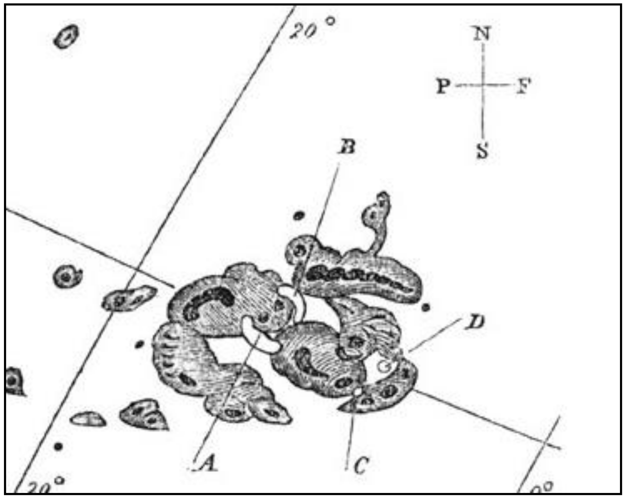
March 11, 2016   NEXT meeting (50 min including discussion)
Kyoto

Threat of the Sun and Superflare

Kazunari Shibata
Kwasan and Hida observatories,
Kyoto University

Carrington flare
(1859, Sep 1, am 11:18 ）

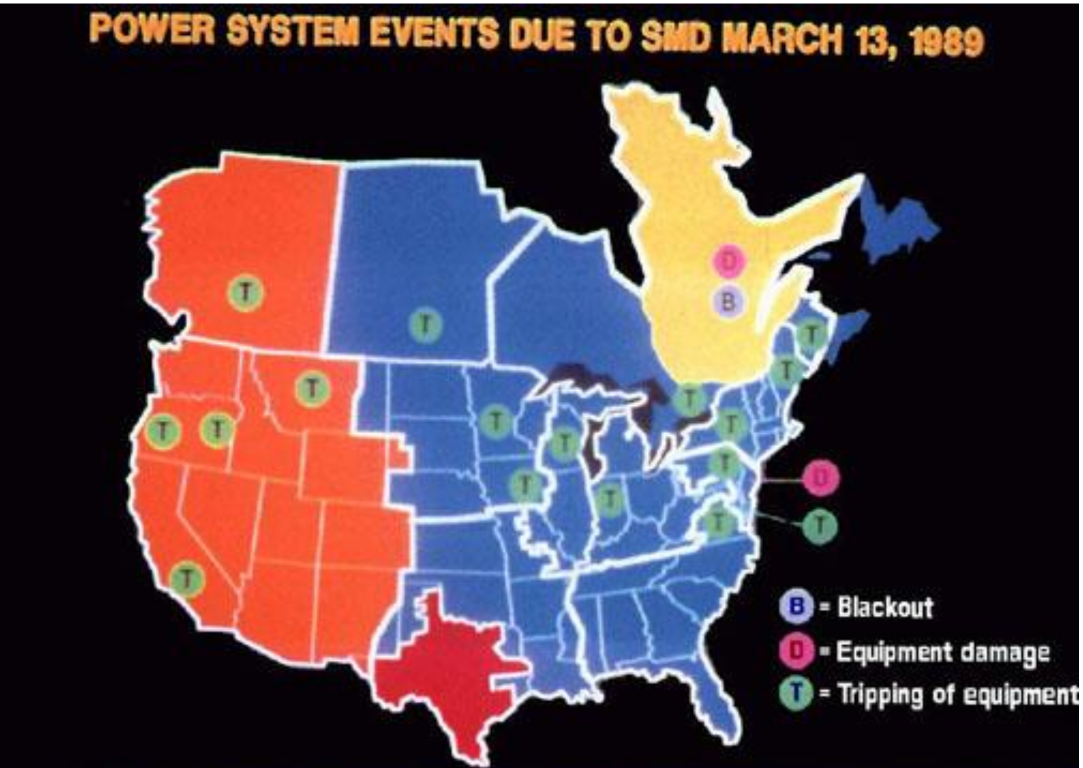
- The first flare that human beings observed
- by Richard Carrington (England)
- white flare for 5 minutes
- very bright aurora appeared next day morning at many places on Earth, e.g. Cuba, the Bahamas, Jamaica, El Salvador, and Hawaii.
- Largest magnetic storm (> 1000 nT) in recent 200 yrs.



Telegraph systems all over Europe and North America failed.
Telegraph pylons threw sparks and telegraph paper spontaneously caught Fire （Loomis 1861）

http://en.wikipedia.org/wiki/Solar_storm_of_1859

Magnetic storm and aurora on 1989 March 13, that lead to Quebeck blackout



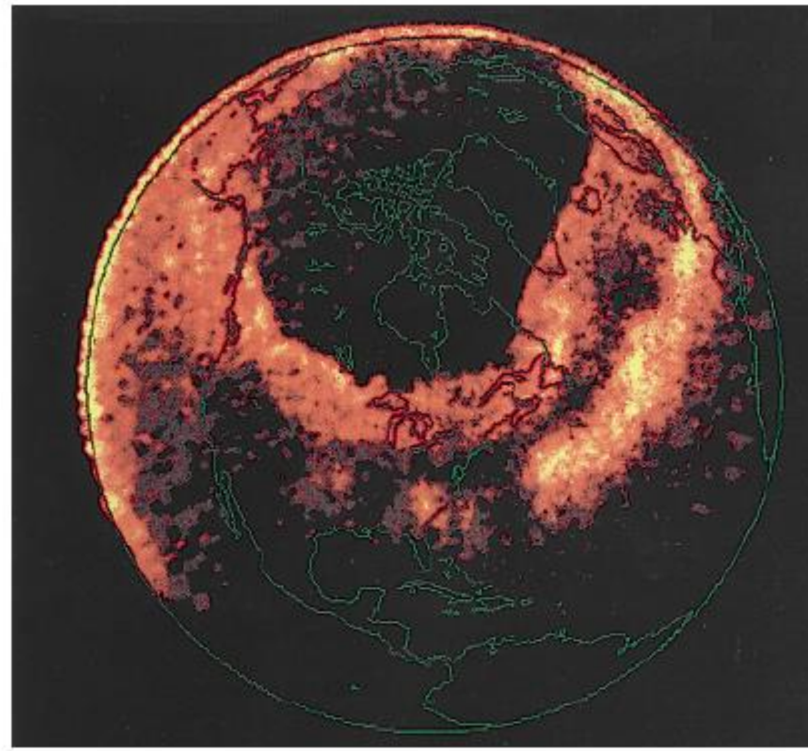


図4　発電所の事故があった日に人工衛星で撮影されたオーロラ。カナダ一帯に強いオーロラが現れたのがわかる。（アイオワ大学 L. A. Frank 教授）

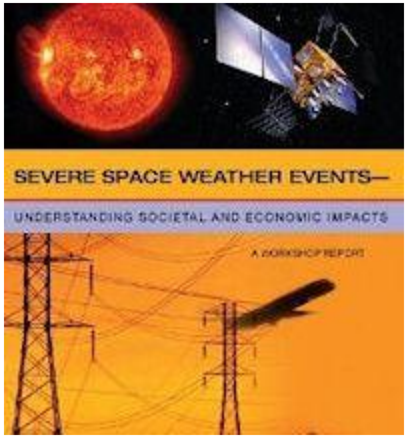
Magnetic storm ~ 540 nT

Produced by a big solar flare (X-class: X4.6)

http://www.stelab.nagoya-u.ac.jp/ste-www1/pub/ste-nl/Newsletter28.pdf

Will the Carrington-class flare occur again ?

- If the Carrington-class flare occur now, what will happen ?
- According to a study by the National Academy of Sciences (2008), the total economic impact could exceed $2 trillion



http://www.nap.edu/catalog.php?record_id=12507

Will the Carrington-class flare occur again ?

Can much bigger flares, superflares ($>10^{33}$ erg), occur on the Sun at present ?

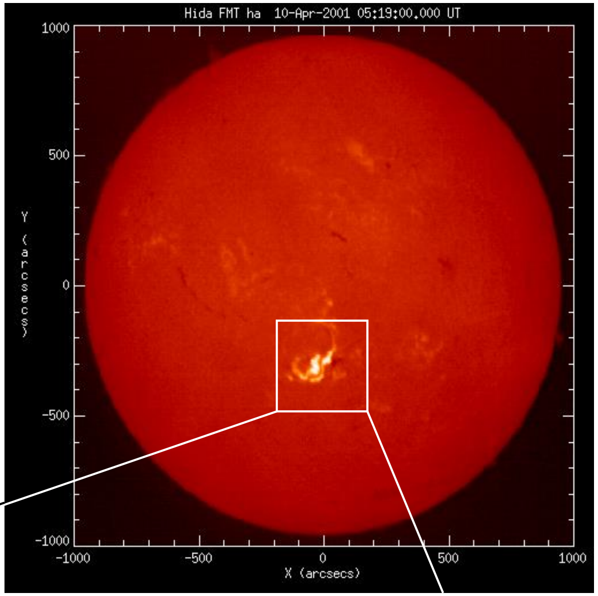
What is the impact of superflares on the Earth, if superflares would occur on the Sun ?

To answer these questions is the subject of my talk.

contents

Solar Flares

Solar flare



Hα

Discovered in 19c

Explosive energy release

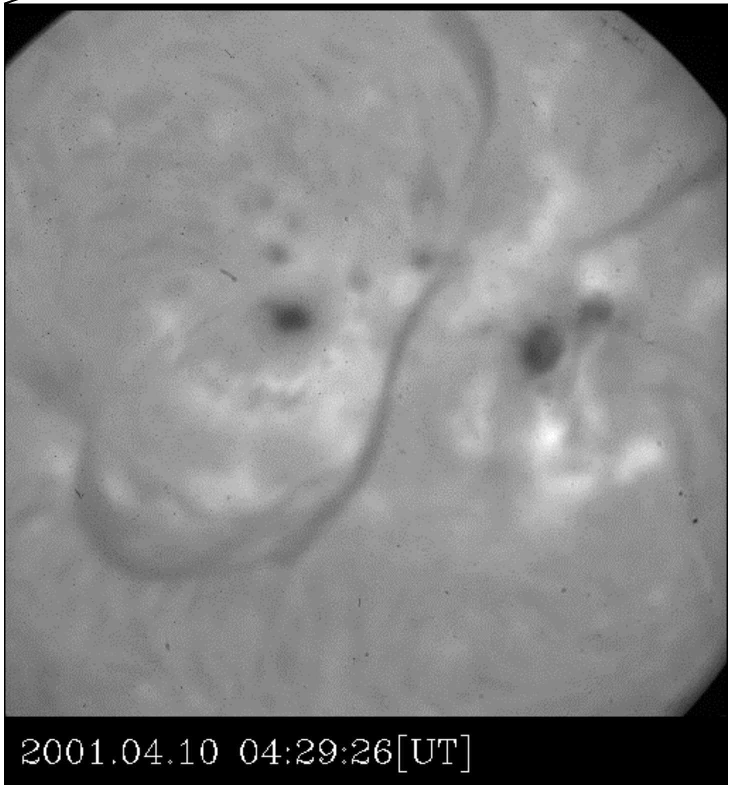
That occur near sunspot

magnetic energy is the source of energy

Size ~ 10^9 – 10^{10} cm

Time scale ~ 1min – 1hour

Total energy ~ 10^{29} - 10^{32}erg

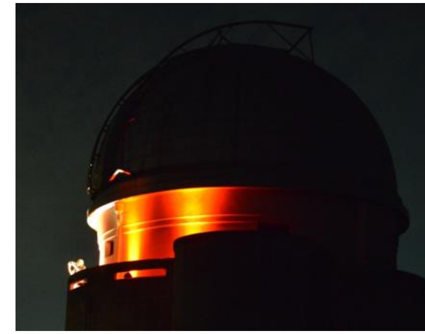


Mechanism has been puzzling since 19c until recently

Hida Obs/Kyoto U.

Special entertainment

Kojiki and Universe



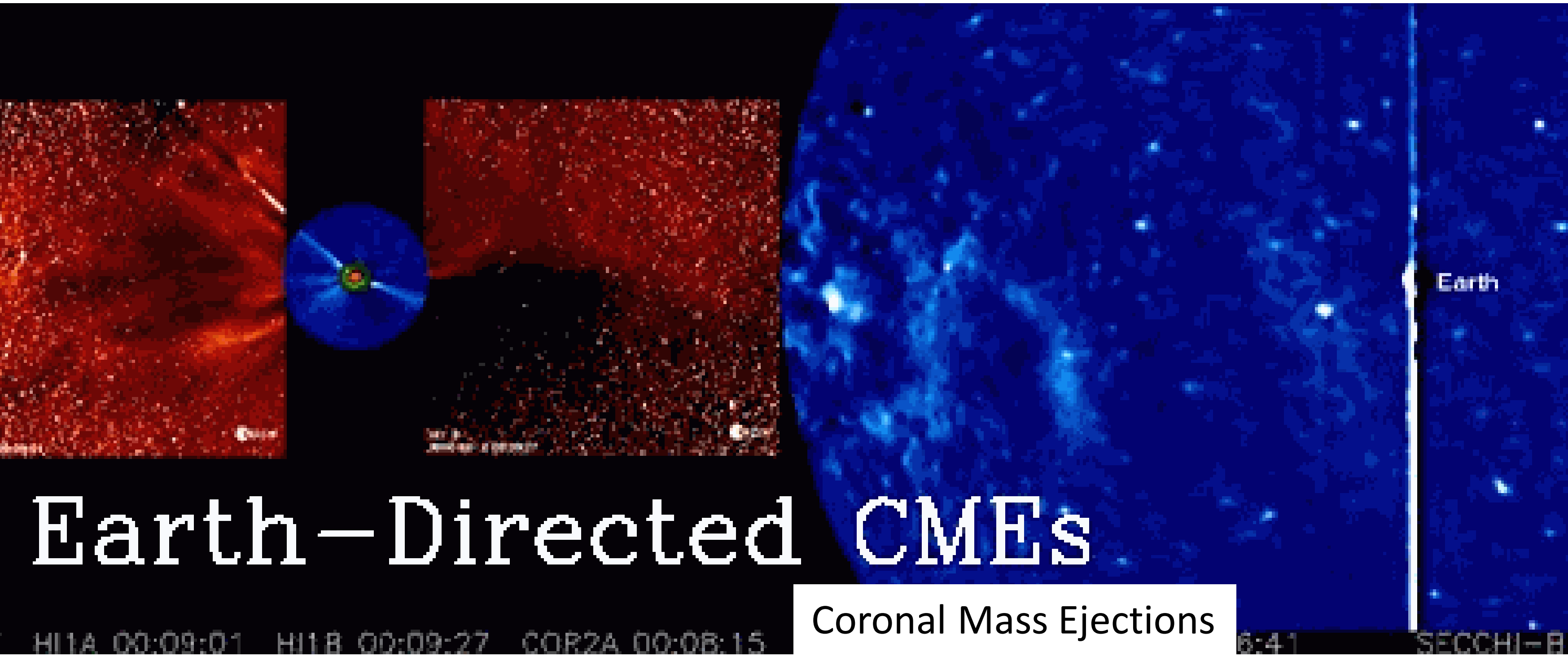
Shibata and Kitaro (musician, Grammy Award Winner)

Let's enjoy Kitaro-san's Music Kojiki (chap 4: Orochi = Monster) with beautiful movies of solar flares and eruptions

(7 min)

Blast Waves from the Sun to the Earth Observed with STEREO

Courtesy of M. Temmer

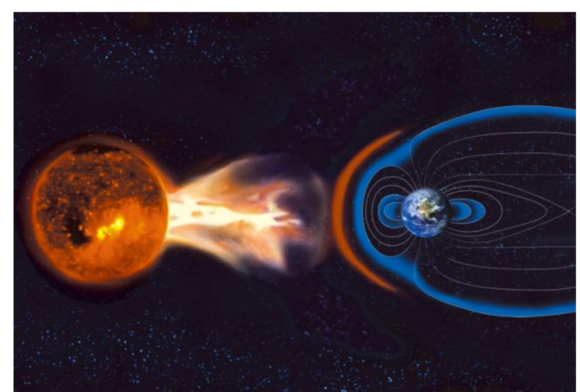


Coronal Mass Ejections

1AU=1.5x10^8 km

These phenomena lead to magnetic storm and various hazards on the Earth

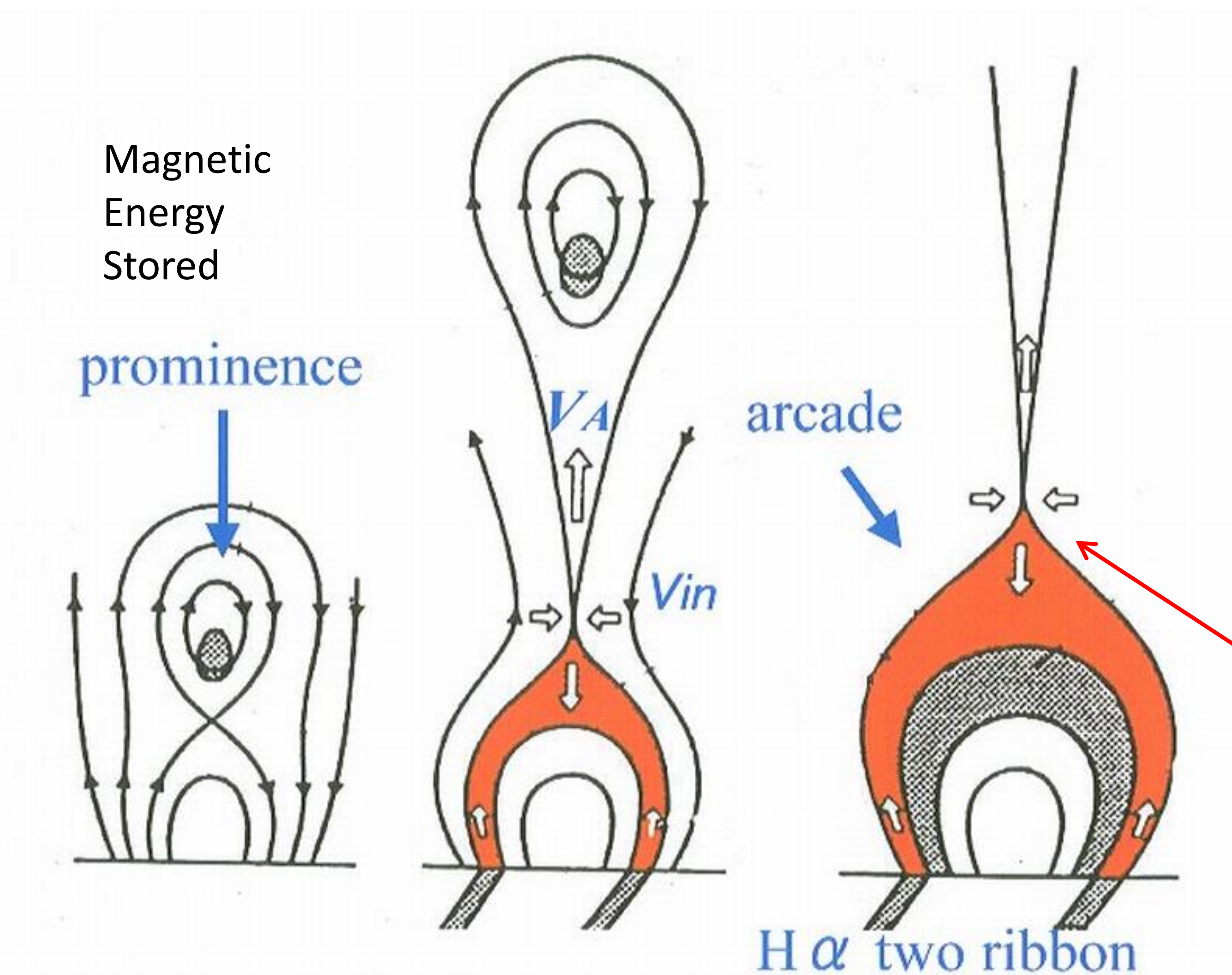
=> Space weather prediction is an urgent issue

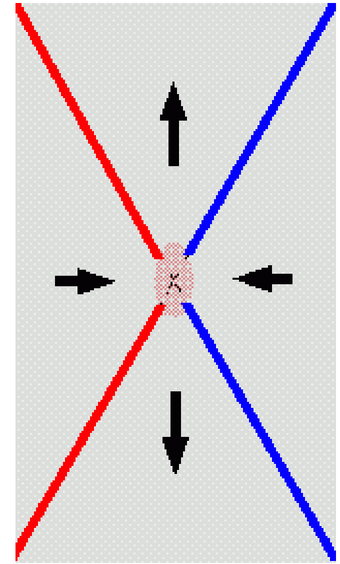


What is the Mechanism of Solar Flares ?

Standard Flare Model

(Carmichael 1964, Sturrock 1966, Hirayama 1974, Kopp and Pneuman 1976)



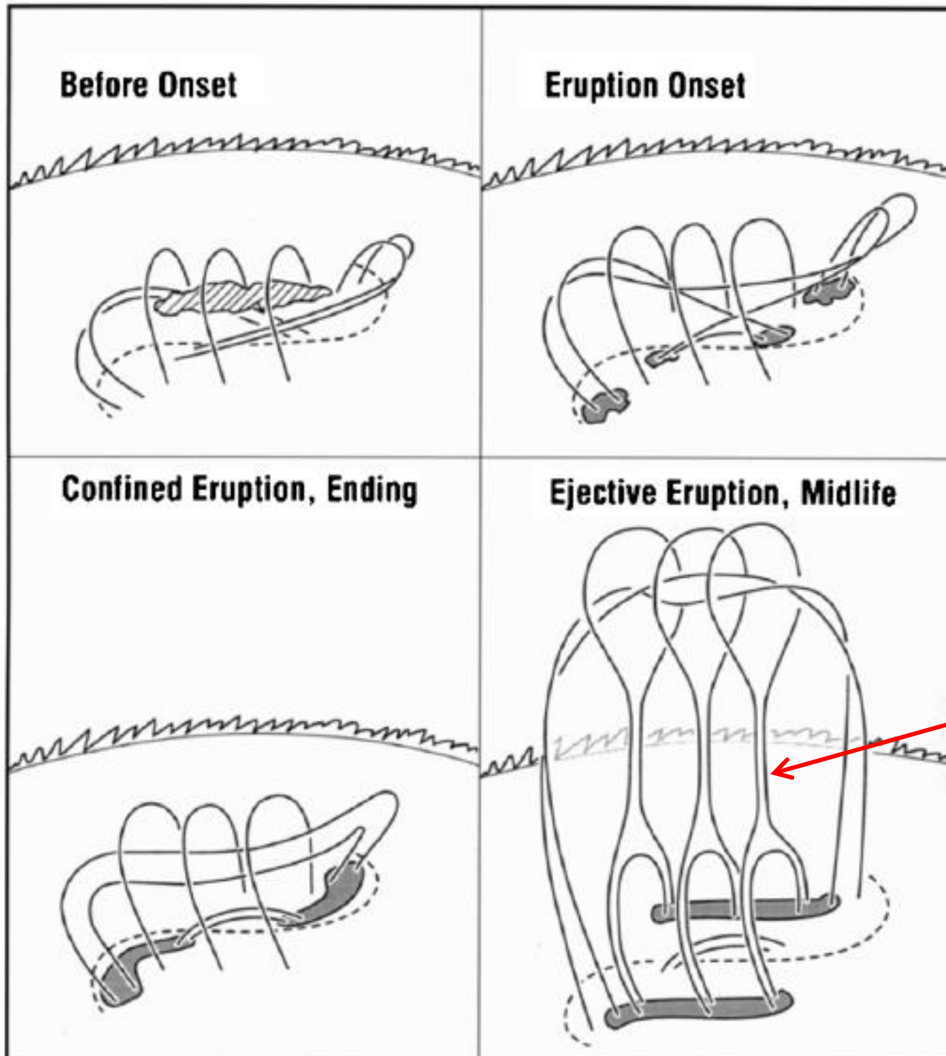


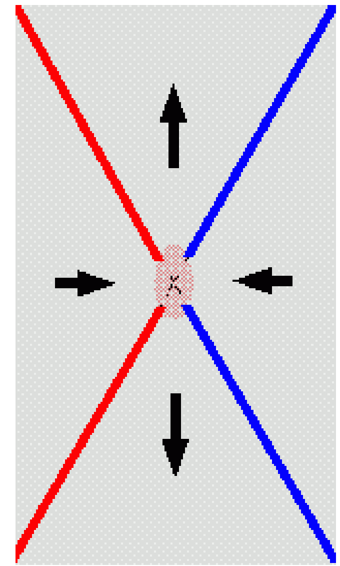
Courtesy of E. Priest

Standard Flare Model

(Carmichael 1964, Sturrock 1966, Hirayama 1974, Kopp and Pneuman 1976)

Magnetic
Energy
Stored





Courtesy of E. Priest

Magnetic
Reconnection

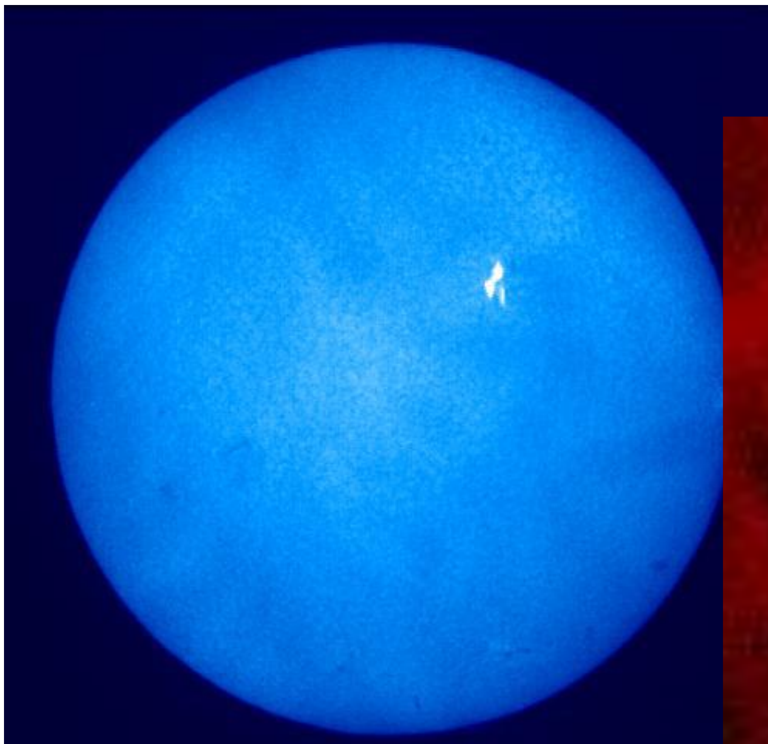
From Moore 2001

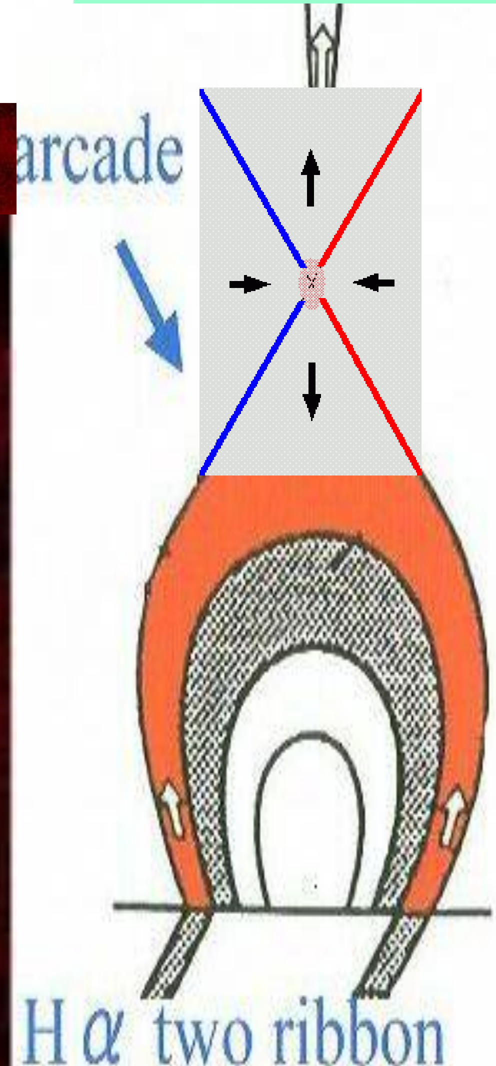
Simultaneous Halpha and X-ray view of a flare

Magnetic reconneciton

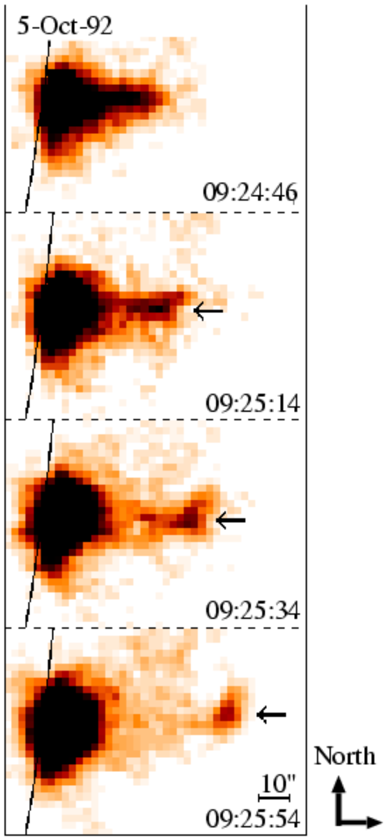
Hα

X-ray

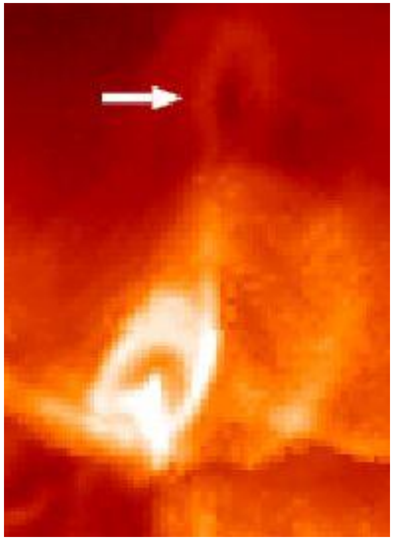




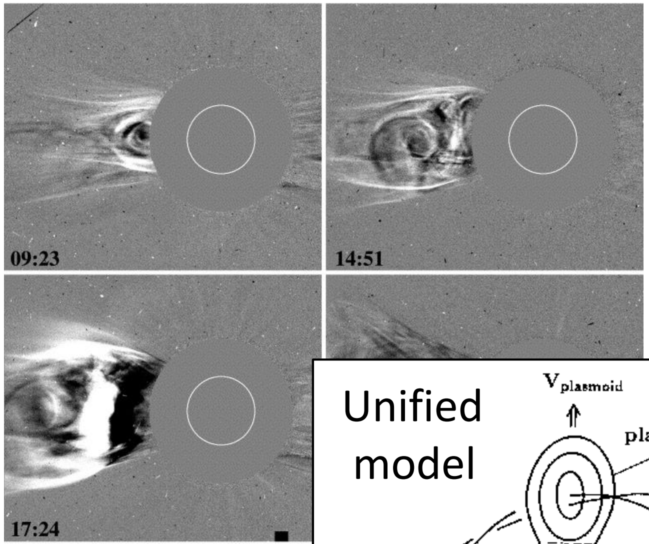
Plasmoid ejections are ubiquitous



impulsive flares
~ 10^9 cm
(Ohyama+S 1998)

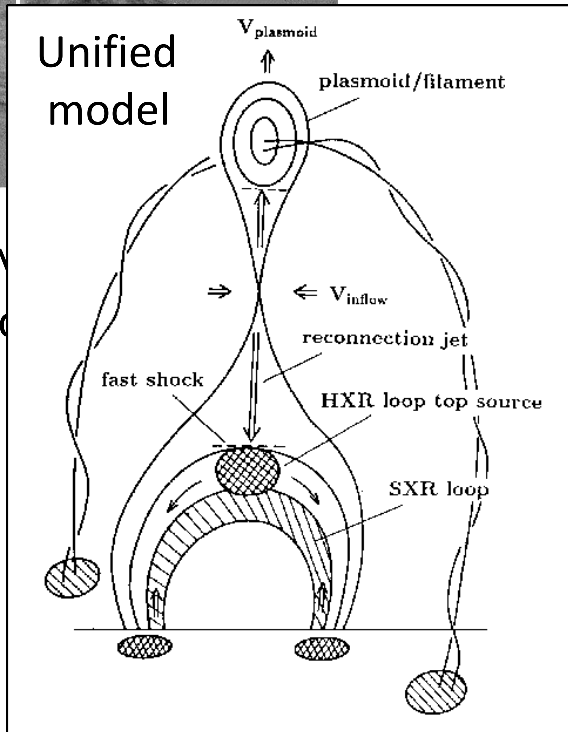


LDE(Long Duration Event) flares
~ 10^10 cm
(Tsuneta 1992, Hudson 1993)



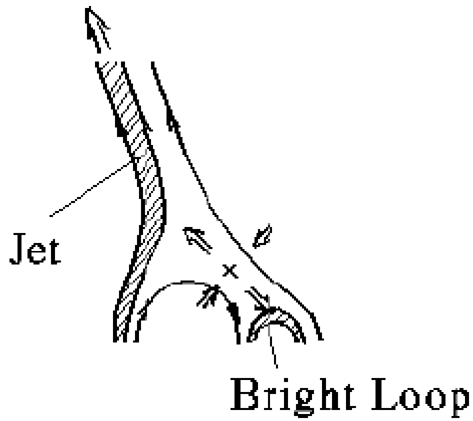
CMEs(Coronal M
from Giant arca
~ 10^11 cm
(Dere 1995)

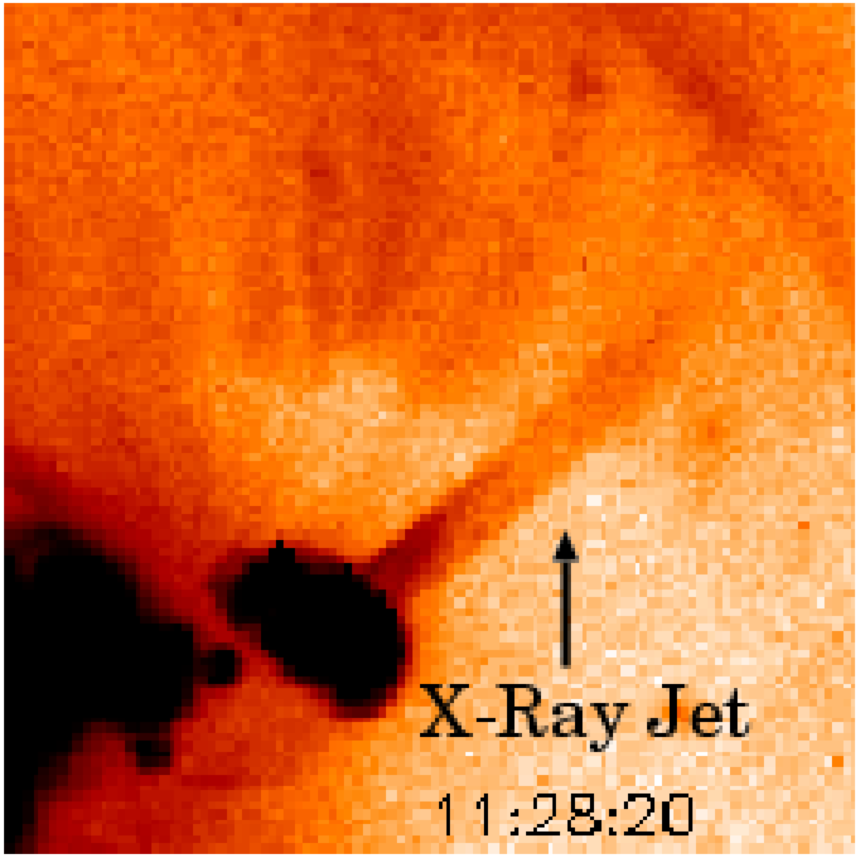
Plasmoid-Induced-Reconnection
(Shibata 1999)



Jets from very small flares (microflares)

- Yohkoh/SXT discovered X-ray jets from microflares
  (Shibata et al. 1992,
  Strong et al. 1992,
  Shimojo et al. 1996)





Summary of observations of "flares" in the solar atmosphere

$$t_A = L / V_A$$

$$V_A = \frac{B}{\sqrt{4\pi\rho}}$$

(Alfven speed)

"flares"	Size (L)	Lifetime (t)	Alfven time (t_A)	t/t_A	Mass ejection
Microflares	10^3 -10^4 km	100-1000sec	1-10 sec	~100	jet/surge
Impulsive flares	(1-3) x 10^4 km	10 min – 1 hr	10-30 sec	~60-100	X-ray plasmoid/ Spray
Long duration (LDE) flares	(3-10)x 10^4 km	1-10 hr	30-100 sec	~100-300	X-ray plasmoid/ prom. eruption
Giant arcades	10^5 -10^6 km	10 hr – 2 days	100-1000 sec	~100-300	CME/prom. eruption

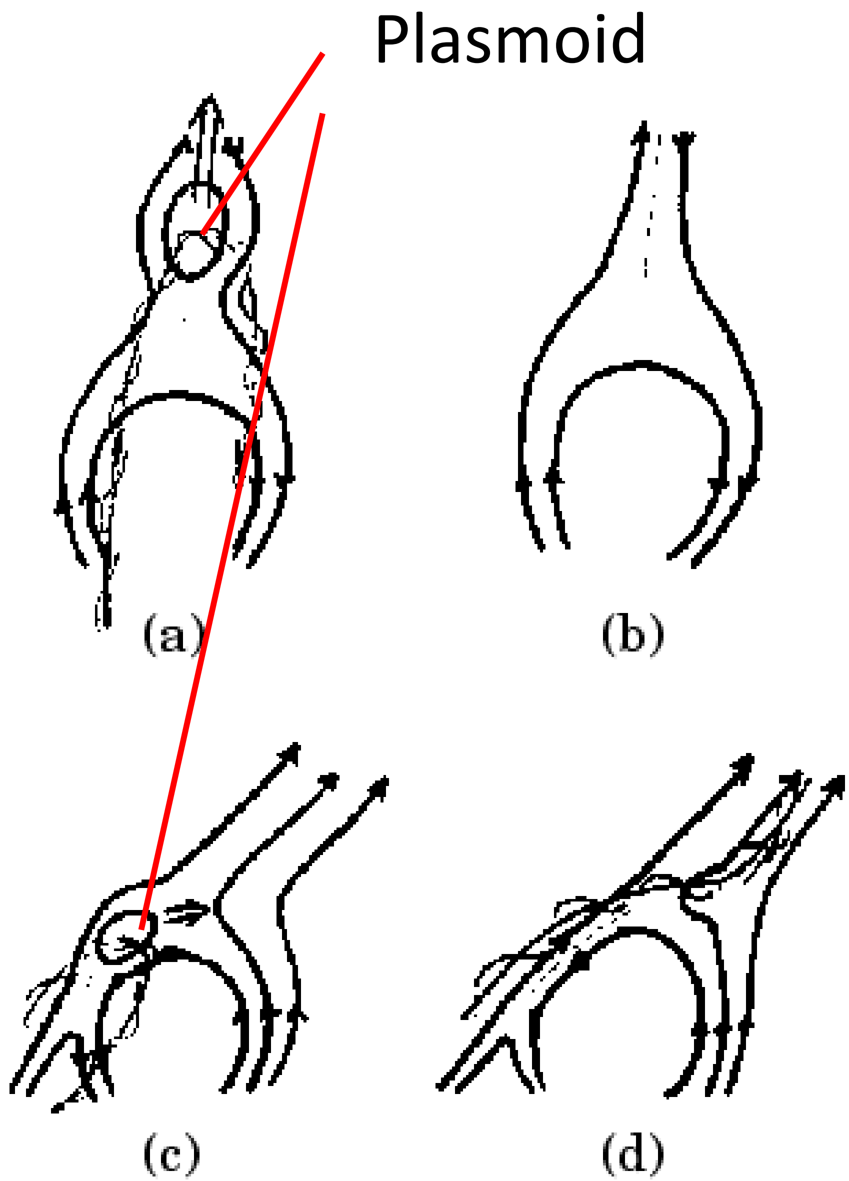
Unified model

(plasmoid-induced reconnection model)

(Shibata 1996, 1999,
Shibata and Tanuma 2001)

(a,b) : large scale flares,
Coronal mass ejections

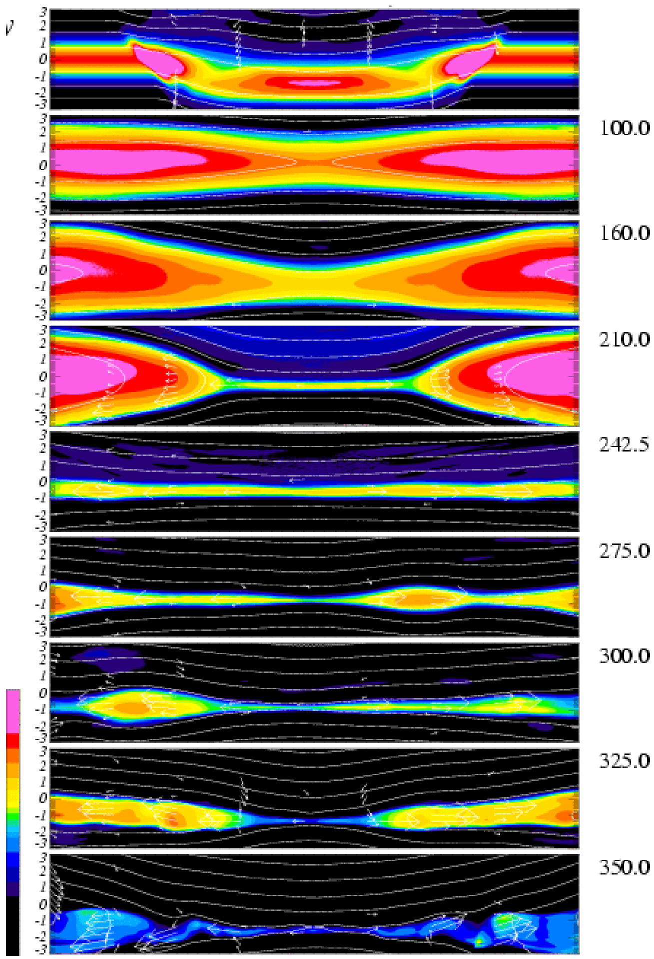
(c,d) : small scale flares,
microflares, jets

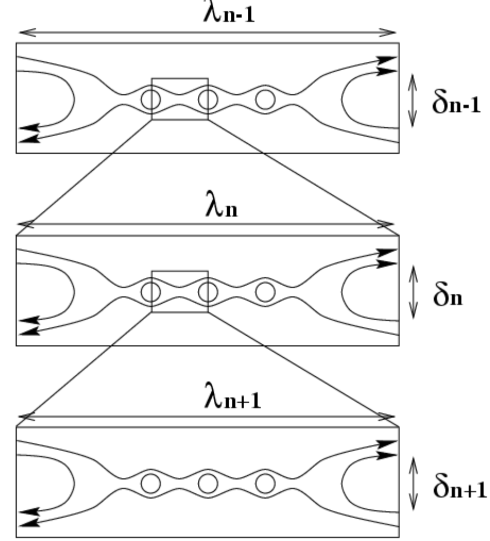


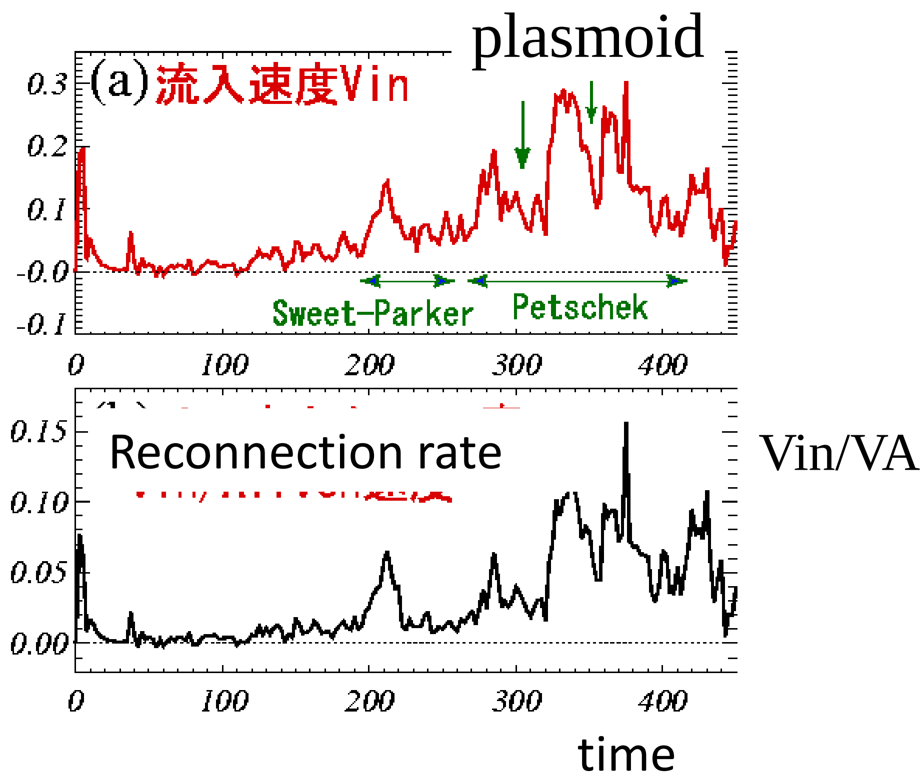
Energy release rate $= \frac{dE}{dt} \approx \frac{B^2}{4\pi} V_{in} L^2 \approx 10^{-2} \frac{B^2}{4\pi} V_A L^2$

MHD simulations show plasmoid-induced reconnection in a fractual current sheet

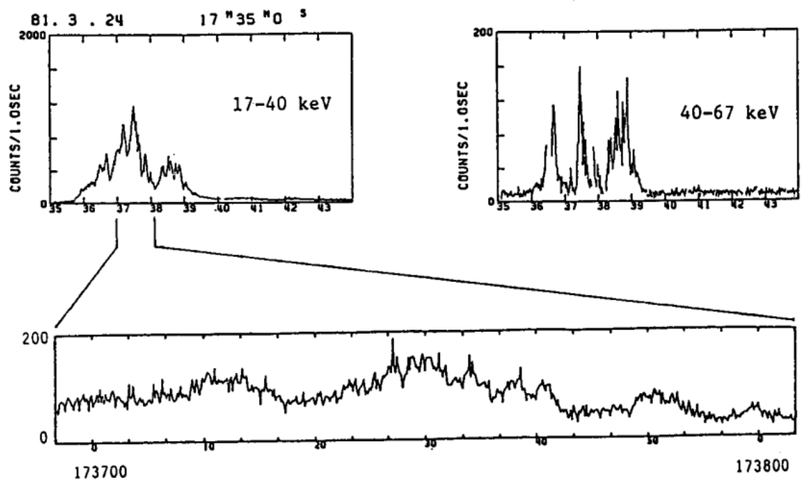
(Tanuma et al. 2001, Shibata and Tanuma 2001)



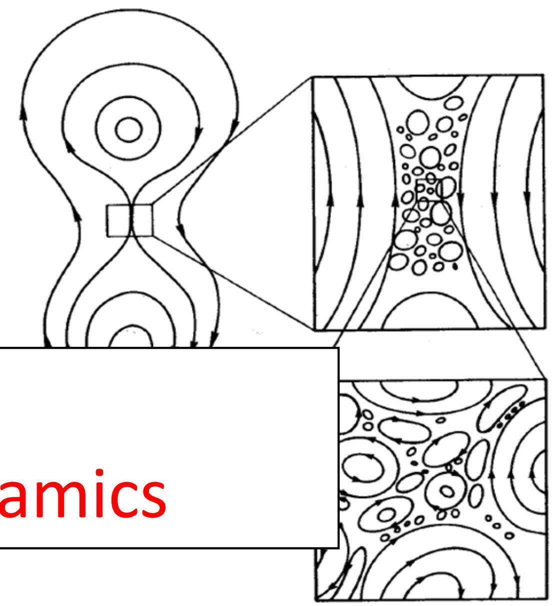




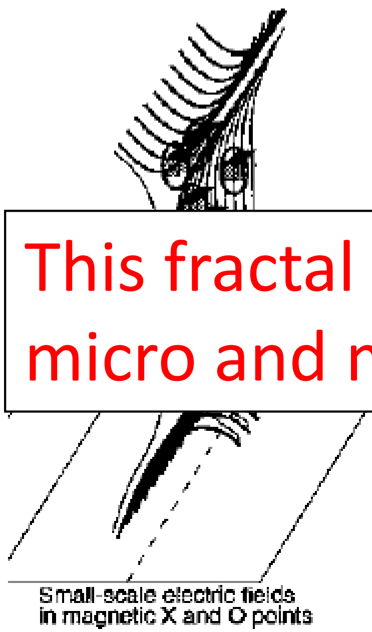
Observation of hard X-rays and microwave emissions show fractal-like time variability, which may be a result of fractal plasmoid ejections



(Tajima-Shibata 1997)



This fractal structure enable to connect micro and macro scale structures and dynamics



Aschwanden 2002

Fractal current sheet

Benz and Aschwanden 1989

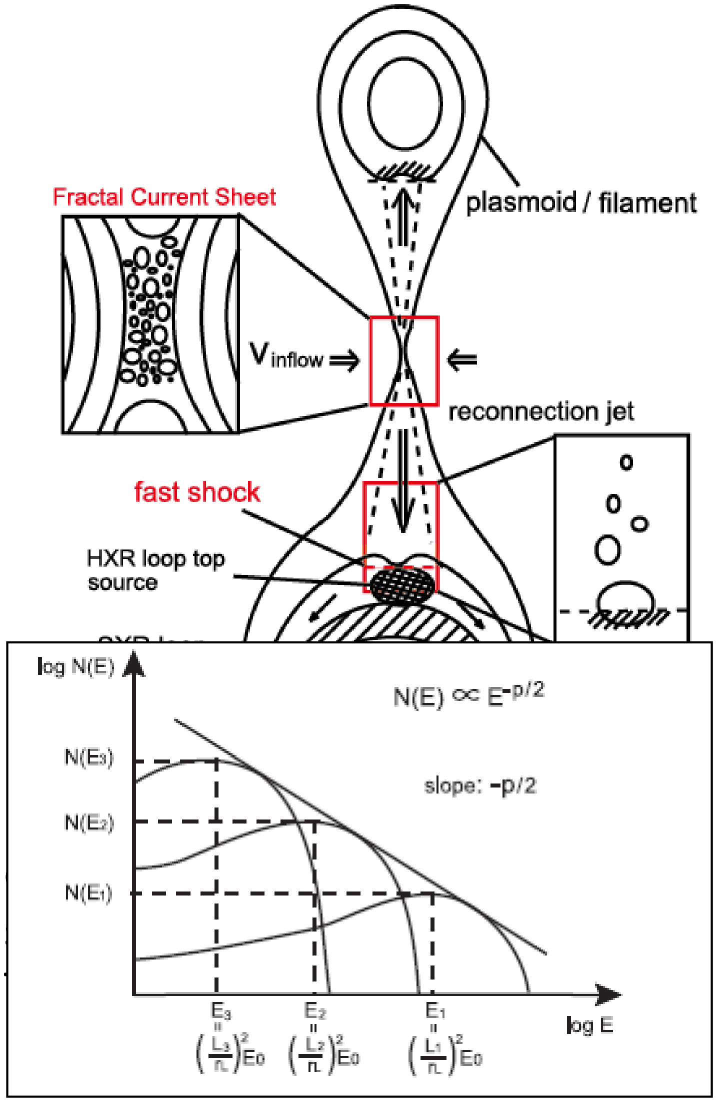
Lazarian and Vishniac 1998

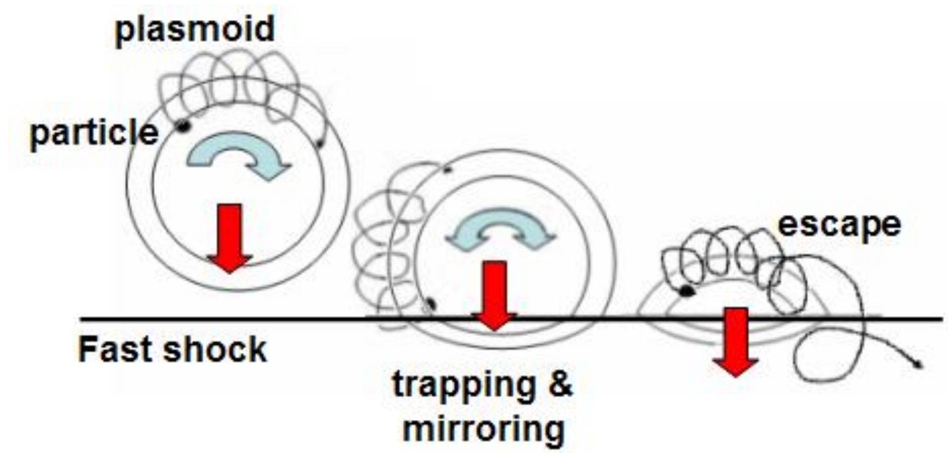
Zelenyi 1996, Karlicky 2004 , Barta, Buechner et al. 2010

Bhattacharjee et al. 2009, Loureiro et al. 2012

Fractal Reconnection & Particle Acceleration by plasmoids colliding with fast shocks

[Nishizuka & Shibata 2013, Phys. Rev. Let. . 110, 051101]

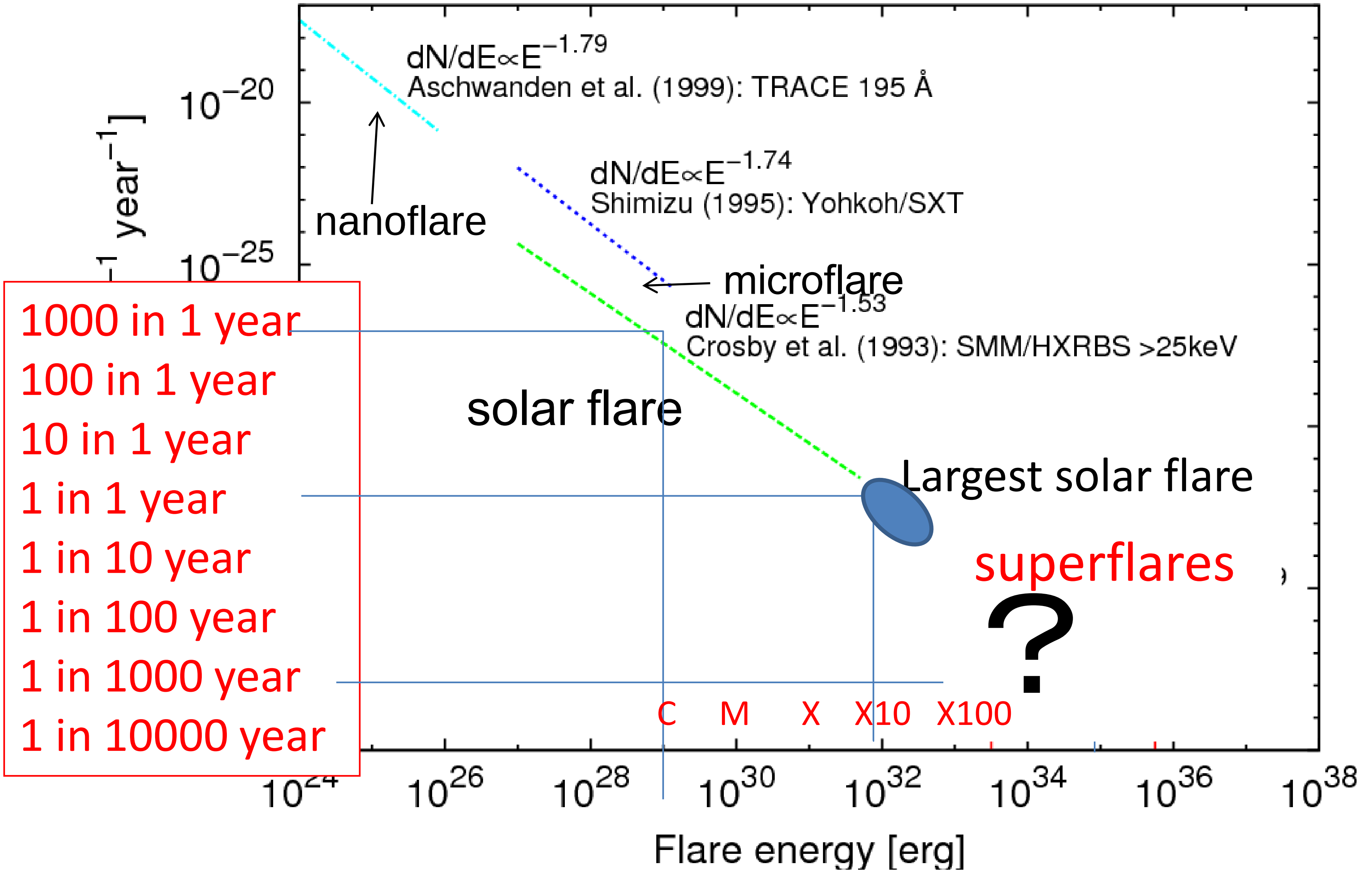




1) Particles are trapped in a plasmoid.
2) Multiple plasmoids collide with fast shock.
3) Particles are reflected due to magnetic mirror effect.
4) Reflection length becomes shorter and shorter.
5) Particles are accelerated by **Fermi process**, until reflection length becomes comparable to ion Larmor radius.

Superflares on Solar Type Stars

statistics of occurrence frequency of solar flares, microflares, nanoflares



How can we observe superflares on the Sun ?

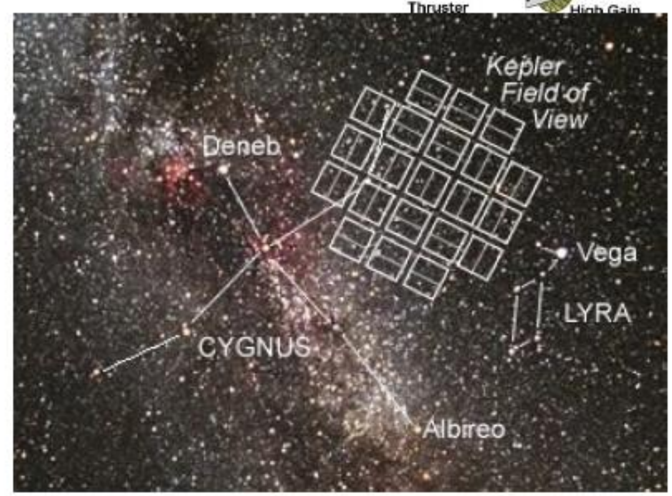
- If empirical statistics rule of solar flares is applied to much larger flares (superflares), then the frequency of superflares with energy 1000 times larger than the largest solar flares might occur once in 10000 years.
- However, the period of modern observations of the Sun with telescope is only 400 years.
- How can we observe the Sun for 10000 years ?

- If we observe 10000 solar type stars (similar to our Sun) for 1 year, we can get the data similar to the data obtained from 10000 years observtions of the Sun !

Prof Sekiguchi kindly told me that
the Kepler satellite is taking such data !

Kepler satellite (NASA)

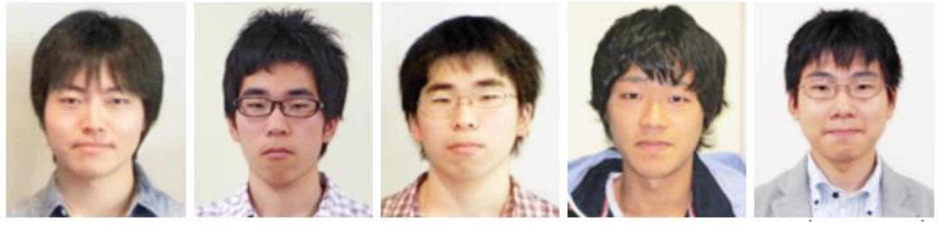
- Space mission to detect exoplanets by observing transit of exoplanets
- 0.95 m telescope
- Observing 160,000 stars continuously (from 2009 to 2013). Among them, 80000 are solar type stars.
- ~30 min time cadence (public data)



Superflares on Solar Type Stars : Our study (Maehara et al. 2012)

- Hence we searched for superflares on solar type stars using Kepler satellite data, which include data of 80000 solar type stars
- Since the data are so large, we asked 1st year undergraduate students to help analyzing these stars,

  because students have a lot of free time (2010 fall)



- Surprisingly, we (they) found 365 superflares on 148 solar type stars (G-type main sequence stars)

LETTER
Published in Nature (2012, May)
doi:10.10

Superflares on solar-type stars

Hiroyuki Maehara[1], Takuya Shibayama[1], Shota Notsu[1], Yuta Notsu[1], Takashi Nagao[1], Satoshi Kusaba[1], Satoshi Hond
Daisaku Nogami[1] & Kazunari Shibata[1]
Undergraduate students

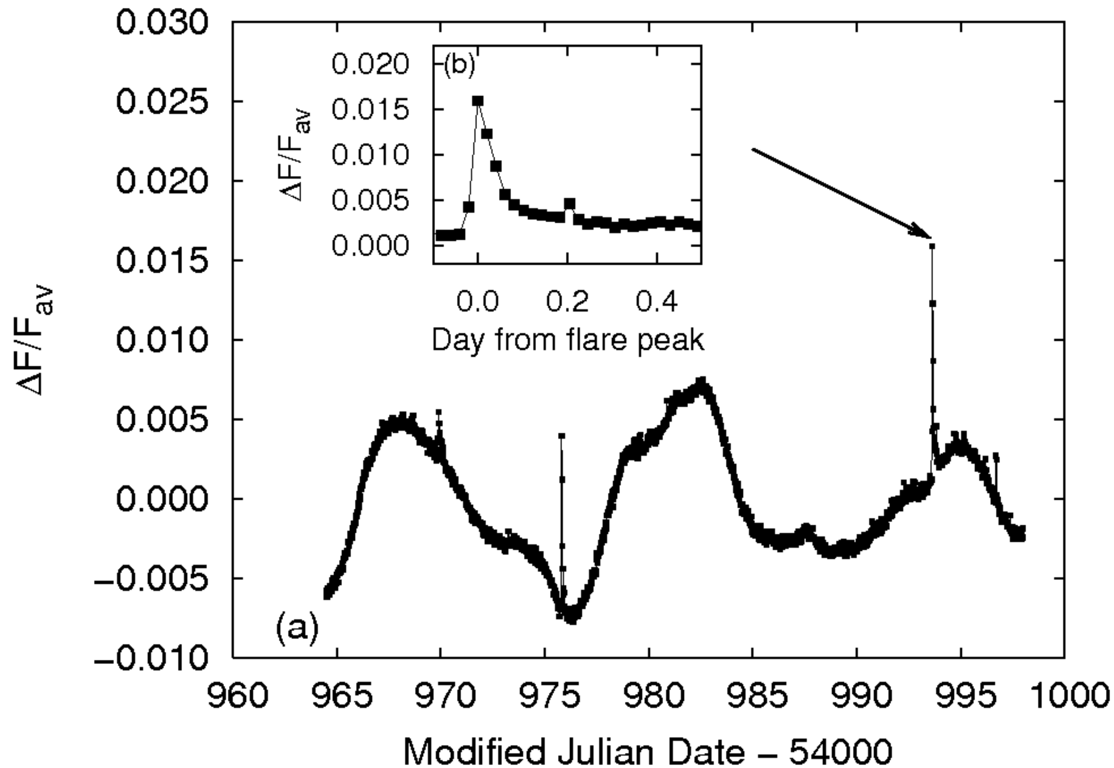
Solar flares are caused by the sudden release of magnetic energy stored near sunspots. They release 10^{29} to 10^{32} ergs of energy on a timescale of hours[1]. Similar flares have been observed on many stars, with larger 'superflares' seen on a variety of stars[2,3], some of which are rapidly rotating[4,5] and some of which are of ordinary solar type[3,6]. The small number of superflares observed on solar-type stars has hitherto precluded a detailed study of them. Here we report observations of 365 superflares, including some from slowly rotating solar-type stars, from about 83,000 stars observed over 120 days. Quasi-periodic brightness modulations observed in the solar-type stars suggest that they have much larger starspots than does the Sun. The maximum energy of the flare is not correlated with the stellar rotation period, but the data suggest that superflares occur more frequently on rapidly rotating stars. It has been proposed that hot Jupiters may be important in the generation of superflares on solar-type stars[7], but none have been discovered around the stars that we have studied, indicating that hot Jupiters associated with superflares are rare.

We searched for stellar flares on solar-type stars
sequence stars) using data collected by NASA's Kepler[8]
the period from April 2009 to December 2009 (a brief s
flare search method is described in the legend of Fig. 1 a
is provided in Supplementary Information). We use
temperature (T_{eff}) and the surface gravity ($\log(g)$) ava
Kepler Input Catalog[9] to select solar-type stars. The se
are as follows: 5,100 K $\leq T_{eff} <$ 6,000 K, $\log(g) \geq 4.0$. Th
of solar-type stars are 9,751 for quarter 0 of the Keple
length of observation period is about 10 d), 75,728 for q
83,094 for quarter 2 (90 d) and 3,691 for quarter 3 (90

We found 365 superflares (flares with energy >10
solar-type stars (light curves of each flare are s
Supplementary Fig. 8 and properties of each flare sta
Supplementary Table 1). The durations of the detec
are typically a few hours, and their amplitudes are ger
0.1–1% of the stellar luminosity. The bolometric lumin
bolometric energy of each flare were estimated from th

typical superflare observed by Kepler

Brightness of a star and a flare



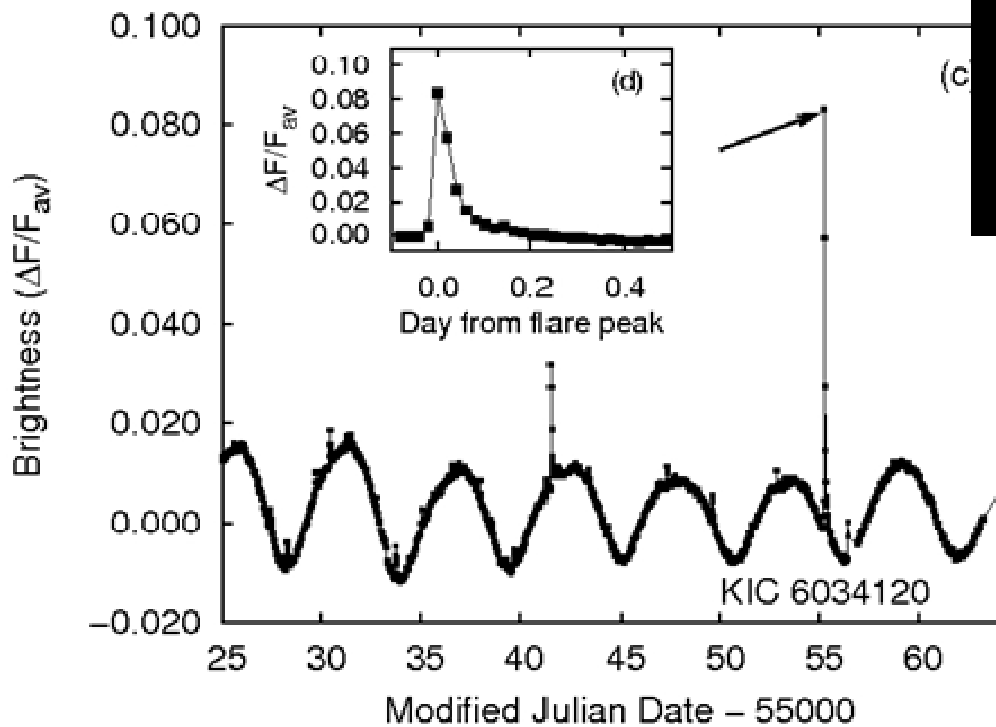
Total energy ~ 10^35 erg

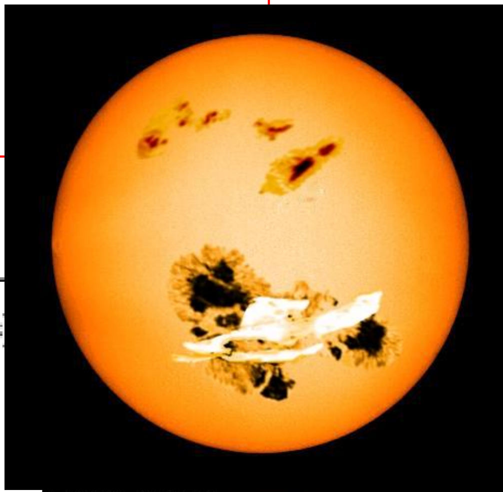
Time (day)

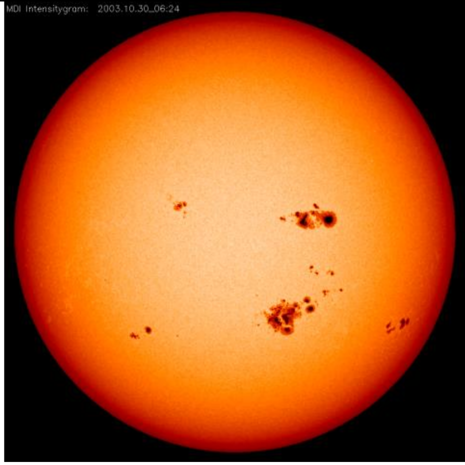
Maehara et al. (2011)

What is the cause of stellar brightness variation ?

Brightness
of a star
and a flare

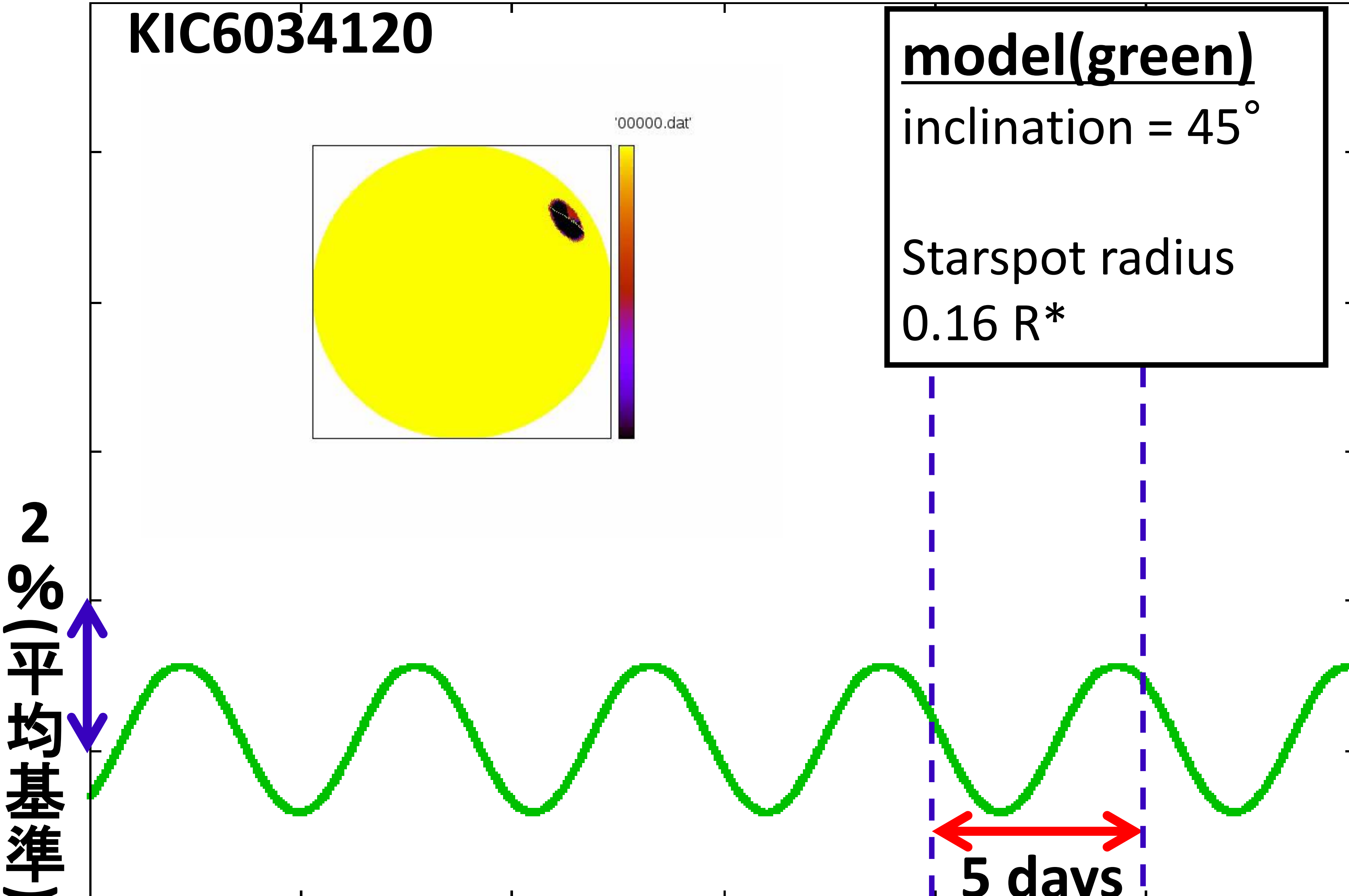






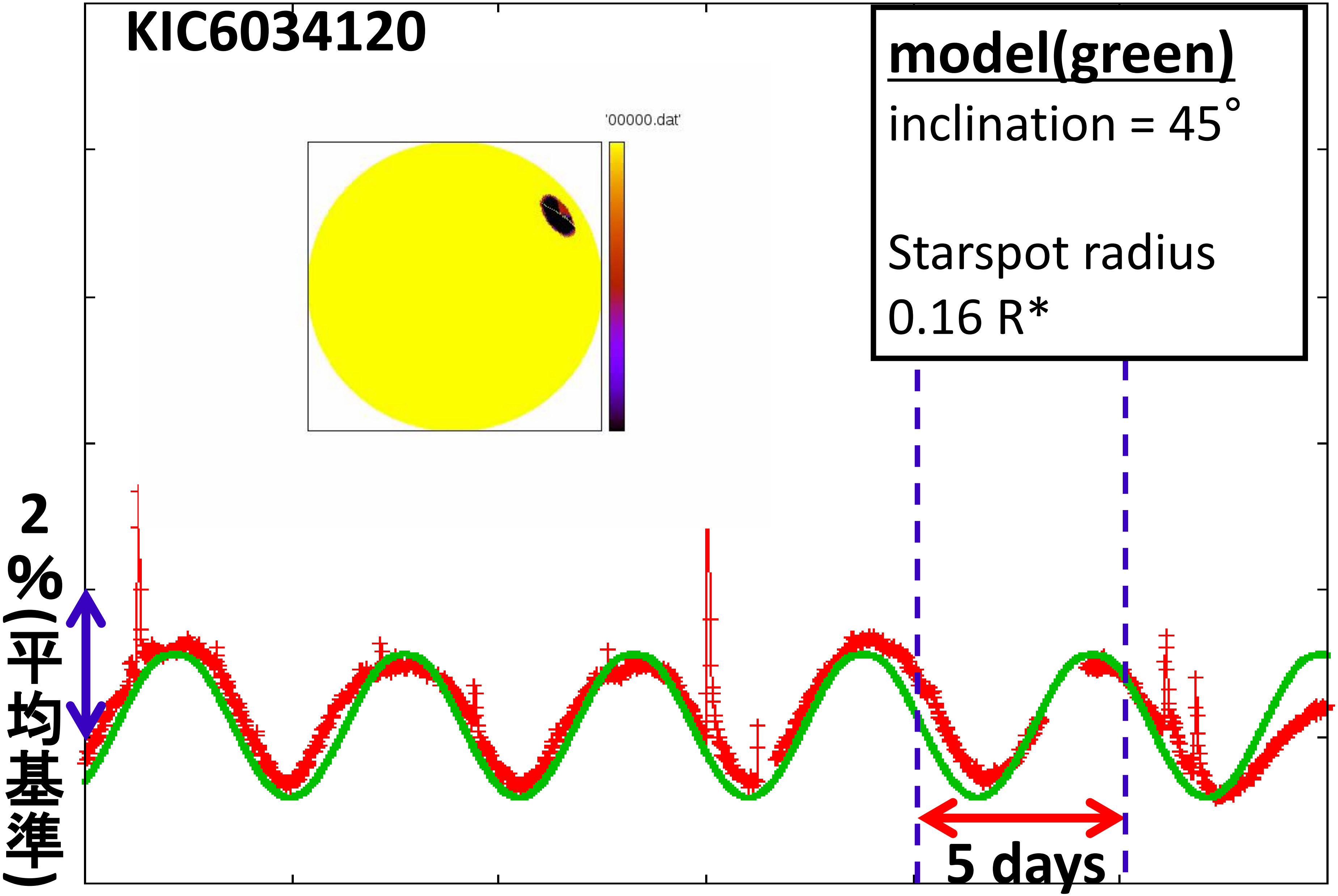
It is likely due to rotation of a star with a big star spot

Model calculation of stellar brightness variation



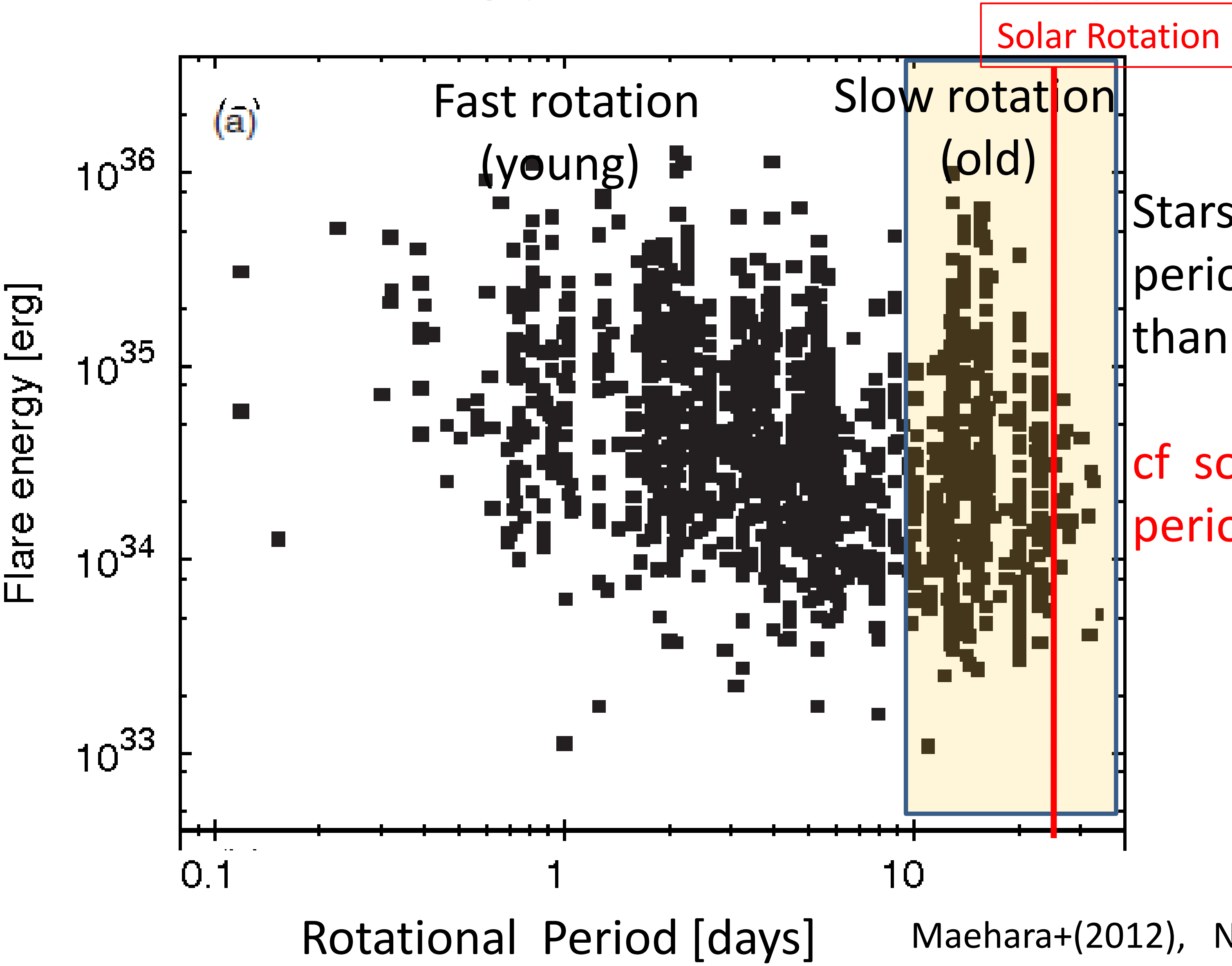
Notsu et al.

Model calculation of stellar brightness variation



Notsu et al.

Flare energy vs rotational period



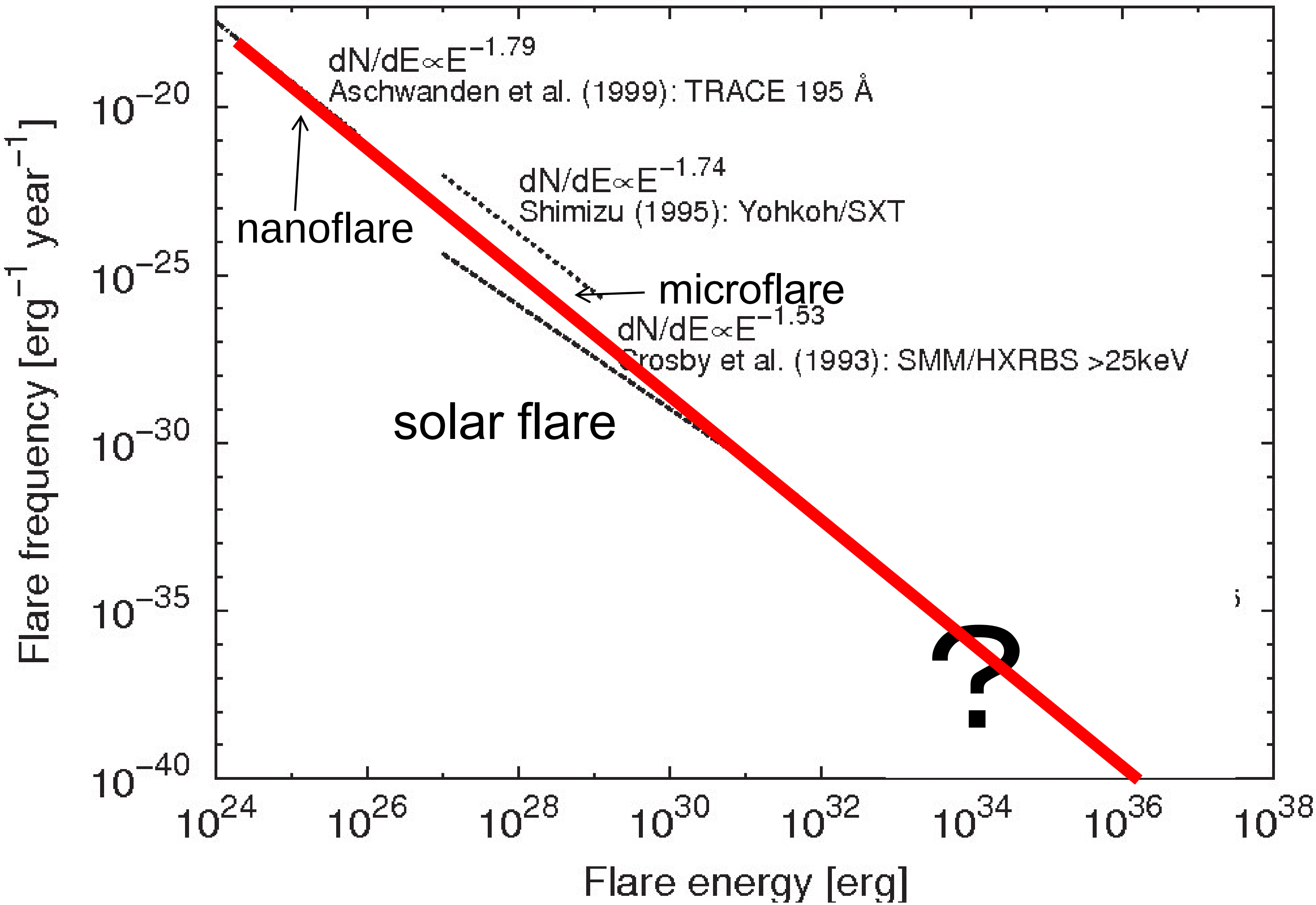
Stars with period longer than 10 days

cf solar rot period ~ 25days

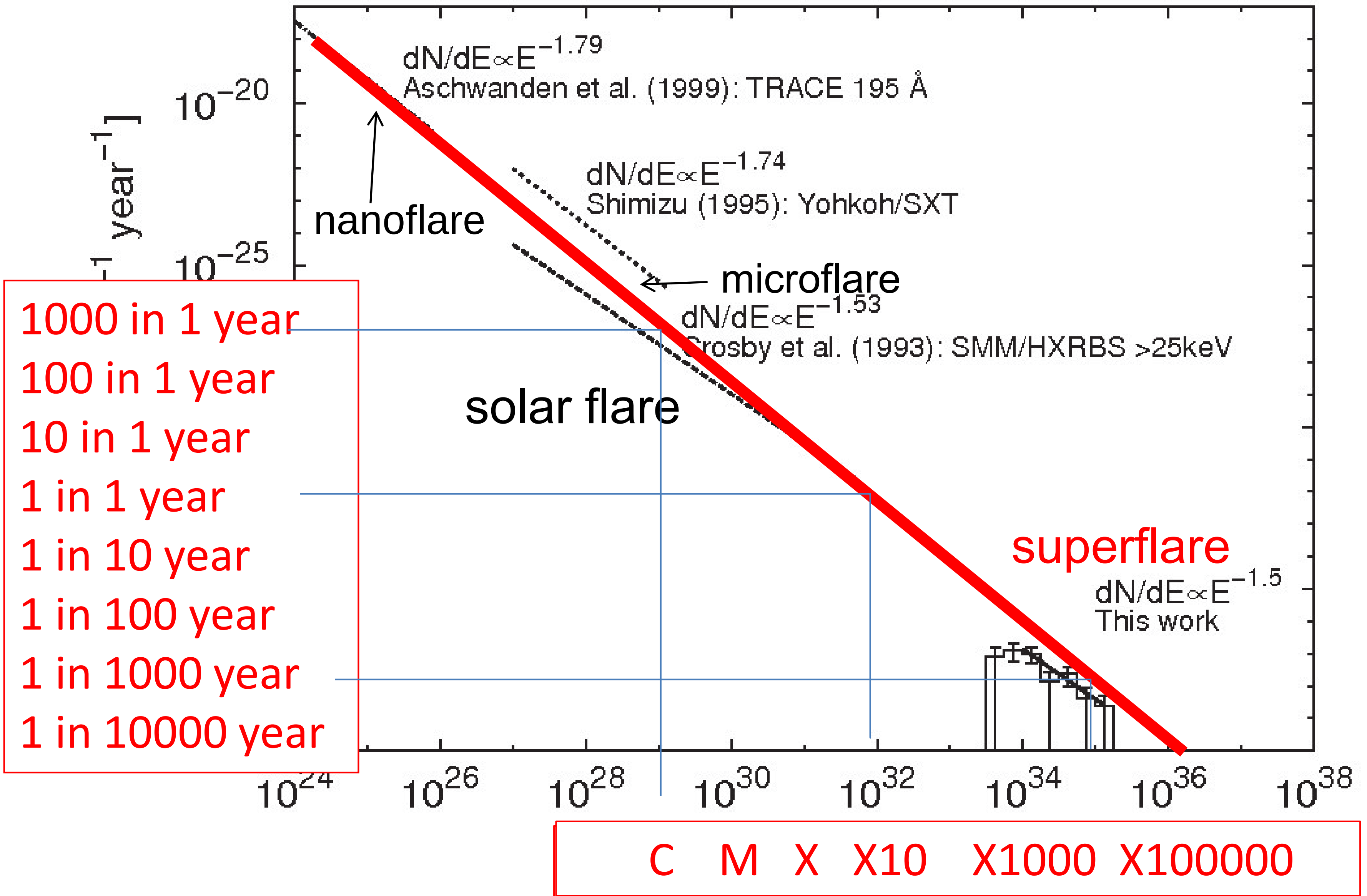
Maehara+(2012), Notsu+ (2013)

Can Superflares Occur on Our Sun ?

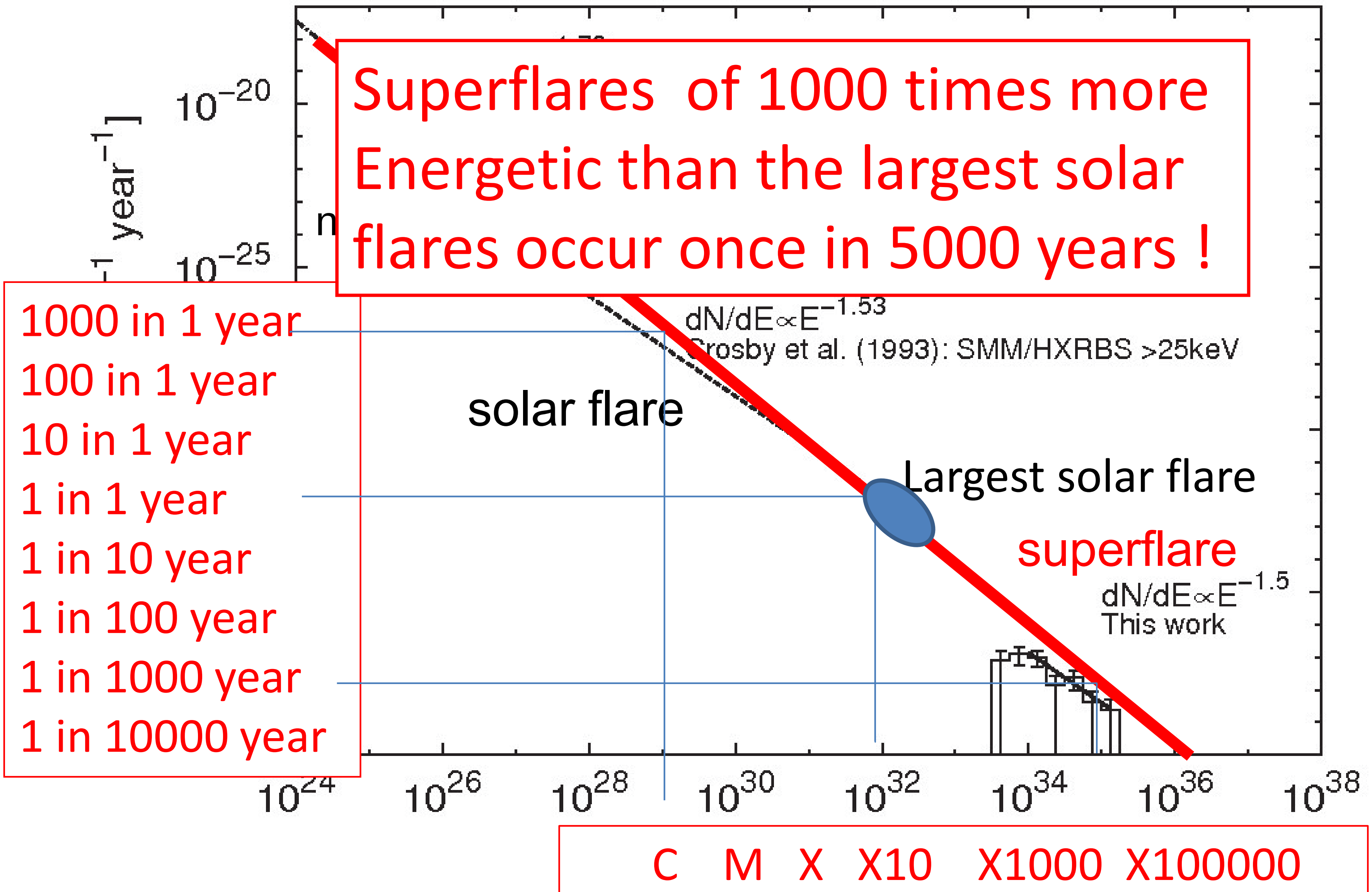
Comparison of statistics between solar flares/microflares and superflares



Comparison of statistics between solar flares/microflares and superflares



Comparison of statistics between solar flares/microflares and superflares



Evidence of a superflare ?

LETTER

doi:10.1038/nature11123

A signature of cosmic-ray increase in AD 774–775 from tree rings in Japan

Fusa Miyake[1], Kentaro Nagaya[1], Kimiaki Masuda[1] & Toshio Naka

Increases in ^{14}C concentrations in tree rings could be attributed to cosmic-ray events[1–7], as have increases in ^{10}Be and nitrate in ice cores[8,9]. The record of the past 3,000 years in the IntCal09 data set[10], which is a time series at 5-year intervals describing the ^{14}C content of trees over a period of approximately 10,000 years, shows three periods during which ^{14}C increased at a rate greater than 3‰ over 10 years. Two of these periods have been measured at high time resolution, but neither showed increases on a timescale of about 1 year (refs 11 and 12). Here we report ^{14}C measurements in annual rings of Japanese cedar trees from AD 750 to AD 820 (the

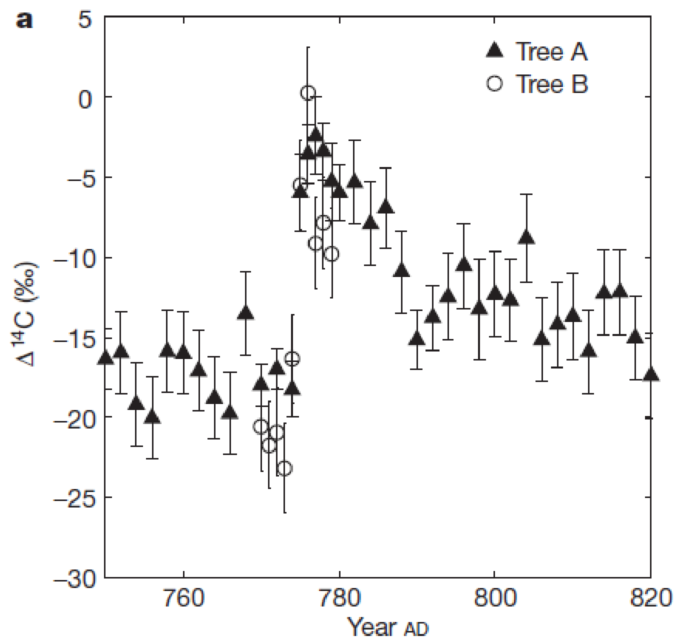


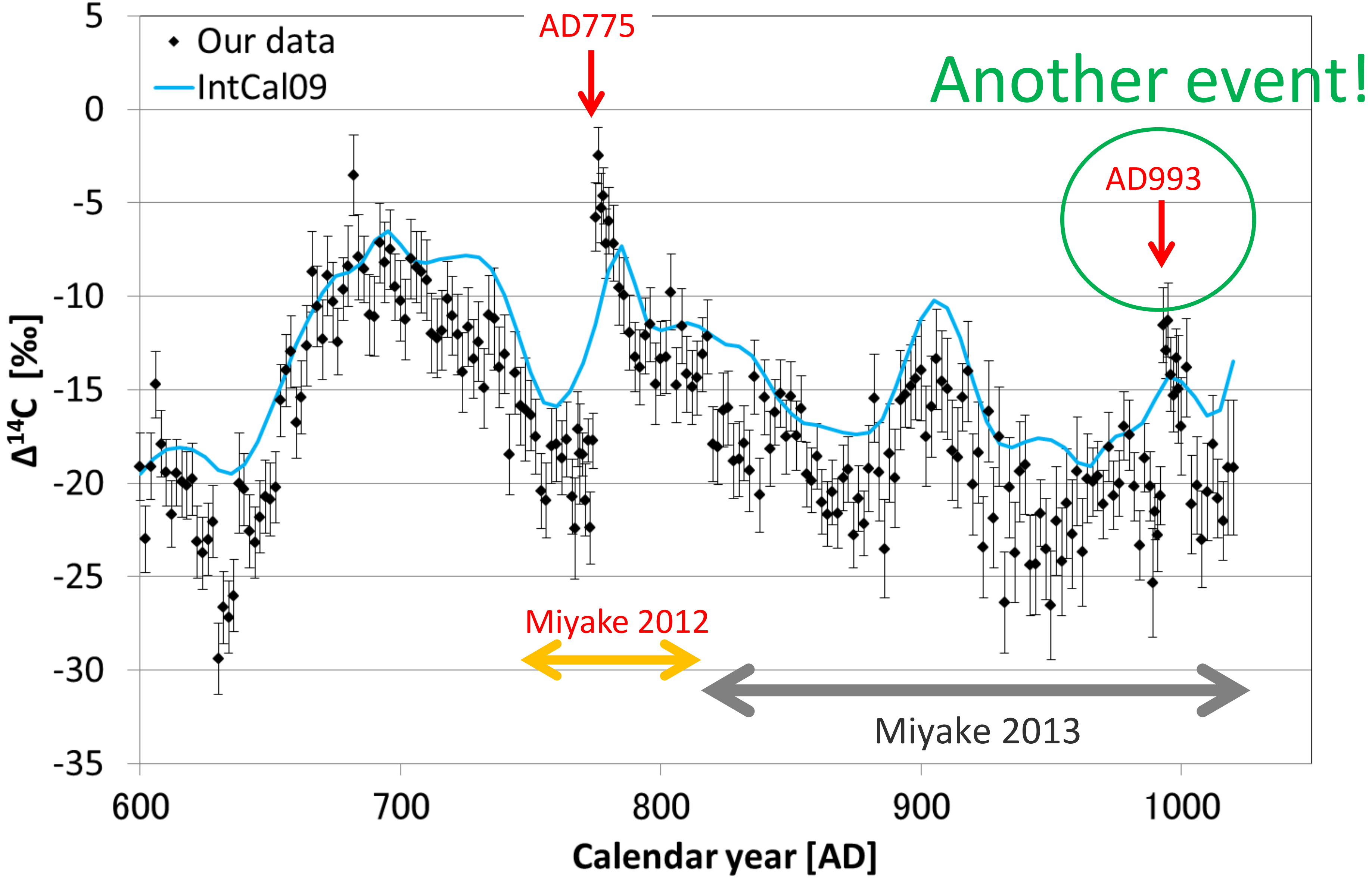
Figure 1 | Measured radiocarbon content and comparison with IntCal98. The concentration of ^{14}C is expressed as $\Delta^{14}C$, which is the deviation (in ‰) of the $^{14}C/^{12}C$ ratio of a sample with respect to modern carbon (standard sample), after correcting for the age and isotopic fractionation[30]. a, $\Delta^{14}C$ data for tree A (filled triangles with error bars) and tree B (open circles with error bars) for the period AD 750–820 with 1- or 2-year resolution. The typical precision of a single

Corresponding to 10^34 erg superflare
If this is due to a solar flare

(Miyake et al. Nature ,
2012, June, 486, 240)

Another evidence ?

From Miyake et al. (2013)
Nature Communications 2783

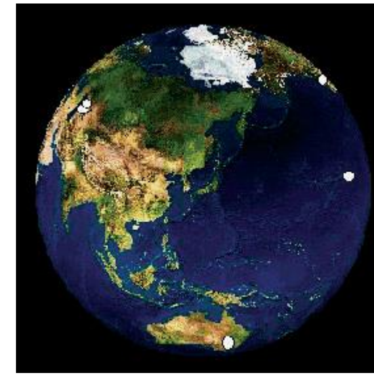


If superflares with energy 1000 times larger than the largest solar flares occur on our Sun, what would happen on our Earth and civilization ?

- All artificial satellites would be damaged ?
- All astronauts and some of airline passengers would be exposed to fatal radiation ?
- Ozone layer depletion would occur ?
- Radio communication trouble would occur all over the world ?
- Global blackout would occur on all over the Earth !?
- All nuclear power stations would lose electricity and hence in a state of meltdown ?

Spectroscopic Observations of Solar type stars causing superflares will be extremely important

Okayama 3.8m New Technology Telescope of Kyoto Univ (under construction)



New Technology

1. Making Mirrors with Grinding
2. Segmented mirror
3. Ultra Light mountin

Budget for operation
Is still lacking.
Please support us !

Will be completed ~ 2017

High speed photometric and spectroscopic observation of

Transient objects

- Gamma ray bursts
- Exoplanets
- Stellar flares (superflares)

courtesy of Prof. Nagata (Department of Astronomy , Kyoto University)

Summary

- Recent observations show unified view of solar flares, mass ejections, jets, and nanoflares (Shibata and Magara 2011).
- Plasmoid-induced-reconnection and fractal reconnection (Shibata and Tanuma 2001) seems to play important role not only for energy release but also for triggering.
- Kepler data revealed superflares of 10^34-10^35 erg occur on Sun-like stars with frequency of once in 800 - 5000 years (Maehara et al. 2012). Hence there is a possibility that superflares of 10^34 – 10^35 erg might occur on our present Sun with similar frequency (Shibata et al. 2013)
 => dangerous for our civilization !

Thank you for your attention