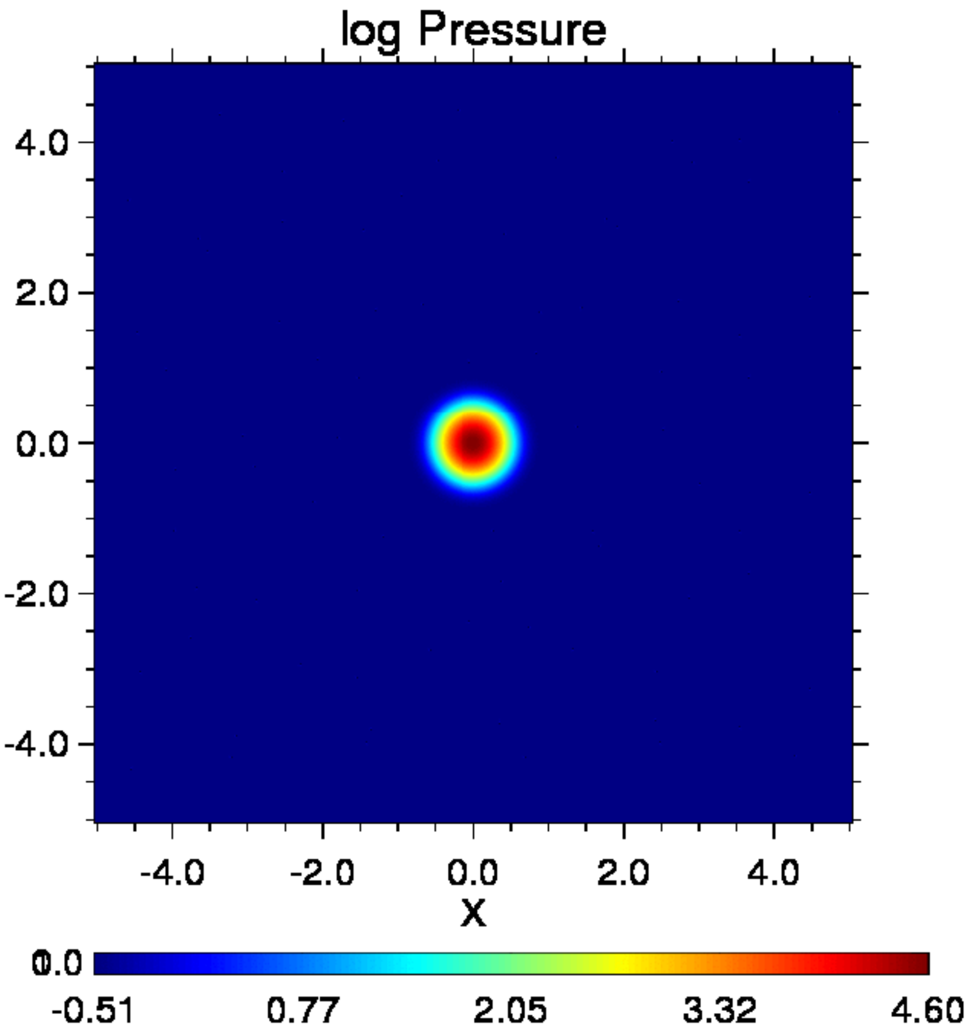
Hinode Seminar @ ISAS
Apr. 23, 2015

Prominence Activation by Coronal Fast Mode Shock

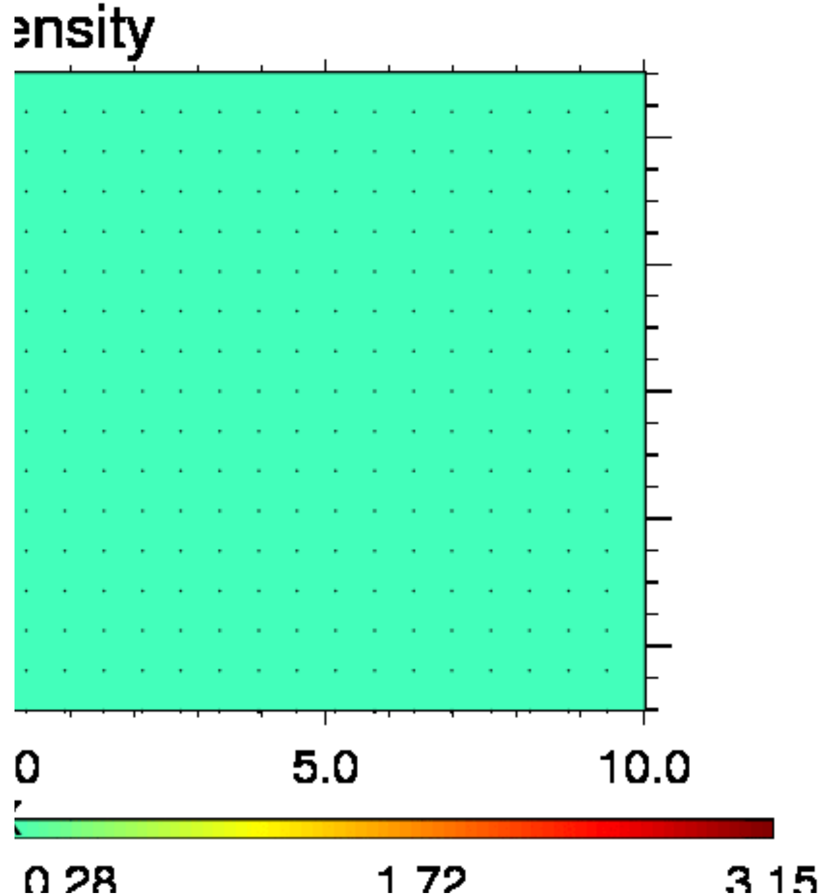
Takuya Takahashi (Kyoto University)

Shock waves associated with explosions

Point source explosion

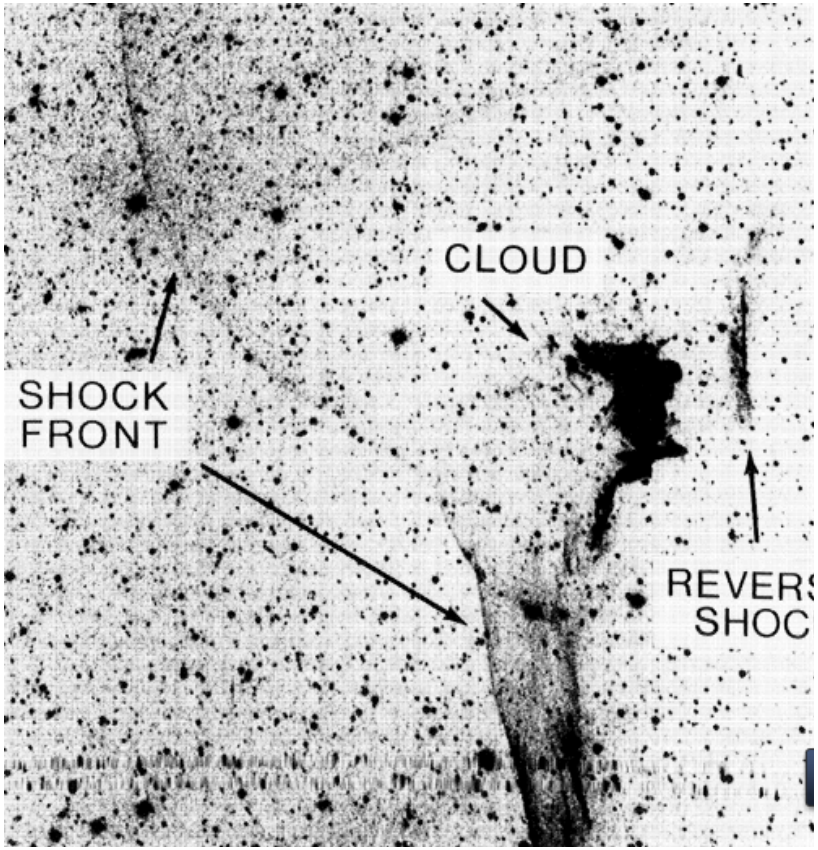


Motion driven shock formation

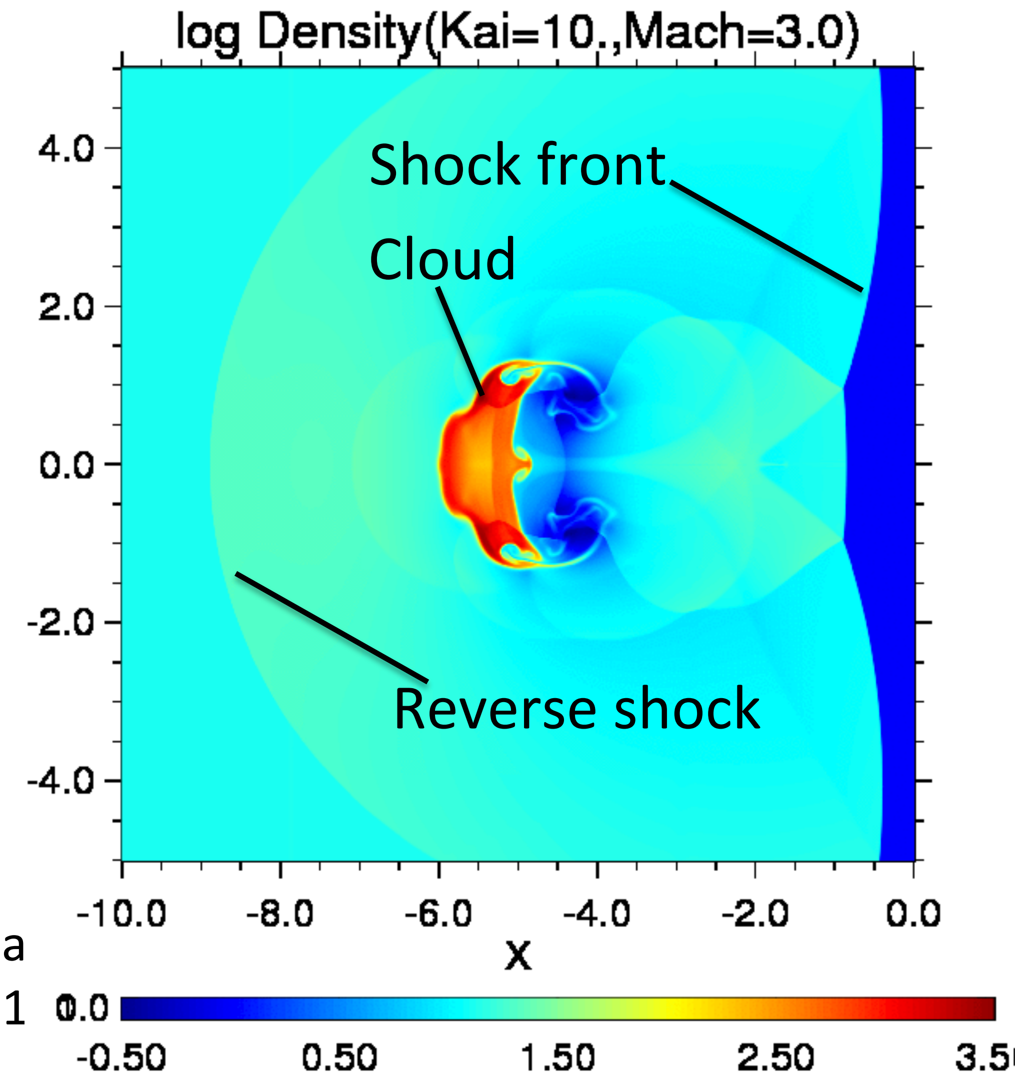


Shock-cloud interaction in Astronomy

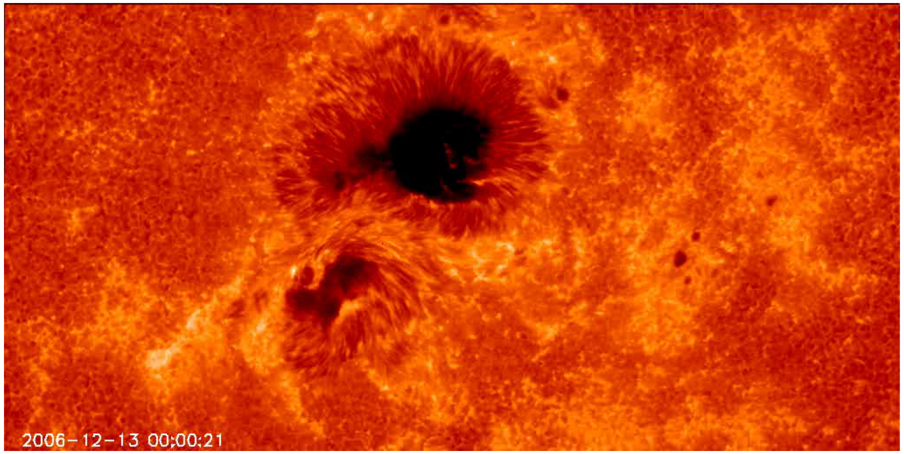
SNR-molecular cloud interaction



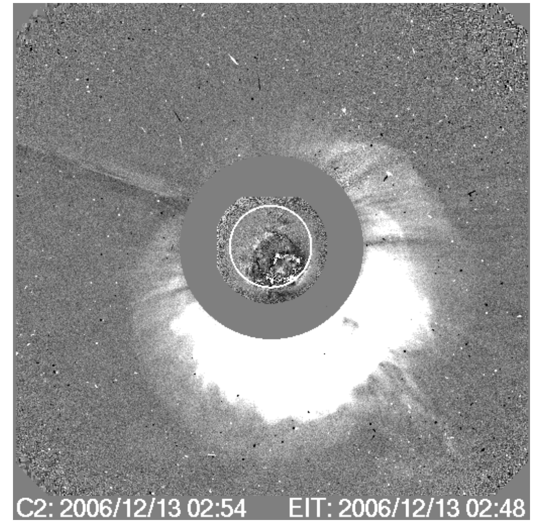
Hα image of the Shock-Cloud interaction a
eastern limb of Cygnus loop.(Fesen et al. 1



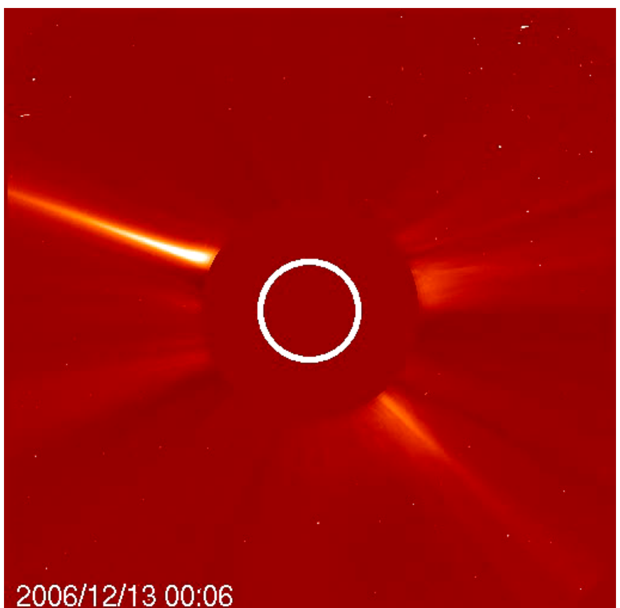
Shock waves associated with solar flares



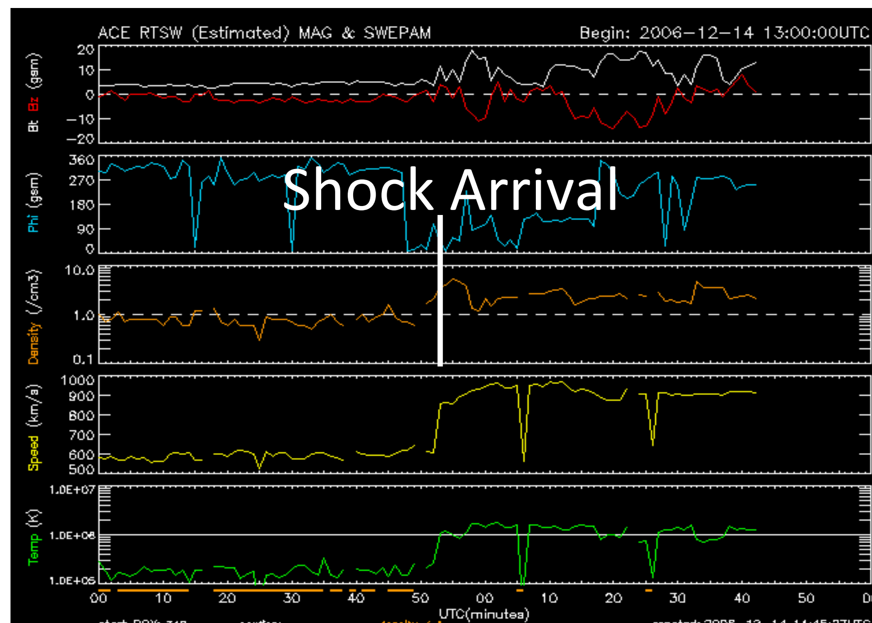
Flare 2006-12-13 (Hinode/SOT Ca)



Difference image of LASCO/C2

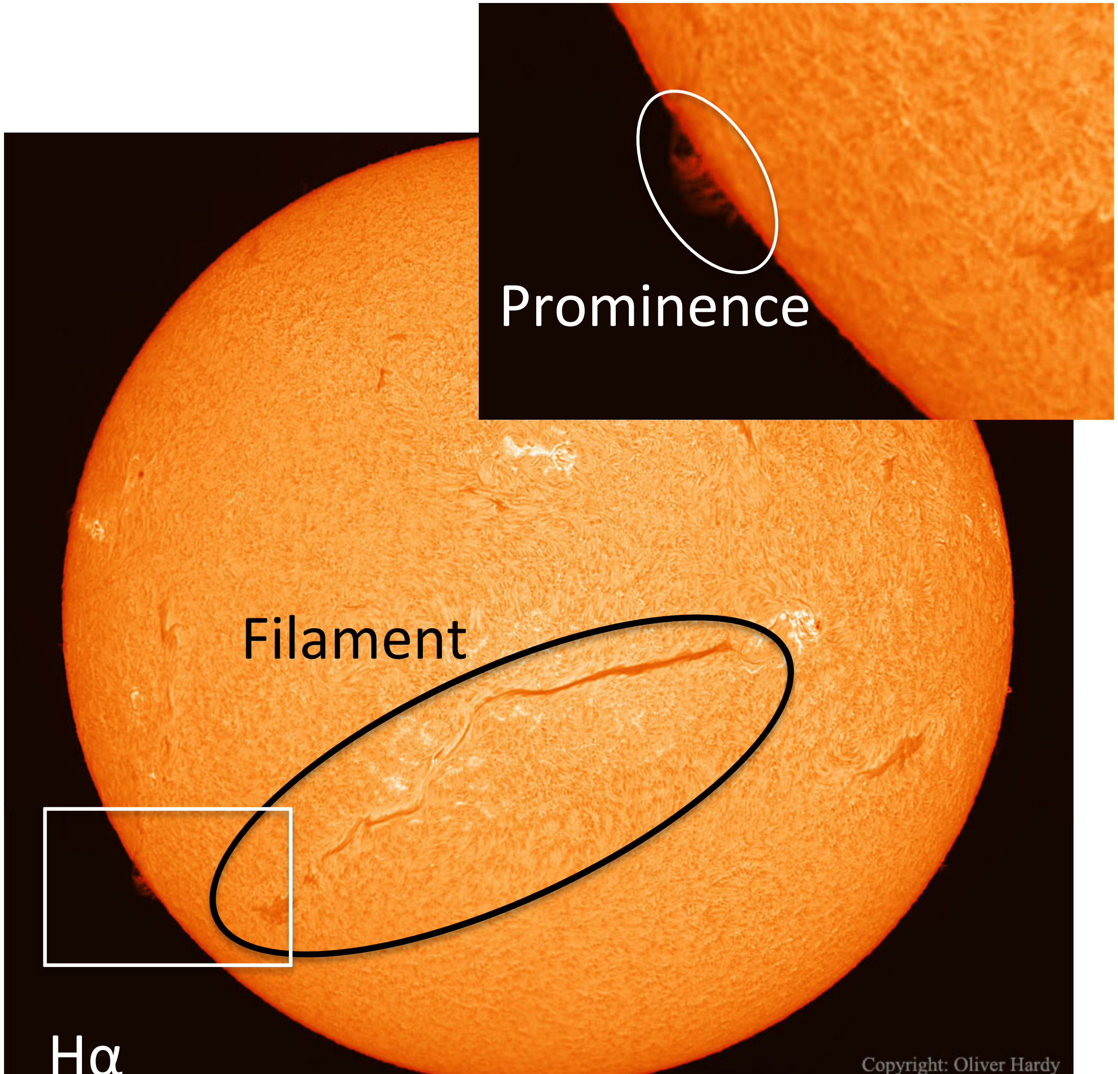


Coronal mass ejection (SOHO/LASCO/C2)



Shock signature in Solar wind

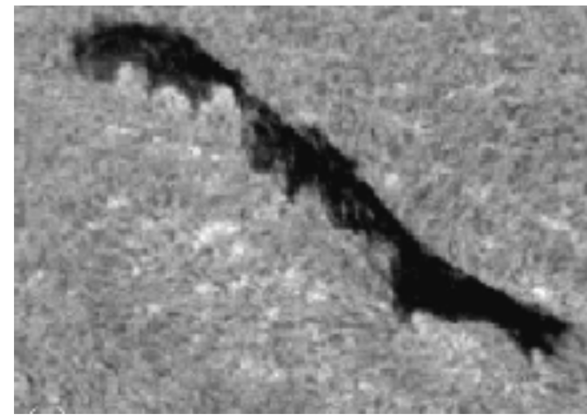
“Clouds” on the Sun -Prominence-

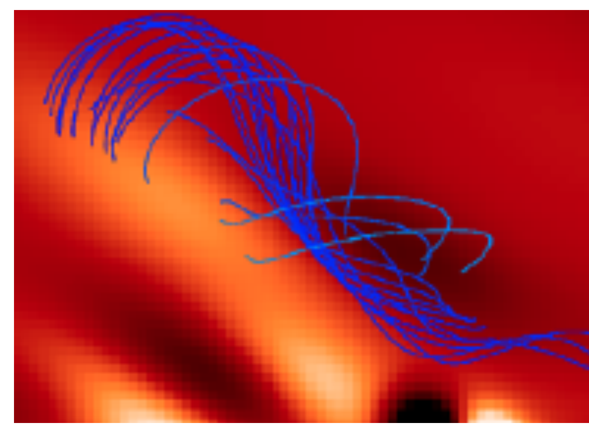


Prominence is Cold and Dense

$T_P \sim 10^4$ K ($\Leftrightarrow T_C \sim 10^6$ K)

$n_P \sim 10^{11}$ cm^{-3} ($\Leftrightarrow n_C \sim 10^9$ cm^{-3})

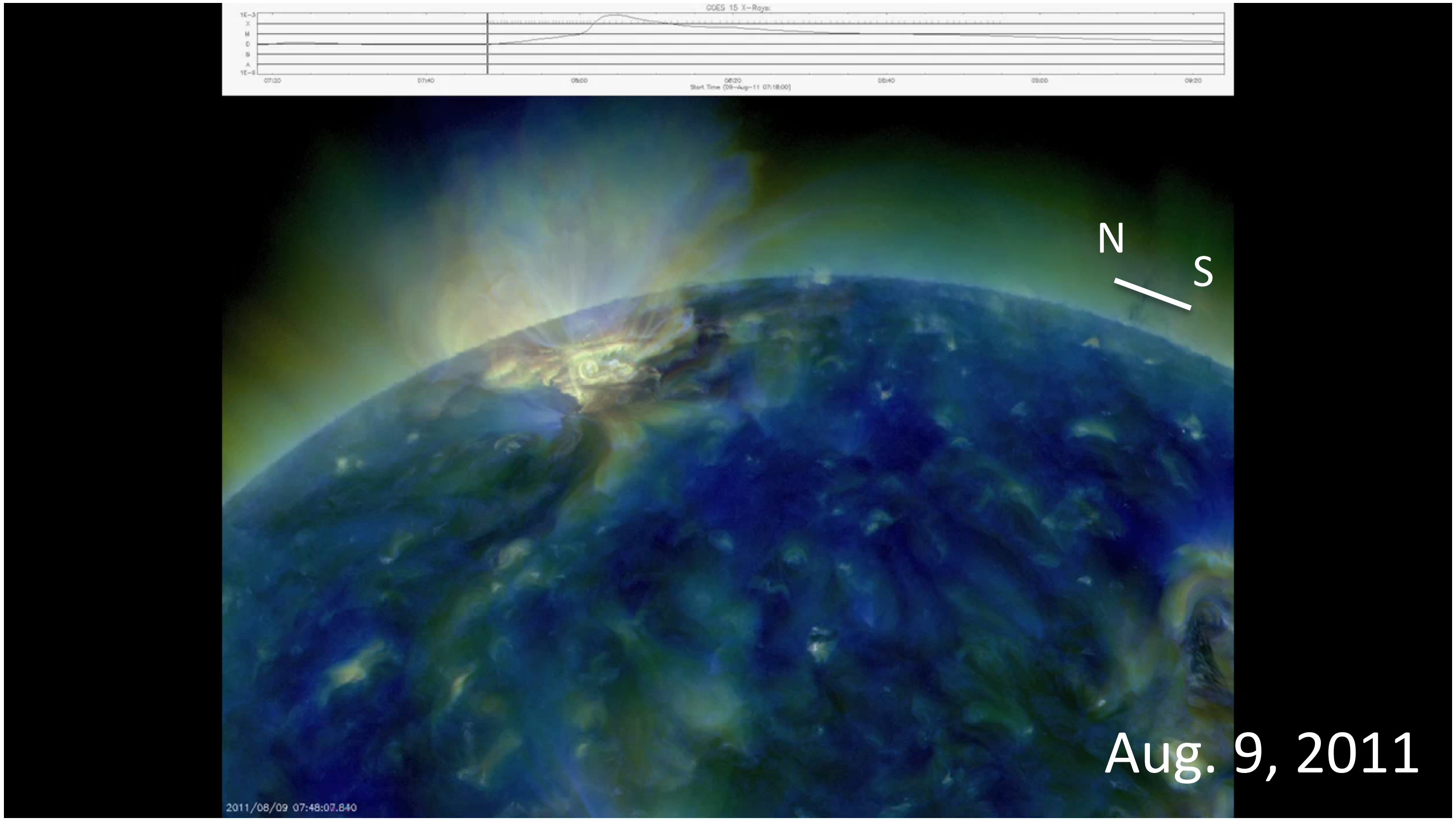


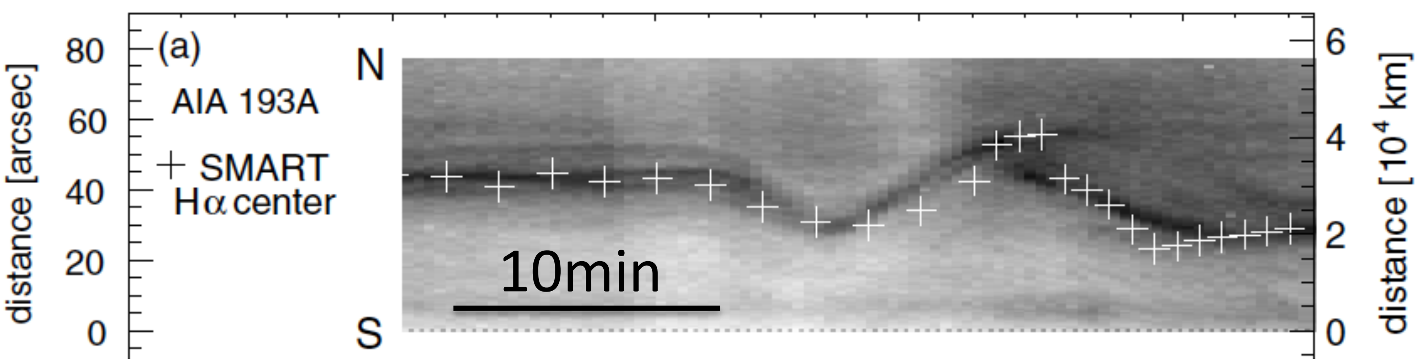


Yeates et al.(2008)

©Oliver Hardy (http://apod.nasa.gov/apod/astropix.html)

Prominence “Oscillation” driven by Shock



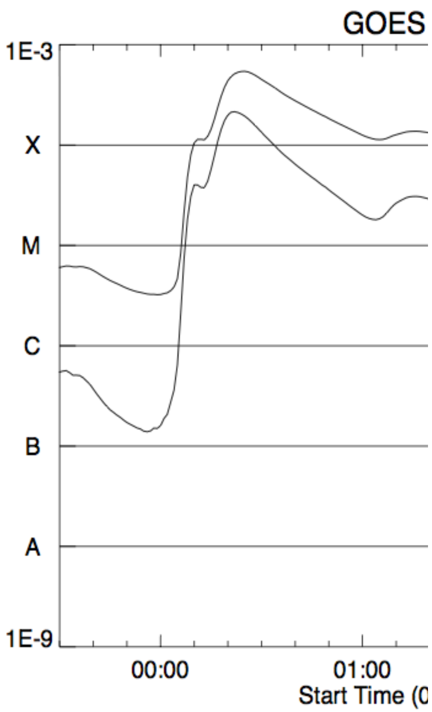


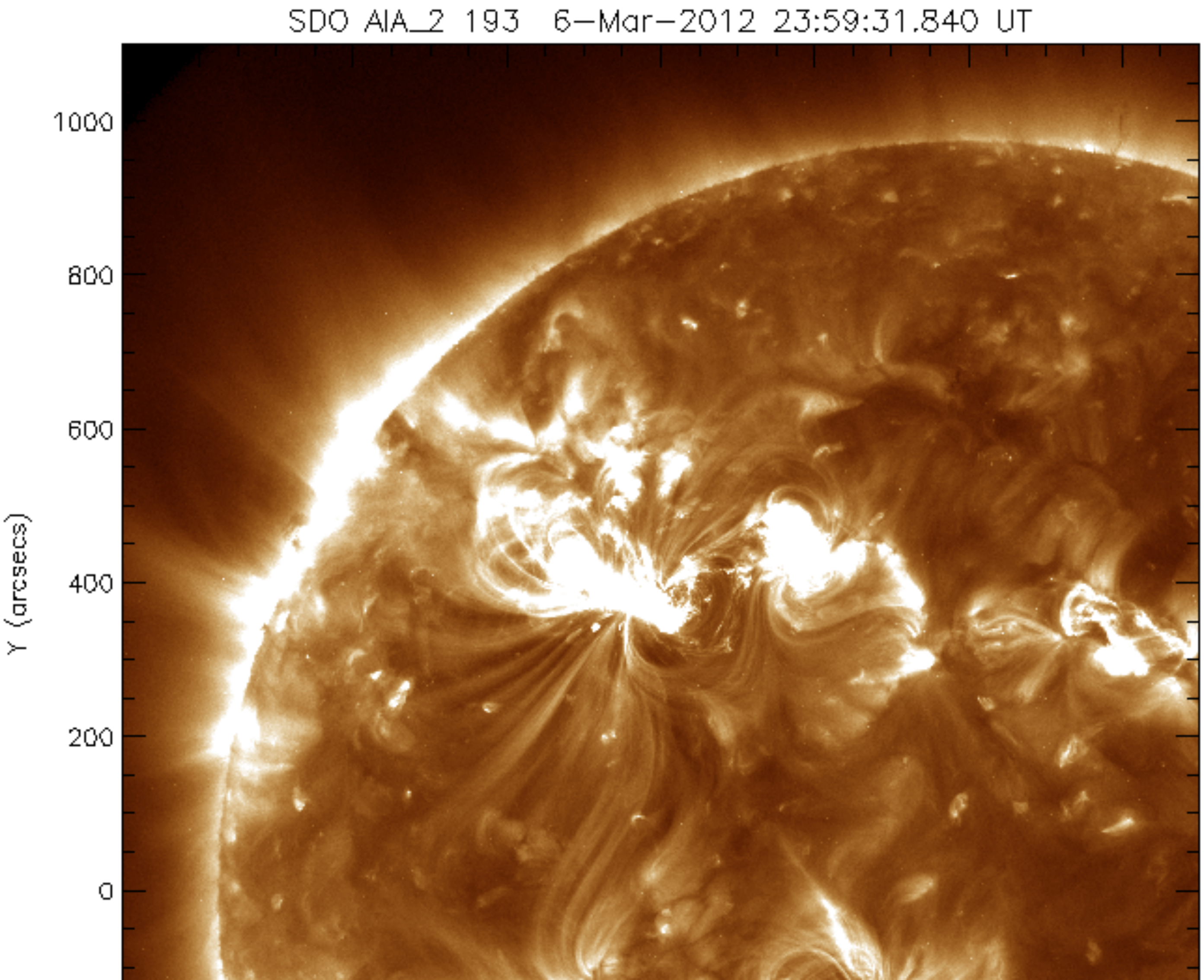
Asai et al.(2012)

X5.4 flare with coronal shock

GOES Soft X-Ray light curve
(March 6,2012 2
-March 7

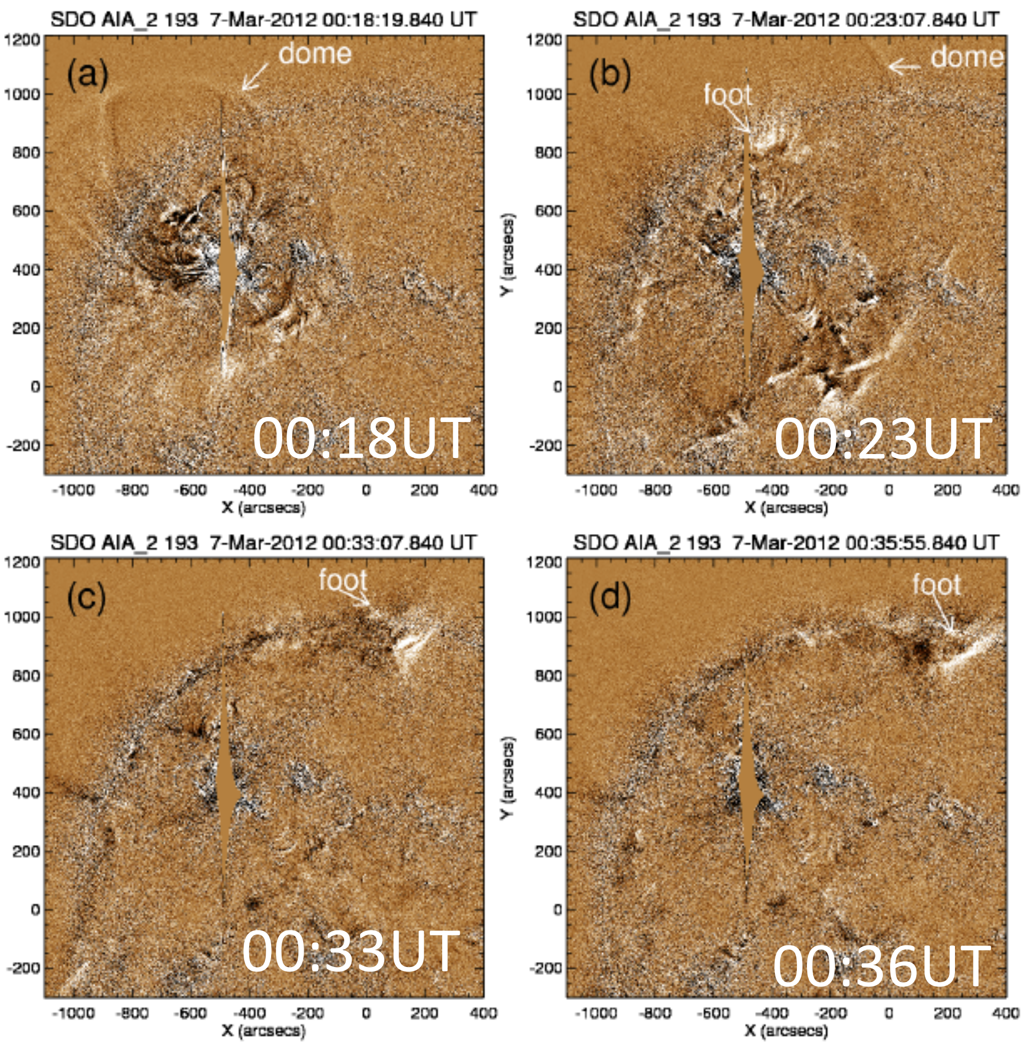
March 7,2012 00:00UT – 02:00UT



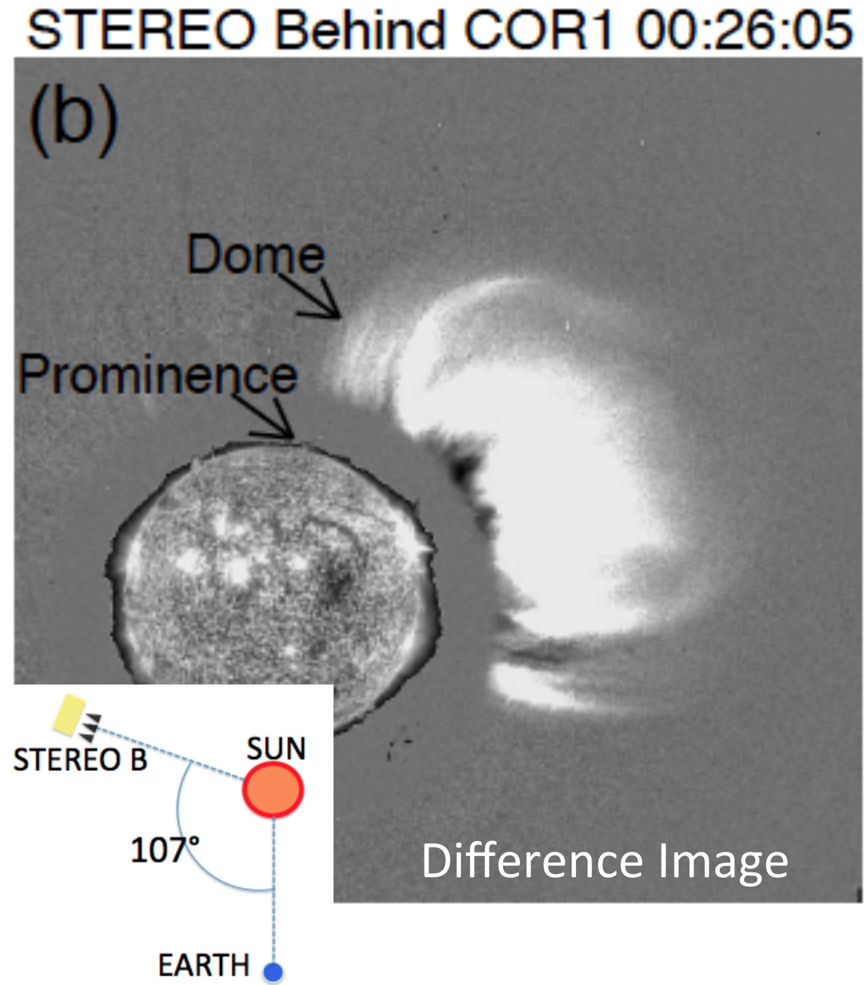


- X5.4 flare
  start 00:04,
- X1.3 flare
  peak 01:14

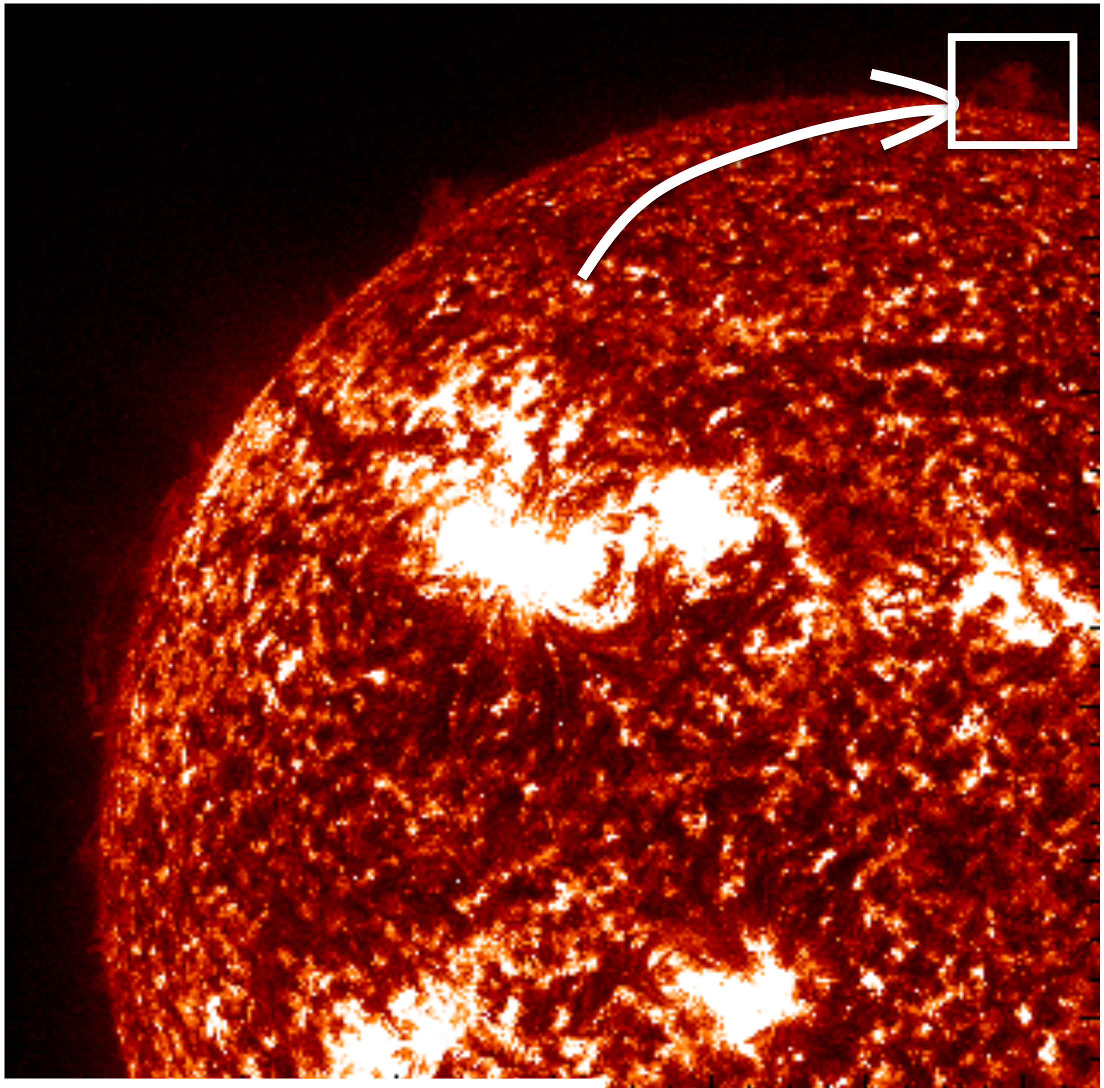
Evolution of coronal shock



SDO/AIA 193 running difference

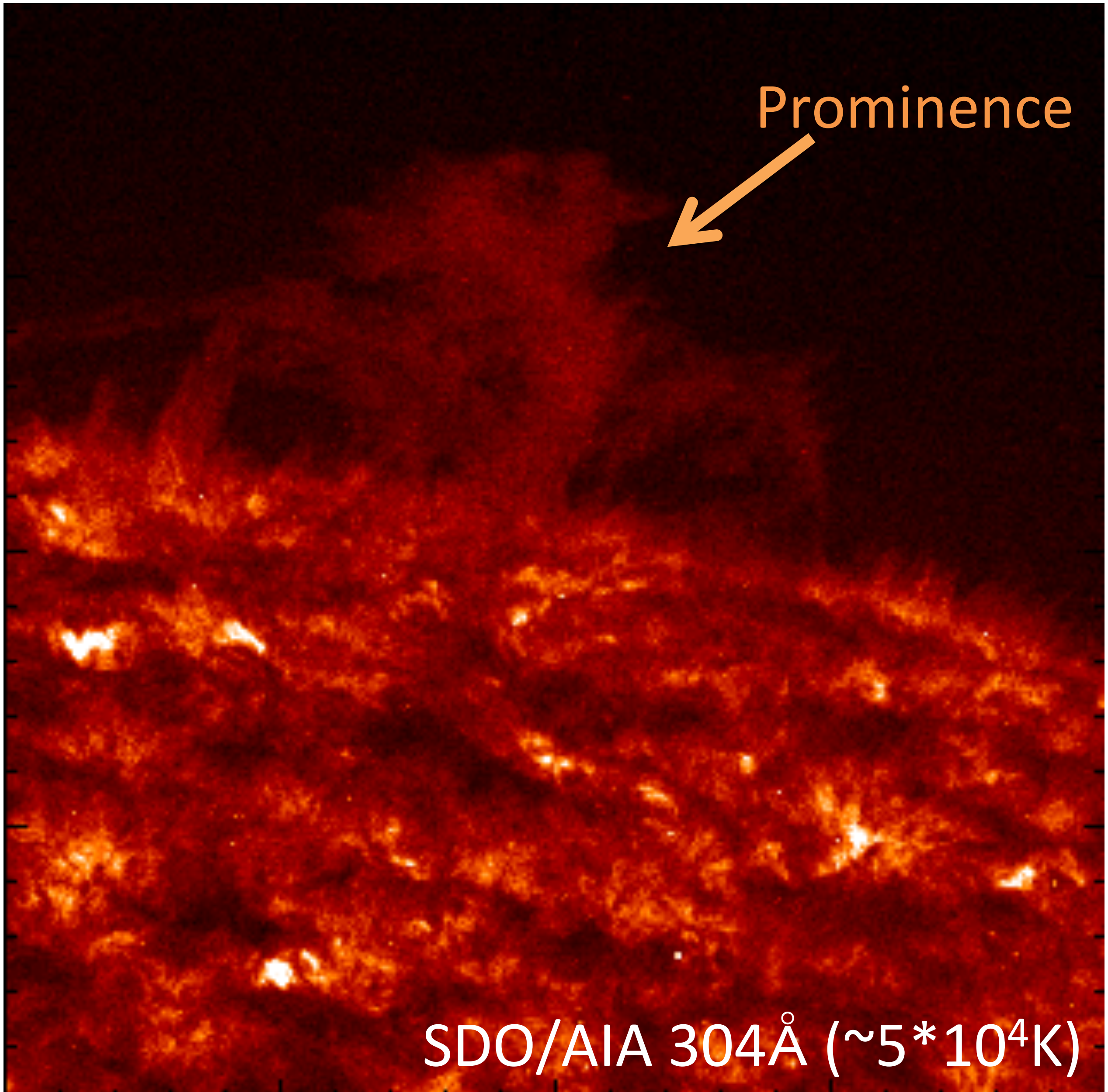


Coronal shock hit a prominence

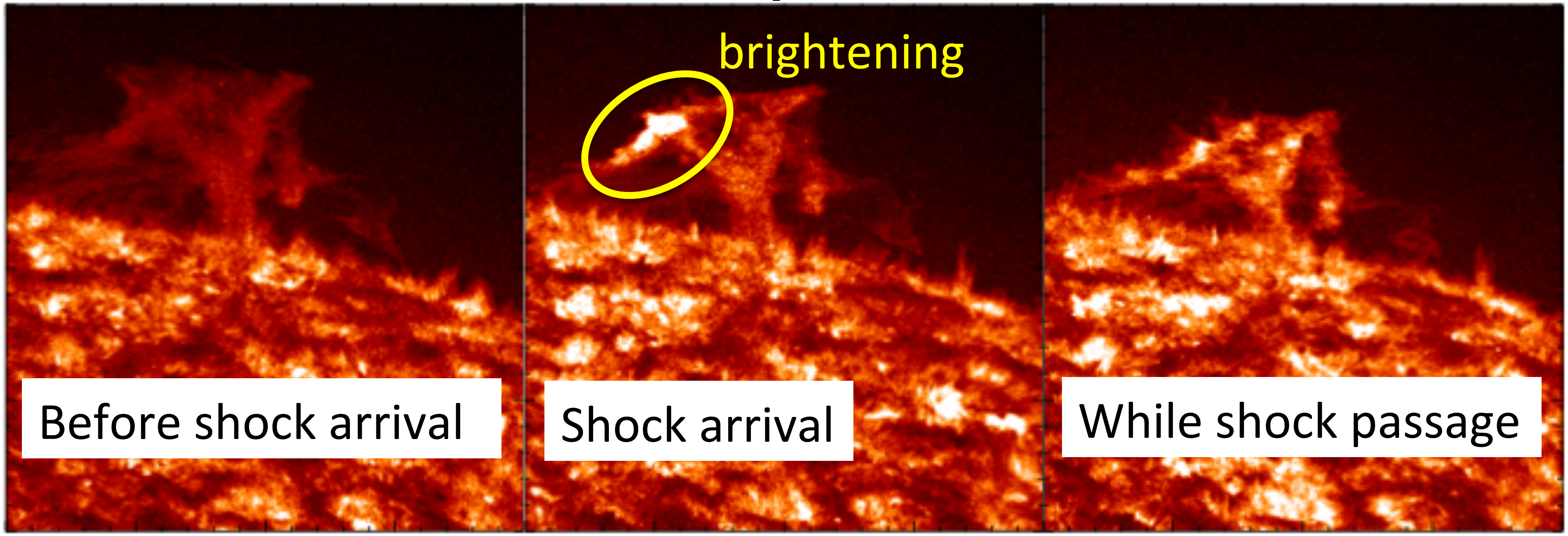


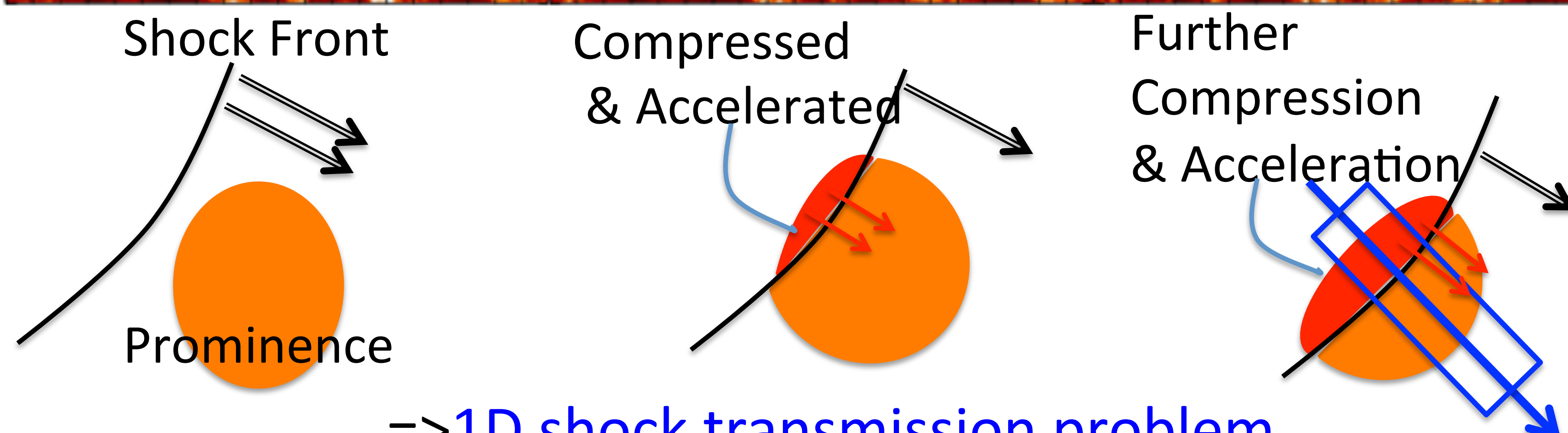
SDO/AIA304Å(~5*10^{4}K)

Prominence Activation



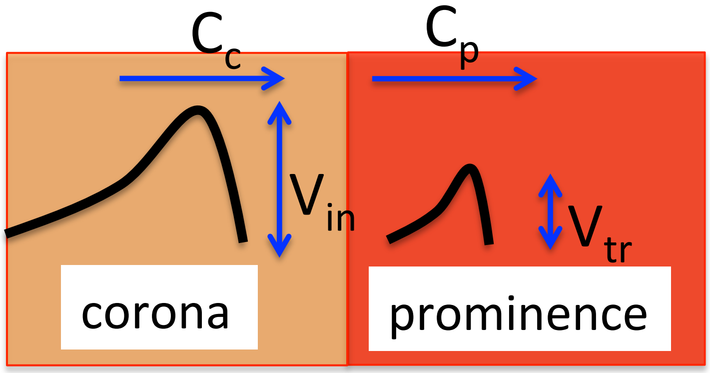
How fast mode shock wave activate a prominence

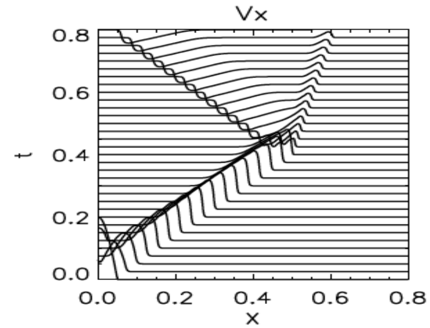




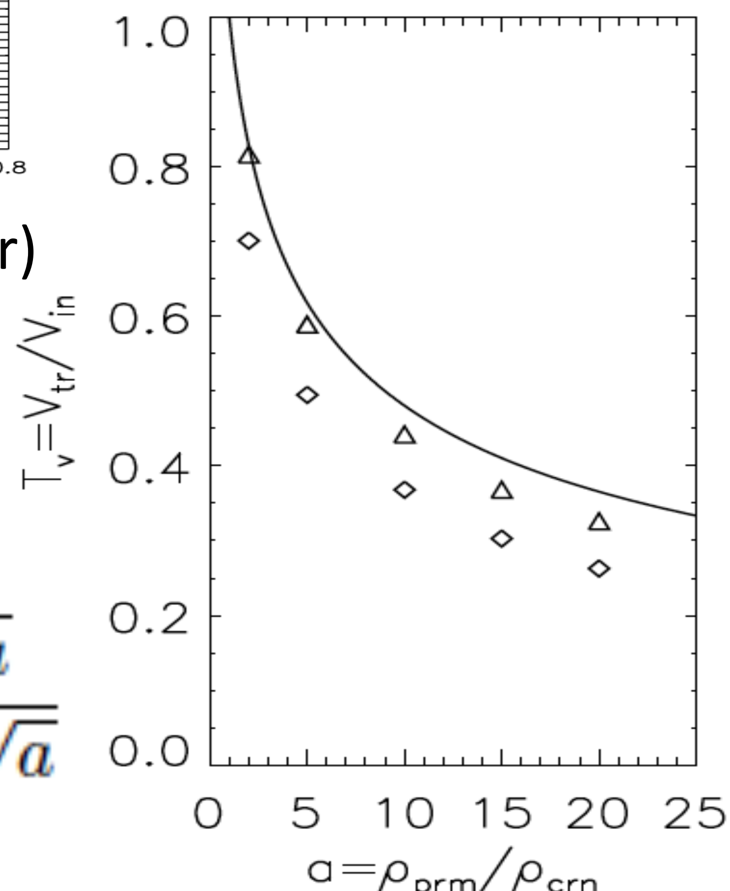
=>[1D shock transmission problem]

1D model of Prominence Activation





Comparison with Numerical simulation



- : linear analytic

△ : quasi linear case

◇ : shock case(M_f=1.17)

Conservation of Momentum & Energy (linear)

$$\rho_c \left({V_{in}}^2 - {V_{rf}}^2\right) C_c = \rho_p {V_{tr}}^2 C_p$$

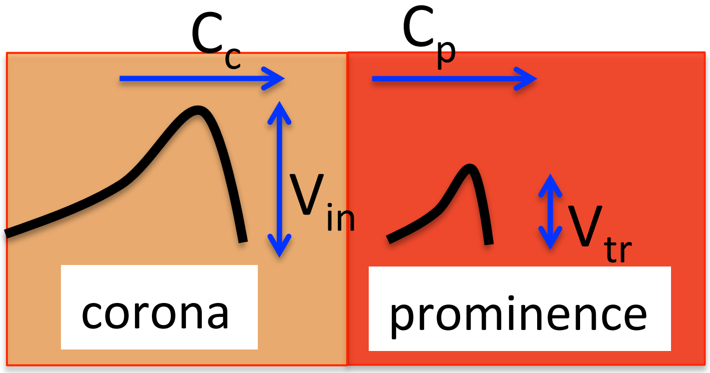
$$\rho_c \left(V_{in} - V_{rf}\right) C_c = \rho_p V_{tr} C_p$$

$$T_V = \frac{V_{tr}}{V_{in}} = \frac{2}{1+\sqrt{a}}, \quad r_{tr} = r_{in}\frac{2\sqrt{a}}{1+\sqrt{a}}$$

$$a = \frac{\rho_p}{\rho_c} = f_V \chi + (1 - f_V)$$

χ~100, f_V~0.001-0.1 ➔ a=1.1~10.9

Coronal shock quantity estimation



$$M_{f,in} = \sqrt{\frac{2r_{in}\left(\left(2-\gamma\right)r_{in} + \gamma\left(\beta_c + 1\right)\right)}{\left(\left(\gamma+1\right) - r_{in}\left(\gamma - 1\right)\right)\left(\gamma\beta_c + 2\right)}}$$

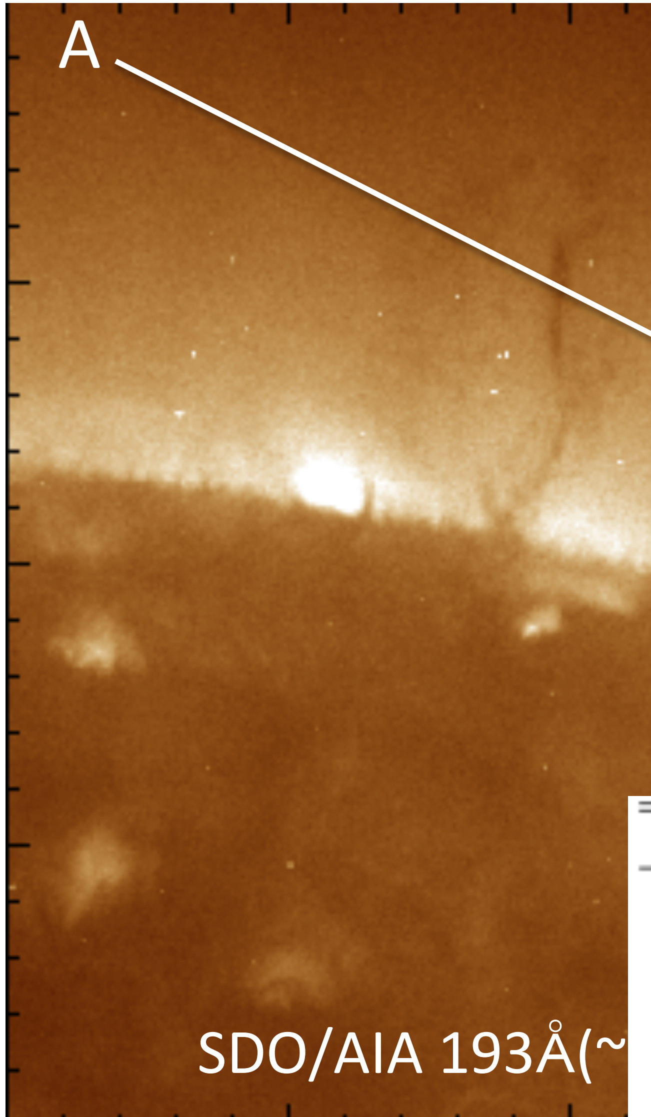
$$r_{in}^{-1} = \frac{C_c - V_{in}}{C_c} \quad \Rightarrow \quad r_{in}^{-1} = 1 - \frac{1+\sqrt{a}}{2}\frac{V_{tr}}{C_c}$$

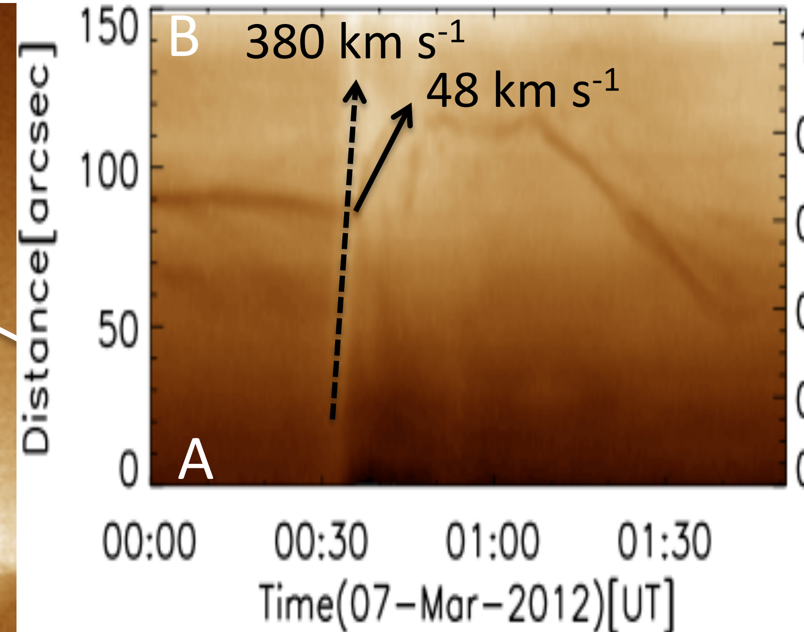
Activated Prominence

Coronal Shock Front

$$T_V = \frac{V_{tr}}{V_{in}} = \frac{2}{1+\sqrt{a}}$$

Estimation of M_f with prominence activation



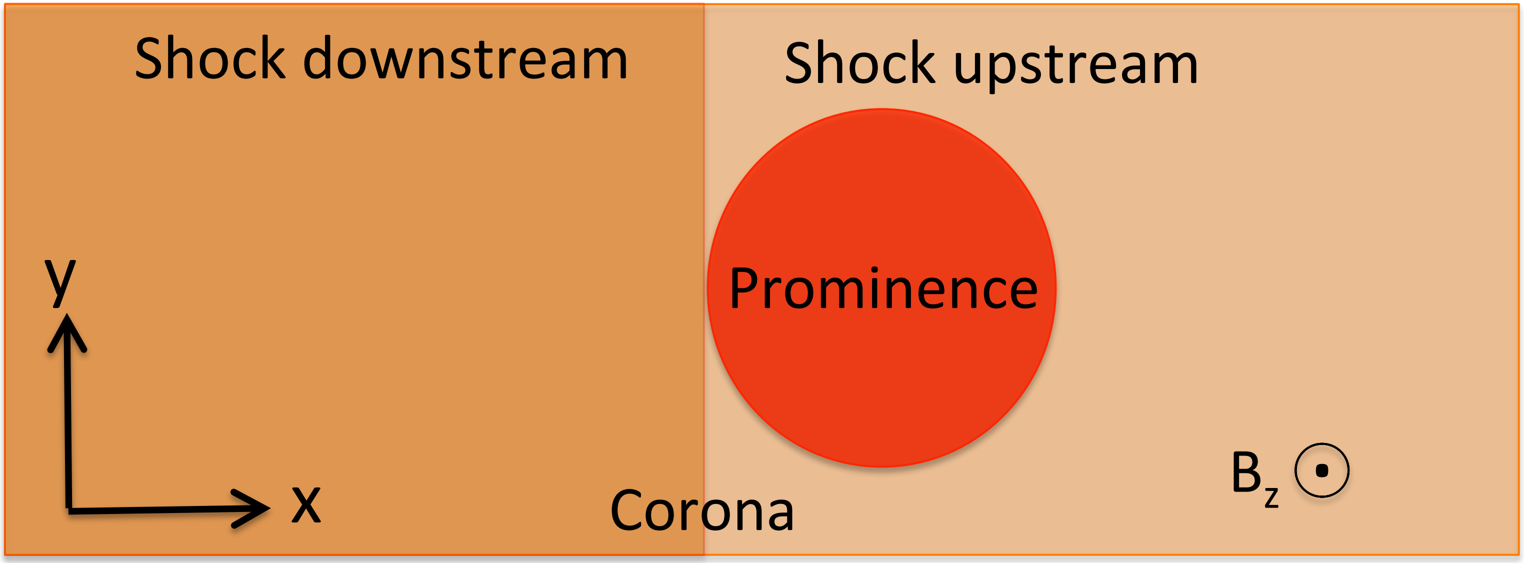


C_c = 380 km s^{-1}, V_{tr} = 48 km s^{-1}

f_V [a]	β_c [b]	r_c [c]	r_p [d]	$M_{f,c}$ [e]
0.001.	0.05	1.15	1.18	1.11
0.001	0.20	1.15	1.18	1.11
0.01	0.05	1.18	1.38	1.14
0.01	0.20	1.18	1.38	1.13
0.1	0.05	1.37	2.11	1.29
0.1	0.20	1.37	2.11	1.29

Takahashi et al.(2015)

2D Modeling of Prominence Activation



2D Ideal MHD equations

$$
\begin{aligned}
\frac{\partial \rho}{\partial t} &= -\frac{\partial}{\partial x}(\rho V_x) - \frac{\partial}{\partial y}(\rho V_y) \\
\frac{\partial}{\partial t}(\rho V_x) &= -\frac{\partial}{\partial x}(\rho V_x^2 + p + \frac{1}{8\pi}B_z^2) - \frac{\partial}{\partial y}(\rho V_x V_y) \\
\frac{\partial}{\partial t}(\rho V_y) &= -\frac{\partial}{\partial y}(\rho V_y^2 + p + \frac{1}{8\pi}B_z^2) - \frac{\partial}{\partial x}(\rho V_x V_y) \\
\frac{\partial B_z}{\partial t} &= -\frac{\partial}{\partial x}(V_x B_z) - \frac{\partial}{\partial y}(V_y B_z) \\
\frac{\partial e}{\partial t} &= -\frac{\partial}{\partial x}(h V_x) - \frac{\partial}{\partial y}(h V_y)
\end{aligned}
$$

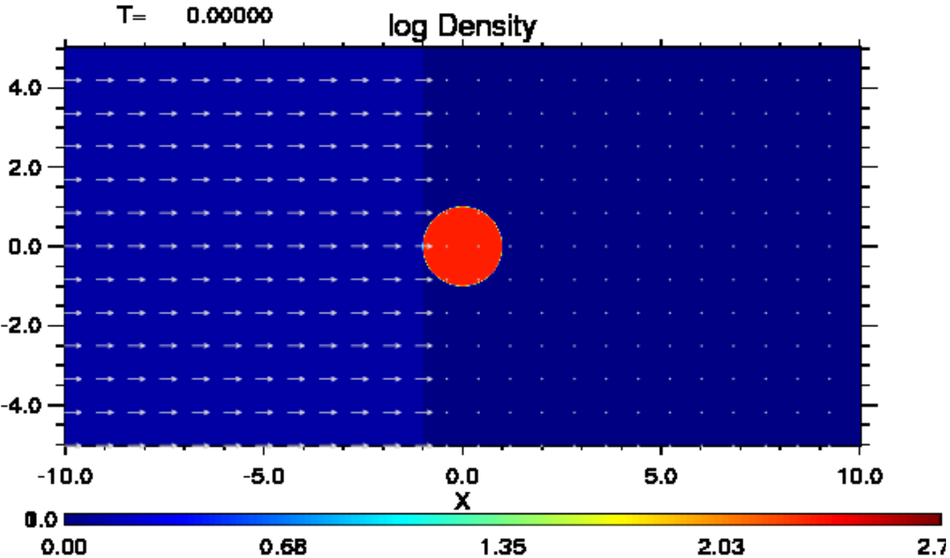
$$
\begin{aligned}
e &= \frac{1}{2}\rho(V_x^2 + V_y^2) + \frac{p}{\gamma - 1} + \frac{1}{8\pi}B_z^2 \\
h &= \frac{1}{2}\rho(V_x^2 + V_y^2) + \frac{\gamma}{\gamma - 1}p + \frac{1}{4\pi}B_z^2
\end{aligned}
$$

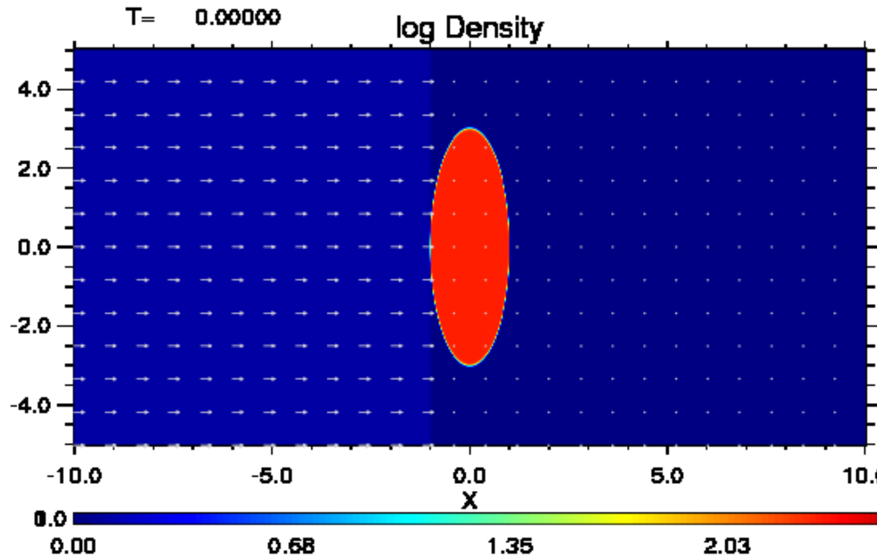
Parameters;

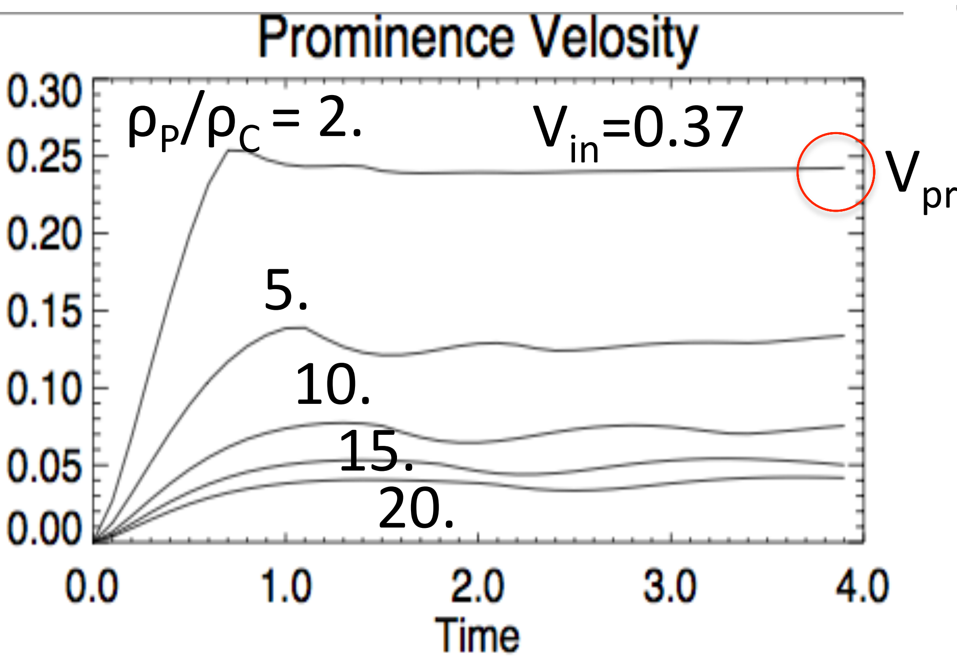
M_f=1.07, β=0.2

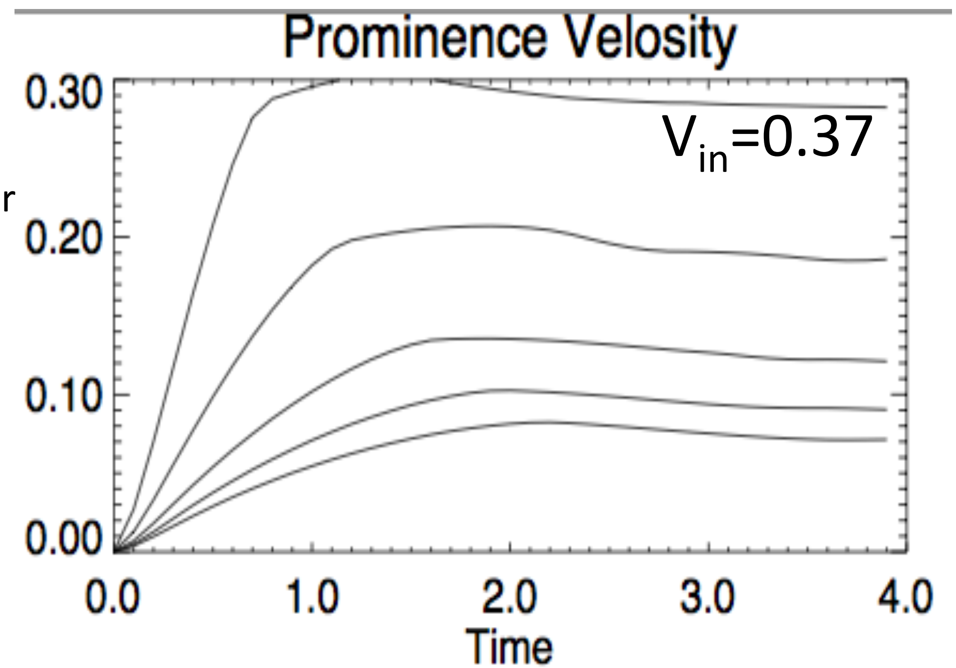
a=ρ_P/ρ_C=2, 5,10, 15, 20

Acceleration Profile

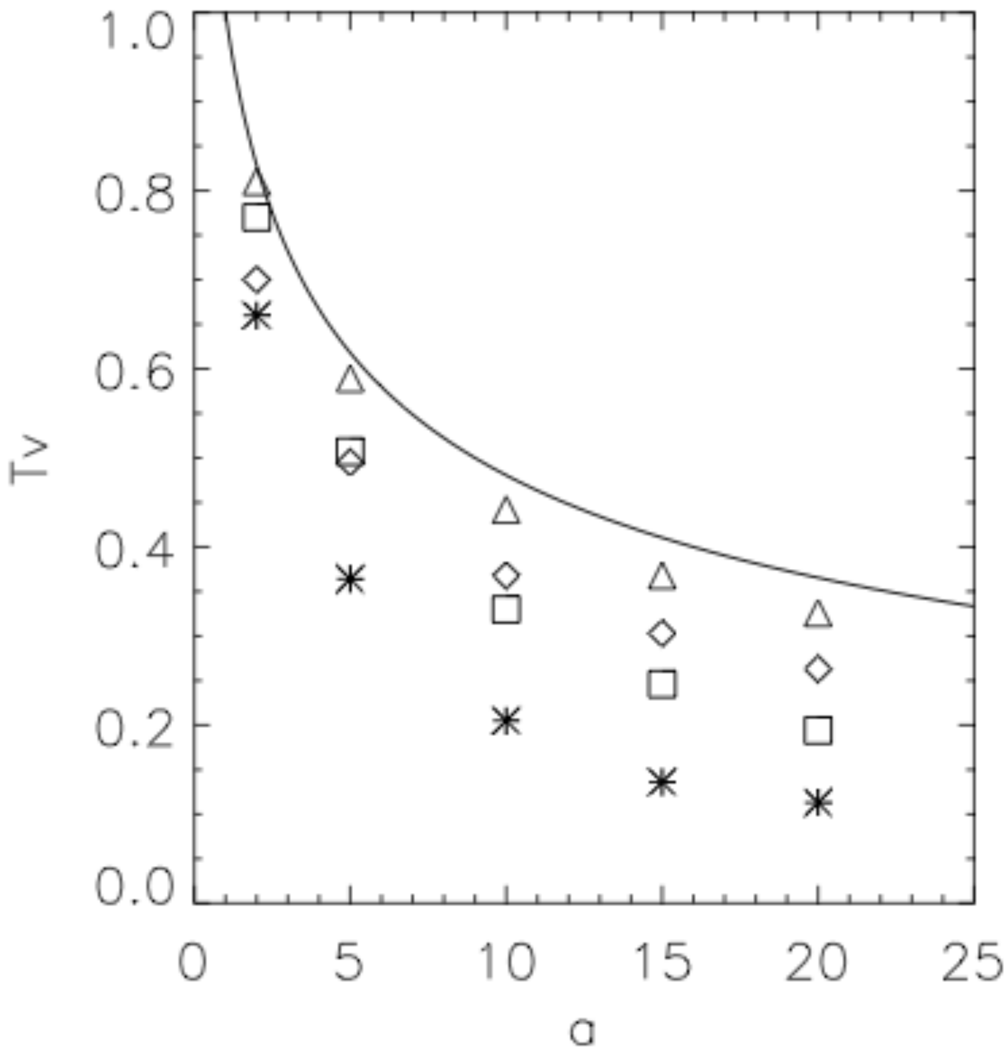








1D vs. 2D



- : linear analytic

△ : 1D quasi linear

◇ : 1D shock (M_f=1.17)

□ : 2D shock (M_f=1.07, elliptical)

* : 2D shock (M_f=1.07, circular)

Summary

1. Coronal shock wave is associated with a large flare on 3/7/2012.

2. The coronal shock hit a polar prominence and activated it.

3. While the activation, the prominence is strongly brightened.

4. We made shock-cloud interaction model of prominence activation.

5. The model expects that denser the cloud is,
   smaller the velocity will be and also stronger the compression will be.

6. The shape of the cloud is also an important factor which determines
   the acceleration profile of the activated prominence.