Flares Seen in Sun-as-a-star Data*

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**Acknowledgement of an ISSI Science Team chaired by Louise Harra*

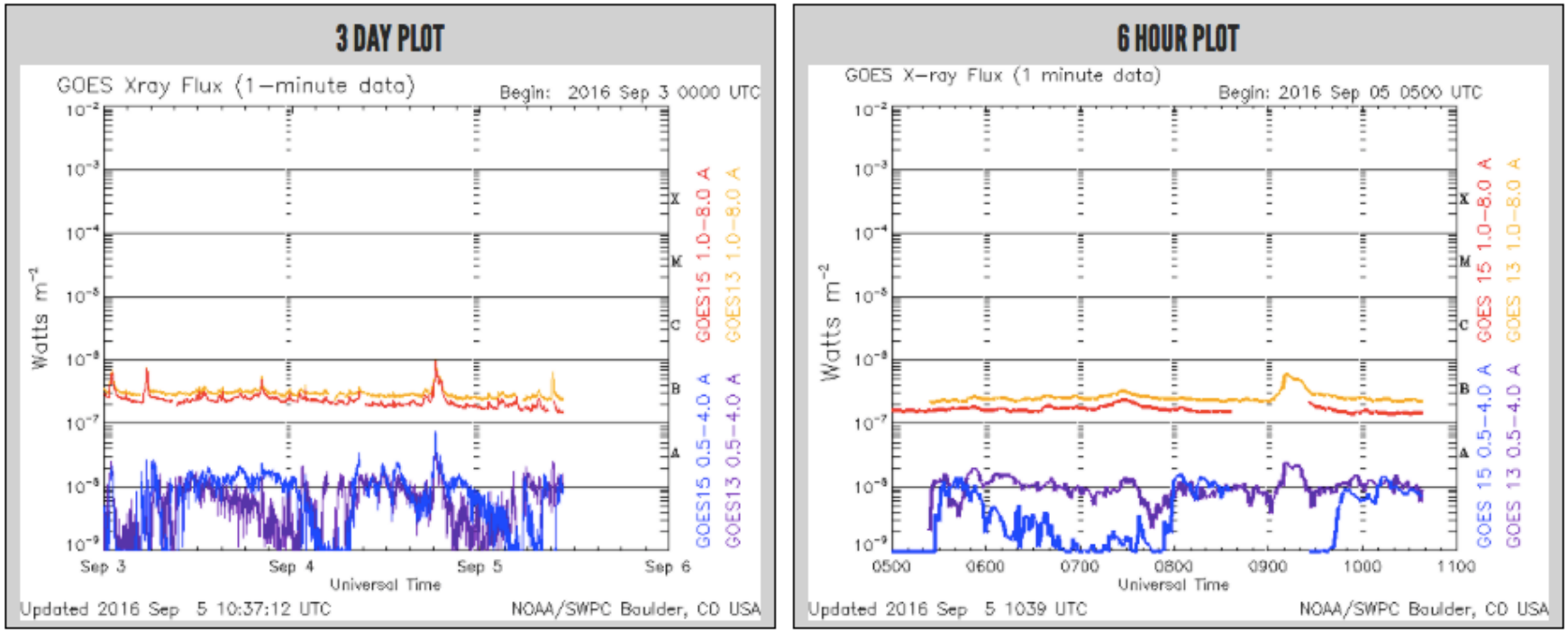
Contents

- Why study the Sun as a star?
- Practice on GOES/XRS, TSI, EVE examples
- Can we record stellar CMEs via timeseries spectrophotometry?
- If so, could we please have a Stellar Dynamics Observatory?

Why Sun-as-a-Star?

- We can learn a great deal about the Sun without actually making images
- We can also calibrate simple time-series signatures against image reality on the Sun
- Solar paradigms are extremely important for the exoplanet community

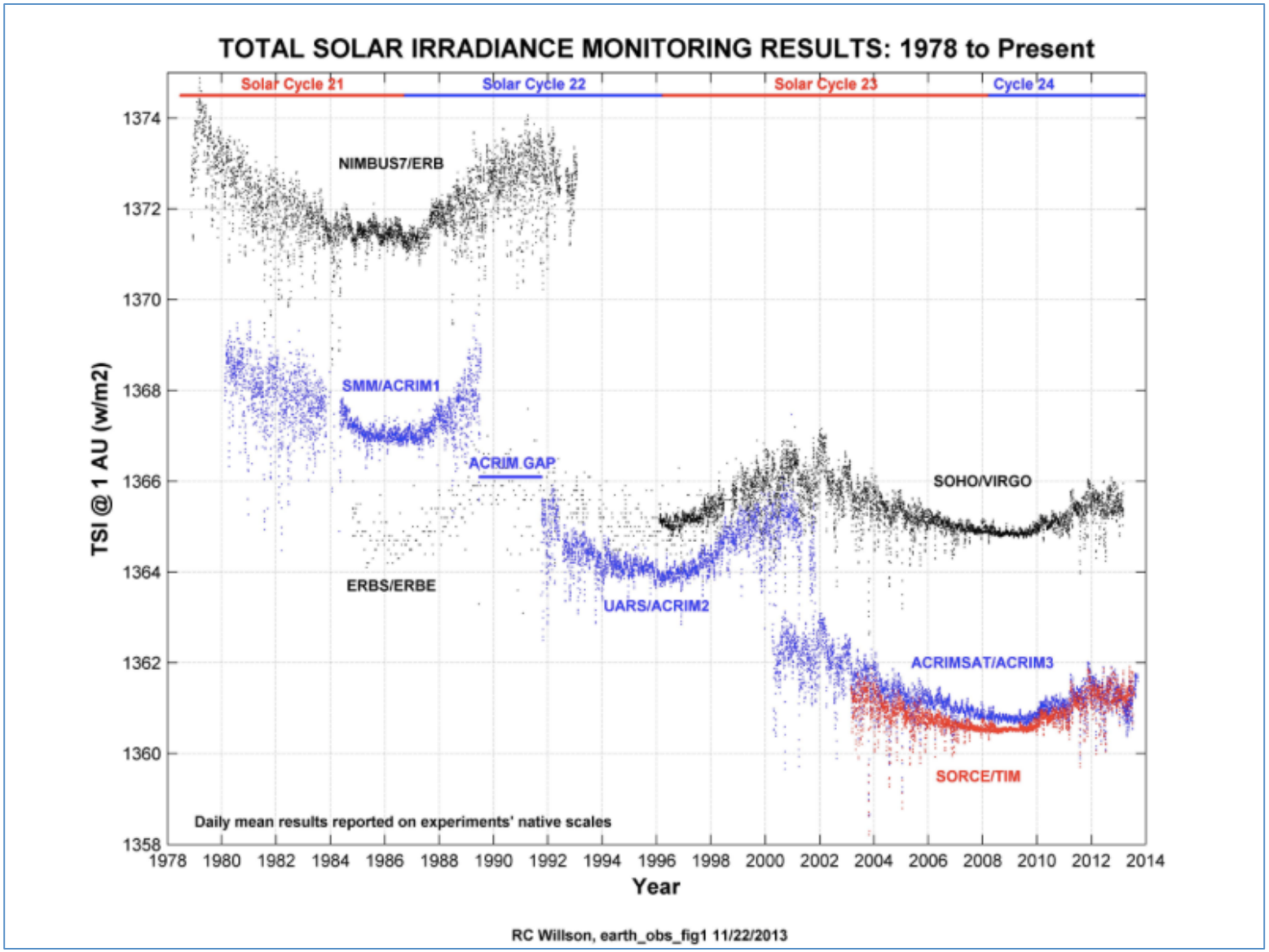
Example #1: GOES/XRS



- The GOES soft X-ray flux has become the standard measure of flares, supplanting Hα (“3B”, for example).

- This does not necessarily correspond to our understanding of flare physics! The chromosphere is what counts.

Example #2: TSI



Example #2: TSI

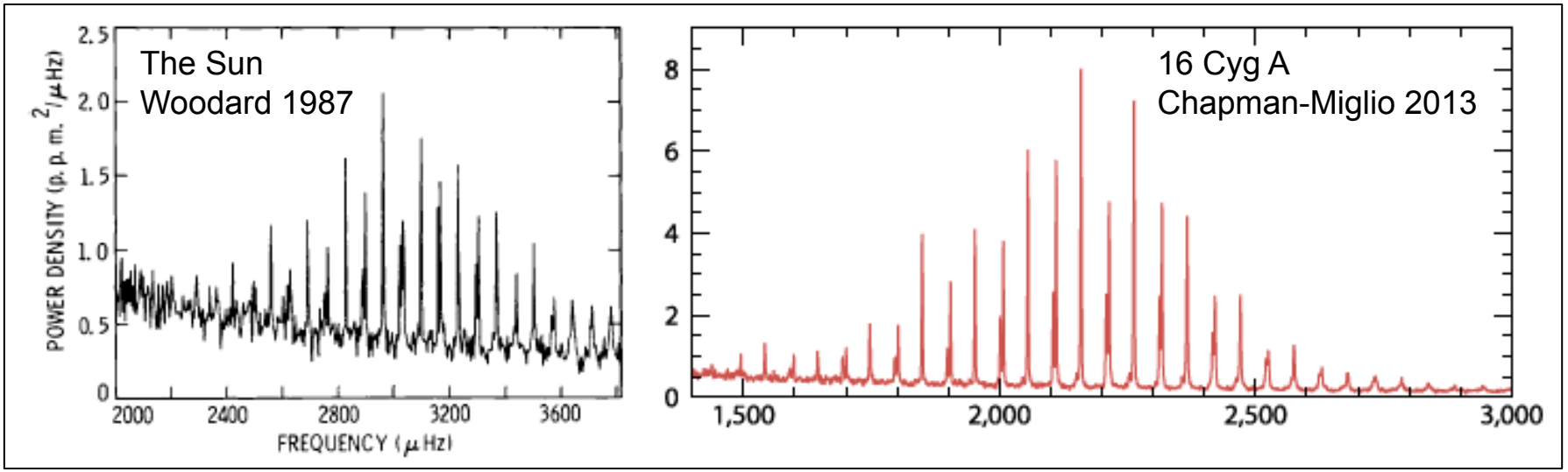
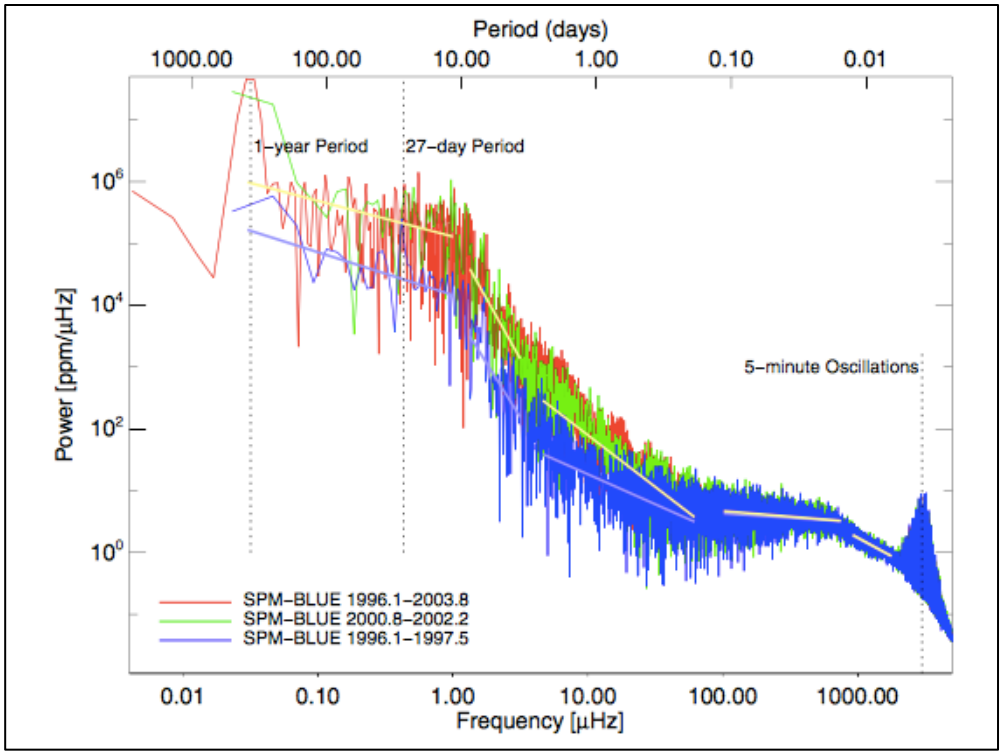


Table 1 Identified variability mechanisms for solar total irradiance

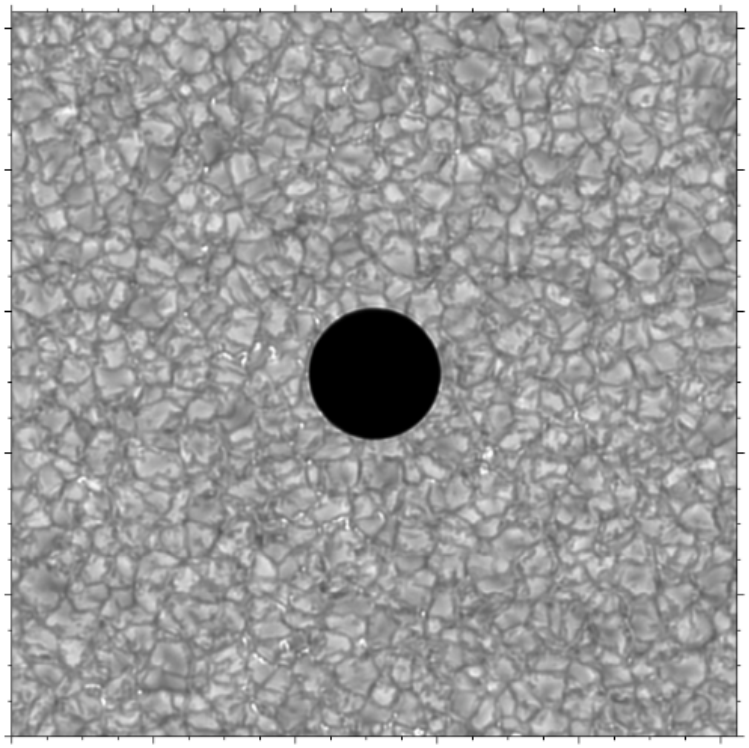
Mechanism	Time scale	Amplitude	Reference
Oscillations	5 min	Few ppm	Woodard & Hudson 1983
Granulation	Tens of min	Tens of ppm	Hudson & Woodard 1983
Sunspots	Few days	<0.2% peak-to-peak	Willson et al. 1981
Faculae	Tens of days	<0.1% peak-to-peak	Willson et al. 1981
Rotation	27 days	Variable	Fröhlich 1984
Active Network	11 yr	~0.1% peak-to-peak	Foukal & Lean 1988

Hudson 1988

“Flicker noise”

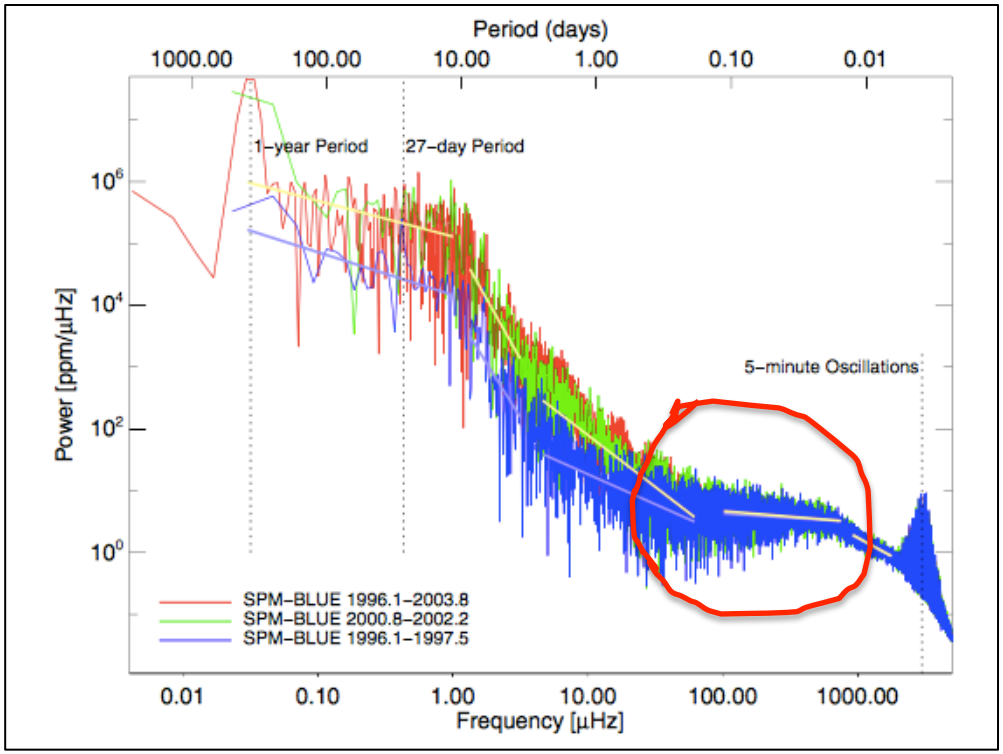


Sun-as-a-star power spectrum:
Virgo sunphotometers (Fröhlich, 2003)



Hinode/SOT flicker-noise image:
Mathew et al. 2009

“Flicker noise”



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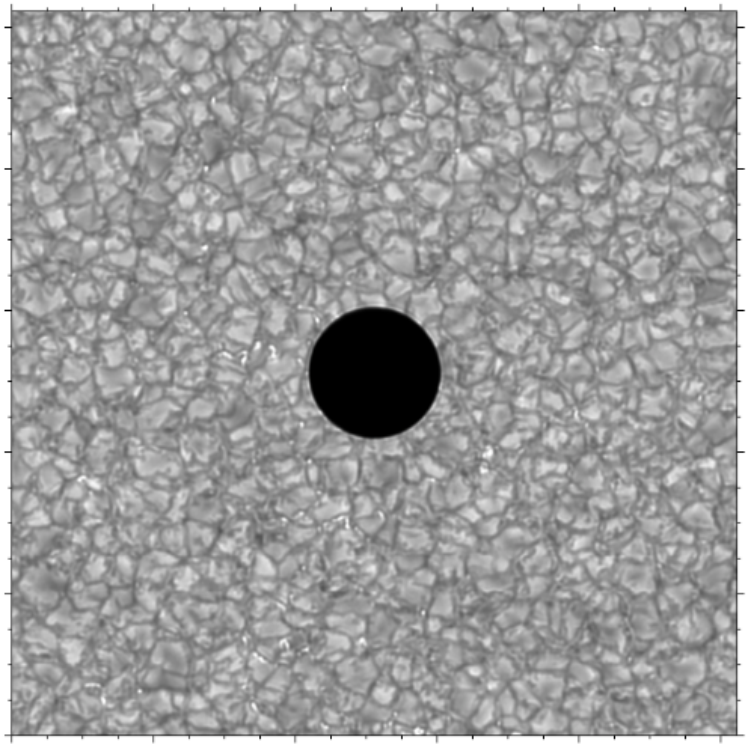
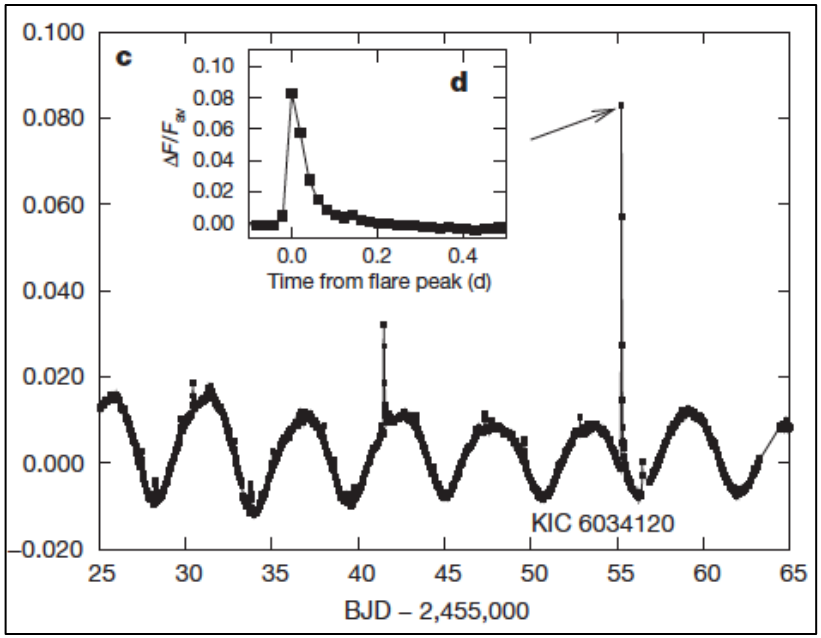
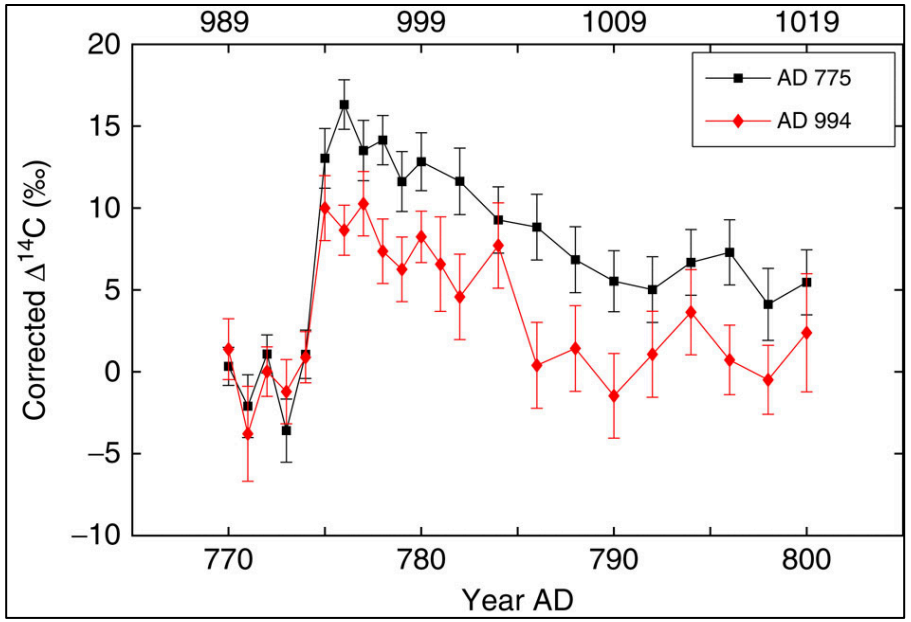


Hinode/SOT flicker-noise image:
Mathew et al. 2009

“Superflares” and extreme events



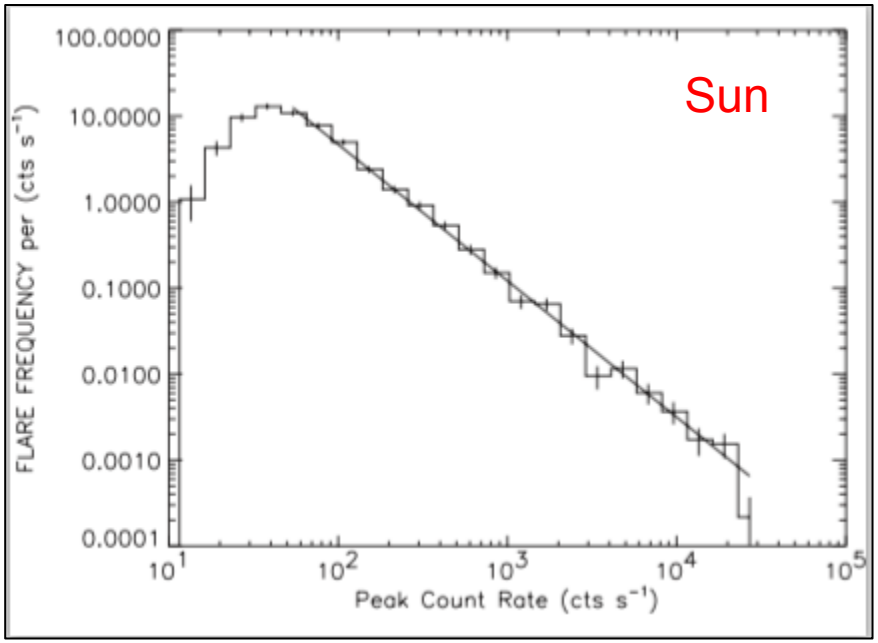
Maehara et al. 2012



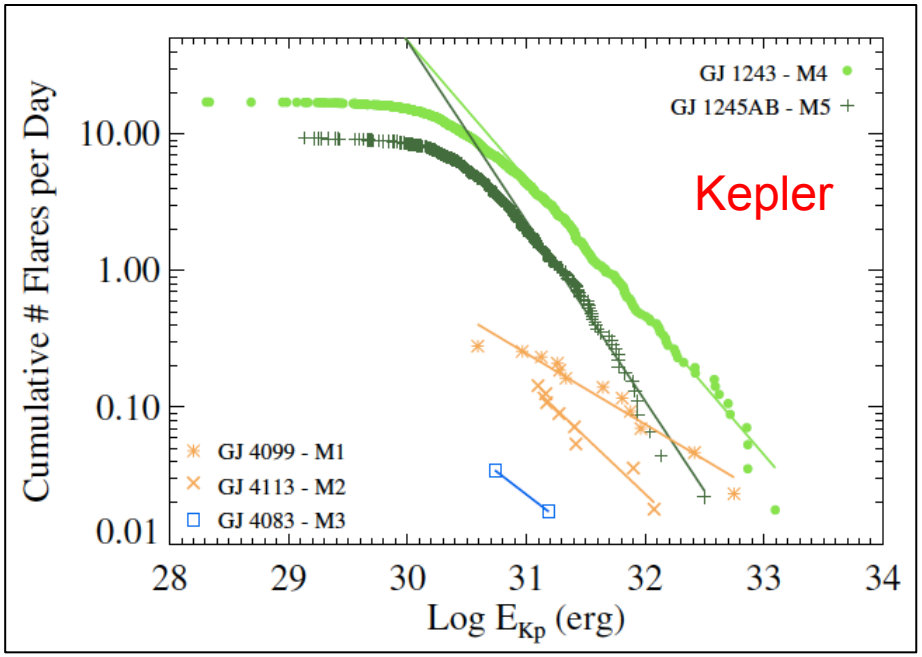
Miyake et al. 2013

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

Flare energy distributions



Crosby et al. 1997

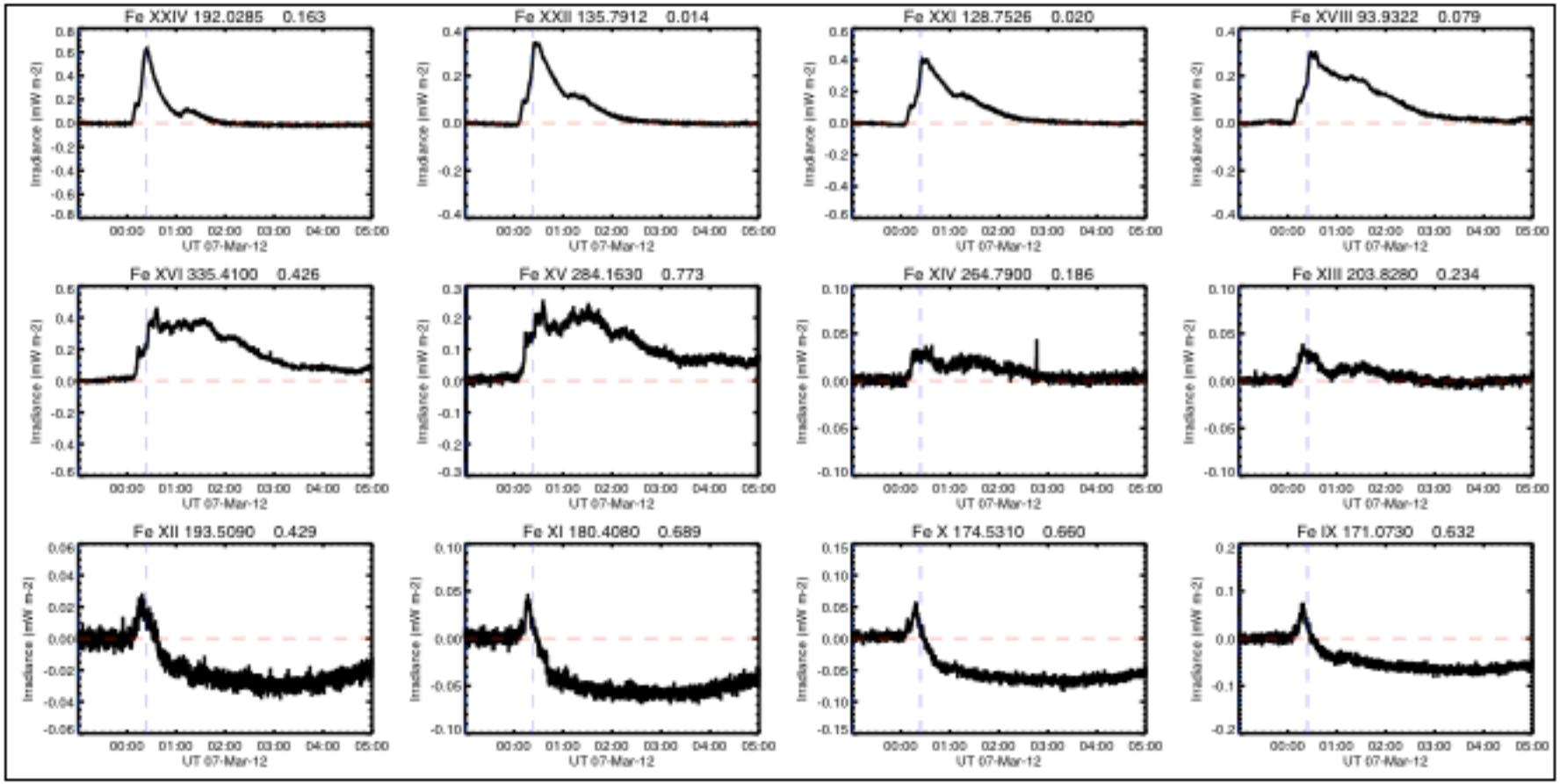


Hawley et al. 2012

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

Example #3: EVE/MEGS-A

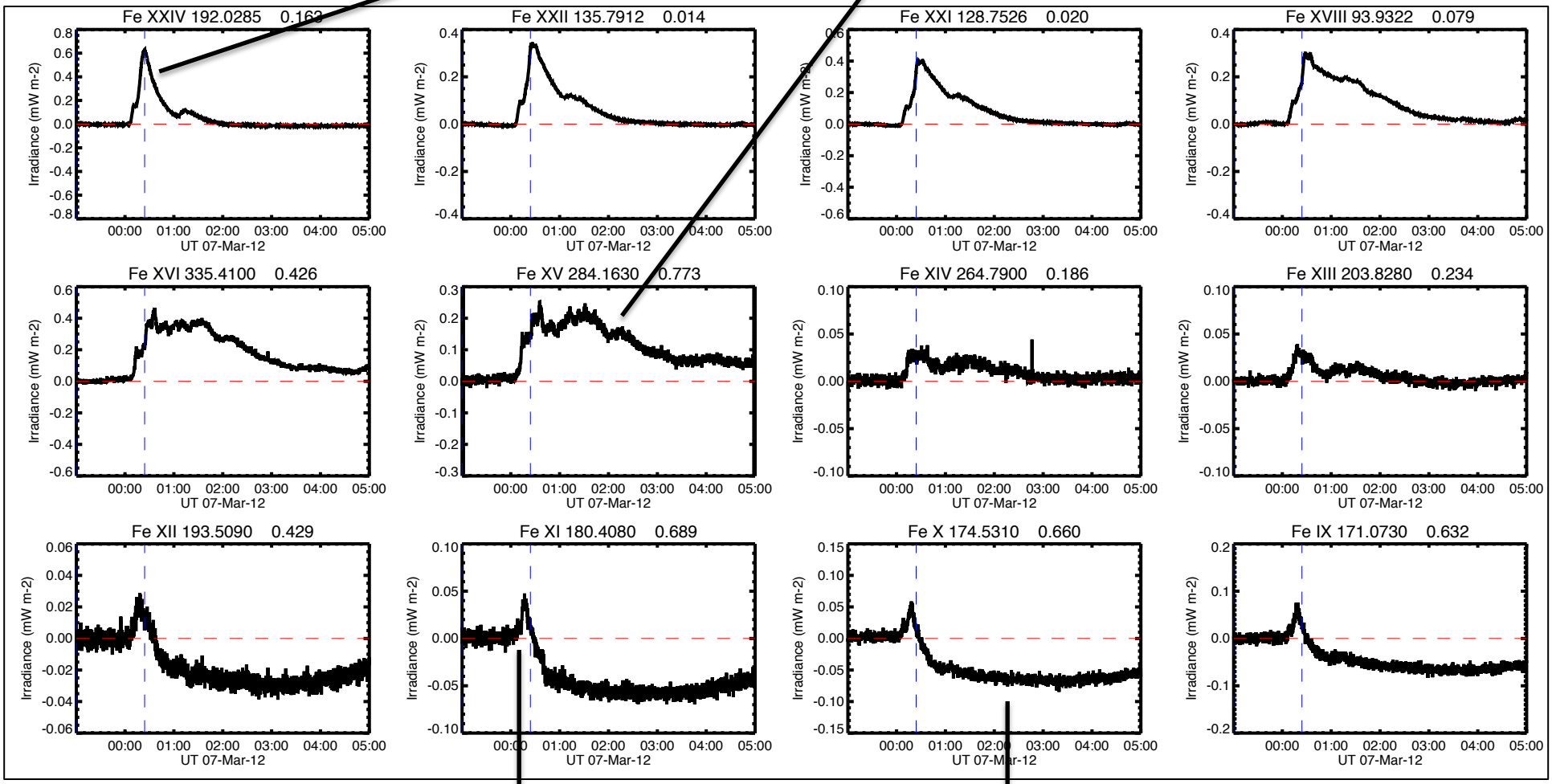
The "Fe Cascade" plot for SOL2012-03-07



HOT

Hot Flare Loops

EVE Late Phase



<- 6 hours ->

COLD

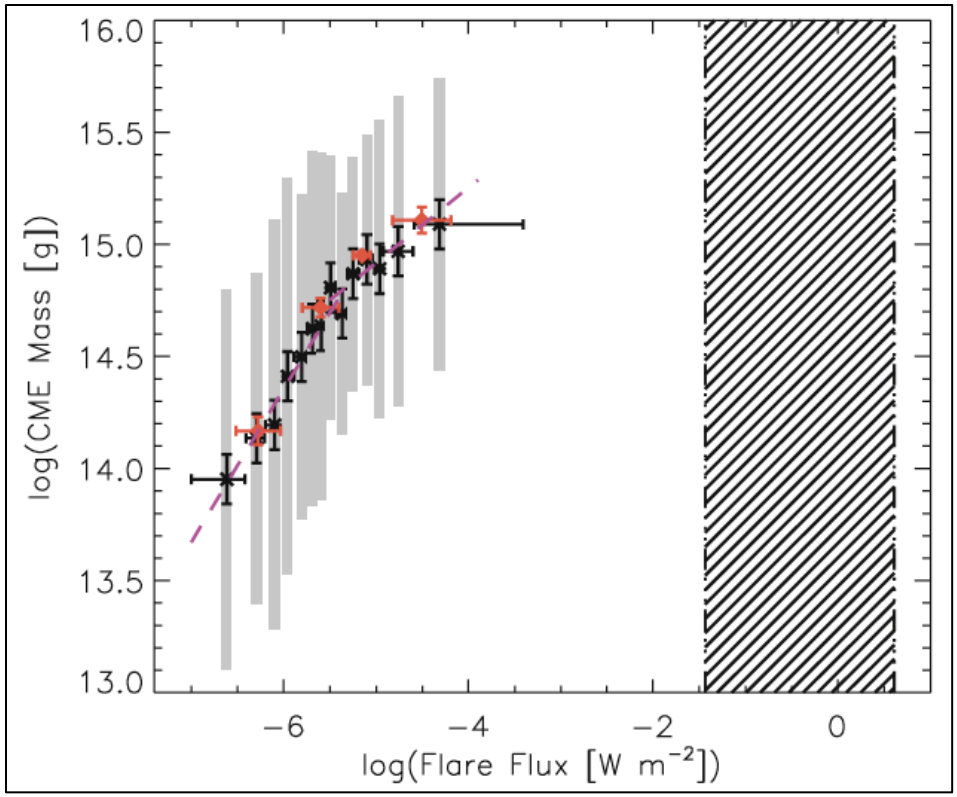
Impulsive Footpoints

Dimming!

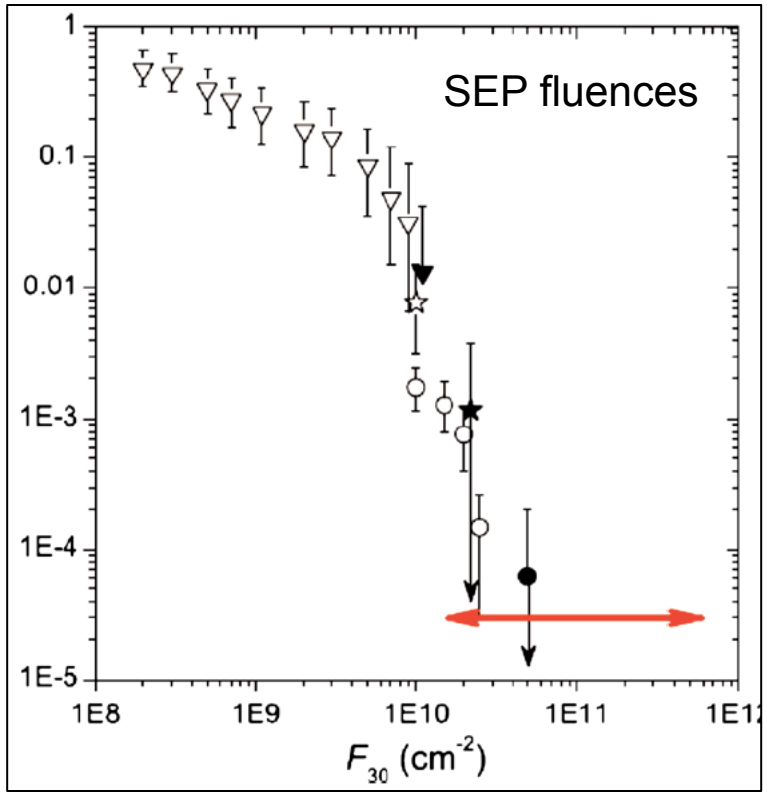
What do we see in EVE, and could we see analogous stellar things?

- Flare loops, flare footpoints, coronal dimming (CME mass loss…)
- Are there stars near enough for EUV coronal detection at 100-200 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?
- We would need $\lambda/\Delta\lambda = 200$, SNR > 100 at 15 nm to study coronal time series properly

First question: how are flares and CMEs related?



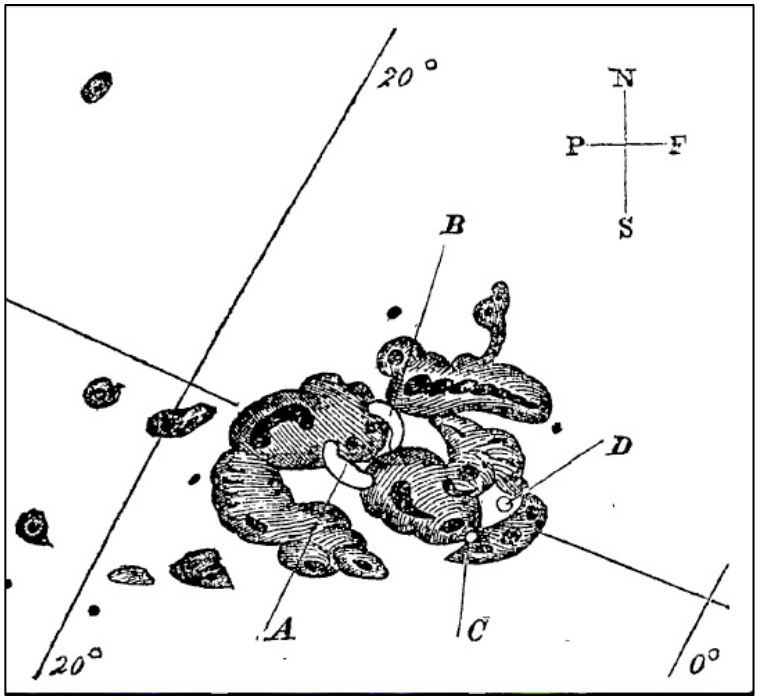
Aarnio et al. 2011



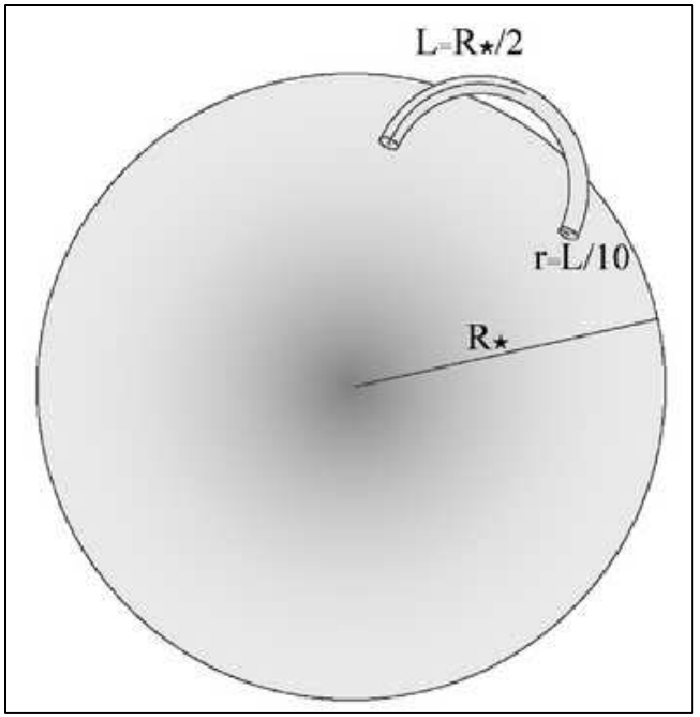
Kovaltsov et al. 2014

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 paradigms work?



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 of an exoplanet

Detecting extrasolar CMEs

"Super CMEs" on stars with exoplanets might accompany "superflares," and these may generate "Super SPEs" injurious to life

- 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)

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

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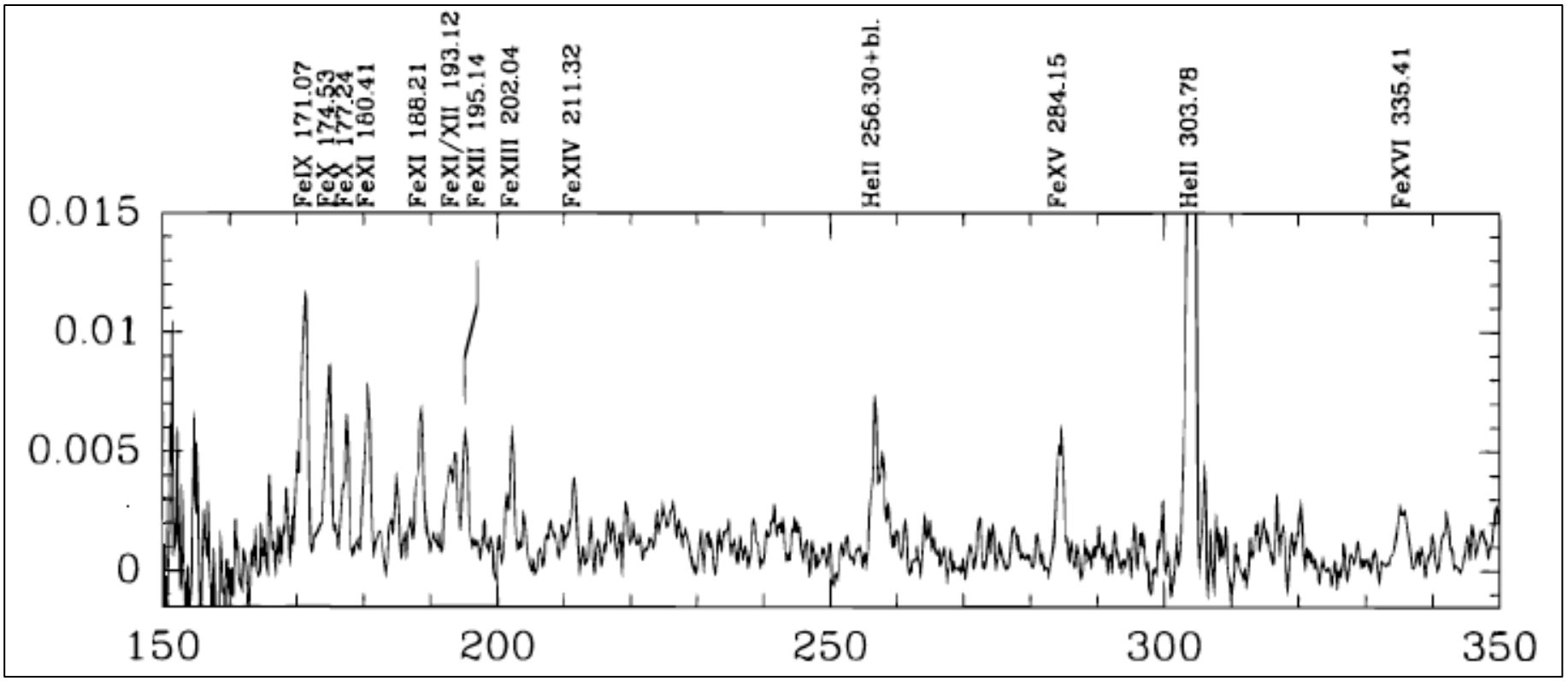
Received 1997 February 11; accepted 1997 May 5

- 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

Conclusions

- Sun-as-a-star solar observables can be related to image data
- Such observations whet our appetite for similar stellar coverage
- Dimming might really be observable via EUV timeseries observations, with major significance for exoplanet research

An “Exoplanet Habitability Observatory”

- Time-series spectropolarimetry of a few nearby solar-type stars in a sit-and-stare mode
- The observed stars must be nearby, bright, solar-type stars with eclipsing planets and flares
- While useful for exobiology, the real return from such a mission would be in its new perspective on solar phenomena

Maru-chan, a Japanese-Scottish cat just
trying to think outside the box