Morphology of solar flares from observations in the lower atmosphere

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Motivation

- Davenport et al (2014) used 800+ Kepler flares on an M dwarf to produce an empirical flare template.
- **Our aim was to produce an empirical solar flare template for comparison.**
- Kepler observes in white light BUT Sun-as-a-star white light flares are rare.
- So we used SDO/AIA 1600, 1700, 304 Å data (i.e. lower atmosphere).

Data preparation:

1. Make sun-as-a-star flare lightcurves.
2. Normalise profiles for magnitude and time based on Davenport et al (2014).
3. Select only smoothly varying 'simple' flares.

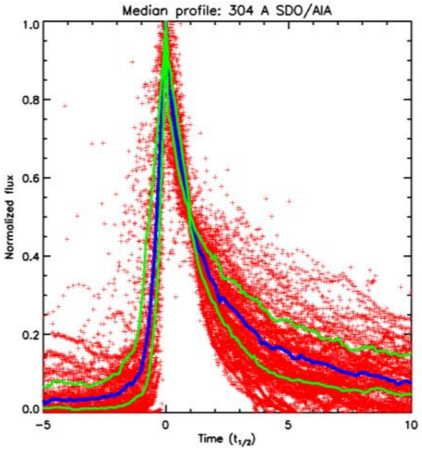

Figure 1: 102 normalised profiles of 304 Å flares (red). Blue: median profile. Green: Interquartile range.

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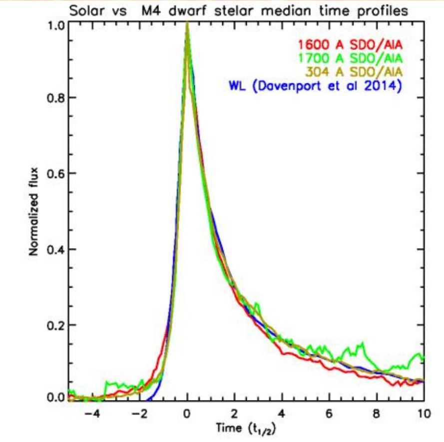
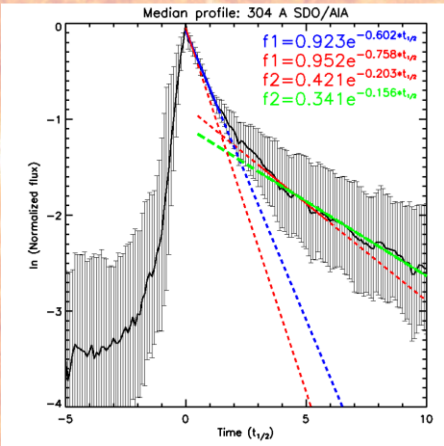
Further plots and info are available on p2.

Result 1: Median solar profiles are consistent with M dwarf flares.





Result 2: Median flare profiles can be described by two exponents.

Result 3: Discrepancies between solar and M dwarf flares possibly due to chromospheric evaporation.

Data fitting:

1. Median can be fitted with two independent exponents (see Result 2), with the optimal time ranges being $[0,0.5]t_{1/2}$ (blue) and $[3,10]t_{1/2}$ (green).
2. Or using a broken power law, where the break time is a free parameter.

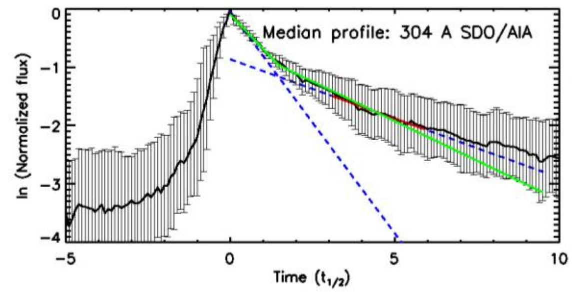


Figure 2: Median profiles fitted with two exponentials (blue & red) and a broken power law (green).

Comparison between solar and M dwarf flares:

- First stage: solar flares cool more slowly.
- Possible evidence in solar flares for chromospheric heating, not in M dwarf flares.
- Second stage cooling more complex than seen in M dwarf flares (fits diverge from data).

Full paper: Kashapova et al (2021), MNRAS, 502, 3922

Reference: Davenport et al. (2014), ApJ, 797, 122, 11

Morphology of solar flares from observations in the lower atmosphere: Further information

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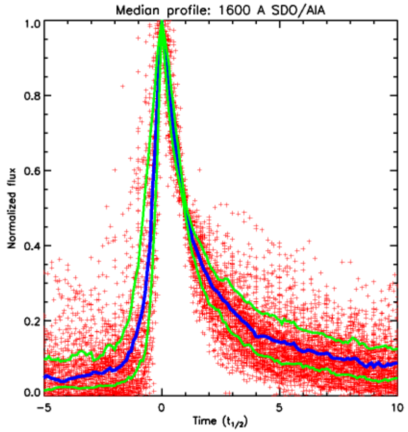


Figure 3: 104 normalised profiles of 1600 Å flares (red). Blue: median profile. Green: Interquartile range.

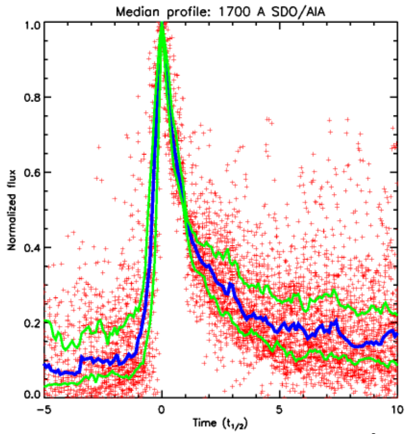


Figure 4: 53 normalised profiles of 1700 Å flares. Colours as above.

Main results from fitting two independent exponentials:

1. **Phases for conductive losses and radiative cooling.**
2. **A longer time range is required to fit the second decay phase in solar flares compared to M dwarf flares.**

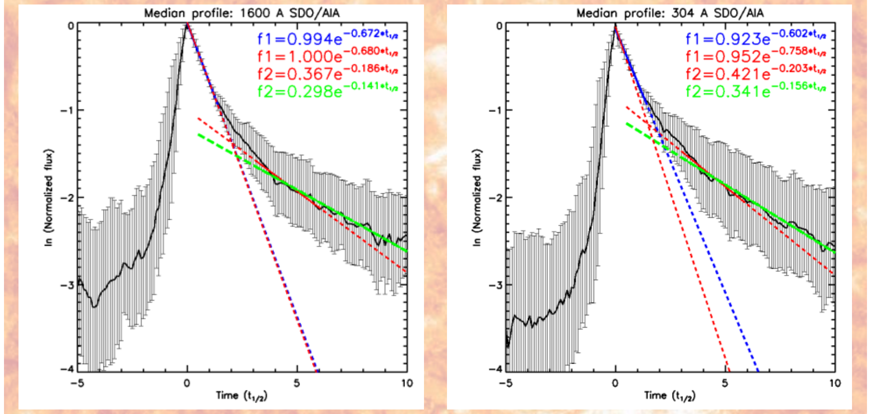
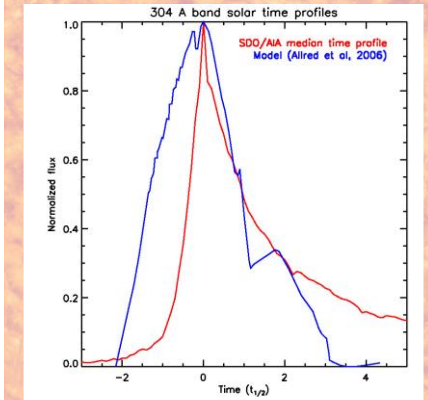


Figure 5: Fits to median profiles for 1600 and 1700 Å. Red shows fits performed over the same range as considered in Davenport et al (2014), namely [0,0.5]$t_{1/2}$ and [3,6]$t_{1/2}$ Blue is the fit for the time range [0,1.5]$t_{1/2}$, while green covers the range [3,10]$t_{1/2}$



Model of Allred et al (2006) predicts:

1. **Chromospheric evaporation kicks in at around 1.5$t_{1/2}$ i.e. around the observed break time (see right panel).**
2. **Model decays more rapidly at high times than observations.**

Broken power law:

$$f(t) = \begin{cases} \exp\left(A_1 t_{\frac{1}{2}}\right) & \text{for } t < t_b \\ \exp\left(A_2 t_{\frac{1}{2}}\right) \times \exp\left([A_2 - A_1] t_{\frac{1}{2}}\right) & \text{for } t > t_b \end{cases}$$

1. Provides a good fit until $6t_{\frac{1}{2}}$
2. Break time $t_b = 1.2 - 1.6$, increases from 1700 Å→ 304 Å → 1600 Å i.e. t_b increases with height in atmosphere.

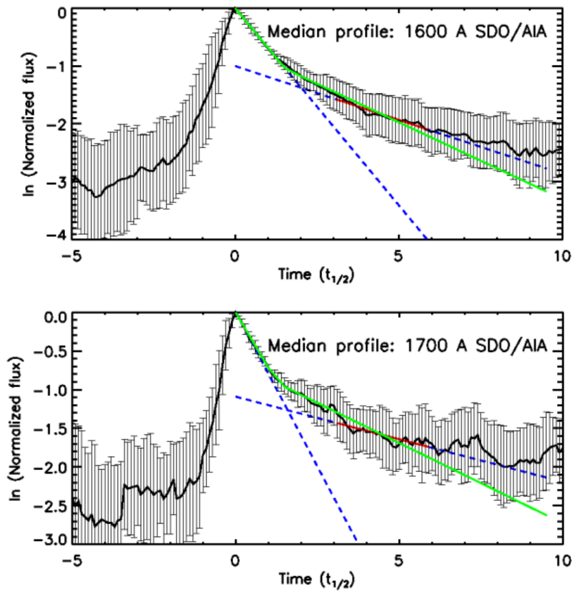


Figure 6: Median profiles fitted with two exponentials (blue & red) and a broken power law (green).

Additional reference: Allred et al (2006), ApJ, 644, 484

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