Superflares on Solar type Stars and Their Implications on the Possibility of Superflares on the Sun

Kazunari Shibata

Kwasan and Hida Observatories,

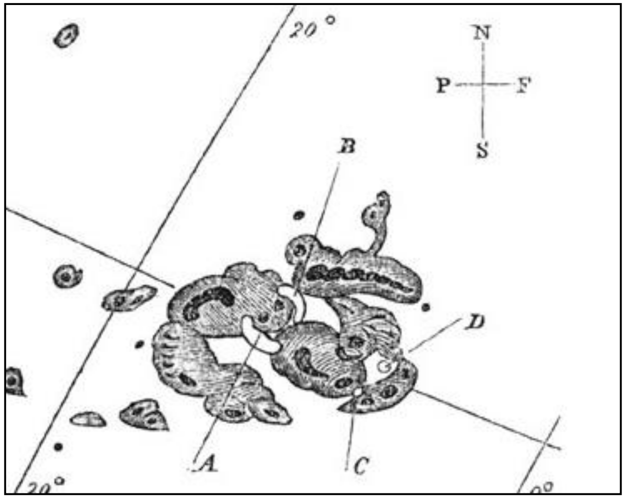
Kyoto University, Kyoto, Japan

Collaborators : Takuya Takahashi, Hiroaki Isobe, Hiroyuki Maehara, Takuya Shibayama, Yuta Notsu, Shota Notsu, Satoshi Honda, Daisaku Nogami

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.

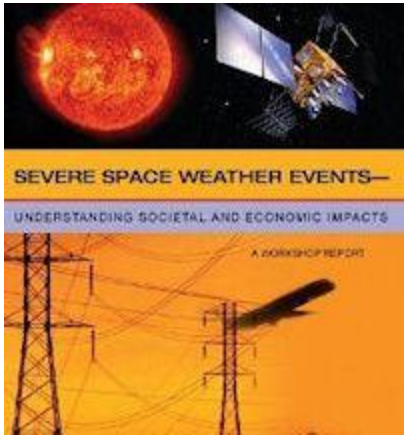


Telegraph systems all over Europe and North America failed.
Telegraph pylons threw sparks and telegraph paper spontaneously caught Fire （Loomis　1861）

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

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

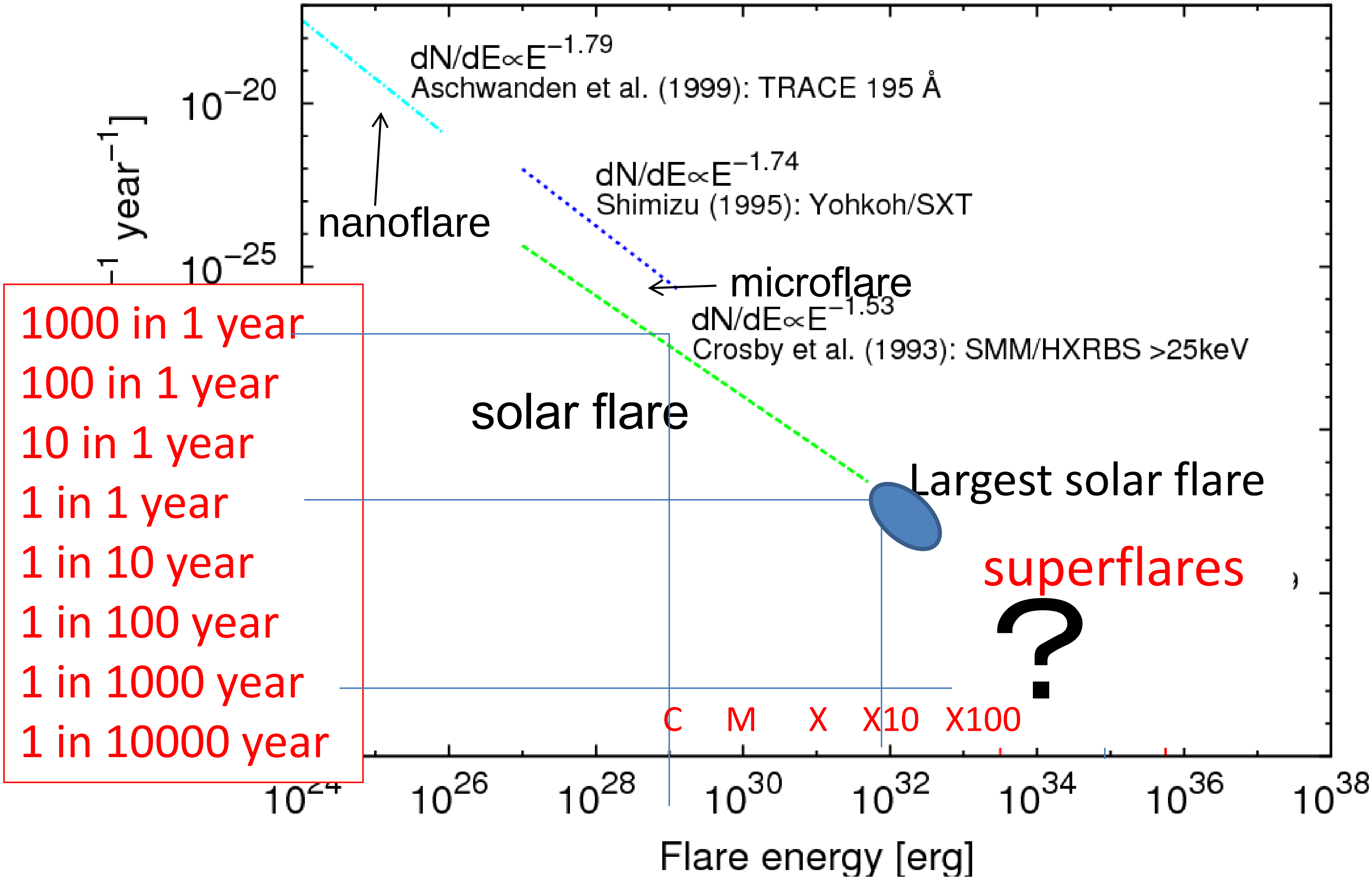
Will the Carrington-class flare occur again ?

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.

statistics of occurrence frequency of solar flares, microflares, nanoflares



How can we observe superflares on the Sun ?

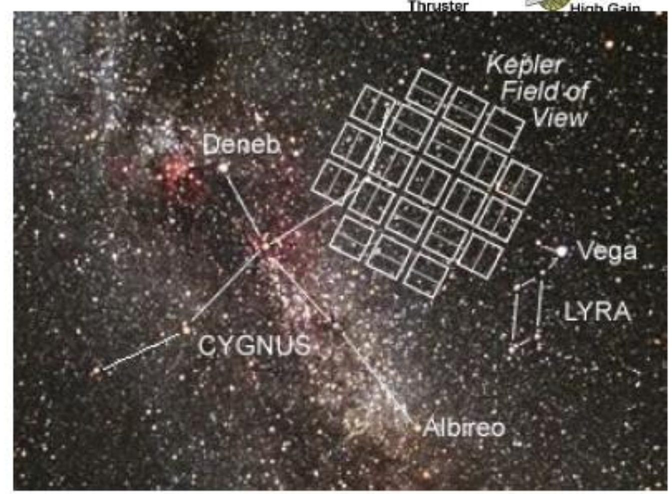
- If empirical statistics rule of solar flares is applied to much larger flares (superflares), then the frequency of superflares with energy 1000 times larger than the largest solar flares might occur once in 10000 years.
- However, the period of modern observations of the Sun with telescope is only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

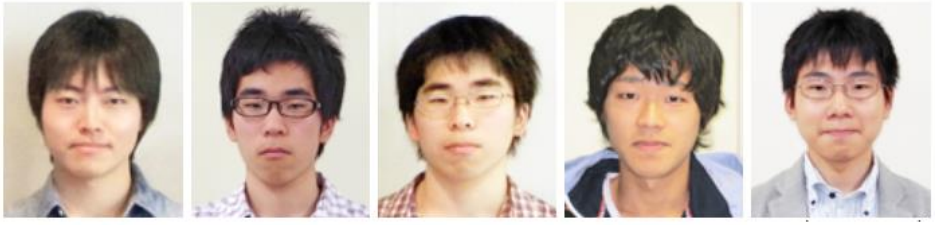
- Space mission to detect exoplanets by observing transit of exoplanets
- 0.95 m telescope
- Observing 160,000 stars continuously (from 2009 to 2013). Among them, 80000 are solar type stars.
- ~30 min time cadence (public data)



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

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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

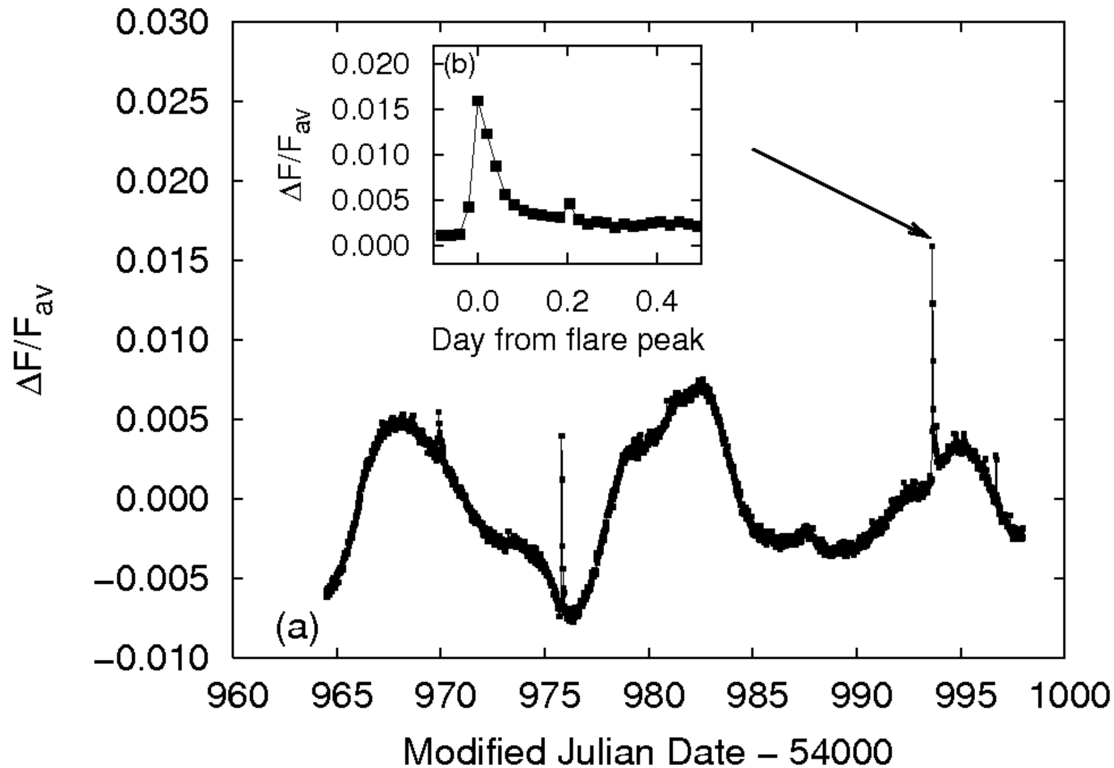
Solar flares are caused by the sudden release of magnetic energy stored near sunspots. They release 10^{29} to 10^{32} ergs of energy on a timescale of hours[1]. Similar flares have been observed on many stars, with larger 'superflares' seen on a variety of stars[2,3], some of which are rapidly rotating[4,5] 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 $\leq T_{\mathrm{eff}} <$ 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 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



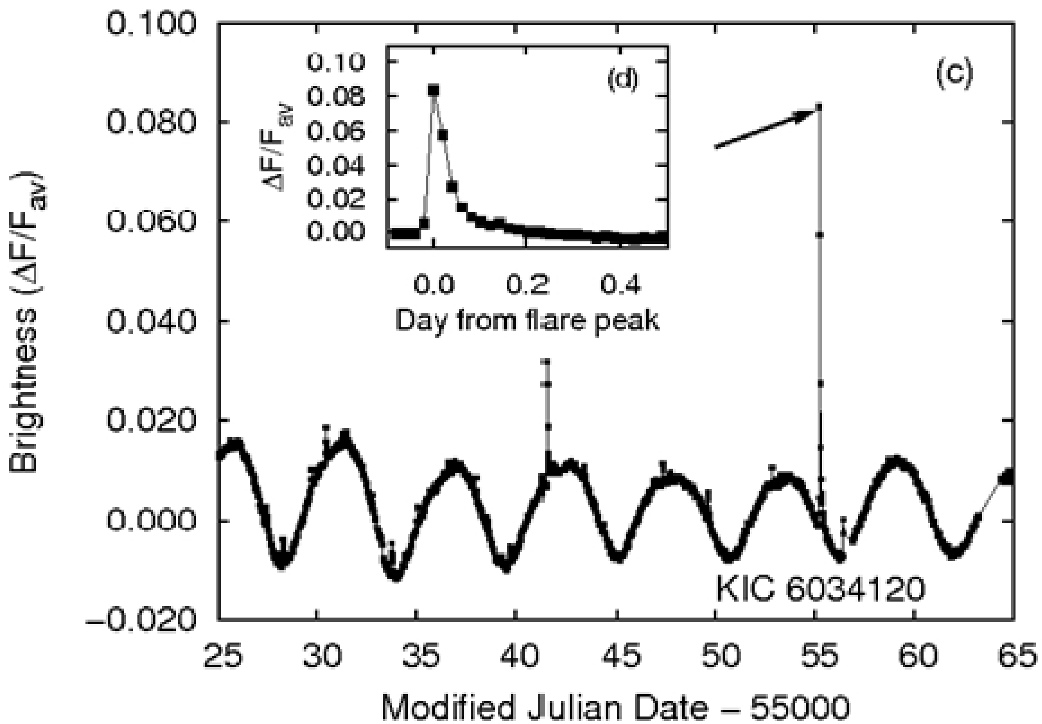
Time (day)

Total energy ~ 10^35 erg

Maehara et al. (2012)

typical superflare observed by Kepler

Brightness of a star and a flare



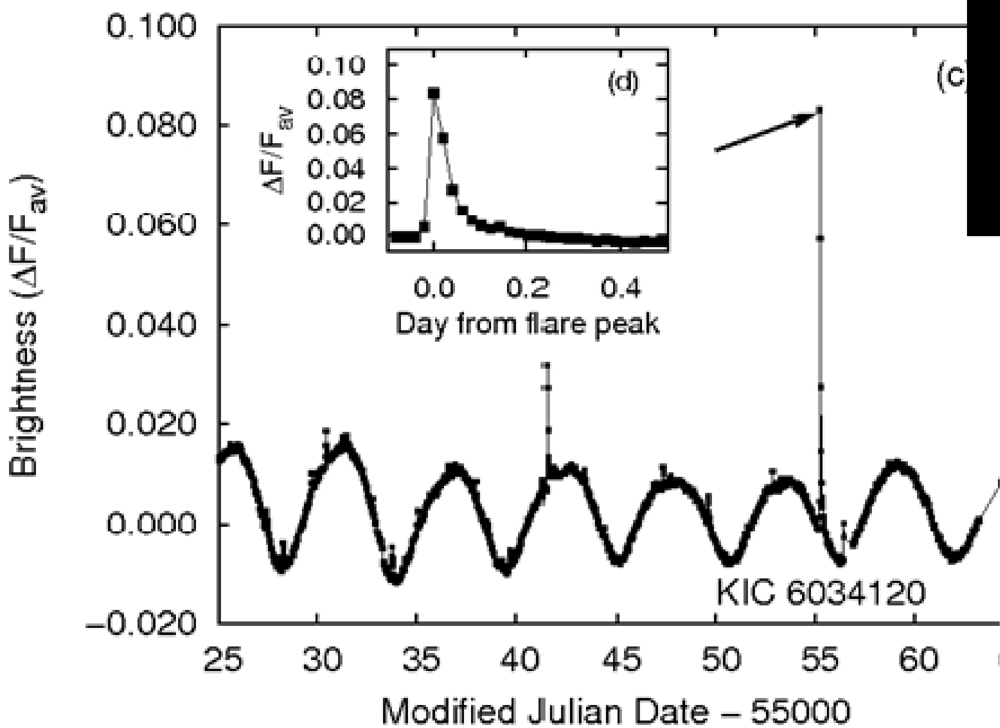
Total energy ~ 10^36 erg

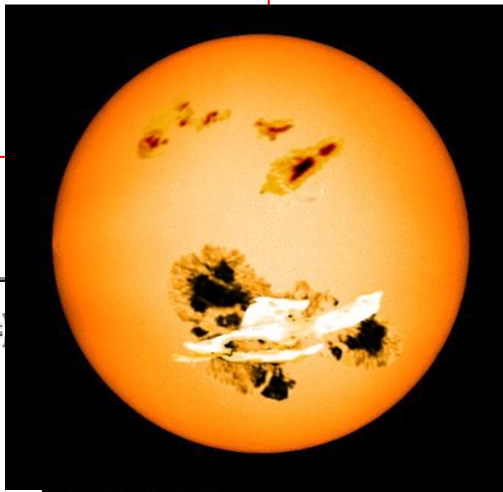
Time (day)

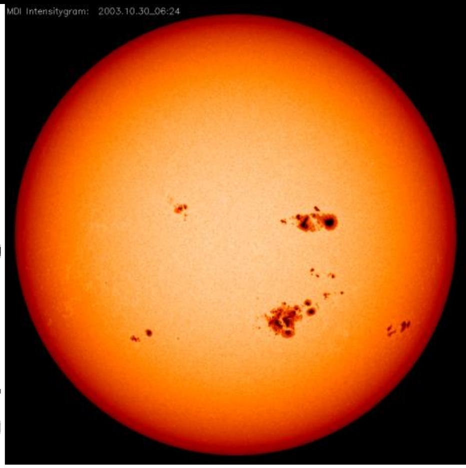
Maehara et al. (2012)

What is the cause of stellar brightness variation ?

Brightness
of a star
and a flare

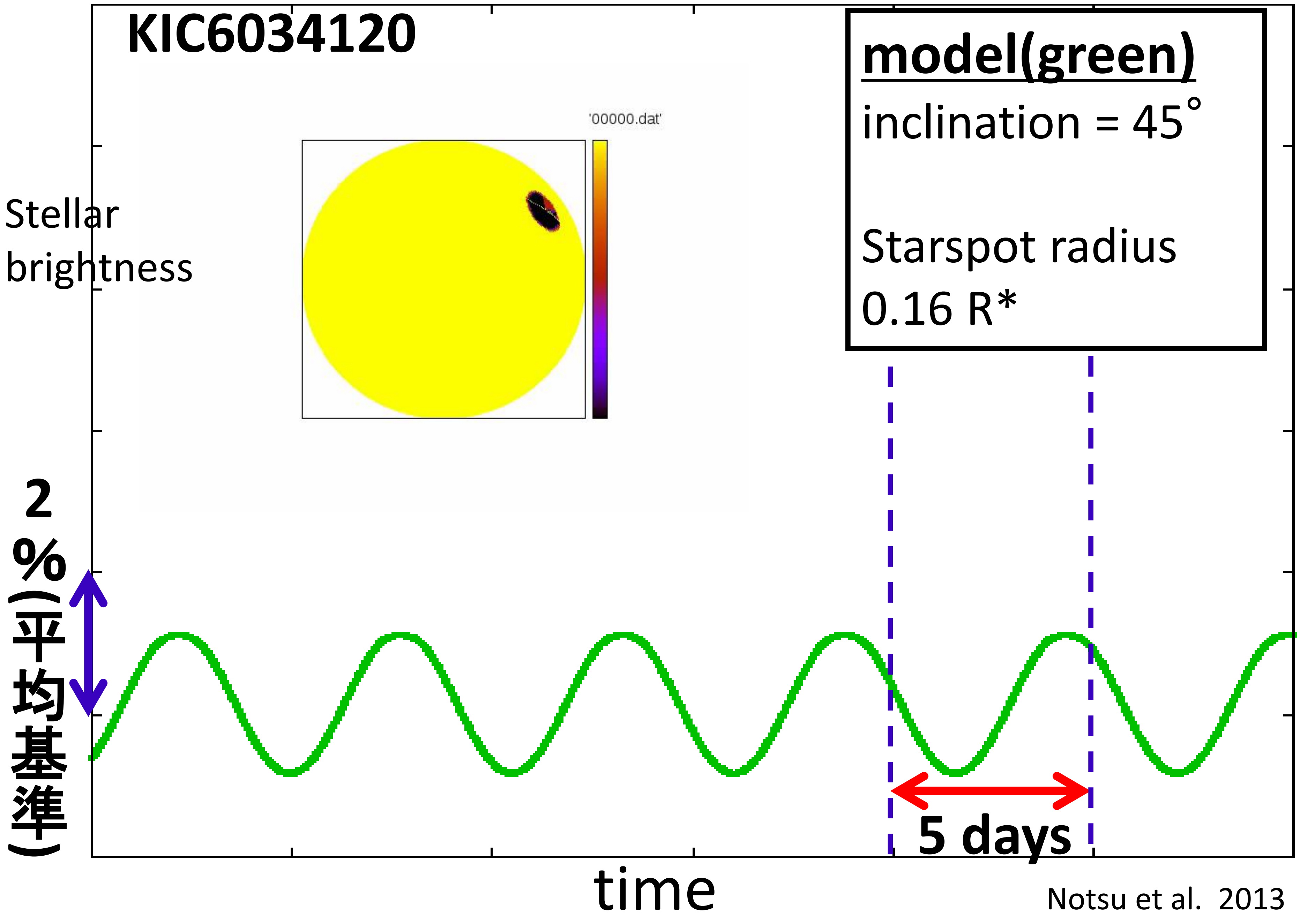




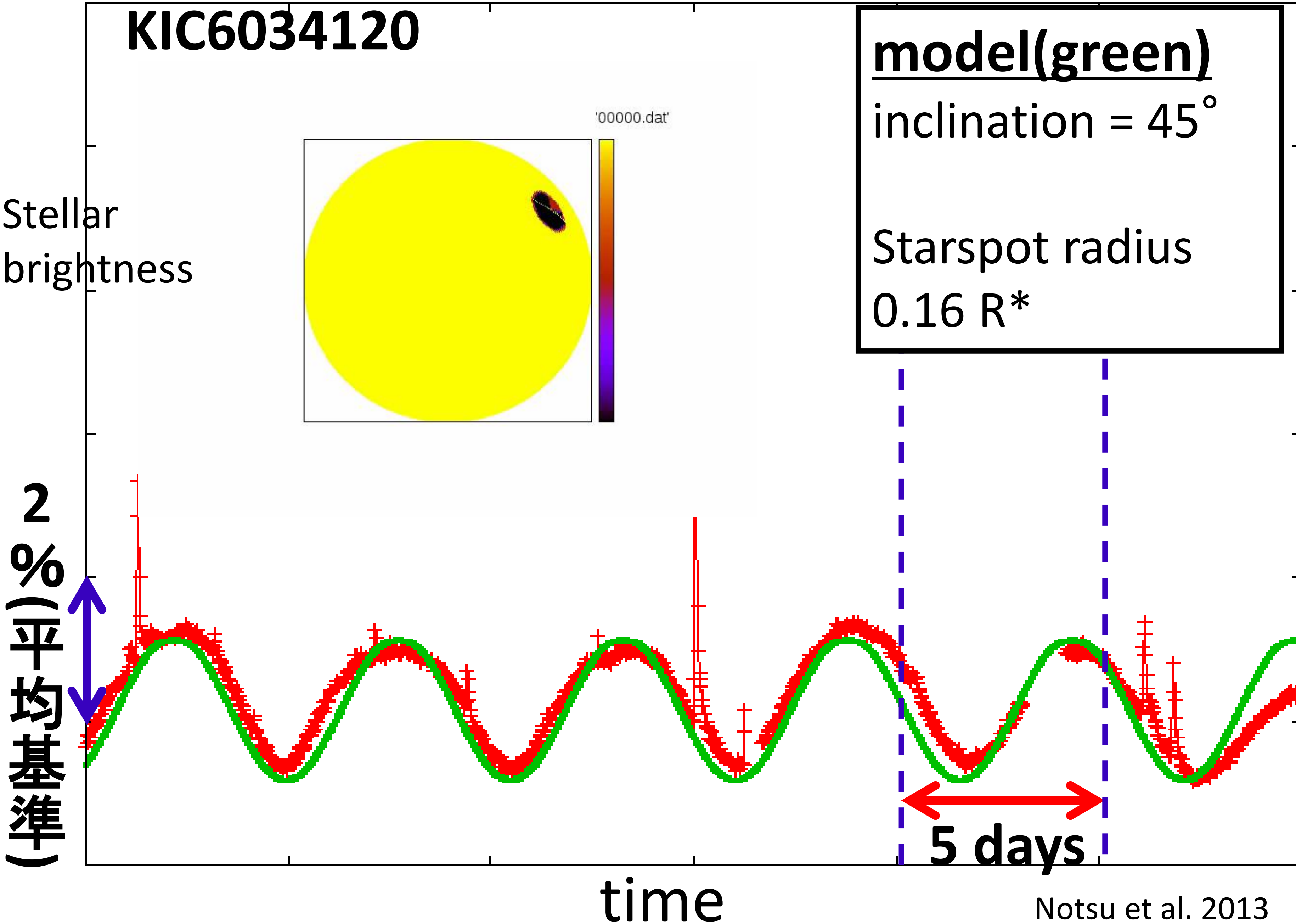


It is likely due to rotation of a star with a big star spot

Model calculation of stellar brightness variation

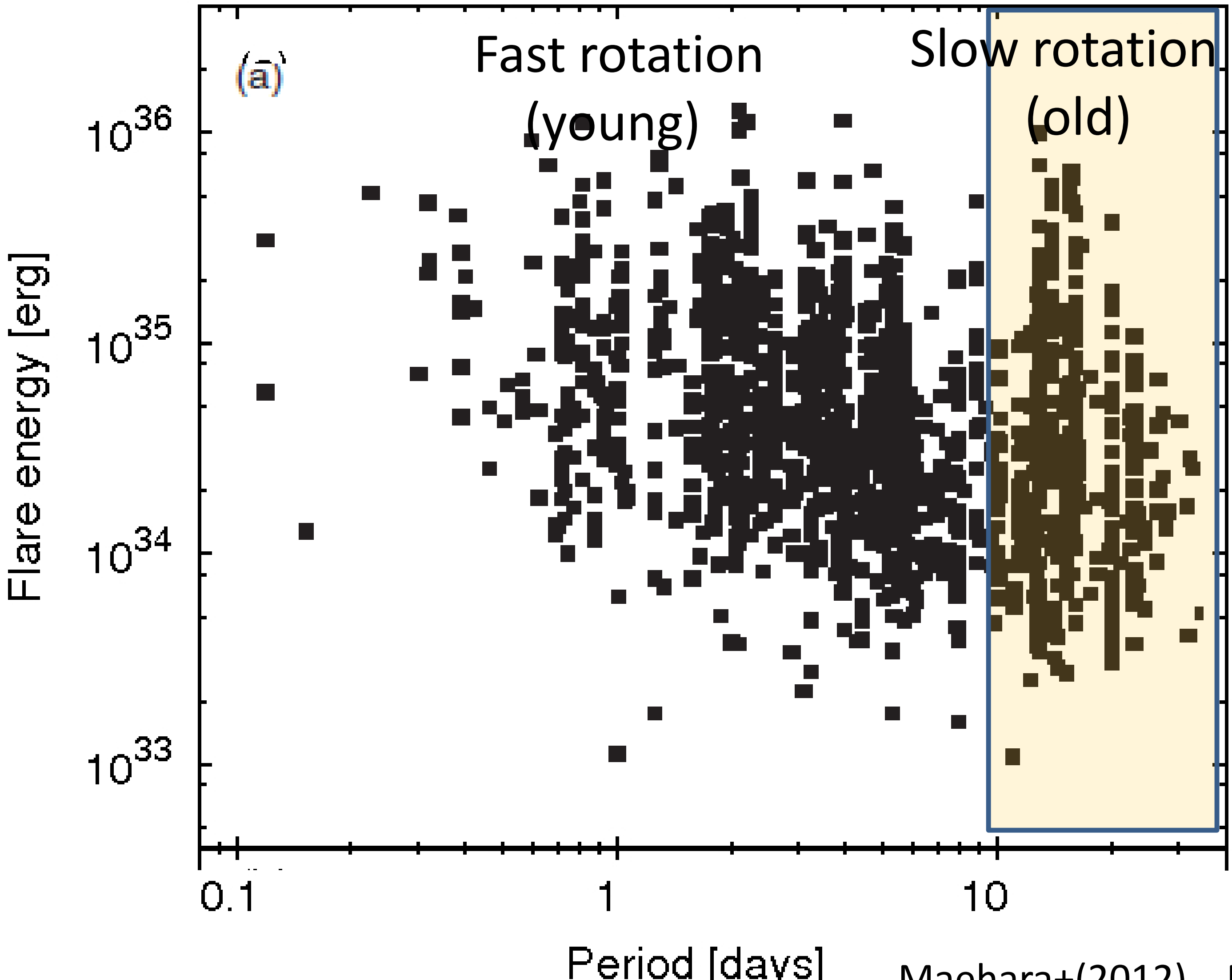


Model calculation of stellar brightness variation



Notsu et al. 2013

Flare energy vs rotational period



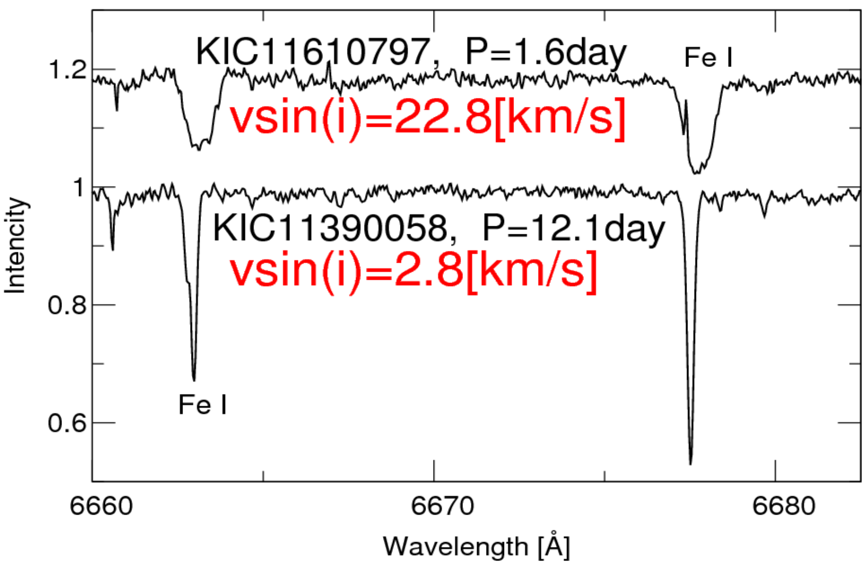
Stars with period longer than 10 days

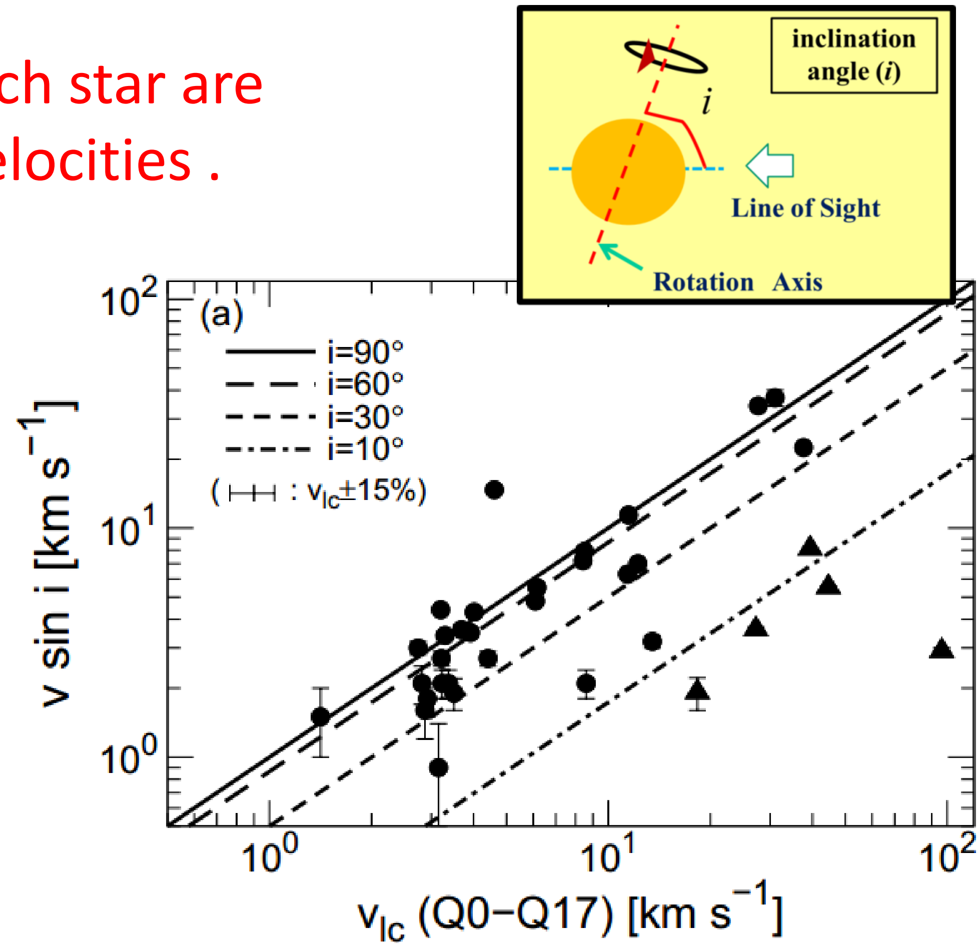
cf solar rot period ~ 25days

Maehara+(2012), Notsu+ (2013)

Spectroscopic Obs of Rotation velocity (Notsu et al. 2015)

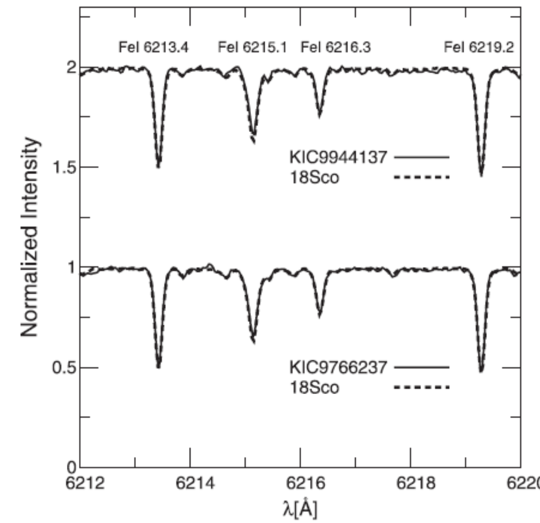
- We performed high-dispersion spectroscopy of 50 superflare stars with Subaru telescope.
- Photometric periods of each star are consistent with rotation velocities .





Notsu et al. 2015.

Two Sun-like Superflare Stars Rotating as Slow as the Sun (Nogami et al. 2014)



Using spectroscopic observations, the rotational period of two superflare stars (Eflare = 10^34 erg) has been determined as

KIC 9766237 P_rot = 21.8 d

KIC 9944137 P_rot = 25.3 d

=> very similar to the Sun !

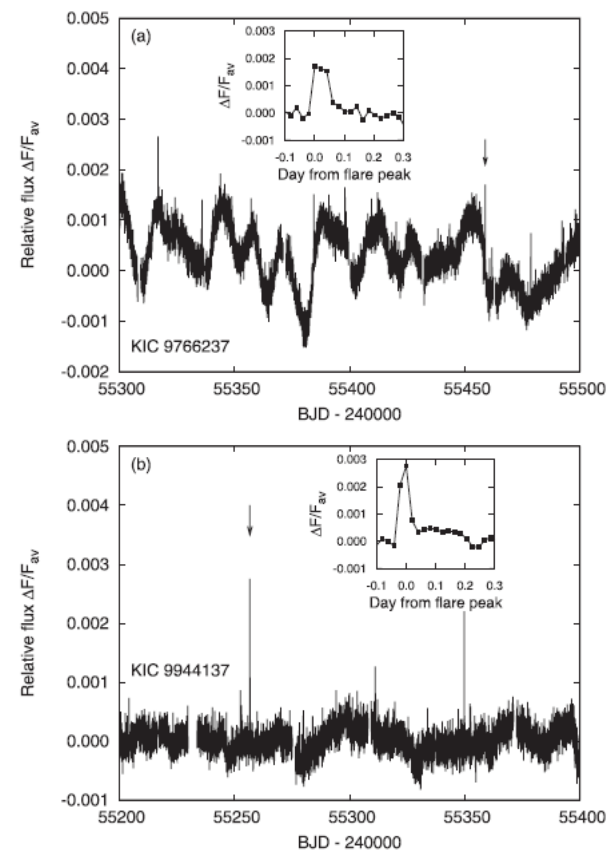
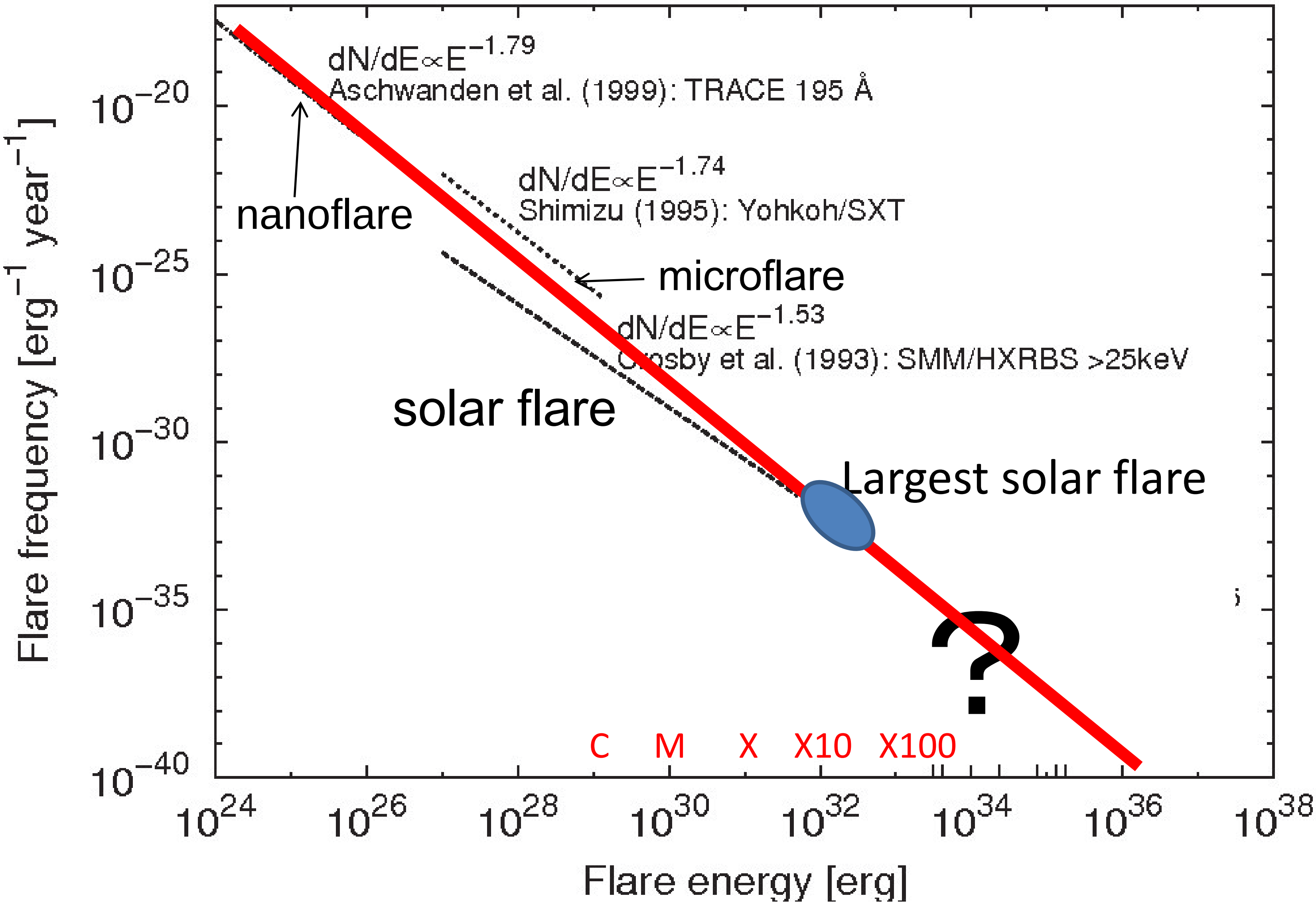


Fig. 1. (a) Typical light curve of KIC 9766237 drawn with the long cadence Kepler data. The *y*-axis represents the relative flux normalized by the average flux: $(F - F_{av})/F_{av}$. Quasi-periodic modulations with a timescale of about 20 d are seen. A tick mark points out the superflare automat-

Comparison of statistics between solar flares/microflares and superflares

Shibata et al. 2013



Comparison of statistics between solar flares/microflares and superflares

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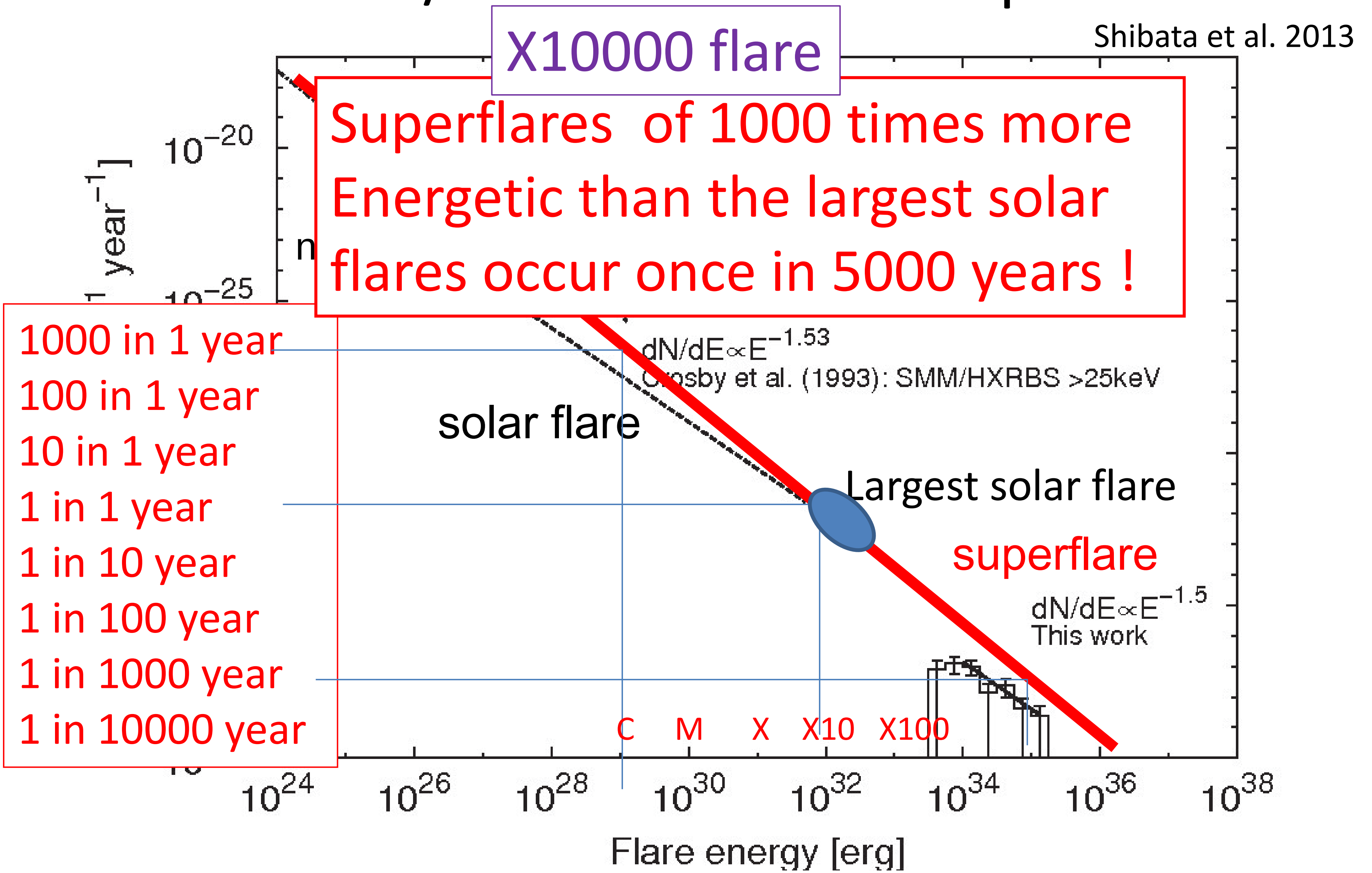


Evidence of superflare ?

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

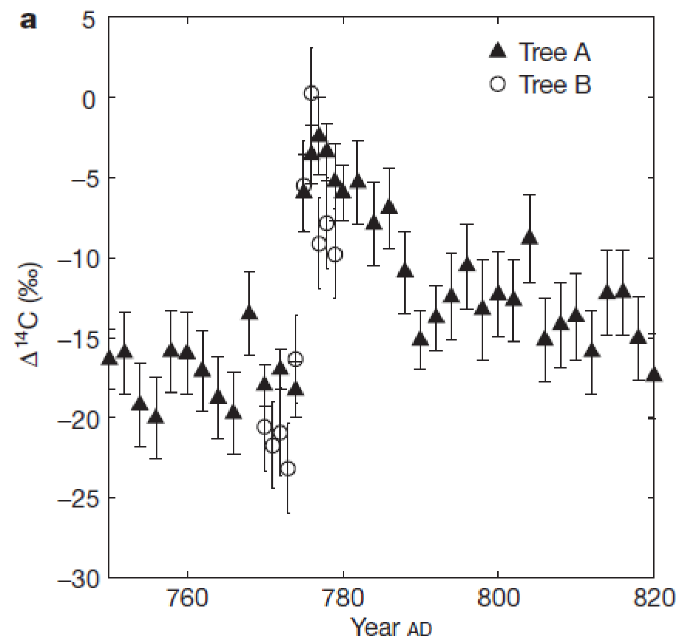


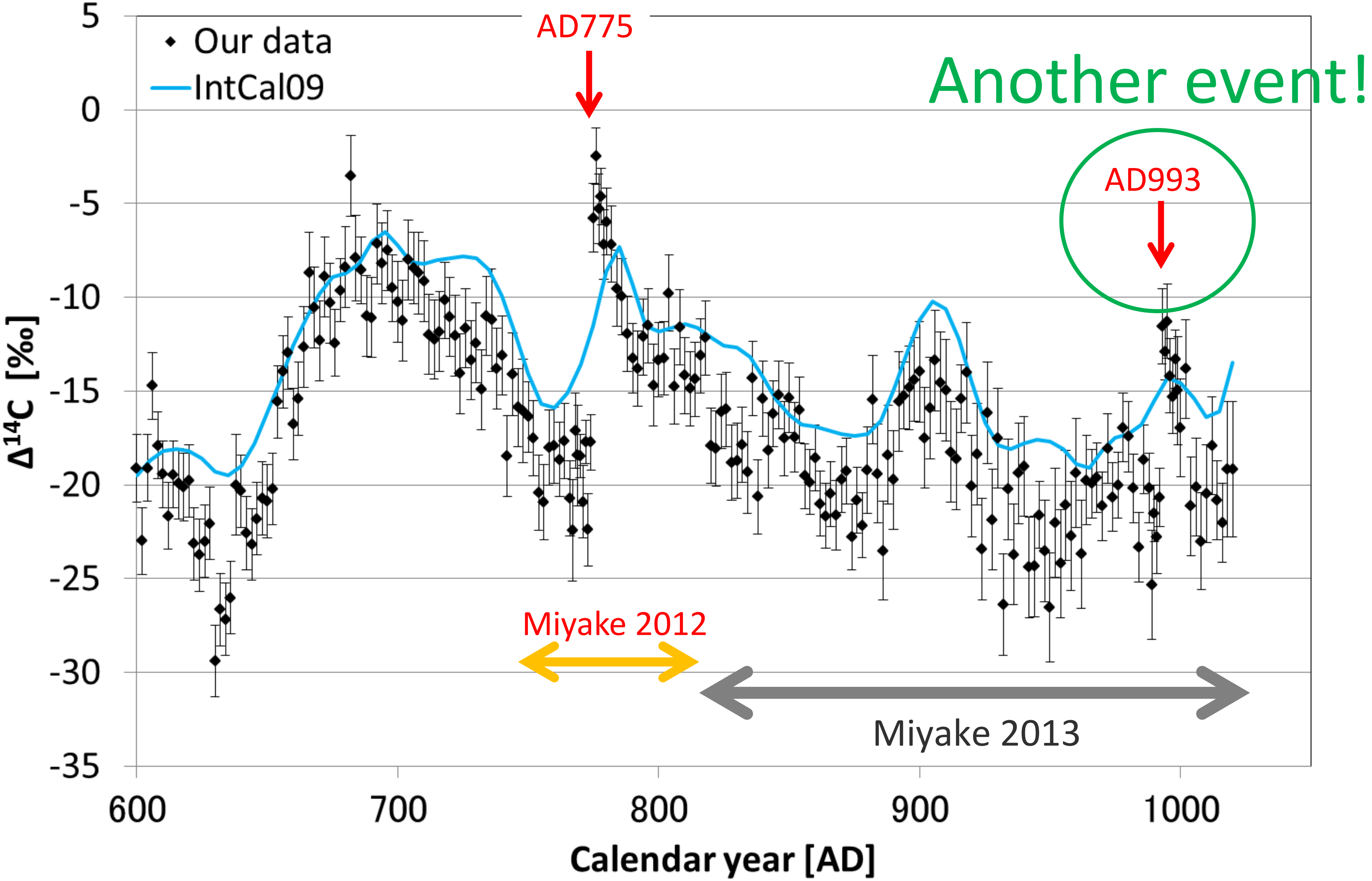
Figure 1 | Measured radiocarbon content and comparison with IntCal98. The concentration of ^{14}C is expressed as $\Delta^{14}C$, which is the deviation (in ‰) of the $^{14}C/^{12}C$ ratio of a sample with respect to modern carbon (standard sample), after correcting for the age and isotopic fractionation[30]. **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 ?

Summary

- Using Kepler data, we found 365 superflares (10^{33}-10^{36} erg) on 148 solar type stars (among 80000 stars) during 120 days (Maehara+ 2012).
  => 1547 superflares from 279 solar type stars during 500 days (Shibayama+ 2013).
- Superflares occur on Sun-like stars (5600-6000K and slow rotation) with frequency such that superflares with energy 10^{34}-10^{35} erg (100-1000 times of the largest solar flare) occur once in 800-5000 years
- There is no hot Jupiter around these superflare stars.
- These stars have big star spot (Notsu+ 2013).
- Rotational velocity and big star spot of 50 superflare stars has been confirmed by spectroscopic observations (Notsu+ 2015)
- Hence we cannot reject the possibility that superflares of 10^{34} – 10^{35} erg would occur once in 800 – 5000 years on the present Sun (Shibata+ 2013, Nogami+ 2014)

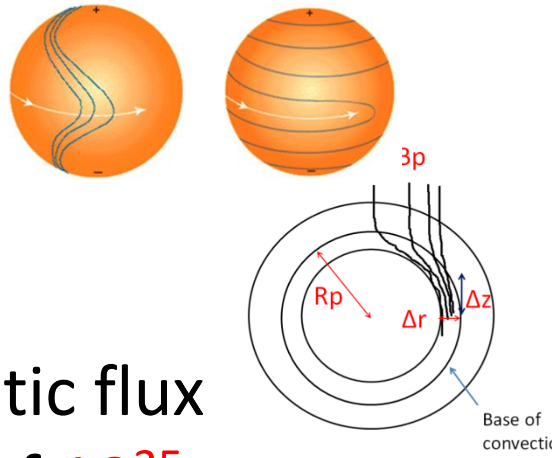
Thank you for your attention

Backup Files

Necessary time to generate magnetic flux producing superflares (Shibata et al. 2013)

$$\frac{d\Phi_t}{dt} \approx \frac{\Delta\Omega}{2\pi} \Phi_p \approx \frac{\Delta\Omega}{2\pi} B_p 2\pi R_p \Delta r$$

$$t \approx 40 \left(\frac{\Phi_t}{10^{24}\,Mx}\right)\left(\frac{\Phi_p}{10^{22}\,Mx}\right)^{-1}\left(\frac{\Delta\Omega}{5.6\times10^{-7}\,Hz}\right)^{-1} years$$



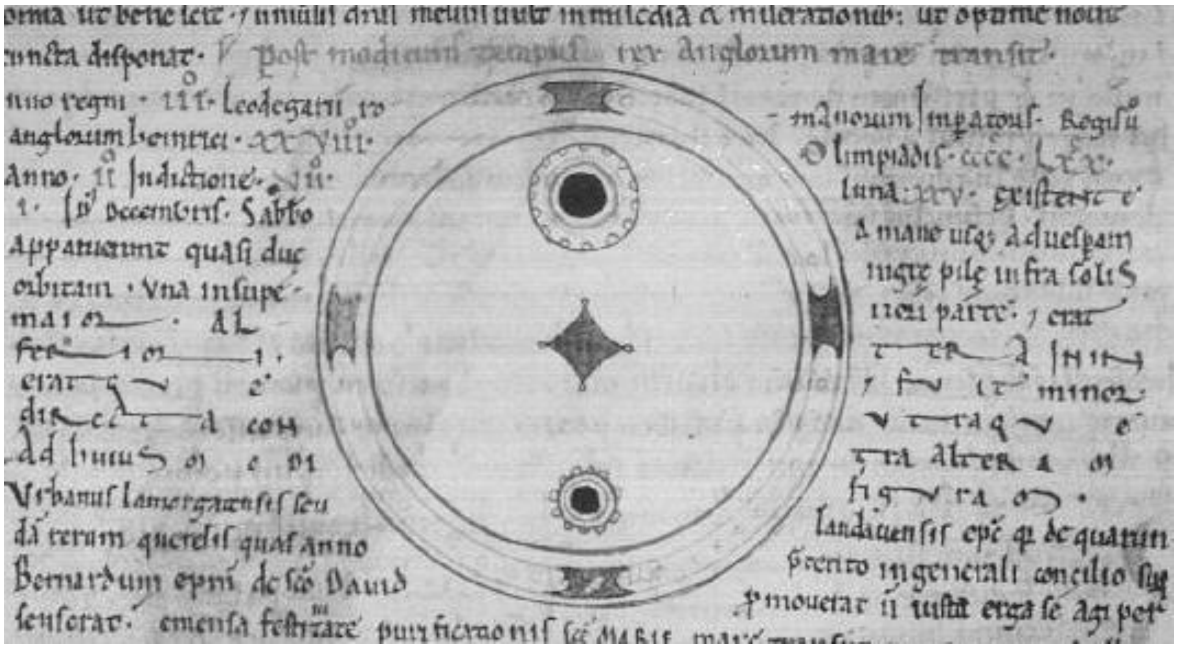
⇒The necessary time to generate magnetic flux of 10^{24} Mx that can produce superflares of 10^{35} erg are 40 years (<< 5000 years) (but > 11 years)

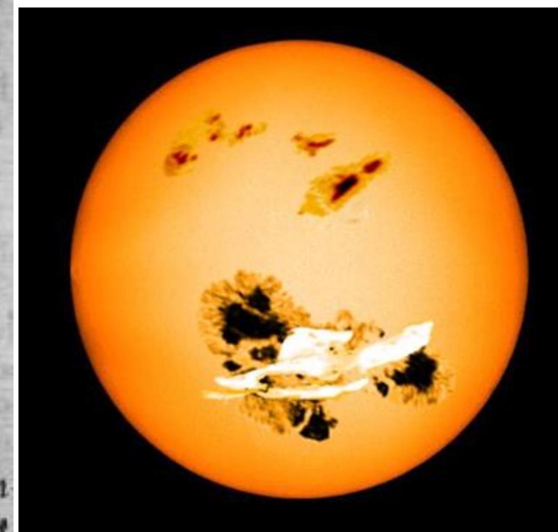
⇒ only 8 years (< 11 years) to generate 2×10^{23} Mx producing superflares of 10^{34} erg => easily occur !?

Is it possible to store such huge magnetic flux below the base of convection zone ?

=> big challenge to dynamo theorist !

Super big spot in 12th century ?





Sunspot drawing in the Chronicles of John of Worcester (England), twelfth century (1128). Notice the depiction of the penumbra around each spot. Reproduced from R.W. Southern, Medieval Humanism, Harper & Row 1970, [Plate VII].