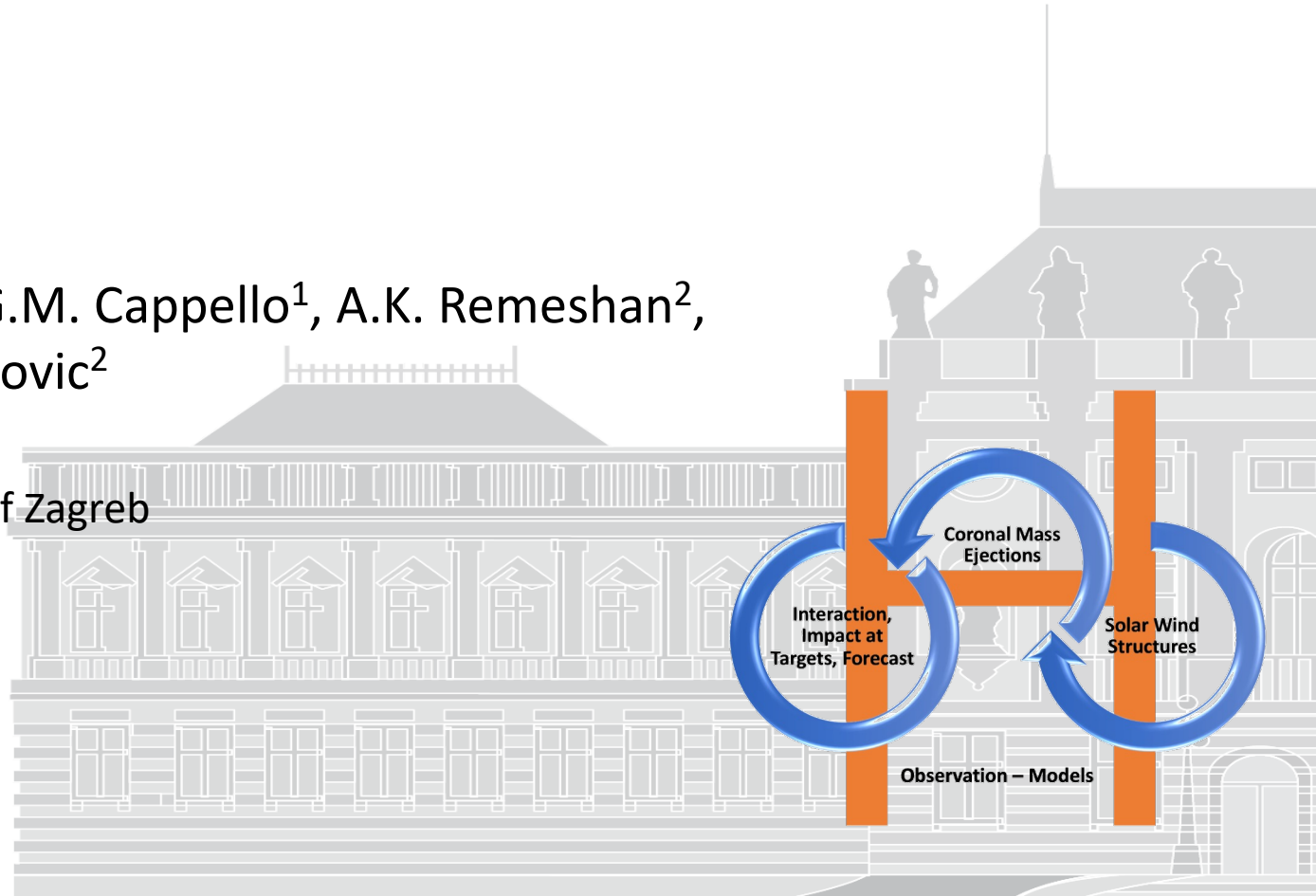
UNIVERSITÄT GRAZ
UNIVERSITY OF GRAZ

Comparison of "homologous" solar eruptive events from two different solar rotations

M. Temmer[1], M. Dumbovic[2], K. Martinic, G.M. Cappello[1], A.K. Remeshan[2], D. Milosic[1], F. Matkovic[2], F. Koller[1], J. Calogovic[2]

[1] Institute of Physics, University of Graz, Austria

[2] Hvar Observatory, Faculty of Geodesy, University of Zagreb



ESPM Meeting 2024 :: Turin Sep 9-13, 2024

Big Solar Storms during cycle 25 (start: Dec 2019)

Events with Dst stronger than –150 nT

- 23-24 Mar 2023 (–170nT) : Le+2024; Jebaraj+2024; Dresing+2024; …
- 23-24 April 2023 (–178, –233 nT) : Li+2024; Burkholder+2024; Chen+2024; …
- 5-6 Nov 2023 (–189 nT) : *Red Aurorae over Europe; visible SAR Arcs; ACRE; :* Gil+2024; Temmer+2024; …

  A full rotation later a similar series of CMEs was launched heading towards Earth.

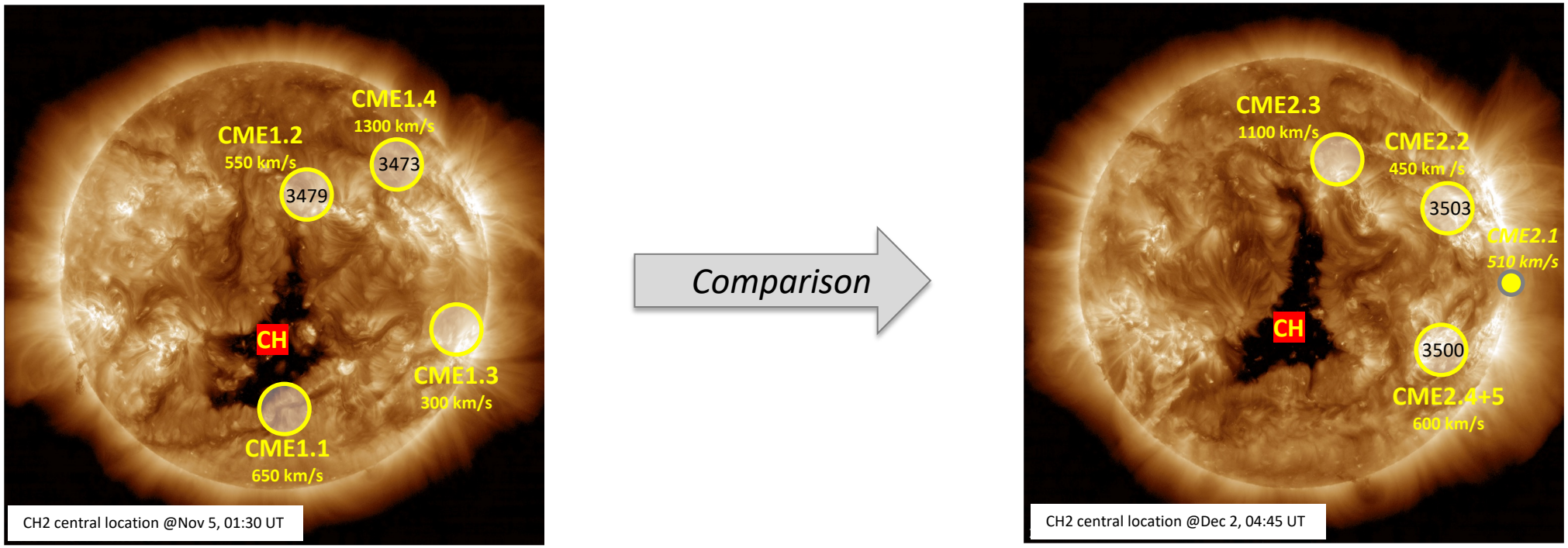
  1 Dec 2023 (–108 nT) : nothing „spectacular“
- 10-11 May 2024 (–412 nT, Superstorm) : Hayakawa+2024; …

Austria, Nov 5, 2023

Croatia, Nov 5, 2023

Investigating two episodes of multiple CME events separated by a full solar rotation

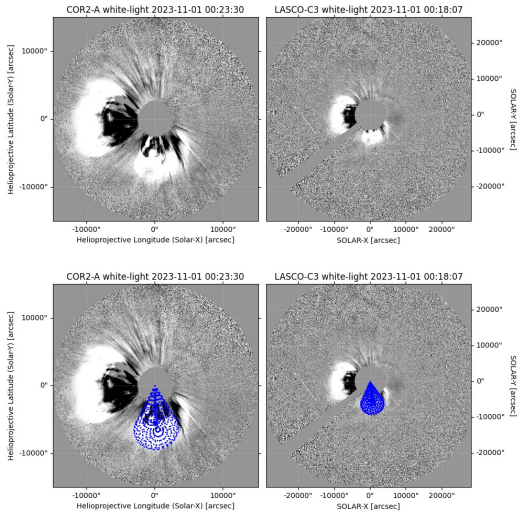
Episode 1: Oct 31 – Nov 3, 2023
Episode 2: Nov 27 – Nov 28, 2023

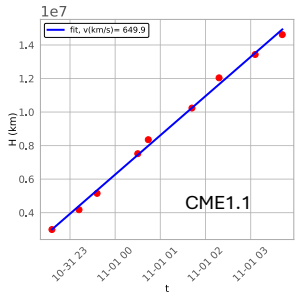


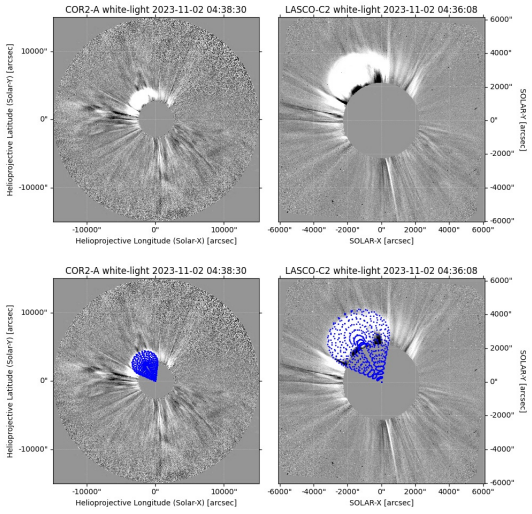
Solar perspective: CME source regions, CHIP from the nearby CH (Gopalswamy+2009), CME 3D characteristics using GCS (Thernisien+2006), CME propagation in IP space using 3D drag-based-model (Vrsnak+2013; 3D DBM covering latitudinal information: Dumbovic+2024, in preparation);

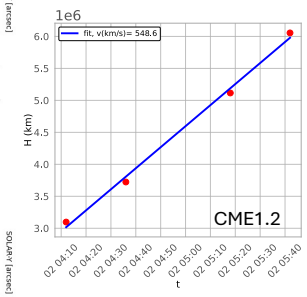
” GCS reconstruction of CME events (2x4 events - 3 out of 4 are shown)

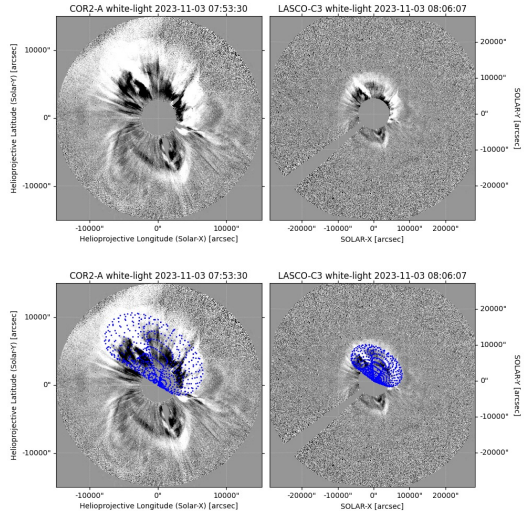
Rotation #1

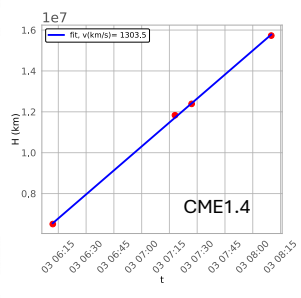






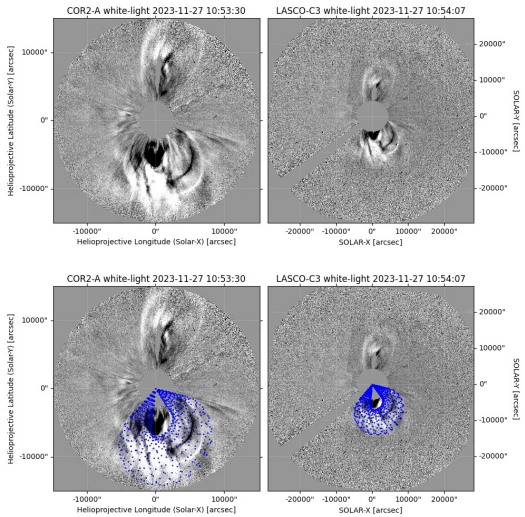


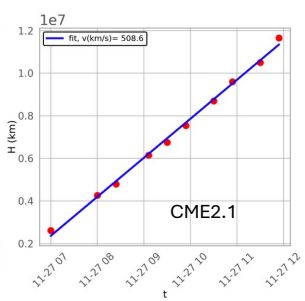


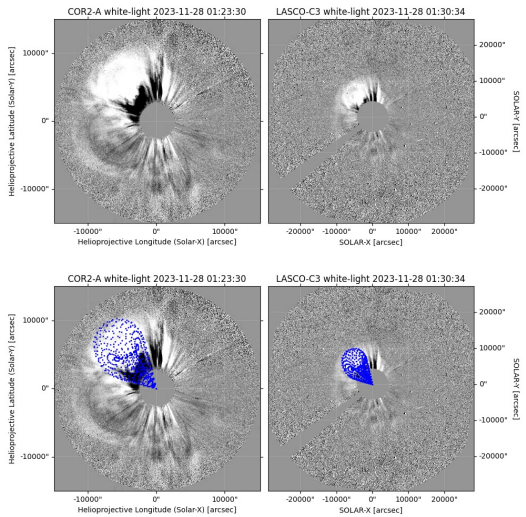


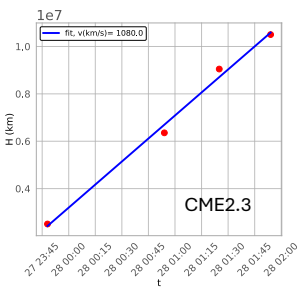
Uncertainties in the GCS derived parameters see Verbeke+2023;

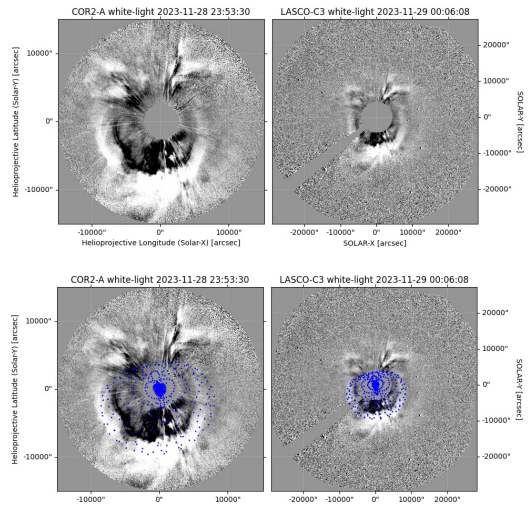
Rotation #2

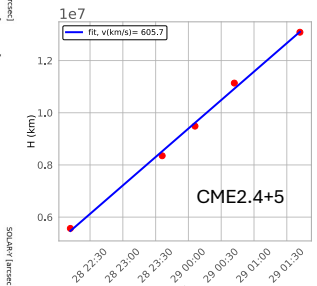


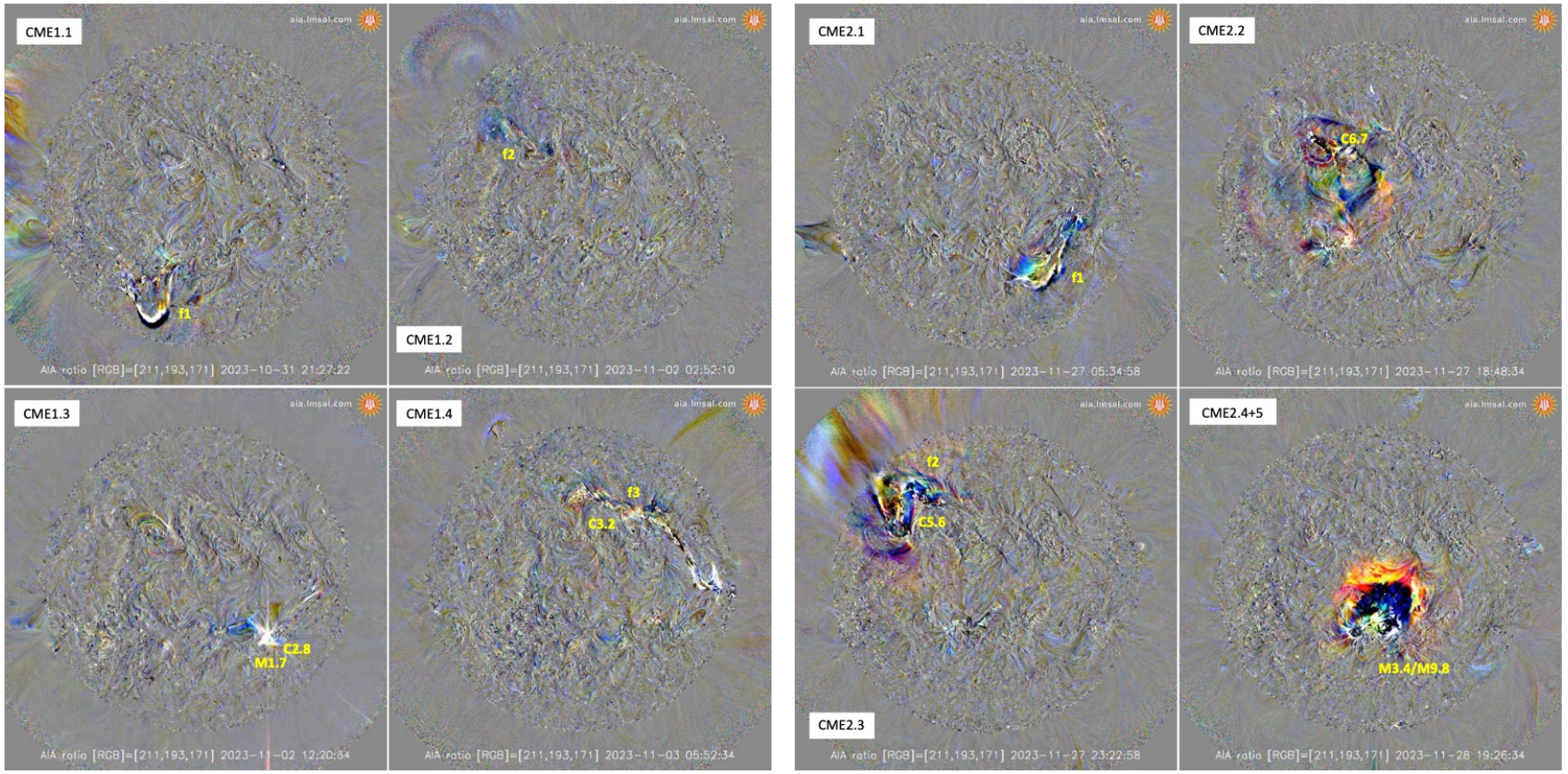






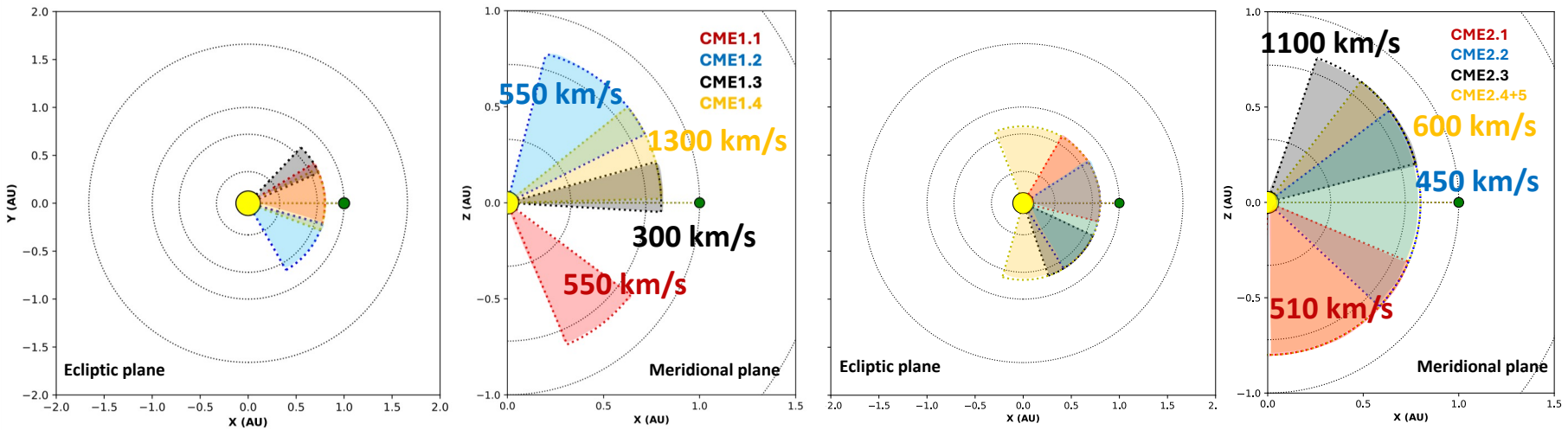






Top two rows: SDO/AIA EUV composite ratio images. Events are annotated with the eruption-related GOES SXR flare classes.

Bottom panels: CME cone geometry derived from GCS results (longitude, latitude, tilt) projected on the ecliptic and meridional plane.

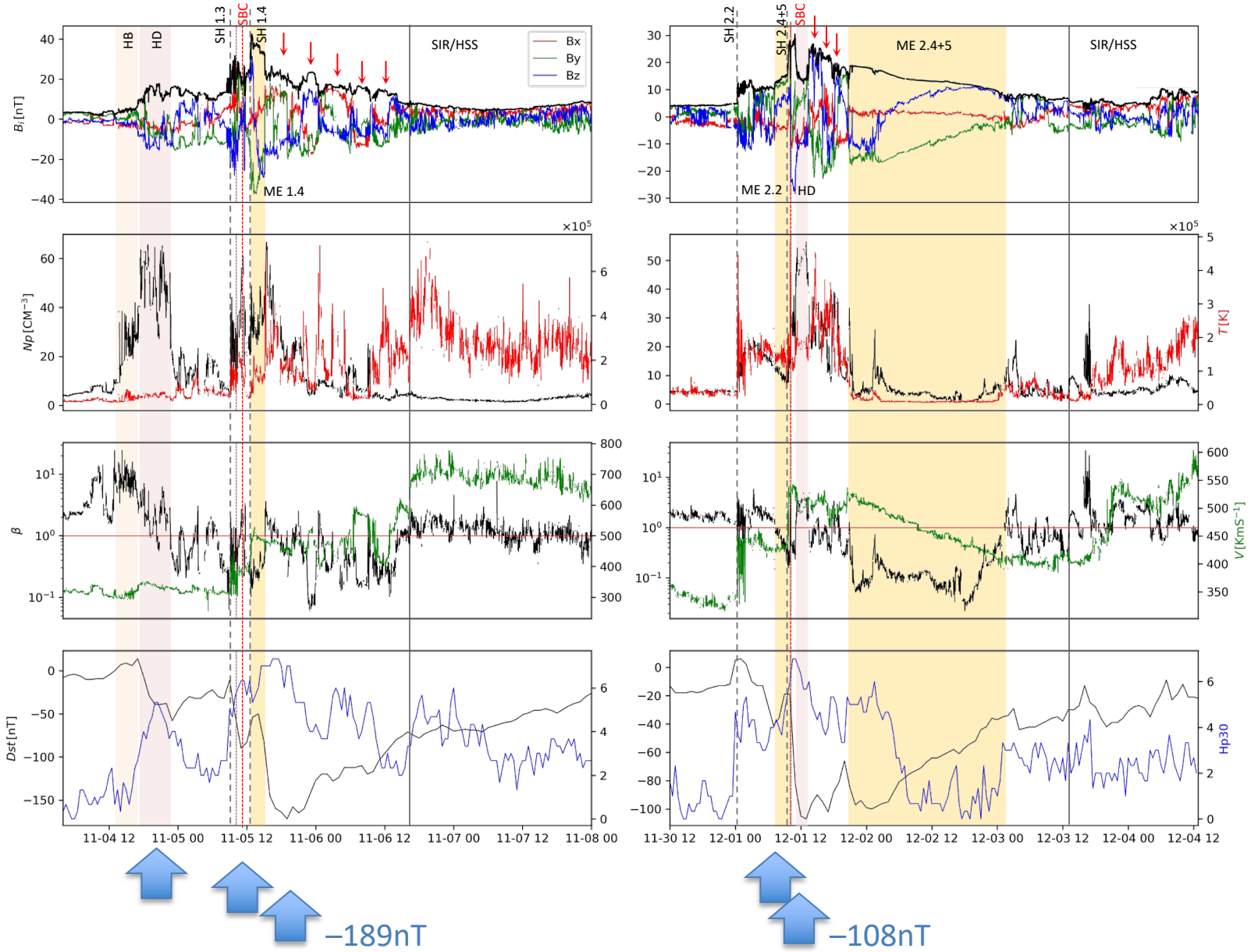


Results from GCS, CHIP, 3D DBM:

Rotation #1: only **CME1.4** is a potential candidate to **partially hit** Earth. CHIP low.

Rotation #2: **CME2.2 and CME2.4+5 might interact** in IP space and **hit Earth**. CHIP low (<2).

In-situ measurements and geoeffectiveness



Marked shaded regions:

1) HB: heliospheric plasma sheet (high plasma-β structure),
2) HD: high-density structure,
3) CME related shocks (SH; dashed vertical lines),
4) sector boundary crossing (SBC),
5) CME related magnetic ejecta (ME),
6) start of the SIR/HSS.

Red arrows:
short-term magnetic field variations associated with strong fluctuations in temperature and density (ripples; see also e.g., Winslow+2016)

Multi-step variations in Dst and Hp30
HD region, SBC, combined with strong neg. B_z

No preconditioning effects found in multi-step Dst storms (e.g., Xie+2008).

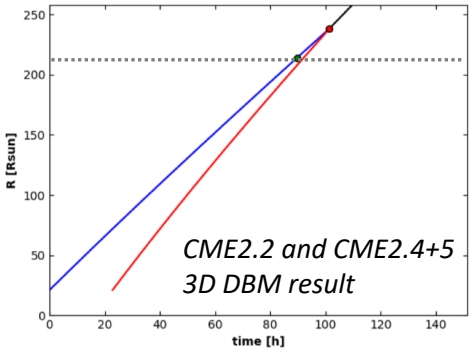
Summary of derived parameters and their quantities

	Rotation #1				Rotation #2			
Event no.	CME1.1	CME1.2	CME1.3	CME1.4	CME2.1	CME2.2	CME2.3	CME2.4+5
Date in 2023	Nov-01	Nov-02	Nov-03	Nov-03	Nov-27	Nov-28	Nov-28	Nov-29
Time at 21.5 Rs [UT]	03:51	10:12	10:32	08:00	13:42	03:40	02:54	02:34
SR location[i]	S30E20	N25E25	S20W30	N15W30	W30S30	N20E10	N25E40	S15W00
Half angle [°]	12	18	5	19	37	24	15	44
κ [rad]	0.23	0.25	0.14	0.2	0.3	0.51	0.31	0.94
Latitude [°]	-52	51	6	20	-58	-3	43	-23
Longitude [°]	8**	322	35	3	23	347	312	3***
Tilt [°]	14	50	25	-33	43	35	-61	11
Speed [km/s]	650	550	300	1300	510	450	1100	600
Flare class	–	–	M1.7/C2.8	C3.2	–	C6.7	C5.6	M3.4+M9.8
FR chirality	right	left	–	left	right	left	left	right
Filament [y/n]	y	y	n	y (huge)	y	n	y	n
CME PA in WL	160–200	0–70	260–280	partial halo	150–250	partial halo	0–90	full halo
CH area [$\times 10^{10}$ km^2]	8.5	8.5	8.5	8.5	10.1	10.1	10.1	10.1
CH B-signed [G]	−5.2	−5.2	−5.2	−5.2	−3.5	−3.5	−3.5	−3.5
CHIP (apex) [G]	1.77	1.77	0.68	0.76	0.27^{+}	0.46	0.70	0.81
Radius at 21.5 Rs [Rs]	3.9	4.2	2.6	3.5	4.8	7.0	5.0	9.8
Density ratio	2	2	2	4	2	2	4	2
γ [10^{-7}km^{-1}]	0.46	0.44	0.7	0.29	0.38	0.26	0.20	0.19
w [km/s]	350	350	350	350	350	350	350	350
3D DBM FR result	miss	miss	miss	flank	miss	hit	miss	hit
3D DBM FR arrival [UT]	–	–	–	2023-11-05 22:42	–	2023-12-01 21:22	–	2023-12-02 22:46
Shock arrival [UT]	–	–	2023-11-05 09:15	2023-11-05 12:30	–	2023-12-01 00:20	–	2023-12-01 09:30
FR arrival [UT]	–	–	–	–	–	2023-12-01 07:10	–	2023-12-01 20:45
FR chirality	–	–	–	left	–	–	–	right

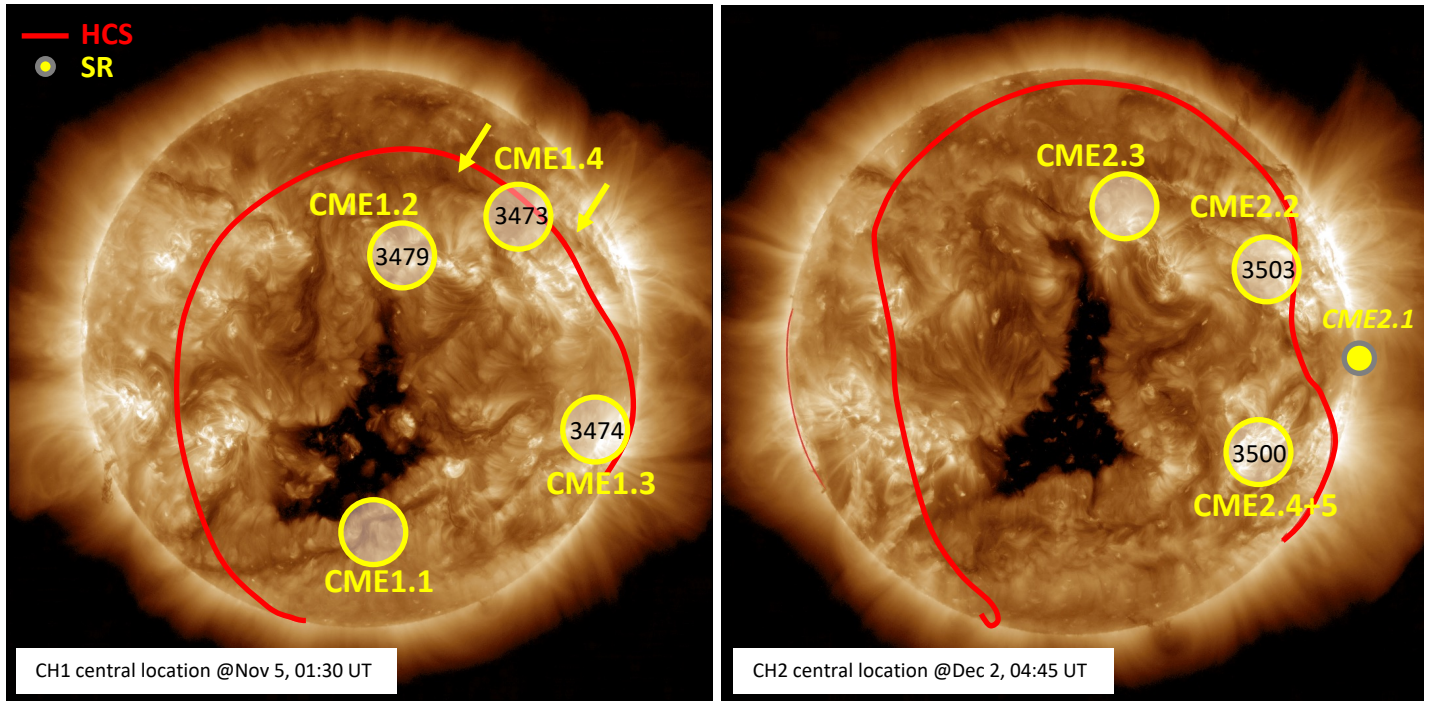
ME-like structure following shock;

Interaction beyond Earth

Rotation#2:
shock of CME2.4+5 in CME2.2 ME (strongly affecting geoeffectiveness; see Lugaz+2016)



Orientation of the heliospheric current sheet (HCS)



The HCS is a fundamental feature of the heliosphere, intimately related to the large-scale dynamical flow of the solar wind (Riley+2002). HCS structure varies strongly over the solar cycle (Hoeksama+1983).

SRs of CME1.3, CME1.4 and CME2.2 next to HCS related to a sector boundary.

- For low-tilted (East-West) HCS, the “same-opposite side effect" has influence on the impact strength of CMEs (see e.g., Henning+1985; Dumbovic+2021).
- High-tilted (North-South) HCS (this study) enhanced impact due to additional compression of the involved magnetic field structures.
- All CME magnetic structures and their shocks which are located at sector boundaries cause geomagnetic effects (Echer & Gonzalez, 2004).

Conclusions

Studying a set of „homologous“ events in October-November 2023 showed many similarities at the Sun, yet, differences in the impact at Earth. We conclude:

- Complexity of magnetic field and interacting large-scale structures during solar cycle maxima is challenging our understanding of CME propagation through heliosphere and their geomagnetic effects (see also COSPAR Space Weather Roadmap; Temmer+2024).

- Multi-step variations in Dst and Hp30 are observed for both rotations covering HD region, SBC, combined with strong neg. B_z; however, preconditioning in multi-step Dst storms is found to have no effect on storm strength (see e.g., Kozyra+ 2002; Xie+2008).

- After each crossing of the sector boundary “ripples” are observed as short-term structures (mesoscale range of several hours) in the total magnetic field separated by abrupt changes in the field orientation in the magnetic field regions, and strong variations in the temperature. Causes are not fully understood (see e.g., Winslow+2016, Viall+2021, Cappello+2024).

- The orientation of the HCS is currently an underrepresented parameter in studies relating solar activity phenomena to geomagnetic effects and might also need more attention in the applied research of Space Weather (Temmer+2024).