

# LOFAR Observation of a Moving Type IV Solar Radio burst

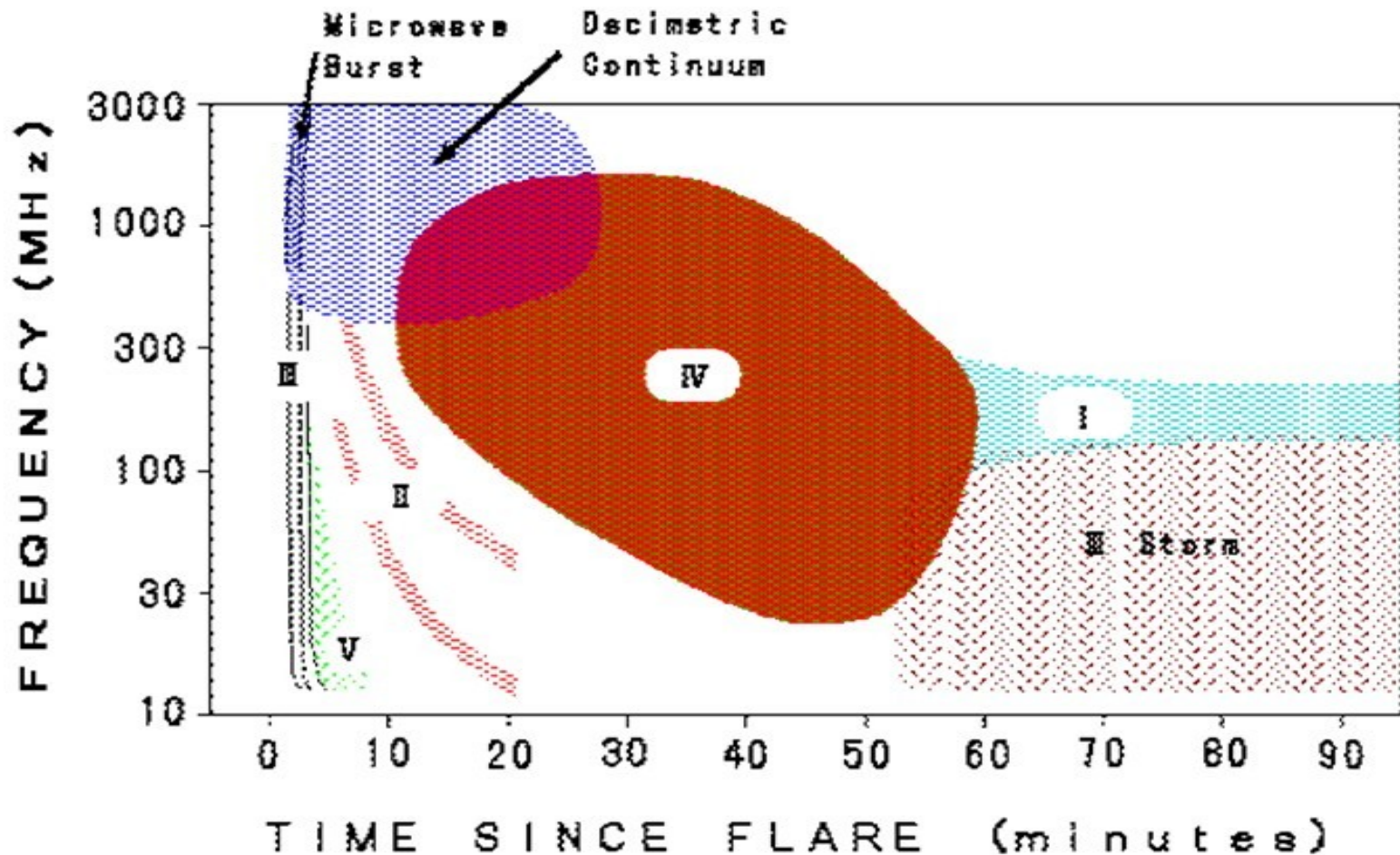
Hongyu Liu, Pietro Zucca, Kyungsuk Cho

et al.

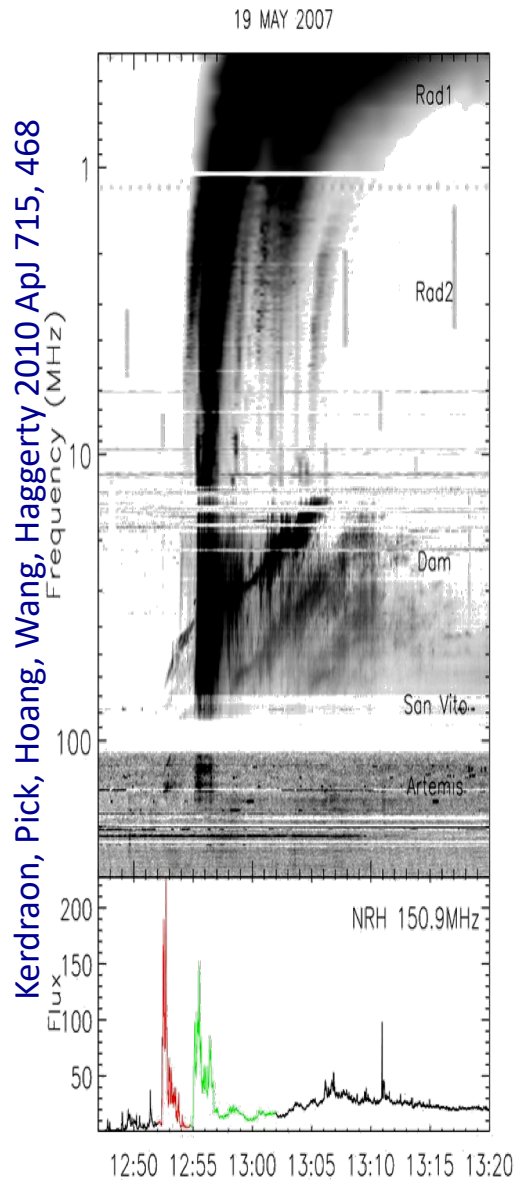
in prep.

# Solar Radio Burst?

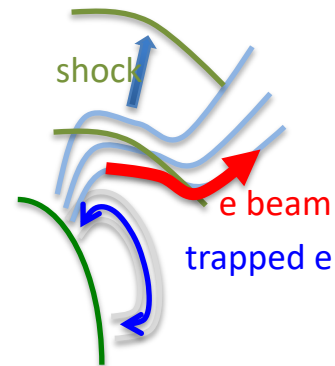
intense increase of [radio frequency](#) radiation induced by [solar eruptions](#)



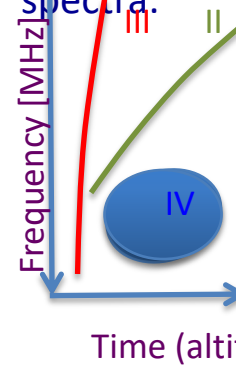
# The Radio Sun



- Propagating exciter in a quasi-static atmosphere or expanding loops (CME):



- Characteristic shapes of the radio burst spectra:

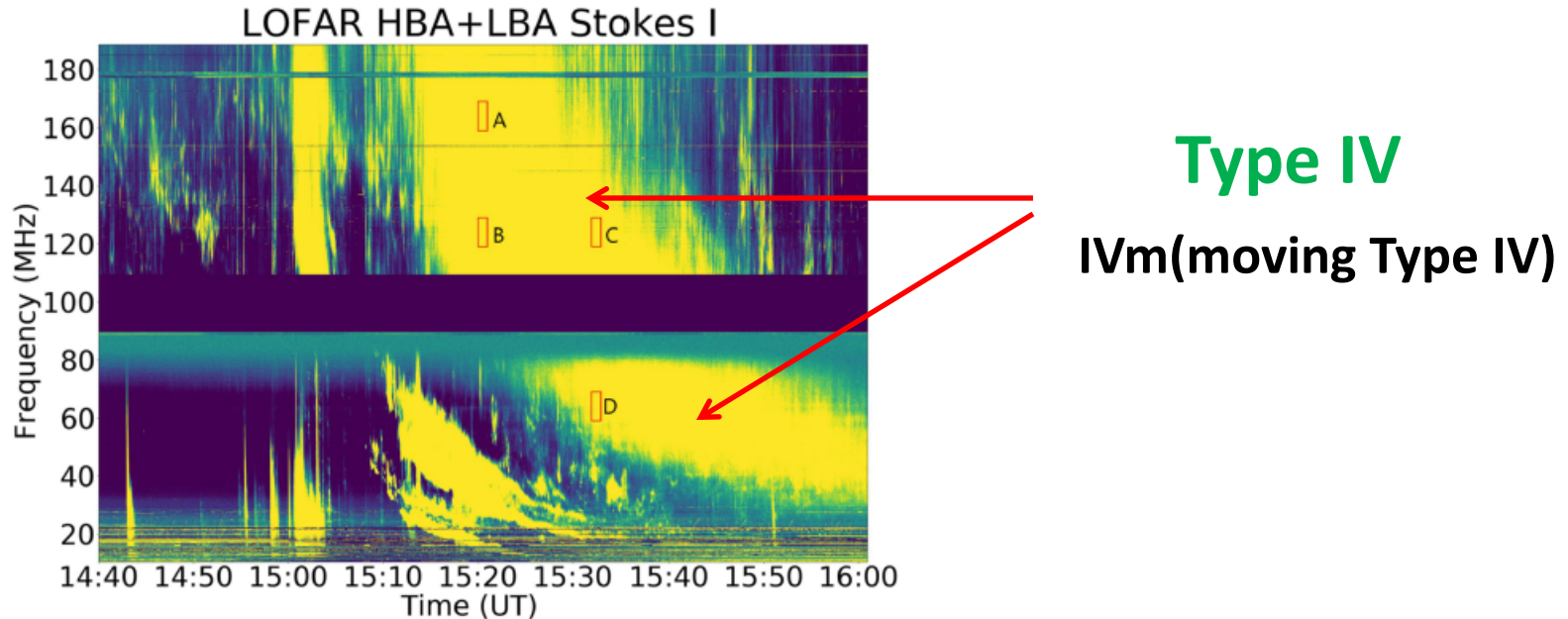


# Instruments

## LOFAR vs Nancay RadioHeliograph

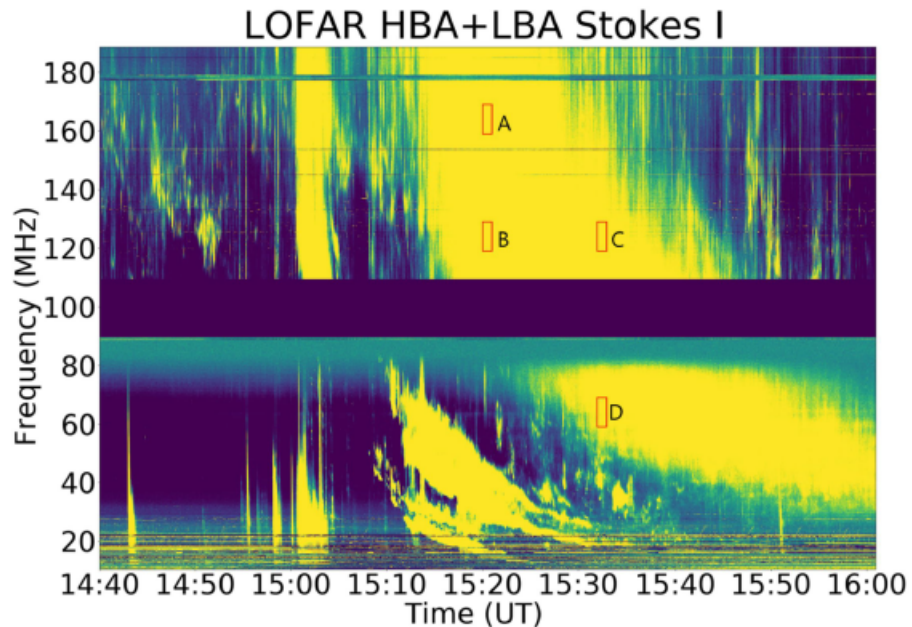
Name	LOFAR	NRH
Country	Netherlands	France
Frequency(MHz)	10 - 230	150 - 445
Time Resolution	83ms	1s
Years active	2012~	1967 ~ Jan. 2015
Freq resolution	12.5kHz	10 channels
Stokes Parameters	I,Q,U,V	I, V

# LOFAR Dynamic Spectrum



**Fig. 1.** LOFAR radio dynamic spectrum on Aug 25, 2014 from 14:40 UT to 16:00 UT. Type III Radio bursts appeared in both HBA (110-190 MHz) and LBA (10-90 MHz) at 15:00 UT, then a type II radio burst appeared in LBA at 15:09 UT. At 15:16, a type IV radio burst appeared in HBA and later in LBA. A, B, C and D are 4 selected areas within the type IV radio burst, and zoom-in plots of these areas are shown in Fig 5

# Event overview



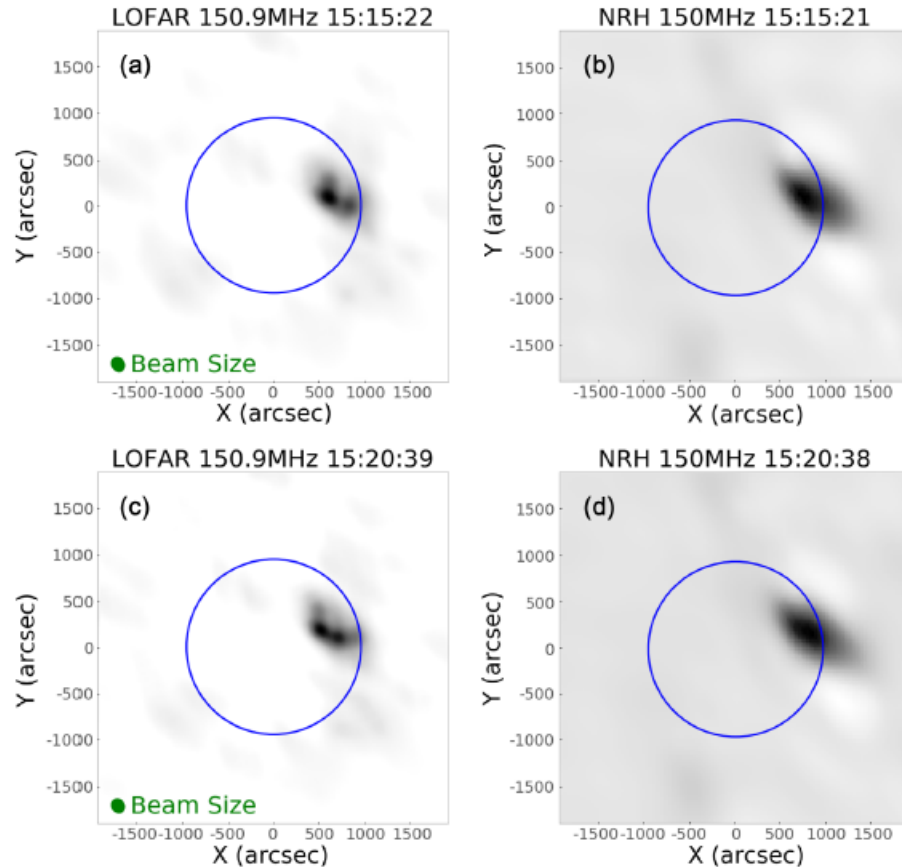
**2014 Aug 25**

**AR 12146**  
**M2.0 flare**  
**CME 15:36 UT**

**Fig. 1.** LOFAR radio dynamic spectrum on Aug 25, 2014 from 14:40 UT to 16:00 UT. Type III Radio bursts appeared in both HBA (110-190 MHz) and LBA (10-90 MHz) at 15:00 UT, then a type II radio burst appeared in LBA at 15:09 UT. At 15:16, a type IV radio burst appeared in HBA and later in LBA. A, B, C and D are 4 selected areas within the type IV radio burst, and zoom-in plots of these areas are shown in Fig 5

# LOFAR vs Nancay Radioheliograph comparison

# LOFAR vs NRH comparison



**Fig. 2.** Comparison of LOFAR and NRH imaging observations of the Sun at 150.9 MHz on Aug 25, 2014. (a) and (b) are respectively LOFAR and NRH observations of the Sun at 15:15 UT while (c) and (d) are the same observations at 15:20 UT. The solar limb is indicated by a blue circle. Beam size of LOFAR is indicated by green ellipses in (a) and (c). (An animation of this figure is available online.)

(a) (c) we see 3  
separate  
sources  
(b) (d) only 1 faint  
source



LoFar resolves  
more details than  
NRH



# Parameter of this type IV - DCP

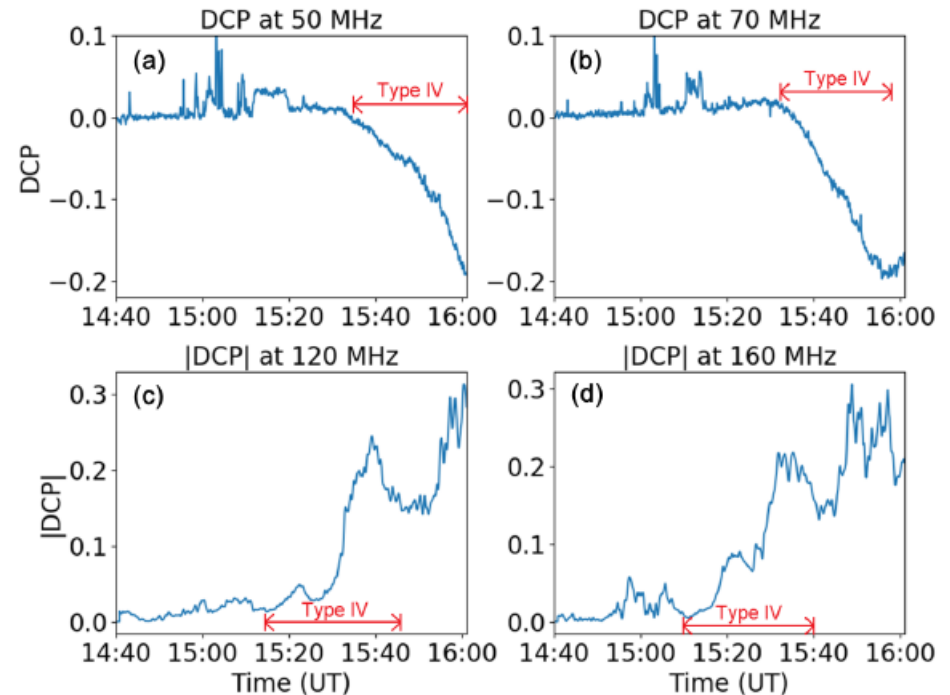
$$DCP = \frac{V}{I}$$

For HBA(110-190MHz),  
instrumental  
effects caused V to  
leak into U, so

$$|DCP_{\text{corr}}| = \frac{\sqrt{V^2 + U^2}}{I}$$

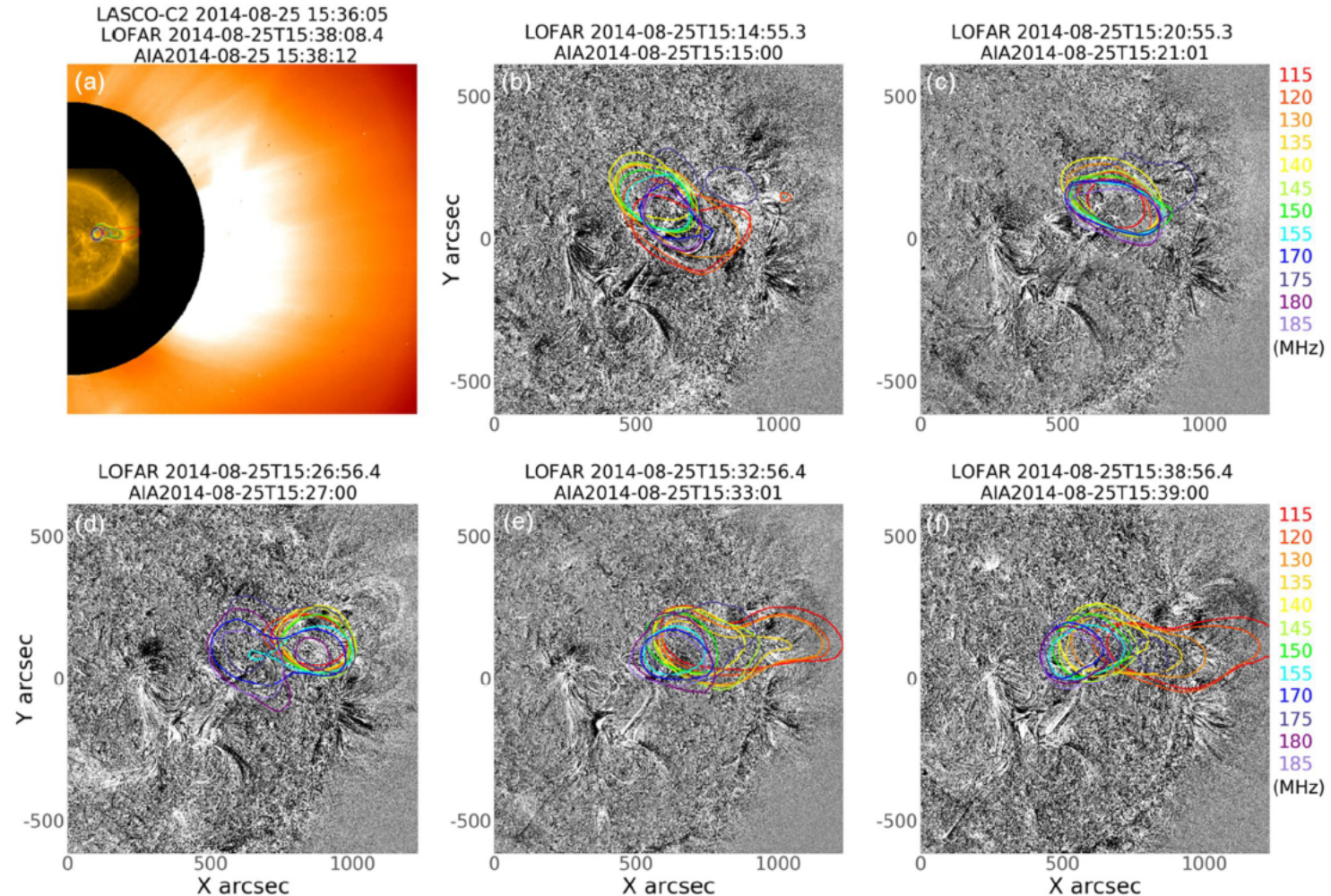
10%-20%

Gradual increase



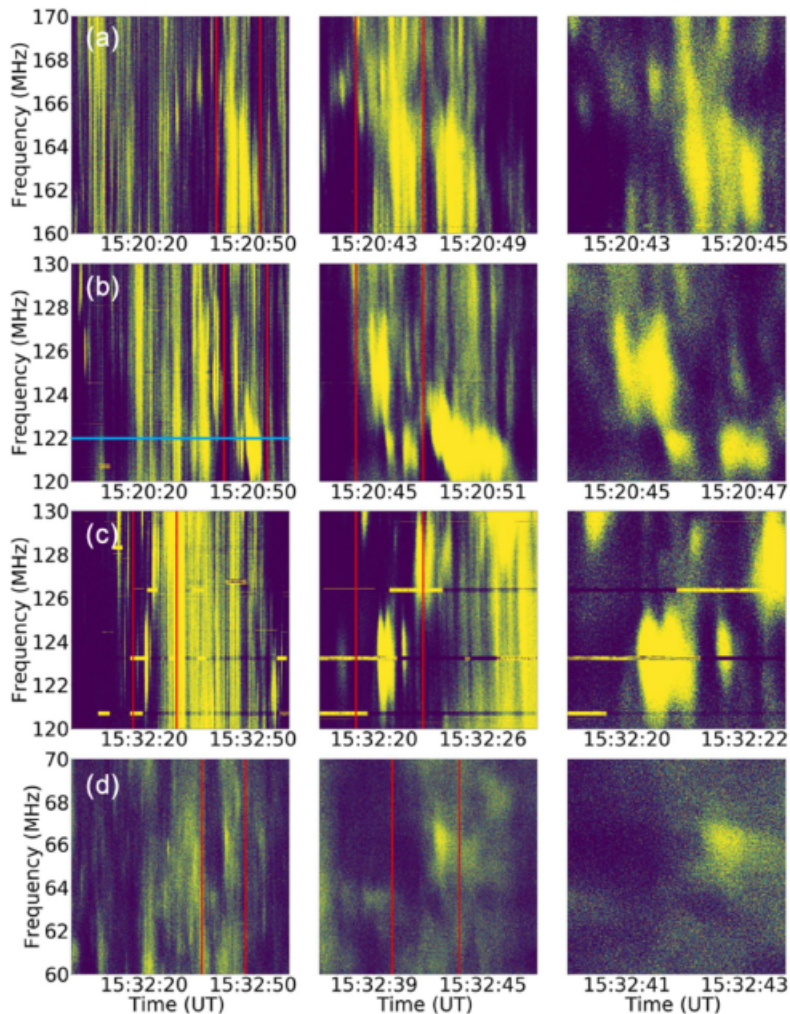
**Fig. 3.** Degree of circular polarization at 4 frequencies. (a) and (b) are DCP at 50 MHz and 70 MHz respectively; (c) and (d) are the absolute values of DCPs at 120 MHz and 160 MHz. The time range is the same with that of Fig 1. Time span of type IV is shown on each panel.

# Propagation



Travels westward, and then CME erupted, should be expanding flare loop near CME core, but not visible in EUV wavelengths (checked all AIA channels)

# Fine structures

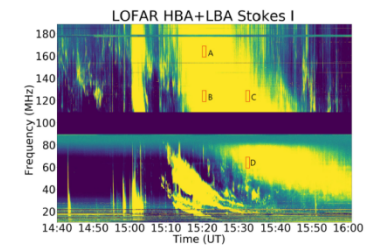


**Fig. 5.** Zoom-in intensity plots of selected areas within Type IV radio burst on Aug 25, 2014. Spectra on left columns of (a), (b), (c) and (d) are 1 minute zoom-in plots of the areas depicted by red box A, B, C and D in Figure 1; Middle columns of (a), (b), (c) and (d) are 12 seconds zoom-in plots of areas between two red lines on left columns of (a), (b), (c) and (d) respectively; Right columns are 4 seconds zoom-in plots of areas between the red lines on middle columns.

Zoom in plot of 1min, 12sec  
and 4s,

Corresponds to ABCD

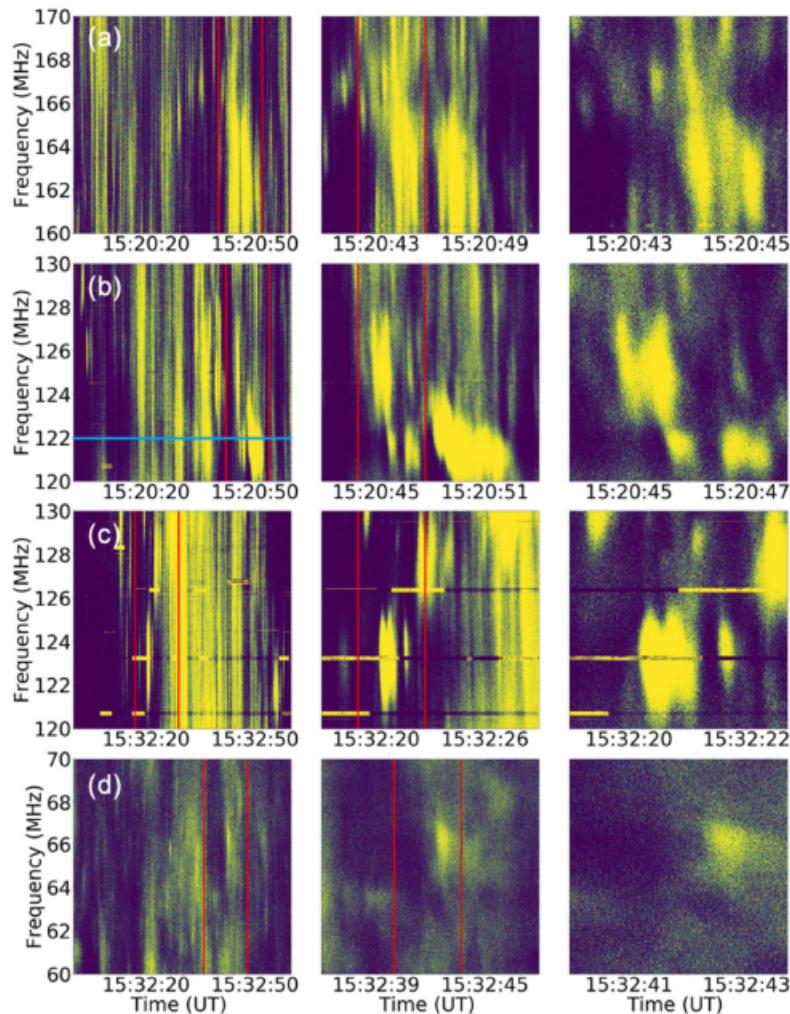
Here →



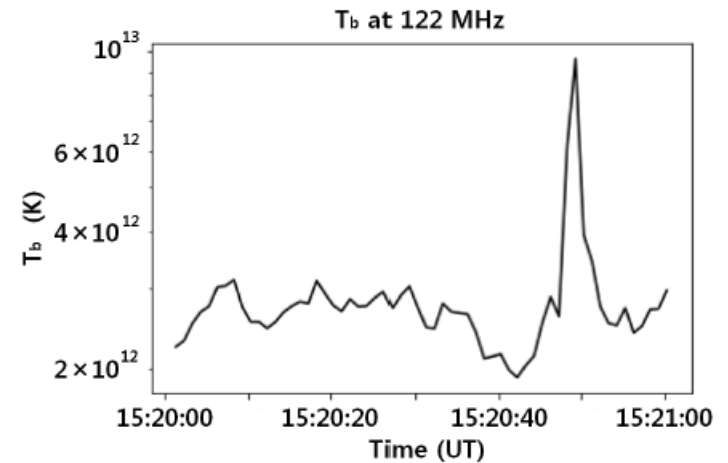
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We see <1 second duration  
fine structures on type IV

# Tb of Fine structures



**Fig. 5.** Zoom-in intensity plots of selected areas within Type IV radio burst on Aug 25, 2014. Spectra on left columns of (a), (b), (c) and (d) are 1 minute zoom-in plots of the areas depicted by red box A, B, C and D in Figure 1; Middle columns of (a), (b), (c) and (d) are 12 seconds zoom-in plots of areas between two red lines on left columns of (a), (b), (c) and (d) respectively; Right columns are 4 seconds zoom-in plots of areas between the red lines on middle columns.



**Fig. 6.** Brightness temperature profile at 122 MHz along the blue line in left panel of Figure 5 (b).

T<sub>b</sub> shows that fine structures are high, but background Type IV is also high

# Generation mechanism

**Table 1.** Characteristics of various radiation mechanisms and our observation.  $T_B$  stands for brightness temperature,  $q$  stands for degree of circular polarization,  $\alpha$  refers to spectral index, and  $\delta$  is the particle energy distribution power law slope. We also list the observational parameters of IVs on Sep 24, 2011 for comparison.

Mechanism	$T_B$	Polarization ( $ q $ )	Spectral Index	Reference
Cyclotron	$<10^9$ K	Any	$\alpha \neq f(\delta)$	Dulk (1985)
Synchrotron	$<10^9$ K	0%(Linear)	power law, $\alpha \propto \delta$	Dulk (1985)
Gyrosynchrotron	$<10^9$ K	Any	$\alpha \neq f(\delta)$	Robinson (1978a)
Fundamental Plasma	$\geq 10^9$ K	$\sim 100\% / \sim 0\%$	$\alpha \neq f(\delta)$ or $\alpha \propto \delta^1$	Robinson (1978b)
2nd Harmonic Plasma	$\leq 10^{13}$ K	$<10\%$		Melrose (1975)
ECM Emission	$\geq 10^{10}$ K	$\sim 100\%$	power law	Winglee (1985)
Our Observation				
IVs of 20110924	$10^{11}$ K	60-100%	power law	

<sup>1</sup>For relativistic electrons, brightness temperature can hardly reach  $10^{10}$  K.

From Liu et al, 2018

# Generation mechanism

The **gradual rise** of DCP of this type IV can't be plasma emission (Stewart 1985) and indicates **gyrosynchrotron emission**.

High  $T_b$  ( $10^{12}$ ) indicates coherent emission, thus not gyrosynchrotron emission,

But there might be smaller scale fine structures to form the background type IV, so the type IV is **gyrosynchrotron emission**, however smaller scale fine structures are generated by **coherent emission**

# Conclusions

A moving type IV radio burst on 2014 Aug 25

NRH and LOFAR comparison shows that LOFAR resolves more details than NRH

DCP of this event is 10-20%, gradual rise during the event

Radio source propagates westward, after which CME eruption happened

Fine structures of  $<1s$  are observed, and  $T_b$  of them can reach  $10^{13}K$ .  
Even background Type IV is  $10^{12}K$

Background type IV consists of **smaller scale fine structures** which are **coherent mechanisms**, but type IV is **gyrosynchrotron** because of the gradual increase of DCP.

Thank you

questions or comments should be sent to  
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