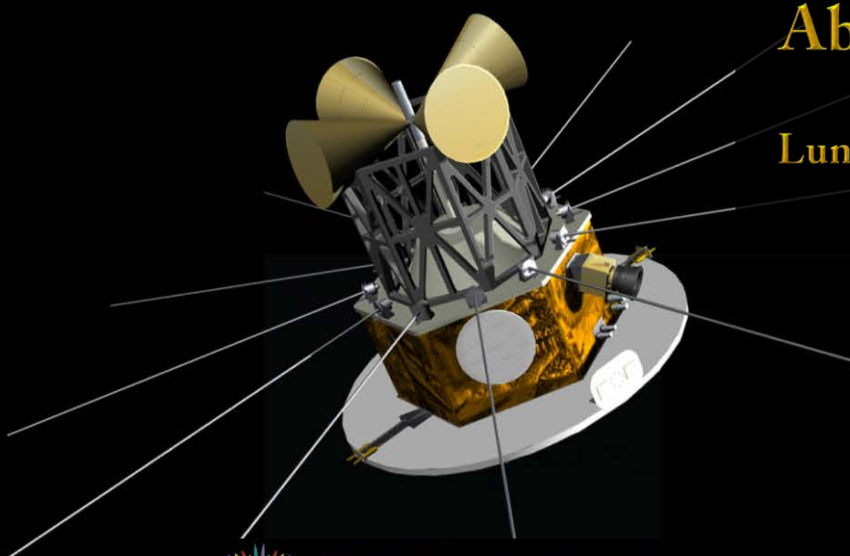
DARE

DARK AGES RADIO EXPLORER

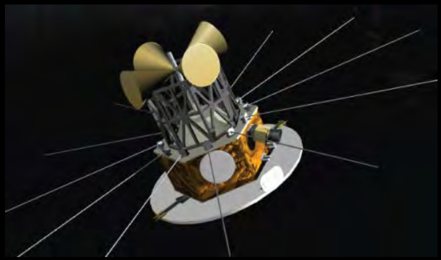
Abhirup Datta for the DARE Team

University of Colorado Boulder,
Lunar University Network for Astrophysics Research,
& NASA Lunar Science Institute



LUNAR UNIVERSITY NETWORK for ASTROPHYSICS RESEARCH

DARE
DARK AGES RADIO EXPLORER



DARE PROJECT TEAM

Principal Investigator:
Jack Burns, U. Colorado

Deputy Principal Investigator:
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Project Manager:
Daniel Andrews, ARC

Deputy Project Manager:
Jill Bauman, ARC

Spacecraft PM:
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Ball Aerospace

Instrument Manager:
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Collaborator: Michael Bicay, ARC

Science Co-Investigators

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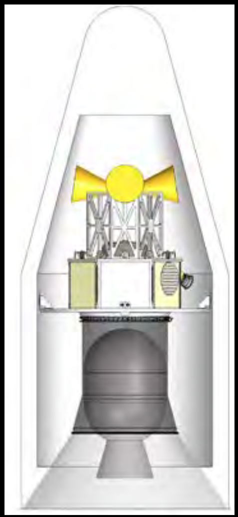
Christopher Carilli, Natl. Radio Astronomy Obsv.

Steven Furlanetto, UCLA

Geraint Harker & Abhi Datta, U. Colorado

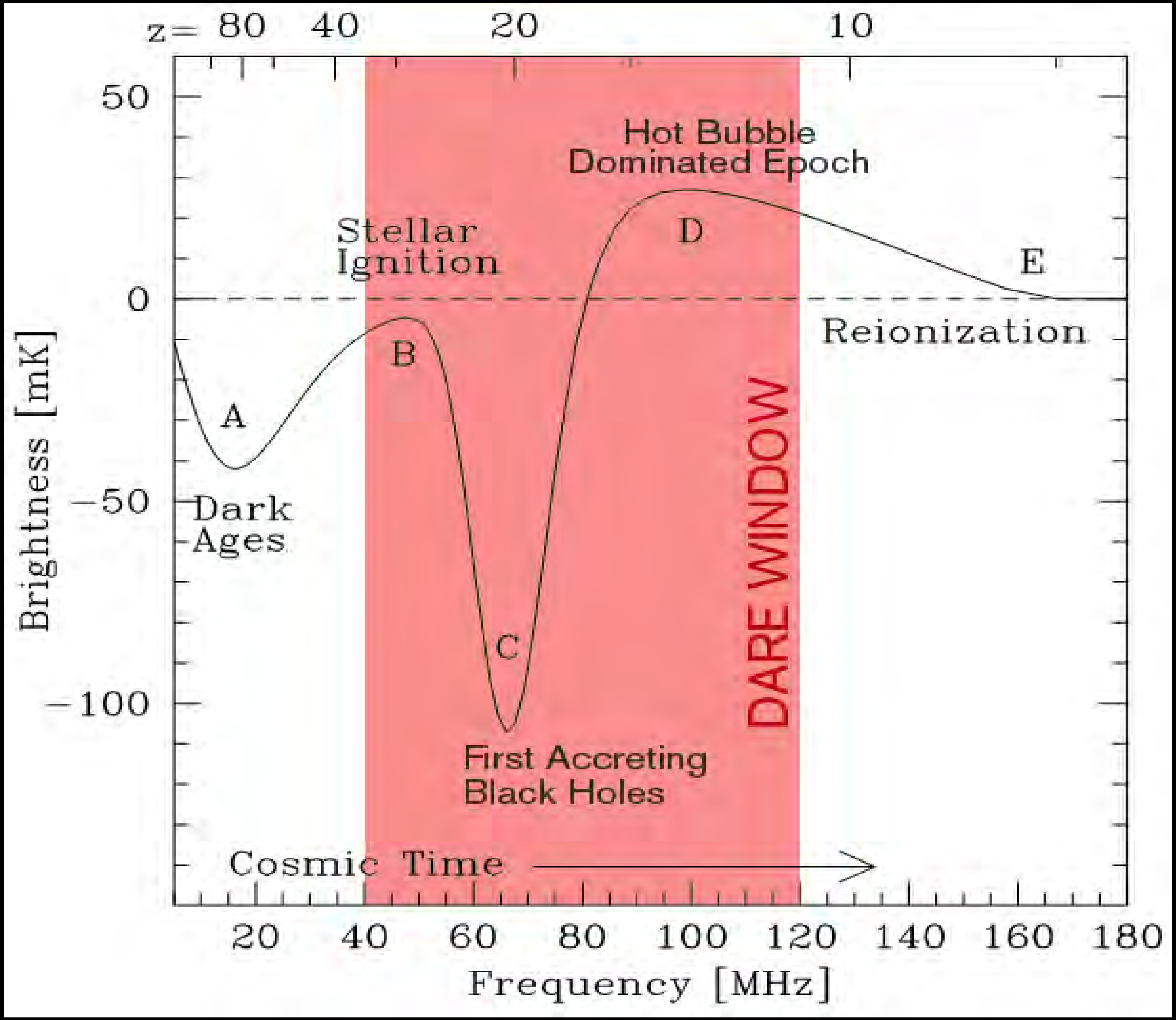
Abraham Loeb, Harvard University

Jonathan Pritchard, Harvard-Smithsonian Center for Astrophysics



PARTNERSHIPS

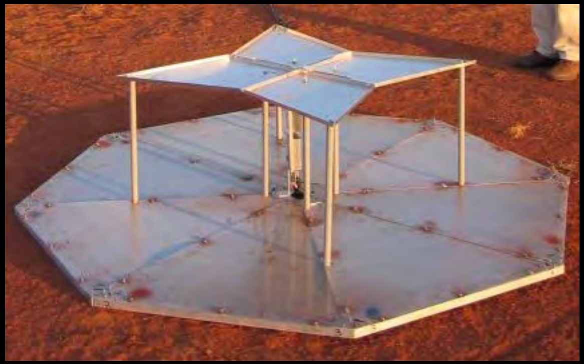
DARE will focus on determining or constraining *Turning Points* B, C, D

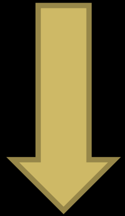


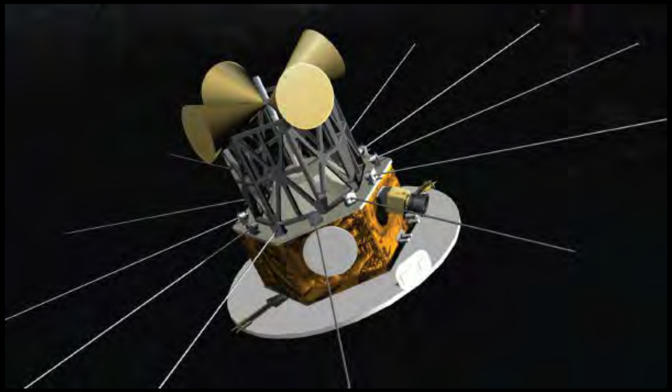
Adapted from Pritchard & Loeb, 2010, *Phys. Rev. D,* 82, 023006

Lessons from EDGES

- $10^{9\text{-}10}$ dynamic range difficult because of RFI =>A/D converters need high bit-depths & be highly linear. Susceptible to internal clock stability errors & digital noise.
- Multipath reflections=> complex spectral interference.
- Complex environment makes transferring instrument response function from lab impossible.
- Ionosphere adds significant noise at <80 MHz.

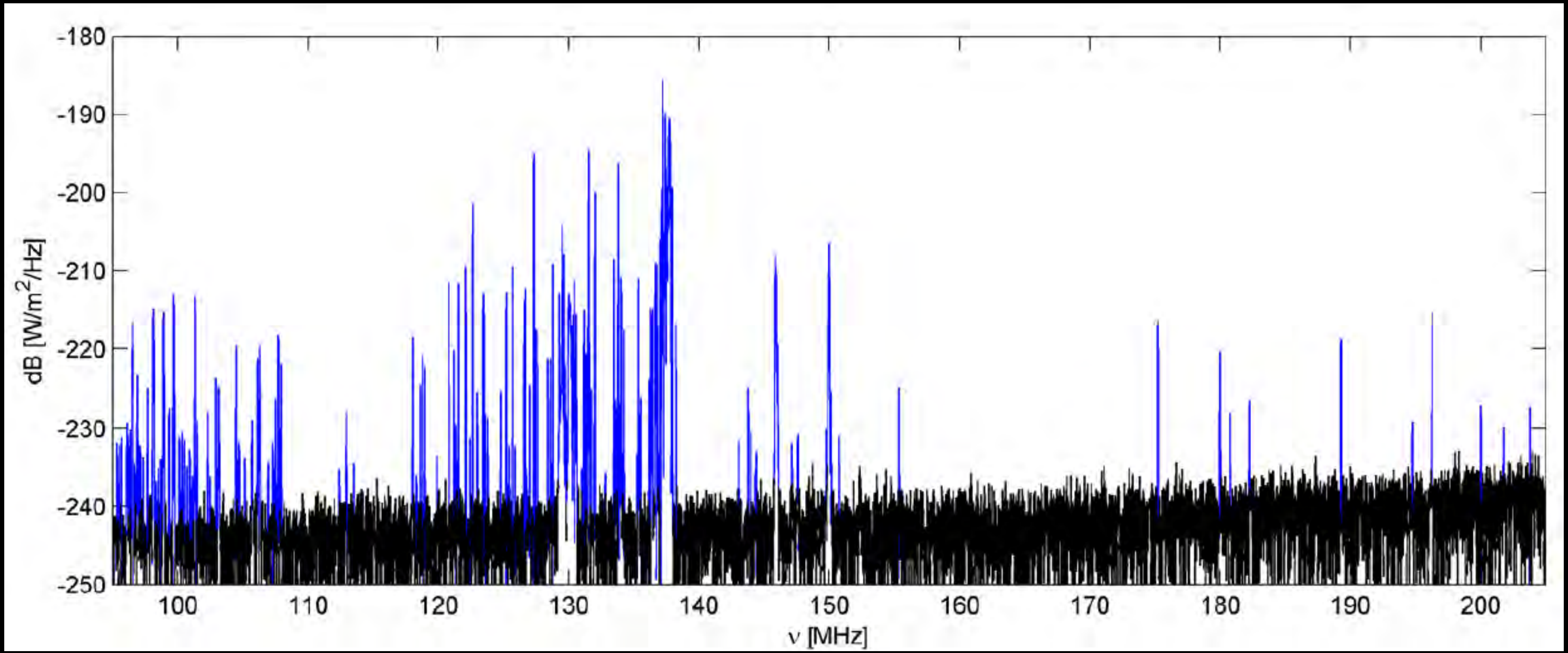




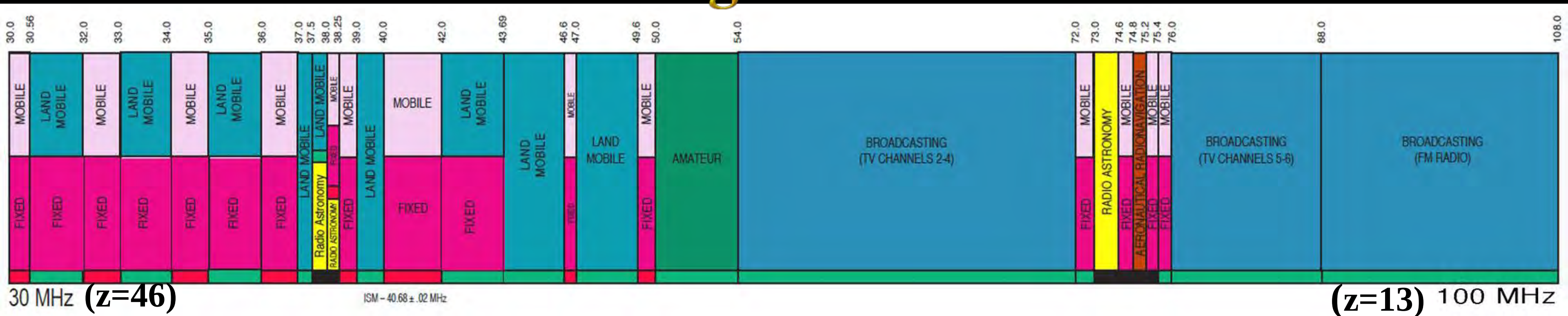


Analogous to why COBE went to space!

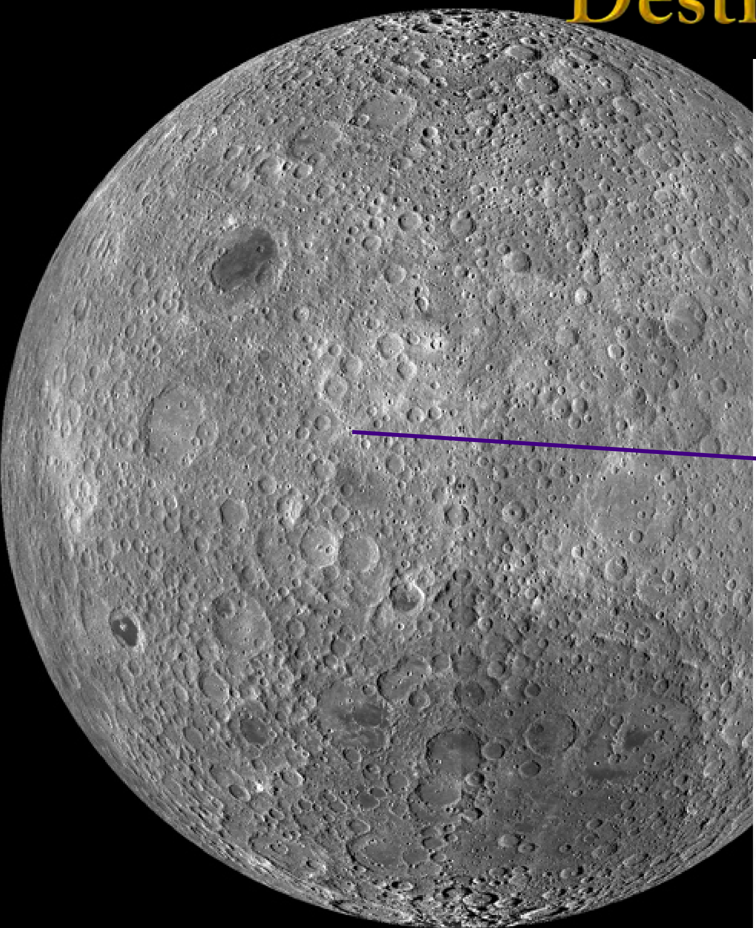
Radio Frequency Interference in Western Australia



Lunar Advantage: No Interference!



Destination: Moon



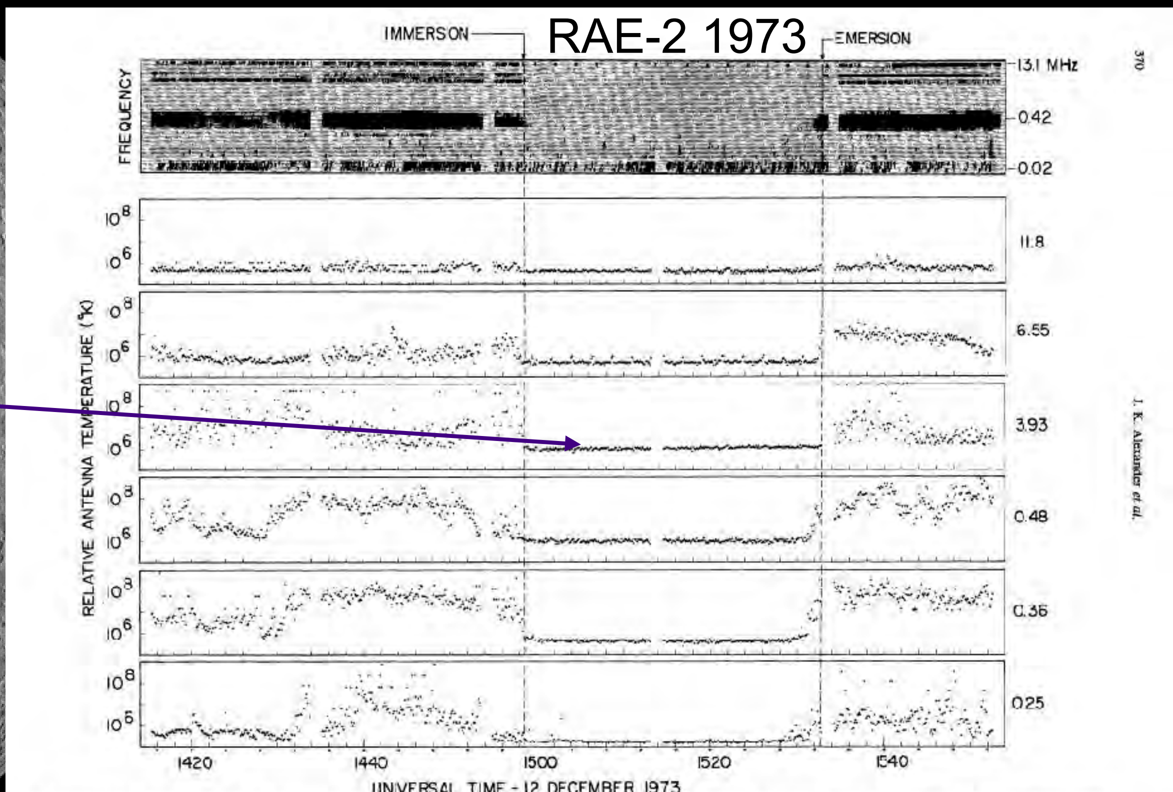
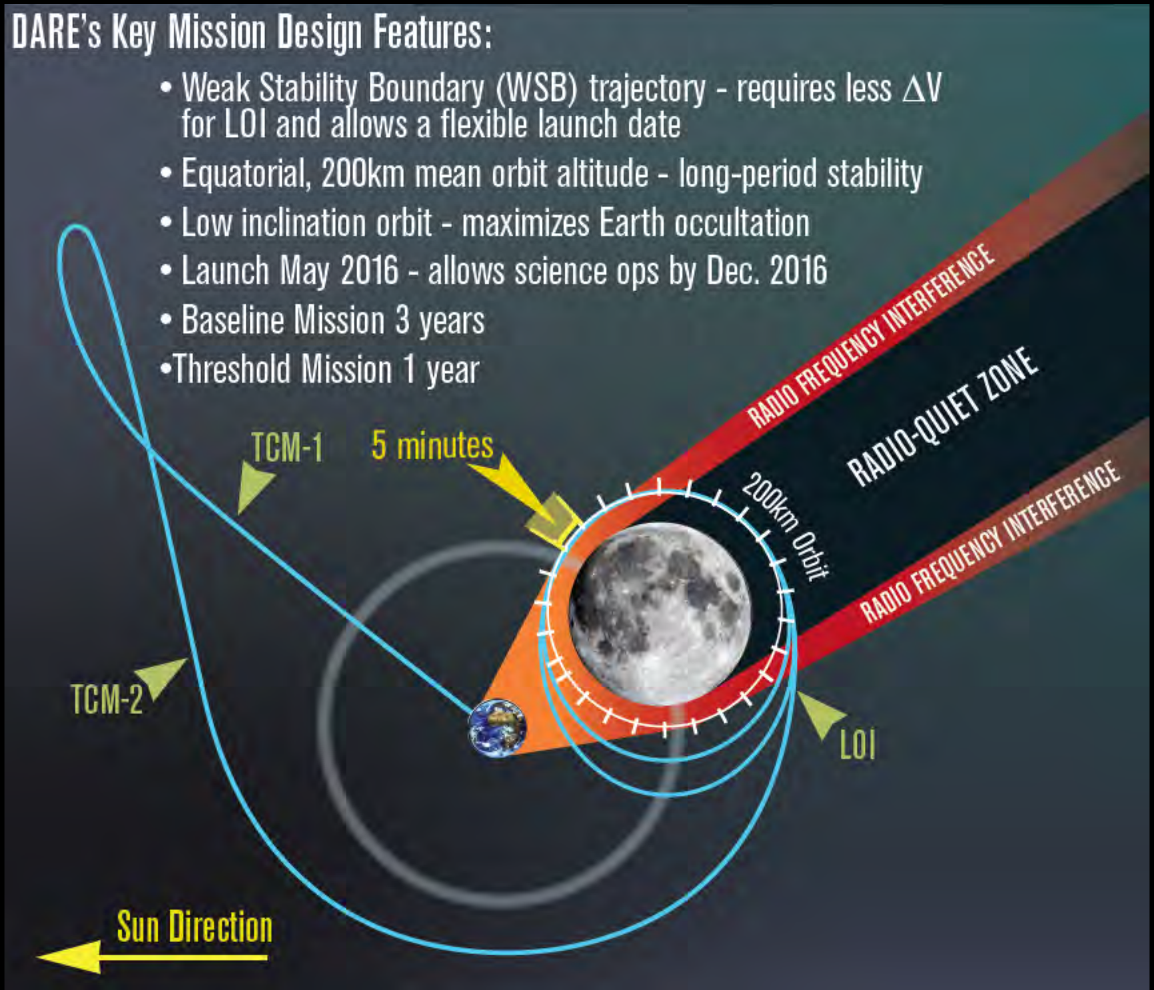


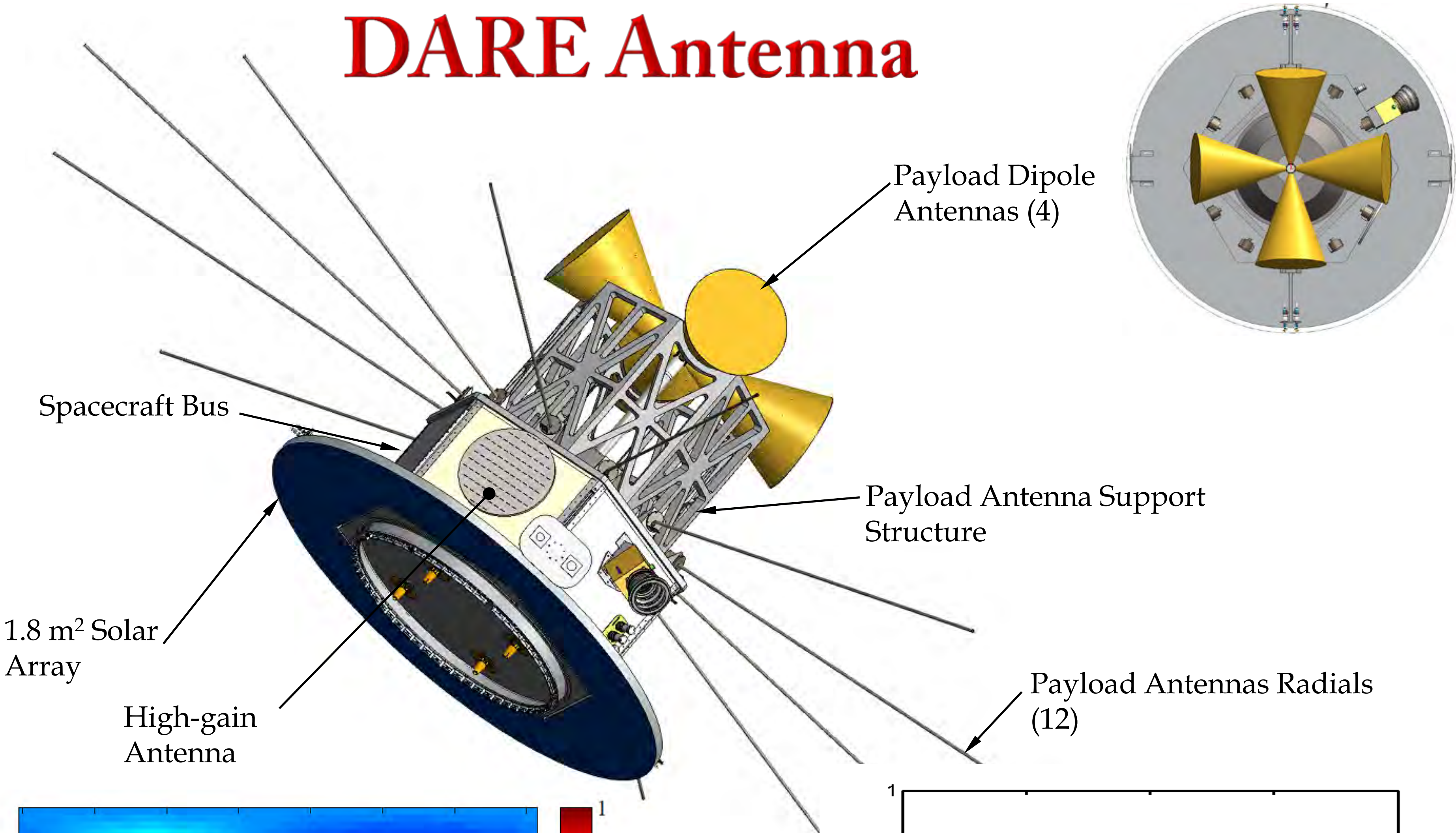
Fig. 5. Example of a lunar occultation of the Earth as observed with the upper-V burst receiver. The top frame is a computer-generated dynamic spectrum; the other plots display intensity vs. time variations at frequencies where terrestrial noise levels are often observed. The 80-s data gaps which occur 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

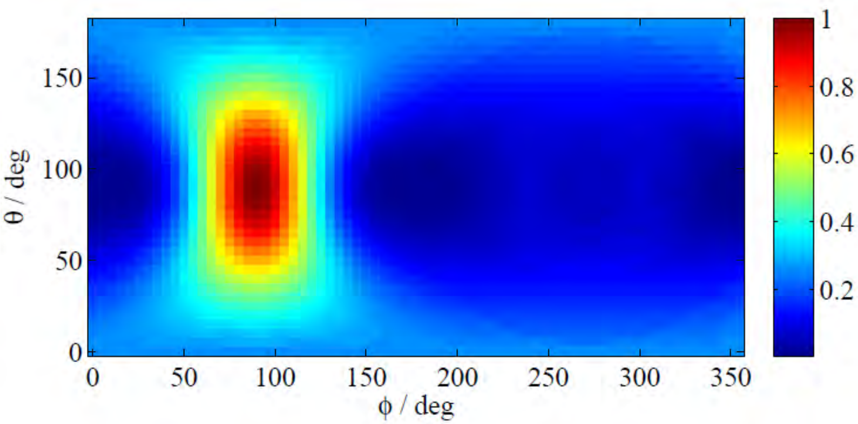
DARE's Biggest Challenge: *Foregrounds*

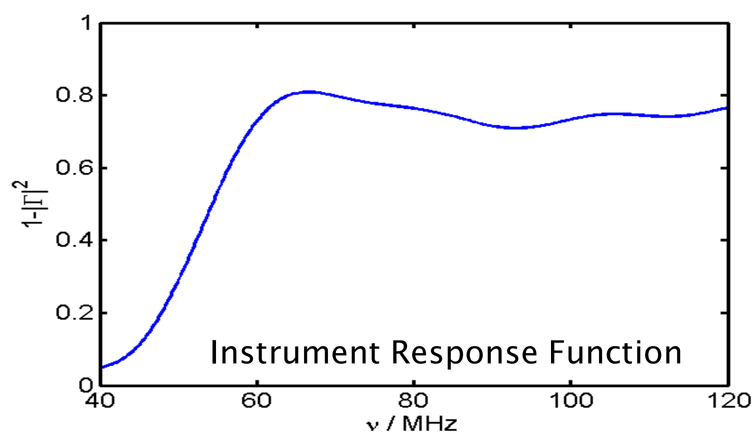
Highest foreground (RFI) eliminated by being above lunar farside!



DARE Antenna

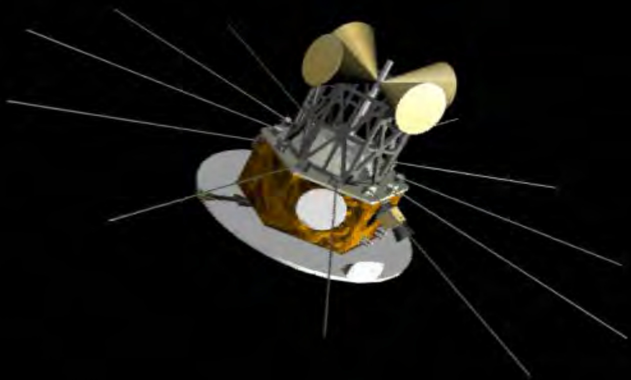






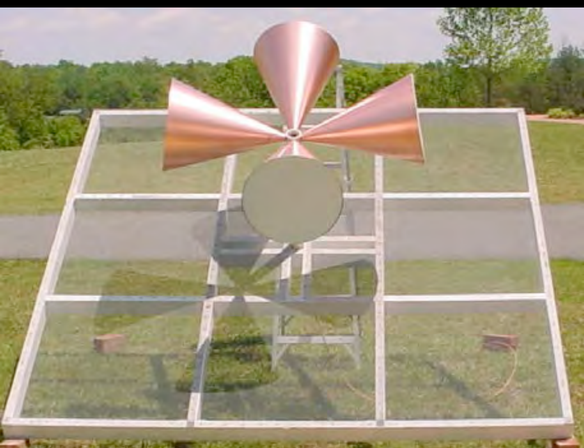
DARE Status & Timeline

- DARE was proposed as a Explorer Mission in February, 2011.
- Mission was not accepted for Phase A study– but very high referee ratings.
- DARE Engineering prototype has been developed (NRAO and JPL).
- Instrument Verification Program includes the initial field tests in Green Bank, WV (Feb-Mar, 2012) as well as the DARE-ground experiment in Western Australia (Mar, 2012 onwards).
- Results from these experiments will be critical in re-proposing DARE for a SMEX mission in late 2013.

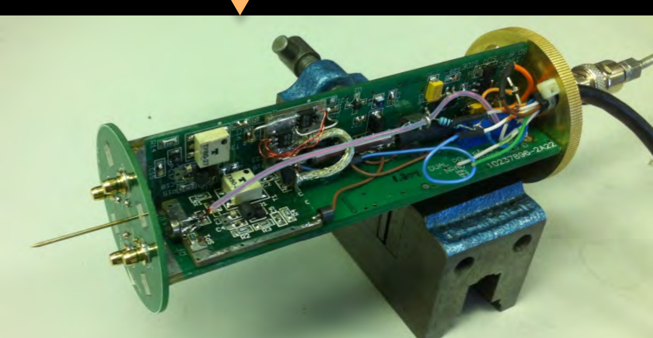


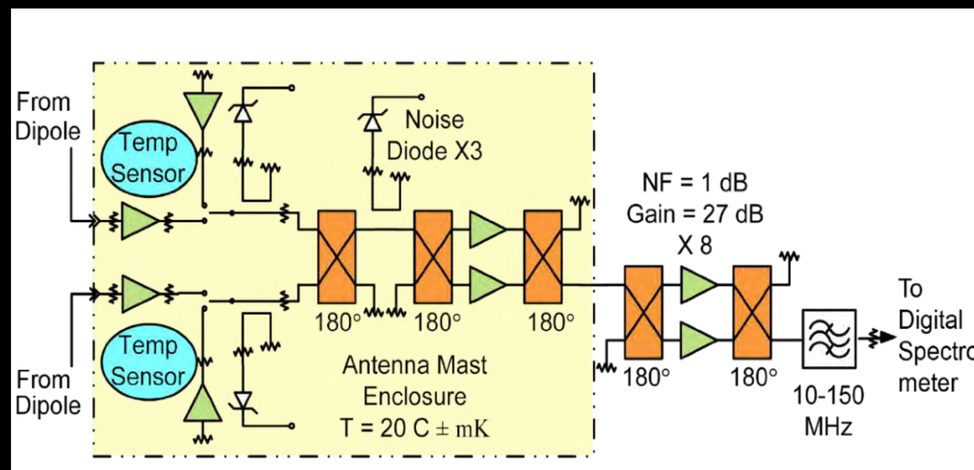
DARE Engineering Prototype: Components

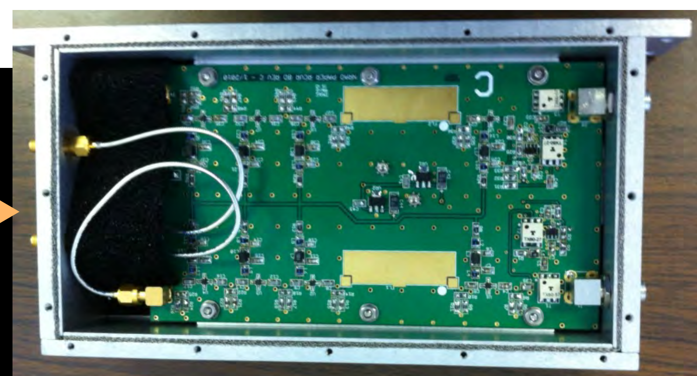
- DARE will operate at low radio frequencies between 40-120 MHz
- Components of all three subsystems (antenna, receiver and spectrometer) are at TRL ≥ 6
- Instrument Verification Program underway to have the integrated instrument at TRL 6



Antenna + BALUN (NRAO)





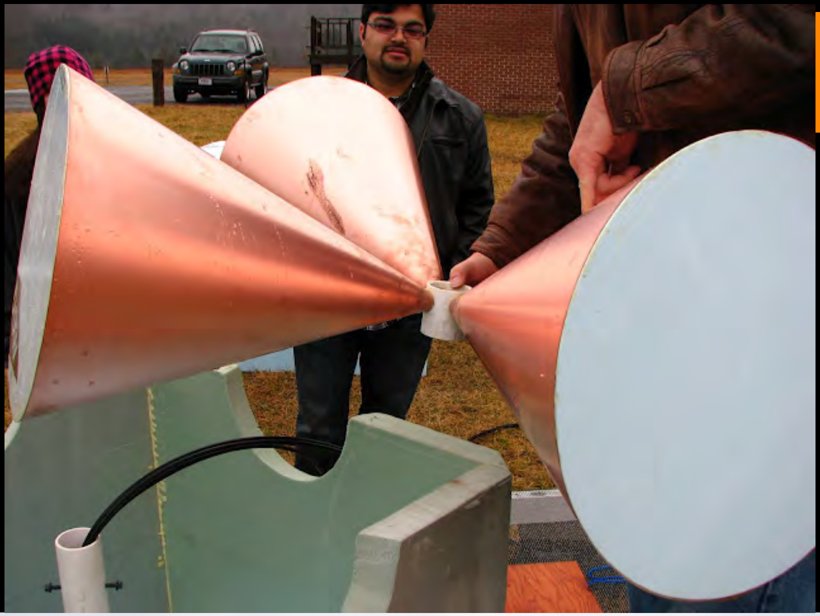


Front End Receiver (NRAO)

Digital Spectrometer (JPL)

Green Bank field tests

- DARE Engineering prototype was deployed at the NRAO site in Green Bank, WV.
- Recorded data for about 2 weeks.
- Initial field tests validated the performance of three stages of DARE instrument: antenna, front-end and digital spectrometer.



Initial Calibration

- $P_{OFF} = g(T_{Load} + T_{Rcvr})\,(1 + n_0)$
- $P_{ON} = g(\,T_{Ant} + T_{Rcvr})(1 + n_1)$

- Equating these two we get :

$$T_{Ant} = \frac{P_{ON}}{P_{OFF}}\,(T_{Load} + T_{Rcvr}) - T_{Rcvr}$$

- To the first order of approximations :

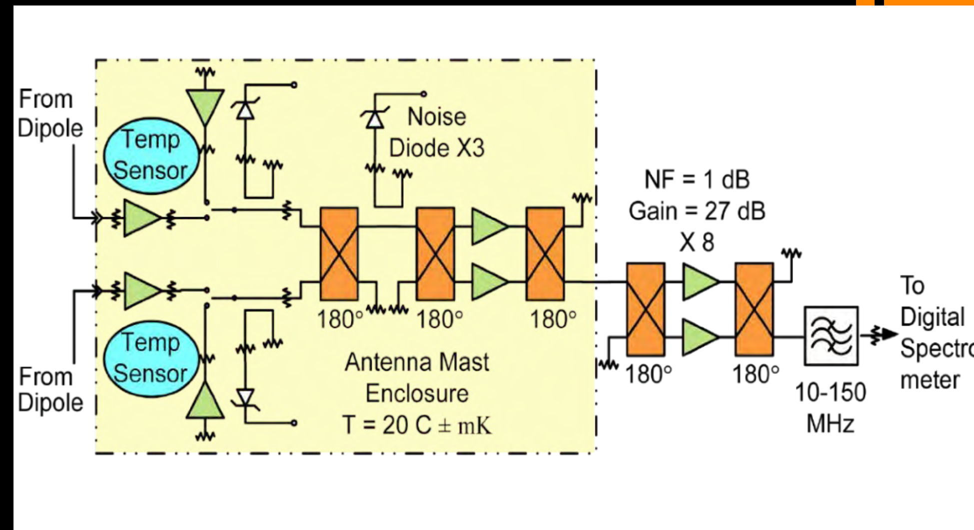
$$T_{sky} \sim {}^{T_{Ant}}\!/_{(1-\,\Gamma^2\,)}$$

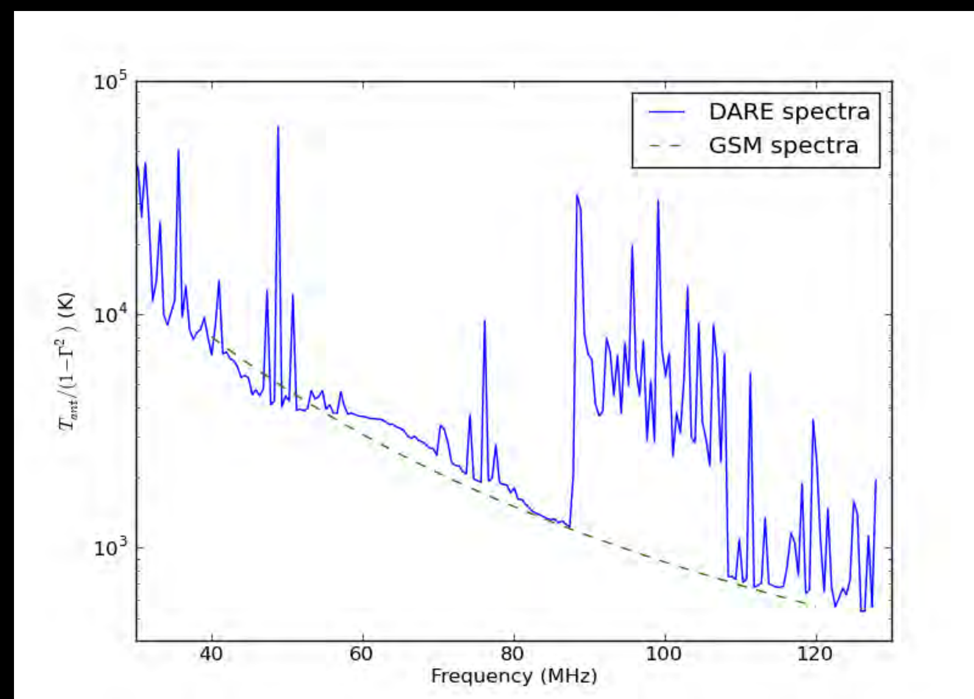
where Γ is the Reflection coefficient.

Calibrated spectra shows effects of :

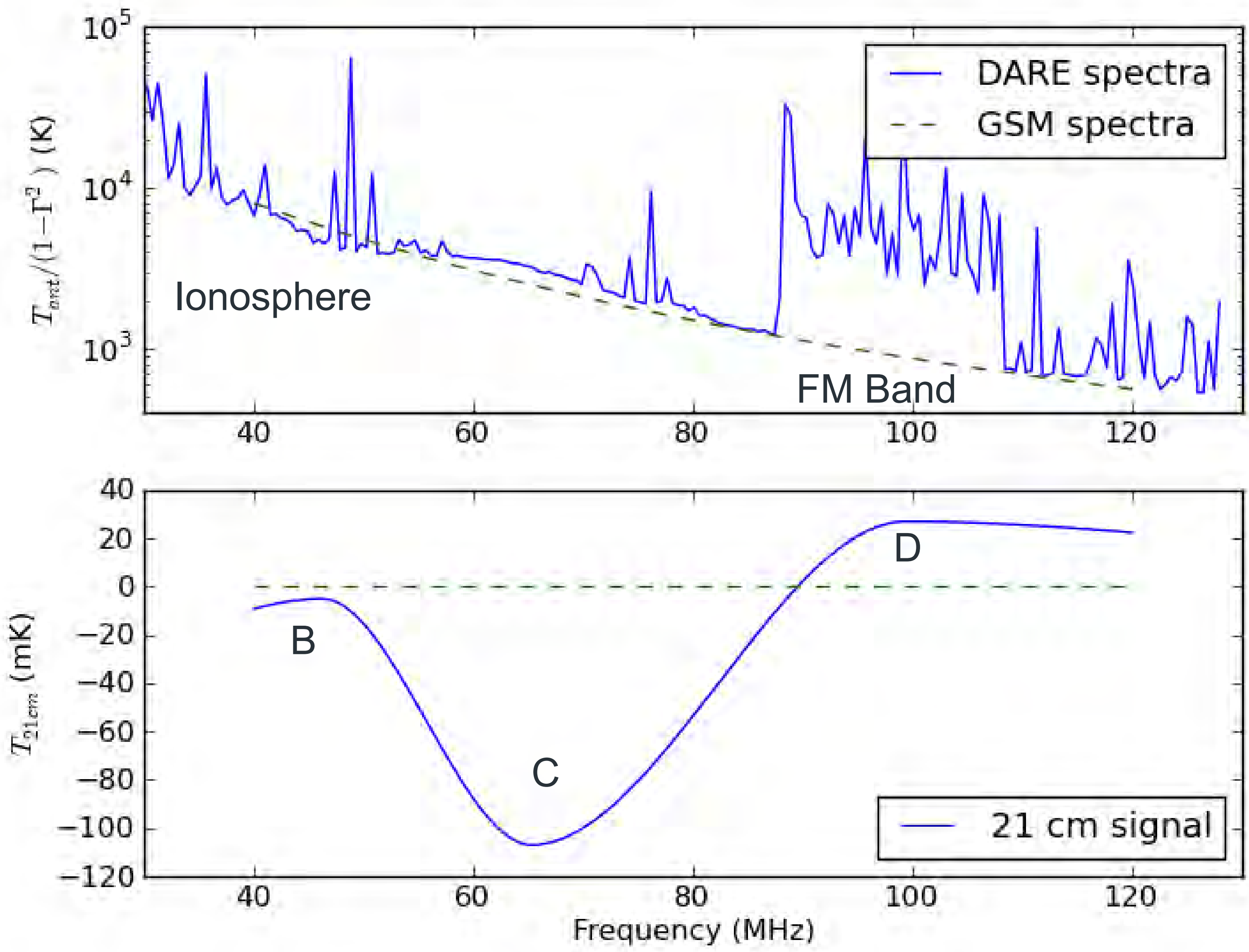
1) Radio Frequency Interference (RFI)
2) Earth's Ionosphere

These are two major challenges for ground based observations at these frequencies.





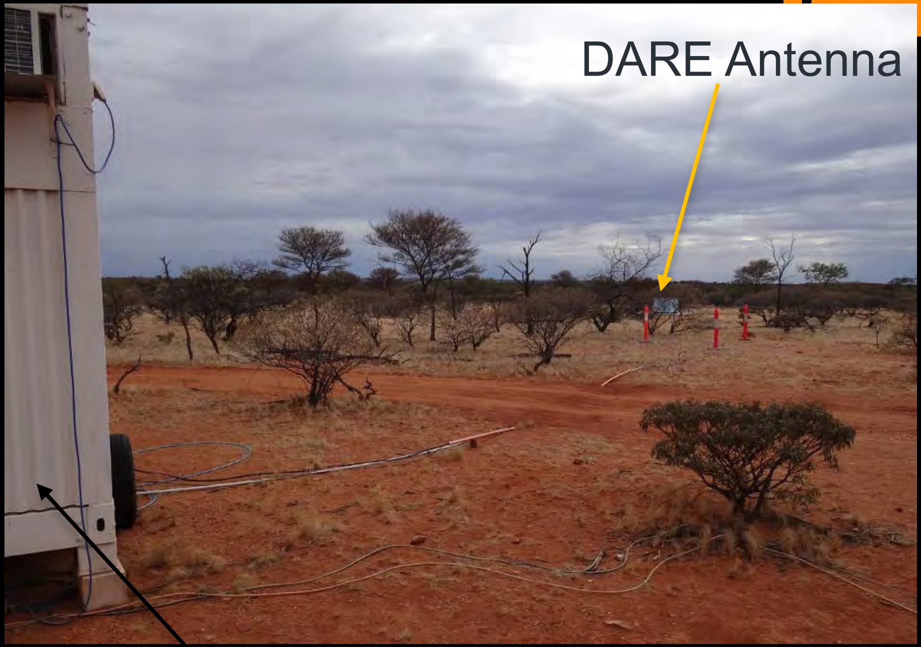
First Results



Galactic synchrotron spectral index ~ 2.7

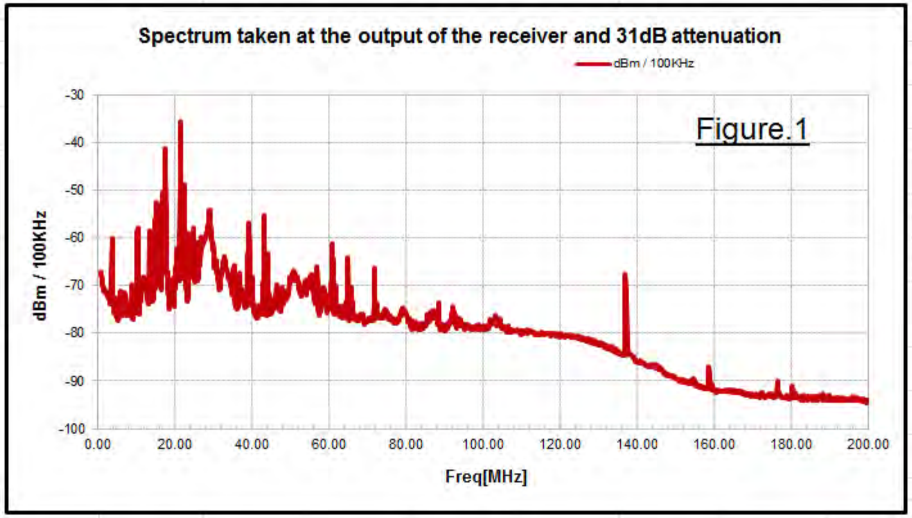
DARE-ground experiment in Western Australia

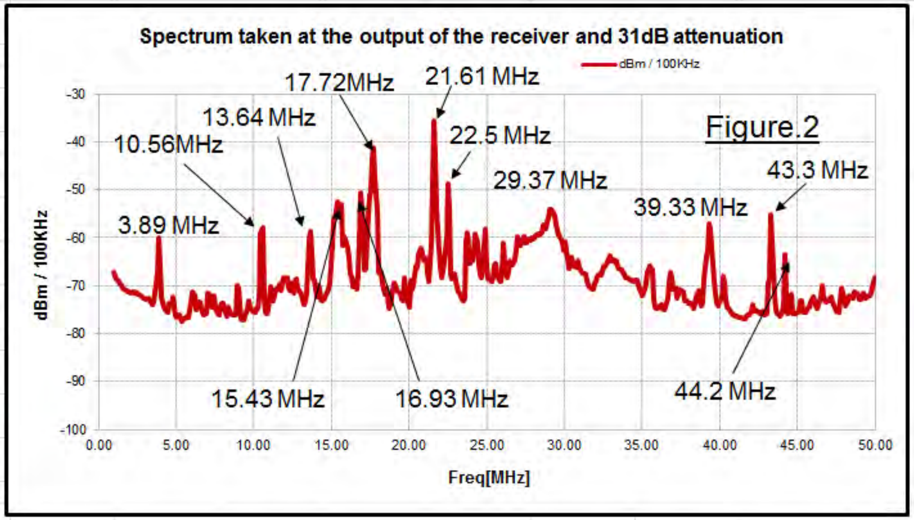
DARE Engineering prototype was deployed on March 21, 2012 at Murchison Radio Observatory (MRO).

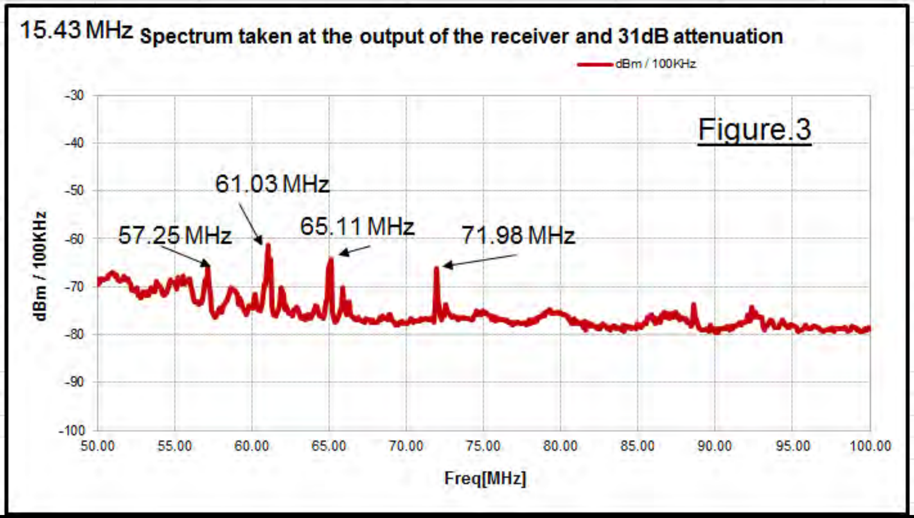


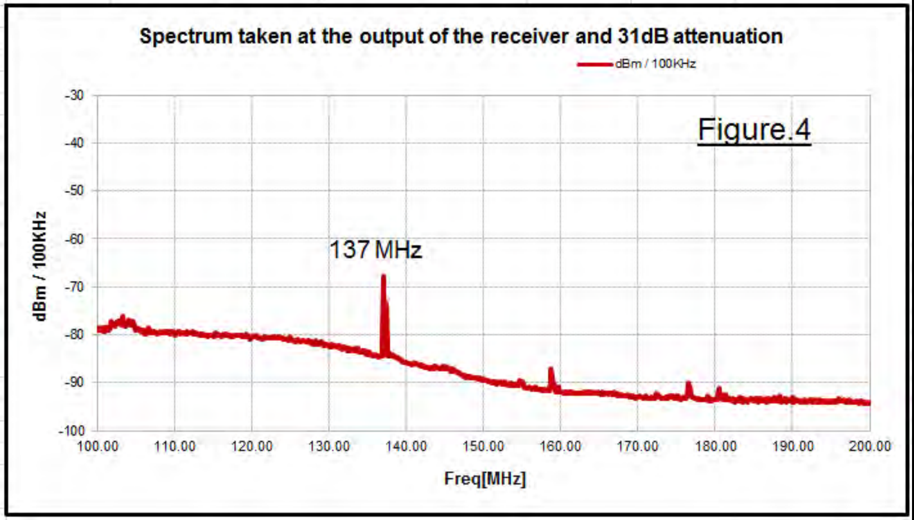
EDGS/DARE Instruments HUT

RFI environment at another Radio-Quiet Zone





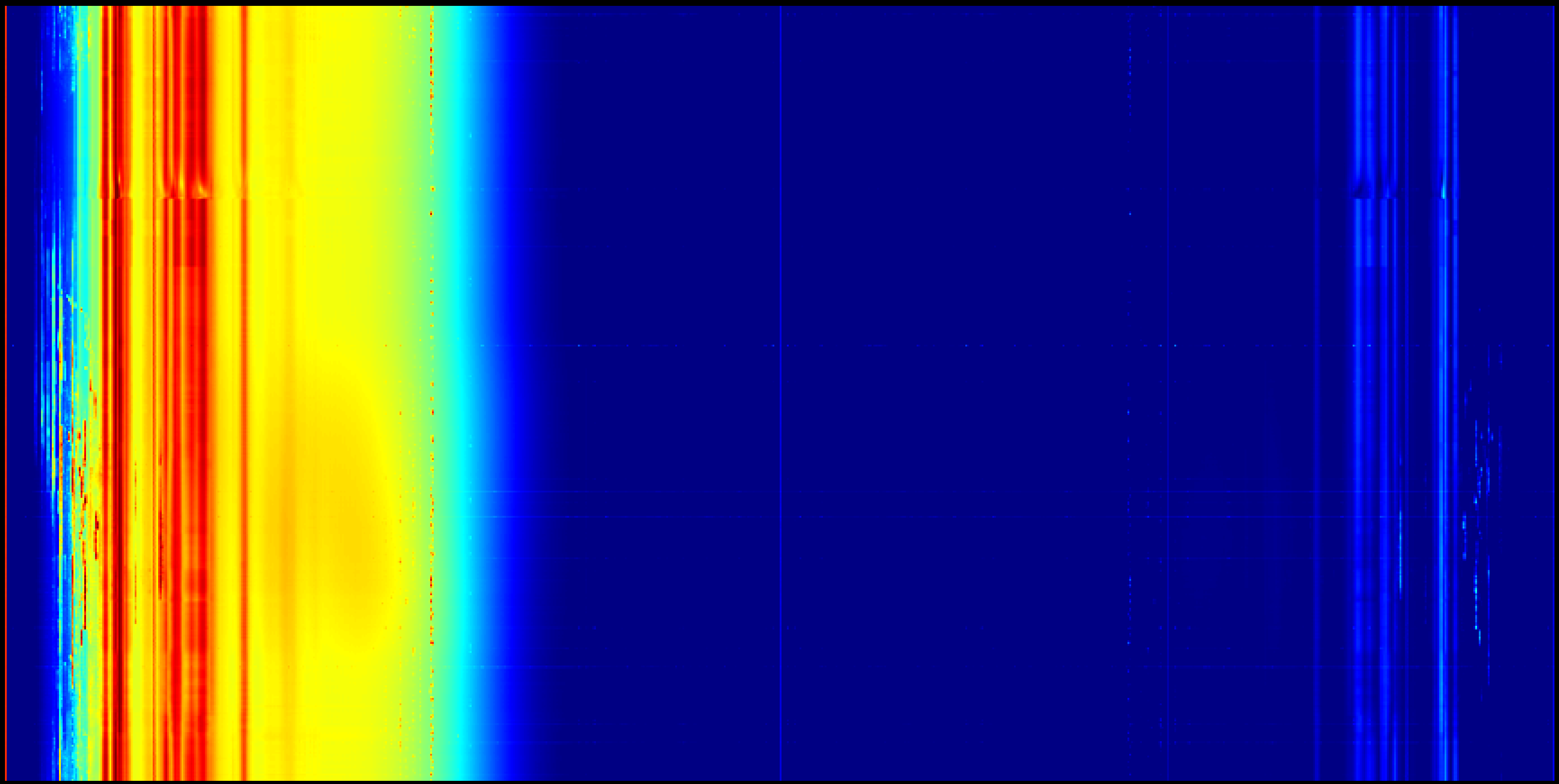




Strong RFI (@ 20 MHz) caused saturation of the receiver. Modified receiver has been installed.

Initial Data at Western Australia

October 30, 2012

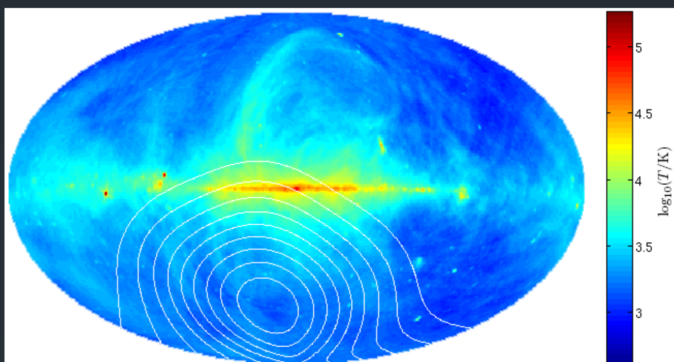


Time (UT hrs)

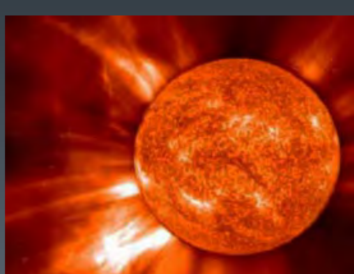
Frequency (MHz)

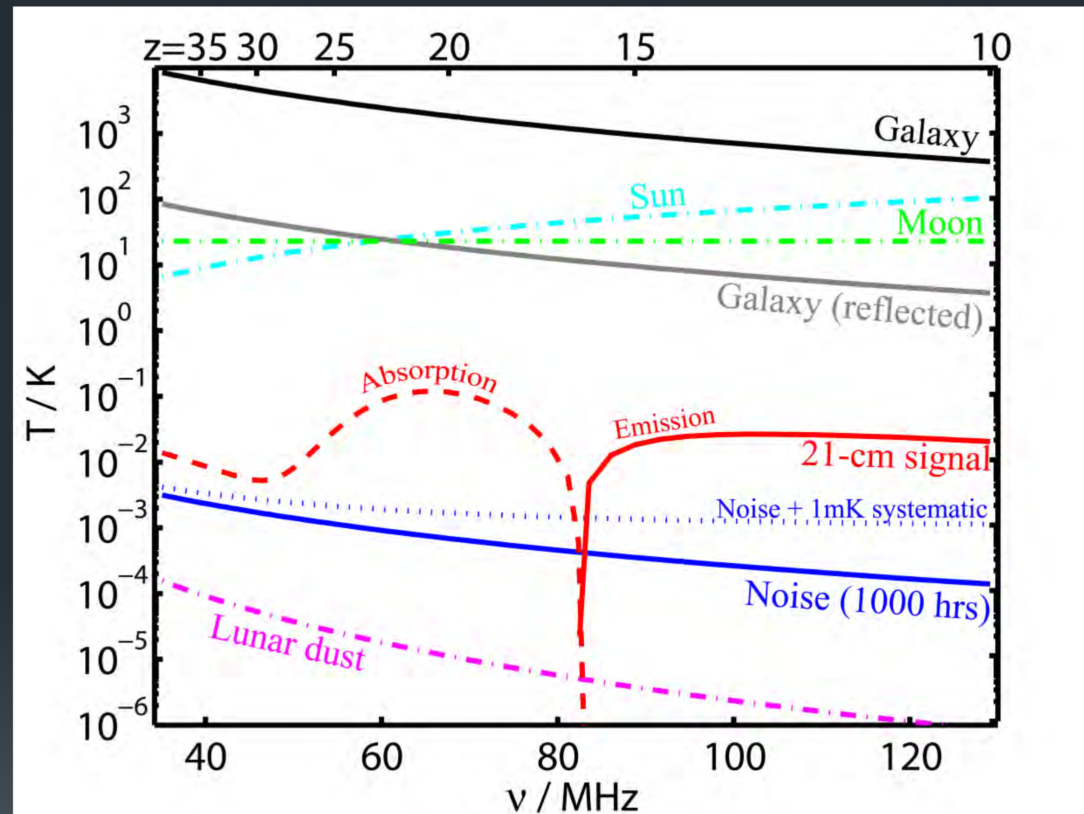
DARE's Biggest Challenge: *Foregrounds*

1) Milky Way synchrotron emission + "sea" of extragalactic sources.

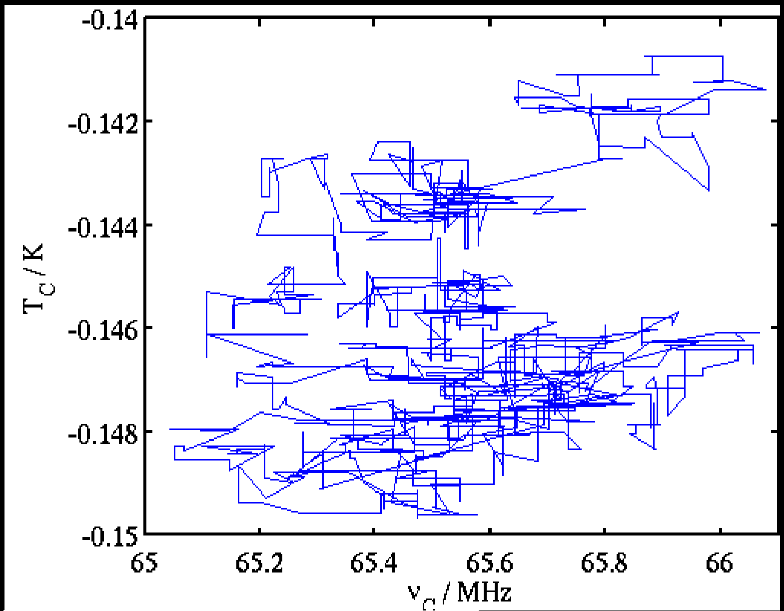


2) Solar system objects: Sun, Jupiter, Moon.





MCMC approach to signal extraction for fiducial DARE mission

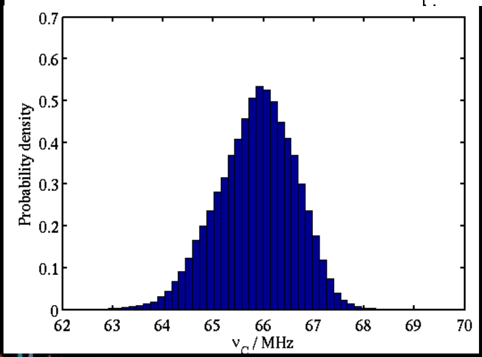


- 68% conf.
- 95% conf.

Positions of turning points B, C and D

↓

Shape of 21-cm signal



Random walk through parameter space
→ unbiased, random samples of the posterior probability distribution

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For details see Harker et al. (2012), MNRAS, 419, 1070

Modeling Earth's Ionosphere

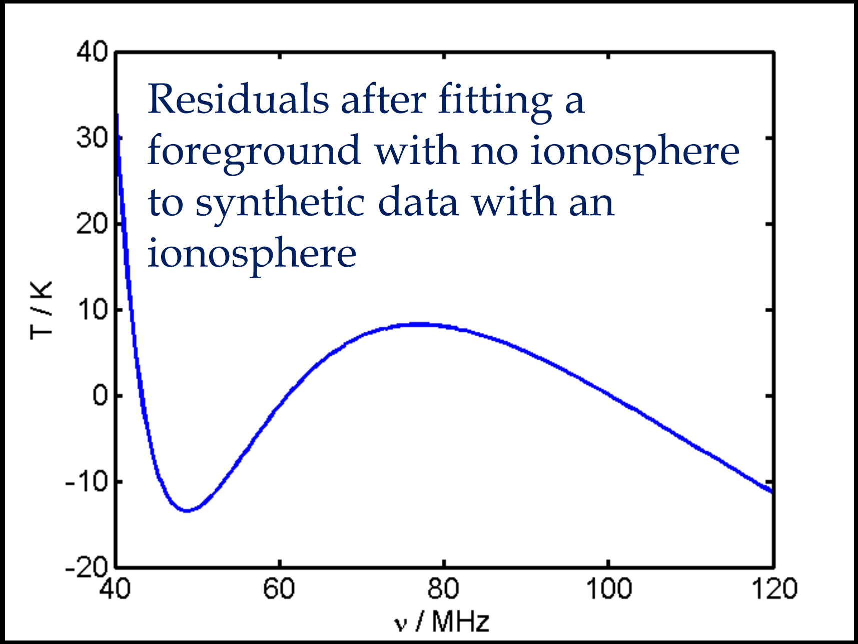
Earth's ionosphere produces a contribution to the spectrum scaling as (frequency)$^{-2}$

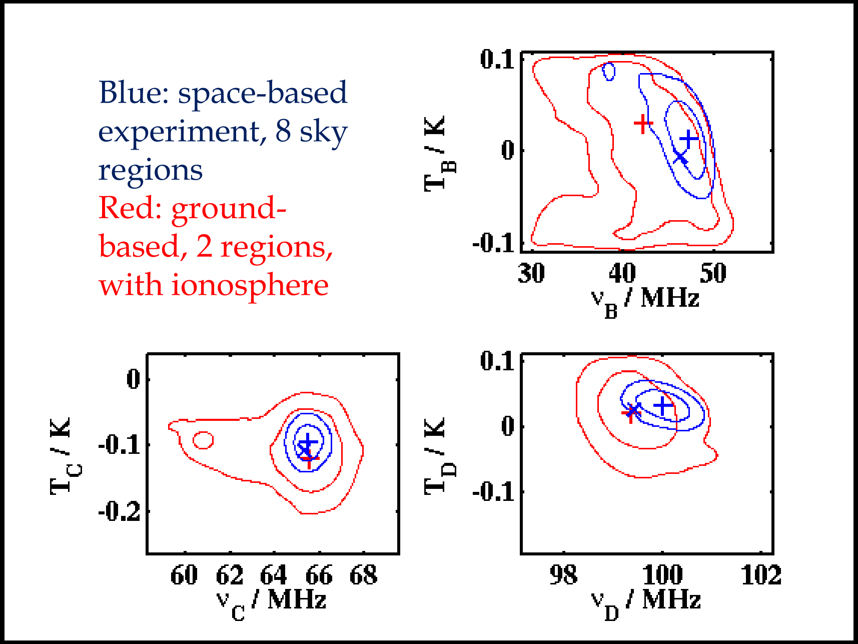
$$T'_{sky} = T_{sky}L_{iono} + (1 - L_{iono})T_e$$

$$L_{iono} = \frac{1.16 \times 10^{-6}}{\nu_{Hz}^2} \int N(m^{-3})\nu_{Hz}^c dS \ (dB)$$

Loss factor

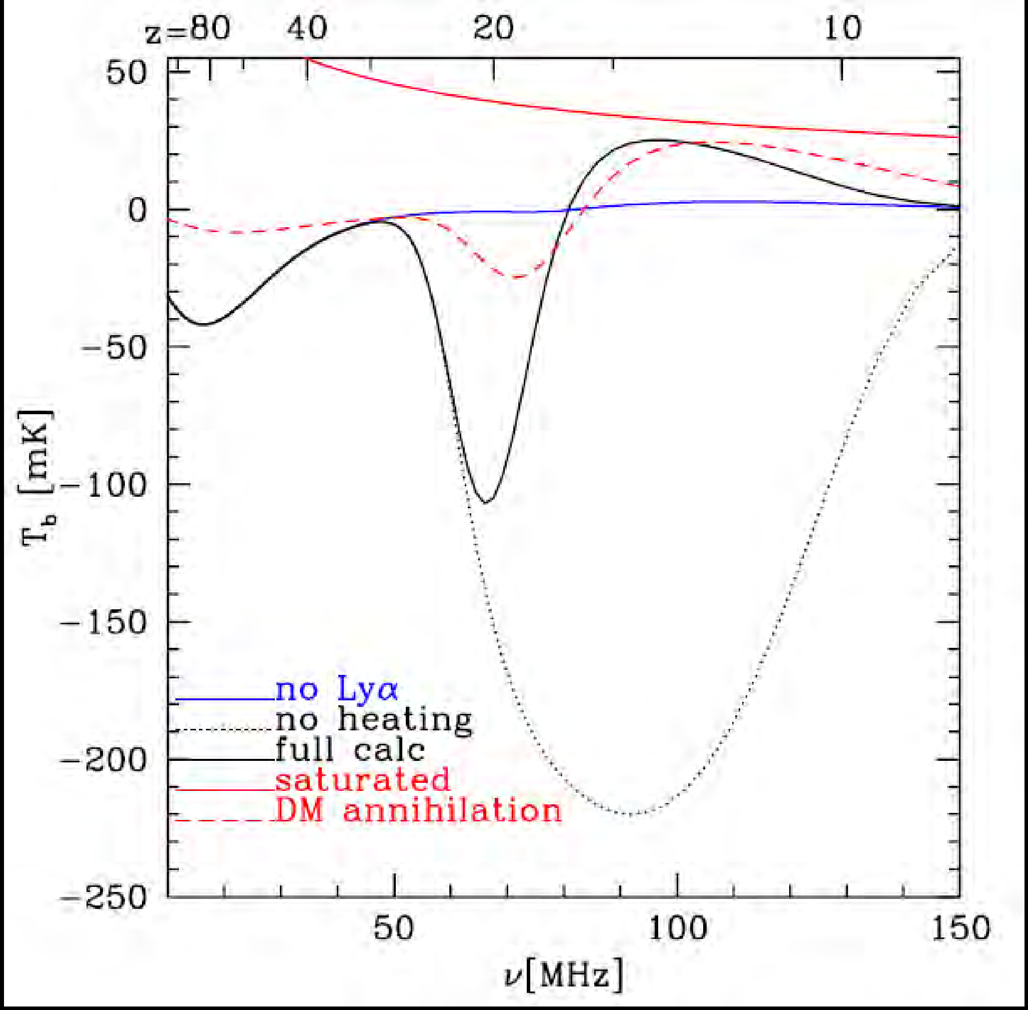
Electron temperature





Future work: alternative signal models

- A wide range of values for the model parameters are allowed by current constraints.
- Alternative models (e.g. including decaying dark matter) may not be described very well by the turning points scheme.
- The nested sampling algorithm will allow us to test how well DARE can select between models with very different shapes.
- We are exploring alternative parametrizations.



Pritchard & Loeb (2010)

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Dark Ages Radio Explorer (DARE)

- DARE is designed to address:
  - When did the First Stars ignite?
  - When did the first accreting Black Holes turn on?
  - When did Reionization begin?
- DARE will accomplish this by:
  - Constructing first sky-averaged spectrum of redshifted 21-cm signal at $11<z<35$.
  - Flying spacecraft in lunar orbit & collecting data above lunar farside -- only proven radio-quiet zone in inner solar system.
  - Using biconical dipole antennas with smooth response function & Markov Chain Monte Carlo method to recover spectral *turning points* in the presence of bright foregrounds.
  - Using high heritage spacecraft bus (WISE) & technologies/techniques from EDGES.

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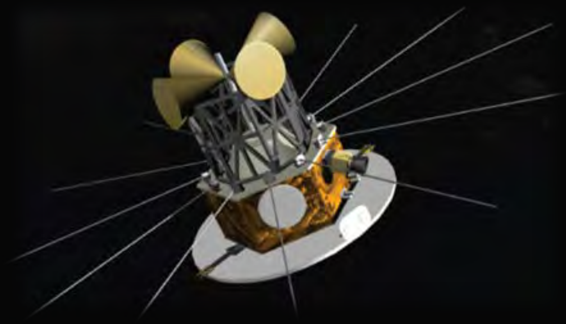

See Burns *et al.*, 2012, *Advances in Space Research*, 49, 433.
http://lunar.colorado.edu/dare/