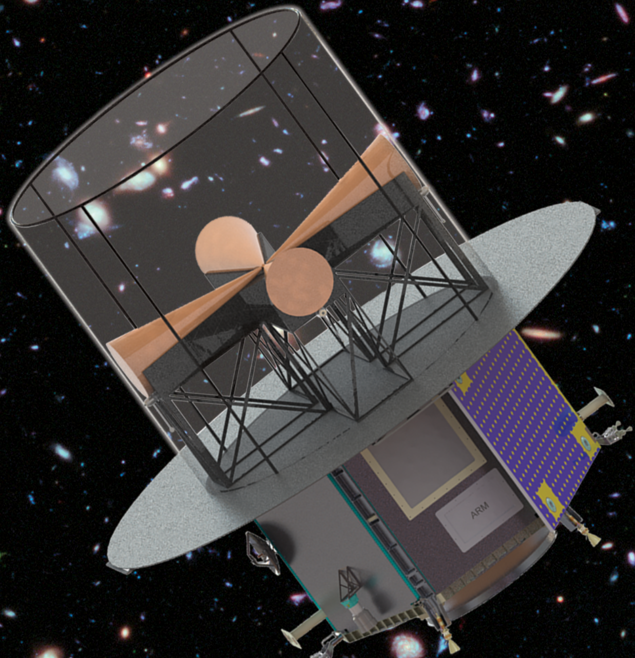
DARE

DARK AGES RADIO EXPLORER



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Project Summary

The Dark Ages Radio Explorer (DARE) investigates the origin and evolution of the first stars and galaxies by detecting and characterizing the features imprinted in the 21-cm (1.4 GHz) spectrum of neutral hydrogen (HI) in the intergalactic medium redshifted (z) into the radio band 40–120 MHz (35>z>11). This spectrum encodes characteristics of the first objects that illuminated the Universe, which ended the pre-stellar "Dark Ages" and commenced the "Cosmic Dawn". DARE will explore, for the first time, the formation of primordial stars and galaxies thereby accomplishing a high priority NASA and Astrophysics Decadal science goal.

DARE is a precision cosmology experiment with science objectives to determine: when the first stars turned on and their properties, when the first black holes began accreting and their characteristics, the reionization history of the early Universe, and if evidence exists for exotic physics such as dark matter decay in the Dark Ages. DARE provides observations of the global 21-cm spectrum with features that constrain the wide range of first luminous object models currently allowed. These observations are performed from the radio-quiet zone above the Moon's farside at night, free of terrestrial radio interference, the Earth's ionosphere, and solar radio emissions. DARE operates over a two year mission lifetime in a 50x125 km, lunar equatorial orbit. Extensive end-to-end modeling places requirementson the spacecraft, the instrument, and the observation strategy while demonstrating that the science objectives are achievable with robust margins.

A wideband dual bicone antenna, pilot tone stabilized polarimetric receivers to separate the unpolarized 21-cm signal from polarized instrumental and sky emission, and a digital spectrometer constitute the science instrument. DARE's radiometer has a well-characterized spectral response, controlled systematics, and heritage from CMB missions and ground-based telescopes. The antenna, receiver, and backend electronics are thermally-controlled to limit solar and lunar driven radiometric responses. The DARE Observatory employs a Faraday cage for spacecraft electronics. Models for the instrument main beam and sidelobes, antenna reflection coefficient, gain variations, and calibrations are validated with electromagnetic simulations, laboratory and anechoic chamber measurements, and monitored on-orbit.

The unique frequency structure of the 21-cm spectrum, its uniformity over large angular scales, and its unpolarized state are unlike the spectrally featureless, spatially-varying, polarized emission of the bright Galactic foreground, allowing a clean separation of the primordial signal from the foreground. The 21-cm signal is extracted in the presence of bright foregrounds using a Bayesian framework with a well-proven Markov Chain Monte Carlo (MCMC) numerical inference technique, with heritage from WMAP, Planck, and LIGO. The DARE data analysis pipeline enables efficient, simultaneous, and self-consistent explorations of multi-parameter models with non-Gaussian probability distributions, while properly accounting for known systematic astrophysical and instrumental uncertainties. The DARE instrument with its data analysis pipeline meets the requirements needed to extract physical parameters of the first stars and galaxies.

DARE management is founded on experienced leadership from the University of Colorado, NASA ARC, NASA GSFC, and Ball Aerospace. This team has established clear roles and responsibilities, management processes and tools, and has assembled a mission concept with low risk and large development cost reserves that meet DARE's science objectives. DARE leverages ARC's experience managing and operating three successful lunar missions, incorporates significant reuse of ARC's LADEE mission operations, utilizes Ball's spacecraft flight heritage, leverages GSFC's experience with WMAP, and has a comprehensive plan to mature the instrument to TRL 6 by PDR.

DARE Mission Overview

The Dark Ages Radio Explorer (DARE) reveals when the first stars and galaxies formed in the early Universe and their characteristics, from the Dark Ages (z=35) to the Cosmic Dawn (z=11) (~80-420 million years after the Big Bang). **This time period in the Universe has never been observed.** The DARE Observatory is composed of a dual bicone antenna, pilot tone stabilized polarimetric receivers, and a spectrometer, which measures the redshifted 21-cm spectrum from neutral hydrogen that surrounds the first luminous objects at frequencies 40-120 MHz. DARE acquires data from the only truly radio-quiet environs while in orbit above the lunar farside. DARE explores an entirely new epoch in the early Universe as a successor to WMAP/Planck observations of the Cosmic Microwave Background and in conjunction with JWST observations of bright galaxies during Cosmic Dawn.

DARE realizes NASA's strategic objective in astrophysics to:

"...explore how (the Universe) began and evolved..."

DARE executes small-scale mission described in Astrophysics Roadmap:

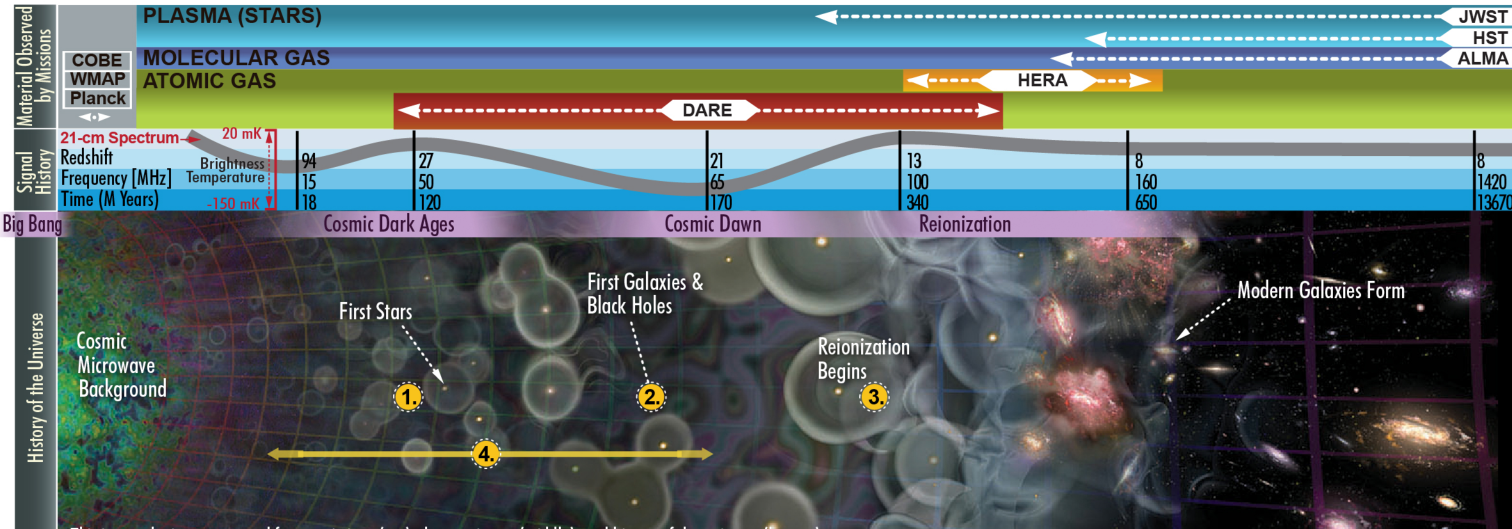
"Mapping the Universe's hydrogen clouds using 21-cm radio wavelengths via lunar orbiter from the farside of Moon."

DARE Science Goal:

Investigate first stars and galaxies along with their environs.

DARE Science Objectives:

1. Determine when the First Stars ignited and their characteristics.
2. Determine when the first Black Holes began accretion and their characteristics.
3. Determine the Reionization history of the early Universe.
4. Determine if there is evidence for exotic physics, such as Dark Matter decay, in the Dark Ages.



This image depicts current and future missions (top), the cosmic age (middle), and history of the universe (bottom).

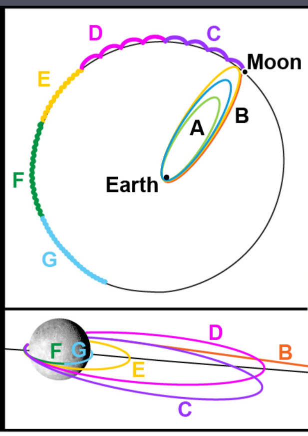
Mission Overview

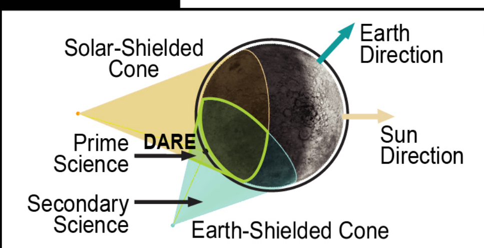
DARE's lunar orbit provides efficient access to the radio-quiet zone above the lunar farside. At this location, the DARE spacecraft is shielded from Earth's ionosphere, human-generated RFI, and solar interference, opening the entire RF spectrum to astronomical use.

Key features of the DARE mission design include:

- Baseline DARE launch date of August 2023
- Compatible with NASA's standard launch service capability
- Proven Earth phasing loop transfer trajectory with insertion into an equatorial lunar orbit
- 50x125 km "frozen" lunar science orbit with 0-3° inclination optimizes science observation and elimnates the need for orbit maintenance
- 2-years of science operations at the moon meets all science requirements
- Ample propellant margin and unused propellant tank capacity

(A) DARE phasing orbits
(B) Lunar transfer orbit
(C) Lunar insertion 18 hr orbit
(D) Inclination trim orbits from 5° or 20° to equatorial 0-3°
(E) Apoapsis lowering into 4 hr orbit
(F) Staging orbit
(G) Frozen science orbit





DARE Project Team

Principal Investigator:
Jack Burns, U. Colorado

Project Scientist:
Robert MacDowall, NASA GSFC

Project Manager:
Dan Andrews, NASA ARC

Project Systems Engineer:
Robert Hanel, NASA ARC

Observatory Manager:
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Instrument SE:
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Spacecraft SE:
Jeremy Stober, Ball

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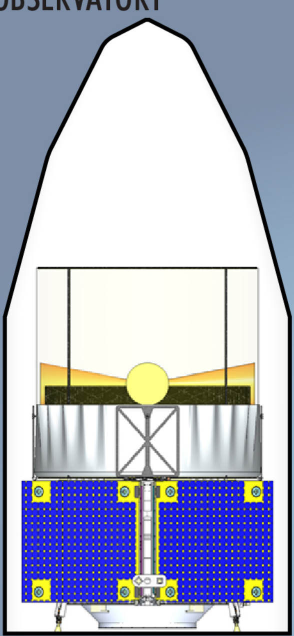
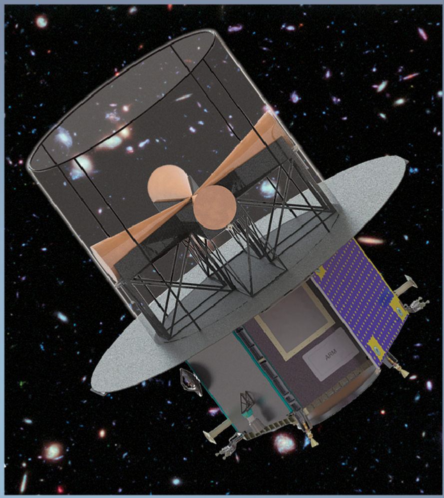
Justin Kasper, U. Michigan
Abraham Loeb, Harvard University
Jordan Mirocha, UCLA
Raul Monsalve, U. Colorado
David Rapetti, U. Colorado
Edward Wollack, NASA GSFC

PARTNER-

OBSERVATORY



DARE is compatible with NASA's standard launch service capability.



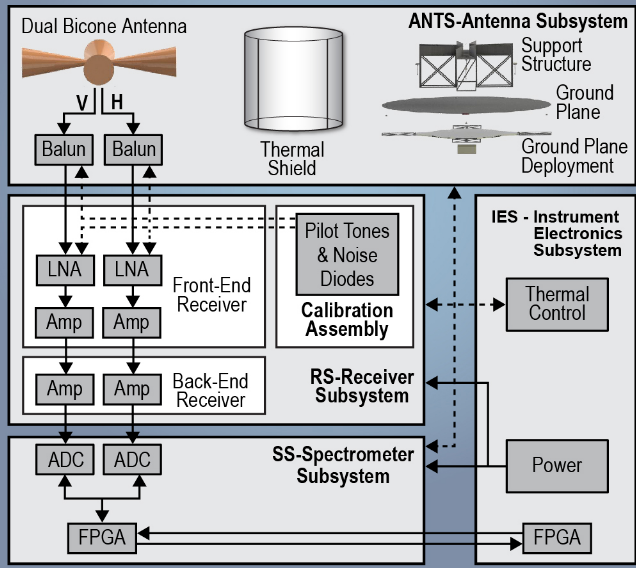
The DARE bus consists of an integrated suite of flight-proven components and traces its high heritage to Kepler, Deep Impact, WISE, STPSat2, STPSat3, and GPIM.

OBSERVATORY CHARACTERISTICS

Total Dry Mass (MEV)	588 kg
Total Wet Mass (MEV)	1002 kg
Array Power BOL/EOL	1010W / 910W
DV Available	1260 m/s
EMI	50 dB shielding better than MIL-STD-461F
Communications	Ka-Band & S-Band
Data Storage	12 GB
Solar Array Type	Fixed panel

SCIENCE INSTRUMENT

The DARE instrument is comprised of four subsystems: dual-polarization Antenna, pilot tone calibration Receiver and temperature control, high-resolution digital Spectrometer, and a standard Instrument Electronics for power, data handling, and instrument control that interfaces simply with the S/C. This radiometer is the only instrument needed to produce the science data that meets the science requirements.



OBSERVATORY MARGINS

		Data Downlink	>3 dB
Launch Mass	59%	EMI	41%
Power (EOL)	31%	Unused Propellant Tank Capacity	11%
Science Data Storage	99%		
Pointing Knowledge & Control	233%/ 73%	ΔV, Statistical losses/corrections	290%

WBS	WBS Element	FY17$K
01	Project Management	5,709
02	Systems Engineering	4,731
03	S&MA	4,127
04	Science/Technology	12,797
05	Instrument	59,182
06	Spacecraft Bus	55,892
07	Mission Operations	24,936
08	Launch Vehicle	-
09	Ground Systems	$7,090
10	Observatory I&T	15,066
	Reserves	54,424
	% Reserves	29%
	ARC CM&O	5,885
PI-Managed Mission Cost:		249,840
Contributions:		2,990
Total Mission Cost:		252,830

Cost Reserves (Phase B-D):
37% Instrument
28% S/C Bus
31% Phases B-D Average

Cost Reserves (Phase E-F):
15% Phases E/F Average

Schedule Reserve & Margin:
33.6 wks FSR on critical path
59.4 wks additional schedule margin

Risk Mitigation Budget Total:
$6,275K

Risk Mitigation Budget Prior to PDR:
$4,325K