Radio Wavelength Observatories in the Exploration Architecture

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Radio Wavelength Observatories on the Moon

• Long history
  – Suggestions pre-date Apollo missions
  – Concept developed in the 1980s, 1990s
  – Attraction of the Moon
    • Shielding of Earth, and Sun, radio emissions on far side
    • No permanent ionosphere

• Compelling science today: EoR

(Furlanetto et al. 2004)
Lunar Sortie Science Outpost

- Presents an opportunity to develop experience for an EoR array
- **Concept studies for Lunar Sortie Science Opportunities**
  - Lunar exploration missions with surface durations of as much as 7 days
  - Instrument packages deployed on lunar surface by astronauts
- **Apollo Lunar Surface Experiments Package (ALSEP) as a model**
  - 100–150 kg
  - Central processing station connected to individual experiments via cables

Apollo 14 ALSEP central station
Radio Observatory for Lunar Sortie Science (ROLSS)

Long-wavelength interferometer on the Moon’s surface

- **Key science**
  - Particle acceleration
  - Lunar ionosphere
  - Pathfinder to larger (EoR) arrays

- **Technical description**
  30–300 m wavelength (1–10 MHz frequency)

- **Future?**
Key Science
Particle Acceleration

• Particles with super-thermal and relativistic velocities in a variety of environments
  – Sun and other dwarf stars;
  – Neutron stars and black holes; and
  – Quasars.

• How and where does particle acceleration occur?
  – *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*
  – *Connecting Quarks with the Cosmos*
Key Science
Particle Acceleration

• Key aspect of particle acceleration mechanism is the low energy population which provides the “seeds” from which the highest energy particles result.
  
  Low energy particles emit, and are best studied at, the longest wavelengths.

• Within the inner heliosphere (2–10 solar radii), intense electron beams produced.
  
  Particle energies can rival “the energies of some accelerated particles in the distant [quasars]”

• Sun is nearby.
  – Physics can be studied in great detail.
  – Technical requirements on ROLSS less demanding.
Key Science
Particle Acceleration

- **Shock acceleration**
  Quasi-perpendicular vs. quasi-parallel
- **Electron and ion acceleration**
- **CME interactions and solar energetic particle events**
- **Low energy electrons in cosmic accelerators**
  Low-energy electron cutoffs and low-energy “reservoirs”

![Cygnus A spectrum](chart.png)
Key Science
Lunar Ionosphere

- Luna spacecraft detected dense plasma layer.
  Reaching > 10 km above surface
- Apollo surface measurements show photoionized layer.
  Limited to 0.1 km (100 m)
- Apollo 15 and 16 subsatellite measurements suggest ionosphere
  Extending to 100 km

Luna plasma density measurements
Lunar Ionosphere

- Implied plasma (cutoff) frequencies have significant range:
  - 0.09–2 MHz
- Possible limit to performance of future radio observatories
- Any connection to electrostatic dust layer?
• Planetary magnetic field immersed in solar wind.
• Solar wind is high-speed plasma with embedded magnetic field.
• Pressure from solar wind impacts and deforms planetary magnetic field.

**Magnetosphere**

*Large* objects, e.g., Jovian magnetosphere is 5x diameter of full Moon
Science
Extrasolar Planets

- Jupiter (and other giant planets) produce intense radio emission below 40 MHz.
  - Earth below 1 MHz
- ~200 extrasolar giant planets known.
  - What will be the solar neighborhood census in 2020?
- Do they produce radio emission?
- Planetary magnetosphere may be important for habitability.
  - Of the solar system planets, only Jupiter can be detected from the ground.

(Lazio et al. 2004)
• 30–300 m wavelength (1–10 MHz frequency)
  – Relevant range for particle acceleration
  – Covers upper range for lunar ionosphere
  – Inaccessible from the ground
• 3-arm interferometer
  First imaging instrument at these wavelengths
• 500-m length arms (but 20 km mobility?)
  – 2° resolution (@ 30 m)
  – Order of magnitude improvement in resolution at these wavelengths
ROLSS Antennas

- Existing long-wavelength array antennas too massive and bulky for lunar deployment.
- Concept is to deposit metal onto a polyimide film
  - Antennas
  - Transmission lines
- Space-rated grades of polyimide film exist
  E.g., Dupont™ Kapton® XC
- ROLSS arms would be stored in rolls and unrolled for deployment.
• 3-arm interferometer
• 16 antennas per arm
• Transmission lines on polyimide film to central electronics package
• Receiver analog stage filters and digitizes signals
• Receiver digital stage performs further filtering and sub-banding
• Downlink to Earth for correlation and imaging
• Fairly standard imaging techniques will suffice.
ROLSS Concept Study

• Antenna
  – Construct and test a single antenna by depositing metal on a polyimide film.
  – Longer arms for higher angular resolution vs. mass, site topography, and astronaut involvement?
  – PF adhesion properties?
  – Countermeasures, should PF not lie flat?
    • low surface gravity
    • long duration storage
    • ASLEP experience
  – Electromagnetic interaction of the dipoles and transmission leads?
  – Acceptable PF thicknesses (1- vs. multi-layer)?
  – Electrical performance, flexibility, and mass of metals for deposition?
  – Optimum between transmission lead width (mass) and micrometer impacts?
• Receiver
  Refine design, indicating how volume and power requirements can be minimized.

• Downlink
  – Alternate downlink possibilities?
  – Availability and use of data relay satellites or combined lunar science infrastructure?
• Correlation and Imaging
  – Specific correlator architecture?
  – Optimum number of antennas per arm as a function of mass to be deposited and imaging performance?
  – Simulate baseline design imaging performance.
• Siting and Deployment
  – Possibility of and need for astronaut involvement in initial deployment and beyond?
  – Impact on crew safety?
  – Recommend deployment plans.
• Operations
  – Thermal loading during day-night transition?
  – Voltage induced along the arms?
  – Nighttime operations?
    • battery lifetime
    • power requirements
    • mass budget
  – Recommend power generation method.
  – Develop “operating modes.”
    heliophysical vs. astrophysical vs. lunar ionosphere
Precursor Missions?

- Understand lunar subsurface at site
  - Dipole pattern may be affected by subsurface structure (e.g., mascons)
- Lunar ionosphere
  - Ionosonde on surface
  - SELENE
- Radio frequency environment
  - Probably more an issue for longer wavelength instruments vs. EoR telescope

(60 kHz, Takahashi & Woan)
Future
Dark Ages Lunar Interferometer

• Obvious expansion routes for ROLSS
  – Increase number of antennas/arms
  – Increase length of arms
  – Expand wavelength range
  – Move to far side
• All are necessary for exploring the Dark Ages and the Epoch of Reionization
  Dark Ages Lunar Interferometer (DALI)
Radio Observatory for Lunar Sortie Science (ROLSS)

- Key science
  - Particle acceleration
  - Lunar ionosphere
  - *Pathfinder to larger (EoR)* arrays

- Technical description
  - 30–300 m wavelength (1–10 MHz frequency)
  - Antennas deposited on polyimide films.
  - Deploy by unrolling.