Measuring the 21-cm global signal with an interferometer

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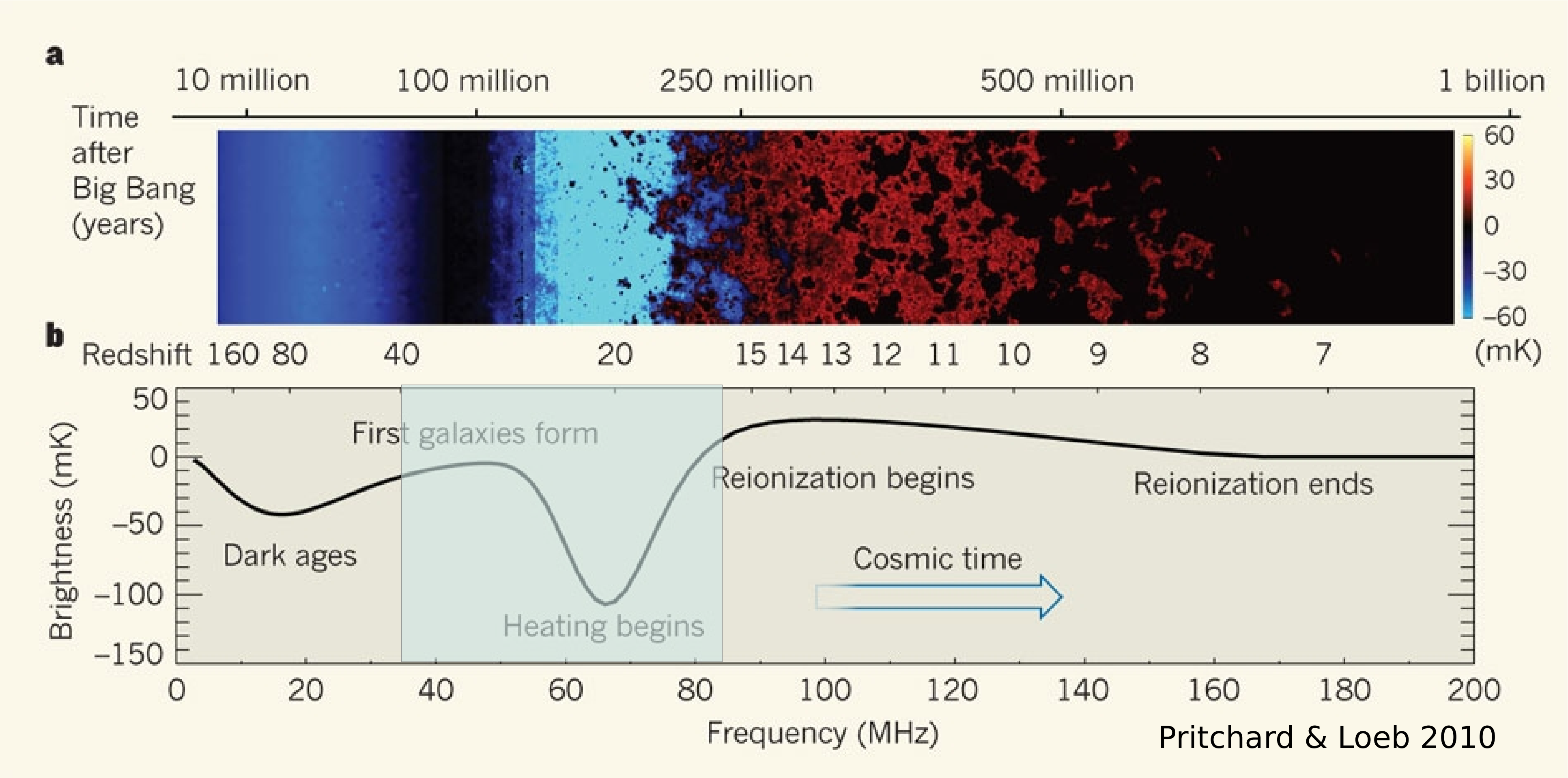
The LOFAR EoR team

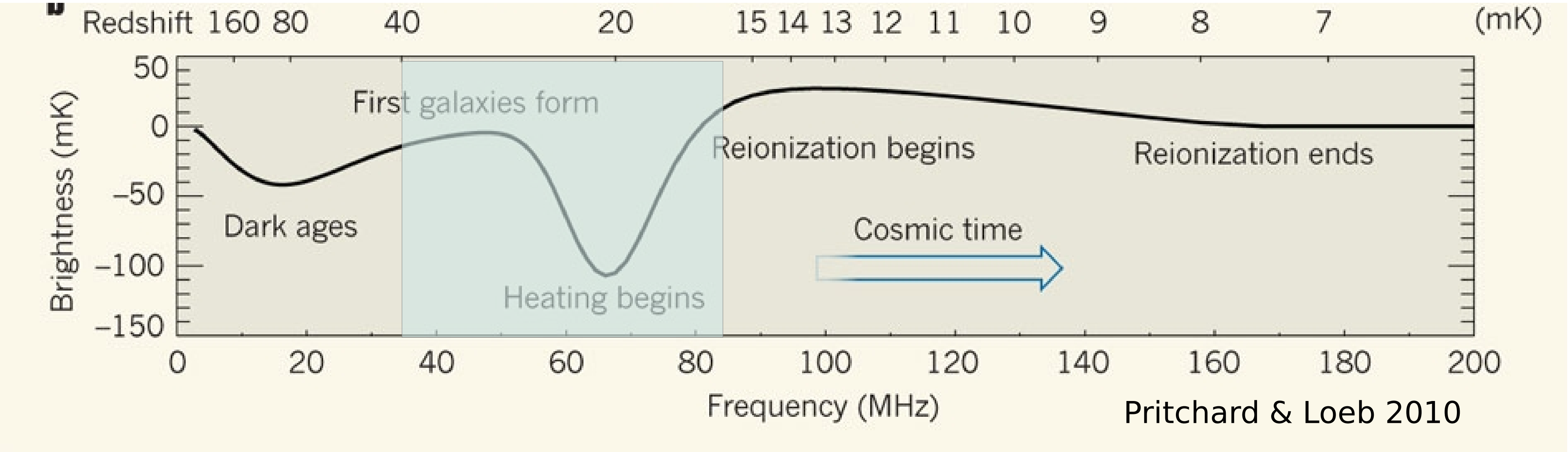
The 21-cm global signal



Pritchard & Loeb 2010

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

Its not a sensitivity issue



Pritchard & Loeb 2010

T_{sky} = 3000 K @ 60 MHz

ΔT_{rms} = 35 mK in 1 MHz channel after 1 hour integration

(with a single dipole !)

Its a calibration issue. Single dipole total-power measurements are difficult to calibrate.

Is there an alternative ?

Interferometer are relatively easier to calibrate

↓

But interferometers are insensitive to a global signal

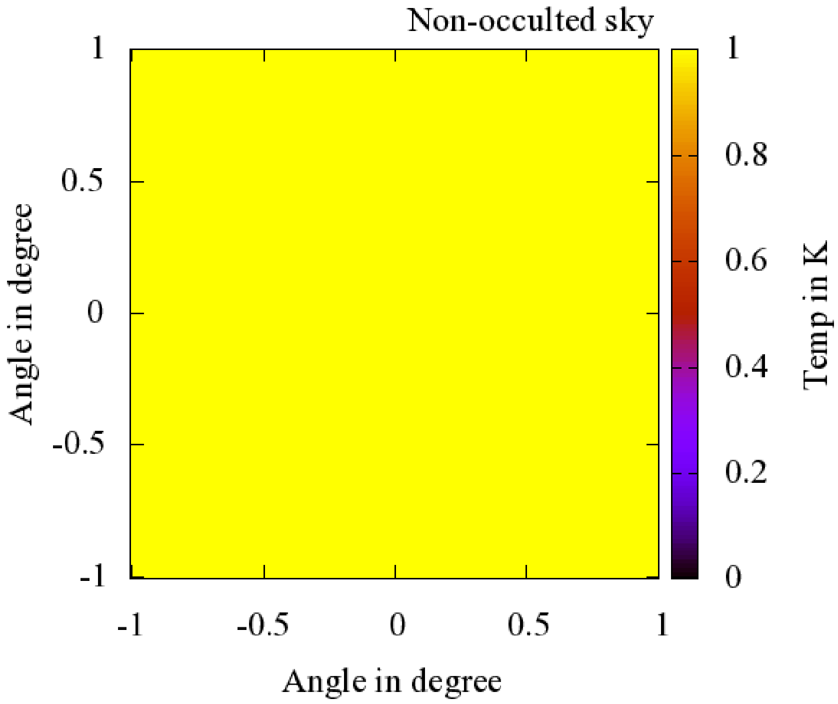
↓

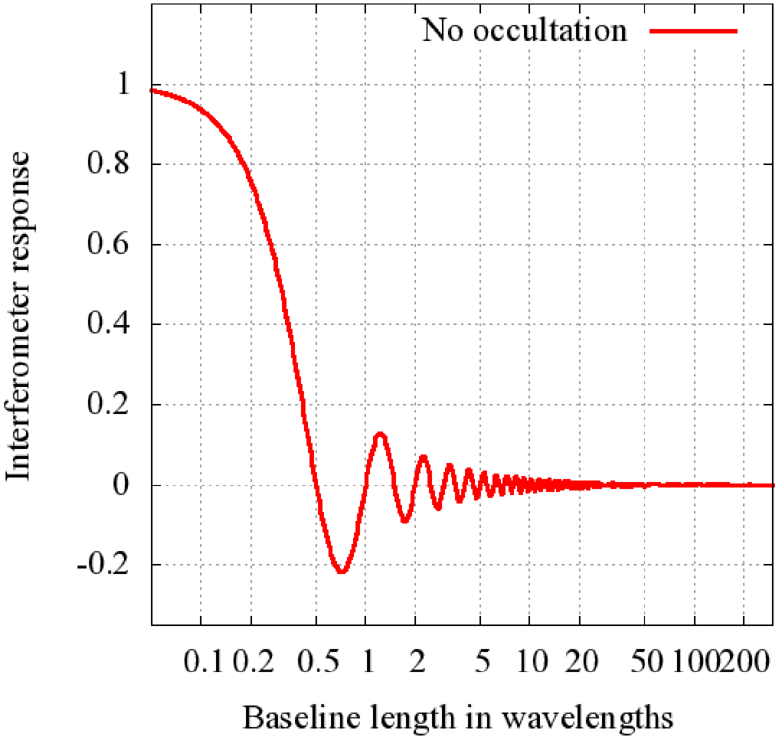
True, but they are sensitive to occultation of a global signal

↓

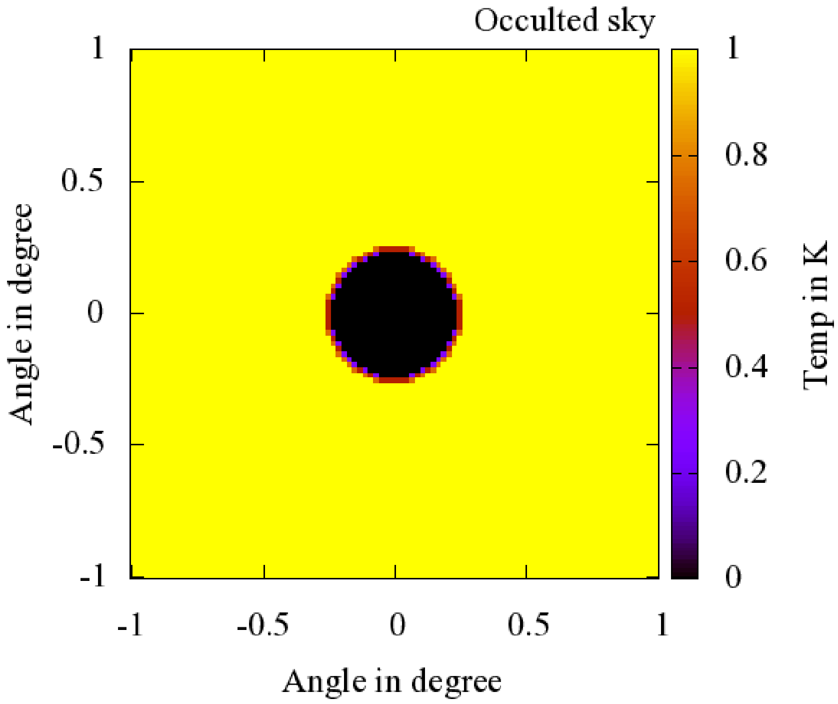
Can we measure the global 21-cm signal interferometrically
via its occultation by the moon ?
(Shaver et al 1999)

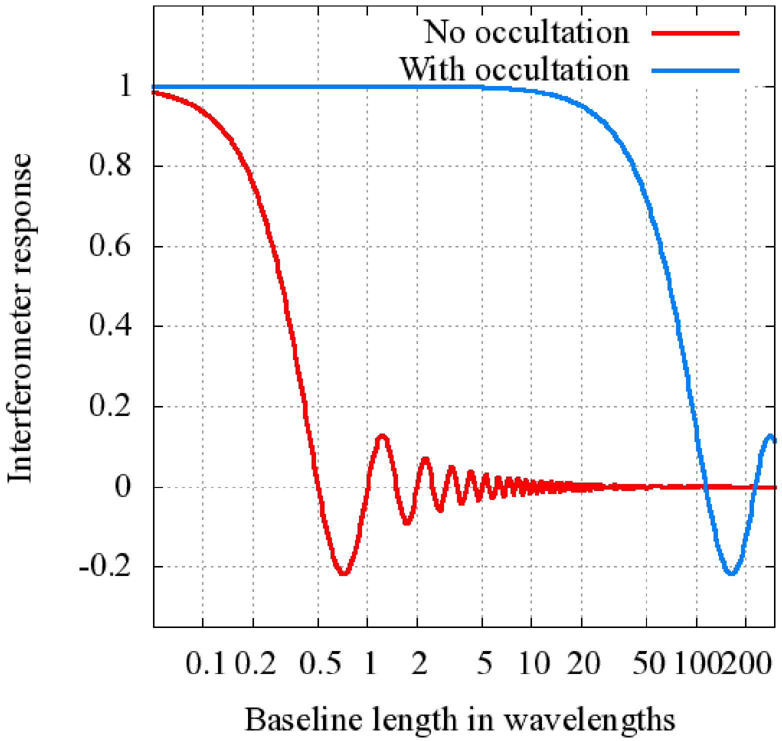
Occultation as seen by an interferometer





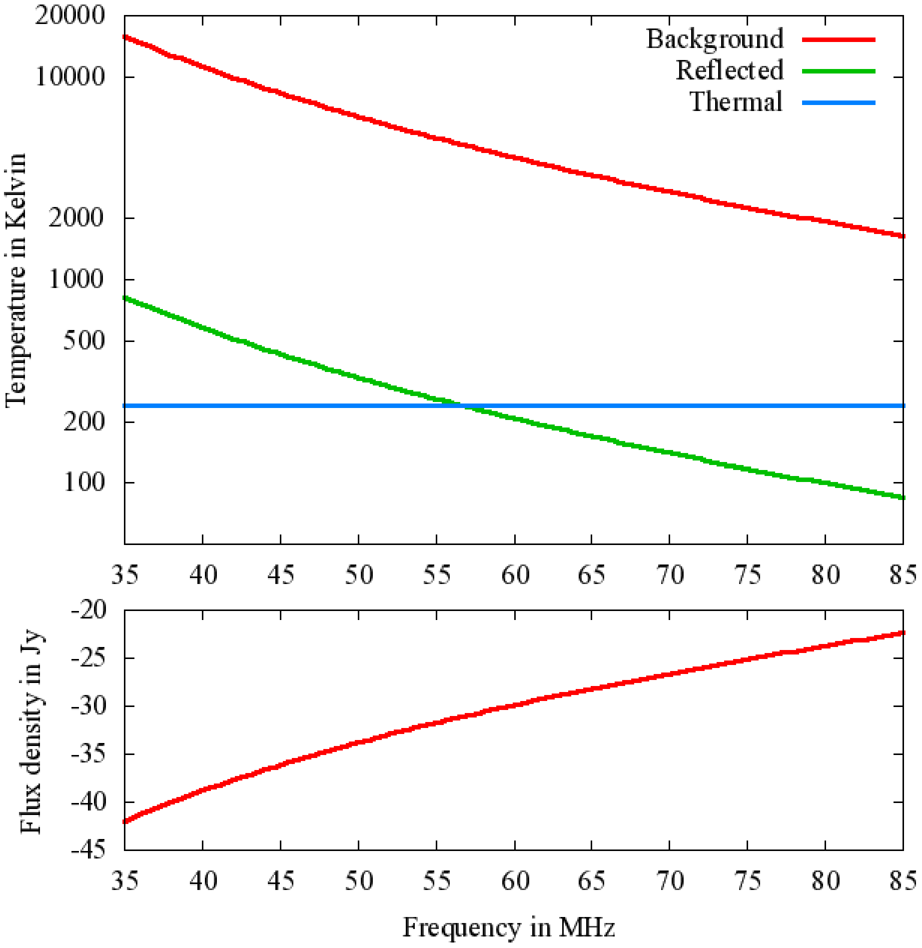
Occultation as seen by an interferometer





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

Expected values of T_B and T_M

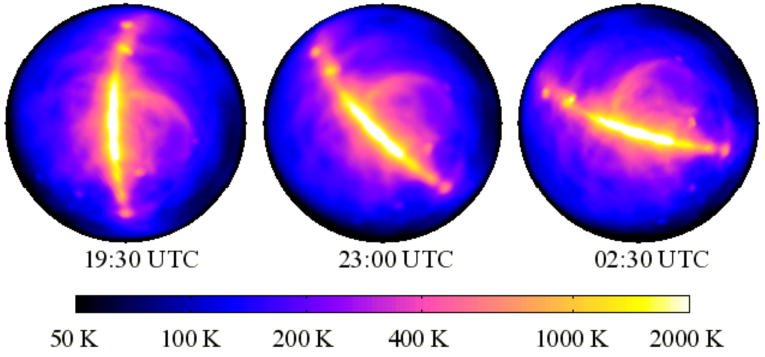


T_B = (Extra) Galactic (3000 K @ 60 MHz)

+ 21-cm signal (10s of mK)

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

+ Reflected Galactic (~200 K @ 60 MHz)

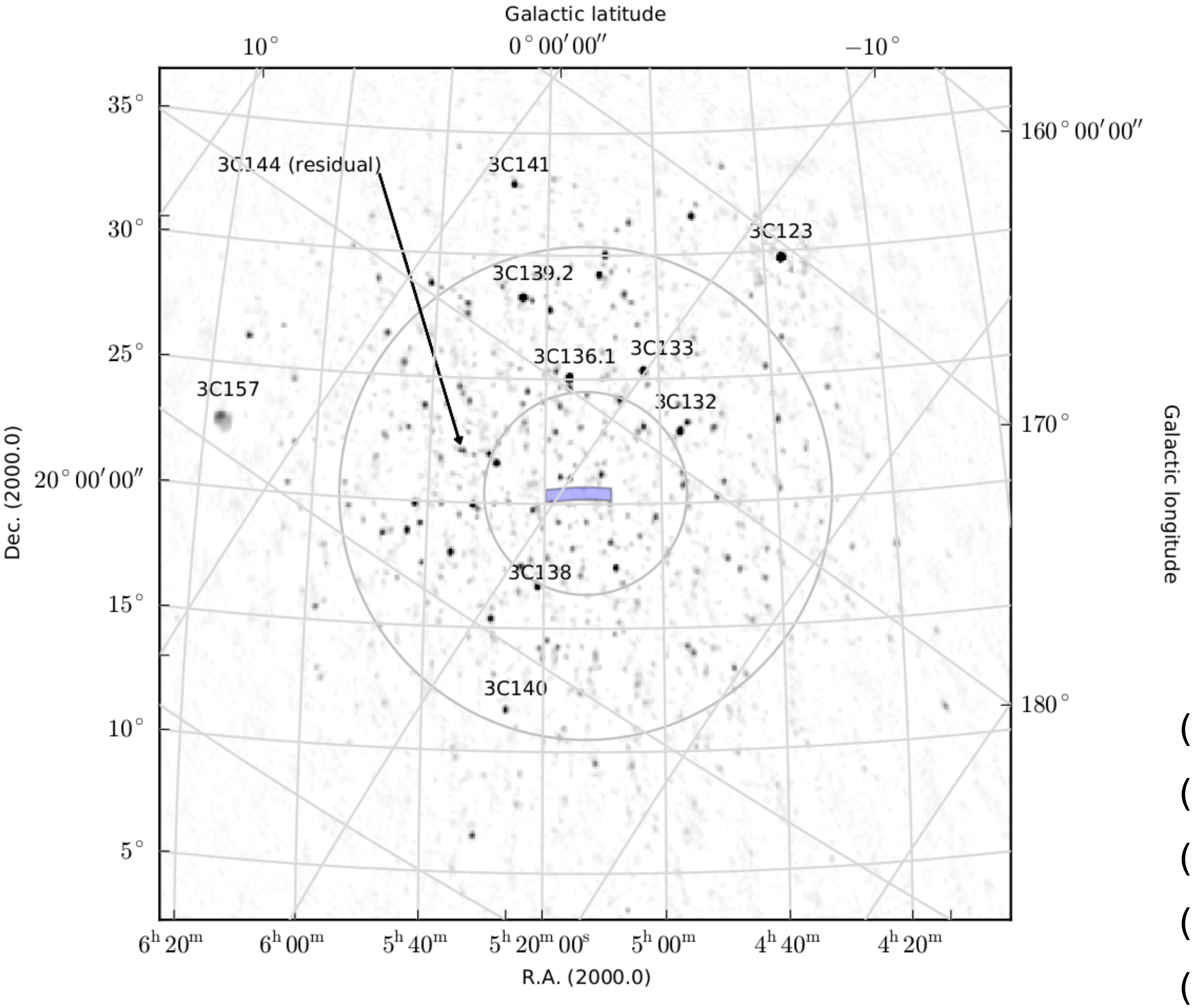


+ Reflected solar (~ 1 K @ 60 MHz)

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

The moon should appear as a negative flux source (-30 Jy) at 60 MHz

LOFAR commissioning data



OBSERVATIONS

Freq range : 35 to 85 MHz
Date : 2012-12-26
Exposure : 7 hours

Beams : 2 (simultaneous)
Beam1 : Lunar transit point
Beam 2 : 3C123 (cal)

stations : 24 core (~ 3 km)
+ 9 remote (~ 50 km)

PRIMARY PROCESSING

(1) Bandpass calibration (3C123)

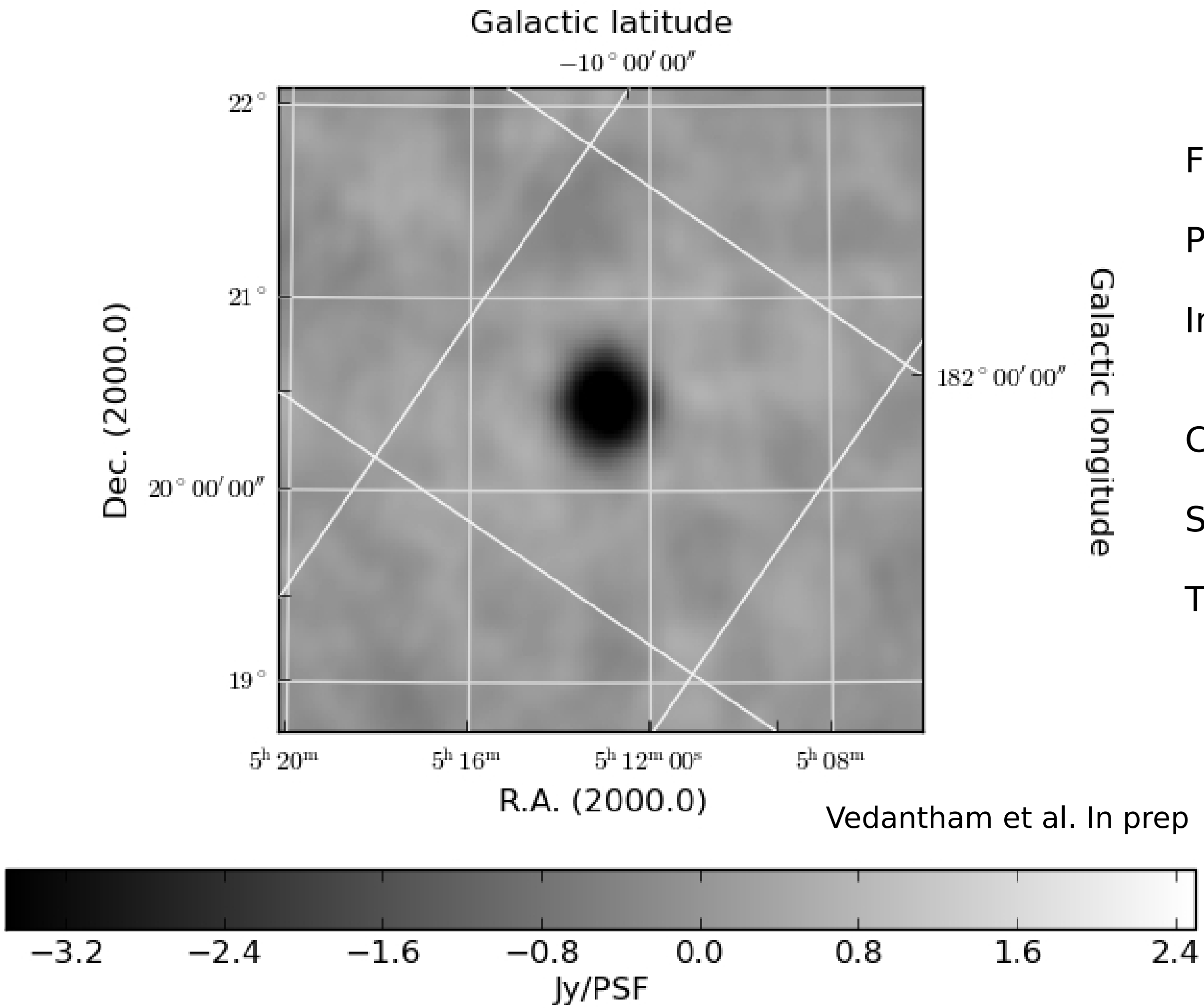
(2) Bright source subtraction (CasA, Crab)

(3) Imaging + faint source extraction

(4) Faint source subtraction (SAGECAL)

(5) Lunar fringe stopping + imaging

A hole in the sky



Vedantham et al. In prep

Freq range = 35 to 50 MHz (continuum)

PSF = 10 arcmin

Image plane noise = 140 mJy/beam

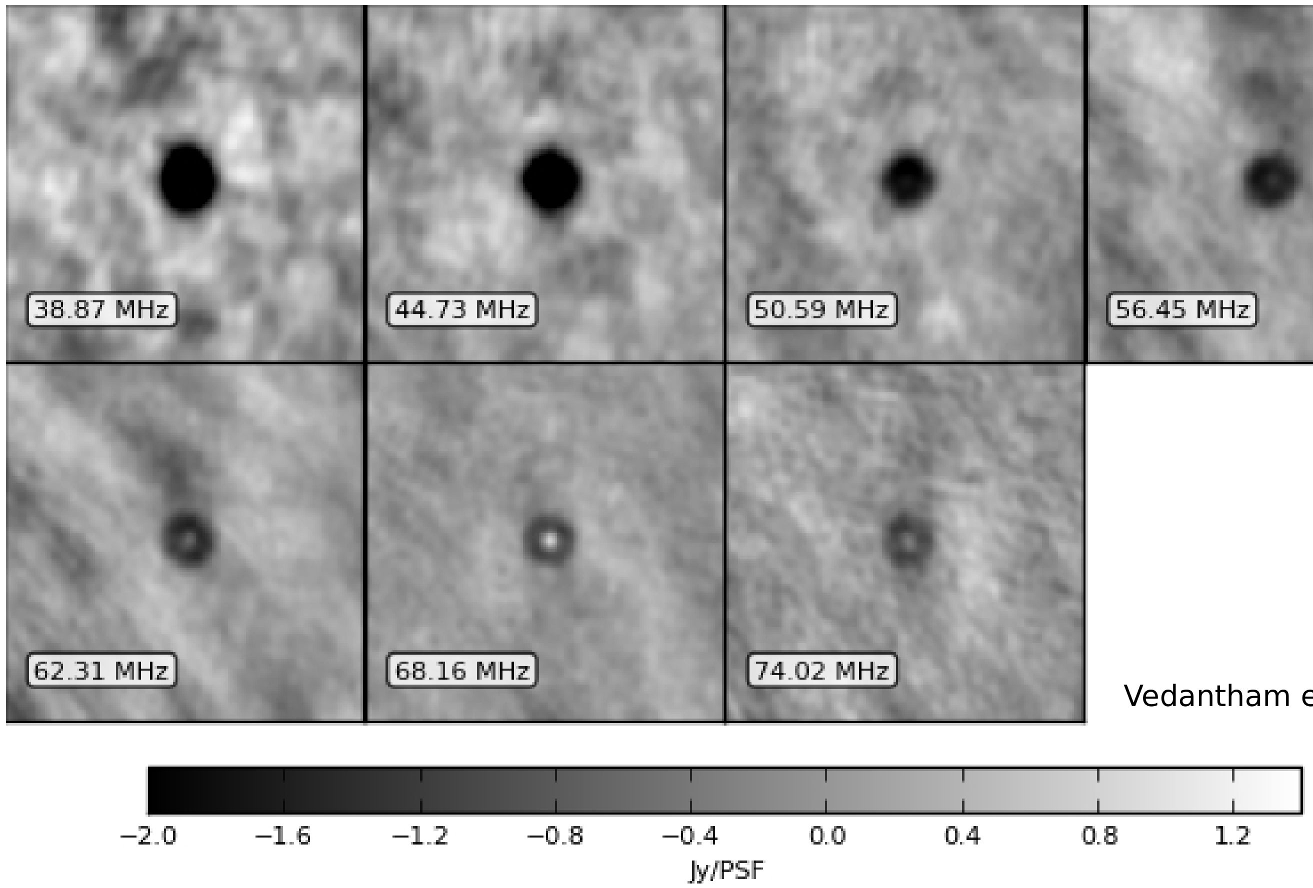
Confusion limit = 25 mJy

Sidelobe confusion (compact src) = 100 mJy

Thermal noise = 10 mJy

We have made the first detection of diffuse galactic emission by observing its occultation by the moon.

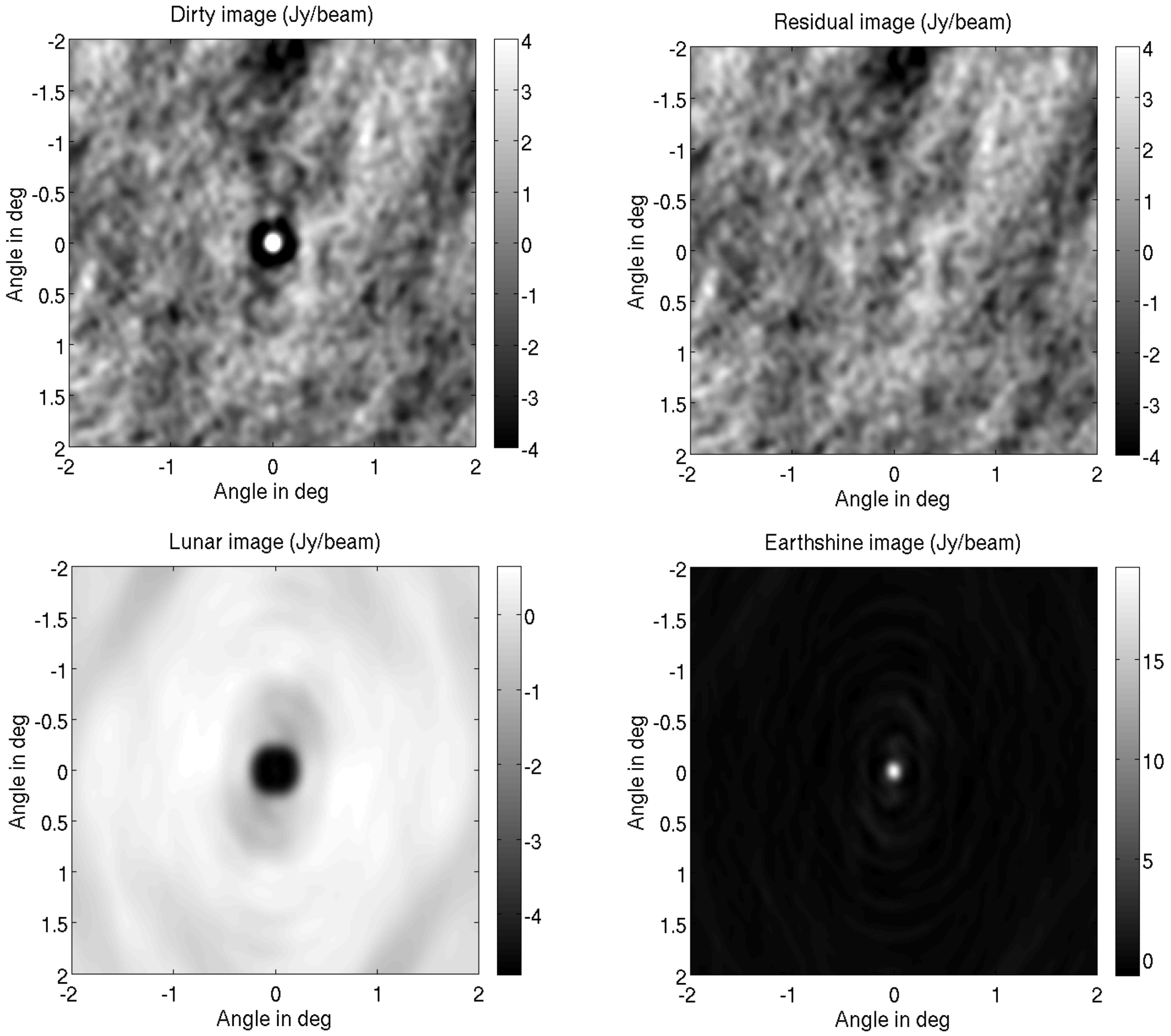
A hole in the sky



Vedantham et al. In prep

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

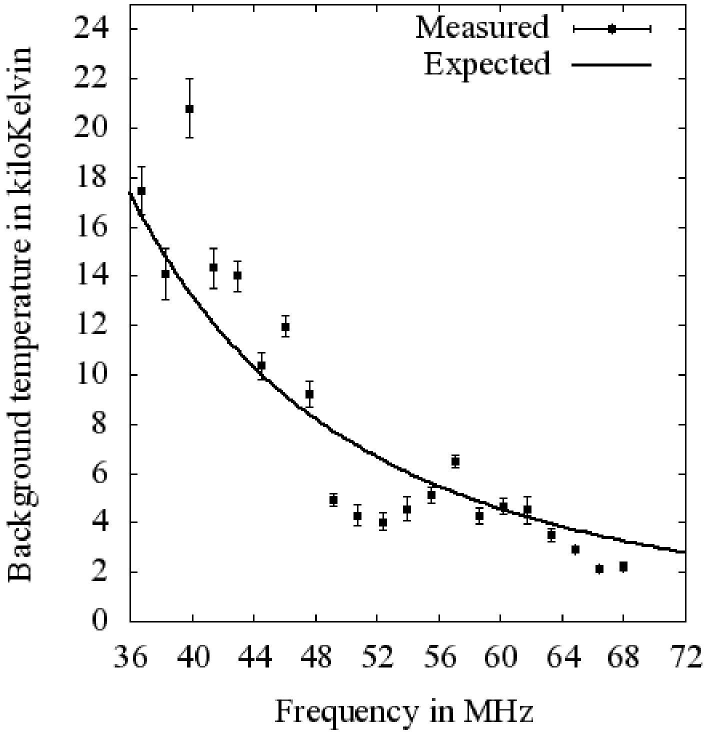
Removing Earthshine

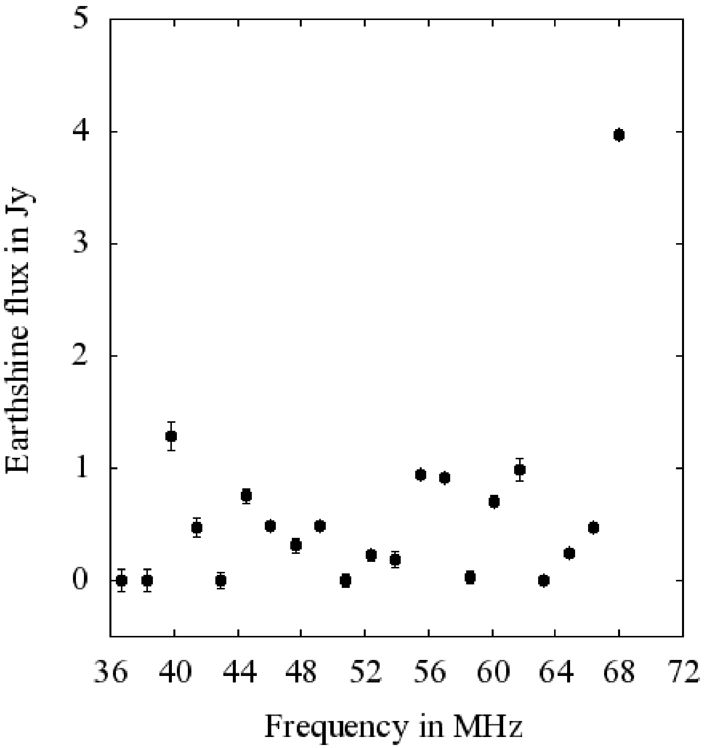


$$\underbrace{\mathbf{d}}_{\text{Dirty image}} = \left(\overbrace{\theta_1}^{\text{Moon flux}} \underbrace{\mathbf{m}}_{\text{Unit disc}} + \overbrace{\theta_2}^{\text{RFI flux}} \right) * \underbrace{\mathbf{p}}_{\text{PSF}}$$

Earthshine can me mitigated using information in longer baselines

Estimated flux of the moon and Earthshine (preliminary)





Bakckground temperature estimates limited by ripple due to sizelobe confusion
Earthshine is < 1 Jy below 72 MHz

Conclusions and outlook

Interferometers can measure an (occulted) global signal

- Alternative observational route for 21-cm experiments?

First detection of diffuse emission via lunar occultation

- No surprises (to first order) in lunar brightness temperature
- The moon is a good noise reference

Earthshine can me modeled and removed using long baselines

- Earthshine is within ~1 Jy below 72 MHz (implications for moon-based experiments)

Background spectrum measurements limited by systematic ripple due to large scale Galactic emission

- Filtering in freq,time,baseline space with current data?
- Need sufficient short baselines to model and remove large scale Galactic structure
- Inter-day differencing ? (Awaiting data this Dec from LOFAR cycle 1)