Lunar science at low radio frequencies

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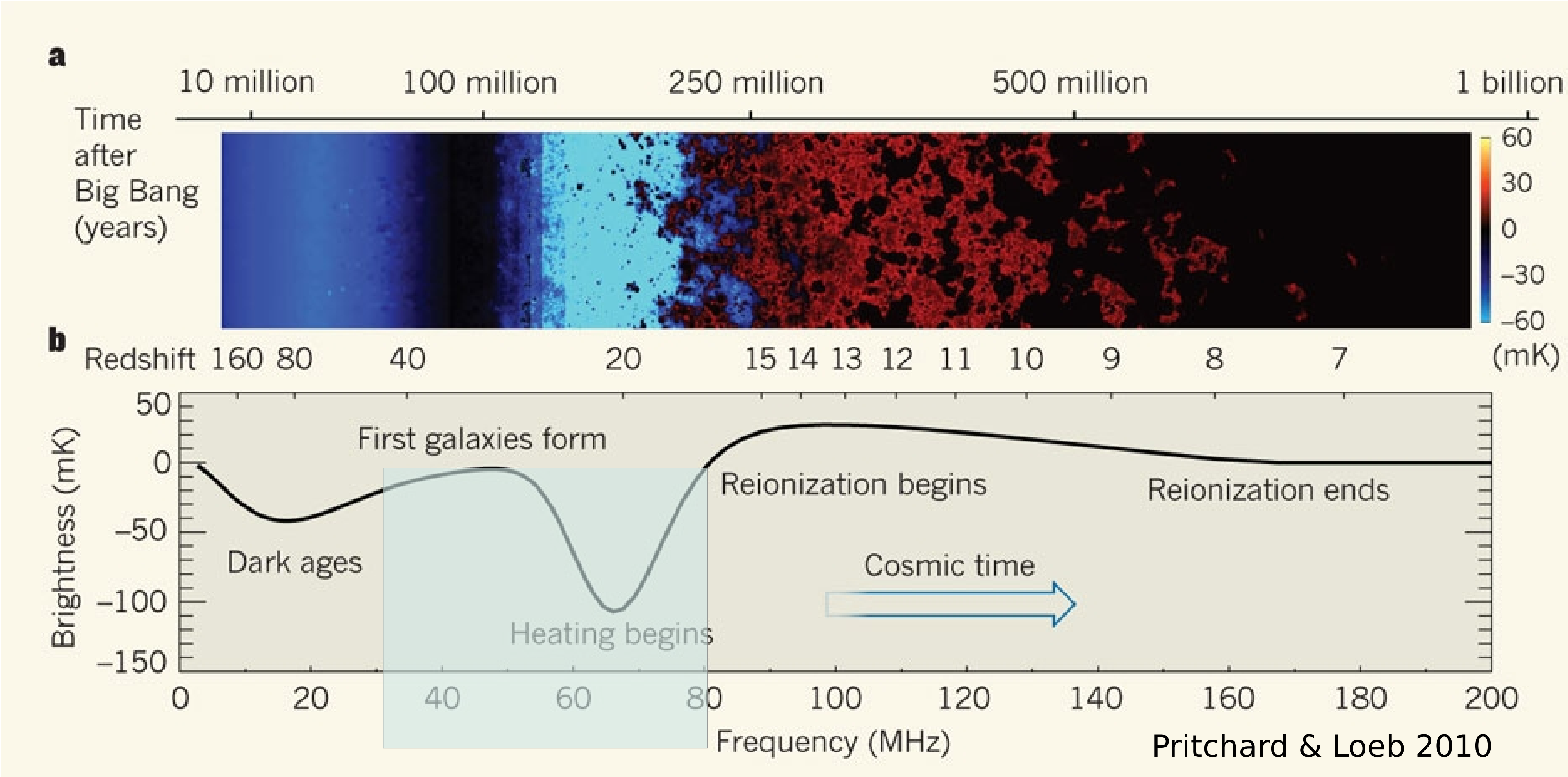
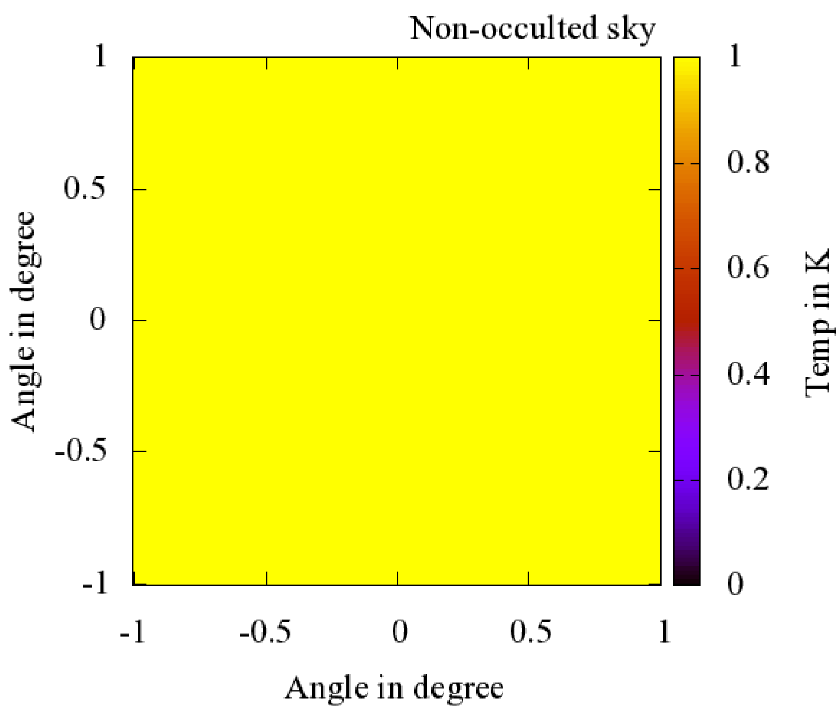
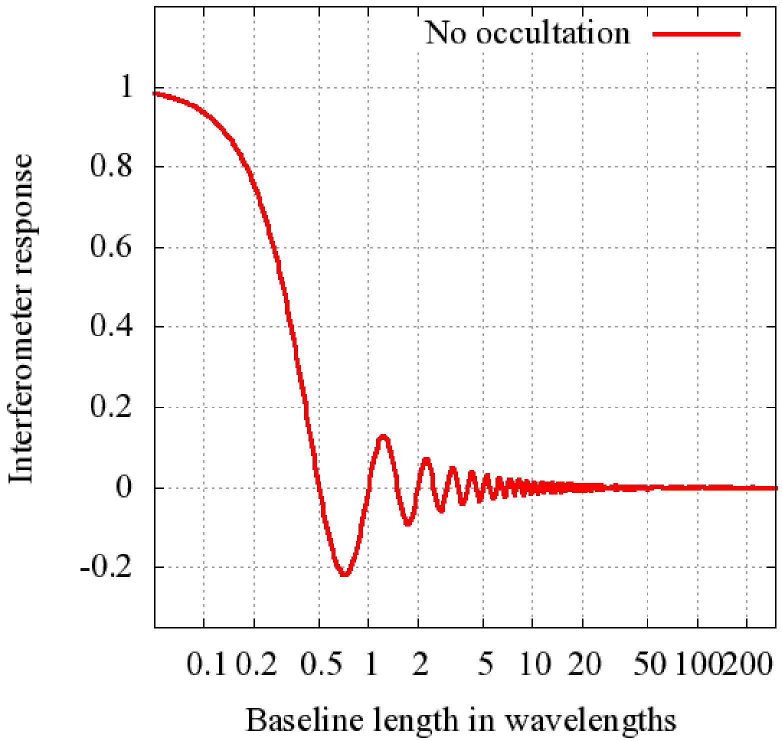
The 21-cm global signal



Position depth and width of the absorption feature is a tracer of Lyα and X-ray flux from the first stars

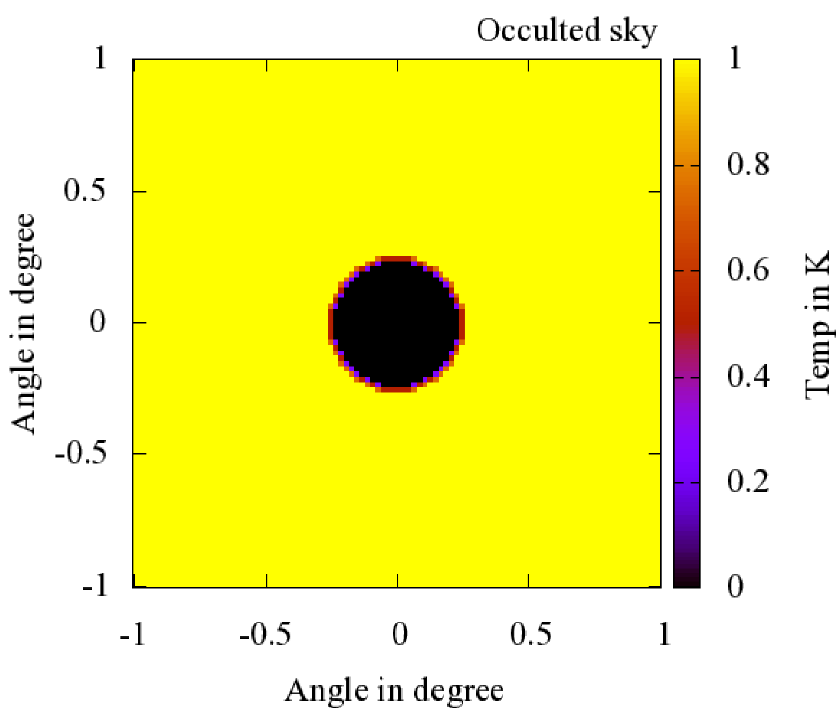
Occultation as seen by an interferometer

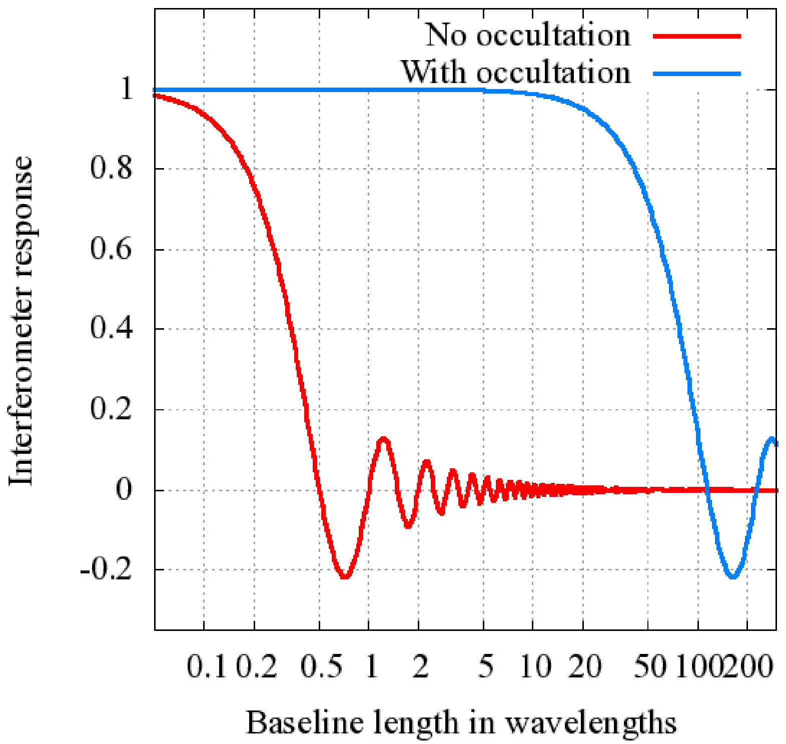




A radio interferometer cannot measure a global signal

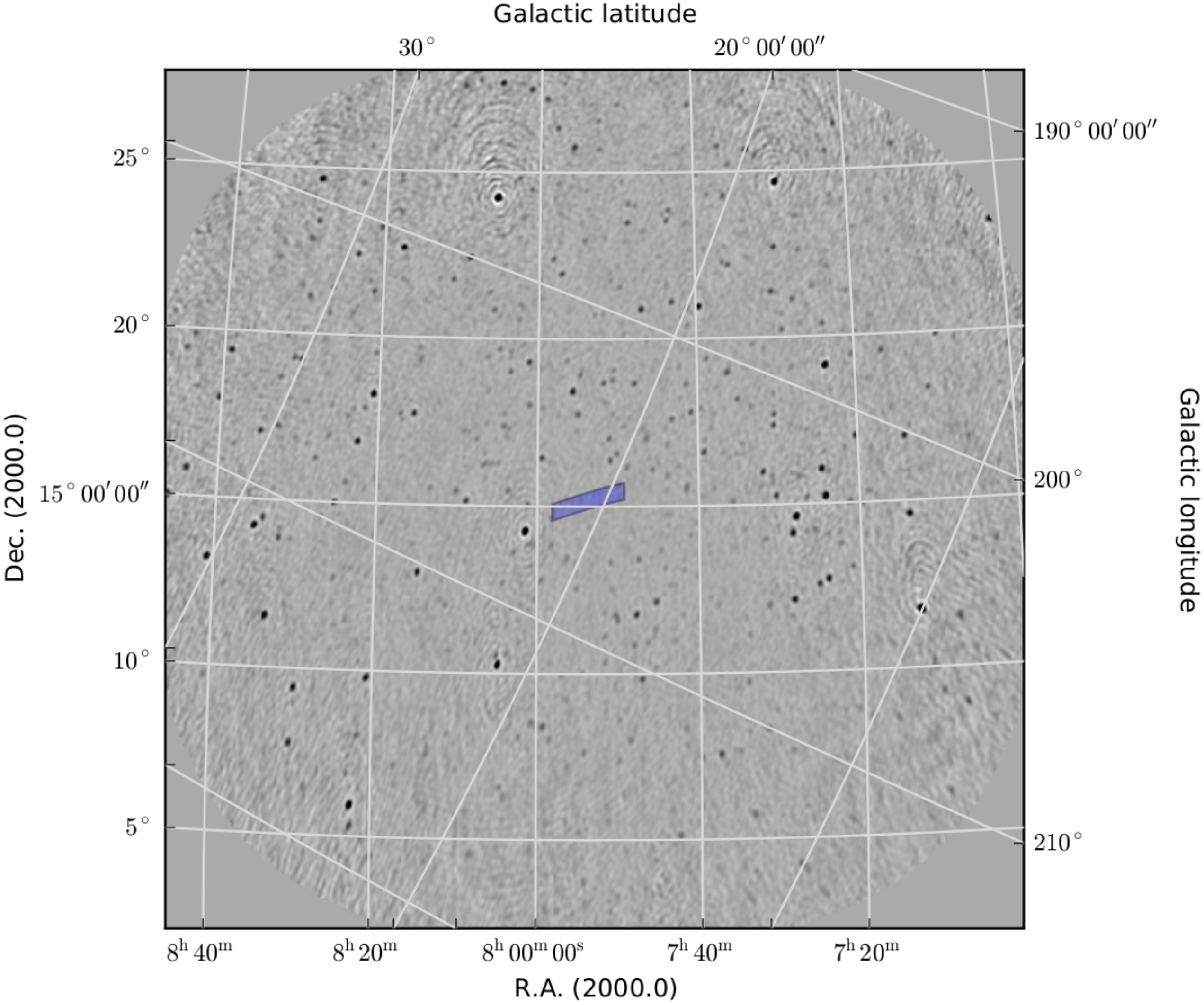
Occultation as seen by an interferometer





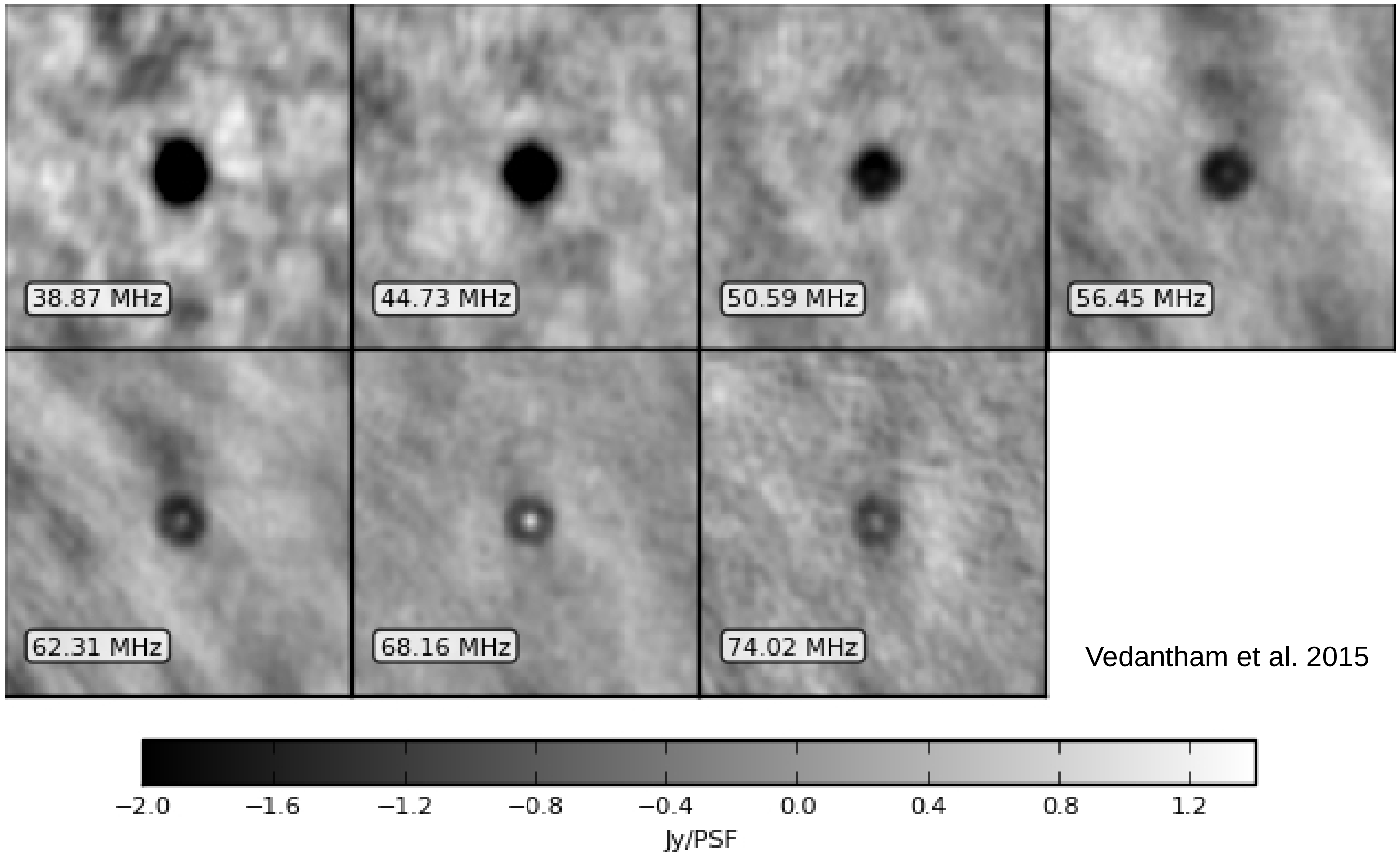
Interferometers measure the brightness difference between the occulting object T_M and the background T_B

Synthesis image of Moon in the field



Need to fringe-stop on topocentric position of the Moon

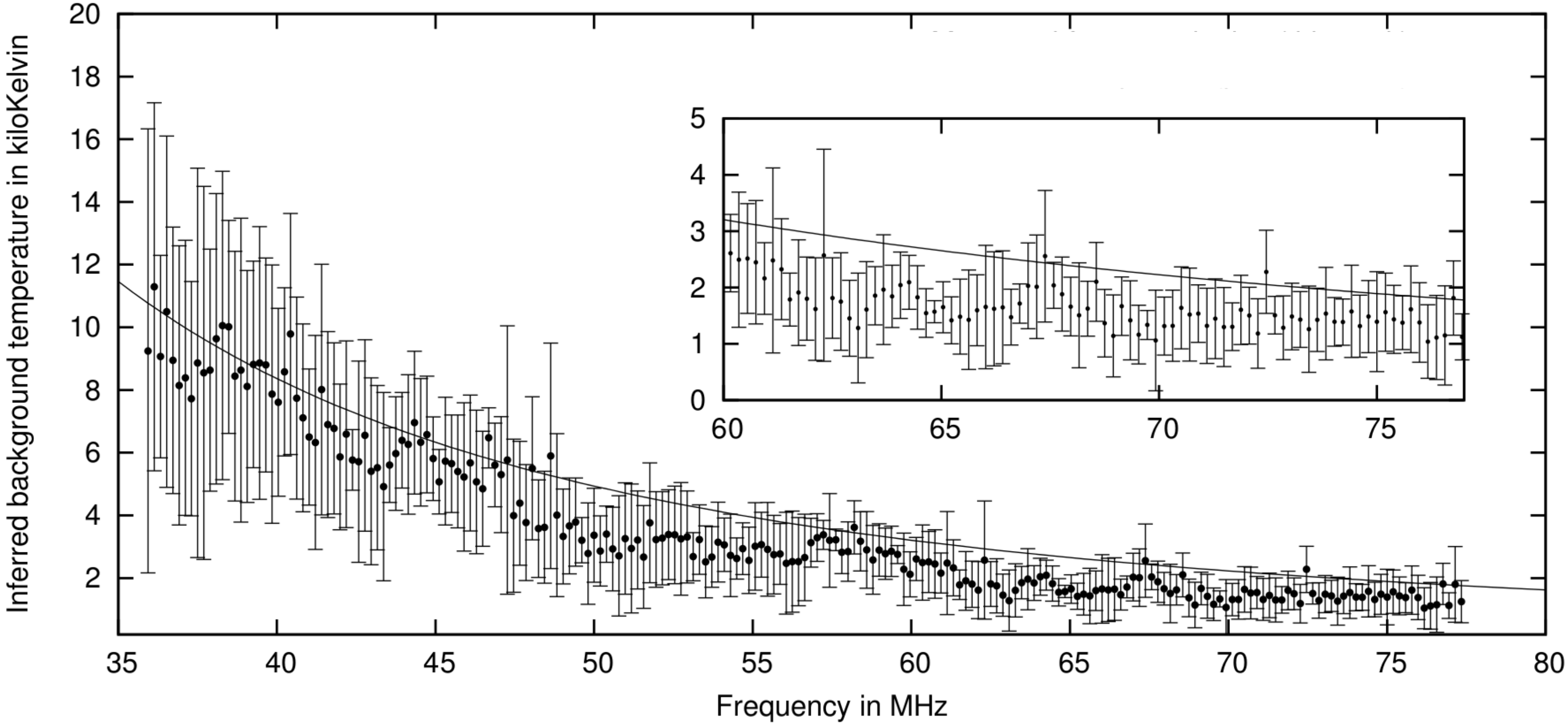
The Moon – a hole in the sky (Commissioning)



Vedantham et al. 2015

Reflected RFI (Earthshine) images to the center of the lunar disc, due to specular nature of reflection

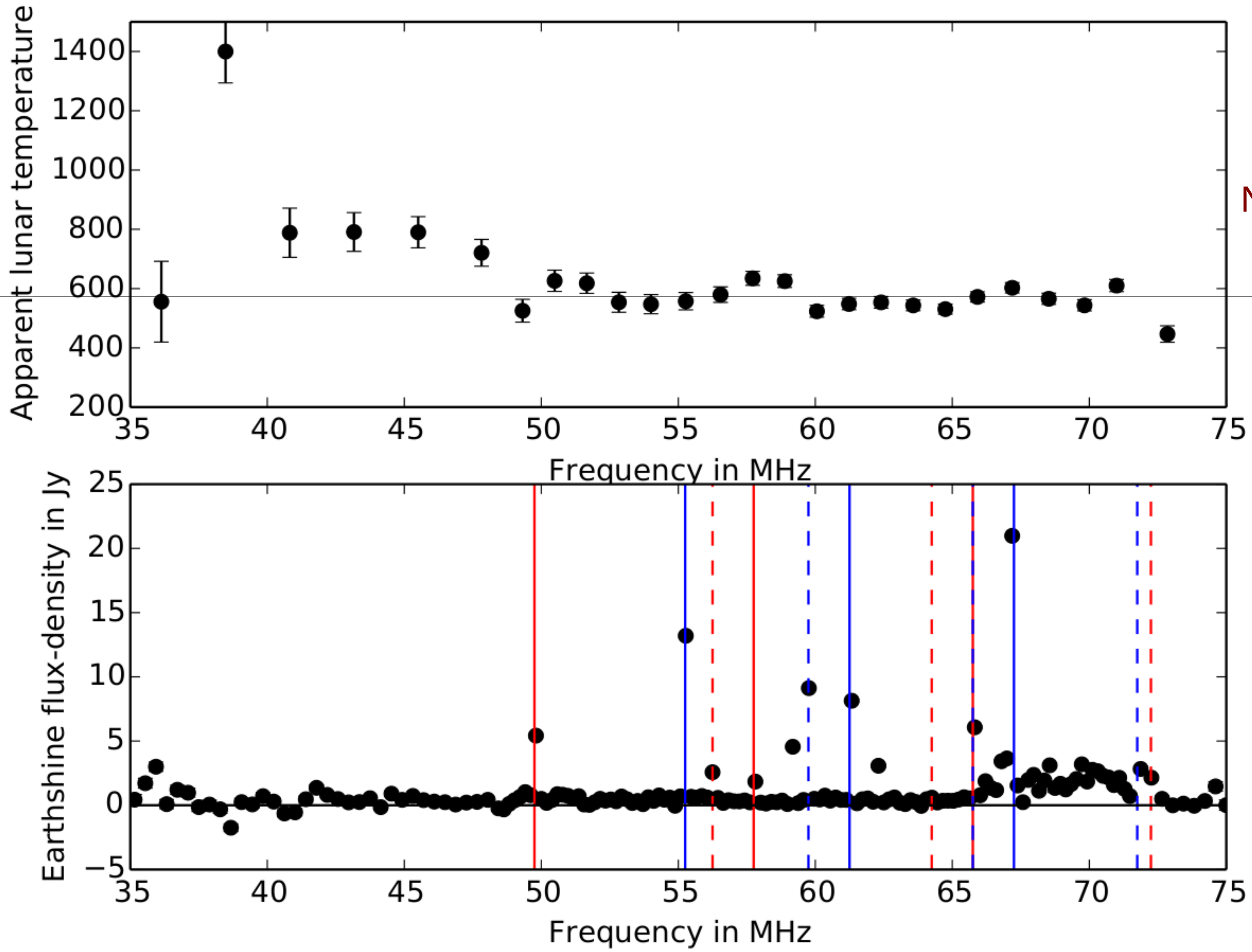
Moon – background temperature contrast (Commissioning)



15-20% ripples due to sidelobe noise

Need to exploit the fact that the Moon moved by 12 deg per day

Inter-night differencing results (new data)

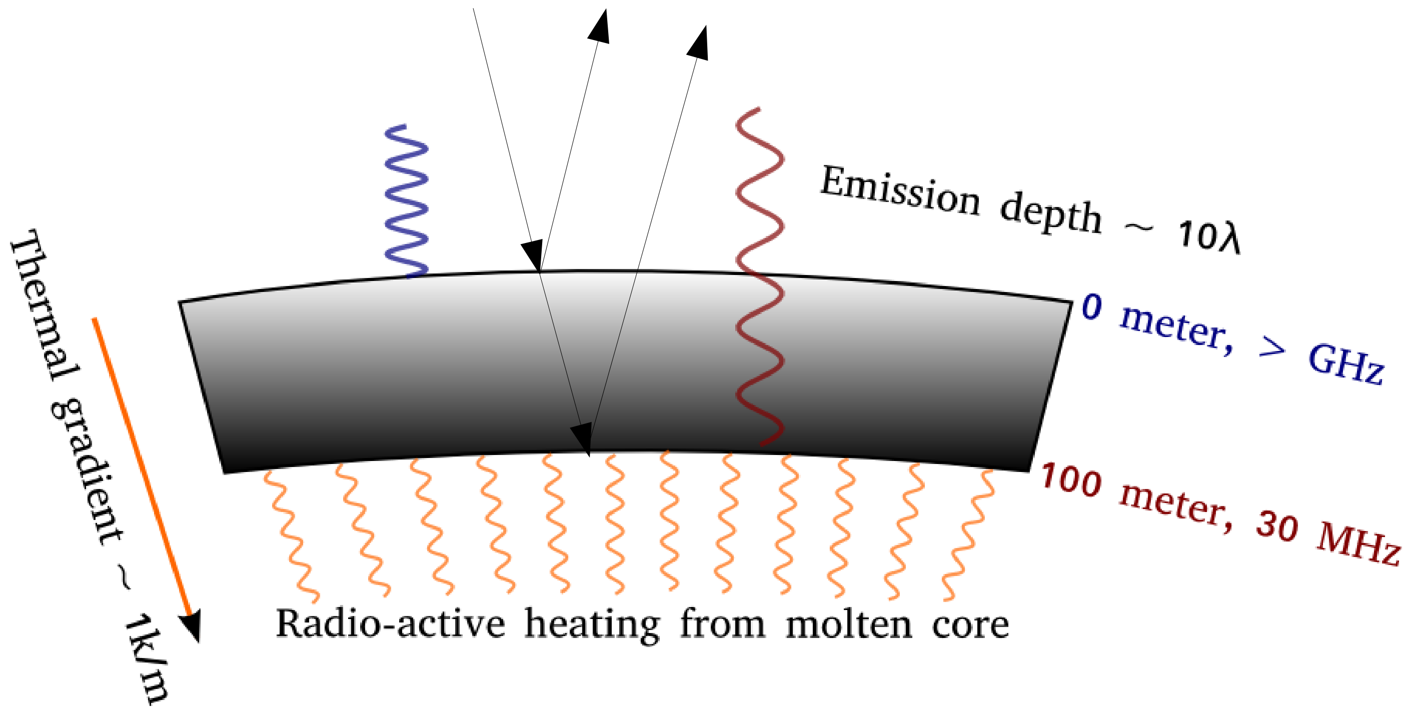


Need absolute calibration to establish Tmoon

OV-LWA?

Scatter is now ~50 K

What is the expected brightness temperature of the Moon?



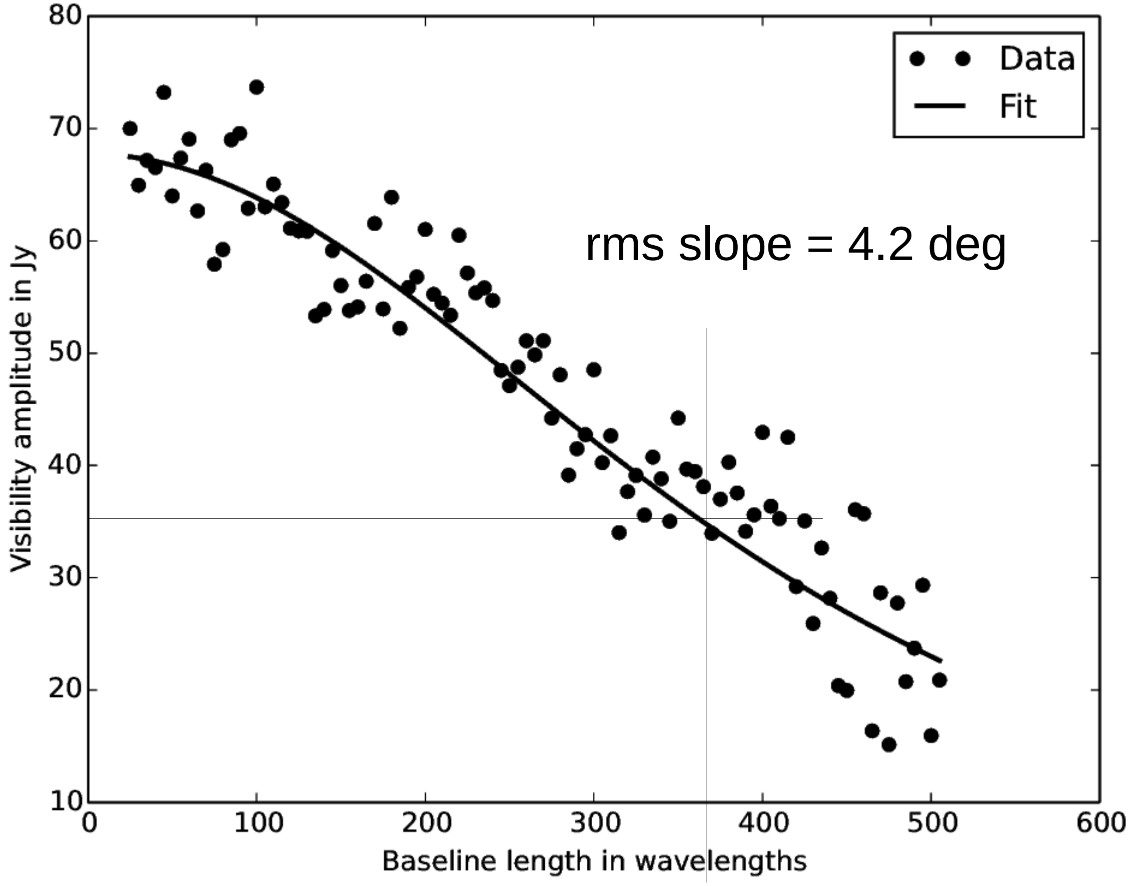
"Open" questions:

1. Evolution of thermal conductivity with depth (regolith heat flow)

2. Whether fractured substrate or boulders?

3. What is the depth of the substrate in the maria and highlands?

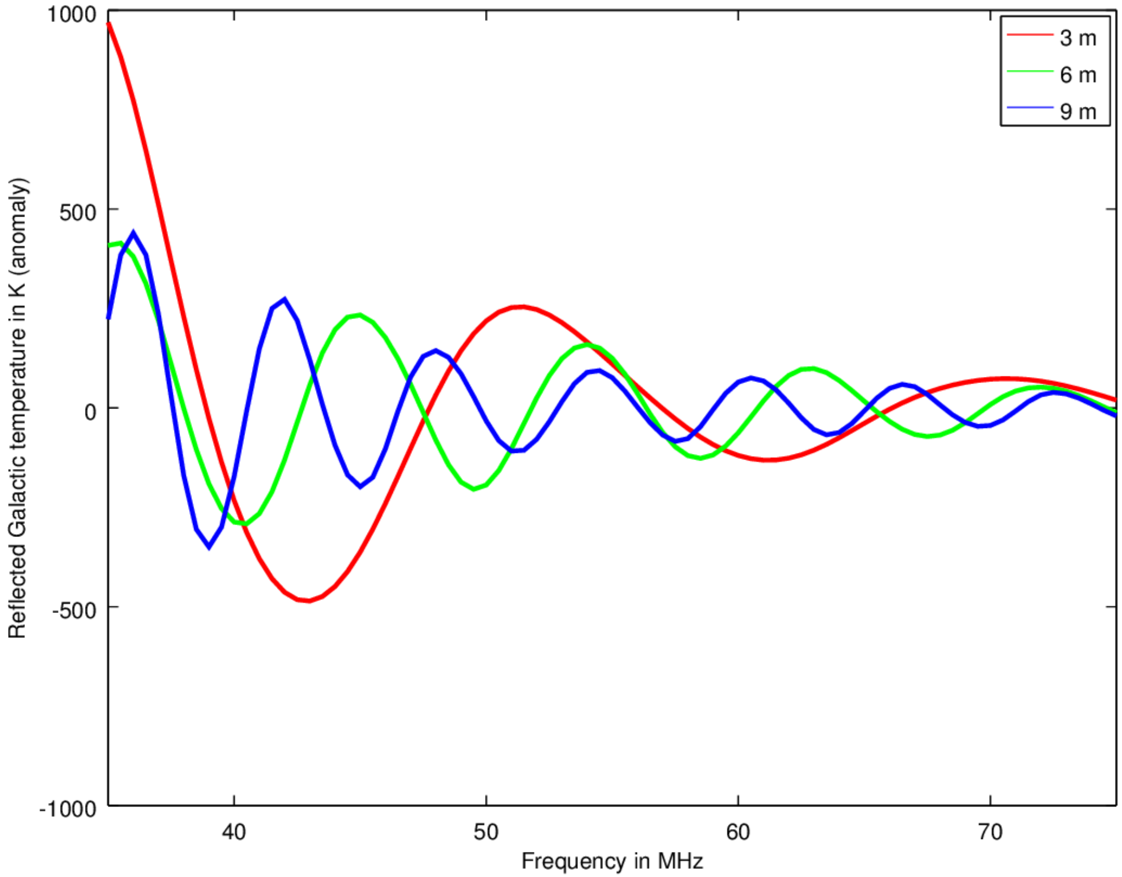
Reflected RFI resolved !



Angular distribution of the RFI “spot” has information on regolith slopes (quasi-specular)
Baselines > 500 lambda have limited use

Very little Rayleigh component → Fractured rock rather than rubble pile

Albedo may be frequency dependent due to thin-film interference (think of soap bubbles)



Might be a show-stopper for cosmic dawn experiment (future work)
Wealth of information on regolith vertical structure (first 10s on meters)

Conclusions

Inter-night differencing has largely mitigated sidelobe confusion
Spectral ripples at ~ 50 K levels, Should reach 5 K level (1 MHz) with DD calibration

Could be due to think film interference (pending confirmation)
Important implications for occultation and Moon-based cosmic dawn experiments

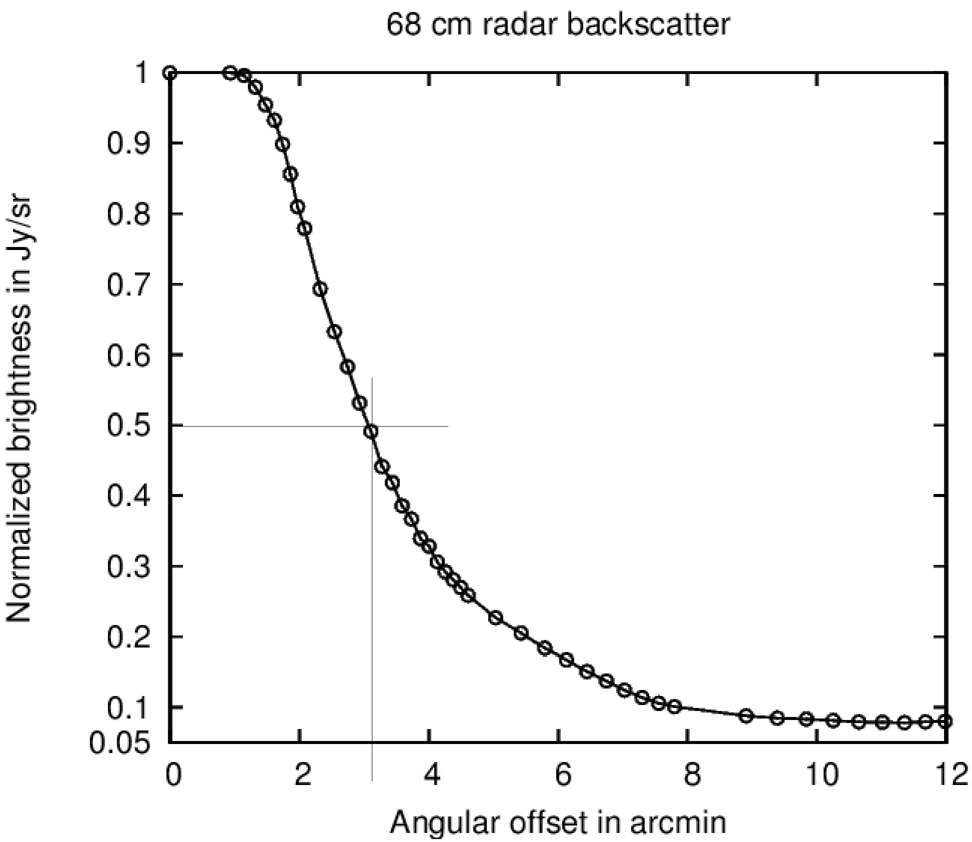
Reflected RFI resolved → rms slope = 4.2 deg (fractured rock instead of boulders)

Ongoing work

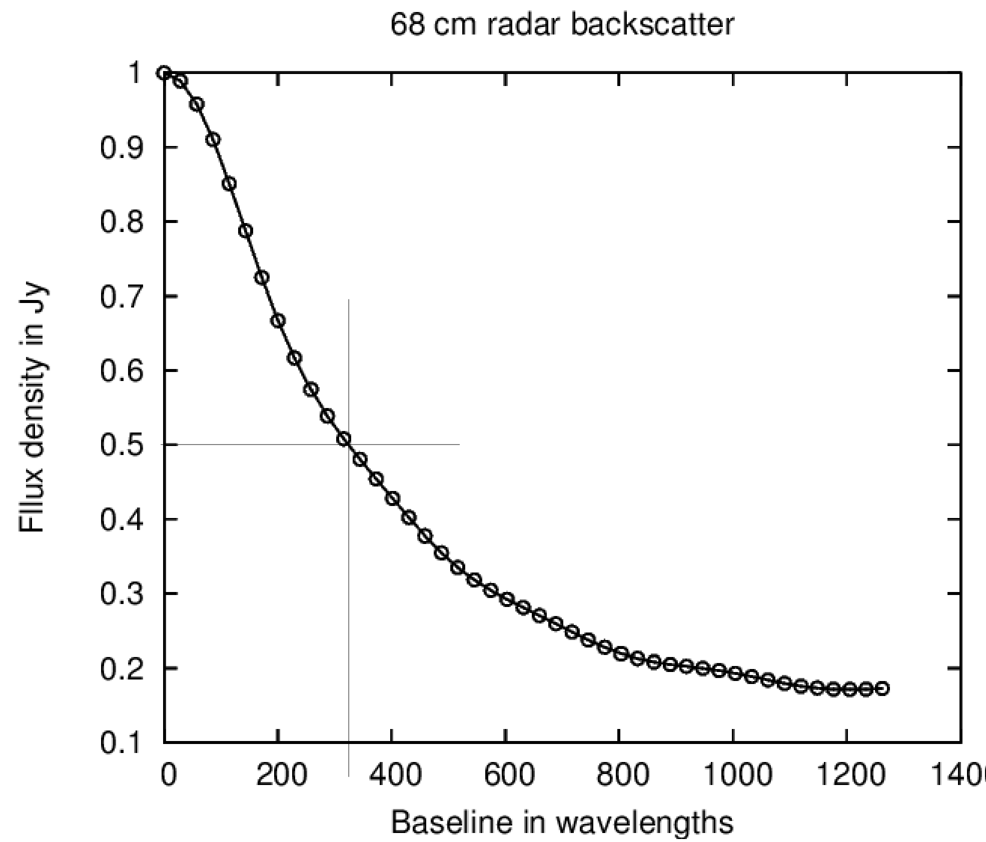
100-200 MHz (LOFAR) + 230-470 MHz (VLA) data →absolute calibration to ~ 3 K to do heat flow

OV-LWA has absolute calibrated LEDA dipoles + excellent PSF
Compact configuration gives ~ few Kelvin level uncertainty per night
Need O(100) remote dipoles on intermediate baselines to model reflected RFI flux

Simulations for spectral albedo for plausible bedrock depth statistics.
Direction dependent calibration to improve inter-night differencing.
Confirmation at 100-200 MHz band

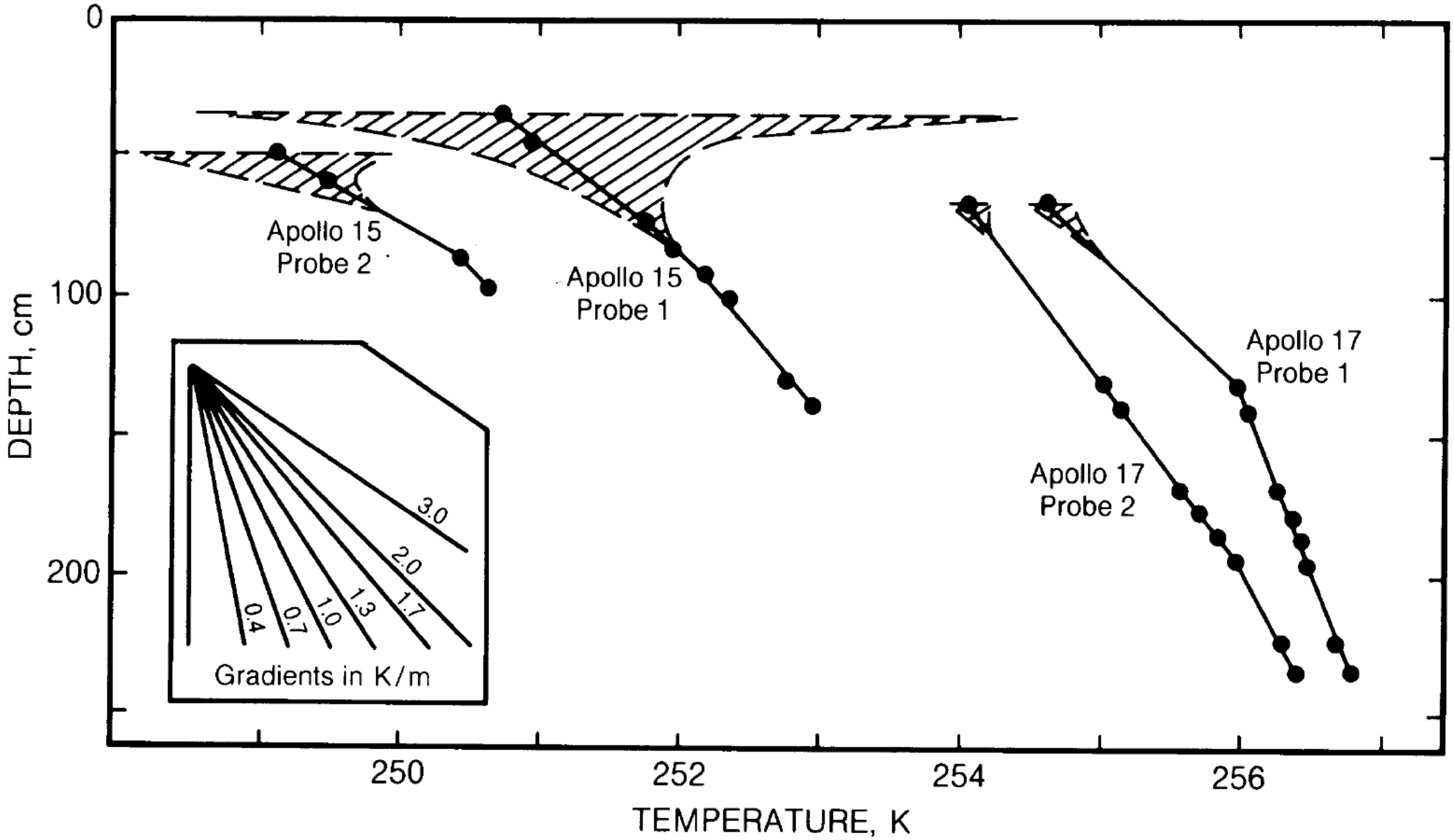


68 cm radar backscatter
Normalized brightness in Jy/sr
Angular offset in arcmin
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.05
0
2
4
6
8
10
12



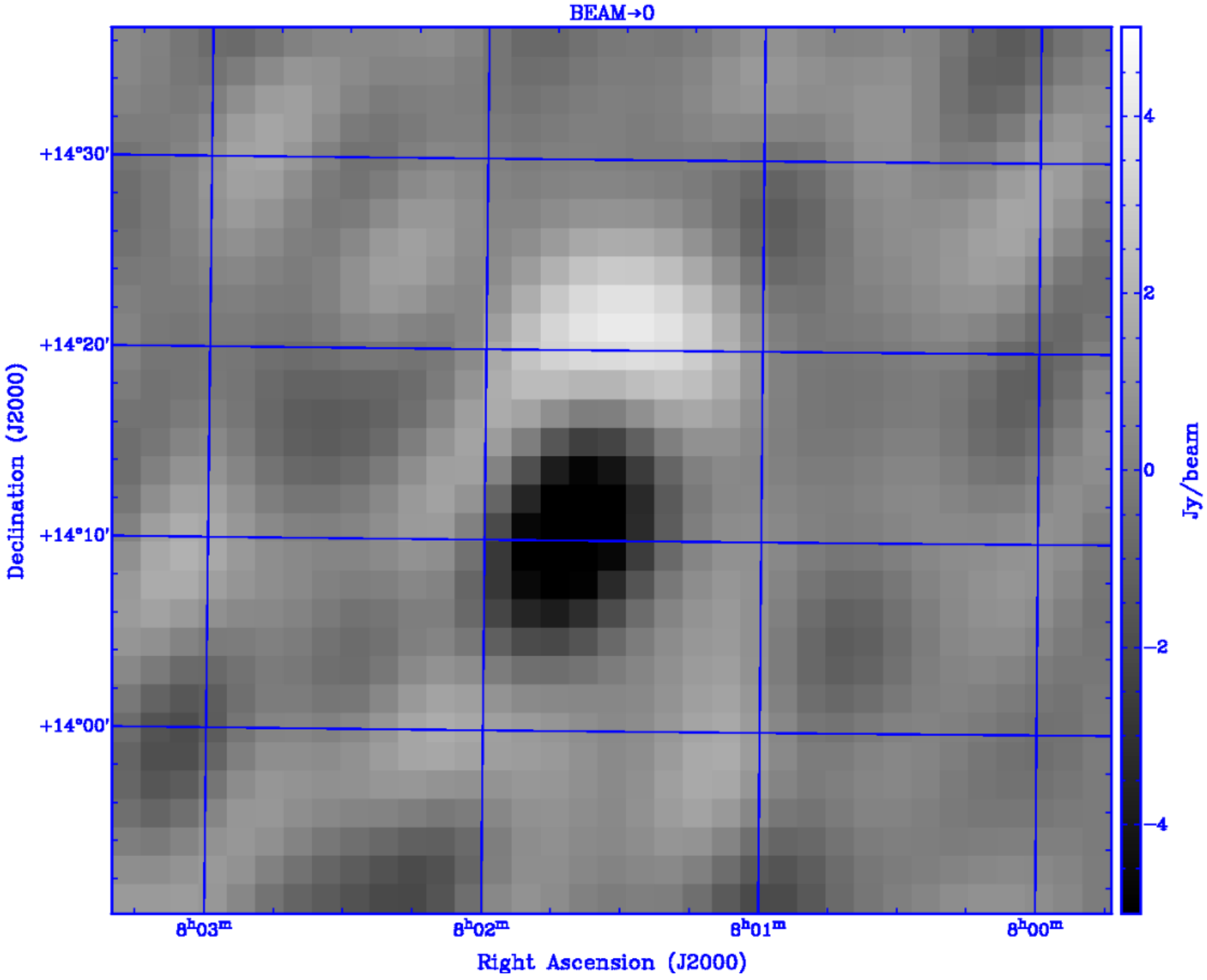
68 cm radar backscatter
Fllux density in Jy
Baseline in wavelengths
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
200
400
600
800
1000
1200
1400

Apollo in-situ measurements



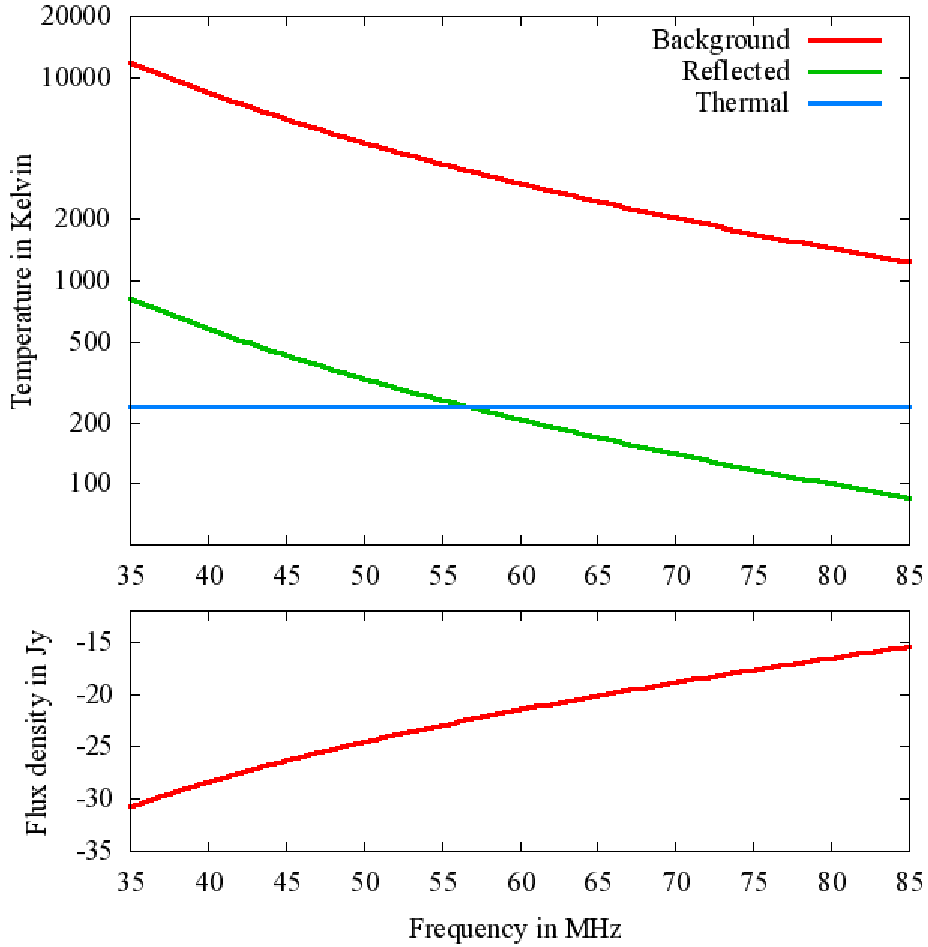
1 Kelvin/meter correponds to 100 K brightness temperature increase at 30 MHz

Differential ionospheric refraction



Sources do not line up on different nights at ~ arcmin level

Expected values of T_B and T_M

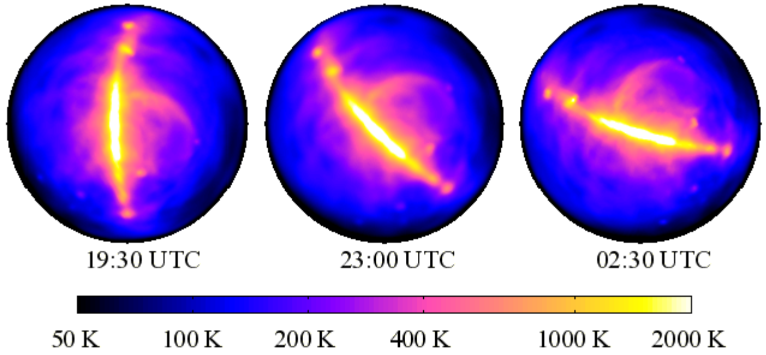


T_B = (Extra) Galactic (3000 K @ 60 MHz)

+ 21-cm signal (10s of mK)

T_M = Intrinsic 240 K blackbody (Heiles & Drake 1963)

+ Reflected Galactic (~200 K @ 60 MHz)



+ Reflected solar (~ 1 K @ 60 MHz)

+ Reflected RFI ? (limiting factor in McKinley et al 2013 ?)

The moon should appear as a negative flux source (-25 Jy) at 60 MHz