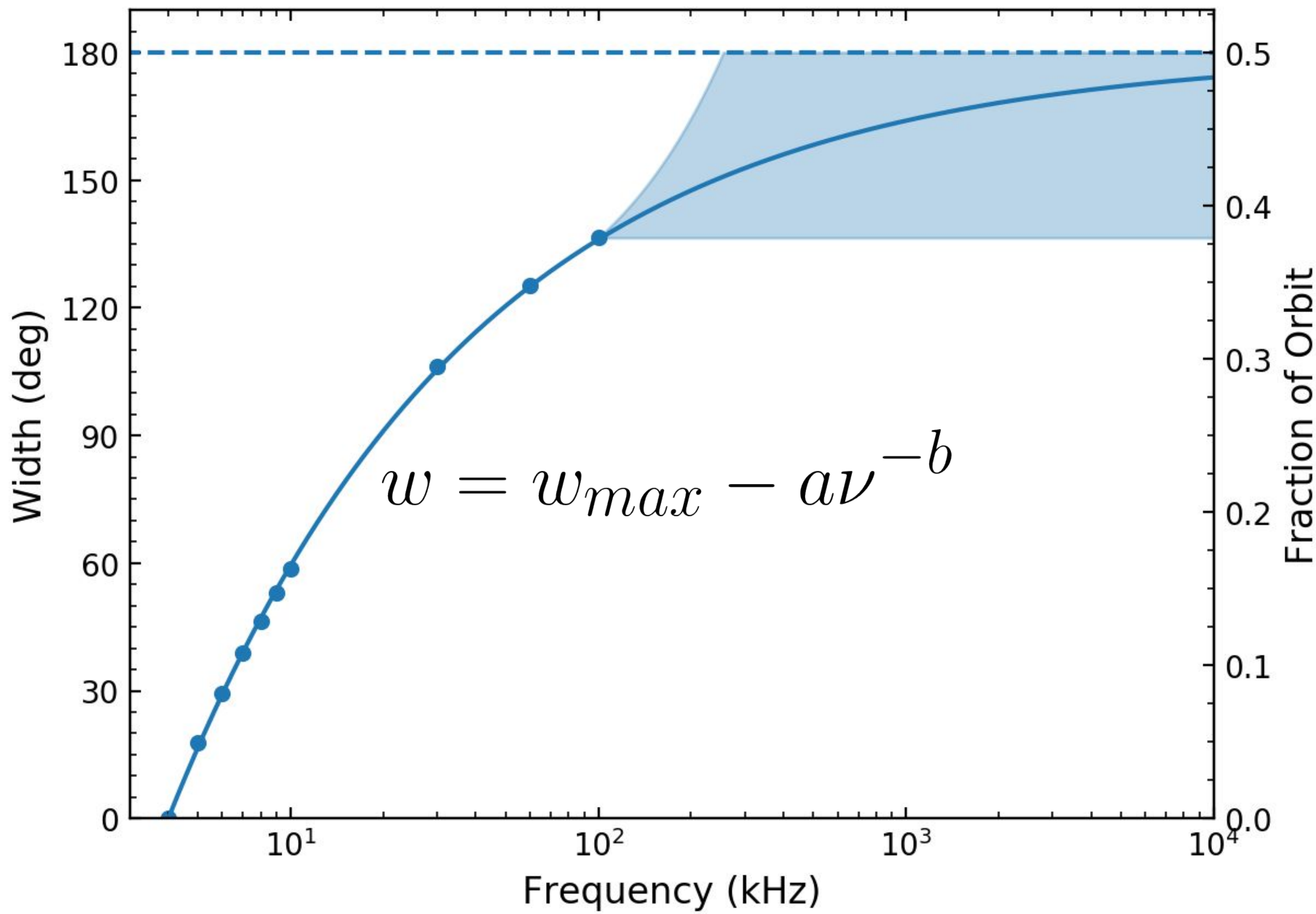

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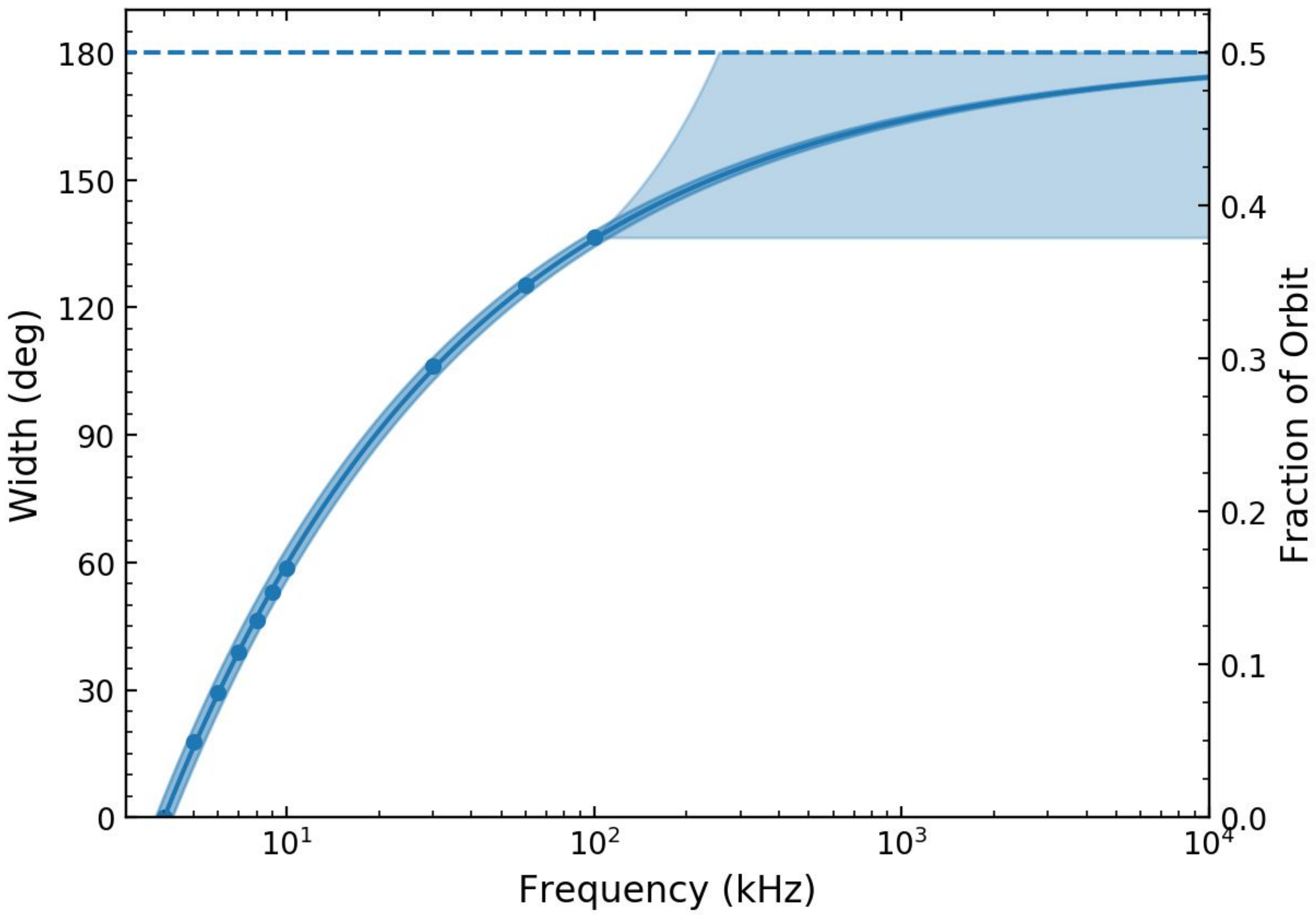

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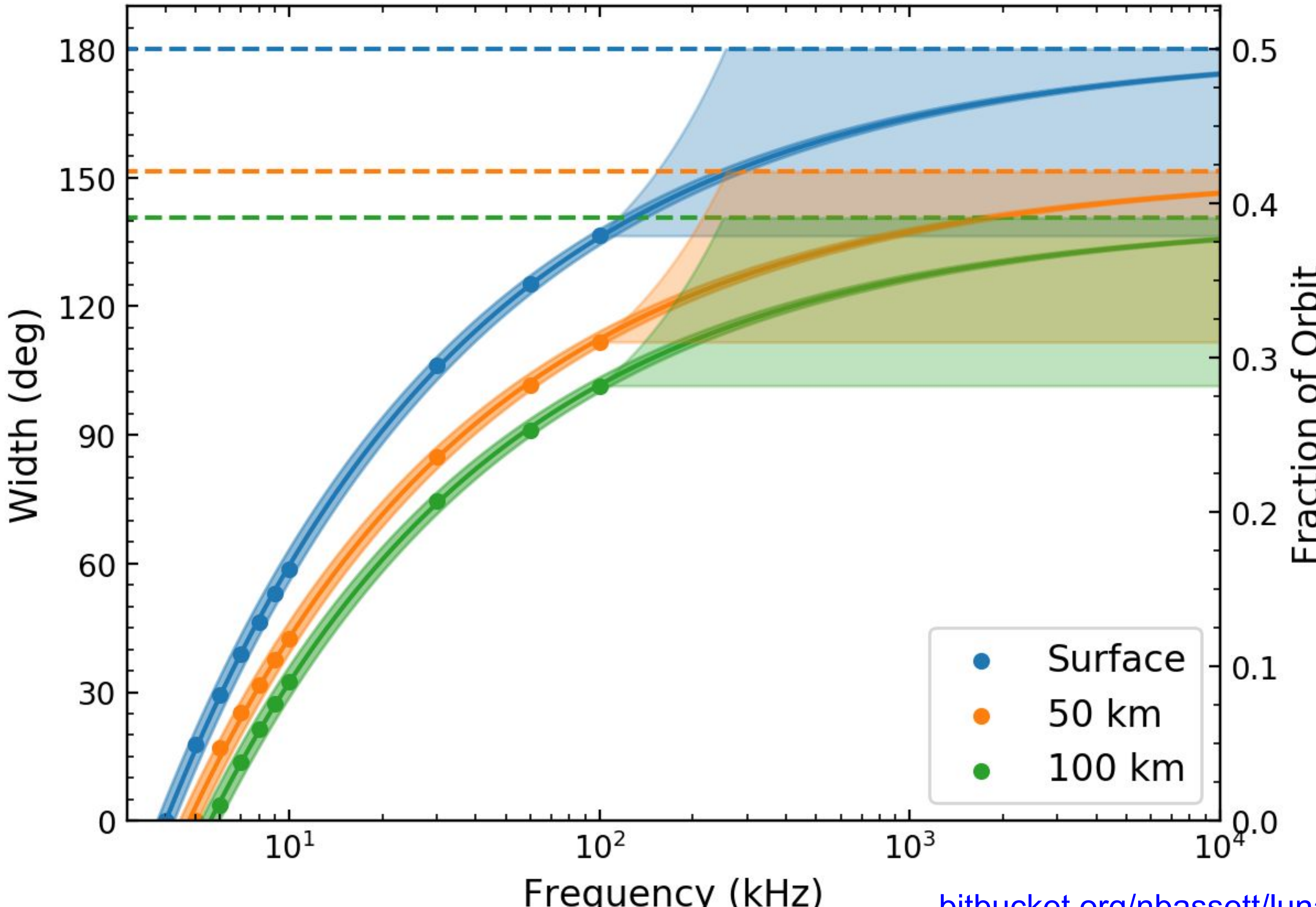
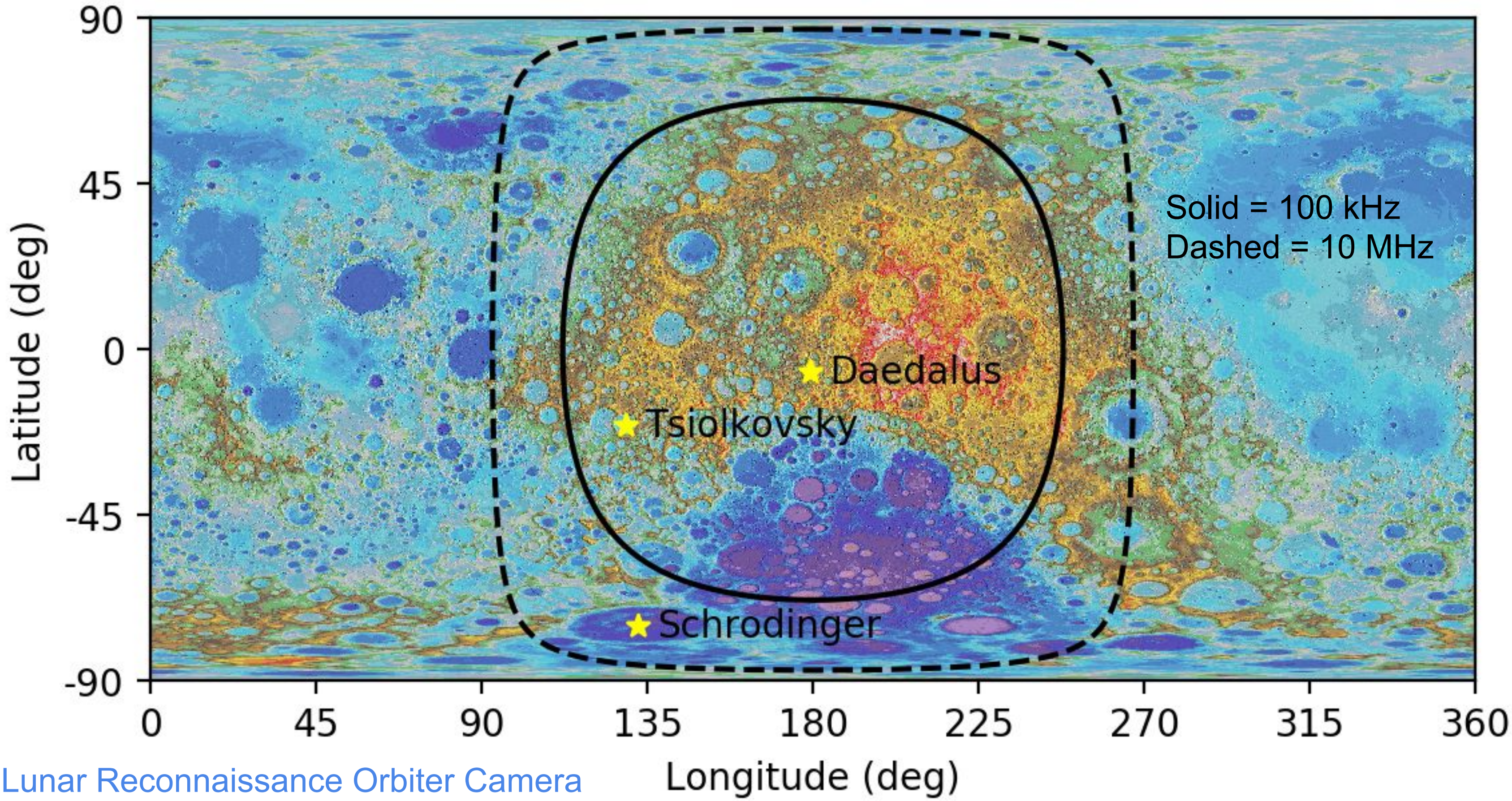


bitbucket.org/nbassett/lunar-rfi

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 and density profile of the Moon do not significantly affect the size of the radio quiet zone

- At frequencies above 10 MHz, nearly all of the farside, including the South Pole Aitken Basin, are shielded from terrestrial RFI at the 80 dB level

Extra Slides