Tracking Solar Type II Bursts with Space Based Radio Interferometers

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AAS 6/7/2018
Session 405.01: The Sun, the Solar System & Laboratory Astrophysics

Earth to Scale

Michigan Engineering

NESS
Network for Exploration and Space Science

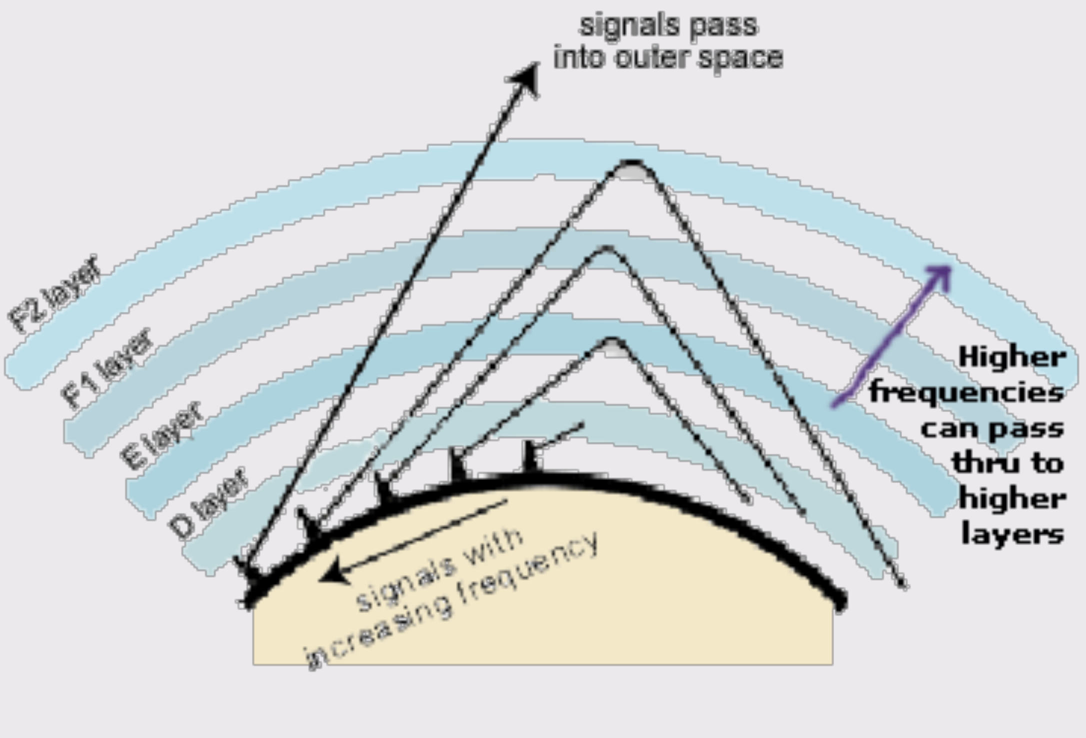
SDO Image

Outline

- What are Solar Radio Bursts?
- SunRISE Array Pipeline
- Lunar Surface Array Pipeline
- MHD Simulations
- Conclusions

Earth to Scale

Why Space? Ionospheric Cutoff < 10 MHz

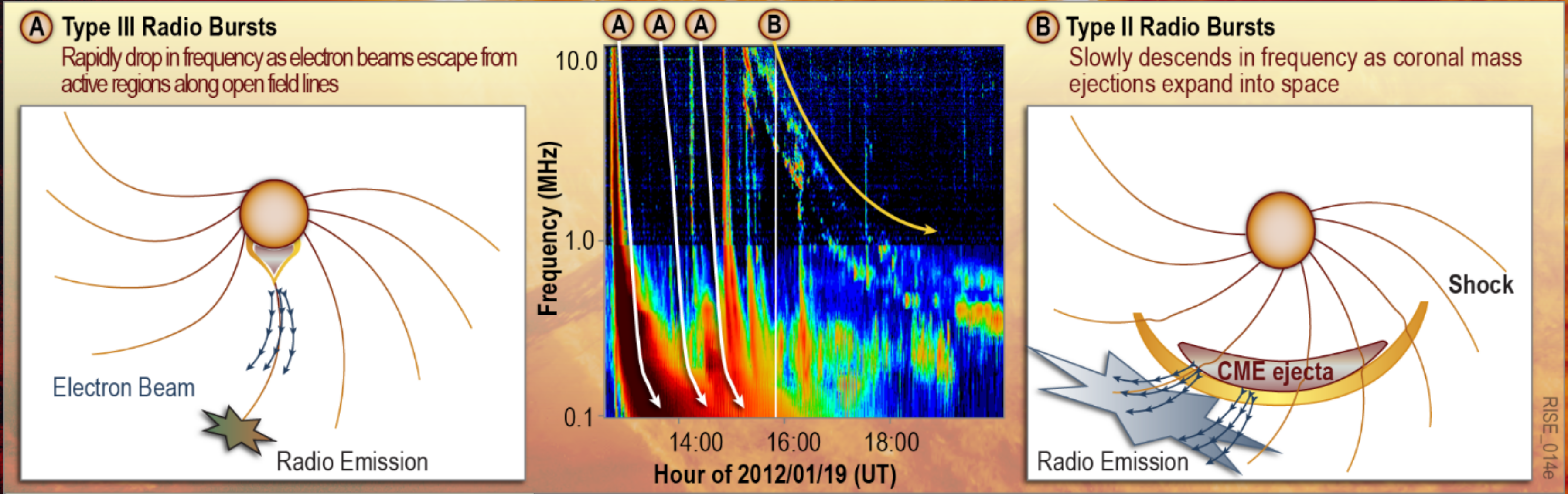


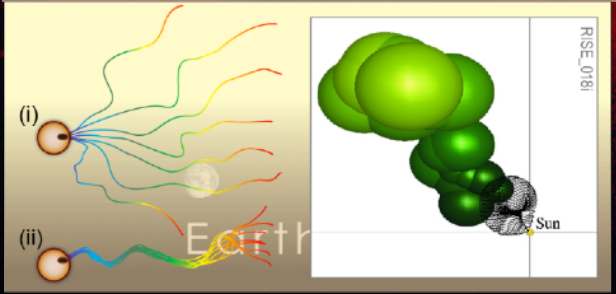
How the ionospheric layers refract different frequencies

Earth

Image from http://www.engineeringwall.com/blogs/entry/1-what-is-ionospheric-bending/

Solar Type II & III Bursts

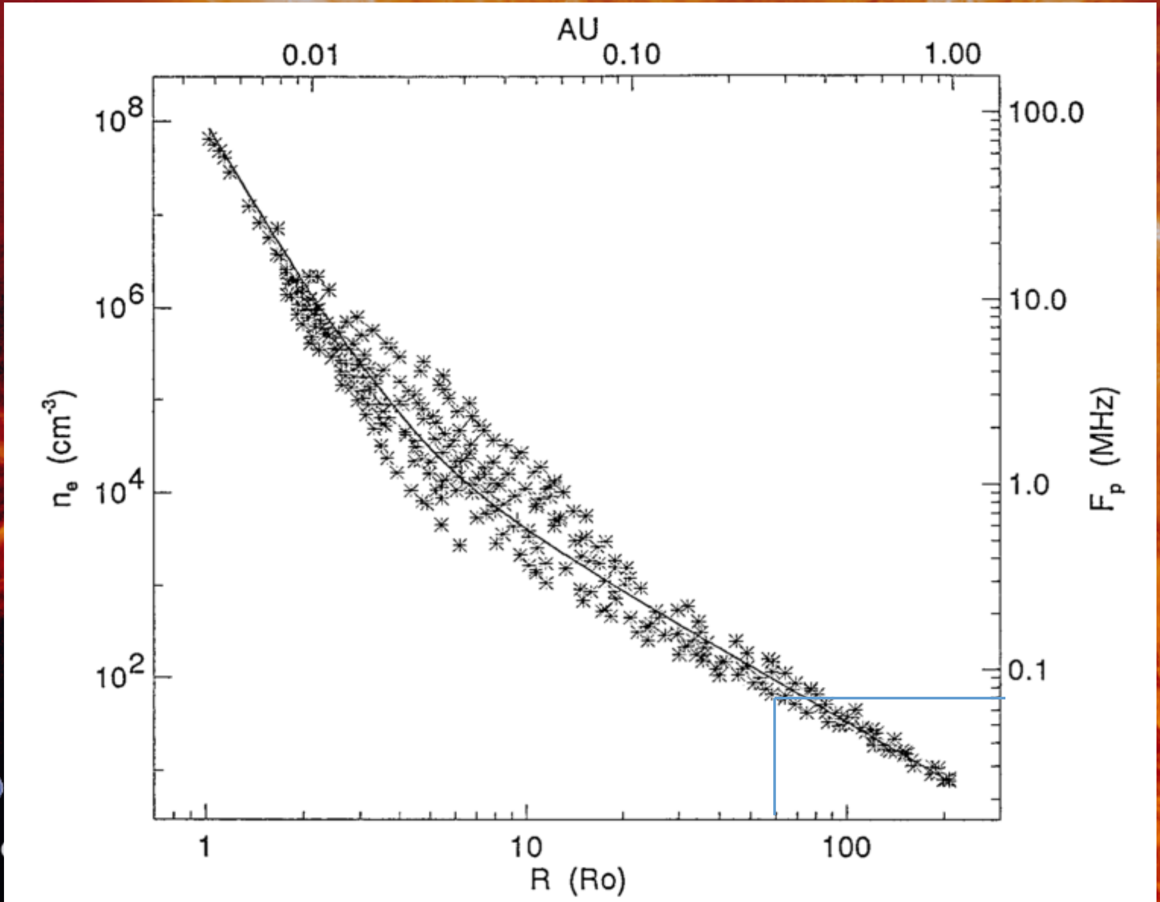




Figures from SunRISE Concept Study

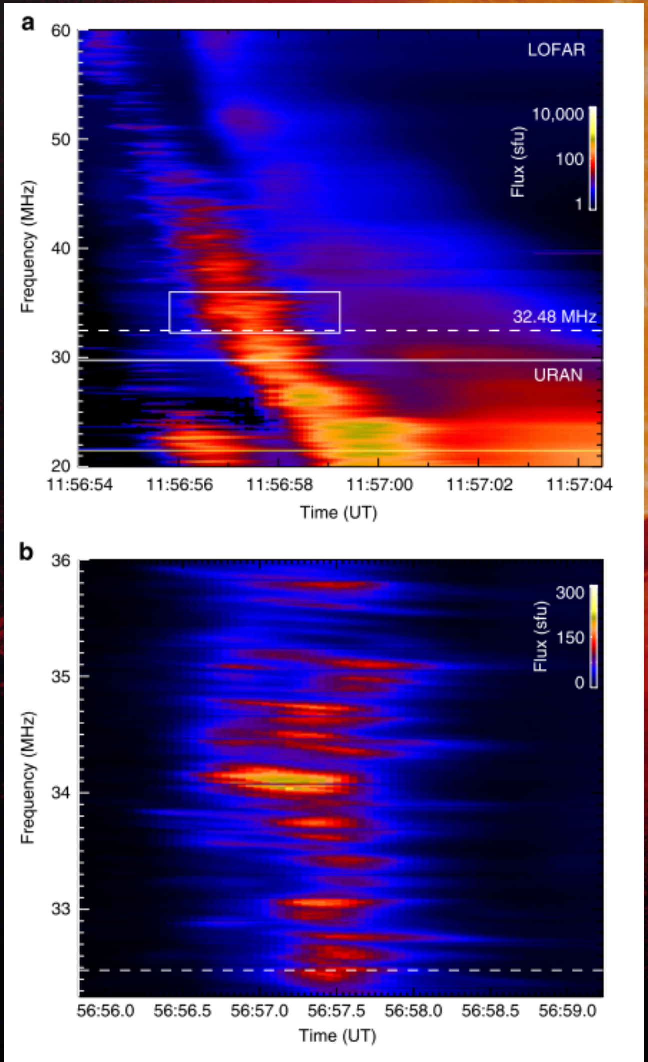
Bougeret, J.-L., M. L. Kaiser, P.J. Kellogg, et al., "WAVES: The Radio and Plasma Wave Investigation on the WIND Spacecraft", *Space Sci Rev*, 71, 5, 1995.

Radio Bursts Trace Plasma Density



0.5 AU => .07 MHz

Leblanc et al. 1998



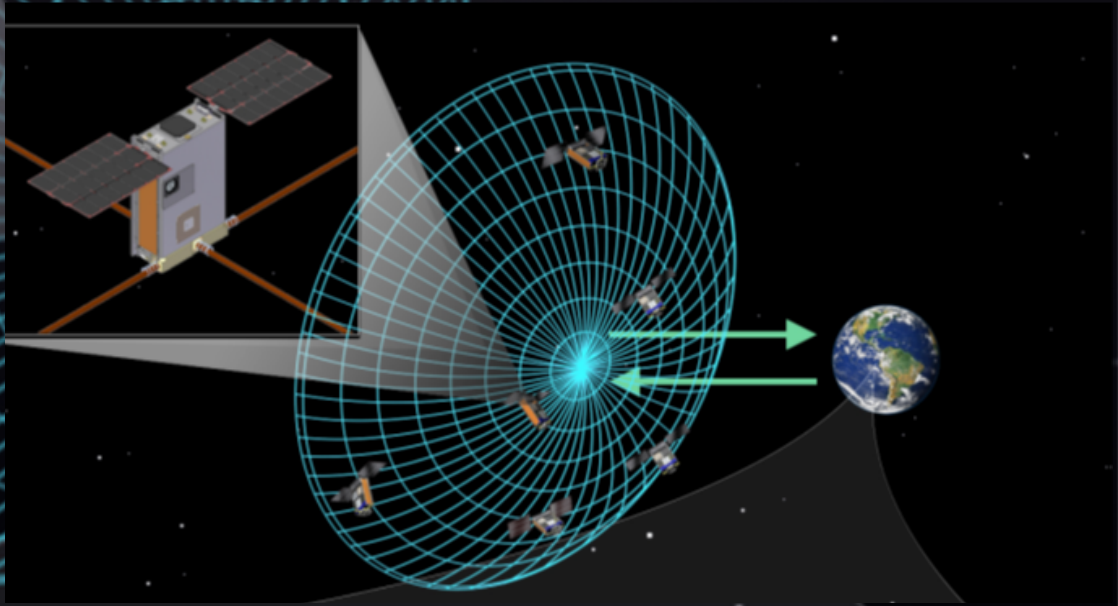
Ultra fine detail reflects turbulent transport

Strong Type IIs seen with every major SEP event, Space Weather Forecasting?

- Winter et al. *ApJ* 809:105 (19pp), 2015 August 10
- Kontar et al. 2017 using LOFAR data

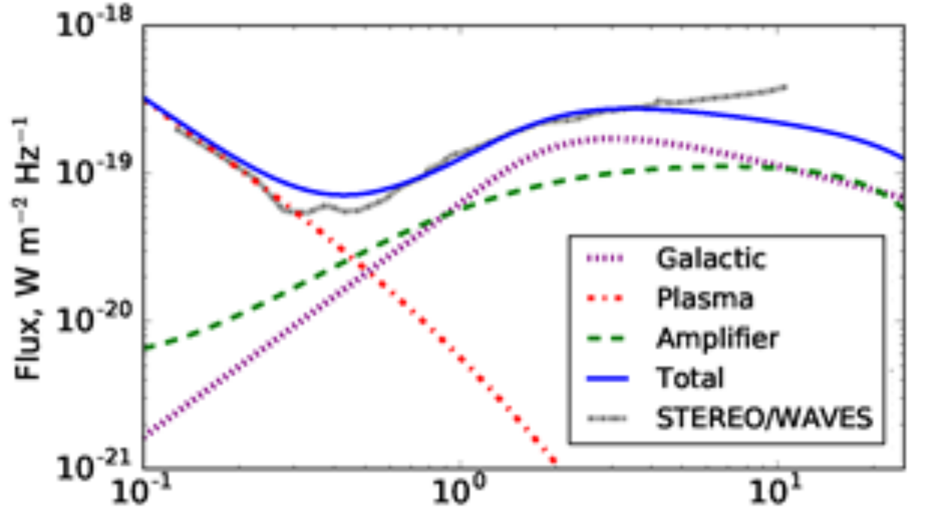
SunRISE – Earth Orbiting Array

- SunRISE – Sun Radio Interferometer Space Experiment
- Heliophysics Explorers Mission of Opportunity
- Currently in Phase A
- Will launch 2022 if funded
- 6 CubeSats in GEO Graveyard Orbit
- Track Bursts to 20 Rs



Signal to Noise Calculation

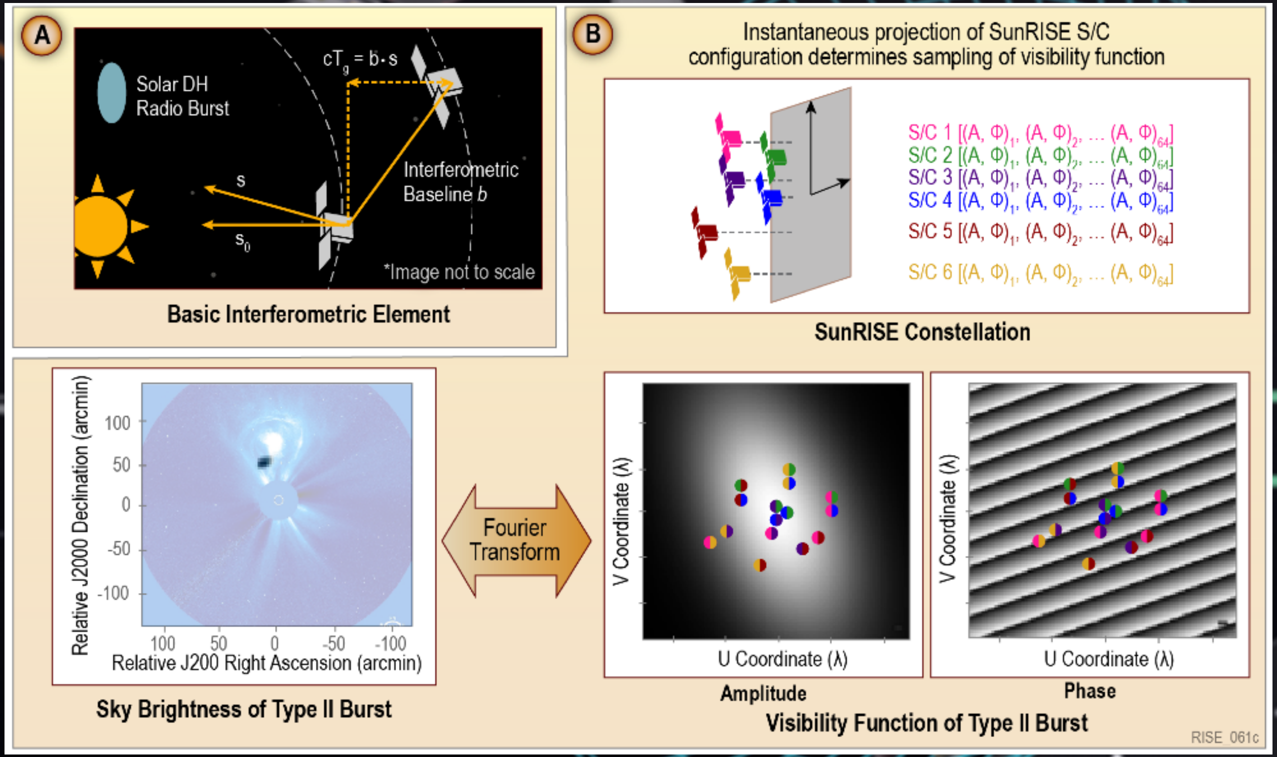
- Assume 5 m dual polarization isotropic dipoles (electrically short)
- 4096 channel Polyphase Filter Bank, 0-25 MHz, 6100 Hz channels, 6.6 ms / sec integration, 0.1 sec cadence
- Type II Signals ≈ Galactic & Plasma Noise
- SNR > 10 is attainable



Taken from SunRISE CSR

$$\sigma = \frac{2\,k_B\,T_{sys}}{\eta_s\,A_{eff}\,\sqrt{N(N-1)(N_{IF}\,\Delta T\,\Delta\nu)}}$$

Radio Interferometry Basics



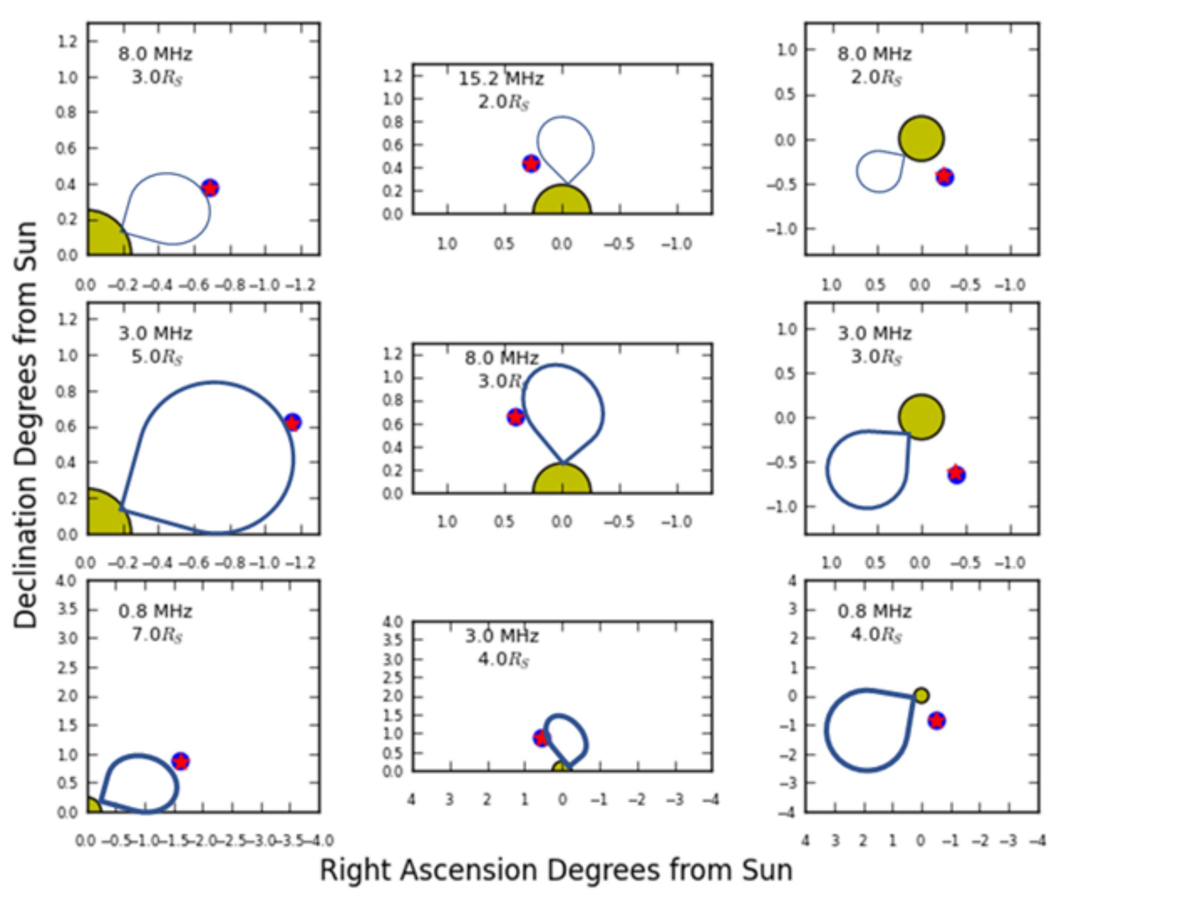
$$\mathcal{V}(u,v,w) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} A_N(l,m) I(l,m) \times \exp\left\{-j2\pi\left[ul + vm + w\left(\sqrt{1-l^2-m^2}-1\right)\right]\right\} \frac{dl\,dm}{\sqrt{1-l^2-m^2}}.$$

- Compute UVW from GPS Files
- Compute Visibilities from Integral definition
- Insert into CASA MS file
- Add Thermal & Phase Noises
- Image & Analysis

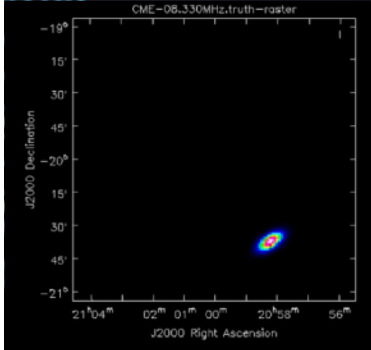
Taken from SunRISE CSR

CASA by McMullin, J. P., et al. 2007, Astronomical Data Analysis Software and Systems XVI, 127.

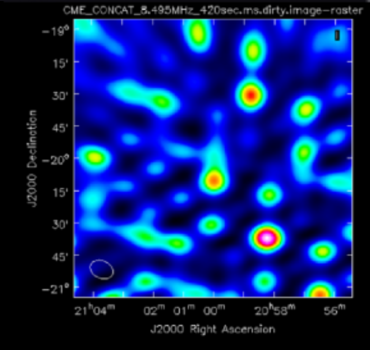
SunRISE Localization



Truth



Dirty Image



Legend

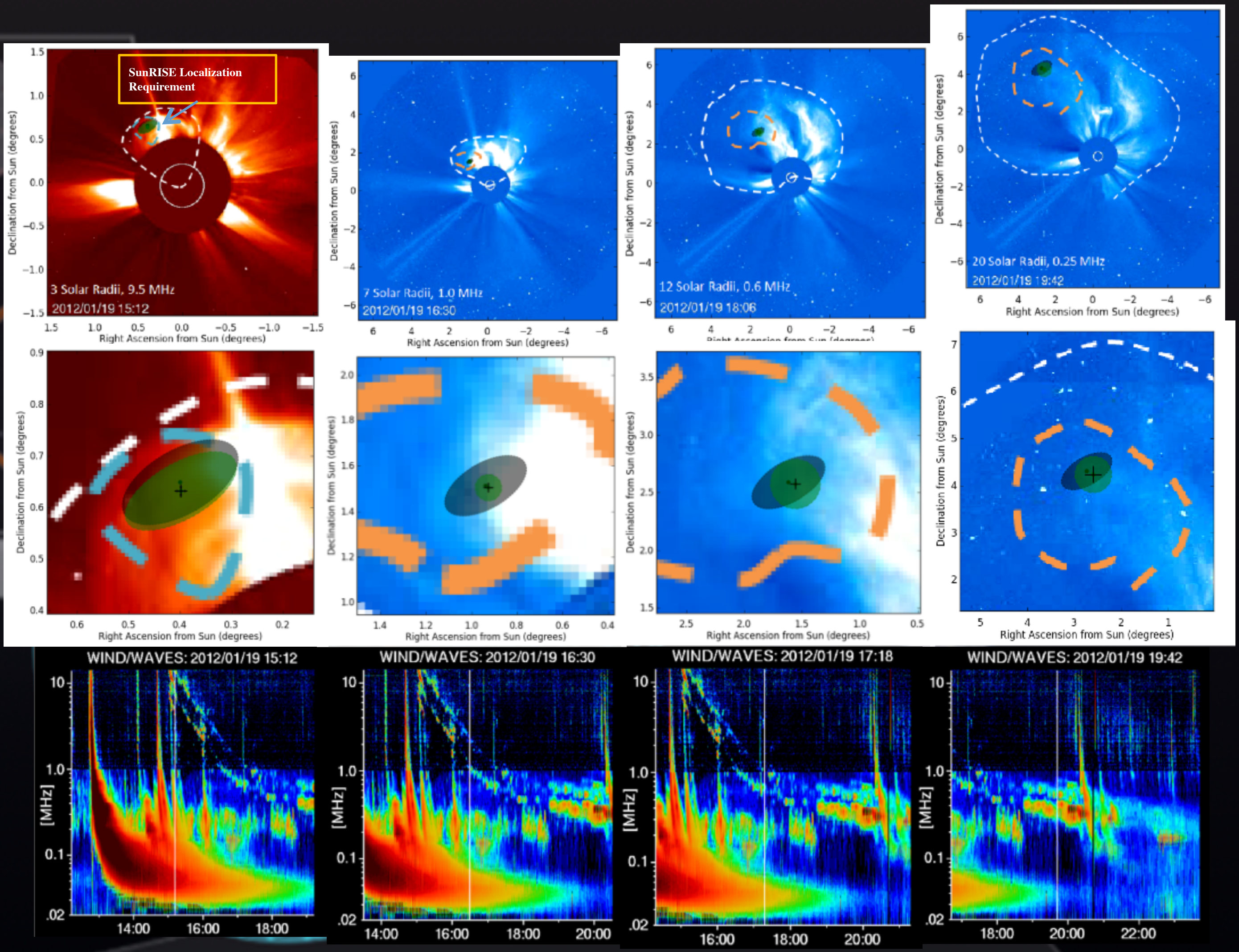
Big Dashed Line:
All Disturbed

Small Dashed Line:
1/3 Size of CME Base Requirement

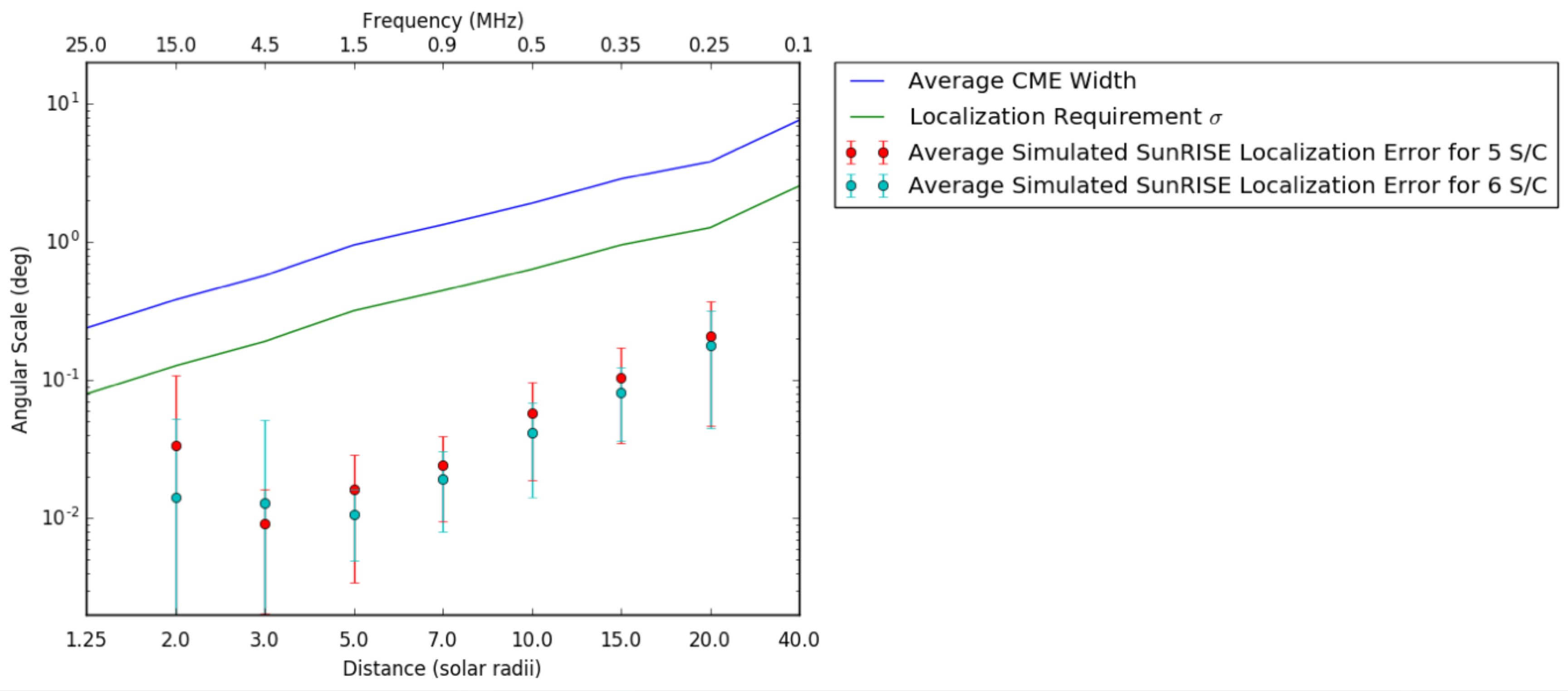
Black Ellipse:
Truth Input

Green Ellipse:
Array Reconstruction

Error Bars:
1 sigma 5 S/C error



SunRISE Performance on Localizing ‘Small’ Sourc



Scattering

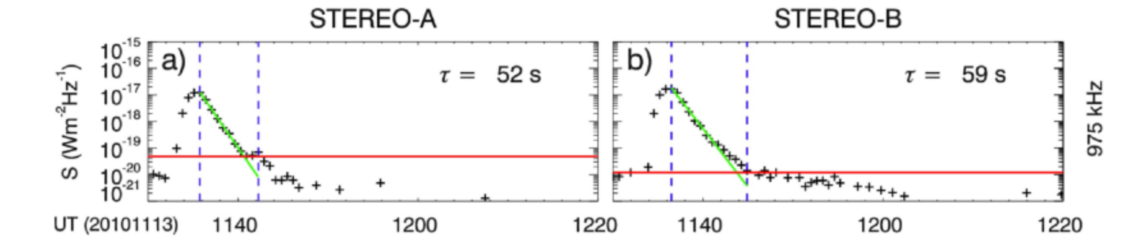
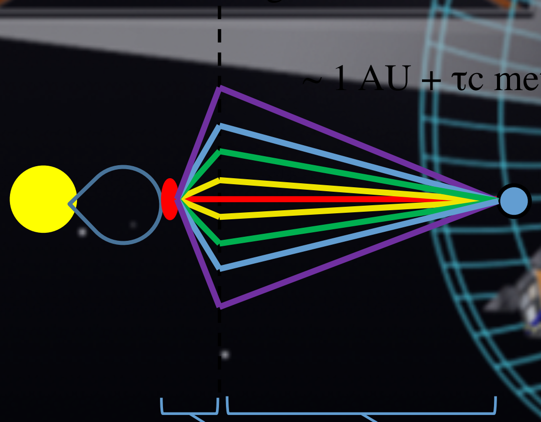


Figure 2. Radio measurements of the 2010 November 13 type III burst. (a)–(h) Fixed-frequency light curves of the radio flux density recorded by *STEREO-A* and *STEREO-B* for four frequency channels. The red lines show median values in the given time intervals. The dashed lines denote peak fluxes and last points above the median values. The green lines show the results of decay time fitting (Equation (1)).

Krupar et al. *ApJ* 857:82 (7pp), 2018 April 20

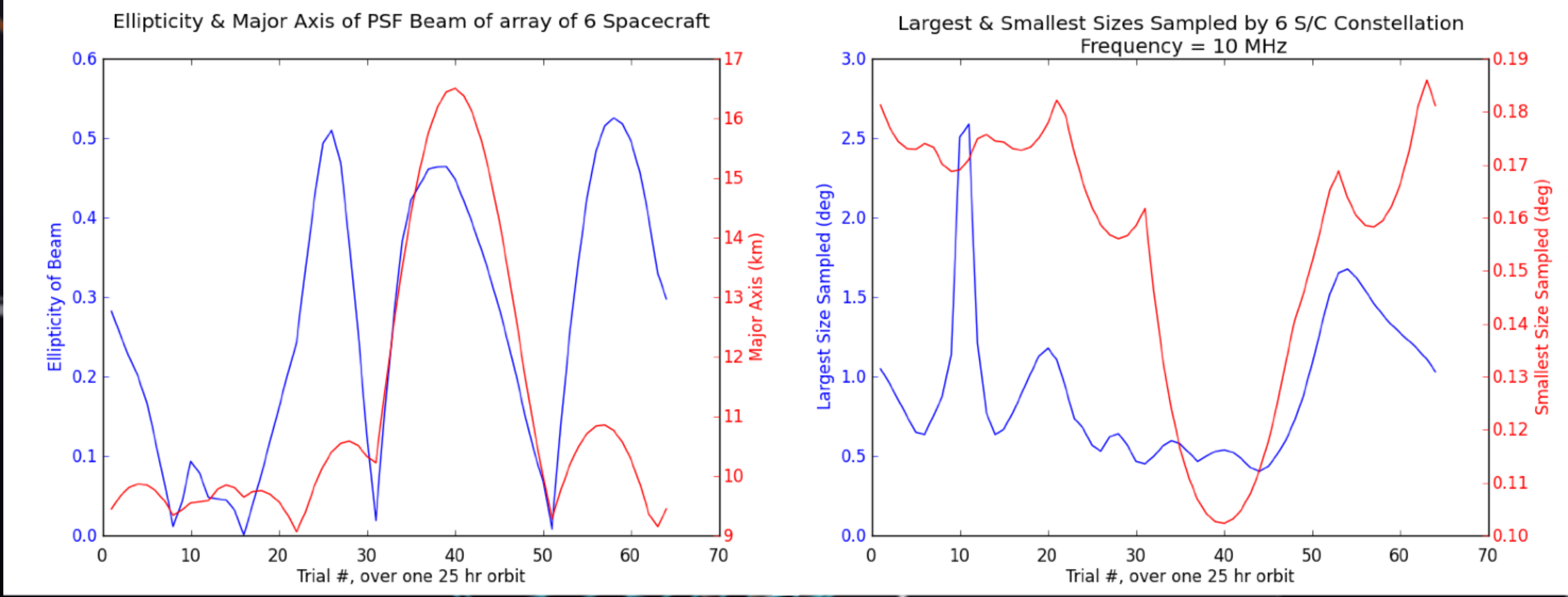
$$\Theta \approx \arctan\left(\frac{\tau c}{1\ AU}\right) \approx \frac{\tau c}{1\ AU}$$ Scattering Angle

Valid for τc << 1 AU down to 0.3 MHz

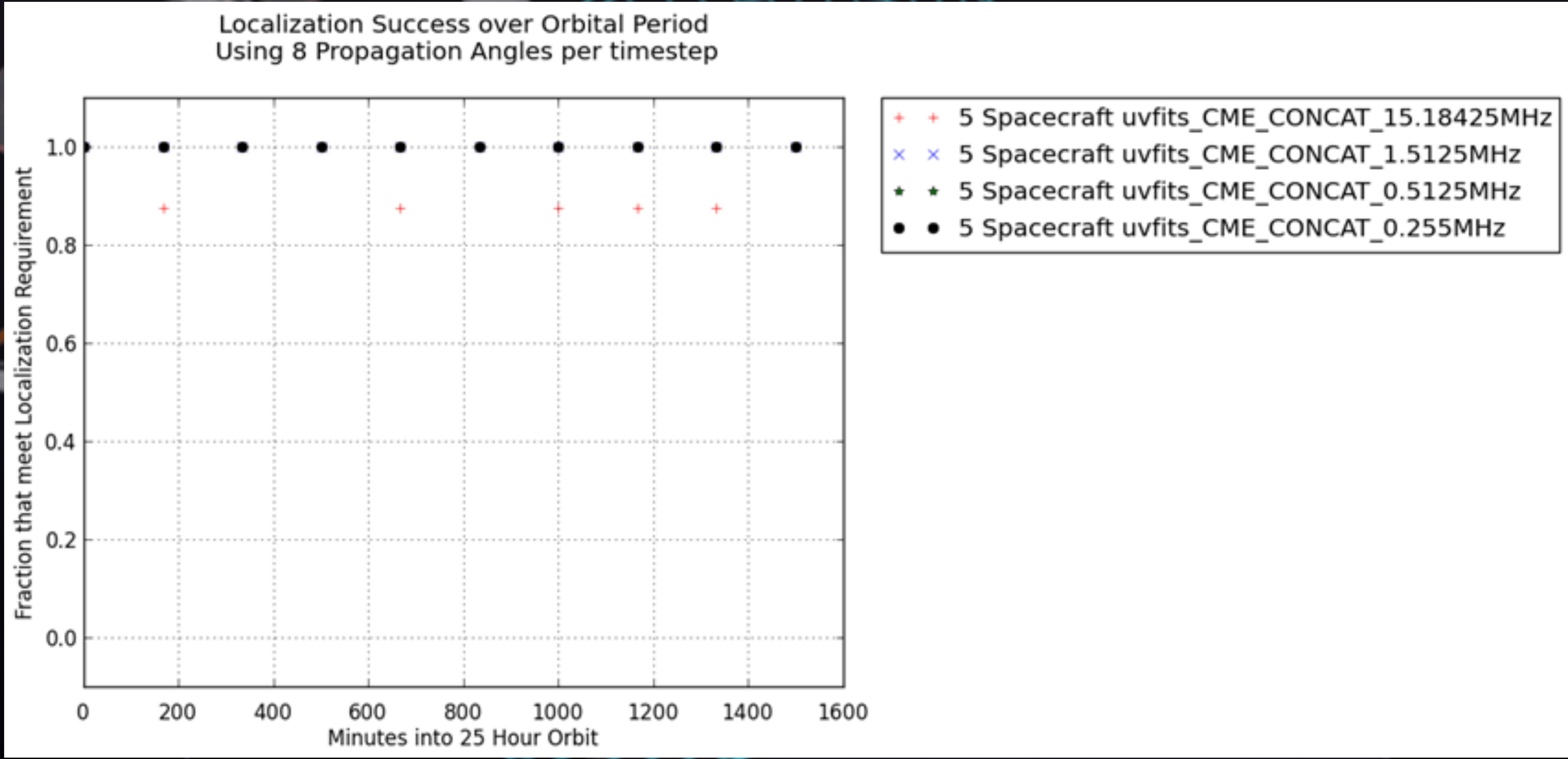


Sky View, Ring expands over time from solid source

Orbiting Arrays are Irregular



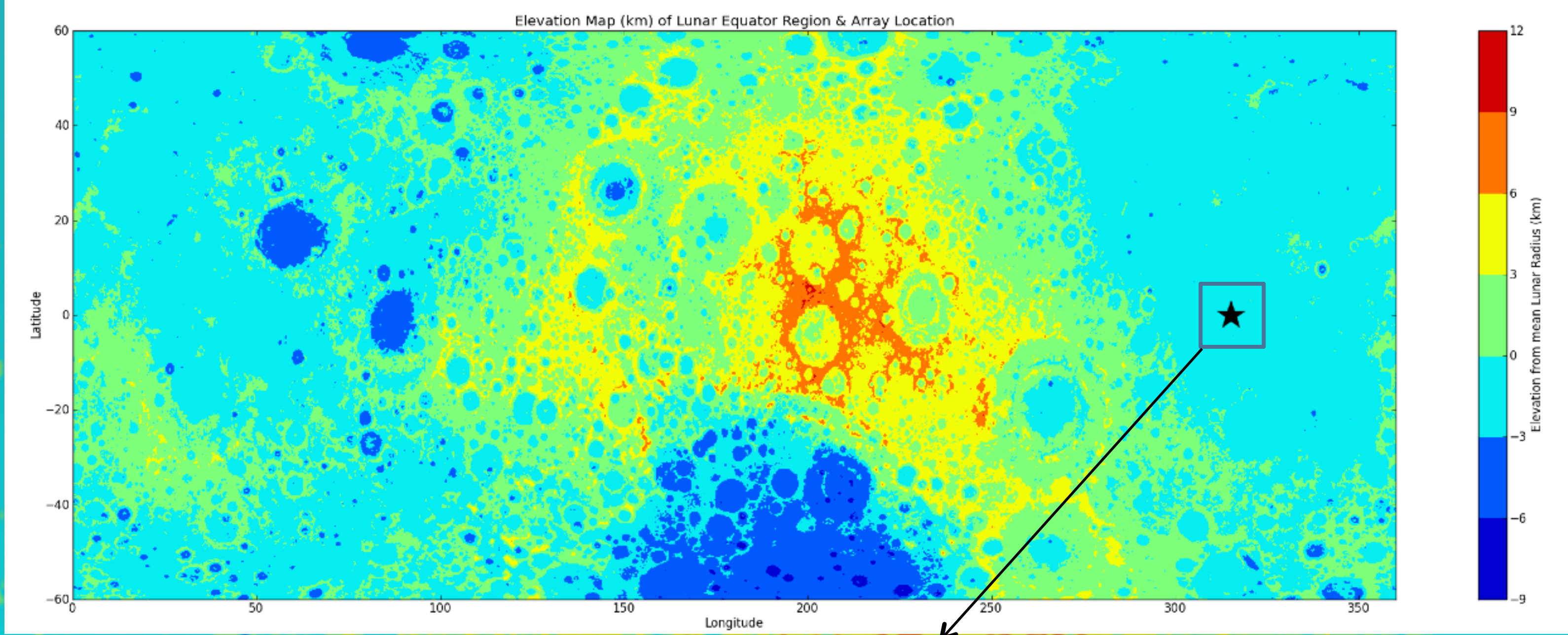
Evaluating Performance over Orbit

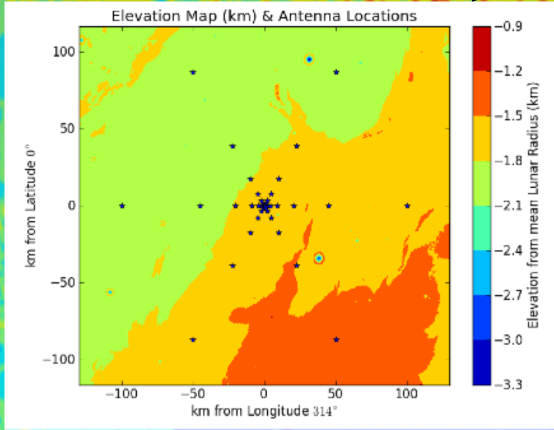


Lunar Surface vs Orbiting Arrays

- Stable
- ~1/3 Sun visibility
- Little Earth AKR Noise
- Easier to sample all scale sizes
- Large Day/Night Difference

- Dynamic
- 100% Sun Visibility ★
- AKR Noise in 10s-100s kHz+
- Cheaper Baseline Cost
- No Day/Night Difference



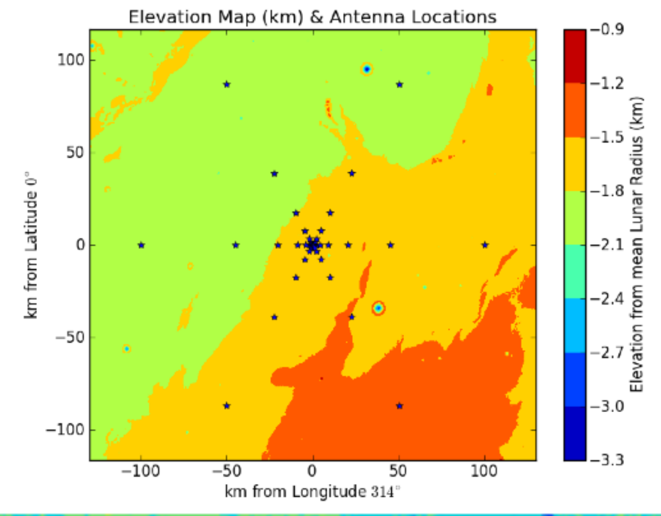


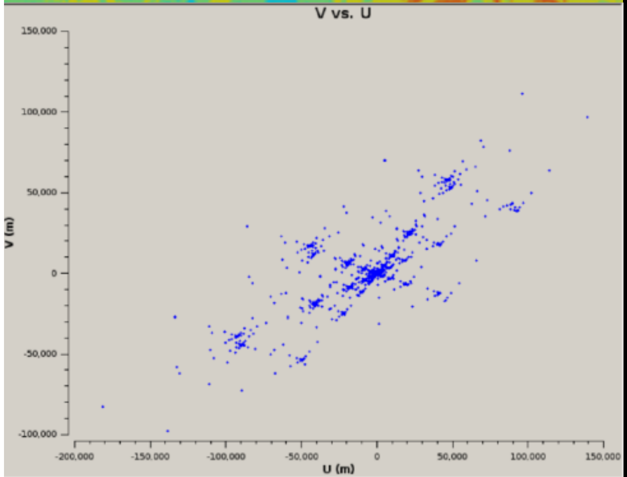
SLDEM 2015
Barker et al. 2016

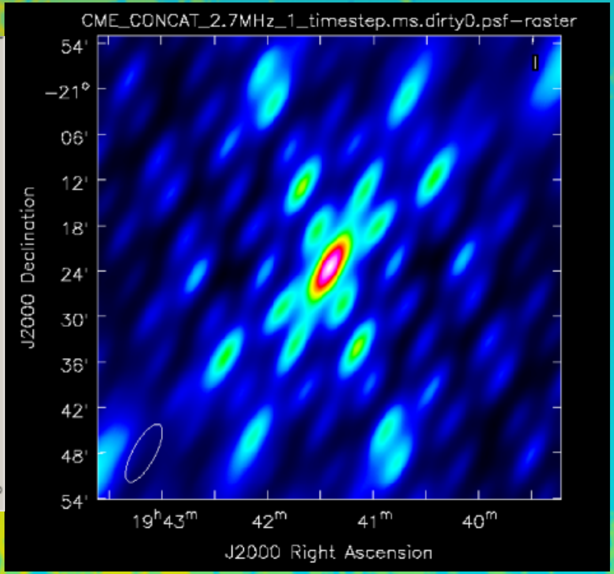
SPICE for coordinate transforms
Acton, C.H.; "Ancillary Data Services of NASA's Navigation and Ancillary Information Facility;" Planetary and Space Science, Vol. 44, No. 1, pp. 65-70, 1996.

6 Radial Arms
10 Logarithmically Spaced Antennas each, 75m – 100km
~3° Lunar Longitude/Arm

UV Coverage & Synthesized Beam



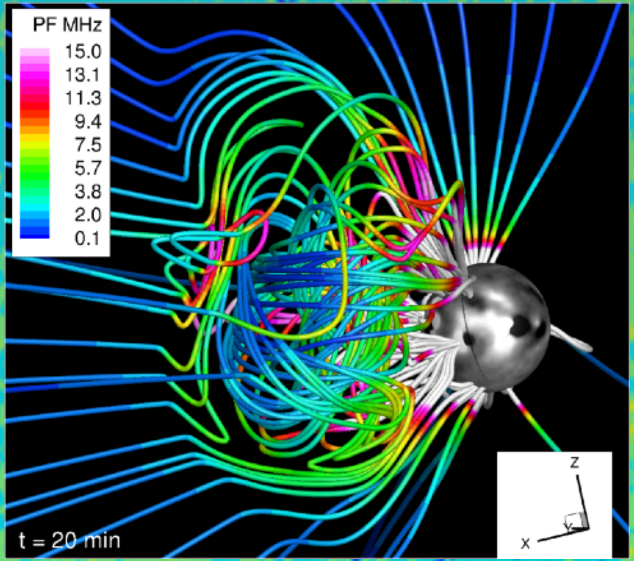




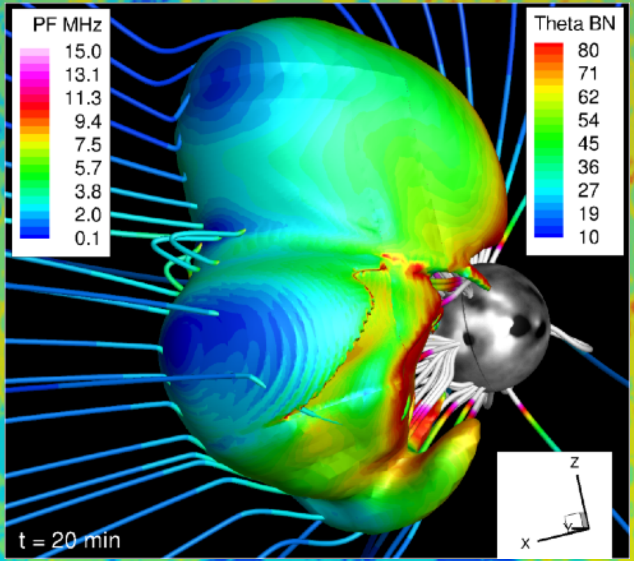
Simulated Date 1/14/2020

CASA by McMullin, J. P., et al. 2007, Astronomical Data Analysis Software and Systems XVI, 127.

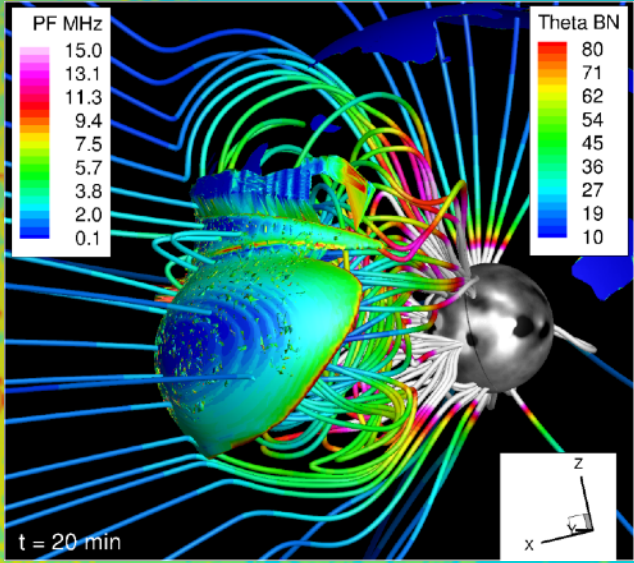
2 Fluid MHD AWSoM Models of CME Eruption
On 2005/05/13 17:20:00, 20 minutes into event



Magnetic Field Lines

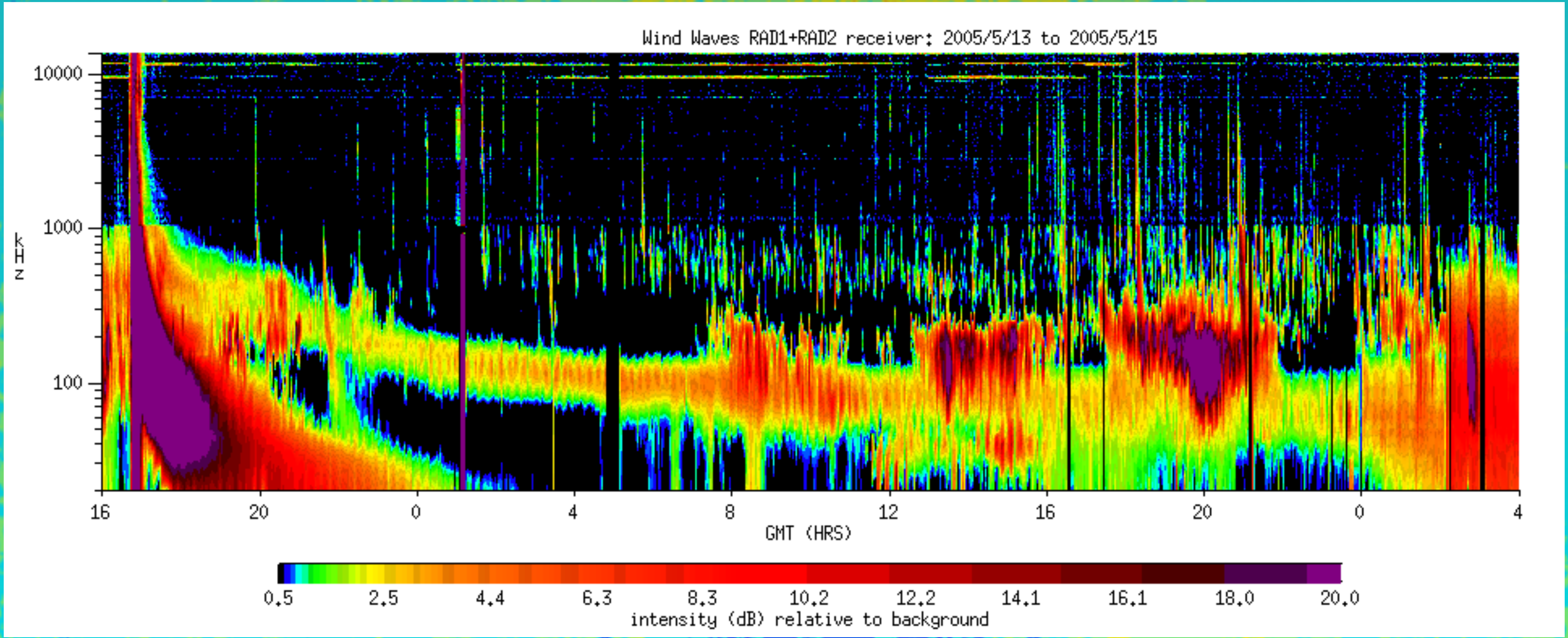


Compression Ratio Shock



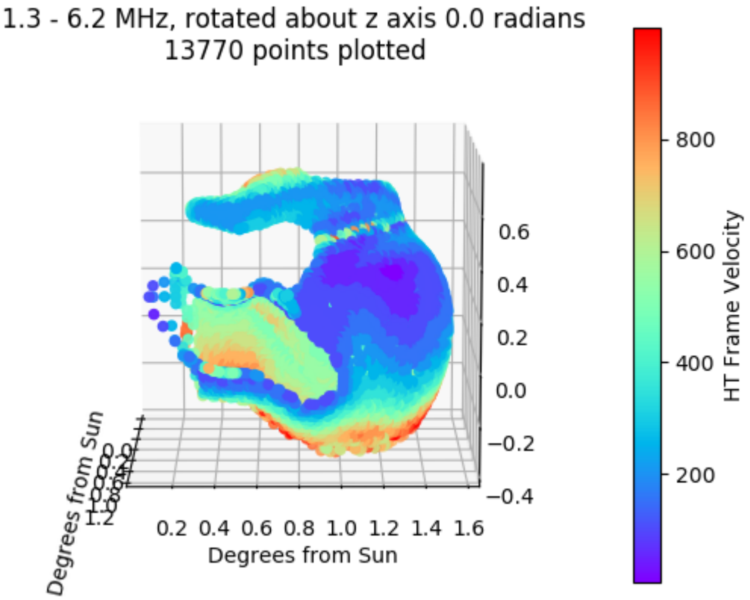
Entropy Ratio Shock

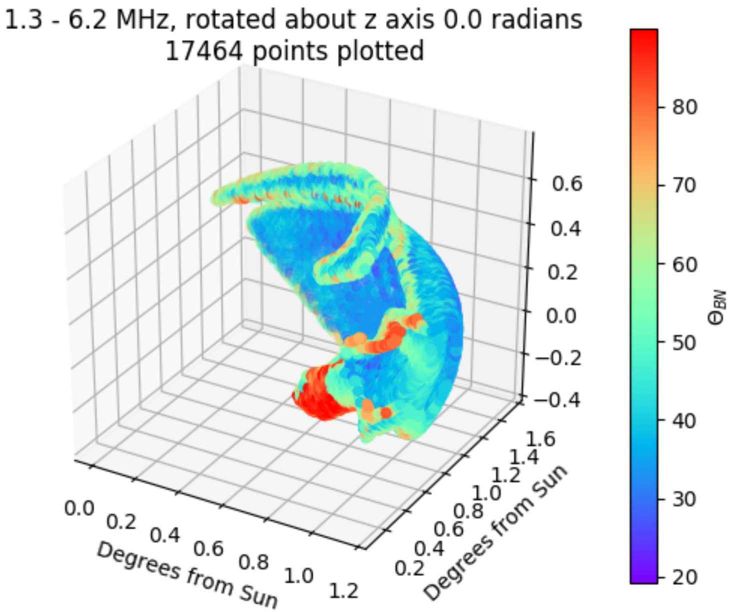
W. B. Manchester, IV et al. Plasma Phys. Control. Fusion 56 (2014) 064006



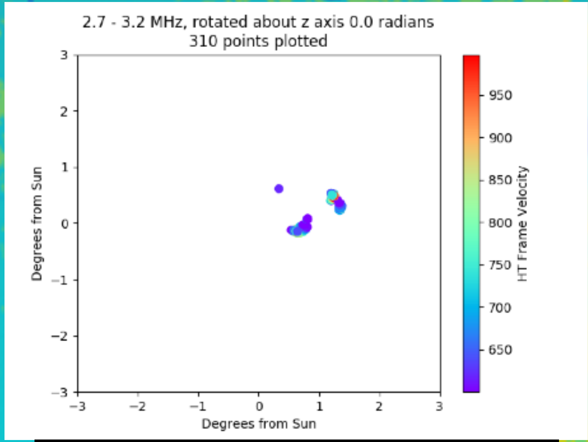
Wind Waves RAD1+RAD2 receiver: 2005/5/13 to 2005/5/15
10000
1000
100
kHz
16
20
0
4
8
12
16
20
0
4
GMT (HRS)
0.5
2.5
4.4
6.3
8.3
10.2
12.2
14.1
16.1
18.0
20.0
intensity (dB) relative to background

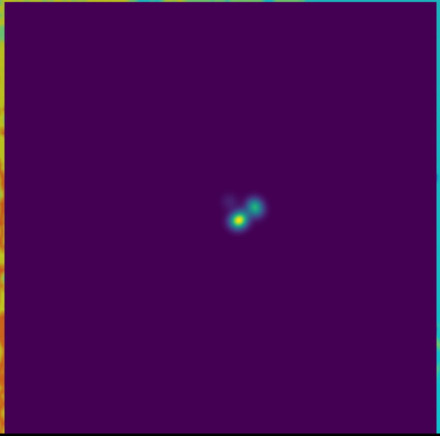
Importing Shock Data & Calculating Plasma Parameters

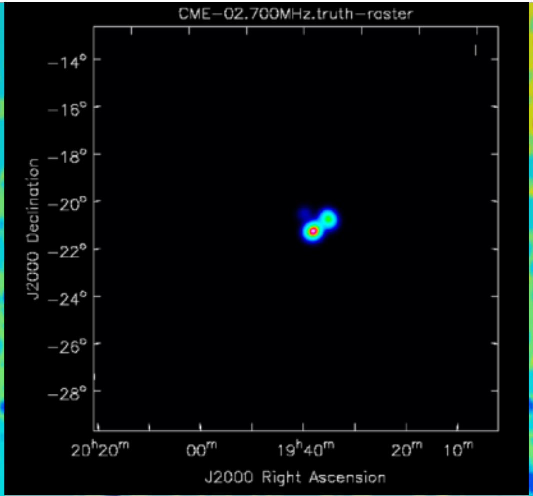


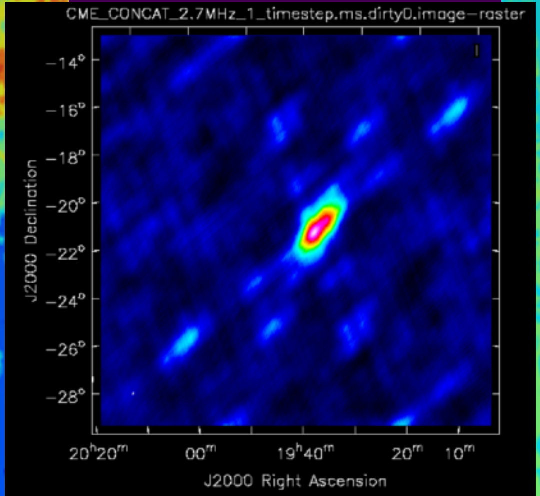


Applying Data Cuts & Exporting to CASA Readable File









Conclusions

- SunRISE can do basic localization of Type II & III Bursts
- Lunar Surface a good location for an array for detailed imaging of Solar Radio Bursts
- Simulation Pipeline is functional and can model response of Orbiting & Lunar Arrays ★

Future Work

- Extend MHD models further into Heliosphere
- Iterate Lunar Array Design & Location(s)
- Create simulated spectra over time, identify correlated plasma parameters
- Address Hardware & Engineering concerns (Lunar Temp & Power)

Thank you SunRISE team!

Questions?

Thank you NESS!

Max and Min scale sizes

1 Rs = .265 deg, 0.5 AU = 28.5 deg, 1AU = 215 Rs

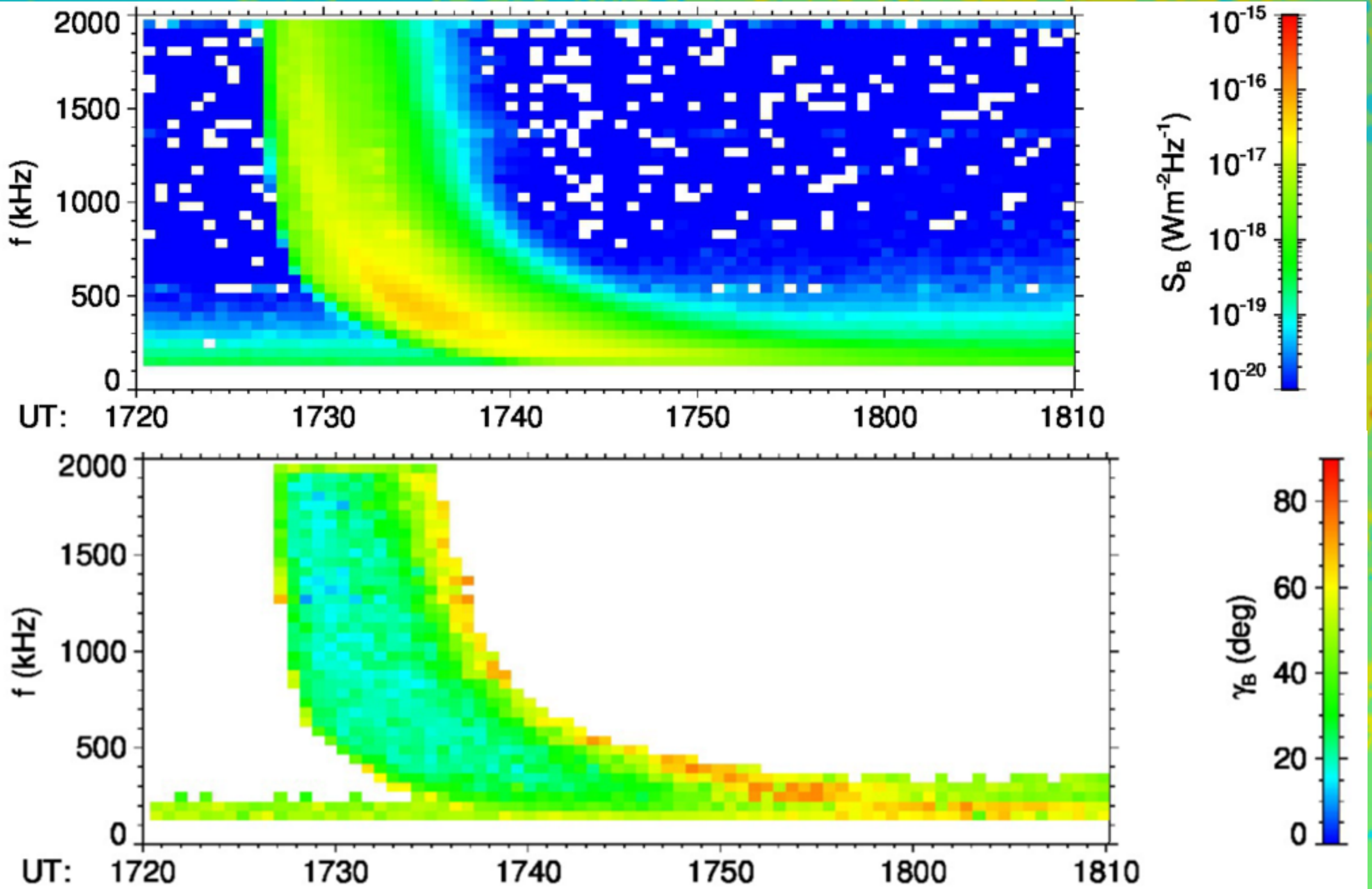
60 Rs => .07 MHz = > λ = 4285.7 m => Θ *D = 299575 (deg meters)
60 deg Θ => 4992.9 m baselines,
6Rs = 1.59 deg Θ => 188412 m baselines , **resolve 10% the distance out from Sun** ★

4 Rs = 2.0 MHz => λ = 150 m => Θ *D = 10485 (deg meters)
.1 deg Θ = 104850 m 'down to 10% the dist out from sun'
60 deg Θ = 175 m **resolve largest scale size**

$$\theta = 1.220 \frac{\lambda}{D}$$

Min = 150 m (75 m radius)
Max = 200 km (100 km radius)

Scattering



Krupar et al. 2014
17:20 to 18:10 UT on
28 January 2008
apparent source size γ_B
and flux density of a
Type III

DH Signal Chain Voltage

$$\langle V_{\mathrm{amp}}^2 \rangle = S D \frac{\lambda^2}{4\pi} 4 R_{\mathrm{ant}} \frac{\left| Z_{\mathrm{amp}} \right|^2}{\left| Z_{\mathrm{amp}} + Z_{\mathrm{ant}} \right|^2}$$

D Directivity in frequency range, the directivity is 1.7 dBi, as expected from a Hertzian dipole, and it never exceeds 2 dB, allowing continuous, unobstructed view of the inner heliosphere

S flux density (W m^{-2} Hz^{-1})

λ is the wavelength of the radiation,

R_{ant} is the resistance of the antenna,

Z_{ant} complex impedance of the antenna

Z_{amp} complex impedance of the amplifier

Fraction determined by method-of-moments codes, is ~-6 to -3 dB