High Dispersion Spectroscopy of Solar-type Superflare Stars

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Flares are energetic explosions on the surface of the stars, and are thought to occur by intense releases of magnetic energy stored around starspots. Superflares are flares $10\sim10^6$ times more energetic ($\sim10^{33-38}$ erg) than the largest solar flares ($\sim10^{32}$ erg). Recently, we analyzed the data of the Kepler spacecraft, and discovered 1547 superflares on 279 solar-type (G-type main sequence) stars [1,2]. This discovery was very important since it enabled us to conduct statistical analysis of superflares for the first time, but more detailed observations were needed to investigate detailed properties of superflare stars.

Based on the initial discovery, we carried out high-dispersion spectroscopic observations on 50 solar-type superflare stars with Subaru/HDS [3,4].

1. More than half of the observed 50 stars show no evidence of binarity. We confirmed the characteristics of the target stars (e.g., temperature, surface gravity) as similar to those of the Sun.

2. On the basis of the Kepler data, superflare stars show somewhat regular, periodic changes in their brightnesses (Figure 1). The typical periods range from one day to a few tens of days. Such variations are explained by the rotation of the star with its large starspots [5]. If this is true, the timescales of the brightness variations should correspond to the stars' rotation speeds. Spectroscopic observations allow us to estimate the rotation velocity from the broadening of absorption lines, and we confirm that a velocity derived from spectroscopic data matches the brightness variation timescale as the star rotates. In addition, the measured rotation velocity of some target superflare stars is as slow as that of the Sun.

3. Based on solar observations, it is known that, the intensity of the Ca II line is a good indicator of starspot coverage. We investigated this line, and found that there is a correlation between the amplitude of the brightness variation of the Kepler data and the intensity of Ca II 8542Å line (Figure 2). We then confirmed that superflare stars have large starspots compared with sunspots.

These results confirm that stars similar to the Sun can have superflares if they have large starspots. In the future, in addition to the continuing spectroscopic observations with Subaru Telescope, we will conduct observations with the Kyoto University's Okayama 3.8m telescope, which is now under construction. This will allow them to investigate more detailed properties and changes in long-term activity of superflare stars.

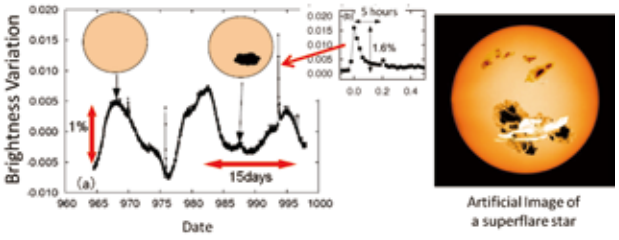

Figure 1: The brightness variation of solar-type superflare stars (from Kepler data). In addition to the sudden brightenings caused by flares, quasi-periodic brightness variations with periods of about 15 days are seen. Right: An artificial image of a superflare star seen with visible light. This figure shows a large superflare (shown in white) occurring in the large starspot area.

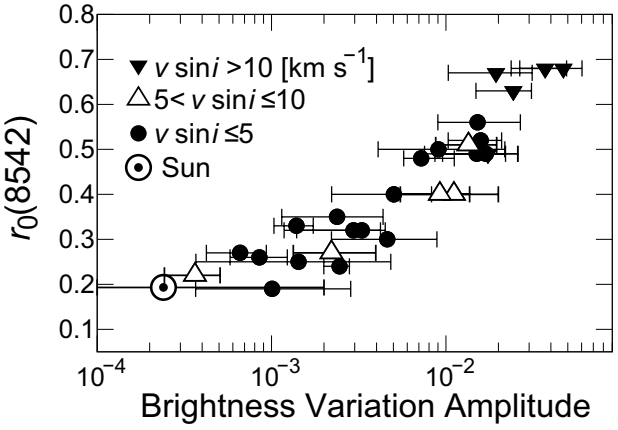

Figure 2: The quantity r_0(8542) (the residual core flux normalized by the continuum level at the line cores of the Ca II 8542Å) as a function of the amplitude of stellar brightness variation estimated from Kepler data.

References

[1] Maehara, H., et al.: 2012, *Nature*, **485**, 478.
[2] Shibayama, T., et al.: 2013, *ApJS*, **209**, 5.
[3] Notsu, Y., et al.: 2015, *PASJ*, **67**, 32.
[4] Notsu, Y., et al.: 2015, *PASJ*, **67**, 33.
[5] Notsu, Y., et al.: 2013, *ApJ*, **771**, 127.