
Brookhaven
National Laboratory
U.S. DEPARTMENT OF
ENERGY
New Opportunities with Commercial Lunar Payload Services
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Introduction

- Moon is a unique place for experiments:
  - extremely stable with no weather, no seasons and long day/night cycles
  - no atmosphere (neither inside experiment nor above)
  - different gravity
  - different seismics
  - different orbit around the Sun
  - among most radio quiet places in Solar System (on far side)
  - weak but finite magnetic fields

- We usually don’t even consider it for our experiments due to price, but perhaps we should

Confluence of a few factors

Department of Energy

Department of Energy and NASA Sign Memorandum of Understanding

OCTOBER 20, 2020

Energy.gov » Department of Energy and NASA Sign Memorandum of Understanding

WASHINGTON, D.C. – Today, U.S. Secretary of Energy Dan Brouillette and NASA Administrator Jim Bridenstine signed a new memorandum of understanding (MOU) furthering the longstanding partnership between the Department of Energy (DOE) and NASA that has enabled 50 years of notable space exploration.

The agreement – discussed during the October 2020 Secretary of Energy Advisory Board meeting – supports President Trump's Space Policy Directive-1 and other U.S. national space policies. Under the directive and NASA's Artemis program, America will land the first woman and the next man on the Moon by 2024 and establish sustainable lunar exploration by the end of the decade to prepare for the first human mission to Mars.

"From achieving a better understanding of the Moon, to providing the nuclear fuels to propel Voyager 1 and 2 into space, DOE and NASA have been strong collaborators in our Nation's space mission for decades," said Secretary Brouillette. "This new MOU will continue our esteemed work together as this Administration strives to reach the next generation of space innovations and exploration."

"Artemis depends on a coalition of partners across U.S. government, industry, and the world," said NASA Administrator Jim Bridenstine. "The DOE's energy, science, and technology expertise remains crucial to the success of NASA missions. Together, we will mature and ready systems for exploring more of the Moon and venturing humans farther into space, all for humanity's benefit on Earth."

Request for Information Related to High Energy Physics and Space-Based Astrophysics

JANUARY 22, 2021

Office of Science » Request for Information Related to High Energy Physics and Space-Based Astrophysics

On behalf of the Department of Energy's (DOE) Office of Science and the National Aeronautics and Space Administration's (NASA) Science Mission Directorate, we invite interested parties to respond to this Request for Information (RFI) on collaborative activities that further scientific advances in high energy physics and space-based astrophysics, in support of our shared scientific goals.

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NASA - DOE MOU

- a top down effort to encourage agencies to collaborate
- request for information asked for short white-papers on:
  - potential lunar surface missions on the far side of the Moon;
  - space-based probes of fundamental physics on the International Space Station;
  - synergies in the use of data from the Vera C. Rubin Observatory, the Nancy Grace Roman Space Telescope, and the Euclid mission.
- Anecdotally, lunar missions and dark energy synergies attracted most attention

CLPS - Commercial Lunar Payload Services

- advent of SpaceX taught NASA that a lot of money can be saved with commercial providers
- a similar program is developed to support Artemis program:
- Now at ~11 eligible vendors that bid on contracts
  - Number of vendors is expected to settle around ~a few.
- awarding 1-4 missions every year
- actively looking for payloads through PRISM (Payloads and Research Investigations on the Surface of the Moon) calls and otherwise
- they view payloads as essentially an exercise in how to run the contracting process
- first launches expected in June 23 (from awards in 2019)

Landers selected in the first round: Peregrine (Astrobotic Technology), Nova-C (Intuitive Machines), Z-01 (OrbitBeyond)

Why is CLPS interesting to DOE?

Pros:

- If you have an instrument that can benefit from lunar environment and is accepted, CLPS covers cost of launch, lander, platform, communications, etc.
- NASA additionally gives full support to teams in terms of selecting a landing site, etc.
- This is at least 1 order of magnitude more expensive than the instrument itself
- It enables interesting experiments in the <$50mil range, which would otherwise be cost prohibitive

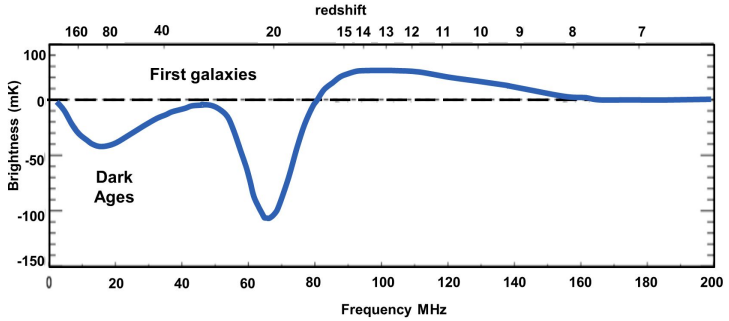
Why is CLPS interesting to DOE?

Cons:

- It is not a science driven process:
  - one is given boundary conditions and need to fit interesting science into those
  - it is a train, not a taxi
  - Moon's orbit is not an option (yet)
- Timelines are extremely compressed
- The first few missions are yet to launch

Science Case 1: Dark Ages Science

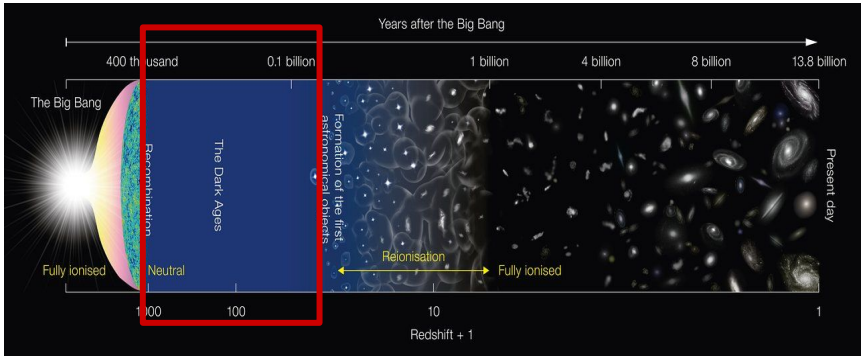
- Dark Ages is an era after light decouples and before stars form
- Physics is linear and exact (general relativity, thermodynamics and atomic physics)
- Highly-redshifted 21-cm radiation is a unique probe of the dynamics of the early universe
- First step is monopole detection (cf. Wilson & Penzias discovery of CMB in 1964) – feasible within the next decade
- Second step is fluctuations (cf. Smooth discovery of CMB fluctuations in 1991)



Decadal Survey on Astronomy & Astrophysics, Panel on Cosmology p.258

DISCOVERY AREA: THE DARK AGES AS A COSMOLOGICAL PROBE

"The panel sees 21 cm and molecular line intensity mapping of the Dark Ages and reionization era as both the discovery area for the next decade and as the likely future technique for measuring the initial conditions of the universe in the decades to follow.



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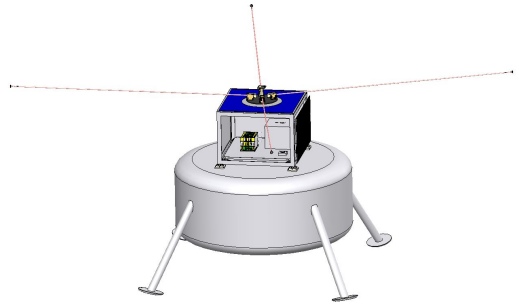
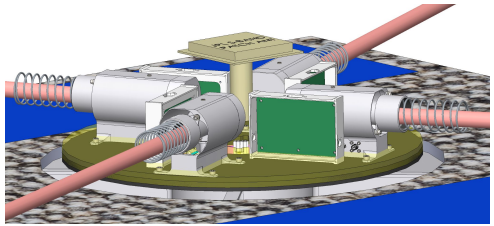
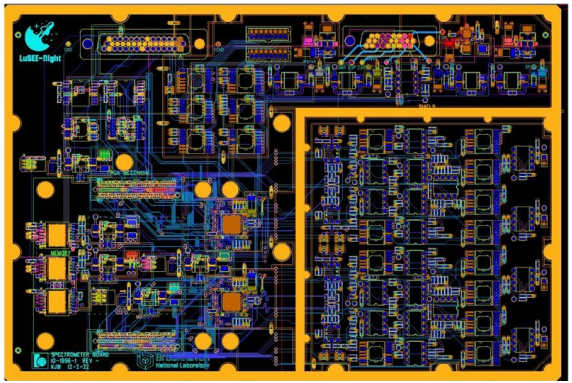
LuSEE-Night

- LuSEE-Night is a demonstration of this synergy in action
- It is a small, sub $20mil lifecycle cost DOE project to land a path-finder radio telescope on the lunar far side:
  - this has been dreamt since 1950s
  - Chinese landed an instrument on Chang'E 4 mission, but it is self-RFI limited
- Manifested on CLPS CS-3 mission in the second half of 2025
- Lunar farside is the among the best places in solar system to perform sub 50MHz radio observation
  - no Ionosphere
  - no man-made and meteorological RFI
- Main science goals:
  - Most sensitive observations of sky <50MHz
  - Demonstration of Lunar far-side as radio-observatory site
  - Most stringent limits on the Dark Ages signal
- Great synergies between capabilities of two agencies with clear scope split:
  - existence proof that it works







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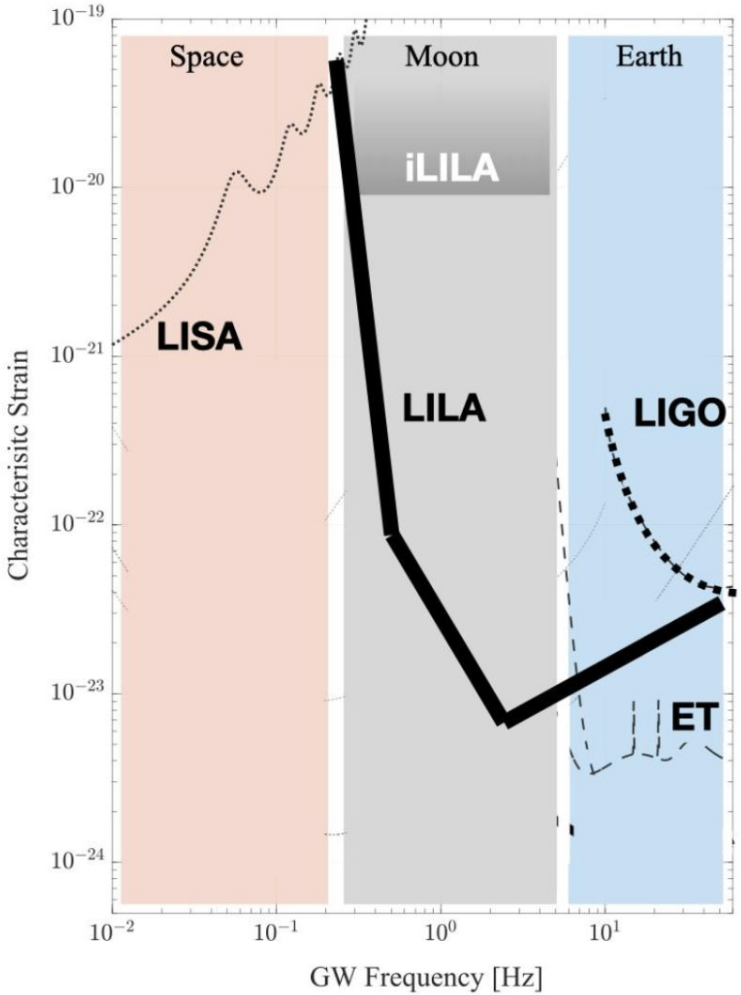
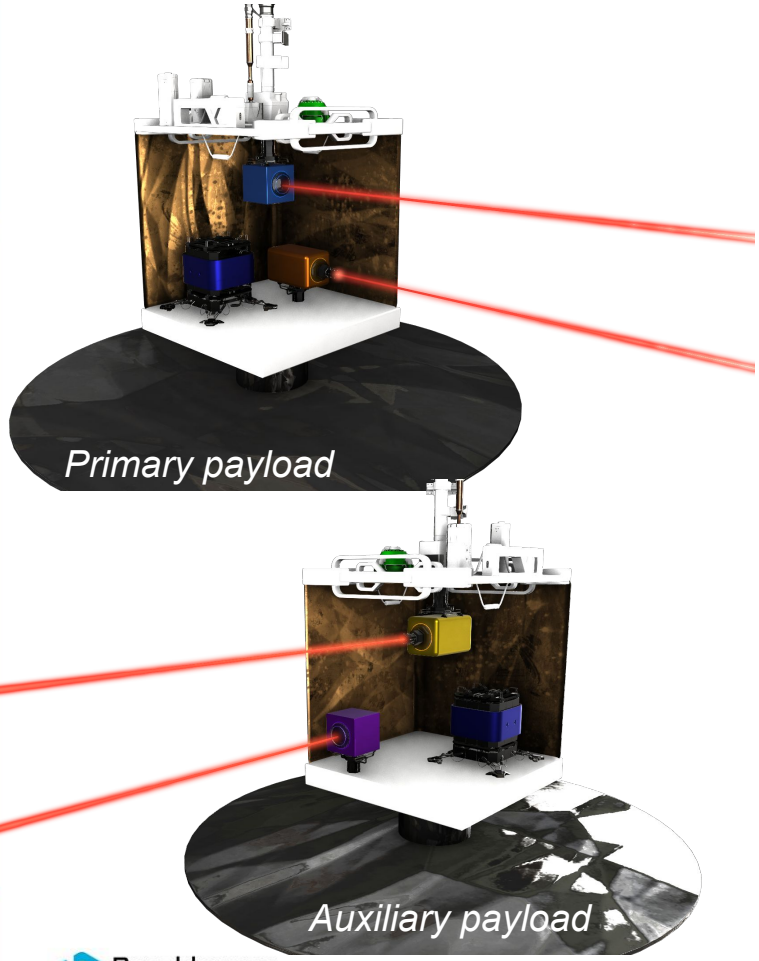
Science Case 2:Deci-Hz gravitational waves

- Balmer et al. (Snowmass 2021 Cosmic Frontier White Paper on Future Gravitational Wave Facilities)
- Jani et al. Snowmass 2021 (LOI) + plenary presentation
- Jani & Loeb, JCAP, 2021
- Three international workshops, white papers endorsed by >100 scientists



Advantage from Moon

- Rare access to GWs between 0.1 - 10 Hz thanks to Moon's low seismic activity
- Cannot be accessed from earth (seismic noise) nor from space (quantum limitation)
- White dwarf mergers (Typ1a SNe progenitors) emit GWs at ~1 Hz. Independent calibration of Standard Candles.
- Binary neutron star can be measured months before merger (LIGO only sees few minutes). Unprecedented accuracy for sky-localization and Neutro Star Equation of State.
- Axion-like Dark Matter scattering off rotating primordial black holes (100 - 1000x solar mass) in early universe emit GWs around 0.1 Hz.



iLILA = Pathfinder Mission

- Goal: First multi-messenger cosmic probe at ~1 Hz.
- Two payloads separated by a kilometer. Technologies inside the payload are TRL-3 or above.
- Two key components (Optical VBB, Retroreflectors) already developed for two CLPS missions.
- Location does not matter (gravitational-wave response is same across the Moon).
- Natural vacuum above Moon's surface is better than ultra-high vacuum in LIGO. Interferometer can be extended without additional cost.
- Energy budget: ~20 Watts.
  Data transmission: ~1 Mbps

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Possible Science Case: HEP paraphernalia

Direct DM detection:

- Because there is no atmosphere, the backgrounds due to cosmic rays will be different
  - no air-showers from interactions of primary particles with atmosphere
  - the overburden considerations for direct DM experiments might be different
- Annual modulation DM experiments (alla DAMA/Libra) could be easier (no seasons, stable temperature swings, etc), 28 day cycle on top of yearly ones

Cosmic Ray Physics:

- Magnetic fields will change rigidity cutoff compared to space
- Can measure the Cosmic Ray Shadow of the Earth, Sun very carefully

Conclusions

- CLPS is an opportunity to land HEP experiments on the Moon
- There are some clear science cases:
  - Dark Ages Cosmology (endorsed by Decadal)
  - deciHz Gravity Waves
- There might be other science cases that could benefit from:
  - natural vacuum
  - low gravity
  - environmental stability
  - Earth shielding (on the far side)