Solar Extreme Events

Hugh Hudson
SSL, UC Berkeley and U. Of Glasgow

1) Nature of solar variability
2) The quandary of the “superflare” stars
3) Radiodendrochronology
4) Assessment

Solar Irradiance Variations

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

Plus (to be up-to-date):

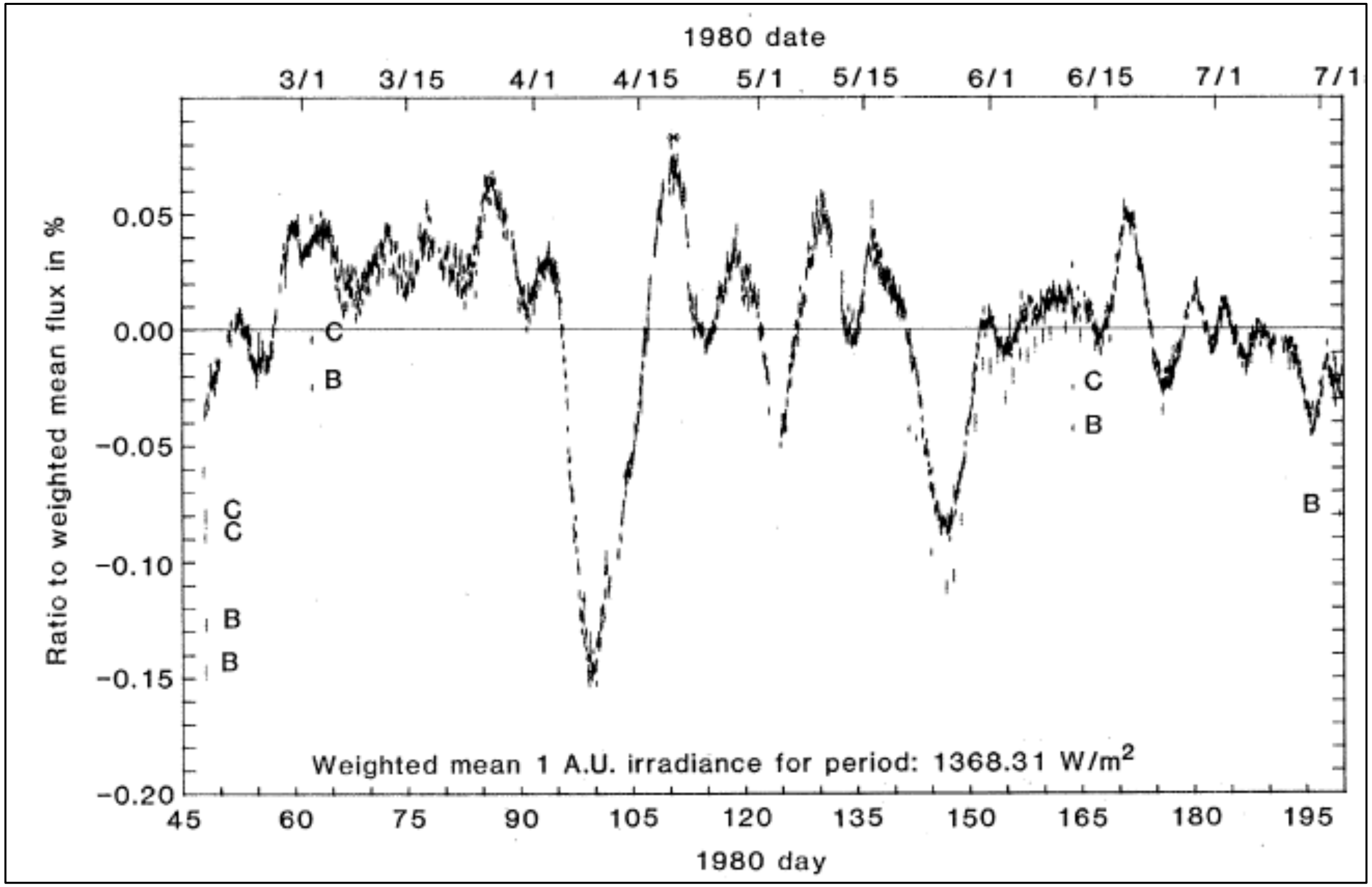
Flares	Few min	Few hundred ppm	Woods et al. 2004
Secular	Cycle	150 ppm	Froehlich 2009
Flicker	Tens of min	Tens of ppm	Bastien et al. 2013 (Harvey 1985)

Flares and Irregular Magnetic Variability

• Flares themselves are *uniquely detectable*, and if frequent the variation may appear to be chaotic and noise-like.
• Something like Parker’s nanoflares may connect these phenomena.
• Stars may differ from the Sun in the nature of the quiescent variability.

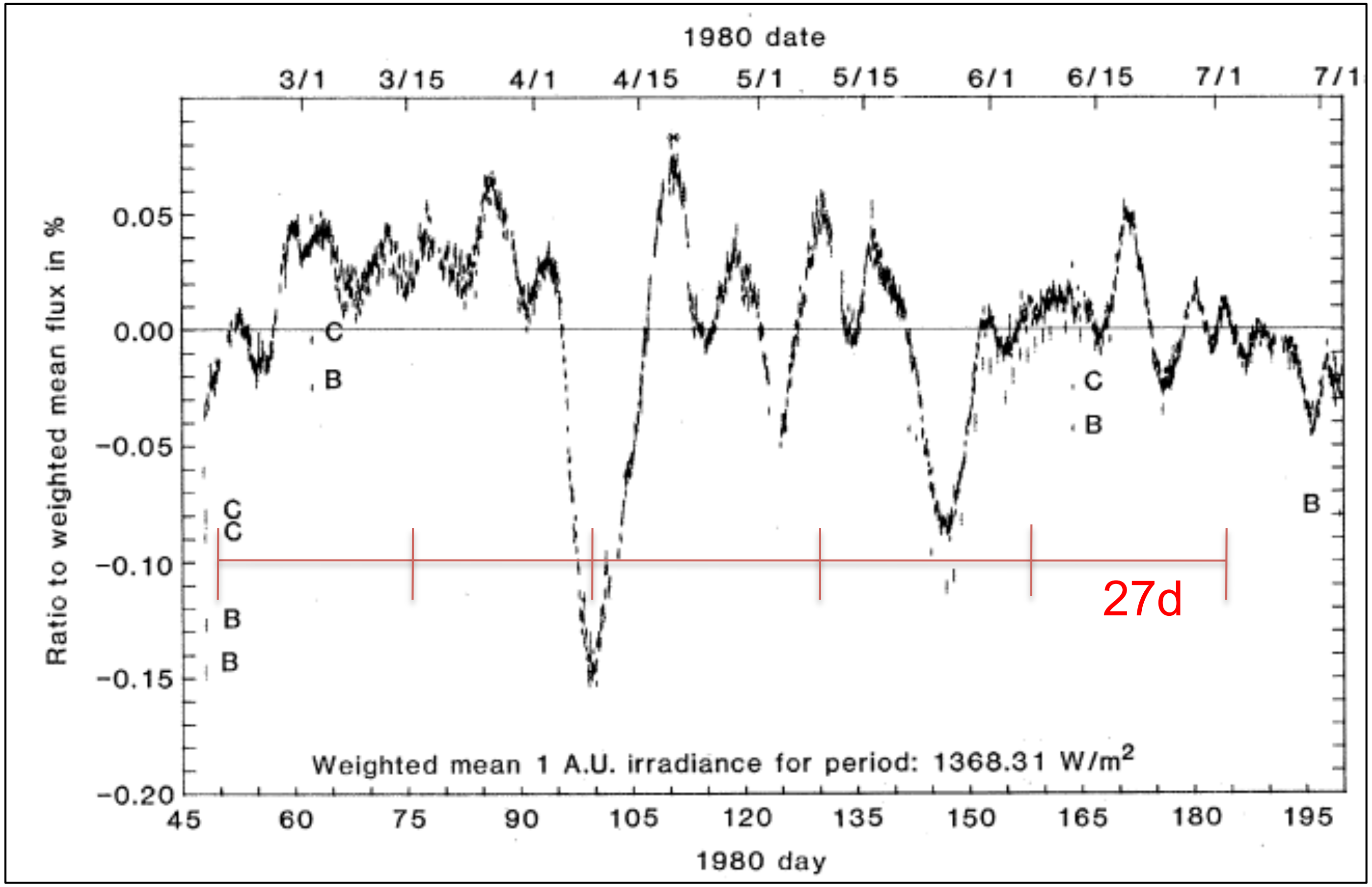
• I will discuss how the Kepler “superflare” stars behave in this respect.

Sunspot TSI dips



Willson et al. 1981

Sunspot TSI dips

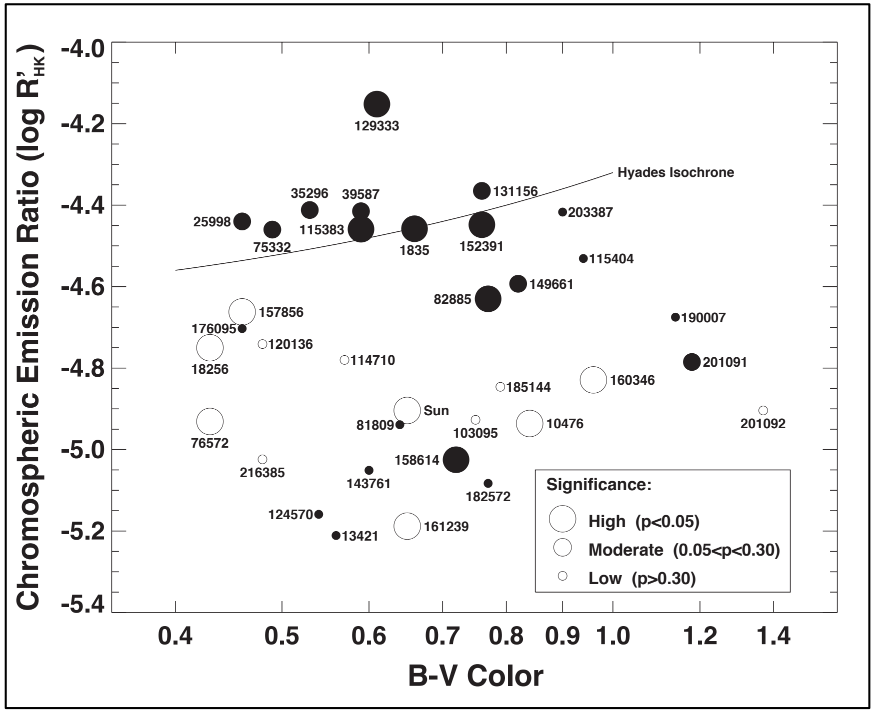


Willson et al. 1981

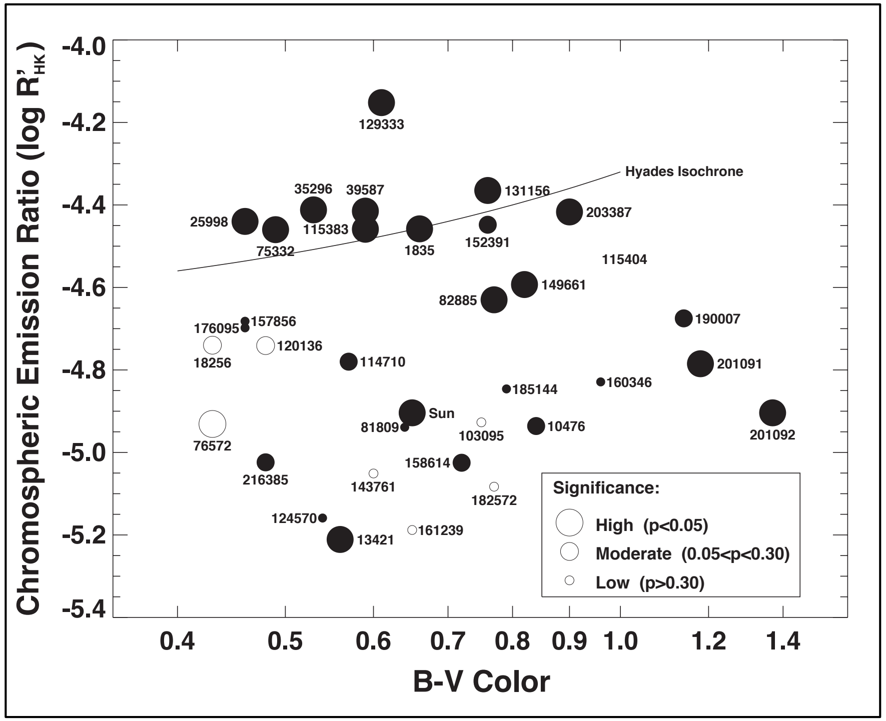
The TSI dips

- Sunspots are darker than their faculae are bright, especially early in their life
- An individual dip lasts for about ¼ rotation, since the projected spot area is foreshortened
- Facular excesses may dominate at the limb passages

Solar-Stellar Magnetic Variability



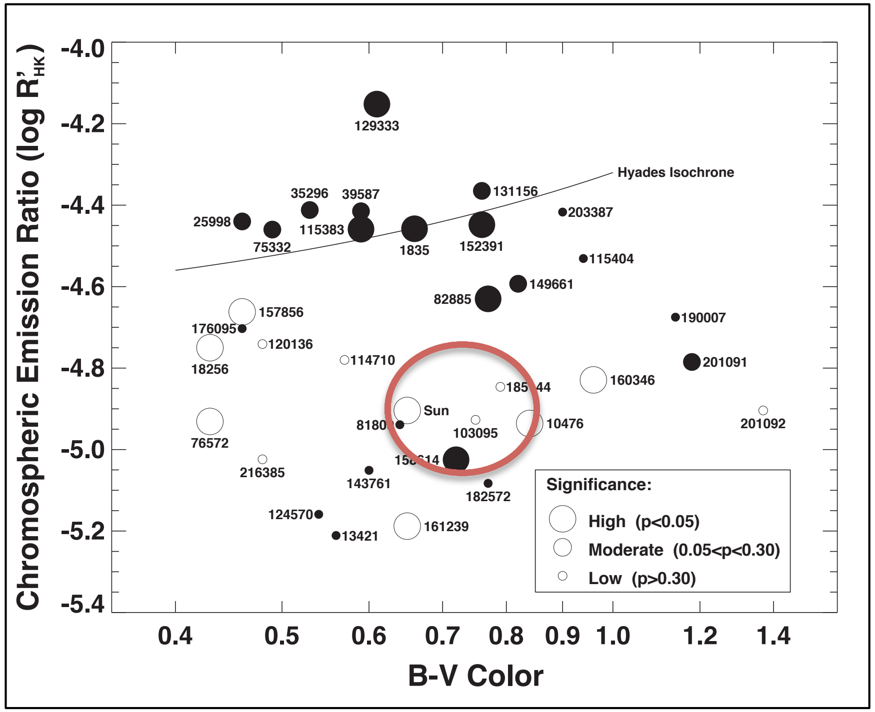
Short-term variation



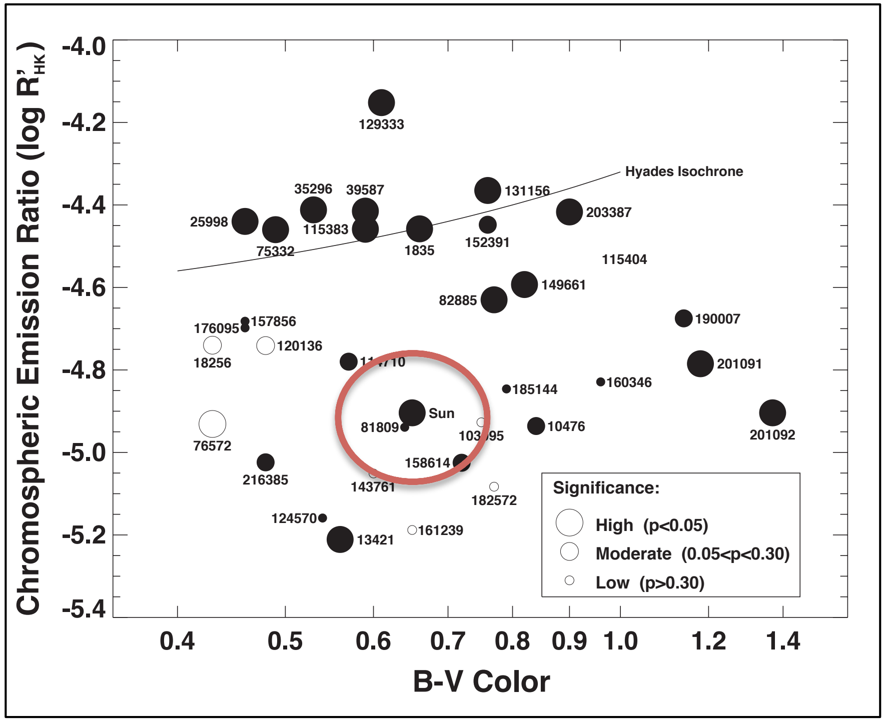
Cycle time scales

Solar TSI has maxima at sunspot maxima; other stars may not behave this way – see Radick et al., 1998.

Solar-Stellar Magnetic Variability



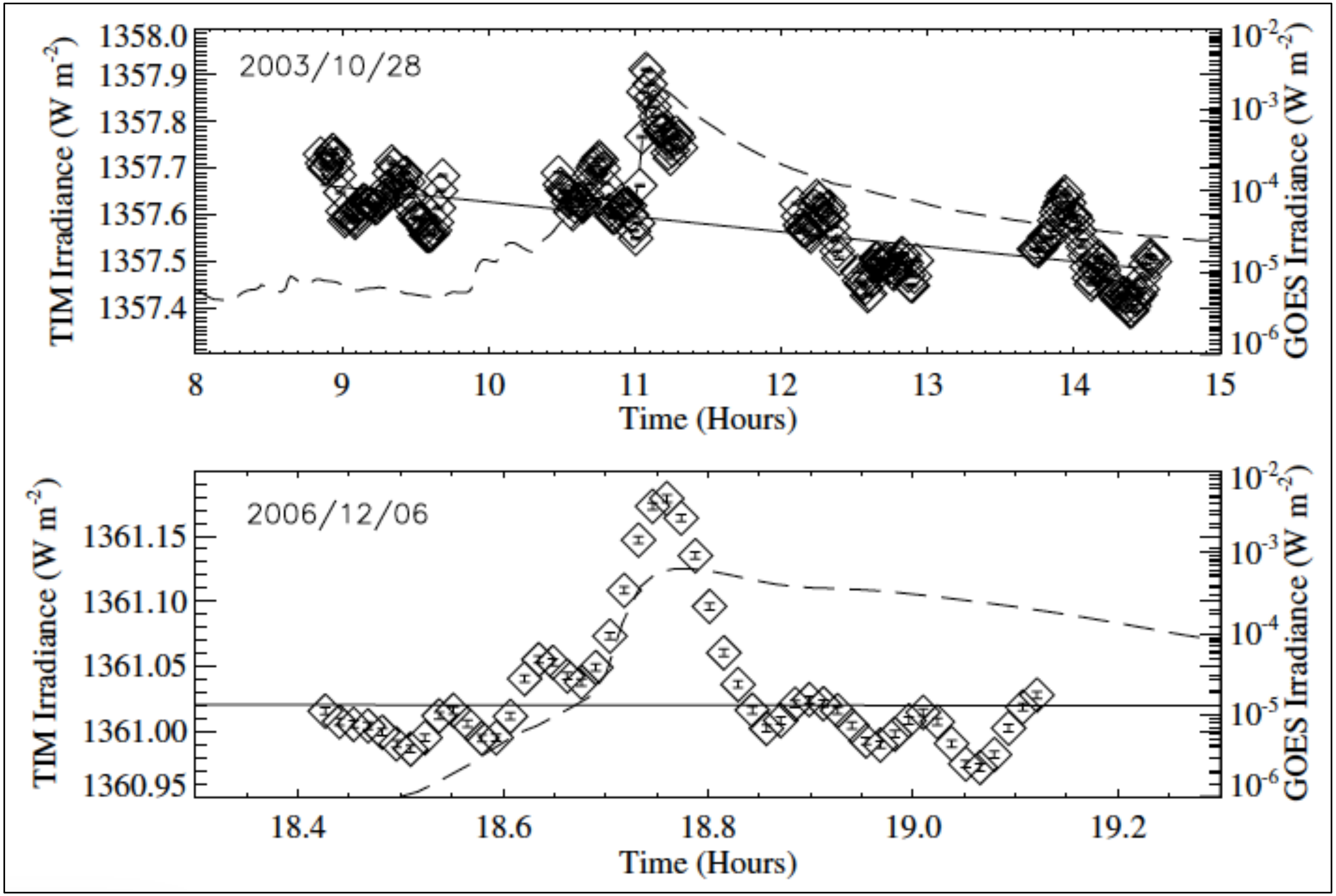
Short-term variation



Cycle time scales

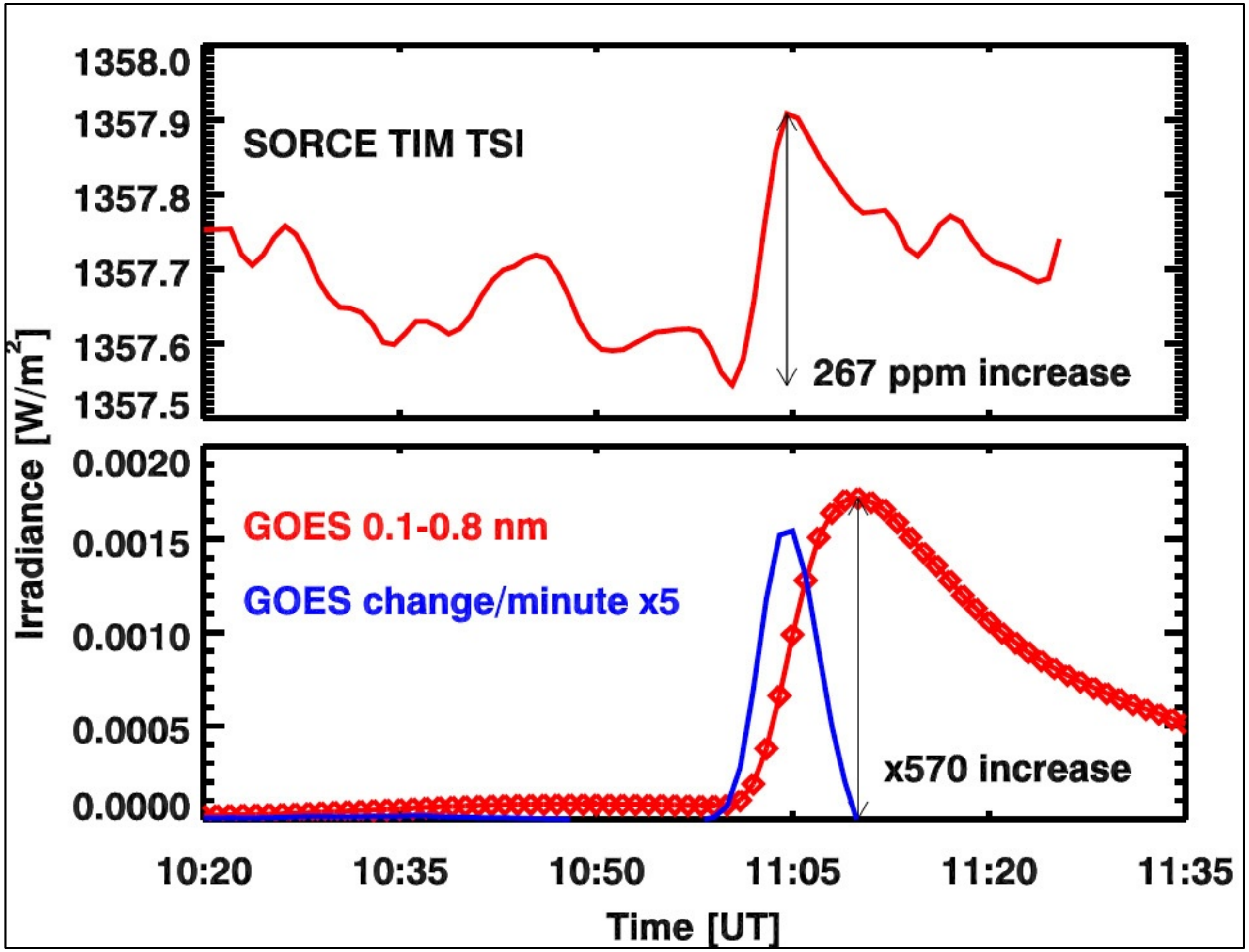
Solar TSI has maxima at sunspot maxima;
other stars may not (e.g. Radick et al. 1998)

Flares in the TSI



Moore et al. 2014

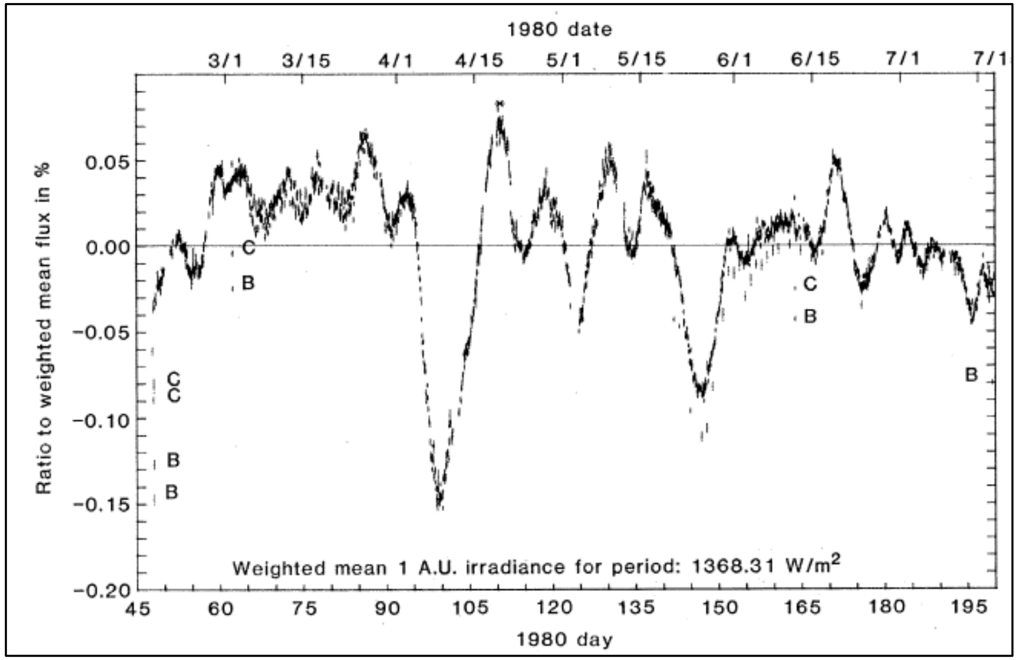
Flares in the TSI



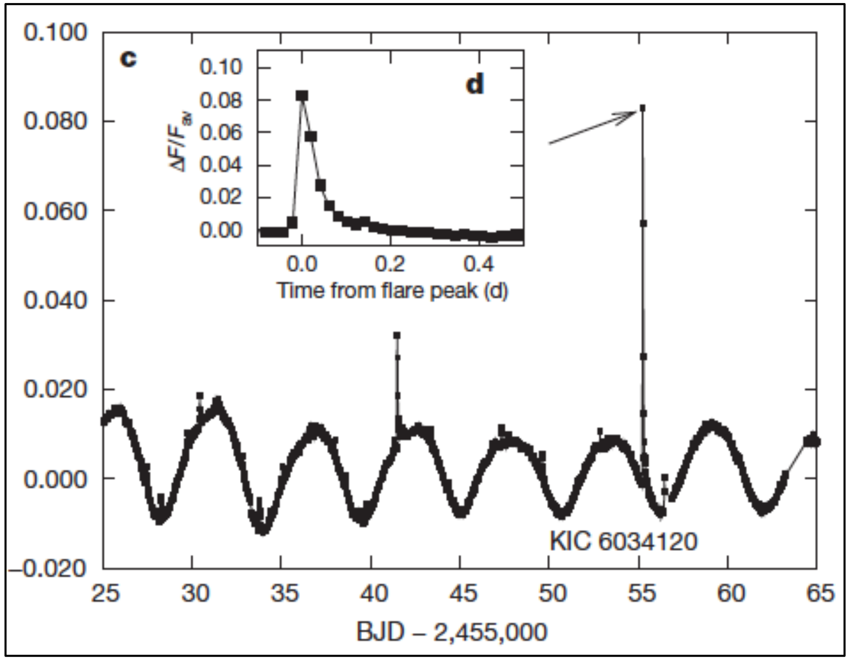
Woods et al. 2004

• Note the clear association with the impulsive phase (cf. Kretzschmar, 2011): flares are *nonthermal*

Solar-stellar quandary



Willson et al. 1971



Maehara et al. 2012

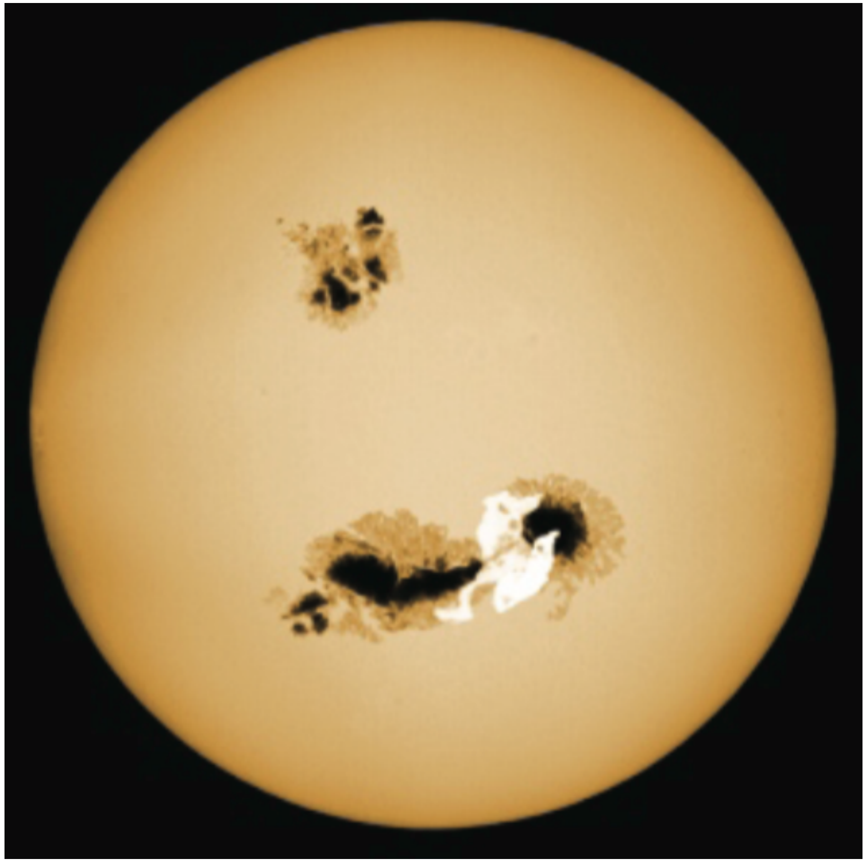
- Faculae are important for solar variability, but *not* for Kepler "superflare" stellar quiescent variations
- There are toy models to explain this, but a lot of unknowns get glossed over

Solar-stellar quandary

• The Sun has short-term weak chaotic variability, *with dips.*
• These Kepler stars have nearly sinusoidal variations, *with flares.*

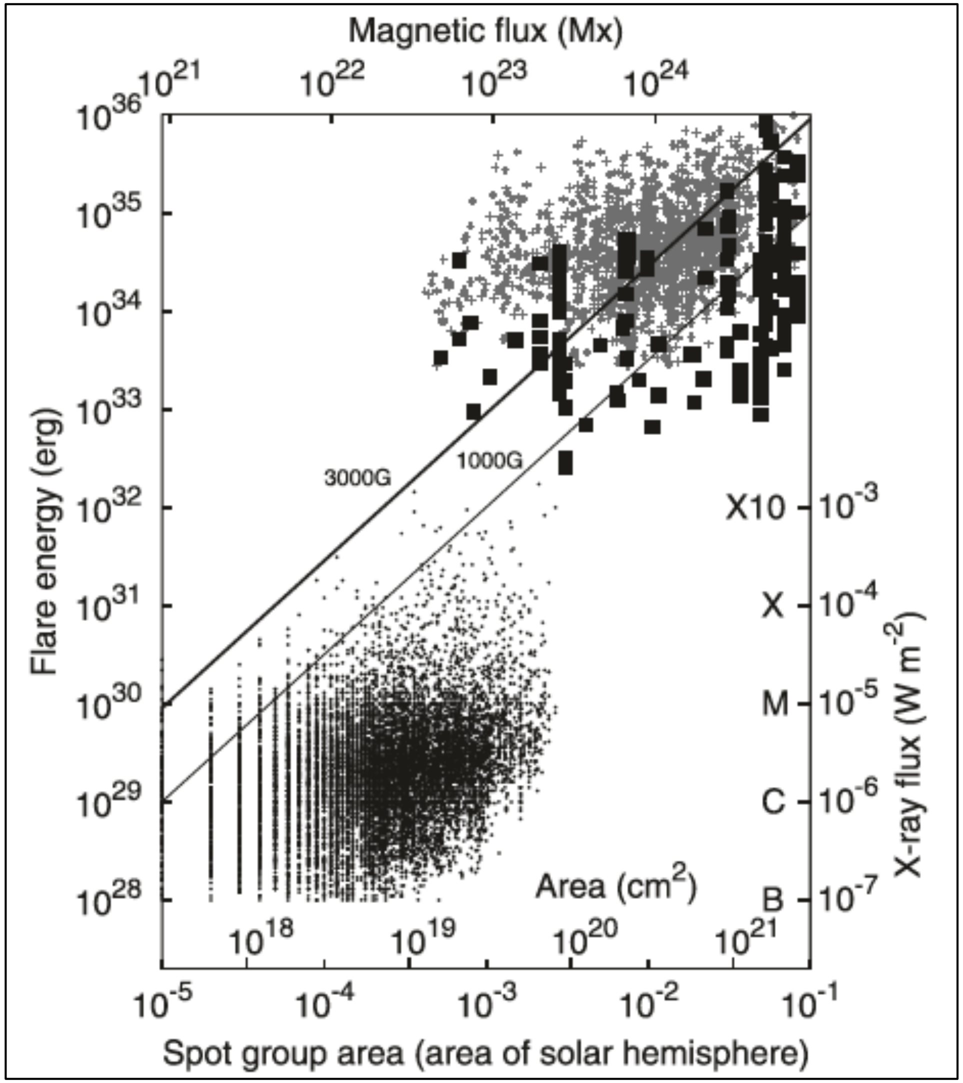
These light curves could not be more different;
where’s the paradigm?

The Kepler “superflares”

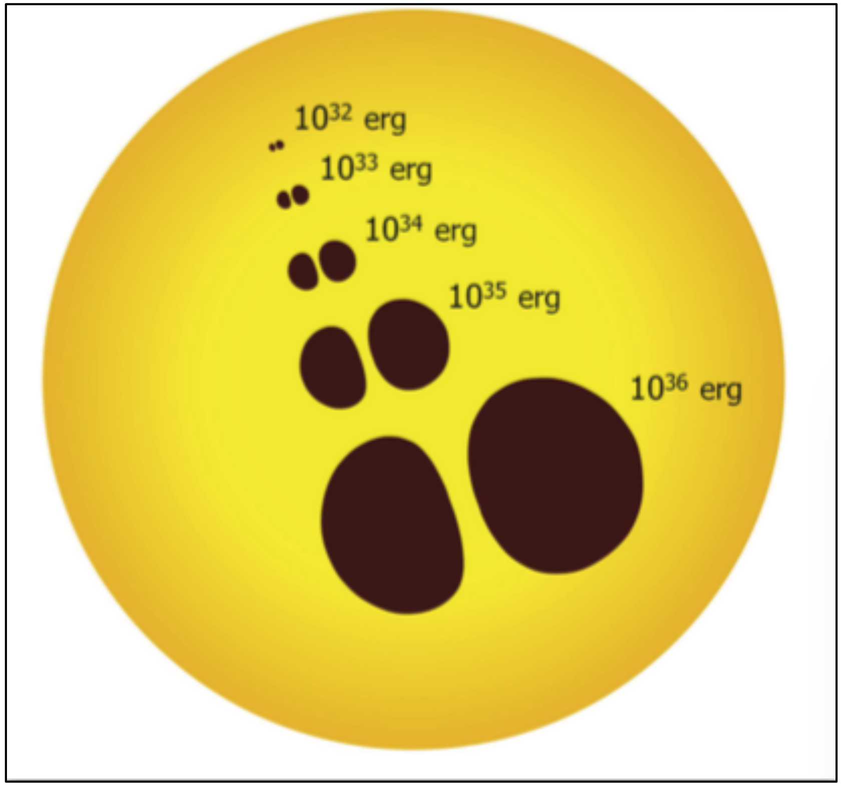


- Where are the faculae?
- How can such spots produce so sinusoidal a rotation modulation?

The Kepler "superflares"



Maehara et al. 2015



Aulanier et al. 2014

"Give me a big spot, and I can give you a big flare."

Radiodendrochronology

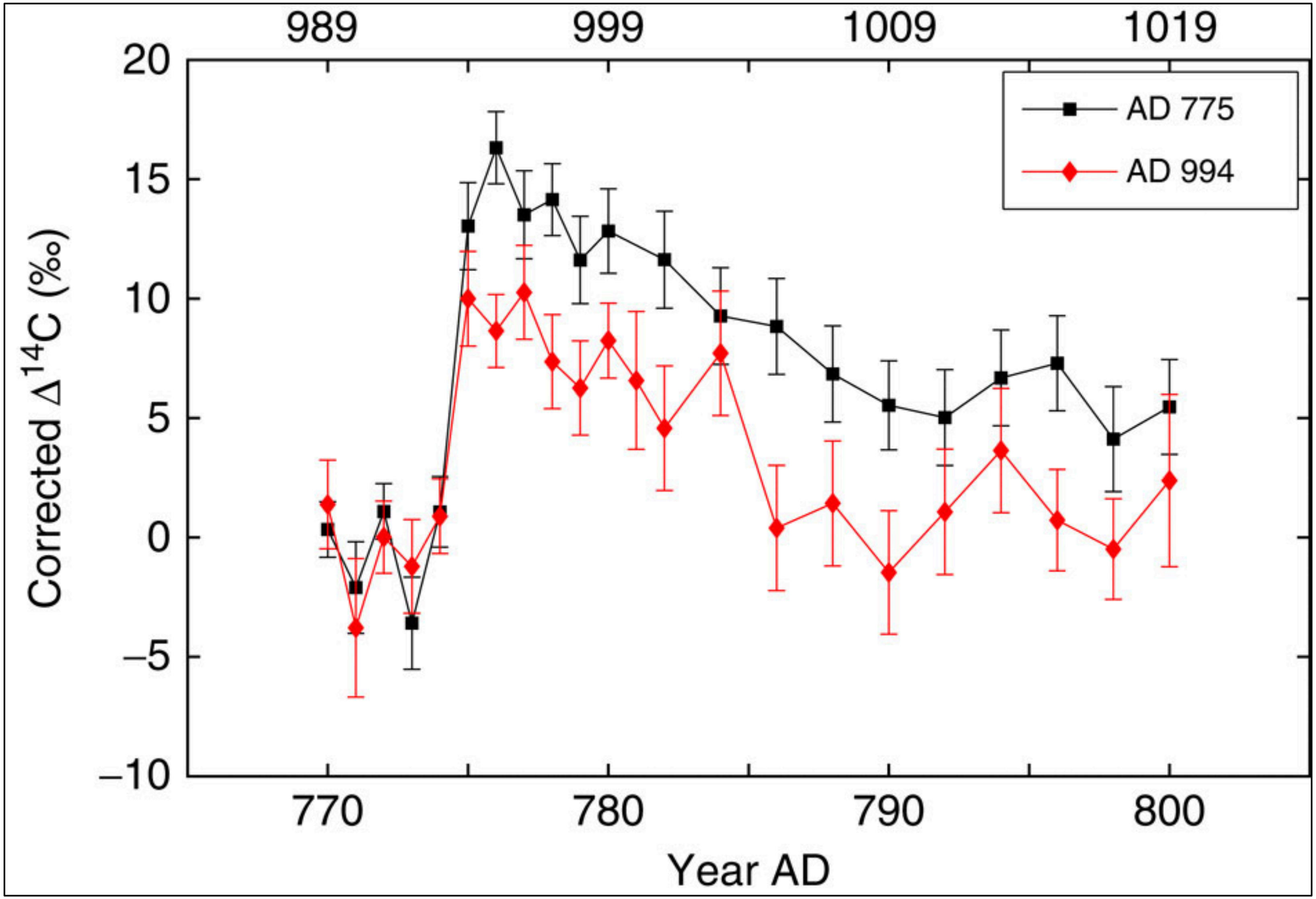
The University of Arizona's new
Laboratory of Tree-Ring Research

Radiodendrochronology

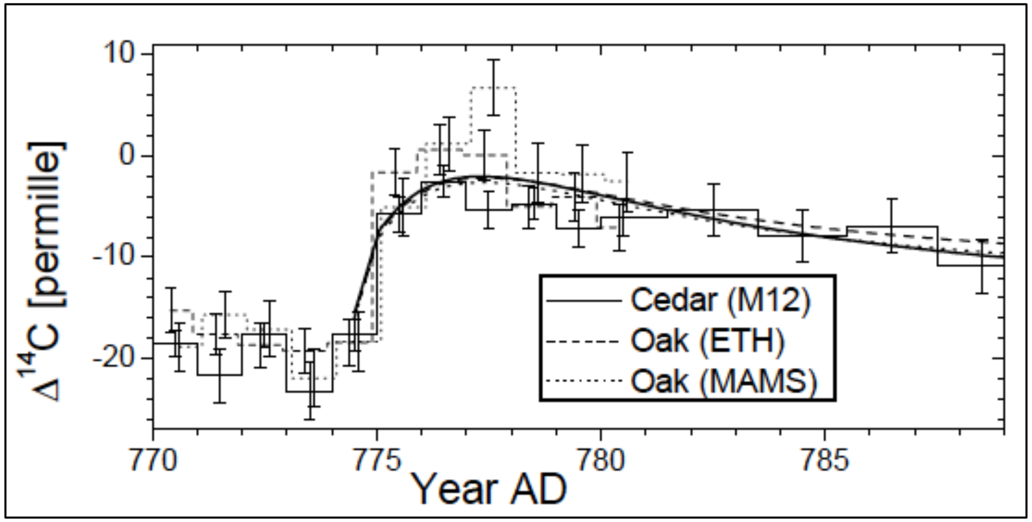
Some *Sugi* (cedar), perhaps at Yakushima, Japan

Nagoya graduate student Fusa Miyake

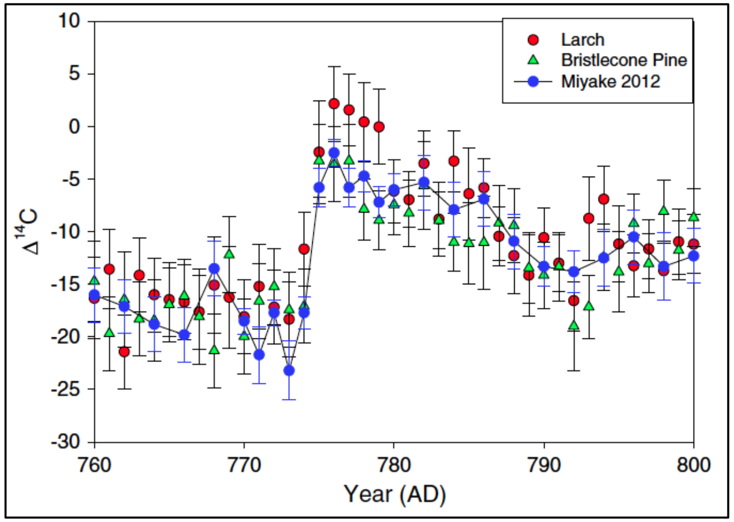
Extreme events in tree rings



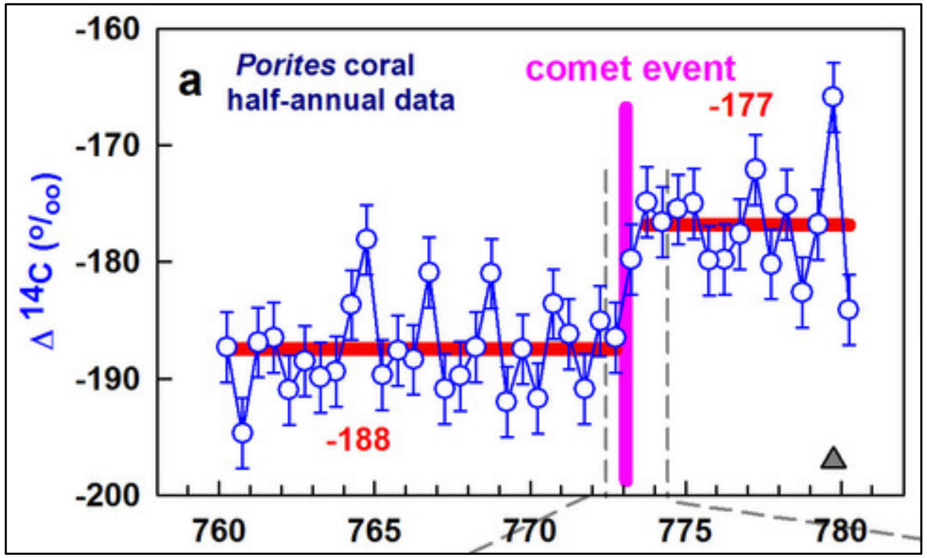
Miyake et al. 2013



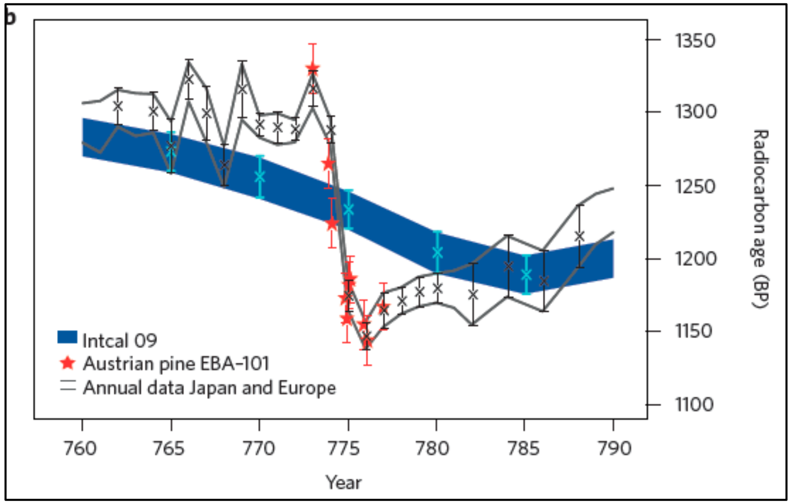
Usoskin & Kovaltsev 2013



Jull et al. 2014



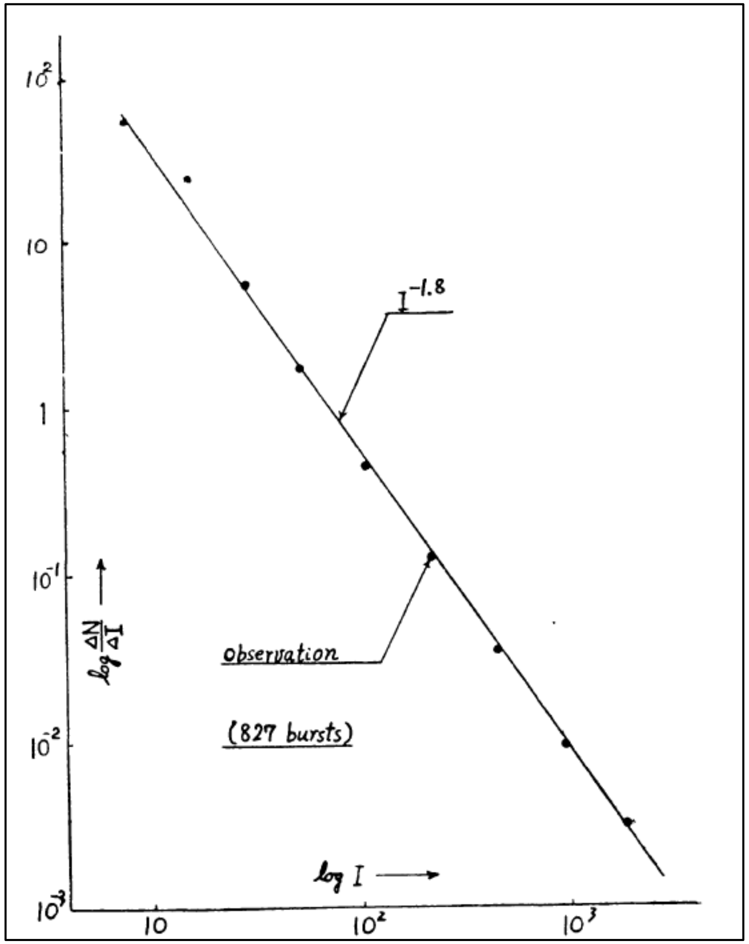
Liu et al. 2014

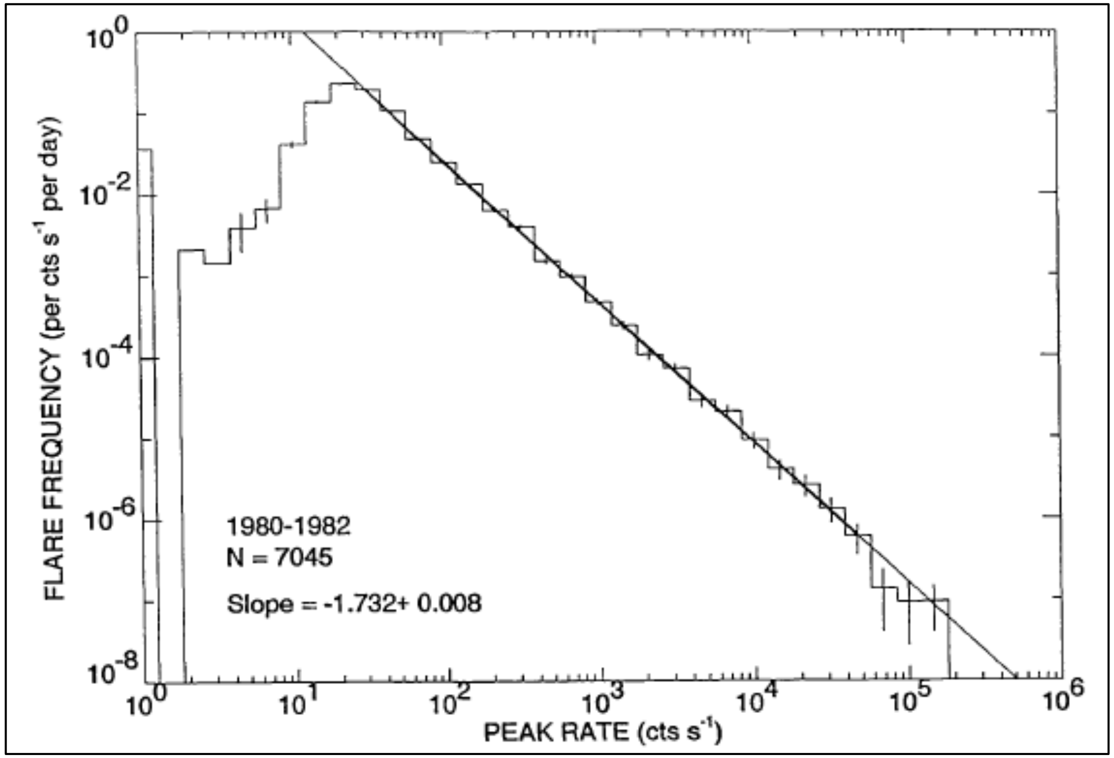


Büntgen et al. 2014

The problem of the power law:

a break is required

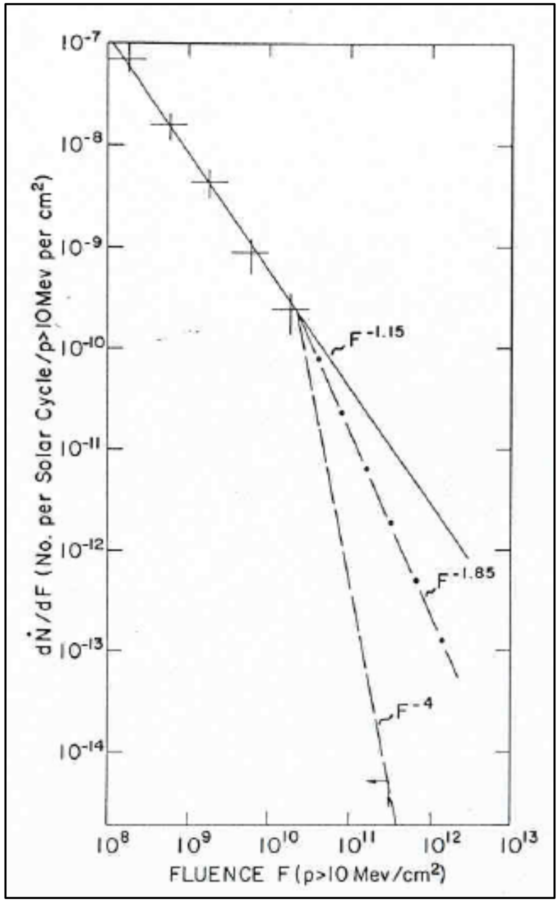




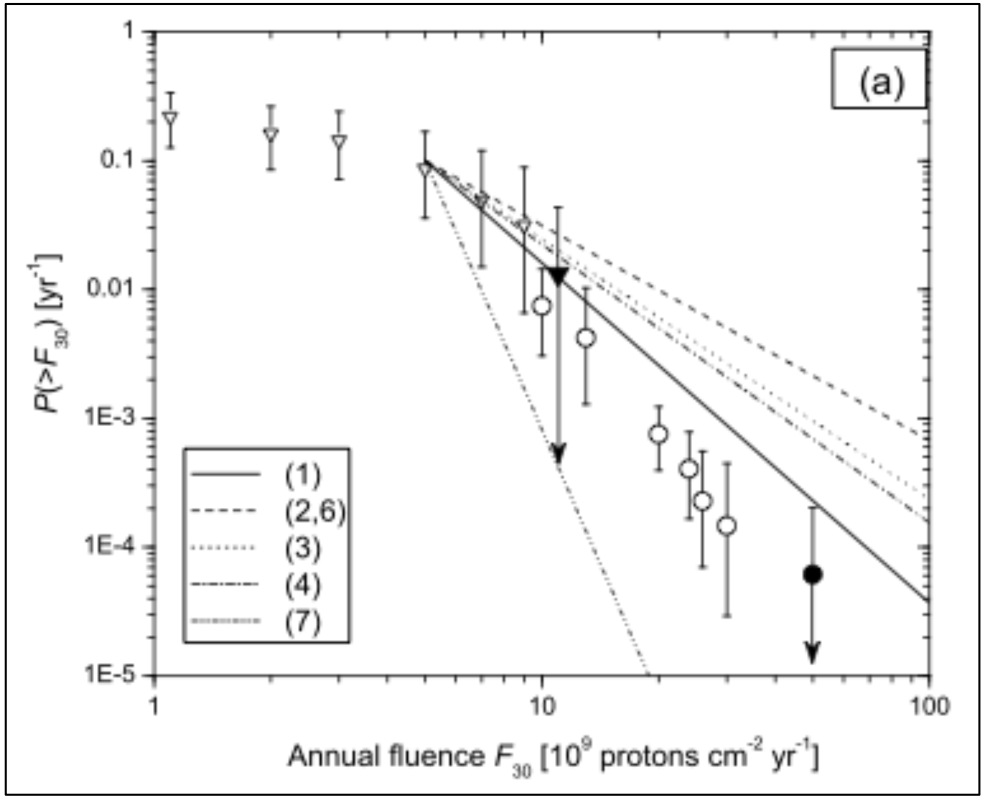
Akabane, 1956

Crosby et al., 1993

Can we see the break in SEPs?



Lingenfelter & Hudson 1980



Kovaltsov & Usoskin 2014

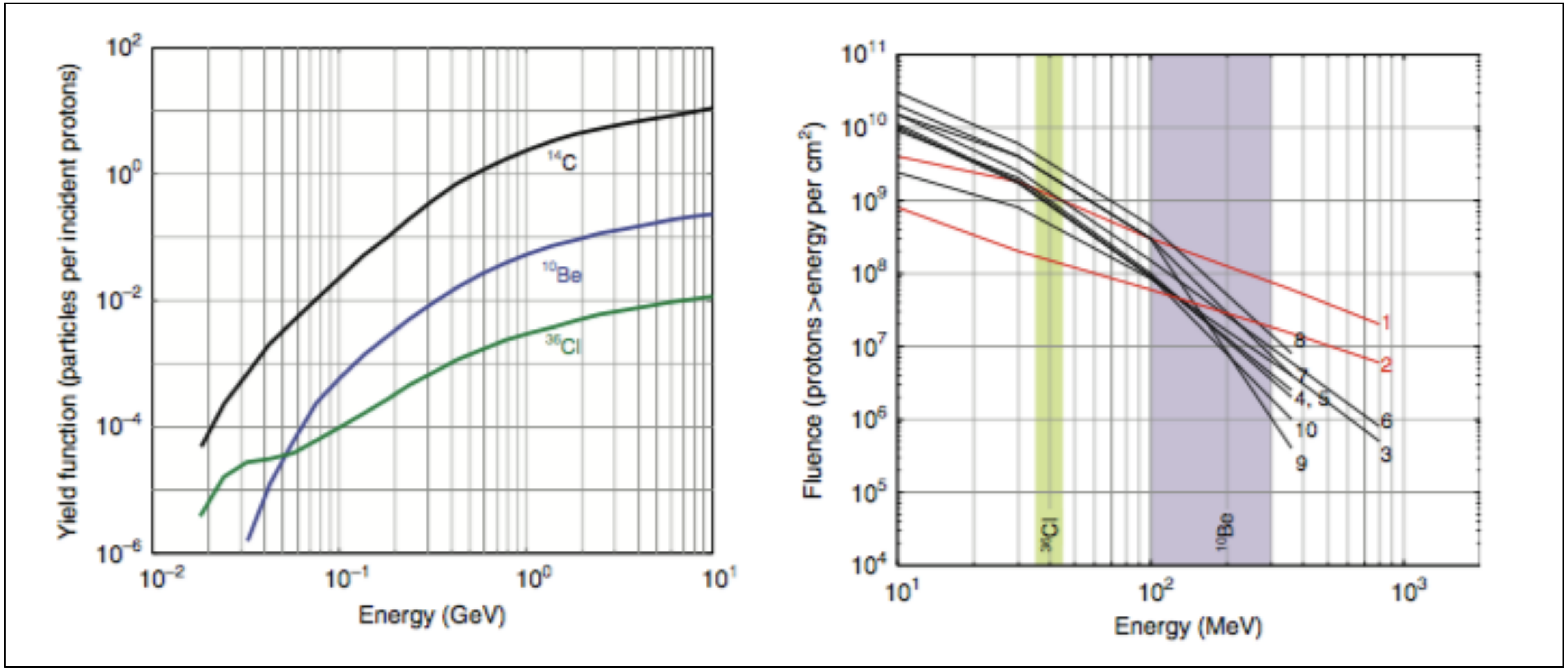
Extreme events

- The Kepler superflares and the radiosotope events suggest that powerful solar flares might occur
- The weight of evidence for the radiosotopes now leans towards the Sun
- To locate the break for solar flares, we need more TSI observations at *higher time resolution*

The breaking news

- Superior work on radiosotopic patterns from Mekhaldi et al. 2015 has appeared
- The weight of evidence for the radiosotopes now leans towards the Sun
- The key distinction in detectability appears to be in the SEP spectral distribution

The breaking news



The events in red (right panel) are the two SPEs for which hard spectra occurred in the historical era: SOL1956-02-23 and SOL2005-01-20. These match the tree-ring requirements for the prehistorical events.

Conclusions

- Flares also contribute to TSI (a SORCE result)
- Recent tree-ring data and Kepler photometry reveal “extreme events” *
- Parker’s nanoflares may be lurking in the quiescent variability – but there is little evidence for this

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

Assessment

- Can we predict extreme events statistically?
- Should our prior include (a) superflares on Kepler stars, or (b) tree rings?
- See J. Love, “Credible occurrence probabilities for extreme geophysical events…” (GRL 2012)