Jack Burns, University of Colorado, P.I.
Joseph Lazio, JPL, Deputy P.I.

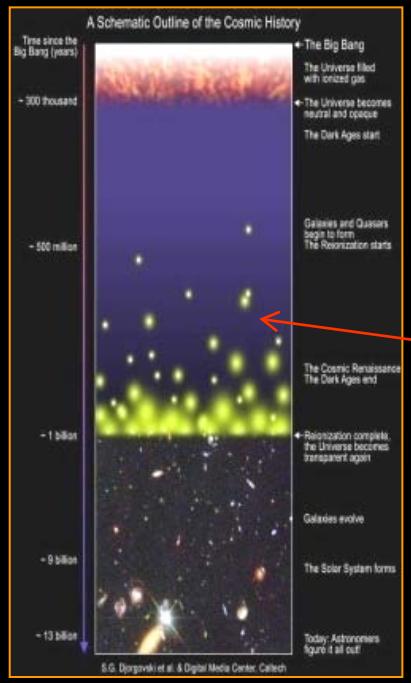
DARE to explore the *Cosmic Dawn*!

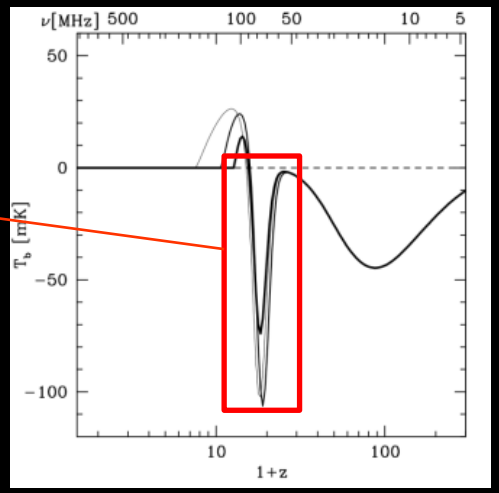
DARK AGES RADIO EXPLORER

Mission Concept

Dark Ages Radio Explorer (DARE)

- Key Science: Detect (highly redshifted) HI signal from intergalactic medium arising from the *Cosmic Dawn* between 40 MHz < ν < 120 MHz.
- Tapered cross-dipoles on lunar orbiting spacecraft.





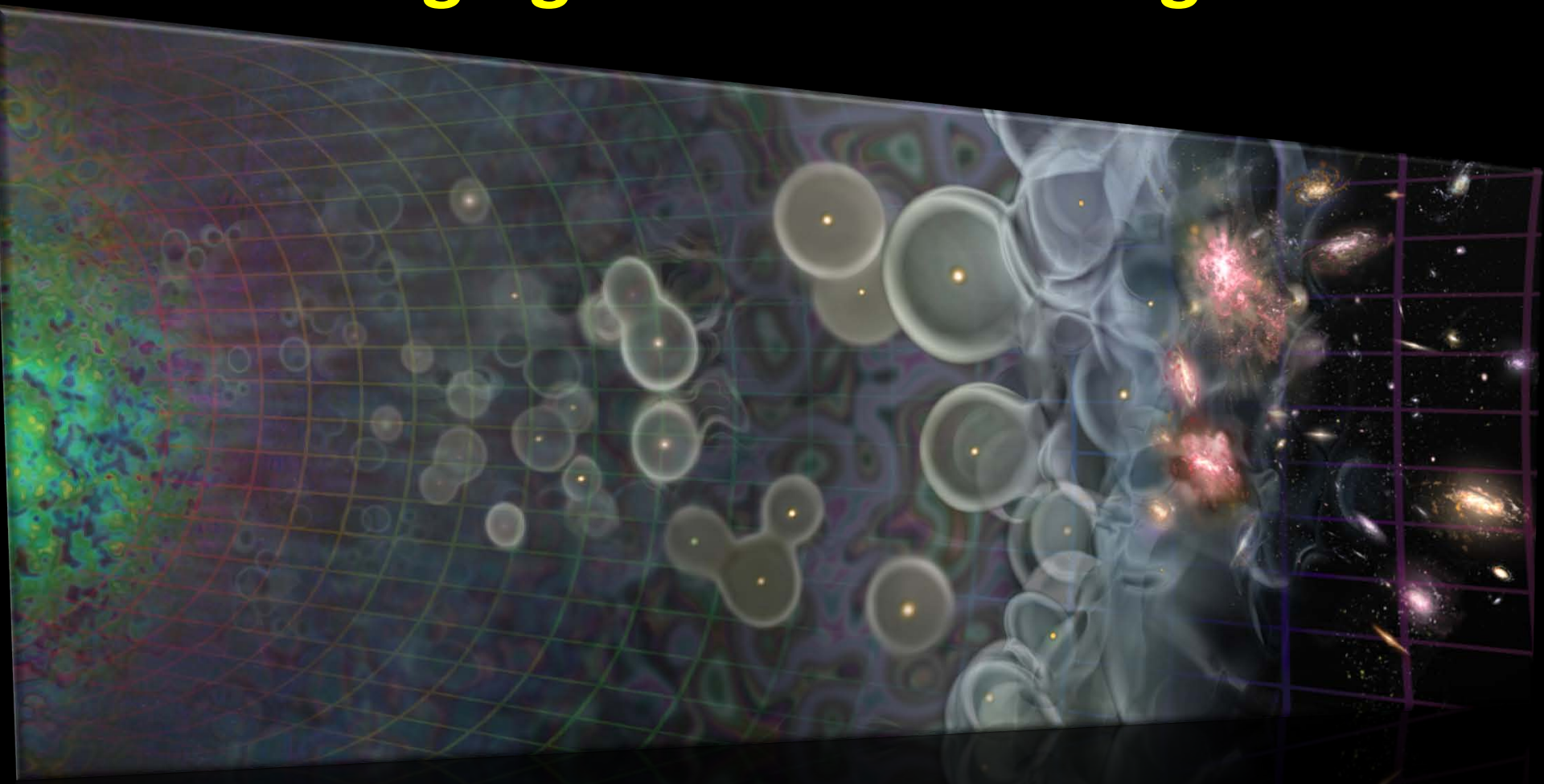
The DARE Devils

- DARE Science Team:

J. Burns, P.I.	J. Lazio, Deputy P.I.	
J. Bowman, ASU	R. Bradley, NRAO	C. Carilli, NRAO
S. Furlanetto, UCLA	G. Harker, Colorado	A. Loeb, Harvard
J. Pritchard, CfA	M. Bicay, ARC	

- Management - Ames Research Center; Larry Webster, Project Manager; Hugo Sanchez.
- Spacecraft - Ball Aerospace; Lisa Hardaway, Development Manager
- Instrument – JPL; Ian O'Dwyer, Instrument lead.
- Mission Ops - LASP, U. Colorado.

Emerging from the Dark Ages



Loeb, A. 2006, *Scientific American*, 295, 46.

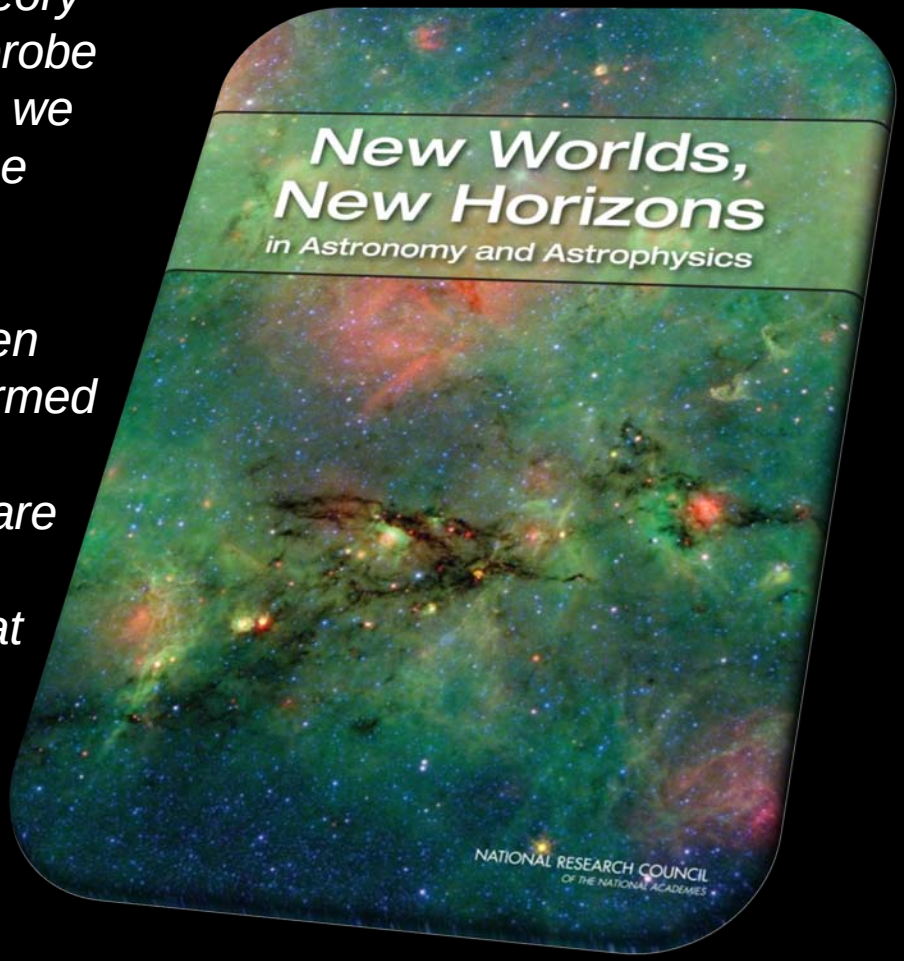
Astro 2010 Decadal Survey

- *The #2 question* listed is "What were the first objects to light up the universe and when did they do it?"

- *Three science objectives*:
  - Cosmic Dawn
  - New Worlds
  - Physics of the Universe

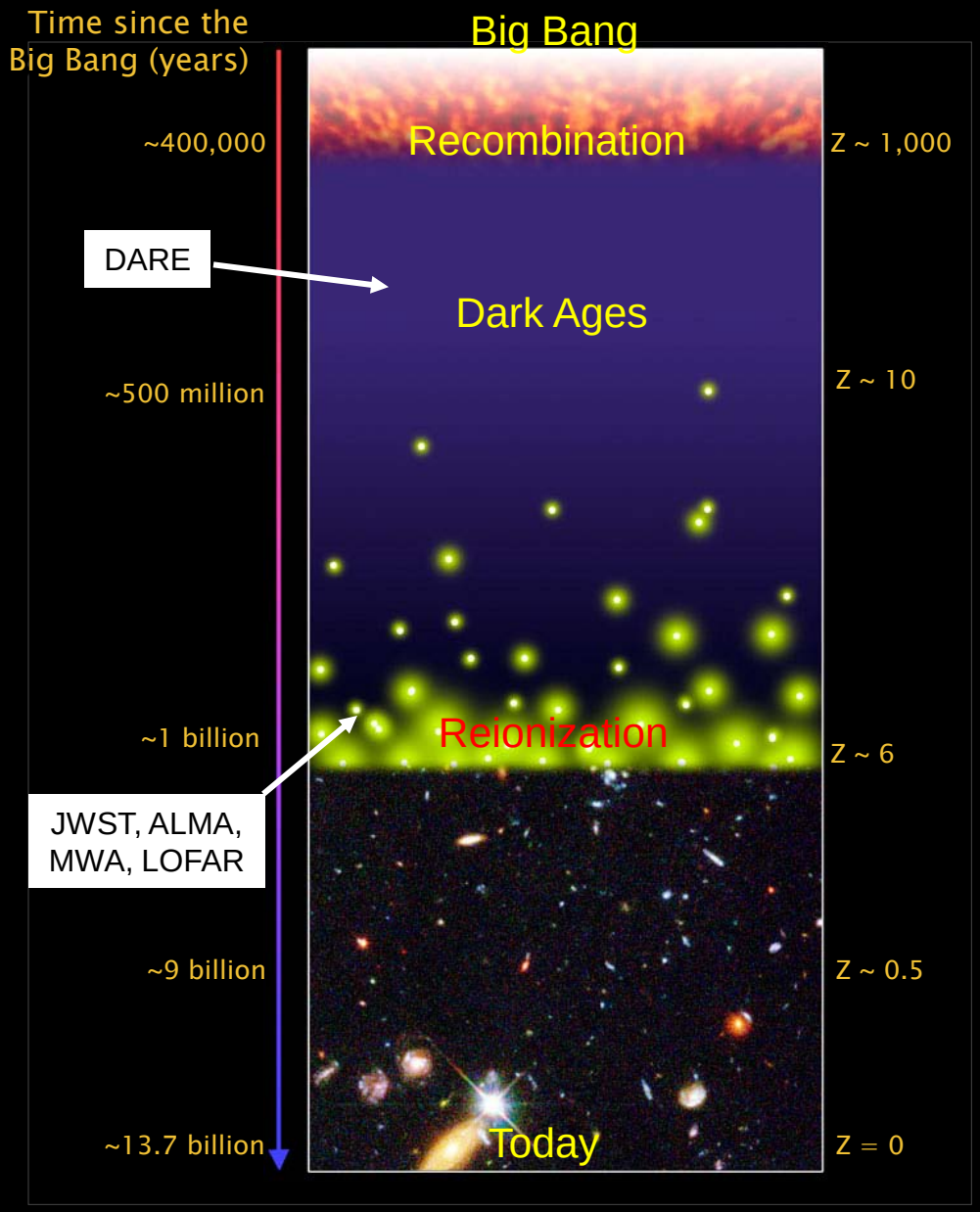
Astro 2010 Decadal Survey

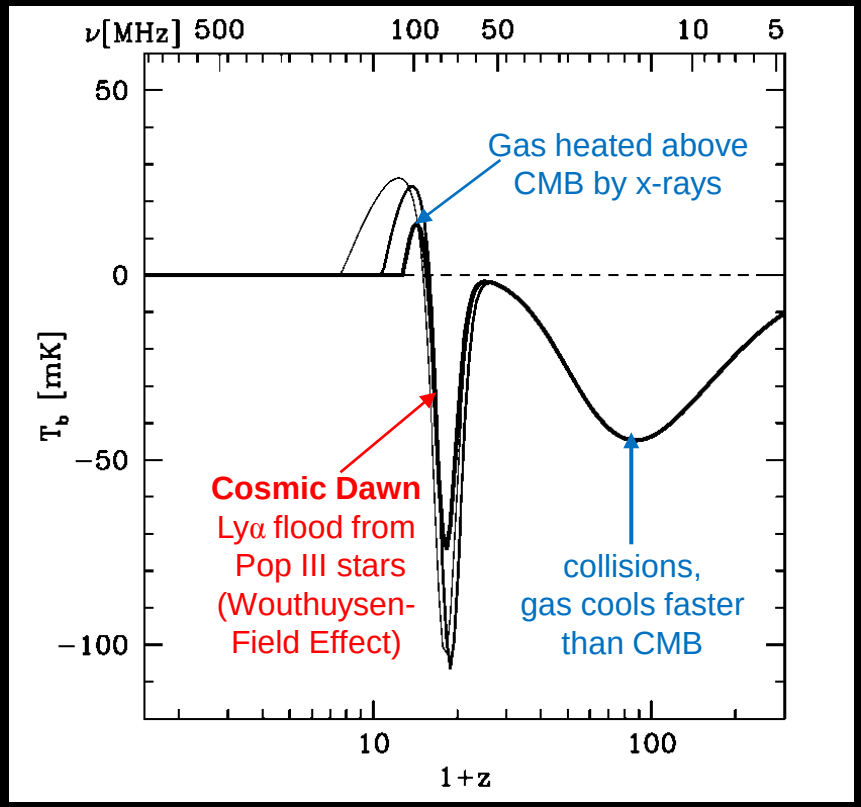
"These events lie largely in the realm of theory today and existing telescopes can barely probe this mysterious era. Over the next decade, we expect this to change. A new window on the cosmos is being opened in several wavelengths: Radio astronomers are constructing telescopes that will tell us when and where the first stars in the universe formed by mapping their effect on the primordial hydrogen at the end of the dark ages and are planning those that will be able to directly observe the primordial hydrogen atoms that permeated the dark ages of the universe."



Reionization and the Dark Ages

$$\delta T_b(z) \approx 23\,(1+\delta)\; x_{HI}\,(1-T_{CMB}/T_S)\,(50\,\Omega_B\,h^2)\,[(0.15\,\Omega_M^{-1}\,h^{-2})\,((1+z)/10)]^{1/2}\ \text{mK}$$

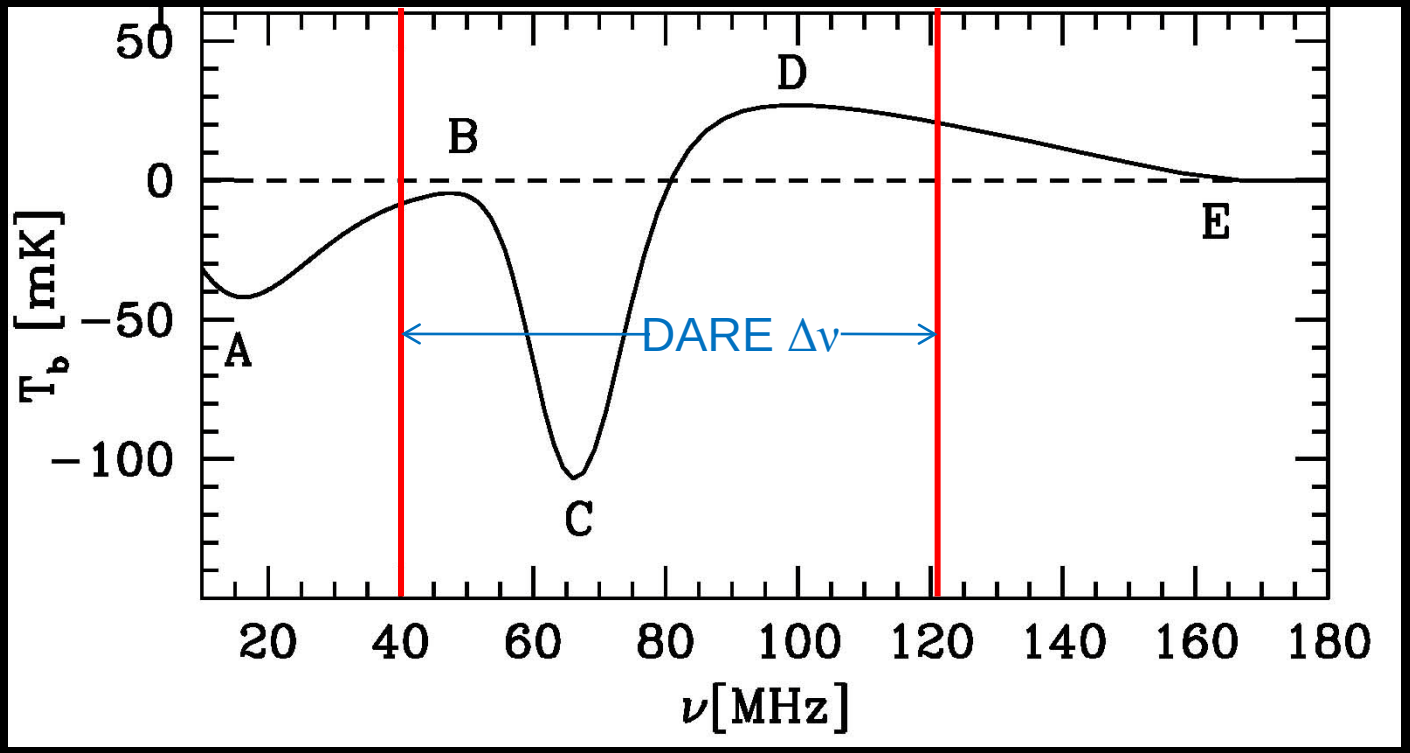




Pritchard & Loeb, 2009, Phys. Rev D, 78, 103511

21 (1+z) cm = 1420/(1+z) MHz
at z=10, λ = 2.3 m (130 MHz)
at z=50, λ = 10.7 m (30 MHz)

DARE will focus on measuring spectral *Turning Points* B, C, D



- Turning Point A – Collisional coupling fails as Universe expands.
- Turning Point B – First star formation leads to renewed coupling due to Ly-α scattering.
- Turning Point C – First black holes heat the IGM with X-rays.
- Turning Point D – Saturation of 21-cm emission signal when gas heated above CMB.
- Turning Point E – Reionization destroys 21-cm signal.

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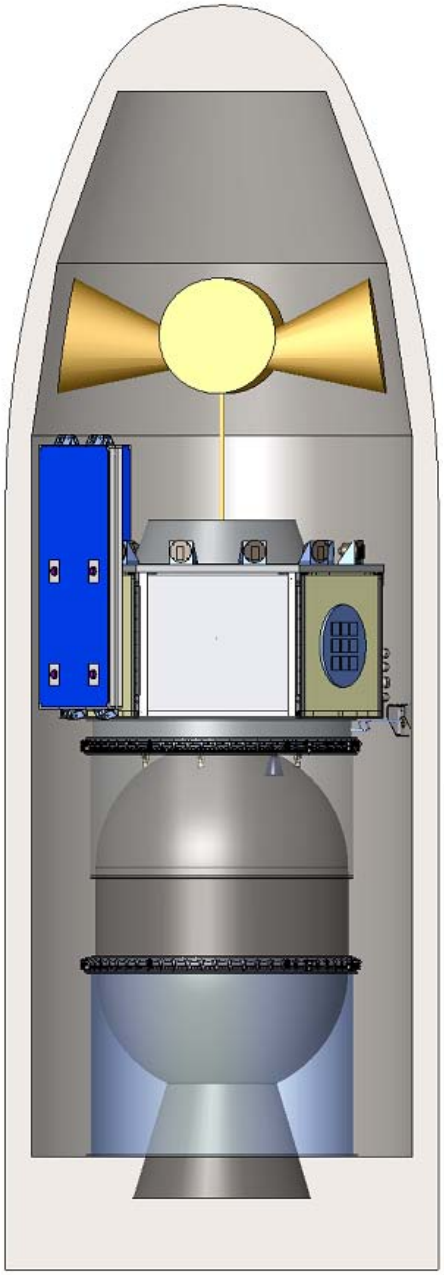
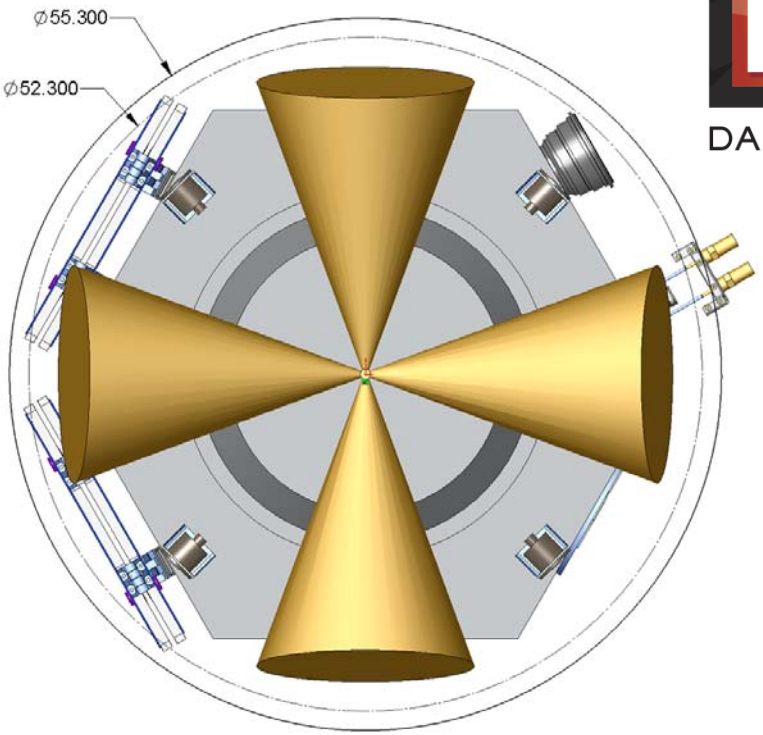
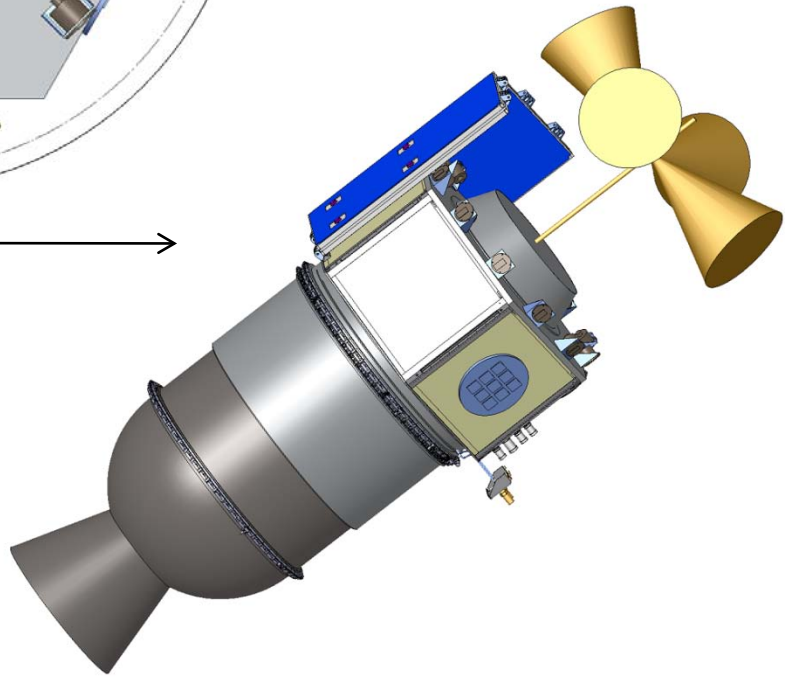
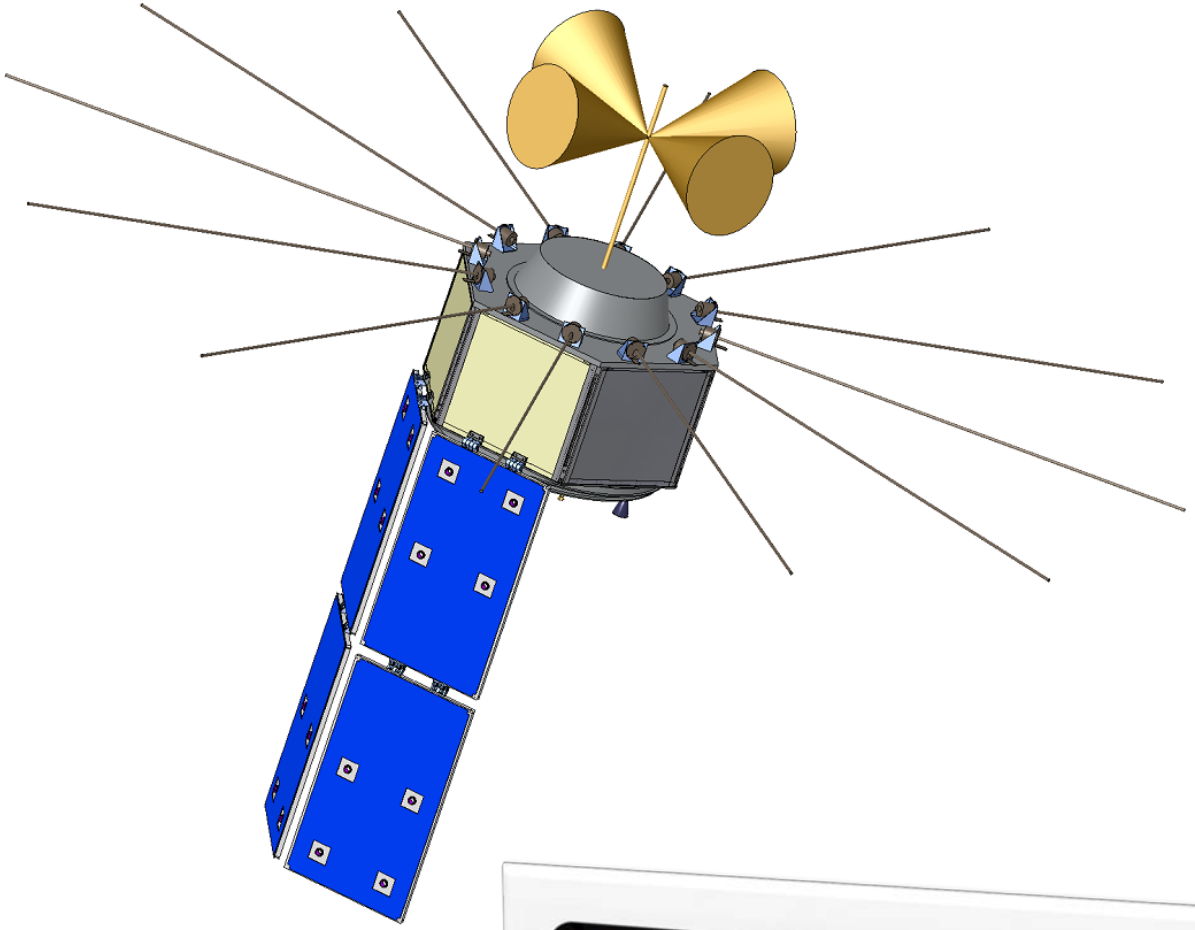
DARK AGES RADIO EXPLORER





1.2 meters





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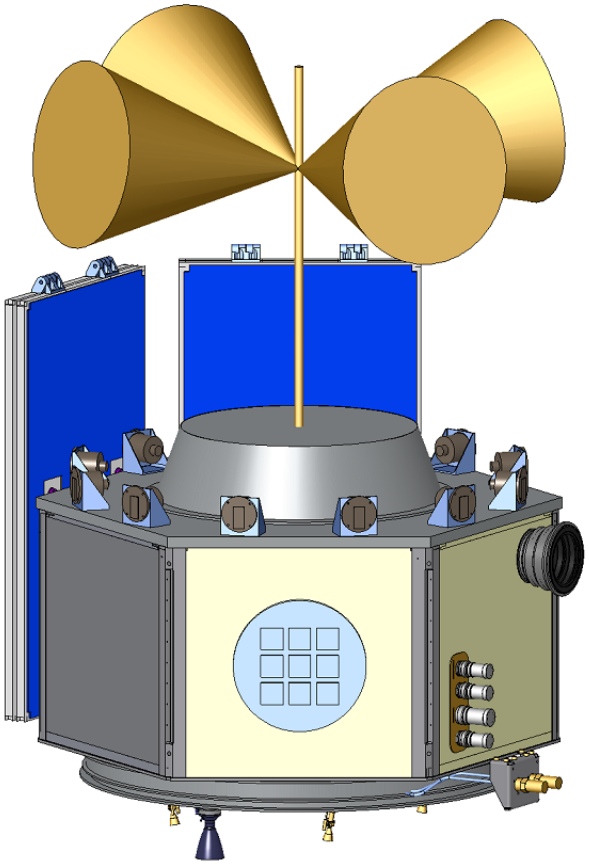
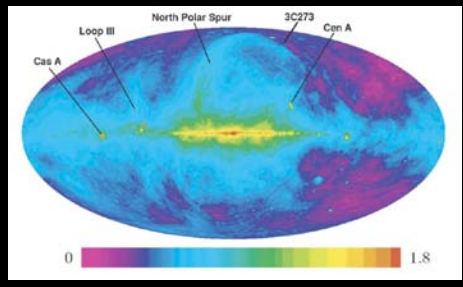
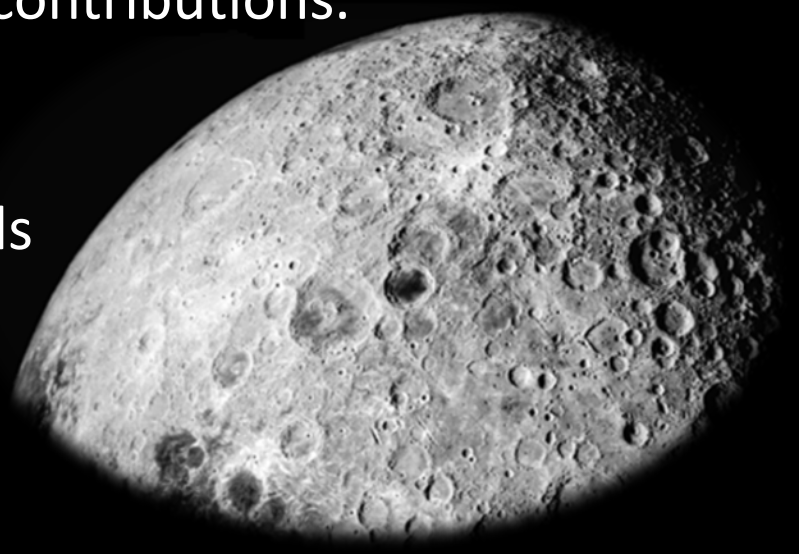


Advantages of DARE Above Lunar Farside

- DARE removes all complications from Earth's ionosphere & terrestrial RFI.
- DARE provides an ideal environment for the science antenna. *Control & characterization of the antenna properties are most important factors for subtracting foregrounds.*
- DARE enables an added calibration step using the Moon to isolate 21-cm signal from instrument contributions.
- DARE is the *only* solution to eliminate RFI in the inner solar system.
- DARE is a proven strategy that parallels the successful history of CMB experiments.





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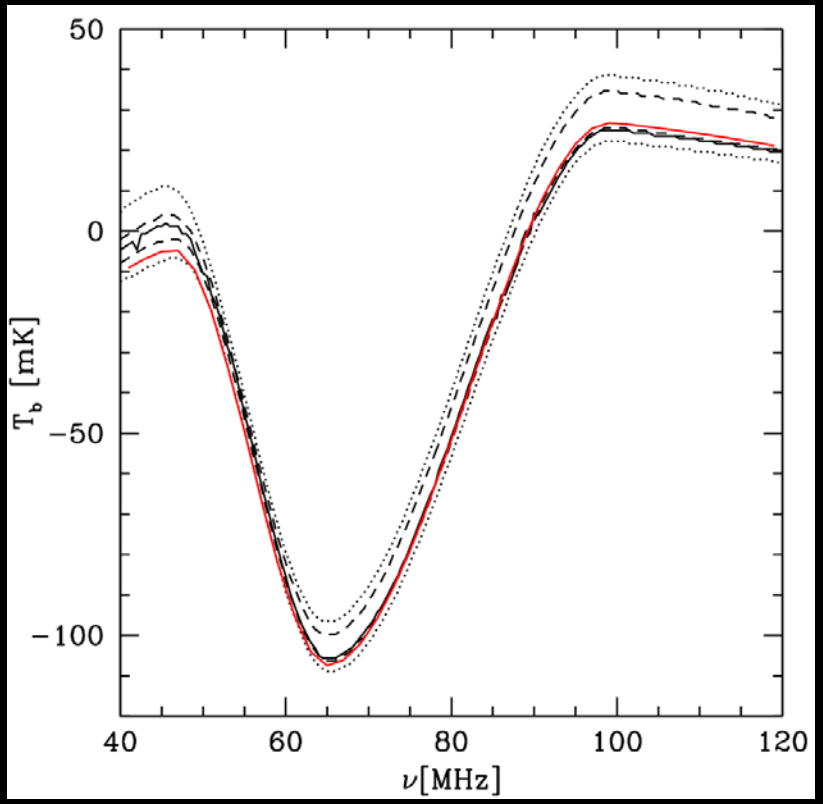
Mission Requirements

Radiometry equation yields thermal noise:

$$T_N = \frac{T_{sky}}{\sqrt{t_{obs}\Delta\nu}} = 1\frac{(T_{sky}/3000\mathrm{K})}{\sqrt{(t_{obs}/1250\mathrm{hrs})(\Delta\nu/2\mathrm{MHz})}}\,\mathrm{mK}$$

⇒Demands of Foreground-fitting require < mK level sensitivity.



Quality of recovery of turning points
2 MHz channels

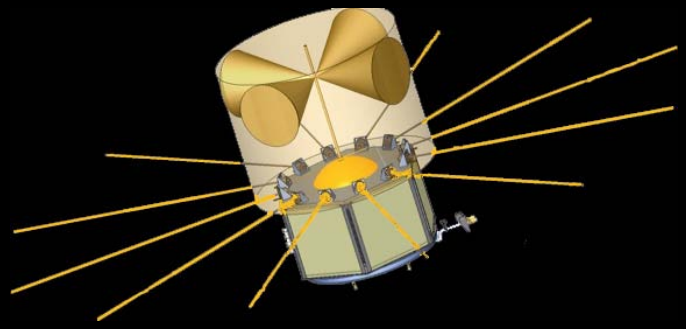
DARE Integration Times

Turning point	Frequency / MHz	Amplitude / mK	Sky temperature / K	Integration time / hrs
B	46.2	-5	7480 (4530)	7770 (2850)
C	65.3	-107	3350 (2010)	1560 (561)
D	99.4	27	1210 (720)	203 (72)

Summary

Dark Ages Radio Explorer

- Key Science: Detect (highly redshifted) HI spectral turning points (40 MHz < ν < 120 MHz) from intergalactic medium occurring during *Cosmic Dawn*.
- Tapered cross-dipoles on lunar orbiting spacecraft.



DARE to explore the *Cosmic Dawn*!