Angular dependence of rise- and decay-time measurements using multi-spacecraft solar radio observations

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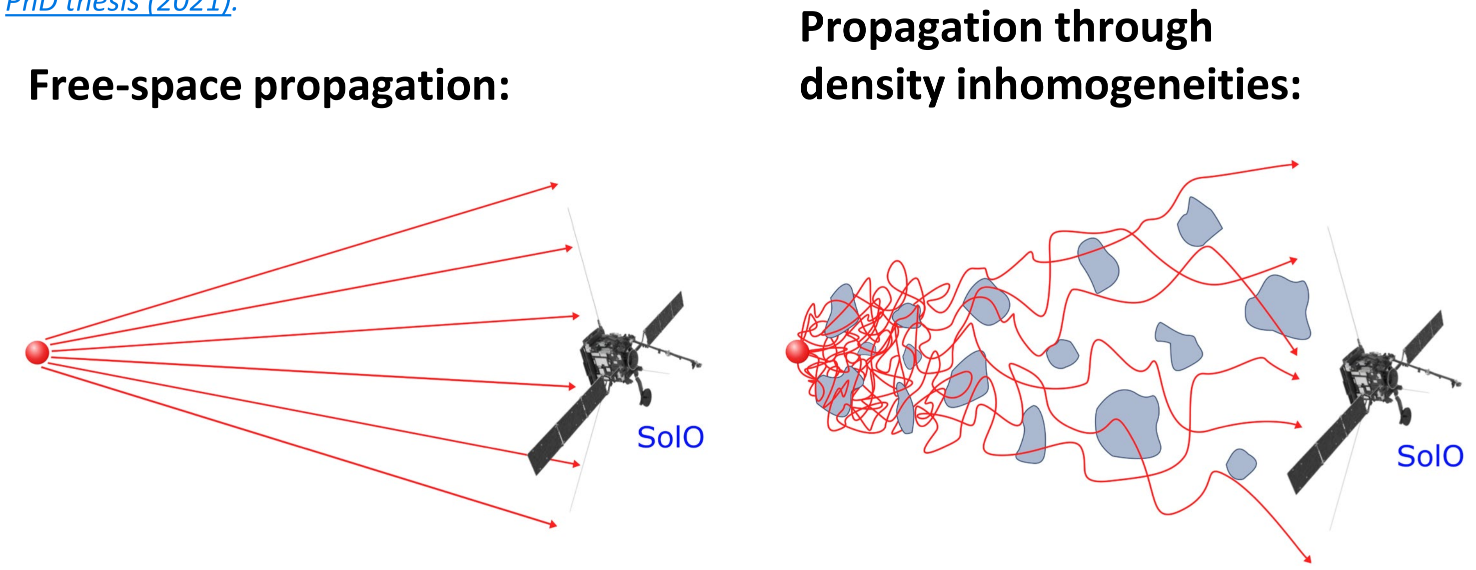
Radio-wave Propagation Effects

Figure adapted from Chrysaphi PhD thesis (2021).



- Density inhomogeneities in the corona **affect the propagation of photons**

⟹ Photons can be scattered, refracted, and absorbed

- Refractive index μ:

$$\mu^2 = 1 - \frac{f_{pe}^2}{f^2}$$

- Important when emitted $\boldsymbol{f \approx f_{pe}}$
- Frequency-dependent ⟹ lower frequencies are affected more
- Scattering dominates the observed properties
- **True (intrinsic) properties of radio sources are distorted**

Anisotropic Scattering

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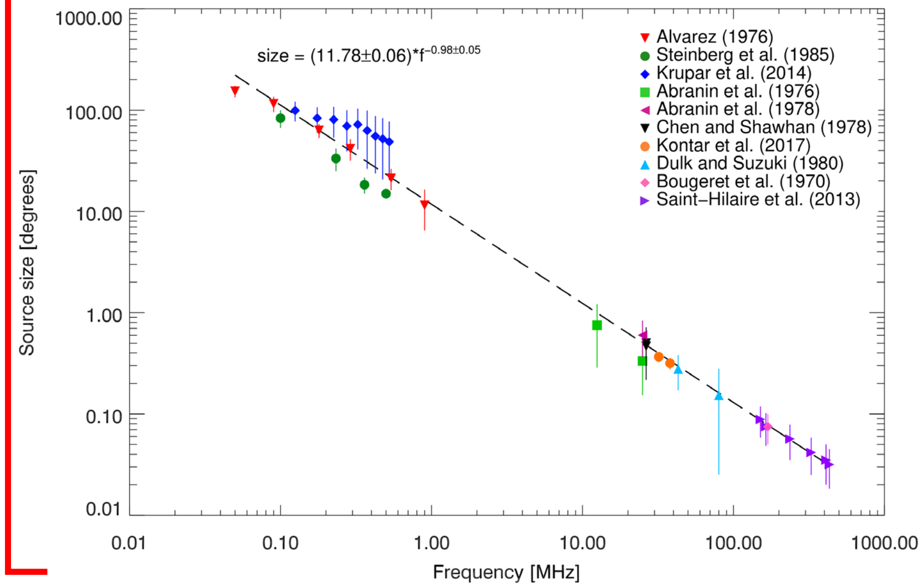
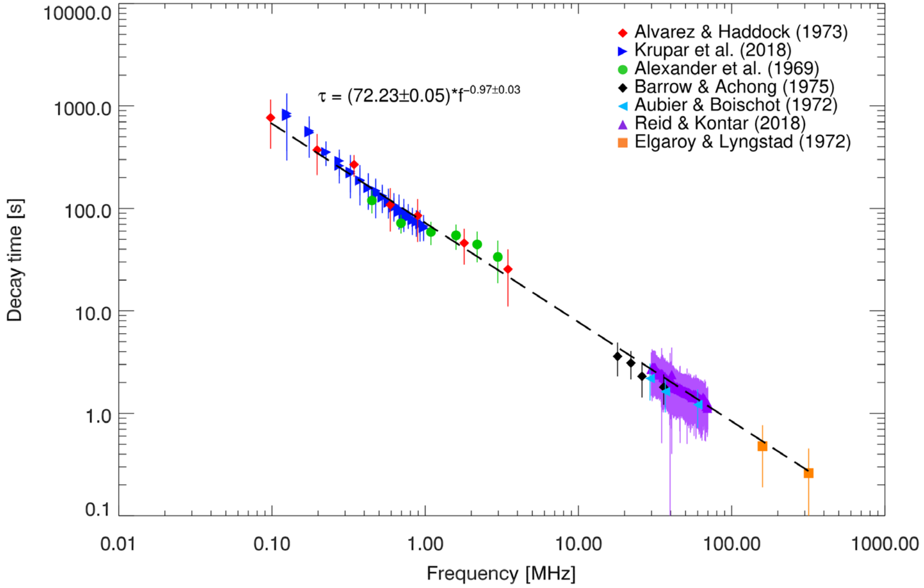
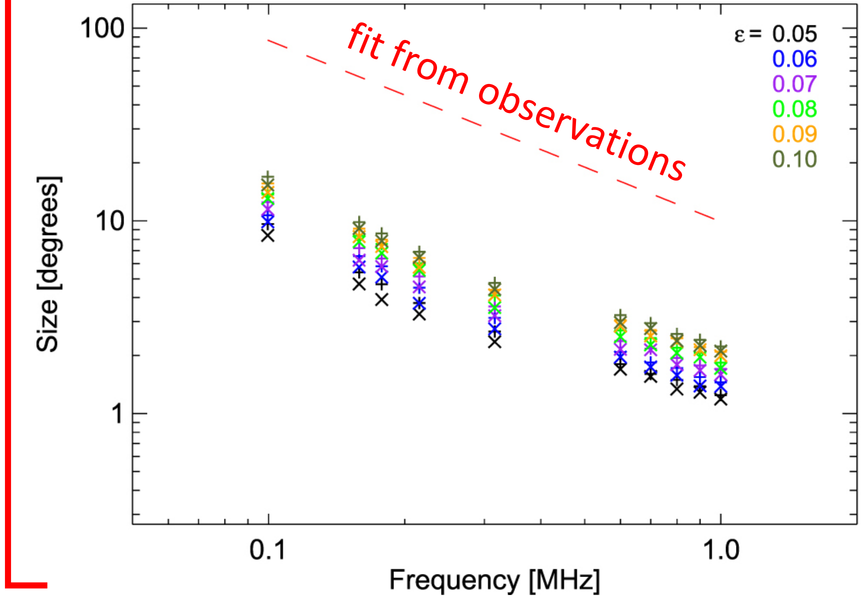
Evaluating Isotropic Scattering

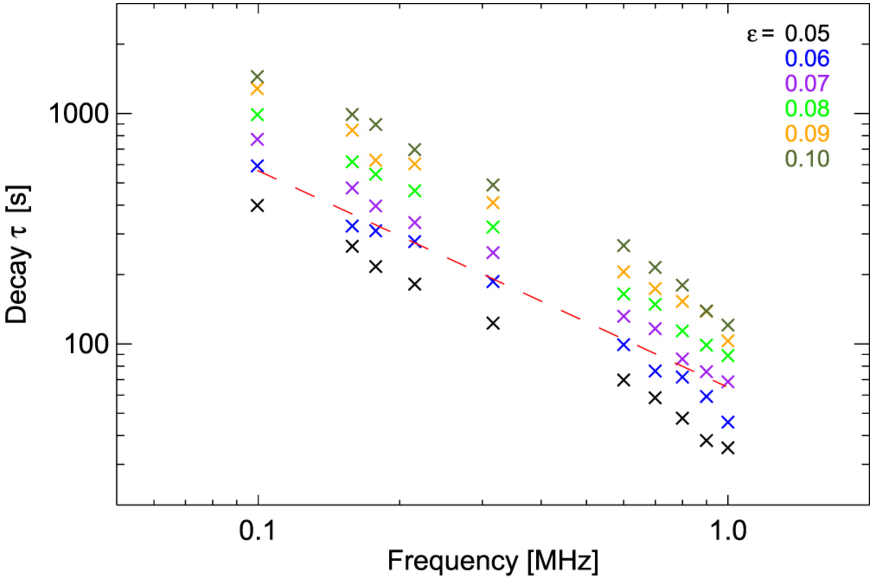
observations





isotropic simulations





- Compared simulations to observed Type III properties over a large range of frequencies
- Isotropic scattering fails to simultaneously describe both observed properties

Anisotropy needed

Kontar et al. 2019, ApJ, 884, 122

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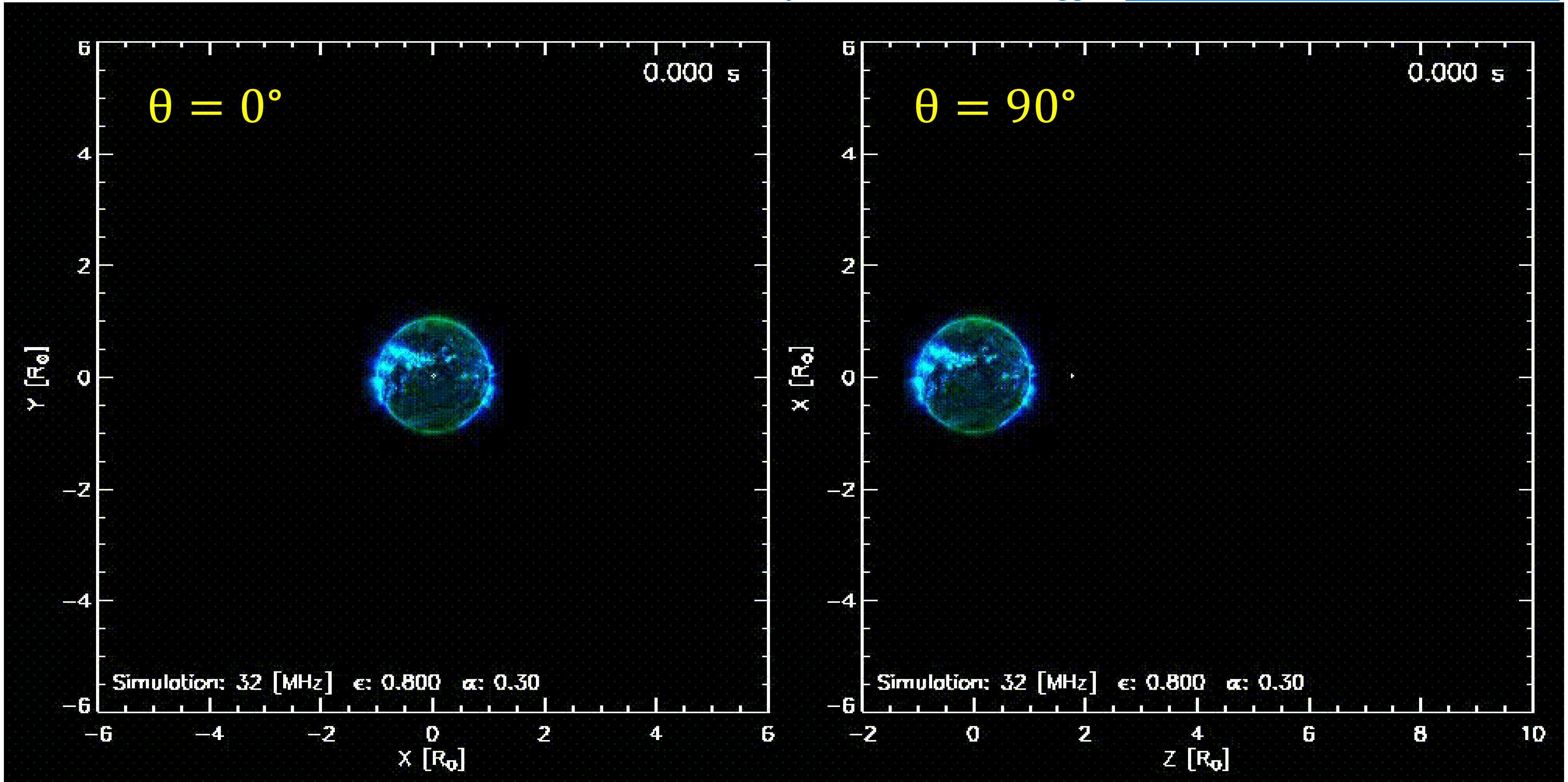
Anisotropic Scattering Simulations

- Anisotropic scattering means that photon propagation is **directional** (mushroom-like shape)
  ⟹ **observer's position is important**

The animation can be found at this CESRA nugget: Chrysaphi et al. (Nov. 2019), Figure 1



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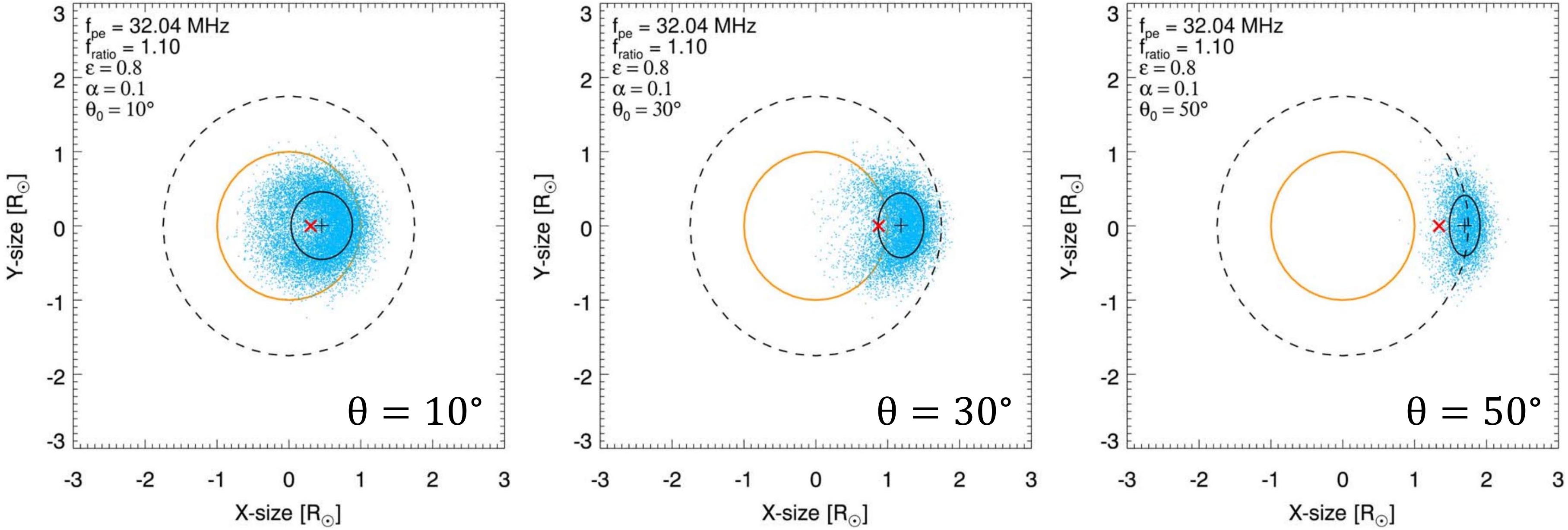
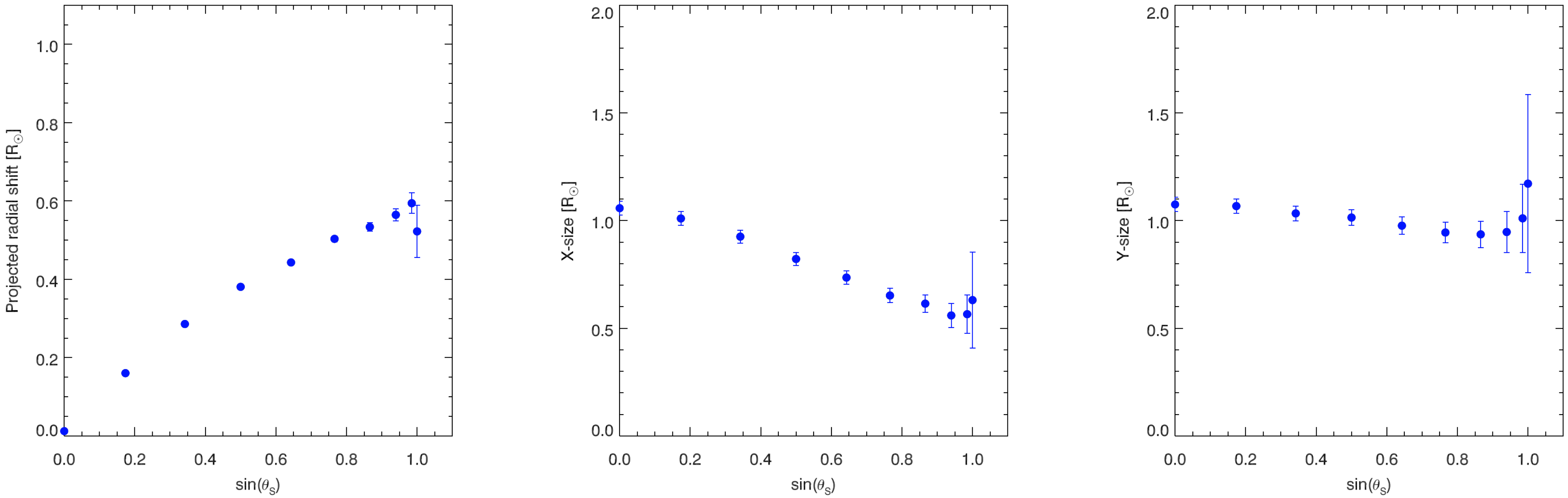
Size and Position vs Viewing Angle

single-frequency simulations



Kuznetsov et al. 2020, ApJ, 898, 94



Kontar et al. 2019, ApJ, 884, 122

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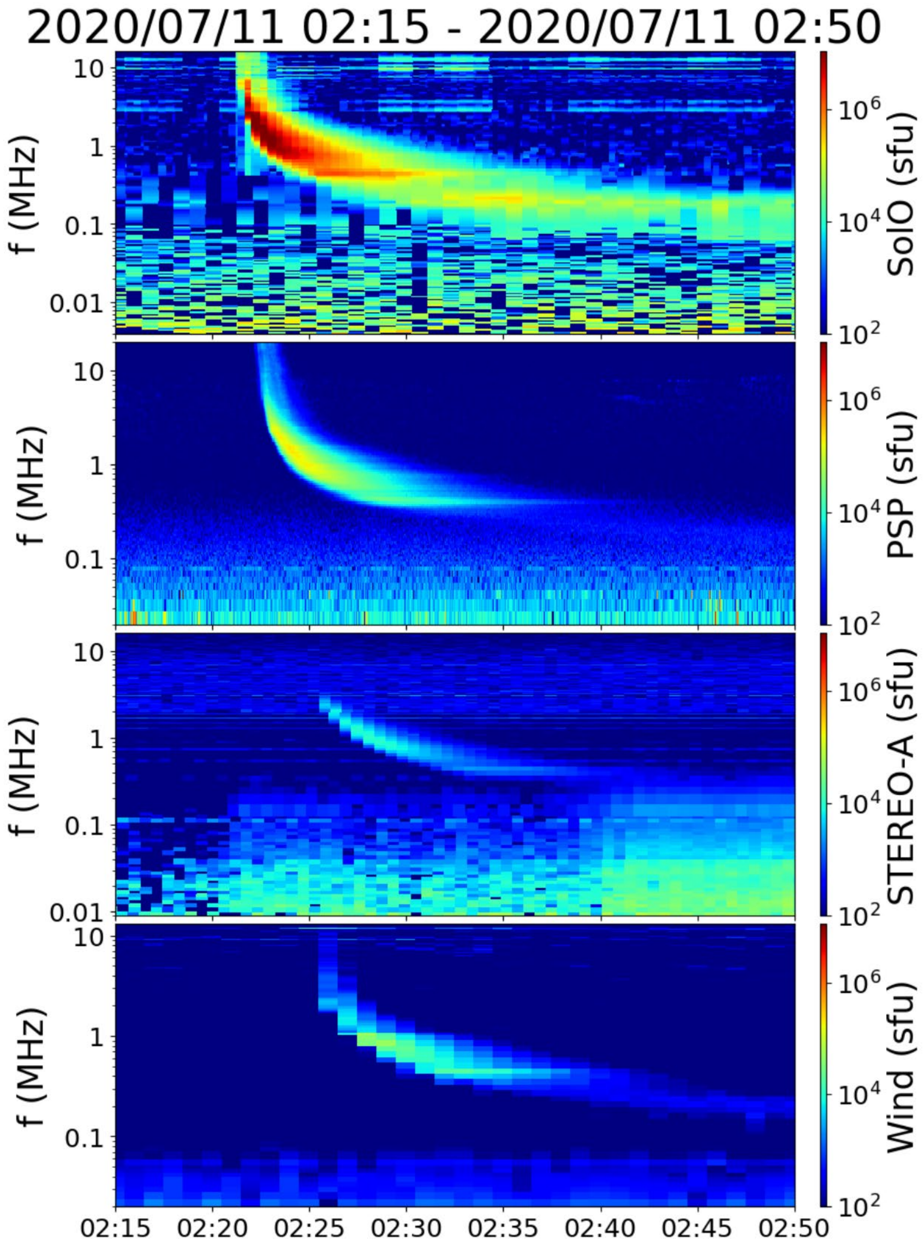
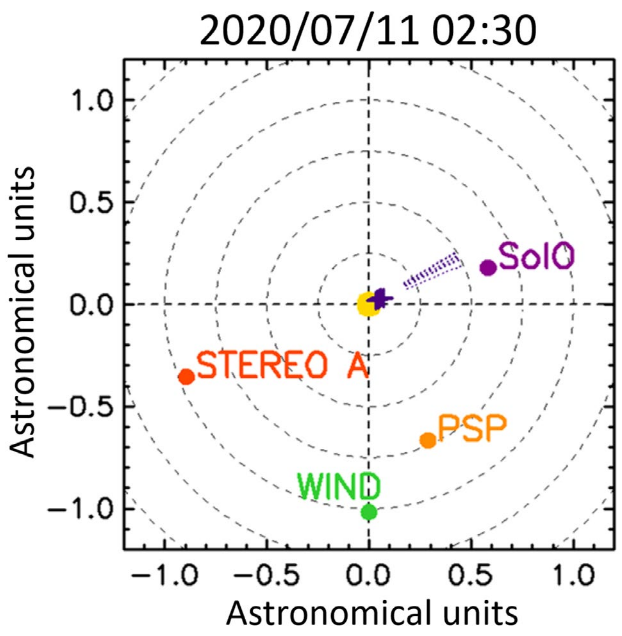
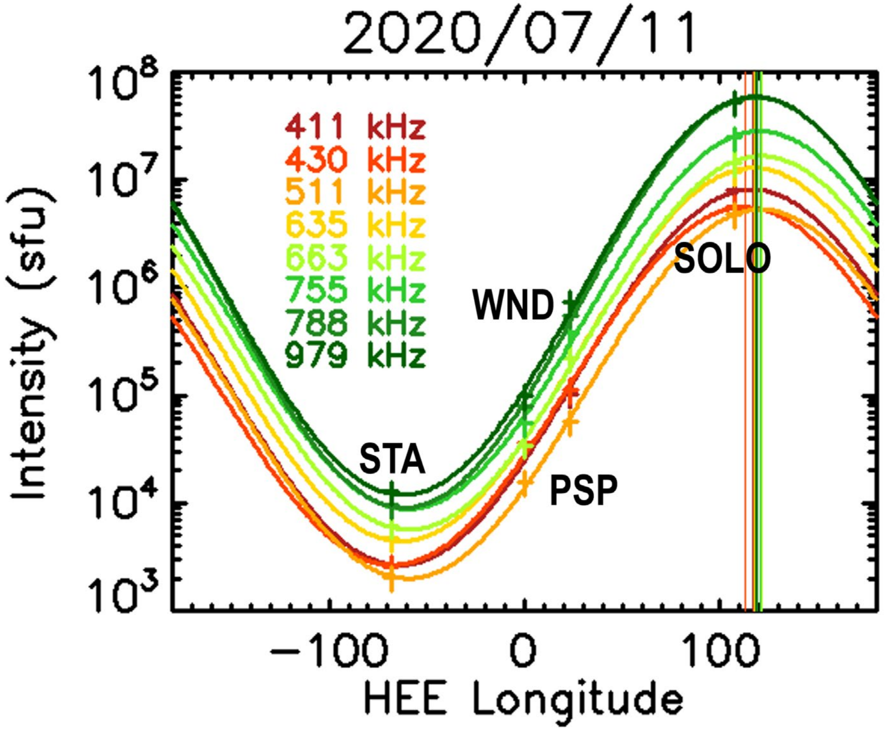
Amplitude vs Viewing Angle







- Measured flux can vary by orders of magnitude at different angular separations

Musset et al. *[2021, A&A, 656, A34]*

Decay time vs Observer's position

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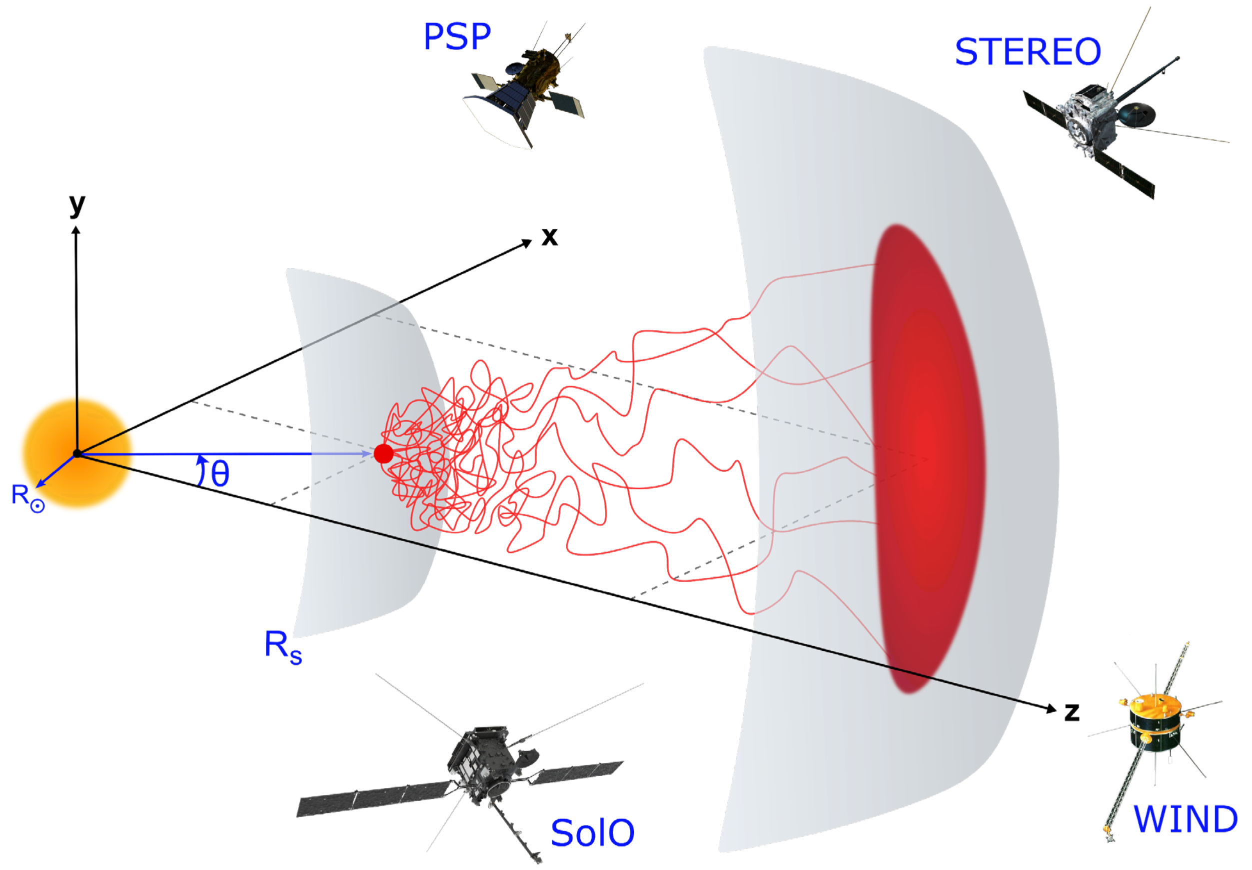
Decay Time

Is the decay time also affected by the observer's position?



Why examine the decay time?

- Decay time **defined by scattering**
- Used as **proxy for estimating scattering strength**
- If dependent on angular separation, measurements will need correction

Chrysaphi et al. (2023, submitted)

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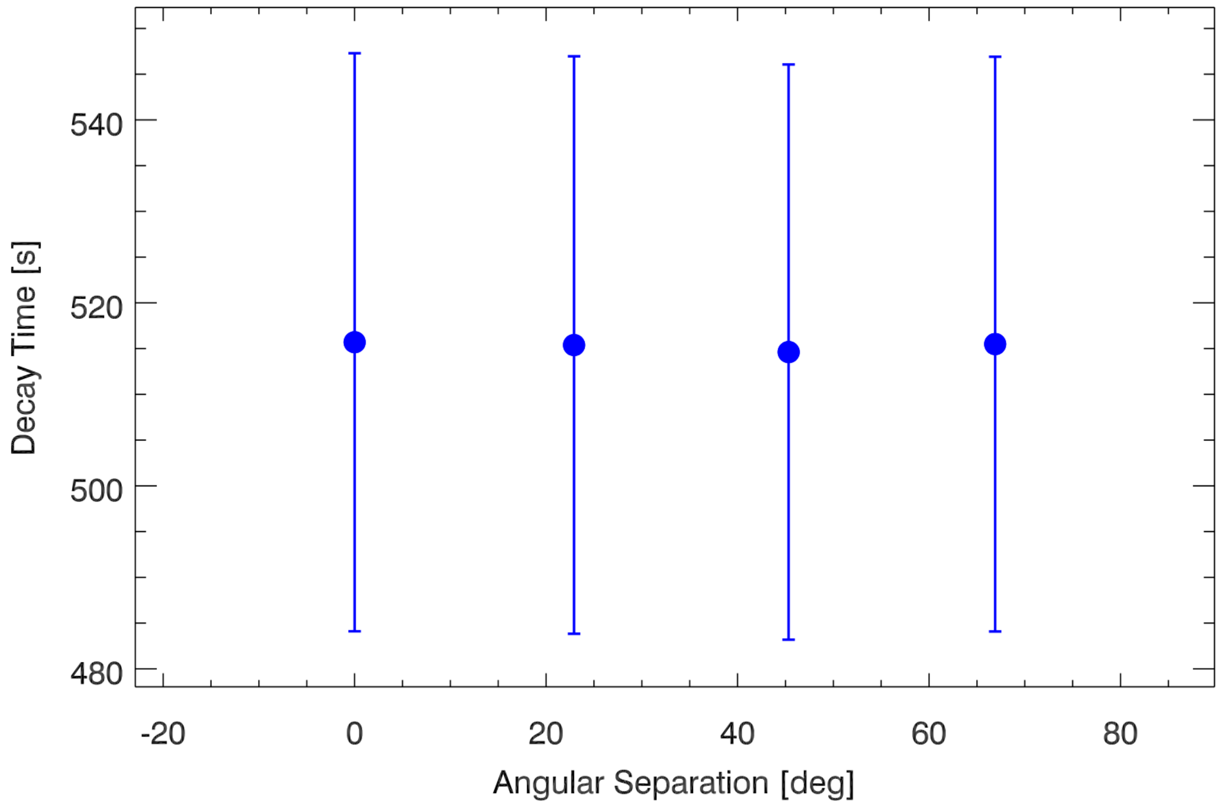
Simulation Prediction



- Used state-of-the-art 3D ray-tracing simulations *(Kontar et al. 2019, ApJ, 884, 122)*
- **Prediction: No dependency** of the decay time on the observer's position

Chrysaphi et al. (2023, submitted)

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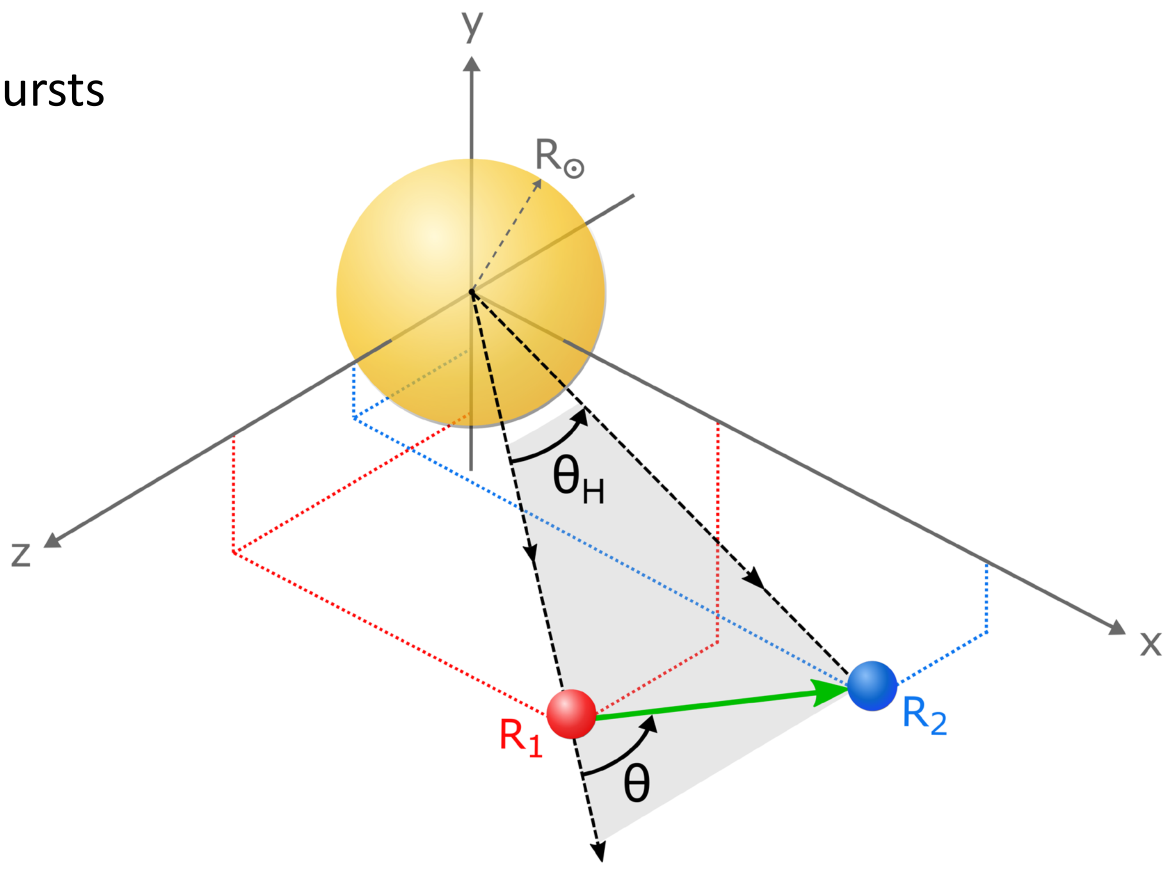
Multi-vantage observations

- Multi-spacecraft observations of single (isolated) Type III bursts
- Used data from:
  - Solar Orbiter
  - PSP
  - STEREO-A
  - WIND
- Selection criteria reduced analysed Type III bursts to 11
- **Langmuir waves** observed by one of the spacecraft
  ⟹ spacecraft location **taken as radio source location**
- (3D) angular separation θ calculated in the **plane of the two spacecraft**, with the Sun-source axis taken as the origin
- Considered the Euclidean distance between the source and spacecraft



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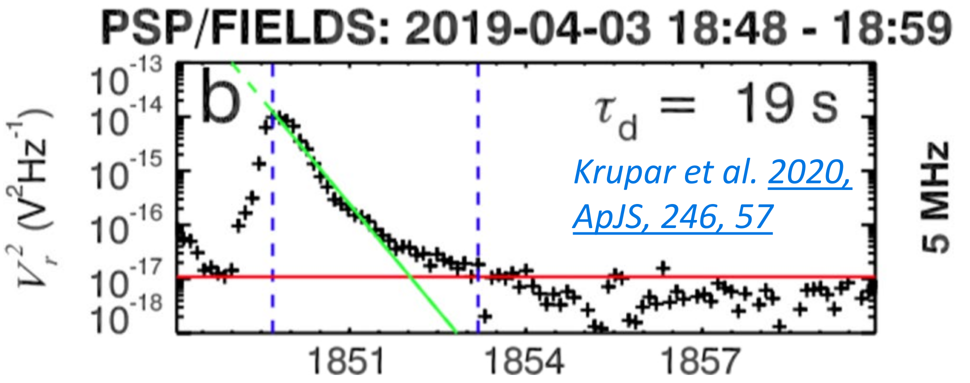
Fitting the entire light curve

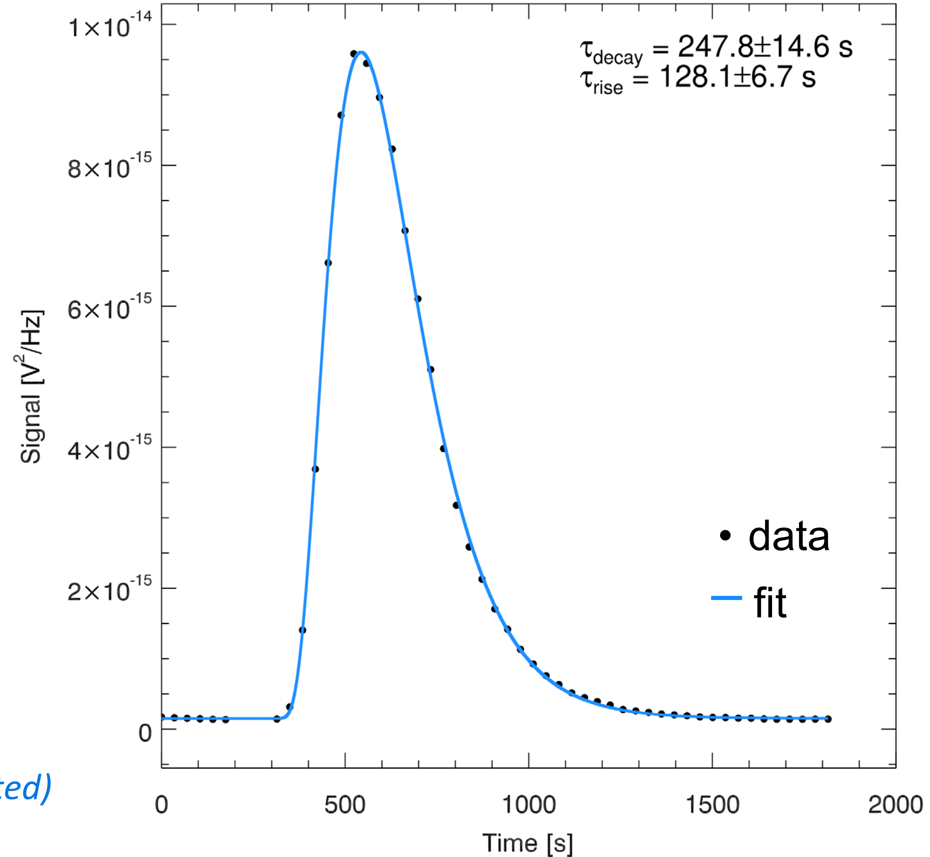
Previous Decay Time Estimations:

- Approximated using a single exponential fit to the decay phase
- Not always a good characterisation
- Peak time not described



We fit the entire light curve **with a single function**, providing an improved estimation of the **decay time**, and a simultaneous estimation of the **rise time and peak flux**:

$$f = \left[A \exp\left(-\frac{\tau_1}{t_i - t_0} - \frac{t_i - t_0}{\tau_2}\right) + C\right] \times H(t, t_0)$$



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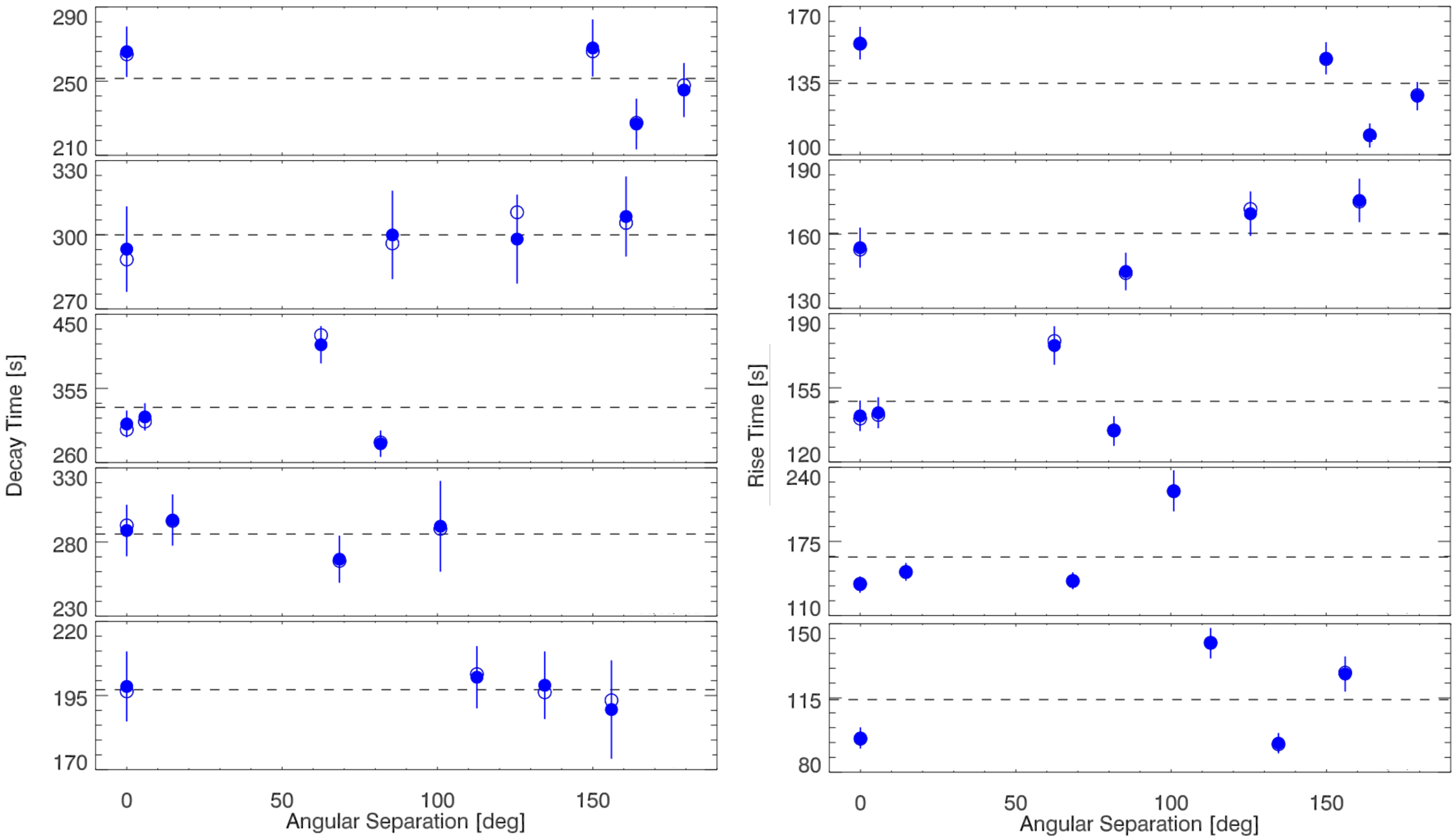
Decay and Rise time vs Angle



- Accounted for frequency differences between spacecraft measurements
- **No consistent dependency**

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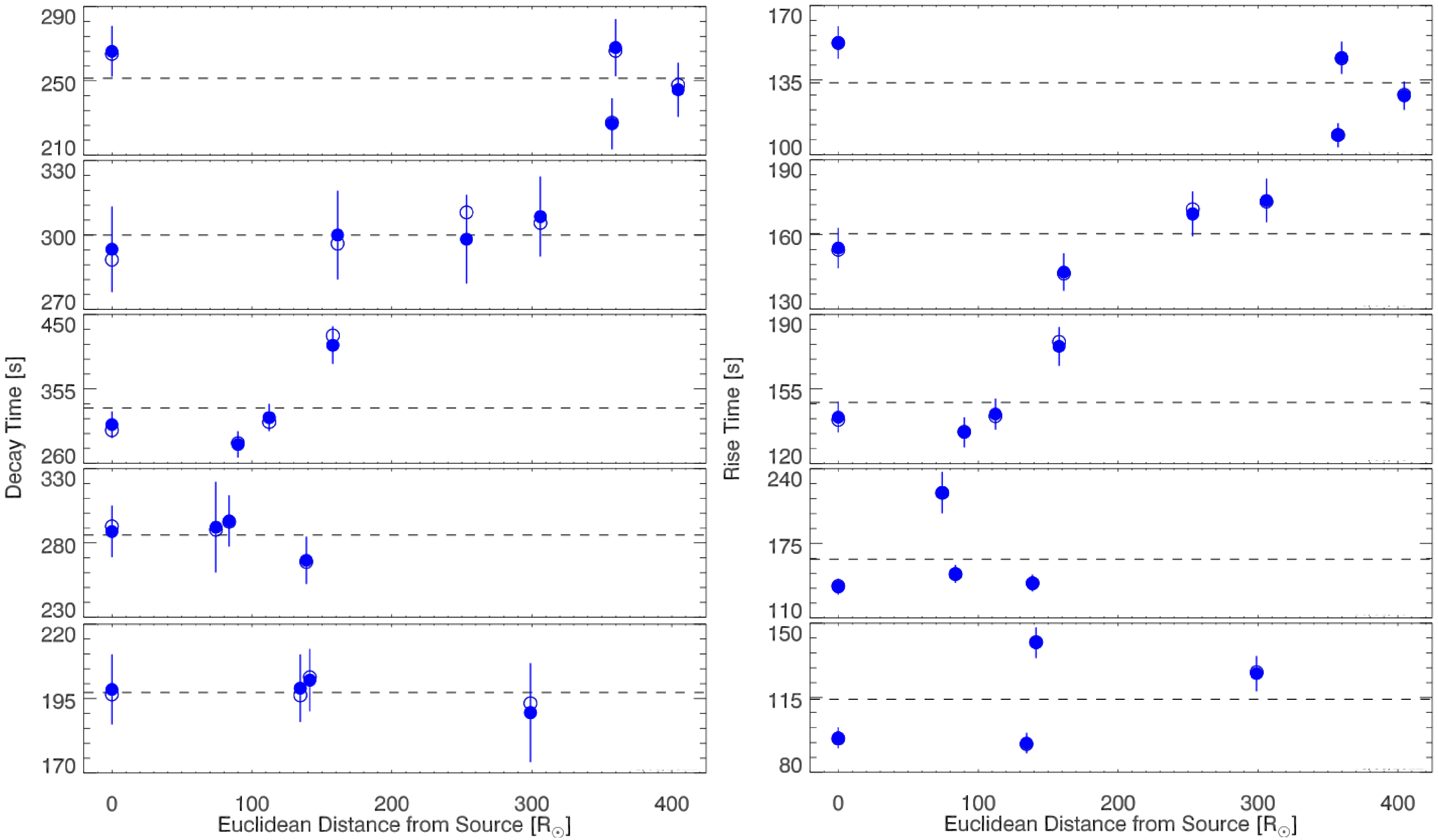
Decay and Rise time vs Distance



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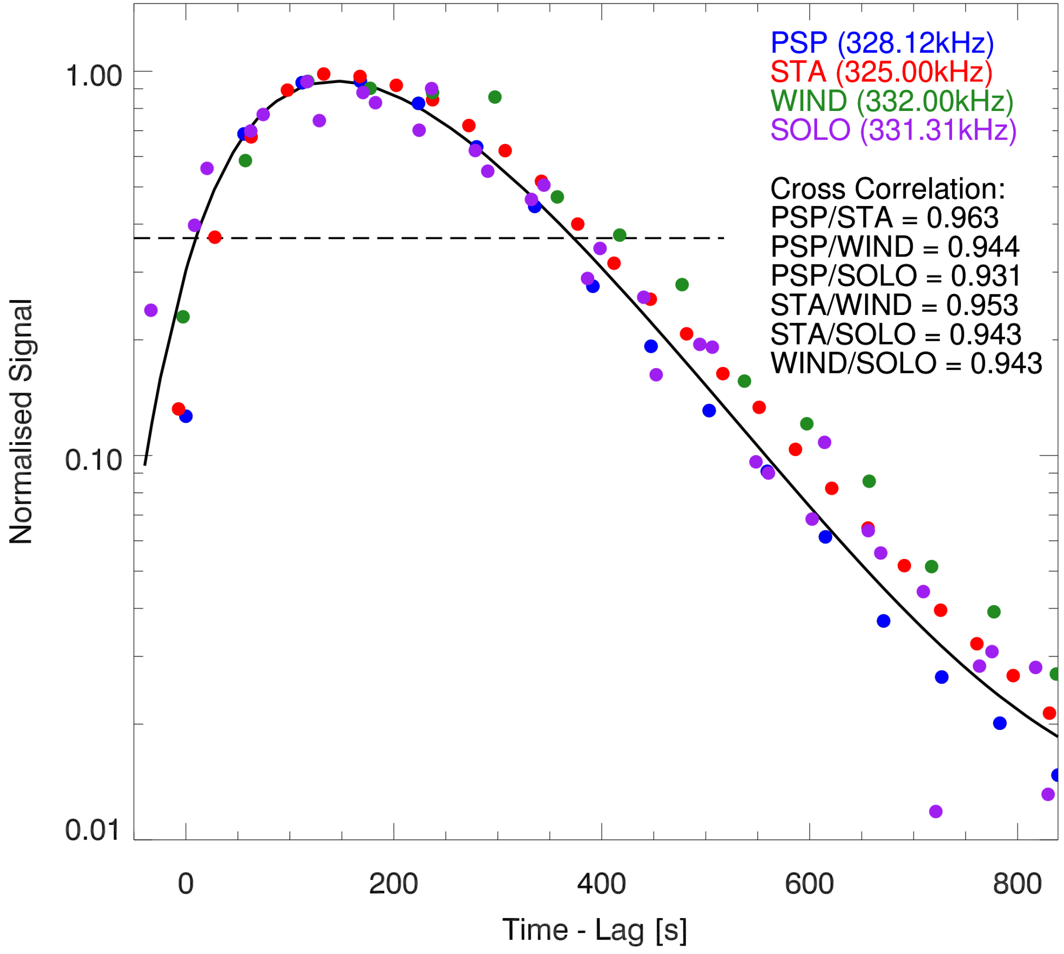
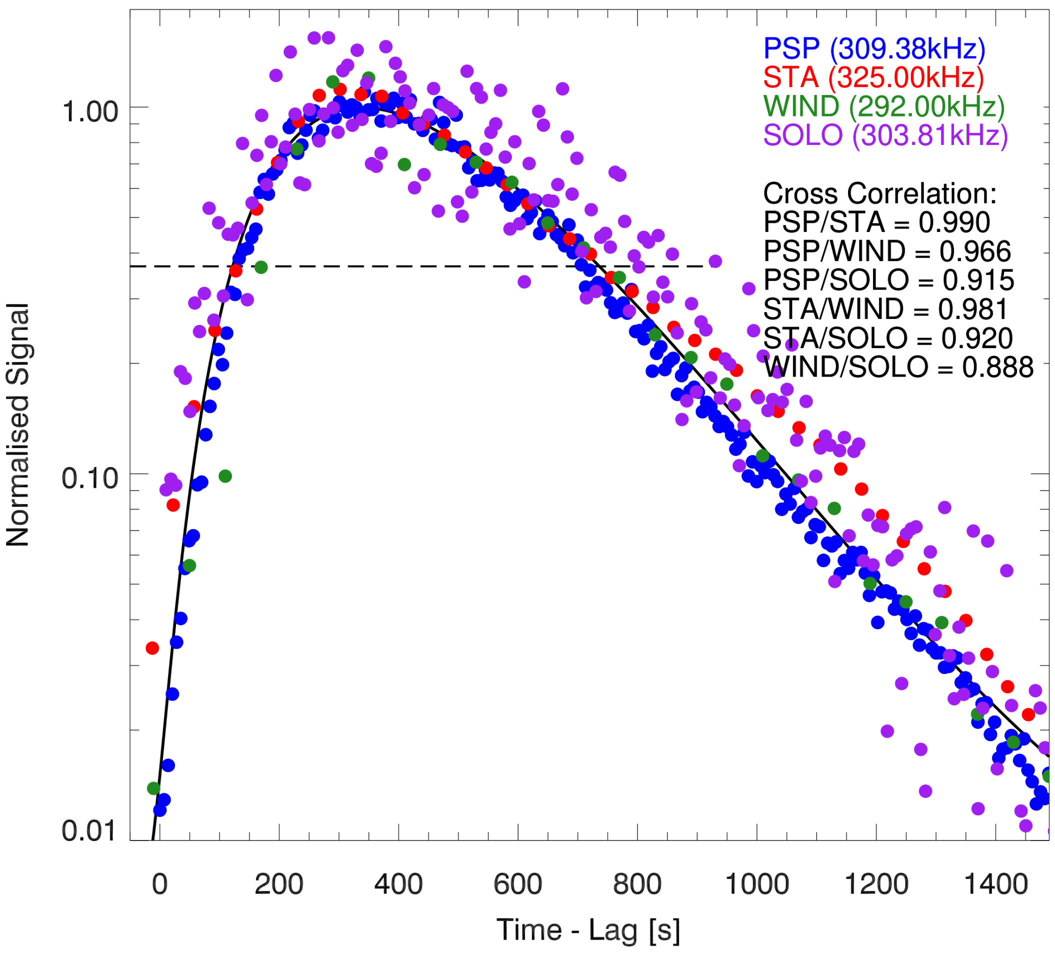
Direct comparison





- Similar time profiles despite that recorded frequencies are not identical

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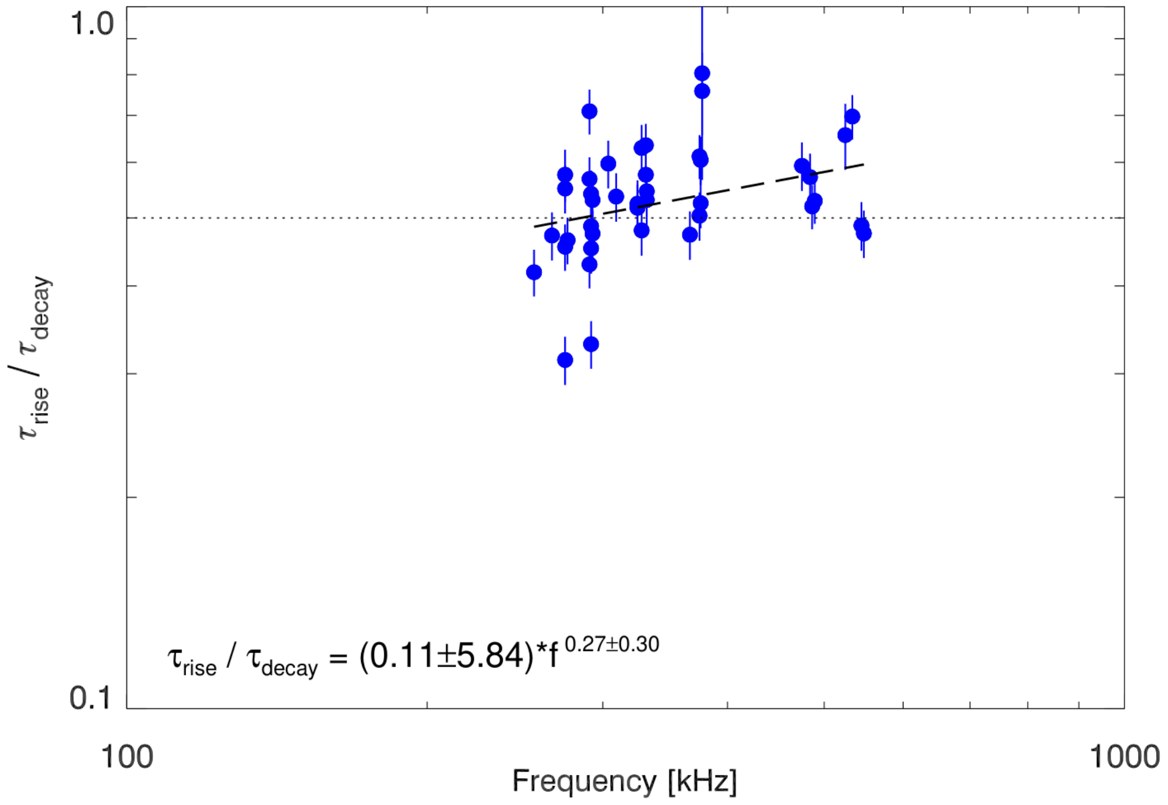
Rise-to-decay time ratio vs Frequency



- τ_r/τ_d found to range between 0.31 – 0.8 for frequencies between ~275 – 550 kHz
- Studies at higher frequencies (up to 130 MHz) find τ_r/τ_d ranging between 0.6 – 0.8
- **Result:** No frequency dependency

⟹ **Rise time is affected by scattering effects in a proportionate manner to the decay time**

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Conclusions

- Scattering is **anisotropic**, leading to highly-directional emissions

⟹ Consider **observer's position**

- **Decay & Rise time:** **No systematic trend** between measurements at various observer positions at comparable frequencies

⟹ Decay & Rise times are the only measurements that can be trusted irrespective of the observer's location

⟹ do not require a correction

- **Rise-to-decay time ratio:** No frequency dependency

⟹ Rise time also dictated by scattering effects

Chrysaphi et al. (2023, submitted)