Comprehensive study of type II radio bursts and the properties of the associated shock waves

Planetary, solar and heliospheric Radio Emission X – 2025

Marseille, France

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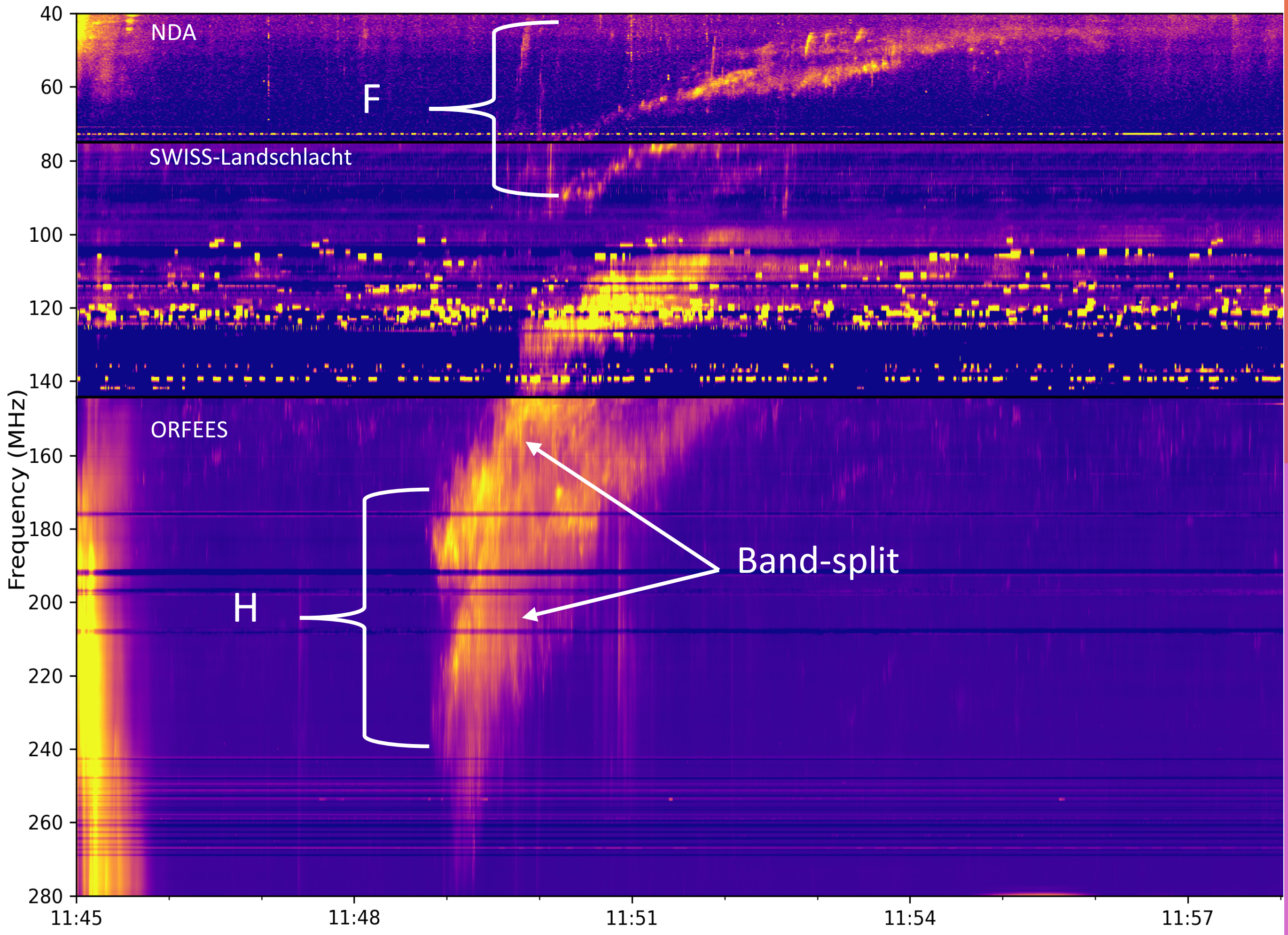
What are type II bursts?

- Slow frequency drift rate (<1 MHz/s) in dynamic spectra.
- Caused by Magnetohydrodynamic (MHD) shocks accelerating electron beams in the solar atmosphere.
- Emissions at local plasma frequency; show fundamental and harmonic bands (ratio ≈ 2).
- Plasma frequency is a function of electron density:

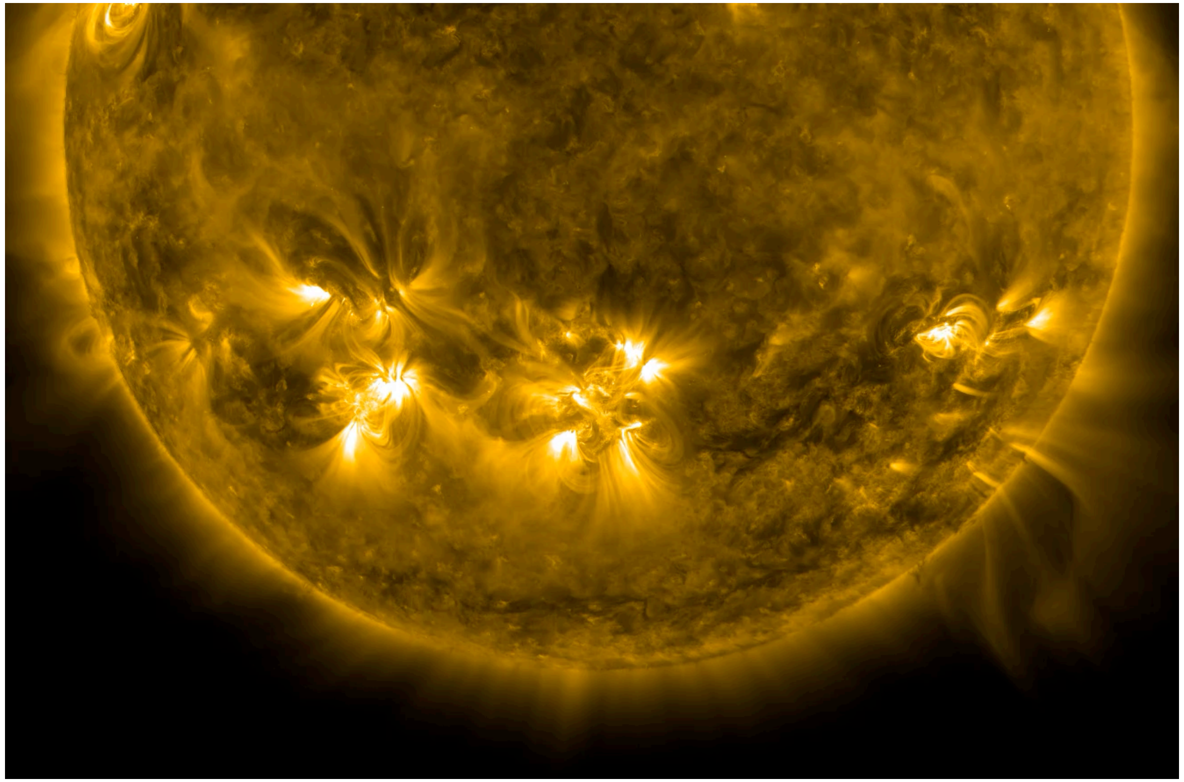
$$\omega_e \propto \sqrt{n_e}$$

- Detected at metric and decametric wavelengths.

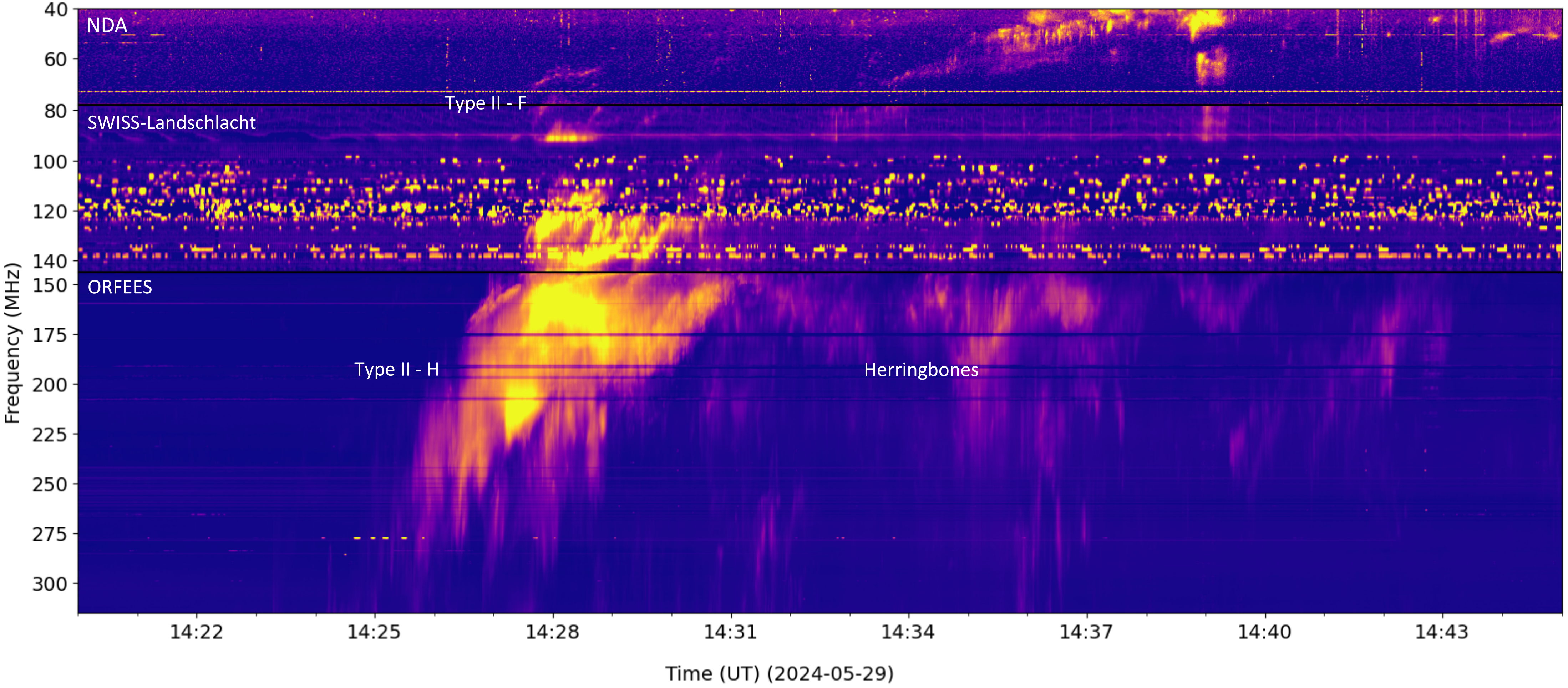


Aim

- Analyze 10 type II solar radio bursts (150–300 MHz) from Solar Cycle 25.
- Map radio emission sources using radio imaging.
- Fit CME shock fronts to extract key shock parameters.
- Integrate observations with MHD (MAS-T) data to infer magnetic field near shocks.
- To determine the properties of electron acceleration regions at shocks.



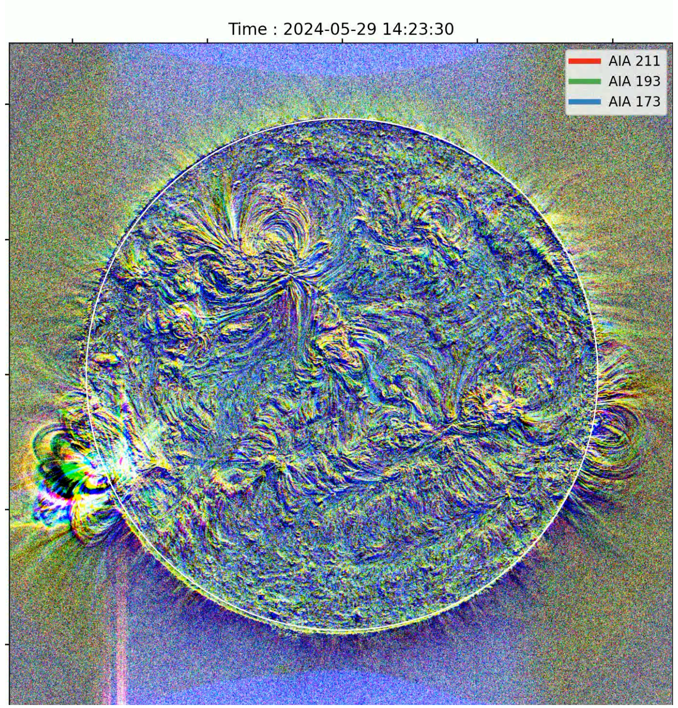
Dynamic spectrum of the observed Type II burst



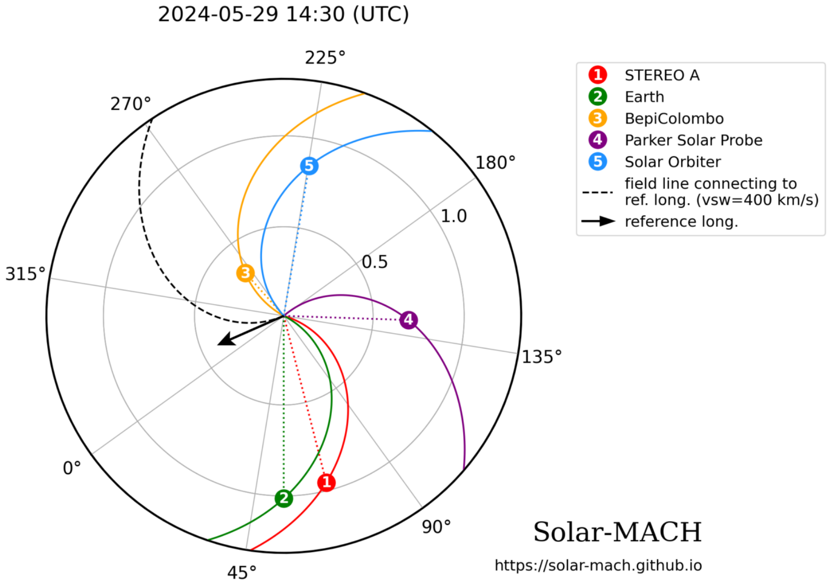
Associated CME

- Date: 29/05/2024
- Flare class: X1.4
- Observed by: SDO, STEREO

Solar Dynamics Observatory (SDO)



Generated using Sunpy



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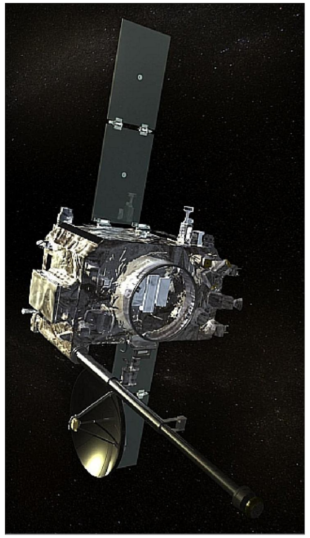
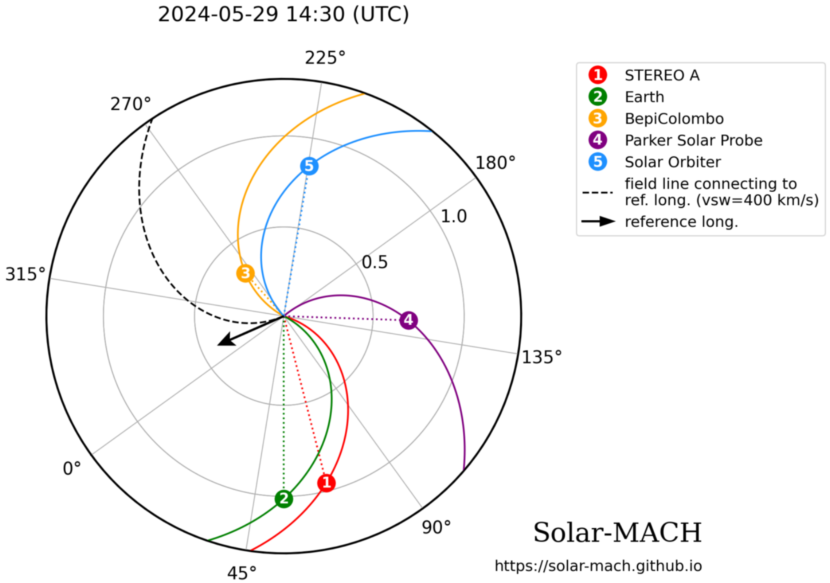
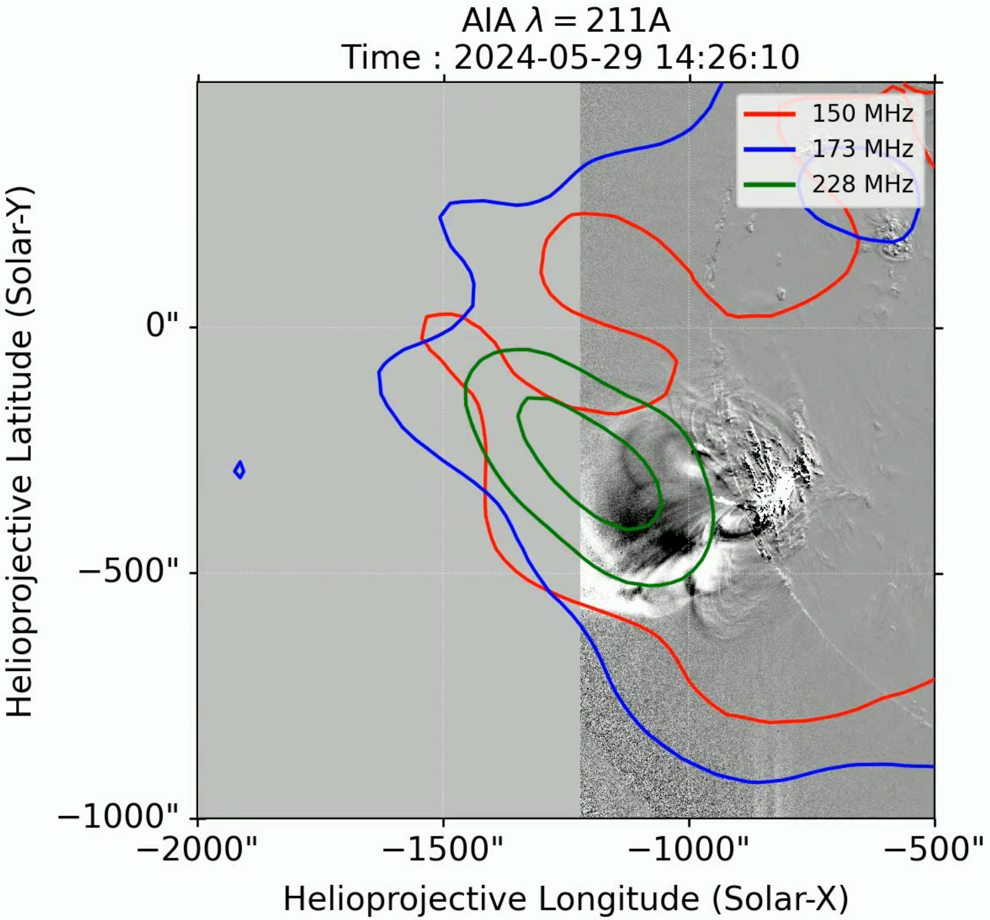


Solar TErrestrial RElations Observatory (STEREO)

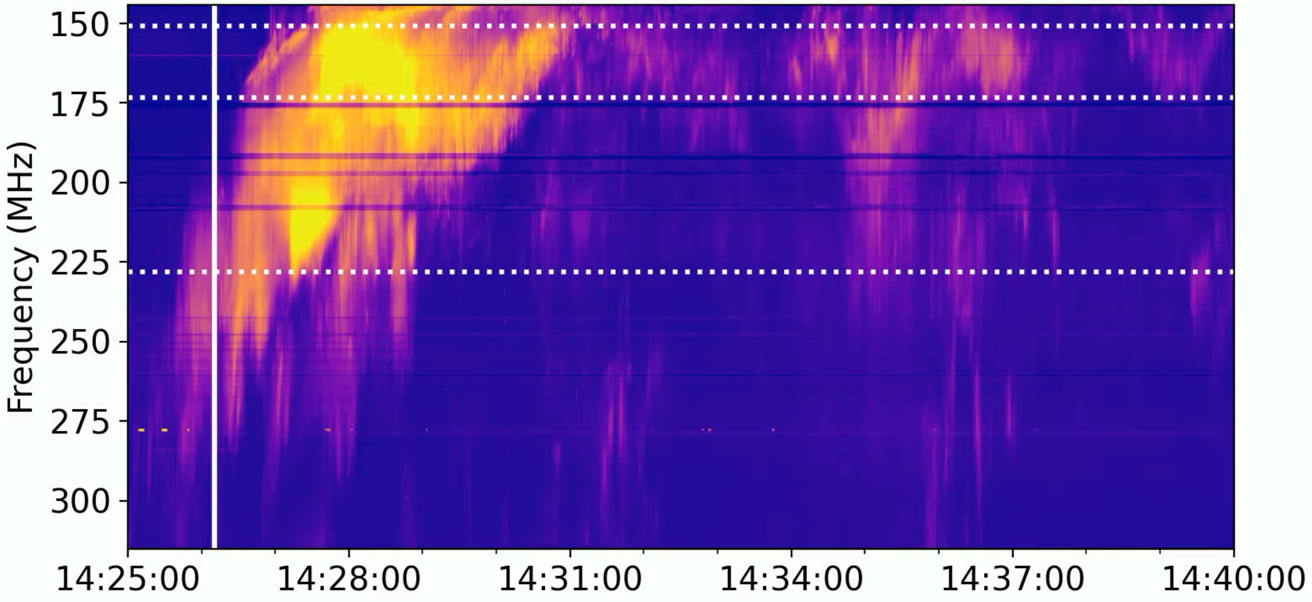
Generated using Sunpy



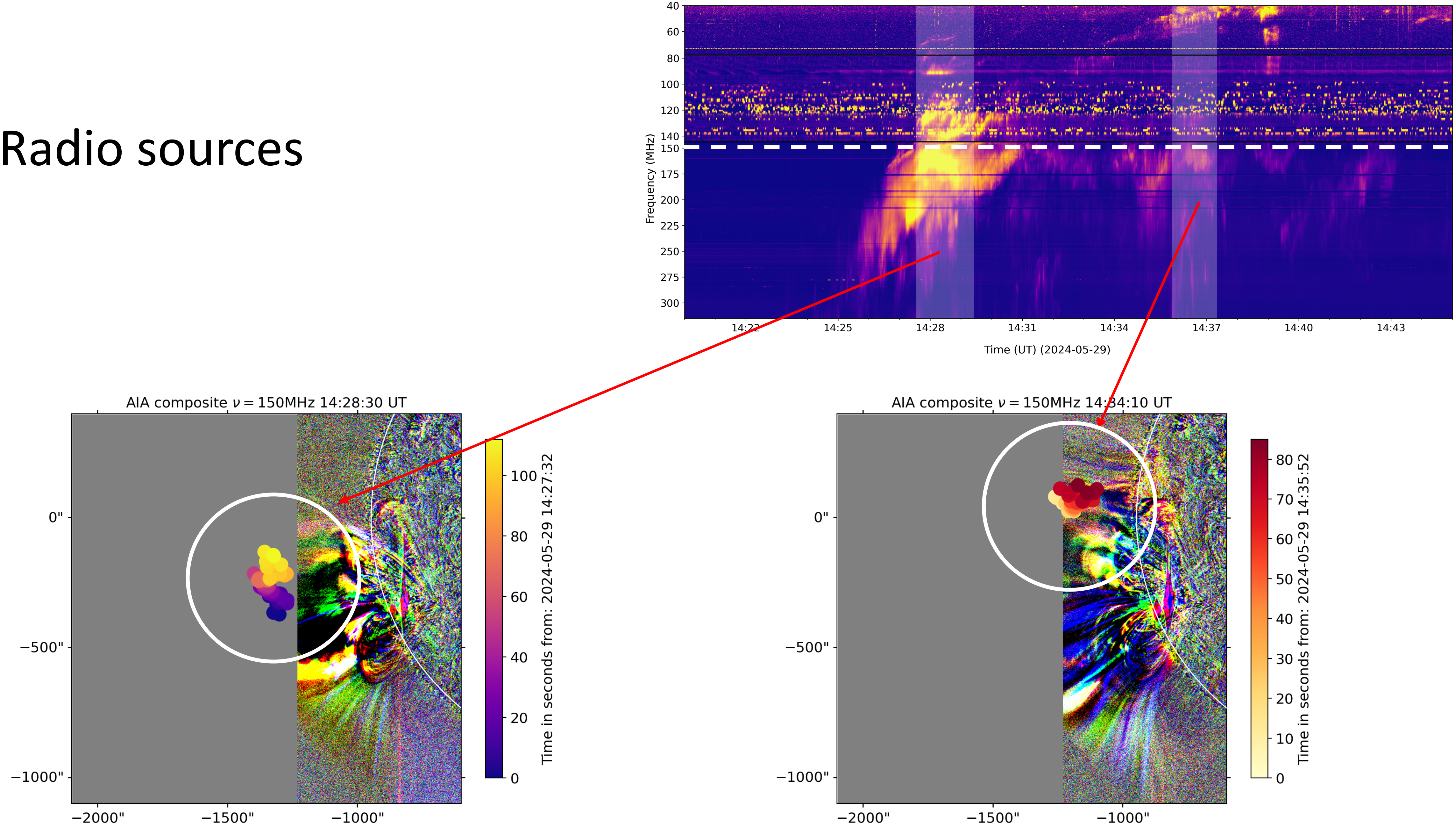
Radio contours



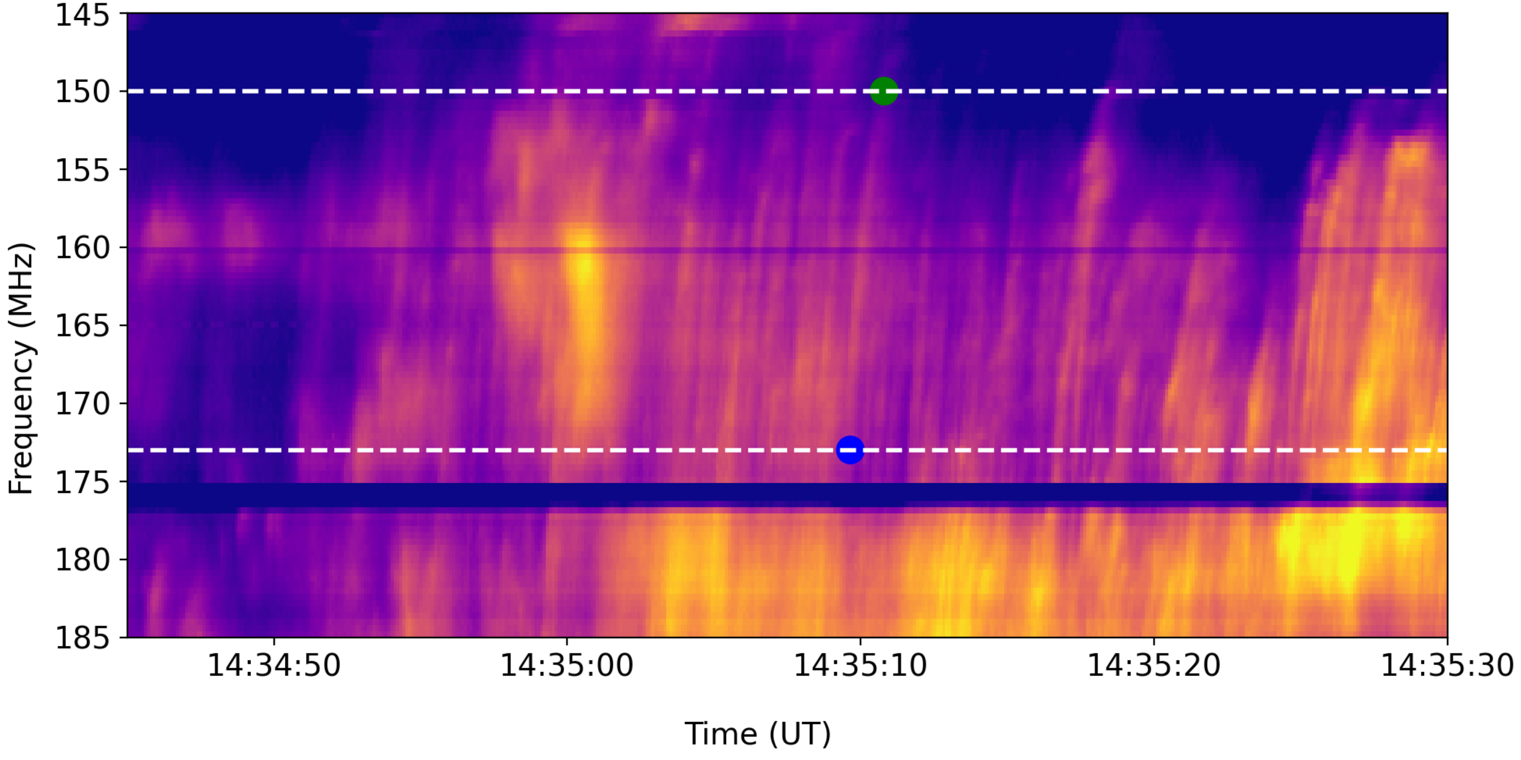
- 40% and 80% radio image contours of multiple frequency on the AIA images.
- Corresponding intensity in dynamic spectrum.

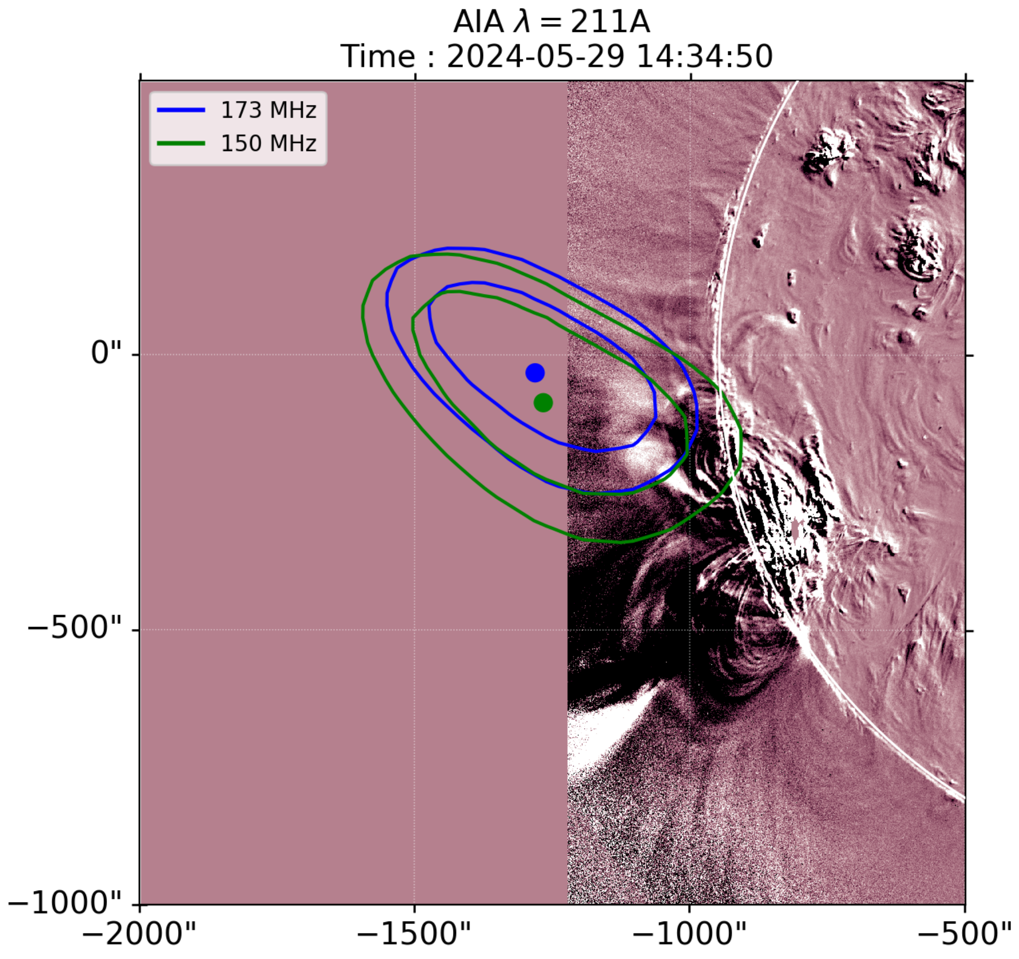


Radio sources



Herringbones



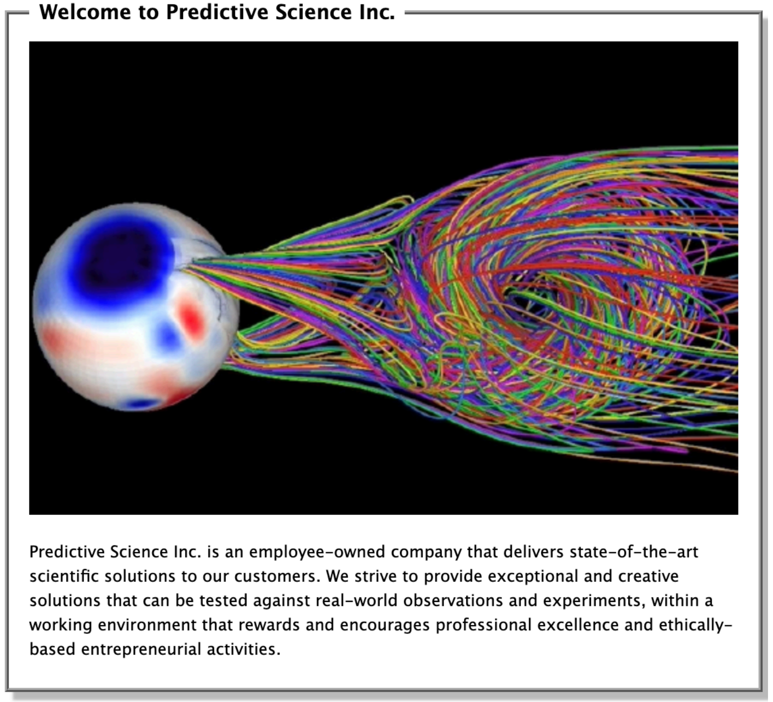


Projected centroid distance: $\Delta d = 40.85\ Mm$

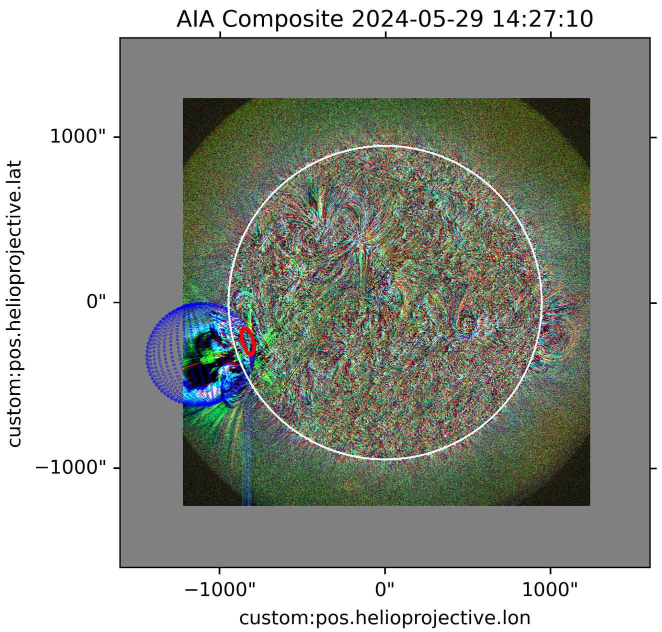
Herringbone energy: $E = 7.76\ keV$

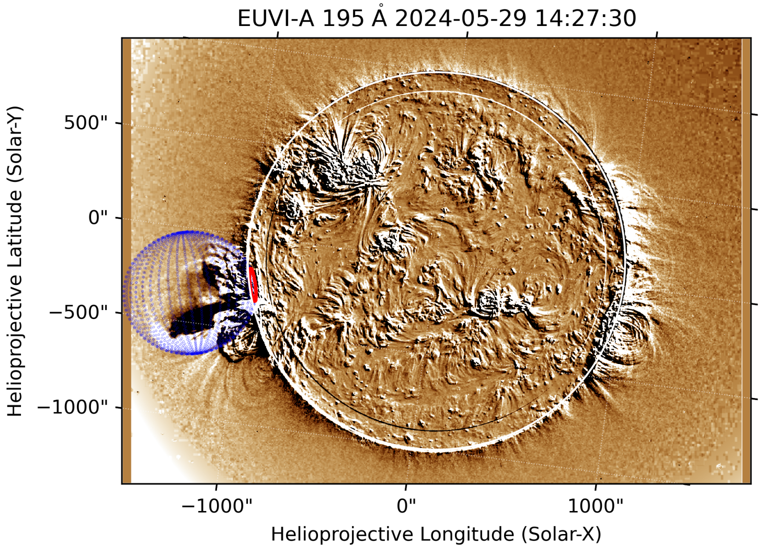
MHD simulations

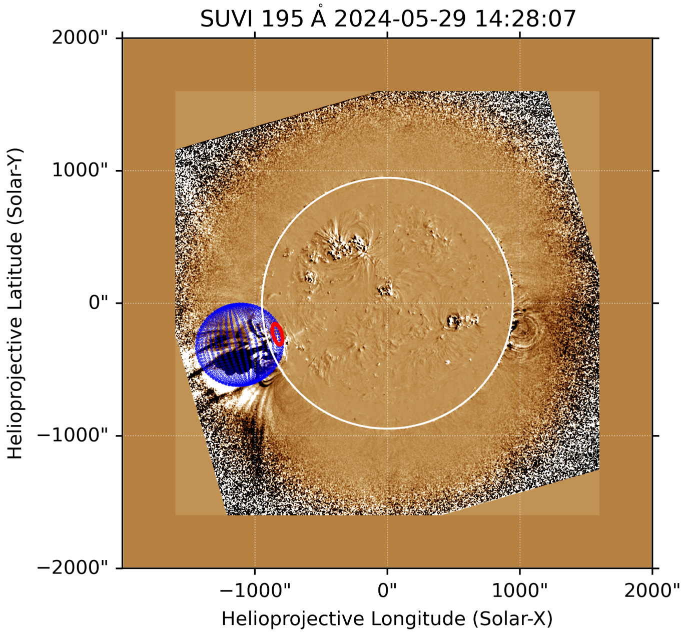
- Used the Magnetohydrodynamics Around a Sphere Thermodynamic (MAS-T) model (Predictive Sciences Inc.).
- Estimated electron density & magnetic field to compute global Alfvén speed.
- Electron densities help locate 3D positions of radio sources.
- Shock normal angle (θ_{BN}) derived from local magnetic field near reconstructed shock (EUV images).
- Model traces coronal magnetic field lines to higher altitudes.



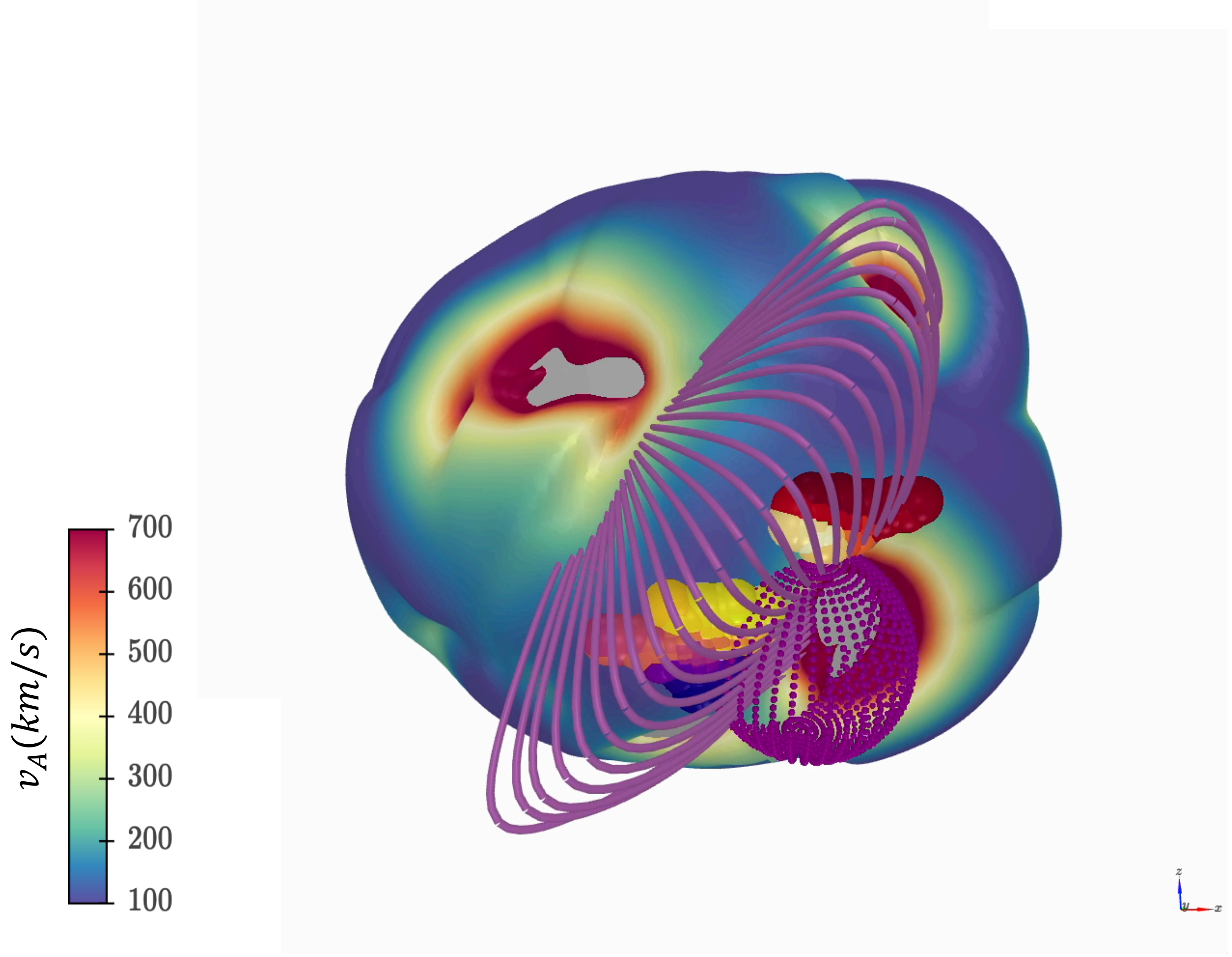
Shock reconstruction

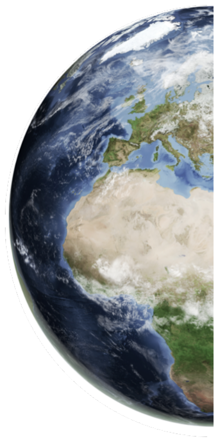




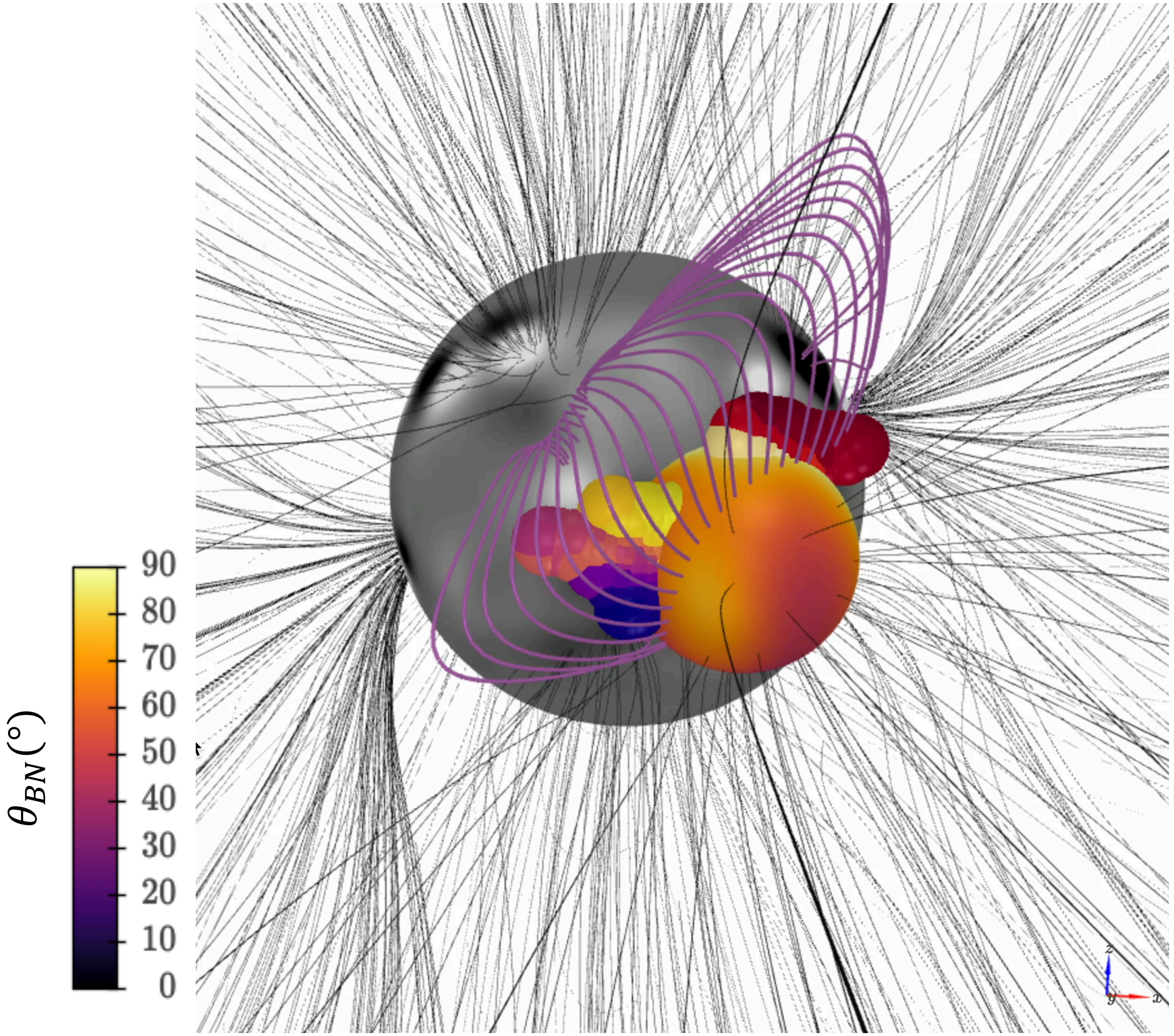


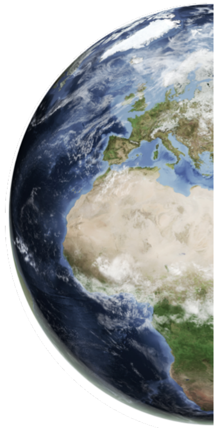
MHD simulation results

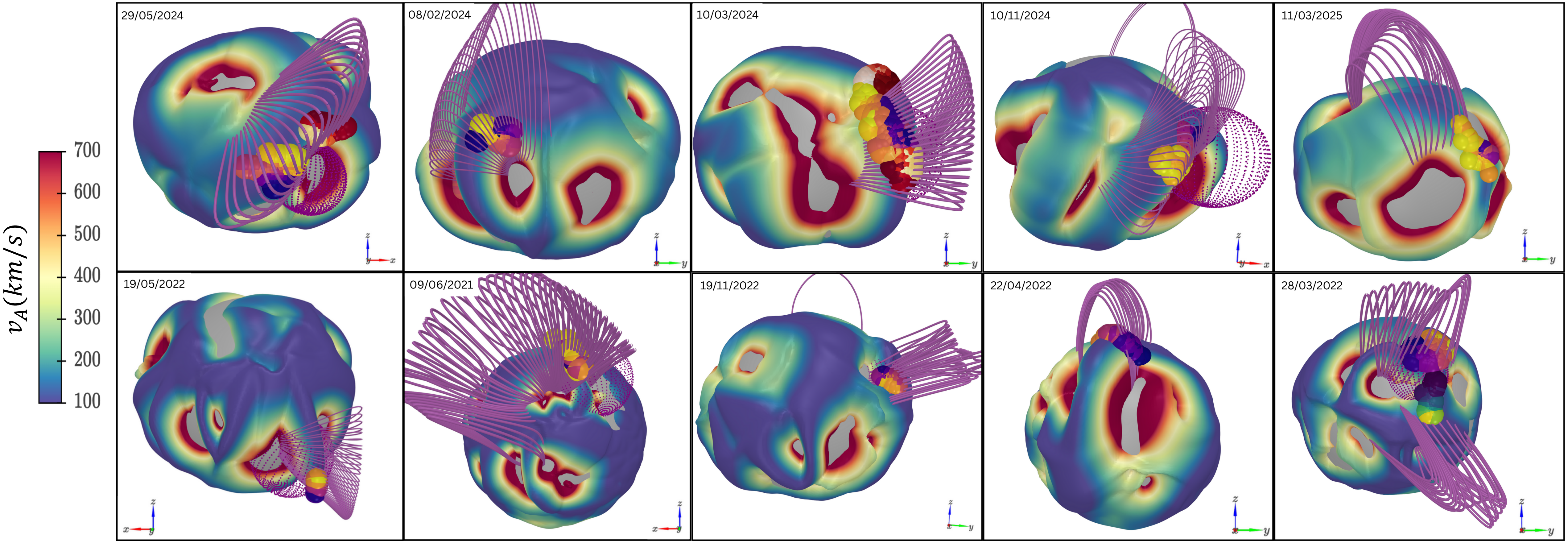


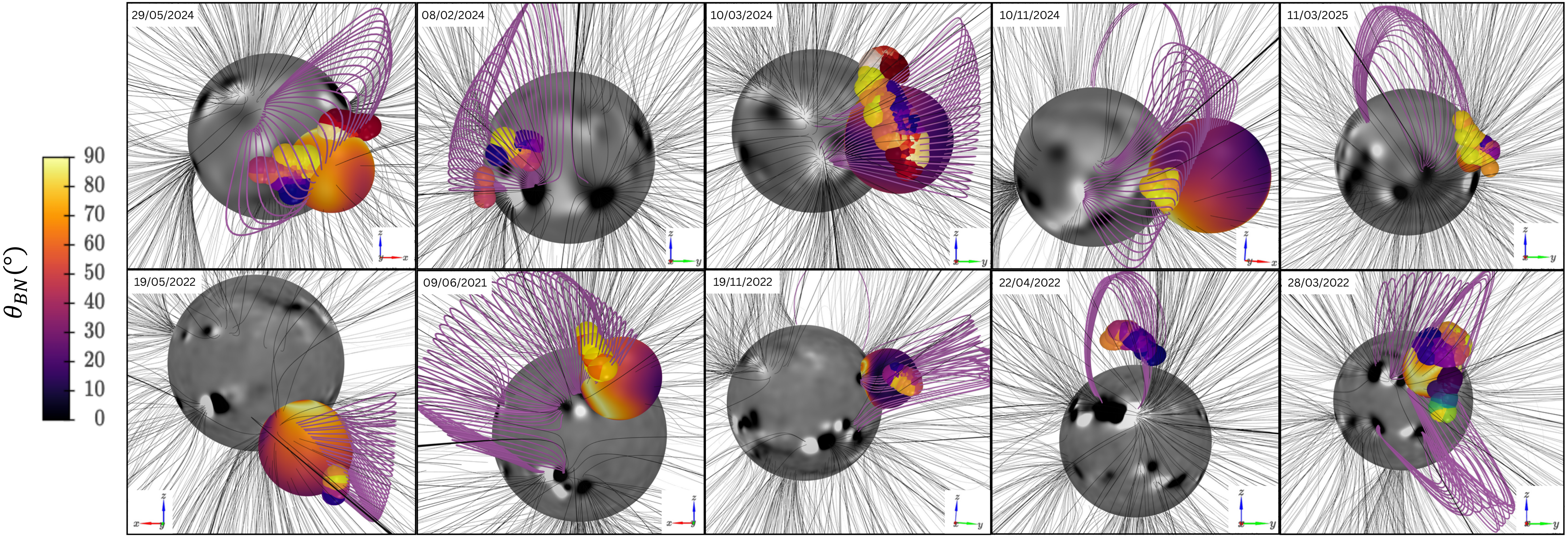


MHD simulation results






700
600
500
400
300
200
100
$v_A(km/s)$
29/05/2024
08/02/2024
10/03/2024
10/11/2024
11/03/2025
19/05/2022
09/06/2021
19/11/2022
22/04/2022
28/03/2022



$\theta_{BN}(°)$
90
80
70
60
50
40
30
20
10
0
29/05/2024
08/02/2024
10/03/2024
10/11/2024
11/03/2025
19/05/2022
09/06/2021
19/11/2022
22/04/2022
28/03/2022

Results

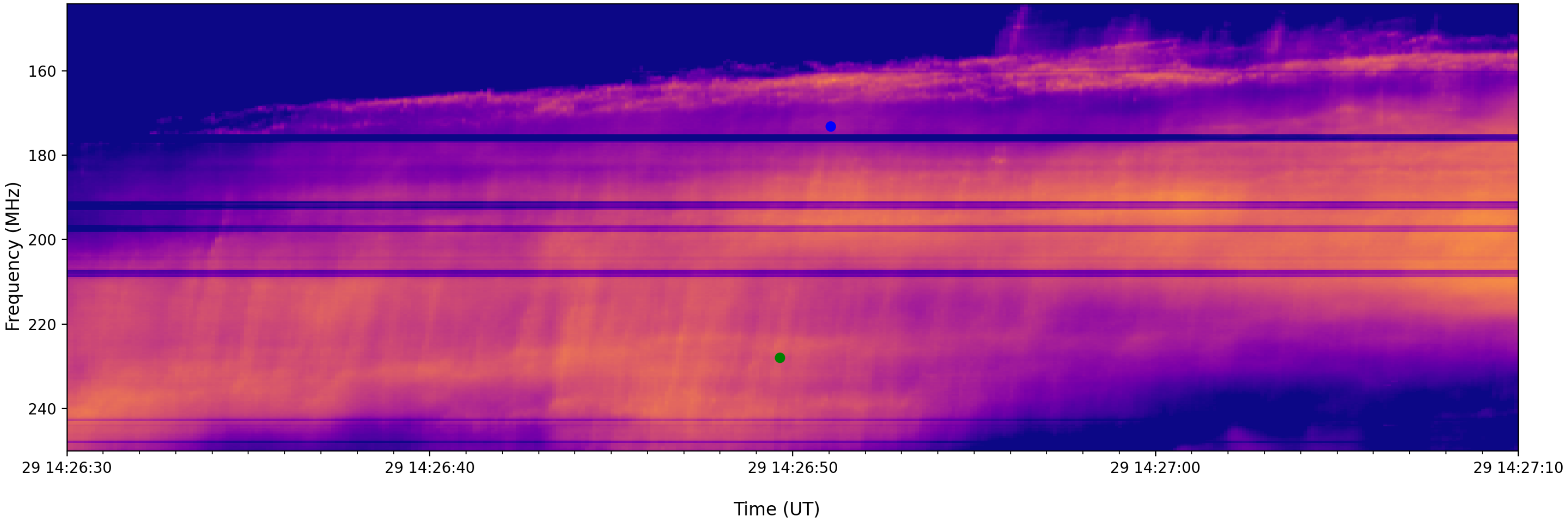
Date	CME Apex speed (km/s)	CME Lateral speed (km/s)	Type II Duration (mins)	Electron beam energy (keV)	Shock normal θ_{BN}	Alfvenic Mach number M_A
29/05/2024	681	561	15	13.07	60-80	3.5
10/03/2024	1500	1307	11	31.13	50-60	6.5
28/03/2022	897	637	14	11.49	50-70	6.4
10/11/2024	587	287	26	6.60	50-60	2.3
08/02/2024	--	--	9	23.59	--	--
09/06/2021	699	487	19	138.73	40-50	6.3
19/05/2022	1044	710	23	145.88	40-50	8.7
19/11/2022	566	401	31	173.60	20-30	4.1
22/04/2022	--	--	6	59.98	--	--
11/03/2025	696	633	8	31.51	30-40	3.5

-- couldn't fit a CME

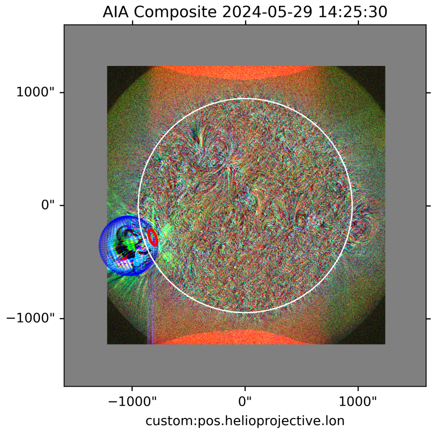
Conclusions

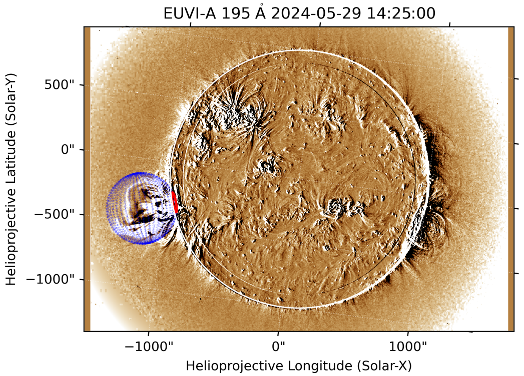
- The radio sources are in regions where the Alfvén speed is relatively low, which leads to a higher Alfvénic Mach number.
- We note that the shock exhibits an oblique orientation, which may suggest the presence of small-scale inhomogeneities in the ambient medium or a rippled shock front. Such structures could locally create quasi-perpendicular geometries, a necessary condition for shock drift acceleration (*Holman and Pesses 1982*).
- The estimated electron beam energies provide evidence for the acceleration of electrons to near-relativistic speeds.

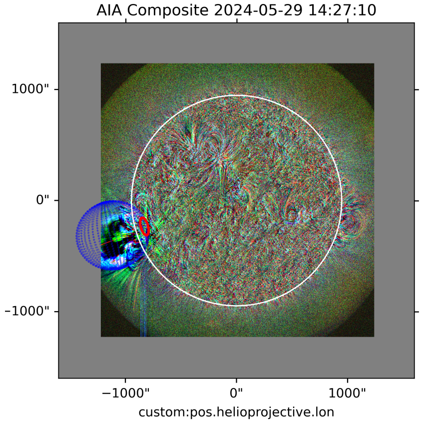

THANK
YOU

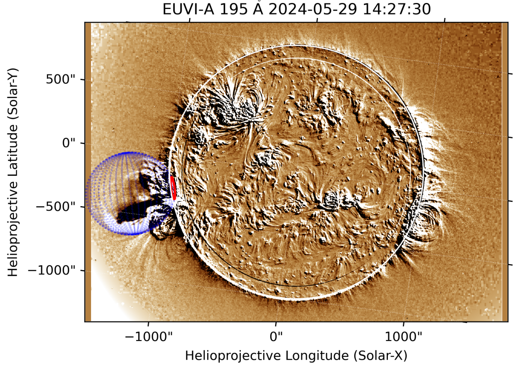


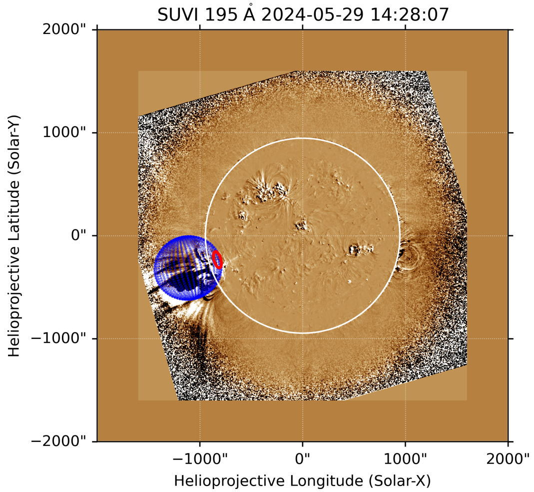
160
180
200
220
240
Frequency (MHz)
29 14:26:30
29 14:26:40
29 14:26:50
29 14:27:00
29 14:27:10
Time (UT)

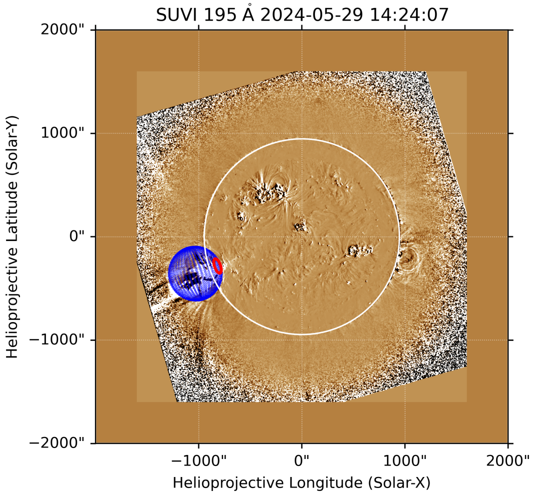

AIA Composite 2024-05-29 14:25:30
1000"
0"
−1000"
−1000"
0"
1000"
custom:pos.helioprojective.lon


EUVI-A 195 Å 2024-05-29 14:25:00
500"
0"
−500"
−1000"
Helioprojective Latitude (Solar-Y)
−1000"
0"
1000"
Helioprojective Longitude (Solar-X)


AIA Composite 2024-05-29 14:27:10
1000"
0"
−1000"
−1000"
0"
1000"
custom:pos.helioprojective.lon


EUVI-A 195 Å 2024-05-29 14:27:30
500"
0"
−500"
−1000"
Helioprojective Latitude (Solar-Y)
−1000"
0"
1000"
Helioprojective Longitude (Solar-X)


SUVI 195 Å 2024-05-29 14:28:07
2000"
1000"
0"
−1000"
−2000"
Helioprojective Latitude (Solar-Y)
−1000"
0"
1000"
2000"
Helioprojective Longitude (Solar-X)


SUVI 195 Å 2024-05-29 14:24:07
2000"
1000"
0"
−1000"
−2000"
Helioprojective Latitude (Solar-Y)
−1000"
0"
1000"
2000"
Helioprojective Longitude (Solar-X)

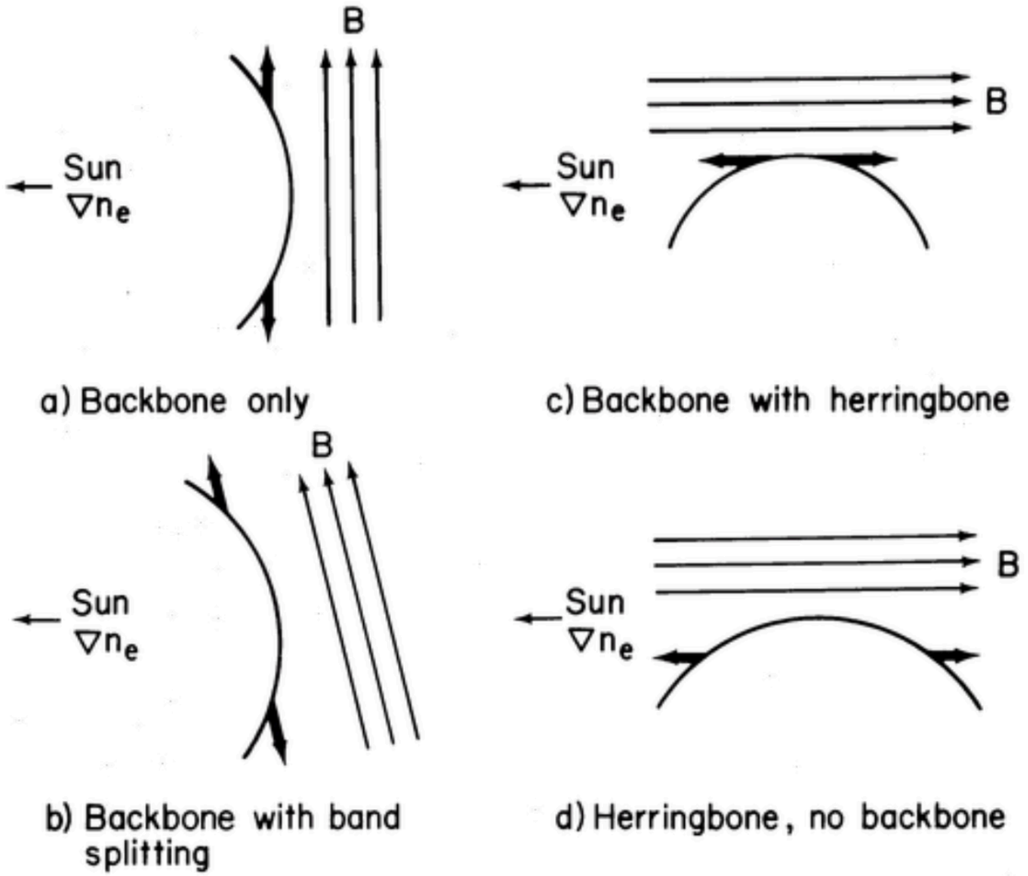
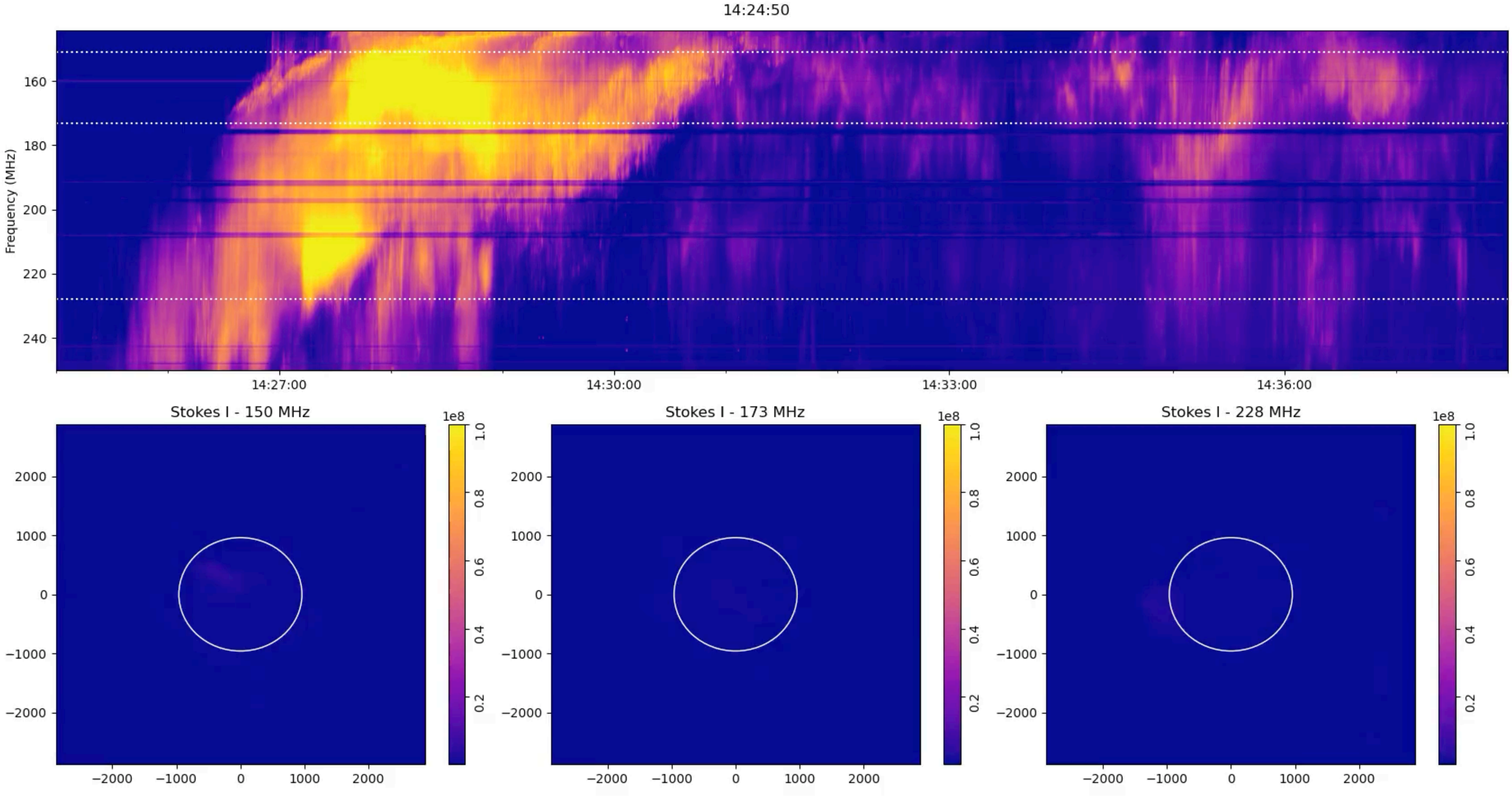
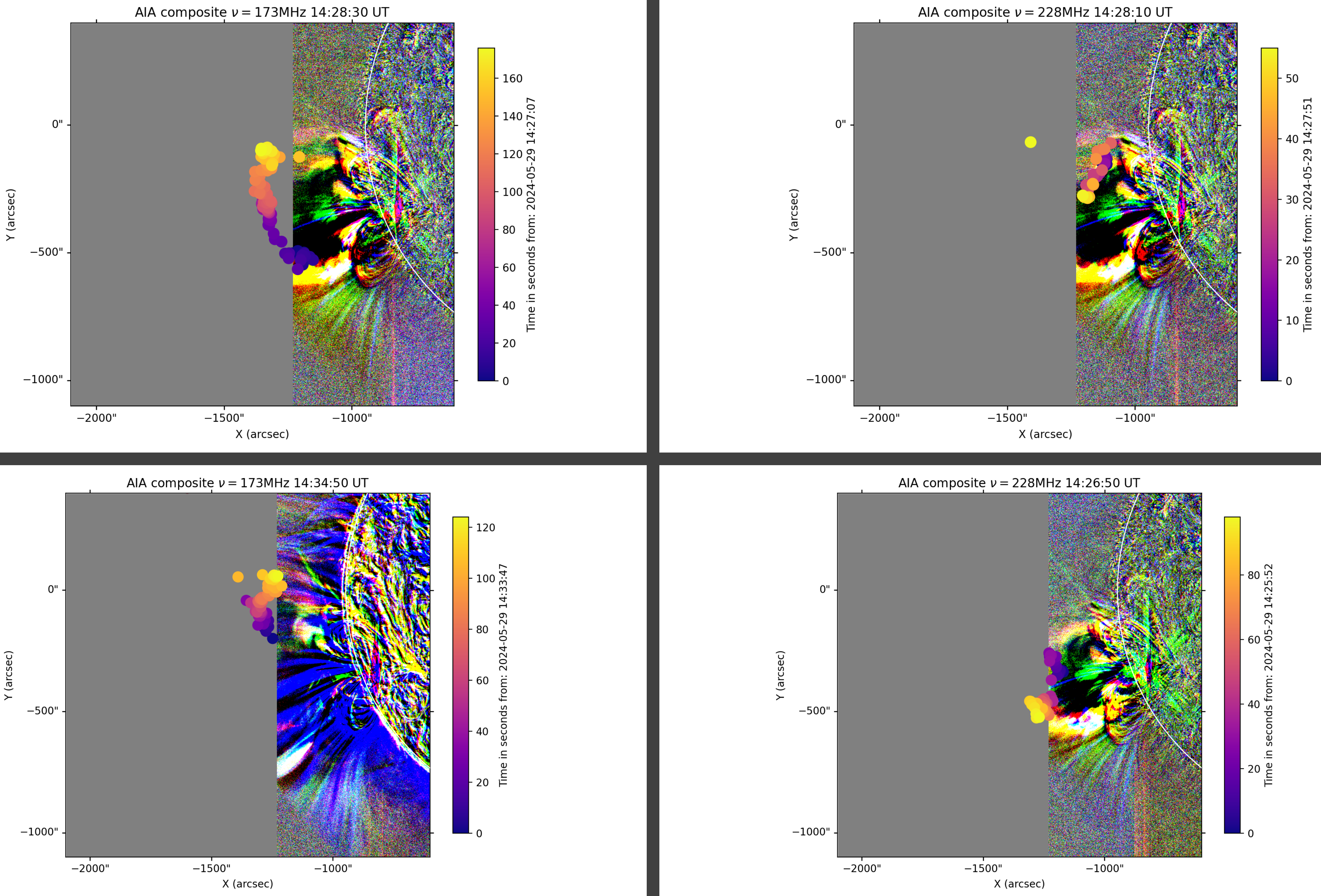


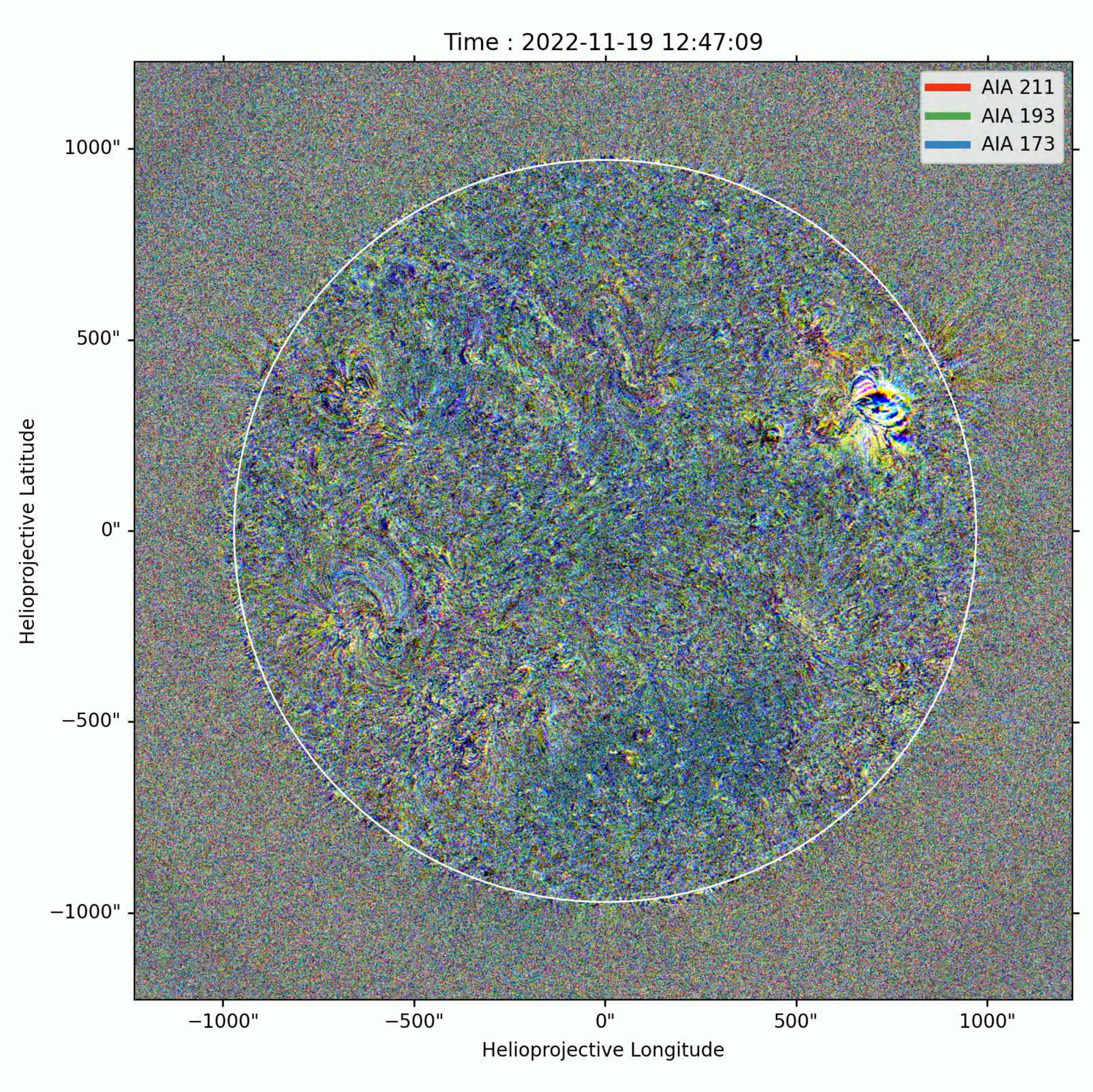
FIG. 2.—Examples of geometries in which band splitting, herringbone structure, and herringbone structure without a backbone will result are shown. The coronal plasma density (n_e) decreases from left to right in each figure. The curved line in each figure represents the shock front. The heavy arrows depict the regions where reflected electrons and plasma emission are produced. Note that, because of the influence of the coronal magnetic field, the density gradient may not always be radial as shown.

Holman and Pesses 1982



14:24:50
Frequency (MHz)
160
180
200
220
240
14:27:00
14:30:00
14:33:00
14:36:00
Stokes I - 150 MHz
Stokes I - 173 MHz
Stokes I - 228 MHz
1e8
1.0
0.8
0.6
0.4
0.2
2000
1000
0
−1000
−2000


AIA composite ν = 173MHz 14:28:30 UT
Time in seconds from: 2024-05-29 14:27:07
AIA composite ν = 228MHz 14:28:10 UT
Time in seconds from: 2024-05-29 14:27:51
AIA composite ν = 173MHz 14:34:50 UT
Time in seconds from: 2024-05-29 14:33:47
AIA composite ν = 228MHz 14:26:50 UT
Time in seconds from: 2024-05-29 14:25:52
X (arcsec)
Y (arcsec)



Outline

- Introduction: What are type II bursts?
- Aim of the study
- Example type II burst analysis
- MHD simulation
- Results