

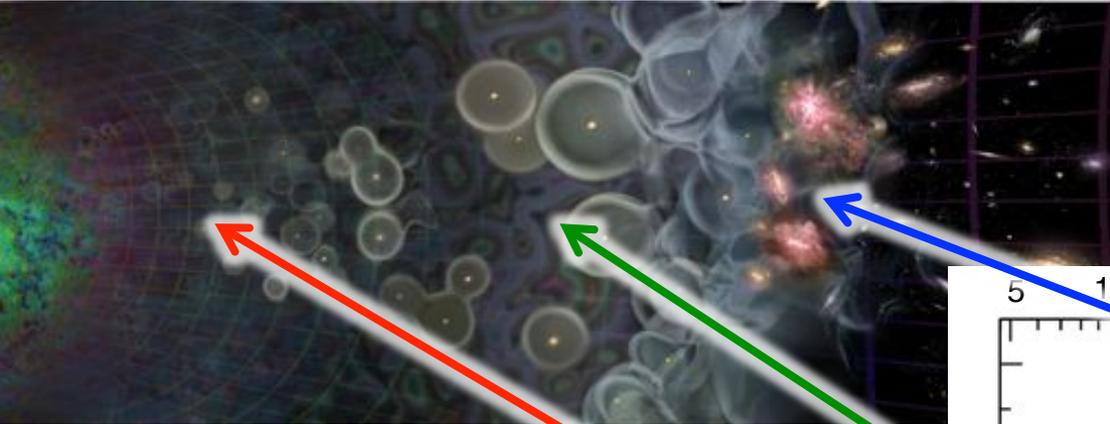


Jet Propulsion Laboratory
California Institute of Technology

Space-based Probes for Cosmic Dawn

Joseph Lazio

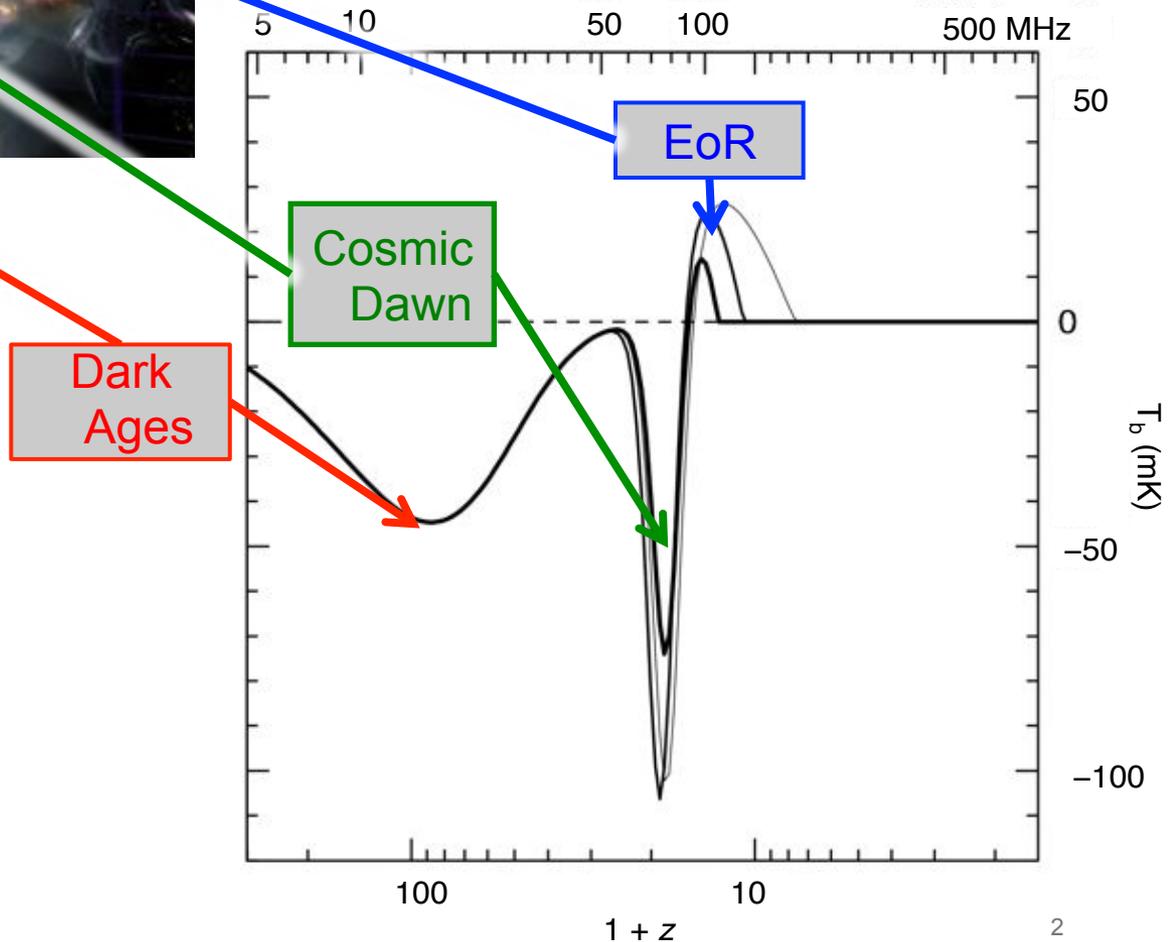
Hydrogen Signal from EoR and Before



A Role for Space?

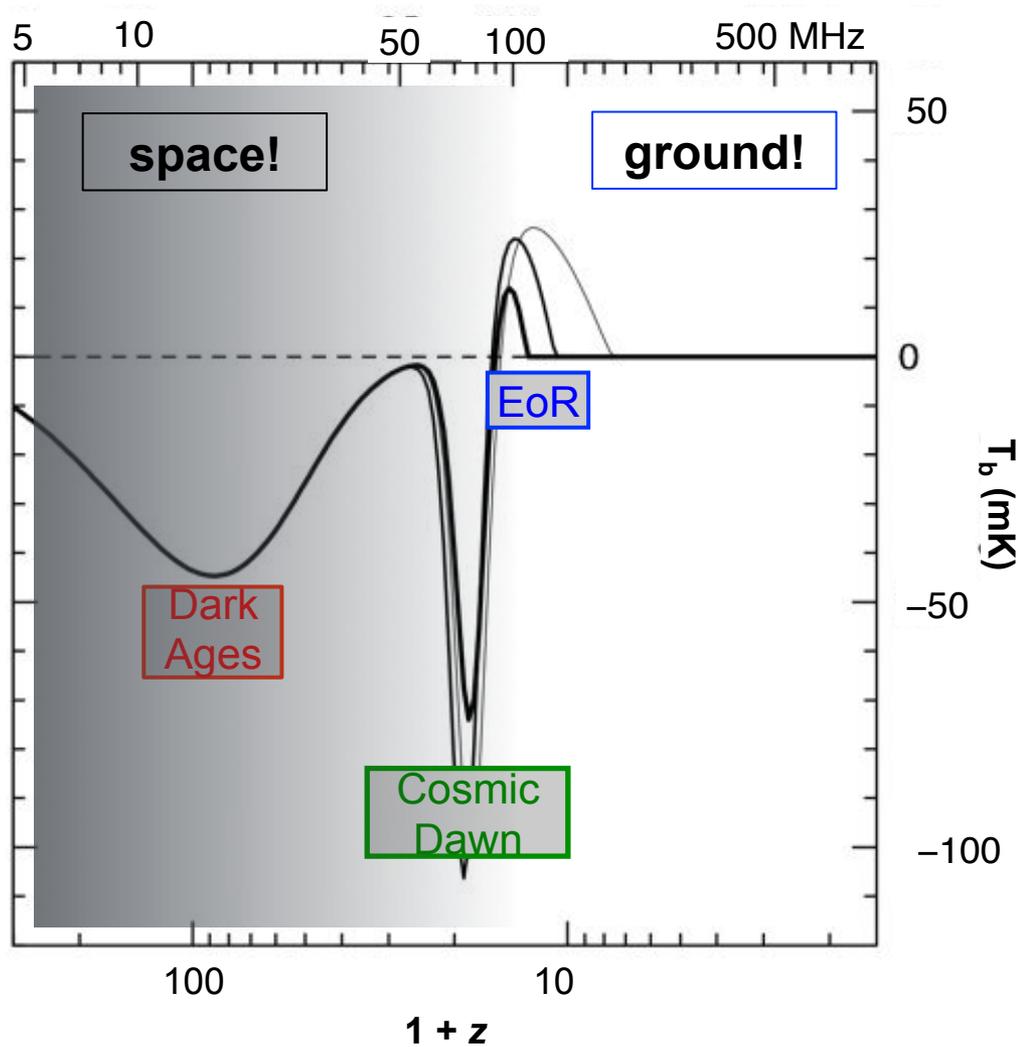
Neutral Hydrogen

21 cm spin-flip transition provides probe of neutral intergalactic medium before and during formation of first stars



Hydrogen Signal from EoR and Before

A Role for Space?



Consider atmospheric (ionospheric) opacity ...
Caveat: RFI

Lunar Radio Telescope

Not a new idea!

- **First proposals pre-date *Apollo* missions**
 - Research Program on Radio Astronomy and Plasma for Apollo Applications Program Lunar Surface Missions: Final Report 1966, North American Aviation Inc.
 - Greiner, J. M. 1967, “Utilization of Crater Reflectors for Lunar Radio Astronomy,” Working Group on Extraterrestrial Resources
- **Far side of Moon long recognized as unique astronomical platform**
 - International Telecommunications Union radio quiet zone
- **EoR-Cosmic Dawn-Dark Ages may provide first compelling scientific motivation**



Astrophysics Missions

NASA Volcabulary

Class	Budget (~ \$M)	Examples
Mission of Opportunity (MoO)	65	INTEGRAL, NICER
Explorer (both Small and Medium)	250	GALEX, WISE, Swift, WMAP, ... NuSTAR, TESS
<i>Probe</i>	< 1000	Fermi, Spitzer, Kepler
Flagship	> 1000	Hubble, JWST, WFIRST

Predicting the Future

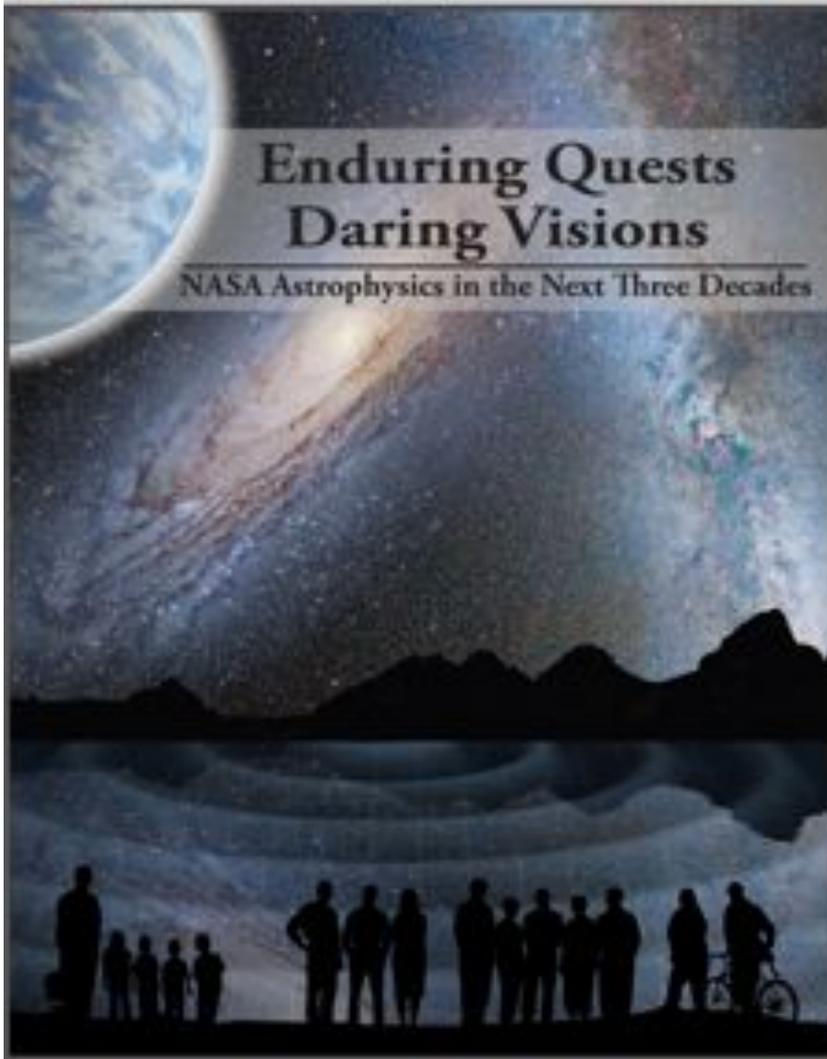
**“It is difficult to make predictions,
particularly about the future.”**

Danish proverb, and probably Yogi Berra

➤ **New discoveries may change
trajectories.**

Predicting the Future I

NASA Astrophysics Roadmap



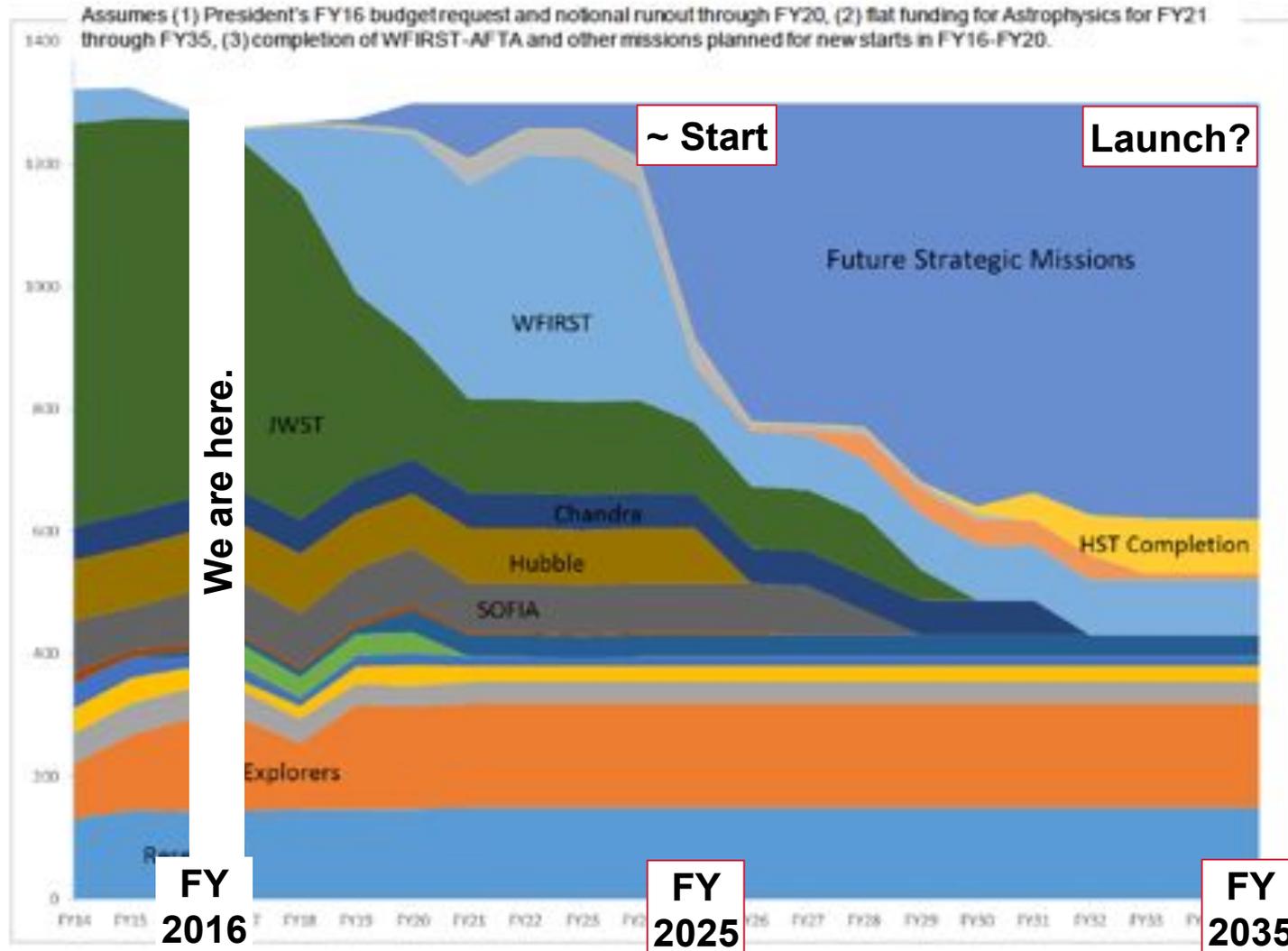


Preparing for the 2020 Decadal Survey Large Mission Concepts

The initial short list (in alphabetical order):

- **FAR IR Surveyor** – The Astrophysics Visionary Roadmap identifies a Far IR Surveyor as contributing through improvements in sensitivity, spectroscopy, and angular resolution.
- **Habitable-Exoplanet Imaging Mission** – The 2010 Decadal Survey recommends that a habitable-exoplanet imaging mission be studied in time for consideration by the 2020 Decadal Survey.
- **UV/Optical/IR Surveyor** – The Astrophysics Visionary Roadmap identifies a UV/Optical/IR Surveyor as contributing through improvements in sensitivity, spectroscopy, high contrast imaging, astrometry, angular resolution and/or wavelength coverage. The 2010 Decadal Survey recommends that NASA prepare for a UV mission to be considered by the 2020 Decadal Survey.
- **X-ray Surveyor** – The Astrophysics Visionary Roadmap identifies an X-ray Surveyor as contributing through improvements in sensitivity, spectroscopy, and angular resolution.

Predicting the Future III



Courtesy
P. Hertz

Astrophysics Missions

NASA Vocabulary

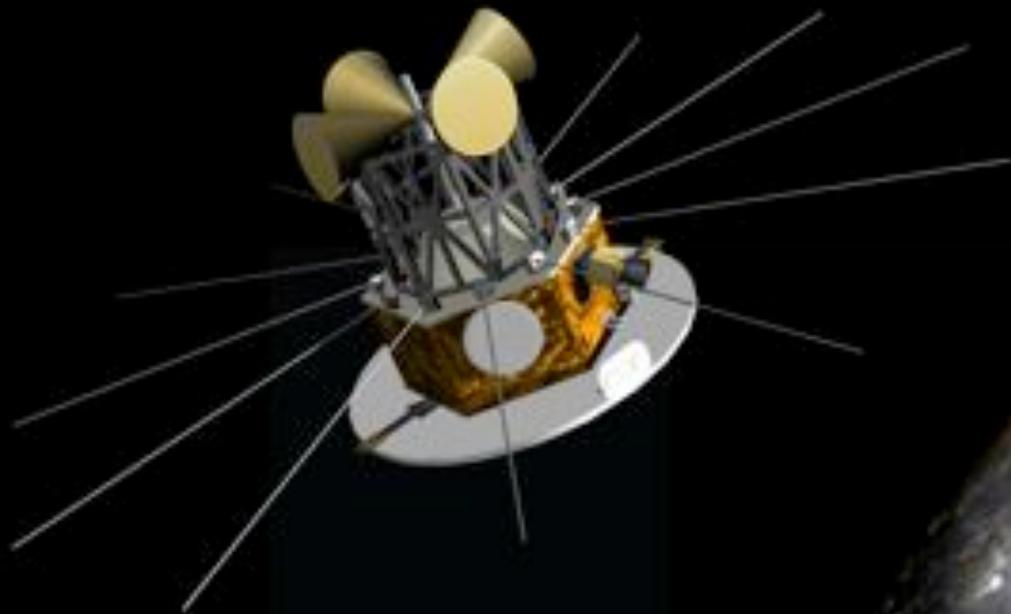
Class	Budget (~ \$M)	Examples
Mission of Opportunity (MoO)	65	competed
Explorer (both Small and Medium)	125--250	competed
<i>Probe</i>	< 1000	??
Flagship	> 1000	{ Far-IR Surveyor HabEx LUVOIR X-ray Surveyor }

Cosmic Dawn Mapper not likely in the near future*

*pending future discoveries

DARE

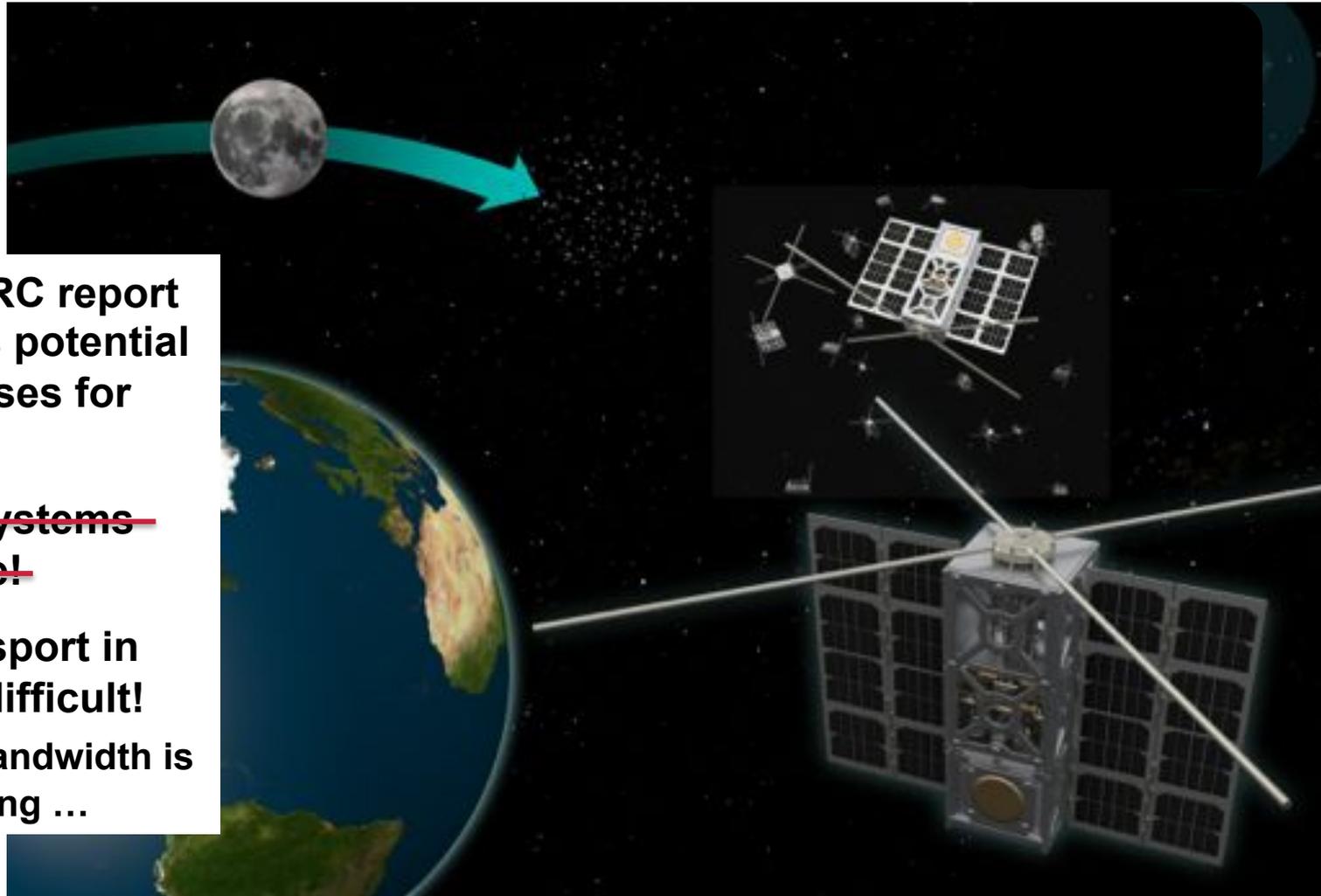
DARK AGES RADIO EXPLORER



Space-based Probes for Cosmic Dawn
Pre-decisional, for information and discussion purposes only

Space-based Cosmic Dawn

Cubesats!

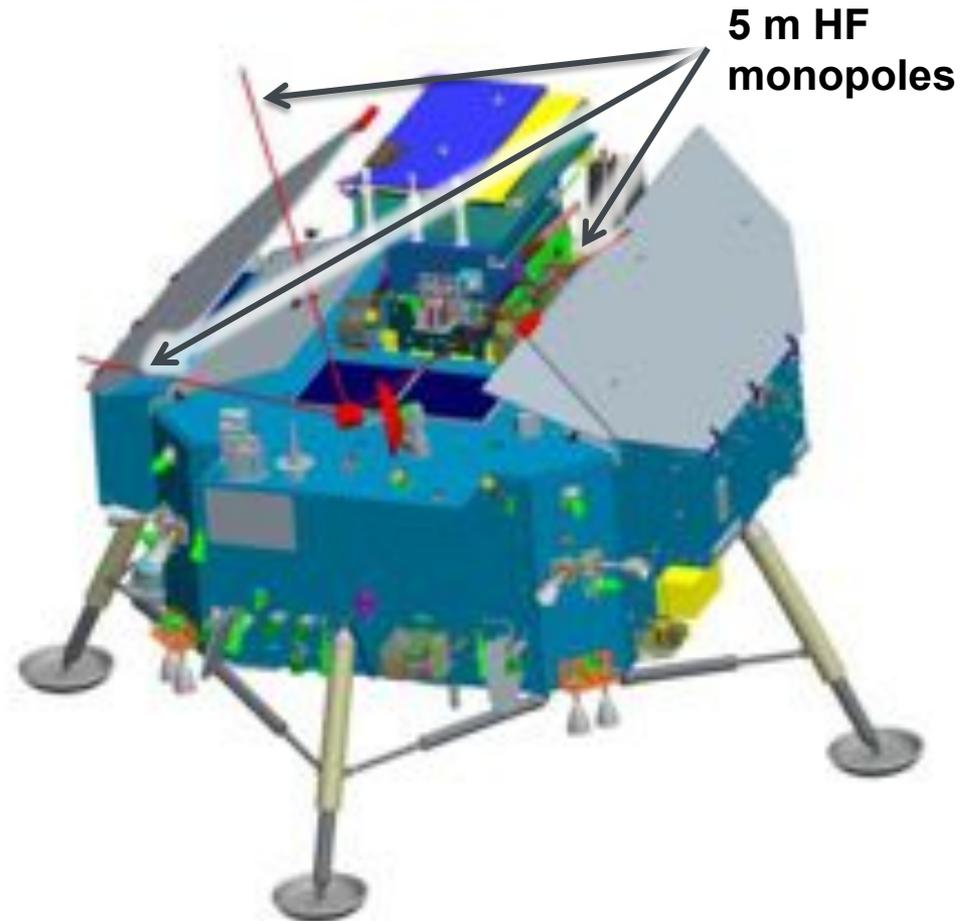


- ✓ Recent NRC report highlights potential science uses for cubesats!
- ✓ ~~HF/VHF systems are simple!~~
- Data transport in space is difficult!
1 MHz of bandwidth is challenging ...

Cosmic Dawn beyond NASA

Chang'E 4 lunar lander

- 0.1--40 MHz system
- Likely to suffer significant interference from on-board ground-penetrating radar



Hydrogen Signal from EoR and Before

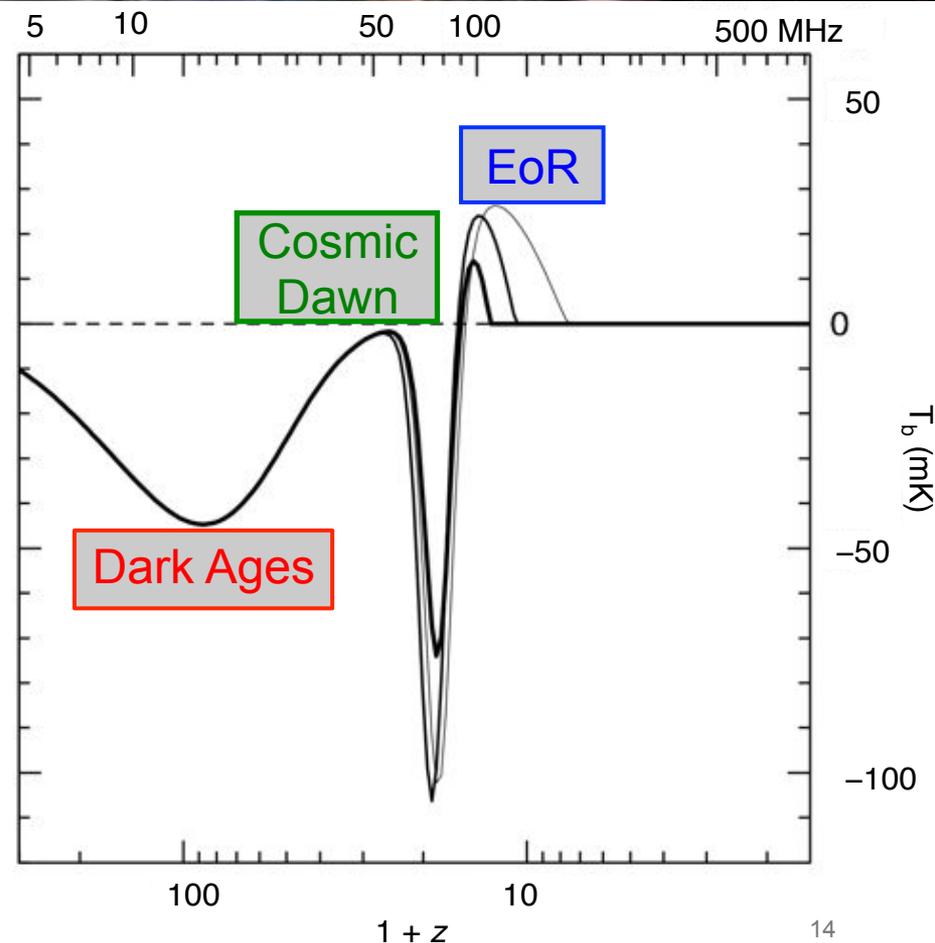
A Role for Space?

Recognition from larger space-based Astrophysics community that H I studies of Cosmic Dawn is valuable

Experience from ground is essential

Large lunar radio astronomy array probably not in near-term future

Potential opportunities for innovative approaches



backup



We have learned much in recent years about the history of the Universe, from the Big Bang to the present day. 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

Probe-class Missions

Cosmic Dawn

- **Ly α + H α Emitters from Reionization (viz. SPHEREx)**
- **Gamma-ray Bursts from First Stars (viz. *Swift*, *Fermi*)**
- **Neutral H I from the Intergalactic Medium**
- **[C I] Intensity Mapping**
- **CO Intensity Mapping**
- **High Throughput UV Probe (for escape fraction of galaxies)**
- **Mid-/Far-IR Probe for PAHs?**
- ...