Leibniz-Institut für
Astrophysik Potsdam

Separating fundamental and harmonic sources in LOFAR solar 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:

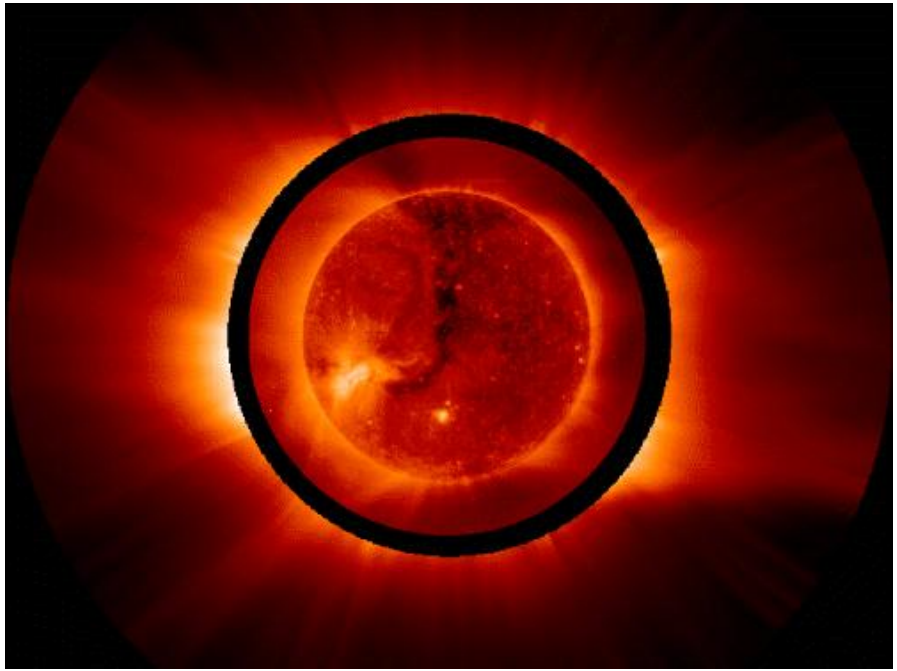
- Thermal: some 10^4 Jy
- Non-thermal: up to 10^8 Jy

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



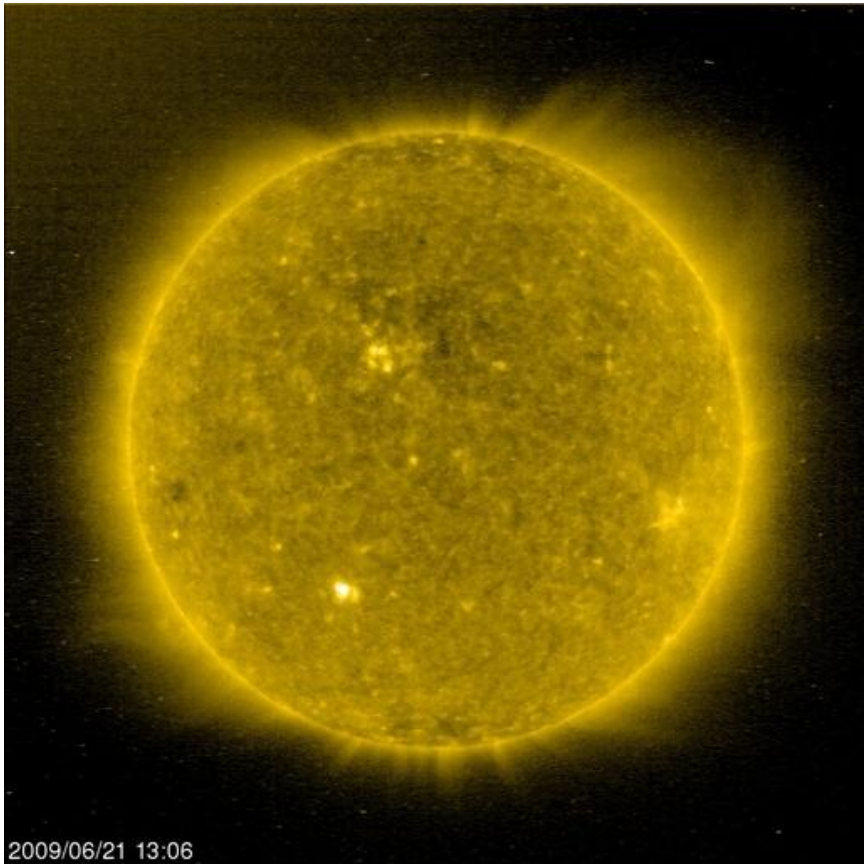
The frequency f depends only on the density N

LOFAR frequencies: Solar corona

f/MHz	r/R_S
240	1.17
170	1.24
100	1.37
70	1.48
40	1.68
30	1.80
20	2.01
10	2.52

LOFAR frequencies:

Middle and upper corona



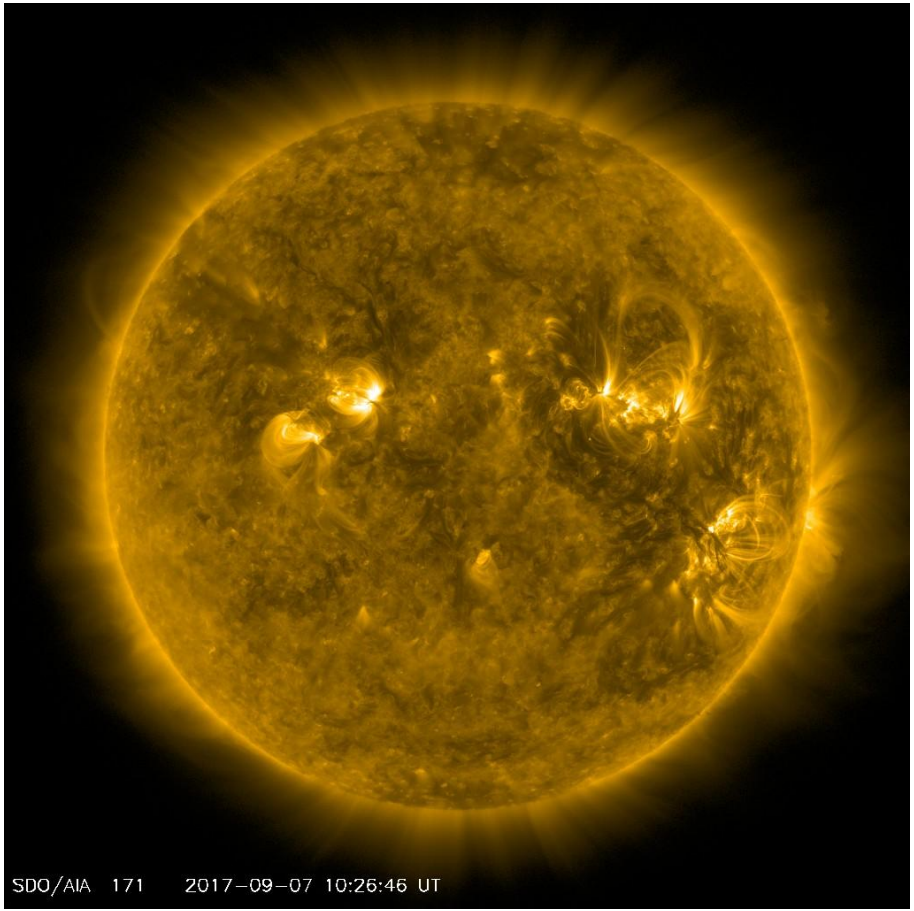
Solar observations on 7 Sep 2017

Scheduled observations:

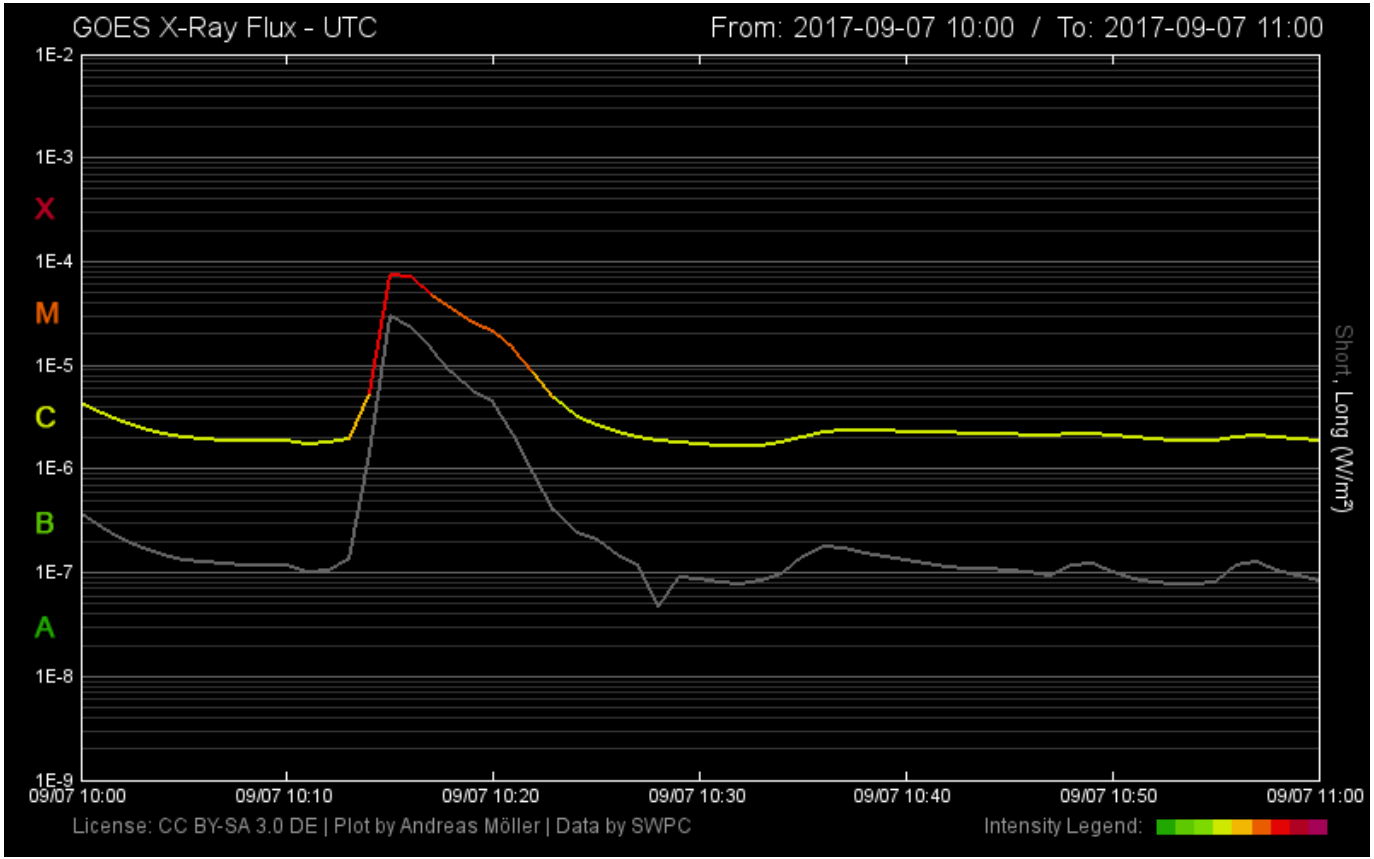
- Observations scheduled for enhanced solar activity
- 6 h observing time over noon
- 0.25 s imaging sequence
- Interferometric in LBA, dynamic spectra in LBA+HBA

Calibrator issue:

- Calibrator beam was accidentally set to Tau A
- Rather than Vir A
- Tau A is 80 deg West of the Sun
- Sets in the afternoon



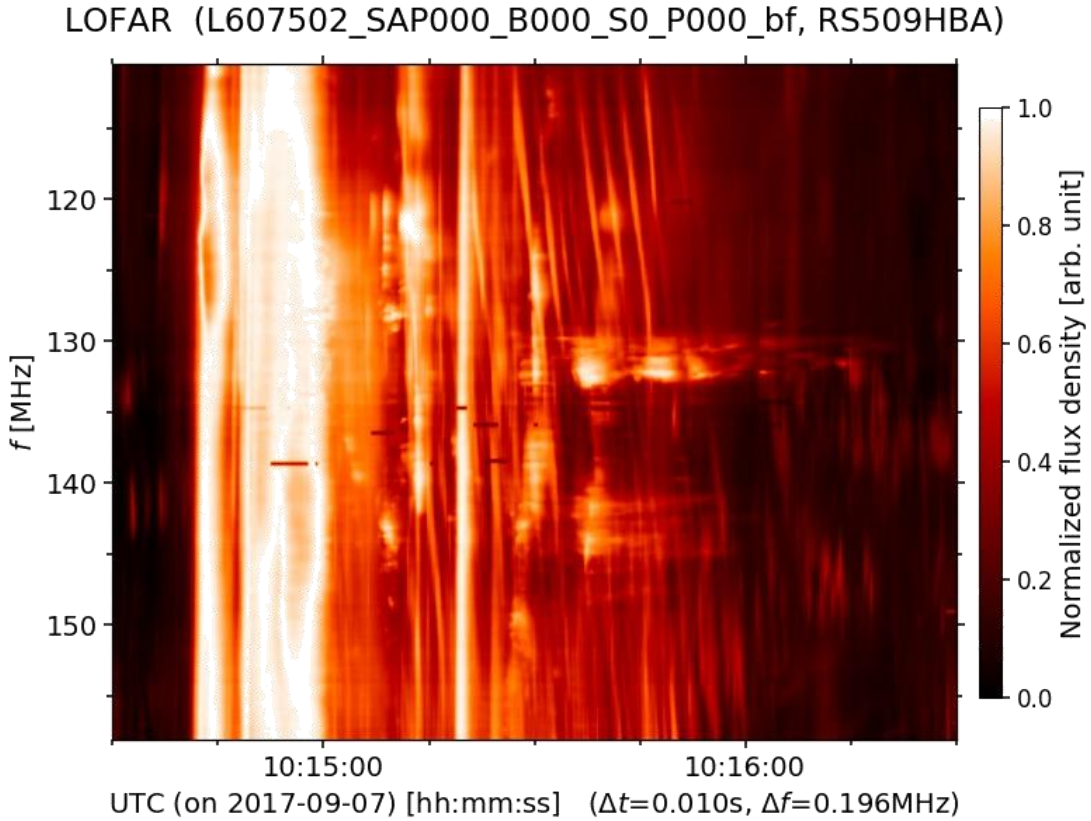
M class flare at 10:14 UT



LOFAR dynamic radio spectra: HBA

Solar flare:

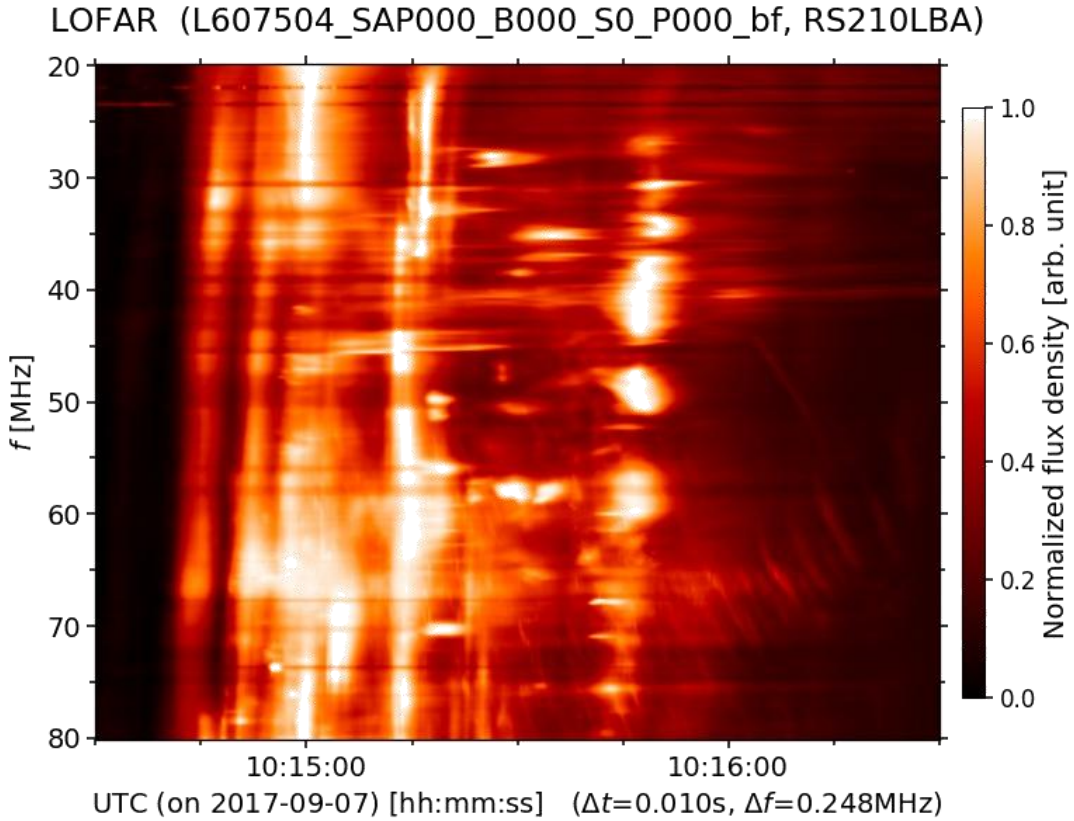
- M class
- Starting at 10:14:40 UT
- Several type III bursts



LOFAR dynamic radio spectra: LBA

Solar flare:

- M class
- Starting at 10:14:40 UT
- Several type III bursts



Calibration of flare data

Problem:

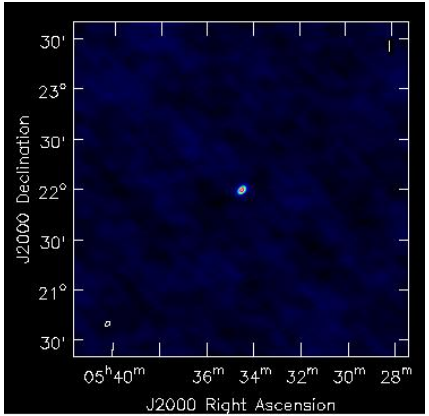
- The active Sun increases the radio flux by a factor ~1000
- Solar signal in Tau data

Solution:

- Use quiescent period before the flare
- Calibrate “quiet” Sun with Tau A

Use quiet Sun solution to calibrate flare data

Tau A:



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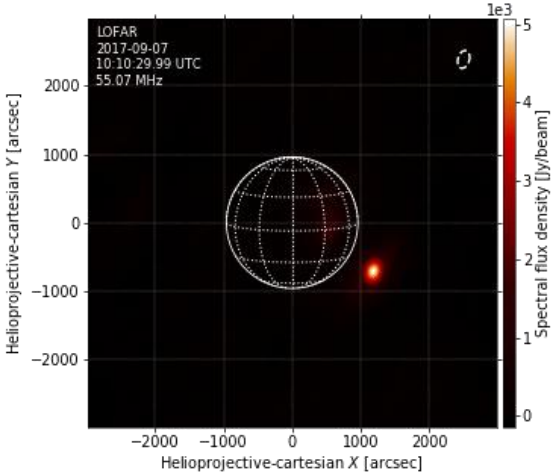
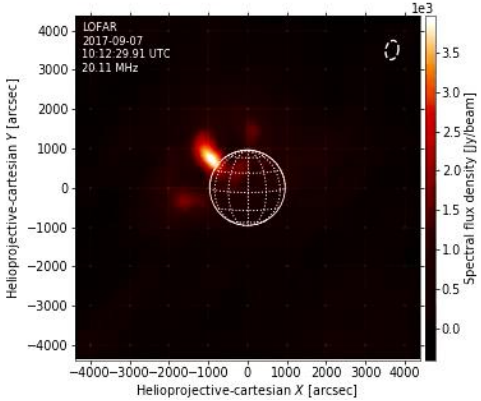


Sun:

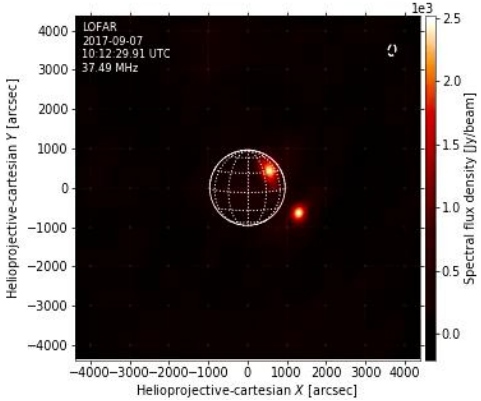
- Dominated by noise storm
- Outshines quiet corona

LOFAR images for the M class flare

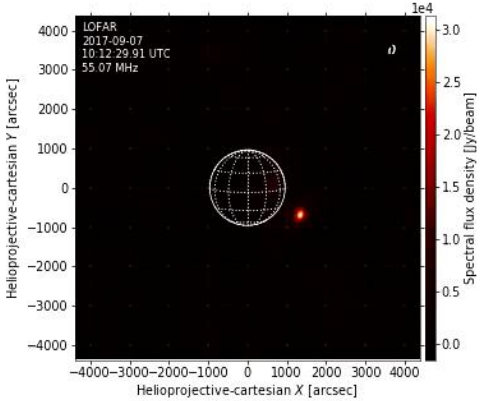
20 MHz:



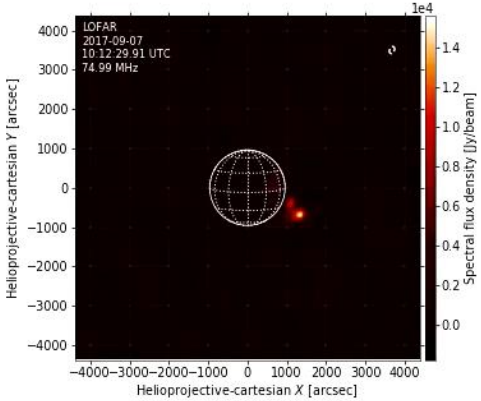
37.5 MHz:



55 MHz:



75 MHz:



Fundamental and harmonic plasma emission: Sources and refraction in the corona

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:

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

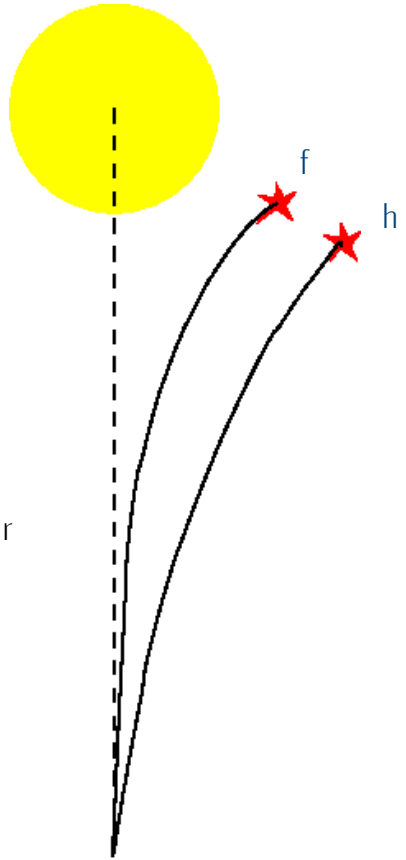
Harmonic emission:

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

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

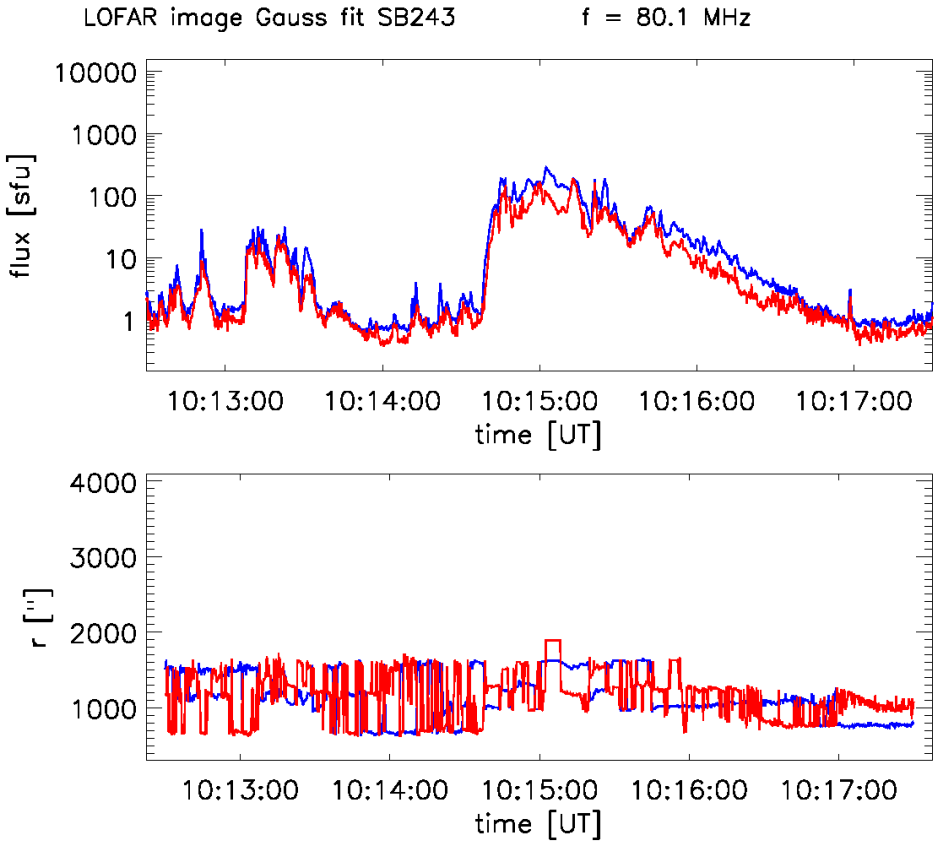
Separation of f and h sources



Radial evolution of f and h sources

Gaussian fits:

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



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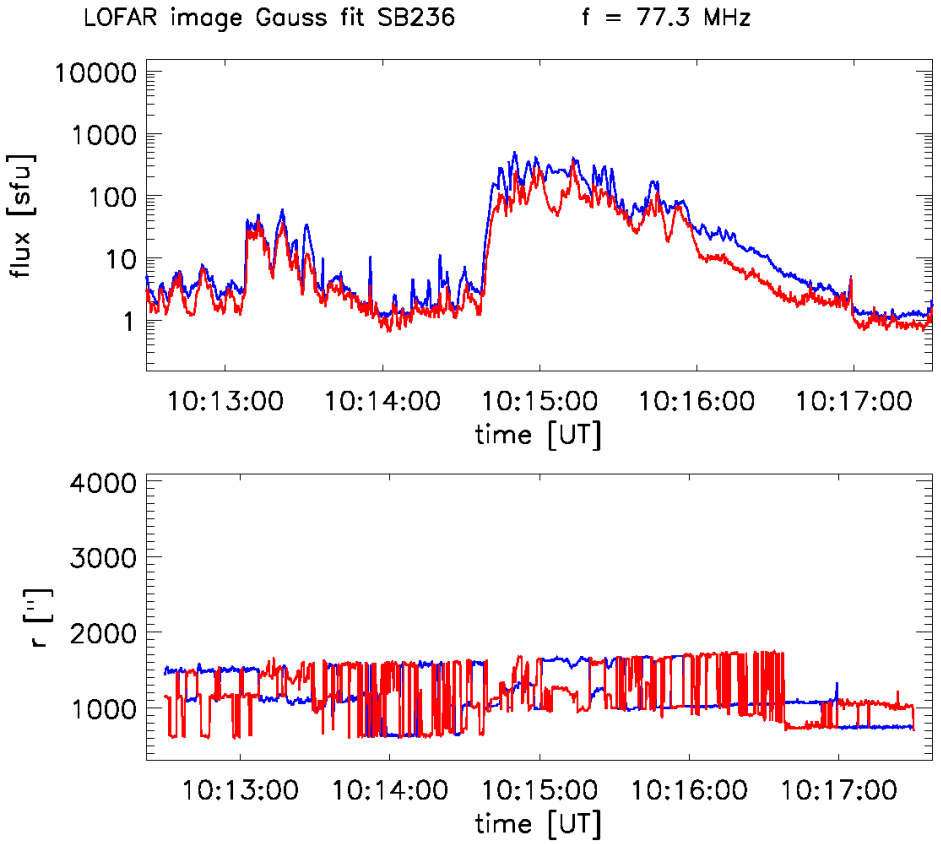

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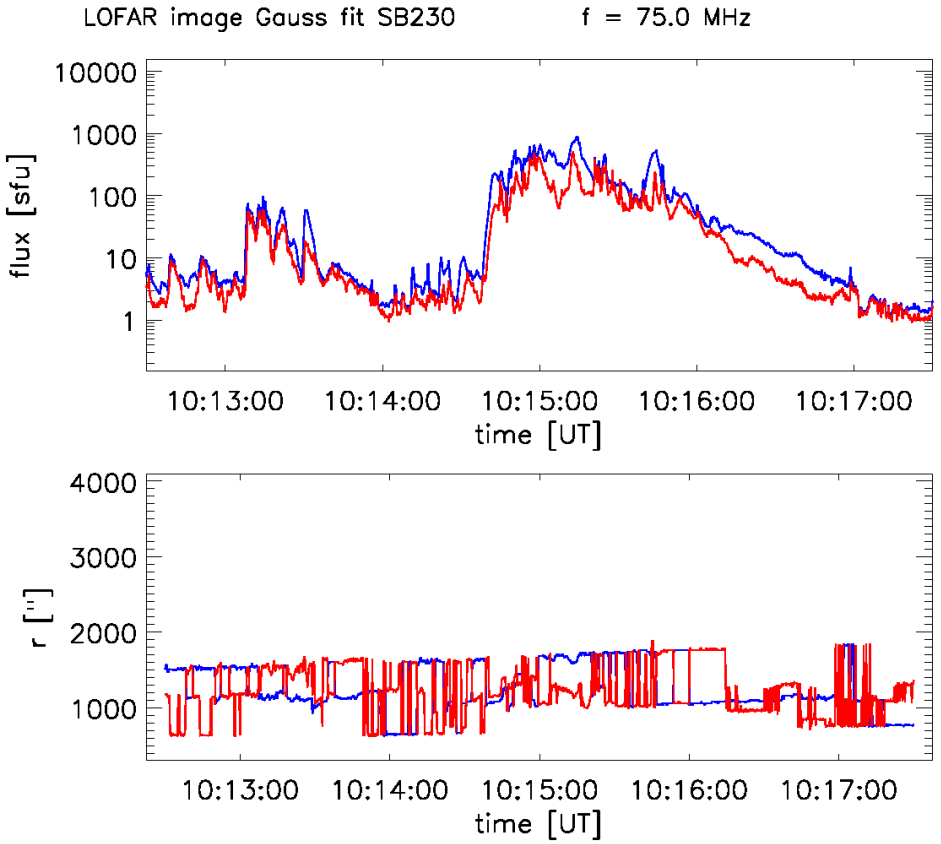

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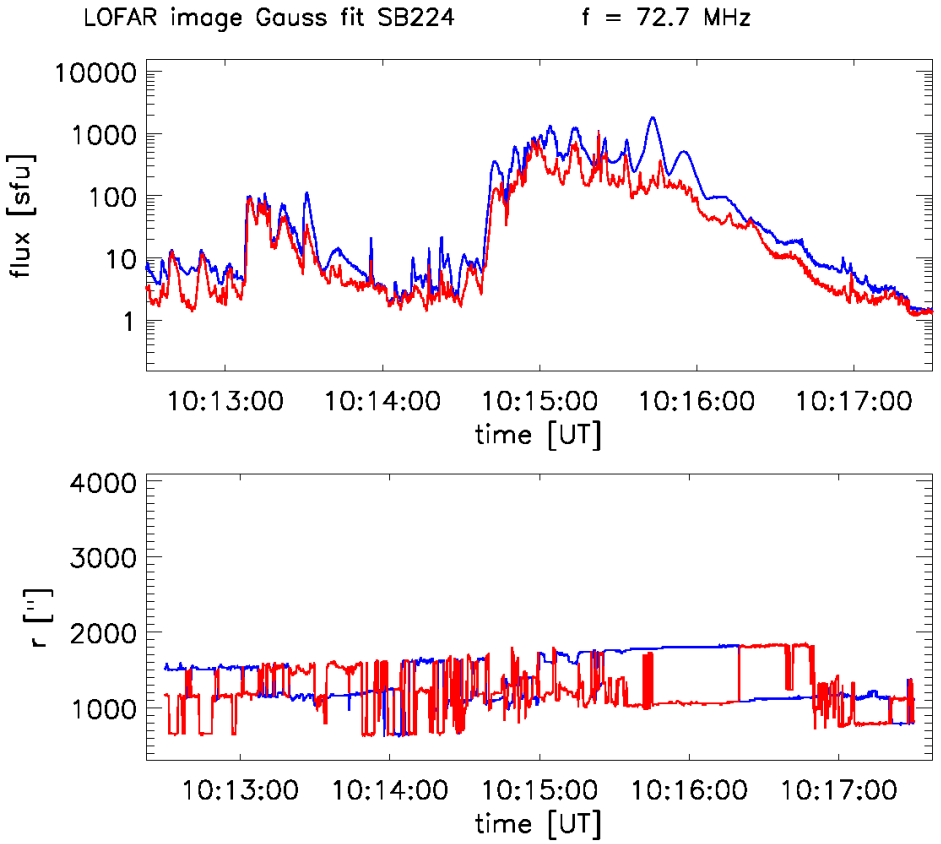

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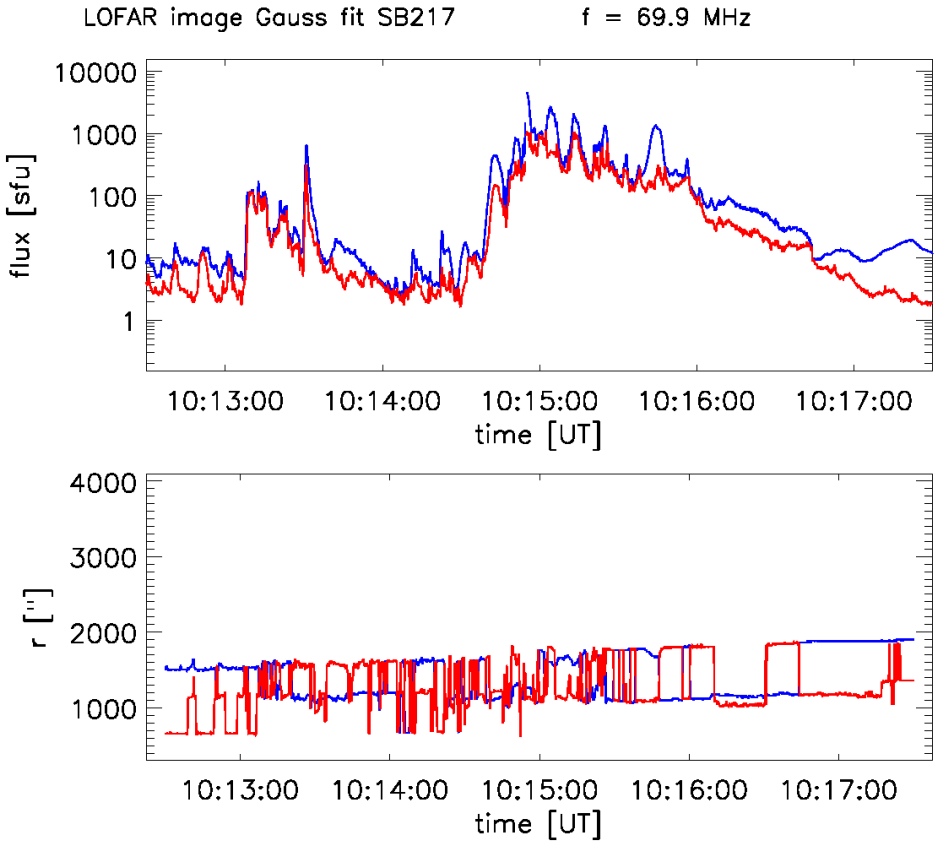

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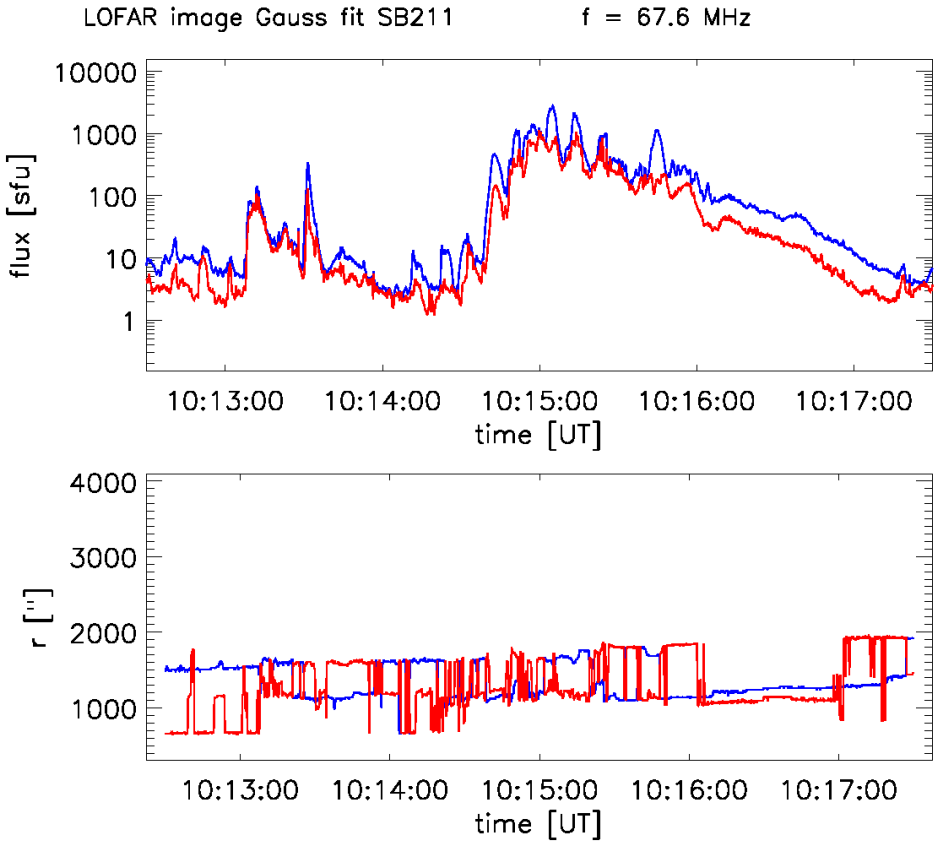

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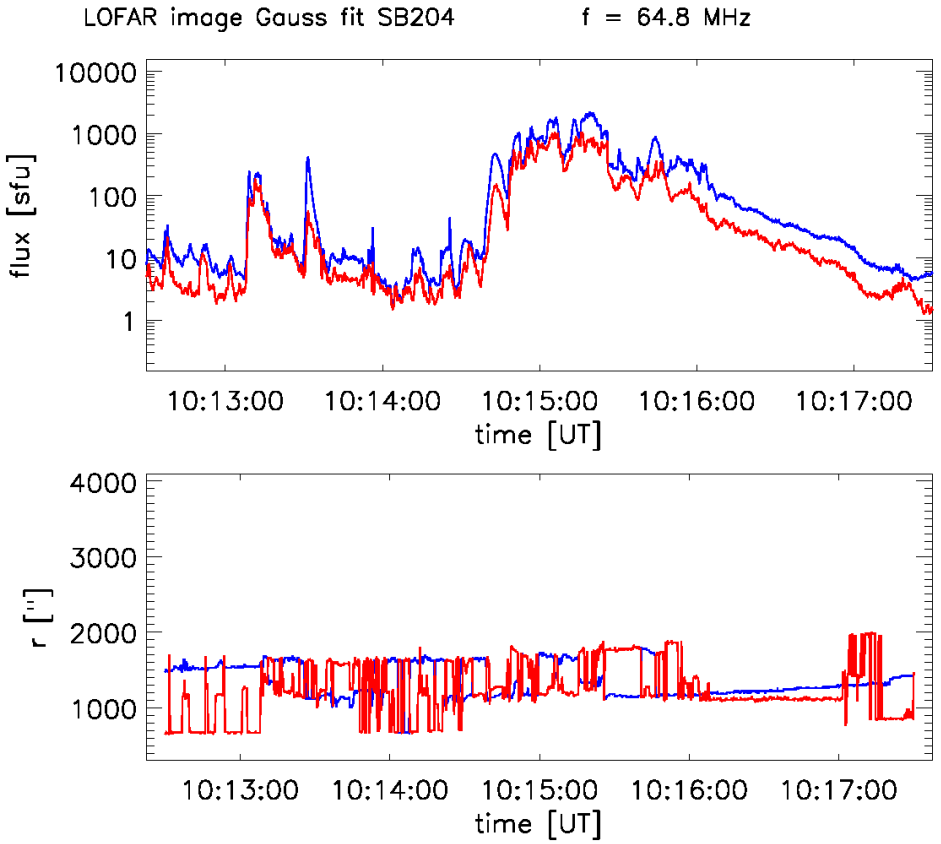

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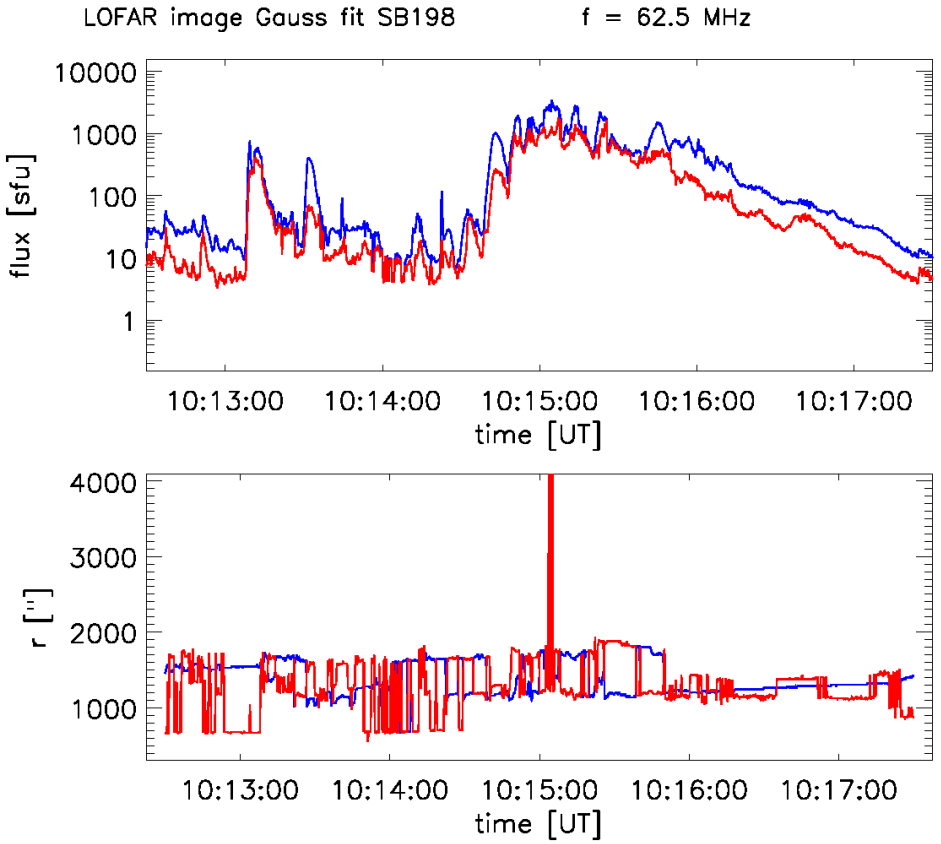

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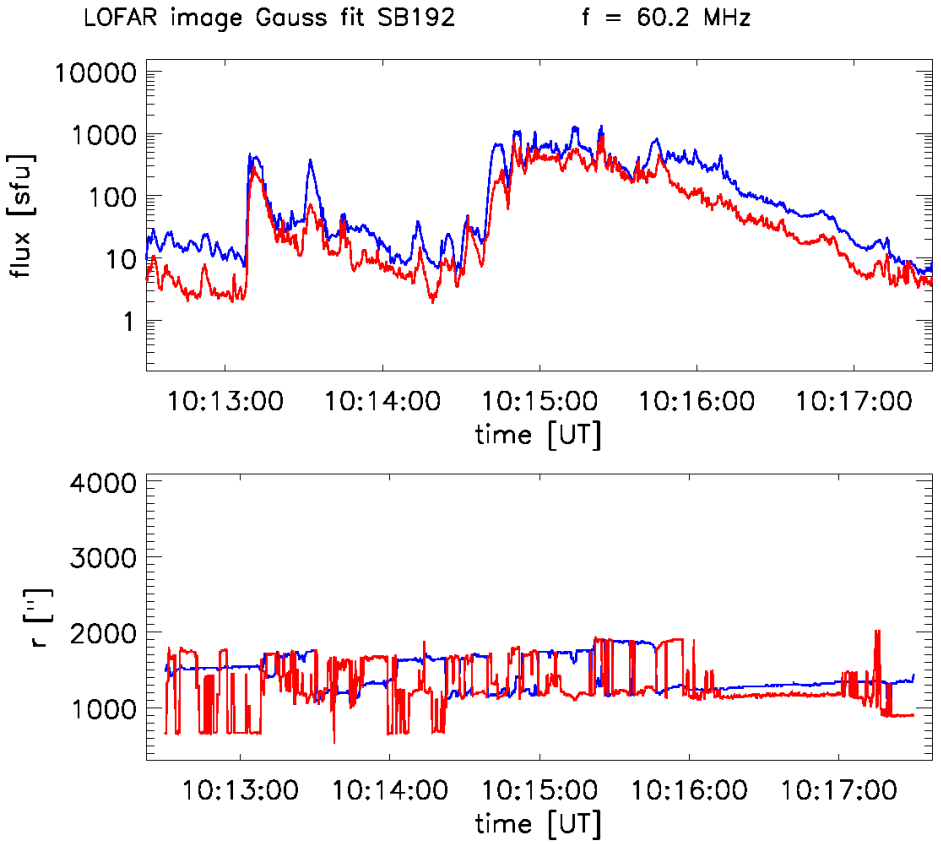

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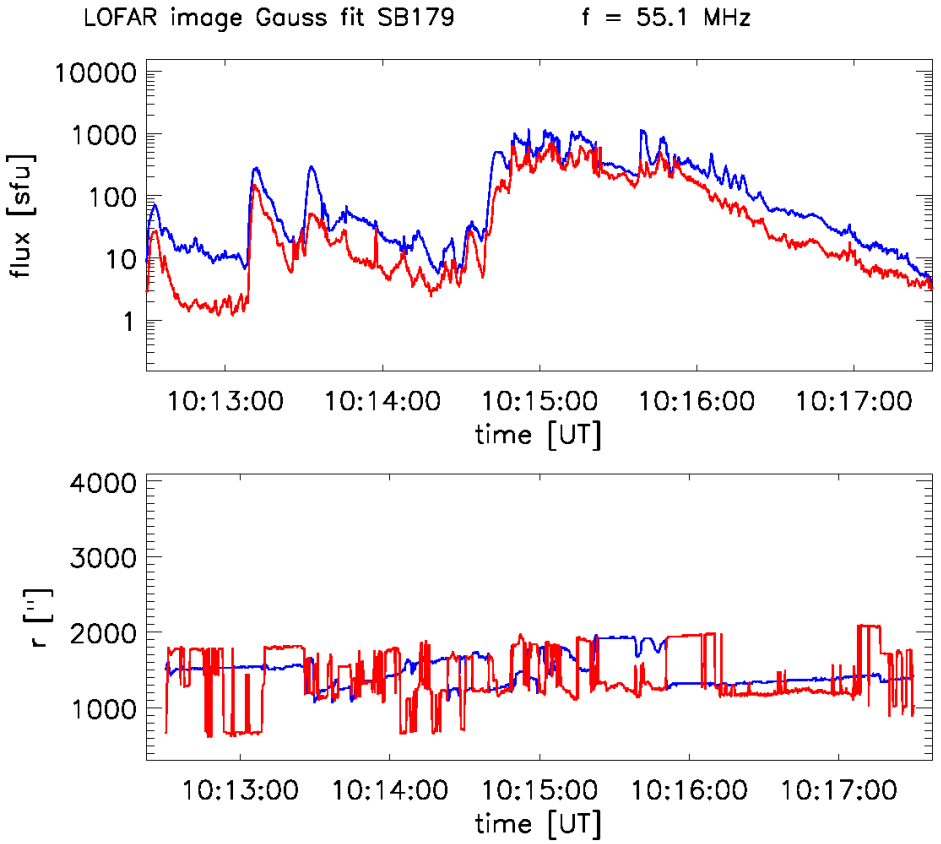

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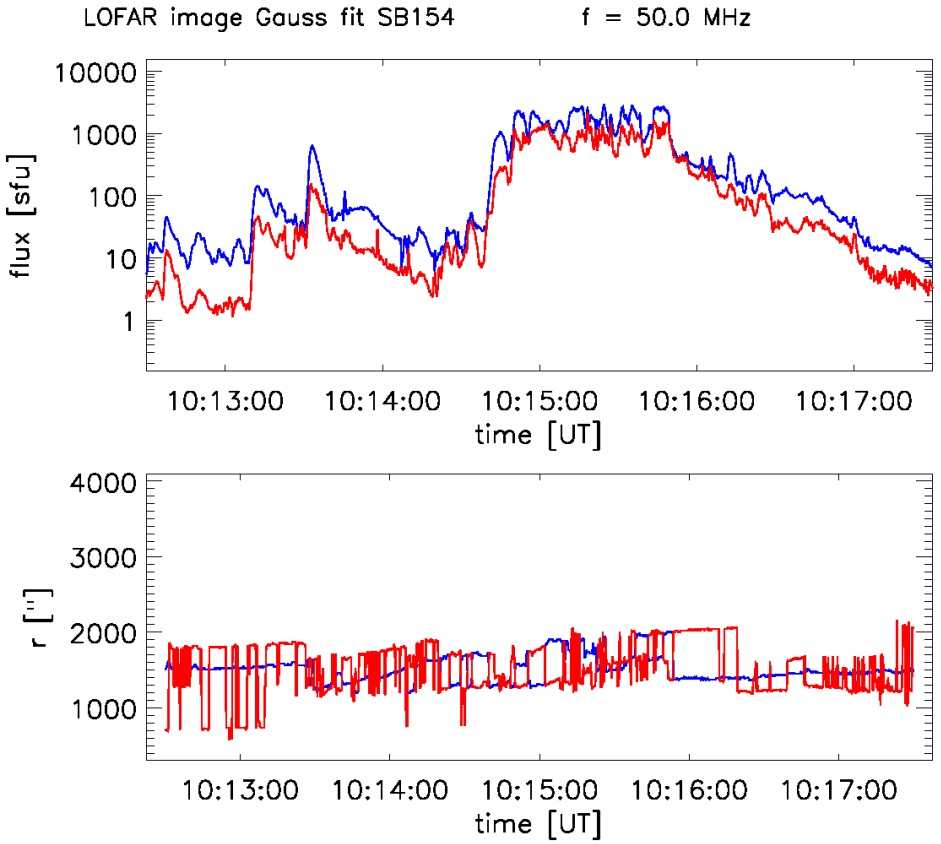

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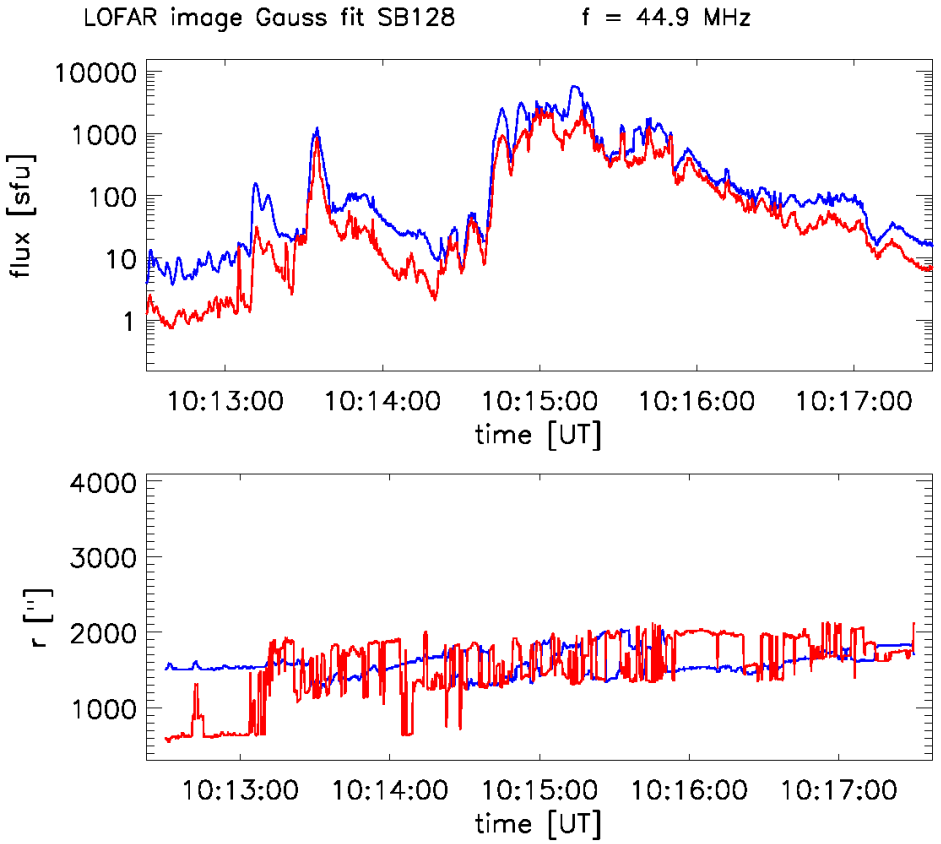

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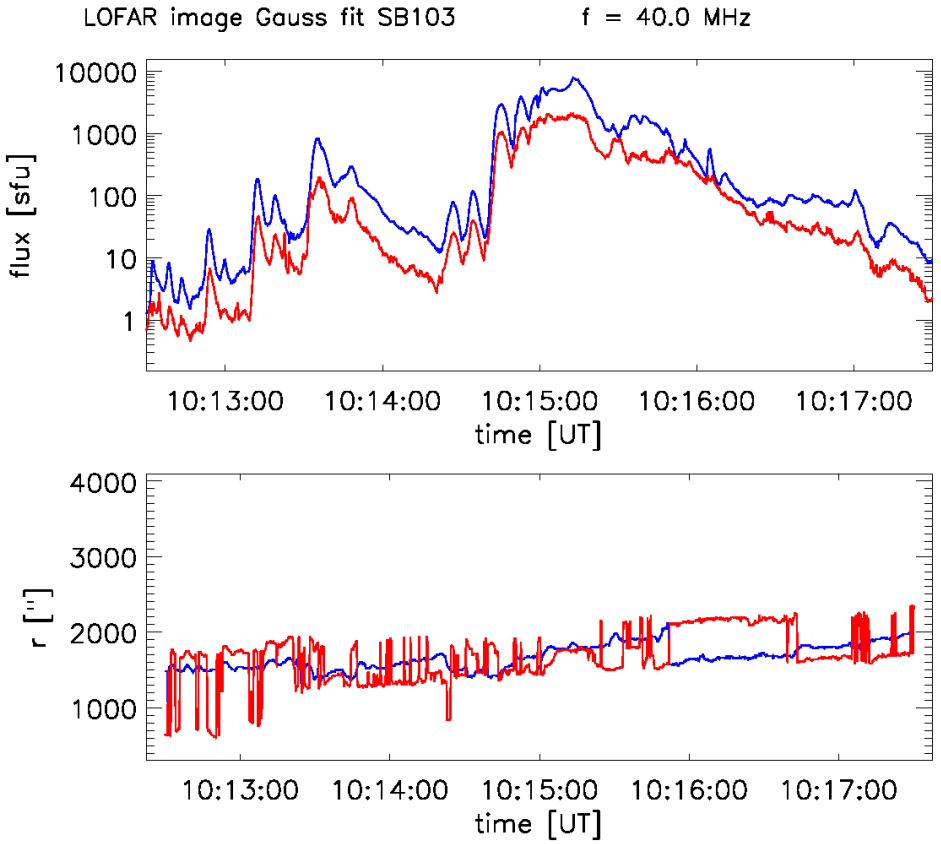

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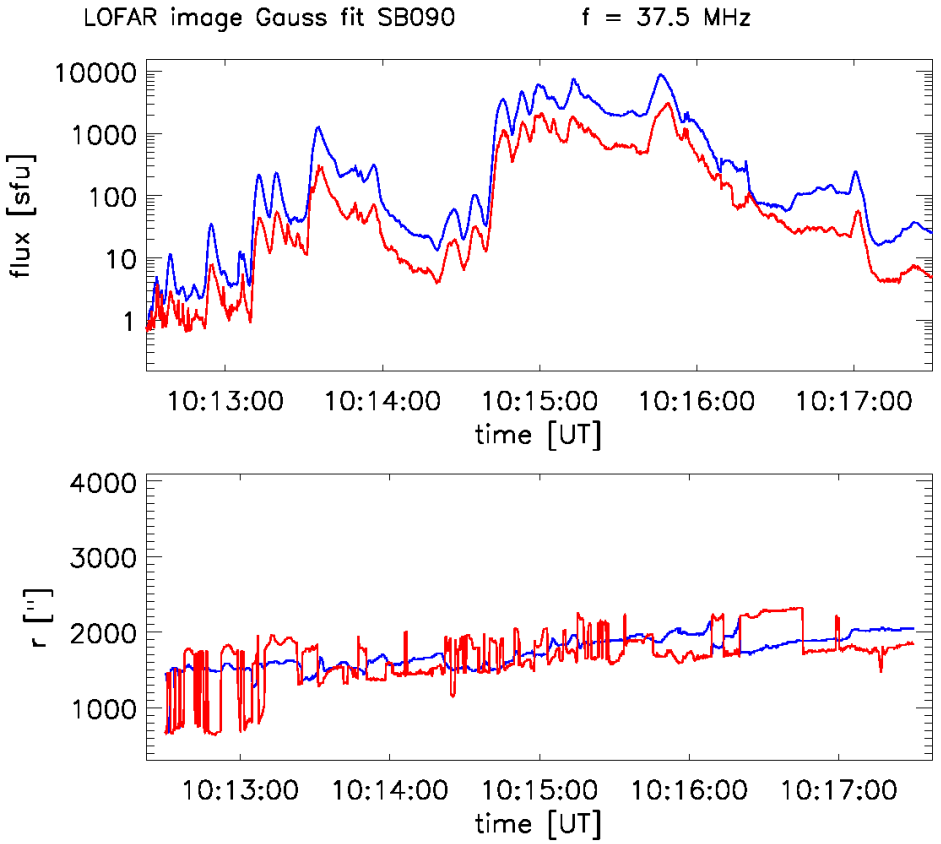

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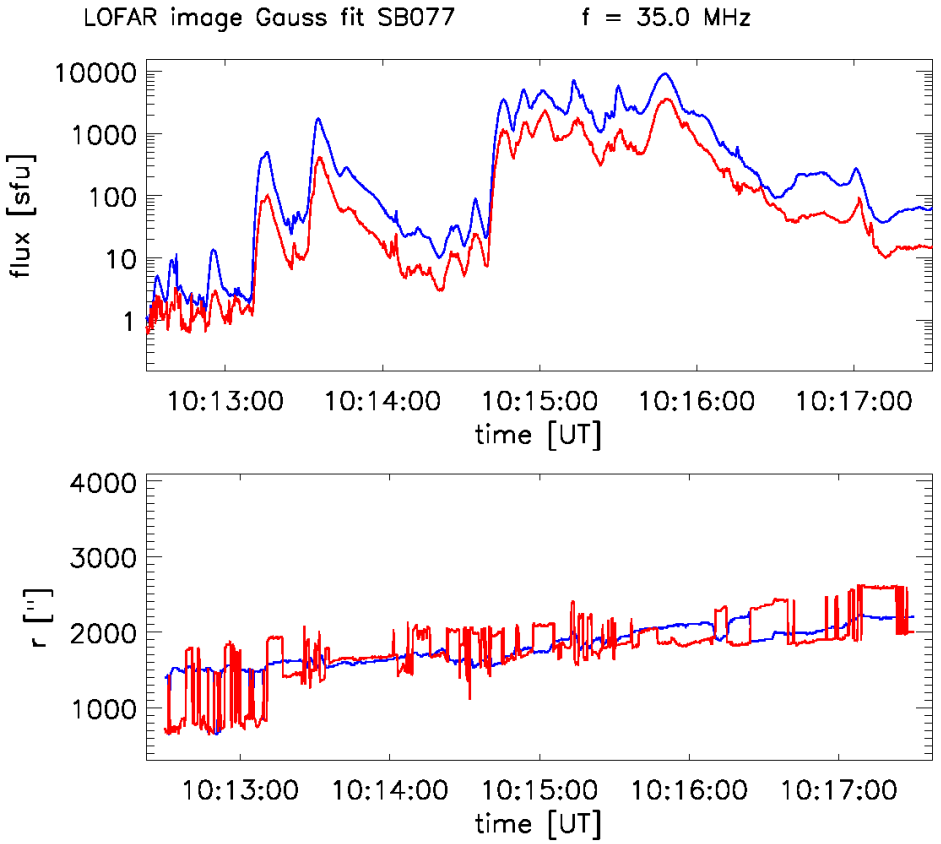

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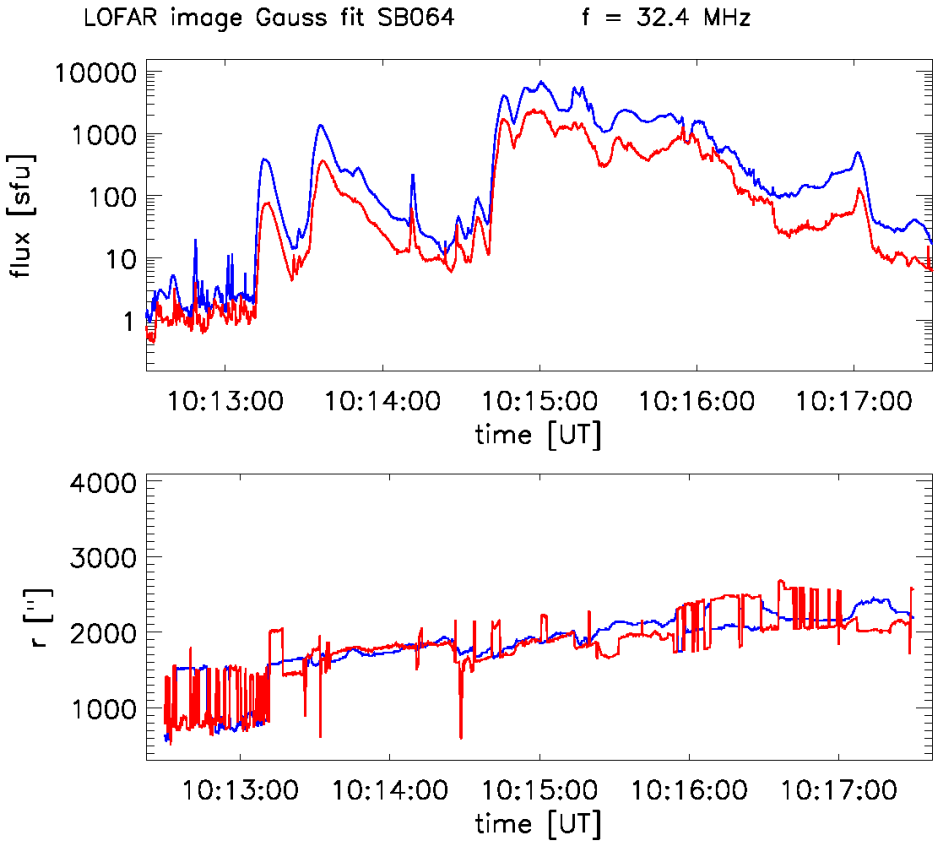

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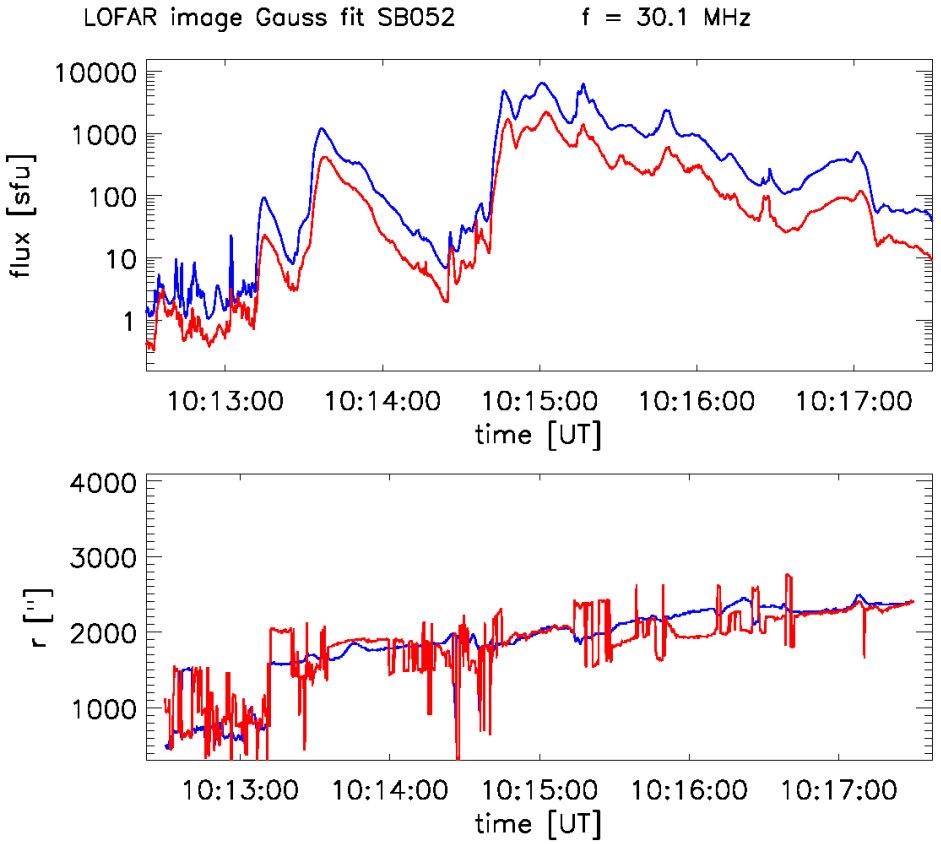

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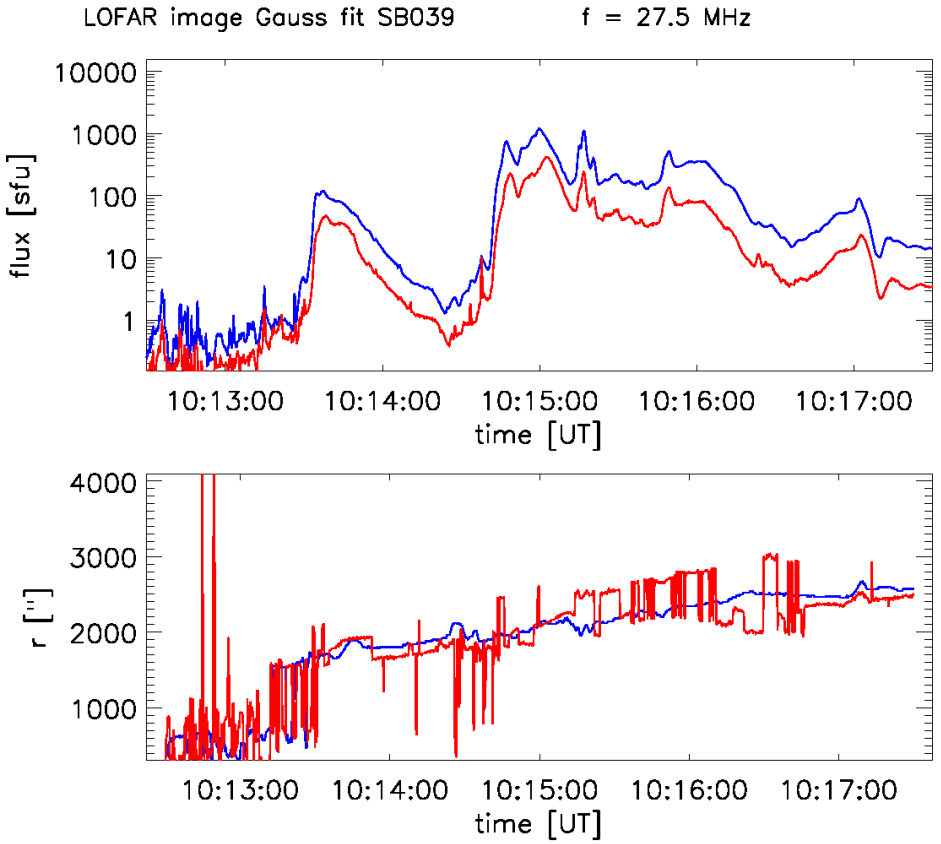

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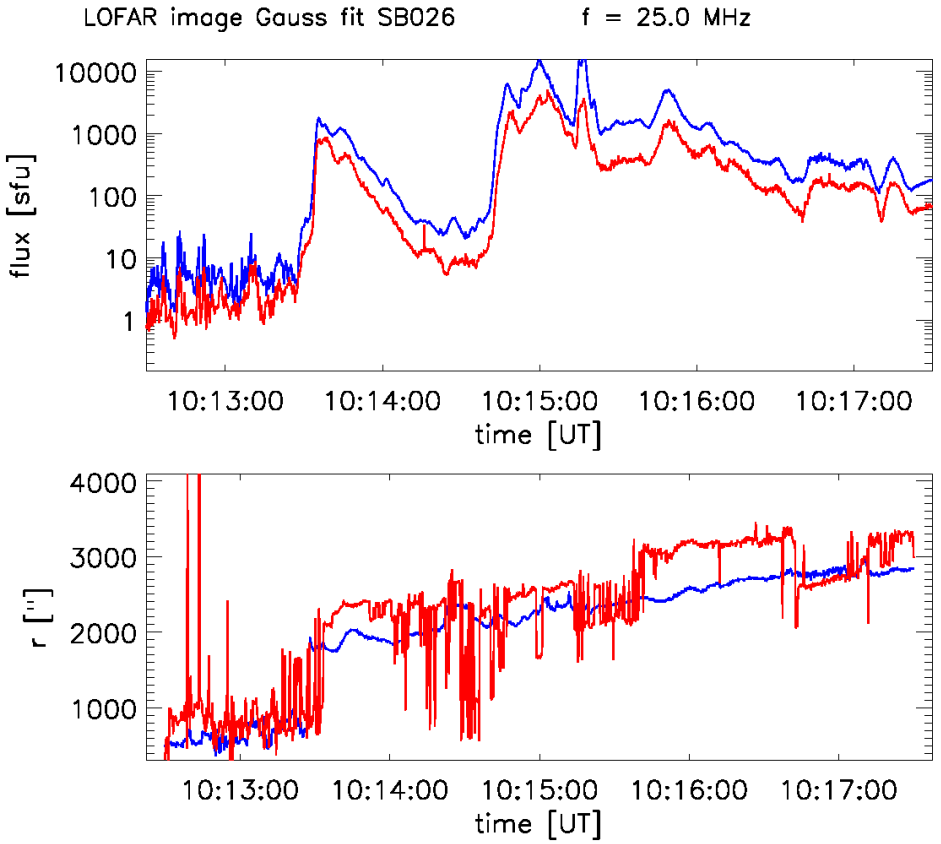

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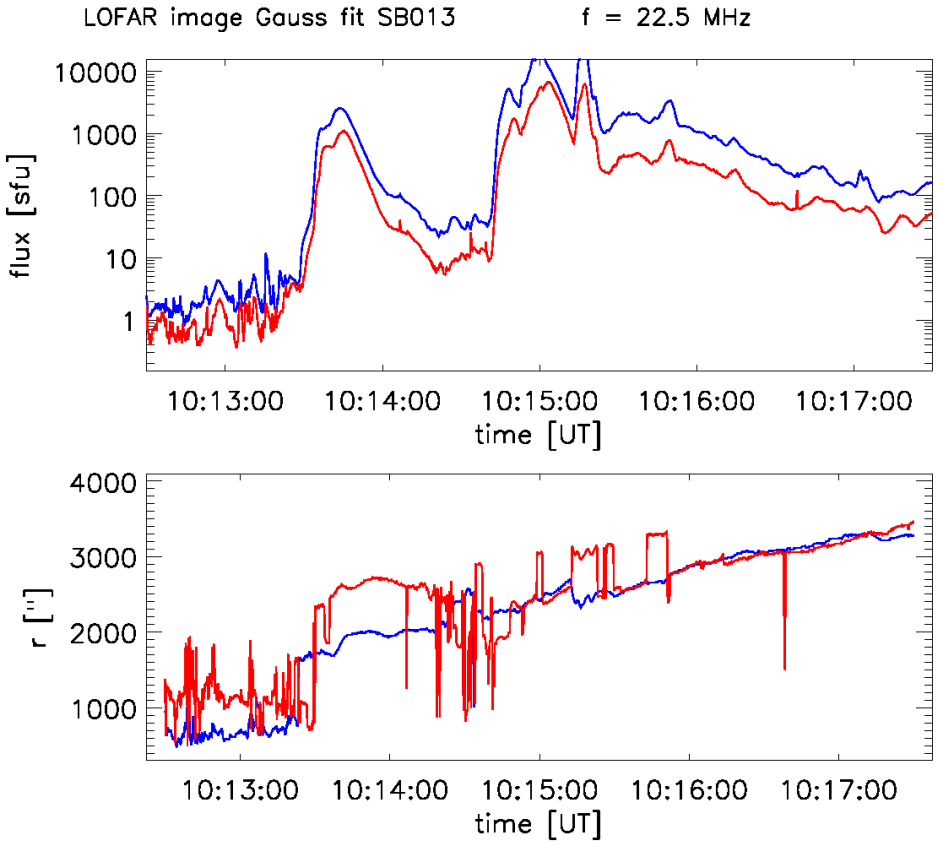

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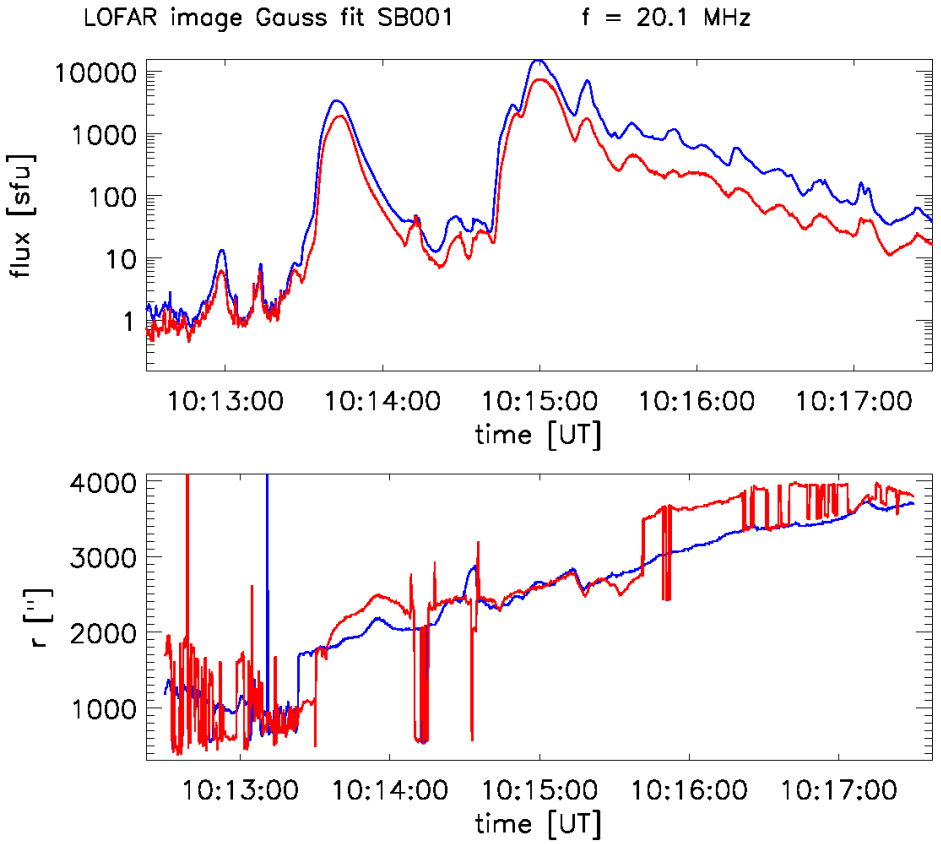


Positions of fundamental and harmonic sources

Source positions:

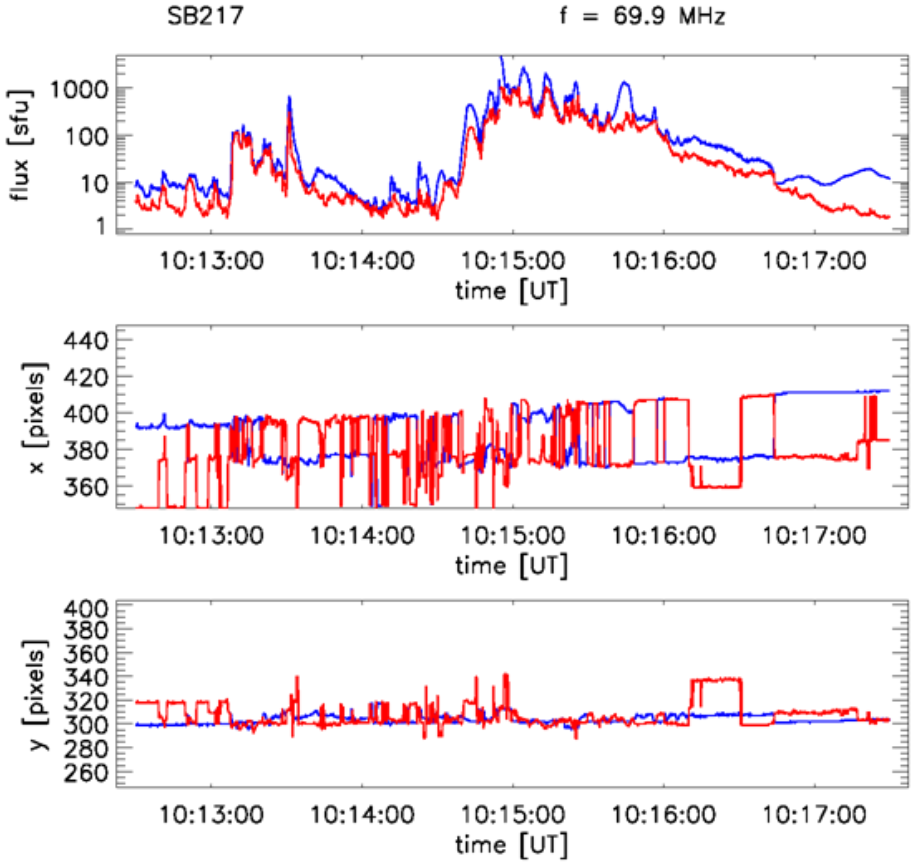
- (x, y) positions from Gaussian fits
- Compensate for drift over time

Fundamental and harmonic fluxes:

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

Result:

Separate lightcurves for fundamental and harmonic sources



Fundamental – harmonic pairs

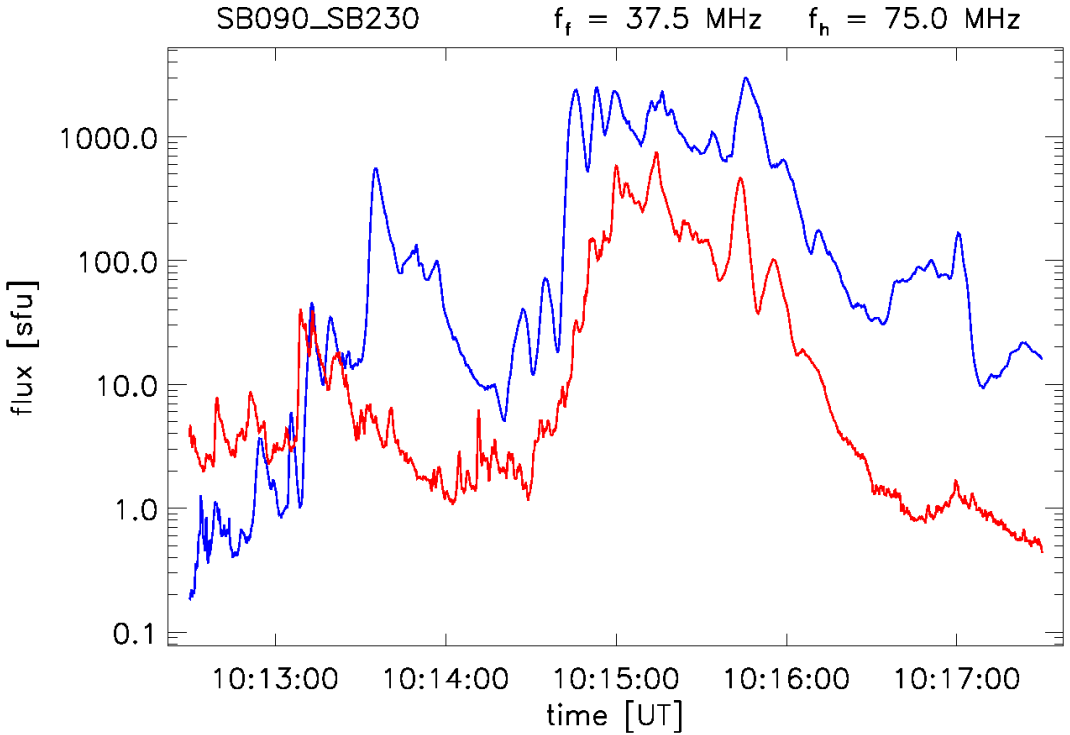
Example: 37.5 / 75 MHz and lower:

- 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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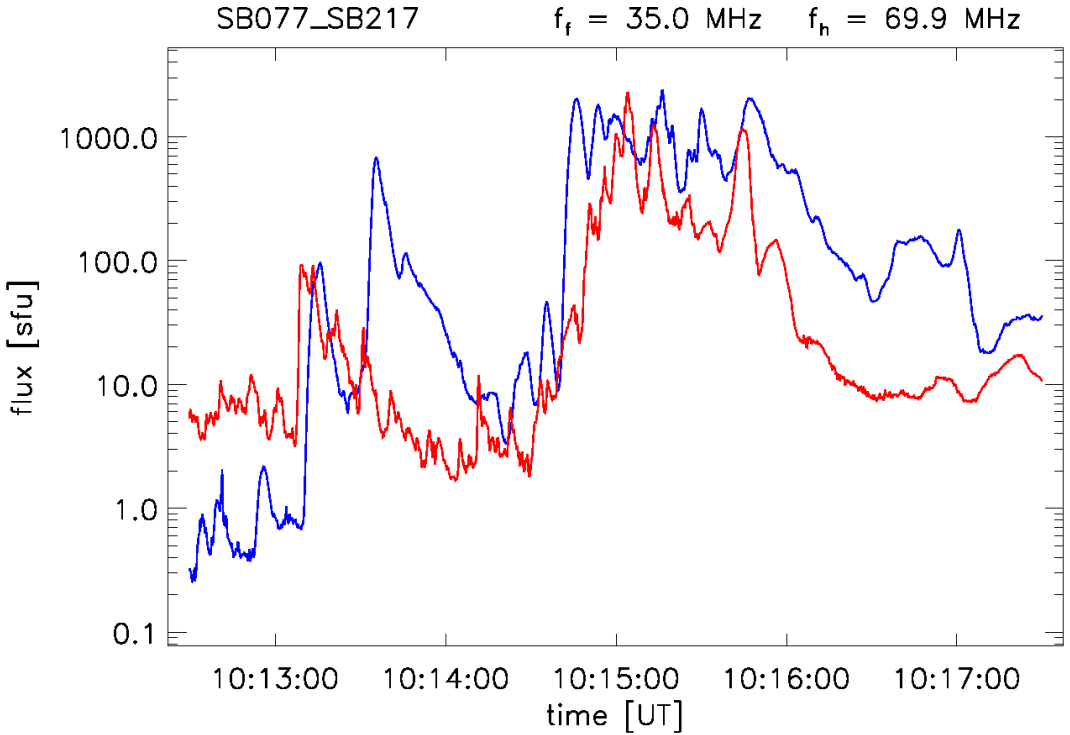

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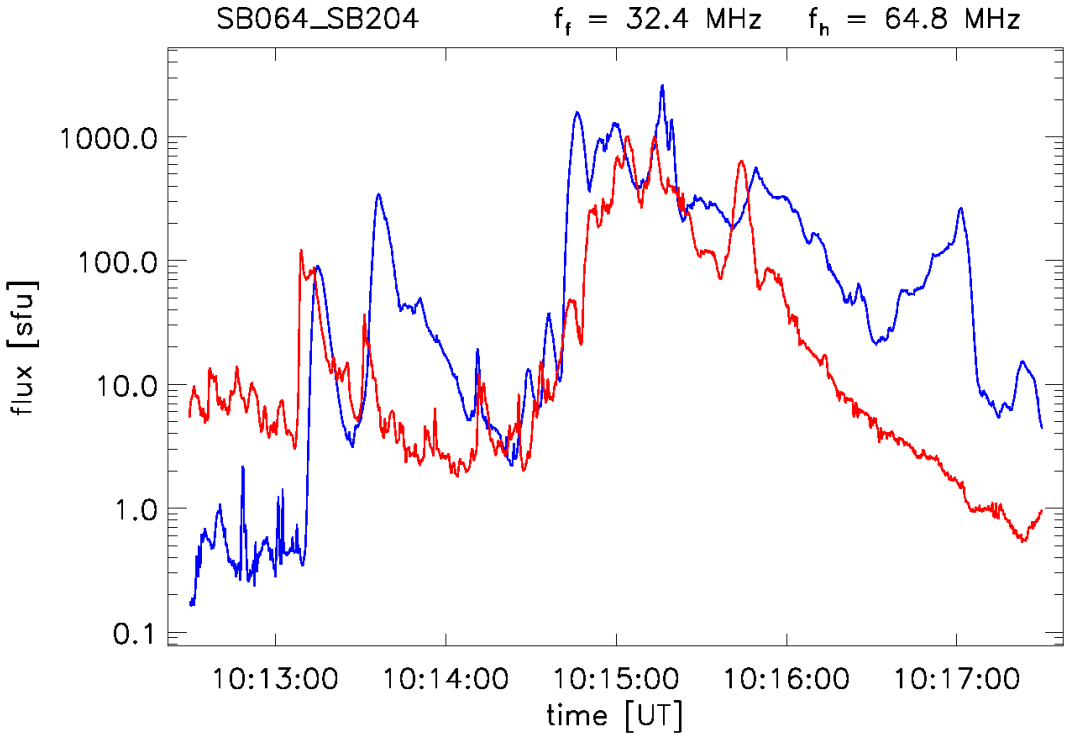

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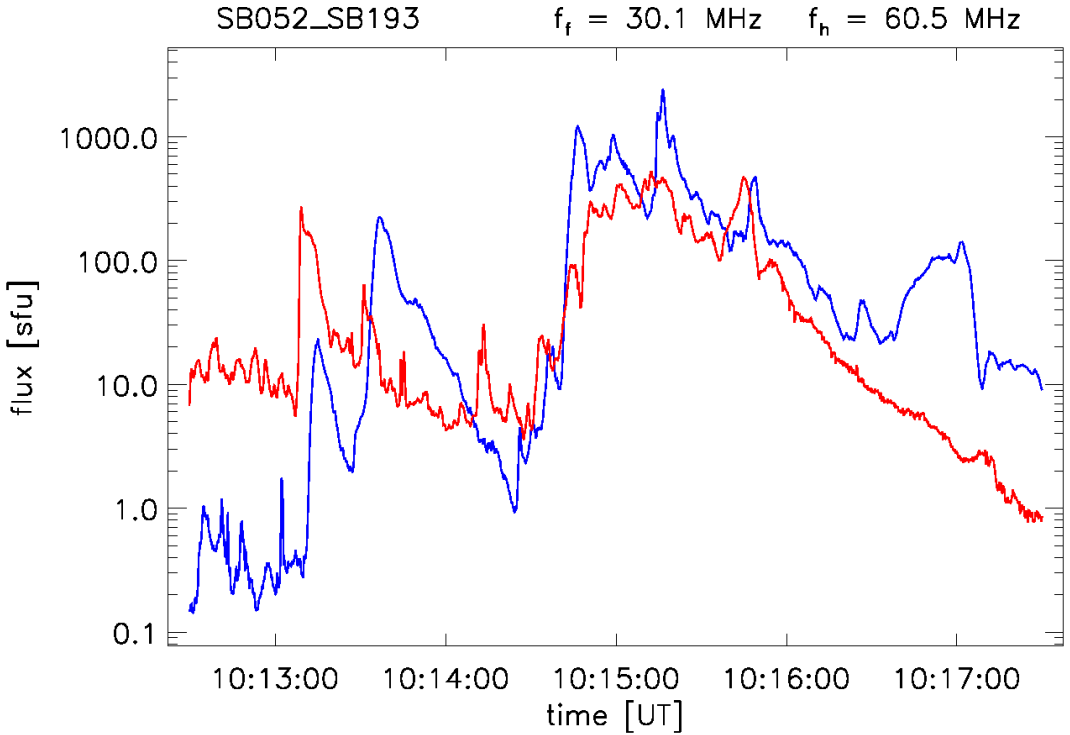
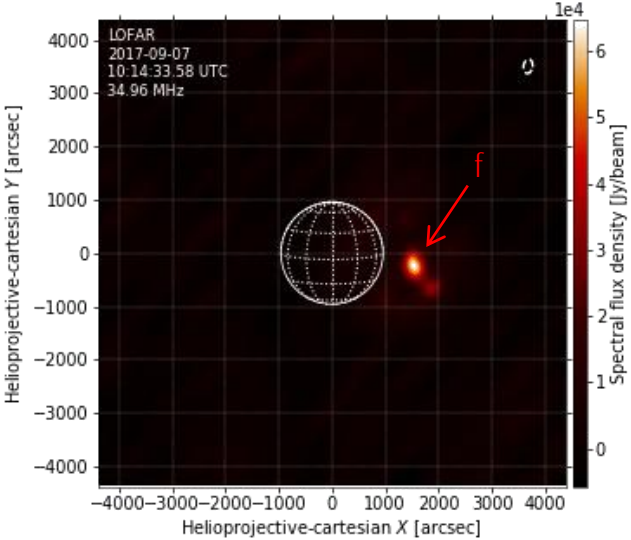
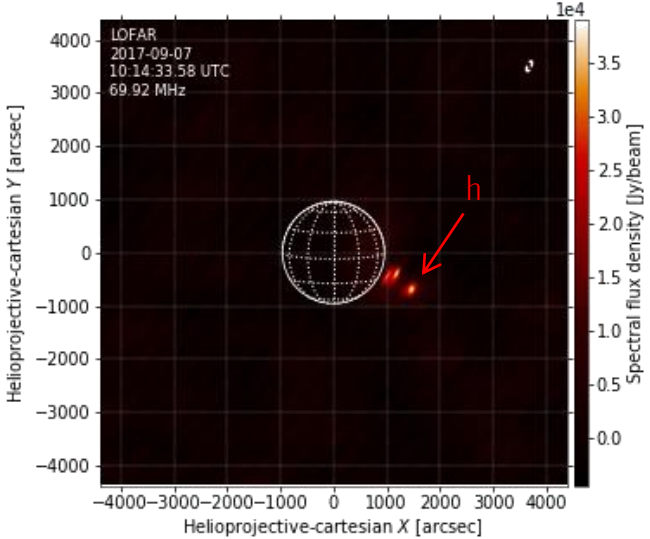


Relative positions of fundamental and harmonic sources





Position of fundamental source:
x = 1528“, y = -226“, r = 1545“

Position of harmonic source:
x = 1430“, y = -667“, r = 1578“

Δx = -98“, Δy = -441“, Δr = 33“

Same source region: Scattering and refraction is stronger for fundamental emission

→ Insights into radio wave propagation in the corona

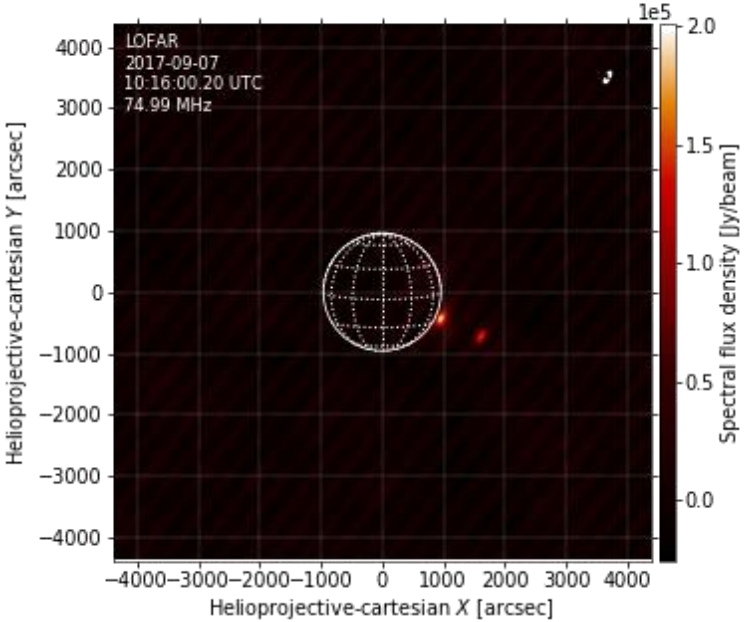
Summary and conclusion

LOFAR M class flare observations:

- Dynamic radio spectra and images
- 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
- Study coronal radio wave propagation and emission characteristics



Outlook

Radio burst observations at low frequencies:

- Harmonic emission at 20 MHz corresponds to a plasma frequency of 10 MHz
- Fundamental emission is inaccessible to ground-based telescopes
- High corona, transition to interplanetary space

Useful aspect for joint observations with spacecraft like Parker Solar Probe and Solar Orbiter