Astronomy/Geology 5835
Interdisciplinary Lunar Science Seminar
Class Syllabus & Website:
http://lunar.colorado.edu/~jaburns/astr5835
For the NLSI, lunar science is broadly defined to include studies:

- **Of the Moon**: Investigations of 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.
Exploring the Cosmos from the Moon
Gravitational Physics & Lunar Structure via Lunar Laser Ranging

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 $< 3 \times 10^{-11}$ times strength of gravity at $10^8$ m scales.
Next-Generation Laser Retroreflector Array for the Moon

Fundamental Questions on Gravity:*

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

*from Science White Papers submitted to Astro2010 & Planetary Sciences Decadal Surveys.
• How does cosmic ray acceleration occur within the heliosphere?
• A low frequency radio array will produce the first resolved (≤2° at 10 MHz), high time resolution images of solar radio emissions (outer corona).
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).
Low-Frequency Cosmology & Astrophysics from the Moon

The Global (sky-averaged) HI Signal


21 (1+z) cm = 1420/(1+z) MHz
At z=10, \( \lambda = 2.3 \) m (130 MHz)
At z=50, \( \lambda = 10.7 \) m (30 MHz)
The Dark Ages Viewed via the Highly Redshifted 21-cm Line

In the beginning of the Dark Ages, electrically neutral hydrogen gas filled the universe. As stars formed, they ionized the regions immediately around them, creating bubbles here and there. Eventually these bubbles merged together, and intergalactic gas became entirely ionized.

Simulated images of 21-centimeter radiation show how hydrogen gas turns into a galaxy cluster. The amount of radiation (white is highest; orange and red are intermediate; black is least) reflects both the density of the gas and its degree of ionization: dense, electrically neutral gas appears white, dense, ionized gas appears black. The images have been rescaled to remove the effect of cosmic expansion and thus highlight the cluster forming processes. Because of expansion, the 21-centimeter radiation is actually observed at a longer wavelength; the earlier the time, the longer the wavelength.
Lunar Advantage: No Interference

100 MHz
z=13

200 MHz
z=6

Destination: Moon!

RAE-2 1973

Fig. 3. Example of a lunar occultation of the Earth as observed with the upper F band receiver. The top frame is a computer-generated dynamic spectrum; the other plots display intensity vs. time variations at frequencies where occulted radio waves are observed. The 880 MHz gaps which occur every 24 h are at times when a high calibrations occur. The short pulse between 1420 and 1440 s is the highest frequency during the occultation period and is due to weak interference from the dipole/VHF transmitters about 10 km away when both the receiver and the lunar occultor are tuned to the same frequency.
Roadmap to the Early Universe via Earth & the Moon

Western Australia

Lunar Orbit

Lunar Farside

EDGES

MWA

PAPER
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?
Possible Other Astrophysics Enabled by a Return to the Moon

8-meter monolithic telescope inside Ares V

20-meter liquid mirror telescope

Lunar Cosmic Ray Detector
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.