The first super geomagnetic storm of solar cycle 24: "The St. Patrick day (17 March 2015)" event

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ABSTRACT

The first super geomagnetic storm of solar cycle 24 occurred on the "St. Patrick's day" (17 March 2015). Notably, it was a two-step storm. The source of the storm can be traced back to the solar event on March 15, 2015. At ~2:10 UT on that day, *SOHO/LASCO* C3 recorded a partial halo corona mass ejection (CME) which was associated with a C9.1/1F flare (S22W25) and a series of type II/IV radio bursts. The propagation speed of this CME is estimated to be ~668 km/s during 02:10 – 06:20 UT (See Figure 1). An interplanetary (IP) shock, likely driven by the CME, arrived at the *Wind* spacecraft at 03:59 UT on 17 March (See Figure 2). The arrival of the IP shock at the Earth may have caused a sudden storm commencement (SSC) at 04:45 UT on March 17. The storm intensified (Dst dropped to -80 nT at ~10:00 UT) during the crossing of CME sheath. Later, the storm recovered slightly (Dst ~ -50 nT) because the IMF turned northward. At 11:01 UT, IMF started turning southward again due to the large magnetic cloud (MC) field itself and caused the second storm intensification, reaching Dst = - 228 nT on March 18. We conclude that the St. Patrick day event is a two-step storm. The first step is associated with the sheath, whereas the second step is associated with the MC. Here, we employ a numerical simulation using the global, three-dimensional (3D), time-dependent, magnetohydrodynamic (MHD) model (H3DMHD, Wu et al. 2007) to study the CME propagation from the Sun to the Earth. The H3DMHD model has been modified so that it can be driven by (solar wind) data at the inner boundary of the computational domain. In this study, we use time varying, 3D solar wind velocity and density reconstructed from STELab, Japan interplanetary scintillation (IPS) data by the University of California, San Diego, and magnetic field at the IPS inner boundary provided by CSSS model closed-loop propagation (Jackson et a., 2015). The simulation result matches well with the in situ solar wind plasma and field data at *Wind*, in terms of the peak values of IP shock and its arrival time (See Figure 3). The simulation also helps us to identify the driver of the IP shock but also demonstrates that the modified H3DMHD model is capable of realistic simulations of large solar event. In this presentation, we will discuss the CME/storm event with detailed data from observations (*Wind* and *SOHO*) and our numerical simulation.

Corona images recorded by SOHO/LASCO C2 during 0000-0312UT on 15 March 2015.

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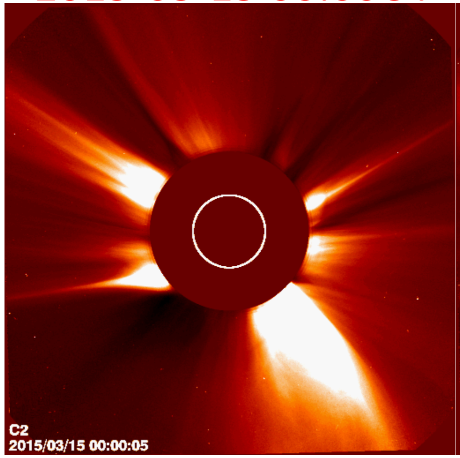

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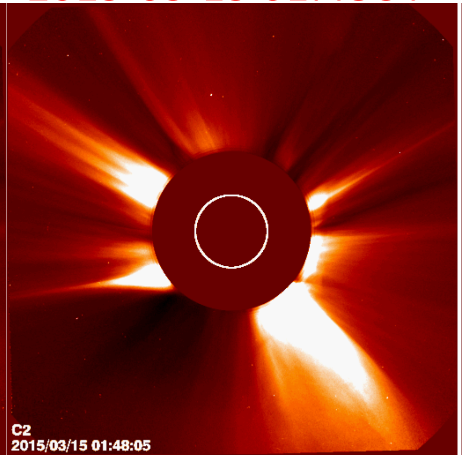

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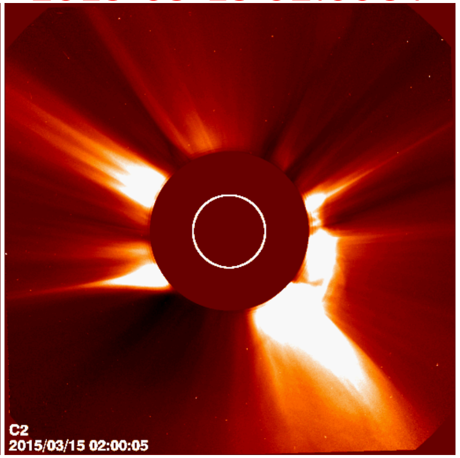

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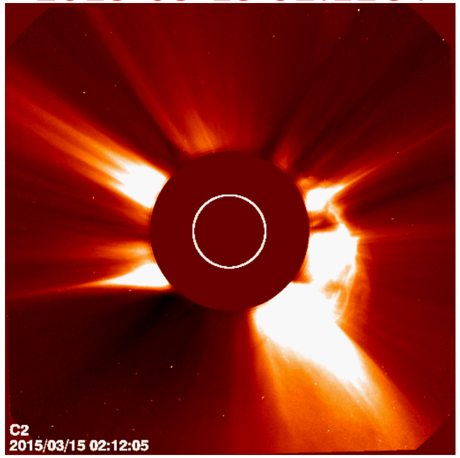

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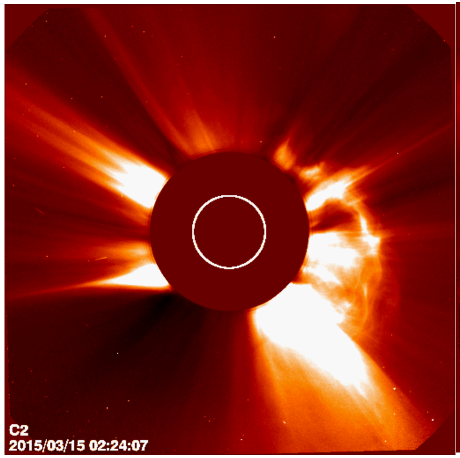

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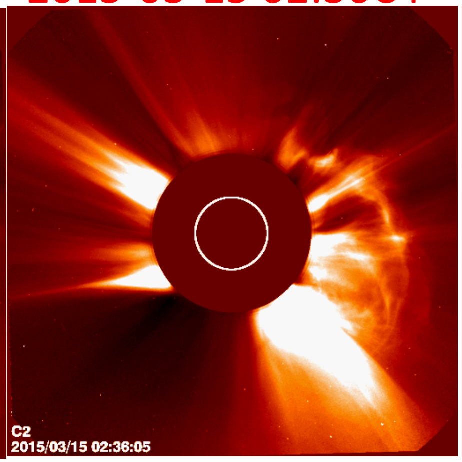

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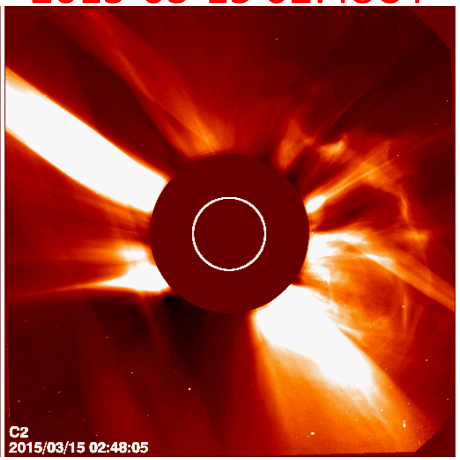

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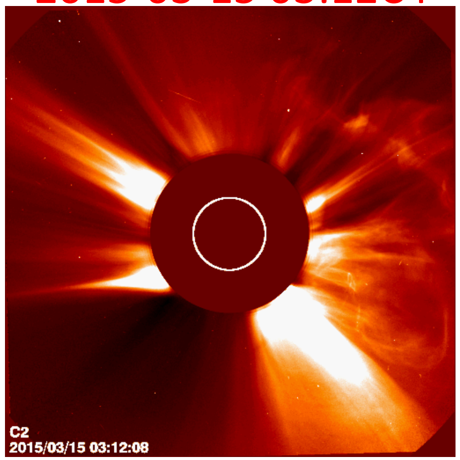
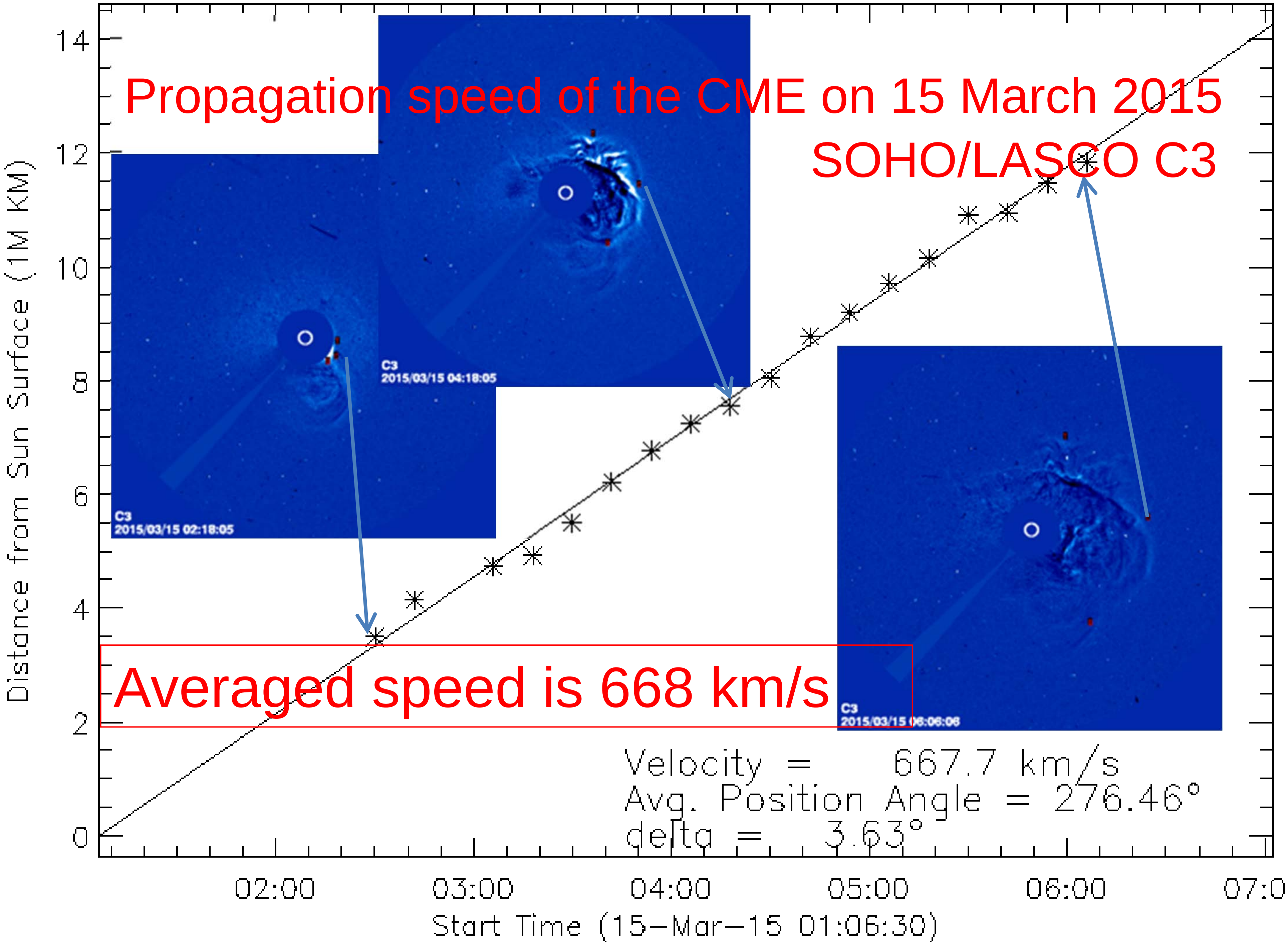
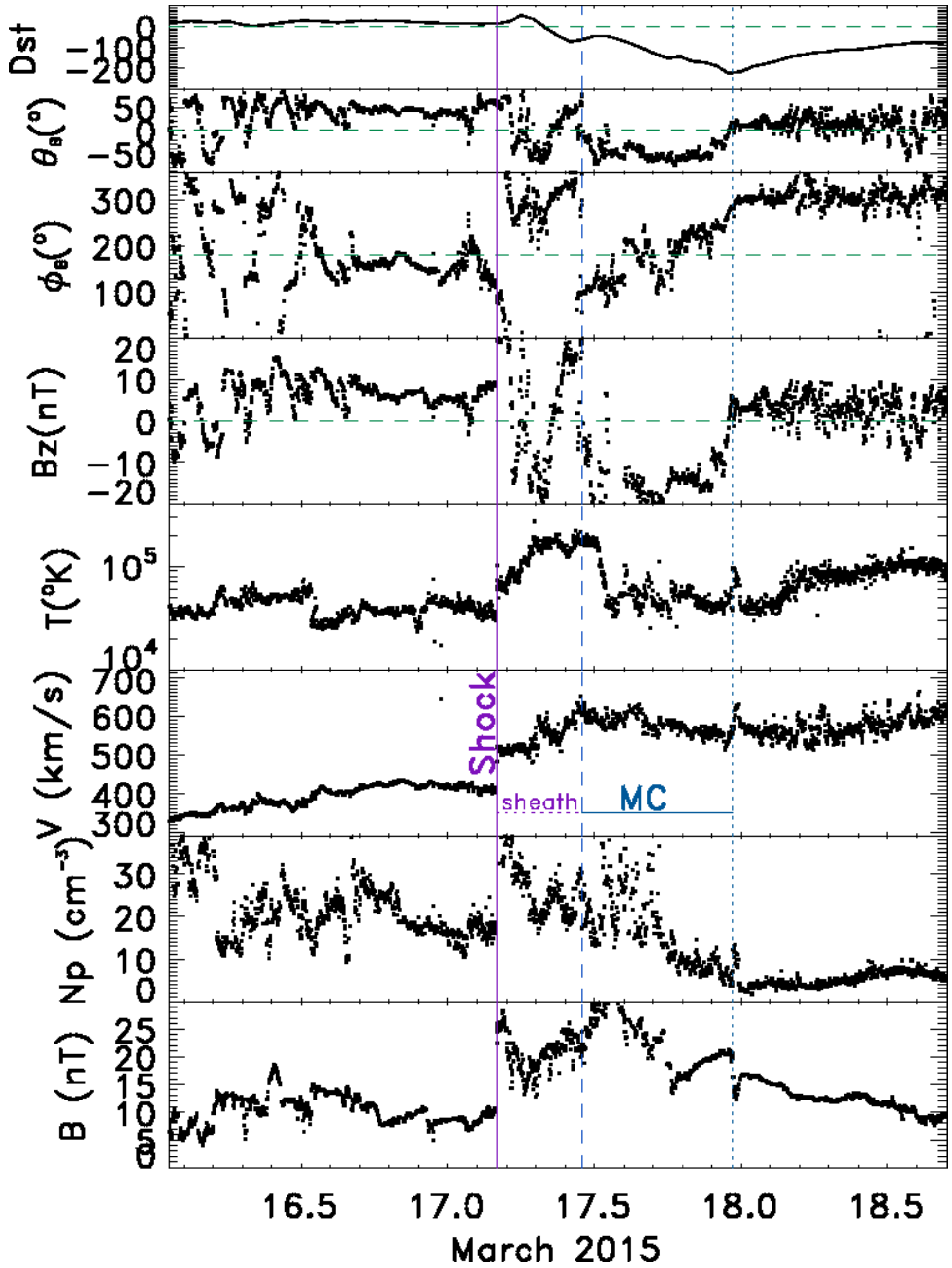


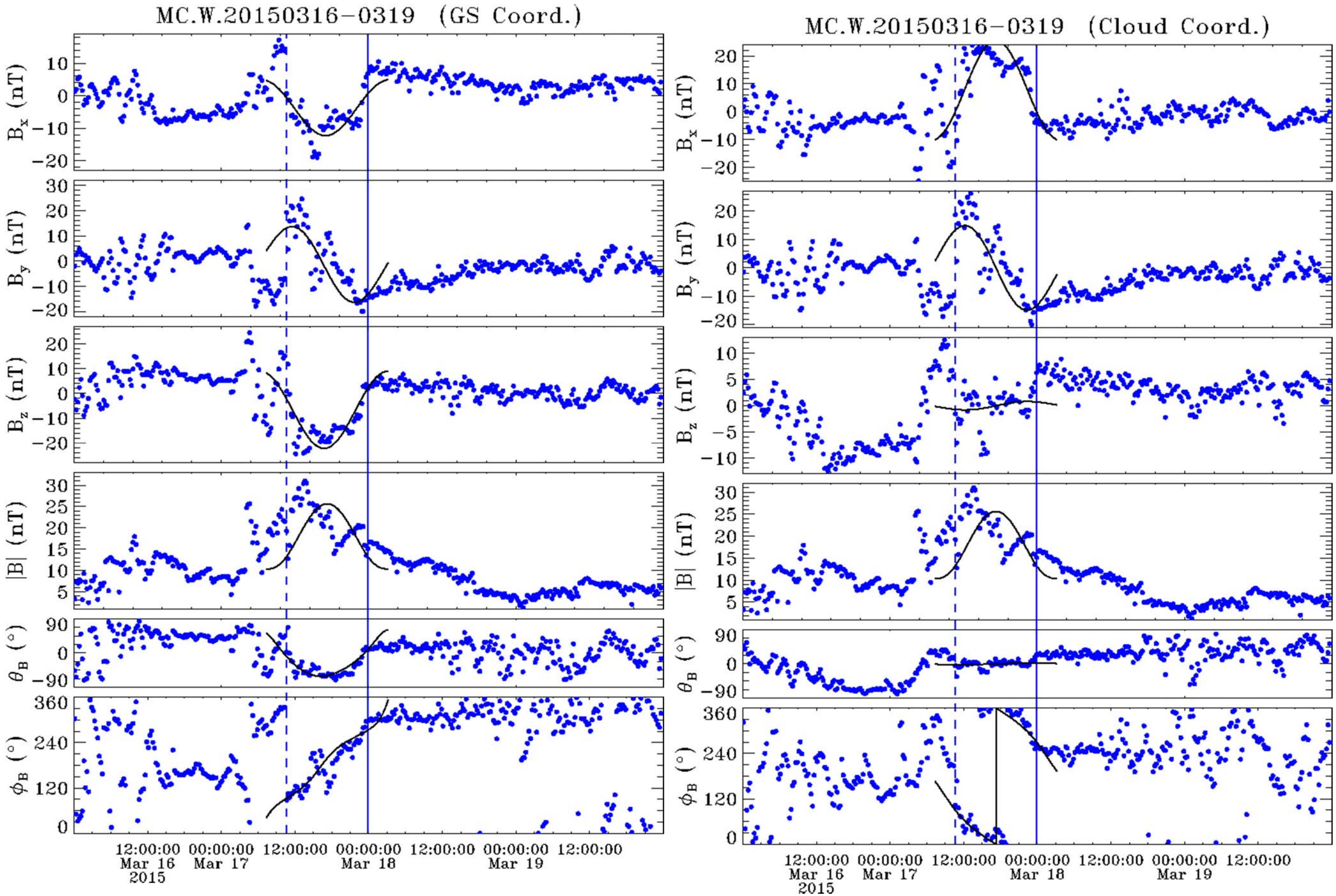

Propagation speed of the CME on 15 March 2015
SOHO/LASCO C3
Averaged speed is 668 km/s
C3
2015/03/15 02:18:05
C3
2015/03/15 04:18:05
C3
2015/03/15 06:06:06
Velocity = 667.7 km/s
Avg. Position Angle = 276.46°
delta = 3.63°
Distance from Sun Surface (1M KM)
0
2
4
6
8
10
12
14
02:00
03:00
04:00
05:00
06:00
07:0
Start Time (15-Mar-15 01:06:30)

In situ solar wind profile during 16-18 March 2015



Geomagnetic activity index (Dst: top panel) and *Wind* observed in situ solar wind parameters (1st - 7th panels) during March 16-18, 2015. From Top to Bottom: Dst, latitude (θ_B) and longitude (φ_B) in GSE cords., Bz of the field in GSE, proton temperature (T), bulk speed (V), and number density (Np), magnetic field (B) in terms of magnitude. The blue horizontal line in the 3rd panel represents the scheme's identification of the extent of this MC candidate [Lepping et al., 1990]. The purple-solid line and blue-dashed lines represent the IP shock and the front boundary of the MC.

Cloud fitting for the MC on 17 March 2015



Global 3-D MHD Simulation

Simulation Domain

Coordinates - Sun-centered spherical coordinate system (r, θ, φ)

$-87.5^\circ \leq \theta \leq 87.5^\circ$

$0^\circ \leq \phi \leq 360^\circ$

$40\ Rs \leq r \leq 345\ Rs$ (MHD)

Earth at (r, θ, ϕ) = (215 Rs, 0°, 0°) in the ecliptic plane

Uniform grids and open boundary condition

Uniform grid step size $\Delta r = 3\ Rs$, $\Delta\theta = 5^\circ$ and $\Delta\phi = 5^\circ$

$\theta = \pm 87.5^\circ$ (no reflective disturbances)

Simulation procedure

Using IPS data at 40 Rs to drive 3DMHD model

Governing Equations

$$\frac{D\rho}{Dt} + \rho \nabla \bullet \mathbf{V} = 0$$

Conservation of mass

$$\rho \frac{D\mathbf{V}}{Dt} = -\nabla p + \frac{1}{\mu_o} (\nabla \times \mathbf{B}) \times \mathbf{B} - \rho \frac{GM(r)}{r^2} \hat{\mathbf{r}}$$

Conservation of momentum

$$\frac{\partial}{\partial t}[\rho e + \frac{1}{2}\rho |\mathbf{V}|^2 + \frac{|\mathbf{B}|^2}{2\mu_o}] + \nabla \bullet [\mathbf{V}\{\rho e + \frac{1}{2}\rho |\mathbf{V}|^2 + p\} + \frac{\mathbf{B} \times (\mathbf{V} \times \mathbf{B})}{\mu_o}] = -\mathbf{v} \bullet \rho \frac{GM(r)}{r^2} \hat{\mathbf{r}}$$

Conservation of energy*

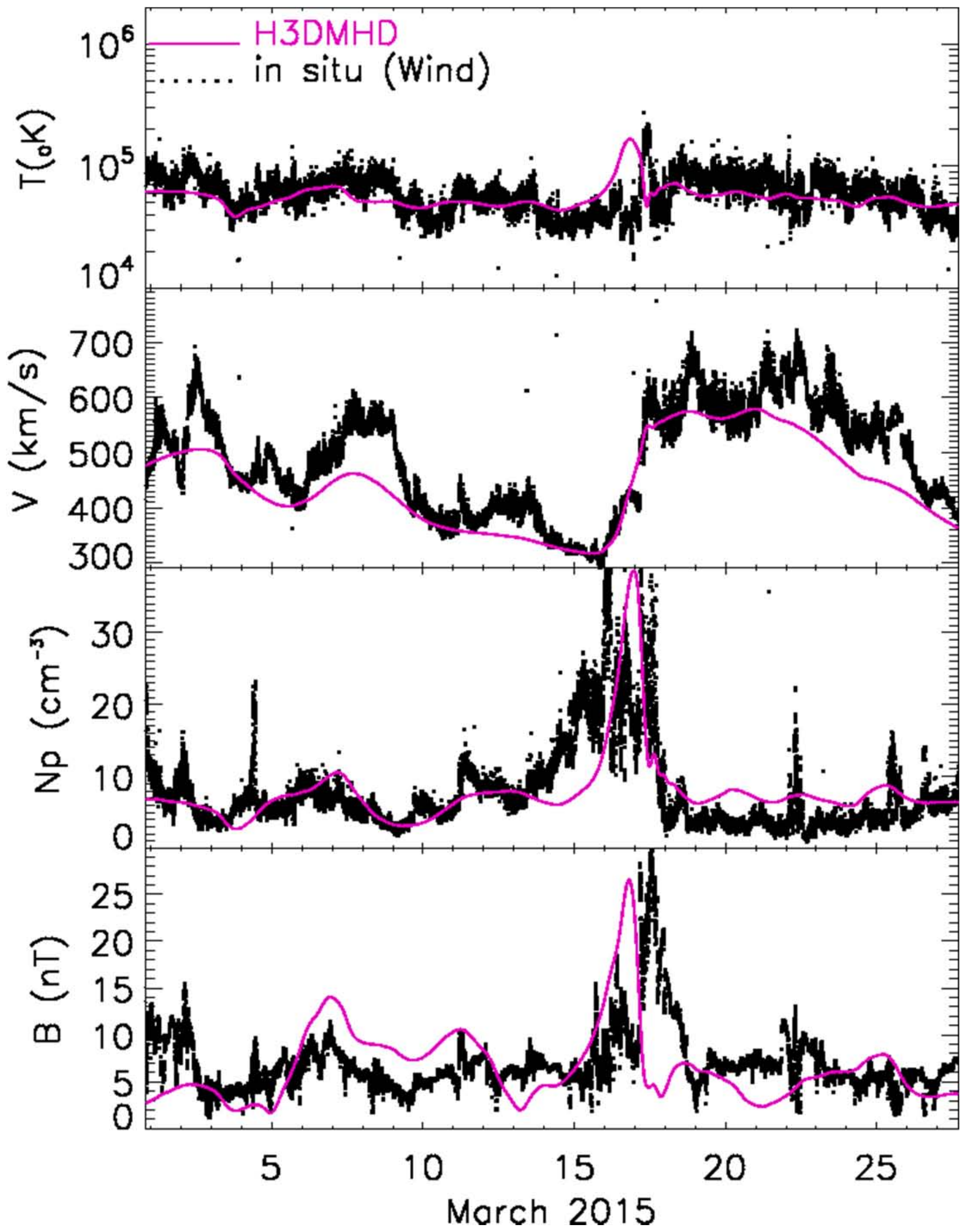
$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{V} \times \mathbf{B})$$

Induction equation

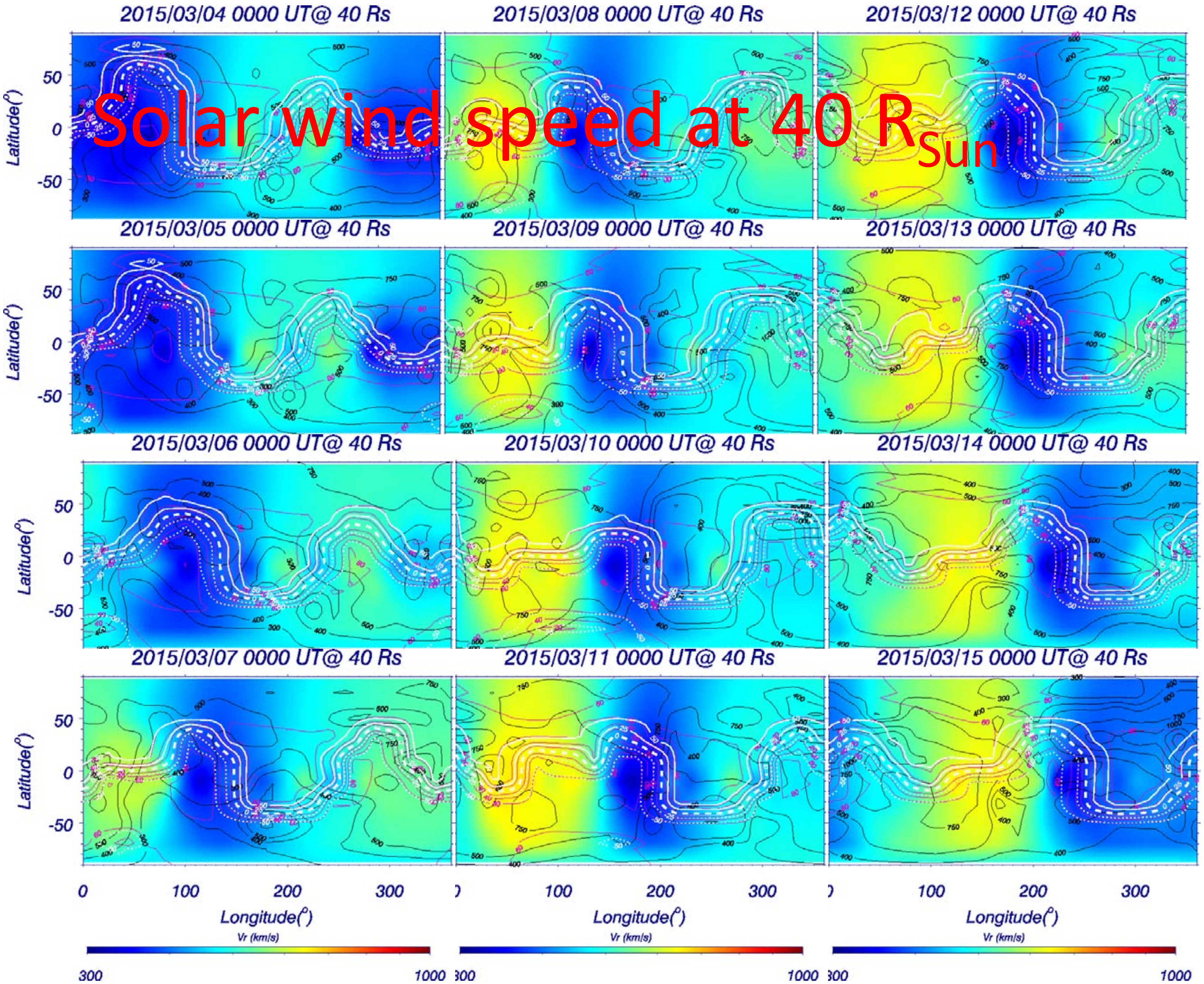
In the equations, *D/Dt* denotes the total derivative, ρ is the mass density, *V* is the velocity of the flow, p is the gas pressure, B is the magnetic field, e is the internal energy per unit mass ($e = p/(\gamma-1)\rho$), *GM(r)* is solar gravitational force, and γ is the specific heat ratio. For this research, we applied an adiabatic gas assumption (i.e.,γ =5/3).

In conservation of energy: we ignored the Coriolis force, Joule heating, thermal conduction, and viscous items.

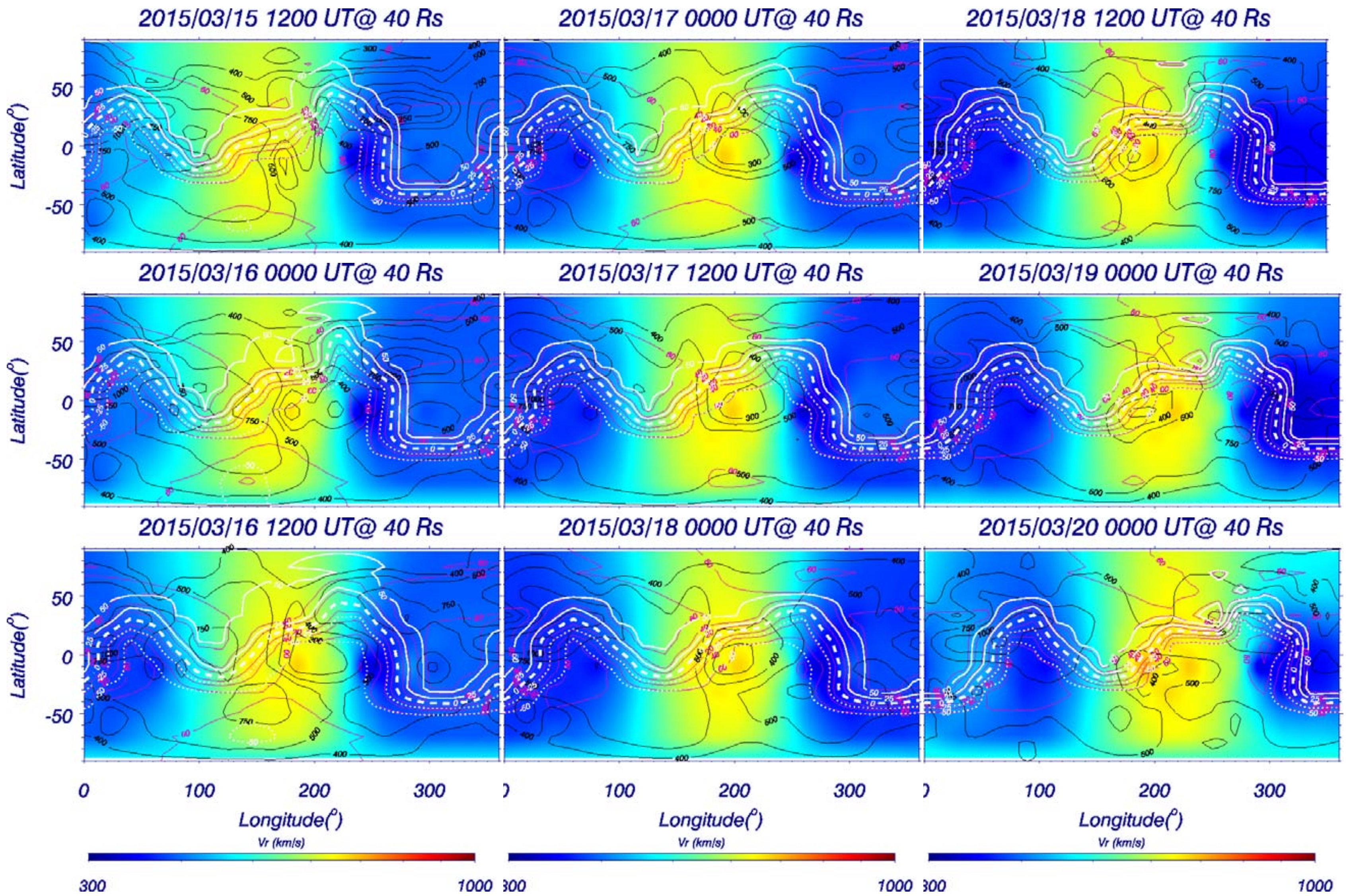
Comparison of IPS-3DMHD and observation



Observation (black-dotted curves observed by *Wind*) and simulation (pink-solid curved simulated by IPS-H3DMHD) of solar wind parameters during 01-27 March, 2015. From Top to Bottom: solar wind temperature (T), bulk speed (V), and number density (Np), magnetic field (B) in terms of magnitude.

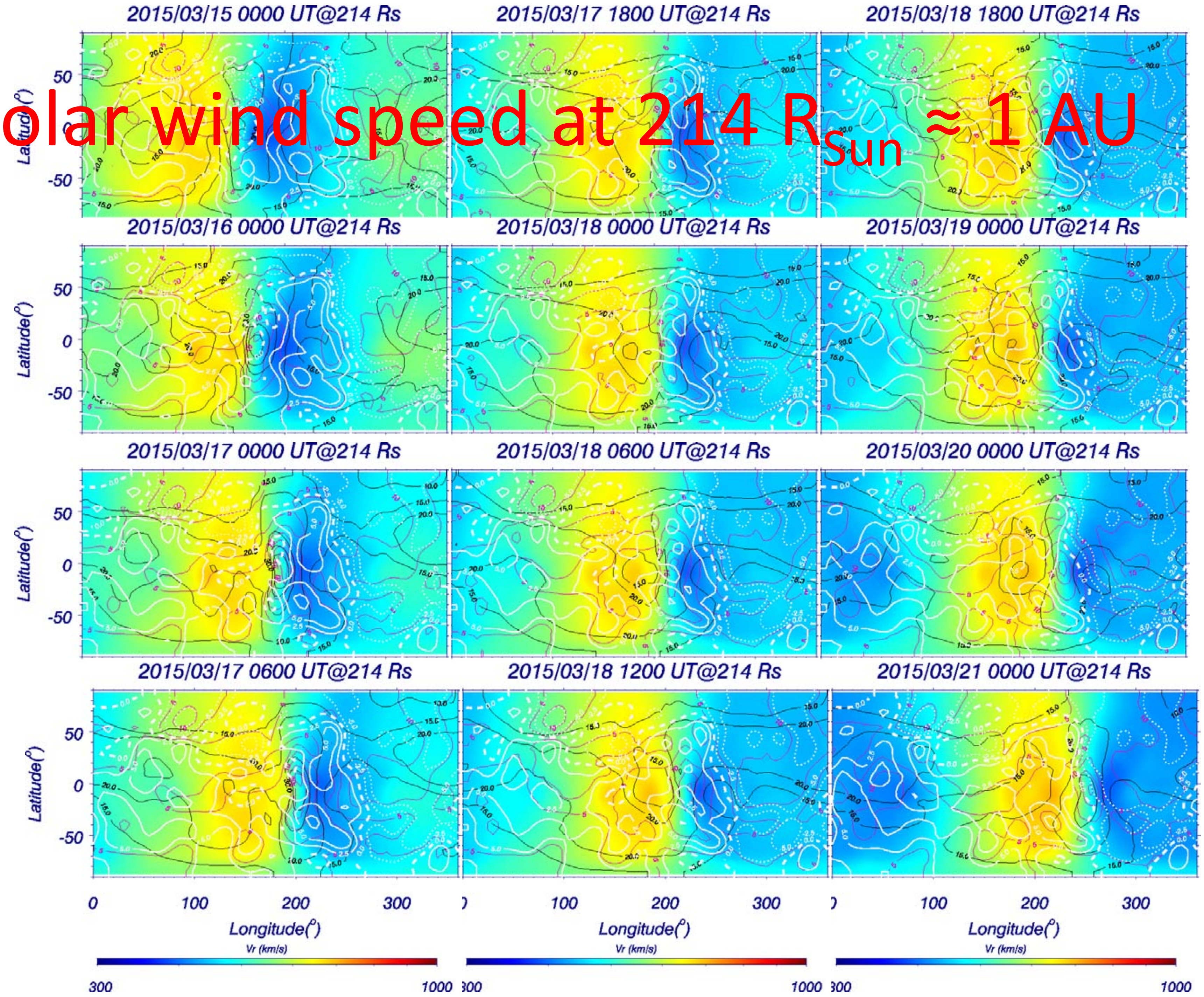


Solar wind speed at 40 R_{Sun}
2015/03/04 0000 UT@ 40 Rs
2015/03/08 0000 UT@ 40 Rs
2015/03/12 0000 UT@ 40 Rs
2015/03/05 0000 UT@ 40 Rs
2015/03/09 0000 UT@ 40 Rs
2015/03/13 0000 UT@ 40 Rs
2015/03/06 0000 UT@ 40 Rs
2015/03/10 0000 UT@ 40 Rs
2015/03/14 0000 UT@ 40 Rs
2015/03/07 0000 UT@ 40 Rs
2015/03/11 0000 UT@ 40 Rs
2015/03/15 0000 UT@ 40 Rs
Latitude(°)
Longitude(°)
Vr (km/s)
300
1000

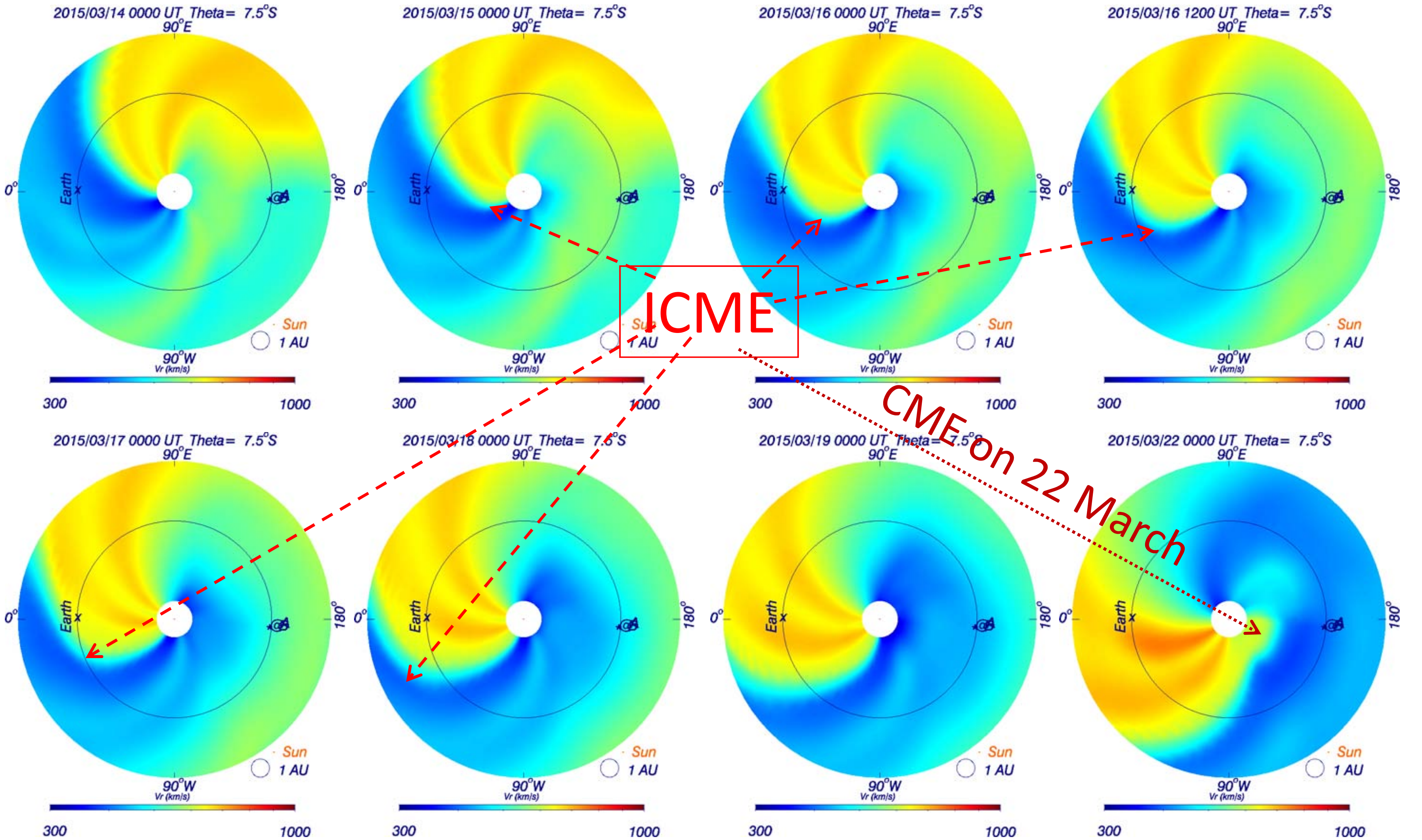


Solar wind speed at 40 R_{Sun}

Solar wind speed at 214 R_{Sun} ≈ 1 AU

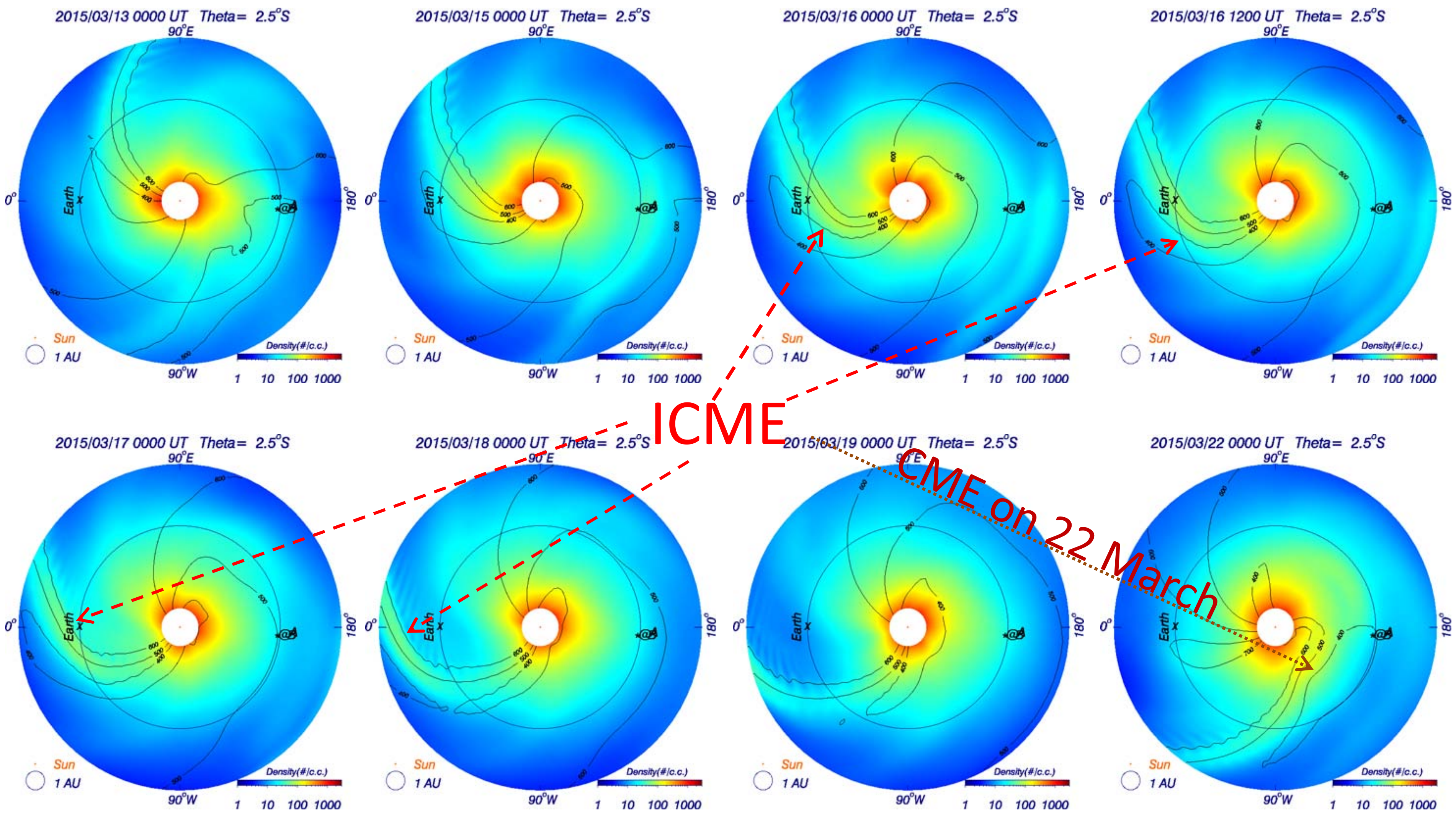


Evolution of CME$_{15March}$ in the r-Φ plane



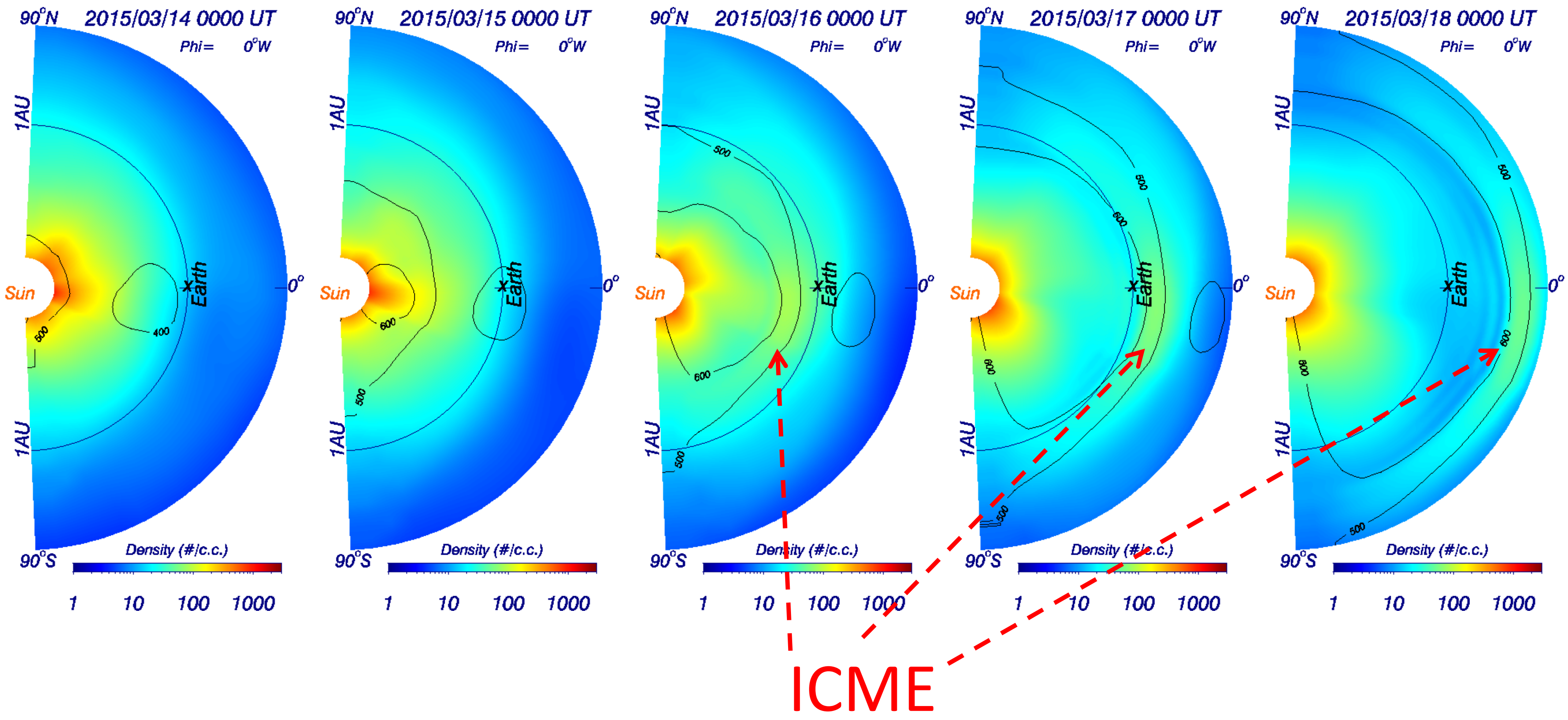
Colors: velocity

Evolution of $CME_{15March}$ in r-Φ plane



Colors: density; Contours: velocity

Evolution of CME$_{15March}$ in a r-θ plane



Colors: density; Contours: velocity

Speed of $CME_{15March}$

	Start time[a]	r [b]	Ending time[c]	Δr [d]	Δt [e]	$V_{shock/cme}$ [f]	V' [g]	Δt_{pred} [h]	Δt_{ERR} [i]
shock	2:30UT 03-15	6.95-18.82	3:57 UT 03-17	208.02	49.45	812.1	668?	60.94	23%
ICME	2:30UT 03-15	6.95-18.82	10:38 UT 03-17	208.02	56.13	715.4	668	60.94	8%
CME	2:00UT 03-15	4.15-6.61	10:38 UT 03-17	210.85	56.63	718.8	606	67.17	19%

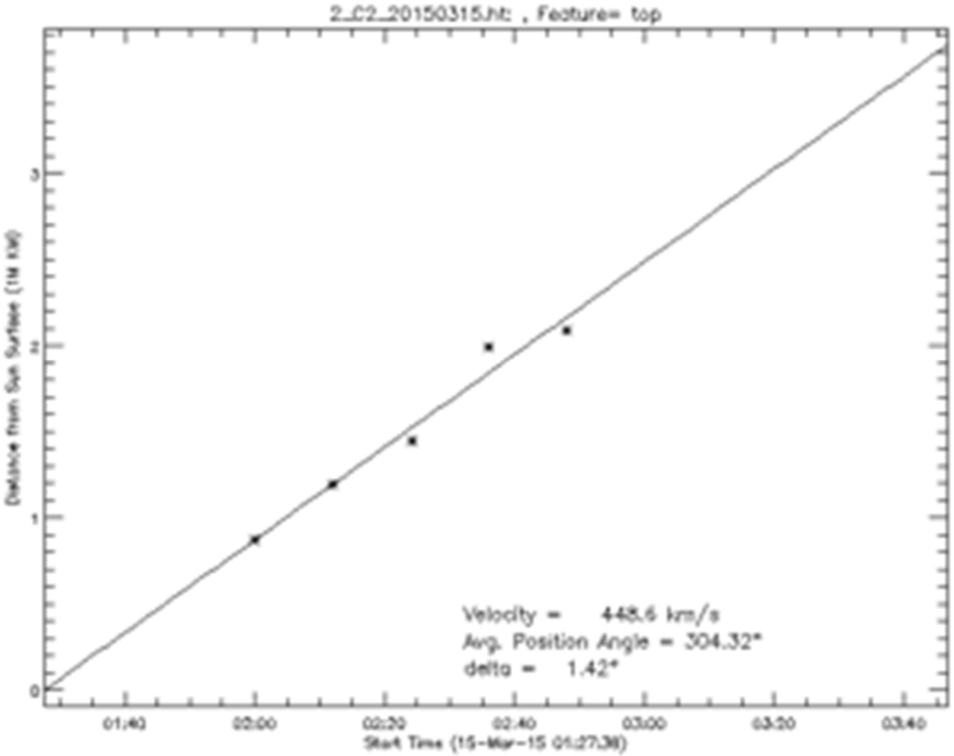
[a] CME/shock was observed by SOHO/LASCO C3; [b] location of leading edge of CME measured by C3 (units in *Rs*); [c] starting point at 1 AU (*Wind*); [d] distance between the initial point observed by C3 (3.63 Rs) and *Wind* (units in *Rs*); [e] Δt : travelling time of shock/CME between 3.63 *Rs* and 1 AU (units in hours); [f] $V_{shock/CME} = \Delta r/\Delta t$ (units in km/s) ; [g] V': $V_{CME/shock}$ measured near the Sun between 6.95 and 18.82 *Rs* (units in km/s); [h] $\Delta t_{prediction}$: predicted travelling time for shock/CME propagating from 3.63 to 215 *Rs* (units in hours); [i] Δt_{ERR}: error on the $\Delta t_{pred} = (\Delta t_{pred} - \Delta t) / \Delta t \times 100$ (%). Note, 1 *Rs* equals to 6.95×10^5 km, and 1 AU equals to 215 *Rs*.

Conclusion

- The first super geomagnetic storm of solar cycle 24 occurred on the “St. Patrick’s day” (17 March 2015). Notably, it was a two-step storm.
- The source of the storm can be traced back to the solar event on March 15, 2015. At ~2:10 UT on that day, *SOHO/LASCO* C3 recorded a partial halo corona mass ejection (CME) which was associated with a C9.1/1F flare (S22W25) and a series of type II/IV radio bursts.
- The propagation speed of this CME is estimated to be ~668 km/s during 02:10 – 06:20 UT (See Figure 1).
- An interplanetary (IP) shock, likely driven by the CME, arrived at the *Wind* spacecraft at 03:59 UT on 17 March.
- We conclude that the St. Patrick day event is a two-step storm. The first step is associated with the sheath, whereas the second step is associated with the MC.
- Here, we employ a numerical simulation using the global, three-dimensional (3D), time-dependent, magnetohydrodynamic (MHD) model (H3DMHD, Wu et al. 2007) to study the CME propagation from the Sun to the Earth.
- The simulation result matches well with the in situ solar wind plasma and field data at *Wind*, in terms of the peak values of IP shock and its arrival time. The simulation also helps us to identify the driver of the IP shock but also demonstrates that the modified H3DMHD model is capable of realistic simulations of large solar event. In this presentation, we will discuss the CME/storm event with detailed data from observations (*Wind* and *SOHO*) and our numerical simulation.

Acknowledgement

Work of CCW was supported by Chief of Naval Research.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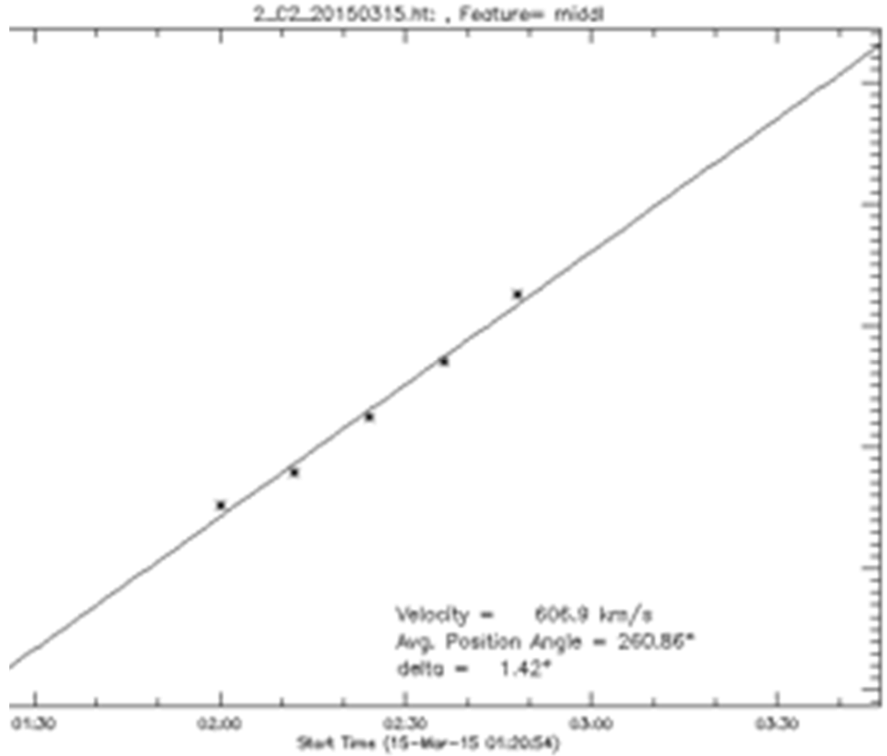
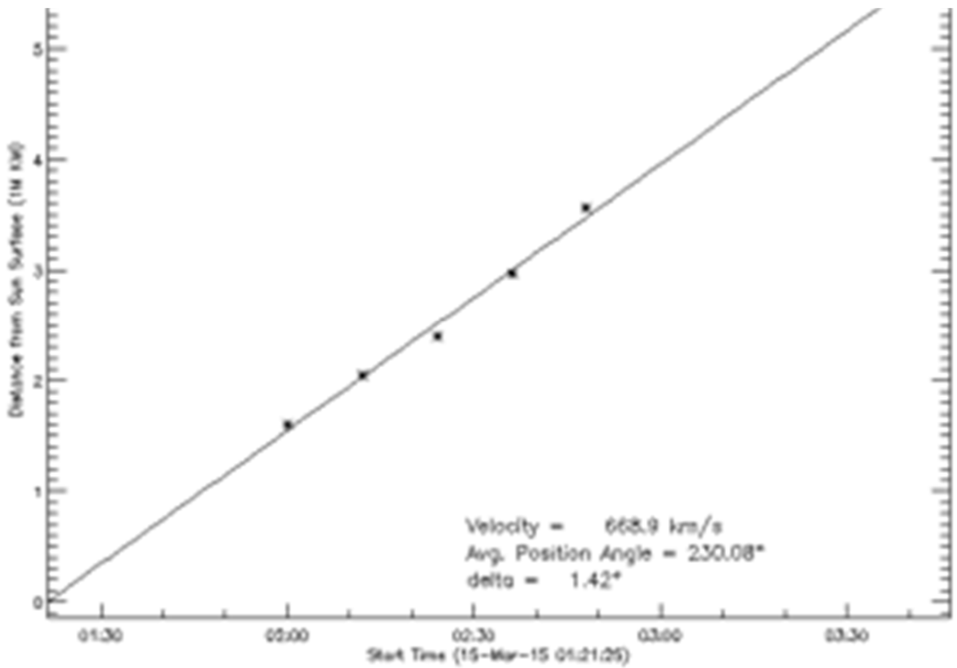
Distance from Sun Surface (1M KM)
Start Time (15-Mar-15 01:27:38)
Velocity = 448.6 km/s
Avg. Position Angle = 304.32°
delta = 1.42°


2_C2_20150315.ht: , Feature= middl
Start Time (15-Mar-15 01:20:54)
Velocity = 606.9 km/s
Avg. Position Angle = 260.86°
delta = 1.42°


Distance from Sun Surface (1M KM)
Start Time (15-Mar-15 01:21:25)
Velocity = 668.9 km/s
Avg. Position Angle = 230.08°
delta = 1.42°