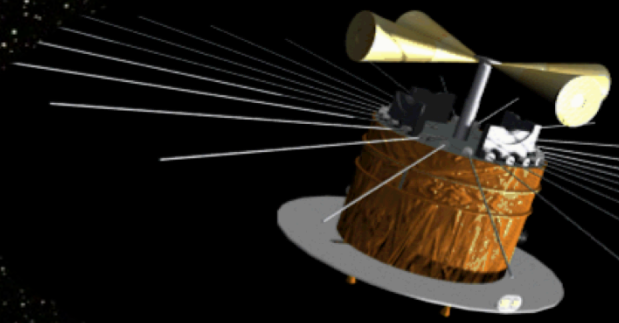
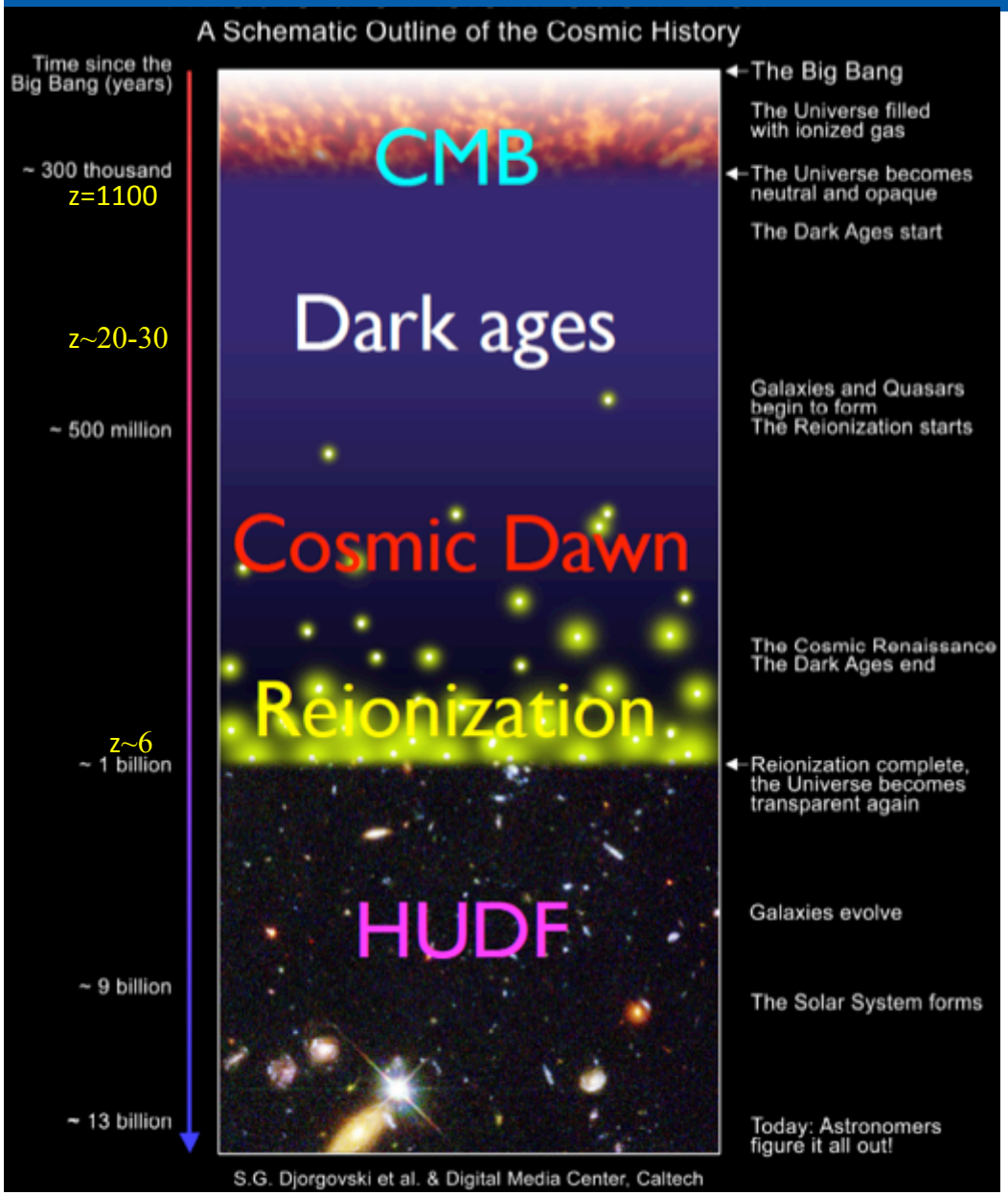
Cosmology from the Moon: The Dark Ages Radio Explorer (DARE)

Jack Burns for the DARE Team
University of Colorado Boulder



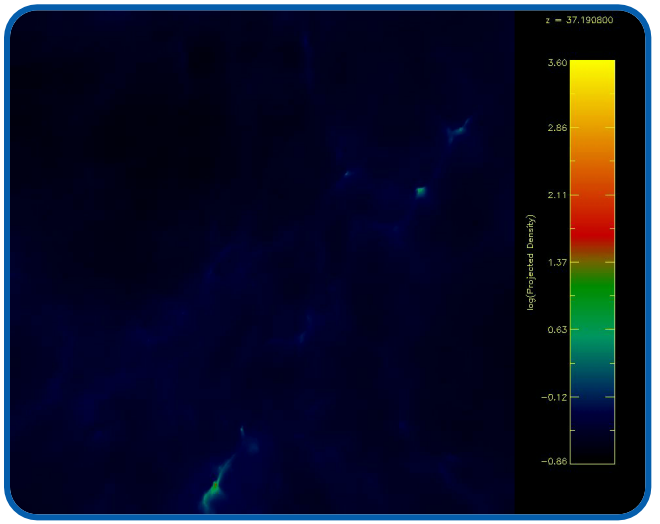
Exploration Science Forum
NASA Ames Research Center
21 July 2015

The First Half-Billion Years



The First Stars

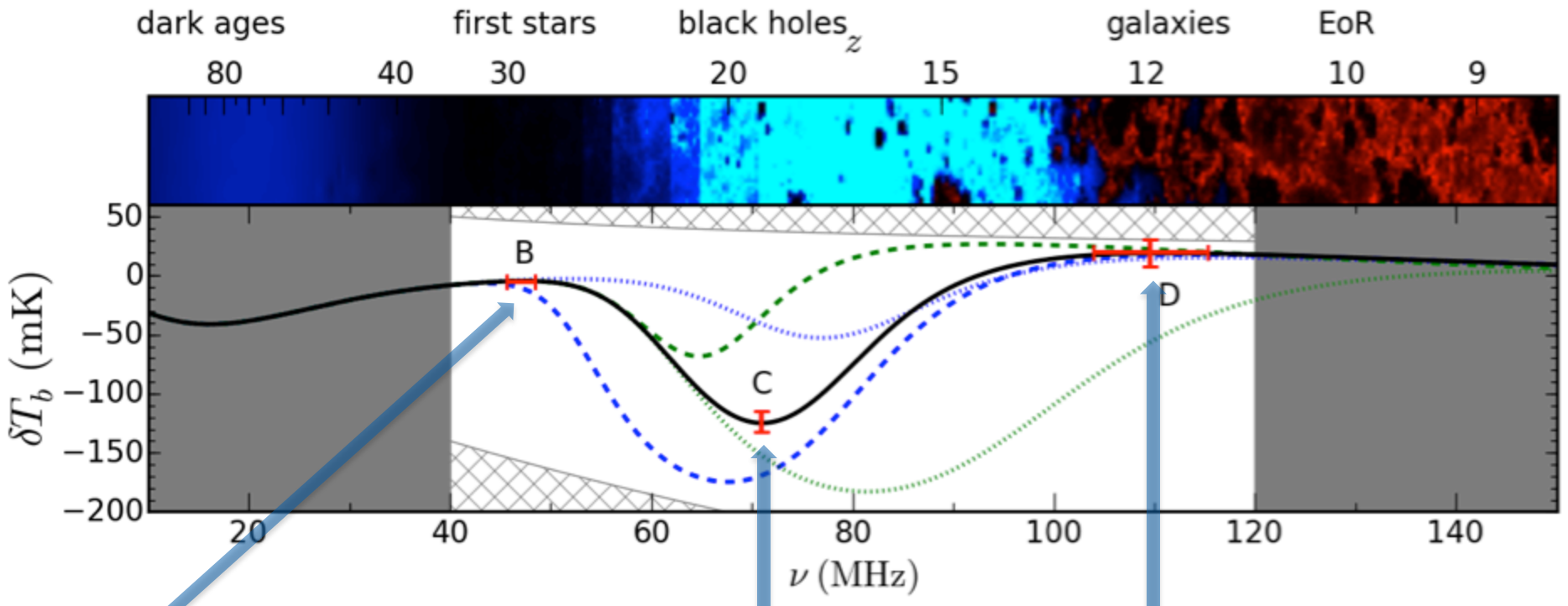
John Wise, Georgia Tech



Science Questions

- When did the First Stars ignite? What were these First Stars?
- When did the first accreting Black Holes turn on? What was the characteristic mass?
- When did Reionization begin?
- What surprises emerged from the Dark Ages?

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



B: ignition of first stars

- When did the First Stars ignite? What were these First Stars?
- What surprises emerged from the Dark Ages?

C: heating by first black holes

- When did the first accreting black holes turn on? What was the characteristic mass?

D: the onset of reionization

- When did Reionization begin?

uncertainties in 1st star models

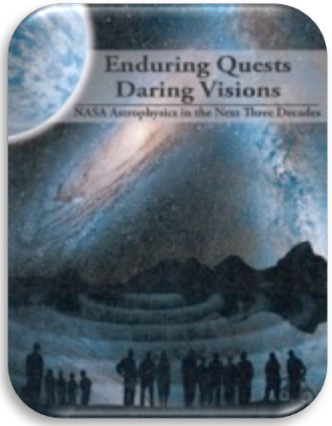
uncertainties in 1st black hole models

DARE
DARK AGES RADIO EXPLORER

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

Astrophysics Decadal Survey & Astrophysics Roadmap identify Cosmic Dawn as a top Science Objective

- "A great mystery now confronts us: When and how did the first galaxies form out of cold clumps of hydrogen gas and start to shine—when was our cosmic dawn?" *New Worlds, New Horizons (NRC 2010)*
  - How Does our Universe Work? Small Mission: "Mapping the Universe's hydrogen clouds using 21-cm radio wavelengths via a lunar orbiter observing from the farside of the Moon" *NASA Astrophysics Division Roadmap (2013)*



"What were the first objects to light up the Universe and when did they do it?" We can uniquely address this mystery with DARE in orbit above the lunar farside.

DARE Project Team

Principal Investigator: Jack Burns, University of Colorado Boulder
Deputy Principal Investigator: Joseph Lazio, JPL/Caltech
Project Manager: Butler Hine, NASA Ames
Deputy Project Manager: Jill Bauman, NASA Ames
Spacecraft Project Manager: John Jonaitis, Ball Aerospace
Instrument Project Manager: Karen Lee, JPL/Caltech

Science Co-Investigators:

Judd Bowman, Arizona State University
Richard Bradley, National Radio Astronomy Observatory
Abhirup Datta, University of Colorado Boulder
Steven Furlanetto, UCLA
Dayton Jones, JPL/Caltech
Justin Kasper, University of Michigan
Abraham Loeb, Harvard University

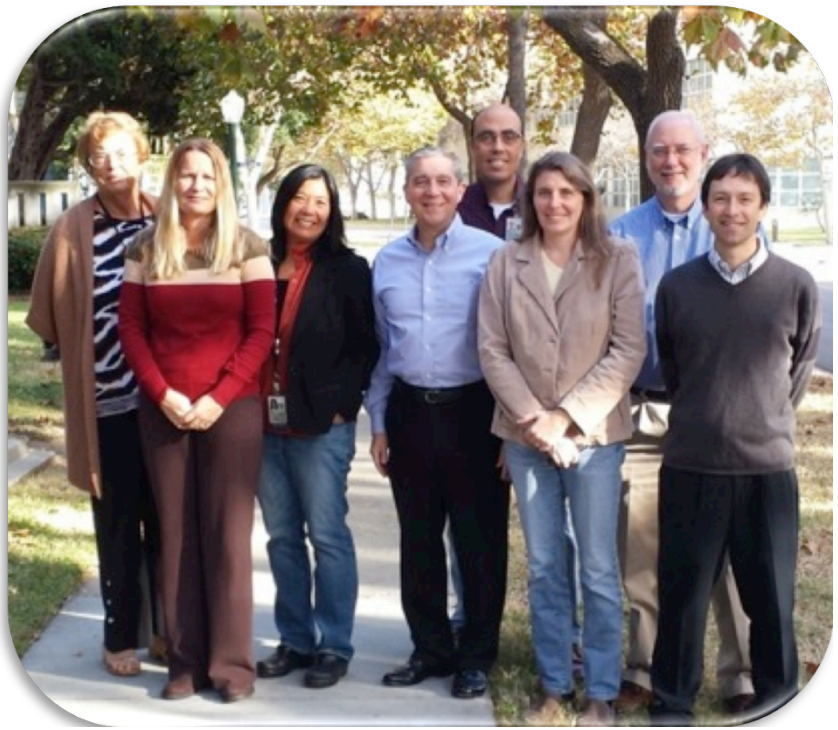
Collaborators:

Michael Bicay, NASA Ames
Geraint Harker, University College London
Jonathan Pritchard, Imperial College
Michael Seiffert, JPL

Graduate Students:

Jordan Mirocha, University of Colorado
Bang Nhan, University of Colorado

Currently under review by NASA's Small Explorer Program



DARE Baseline Mission Concept

Time in radio-quiet, solar eclipse cone	≈1000 hrs over 2 years
Instrument	3-meter length biconnical antennas; correlation receiver; digital spectrometer; operates at 40-120 MHz
Launch Date	Q3/4 2020
Launch Vehicle	Secondary payload on ULA Atlas V
S/C Structure	60-inch ESPA as S/C structure and Faraday cage
Instrument I/F	Stack second ESPA to house instrument
Launch Injection Orbit	GTO
Earth-to-Moon trajectory	Translunar injection with lunar flyby
Propulsion	Regulated monoprop capable of delivering Δv = 2200 m/s (includes: TLI, TCMs, Lunar Targeting, LOI, orbit maintenance)
Lunar Orbit	125 km circular, ≈0° inclination

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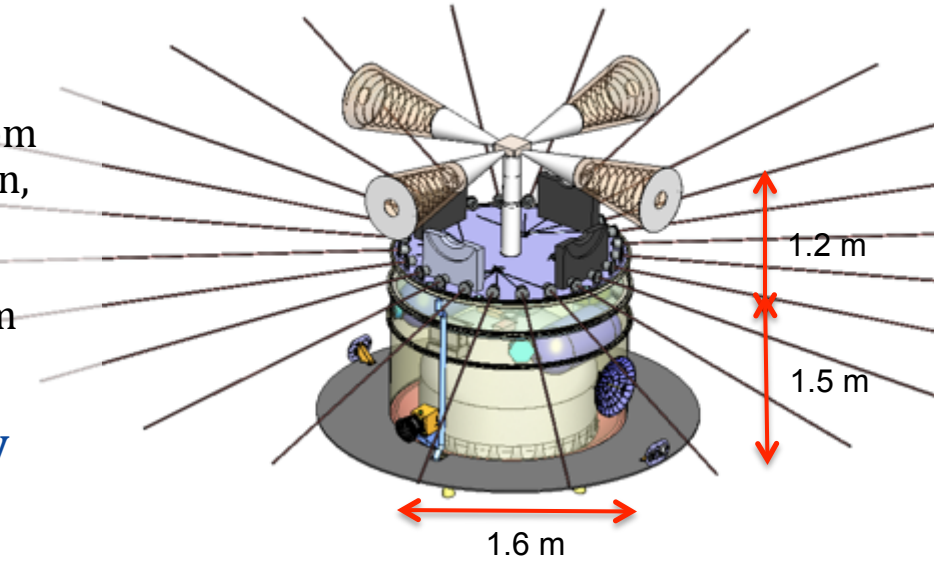
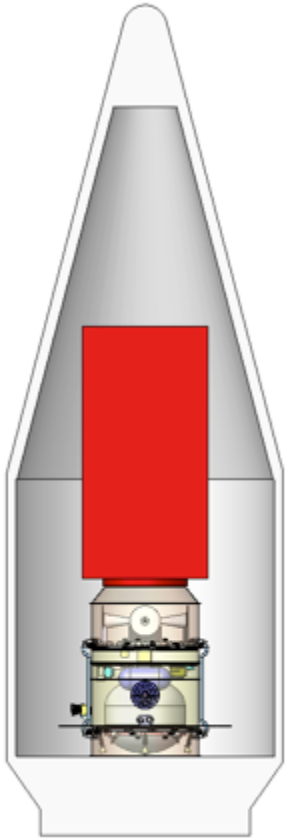
Spacecraft Concept

- **2200 m/s of ΔV**
  - Trans-lunar injection from GTO, lunar orbit insertion, trajectory correction maneuvers, orbit maintenance, momentum management
- **Ability to launch as a secondary on a ULA Atlas V with a 4000 kg primary PL**



DARE performance margins are substantial in all areas

Requirements and Margins	Requirement	Performance	Margin
Observatory Wet Mass	1,600 kg	1,155 kg	38%
Science Data Storage Capacity	1.6 GB	4 GB	150%
Power generation during science	257 Watts	361 W EOL	40%
Pointing Knowledge (3-sigma/per axis)	1 degree	0.028 deg	3471%
Pointing Control (3-sigma/per axis)	1 degree	0.028 deg	3471%
Propellant Load	565 kg	714 kg	21%**
Propellant Tank Capacity	714 kg	959 kg	34%
EMI	100 dB shielding	106 dB shielding	6 dB



DARE in a ATLAS V fairing

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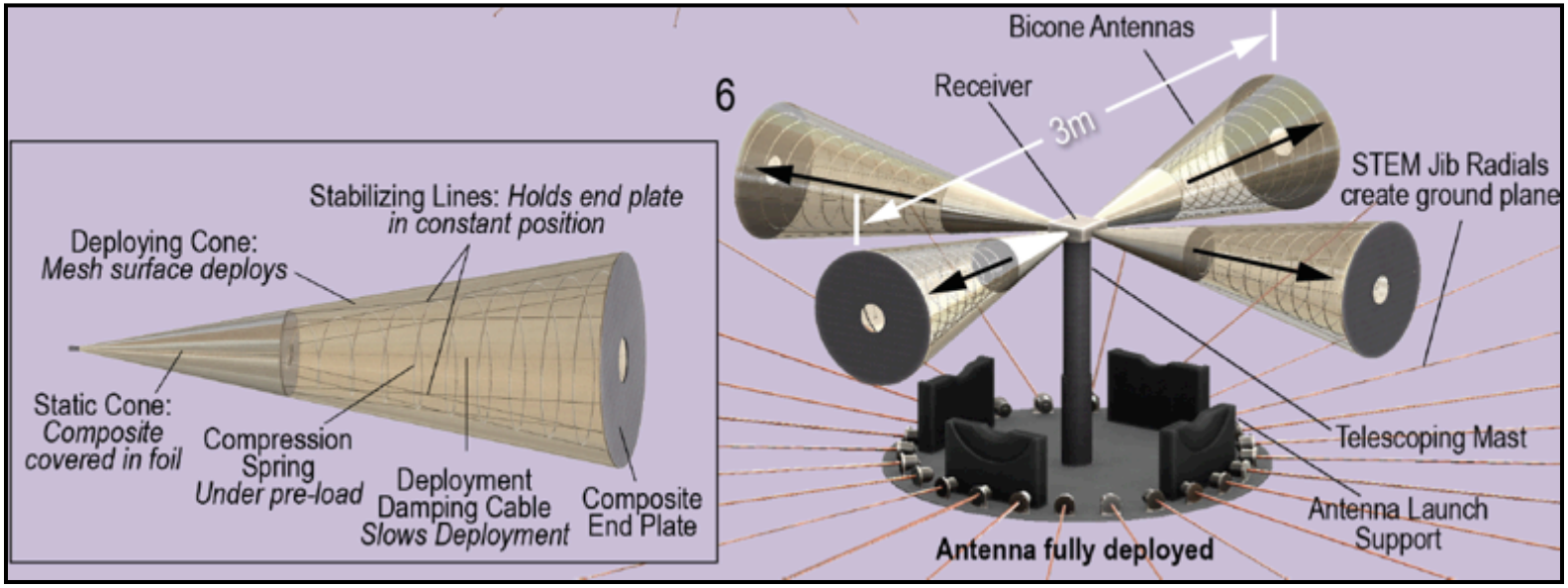
Science Instrument: Baseline Design



Antenna: Dual, deployable bicones to accommodate launch volume

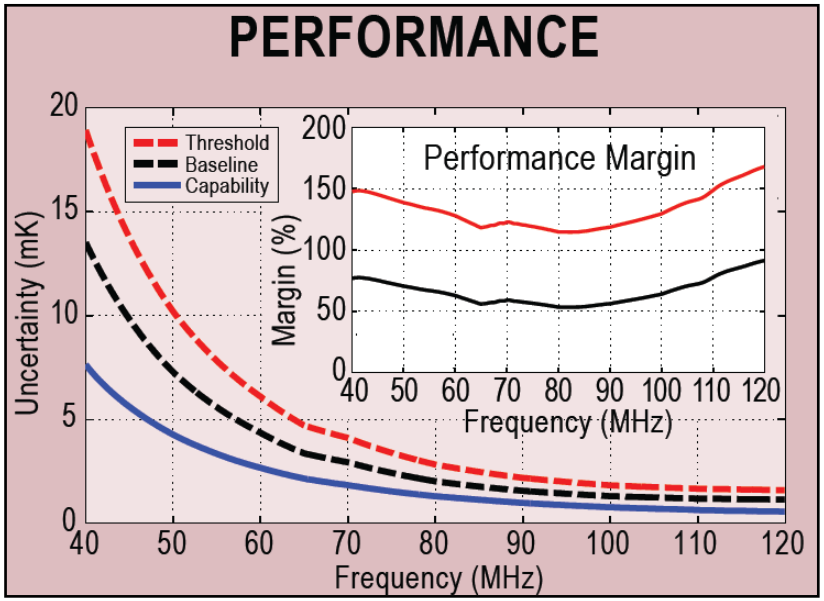
- Mast deploys bicones above S/C deck
- Bicones deploy to achieve length
- Jib Radials deploy to form ground plane

Receiver: Pseudo-correlation Architecture + Reflectometer

- Heritage from WMAP, Planck, Microwave Limb Sounder on UARS.
- Thermally controlled front-end receiver electronics enclosure

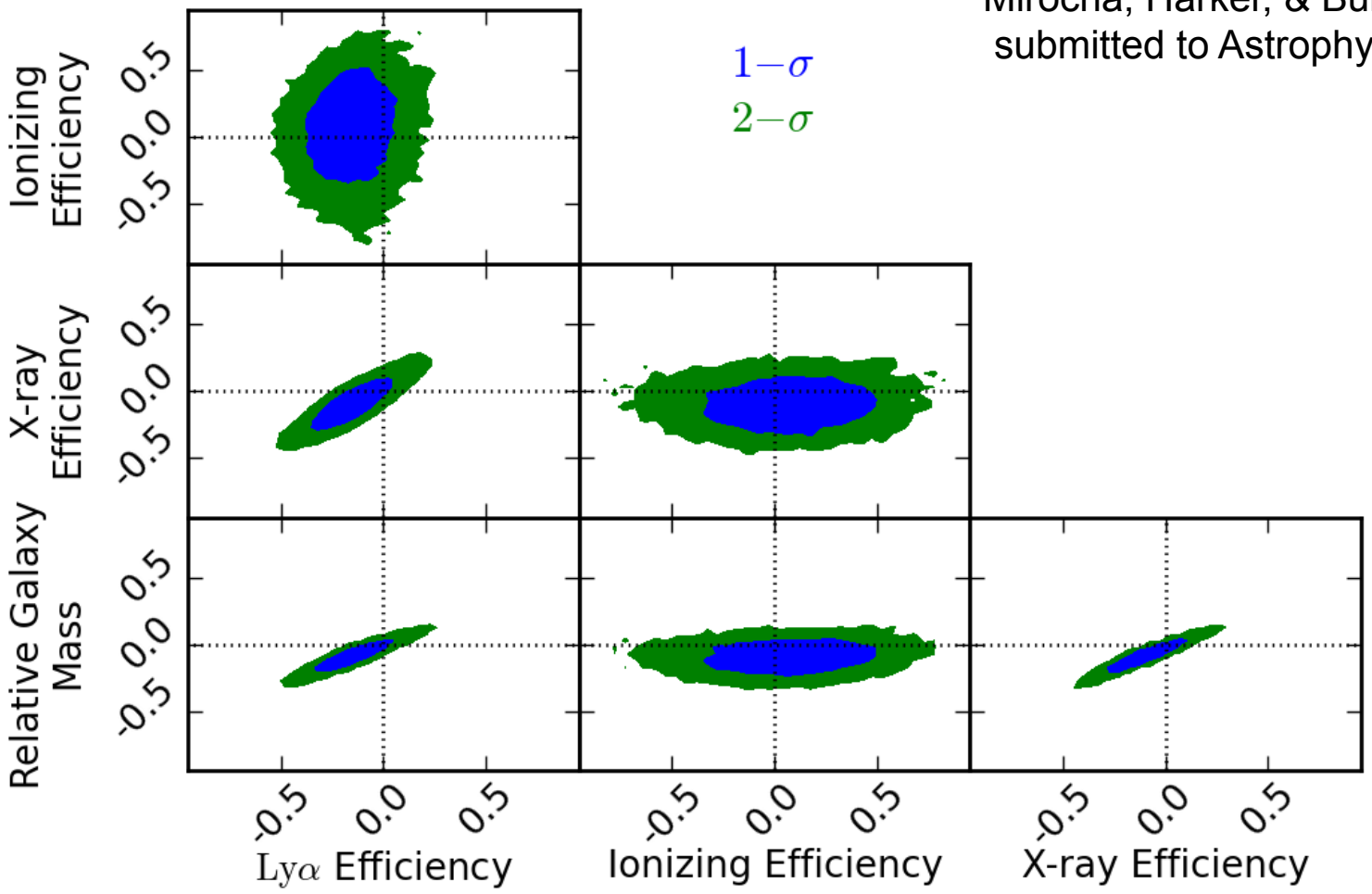
Spectrometer

- Achieves 10^6 dynamic range
- Uses space-qualified FPGAs.



Characterizing the First Stars & Galaxies

Mirocha, Harker, & Burns, 2015, submitted to Astrophys. J.



DARE will bound the properties (e.g., mass, spectra) of the first generation of stars, black holes, & galaxies for the first time.

DARK AGES RADIO EXPLORER

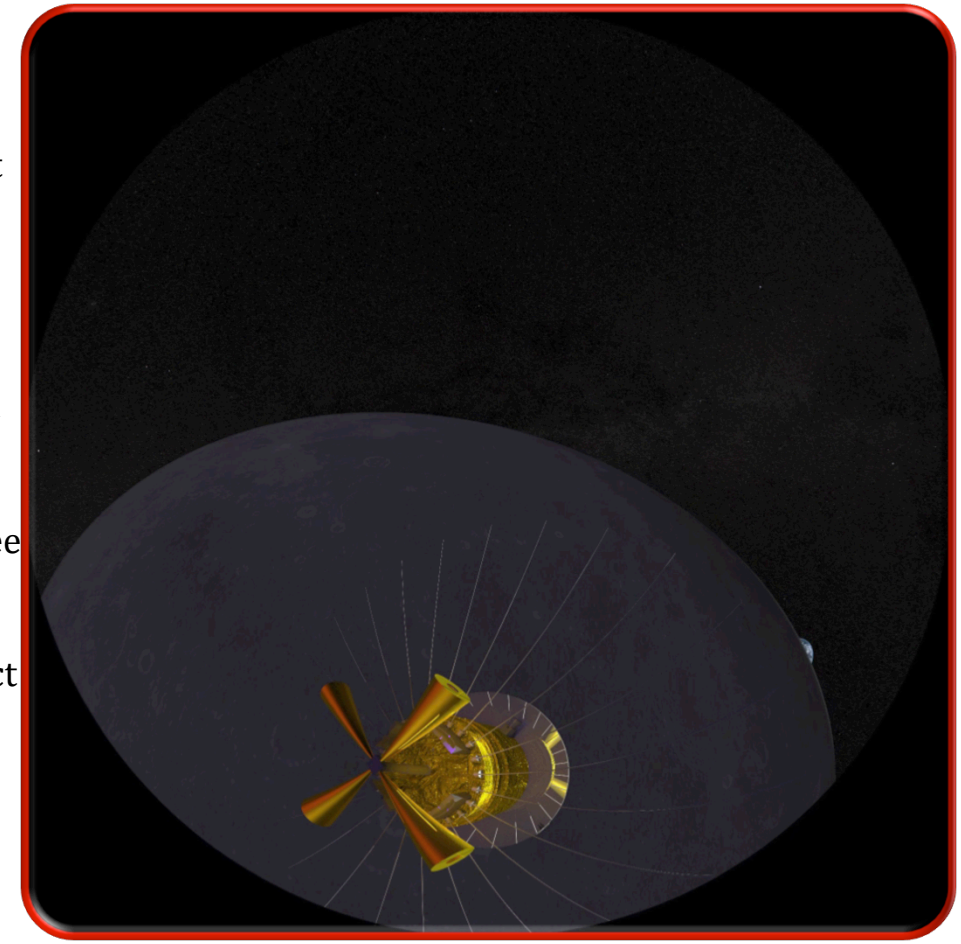
Dark Ages Radio Explorer (DARE)

DARE is designed to address:

- When did the First Stars ignite? What were these First Stars?
- When did the first accreting Black Holes turn on? What was the characteristic mass?
- When did Reionization begin?
- What surprises emerged from the Dark Ages?

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, ionosphere-free zone in inner solar system.
- Using biconical dipole antennas with smooth response function & Markov Chain Monte Carlo method to extract spectral *turning points* in the presence of bright foregrounds.
- Using high heritage spacecraft bus & technologies/ techniques from DARE engineering prototype.
- DARE was submitted to NASA as a SMEX proposal in December 2014.



Burns *et al.* 2012, *Advances in Space Research*, 49, 433.
Burns et al. 2015, Astrophys. J., in preparation.
http://lunar.colorado.edu/dare/