LOW-FREQUENCY RADIO OBSERVATORY PATHFINDER ON THE NEAR-SIDE LUNAR SURFACE

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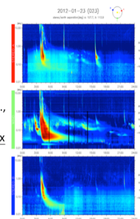
Network for Exploration and Space Science

Introduction

- A radio observatory on the lunar surface will use aperture synthesis to image solar radio bursts and other sources. Radio burst imaging will improve understanding of radio burst mechanisms, particle acceleration, and space weather, compared to the single spacecraft observations made to date.
- Low-frequency precision observations (less than ~20 MHz) must be made from space, because lower frequencies are blocked by Earth's ionosphere.
- Solar radio observations do not mandate an observatory on the farside of the Moon, although such a location would permit study of less intense solar bursts because the Moon occults the terrestrial radio frequency interference.
- This Low-frequency Radio Observatory on the Lunar Surface (L-ROLS) on the near-side for solar and terrestrial burst observations, should be designed to serve as a PATHFINDER for the larger, astrophysics radio observatory to be located on the far-side of the Moon.

Science goals

- The overall goal is to provide imaging of solar radio bursts as a function of frequency and time (and terrestrial magnetospheric radio emission gaps) that has never been done at low frequencies less than ~ 20 MHz.
- Where do solar radio bursts indicate that type II burst electrons are accelerated, e.g., what shock geometry?
- What are the sources of unusually complex type III radio bursts that are associated with solar energetic particle (SEP) events?
- How can we use the detailed information from solar radio burst imaging to improve diagnostic indications of energetic particles/space weather at 1 AU?
- What other new discoveries will we make with the first imaging of low-frequency solar radio bursts?



Above figure shows a type III burst, followed by a type II burst, as seen by STEREO-A, Wind, and STEREO-B (intensity as a function of time and frequency)

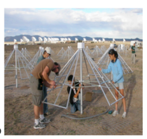
Traceability matrix

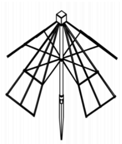
Science Traceability Matrix			
Decadal Science Goals	Science Objectives	Science Measurements	Instrument requirements
1) How do the heliosphere and planetary space environments respond to solar variability?	1) Where do solar radio bursts indicate that type II burst electrons are accelerated? 2) What are the sources of unusually complex type III radio bursts?	1) Image solar radio bursts with angular resolution < 2 degrees 2) Cover the freq. range 100 kHz-10 MHz 3) Obtain images every 10 sec or less 4) Continue observations for >1 yr during solar maximum	1) Aperture synthesis radio array on lunar surface 2) Radio receivers, timing system, etc., to provide data for synthesis 3) Hardware that is radiation and thermally tolerant to survive the lunar environment 4) Deployer for chosen antenna design
2) What are the impacts on humanity?	3) How can we use the detailed information from solar radio burst imaging to improve their diagnostic indications of energetic particles/space weather at 1 AU?		

Hardware list

- The components of the lunar radio observatory array are:
  - the antenna system consisting of 20 – 100 antennas distributed over a square kilometer or more; the number will depend partially on the lander and deployer used
  - the system to transfer the radio signals from the antennas to the central processing unit; electronics to digitize the signals and possibly to calculate correlations
  - storage for the data until it is down-linked to Earth. Such transmission requires a high-gain antenna system or possibly laser comm. For observatories on the lunar farside a satellite or other intermediate relay system is required to direct the signal to Earth.
  - On the ground, the aperture synthesis analysis is completed to display the radio images as a function of time and frequency.
- Other requirements for lunar surface systems include the power supply, utilizing solar arrays with batteries to maintain the system at adequate thermal levels during the lunar night. An alternative would be a radioisotope thermoelectric generator (RTG) potentially requiring less mass and volume.

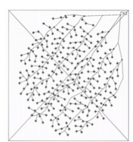
Antennas



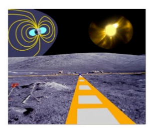


- To serve a key role as the lunar astrophysics observatory pathfinder, L-ROLS should use the same antennas and deployment as the far-side astrophysics array.
- It would seem that crossed dipole antennas like those used by the Long Wavelength Array (LWA) terrestrial observatories (San Augustin, New Mexico & Owens Valley, California) would be an ideal design.
- The antenna shown a right could easily be folded to a minimum volume and spring-loaded to self-deploy; a low mass design is being developed.
- The design must be tested for compatibility with deployment by the mission's rover.

Data transfer to processing center

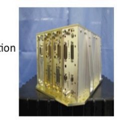


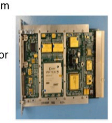
- The individual antennas might be designed with their own solar arrays and electronics to transmit data to the central processing unit via a wireless frequency, but surviving lunar night would be a challenge. Harnesses for power and data transfer from the antennas to the central processing unit are an alternative (like LWA at right), but a harness-based system complicates deployment.



- The concept of depositing the antennas and harnesses on rolls of polyimide and rolling them out may be a solution for solar radio observations, but it probably does not provide a sufficiently-uniform beam for other science targets.

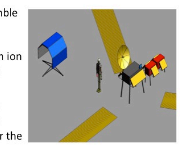
Central processing system

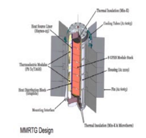




- The central processing system performs a number of functions:
  - Amplify and digitize radio signals as a function of frequency
  - Store these data with precise time tagging
  - Probably L-ROLS would use a correlator similar to the LWA
  - The GSFC Space Cube FPGA computing system with high TRL may be an option (shown at right).
- Correlator – we are considering using a correlator similar to the Owens Valley LWA correlator that performs full cross-correlation of 512 signal paths.
- The central processing system also controls the communication systems and transmits the data to Earth.

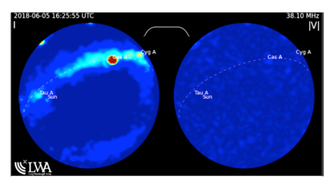
Power system





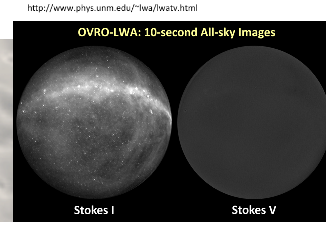
- The generic power system would resemble that of the GSFC study for the Radio Observatory for Lunar Sortie Science (ROLSS) – solar arrays (blue) and lithium ion batteries (red boxes) being the primary components.
- The problem with such a system is that battery mass to maintain temperatures during lunar night that are adequate for the electronics is very heavy ~ 150 kg.
- If available, a radioisotope thermoelectric generator, like that used by the Mars Science Laboratory, would provide uniform power during lunar day and night, with a lower mass. Its Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) provides 120 watts and weighs 45 kg.

Aperture synthesis example – LWA TV

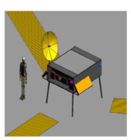


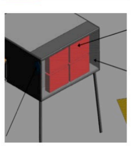
These movies show the sky above the first LWA station. Each image shows the full sky. Depending on the operating mode, there may be one or 2 images – the left shows total intensity, the right shows the intensity of circularly polarized waves.

http://www.phys.unm.edu/~lwa/lwatv.html



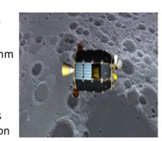
Thermal system

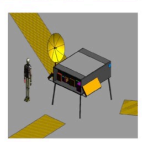




- The temperature variation from lunar day (~ 127 C.) to lunar night (~ -173 C.) near the lunar equator, with day and night each ~ 13.5 days long represents a major problem for lunar mission electronics.
- We are considering using the thermal system proposed by the GSFC study for ROLSS, as shown at the right – it uses louvers to help reduce heat build up and heaters driven by lithium ion batteries to maintain a temperature adequate for the electronics.
- If the MMRTG were available, it would replace almost all of the batteries.

Communication system





- To facilitate a high rate of data transfer with limited power utilization, we are investigating use of an optical laser comm system. The LADEE lunar-orbiting spacecraft tested such a system, demonstrating a down-link rate of 622 Mbps, with 50% less mass and 25% less power required. NASA is now working on the LCRD follow-on mission, for use by future missions.
- This may be one area where the near-side observatory does not serve as a pathfinder, because it is likely that the far-side array will communicate with a communication relay system using X-band or Ka-band via a high-gain antenna (like ROLSS).

Summary

- A lunar near-side aperture-synthesis radio astronomy observatory will provide important data for several science goals related to solar phenomena and serve as a pathfinder for the larger, far-side astrophysics array.
- We are working on the electronic and mechanical design, laser comm, enhanced thermal and power systems.
- Laser comm would provide a faster down-link rate for the available power and mass.
- A Multi-mission RTG like that used for the Mars Science Laboratory "Curiosity" would save mass compared to a battery-based system and simplify aspects of the power system (in most ways).
- During the next solar maximum, we hope to broadcast L-ROLS TV, like the current LWA TV,

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