

## **A Report on the Workshop “Superflares on Solar-type Stars and Solar Flares, and Their Impacts on Exoplanets and the Earth.” held in 2016 March 1st (Tue)– March 4th (Fri)**

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**Abstract.** A workshop on superflares on solar-type stars and related subjects was held in March, 2016 at Kyoto University. Here, a report on the workshop is given, including the purpose of the workshop, SOC, LOC, invited speakers, the program, and a brief summary of talks and discussions.

**Keywords:** Stars: flare, Stars: activity, Sun: flare, Sun: activity, Astrobiology

### **1. Purpose of the Workshop**

We held the workshop “Superflares on Solar-type Stars and Solar Flares, and Their Impacts on Exoplanets and the Earth” at Faculty of Science of Kyoto University on March 1st (Tue)– March 4th (Fri), 2016, supported by the International Research Unit of Advanced Future Studies, Kyoto University.

The main reason why we held the workshop at Kyoto was that the study of superflares on solar-type stars has been significantly developed by the Kyoto group in recent years (Maehara et al. 2012, Shibata et al. 2013, Shibayama et al. 2013, Notsu, Y. et al. 2013, Notsu, S. et al. 2014, Nogami et al. 2014, Maehara et al. 2015, Notsu, Y. et al. 2015a,b, Honda et al. 2015).

Using Kepler data, Maehara et al. (2012) discovered many superflares (with energy of  $10^{34}$ – $10^{36}$  erg) on solar type stars (G-type main sequence stars). In the case of the Sun-like stars (with surface temperature 5600–6000 K and slowly rotating with a period longer than 10 days), the occurrence rate of superflares with an energy of  $10^{34}$ – $10^{35}$  erg is once in 800–5000 yr. There is evidence that these superflare stars have extremely large starspots with a size about 10 times larger than that of the largest sunspot (Shibayama et al. 2013, Notsu, Y. et al. 2013). There was no signature of hot Jupiter on these stars against previous prediction (Schaefer et al. 2000, Rubenstein and Schaefer 2000), suggesting the possibility of superflares on the Sun. Such a possibility of solar superflares (with energy  $10^{34}$  erg) was theoretically supported using order-of-magnitude estimate of total magnetic flux that can be generated by the differential rotation of the present Sun on the basis of a current solar dynamo model (Shibata et

al. 2013). The spectroscopic observations of these superflare stars have started (Notsu, S. et al. 2014), and two Sun-like superflare stars rotating as slow as the Sun were discovered (Nogami et al. 2014). More recently, using spectroscopic data of 34 superflare stars taken by Subaru telescope, it was confirmed that the rotational velocity,  $v \sin i$ , and spot coverage are consistent with those estimated from the brightness variation observed by Kepler (Notsu, Y. et al., 2015a,b). The Lithium abundance of these superflare stars was also measured from Subaru data (Honda et al. 2015).

Since the subject is so important for both solar and stellar physics as well as for astrobiology, the idea to hold this workshop has emerged on the basis of the recent active research on superflares by the Kyoto group as discussed above.

Main purpose of this workshop was to review and discuss superflares on solar-type stars and related stars, solar white-light flares, modelling of optical spectra of solar white-light flares and stellar flares, long-term variations of the stellar activity and starspots, the dynamo theory of big spots leading to superflares on solar-type stars, and to discuss the possibility of superflares on the Sun, impacts of stellar superflares on exoplanets, and future possible impacts of solar superflares on the Earth. Collaboration on these subjects among participants has also been encouraged during the workshop and future.

## **2. SOC and LOC**

SOC members are as follows:

- Kazunari Shibata (Kyoto University, Chair)
- Suzanne Hawley (University of Washington)
- Hiroyuki Maehara (NAOJ)
- Satoshi Honda (University of Hyogo)
- Kiyoshi Ichimoto (Kyoto University)
- Hiroaki Isobe (Kyoto University)

LOC members are as follows:

- Daisaku Nogami (Kyoto University, Chair)
- Ayumi Asai (Kyoto University)
- Takako T. Ishii (Kyoto University)
- Yuta Notsu (Kyoto University)
- Shota Notsu (Kyoto University)
- Kosuke Namekata (Kyoto University)

Invited speakers are:

- Suzanne L. Hawley (University of Washington, USA)
- Adam F. Kowalski (NASA, GSFC, USA)
- Steven Saar (Harvard-Smithsonian Center for Astrophysics, USA)
- Luis A. Balona (South African Astronomical Observatory, South Africa)
- Valery M. Nakariakov (University of Warwick, UK)
- Kyoko Watanabe (National Defense Academy of Japan, Japan)
- Masashi Omiya (NAOJ, Japan)
- Yoichi Takeda (NAOJ, Japan)
- Hideyuki Hotta (Chiba University, Japan)

### **3. Program**

The program of this workshop was as follows:

#### **3/1 (Tue) Observation of Stellar Superflares and Solar White Light Flares**

Time	Name	Rough contents of the talk
Chair: Kazunari Shibata		
10:00-10:10	Kazunari Shibata	Opening remarks
10:10-11:00	Hiroyuki Maehara	Superflares and starspot activity on solar-type stars
11:00-12:00	Suzanne Hawley	Observation of stellar flares
12:00-13:30	Lunch	
Chair: Ayumi Asai		
13:30-14:30	Adam Kowalski	Modeling of optical spectrum of stellar flares
14:30-15:30	Kyoko Watanabe	Solar white-light flares
15:30-16:00	Break	
Chair: Kiyoshi Ichimoto		
16:00-16:30	Takako T. Ishii	White light flares observed at Hida Observatory
16:30-16:45	Kosuke Namekata	Statistical properties of solar white-light flares
16:45-17:00	Han Yuan Chang	A LAMOST-Kepler spectrophotometric study of hyper flares of M dwarfs
17:00-17:15	Li-Ching Huang	Physical Properties of G-type Kepler Eclipsing Binaries

#### **3/2 (Wed) Observation of Stellar Superflares and Spectroscopic Observations**

Chair: Hiroaki Isobe		
10:00-11:00	Luis A. Balona	Flare stars across the H-R diagram
11:00-12:00	Valery Nakariakov	Oscillations of stellar flares
12:00-13:30	Lunch	
Chair: Suzanne Hawley		
13:30-14:15	Yuta Notsu	Spectroscopic observations of solar-type superflare stars
14:15-14:30	Satoshi Honda	Spectroscopic observations of flare star EV Lac at NHAO
14:30-15:00	Break	
Chair: Satoshi Honda		
15:00-16:00	Yoichi Takeda	Activities and related properties of solar-type stars
16:00-17:00	Steven Saar	Observations of Magnetic Cycles in Late-type Single Dwarfs: What are They Telling Us?
17:00-17:30	Mark Cheung	Evolving Models of Stellar Photospheric and Coronal Magnetic Fields
19:00~	Banquet at Ganko Nijo	

#### **3/3 (Thu) Possibility of Superflares on the Sun**

Chair: Hiroyuki Maehara		
10:00-10:30	Kazunari Shibata	Can superflares occur on the Sun?
10:30-11:30	Hideyuki Hotta	Current understanding of solar global scale magnetic field and dynamo
11:30-11:45	Hisashi Hayakawa	World-Wide Records of Solar Flare Candidates in the 10th century and the 18th century

11:45- Lunch

PM Tour to Kwasan Observatory (Excursion)

[http://www.kwasan.kyoto-u.ac.jp/general/facilities/index\\_kwasan\\_en.html](http://www.kwasan.kyoto-u.ac.jp/general/facilities/index_kwasan_en.html)

### 3/4 (Fri) Planets (AM) & Future Plans (PM)

Chair: Takanori Sasaki

10:00-11:00 Masashi Omiya Observations of exoplanets and stellar activity

11:00-11:15 Takuya Takahashi CMEs of solar superflares

11:15-11:45 Daisaku Nogami Kyoto 3.8m telescope and future plans of our superflare studies

11:45-13:30 Lunch

Chair: Daisaku Nogami

13:30-17:00 Discussion ~Future plans of superflare studies~

(Moderators: Daisaku Nogami and Kazunari Shibata)

#### Short comments & Topics

-Daisaku Nogami: Future plans of our superflare studies

-Fumihide Iwamuro: Short comment on spectrograph of Kyoto 3.8m telescope

-Suzanne L. Hawley: Some thoughts on observing flares and starspots with new Japanese 3.8m telescope

-Bun'ei Sato: Comment on spectroscopic observations with Kyoto 3.8m telescope (Introduction of TESS)

-Hiroyuki Ishikawa: Comment on the habitability of M-type stars

-Possibility of International Collaboration

## 4. Talks and Discussions

Though the total number of participants was limited by the size of the room for the purpose of effective discussion, the workshop was attended by total number of 39 participants including 8 foreign researchers from 4 countries. Figure 1 shows a group photograph of this workshop.

As shown in the program, the workshop mainly consisted of invited review talks:

On the 1<sup>st</sup> day, Maehara gave a review of the study of superflares and related starspots based on Kepler data. Hawley presented an excellent review on optical observations of stellar flares. Kowalski introduced a detailed review on modeling of optical spectrum of stellar flares. Stellar flares spectroscopically observed in the optical light are physically the same as white light flares on the Sun. Hence, Watanabe presented a nice review on solar white light flares based on recent space observations, whereas Ishii discussed recent ground-based observations of solar white light flares taken at Hida Observatory of Kyoto University.

On the 2<sup>nd</sup> day, Balona reviewed flare stars across the H-R diagram, including the amazing discovery of superflares on A stars. Nakariakov discussed interesting study of oscillations of superflares on stars. Notsu (Y.) gave a review of spectroscopic observations of solar-type superflare stars taken with the Subaru 8.2m telescope, and Takeda gave a comprehensive review of activities and related properties of solar-type stars. Saar presented an interesting review on observations of magnetic cycles in late-type single dwarfs. Cheung commented a future plan of the study of the stellar flare activity as an extension of the solar flare study.

On the 3<sup>rd</sup> day, Shibata discussed “Can superflares occur on the Sun?” from the theoretical point of view. Hotta gave an excellent review on the current understanding of the solar dynamo theory.

On the 4<sup>th</sup> day, Omiya discussed an interesting plan of observations of exoplanets and related stellar activity. Since one of the important targets of the Okayama Kyoto 3.8m telescope is superflares and their host stars, Nogami discussed future plans of the superflare studies using the Kyoto Okayama 3.8m telescope. Especially in the afternoon of the 4<sup>th</sup> day, future plans of spectroscopic observations of

superflares and their host stars with Kyoto 3.8m telescope have been extensively discussed (see Fig 2). Finally, possibility of international collaboration has been discussed.

## **5. Acknowledgement**

We would like to thank all invited and contributed speakers to present interesting and informative talks, and thank all participants to attend this workshop and to have active discussion.

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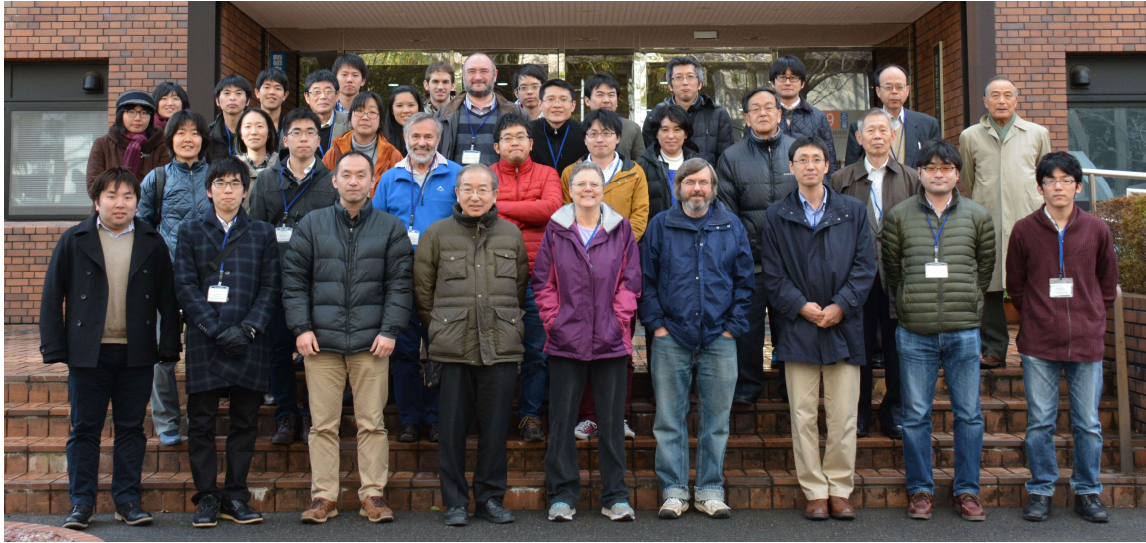


Fig 1 Group photo of participants of the superflare workshop, on March 1, 2016, in front of the entrance of the building 4 (Dept of Astronomy) of graduate school of science, Kyoto University.



Fig 2 One scene of discussion on future plans of the superflare research using the Kyoto Okayama 3.8m telescope.