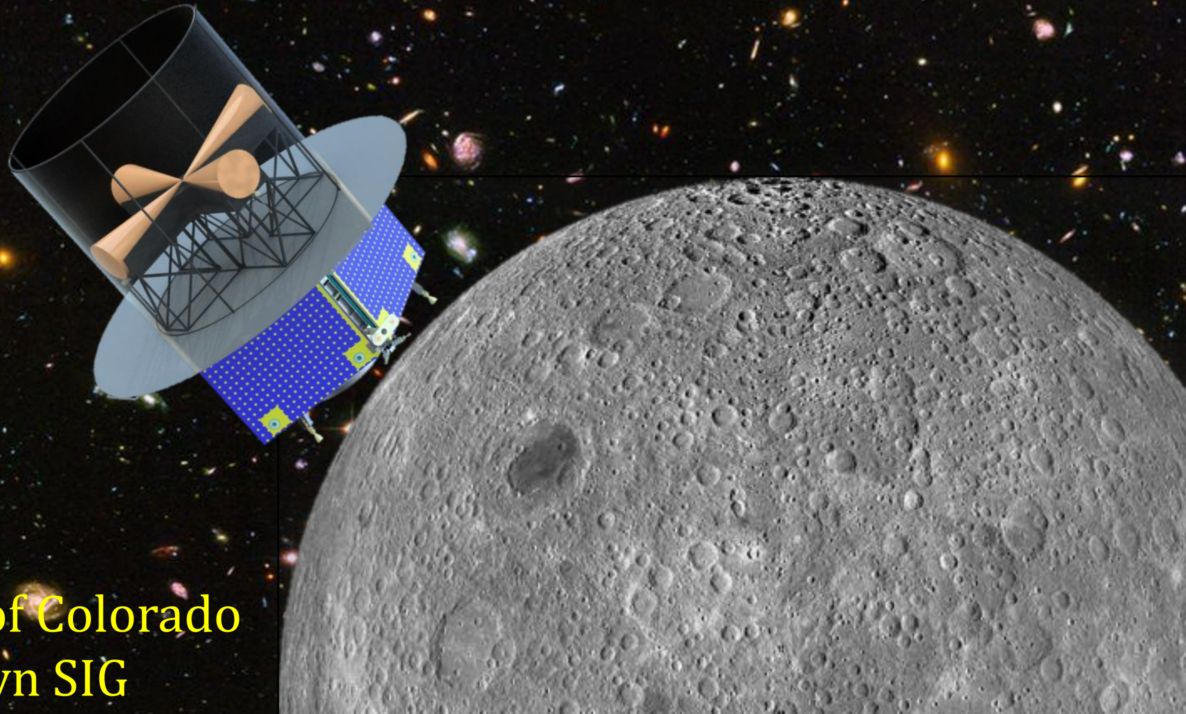
DARE

Technology Challenges for Global 21-cm Cosmology Space Missions



Jack Burns
University of Colorado
Cosmic Dawn SIG

DARE Project Team

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Observatory Project Management: Ball Aerospace & Technologies Corp.: W. Purcell & D. Newell

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Graduate Students:

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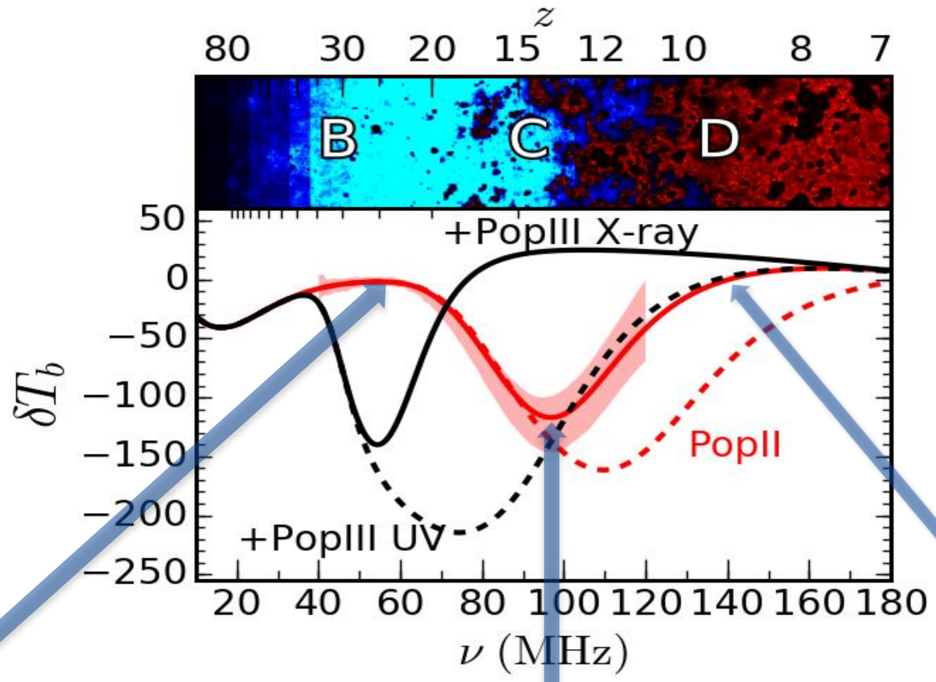
The 21-cm Global Signal Reveals the Birth & Characteristics of the First Stars & Galaxies

$$\delta T_B = 25 x_{HI} \left(\frac{1+z}{10}\right)^{1/2} \left(1 - \frac{T_{CMB}}{T_S}\right) \text{mK}$$



B: ignition of first stars

- When did the First Stars ignite? What were their characteristics?
- Is there evidence for exotic physics (e.g. Dark Matterr decay) in the Dark Ages?

C: heating by first black holes

- When did the first accreting black holes turn on? What were their characteristics?

D: the onset of reionization

- What was the history of Reionization in the early Universe?

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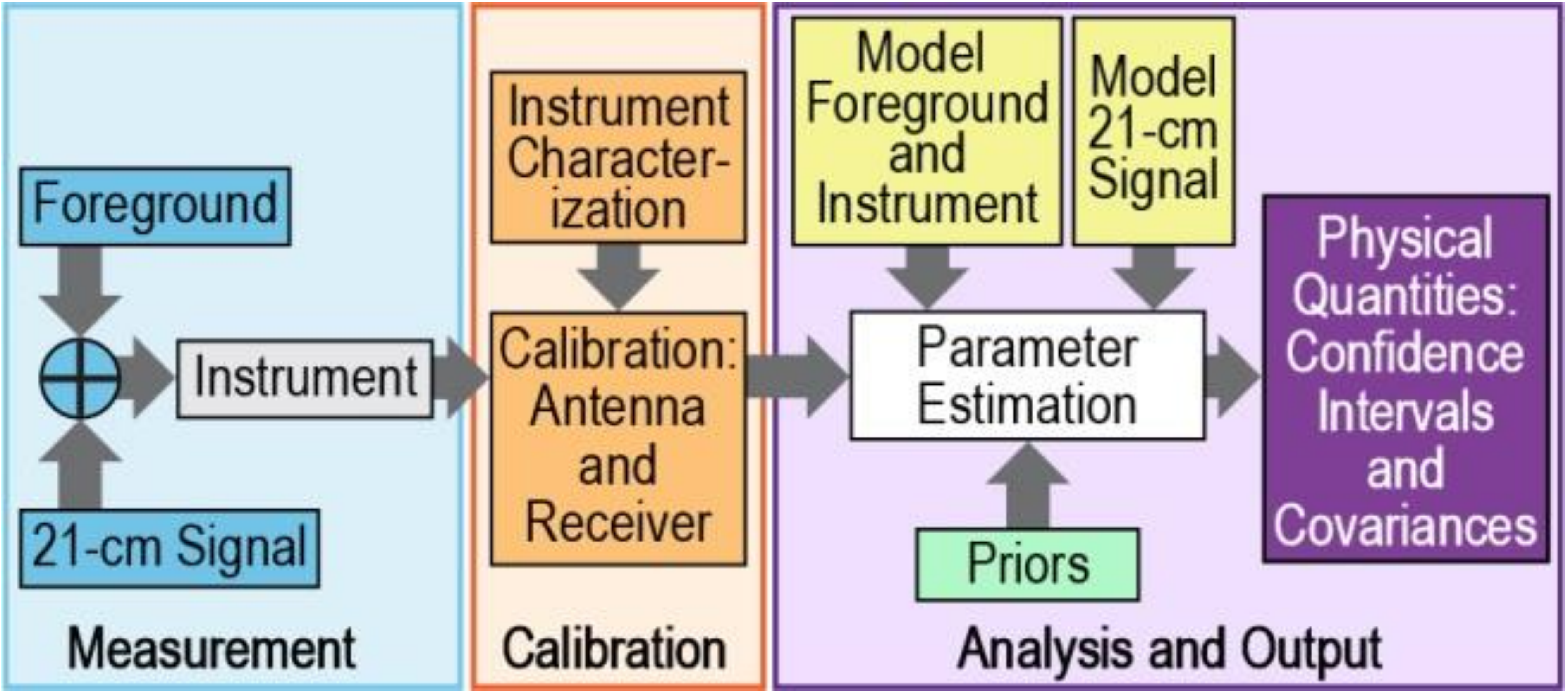
Adapted from Pritchard & Loeb, 2010, *Phys. Rev. D,* 82, 023006 and Mirocha, Harker, & Burns, 2015, ApJ, 813, 11.

DARE observational strategy



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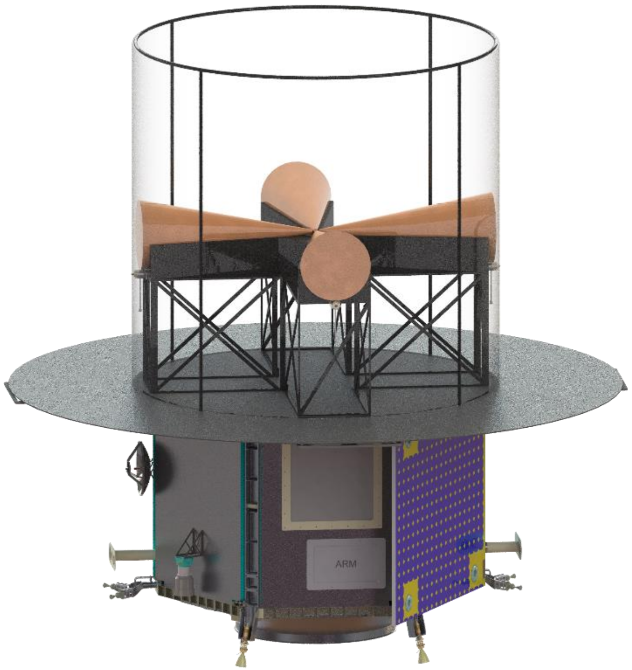
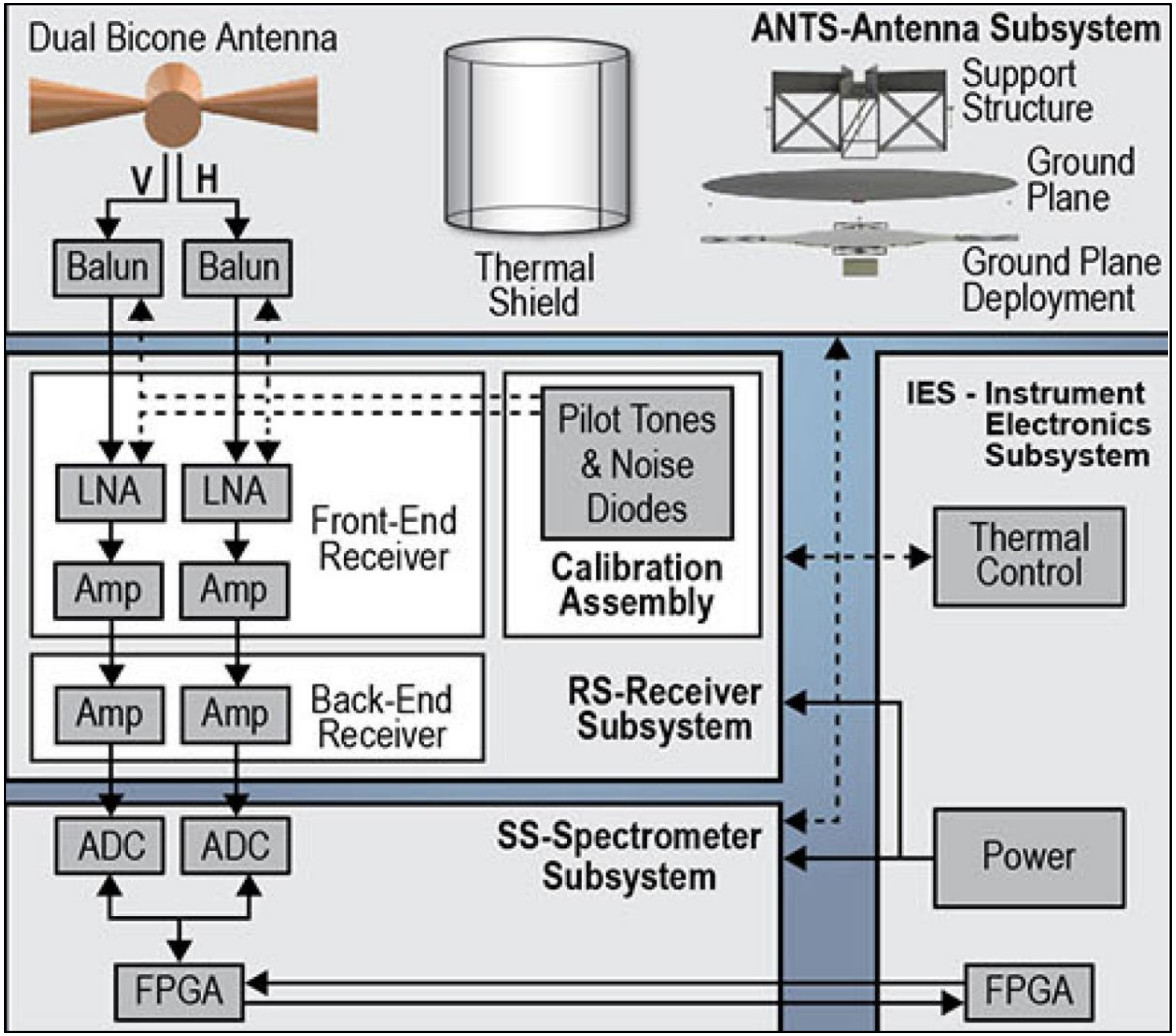
DARE Observatory

Two Year Mission Lifetime

- ~1000 hrs integration above lunar farside.
- shielded from Sun.
- 50x 125 km circular, equatorial orbit.





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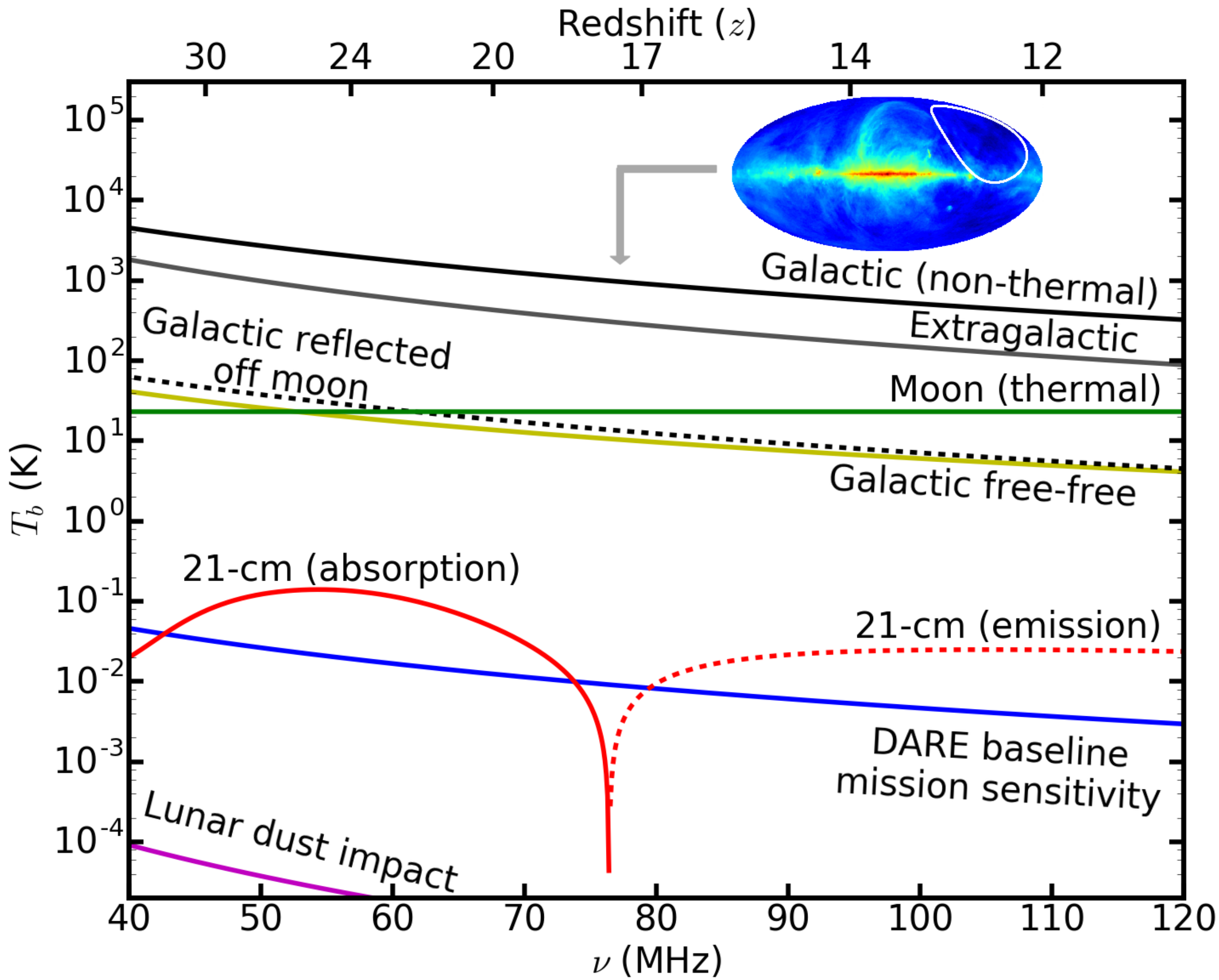
DARE probes z=11-35 with ν=40-120 MHz

Foregrounds and Beam Chromaticity



$$T_{ant}(\nu) = \frac{\int_0^{2\pi} \int_0^{\pi/2} T_{sky}(\nu,\theta,\phi) F(\theta,\phi,\nu) \sin\theta d\theta d\phi}{\int_0^{2\pi} \int_0^{\pi/2} F(\theta,\phi,\nu) \sin\theta d\theta d\phi}$$

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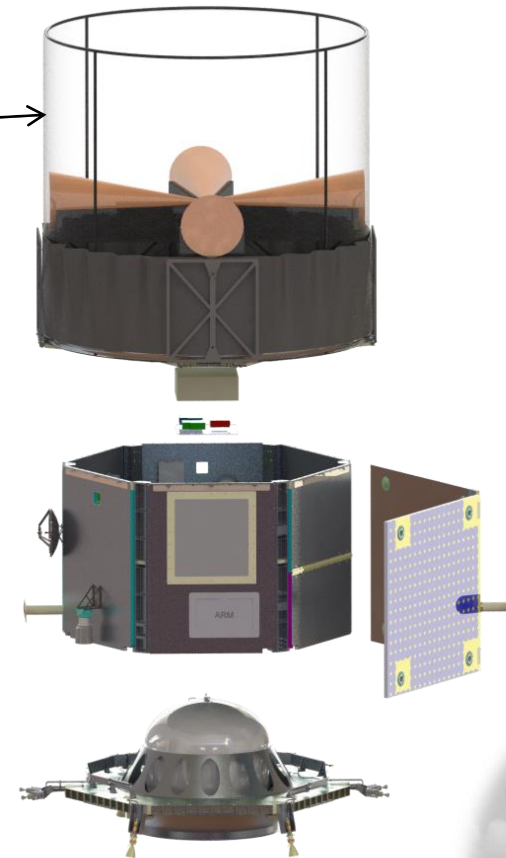
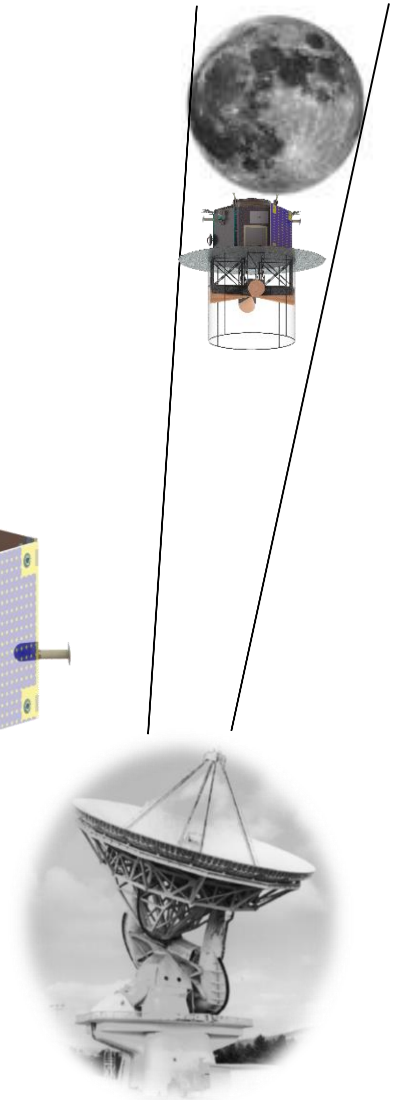
Chromaticity: Design Considerations

- Build antenna with low CTE material & minimize antenna thermal distortions (<10°C) with sunshade.
- Accurate modeling & measurement before launch.
- Measure beam on-orbit using frequency tones transmitted from Earth:
  - Circularly polarized, PSK modulated carriers (6) are sent from ground to DARE.
  - DARE receives signals as the spacecraft orbits above near side of the Moon to sweep beam.
  - Carrier levels are measured by DARE every 20 seconds to produce sampled beam cut.
  - A weak signal is also measured on its return trip to the Earth (Moon reflection) to estimate real-time path loss through the ionosphere.





$$P_{echo} = \left(\frac{c^2}{64\pi^3}\right)\cdot\left(\frac{1}{\nu^2}\right)\cdot\left(\frac{P_t G_t^2 L_i^2 \sigma_m}{R_{t-M}^4}\right)$$ = echo power at 140-ft

Green Bank Observatory
140-ft antenna

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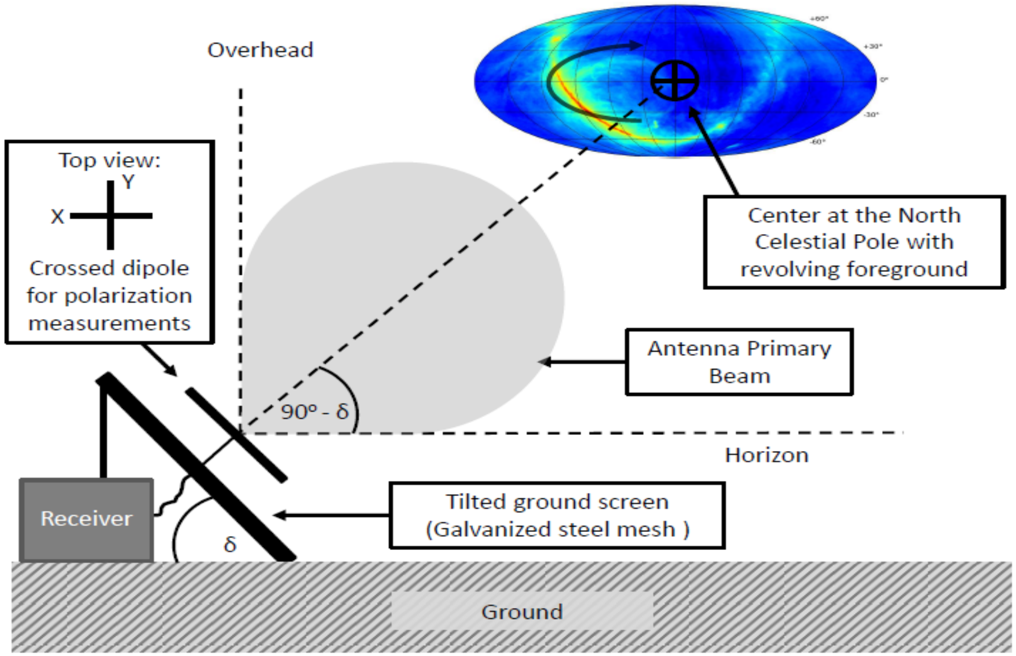
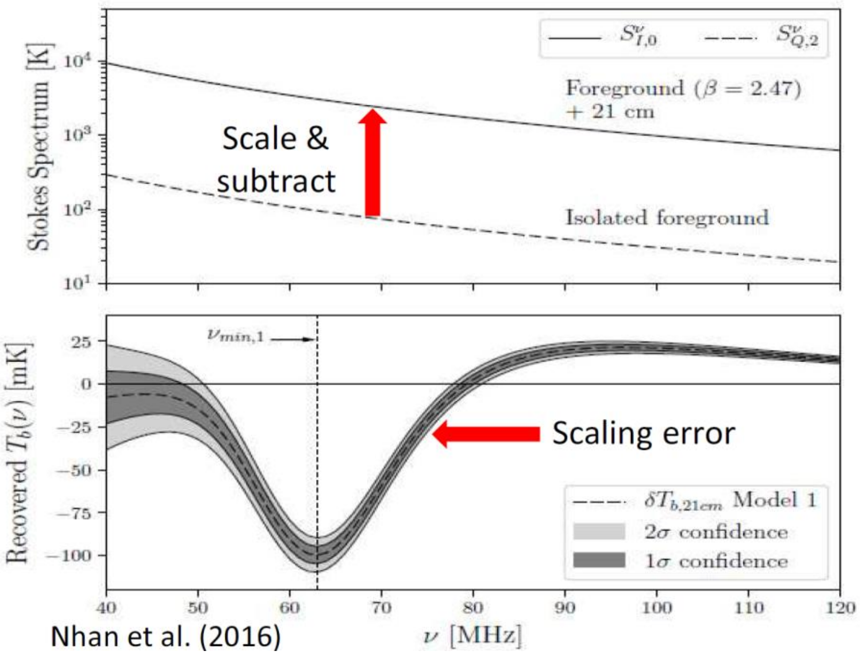
Polarimeter: Model-independent Foreground

Nhan, Bradley, & Burns, 2017, AJ, submitted, arXiv:1611.06062.





Cosmic Twilight Polarimeter: Ground-based DARE Prototype

Polarimetry Process to measure Foreground

1. Measure "polarization leakage" caused by ν-dependence of power patterns of linearly polarized dipoles. Rotate spacecraft to measure modulated Stokes Q,U
2. Harmonic decomposition of modulated Q,U signal, scale to Stokes I, and subtract.

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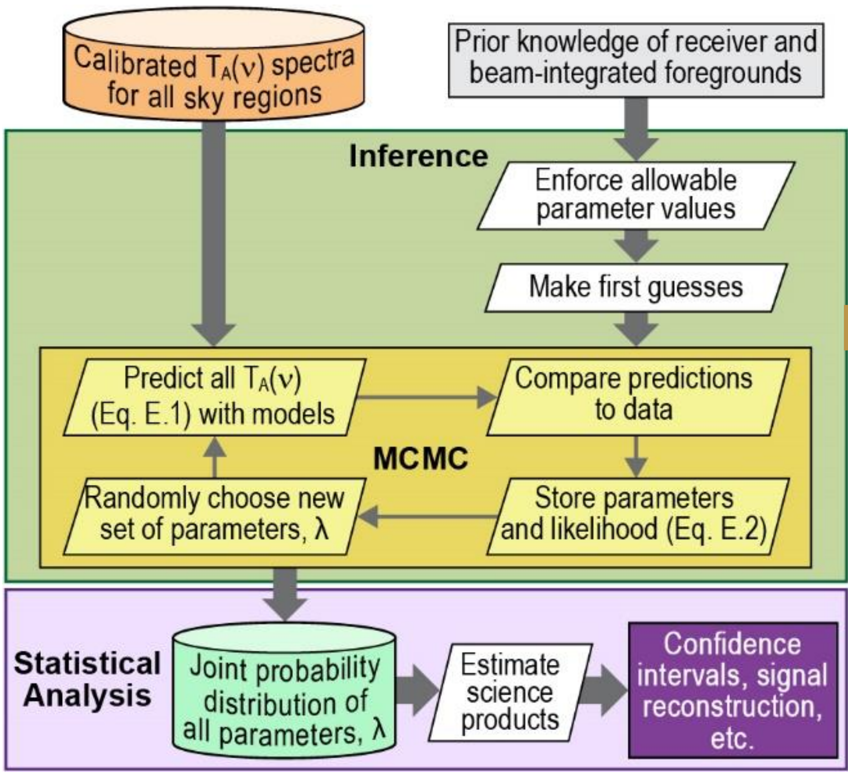
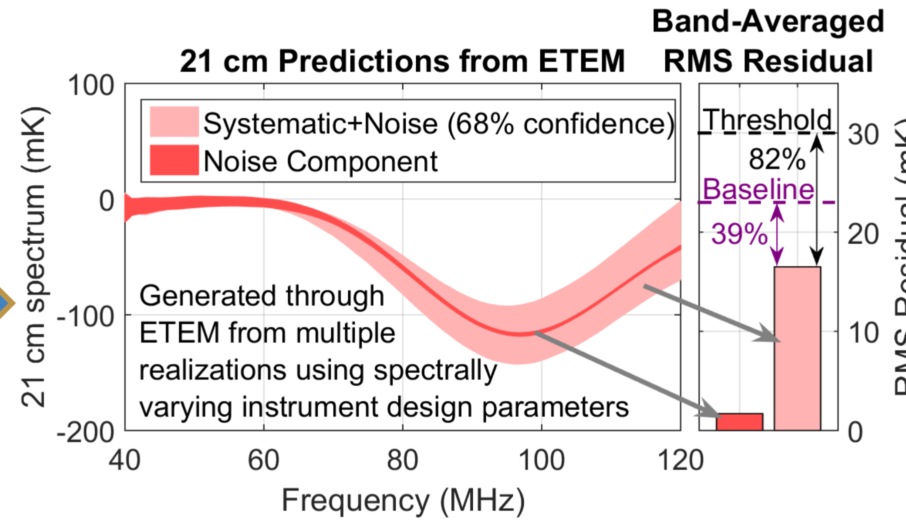
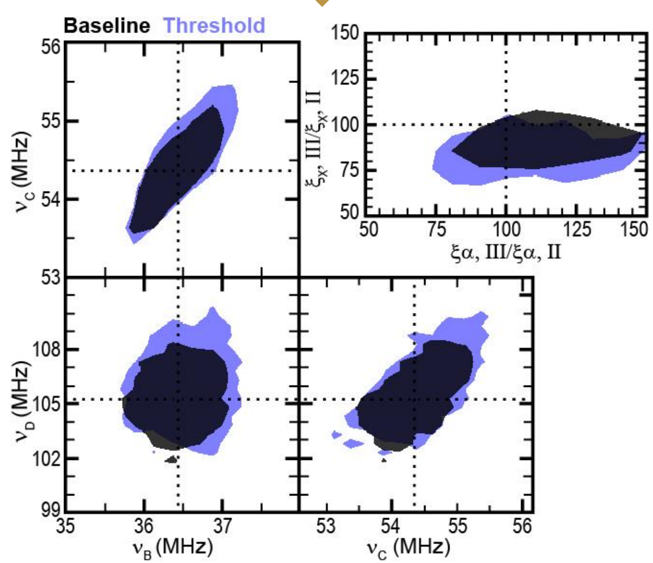
DARE Signal Parameter Pipeline: Parameter Estimation



$$T_{A,M}^{(r)}(\nu,\lambda) = \sum_i (\lambda_{21})_i \, f_i(\nu) + \sum_j \left(\lambda_{sys}\right)_j^{(r)} g_j(\nu) \quad Eq. E.1$$

$$\ln L(\lambda) = -\frac{1}{2} \sum_r \sum_\nu \left[\frac{T_{A,D}^{(r)}(\nu) - T_{A,M}^{(r)}(\nu,\lambda)}{\sigma_r(\nu)}\right]^2 \quad Eq. E.2$$





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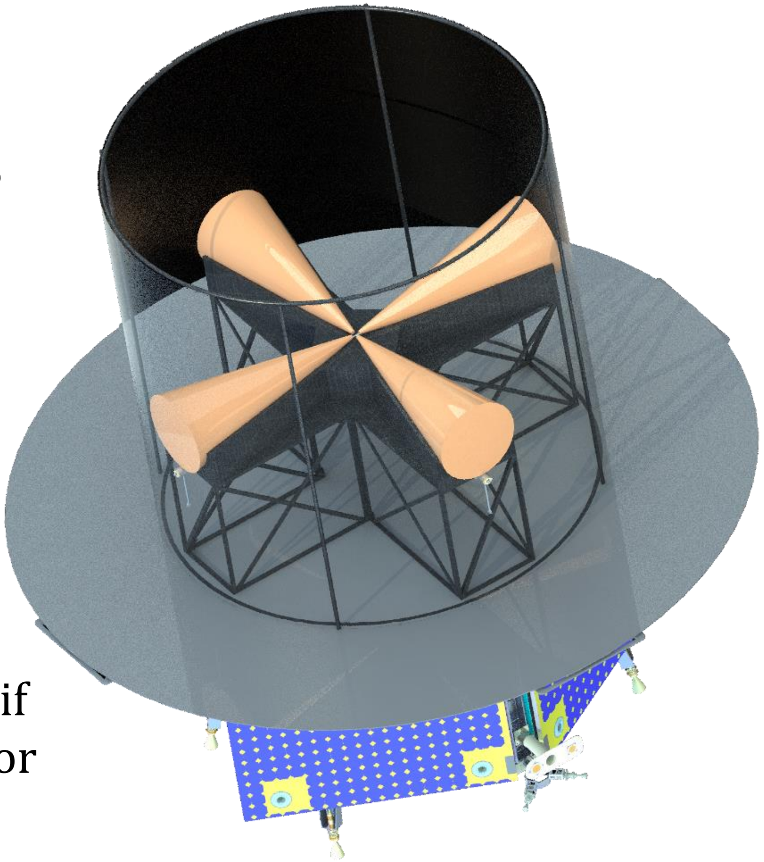
Summary and Conclusions

- The Global 21-cm Monopole signal is a powerful tool to explore the first luminous objects in the Universe and their environs at z>10.
- *DARE science instrument*: biconical dipole antenna, pilot-tone injection receiver, digital spectrometer, polarimeter.
- Challenge of observing weak 21-cm signal in presence of bright foreground is addressed via careful measurements of antenna beam & independent measure of foreground via polarimetry.
- *DARE will set meaningful constraints on:* Ly-α, ionizing, & X-ray backgrounds that will determine if Pop II or Pop III stars dominated the light output for the first galaxies.
- DARE has been submitted as a mission proposal to NASA's MIDEX program.



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