High Dispersion Spectroscopy of Solar-Type Stars showing Superflares

Yuta Notsu[1] (ynotsu@kwasan.kyoto-u.ac.jp), Satoshi Honda[2], Hiroyuki Maehara[3], Shota Notsu[1], Takuya Shibayama[1], Daisaku Nogami[1], Kazunari Shibata[1]

[1] *Kyoto University (Kwasan and Hida Observatory)*, [2] *University of Hyogo (Nishi-Harima Observatory)*, [3] *University of Tokyo (Kiso Observatory)*

Yuta Notsu

Shota Notsu

We report the results of our high-dispersion spectroscopic observations of 25 solar-type (5100<T<6000K, log g>4.0) **superflare** stars, which we found from Kepler data (cf. Maehara's presentation and Shibayama's poster). Many of superflare stars show quasi-periodic brightness variations with the typical period of 1~ a few tens of days. In this observation, we aim to investigate whether these brightness variations correspond to the rotation of stars with large starspots.
The binary fraction of superflare stars is consistent with that of field stars and we carried out detailed analyses for the targets which are confirmed to be single stars.
All the targets which are expected to have large starspots show high chromospheric activity compared to the Sun. Assuming that the brightness variation period corresponds to the rotational period is consistent with the value of $v \sin i$ (projected rotational velocity) measured from the spectroscopic results. We have already reported the results of the spectroscopic observation for one superflare star KIC6934317 in Notsu, S. et al. (2013, PASJ, 65, 112) (cf. S.Notsu's poster)

1. Subaru HDS observation

- Telescope : Subaru Telescope (Maunakea, Hawaii)
- Instrument: HDS (High Dispersion Spectrograph)
- Wavelength Resolution (=λ/Δλ)~55,000 λ: 6100~8820Å (Ca II IRT, Hα, Li)
- Brightness variation period: 0.7 < P ≲ 20 (day) (mainly P< 10d in this observation)
- S/N ~ 100 @ 8500Å
- Exposure time: 1-2h x (2~3) (10 ≦I mag ≦ 14)

Half of the target stars are found to be single stars!

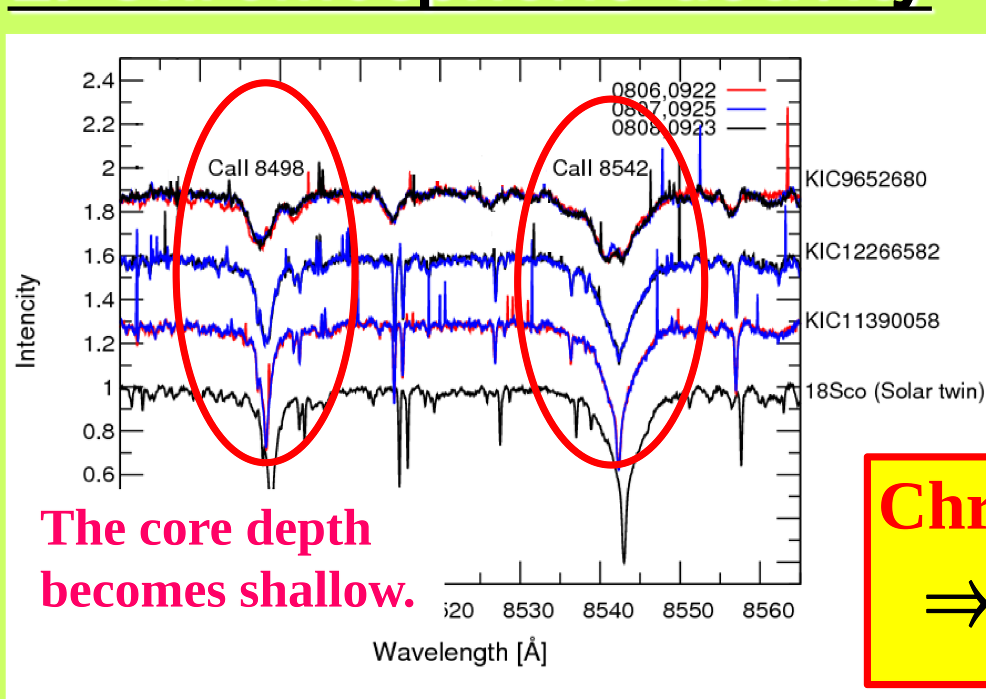
(Targets: Total: 25 stars, Single: 13 stars)

＊More than half of field stars are binary.

⇒**The binary fraction of superflare stars is consistent with that of field stars.**

We will discuss the results of the single stars in the following.

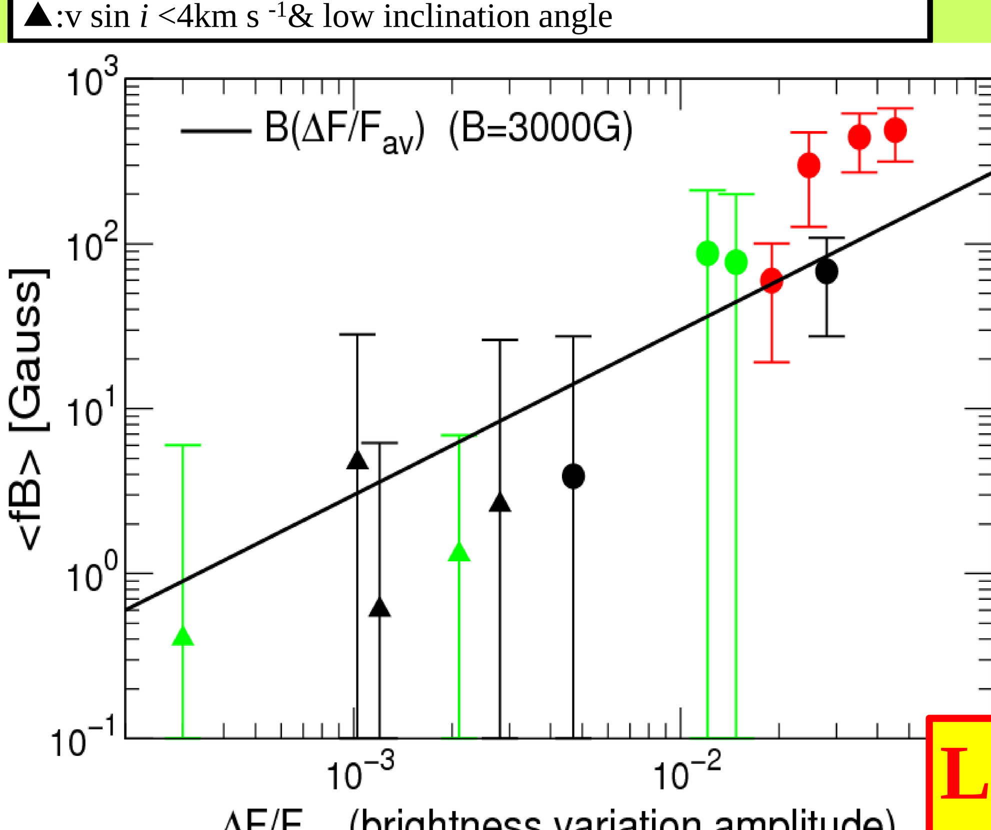
2. Chromospheric activity



As the activity enhanced, **the core depth of Ca II IRT lines become shallow** because of the greater amount of the emission from the chromosphere.

Chromospheric activity ⇒existing large starspots !!

●: $v \sin i$ >10km s^{-1}, ●: $v \sin i$ =4~10km s^{-1},
●: $v \sin i$ <4km s^{-1},
▲: $v \sin i$ =4~10km s^{-1}& low inclination angle
▲: $v \sin i$ <4km s^{-1}& low inclination angle



Corresponding to Starspot coverage.

We can roughly estimate **<fB>** (mean intensity of stellar magnetic field) of superflare stars from the observed intensity of Ca II 8542 (**r(8542) index**: residual flux normalized by the continuum at the line cores of the Ca II 8542) , by using an empirical relationship which we explain in **S.Notsu's poster.**

Large brightness variation amplitude (large starspots)

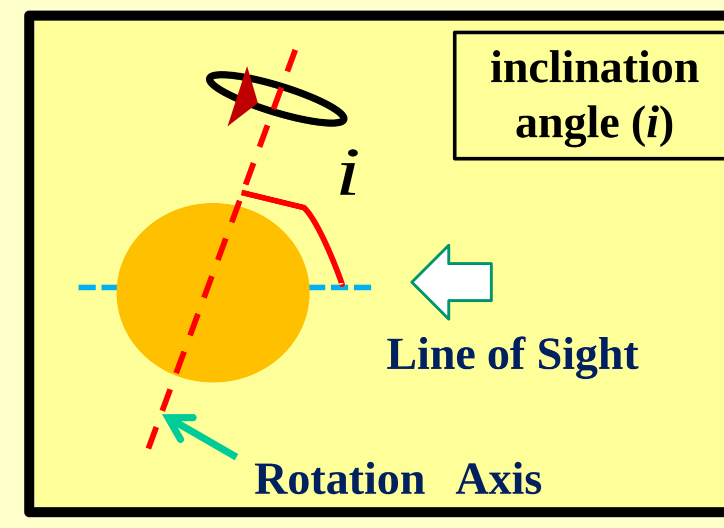
⇒ Large <fB> value !

f: filling factor

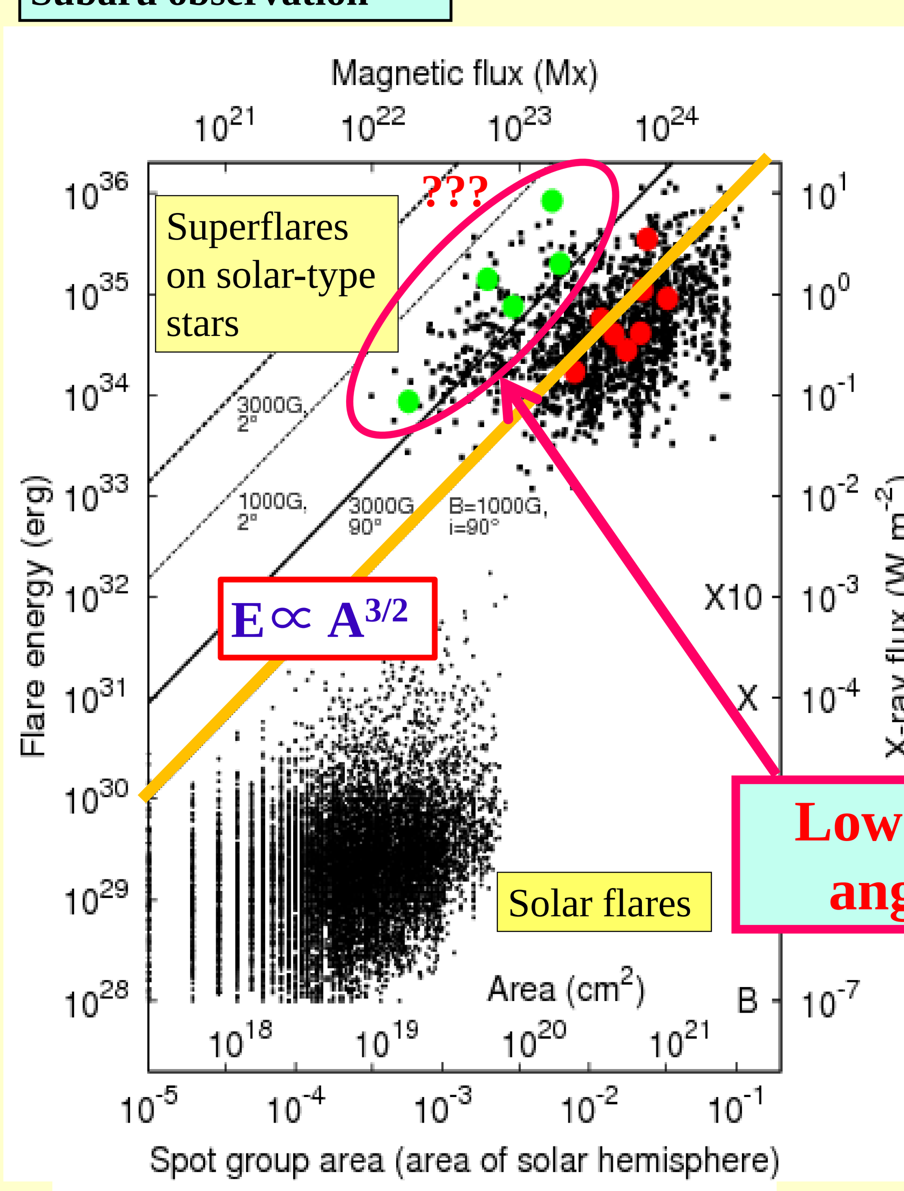
＊The error bars are estimated from standard deviation of <fB>'s destribution in the relationship of "r(8542) vs <fB>".

3. Does brightness variations correspond to rotation?

We measure "$v \sin i$"(projected rotational velocity) by fitting Fe lines.



●,●: Targets of Subaru observation



↑ Notsu, Y. et al. (2013 ApJ 771 127)

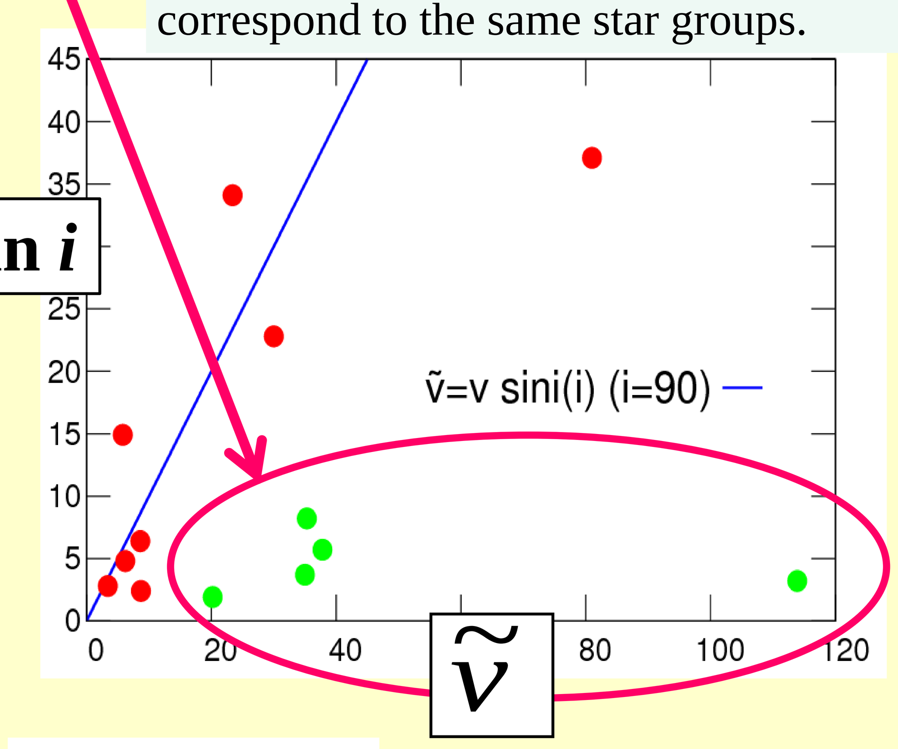
If we assume brightness variations are caused by the rotation of stars with large starspots, we can expect flare energy is explained by the magnetic energy stored around the starspots.

$$E_{flare} \le E_{mag} \approx \frac{B^2}{8\pi} A_{spot}^{3/2}$$

Is this relation ($E \propto A^{3/2}$) OK? What is the meaning of the data points above the line of $E \propto A^{3/2}$??

Low inclination angle stars !!

The same color data points in each figure correspond to the same star groups.



If the object has low inclination angle, the data point is expected to locate in the left side.

On the other hand. we can estimate inclination angle by comparing spectroscopic **"$v \sin i$ "** with the **brightness variation period (P).**

$$\tilde{v} \approx \frac{2\pi R_{star}}{P} \qquad i \approx \arcsin\left[\frac{(v \sin i)_{spec}}{\tilde{v}}\right]$$

These two Figures are consistent !!!

Assuming that the brightness variation period corresponds to the rotational period is consistent with the value of $v \sin i$ measured from spectroscopic results.

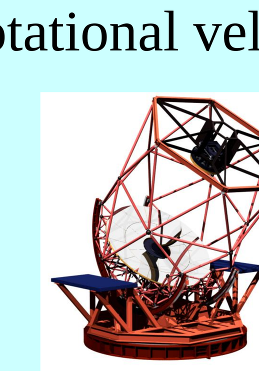
4. Summary

– The binary fraction of superflare stars is consistent with that of field stars. (Half of the targets seems single stars.)

– Superflare stars show **high choromospheric activity** and this suggests the existence of **large starspots.**

– Assuming that the brightness **variation period** corresponds to the rotational period is **consistent with the value of $v \sin i$** (projected rotational velocity) measured from spectroscopic results.

[Future]
- Observing more Sun-like (especially slowly rotating) targets.
- Using other lines (e.g., Ca II H+K). .
- Kyoto University Okayama 3.8m new telescope (survey).



5. Reference

- Maehara, H. et al. (2012, Nature 485,478)
- Shibayama, T. et al. (2013, ApJS, 209, 5)
- Notsu, Y. et al. (2013, ApJ 771 127)
- Notsu, S. et al. (2013, PASJ, 65, 112)
- Shibata, K. et al. (2013, PASJ, 65, 49)

Related Talk & Posters
- Maehara's Talk (S6-I-01)
- Shibayama's poster (S6- P- 07)
- S. Notsu's poster (S6- P- 09)