ASTR 4800 - Space Science: Practice & Policy
Today: Radio Astronomy from the Moon

- Next Class: JWST & Roman Space Telescope.
- Readings: links to NASA websites on class webpage for Nov. 30.
- Final paper due on Dec. 7. Be sure to address all the requirements.
- Fill out FCQs. Visit colorado.campuslabs.com/courseeval

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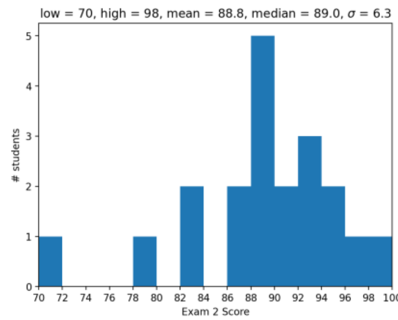
Results for Exam #2



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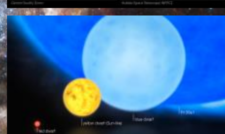
THE LARGEST STAR: NOT AS LARGE AS WE THOUGHT?

by Evan Walsh

- R136a1 is a Wolf-Rayet star (spectral type WN5h) located in the NGC 2070 star cluster of the Tarantula Nebula in the Large Magellanic Cloud satellite galaxy, some 160,000 light years away from Earth.
- From its apparent luminosity from Earth, its calculated distance, and observed spectral type, R136a1 have has historically been estimated to have a mass up to ~300 times that of our sun.
- Using the Gemini South Telescope in Chile, astronomers used a technique called speckle interferometry to observe the star more carefully. Because the Earth's atmosphere warps starlight, very distant faint stars can appear blurry even in large powerful telescopes. Speckle interferometry involves taking thousands of very short exposures with different color filters and then combining them to create a sharper image.
- The results of the observations yield a mass of around 196 solar masses (possibly as low as 169 and possibly as high as 230 solar masses when accounting for uncertainty), much lower than the previous ~300 solar mass estimate.
- Studying ultra massive stars like R136a1 are important to questions about stellar evolution and just how massive stars can get.



Article: https://www.syfy.com/syfy-wire/bad-astronomy-new-images-of-star-r136a-show-it-to-be-200-times-the-suns-mass

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Orion above the Moon's Far Side

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Courtesy of Intuitive Machines

NASA Commercial Payload Services (CLPS)

- "NASA's Commercial Lunar Payload Services (CLPS) initiative allows rapid acquisition of lunar delivery services from commercial companies for payloads that advance capabilities for science, exploration or commercial development of the Moon…under the Artemis approach"
- **Delivery Timeline**
  - *Astrobotic* will carry 11 payloads to Lacus Mortis, a larger crater on the near side of the Moon.
  - *Intuitive Machines* will carry multiple payloads, including our ROLSES radio science experiment, to Moon's South Pole with a landing now expected in Spring 2023.

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Intuitive Machines Payloads (IM-1)

- Lunar Node 1 Navigation Demonstrator (LN-1): LN-1 is a CubeSat-sized experiment that will demonstrate autonomous navigation to support future surface & orbital operations.
- Stereo Cameras for Lunar Plume-Surface Studies (SCALPSS): SCALPSS will capture video and still image data of the lander's plume as the plume starts to impact the lunar surface until after engine shut off, which is critical for future lunar and Mars vehicle designs.
- Low-frequency Radio Observations for the Near Side Lunar Surface (ROLSES): ROLSES will use a low-frequency radio receiver system to determine the plasma sheath density and scale height. Also, ROLSES will explore the effects on the antenna response of the lunar environment. In addition, the ROLSES measurements will confirm how well a lunar surface-based radio observatory could observe and image solar radio bursts.

Courtesy of Intuitive Machines

https://www.intuitivemachines.com/lunawesome-photos?pgid=ko1mw3k2-74a26877-e975-49f6-b0a2-5b136310f3e9

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IM-1 with ROLSES antennas deployed

Stowed STACER antennas

ROLSES spectrometer board

Radio wave Observations at the Lunar Surface of the Electron Sheath (ROLSES)

- ROLSES Instrument Team: Robert MacDowall (PI), William Farrell, Jack Burns, Damon Bradley, Nat Gopalswamy, Michael Reiner, Ed Wollack, David McGlone, Mike Choi, Scott Murphy, Rich Katz, Igor Kleyner.
- ROLSES instrument is a new build with heritage from STEREO/SWAVES & SMAP:
  - Four 2.5-m monopoles forming cross-dipole antennas.
  - Radio spectrometer with 2 bands: 10 kHz – 1 MHz and 300 kHz – 30 MHz.
- Scheduled to land on lunar nearside using *Intuitive Machines (IM-1) Nova-C.*

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Courtesy of Intuitive Machines

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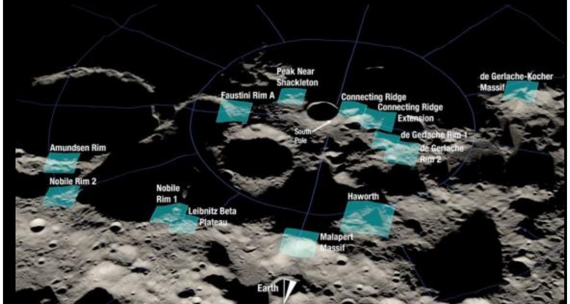
IM-1 LANDING SITE – THE MOON'S SOUTH POLE



Courtesy of NASA

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Courtesy of Intuitive Machines

ROLSES Science Goals

- Determine the electron sheath density from ~1 to ~3 m above the lunar surface by measuring electron plasma frequency.
- Demonstrate detection of solar, planetary, & other radio emission from lunar surface.
- Measure Galactic spectrum at <30 MHz.
- Aid development of lunar radio arrays.
- Measure the local EM environment, including that from the lander.
- Measure reflection of incoming radio emission from lunar surface and below.

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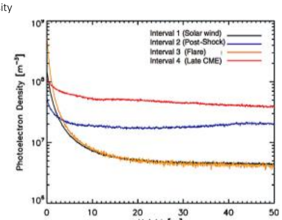
Lunar surface electron sheath

- ROLSES will determine the plasma sheath density from 0 to ~3 m above the lunar surface.
- This is of scientific value and is also important to determine the effect on the antenna response of larger lunar radio observatories with antennas on the lunar surface.
- The photoelectron density as a function of height above the lunar surface is indicated in the plot at right from the simulation code by Poppe and Horanyi [2010] for various solar wind environments. At 1 m height in typical solar wind, density shown as 5 x 10^7 m^{-3} which corresponds to a plasma electron frequency (f_{pe}) ~ 64 kHz.



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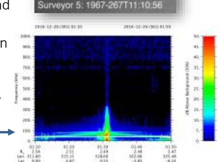
Interplanetary/Interstellar Dust Impacts

- Spacecraft in the interplanetary environment or orbiting planets may be struck by dust particles, which releases electrons and ions from the surface, affects the surface photoelectron environment, and creates signals that are detectable.
- Surveyor 5 observed a "horizon glow" on the Moon that some believe is produced by scattered light from electrostatically-elevated dust.
- The plot at right shows the dust signal detected by the Cassini spacecraft when crossing the Saturn F-ring.
- ROLSES might detect dust impacting the NOVA-C lander in a similar way. The time resolution of 5 seconds does not permit detecting individual dust particles but could detect dust "clouds".



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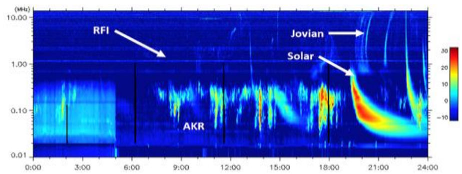
Demonstrate detection of solar, planetary, and other radio emission from lunar surface



The WAVES instrument on the Wind spacecraft at Solar-Earth L1 shows solar radio bursts, Earth's auroral radio bursts, terrestrial ground-based transmitters, and Jovian radio emissions, during the 24 hr interval of 2/20/2012. ROLSES could do the same.

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ROLSES delivery to the Moon on Intuitive Machines-1 lander in Spring 2023

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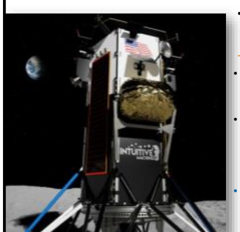
The Path Forward



Courtesy of Intuitive Machines

- NASA's CLPS program is a high risk/high reward program that could be a game-changer with regular access to the lunar surface 2-3 times per year.
- The first NASA radio science payload, ROLSES, is planned to land at the South Pole in Spring 2023. It will measure the electron plasma sheath near the surface, the Galaxy spectrum at <30 MHz, and the EM interaction with the dielectric lunar subsurface.
- ROLSES is a pathfinder for LuSEE-Lite & LuSEE-Nite. Plasma, dust, subsurface, and Galaxy measurements will prepare the way for nighttime observations of the radio band corresponding to the early Universe's Dark Ages.
- These CLPS radio science missions will prepare the way for a future array of low frequency radio antennas on the lunar surface.

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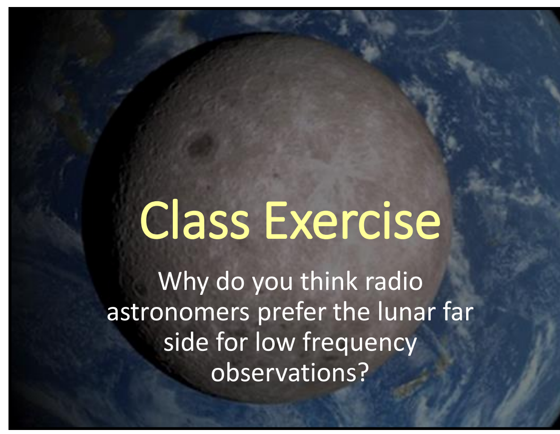

Class Exercise

Why do you think radio astronomers prefer the lunar far side for low frequency observations?

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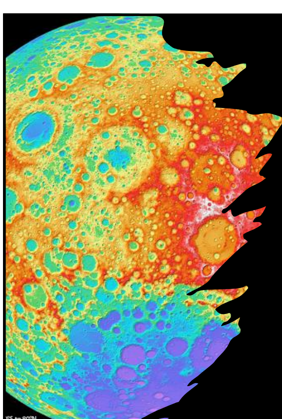

NASA's Commercial Lunar Payload Services (CLPS) provides regular access to the Moon (2 landers/yr) and, thus an unparalleled opportunity to perform low radio frequency cosmology due to the lunar farside's

- unique radio-quiet,
- lack of a significant ionosphere,
- dry, stable environment.

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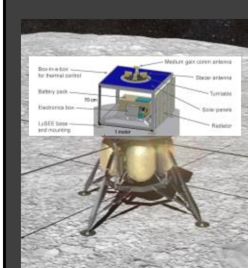

The Lunar Surface Electromagnetics Experiment (LuSEE)

Stuart D. Bale (PI), Keith Goetz, Peter Harvey, John Bonnell, Jack Burns, Thierry Dudok de Wit, Bob MacDowall, David Malaspina, Marc Pulupa, Anze Slosar, Aritoki Suzuki + a big LuSEE science team

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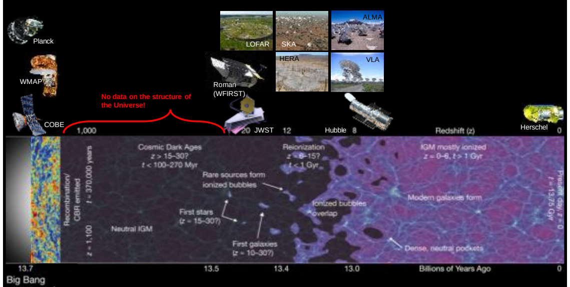
Evolution of the Universe



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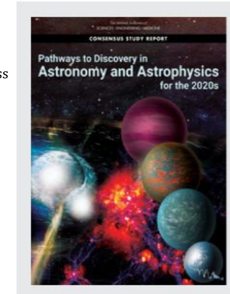
"Dark Ages" identified as THE Discovery area in Cosmology by Decadal Survey

- "Finding innovative ways to probe cosmology in the "dark ages" prior to any significant star formation…the nature and origin of its key ingredients—dark matter, dark energy, and a nearly scale-invariant spectrum of primeval mass fluctuations—remain some of the biggest mysteries in science."
- "The [cosmology] panel sees 21 cm 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."
- "Needed capabilities include next-generation 21 cm interferometers. Progress will require both higher sensitivity and a better understanding of instrumental systematics and astrophysical couplings."



Astronomy 4800 – Space Science: Practice & Policy

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FARSIDE: Farside Array for Radio Science Investigations of the Dark ages and Exoplanets

Principal Investigator: Jack Burns, University of Colorado Boulder
Deputy P.I.: Gregg Hallinan, Caltech
Design Lead: Lawrence Teitelbaum, JPL

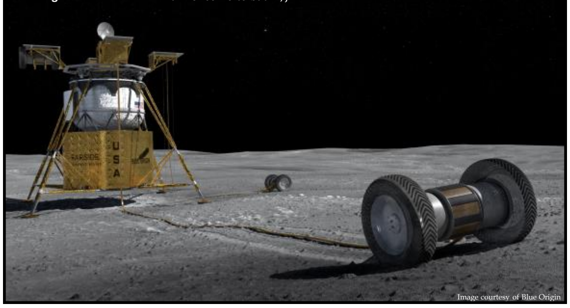

Image courtesy of Blue Origin

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FARSIDE Mission Architecture

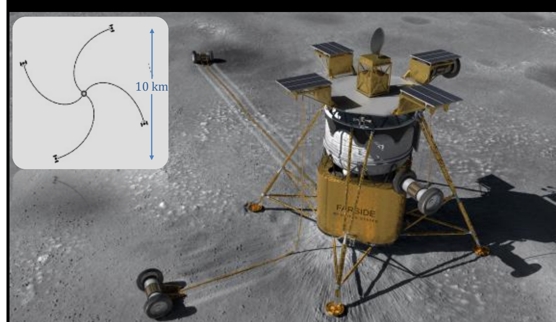

Image courtesy of Blue Origin

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100,000 Dipole Antenna Radio Array

FarView - An In-Situ Manufactured Lunar Far Side Radio Observatory

Ronald S Polidan, PI
Alex Ignatiev, Elliot Carol
Lunar Resources, Inc.
Jack O Burns
University of Colorado

Phase I study funded by NASA Innovative Advanced Concepts (NIAC)

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FarView - An In-Situ Manufactured Lunar Far Side Radio Observatory

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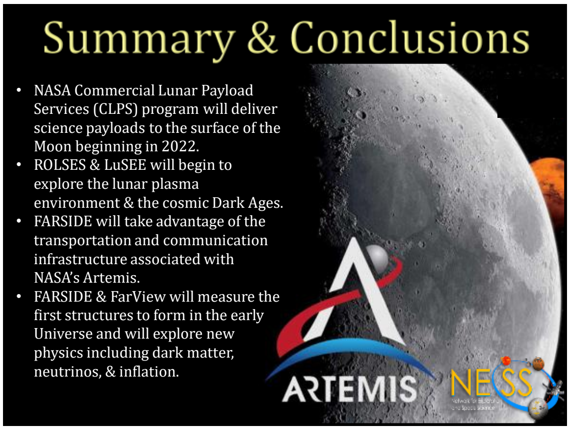
Summary & Conclusions
• NASA Commercial Lunar Payload Services (CLPS) program will deliver science payloads to the surface of the Moon beginning in 2022.
• ROLSES & LuSEE will begin to explore the lunar plasma environment & the cosmic Dark Ages.
• FARSIDE will take advantage of the transportation and communication infrastructure associated with NASA's Artemis.
• FARSIDE & FarView will measure the first structures to form in the early Universe and will explore new physics including dark matter, neutrinos, & inflation.
ARTEMIS
NESS

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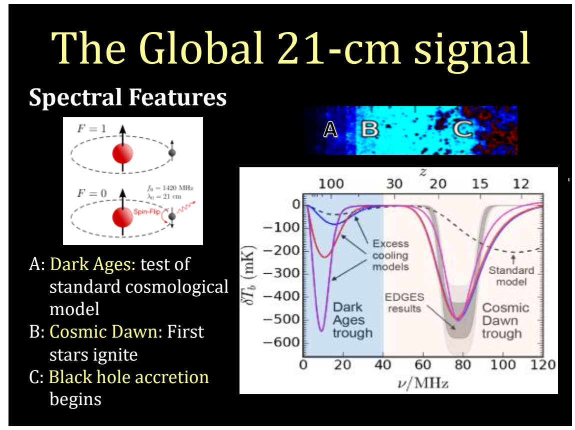
The Global 21-cm signal
Spectral Features
F = 1
F = 0
Spin-Flip
A B C
A: Dark Ages: test of standard cosmological model
B: Cosmic Dawn: First stars ignite
C: Black hole accretion begins
z
100 30 20 15 12
0 −100 −200 −300 −400 −500 −600
δT_b (mK)
Excess cooling models
Standard model
EDGES results
Dark Ages trough
Cosmic Dawn trough
0 20 40 60 80 100 120
ν/MHz

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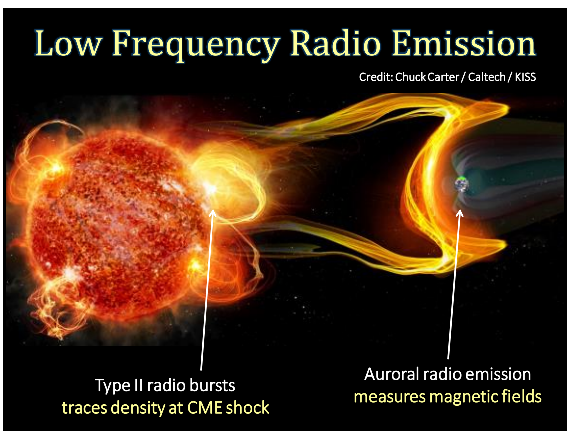
Low Frequency Radio Emission
Credit: Chuck Carter / Caltech / KISS
Type II radio bursts
traces density at CME shock
Auroral radio emission
measures magnetic fields

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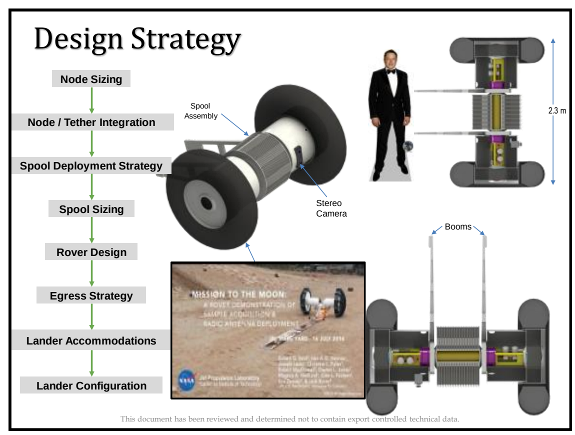
Design Strategy
Node Sizing
Node / Tether Integration
Spool Deployment Strategy
Spool Sizing
Rover Design
Egress Strategy
Lander Accommodations
Lander Configuration
Spool Assembly
Stereo Camera
Booms
2.3 m
MISSION TO THE MOON:
This document has been reviewed and determined not to contain export controlled technical data.

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