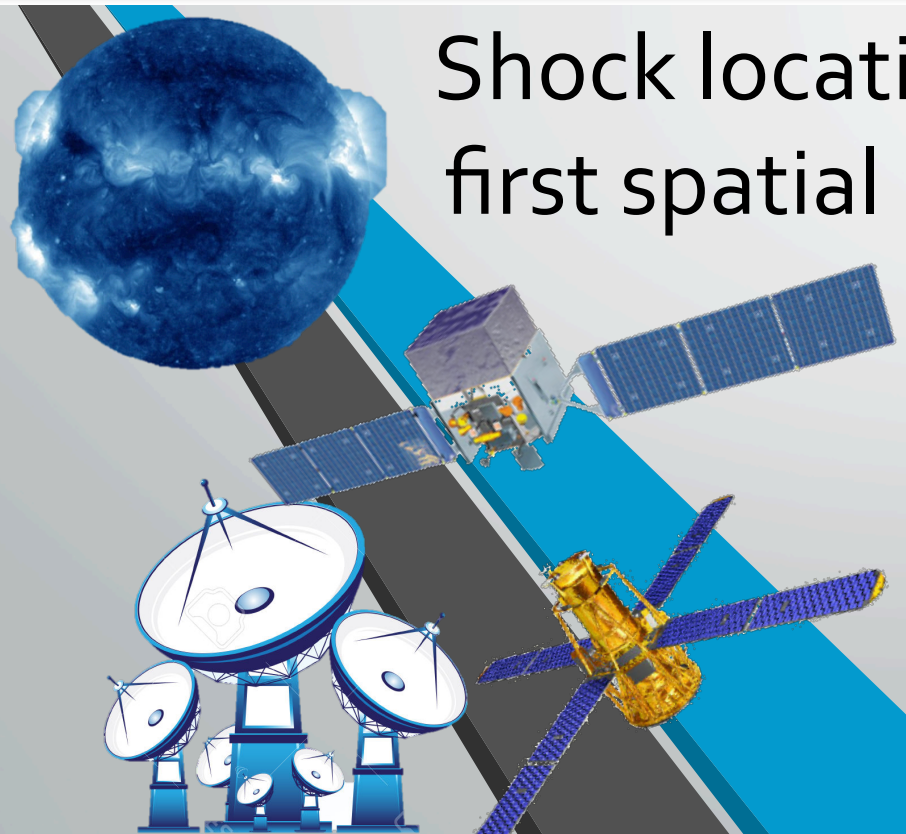


Shock location and CME 3D reconstruction of the first spatial resolved solar type II radio burst with LOFAR.

Pietro Zucca
and Solar KSP members
ASTRON Netherlands institute for radio astronomy

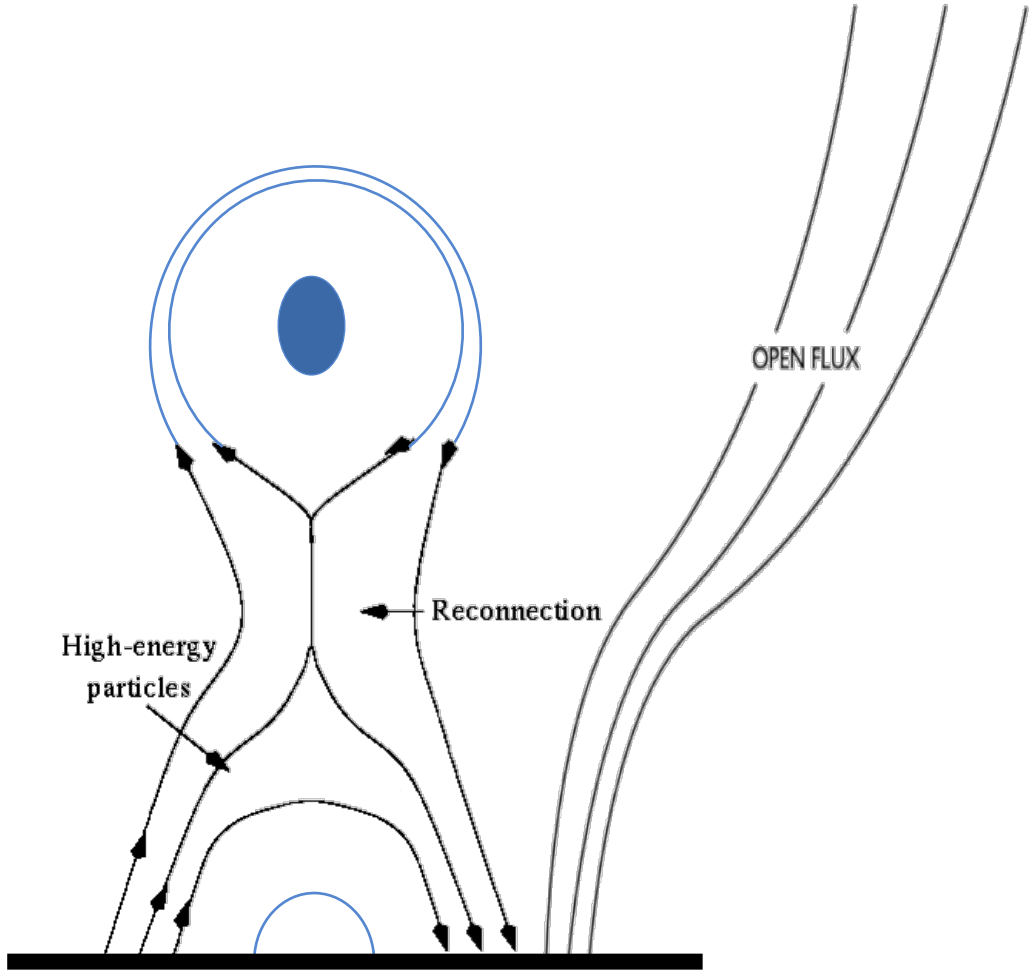
ASTRON
Netherlands Institute for Radio Astronomy

LOFAR

Outline

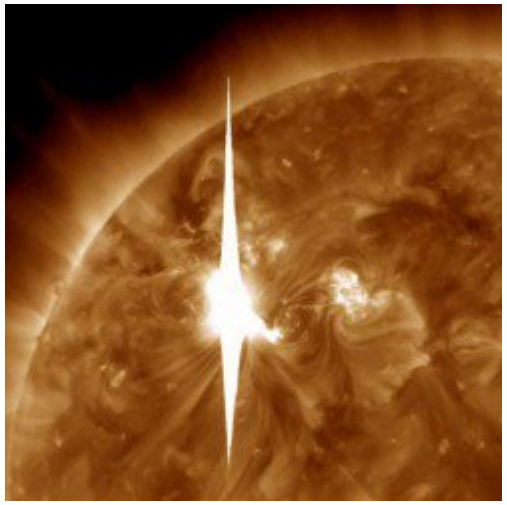
- Introduction – Particle acceleration from the Sun
- Radio signatures and their characteristics
- Shocks driven by CMEs
- Forecasting tools and applications for Space Weather
- Future Work
- Conclusions

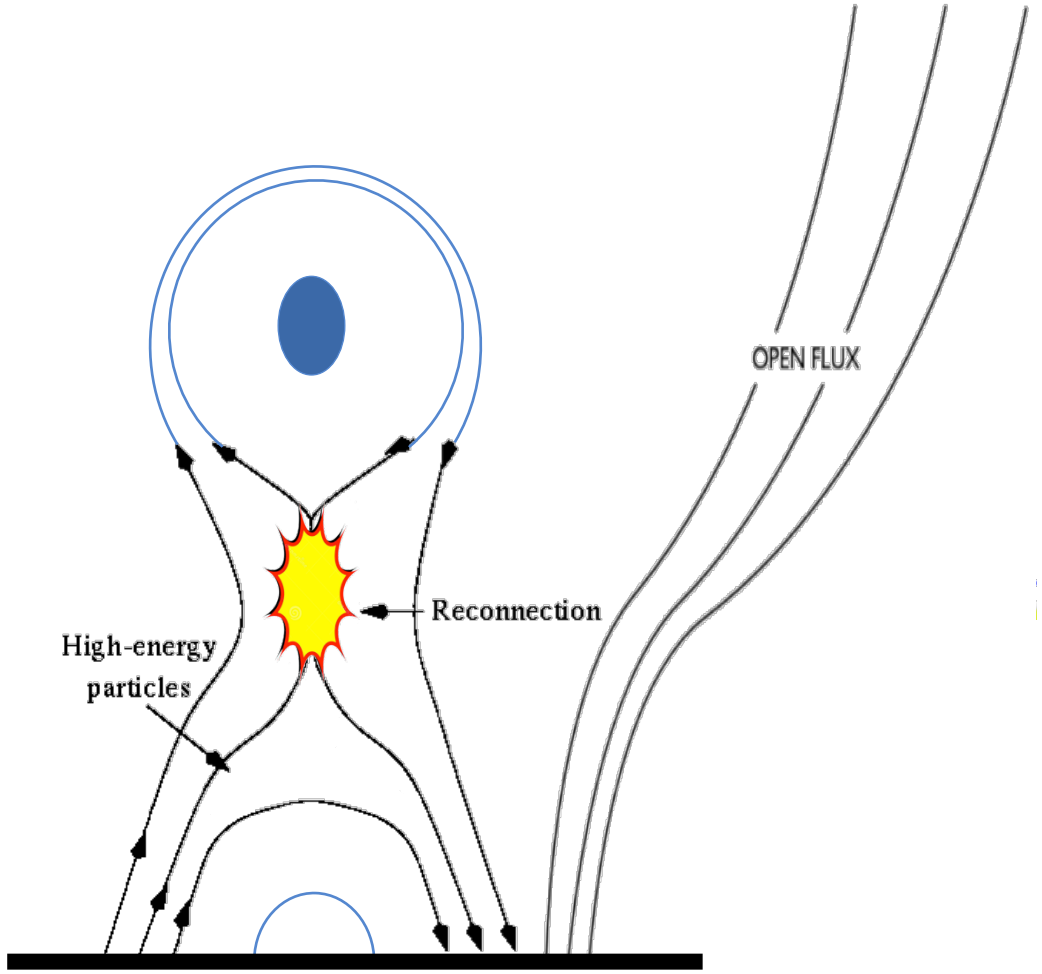
Where particles can be accelerated?



Where particles can be accelerated?

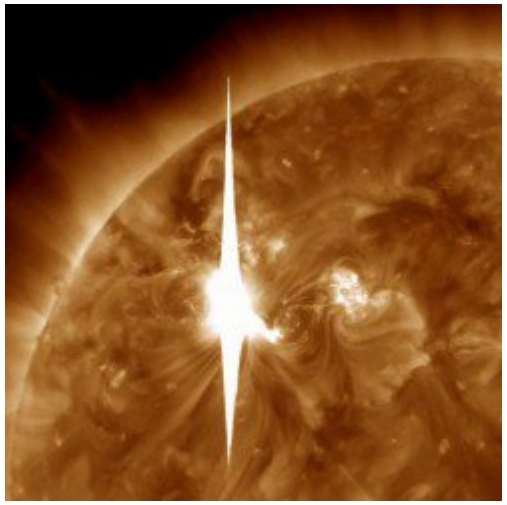
Solar Flares

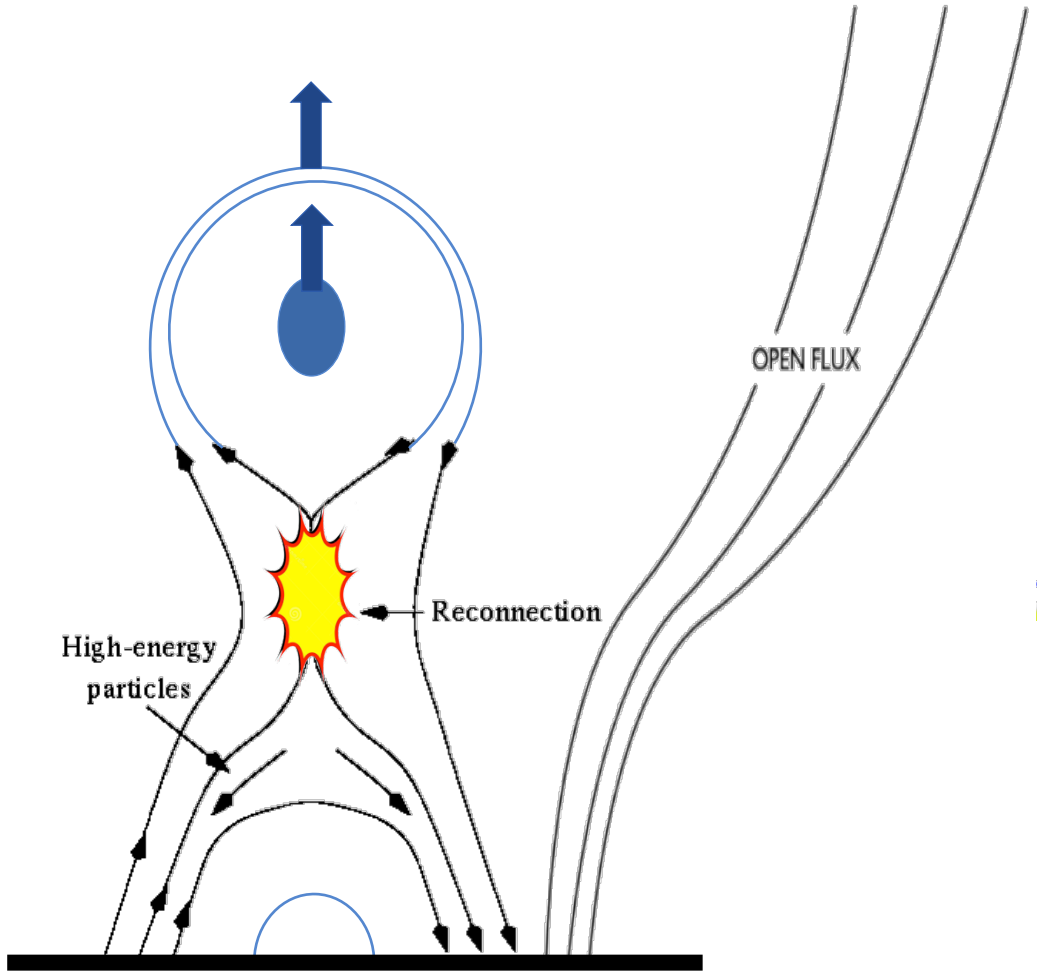




Where particles can be accelerated?

Solar Flares

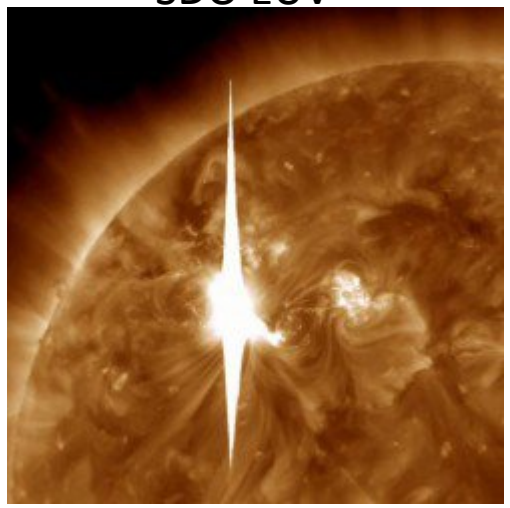




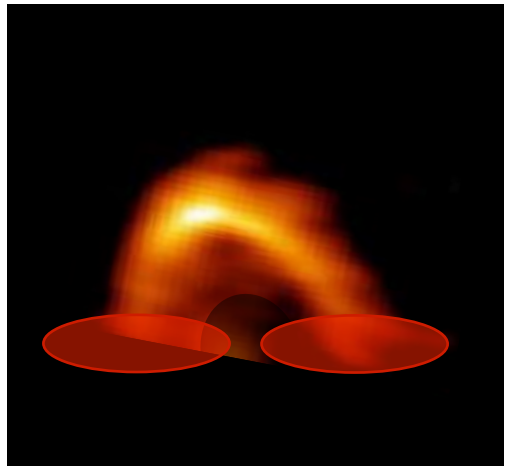
Where particles can be accelerated?

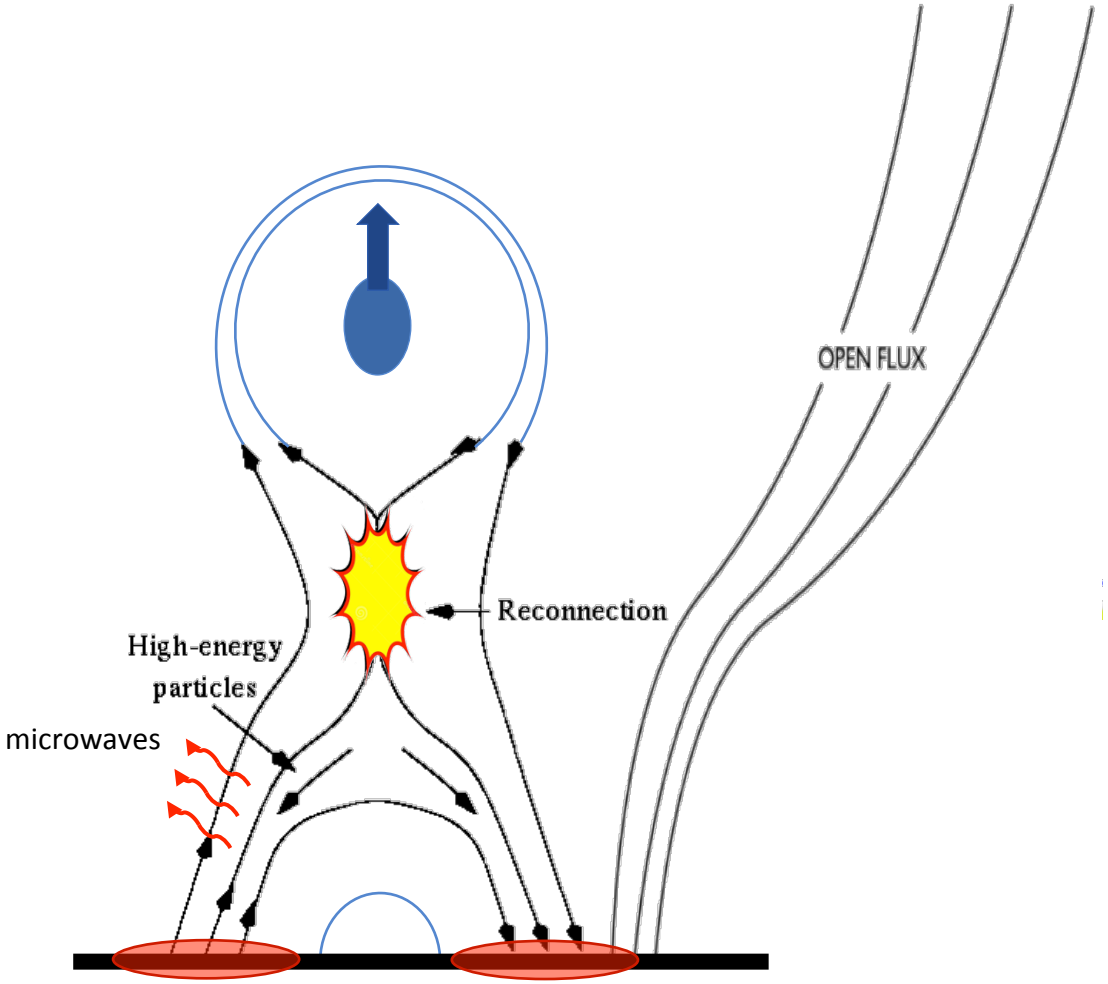
Solar Flares

SDO EUV



Nobeyama 17 GHz





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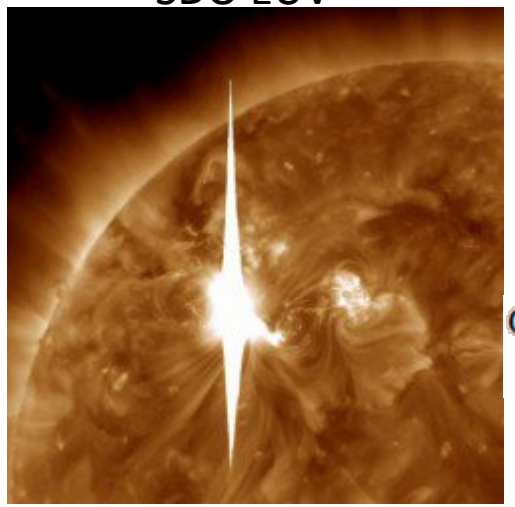
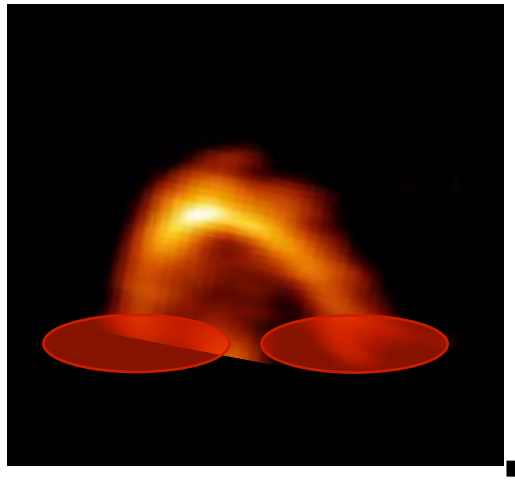
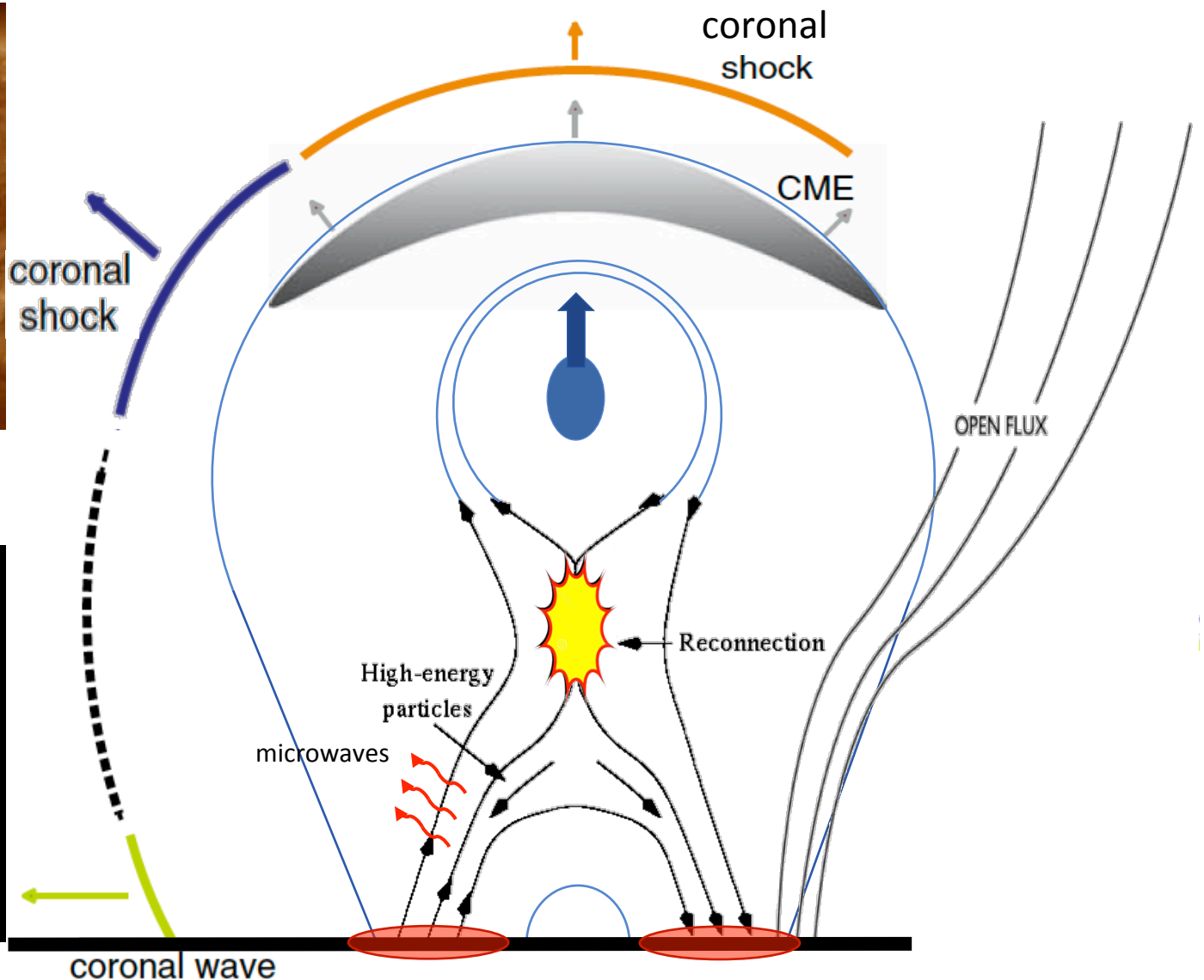


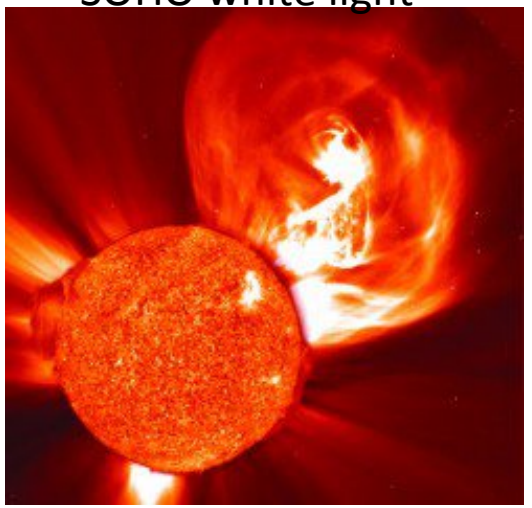
Nobeyama 17 GHz





Coronal Mass Ejections

SOHO white light



Where particles can be accelerated?

Solar Flares

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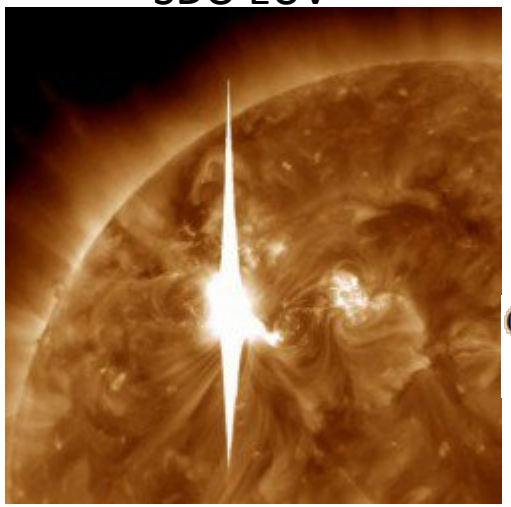
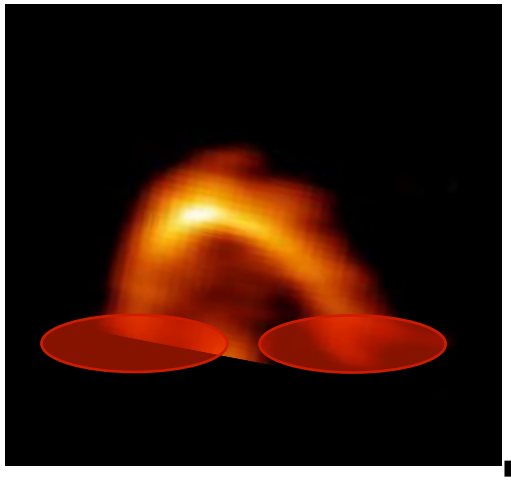
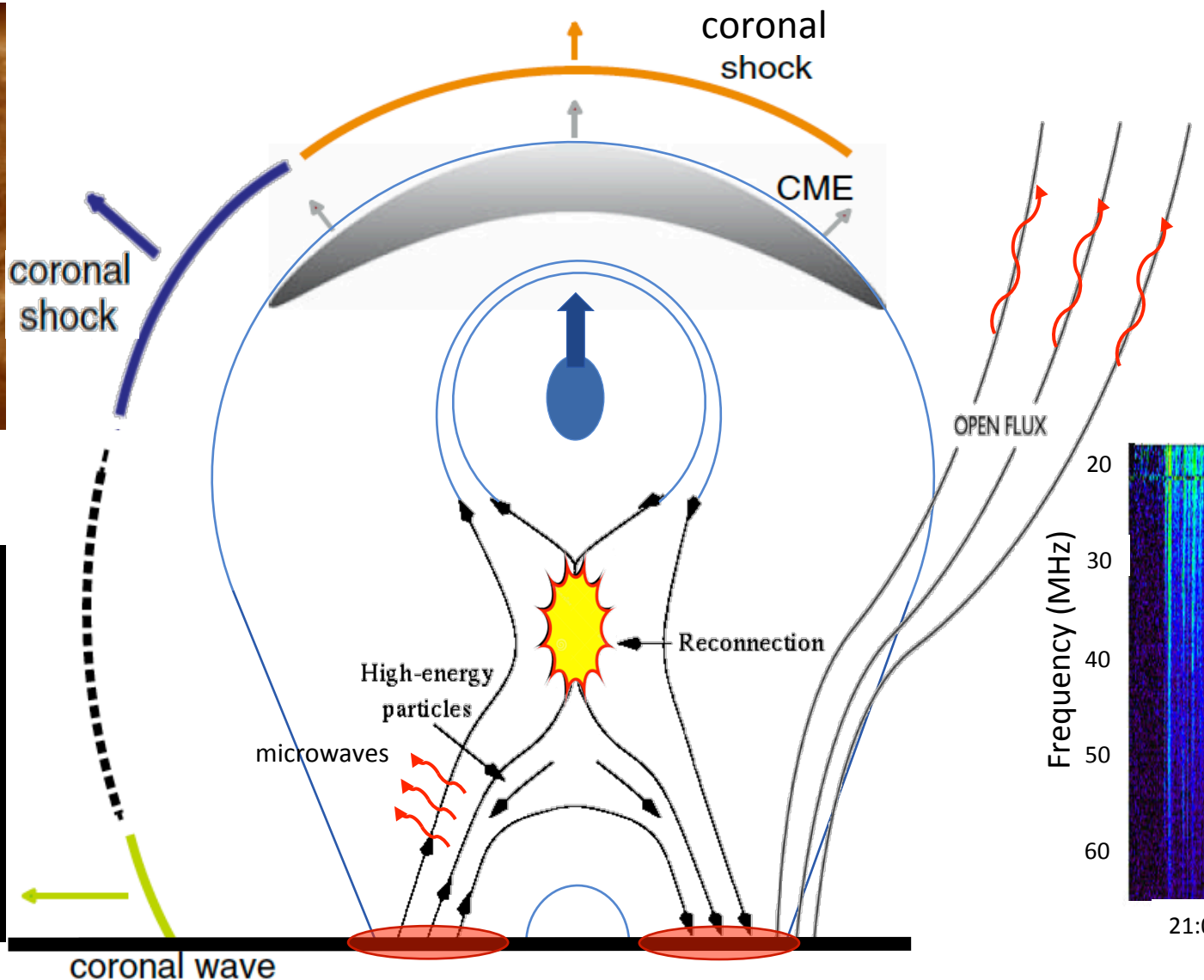


Nobeyama 17 GHz





Coronal Mass Ejections

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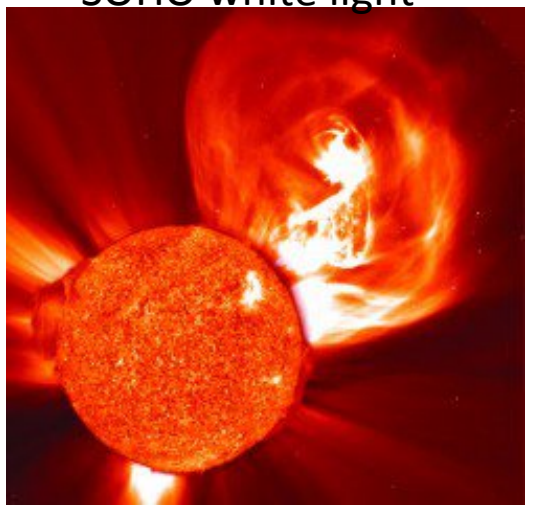

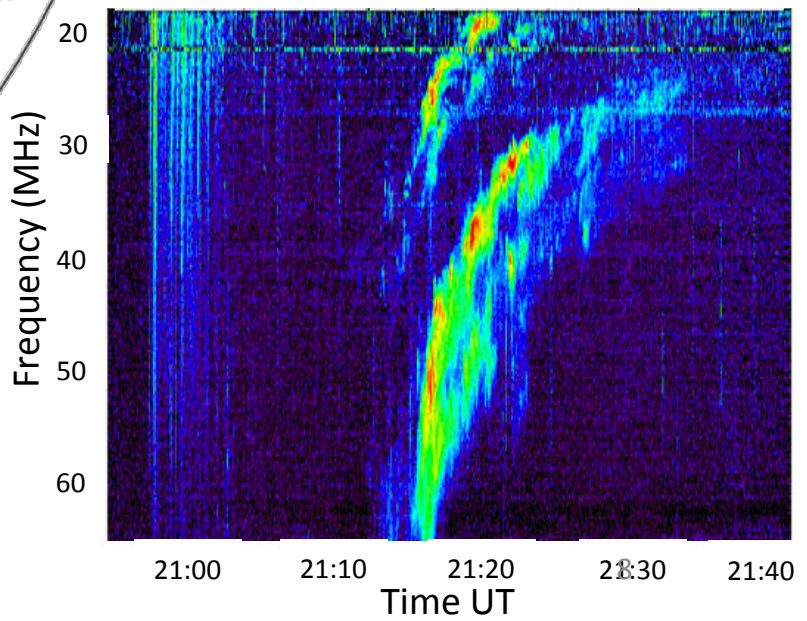

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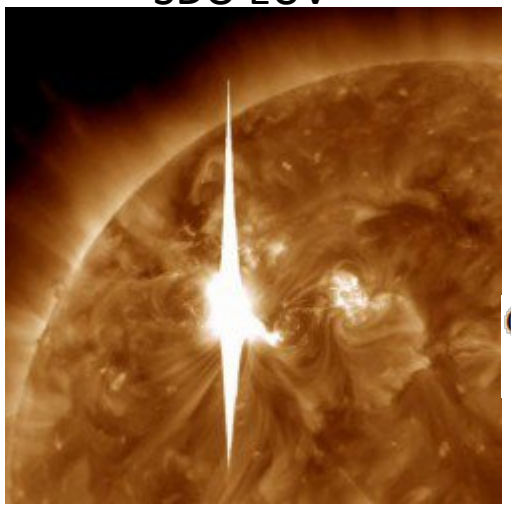
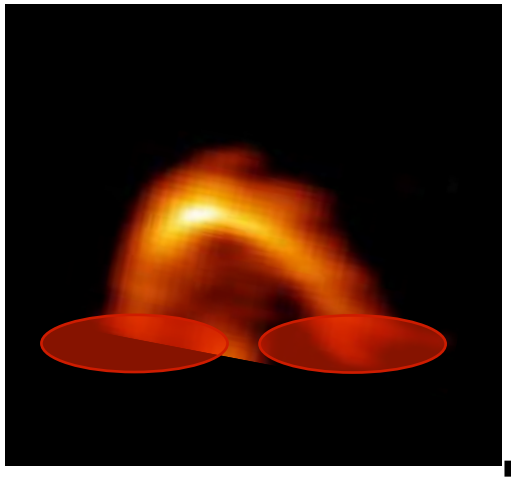
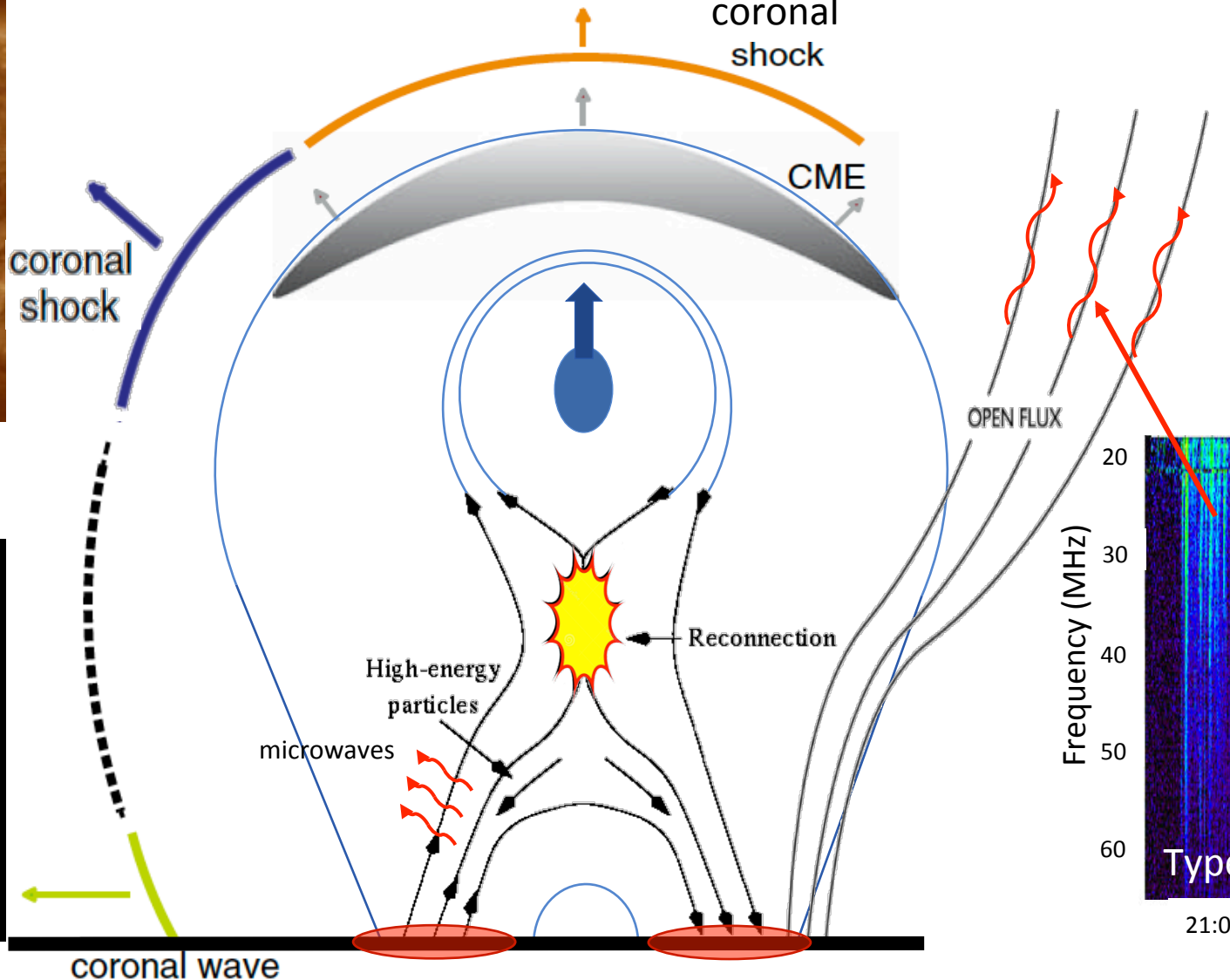


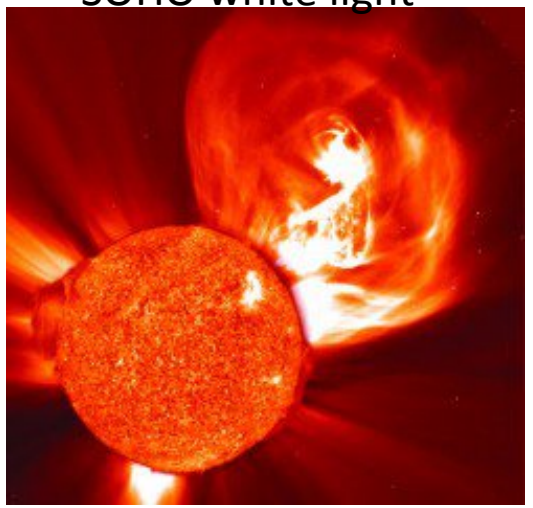
Nobeyama 17 GHz

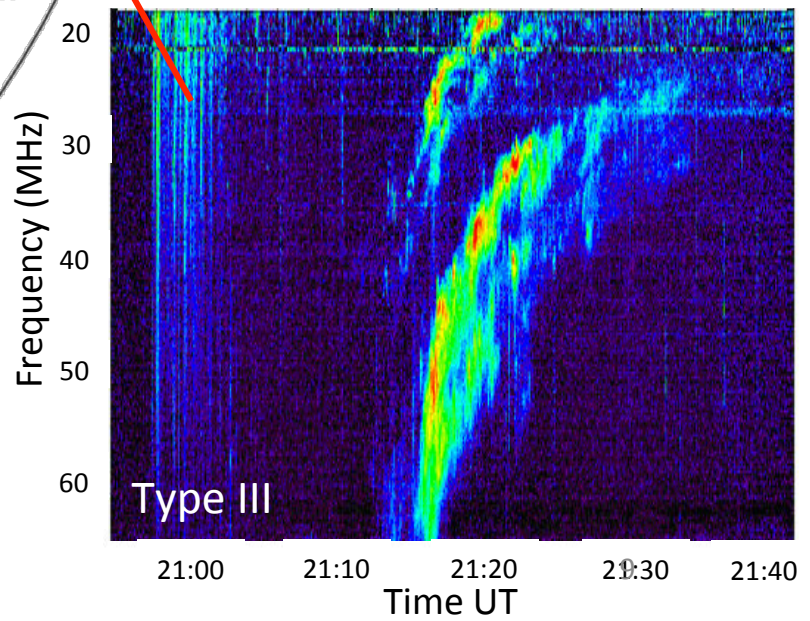




Coronal Mass Ejections

SOHO white light





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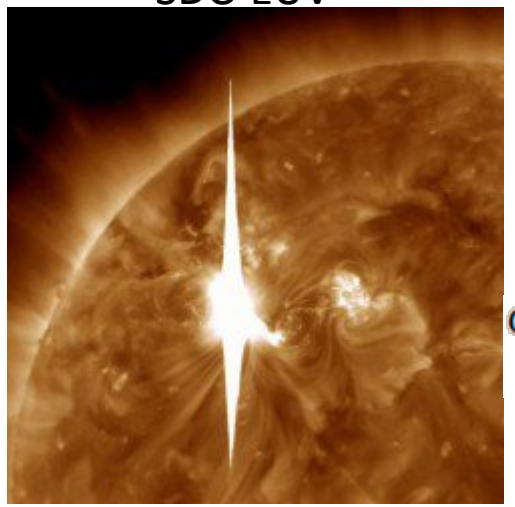
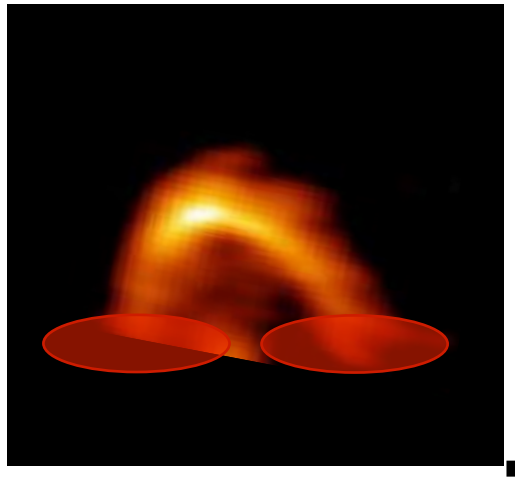
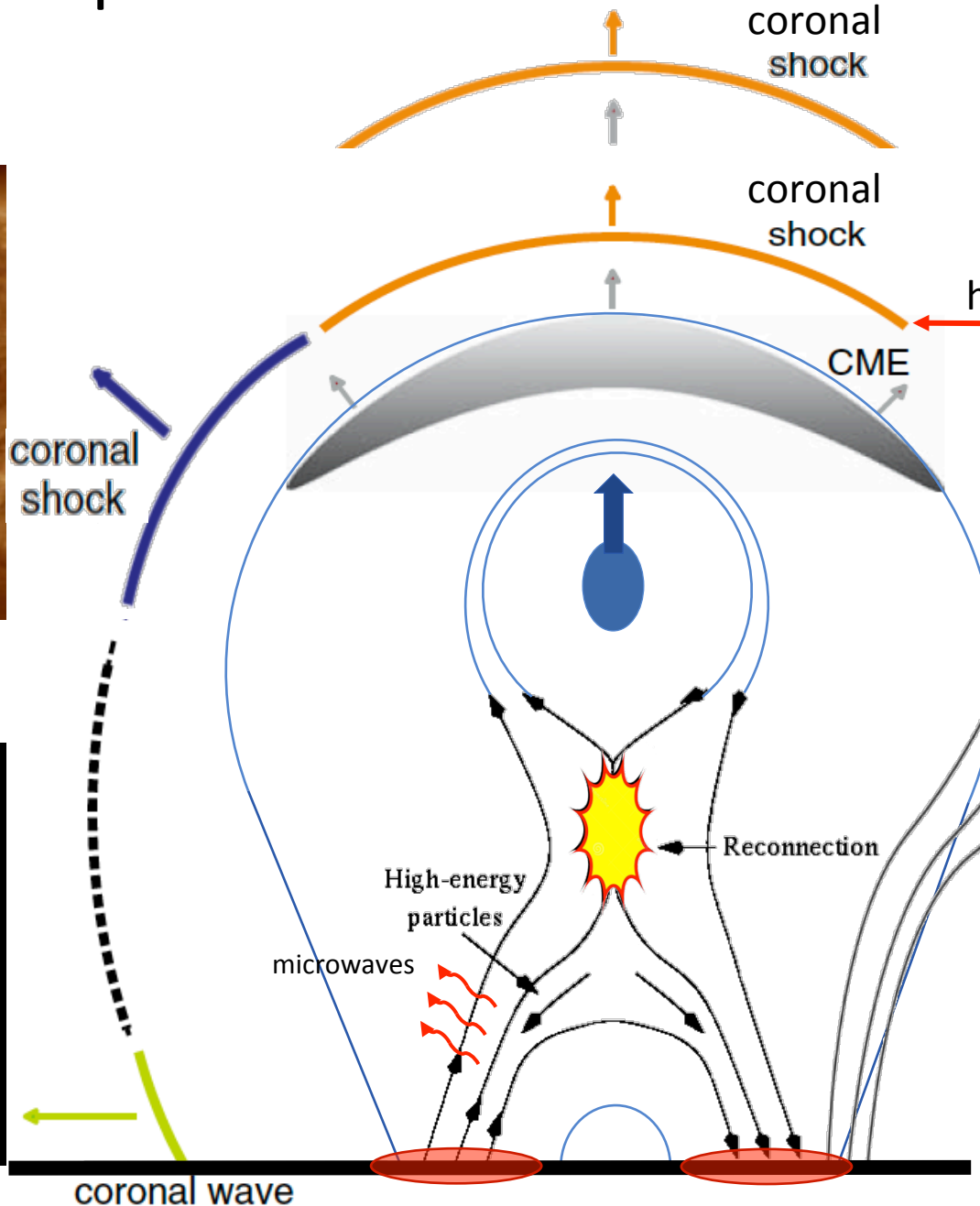
SDO EUV



Nobeyama 17 GHz





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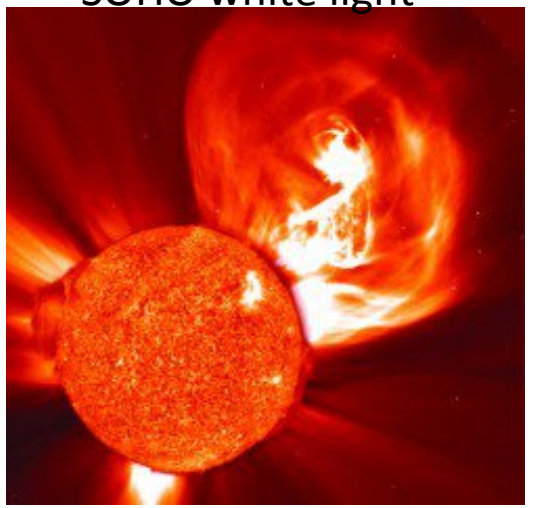

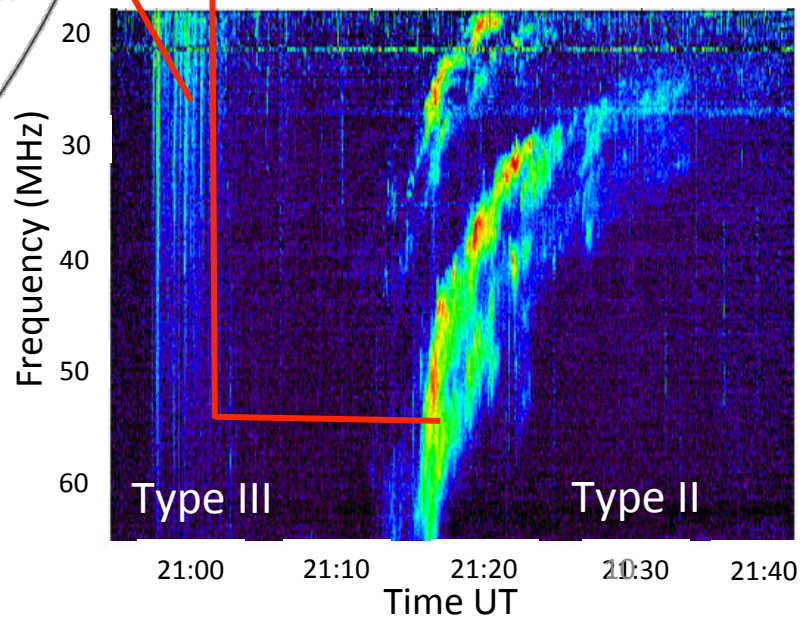

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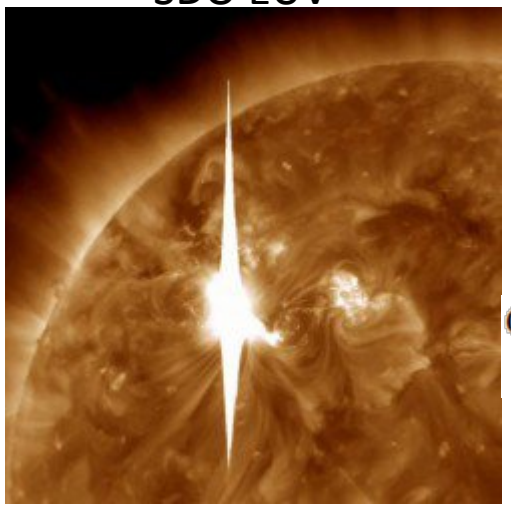
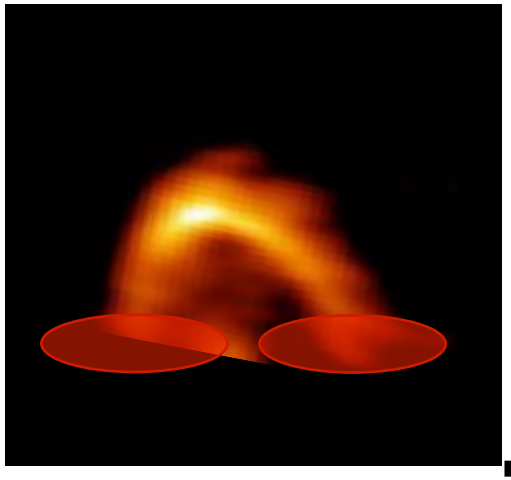
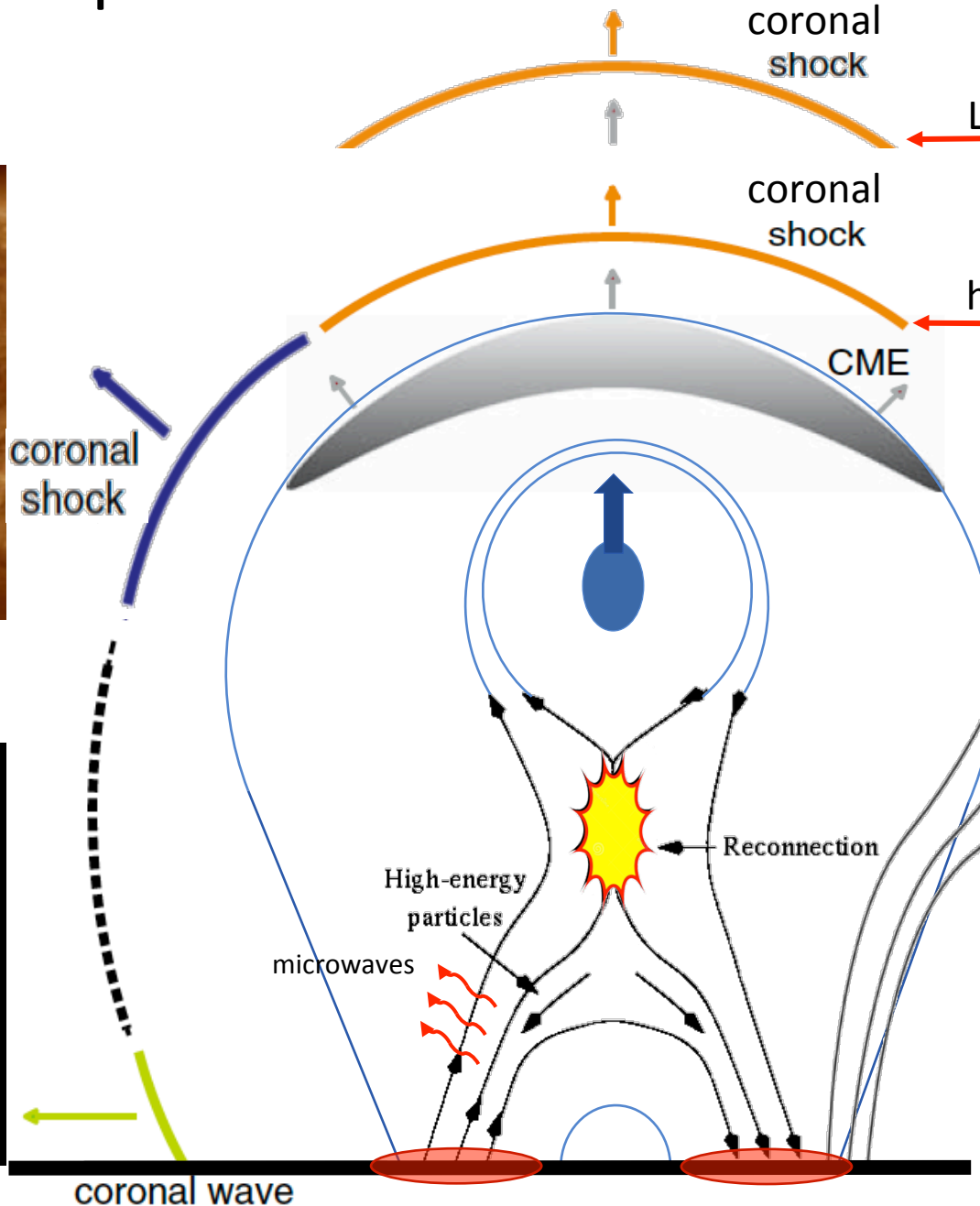
SDO EUV



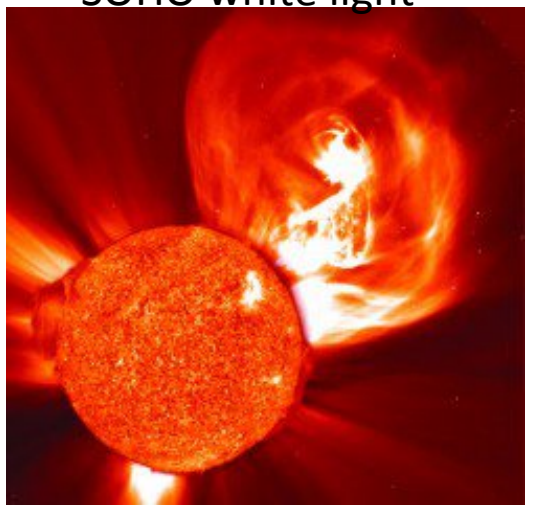
Nobeyama 17 GHz



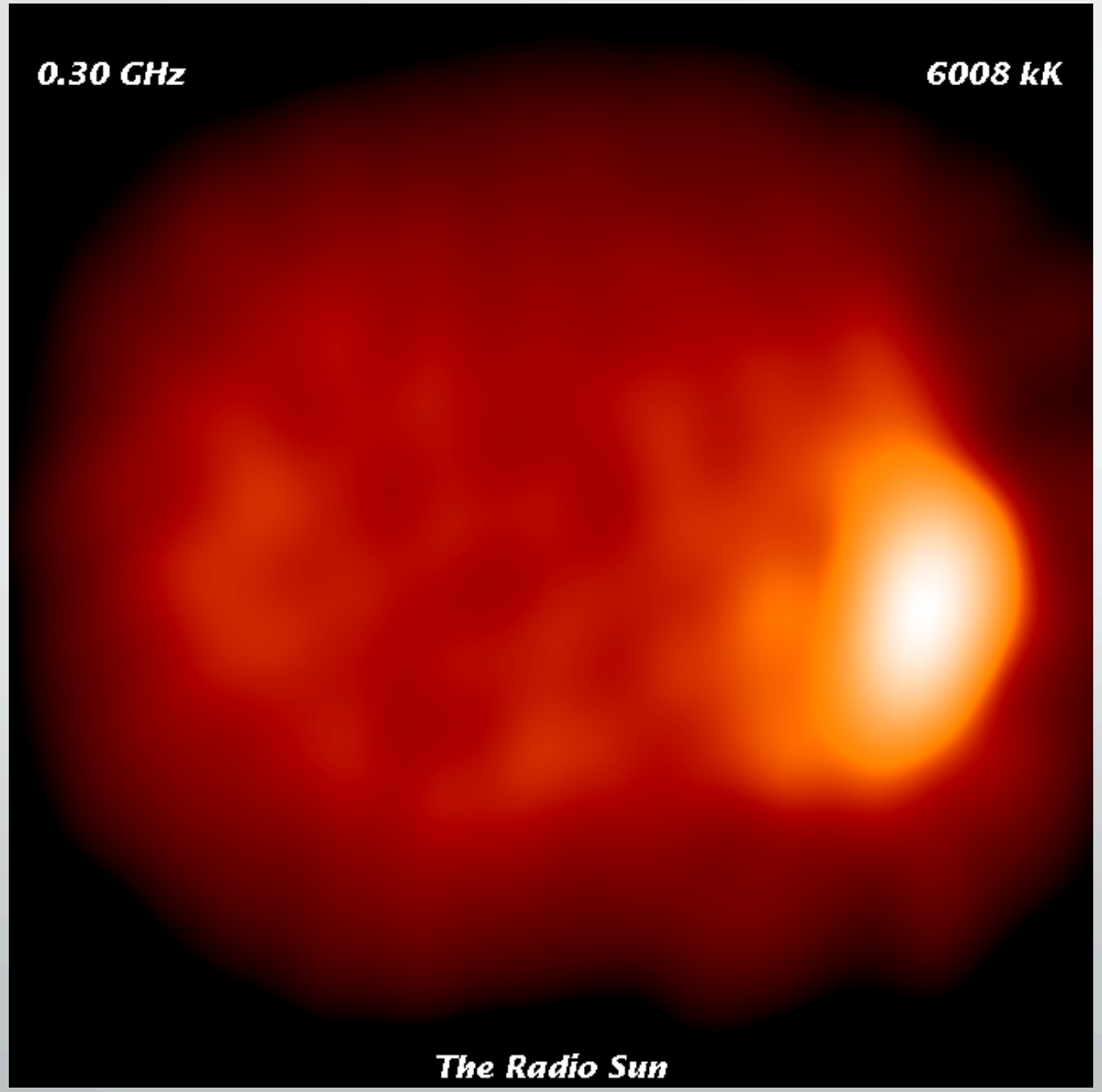


Coronal Mass Ejections

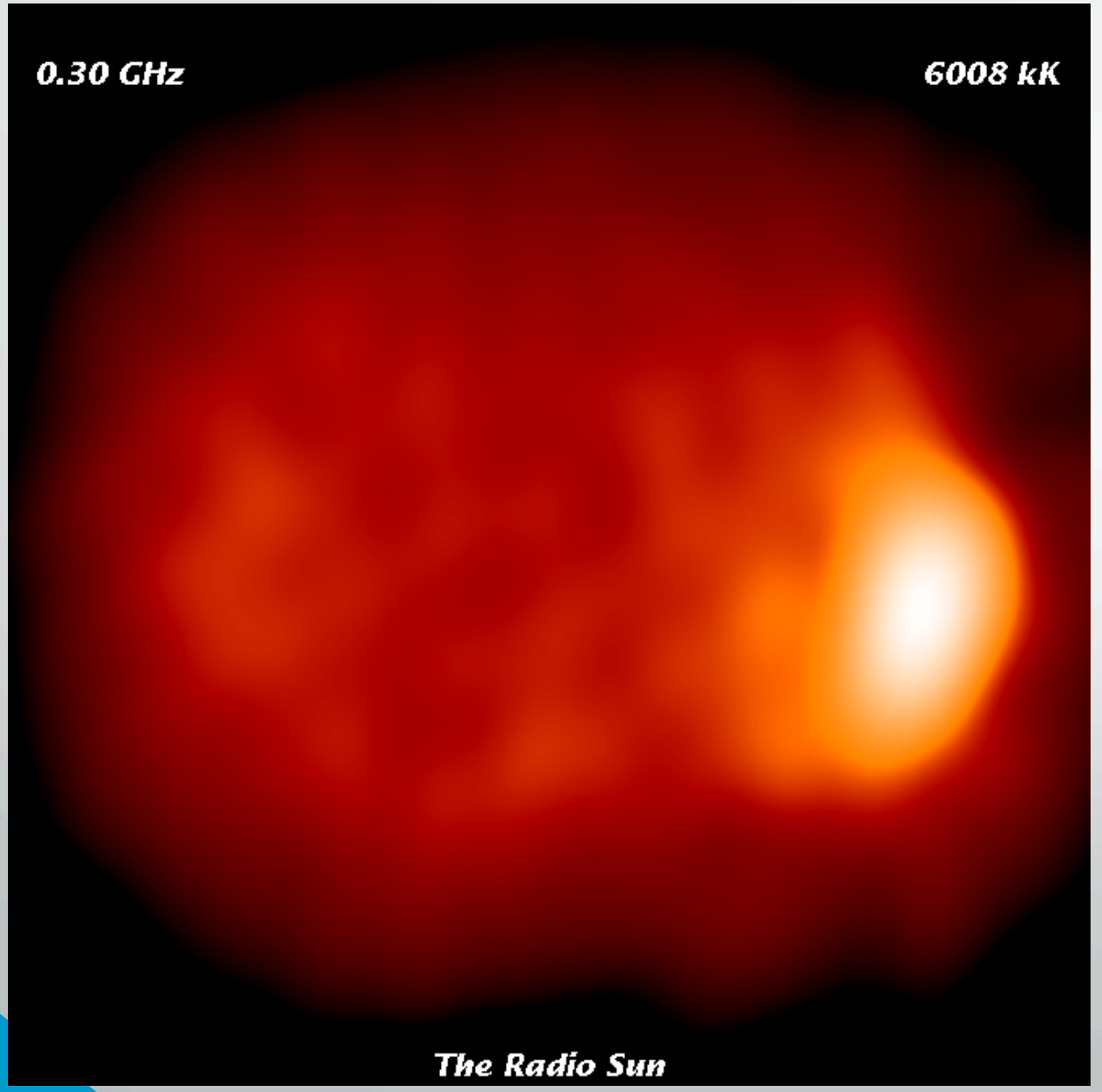
SOHO white light

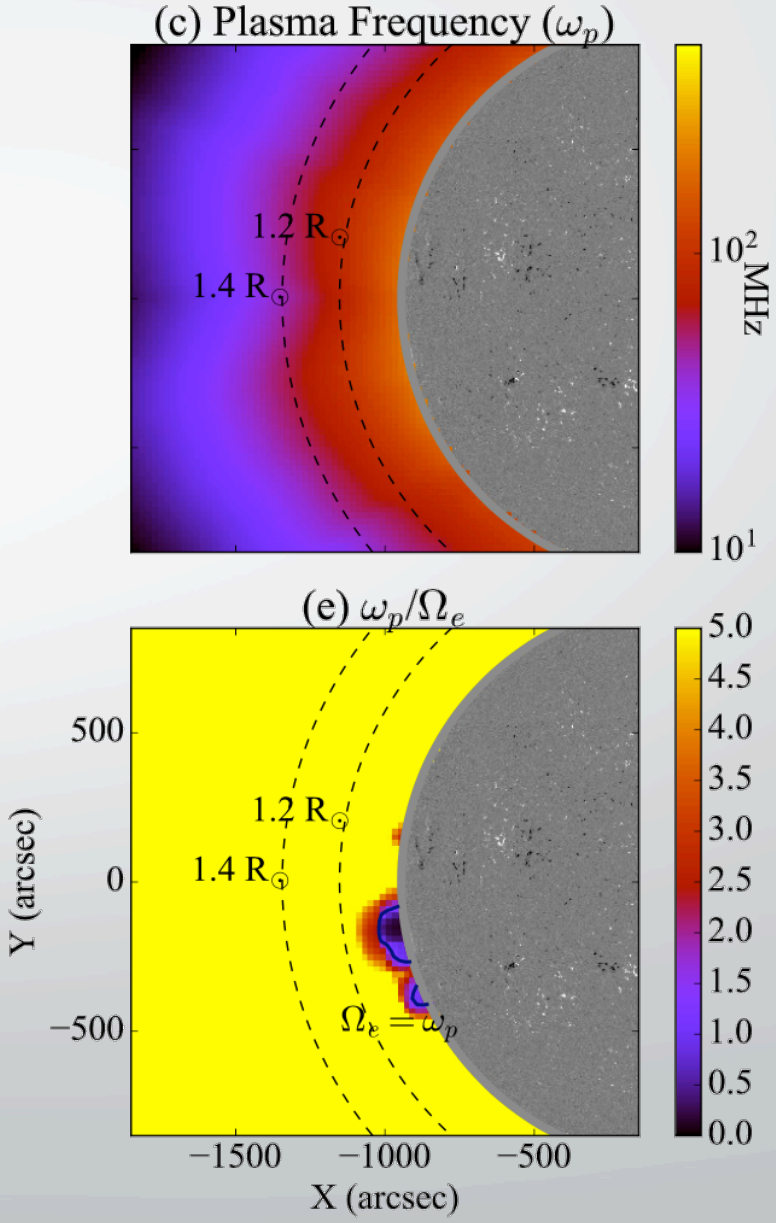


The Radio Sun



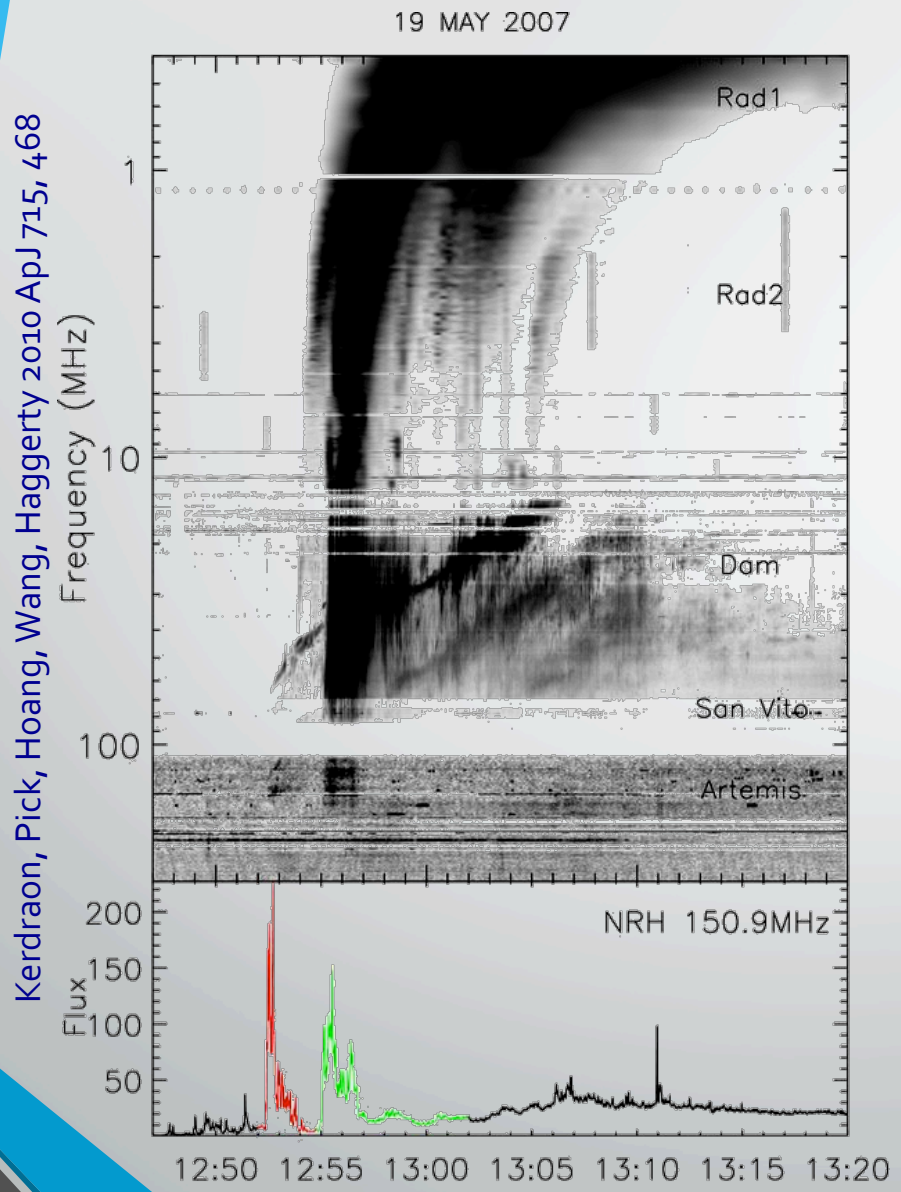
The Radio Sun



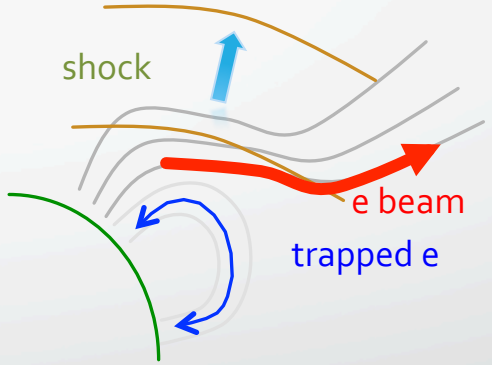


Morosan, Zucca et al. 2016

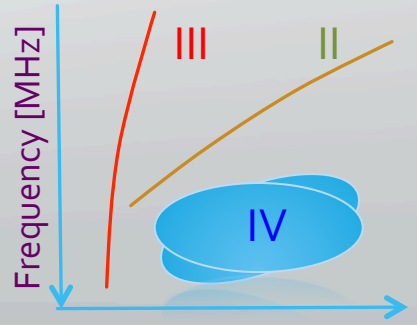
The Radio Sun



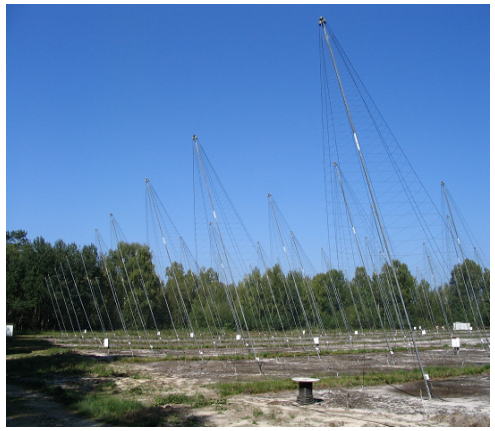
- At ≥ dm-λ waves: emission at $\nu \sim \nu_{pe} \sim \sqrt{n_e}$
  - Propagating exciter in a quasi-static atmosphere or expanding loops (CME):



  - Characteristic shapes of the radio burst spectra:

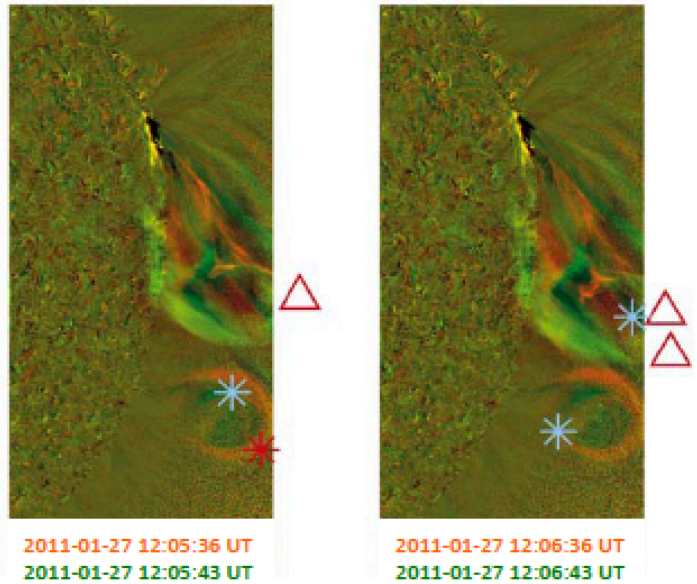


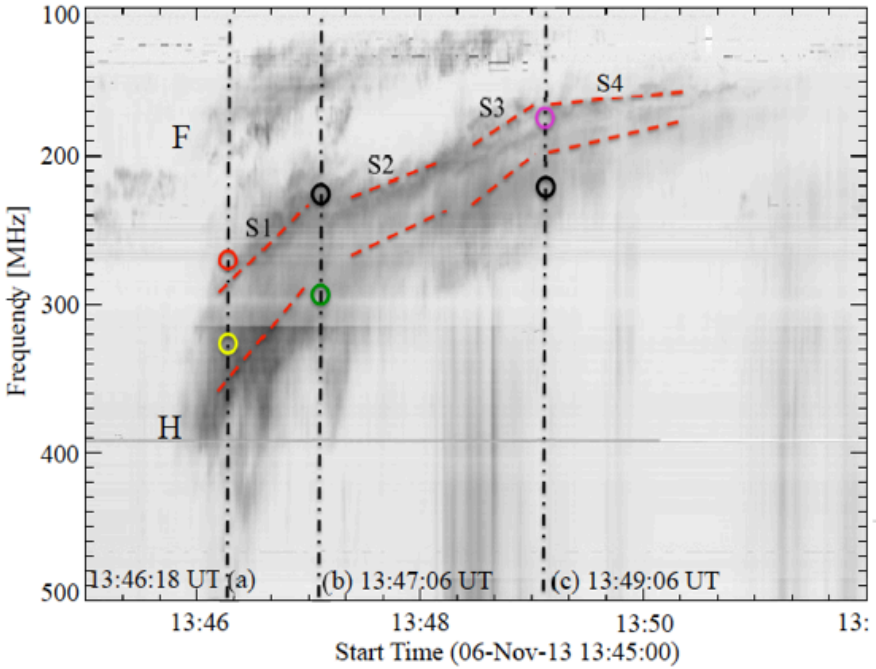
Imaging and spectroscopy of CME-driven shocks

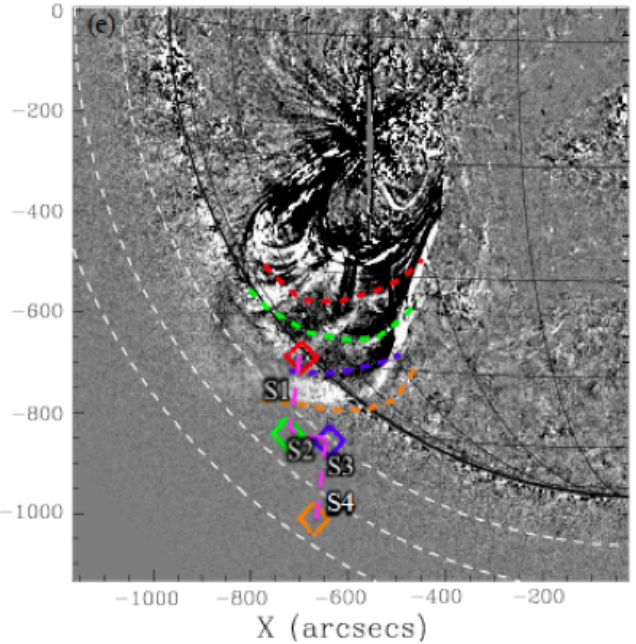


NRH, ORFEES and DAM

Pick, **Zucca** et al. **ApJ** (2016)

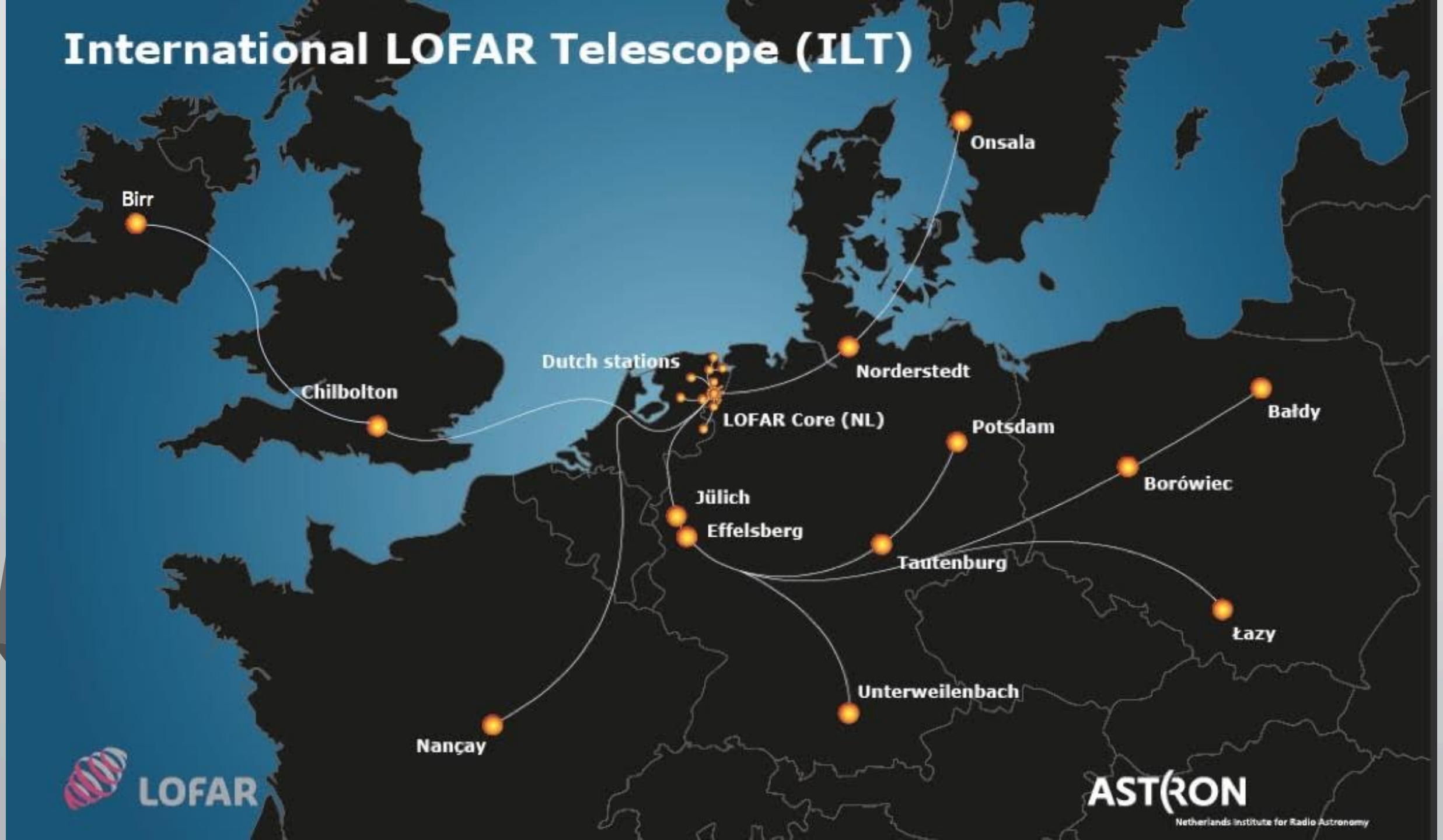




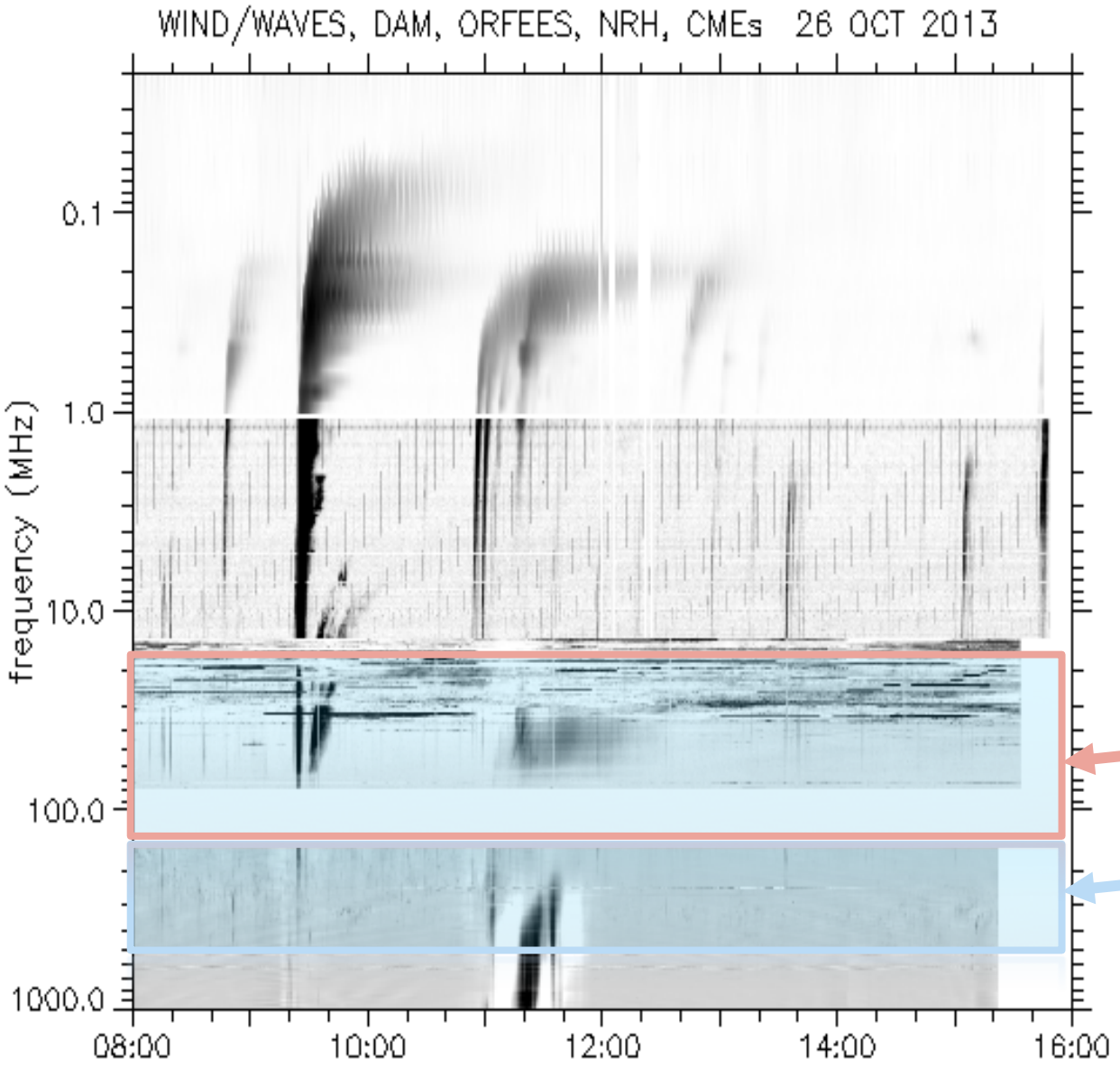


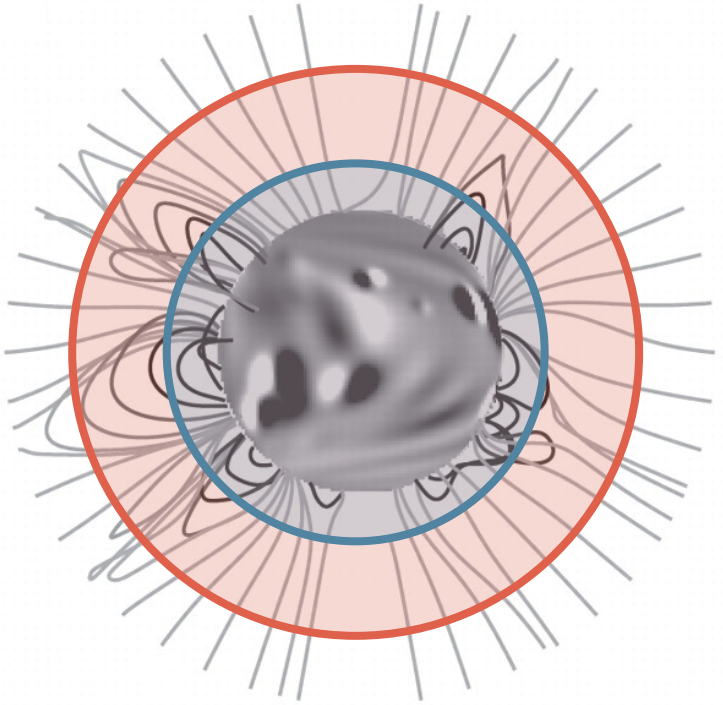
Zucca et al. **ApJ** (2014b)

- Track the shock evolution with the CME
- Relate the spectral characteristics with the complex coronal environment


International LOFAR Telescope (ILT)
Onsala
Birr
Dutch stations
Norderstedt
Chilbolton
LOFAR Core (NL)
Potsdam
Bałdy
Borówiec
Jülich
Effelsberg
Tautenburg
Łazy
Unterweilenbach
Nançay
LOFAR
ASTRON
Netherlands Institute for Radio Astronomy

LOFAR radio Imaging

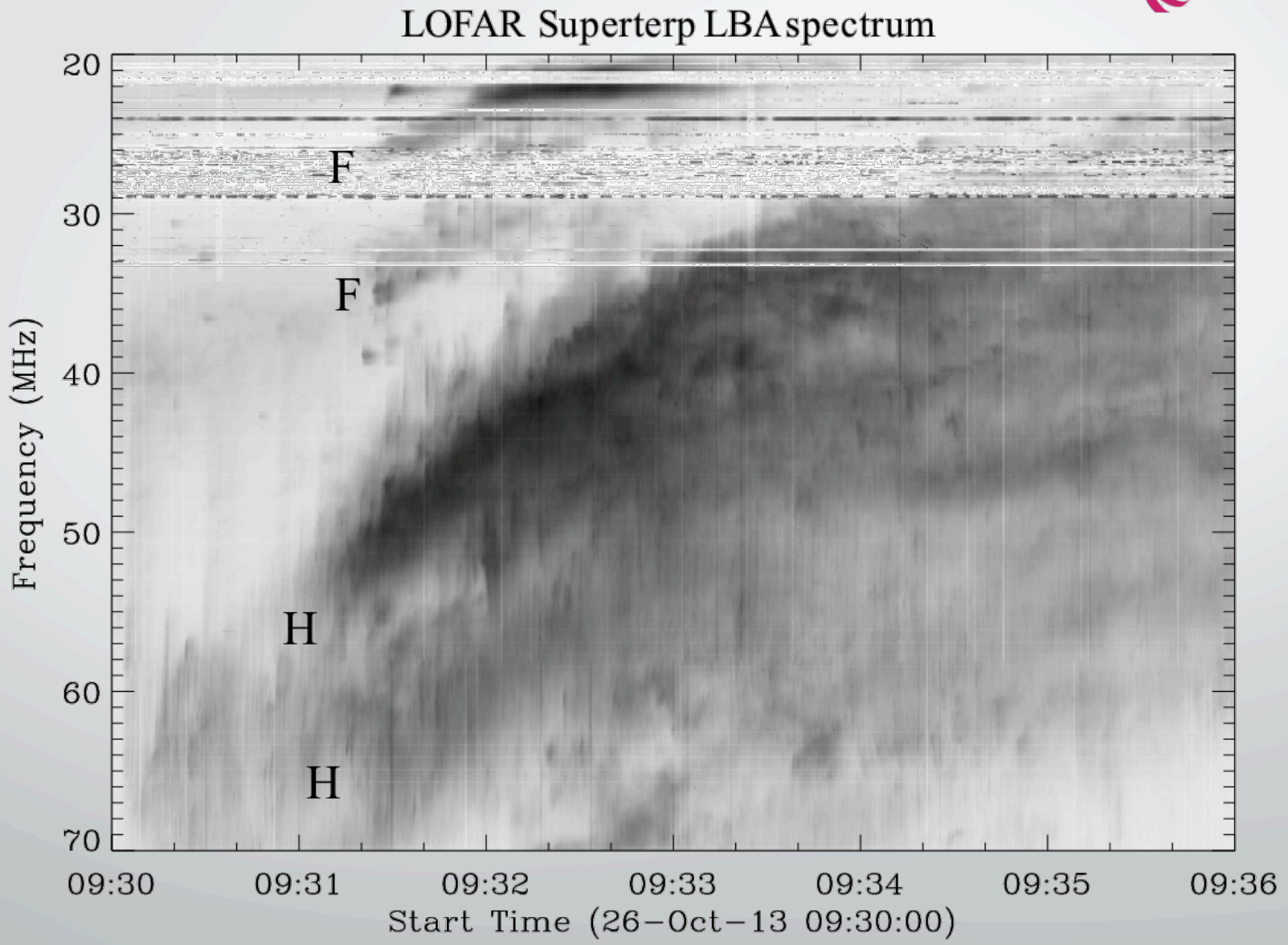




Imaging with LOFAR

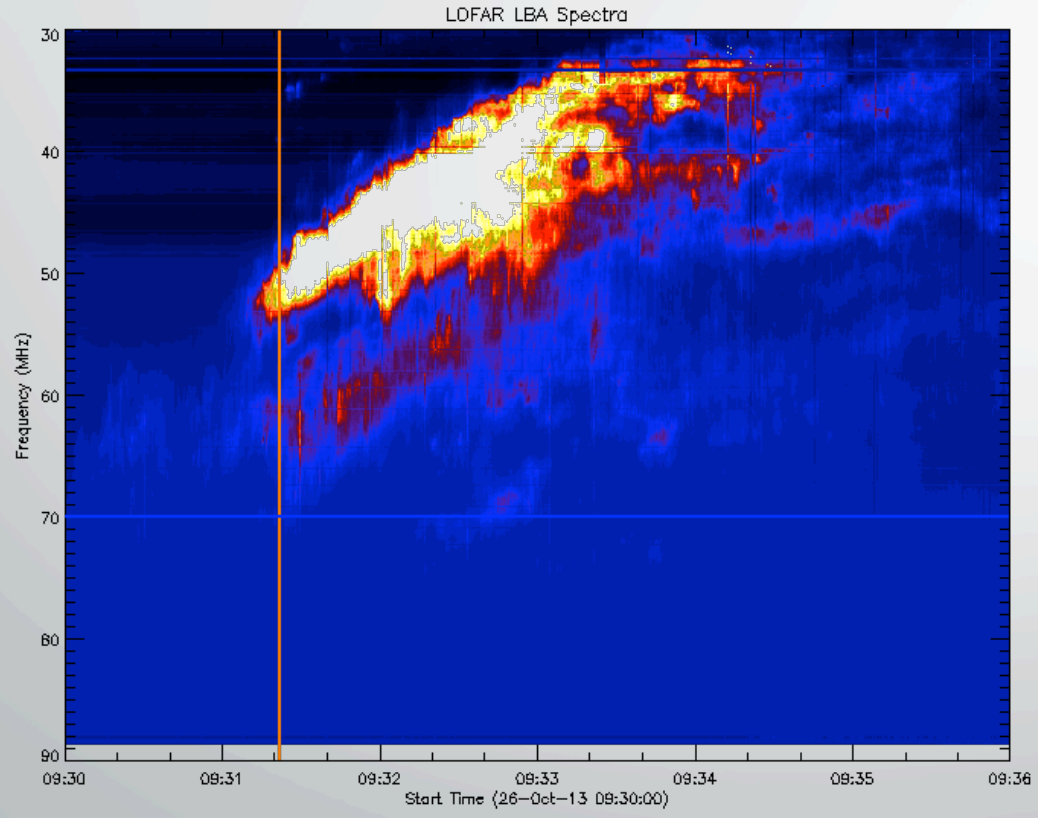
Imaging with Nançay

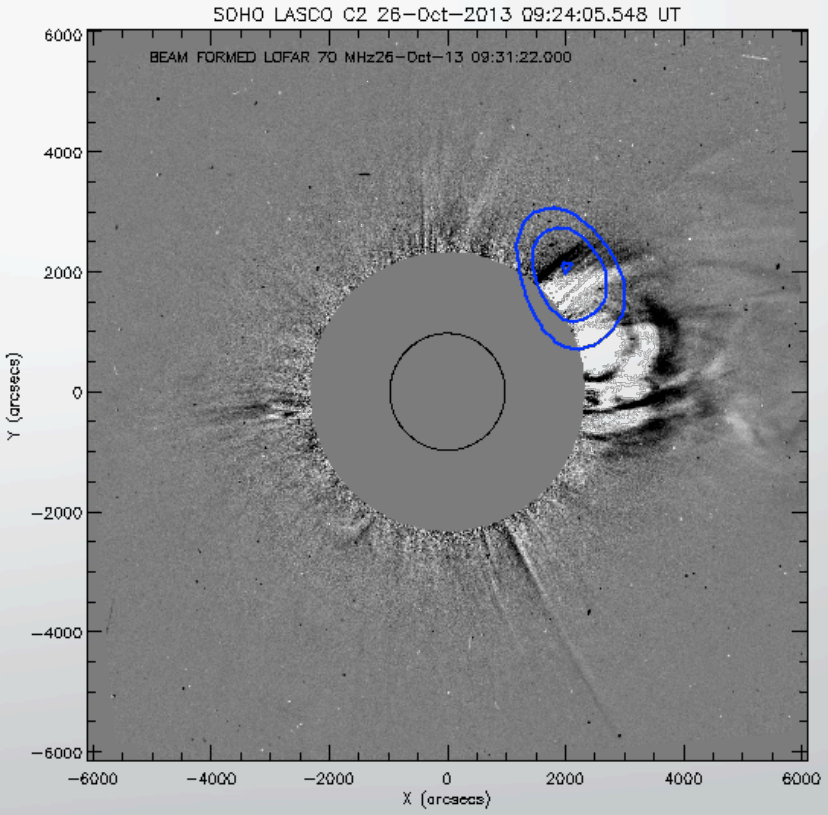
Imaging of a Type II below 80 MHz



Zucca et al. 2017 Submitted

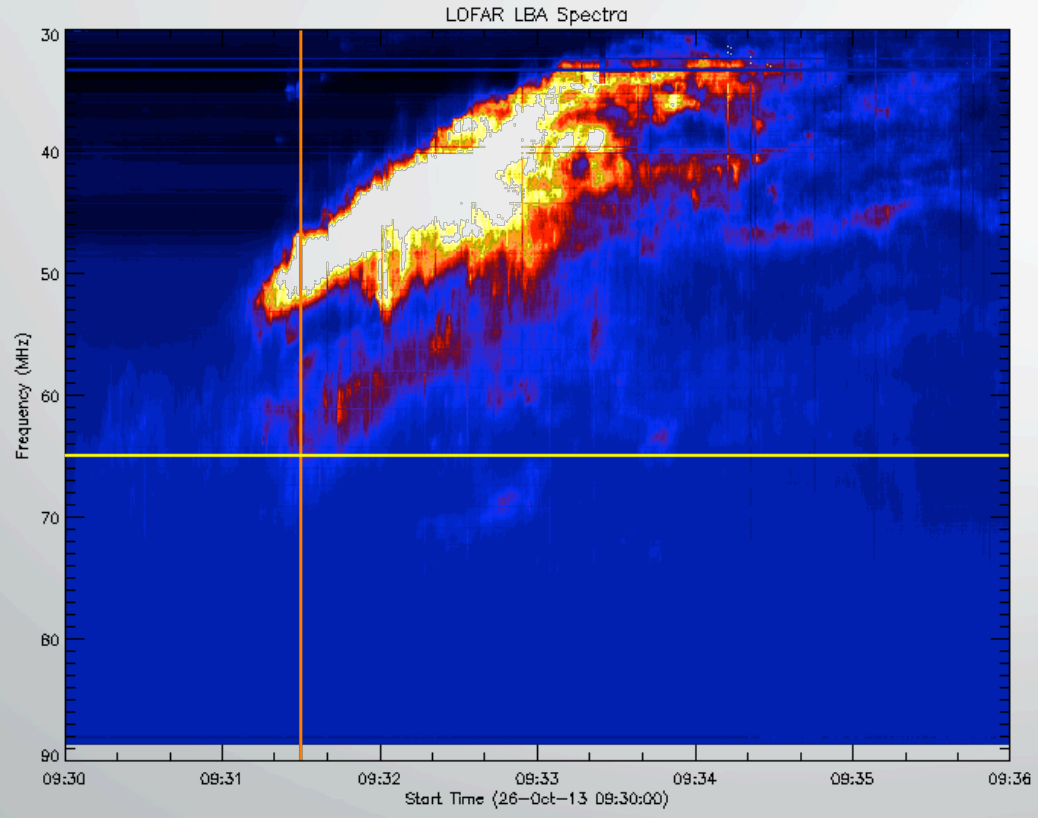
First Imaging of a Type II below 80 MHz

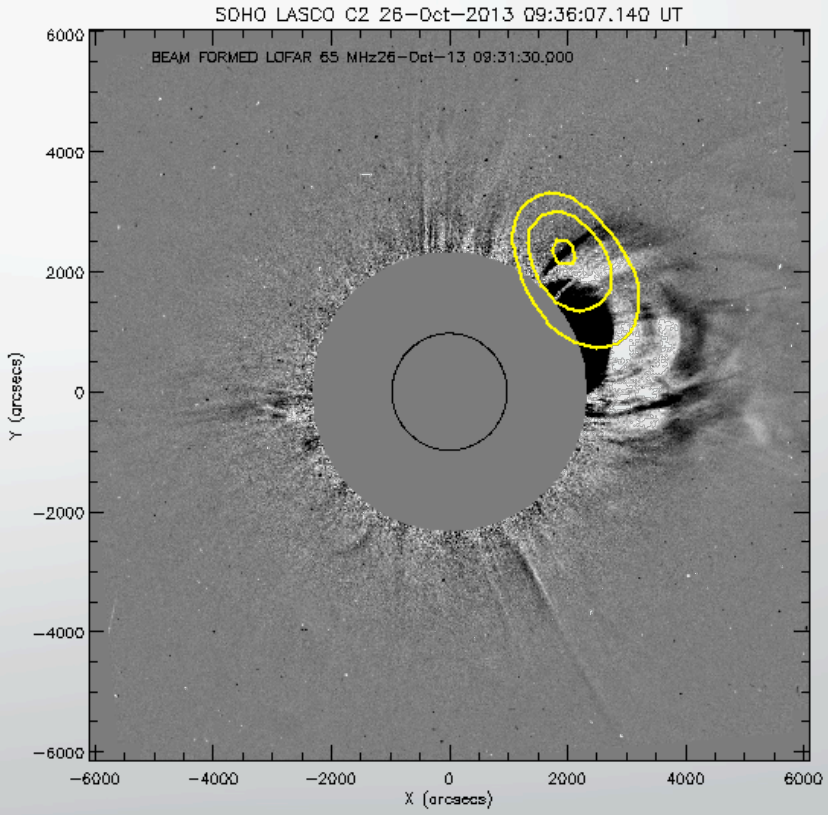




Zucca et al. 2017 Submitted

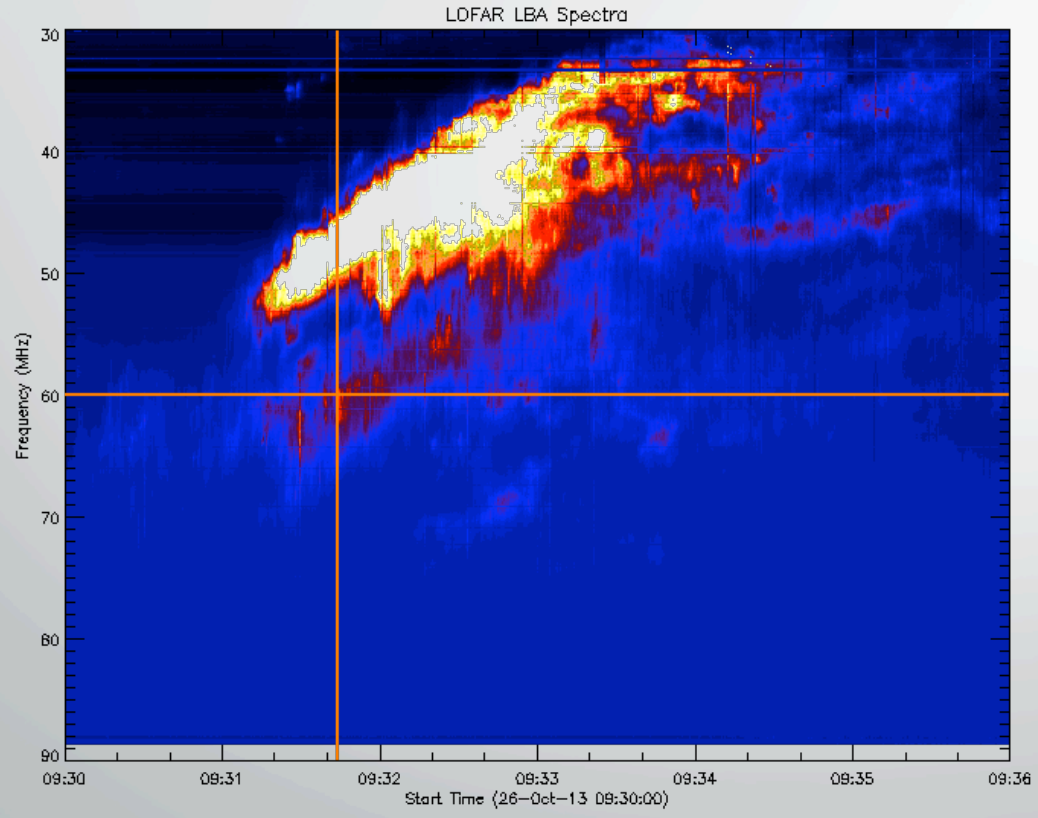
First Imaging of a Type II below 80 MHz

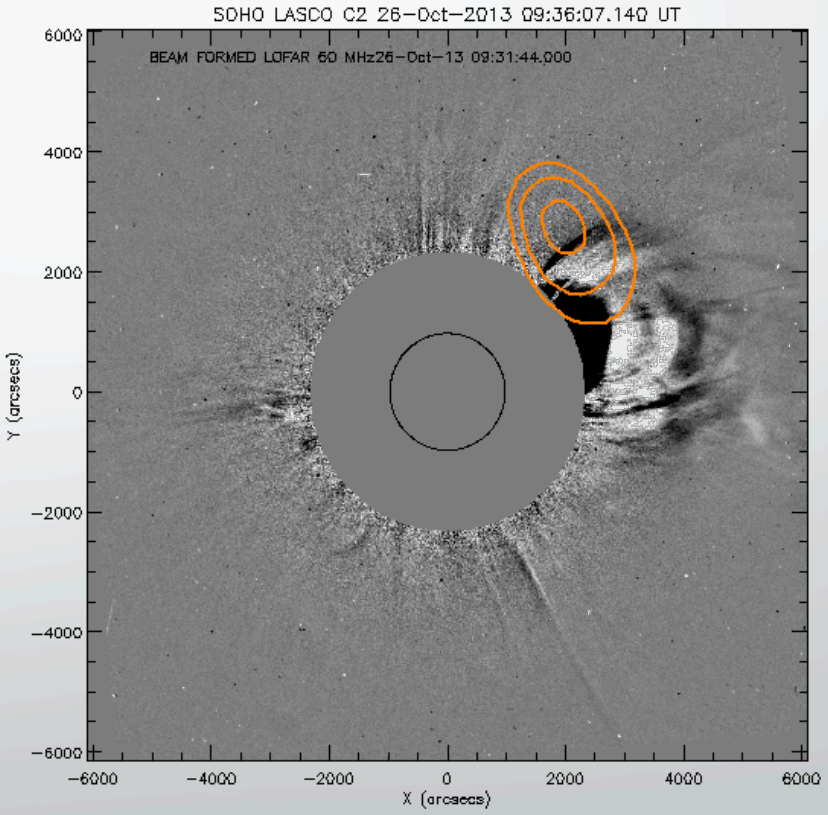




Zucca et al. 2017 Submitted

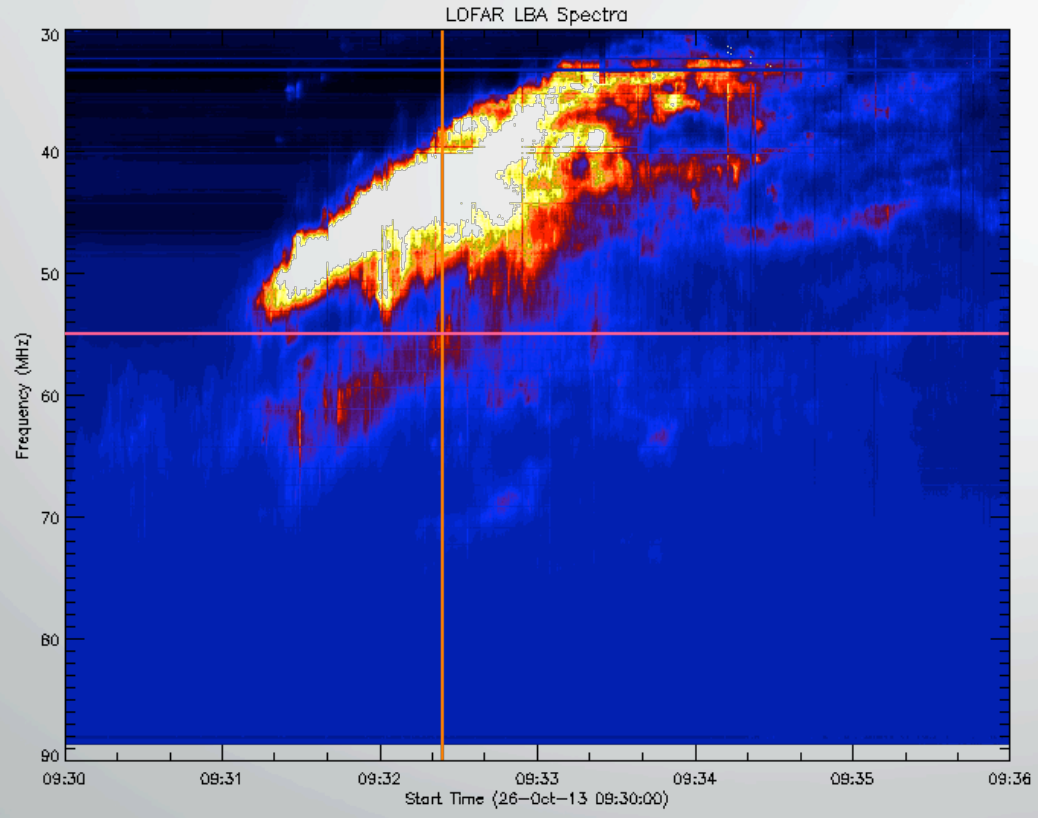
First Imaging of a Type II below 80 MHz

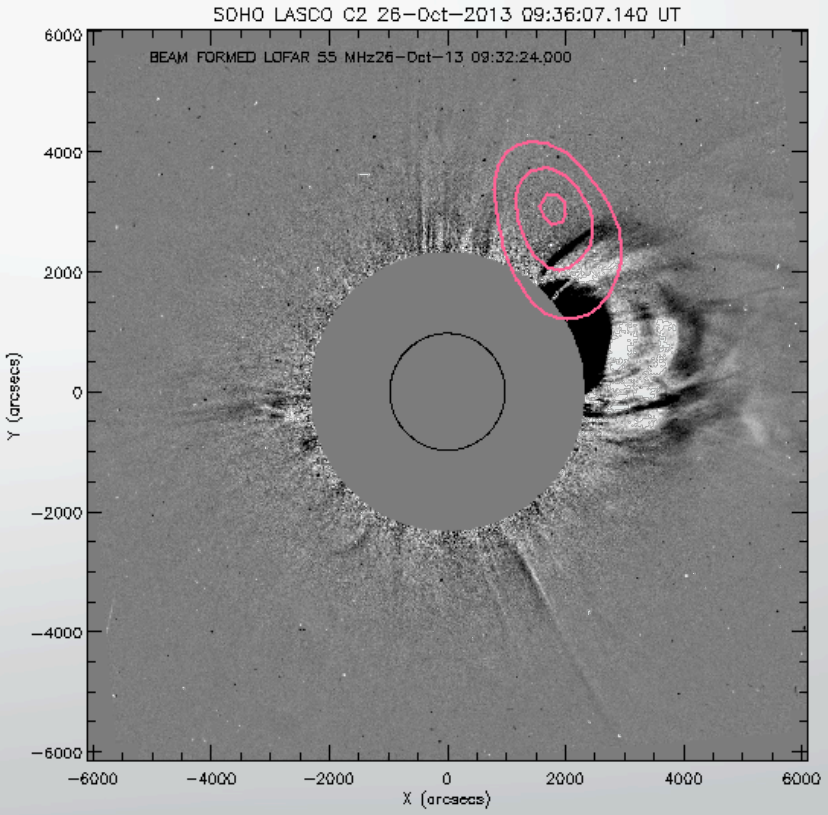




Zucca et al. 2017 Submitted

First Imaging of a Type II below 80 MHz





Zucca et al. 2017 Submitted

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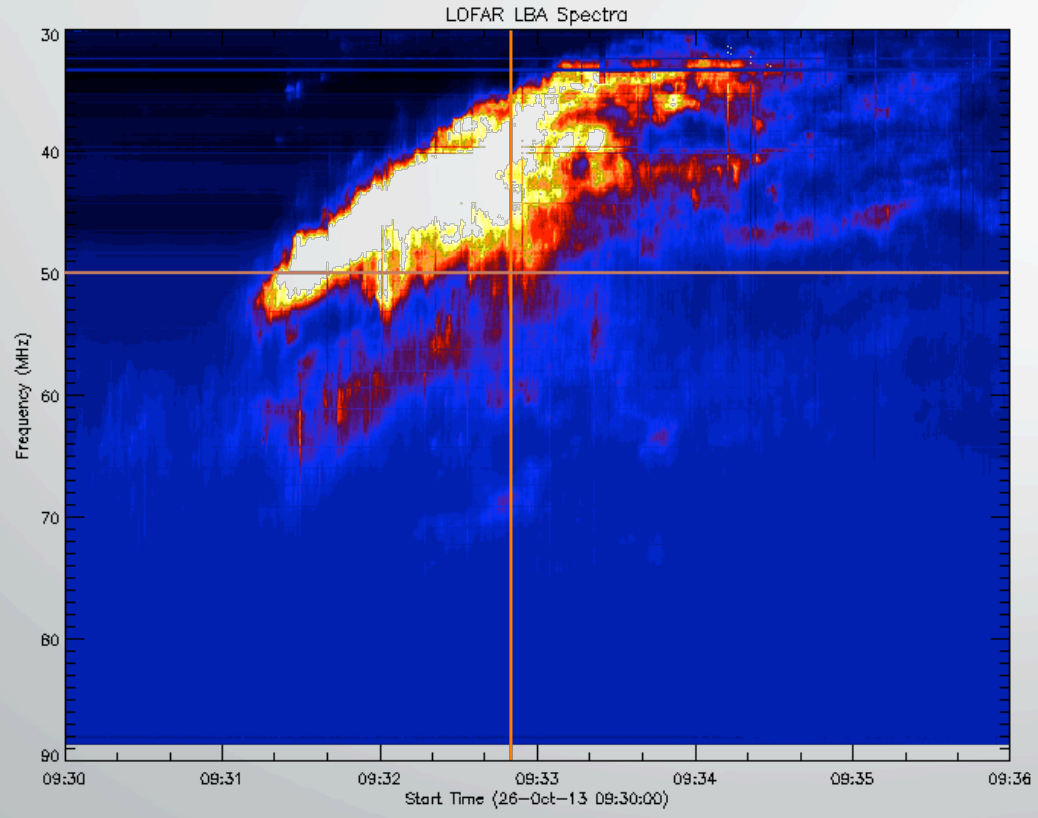

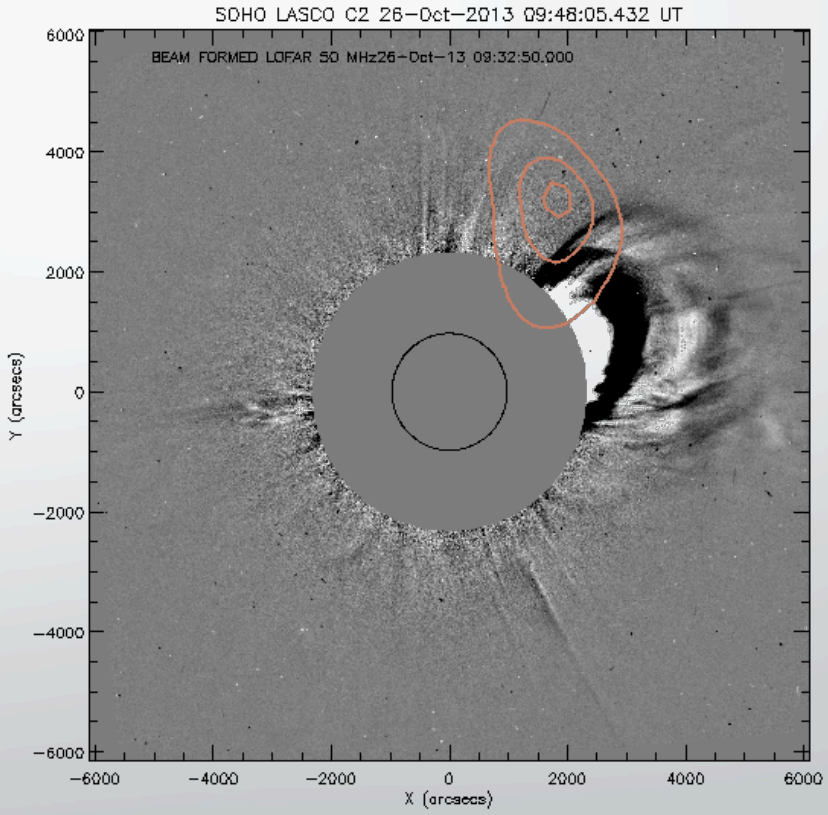

Zucca et al. 2017 Submitted

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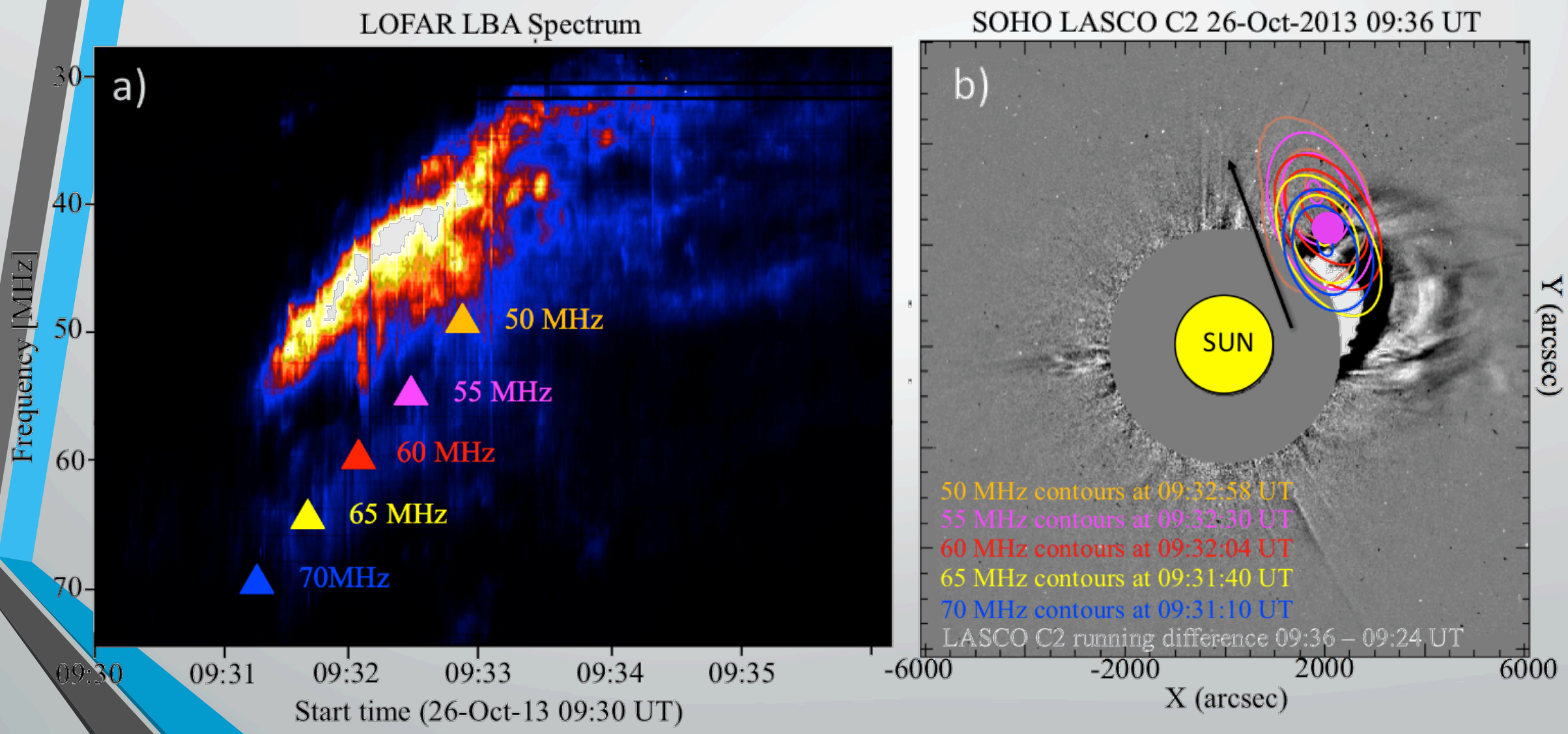
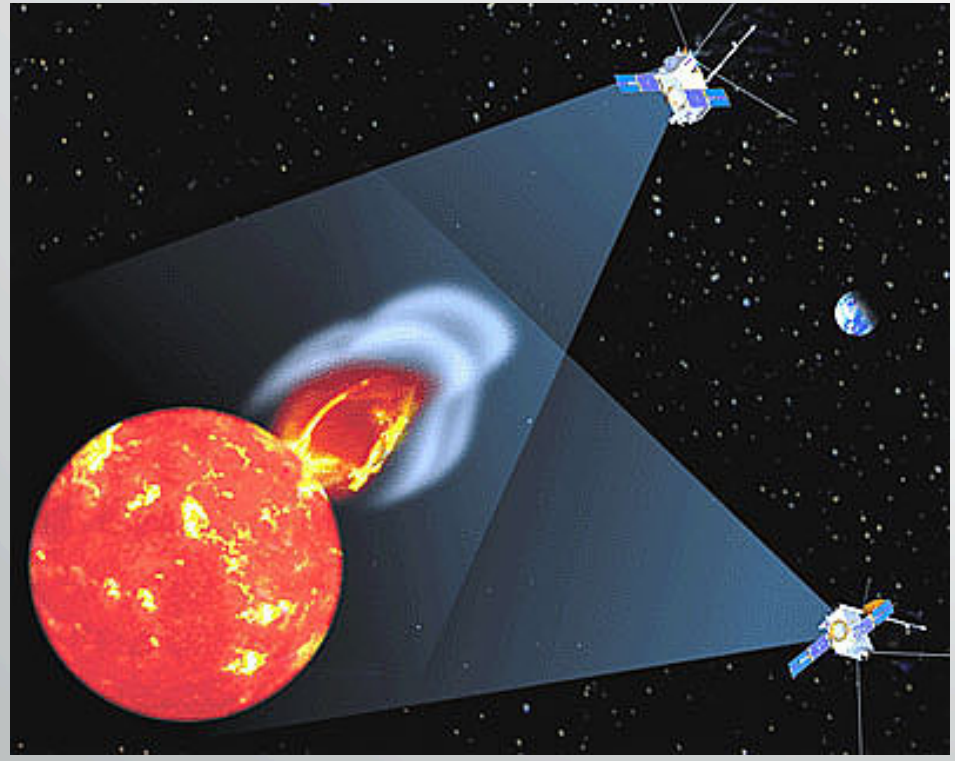


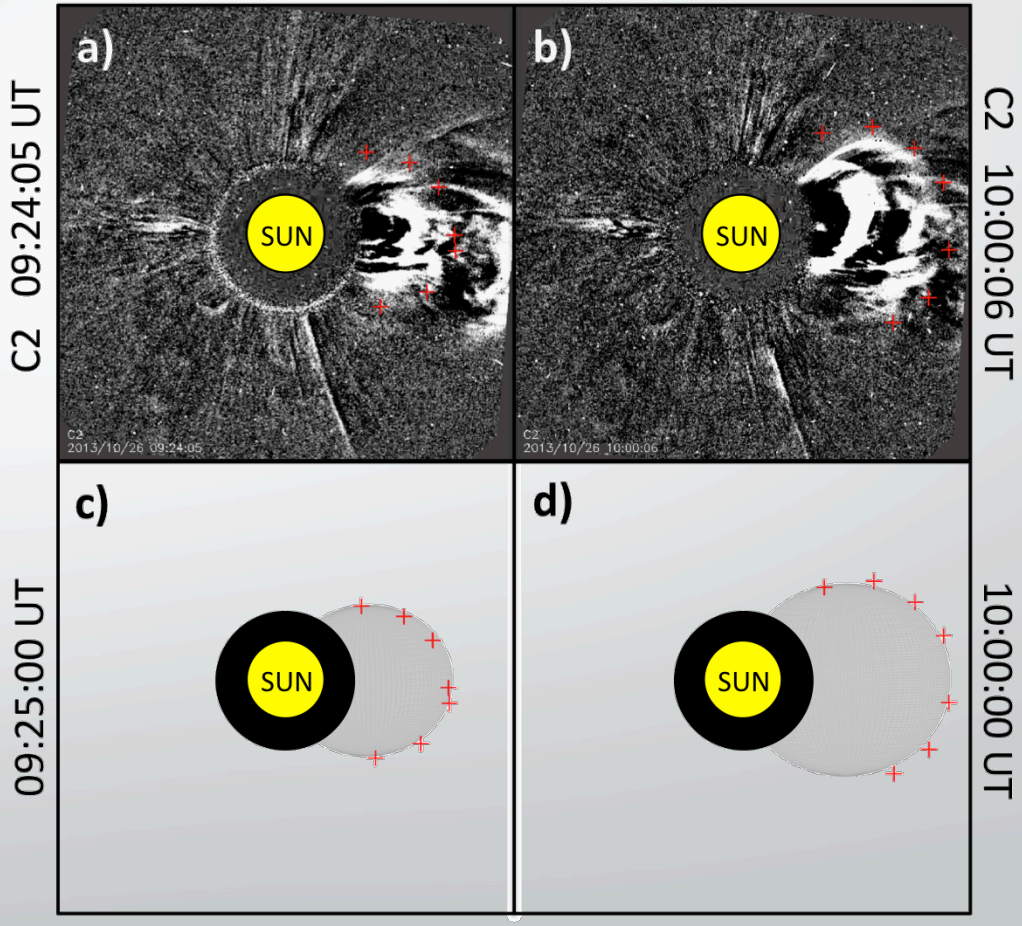
Zucca et al. 2017 Submitted

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)



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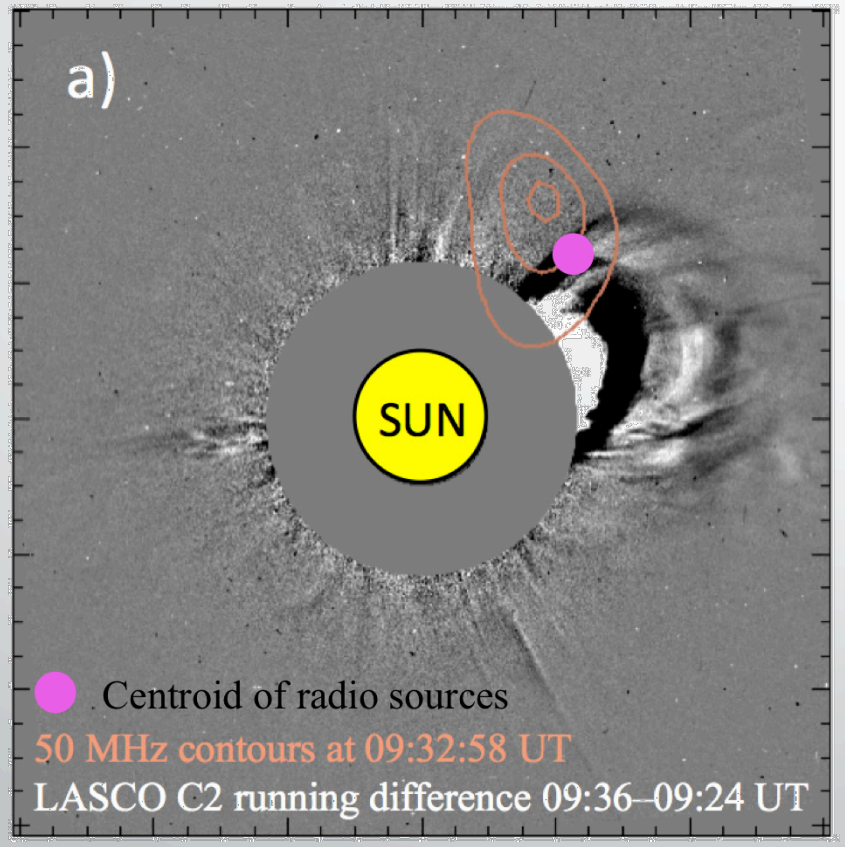
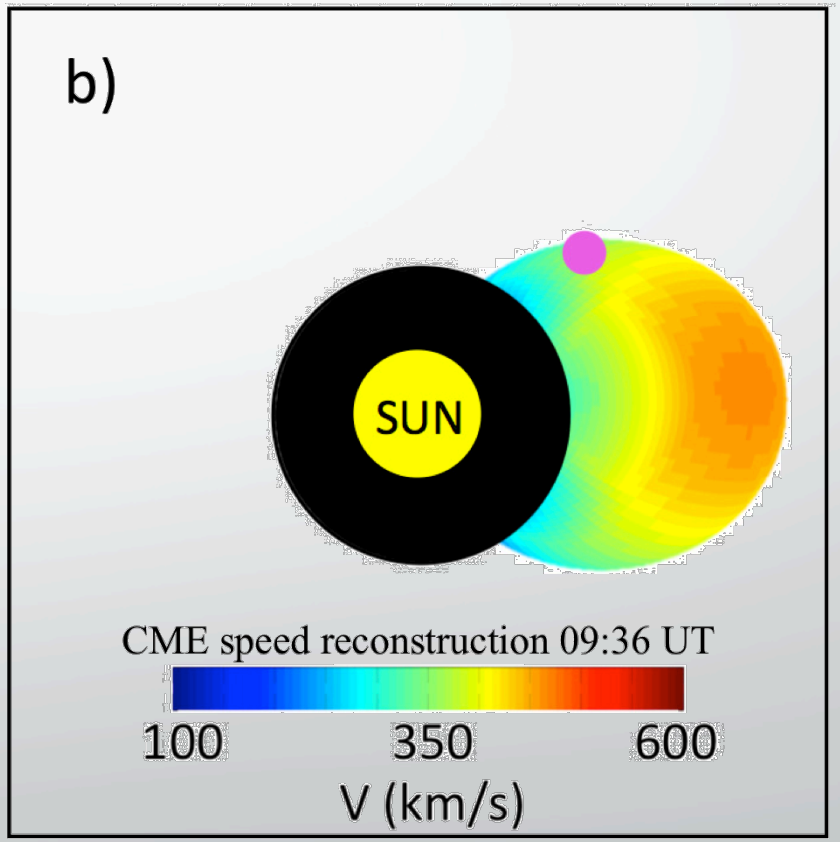
CME speed and radio emission

- Expansion of the flank slower than the apex



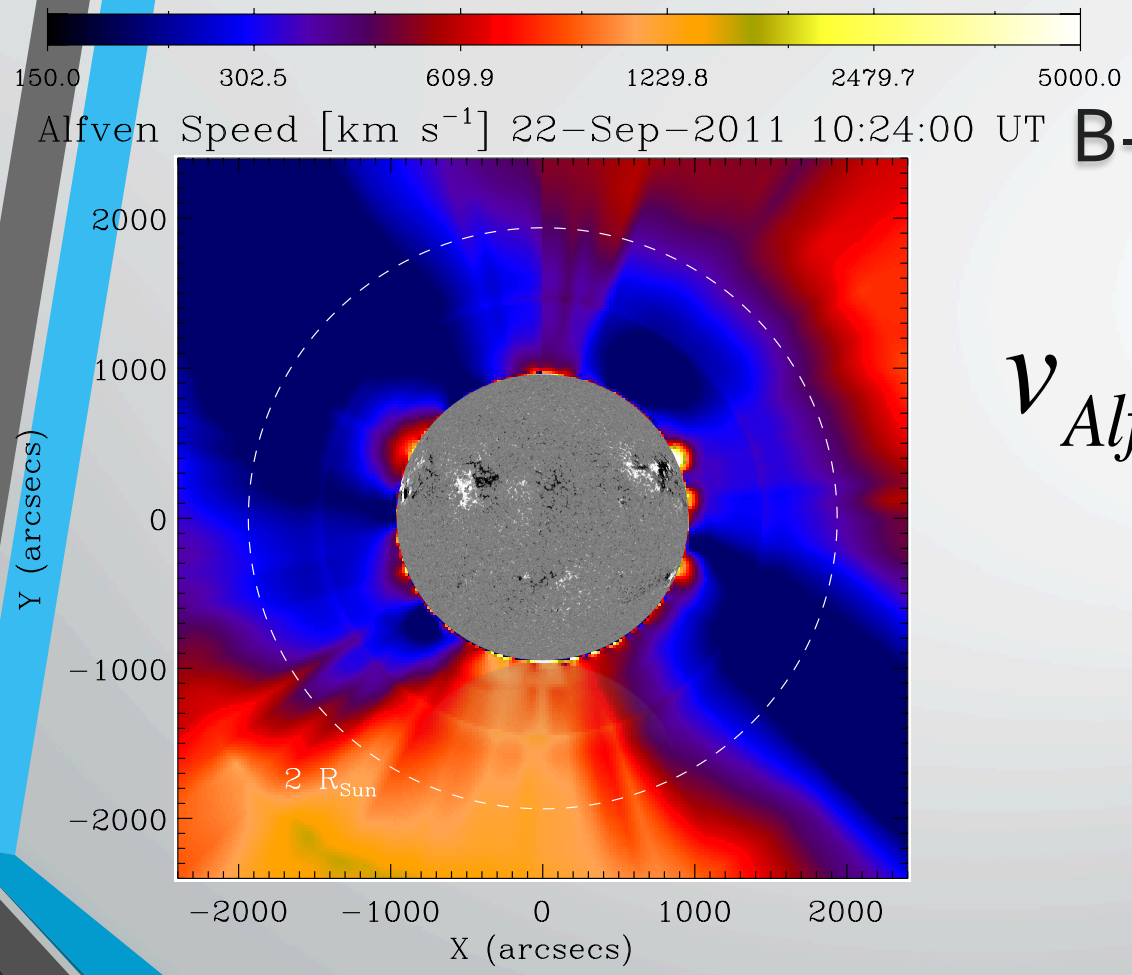


Triangulation of CME using Alexis Rouillard method

AP Rouillard et al. ApJ (2016)

Zucca et al. 2017 Submitted

Estimating the Mach number



B-Field with PSFF

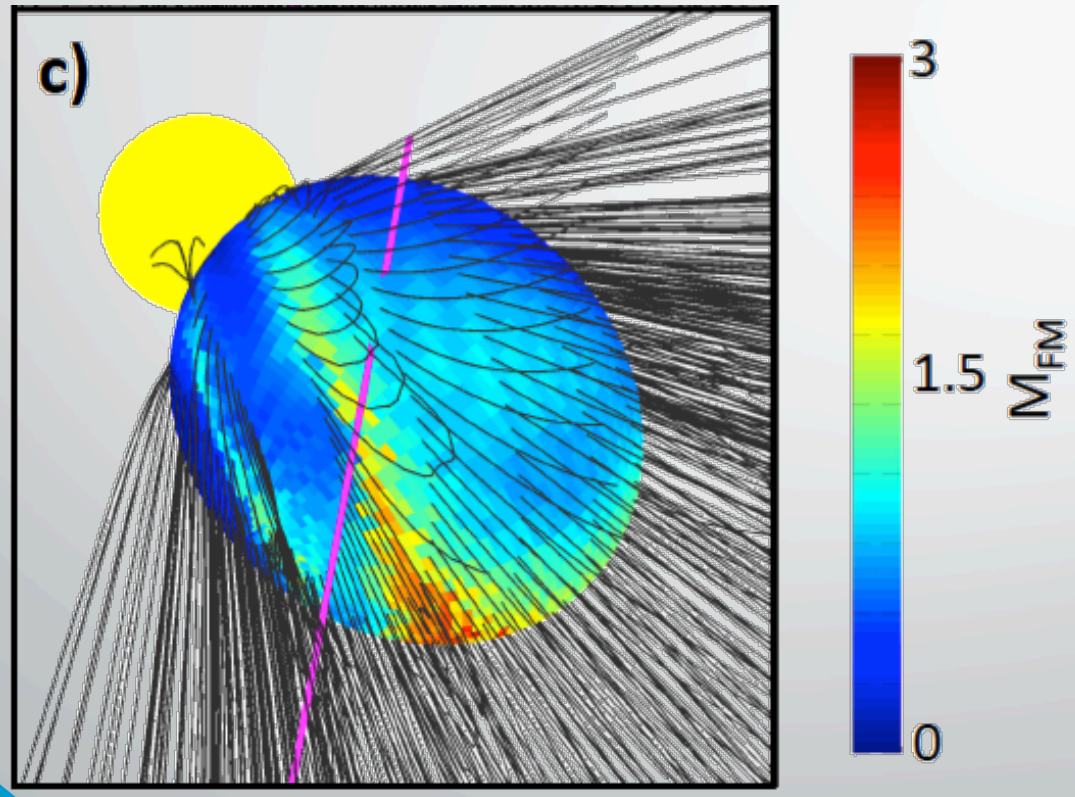
$$v_{Alfven}(x,y) = \frac{B(x,y)}{\sqrt{\mu m_p n_e(x,y)}}$$

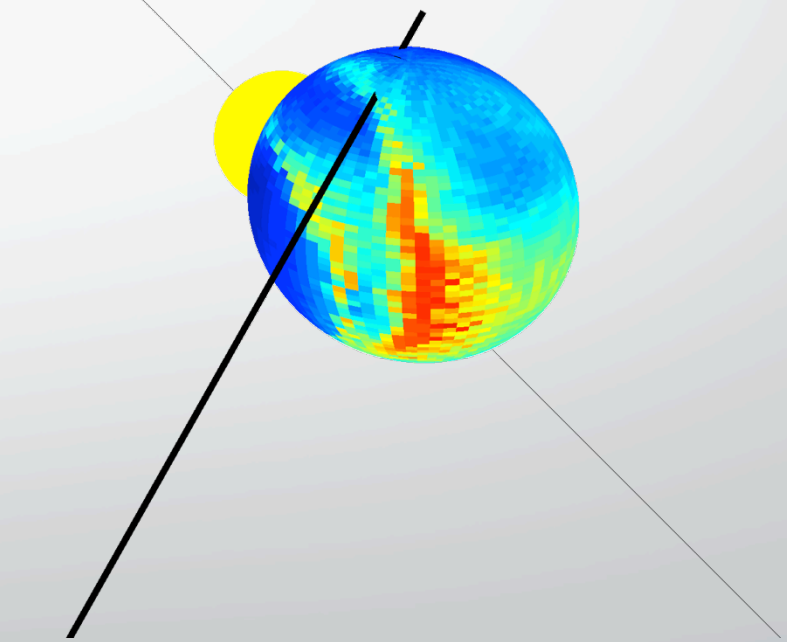
Density Map with SDO/ AIA and SOHO/LASCO

Zucca et al. 2014a

3D reconstruction – Mach Number

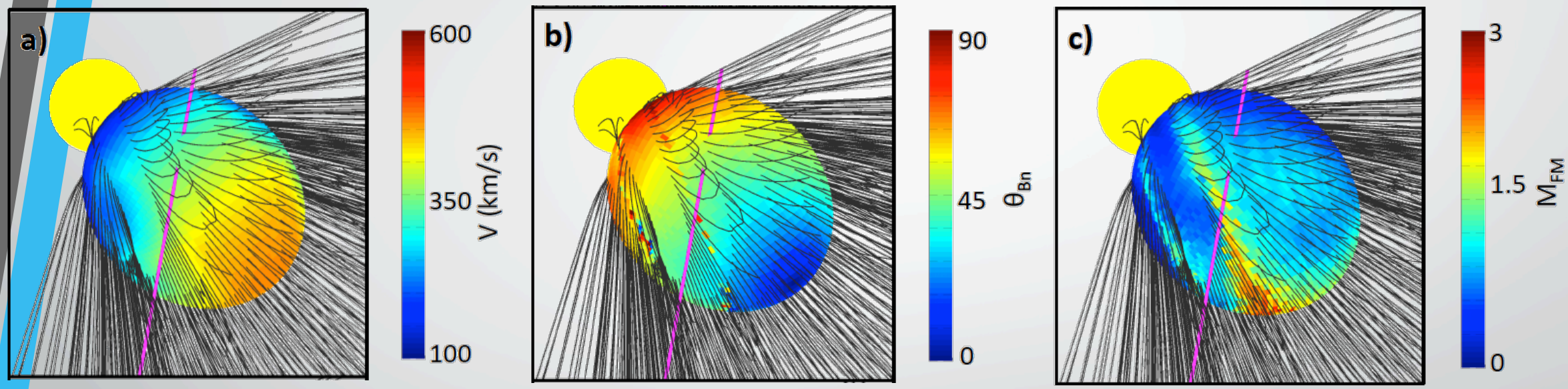
Mach number calculation using the CME front propagation and the local Alfven Speed.





Mach number at the flank 1.2 to 1.5

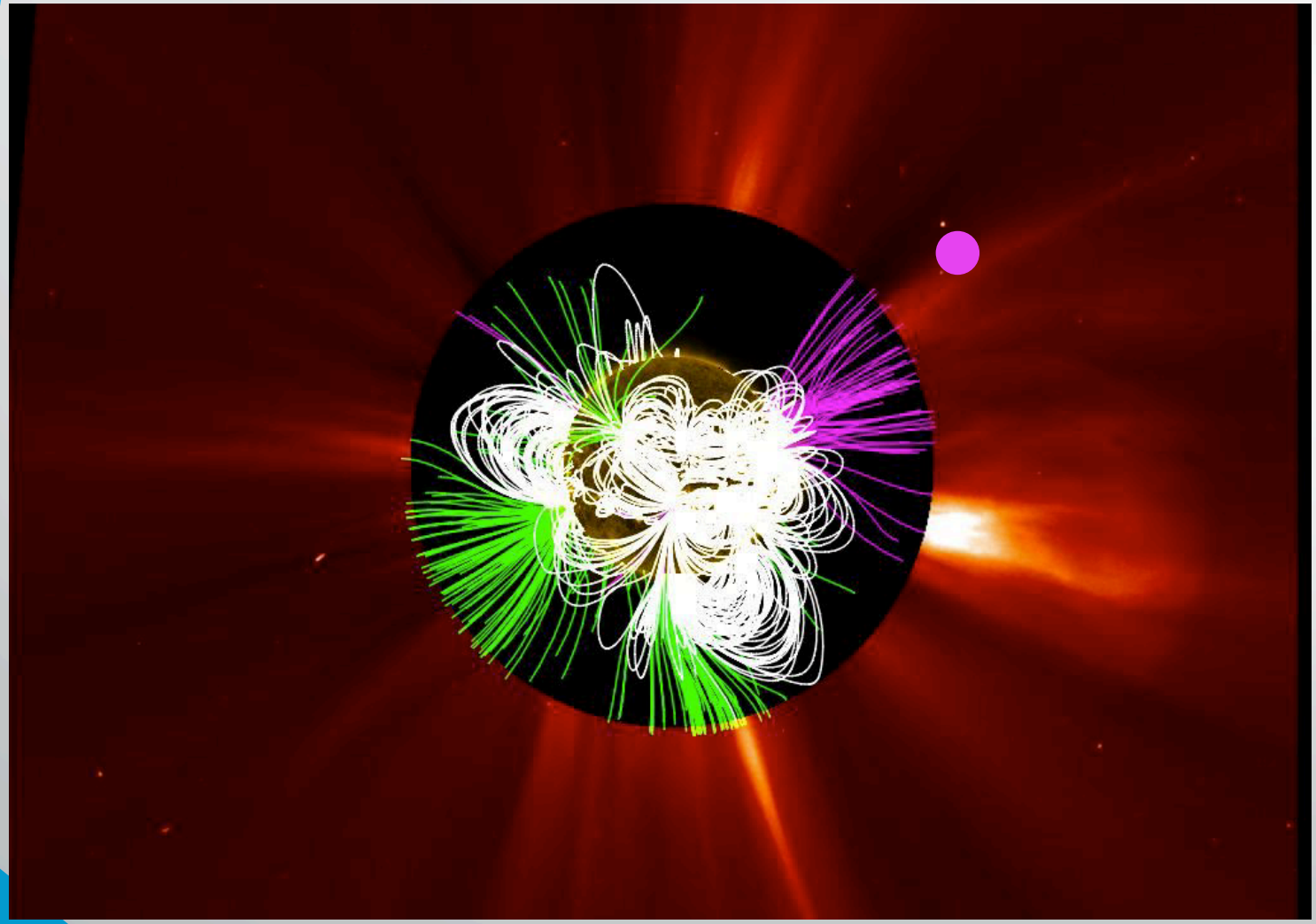
3D – Shock geometry

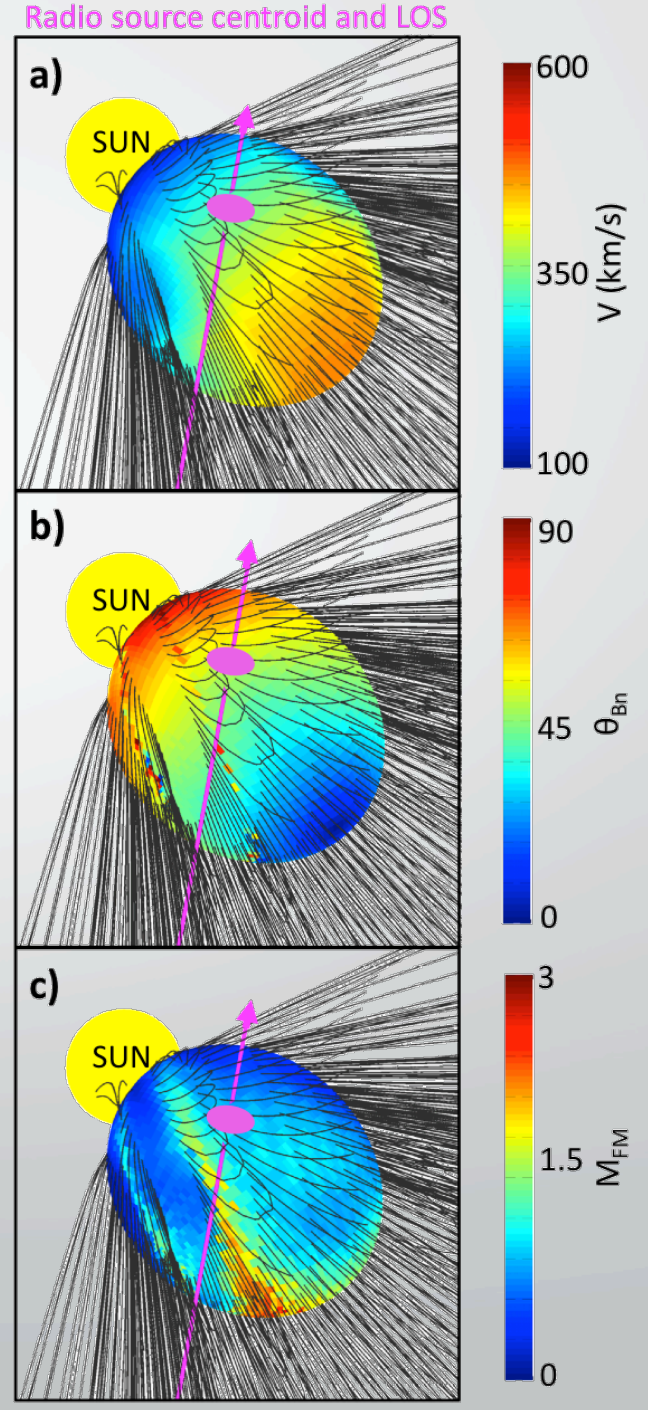


The geometry of the shock was obtained Comparing the b-field orientation with the normal to the CME front

The flank of the CME shows a Quasi-perpendicular geometry

Mach Number and B-field Geometry





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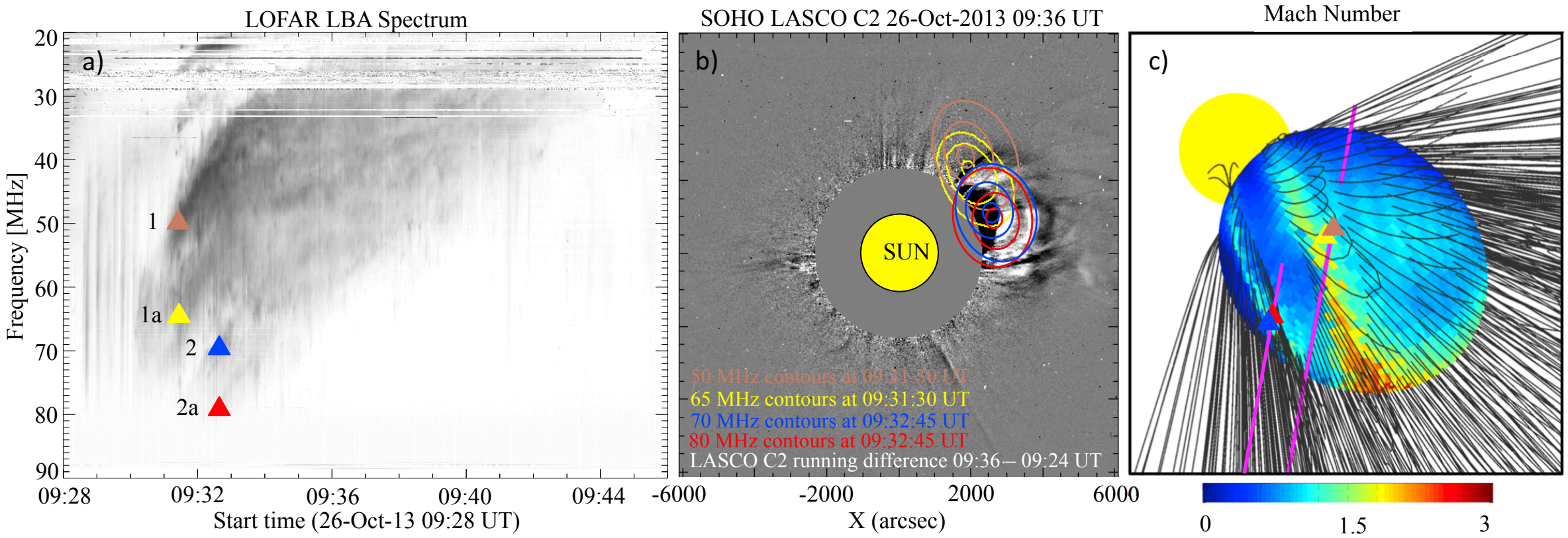
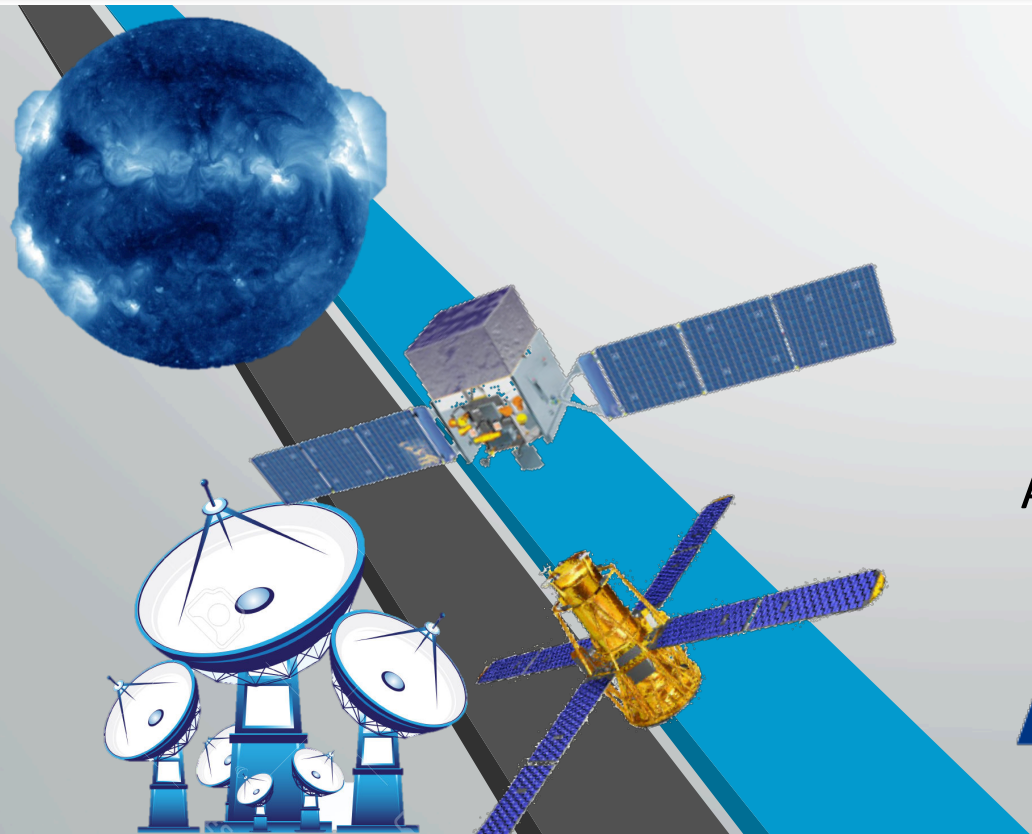
Type II burst band splitting and multi-lane





FUTURE WORK

Pietro Zucca
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Netherlands Institute for Radio Astronomy

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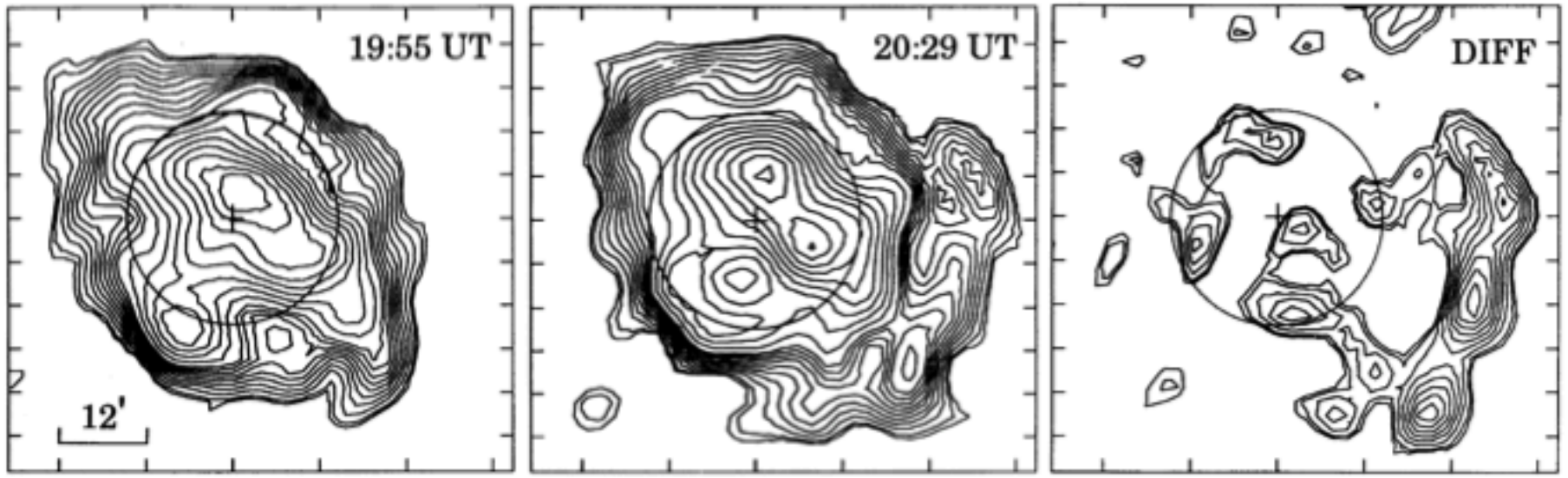
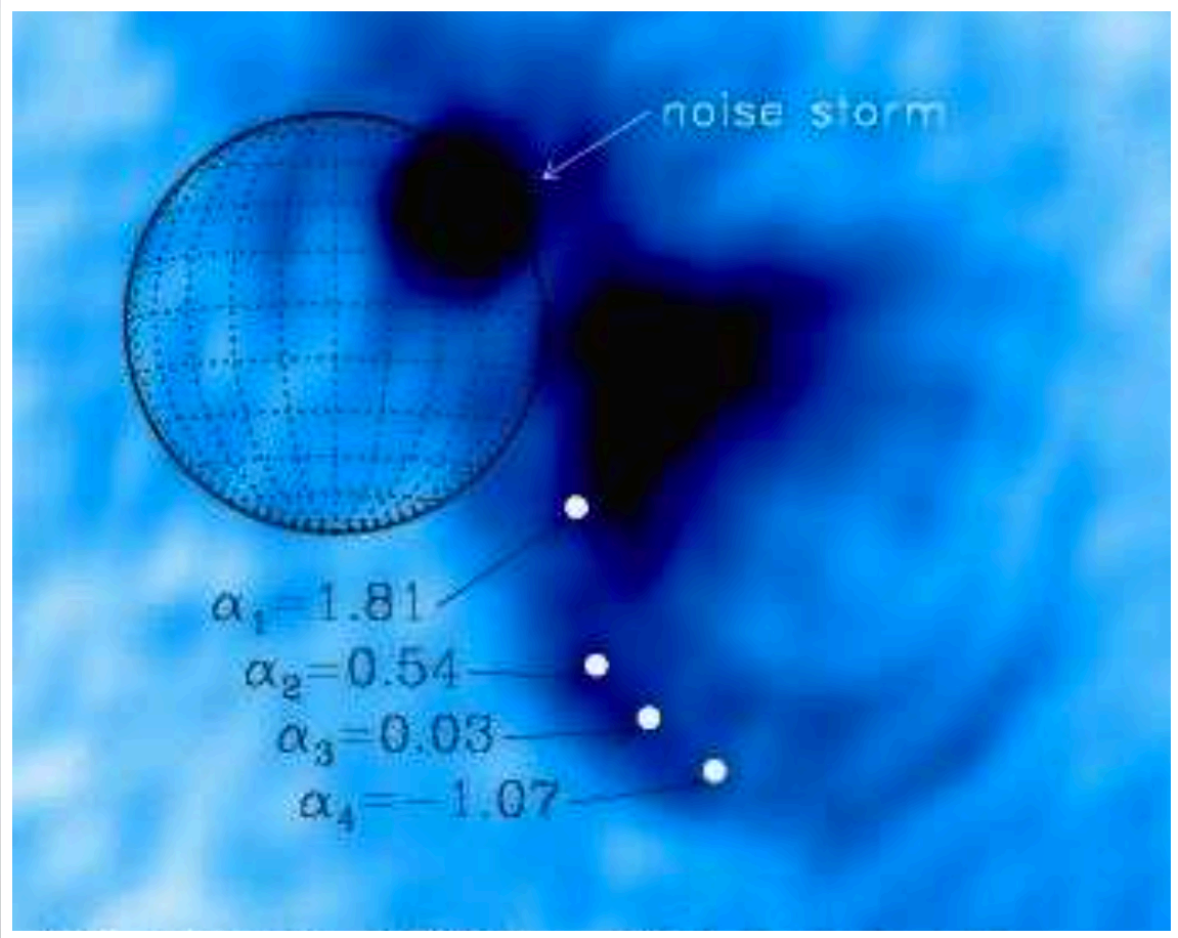
Radio Imaging of CMEs



Thermal emission of a CME from Gopalswamy & Kundu 1992. Observation made in 1986 using Clark Lake Radioheliograph at 73.8 MHz.

Radio Imaging of CMEs



Snapshot map of the radio CME loops at 164 MHz. The background disk emission has been removed. A noise storm is present at the northwest. The spectral indices at a few locations are also shown. From Bastian et al. (2001).

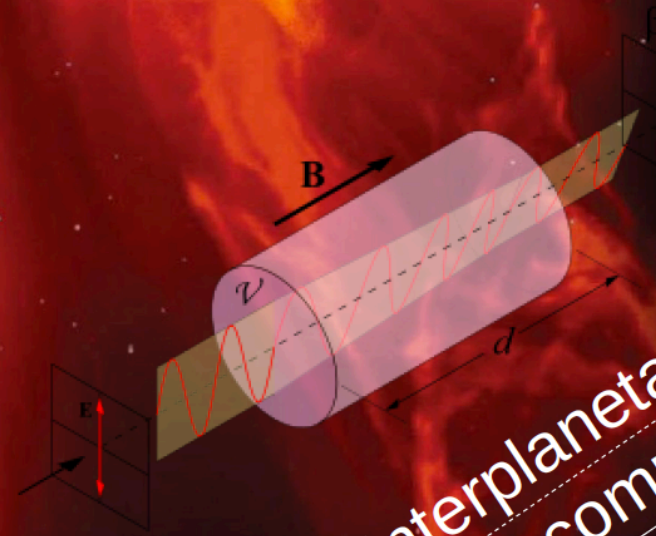
Interplanetary magnetic field

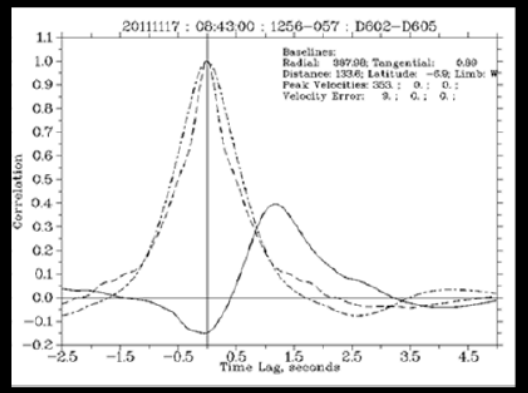
Faraday Rotation from polarised source

Interplanetary Scintillation from compact source

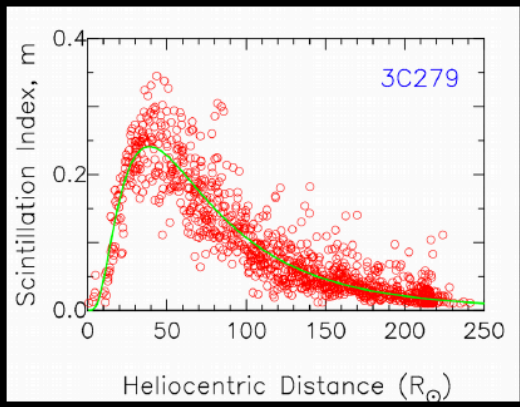
Solar wind density and velocity

Ionospheric scintillation





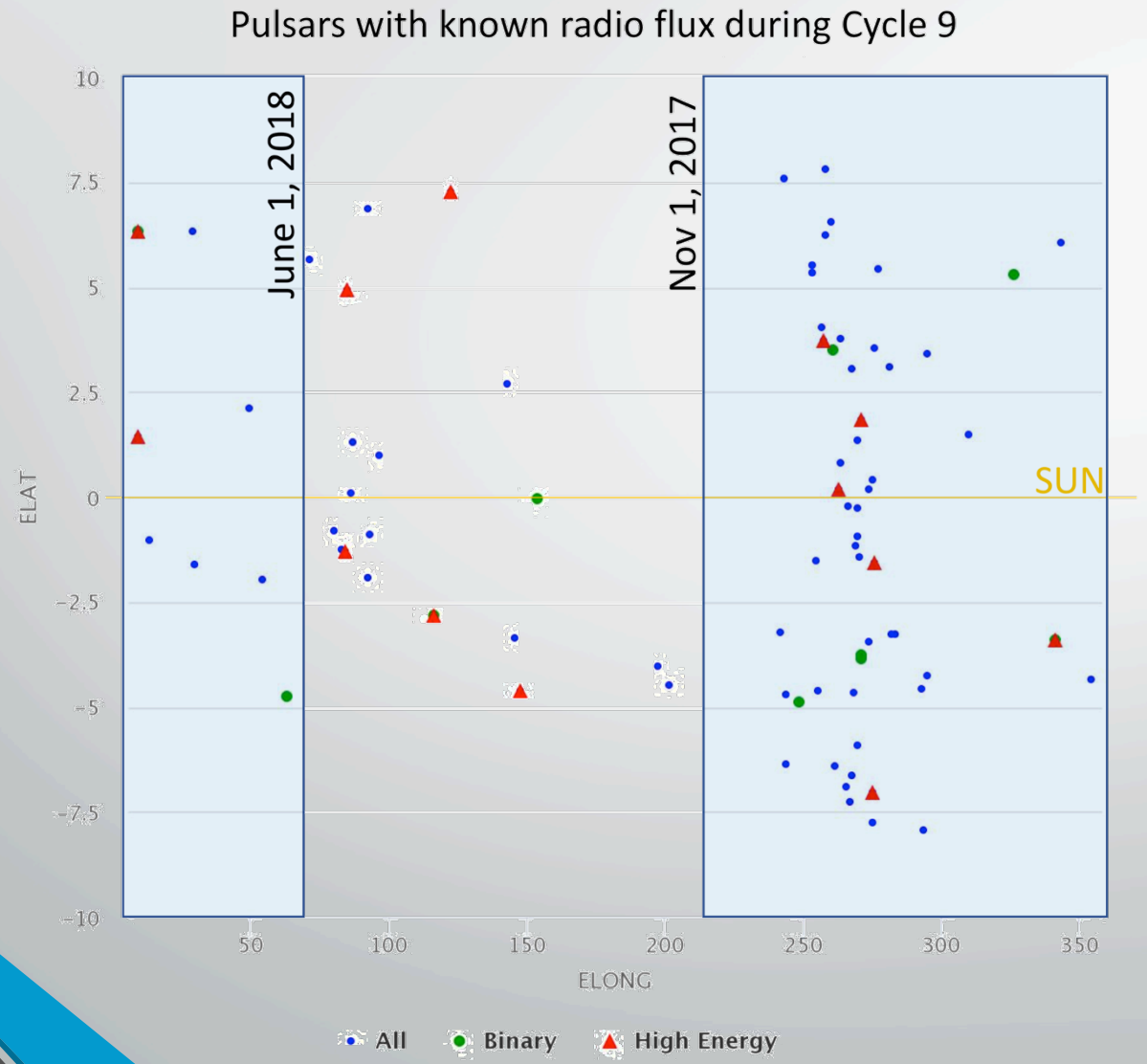
Cross-correlation of time series -> velocity



Variation in amount of scintillation -> density

Tests and preliminary studies made by R.Fallows and M.Bisi

Bz from CMEs using Pulsars

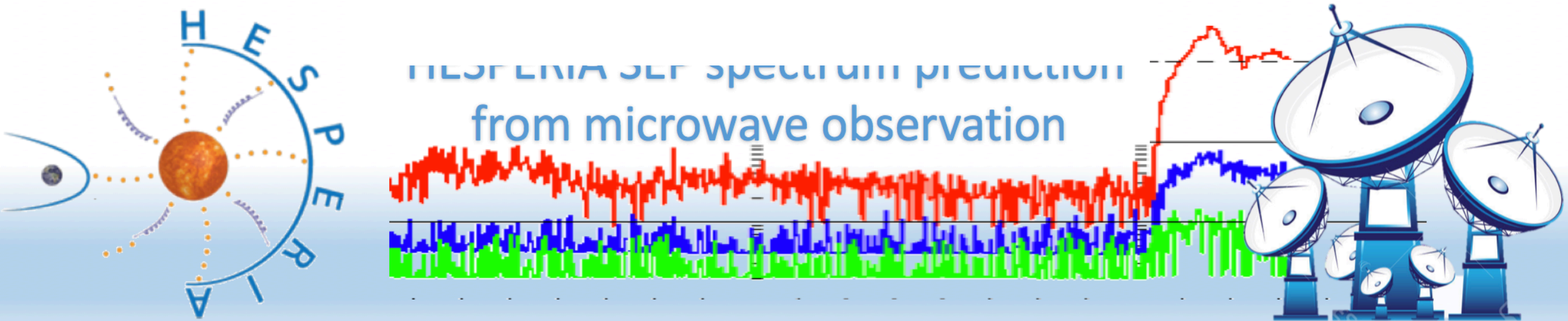


Observing proposal with LOFAR

Dispersion Measure to infer the electron density

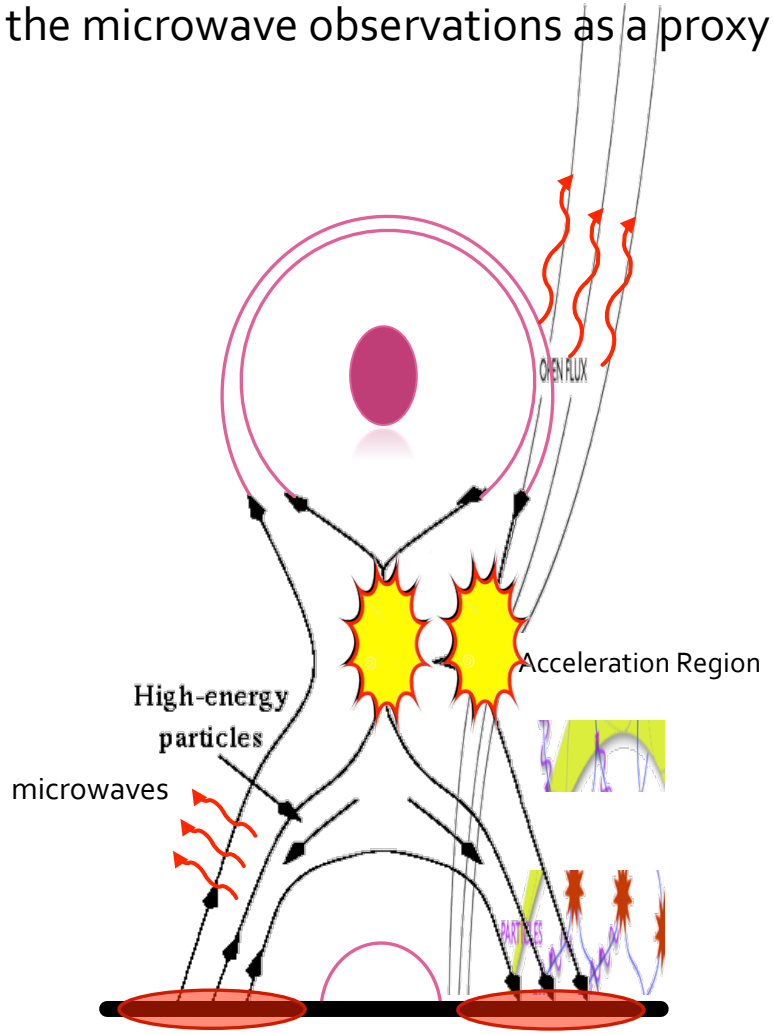
Faraday Rotation to infer the Magnetic Field

Predicting Solar Energetic Particles (SEP) using Microwave observations

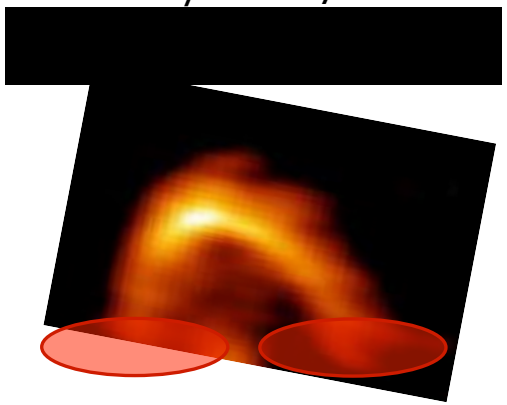


Signature of particle acceleration

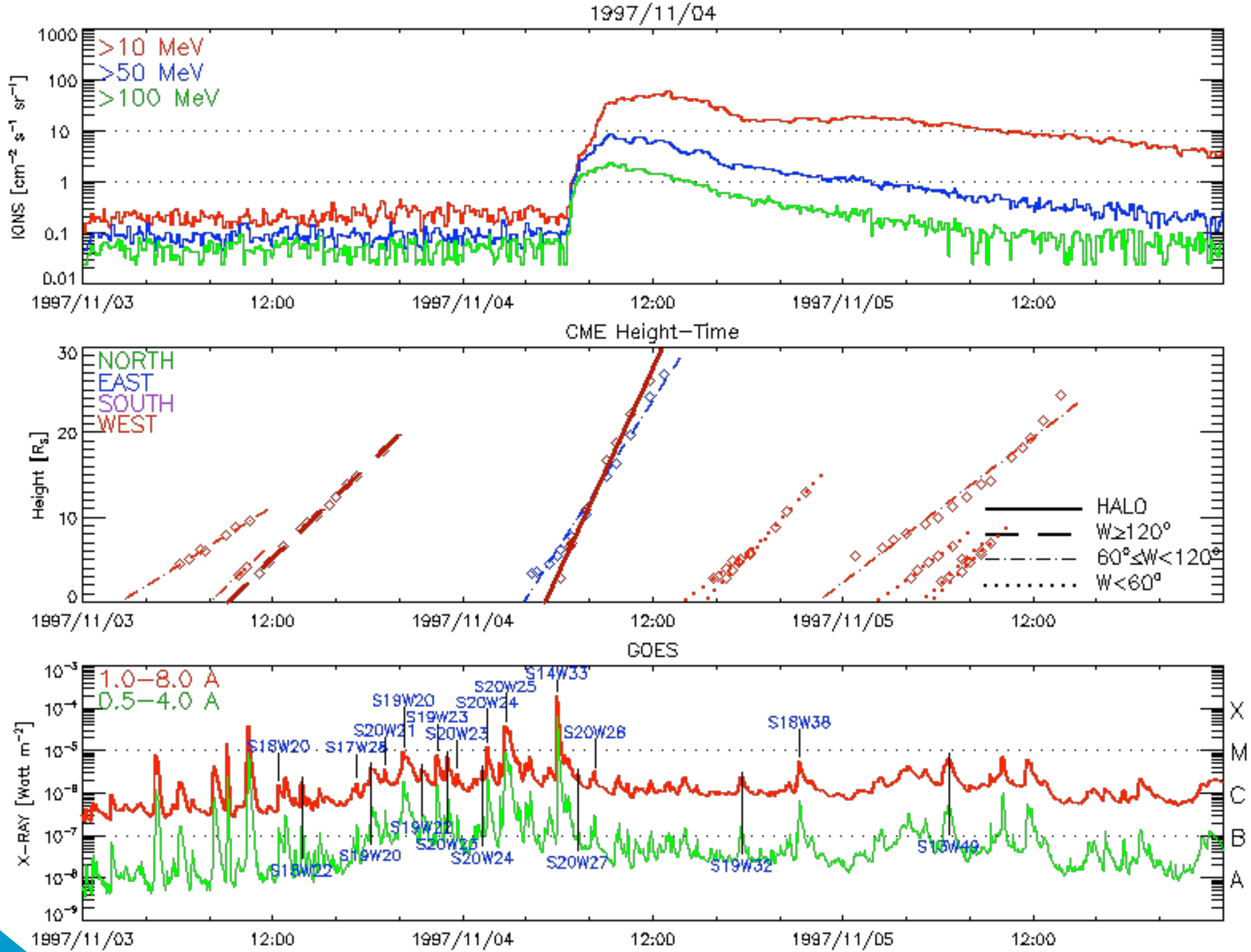
Can we use the microwave observations as a proxy for the energetic particles ?

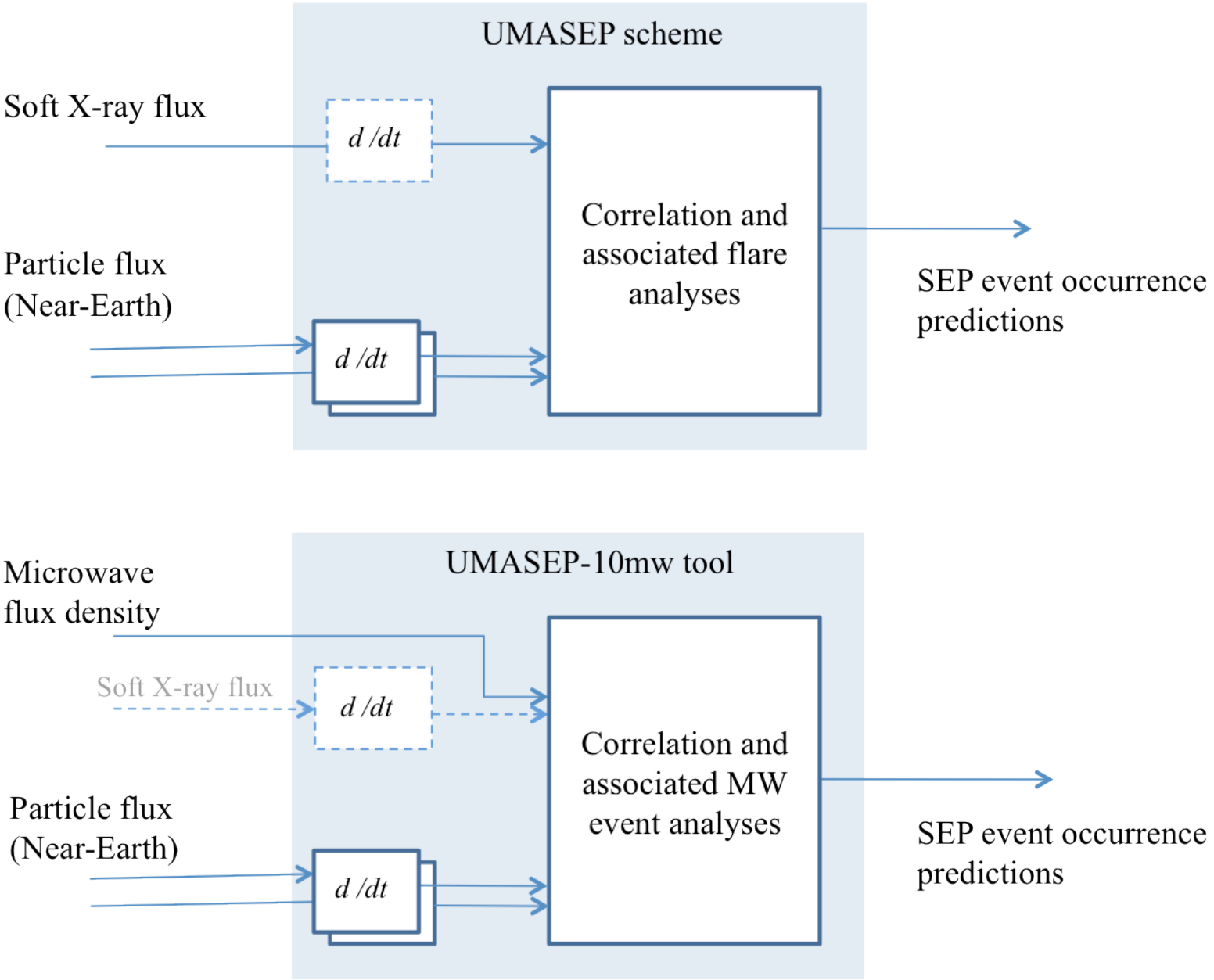


Nobeyama 17 GHz



SEP event


1997/11/04
>10 MeV
>50 MeV
>100 MeV
IONS [cm⁻² s⁻¹ sr⁻¹]
CME Height–Time
NORTH
EAST
SOUTH
WEST
Height [Rs]
HALO
W≥120°
60°≤W<120°
W<60°
GOES
1.0–8.0 A
0.5–4.0 A
X-RAY [Watt m⁻²]
X
M
C
B
A
S14W33
S20W25
S19W20
S20W24
S19W23
S20W21
S20W23
S18W20
S17W28
S20W28
S18W38
S20W24
S20W27
S19W20
S18W22
S19W32
1997/11/03
12:00
1997/11/04
12:00
1997/11/05
12:00



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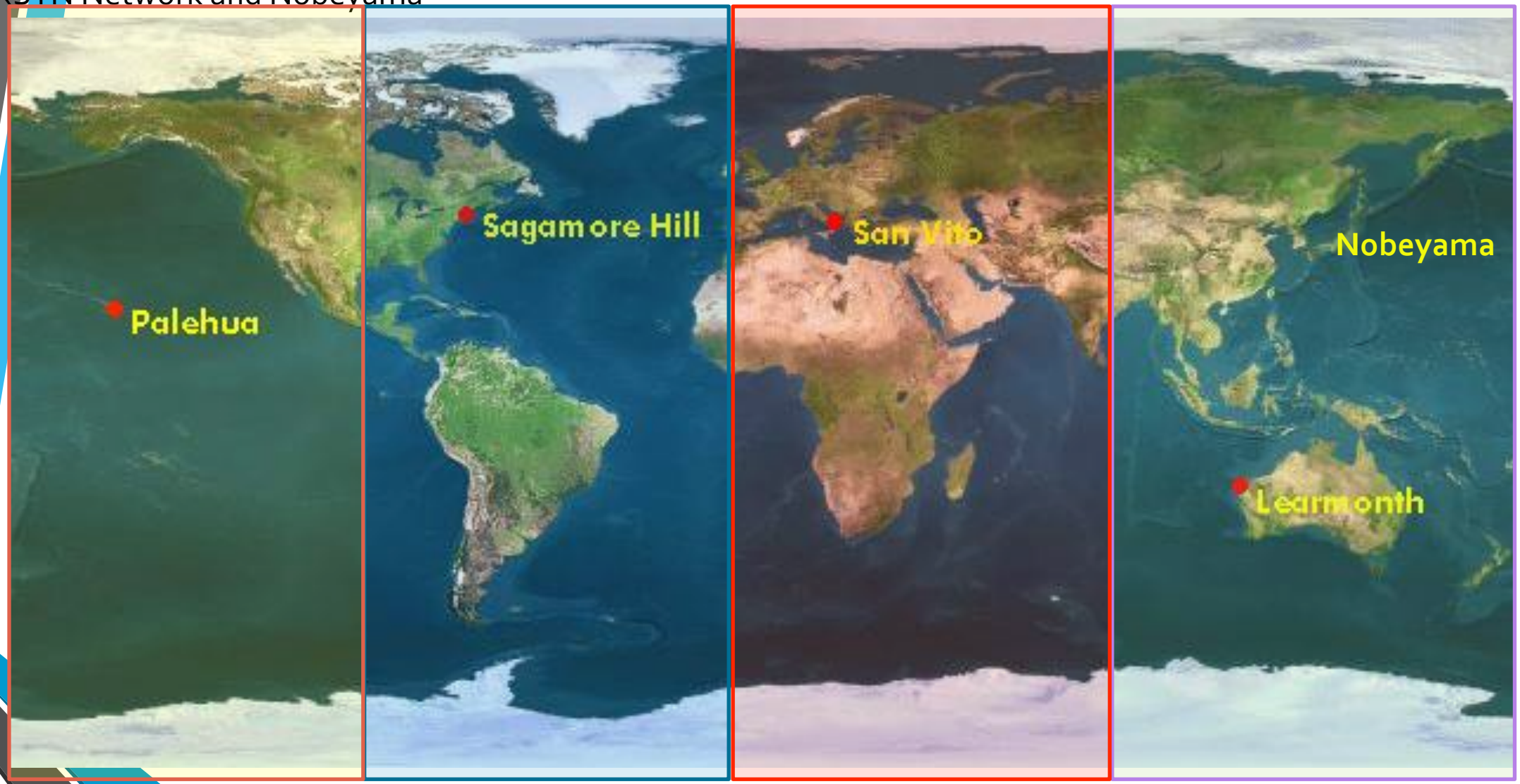
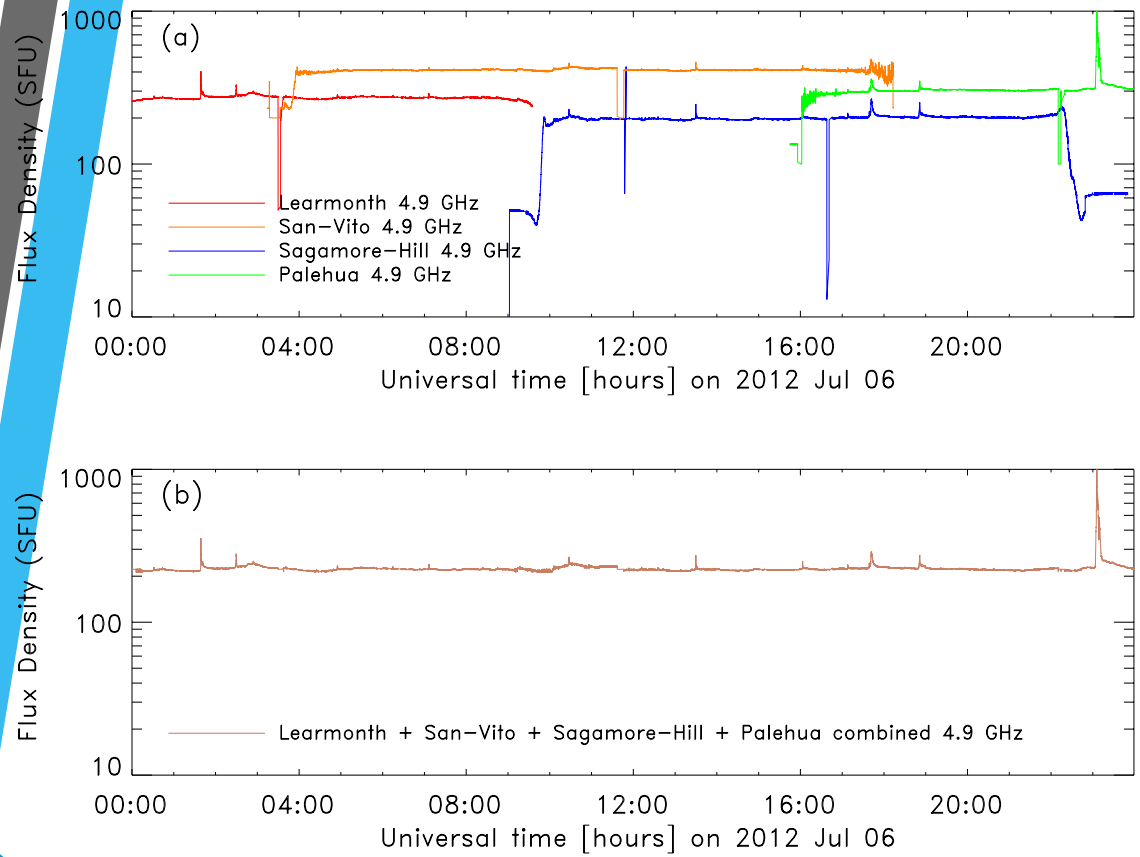
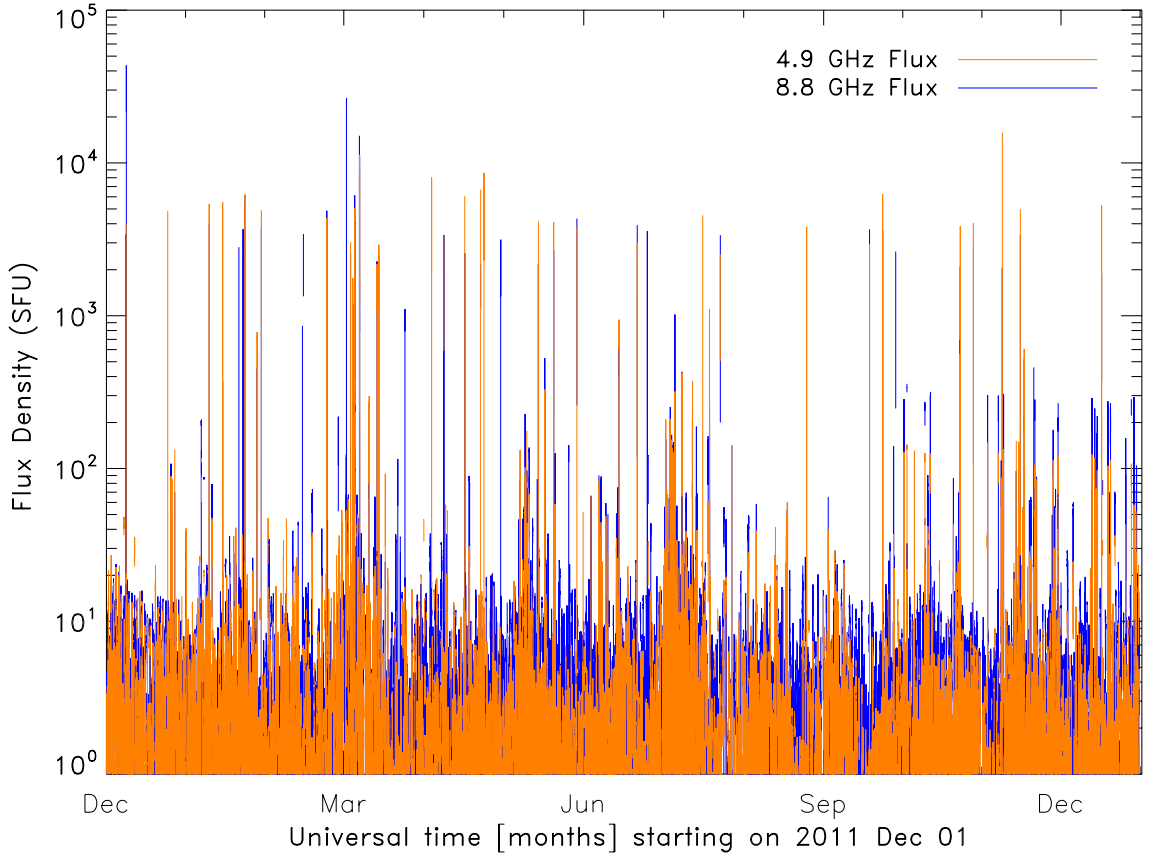
Microwave Observations

RSTN Network and Nobeyama



Microwave Observations (Long Duration)





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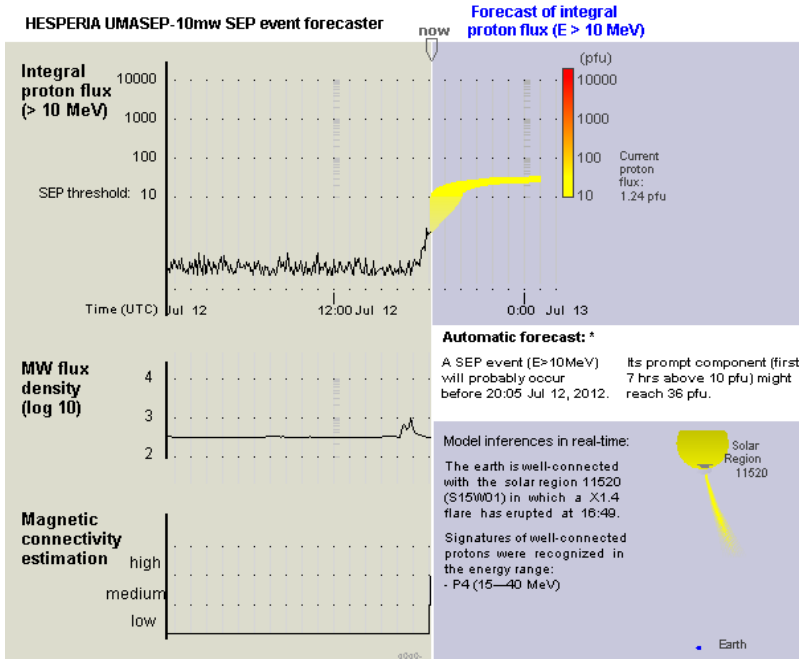
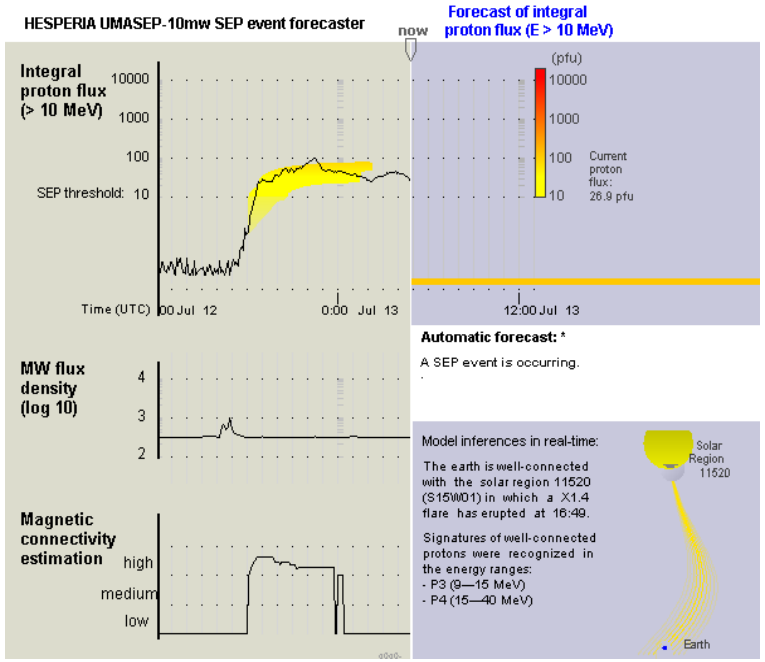
UMASEP-10mw



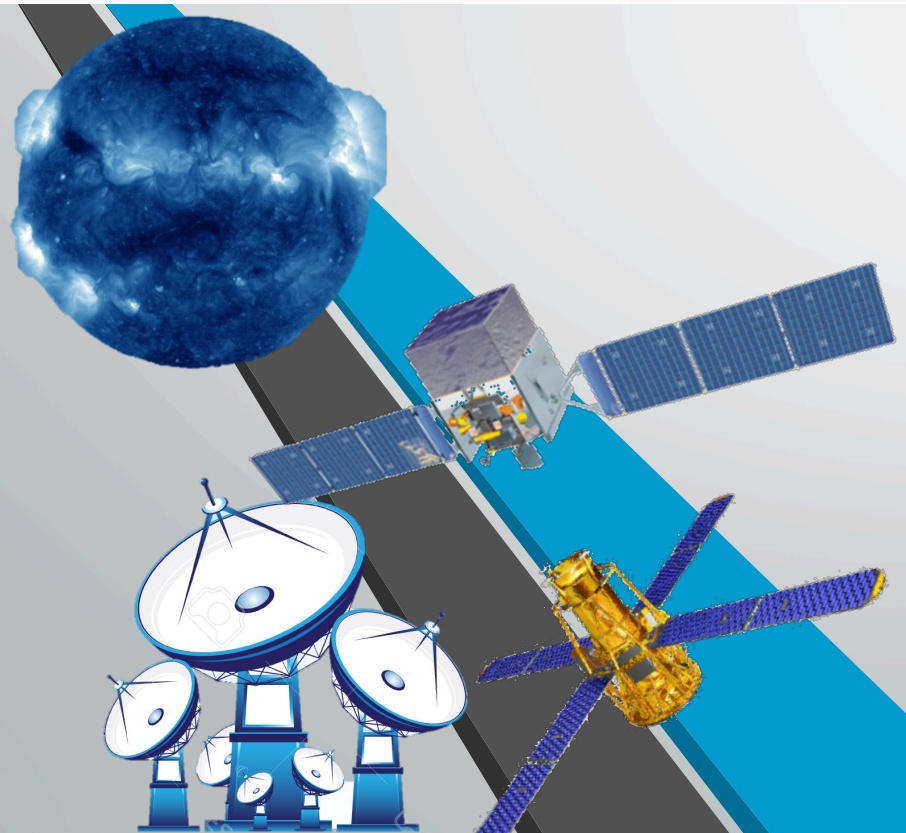


	UMASEP-10mw (5 GHz)	UMASEP-10mw (9 GHz)	UMASEP-10 (SXR)
Probability of Detection	77.8% (7/9)	77.8% (7/9)	77.8% (7/9)
False Alarm Rate	0% (0/6)	0% (0/7)	12.5% (1/8)
Average Warning Time	30.7 min	30.7 min	26.4 min

Zucca et al. (2017) JSWSC

Summary

- Understanding the EM signatures and the role of each mechanism on accelerating particles can provide important applications for space wetaher.



THANK YOU

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