

LUNAR UNIVERSITY NETWORK FOR ASTROPHYSICS RESEARCH

Joseph Lazio

Jet Propulsion Laboratory,
California Institute of Technology

Jack Burns

University of Colorado Boulder
&
NASA Lunar Science Institute



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6 other lunar science teams

The central logo for the LUNAR network. At the top left is a stylized starburst or firework-like graphic in blue and yellow. To its right, the word "LUNAR" is written in large, blue, 3D block letters. Inside the letters of "LUNAR" is a green and blue globe representing Earth. Below "LUNAR" is the text "LUNAR UNIVERSITY NETWORK for ASTROPHYSICS RESEARCH" in a white, sans-serif font. In the center is the University of Colorado Boulder logo, consisting of a gold 'CU' monogram and the text "University of Colorado Boulder" below it. The background of the logo is a dark space scene with a grey, cratered lunar surface in the foreground. In the distance, there are blue concentric circles representing gravitational waves or a signal, a green cone of light, and a bright orange and red celestial body. At the bottom of the logo is a row of partner logos: NASA, JPL, the NASA Lunar Science Institute logo, NRAO, and CFA. Below these are logos for MIT, UCLA, UCSD, UNM, and another university logo.

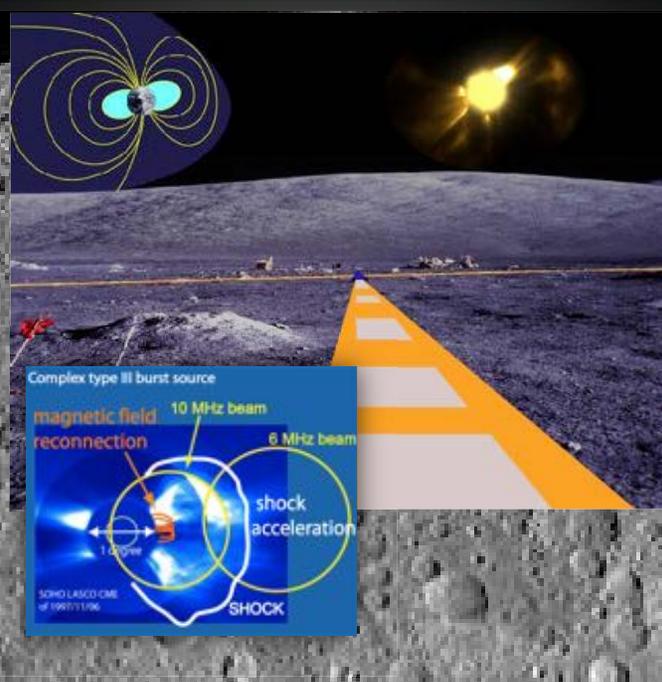
LUNAR

LUNAR UNIVERSITY NETWORK for ASTROPHYSICS RESEARCH

Cosmology & Astrophysics

Heliophysics

Gravitation & Lunar Laser Ranging



COSMIC DAWN

Astro 2010

“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?** Observations and calculations suggest that this phenomenon occurred when the universe was roughly half a billion years old, when light from the first stars was able to ionize the hydrogen gas in the universe from atoms into electrons and protons—a period known as the **epoch of reionization**... Astronomers must now search the sky for these infant galaxies and find out how they behaved and interacted with their surroundings.” => **DARE science!**



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

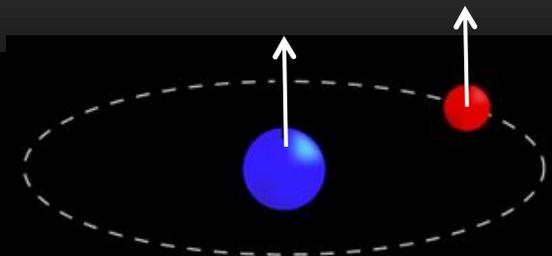
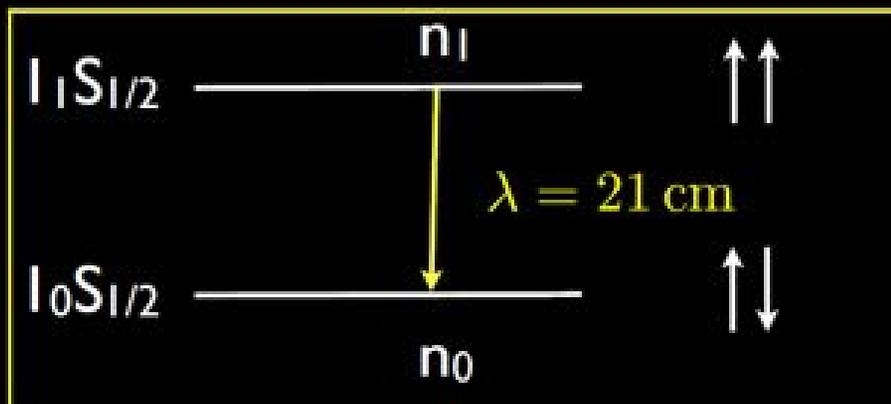


21-CM HYPERFINE LINE OF NEUTRAL HYDROGEN

Precisely measured transition from water masers

$$\nu_{21\text{cm}} = 1,420,405,751.768 \pm 0.001 \text{ Hz}$$

Hyperfine transition of neutral hydrogen



Useful numbers:

- 200 MHz $\rightarrow z = 6$
- 100 MHz $\rightarrow z = 13$
- 70 MHz $\rightarrow z \approx 20$
- 40 MHz $z \approx 35$

- $t_{\text{Age}}(z = 6) \approx 1 \text{ Gyr}$
- $t_{\text{Age}}(z = 10) \approx 500 \text{ Myr}$
- $t_{\text{Age}}(z = 20) \approx 150 \text{ Myr}$

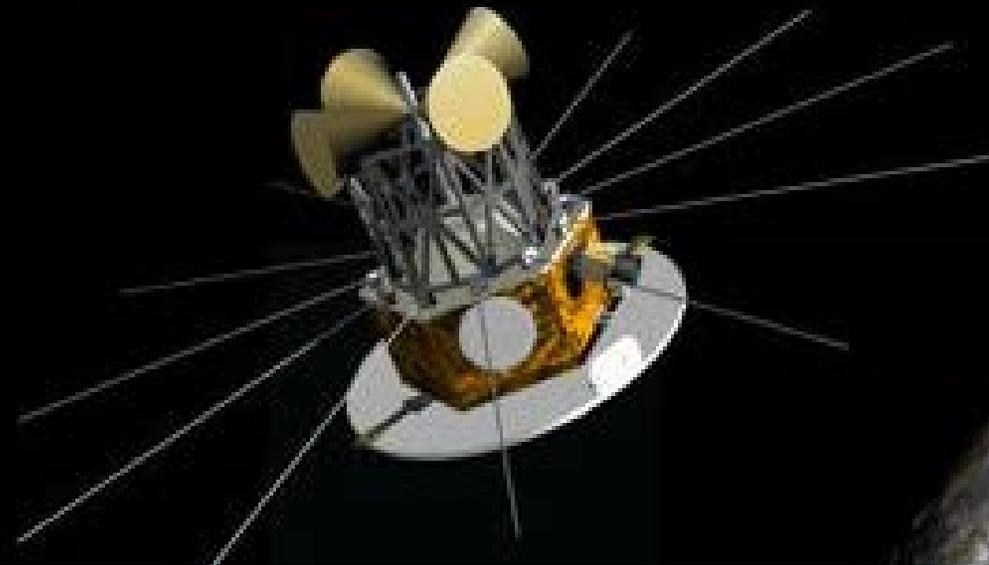
Spin temperature describes relative occupation of levels

$$n_1/n_0 = 3 \exp(-h\nu_{21\text{cm}}/kT_s)$$



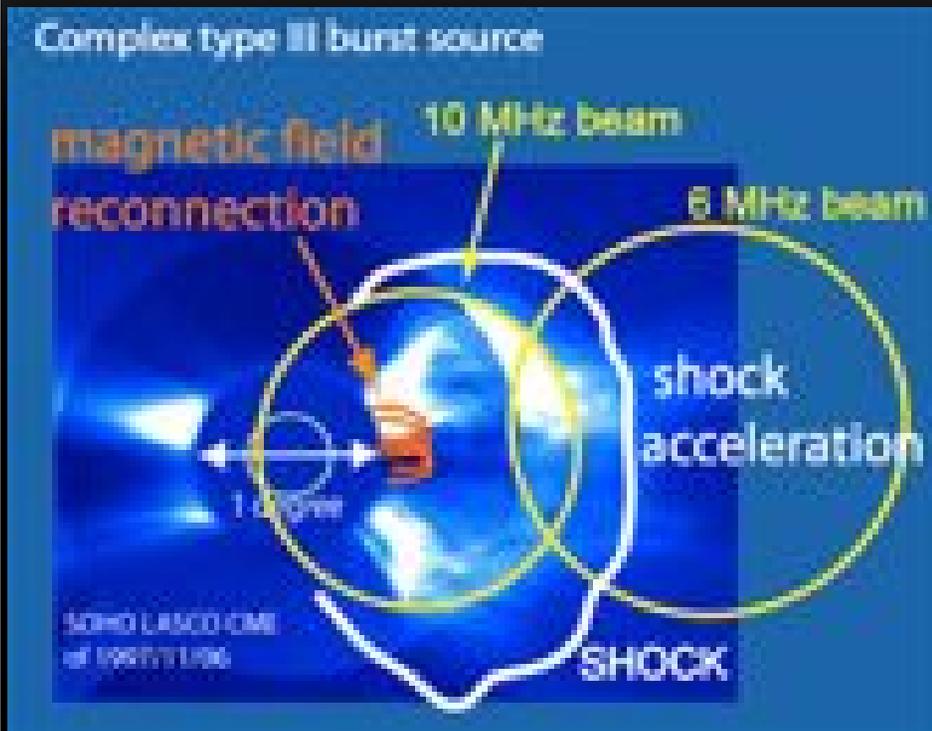
DARE

DARK AGES RADIO EXPLORER



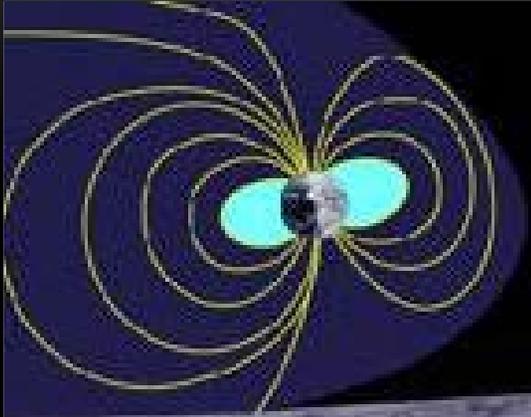
Burns *et al.*, 2012, *Advances in Space Research*, 49, 433
<http://lunar.colorado.edu/dare/>

RADIO HELIOPHYSICS FROM THE MOON



A low frequency radio array will produce the first resolved ($\leq 2^\circ$ at 10 MHz), high time resolution images of solar radio emissions (outer corona).

ROLSS: RADIO OBSERVATORY FOR LUNAR SOLAR SCIENCE



- 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).

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



ASTRO2010 DECADAL SURVEY

PANEL ON PARTICLE ASTROPHYSICS & GRAVITATION

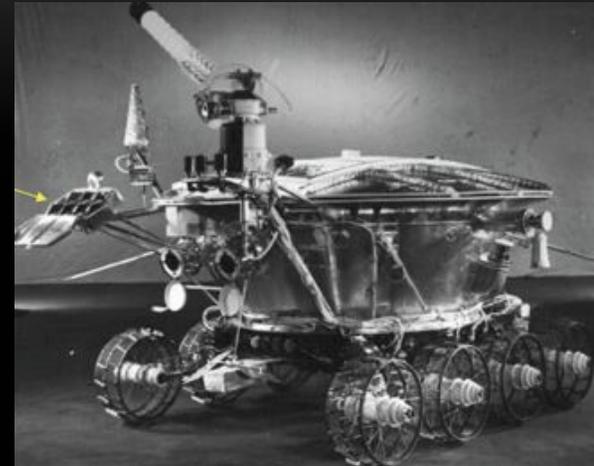
- The direct detection of gravitomagnetic effects (e.g., Lense-Thirring precession) is from Lageos/GRACE, Gravity Probe B, and **Lunar Laser Ranging**.
- Limits on the fractional rate of change of Newton's Gravitational constant G ($10^{-12}/\text{yr}$) from **Lunar Laser Ranging**.
- Strong & weak Equivalence Principle limits. Better determination of PPN and \dot{G}/G from next generation **Lunar Laser Ranging**.



RECOVERY OF LUNOKHOD 1 RETROFLECTOR WITH APOLLO

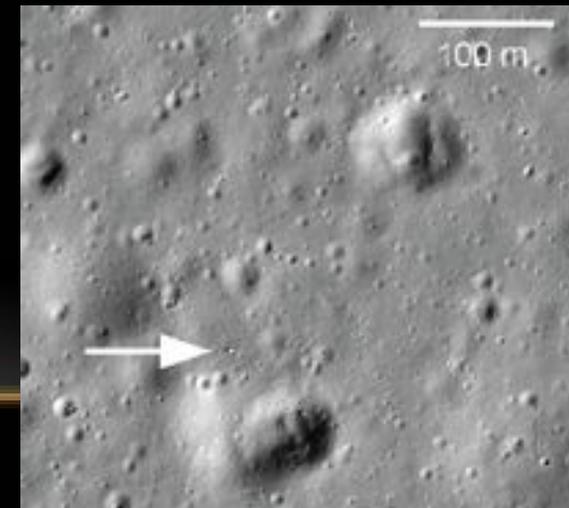


Apache Point Observatory Lunar Laser-ranging Operation (APOLLO)



Lunokhod 1 Lander

- Offset was 40 m (270 ns) in projected range (100 m lateral), putting signal at edge of gate.
- **Potential Science:** Offers best leverage on libration determination => key for Center of Mass determination & lunar interior study.



LROC image of Lunokhod 1 site

T. Murphy, University of California,
San Diego

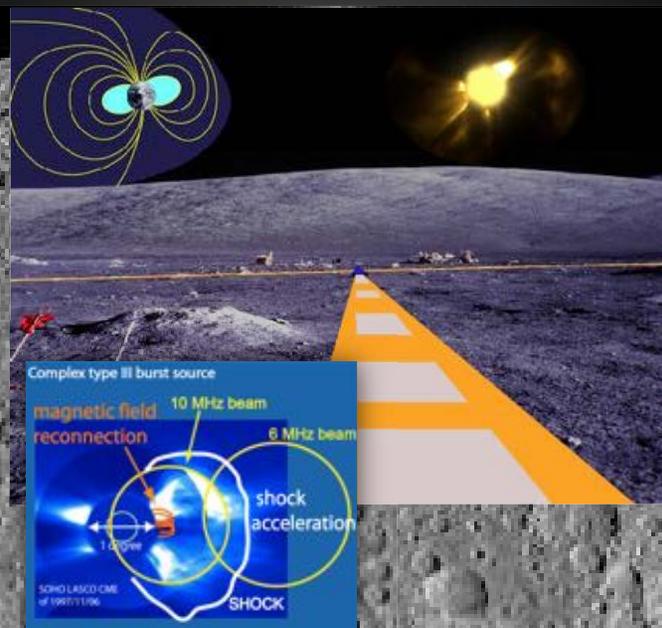
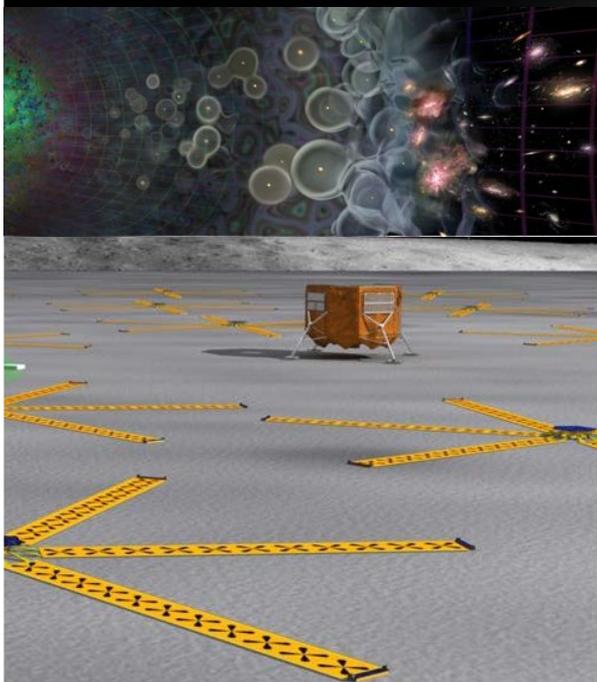
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SUMMARY OF THE FIRST 3 YEARS OF LUNAR

- **Some Statistics**

- Number of Co-Is and Collaborators involved in LUNAR research: **Over 50**
- Number high school, undergraduate & graduate students, postdoctoral students who have been “influenced” by LUNAR research & training: **45**
- Number of refereed publications: **62**
- Number of conference proceedings, conference presentations, & abstracts: **220**

- **Awards to LUNAR Team Members**



- **Steven Furlanetto (UCLA)** – Helen B. Warner Prize from the American Astronomical Society given to astronomer who is <36 yrs old for significant work in theoretical astronomy.



- **Justin Kasper (Smithsonian CfA)** – Presidential Early Career Award.



- **Judd Bowman (Arizona State)** – NASA Roman Technology Fellowship.

- **Jack Burns (U. Colorado)** – NASA Medal for Exceptional Public Service; elected Fellow of the American Association for the Advancement of Science.