Fine Structures of the Solar Radio Burst Observed by LOFAR

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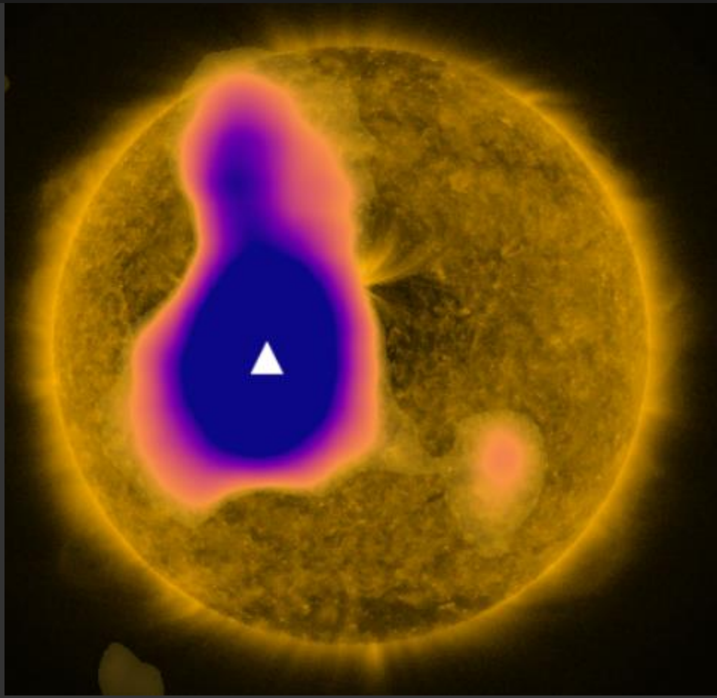
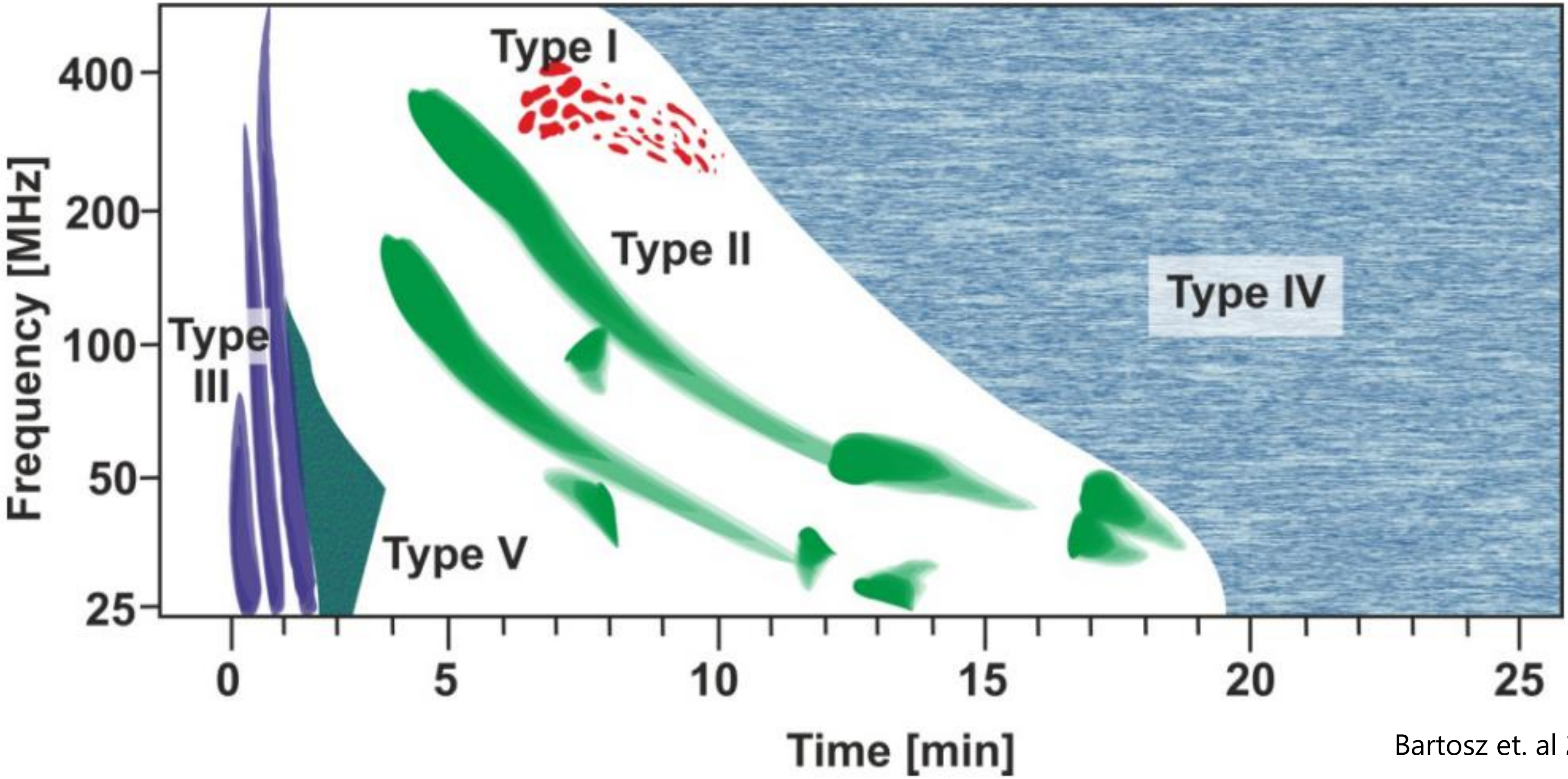


Solar Radio Burst

- The sun is active at the radio band, solar radio burst can have the brightness temperature at the scale of 10^8K
- There are various types of solar radio burst

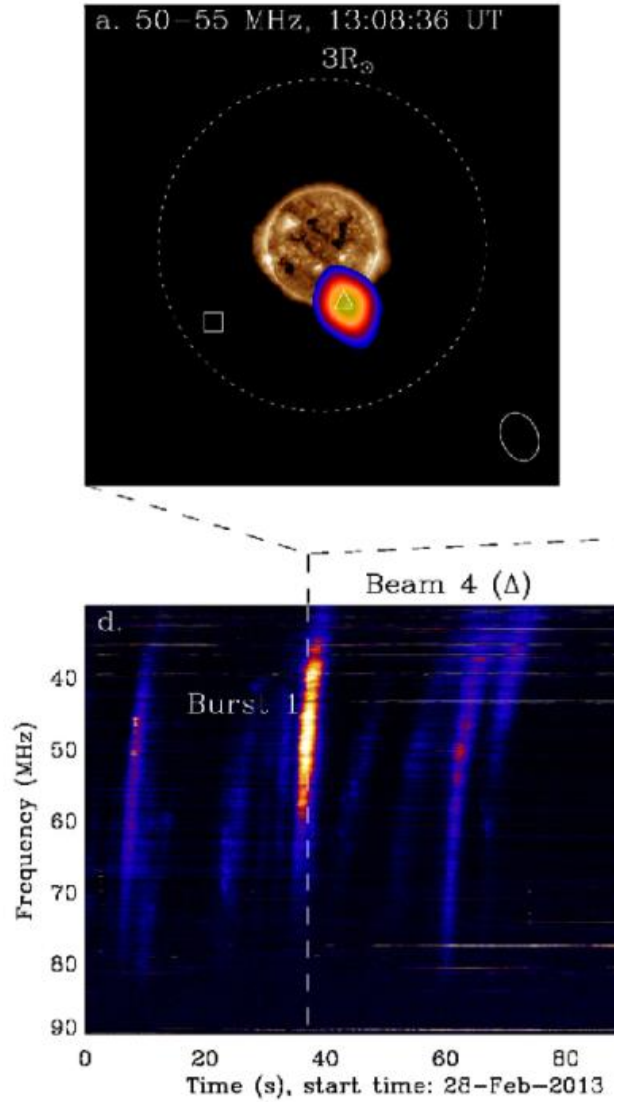


Bartosz et. al 2016

The Emission of Solar Type III radio burst

- **Solar activities will generate electron beams which can pass through the plasma**

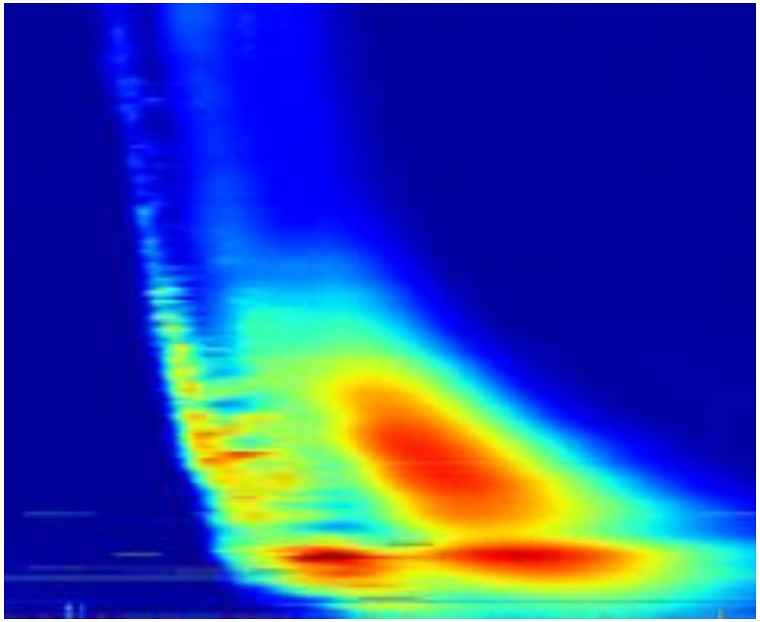
- **The electron beam can trigger Langmuir wave to generate electrostatic wave then converted to the fundamental and harmonic EM waves**



Diana 2014

Fine structure: Type IIIb-III pair

- Type IIIb-III pair is a special kind of type III F-H pair events.
- The fine structures appears in fundamental part
- The generation mechanism of the type IIIb resulting in these fine structures in the spectrum is still debated. [ECM and plasma emission]



LOFAR : the Low Frequency Array

- LOFAR 2.0
- Longest baseline: 121km (core and remote station)
- Theoretical Spatial resolution : ~36 asec
- Actual Spatial resolution : ~150 asec
- Cadence : 1/6 s (12s for LOFAR 1.0)

Observation and Data reduction

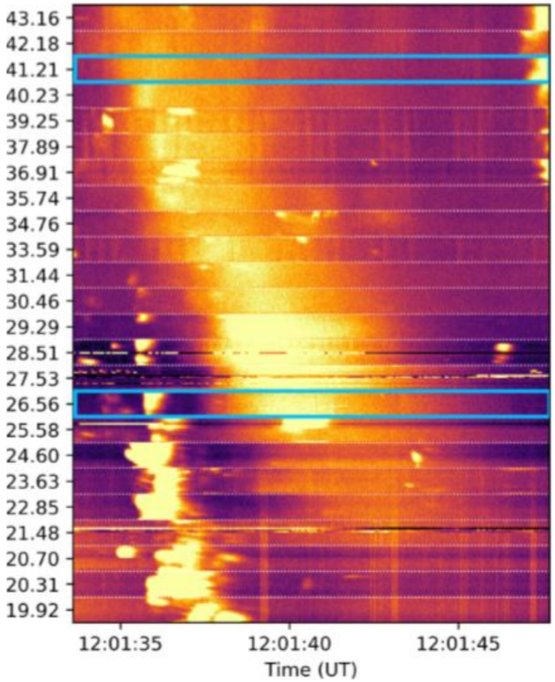
- Instrument: LOFAR LBA
  - Cadence : 0.168s

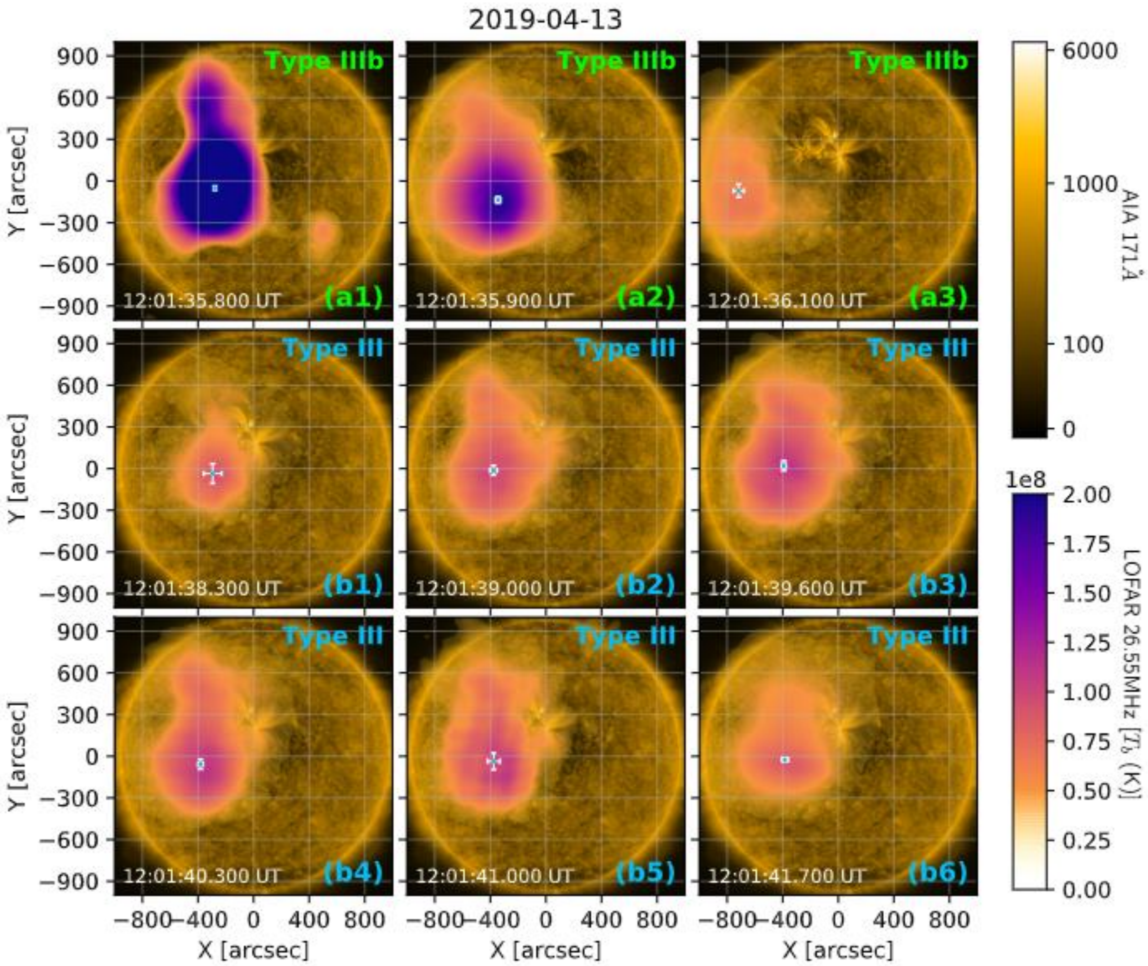
- Preprocessing
  - Preprocessed with Default Pre-Processing Pipeline (DPPP; van Diepen et al)
  - Calibrator : Taurus A

- Imaging
  - WSClean (https://sourceforge.net/p/wsclean/wiki/Home/)
  - https://github.com/Pjer-zhang/LOFAR_Solar

Imaging and spectroscopy of IIIb-III pair

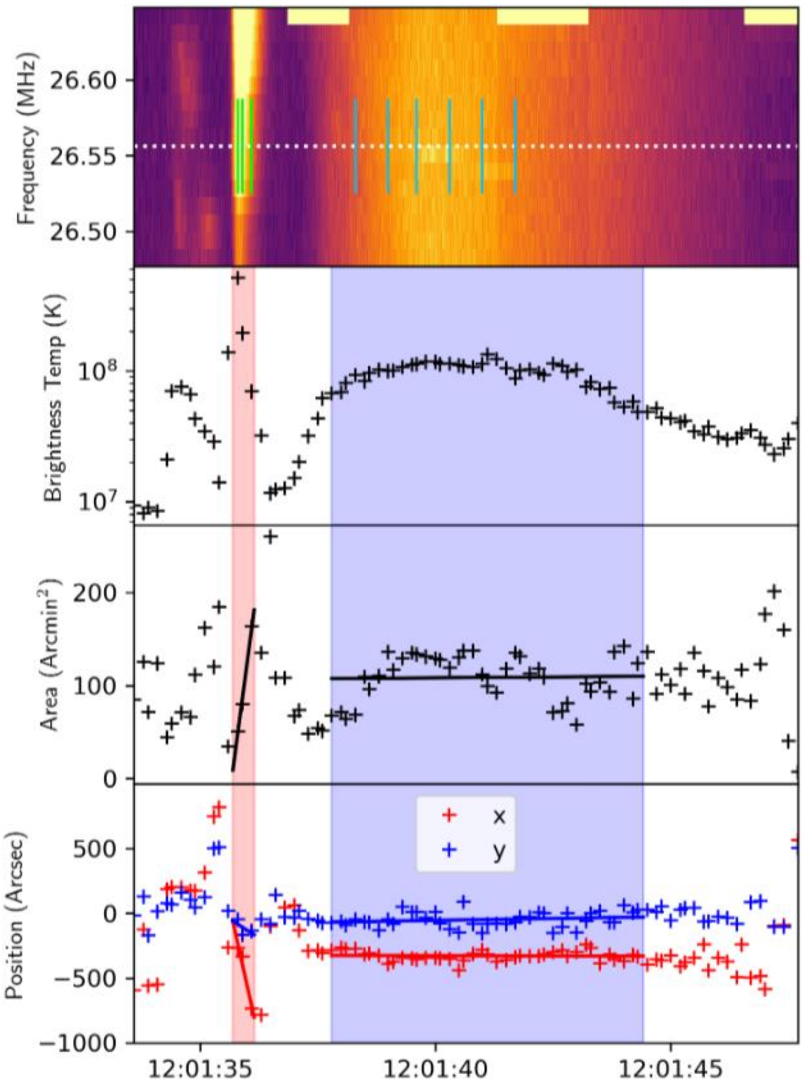
- The dynamic spectrum and snap shot of images

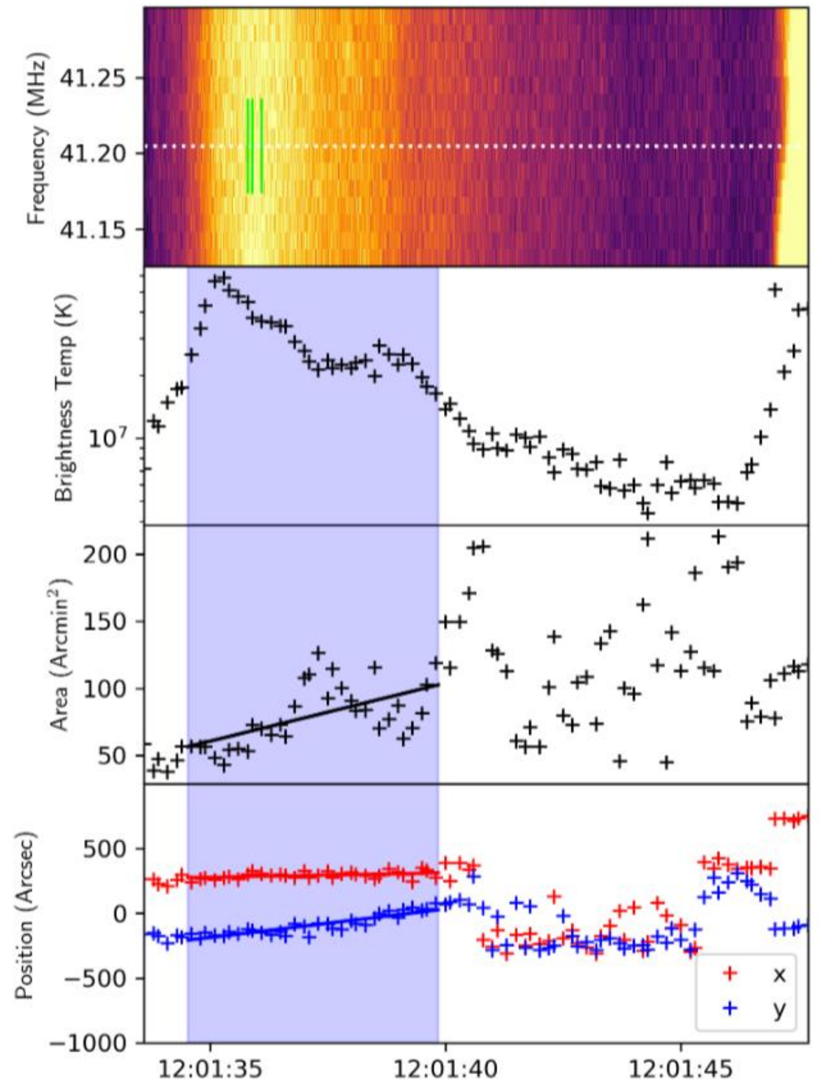




Clarke et al. 2019

Source size and position





Statistics

- **Source size and position**

	26.6MHz (F)	III 26.6MHz (H)	III 41.2MHz (H)
t_{FWHM} [s]	0.45	6.61	5.31
A_0 [Arcmin^2]	9.0	107.4	56.5
dA/dt [Arcmin^2/s]	382.0	0.4	8.7
$\overline{x}$ [Arcsec]	-446.0	-328.5	293.2
$\overline{y}$ [Arcsec]	-115.0	-48.9	-89.9
v_x [c]	-3.956	-0.002	0.017
v_y [c]	-0.570	0.015	0.106

Observation result

- For the frequency of 26.56 MHz, the source area of the fundamental emission increase from about 50 $arcmin^2$ to 200 $arcmin^2$ within 0.45 seconds, while the source area of the fundamental is stable near about 100 $arcmin^2$ for the 6.61 seconds of duration.

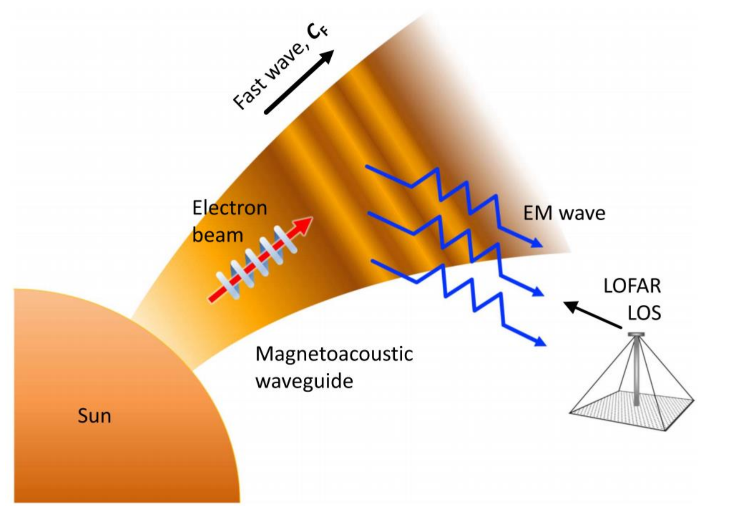
- For the frequency of 41.21 MHz, only harmonic emission is observed. The visual source area increase from about 50 $arcmin^2$to 100 $arcmin^2$ in 5.31 seconds.

- The visual speed of the source of fundamental emission at 26.56 MHz is about four times the speed of light.

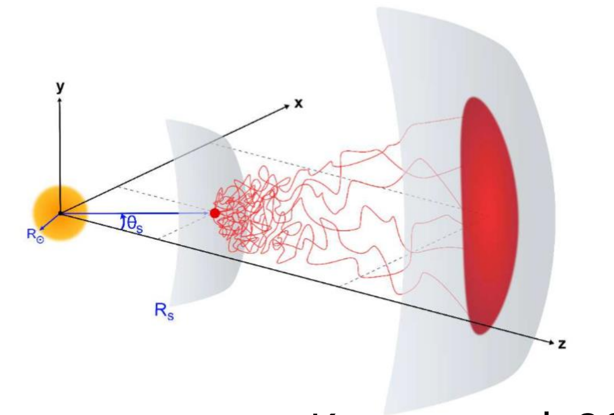
- The visual speed of the sources of harmonic emission at 26.56 MHz and 41.21 MHz are lessthan 0.11 times the speed of light.

Possible mechanism

- Source expansion
  - scattering effect
- Source movement
  - Scattering effect
  - Ducting by the magnetic tube
  - Refraction
- **Both the wave refraction and the scattering can contribute to the high speed visual movement of the source.**



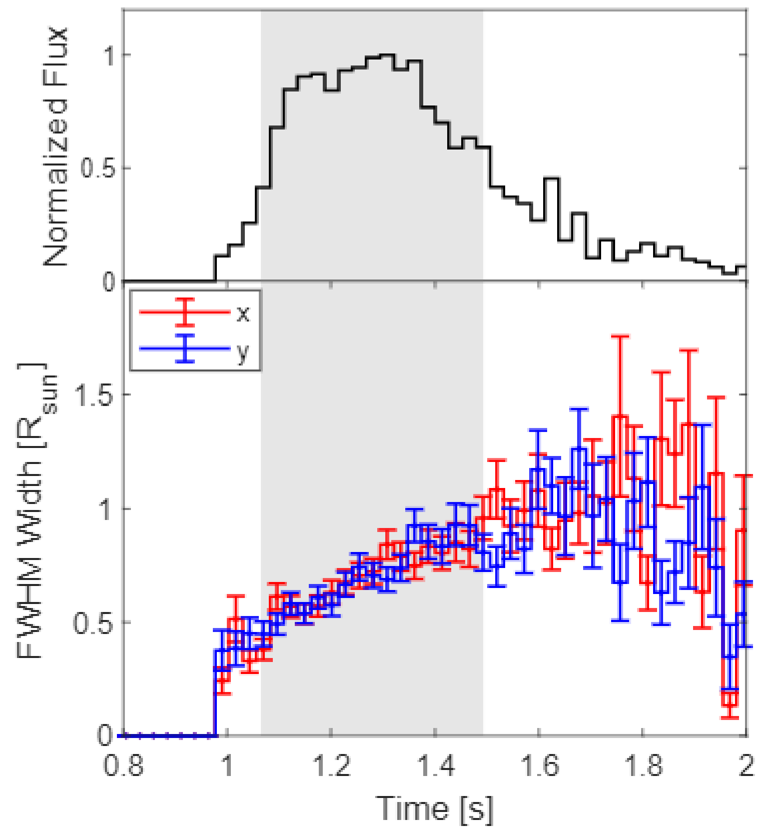
Clarke et al. 2019



Kontar et al. 2019

Simulation with anisotropic scattering

- **The source size can be well reproduced by the scattering effect during its propagation in the corona**
- **We used the simulation method provided by Kontar et. al 2019 and the source size increasing trend is similar to the observation.**



Summarize

- We did a interferometry for the sun with the longest baseline of 121km, and at time resolution of 0.167s per frame
- For the frequency of 26MHz, the source size of the fundamental wave increase from about 50 Arcmin2 to 200 Arcmin2 within 0.5 s, while the source size of the fundamental is stable near about 100 Arcmin2 for the 6.61 seconds of duration.
- For the frequency of 41MHz, only harmonic wave is observed. The visual source size increase from about 50 Arcmin2 to 100 Arcmin2 in 5.31 s.
- Visual speed of fundamental wave is about 4c
- Visual speed of harmonic wave is slow
- We suppose that the movement of the source is due to the refraction of the wave