High Dispersion Spectroscopy of Solar-type Superflare Stars. Lithium Abundances

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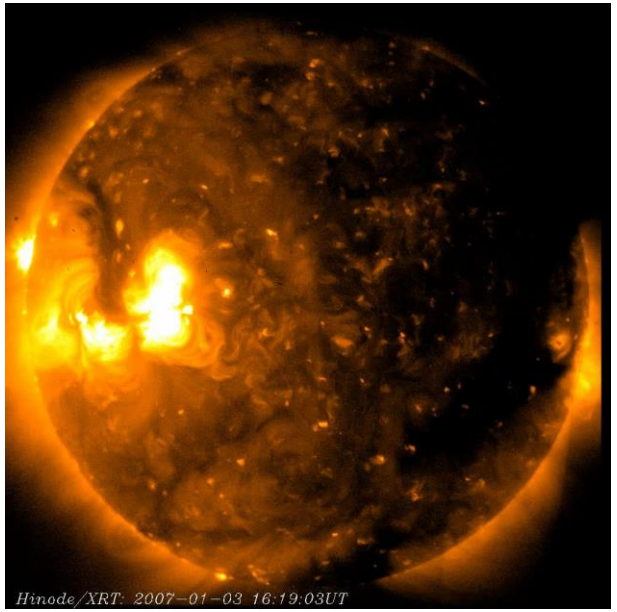
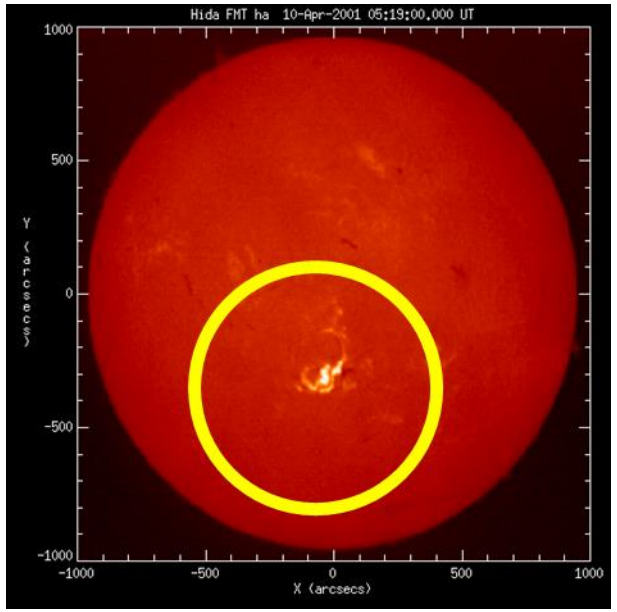
Subaru UM @ Atami 2016.1.19-21

Solar flares

- Most energetic explosions on the surface of the Sun, and are thought to occur by release of magnetic energy (c.f., Shibata & Magara 2011).
- Release of the magnetic energy stored around the sunspot.
- Hα, X-ray emission, radio, etc
- Time scale : minutes – hours
- Total energy ~ 10^{29} - 10^{32}erg
- Huge flare effects on the earth.



Hinode / ISAS Soft X-ray (1keV)



Hα 10,000K Hida Obs./Kyoto Univ.

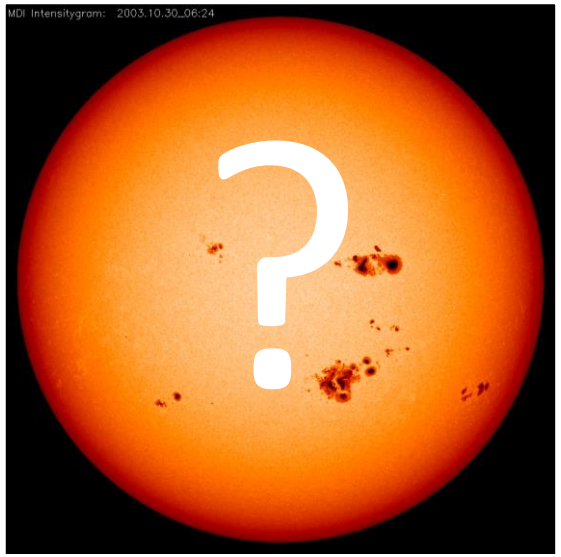
Stellar flare

- Flares are also known to occur on various types of stars including solar-type stars.
- The rapid rotation stars tend to cause the **superflare**, which is larger than 10 – 10^4 times the largest Sun's flare.
  - T Tauri star, close binary stars, dMe stars, etc.

- The Sun is the single and slowly rotating star.
- It has been recognized that the superflares will not occur on the Sun.
- Can such superflares occur on the present Sun ?
  - Shibata et al. 2013 -> possible ! (from the theoretical point of view)

Superflare on EV Lac

http://www.nasa.gov/multimedia/imagegallery/image_feature_1087.html



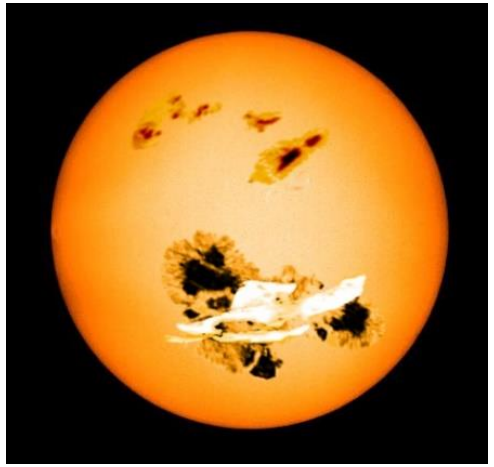
SOHO/MDI 2003.10.3

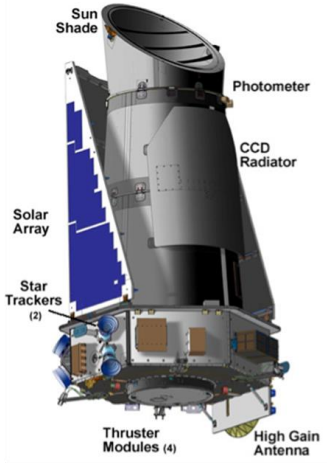
Superflare stars

- We discovered many (> 1000) superflares on many (～ 300) solar-type (G-type main sequence) stars from Kepler photometric data.
  - Maehara et al. 2012
  - Shibayama et al. 2013

- Many superflare stars show brightness variations and these variations are thought to be caused by the rotation of a star having starspots.
  - Y. Notsu et al. 2013

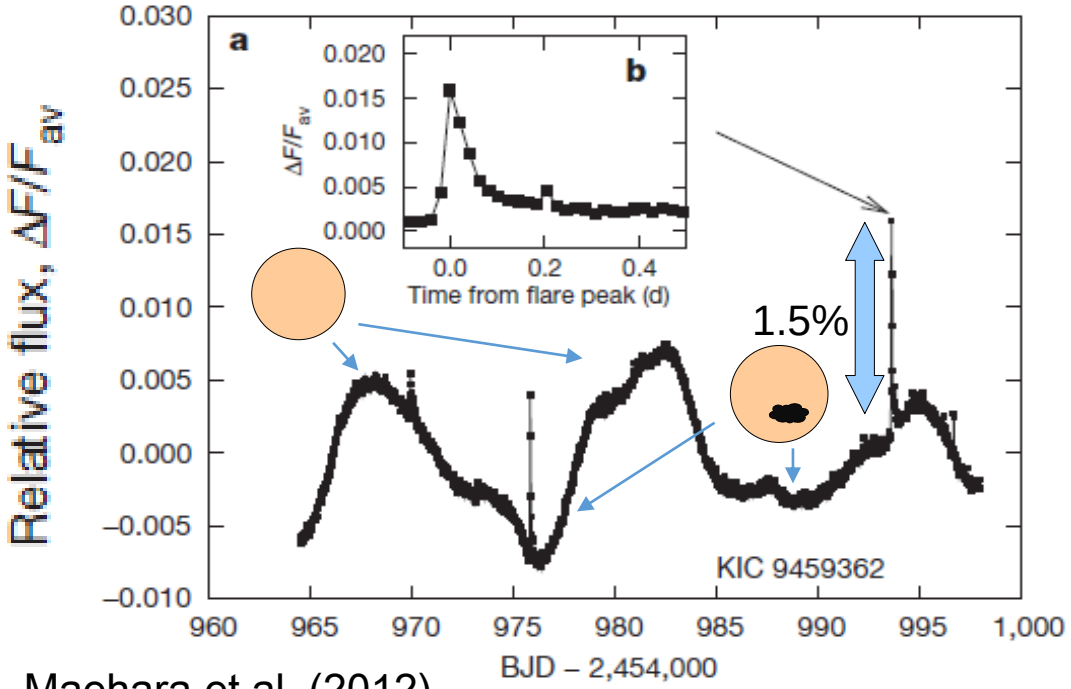
Imaginary drawings of a superflare star





Kepler NASA

Lightcurve of superflare ↓



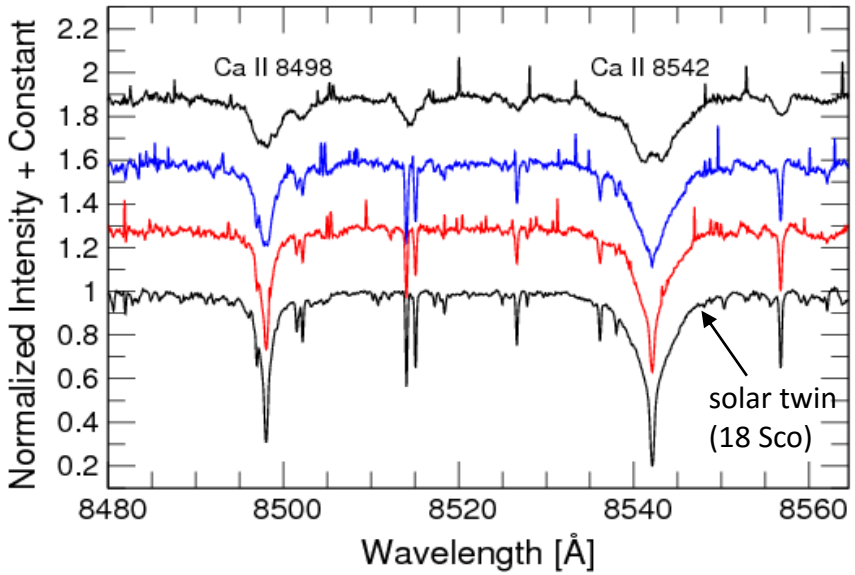
Maehara et al. (2012)

High dispersion spectroscopy of Superflare stars by Subaru/HDS

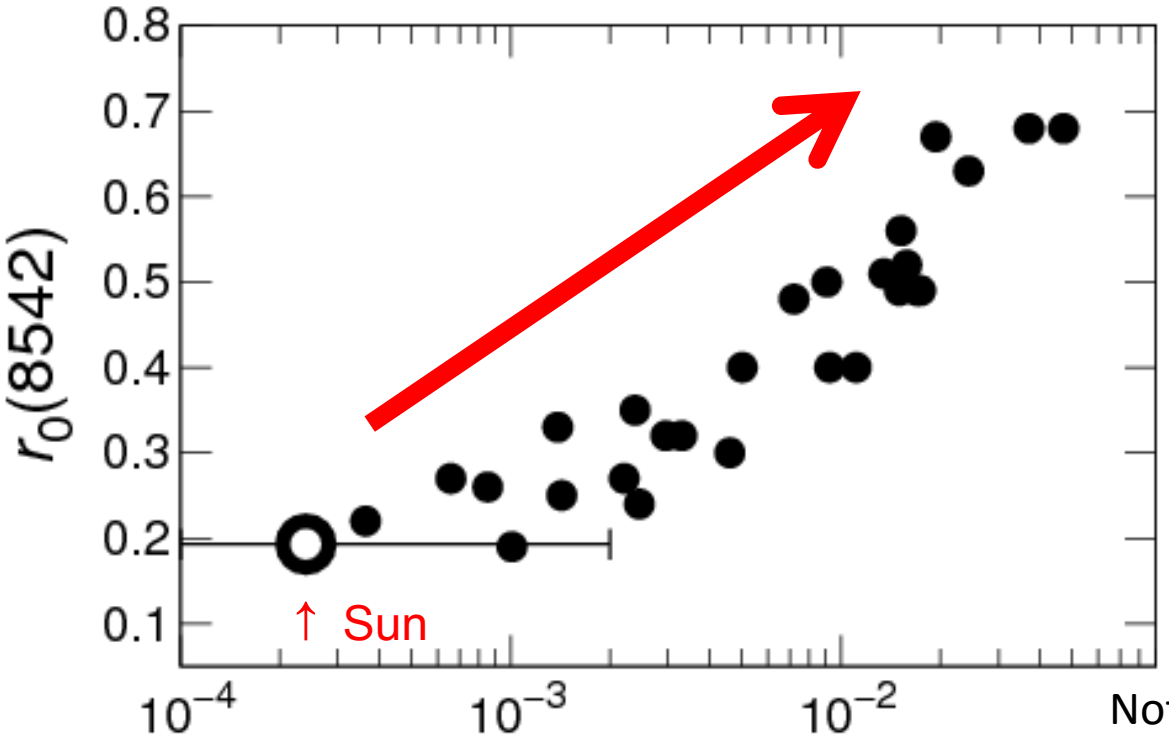
- We observed 50 superflare stars.
- Total 6 night（S11B, S12B, S13A）
- Wavelength range 6100 – 8800 A
- R = 50,000 – 100,000

HDS

- We found that 34 stars have **no evidence of binary** system.
- CaII lines show **high chromospheric activity**.
- Rotational velocity and large star spot of superflare stars has been confirmed by spectroscopic observations.
  - S. Notsu et al. 2013, Nogami et al. 2014, Y. Notsu et al. 2015a,b

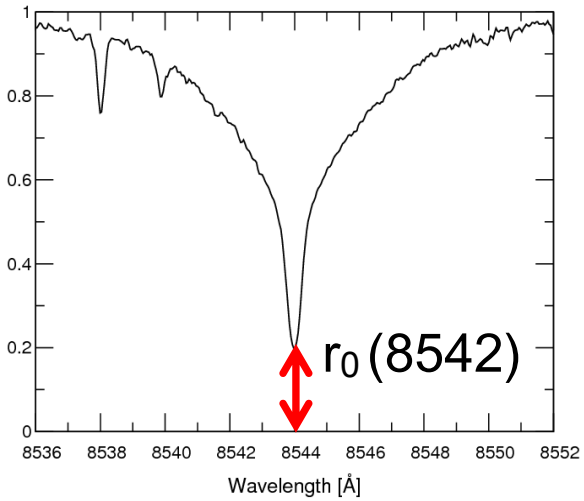


Starspot coverage vs Ca II 8542 intensity



Notsu et al. 2015b

r_0: Normalized intensity of Ca II 8542

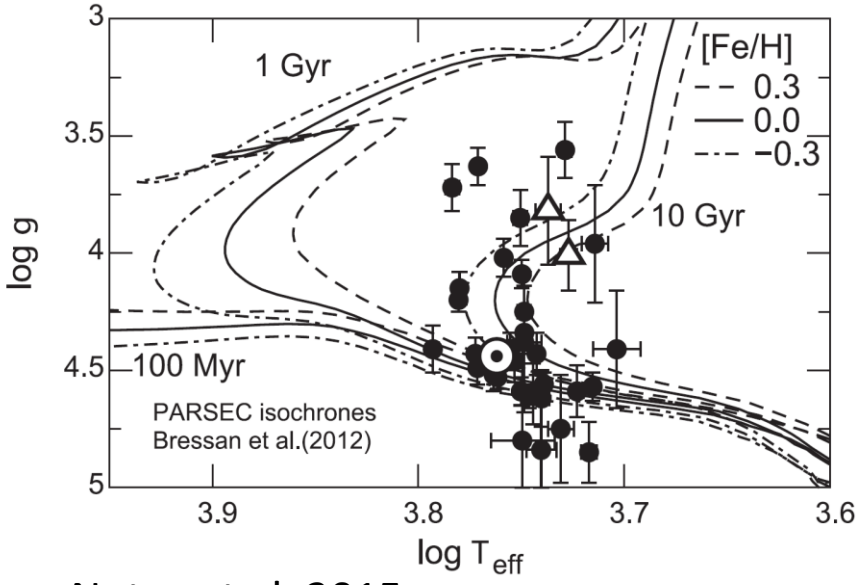


Brightness Variation Amplitude ≒ starspot coverage

All the targets that are expected to have large starspots because of their large brightness variation amplitude in Kepler data show high (Ca II) magnetic activities.

Are superflare stars very young stars ?

- What kind of single solar-type stars occur superflare ?
- Very young stars generally rotate fast and occur superflares.
- These stars will have large star spots and high activities of chromosphere.
- Are superflare stars young stars like WTTS ?
- However, Hα lines of superflare stars do not show emission.
- There are slowly-rotating stars.
- It is difficult to determine the age of stars.



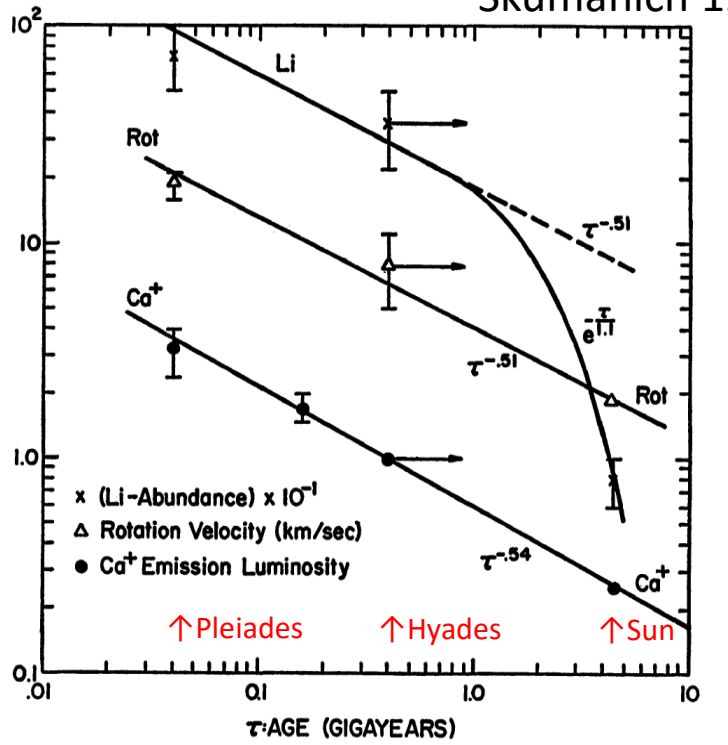
Notsu et al. 2015a

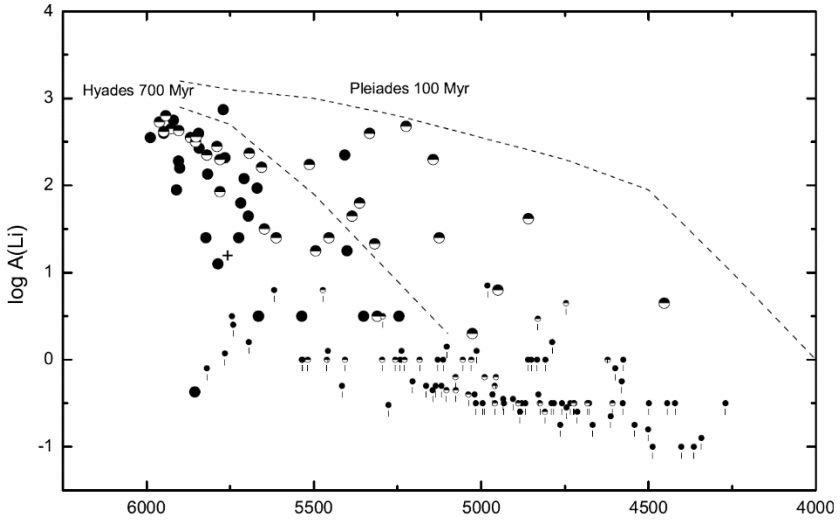
Lithium abundances

- Li is easily destroyed in the hotter region of stellar atmospheres.
- It will be reflect the age of solar-type stars. (e.g., Herbig 1965)
- Young stars have high Li abundance, rapid rotation, and high activity. (e.g., Skumanich 1972)
- We can estimate the age of superflare stars using Li abundance.

- ^{6}Li could be produced by the reaction ^{4}He (^{3}He, *p*) ^{6}Li in situ by solar like flares. (e.g., Tatischeff & Thibaud 2007)
- There is no clear evidence of production of Li by stellar flares, yet.
- Superflare stars are good objects to investigate whether flare can make Li or not.

Skumanich 1972

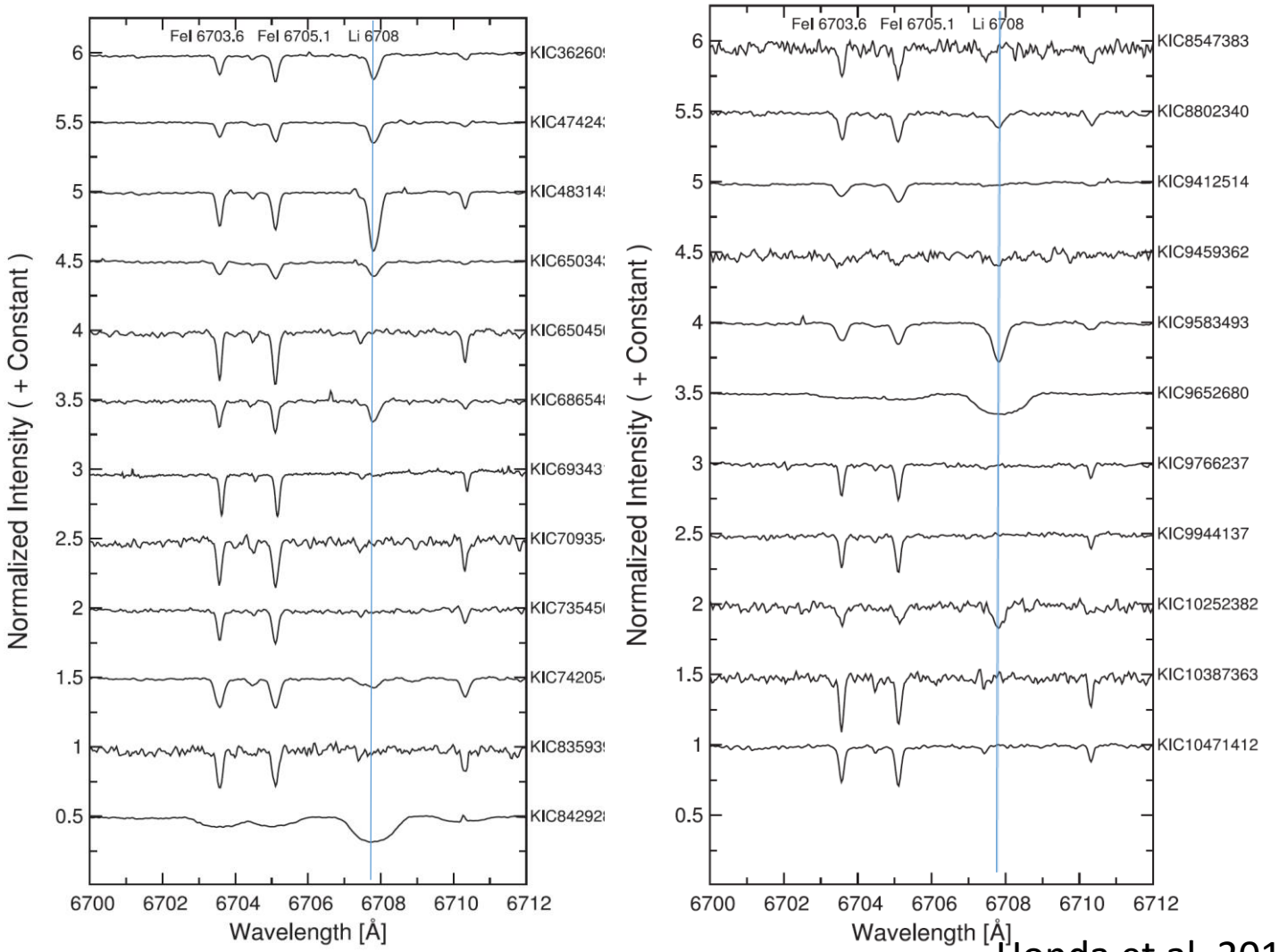




Mishenina et al. 2012

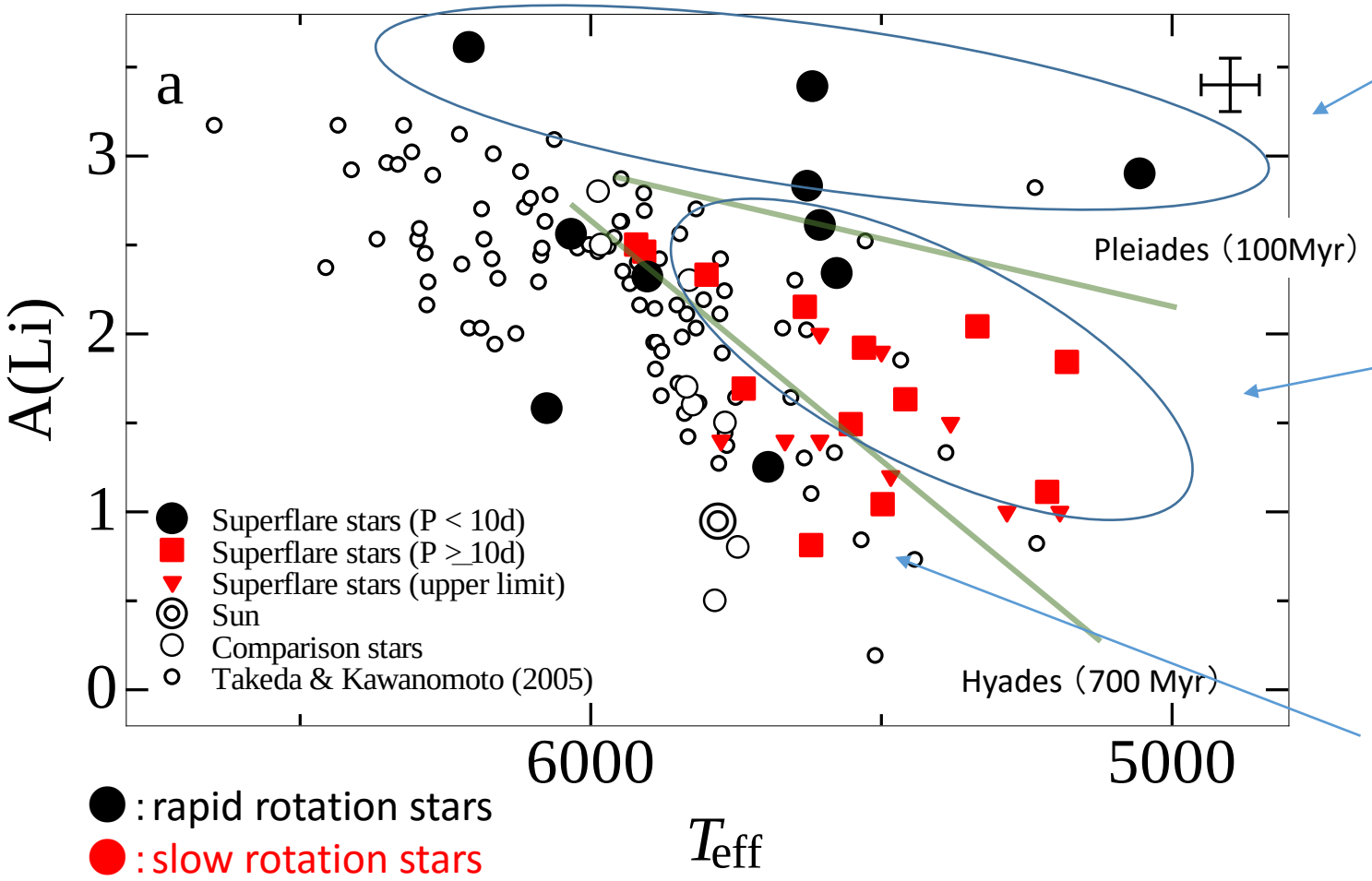
Sample spectra of Li 6708A regions

- We derive the Li abundances for 34 single superflare stars.
- Atmospheric parameters determined by Notsu et al. (2015a)
- We used the analysis program SPTOOL (Takeda 1995) based on Kurucz's ATLAS9/WIDTH (Kurucz 1993).



Honda et al. 2015

Lithium abundances and effective temperature of Superflare stars



● : rapid rotation stars

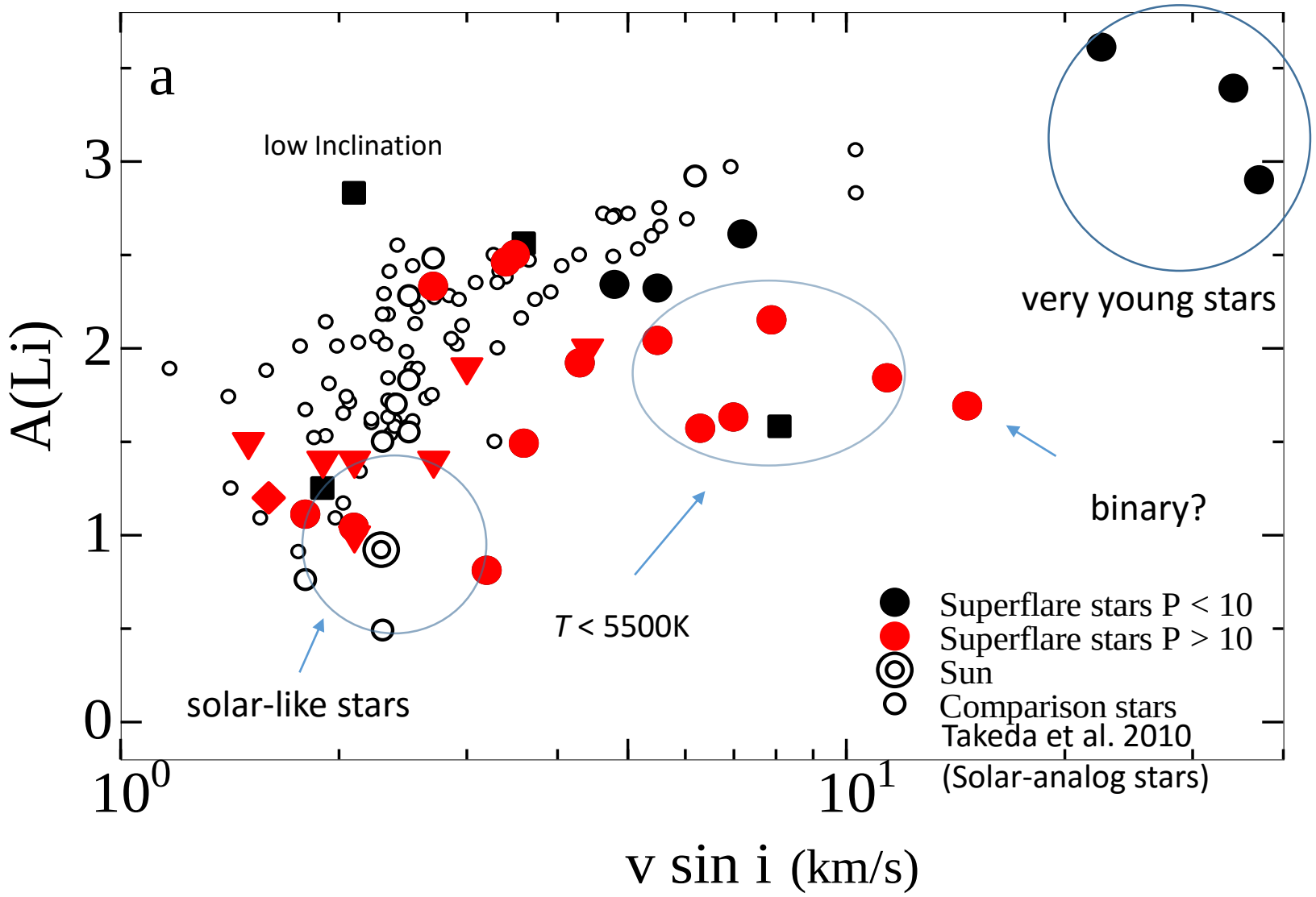
● : slow rotation stars

These stars show an especially high value of Li, to be very young stars.

The half of stars show high Li compared with Hyades cluster which is old open cluster but is younger than the Sun.

More than 10 stars with superflares do not show high value of Li compared with Hyades cluster.

v sin i (projected rotational velocity) and Lithium



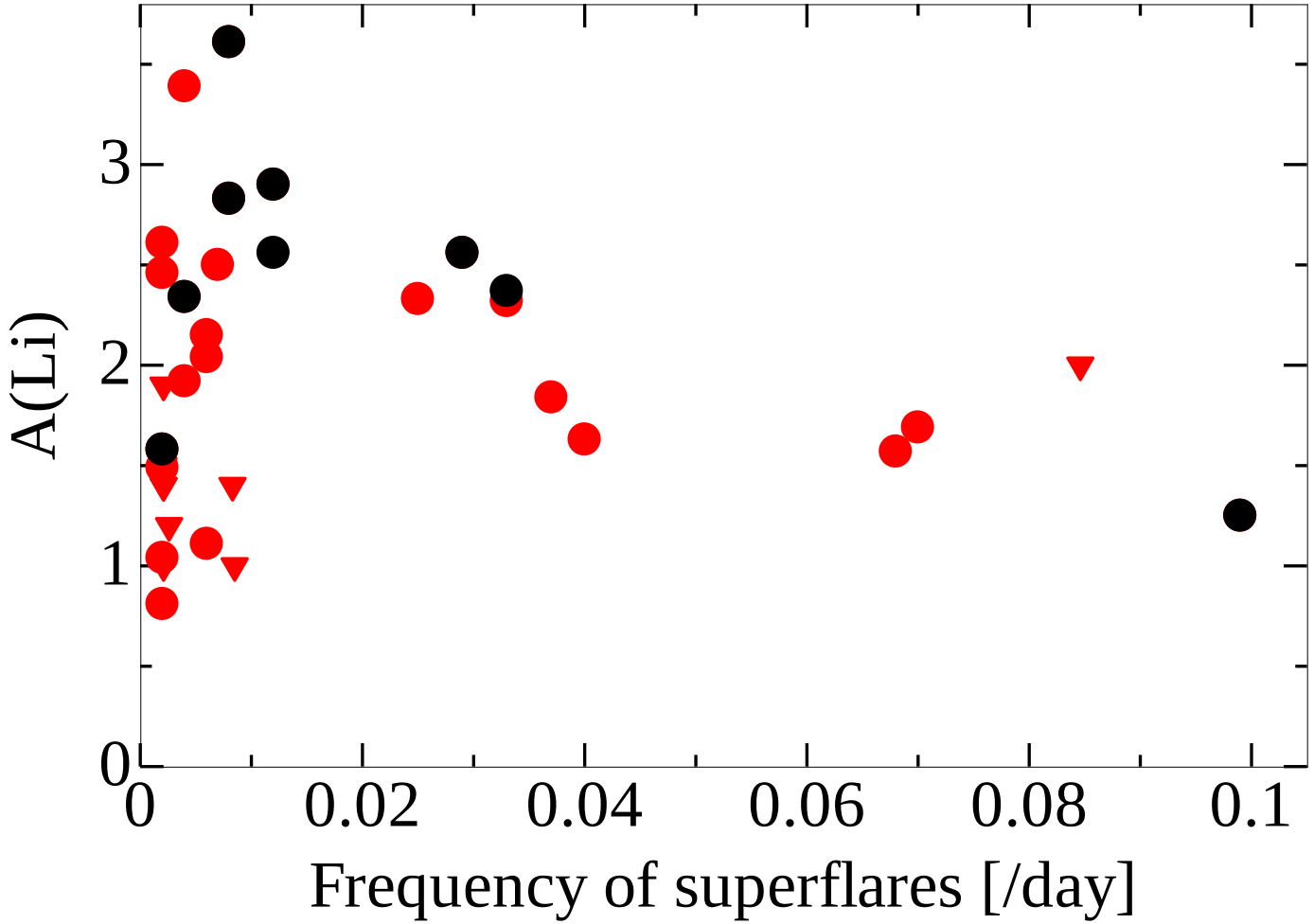
In general, the stellar rotation has a correlation with the age and activity.

Some superflare stars show small vsini and low Li abundance.

This results may indicate that those stars are not young.

Superflare stars are not necessarily young.

Li abundances and Frequency of superflares



Li abundance decrease as the number of superflares increases.

→

- No evidence of Li production by superflare.
  - An increase of Li is seen only for just after the end of flare ?
  - Our observations could not show the small contributions of ^{6}Li.

It is important to investigate the ratio of ^{6}Li to ^{7}Li in superflare stars, and we need time-series data.

Summary and Future Work

- We have estimated the Li abundance of superflare stars and investigated the correlations of Li abundance with stellar parameters.
- Our spectroscopic observations show that slightly young (rapid rotation) solar-type stars tend to produce superflares, but that **old superflare stars exist**.
- There is a possibility that **superflares could be generated on our Sun**.
  - It is important continuous monitoring of sun-like superflare stars to investigate the long-term activity change.
  - TESS and K2 mission may discover the good candidate of solar-twin superflare stars.
- We could **not find any evidence of nucleosynthesis of Li** in stellar flares from our observations.
  - Li isotope abundances of superflare stars would clarify the issue of Li production in stellar flare.

Flare energy vs. area of starspots