The effect of scattering on split-band Type II solar radio bursts

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CMEs: Coronal Mass Ejections

Click here to view an online movie of this event on the 'SOHO/LASCO CME Catalog'.

Data courtesy of the SOHO and SDO teams.

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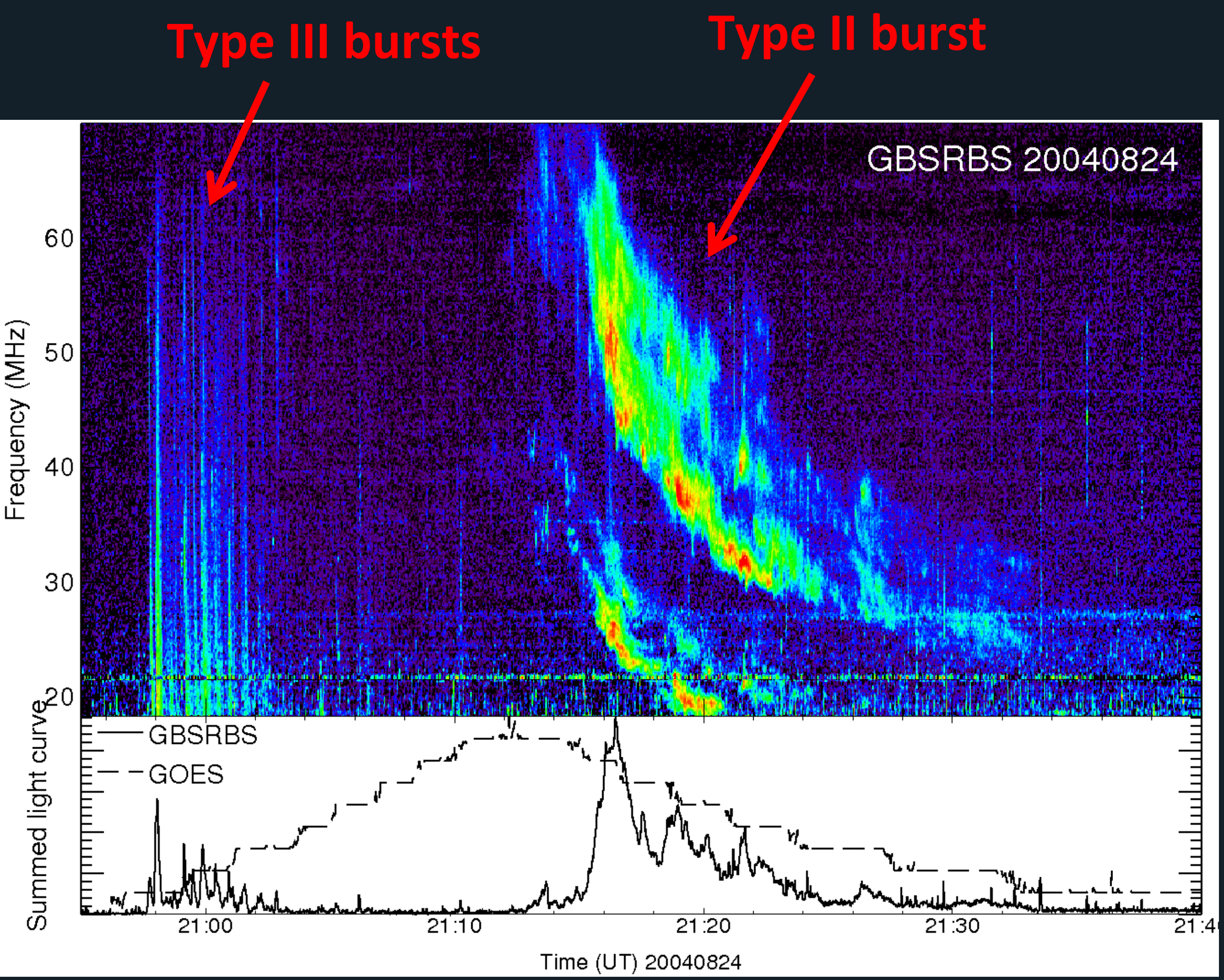
Type II bursts



White, S. M. 2007, Asian J. Phys., 16, 189

- Excited by shock waves
- Slow drift from high to low frequencies
- Sometimes show Fundamental-Harmonic pairs
- Fundamental/Harmonic bands can further split into thinner lanes ⟹ "band splitting"

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Band-splitting models

Smerd et al. (1974; 1975) model:

- Simultaneous emission from the upstream and downstream parts of a shock front
- Emission source locations required to be virtually co-spatial

Holman and Pesses (1983) model:

- Emission from different parts upstream of the shock where the shock front is quasi-perpendicular to the B-field
- Emission sources must be physically separated

Holman, G. D., & Pesses, M. E. 1983, ApJ, 267, 837; Smerd, S. F., et al. 1974, IAUS, 57, 389; Smerd, S. F., et al. 1975, ApL, 16, 23

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Observational Evidence

In the 1970s…

“Split bands have been found to be separated by about 1 to 4 arcmins”

$\Longrightarrow$ about $0.06 - 0.25\ R_\odot$

Smerd et al. (1975) thought…

- “2 components of a split band spectrum [imaged] at the same frequency, but at different times”

  $\Longrightarrow$ time-delay ambiguities

- “radiation is scattered”

  $\Longrightarrow$ “the actual amount and direction of source separation would have to be evaluated”

Smerd, S. F., et al. 1975, ApL, 16, 23

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LOFAR: the LOw-Frequency ARray

About 40 years later…

We built LOFAR!

- Radio interferometer
- Imaging and spectroscopy
- Observes between 10-240 MHz

Still expanding…

Image courtesy of ASTRON.

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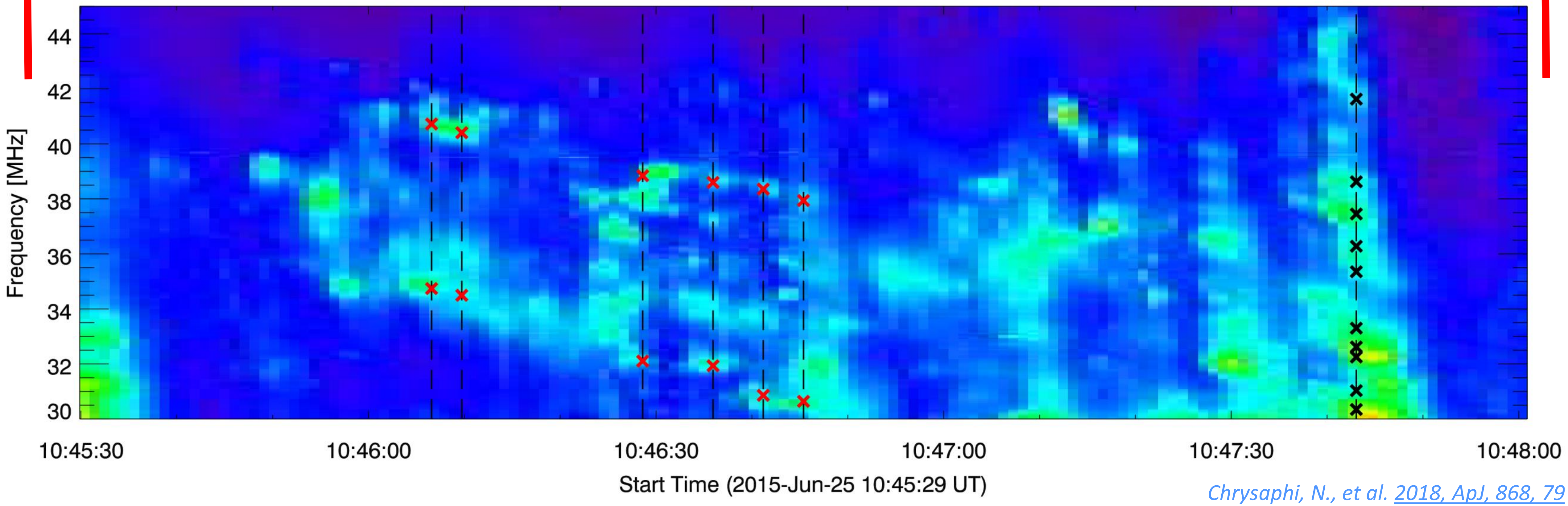
Type II observations with LOFAR

- Observed with spectral and temporal resolutions of 12 kHz and 0.01 seconds
- Images at all frequencies for every 0.01 s step ⟹ Simultaneous imaging of both sub-bands

~ 18.5 million images!



Chrysaphi, N., et al. 2018, ApJ, 868, 79

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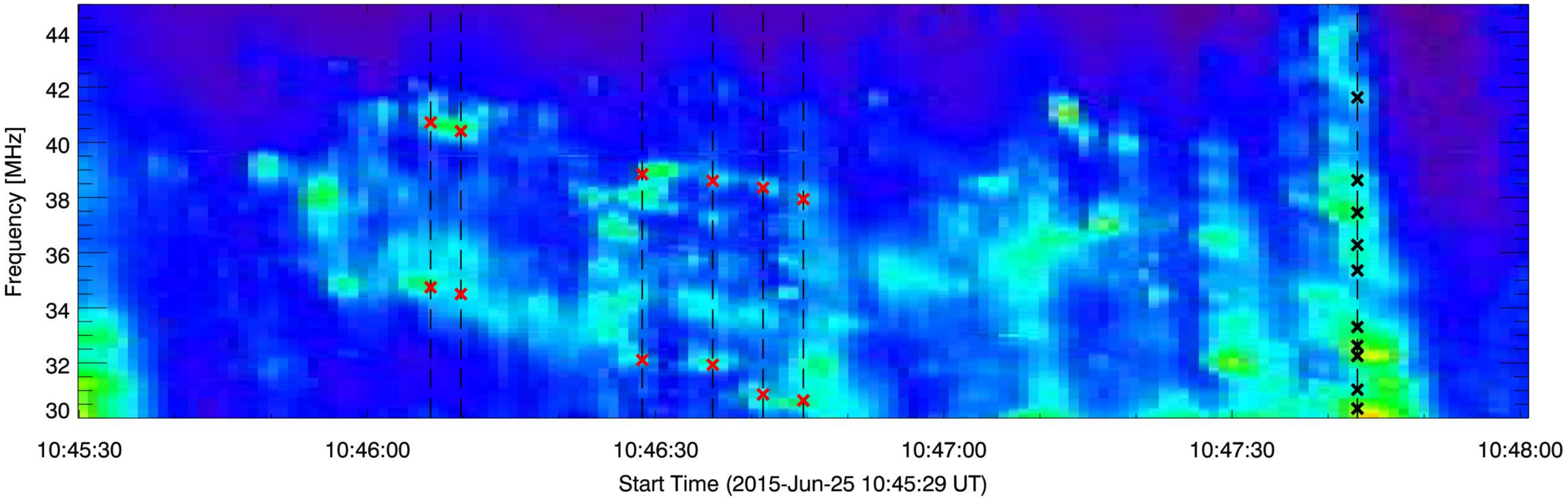
Type II observation

- Typical frequency-drift rate, $\frac{df}{dt} \approx -0.1$ MHz/s
- Band splitting $\Longrightarrow \frac{\Delta f}{f} \approx 0.21 \Longrightarrow$ density jump of ~ 1.46

Chrysaphi, N., et al. 2018, ApJ, 868, 79



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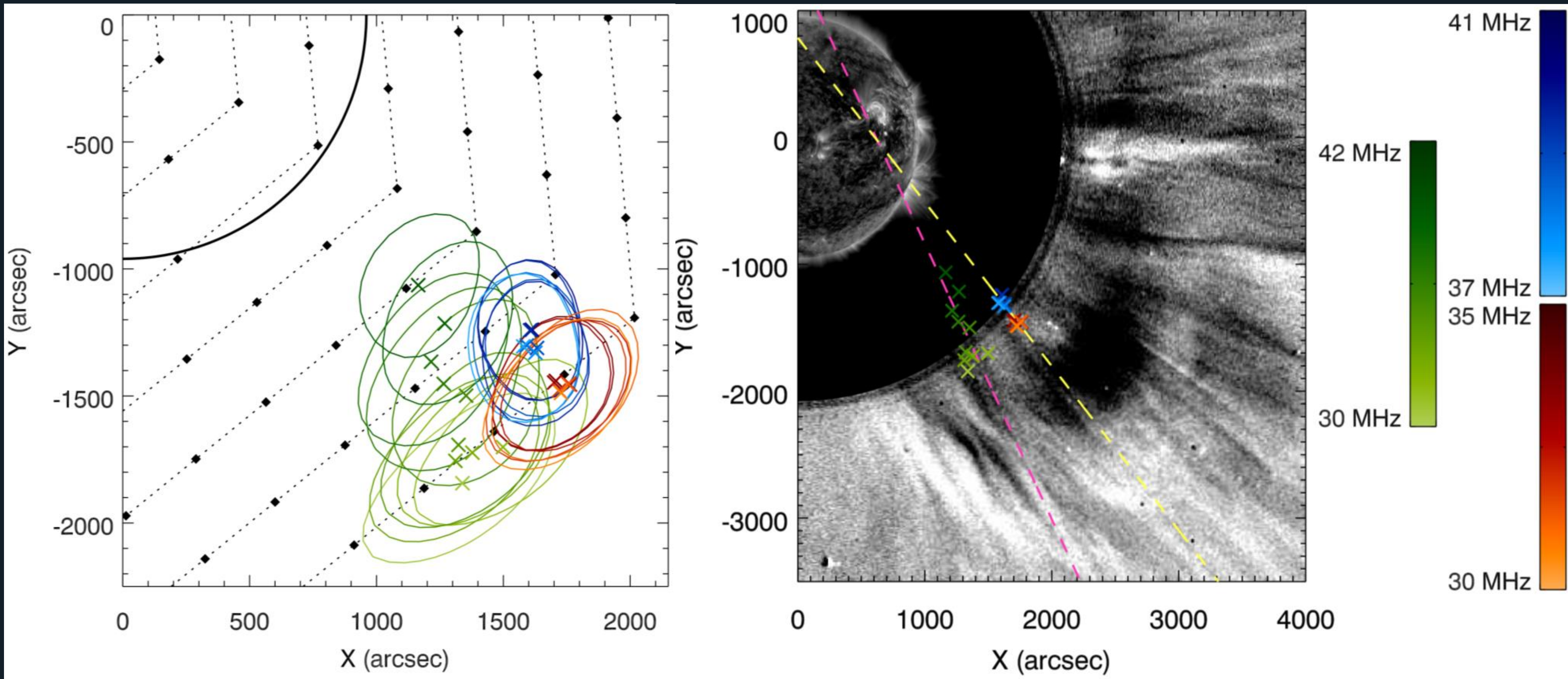
LOFAR imaging

- Centroid locations estimated using a 2D elliptical Gaussian fit
- Observed average separation between the upper and lower sub-bands is $0.2 \pm 0.05\ R_{\odot}$



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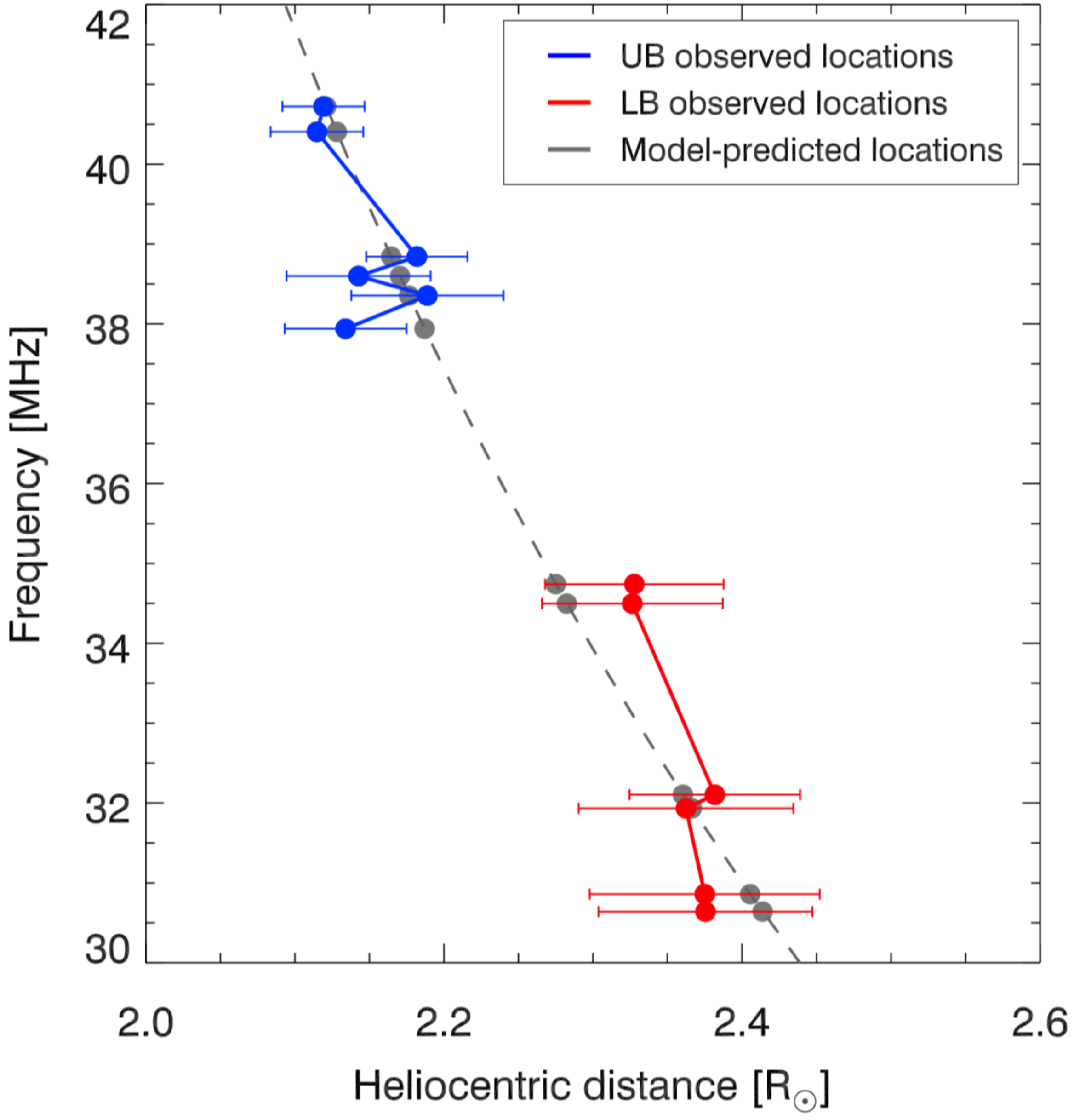
LOFAR imaging



Compared the observed heliocentric locations to the (Newkirk) model-predicted locations

⟹ observations best matched by the 4.5xNewkirk (1961) model

Chrysaphi, N., et al. 2018, ApJ, 868, 79
Newkirk, J. G. 1961, ApJ, 133, 983

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First impressions…

- Got rid of the time-delay ambiguities in the observations:

    1. Large separation observed between the two sub-bands
    2. Both sub-bands described by the same density model, i.e. no density jump observed
    3. Type II sources appear at the CME flank near the streamer, i.e. the shock front is quasi-perpendicular to the B-field (?)

  } Match the Holman and Pesses (1983) interpretation

- What about the extend of scattering effects?

Holman, G. D., & Pesses, M. E. 1983, ApJ, 267, 837

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Estimating Scattering Effects

How much does scattering affect split-band Type II sources?

- Sources radially shifted away from the true location (frequency dependent)

- Calculated scattering effects assuming:
  1. Homogeneous and stationary density fluctuations
  2. 1xNewkirk (1961) density model
  3. Value of ε^2/h to be constant

- Derived an analytical expression $\Longrightarrow$ No simulations needed

Chrysaphi, N., et al. 2018, ApJ, 868, 79; Newkirk, J. G. 1961, ApJ, 133, 983

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Estimating Scattering Effects

- Obtain an expression for the optical depth of scattering:

$$\tau(r) = \int_r^{1AU} \frac{d\langle\Delta\theta^2\rangle}{dr} dr = \int_r^{1AU} \frac{\sqrt{\pi}}{2} \frac{f_{pe}^4(r)}{\left(f^2 - f_{pe}^2(r)\right)^2} \frac{\epsilon^2}{h} dr$$

- Optical depth τ calculated for

$$\frac{\varepsilon^2}{h} = 4.5 \times 10^{-5} - 7 \times 10^{-5}\ km^{-1}$$

where: $\varepsilon = density\ modulation\ index\ \left(\frac{\delta n}{n}\right)$
$h = density\ scale\ height$

- Take values where $\tau = 1$ as the result

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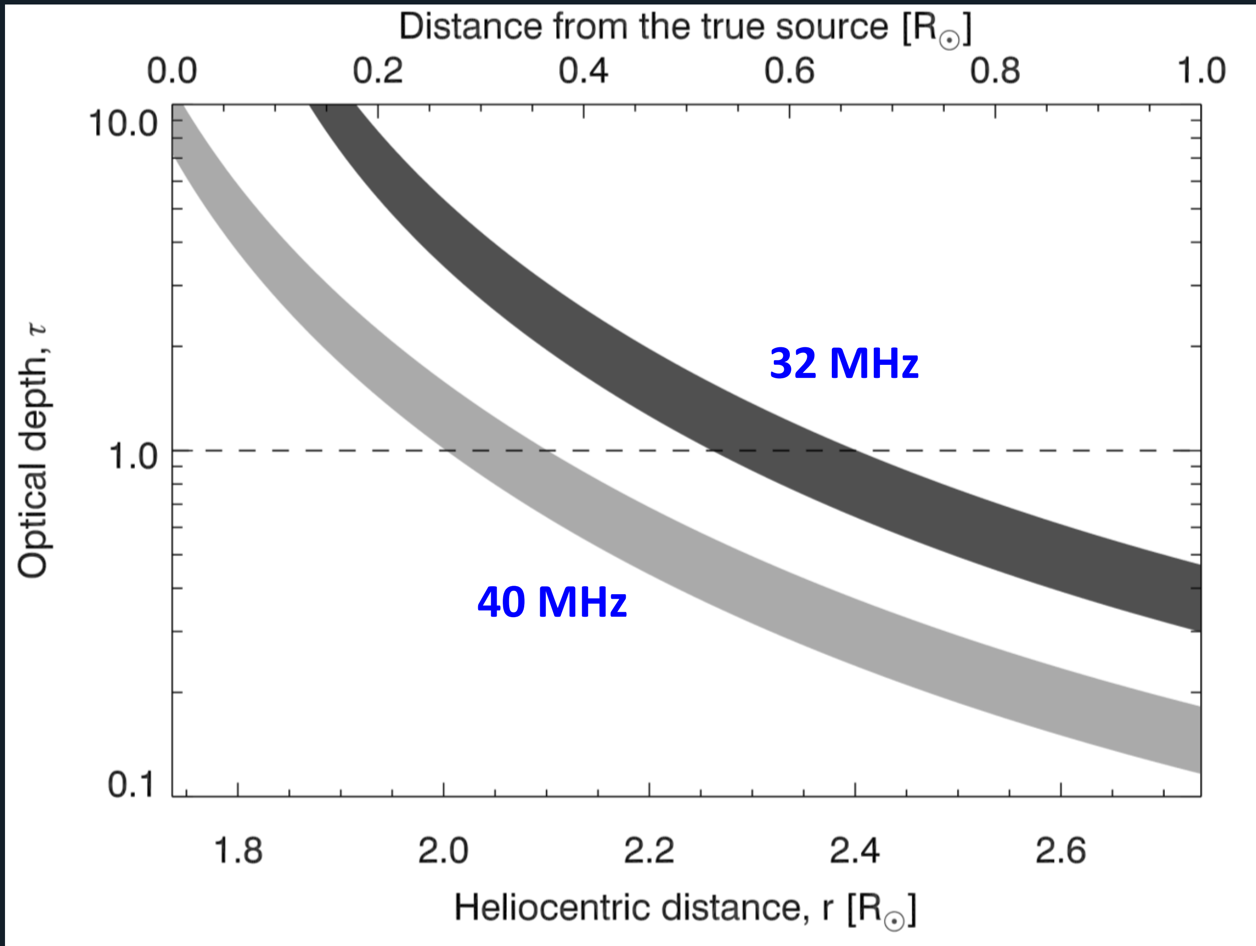
Estimating Scattering Effects

- A 40 MHz source shifts by 0.3 $R_\odot$ from true location, but a 32 MHz source shifts by 0.6 $R_\odot$
- A source at 32 MHz shifts by 0.3 $R_\odot$ away from a 40 MHz source

$\Longrightarrow$ Imaged separation of 0.2 ± 0.05 $R_\odot$ results from scattering of the radio waves



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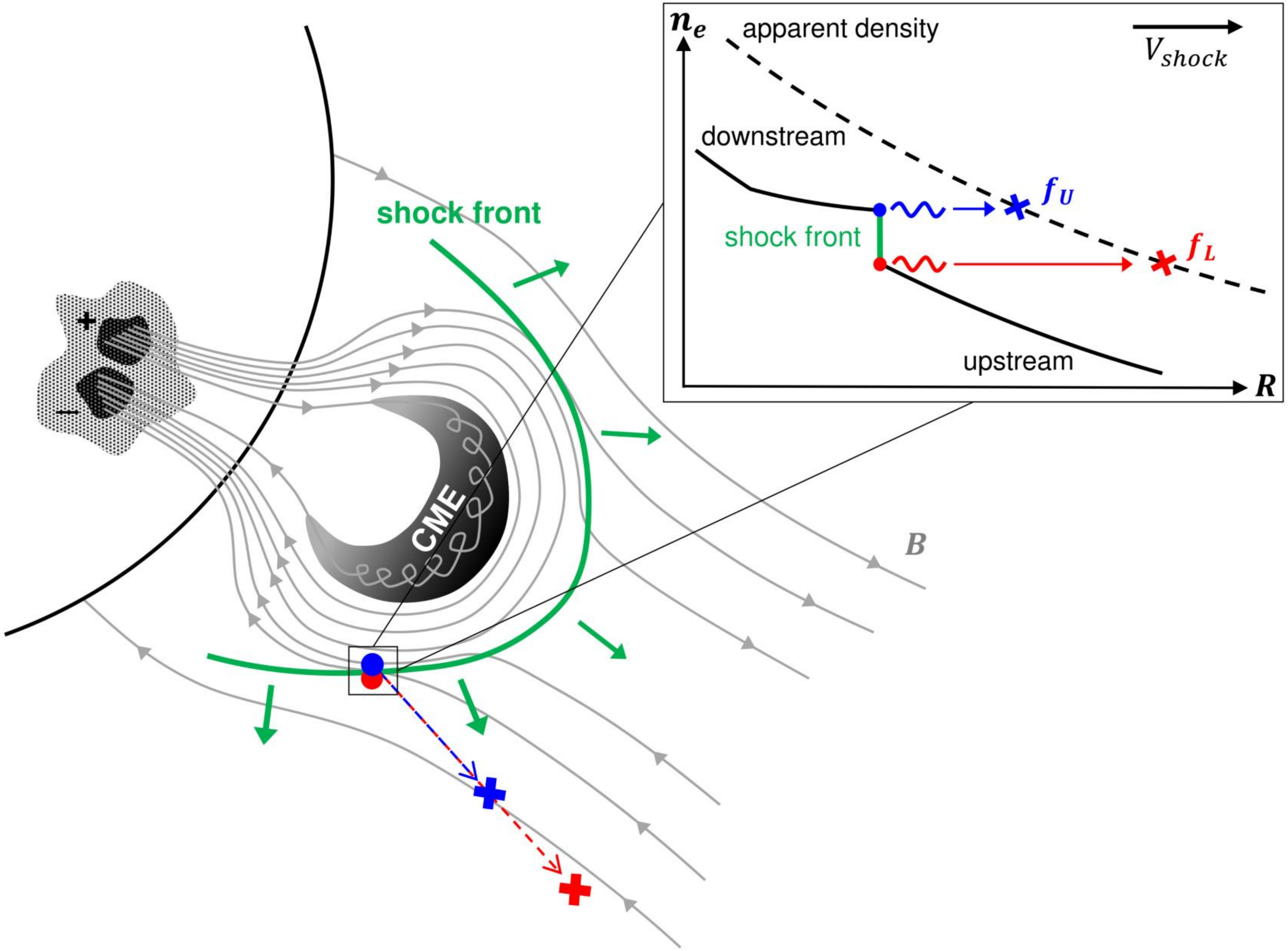
Schematically…



Apparent Newkirk density increases by a factor of 4.3

⟹ Factor of 4.5 estimated from the images results from scattering

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Overview & Conclusions

- Split-band Type II emission sources appear physically separated (no time-delay ambiguities)

- Derived an analytical expression to estimate the radial shift caused by scattering

  $\Longrightarrow$ can be used for any radio observation

- Correcting for scattering effects:
  a) Split-band Type II sources are virtually co-spatial
  b) High density values observed are a scattering side-effect
  c) Density jump (from images) becomes ~ 1.46
  $\Longrightarrow$ matches the value deduced from the dynamic spectrum

- Results support models requiring co-spatial sources (like the Smerd et al. model)

- Do NOT ignore scattering effects – they could affect your conclusions!

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