極端宇宙天気研究会@宇治 2013/10/1

500日間のKepler観測データを用いたスーパーフレアの発生頻度

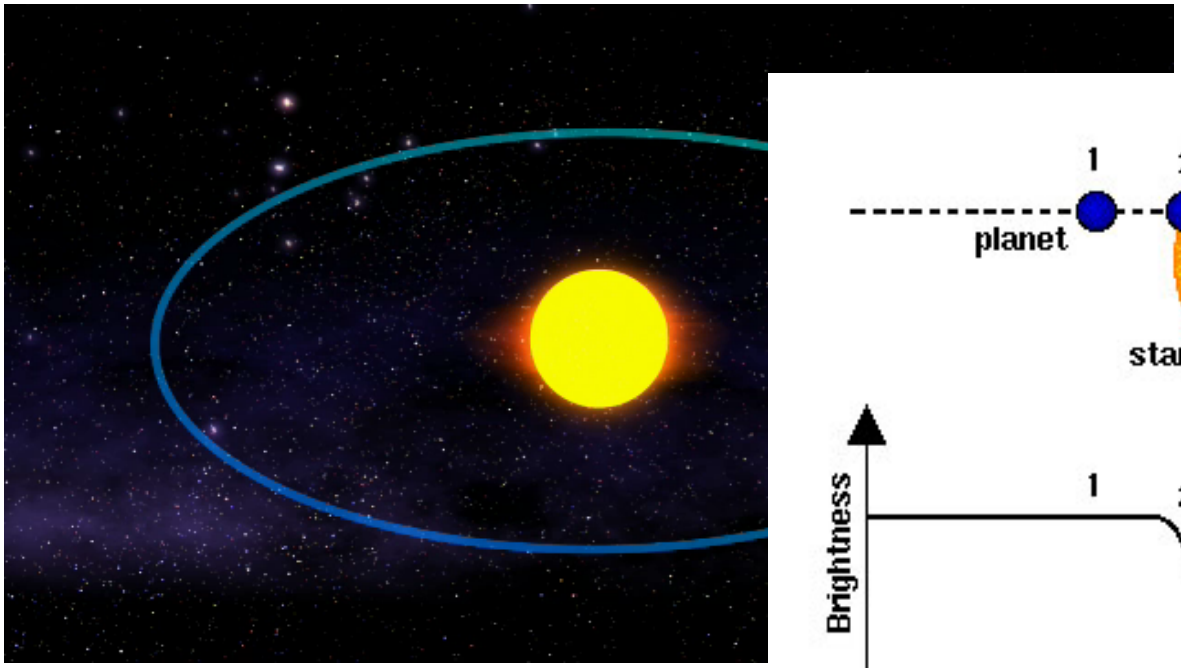
柴山拓也

京都大学宇宙物理(B4)

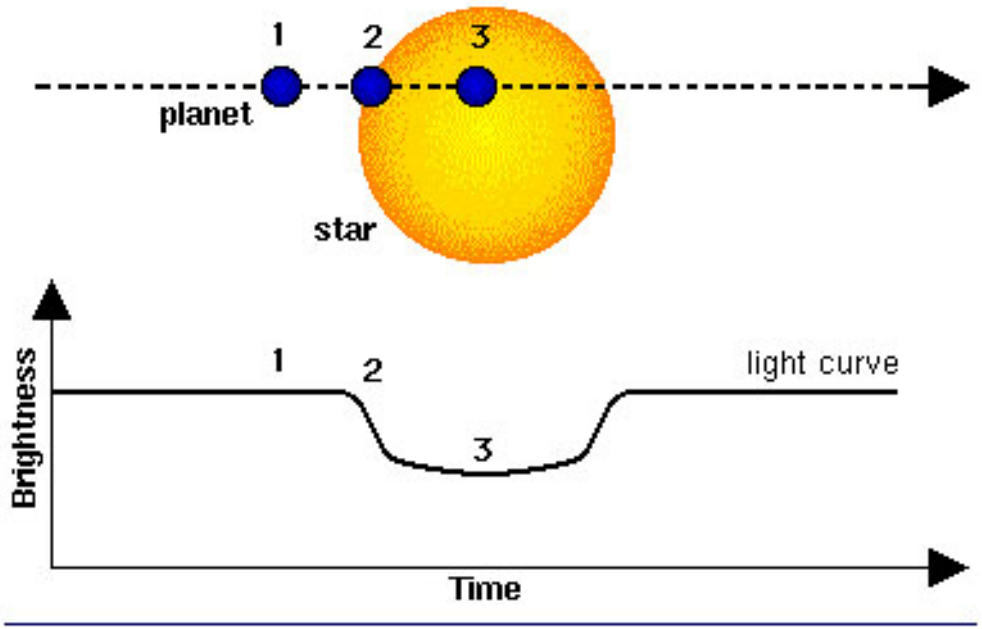
共同研究者：前原裕之(東京大学)、野津湧太、野津翔太(京都大学)、本田敏志(兵庫県立大学)、野上大作、柴田一成(京都大学)

ケプラー宇宙望遠鏡

- 80,000個のG型主系列星を4年間観測
- それぞれの星の光度の時間変化を観測
- 時間分解能は30分と1分

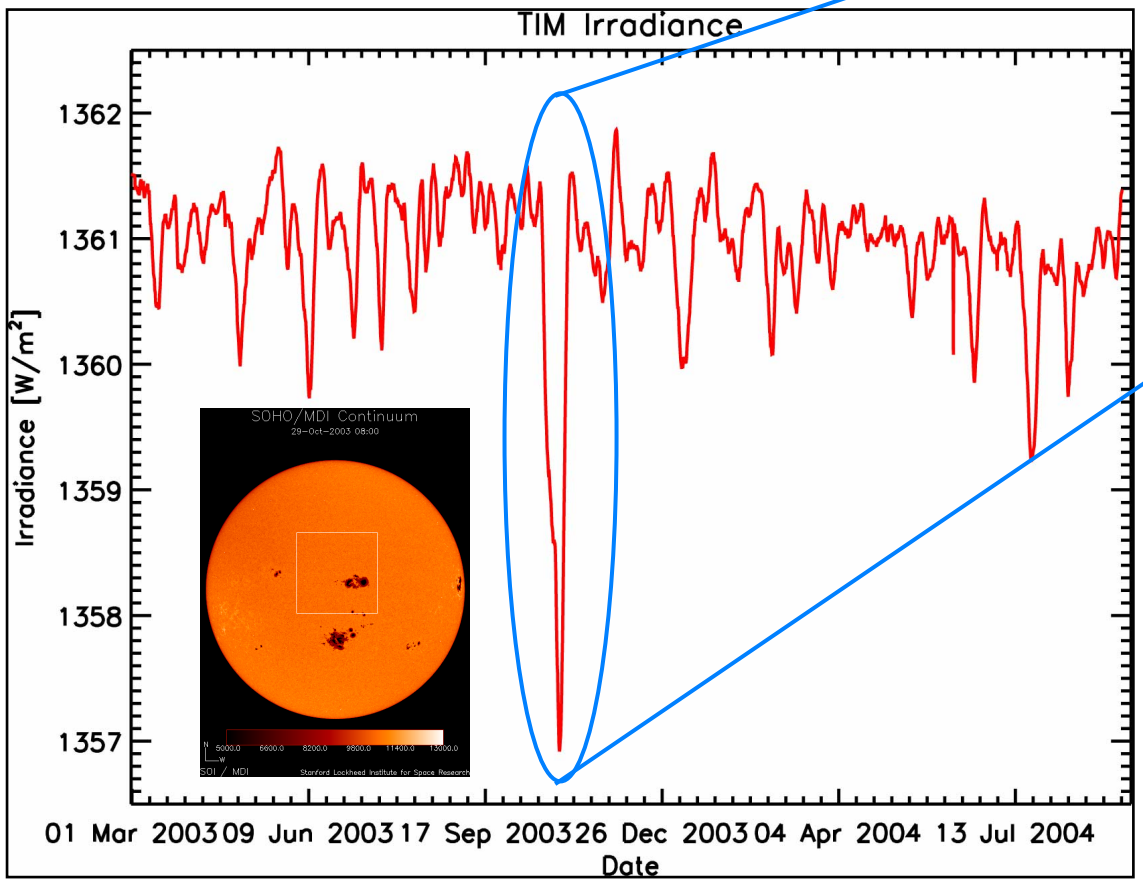


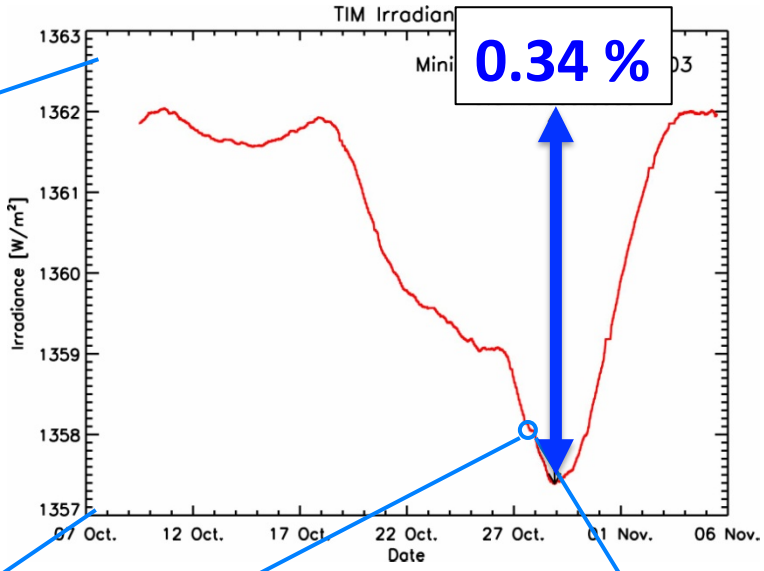
http://www.k

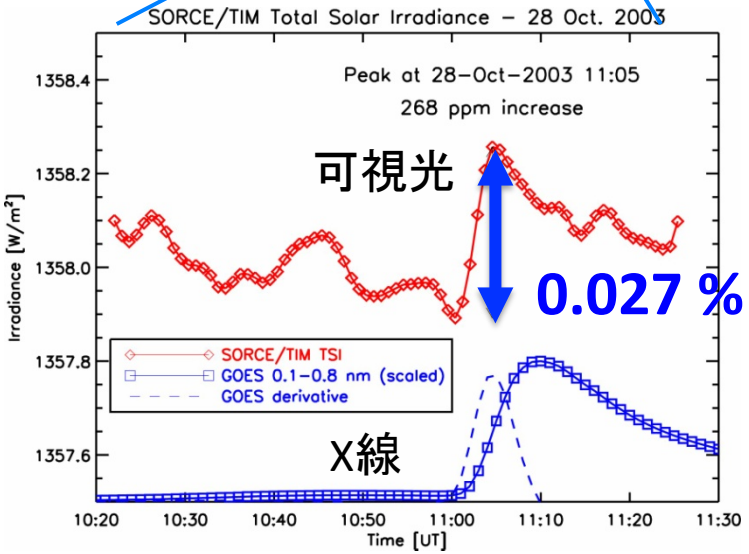


SORCE TIM Clearly Detects X17 Flare in TSI Time Series

全球光度からの初めてのフレア検出
(G. Kopp, 2003)







LETTER

365 superflares on 148 G-type dwarfs

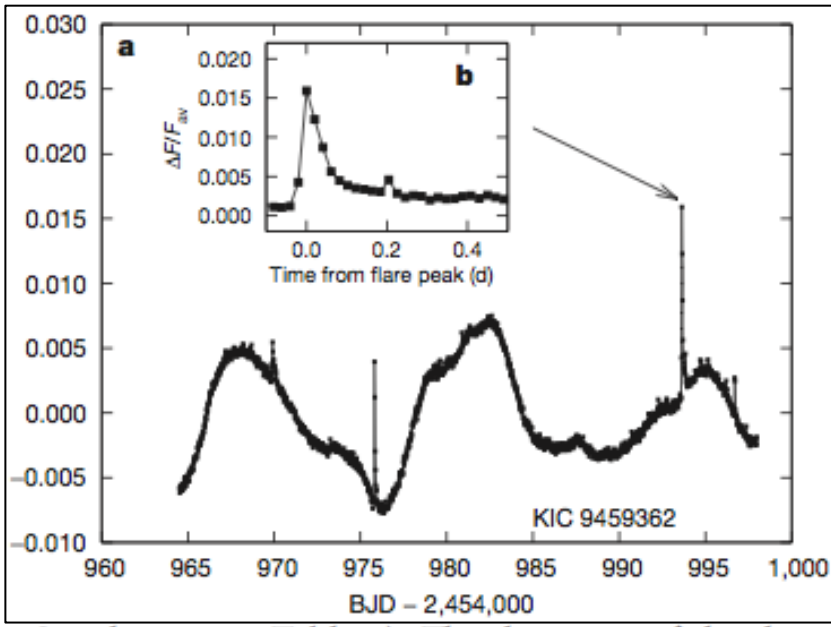
doi:10.10

Maehara et al. 2012 Nature, 485, 478

Superflares on solar-type stars

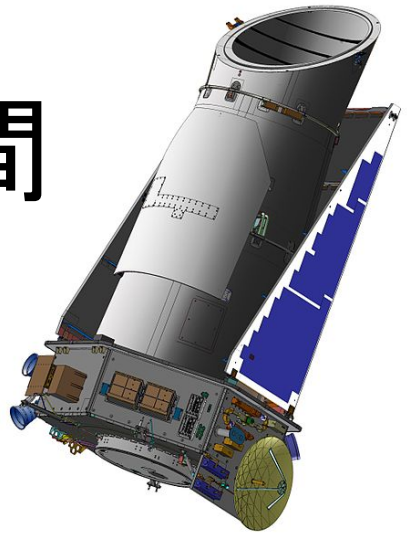
Hiroyuki Maehara[1], Takuya Shibayama[1], Shota Notsu[1], Yuta Notsu[1], Takashi Nagao[1], Satoshi Kusaba[1], Satoshi Hond
Daisaku Nogami[1] & Kazunari Shibata[1]

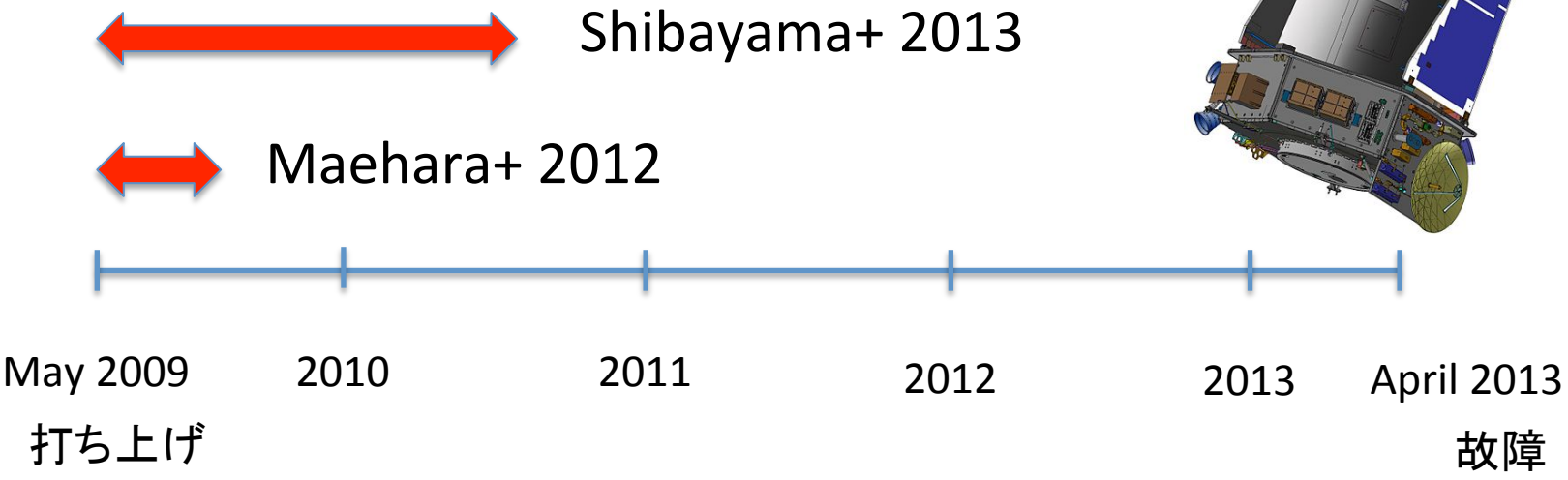
Solar flares are caused by the sudden release of magnetic energy stored near sunspots. They release 10^{29} to 10^{32} ergs of energy on a timescale of hours[1]. Similar flares have been observed on many stars, with larger 'superflares' seen on a variety of stars[2,3], some of which are rapidly rotating[4,5]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



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 lumir
bolometric energy of each flare were estimated from th

ケプラーの観測期間





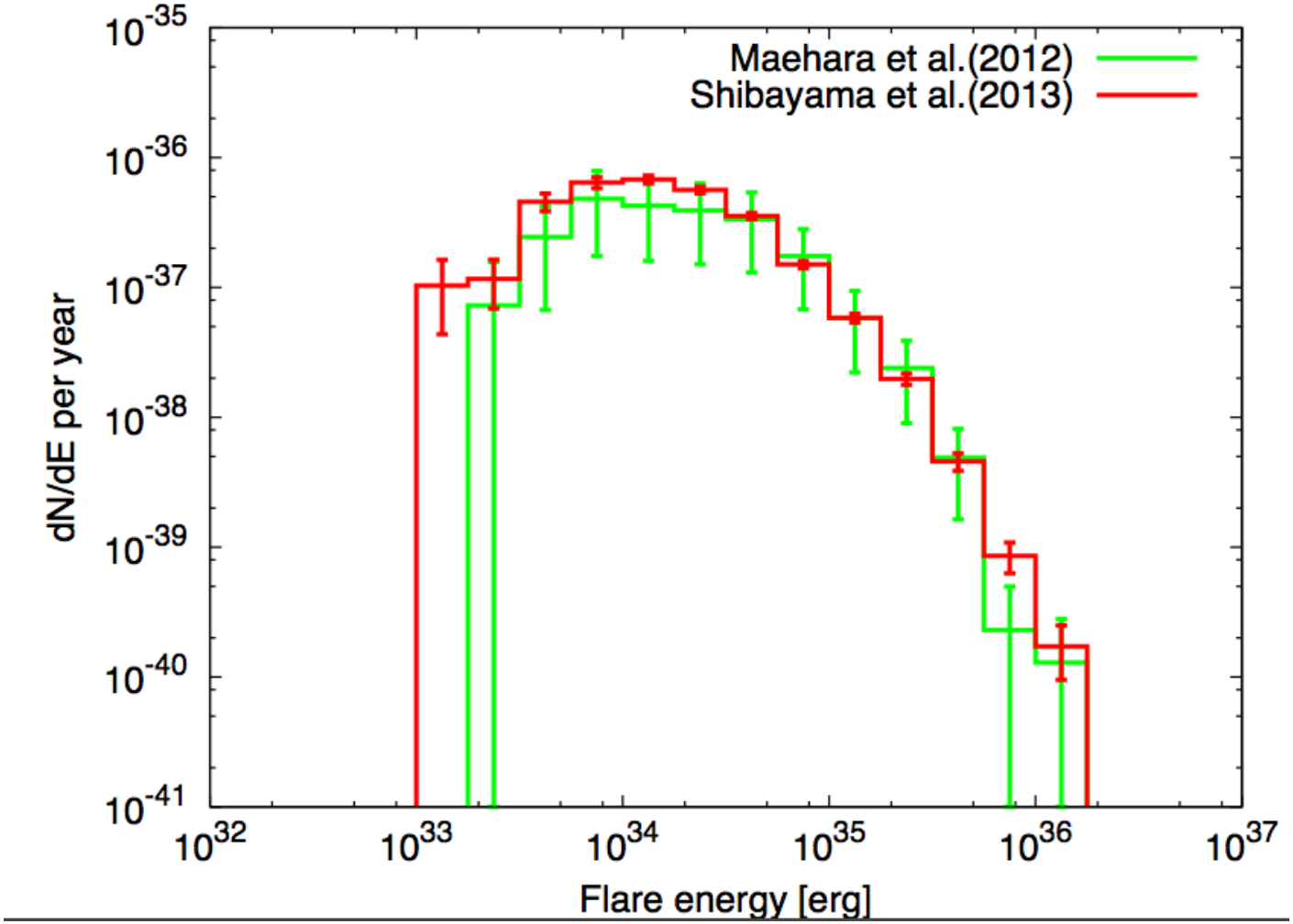
- 120 日 → 500 日
- 279個のG型主系列星で1547スーパーフレア
- 19個の太陽類似星で44スーパーフレア
- Accepted to ApJS (arXiv:1308.1480)
- ホットジュピターを持つ星は発見されなかった。

時間分解能：30分

新しいデータでのフレア発生頻度統計

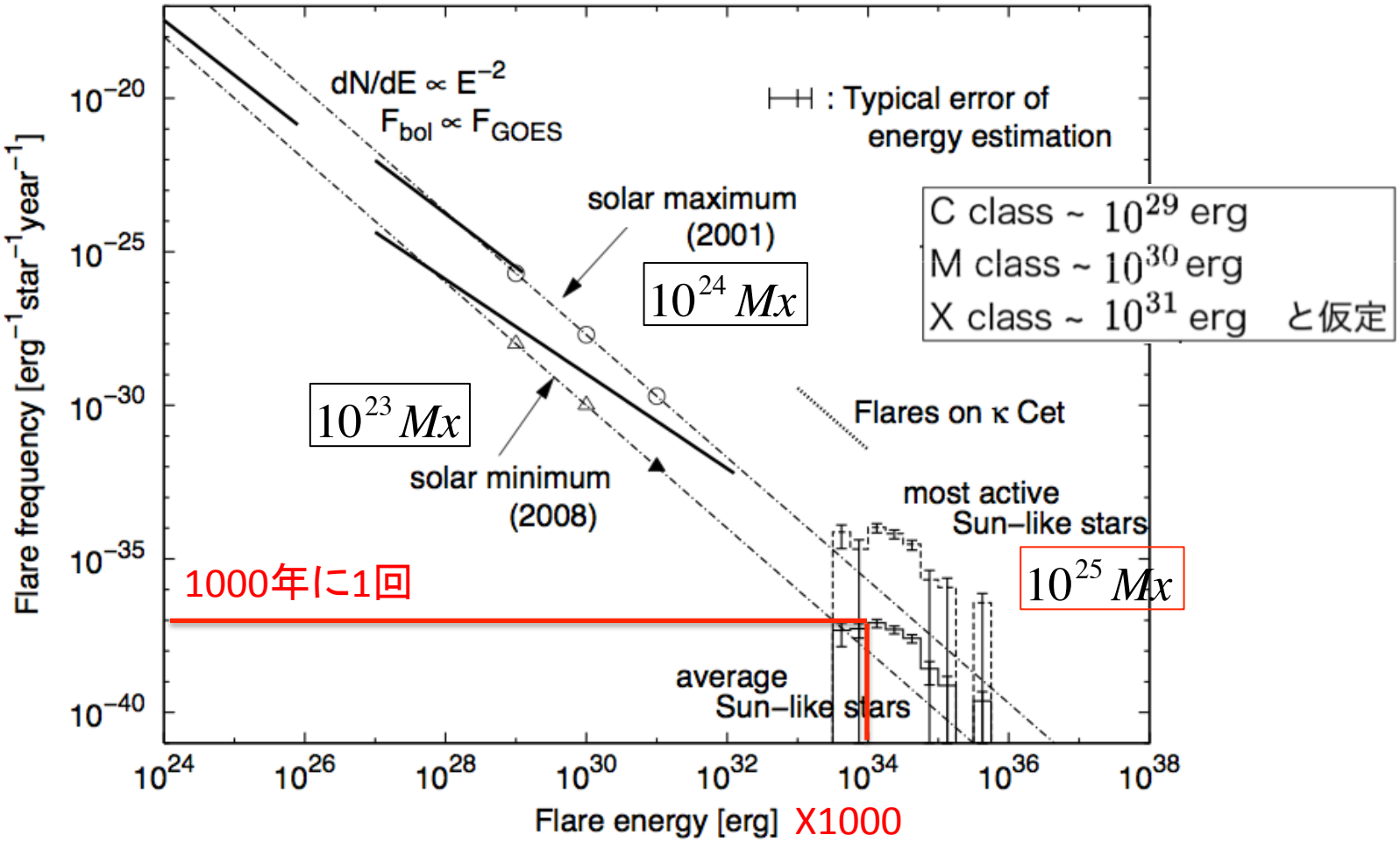
Shibayama et al. 2013 (arXiv:1308.1480)

- Maehara+ 2012 の結果と一致（制度は向上）

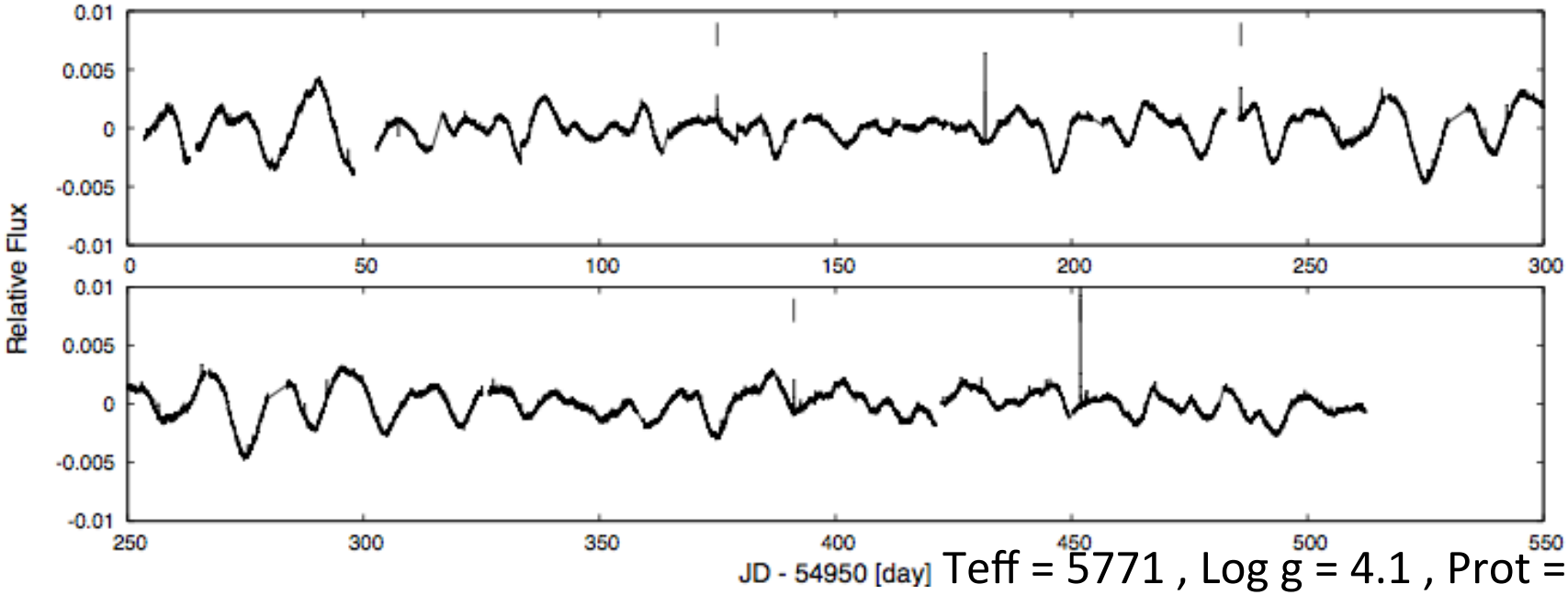


Sun-like Starでのスーパーフレア

- 5600 < Teff < 6000 K, log g > 4.0, Prot > 10 days



Active Sun-like star



Teff = 5771 , Log g = 4.1 , Prot = 15.1

- 500日間に4回のスーパーフレア
  →約100日に1回
- Sun-like star : 5600 < Teff < 6000, log g > 4.0
  and Prot > 10 days

7: Parameters of superflare Sun-like stars

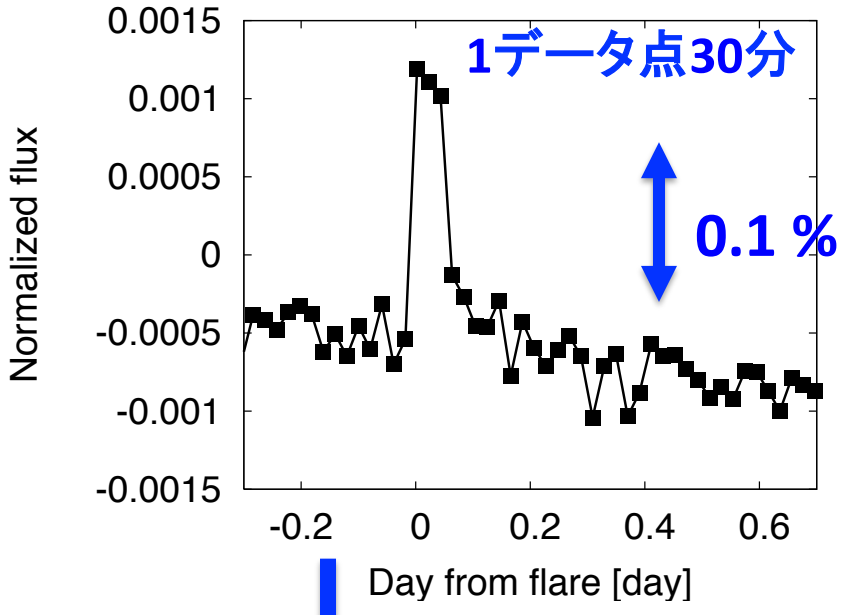
KeplerID	$T_{\rm eff}$ † (K)	log g ‡	$R/R_{\odot}$ ††	KPmag	$P_{\rm rot}(day)$ *	# of flares
5522535	5732	4.3	1.3	13.8	20.3	1
6750902	5654	4.4	1.1	14.7	-	1
6865484	5688	4.4	1.1	13.8	11.2	12
7133671	5657	4.4	1.1	15.5	15.8	1
7354508	5714	4.4	1.1	13.4	17.0	1
7597685	5834	4.6	0.9	15.9	21.8	1
8212826	5811	4.2	1.4	14.0	26.3	2
8880526	5936	4.3	1.2	12.8	-	1
9574994	5925	4.4	1.1	15.1	12.3	1
9766237	5674	4.6	0.9	13.9	21.8	1
9944137	5725	4.6	0.8	13.8	25.3	1
10471412	5771	4.1	1.6	13.4	15.1	4
10524994	5747	4.5	1.0	15.3	12.0	5
11390058	5785	4.3	1.3	12.6	12.1	3
11401109	5732	4.5	0.9	14.5	29.1	1
11455711	5664	4.7	0.8	14.0	13.9	3
11494048	5929	4.4	1.1	13.4	14.9	1
11612371	5826	4.4	1.1	13.4	-	2
11961324	5750	4.4	1.1	14.2	-	2

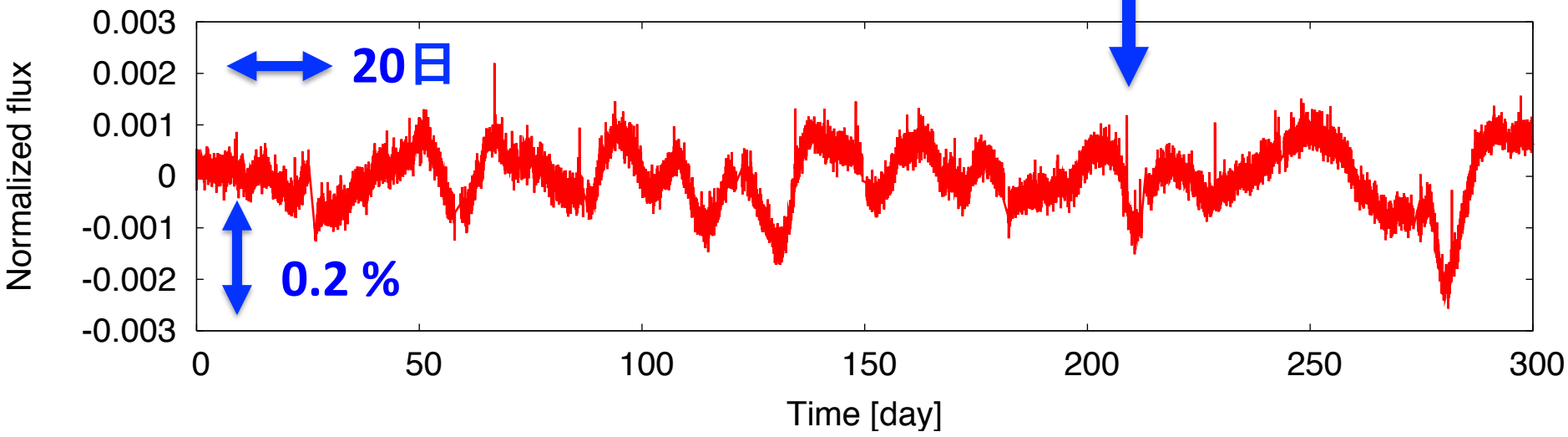
Sun-like Starでのスーパーフレア

- 19星のうち6星は周期20日以上の低速自転星

周期21.8日のSun-like Star

- KIC9766237
- Teff = 5674K
- 1.1 x 10^34 erg のスーパーフレア(最大の太陽フレアの100倍)
- 白色光増光の継続時間は1.5時間程度と太陽フレアよりずっと長い。





そんなフレアが太陽で起こるのか!?

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

スーパーフレアなら10^35 ergに相当?

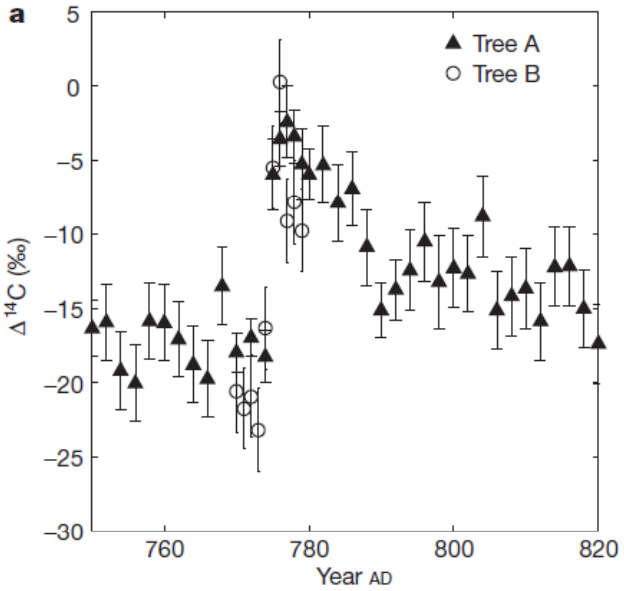
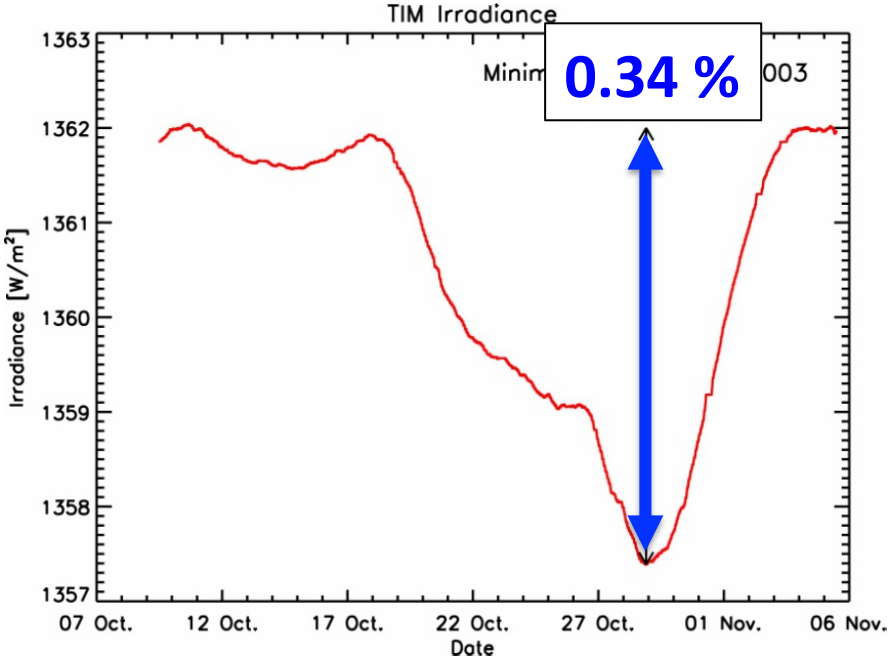
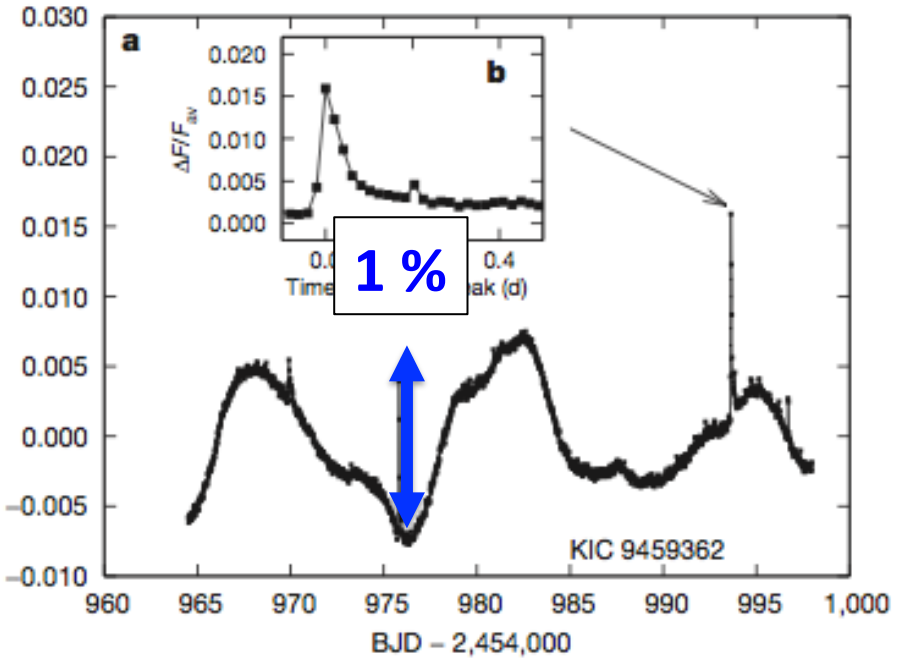


Figure 1 | Measured radiocarbon content and comparison with IntCal98. The concentration of ^{14}C is expressed as $\Delta^{14}C$, which is the deviation (in ‰) of the $^{14}C/^{12}C$ ratio of a sample with respect to modern carbon (standard sample), after correcting for the age and isotopic fractionation[30].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

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

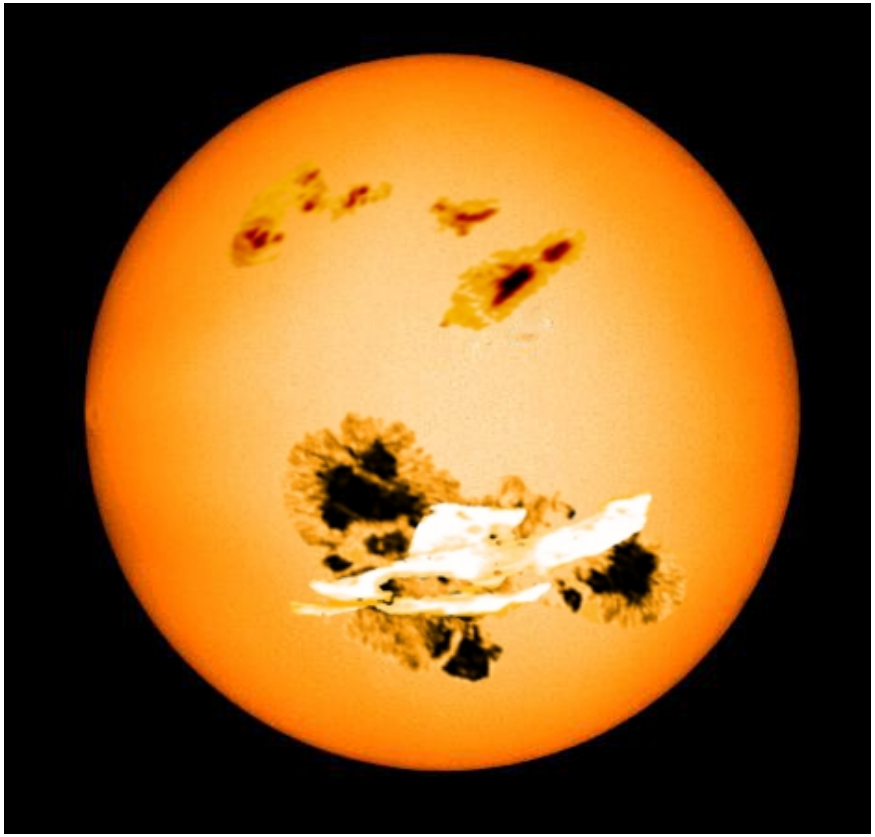
黒点による光度変化



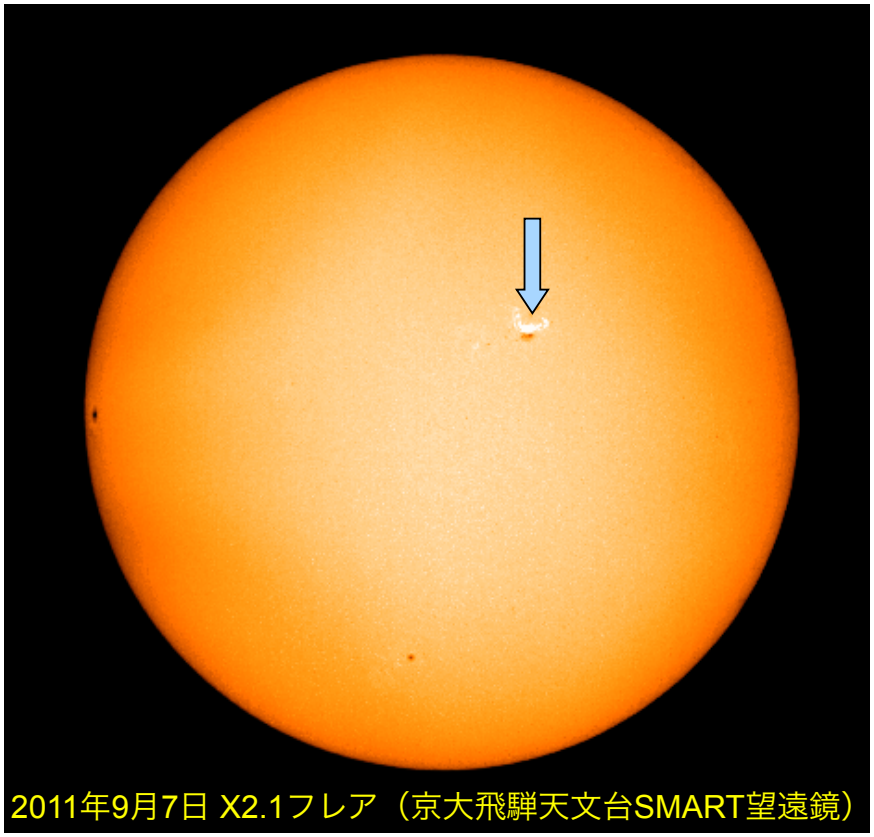


- 太陽の光度変化とよく似た変光

スーパーフレアの想像図



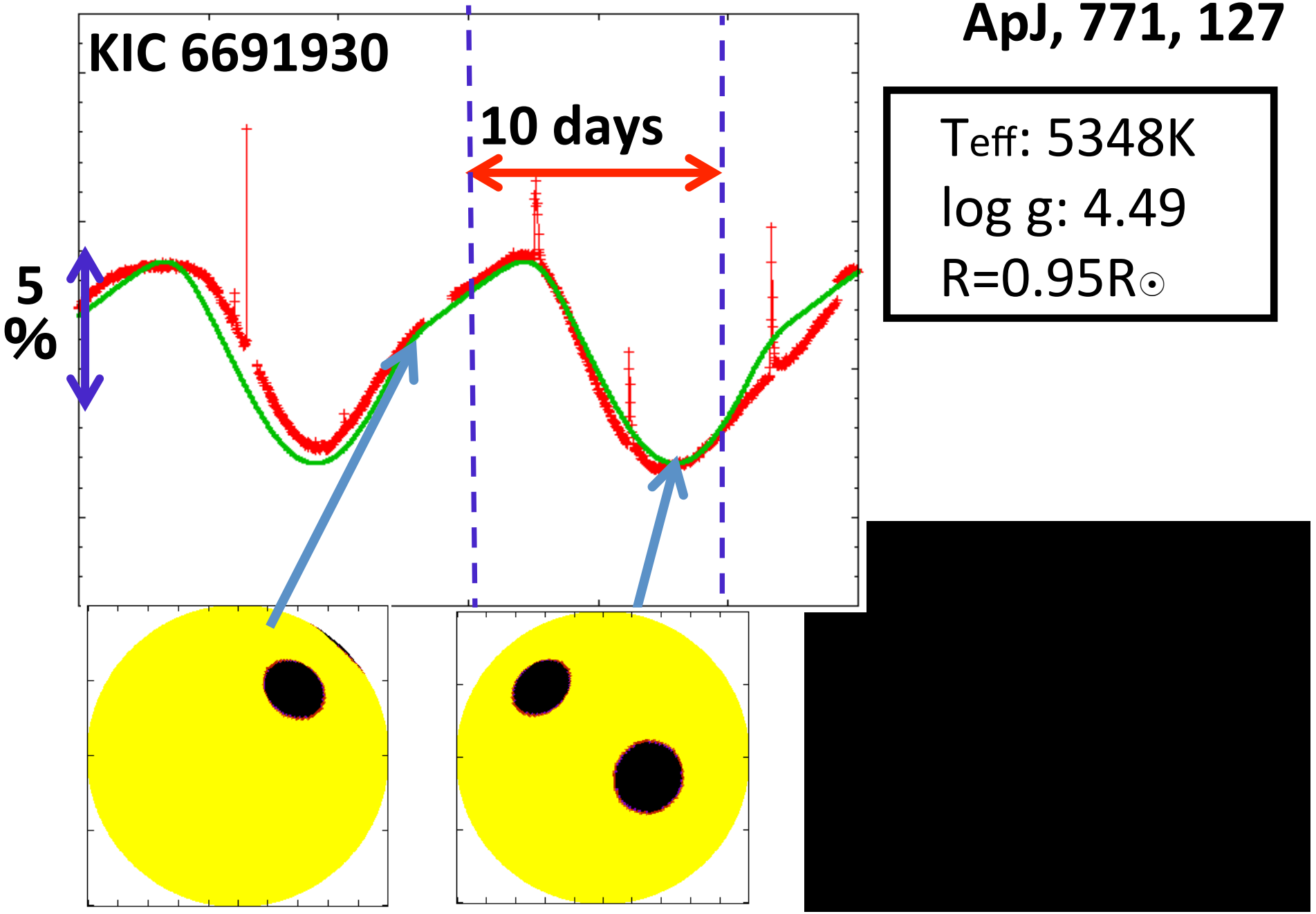
太陽フレア
（実際の観測）



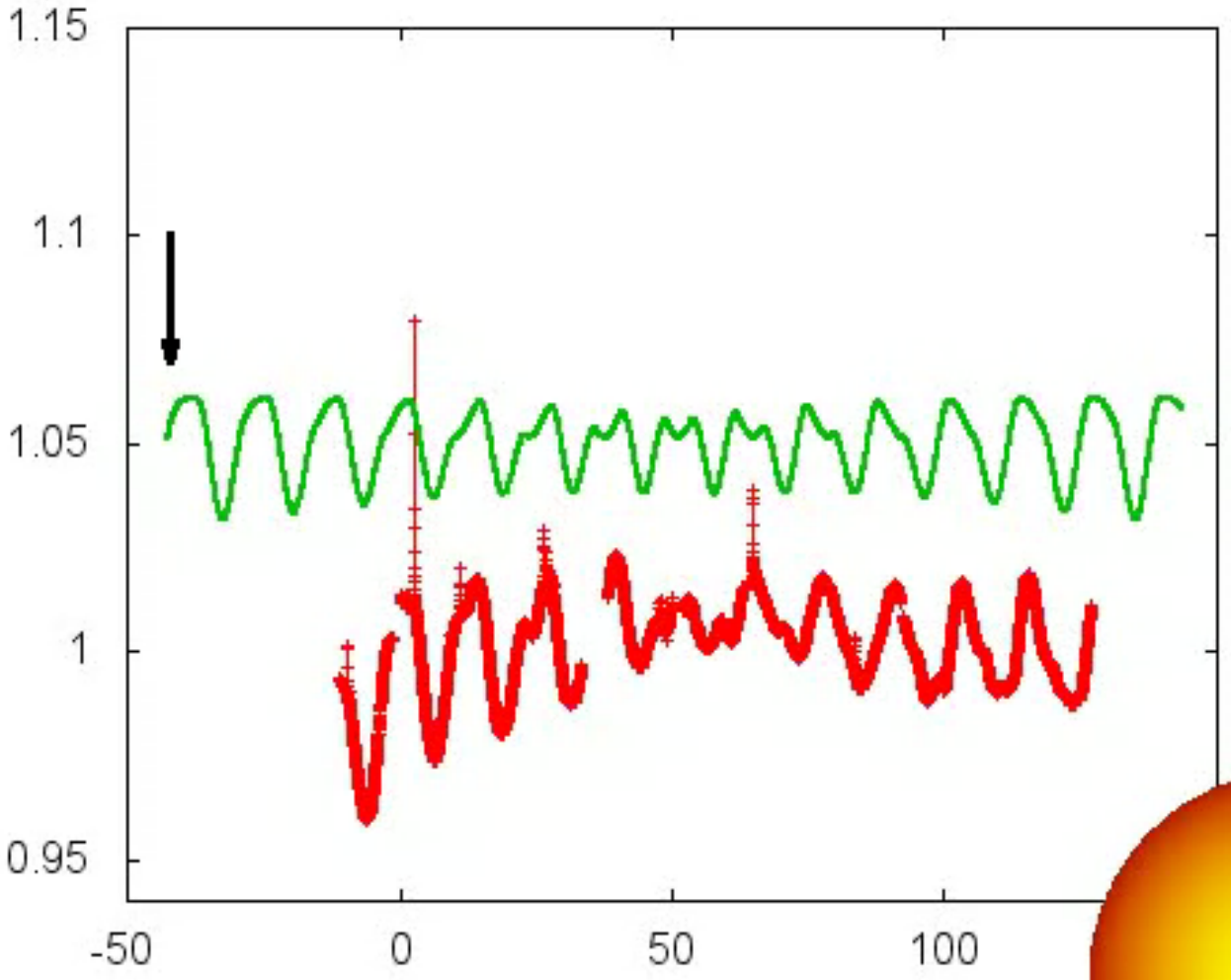
2011年9月7日 X2.1フレア（京大飛騨天文台SMART望遠鏡）

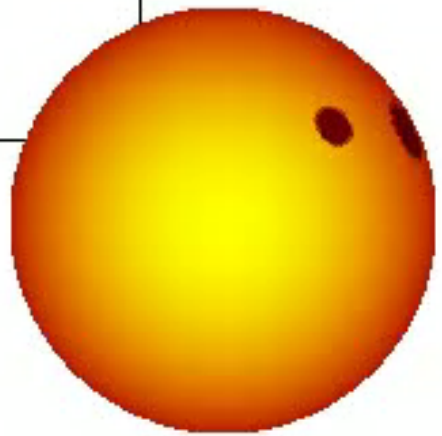
黒点モデル計算 (Notsu et al. 2013 APJ)

ApJ, 771, 127



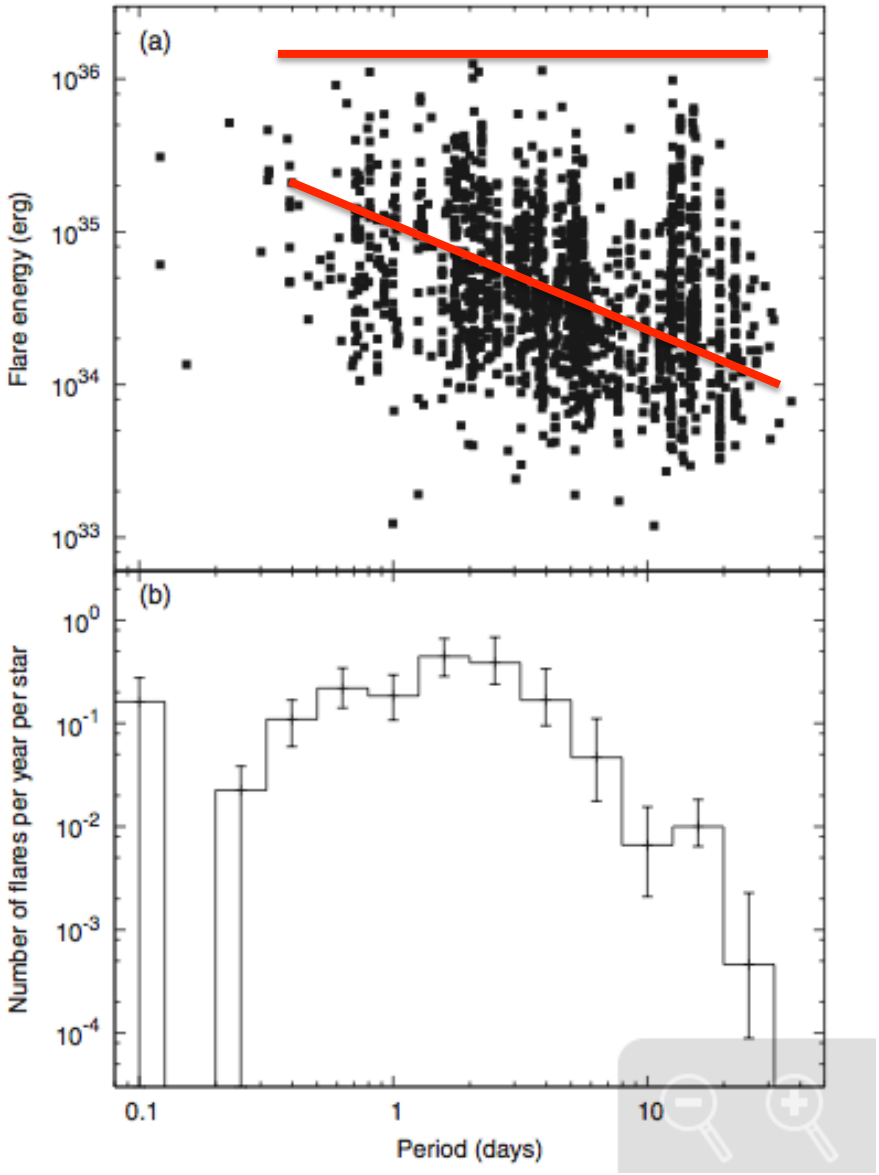
ライトカーブ形状の時間変化も説明





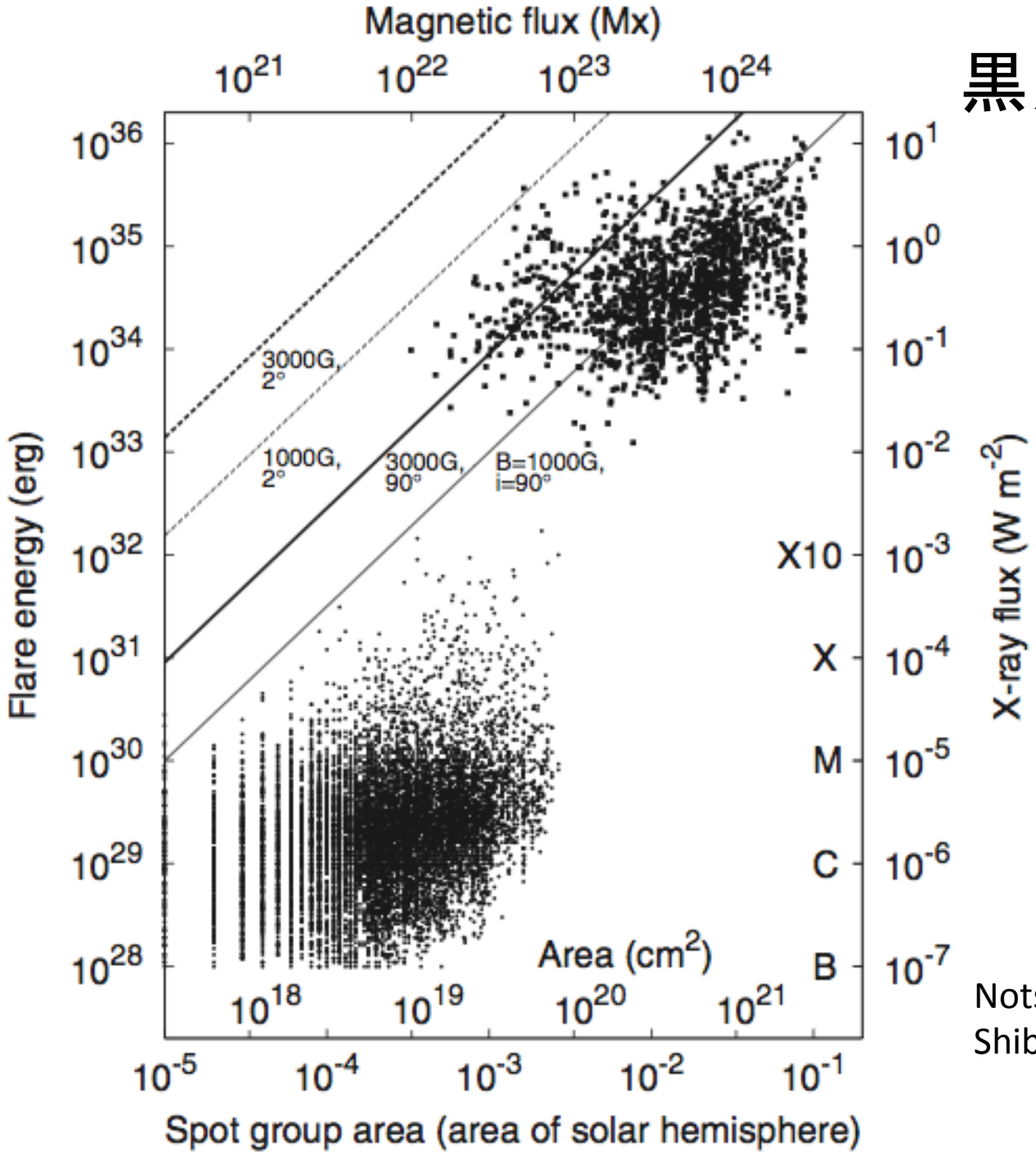
ディファレンシャルローテーション + 黒点2つ

自転周期とフレアエネルギー



- 自転周期(∝活動性)と起こしたフレアのエネルギー
- 最大エネルギーは自転周期とは無関係？

Notsu et al. 2013 APJ, 771, 127
Shibata et al. 2013 PASJ, 65, 49



黒点面積とフレアエネルギー

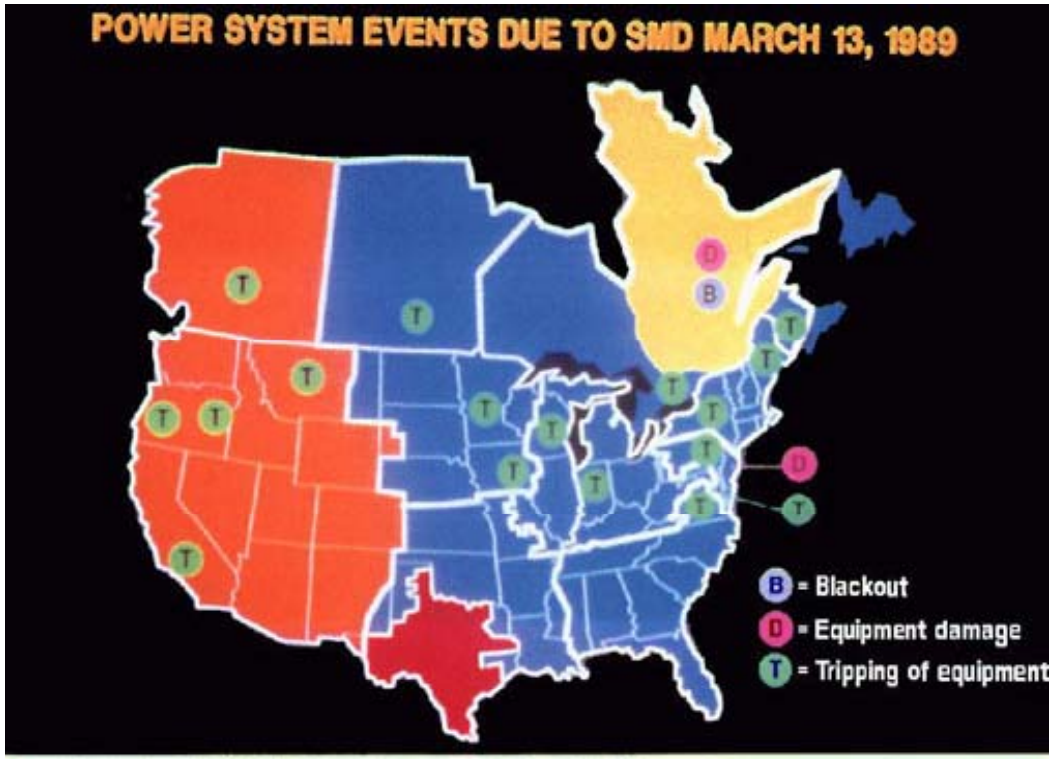
- 太陽黒点と太陽フレアの関係より軌道傾斜角の効果で説明可能

Notsu et al. 2013 APJ, 771, 127
Shibata et al. 2013 PASJ, 65, 49

太陽でスーパーフレアが起こったら

境界条件としてのスーパーフレア研究

磁気嵐が原因で発生した1989年3月13日のカナダ・ケベック州の大停電（600万人が9時間停電の被害を受ける）



PJM Public Service
Step Up Transformer
Severe internal damage caused by the space storm of 13 March, 1989

ニュージャージー州の変圧器故障

このときの太陽フレアは数年に1度の大フレア、
磁気嵐の強さ ~ 540 nT、被害総額は数100億円以上

http://www.stelab.nagoya-u.ac.jp/ste-www1/pub/ste-n

スーパーフレアが起きたら
地球はどうなるか？

	巨大フレア （1989年3月13日）	キャリントン・ フレア （1859年）	スーパー・ フレア （巨大フレアの 100~1000倍）
放射線 （航空機内の推定値）	4mSv	20mSv	400～4000mSv？
地磁気嵐	540nT （全米でオーロラ）	1760nT （赤道帯でオーロラ）	5000～ 15000nT？
社会への影響	ケベック州大停電 電波通信障害 気象衛星故障 衛星放送停止 （被害総額数100億円以上）	電信局の火事 ＞今起きたら 中高磁気緯度の大停電 多くの衛星の故障 地球規模の通信障害 GPS故障 （被害総額1兆～2兆ドル）	地球規模の大停電 オゾン層破壊 全衛星の故障 地球規模の通信障害 全航空機飛行停止 船舶運航停止 GPS停止 ITインフラの破壊

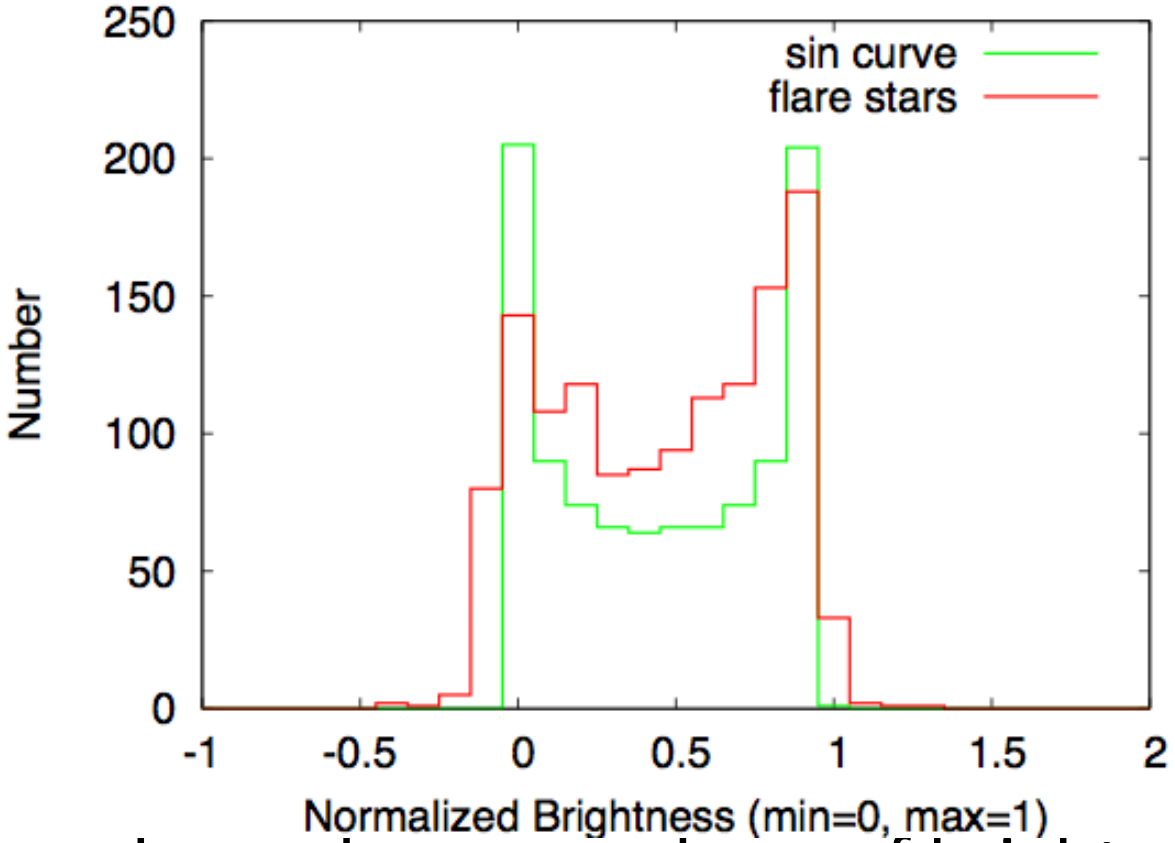
まとめ

- 500日間の光度データから19個の太陽類似星で44スーパーフレア

  →近々4年分すべて解析？
- フレア星では巨大黒点の存在
- 太陽スーパーフレアによる地球への影響は？

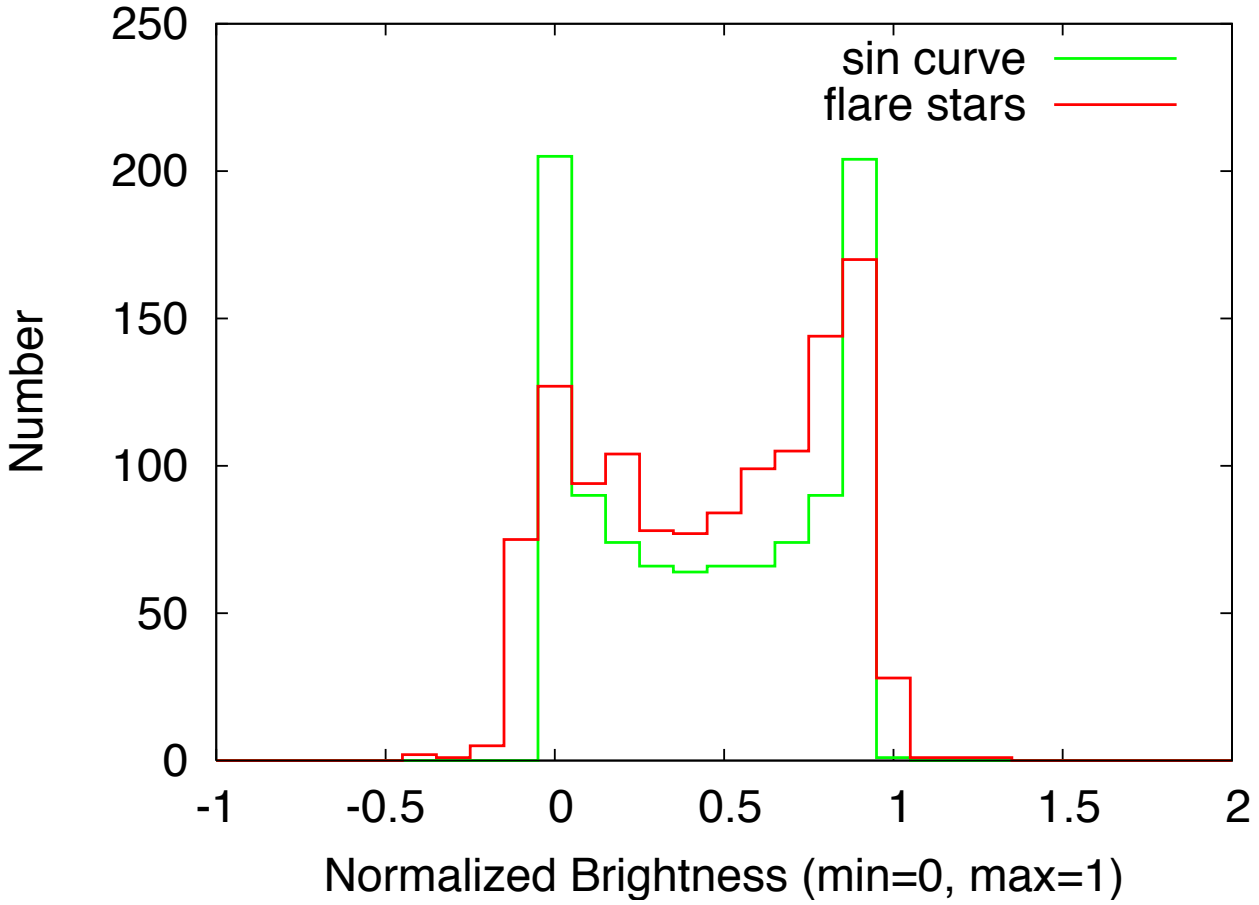
  →皆さん教えてください。

Phase of Flare (Preliminary)

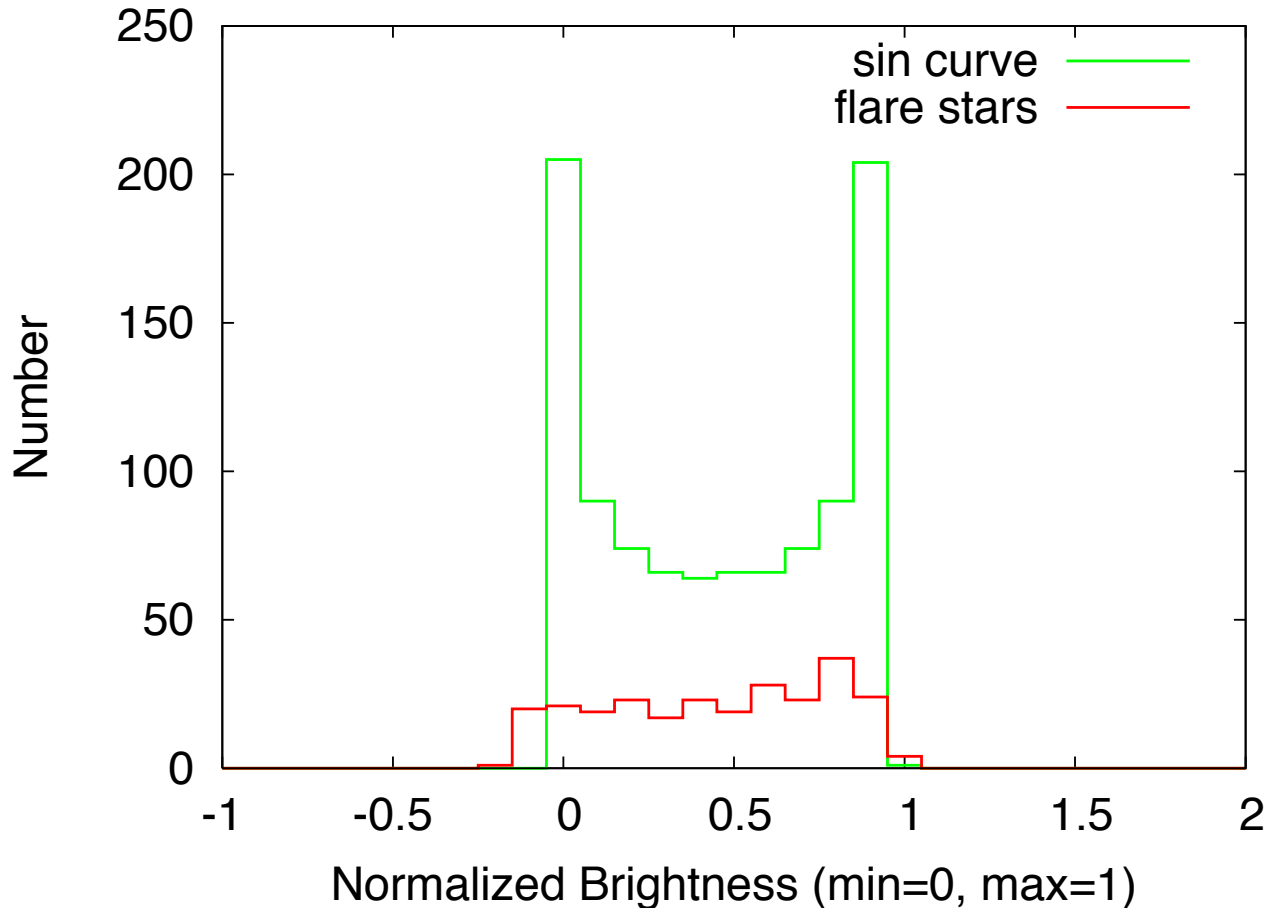


- No clear dependence on phase of brightness variation
- Existence of more than one spot?

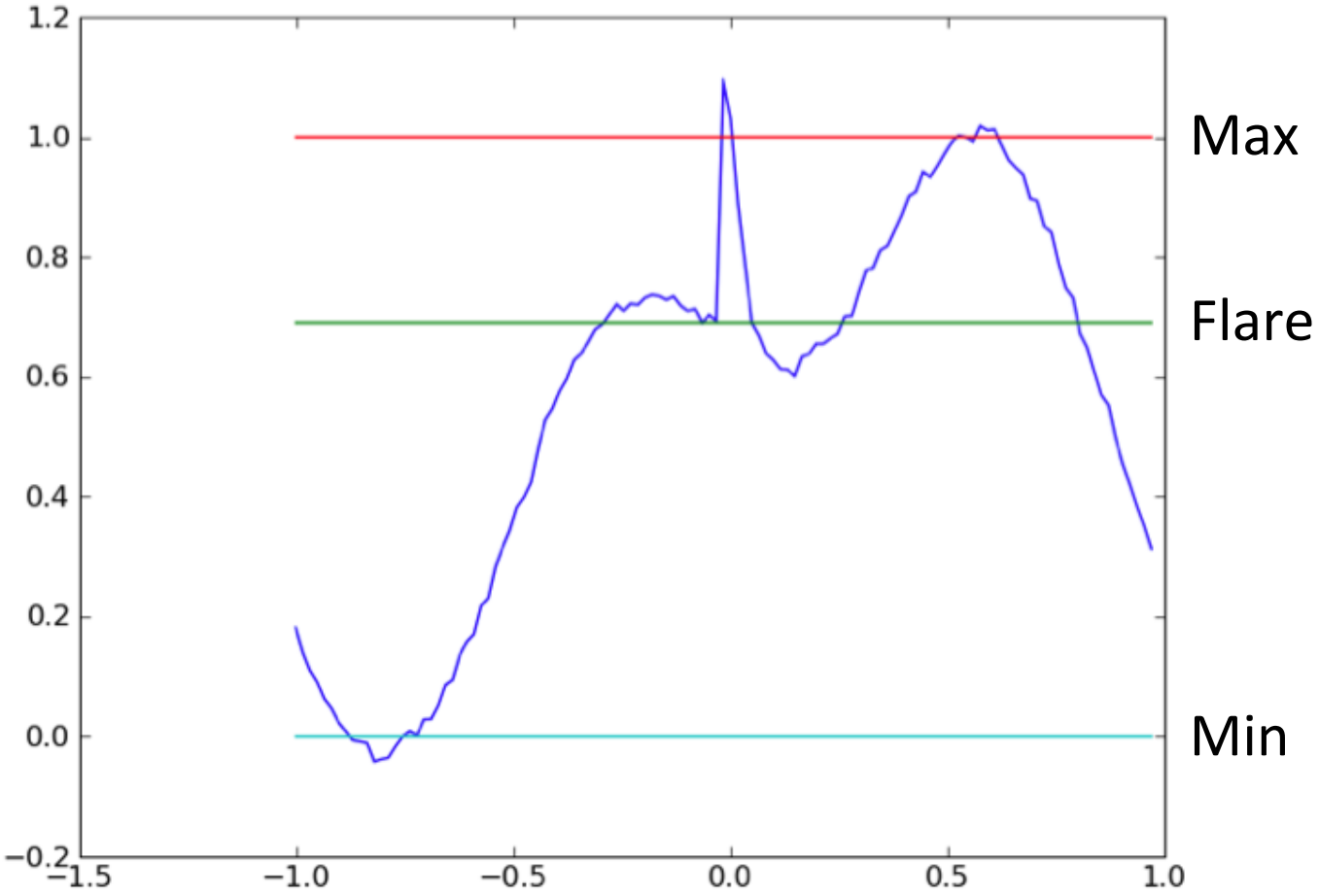
Phase of Flare (>10^34 erg)



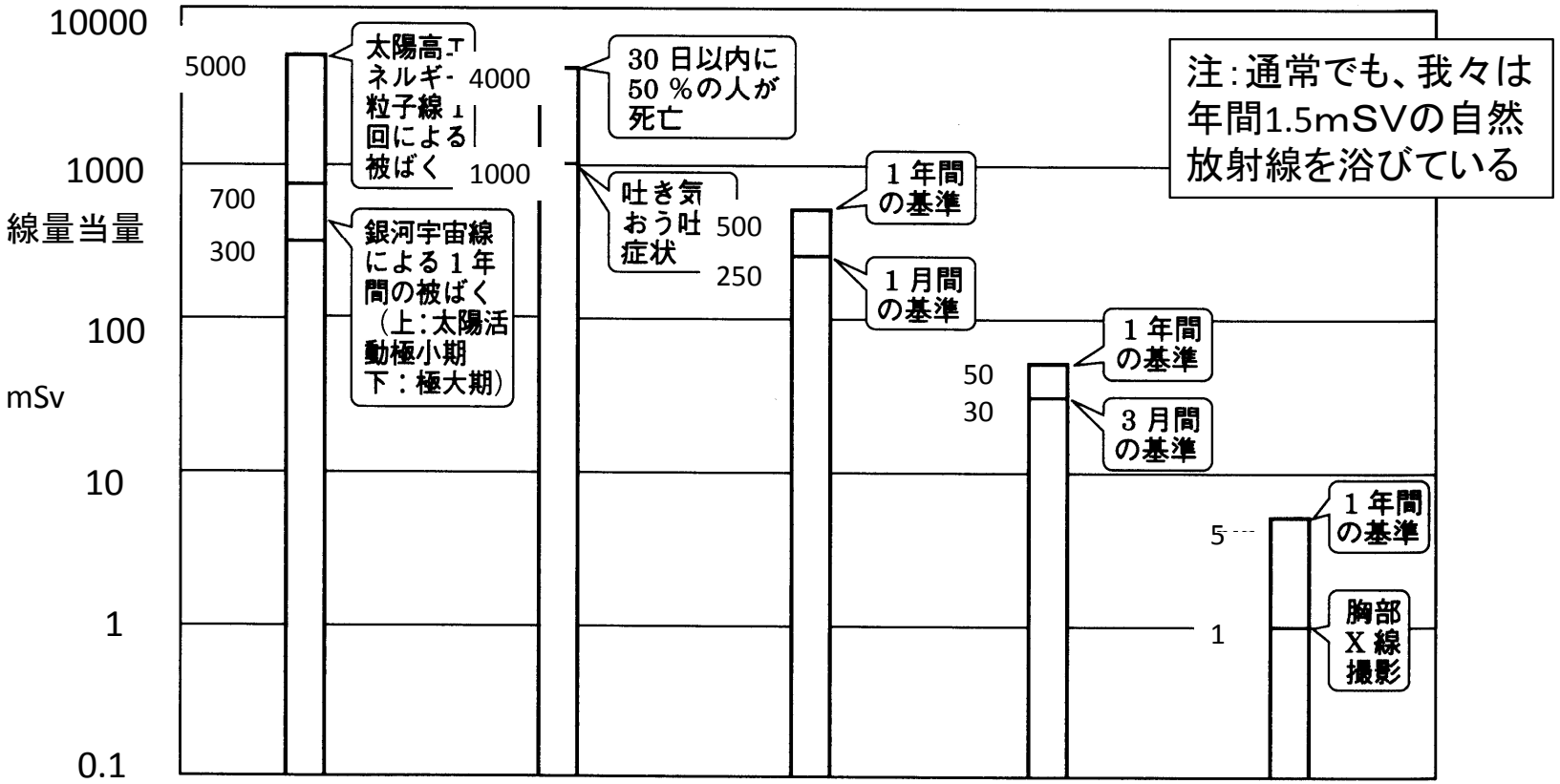
Phase of Flare (>10^35 erg)



Detection of Phase of Flare



太陽放射線による被爆の危険性



恩藤・丸橋「宇宙環境科学」より