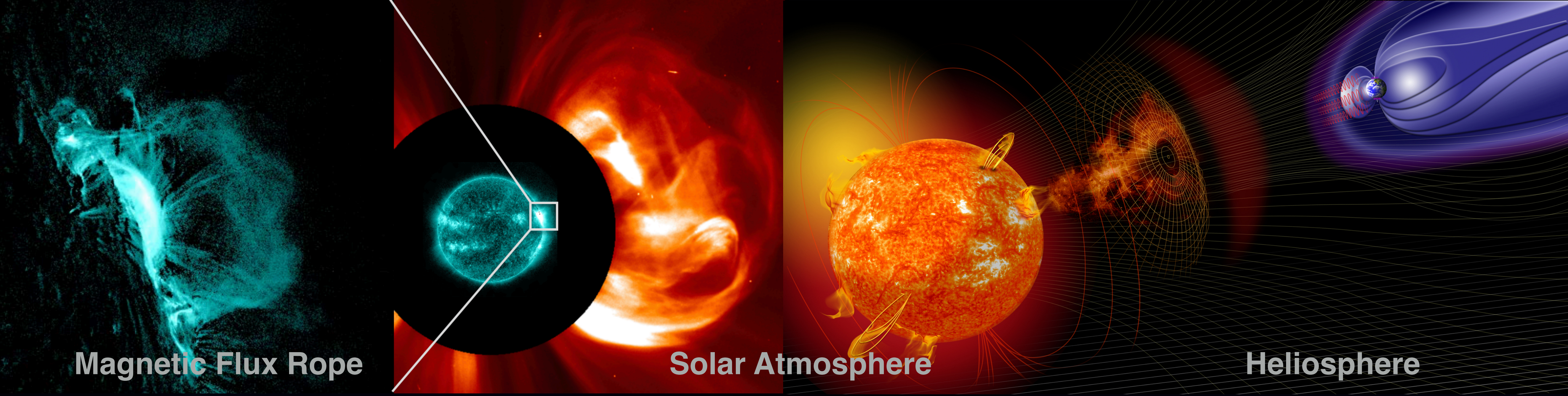

Initiation and Early Kinematics of Solar Eruptions

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Max-Planck-Institut für Sonnensystemforschung

Predictive Science, Inc.

Outline:

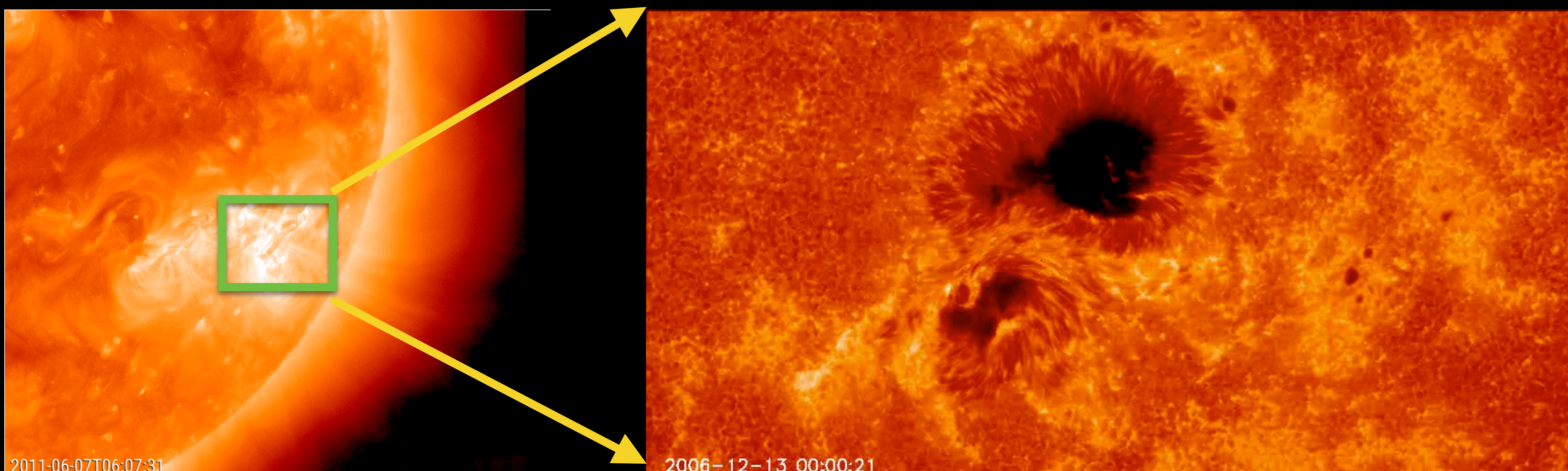
I.

II.

III.

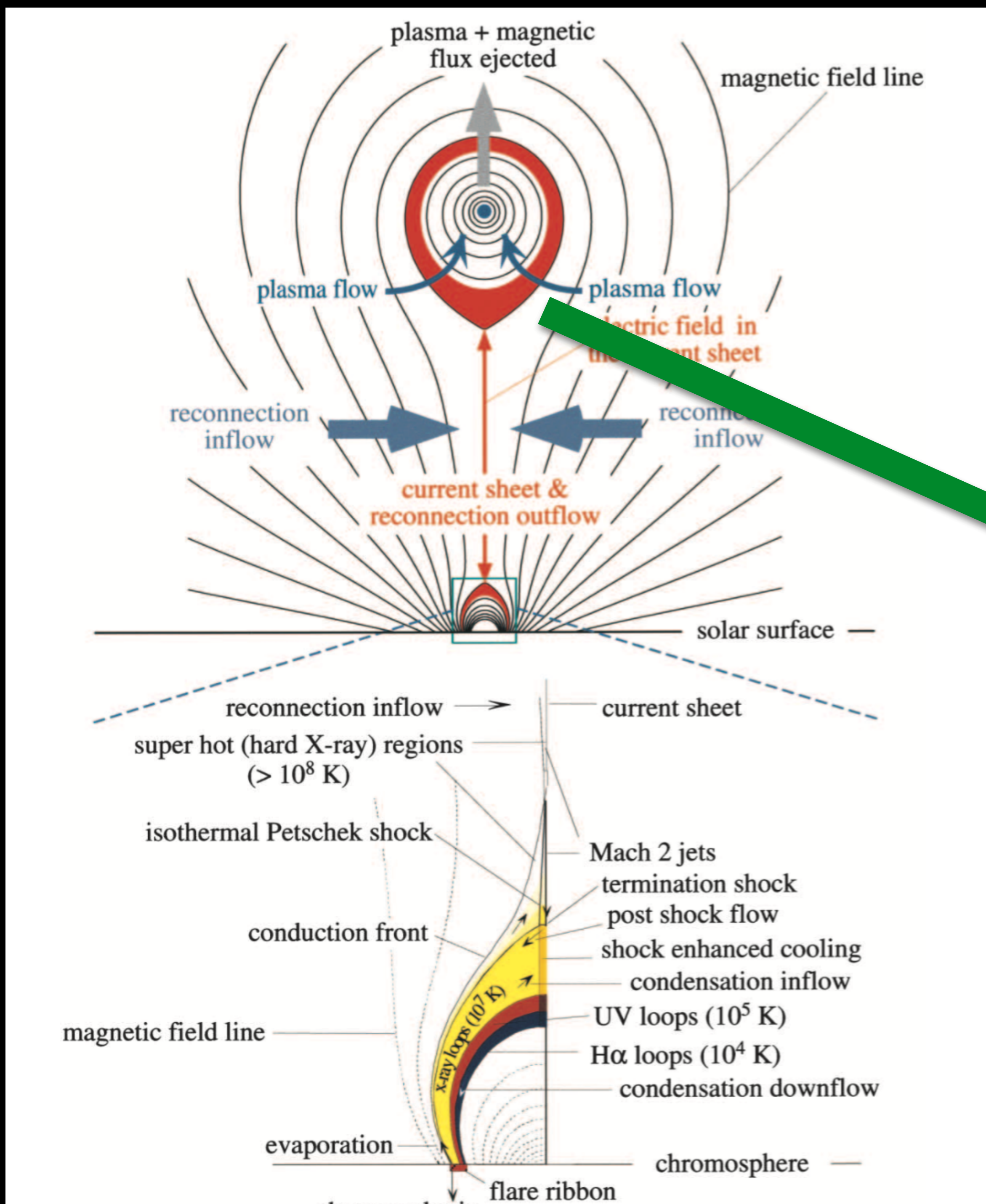
IV.

Two most explosive phenomena in our solar system: CMEs and Flares



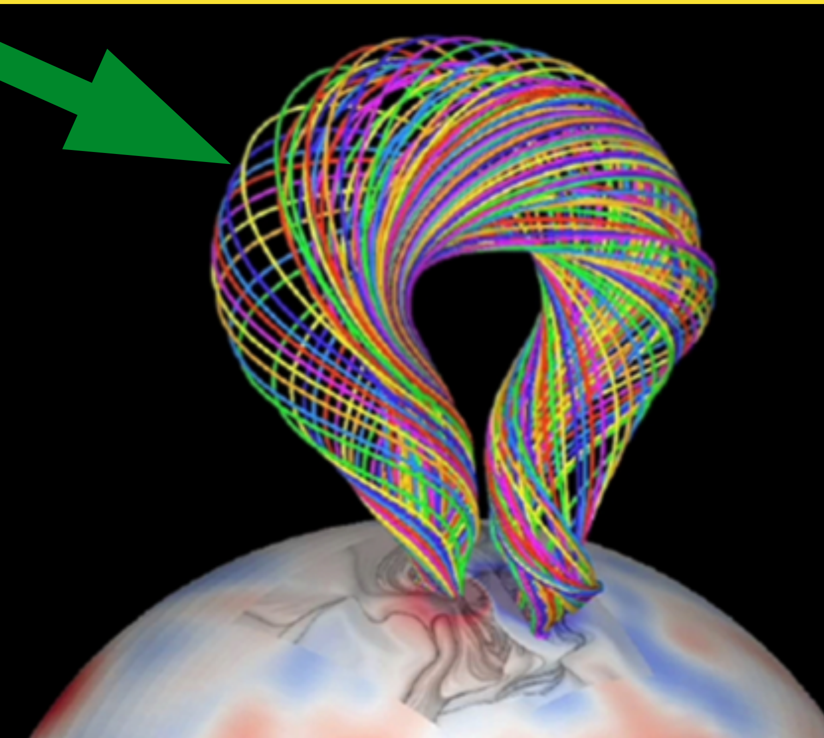
Expulsion of a large quantity of plasma and magnetic flux from the corona into solar wind…	*Sudden and rapid increase of the emission over the whole electromagnetic spectrum, two elongated ribbons in the chromosphere and bright loops in the corona…*

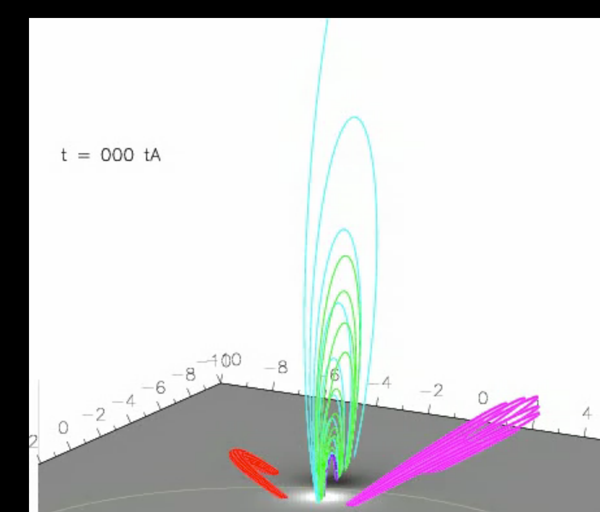
CME/flare models



(Lin & Forbes 2000)

Magnetic flux rope is believed to be the fundamental structure in the solar atmosphere. It erupts upward to become a CME and gives rise to a flare underneath at the same time (Shafranov 1966; Chen 1989; Forbes & Isenberg 1991; Shibata 1995; Titov & Demoulin 1999).



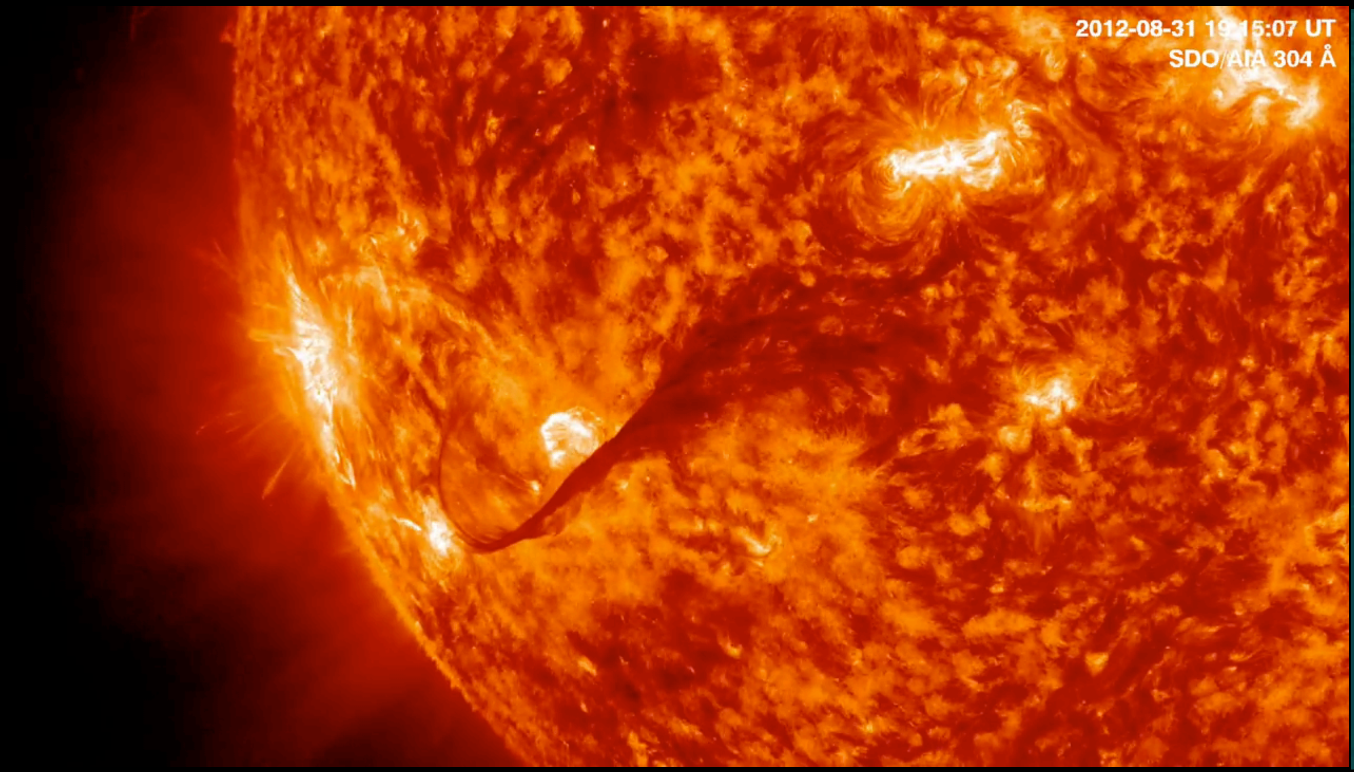


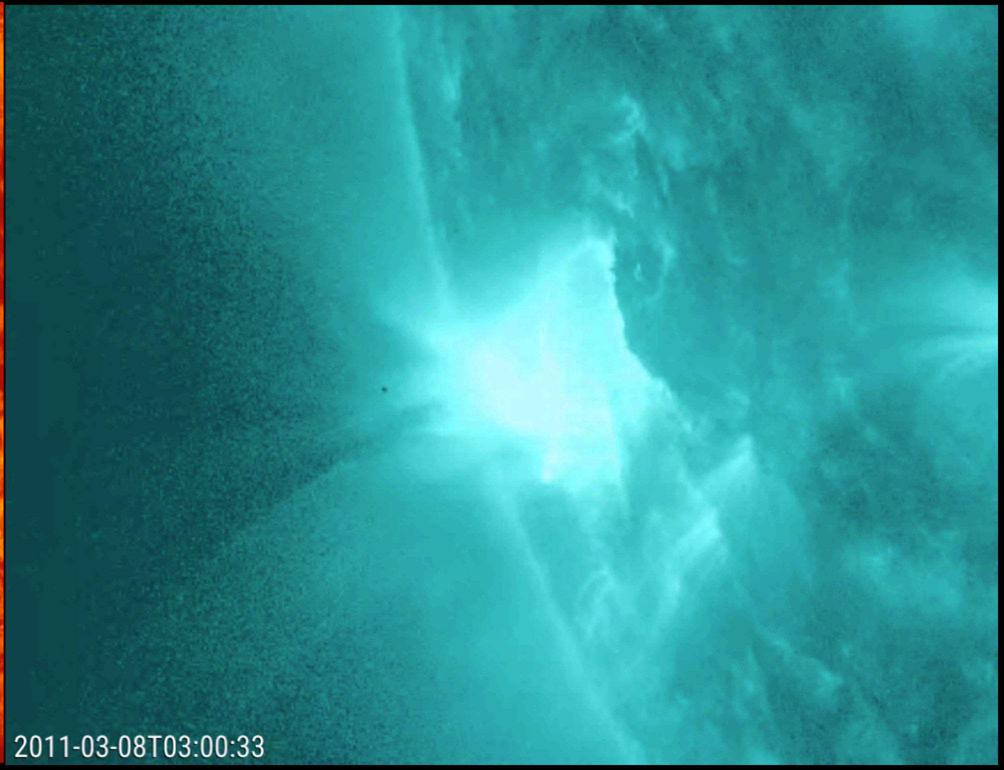
(Aulanier et al. 2010)

Two manifestations of flux rope

Filaments

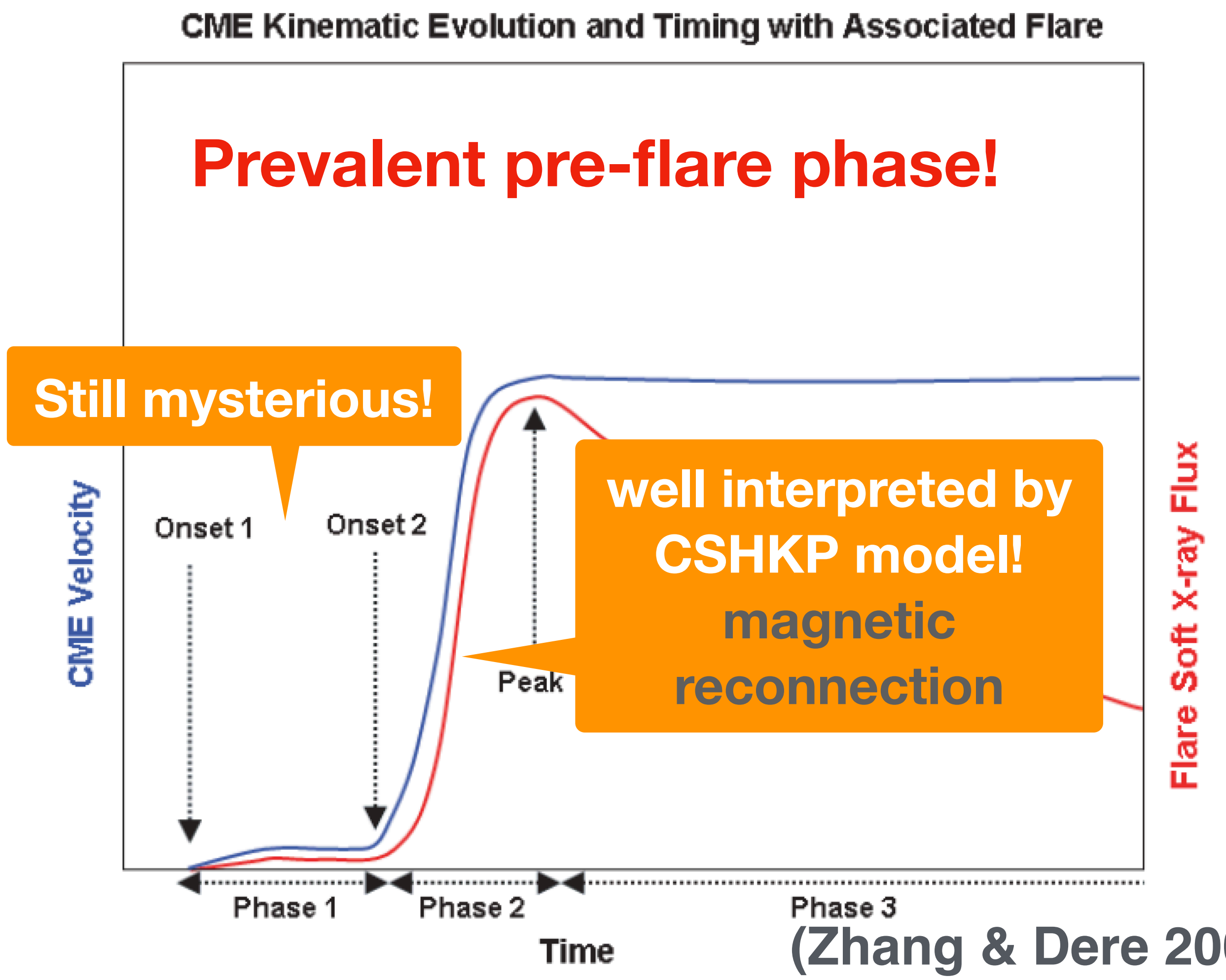
Hot channel





- ☑ **Filaments: Collection of cool and dense plasma in the hot and tenuous corona.**
- ☑ **Hot Channels: EUV high temperature coherent structure in the AIA 131 and 94 passbands.**

Motivation:



(Zhang & Dere 2006)

Three-phase of CME/flares:

Such a pre-flare seems to be prevalent!

Kinematic evolution

Motivation:

To distinguish initiation models

Reconnection type

1. **Tether-Cutting** (Moore & Labonte 1980…)
2. **Breakout** (Antiochos et al. 1999)
3. **Flux Emergence** (Chen & Shibata 2000)

Ideal MHD type

1. **Torus Instability** (Kliem & Torok 2006; Olmedo & Zhang 2010; Démoulin & Aulanier 2010)
2. **Kink Instability** (Hood & Priest 1981; Torok & Kliem 2004…)
3. **Loss of equilibrium** (Forbes & Isenberg 1991…)

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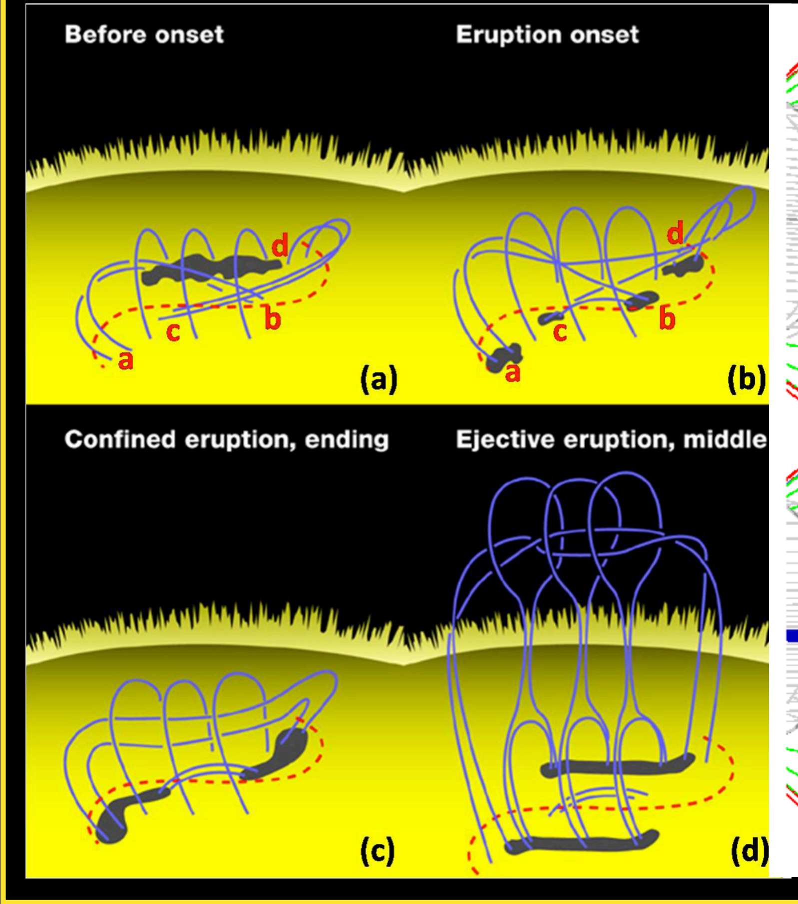

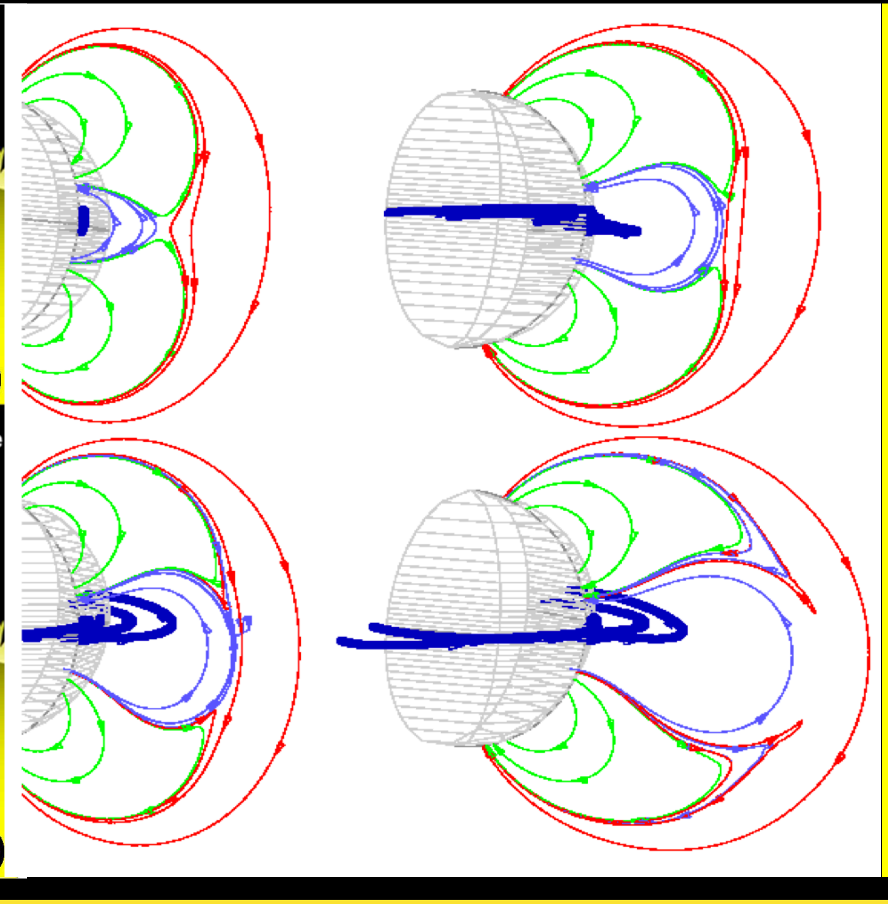

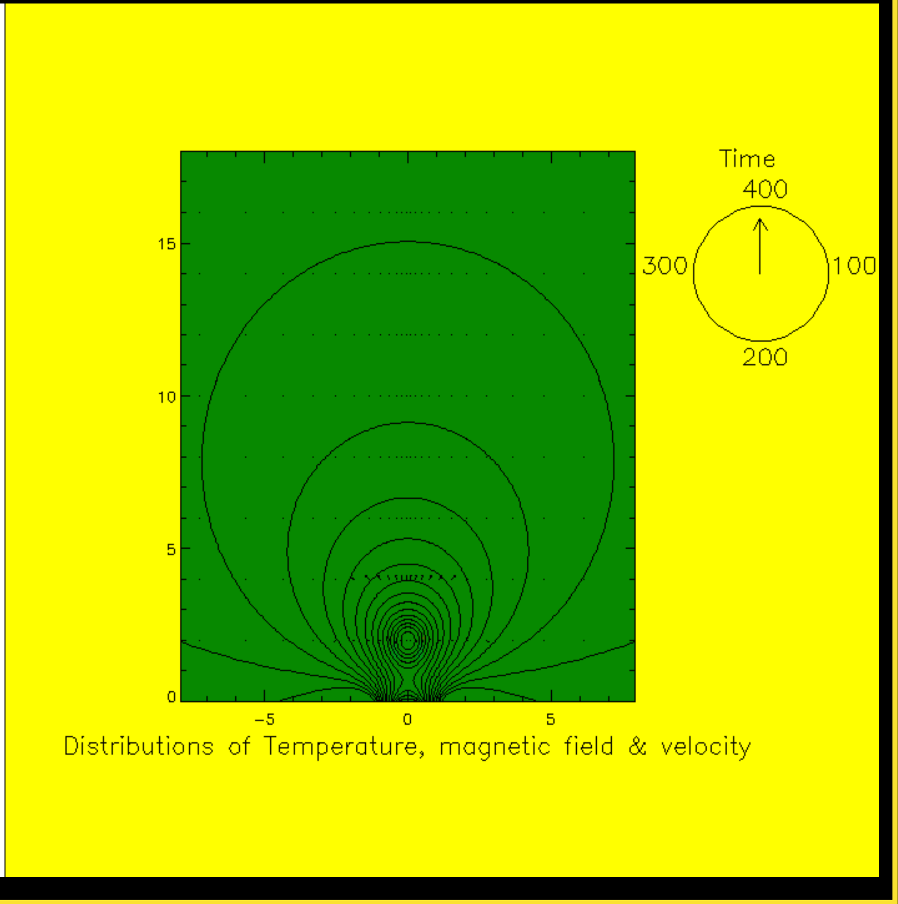

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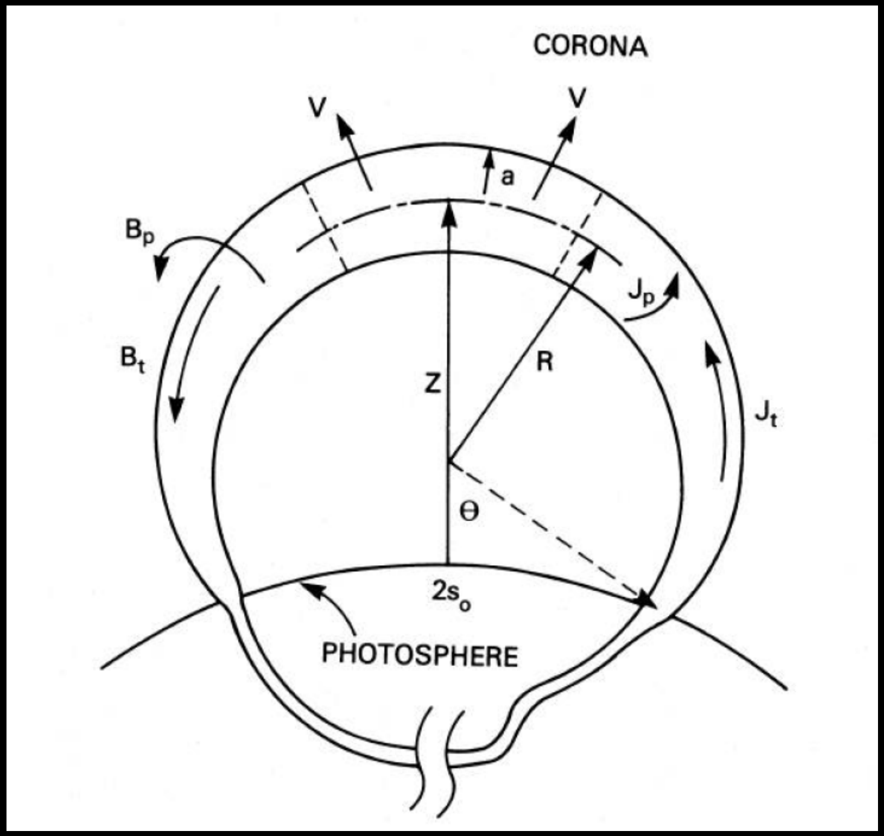
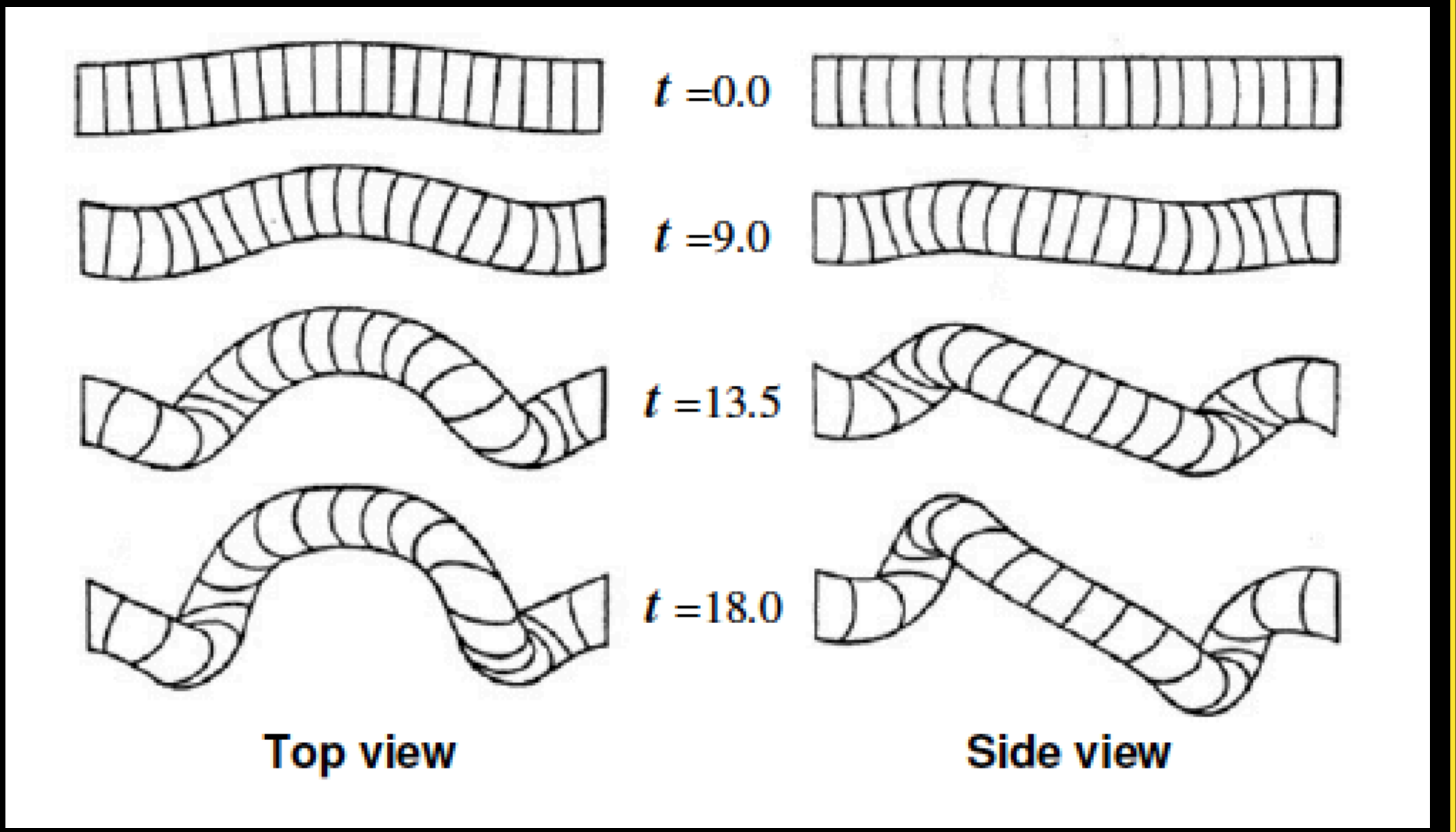




Motivation:

Some valuable characteristics

- A break exists in the early H-T profiles? if yes, against the tether-cutting model (Moore et al. 2001) as only one process—“runaway” reconnection—drives the eruptions

- Temporal offset between H-T profile and flare light (Fsxr) curve, favors ideal MHD (reconnection) models if H-T profile (Fsxr) precedes.

- Correlation between the onset of eruptions, either the slow-rise phase or main-acceleration phase, and the threshold of torus or kink instability favors ideal MHD models, as it is not required in reconnection models.

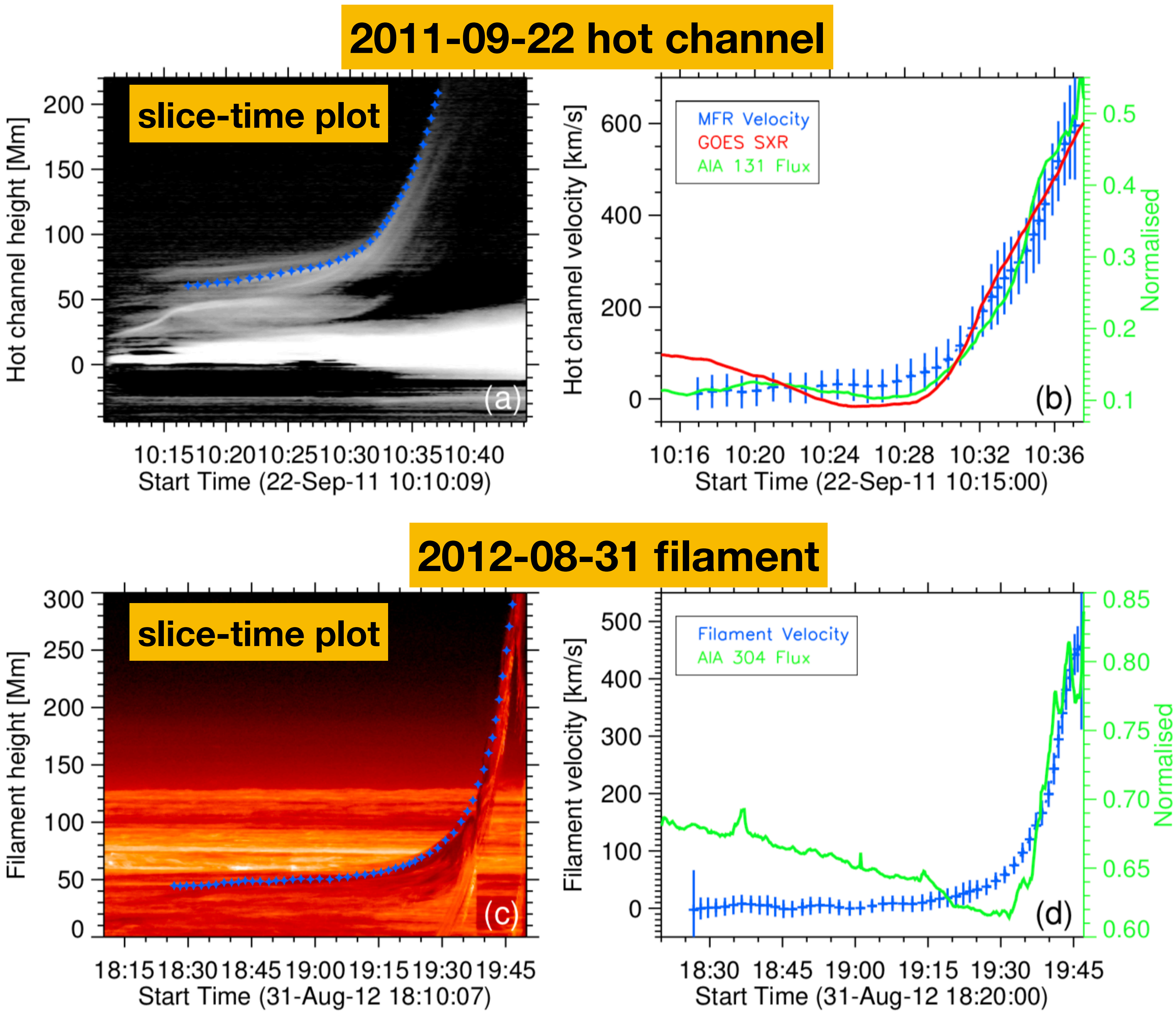
Event list:

		Hot Channel Eruptions			
		Quiescent Filament Eruptions			

From strong B region

From weak B region

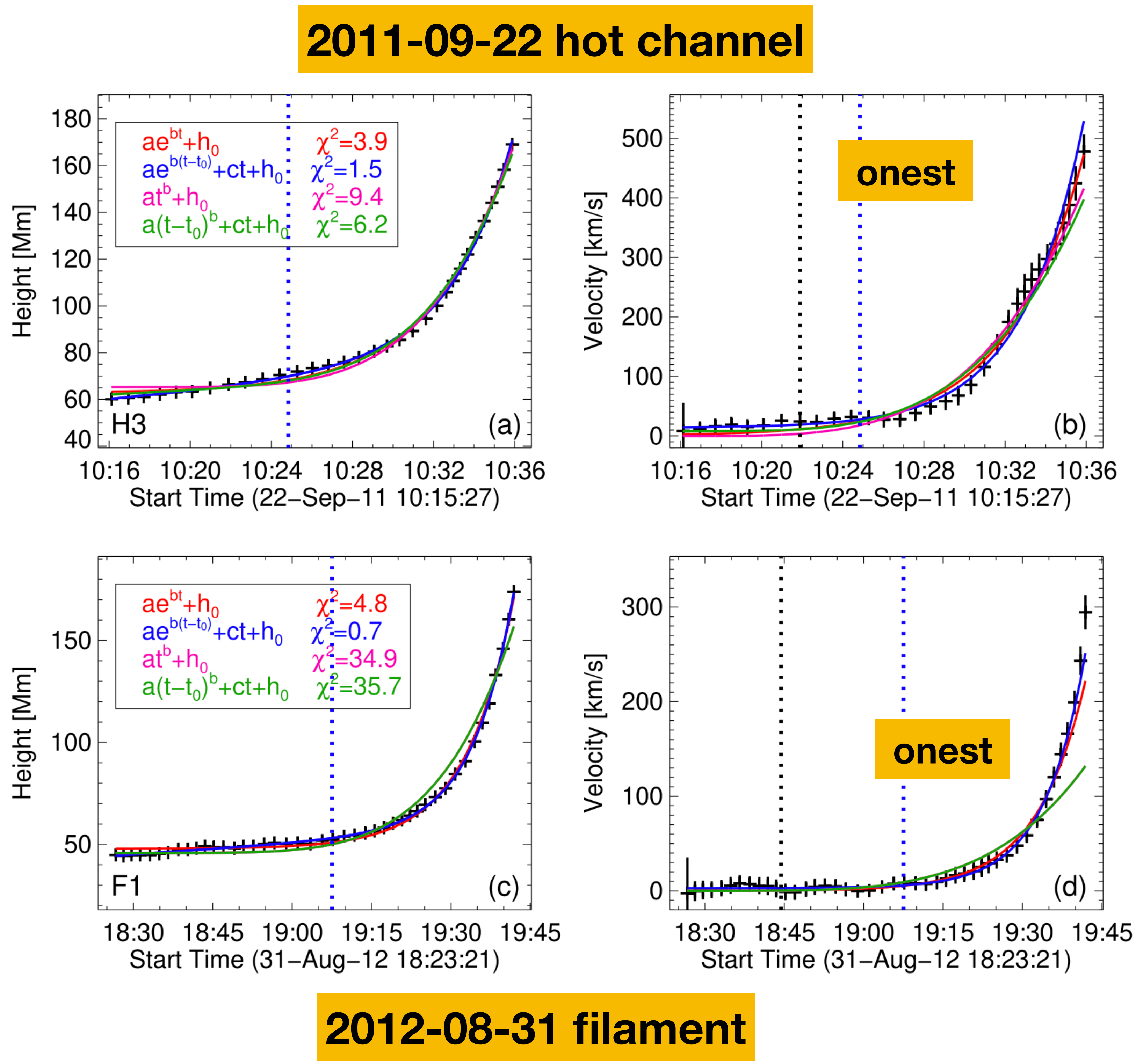
H-T profiles of CMEs in the early phase



- two phases
- 10 mins
- very long duration
- synchronized with

synchronized in the main phase for filaments.

Fit the early evolution of CMEs



- an exponential

  power law

-

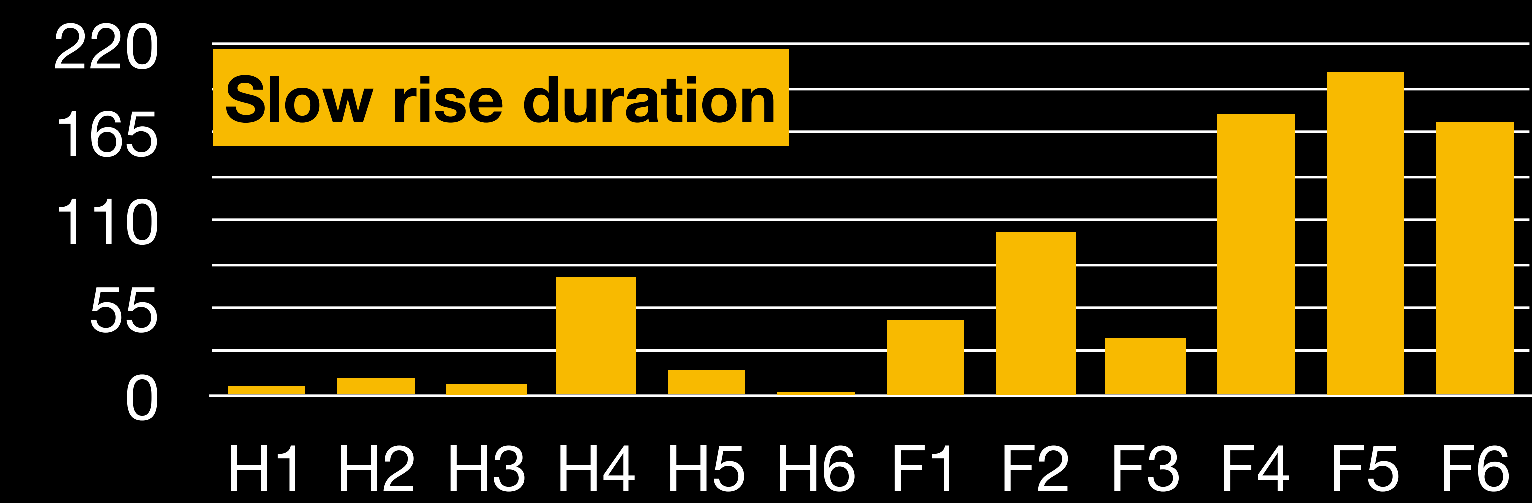
-

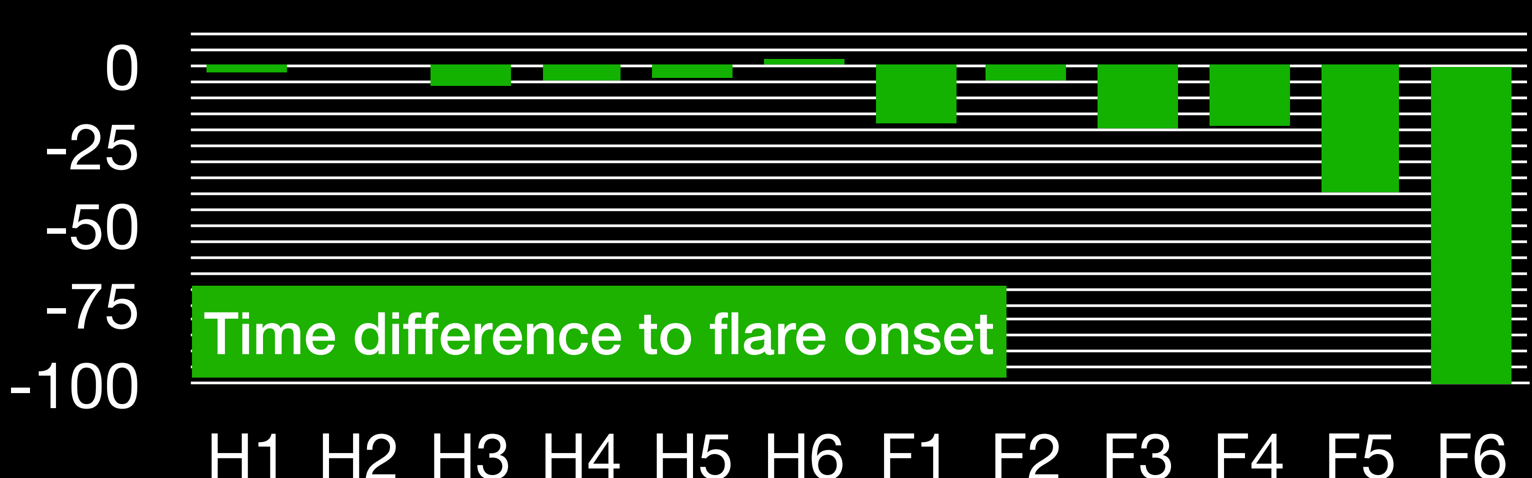
$$h_1(t) = a_1 \exp(b_1 t) + d_1,$$
$$h_2(t) = a_2 \exp[b_2(t - t_0)] + c_2 t + d_2,$$
$$h_3(t) = a_3 t^{b_3} + d_3,$$
$$h_4(t) = a_4 (t - t_0)^{b_4} + c_4 t + d_4,$$

- onset of the main-acceleration

Table 2. Metrics for fitting goodness of different functions.

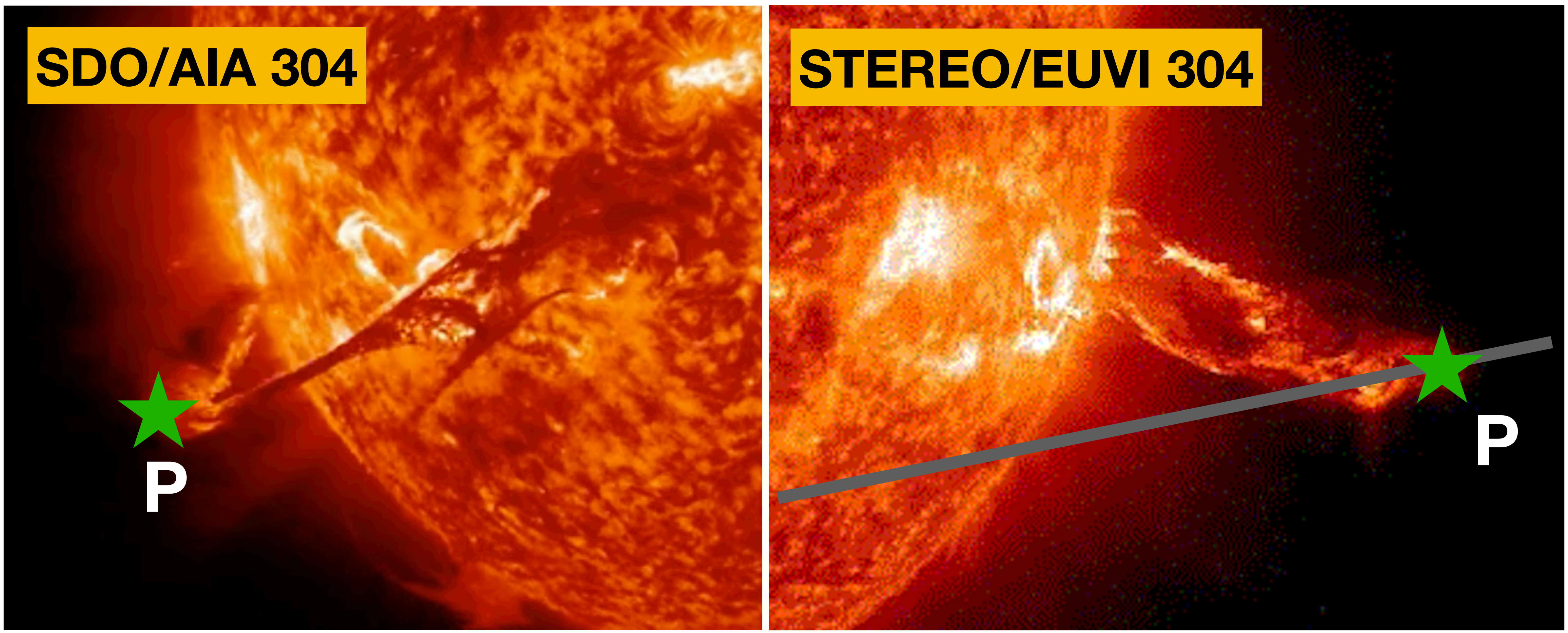
Events	$a_1 e^{b_1 t}+h_0$	$a_2 e^{b_2(t-t_0)}+c_2 t+h_0$	$a_3 t^{b_3}+h_0$	$a_4(t-t_0)^{b_4}+c_4 t+h_0$
	$\chi^2_{\nu 1}$	$\chi^2_{\nu 2}$	$\chi^2_{\nu 3}$	$\chi^2_{\nu 4}$
H1	3.7	0.5	12.7	1.0
H2	10.6	0.9	16.1	5.4
H3	3.9	1.5	9.4	6.2
H4	37.0	1.7	62.6	17.3
H5	2.6	2.8	9.5	1.8
H6	3.5	3.8	1.7	1.5
F1	4.8	0.7	34.9	35.7
F2	4.5	1.4	7.6	9.1
F3	3.7	0.5	6.0	3.7
F4	14.5	1.6	29.2	33.1
F5	42.2	1.5	926.3	949.8
F6	7.8	0.9	18.8	21.7





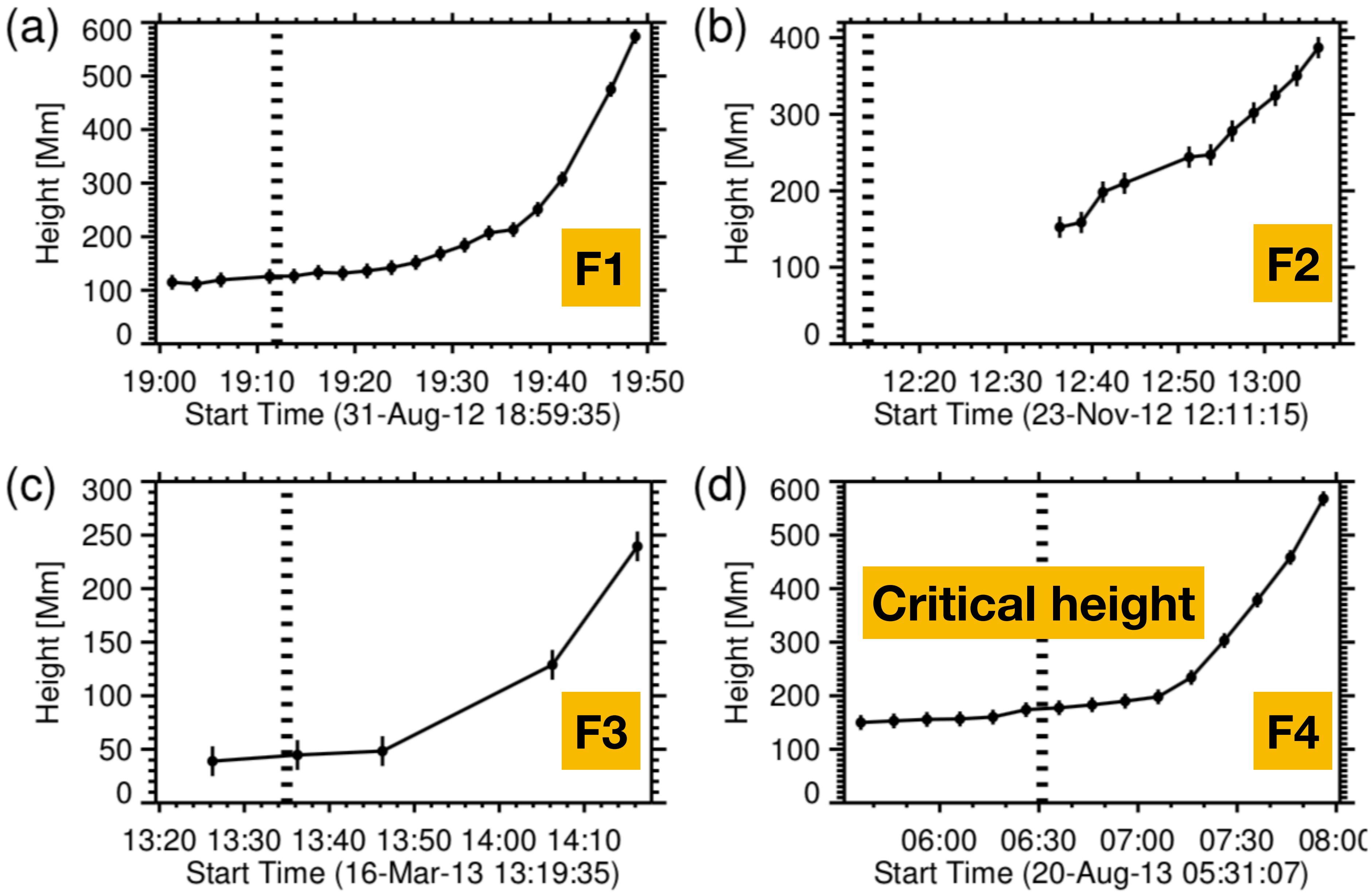
- The best one is the function consisted of the linear + exponential (9) or power-law (3),
- Duration of the slow-rise phase for the hot channels (several mins) is mostly shorter than that of the filaments (>35 mins)
- For hot channels, the time difference is very small, the speed evolution is completely synchronised with the variation of the flare emission,
- For quiescent filaments, the time difference is large, the main-acceleration starts earlier than that of flares.

3D height of filaments



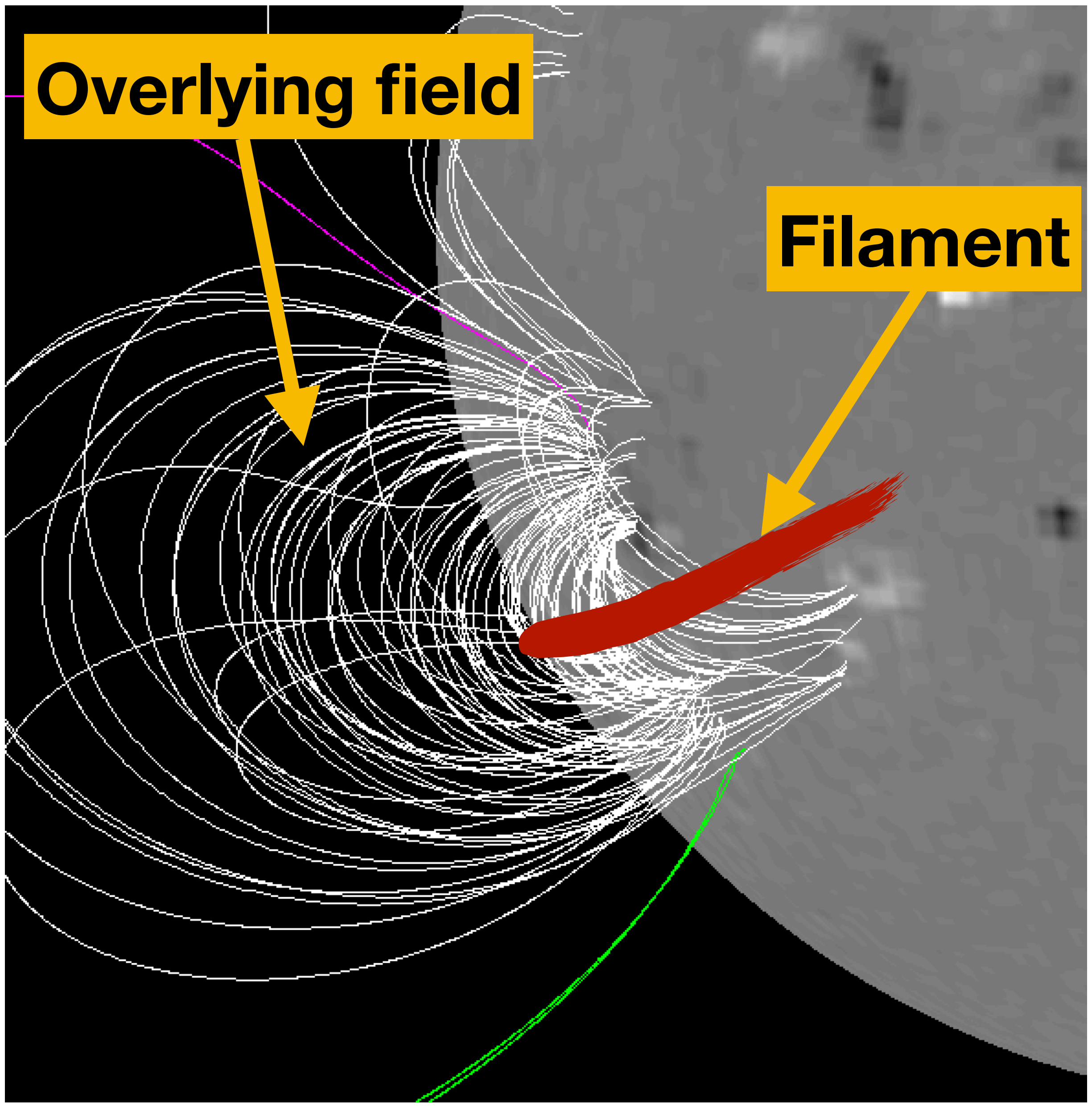
Determining 3D locations (r, Lon, Lat) of filament top by SCC_measure.pro

3D heights of filaments



critical height

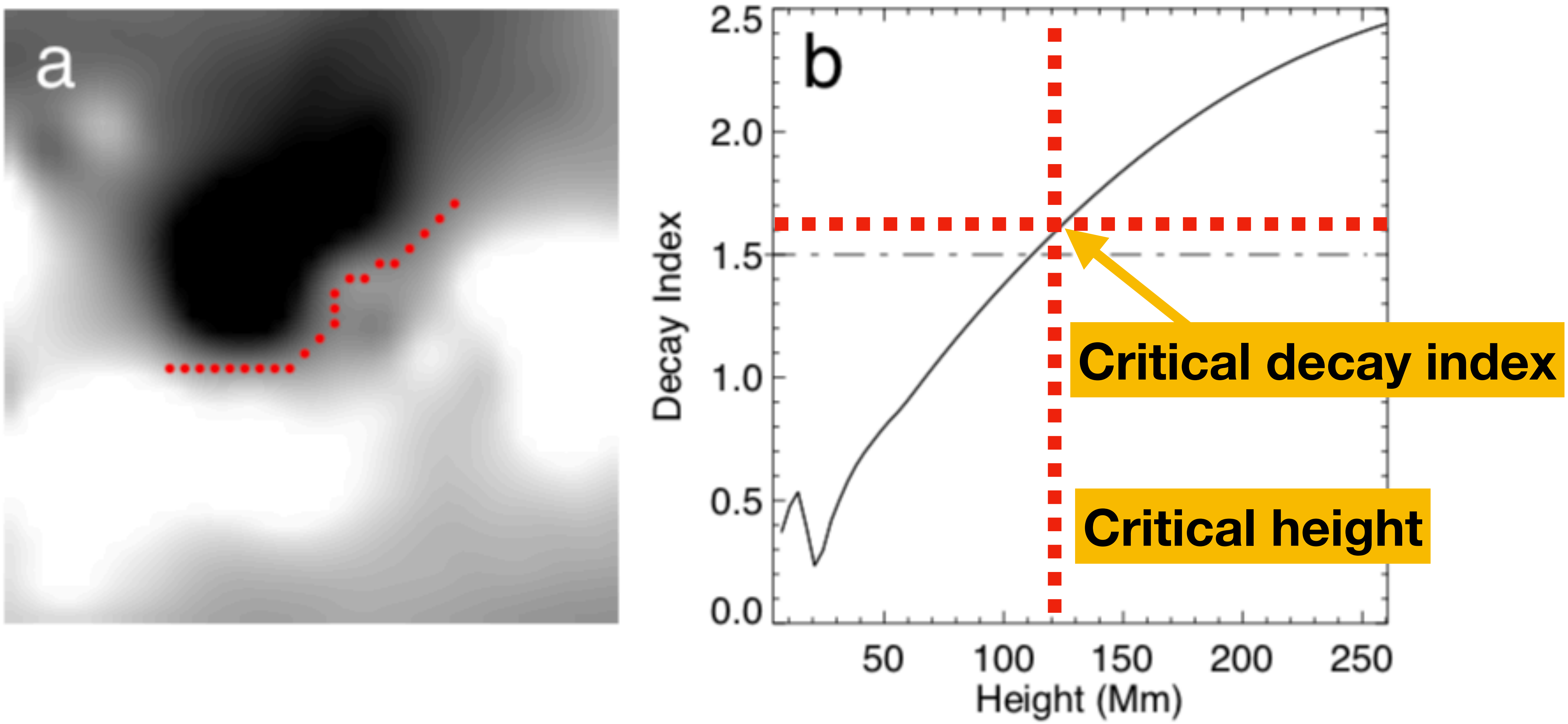
Calculating the background field



- For hot channels, we estimate the background magnetic field through potential field model based on HMI line-of-sight data before or after the eruptions.

- For quiescent filaments, we calculate 3D field through PFSS model based on daily updated synoptic map.

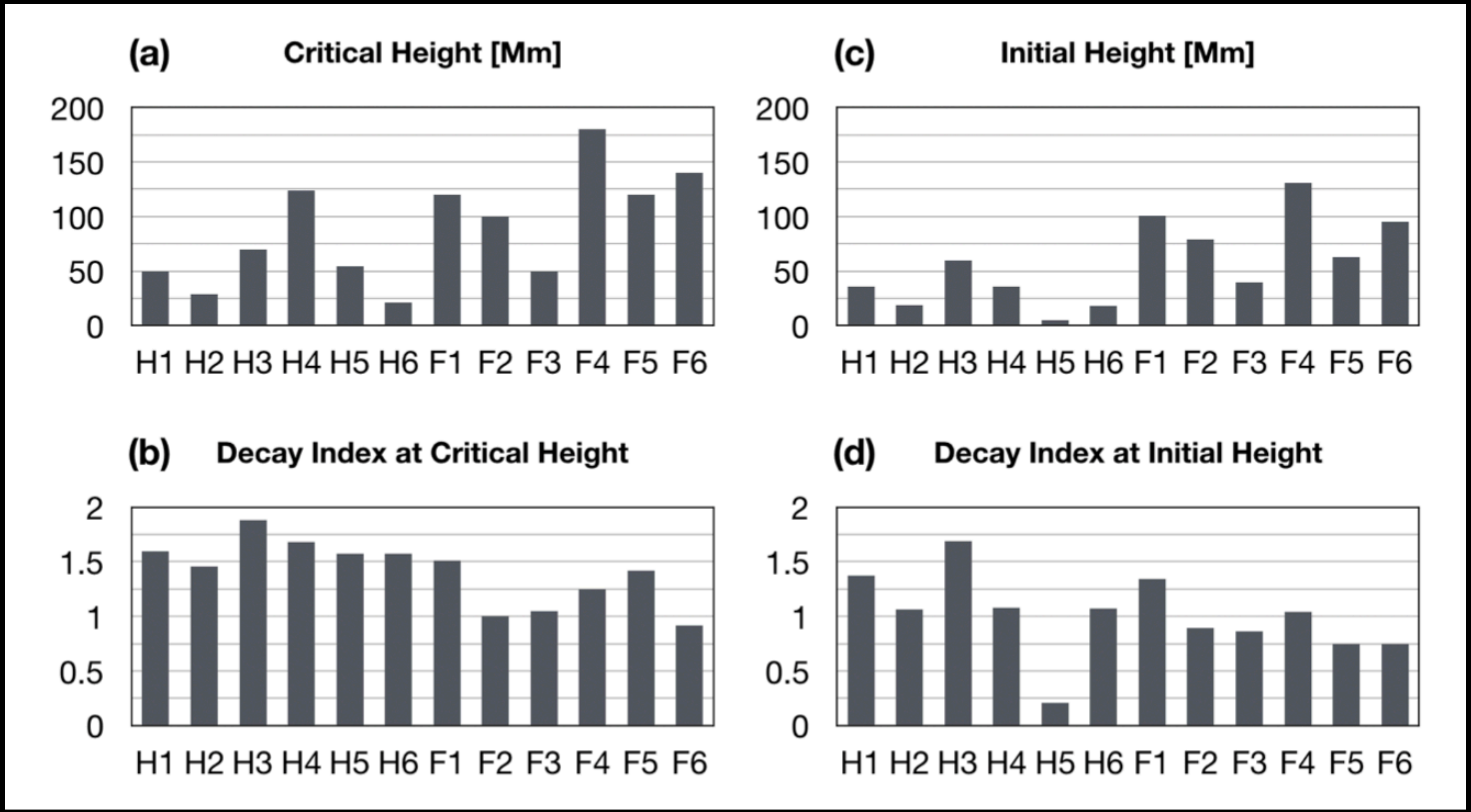
Determining critical decay index



Calculating the distribution of the decay index above hot channels or filaments:

$$n = -\frac{d\,(\ln B_h)}{d\,(\ln h)}$$

Decay index values at critical and initial heights



- The critical heights for the hot channels are systematically smaller than those for the filaments.
- The critical decay indices for the former, ranging from 1.46±0.08 to 1.88±0.03 with an average of about 1.6, are greater than those for the latter, which in the range of 0.92±0.11–1.51±0.24 with an average of 1.2.
- The values for the hot channels are close to the threshold of the torus instability for the circular flux rope (1.4–1.9; Torok & Kliem 2005; Kliem & Torok 2006; Fan & Gibson 2007; Aulanier et al. 2010) and the values for the quiescent filaments are comparable with the threshold for the straight flux rope (1.1–1.3; Forbes & Isenberg 1991; Demoulin & Aulanier 2010)
- The decay indices at initial heights of hot channels, ranging from 0.21±0.12 to 1.69±0.04 with an average of about 1.1, that for the filaments in the range of 0.75±0.14–1.34±0.27 with an average of 0.9.

Conclusions:

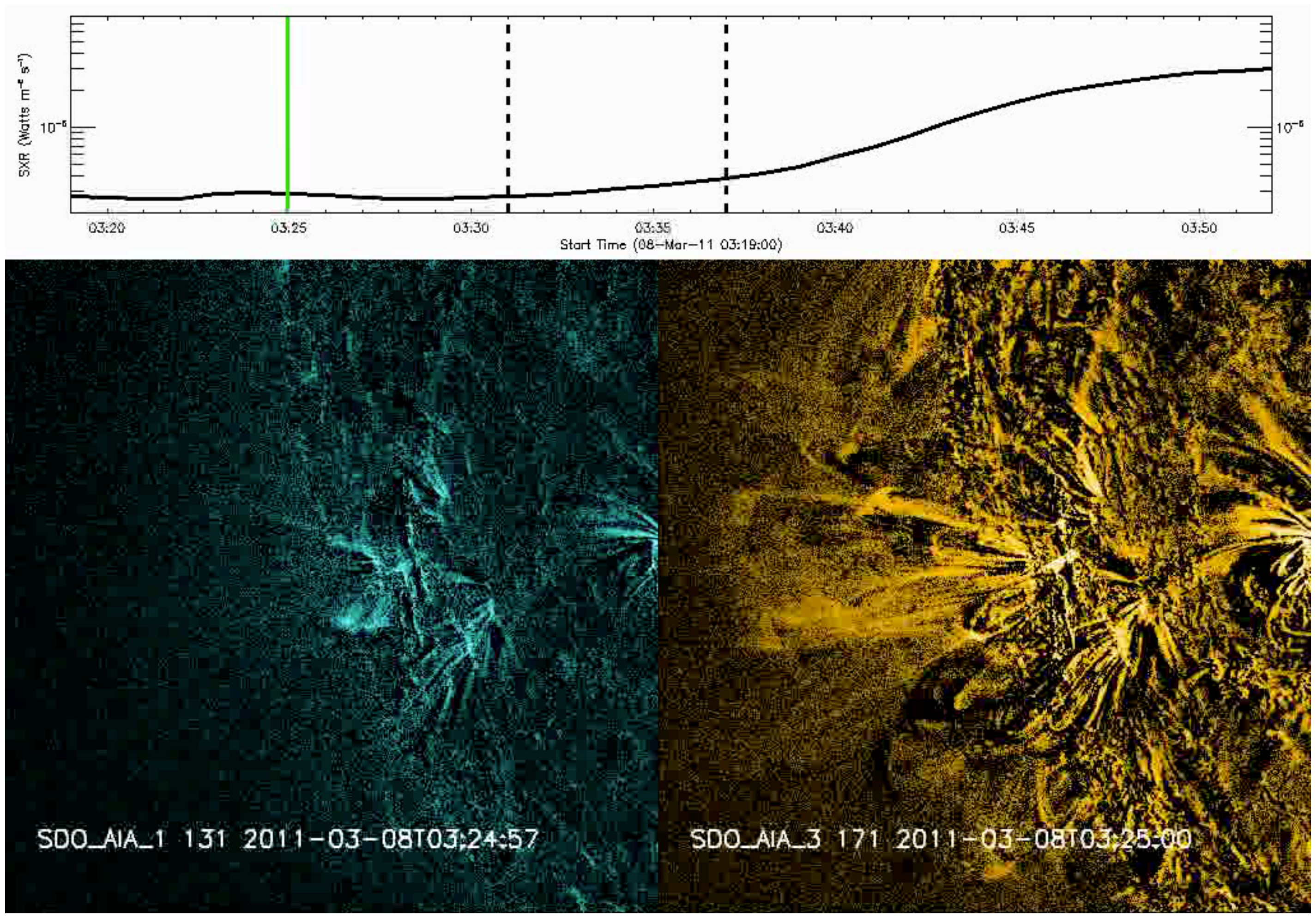
a slow-rise phase followed by a
main-acceleration phase differ markedly
a linear and an exponential function
different physical processes dominate in these phases, which
is at variance with models that involve a single process.

to be synchronized with

A delayed onset the majority of
the filament
favor ideal MHD instability models

close to the threshold of the torus instability
instability initiates and possibly drives the main
acceleration.

Toward better understanding initiation of solar eruptions, X-ray observations of pre-flare phase are needed!



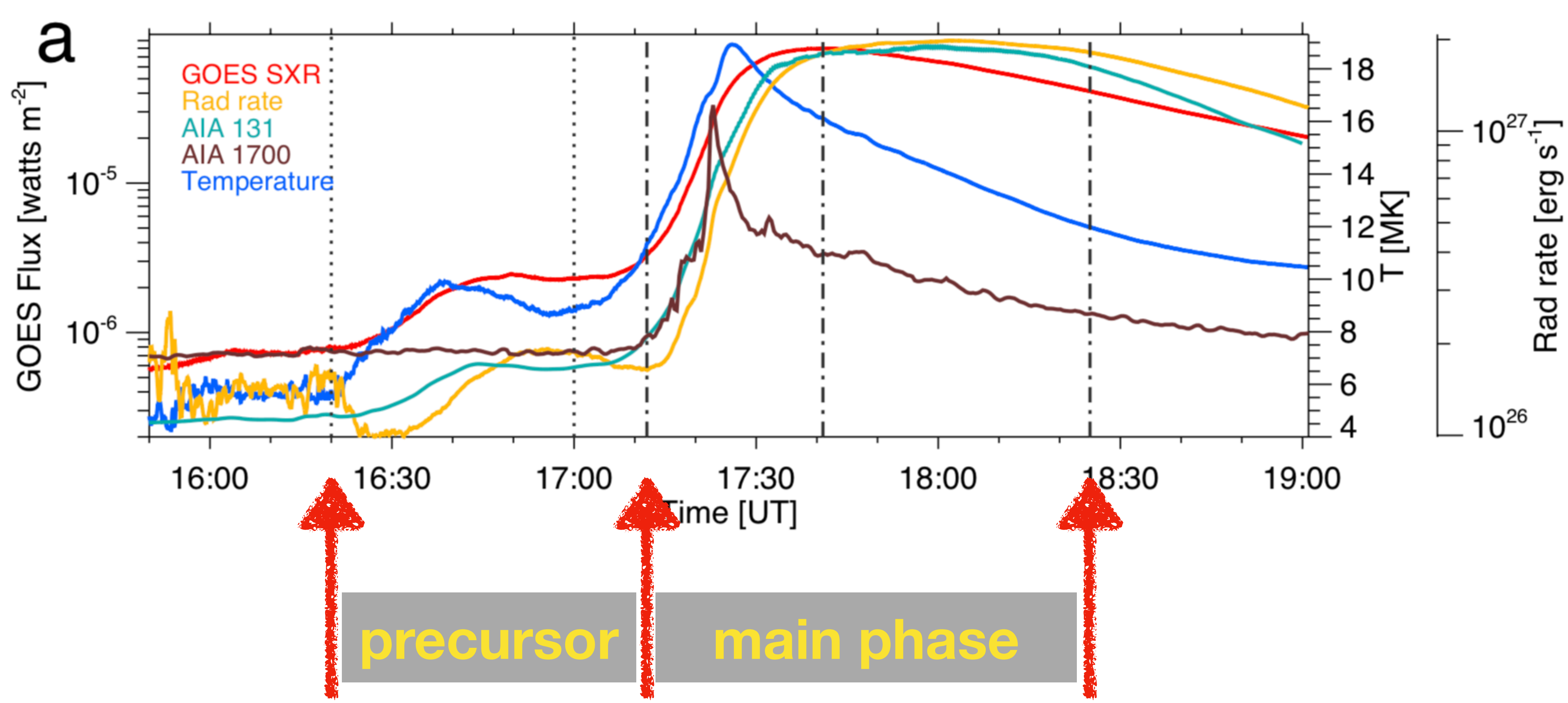
Why is it so Hot?
Hot = reconnection?
What physics control its evolution toward the main eruption?

- **How** does the reconnection proceed in precursor phase?
- **How** does it transit to the main flare reconnection process?
- **How** different is the reconnection in different phases?

(see some examples in Wang et al. 2017, Hernandez-Perez et al. 2019……)

Events we need:

- long
- strong and high
- contaminated



Thanks for your attention!!

Cheng, X., Zhang, J., Kliem, B., Xing, C., Zhou, Z.J., Torok, T. & Ding, M.D. 2020 ApJ
Cheng, X. et al. 2020, in preparation

Code: https://astronomy.nju.edu.cn/szll/szgk/fjs/20191102/i44994.html