INTERNATIONAL SPACE WEATHER INITIATIVE WORKSHOP

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ISTITUTO NAZIONALE DI ASTROFISICA INAF

OSSERVATORIO ASTROFISICO DI TORINO

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PREDICTING THE INTERPLANETARY EVOLUTION OF THE 2017 SEPTEMBER 6 CME WITH RESOLVED

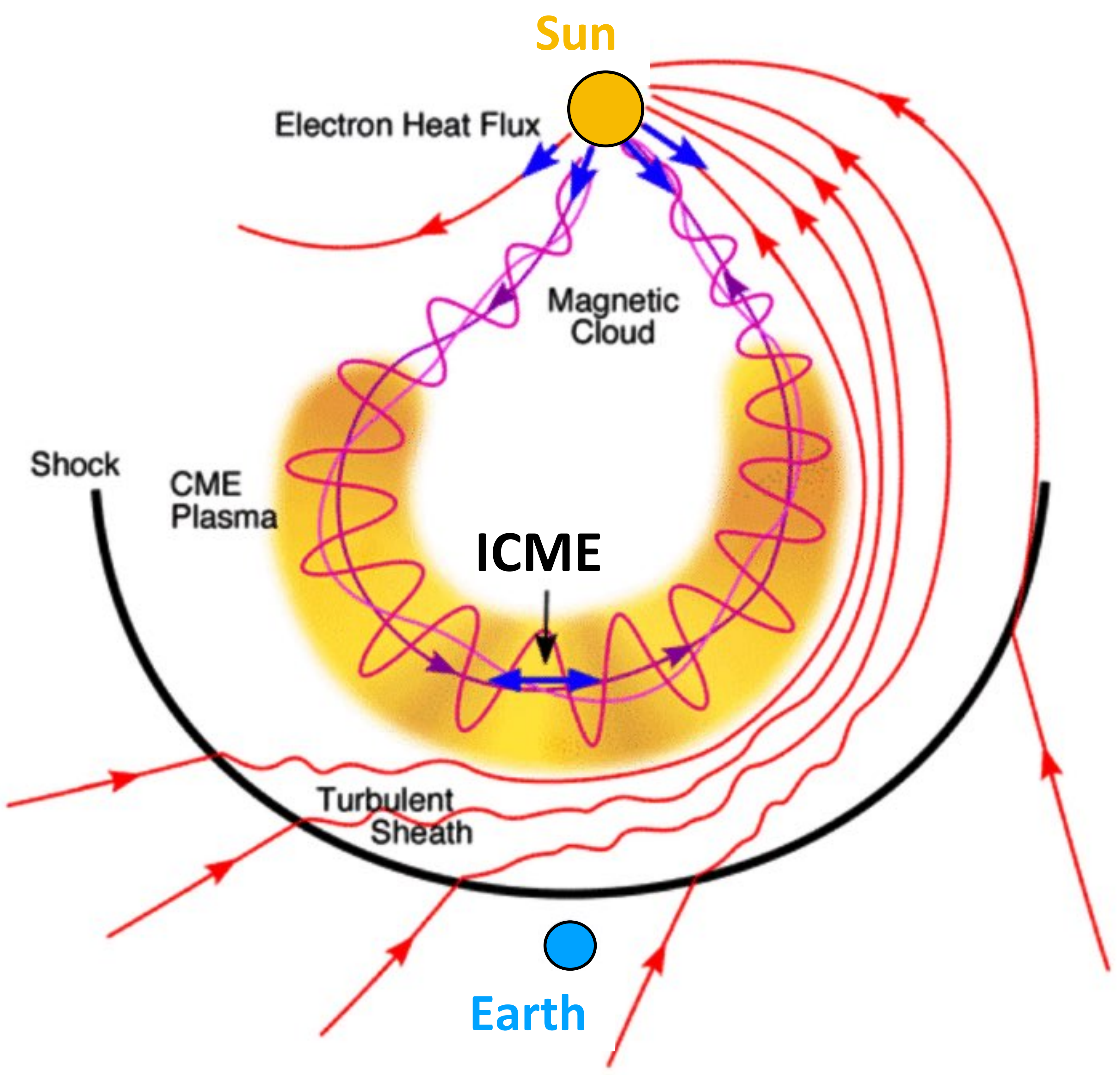
Credit: NASA

OUTLINE

- background: CME propagation models
- the sola**r** **e**ruption drag-ba**s**ed m**o**de**l** with **v**ariabl**e** win**d** — **resolved**
- test case: the 2017 September 6 coronal mass ejection
- results and conclusions

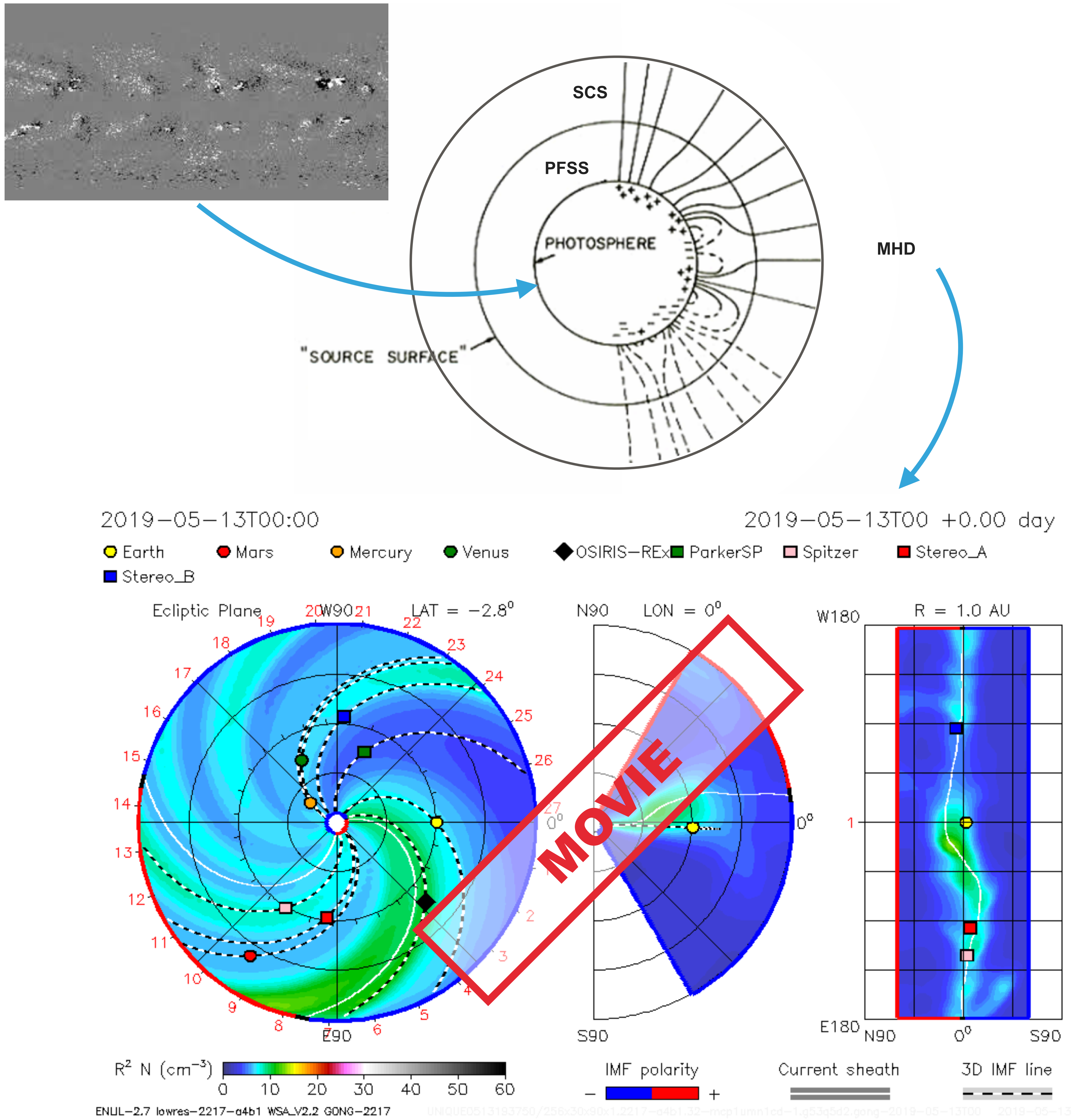
BACKGROUND: CME PROPAGATION MODELS

- numerical MHD models
  - WSA-ENLIL (Odstrčil et al. 2004), EUHFORIA (Pomoell & Poedts 2018)
- analytical drag-based models
  - DBM (Vršnak et al. 2013), enhanced DBM, DBEM, ElEvo/ElEvoHI (Möstl et al., 2015; Amerstorfer et al. 2018)
- empirical models
  - EAMv2 (Paouris & Mavromichalaki, 2017), SARM (Núñez et al., 2016)



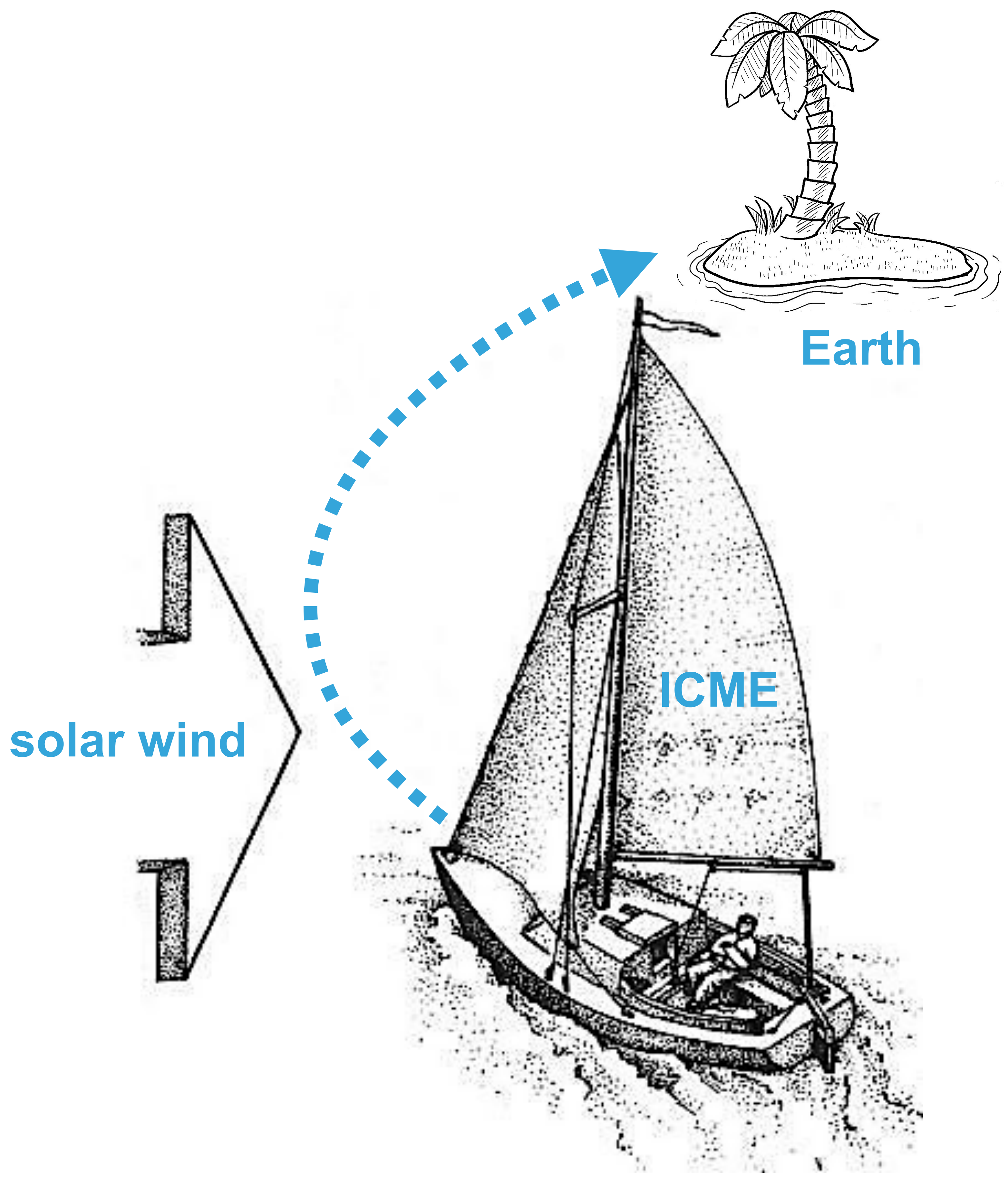
BACKGROUND: MHD MODELS

- in the inner corona the magnetic field is given by the Potential Field Source Surface model combined with the Schatten Current-Sheet model to extend the field in a nearly radial fashion while retaining a thin structure for the heliospheric current sheet
- the solar wind model relies on semi-empirical relationships between topological properties of the coronal magnetic field and the measured solar wind parameters
- the inner heliosphere model consists of a three-dimensional time-dependent MHD simulation
- CMEs are injected as slices of dense plasma spheres with constant radius and no flux-rope structure
- the mean absolute prediction error for these models has been estimated in ~ 10 hrs



BACKGROUND: THE DRAG-BASED MODEL

- it assumes that at a certain distance from the Sun, the dynamics that govern the evolution and propagation of the CME are dependent on the aerodynamic drag force resulting from the interaction between the CME and the solar wind
- it allows for the equation of motion to be solved analytically and offers a very fast application to predict arrival time and impact speed of ICMEs
- usually, average constant values of solar wind speed and density are used as input in all propagation models based on the DBM
- it has been demonstrated that the DBM model offers similar accuracy in predicting the ICME arrival at Earth as full MHD models (Vršnak et al. 2014)

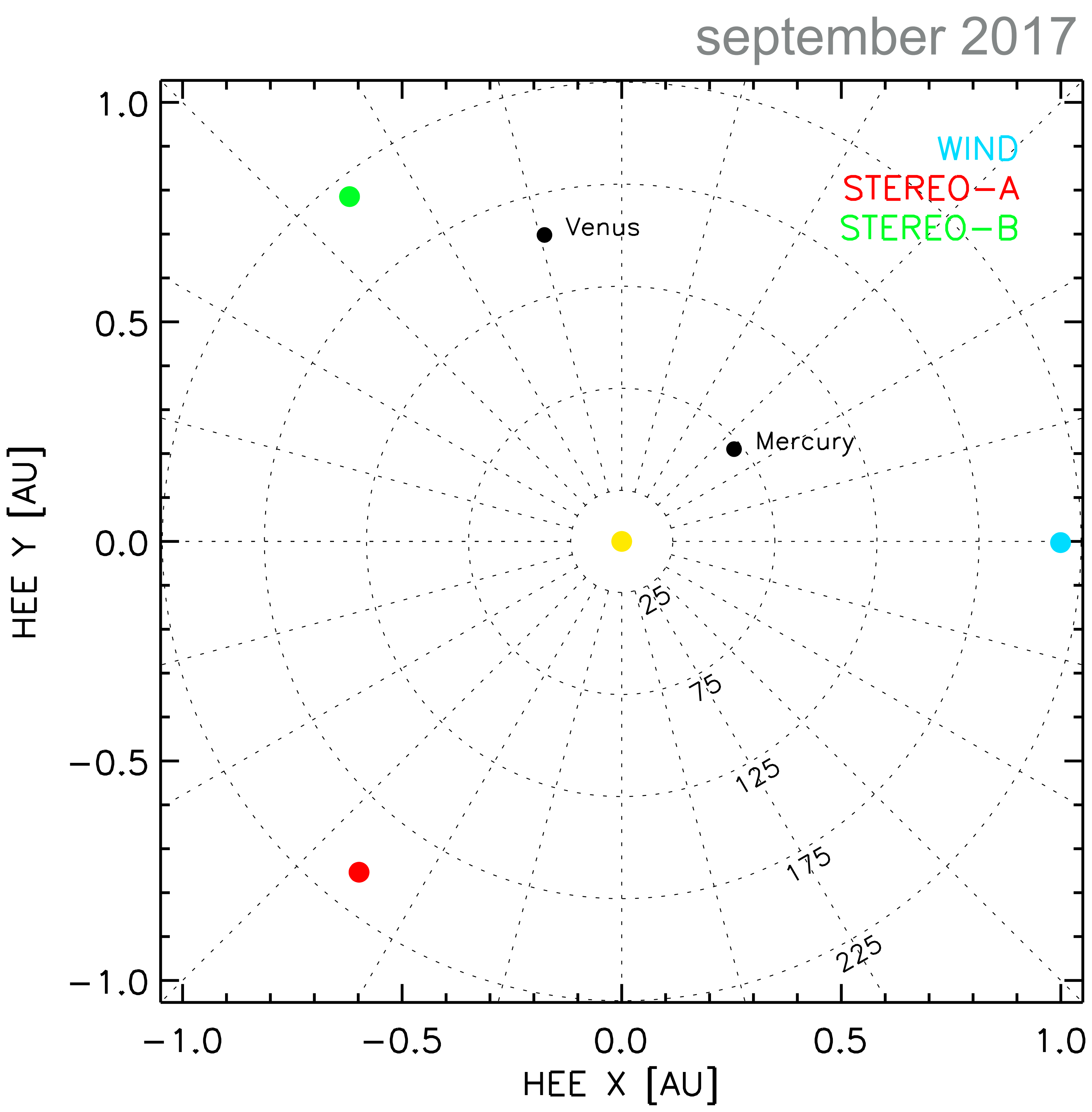


$$a = G \cdot \rho_{wind} \cdot (v - v_{wind})^2$$

where G depends on the mass and geometry of the CME

RESOLVED — SOLAR ERUPTION DRAG-BASED MODEL WITH VARIABLE WIND

- it is based on the DBM, but it assumes 2D distributions of the solar wind speed and density
- the configuration of the interplanetary solar wind is obtained by combining measurements of the wind parameters at 1 AU from in-situ instruments on board the WIND and STEREO satellites
- observations from only a small fraction of solar rotation are necessary to build a sufficiently wide wind model (twice the angular separation of the two spacecraft)
- the evolution of the whole ICME front in 2D on the ecliptic plane is derived starting from a circular geometry and taking into account the different wind regimes met by the ICME during its propagation



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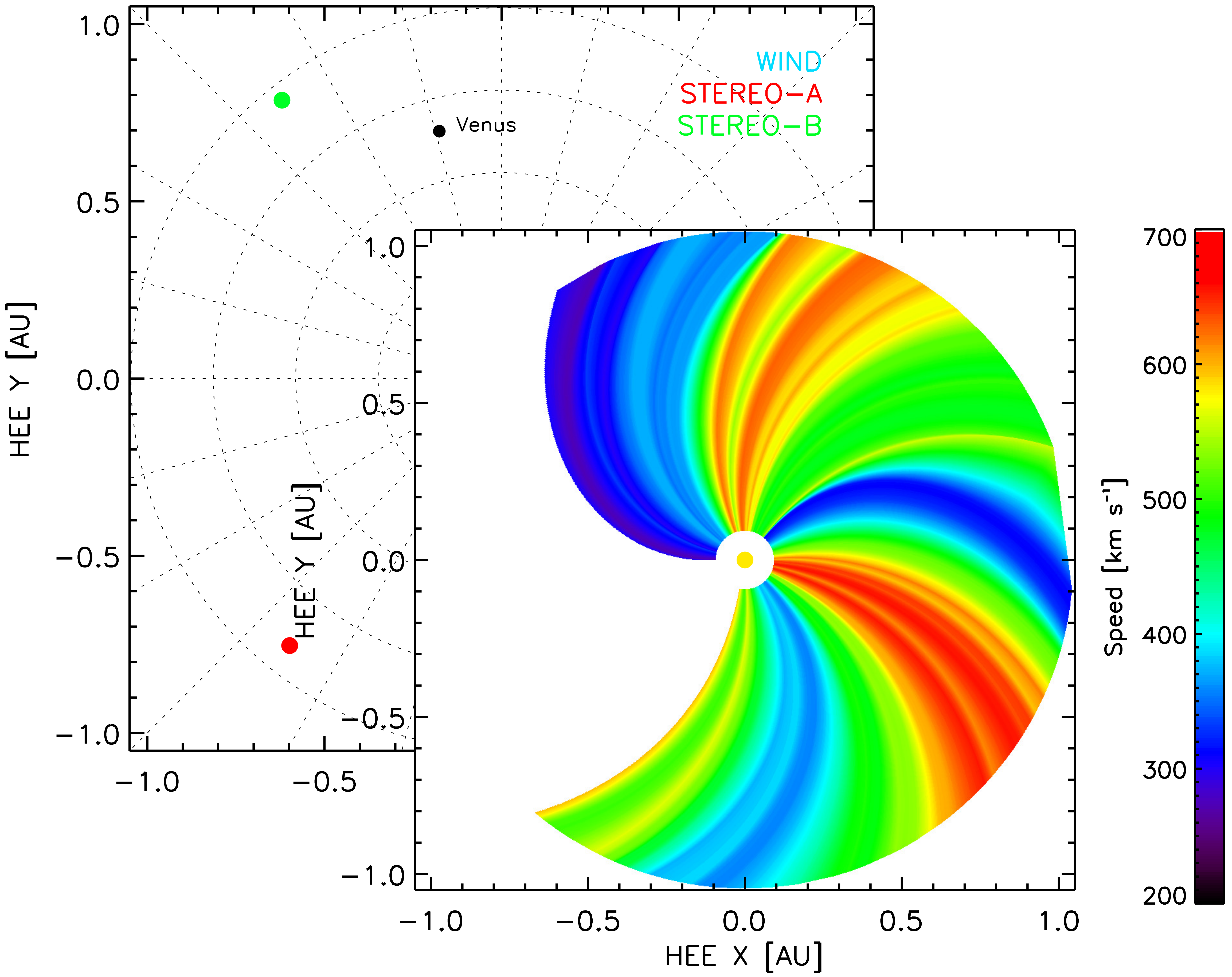
- the configuration of the interplanetary solar wind is obtained by combining measurements of the wind parameters at 1 AU from in-situ instruments on board the WIND and STEREO satellites
- only cumulative observations from a fraction of solar rotation are needed to build a relatively wide wind model
- the evolution of the whole ICME front in 2D on the ecliptic plane is derived starting from a circular geometry and taking into account the different wind regimes met by the ICME during its propagation

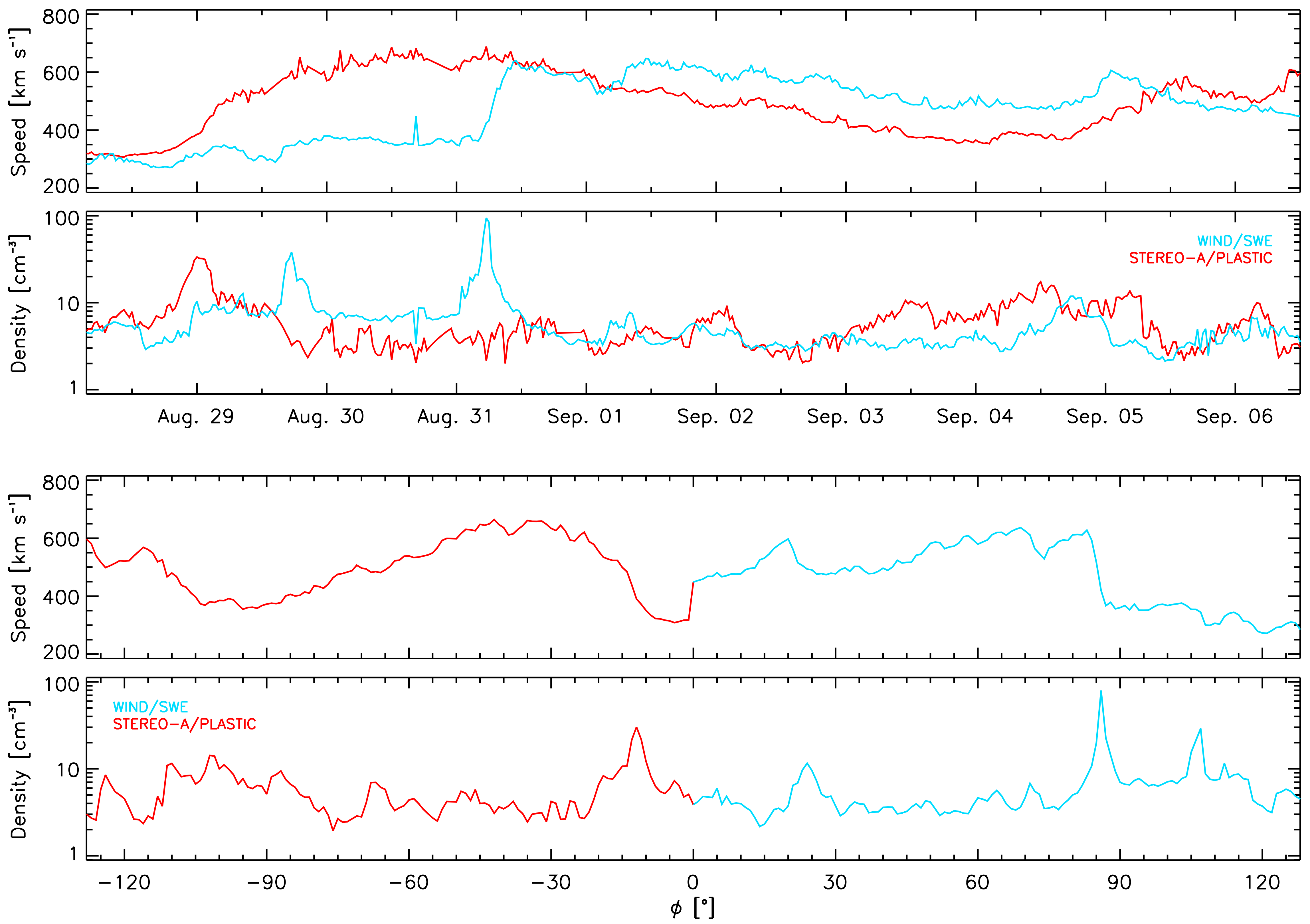
september 2017

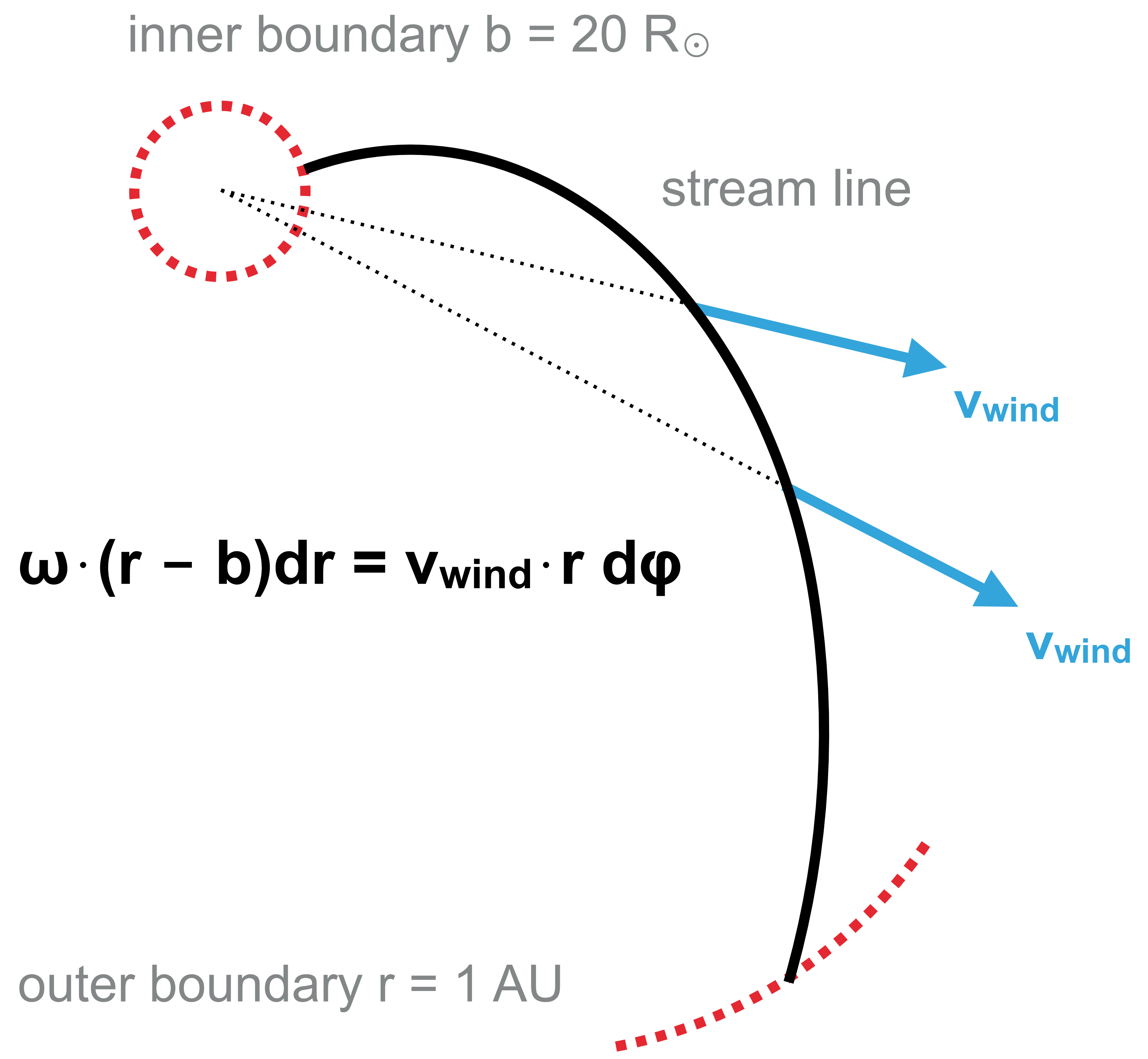


Susino et al. 2019, in preparation

RESOLVED

- the analytical model of Parker (1958) is used to reconstruct the solar wind spiral structure using wind data from WIND/SWE and STEREO-A/PLASTIC





$$\omega \cdot (r - b)dr = v_{wind} \cdot r \, d\varphi$$

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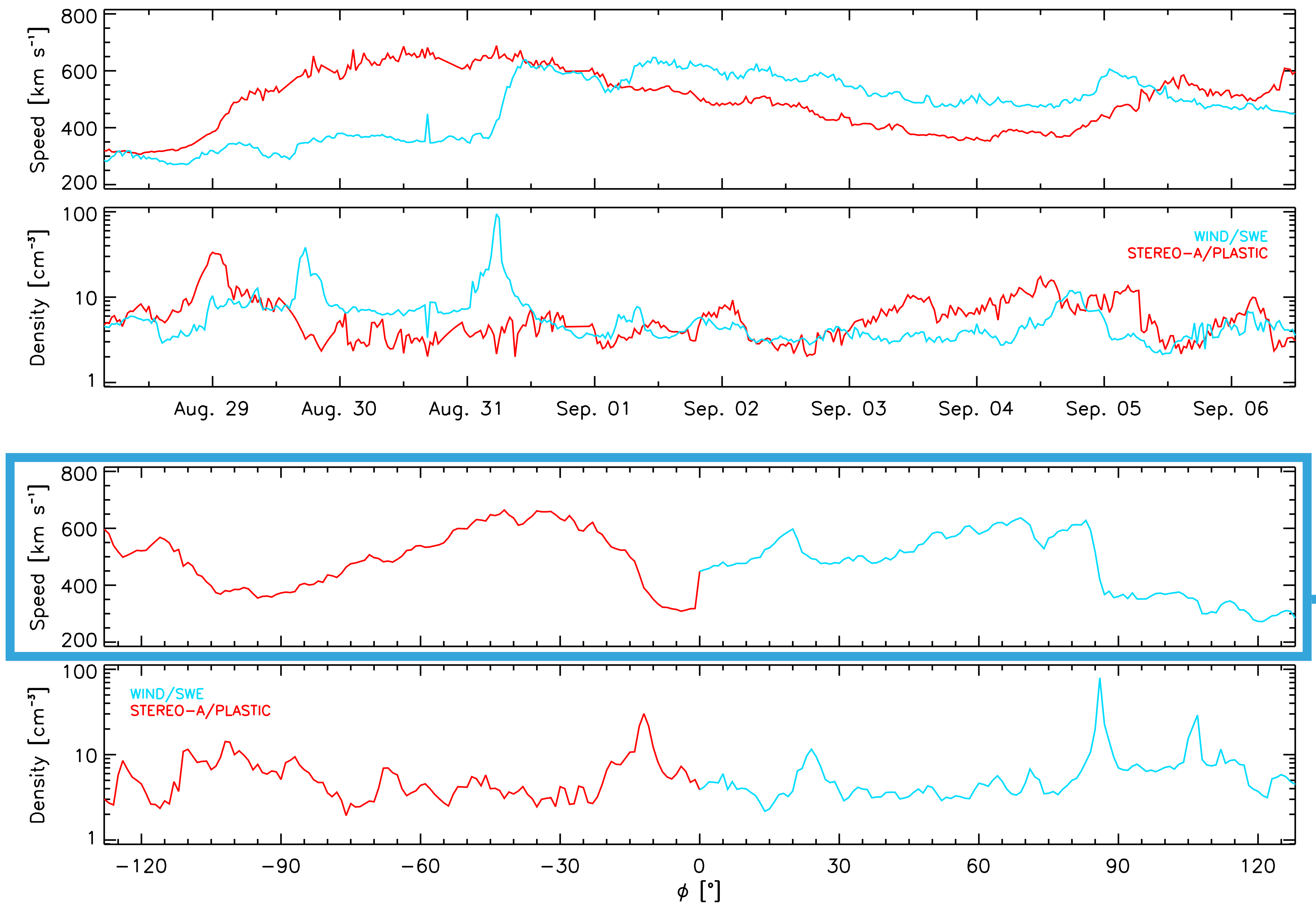
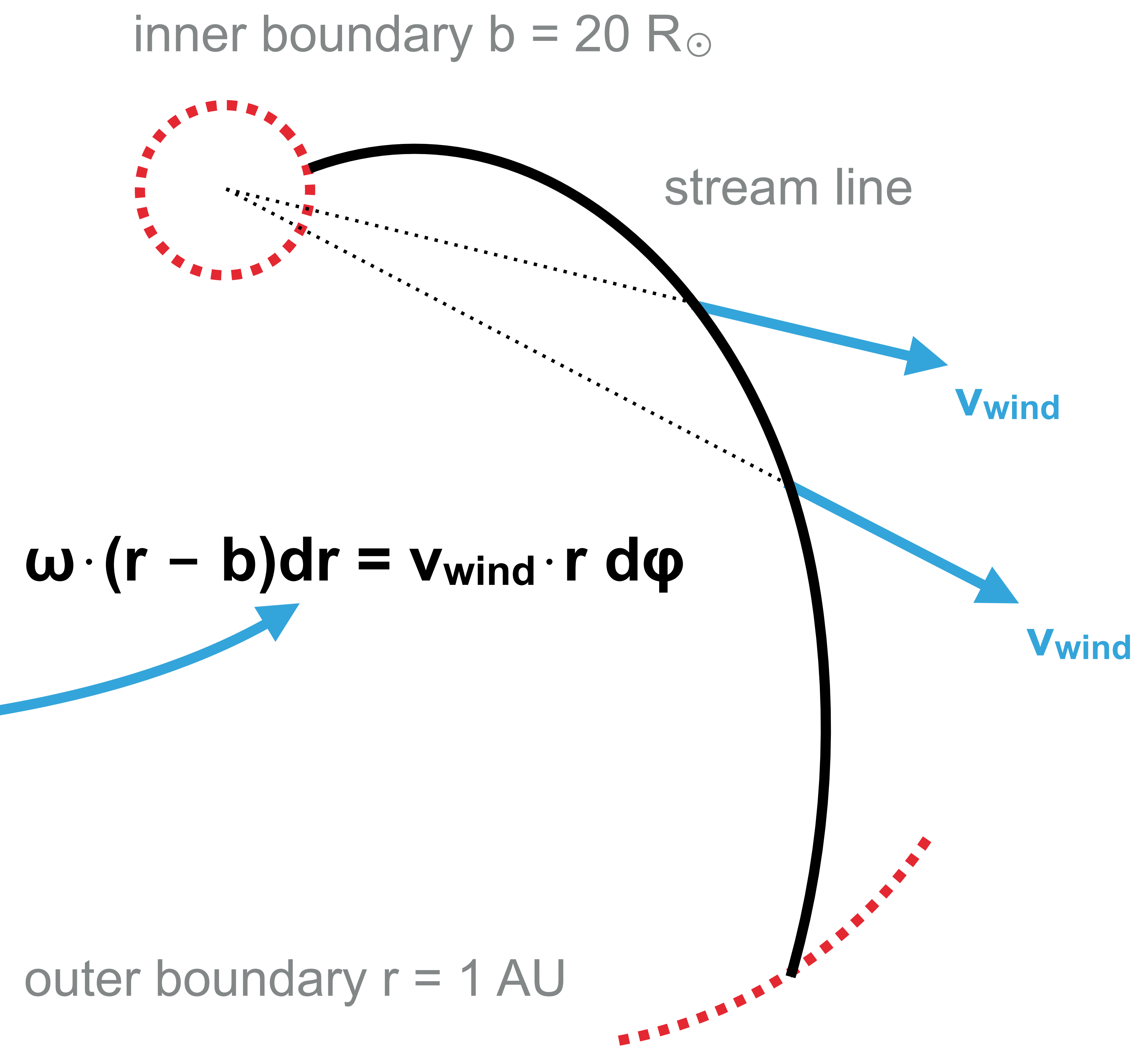




$$\omega \cdot (r - b)dr = v_{wind} \cdot r\, d\varphi$$

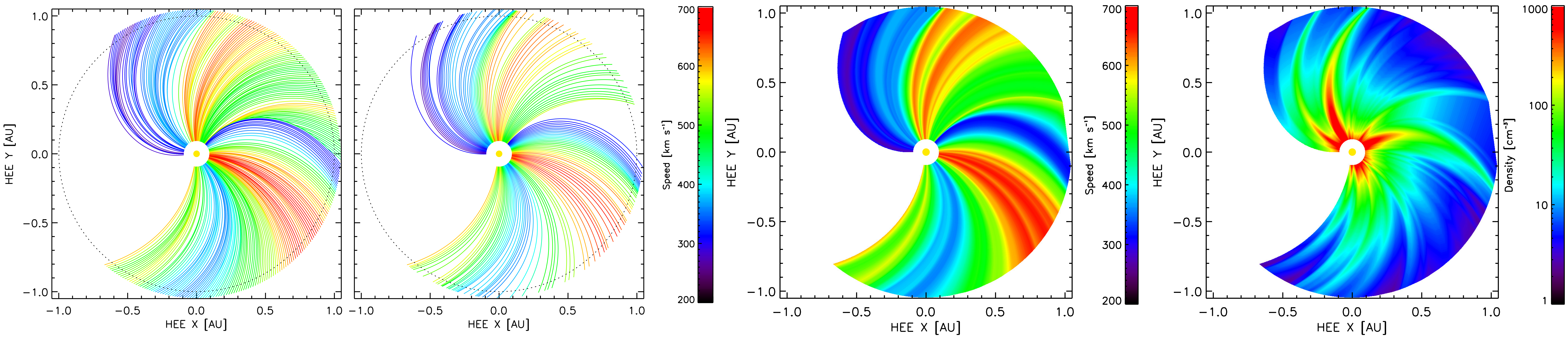
RESOLVED

double integration to avoid intersection of the stream lines

interpolation

$$r^2 \cdot \rho_{wind} \cdot v_{wind} = const.$$

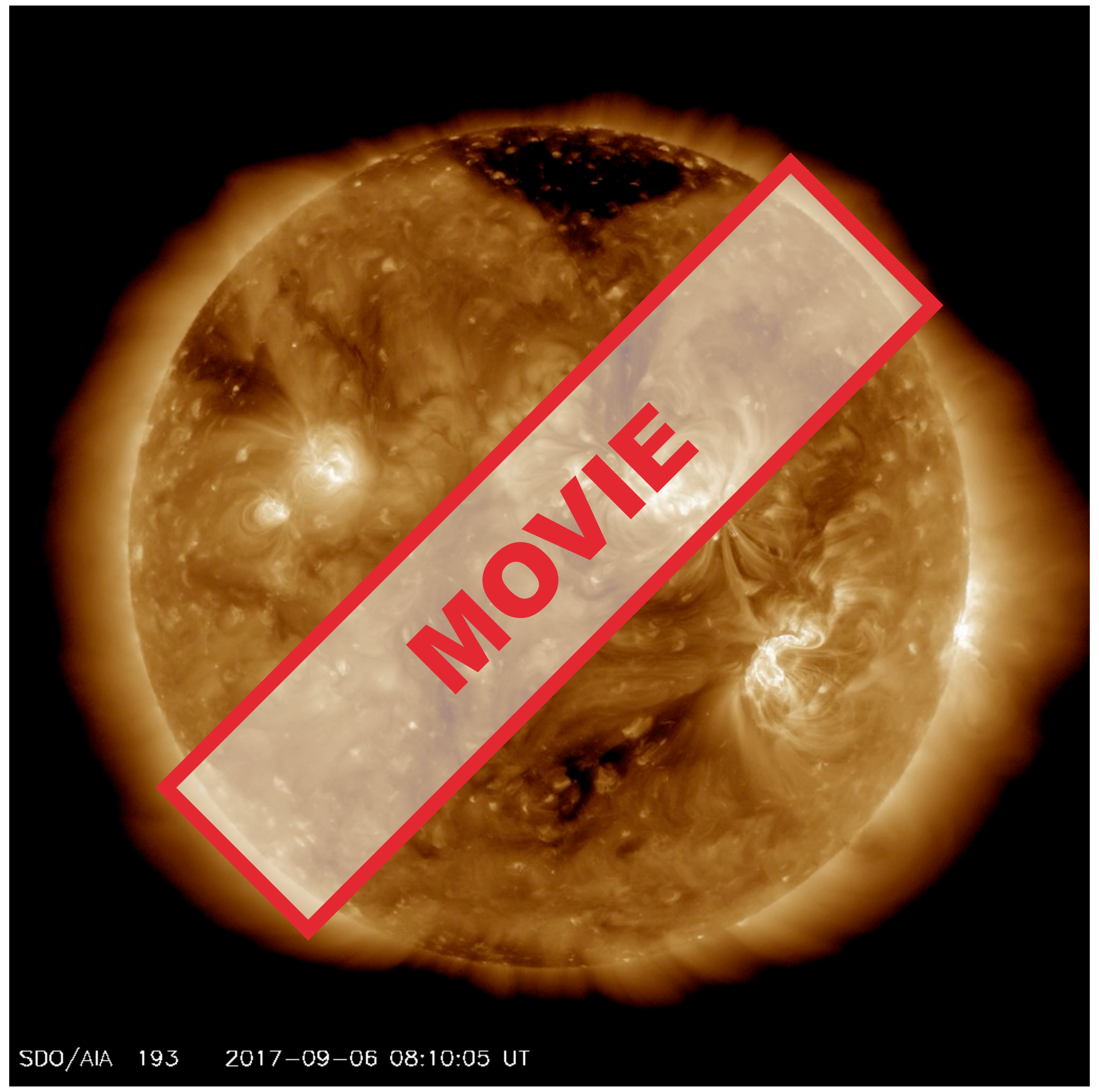
mass flux conservation



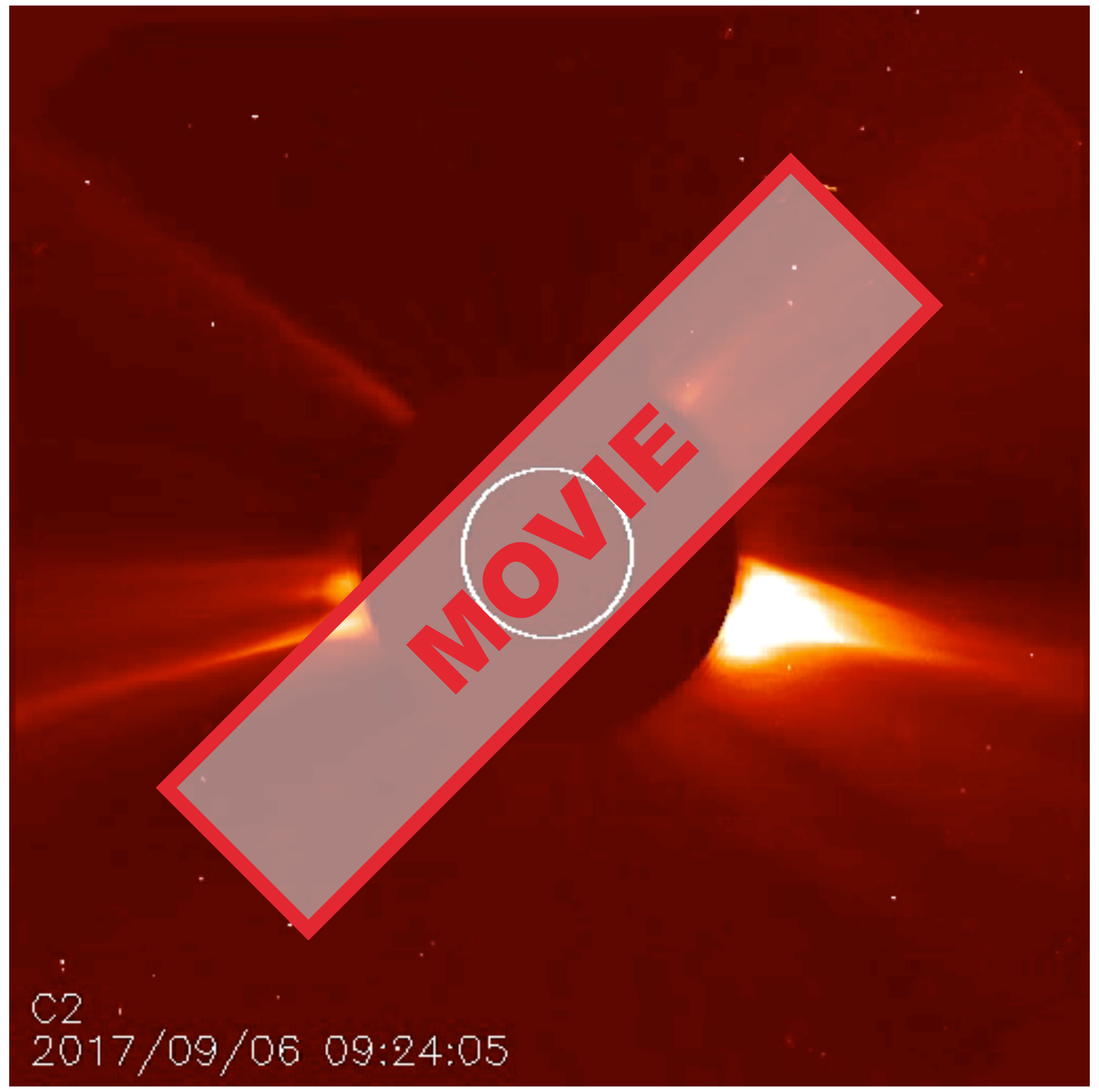
TEST CASE: THE 2017 SEPT. 6 CME — REMOTE SENSING OBSERVATIONS

- a series of three CMEs erupted from the same active region between 4–6 September 2017
- the third CME occurred on September 6 at 12:24 UT, reached a velocity of 1480 km s^{-1}, surpassing the speed of all previous CMEs, and its eruption was concurrent with an X9.3 class flare at 11:53 UT
- this CME appeared as an asymmetrical halo with a large angular extent in the LASCO and COR2 fields of view

SDO/AIA 193 Å

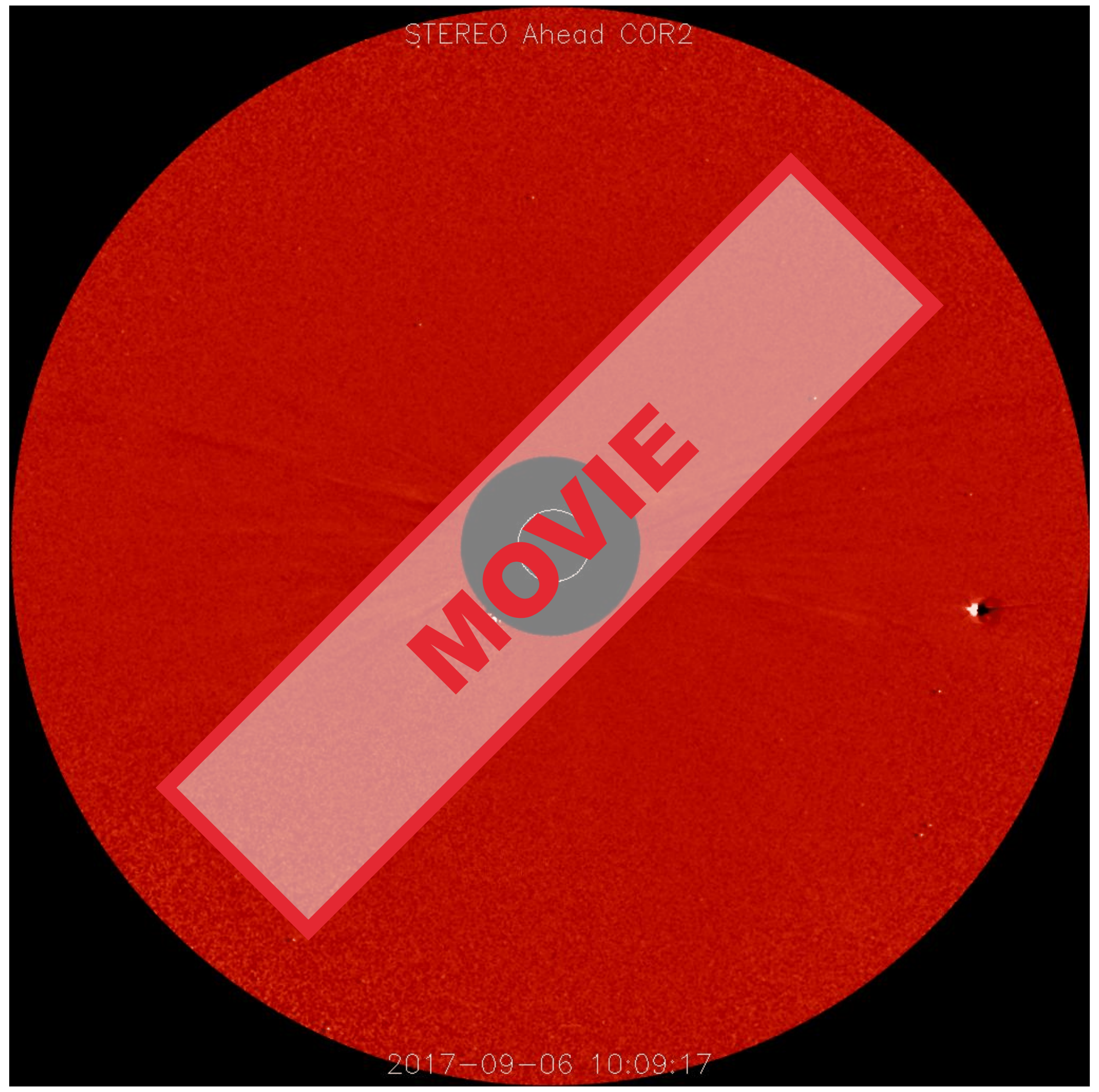


LASCO C2

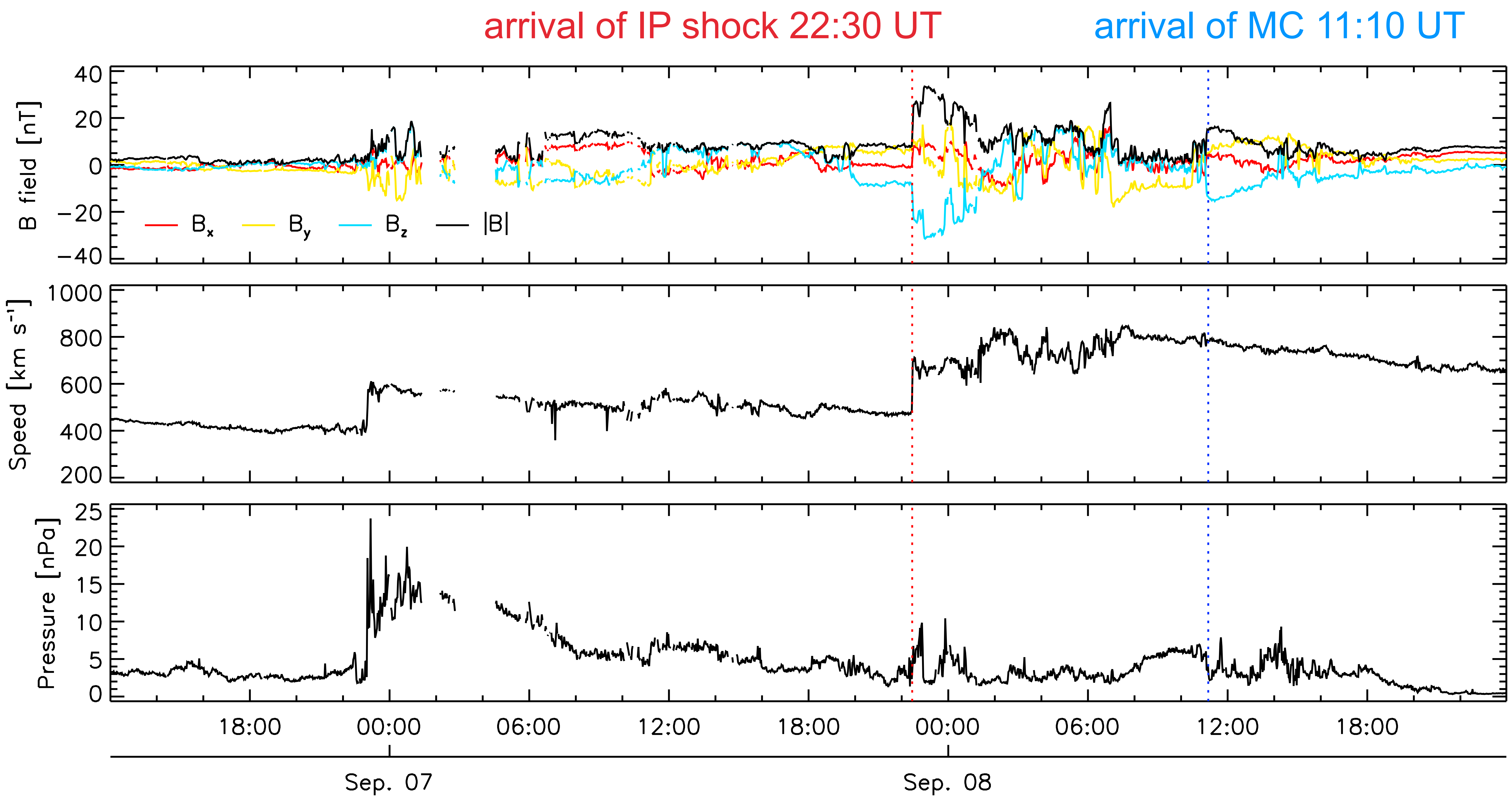


LASCO C3

STEREO-A/COR2



TEST CASE: THE 2017 SEPT. 6 CME — IN-SITU OBSERVATIONS

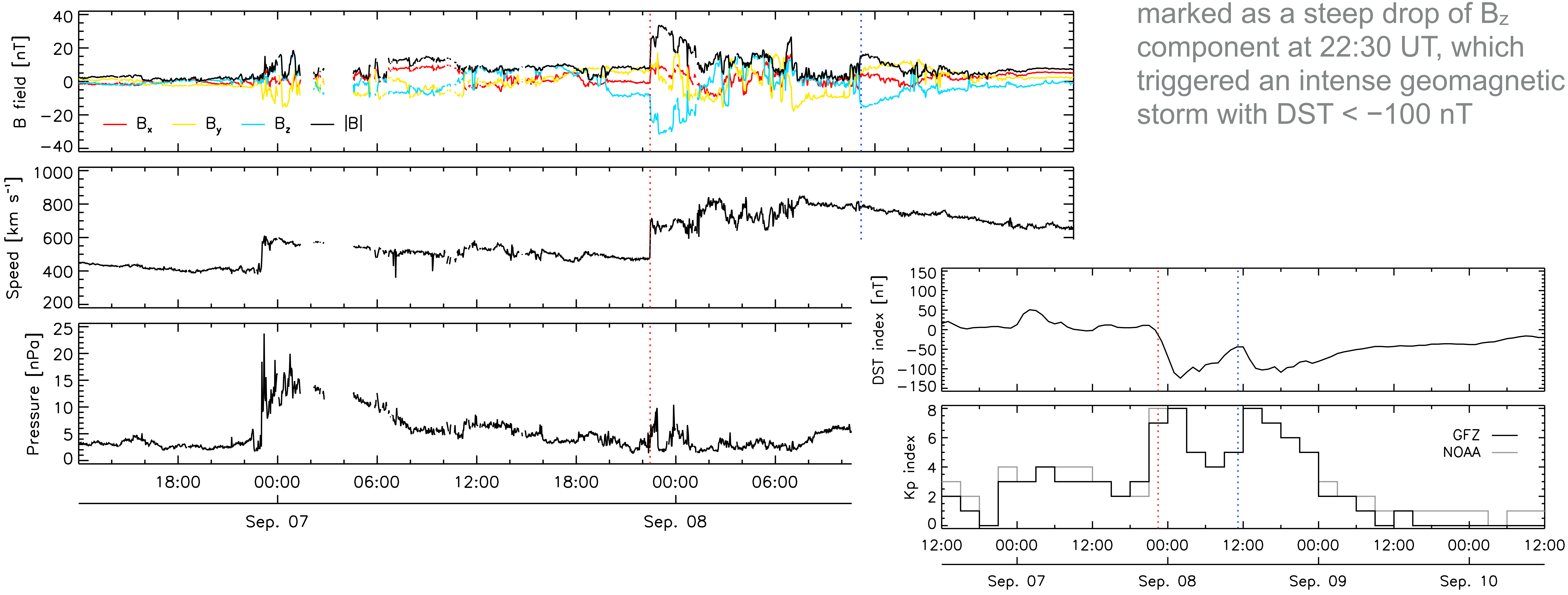


- the arrival of IP shock was marked as a steep drop of B_z component at 22:30 UT, which triggered an intense geomagnetic storm with DST < −100 nT

TEST CASE: THE 2017 SEPT. 6 CME — IN-SITU OBSERVATIONS

arrival of IP shock 22:30 UT

arrival of MC 11:10 UT



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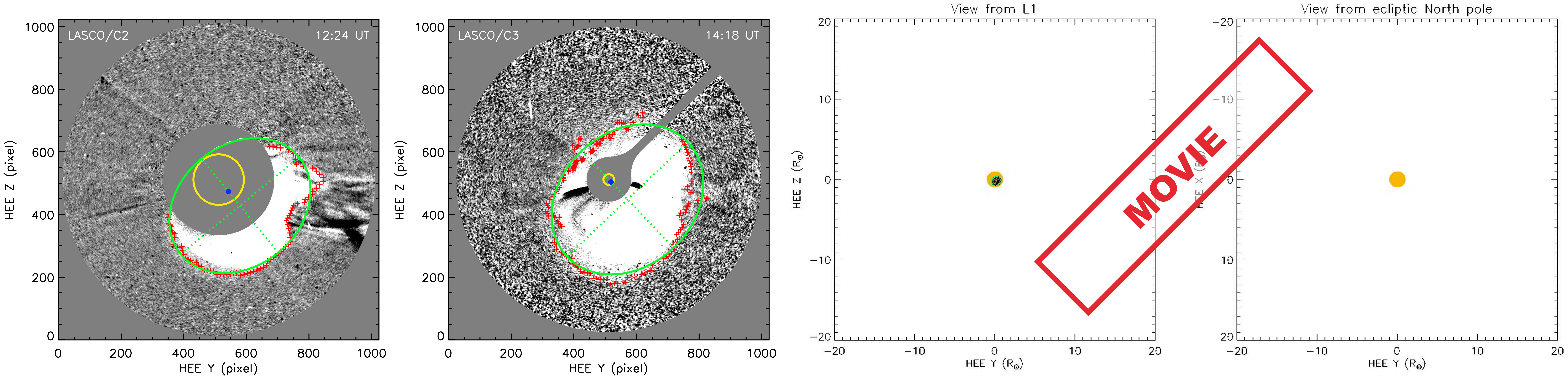
RESULTS: FORECASTS

source: CME Scoreboard (https://swrc.gsfc.nasa.gov/main/cmemodels)

Forecast	Uncertainty (hrs)	Δt (hrs)	Method
Sept. 8 18:27	±7	+20.0	WSA-ENLIL + Cone (GSFC SWRC)
Sept. 8 17:00	±12	+18.5	Other (SIDC)
Sept. 8 22:00	—	+23.5	WSA-ENLIL + Cone (NOAA/SWPC)
Sept. 8 10:25	—	+11.9	SARM
Sept. 8 06:00	±3	+7.5	WSA-ENLIL + Cone (Met Office)
Sept. 8 08:00	—	+9.5	DBM + ESWF
Sept. 8 13:00	±7	+14.5	Other (NSSC SEPC)
Sept. 8 07:32	−5/+6	+9.0 Sept. 8	DBM
Sept. 8 10:16	±4	+11.8	EAM (Effective Acceleration Model)
Sept. 8 16:30	+14	+18.0	ElEvo
Sept. 8 15:48	−9/+10	+17.3	Ensemble WSA-ENLIL + Cone (GSFC SWRC)
Sept. 8 13:52	—	+15.4	SPM2
Sept. 8 10:42	—	+12.2	SPM
Sept. 8 06:00	±2	+7.5	Ooty IPS
Sept. 8 16:00	—	+17.5	WSA-ENLIL + Cone (BoM)
Sept. 8 12:46	**—**	**+14.3**	**Average of all methods**

RESULTS: CME GEOMETRICAL RECONSTRUCTION AND DYNAMICS

- the cone model (Zhao et al. 2004) is used to derive the CME directionality (latitude and longitude), the front angular width, and to correct the CME speed for projection effects



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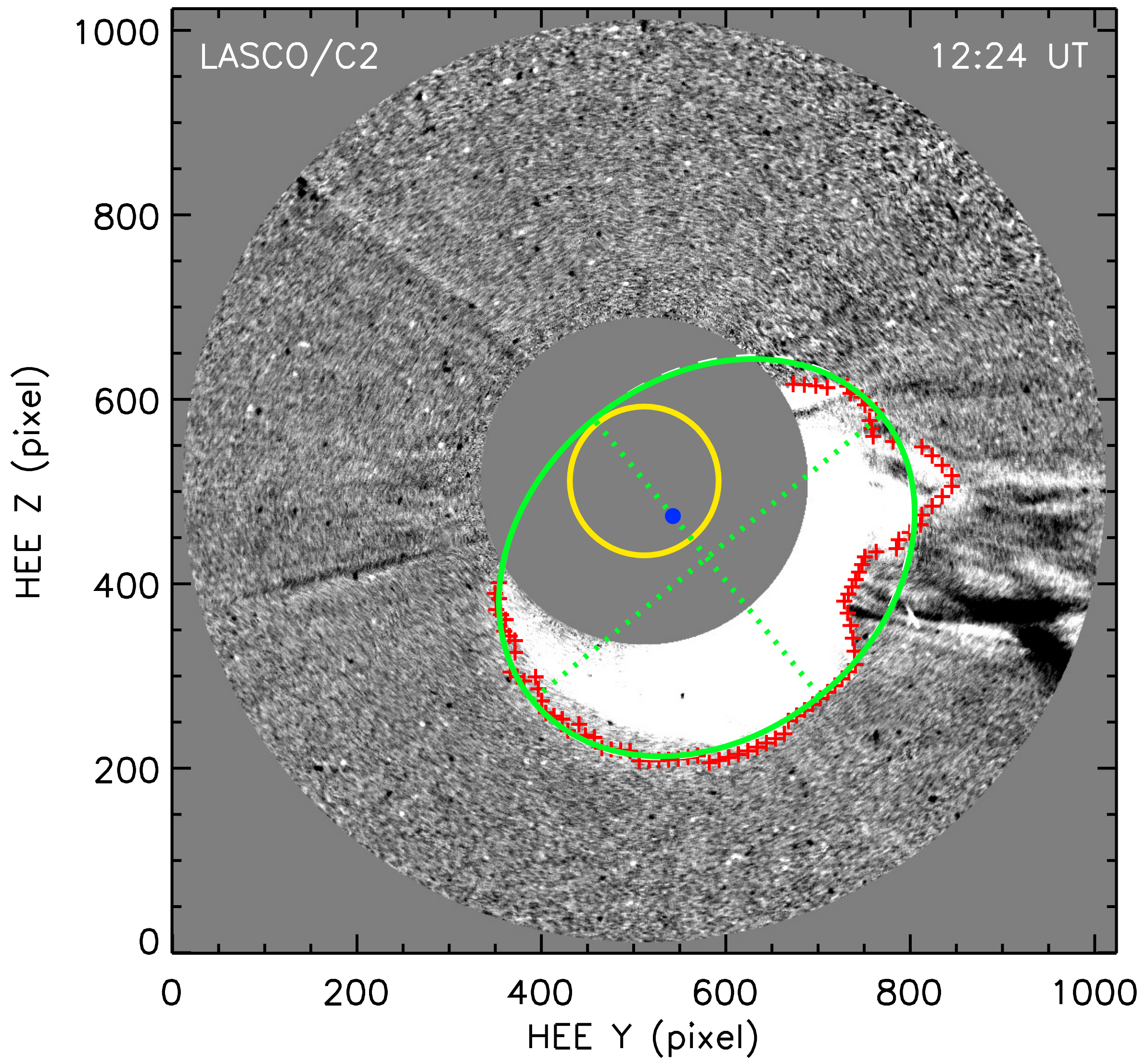

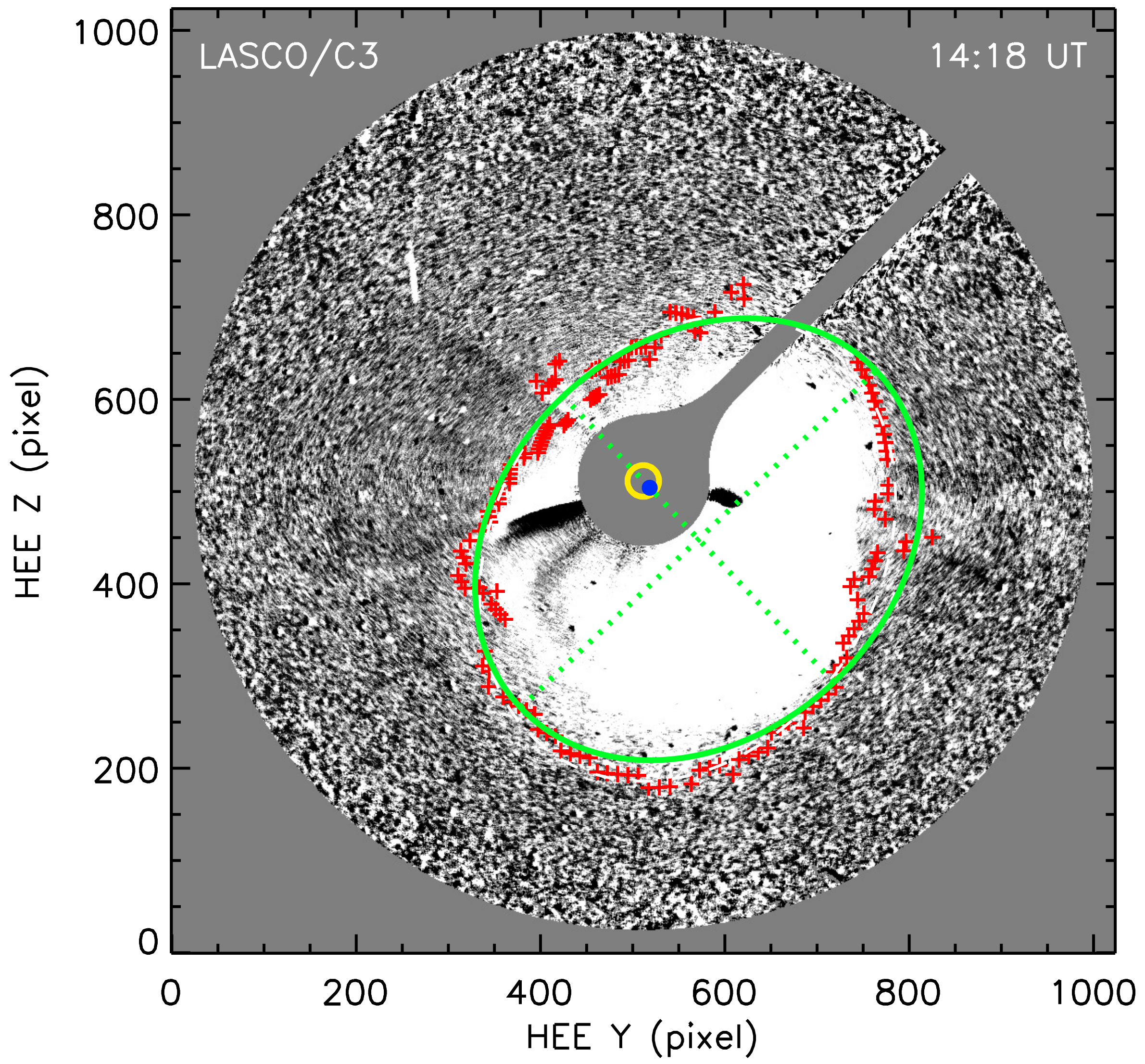

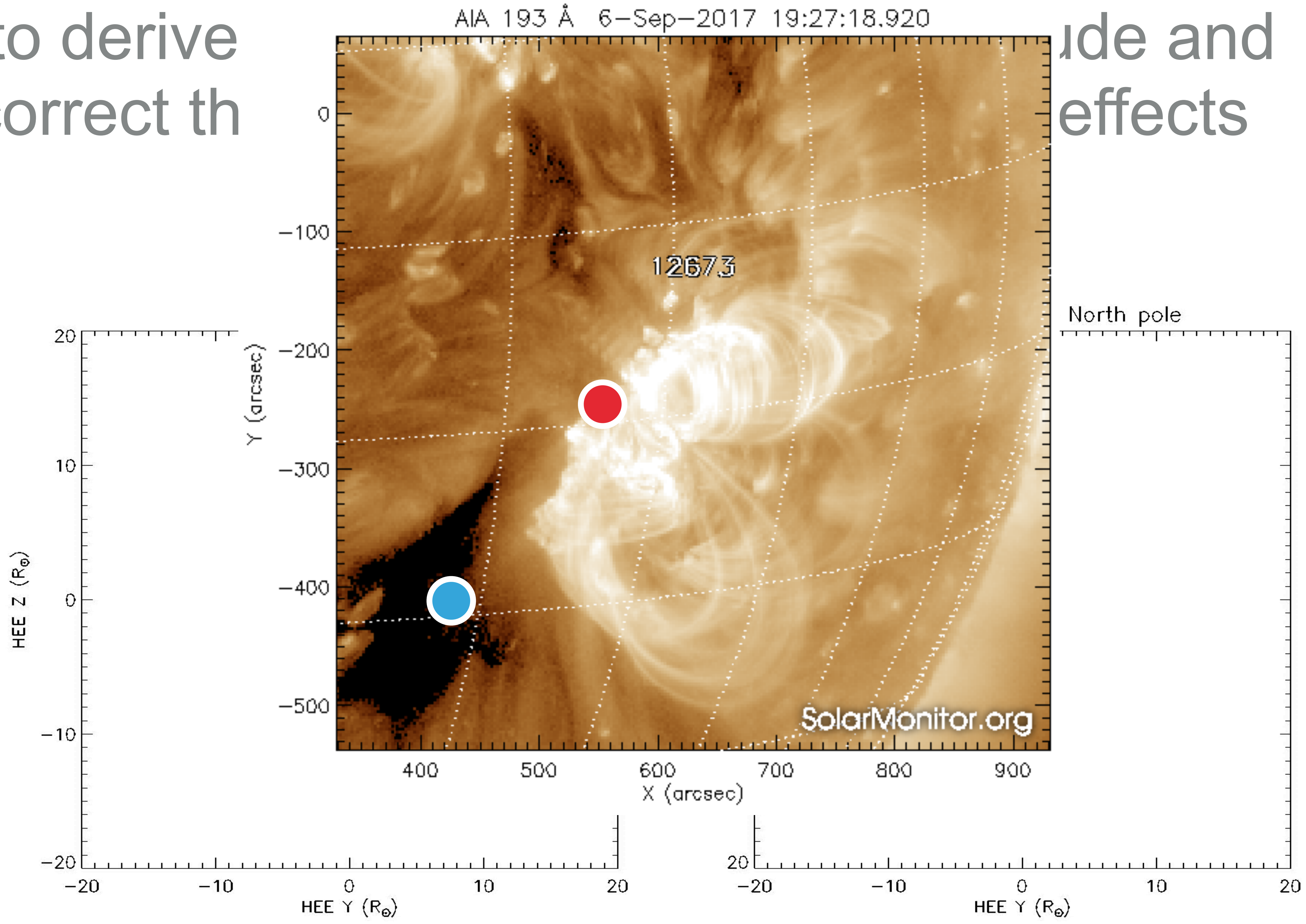

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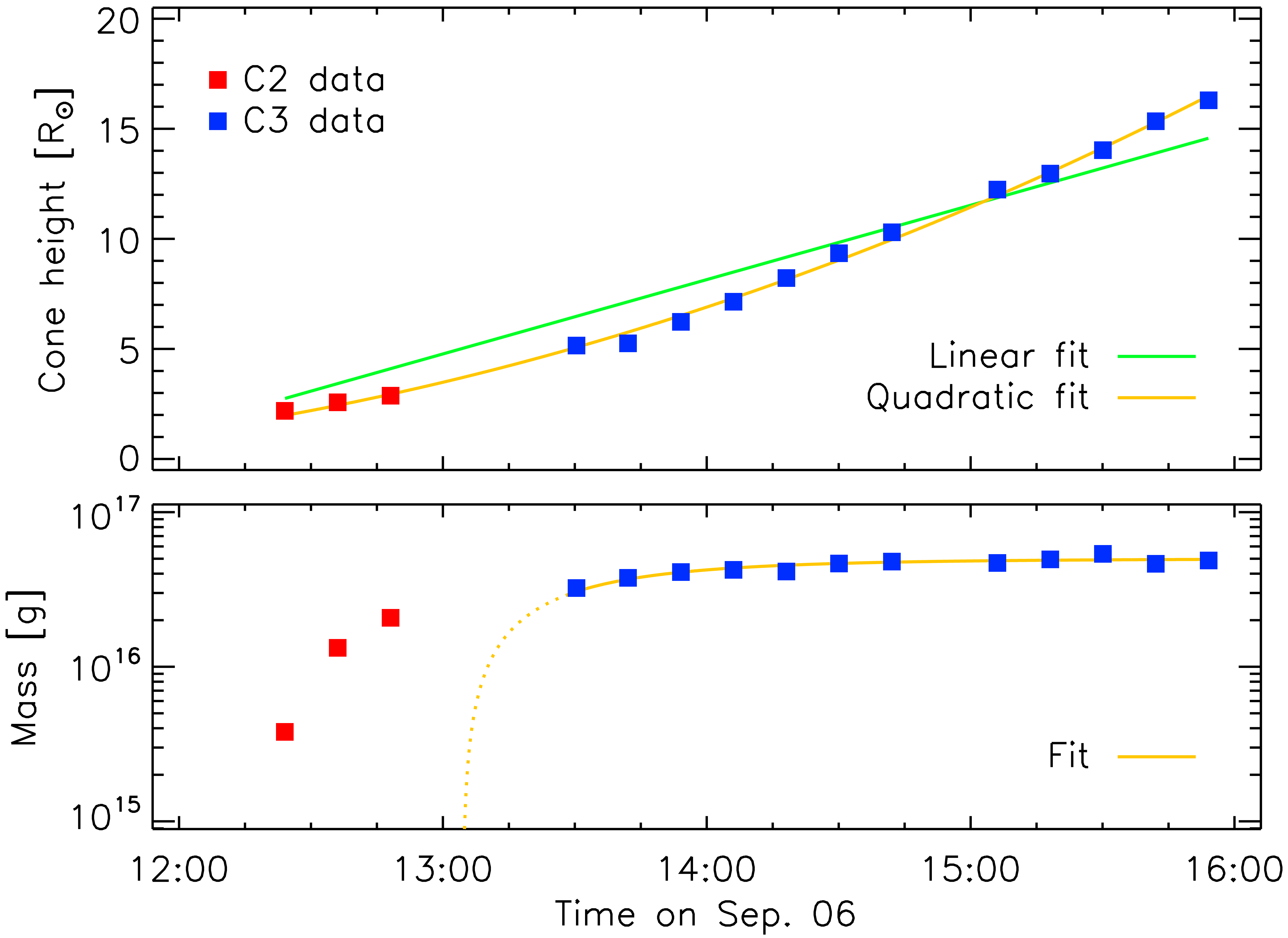
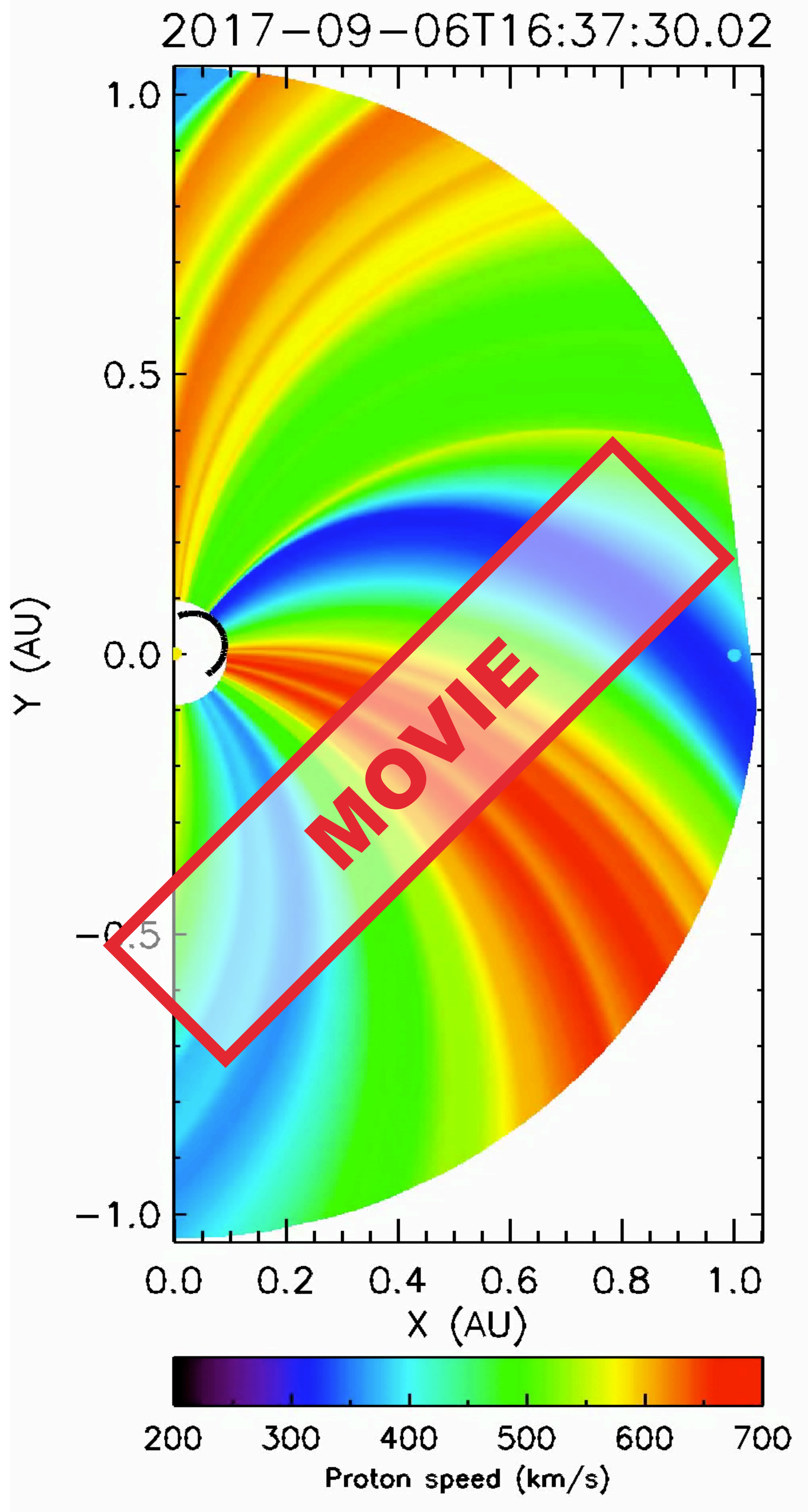
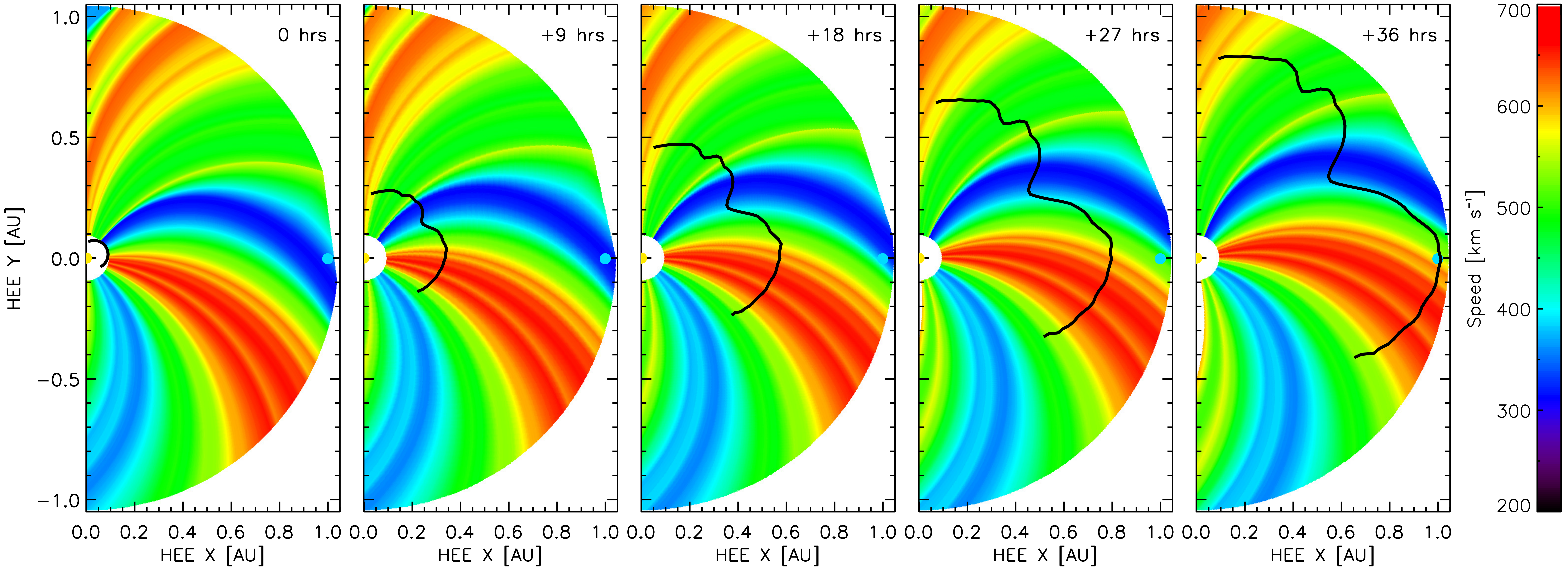


Time @ 20 R⊙	16:37 UT
Half width	58.7º
Propagation angle	54.5º
Heliolatitude	-25.2º
Heliolongitude	25.7º
Acceleration	0.06 km s^{-2}
Initial speed	1260 km s^{-1}
Mass	5×10^{16} g

RESULTS: INTERPLANETARY PROPAGATION

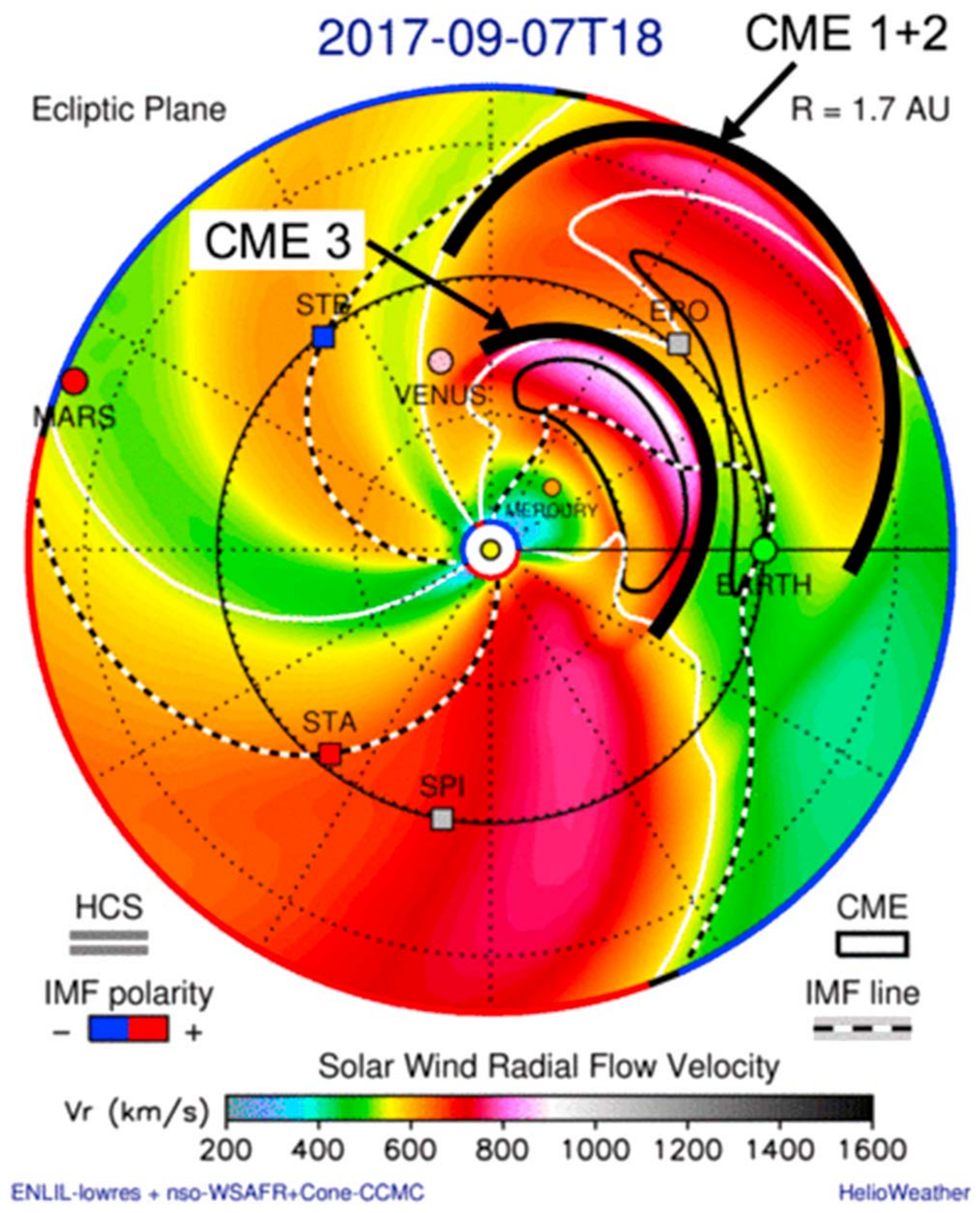


Arrival time	Transit time	Δt	Speed
Sept. 8 04:06 UT	35.5 hrs	+5.6 hrs	970 km s^{-1}



RESULTS: FORECAST AND COMPARISONS

	Our work	Werner et al. 2019
Start time	16:37 UT	14:13 UT
Half width	58.7º	46.0º
Heliolatitude	-25.2º	-18.1º
Heliolongitude	25.7º	33.0º
Initial speed	1260 km s^{-1}	1410 km s^{-1}
Mass	5 × 10^{16} g	?
WSA-ENLIL	**—**	**+4/+14 hrs**
resolved	**+5.6 hrs**	**+2.2 hrs**



from Werner et al. 2019

RESULTS: SENSITIVITY TO THE MODEL PARAMETERS

- variation of the delay time Δt in response to a fixed ±15% uncertainty on the model parameters

	-15%	+15%
Half width	+6.2	+5.5
Heliolatitude	+5.1	+6.2
Heliolongitude	+5.1	+6.2
Initial speed	+10.1	+2.4
Mass	+6.1	+5.2
Drag coefficient	+5.1	+6.1

SUMMARY

- resolved is an evolution of the drag-based model in which constant wind parameters are replaced by 2D distributions over the ecliptic plane
- resolved exploits data from two satellites to reconstruct the configuration of the heliosphere, thus reducing uncertainties relating to the solar wind variability in the time interval necessary to accumulate the data
- first results for the complex test case coronal mass ejection of September 6, 2017, are encouraging
- however, presently there are some limitations:
    - the model relies on the relative position of two spacecraft, one of which is moving, progressively approaching the other
    - no interactions between CMEs and the ambient solar wind are considered, but it is crucial to take preconditioning of the IP medium into account when making forecasts
    - also, CIRs are rendered only artificially in the model, they need a more thorough physical treatment
    - predictions critically depend on the reliability of the geometrical reconstruction of the CME: observations are needed! especially from different viewpoints (L1 and L5)