**Solar Radiophysics with HF Radar**

Workshop on Solar Radiophysics
With the Frequency Agile Solar Radiotelescope (FASR)

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Green Bank, WV

Paul Rodriguez
Information Technology Division
Naval Research Laboratory
Washington, DC

The Solar & Lunar HAARP
Range of Space Experiments with HF Radiowaves

Radial Distance

1 AU — Solar Corona
- Detection of CMEs & prediction of geomagnetic storms
- Densities, temperatures of solar corona
- Large scale structure, dynamics, wave spectrum

0.5 AU — Planetary Surfaces
- Detection of near earth asteroids, comets

60 Re — Selenosphere
- Lunar surface penetration by HF radiowaves
- Charged lunar dust atmosphere?
- Lunar wake structure

30 Re — Solar Wind
- Solar wind large scale density structures
- Bow shock irregularities and dynamics

15 Re — Magnetosphere
- Boundary and global scale dynamics
- Response to geomagnetic storms
- Magnetospheric wave-particle interactions

0.05 Re — Ionosphere
- Modification (growth and decay scales of irregularities)
- Long distance radiowave propagation
- Density irregularity spectrum
- Meteor showers (Leonids; dusty plasmas)

Effective Radiated Power

0.1 MW 1 MW 10 MW 100 MW 1000 MW
El Campo, Texas  Solar Radar Antenna Array

Operated by
MIT/Lincoln Laboratory
1961-1969

Operating Frequency:  38.25 MHz
Transmitting Dipoles:  128 x 8 EW
Receiving Dipoles:  128 x 8 EW
128 x 4 NS
Total Area:  18,000  m²
Antenna Gain:  32-36 dB
Beam Size (NS x EW):  1° x 6°
Total Power:  500 kW
Effect. Radiated Power:  1300 MW
Motivation for initial solar radar experiments

• to determine radar cross section of the solar corona (however, it was recognized there was no ‘hard surface’)
• to investigate dynamics of solar corona

Present scientific motivation

• profile of corona electron density
• backscatter from a hot, magnetized plasma
• remote sensing of wave-particle interactions in the corona (small scale dynamics)
• measurement of large scale MHD (i.e., CMEs)
• understanding of nonthermal development of various spectra (density fluctuations, waves, radio, etc)
• direct measurements of stellar plasma and how it affects planetary environment
Solar Radar Performance

The radar equation is

\[ P_r = \frac{P_t G_t A_r \sigma p}{4\pi R^2} \]

where:

- \( P_r \) - received power (watts)
- \( P_t \) - transmitted power (watts)
- \( G_t \) - transmitting antenna gain
- \( A_r \) - receiving antenna area (m²)
- \( \sigma \) - scattering cross-section (m²)
- \( p \) - polarization fraction
- \( R \) - range to scattering cross-section (m)
- \( R_o \) - solar radius (m)

\[ R = 1.5 \times 10^{11} \text{ m} \text{ (1 AU)} \]
\[ R_o = 7 \times 10^8 \text{ m} \text{ (solar radius)} \]
\[ \sigma \approx 1 \pi R_o^2 = 1.54 \times 10^{18} \text{ m}^2 \text{ (typical value obtained by El Campo)} \]
\[ p = 0.5 \text{ (one of two polarizations)} \]

\[ N = k_B T(f) B \text{ (noise power of sun), where} \]

- \( k_B = 1.38 \times 10^{-23} \text{ watt-s °K}^{-1} \text{ (Boltzman’s constant)} \)
- \( T(f) = \text{noise equivalent temperature of sun (°K)} \)
- \( B = \text{receiver bandwidth (Hz)} \)
El Campo Solar Radar (38.25 MHz)
El Campo Corona Echo Signal Spectrum

Typical RDA spectrum.

Among spectral types observed were “high corona echoes,” which may have been CME signatures.

However, CMEs were unknown in the 1960s.
Solar Radar Detection of Earthward-Directed Coronal Mass Ejections
The Doppler shifts expected for HF radar frequencies of 9, 25, and 38 MHz, for the range of CME velocities observed with coronagraphs.
Solar Radar Experiment  21 July 1996

**SURA Transmitted Signal  UT 0911-0927**

- Full Power
- ON/OFF
- 8.920 MHz
- 8.880 MHz

**UTR-2 Return Signal Spectra  UT 0927-0943**

- Frequency Shift (kHz)
- 8.925 MHz
- 8.885 MHz

Time (sec) Relative to Transition
Integrated Return Signal Time Profiles and Spectra
HAARP Research Facility  
Gakona, Alaska  
*Operated by Advanced Power Technologies, Inc. under contract from U. S. Air Force/Navy*  

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiating x-dipoles</td>
<td>48</td>
<td>180</td>
</tr>
<tr>
<td>Total area (m²)</td>
<td>20,000</td>
<td>124,000</td>
</tr>
<tr>
<td>Transmitters</td>
<td>96</td>
<td>360</td>
</tr>
<tr>
<td>Power (kW)</td>
<td>960</td>
<td>3600</td>
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<tr>
<td>ERP (MW)</td>
<td>190</td>
<td>3200</td>
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<tr>
<td>Frequencies (MHz)</td>
<td>2.8 to 8</td>
<td>2.8 to 10</td>
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</tbody>
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Gakona, Alaska
Sun As Seen From HAARP at
UT 2000 (o), 2100 (◊), 2200 (Δ), 2300 (x)
LT 1100 (o), 1200 (◊), 1300 (Δ), 1400 (x)
Each LOFAR Station consists of 256 Active Dipoles above their ground screens.

~ 160 m (5 acres)

LOFAR will be:

- ≥ 40 stations
- ≥ 10,000 dipoles
- ≥ 1 km² collecting area (~20x Arecibo)
- Δν ~ 10-250 MHz
- ≥ 2 independent beams

Possible LOFAR Station sites:

LOFAR: CONCEPTUAL LAYOUT

VLA

Los Alamos

New Mexico
HAARP Frequency = 10 MHz
LOFAR Effective Area ~ 10^6 m^2
Solar Radar X-Section = 1

Net Signal/Noise Ratio (dB)
Integration Time (s)

Total Power (MW)
- Present HAARP Power
- Design HAARP Power

5-dB Threshold
Initial HAARP Power
Summary and Conclusions

- Solar radar experiments will ‘open’ a new window on plasma physics of the sun and magnetosphere.

- Solar radar has applications to many other phenomena of local astrophysics.

- HAARP is capable of being a solar radar, in bistatic configuration with existing and planned receiving arrays.

- The CME detection problem and geomagnetic storm effects at earth is a practical motivating issue.