LOFAR Tied-array Imaging and Spectroscopy of Solar Radio Bursts

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The Solar and Space Weather LOFAR Key Science Project

IRISH RESEARCH COUNCIL
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Trinity College Dublin
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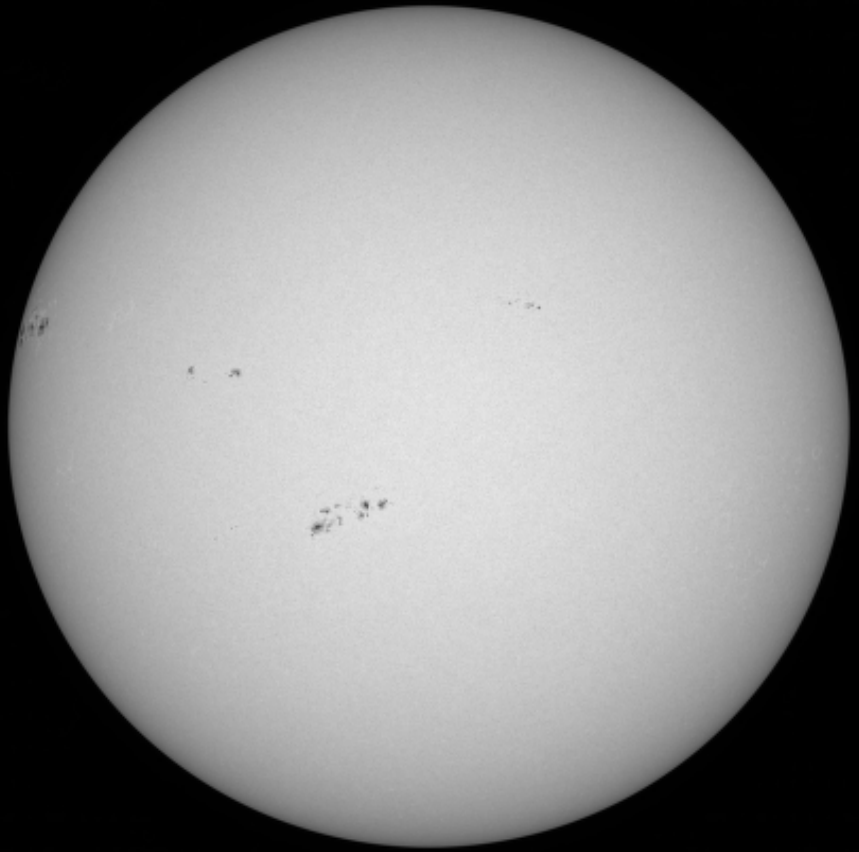
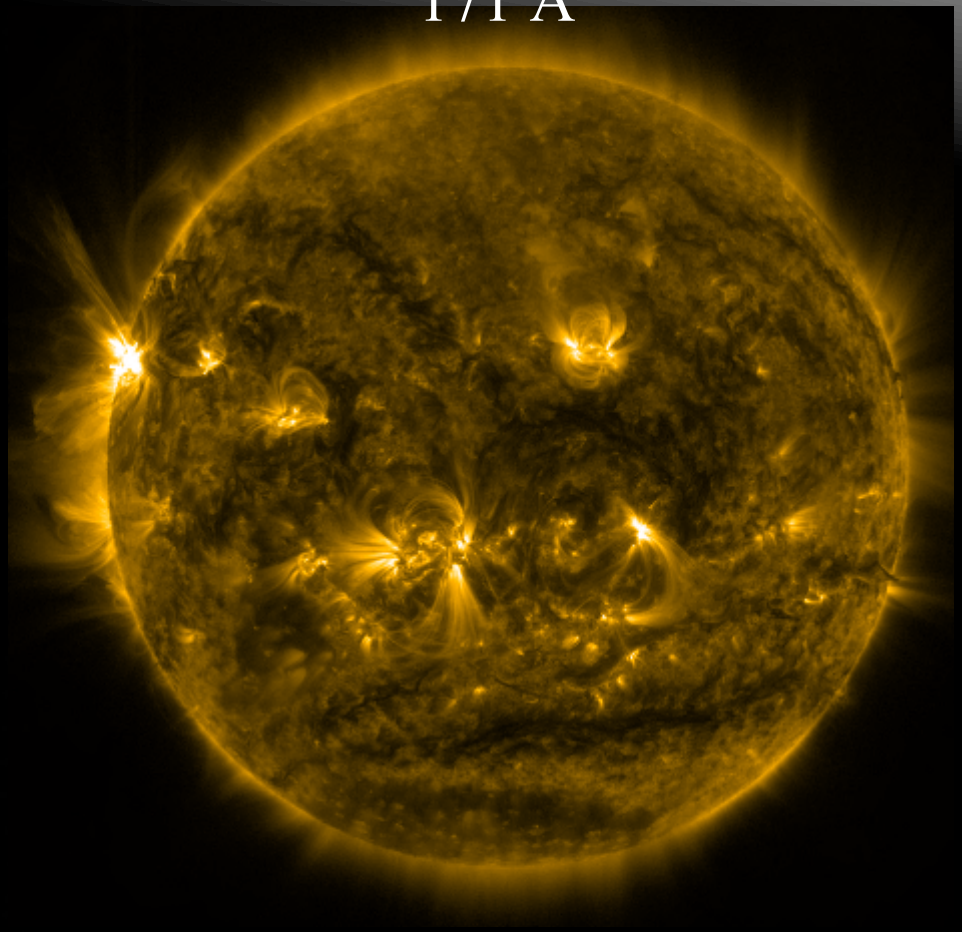
The University of Dublin

The Dynamic Solar Corona

6173 Å

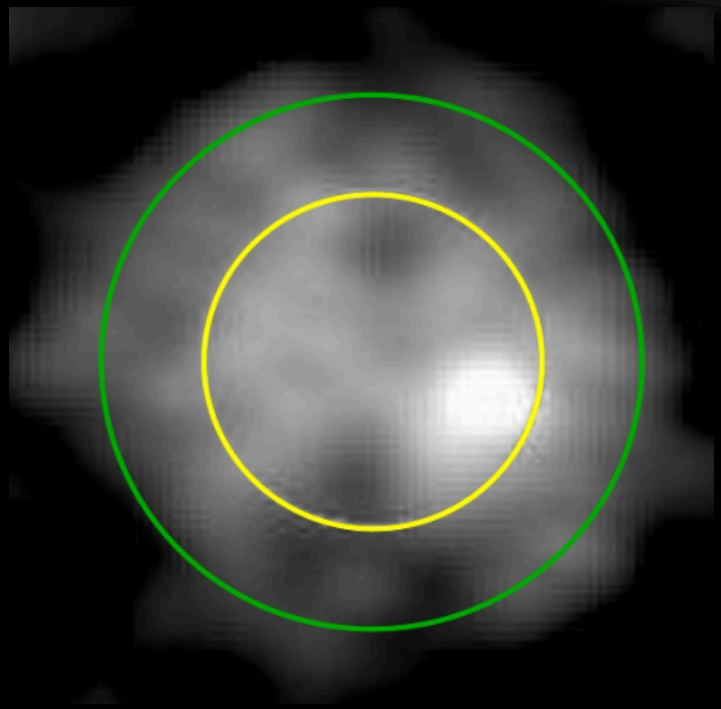


171 Å

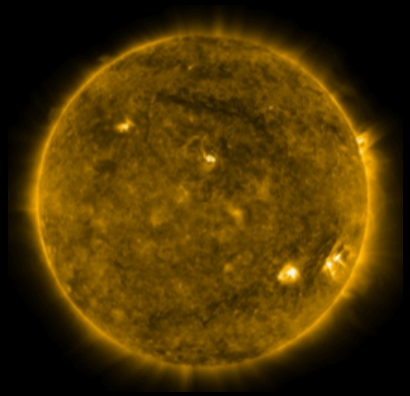


Solar Dynamics Observatory (SDO)

The Dynamic Solar Corona at Radio Wavelengths

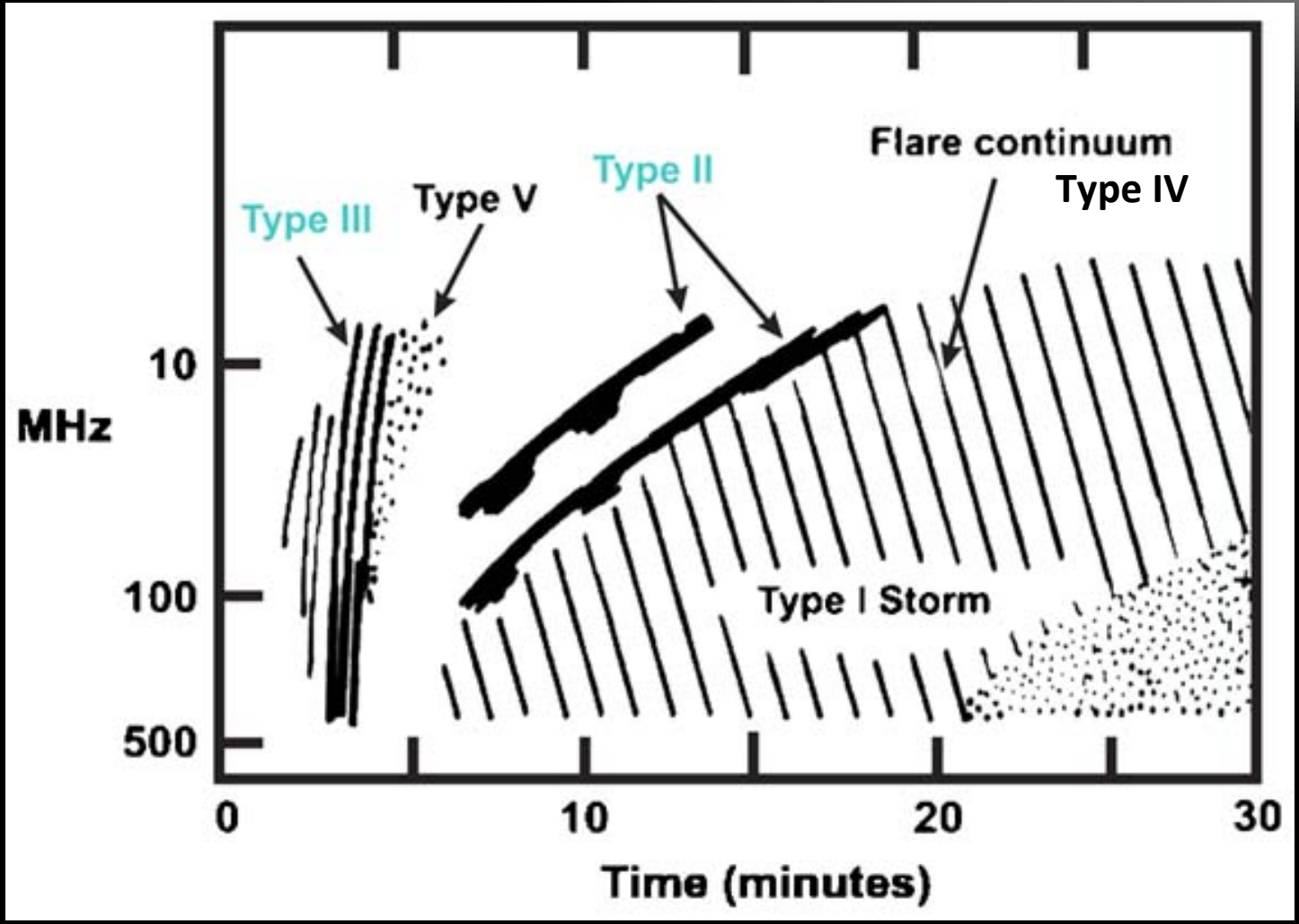


LOFAR 135 MHz
(Credit: Gottfried Mann, AIP)

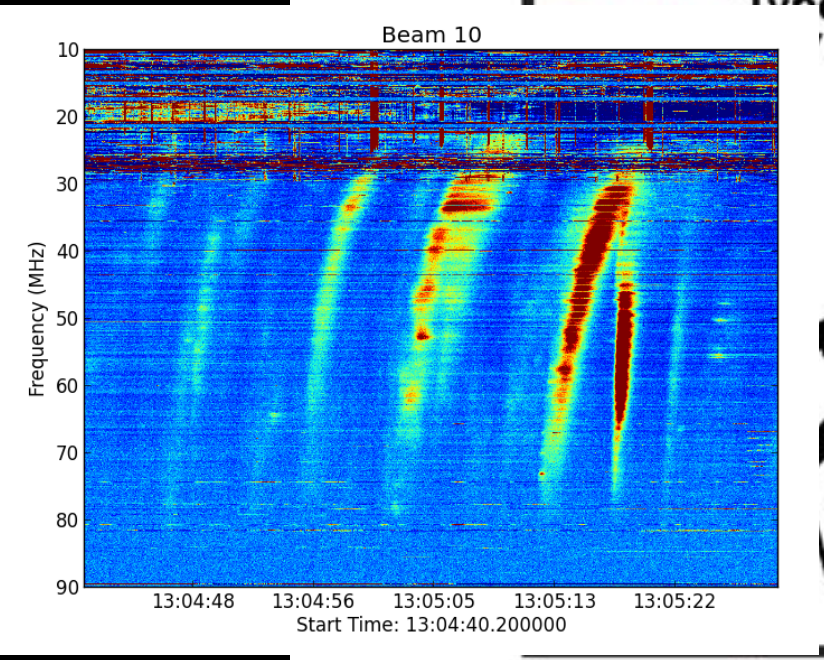


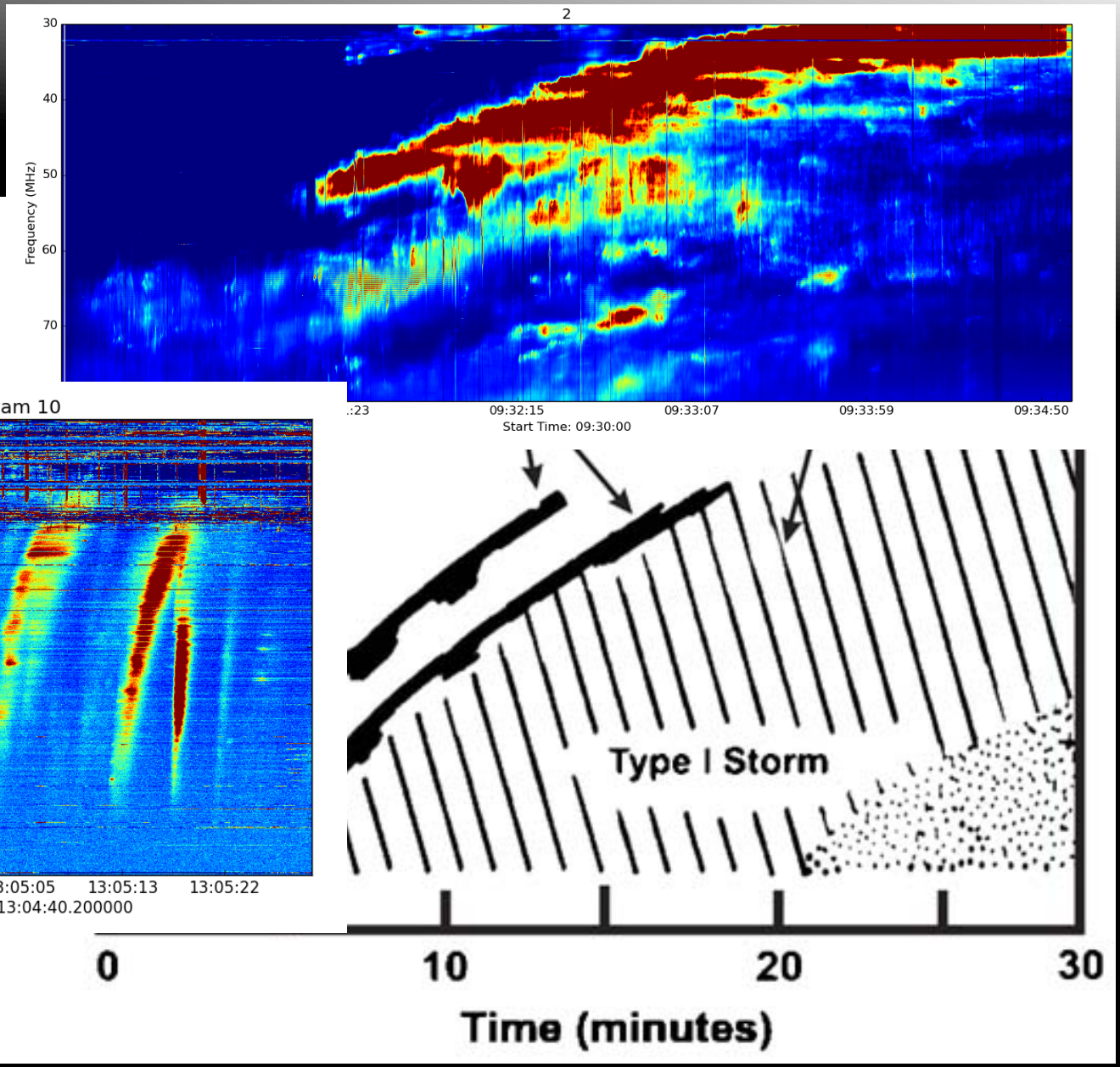
SDO AIA 171 Å

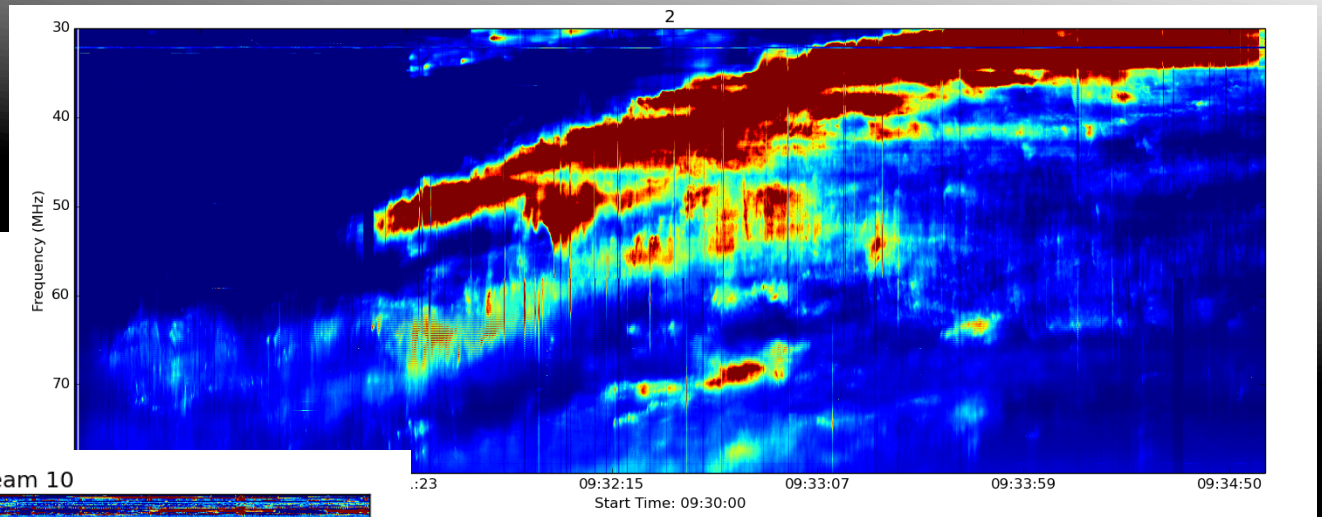
Solar Radio Bursts



Solar Radio Bursts




2
Frequency (MHz)
30
40
50
60
70
09:32:15
09:33:07
09:33:59
09:34:50
Start Time: 09:30:00
Beam 10
Frequency (MHz)
10
20
30
40
50
60
70
80
90
13:04:48
13:04:56
13:05:05
13:05:13
13:05:22
Start Time: 13:04:40.200000
Type I Storm
0
10
20
30
Time (minutes)


2
Frequency (MHz)
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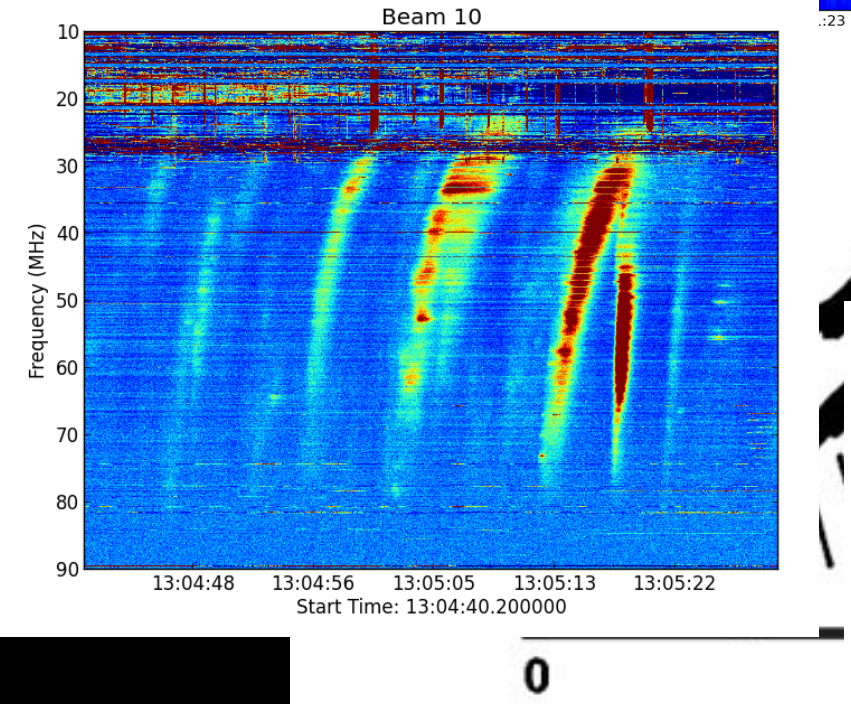
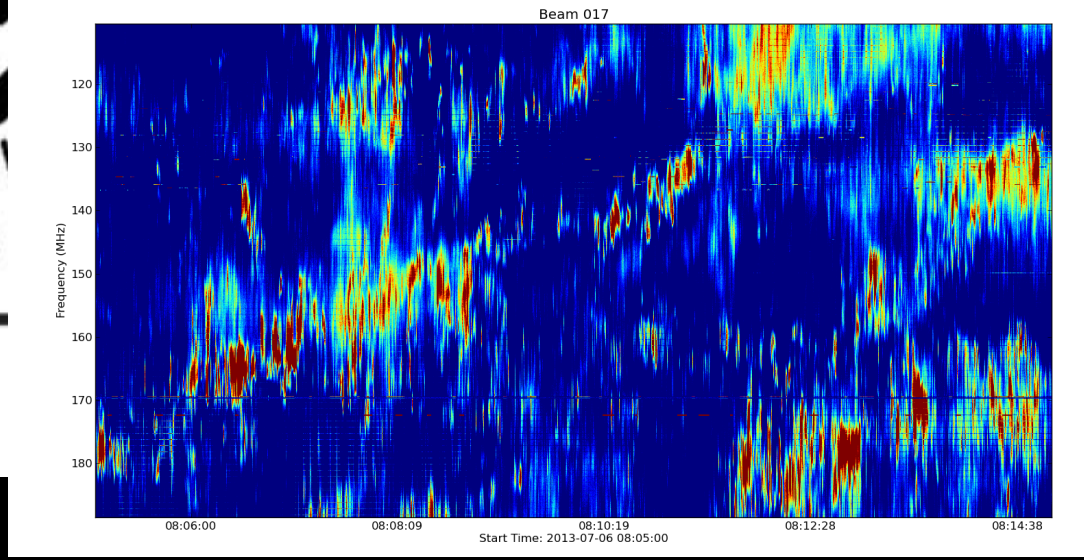
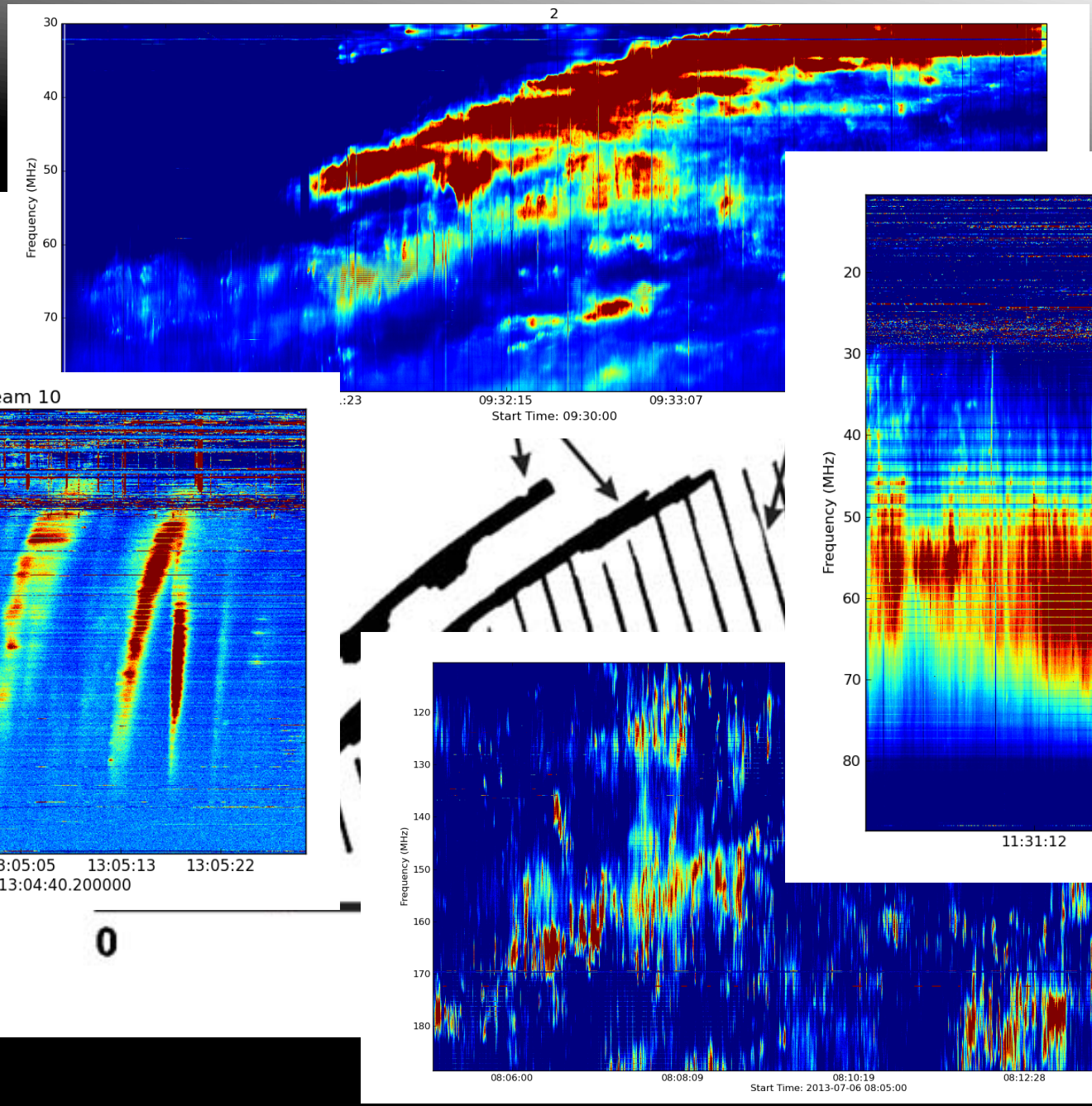
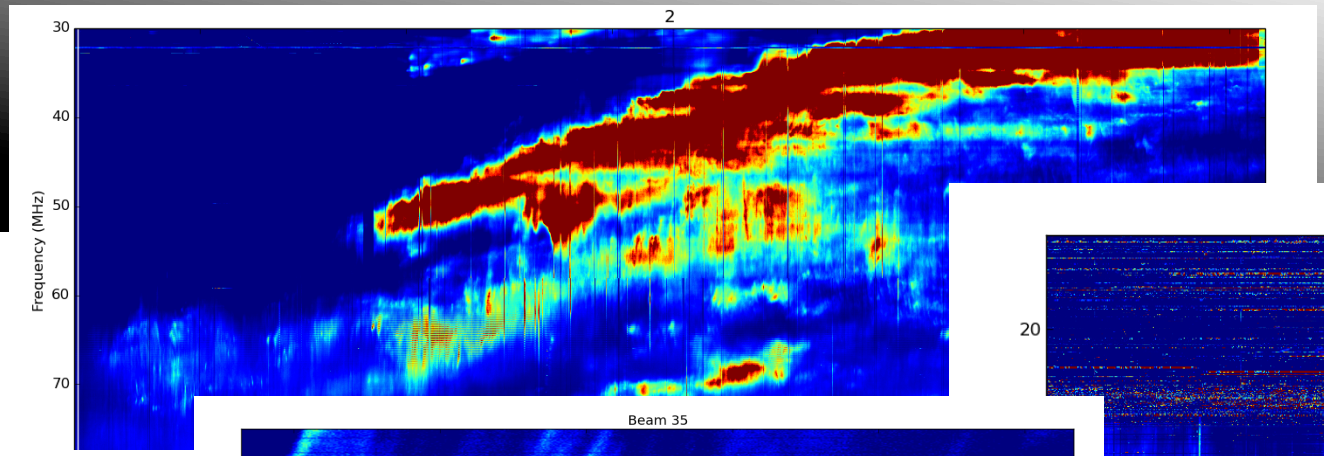
40
50
60
70
09:32:15
09:33:07
09:33:59
09:34:50
Start Time: 09:30:00

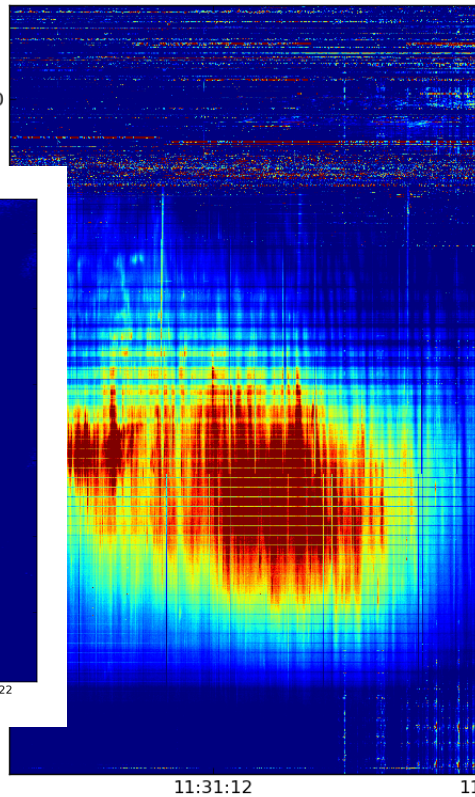

Beam 10
Frequency (MHz)
10
20
30
40
50
60
70
80
90
13:04:48
13:04:56
13:05:05
13:05:13
13:05:22
Start Time: 13:04:40.200000

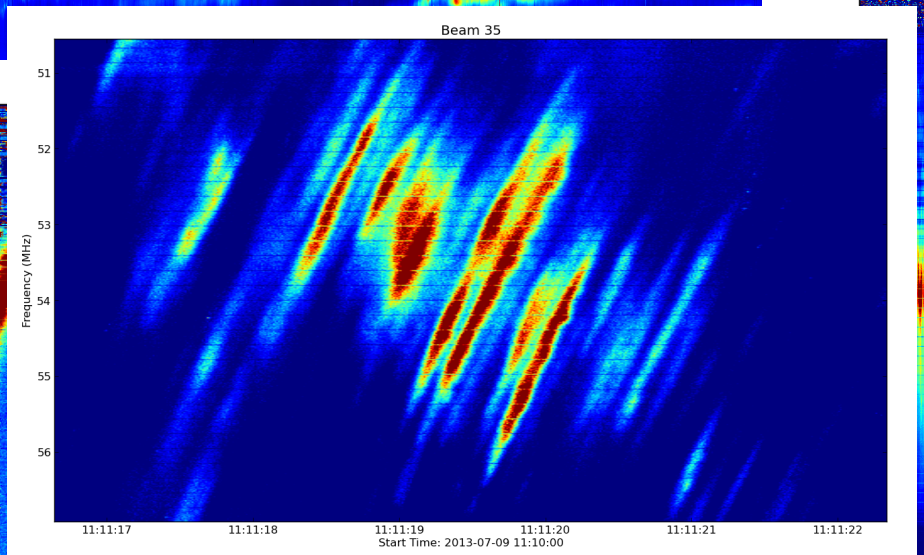

Beam 017
Frequency (MHz)
120
130
140
150
160
170
180
08:06:00
08:08:09
08:10:19
08:12:28
08:14:38
Start Time: 2013-07-06 08:05:00

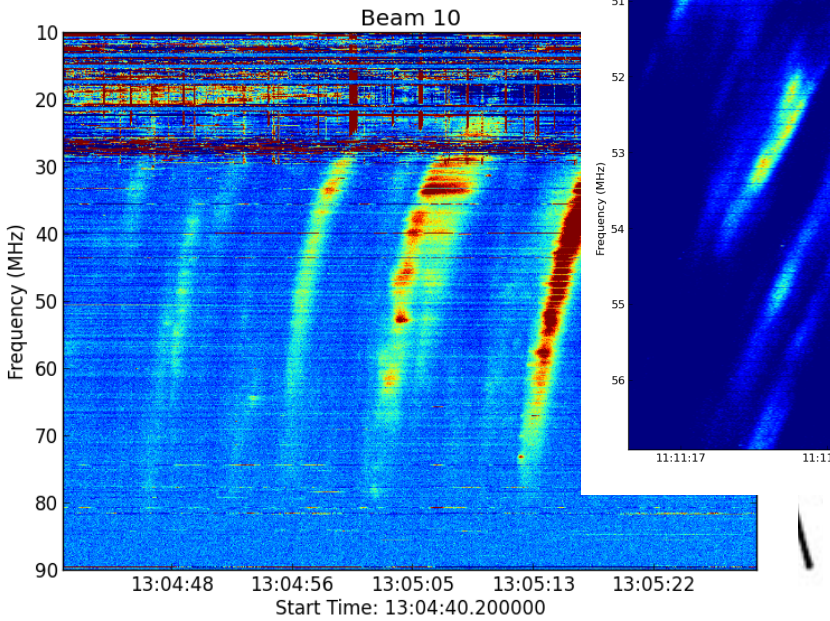
0

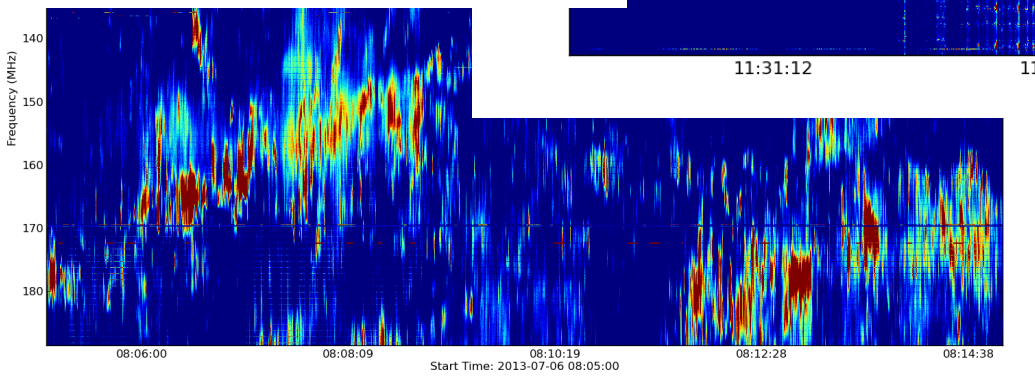

2
Frequency (MHz)
30
40
50
60
70
09:32:15
09:33:07
Start Time: 09:30:00
Beam 10
Frequency (MHz)
10
20
30
40
50
60
70
80
90
13:04:48
13:04:56
13:05:05
13:05:13
13:05:22
Start Time: 13:04:40.200000
0
Frequency (MHz)
20
30
40
50
60
70
80
11:31:12
Frequency (MHz)
120
130
140
150
160
170
180
08:06:00
08:08:09
08:10:19
08:12:28
08:14:38
Start Time: 2013-07-06 08:05:00


2
Frequency (MHz)
30
40
50
60
70


20
11:31:12

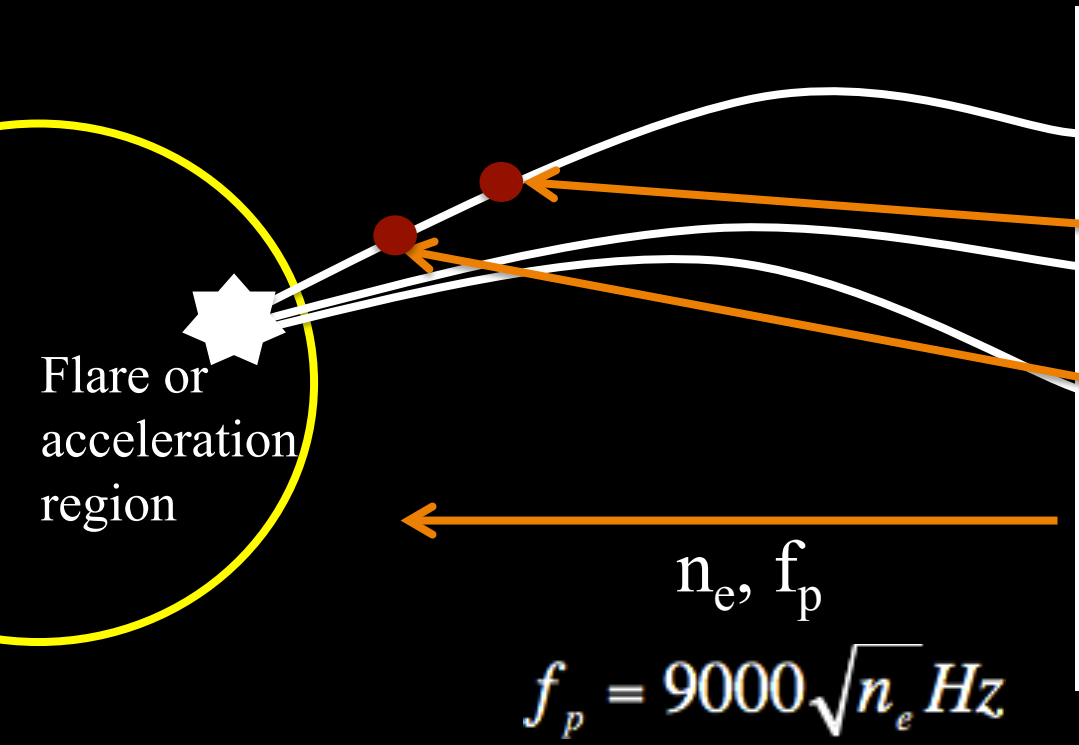

Beam 35
Frequency (MHz)
51
52
53
54
55
56
11:11:17
11:11:18
11:11:19
11:11:20
11:11:21
11:11:22
Start Time: 2013-07-09 11:10:00

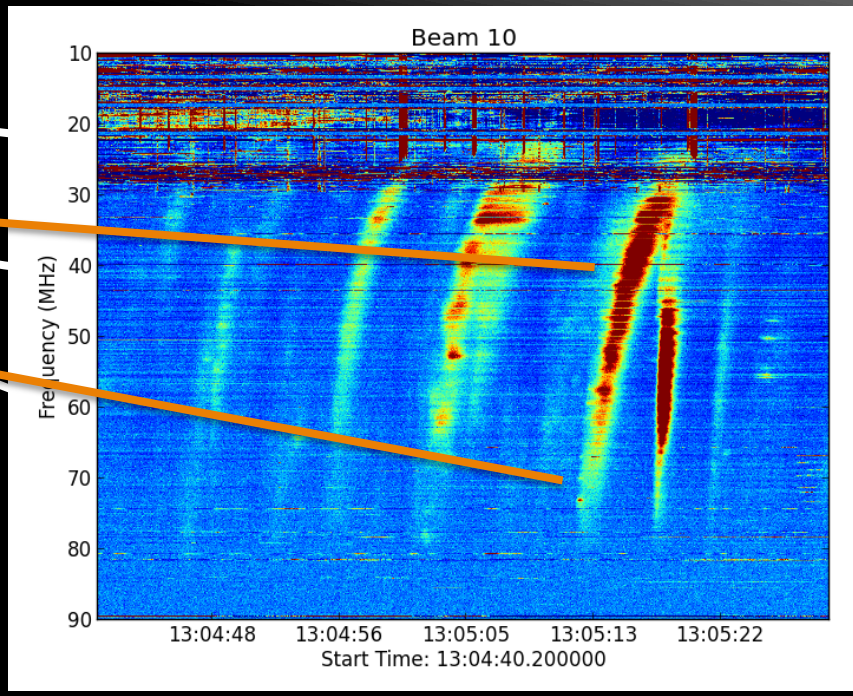

Beam 10
Frequency (MHz)
10
20
30
40
50
60
70
80
90
13:04:48
13:04:56
13:05:05
13:05:13
13:05:22
Start Time: 13:04:40.200000


Frequency (MHz)
140
150
160
170
180
08:06:00
08:08:09
08:10:19
08:12:28
08:14:38
Start Time: 2013-07-06 08:05:00

0

Type III Radio Bursts

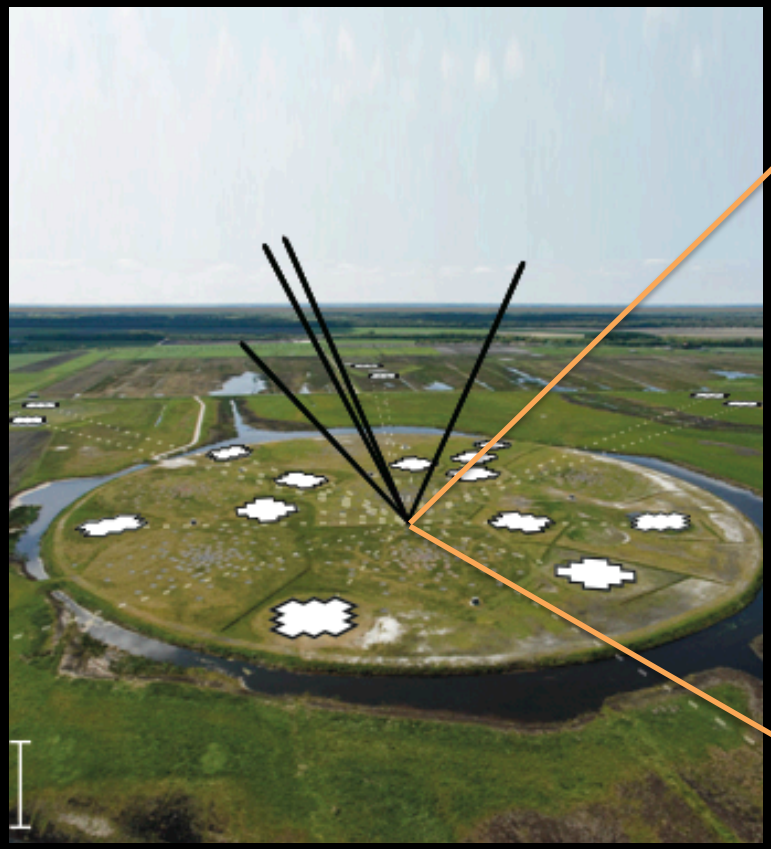


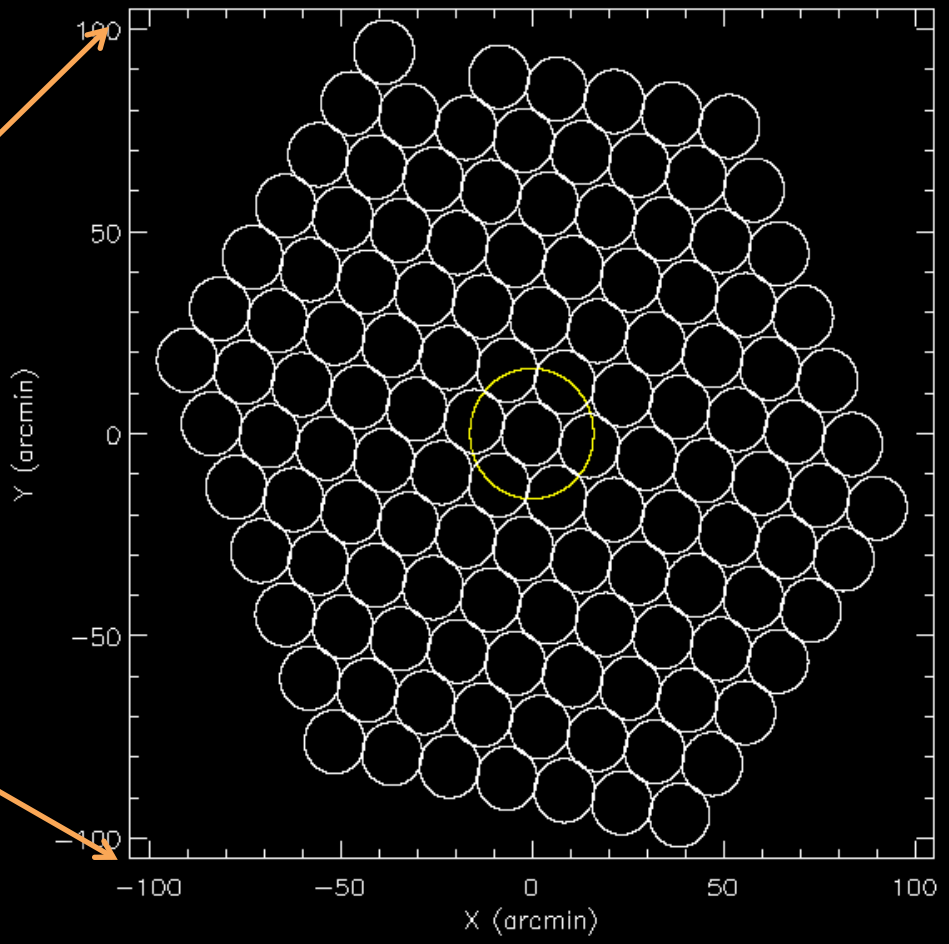


Signatures of electron beams travelling along open magnetic field lines generated by the plasma emission mechanism.

Tied-array Observations of the Sun

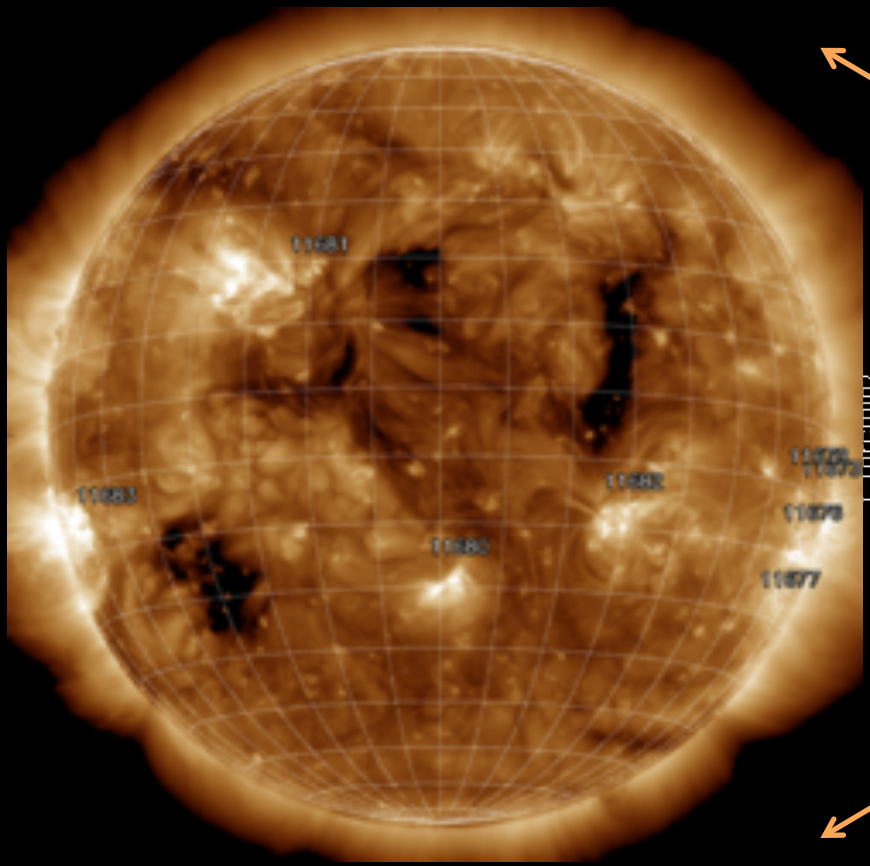
Coherent combination of multiple station beams is called a "tied-array" beam.

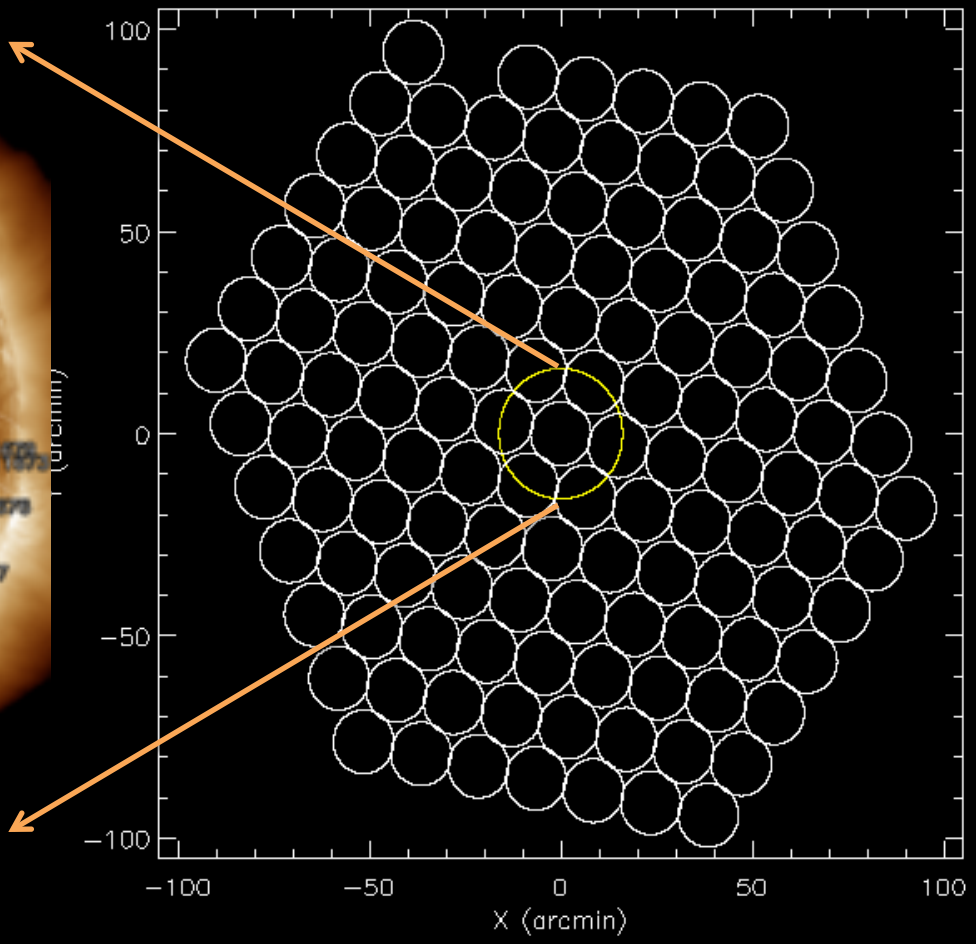




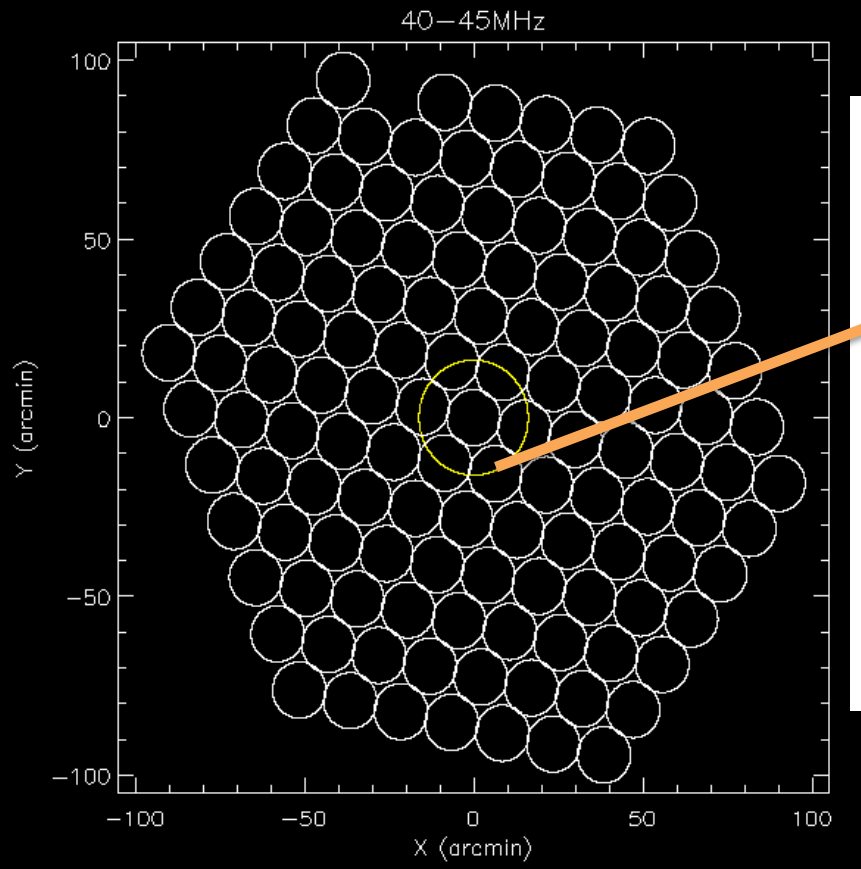
Tied-array Observations of the Sun During a ‘Quiet Day’

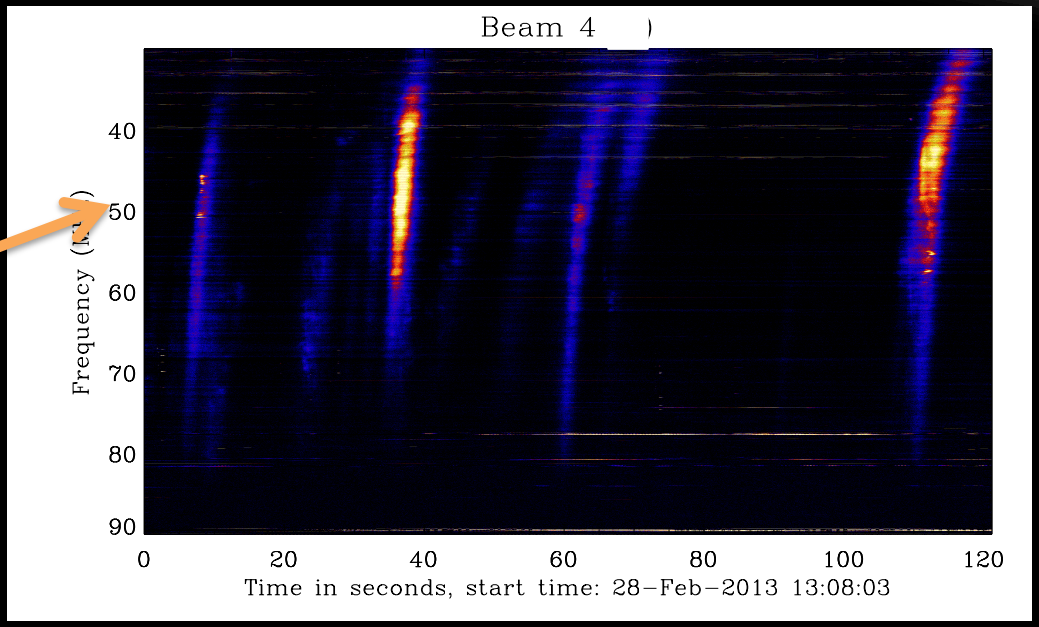
SDO AIA 193 Å





LBA Tied-Array Dynamic Spectra

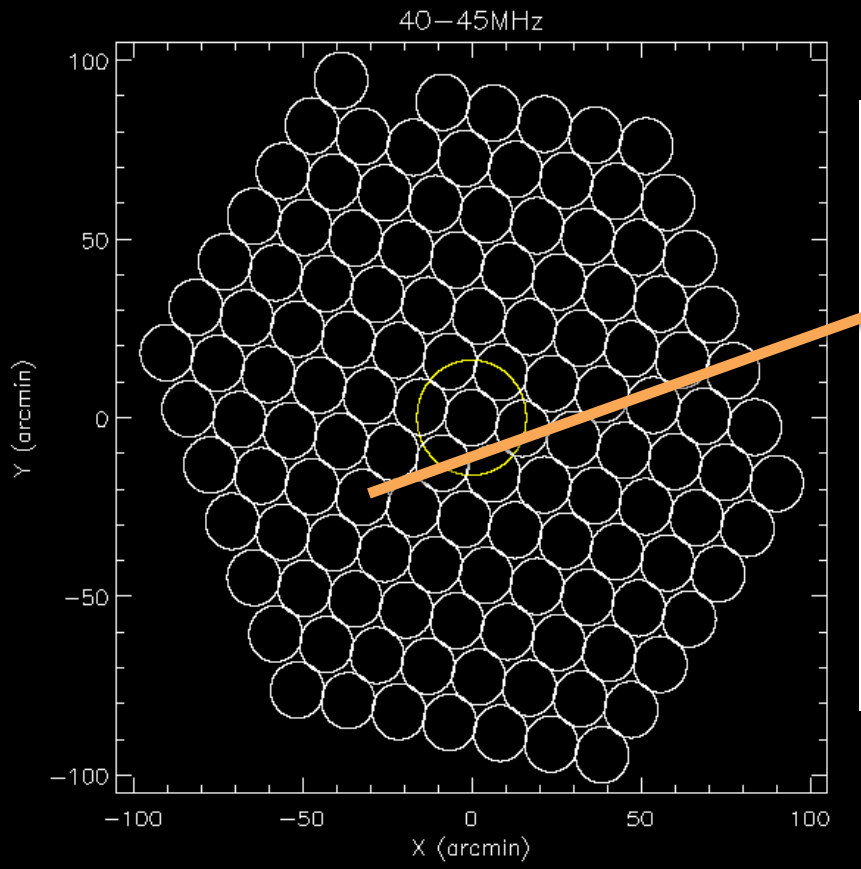


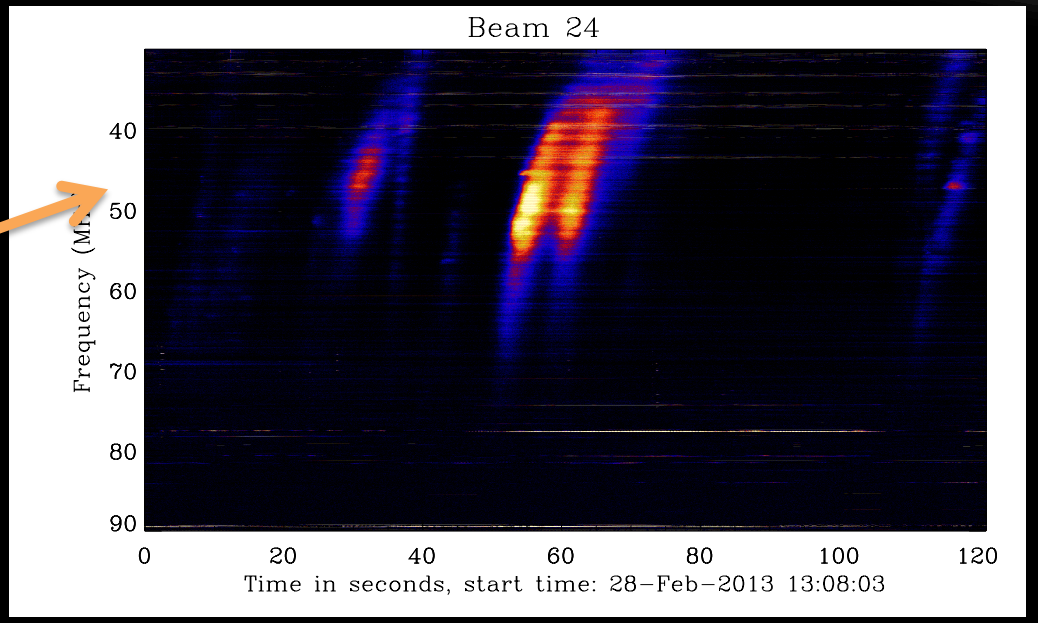


2 mins

Multiple Type III Radio Bursts - fast frequency drift bursts occurring in groups or storms

LBA Tied-Array Dynamic Spectra

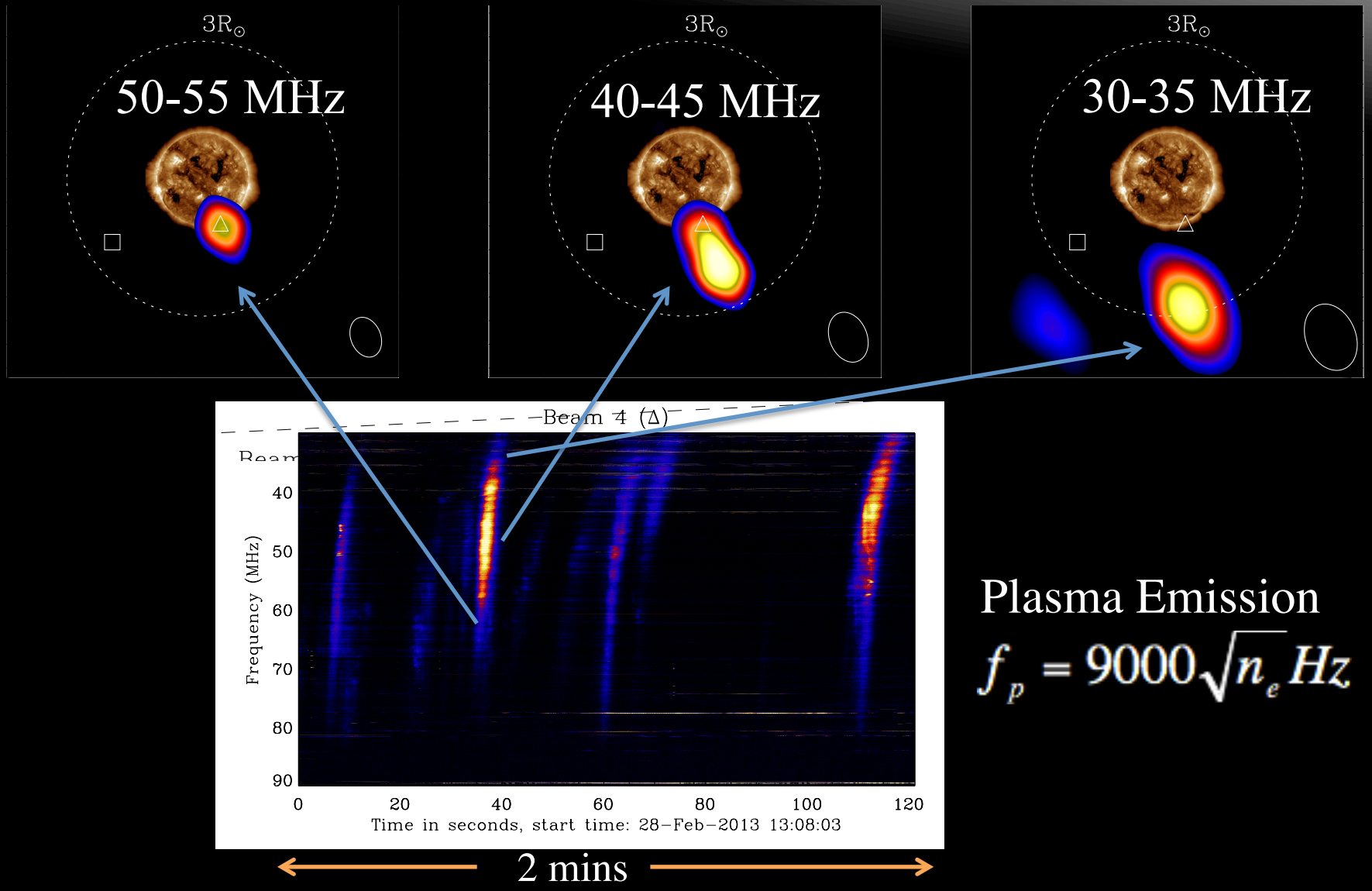




2 mins

Multiple Type III Radio Bursts - fast frequency drift bursts occurring in groups or storms

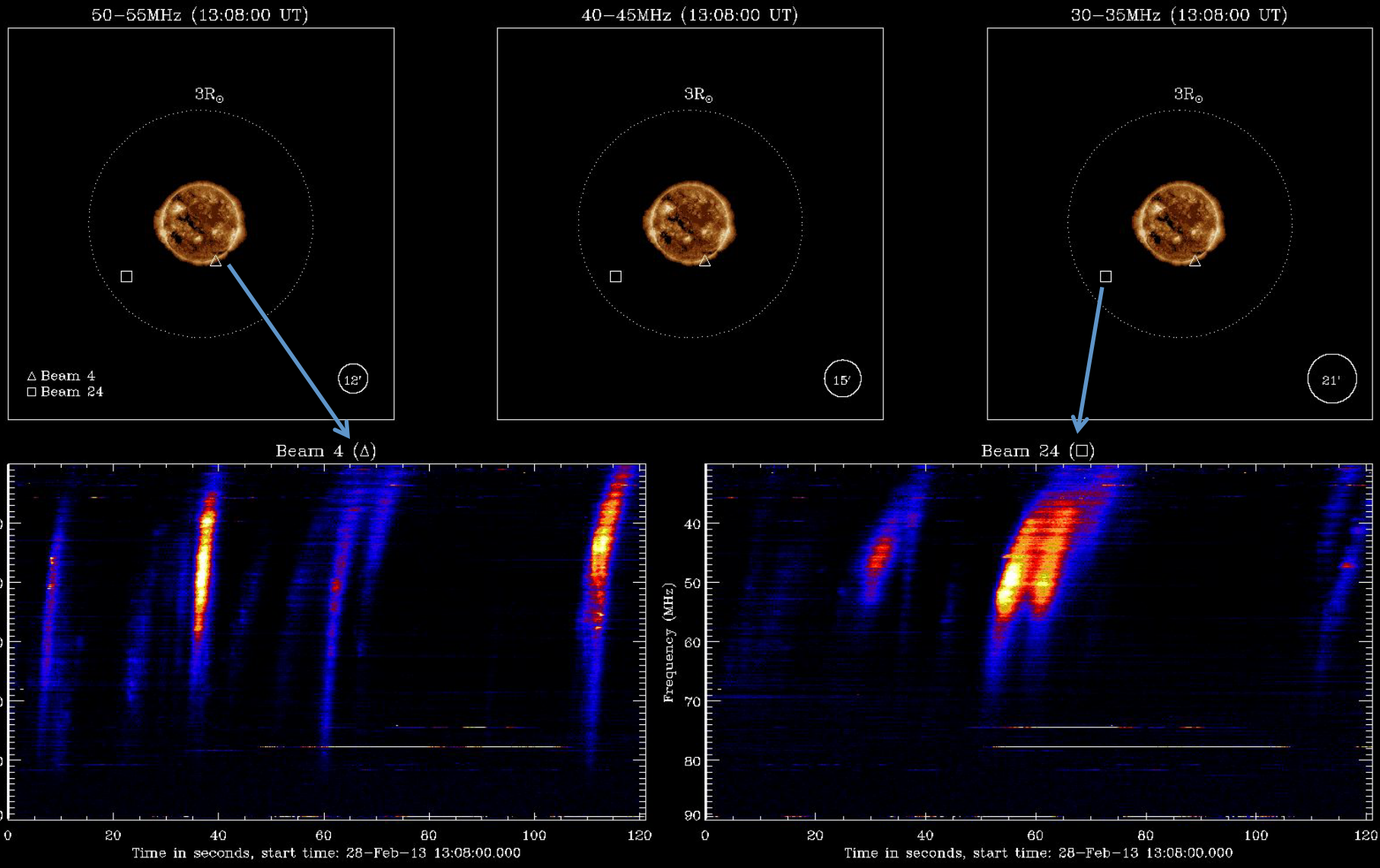
Spatial Information of Type III Radio Bursts Using Tied-Array Beams



Plasma Emission

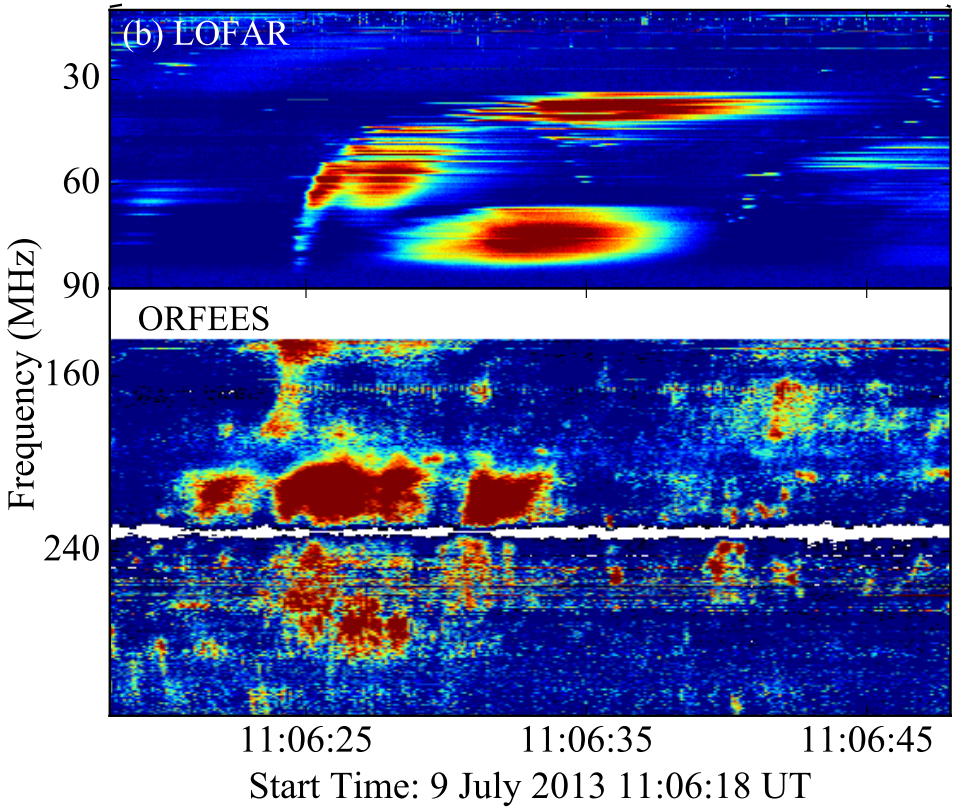
$$f_p = 9000\sqrt{n_e}\,Hz$$

50-55 MHz 40-45 MHz 30-35 MHz



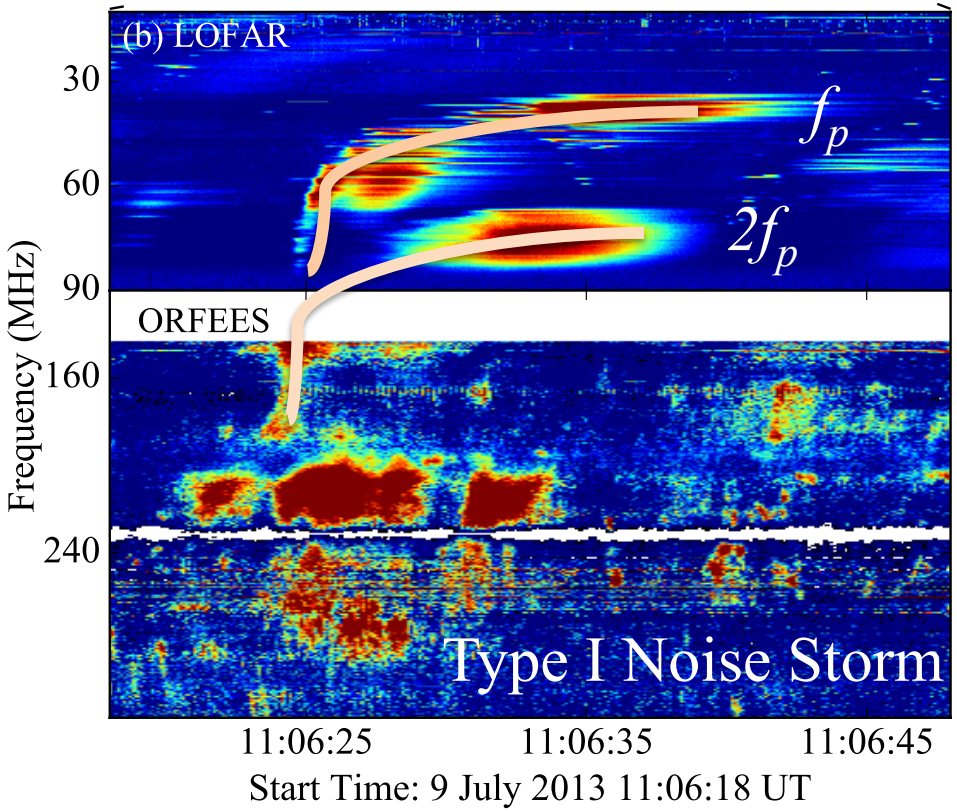
Morosan et al.,2014

Unusual Type III Radio Burst with LOFAR and ORFEES



Unusual Type III burst. Emission stops abruptly at 33 MHz.

Unusual Type III Radio Burst with LOFAR and ORFEES

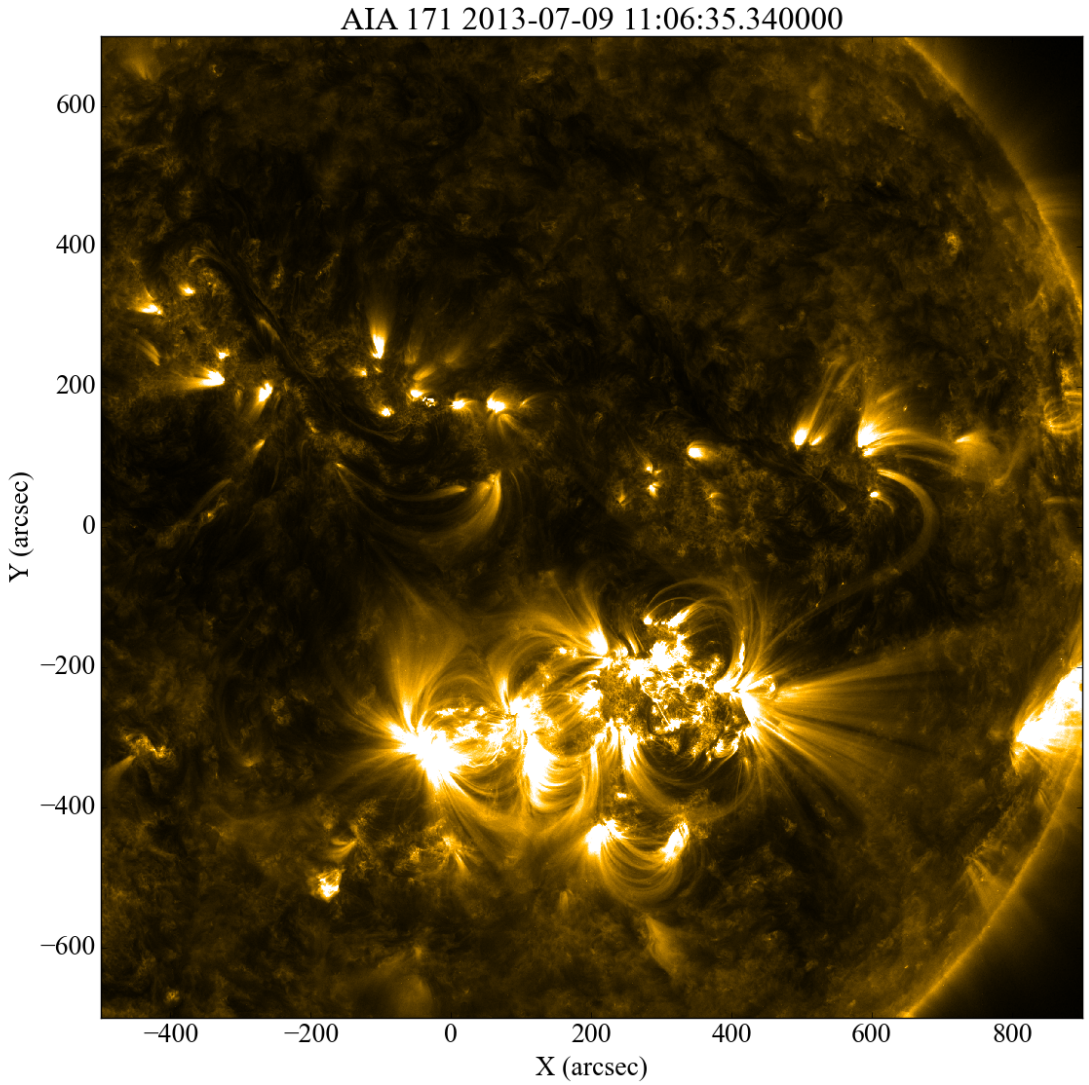


Fundamental Emission f_p

Harmonic Emission $2f_p$

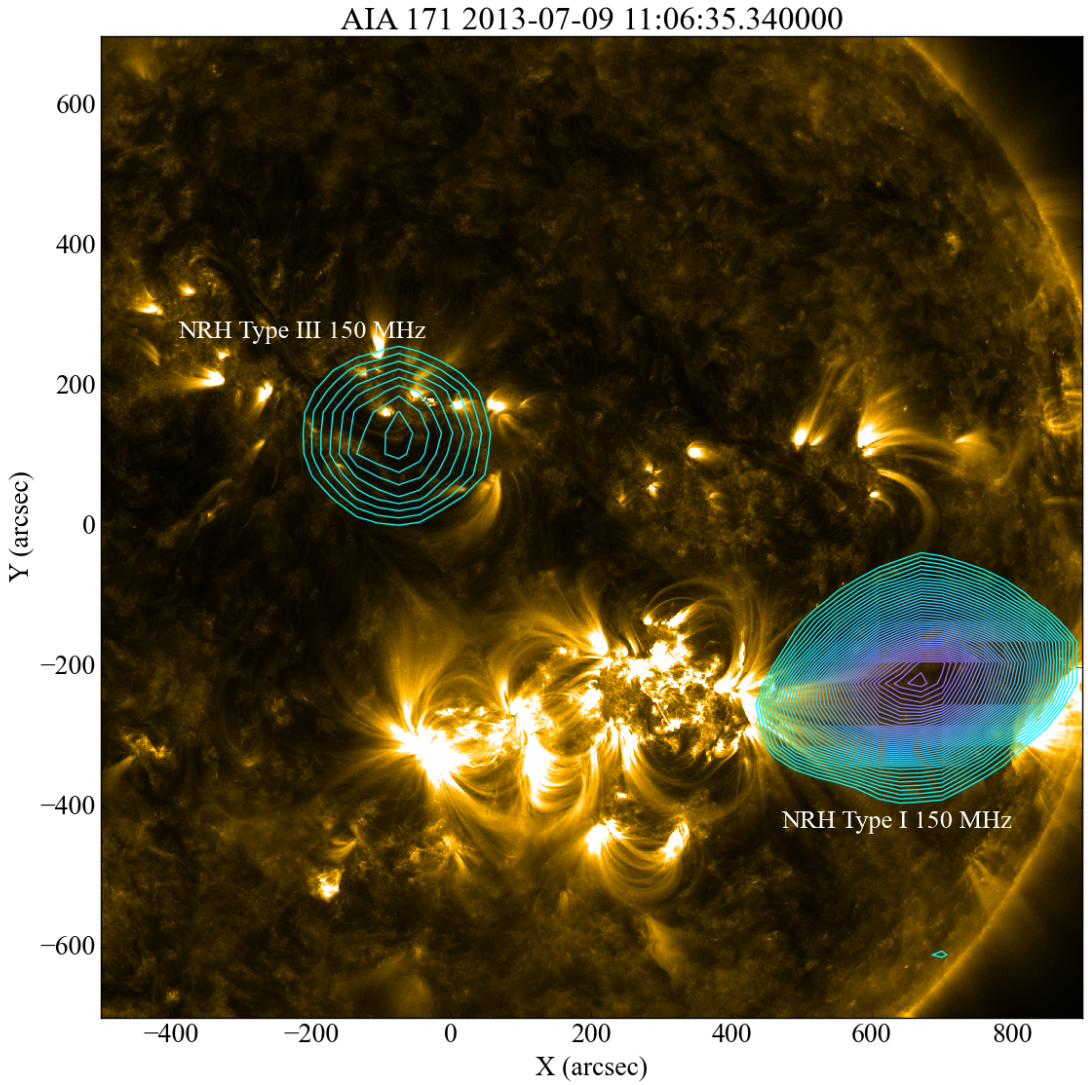
Fundamental and Harmonic J-burst Emission

Electron Acceleration in the Solar Corona



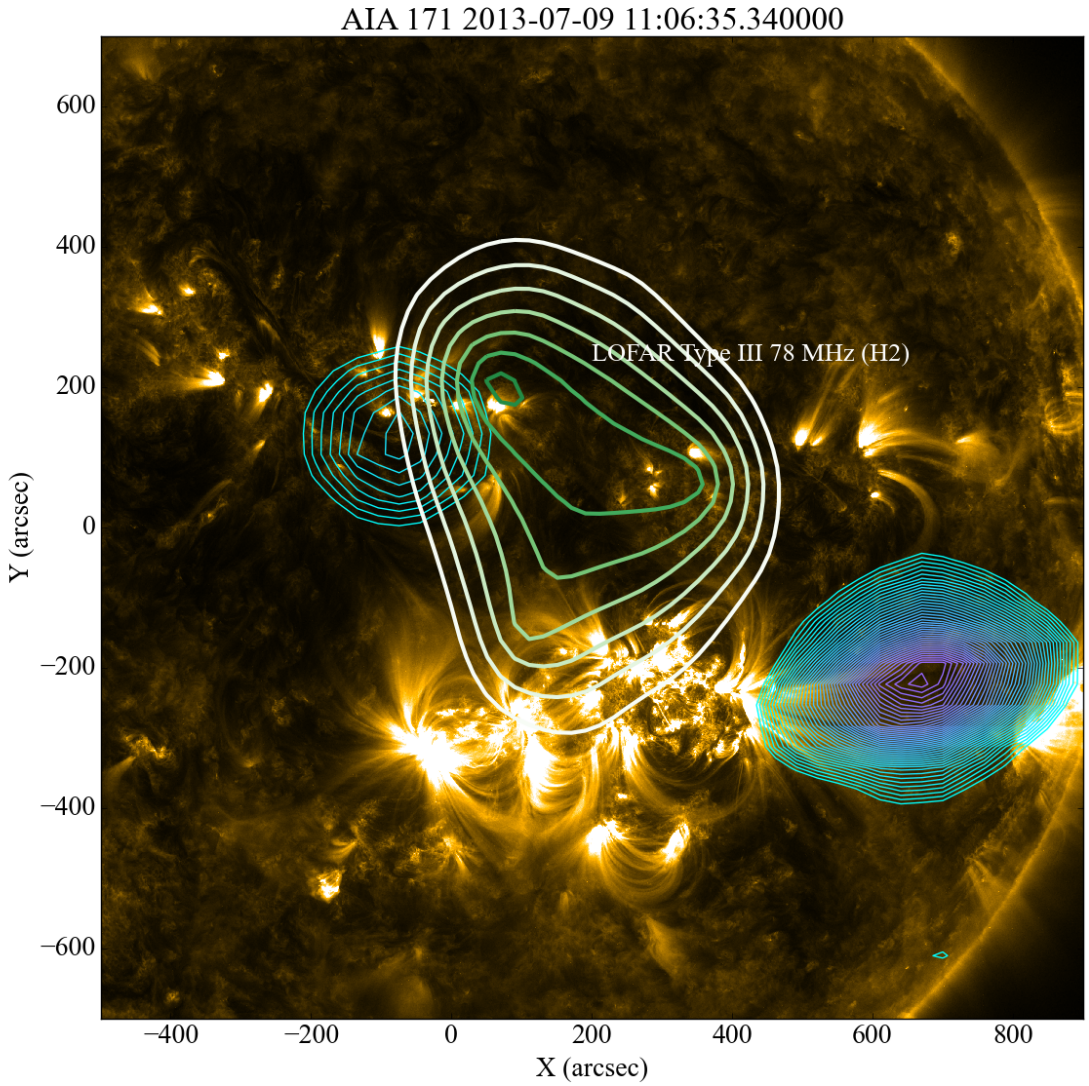
Sun at 171 Å

Electron Acceleration in the Solar Corona



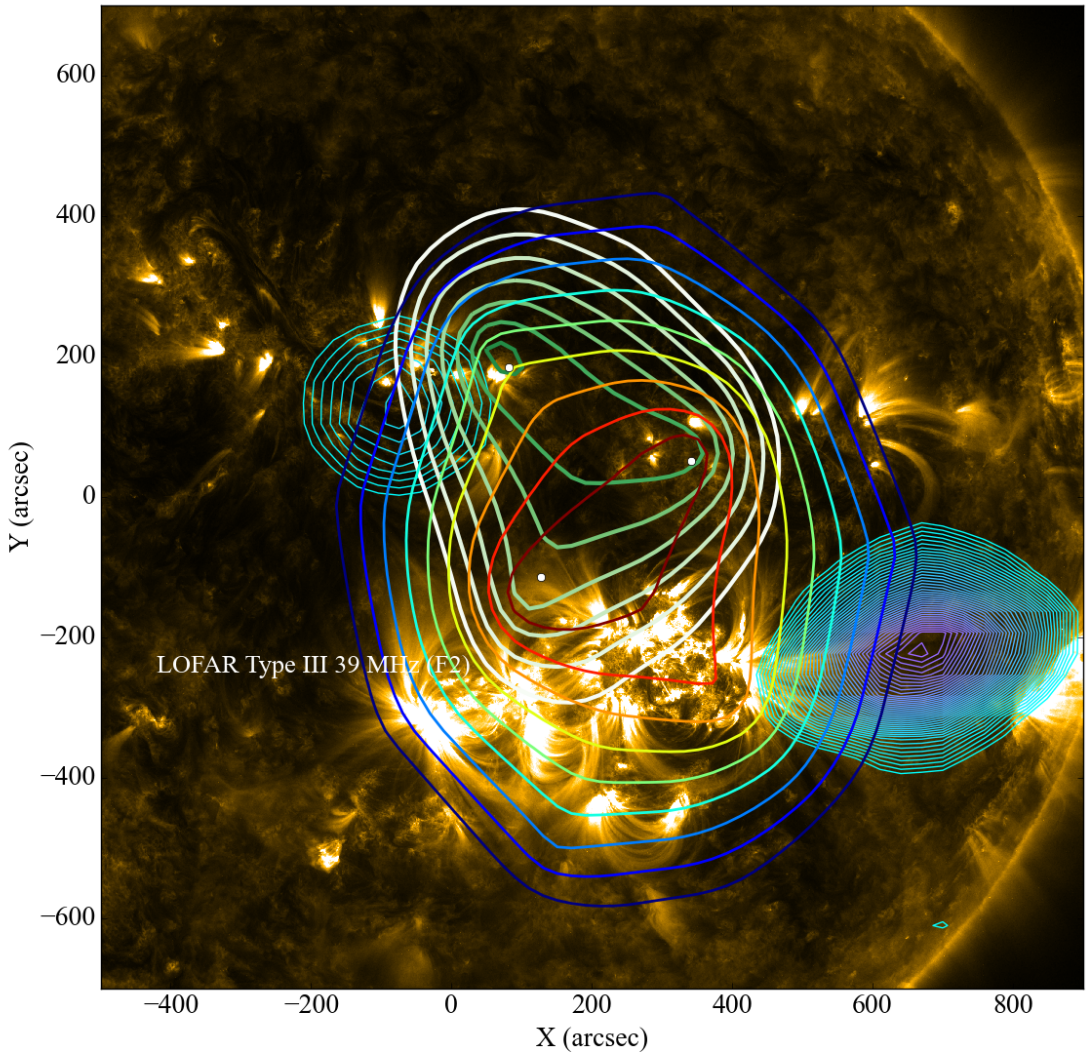
NRH Type III and Type I 150 MHz

Electron Acceleration in the Solar Corona



NRH Type III
78 MHz

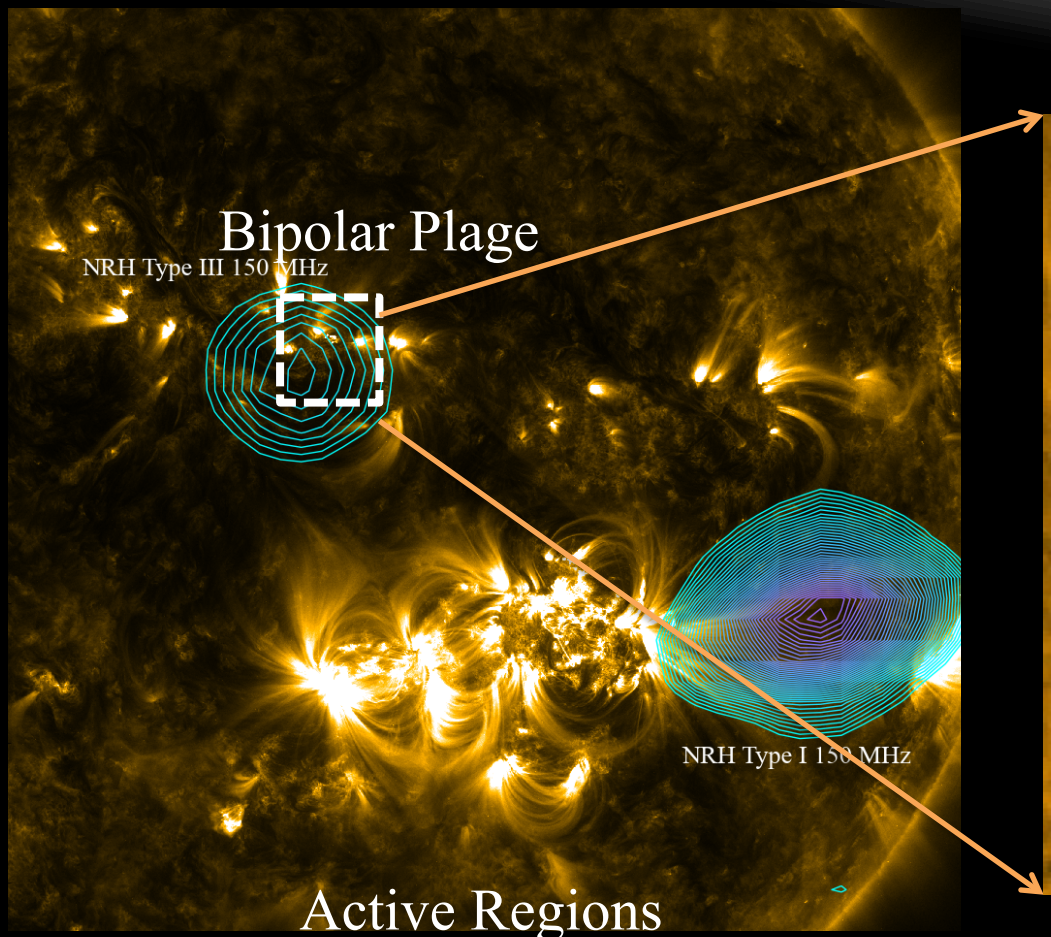
Electron Acceleration in the Solar Corona

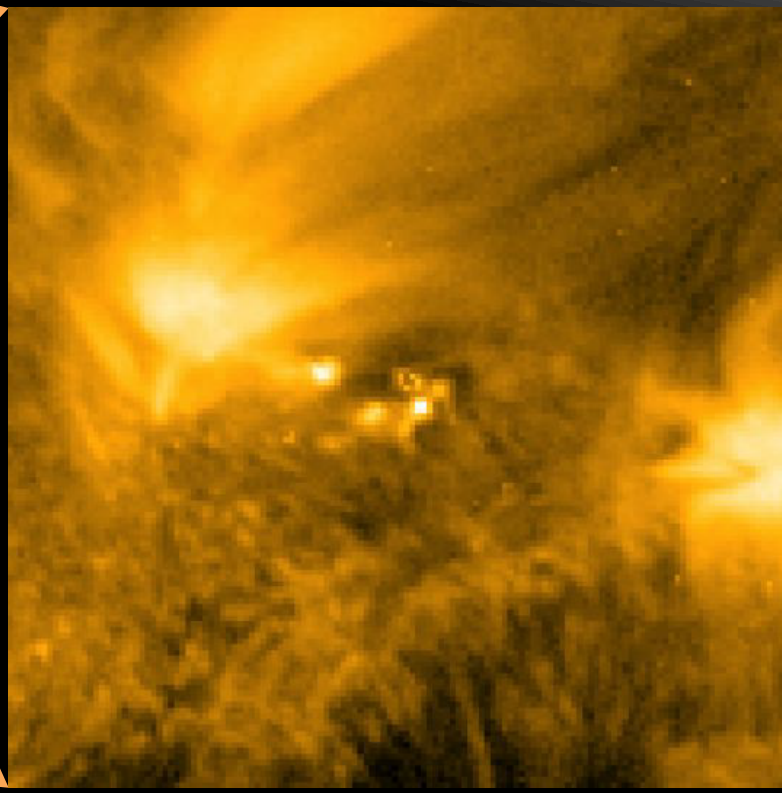


LOFAR Type III
39 MHz

Morosan et al., accepted in A&A

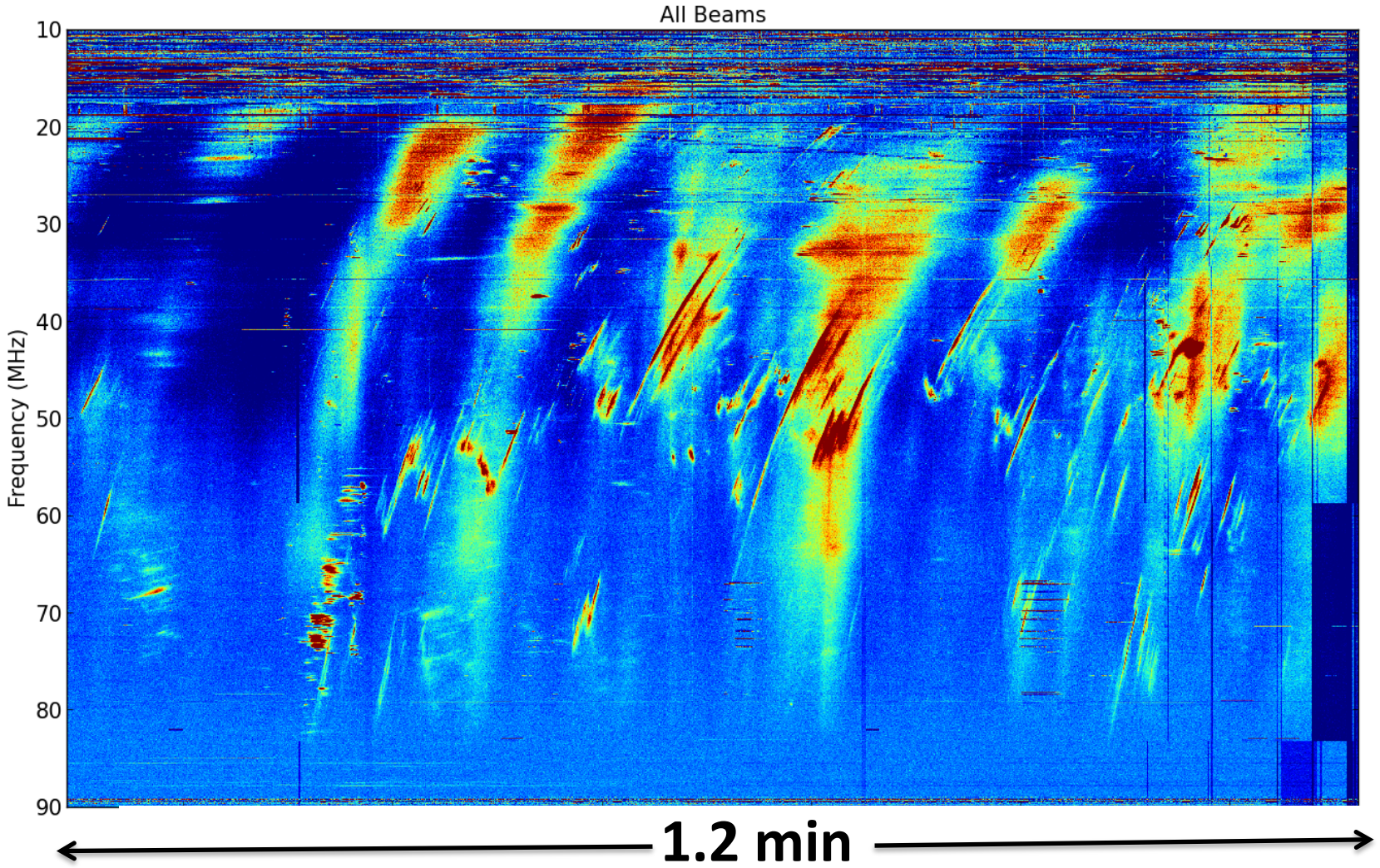
Electron Acceleration in the Solar Corona



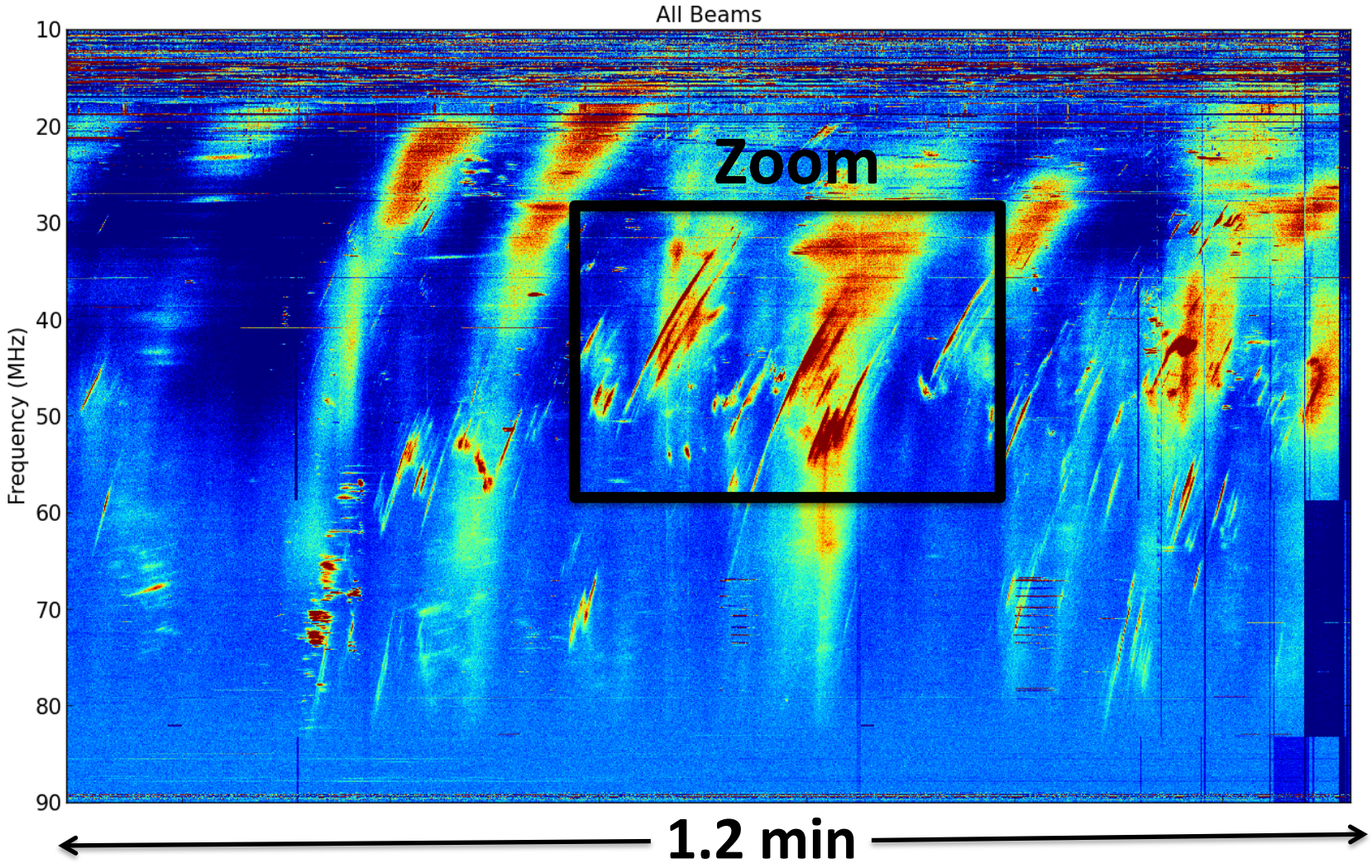


Solar jet correlated with Type III radio burst.

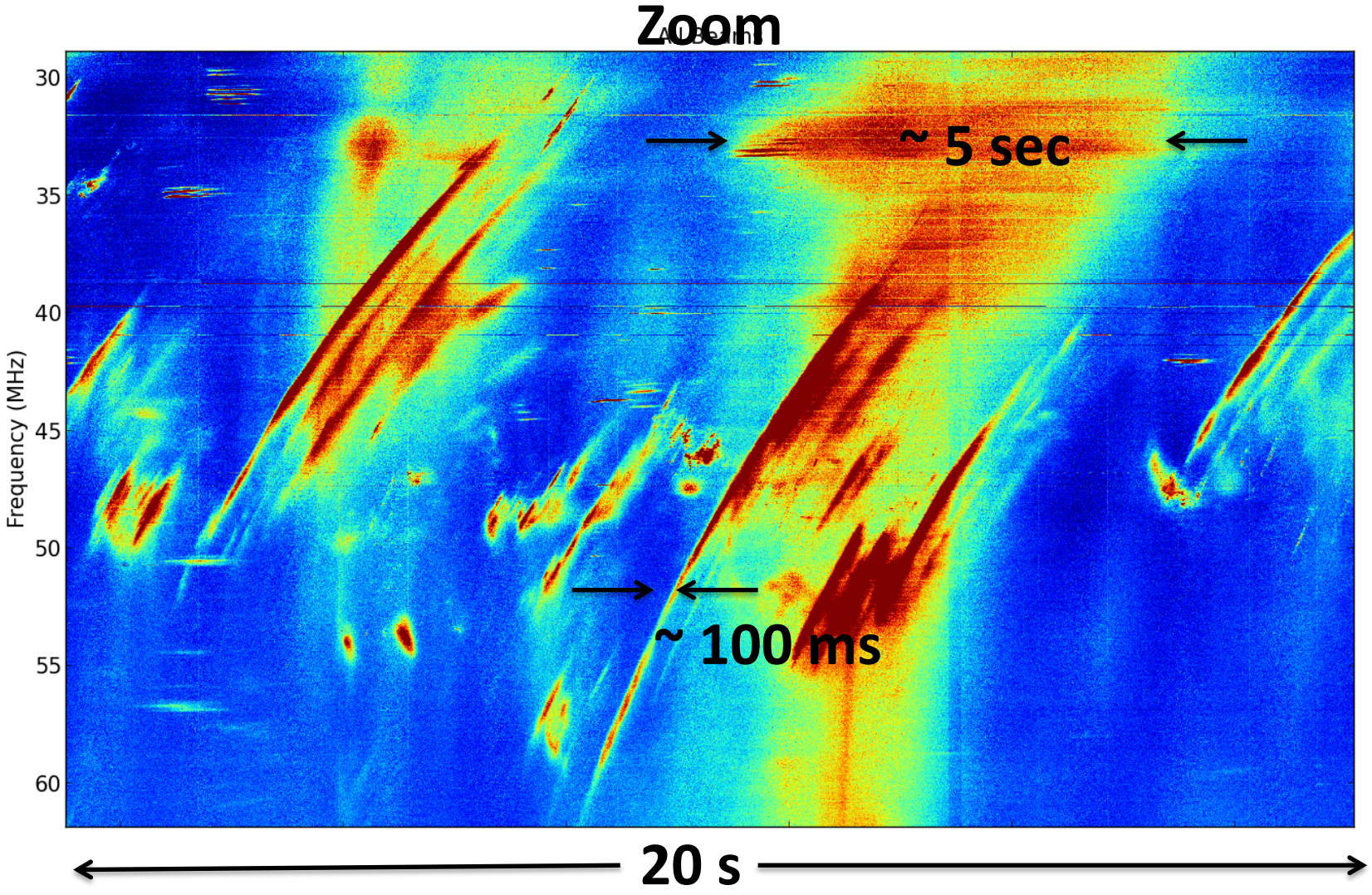
1 Minute Solar Observation during Non-flaring Day



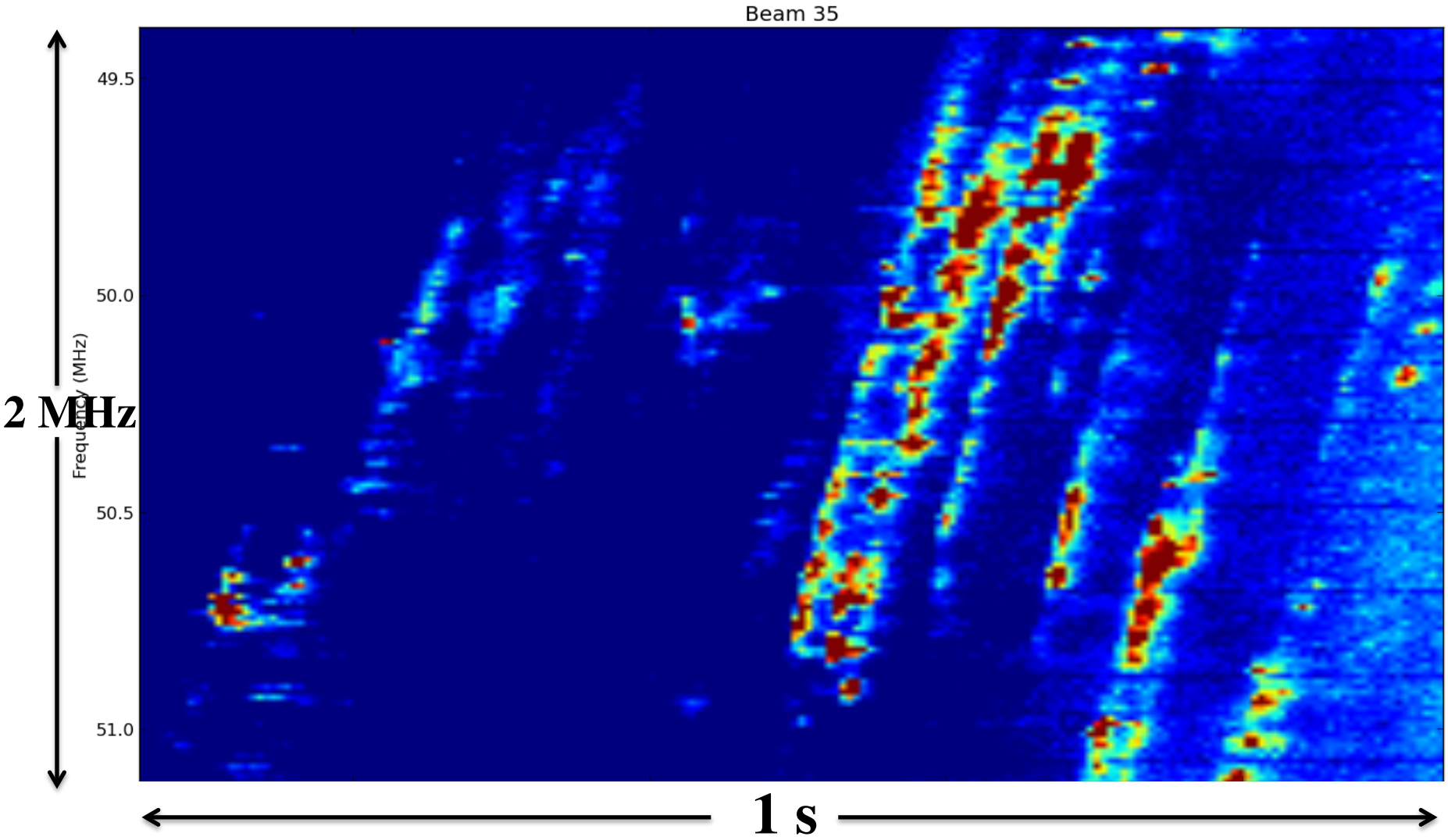
S Bursts with Full LOFAR Core

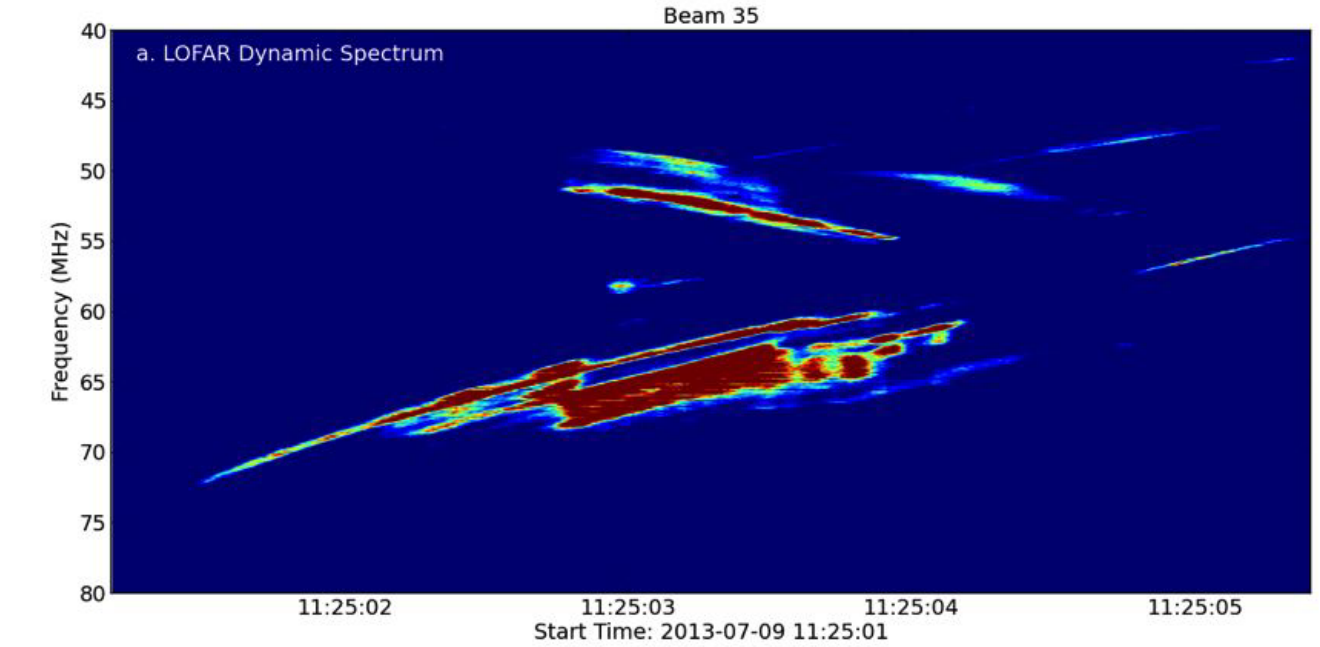


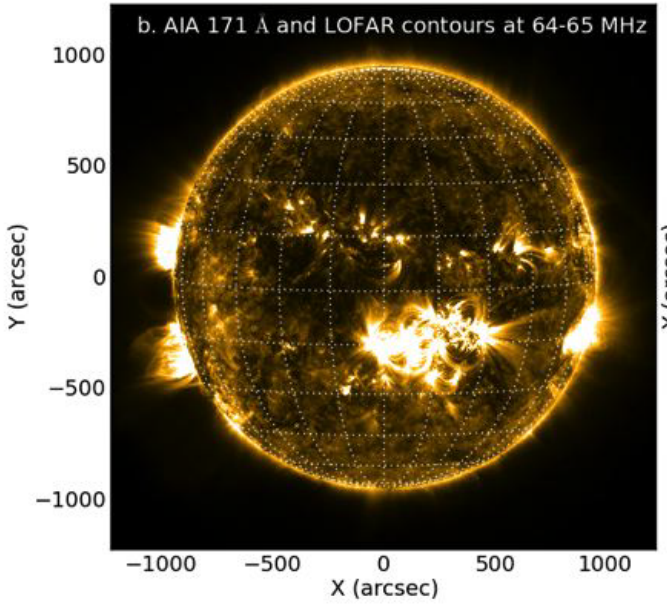
S Bursts with Full LOFAR Core

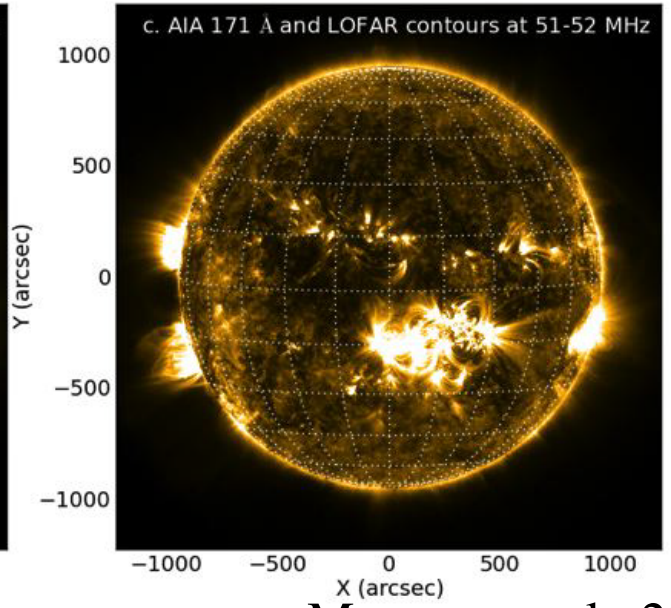


S Bursts with Full LOFAR Core
Need temporal resolution <10ms









Morosan et al., 2015

Conclusions – LOFAR Tied-array Imaging

- LOFAR tied-array beams easily provide spatial and spectral information on solar radio bursts with no immediate need for calibration and CLEANing ⟶ suitable for long term studies of Type IIIs and even space weather monitoring

- Relatively low data volume rates when using tied-array imaging

- SKA will provide increased capabilities for tied-array imaging: 2000 simultaneous beams using larger baselines which will increase spatial resolution