PUNCH
6 Science Meeting

Understanding CME Evolution

Influence of Solar Wind & other CMEs

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UCAR COMMUNITY PROGRAMS | CPAESS | NASA | LWS | CU | SWx TREC

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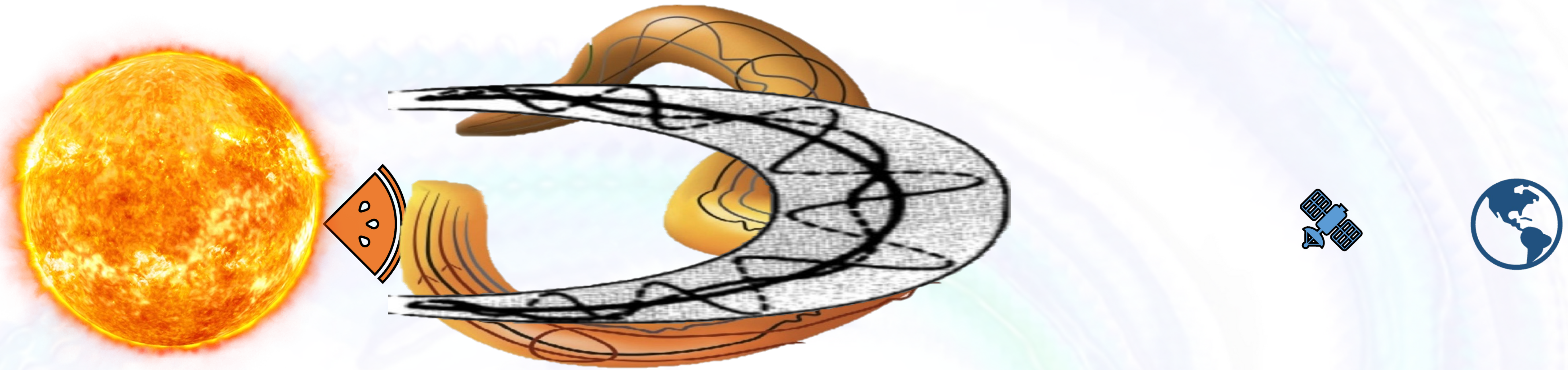


Nada & Lugaz 2025

To Explore:

- Nature of Interaction
- Property Change
- Volume Evolution
- Geo-effectiveness
- Impact of Coronal Properties
- . . .

Approach:

- **Realistic Solar Wind background**
- **Global View of Interaction Process**

Space Weather Adaptive SimulaTion framework

SWASTi framework

- Godunov-type scheme – PLUTO code
  Mignone et al., 2007 [ApJS]
- Solver: hll, **hllc**, hlld, roe
- Reconstruction: **Linear**, WENO3, LimO3, PARABOLIC
- Time-stepping: **RK2**, RK3, ChTr
- Div.B: **Eight Waves**, Hyperbolic Div, CT

Thermal Conduction

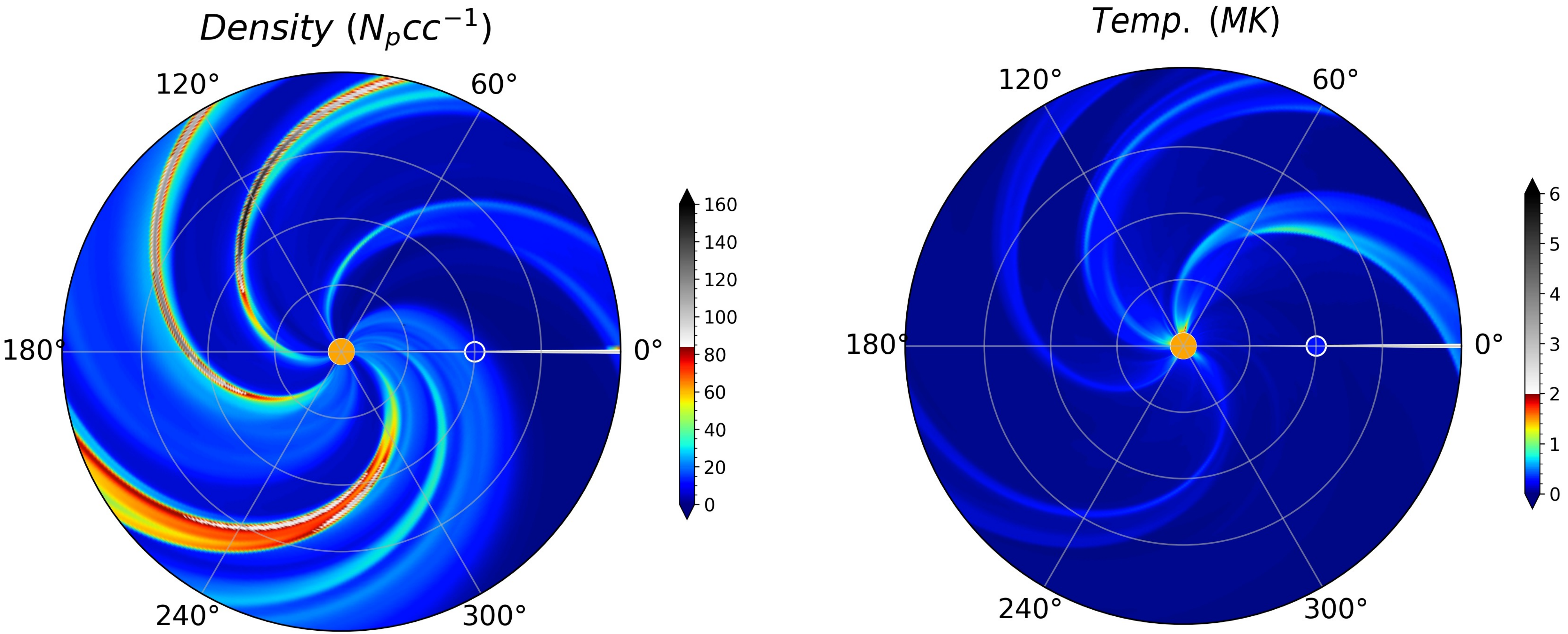
Resistivity

CME Tracer

Solar Wind
Mayank et al., 2022 [ApJS]

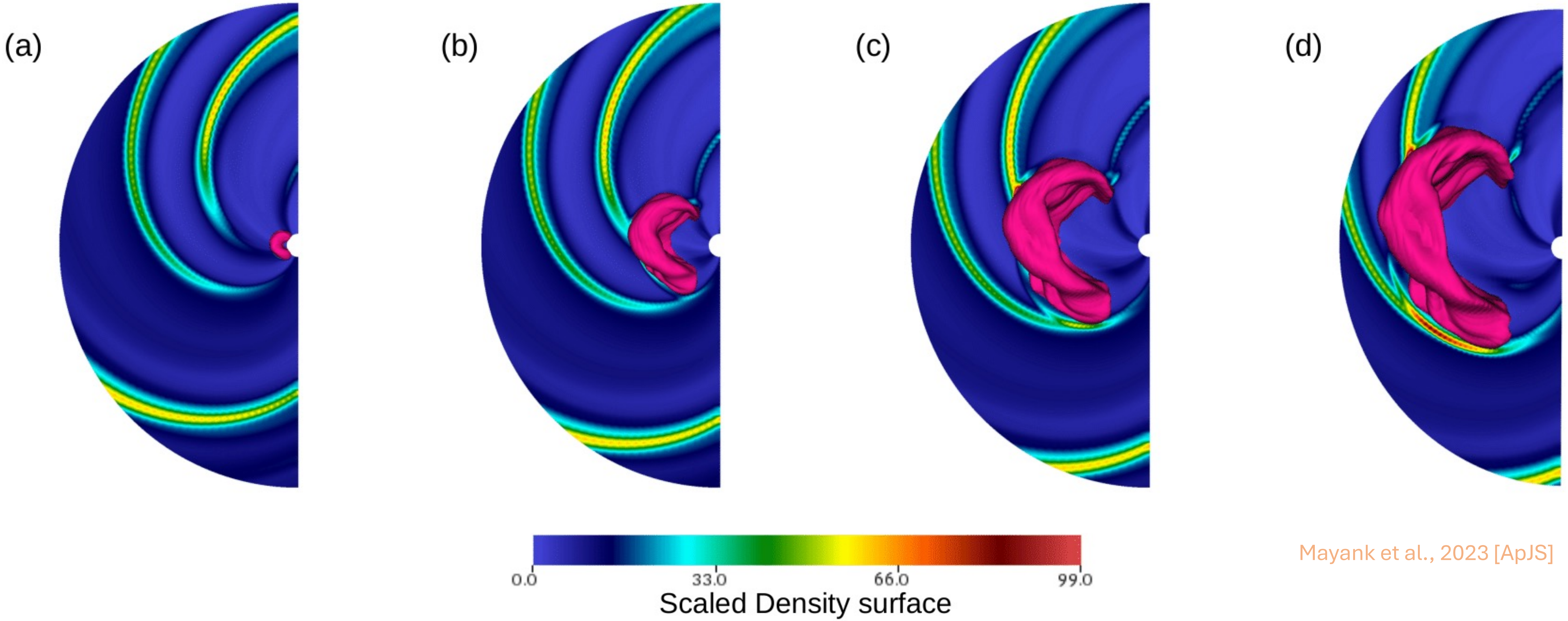
CME
Mayank et al., 2023 [ApJS]

MHD Simulation



How to trace the CME structure in simulation?

CME Tracing



Mayank et al., 2023 [ApJS]

Analogous to usage for astrophysical jets (e.g., S. Walg et al. 2013)

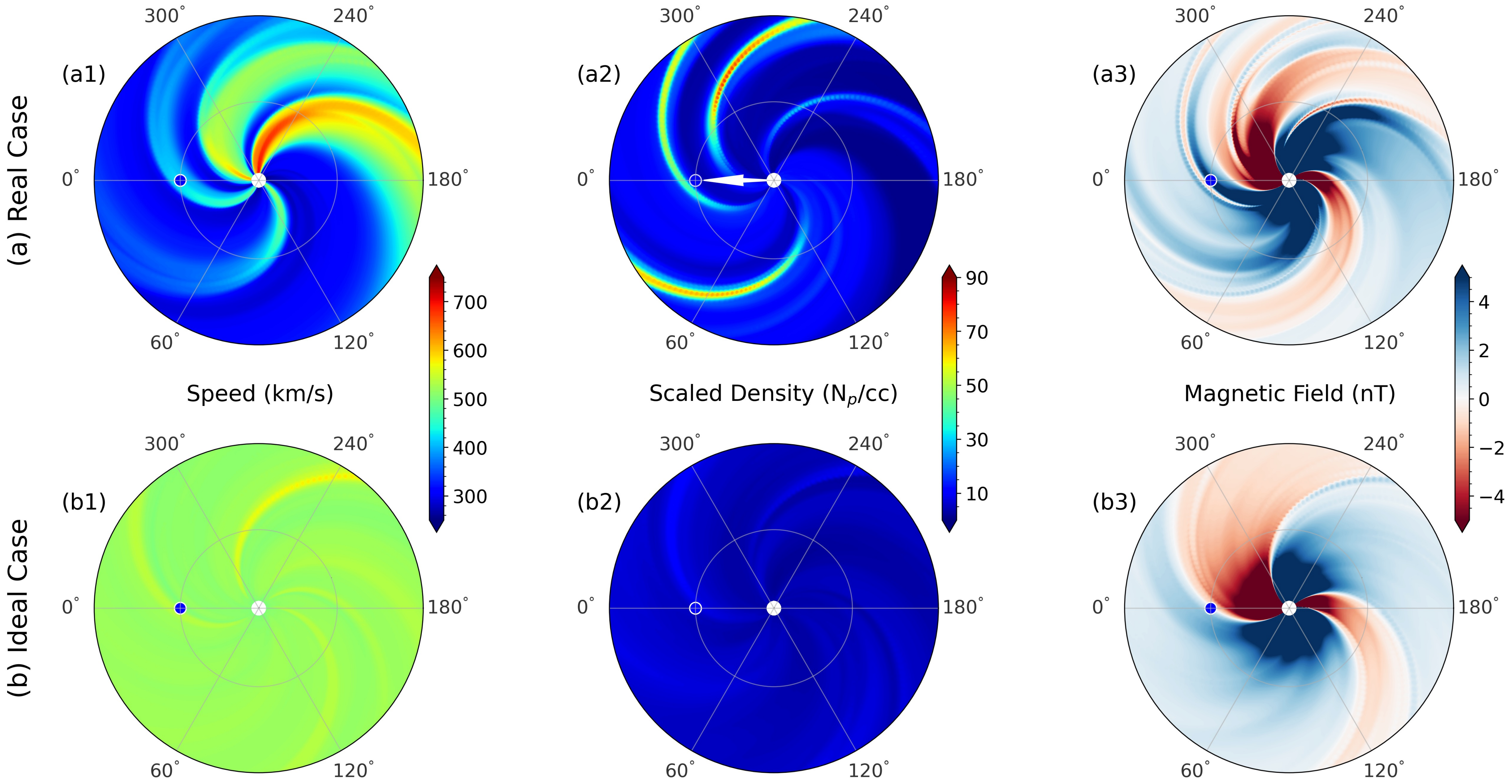
CME - SW Interaction: Setup

Real Case

- ***Ambient SW***: observation based SWASTi simulation result
- *SIR/CIR and HSS*: present

Ideal Case

- ***Ambient SW***: constant speed at inner-boundary
- *SIR/CIR and HSS*: absent



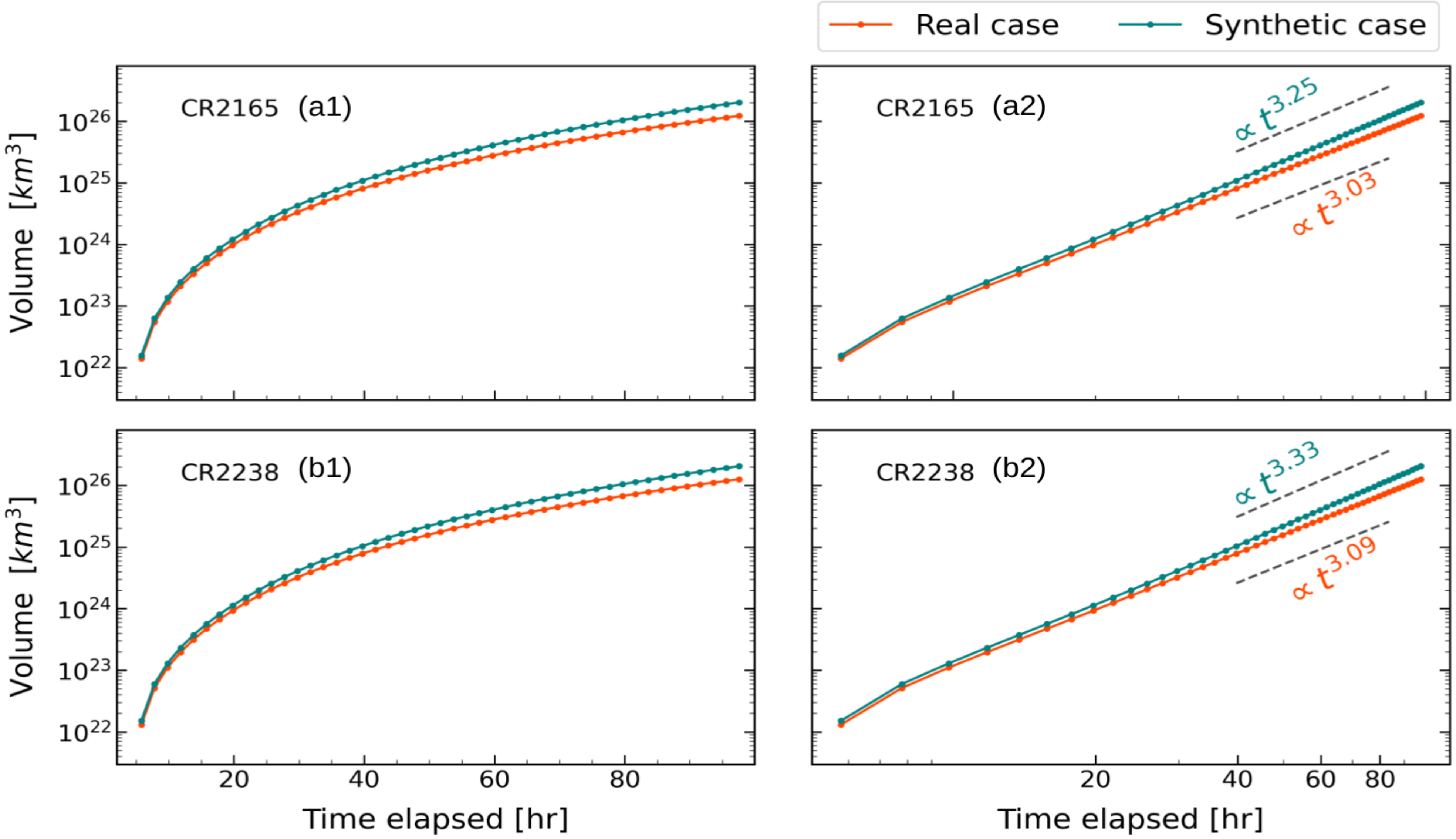
Effects of HSS and SIR/CIR ⋙ ***Difference between Ideal & Real cases***

Volume Evolution

CME Volume ∝ time $^{\alpha}$

<u>Log & log-log plot</u> [vol.(***t***)]

- Greater expansion in synthetic case
- All CMEs follow **power law**



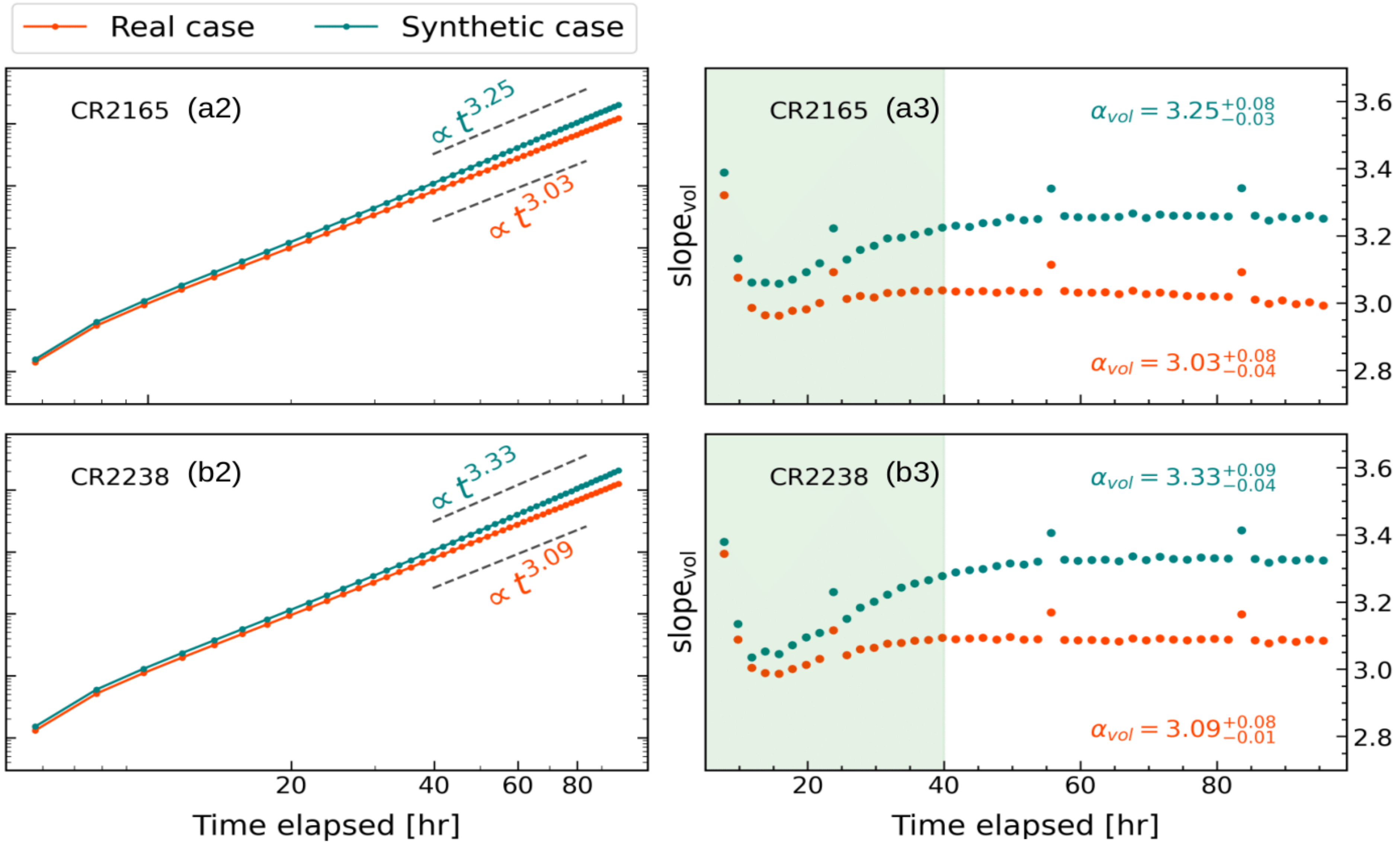
Volume Evolution

$$\log(vol._t) = \alpha . \log(t) + \log(vol.0)$$

$$slope_{vol} = \alpha_{vol} = \frac{\log(vol._{n+1}) - \log(vol._n)}{\log(t_{n+1}) - \log(t_n)}$$

<u>Slope plot</u> [α(***t***)]

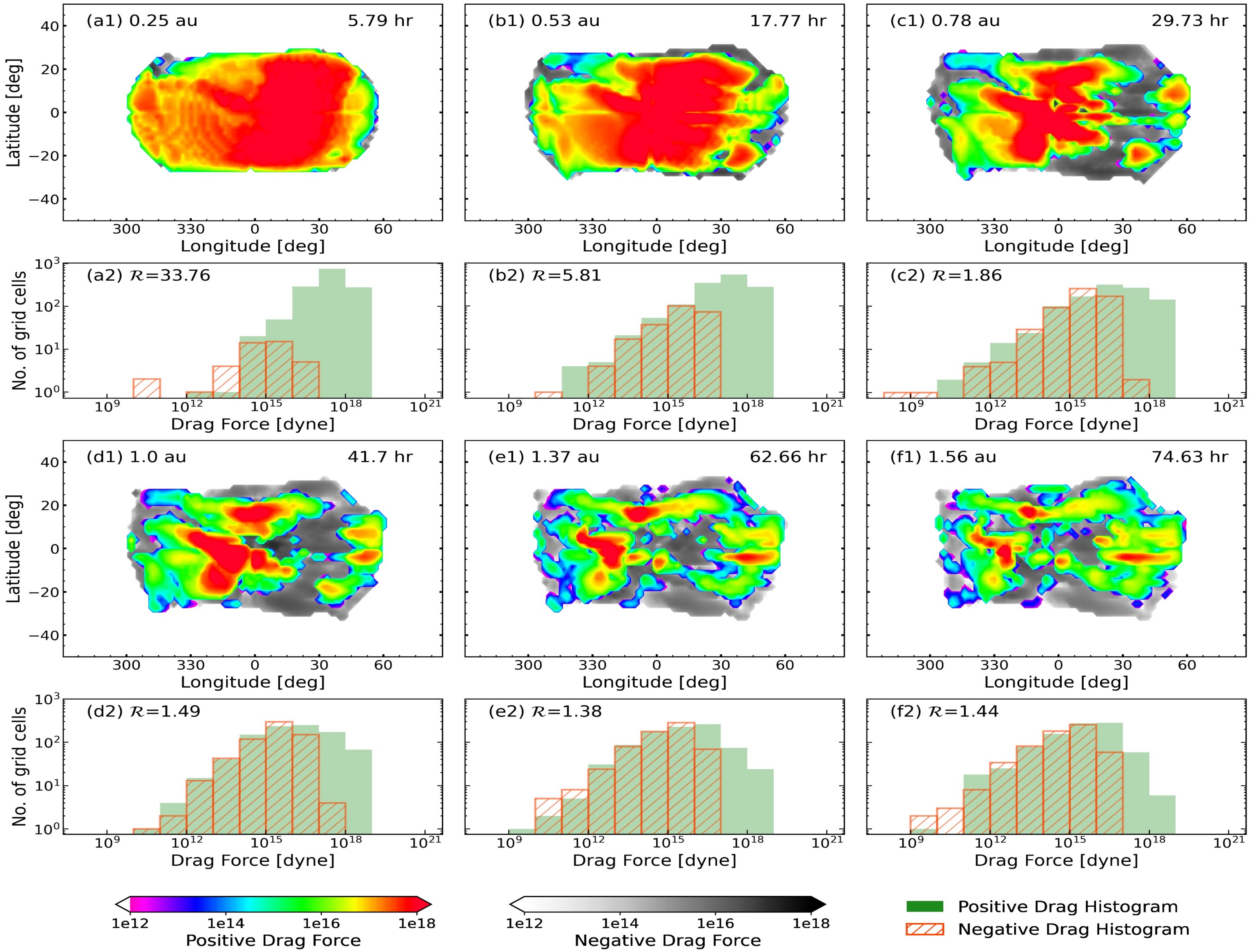
- < 40 hr: greater diff. in rate of expansion
- >40 hr: follows strict power law



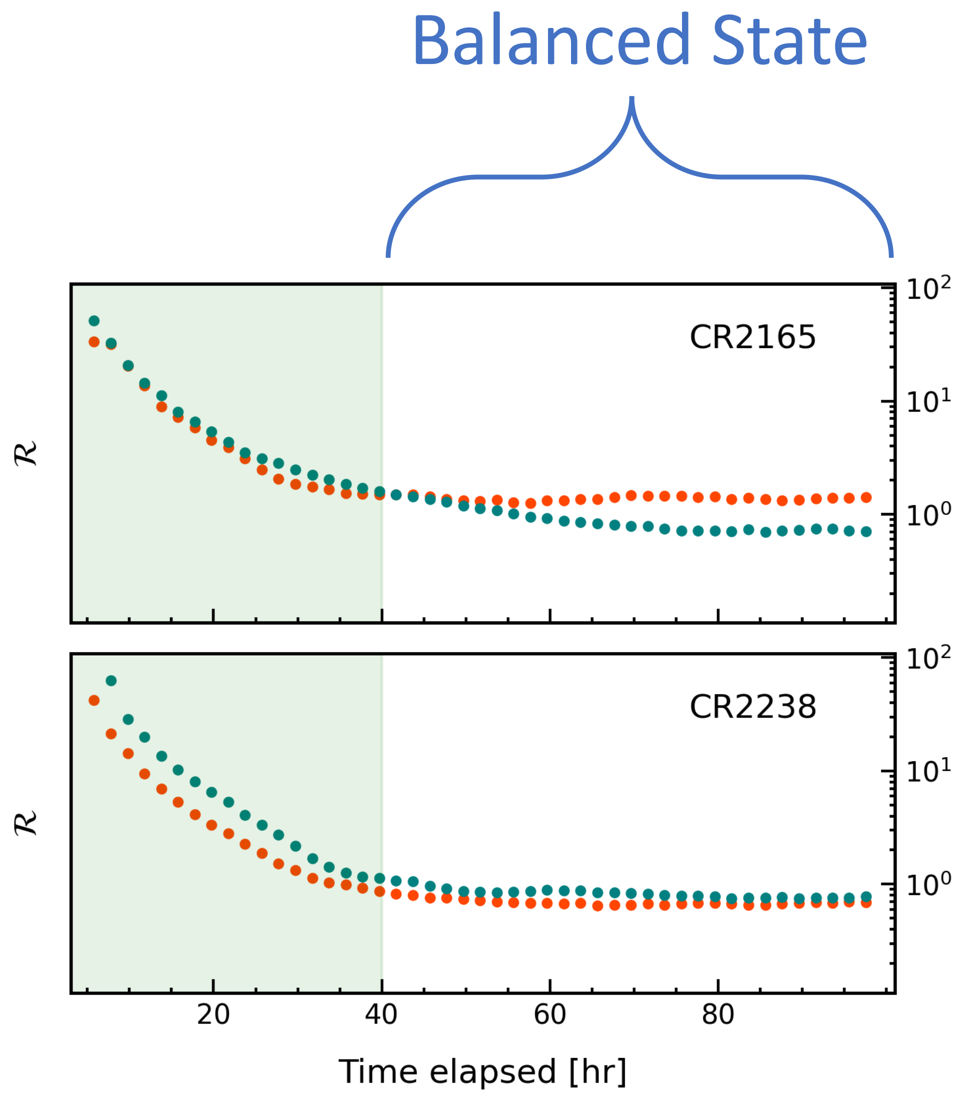
Drag Force

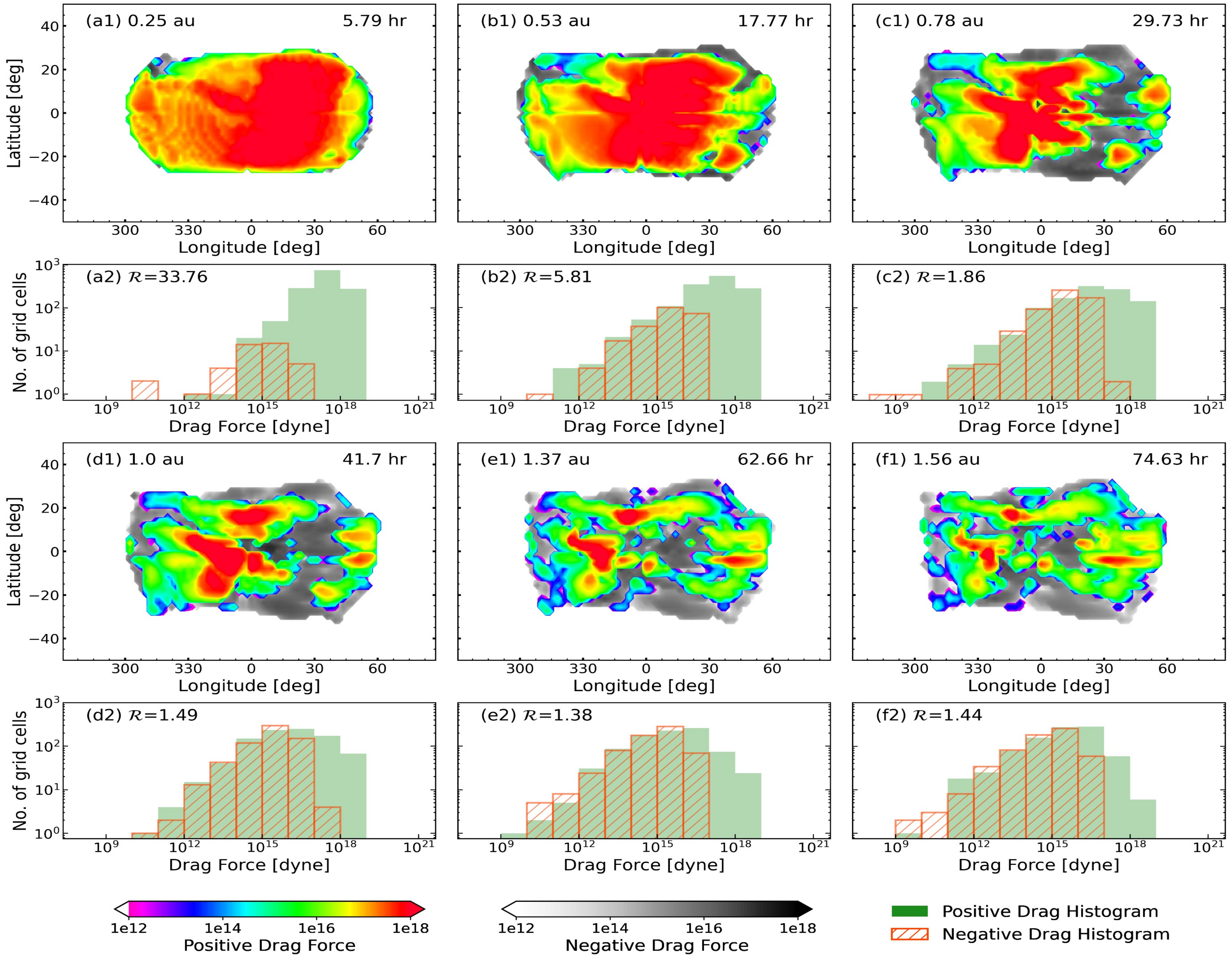
⇝ ***Non-uniform distribution***

⇝ ***Skewed normal distribution***

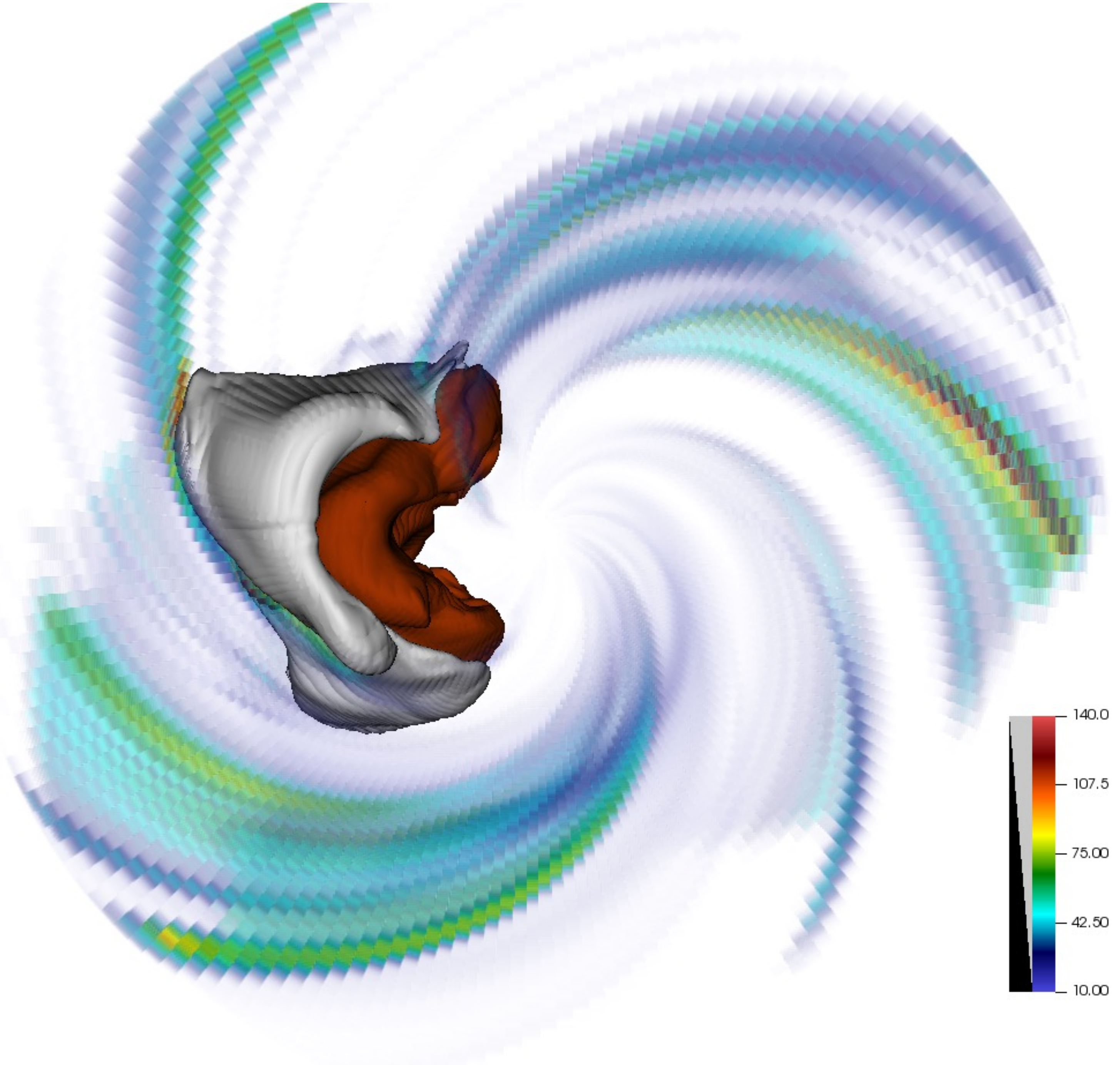


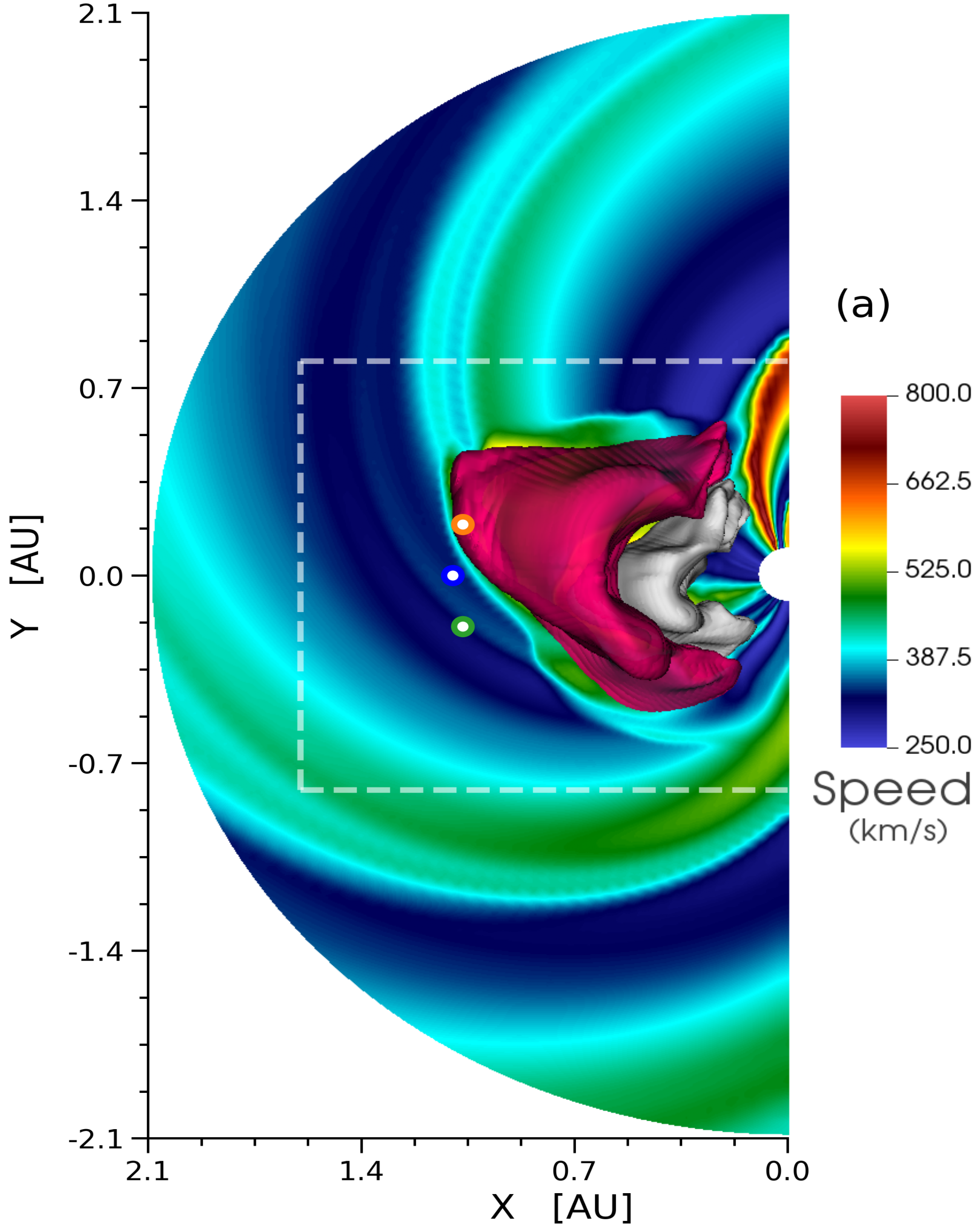
Drag Force


Balanced State
CR2165
CR2238
$\mathcal{R}$
10^2
10^1
10^0
20
40
60
80
Time elapsed [hr]

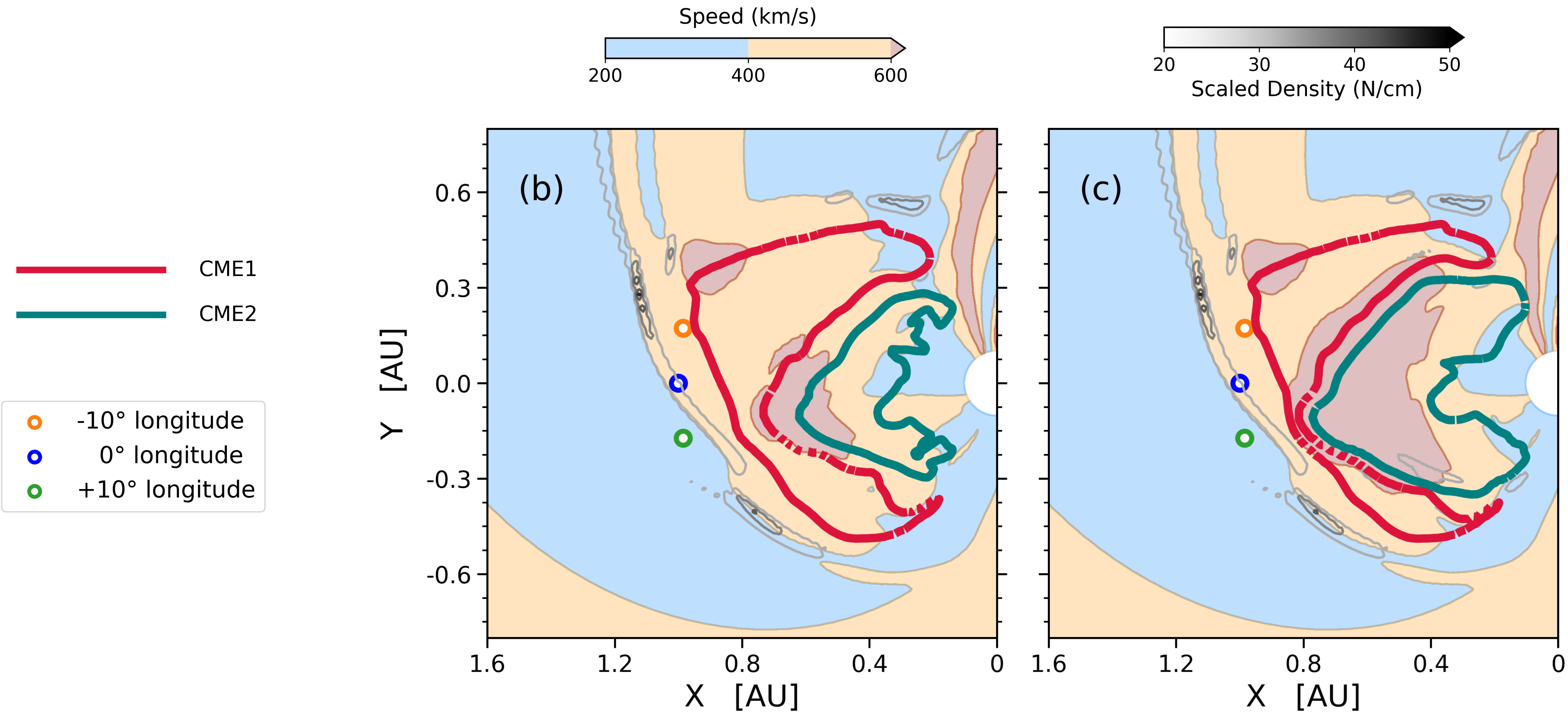

(a1) 0.25 au 5.79 hr
(b1) 0.53 au 17.77 hr
(c1) 0.78 au 29.73 hr
Latitude [deg]
Longitude [deg]
(a2) $\mathcal{R}$=33.76
(b2) $\mathcal{R}$=5.81
(c2) $\mathcal{R}$=1.86
No. of grid cells
Drag Force [dyne]
(d1) 1.0 au 41.7 hr
(e1) 1.37 au 62.66 hr
(f1) 1.56 au 74.63 hr
(d2) $\mathcal{R}$=1.49
(e2) $\mathcal{R}$=1.38
(f2) $\mathcal{R}$=1.44
1e12
1e14
1e16
1e18
Positive Drag Force
Negative Drag Force
Positive Drag Histogram
Negative Drag Histogram

CME - CME Interaction

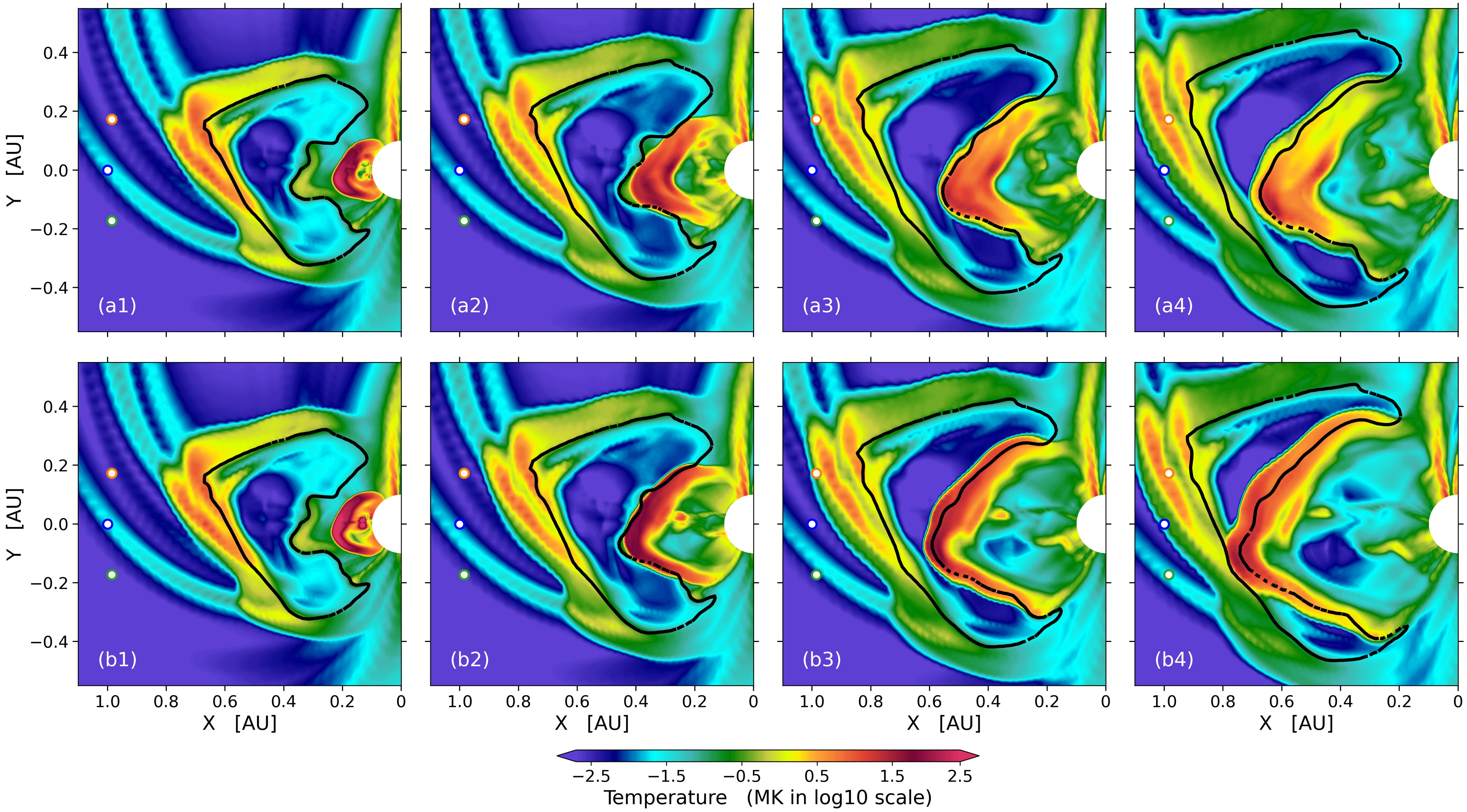




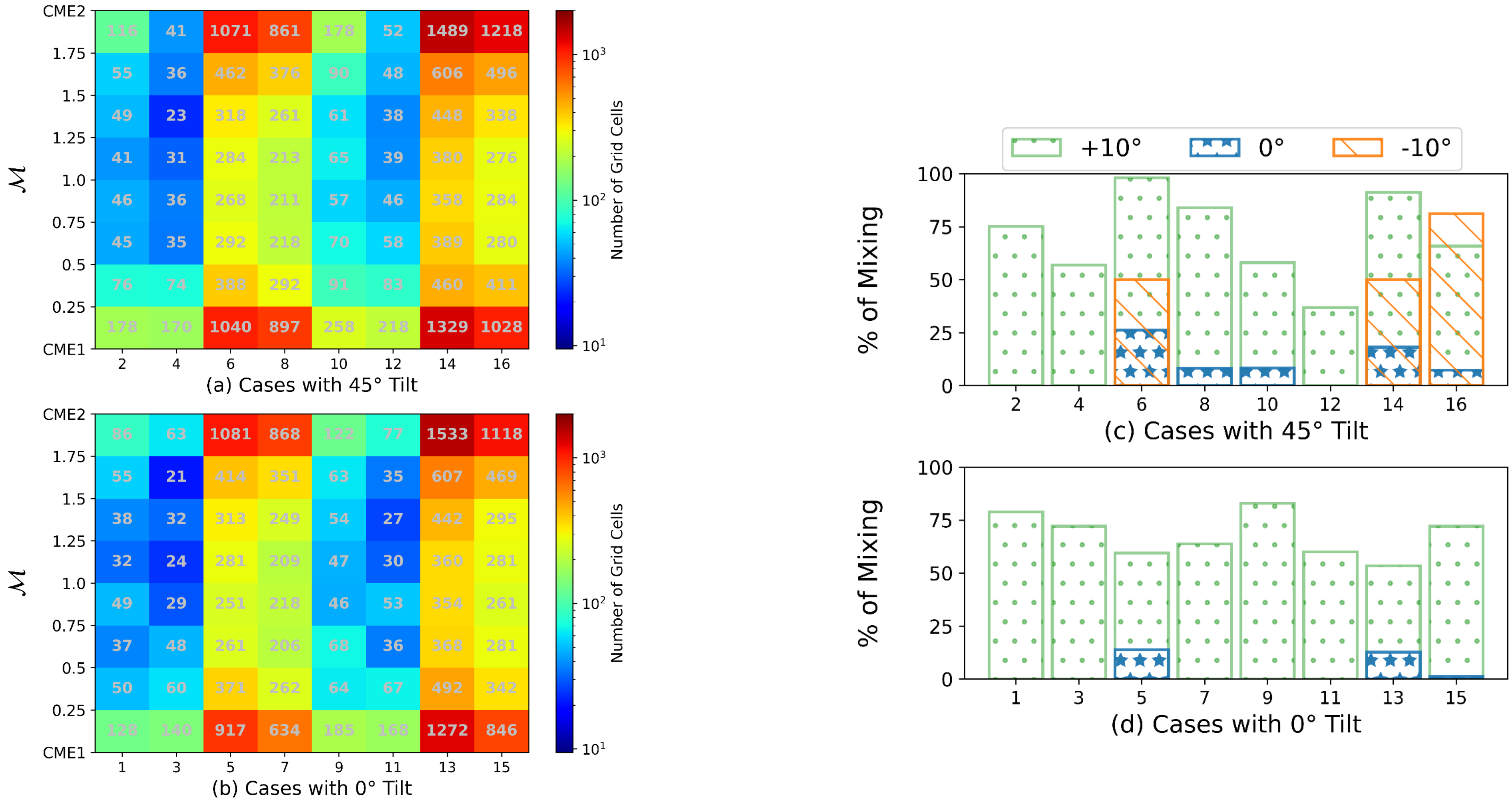
CME – CME Interaction



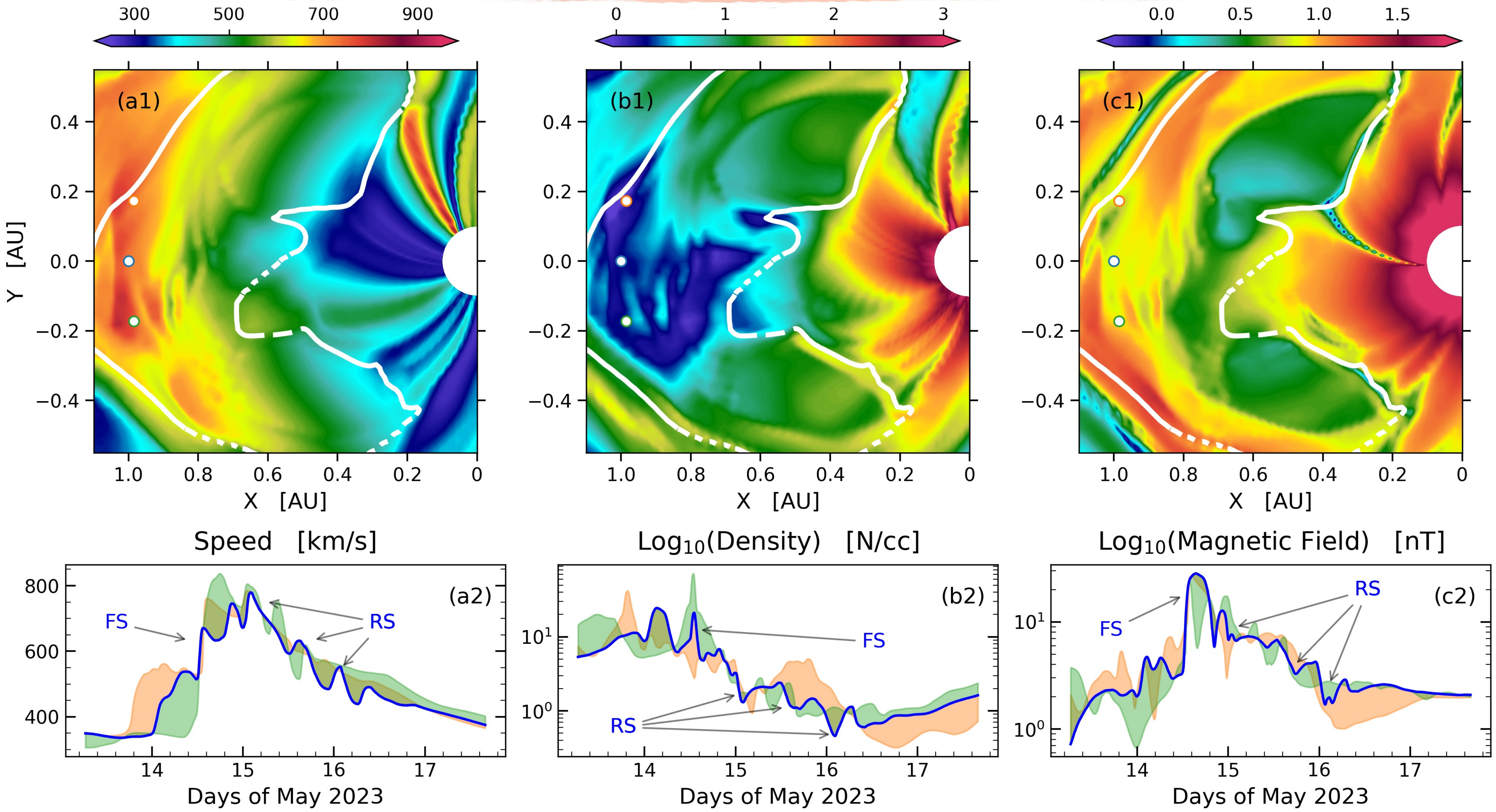
Stages of CME – CME Interaction



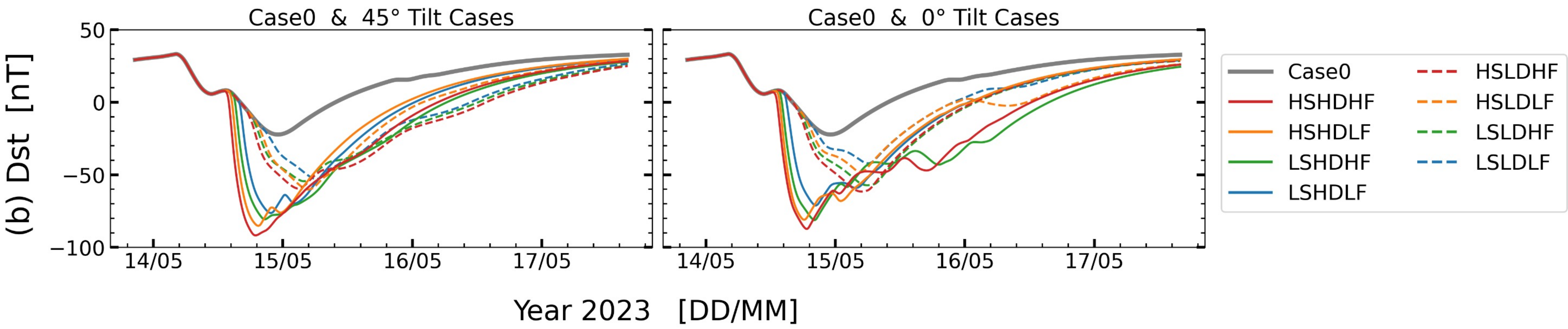
Non-uniform Mixing



Reverse Shock



All Cases

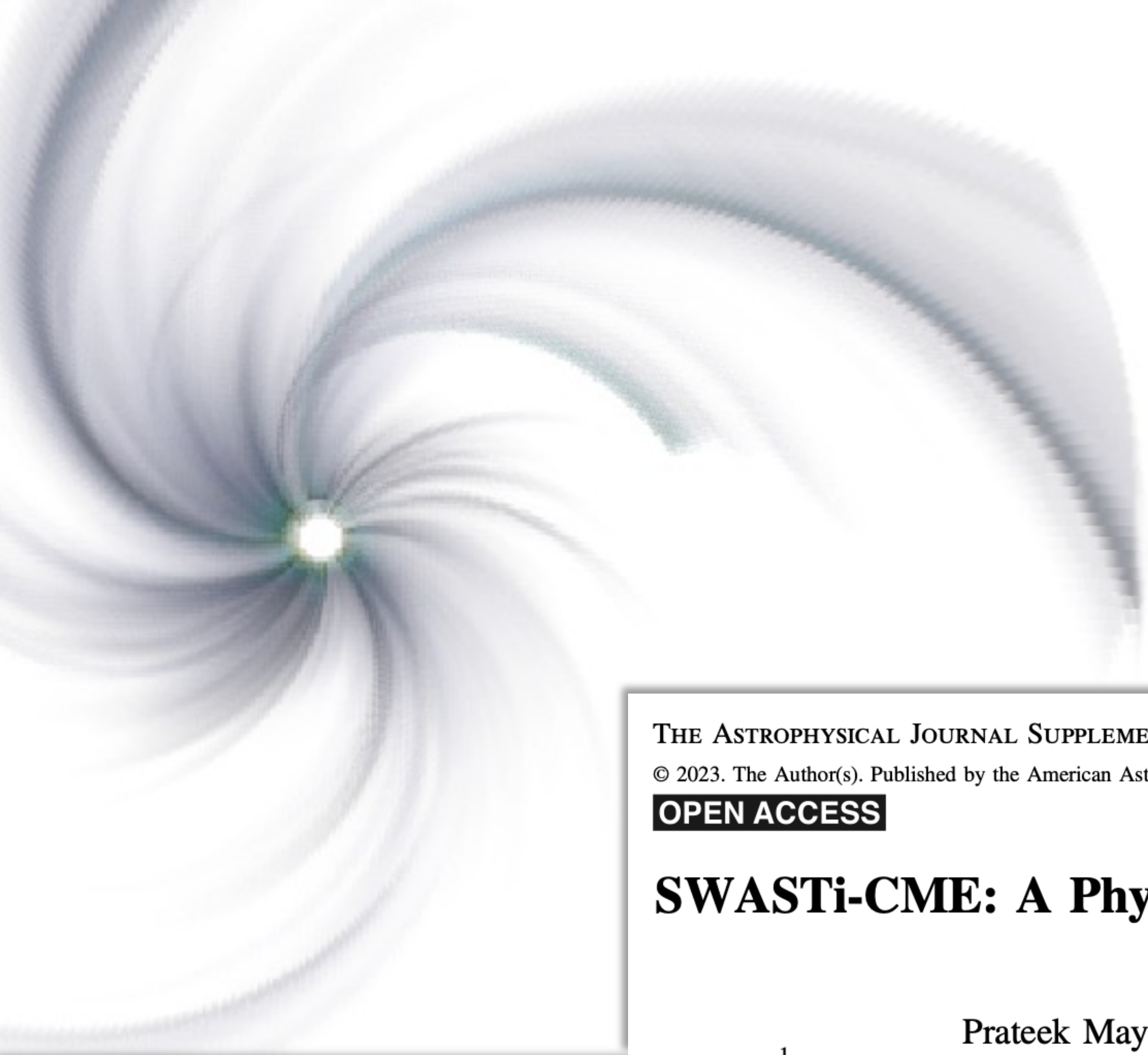


Impact of Increase in initial values	**Density – enhance 66%** **Tilt – enhance 81%** **Flux – diminish 19%**

Increase in CME2's any initial property mostly leads to **stronger (72% of cases)** and **prolonged (63% of cases)** storms.

SUMMARY

Impact of SW	inhomogeneity affects the structure, kinematics, and thermodynamic properties of CMEs
CME Volume	not self-similar but follows power law after attaining balanced state, showing two phases of evolution
Mixing	interactions can lead to the mixing of plasma between CMEs, and is non-uniform across longitudes
Geo-effectiveness	formation of reverse shock prolongs the recovery phase, initial density and tilt are most sensitive to Dst



THANK YOU!

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SWASTi-CME: A Physics-based Model to Study Coronal Mass Ejection Evolution and Its Interaction with Solar Wind

Prateek Mayank[1], Bhargav Vaidya[1,2], Wageesh Mishra[3], and D. Chakrabarty[4]

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Study of Evolution and Geo-effectiveness of Coronal Mass Ejection–Coronal Mass Ejection Interactions Using Magnetohydrodynamic Simulations with SWASTi Framework

Prateek Mayank[1], Stefan Lotz[2], Bhargav Vaidya[1,3], Wageesh Mishra[4], and D. Chakrabarty[5]