Astrophysics Enabled by the Return to the Moon

“One’s Destination is never a place but rather a new way of looking at things.”
 – Henry Miller

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BRIEF OUTLINE

• What are major questions in astrophysics?
• How can the VSE address these questions?
• Smaller-scope experiments.
• Conclusions
The meeting was organized by STScI in collaboration with JHU, AURA, and NASA, with about 160 participants.
Goals of the Workshop Were:

• To identify what are intriguing astrophysical questions for the next two decades and beyond.
• To explore how the VSE and the return to the Moon can provide opportunities for significant progress toward answering those questions.
Big Questions in Astrophysics

Why is the universe accelerating?

Which astronomical objects were involved in the “first light”?

Are there habitable extrasolar planets?

How did galaxies and the large-scale structure form?
The VSE will enable progress in all of these areas of Astrophysics

• Capabilities are ideally suited for transportation of large-aperture telescopes (or their components), of the type envisioned for a broad range of future astronomical missions.

• Progress in some areas will be best achieved by observations from free space (in particular Lagrange points). Some interesting observations can be done from the lunar surface.
1. The Accelerating Universe
Dark Energy or Alternative Gravity

Currently envisioned to be addressed by wide-field observations from free space.

\[ H^2 - \frac{H}{r_c} = \frac{8\pi}{3} G_N \left( \rho + \rho_{DE} \right) \]

Can be tested by experiments on the lunar surface.
Lunar Ranging Experiments and Theories of Gravity

Measurements of lunar perihelion precession with an accuracy of $\delta \Phi = 1.4 \times 10^{-12}$ to test alternatives to general relativity.

Currently accuracy is $2.4 \times 10^{-11}$.

Placing a carefully designed array of transponders expected to achieve desired accuracy.
2. The Epoch of Reionization and Beyond

Reionization

Fluctuations are about 10 mK
Observations of redshifted 21 cm (in the frequency range 10–200 MHz) neutral hydrogen emission could probe $7 \leq z \leq 100$ (100 million – 1 billion years after the Big Bang)

On Earth

On the Moon

Far side of Moon offers:
1. Very little RFI
2. Avoids Earth’s ionospheric frequency cutoff (at ~10 MHz)
3. No ionospheric distortion at higher frequencies
4. No disturbances from weather and human activity.

“Everyone is a Moon, and has a dark side.”
— Mark Twain
Low frequency radio observations require only lightweight dipoles.
3. Are There Extrasolar Habitable Planets?

a. Potential observations from free space. External occulter throws deep shadow over JWST, but allows planet light to pass.
b. Potential observations from the lunar surface.

The occulter is 30 m in diameter at a distance of ~20,000 km from the telescope.
c. What does a life-bearing planet look like?

Potential precursor observations from the lunar surface:
A small telescope to observe the Earth to characterize
the time-dependent signature of a life-bearing planet

“Viewed from the distance of the Moon, the astonishing thing about
the Earth...is that it is alive.”
— Lewis Thomas
4. The Assembly of Structure

a. Potential observations from free space

Structure of the cosmic web and the intergalactic medium can be best studied by ultraviolet spectroscopy from L2.
b. Potential observations from the lunar surface:
A small far-UV telescope to examine the structure and composition of the hot (T ~ 10^5–10^6 K) Galactic medium

The hot gas is probably the least understood baryonic component of the Milky Way.
c. Deep-field observations from the lunar (north) pole could produce images deeper than the Hubble Ultra Deep Field, to study galaxy evolution.

Liquid mirror could be 20–100 m in diameter.
A More Specialized Scientific Topic

How are Galactic cosmic rays accelerated?

A calorimeter to study intermediate-energy ($E \sim 10^6$ GeV/particle) cosmic rays

Will use ~150 tons of layered regolith. Can detect the primary particles.
CONCLUSIONS

1. The return to the Moon will enable significant progress in astrophysics.

2. The workshop identified some important astrophysical observations, as well as a few smaller experiments that can be uniquely carried out from the lunar surface.
CONCLUSIONS

3. Observations from free space (in particular Lagrange points) offer the most promise for broad areas of astrophysics.

Capabilities in free space include:

- All-sky access
- Diffraction-limited performance
- Very precise pointing and attitude control
- Thermal equilibration and temperature stabilization
- Efficient operations
CONCLUSIONS

4. The VSE should be planned so as not to preclude — and to the extent possible to include — capabilities that will enable astrophysics from free space.

Capabilities of great interest include:

- Large fairings
- Advanced telerobotics
- EVA capabilities
- High-bandwidth communication
- A low-cost transportation system (e.g. between Lagrange points)
How Do You Take Six Billion People to the Moon?

Motivation

Just as the Vision for Space Exploration will provide new prospects for scientific research, it will also provide new opportunities in education and public outreach. Coaxing the new science enabled by our return to the moon with personalization and public outreach strategies will enable us to engage six billion people in astronomy and space science. The trip to the moon and the scientific research done on the moon will provide countless “teachable moments” and new, exciting avenues of outreach. EPO professionals will be able to give everyone in the U.S. (and around the world) a unifying, educational “lunar experience.”

Goals for Lunar Science EPO Programs

- Engage and excite the public and students about the lunar exploration program through the scientific discovery, development, and return to the moon.
- Use lunar-based science efforts and results to inspire and educate both public and internal audiences in science, technology, engineering, and mathematics (STEM), spark student interest in STEM careers, and provide new means for supporting such careers.
- Provide effective and appropriate access to lunar exploration and science programs for educators, students, and the public.

Planning for the Future

There are important questions to consider as we move toward our full engagement with the vision of the future of space exploration.

- How can we continue the adventure into greater public engagement, science literacy, and interest in space exploration?
- How do we get the public to care about lunar-based science and technology (and science and technology in general) and the entire lunar program?
- How can the public be encouraged to take the lessons of our lunar exploration to the local community and beyond?
- How can educators and citizens bring together the public and the science, technology, engineering, and mathematics (STEM) to explore lunar science?
- How can we engage the public in the planning and investment of the future?

Key Elements to Consider

- Harnessing new technologies to communicate lunar-based science to people of all ages.
- Today, for example, social media is a popular tool. Yet there are also ways to use non-proprietary software like educational research tools and other technologies that can enhance the experience.
- Building program-wide commitment to communicating science to the public. Educators, engineers, and students need to work together to identify and integrate elements that will increase our ability to engage the public.
- Providing quick access to scientific results and data. In future space missions, we need to ensure rapid dissemination of this data to the public.
- Involving local communities in the exploration of lunar science and technology.

Conclusions

Through innovative and coordinated efforts to engage the public of Earth in a new lunar-based science education, we can create a more engaged and informed populace. This can also create a greater understanding of lunar-based science and technology concepts and can also foster a stronger appreciation for the process of science — a critical component for the next generation of scientists and engineers.

Educators will be able to bring their students on virtual journeys to the moon and, with our help, will engage students with exciting, new scientific results and research to improve STEM teaching, enhance science and technology curricula, and encourage the consideration of STEM careers.

This is a science education opportunity not to be missed, and this is the time to start planning.
How Do You Take Six Billion People to the Moon?

The potential for significant science returns exists in our return to the moon. This endeavor also presents a unique opportunity in science education. With proper planning, the Education and Public Outreach (EPO) community can use new lunar science achievements prompted by the Vision for Space Exploration to provide excitement, inspiration, and learning that will revitalize the public’s interest in space exploration and make students and the public highly engaged in astronomy and space science. The trip to the moon and the scientific research done on the moon will provide countless “teachable moments” and new, exciting avenues of outreach. EPO professionals will be able to give everyone in the U.S. (and around the world) a unifying, educational “lunar experience.”

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