Sun-as-a-star and (maybe) stellar CME signatures

Hugh Hudson (UC Berkeley and U. of Glasgow)

Contents

- Flares, superflares, extreme events
- Extrasolar coronal mass ejections (CMEs), interesting for a variety of reasons
  - Stellar evolution
  - Flare physics
  - Exobiology
- Sun-as-a-star observations, ie without imaging, can provide some guide to the process and its detectability

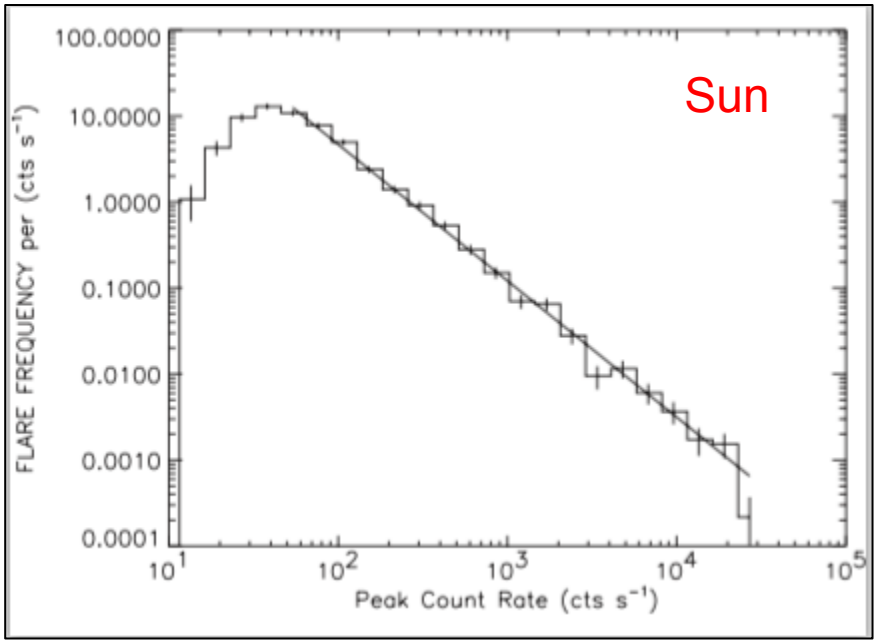
What is a CME?

- The Sun can eject clouds of plasma with the evident geometry of magnetic field rising beyond the Alfvén point, hence becoming “open”

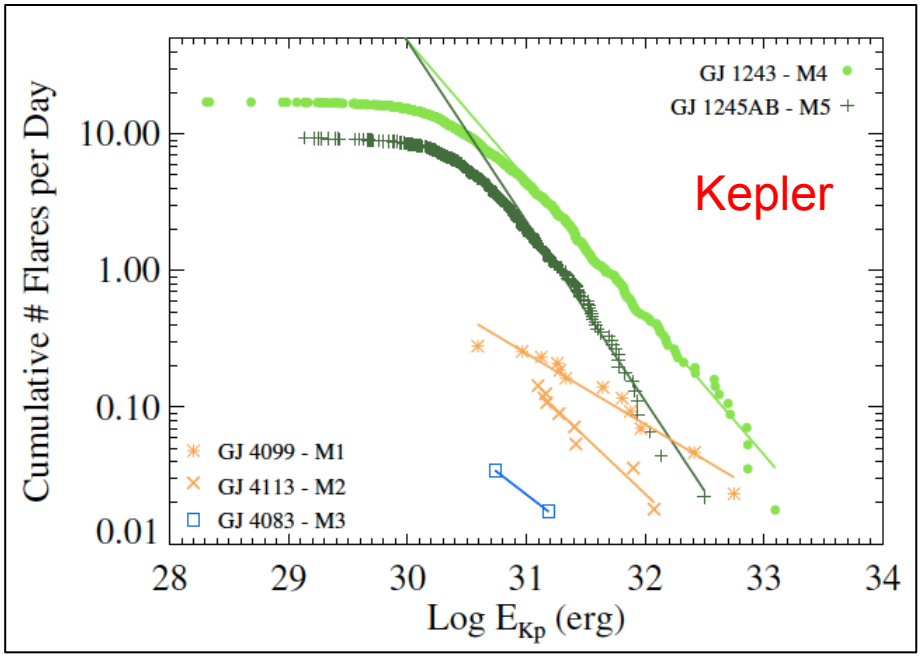
- As working definitions, a “CME” is a perpendicular plasma flow leading to open fields, and a “jet” is a parallel flow

- We know empirically that CME ejecta correlate well with very strong particle acceleration, and with (major) flares

Flare energy distributions



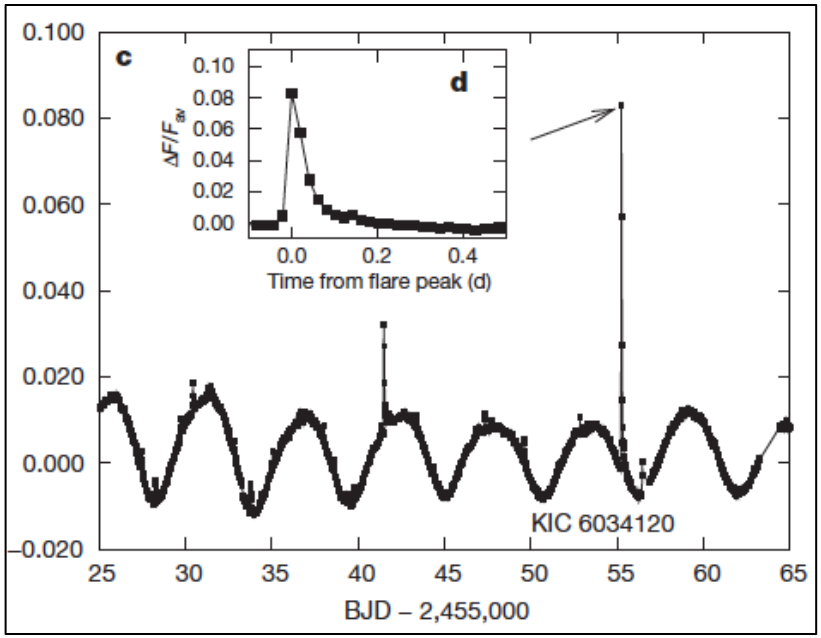
Crosby et al. 1997



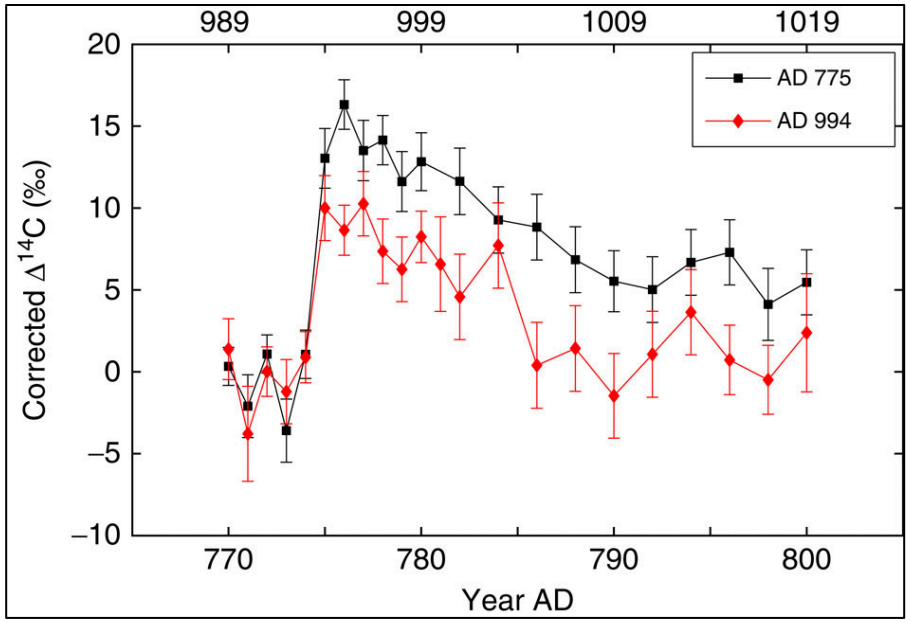
Hawley et al. 2012

Solar and stellar flares follow power-law distributions with no obvious high-energy cutoff

“Superflares” and extreme events



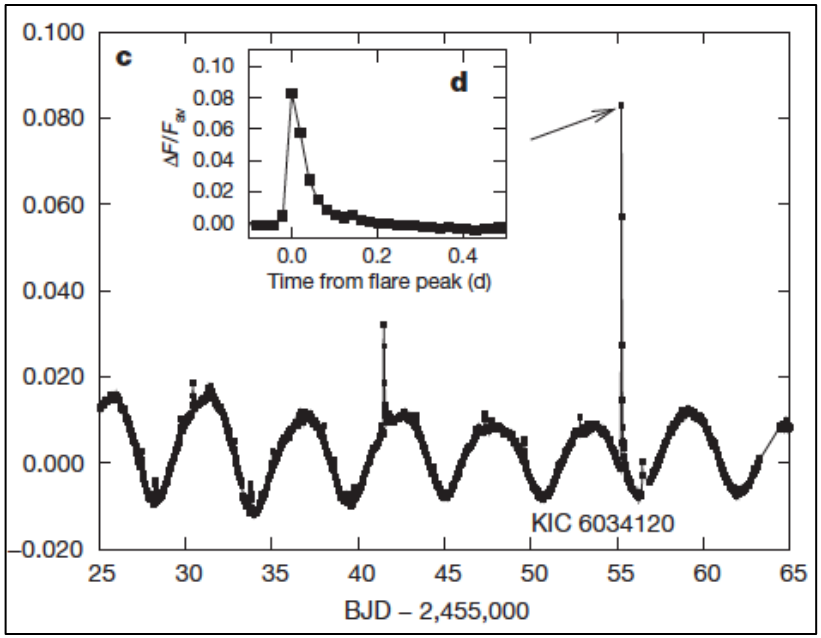
Maehara et al. 2012



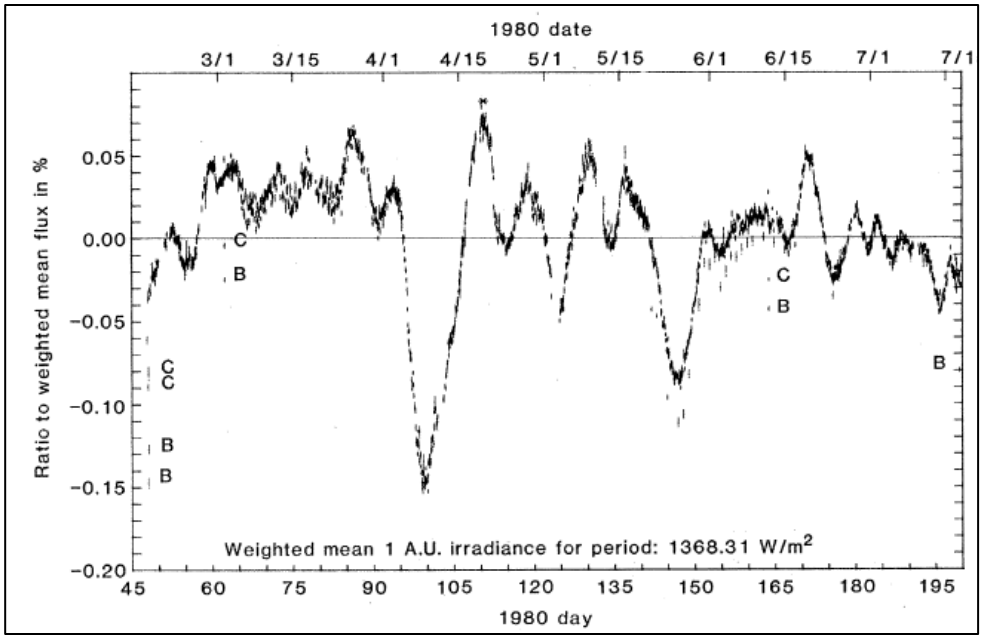
Miyake et al. 2013

Two important recent discoveries: The *Kepler* “superflares” on “solar-type” stars, and the ^{14}C tree-ring events, probably solar

Comment



Maehara et al. 2012



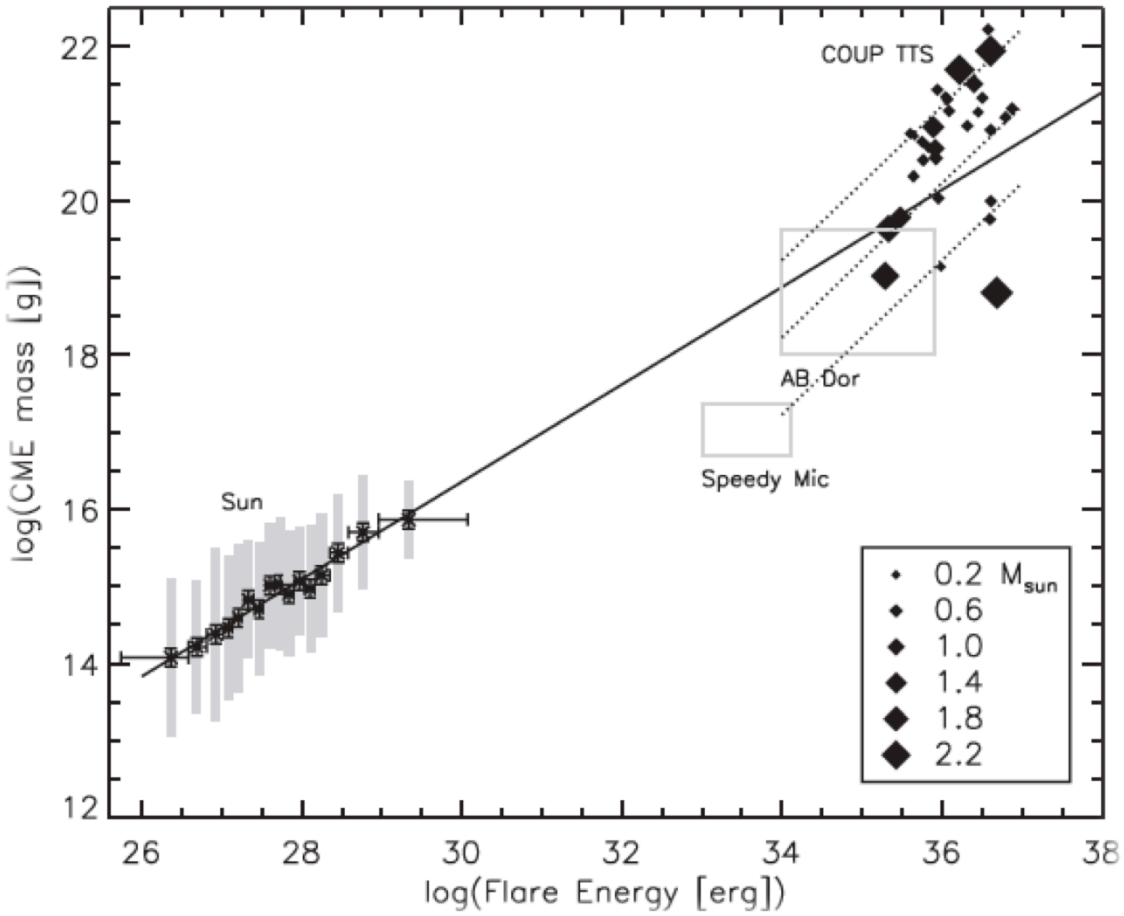
Willson et al. 1981

The *Kepler* "superflare" stars have flares and no dips, and the quiescent variability is large and smooth: not "solar-type" patterns – could not be more different!

Stellar CME implications

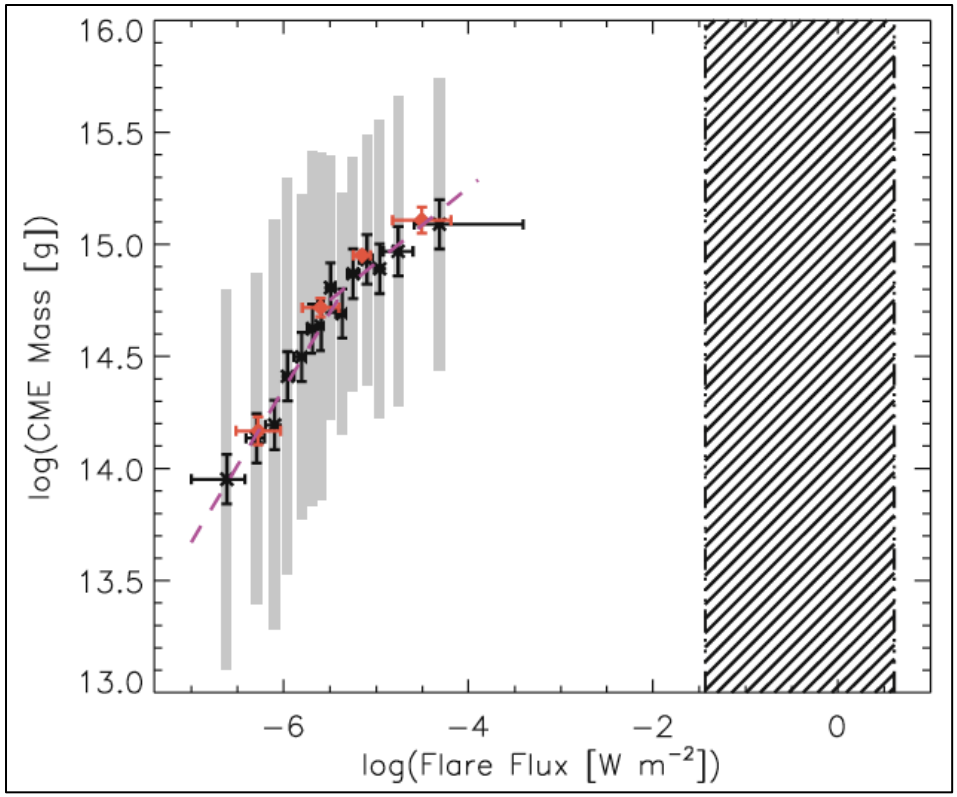
- If we adopt solar CME/flare scaling, what does that imply for very active stars?
- We have a flood of new stellar flare observations from *Kepler* now.
- Interesting papers by Aarnio, A. N., Stassun, K. G., & Matt, S. P. 2010, *ApJ, 717, 93 et seq.*

First question: how are flares and CMEs related?

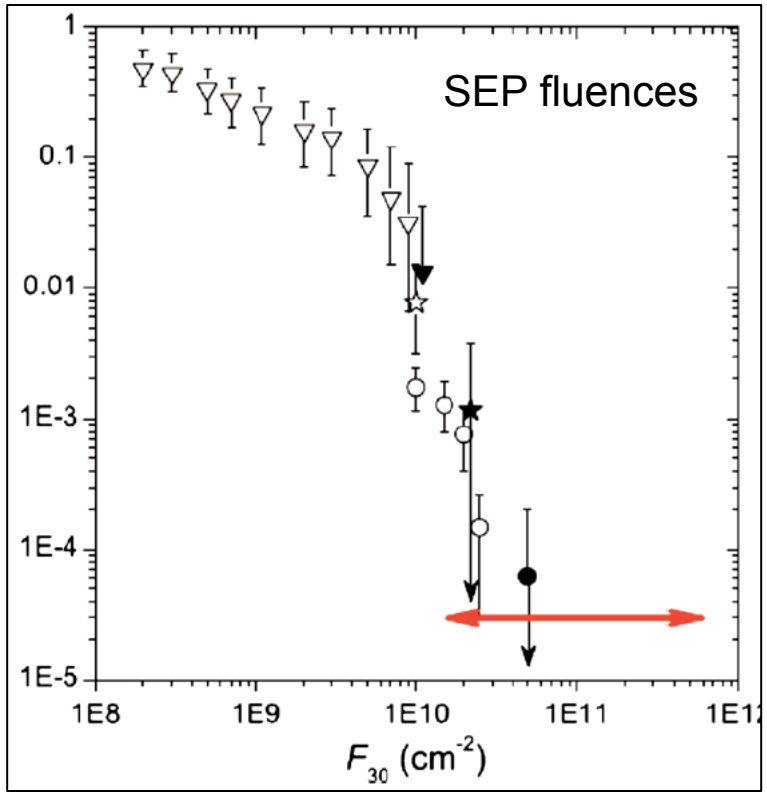


- Overview from Aarnio et al.
- Is the Sun really this orderly?
- Is the solar paradigm used correctly here?

First question: how are flares and CMEs related?



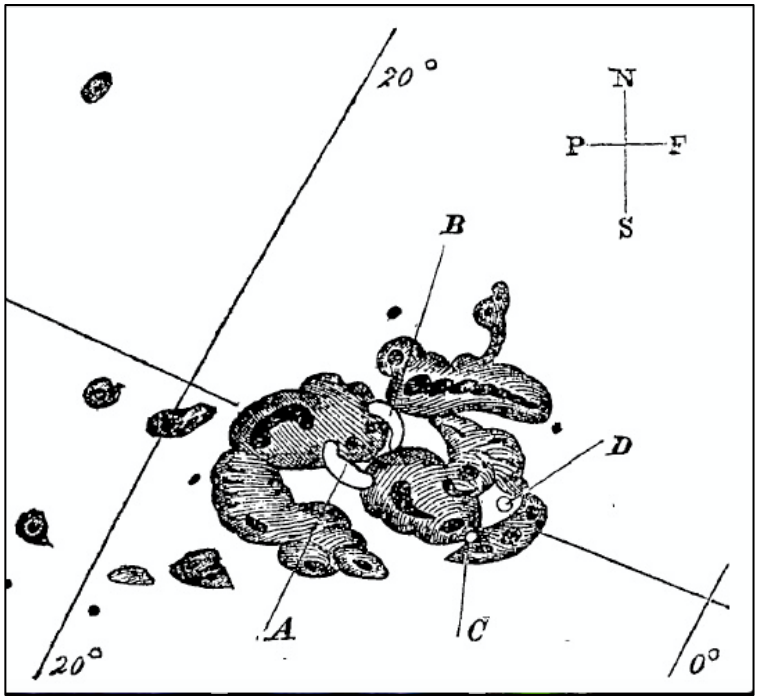
Aarnio et al. 2011



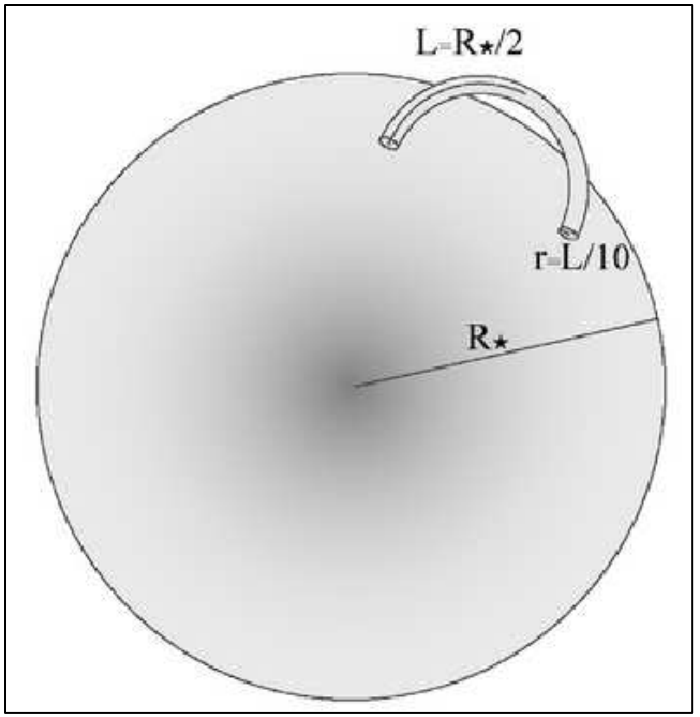
Kovaltsov et al. 2014

Answer: Flares and CMEs are indeed correlated, but over a limited magnitude range. There may be a break in the otherwise universal power law

Second question: what solar paradigm works?



Carrington, 1859



Testa et al. 2007

Answer: A simple loop in conductive equilibrium does not describe a solar flare very well, and should not be forced to fit stellar observations.

Comments

- The *Kepler* and tree-ring data challenge us to find the limit of flare energies
- In very active stars, simple scaling from solar flare/CME relationships might predict enormous mass loss and particle bombardment

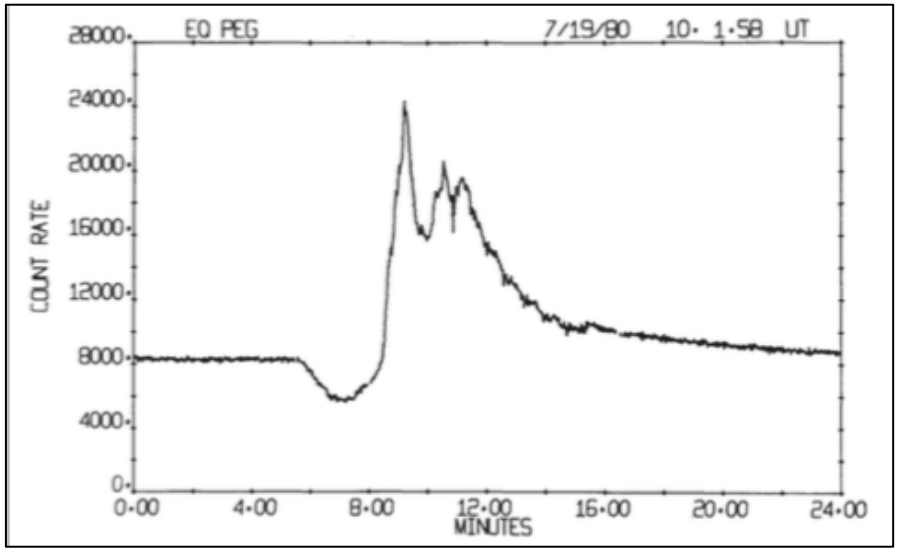
So… how do we learn about CMEs on stars with exoplanets?

Detecting extrasolar CMEs

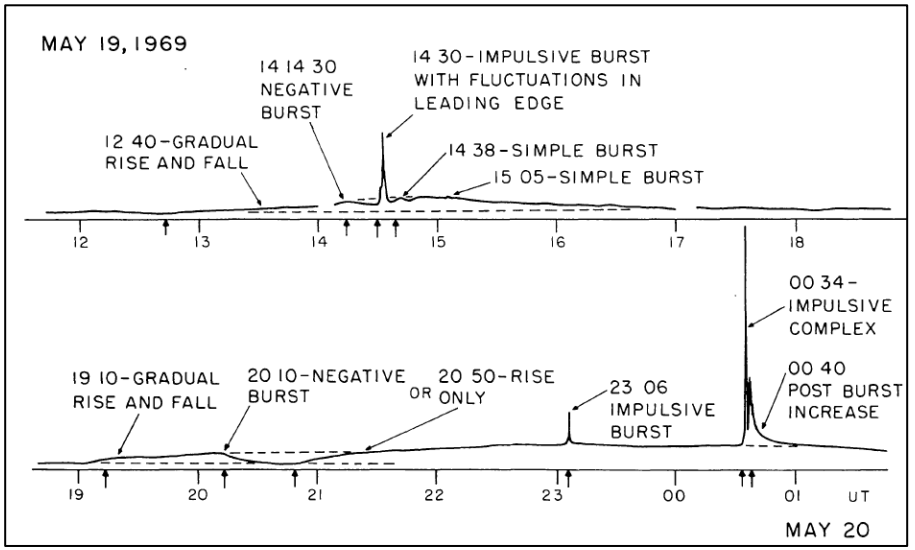
So… how do we learn about CMEs on stars with exoplanets?

- Chromospheric phenomena (eg, Collier Cameron & Robinson 1989)
- Radio analogs of type II bursts
- X-ray activity (GOES for the Sun)
- Coronal dimming events (SDO/EVE)

Negative flares

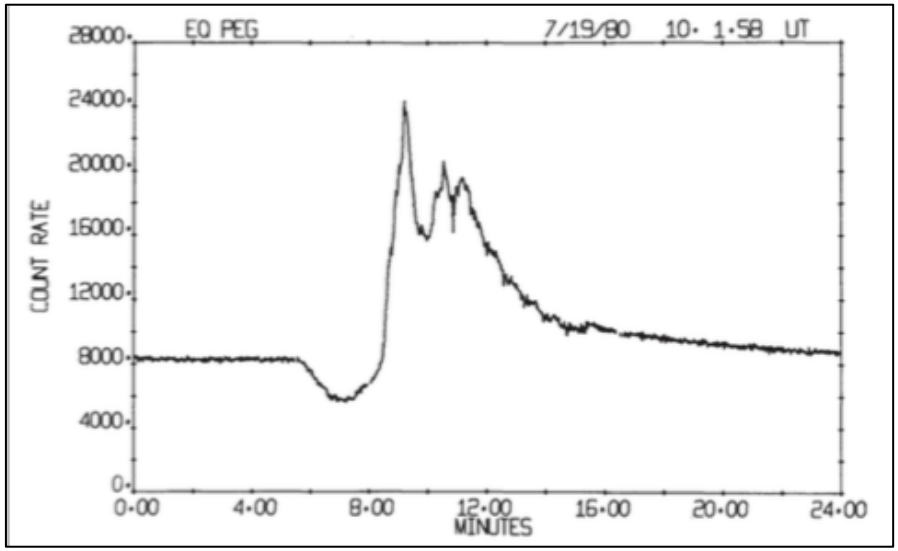


Giampapa, 1982 (a star)



Covington, 1973 (the Sun)

Negative flares



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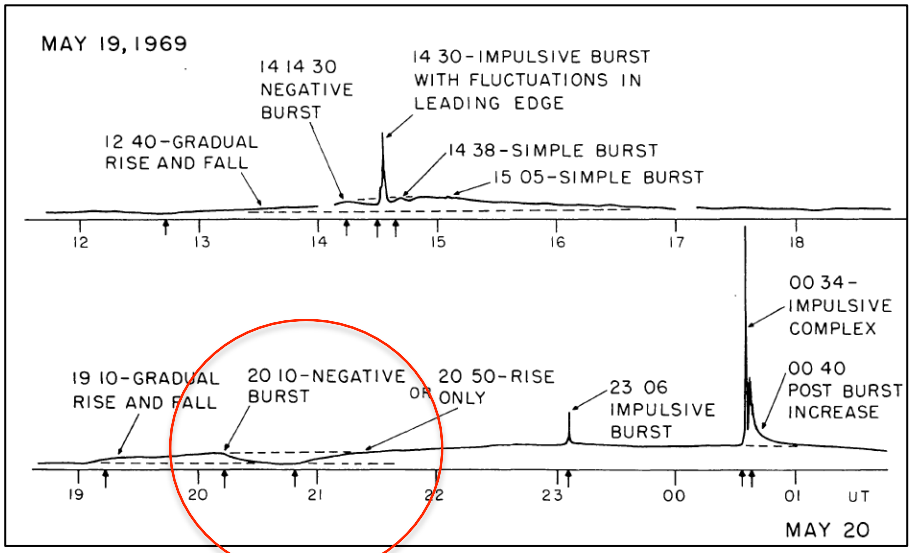


Covington, 1973 (the Sun)

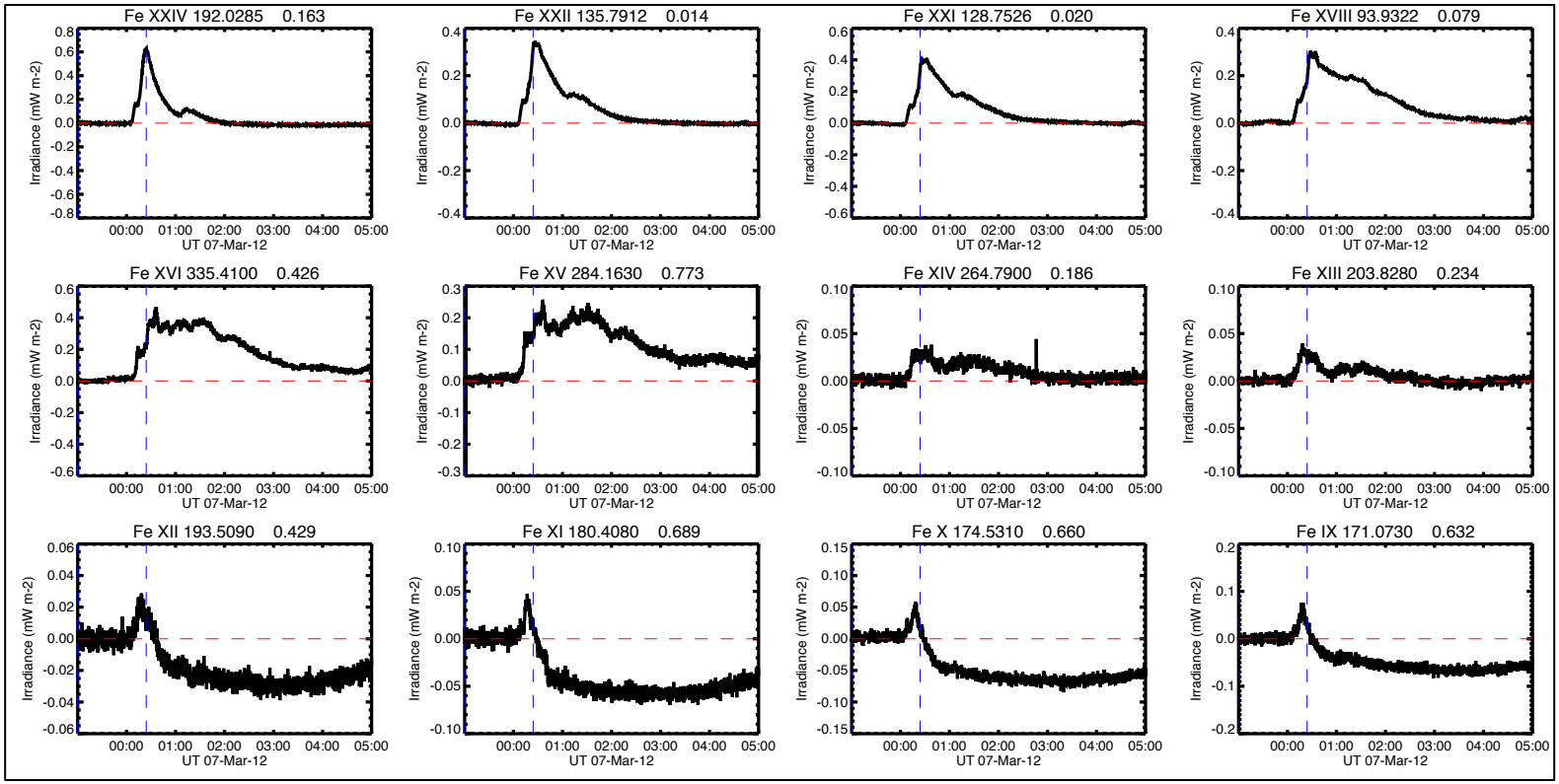
Brief history of dimming*

- Coronal depletions (Hansen et al. 1974)
- Transient coronal holes (Rust & Hildner 1976)
- X-ray dimmings (e.g. Harra & Sterling, 2001)
- EUV dimmings (EIT, TRACE…)
- EVE Sun-as-a-star observations

* A “dimming” is a stepwise change in the corona

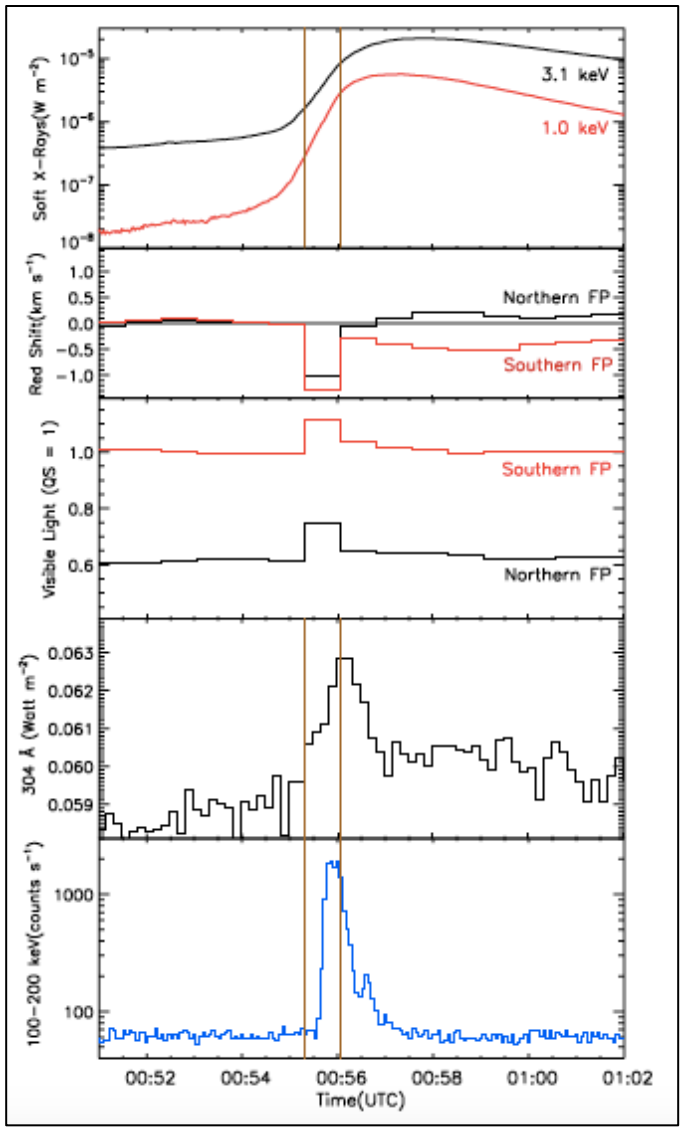
Proxy detection of solar (and maybe stellar) coronal mass ejections

Can we remotely detect threats to life on exoplanets?

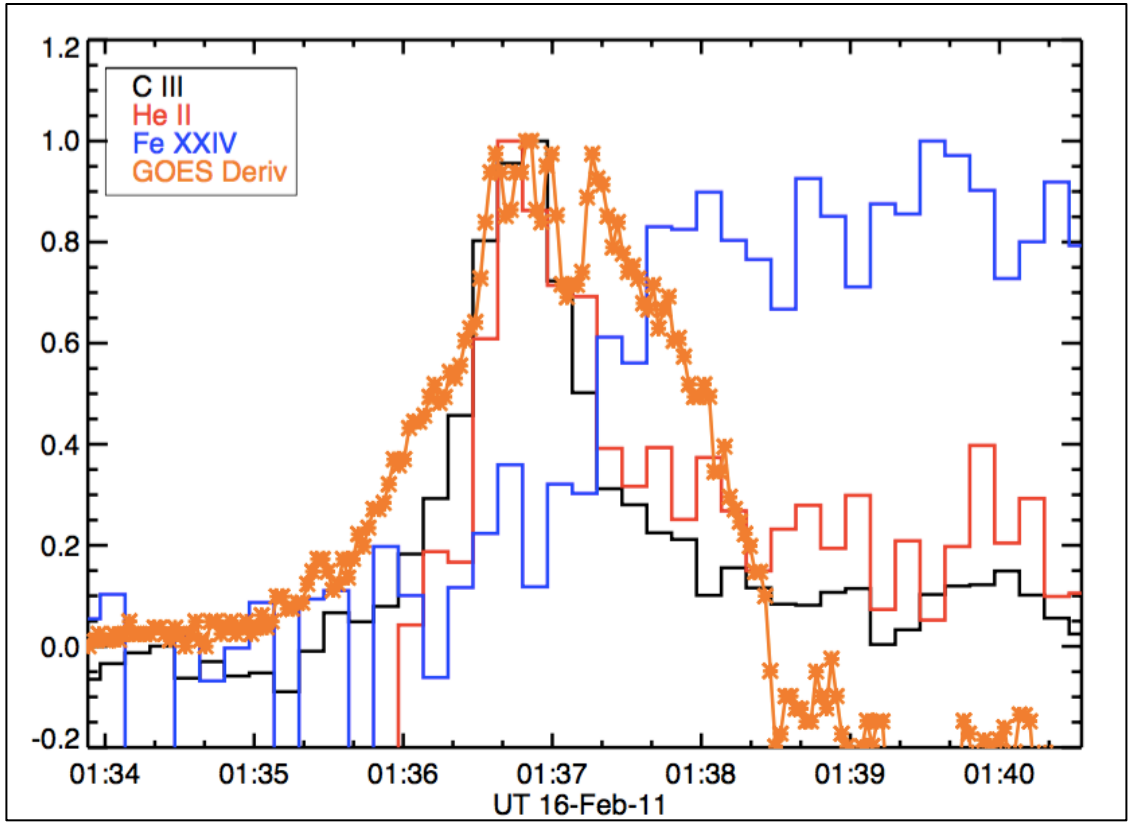


SDO's EVE instrument observes the Sun as a star over 6-105 nm, at 10 s cadence

An aside: the impulsive phase

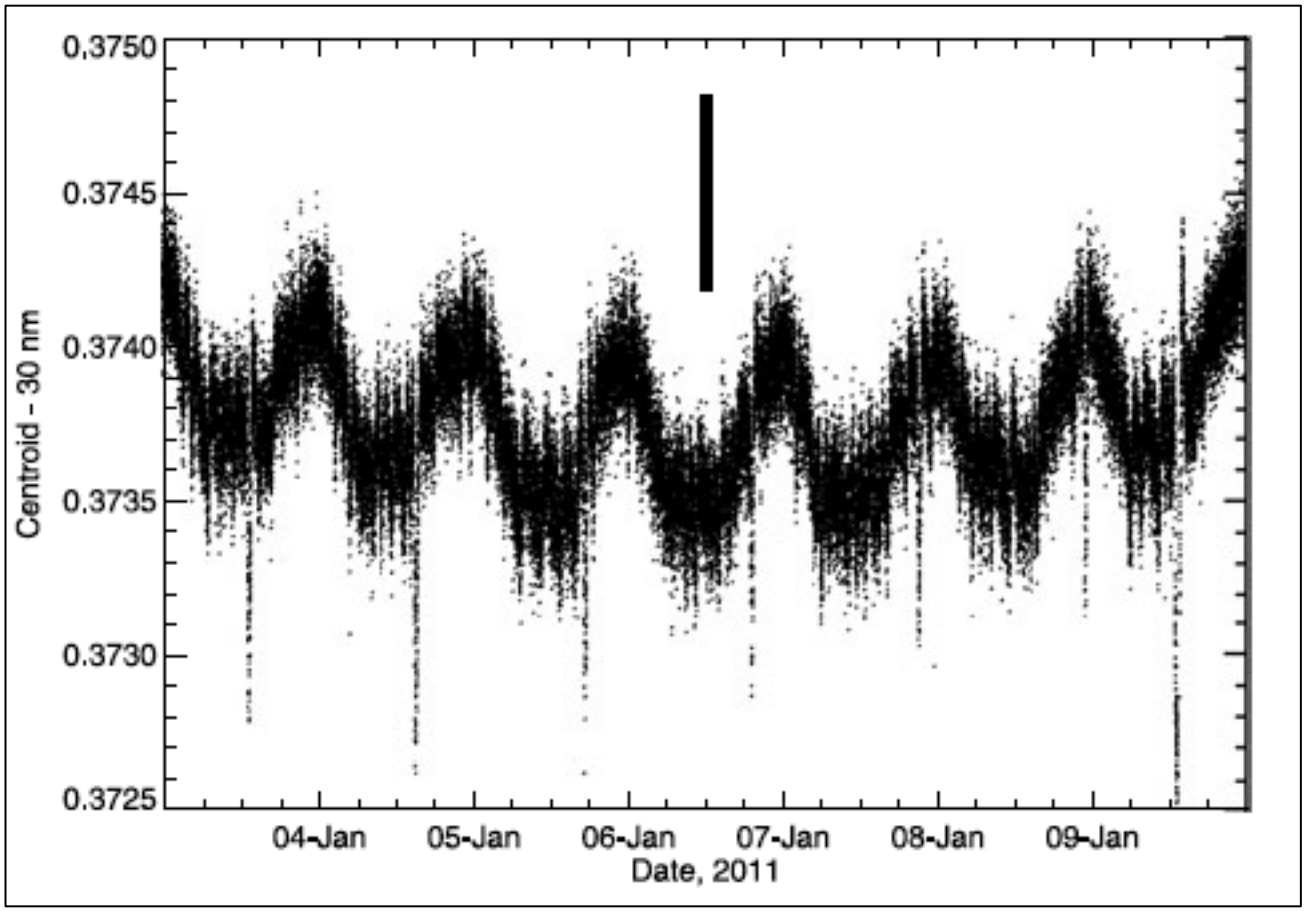


Martinez Oliveros et al. 2011



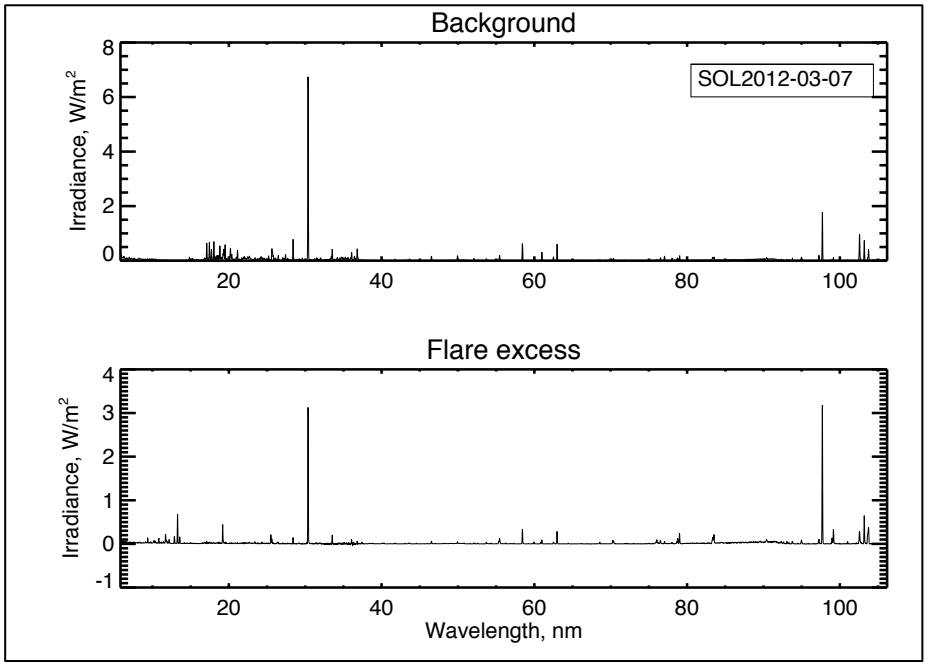
"Impulsive footpoints";
cf. Simoes et al. 2016

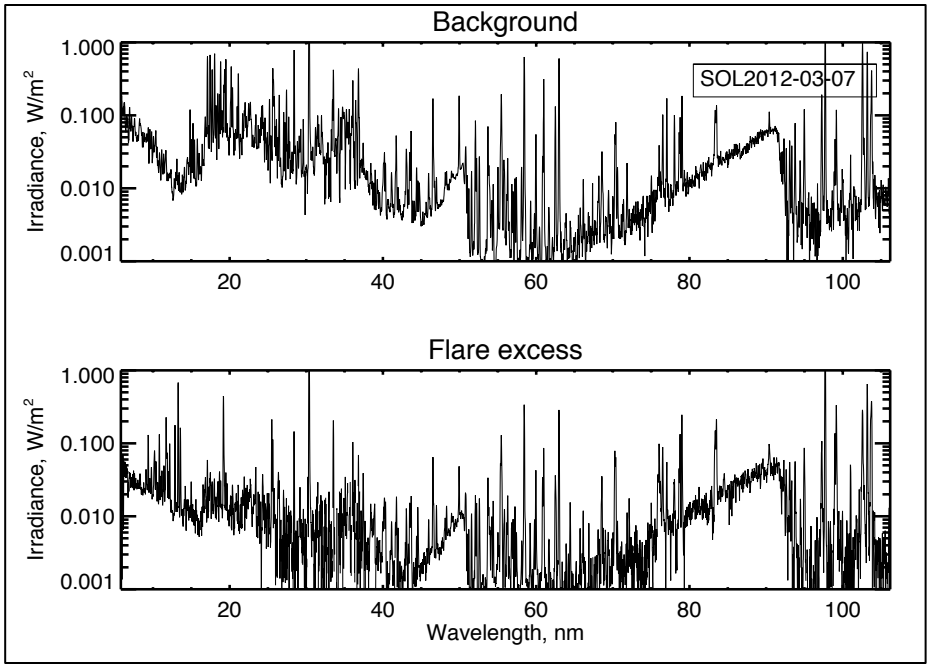
Another aside: Doppler shifts



Hudson et al. 2011

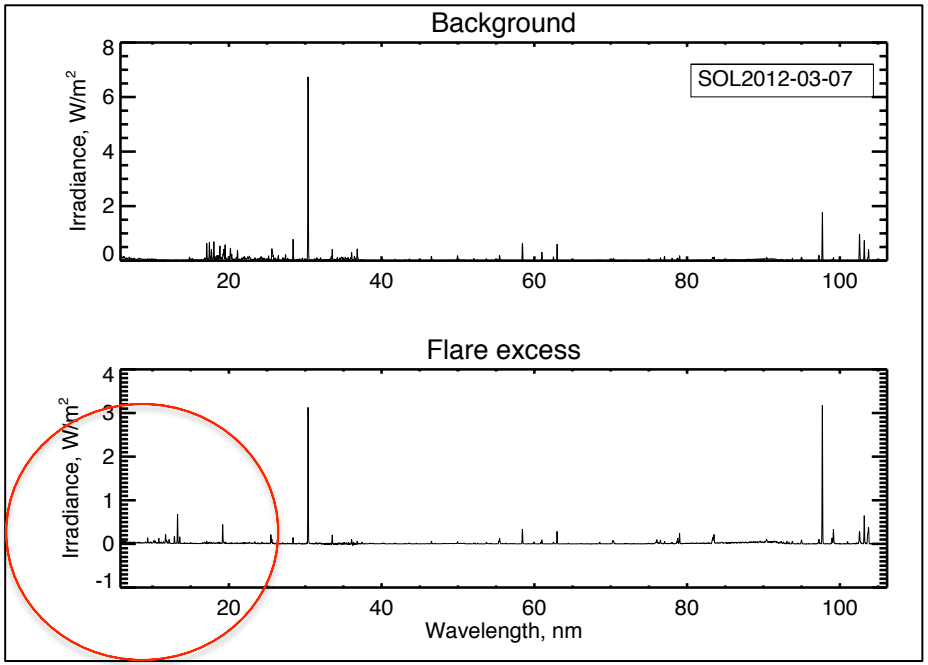
EVE flare spectra

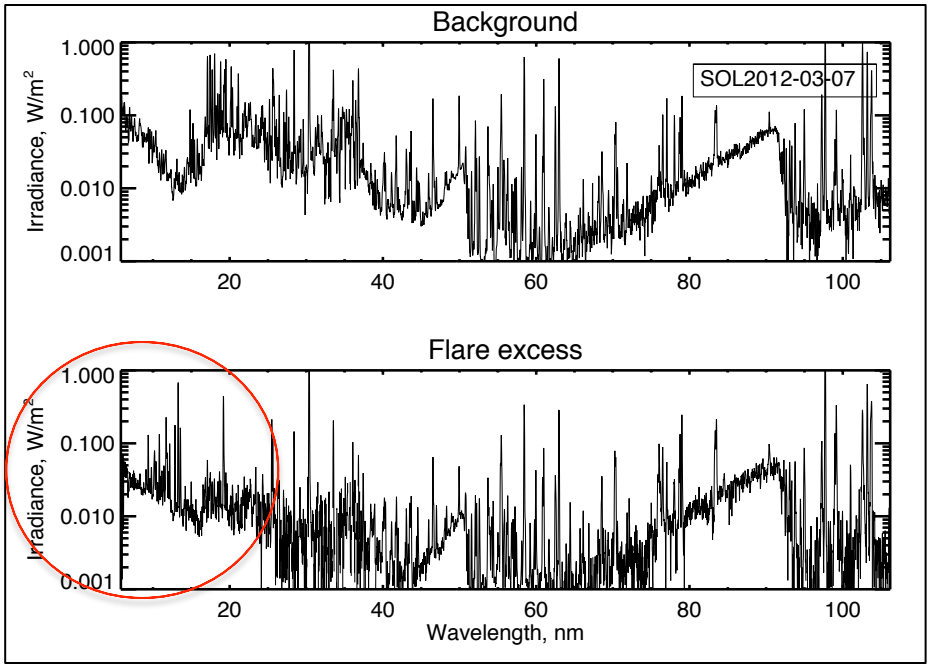




- SOL2012-03-07 – the *best* EVE event
- Flare excess right across the whole spectrum

EVE flare spectra





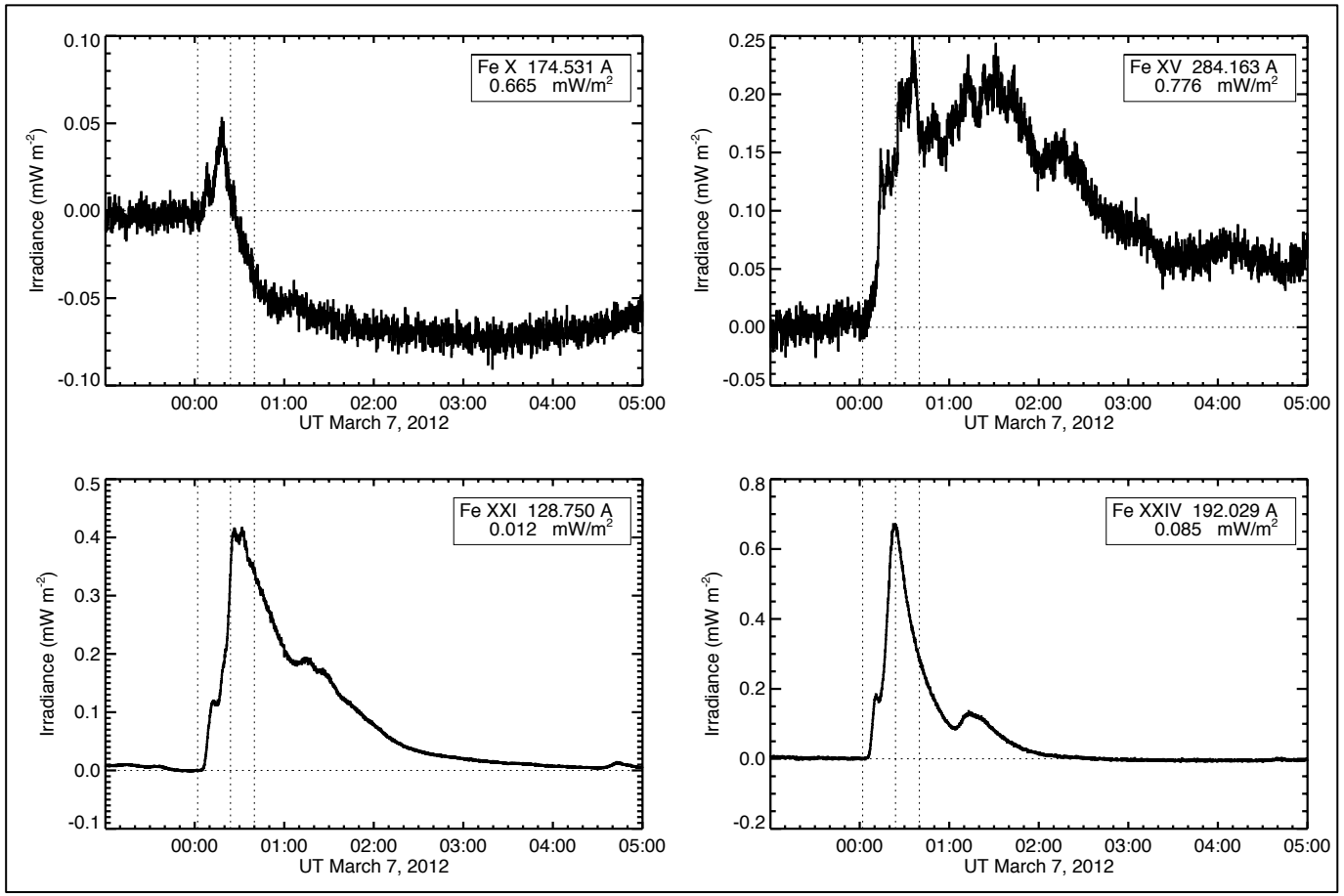
- The good dimming lines are at 15-20 nm

What do we see in EVE, and could we see analogous stellar things?

- Flare loops, flare footpoints, coronal dimming (CME mass loss…)
- Are there stars near enough for EUV coronal detection at 150-200 A, at SNR 100?
- Ground-based observations fail to do well with Fe XIII 338.8 nm (Wallerstein & Tyagi 2005); M dwarf coronae too cool?

Proxy detection of solar (and maybe stellar) coronal mass ejections

Can we remotely detect threats to life on exoplanets?



Can any stars be detected at 15 nm well enough for a dedicated “stare at a star” observation?

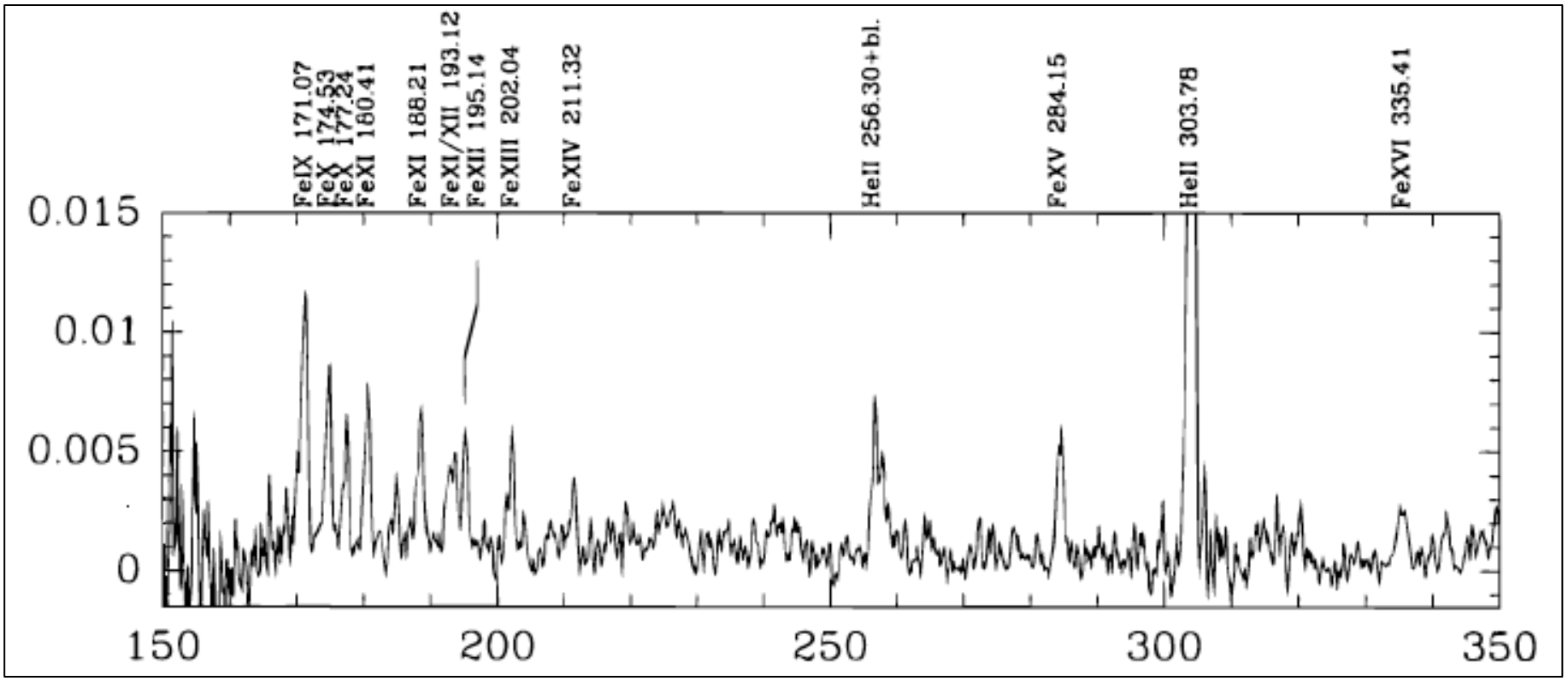
THE *EXTREME ULTRAVIOLET EXPLORER* STELLAR SPECTRAL ATLAS

N. CRAIG,[1] M. ABBOTT,[1] D. FINLEY,[1] H. JESSOP,[1] S. B. HOWELL,[2] M. MATHIOUDAKIS,[3] J. SOMMERS,[1] J. V. VALLERGA,[1] AND R. F. MALINA[1,4]

Received 1997 February 11; accepted 1997 May 5

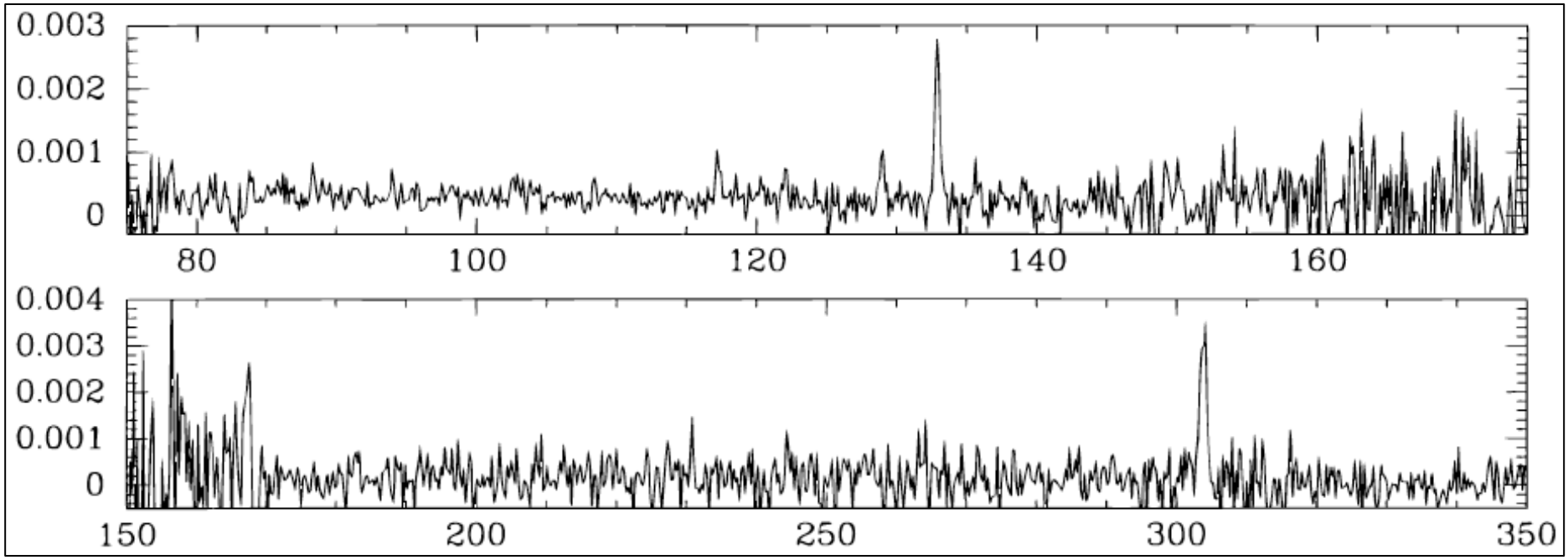
- Observation 100-200 ksec typically
- Many stars observed
- Slitless spectrograph, 40 cm primary, R=300
- There may be line detections, but are they good enough (200σ)?

Procyon (F5 IV-V)



EUVE 229 ksec observation

II Peg (K0 V)



- EUVE observation 211 ksec

A Stellar EVE experiment? "Stare at a star…"

- The dimming method for CME detection should work, with the right data
- We would need $\lambda/\Delta\lambda$ = 200, SNR > 100 at 15 nm to study coronal time series properly
- This seems to preclude a Cubesat mission

Conclusions

- There are many good reasons to want to know about CME occurrence on active stars
- The dimming signature is attractive, but an EUV mission is beyond Cubesat capability
- Radio techniques may develop