Cosmology from the Moon: Observing the Dark Ages of the Early Universe from the Farside

NESS
Network for Exploration and Space Science
A NASA-funded SSERVI Team

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Co-Investigators:
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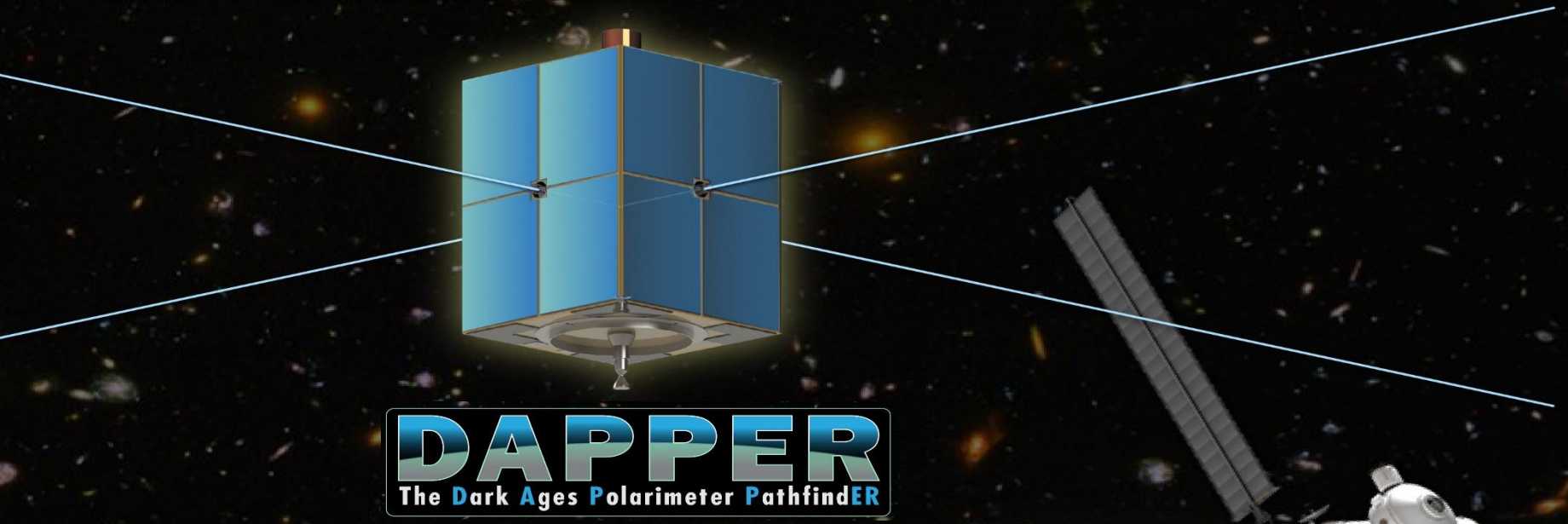
NASA Ames Research Center



DAPPER
The Dark Ages Polarimeter PathfindER

NASA Exploration Science Forum
Ames Research Center, 23 July 2019

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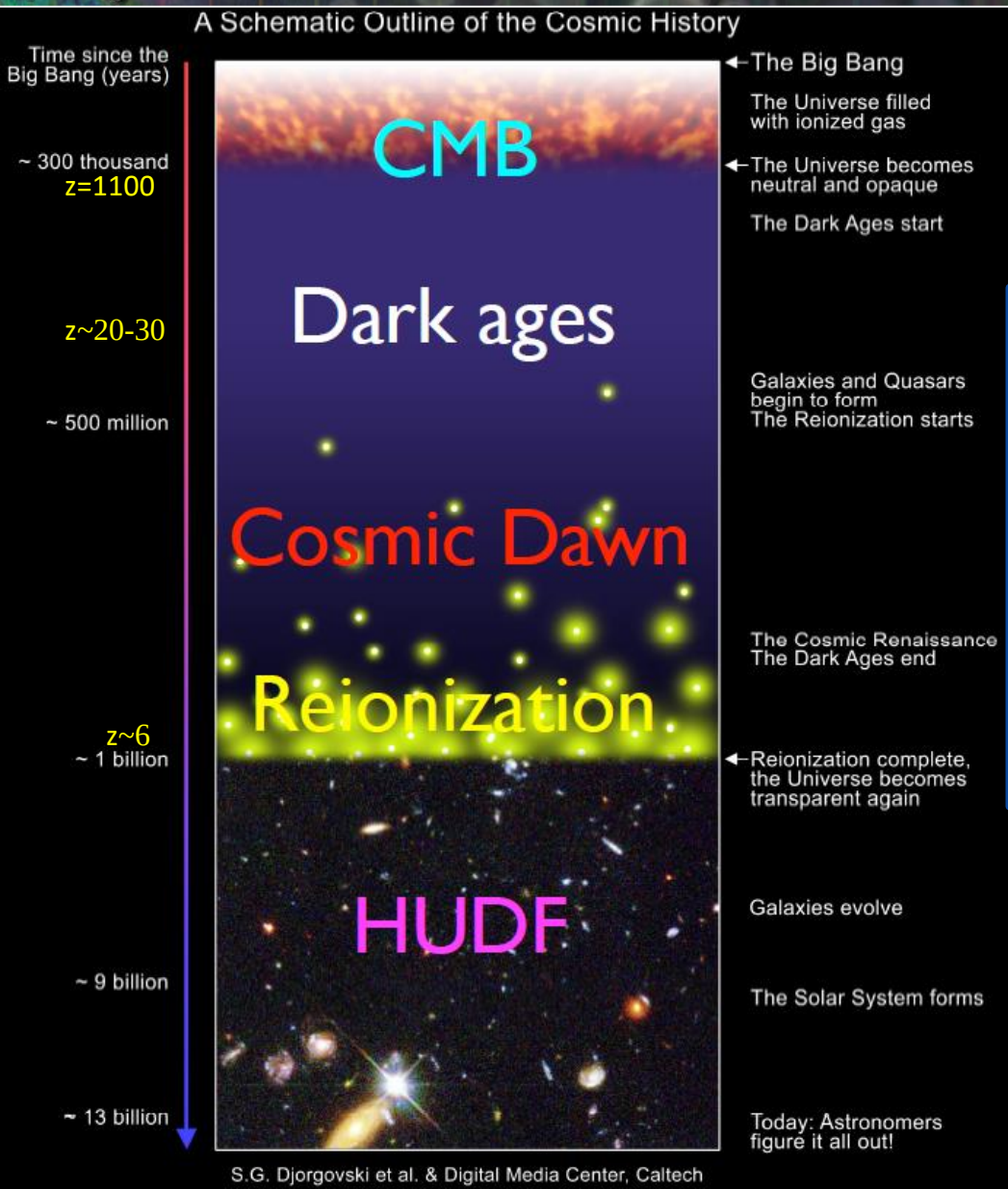
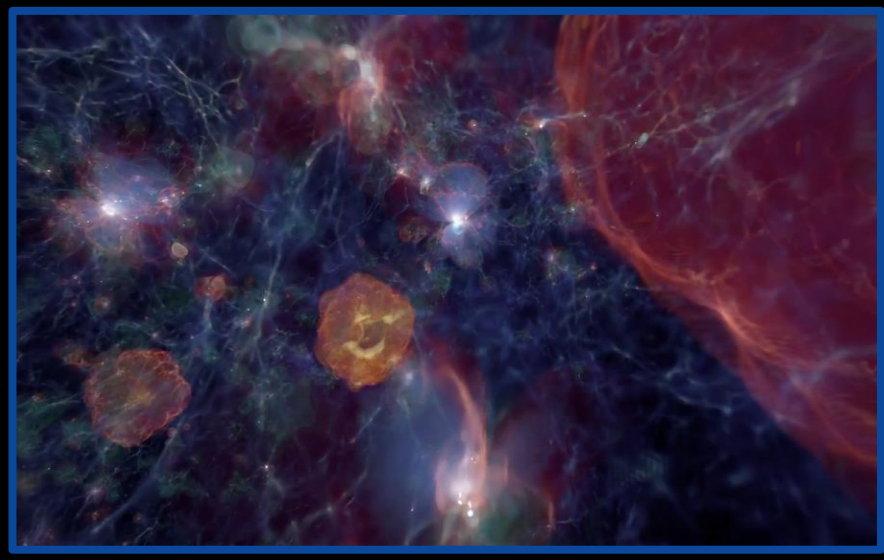
Dark Ages Polarimeter PathfindER

DARK COSMOLOGY:
INVESTIGATING DARK MATTER IN THE DARK AGES



The First Stars

M. Norman, B. O'Shea et al.



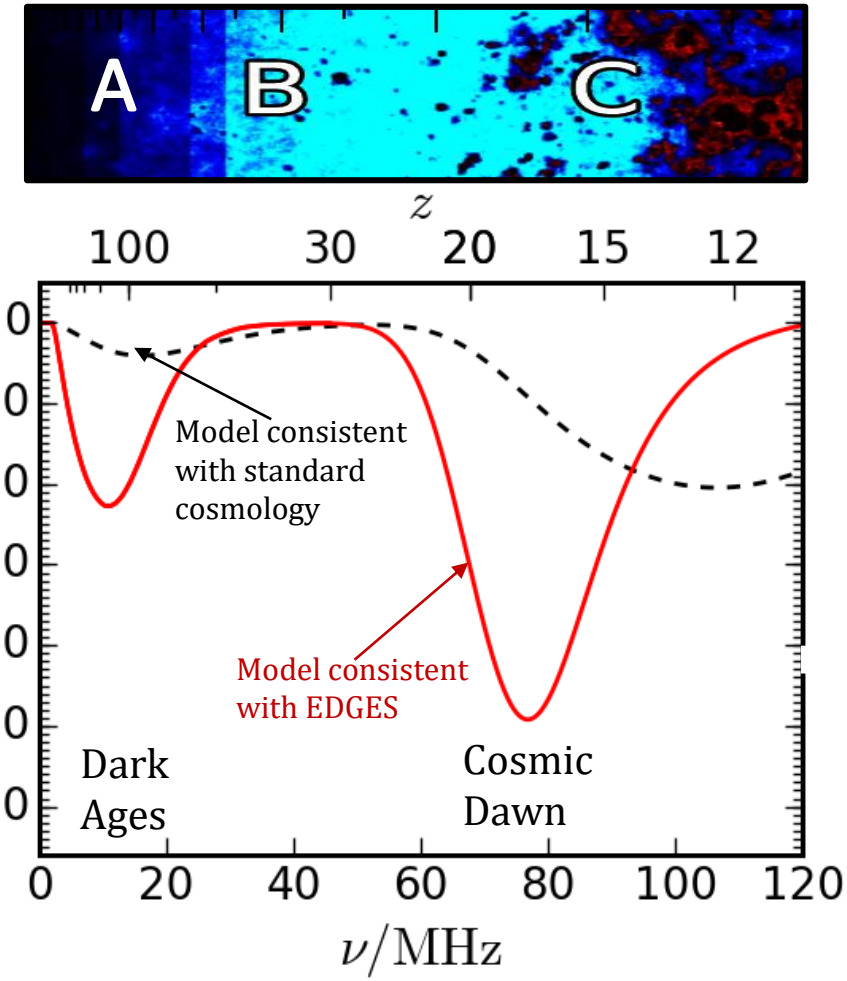
What is the 21-cm Global signal?

Spectral Features:

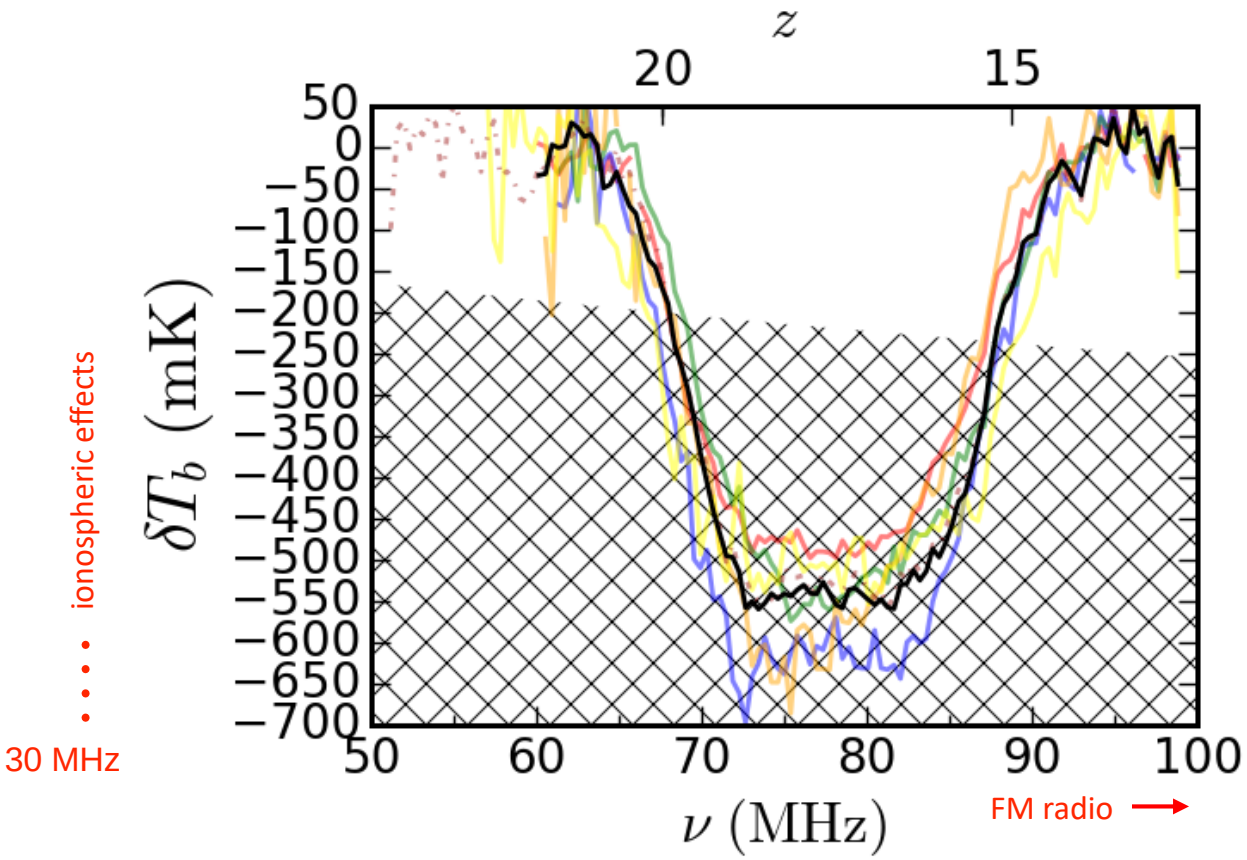
A: Dark Ages: test of standard cosmological model

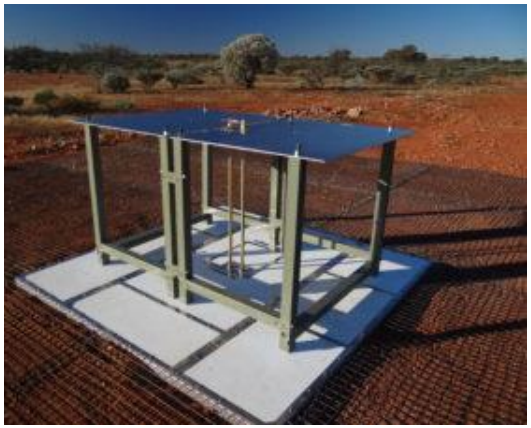
B: Cosmic Dawn: First stars ignite

C: Black hole accretion begins



EDGES: Key Features





Bowman et al. 2018, Nature, 555, 67

How to amplify signal by a factor of 2-3?

$$\delta T_b \simeq 27\, \overline{x}_{\mathrm{H\ I}} (1+\delta) \left(\frac{\Omega_{b,0}h^2}{0.023}\right) \left(\frac{0.15}{\Omega_{m,0}h^2}\frac{1+z}{10}\right)^{1/2} \left(1-\frac{T_{\mathrm{R}}}{T_{\mathrm{S}}}\right)\ \mathrm{mK}$$

1. Increase T_R via Dark Matter decay or synchrotron radiation from black holes, galaxies.
   - Feng & Holder, Ewall-Wice et al., Fraser et al., Mirocha & Furlanetto
2. Alter the cosmology.
   - McGaugh, Costa et al., Hill et al.
3. Decrease T_S via baryon-Dark Matter interactions which cools the hydrogen.
   - Barkana, Munoz & Loeb, Fialkov et al., Berlin et al., Slatyer & Wu

DAPPER

Dark **A**ges **P**olarimeter **P**athfind**ER**

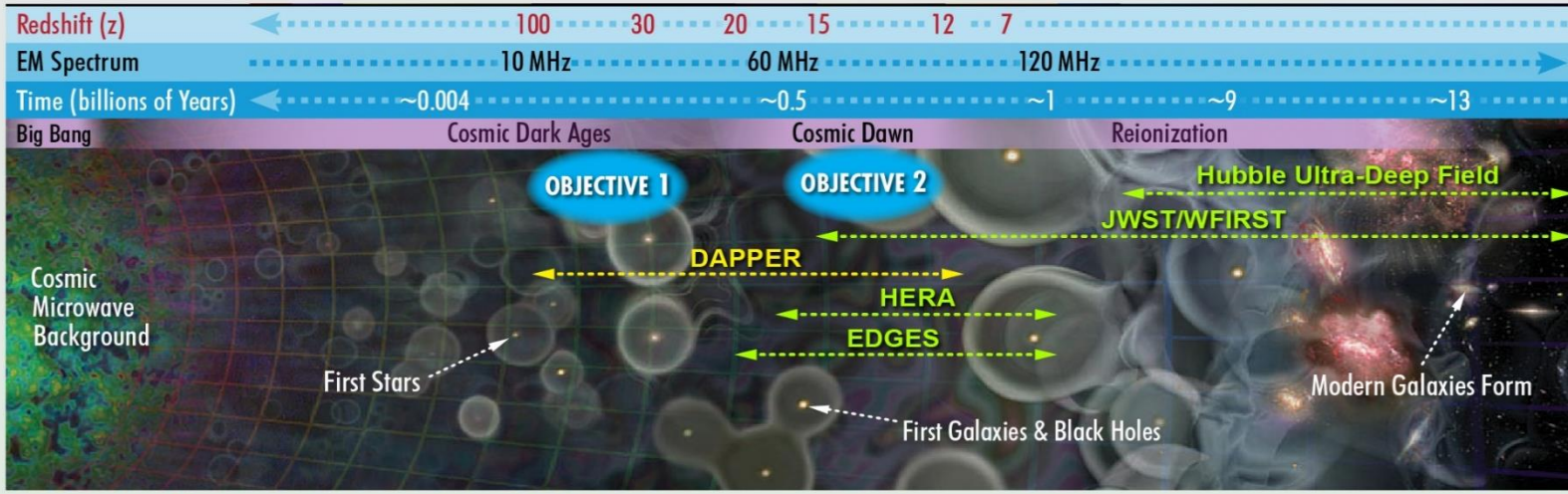
DARK COSMOLOGY:
INVESTIGATING DARK MATTER IN THE DARK AGES

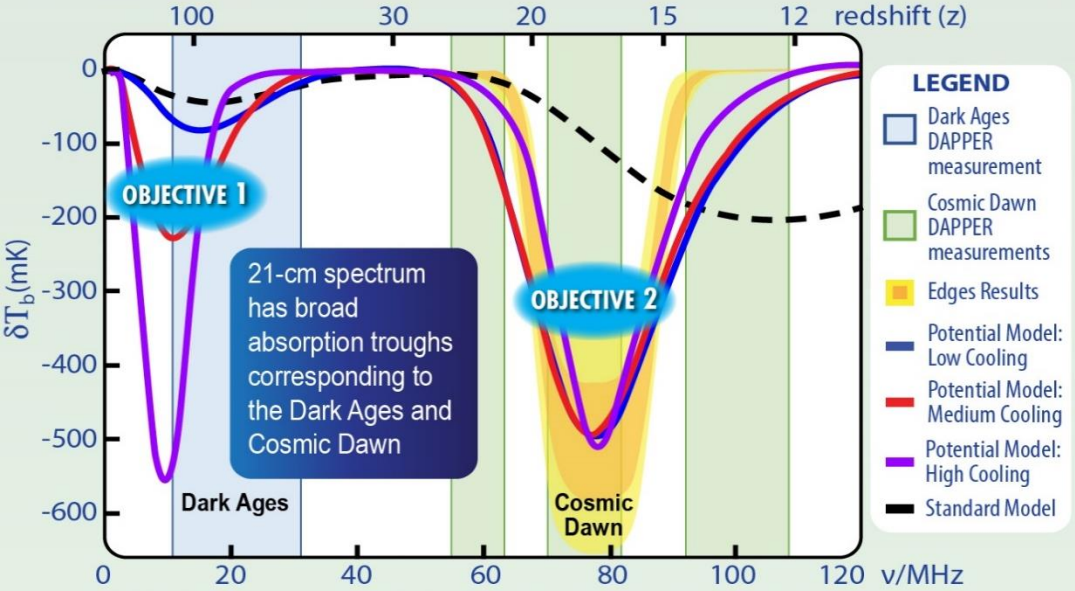
SCIENCE

OBJECTIVE 1:
- Determine the level of (dis)agreement with the standard cosmological model caused by dark matter in the Dark Ages.

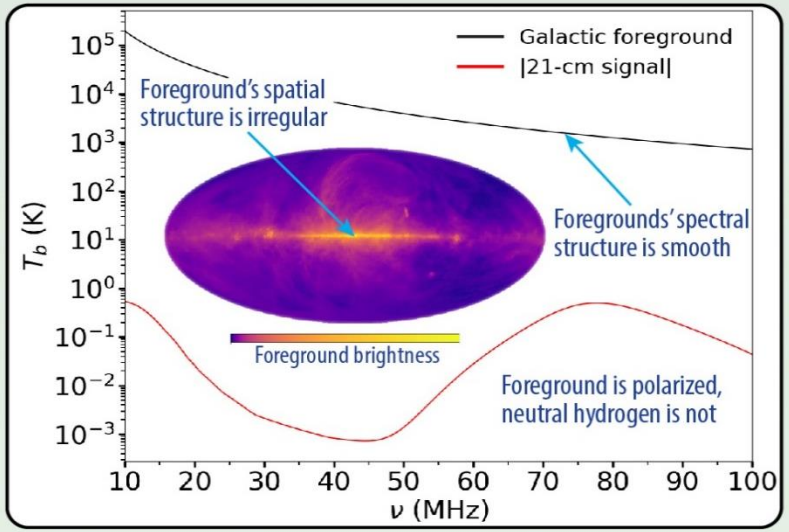
OBJECTIVE 2:
- Determine the level of excess cooling above the adiabatic limit for Cosmic Dawn.
- Determine when the first stars and black holes formed.

Will the observed behavior of redshifted neutral hydrogen redefine the standard cosmological model?





DAPPER uses the 21-cm all-sky signal to observe redshifts z = 83-12, associated with the Dark Ages and the Cosmic Dawn.



DAPPER separates Galaxy foreground from 21-cm signal using differences in spectral shapes, spatial structure, and polarization.

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DARK COSMOLOGY:
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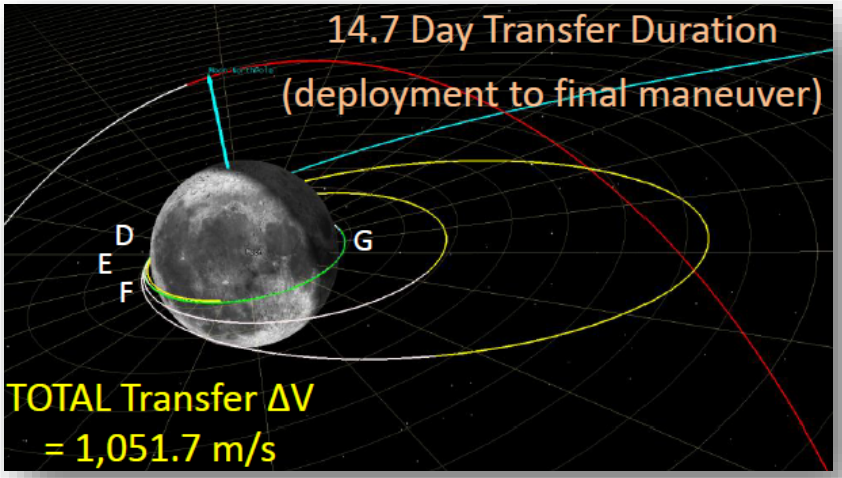
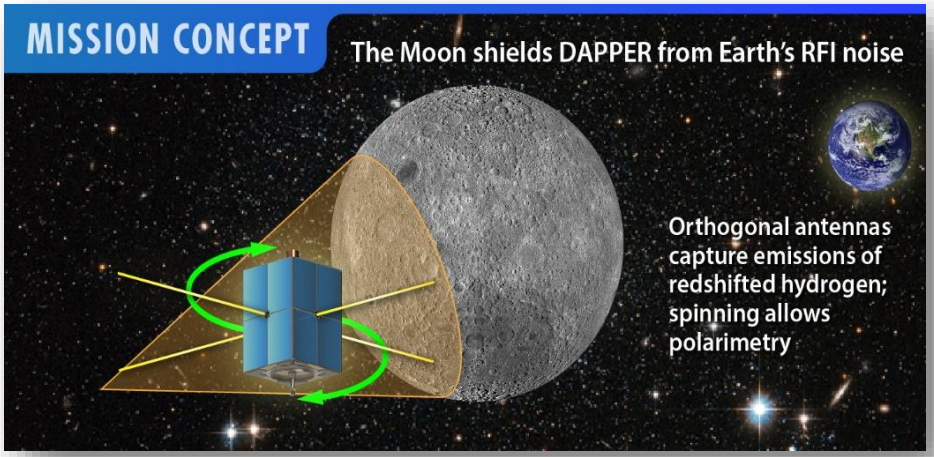
Mission Overview

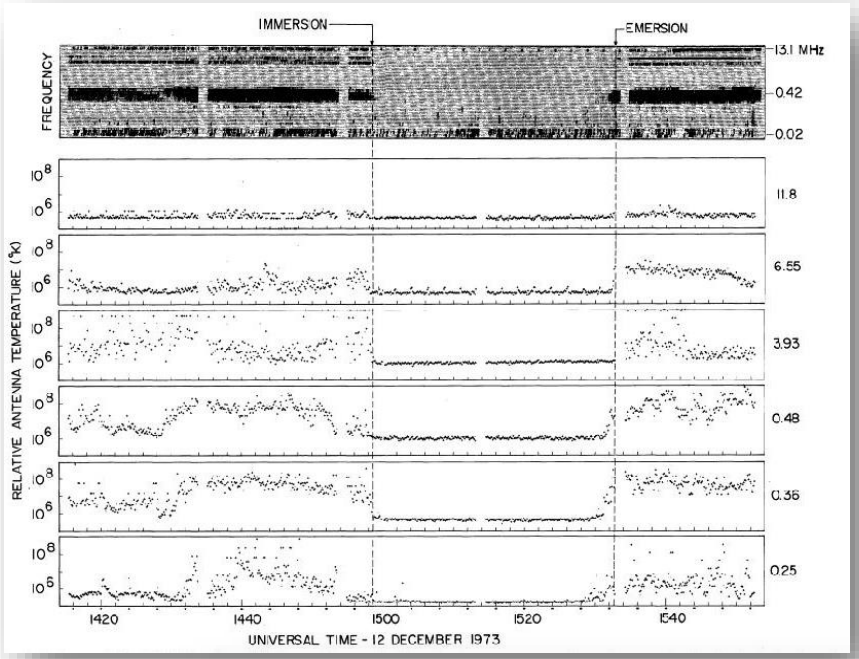
- DAPPER will deploy from vicinity of NASA's Lunar Gateway & transfer to a 50×125 km low lunar orbit.
- Operates over primary bandwidth of 17-38 MHz ($83 \geq z \geq 36$) and sparse secondary sampling from 55-107 MHz ($25 \geq z \geq 12$).
- Low noise amplifiers & dual channel receiver to measure all 4 Stokes parameters. Based upon FIELDS instrument currently flying on Parker Solar Probe (TRL = 8).
- Projection-induced polarimetry used to independently constrain foreground.
- Baseline mission duration = 26 months.

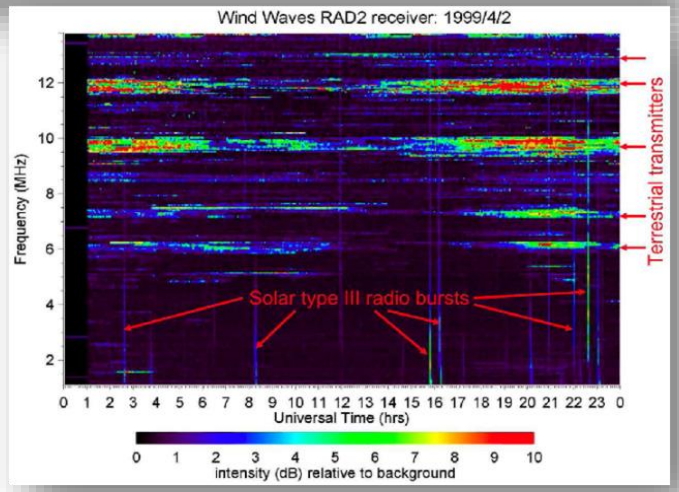


Lunar Farside: No RFI or Ionosphere!



RAE-2 1973





Wind/Waves data near the Moon

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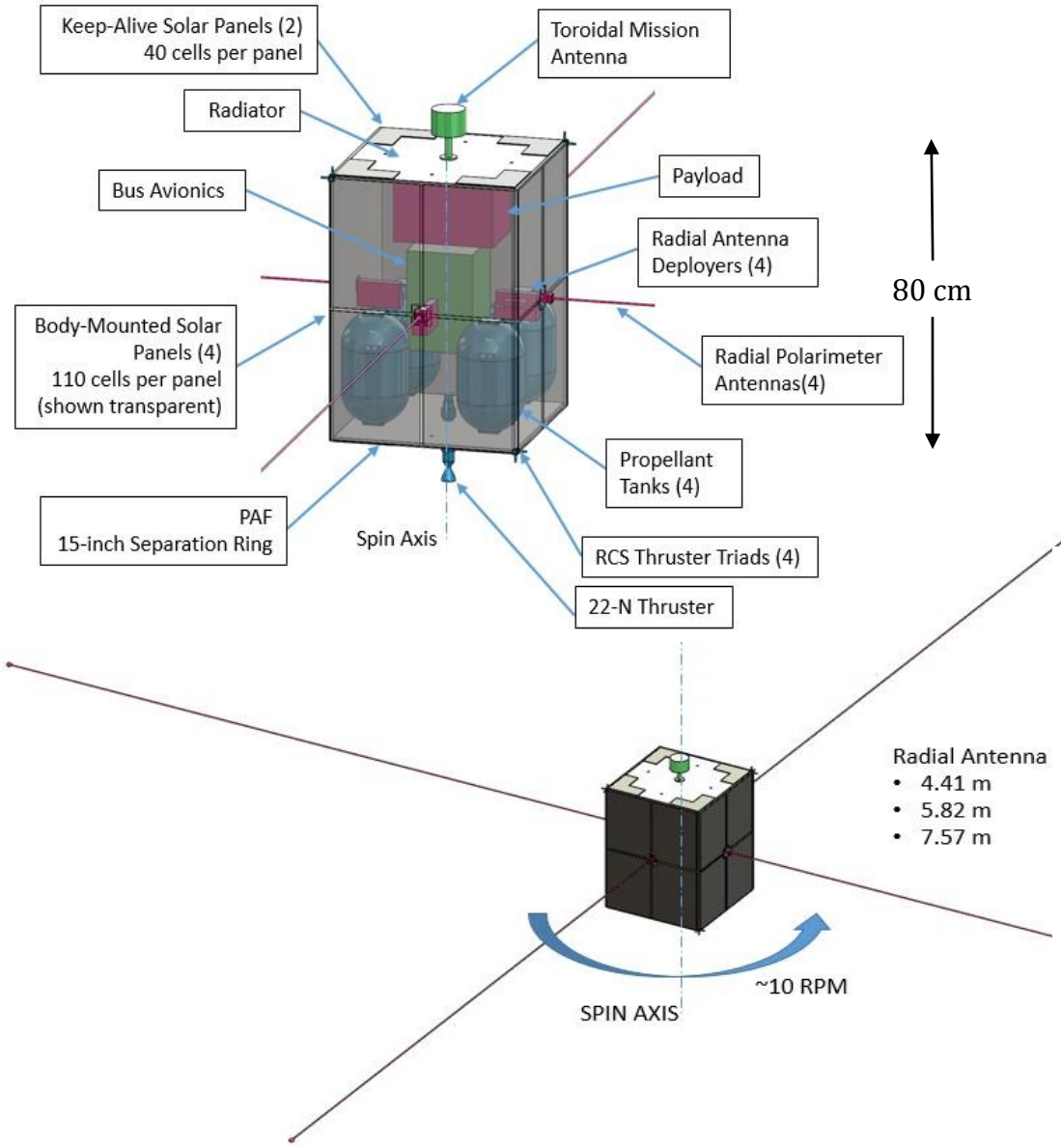
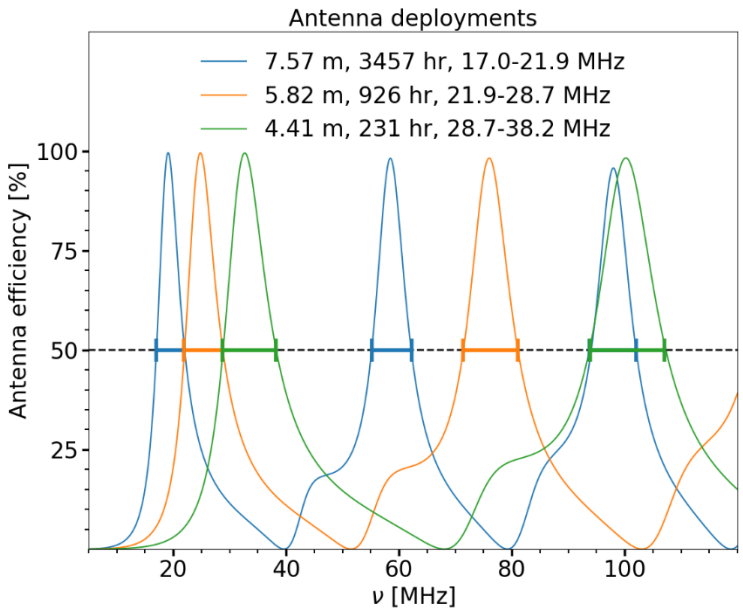


Spacecraft

- Deep Space Xplorer bus by Bradford Space Industries.
- High impulse, high ΔV.

Antennas

- Deployable, spinning, wire boom antennas arranged in 2 orthogonal, co-linear pairs.
- 3 length deployments to "tune" instrument.



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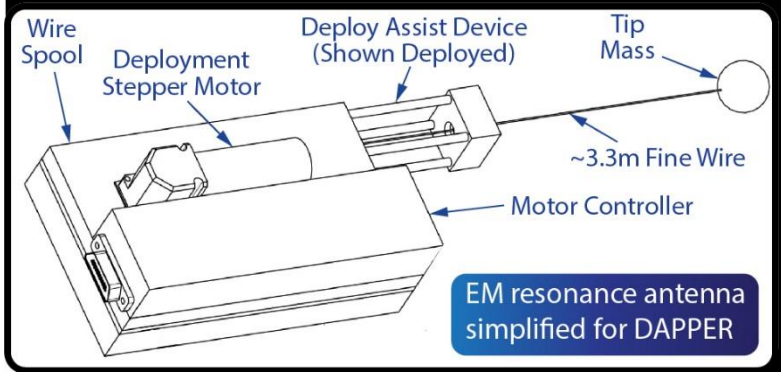
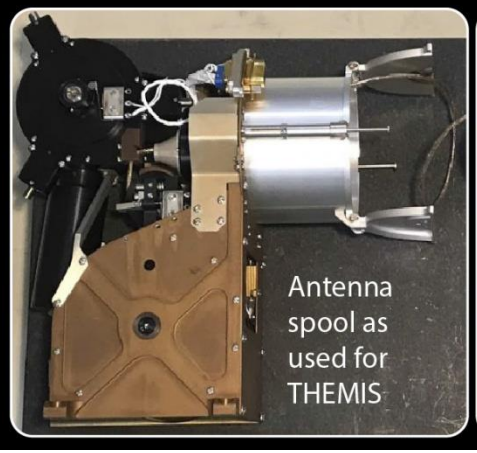
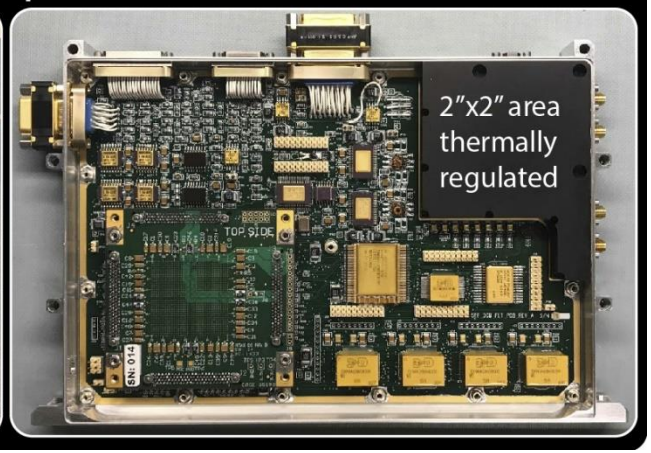
INSTRUMENT

Thermally robust antennas have been deployed in near-sun environment and in deep space.





Spectrometer/Polarimeter used for Parker Solar Probe



DAPPER Instrument

- High heritage from Parker Solar Probe, THEMIS, Van Allen Probes.
- Receiver gain variations:
  - Measured with high fidelity by frequency tones.
  - Controlled by stabilizing temperatures to $\pm 1°C$.
- Calibration:
  - Pre-launch lab measurements.
  - In-flight verification.
  - Fitting receiver characteristics using pattern recognition/MCMC pipeline.

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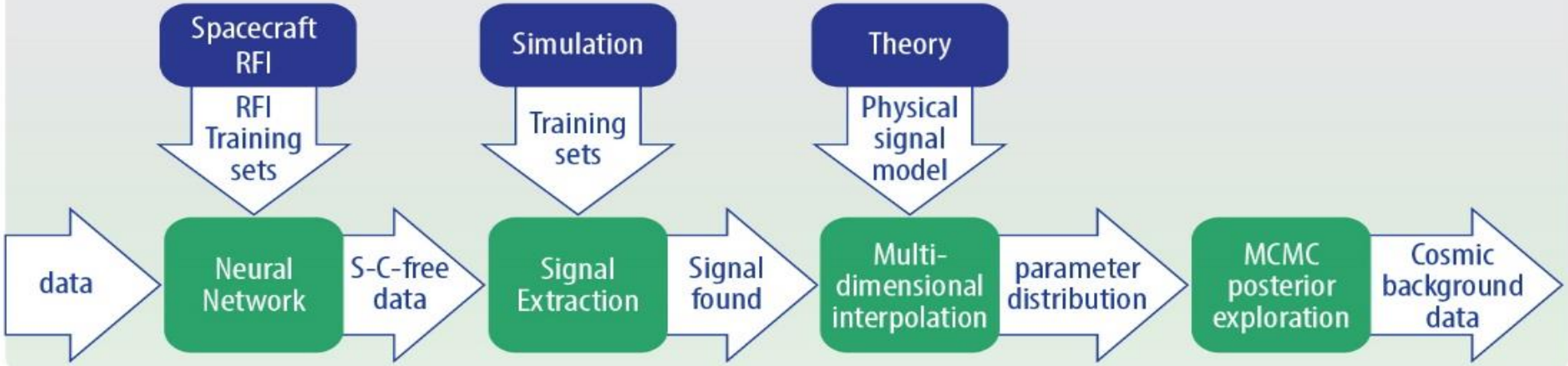
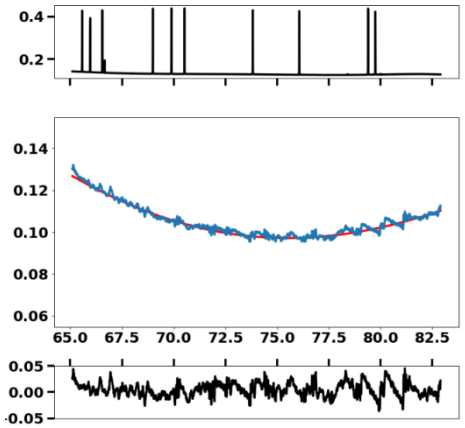
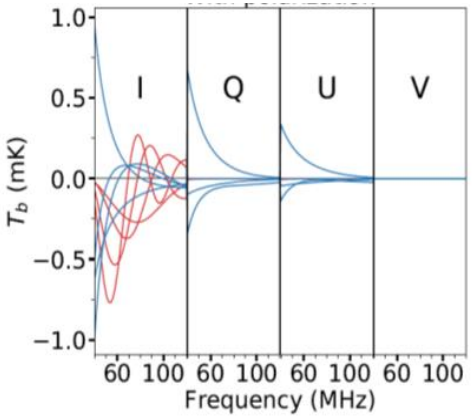
DATA PROCESSING PIPELINE

Pipeline uses pattern recognition and training sets to separate signal from known S/C, foreground, and systemic effects, and then fits cosmological models to the data.

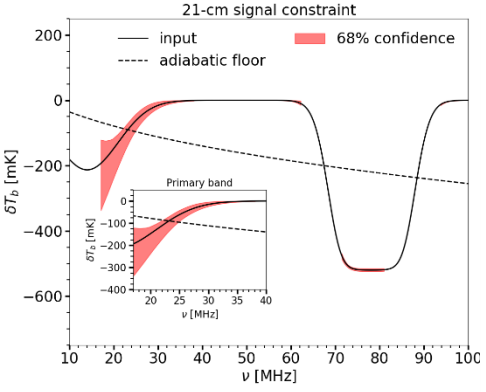




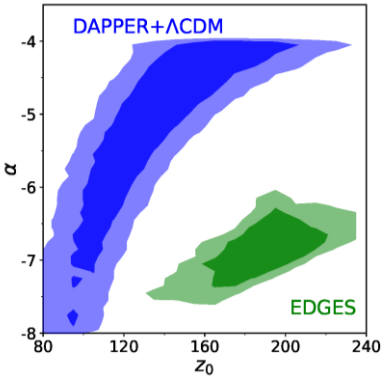
Removal of RFI using Kurtosis & Neural Network



Separate foreground from 21-cm signal using polarization & SVD



End-to-end simulation with sky + instrument systematics, signal models



DAPPER separates standard cosmology from added-cooling at >5σ

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Summary

- The redshifted 21-cm Global Spectrum at $\lesssim$30 MHz offers the prospect of probing the nature & character of Dark Matter in the Dark Ages.
- These observations need to be conducted in space, in orbit of the Moon, to eliminate Earth ionospheric, RFI, & ground effects.
- Projection-induced polarization provides an independent measure of the galactic foreground.
- We developed a method which transforms the 21-cm signal extraction task from one where *absolute knowledge of system parameters* is required to one of *composing training sets where knowledge of the modes of variation* are used.
- DAPPER will differentiate between the standard cosmology model & added cooling models at >5σ level.

MANAGEMENT & ORGANIZATION

DAPPER SCIENCE TEAM

Member	Role	Institution
J. Burns	PI	University of Colorado
S. Bale	Co-I	UC Berkley
R. Bradley	Co-I	NRAO
N. Bassett	Grad Student	University of Colorado
D. Bordenave	Grad Student	University of Virginia
J. Bowman	Collaborator	ASU
H. Falcke	Collaborator	Radbound University
S. Furlanetto	Collaborator	UCLA
M. Klein-Wolt	Collaborator	Radbound University
R. MacDowall	Collaborator	NASA GSFC
J. Mirocha	Collaborator	McGill
B. Nhan	Collaborator	University of Virginia
D. Rapetti	SOC Lead	University of Colorado
K. Tauscher	Grad Student	University of Colorado

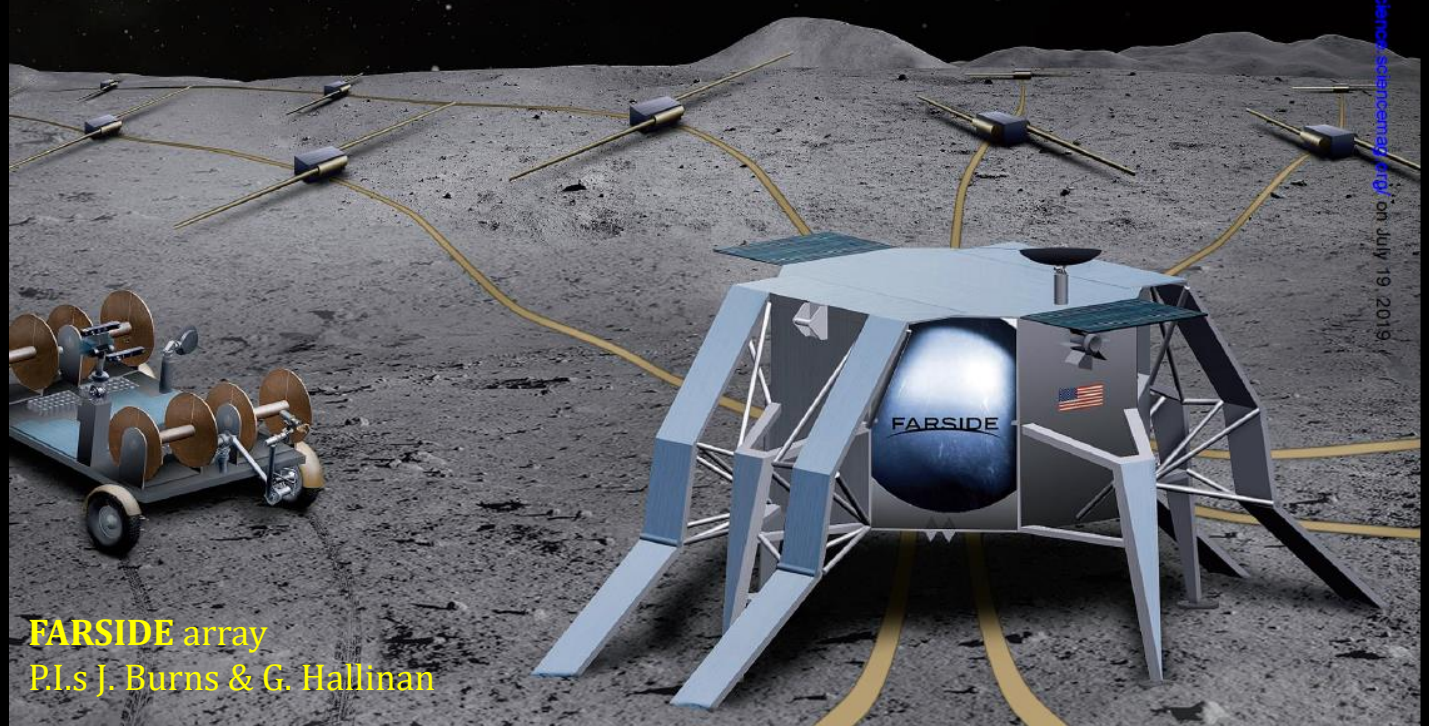
Burns, J.O., et al. 2019, "Dark Cosmology: Investigating Dark Matter & Exotic Physics in the Dark Ages using the Redshifted 21-cm Global Spectrum", Astro2020: Decadal Survey on Astronomy and Astrophysics, science white papers, no. 6; BAAS, Vol. 51, Issue 3, id. 6.

MOON GAZING

Nearly 50 years ago, NASA put a telescope on the Moon. Astronomers have been trying to return ever since

By **Daniel Clery**

Science
AAAS



FARSIDE array
P.I.s J. Burns & G. Hallinan