Leibniz-Institut für
Astrophysik Potsdam

Evolution of fundamental and harmonic sources in LOFAR type III radio burst images

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Solar observations with LOFAR

The Sun is a strong radio source:

- Thermal: 10^6 K corona
- Non-thermal: Flares, CMEs

Intensities:

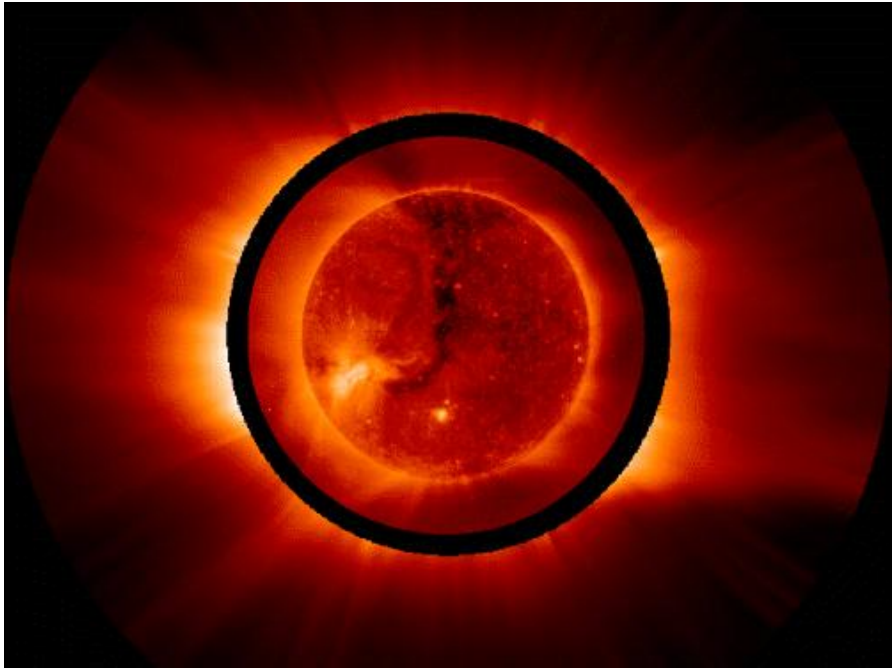
- Thermal: some 10^4 Jy
- Non-thermal: up to 10^8 Jy

Non-thermal radio wave emission:

- Plasma emission
- Energetic electrons in the Plasma
  - ➢ Electrostatic instability, Langmuir waves
  - ➢ Wave-wave interaction creates radio waves
  - ➢ Wave emission at local plasma frequency:

$$f = \sqrt{Ne^2/(m_e\epsilon_0)}/(2\pi)$$

and its harmonics

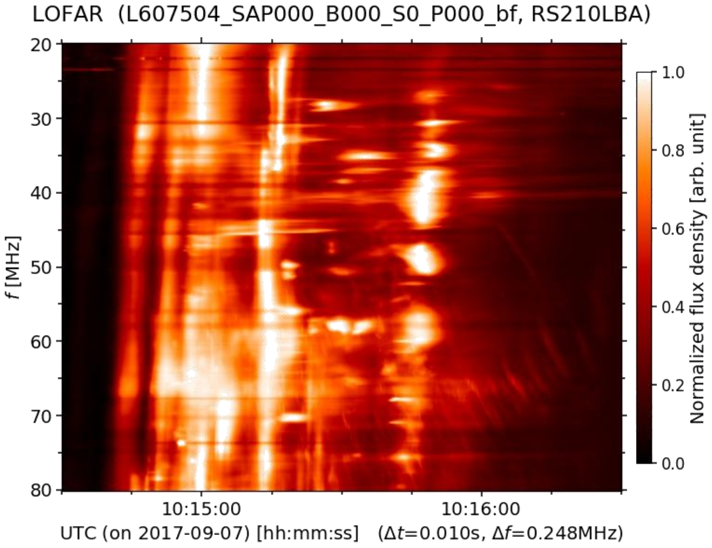


The frequency f depends only on the density N

LOFAR observation of an M class flare

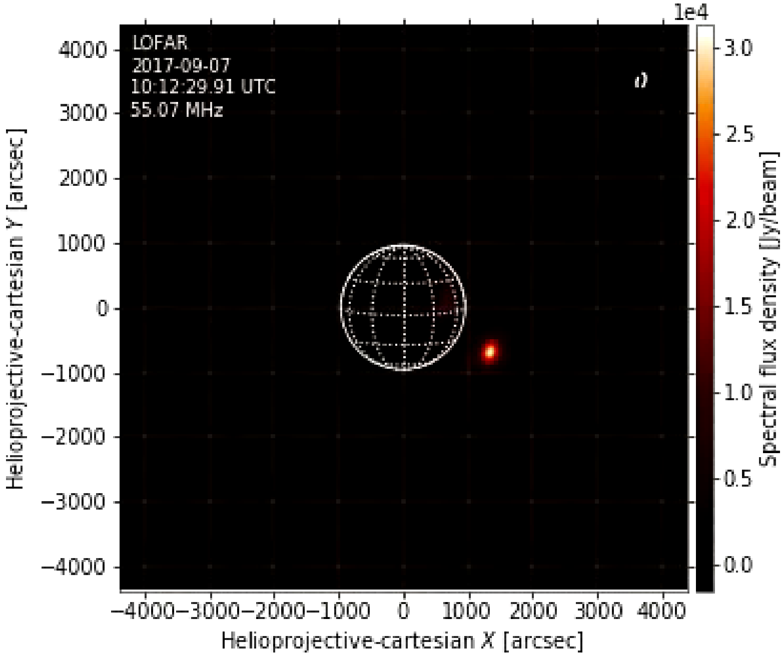
Solar M class flare on 7 September 2017:

- Starting at 10:14:40 UT
- Accompanied by several type III bursts



LOFAR images of the type III bursts:

- Intermittent dual-source structure



Interpretation: Fundamental and harmonic plasma emission

Given observation frequency: f_{obs}

Plasma frequency:

$f_p = (N e^2 / (m_e \varepsilon_0))^{1/2} / (2\pi)$

Refractive index:

$n = (1 - f_p / f)^{1/2}$

Fundamental emission:

$f_p = f_{obs}, n \rightarrow 0$

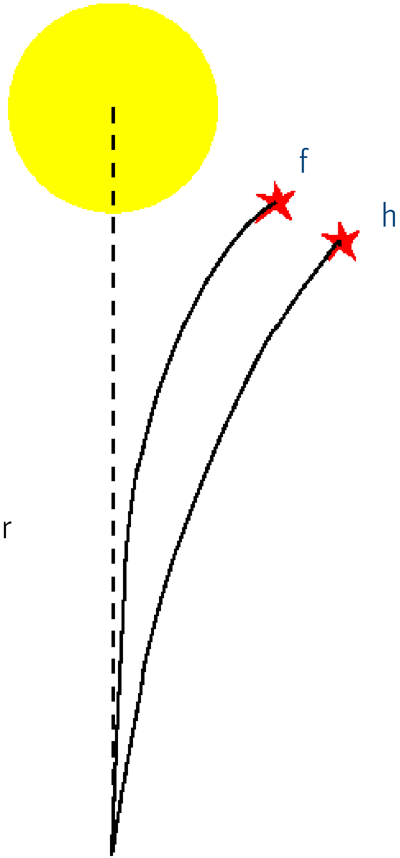
Harmonic emission:

$f_p = f_{obs} / 2, n = 0.886$

Fundamental and harmonic sources:

- h source: local plasma frequency is $f_{obs} / 2$
- located higher in the corona
- less refraction towards the solar disk center in the large-scale coronal density decrease with height than for the f source

Separation of f and h sources



Radio wave propagation in the corona

Competing effects: Refraction and scattering

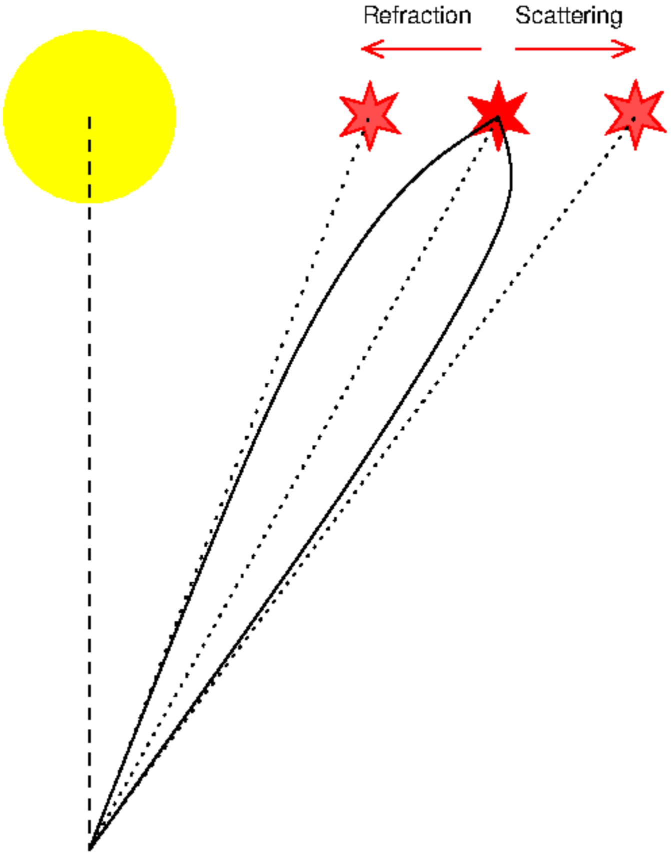
Refraction:

- Large-scale density decrease with height
- Refractive index increases
- Snell‘s law
- Ray path curved away from the Sun

Scattering:

- Turbulent density fluctuations
- Variation of refractive index
- Distortion of wave fronts
- Not isotropic
- Net result is an apparent source position away from the Sun

These effects are stronger for f than for h emission.



Evolution of f and h sources

Gaussian fits:

- Strongest source (blue)
- Subtract this source
- Second strongest source (red)

Source positions:

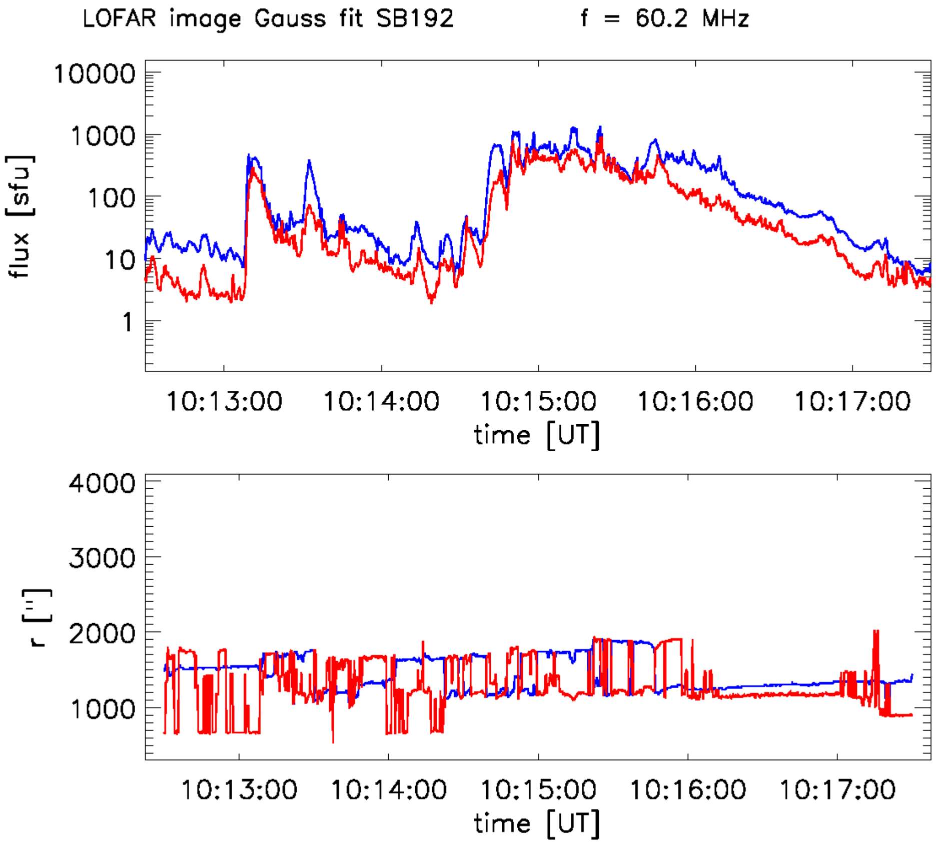
- (x, y) positions from Gaussian fits
- Compensate for drift over time

Fundamental and harmonic fluxes:

- Areas around (x, y)
- Integrate flux over these areas

Result:

Separate lightcurves for fundamental and harmonic sources



Fundamental – harmonic pairs

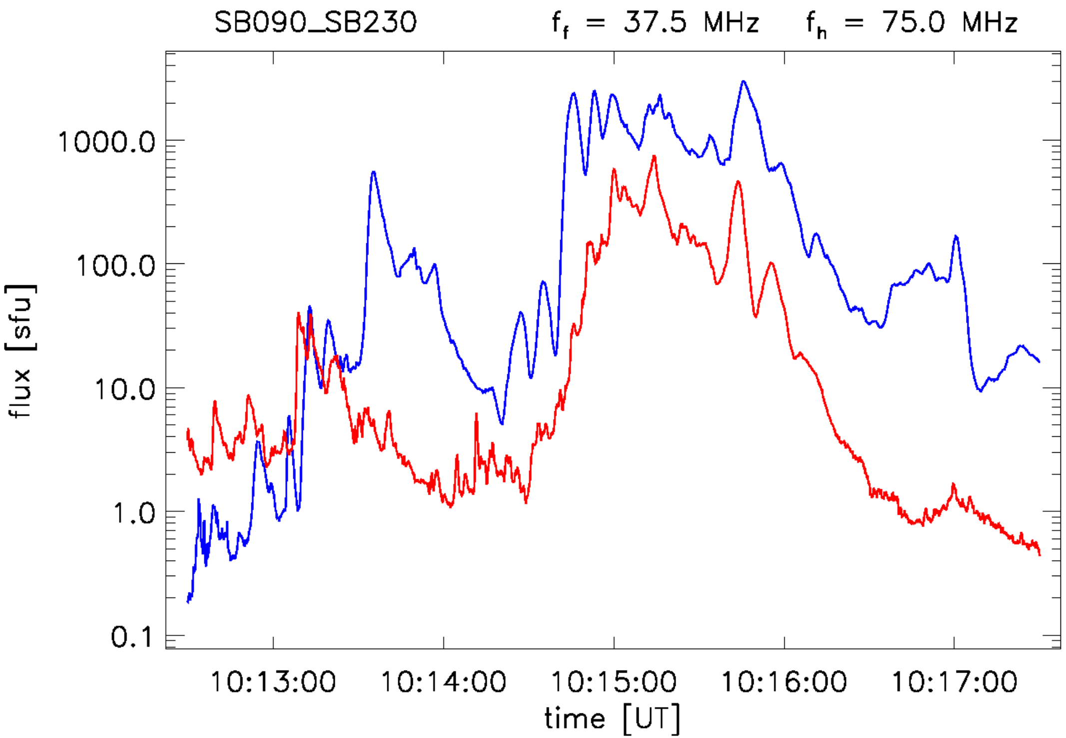
Example: 37.5 / 75 MHz and lower:

- Fundamental emission at 37.5 MHz
- Harmonic emission at 75 MHz
- Originate from the same source region

Differences between lightcurves:

- Earlier onset for harmonic at 10:13:05 UT
- Not visible at 10:14:30 UT
- Source finding method can impact results
- Influence of coronal scattering, especially on fundamental emission

Such plots can provide information on coronal radio wave propagation



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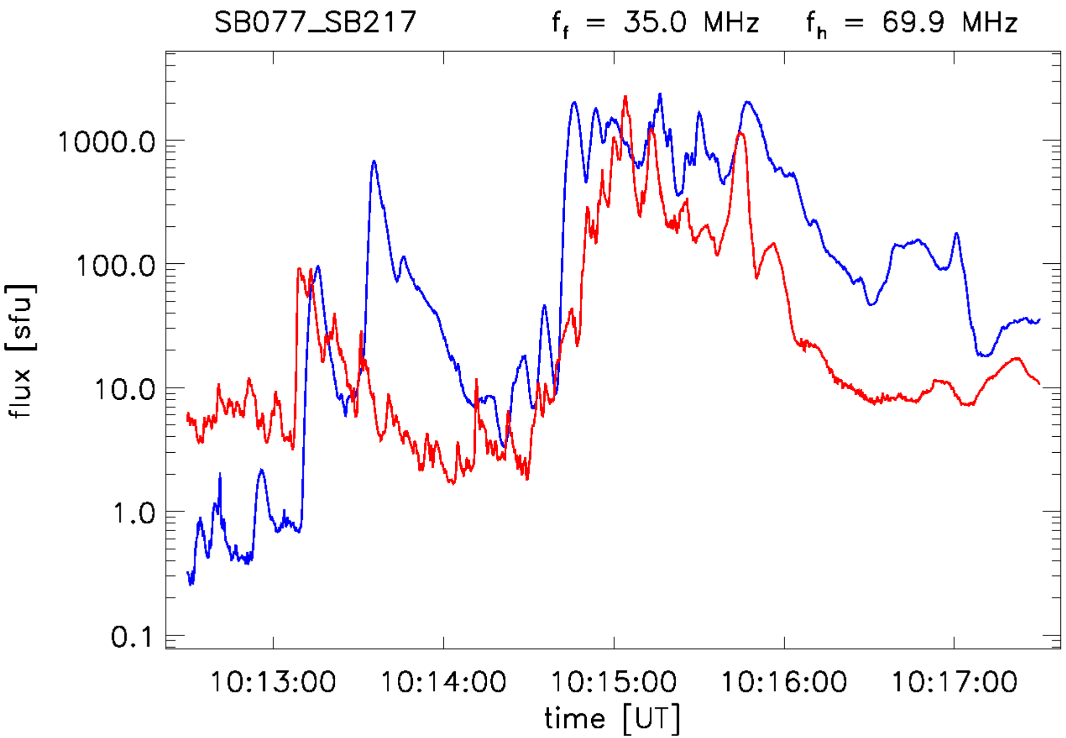

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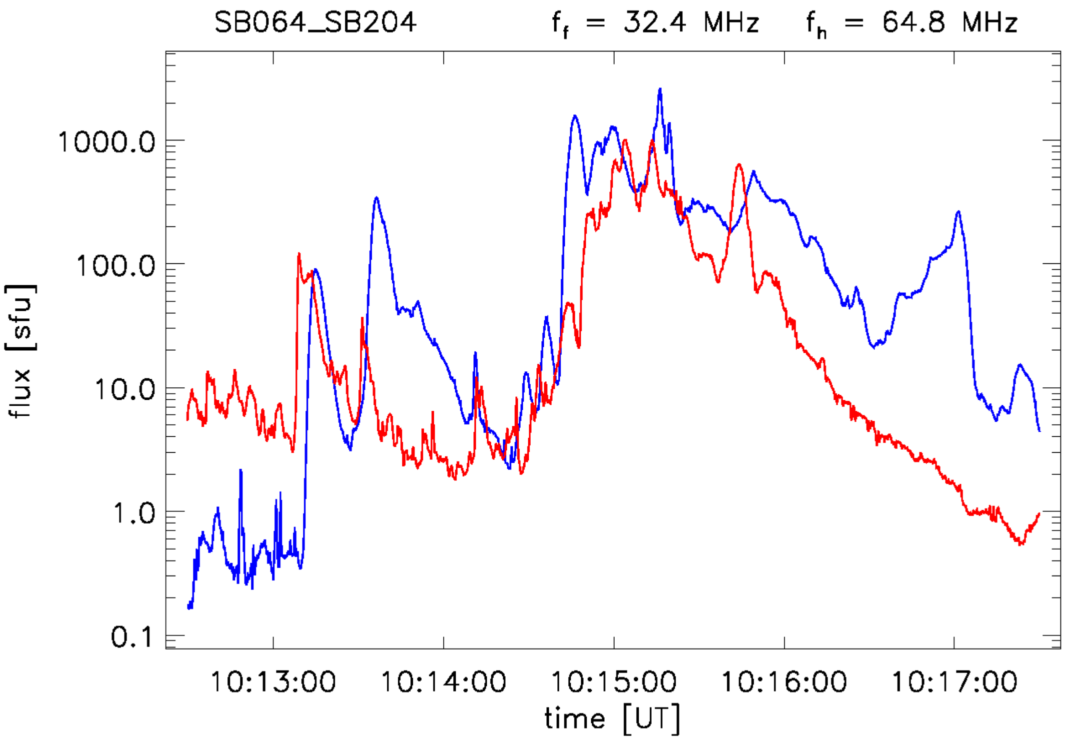

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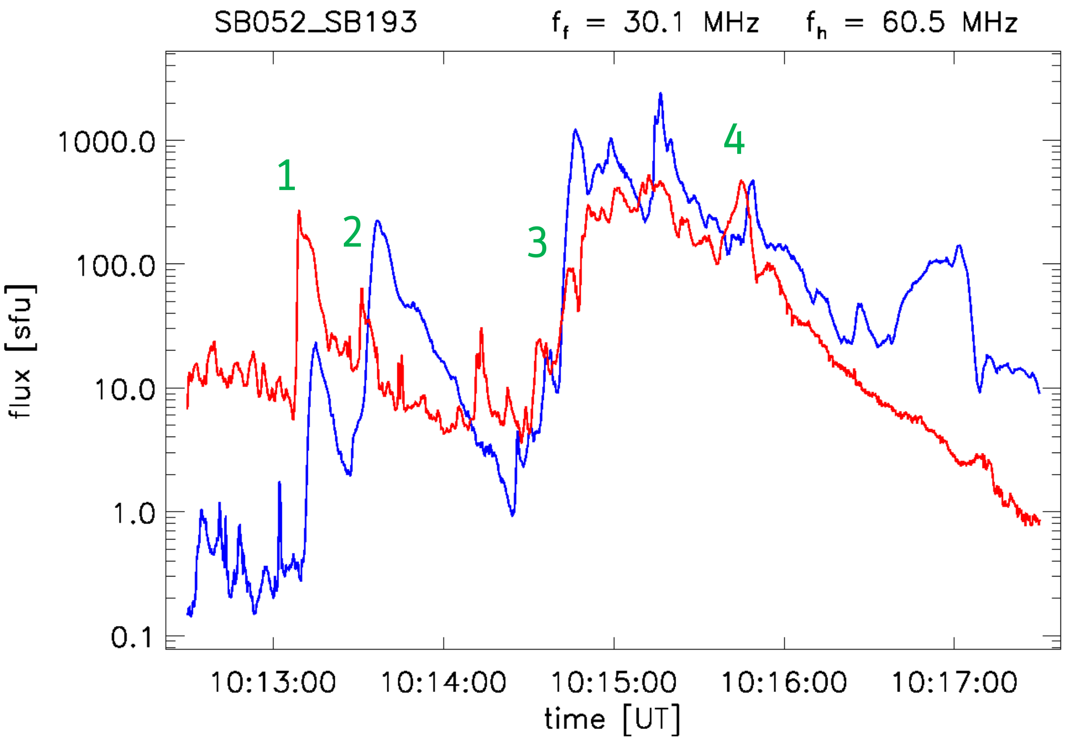
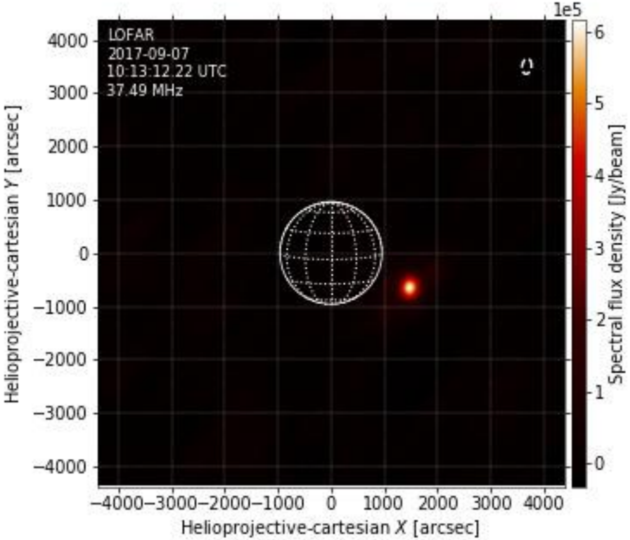
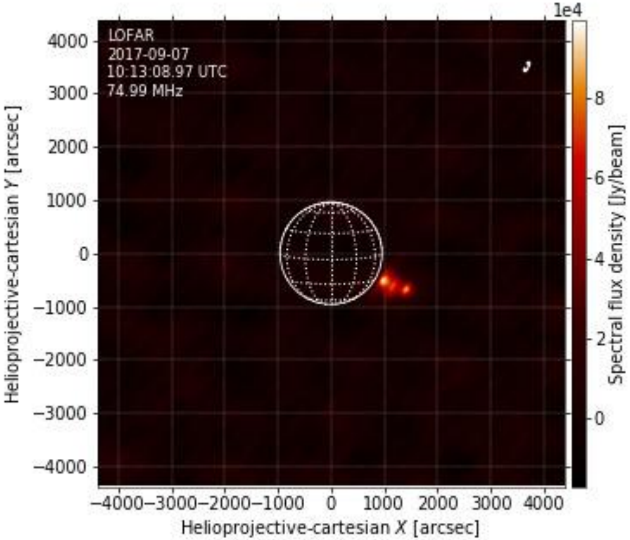


Relative positions of fundamental and harmonic sources

Event 1:





Position differences: Δ(x, y) = pos(h) – pos(f)

37.5 MHz: Δx = -65'' Δy = -33''

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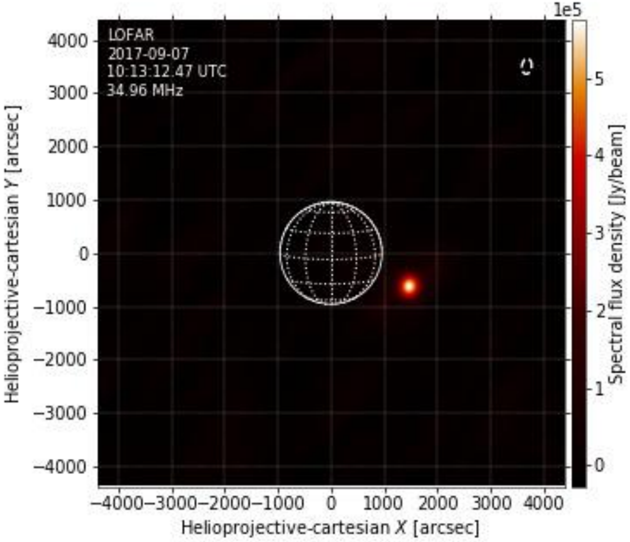

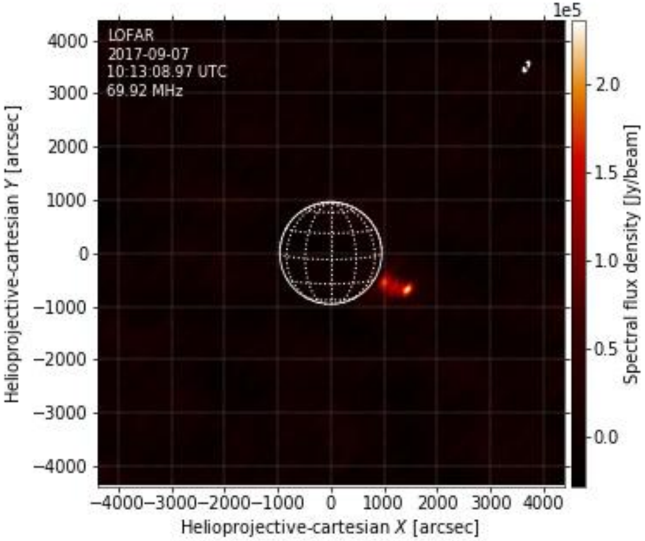

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35.0 MHz: Δx = -32'' Δy = -65''

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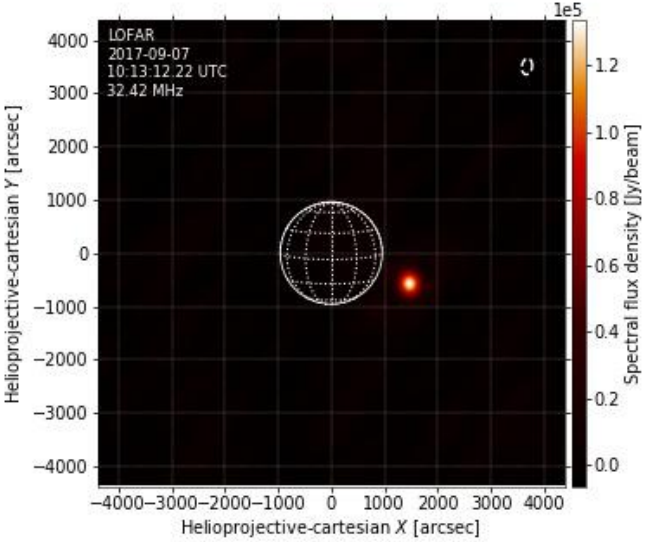

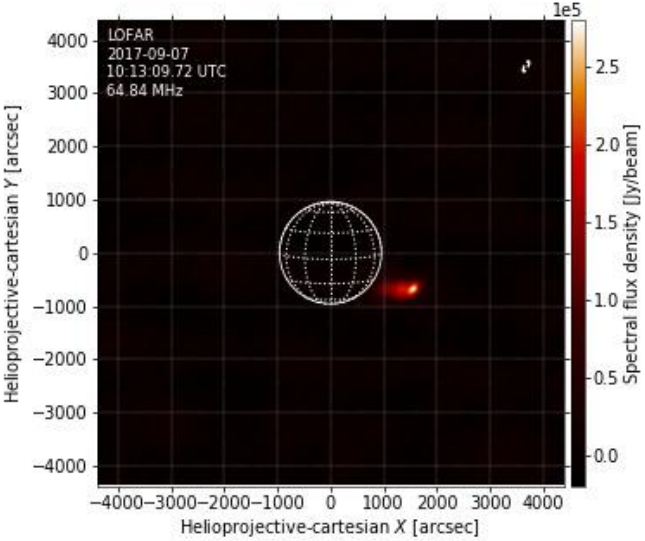

Position differences: Δ(x, y) = pos(h) – pos(f)

37.5 MHz: Δx = -65'' Δy = -33''

35.0 MHz: Δx = -32'' Δy = -65''

32.5 MHz: Δx = 98'' Δy = -98''

Relative positions of fundamental and harmonic sources

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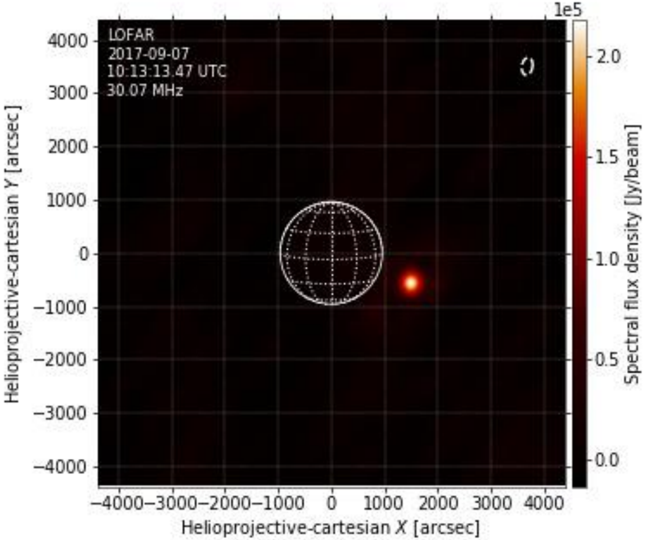
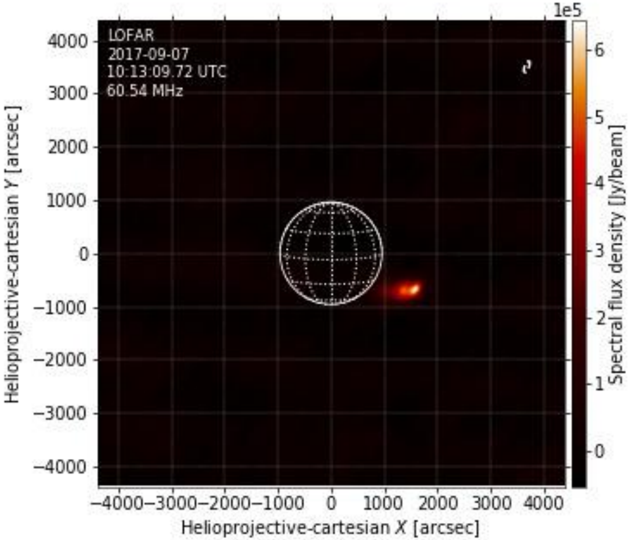




Position differences: Δ(x, y) = pos(h) – pos(f)

37.5 MHz: Δx = -65'' Δy = -33''

35.0 MHz: Δx = -32'' Δy = -65''

32.5 MHz: Δx = 98'' Δy = -98''

30.0 MHz: Δx = 97'' Δy = -130''

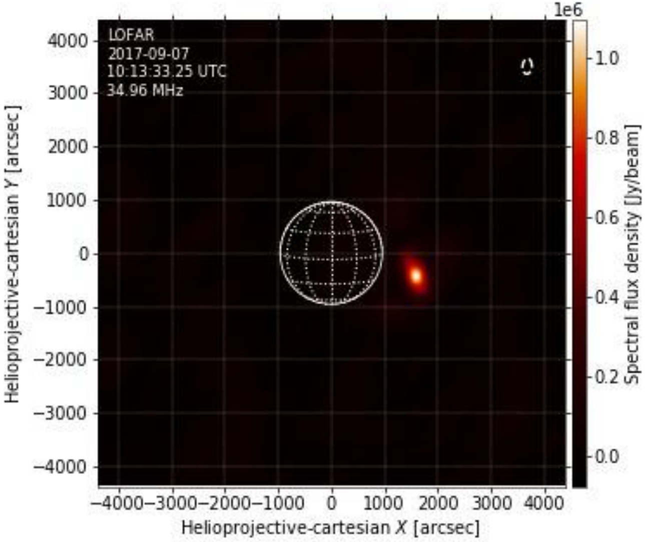
Conclusion:

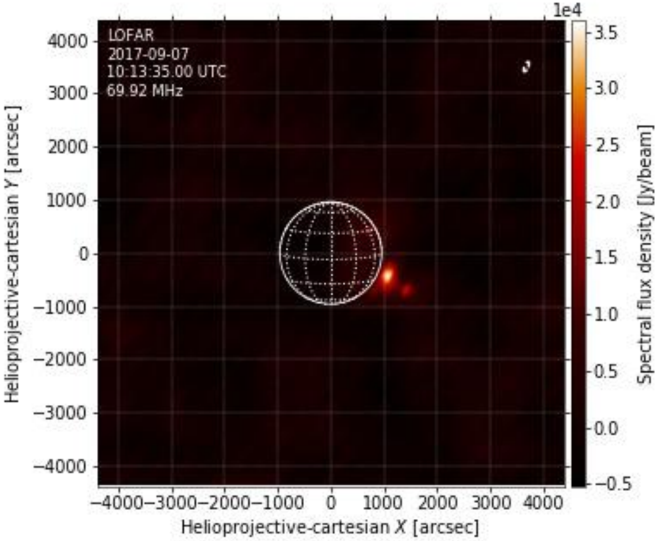
f source moves sunwards relative to h source

→ f refraction becomes stronger than scattering with decreasing frequency

Relative positions of fundamental and harmonic sources

Event 2:



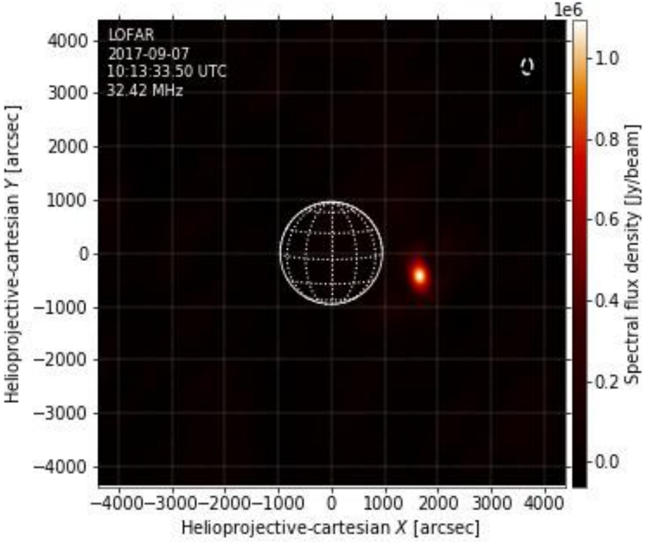


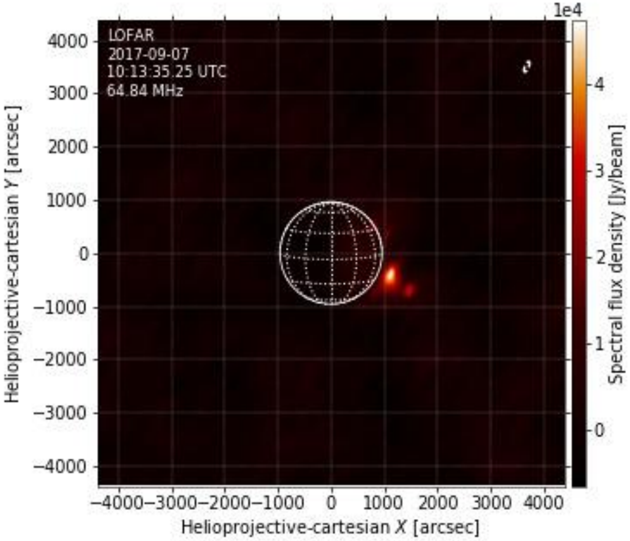
Position differences: Δ(x, y) = pos(h) – pos(f)

35.0 MHz: Δx = -162'' Δy = -292''

Relative positions of fundamental and harmonic sources

Event 2:





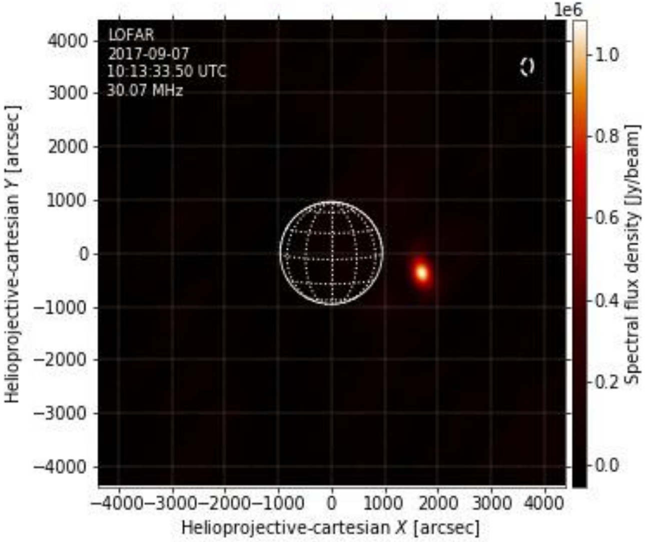
Position differences: Δ(x, y) = pos(h) – pos(f)

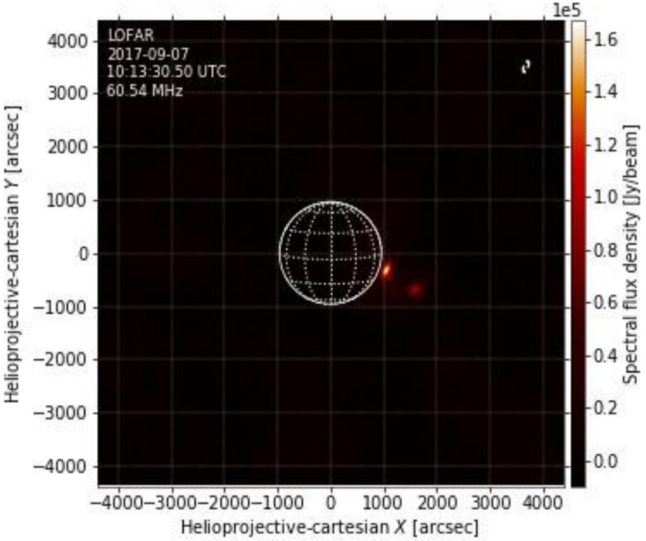
35.0 MHz: Δx = -162'' Δy = -292''

32.5 MHz: Δx = -196'' Δy = -292''

Relative positions of fundamental and harmonic sources

Event 2:





Position differences: Δ(x, y) = pos(h) – pos(f)

35.0 MHz: Δx = -162'' Δy = -292''

32.5 MHz: Δx = -196'' Δy = -292''

30.0 MHz: Δx = -98'' Δy = -325''

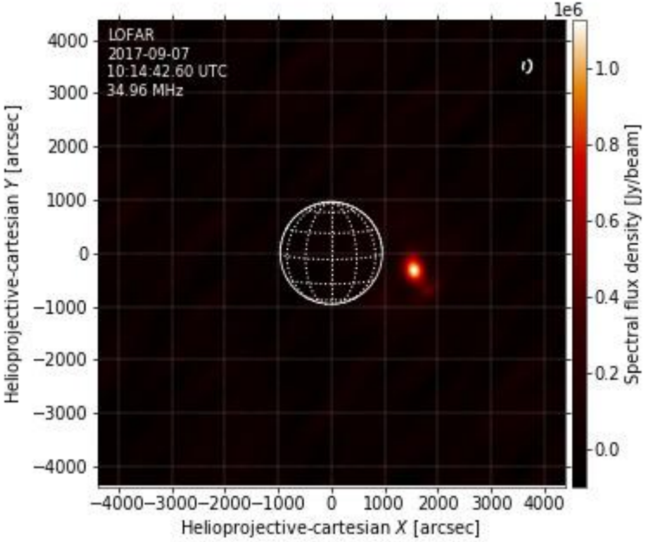
Conclusion:

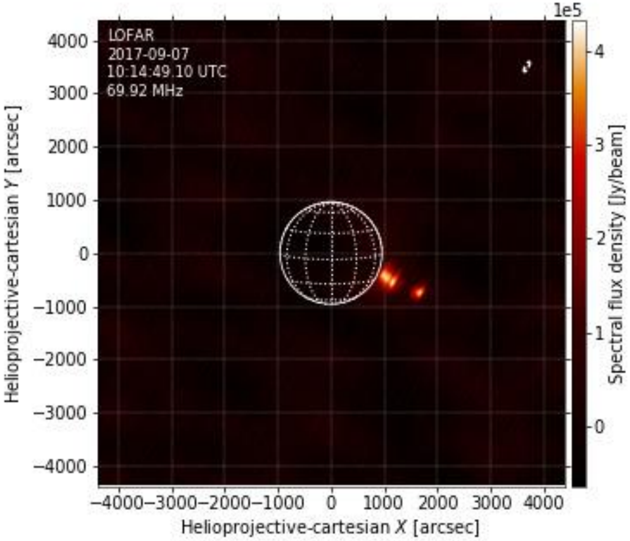
Less clear relation between F and H increases here, but the same tendency

At 65 MHz the f increase outshined the h increase, h source position was hard to measure

Relative positions of fundamental and harmonic sources

Event 3:



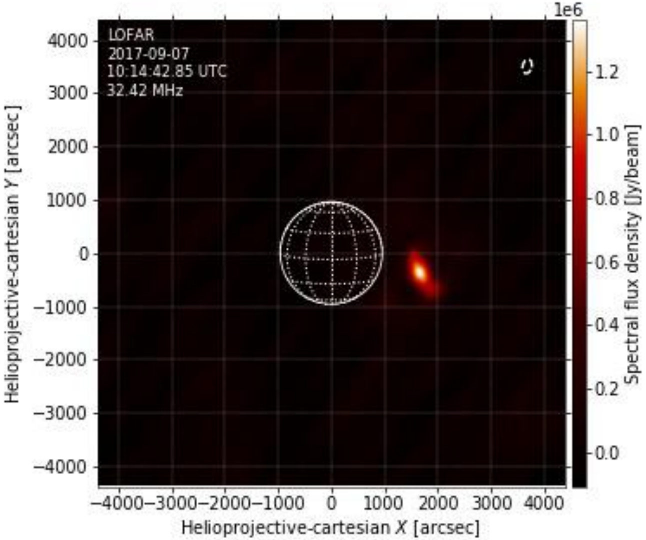


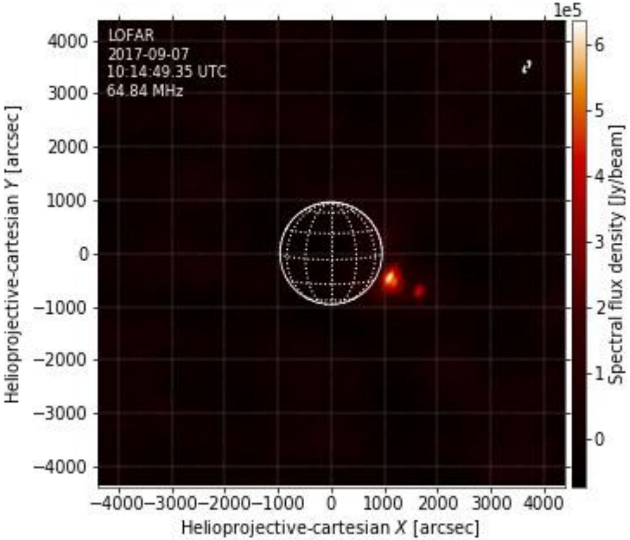
Position differences: Δ(x, y) = pos(h) – pos(f)

35.0 MHz: Δx = 98'' Δy = -423''

Relative positions of fundamental and harmonic sources

Event 3:





Position differences: Δ(x, y) = pos(h) – pos(f)

35.0 MHz: Δx = 98'' Δy = -423''

32.5 MHz: Δx = 0'' Δy = -357''

Relative positions of fundamental and harmonic sources

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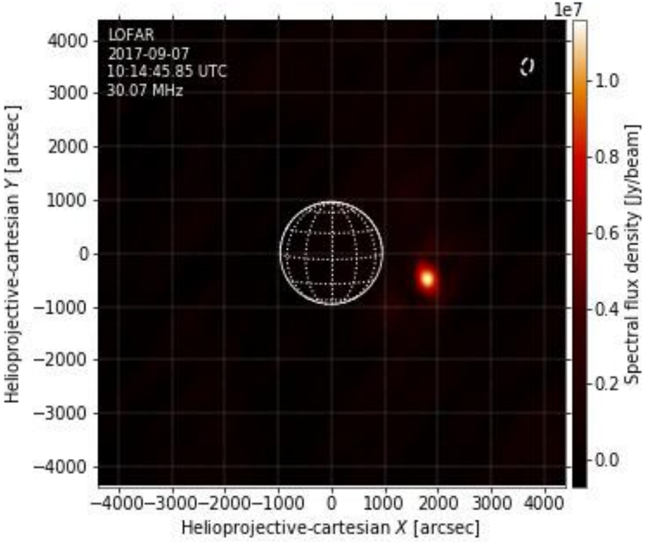
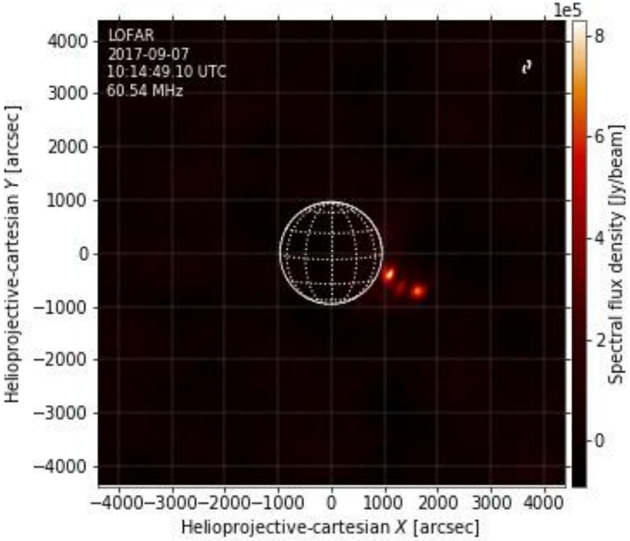




Position differences: Δ(x, y) = pos(h) – pos(f)

35.0 MHz: Δx = 98” Δy = -423”

32.5 MHz: Δx = 0” Δy = -357”

30.0 MHz: Δx = -195” Δy = -227”

Conclusion:

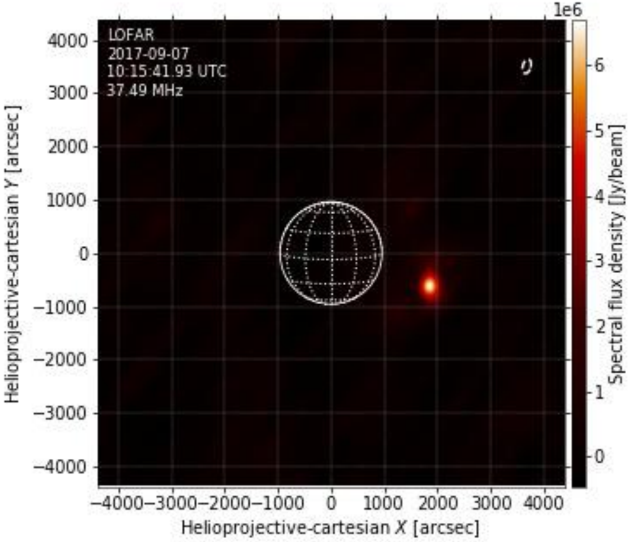
Opposite trend: f moves anti-sunward

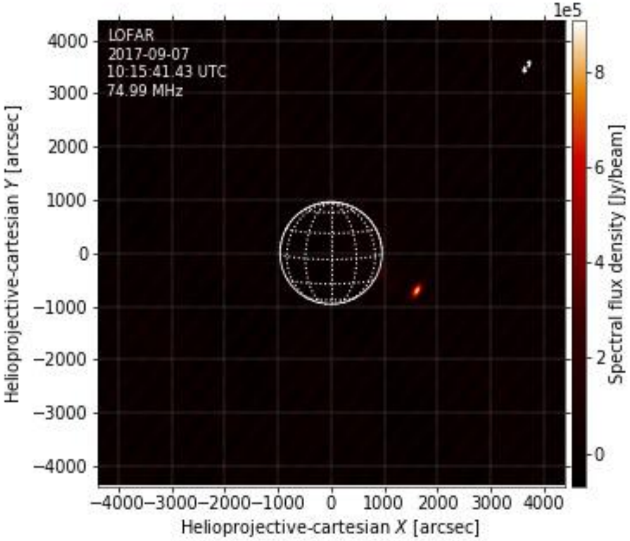
→ f scattering becomes stronger than refraction with decreasing frequency?

But: h is lagging f emission, not the same source?

Relative positions of fundamental and harmonic sources

Event 4:



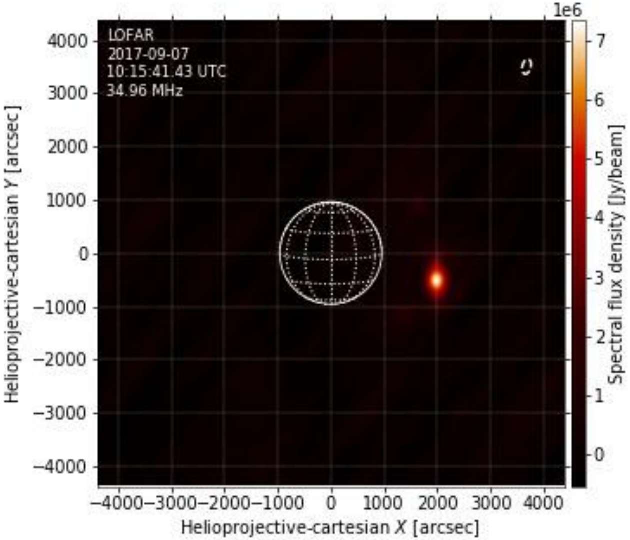


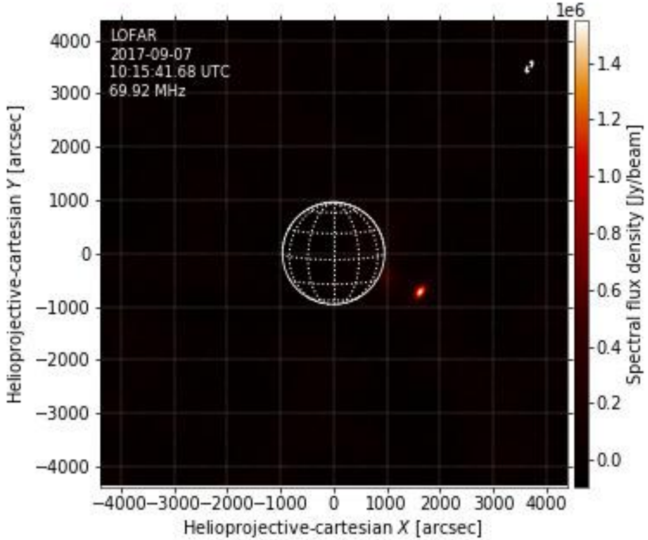
Position differences: Δ(x, y) = pos(h) – pos(f)

37.5 MHz: Δx = -228'' Δy = -97''

Relative positions of fundamental and harmonic sources

Event 4:





Position differences: Δ(x, y) = pos(h) – pos(f)

37.5 MHz: Δx = -228'' Δy = -97''

35.0 MHz: Δx = -358'' Δy = -195''

Relative positions of fundamental and harmonic sources

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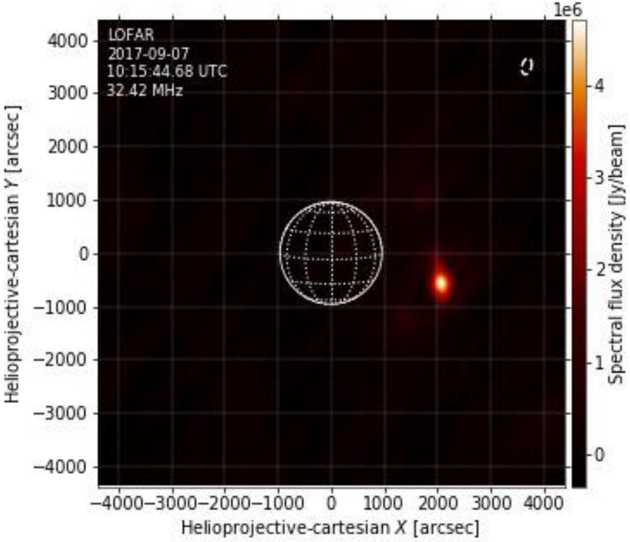

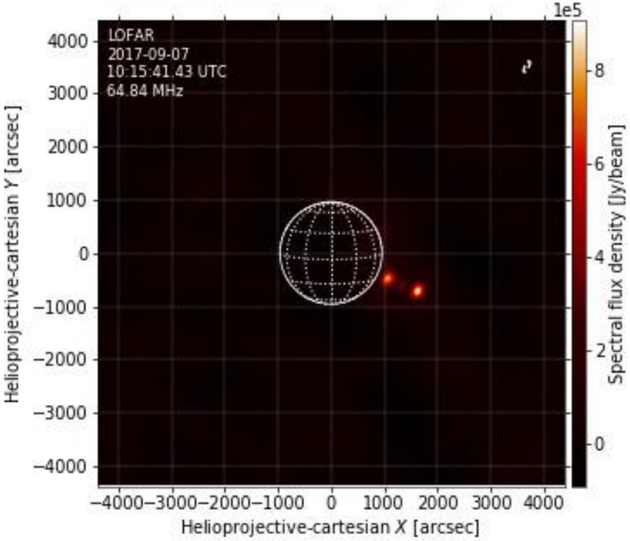

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37.5 MHz: Δx = -228'' Δy = -97''

35.0 MHz: Δx = -358'' Δy = -195''

32.5 MHz: Δx = -455'' Δy = -130''

Relative positions of fundamental and harmonic sources

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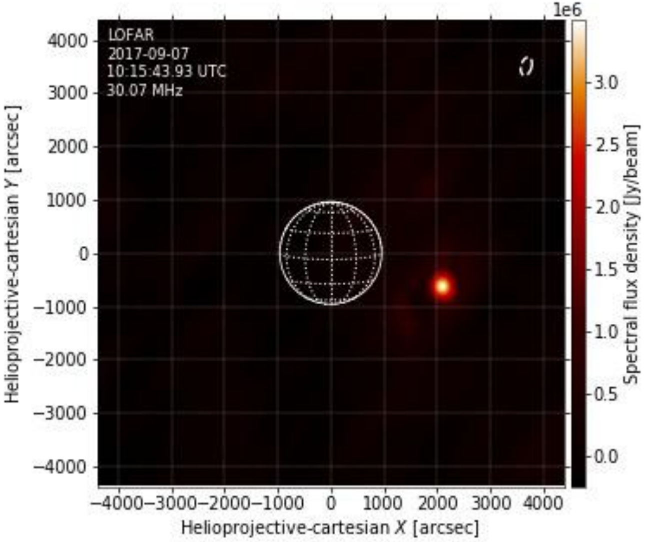

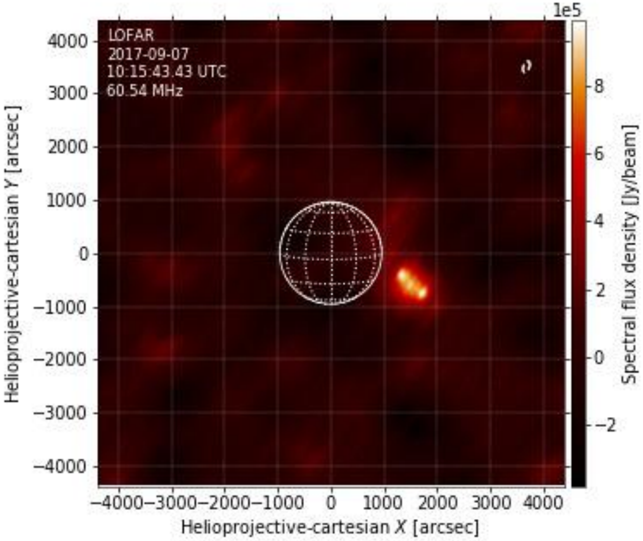

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32.5 MHz: Δx = -455'' Δy = -130''

30.0 MHz: Δx = -390'' Δy = -130''

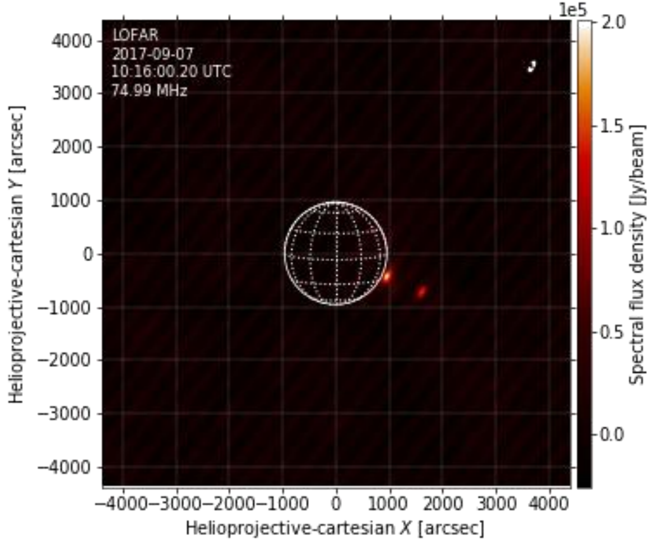
Conclusion:

f source clearly moves anti-sunwards relative to h source

→ f scattering becomes stronger than refraction with decreasing frequency

→ Increased turbulence due to previous M flare and type III?

Summary and conclusion



LOFAR M class flare observations:

- Dominated by strong type III emission
- Images show intermittent dual source structure

Interpretation: fundamental and harmonic emission

- At given frequency: Outer source is harmonic, inner is fundamental
- Separate lightcurves for both sources
- Fundamental-harmonic pairs: Same source region
- Relative source positions determined by competing effects of refraction and scattering
- No unique trend with frequency found
- This is to be expected if coronal conditions change

→ Useful tool for investigating radio wave propagation in the solar corona