Oh Nooo - Another Carrington event?

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SSL, UC Berkeley and U. of Glasgow

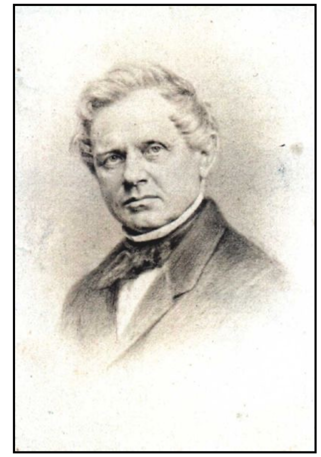
- History
- What is a Carrington Event?
- (What is any event?)
- Tree rings and stellar flares
- Will an extreme event smite us?
- How else could the Sun help things go dreadfully wrong?

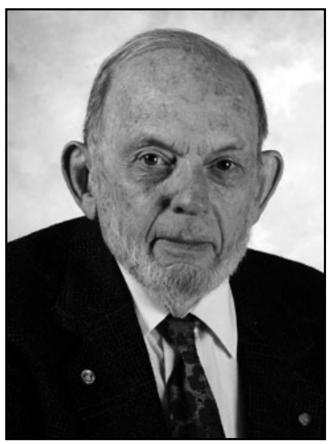
Prepared for Hard-Sci SF Zoom, Nov. 2, 2024

- Hamlet: “To be, or not to be…”
    - Optician: “To see, or not to see…”
        - Astronomer: ”2D, or not 2D…”

Academic Background

- Rice (1961), UC Berkeley (1966)
- Kinsey Anderson (PhD Minnesota 1955)
- John Winckler (PhD Princeton 1946)
- Rudolph Ladenburg (PhD Munich 1906)
- Wilhelm Conrad Röntgen (PhD Zurich 1869)
- August A.E.E. Kundt (PhD Berlin 1864)
- Heinrich Gustav Magnus (PhD Berlin 1827)
- Miscellaneous German chemists…





Science fiction background

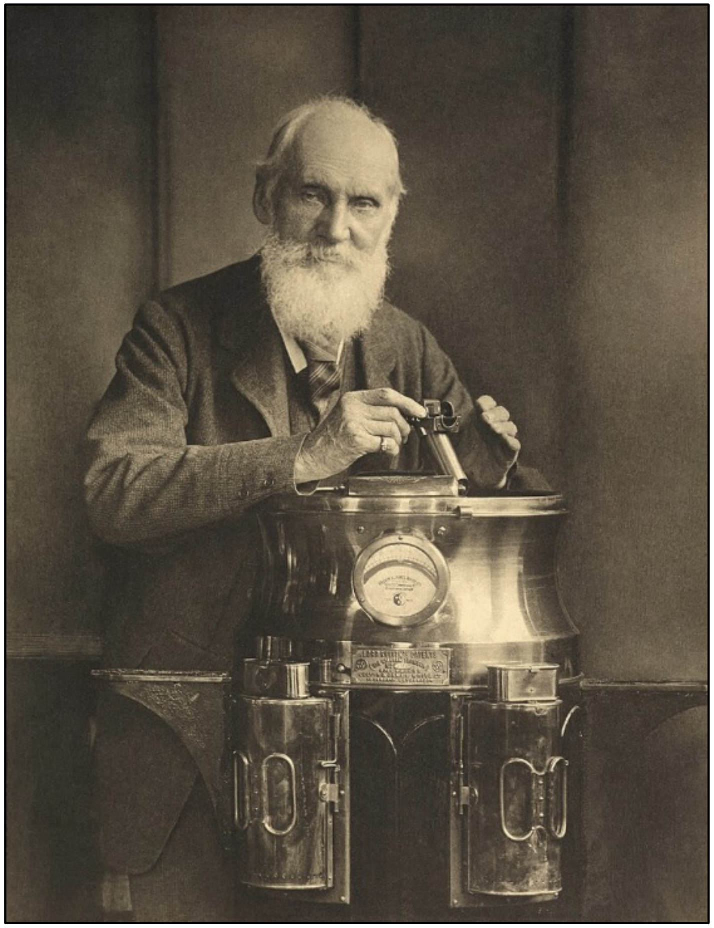
- Teenage years: Avid reader 1950-1959 (Heinlein, Asimov, Bradbury; every issue of Amazing or Astounding
- College years: mostly science reading; disliked books by Tolkien and Ayn Rand
- Postdoc era acquaintances, 1966-1991 at UCSD: Vernor Vinge, David Brin, Greg Benford
- 1991, wrote "A Space Parasol as a Countermeasure Against the Greenhouse Effect" (JBIS 44, 139)

Who was Carrington?

Cliver & Keer 2013

- An English advanced amateur, independently wealthy (b. 1826)
- Probably a difficult man, but very productive for about 10 years
- The flagship journal of the Royal Astronomical Society had to swell to accommodate his data!

Who was Carrington Not?



- This is actually Lord Kelvin, our Glasgow patron saint, resting on a binnacle

- There was a Lord Carrington, but not related

- There is no known likeness of Carrington himself, even though photography existed then

Table 1
Signatories of the round-robin letter

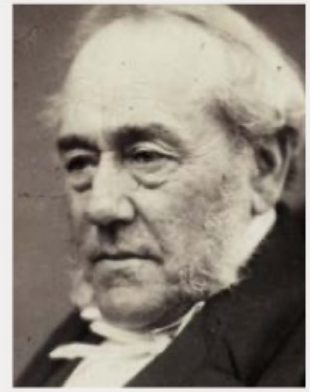
Including references to obituaries in *Monthly Notices*.
(Fisher: Royal Society. Airy, De la Rue, Glaisher, Lee, Smyth: NPG. Main, Perigal, Pritchard: RAS/SPL. May: http://www.oasi.org.uk/History/May.php)

George Airy
1801–92
Astronomer Royal 1835–81
Turner (1892)

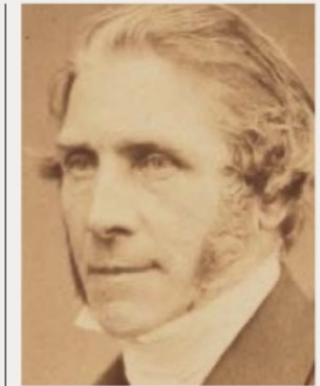
?

Richard Carrington
1826–75
Discoverer of solar differential rotation; first to observe (with Hodgson) a solar flare
Anonymous (1876)

Warren De la Rue
1815–89
Pioneer of solar photography
Knobel (1890)

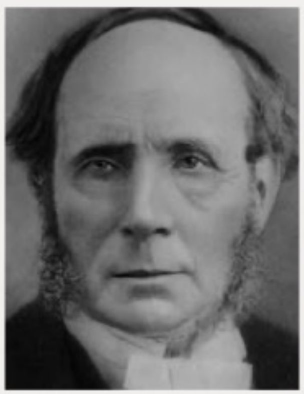


George Fisher
1794–1873
Astronomer on British expeditions to the Arctic in 1818 and 1821
Anonymous (1874)



James Glaisher
1809–1903
Meteorologist and pioneering balloonist
Ellis (1904)

John Lee
1783–1866
Founder of Hartwell Observatory
Anonymous (1867)



Robert Main
1808–78
First assistant at Greenwich; director of Radcliffe Observatory
Anonymous (1879)

Charles May
1800–60
Manufacturer of instruments for Greenwich Observatory
Anonymous (1861)

Henry Perigal, Jr
1801–98
A "paradoxer" who provided a dissection-based proof of the Pythagorean theorem
Anonymous (1899)

Charles Pritchard
1808–93
Savilian professor of astronomy at Oxford
Turner (1894)

William Smyth
1788–1865
Naval officer, geographer, hydrographer, astronomer, antiquarian
Anonymous (1866)

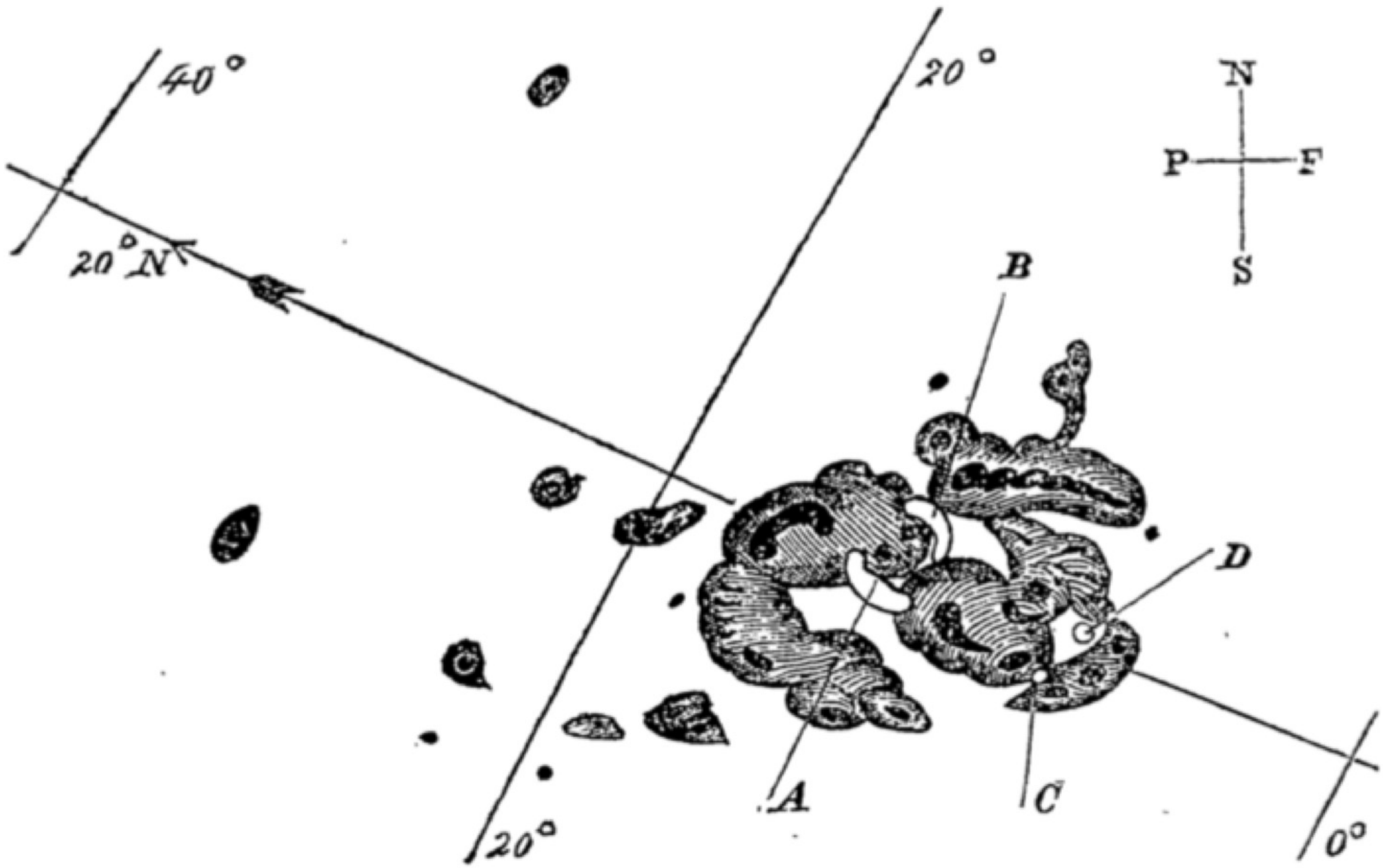
Cliver et al. 2021

Precise sunspot measurements

Prosser 2019

- Carrington made exact sketches via projection onto a screen of a "pale distemper of straw"
- He also used timing for precise definition of the geometry of spots and their motions
- On this huge spot group in 1859, he was making such measurements when the flare popped off

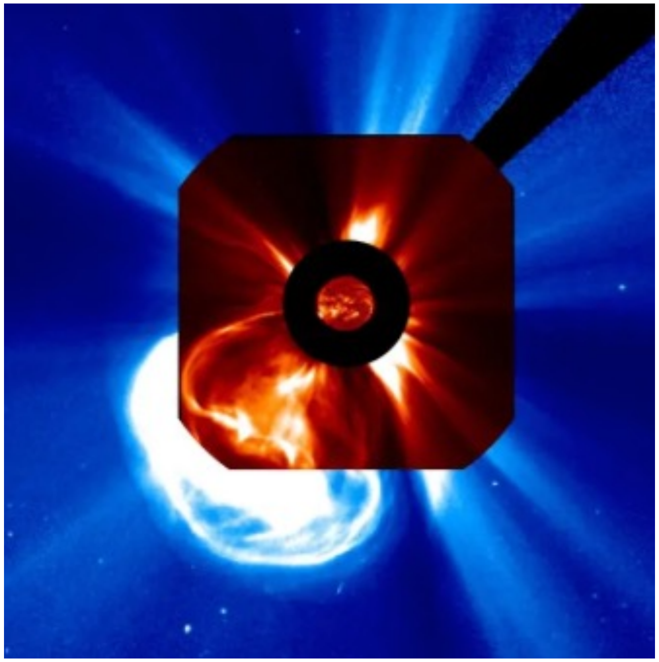
The Flare

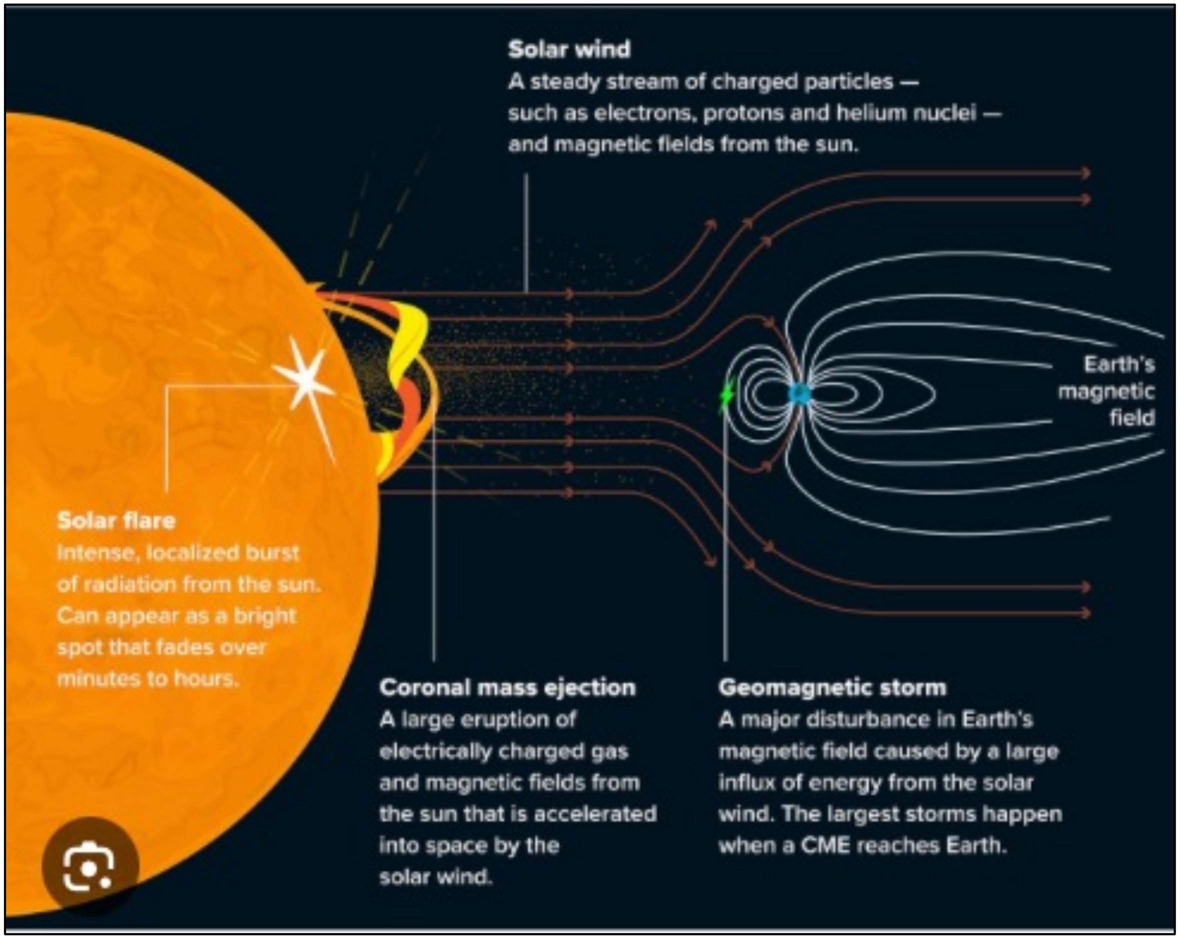


What is a flare?

- In 1859 this was totally unexpected, and of course inexplicable. The term “flare” arose much later
- There was a simultaneous perturbation of the Earth’s magnetic field. Also unexpected and inexplicable!
- Solar “multimessenger astronomy” had already begun, but here was “space weather”

What is a flare?





What is a flare?

- Briefly, a flare shows the sudden release of magnetic energy into other forms.
- A coronal mass ejection is similar, but involves launching a huge plasma mass into the void.
- Flares/CMEs may accelerate relativistic particles much like cosmic rays, except not so energetic.

“Space Weather”

- Briefly, a flare shows the sudden release of magnetic energy into other forms.
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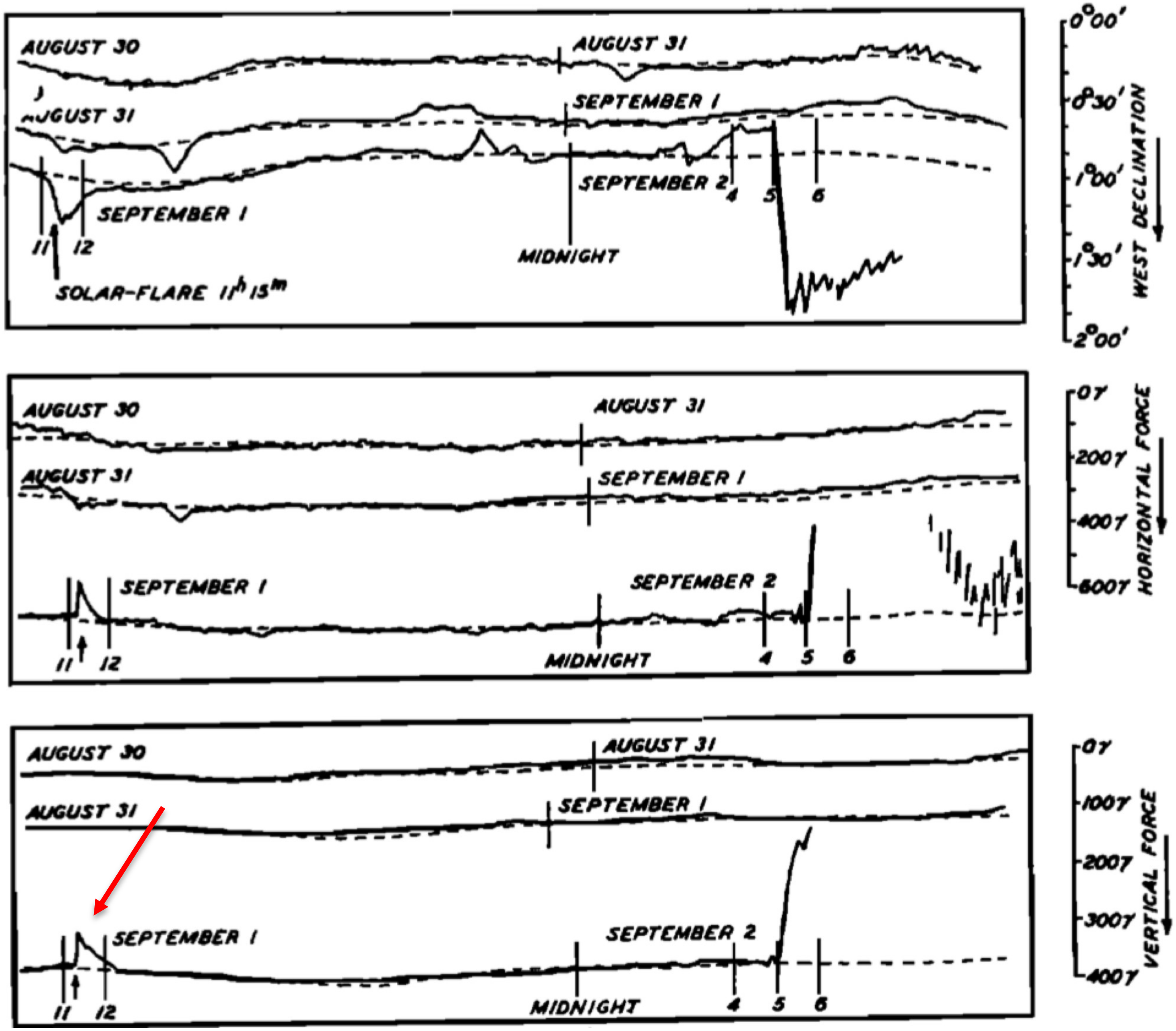
The compass deflection

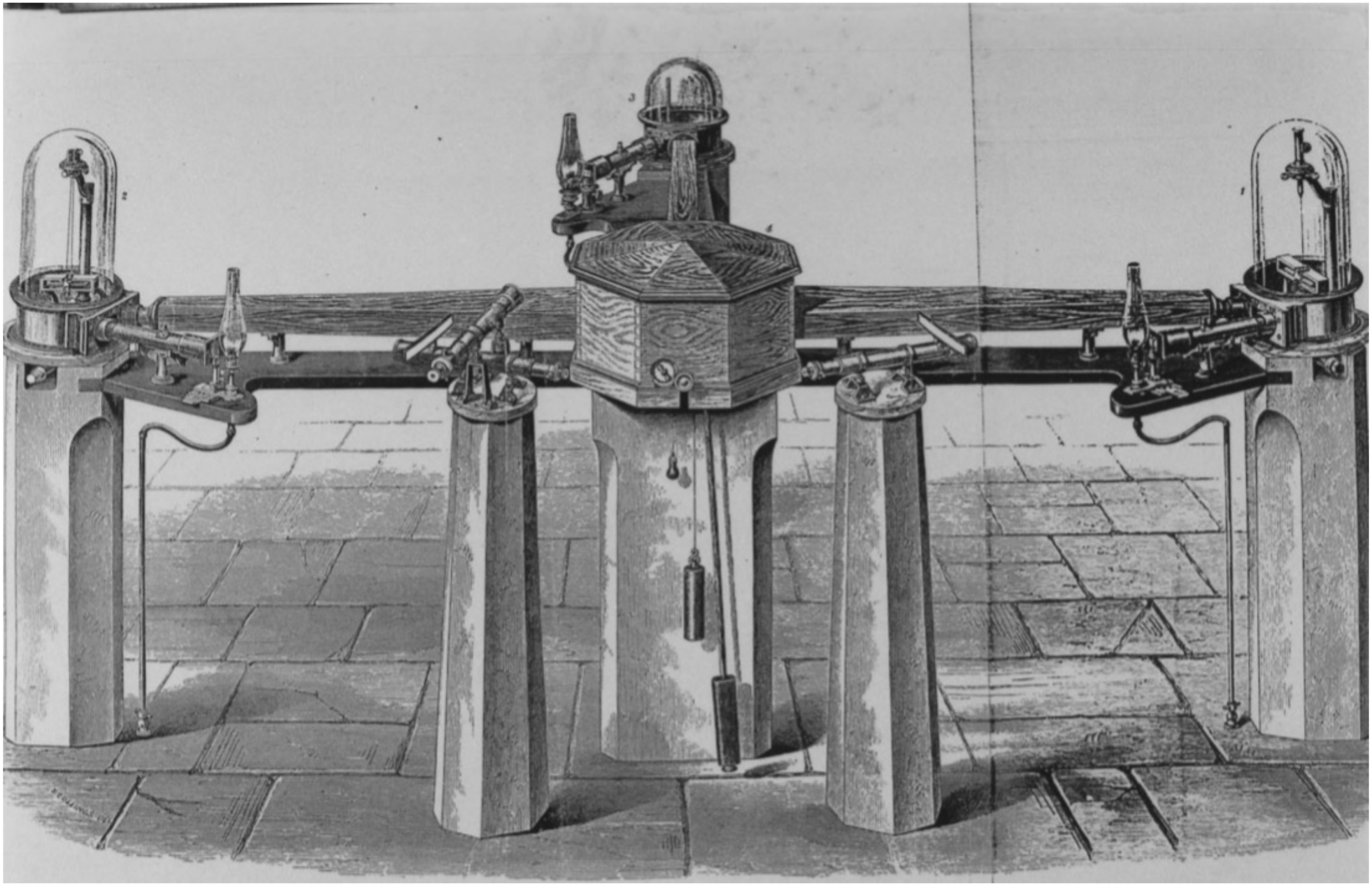


- The diurnal pattern
- The "crochet," aka "Solar Flare Effect"
- The storm sudden commencement
- A superstorm:
  - Dst -900 nT
  - Aurora in Havana

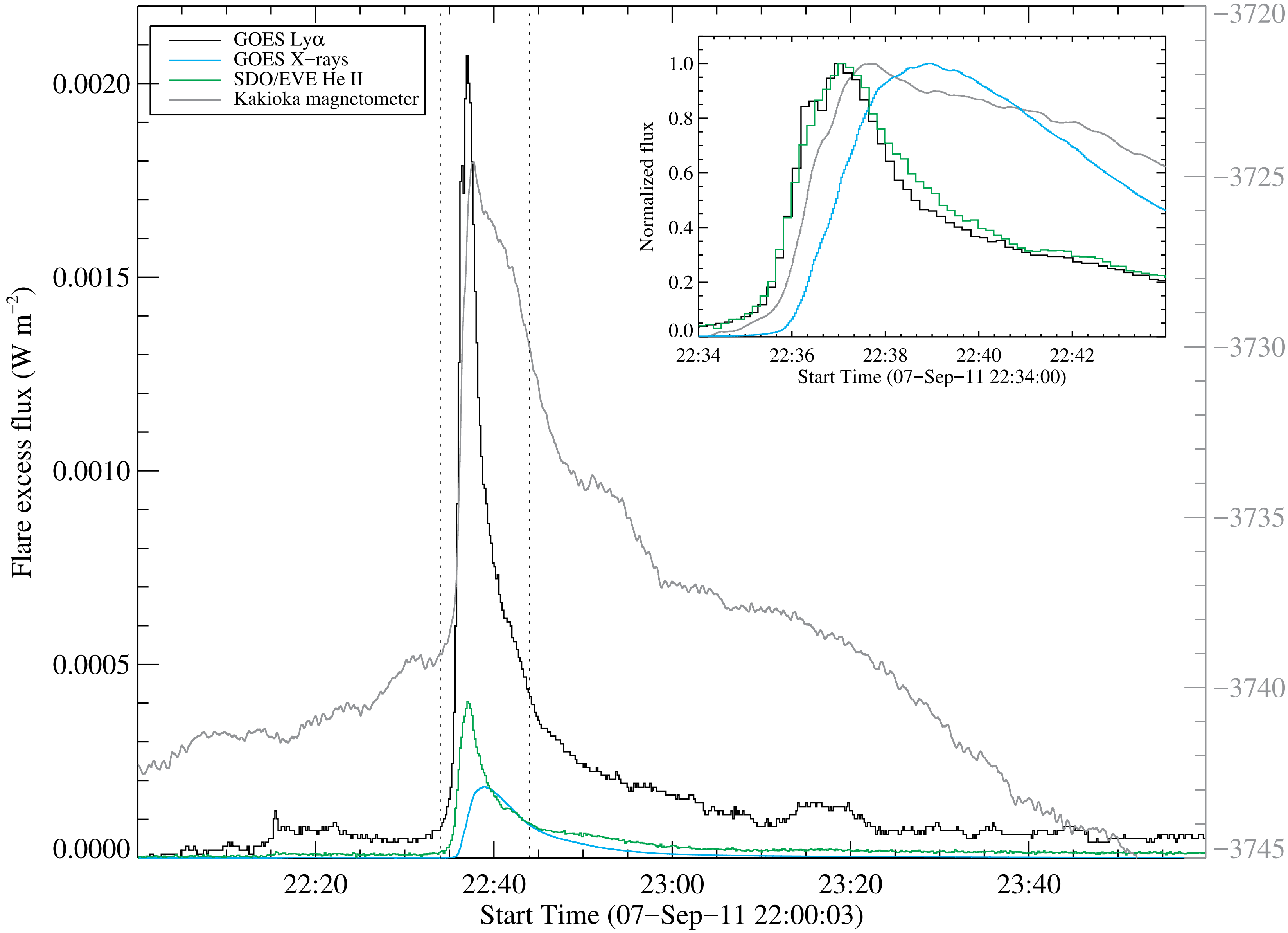
Credit E. Loomis for following up with The terrestrial effects (Shea & Smart 2006)

Balfour Stewart, 1860

A self-recording magnetograph



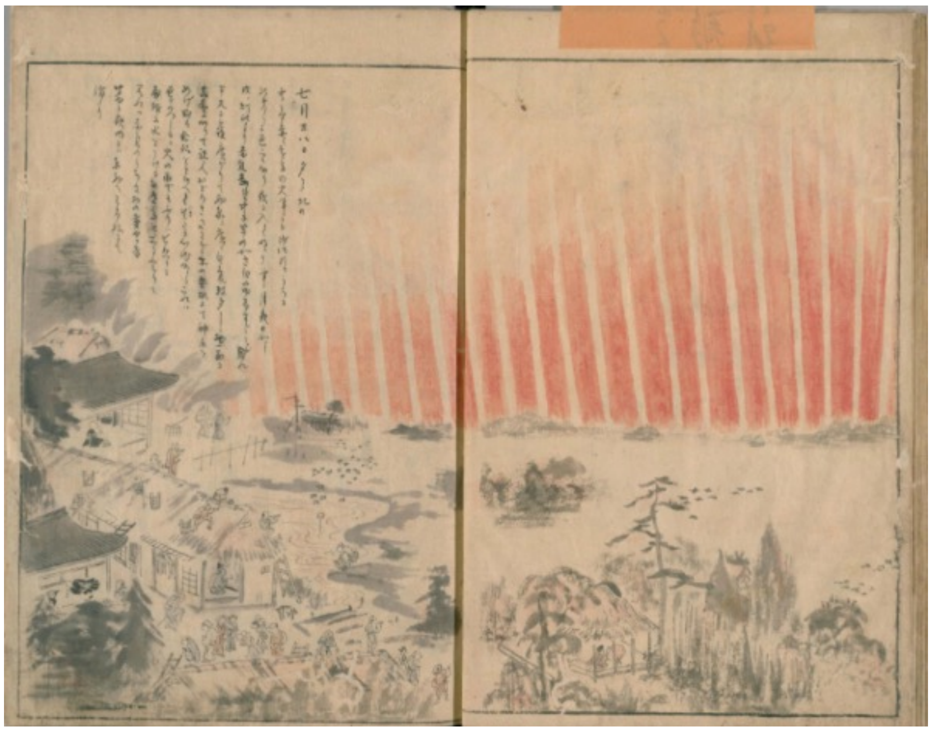
A modern crochet



Milligan et al. 2020

Before Carrington

Nagoya 1770-09-17 (latitude < 30)



Hayakawa et al 2017

Glasgow 2024-10-05 (latitude 55)

My living-room window

A simple energy estimate

- Flare intensity: roughly double the quiet photosphere
- Flare area: 100 MSH (~0.01% of solar disk)
- Flare duration: 300 s

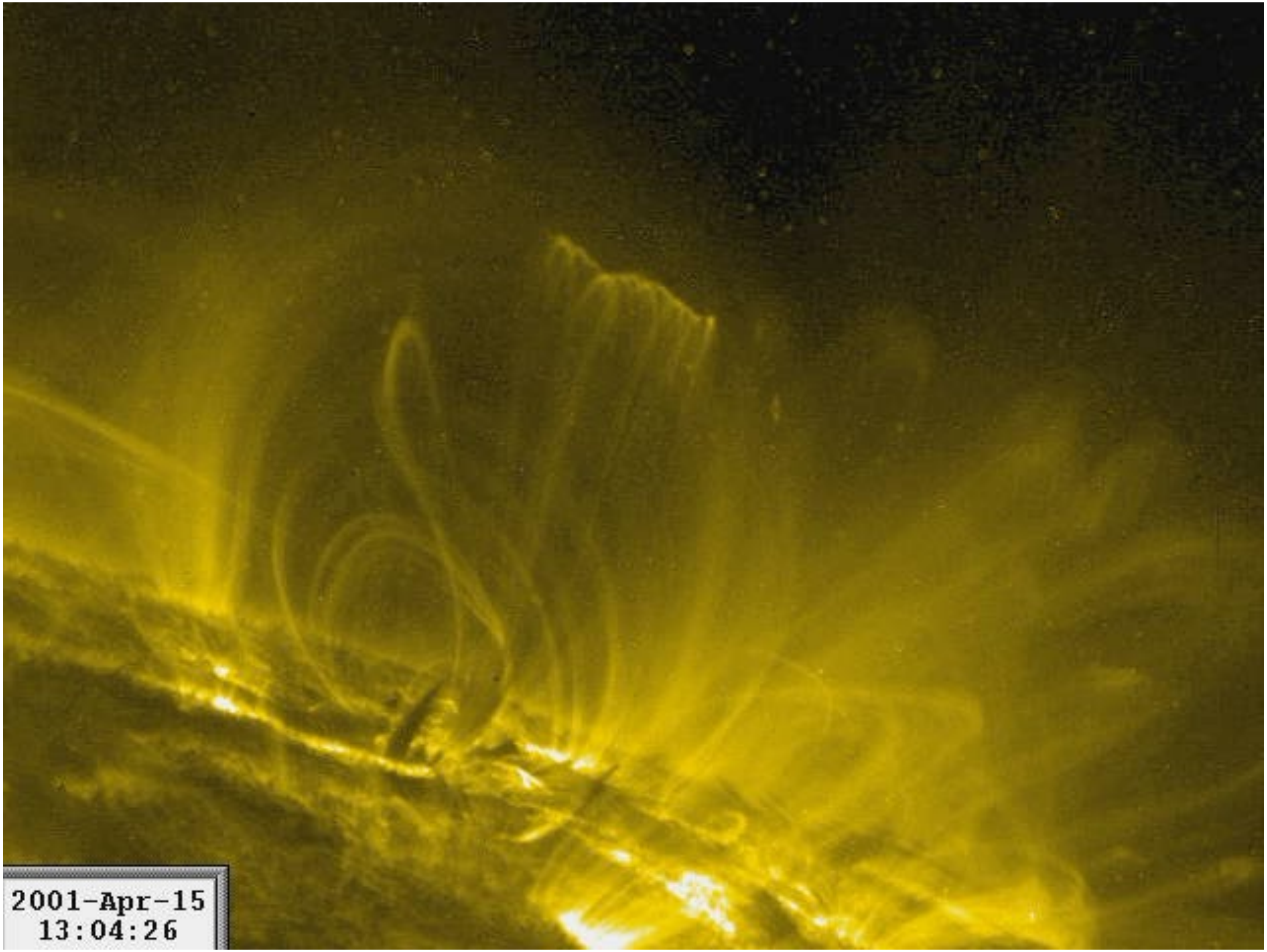
This compounds to 2.5×10^{32} erg

- ICME mass guessed at 10^{16} g: also 2.5×10^{32} erg

(roughly the mass of a city the size of Tucson)

Total event energy 5×10^{32} erg

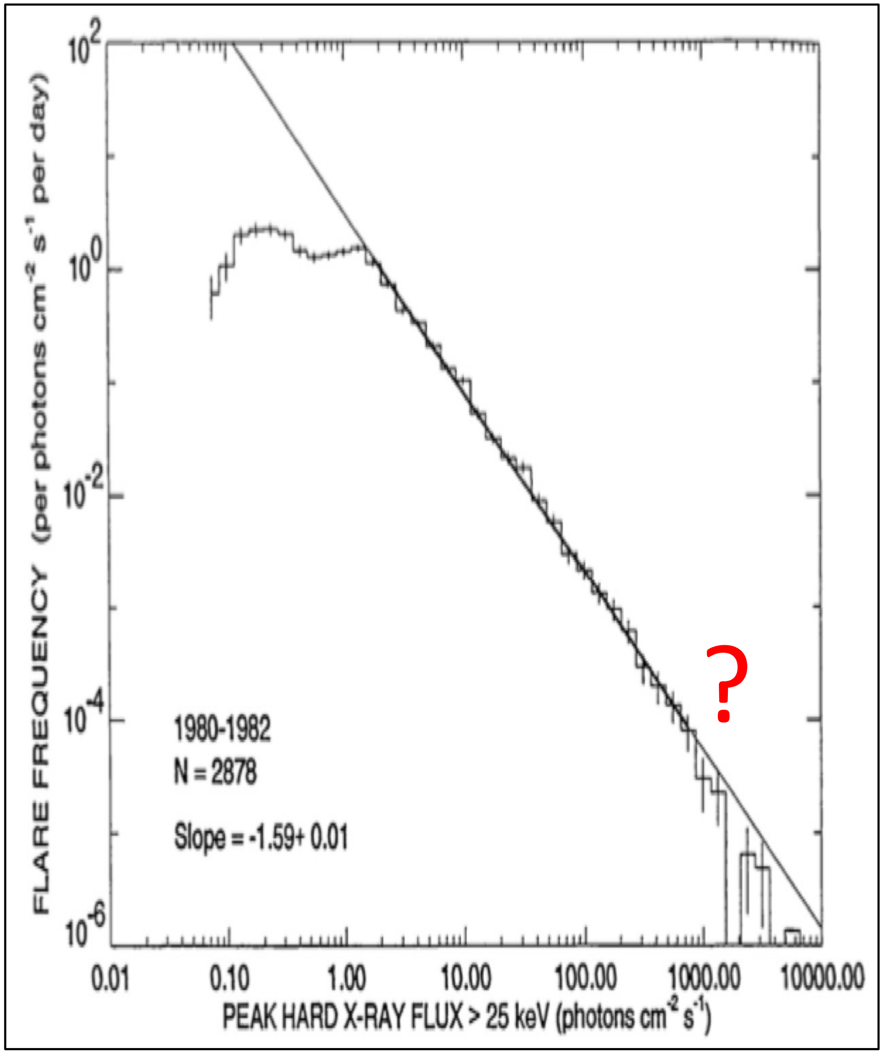
Carrington could have made this estimate, but the physics was far in the future. For example, the unit "erg" had not yet been invented (1873).


2001-Apr-15
13:04:26

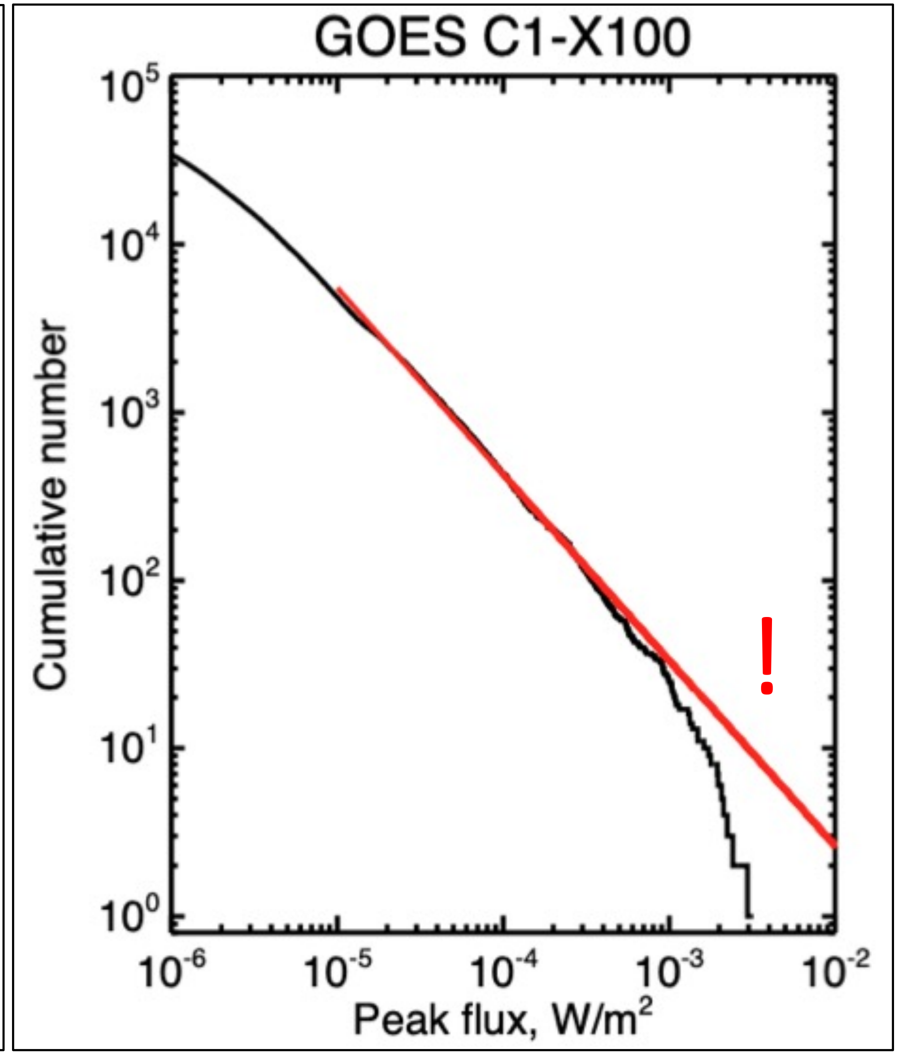
How dangerous can a flare be?

- Flares occur over a wide range of magnitudes, just like earthquakes
- A “power-law distribution” of occurrence is open-ended, and so a huge event might be possible: Carrington!

The power law updated



Crosby et al. 1993



Hudson et al. 2024

Power laws generally; Black Swans and Dragon-Kings

- These very commonly describe the occurrence distributions of natural phenomena
  - Earthquakes
  - Nile floods
  - City populations
  - Word frequencies in the Bible *etc. etc*.

- Based on this law, we can easily estimate the probability of a future Carrington-class event (e.g. Love 2012)

  - But what if something else is possible? A "Dragon-King" may lurk in the dimly lit corner. This would not follow the same physics as the power-law events do

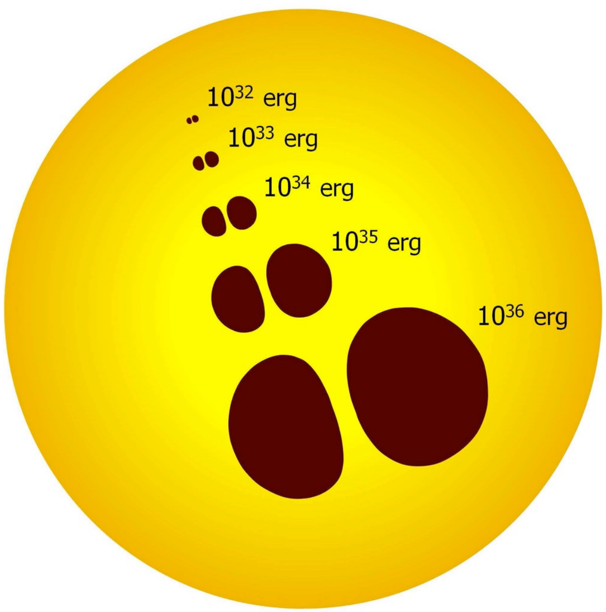
Black Swans and Dragon-Kings

Black Swan
(Cygnus Atratus)
Photo: Dave Key

Mute Swan
(Cygnus Olor)
Photo: Dave Key

Initial Conclusion

- We can define a Carrington Event as a flare/CME/storm at the top of the scale
- The archetype Carrington event itself was not superlative and a similar one would probably not be disastrous



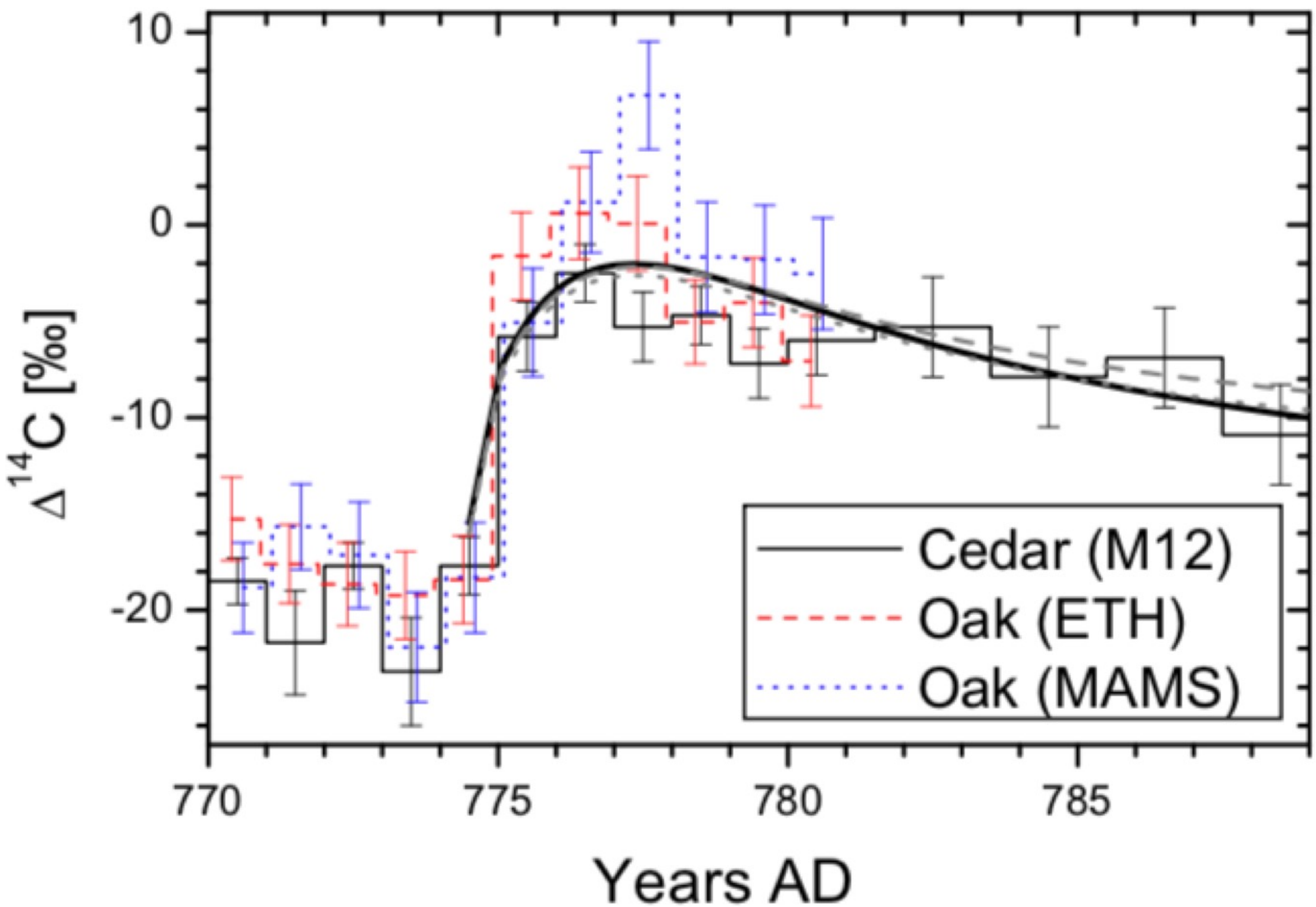
State of the art in theory, Aulanier et al. 2013. In essence, "Give me a big enough sunspot, and I will give you a superflare!"

Two new discoveries about extreme events

- Three radionuclide events in the Holocene (Miyake et al. 2012, 2013; O'Hare et al. 2019), the first in ~775 AD
- *Kepler* observation of "superflares" on slowly-rotating "solar-type" stars (Maehara et al. 2012)

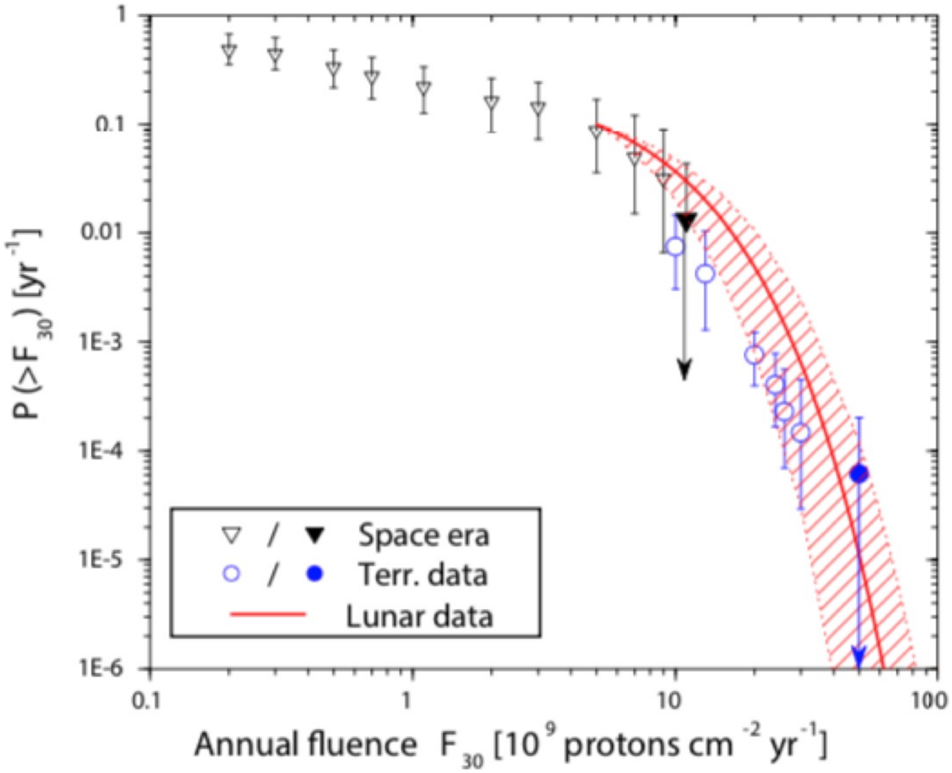
Then (2012, not 775) graduate student Fusa Miyake

AD 775 Solar (?!) Event

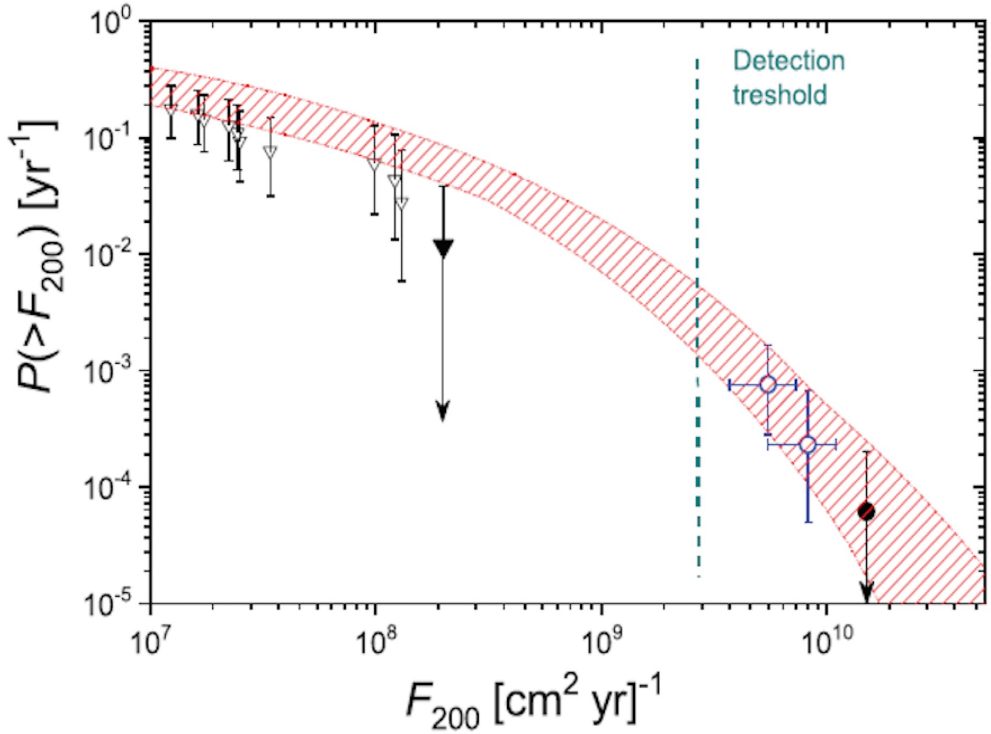


Kovaltsov-Usoskin 2013

SEPs as event proxies



Kovaltsov-Usoskin 2013
cf. Lingenfelter-Hudson 1980



The observed flare-occurrence power law in energy may have a break (Hudson 1991)

Threat assessment

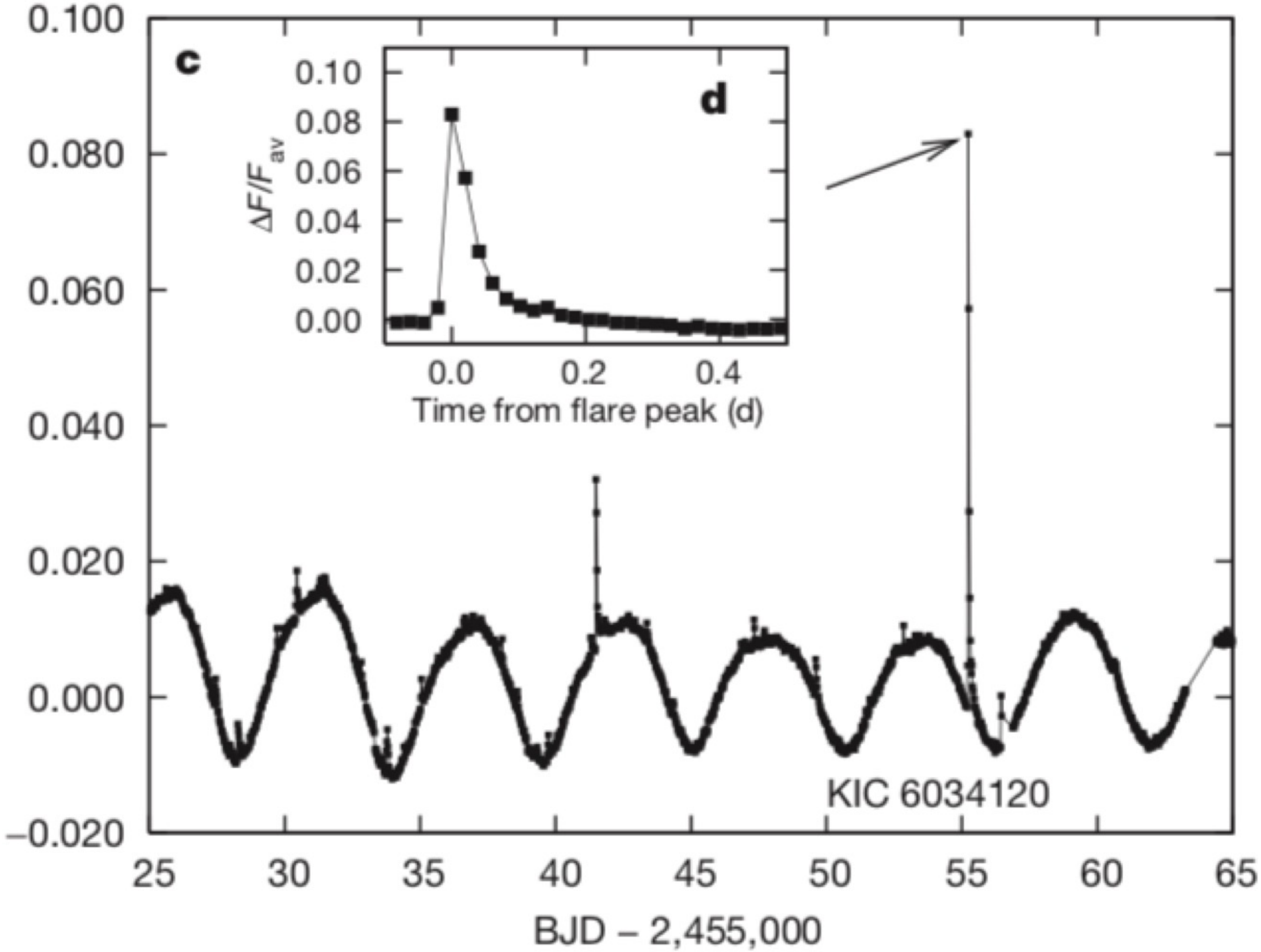
- A Carrington event is like a 100-year flood, and the human race would easily survive one
- A thousand-year event? Or greater?

  - we have strong statistical hints that we've seen the worst already

Suppose we can’t have a Carrington-event disaster?

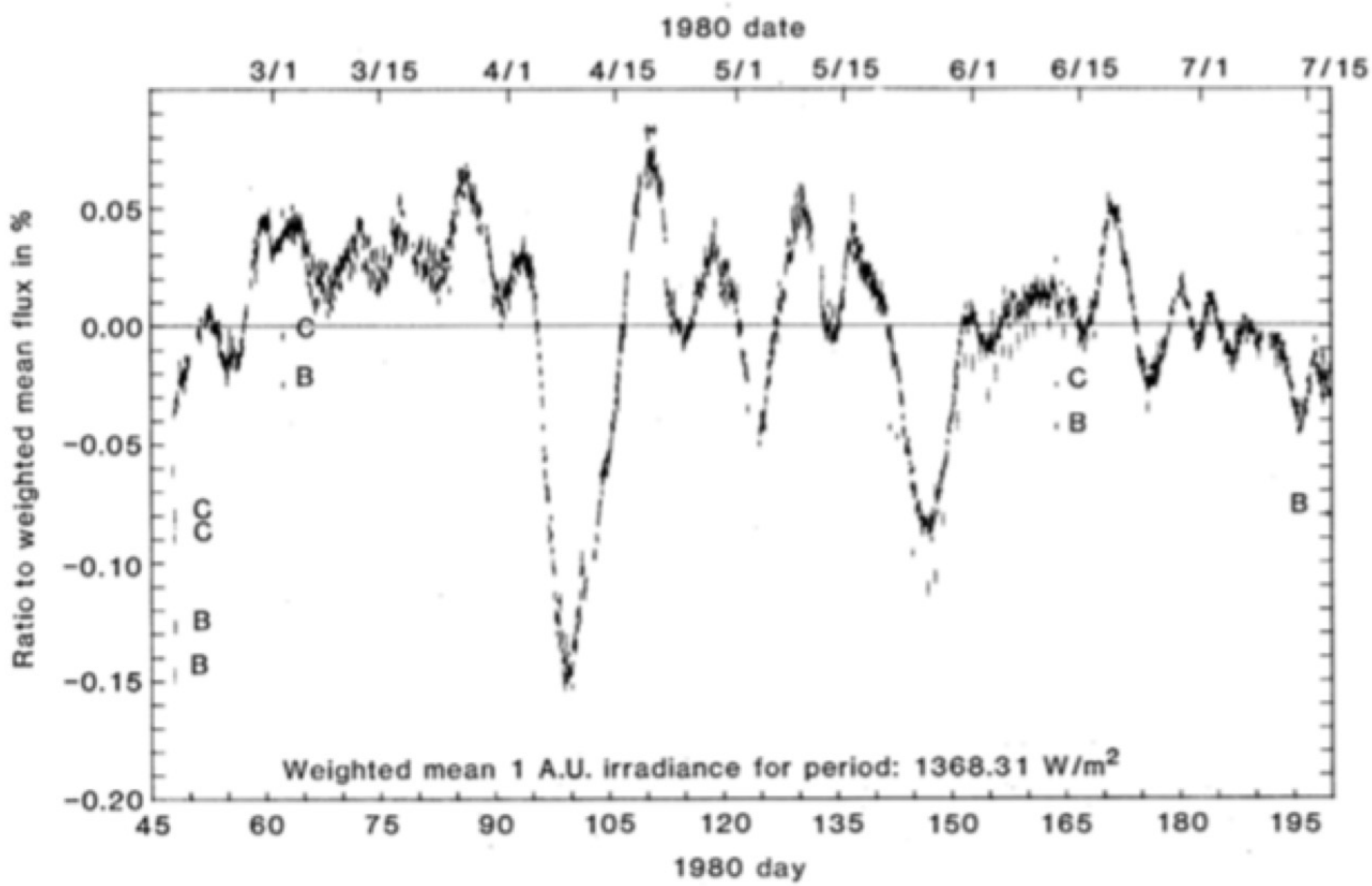
- Rogue dMe star / EMP
- Orphan planet
- Buried black hole / interior accretion
- Sentient Sun

Kepler Stellar Photometry



Maehara et al. 2012

TSI Solar Photometry



Willson et al. 1981

Solar variability is facula-dominated on solar-cycle time scales

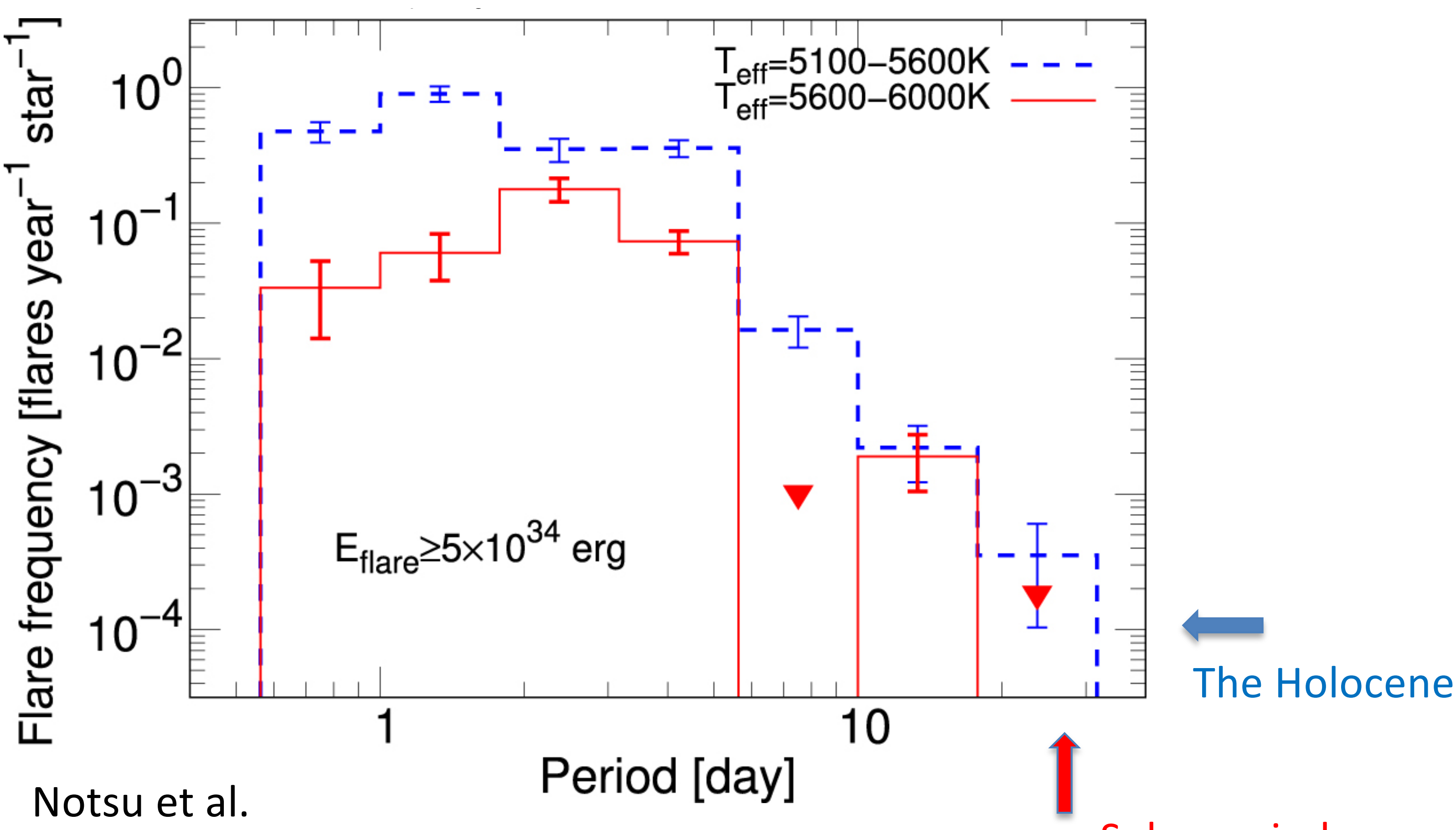
Flariness vs Dippiness

Flariness vs. dippiness

The solar TSI exhibits low-level (of order 50 ppm per 2-min sample) fluctuations due to convection and p-mode oscillation, and pronounced dips due to one-off sunspot transits – *dippiness*. Flares only marginally exceed these fluctuations. The *Kepler* timeseries for most superflare stars do not show dips, but instead have persistent quasi-sinusoidal variability at large amplitude (percents), plus the striking flare excesses – *flariness*.

- The Kepler “solar type” stars are not at all like the Sun in this property
- Sunspot/facular dominance of activity properties varies across the stellar types

Kepler Observations Misunderstood?



Notsu et al. 2019

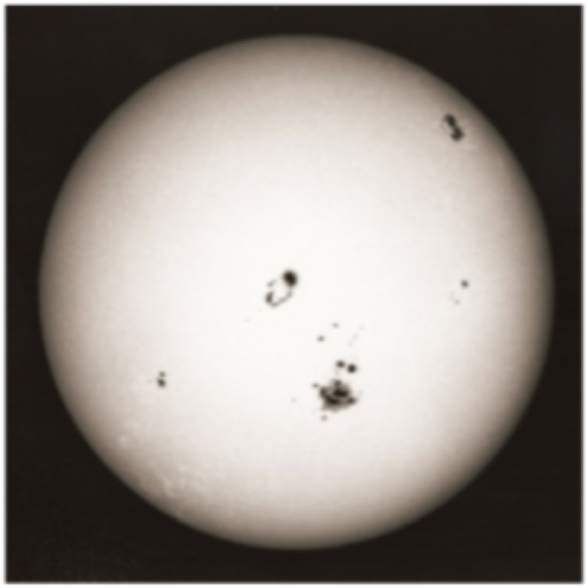
- **Superflare occurrence depends strongly on rotation period**
- **There are actually no statistics here!**

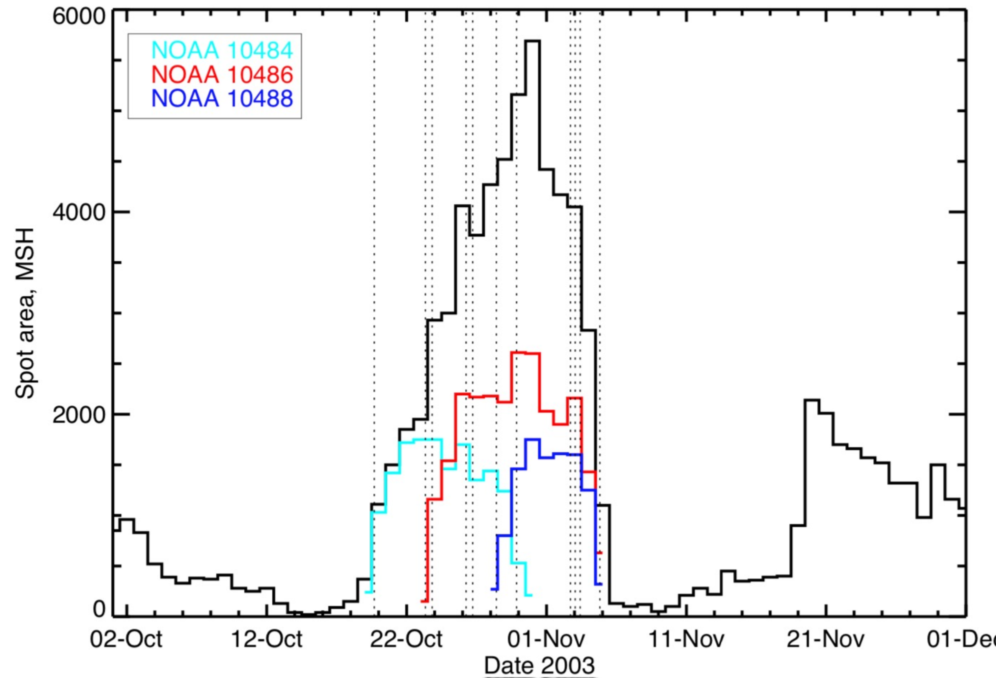
What have we learned from the tree rings and the Kepler events?

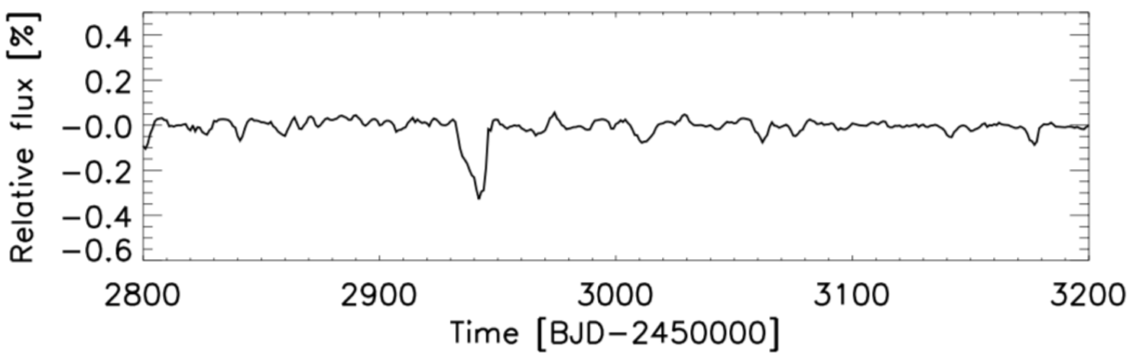
- The tree-ring events appear to have had much greater SEPs fluences than even SOL1956-02-23
- The Kepler events don't suggest a reasonable basis for extrapolation to the solar case

- The meaning of "event" must be extended to compound events
- We should look to stellar CMEs to understand the tree-ring link better

TSI Solar Photometry



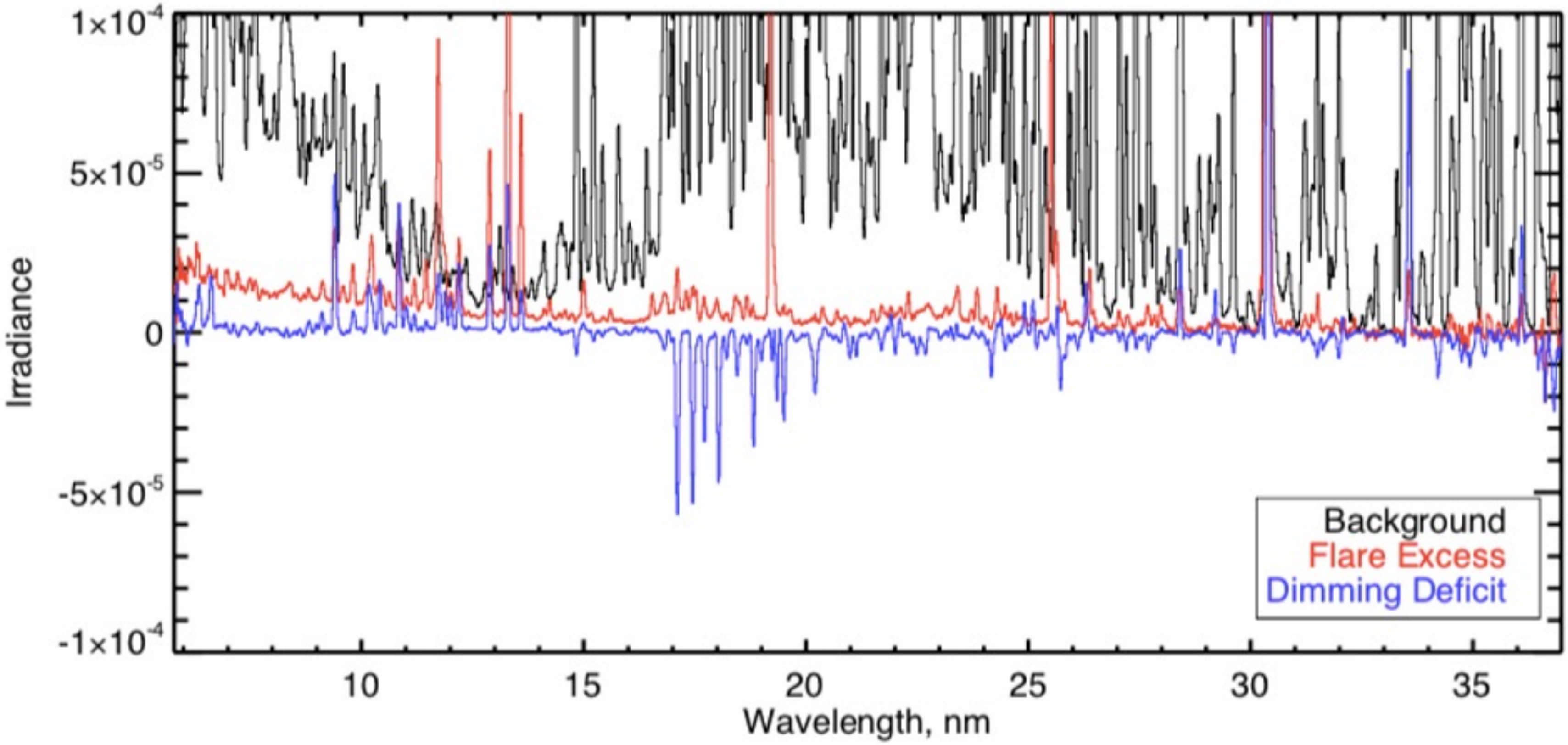




Isik et al. 2020

- **These events together match the Carrington spot and flare magnitudes pretty well – the famous 2003 "Halloween events"**

CME detection via EUV dimming



SDO/EVE spectroscopy readily detects solar mass ejections (Mason et al. 2016)

CMEs on stars

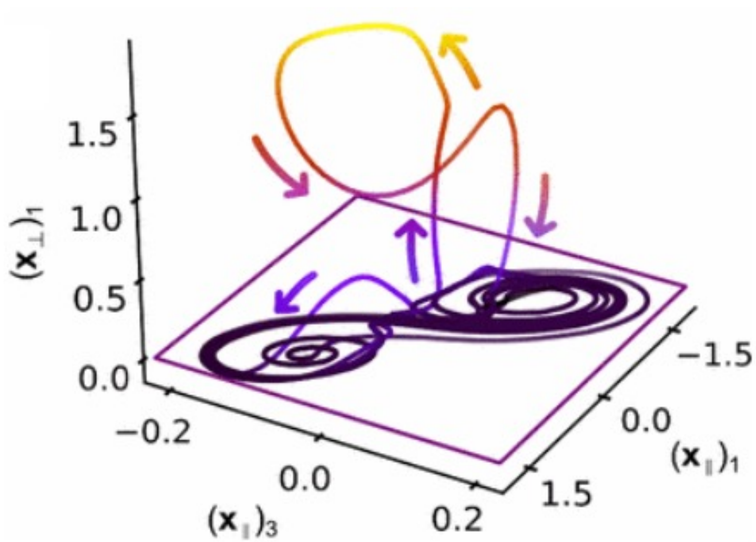
- There are many stars close enough to observe in the EUV.
- A dedicated stellar EUV instrument, doing what EVE does, would be very fruitful, for example just staring at Prox Cen

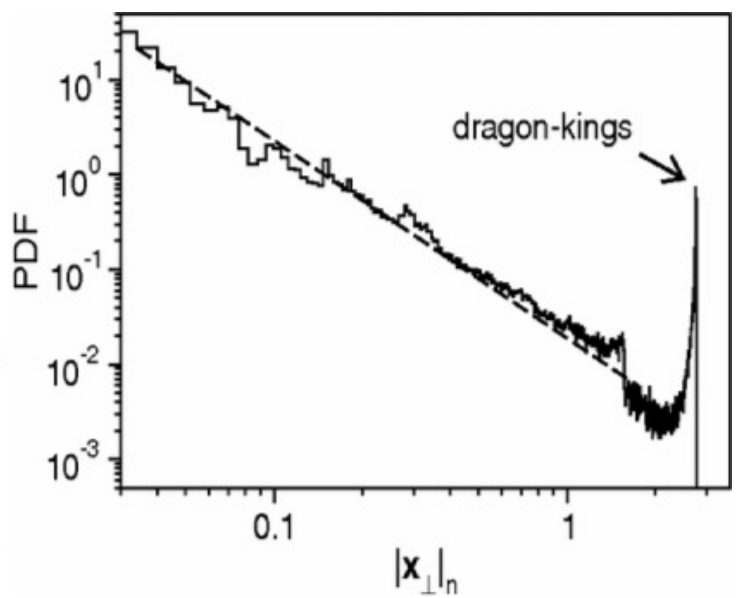
- The problem is SNR. Large aperture is needed to resolve event timescales. Veronig *et al*. (2021) provide some credible examples of stellar dimming events

Coupled oscillators “bubbling”

Sornette’s Dragon-King hypothesis

Poincaré and the theory of dynamical systems





19^{th} Century Natural Disasters

- The Carrington event: 10^{17} g in the heliosphere – a few singed beards
- The Tambora eruption: 10^{17} g in the stratosphere – countless fatalities

YouTube solar disaster movies

- CAT 8 (2013): My rating Awful 1/10
- Solar Flare (2008): Bad 3/10
- Solar Attack (2006): Bad 3/10
- Solar Impact (2019): Awful 1/10
- Solar Crisis (1990): Mediocre 5/10
- The End of the World (2018): Disaster 0/10

Books with solar disasters

- Currently reading Clarke & Baxter 2005, “Sunstorm”

Conclusions

- We can define a ”Carrington event” as major flare/CME/storm of the greatest magnitude
- The archetype Carrington event(s) itself was not superlative and a similar occurrence would probably not be disastrous
- No new physics needed

- But… do the radioisotopes hint at a Dragon-King risk outside our extrapolations?
  - We must study these extreme events
  - We must be prudent about risk

Solar disaster menu

- Super-Carrington... this one we can do statistics for, and dismiss as a threat
- EMP from the solar impact of a (very small) magnetized star... note Ocean's 11. The conspiracy-theory trap; also, we can do the statistics
- Deep penetration by a dead-vertical orphan planet (huge hydro CME)... note Clarke-Baxter 2005 and the earlier parasol discussions
- Solar sentience (why is magnetoconvection not self-aware?)... duhh, too hot for stable currents; but could relatively cool filaments support magnetovores?
- A super-Miyake event, or any Dragon King
- Embedded black hole... the conspiracy-theory trap

An embedded solar black hole

- A tiny black hole forms the initial seed mass for solar accretion
- Further accretion, at an inclined rotation, envelops the black hole, which creates an interior cavity (think Pellucidar)
- As the bulk of the Sun evolves normally, accretion from the inner cavity boundary increases slowly, forming a powerful accretion disk hidden from view
- A jet (think M87) forms, blowing through the body of the Sun (think Alien), and blasting the Earth.