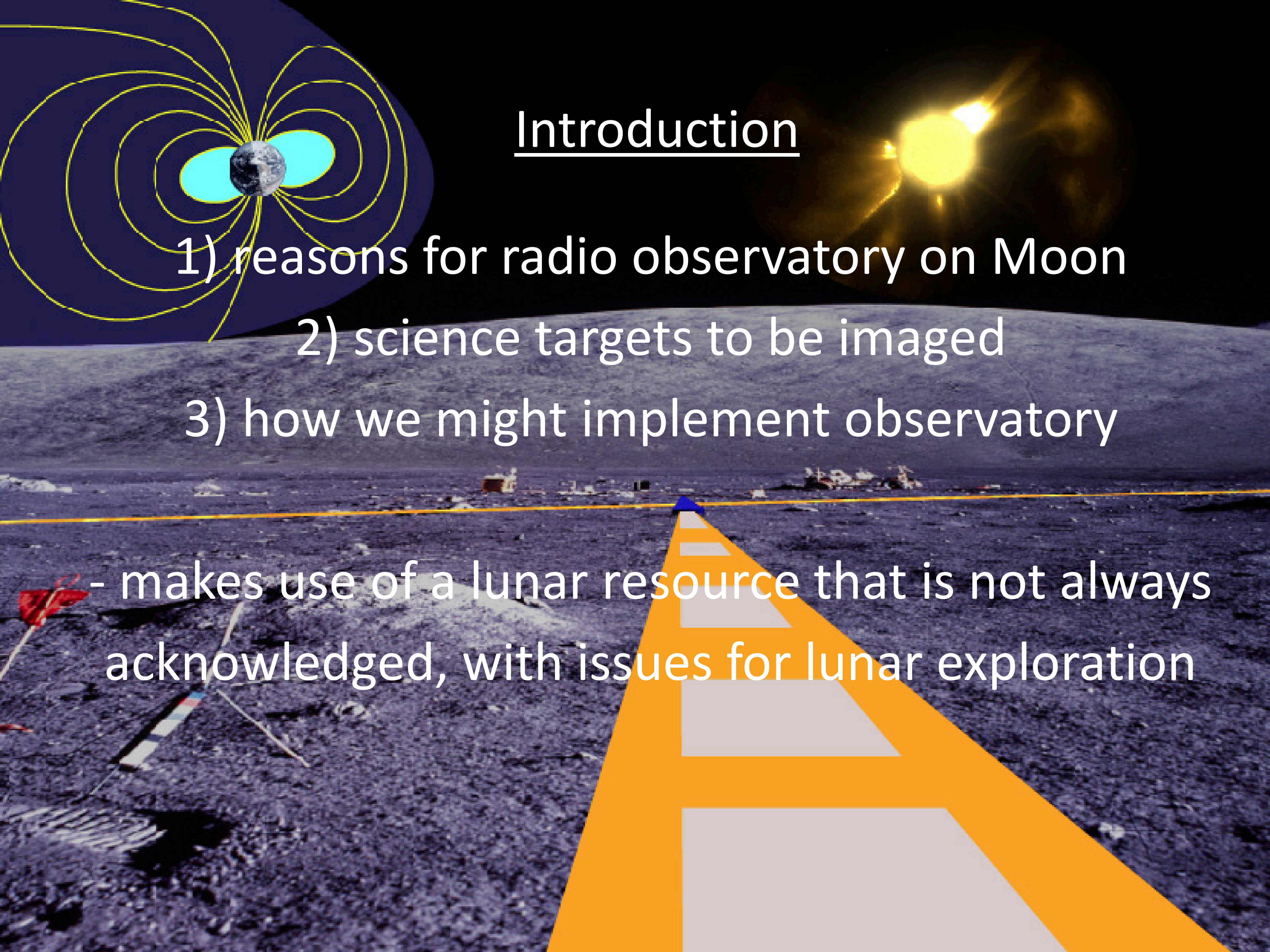
Low Frequency Radio Astronomy from the Lunar Surface

R. J. MacDowall (1), T. J. Lazio (2), J. Burns (3)

(1) NASA/GSFC, Greenbelt, MD, USA
(2) JPL/Caltech, Pasadena, CA, USA
(3) U. Colorado, Boulder, CO, USA



Introduction

1) reasons for radio observatory on Moon

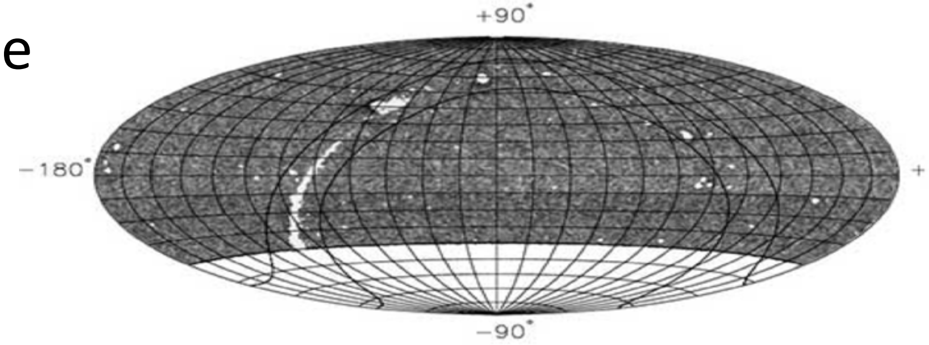
2) science targets to be imaged

3) how we might implement observatory

- makes use of a lunar resource that is not always acknowledged, with issues for lunar exploration

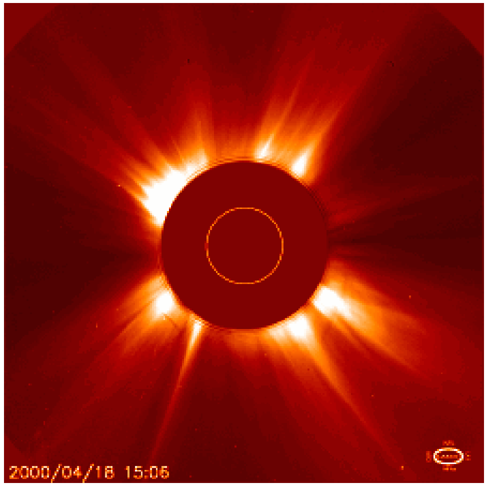
Radio astronomy observatories

- Significant radio astronomy from ground-based observatories - VLA, LOFAR, LWA, GMRT, etc.
- Mapping of radio sky and imaging of transients
- Longer wavelengths <30 MHz need larger aperture to image (kilometers) + need to be outside the ionosphere
- Lunar surface is a potential location with key advantages

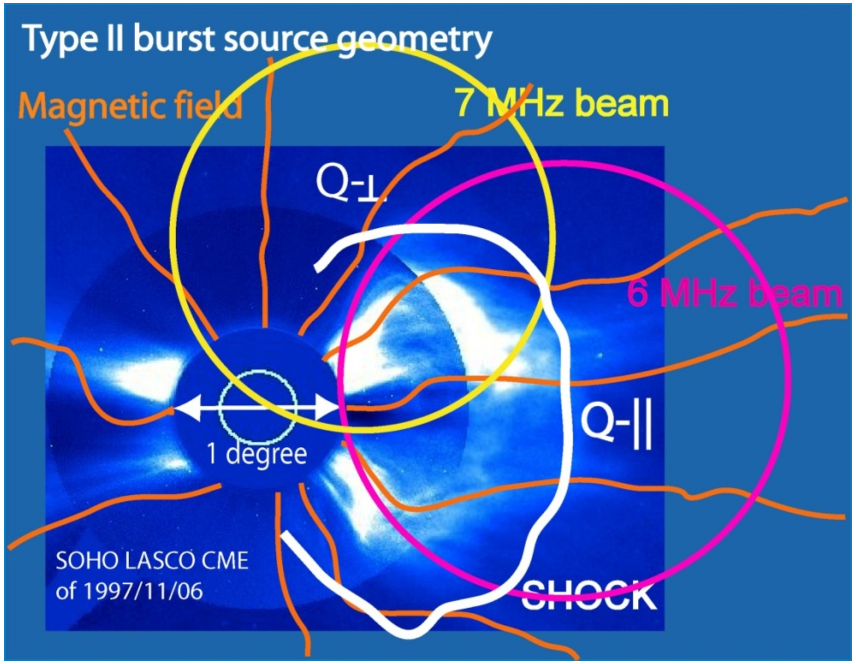


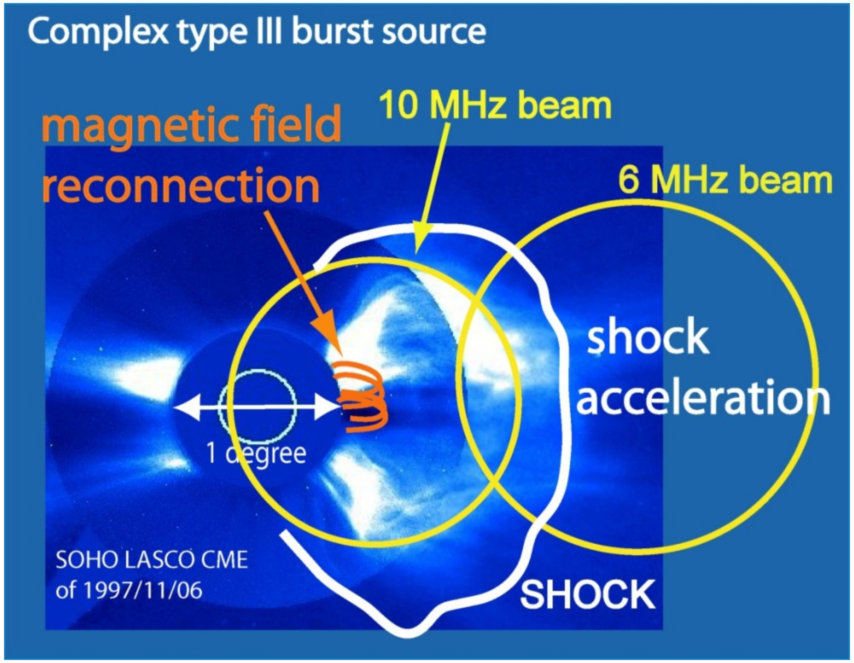
VLA sky map (Credit: MRAO/AUI/NSF)

Solar Radio Targets

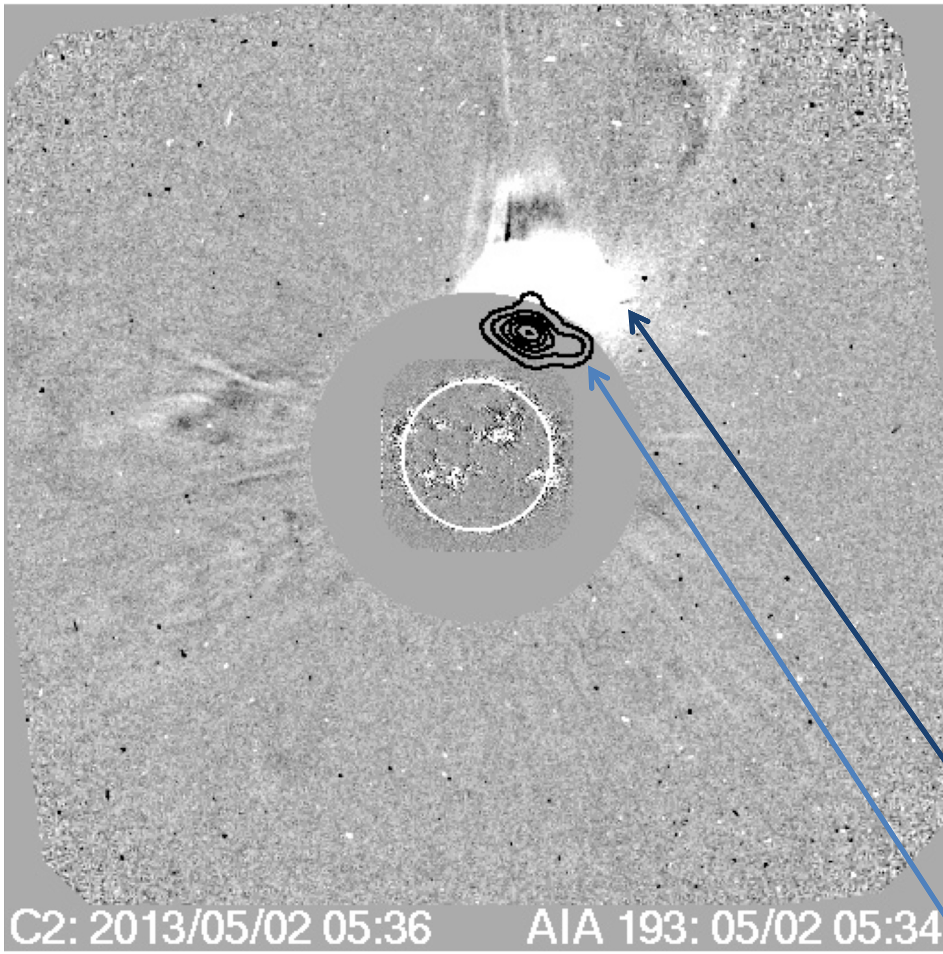


- CMEs and other solar activity produces radio bursts
- These bursts have never been imaged at <30 MHz
- Lunar radio observatory would address this issue
- Specific questions:
  - Where on shock does electron acceleration occur?
  - Does shock acceleration or reconnection cause Type III-Ls?
  - Does CME "cannibalism" produce enhanced Type II bursts and solar energetic particle (SEP) events?





CME Magnetic Fields and Evolution



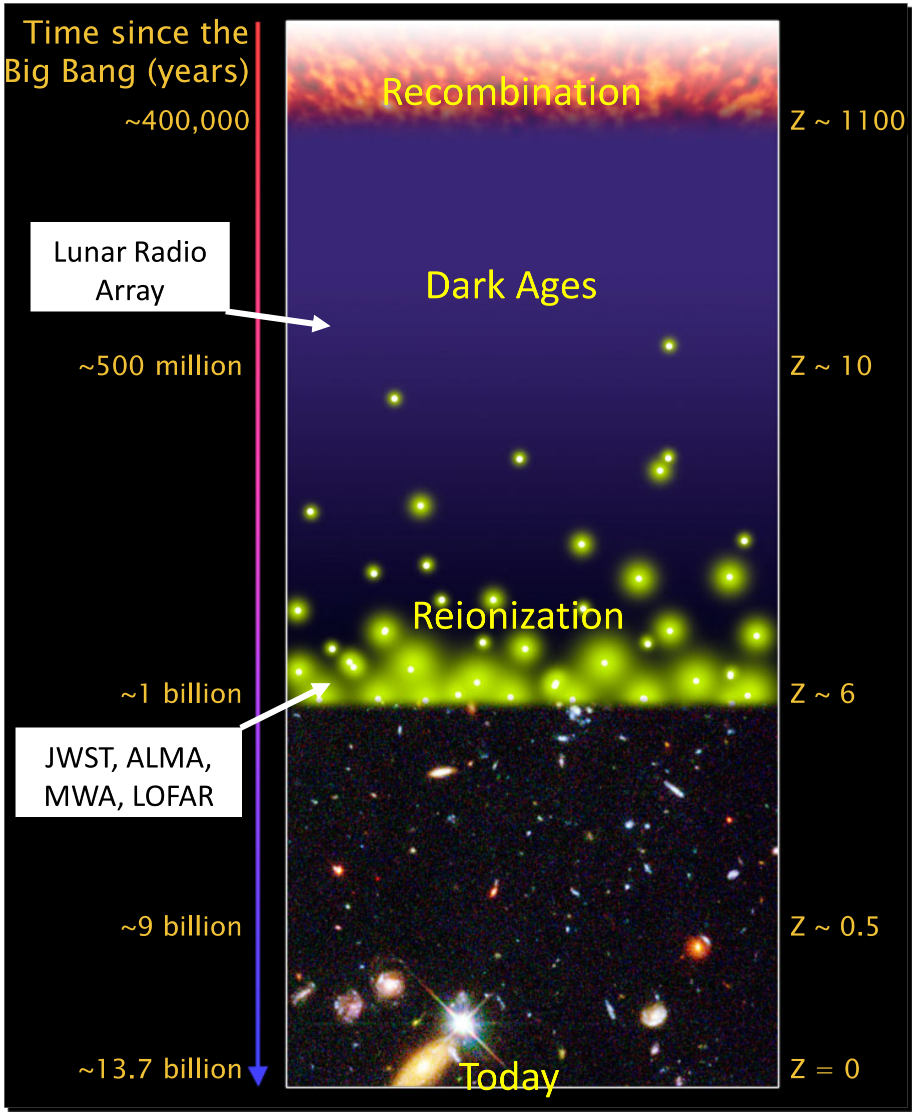
SDO-AIA 193 Å and SOHO-LASCO C2 images

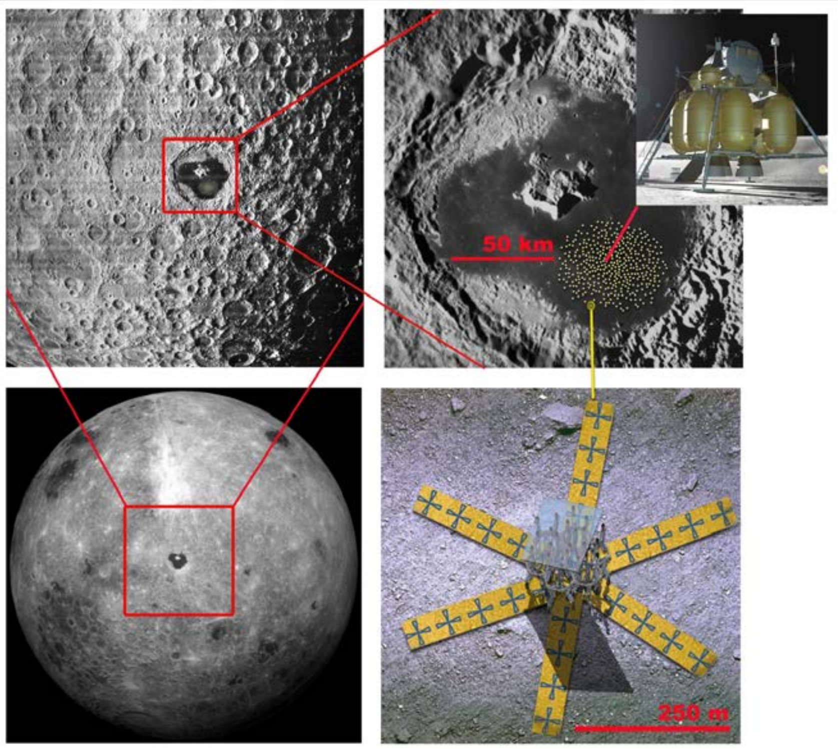
State-of-the-art can determine magnetic field strength, approximate location

- **Ground-based measurements limited to $r \sim 2\,R_\odot$**
- **Limited frequency range cannot track evolution, limits extent to which radio-optical images can be aligned/correlated**

(Hariharan et al. 2014)

Other low frequency radio targets





- Doppler shifted 21 cm emission from the Dark Ages is detectible from 20-200 MHz.
- Provides structure and evolution of Universe (in absorption of 21 cm emission)
- Requires low noise (far side of Moon) and high sensitivity (large array)

Magnetospheres of exoplanets

- Detection of exoplanet magnetospheres is typically oriented towards detection of magnetospheric radio emissions, similar to those of Earth, Jupiter, etc.
- Frequencies explored to date are those available from ground-based observatories. For example, see "Search for 150 MHz radio emission from extrasolar planets in the TIFR GMRT Sky Survey," Sirothia et al., A&A 562, A108 (2014)

150 MHz

A&A 562, A108 (2014)

1.4 GHz

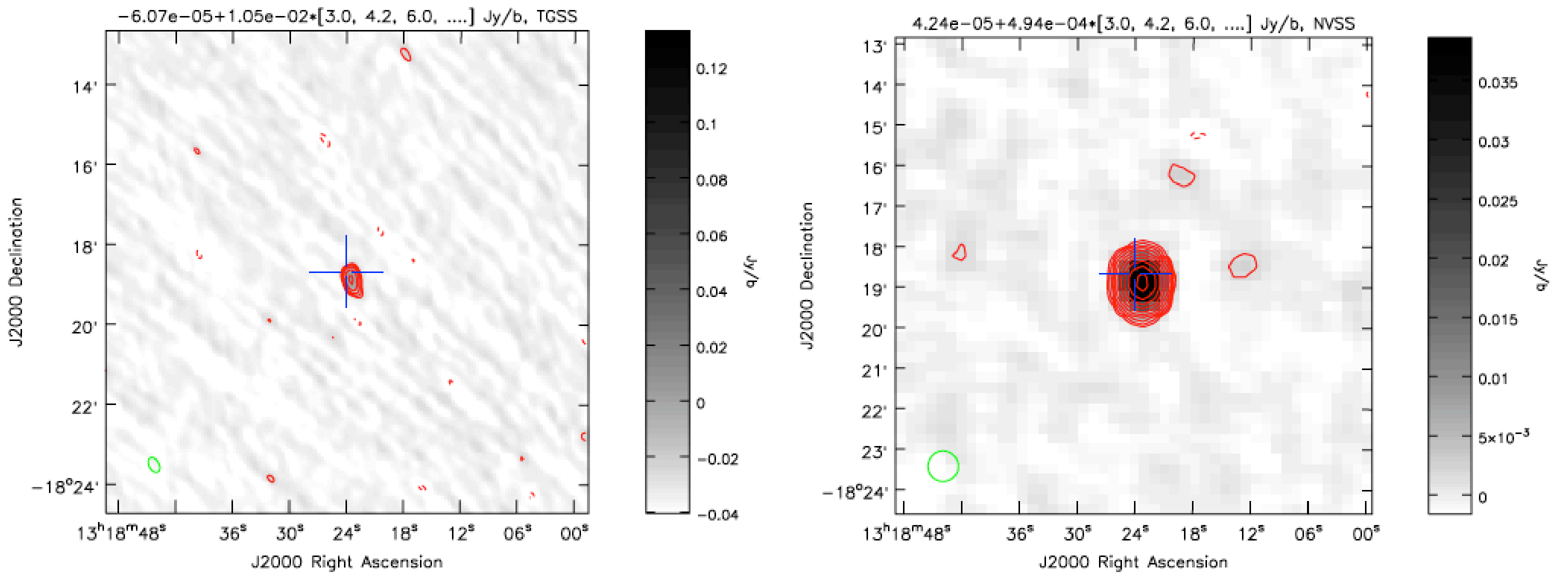
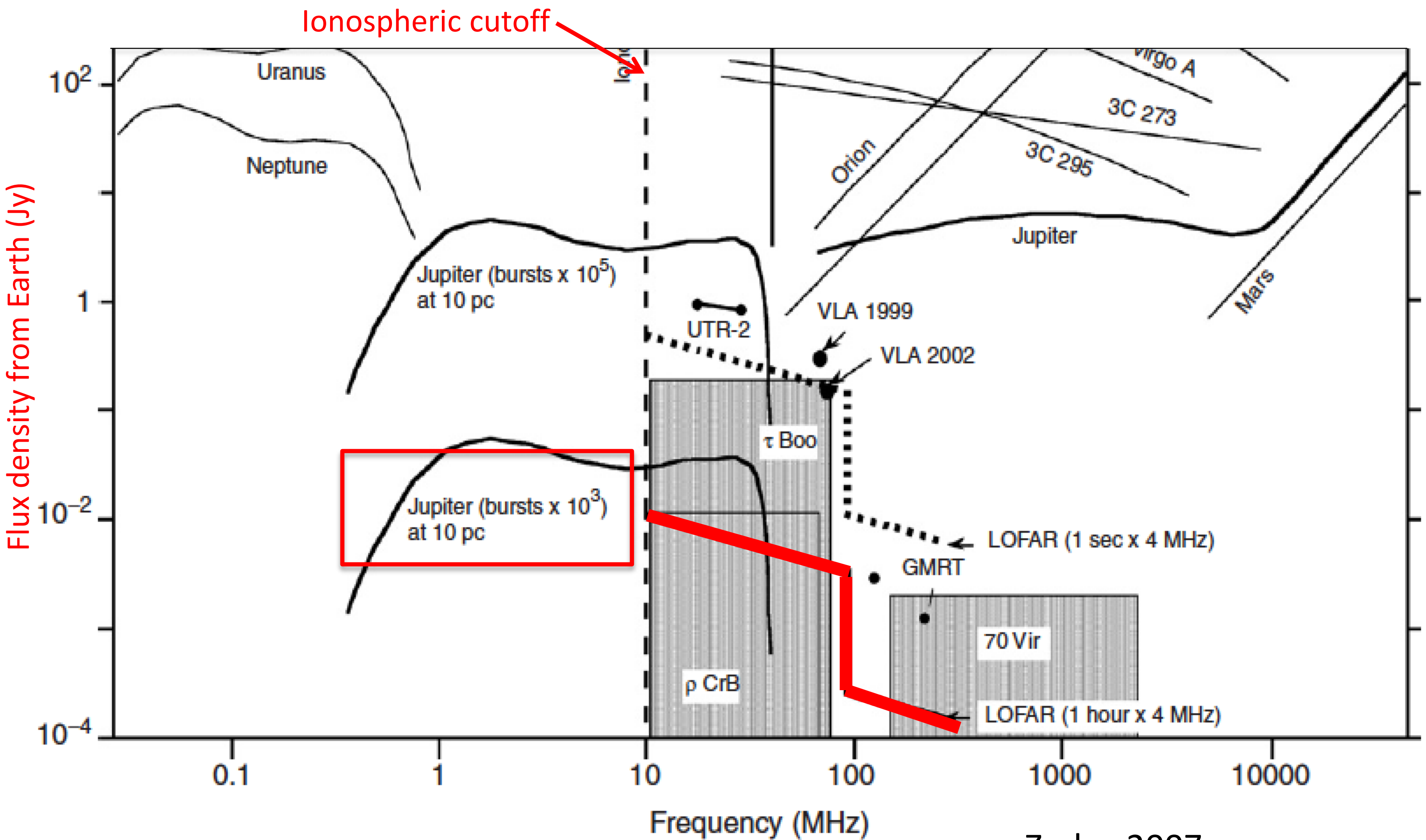


Fig. 9. TGSS (*left panel*) and NVSS images (*right panel*) of the 61 Vir field at 150 MHz and 1.4 GHz.

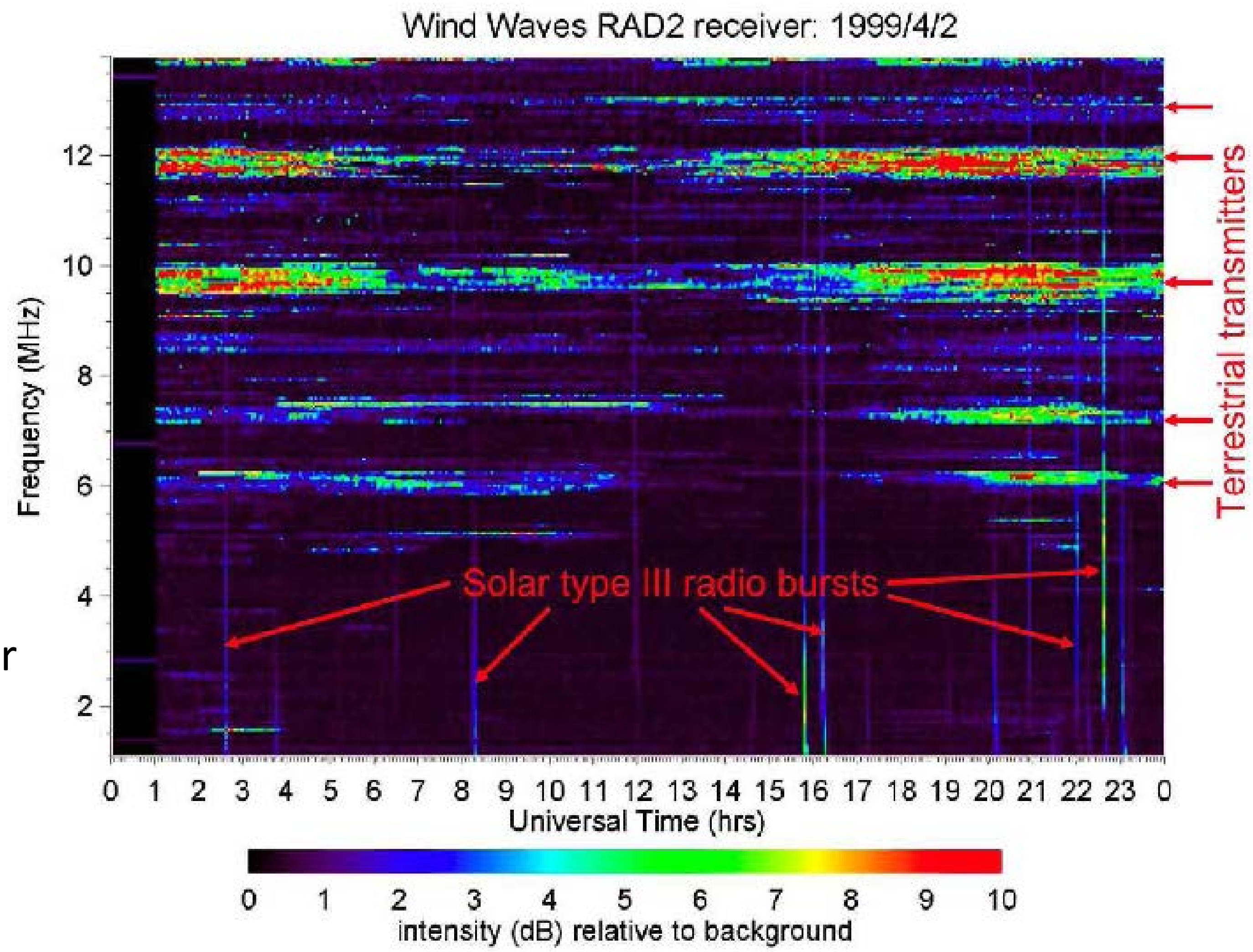
Exoplanet magnetosphere detection



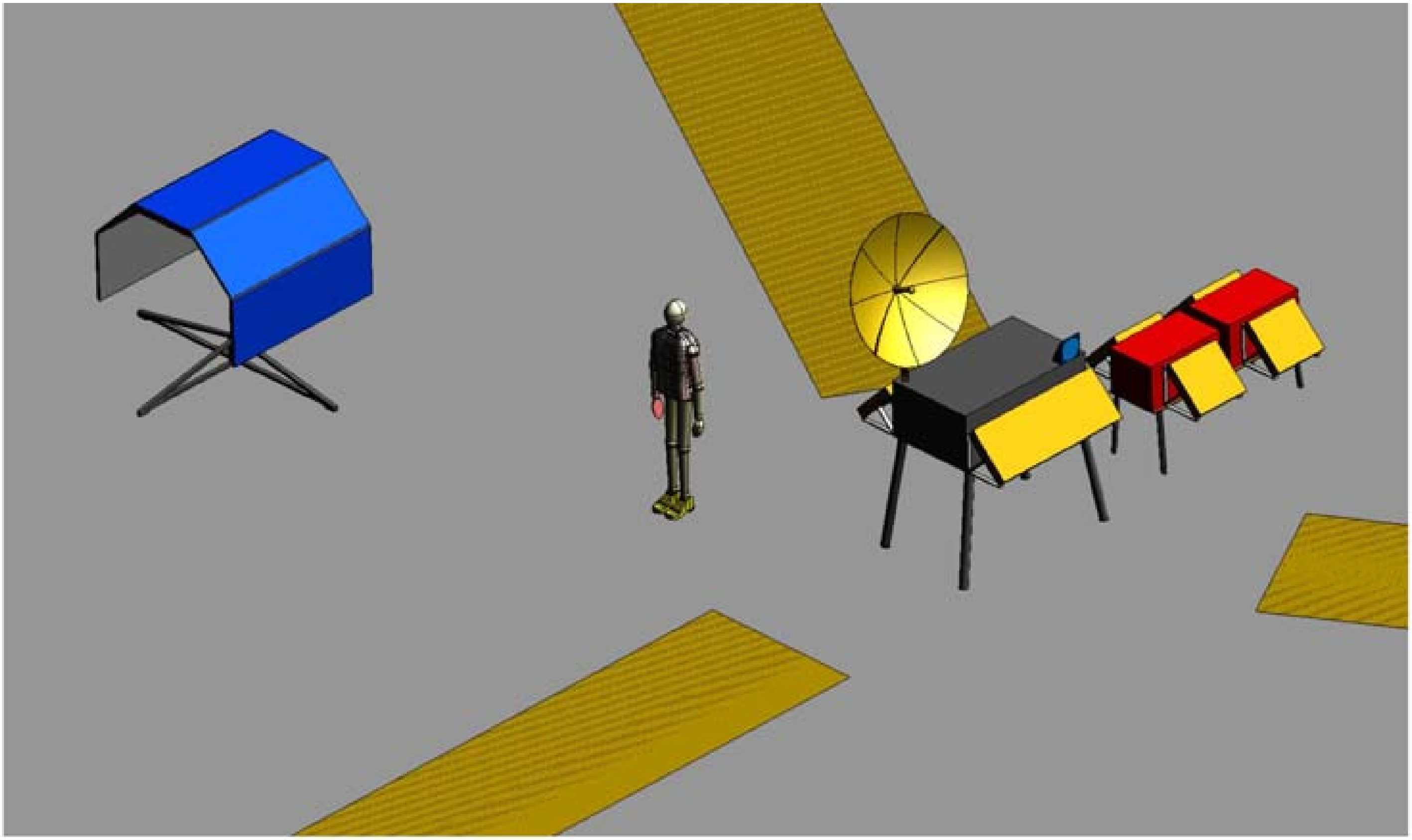
Zarka, 2007

Low frequency radio environment at moon

- Wind Waves RAD2 dynamic spectrum
- 24 hour interval from 1999/4/2 when Wind flew by the moon
- Moon on terrestrial nightside, as it would be for solar observations
- Note terrestrial transmissions & type IIIs



Early design lab - ROLSS



GSFC concept study components from the days of “lunar sortie science”: Segmented solar array, electronics boxes with thermal control, high gain antenna, S-band antenna, science antenna (to be connected to boxes by astronaut); now called Radio Observatory on Lunar Surface for Solar Studies (ROLSS)

Double-probe Instrumentation for Measuring Electric-fields (DIME)

A spinning CubeSat, like DIME, would permit deployment of much longer antennas. Investigation of the maximum stable length is required.

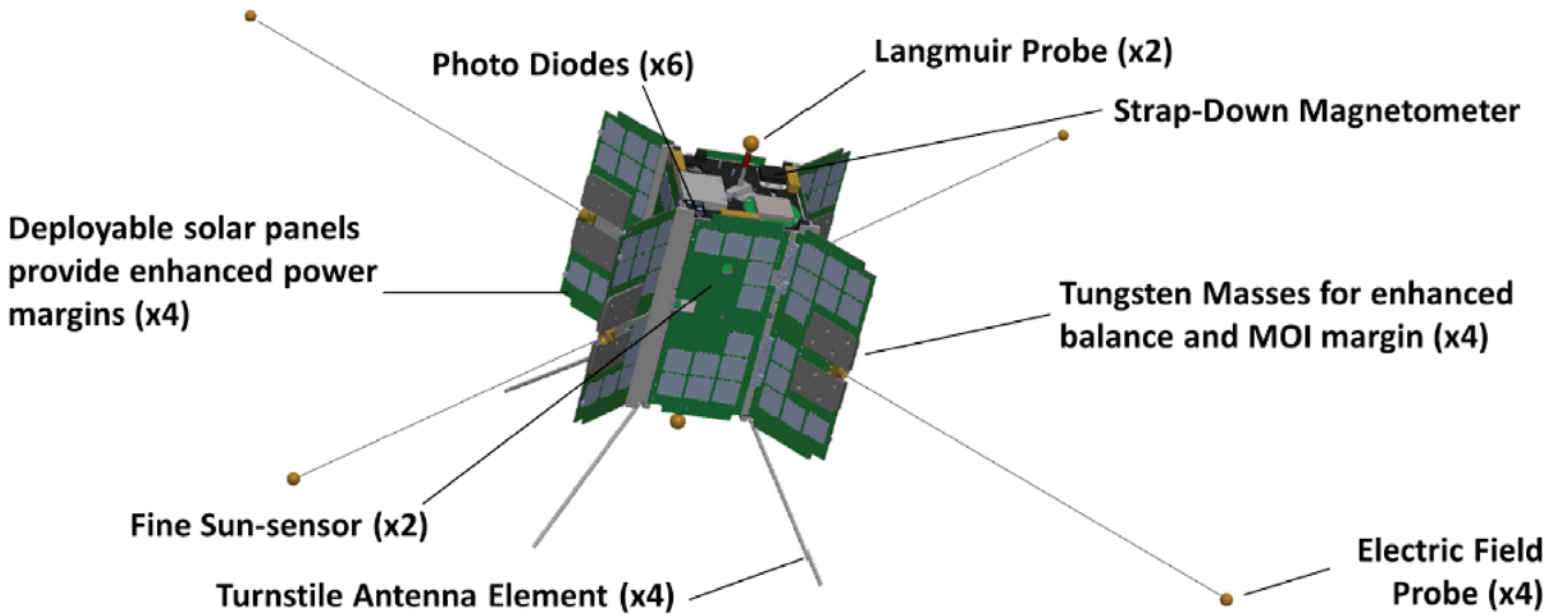
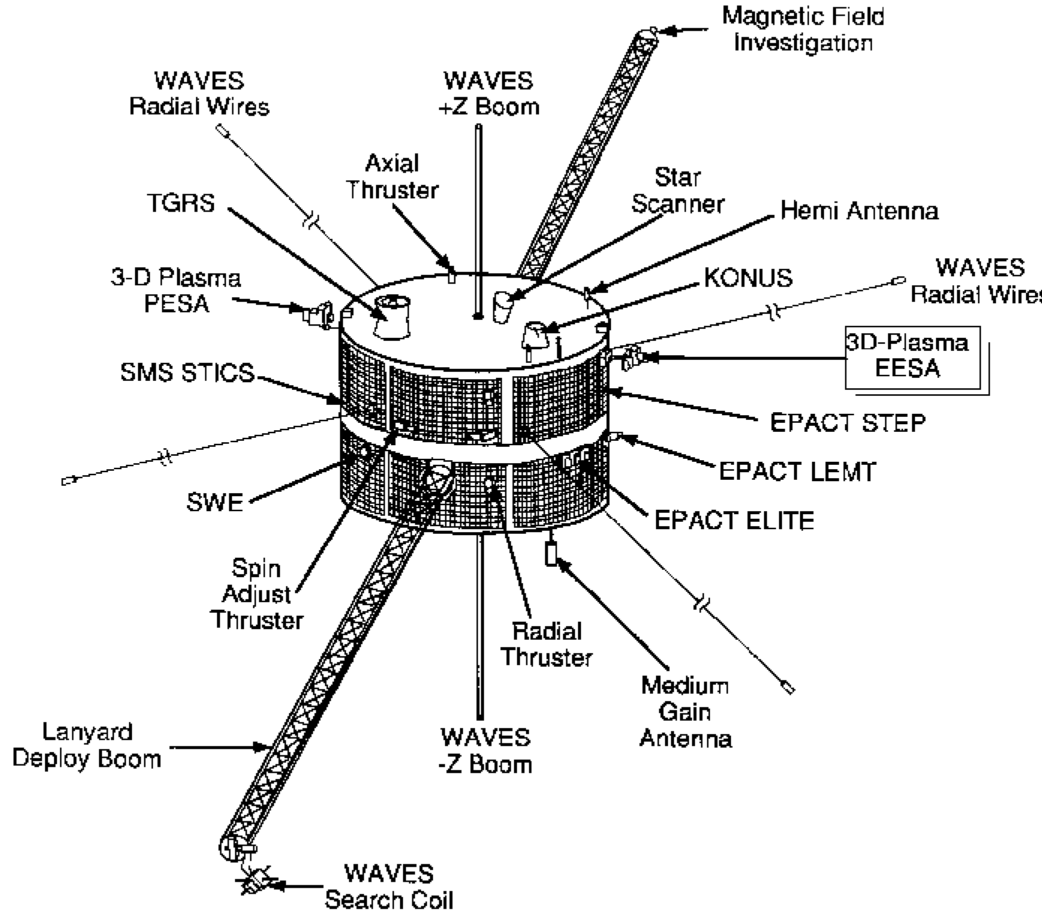


Figure 11. The DIME sensor-sat risk-reduction mission.

- The DIME spin rate is intended to be 1.5 Hz, to support 3 m cable booms.
- Lunar orbit, like that of Lunar IceCube would provide window of time when Earth transmissions were blocked

Deployed wire boom antennas

- The Wind spacecraft has 2 sets of electric field dipole antennas – each consisting of wire antennas held straight by the force of spacecraft spin on antenna tip masses.
- Longer antennas ~ 100 m dipole
- Wind spins at 20 RPM.
- A spinning spacecraft can support much longer antennas than stacer or other mechanically-erected antennas used on spin-stabilized spacecraft.
- Contemplate an array of >30 6U CubeSats with antenna lengths close to Wind's



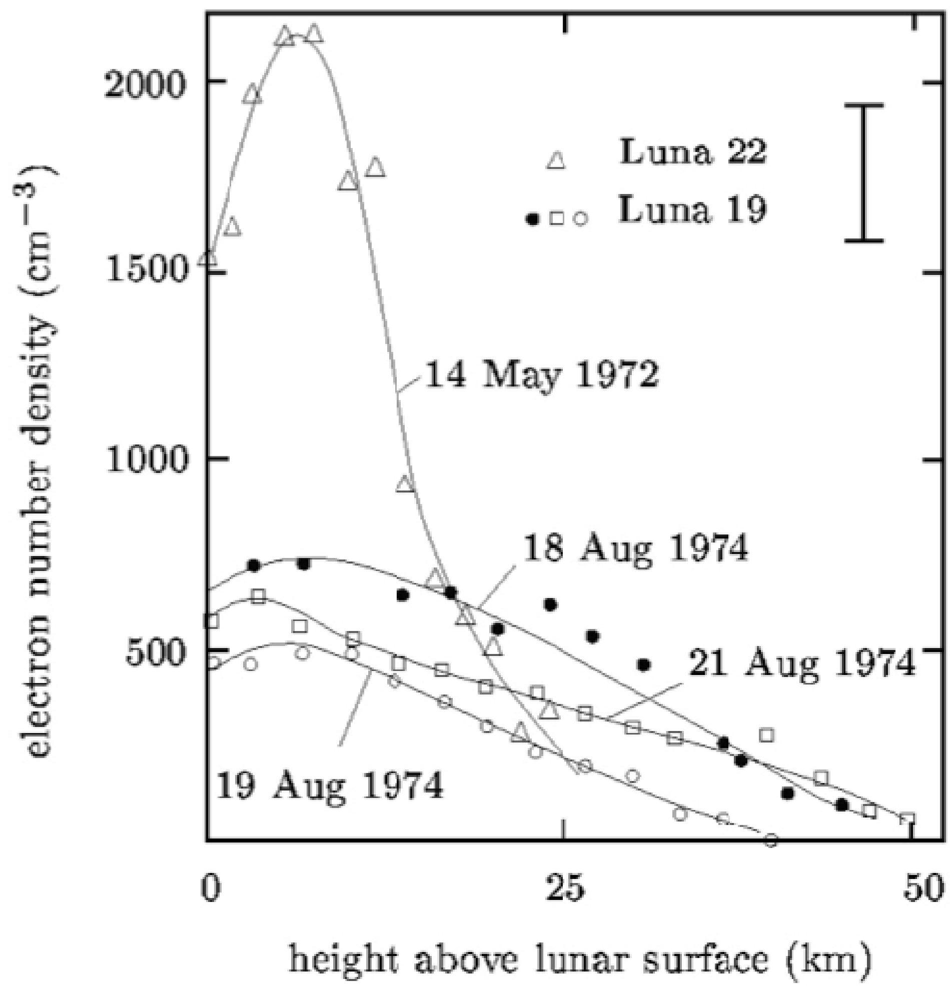
Summary

- Although other antennas designs exist, testing funded by the NLSI indicates that antennas on Kapton film would work well for solar radio bursts.
- The ROLSS concept, adapted to robotic deployment, would have:
  - 3 antenna arms of 500 m length each appropriate for solar radio imaging
  - Central electronics box with COM antennas, thermal and power systems
  - Data rate of 80 Mbs, unless correlation down on-site
- We continue to work the technology issues and to look for a ride for a first pathfinder; CubeSat arrays are also being studied
- Need to carry out sensitive studies before lunar radio frequency interference levels become significant.

Backup

Lunar photoelectron sheath

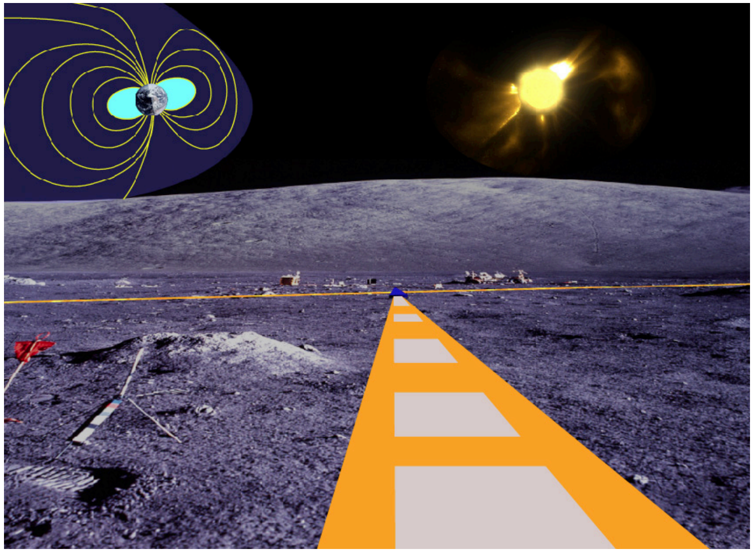
- Moon's photoelectron sheath and any "ionosphere" will interfere with low frequency measurements; otherwise, important to study
- Measuring the ionosphere has proven difficult; assume that maximum electron densities are of order 500 cm^{-3}
- Yields max ionospheric electron plasma freq ~ 200 kHz
- Bill Farrell says daytime photo-electron sheath has 0.5 m scale height – 100 cm^{-3} at surface, 10 cm^{-3} at 1 m
- ROLLS will provide data (or upper limits) for the electron density (from type III burst cutoffs).

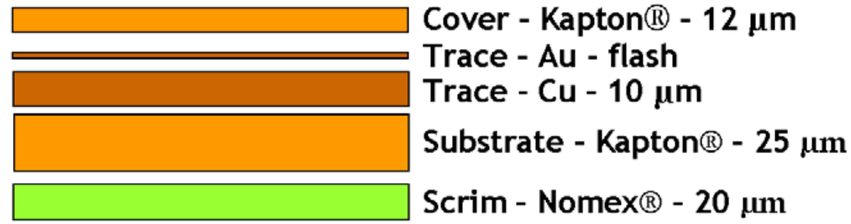


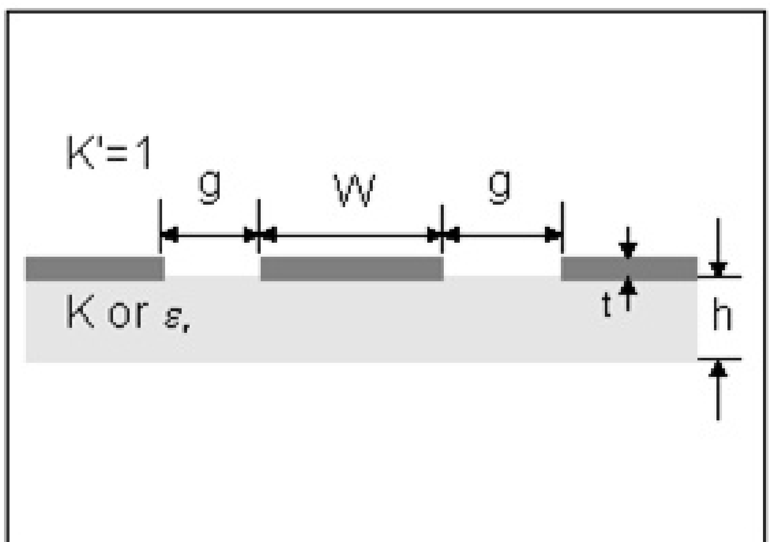
ROLSS Science Requirements

Parameter	Values	Comments
Wavelength (Frequency)	30-300 m (10-1 MHz)	• Matched to outer corona radio emissions • Probe lunar ionosphere • Operate longward of terrestrial ionospheric cutoff
Angular resolution	2 deg (at 10 MHz)	• Required to separate sources • Corresponds to coronal scattering
Bandwidth	100 kHz	Track evolution of bursts
Lifetime	1 year	Measure >10 solar rotations

ROLSS: Science Antennas

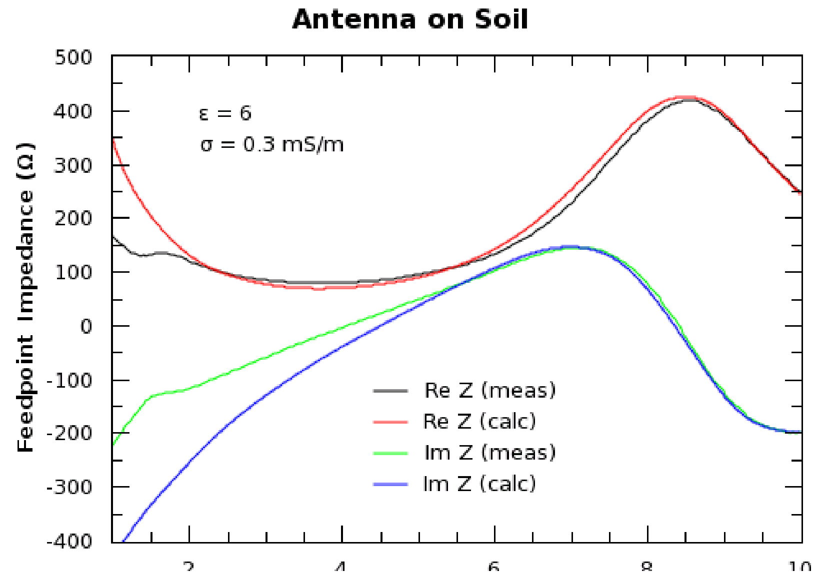


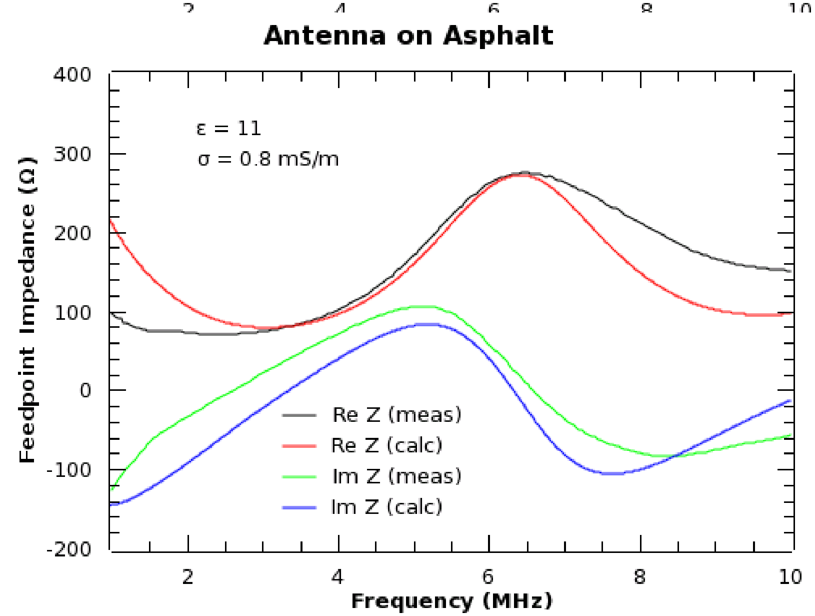




- The three 500-m arms of ROLSS (in GSFC concept) are multilayer as shown above – for strength and durability
- Total (terrestrial) weight for 1500 m by 1.5 m = 188 kg (using multilayer above)
- Signal transmission uses a planar wave guide, shown at left
- Losses are 0.05 dB/m at 10 MHz, acceptable for solar studies, but active preamp desirable. Multiple implications.

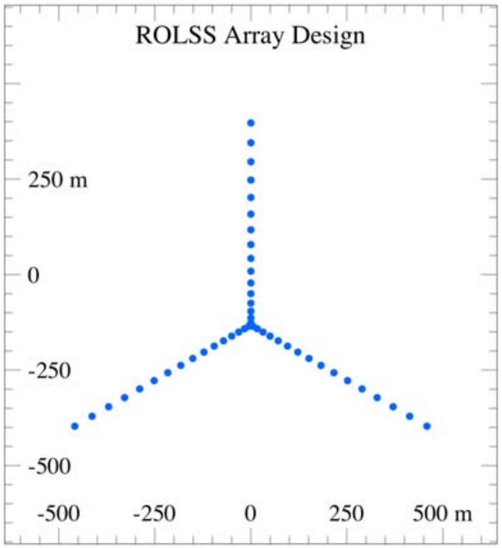
ROLSS: Antenna Testing

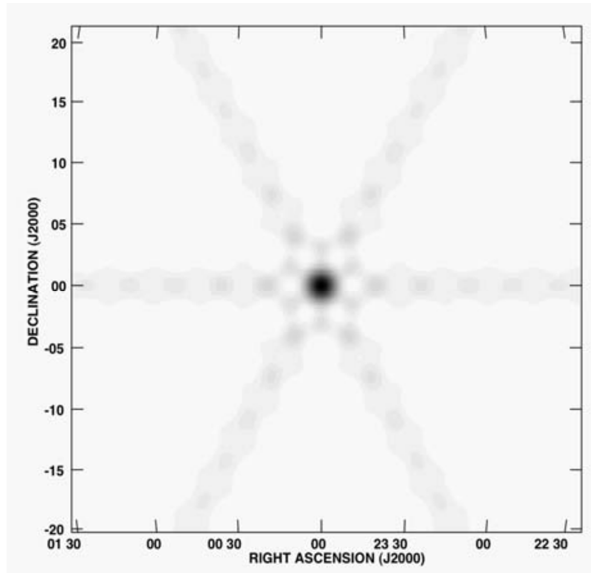




- Material is 5 microns of Cu on 25 microns of Kapton; roll is 12 inches wide
- Manufactured by Sheldahl
- Tested at Goddard “optical site”
- Goal was to demonstrate that modeling software agreed with observed impedance
- Good agreement on sandy soil and asphalt (need to demonstrate in dry desert)
- Vacuum chamber testing at U. Colorado

ROLSS: Synthesis Testing



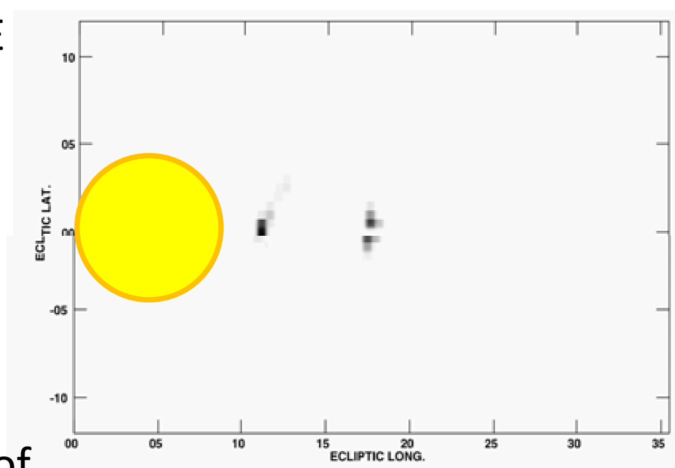


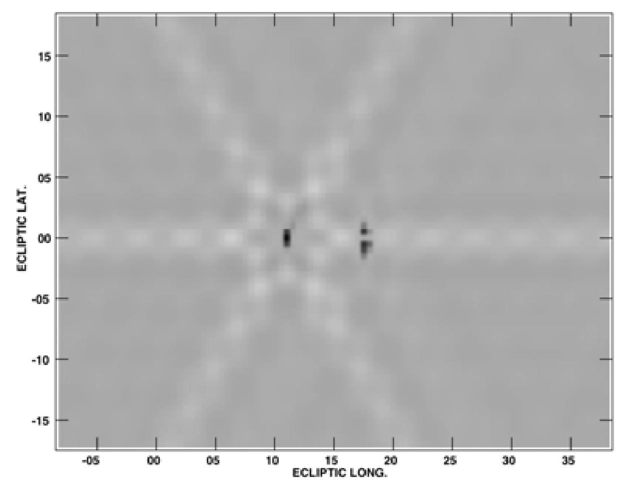
Far left: Nominal science antenna distribution along the antenna arms (16 per arm)

Left: Point-spread function (“beam”) for a snapshot image. The maximum sidelobe is at −5.9 dB, and the rms sidelobe level is −15 dB.

Right: Model of a CME

Far Right: The imaged CME. Front & back of CME are clearly distinguished, even though residual beam effects also apparent. Only modest amount of CLEANing used.





ROLSS concept study mass budget

Sections	Mass CBE (kg)	% of Total Instrument Mass
Antenna Arms	187.73	34.91%
Central Electronics Package	257.34	47.86%
Lithium Ion, Battery 80 Ah 90% DOD	148.00	27.53%
CEP Thermal Subsystem	26.86	5.00%
RF/Comm Subsystem	25.18	4.68%
Solar Panel Assembly	22.34	4.15%
Anntenna Arm Deployment Mechanical Assembly	19.50	3.63%
TOTAL (+ 5% hardware and no margin):	537.69	

- Consolidation/miniaturization critical; has been studied, but need more development
- A number of antenna deployment methods have been studied; mini-rover preferred