The solar radio bursts observations with LOFAR

B. Dabrowski, A. Wołowska, C. Vocks, P. Flisek, A. Krankowski, P. Zhang, J. Magdalenic, A. Warmuth, D. E. Morosan, M. Bröse, M. M. Bisi, L. Błaszkiewicz, E. P. Carley, R. A. Fallows, A. Froń, P. T. Gallagher, M. Hajduk, K. Kotulak, G. Mann, P. Rudawy, T. Sidorowicz, Y. Wu, P. Zucca, K. Mikuła and KSP "Solar Physics and Space Weather with LOFAR" team

Space Radio-Diagnostics Research Centre, University of Warmia and Mazury in Olsztyn, Poland

LOFAR
Solar and Space Weather
KSP

NATIONAL SCIENCE CENTRE
POLAND

Beethoven Classic 3
LOFAR observations of the solar corona
during Parker Solar Probe perihelion passages

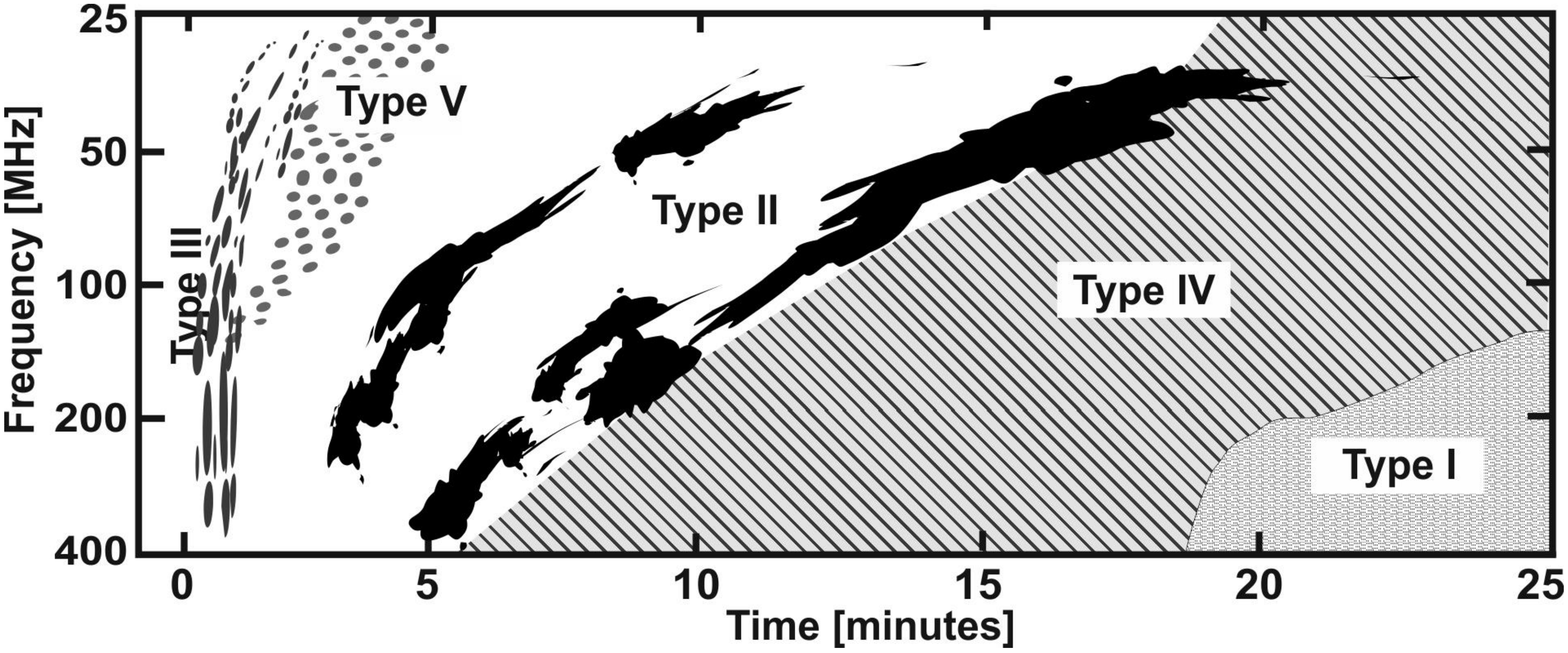
DFG Deutsche Forschungsgemeinschaft
German Research Foundation

UNIWERSYTET WARMIŃSKO-MAZURSKI W OLSZTYNIE

AIP Leibniz-Institut für Astrophysik Potsdam

Solar radio bursts

Meter-λ bursts were originally classified (in 1950) into three types, denoted **type I**, **type II** and **type III**. Later (*circa* 1960) this classification was extended to include **types IV** and **V** bursts.

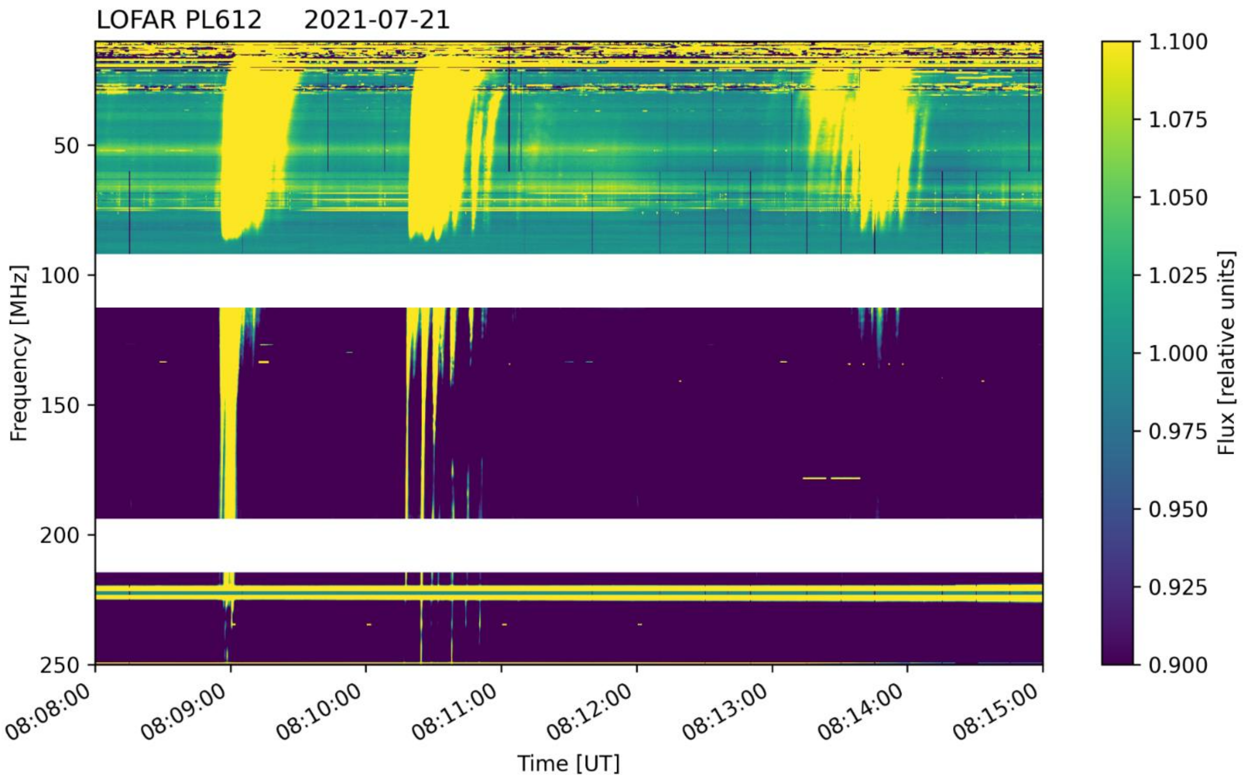


Schematic diagram shows the basic classification of solar radio bursts in the frequency range 25-400 MHz (based on: Wild et al., 1963).

Type III & IIIb solar radio bursts

TYPE III BURSTS

On the dynamic spectra, they usually form groups of a dozen or so almost vertical bands



LOFAR Bałdy PL612

Type III bursts are the radio signature of electrons beams moving through the corona and into interplanetary space along open magnetic field lines (Lin 1974).

Type III bursts are particularly important for understanding the processes occurring during solar flares.

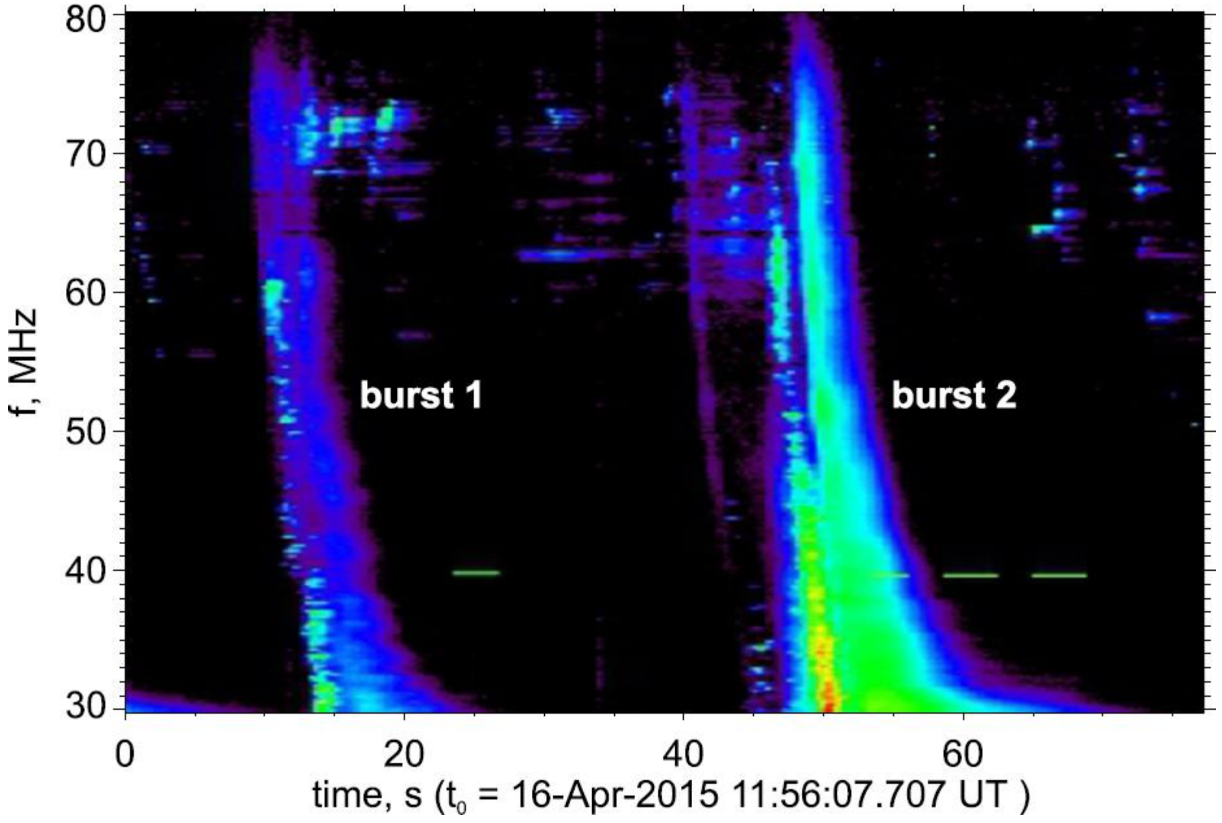
Characteristics	Type III & IIIb*
Duration	
single burst	1 – 3 s
group	1 – 5 min
storm	minutes – hours
Frequency range	10 kHz – 1 GHz
Associated phenomena	
	active regions
	flares

*characterized by many narrowband bursts with slow drift, known as a stria-burst (de La Noe & Boischot 1972)

The most typical scenario for the formation of striae are plasma density fluctuations along the electron beam path (Takakura & Yousef 1975).

Type IIIb solar radio bursts

TYPE IIIb BURSTS



Sharykin et al., 2018

Characteristics	Type III & IIIb*
Duration	
single burst	1 – 3 s
group	1 – 5 min
storm	minutes – hours
Frequency range	10 kHz – 1 GHz
Associated phenomena	
	active regions
	flares

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Dabrowski et al., *Type III Radio Bursts Observations on 20th August 2017 and 9th September 2017 with LOFAR Bałdy Telescope*, 2021, Remote Sensing, **13**, 148

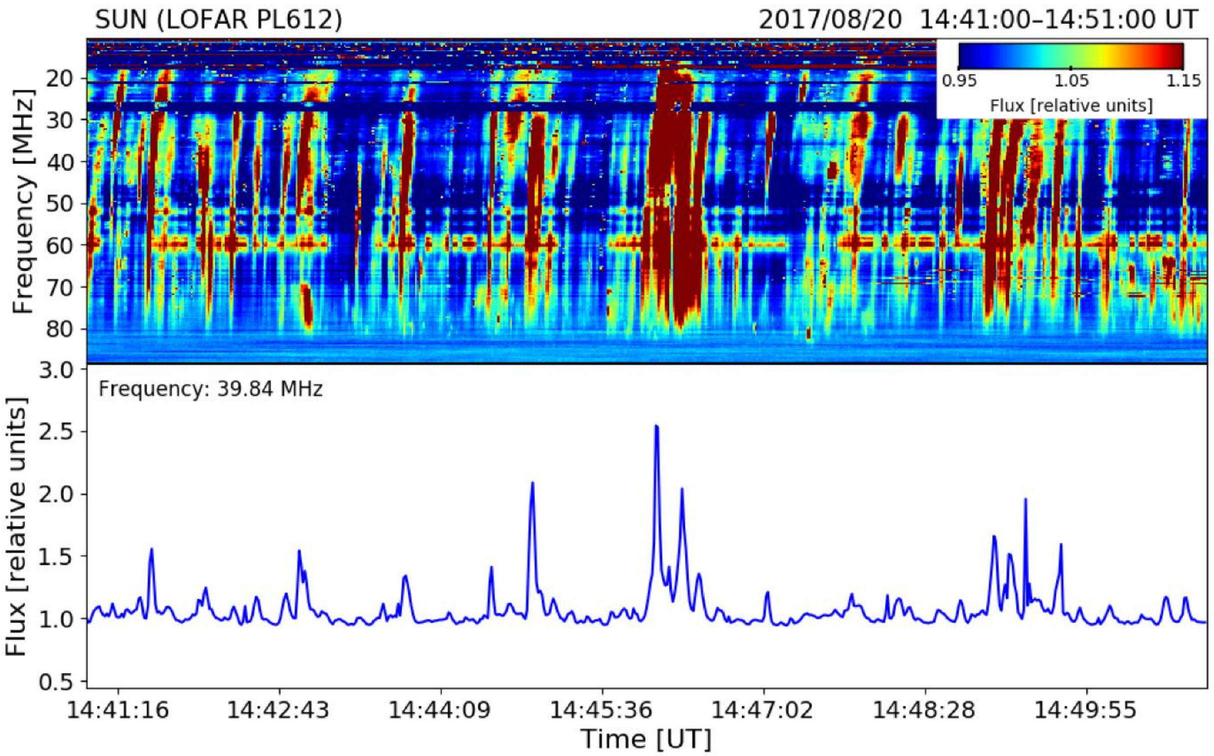
In this work we presented study of the two solar radio events consisting of type III bursts, observed by LOFAR telescope in Bałdy in the single mode.

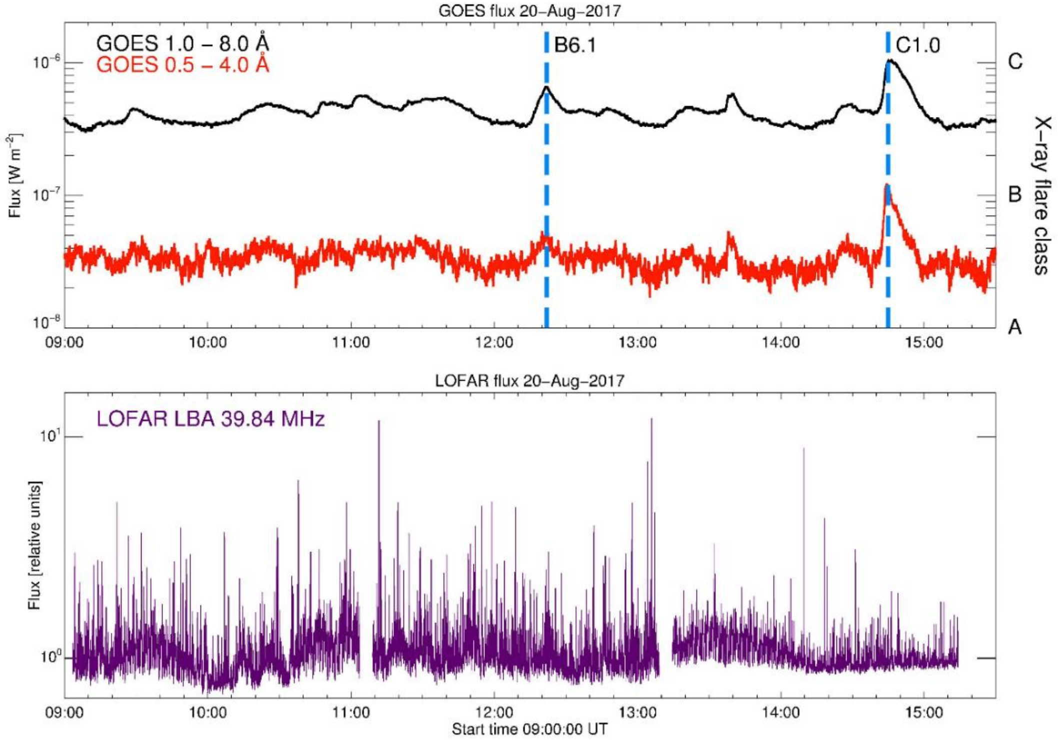
It was the first so comprehensive study of such events observed by LOFAR telescope in Bałdy.

Type III events	Flare class	NOAA	Location
2017-08-20 (09:03:32-15:14:36 UT)	B6.1 (12:16-12:21-12:26 UT)	12671	34”N 144”W
	C1.0 (14:40-14:45-14:52 UT)	12672	75”N 945”E
2017-09-09 (10:03:32-14:09:08 UT)	M3.7 (10:50-11:04-11:42 UT)	12673	187”S 883”W

Storm of type III radio bursts recorded on 20th August 2017

Ten-minutes part of the solar dynamic spectrum of the storm of type III bursts.



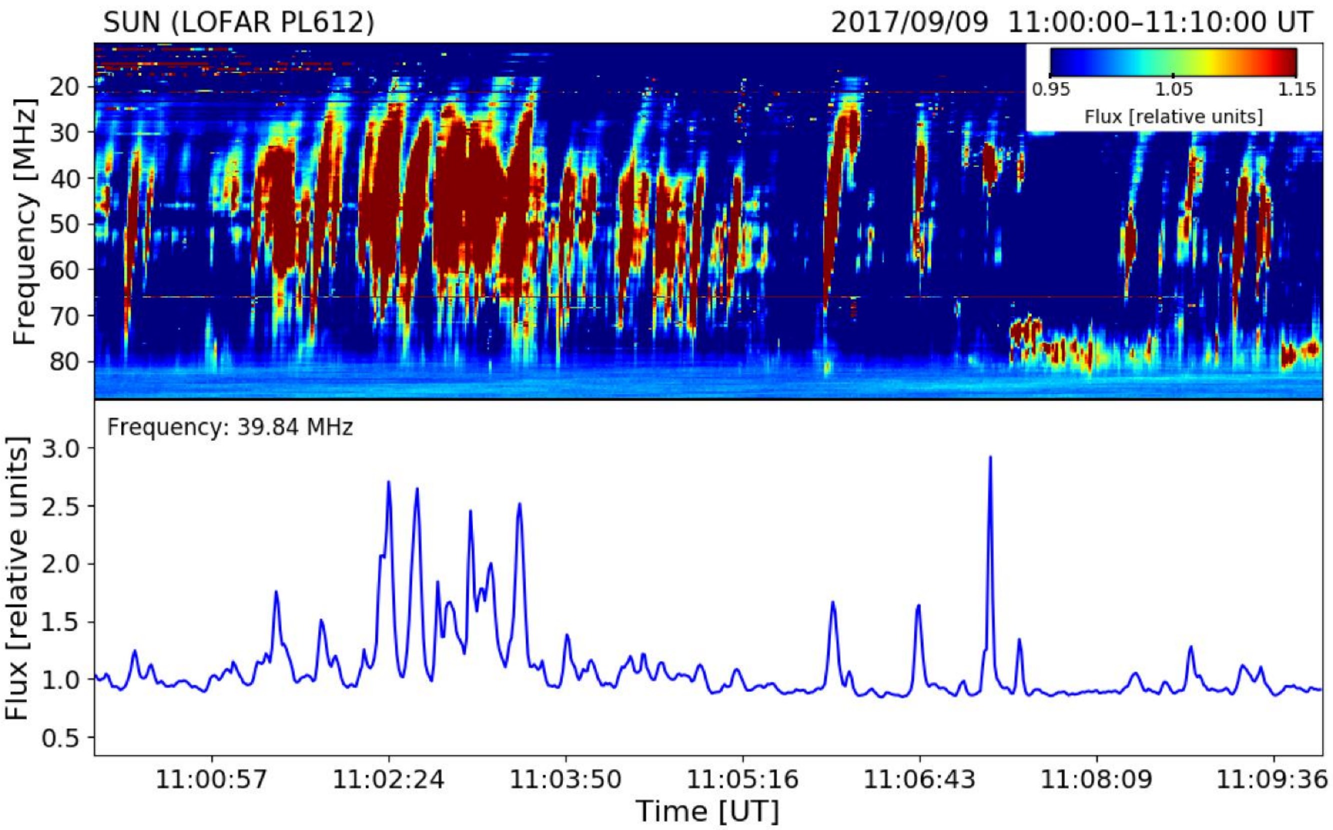


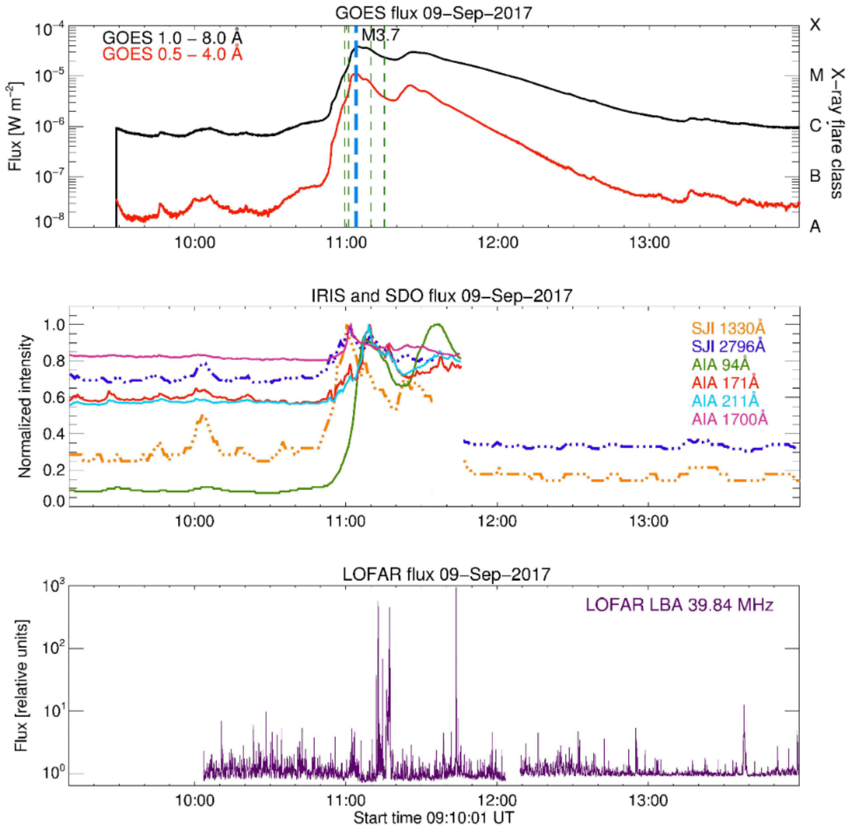
Radio flux at frequency of 39.84 MHz, extracted from dynamic spectrum.

We do not see any relation of the radio flux recorded by the LOFAR with the X-ray (GOES) during the event on 20th August 2017. The reason for this are probably weak solar flares (B6.1 and C1.0) during this event.

Dabrowski et al., *Type III Radio Bursts Observations on 20th August 2017 and 9th September 2017 with LOFAR Bałdy Telescope*, 2021, Remote Sens., **13**, 148

Storm of type III radio bursts recorded on 9th September 2017





Comparison of the radio flux recorded by the LOFAR with the X-ray and UV during the 9 September 2017 event revealed that the type III bursts were not associated with an increase in X-ray and UV emissions.

The velocity of the electrons is not related to the GOES flare class: 2017-08-20 (B & C) and 2017-09-09 (M).

Dabrowski et al., *Type III Radio Bursts Observations on 20th August 2017 and 9th September 2017 with LOFAR Bałdy Telescope*, 2021, Remote Sens., **13**, 148

Physical parameters of the studied events

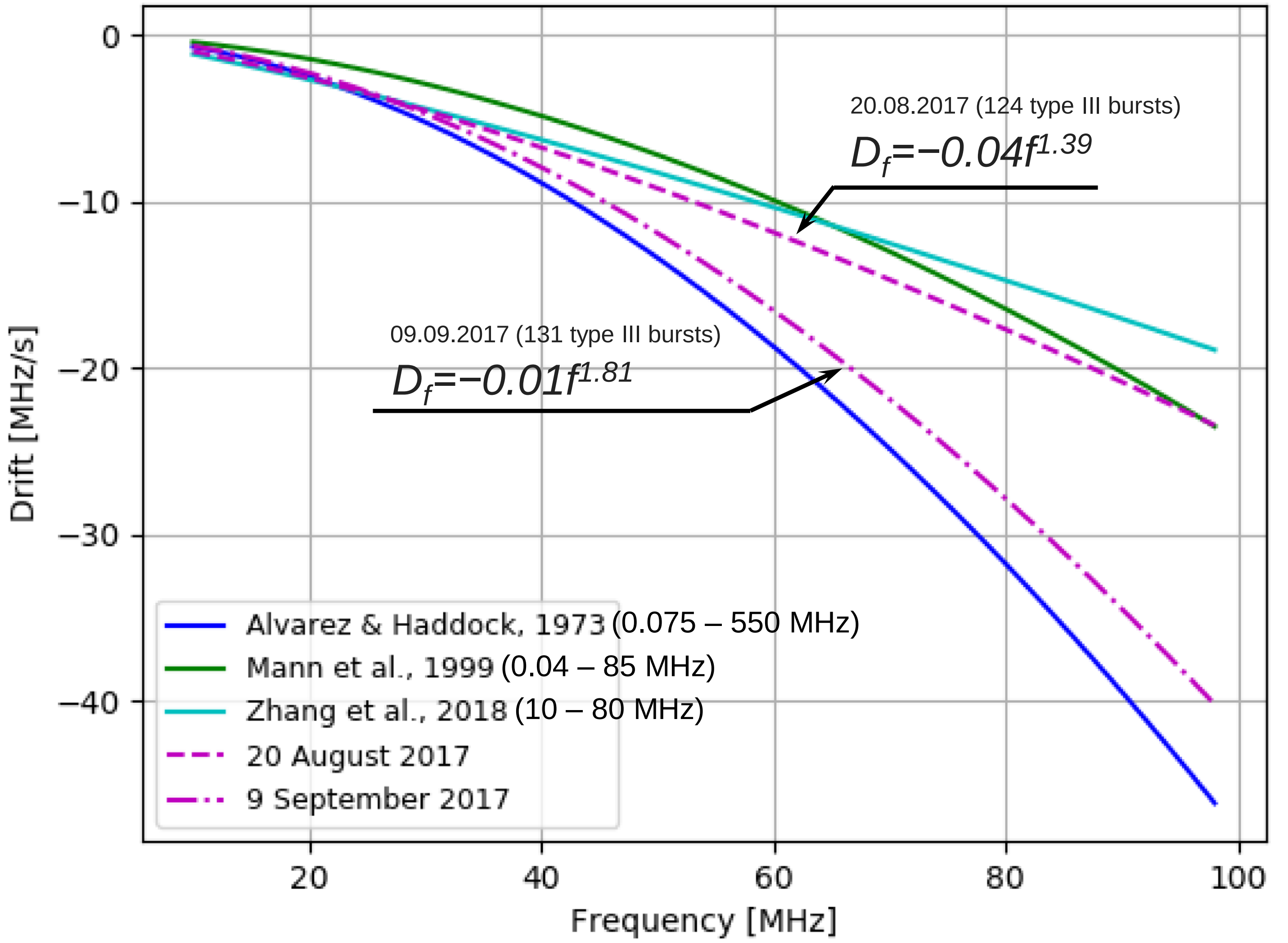
Physical parameters of the studied events on 20th August 2017 and 9th September 2017.

Events	Number of bursts	Drift [MHz/s]	Central freq. [MHz]	Mann et al. model		Newkirk model	
				v_r [km/s]	Energy [keV]	v_r [km/s]	Energy [keV]
2017-08-20	124	−9.4	53.3	43704 (0.15c)	6.09	54287 (0.18c)	9.55
2017-09-09	131	−7.3	56.0	30960 (0.10c)	3.16	38119 (0.13c)	4.83

Estimated velocities of bursts generally stick to the lower boundary of standard type III radio burst velocities of 0.1–0.6c (Benz 2002).

The energy of electrons exciting type III bursts for radio event observed on 2017-08-20 is twice as large in comparison to the energy of electrons exciting type III bursts for radio event observed on 2017-09-09. It is possible that the difference is related to different configuration of the magnetic fields of the active regions.

Comparison of drift rates versus frequency presented by different authors



Different values of drift rates resulting from our research for the both analysed radio events suggest that electron beams (responsible for the generation of the type III bursts) propagate through the plasma in solar corona with different density, temperature, velocity and the geometric configuration of the magnetic field.

Dabrowski et al., *Type III Radio Bursts Observations on 20th August 2017 and 9th September 2017 with LOFAR Bałdy Telescope*, 2021, Remote Sens., **13**, 148

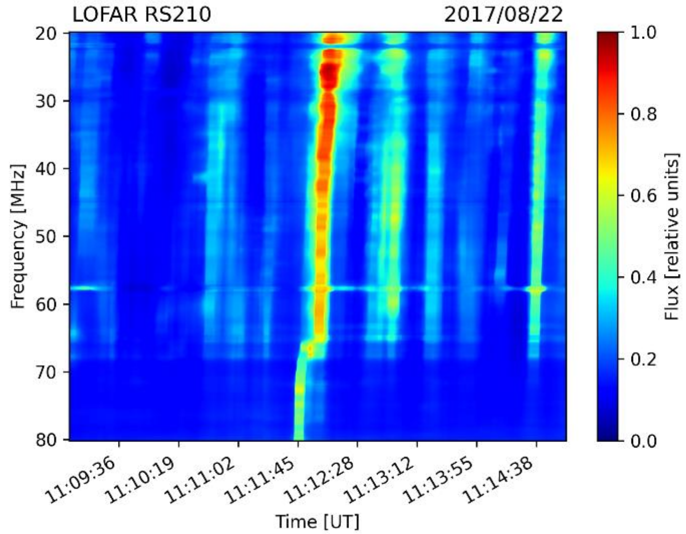
Dabrowski et al., *Interferometric imaging of the type IIIb and U radio bursts observed with LOFAR on 22 August 2017*, 2023, A&A, **669**, A52

In this study the source size of type IIIb and U solar bursts in a relatively wide frequency band from 20 to 80 MHz was determined.

PI (LC8_013): Interferometric Observations of the Active Regions in Radio Domain Before and After the Total Solar Eclipse on 21 August 2017

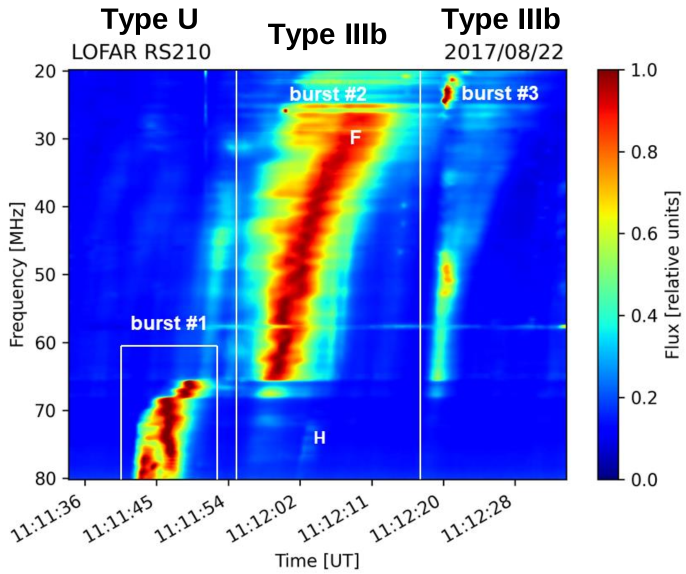
LOFAR project LC8_013	
No. of stations	35 (23 core & 12 remote)
Baseline	about 58.4 km
Spatial resolution	10.6 arcsec (80 MHz)
Band	20–80 MHz
Calibrator	Taurus A
Interferometric images	5 MHz intervals
Dynamic spectra	
Temporal resolution	0.0104 s
Frequency resolution	0.0154 MHz
X-ray	GOES & RHESSI
EUV	SDO AIA 171 Å

Part of the solar dynamic spectrum (09:00:00–13:59:59 UT) with the series of the type III solar radio bursts recorded on 22 August 2017.



Particularly interesting are the bursts that occurred around the single strong peak in the total radio flux at 11:11:46 UT.

The studied bursts were associated with a GOES C1.0 solar flare (NOAA 12671).



Radio images of the three analyzed bursts

TYPE U BURST
burst #1

TYPE IIIb BURST
burst #2

TYPE IIIb BURST
burst #3

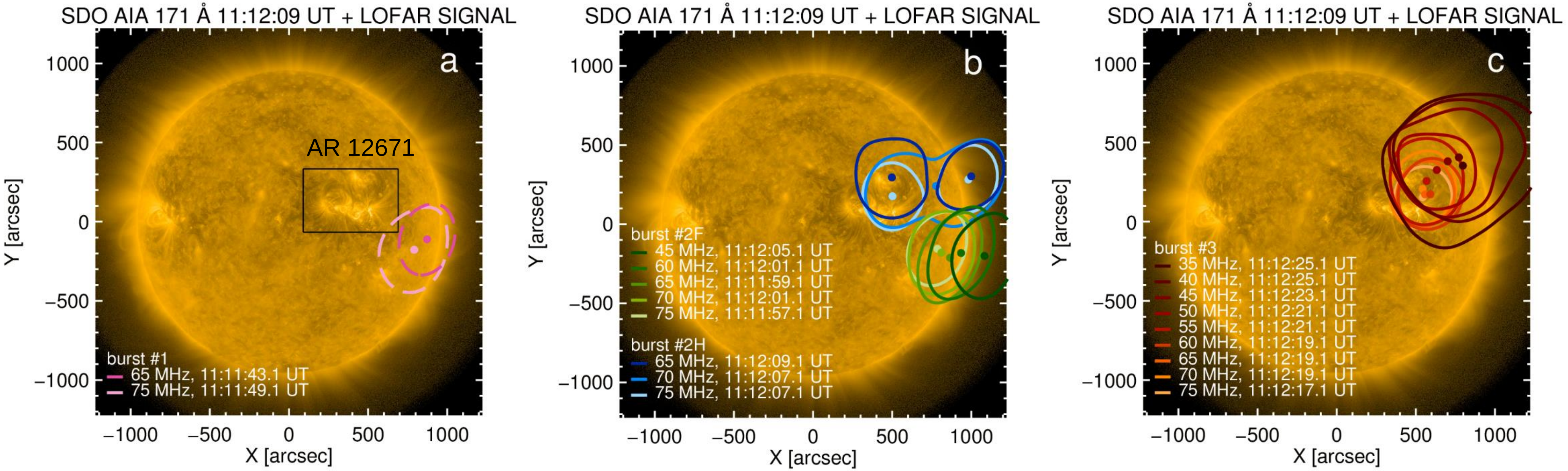


Image of the Sun received in the AIA 171 Å channel by SDO with superimposed color contours showing bursts #1, #2, and #3, at a range of frequencies.

The propagation path of the burst #3 seems to be more radial than the other two bursts, indicating that the electron beam is propagating along a different set of magnetic field lines.

Physical parameters of bursts

	Type U Burst #1	Type IIIb Burst #2		Type IIIb Burst #3
		F	H	
Dynamic spectrum				
Time [UT]	11:11:47	11:12:00	11:12:03	11:12:20
Freq. band [MHz]	80−65	77−29	79−73	74−28
Height [$R_\odot$]	1.3−1.4	1.3−1.8	1.3−1.4	1.3−1.8
Central freq. [MHz]	72.5	53.1	75.7	50.8
Drift rate [MHz/s]	−2.6±0.2	−4.3±2.1	−4.9*	−9.0±4.8
Velocity [c]	0.03±0.002	0.08±0.04	0.08	0.19±0.10
Energy [keV]	0.24±0.04	1.76±1.73	1.72	9.06±9.92
Images				
Freq. band [MHz]	75−65	75−45	–	75−35
Height [$R_\odot$]	1.3−1.4	1.3−1.6	–	1.3−1.7
Velocity [c]	–	$0.06\pm1.08\times10^{-4}$	–	$0.09\pm3.2\times10^{-5}$
Energy [keV]	–	0.92±0.03	–	2.26±0.002

* We were able to estimate only two, which makes the drift rate error unobtainable. measuring points for the harmonic burst.

Estimated velocities of bursts IIIb and U generally stick to the lower boundary of standard type III radio bursts velocities of 0.1–0.6c (Benz 2002).

The low electron velocity (equal to 0.03c) of type U burst is due to the magnetic field line having a significant horizontal component.

We also observe different energies of the electron beams responsible for type IIIb and U bursts formation. It ranges from around 0.2 to over 9.0 keV and is different for each burst.

We can conclude, that the different values of velocity of the electron beam responsible for the generation of analyzed bursts suggest their propagation in the solar corona with different geometric configuration of the magnetic field.

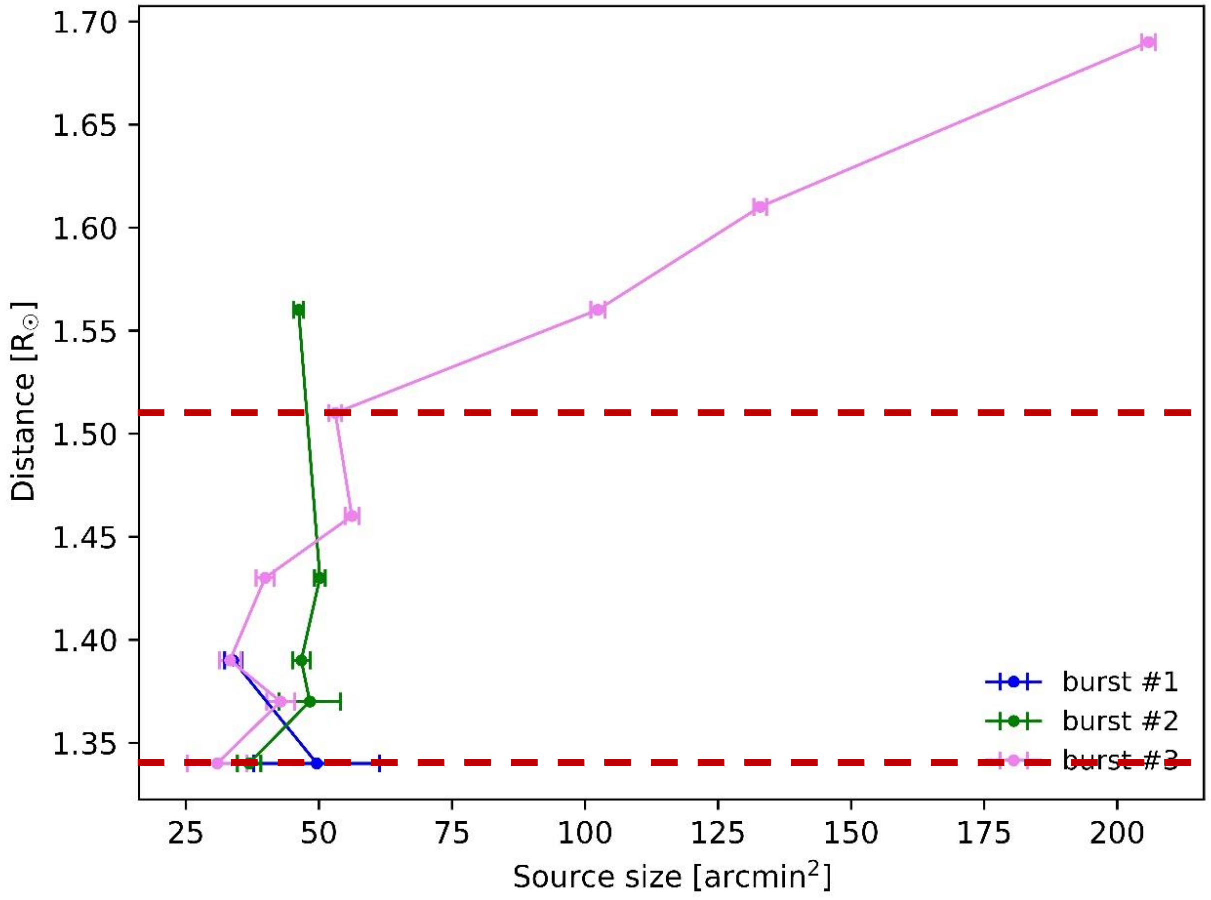
Sources size of the bursts #1, #2 and #3 on different heights

Burst #1 (Type U)
Determined only for two altitudes of 1.34 $R_\odot$ and 1.39 $R_\odot$.

Burst #2 (Type IIIb)
The size of the emission sources at different altitudes are similar.

Burst #3 (Type IIIb)
Example of burst evolution through the corona, ranging from 1.34 $R_\odot$ to 1.69 $R_\odot$. **We note the significant increase in the size of the source of the emission between 1.51 $R_\odot$ and 1.69 $R_\odot$.**

The analysis shows that **for a fixed height** of 1.34 $R_\odot$ (75 MHz) the size of the emission area for analysed bursts are similar.



Change in the size of the emission area with the height for the investigated bursts.

Dabrowski et al., *Interferometric imaging of the type IIIb and U radio bursts observed with LOFAR on 22 August 2017*, 2023, A&A, **669**, A52

Sources size – comparision

Source sizes (150–450 MHz) are smaller at higher frequencies than at lower ones, and their sizes decrease as $f^{-3.3}$ (f – frequency, Saint-Hilaire et al. 2013).

The variation in the source sizes of type III bursts with frequency depends on such effects as:
(1) divergence of the magnetic field lines as a function of height in the corona, **(2)** the spatial width of the electron beam, **(3)** refractive propagation effects, **(4)** scattering.

Comparison of our results with those obtained by other authors.

Burst #3 (type IIIb) (interferometric)	**Kontar et al. (2017) (tied-array beam)**	**Sharykin et al., 2018 (tied-array beam)**	**Zhang et al., 2020 (interferometric)**	**Murphy et al., 2021 (interferometric)**
205.9 arcmin^2 35 MHz	400 arcmin^2 32.5 MHz	320 arcmin^2 30.11 MHz	100 arcmin^2 26.56 MHz	150.6 arcmin^2 34.76 MHz
132.9 arcmin^2 40 MHz		145 arcmin^2 41.77 MHz		

Coronal scattering might affect the apparent positions of the sources (e.g. Chrysaphi et al. 2018):

35 MHz and 75 MHz – this corresponds to the bandwidth of the Burst #3 (type IIIb)
source obser. at 35 MHz –> shifted by ~0.6 $R_\odot$ –> R_{35} = 1.69+0.6 = 2.29 $R_\odot$

source obser. at 75 MHz –> shifted by ~0.2 $R_\odot$ –> R_{75} = 1.34+0.2 = 1.54 $R_\odot$