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.

Can be tested by experiments on the lunar surface.

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

Time since the Big Bang (years)

- ~400,000
- ~500 million
- ~1 billion
- ~9 billion
- ~13.7 billion

Reionization

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

On Earth

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

On the Moon

“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 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

Sun-Earth Lagrange points (not to scale)
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?

Matt Bobrowsky, Denise Smith, James Manning, Bonnie Eisenhammer, and the Office of Public Outreach, STSci

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."

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. Crucial for the new science enabled by the return to the moon with proper education and public outreach, strategies will enable us to engage six billion people in the adventure, the science, and the story of the return to the moon.

Goals for Lunar Science EPO Programs

- Strive and excite the public and students about the lunar exploration program through the scientific discoveries made possible by that return to the moon.
- Use lunar-based science efforts and results to inspire and educate both public and student audiences in science, technology, engineering, and mathematics (STEM), spark student interest in STEM careers, and provide new avenues for exploring 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 if we are going to take full advantage of our return to the moon and the science we will discover:

- How can we translate 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 we make lunar-based research a part of the daily lives of people on Earth and help them to feel a personal connection to our return to the moon?
- How do we encourage the public to consider the benefits of going back to the moon?
- How can we help educators to extract teachable moments from our return to the moon, and use the scientific discoveries to increase the teaching of science and technology both in and out of the classroom?
- How can scientists and educators work together to use our return to the moon to increase the skill base that students will pursue careers in science and technology?

Key Elements to Consider

- Harnessing new technologies to communicate lunar-based science to the people of the world.
- Today, for example, podcasts are a popular medium. We will need to be prepared with whatever communication mechanisms and other technologies arise in the coming years.
- Building program-wide commitment to communicating science to the public. Scientists, engineers, and educators will need to work together to identify and include curriculum elements that will increase our ability to engage the public.
- Providing quick access to scientific results and data. Just as Haboobs in Marsocore, early releases of lunar science data will aid in the development of new science.
- Providing students with opportunities to see new science and to see human values at the forefront of science.

Conclusions

Through innovative and coordinated efforts to engage the public, there is a new lunar-based science education, students, educators, and the public can gain a greater understanding of lunar-based science and technological concepts and can attain a deeper appreciation for the process of science — culturally important at a time when there is so much misunderstanding about what science is and why it is so important to our future.

Evaluators will be able to take these students on virtual journeys to the moon and, with our help, will engage students with exciting, new scientific results and new technologies, and share their excitement. This experience will create a new generation of lunar-based 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.

[Image of a space observatory]