Observations of Radio Burst Source Sizes and Scattering in the Solar Corona

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Background

- Low frequency radio wave propagation in the sun’s atmosphere (the corona) is not fully understood.
- Radio bursts in the corona are observed to be much larger than predicted.
- This is most likely due to radio waves scattering off of plasma density inhomogeneities in the corona.
- Some solar radio bursts offer density diagnostics of the corona (Figure 1b).
- Fine scale spectral structure of these bursts indicate a small source size (Figure 1b inset).
- Radio interferometers such as the LOw Frequency ARray (LOFAR) have high angular resolution and can help determine the level of scattering.
- A better understanding of scattering may lead to new insights into the nature of coronal turbulence.

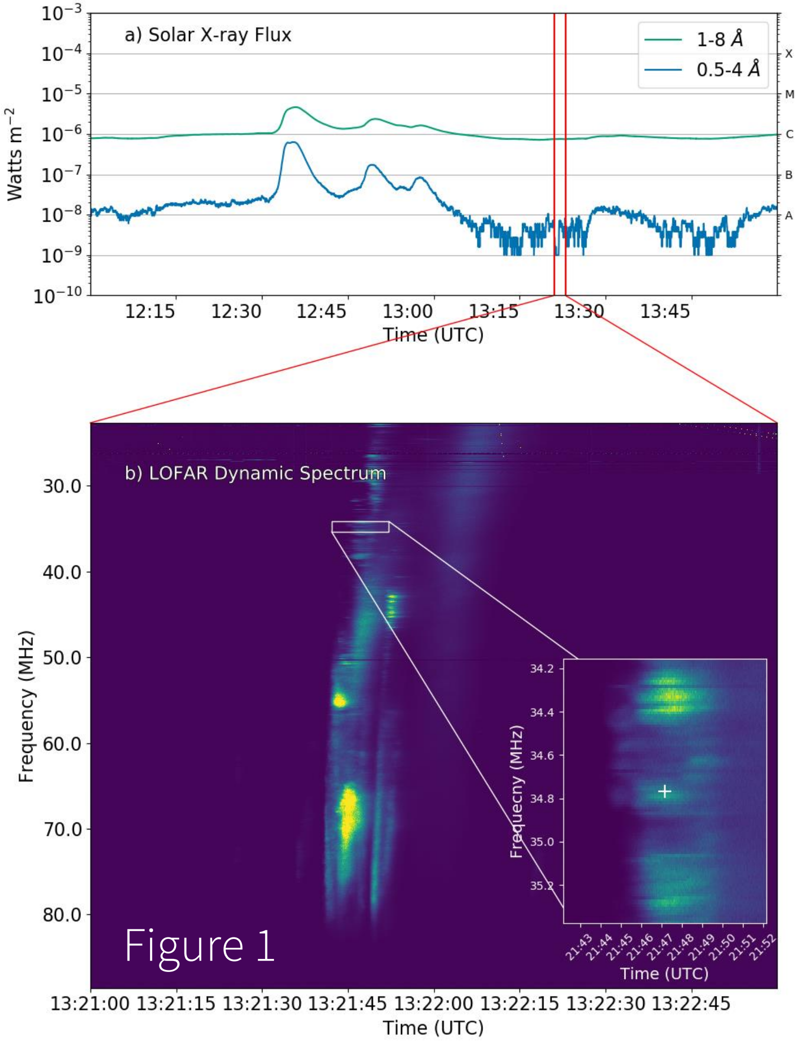

Figure 1

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Methods: Fitting in Fourier Space to Learn About a Solar Radio Burst

- LOFAR measures the Fourier Transform of the radio sky.
- The distance between each pair of antennae is called a baseline.
- The baselines of LOFAR sample the amplitude and phase information of the solar radio burst.
- Imaging algorithms are often used to recreate the radio burst from interferometric observations.

- Radio imaging algorithms rely on a number of input parameters to create an image.
- This can introduce artefacts, including changes to the size and shape of the source.
- To avoid ambiguity in source characteristics we directly fit a model to the observation in Fourier space, also known as *uv* space (Figure 2).

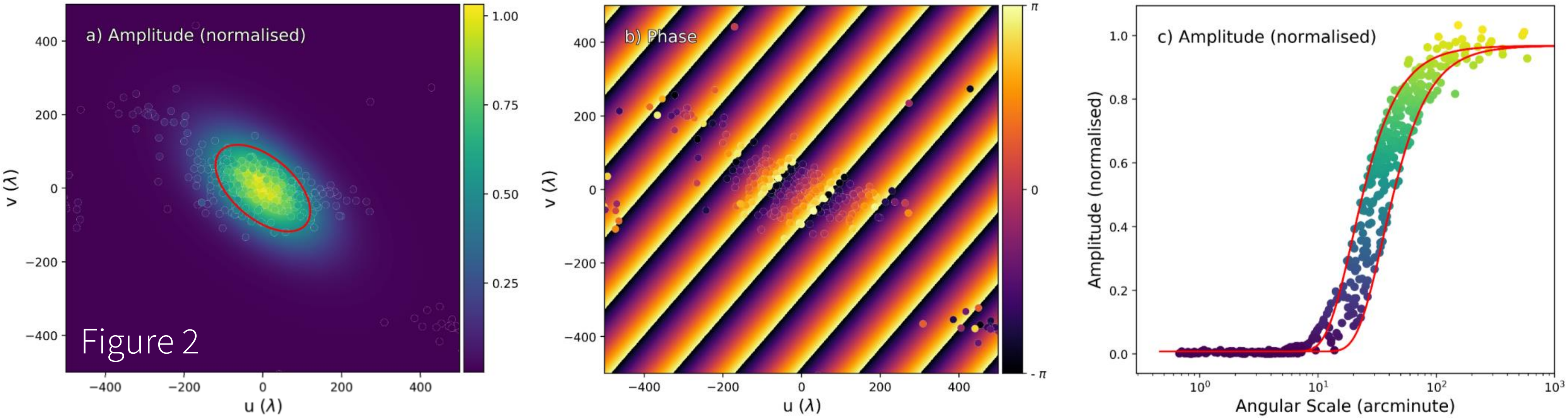

Figure 2

Results: Using a Solar Radio Burst to Learn About Radio Wave Scattering

- The fit in *uv* space reveals a source with a FWHM in real space of 18.8′ ±0.1′ and 10.2′ ±0.1′ (contours in Figure 3).
- The size predicted by the fine scale spectral features is 3.18″.
- The observed source shows no structure <10′ (Figure 2c).
- The large source size is not due to low angular resolution or an imaging algorithm.

- Radio wave scattering is the cause of the increased source size.
- The level of scattering is determined by the relative root mean square density fluctuations $\varepsilon = \sqrt{<\delta n^2>}/n$ of turbulent coronal plasma.
- The apparent radio burst position can be used to calculate $\varepsilon = 0.16$.

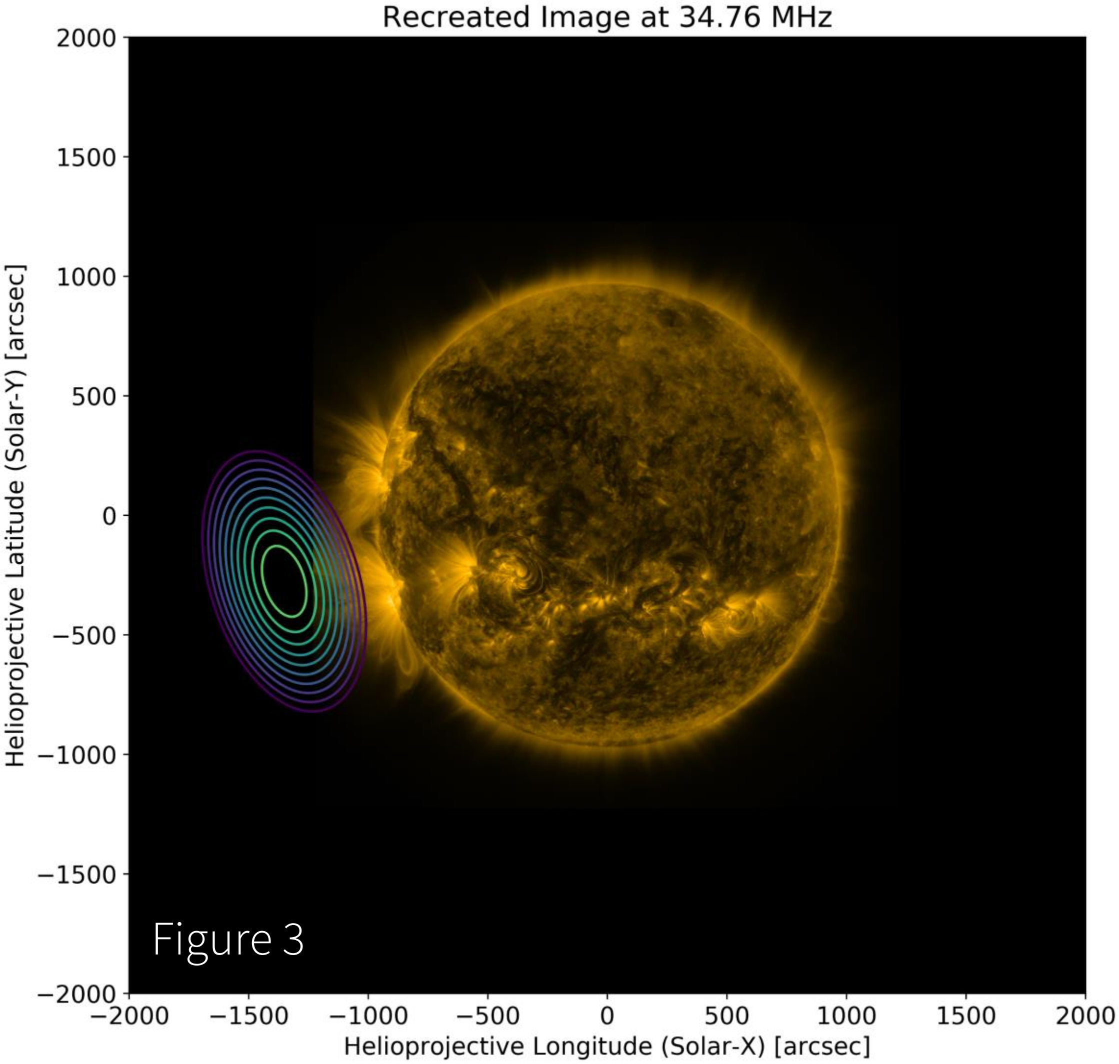

Figure 3

Conclusions: It's More Complicated Than We Thought!

- The calculated value of ε **depends on the characteristic length scale**, h, on which scattering occurs.
- This in turn depends on the assumed power density spectrum of density fluctuations in the corona.
- It is often assumed the power density spectrum is that of the Kolmogorov description of turbulence.
- This has been shown not to be the case.

- Using a length scale appropriate to the power density spectrum described by Coles & Harmon (1989) reduces $\boldsymbol{\varepsilon}$ by 2 orders of magnitude.
- We conclude that until an accurate value of h is determined, **it is only possible to estimate an upper limit of $\boldsymbol{\varepsilon}$ in the solar corona.**
- Thus, it is likely that previously quoted values of $\boldsymbol{\varepsilon}$ in the literature are too big.

Summary

- Studying solar radio bursts at low frequencies may lead to new insights into the nature of coronal turbulence.
- A solar radio burst observed with LOFAR was fit in the *uv* plane to determine its size and position in real space.
- The radio source observed is much larger than predicted due to **radio wave scattering in the solar corona**.
- The extent of scattering was estimated from the radio burst position and given an **upper limit of $\boldsymbol{\varepsilon} = 0.16$**.

References

- **Murphy et al. 2020 (in review)**, Coles & Harmon 1989 1989ApJ...337.1023C