Anisotropic Radio-wave Scattering and the Source Positions, and Sizes of Interplanetary Type III Bursts

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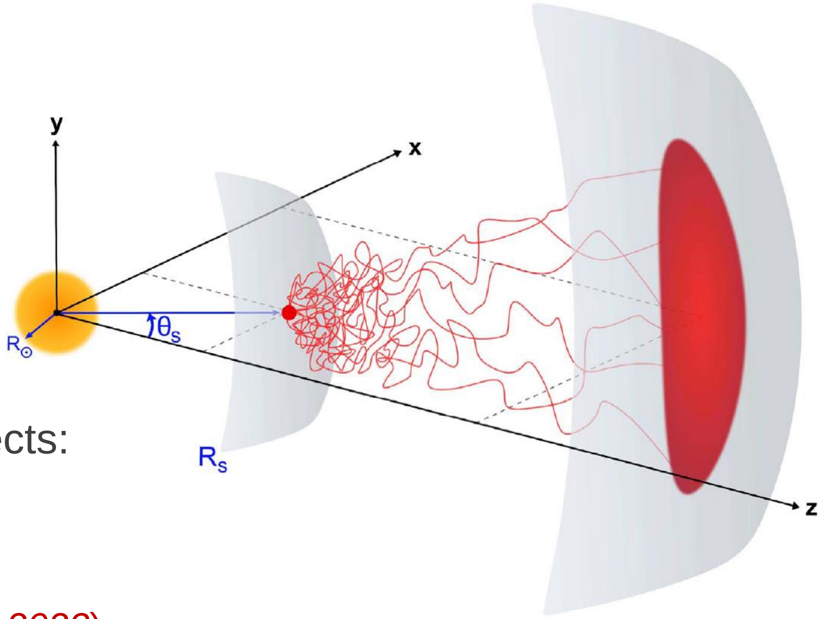
Anisotropic Radio-wave Scattering & the Parker Spiral



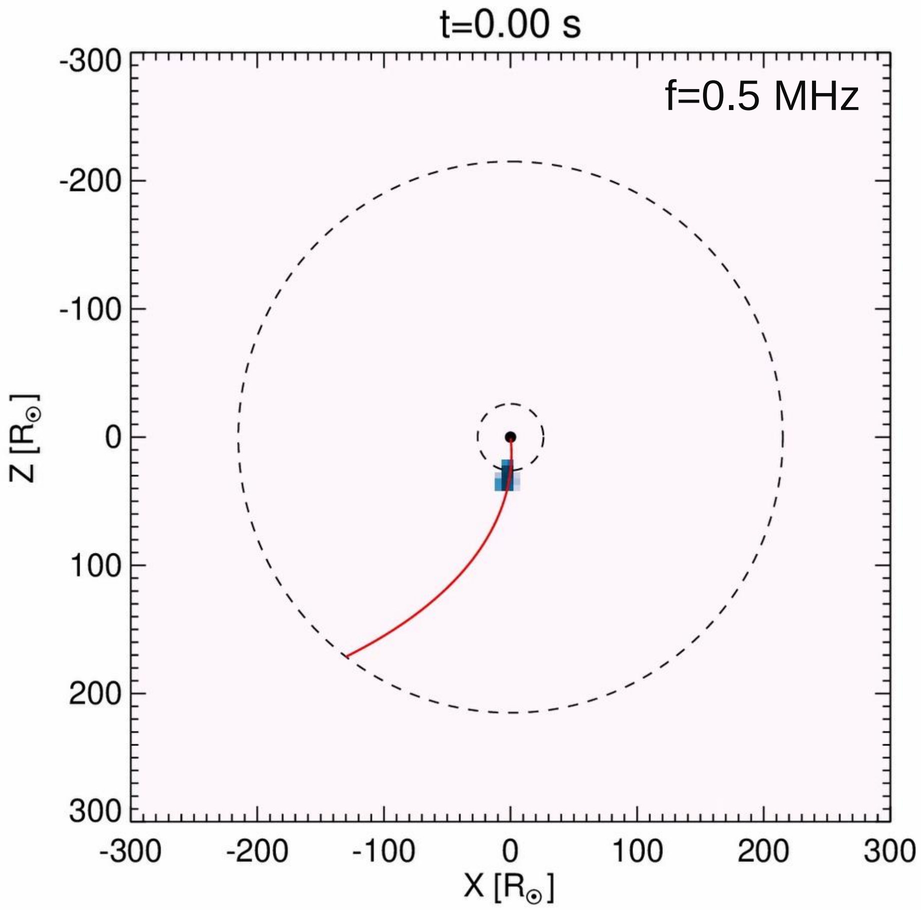
Anisotropic radio-wave scattering affects:

- Time profile
  - ⇢ Extended decay time
  - ⇢ Delayed peak time (*Chen et al. 2023*)
- Apparent sizes (*Kontar et al. 2017, 2023*)
- **Apparent positions** (*Kontar et al. 2017, 2023*)

Kontar et al. (2023) find $\alpha = 0.25$ for fundamental emission, and $\alpha = 0.4$ for harmonic emission (matching simulations to observations)

Radio emission propagates preferentially along the guiding magnetic field.

Above 1 MHz, ambient magnetic field is approximately radial. Below 1 MHz, the curvature of the Parker spiral becomes noticeable.

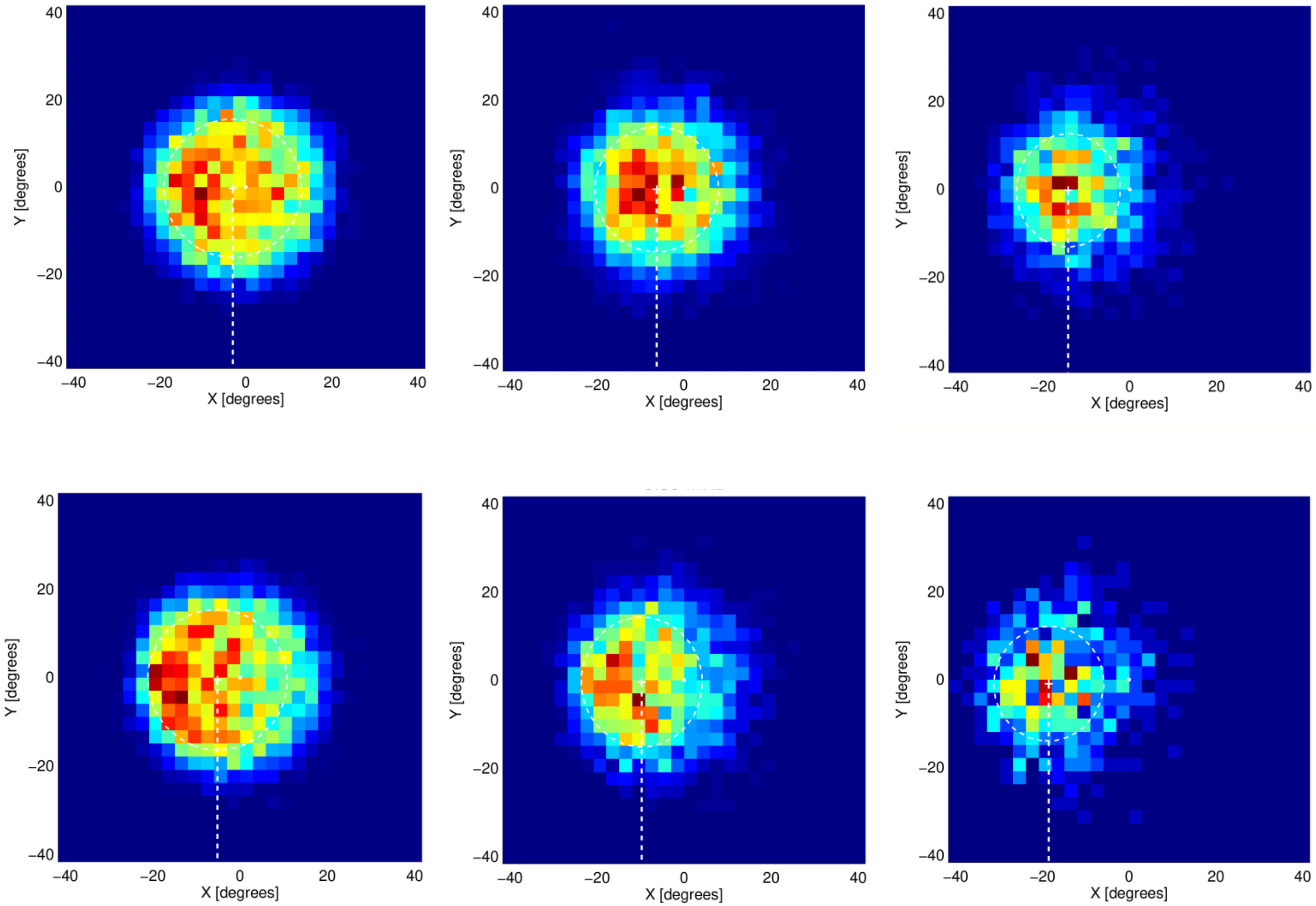


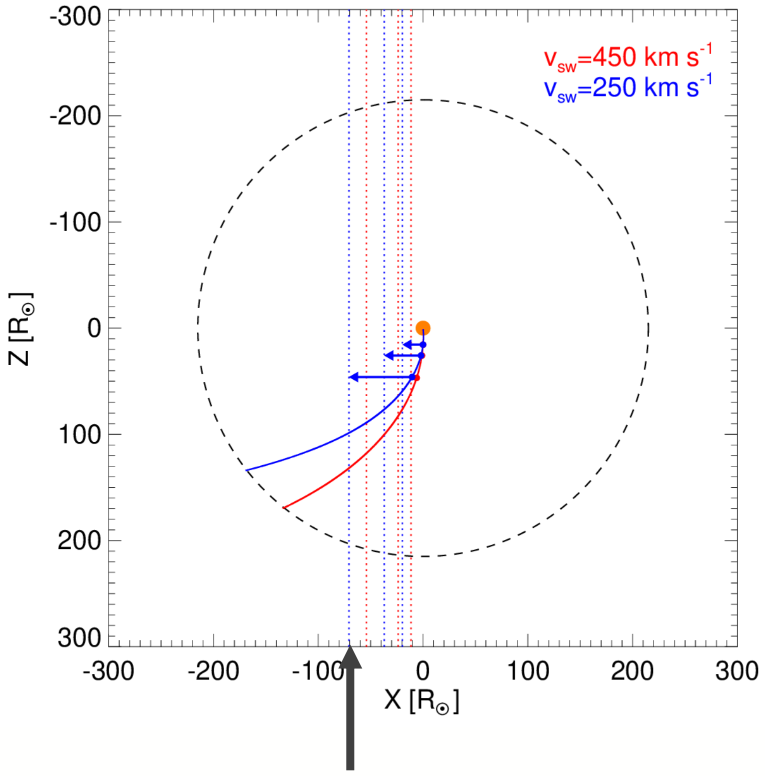
Simulated Images at Decreasing Frequencies

0.9 MHz | 0.5 MHz | 0.25 MHz

v_{sw} 450 km s^{-1}

v_{sw} 250 km s^{-1}





Observed sky-plane centroids

Multi-spacecraft Simulations

$N = 2\times10^7$

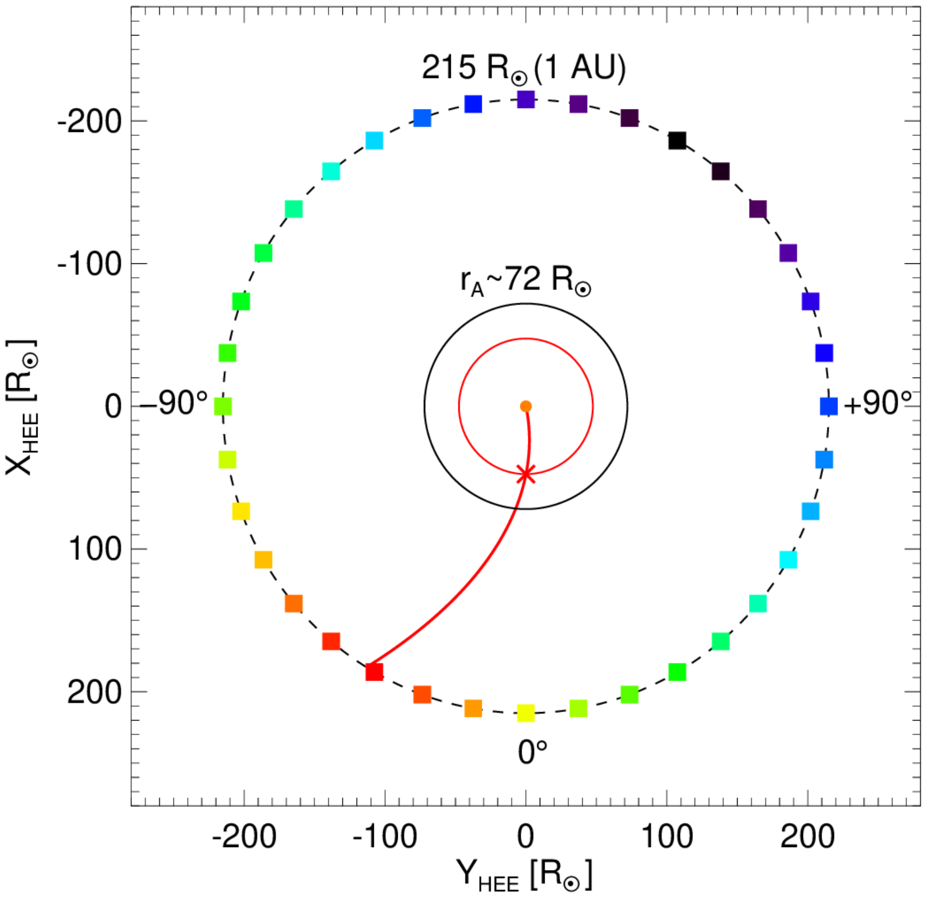
$f_{obs} = 0.25$ MHz

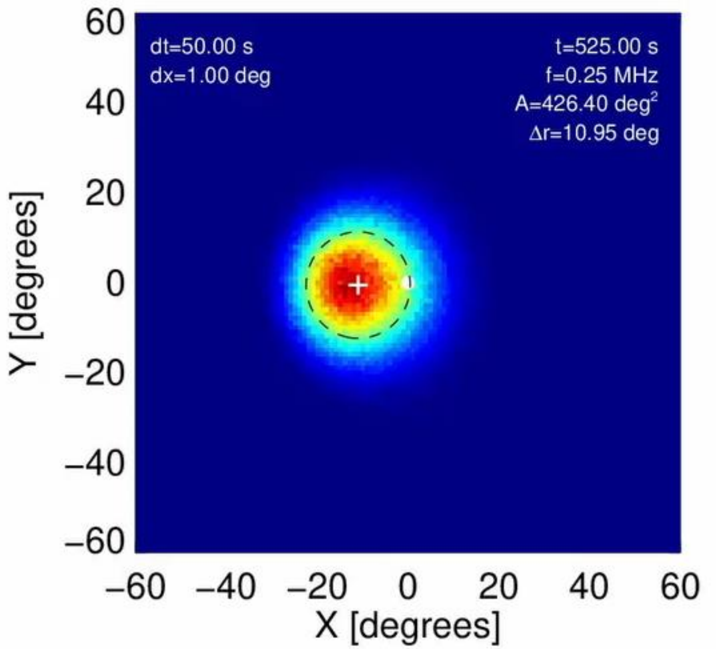
$f_{obs}/f_{pe} = 2.0$ (harmonic)

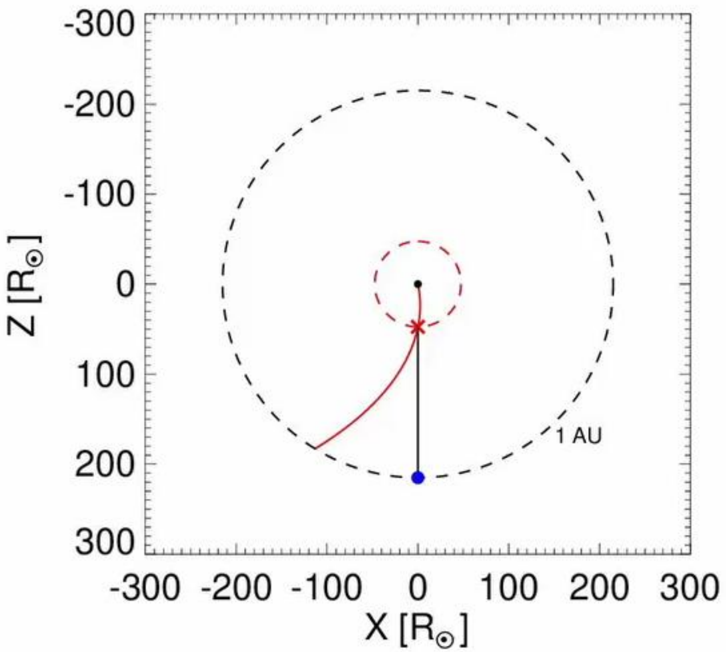
$\epsilon = 1.0$

$\alpha = 0.4$

- Photons collected 360° around the heliosphere
- Peak intensity is offset from the emitter location by -30°
- Images at angles opposite that of the peak intensity are obscured by the plasma frequency surface

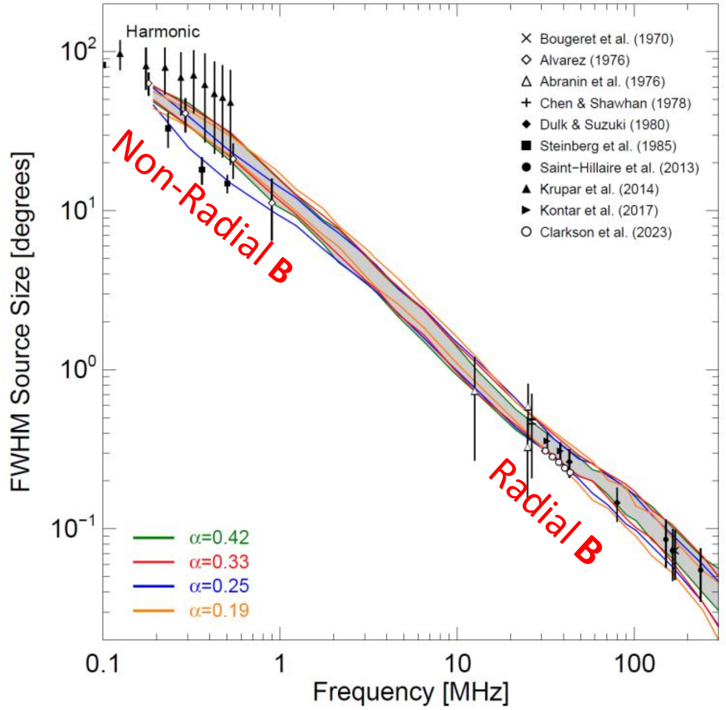




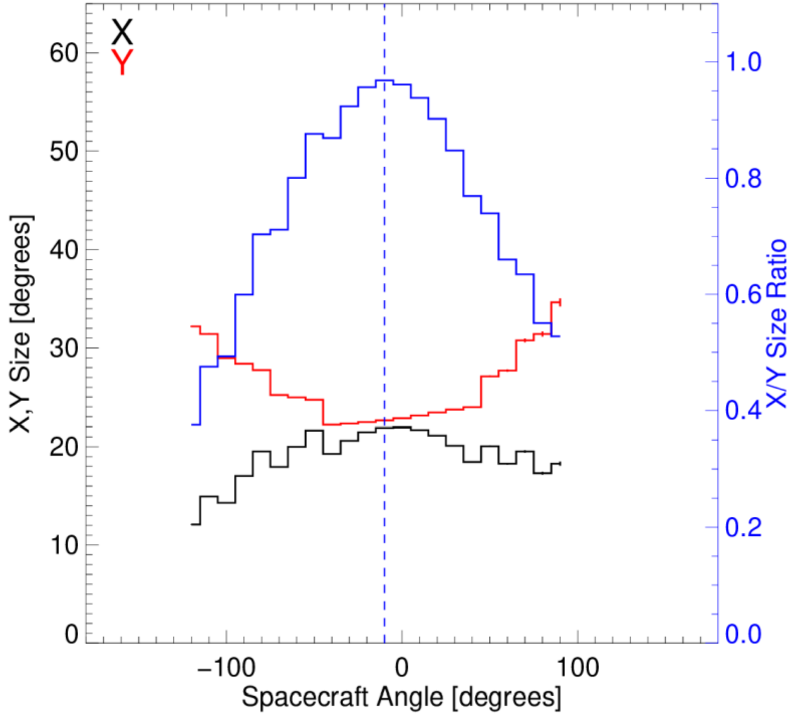


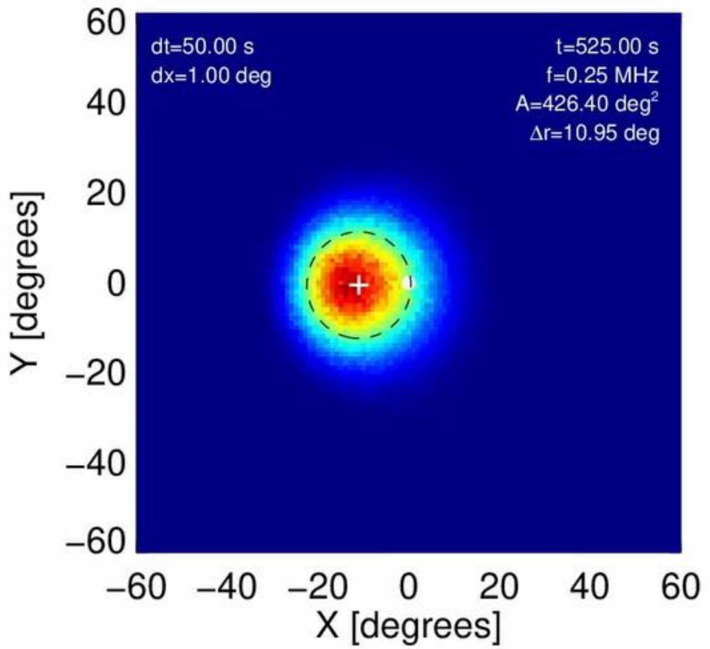
Simulated Apparent Source Sizes

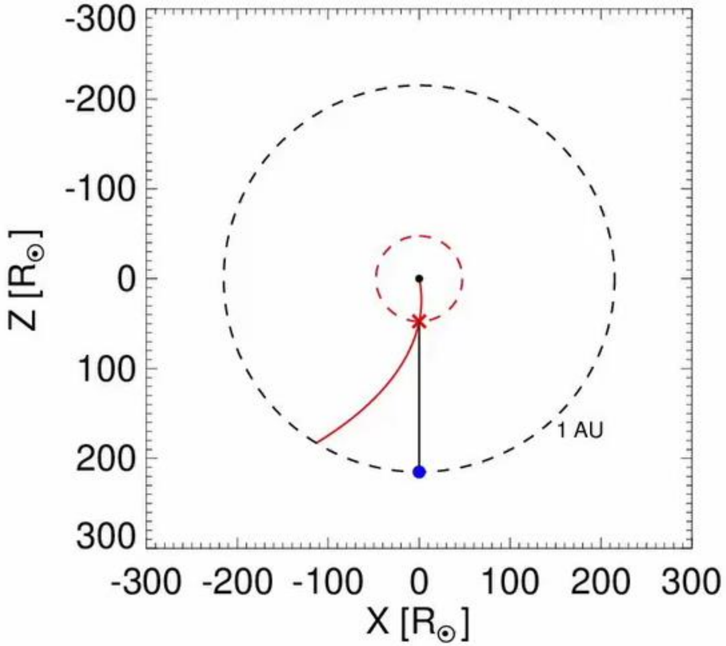
Kontar et al. (2023)



$f_{\mathrm{H}} = 0.25\ \mathrm{MHz}$







- Spherical apparent source in *xy*-plane near -10° where the Parker spiral is approximately tangent to the line-of-sight near the surface of last scattering.
- Apparent source sizes increases towards the rear of the heliosphere.

  ⇢ possibly due to observers only receiving emission from the edge of the plasma frequency surface and beyond, causing the apparent source to be distorted towards a crescent shape.

Apparent Source Position

Radio Emission Directivity

Peak intensity of a burst from each spacecraft location can be described by

$$I = I_0 \exp\left(-\frac{1-\cos(\theta_s - \theta_0)}{\Delta\mu}\right)$$

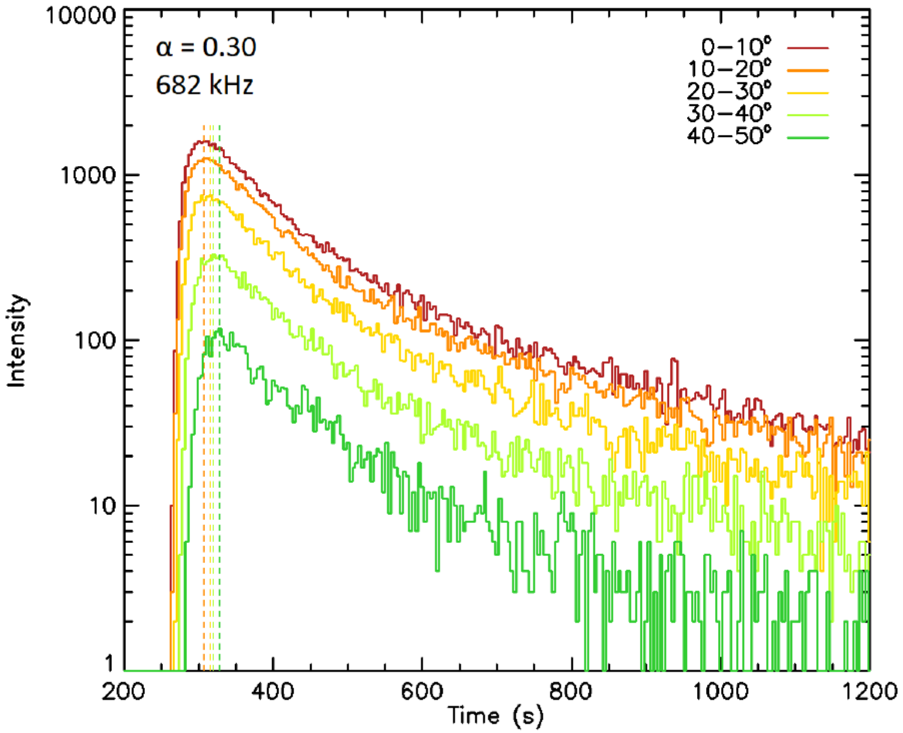
θ_s = longitude of spacecraft
θ_0 = source longitude at peak intensity
$\Delta\mu$ = describes the shape of emission directivity pattern

Observed intensities are corrected to 1 au, and the spacecraft are assumed to be in the ecliptic plane.

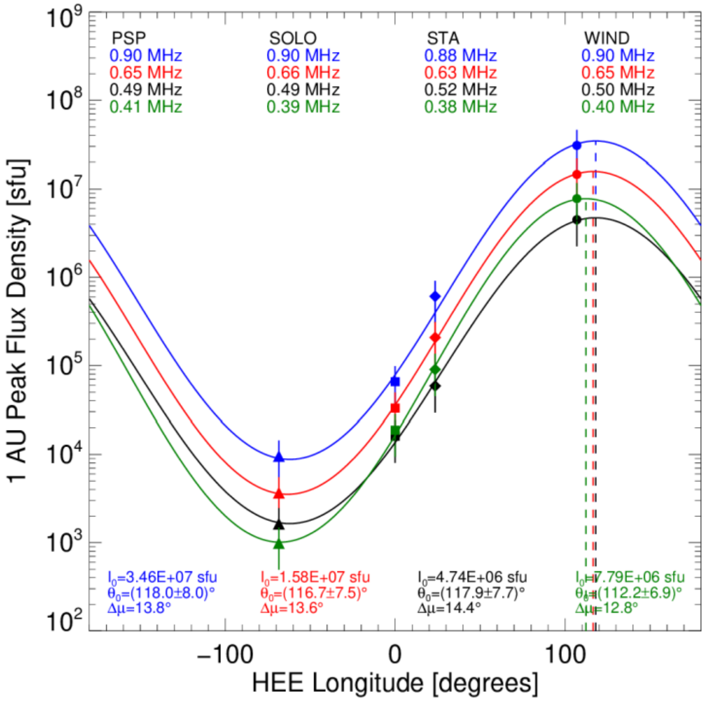
⟹ reveals direction of the **apparent** source that deviates from that of the intrinsic emitter

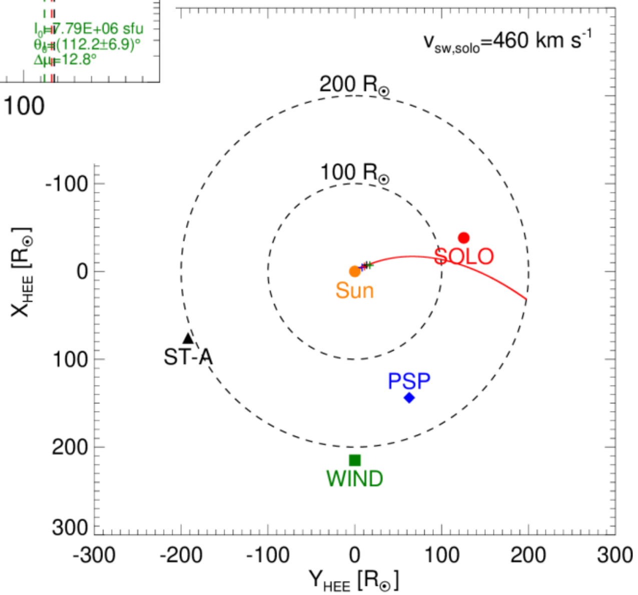
⟹ closely aligned with the angle of the Parker spiral (Chen et al. 2023)

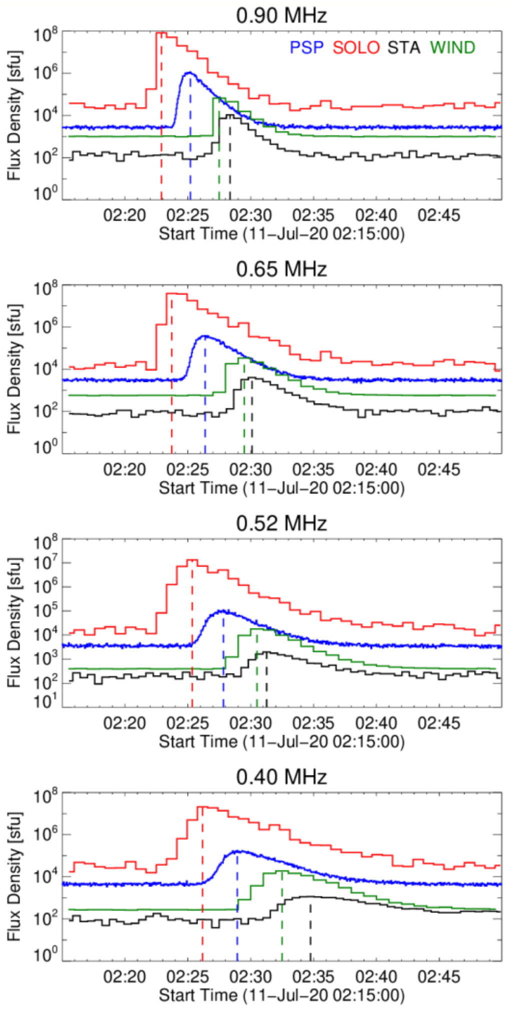
Musset et al. (2021)

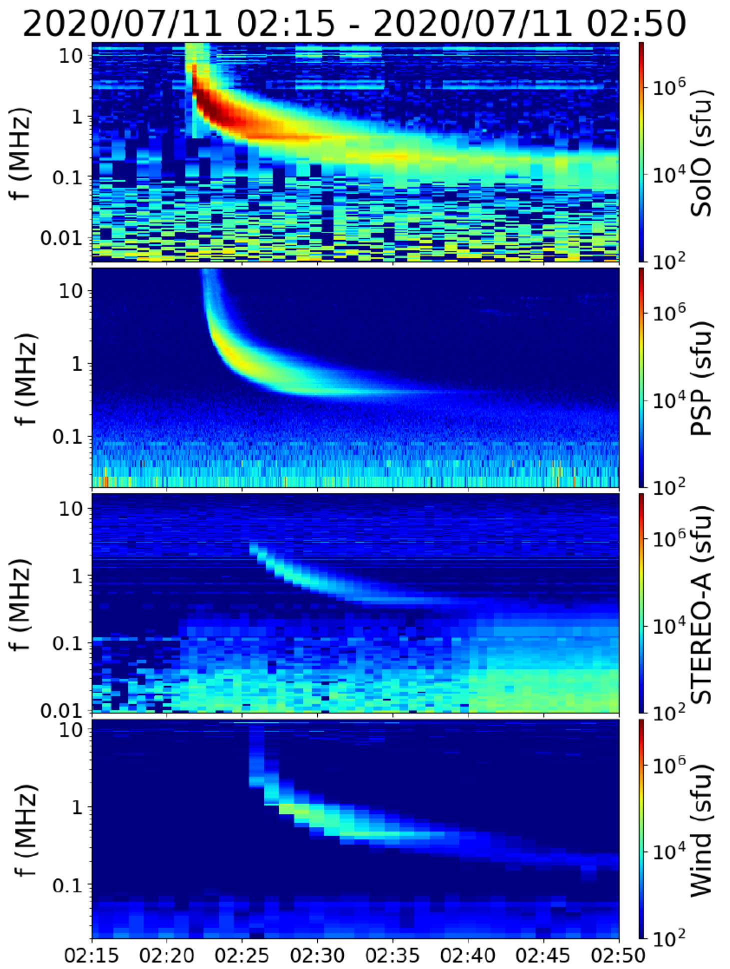


Multi-Spacecraft Observations Intensity Fitting







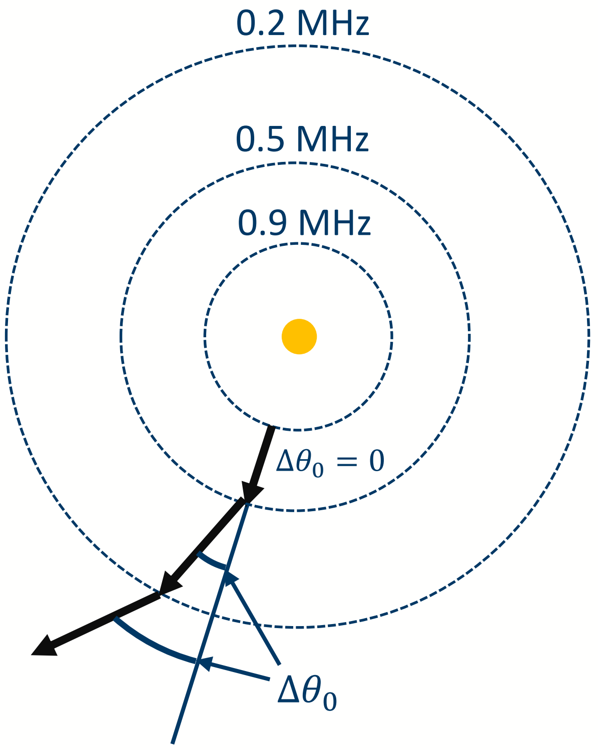


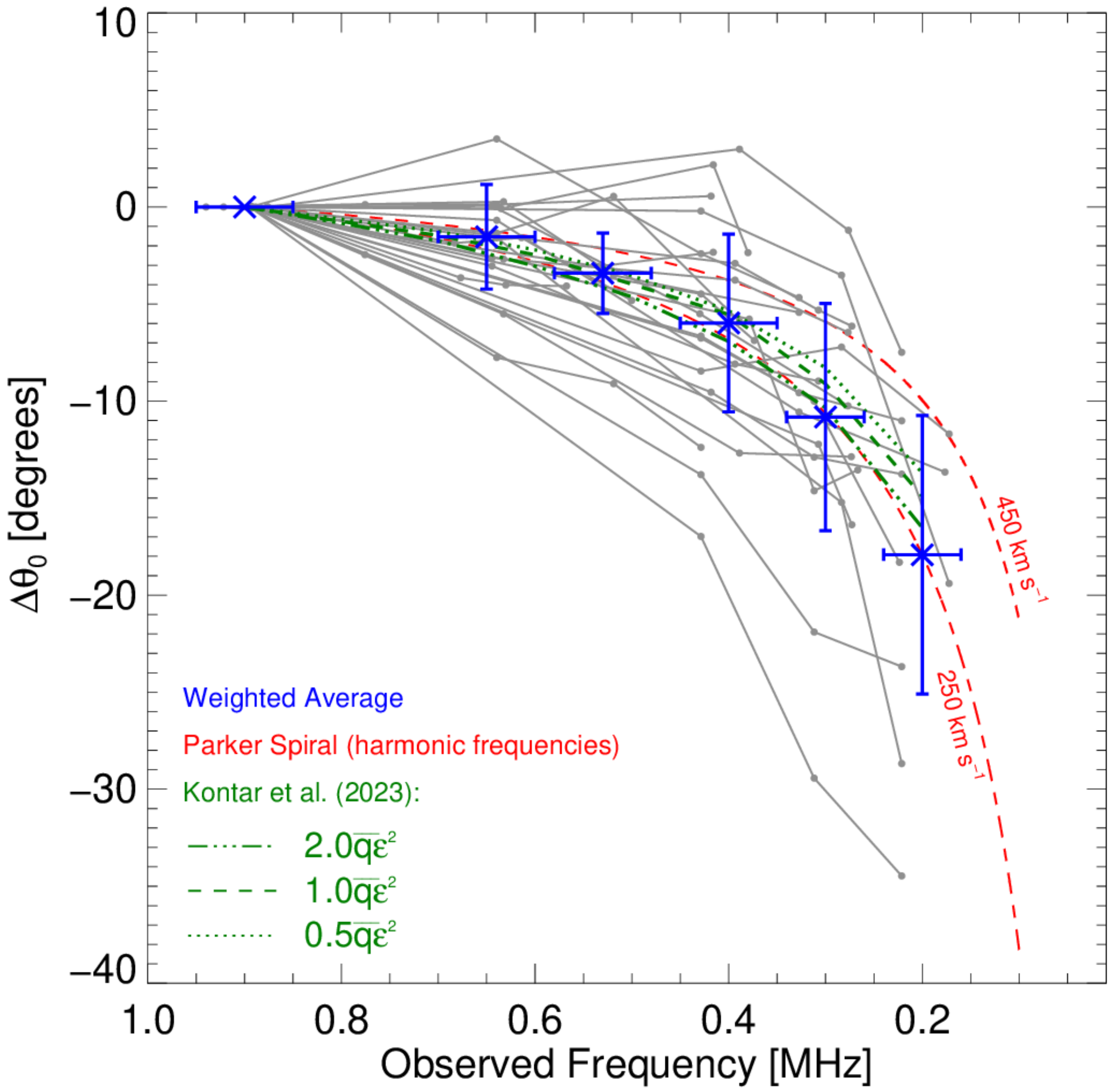
Musset et al. (2021)

Apparent Source Position

27 Type III events
19 Type III observed by **4** spacecraft
8 Type III observed by **3** spacecraft

- Angular deviation between 0.9-0.2 MHz of approximately 20°
- Spread in data between events could be due to:
  - Solar wind speed
  - Anisotropy factor
  - Scattering rates





Summary

- Anisotropic radio-wave scattering shifts interplanetary burst emission in the direction of the Parker spiral.

- High photon count simulations show 360° scattering around the heliosphere

  ⇢ Angle of peak intensity is shifted away from that of the emitter.

  ⇢ The observed sizes and shapes at the rear of the heliosphere are distorted and obscured due to the plasma frequency surface.

- Triangulation using the peak intensities provides the direction of the scattered apparent source but fails to retrieve the true source location.

- Intensity fits from 4 spacecraft observations show an average angular deviation up to 20° between 0.9-0.2 MHz, similar to the Parker spiral at distances corresponding to harmonic emission.

- The observed spread in angular deviation could be due to different solar wind speeds, anisotropy factor, and scattering rates.