Introduction to Solar Observations with LOFAR

LOFAR DATASCHOOL 2018

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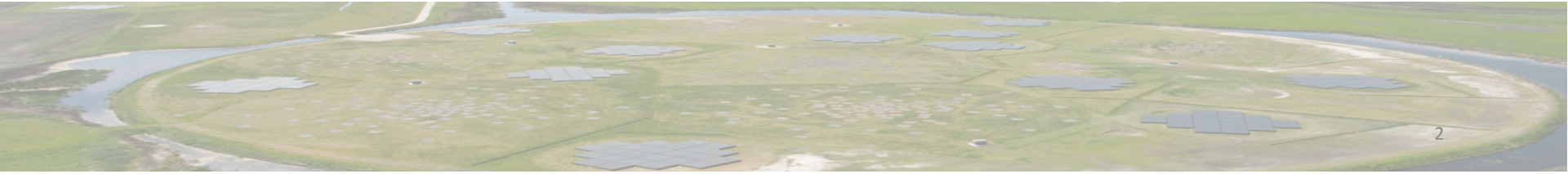
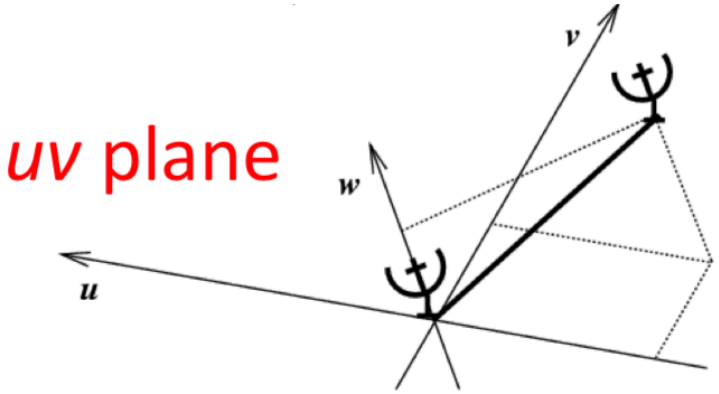
OUTLINE

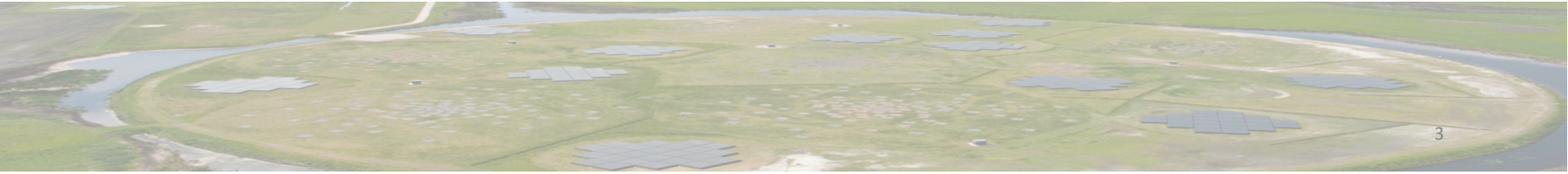
- Introduction
  - Interferometric
  - Tied-Array Beam
- Spatial Resolution
- Complex observing settings
  - Simultaneous Interferometric + Tied Array
  - Imaging + Faraday rotation + Scintillation
- Conclusions



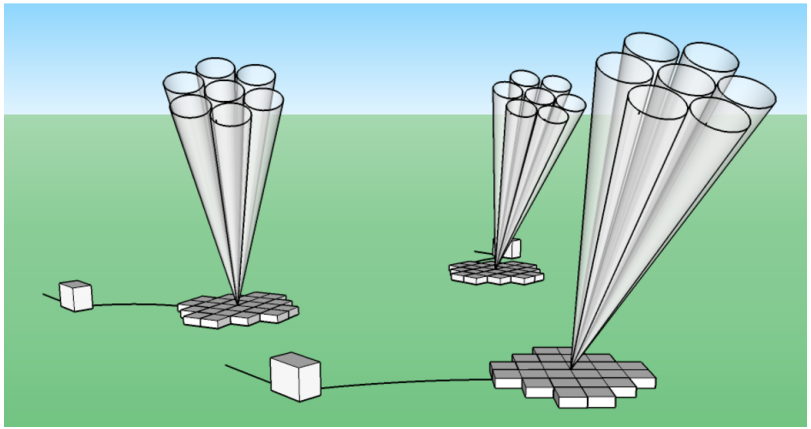
Interferometric mode

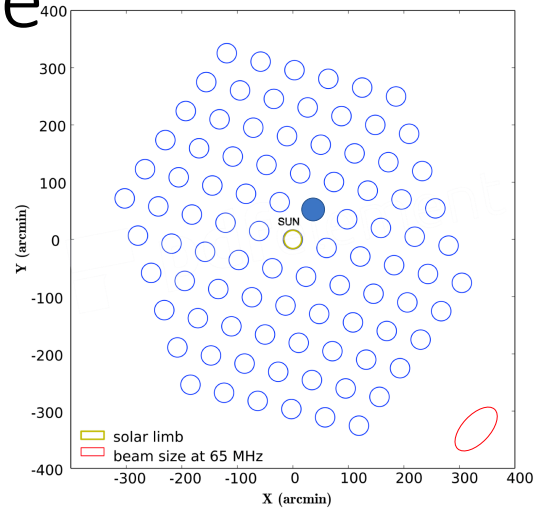
- the complex visibility, V(u,v), is the 2D Fourier transform of the brightness on the sky, T(x,y)



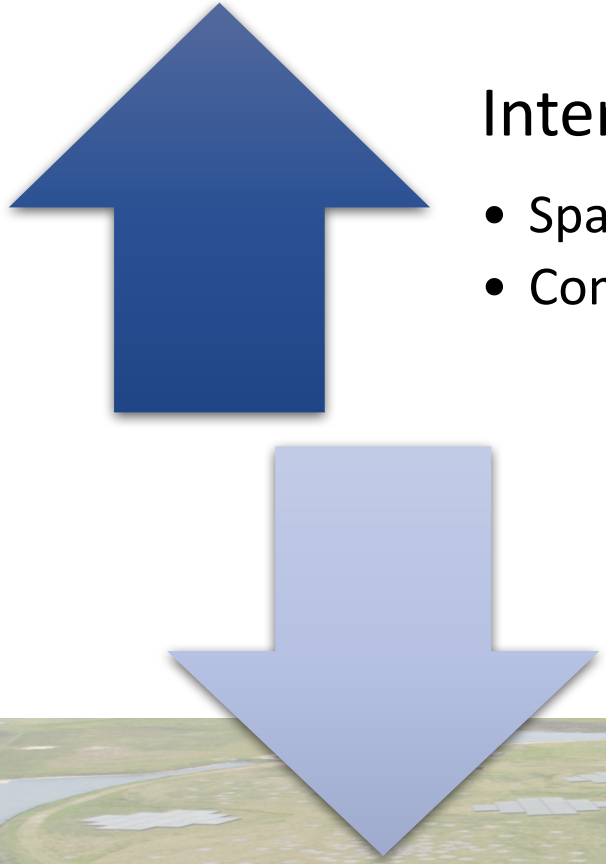


Tied-Array beam mode





- A set of beams in an array around the Sun in order to recreate a micropixel map.



Interferometric

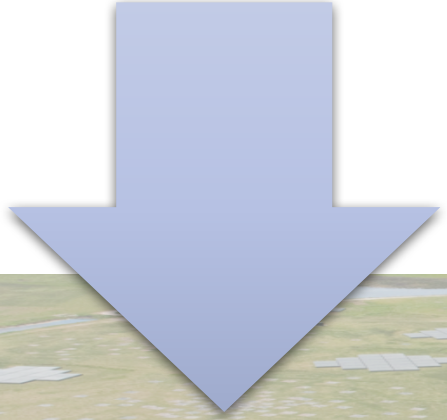
- Spatial resolution and quality of the imaging
- Complex sources with multiple peaks

Tied-Array

- Limited spatial resolution (beam spacing and size)
- Localization of the radio source without clear shape of the source

Tied-Array

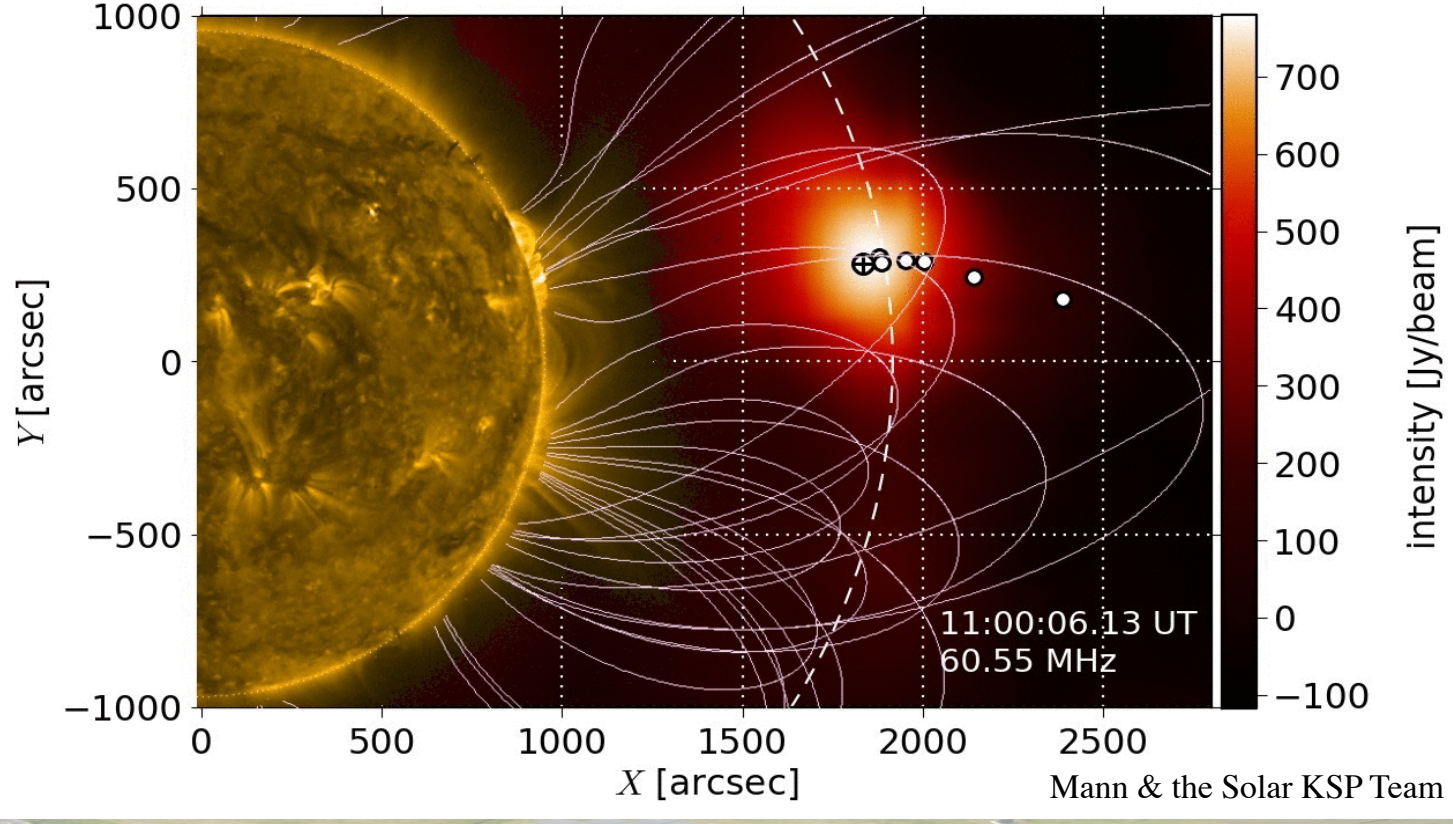
- Time resolution (milliseconds)
- Advantage for quasi-relativistic beam propagation



Interferometric

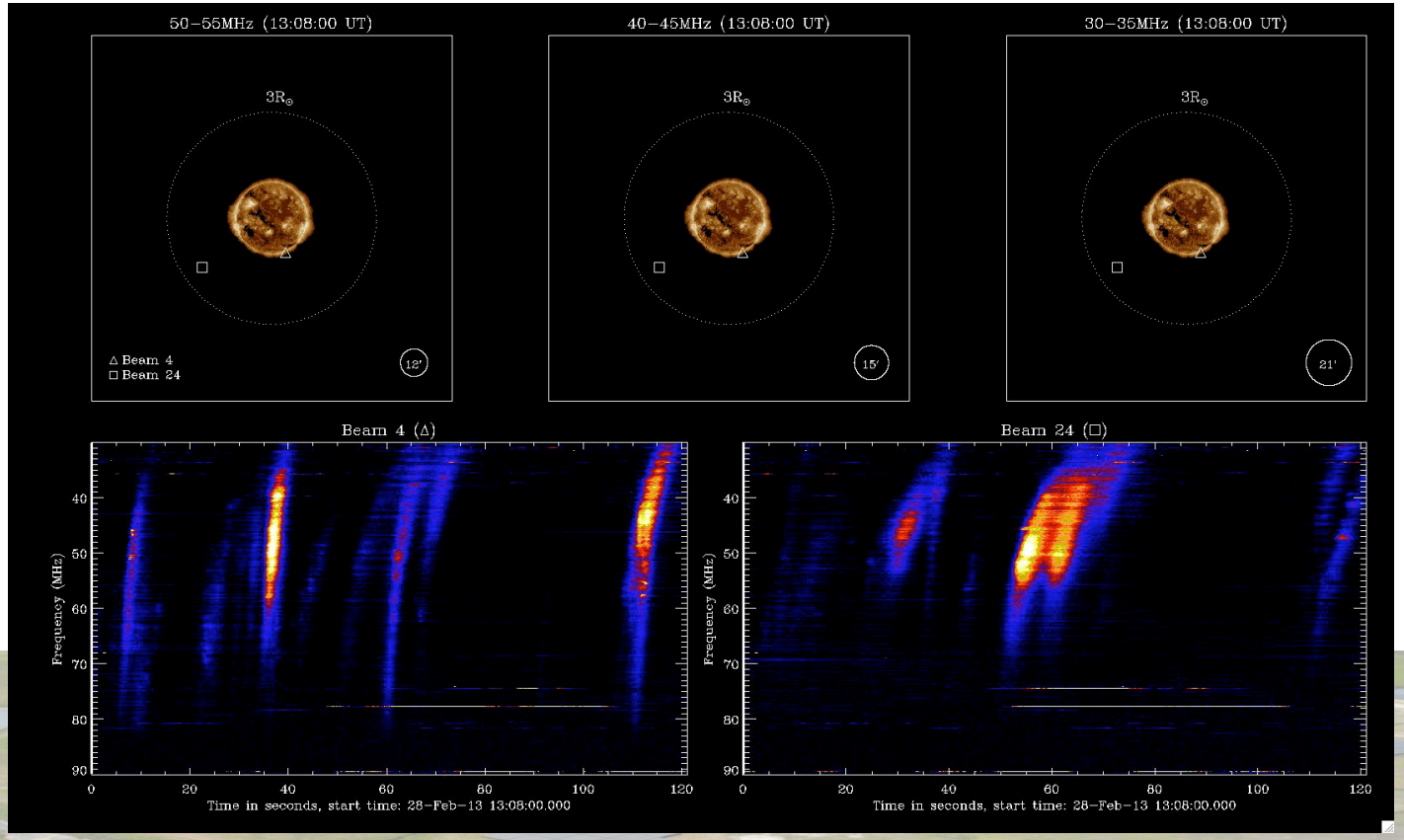
- Limited time resolution (0.25 seconds)
- Not ideal for quasi-relativistic beam propagation

Interferometric example



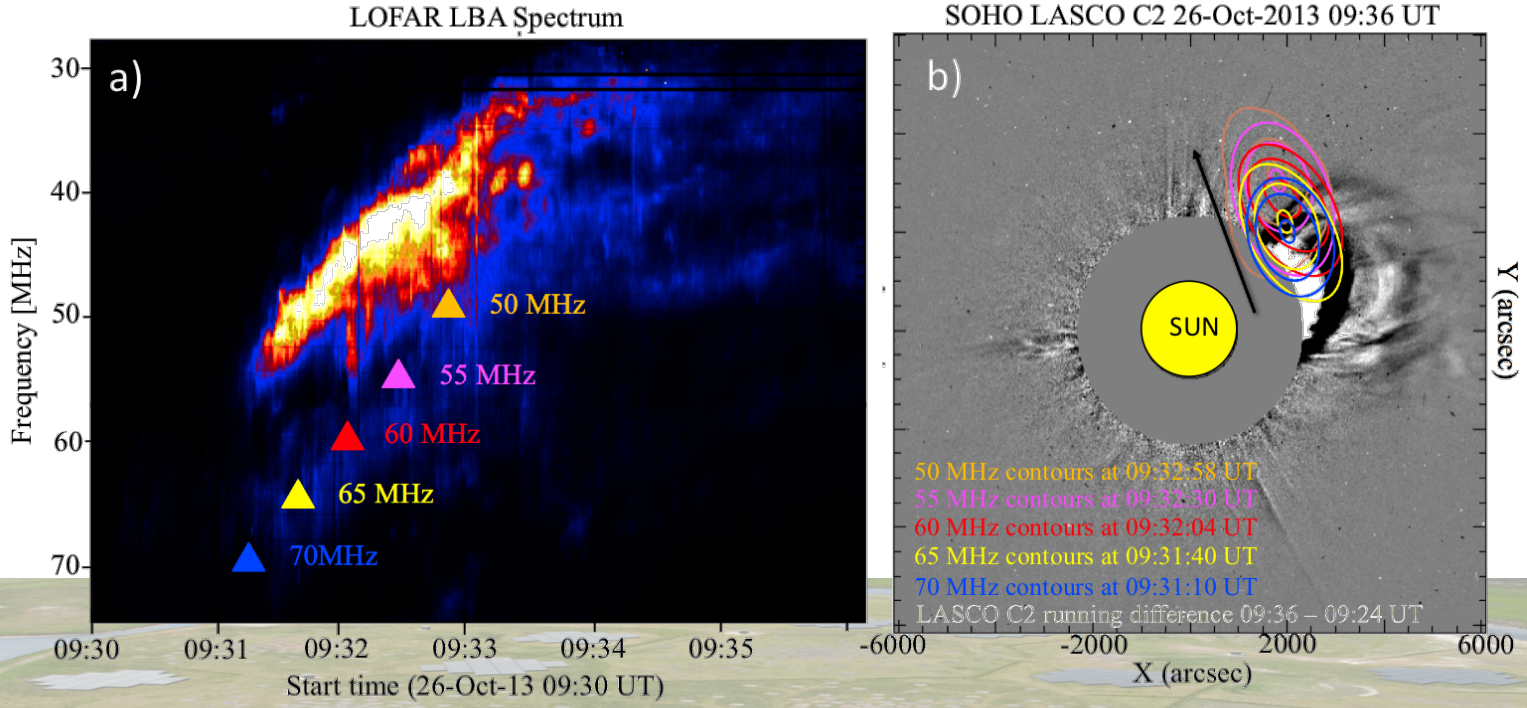
Tied-Array Beam example

Morosan et al. 2014

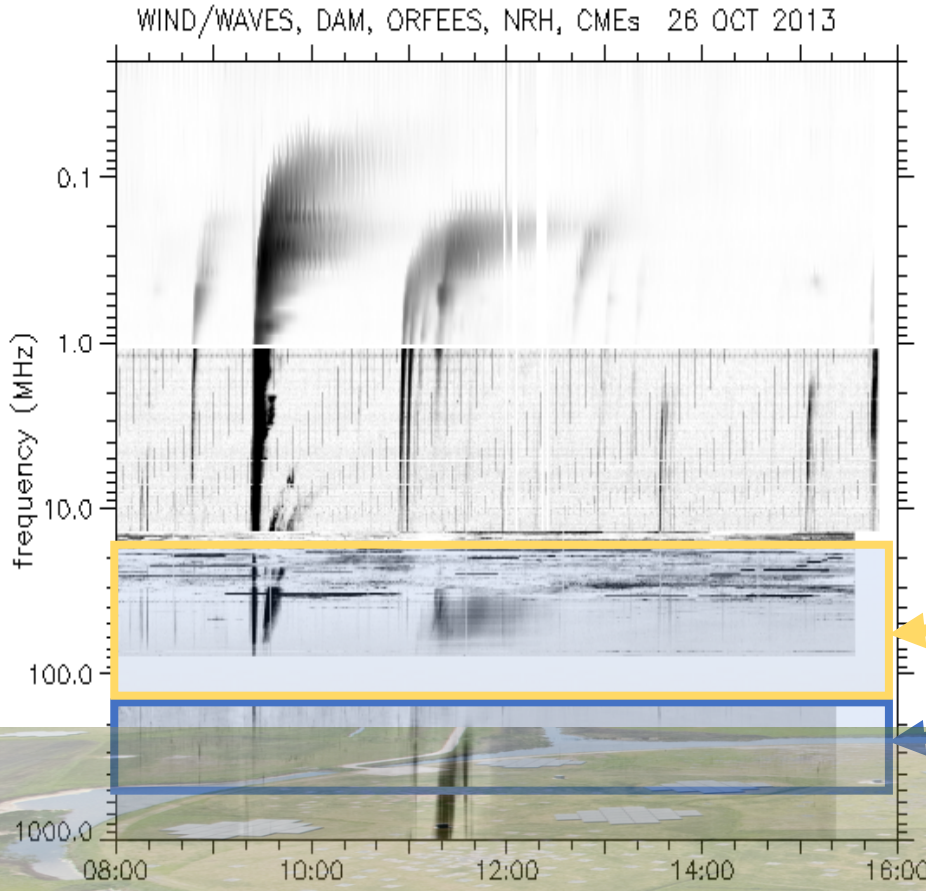


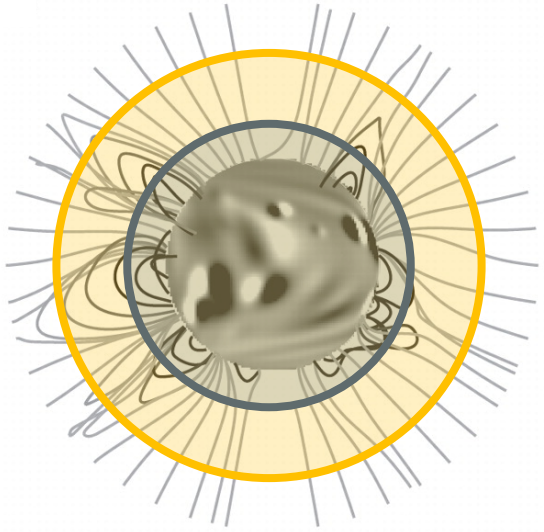
Tied-Array Beam example

Zucca et al. 2018



LOFAR imaging of the solar corona

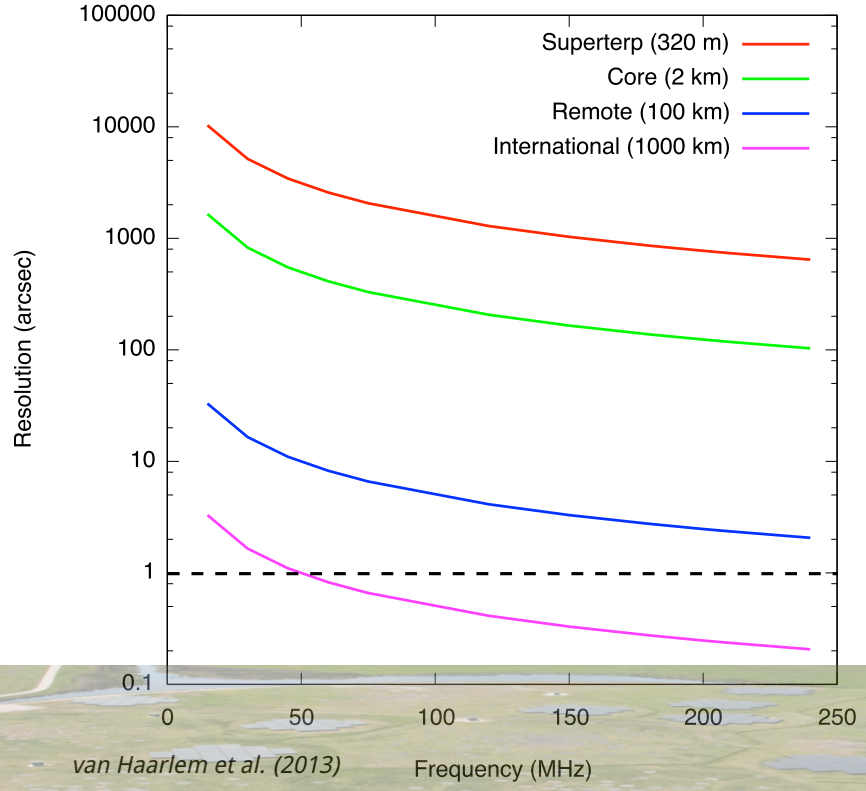




Imaging with LOFAR

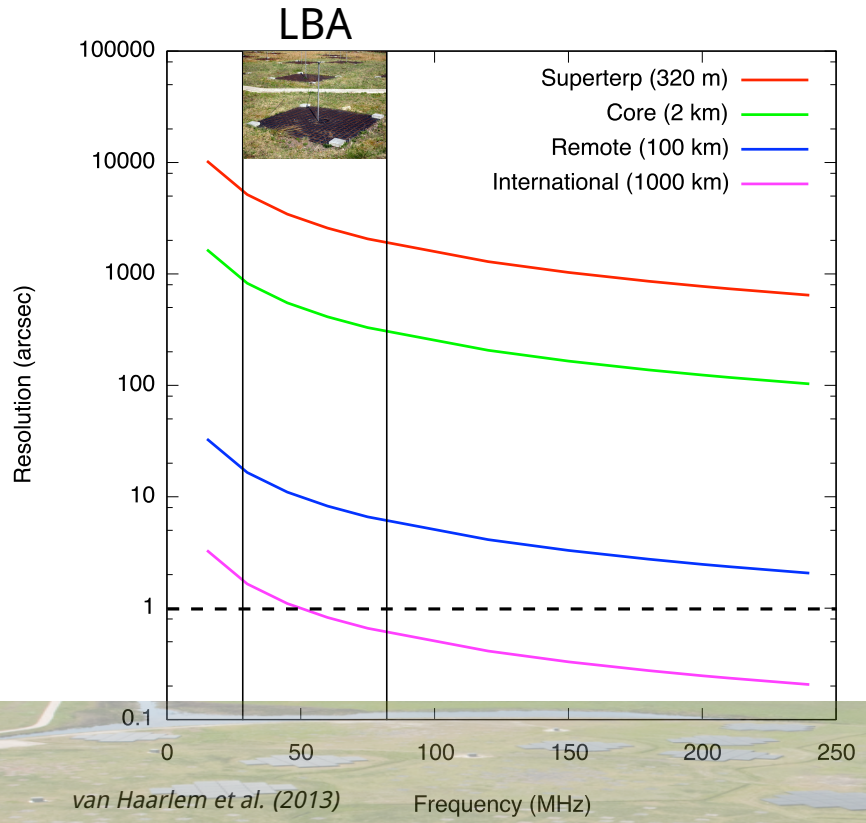
Imaging with Nançay

Spatial Resolution



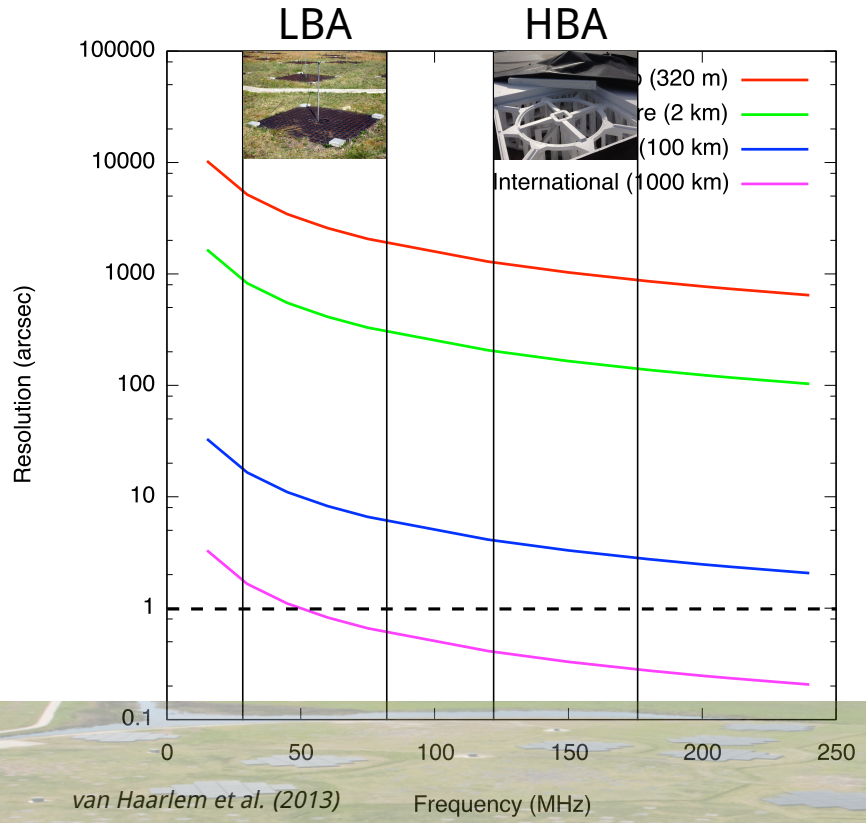
van Haarlem et al. (2013)

Spatial Resolution



van Haarlem et al. (2013)

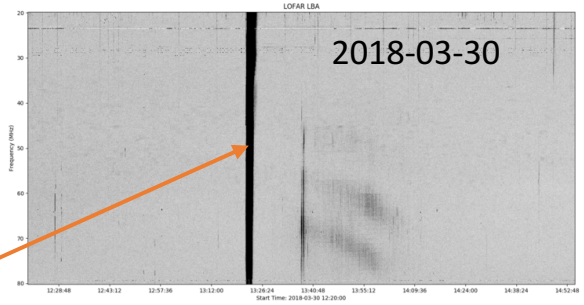
Spatial Resolution

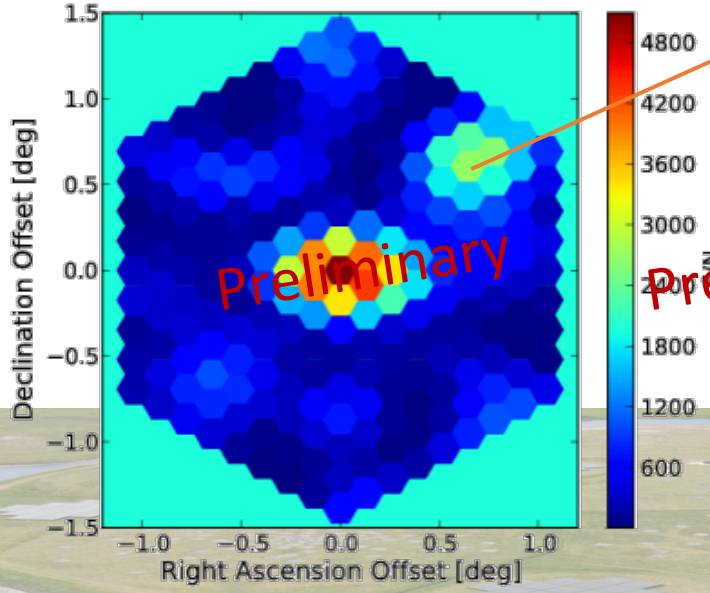


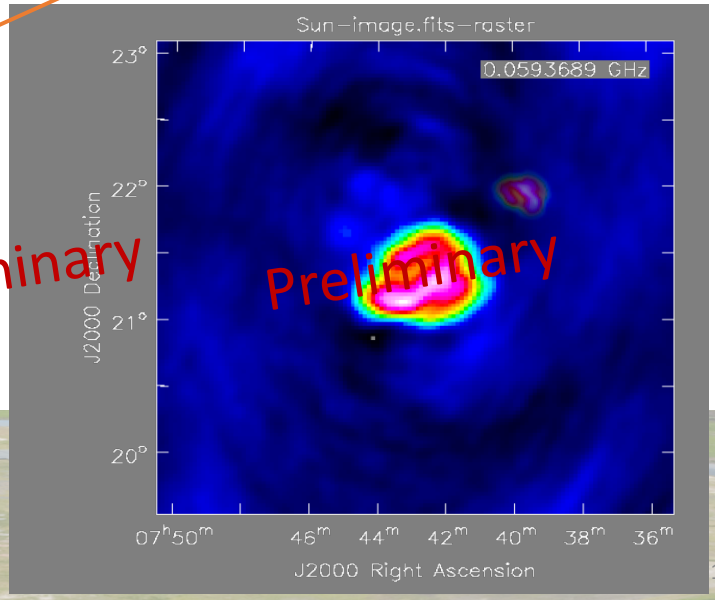
van Haarlem et al. (2013)

Complex Observing Settings

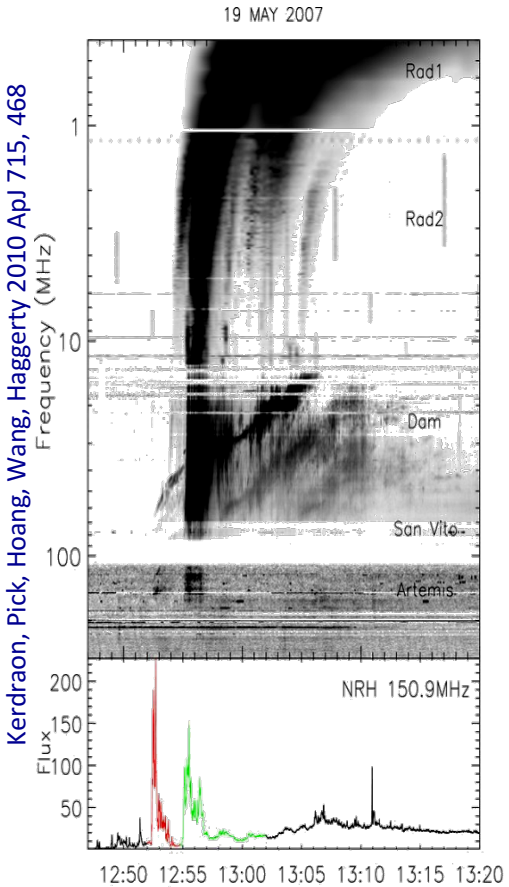
- Simultaneous Tied-Array and Interferometric
- First tests on the Sun currently in Cycle 9
- First comparison on the methods





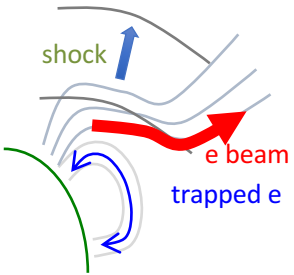


The Radio Sun

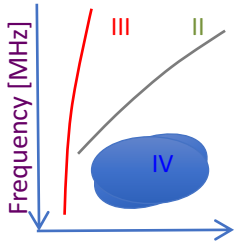


Courtesy: Pietro Zucca

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

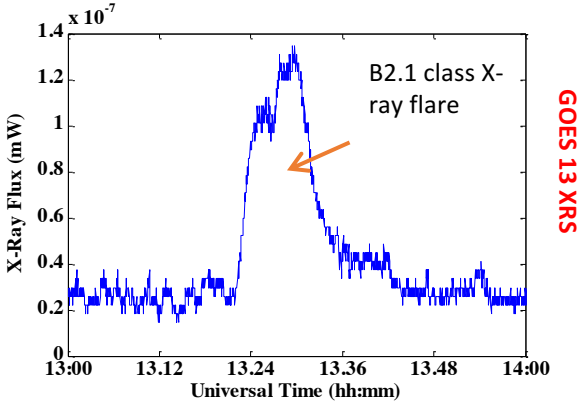


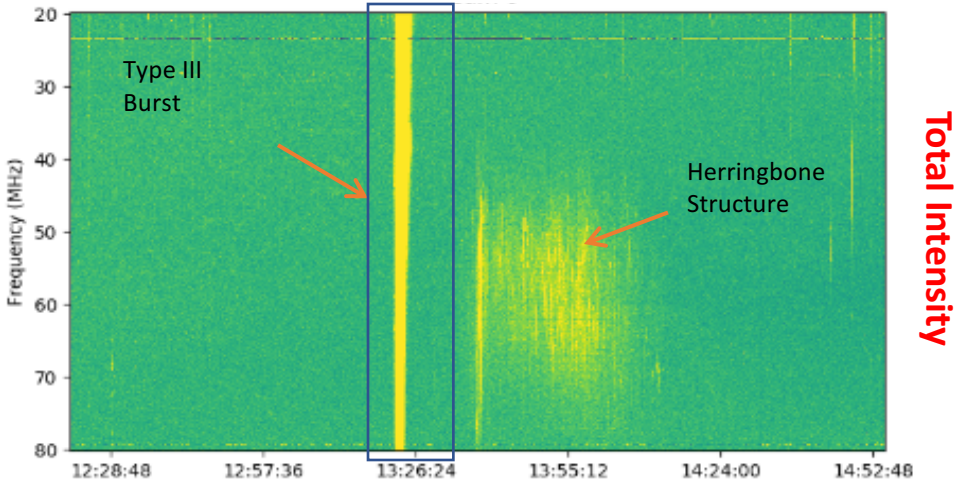
- Characteristic shapes of the radio burst spectra:



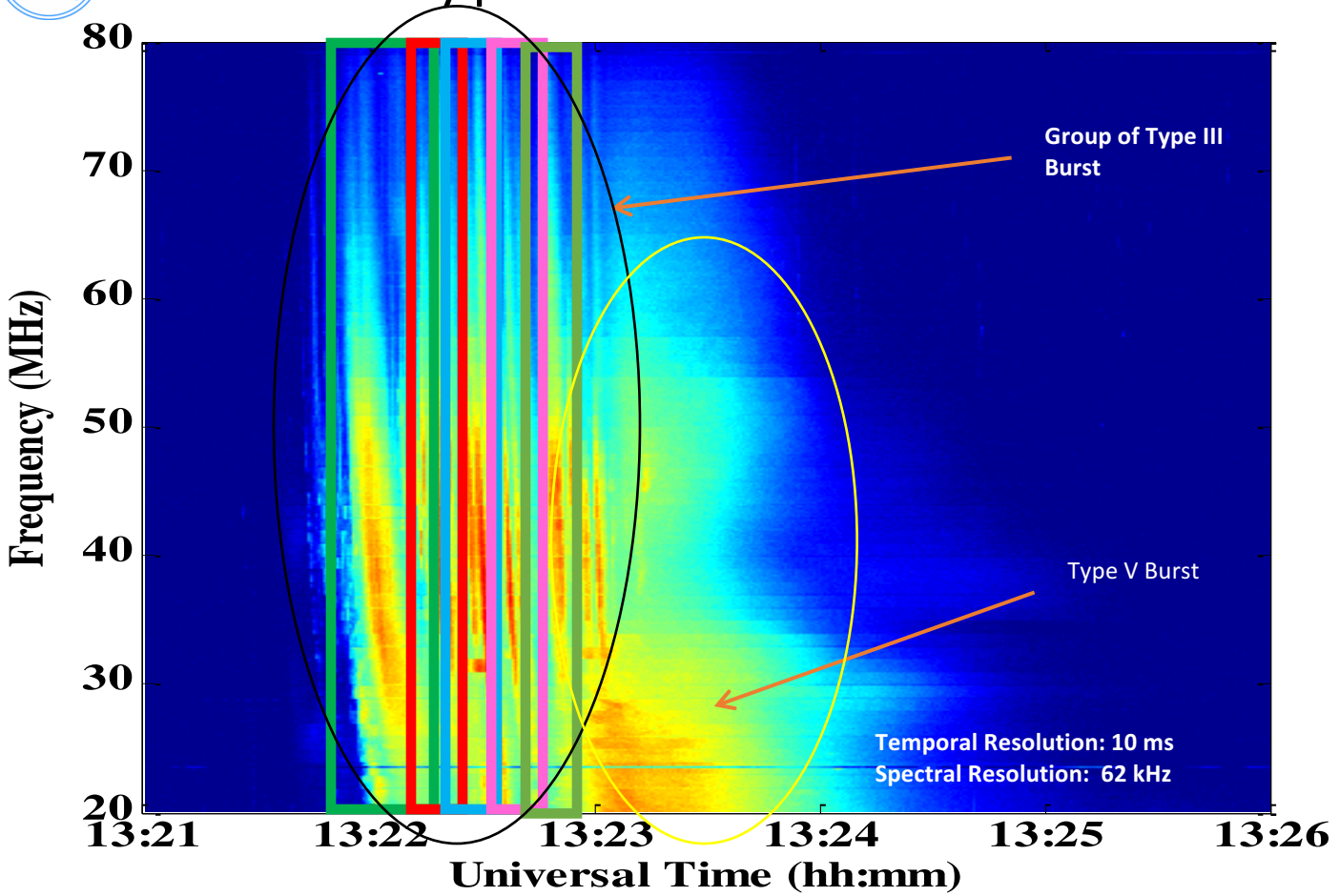
Type III: 30 March 2018

- AR2703
- Location: S06W69
- X-ray flare: B2.1
- Radio Signatures: 80-20 MHz
- Time: 13:22-13:24 UT

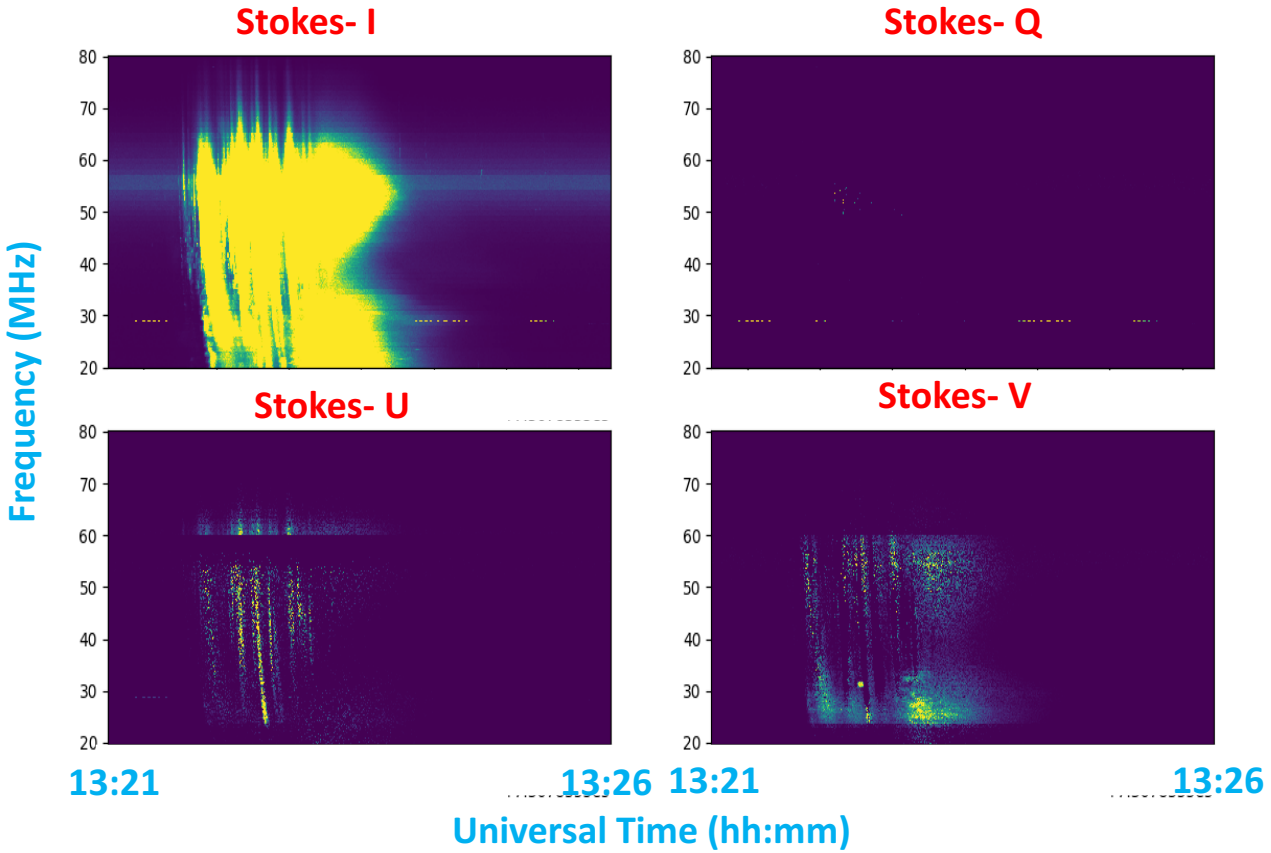




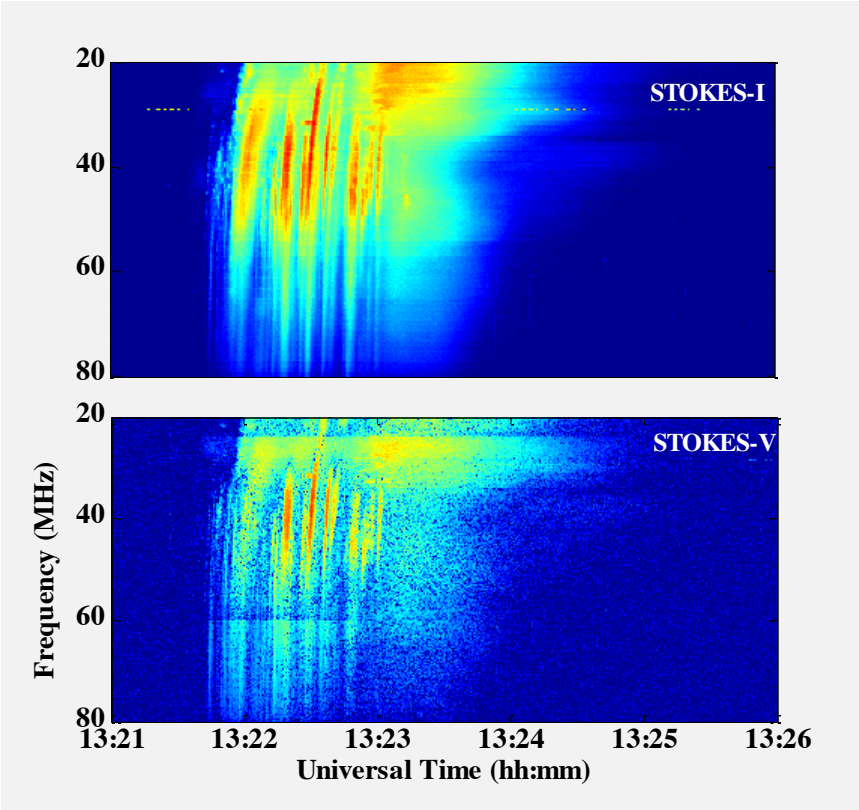
ndividual Type IIIs

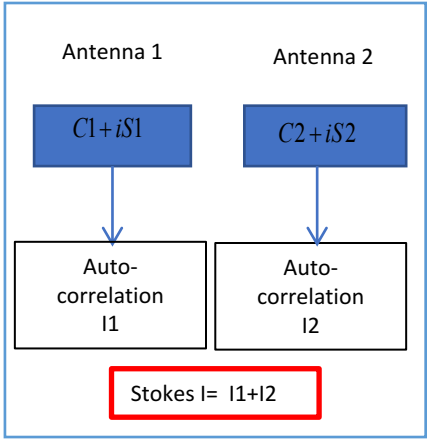


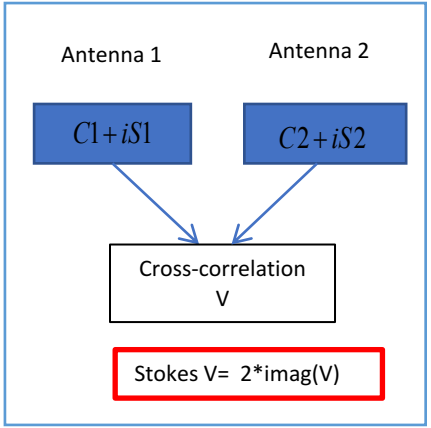
Beam Formed Observations



Stokes I & Stokes V Spectra

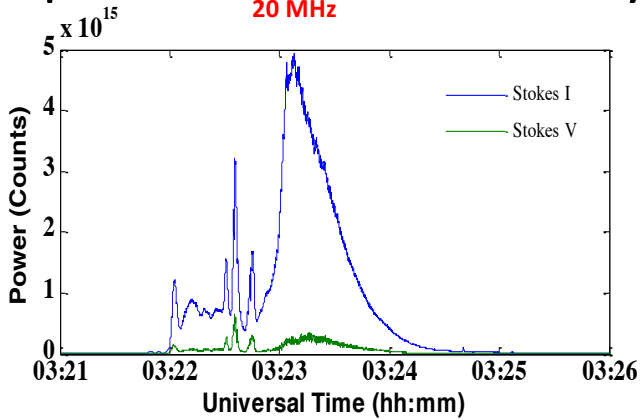




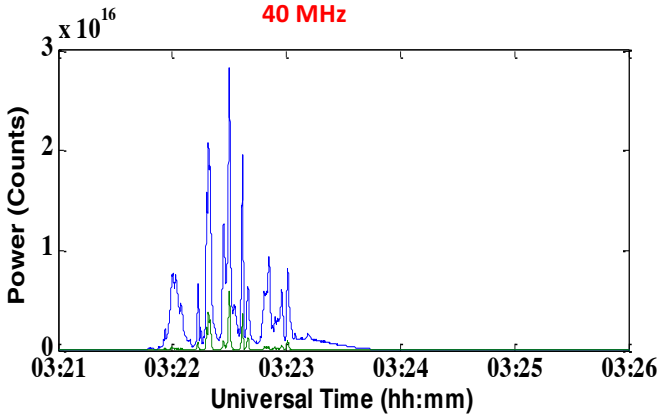


Temporal Profile of Type III Bursts

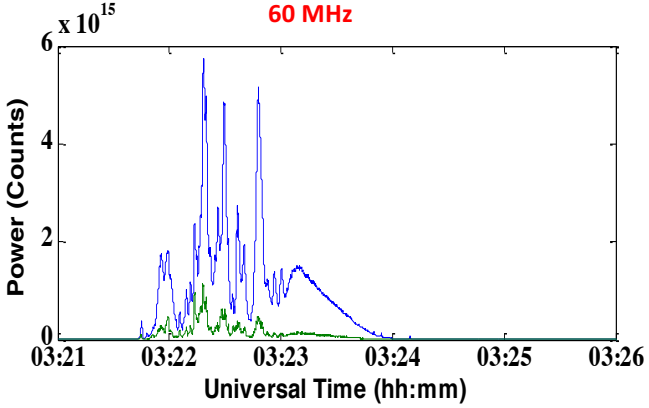
20 MHz



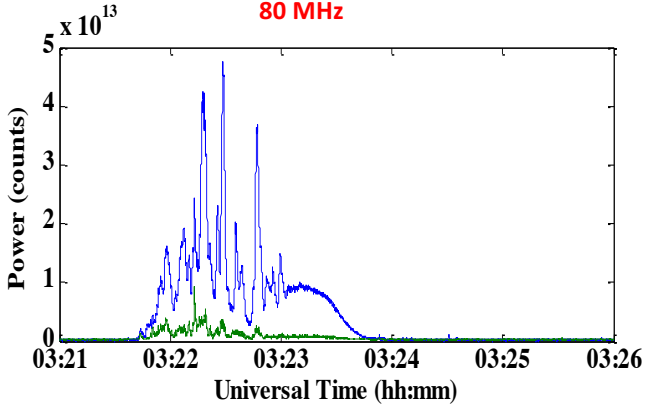
40 MHz



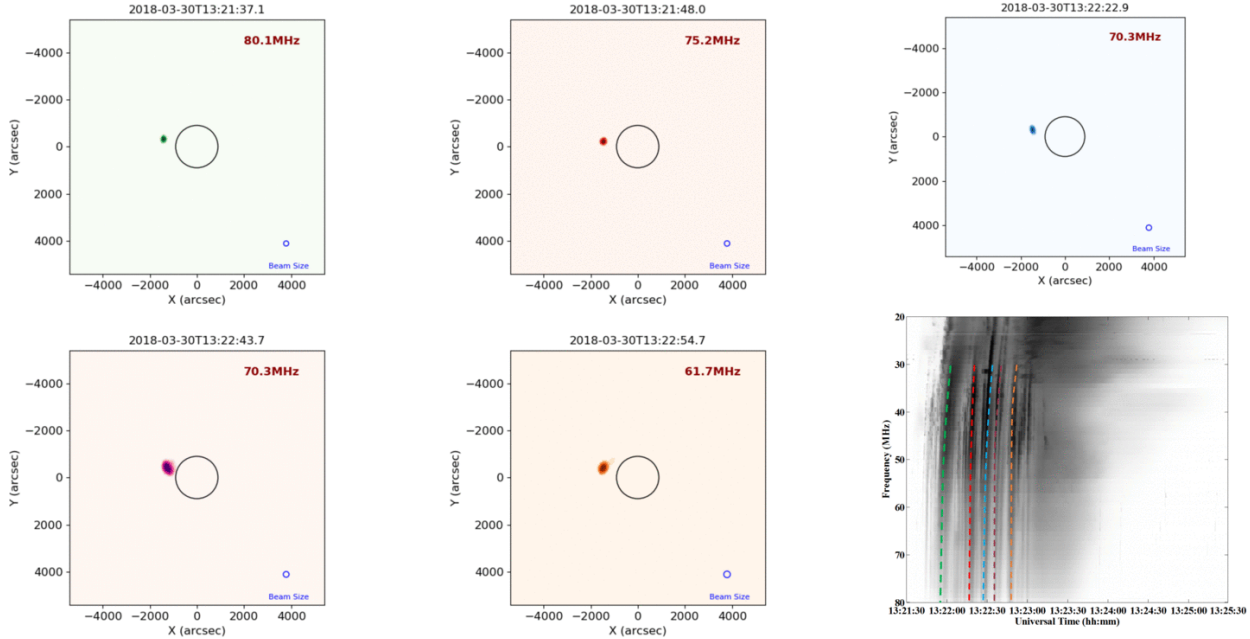
60 MHz



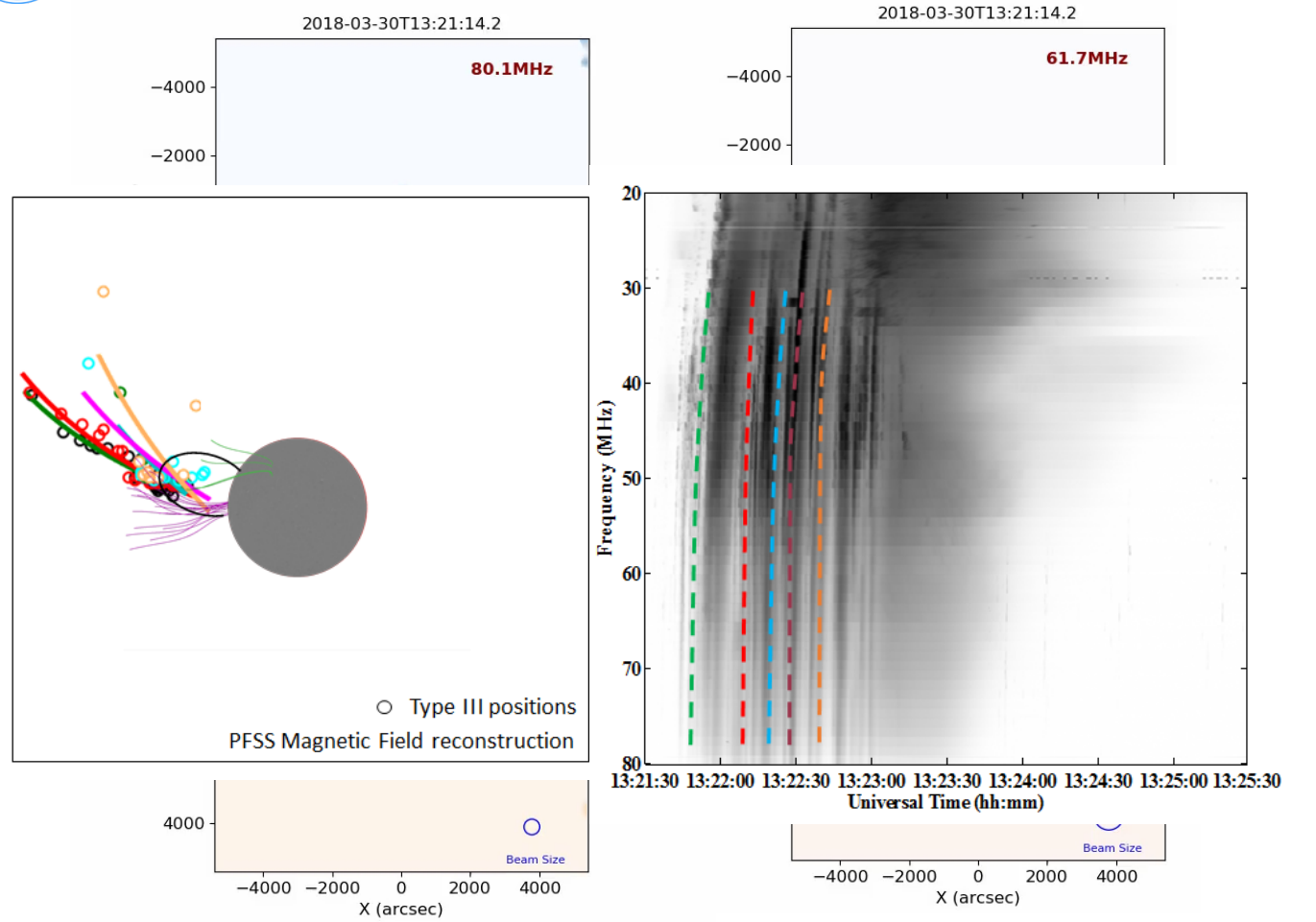
80 MHz



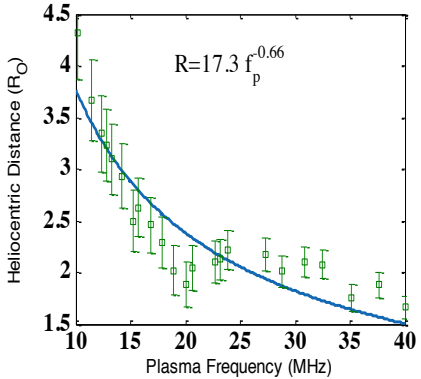
Interferometric Images of Type III bursts

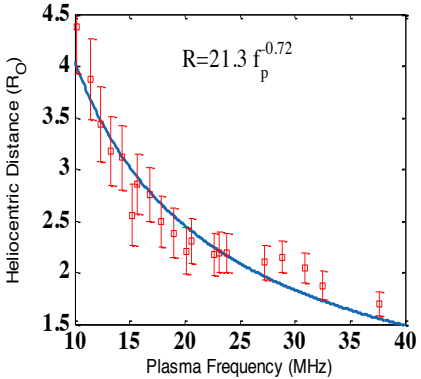


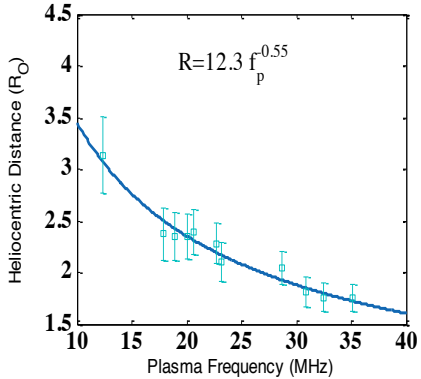
Temporal Resolution: 160 ms
Spectral Resolution: 195 kHz

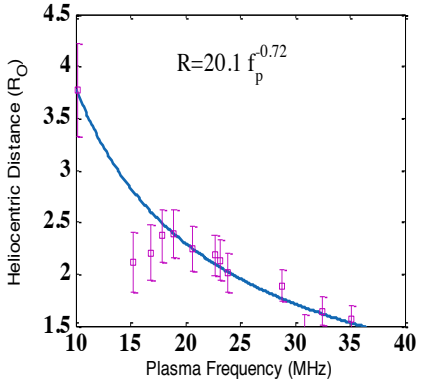

2018-03-30T13:21:14.2
80.1MHz
−4000
−2000
Type III positions
PFSS Magnetic Field reconstruction
4000
Beam Size
−4000 −2000 0 2000 4000
X (arcsec)
2018-03-30T13:21:14.2
61.7MHz
−4000
−2000
20
30
40
50
60
70
80
Frequency (MHz)
13:21:30 13:22:00 13:22:30 13:23:00 13:23:30 13:24:00 13:24:30 13:25:00 13:25:30
Universal Time (hh:mm)
Beam Size
−4000 −2000 0 2000 4000
X (arcsec)

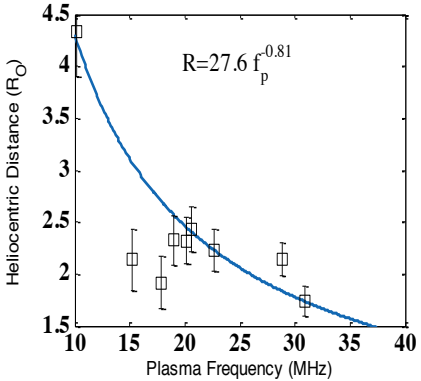
Height vs Plasma frequency

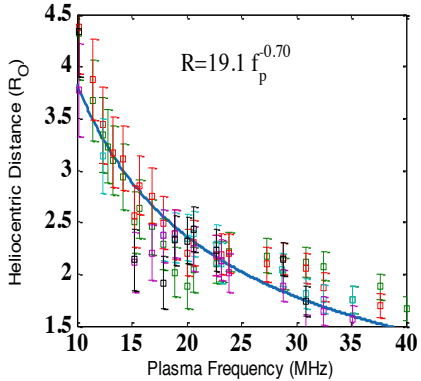




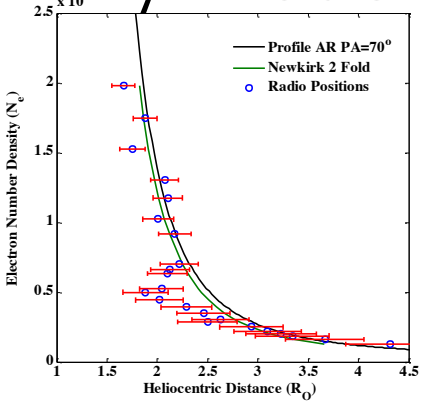


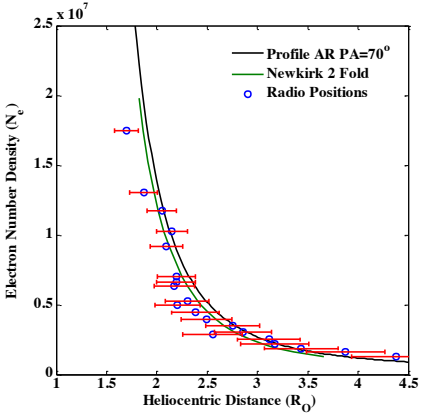


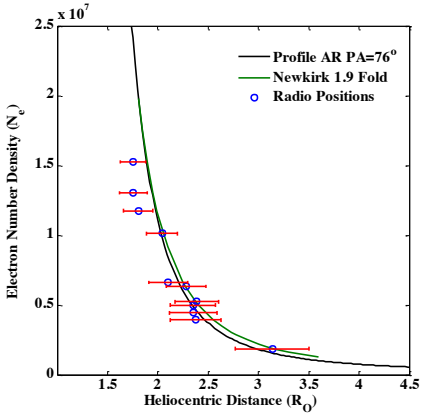


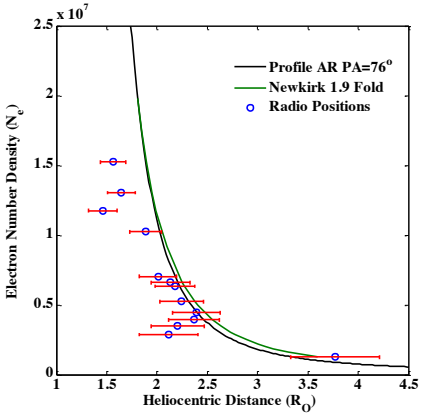


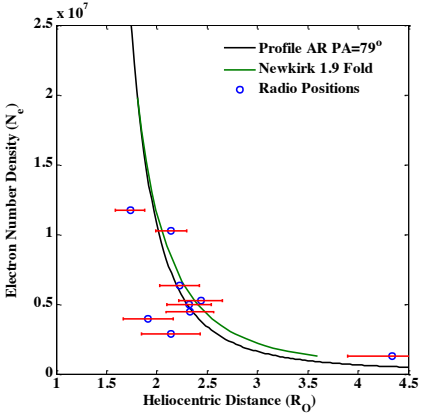
Density Model











$$f_p \propto \sqrt{N_e(r)}\ ;\ \mathrm{N}_e \propto\ 10^{\frac{4.32}{r}}$$

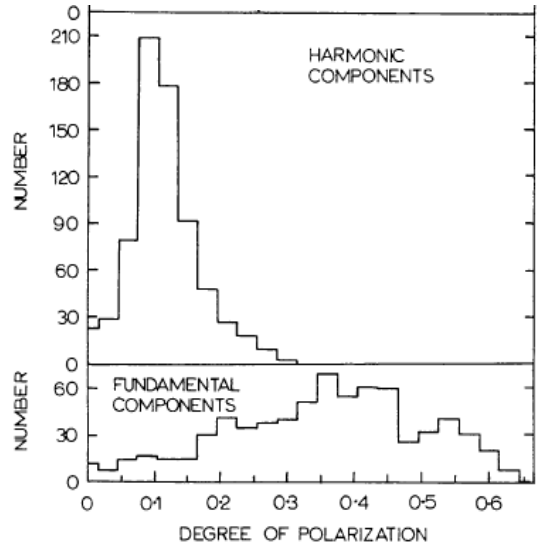
$f_p =$ plasma frequency

$N_e =$ electron no. density

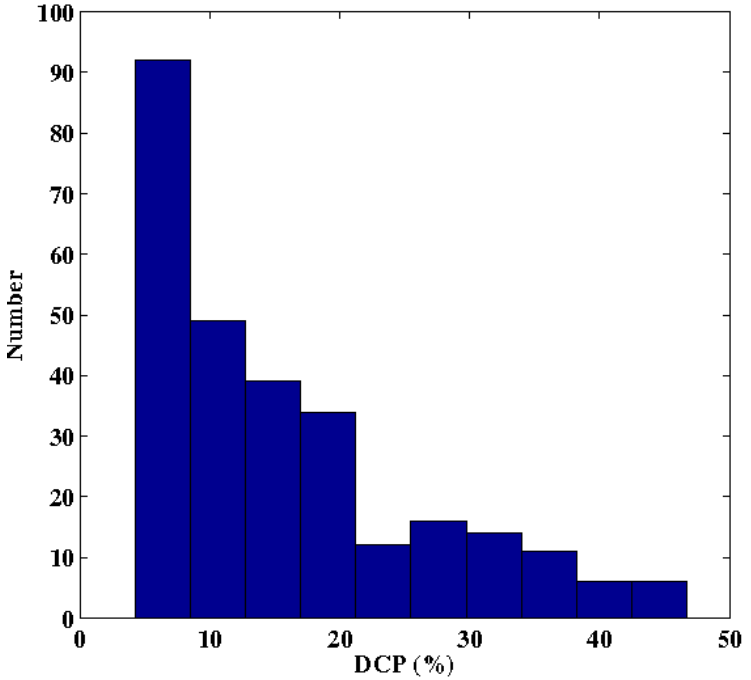
Newkirk 1961

Zucca et al 2014

Degree of Circular Polarization

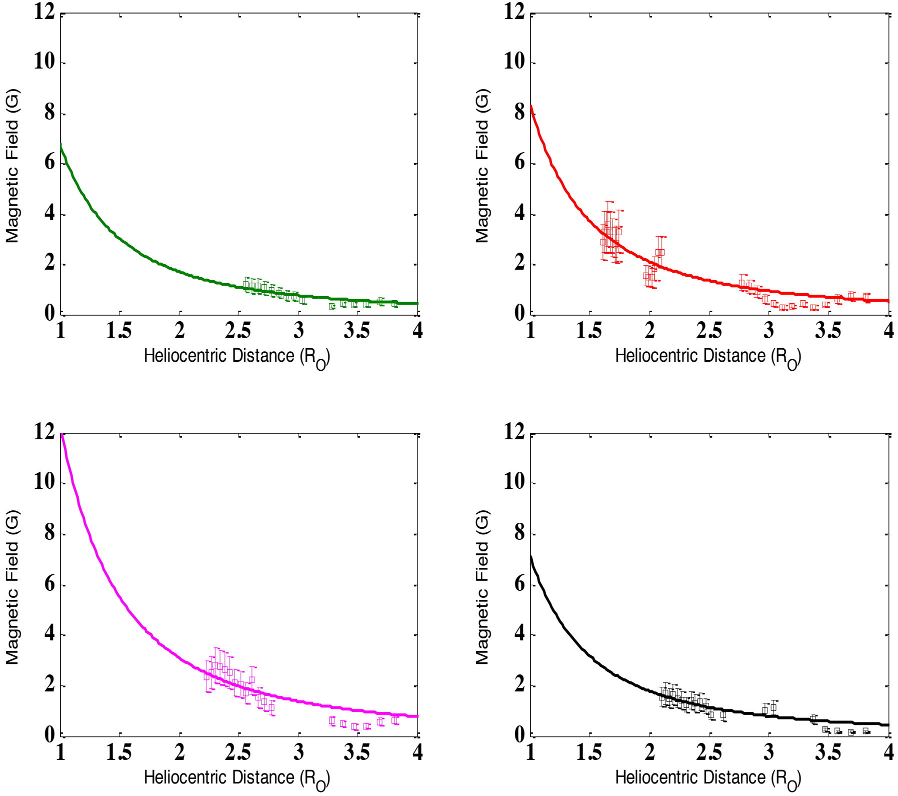


Dulk et al 1979



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

B field along Type III bursts



$B(r) = B_o\, r^{-2}$

B_o (T1) = 6.8 G

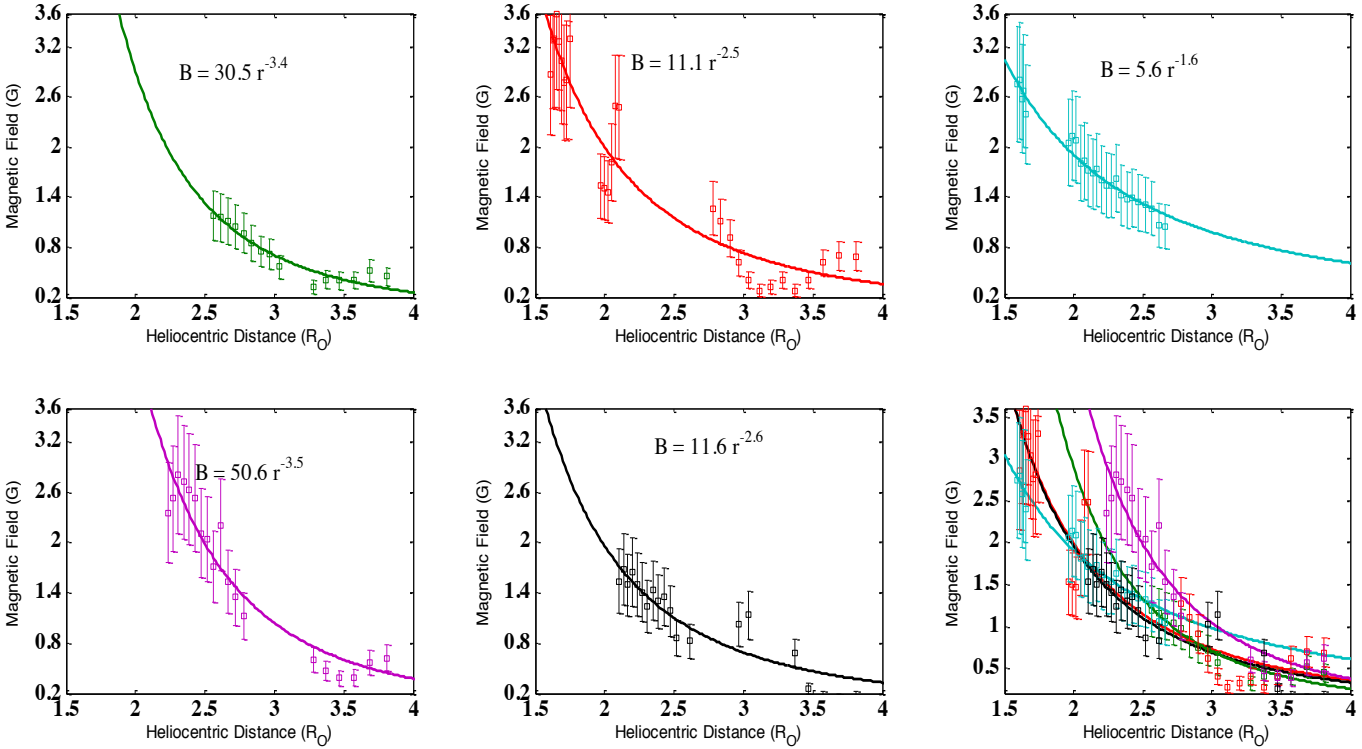
B_o (T2) = 8.3 G

B_o (T3) = 7.5 G

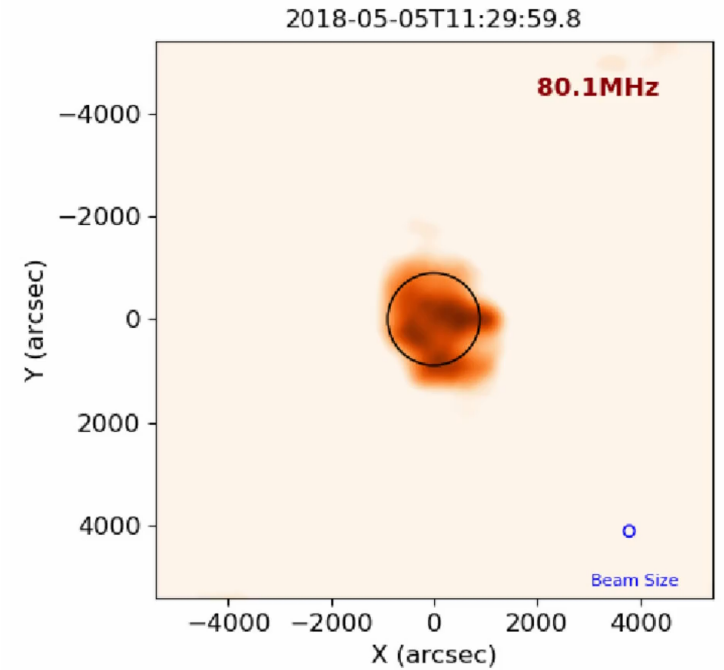
B_o (T4) = 12.3 G

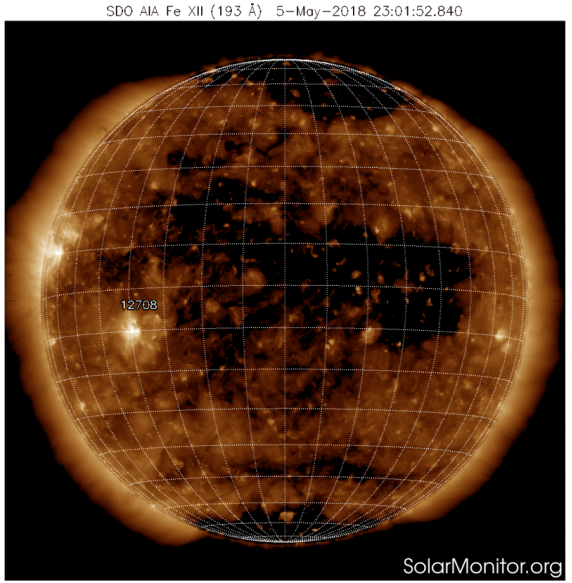
B_o (T5) = 7.1 G

B field along Type III bursts



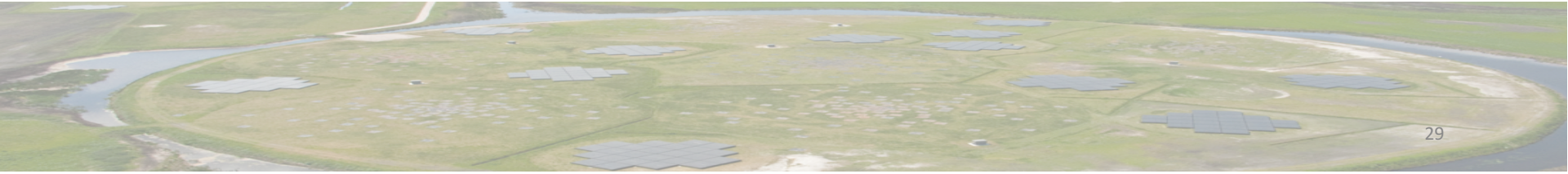
Coronal Hole Imaging with LOFAR





Complex Observing Settings

- Simultaneous Tied-Array and Interferometric
- First tests on the Sun currently in Cycle 9
- First comparison on the methods (they seem to be consistent)
- At the same time we can also observe Faraday Rotation from pulsars to estimate the B-field of CMEs (see Richard Fallows talk)



CONCLUSIONS

- LOFAR can observe the Sun in interferometric and tied-array beam mode.
- Interferometric mode has advantages as it returns the real image of the radio sources (limitation for the time resolution; possibility to push the correlator to 0.1 seconds).
- Tied array beam has the advantage of the time resolution (both methods simultaneously are the optimal observing campaign).
- Up to 5 simultaneous observations including solar, pulsar FR and scintillation have been successfully tested.