Hot Onset Precursor Events (HOPEs)

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Poster layout

[1] Background
[2] New results and applications
- **HOPE appears in "stealth" CMEs**
- **A practical flare warning tool: FAI**

[3] Significance
- **So what and who cares?**
- **Challenges**
- **What to do next**

Significance

Because a HOPE phase always occurs, it seems likely that this process itself - the loading of the corona with slowly injected hot plasma, containing relatively little mass - actually reflects the fundamental instability of the flare process, and that everything else (particle acceleration, CME ejection, reconnection, and all of CSHKP) occur as secondary effects enabled by the development of this initial instability.

1

Definitions: Onset vs. Precursor

There is a huge literature on "***flare precursors***", because of their obvious significance for physics and flare forecasting. Many phenomena appear under this umbrella term. The ***"hot onset"*** of a flare has a narrower meaning: a continuous slow increase of soft X-radiation prior to the impulsive phase. Hudson et al. (2021) showed that these onsets do not exhibit "heating' in the sense of increasing temperature. Flares almost invariably begin with high (of order 10 MK) isothermal-fit X-ray temperatures. See confirmations by Battaglia *et al.* 2023, da Silva *et al.* 2023, and Telikicherla *et al.* (2024) of the basic **HOPE** phenomenon (Hot Onset Precursor Event).

The "horizontal branch"

Figure 1 shows a beautiful HOPE example. The key HOPE feature is horizontal branch on the diagnostic diagram following the joint evolution of T *vs.* EM as a flare develops. Jakimiec *et al.* (1992) studied this diagnostic as an aid in understanding flare loop simulations. The horizontal branch results from steadily increasing emission measure at relatively constant high temperature.

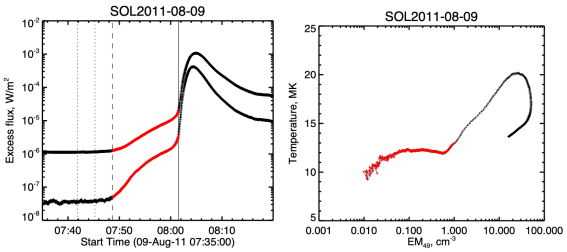

Figure 1: *Left, the GOES timeseries for SOL2011-08-09 (X6.9), showing a precursor increase that also appears as a* ***HOPE****. The vertical lines show background interval (dots), the hot onset (dashes), and HXR onset (solid line). Right, the diagnostic diagram showing the evolution of the GOES isothermal fits. The horizontal branch (red) shows no microflaring in this case.*

2

Is HOPE truly universal?

Published results have revealed the ubiquitous presence of HOPE prior to solar flares above B class, and this is the basis for the "Flare Anticipation Index" described below. Figure 3 shows that CMEs with minimal low-coronal emission (the "stealth" filament-eruption events) also indeed have HOPE. So, "yes."

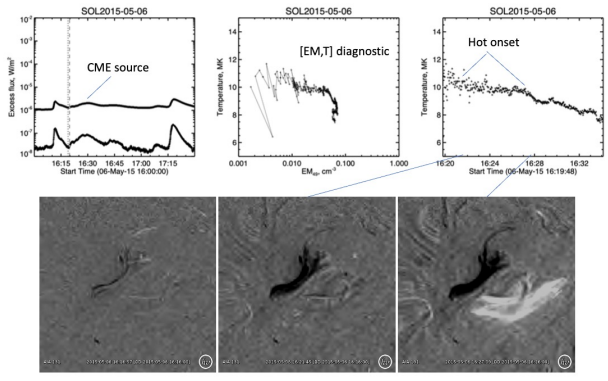

Figure 2: *An event with minimal GOES soft X-rays, but a major CME (Nitta et al., 2021). Upper panel, the GOES time and the diagnostic diagram. Top right shows that the HOPE temperature exceeded the flare peak. Lower panels show the AIA image development (base differences).*

...GOES Flare Anticipation Index...

3

Loop Modeling

There is a rich history of modeling solar flares as essentially 1D magnetic flux tubes (the "building blocks") of the corona; see Reale 2012 for a detailed review of this approach. It is widely extended into the stellar domain where one often ignores the 3D effects. In this approximation, the basic development can be described by two parameters. Figure 4 is an early representation of how these parameters can evolve in time.

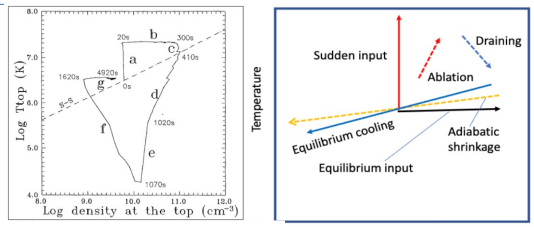

Figure 4: *The diagnostic diagram for the evolution of an isothermal flare model with time. Left, the original formulation by Jakimiec (1992) based on numerical simulations; see the original paper for commentary. Right, a schematic view showing the directions of motion for different physical processes. Note the "Equilibrium input" of the initial horizontal branch seen in Figure 1 and, actually, in all flares. What is the physics?*

So what? And who cares? The Science Future

There's a practical application here (the FAI; see Figure 3). But the main importance here is that the HOPE physics underlies all flare and CME activity, and so it should be a primary object of theoretical and modeling studies. It appears that HOPE was not foreseen by theorists, nor has it appeared (even if unanticipated) in numerical simulations yet.

Challenges:

1) What is the systematic nature of HOPE evolution, and why does it proceed so slowly?
2) What is the microphysics that regulates the electron temperature to a narrow range, and why can we not detect the actual *increase* of temperature?

The Practical Future

It seems likely that the FAI capability can be reproduced using AIA images, with the added great advantage of event localization {Massa *et al.* 2024).

Sun-as-a-star data, including Si spectroscopy, remain interesting for seeking the earliest anticipation times, and for gleaning information about the character of the flare that will happen. Systematic statistical studies remain to be done.

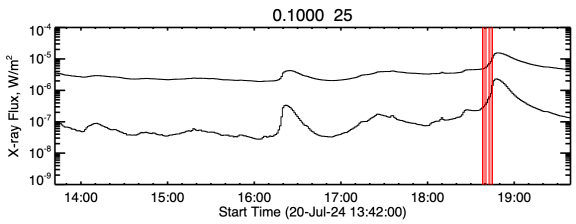

Figure 3: *The GOES-based "Flare Anticipation Index": The ΔEM threshold here, 0.1 x 10⁴⁹ cm⁻³ / 5 min, corresponds roughly to GOES M class (Hudson, 2024), and the sampling is 1 minute. Here the advance warning leads flare peak by about 12 minutes. The ΔEM correlates well with the magnitude of the ensuing flare. The anticipation is universal, with negligible false positives down to B class. The setting of the flag (the red lines) is a necessary and sufficient condition for flare occurrence.*

References

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