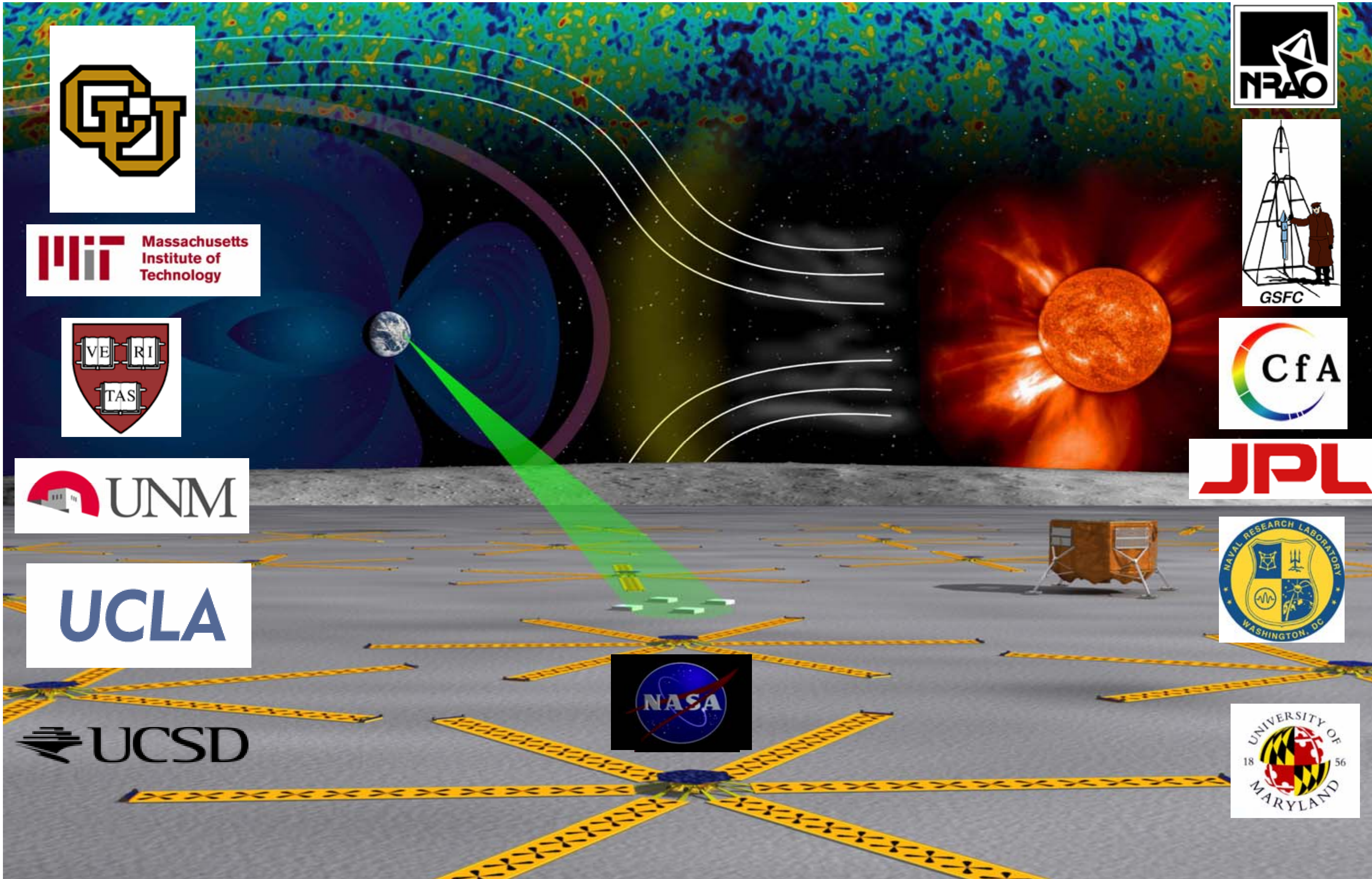
CASA
CENTER FOR ASTROPHYSICS AND SPACE ASTRONOMY

*L*unar *U*niversity *N*etwork for *A*strophysics *R*esearch
LUNAR

Jack Burns, Director
Eric Hallman, Deputy Director
Doug Duncan, E/PO Lead Scientist

NASA LUNAR SCIENCE INSTITUTE



NLSI MISSION

- Carrying out and supporting collaborative research in lunar science, investigating the Moon itself and using the Moon as a unique platform for other investigations;

- Providing scientific and technical perspectives to NASA on its lunar research programs, including developing investigations for current and future space missions;

- Supporting and catalyzing the lunar science community and training the next generation of lunar science researchers; and

- Supporting education and public outreach by providing scientific content for K-14 education programs, and communicating directly with the public.

WHAT IS LUNAR SCIENCE?

For the NLSI, lunar science is broadly defined to include studies:

- ***Of the Moon:*** Investigations the nature and history of the Moon (including research on lunar samples) to learn about this specific object and thereby provide insights into the evolution of our solar system

- ***On the Moon:*** Investigations of the effects of the lunar environment on terrestrial life and the equipment that supports lunar inhabitants, and the effects of robotic and human presence on the lunar environment

- ***From the Moon:*** Use of the Moon as a platform for performing scientific investigations, including observations of the Earth and other celestial phenomena that are uniquely enabled by being on the lunar surface.

LUNAR

University of Colorado (CU)
Team Leader: J. Burns
Deputy: E. Hallman

E/PO

D. Duncan, CU

Key Projects

Low Frequency Astrophysics & Cosmology

J. Lazio, NRL
J. Hewitt, MIT
C. Carilli, NRAO

Radio Heliophysics

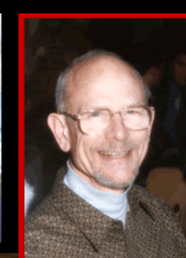
J. Kasper, CfA
R. MacDowall, GSFC

Lunar Laser Ranging

T. Murphy, UCSD
D. Currie, Maryland
S. Merkowitz, GSFC

Other Astrophysics

E. Hallman, CU



Other Members at CU
- J. Darling
- J. Stocke
- D. Ratchford
- M. Kaiser

Key Project: Gravitational Physics & Lunar Science via Lunar Laser Ranging

Lead Scientists: T. Murphy (UCSD), D. Currie (U. Maryland), S. Merkowitz (GSFC)

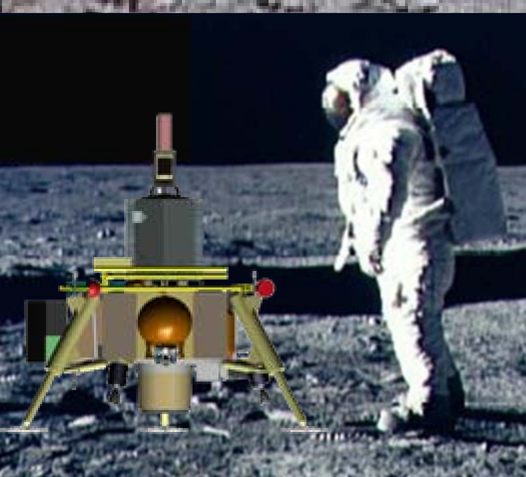

Apollo 14 retroreflector at Fra Mauro

Current Capabilities

- Accuracy ≈ 1 mm.
- Strong Equivalence principle $\eta < 4 \times 10^{-4}$.
- $\dot{G}/G < 6 \times 10^{-13}$ per year.
- Deviation from inverse-square law is < 3×10^{-11} times strength of gravity at 10^{8} m scales.


APOLLO = Apache Point Observatory Lunar Laser-ranging Operation

Next-Generation Laser Retroreflector Array for the Moon



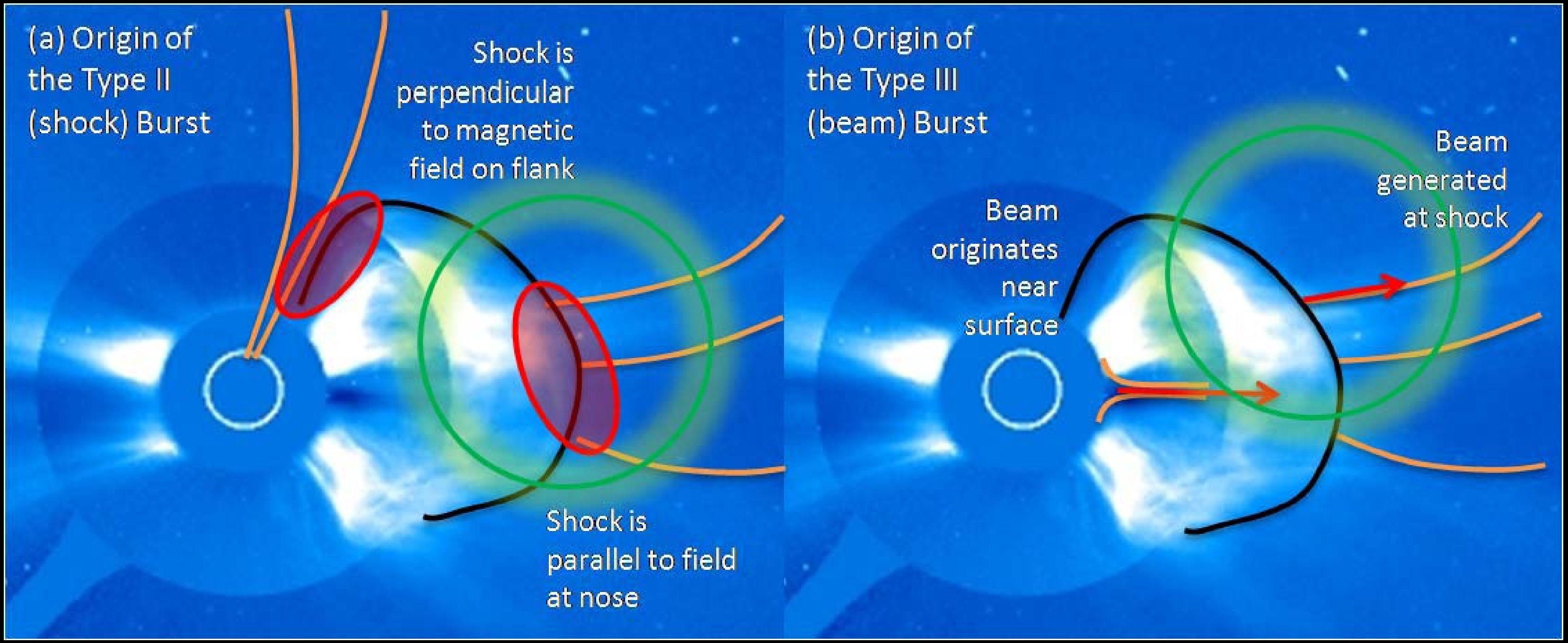
Fundamental Questions:*

- Does Dark Energy exist?
- Is the Equivalence Principle exact?
- Do the Fundamental Constants of Nature vary with space and time?
- Do extra dimensions or other new physics alter the inverse square law?

**Opportunities for Probing Fundamental Gravity with Solar System Experiments*, Science White Paper submitted to Astro2010.

Key Project: Radio Heliophysics from the Moon

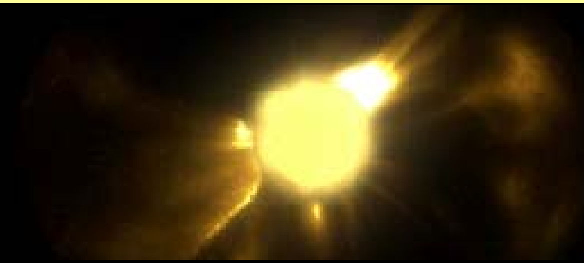
Lead Scientists: J. Kasper (CfA) and R. MacDowall (GSFC)



Type II Burst source location **Complex Type III source location**

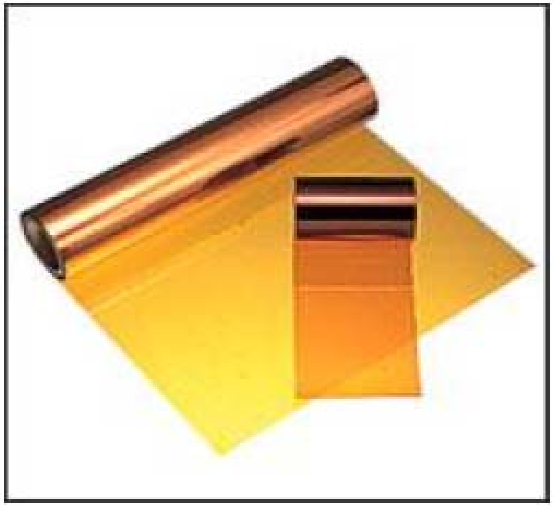
- How does cosmic ray acceleration occur within the heliosphere?
- A low frequency radio array will produce the first resolved ($\sim 1^{o}$ at 10 MHz), high time resolution images of solar radio emissions (outer corona).

ROLSS: Radio Observatory for Lunar Sortie Science

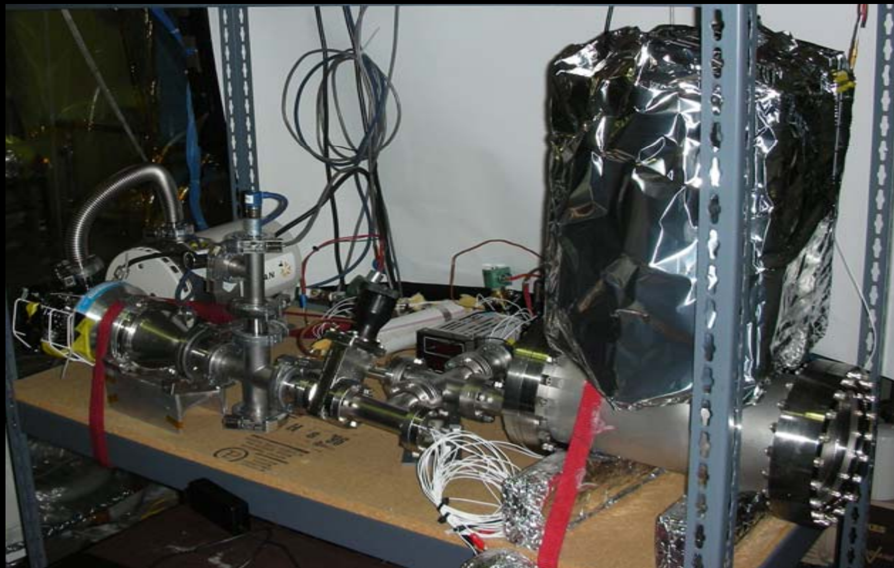


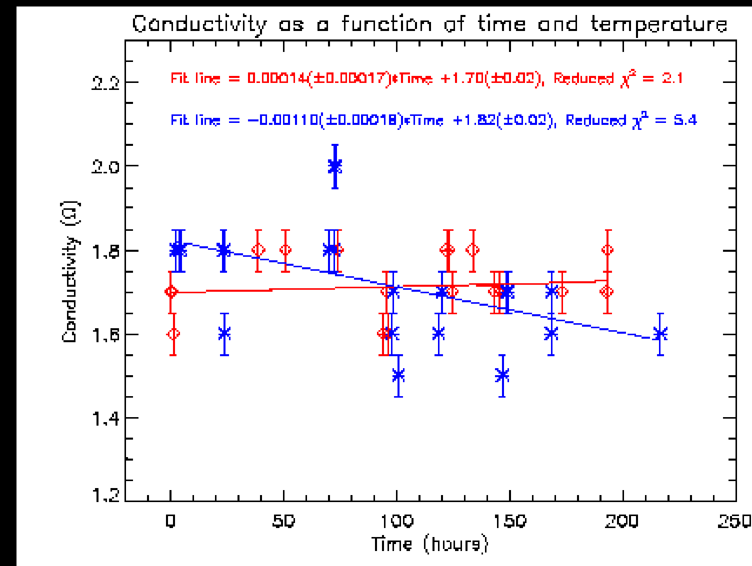
A Pathfinder for a future long-wavelength farside lunar array (10-100 sq. km). Operating at 1-10 MHz (30-300 m). Array consists of three 500-m long arms forming a Y; each arm has 16 antennas.

- Arms are thin polyimide film on which antennas & transmission lines are deposited.
- Arms are stored as 25-cm diameter x 1-m wide rolls (0.025 mm thickness).



Laboratory Testing of Polyimide Film as Low Frequency Antenna Backbone



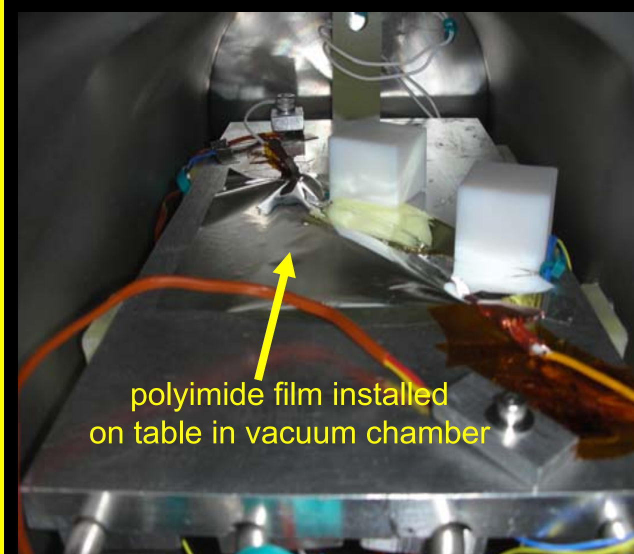


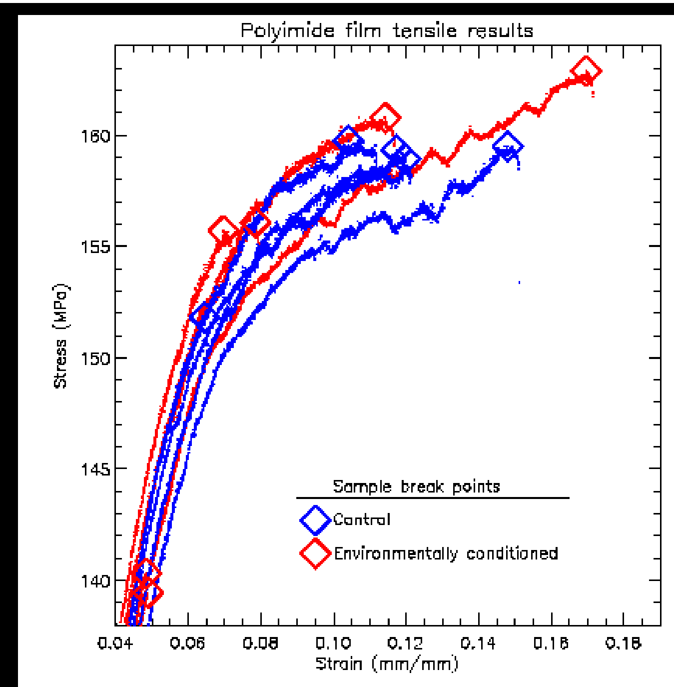
Experimental Set-up

- 12 24-hr duty cycles with T = -150 C to 100 C.
- Exposed to UV with deuterium lamp during “day cycle”.

Results

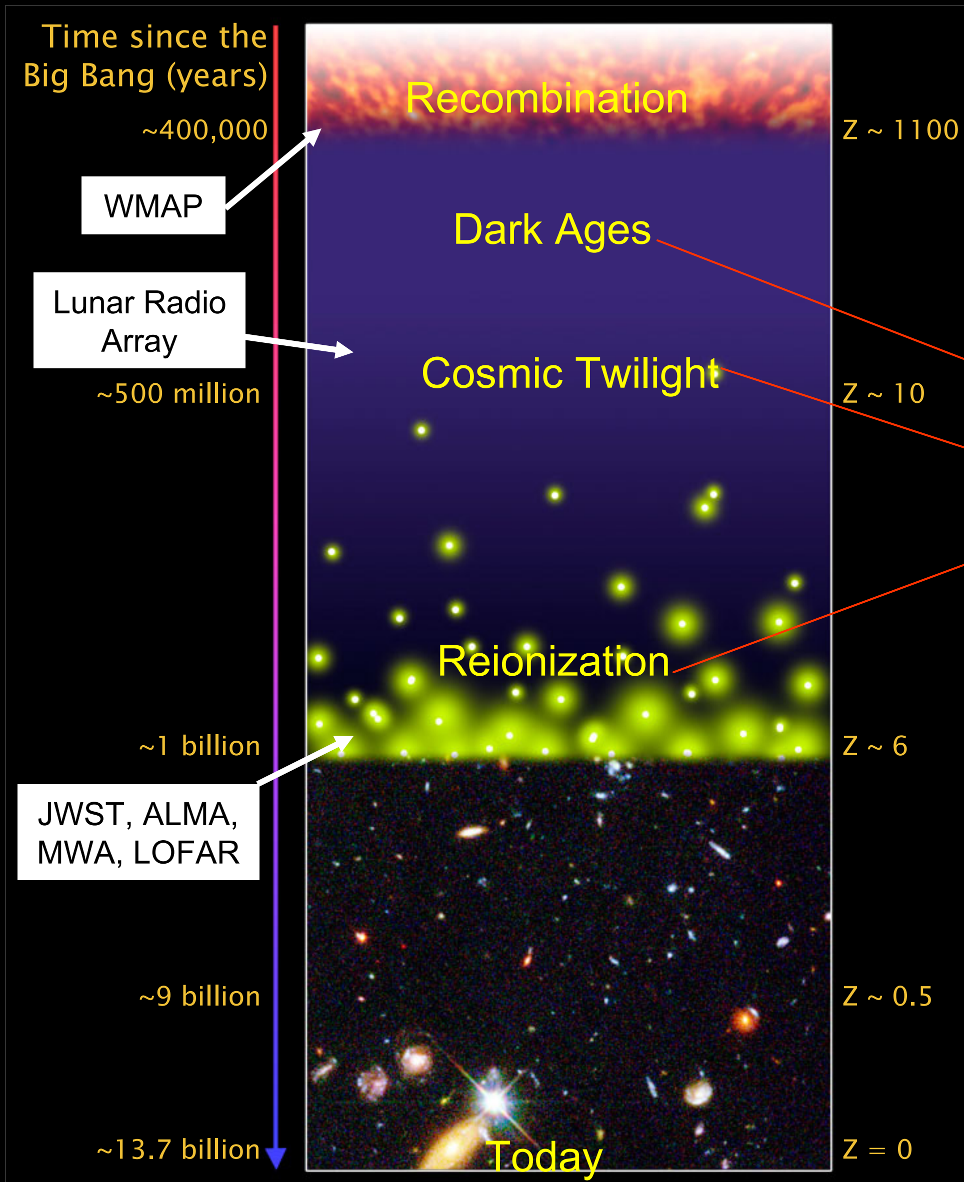
- No significant change in material or electrical characteristics during thermal cycling.





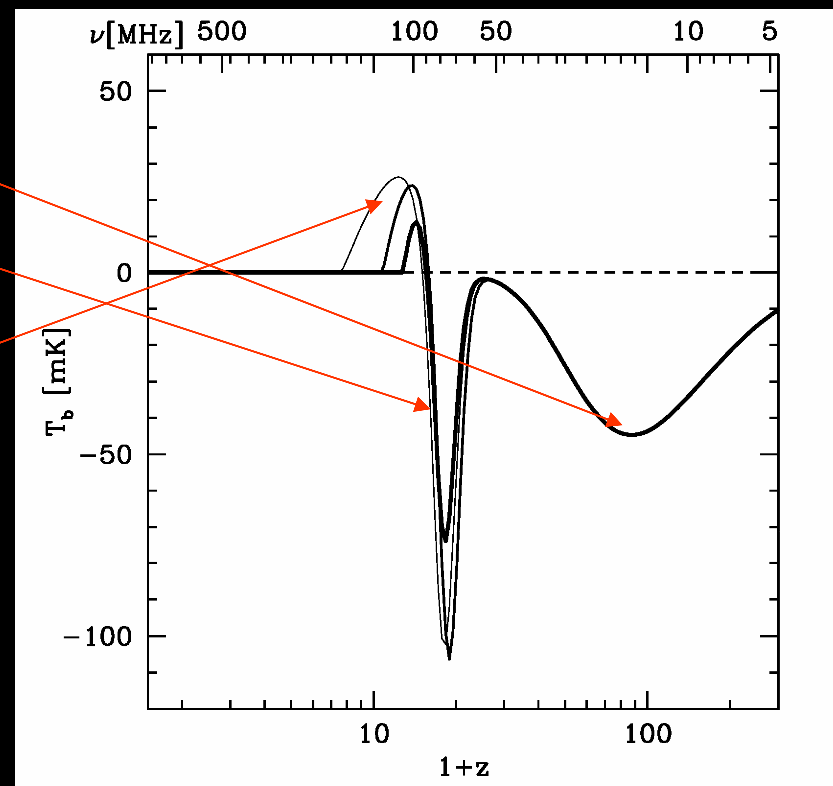
J. Burns with Ted Schultz and Bobby Kane, CU CASA

Key Project: Low-Frequency Cosmology & Astrophysics from the Moon



Lead Scientists: J. Lazio (NRL), J. Hewitt (MIT), C. Carilli (NRAO)

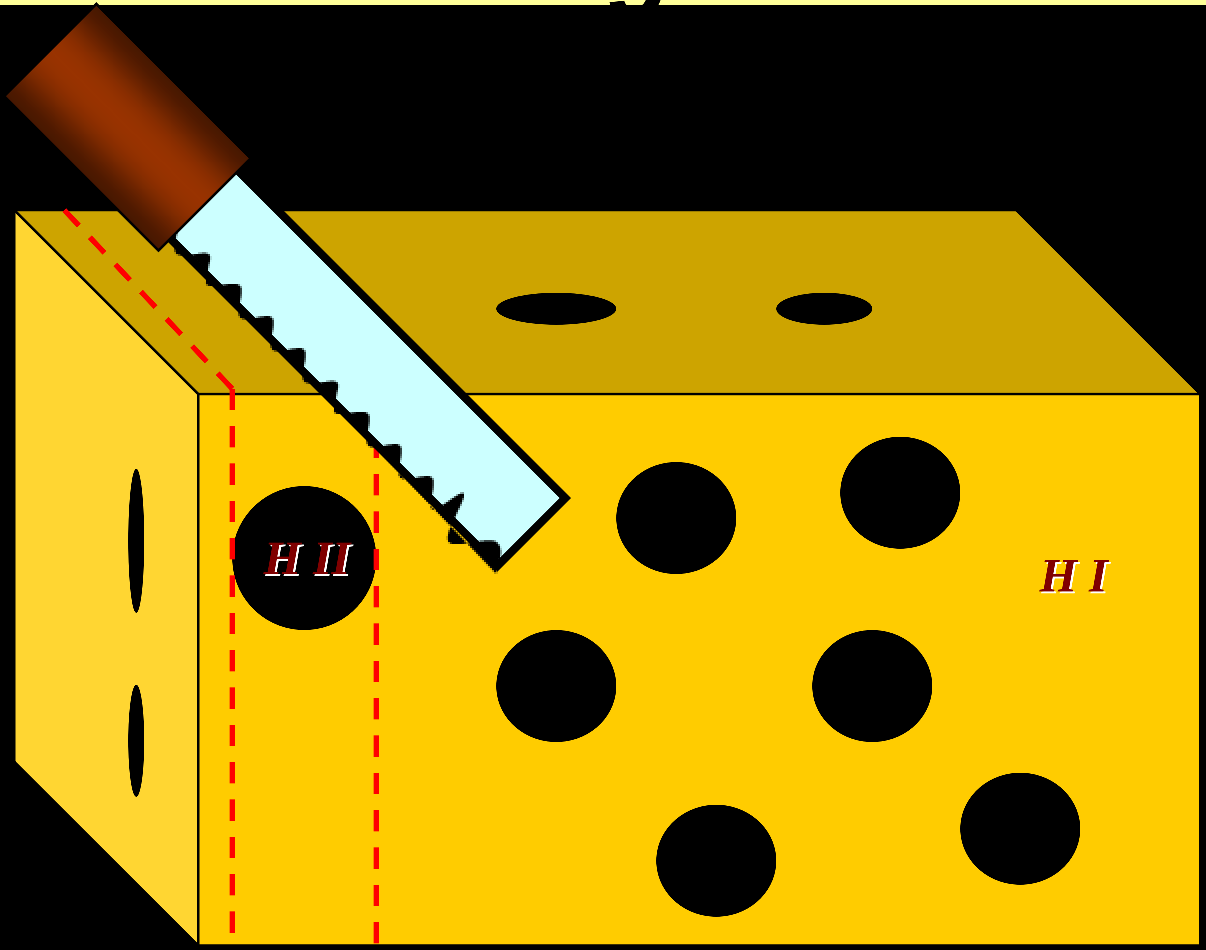
The Global (sky-averaged) HI Signal



Pritchard & Loeb, 2008, Phys. Rev. D., 78, 3511.

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)

21cm Tomography of Ionized Bubbles During Reionization is like *Slicing Swiss Cheese*

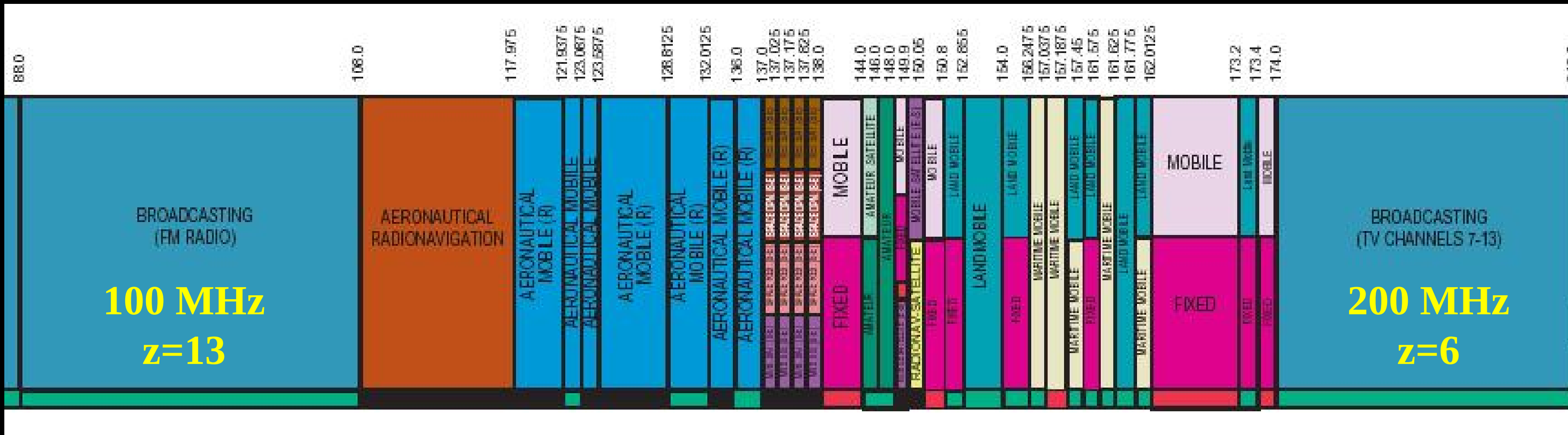


Observed wavelength ⇔ distance

21cm (1+z)

(Loeb, 2006, astro-ph/063360)

Lunar Advantage: No Interference



Destination: Moon!

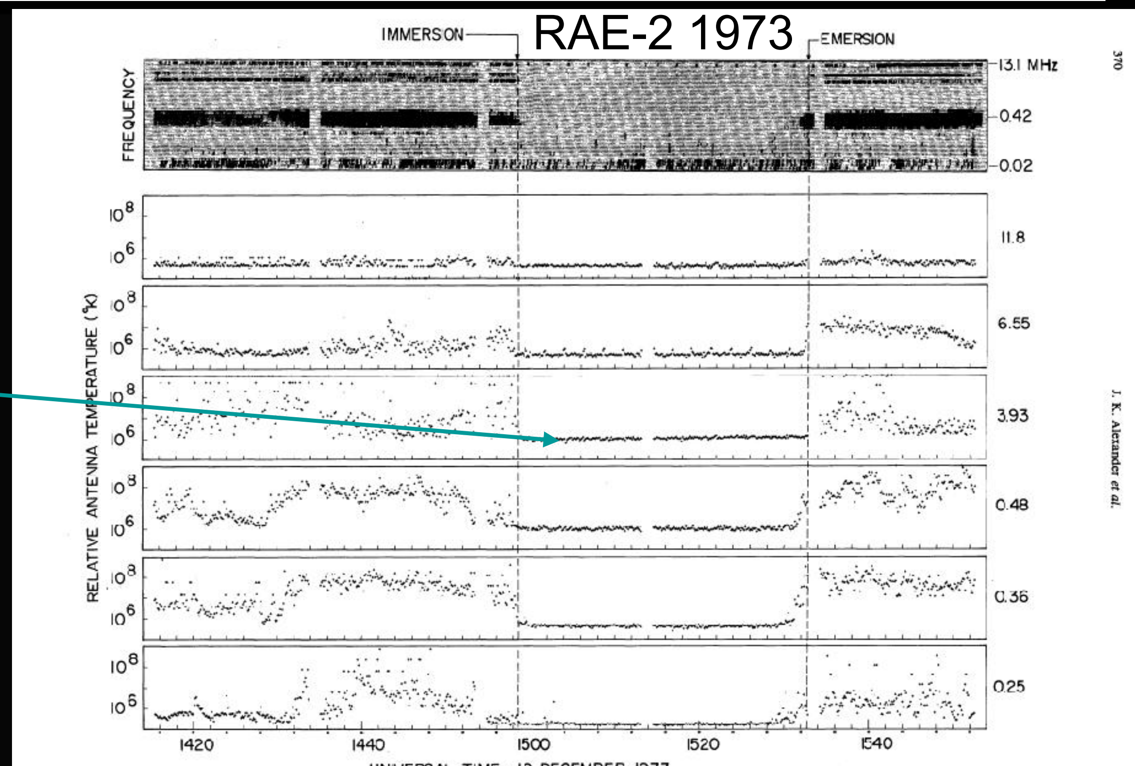
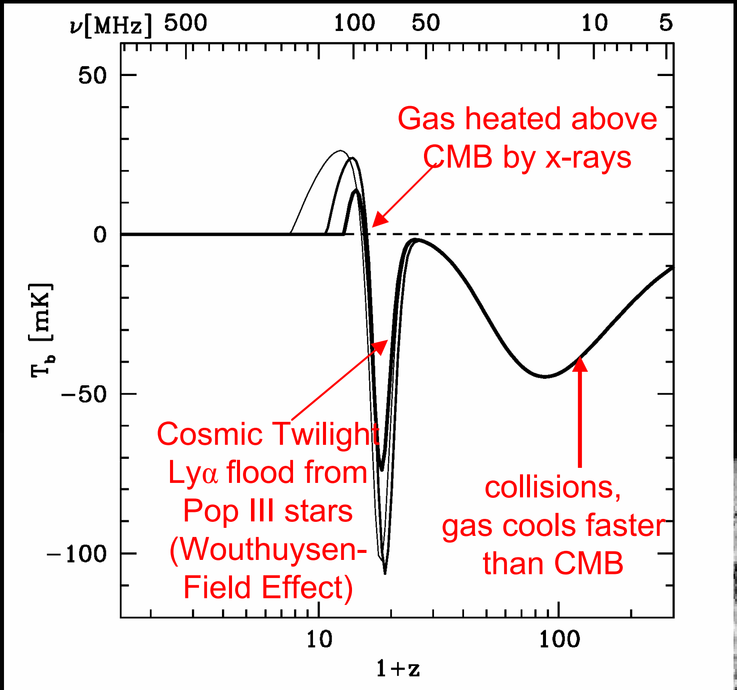
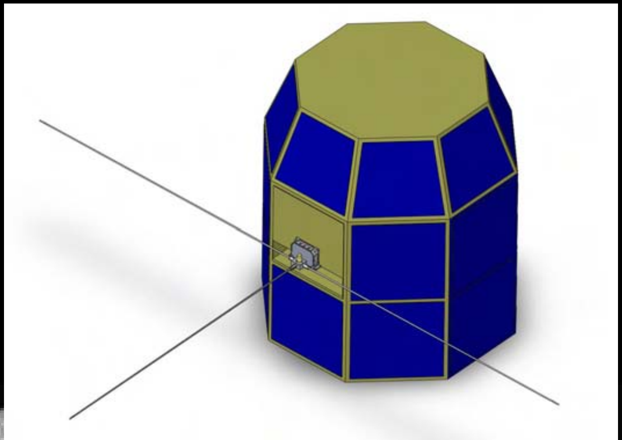


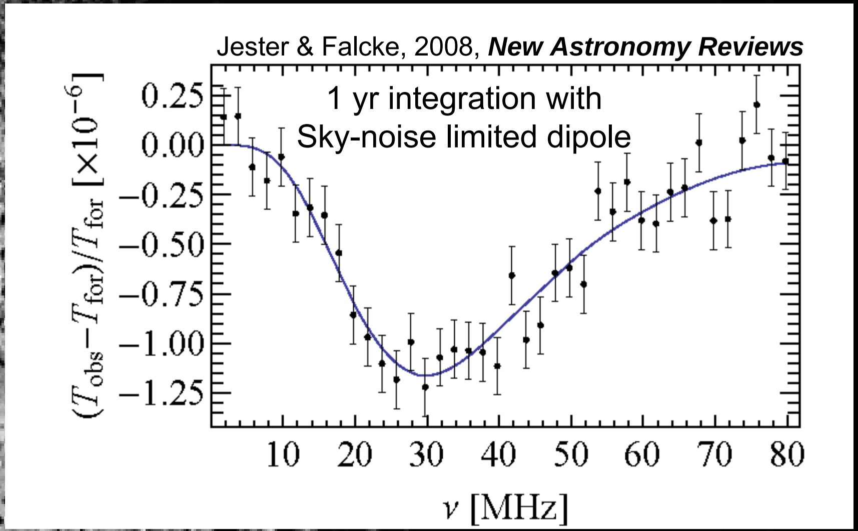
Fig. 5. Example of a lunar occultation of the Earth as observed with the upper-V burst receiver. The top frame is a computer-generated dynamic spectrum; the other plots display intensity vs. time variations at frequencies where terrestrial noise levels are often observed. The 80-s data gaps which occur every 20 m are at times when in-flight calibrations occur. The short noise pulses observed every 144 s at the highest frequencies during the occultation period are due to weak interference from the Ryle-Vonberg receiver local oscillator on occasions when both that receiver and the burst receiver are tuned to the same frequency

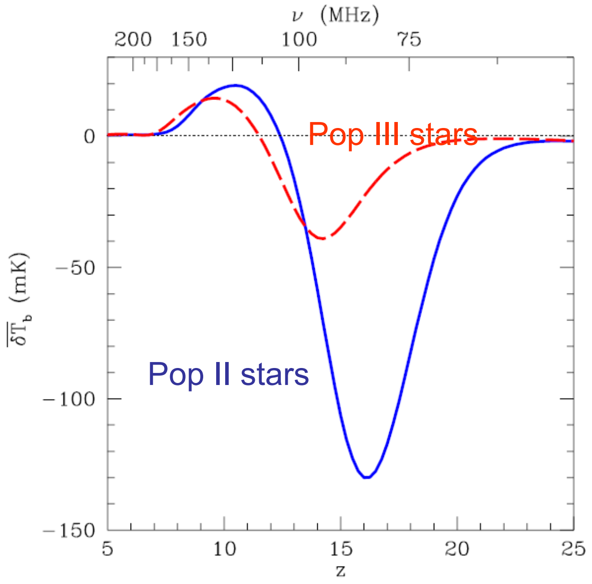
The Global (sky-averaged) HI Signal





Global signal can be detected by single dipole in orbit above lunar farside!

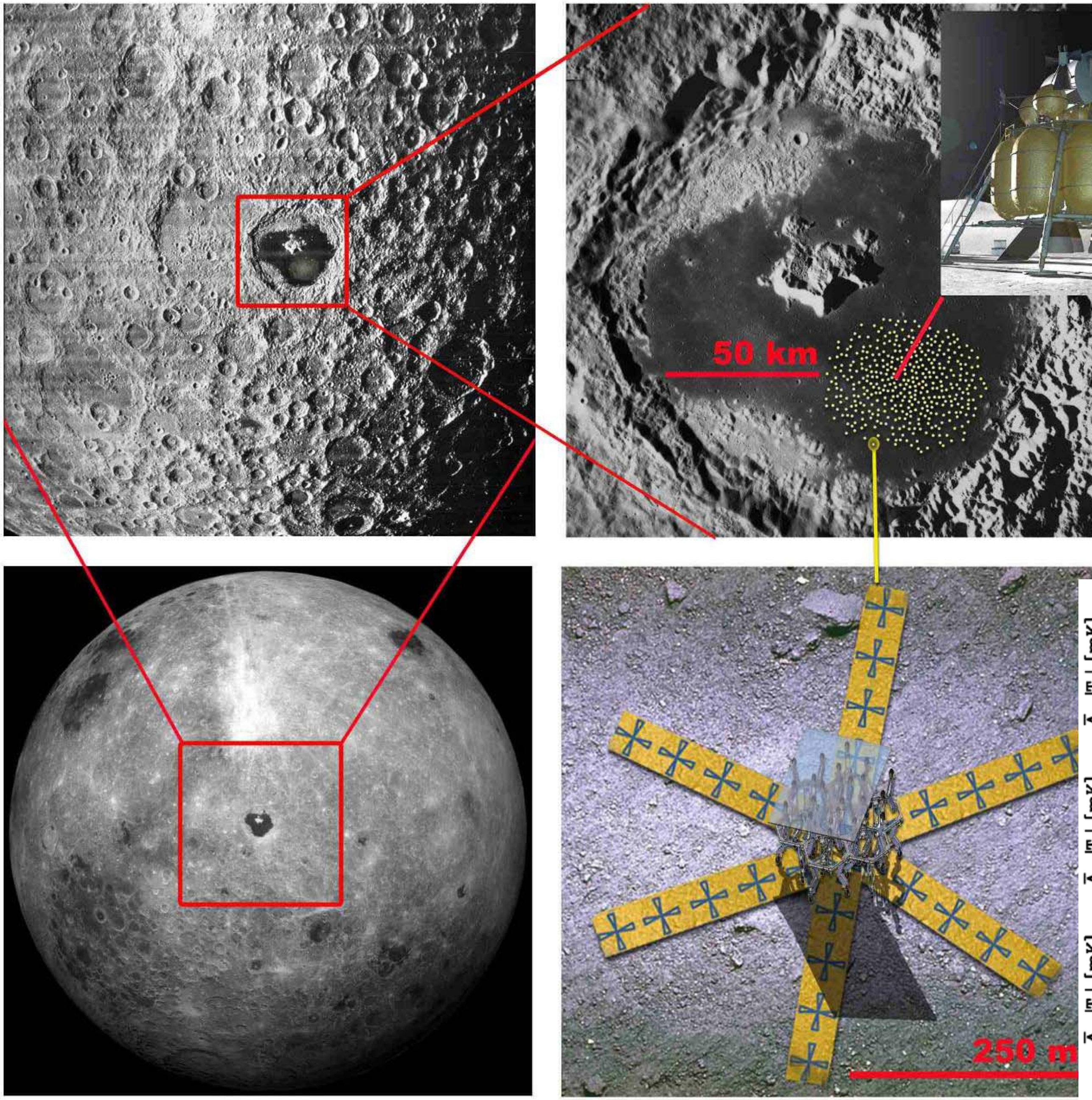




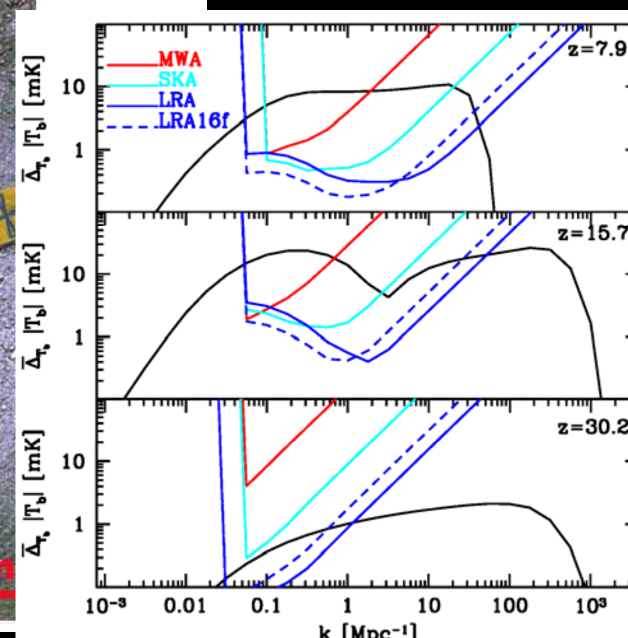
$\Delta T_{min} = T_{sys}/(\Delta\nu \cdot t)^{1/2}$

where T_{sys} = sky temperature ~17,000 K at 30 MHz

One Concept: Dark Ages Lunar Interferometer (DALI)



DALI concept. *(Left, upper right)*: Possible location in the Tsiolkovsky crater. *(Upper right insert)*: Artist's concept of lander; DALI would have pallets of rovers instead of an astronaut habitat module. *(Lower right)*: Individual station contains ~100 electrically-short dipoles. ~1000 stations are planned.



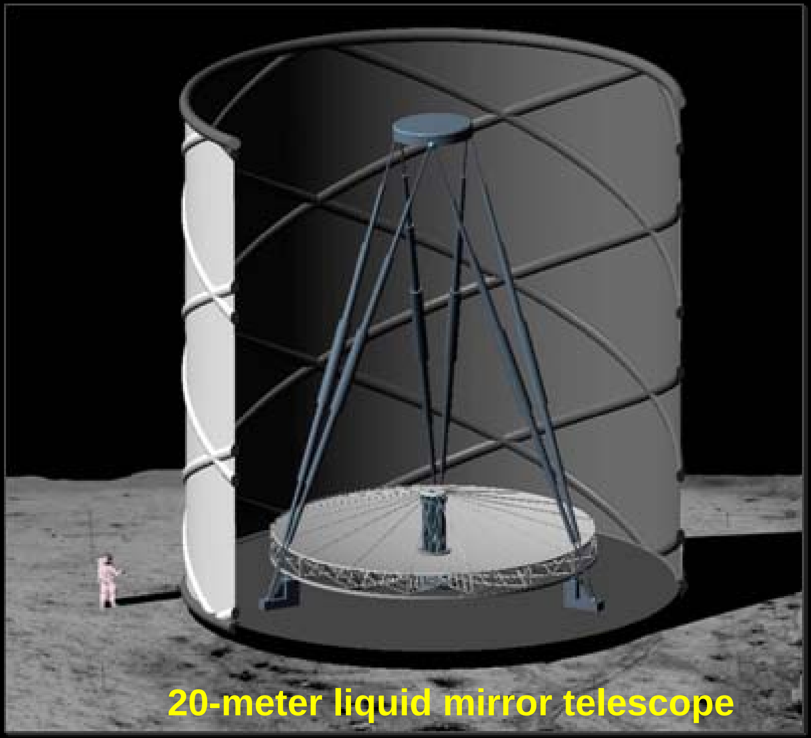
Big Questions in Cosmology that a Farside Radio Array may help to answer

- What is the correct theory of inflation (deviations from Gaussianity in 21-cm power spectrum)?
- What is Dark Energy and how does it evolve in time?
- Were there “exotic” heating mechanisms, such as Dark Matter decay, that occurred before the first stars formed?
- How did matter assemble into the first galaxies, stars, and black holes?

Key Project: Assessment of Other Astrophysics Enabled by a Return to the Moon

Lead Scientists: E. Hallman and J. Burns (Colorado)

8-meter monolithic telescope inside Ares V

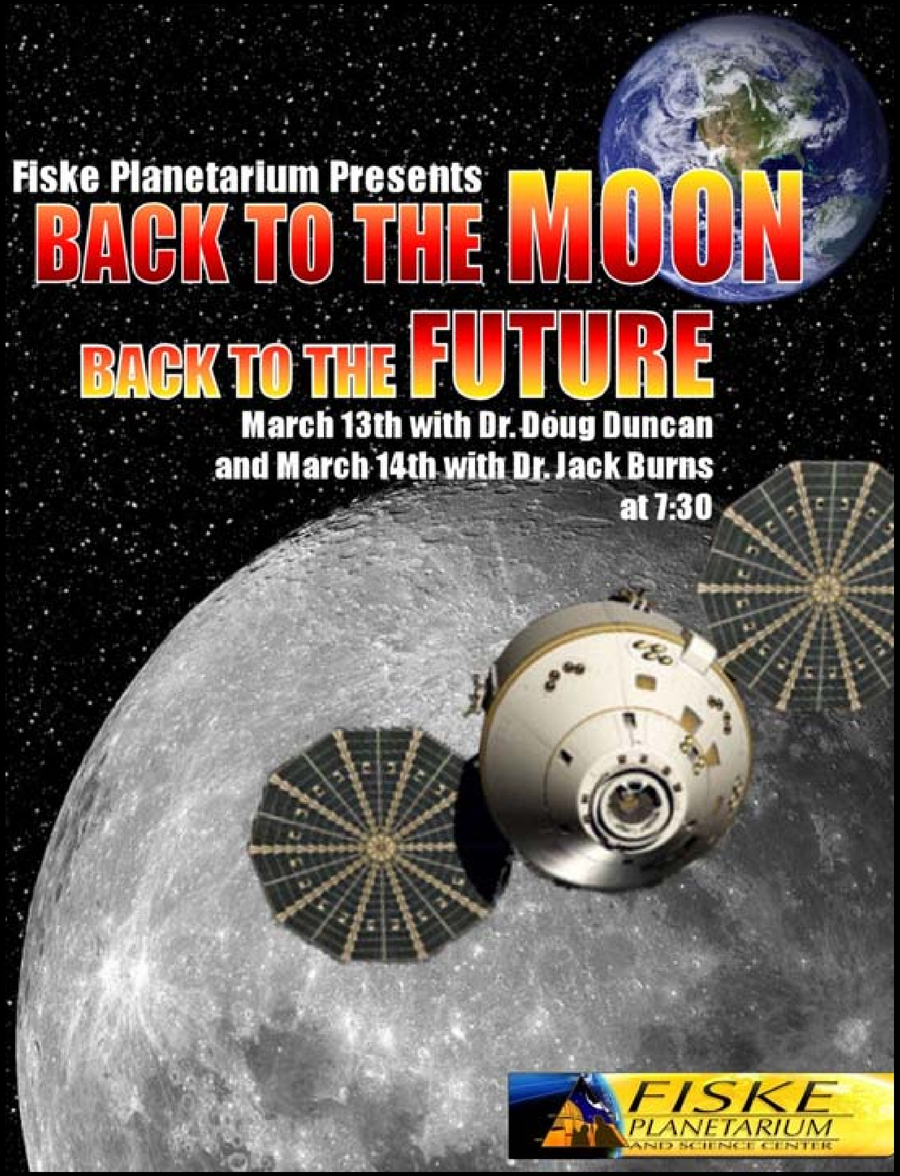


20-meter liquid mirror telescope

Lunar Cosmic Ray Detector

Education and Public Outreach

Lead Scientist: Doug Duncan (Colorado)



- **Planetarium Programs**
  - *Back to the Moon, Back to the Future* (adult, bilingual, science of/on/from the Moon).
  - *Max Goes to the Moon* (children's program).
  - Formative evaluation & assessment; national distribution; content drawn from all NLSI teams.
- **Teacher Workshops**
  - Adapt & develop curriculum focusing on lunar science.
  - Hands-on classroom activities, including Galileoscope (IYA).
  - Participate in Moon analog deployment activities for astrophysics instruments.

Curricula in Space Science

- Update curricula in some current classes (e.g., Astr 4800).
- Focus updates to curriculum based on the current missions, space science policies for Astr 4800, and possibly Astr 2020.
- All will include some aspects related to lunar science (on the moon, of the moon, and from the moon).
- Develop interdisciplinary graduate seminar on science of, on, & from the Moon.

Summary of LUNAR Components

- Gravitational Physics via Lunar Laser Ranging.
- Low Frequency Radio Heliophysics.
- Low Frequency Cosmology & Astrophysics.
- Assessment of other Astrophysics from the Moon.
- Education & Public Outreach via planetarium shows & teacher workshops.