Initiation and early kinematic evolution of solar eruptions

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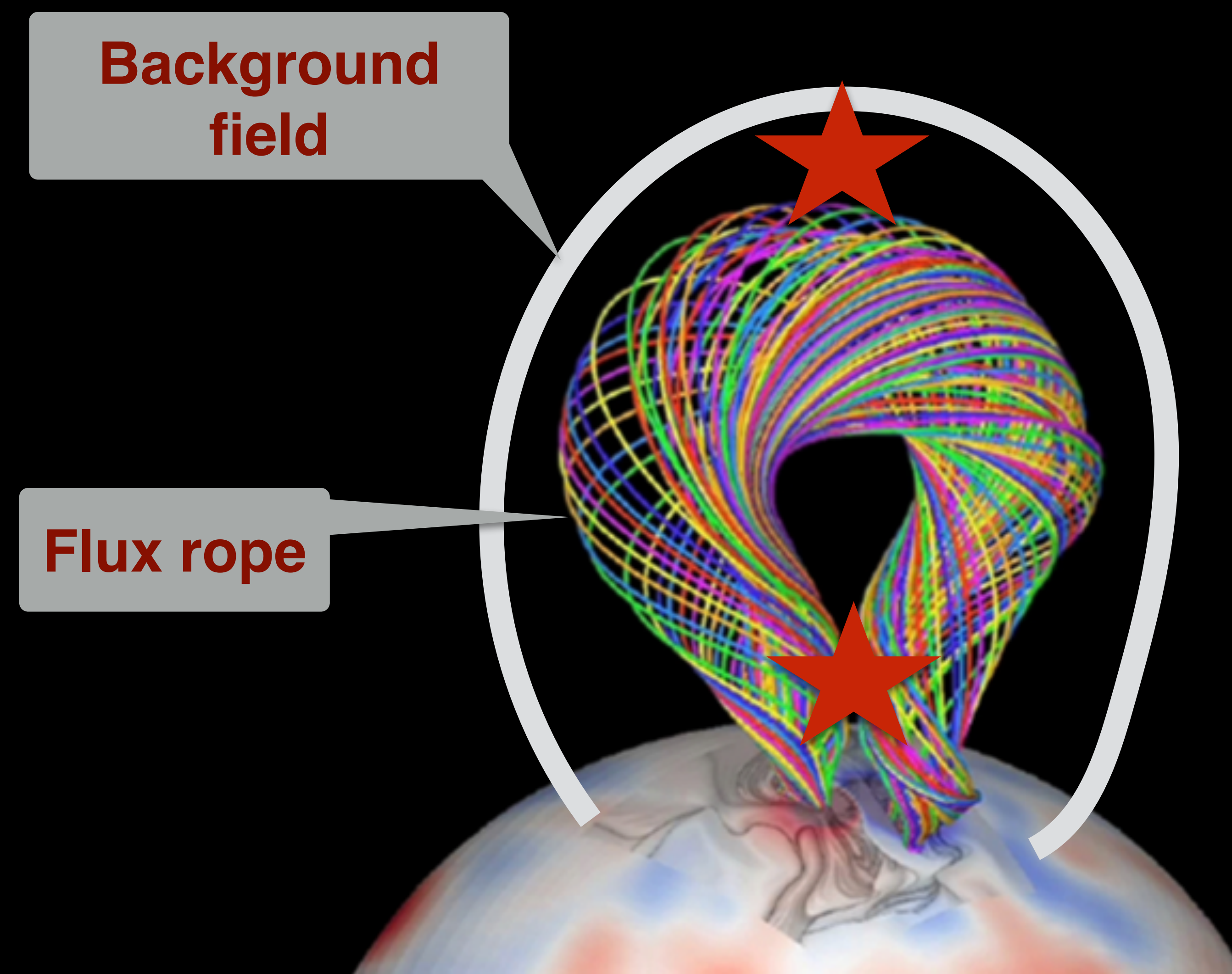
Initiation models

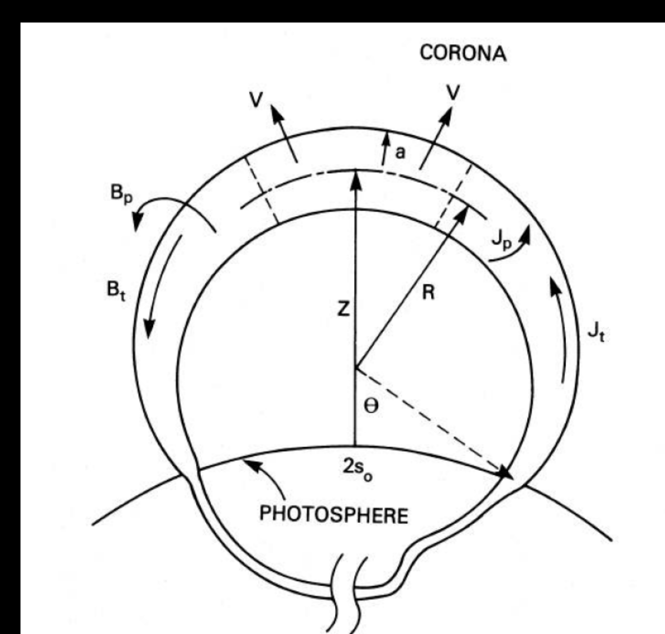
Reconnection type

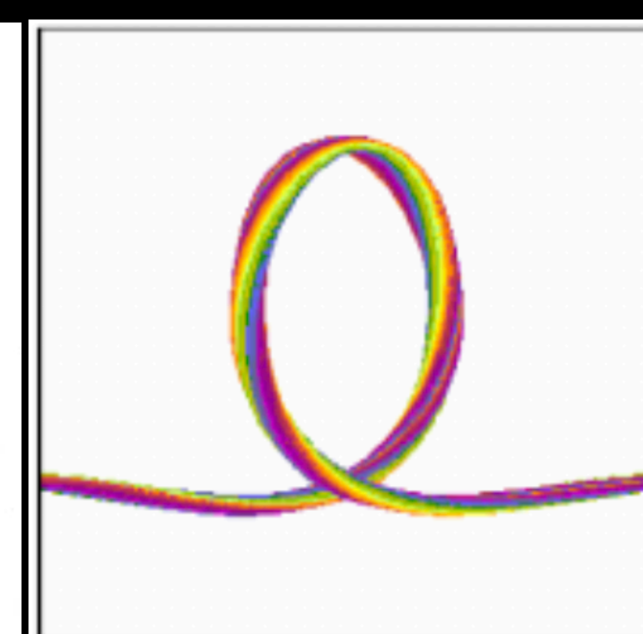
- **Tether-cutting** (Moore et al. 2001)
- **Breakout** (Antiochos et al. 1999)
- **Flux emergence** (Chen et al. 1999)



Ideal instability type

- **Torus instability** (Kliem & Torok 2006)
- **Kink instability** (Torok & Kliem 2004)
- **Loss of equilibrium** (Lin et al. 2001)





Motivation:

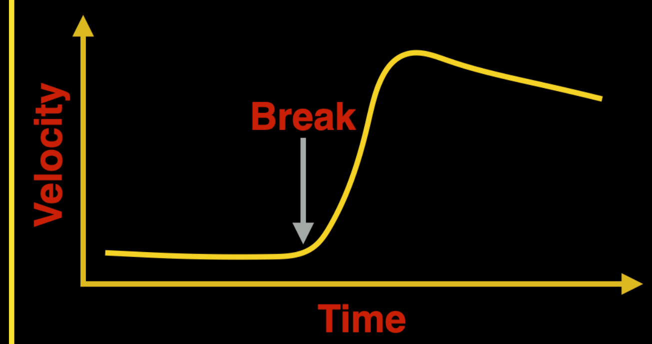
To distinguish initiation models based on kinematics

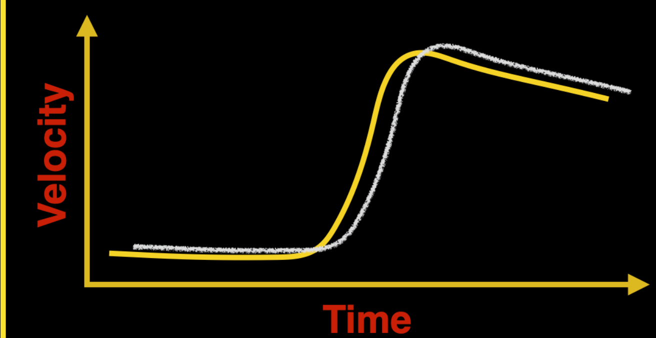
Some valuable characteristics for diagnosing

- 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

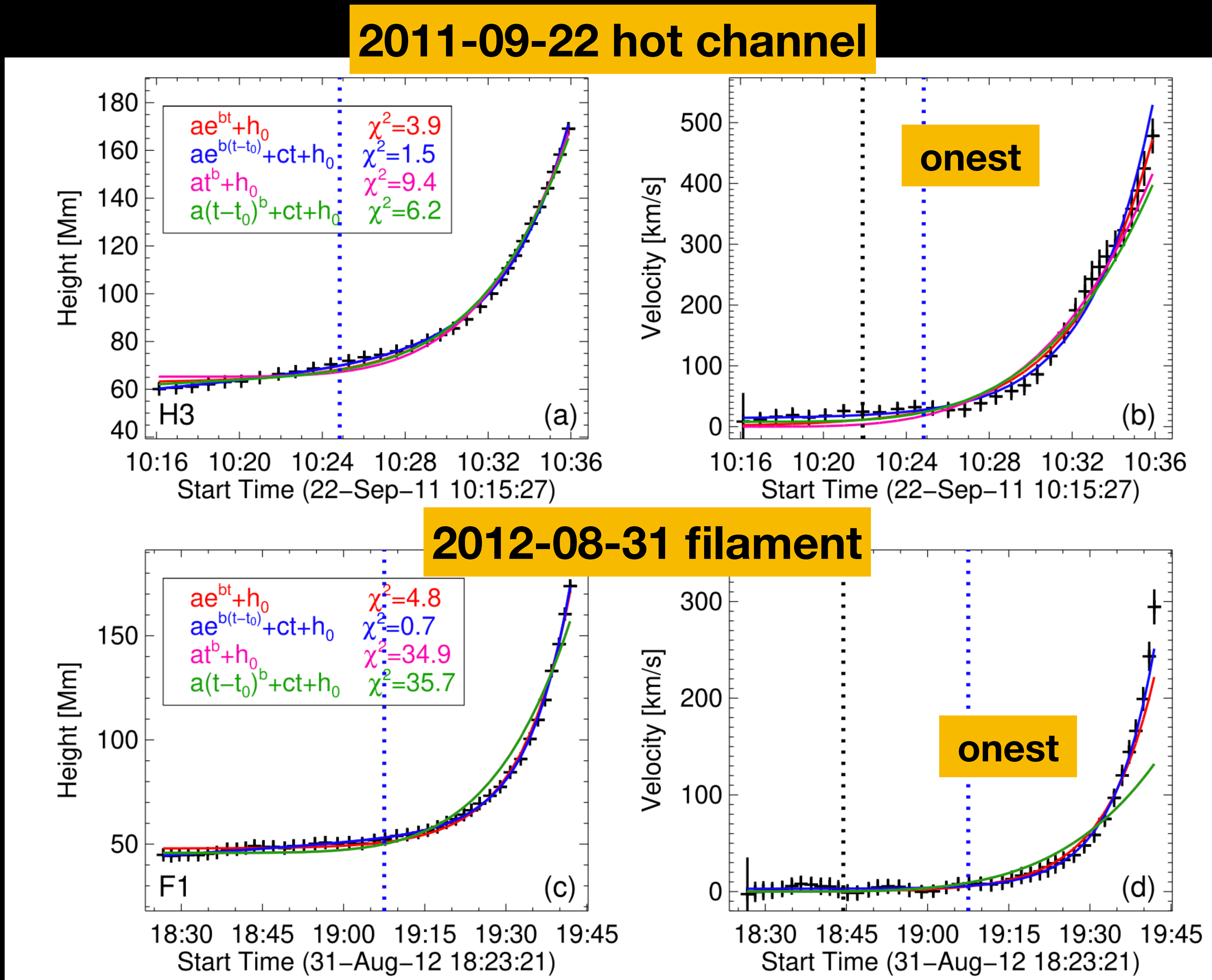
- Temporal offset between H-T profile and flare light (Fsxr) curve, favors ideal MHD (reconnection) models if H-T profile (Fsxr) precedes.

- 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.





H-T profiles and fitting of CMEs



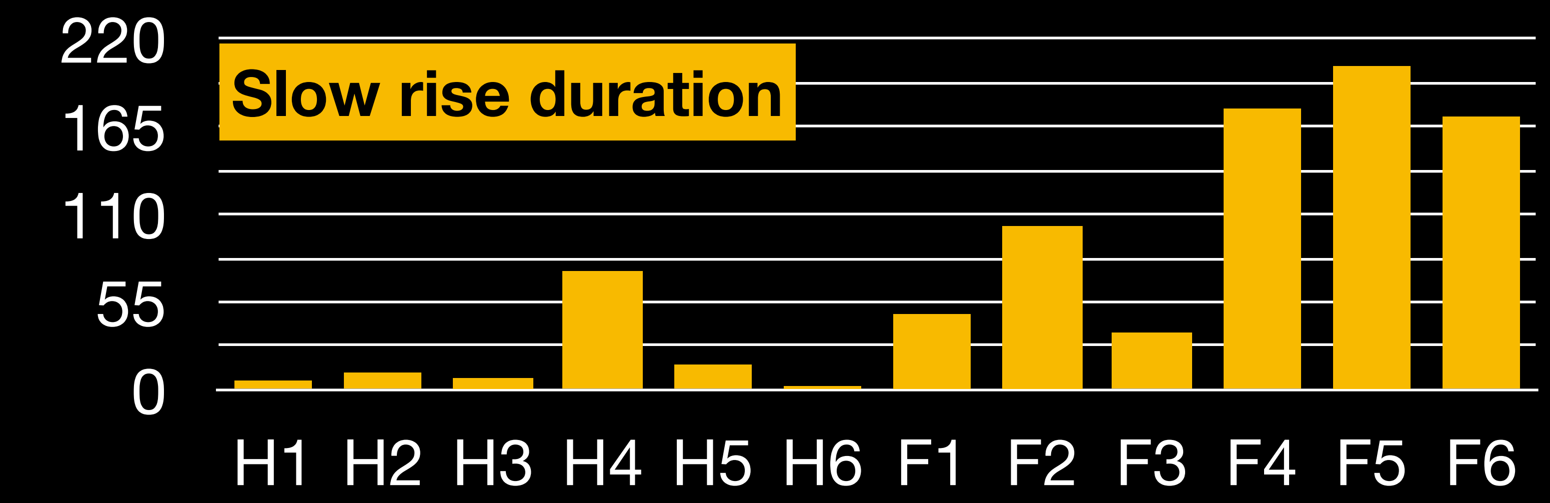
- **H-T presents two phases: slow rise+impulsive acceleration**
- **Fitting with functions:**

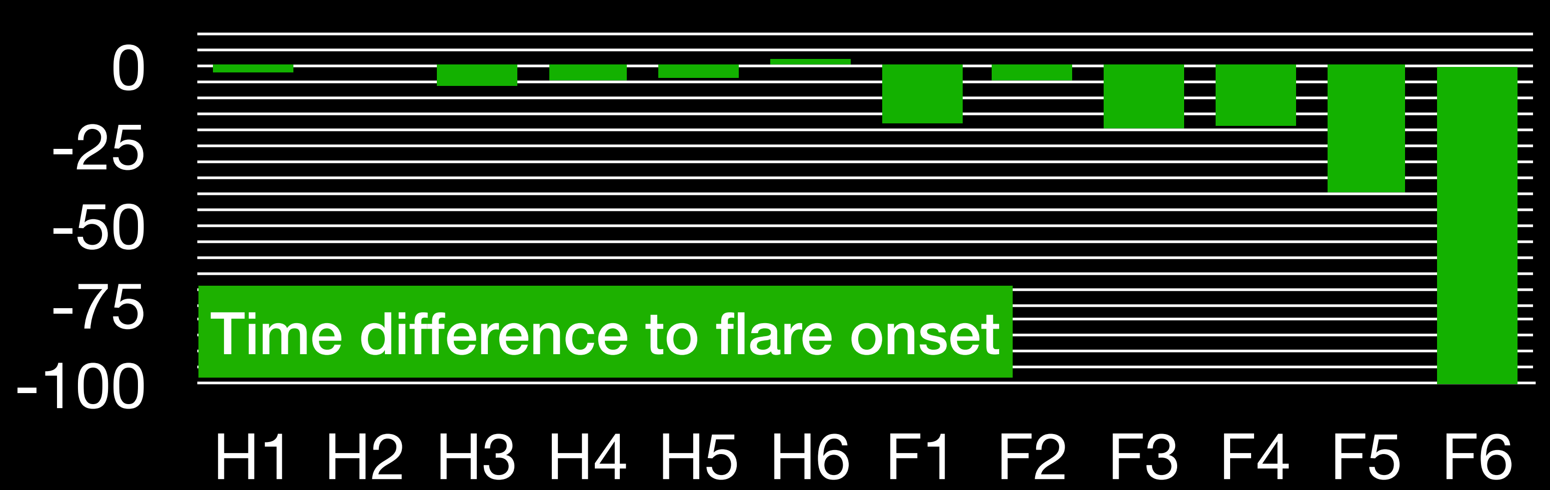
$$h_1(t) = a_1 \exp(b_1 t) + d_1,$$
$$h_2(t) = a_2 \exp[b_2(t - t_0)] + c_2 t + d_2,$$
$$h_3(t) = a_3 t^{b_3} + d_3,$$
$$h_4(t) = a_4 (t - t_0)^{b_4} + c_4 t + d_4,$$

- **Defining the onset of the acceleration (nonlinear) phase, i.e., taking over the linear one.**

Table 2. Metrics for fitting goodness of different functions.

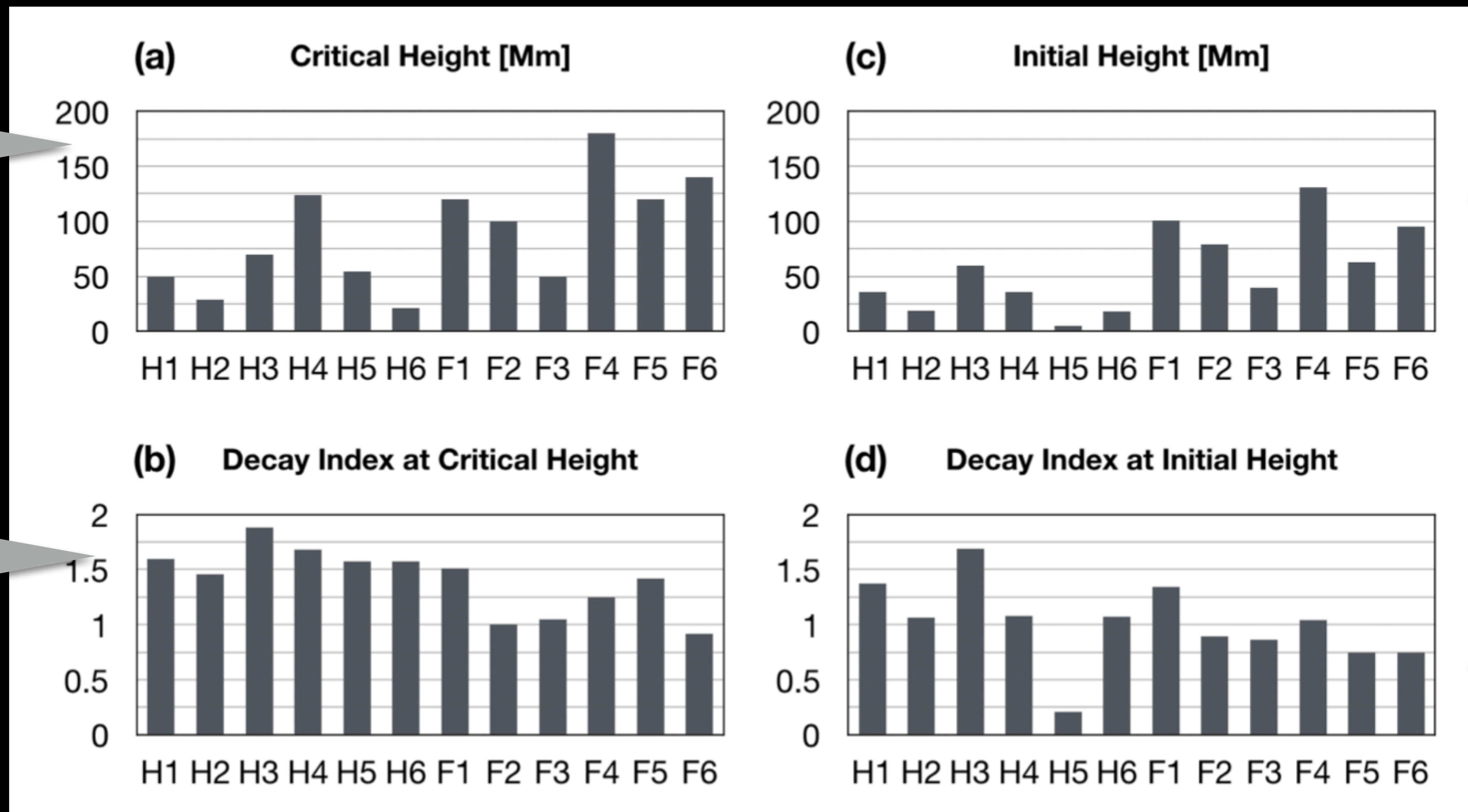
Events	$a_1e^{b_1t}+h_0$ $\chi^2_{\nu 1}$	$a_2e^{b_2(t-t_0)}+c_2t+h_0$ $\chi^2_{\nu 2}$	$a_3t^{b_3}+h_0$ $\chi^2_{\nu 3}$	$a_4(t-t_0)^{b_4}+c_4t+h_0$ $\chi^2_{\nu 4}$
H1	3.7	0.5	12.7	1.0
H2	10.6	0.9	16.1	5.4
H3	3.9	1.5	9.4	6.2
H4	37.0	1.7	62.6	17.3
H5	2.6	2.8	9.5	1.8
H6	3.5	3.8	1.7	1.5
F1	4.8	0.7	34.9	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.

Decay index at critical and initial heights



Critical height

Critical decay index

Initial height

Initial decay index

- The average of decay indices are close to the threshold of torus instability.
- The critical decay indices have a range: 1.46±0.08–1.88±0.03 for the former; 0.92±0.11–1.51±0.24 for the latter.
- The decay indices at initial heights are too small to initiate torus instability.

Conclusions:

1. The early evolution of all events consists of a slow-rise phase followed by a main-acceleration phase, the height-time profiles of which differ markedly and can be best fit, respectively, by a linear and an exponential function. This indicates that different physical processes dominate in these phases, which is at variance with models that involve a single process.

2. The kinematic evolution of the eruptions tends to be synchronized with the flare light curve in both phases. The synchronization is often but not always close. A delayed onset of the impulsive flare phase is found in the majority of the filament eruptions (5 out of 6). This delay, and its trend to be larger for slower eruptions, favor ideal MHD instability models.

3. The average decay index at the onset heights of the main acceleration is close to the threshold of the torus instability for both groups of events, suggesting that this instability initiates and possibly drives the main acceleration.

Reference: Cheng, X., Zhang, J., Kliem, B., Torok, T., Xing, C., Zhou, Z. J., Inhester, B. & Ding, M. D., Initiation and Early Kinematic Evolution of Solar Eruptions, 2020, **ApJ**, 894, 85