Our ongoing projects and one suggestion of research on stellar flares

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3. Ongoing project with Seimei telescope
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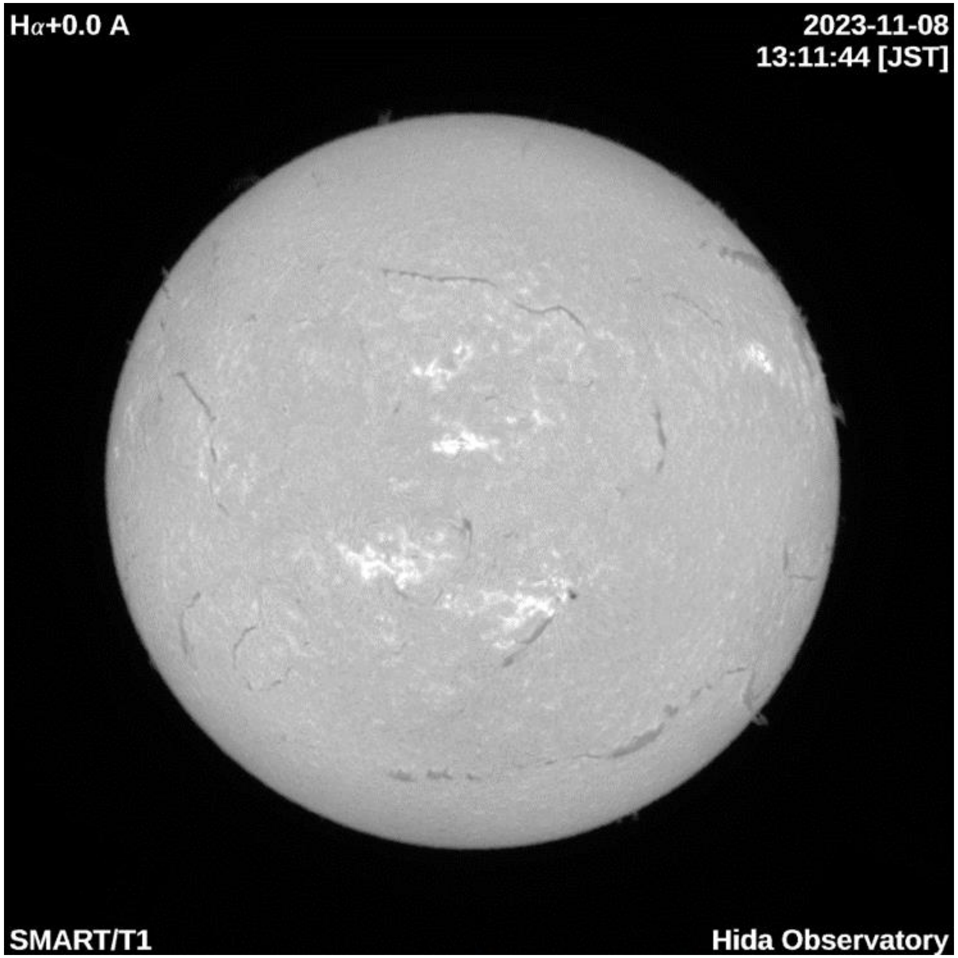
I. The Sun and solar flares

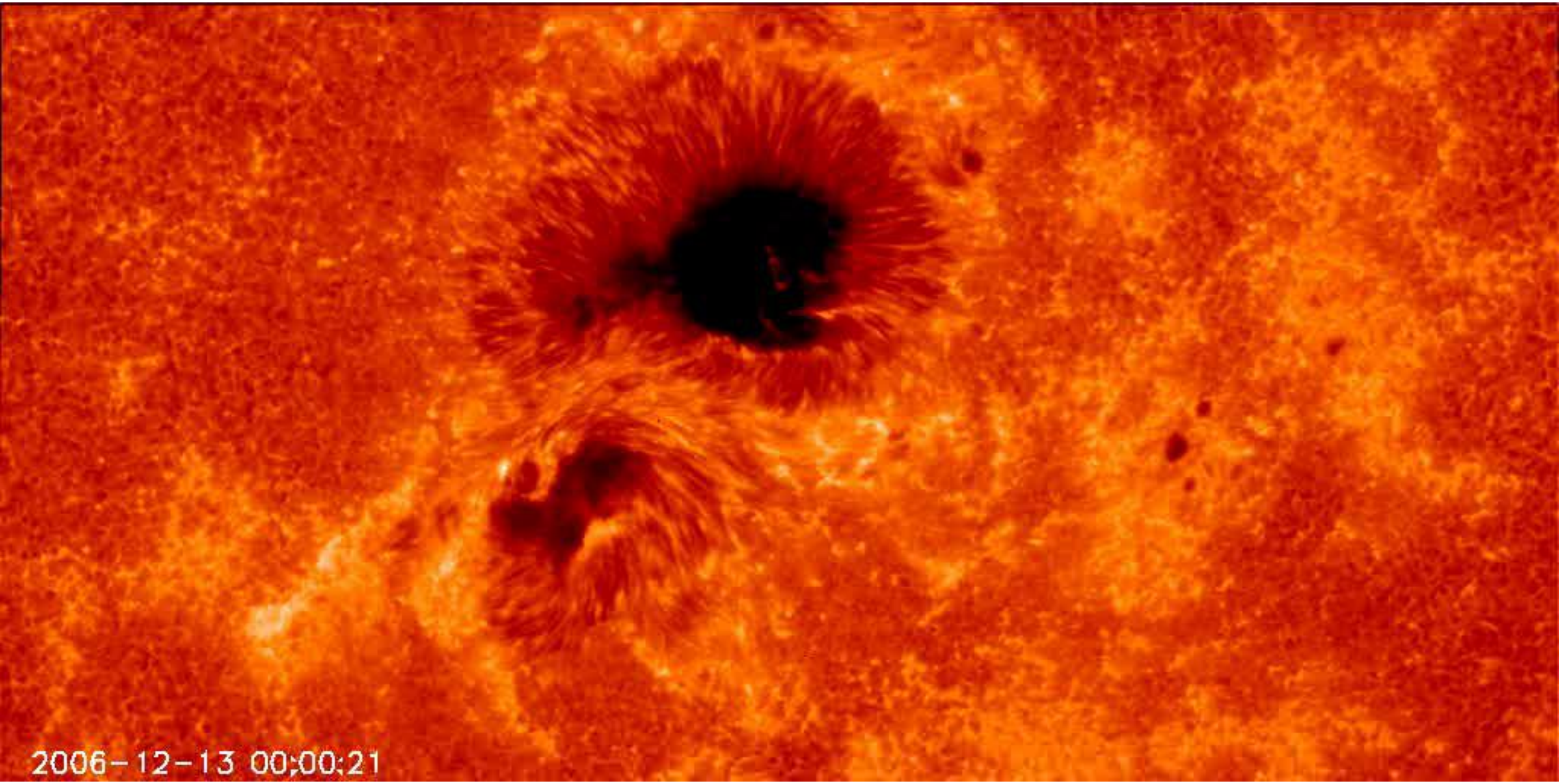
I. The Sun and solar flare

The nearest star = Celestial objects that emits their own lights with the energy of nuclear fusion reactions.



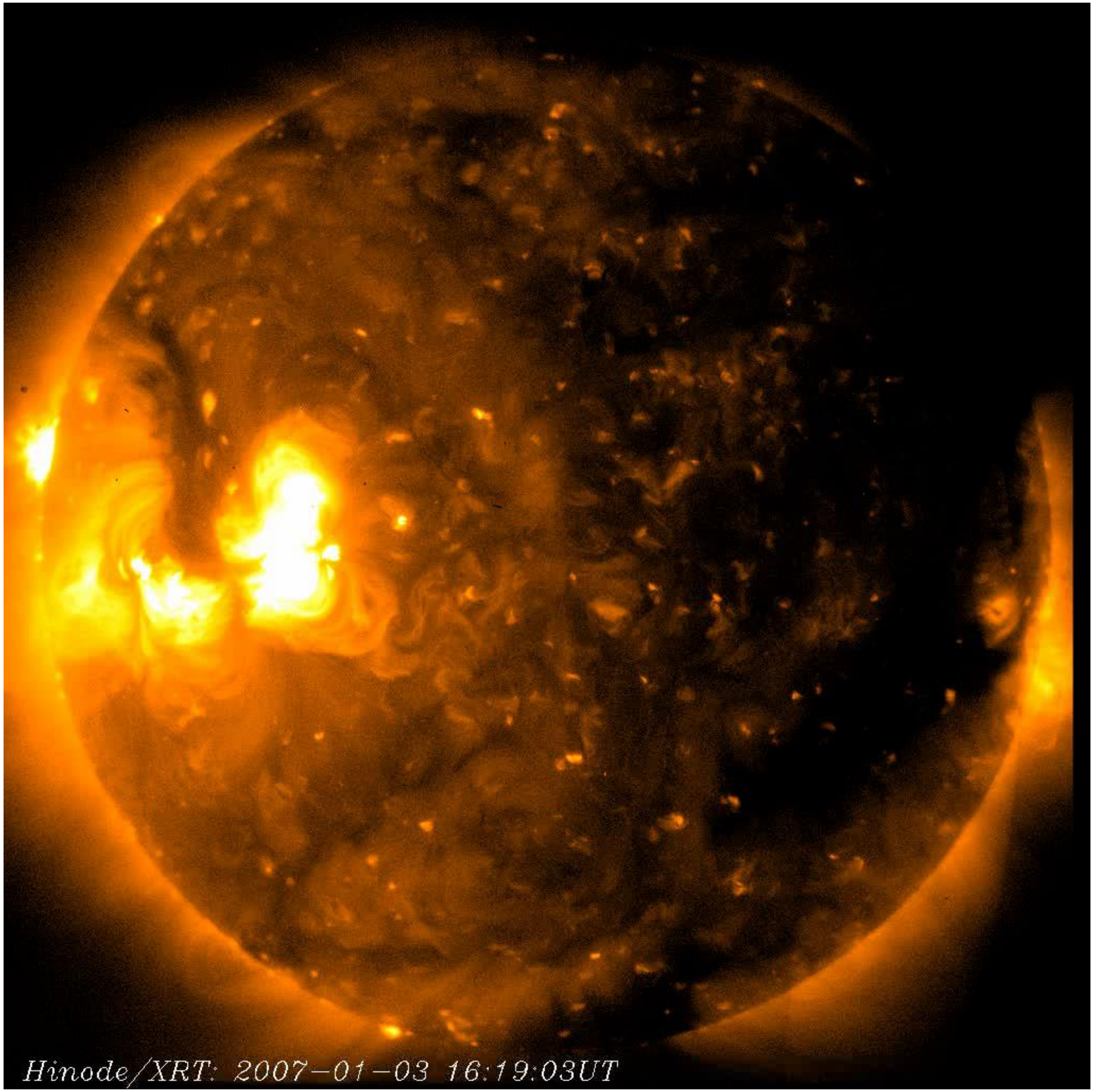
The Sun observed at Hida Observatory with an Hα filter on 2023 Nov. 8th.

The Sun appears quite brighter than stars. It is just because the Sun is much closer to us, and the Sun and stars are essentially the same.



A close-up movie of a solar flare by the satellite HINODE using a Ca II filter

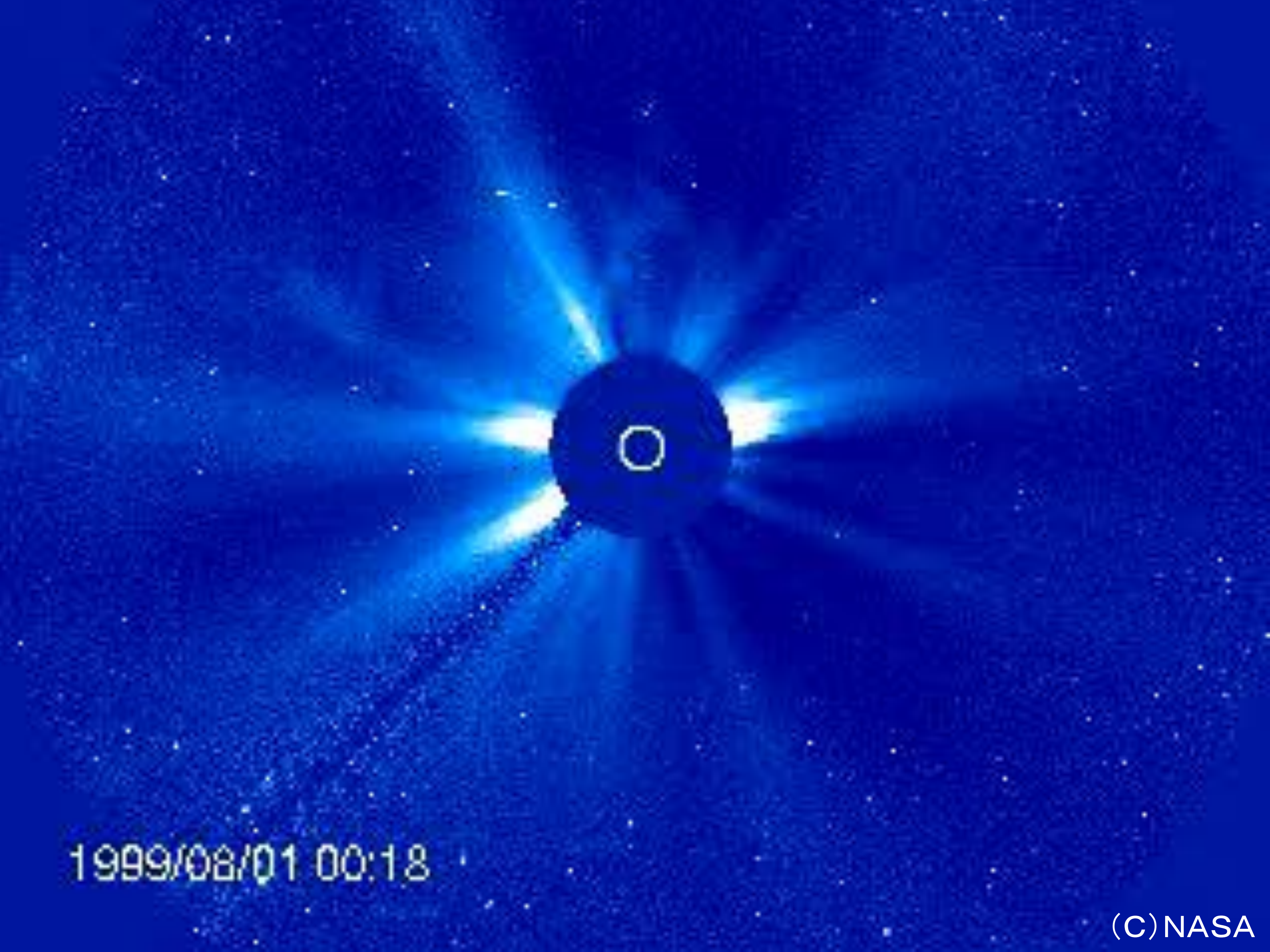
Flares occure everywhere on the Sun



(C) JAXA/ISAS

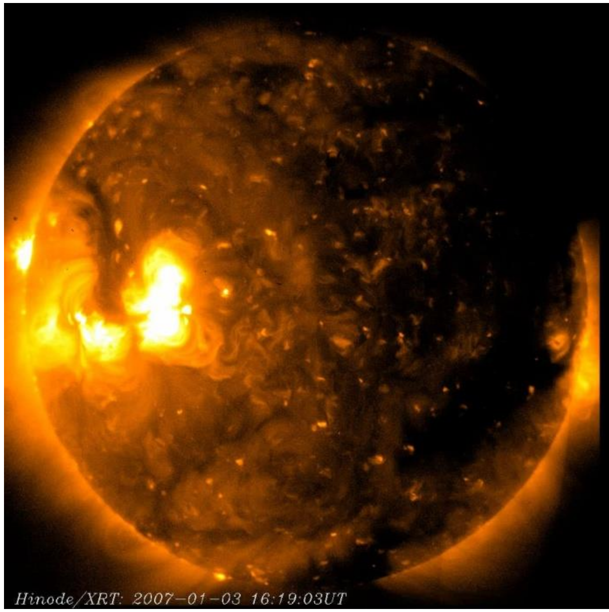
The Sun observed by an X-ray telescope onboard the satellite HINODE。
The place where the flare is occurring appears to shine.

A solar flare observed in the UV light on 2011 June 7th.

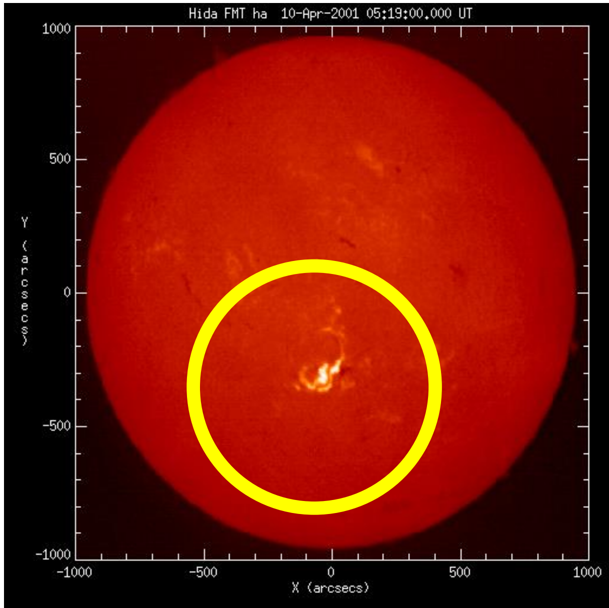

1999/08/01 00:18

Summary of the solar flare

- The most energetic explosions that occur on the solar surface
- To be observed in all wavelengths from X-ray to radio.
- Timescale: minutes to hours
- The resource is magnetic energies stored around sunspots
- The total energy: 10^{29}–10^{32} erg



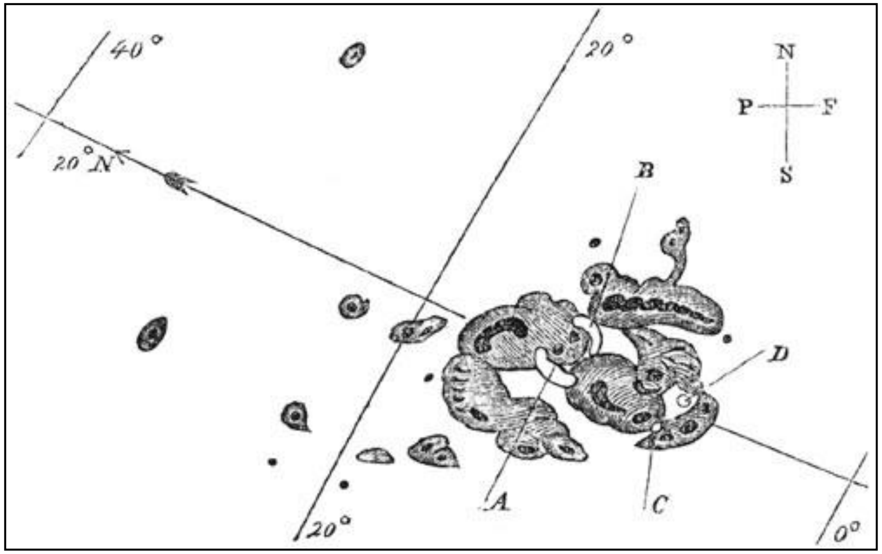
Soft X-ray image of the Sun ©JAXA/ISAS



Hα image of the Sun ©Kyoto U.

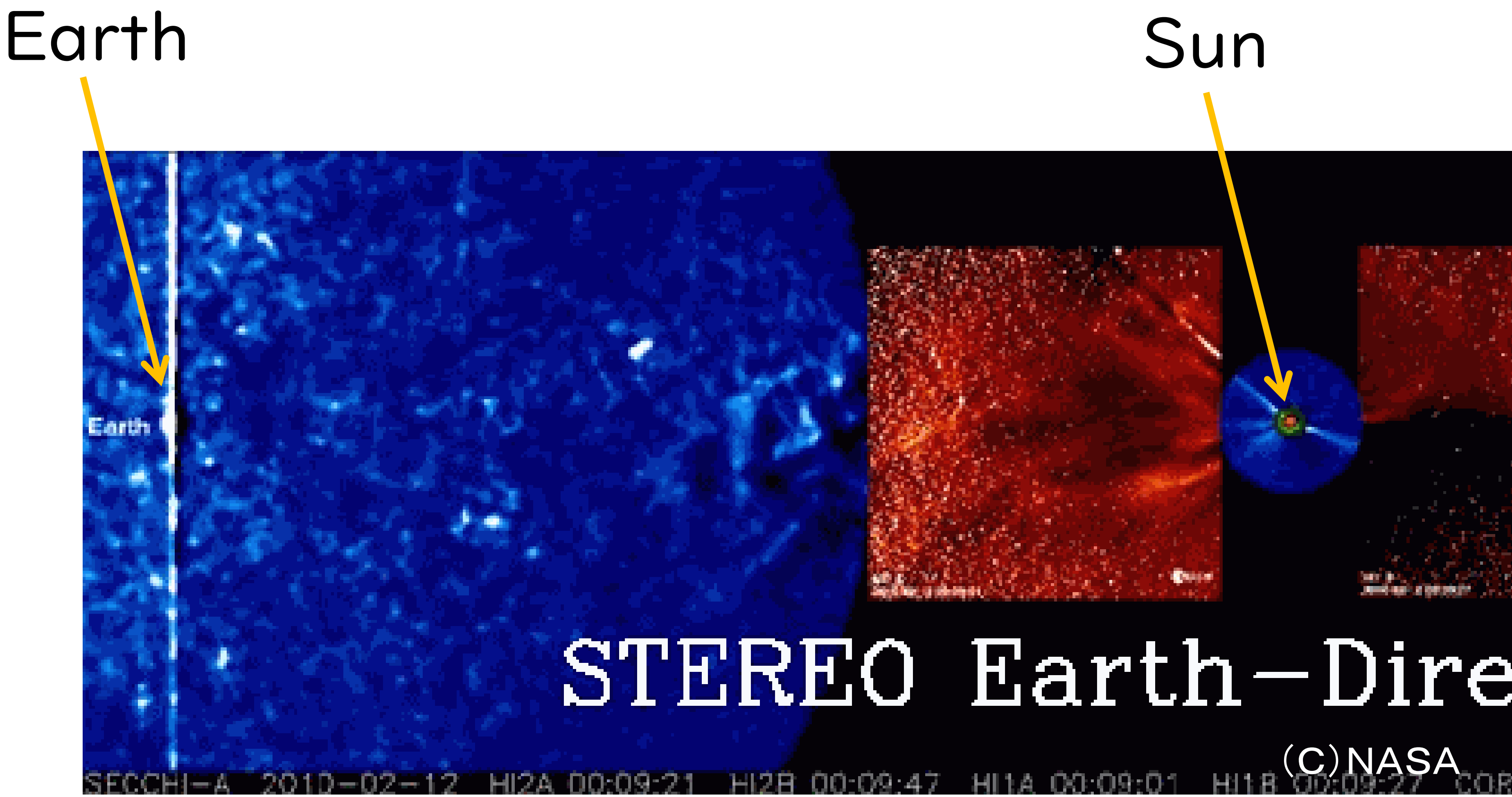
Carrington Flare
(1859 Sep. 1st 11:18)

- The flare that was detailedly recorded by Richard Carrington, for the first time in the human history.
- A white-light flare for about 5 minutes.
- Next day, a bright aurora was observed in many places incl. Hawaii, mid-America, etc.
- Estimated to be 10^{32} erg, the most energetic ever observed.



Carrington (1859)

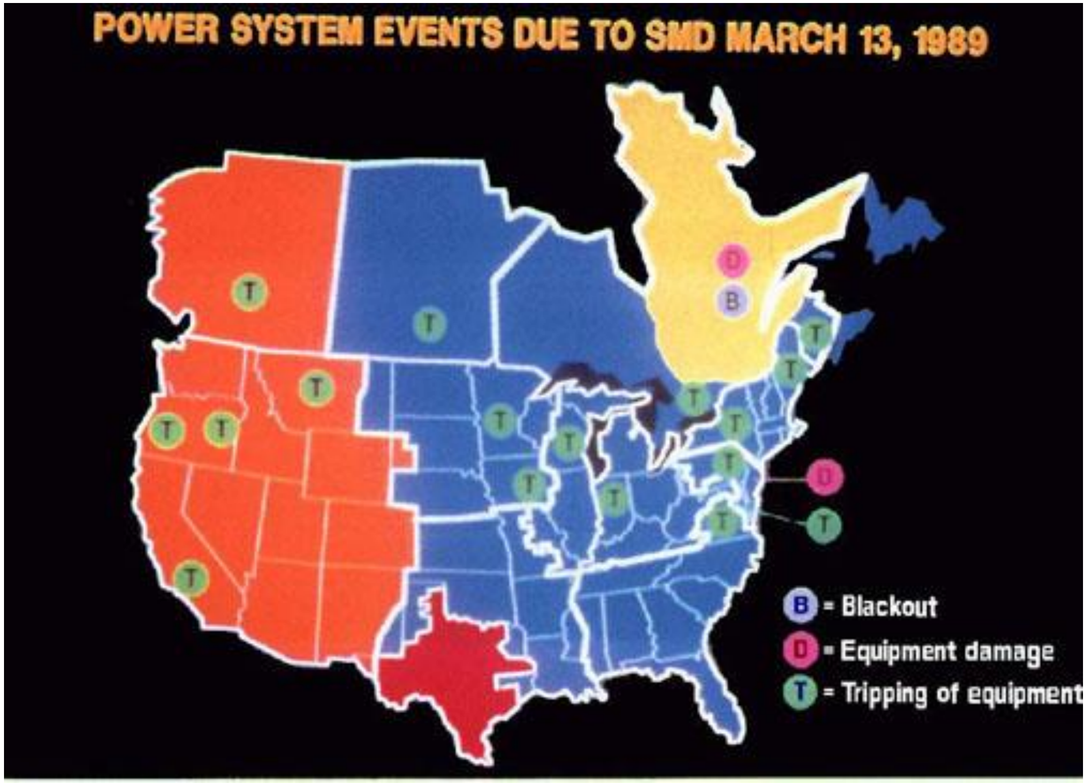
- The most energetic geomagnetic storm (> 1000 nT) was observed for the recent 200 years.
- Telegraph system failures occurred in Europe, US, etc.



Large amounts of plasmas, radiation, and energetic particles fly through interplanetary space

→ Effects on Earth's environment

Major power outage in Quebec caused by a magnetic storm on March 13, 1989



PJM Public Service
Step Up Transformer

Severe internal damage caused by the space storm of 13 March, 1989

Fairly large solar flare
→geomagnetic storm (~540 nT)
→Power outage affecting 6M families

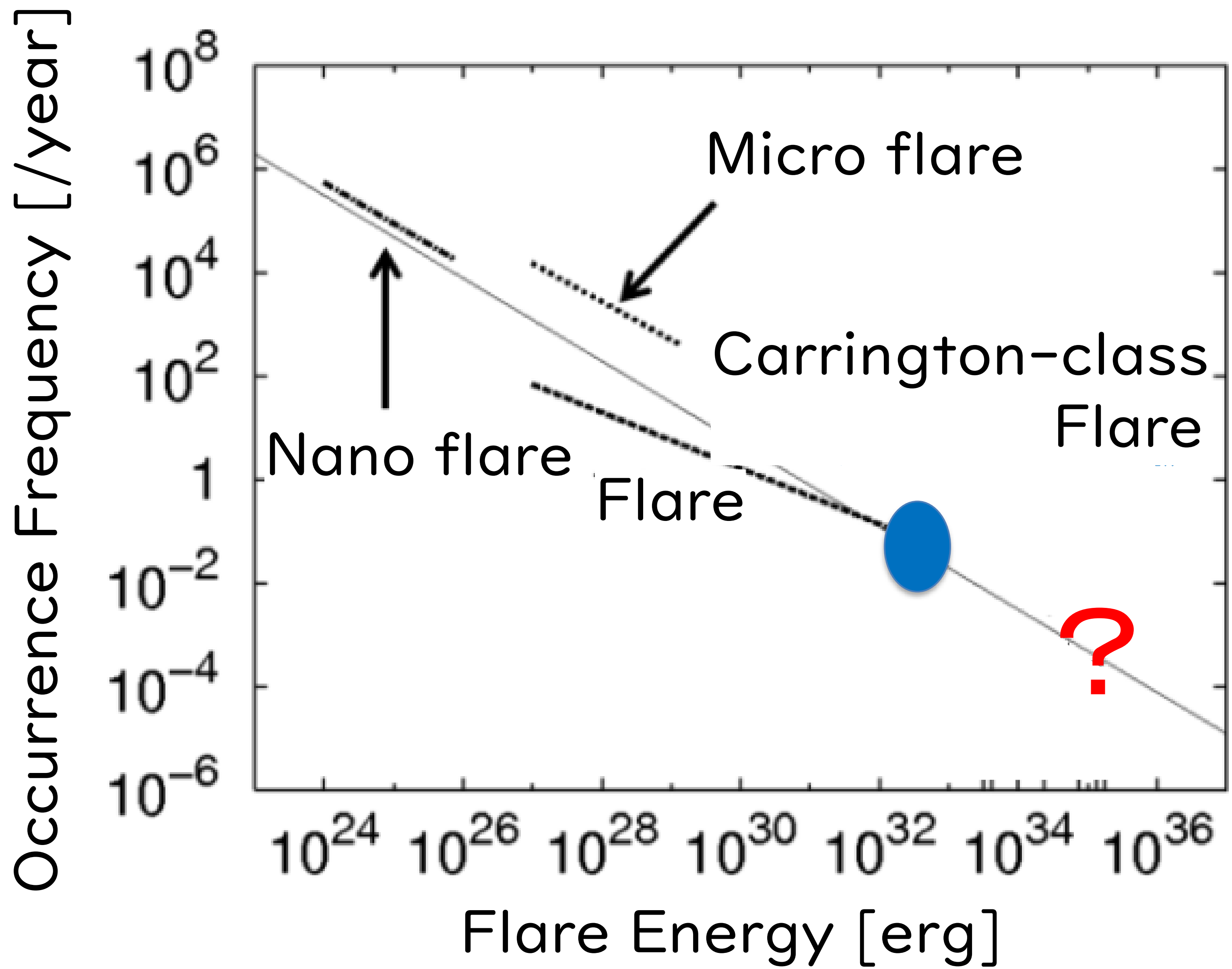
http://www.stelab.nagoya-u.ac.jp/ste-www1/pub/ste-nl/Newsletter28.pdf

If a Carrington-class flare occur now?

- Power outage all over the world?
- Long time communication failure?
- Control loss of artificial satellites?
- Massive exposure of astronauts?

If you are interested, please visit
http://science.nasa.gov/science-news/science-at-nasa/2008/06may_carringtonflare/

Occurrence frequency of solar flare



Can a superflare occur on the Sun?

However, there is only one sun, and observing it for 10,000 or 100,000 years is too long!

→OK! Let's observe solar-type stars!

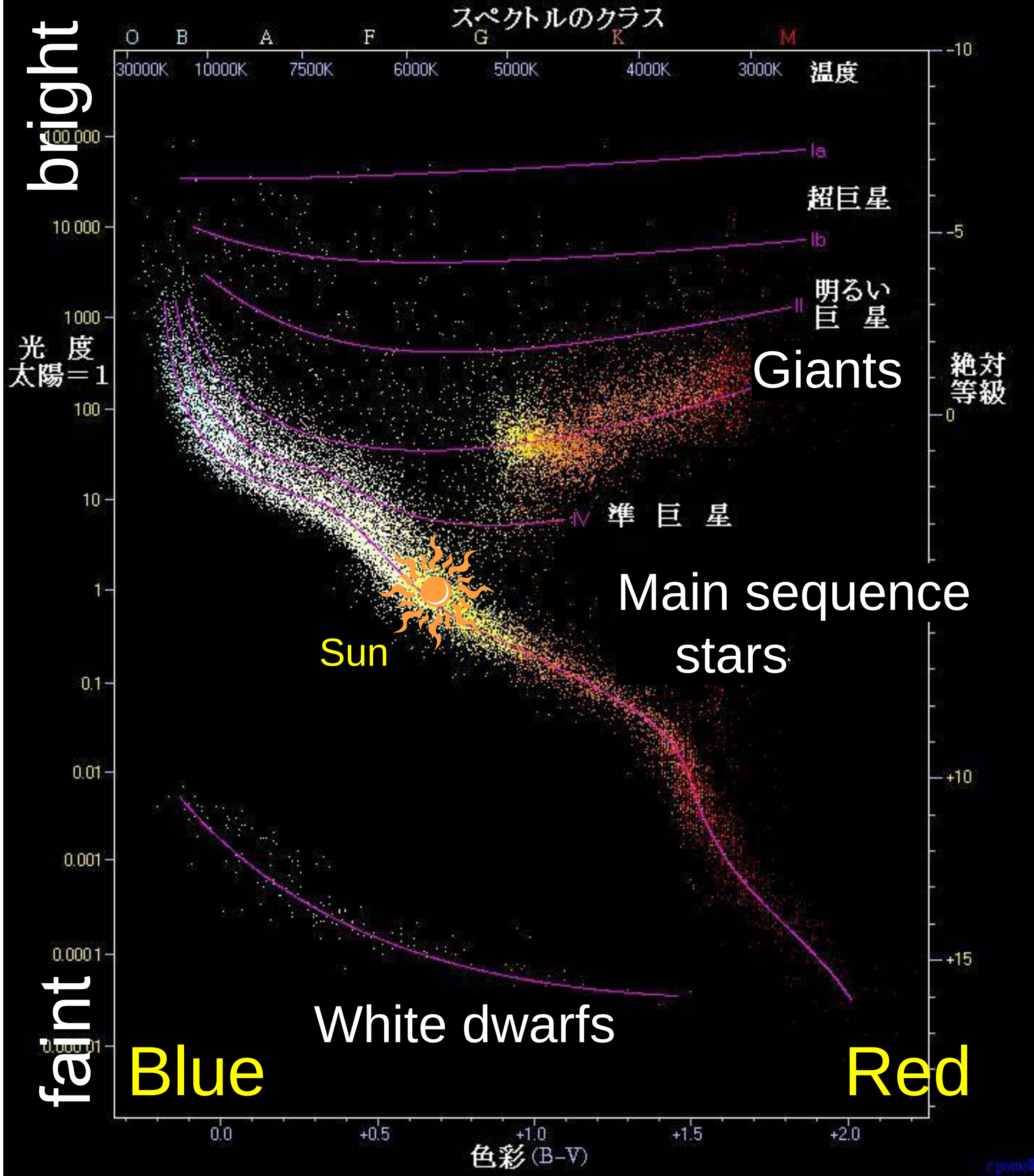
Obs. of the Sun for 10^5 years

≒

Obs. of 10^5 solar-type stars for 1 year

2. Stellar superflare

H-R diagram



http://members.ld.infoseek.co.jp/the_cosmos/cosmos-map/h-r.html

Quiz!

The closest visible star to Earth is Alpha Centauri (α Cen), but how many times farther to this star is it, compared with "from Earth to the Sun"?

1. ~3,000 times
2. ~30,000 times
3. ~300,000 times

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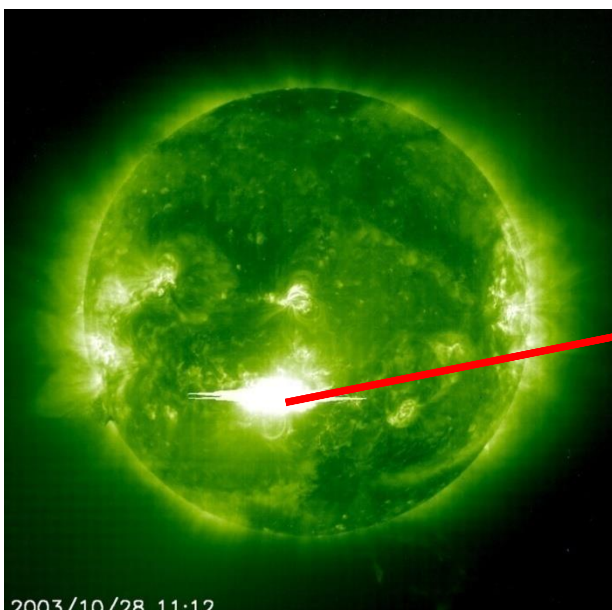
Since α Cen is distant, it appears dark and just a point.

Flare-induced brightness variation in a star

- It is difficult to detect a superflare in a solar-type star, it is because
  - Even Carrington-class flare changes the solar total brightness by ~0.01 %.
  - The occurrence frequency is too low (<1 /1000 year)



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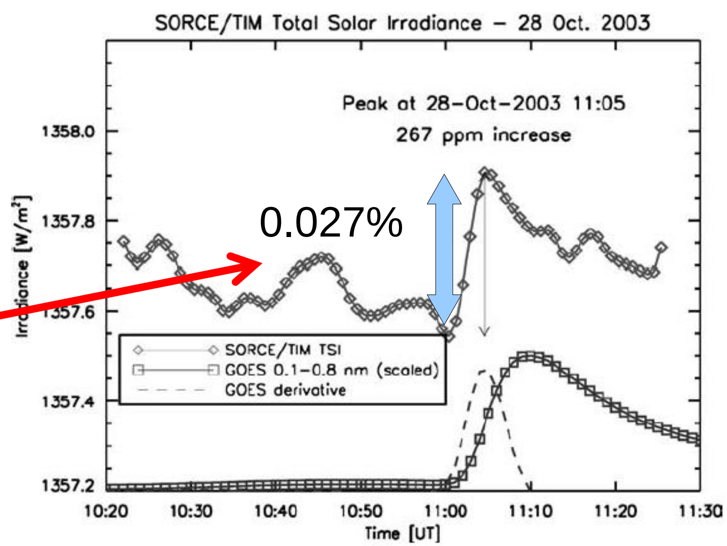
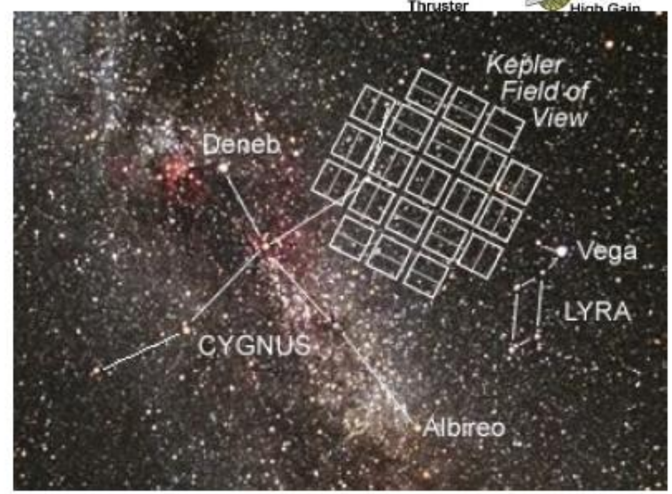


Kopp et al., Solar Phys. 230, 129 (2005)

“Kepler” satellite

- A satellite to detect transits of exoplanets in front of the host star
- 0.95m telescope
- To observe ~1.5 x 10^5 stars in a limited region continuously
- 30-min cadence and very high precision (<10^(-4)) observation

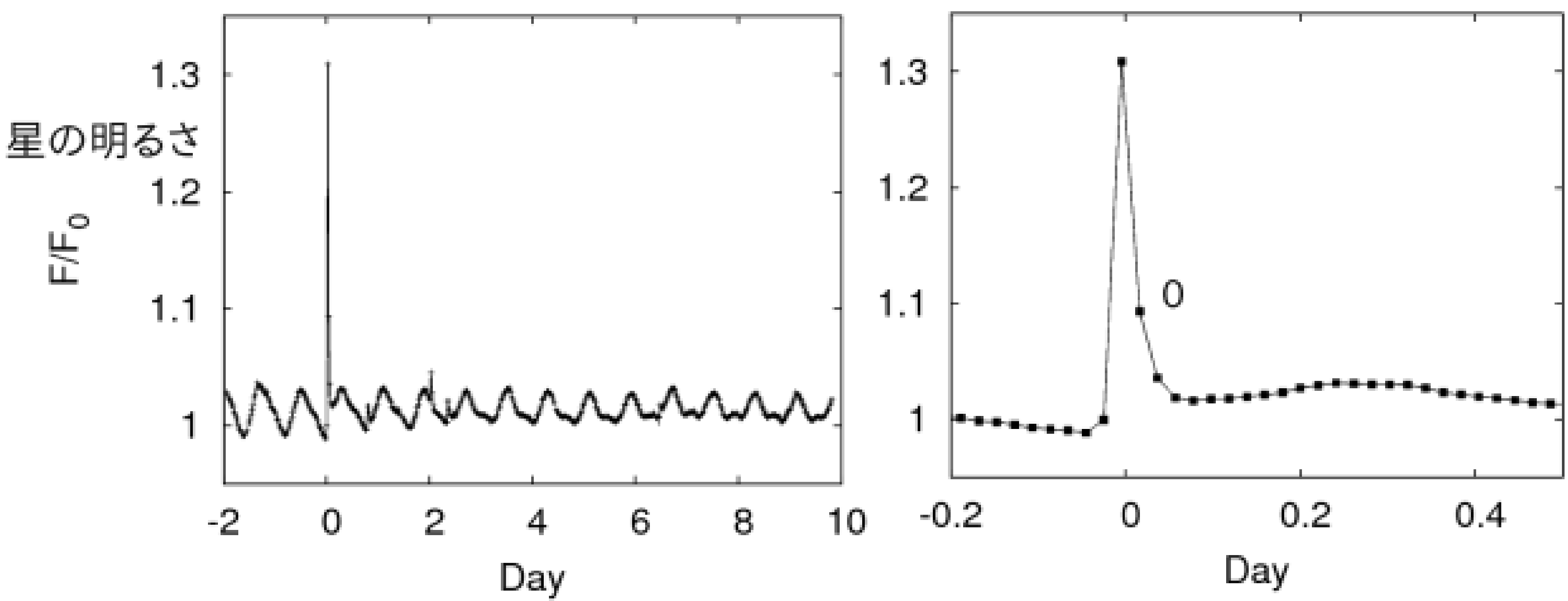


©NASA

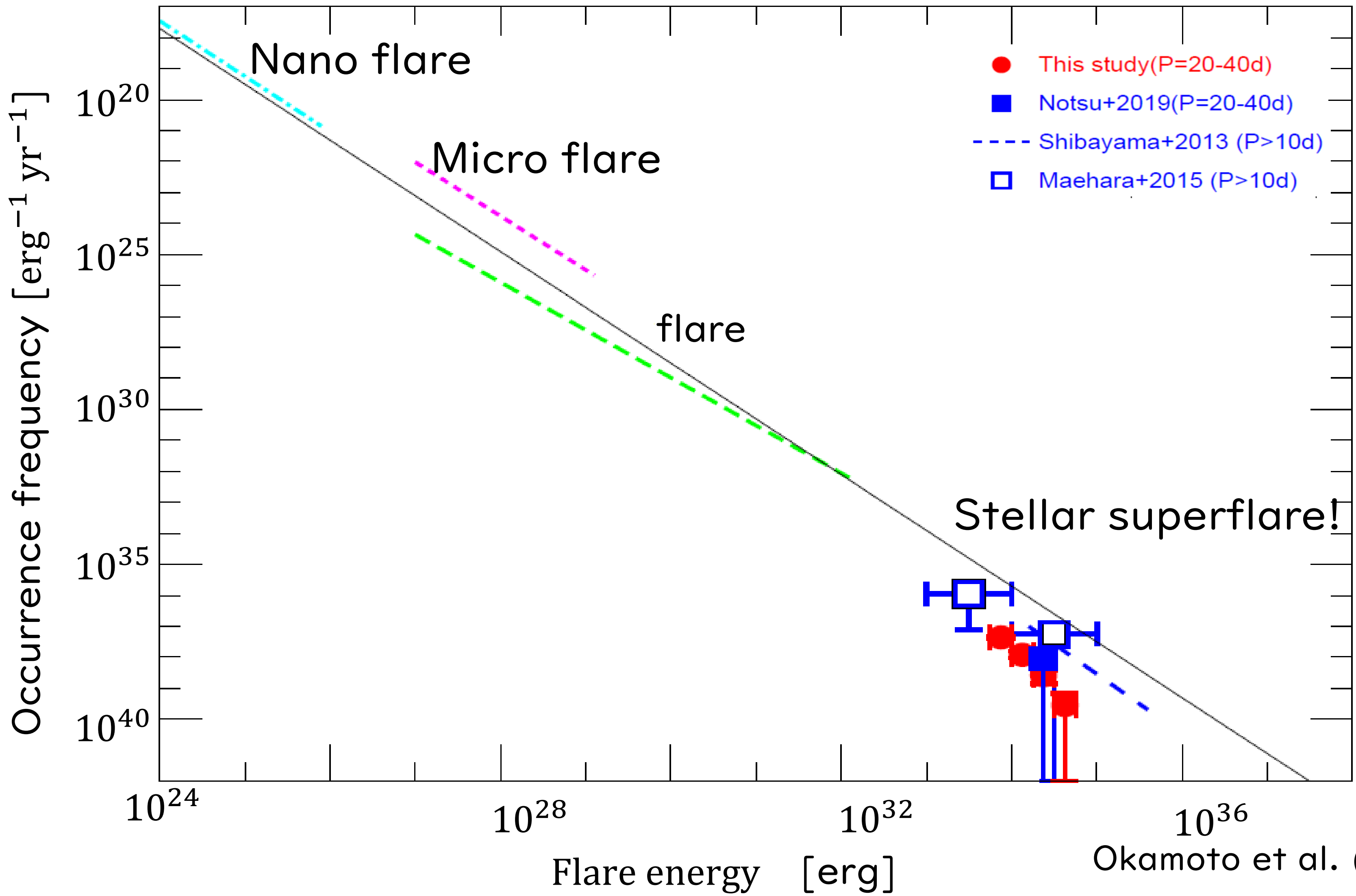
We found about 1,500 superflares in about 300 stars based on Kepler data of about 90,000 solar-type stars (G-type main-sequence stars) obtained between April 2009 and August 2010! (Maehara et al. 2012, Nature, 475, 478; Shibayama et al. 2013, ApJS, 209, 5)

Detection exmple

- KIC12354328
- Flare amplitude: about 30% of the stellar luminosity
- Flare energy: 2.6×10^{35} erg
  (about 2,600 times larger than Carrington flare)



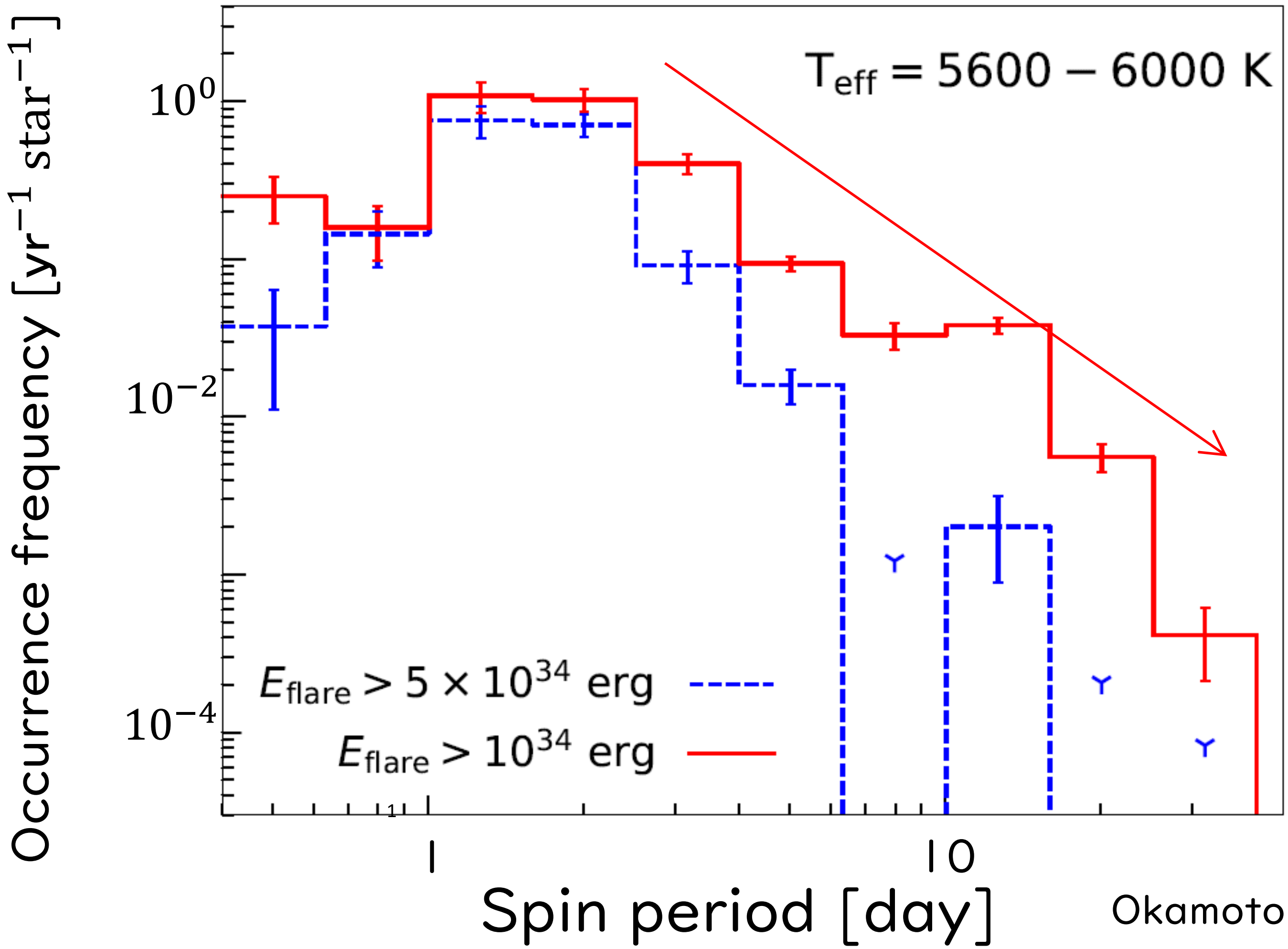
Flare energy vs occurrence frequency



Okamoto et al. (2021)

A superflare with the energy 100 times larger than that of the Carrington flare occur once per 6,000 years?

Stellar age vs occurrence frequency



Okamoto et al. (2021)

The longer the rotation period (i.e., the older the star gets), the less frequently flares occure.

3． Ongoing project with Seimei Telescope

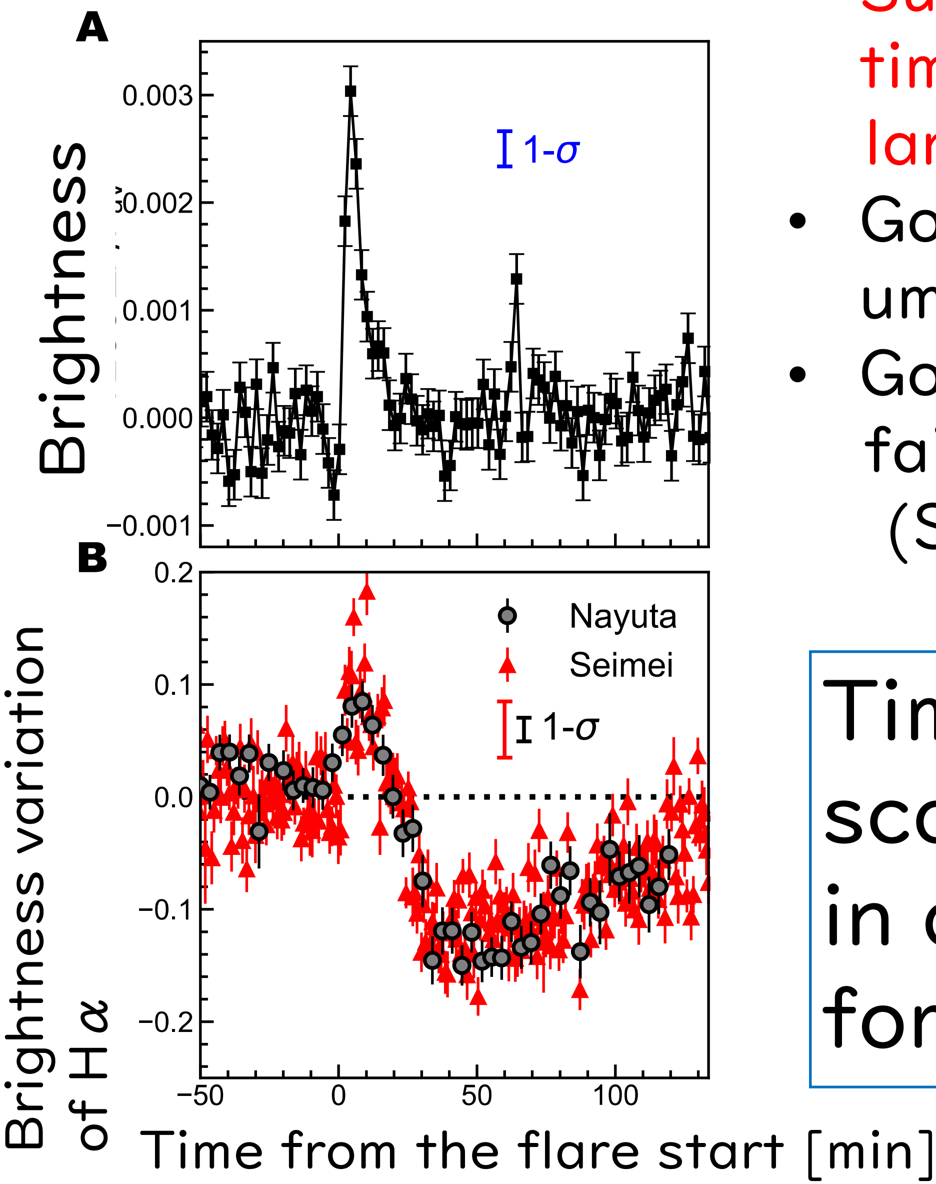
Superflares on solar-type star EK Dra

- A very young star estimated to be ~100 million years old (rotation period of 2.6 days)
- So-called solar-twin (T=5560-5700)
- Famous as a bright (V~7.6等) and active star

→We guessed, "We could observe a superflare, if we continued to observe this star for 20 nights!".

→Let's observe it with Seimei telescope!
(With TESS satellite and other telescopes)

Data of EK Dra I

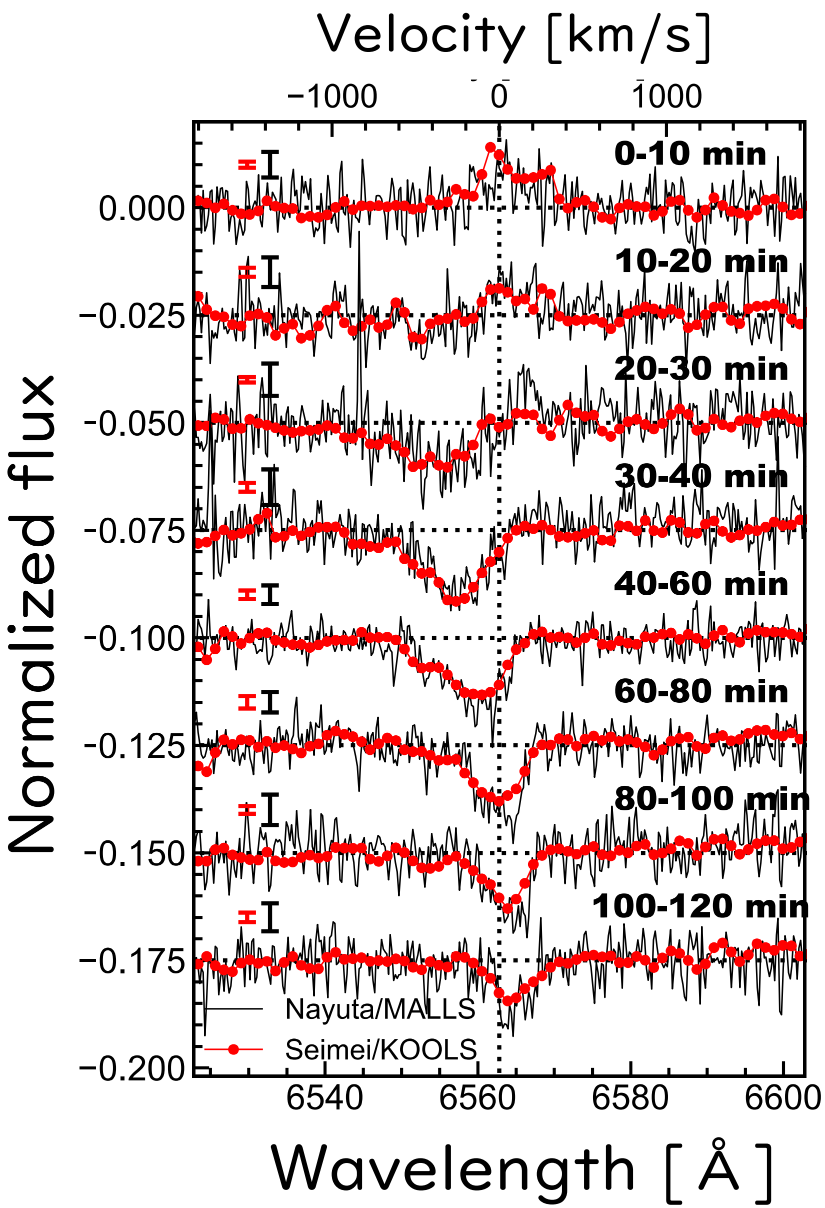


- Superflare with the energy 20 time larger than that of the largest solar flare!
- Got bright by 0.3 % at maximum (TESS)
- Got bright in H α and then fainter than before the flare (Seimei and Nayuta tel.)

Time-resolved spectroscopy during a flare in a solar-type star for the first time!

Namekata et al. (2022, Nature Astronomy)

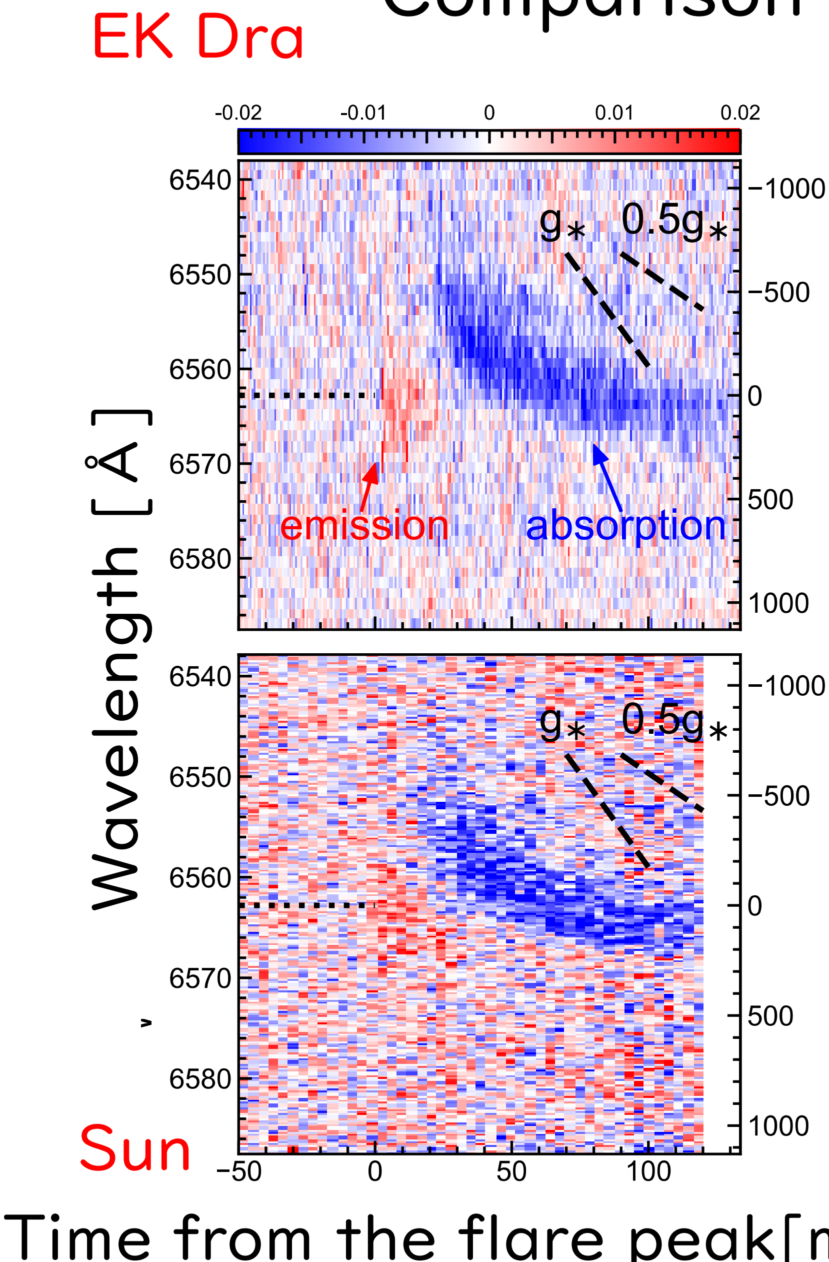
Data of EK Dra 2



- Hα get brighter at the line center at first
- Then, a blue-shifted absorption component appear. →plasmas moving to us!
- The amount of the blue-shift getting smaller.
- At last, the velocity get positive?

Namekata et al. (2021, in preparation)

Comparison of solar flare data



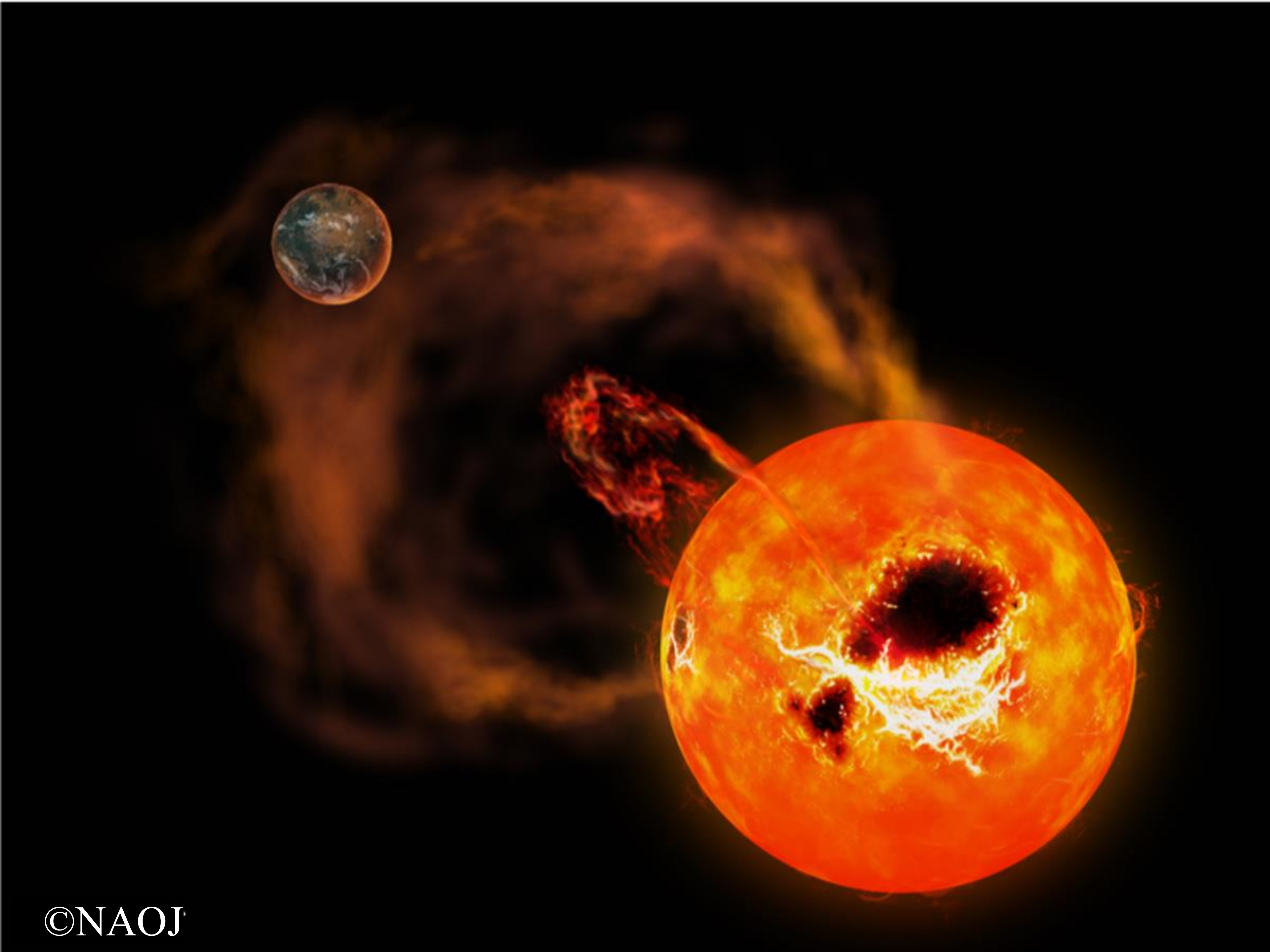
- The blue-shift velocity got smaller with the gravity.
- The time variations in EK Dra and the Sun are quite similar

This indicates that

- Mass loss occur by the same mechanism as the solar case
- The ejected mass is roughly proportional to the flare energy.

→The impact of the superflare could be enormous.

Namekata et al. (2022, Nature Astronomy)



Direction of our project

Concerning the stellar flare

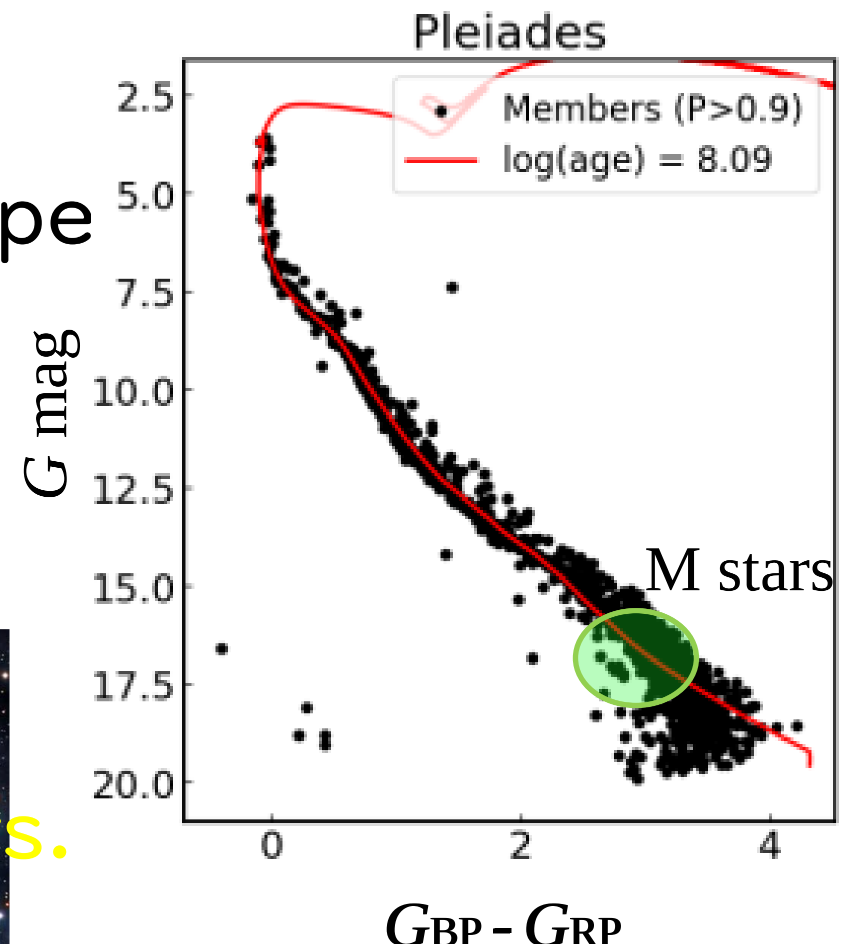
- There are only several flares ever observed. We have to observe many flares to explore flare diversity.
- Multi-wavelength observations from X-ray to radio are needed.
- We should clarify the activity variation due to the stellar age and stellar type (G, K, M-type, YSOs,..)
- Detailed research of the mechanisms and precursor by comparing stellar flares with solar ones and theoretical simulations.

Estimation of the superflare impact to (exo)planets

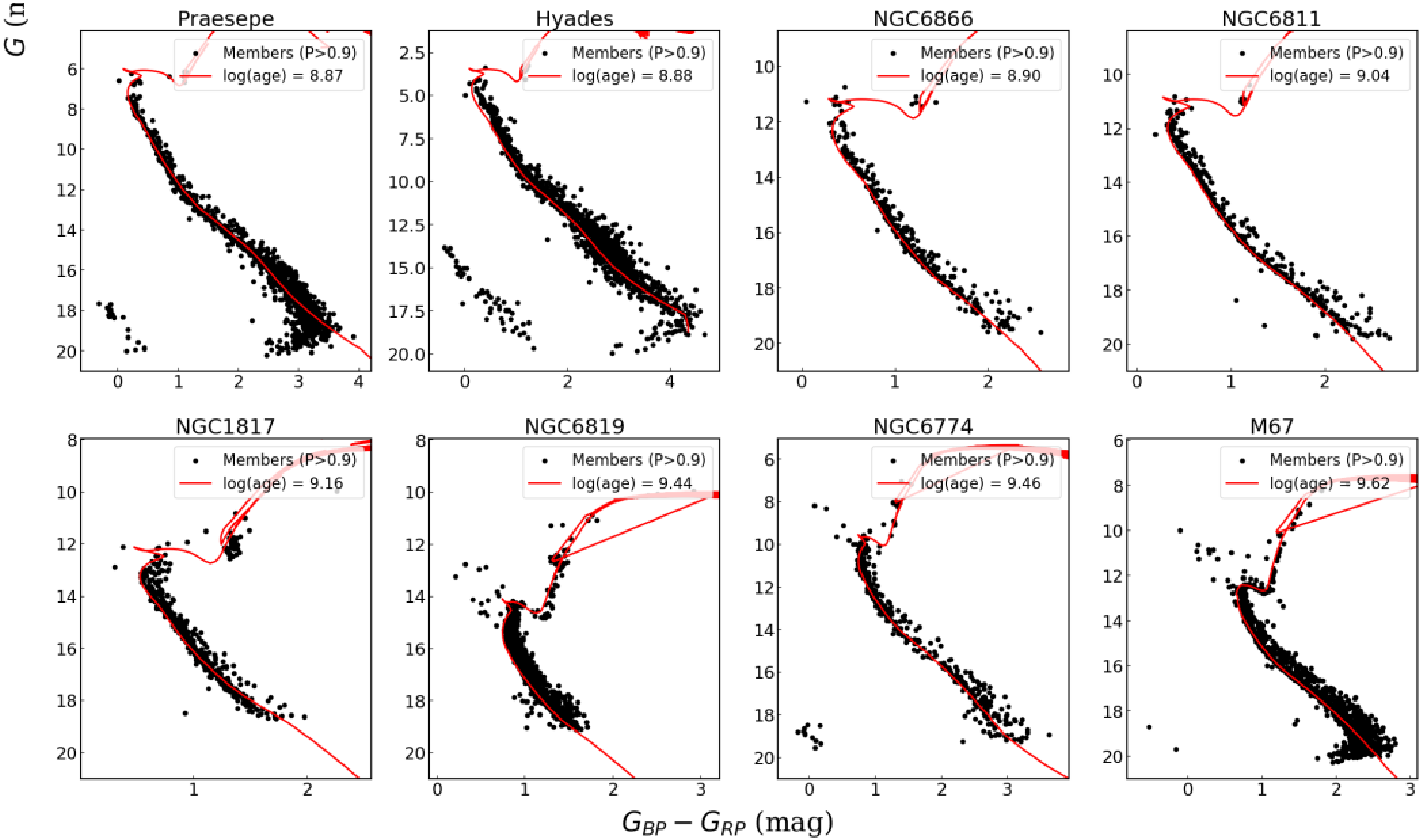
- Effect on the atmosphere of the (exo)planets?
- Effect on the habitability of the (exo)planets?
- Time variability of the effects?

4 A research plan suggestion

- There are many open clusters having M-type stars brighter than 20 mag.
- Long-time obs. will detect many flares on many M-type stars.



Liu et al. (2023)



For example, Long+2023 (ApJS, 268, 30) give information of many open clusters including the age. By comparing the flare activity in these open clusters may give us the activity variation with the stellar age and type.

- Statistical analyses
  - Flare frequency vs flare energy
  - Flare frequency vs spectral type
  - Flare frequency vs age
  - …
- These will give new basic info. on the inner stellar structure and stellar evolution.