Radio emissions in the era of PSP & SO

Immanuel C. Jebaraj

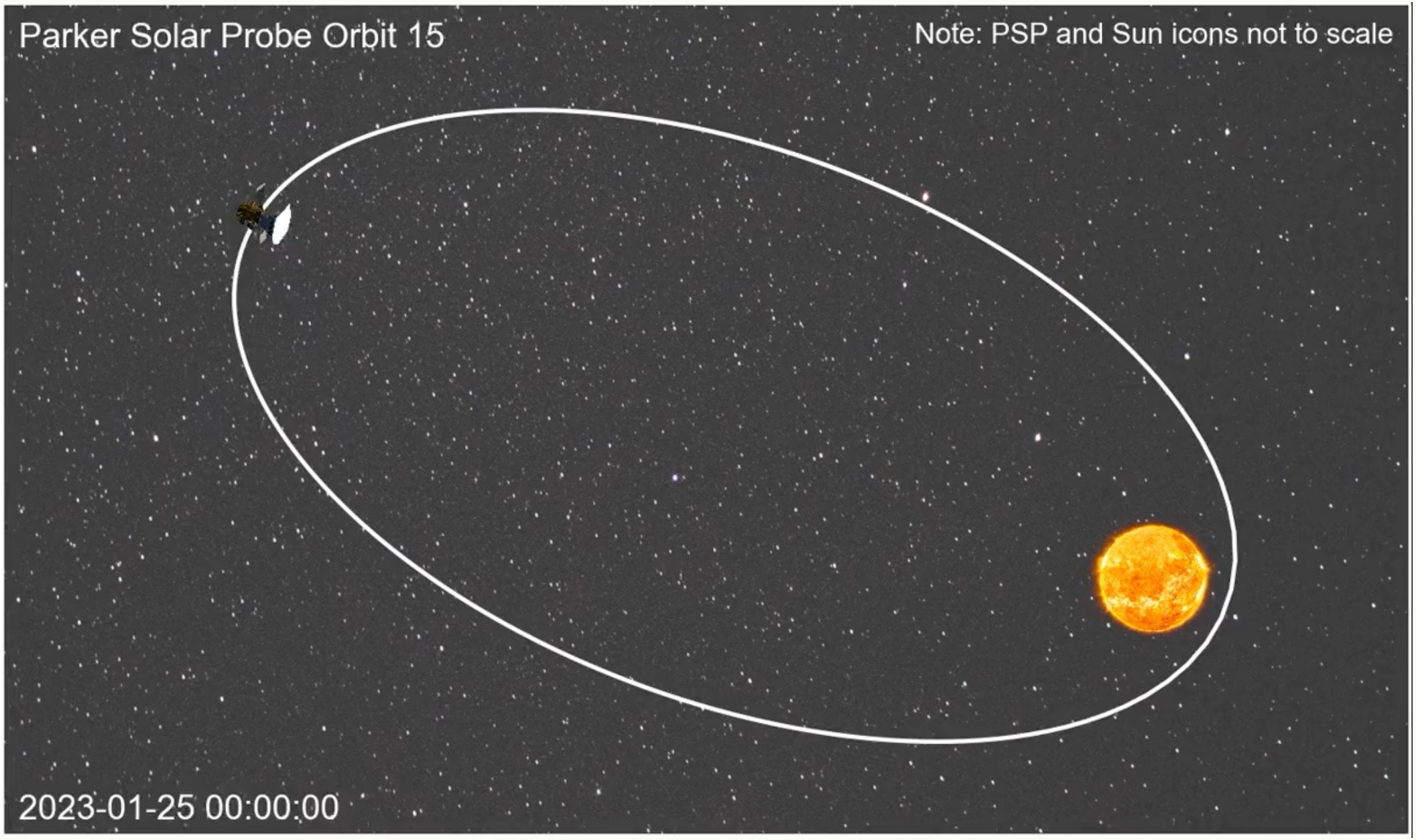
My main collaborators: V. Krasnoselskikh, M. Pulupa, J. Magdalenic, S. Bale

PSP & SO



from www.esa.int

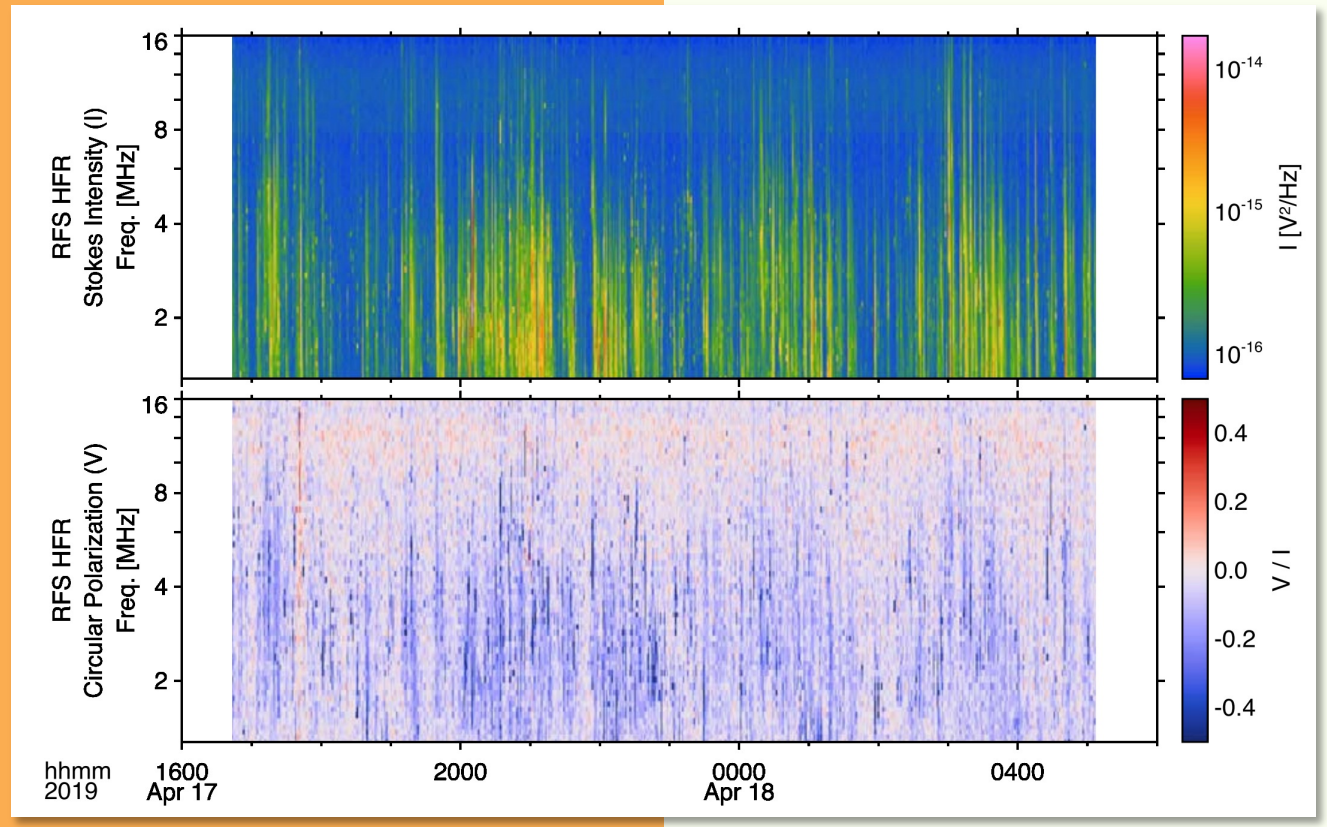
- Positional significance – PSP & SO
  - Radial position (close to the source)
  - Longidutinal positioning.
- Capabilities
  - High time-resolution of PSP
  - HiRes frequency resolution (1%)
  - Polarization from 20 MHz onward
  - Instrument suite on SolO (EAS+STEP+EPD)



from Erika Palmerio's Twitter (@erikapal)

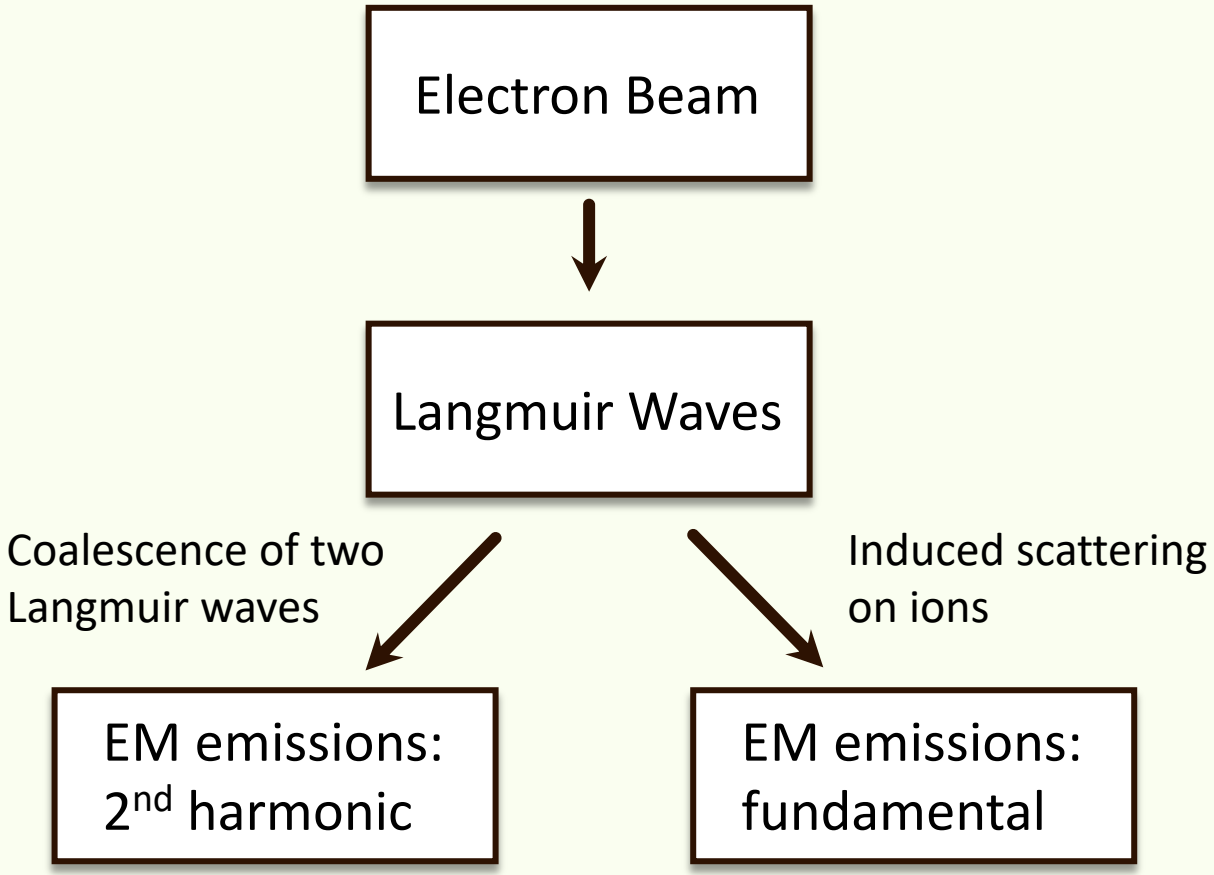
FIELDS/RFS observations

- Unique because of observing the emission close to the Source
- Aphelion resolution: ~60s temporal, 4% frequency (1% HiRes)
- Perihelion resolution: 3.5s temporal (6th CE onward), 4% frequency (1% HiRes)



Pulupa et al. 2020 (ApJS)

Emission mechanism



- Plasma mechanism as proposed by Ginzburg & Zheleznyakov (1958)
- Improved later by Melrose (1980)
- Fundamental and harmonic emission explained well
- Efficiency of the mechanism is improved by later models which consider direct transformation from electrostatic to electromagnetic (e.g., Voshchepynets et al. 2015)

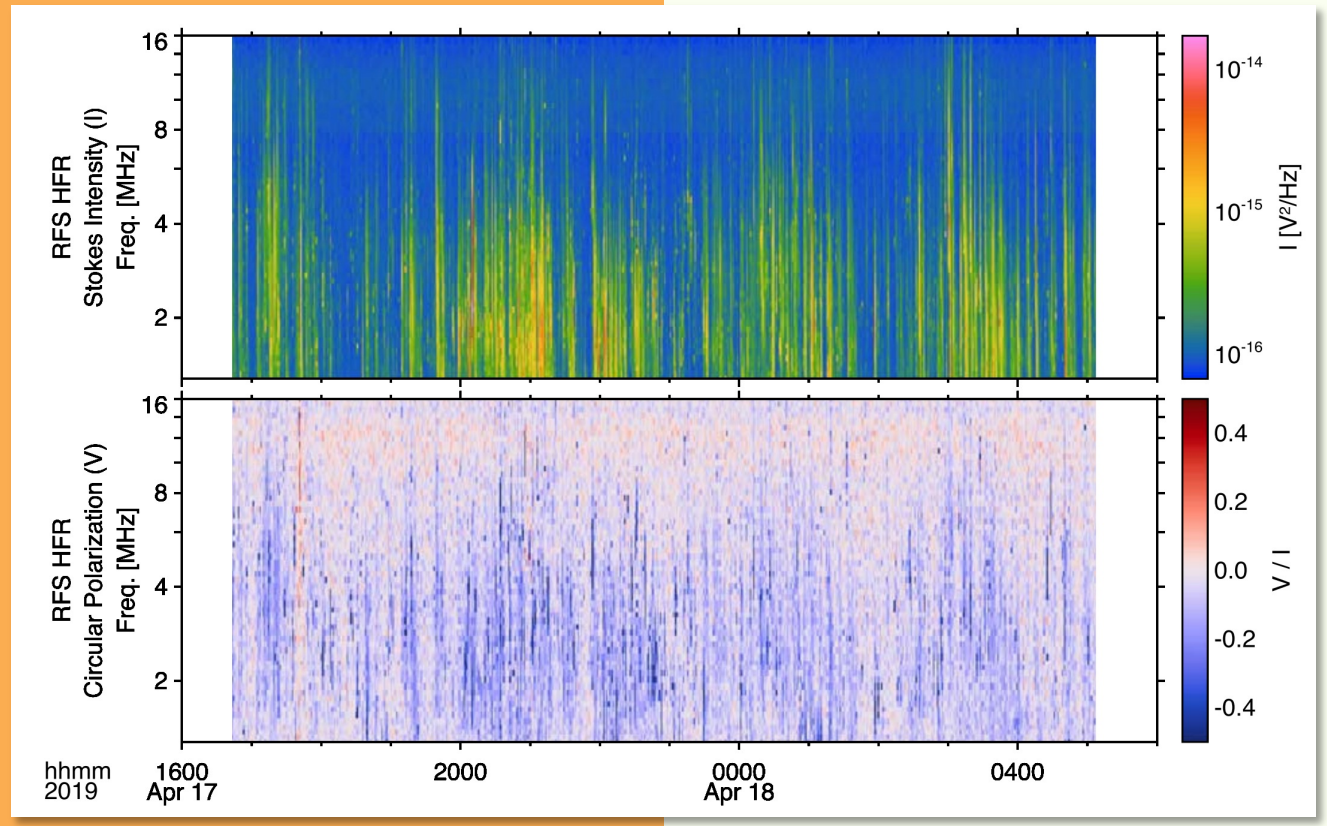
Open questions

- Are the type III radio bursts **fundamental** or **higher harmonic** or **both**?
- What about **fine structures**?
- How does the beam-plasma system evolve, and how it related to the observed emission?
- How are the radio waves generated?
- What are their properties close to the source?

These questions have been explored in the metric wavelengths thanks to the observational capabilities!

FIELDS/RFS observations

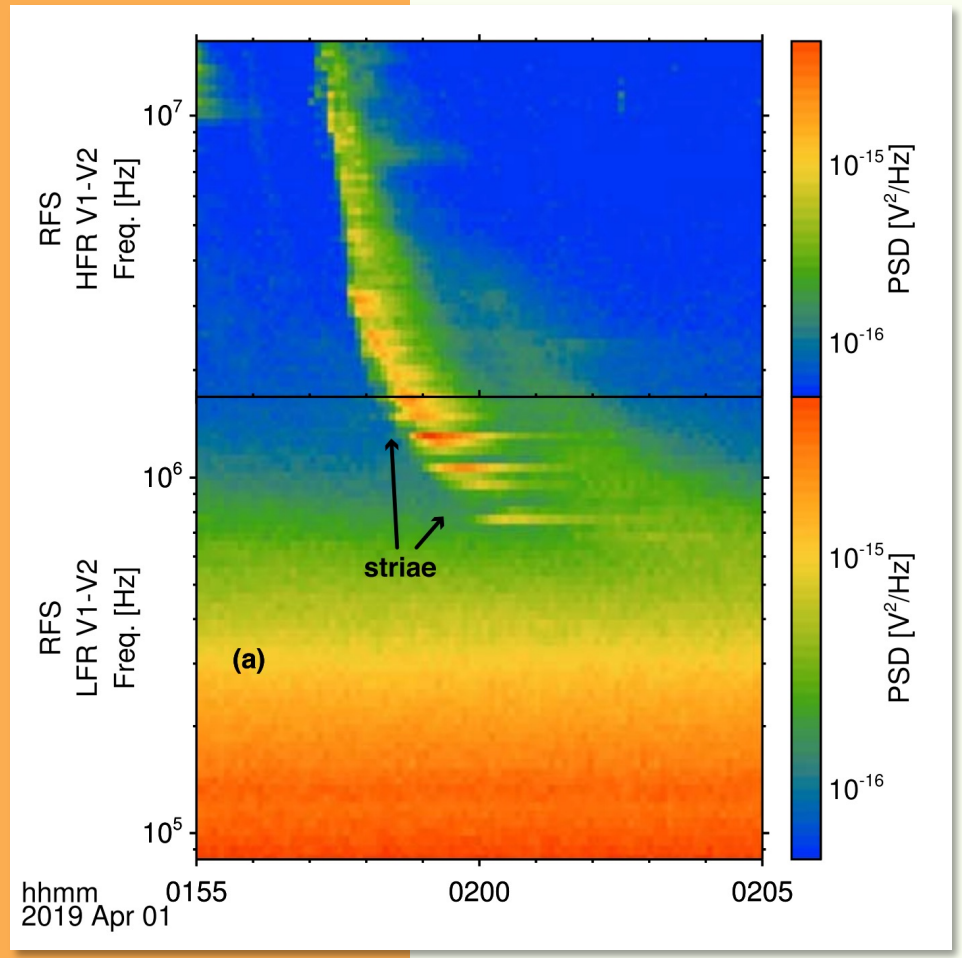
- Unique because of observing the emission close to the Source
- Aphelion resolution: ~60s temporal, 4% frequency (1% HiRes)
- Perihelion resolution: 3.5s temporal (6th CE onward), 4% frequency (1% HiRes)
- They showed high polarization during a type III storm
- Previous study: Reiner et al. 2007 showed almost an order of magnitude lower polarization on average. (using Wind/WAVES)



Pulupa et al. 2020 (ApJS)

FIELDS/RFS observations

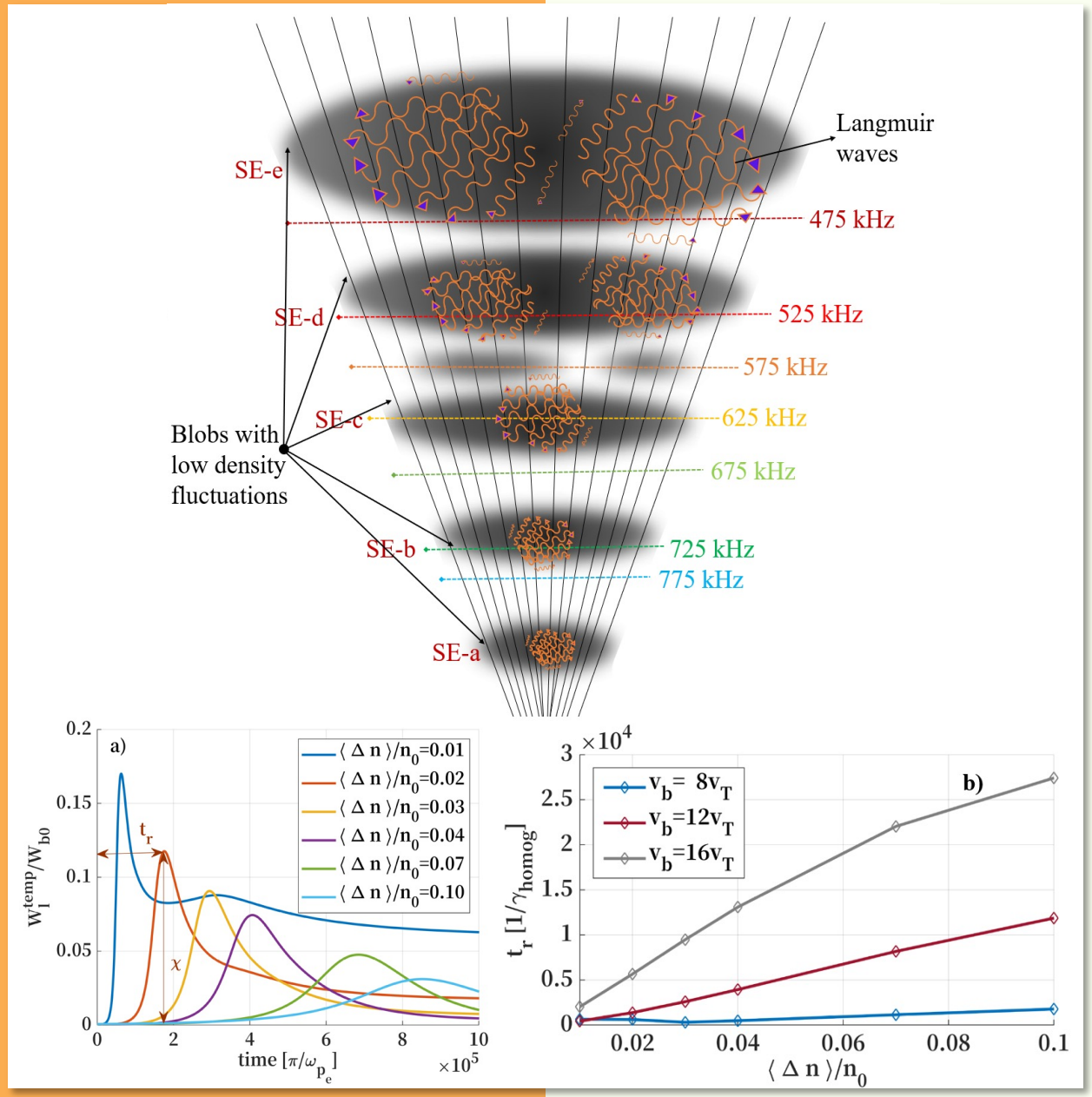
- PSP has also observed quite a lot of structured radio bursts
- Reported on in STEREO/WAVES and Wind/WAVES observations too (Jebaraj et al. 2023 A&A)
- Morphological similarities to metric-decametric fine structures
- A generation mechanism for this was proposed by Jebaraj et al. 2023 (A&A) which considered Langmuir wave growth in inhomogeneous plasma
- Probabilistic model: Voshchepynets et al. 2015, Krasnoselskikh et al. 2019
- Similar results using simulation by Krafft et al. 2013, 2015



Pulupa et al. 2020 (ApJS)

Striae elements

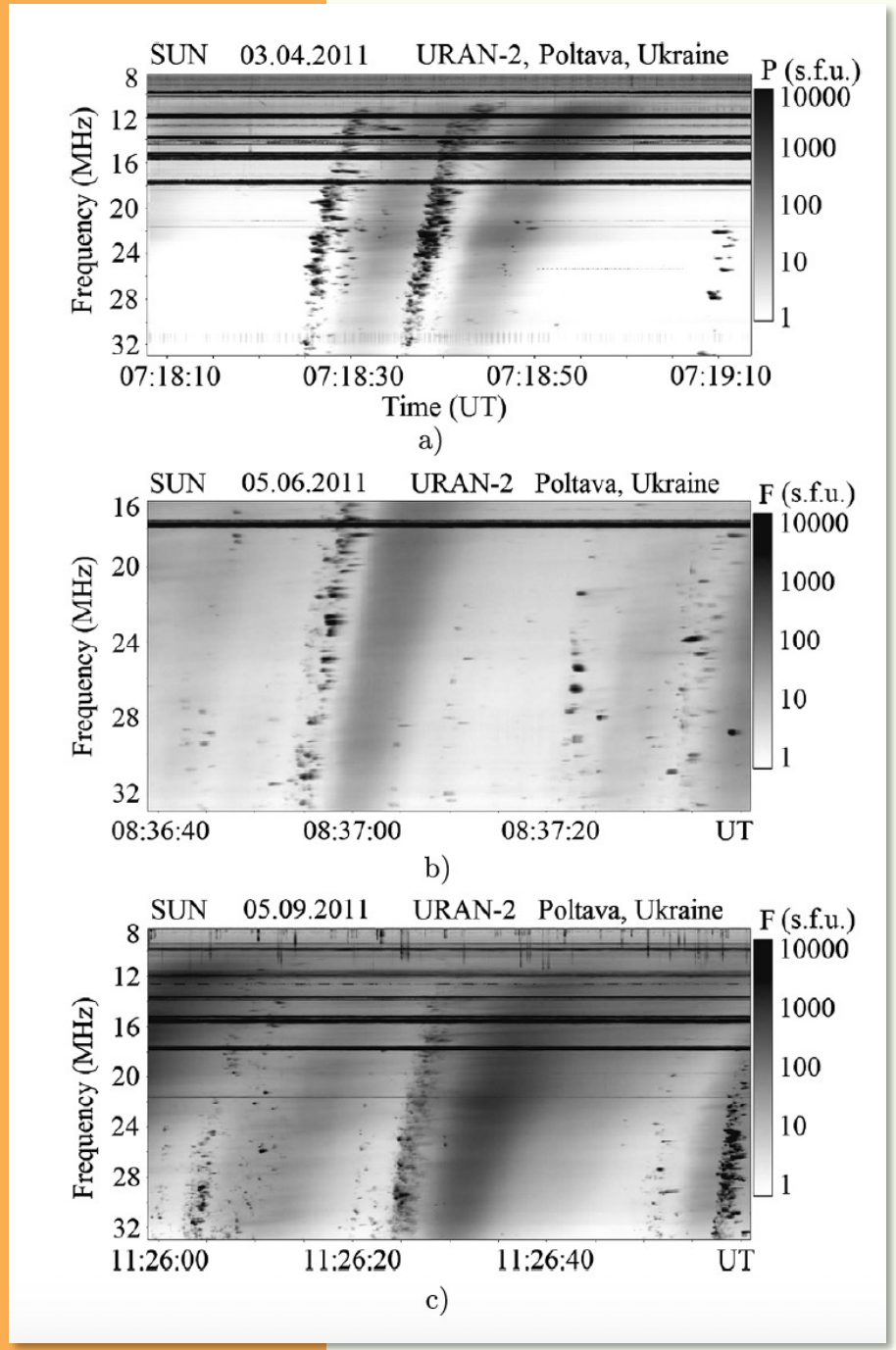
- Formed as natural consequences of beam evolution in randomly inhomogeneous plasma
- Relatively low-density fluctuations = Intense emission of striae elements
- High density fluctuations = Envelope emission
- Magnetic field divergence results in larger area of the beam, so higher level of density fluctuations affect Langmuir wave growth



Jebaraj et al. 2023a (A&A)

F-H pairs

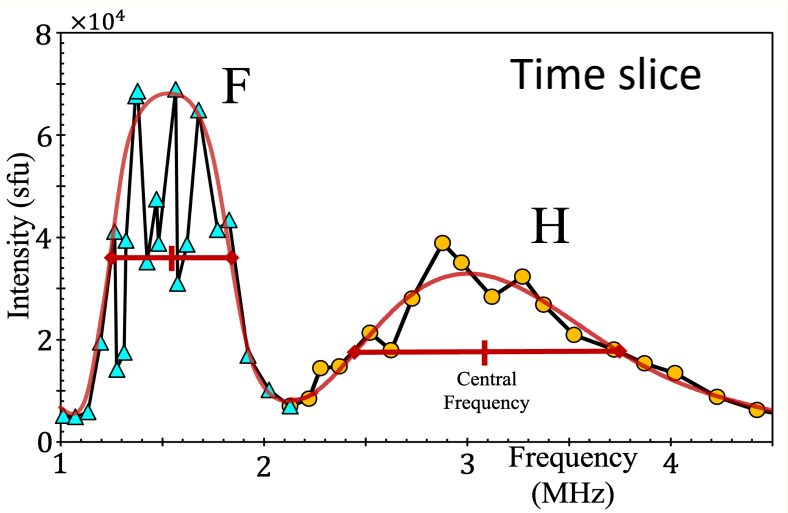
- Plasma emission mechanism predicts the generation of harmonics.
- Occasionally observed for type II radio bursts – but easier to distinguish.
- Difficult to distinguish for type III radio bursts – rare!
- Rare even in metric-decametric.
- Never been observed in deca-hecto-kilometric! (PSP's observational range)

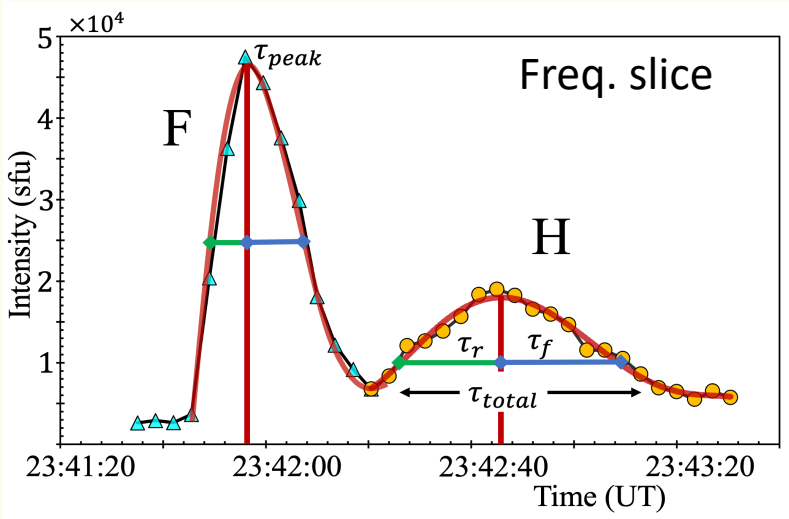


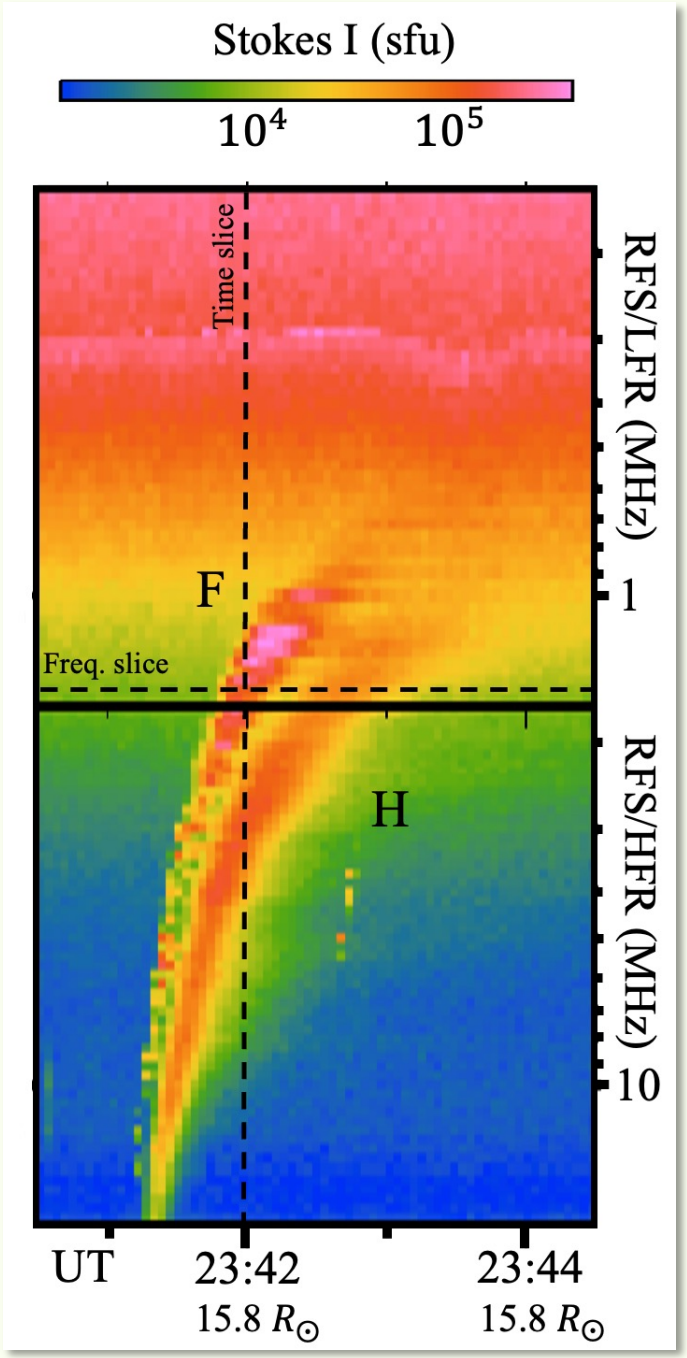
Melnik et al. 2018

PSP observations of F-H pairs

- During CE, a majority of the type III are F-H pairs.
- Proximity to the source and the enhanced time resolution during CEs.
- Sensitivity of the FIELDS/RFS instrument.



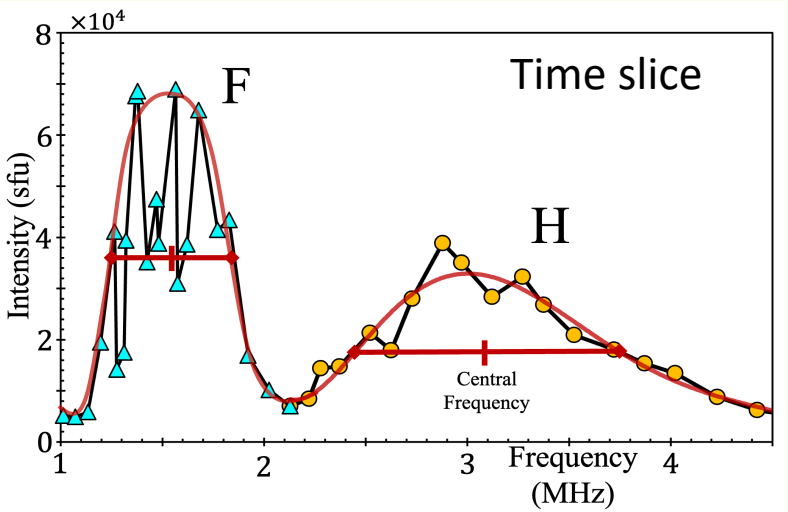


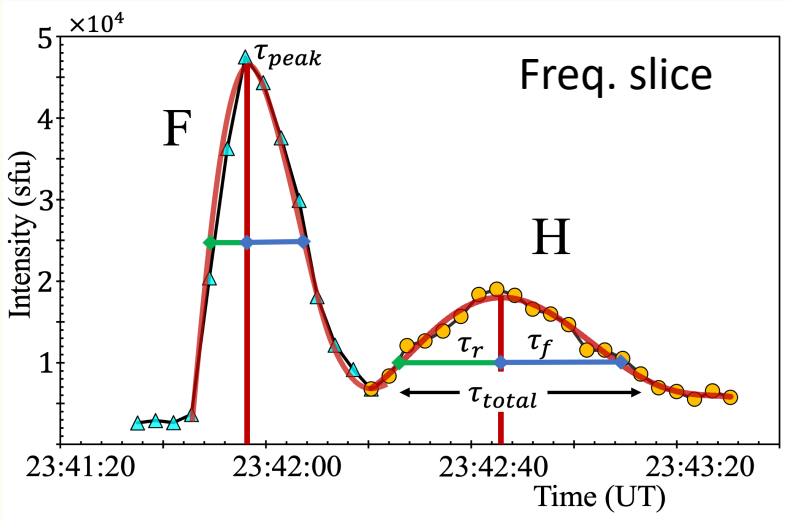


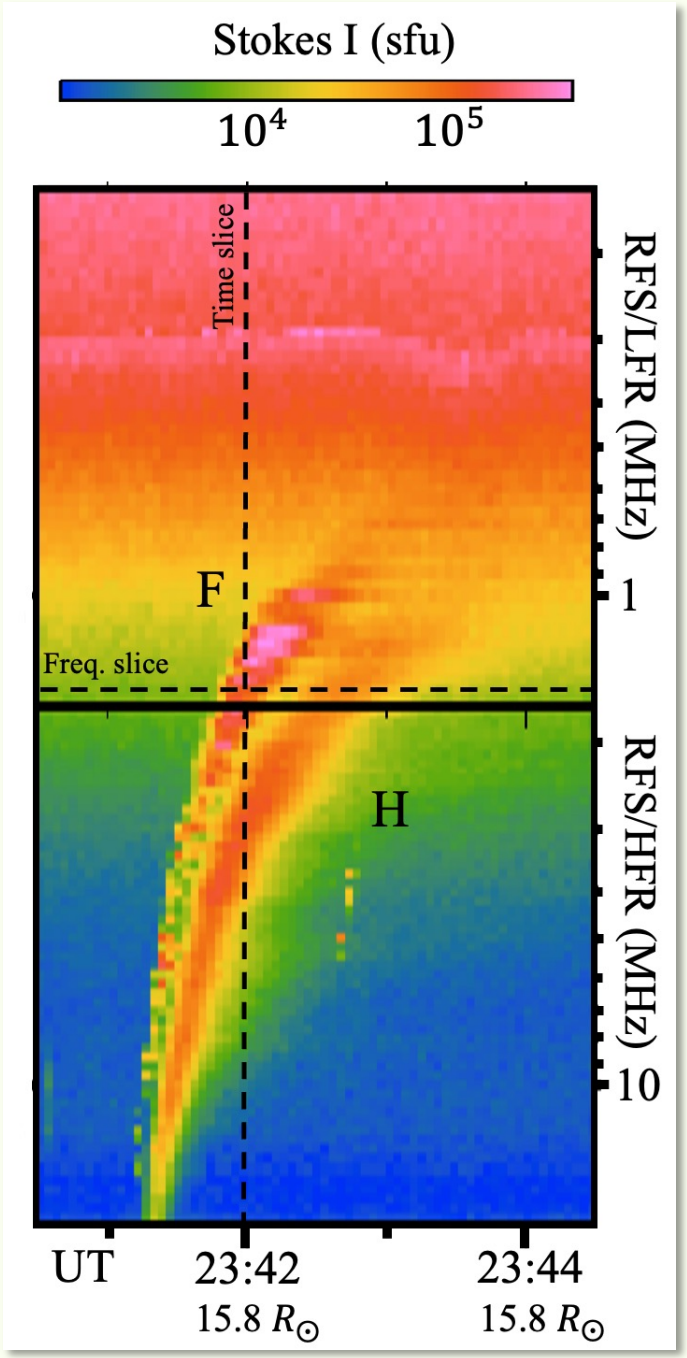
Jebaraj et al. 2023 (ApJL)

PSP observations of F-H pairs

- Time slice demonstrates clearly that the pair observed here is F-H.
- F-component is strongly structured, H -component is smooth/diffuse and only shows weak structuring.

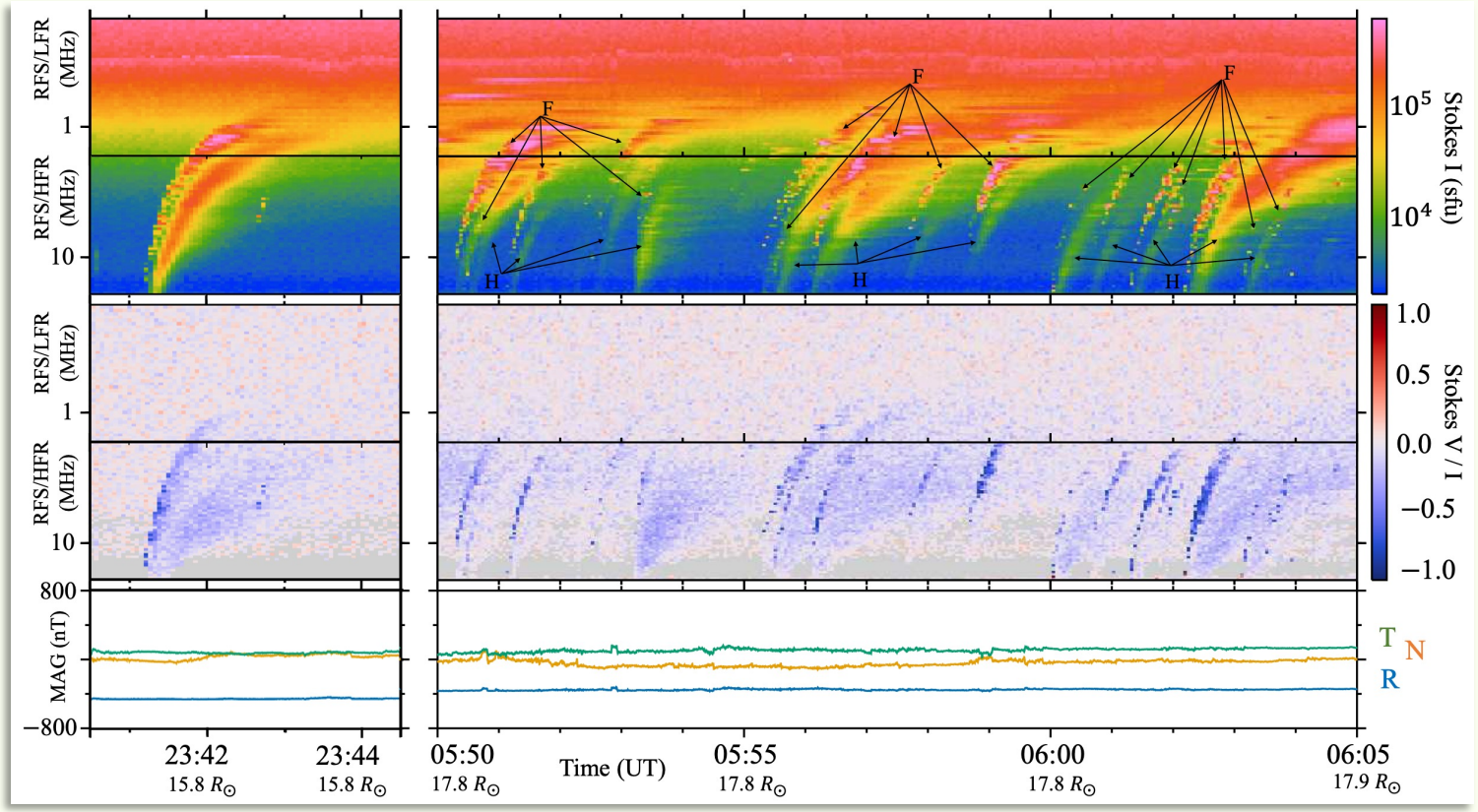






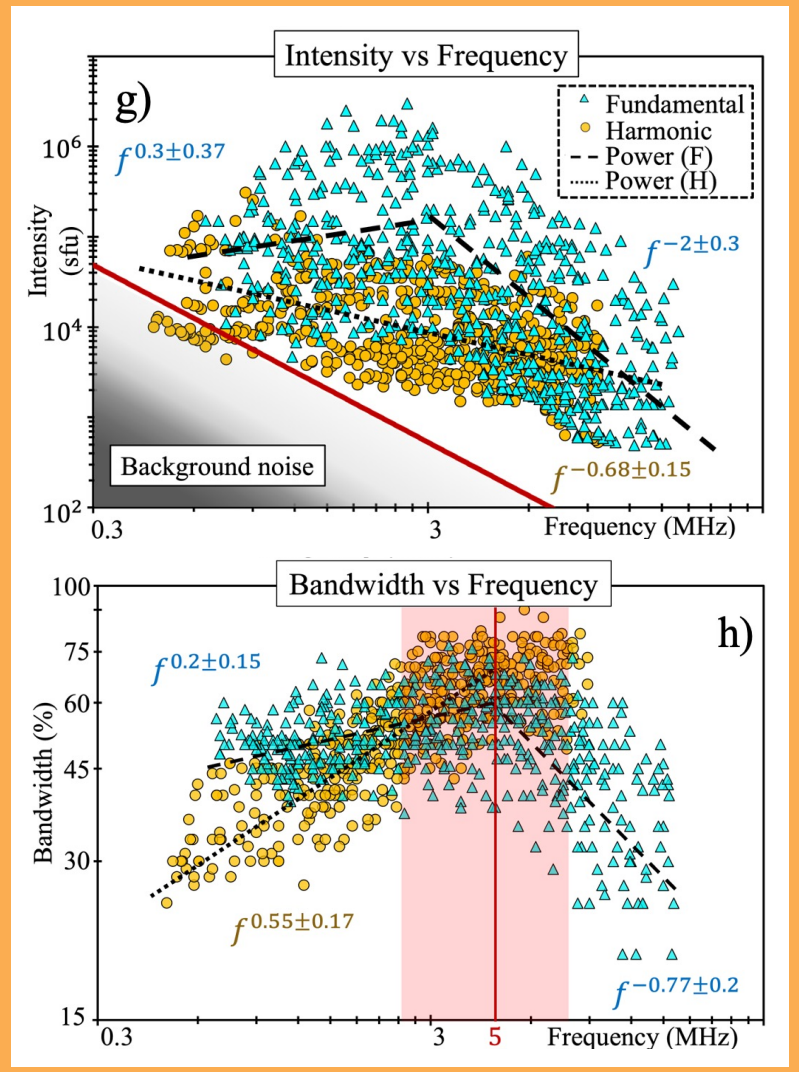
Jebaraj et al. 2023 (ApJL)

Polarization



- Degree of polarization is generally high
- F is polarized to a greater degree (>60%).
- H is weakly polarized by a few factors.
- F is sharp and structured.
- H is diffuse and smooth.
- Effect of generation: F is considered to be purely o-mode.
- H is emitted at both x and o-mode.
- Polarization demonstrates further the nature of the F-H pairs.

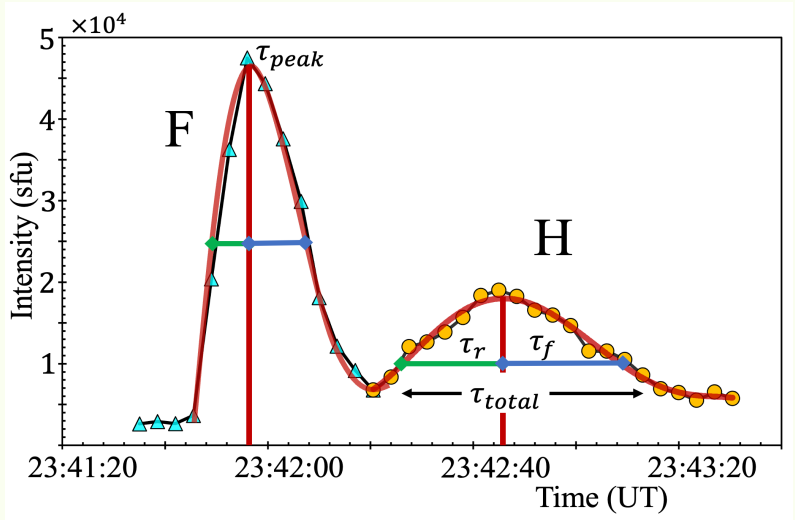
Spectral Characteristics

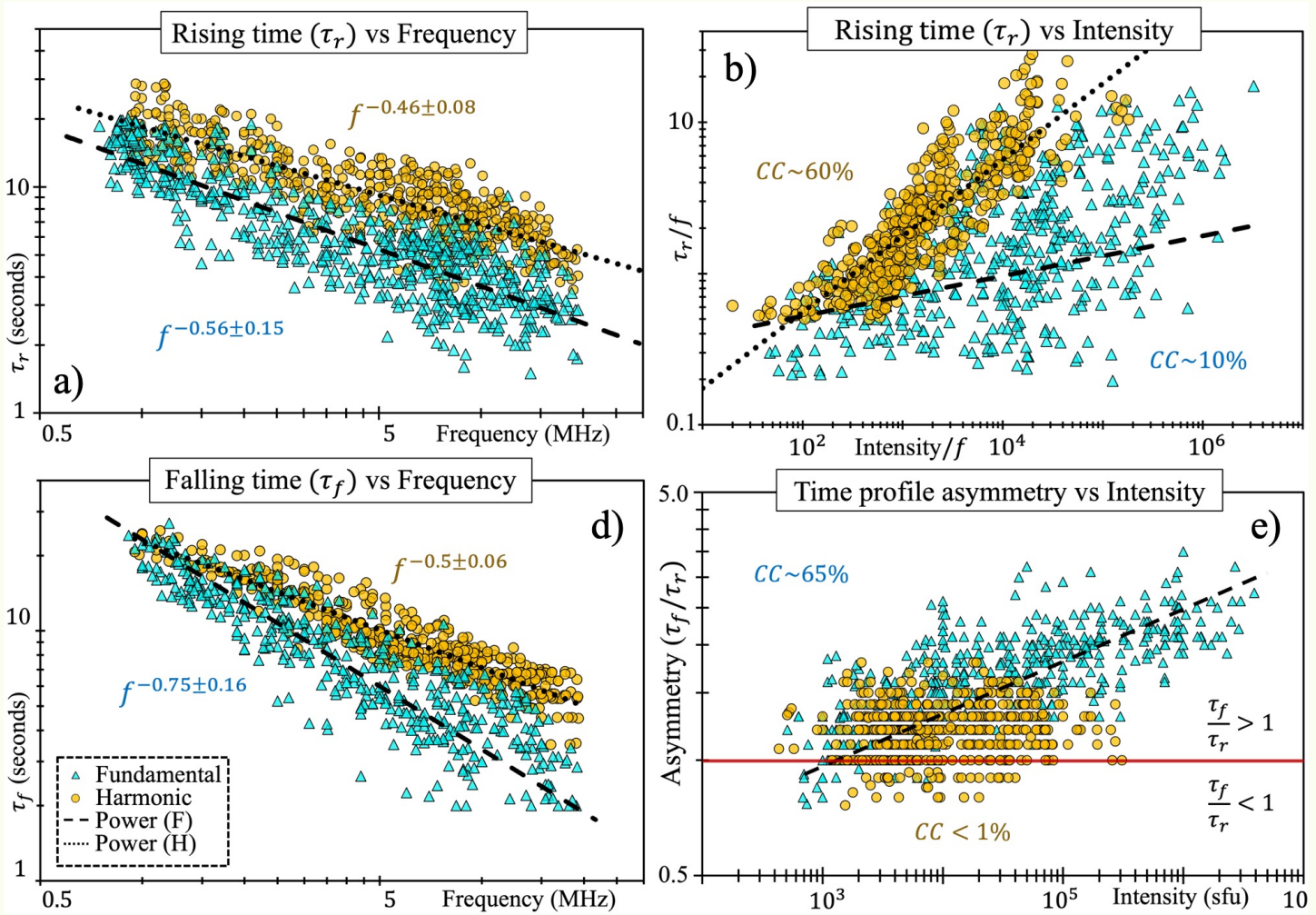


- The intensity of F increases rapidly and peaks around ~ 2 MHz. After which it flattens or decreases.
- Intensity of H monotonically increases.
- Bandwidth of F and H are similar.
- Decrease may be due to increasing background.
- H has a slightly systematically higher peak bandwidth.

Time profile characteristics

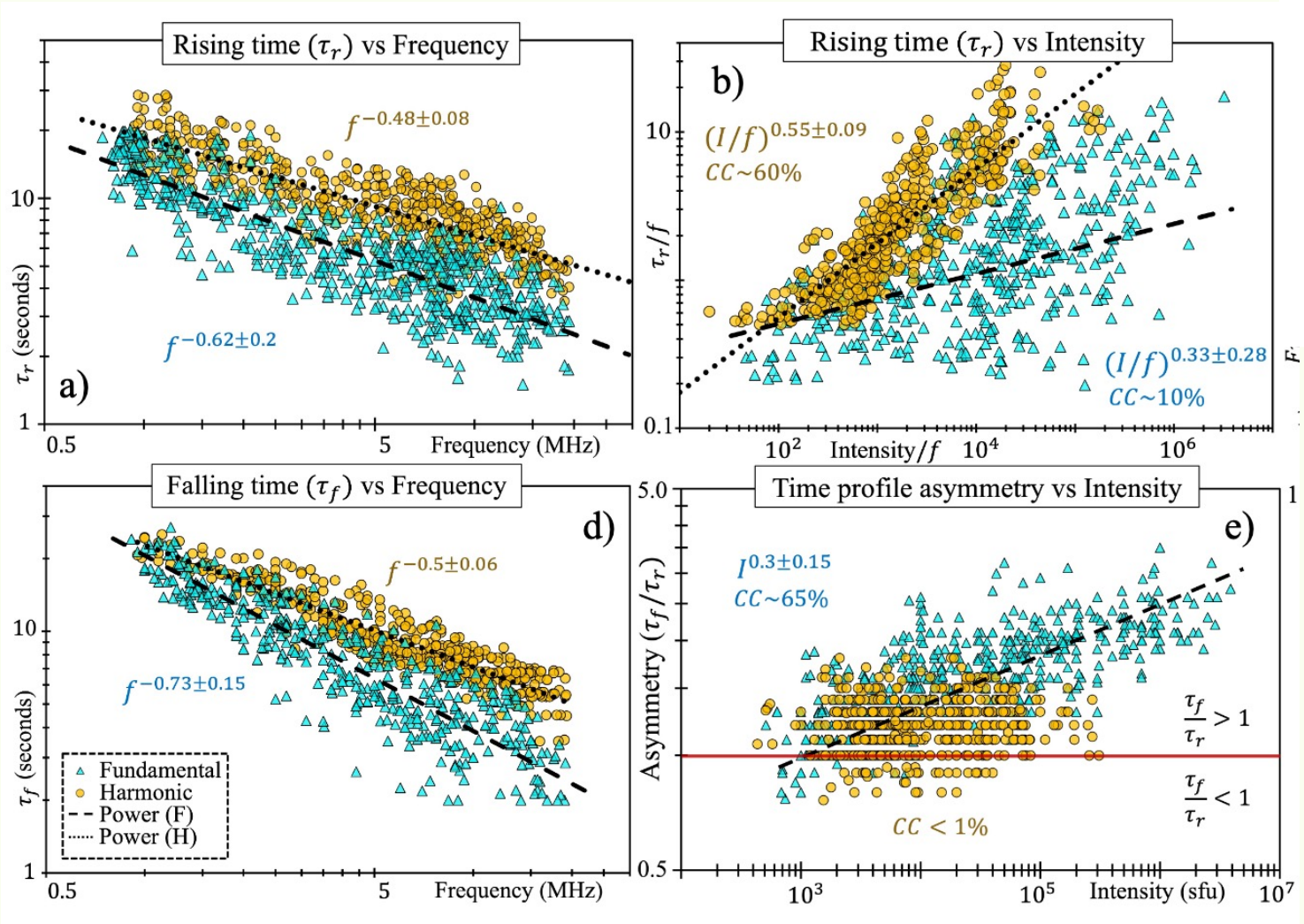
- Rising time of both F and H scale similarly as $\frac{1}{\sqrt{f}}$
- Generally, rising time of F is 70% of H.
- Rising time is also affected by the intensity of the emission.
- F emission has large intensity variations resulting in a widespread and low CC.





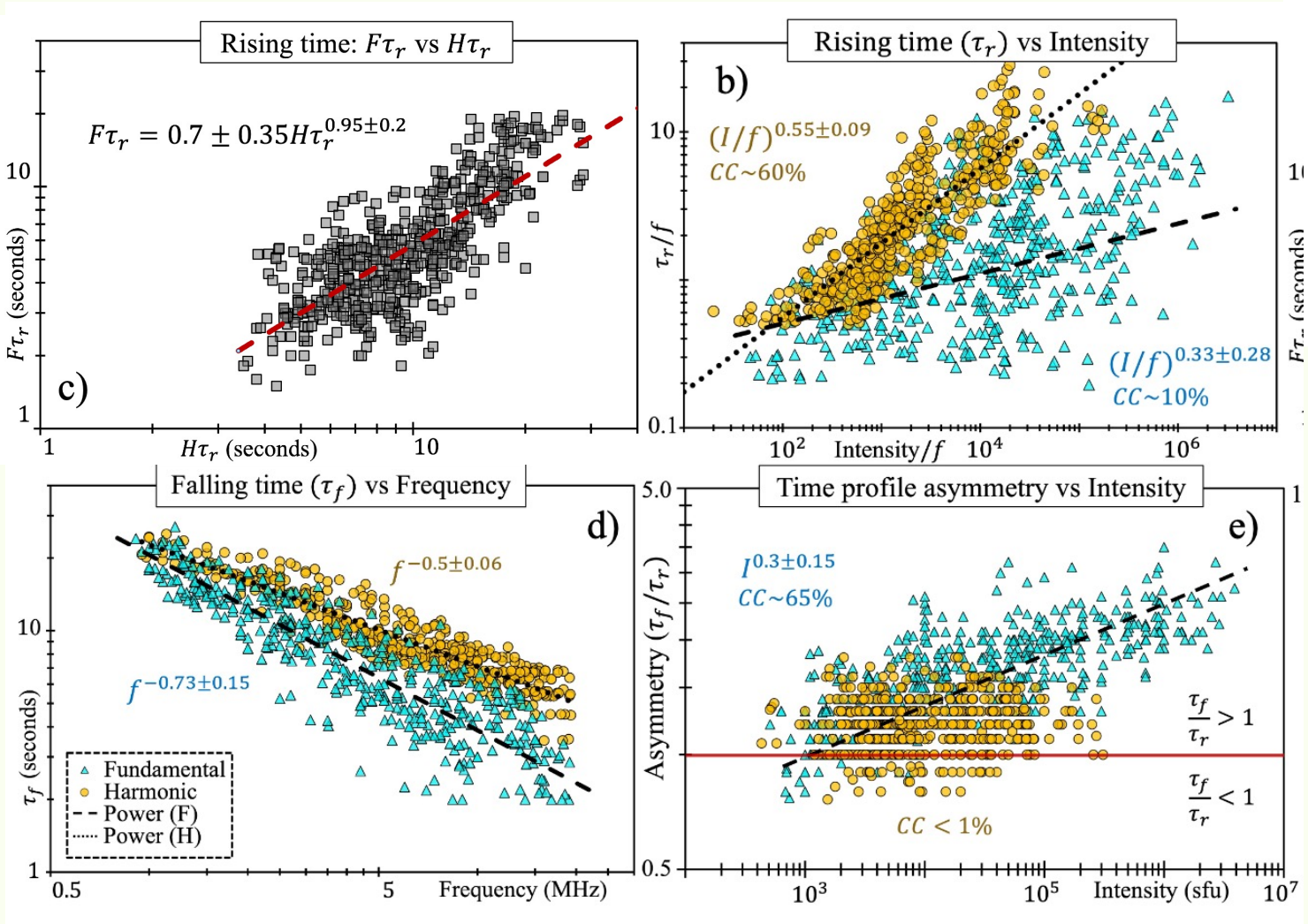
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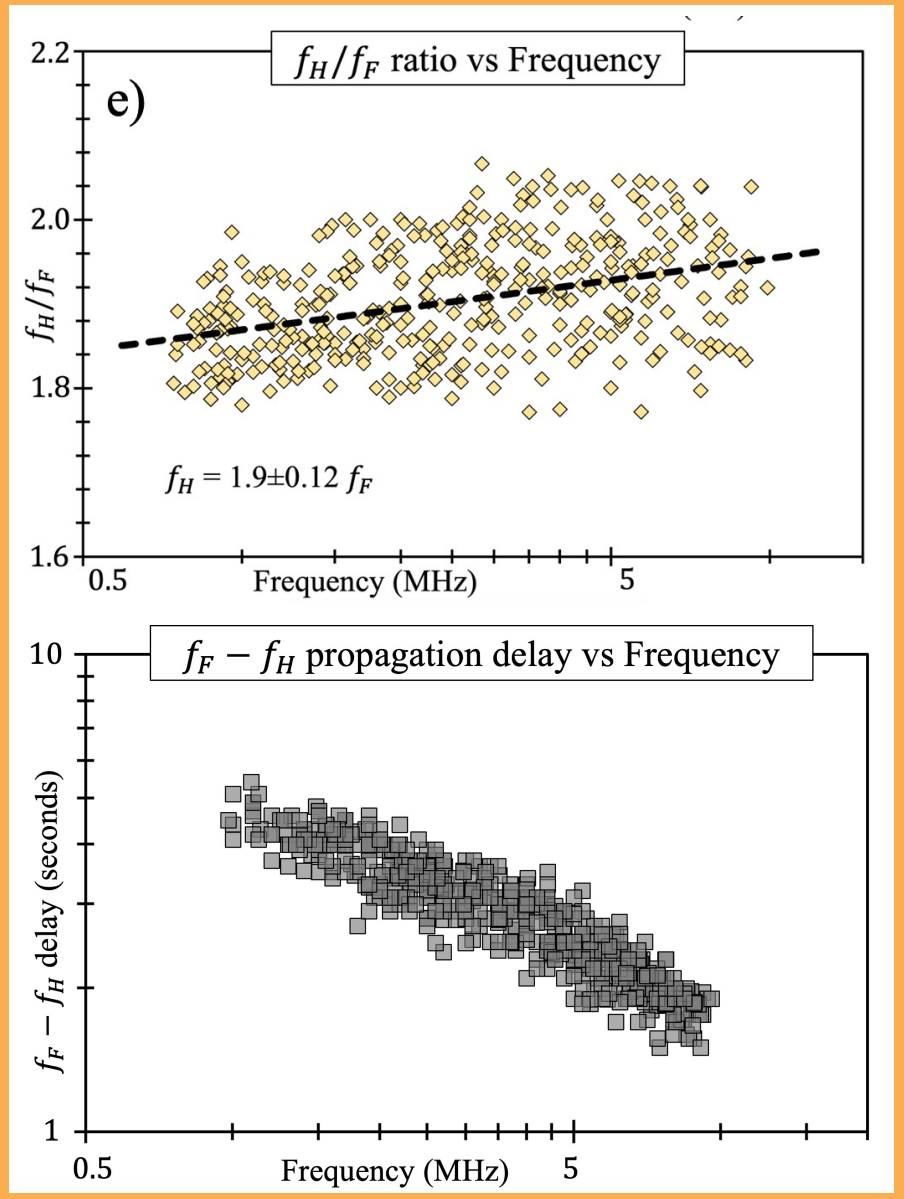
- H emission shows a smooth increase with little variation with high CC.
- Falling time is different for F and H.
- H scales as $\frac{1}{\sqrt{f}}$, F scales a bit steeper as $\frac{1}{f^{3/4}}$
- This means, F emission is systematically asymmetric.
- The asymmetry shows some correlation with intensity.
- H shows no such correlation.



Time profile characteristics

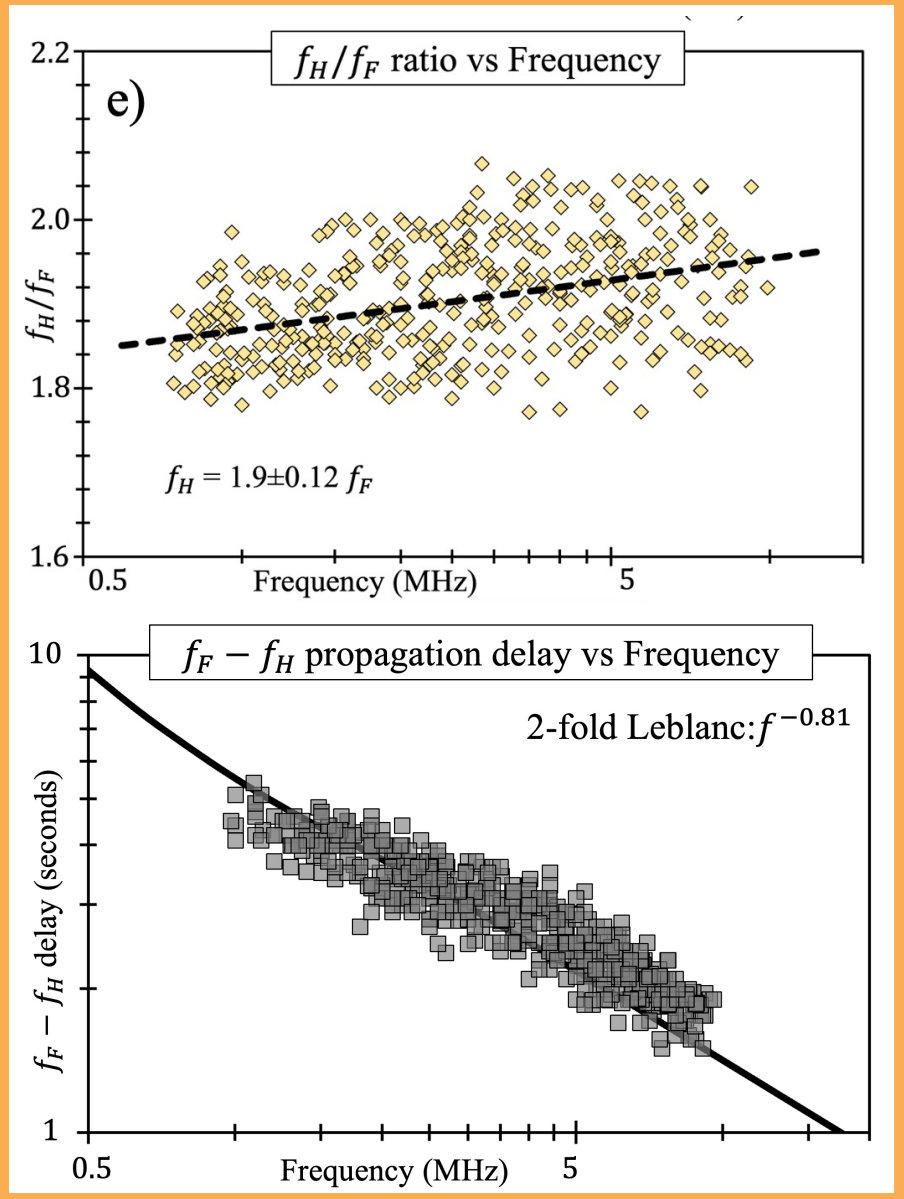
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- H scales as $\frac{1}{\sqrt{f}}$, F scales a bit steeper as $\frac{1}{f^{3/4}}$
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- The asymmetry shows high correlation with intensity.
- H shows no such correlation.





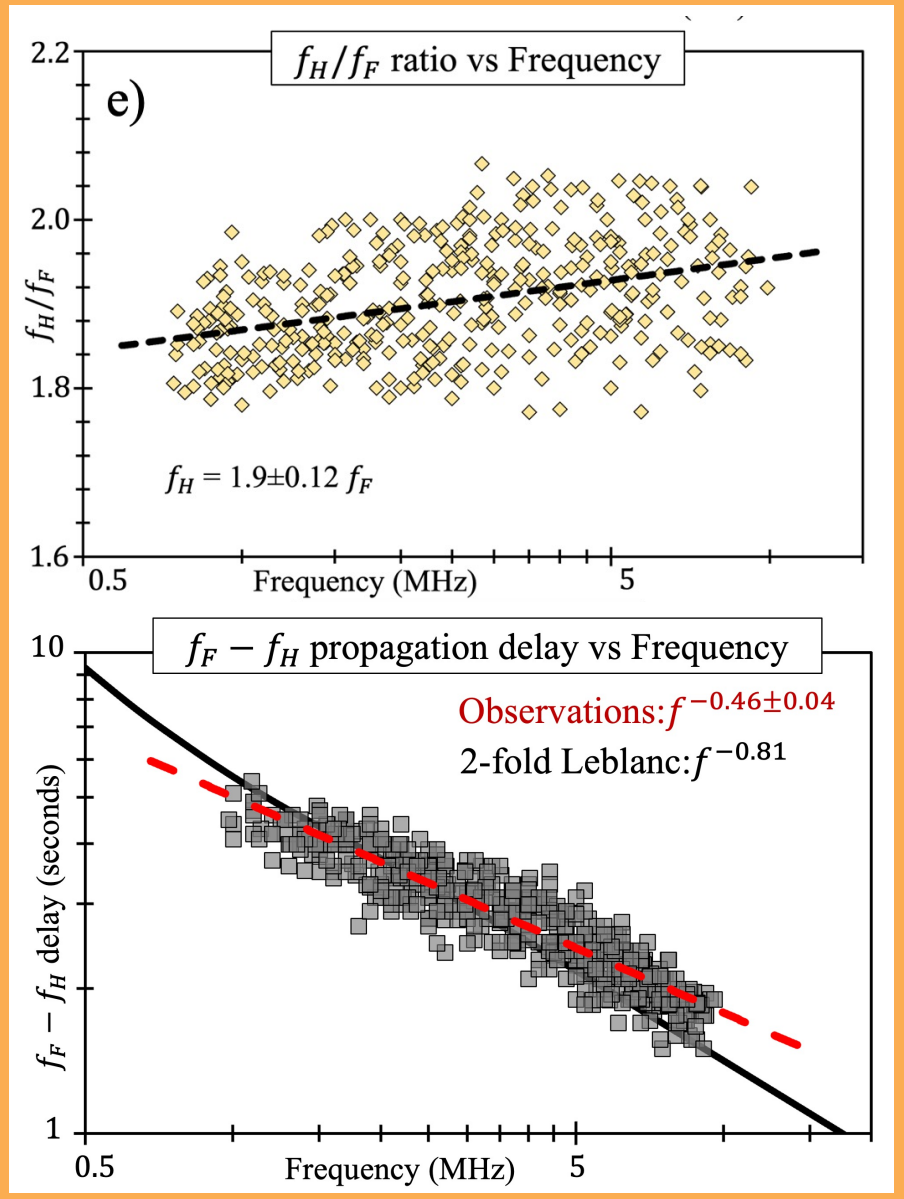
Time-delay

- H/F ratio shows the observed deviation from the theoretical prediction of $H \sim 2F$
- This propagation delay can therefore be measured considering this ratio in the data.



Time-delay

- $\int_1^R \frac{dR}{V_{gr}}$ gives the time of propagation of the wave from source to observer
- This can be used to estimate the time delay as the group velocity of F and H are different
- Considering a simple and widely used density model (Leblanc et al. 1998), we obtain a fit



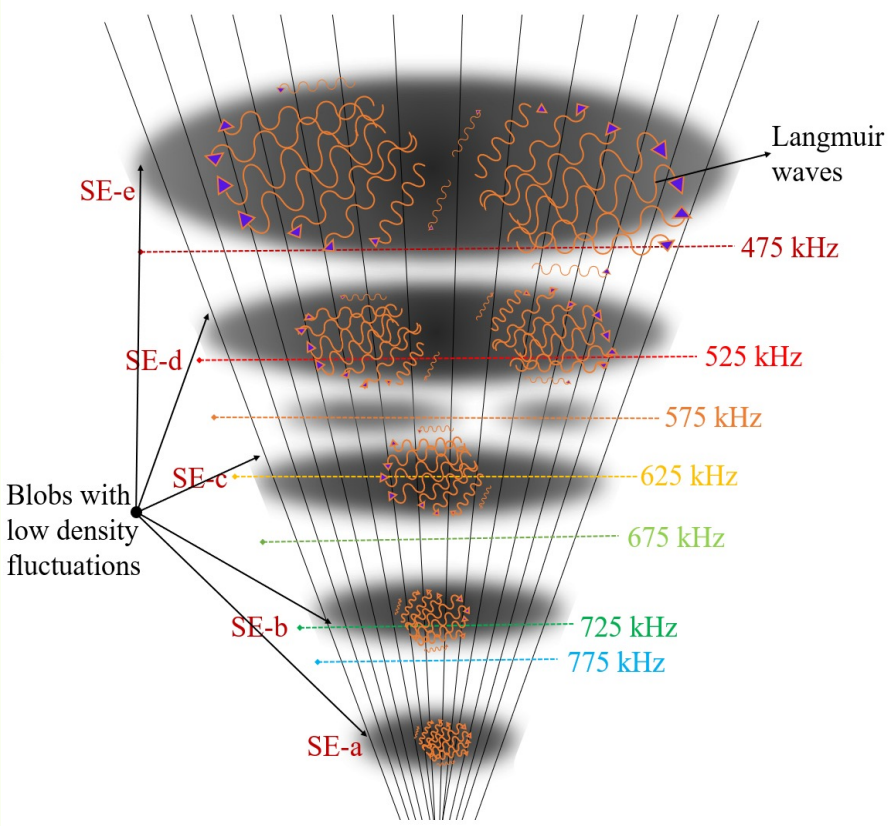
Time-delay

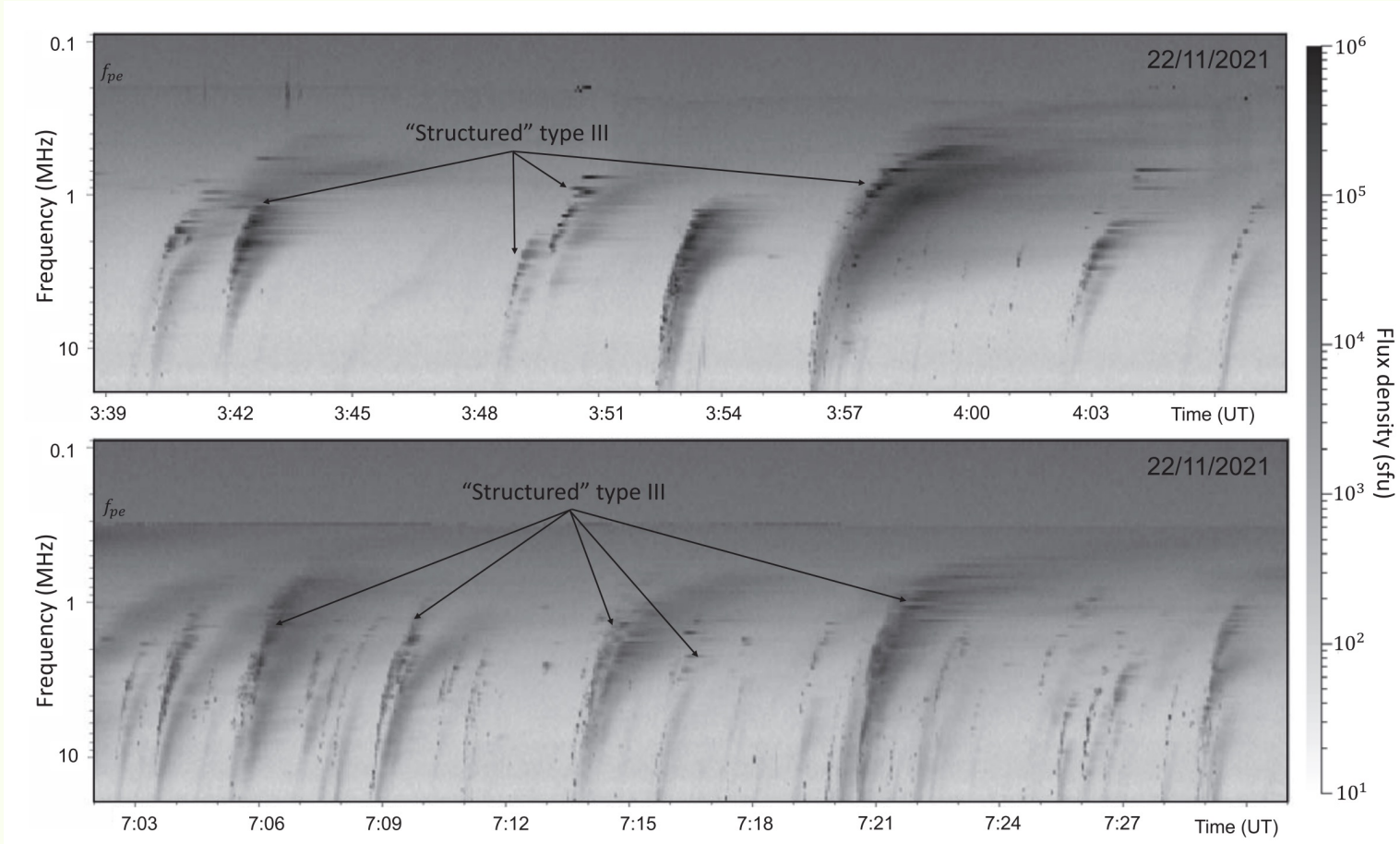
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- This can be used to estimate the time delay as the group velocity of F and H are different
- Considering a simple and widely used density model (Leblanc et al. 1998), we obtain a fit
- **Surprisingly, our fit is not too far from the data**

Conclusions

- A majority of the type III radio bursts ($> 75\%$) observed during Parker's close encounter are F-H pairs. F is structured, H is diffuse and smooth.
- The systematic deviation of F and H from the predicted $H \sim 2F$ is consistent with recent decameter observations.
- Estimate of propagation of F and H also show good correspondence and suggest that the difference in group velocity plays an important role.
- The rising time of F is systematically faster than H.
- The rising time and duration of F are highly dependent upon intensity.
- F emission is polarized to a high degree (and structured), while H is diffuse and smooth with far lower polarization.
- Duration parameters of F and H scale as $\frac{1}{\sqrt{f}}$ for rising time, but F scales as $\frac{1}{f^{3/4}}$ for falling, while H scales as $\frac{1}{\sqrt{f}}$

F-emission structuring is ubiquitous!





Sishtla et al. 2023 (ApJL)

Plasma probe

- In the frame of the fast electron beam, the fluctuations in the plasma that affect the beam are nearly at rest.
- In a PDI dominated solar corona, density fluctuations are natural consequences.
- **i.e. Striations are natural consequences.**

