Solar Radiophysics with HF Radar

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

23-25 May 2002
Green Bank, WV

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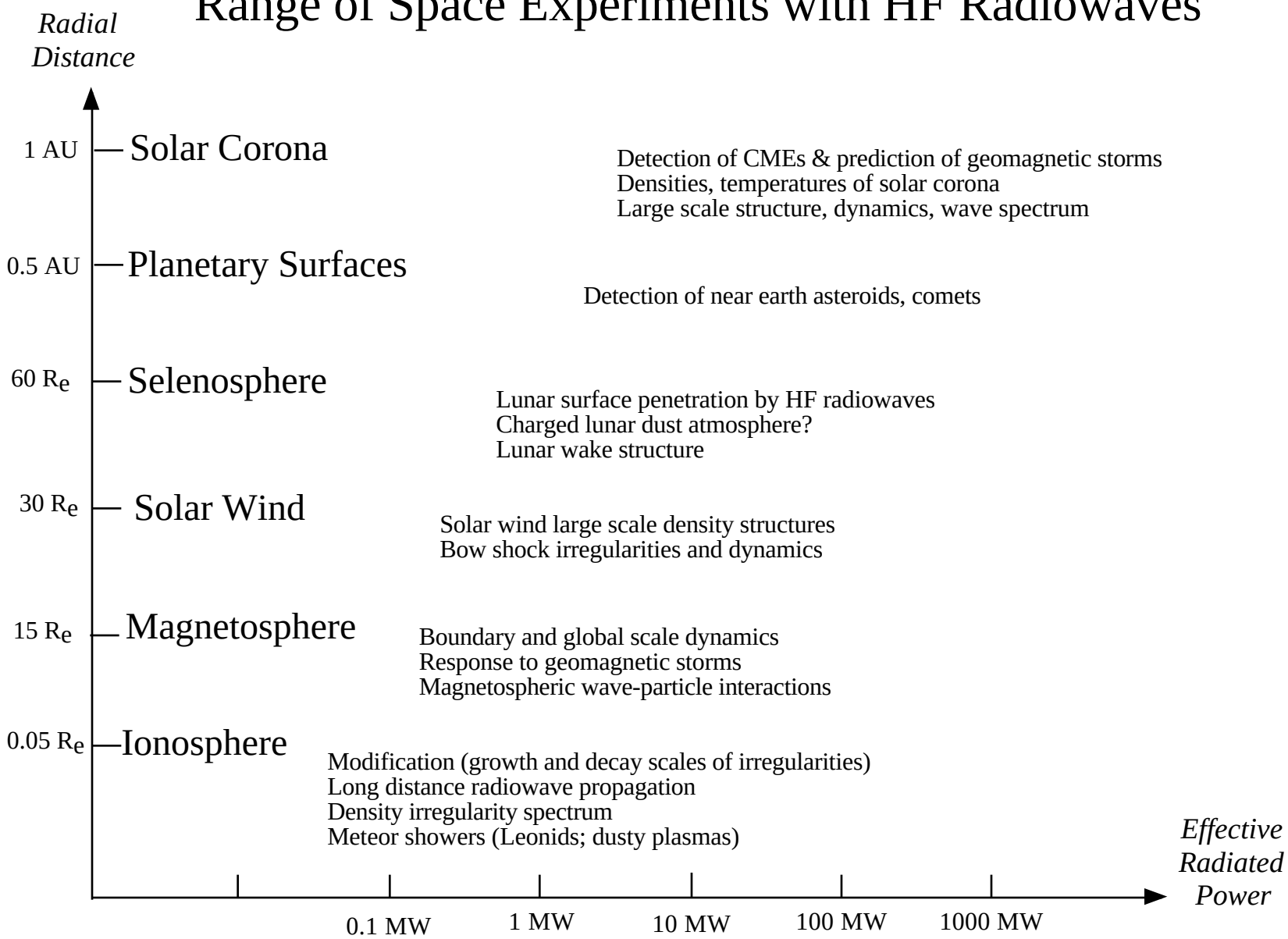
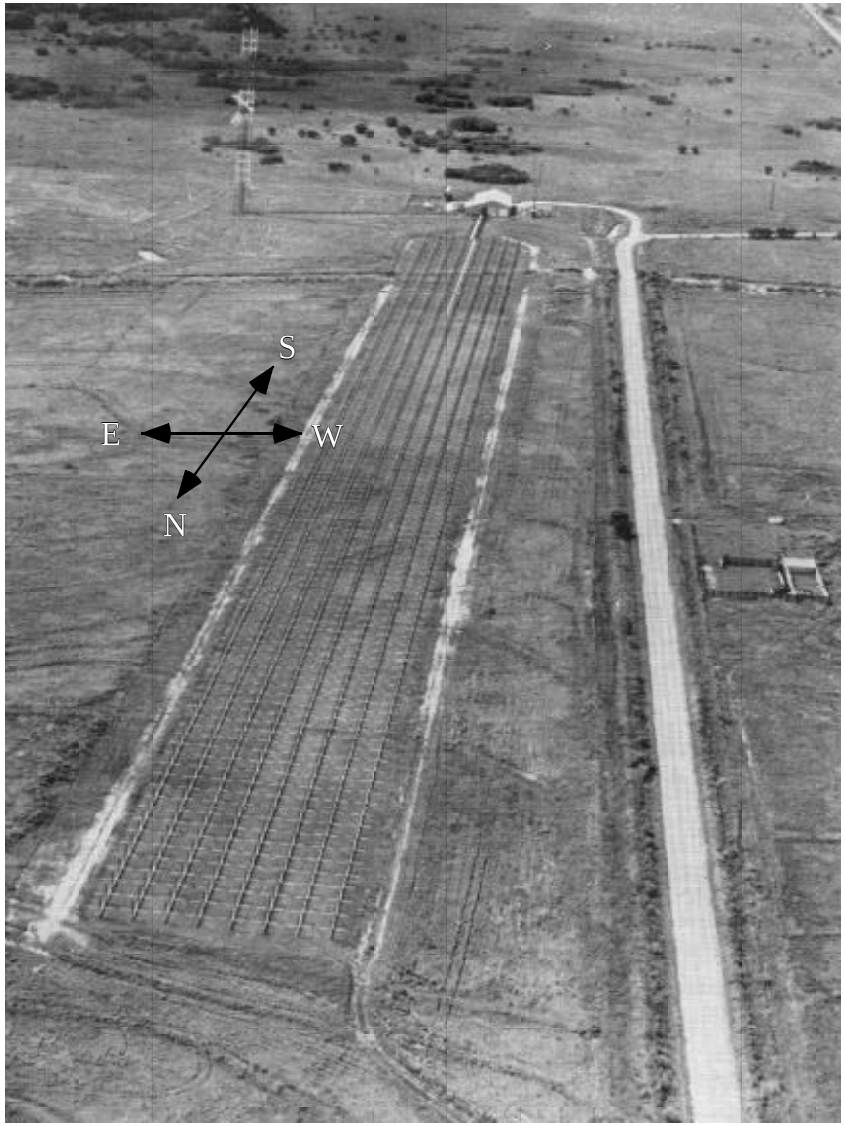
Information Technology Division
Naval Research Laboratory
Washington, DC

The Solar & Lunar HAARP

Range of Space Experiments with HF Radiowaves



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 m^2
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

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

where:

P_r - received power (watts)

P_t - transmitted power (watts)

G_t - transmitting antenna gain

A_r - receiving antenna area (m^2)

σ - scattering cross-section (m^2)

p - polarization fraction

R - range to scattering cross-section (m)

R_o - solar radius (m)

$R = 1.5 \times 10^{11}$ m (1 AU)

$R_o = 7 \times 10^8$ m (solar radius)

$\sigma \sim 1 \pi R_o^2 = 1.54 \times 10^{18}$ m^2 (typical value obtained by El Campo)

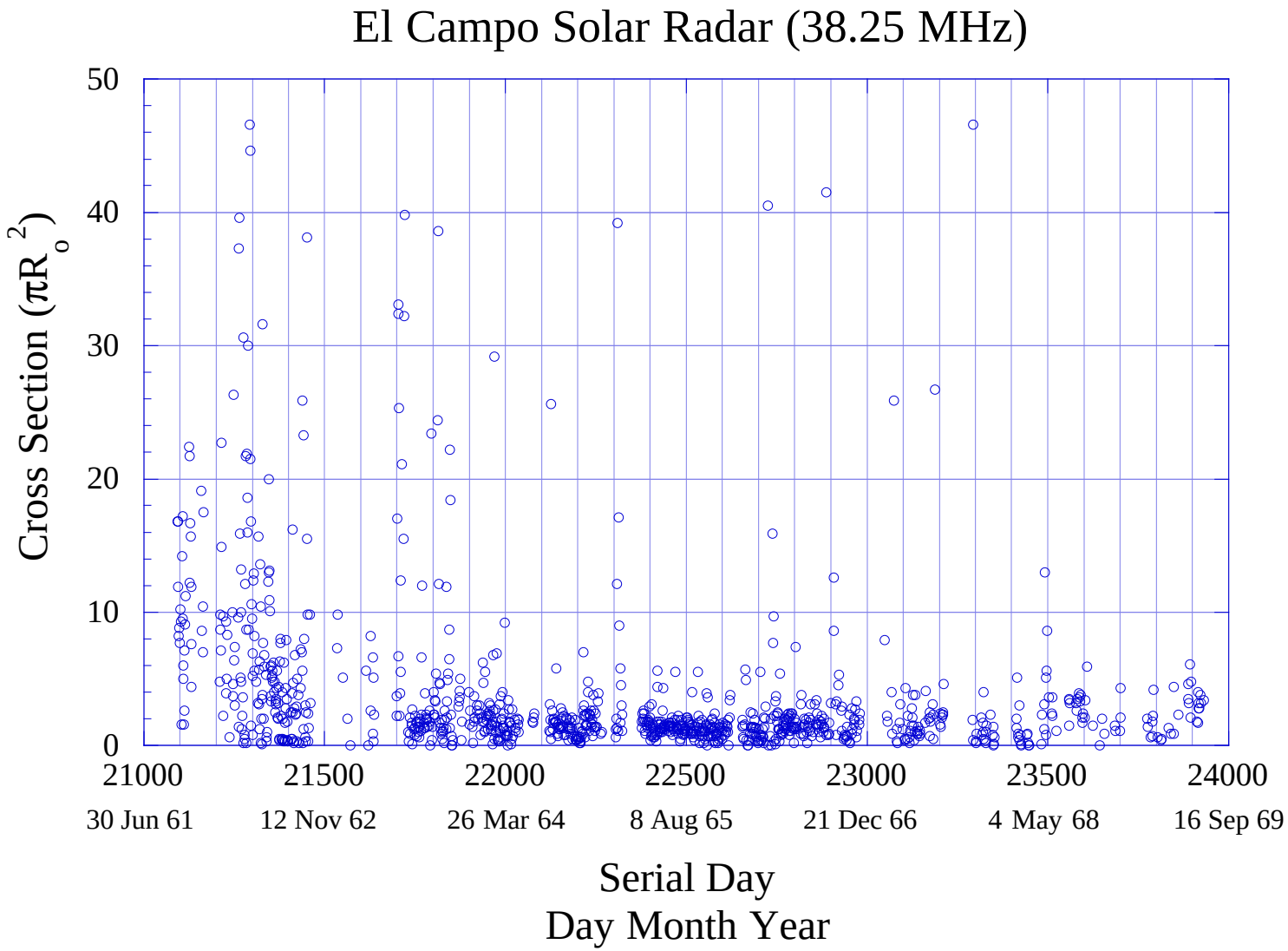
$p = 0.5$ (one of two polarizations)

$N = k_B T(f) B$ (noise power of sun), where

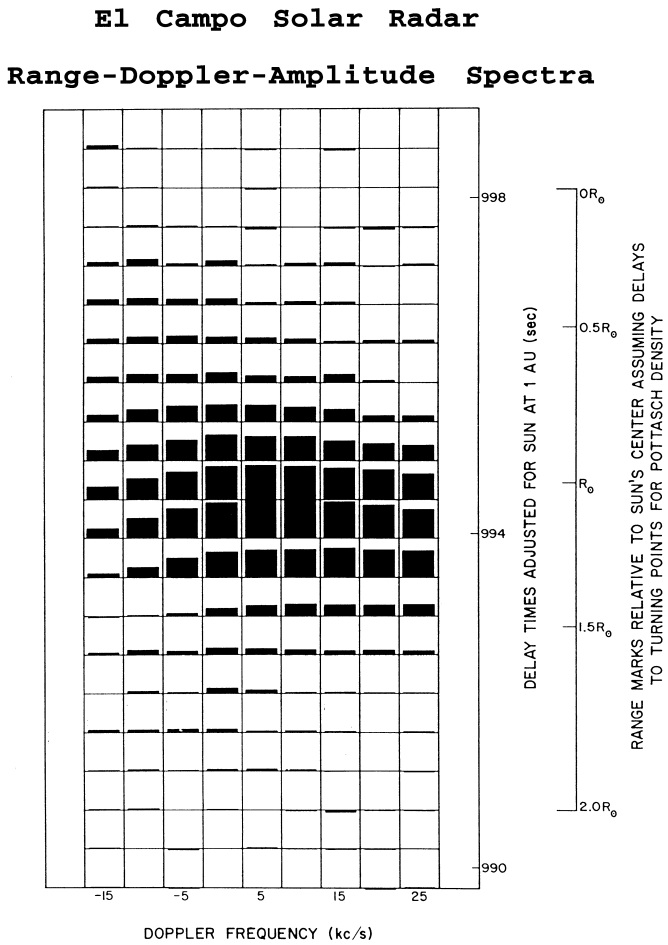
$k_B = 1.38 \times 10^{-23}$ watt-s °K^{-1} (Boltzman's constant)

T(f) = noise equivalent temperature of sun (°K)

B = receiver bandwidth (Hz)


El Campo Solar Radar (38.25 MHz)
Cross Section (πR_o^2)
50
40
30
20
10
0
21000
21500
22000
22500
23000
23500
24000
30 Jun 61
12 Nov 62
26 Mar 64
8 Aug 65
21 Dec 66
4 May 68
16 Sep 69
Serial Day
Day Month Year

El Campo Corona Echo Signal Spectrum

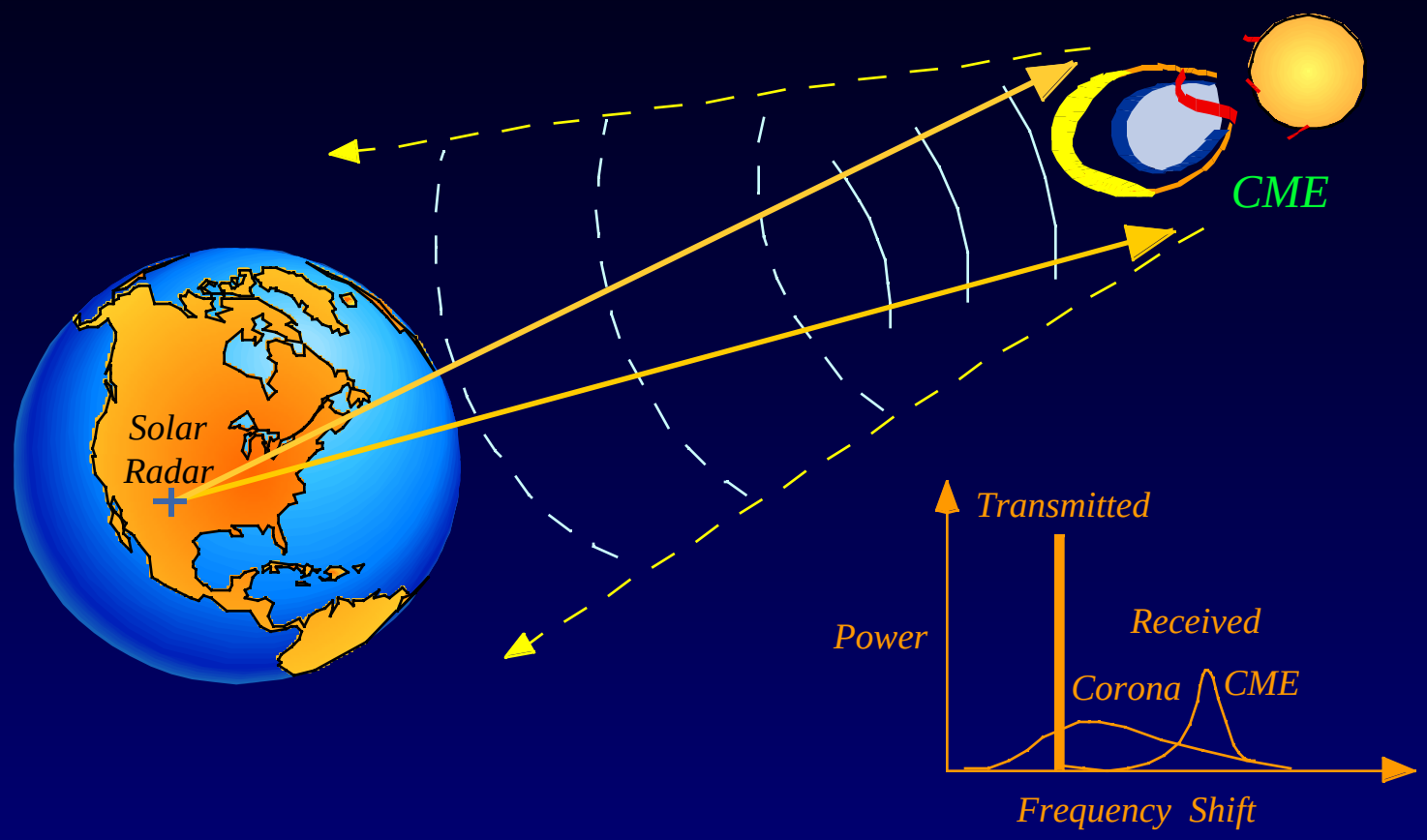


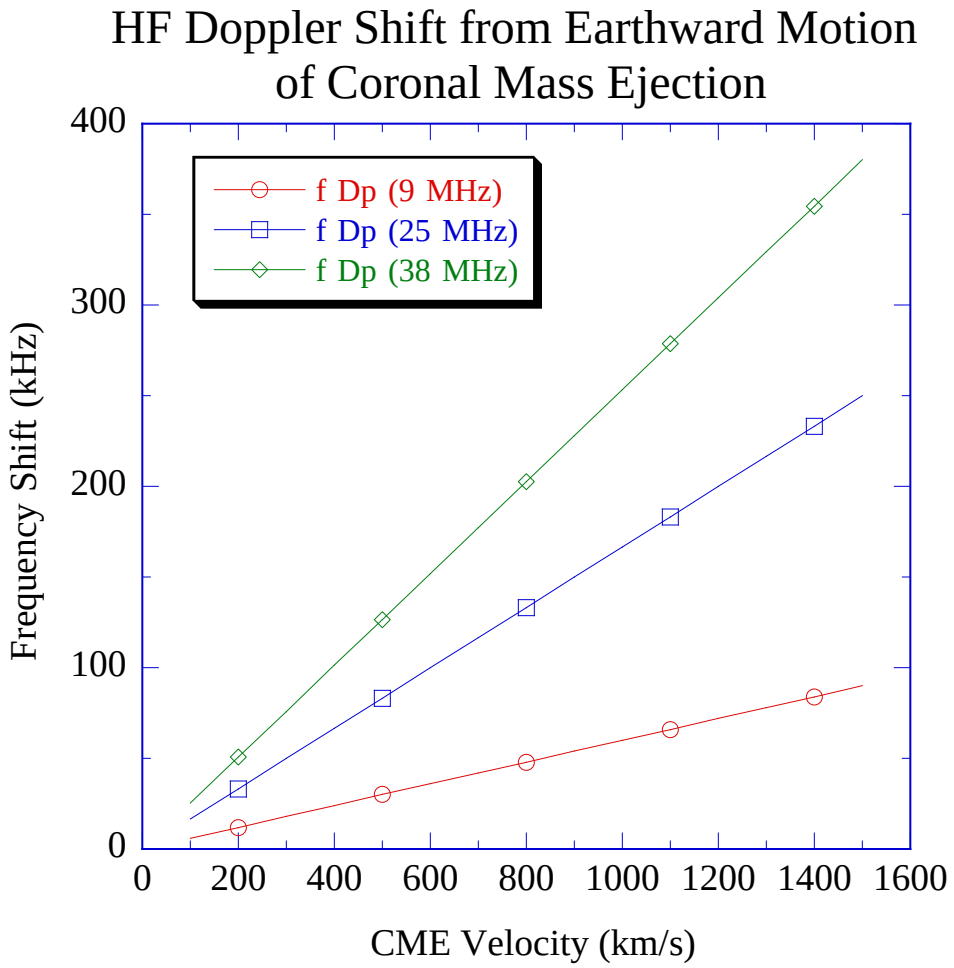
Typical RDA spectrum.

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

However, CMEs were unknown in the 1960s.

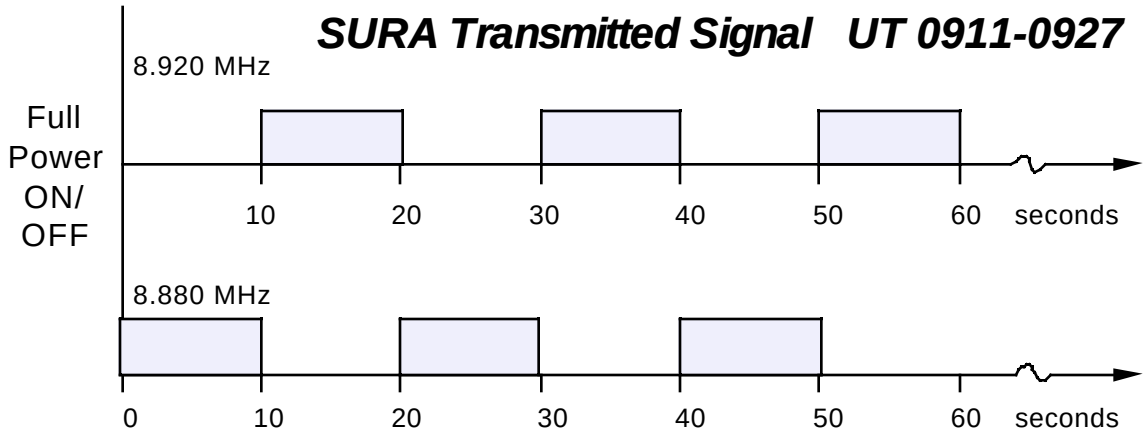
Solar Radar Detection of Earthward-Directed Coronal Mass Ejections

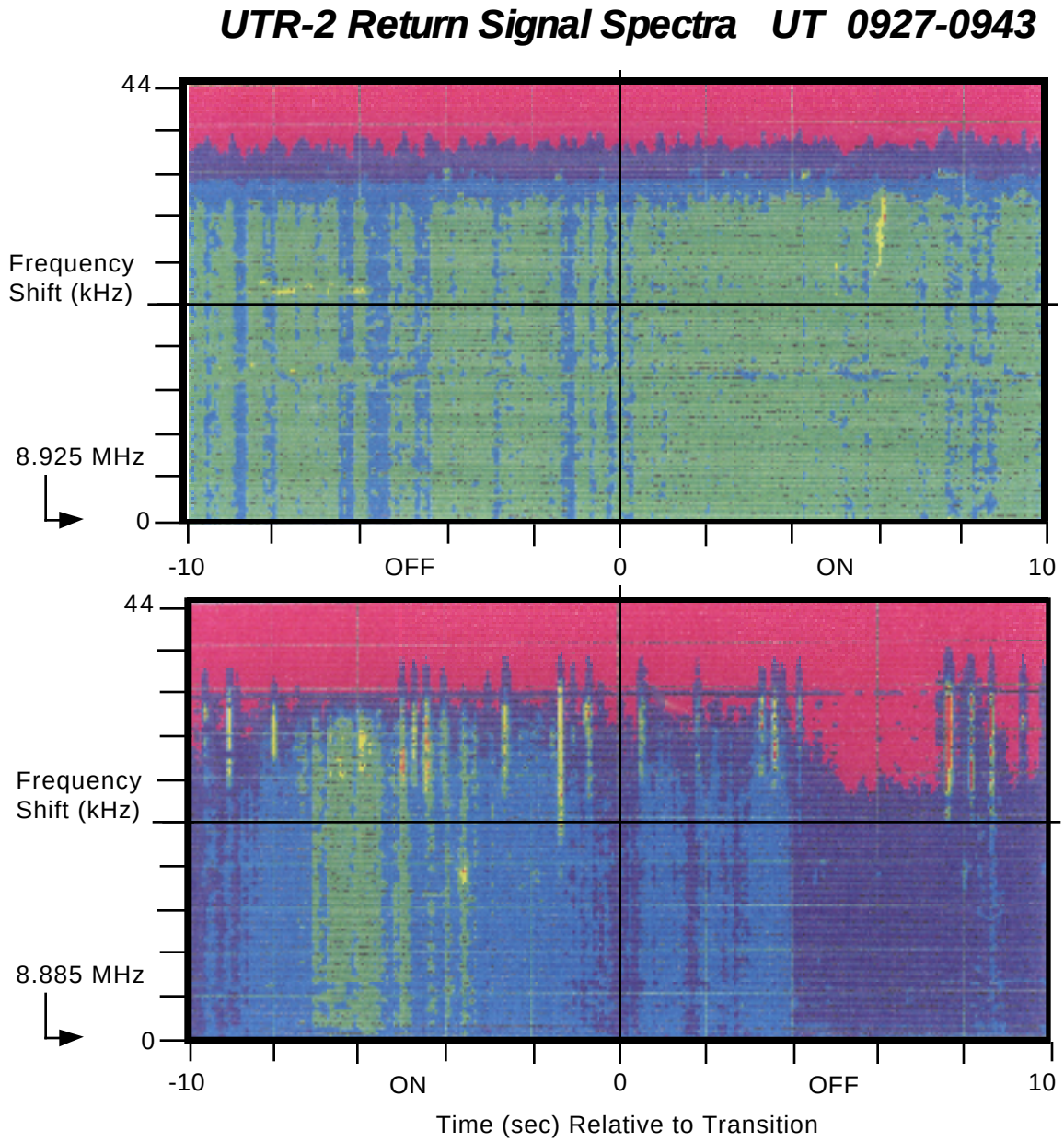




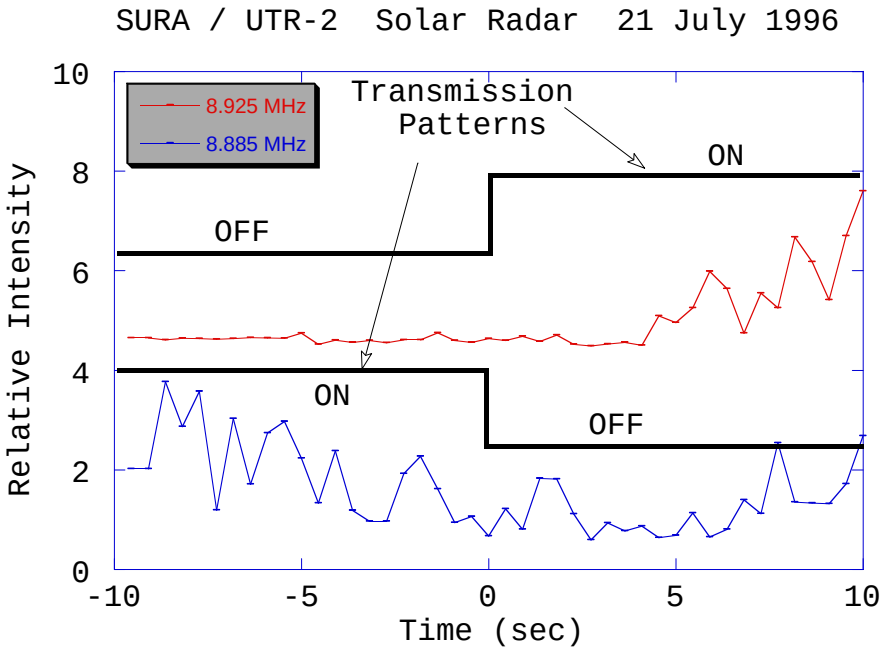
The Doppler shifts expected for HF radar frequencies of 9, 25, and 38 MHz, for the range of CME velocities observed with coronagraphs.

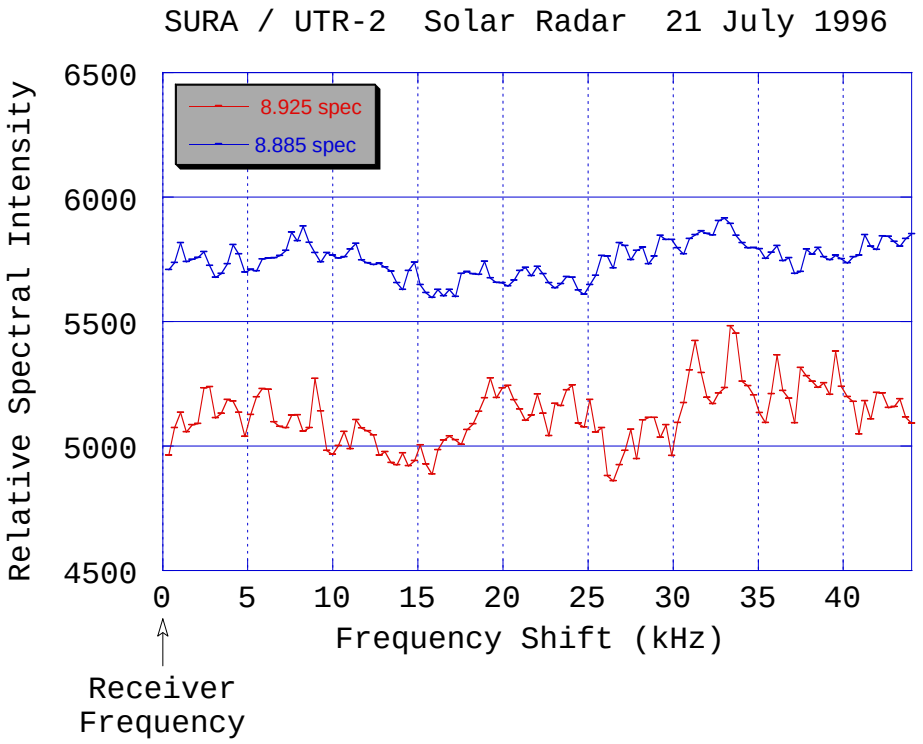
Solar Radar Experiment 21 July 1996





Integrated Return Signal Time Profiles and Spectra



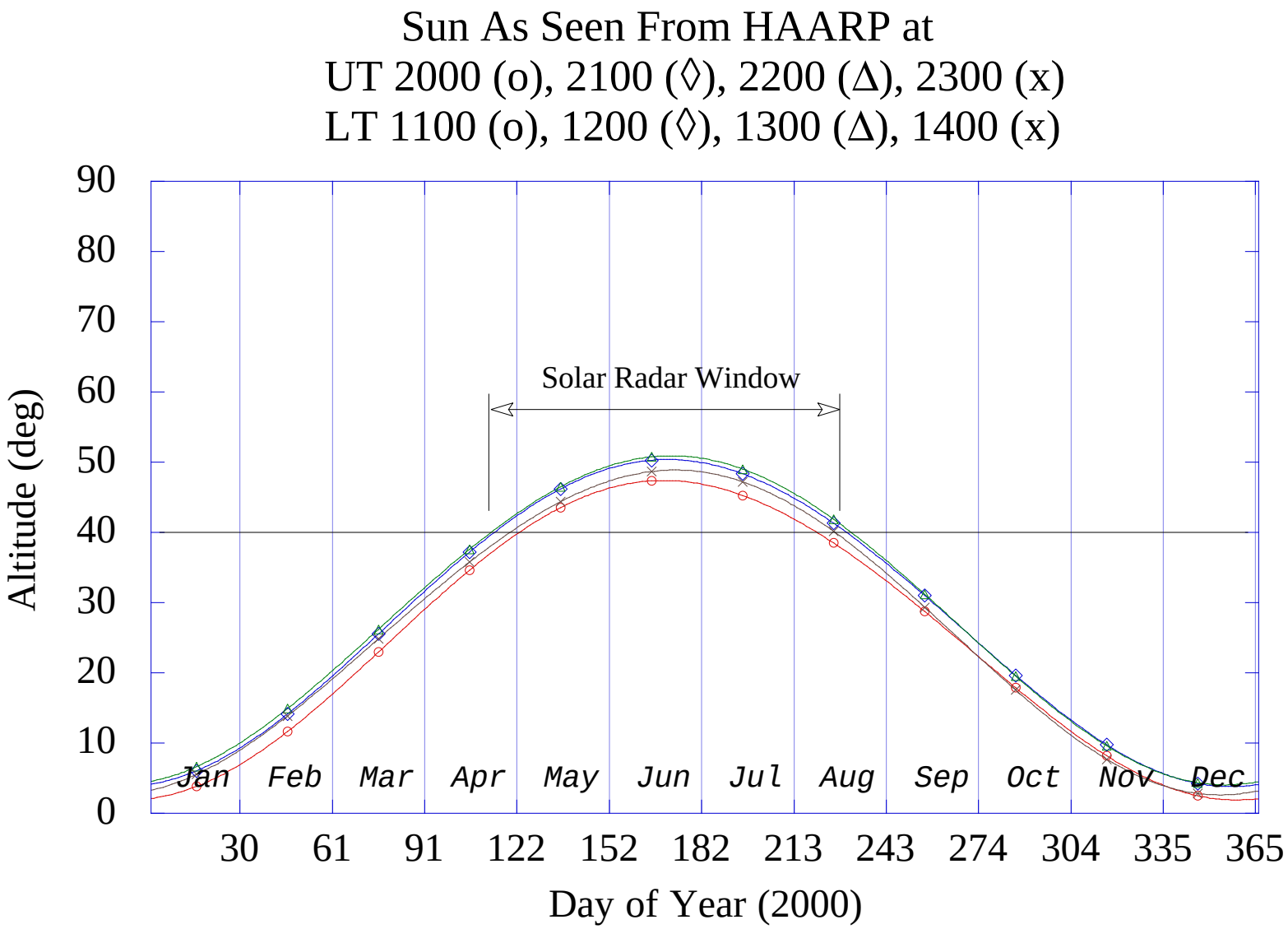


HAARP Research Facility

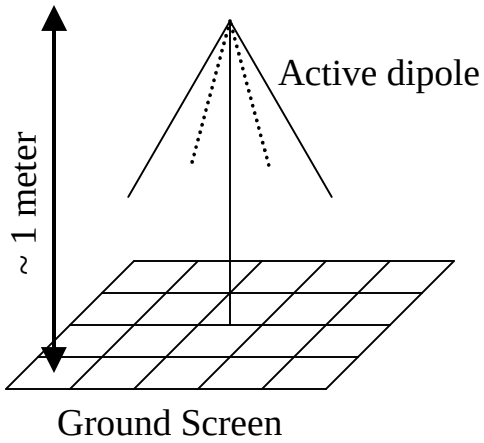
Gakona, Alaska

Operated by Advanced Power Technologies, Inc. under contract from U. S. Air Force/ Navy

	Current	***Design***
Radiating x-dipoles:	48	180
Total area (m^2):	20,000	124,000
Transmitters:	96	360
Power (kW):	960	3600
ERP (MW):	190	3200
Frequencies (MHz):	2.8 to 8	2.8 to 10

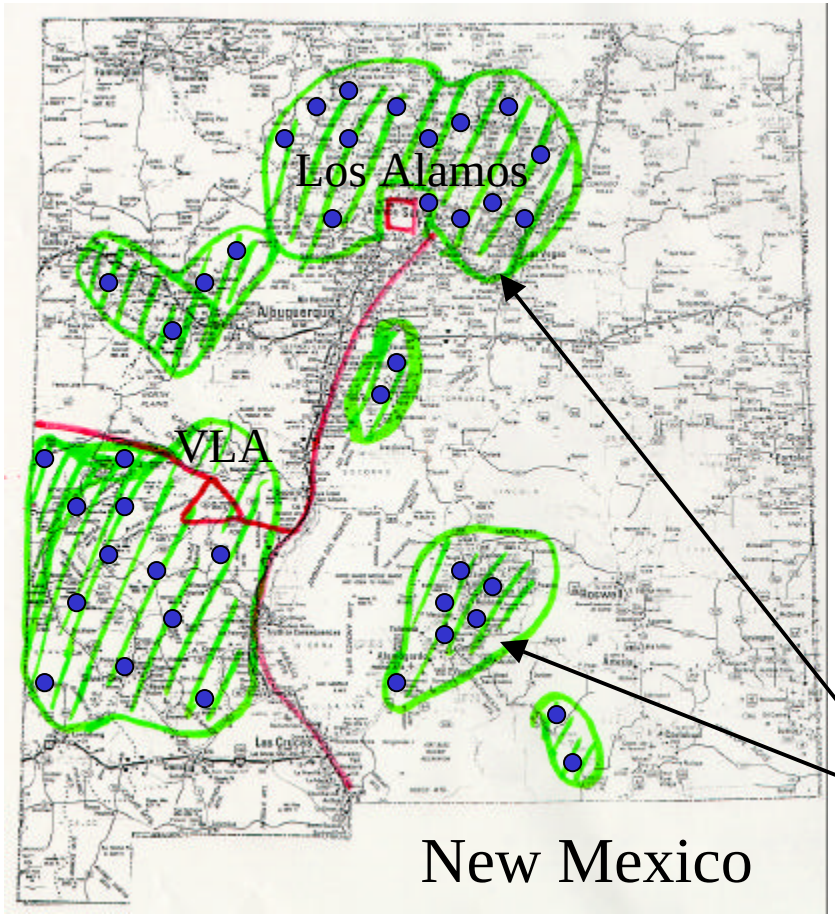

Sun As Seen From HAARP at
UT 2000 (o), 2100 (◊), 2200 (Δ), 2300 (x)
LT 1100 (o), 1200 (◊), 1300 (Δ), 1400 (x)
Solar Radar Window
Altitude (deg)
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
30
61
91
122
152
182
213
243
274
304
335
365
Day of Year (2000)

LOFAR: CONCEPTUAL LAYOUT



Each LOFAR ***Station*** consists of 256 Active Dipoles above their ground screens

~ 160 m (5 acres)

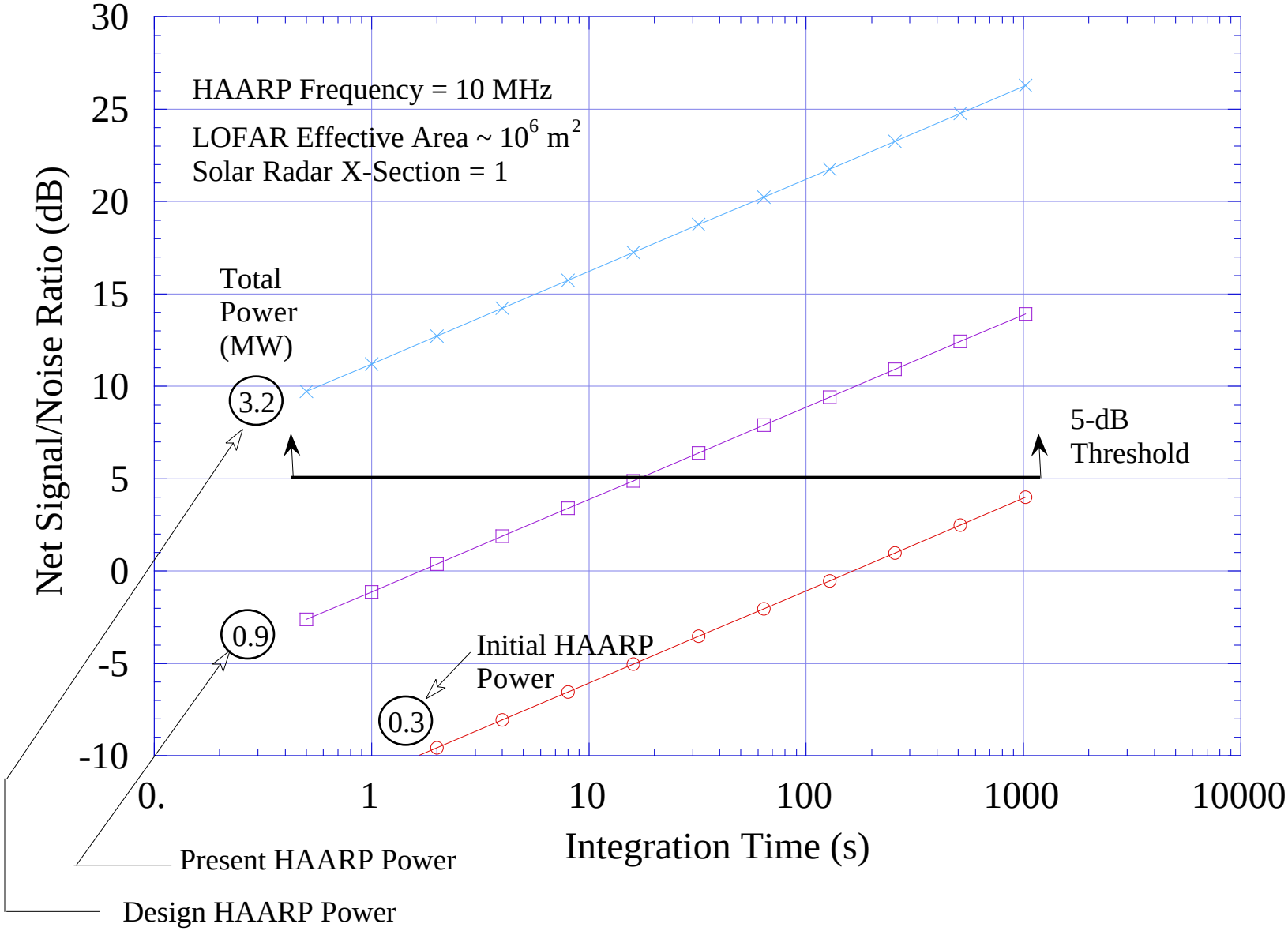


Possible LOFAR Station sites

LOFAR will be:

- ≥ 40 stations
- ≥ 10,000 dipoles
- ≥ 1 km^2 collecting area – 20x Arecibo
- $\Delta\nu$ ~ 10-250 MHz
- ≥ 2 independent beams

HALO Solar Radar



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.