Tracking Solar Type II Bursts with Space Based Radio Interferometers

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Outline

- What are Solar Radio Bursts?
- SunRISE Array Pipeline
- Lunar Surface Array Pipeline
- MHD Simulations
- Conclusions
Why Space? Ionospheric Cutoff < 10 MHz

How the ionospheric layers refract different frequencies

Image from http://www.engineeringwall.com/blogs/entry/1-what-is-ionospheric-bending/
Solar Type II & III Bursts

Figures from SunRISE Concept Study

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?

- 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 $\approx$ Galactic & Plasma Noise
- SNR $>10$ is attainable

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

Taken from SunRISE CSR
Radio Interferometry Basics

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

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

Taken from SunRISE CSR
SunRISE Localization
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
Over 80 Trials
SunRISE Performance on Localizing ‘Small’ Sources

![Graph showing performance vs. distance and frequency]
Scattering

\[ \Theta \approx \arctan\left( \frac{\tau c}{1 \text{AU}} \right) \approx \frac{\tau c}{1 \text{AU}} \text{ radians} \]

Valid for \( \tau c \ll 1 \text{ AU} \) down to 0.3 MHz

Scattering Screen

\( \sim 1 \text{ AU} + \tau c \) meters traveled

Sky View, Ring expands over time from solid source
Orbiting Arrays are Irregular
Evaluating Performance over Orbit

Localization Success over Orbital Period
Using 8 Propagation Angles per timestep

<table>
<thead>
<tr>
<th>Fraction that meet Localization Requirement</th>
<th>Minutes into 25 Hour Orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0</td>
</tr>
<tr>
<td>0.8</td>
<td>200</td>
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<tr>
<td>0.6</td>
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<td>600</td>
</tr>
<tr>
<td>0.2</td>
<td>800</td>
</tr>
<tr>
<td>0.0</td>
<td>1000</td>
</tr>
</tbody>
</table>

- 5 Spacecraft uvfits_CME_CONCAT_15.18425MHz
- 5 Spacecraft uvfits_CME_CONCAT_1.5125MHz
- 5 Spacecraft uvfits_CME_CONCAT_0.5125MHz
- 5 Spacecraft uvfits_CME_CONCAT_0.255MHz
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

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

Simulated Date 1/14/2020

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

Importing Shock Data & Calculating Plasma Parameters

1.3 - 6.2 MHz, rotated about z axis 0.0 radians
13770 points plotted

1.3 - 6.2 MHz, rotated about z axis 0.0 radians
17464 points plotted
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)

Questions?

Thank you SunRISE team! Thank you NESS!
Max and Min scale sizes

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

60 Rs \Rightarrow .07 \text{ MHz} \Rightarrow \lambda = 4285.7 \text{ m} \Rightarrow \Theta * D = 299575 \text{ (deg meters)}

60 \text{ deg } \Theta \Rightarrow 4992.9 \text{ m baselines},

6 \text{ Rs} = 1.59 \text{ deg } \Theta \Rightarrow 188412 \text{ m baselines, resolve 10% the distance out from Sun}

4 \text{ Rs} = 2.0 \text{ MHz} \Rightarrow \lambda = 150 \text{ m} \Rightarrow \Theta * D = 10485 \text{ (deg meters)}

.1 \text{ deg } \Theta = 104850 \text{ m ‘down to 10% the dist out from sun’}

60 \text{ deg } \Theta = 175 \text{ m resolve largest scale size}

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

\text{Min = 150 m (75 m radius)}

\text{Max = 200 km (100 km radius)}
Scattering

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

DH Signal Chain Voltage