MR2012 2012 May 24 (15+5 min)

Superflares on Solar Type Stars

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Yamada-san

- Yamada-san is not only a leader of reconnection experiment, but also an educator and an organizer, connecting different fields related to reconnection, such as plasma physics, space physics, solar physics, and astrophysics via magnetic reconnection.

How Yamada-san was a good teacher ?

2004 Dec 4

REVIEWS OF MODERN PHYSICS, VOLUME 82, JANUARY–MARCH 2010

Magnetic reconnection

Masaaki Yamada, Russell Kulsrud, and Hantao Ji

Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas, Princeton Plasma Physics Laboratory, Princeton University, Princeton, New Jersey 08543, USA

(Published 5 March 2010)

The fundamental physics of magnetic reconnection in laboratory and space plasmas is reviewed by discussing results from theory, numerical simulations, observations from space satellites, and recent results from laboratory plasma experiments. After a brief review of the well-known early work, representative recent experimental and theoretical works are discussed and the essence of significant modern findings are interpreted. In the area of local reconnection physics, many findings have been made with regard to two-fluid physics and are related to the cause of fast reconnection. Profiles of the neutral sheet, Hall currents, and the effects of guide field, collisions, and microturbulence are discussed to understand the fundamental processes in a local reconnection layer in both space and laboratory plasmas. While the understanding of the global reconnection dynamics is less developed, notable findings have been made on this issue through detailed documentation of magnetic self-organization phenomena in fusion plasmas. Application of magnetic reconnection physics to astrophysical plasmas is also discussed.

DOI: 10.1103/RevModPhys.82.603 PACS number(s): 52.35.Vd, 94.30.cp, 96.60.Iv

Magnetic reconnection

- Historically, the concept “magnetic reconnection” has been proposed to explain solar flares (Giovanelli 1946, Holye 1949, Sweet 1958, Parker 1957, Petschek 1964).
- However, the reconnection model of solar flares has been questioned by many solar physicists until Yohkoh was launched (1991).
- These years (1991-1992) were the time when we met Yamada-san. We were encouraged by Yamada-san who supported the reconnection model of solar flares from experimental point of view.

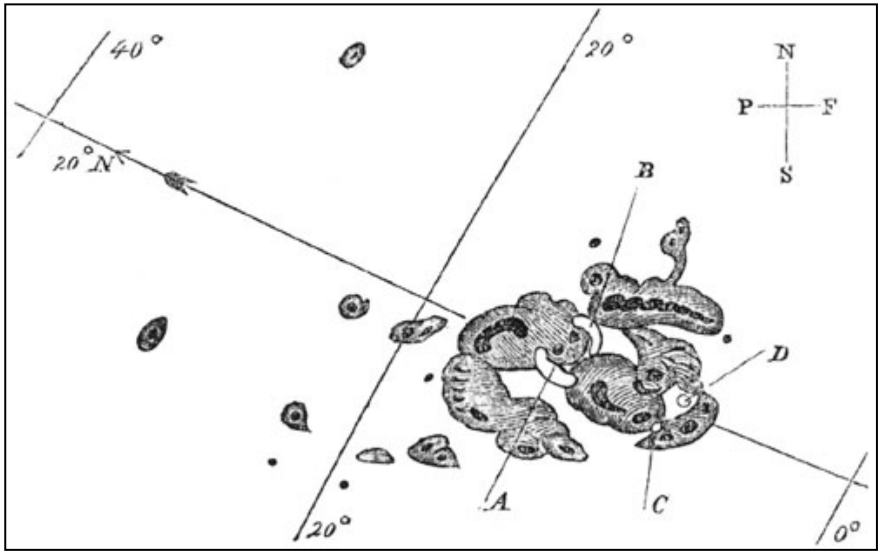
This talk

- Today I will talk about very big flares, superflares, since I believe superflares on solar type stars are the largest explosions caused by magnetic reconnection in our universe (with various indirect evidence of reconnection) , and yet that are most influential on our society and life.

Carrington flare

(1859, Sep 1, am 11:18)

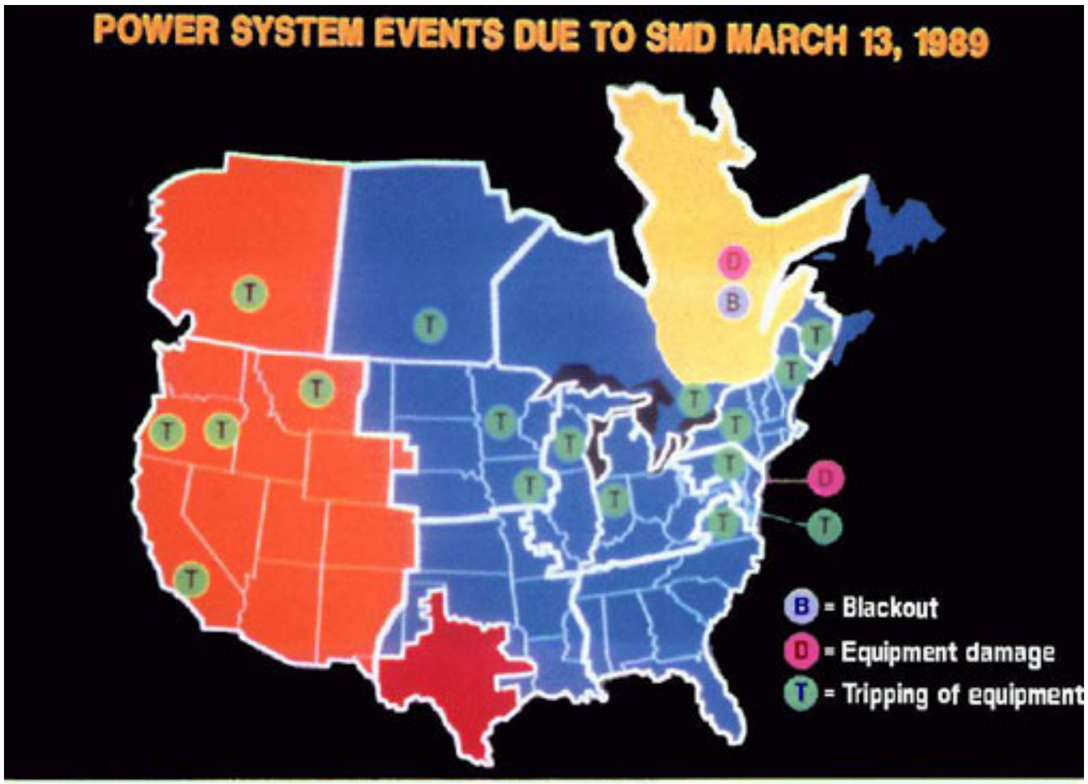
- Richard Carrington (England) first observed a solar flare in 1859
- white flare for 5 minutes
- very bright aurora appeared next day at many places on Earth, e.g. Cuba, the Bahamas, Jamaica, El Salvador, and Hawaii.
- Largest magnetic storm (> 1000 nT) in recent 200 yrs.

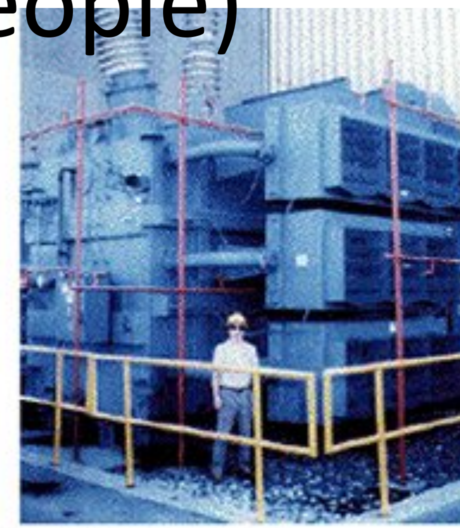


Telegraph systems all over Europe and North America failed, in some cases even shocking telegraph operators. Telegraph pylons threw sparks and telegraph paper spontaneously caught Fire （Loomis 1861）

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

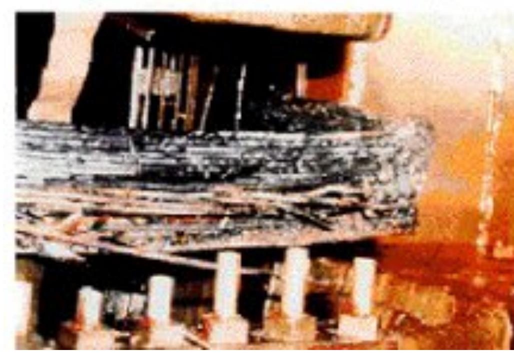
Magnetic storm and aurora on 1989 March 13, that lead to Quebeck blackout (for 6 million people)





PJM Public Service
Step Up Transformer

Severe internal damage caused by the space storm of 13 March, 1989



Magnetic storm ~ 540 nT

Solar flare X4.6

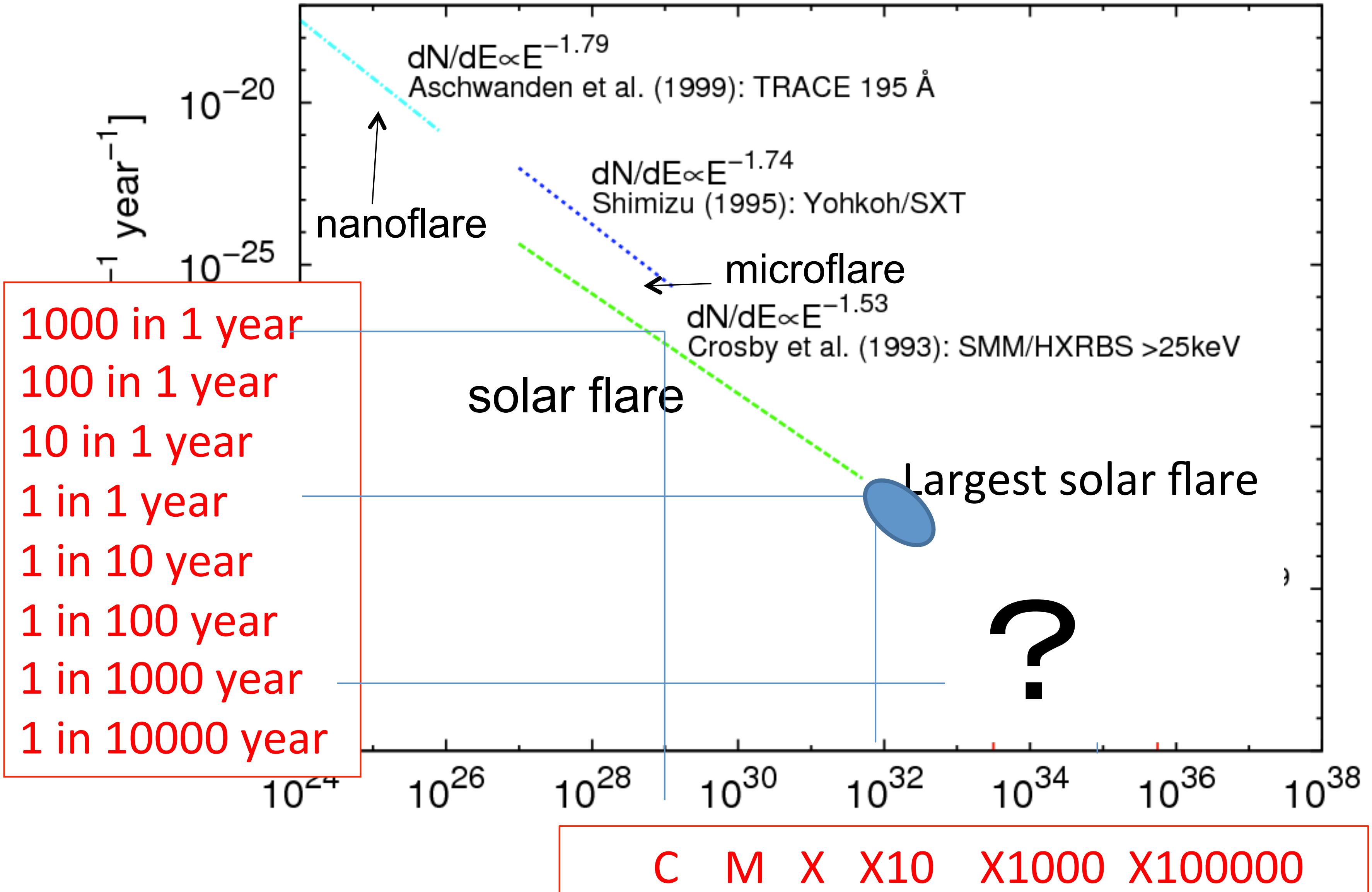
http://www.stelab.nagoya-u.ac.jp/ste-www1/pub/ste-nl/Newsletter28.pdf

Will the Carrington-class flare occur again ?

- If the Carrington-class flare occur now, what will happen ?
- a recent paper estimates potential damage to the 900-plus satellites currently in orbit could cost between $30 billion and $70 billion.

- http://science.nasa.gov/science-news/science-at-nasa/2008/06may_carringtonflare/

statistics of occurrence frequency of solar flares, microflares, nanoflares



Question

- Will our Sun produce superflares which are much more energetic than the largest flare we observed before ?

Discovery of superflares on ordinary solar type stars

Schaefer, B. E., King, J. R., Deliyannis, C. P.

ApJ, 529, 1026 (2000)

- 9 superflares (with energy 10 ~ 10^6 times that of largest solar flares) were discovered
- Main sequence stars with spectral type F8-G8
- Rotational speeds are low (like our Sun), not young stars

superflares

TABLE 1

SUPERFLARES

Shaefer et al. (2000) ApJ 529, 1026

Star	Detector	V_{normal}	Amplitude	Duration	Energy (ergs)
Gmb 1830	Photography	6.45	$\Delta B = 0.62$ mag	18 minutes	$E_B \sim 1 \times 10^{35}$
κ Cet	Spectroscopy	4.83	EW(He) = 0.13 Å	$\sim$40 minutes	$E \sim 2 \times 10^{34}$
MT Tau	Photography	16.8	$\Delta U = 0.7$ mag	$\sim$10 minutes	$E_U \sim 1 \times 10^{35}$
π^1 UMa	X-ray	5.64	$L_X = 10^{29}$ ergs s^{-1}	$> \sim$35 minutes	$E_X = 2 \times 10^{33}$
S For	Visual	8.64	$\Delta V \sim 3$ mag	17–367 minutes	$E_V \sim 2 \times 10^{38}$
BD $+10°2783$......	X-ray	10.0	$L_X = 2 \times 10^{31}$ ergs s^{-1}	$\sim$49 minutes	$E_X \gg 3 \times 10^{34}$
o Aql	Photometry	5.11	$\Delta V = 0.09$ mag	$\sim$5–15 days	$E_{BV} \approx 9 \times 10^{37}$
5 Ser	Photometry	5.06	$\Delta V = 0.09$ mag	$\sim$3–25 days	$E_{BV} \approx 7 \times 10^{37}$
UU CrB	Photometry	8.63	$\Delta I = 0.30$ mag	$> \sim$57 minutes	$E_{opt} = 7 \times 10^{35}$

Only 9 events. Too few to discuss statistics

Schaefer argued that superflares would not occur on Our Sun because there are no historical record in recent 2000 years and there are no hot Jupiters on our Sun

Are superflares really occurring on solar type stars ?

Our study (Maehara et al. 2012)

- Hence we searched for superflares on solar type stars using Kepler satellite data
- Surprisingly, we found 365 superflares on 148 solar type stars (G-type main sequence stars)

LETTER

Published in Nature (2012, May 17)

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]

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 $\leq T_{\mathrm{eff}} <$ 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

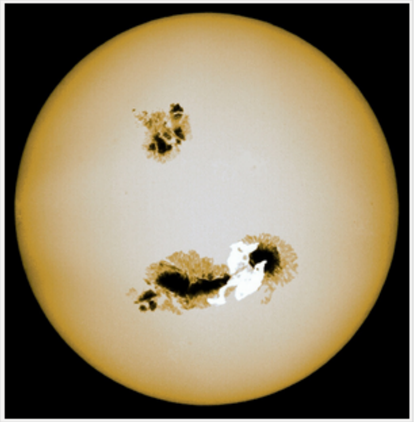
We found 365 superflares (flares with energy >10
solar-type stars (light curves of each flare are s
Supplementary Fig. 8 and properties of each flare st
Supplementary Table 1). The durations of the detec
are typically a few hours, and their amplitudes are ge
0.1–1% of the stellar luminosity. The bolometric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

朝日新聞デジタル　2012年5月17日

朝日新聞 THE ASAHI SHIMBUN DIGITAL

現在位置: 朝日新聞デジタル > 記事　　2012年5月17日 05時38分

太陽表面で大爆発の可能性　通信障害など懸念　京大解析



スーパーフレア（白い部分）の想像図。太陽の暗い部分（黒点）が大きく広がった直後に爆発する＝京都大提供

太陽では起きないと考えられていた大規模な爆発現象「スーパーフレア」が起きるかもしれないことが、京都大グループの解析でわかった。発生すれば、広範囲での通信障害や停電、上空の航空機内での放射線被曝（ひばく）といった大きな被害が出かねない。英科学誌ネイチャーで17日発表する。

太陽表面での爆発はフレアと呼ばれ、大量の放射線やプラズマが飛び出て、地球の電離層や磁場に影響を与える。1989年のフレアではカナダのケベック州で600万人が9時間の大停電に遭った。スーパーフレアは、最大級のフレアの10倍以上、水爆10億個以上のエネルギーをもつ。

京大付属天文台の柴田一成教授らは、米国の天文衛星が2009年に観測した約8万3千個の太陽に似た星のデータを調べた。星の明るさの変化から148個の星で365回のスーパーフレアが見つかった。

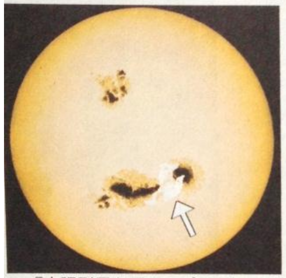
スーパーフレアが起きるには、恒星のすぐそばに木星のような大きな惑星が必要というのが通説だった。だが、今回の調査でそのような惑星は見つからず、太陽では起きないという説に根拠がないとわかった。

計算すると、最大級のフレアの100倍の爆発（水爆100億個分）で800年に1回、1千倍（同1千億個分）で5千年に1回起こる確率だった。今後、南極の氷などに過去のスーパーフレアの跡がないかも調べる。（鍛治信太郎）

産経新聞　2012年5月17日

「太陽でも超巨大爆発」

京大解析、通説に疑義



「太陽型星」でスーパーフレア（矢印）が起こる場合の想像図（京都大付属天文台提供）

超巨大な爆発現象「スーパーフレア」が、太陽の表面で起こるかもしれないとの解析結果を京都大付属天文台のグループがまとめ、16日付の英科学誌ネイチャー電子版に発表した。

太陽では、太陽系最大の爆発現象とされる通常のフレアが起きており、その際に生じる磁気嵐で通信障害や停電などが発生している。

スーパーフレアは、放出されるエネルギーが太陽フレアのうち最大級のものの10倍～100万倍に達する。太陽でスーパーフレアは起きないという通説に疑義を唱える結果で、グループは「起きれば地球は大きな被害を受けると予想され、研究を進めたい」としている。

グループの柴田一成教授（太陽・宇宙プラズマ物理学）らは、米航空宇宙局（NASA）の惑星探査機「ケプラー」が2009（平成21）年4～12月に観測したデータを利用。地球から数百～千光年離れた天の川銀河系にあり、大きさや表面温度が太陽と似た「太陽型星」約8万3千個を対象に、30分ごとの明るさの変化を解析した。

その結果、148個の表面でスーパーフレアが365回起こっていた。

グループによると、太陽型星のスーパーフレアの原因は、星と惑星それぞれの磁場の相互作用とされ、発生にはホットジュピターと呼ばれる、恒星の近くを回る巨大惑星の存在が必須と考えられてきた。しかし今回、スーパーフレアが確認された太陽型星でホットジュピターは見つからず、太陽でもスーパーフレアが起こる可能性が出てきたとみている。

解析では、急に増光した後に時間をかけて暗くなり、爆発現象で明るさが0・1～10％増した場合をスーパーフレアと判断した。

日本経済新聞2012年5月17日

「太陽フレア」大規模の恐れ

通信障害拡大も

京都大の柴田一成教授らは、太陽表面で起きる巨大な爆発現象で通信障害の原因となる「太陽フレア」が、従来の想定よりも大規模に発生する可能性があることを突き止めた。太陽と似た星の分析から、太陽で大規模爆発は起きないとしてきた従来理論が説明できないことが分かった。フレアの規模が大きければ、通信障害も大きくなる。

研究成果は英科学誌「ネイチャー」に17日、掲載される。

研究グループは、米航空宇宙局（NASA）が打ち上げた人工衛星の観測データから、はくちょう座方面にある約8万3千個の太陽に似た星を分析。太陽フレアの約1000倍のエネルギーを持つ「スーパーフレア」という大規模爆発の発生を、148の星で365例確認した。

従来理論はスーパーフレアの発生には近くに木星のような大きな惑星が必要としていたが、スーパーフレアを観測した星のいずれの近くにも大きな惑星はなかった。太陽も近くに大きな惑星はないが、大規模な爆発の可能性が出てきたという。

DiscoveryNews ... saw something cross the sun.

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Discovery News > Space News > Superflares Found on Sun-like Stars

SUPERFLARES FOUND ON SUN-LIKE STARS

There is no explanation for how flares more than 1 million times more powerful than solar flares are occurring.

By Irene Klotz
Wed May 16, 2012 01:09 PM ET
(0) Comments | Leave a Comment

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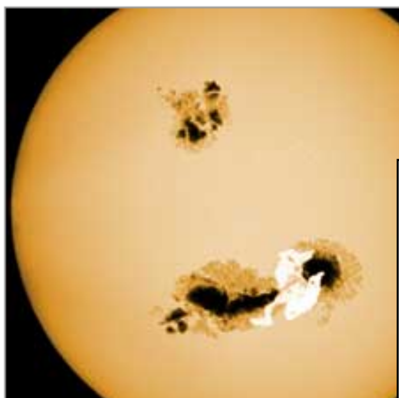

THE GIST

- Some sun-like stars have flares times more powerful than our s
- Scientists don't yet understand

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Colossal Superflares Erupt from Sun-Like Stars

by Charles Q. Choi, SPACE.com Contributor
Date: 16 May 2012 Time: 01:00 PM ET

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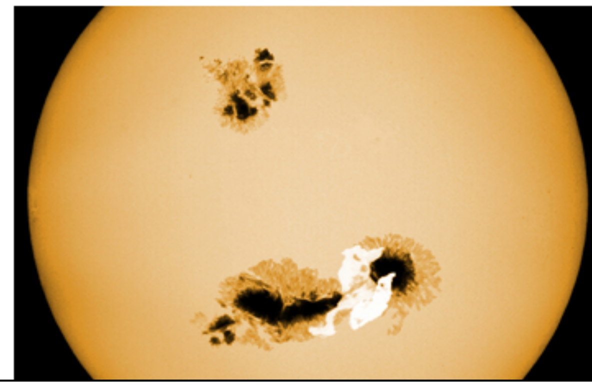

Stars like our sun can release "superflares," explosions of up to 10,000 times more energy than the solar flares seen from our sun, researchers say.

However, it looks unlikely that our sun currently has superflares, scientists added.

Astronomers have previously

THURSDAY MAY 24, 2012 JOBS | REAL ESTATE | CLASSIFIEDS | FRIENDS | FORUM

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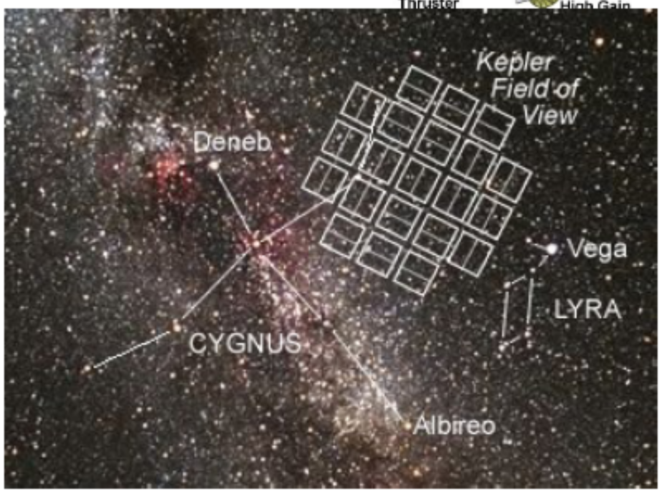
Japan, U.S. disagree on possibility of solar apocalypse

By Jessica Ocheltree

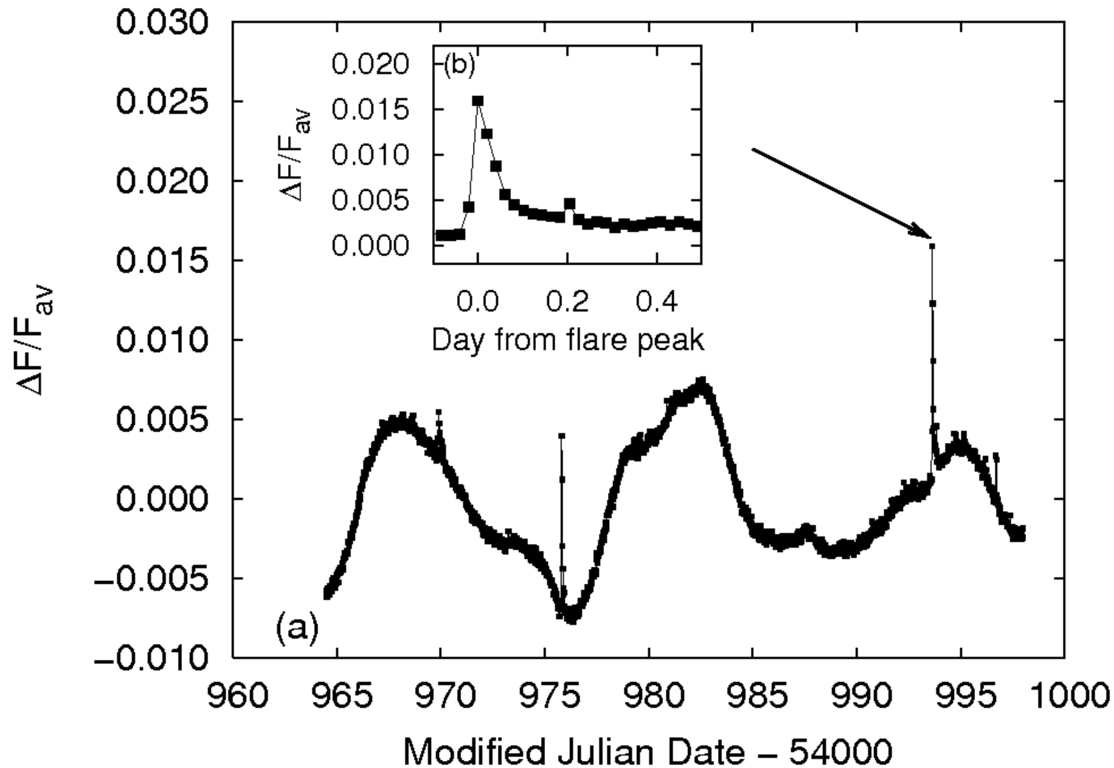
Kepler satellite

- Space mission to detect exoplanets by observing transit of exoplanets
- 0.95 m telescope
- Observing 150,000 stars for a few months
- ~30 min time cadence (public data)



typical superflare observed by Kepler

Brightness
of a star
and a flare



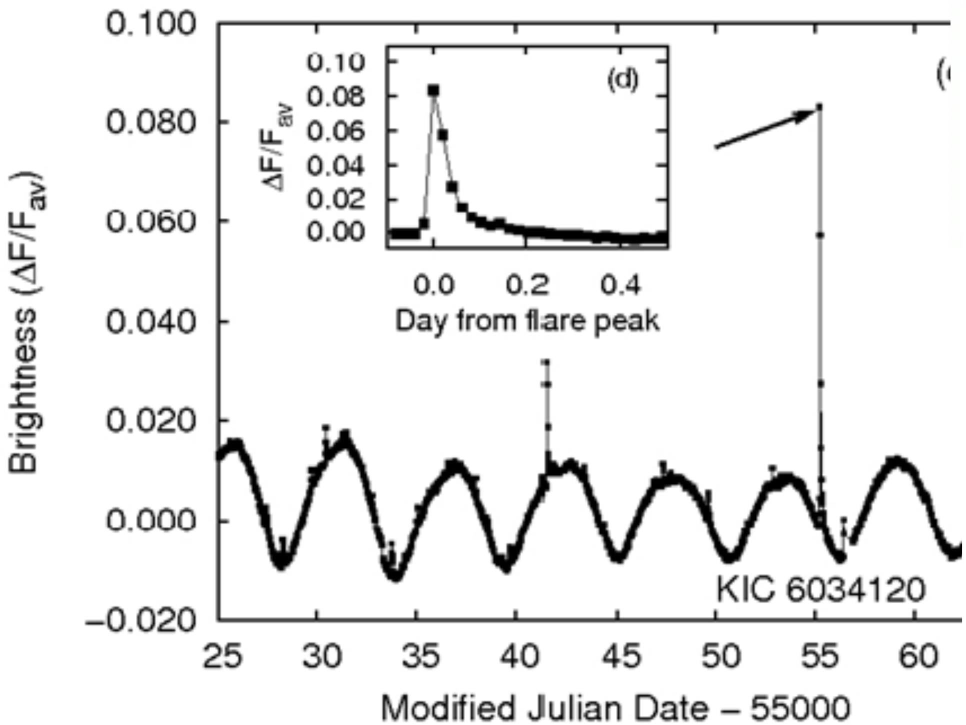
Time (day)

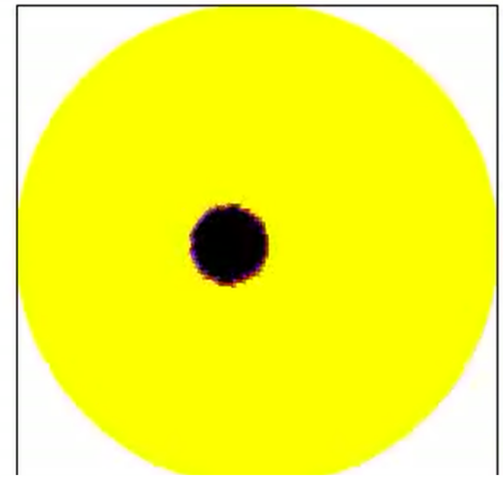
Total energy
~ 10^35 erg

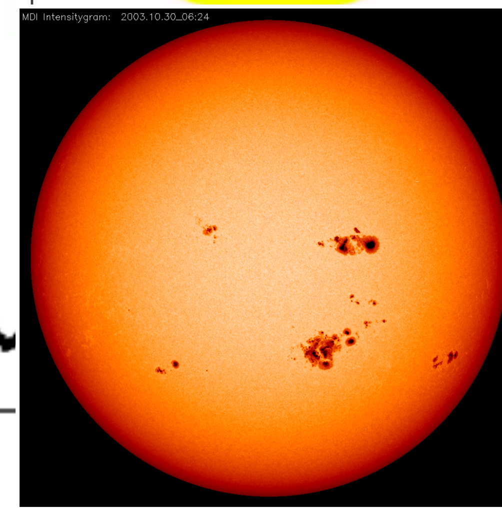
Maehara et al. (2011)

What is the cause of stellar brightness variation ?

Brightness
of a star
and a flare

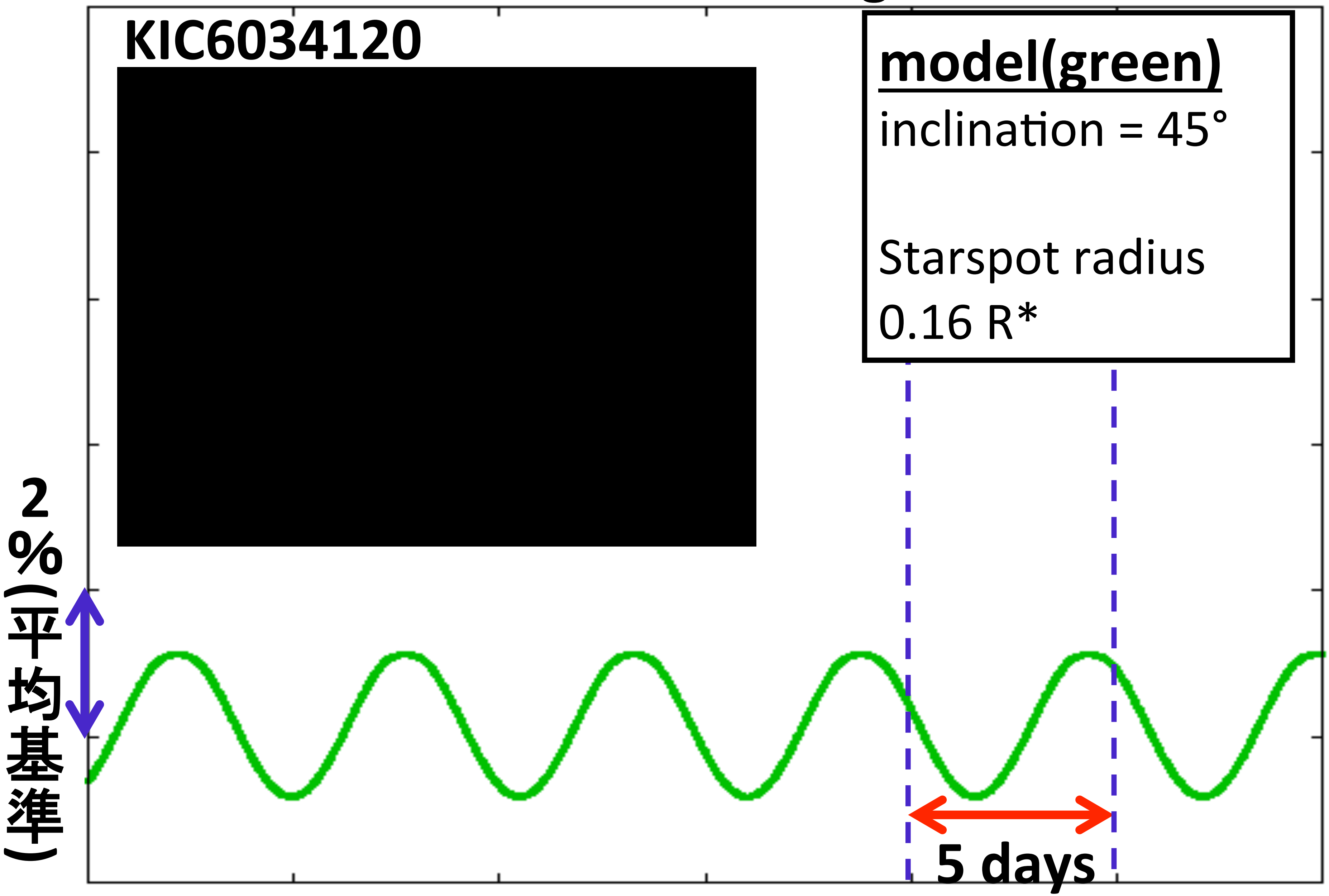






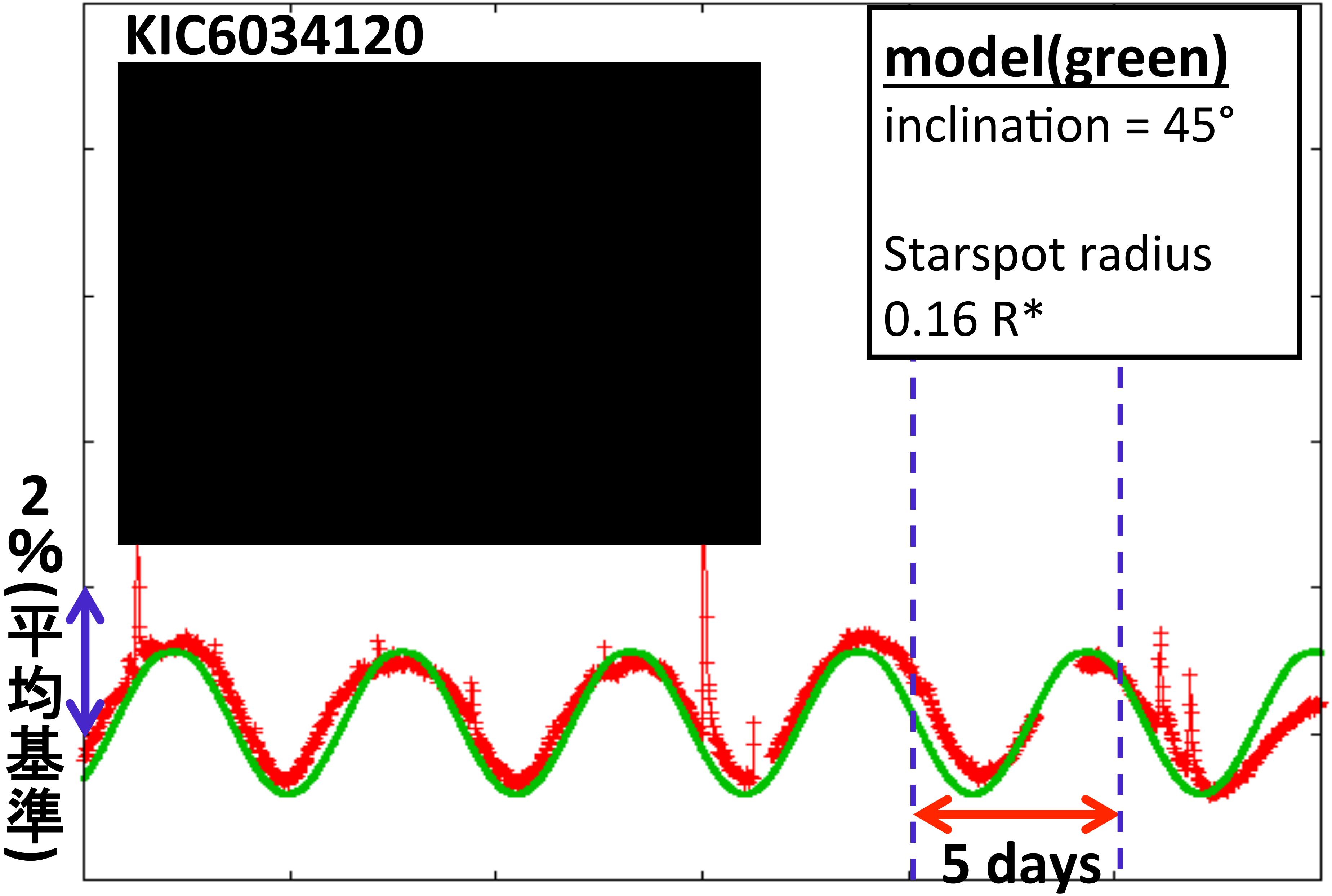
It may be due to rotation of a star with a big star spot

Model calculation of stellar brightness variation



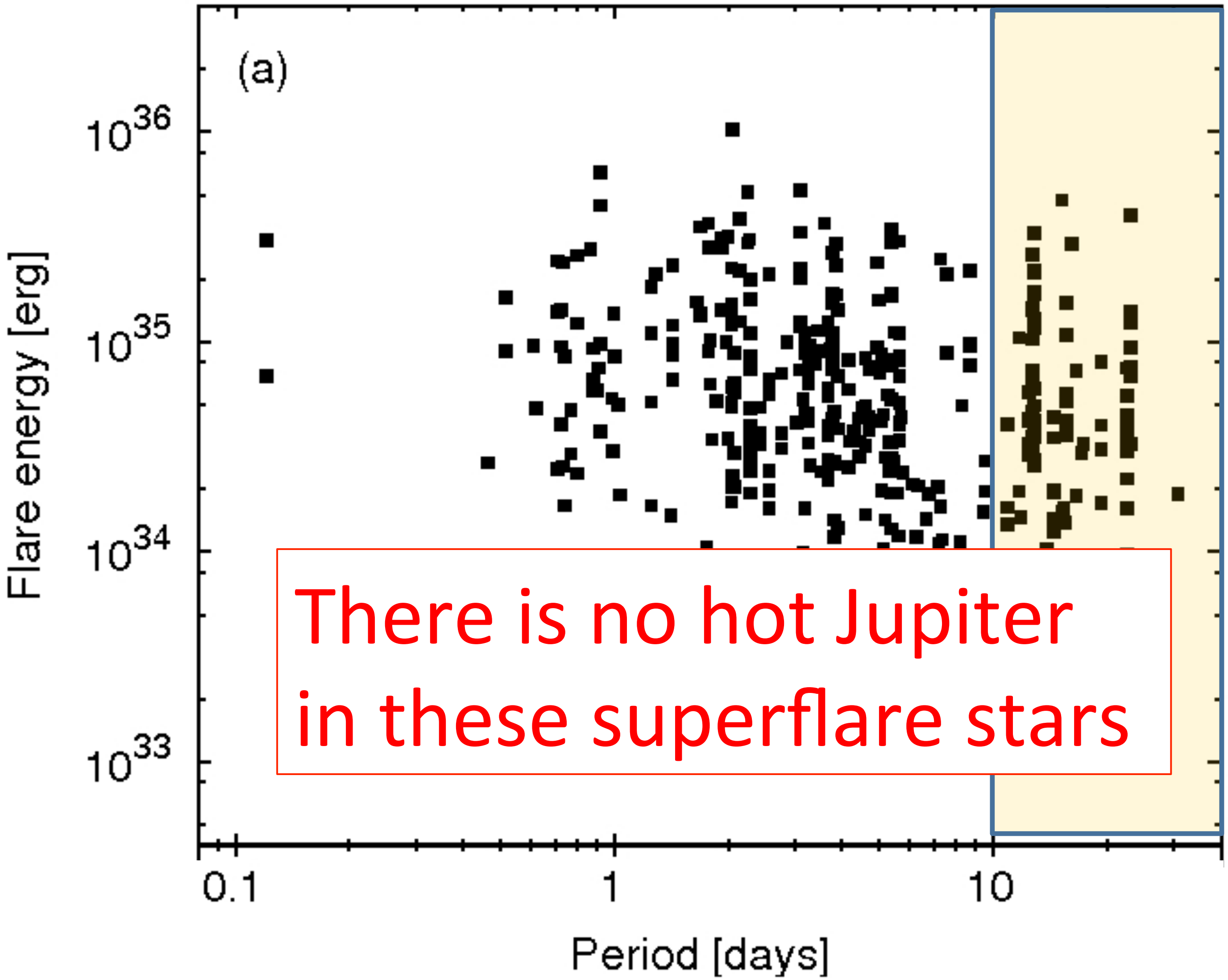
Notsu et al.

Model calculation of stellar brightness variation



Notsu et al.

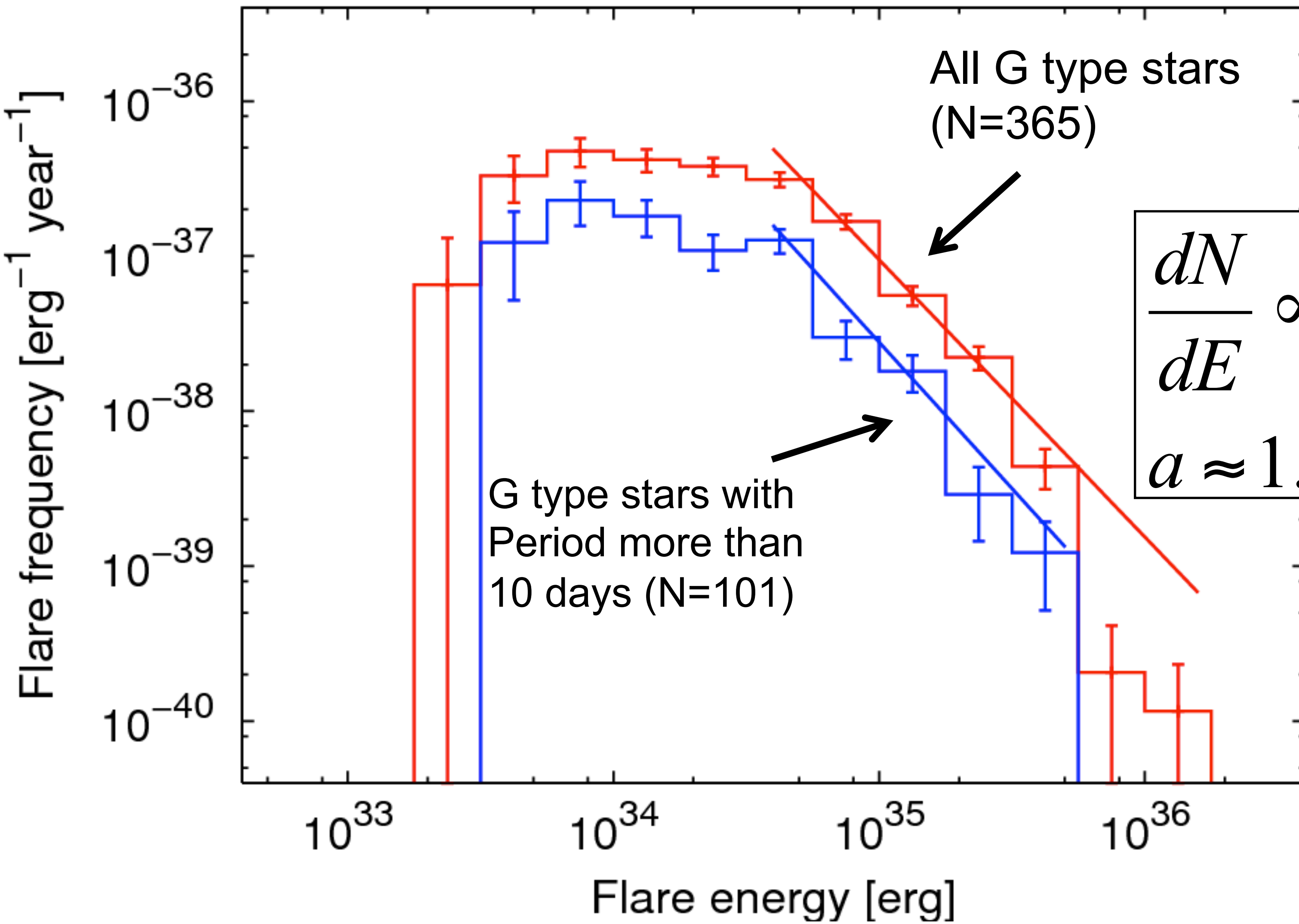
Flare energy vs rotational period



Stars with period longer than 10 days

cf solar rot period ~ 25days

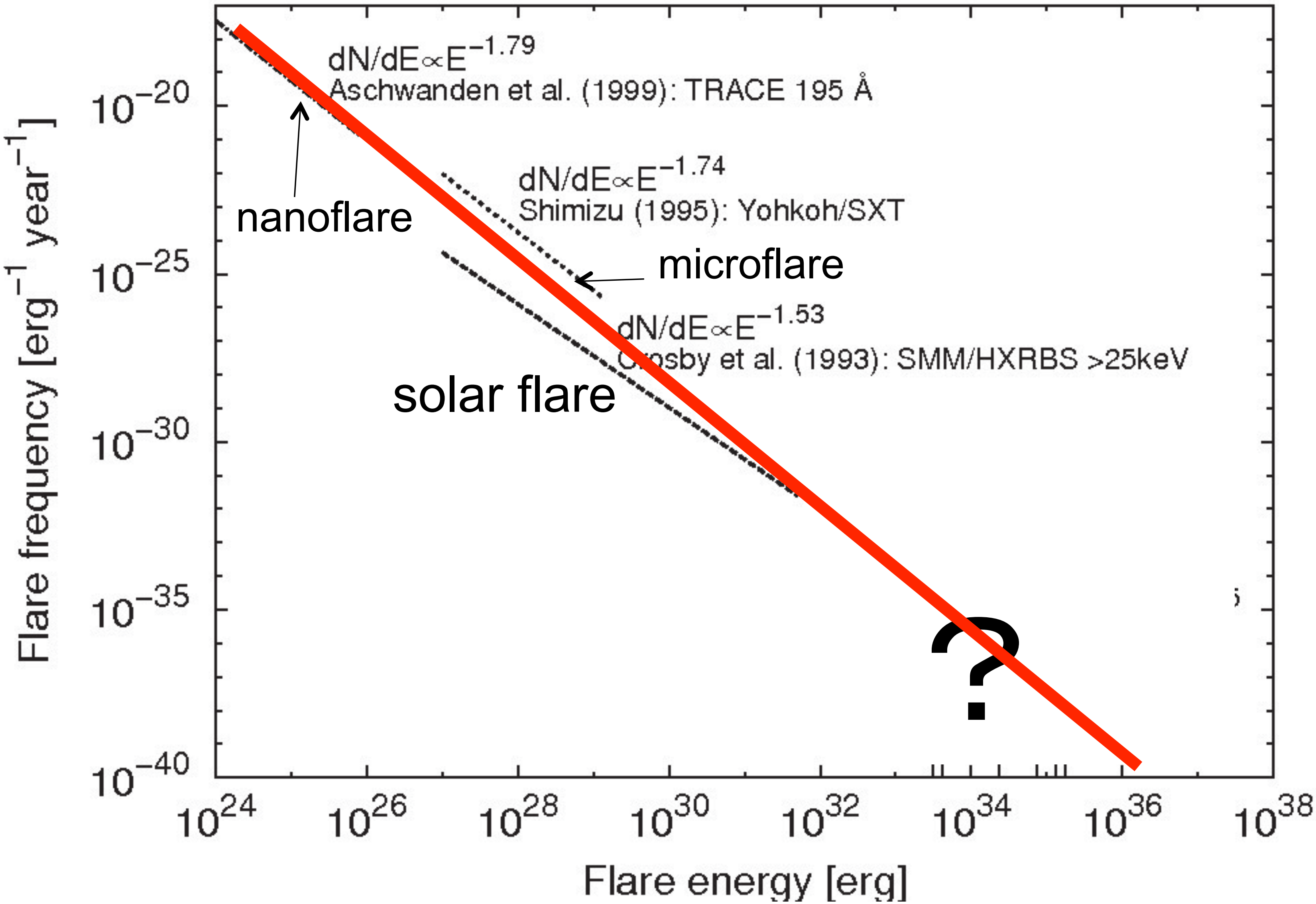
Occurrence frequency of superflares as a function of flare energy



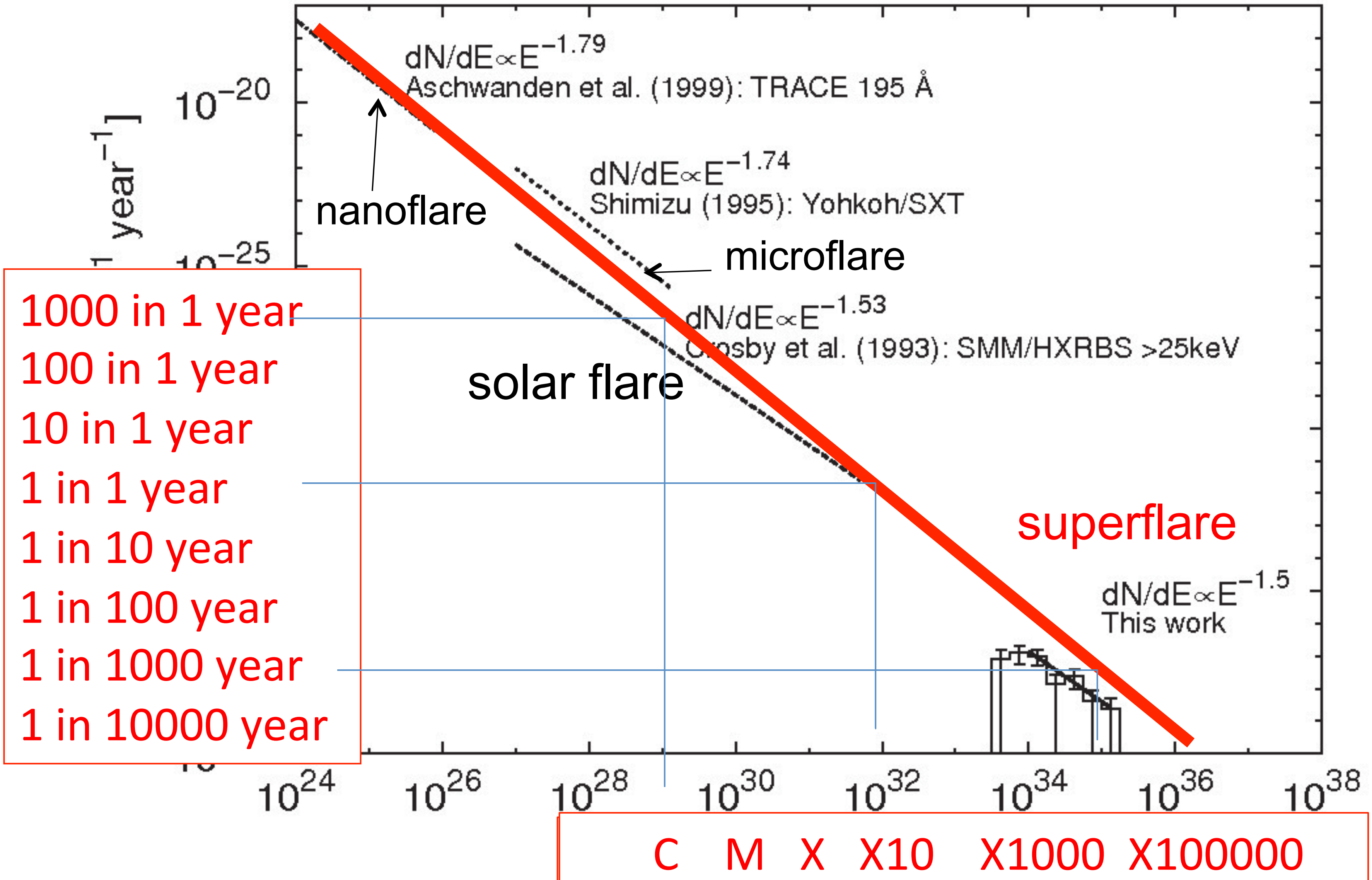
$$\frac{dN}{dE} \propto E^{-a}$$

$$a \approx 1.5 - 1.9$$

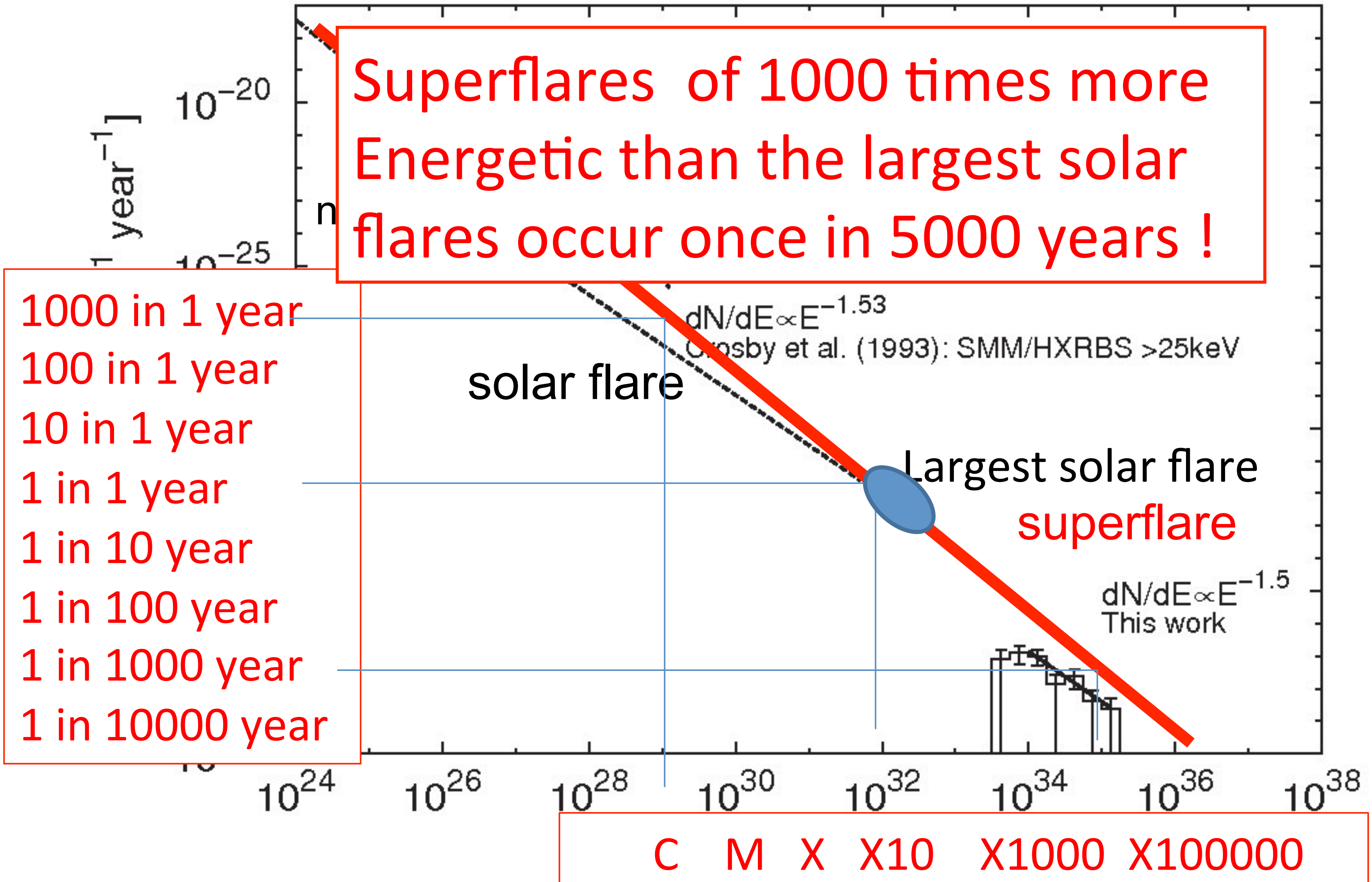
Comparison of statistics between solar flares/microflares and superflares



Comparison of statistics between solar flares/microflares and superflares



Comparison of statistics between solar flares/microflares and superflares



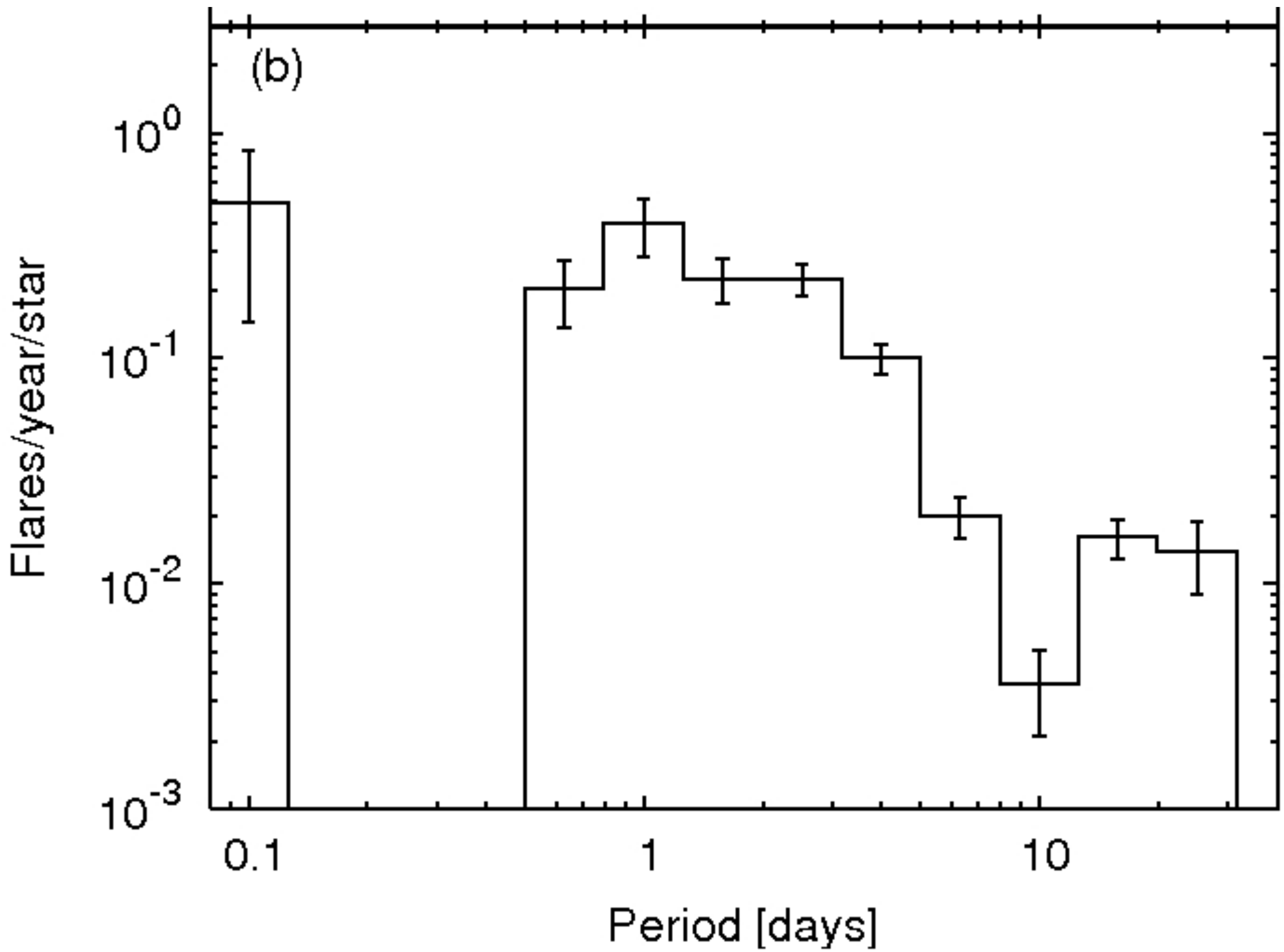
Spectroscopic Observations of Solar type stars causing superflares will be extremely important

Summary

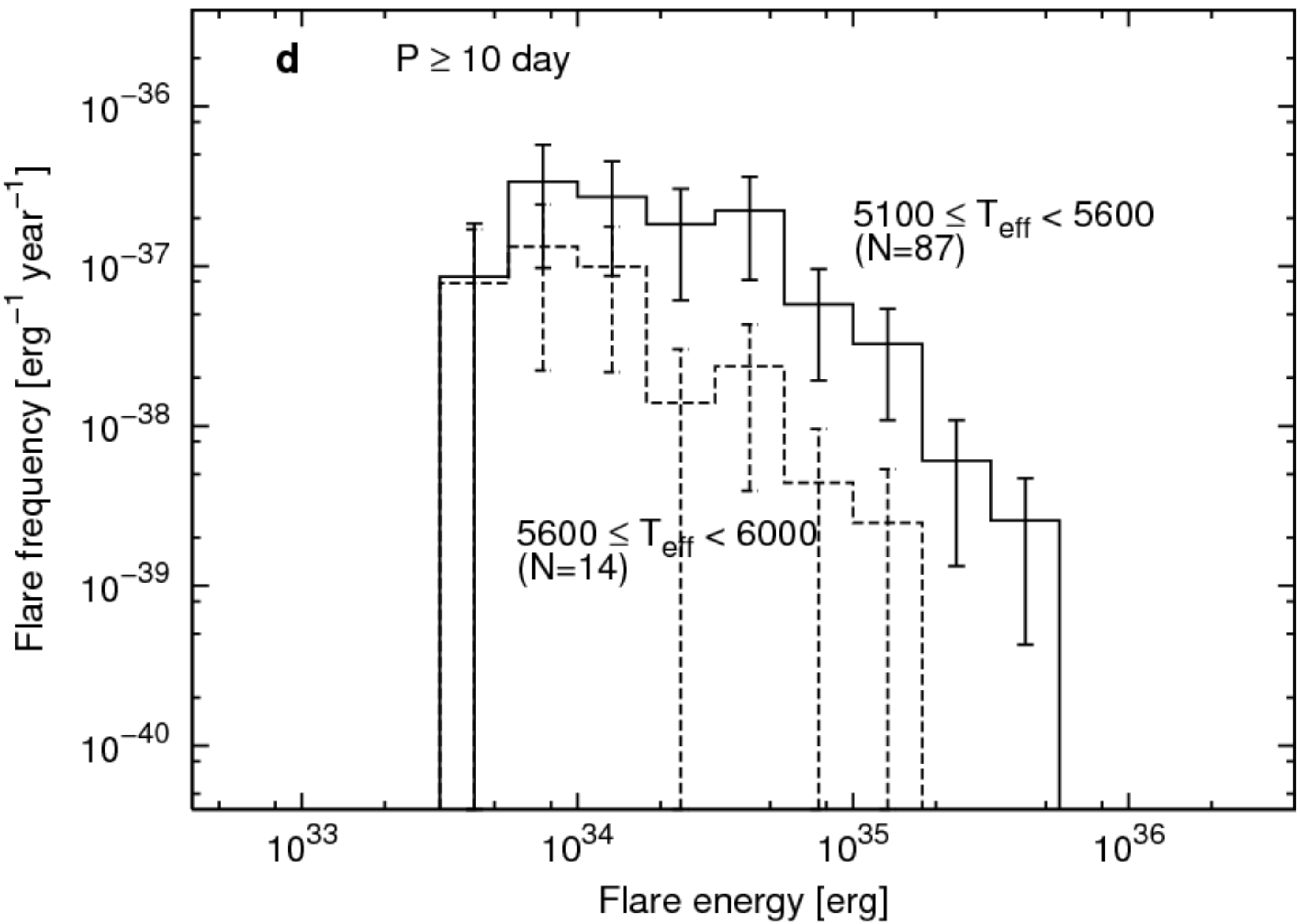
- Using Kepler data, we found 365 superflares (10^33-10^36 erg) on 148 solar type stars (G type main sequence stars), including 101 from slowly rotating solar-type stars, from ~83,000 stars observed over 120 days (Maehara et al. 2012).
- It is found that superflares occur on solar twins with frequency such that superflares with energy 10^35 erg (1000 times of the largest solar flare) occur once in 5000 years (Maehara et al. 2012).
- There is no hot Jupiter around these superflare stars.
- Hence it is likely that such superflares would also occur on our present Sun with similar frequency.

Backup slides
on superflares

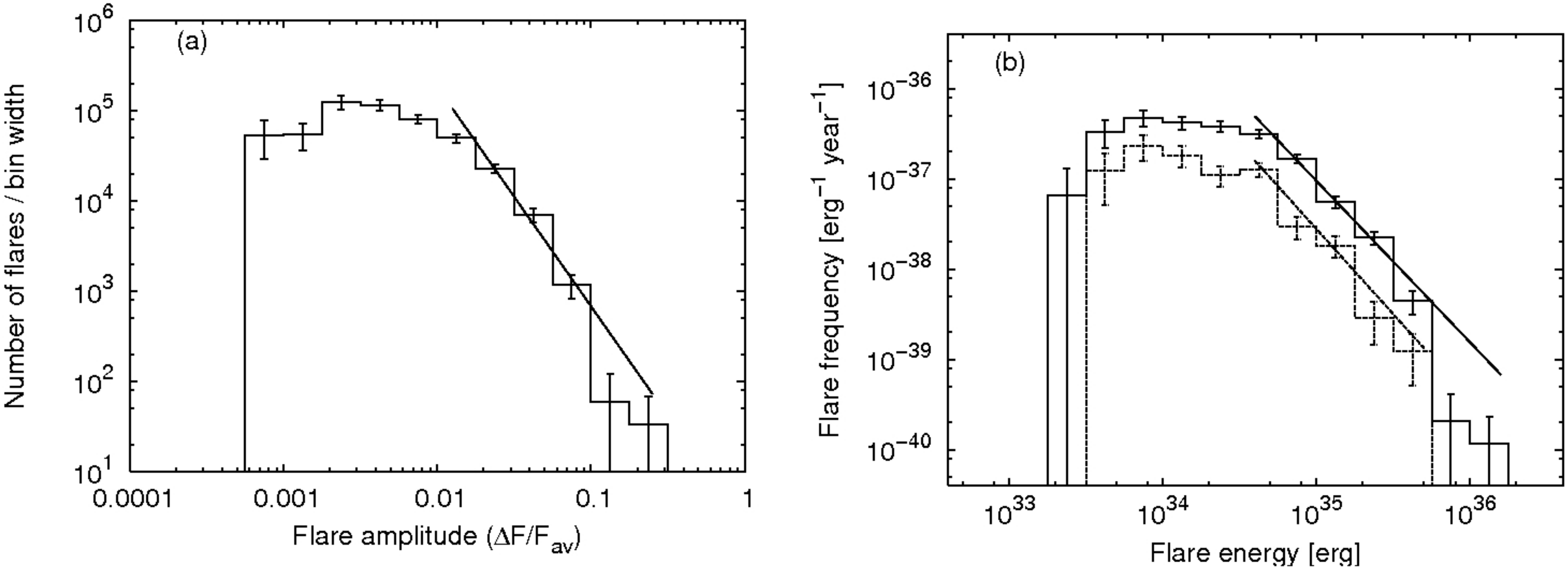
Occurrence frequency vs rotational period



Occurrence frequency of superflares on solar twins



Occurrence frequency of superflares observed by Kepler as a function of flare peak brightness



$$\frac{dN}{dE} \propto E^{-1.9}$$

Maehara et al. (2011)

Mechanism of superflare occurrence

- Big starspot is necessary

$$E_{flare} \approx fE_{mag} \approx f\,\frac{B^2L^3}{8\pi} \approx f\,\frac{B^2}{8\pi}A_{spot}{}^{3/2}$$

$$\approx 10^{32}\ [erg]\left(\frac{f}{0.1}\right)\left(\frac{B}{10^3G}\right)^2\left(\frac{L_{spot}/R_\Theta}{0.04}\right)^3$$

- $If\ \ L_{spot} \approx 0.2 - 0.4\,R_\Theta\ \ ,\ \ E_{flare} \approx 10^{34} - 10^{35}\ erg$

$$\Phi \approx BL_{spot}{}^2 \approx 1-4\ \times 10^{24}\ [Mx]$$

How to make big star spot ?

$$\frac{dB}{dt} = rot\ (V \times B) \approx rot\ (r\Omega\ \times B)\ \approx \Delta\Omega\ B_p$$

$$\boxed{\frac{d\Phi}{dt} \approx \frac{d(BS)}{dt}\ \approx\ \Delta\Omega\ \ B_p\ \ S}$$

$$\Delta\Omega \approx \Delta r (d\Omega / dr)$$
$$\approx\ 2.5 \times 10^{-8}\ \ [Hz]$$

$$\frac{d\Phi}{dt} \approx 5 \times 10^{21}\ [Mx / day] \approx 5 \times 10^{16}\ [Mx / \sec]$$

⇒The necessary time to generate total magnetic flux of 3 x 10^{24} Mx that can produce superflares of 10^{35} erg are 2 years (< 11 years)

Estimate of maximum magnetic energy stored near starspots

Sun:

$$L_{corona} = 10^{27}\ \text{erg/s}, \quad \Phi = 10^{23}\ \text{Mx}\ (= \text{G} \cdot \text{cm}^2)$$

$$\Phi = 1000\text{G} \times \underline{(10^{10}\ \text{cm})}^2 = 10^{23}\ \text{Mx}$$

$$\text{mag energy} = (100\text{G})^2/(8\pi) \times \underline{(10^{10}\ \text{cm})}^3 = 4 \times 10^{32}\ \text{erg}$$

T Tauri:

$$L_{corona} = 10^{32}\ \text{erg/s}, \quad \Phi = 10^{27}\ \text{Mx}$$

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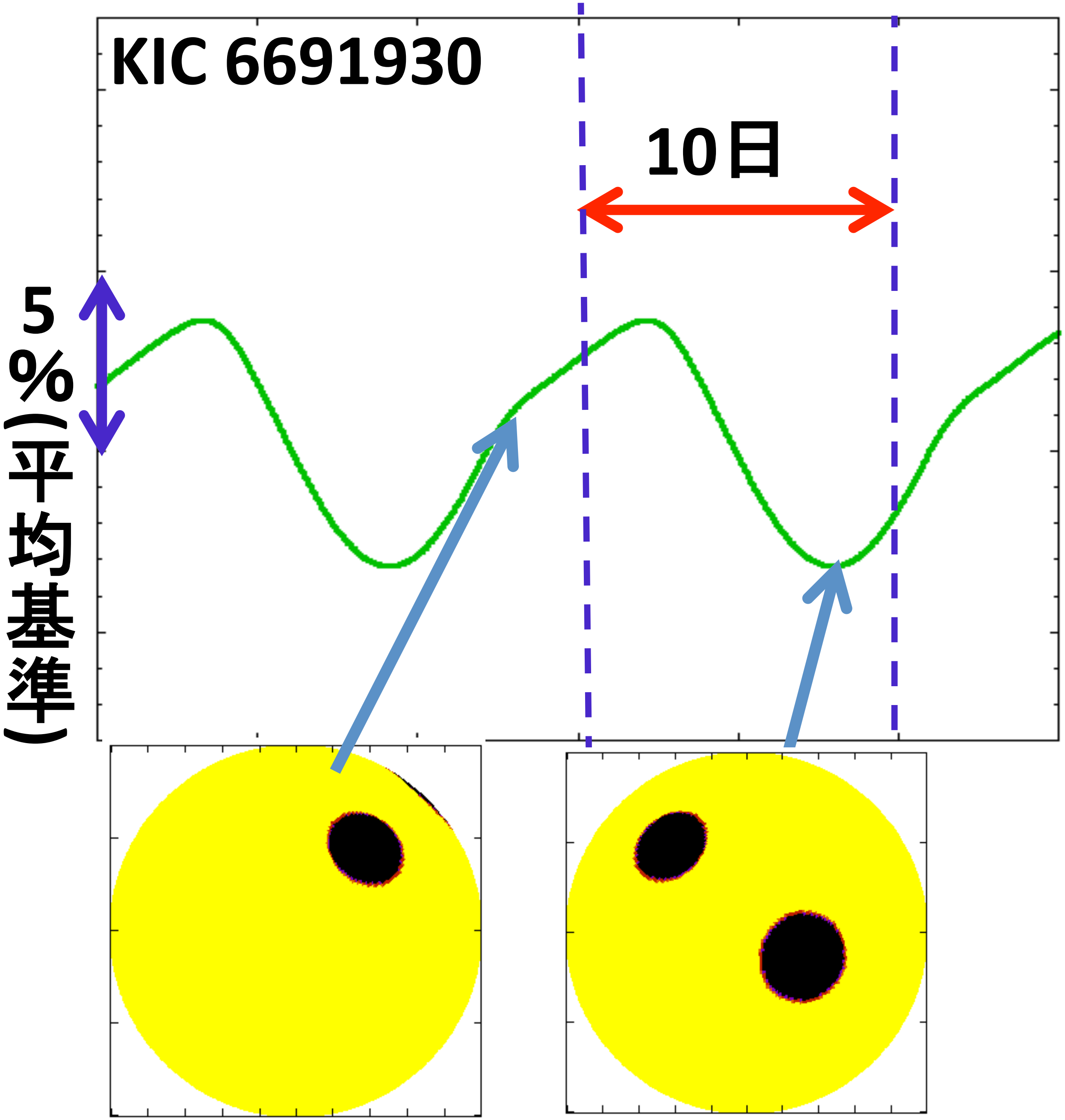
「黒点(複数)＋自転(数日)+振幅大」のモデル計算



<u>モデル計算(緑)</u>

inclination =40 °

経度差:80

<u>○黒点1</u>

半径:星半径の0.25倍

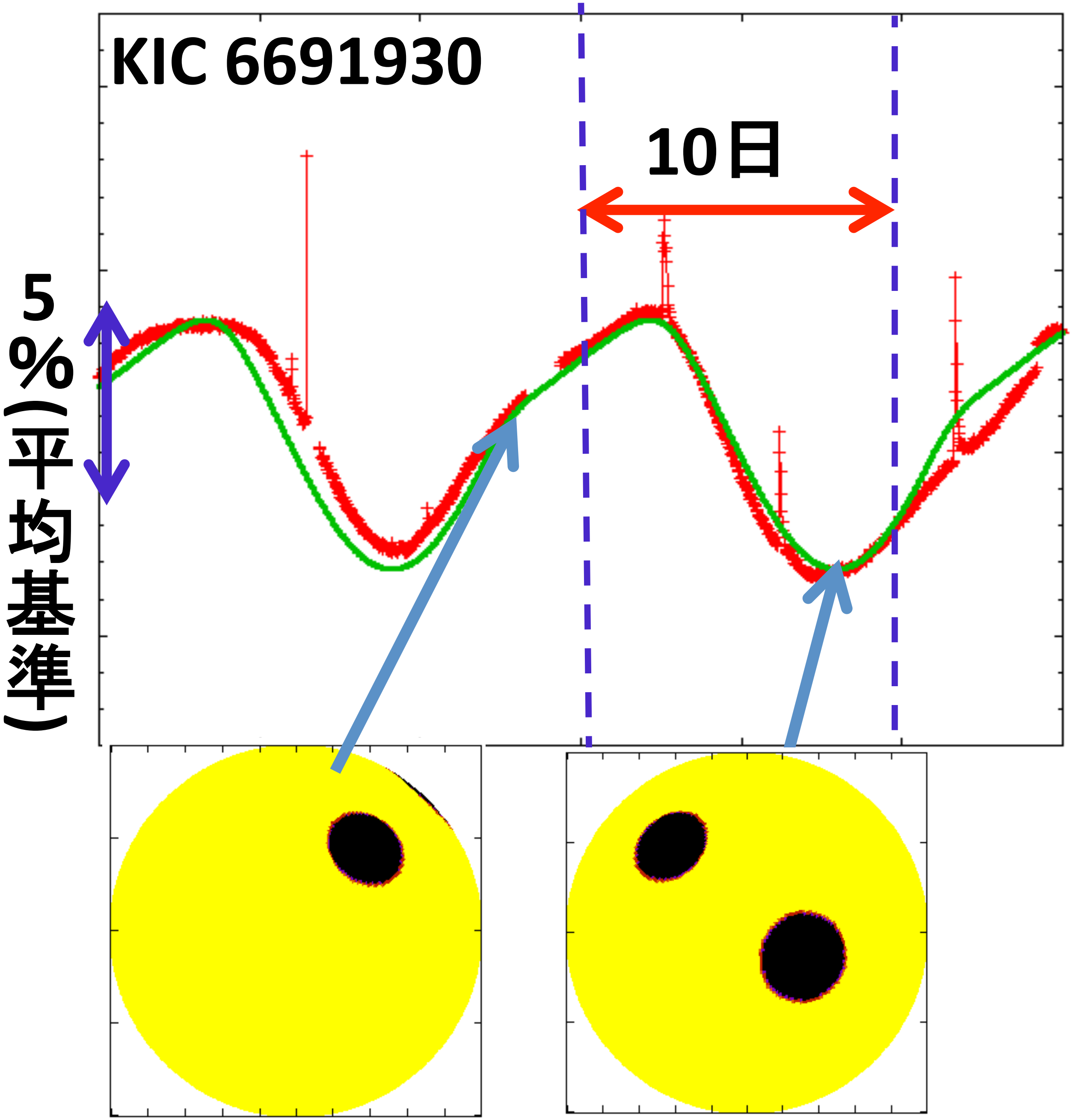
位置:北緯30度

<u>○黒点2</u>

半径:星半径の0.22倍

位置:北緯60度

「黒点(複数)＋自転(数日)+振幅大」のモデル計算



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半径:星半径の0.22倍

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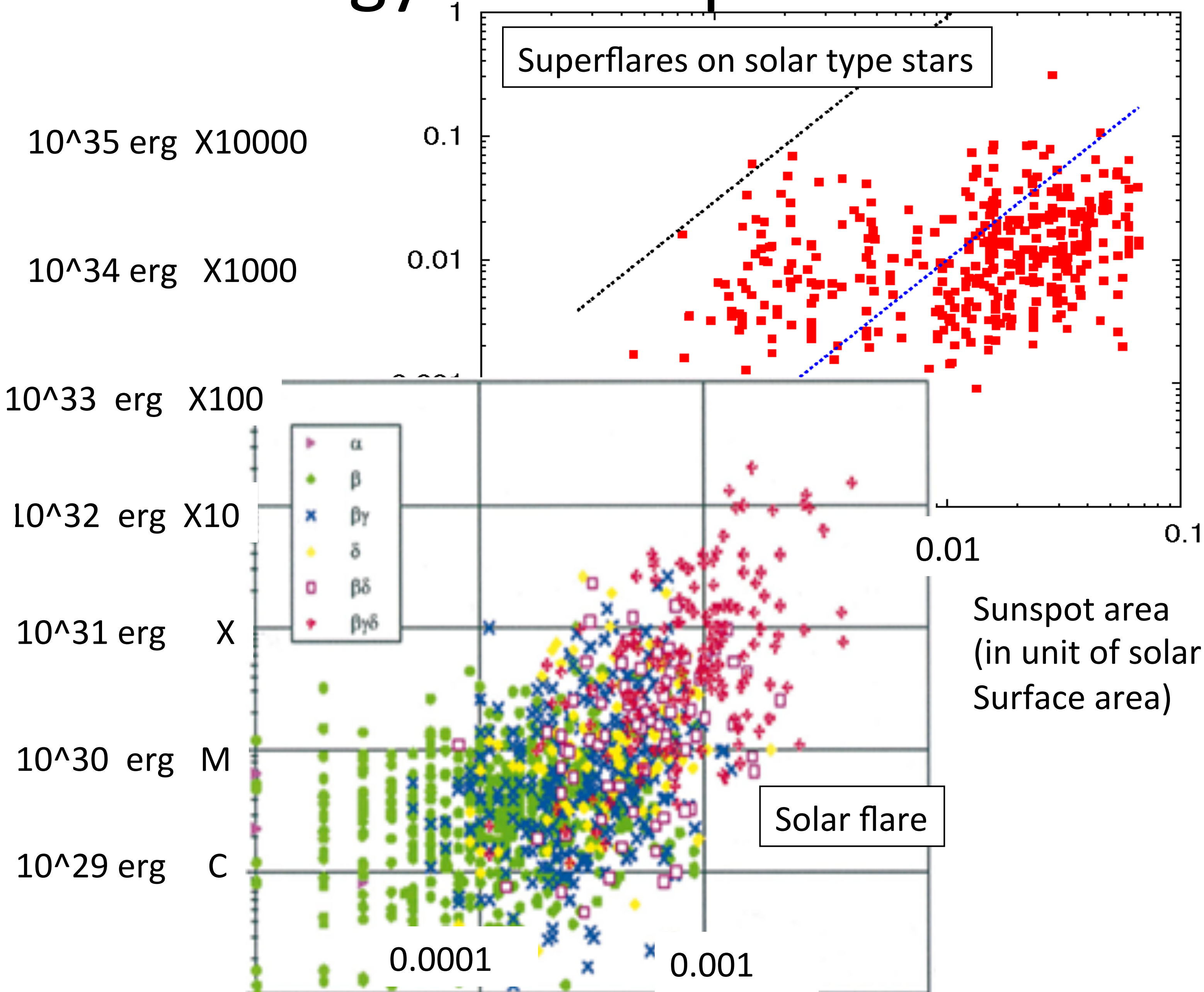
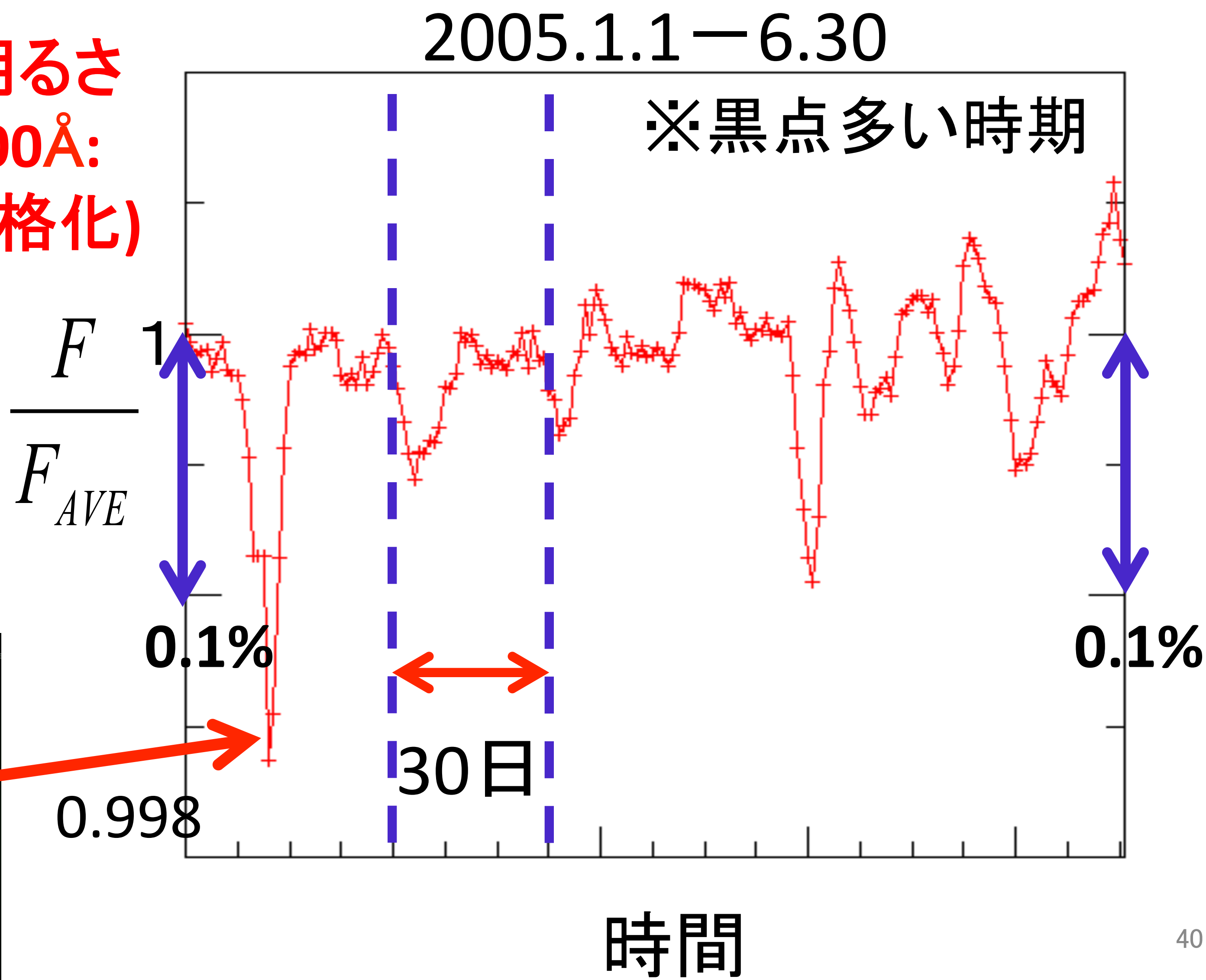
Flare energy vs sunspot area



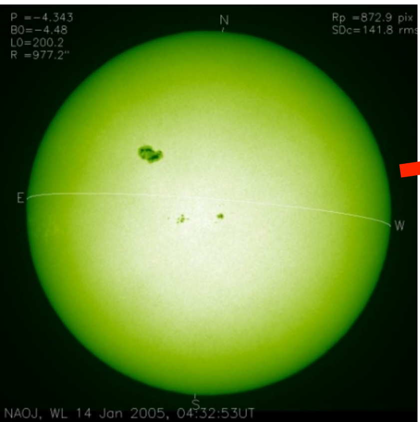
「黒点＋自転」の例として －太陽の明るさ変動－

↓(SORCE衛星可視光明るさと黒点面積の対応) ↓

赤:太陽明るさ
(4500-8000Å:
平均で規格化)



2005/1/14
白色光全面観測
@国立天文台
太陽観測所↓



「黒点＋自転」の例として ー太陽の明るさ変動ー

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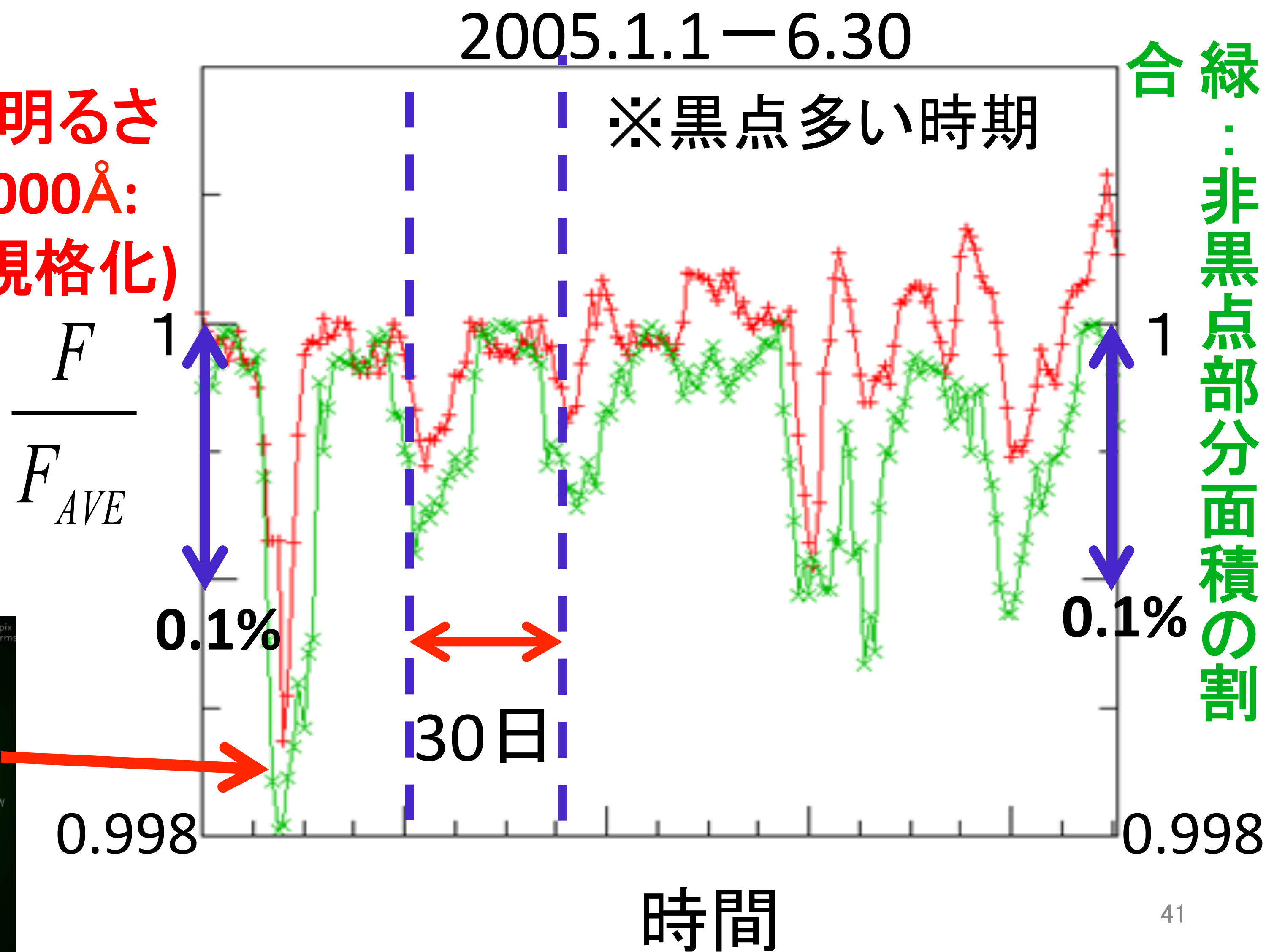

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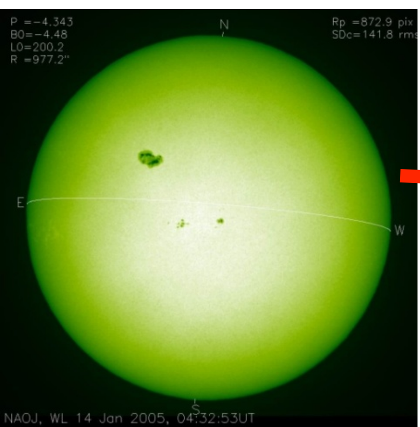


グリーンランドの氷中の窒素酸化物（Noy）量の時間変化から、地球に届いたプロトン・フラックスが推定できる

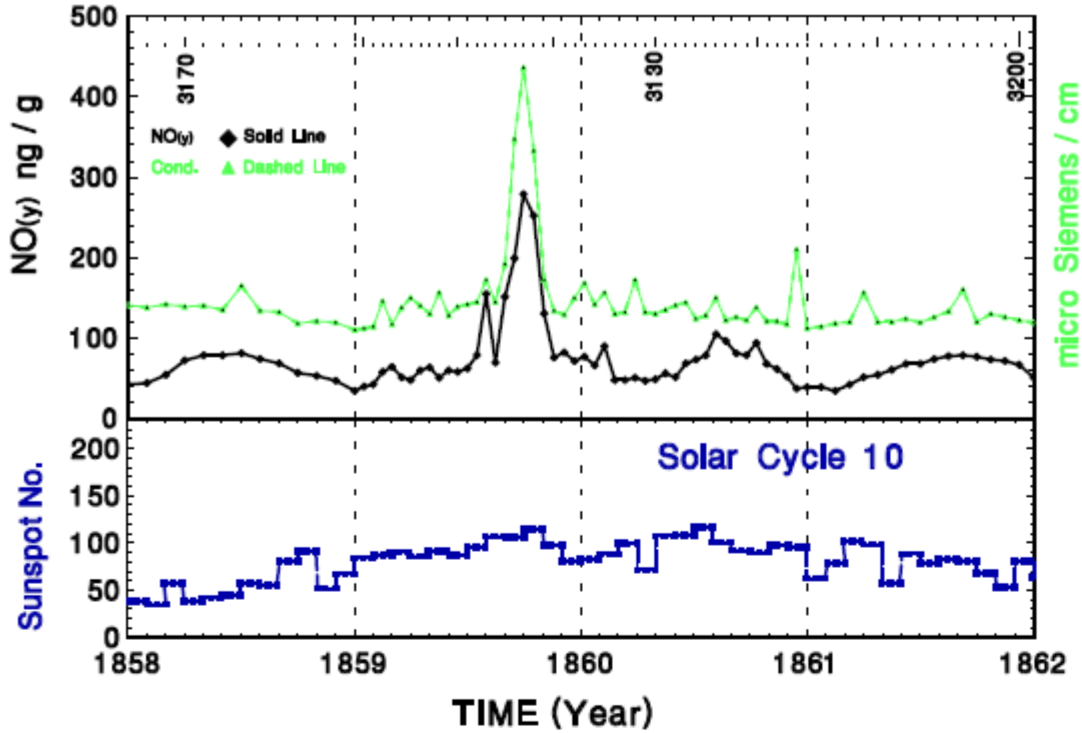


Fig. 4. The impulsive NOy deposition event in Greenland polar ice that corresponds to the Carrington event of 1 September 1859. The black line shows the NOy deposition. The light line indicates the electrical conductivity used to identify volcanic eruption time markers. (It also responds to the HNO_3 produced by solar protons – see text.) The sample number in the ice core is indicated at the top of the figure. The monthly sunspot number for this period of solar cycle 10 is indicated at the bottom of the figure.

Shea et al. (2006) Adv SpRes 38, 232

最近450年間の巨大フレアから地球に届いたプロトン・フラックス

Table 2
Solar proton events between 1570 and 1950 as identified from impulsive nitrate enhancements in Polar ice

Solar cycle	Cycle start	Event date	Rank	>30 MeV fluence	G Mag storm	Mid-lat aurora	Sequence of activity
		1603.6	18	5.2×10^9		Kr	
		1605.7	8	7.1×10^9		Kr	
−11	1619.0	1619.6	5	8.0×10^9			
−10	1634.0	1637.7	12	6.1×10^9		Kr	P
−9	1645.0	1647.9	17	5.2×10^9			
−4	1698.0	1700.8	14	5.8×10^9			
−3	1712.0	1719.5	7	7.4×10^9		Kr	P
−2	1723.5	1727.9	11	6.3×10^9		Kr, Yau	P
1	1755.2	1756.0	16	5.4×10^9			
4	1784.7	1793.6	15	5.5×10^9		Kr	
6	1810.6	1813.2	10	6.4×10^9		Kr	
9	1843.5	1851.8	3	9.3×10^9	G, CM	Kr	P
10	1856.0	1859.8	1	18.8×10^9	G, CM	Kr	Yes
10	1856.0	1864.8	9	7.0×10^9	G	Kr	
11	1867.2	1878.6	19	5.0×10^9	G, CM	Kr	P
13	1889.6	1894.9	6	7.7×10^9	G, CM	Kr	Yes
13	1889.6	1895.7	2	11.1×10^9	G, CM	Kr	P
13	1889.6	1896.7	4	8.0×10^9	G, CM	Kr	Yes
18	1944.2	1946.5	13	6.0×10^9	G, CM	Sil	

All events have > 30 MeV Fluence $\geqslant 5 \times 10^9$ cm^{-2}.
Notation:
G, geomagnetic Storm within a three-month period prior to the nitrate enhancement.
CM, sunspot region observed near central meridian.
Kr, data from Křivský and Pejml (1988).
Yau, data from Yau et al. (1995).
Sil, data from Silverman (2002).
P, possible sequence of solar activity.
Yes, known sequence of solar activity.
The event of 1946.5 in the 18th solar cycle is from the Antarctic ice core; all other events are from the GISP2-H core drilled at Summit, Greenland.

Carrington flare

Shea et al. (2006) Adv SpRes 38, 232

Carrington Flare

MNRAS 20, 13 (1859)

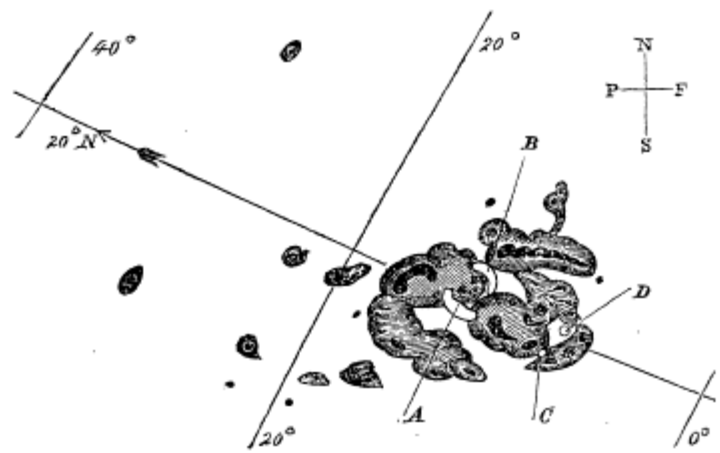
Lead to Biggest Magnestic Storm in recent 200 years

bination with the ancient measures, to a new computation by M. Oom, of the Royal Observatory of Lisbon, at present living at Pulkowa. The results of his computation have entirely confirmed my father's conclusions, that the changes observed in the course of 28 years in the relative positions of the two stars find a complete explanation in the proper motion of the principal star, but the new formula does but very little diminish the discordance of the results obtained in 1823 by transit observations.

Pulkowa, October, 1859.

Description of a Singular Appearance seen in the Sun on September 1, 1859. By R. C. Carrington, Esq.

While engaged in the forenoon of Thursday, Sept. 1, in taking my customary observation of the forms and positions of the solar spots, an appearance was witnessed which I believe to be exceedingly rare. The image of the sun's disk was, as usual with me, projected on to a plate of glass coated with distemper of a pale straw colour, and at a distance and under a power which presented a picture of about 11 inches diameter. I had secured diagrams of all the groups and detached spots, and was engaged at the time in counting from a chronometer and recording the contacts of the spots with the cross-wires used in the observation, when within the area of the great north group (the size of which had previously excited general remark), two patches of intensely bright and white light broke out, in the positions indicated in the appended diagram by the letters A and B, and of the forms of the spaces left white. My



first impression was that by some chance a ray of light had penetrated a hole in the screen attached to the object-glass, by

Geomagnetic disturbance observed at Bombay, India

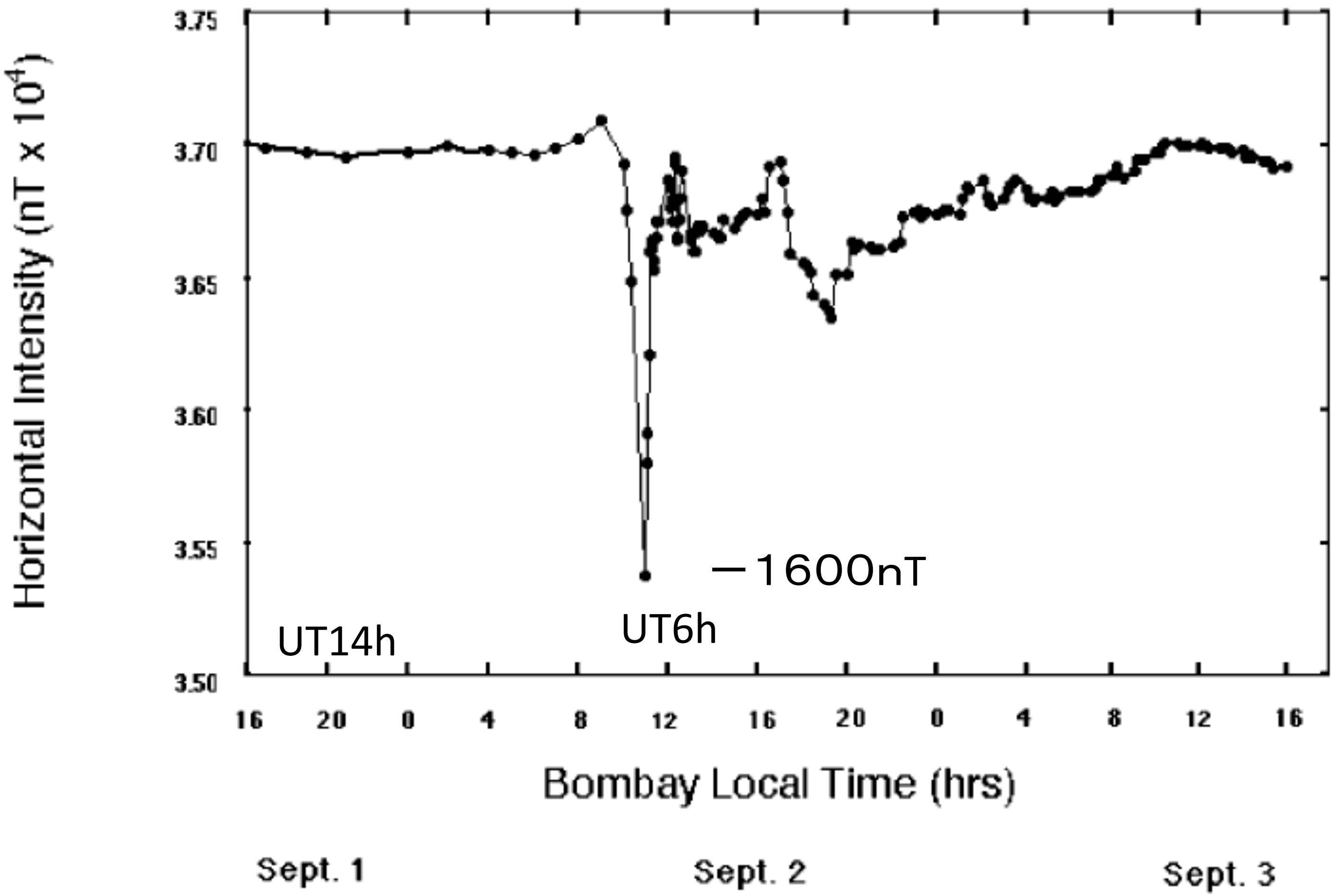


Figure 3. The Colaba (Bombay) magnetogram for the 1–2 September 1859 magnetic storm.

Cf) Blackout on 1989 March 13 (Canada, Quebec)

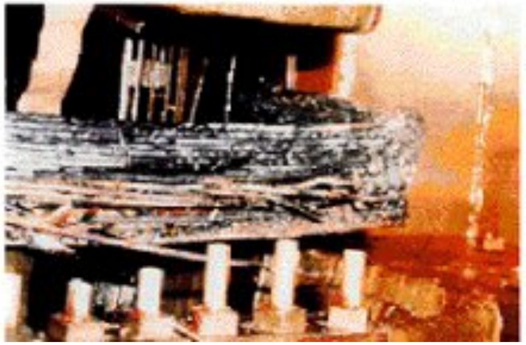
- Geomagnetic storms induce electrical currents that can have significant impact on electrical transmission equipment. Electric power companies have procedures in place to mitigate the impact of geomagnetic storms. However, in a worse-case scenario, a geomagnetic storm can result in a widespread blackout. On March 13, 1989, in Montreal, Quebec, 6 million people were without commercial electric power for 9 hours as a result of a huge geomagnetic storm.

http://www.noaawatch.gov/themes/space.php

Magnetic storm ~ 540 nT

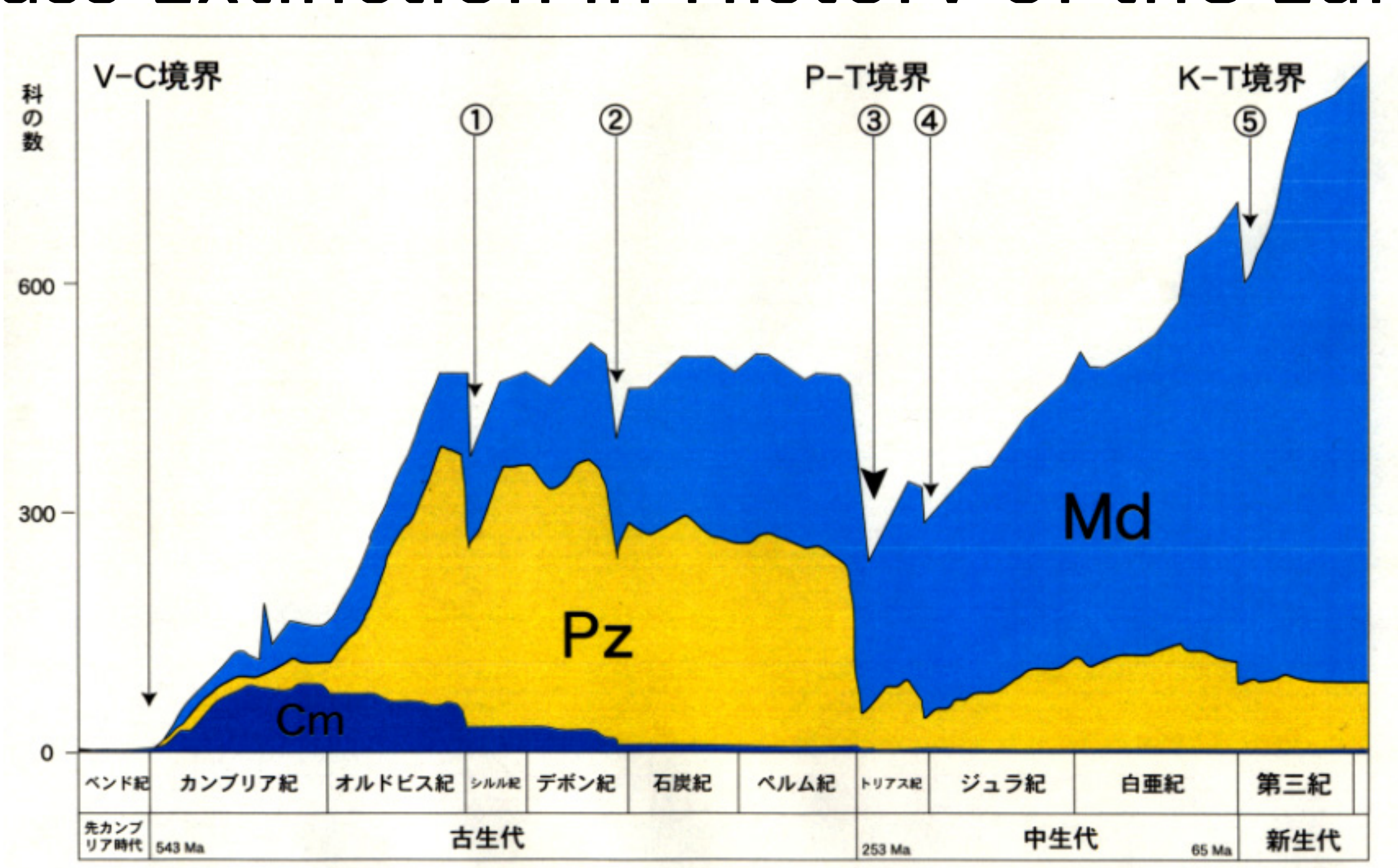
PJM Public Service
Step Up Transformer

Severe internal damage caused by the space storm of 13 March, 1989



生命の大量絶滅

Mass Extinction in History of the Earth



5億4千万年前　2億5千万年前　6500万年前

Md=現代型、Pz＝古生代型、Cm＝カンブリア紀型

磯崎氏より

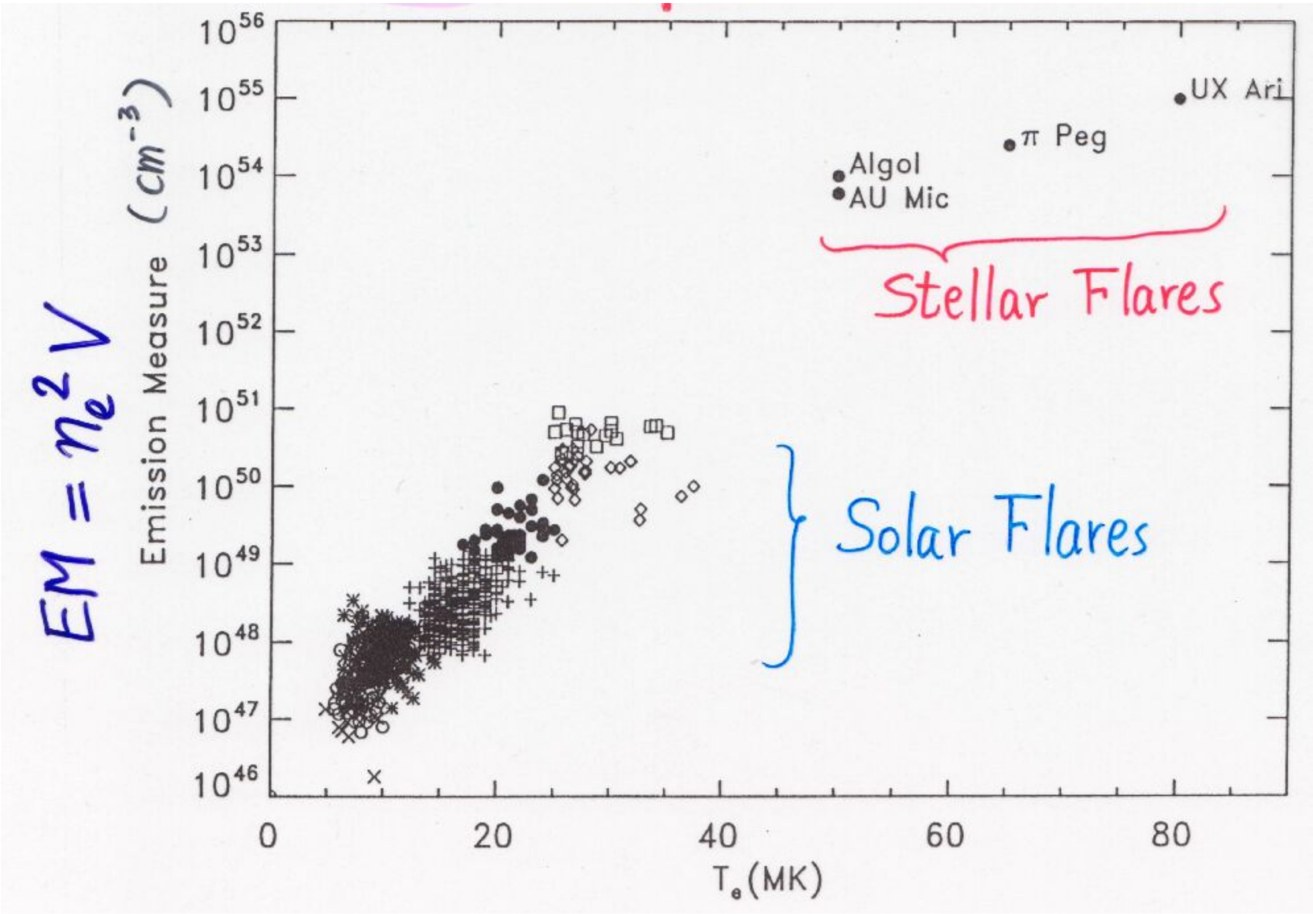
Stellar flares

Can stellar and protostellar flares be explained by magnetic reconnection mechanism ?

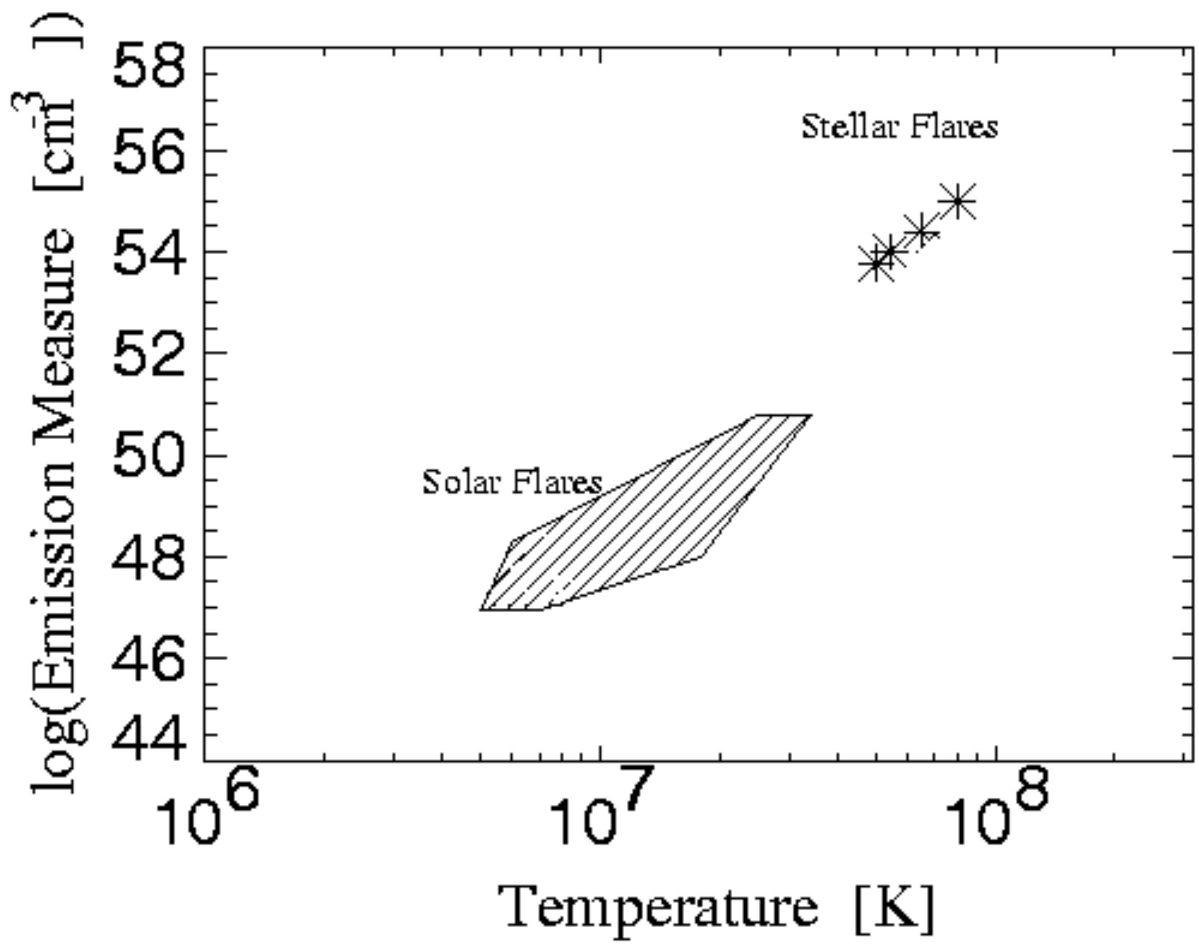
- Yes !
- Indirect evidence has been found in empirical correlation between Emission Measure ($EM = n^2 L^3$) and Temperature (Shibata and Yokoyama 1999, 2002)

Emission Measure（EM＝n^2V）of Solar and Stellar Flares increases with Temperature（T）

（n：electron density、V： volume）(Feldman et al. 1995)



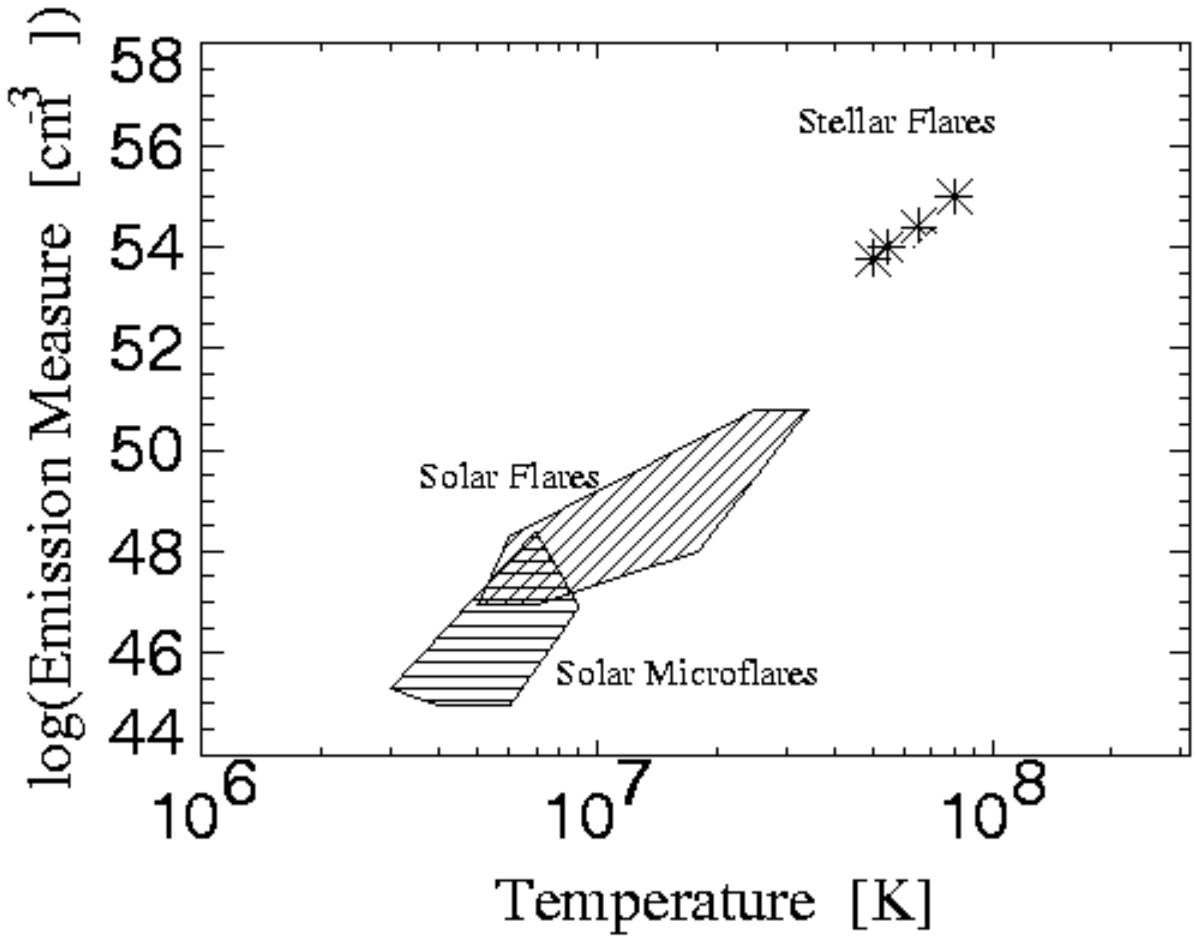
EM－T relation of Solar and Stellar Flares



Log-log plot of Feldman etal (1995)'s figure

Shibata and Yokoyama, 1999, 2002

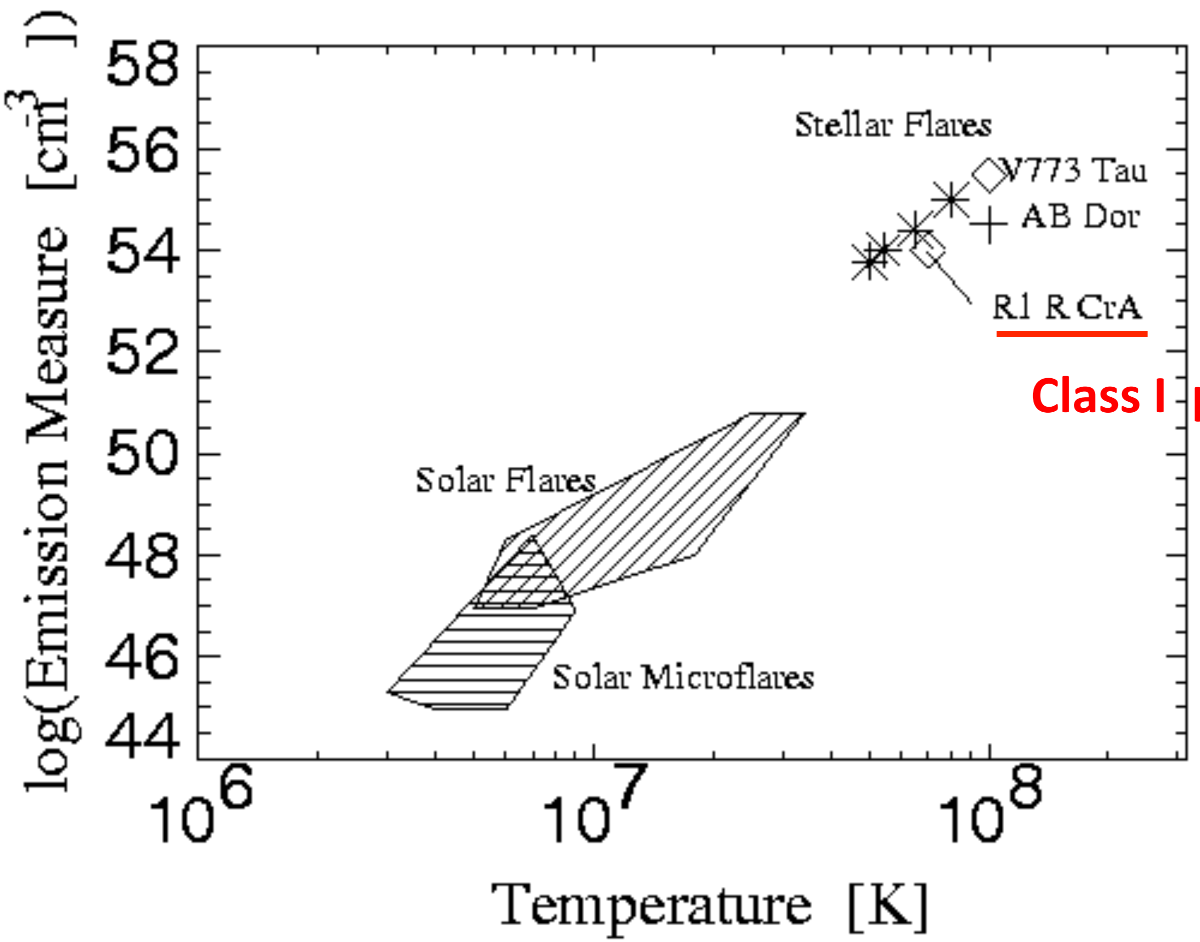
EM－T relation of Solar and Stellar Flares



microflare
(Shimizu 1995)

Shibata and Yokoyama, 1999, 2002

young-star and protostellar flares



Tsuboi (1998)
Pallavicini (2001)
Koyama (1996)

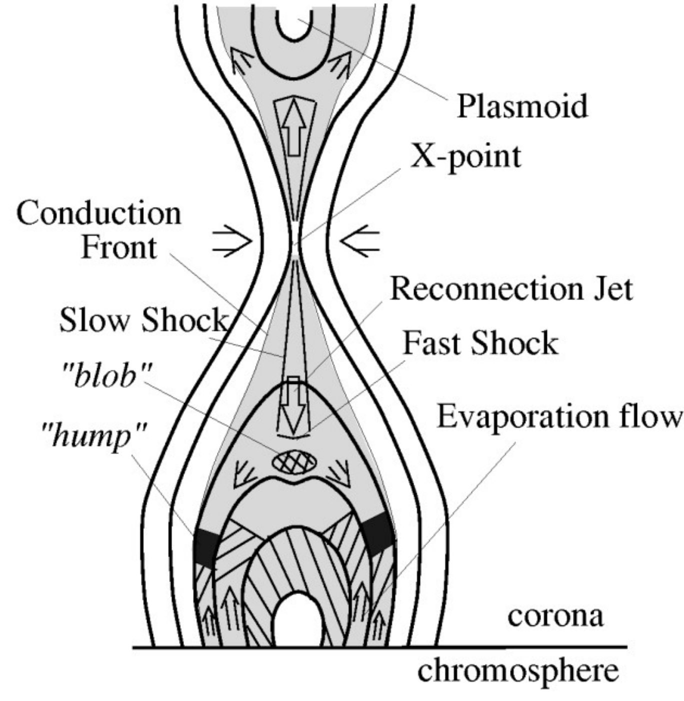
Shibata and Yokoyama (1999) ApJ 526, L49

Flare Temperature Scaling Law

- Reconnection heating＝conduction cooling
  (Yokoyama and Shibata 1998)

$$B^2 V_A / 4\pi = \kappa T^{7/2} / 2L$$

$$T \propto B^{6/7} L^{2/7}$$



Flare Emission Measure

(Shibata and Yokoyama 1999)

- Emission Measure

$$EM = n^2 L^3$$

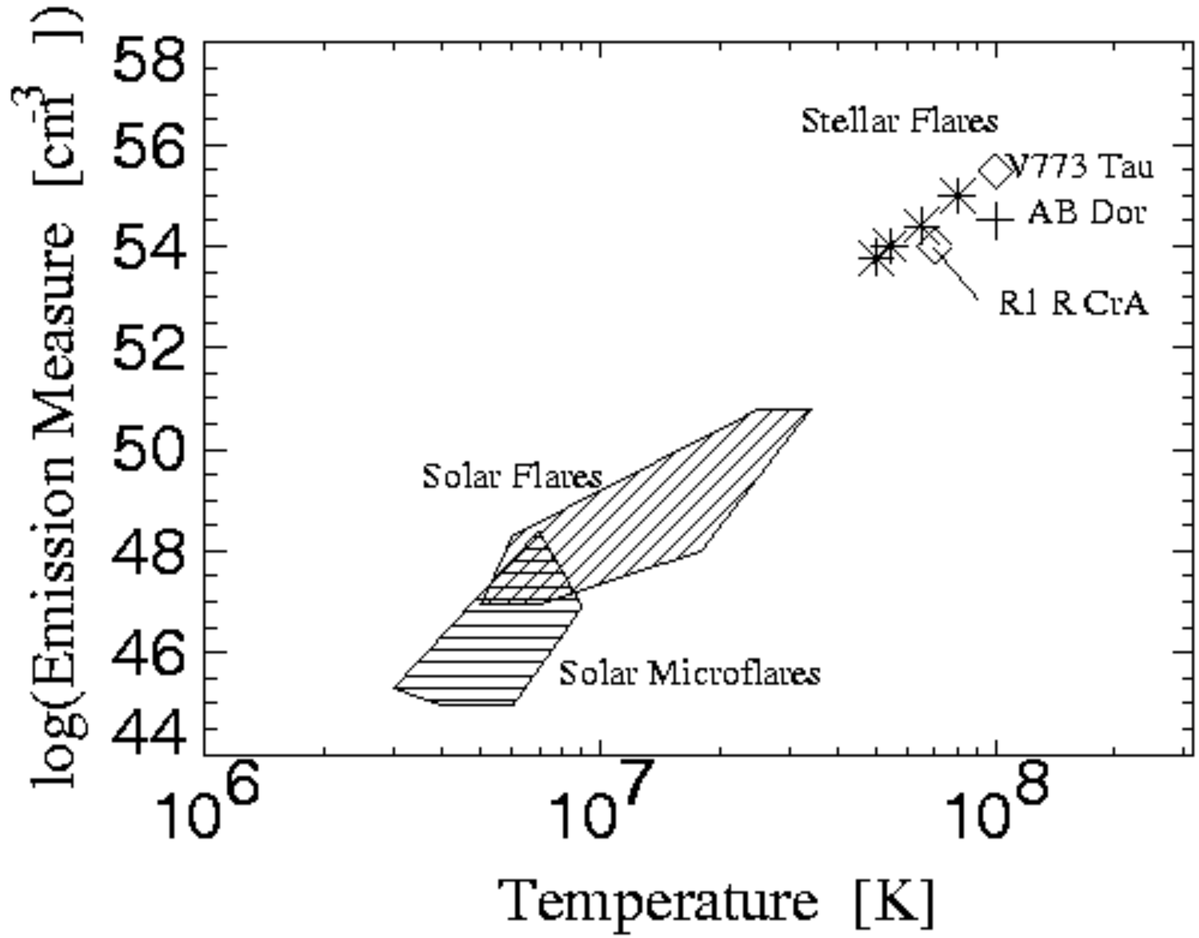
- Dynamical equilibrium (evaporated plasma must be confined in a loop)

$$2nkT = B^2 / 8\pi$$

- Using Flare Temperature scaling law, we have

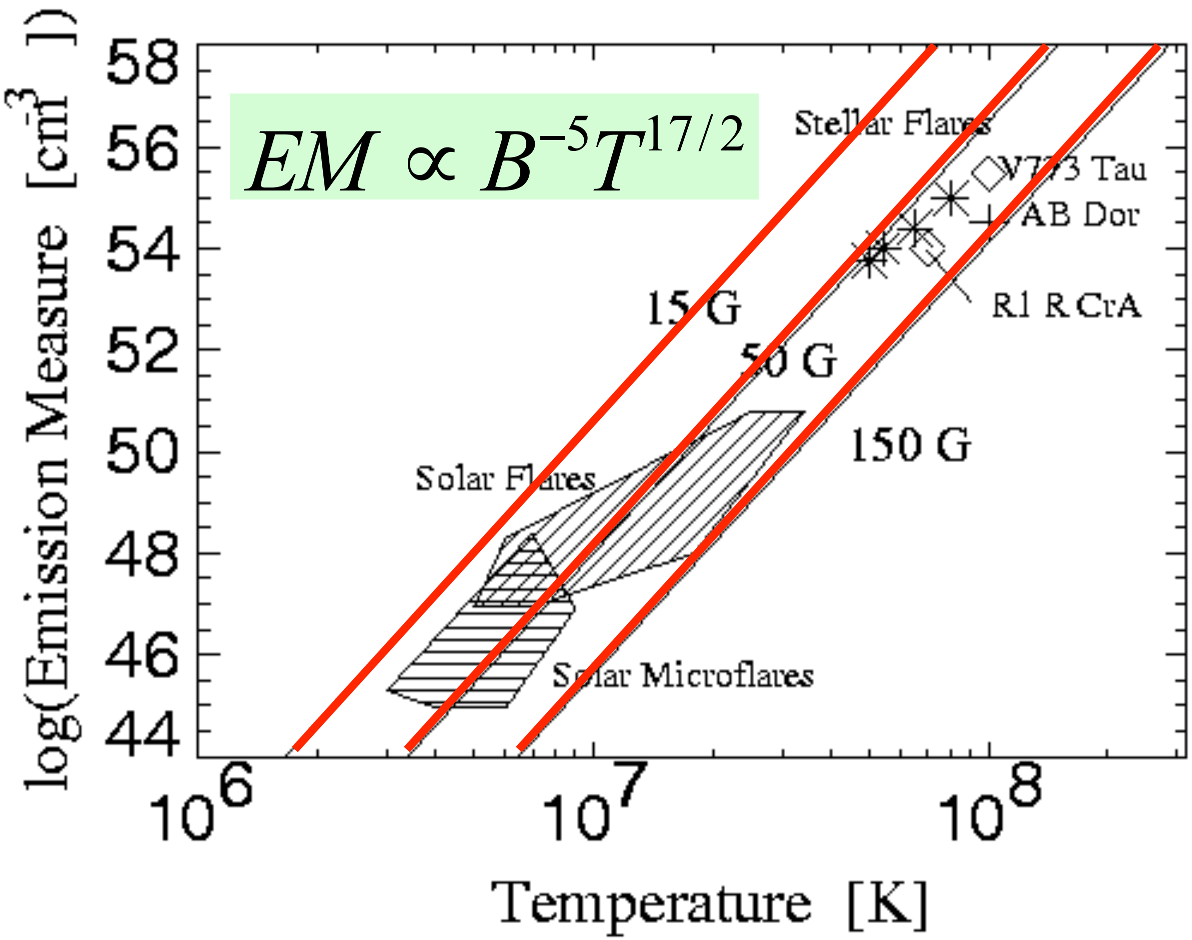
$$EM \propto B^{-5} T^{17/2}$$

EM-T correlation for solar/stellar flares



Shibata and Yokoyama (1999,

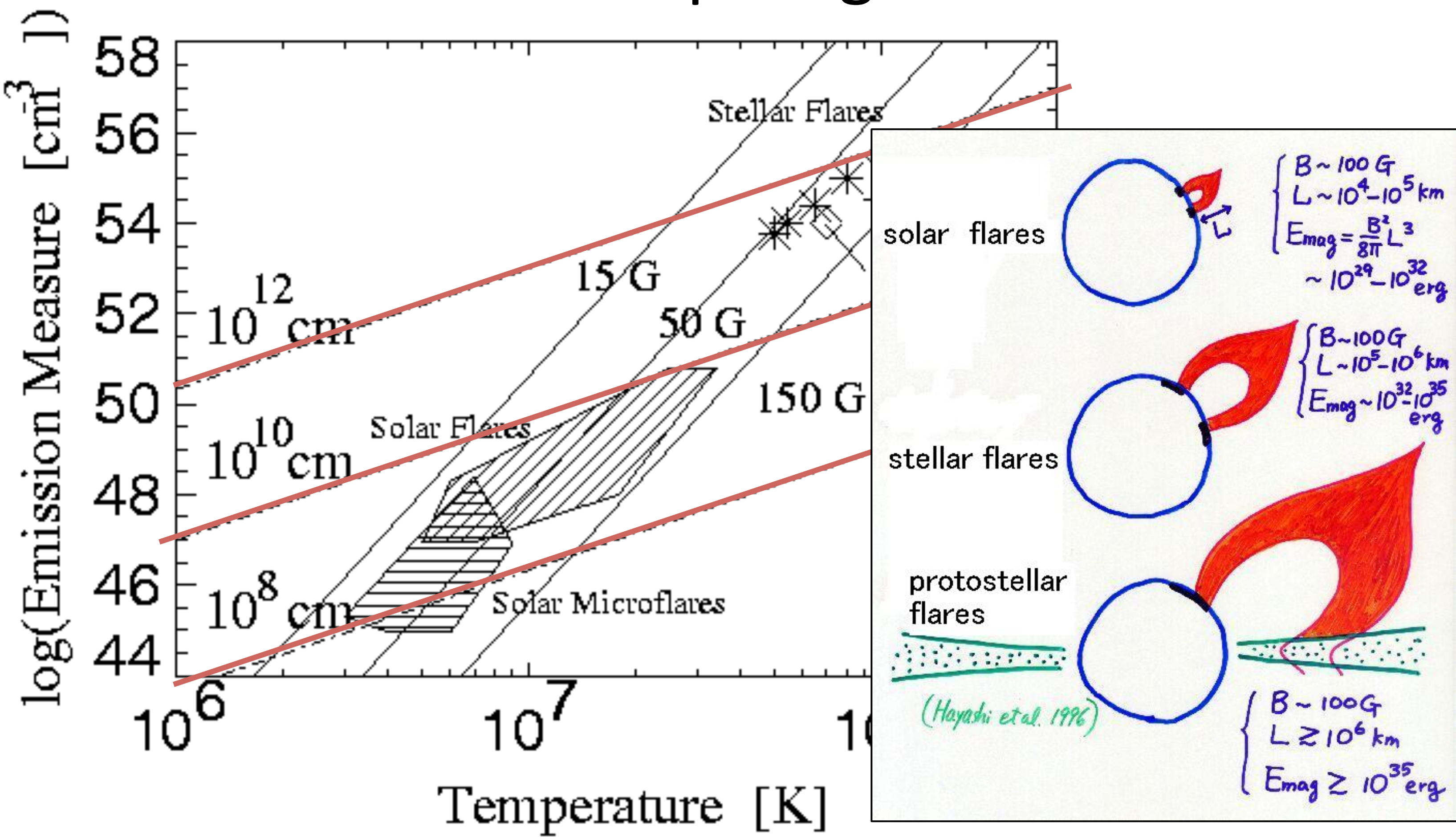
Magnetic field strength（B）＝constant



Magnetic field strengths of solar and stellar flares are comparable ~ 50-100 G

Shibata and Yokoyama (1999,

Q: What determines the total energy of flares ?
A: It is the loop length.



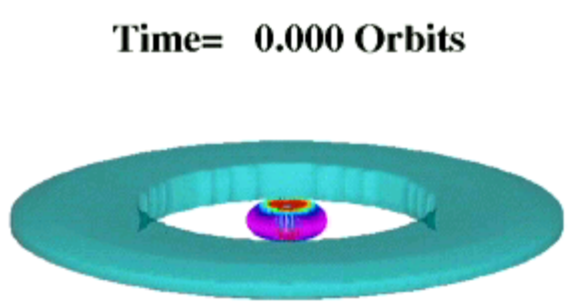
The reason why stellar flares are hot
=> loop lengths of stellar flares are large

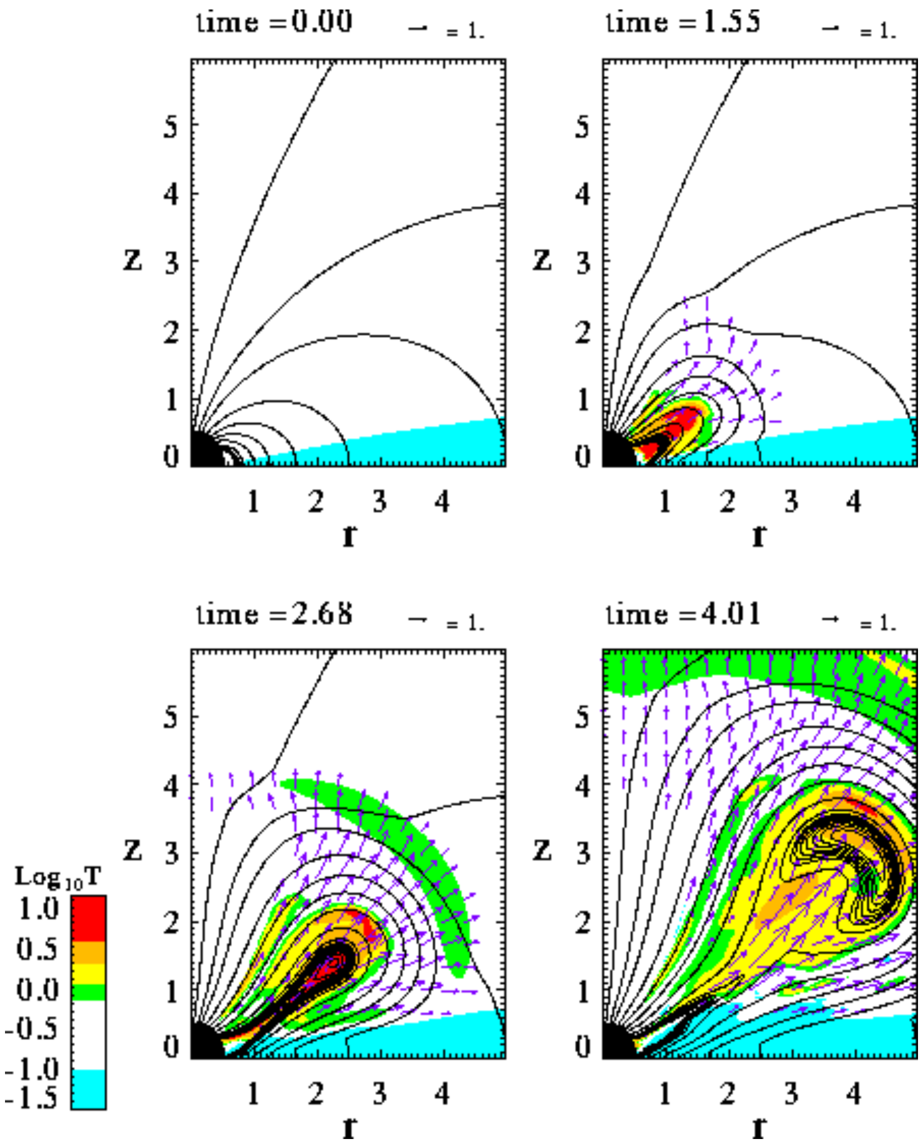
Cf   Isobe et al. 2003,
Kawamiti et al. 2008

Shibata and Yokoyama (2002)

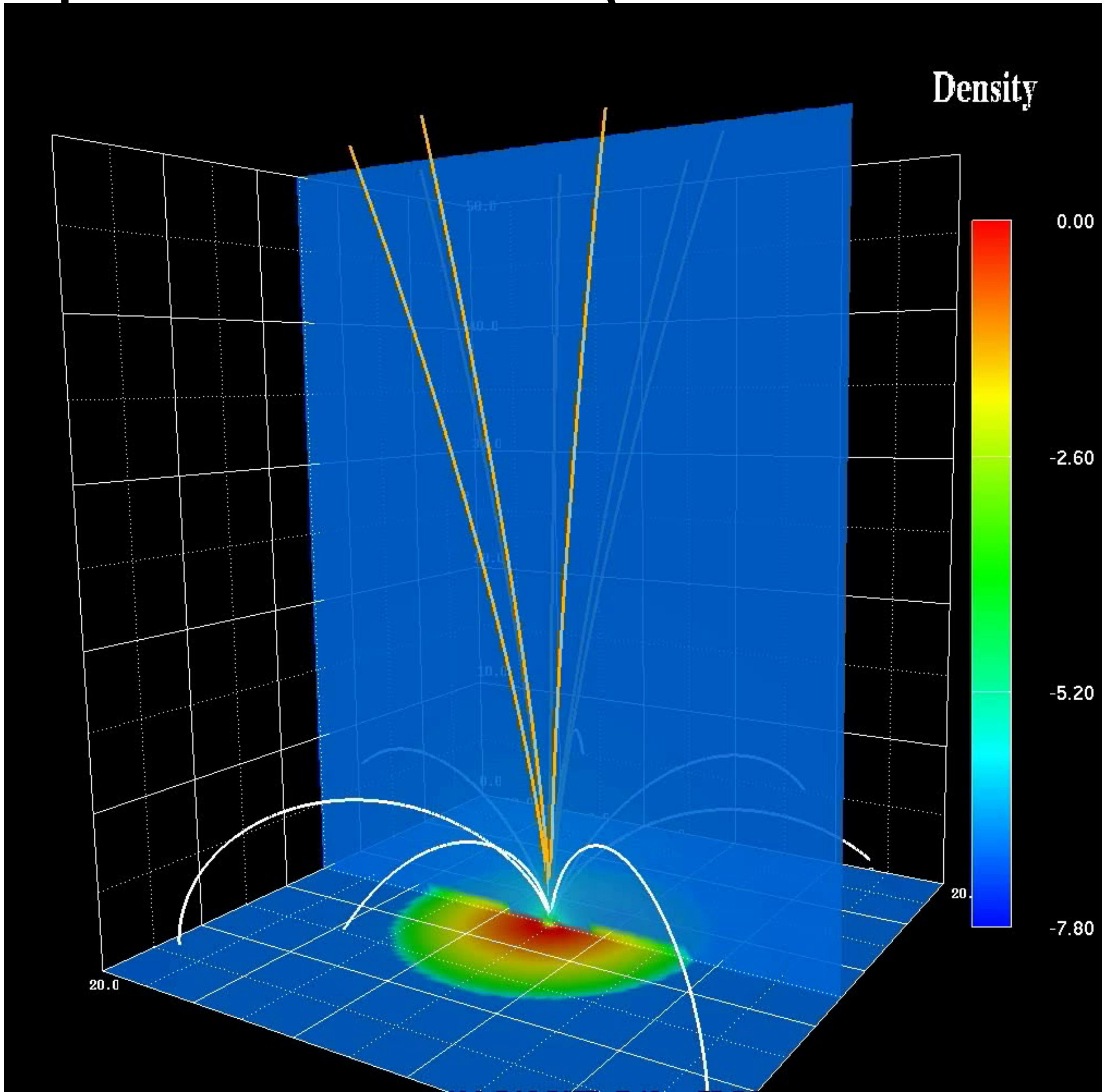
reconnection model of protostellar flare and jets

(Hayashi, Shibata, Matsumoto 1996)

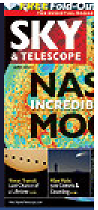




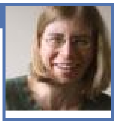
Protostellar jet evolving from a superflare CME (Uehara 2005)



SKY & TELESCOPE
THE ESSENTIAL MAGAZINE OF ASTRONOMY



HOMEPAGE NEWS by Monica Young



Superflares from Sun-like Stars

NASA's Kepler mission is finding solar-type stars that emit jaw-dropping explosions of high-energy particles and radiation. Now astronomers are looking into why some solar-type stars emit superflares — and why the Sun never will.

In 1859 the Sun emitted the most powerful flare in recorded history, the so-called Carrington event. Energetic particles danced off telegraph lines, creating sparks that shocked operators and ignited fires in telegraph paper. Brilliant aurora were seen as far