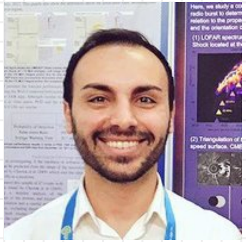
Interferometric and beam-formed observations of the Sun with LOFAR:

Present situation and future challenges

Pietro Zucca



HELLO!

I am Pietro Zucca

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Solar and Space weather observations

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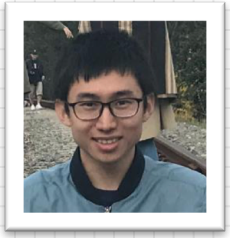
ASTRON LOFAR

ASTRON visiting Students

Anshu Kumari
Radio Astronomy Field Station, Gauribidanur
Indian Institute of Astrophysics, Bangalore, India



Hongyu Liu
KASI - Korea Astronomy and Space Science Institute,
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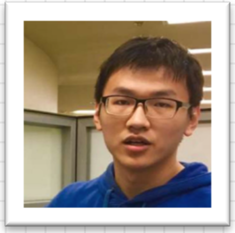

Pei Jin Zhang
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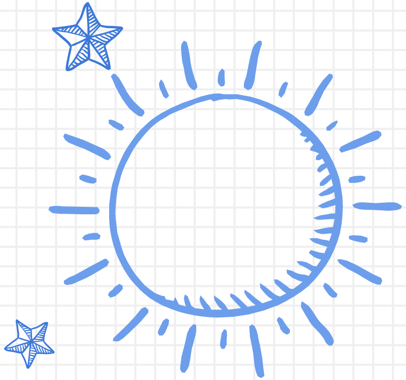
University of Science and Technology of China
Hefei, Anhui, China

Summary

- ✗ Observing the Sun with LOFAR
- ✗ Three consecutive shock signatures
- ✗ Open Challenges and Future Work

ASTRON LOFAR

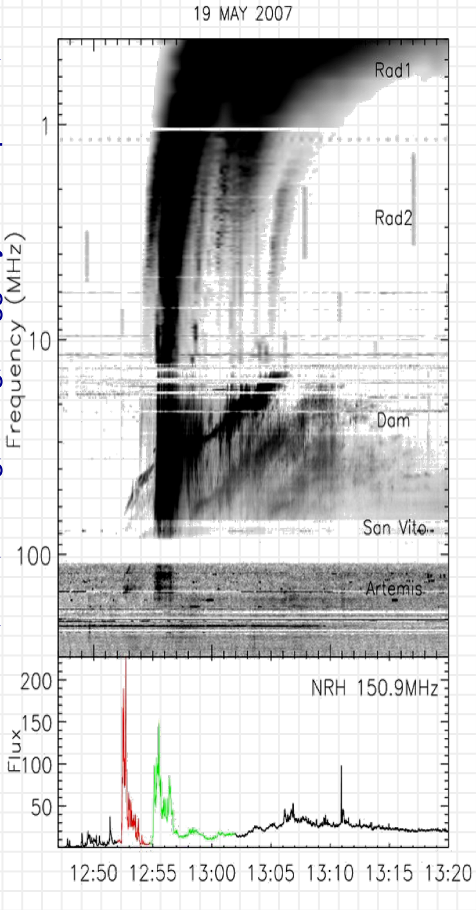


Observing the Sun

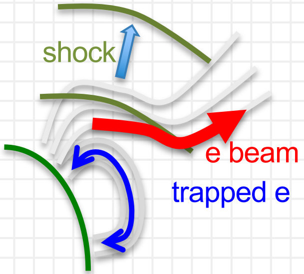
with LOFAR

The Radio Sun

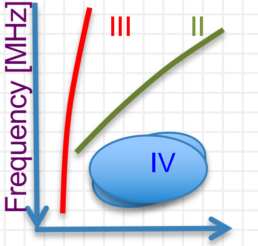
Kerdraon, Pick, Hoang, Wang, Haggerty 2010 ApJ 715, 468



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

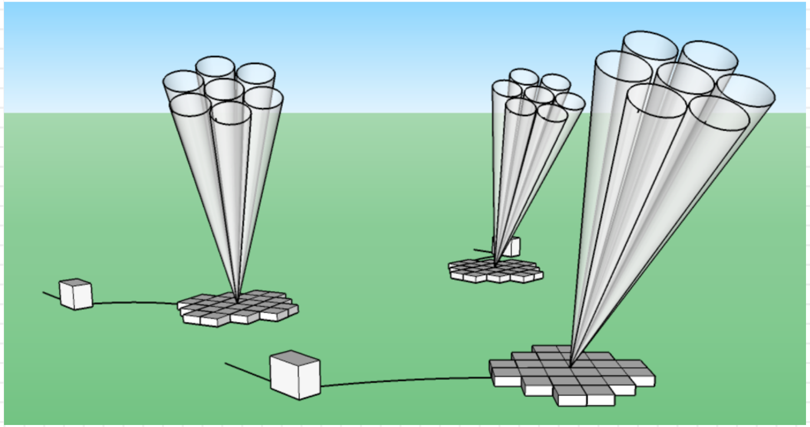


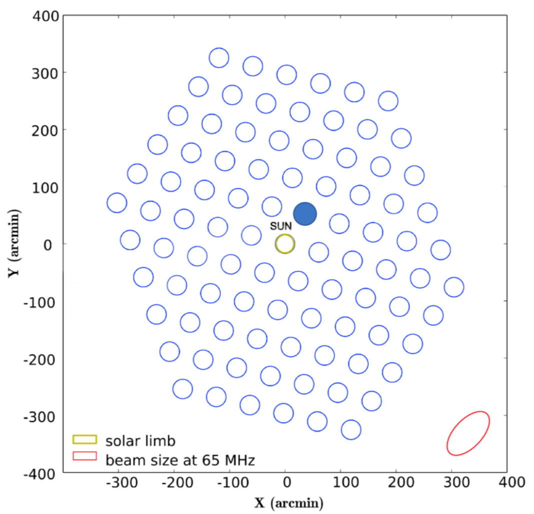
- Characteristic shapes of the radio burst spectra:




LOFAR
Birr
Dutch stations

Tied-Array beam mode

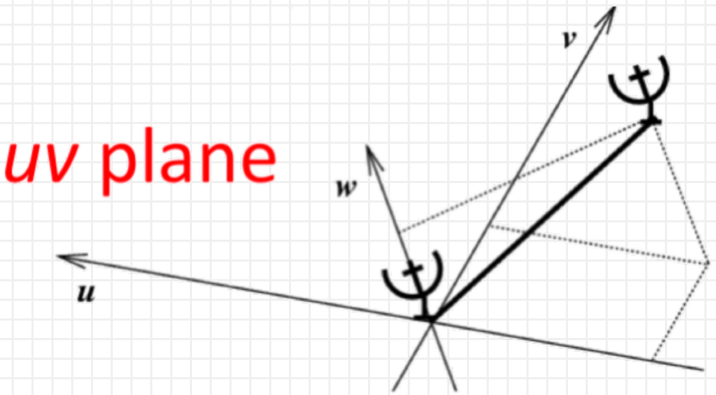




- A set of beams around the Sun in order to recreate a micropixel map.

Interferometric mode

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



ASTRON

LOFAR

Interferometric

- Spatial resolution (remote and international baselines)

Tied-Array

- Limited spatial resolution (only core stations)

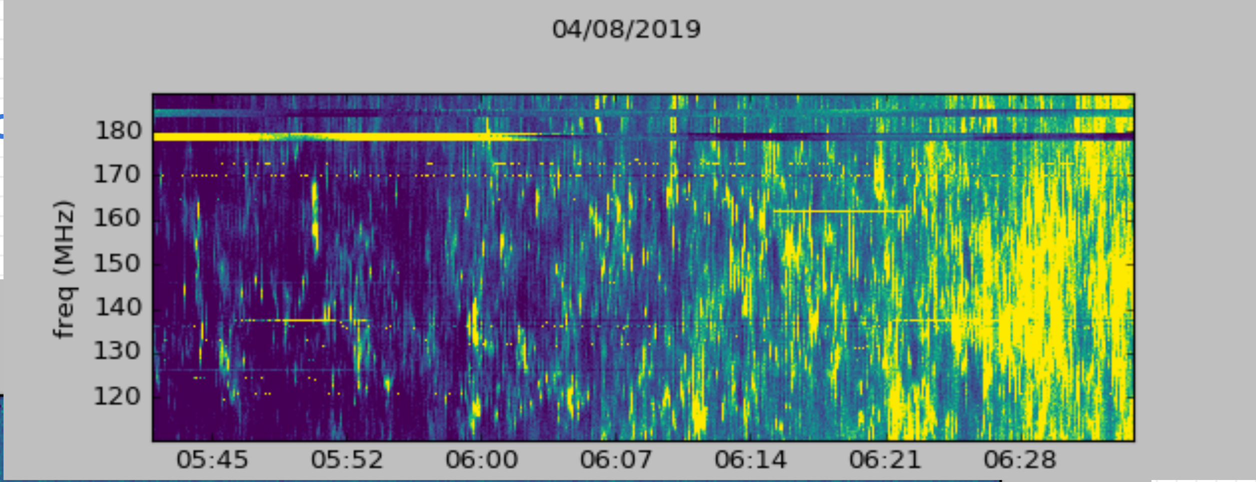
Tied-Array

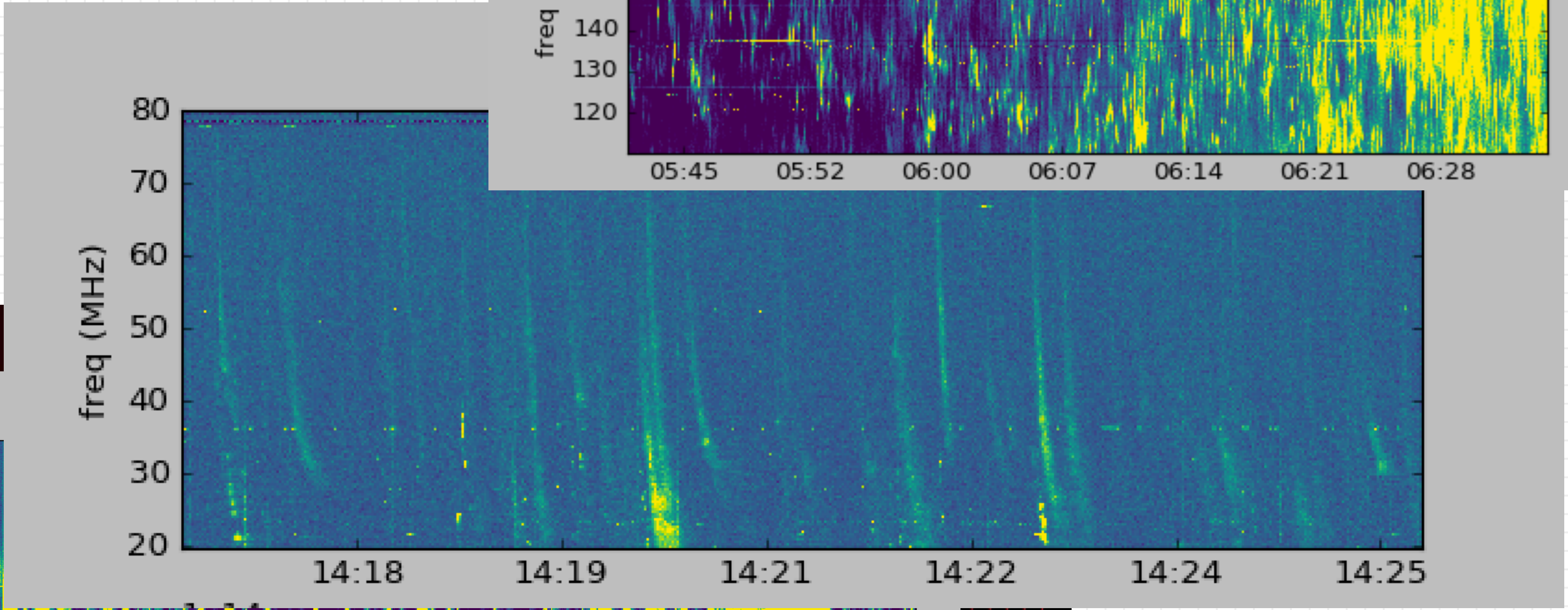
- Time resolution (milliseconds)

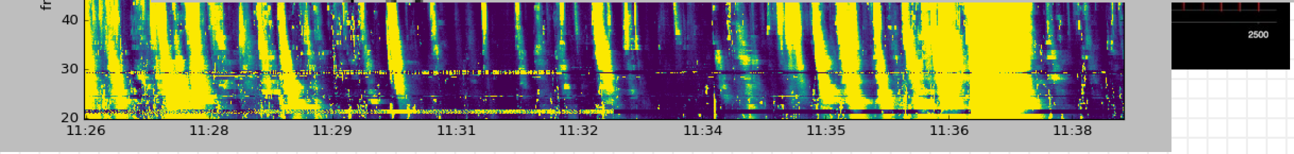
Interferometric

- Limited time resolution (0.16 seconds)

LOFAR can observe Tied
same time...



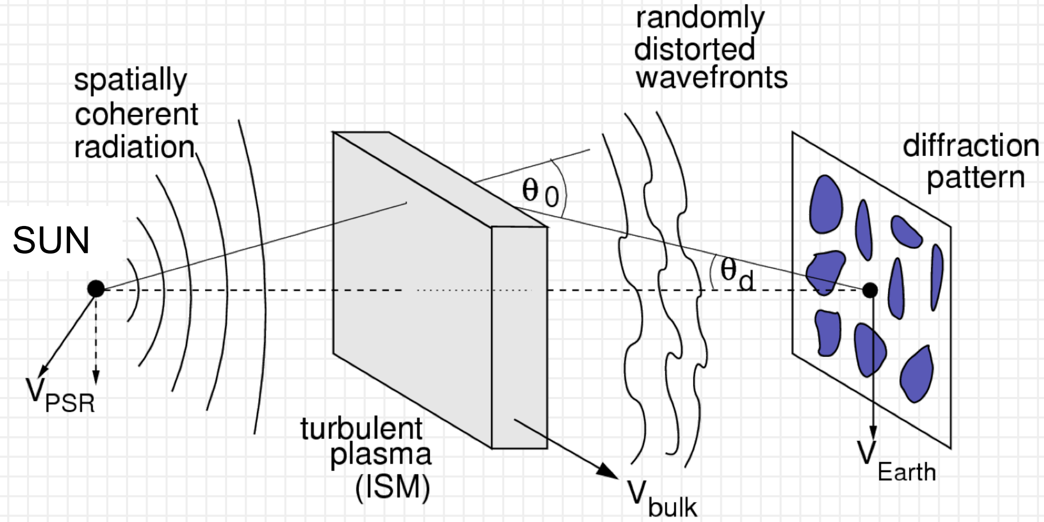




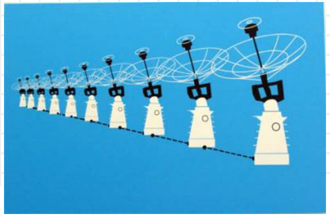
Using long baseline

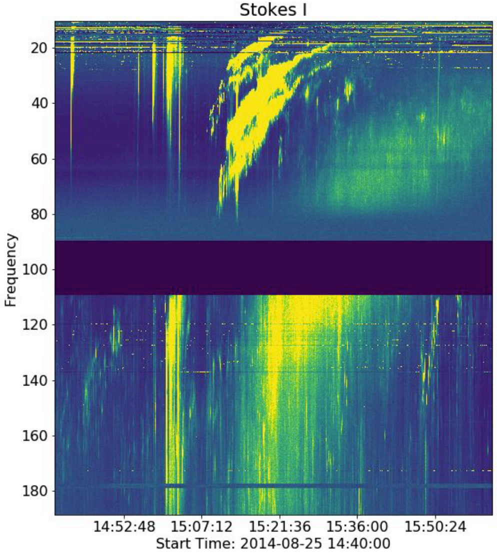
Validating LOFAR observations – Comparison with NRH

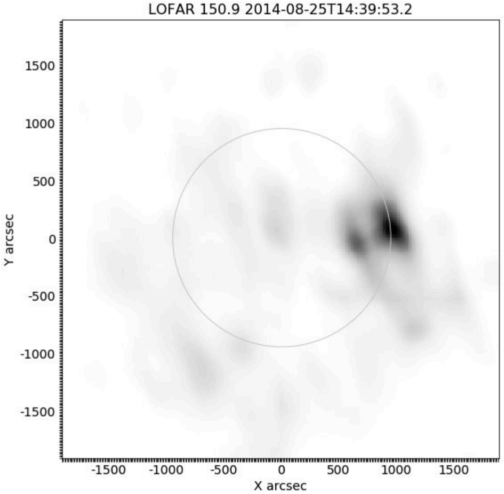
radio wave scattering and turbulence

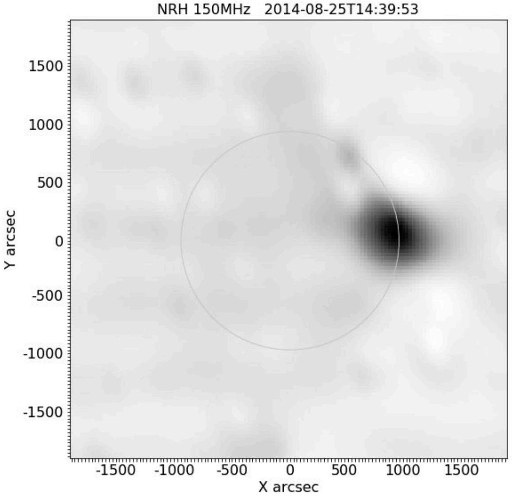


Comparison of LOFAR imaging with NRH

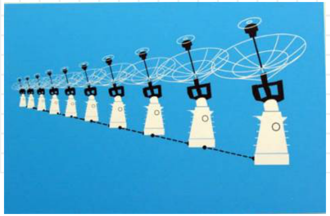


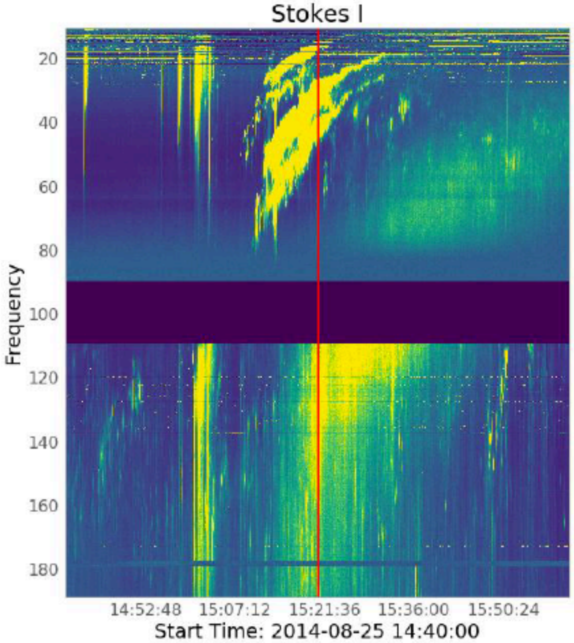


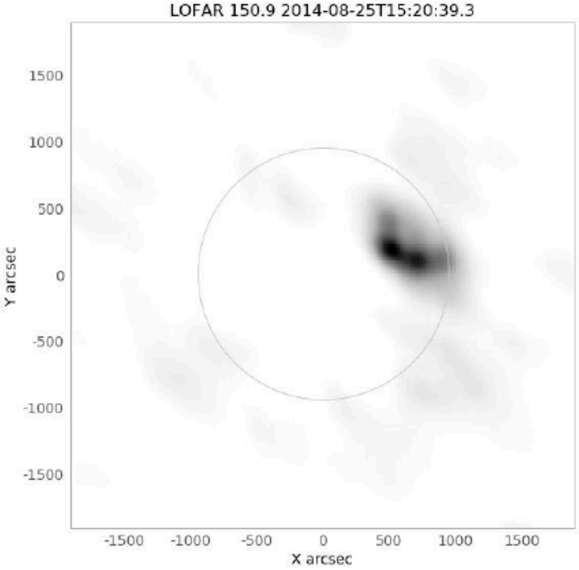


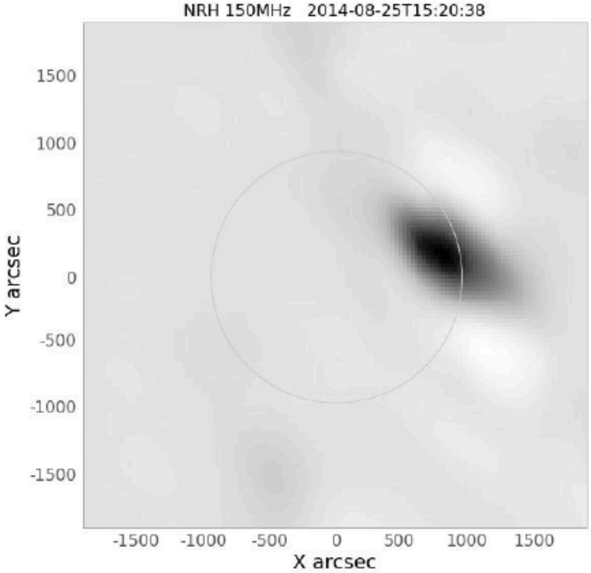


Comparison of LOFAR imaging with NRH

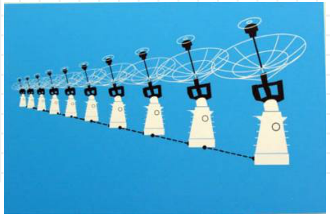


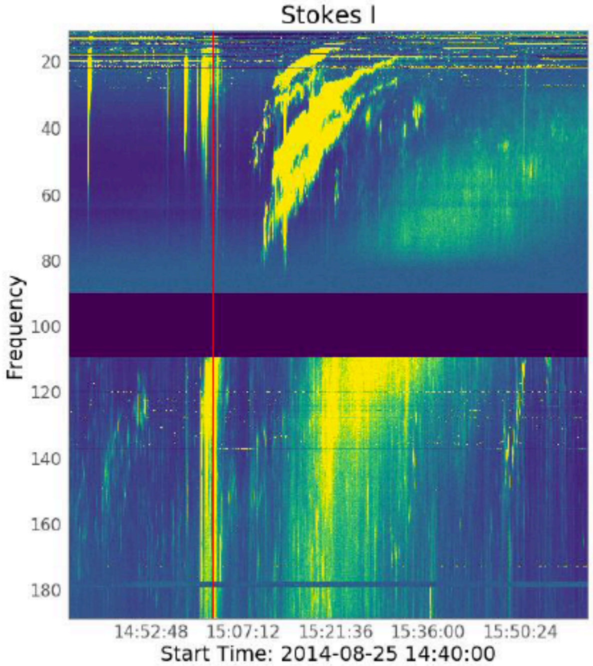


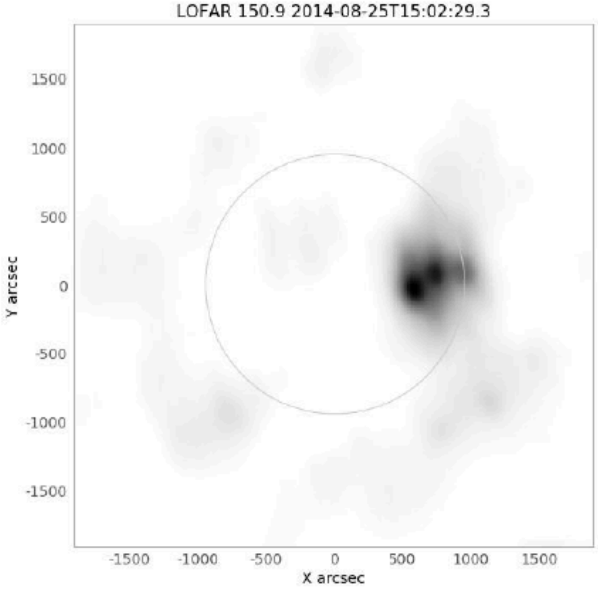


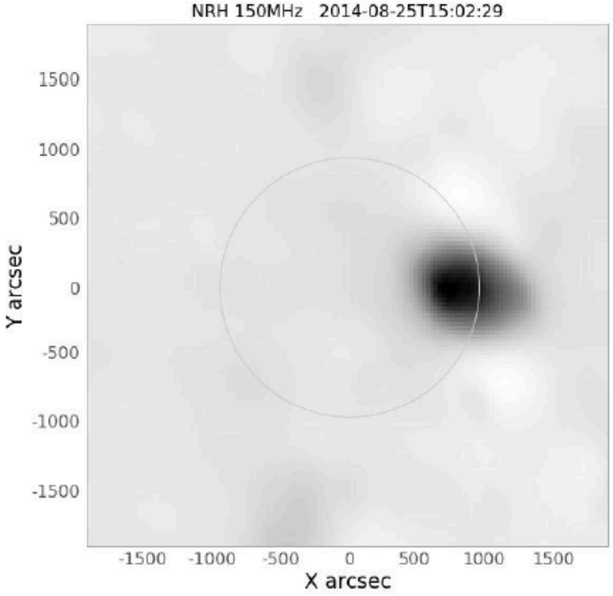


Comparison of LOFAR imaging with NRH

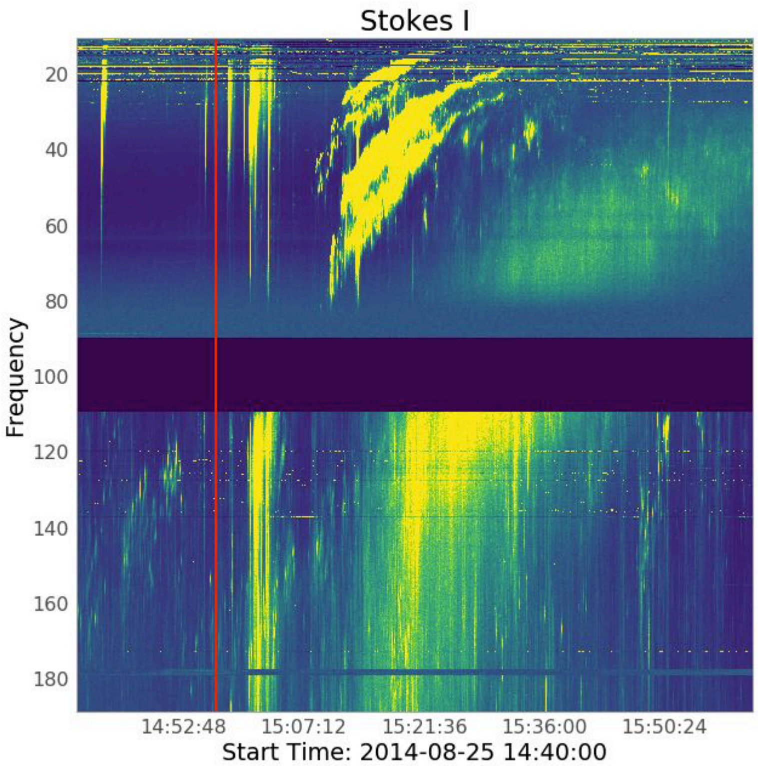


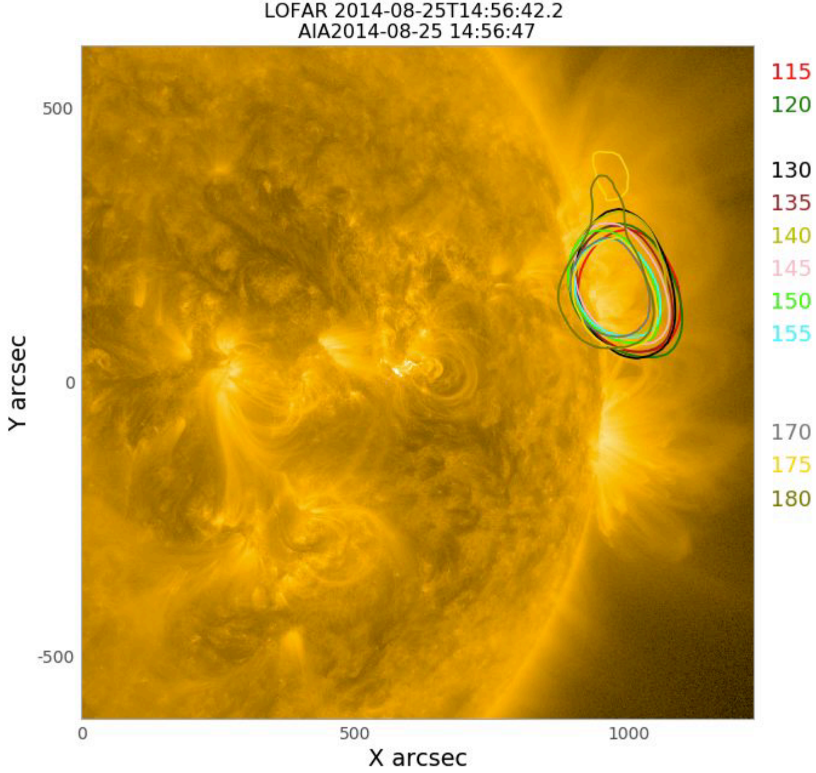






Imaging of a Type IV radio burst

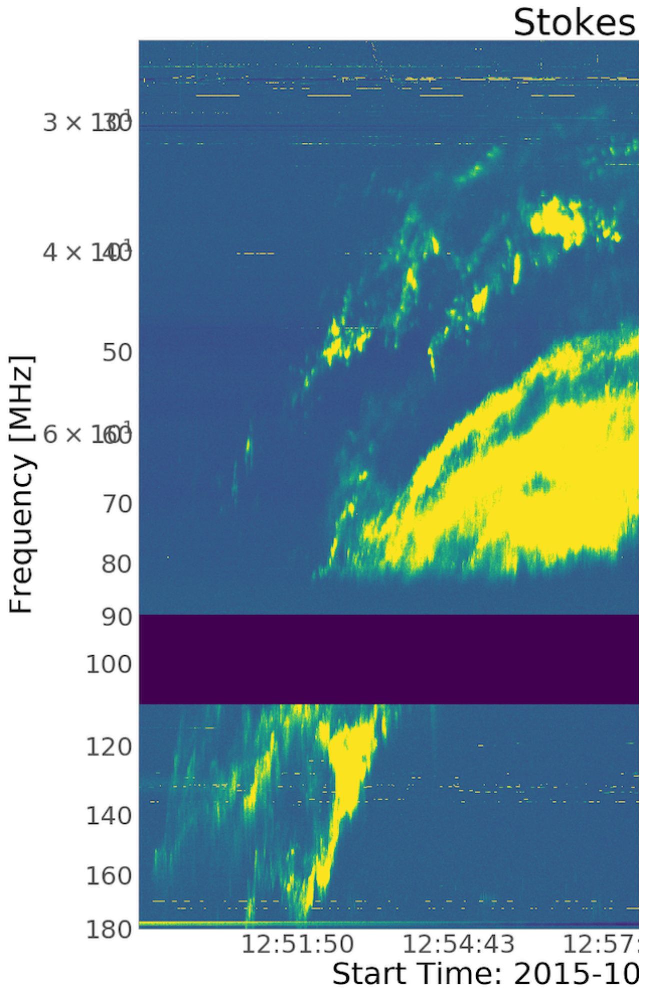




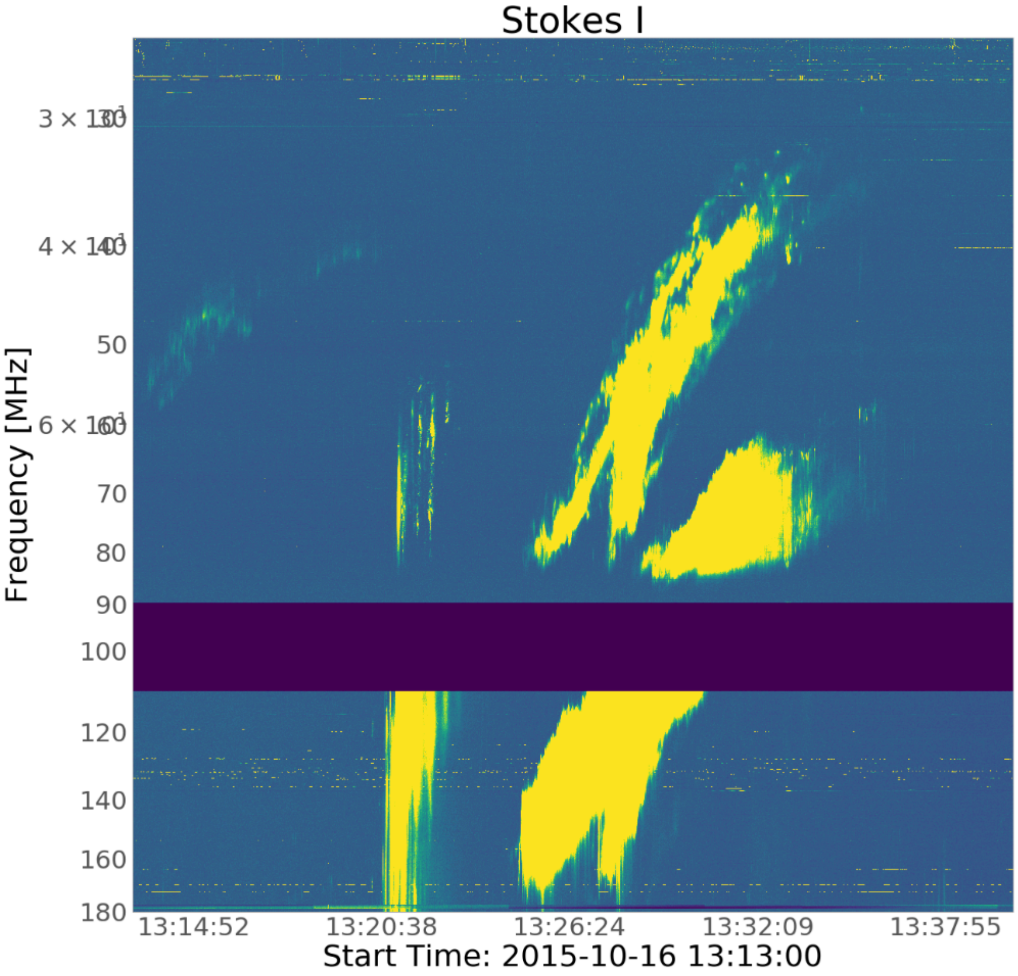
Liu, Zucca, Cho et al. in prep.

Shock Signatures in the Corona

Type II radio burts

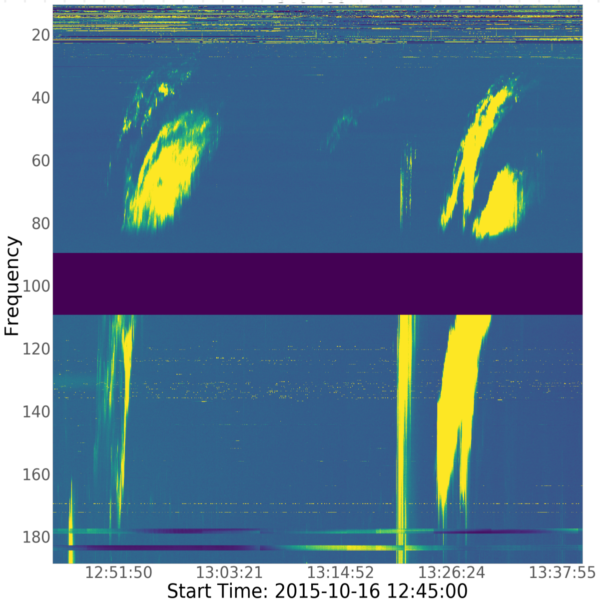


Stokes
3 × 10^1
30
4 × 10^1
40
50
6 × 10^1
60
70
80
90
100
120
140
160
180
Frequency [MHz]
12:51:50
12:54:43
12:57:
Start Time: 2015-10

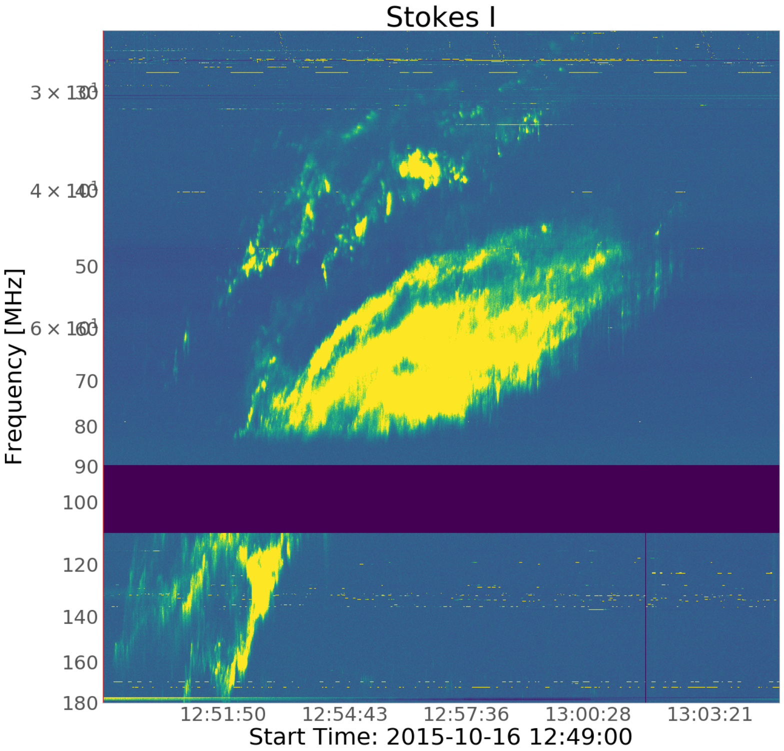


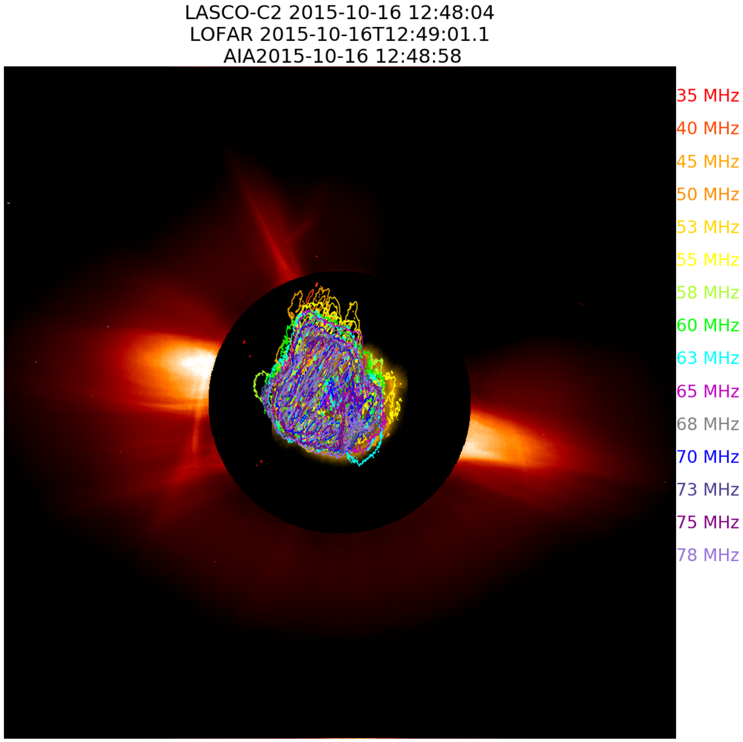
Stokes I
3 × 10^1
30
4 × 10^1
40
50
6 × 10^1
60
70
80
90
100
120
140
160
180
Frequency [MHz]
13:14:52
13:20:38
13:26:24
13:32:09
13:37:55
Start Time: 2015-10-16 13:13:00

Event – CME – Flare

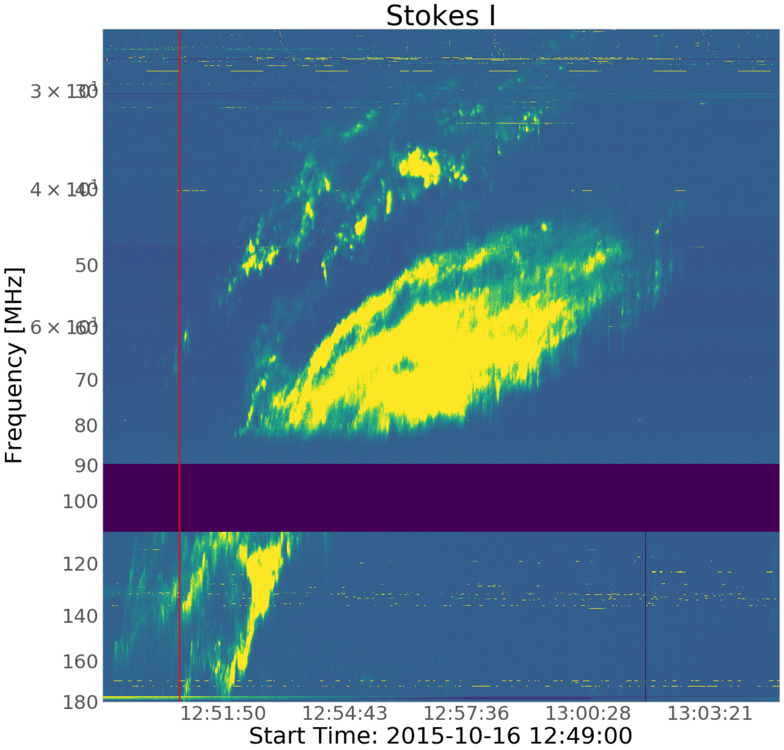


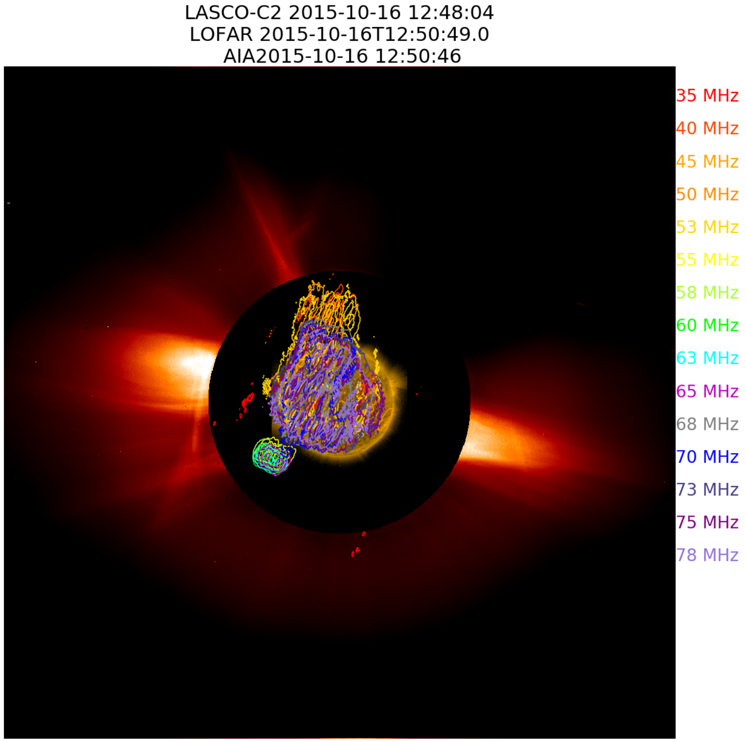
First Type II sequence



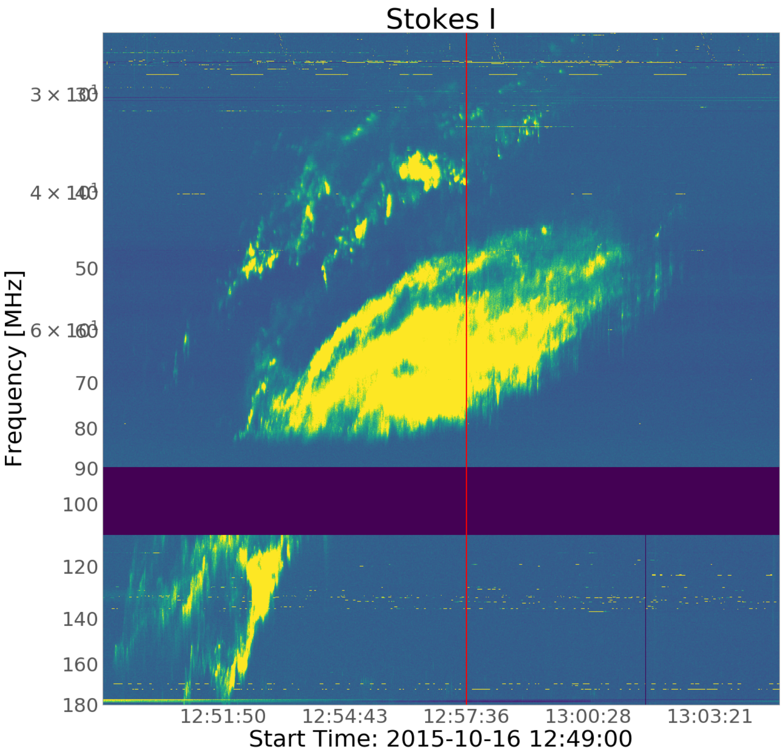


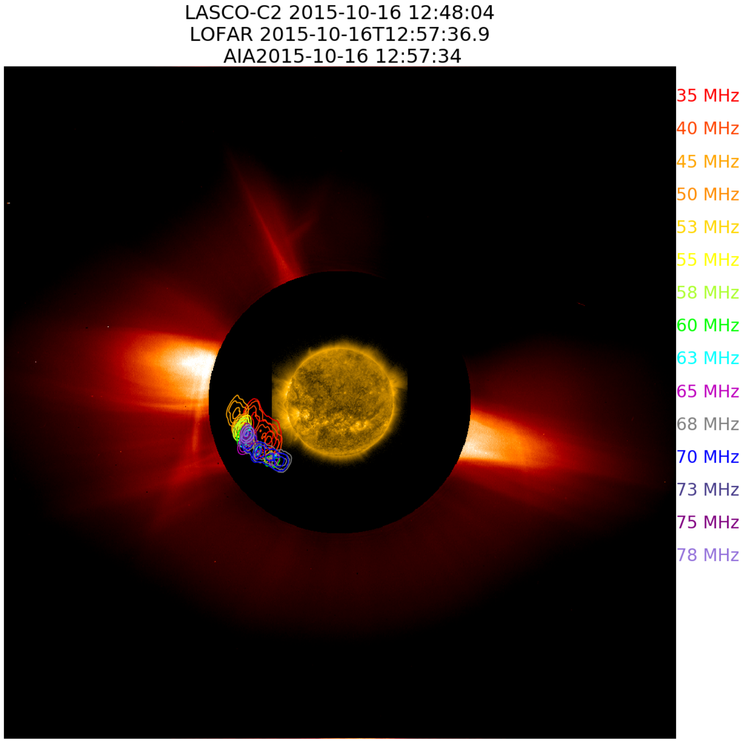
First Type II sequence



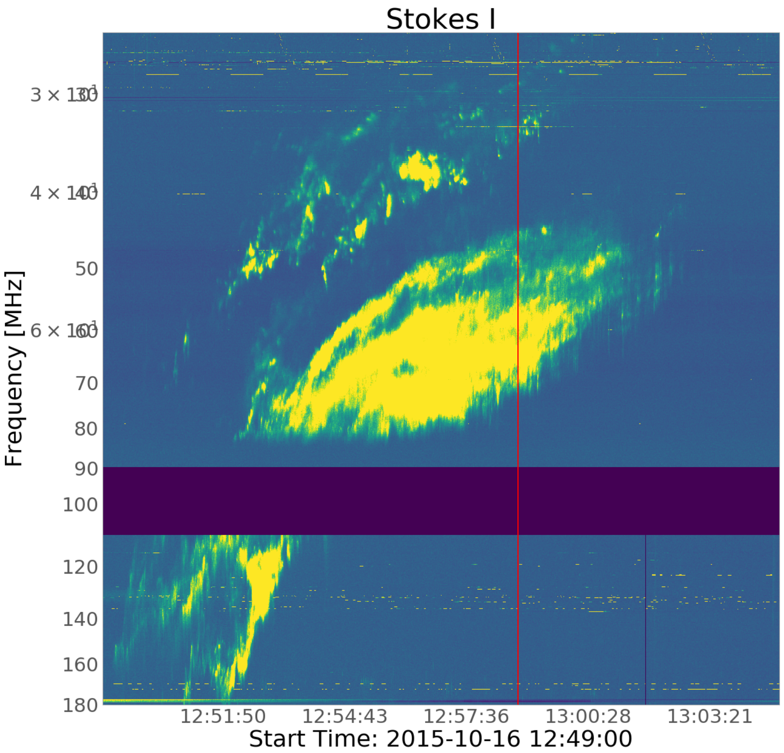


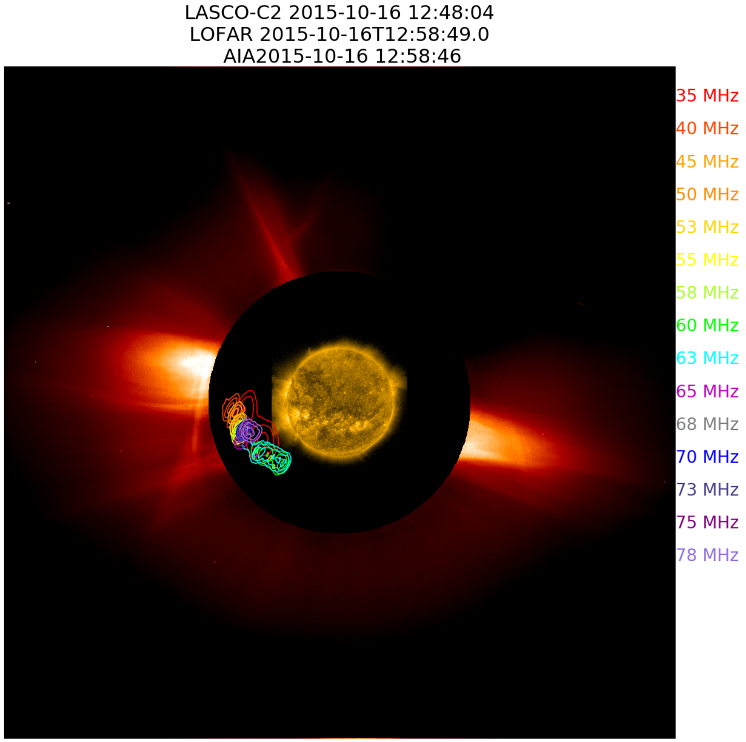
First Type II sequence



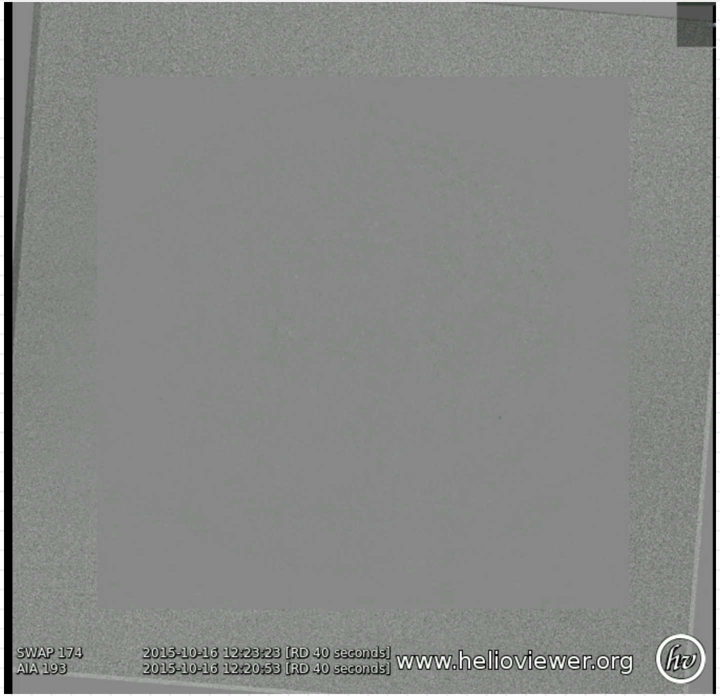


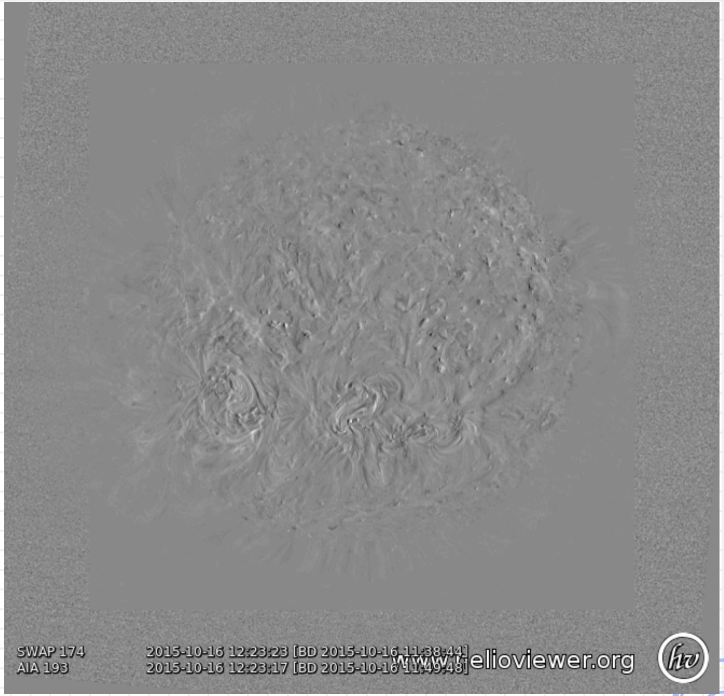
First Type II sequence



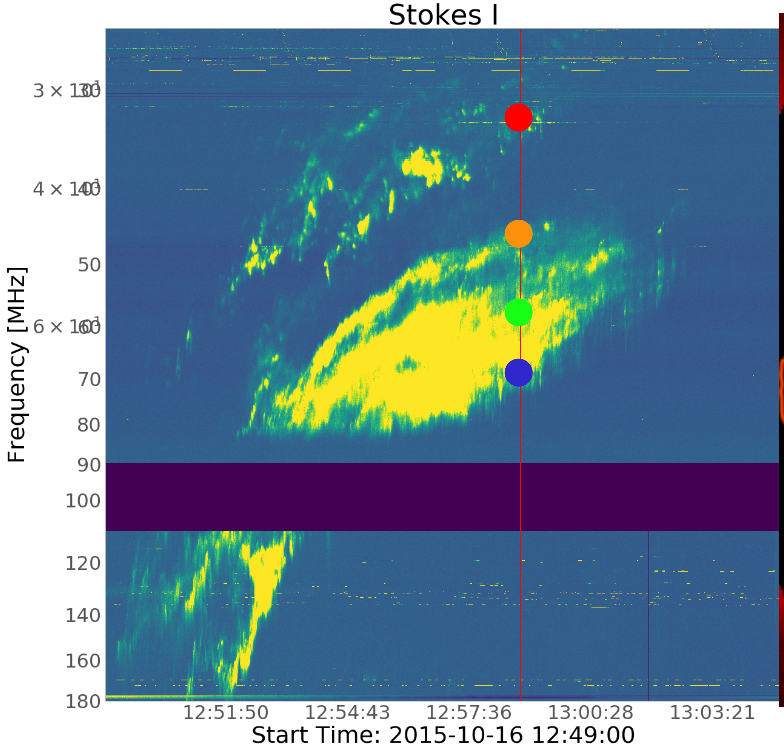


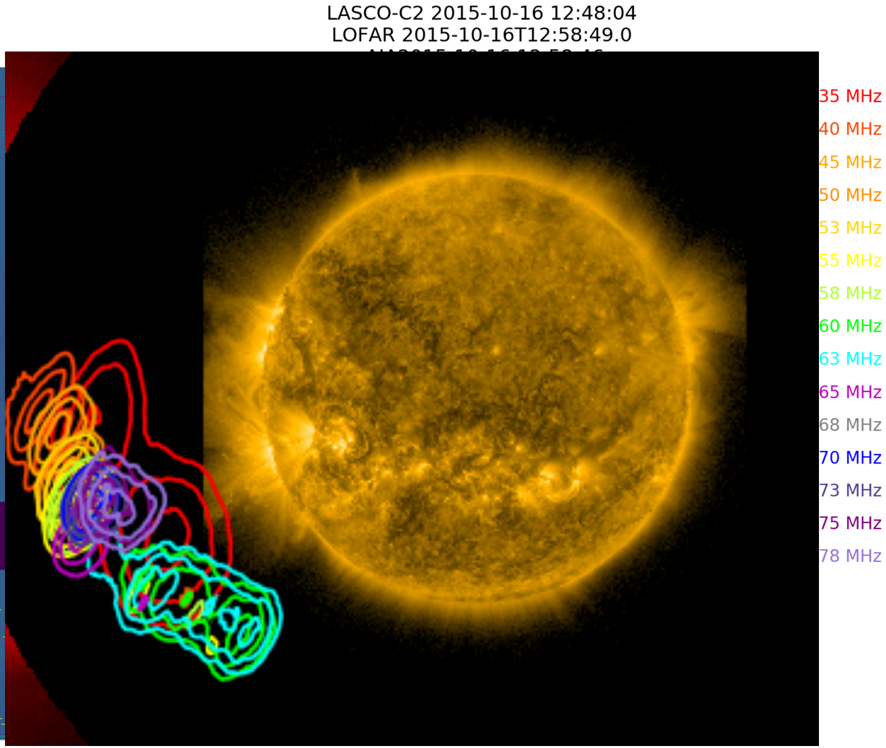
EUV running difference

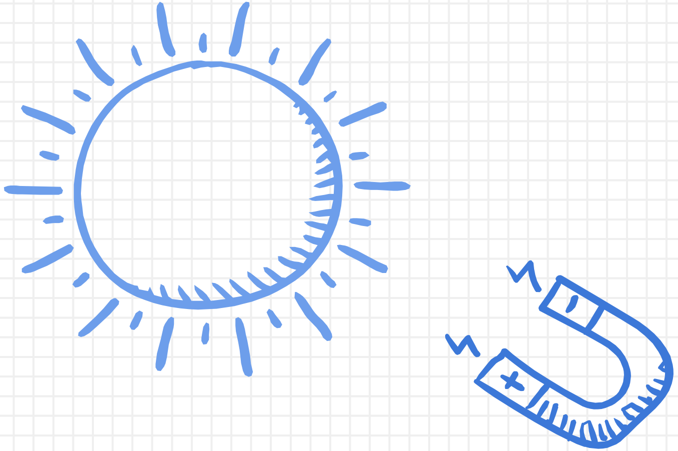




EUV running difference







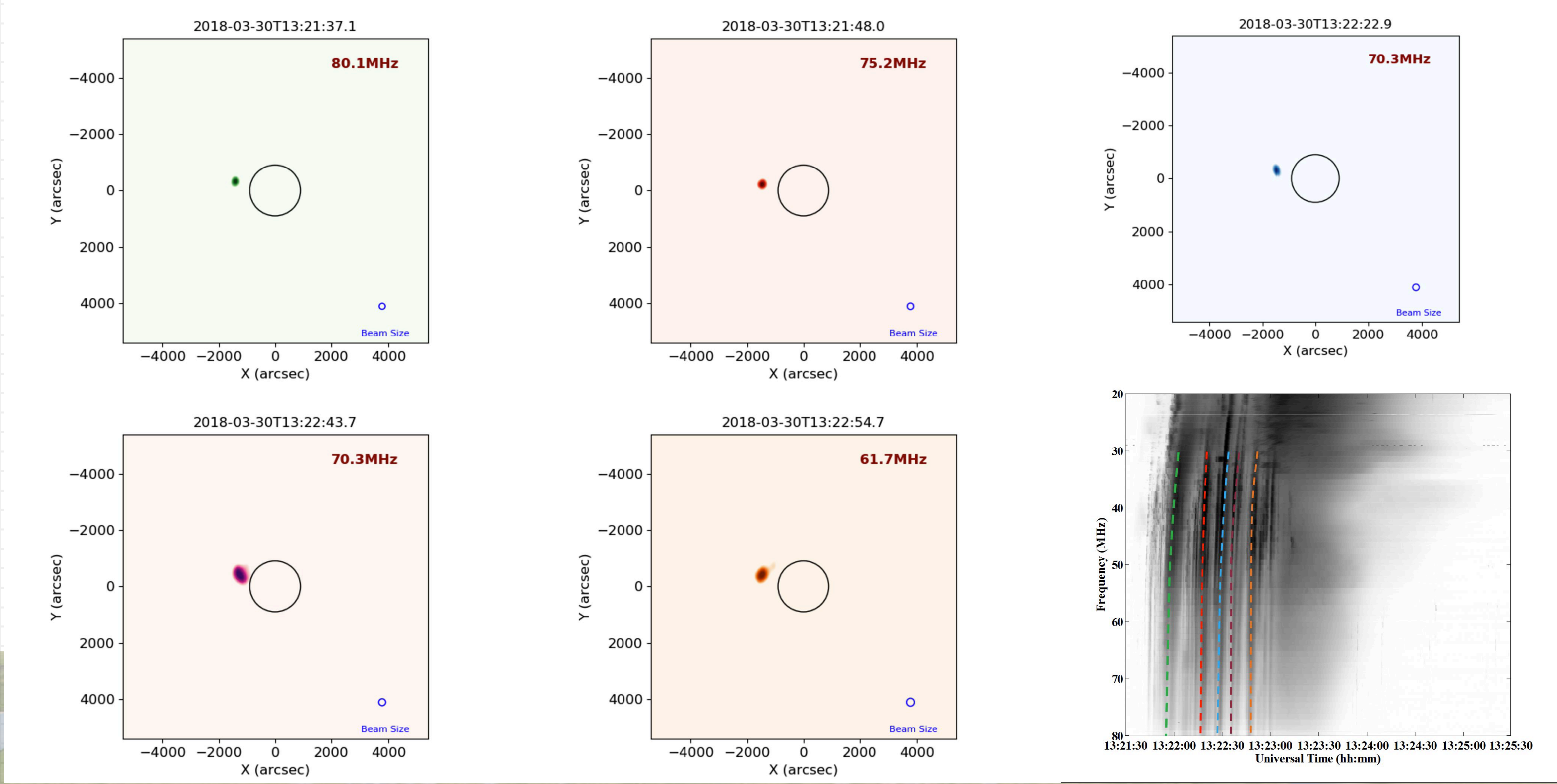
Coronal B-Field diagnostics

using radio polarization

ASTRON LOFAR

Interferometric observations

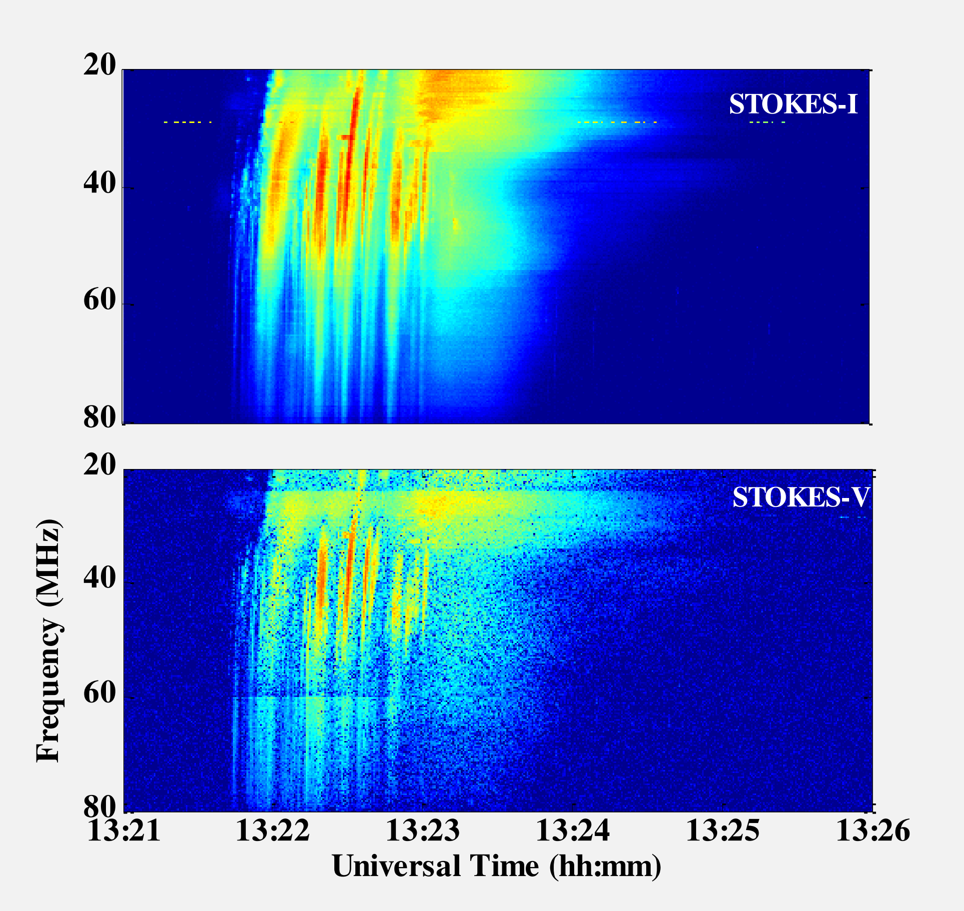
Temporal Resolution: 160 ms
Spectral Resolution: 195 kHz



Using the remote stations we can achieve ~13 arcsec at 50 MHz

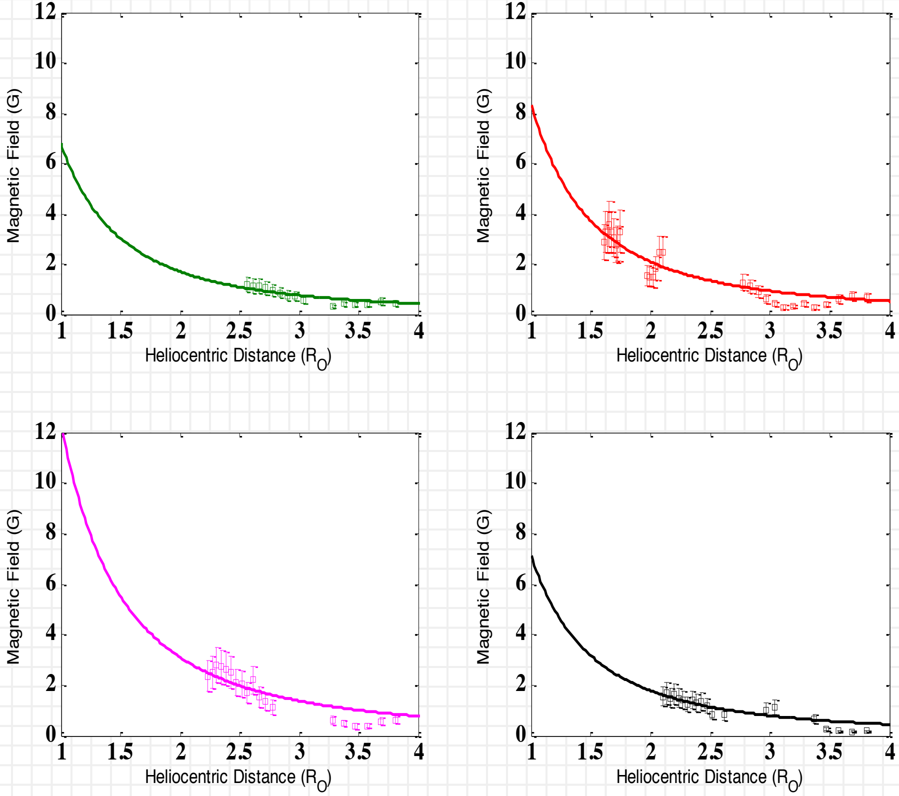
Kumari, Zucca et al. in prep

Full Stokes observations



Kumari, Zucca et al. in prep

Estimation of B –field along Type III bursts



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

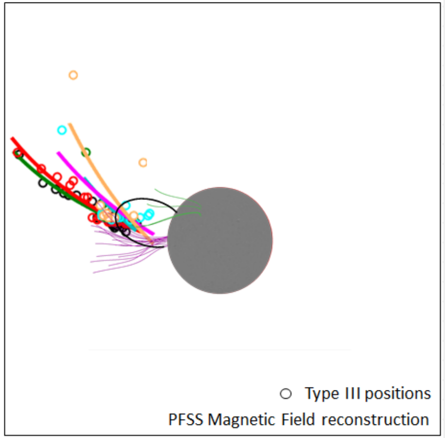
B_o (T1) = 6.8 G

B_o (T2) = 8.3 G

B_o (T3) = 7.5 G

B_o (T4) = 12.3 G

B_o (T5) = 7.1 G



Using full Stokes parameters from LOFAR spectrum we can estimate the coronal B-field along the type III burst propagation.

Kumari, Zucca et al. in prep

Let’s summarize some concepts

Long Baselines

✗ Use remote and international baselines

Full spectro-imagery

✗ Understand the origin of fine structures

Polarisation

✗ B-field diagnostics

ASTRON LOFAR

THANKS!

Any questions?

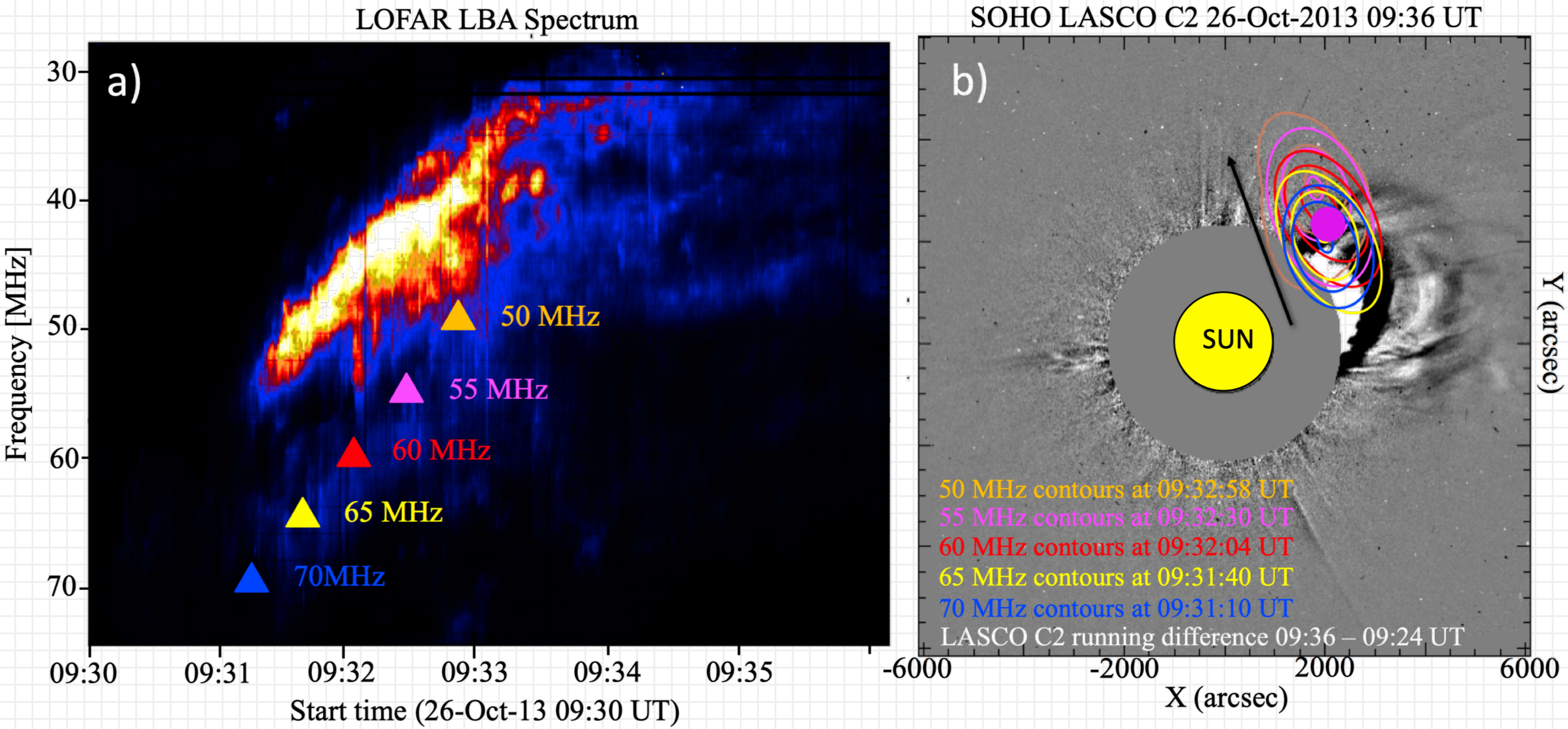
You can find me at

- @pietrozucca
- zucca@astron.nl

Extra Slides

Questions CME

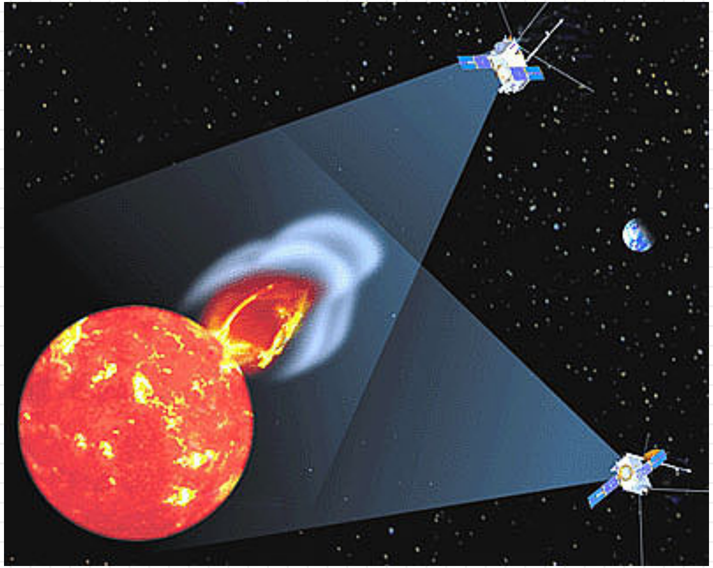
First Imaging of a Type II below 80 MHz



Zucca et al. 2018 A&A

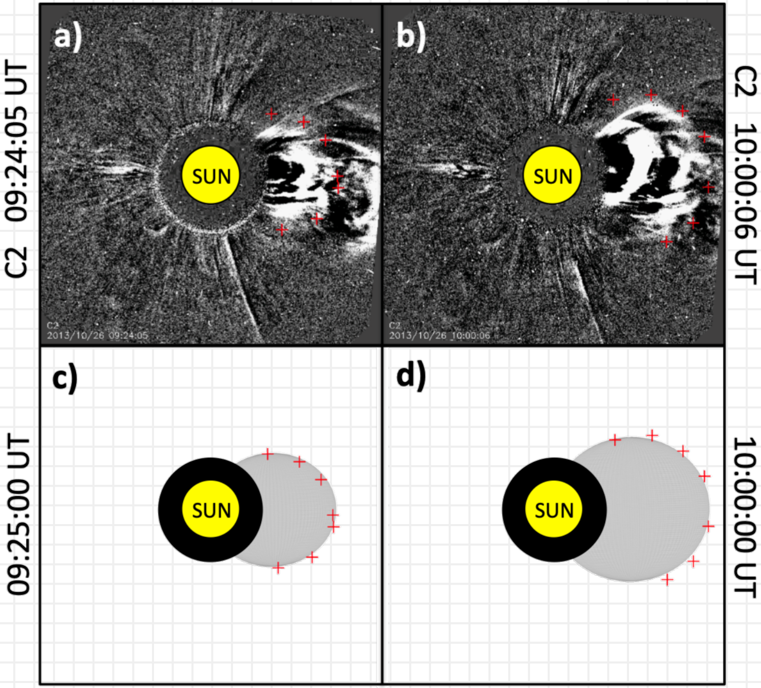
Multi-viewpoint observations

- Using STEREO and SOHO the CME can be triangulated and reconstructed in 3D



Triangulation of CME using Alexis Rouillard method

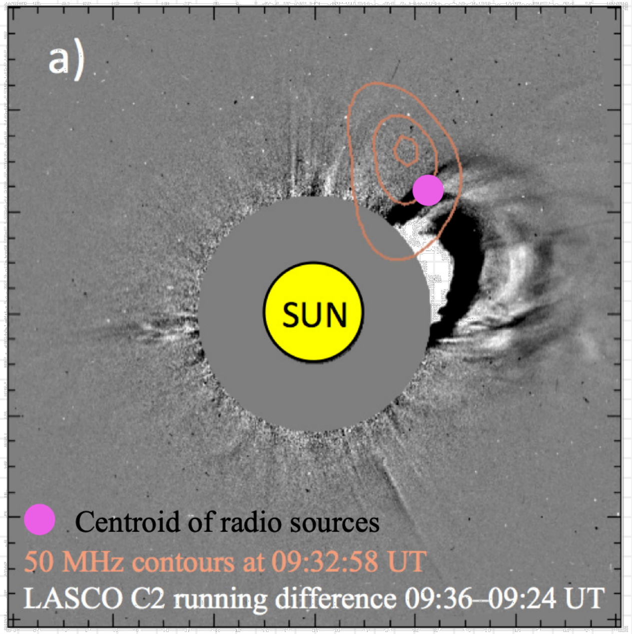
AP Rouillard et al. ApJ (2016)

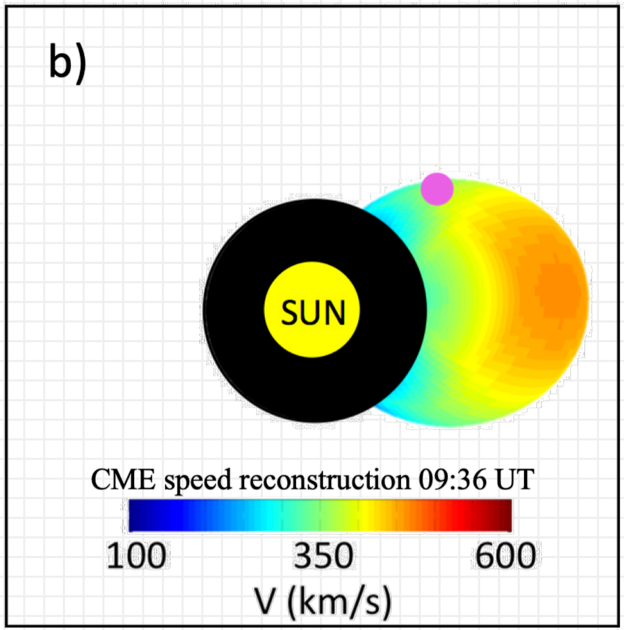


Zucca et al. 2018 A&A

CME speed and radio emission

- Expansion of the flank slower than the apex

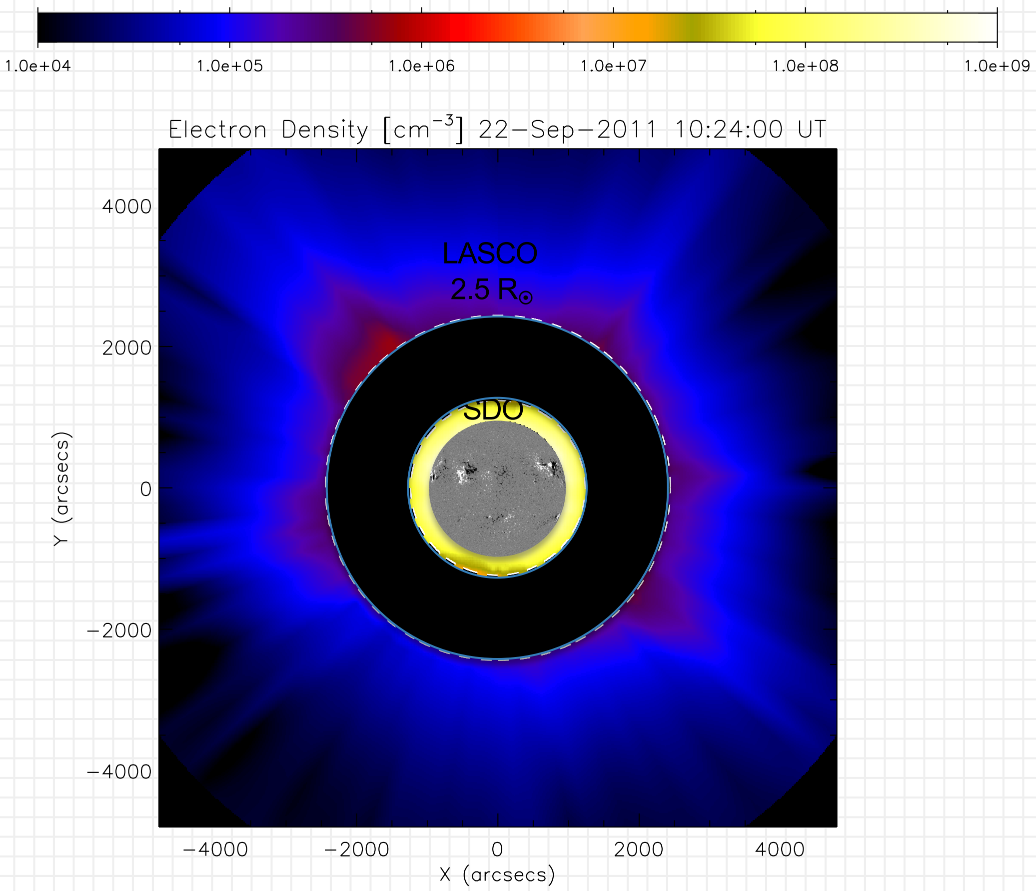




Triangulation of CME using
Rouillard et al. ApJ (2016) method

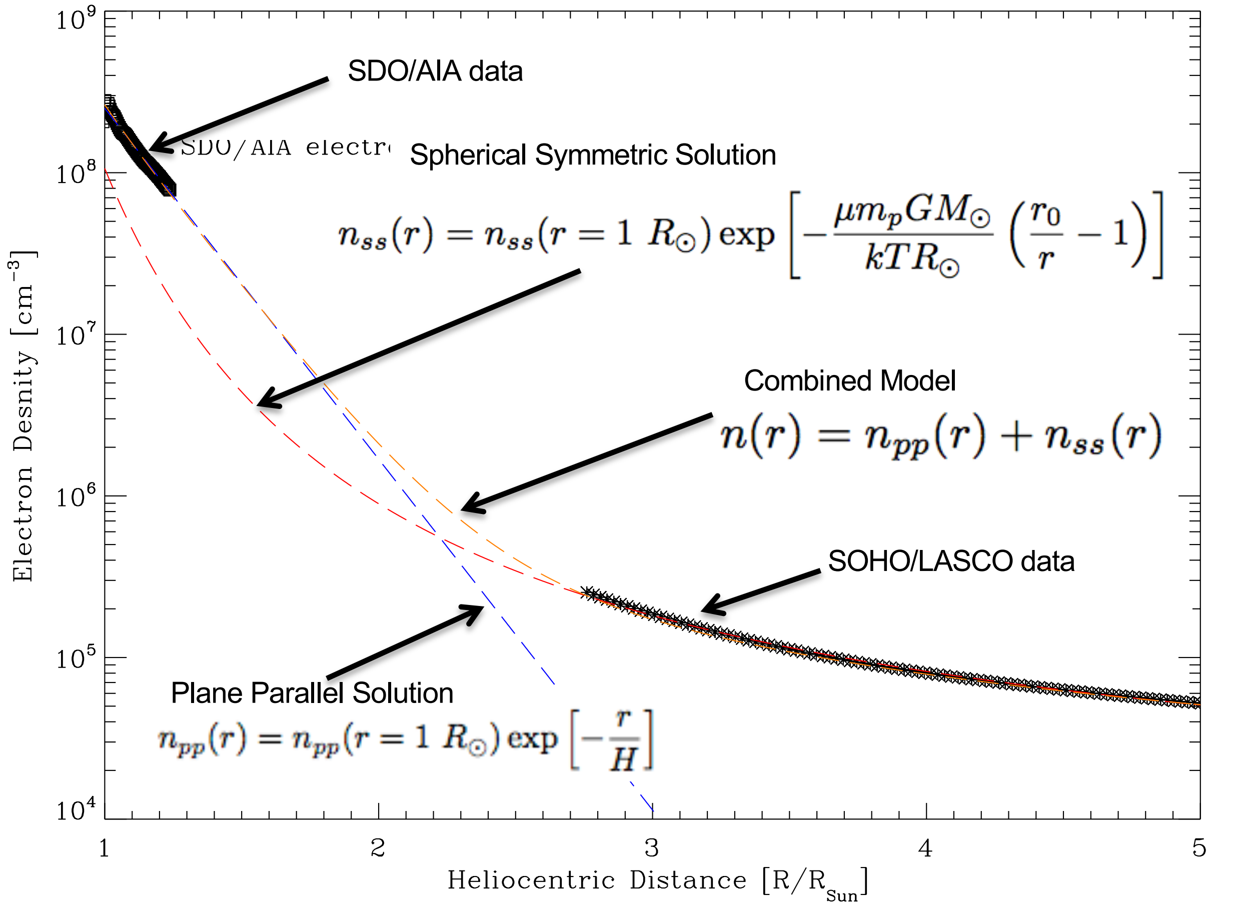
Zucca et al. 2018 A&A

Density Estimations

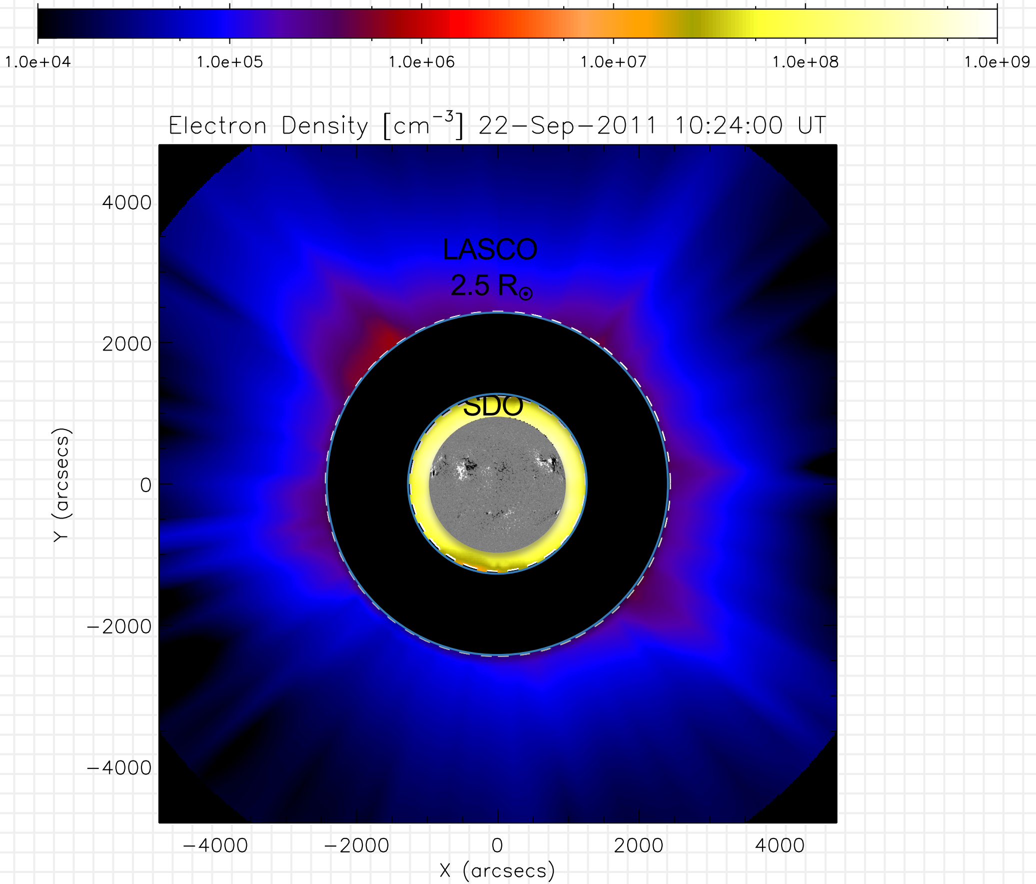


Zucca et al. **A&A** (2014)

Density Estimations

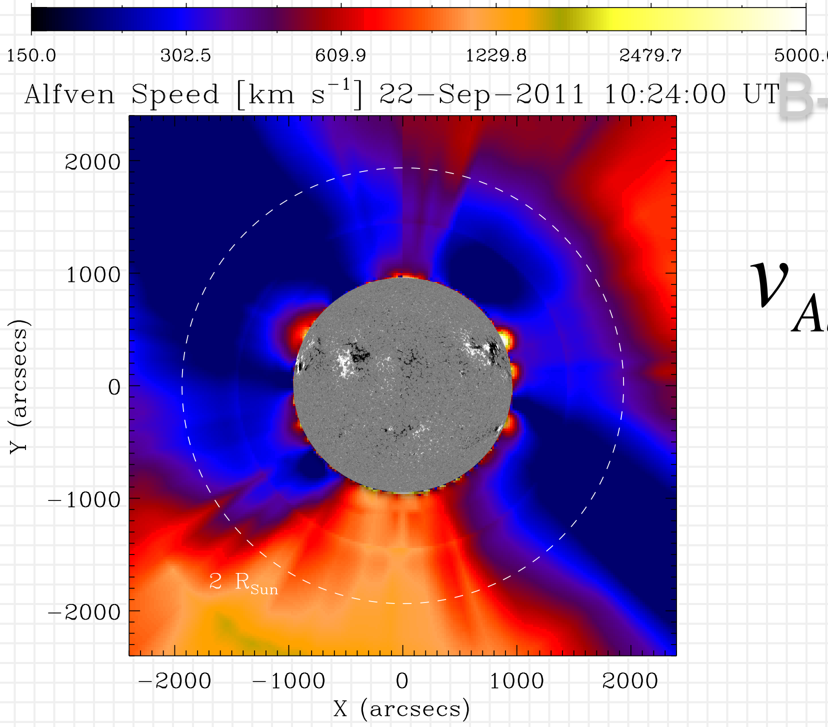


Density Estimations



Zucca et al. **A&A** (2014)

Estimating the Mach number



Zucca et al. 2014a

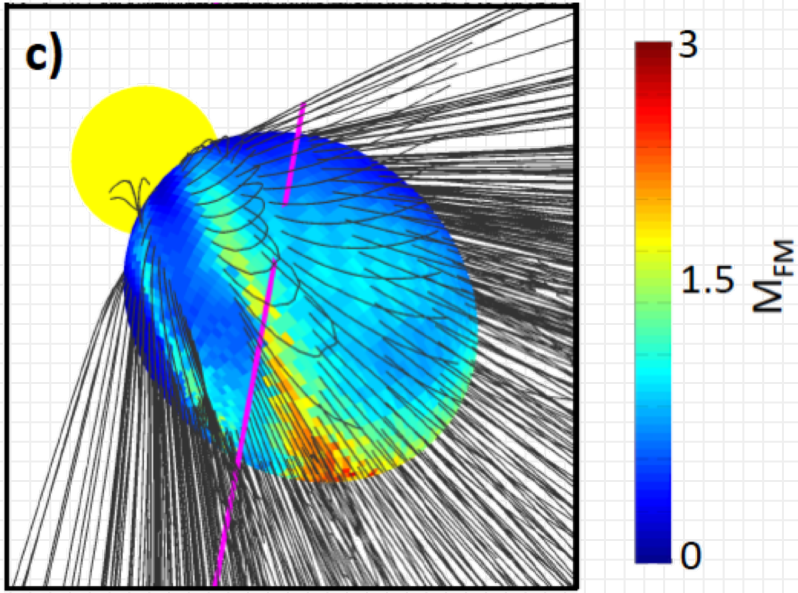
B-Field with PSFF

$$v_{Alfven}(x,y) = \frac{B(x,y)}{\sqrt{\mu m_p n_e(x,y)}}$$

Density Map with SDO/AIA and SOHO/LASCO

3D reconstruction – Mach Number

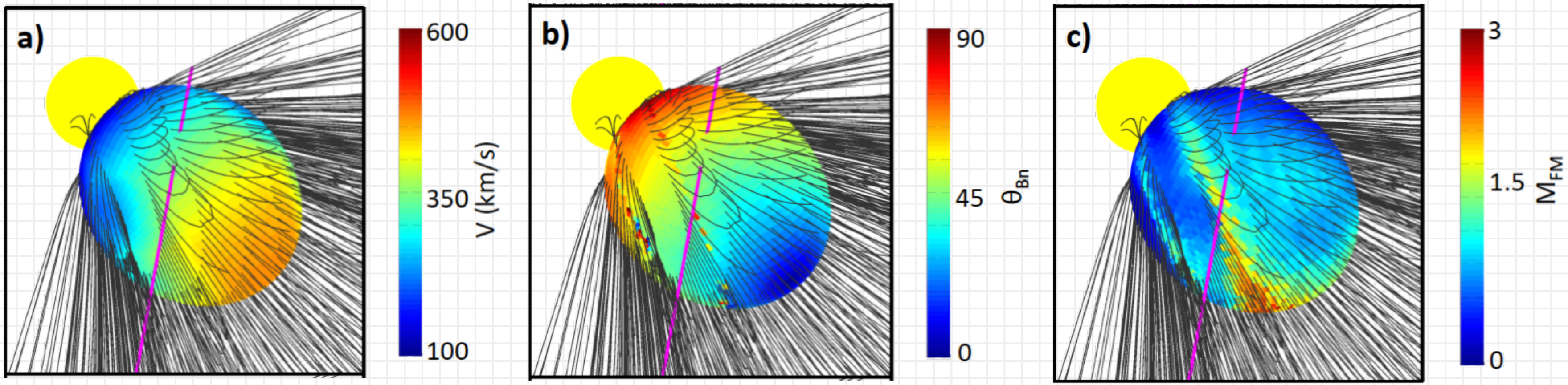
Mach number calculation using the CME front propagation and the local Alfven Speed.



Rouillard et al. ApJ (2016) method

Mach number at the flank 1.4 to 1.6

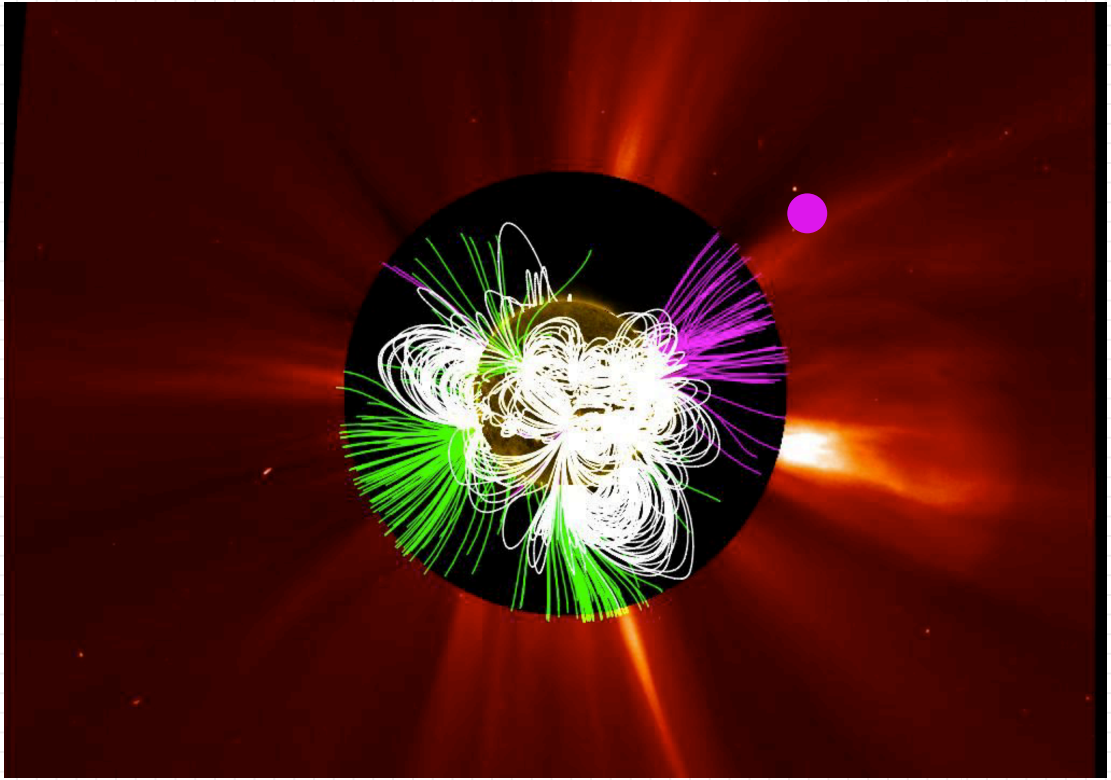
3D – Shock geometry

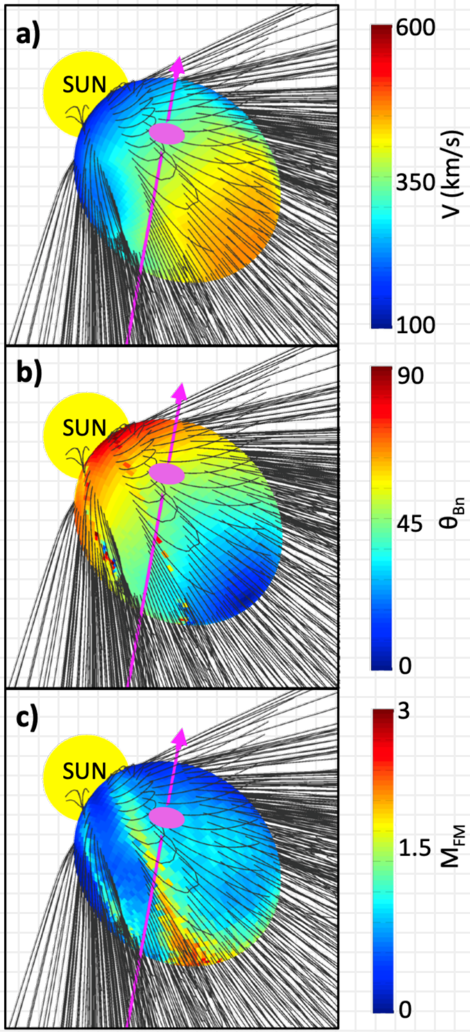


- The geometry of the shock was obtained comparing the b-field orientation with the normal to the CME front.
- The flank of the CME shows a quasi-perpendicular geometry.

Zucca et al. 2018 A&A accepted

Mach Number and B-field Geometry



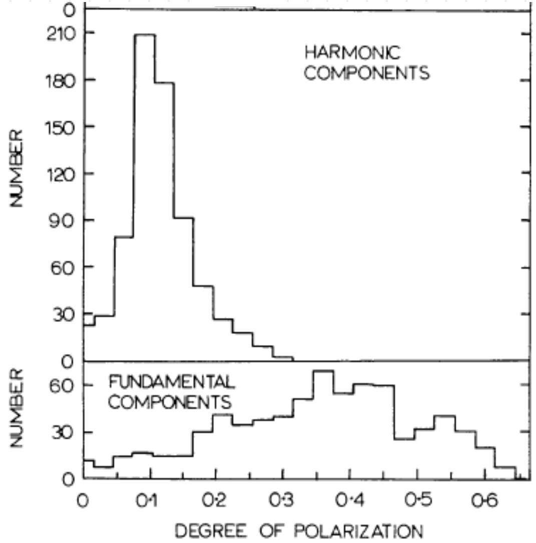


Zucca et al. 2018 A&A

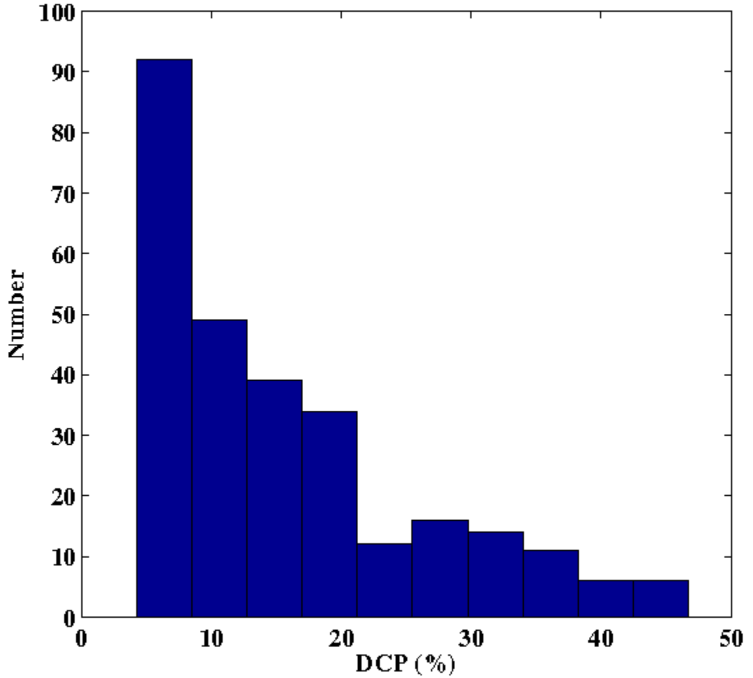
Extra Slides

Questions B-Field

Degree of Circular Polarization



Dulk et al 1979

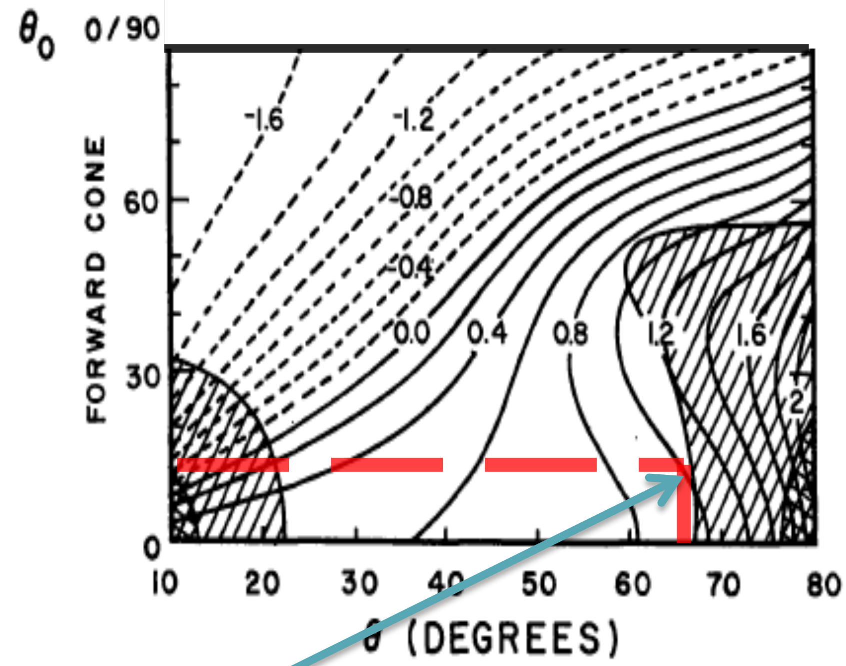


$$\mathrm{DCP} = \frac{V}{I}$$

B field Estimation

$$B = \frac{DCP \times f_p}{2.8 \times a(\theta)}$$

Melrose et al 1977

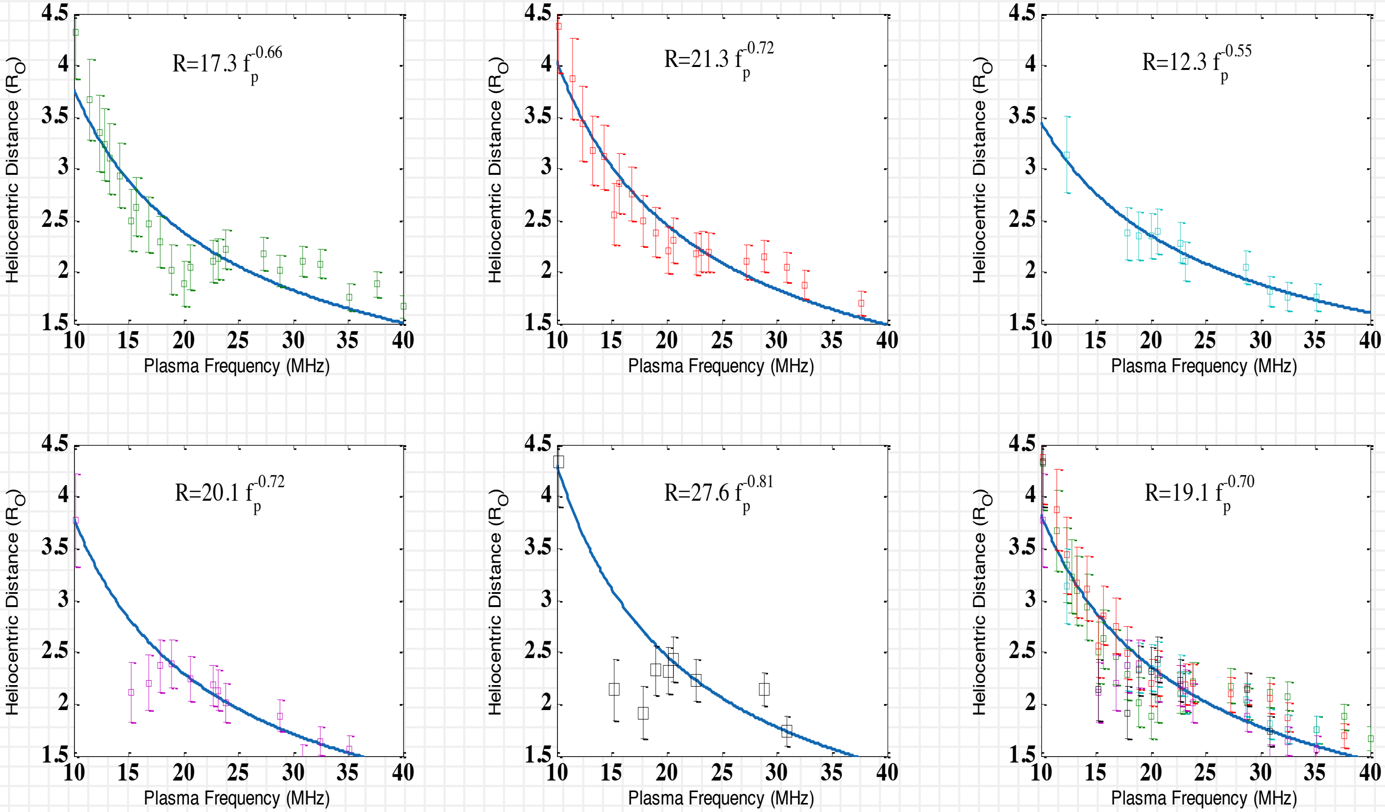


$$a(\theta) = 1$$

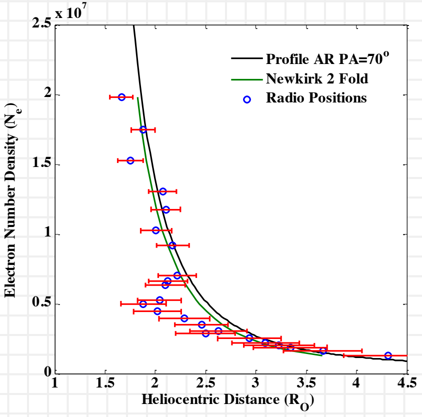
Extra Slides

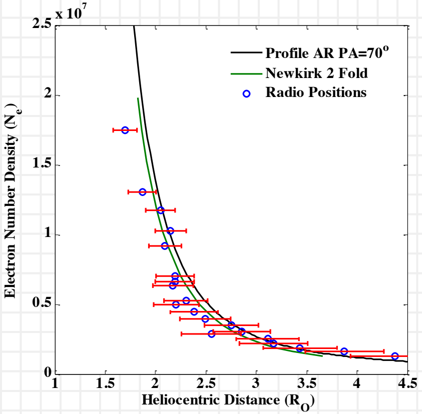
Questions Scattering

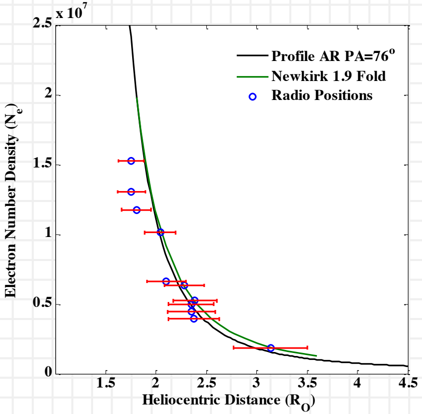
Height vs Plasma frequency

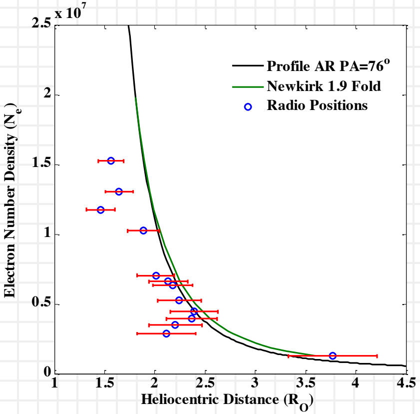


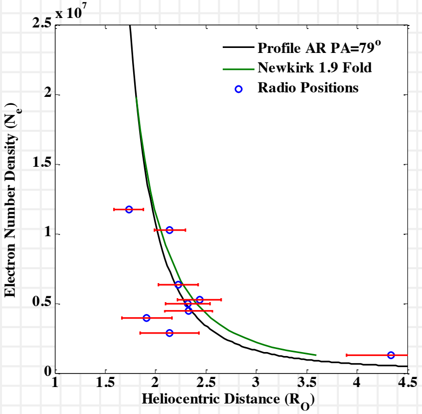
Density – Comparison











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

$f_p =$ plasma frequency

$N_e =$ electron no. density

Newkirk 1961

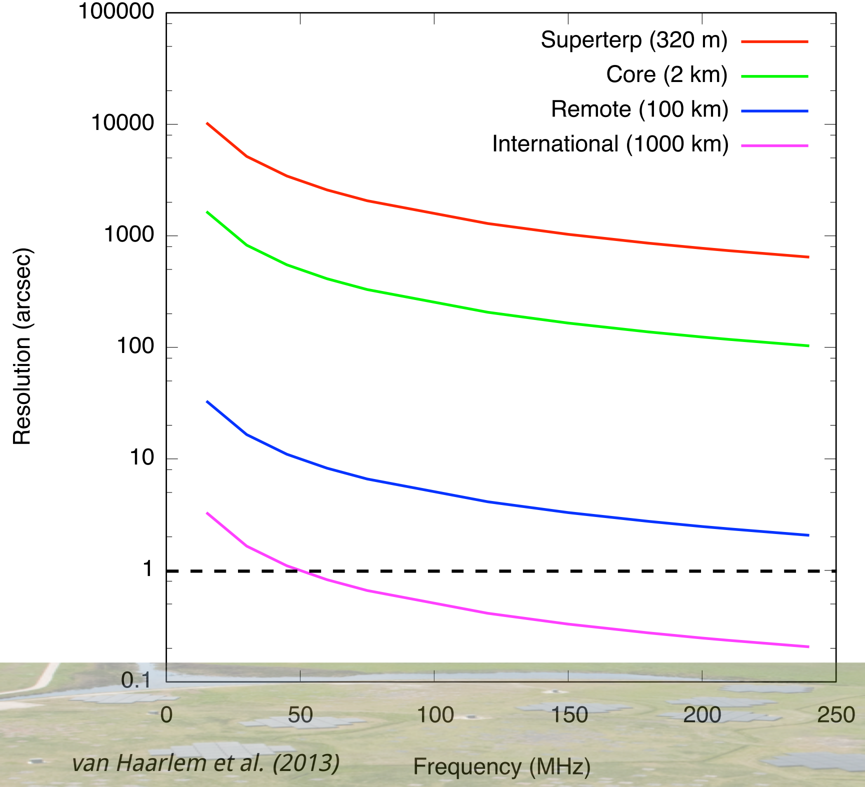
Zucca et al 2014

Extra Slides

Questions resolution

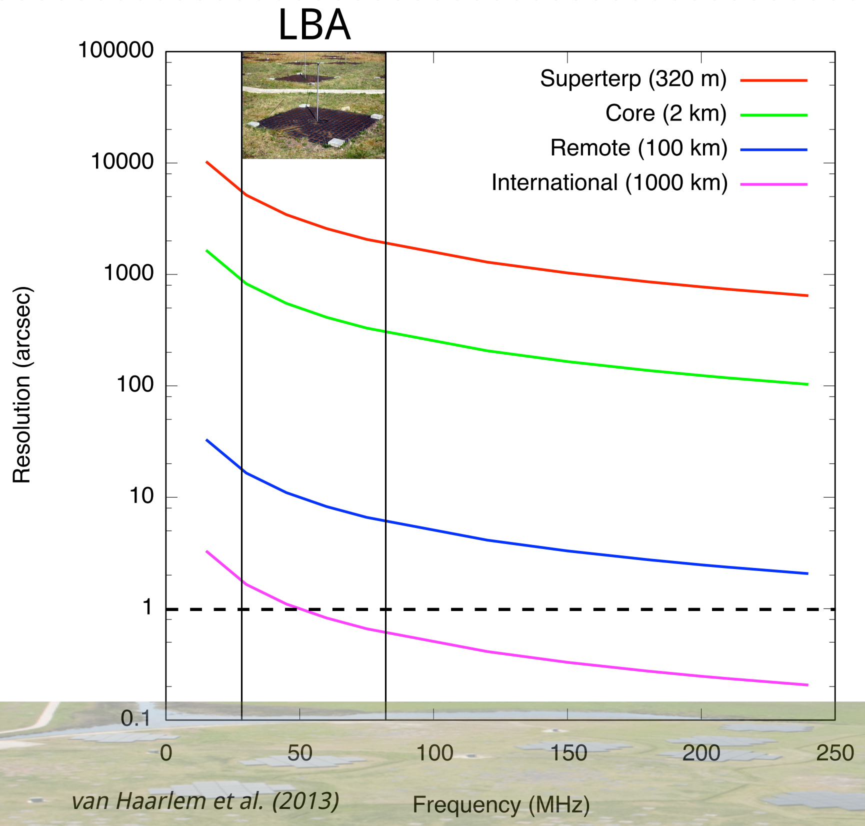
ASTRON LOFAR

Spatial Resolution



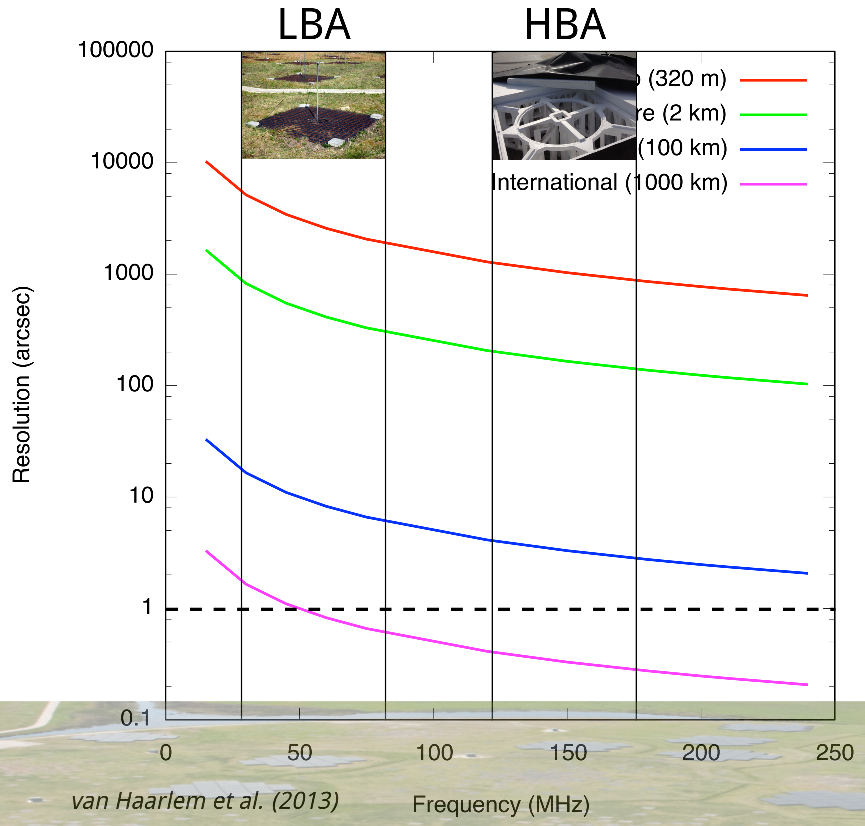
van Haarlem et al. (2013)

Spatial Resolution



van Haarlem et al. (2013)

Spatial Resolution



van Haarlem et al. (2013)