Lunar Riometry Proof-of-Concept Instrument Package

Joseph Lazio (JPL/CIT, NASA Lunar Science Institute)

Dayton Jones (JPL/CIT, NLSI), Robert MacDowall (NASA/GSFC, NLSI), Ken Stewart (NRL, NLSI), Jack Burns (Colorado, NLSI), W. M. Farrell (NASA/GSFC, NLSI), Justin Kasper (CfA, NLSI), Louis Giersch (JPL/CIT), Ian O'Dwyer (JPL/CIT), & Jake Hartman (NPP)

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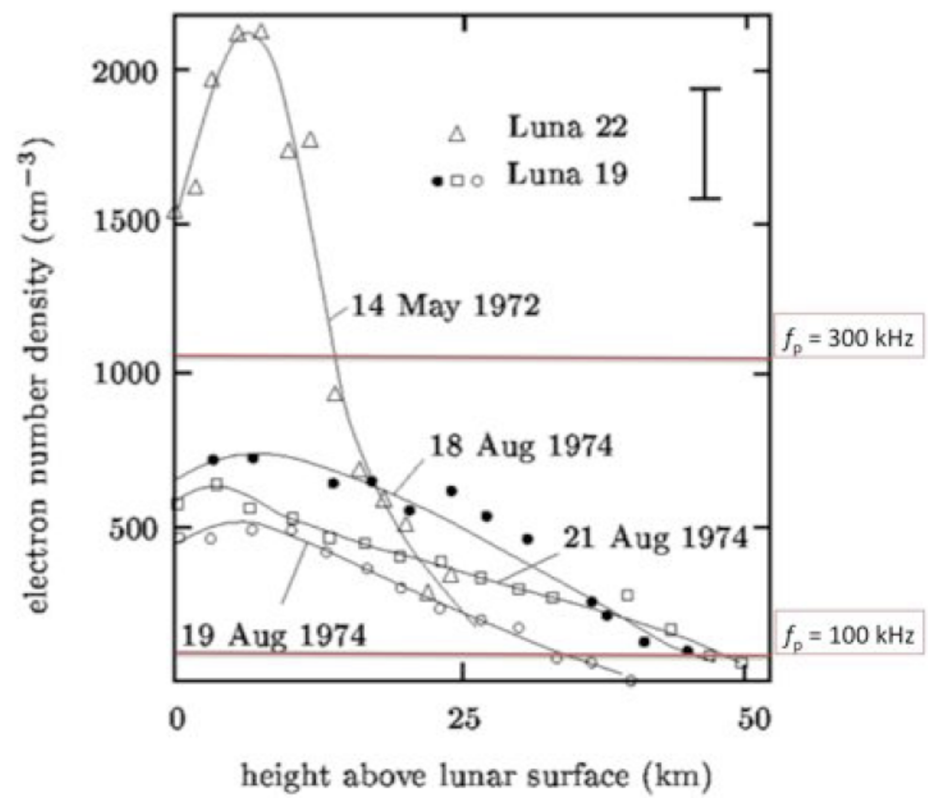
Lunar Ionosphere

- Existing measurements suggest highly variable exosphere, both in density and altitude
  - 10^3 to 10^4 cm^{-3}
  - Up 10 km
- Spacecraft based measurements subject to (well-known) systematic errors
  - Need to correct for *much* larger terrestrial contribution
  - Short duration

  SMART-1, *Cassini*, Venus Express, SELENE (KAGUYA)



Lunar exosphere densities derived from radio occultation measurements with the Luna 19 and Luna 22 spacecraft (Vyshlov 1976; Vyshlov & Savich 1978).

Scientific Context I

"Planetary exospheres [on] the Moon, Mercury, asteroids, and some of the satellites of the giant planets, are poorly understood …. Insight into how they form, evolve, and interact with the space environment would greatly benefit from comparisons … on a diversity of bodies."

Vision and Voyages for Planetary Science in the Decade 2013-2022

The Inner Planets: The Key to Understanding Earth-like Worlds (Chapter 5)

– **Science goal**: Understand the processes that control climate on Earth-like planets.
  - **Science objective**: Characterize the record of and mechanisms for climate evolution on Venus, with the goal of understanding climate change on terrestrial planets ….
    - – **Science question**: What are the critical processes involved in atmospheric escape of volatiles from the inner planets?
      - » Understanding volatile gas release, including the possibility that "**areas on the Moon have recently released gases**"
      - » Role of volatile gasses in driving pyroclastic eruptions, flows, and deposits on Mercury and the Moon

Satellites: Active Worlds and Extreme Environments (Chapter 8)

– **Science goal**: What processes control the present-day behavior of these bodies?
  - **Science objective**: What processes control the chemistry and dynamics of satellite atmospheres?
    - – **Science question**: What are the relative roles of sublimation, molecular transport, sputtering and active venting in generating tenuous satellite atmospheres?

Scientific Context II

Scientific Context for the Exploration of the Moon

- Lunar Environment Theme: The surface of the Moon is accessible and special. The lunar atmosphere, though tenuous, is the nearest example of a surface boundary exosphere, the most common type of satellite atmosphere in the solar system.

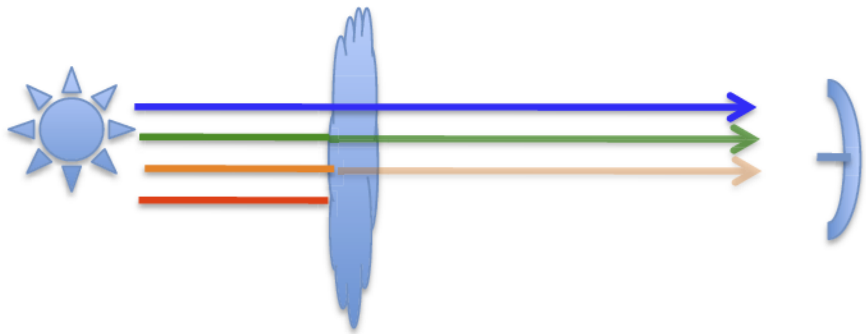
- Concept 8: Processes involved with the atmosphere and dust environment of the Moon are accessible for scientific study while the environment remains in a pristine state.
  - Science Goal 8a—Determine the global density, composition, and time variability of the fragile lunar atmosphere before it is perturbed by further human activity.

    The nearest example of a surface boundary exosphere (SBE) is the lunar atmosphere.

Relative Ionospheric Opacity Measurements (Riometry)

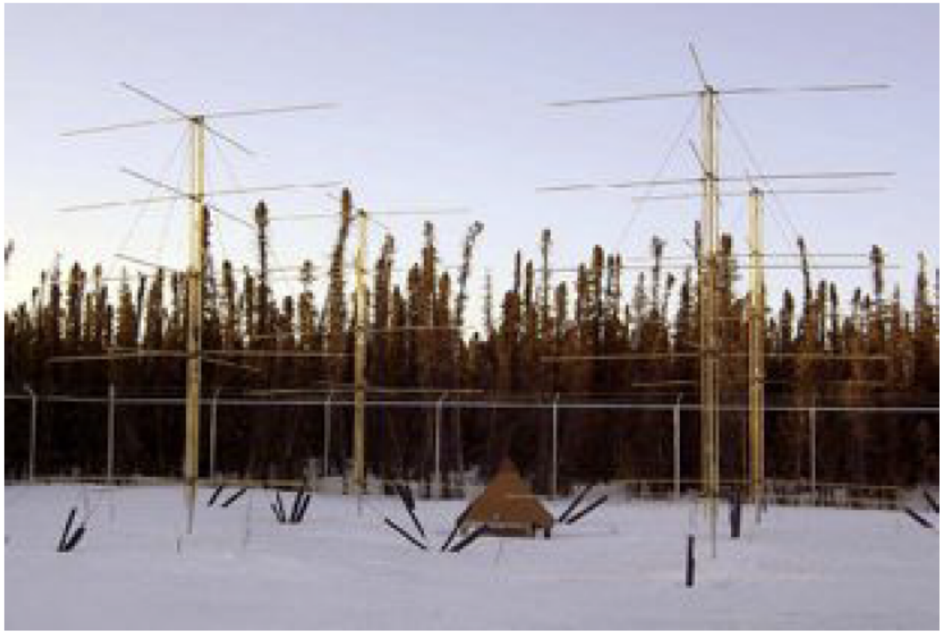
Physical principle: Electromagnetic waves below **plasma frequency** cannot propagate:

$$f_p = 9 \text{ kHz} \sqrt{n_e}$$



- Measure power of background emitter as a function of frequency
- Below a certain frequency, background emitter is absorbed

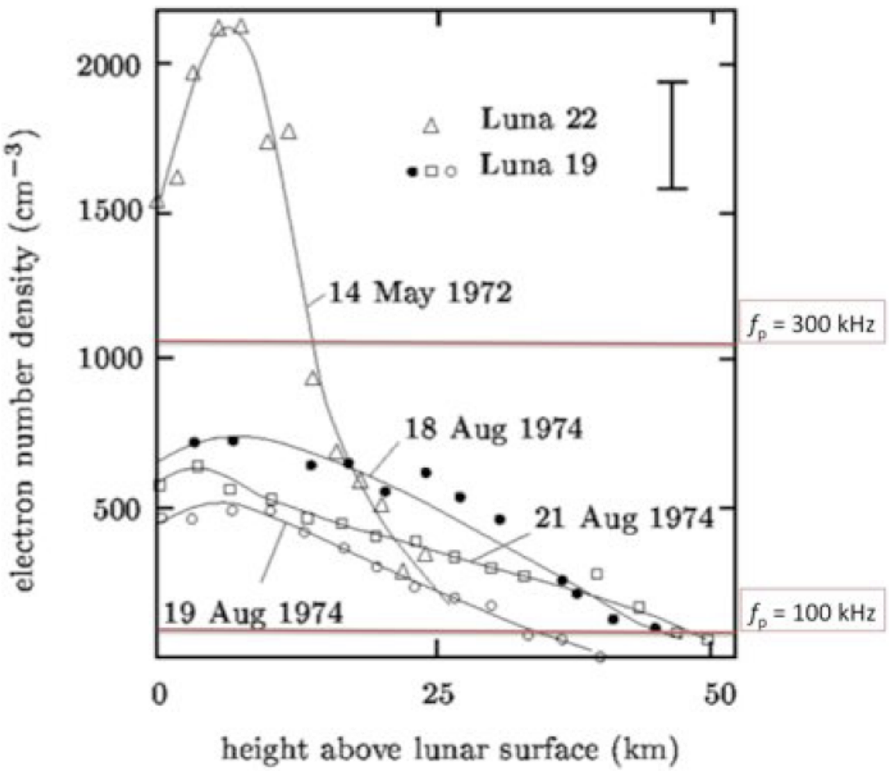
    Reason that metals are opaque



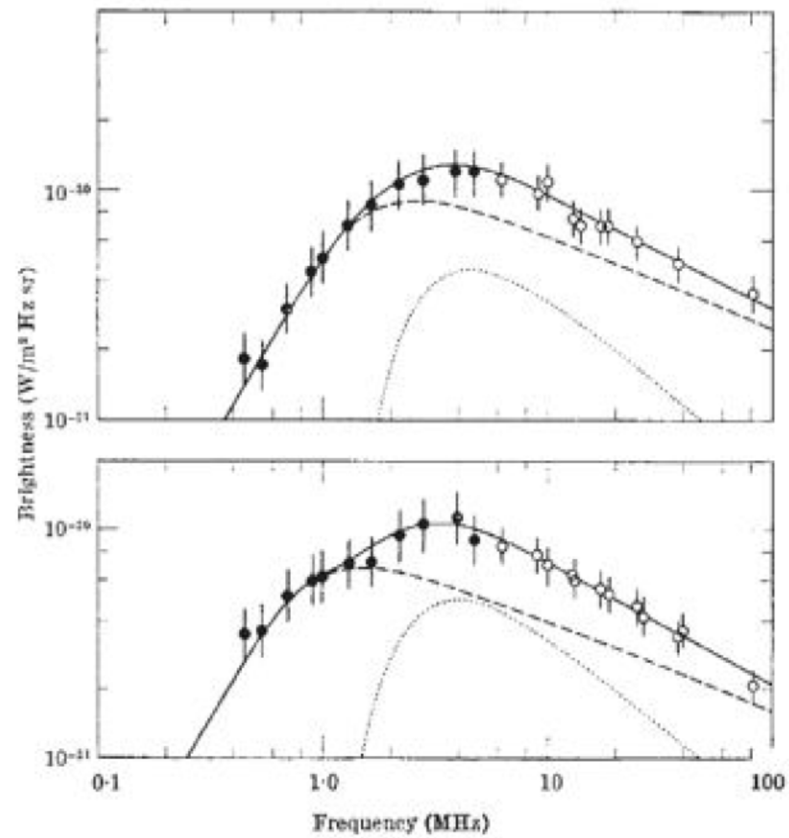
HAARP Riometer

- Standard procedure used in remote and hostile environments on Earth

Lunar Ionosphere

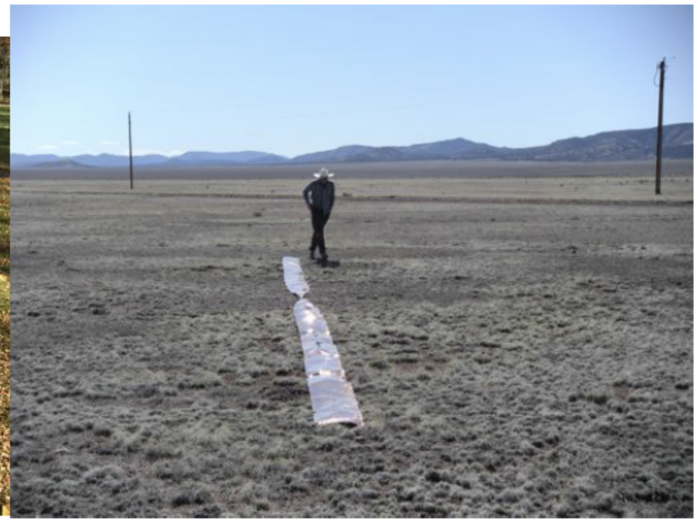


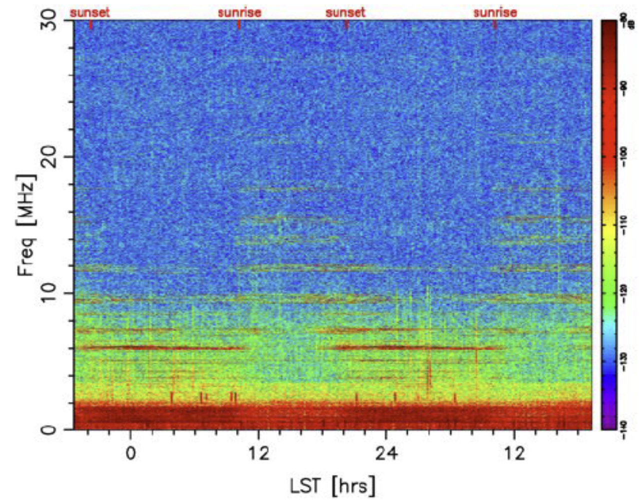
Lunar exosphere densities (Vyshlov 1976; Vyshlov & Savich 1978)---Horizontal lines show implied plasma frequencies



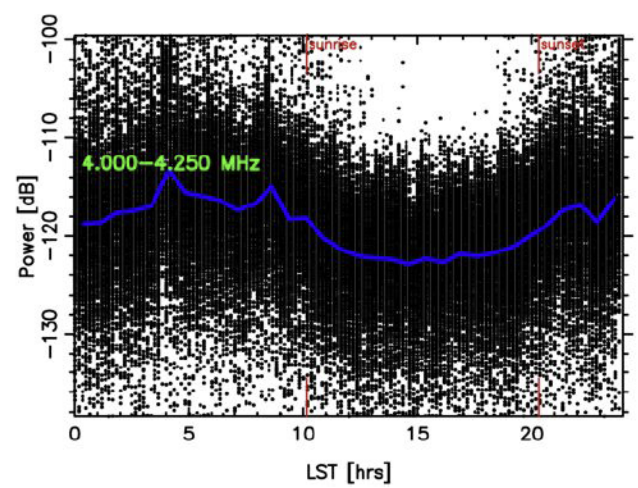
- Measurements suggest variable exosphere with densities ~ 10^3 to 10^4 cm^{-3}
- Implied plasma frequencies are 100--1000 kHz
  - ➢ Below Earth's ionosphere plasma frequency, *near side* deployment feasible
- Galaxy is background emitter

Surface Antenna Concept
Polyimide Film Antenna Field Tests





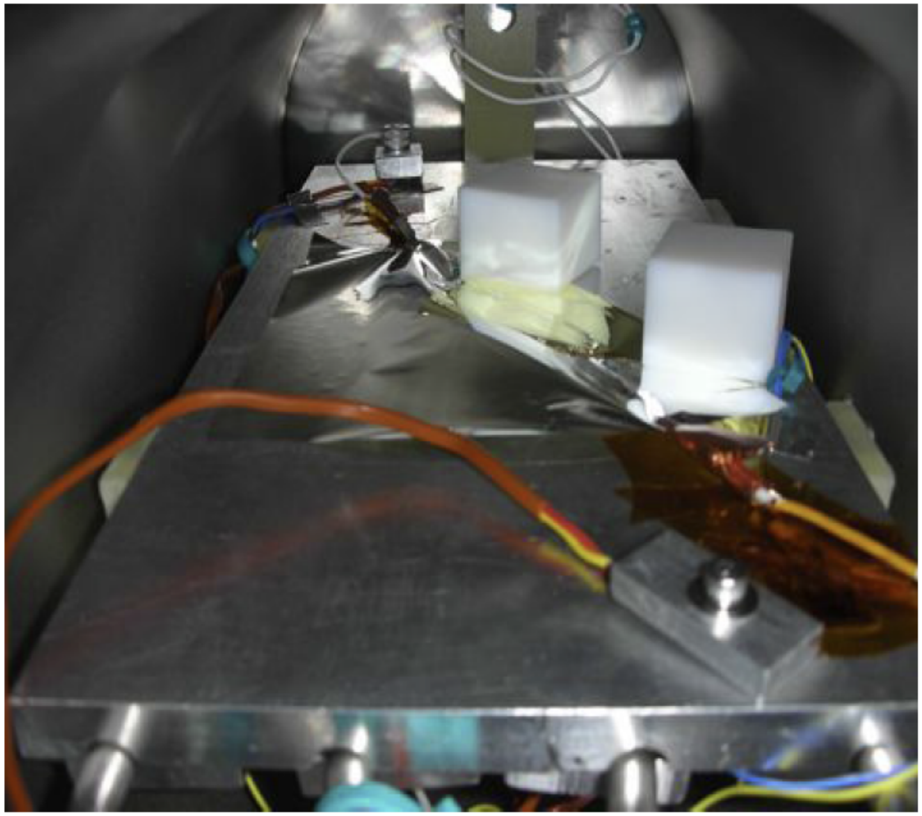
- 5 µm thick Cu layer deposited on 25 µm thick Kapton
- Dipole arm was 8 m long and 30.5 cm wide
- Inner 1 m of each arm tapered to a point at which a 1:1 wideband balun attached
- Good agreement with models (*not shown*)
- Spectrum recorded from 1–30 MHz every 10 min for just over 2 days
- Local noon occurred at LST ~ 15 hrs
- ➢ Decrease in power below 7 MHz is due to absorption by the D layer of the ionosphere



Antenna Testing

Lunar surface condition exposure

- Thermal-vac chamber constructed, with interior UV lamp
- Polyimide film exposed to UV light and temperature cycled to simulate lunar environment
- No degradation of polyimide film properties after 1 year equivalent of exposure

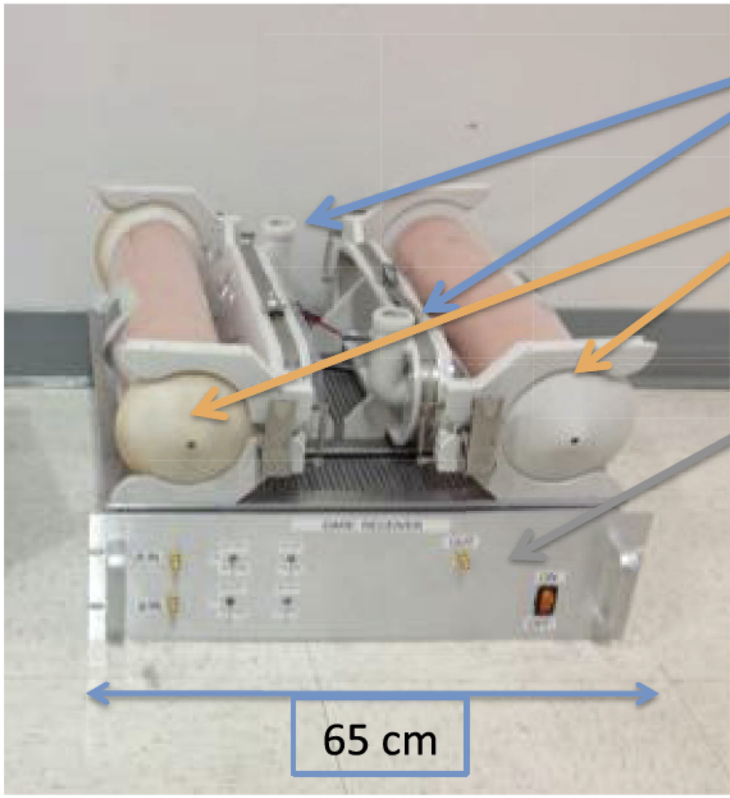


Deployment Tests

Start of test …

The challenge

Riometer Instrument Package



- Inflator attachments
- Polyimide film-based antennas (rolled)
- Antenna electronics box
- *(not shown)* power, command & data handling

Summary

- Lunar ionosphere/exosphere is accessible surface boundary layer
  - Measure of any continued out-gassing
  - Responds to solar wind
- Riometry is simple, well-understood technique for tracking ionosphere
- Instrument package definition progressing

Deployment on near *or* far side