High-Dispersion Spectroscopy of the Superflare Star KIC6934317

Shota Notsu[1] (*snotsu@kwasan.kyoto-u.ac.jp*),
Satoshi Honda[2], **Yuta Notsu**[1], **Hiroyuki Maehara**[3], **Takuya Shibayama**[1], **Daisaku Nogami**[4], **Kazunari Shibata**[4]
[1] (*Department of Astronomy, Kyoto University*), [2](*Center for Astronomy, University of Hyogo*), [3] (*Kiso Observatory, University of Tokyo*), [4] (*Kyoto University, Kwasan and Hida Observatory*)

Shota Notsu

We conducted high-resolution spectroscopic observation with Subaru/HDS for a G-type superflare star (KIC6934317). We selected this star from the superflare stars we discovered from Kepler data. The core depth and the emission flux of the Ca II infrared triplet lines and the Hα line show high chromospheric activity in this star. This star probably has large starspots that can store a large amount of magnetic energy, sufficient to give rise to superflares. We also estimated the stellar parameters, such as effective temperature, surface gravity, metallicity, and projected rotational velocity ($v \sin i$). KIC6934317 is then confirmed to be an early G-type main sequence star. The value of $v \sin i$ is estimated to be ~1.91 km s^{-1}. In contrast, the rotational velocity is calculated to be ~20 km s^{-1} by using the period of the brightness variation as the rotation period. This difference can be explained by its small inclination angle (nearly pole-on). The small inclination angle is also supported by the contrast between the large superflare amplitude and the small stellar brightness variation amplitude. **For more details, see Notsu, S., et al. 2013a, PASJ, 65, 112.**

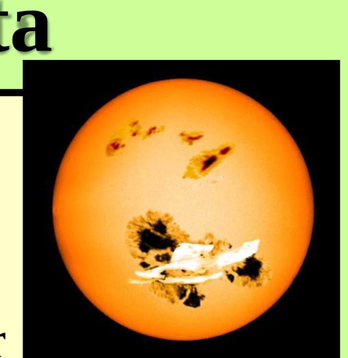
1. Superflares discovered by Kepler data

Superflares: 10- 10^6 times more energetic (10^{33}-10^{38}erg) than the largest solar flares (~10^{32}erg).

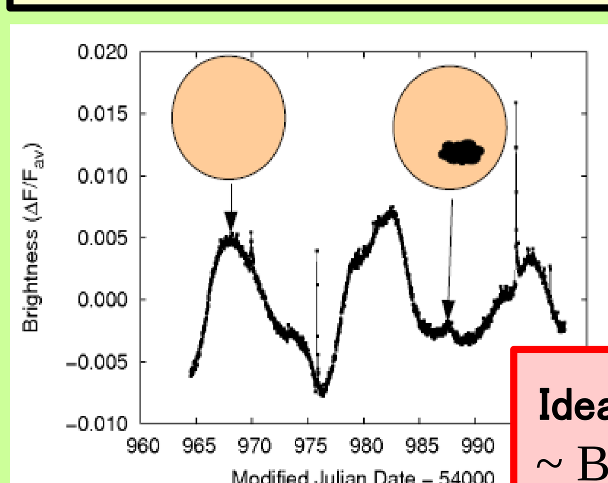
-- **We found many superflares on solar-type stars** (G-type main sequence stars; 5100< $T_{\rm eff}$ <6000, log g > 4.0) by using Kepler photometric data (Maehara et al. 2012, Nature & Shibayama et al. 2013).

-- Superflare stars show **quasi-periodic brightness variations**

・Period : 1 ~ a few tens of days ・Amplitude: 0.1~10%



Artistic illustration



Lightcurve of Superflare star KIC9459362 (Maehara et al.2012)

What is the cause of stellar brightness variation ??

Idea: **Rotation of a star with large starspots !?**

~ Brightness variation ~

Period ⇒ Stellar rotation period

Amplitude ⇒ Coverage of starspots on the stellar surface

(Notsu et al. 2013b, Shibata et al. 2013)

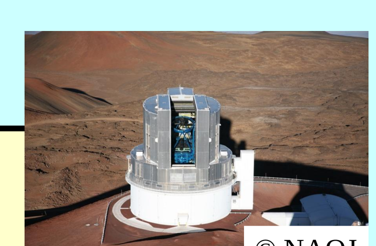
Spectroscopic Observations !!

Investigating whether solar-type stars really have superflares.

2. Our Subaru observation & Target star

○Details of our Subaru Observation

- ・Obs. Date : 2011 August 3
- ・Telescope : 8.2m Subaru Telescope (NAOJ, Mauna Kea, Hawaii)
- ・Equipment : High Dispersion Spectrograph (HDS: Noguchi et al. 2002)
- ・Spectral resolution (R=λ/Δλ) : ~97000 ・S/N ratio : ~140@8500Å
- ・Spectral Coverage : 6100~8820Å (Ca II IRT, Hα, Li I 6708)

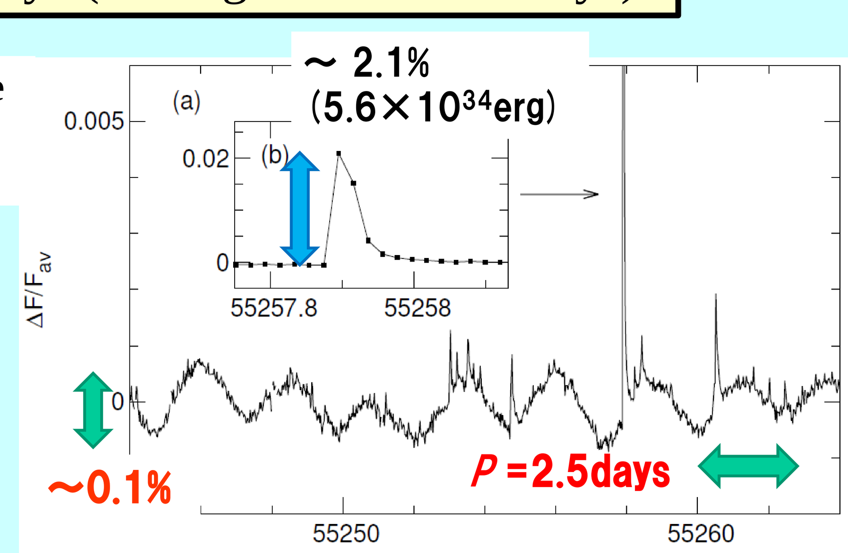


Subaru Telescope

○ Target stars : KIC6934317 (**G-type superflare star**, V =12.5mag)

- exhibited 48 superflares in ~ 617 days (Average: once in 13 days)

Lightcurve of superflare star KIC6934317 (Notsu et al. 2013a)



○Comparison stars: 59Vir & 61Vir

59Vir: rather rapidly rotating, strong magnetic fields (~500G).

61Vir: slowly rotating, no magnetic field could be detected.

○Atmospheric parameters of KIC6934317

effective temperature ($T_{\rm eff}$) = 5694±25K
surface gravity (log g) = 4.42±0.08
metallicity ([Fe/H]) = -0.03±0.07

(Notsu et al. 2013a)

・We estimated atmospheric parameters of target stars by a lot of Fe I and Fe II lines.

・Detailed methods are described in Takeda et al. (2002, 2005b).

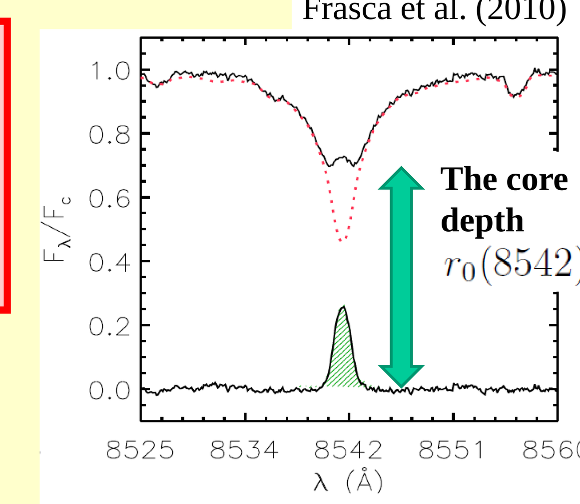
KIC6934317 is an early G-type main sequence star, and the atmospheric parameters of this star are nearly the same as the Sun.

3. Confirm magnetic activity of G-type stars

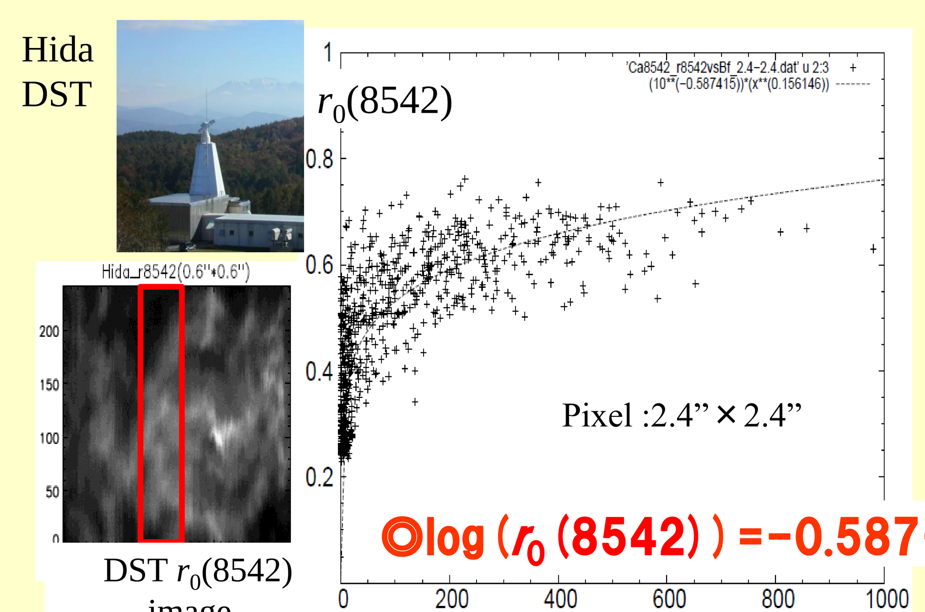
The core depth and emission flux of Ca II infrared triplet (8498, 8542, 8662Å) lines indicate the chromospheric magnetic activity of the Sun and G-type stars.

⇐This is because these are collision-dominated lines and their cores are formed in the chromosphere, reflecting the temperature rise in their profiles which go from filled-in to pure emission, depending on the magnetic activity level.

Frasca et al. (2010)



Spectrum of a young G-type star around Ca II 8542



We investigate rough correlations between r_0(8542) and <fB> by observing (scanning) solar active regions (including plages) and quiet regions (not including dark spots).

cf. Similar relationship about Ca K line vs <fB> (Schrijver et al. 1989)

○log (r_0 (8542)) =−0.587+0.156×log (<fB>)

<f>: filling factor

<fB> : mean photospheric magnetic field strength [gauss] : **SDO HMI data**

○Other magnetic activity indicators : cf., Martínez-Arnáiz et al.(2011)

Hα (6563Å) line, Ca II H+K (3934, 3968Å) lines, X-ray flux etc.

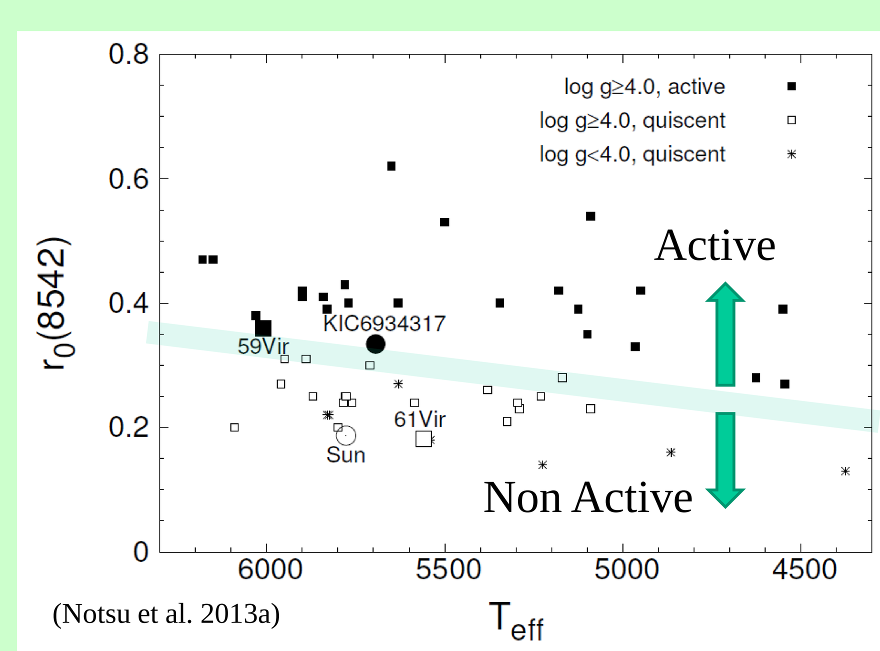
Using these indicators, we can confirm the presence of large starspots causing Superflare indirectly !

※Directly observing the intensity of magnetic field of G-type stars is difficult since it needs very high precision.

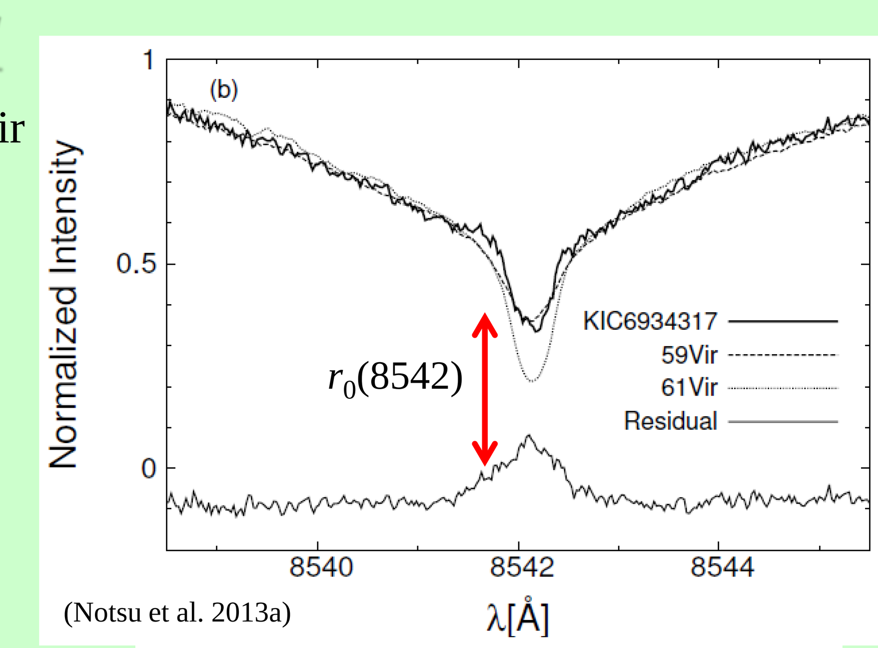
4. Chromospheric activity of KIC6934317

High Chromospheric Activity !!

r_0(8542) of KIC6934317 is larger than 61Vir (comparable to that of 59Vir.)



(Notsu et al. 2013a)

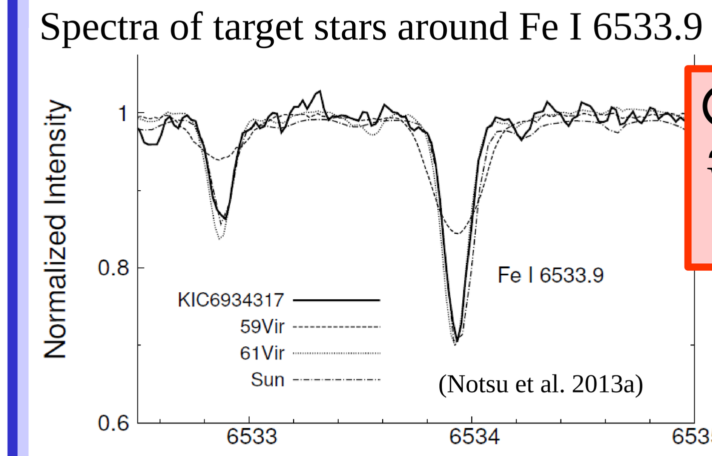


(Notsu et al. 2013a)

Spectra of target stars around Ca II 8542

5. Rotational velocity and Inclination angle

Spectra of target stars around Fe I 6533.9



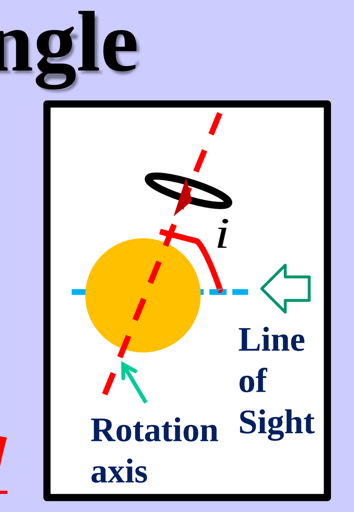
(Notsu et al. 2013a)

$$\tilde{v} \approx \frac{2\pi R_{star}}{P}$$

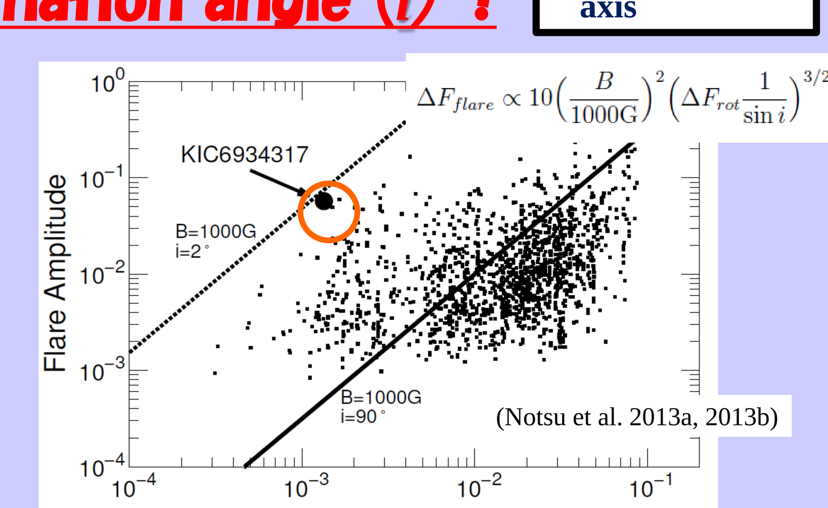
○KIC6934317

$\tilde{v}$ (rotational velocity) ~ **20 km s^{-1}**

$v \sin i$ ~ 1.91 km s^{-1}



Low inclination angle (i) !



(Notsu et al. 2013a, 2013b)

The small inclination angle is also supported by the contrast between the large superflare amplitude and the small stellar brightness variation amplitude shown the right figure. (For more details of this figure, **see Y. Notsu's poster**)

Reference

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

Related Talk & Posters

- ・Maehara's Talk (S6-I-01)
- ・Shibayama's poster (S6-P-07)
- ・Y. Notsu's poster (S6-P-08)