Extreme Radiation Events*

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1) Flares, CMEs, and SEPs
2) Kepler superflares and tree rings
3) Give me a break
4) Assessing the risk

*http://arxiv.org/abs/1504.04755

Definitions

- Flares are sudden bursts of radiation, nowadays rated by GOES soft X-ray class
- CMEs are sudden solar ejecta progressing beyond the Alfven radius. I like to define
  - true CMEs as perpendicular flows
  - jets as parallel plasma flows
- SEPs are bursts of particles detectable in the heliosphere

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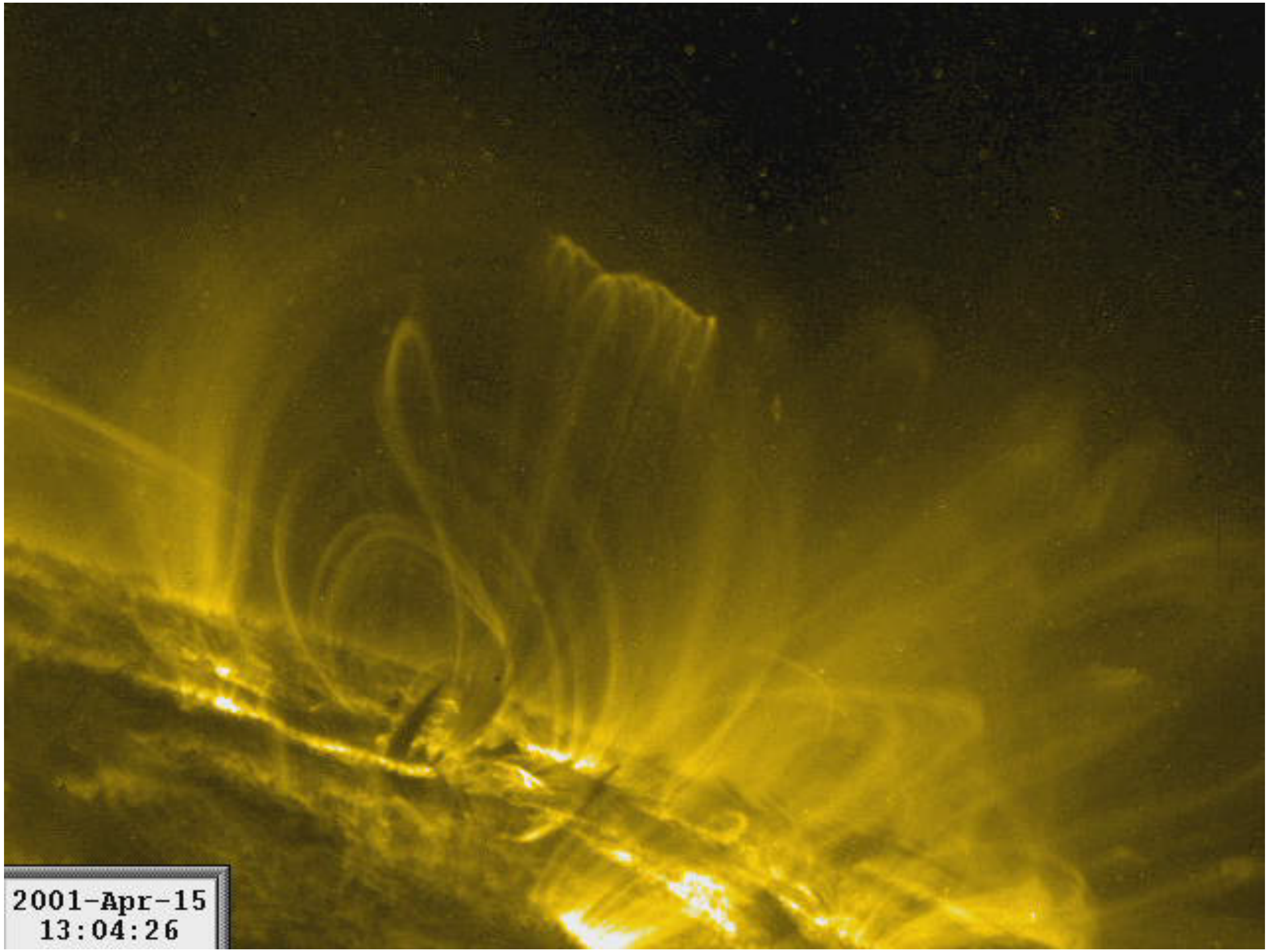
Flares vs. CMEs

- Flares and CMEs have close timing, especially in the case of energetic events
- Both involve powerful particle acceleration
- Either a flare or a CME can occur without much trace of the other
- Many SEP phenomena point to CME-driven shock fronts as sites of particle acceleration

This event seems to have it all!



SOL2001-04-15 (TRACE)

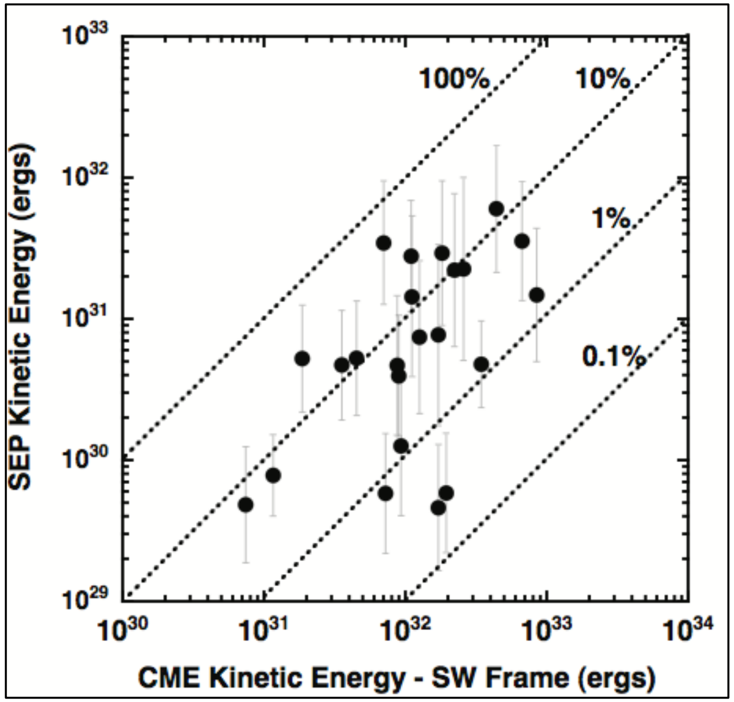
Things to have noticed

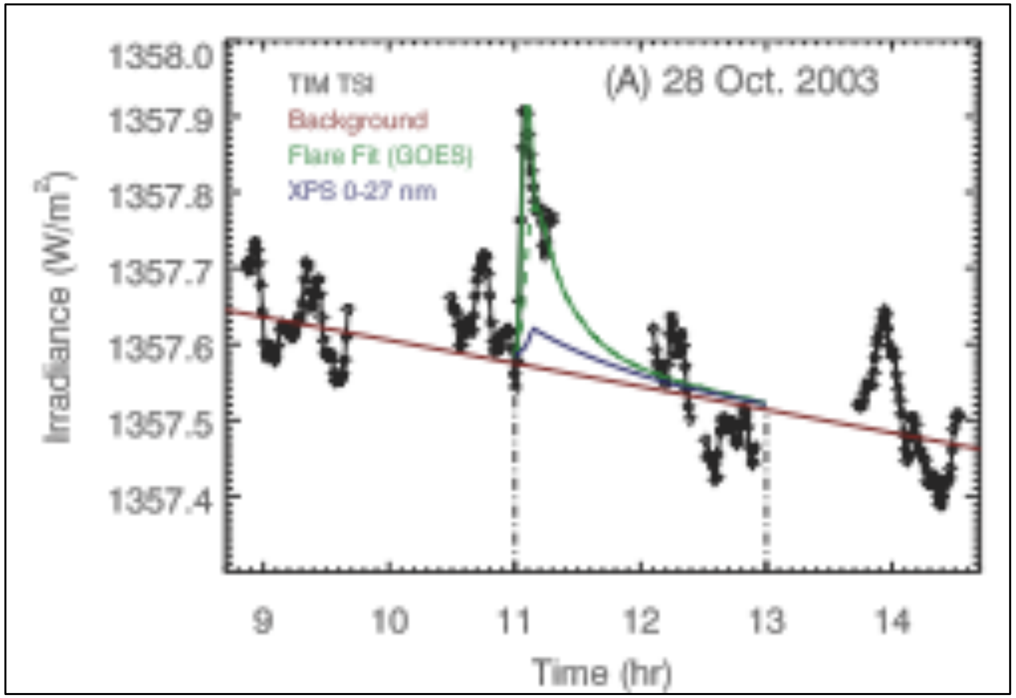
- Implosion
- Dimming
- Compact initial disturbance
- Coupled oscillations
- Lack of erupting filament
- Lack of “snowstorm”

Solar flares and CMEs

- The essential physics is highly nonthermal
- There is almost no detectable “heating” as such, ie energy release not mediated by accelerated particles
- We detect flares best with hard X-rays, γ-rays, radio waves, particles

Energy in accelerated particles

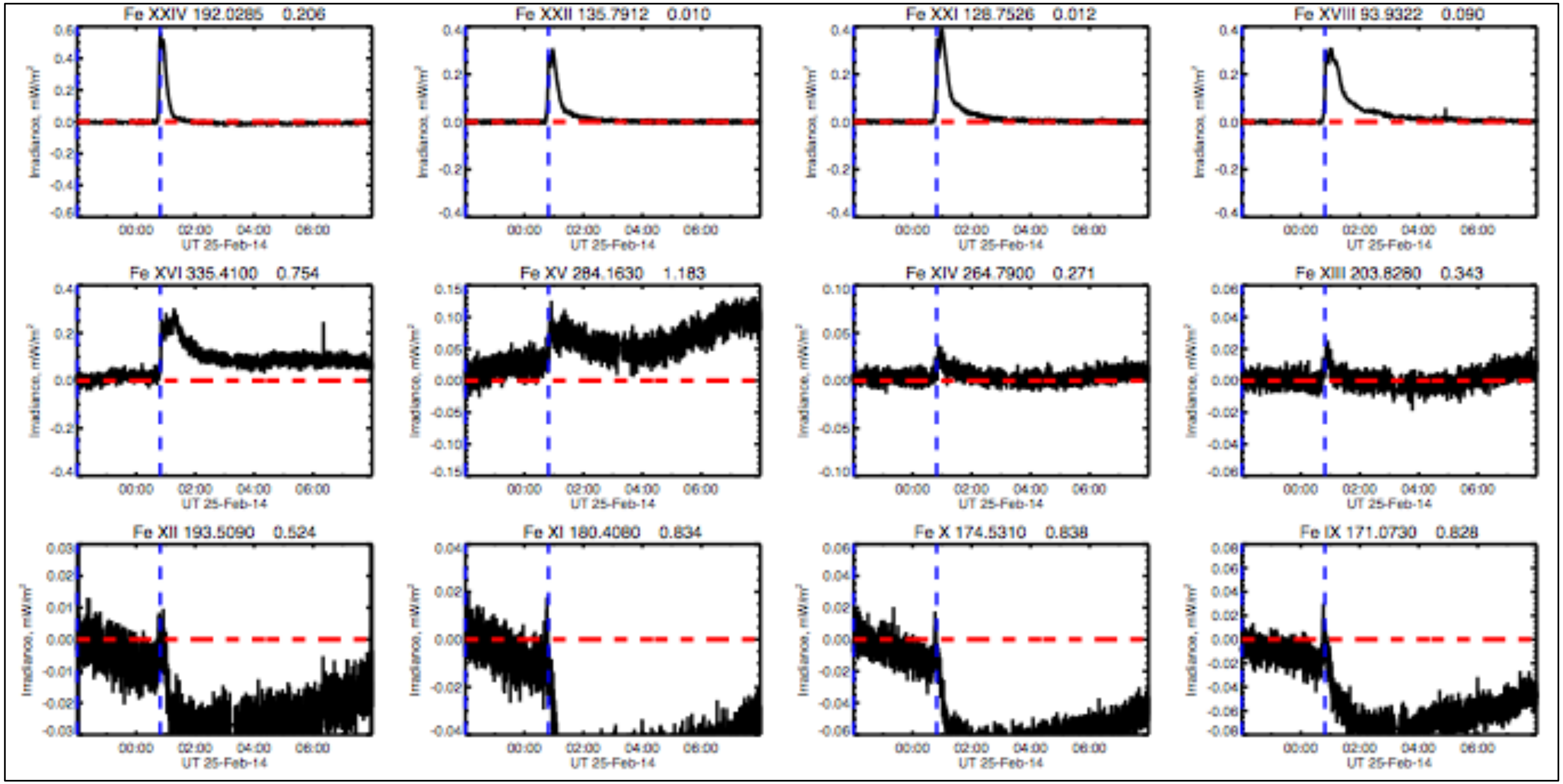




Mewaldt et al. 2004: massive energy in the SEPs themselves

Woods et al. 2004: Flare detection in TSI implicates the flare impulsive phase (we already knew about hard X-rays)

The Sun as a star with EVE spectroscopy



“Fe Cascade” plots for SOL2012-02-25

So, what is an “extreme event”?

- A Black Swan
- Something worse than a Carrington flare
- A myth

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- A Black Swan*
- Something worse than a Carrington flare*
- A myth

* Something that is unthinkable, until it actually happens and must be thought about

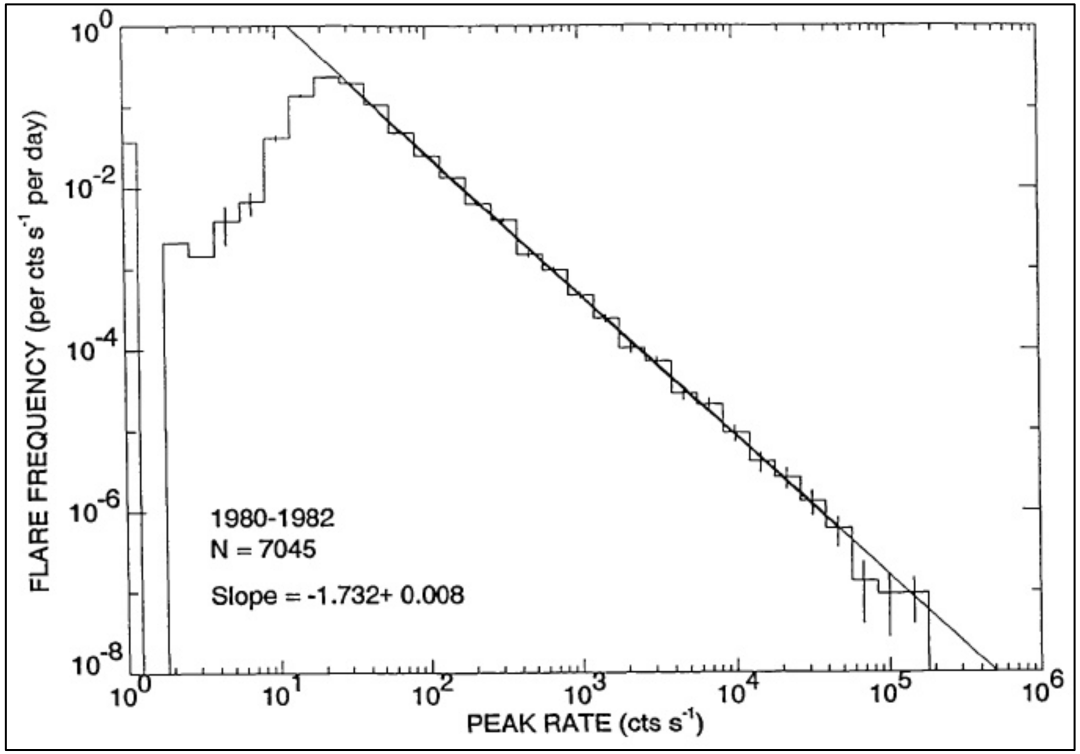
* Something with enough prior knowledge that we may anticipate it

THE BLACK SWAN

The Impact of the
HIGHLY IMPROBABLE

Nassim Nicholas Taleb

Occurrence distributions



Hard X-rays: Crosby et al. 1993

$$dN/dS \propto S^{-\alpha}$$

- S represents any BFS* item
- These data from HXRBS

* Big Flare Syndrome

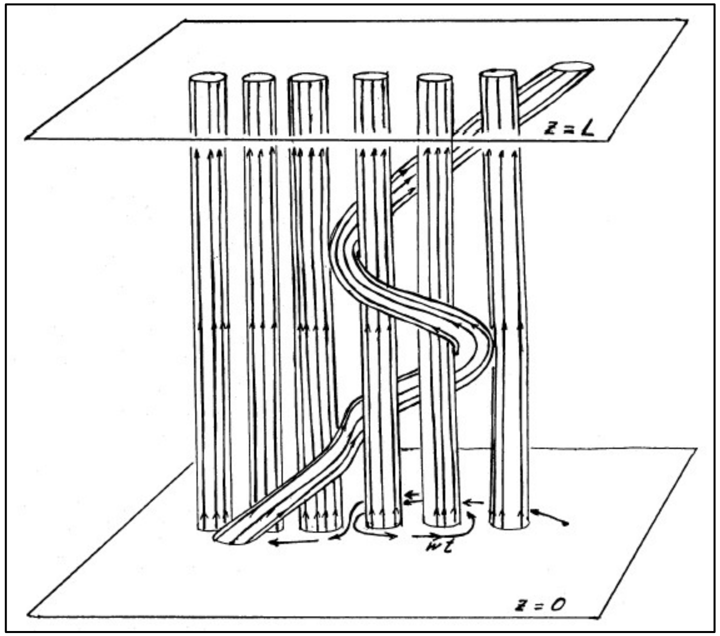
Implications of $dN/dS \propto S^{-\alpha}$

- We observe α < 2
- Ergo, the “nanoflare” end of this distribution is unimportant; and,
- The major events dominate the total energy; and,
- The total diverges, and there must be a limit for this empirical law

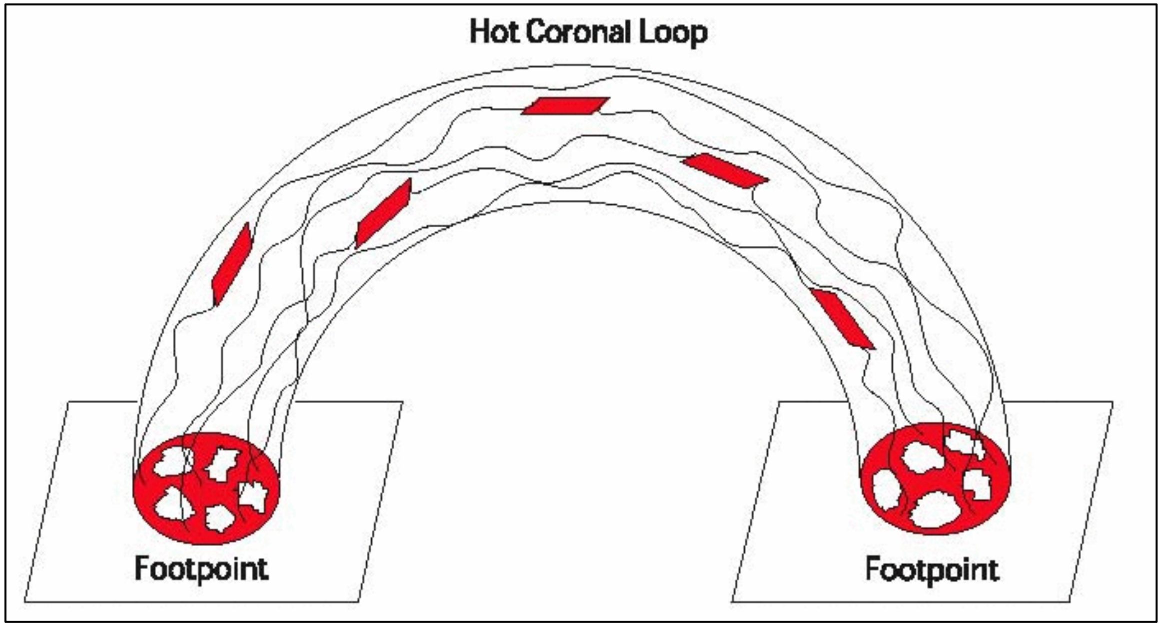
If the flux S scales with energy E, then total energy W diverges if α < 2:

$$W(>E) \propto \int_E^\infty E^{-\alpha}\, E\, dE \propto E^{2-\alpha}$$

Nanoflares?



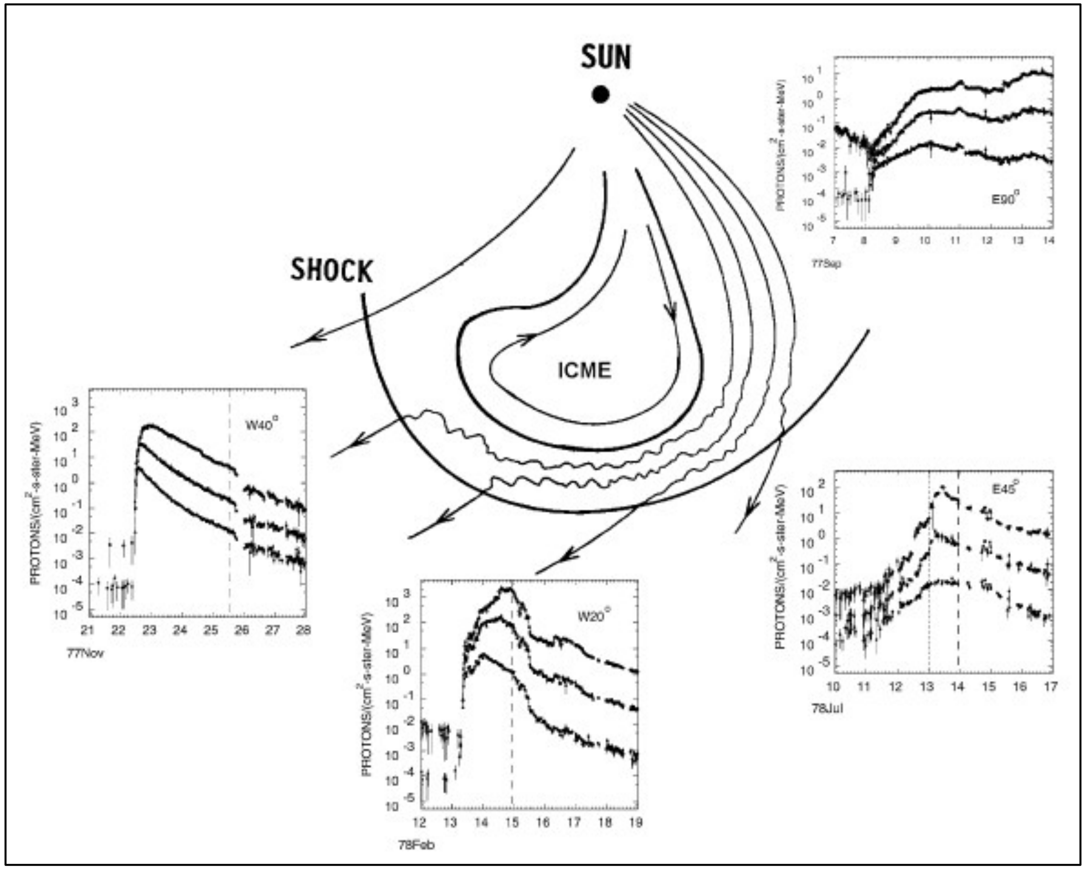
Parker 1983



Kittanaradorn et al. 2009

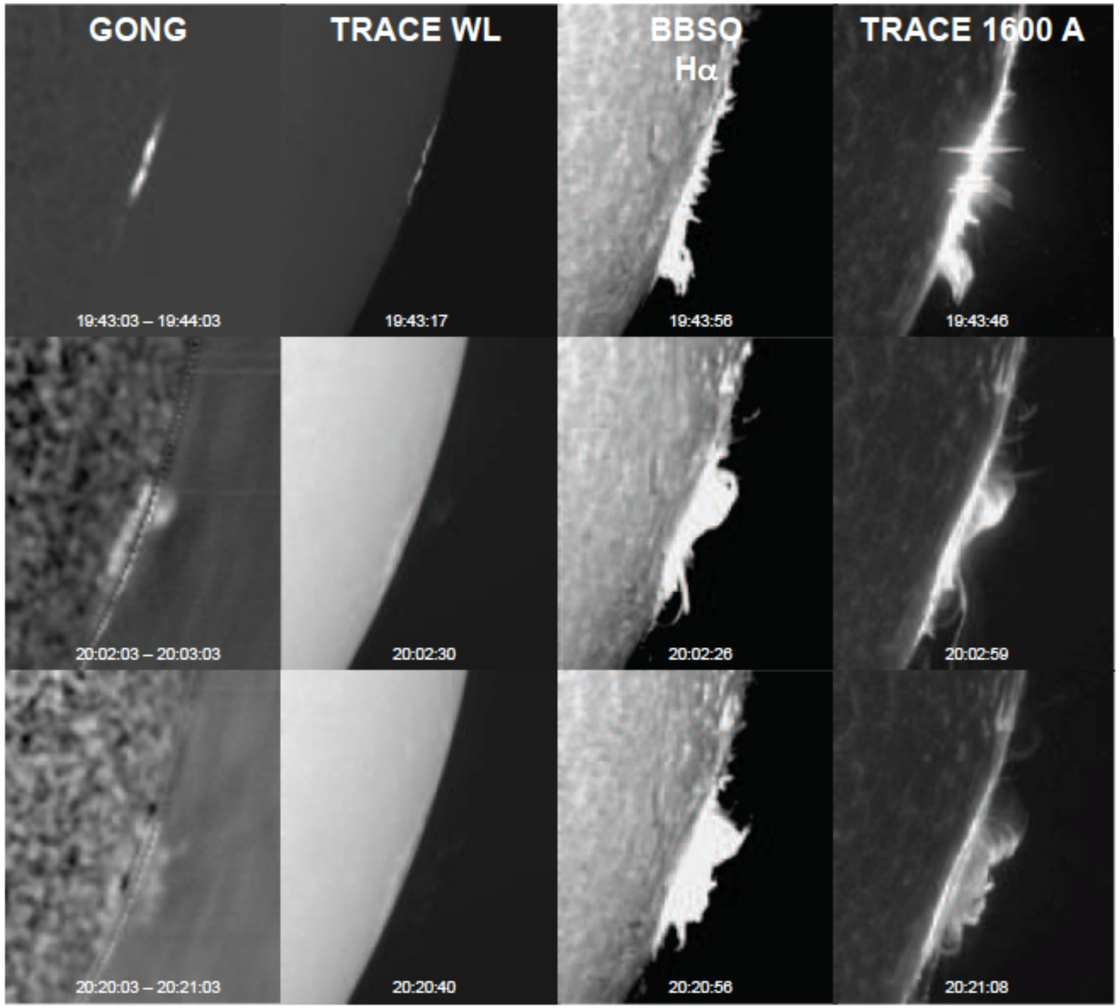
- Random twisting of coronal magnetic loops leads to episodic energy release
- No direct evidence for this picture exists, nor can it
- Cartoons from the flare cartoon archive

Test of flare cartoon archive



- Yes, SHINE's favorite cartoon is there
- See http://solarmuri.ssl.berkeley.edu/
~hhudson/cartoons/

A solar "mini-superflare": SOL2003-11-04



Leibacher et al. 2004

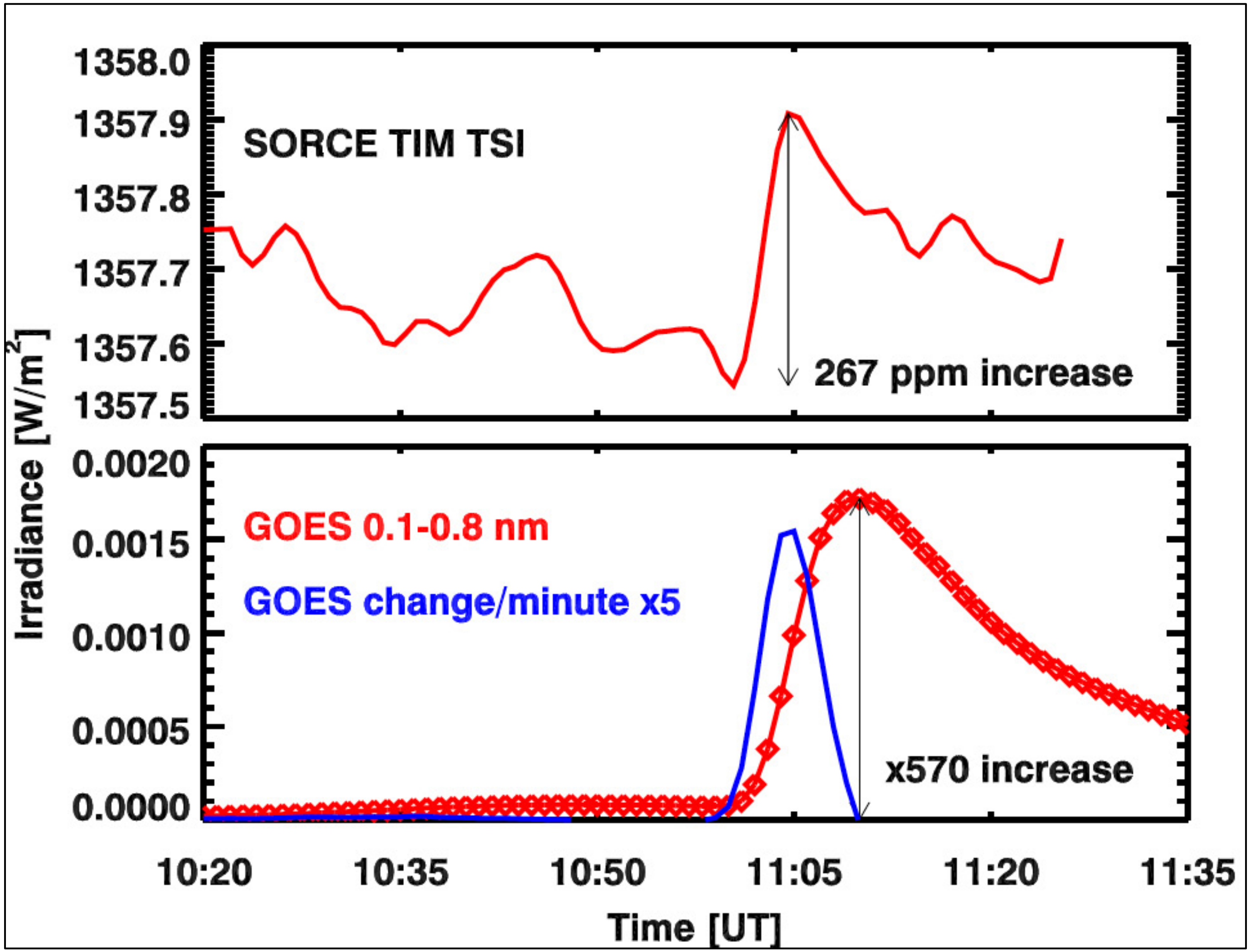
The Carrington flare

- Carrington himself could have inferred a total flare energy of order 10^{32} erg*
- The magnitude of the geomagnetic storm has been overestimated in the past
- This event may not have been much more powerful than, say, SOL2003-11-04**

* Ergs were introduced in 1873

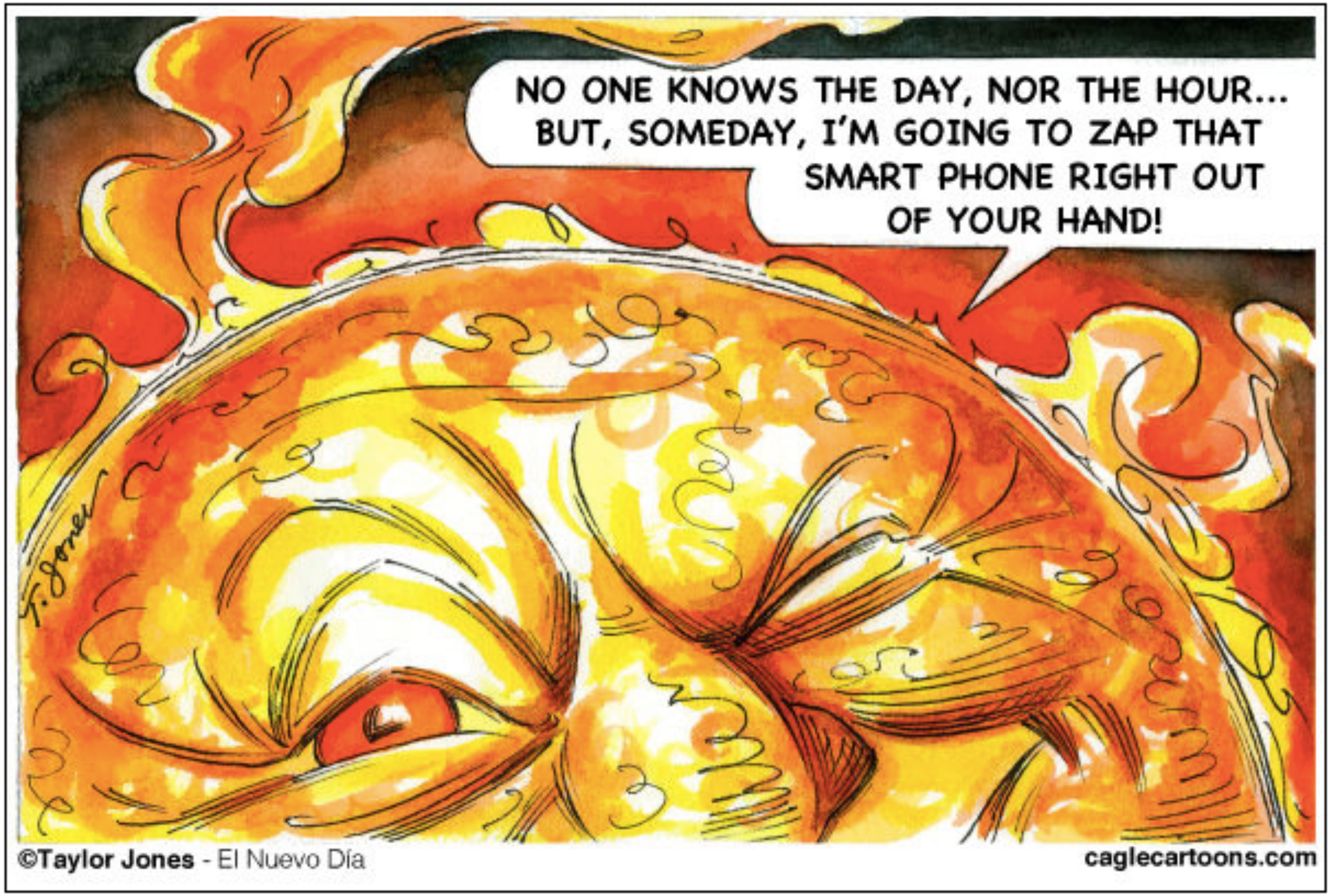
**See, e.g. Cliver & Keer, 2012

Flares in TSI (bolometric)

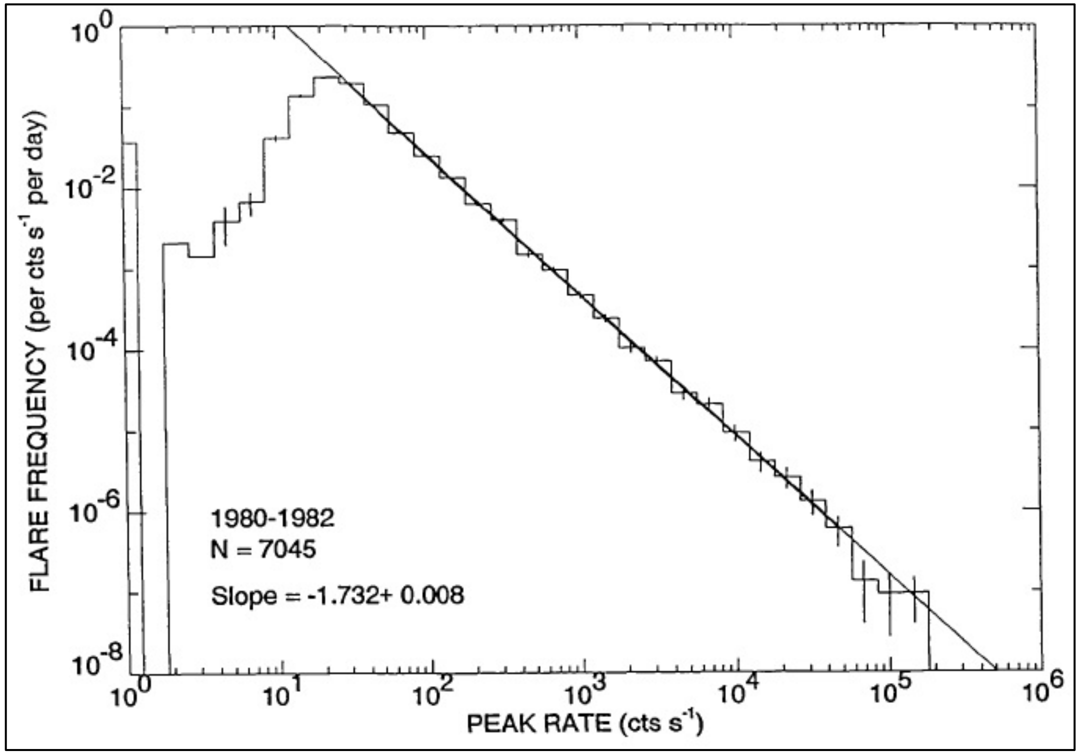


Woods et al. (2006)

Superflares



Occurrence distributions



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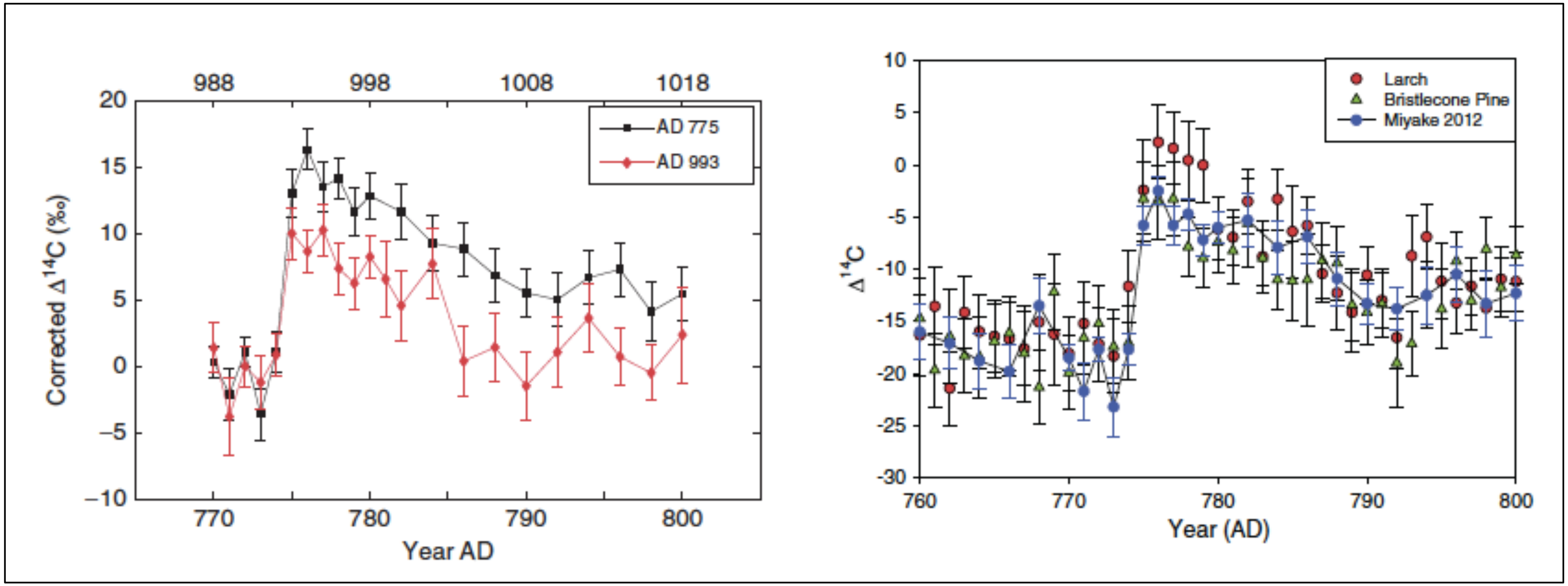
Two new ways of dealing with the Black Swans?

- Sensitive ^{14}C analysis has now revealed discrete events. Could these have been solar?
- The *Kepler* stellar photometry shows us surprising “superflares” on solar-type stars. Can we somehow add these to our solar record?

Tree rings (Miyake et al. 2012, 2013)



- Hard radiation produces long-lived fossil radioactivity, notably ^{14}C.
- These are the first discrete radioisotope events, obtained via 1-year sampling on Yaku island cedars

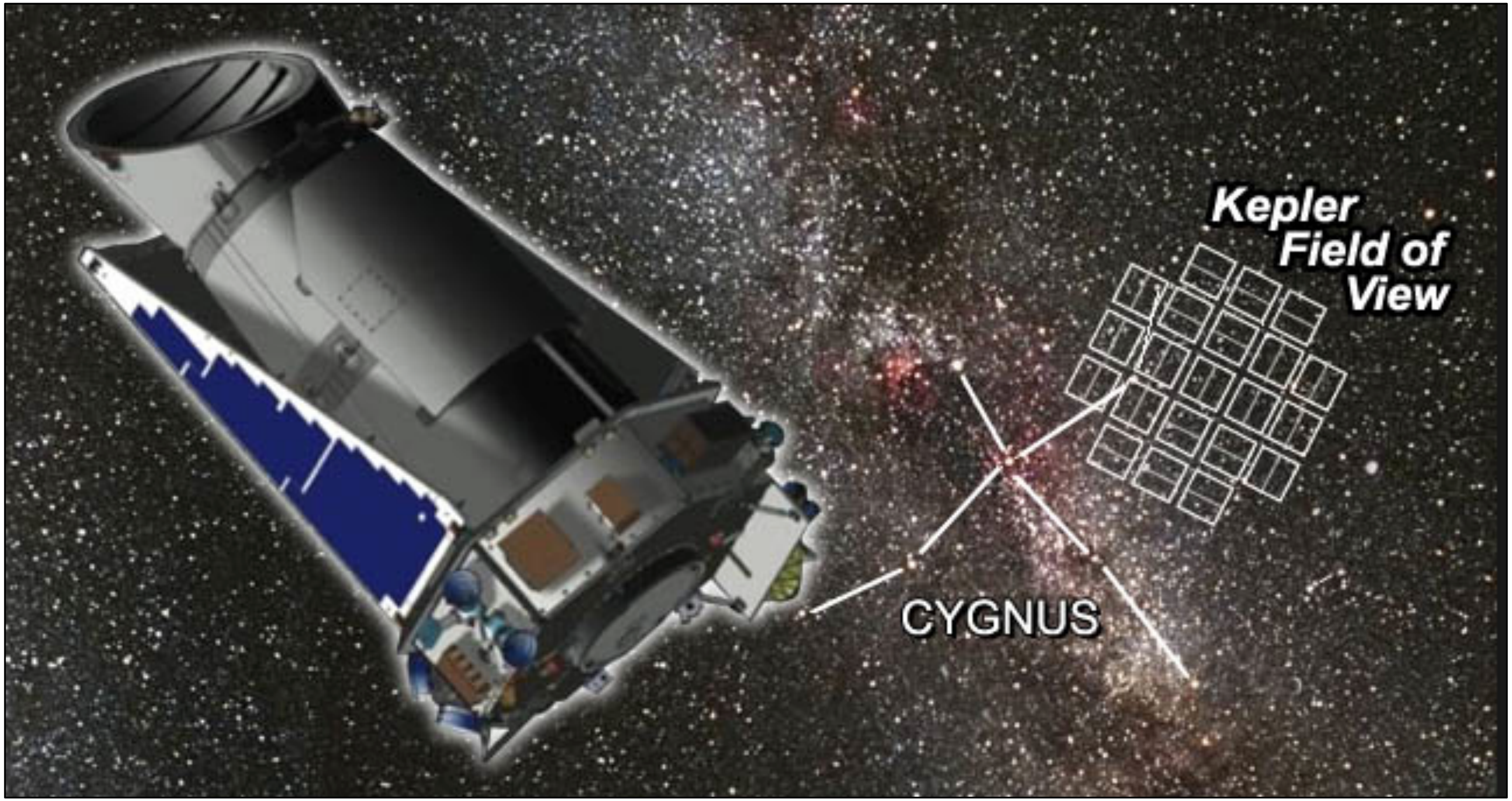
Sugi (Japan)

Kauri (NZ)

Bristlecone pine (US)

Trees all around the world confirm the ^{14}C detection of 775 AD – it's a global effect. Confirmation also comes from ^{10}Be in ice cores (Kovaltsov & Usoskin, 2012).

Revolutionary astronomy with *Kepler*



Kepler

- Kepler’s mission was to stare at the many stars for very long periods of time, basically to search for planets
- But many other interesting things popped up, of course

Kepler

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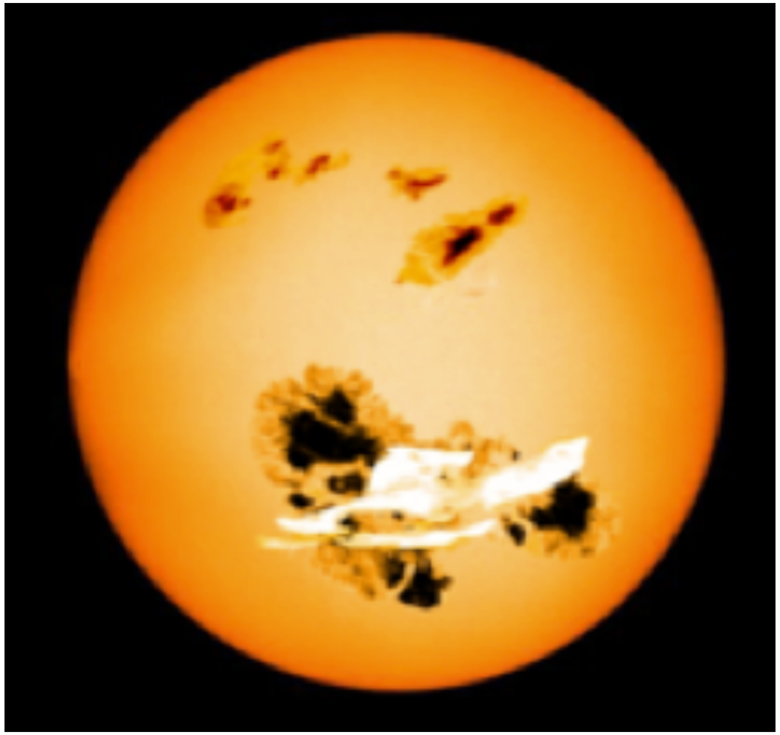
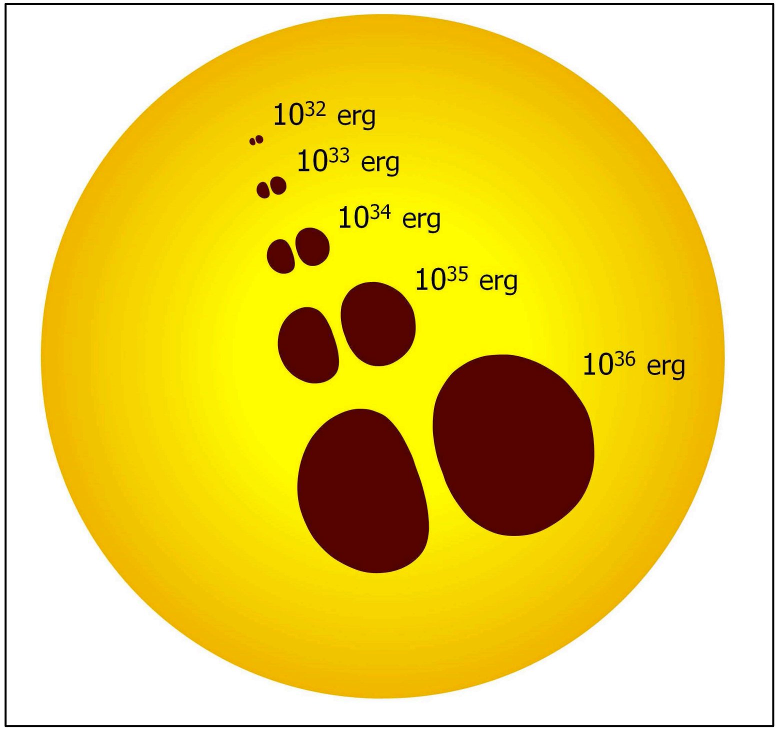
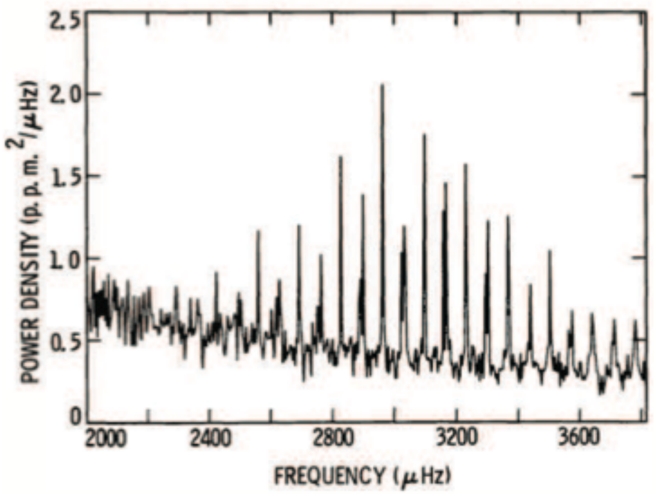


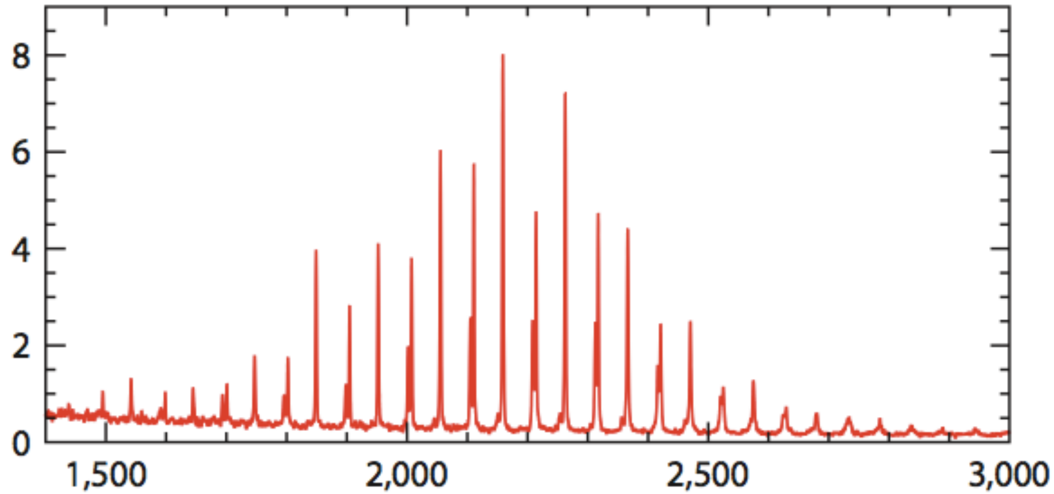
PR puff 2014



Aulanier et al. 2012

Stellar p-modes

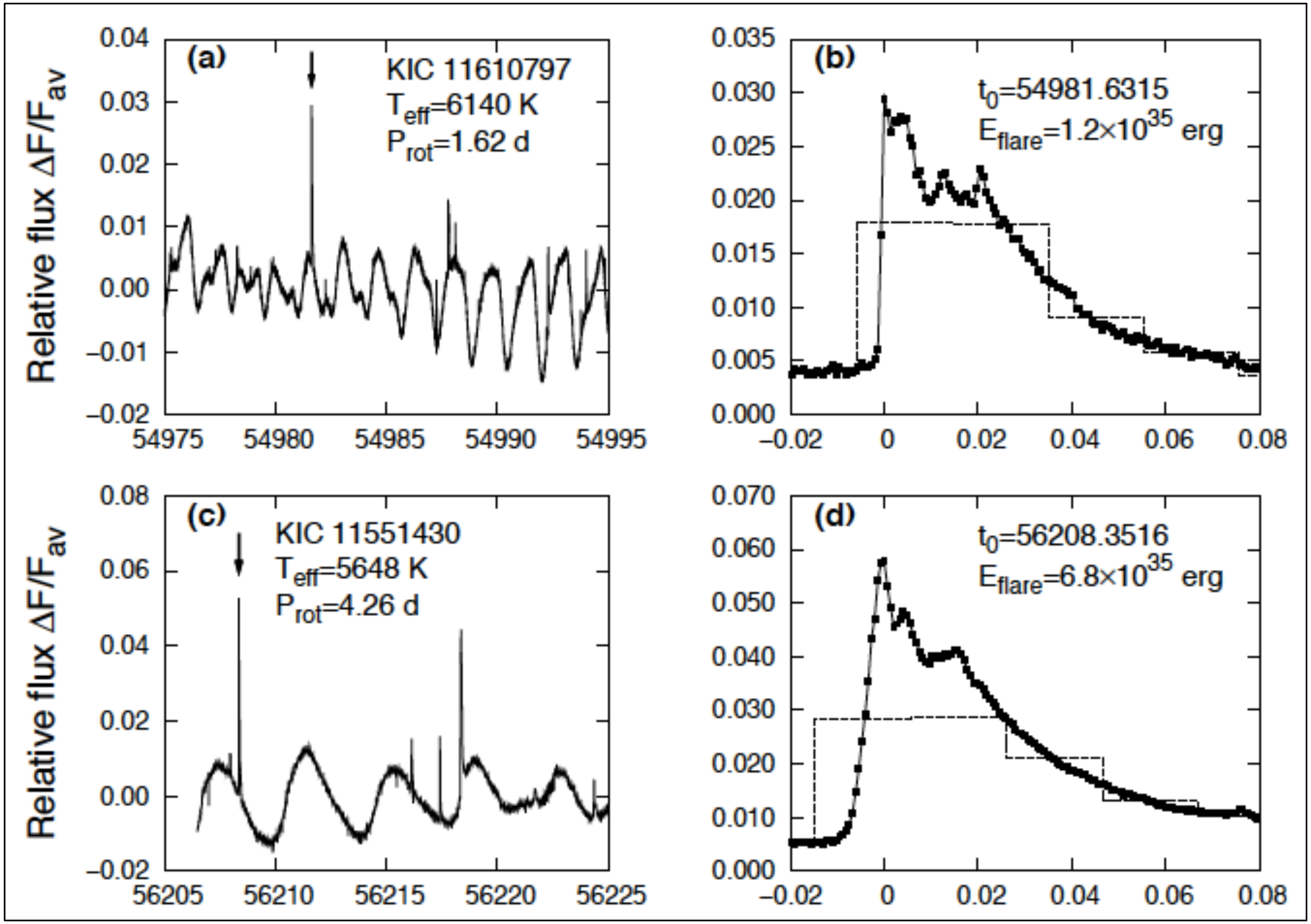




The Sun (M. Woodard), using TSI data, ca. 1984

Solar-type 16 Cyg A (m_V = 6), using Kepler data (Chaplin & Miglio, 2013

Maehara et al. (2015)



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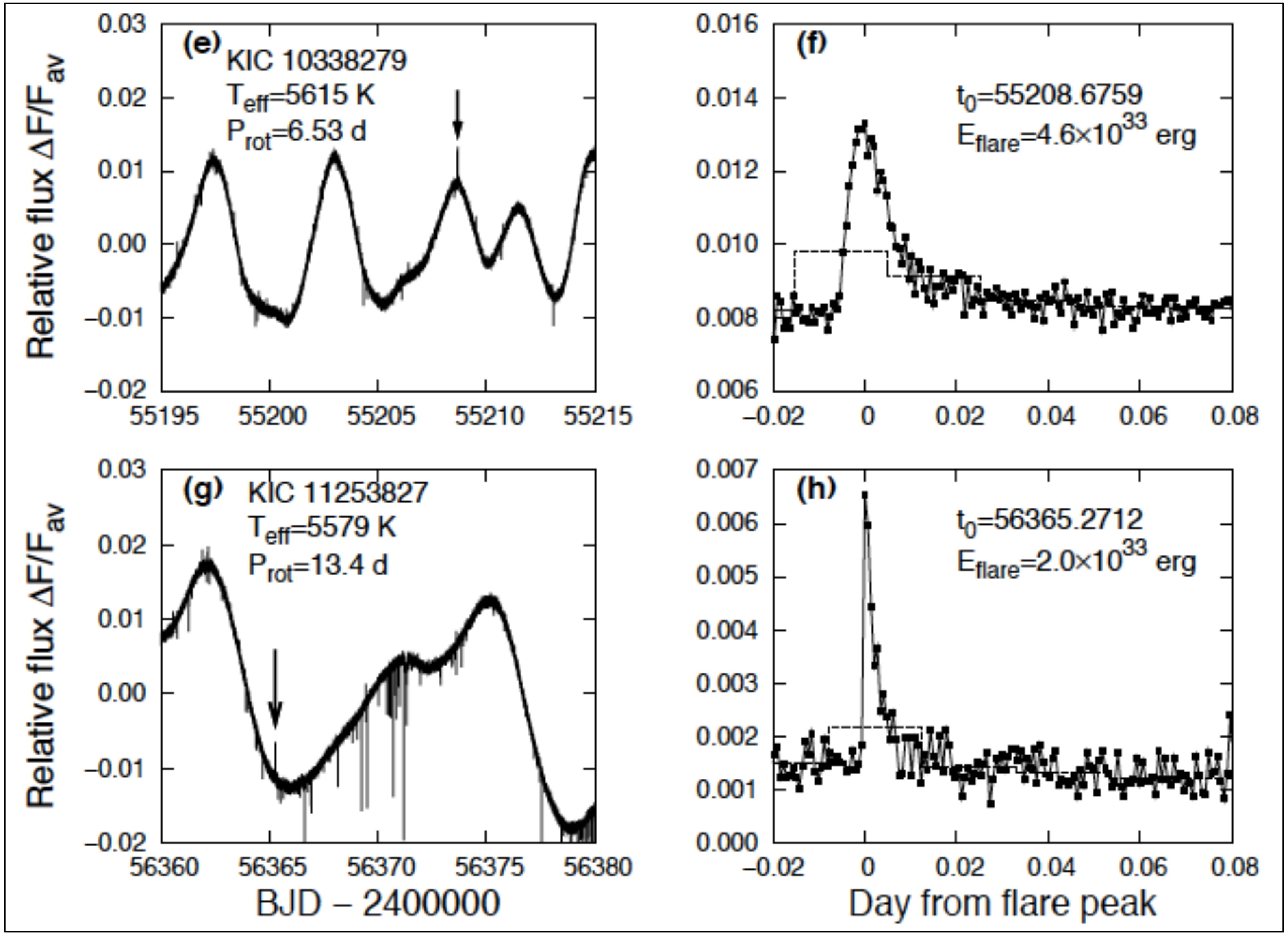
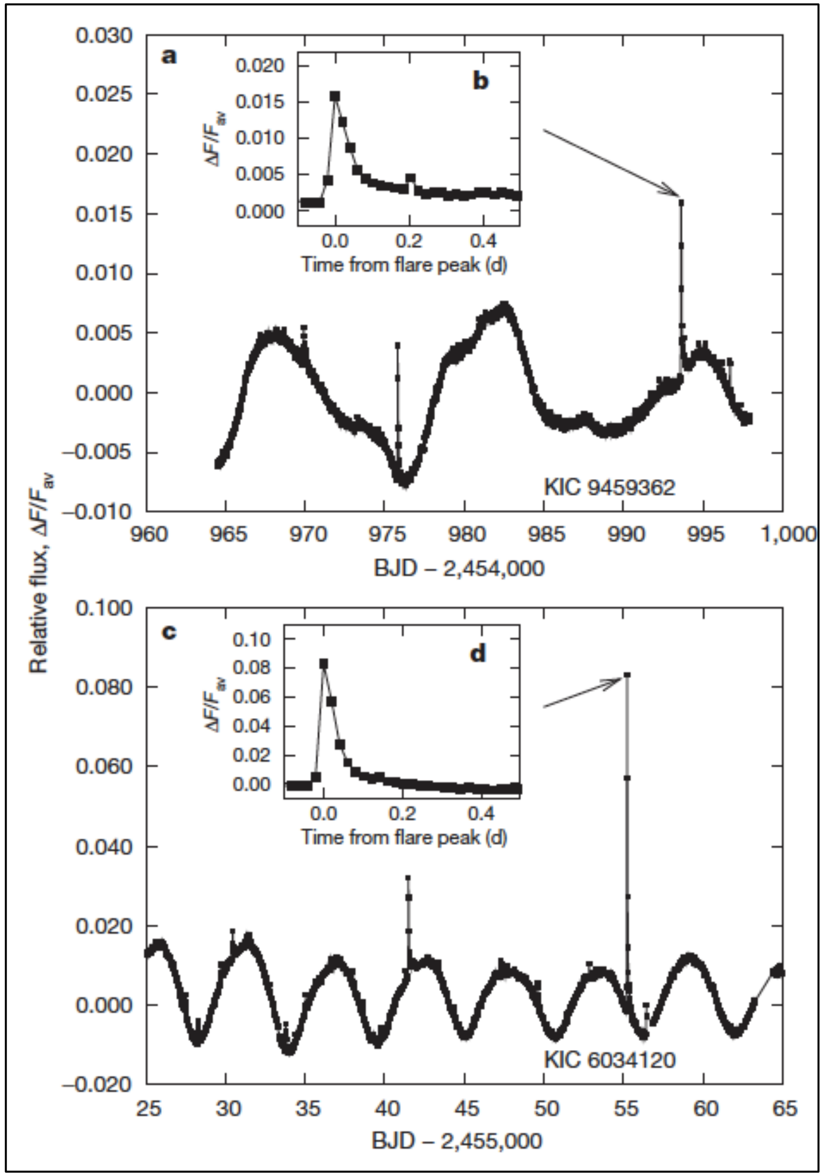


Kepler and solar light curves



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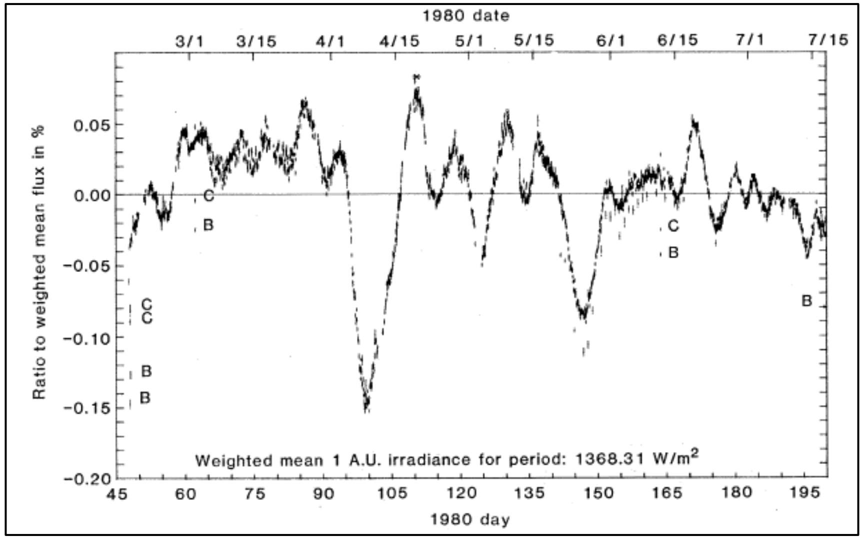
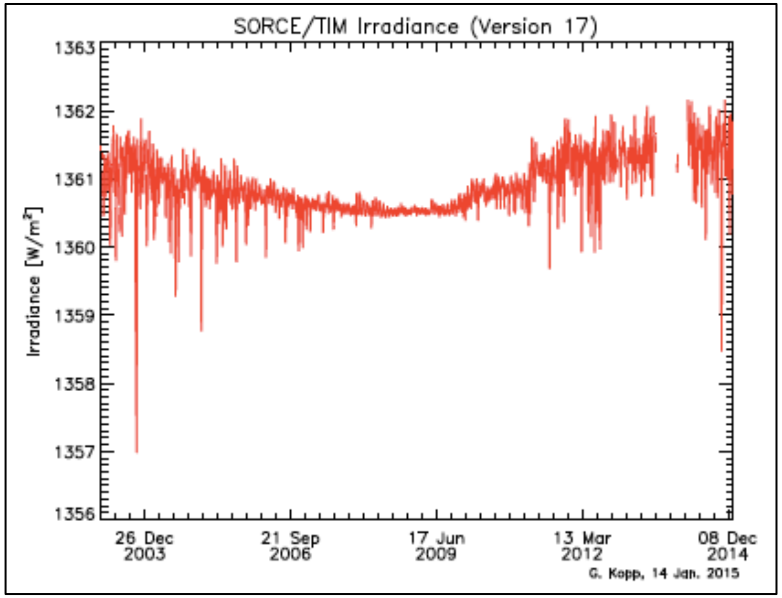
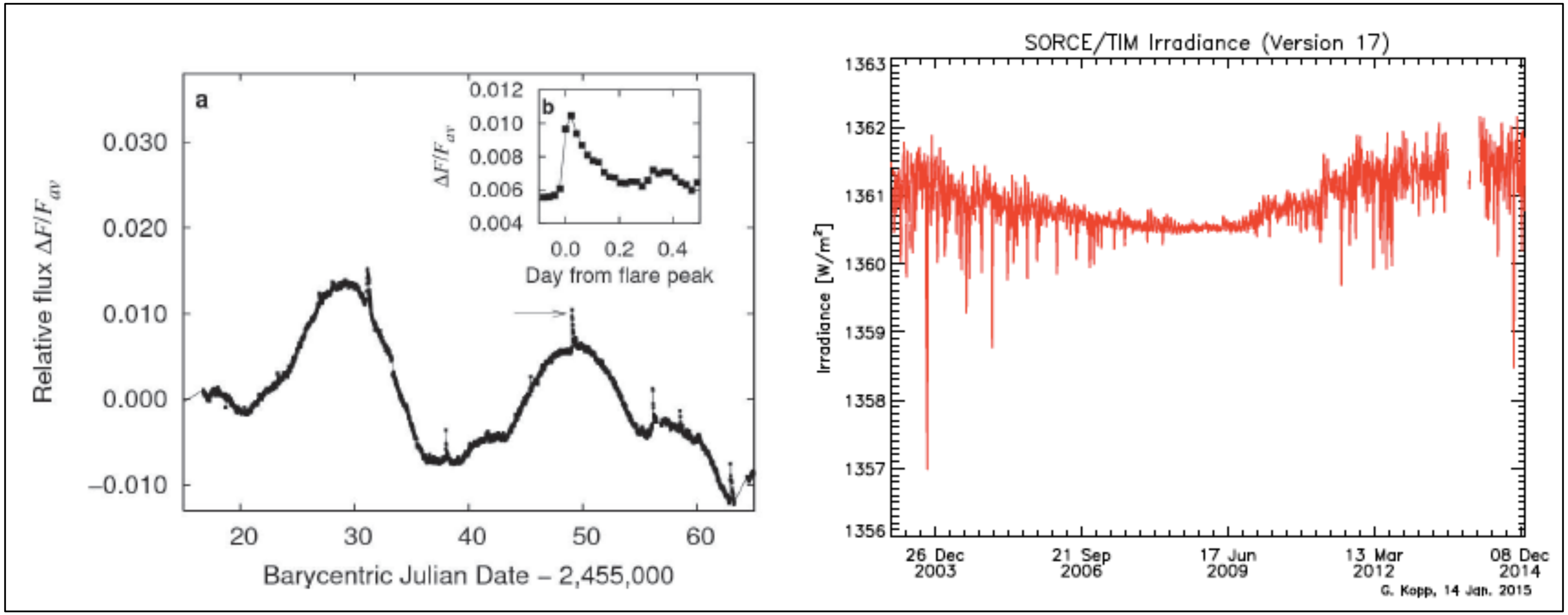


Willson et al. 1981

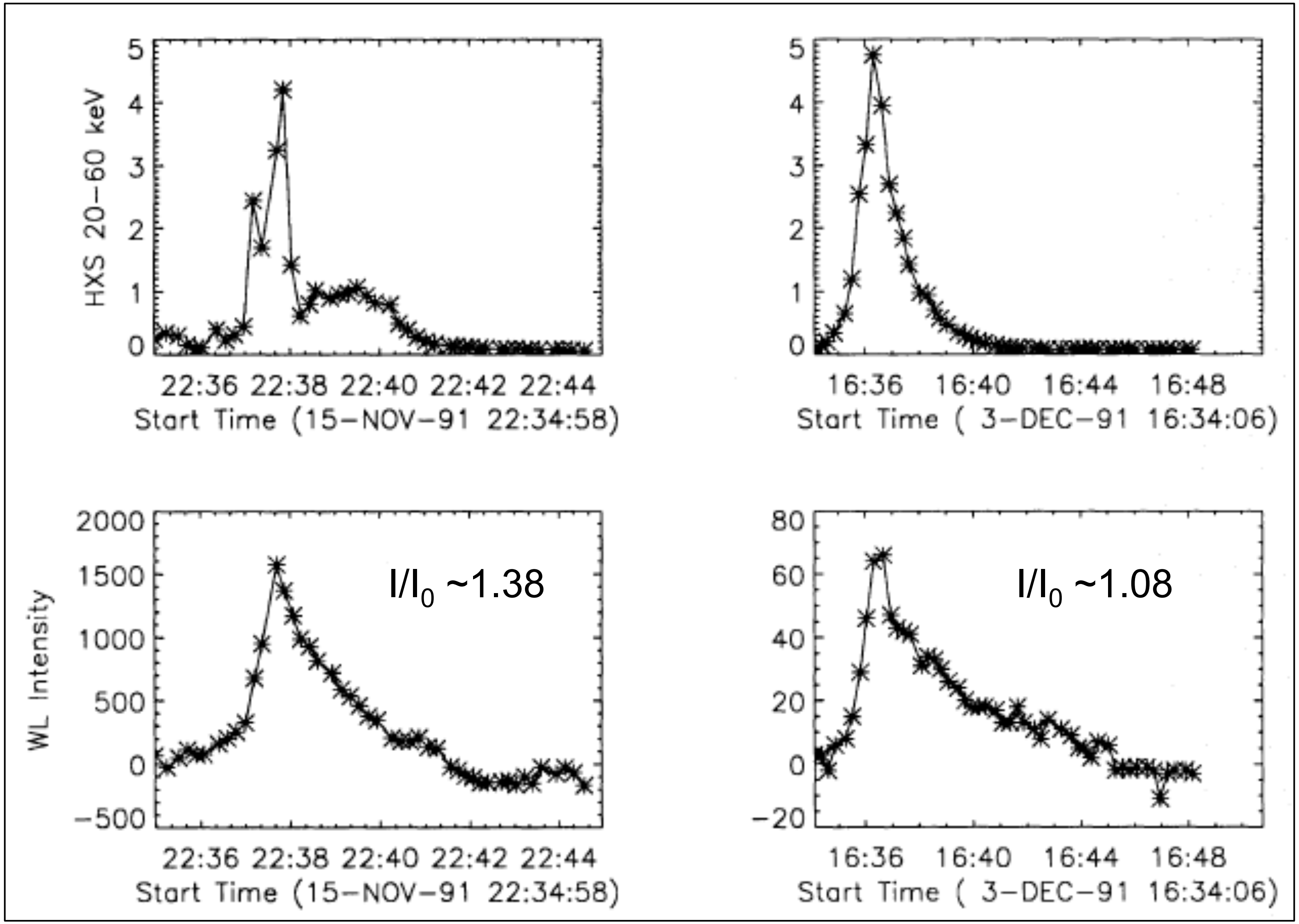


A flawed solar paradigm?



- The quiescent variations of “solar-type” Kepler stars show large, slow variations, plus flares
- The Sun shows rapid variations with dips, and only the feeblest of flares
- The paradigm looks wrong!

Yohkoh G-band and HXR



Hudson et al. 1992

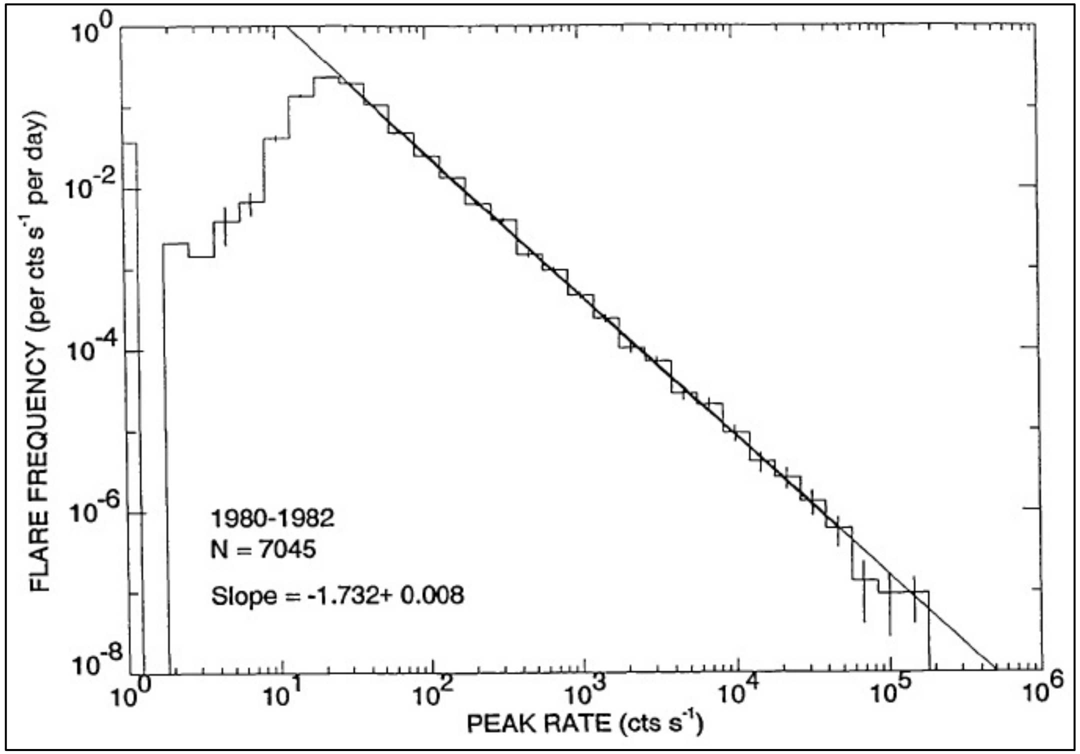
Kepler and solar light curves

- The variability patterns could not be more different:

  - Kepler superflare stars show large nearly sinusoidal variations, plus flares

  - The Sun shows erratic small variations, plus “dips”
- The solar sunspot dips are ¼ rotation in length because of foreshortening; they are not sinusoidal at all
- But there is nothing strange about the Kepler flares at all!

Occurrence distributions



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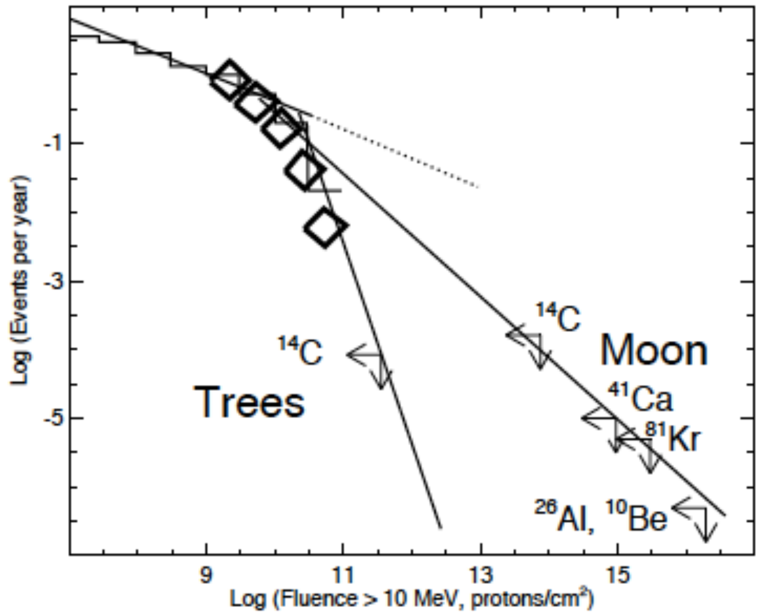
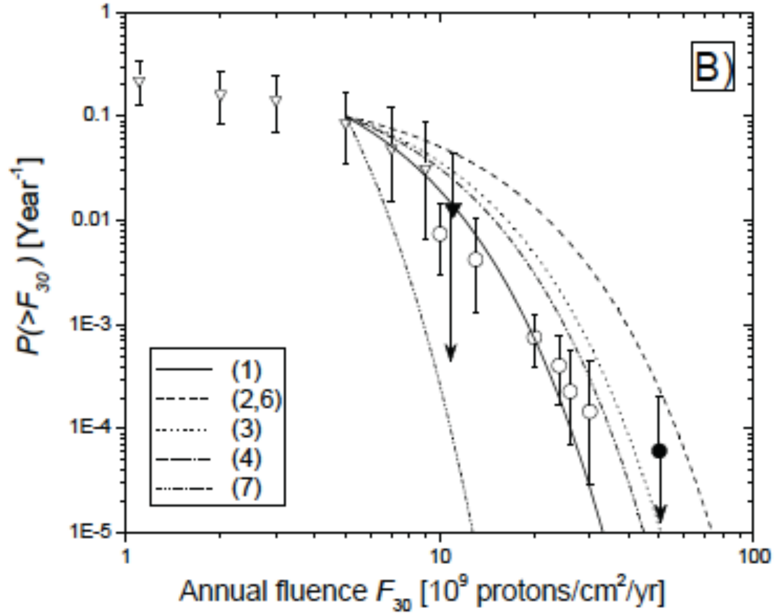
The break in the fluence distributions





Hudson 2012

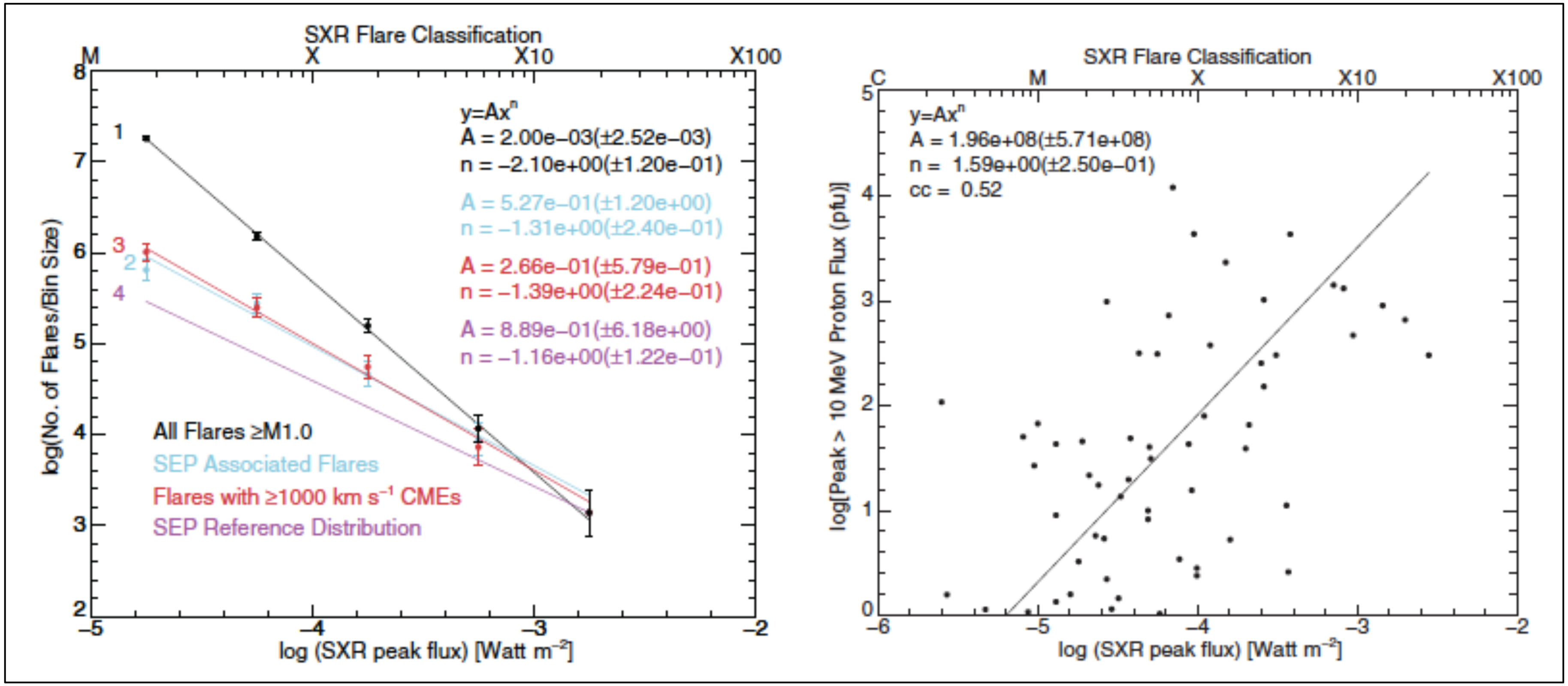
Kovaltsov & Usoskin 2012

Richard Lingenfelter had shown that the fossil radioactivity in ^{14}C was inconsistent with an extension of the SEPs fluence distribution of Van Hollebeke et al. (1975). This was confirmed with other radioisotopes in the lunar regolith (Bob Reedy)

What are we measuring?

- Is it possible to relate the SEPS fluence distribution to the flare distribution?
- And are Kepler flares really like solar flares, if the quiescent variability does not match the solar paradigm?
- Do flare magnitudes correlate with spot area?

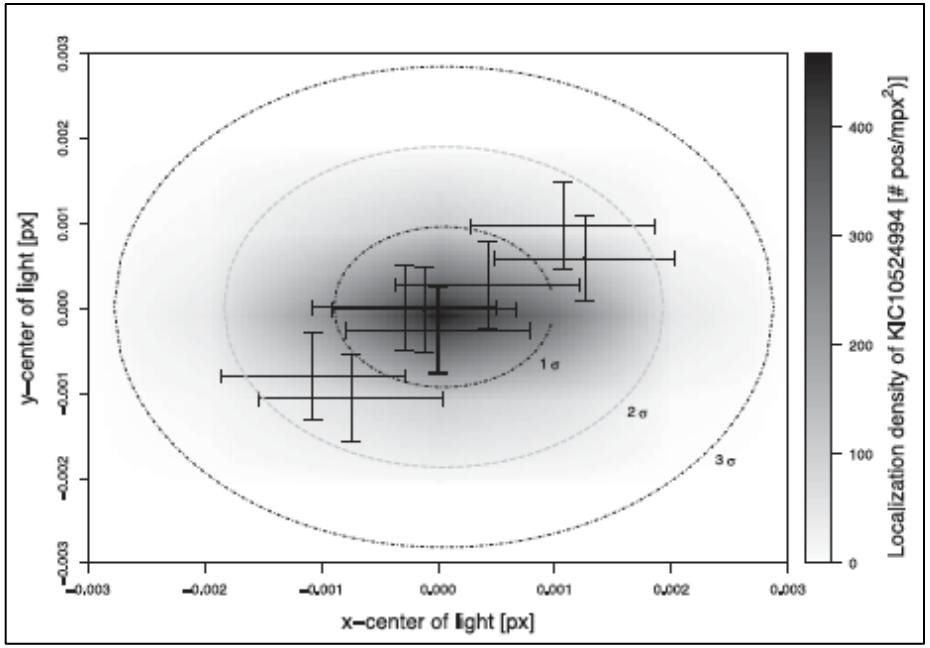
Flare/fluence Correlations



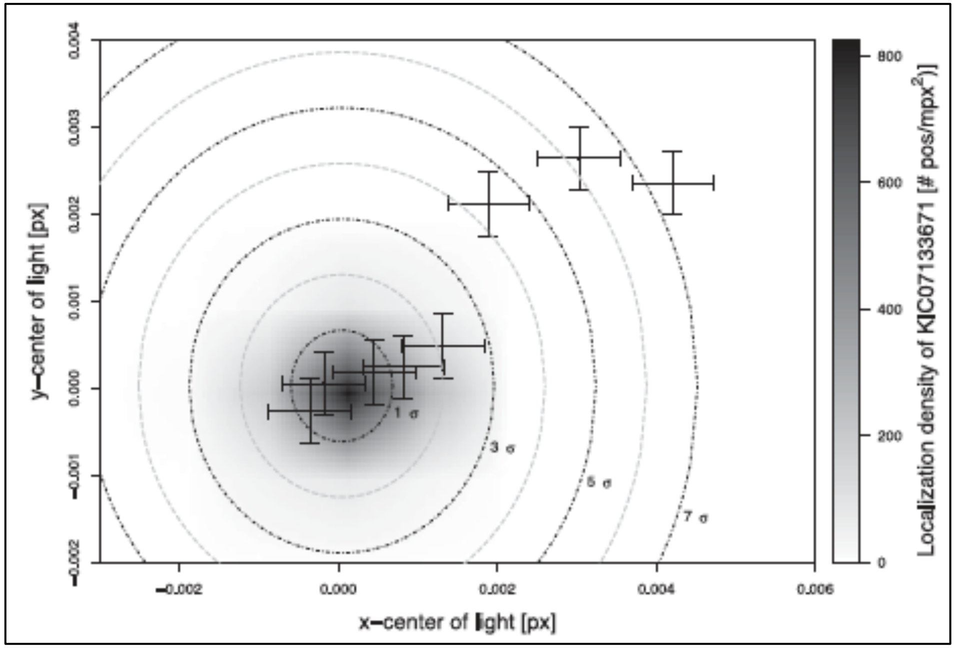
From Cliver et al. 2013:

- Flat fluence distributions confirmed
- The subset of flares thus selected also have a flat distribution
- There is a flare/fluence correlation, but weak

The “random dMe star” peril



KIC10524994



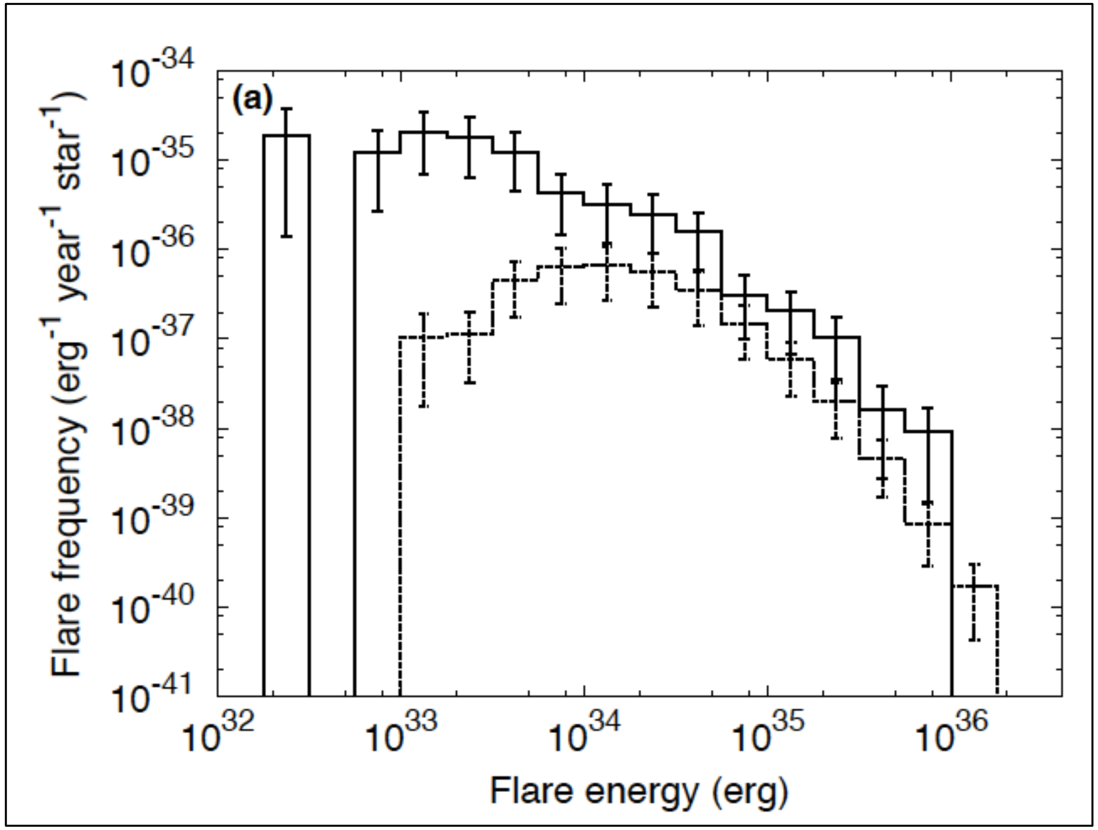
KIC07133671

From Kitze et al. 2014

Do starspot sizes correlate?

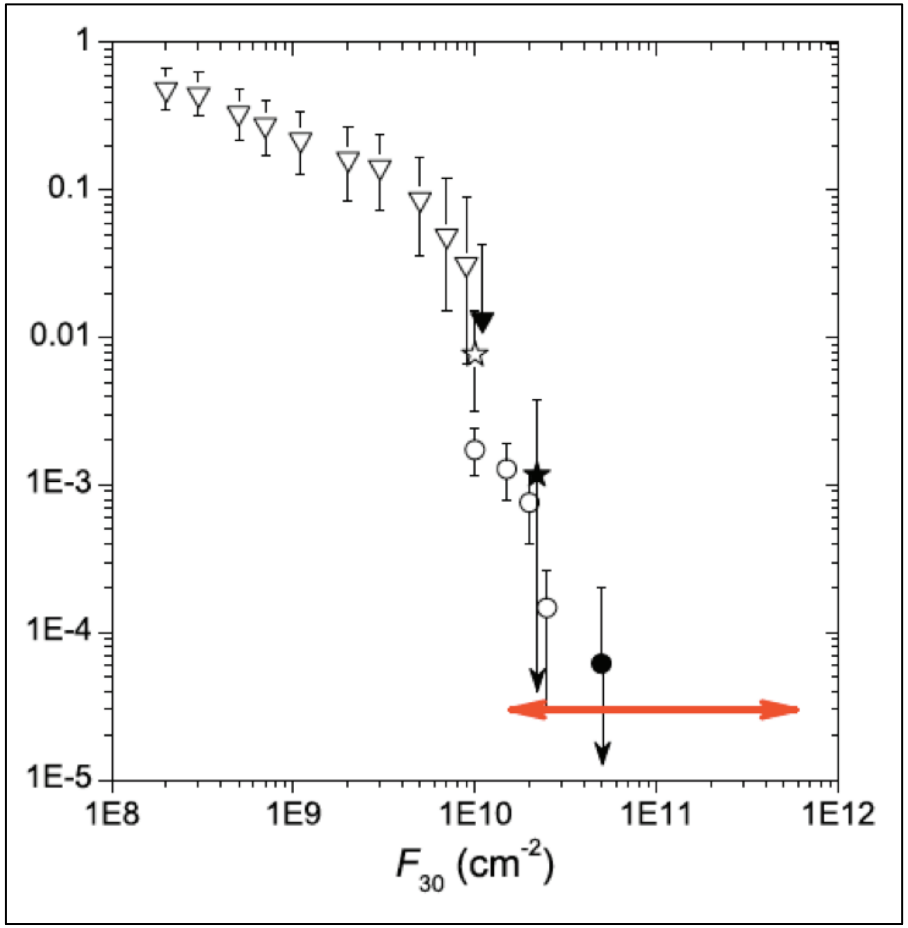
$$E_{\rm flare} \sim 7 \times 10^{32}({\rm erg}) \left(\frac{f}{0.1}\right) \left(\frac{B}{1000{\rm G}}\right)^2 \left[\frac{A_{\rm spot}/2\pi R_\odot^2}{0.001}\right]^{3/2}$$

???

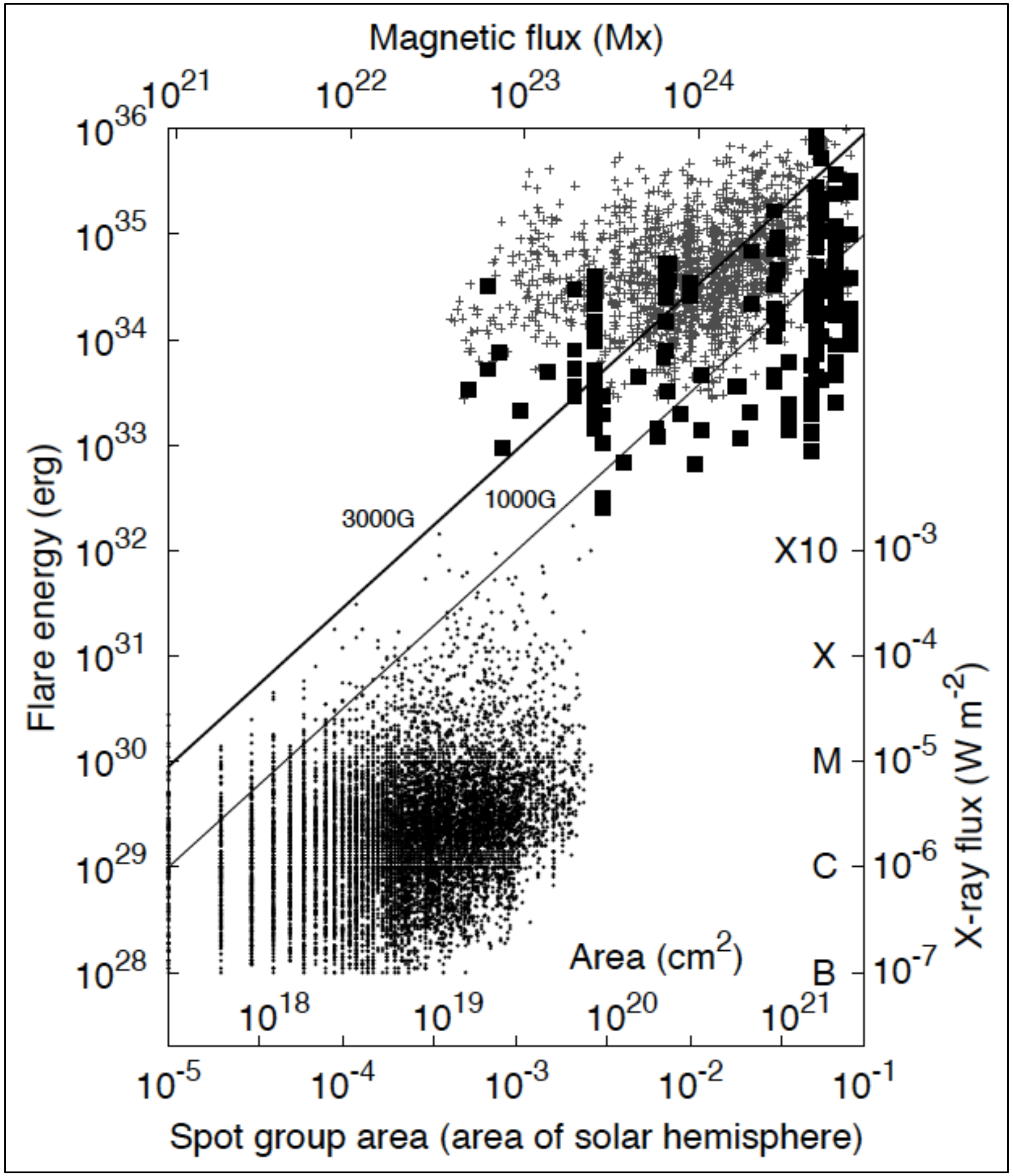


From Maehara et al. (2015); bold from 1-min data

Are there solar "Black Swans"?



Kovaltsov et al. 2012



Maehara et al. 2015

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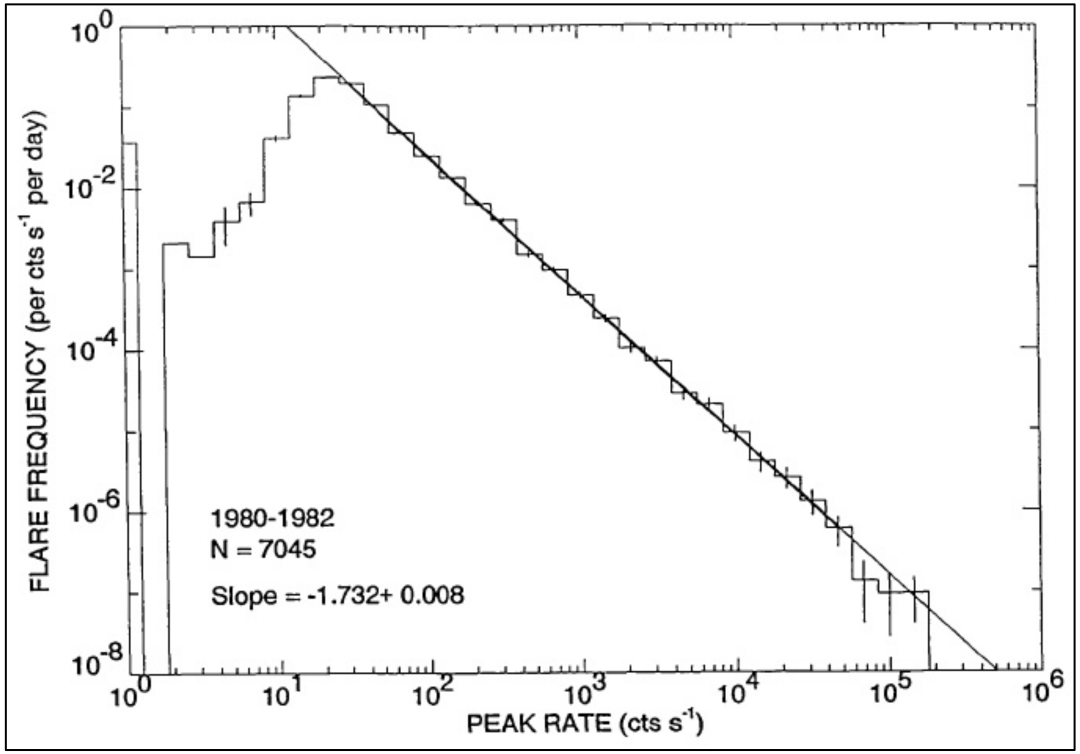

Hard X-rays: Crosby et al. 1993

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Where’s the break?

- The flare observables over the recent three cycles do not readily show a break
- This is roughly consistent with the statistics: one Carrington flare every cycle or two
- Is the proxy break in SEPs the result of selection, or a hint at the “true” break in event energy?

Conclusions

- The solar paradigms may or may not be appropriate for Kepler “superflare” stars.
- The Kepler and solar time series look quite inconsistent – do we understand what a “starspot” is?
- We cannot safely use the Kepler statistics for prediction of solar extreme events
- The tree-ring events are probably not solar.

Conclusions II

- But even if the tree-ring events are not solar, they could still be lethal – Black Swans after all!
- See Love (2012) for "Credible occurrence probabilities…" at 2σ:

0.016 (+.09,-.003) C-events/decade