Acceleration and Deceleration of Flare/Coronal Mass Ejection Induced Shocks

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Motivation

- To investigate flare/coronal mass ejection induced shock acceleration and decelleration from the corona/surface of the Sun to the inner heliosphere (2 AU) using a 1.5D MHD simulation with drag force.

- The simulation results have compared with observation of ACE data.

- Drag force has compared with Cargill drag force.

Governing Equations

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

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

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

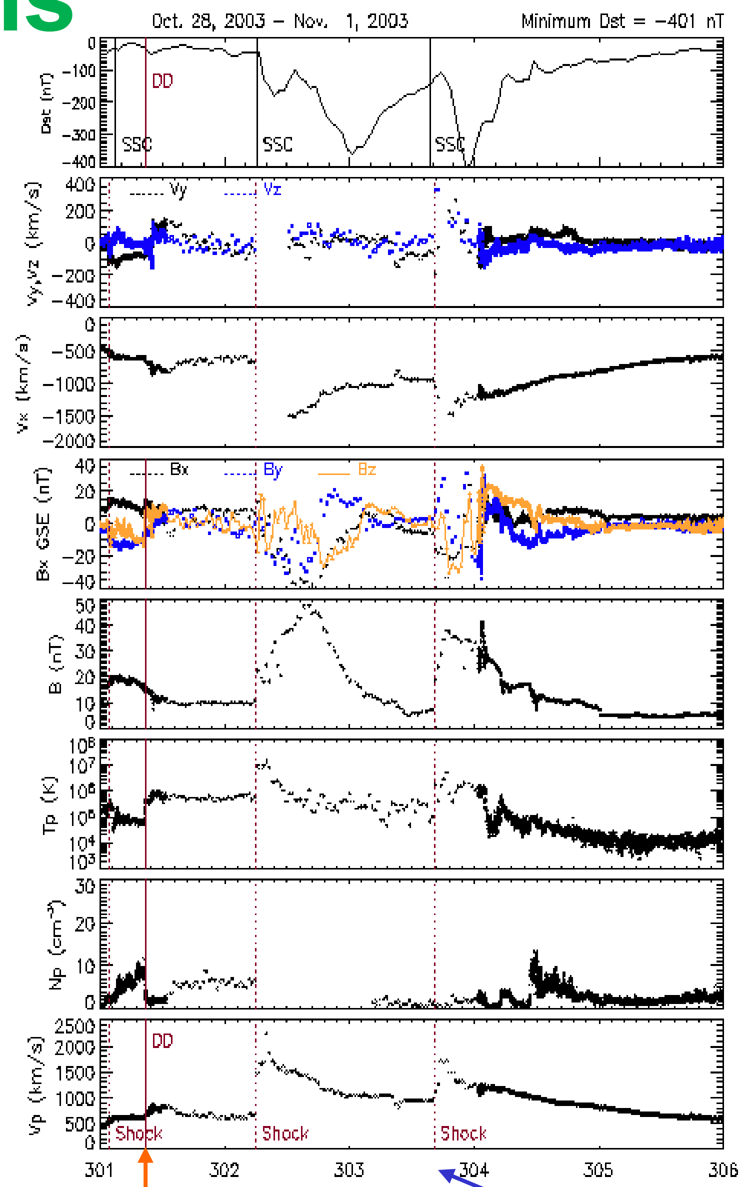
$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{V} \times \mathbf{B})$$ Induction equation

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 ($e = p/(\gamma\text{-}1)\rho$), *GM(r)* is solar gravitational force, and γ is the specific heat ratio. For this research, we applied an adiabatic gas assumption (i.e., $\gamma = 5/3$). F and $\mathcal{F}$ are a dissipative force and Rayleigh dissipation function, respectively. The former as a "frictional force which is proportional to the velocity of the particle", and the latter as one-half "the rate of energy dissipation due to friction".

Observations

Halloween 2003 Event

- LDE M1.7/SF flare at N00W15
  0522 UT, October 25, 2003
- LDE X1.2/3N flare at S18E33
  0617 UT, October 26, 2003
- X17/4B flare at S15E44 with a Halo CME
  1102 UT, October 28, 2003
- X10/2B flare at S15W02 with a Halo CME
  2042 UT, October 29, 2003



Shock 1
0150 28/10/2003

DD

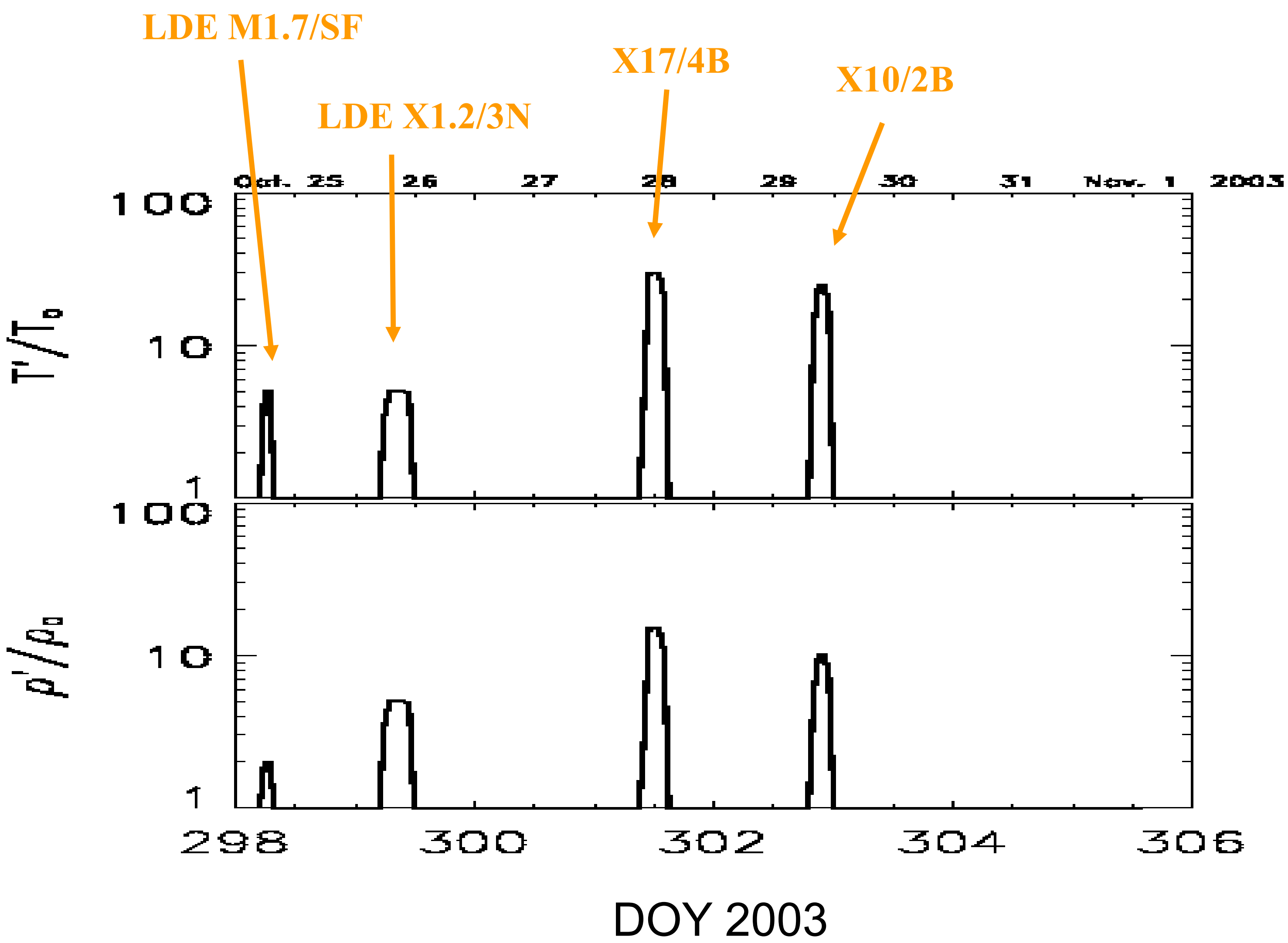
Shock 2
0600 29/10/2003

Shock 3
1620 30/10/2003

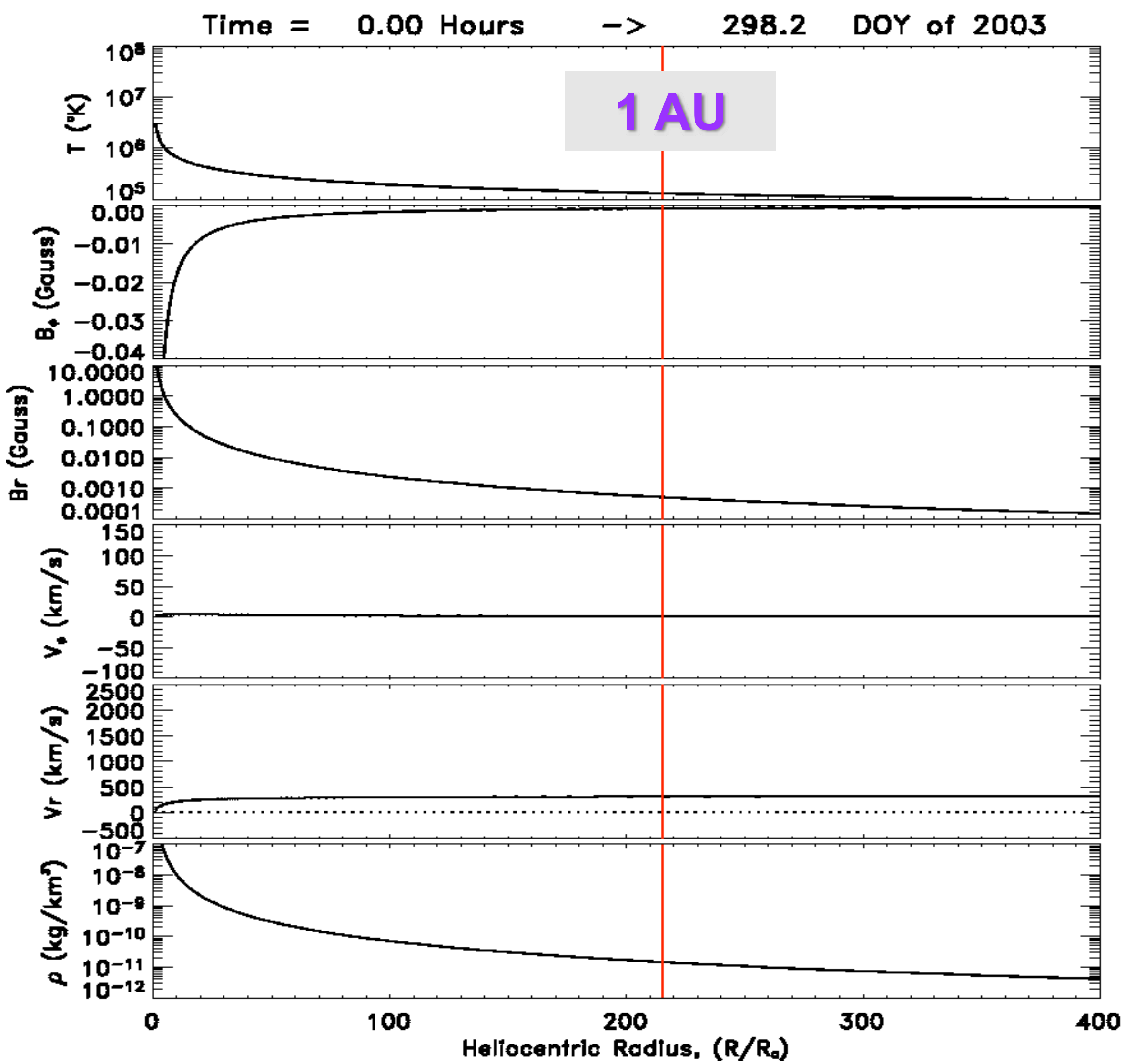
Simulation Procedure

- **A one-dimensional MHD simulation model with adaptive grids was employed to study this event in Sun-Earth direction.**
- **We construct the back ground solar wind structure from the "surface of Sun" to the heliospher for study the propagation of the shock events during the Halloween epoch.**
- **To initiate the simulation, we introduce four pressure pulses corresponding to 4 observed flares. These four pressure pulses were introduced at the lower boundary (1 solar radius, Rs) at the time = 0, 24, 77, 110 hours which correspond to time = 298.24 (DOY), 299.26, 301.45, 302.86 of year 2003 according to observations, respectively.**
- **Six simulated parameters (i.e., density (Np), T, Vr, V_{Φ}, Br and B_{Φ}) are presented.**

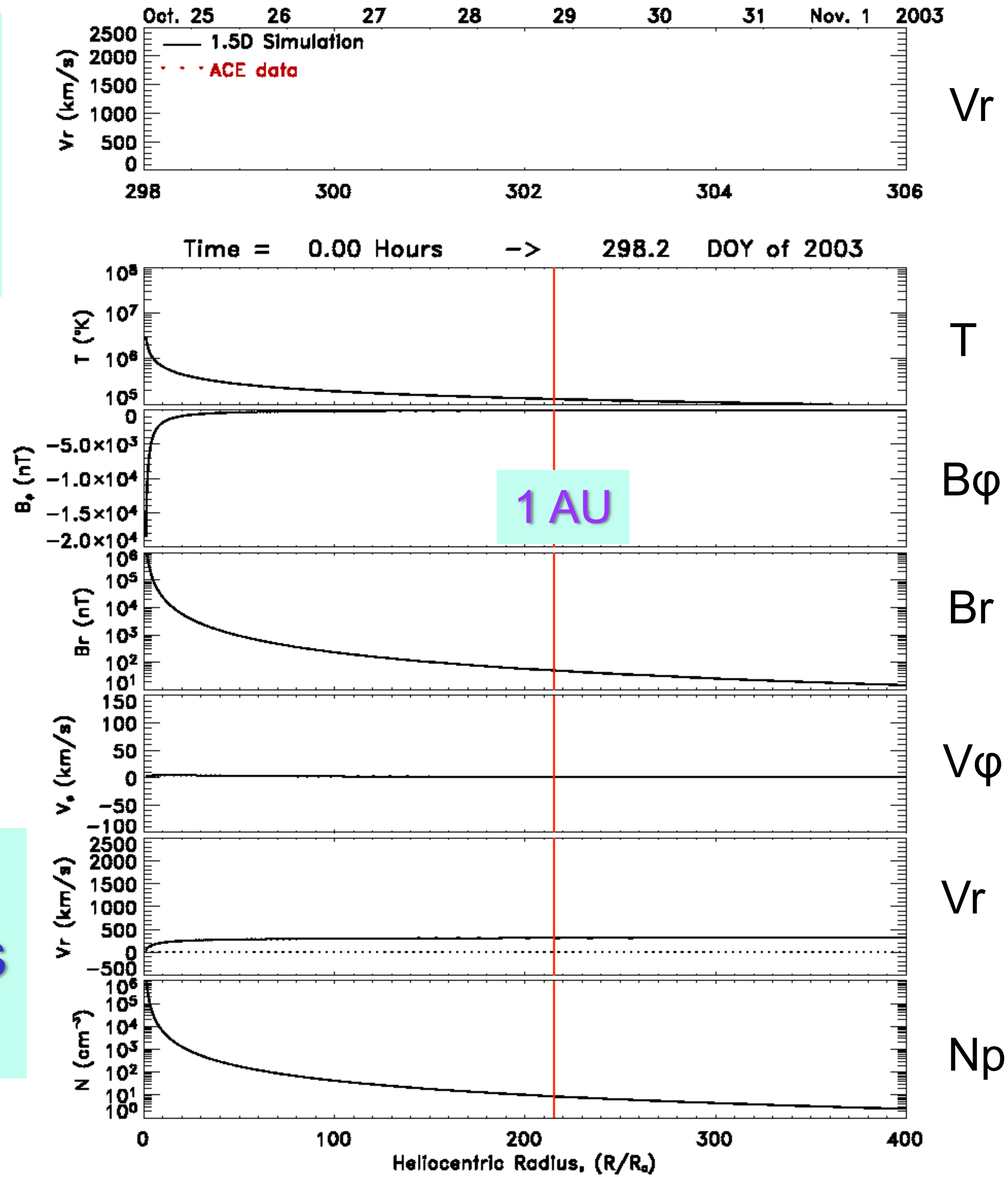
Simulation Inputs at lower boundary (1 Rs)



Steady state solar wind condition



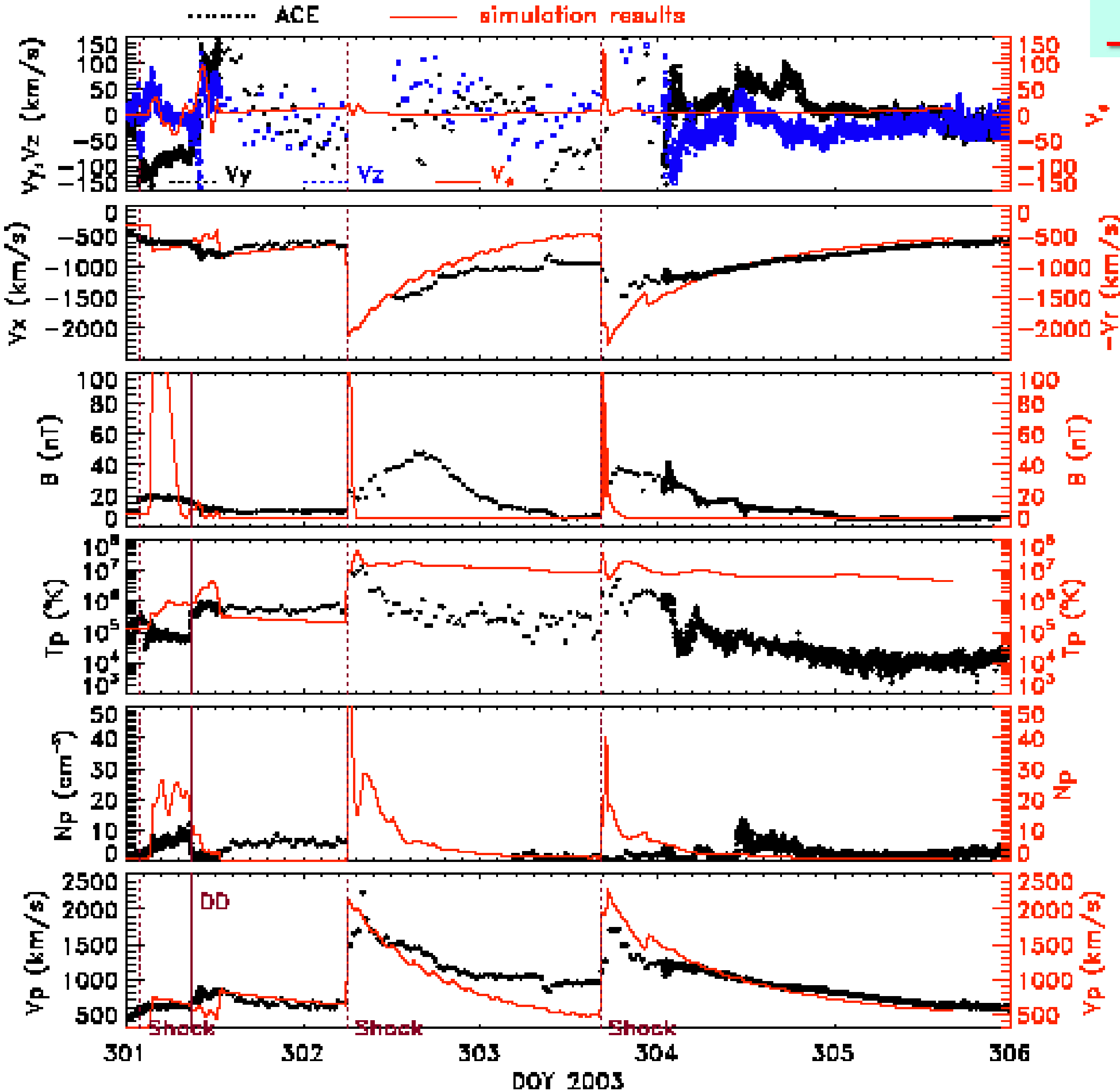
.... ACE
______Simulation



Simulation Results

COMPARISON: Simulation Results vs. Observation

….. ACE
___Simulation

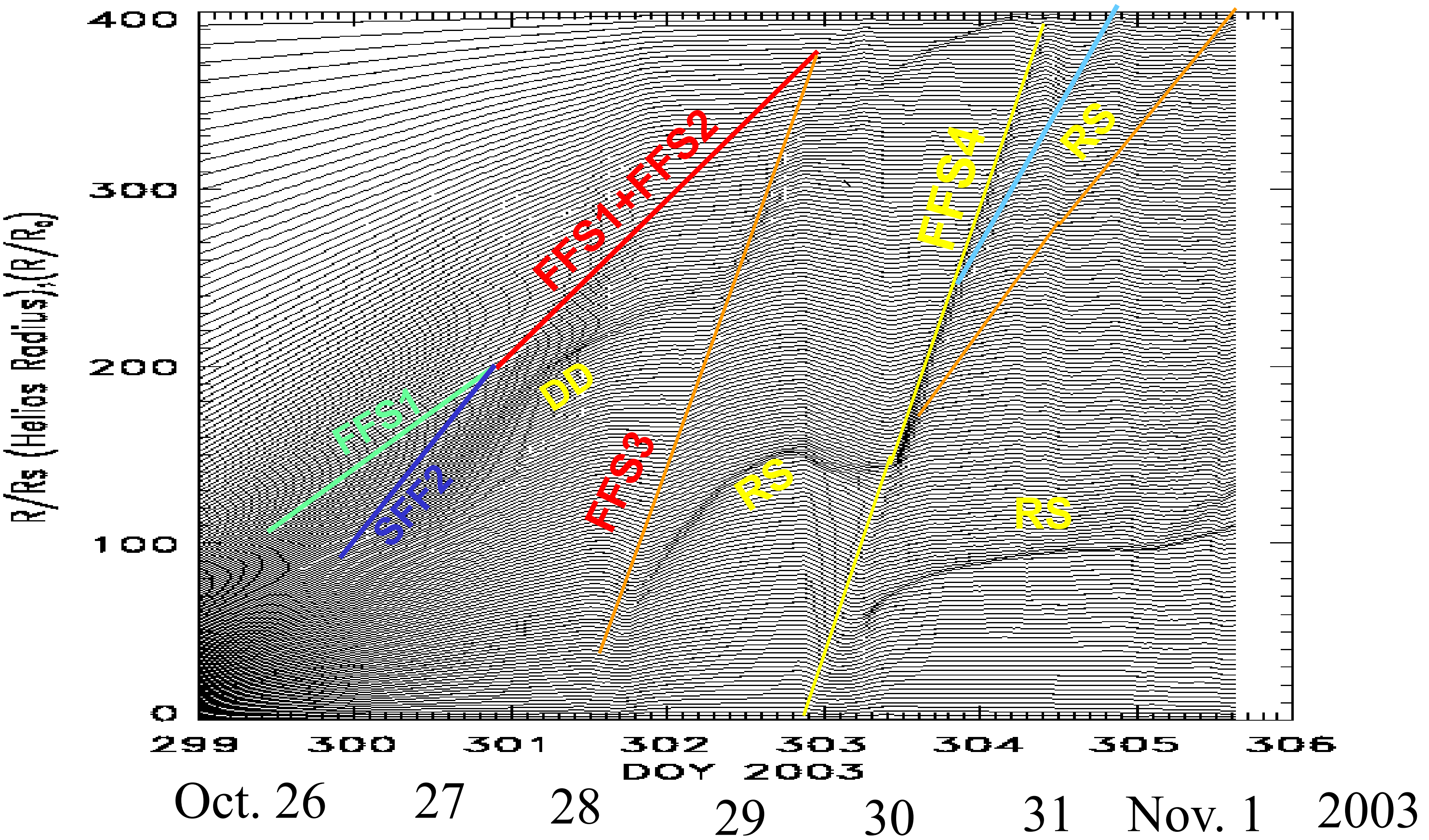


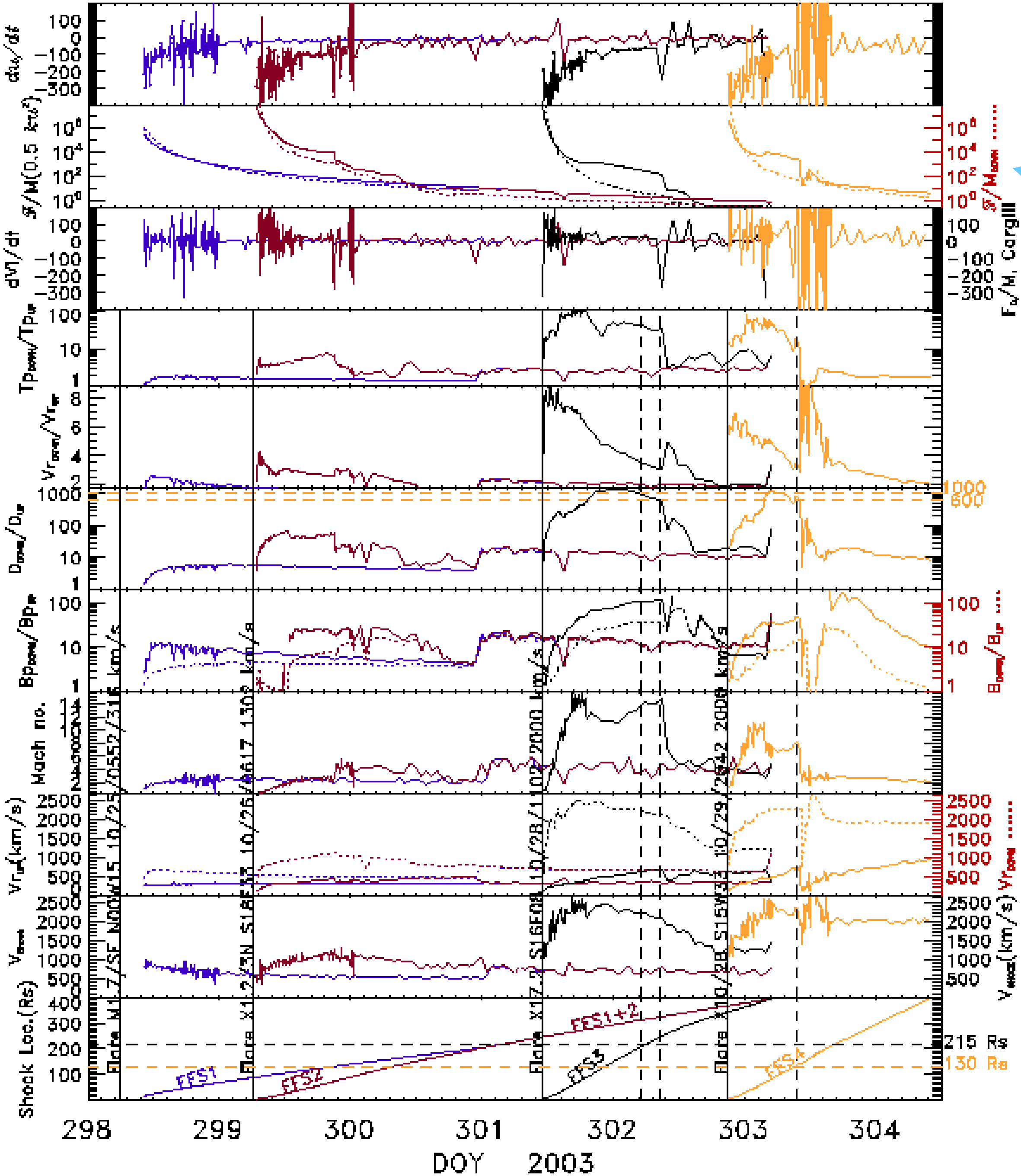
$V\varphi = Vy$

$-Vr = Vx$

$Vp = V_{total}$
$= \mathrm{sqrt}(Vx^2+Vy^2+Vz^2)$
$= \mathrm{sqrt}(Vr^2+V\varphi^2)$

Histogram of grids and waves location





$du/dt = u/(2\mathcal{F})\ \ d\mathcal{F}/dt$

$\mathcal{F} = \frac{1}{2} k u^2$

Friction force (Wu et al.,1975)[b]

Drag force (Cargill, 2004)[a]

$dV_i/dt = F_D/M_*$

$= -\gamma C_D (V_i - V_e)/|V_i - V_e|$

DISCUSSION

$\mathcal{F} = \frac{1}{2} k u^2$

$k = 3 \times 10^{-3} (R_{\odot}/r)^6$

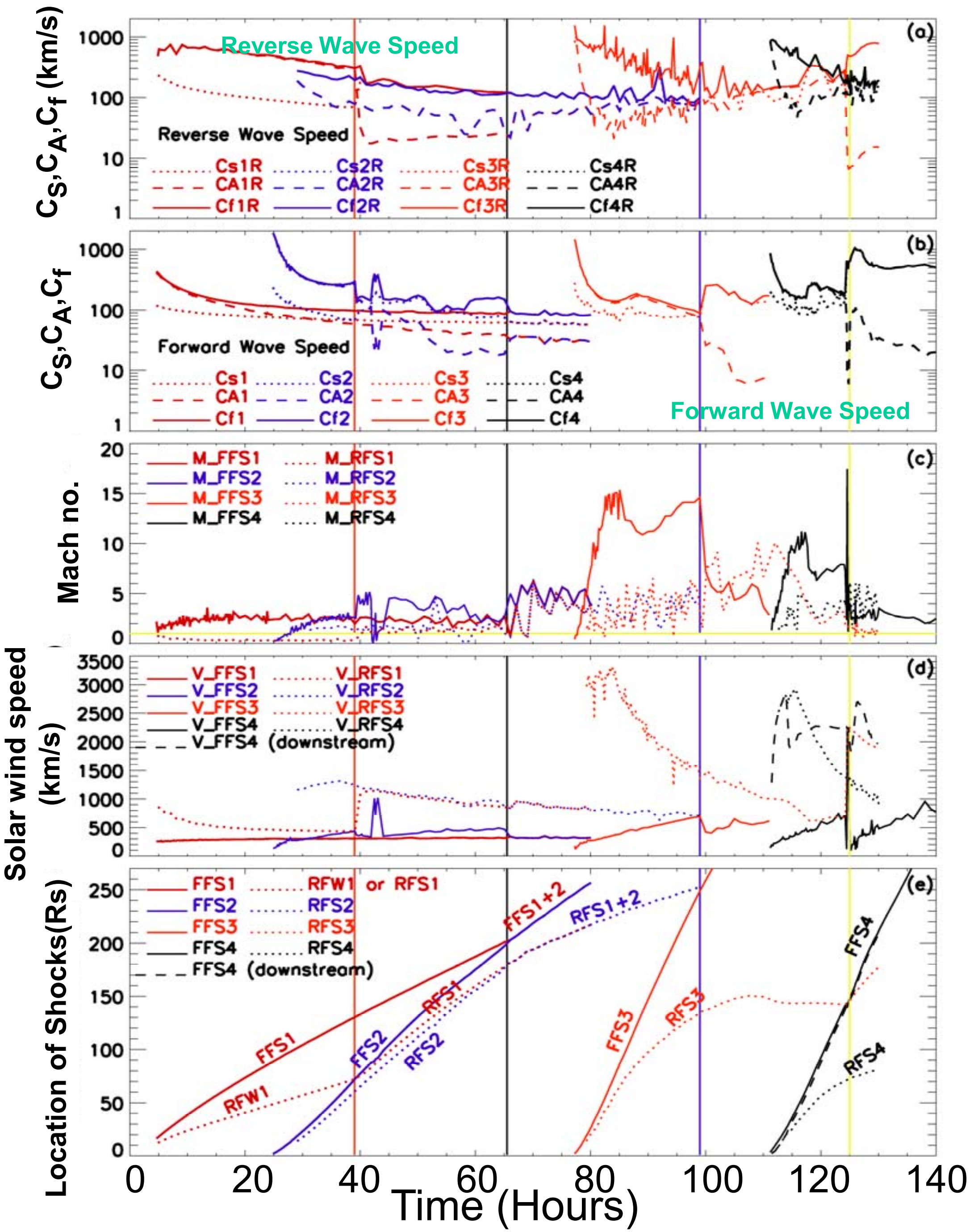
k: a constant depend on the physical process.

REFERENCE:
[a] Cargill, Solar Physics, 221, 135-149, 2004.
[b] Wu et al., Solar Physics, 44, 117-133, 1975.

Conclusion

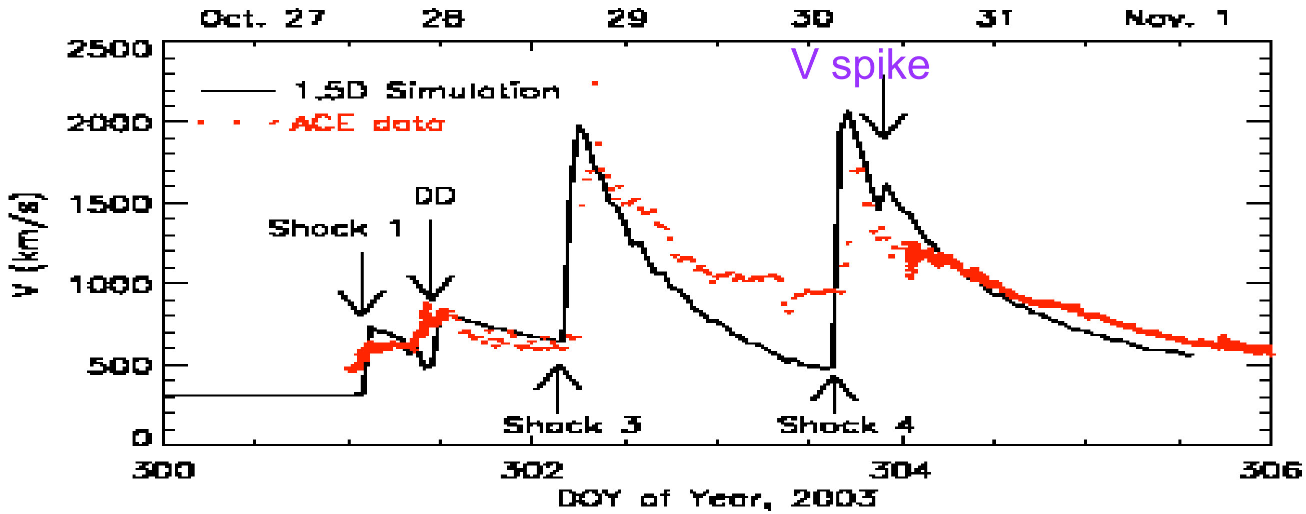
- **Acceleration and Deceleration of Flare/Coronal Mass Ejection induced shocks have been simulated by 1.5D MHD model.**
- **Cause of deceleration due to drag force can be estimated from the numerical simulation. Our drag force deduced from simulation are similar to the Cargill results (2005).**
- **We plan to use this simple model to track the STEREO observed shocks.**

The End

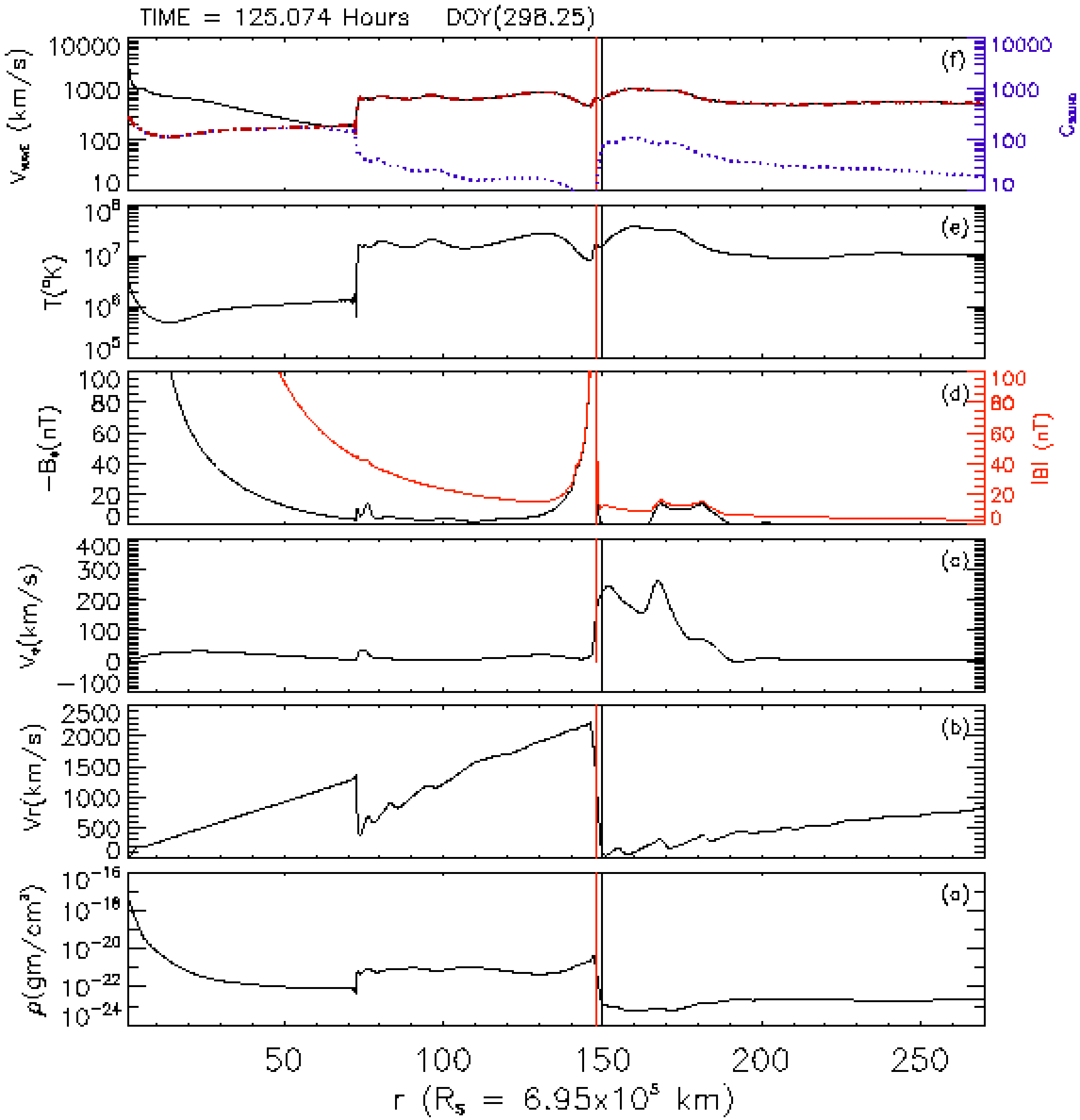


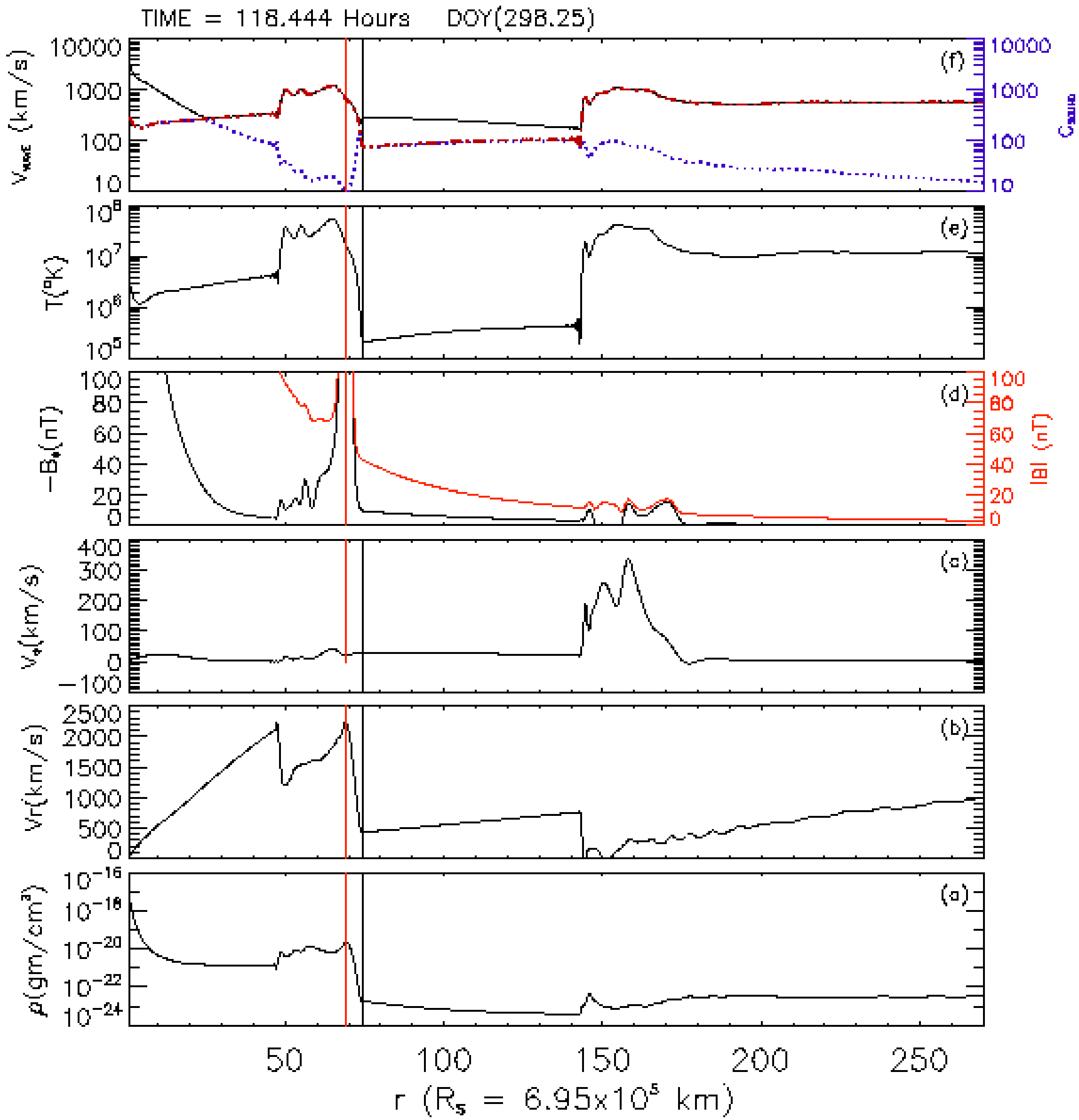
Characteristic wave speeds, magnetosonic Mach Number solar wind speeds, and locations of forward and reverse shock waves as a function of time after the first flare-generating CME and shock. (a) Cf (fast wave speed), Cs (sound wave speed), and CA (Alfven wave speed) for fat reverse shocks (for example, Cf1R is the fast wave speed on the sunward side of RFS1); (b) Cf, Cs, and CA for the fast forward shocks (for example, Cf1 is the fast wave speed on the anti-sunward side of FFS1); (c) magnetosonic Mach Number of both forward and reverse fast shocks; (d) solar wind plasma speed; and (e) locations (or trajectories) of various forward and reverse shocks as well as the reverse fast compression wave, RFW1, that becomes RFS1 after it is overtaken by FFS2 at t ≈ 40 hours. The solid vertical lines (orange/red, black, blue, and yellow) are the points of two shocks collision (*Wu et al*., JGR, 2006).

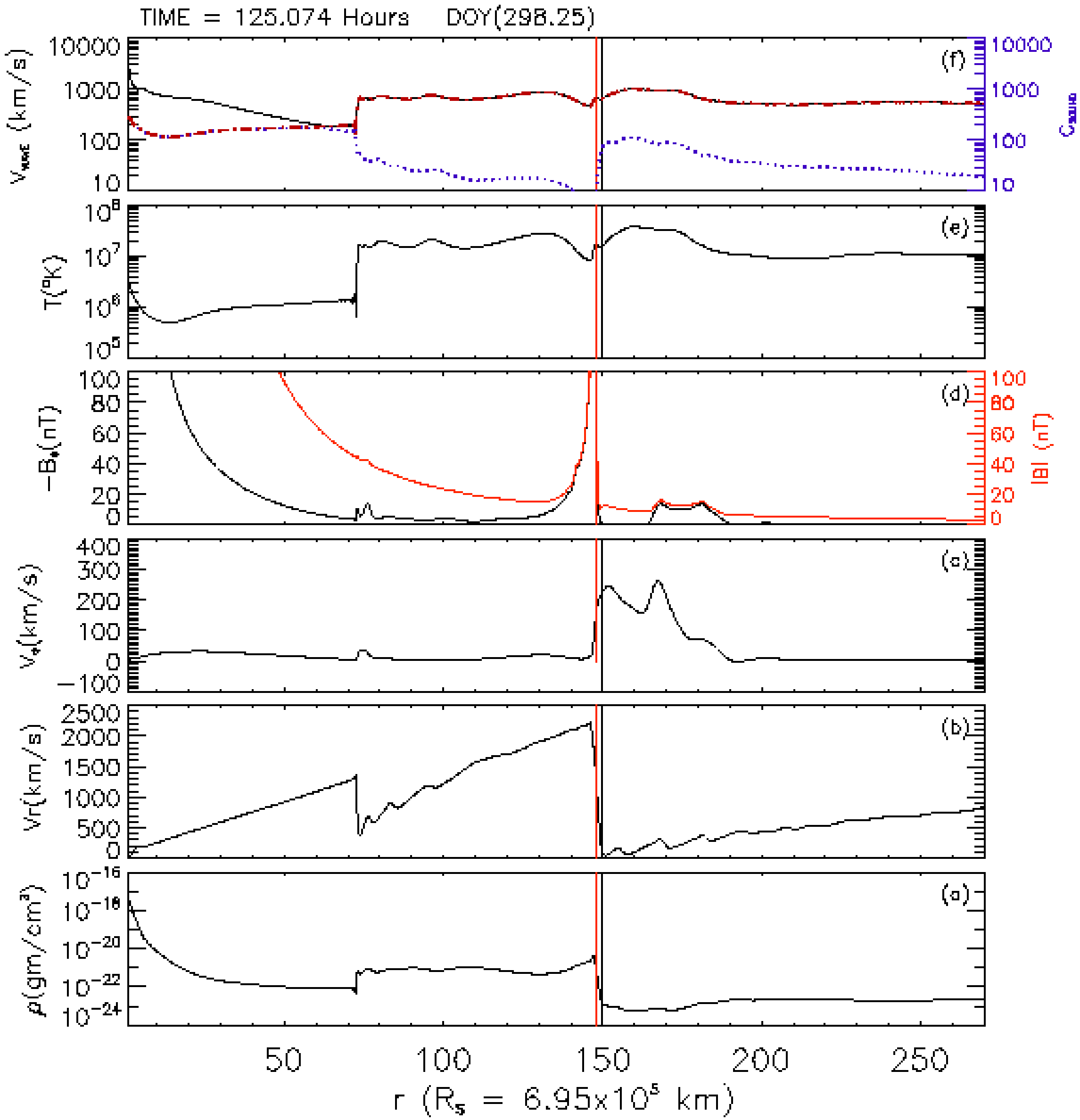
Velocity profile from 1.5D MHD model with adaptive grids (Wu et al., JGR, 2005)



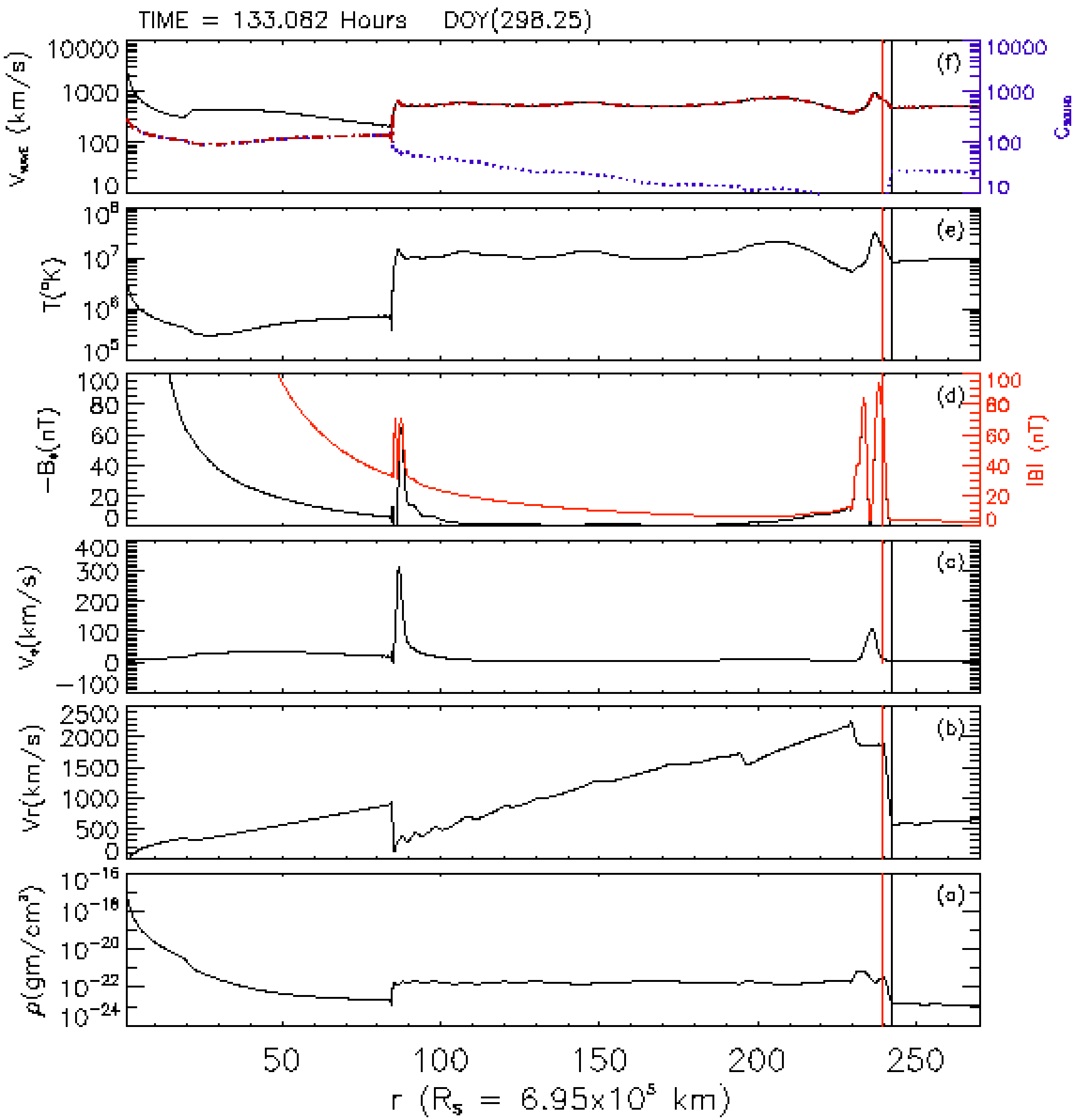
Simulation (solid line) and observed (dotted line) solar wind plasma speed. Excellent agreement with the observations is shown for the simulated shock times of arrival at ACE as well as the "V spike", following Shock 4, is a reverse shock. (Wu et al., *JGR*, *111*, A09S17, 2005)


TIME = 125.074 Hours DOY(298.25)
(f)
(e)
(d)
(c)
(b)
(a)
V_{MAX} (km/s)
C_{sound}
$T(^oK)$
$-B_\phi$(nT)
|B| (nT)
V_ϕ(km/s)
Vr(km/s)
ρ(gm/cm^3)
r (R_s = 6.95x10^5 km)

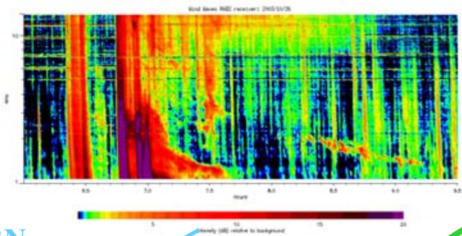

TIME = 118.444 Hours DOY(298.25)
(f)
(e)
(d)
(c)
(b)
(a)
T(°K)
−B_φ(nT)
|B| (nT)
V_φ(km/s)
Vr(km/s)
ρ(gm/cm³)
r (R_s = 6.95x10⁵ km)

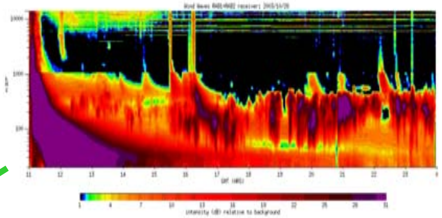


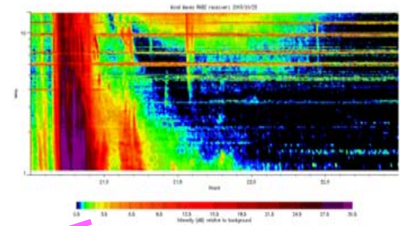
TIME = 125.074 Hours DOY(298.25)
(f)
(e)
(d)
(c)
(b)
(a)
−B$_\phi$(nT)
|B| (nT)
T(°K)
V$_\phi$(km/s)
Vr(km/s)
ρ(gm/cm³)
r (R$_S$ = 6.95x10^5 km)


TIME = 133.082 Hours DOY(298.25)
(f)
(e)
(d)
(c)
(b)
(a)
T(°K)
−Bφ(nT)
|B| (nT)
Vφ(km/s)
Vr(km/s)
ρ(gm/cm³)
r (Rs = 6.95x10⁵ km)

No Wind/WAVES Type II or III available for LDE M1.7/SF on October 25, 2003



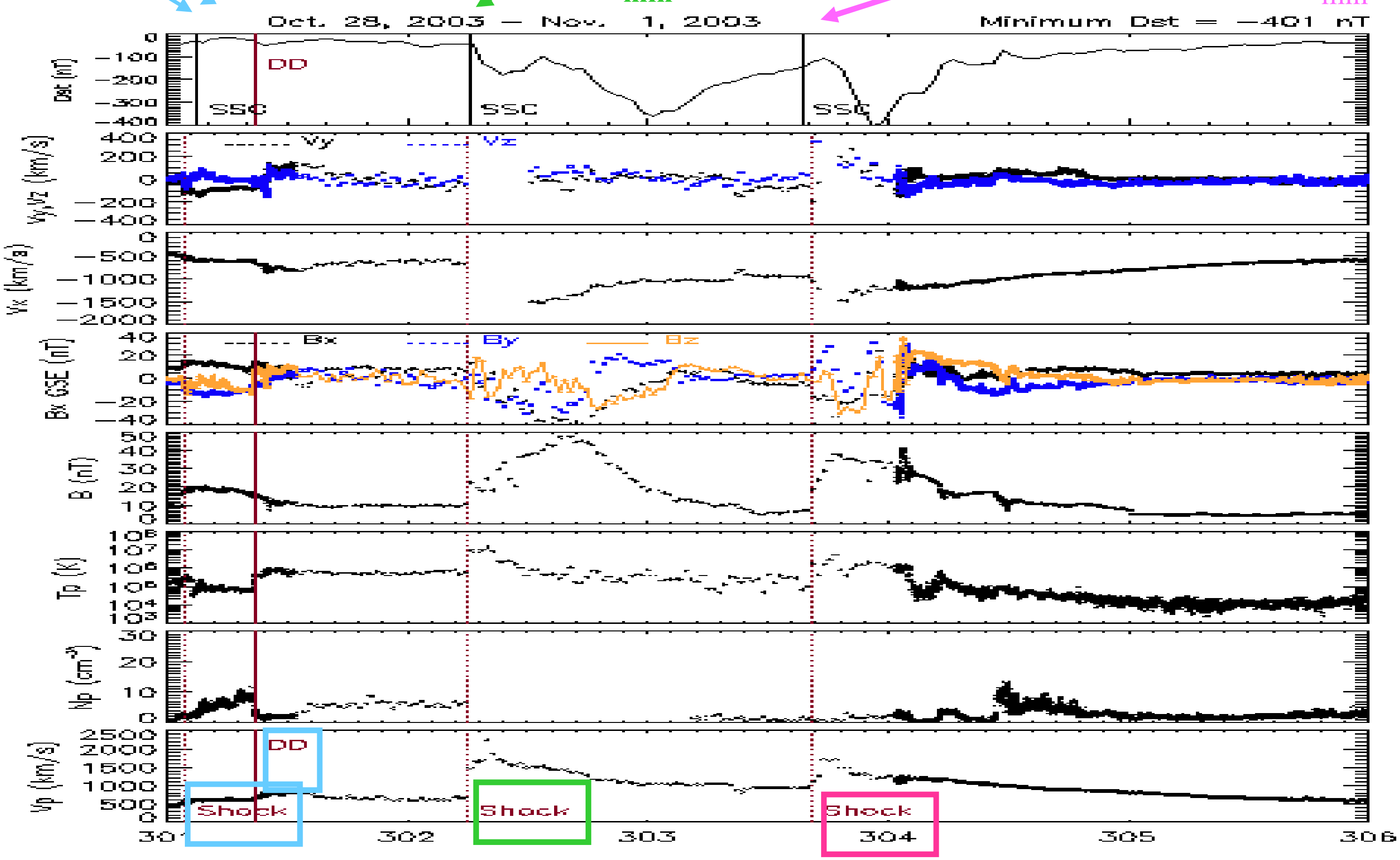




The M1.7/SF and X1.2/3N flares caused a geomagnetic storm with Dst_{min}= -48 nT

The X17/4B flare caused a geomagnetic storm with Dst_{min}= -363 nT

The X10/2B flare caused a geomagnetic storm With Dst_{min} = -401 nT



Oct. 28 29 30 31 Nov. 1 2003

Fourth pressure pulse launched

Third pressure pulse launched

Second pressure pulse launched

First pressure pulse launched