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LOFAR observations of fundamental and harmonic type III emission during an M class flare

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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

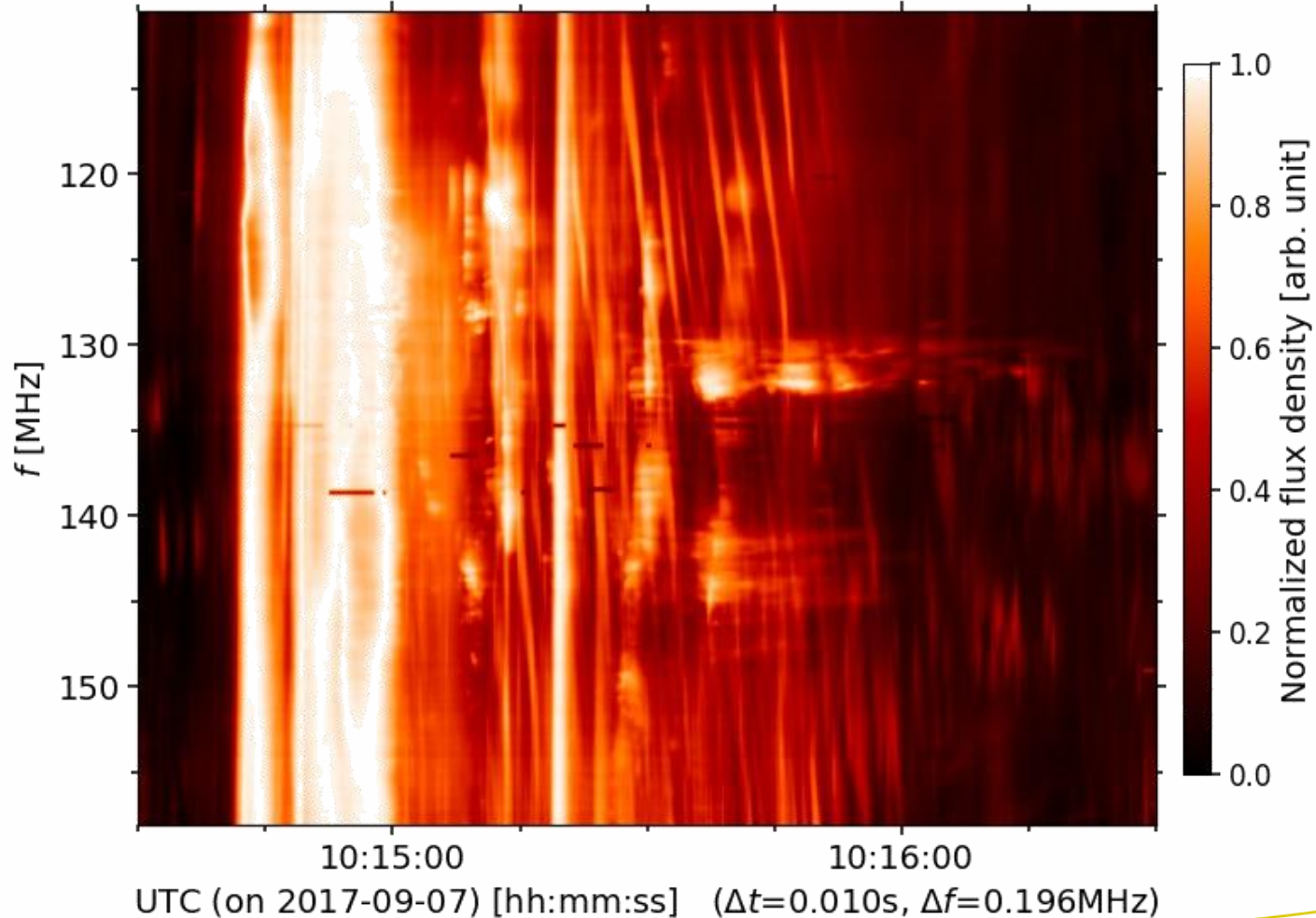
Calibrator issue:

- 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

LOFAR dynamic radio spectra



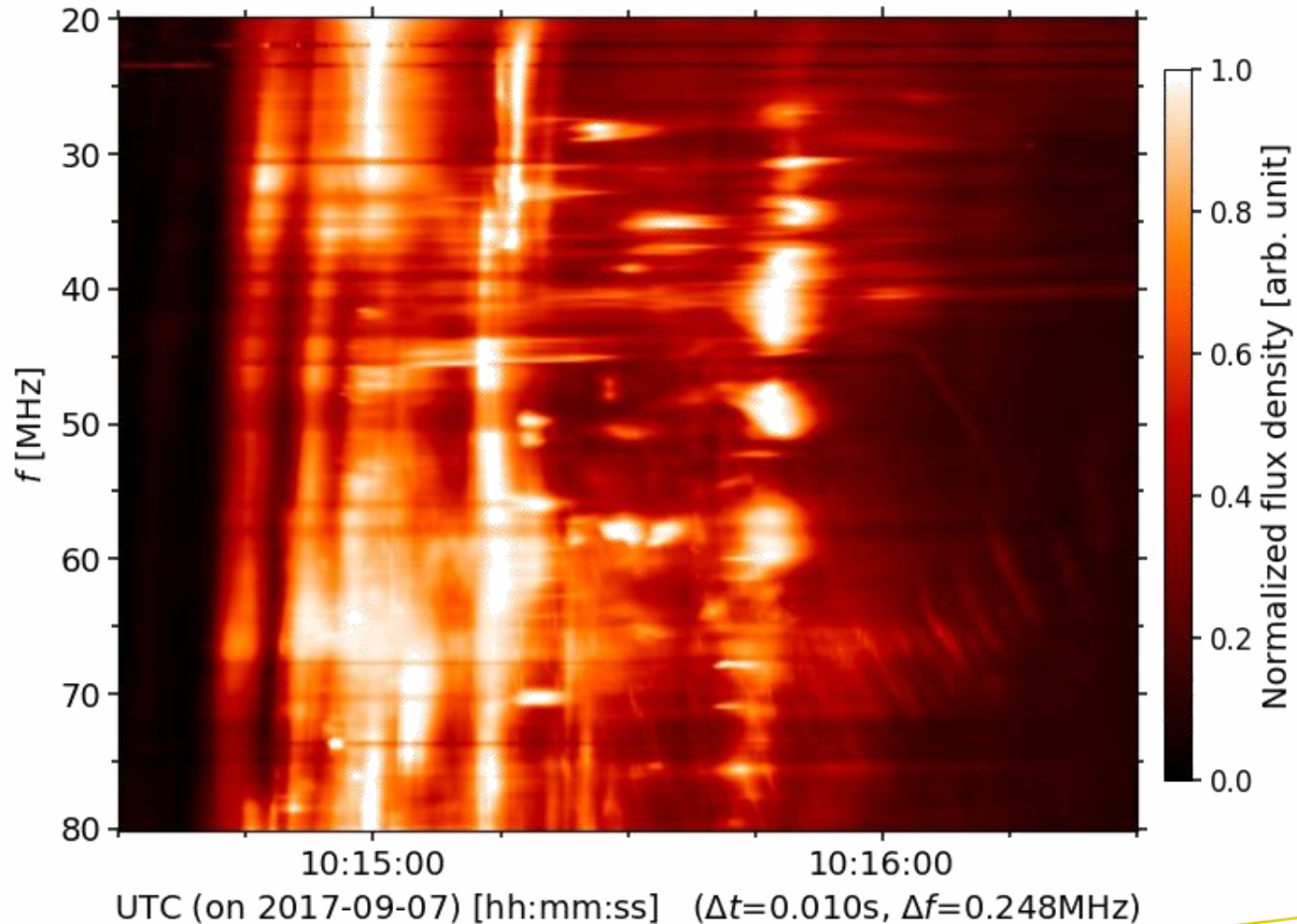
LOFAR (L607502_SAP000_B000_S0_P000_bf, RS509HBA)



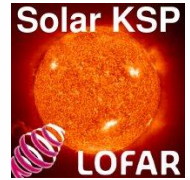
LOFAR dynamic radio spectra



LOFAR (L607504_SAP000_B000_S0_P000_bf, RS210LBA)



Calibration of flare data



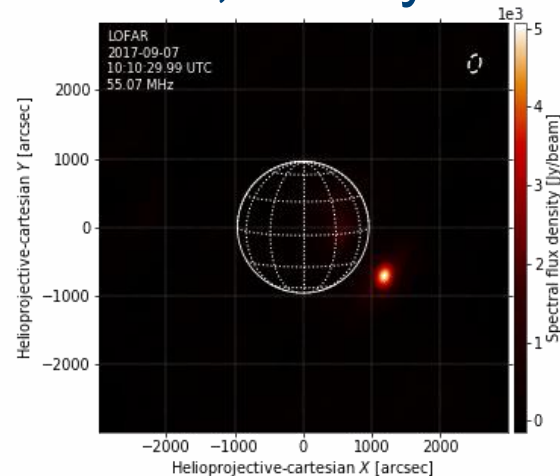
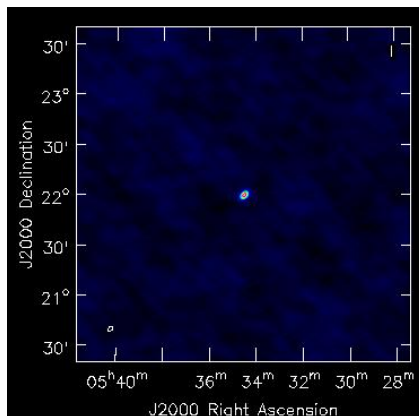
Problem:

- 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, two cycles of self-cal

Tau A:

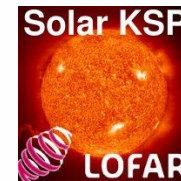


Sun:

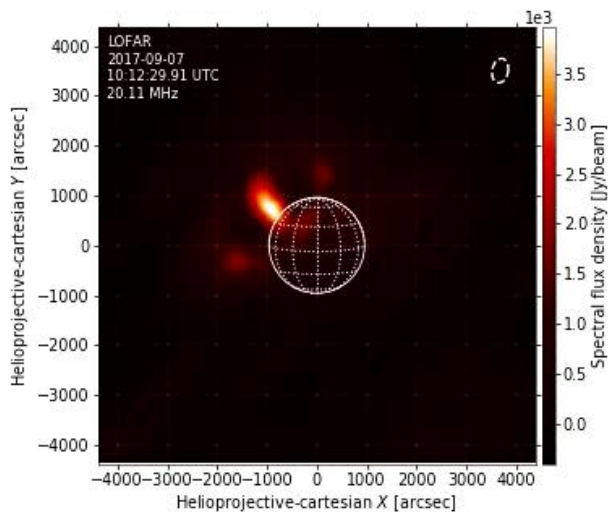
- Dominated by noise storm
- Outshines quiet corona

Use quiet Sun solution to calibrate flare data

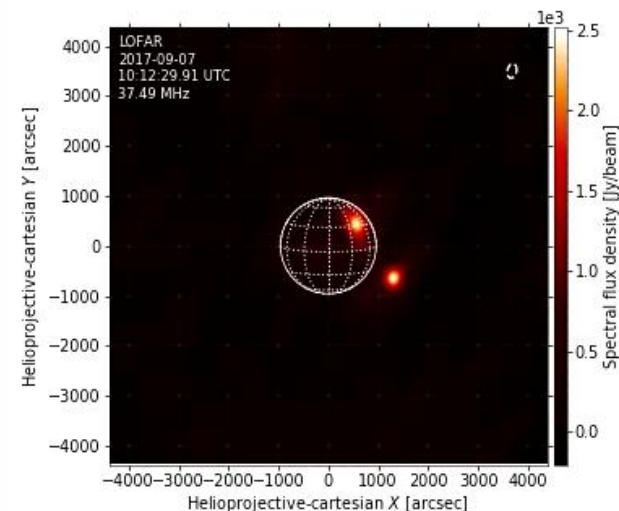
LOFAR images for the M flare



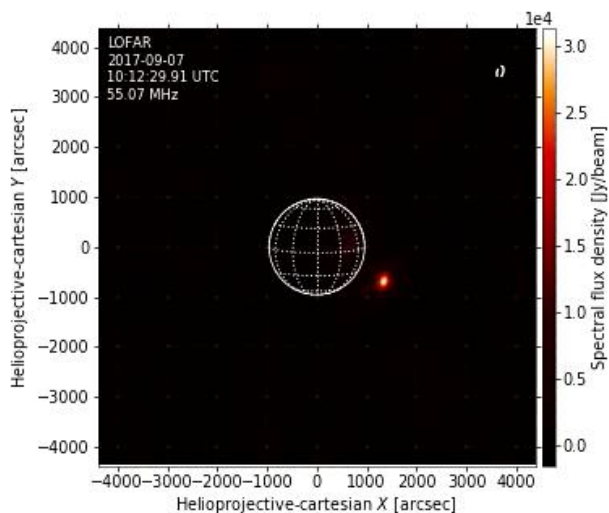
20 MHz:



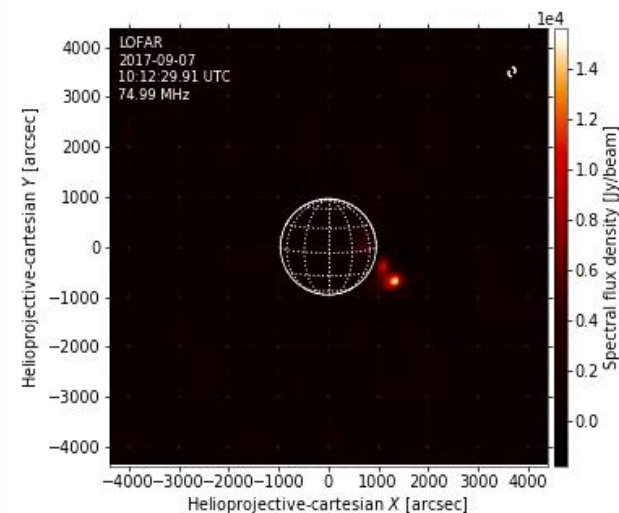
37.5 MHz:



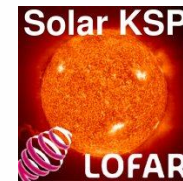
55 MHz:



75 MHz:



Fundamental and harmonic plasma emission



Observed frequency: f_{obs}

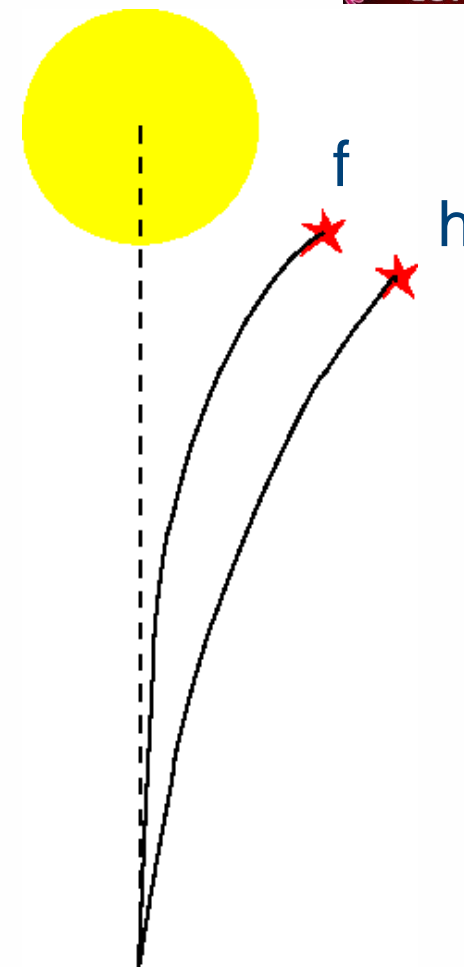
Plasma frequency:

$$f_p = (N e^2 / (m_e \epsilon_0))^{1/2} / (2 \pi)$$

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

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

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



Separation of fundamental and harmonic sources

Radial evolution of f and h sources

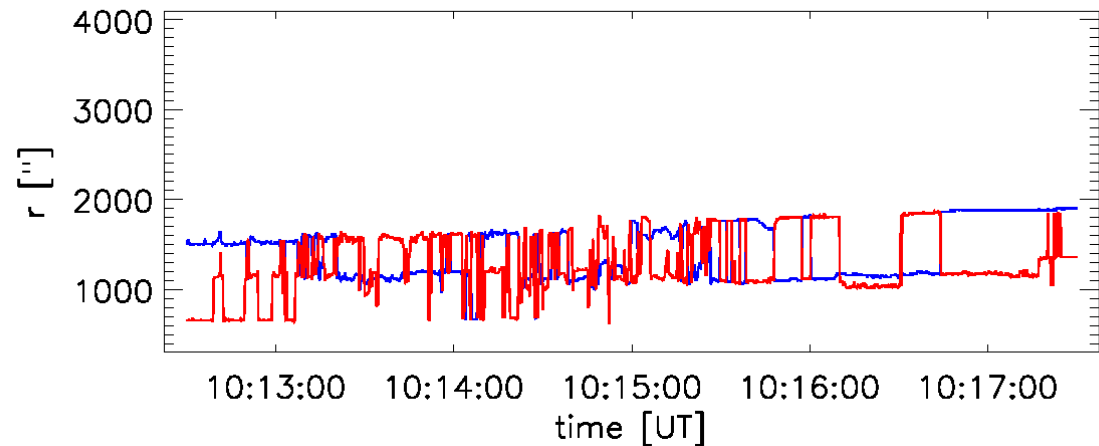
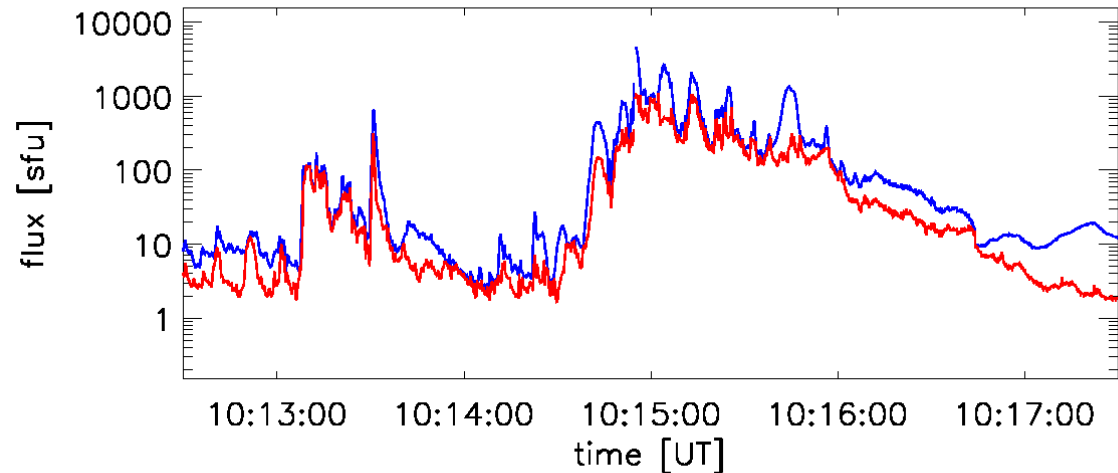


Gaussian fits:

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

LOFAR image Gauss fit SB217

$f = 69.9 \text{ MHz}$



Fundamental-harmonic pairs



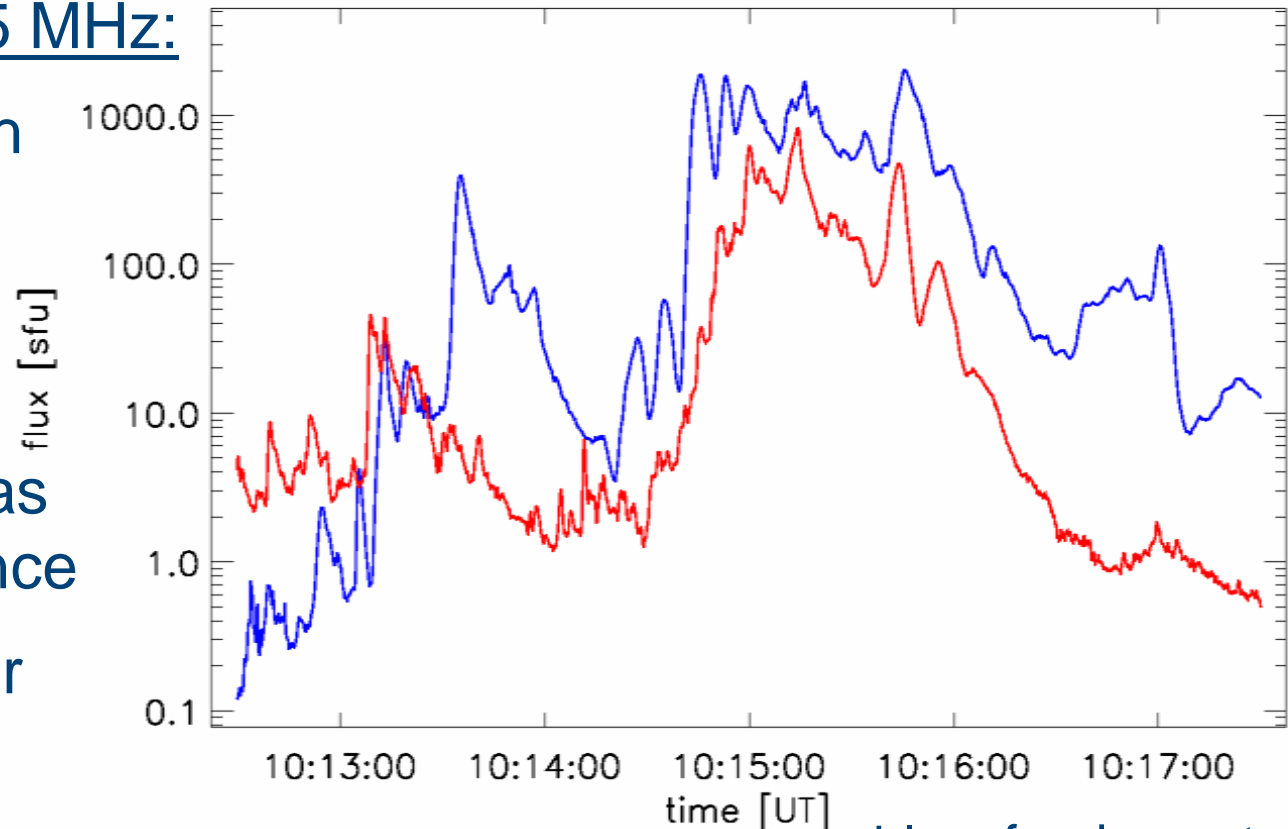
SB090_SB230

$f_f = 37.5$ MHz

$f_h = 75.0$ MHz

Example: 37.5 / 75 MHz:

- Earlier onset for h at 10:13:05 UT
- Not visible at 10:14:30 UT
- Source finding has significant influence
- Method still under development



Such plots can provide information on coronal radio wave propagation

blue: fundamental
red : harmonic

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 h, inner f
- Separate lightcurves
- Fundamental-harmonic pairs: Same source region
- Study coronal radio wave propagation

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