KOOLS-IFUの広波長域分光観測で迫るポストフレアループを伴う白色光フレアの時間発展

市原晋之介[1]

野上大作[1]，行方宏介[1]，前原裕之[2]，野津湧太[3]，幾田佳[4]，

本田敏志[5]，大津天斗[1]，　柴田一成[6]

[1]京都大，[2]国立天文台，[3]コロラド大，[4]一橋大，[5]兵庫県立大，[6]同志社大.

About this research

Published in PASJ (印刷中)

PASJ Publications of the Astronomical Society of Japan

Issues | Advance articles | Subject ▾ | Submit ▾ | Purchase | About ▾ | Publications of the A ▾ | Se

Article Contents

JOURNAL ARTICLE

Time evolution of a white-light flare accompanied by probable postflare loops on the M-type dwarf EV Lacertae

Shinnosuke Ichihara ✉, Daisaku Nogami, Kosuke Namekata, Hiroyuki Maehara, Yuta Notsu, Kai Ikuta, Satoshi Honda, Takato Otsu, Kazunari Shibata

Publications of the Astronomical Society of Japan, psaf080, https://doi-org.kyoto-u.idm.oclc.org/10.1093/pasj/psaf080

Published: 01 August 2025 **Article history** ▾

What is flares?

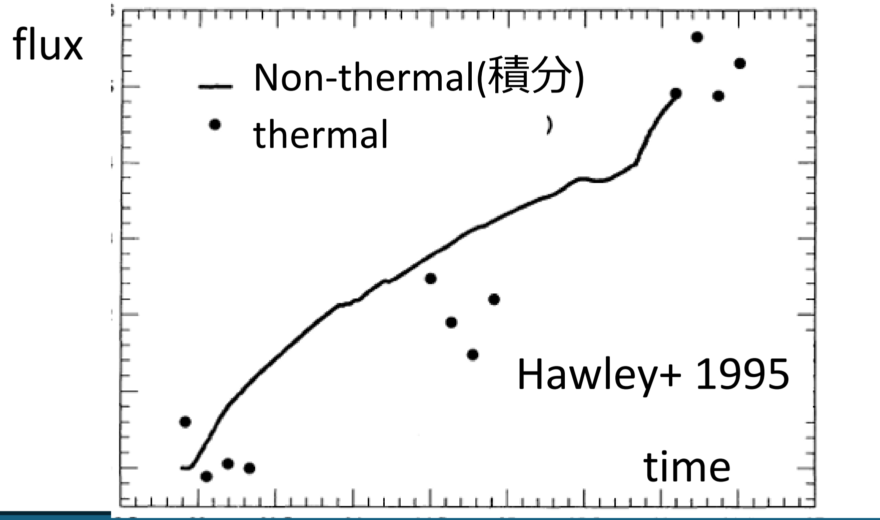
◆Sudden explosion events which occur on the surface of the Sun/stars

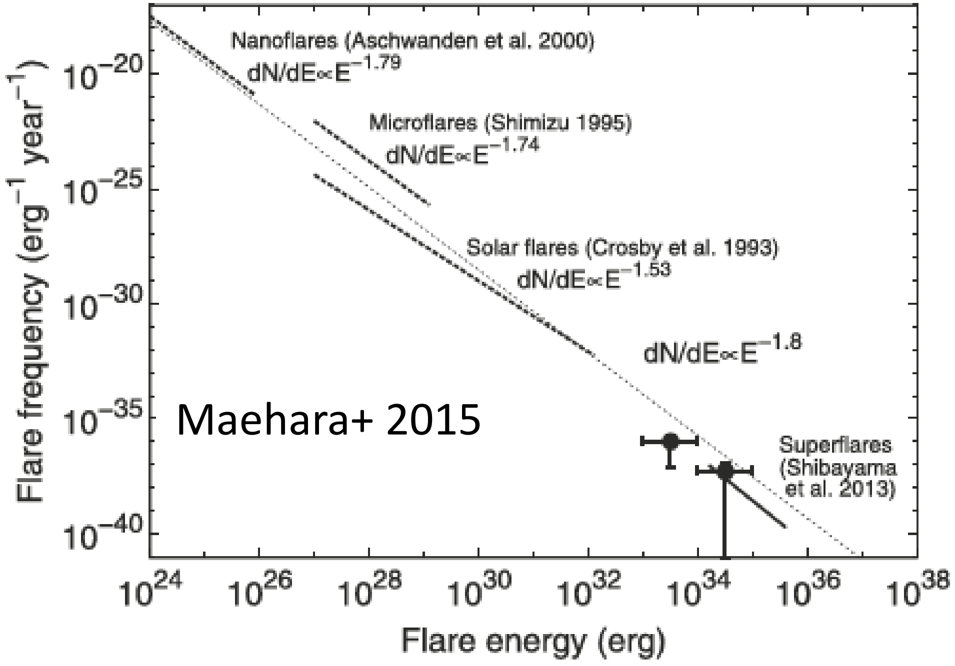
◆Some similar features suggests that

solar and stellar flares occur via the same physical processes.

e.g. Flare Frequency Distributions(in 野上さん's talk)⇨

Neupert effect ($F_{\mathrm{non-thermal}} \propto \frac{dF_{\mathrm{thermal}}}{dt}$)⇦



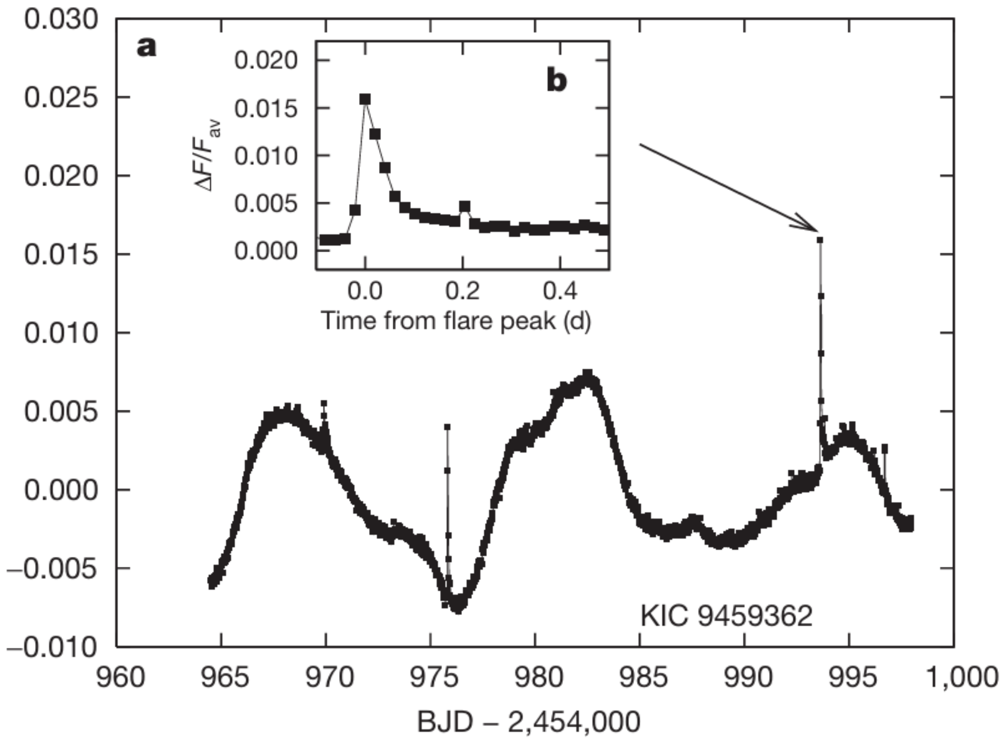


White-light flares

◆Accompanied by enhanced NUV/optical continuum radiation

◆Rare event on the Sun,
but often occur on other stars,
especially on **<u>young M-type stars.</u>**

◆Well correlated with hard X-ray emission spatially & temporally (e.g. Watanabe+ 2010)
➡<u>high-energy electron</u> is thought to be the origin of WLF, but process has not been clarified.



Maehara+ 2012

SED of white-light flares

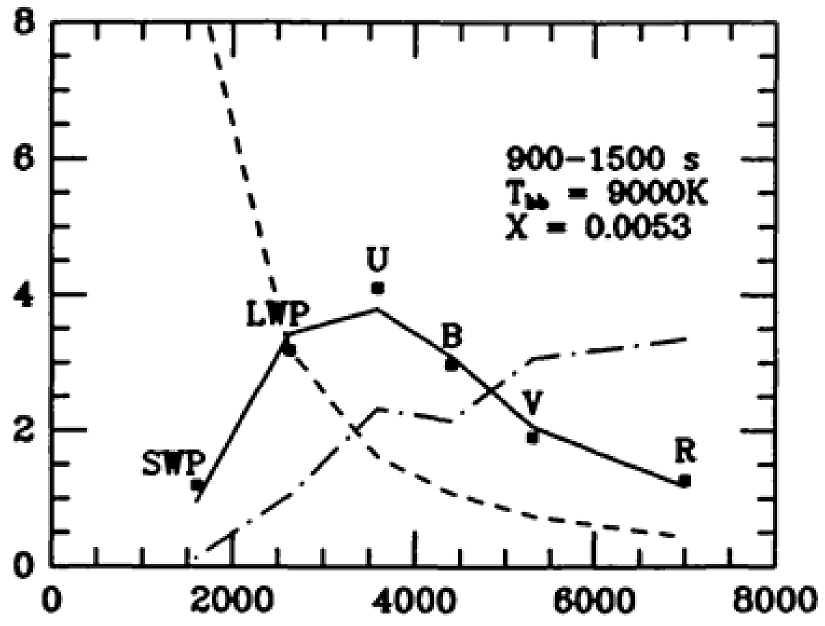
◆White-light continuum (of optical) is well explained with **blackbody spectrum at ~10^4 K** (e.g., Hawley & Fisher1992)

➡ A lot of studies about stellar flares have estimated the radiative energy <u>under the assumption that white-light continuum is blackbody at ~ 10^4 K.</u>

(Shibayama+ 2013)

flux

Hawley＆Fisher 1992



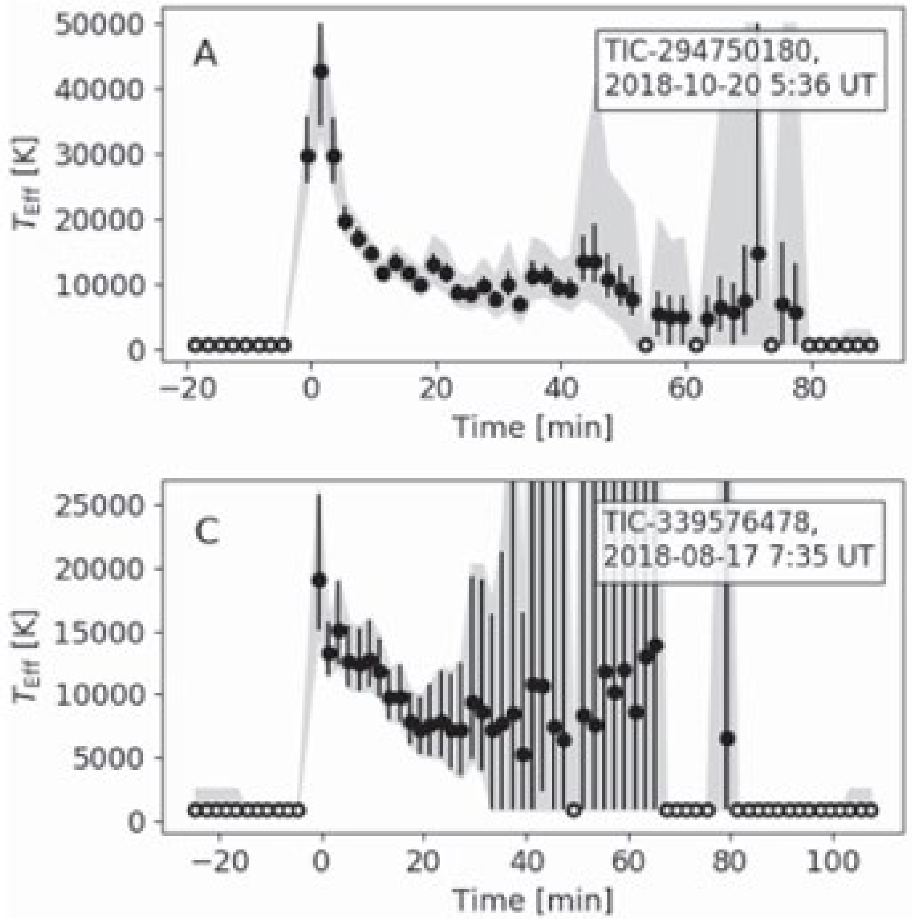
Wavelength [Å]

SED of white-light flares

◆Some previous studies(e.g. Howard+ 2020, Bicz+ 2025)
indicated that the rapid decrease of radiative temperature (in several minutes)
with multi-color photometry.

◆However, the results of these two papers include large uncertainty because

1. Multi-color photometry cannot devide some emission lines (e.g.Hα) and optical continuum,
2. TESS has redder wavelength range(6000-10000Å)
   >> less sensitive to high temperature



Howard＋ 2020

Question

- How accurate is the blackbody assumption?
- How different are the energy calculated with fixed temperature ($\sim 10^4$ K) and changing temperature?

➢ We analyze <u>**high-time-cadence**</u> **&** <u>**optical spectroscopic**</u> data

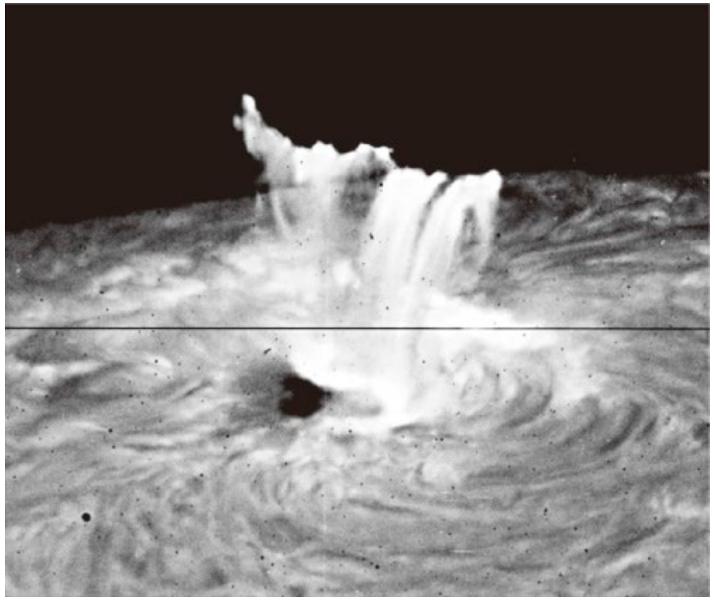
but the numbers of such observations is still small.

Postfare loops

- Postflare loops are one of the components of flares.
- Flare occurs.

  ➡Soft X-ray loops ($\sim 10^7$ K) form and cool via radiation.

  ➡Postflare loops ($\sim 10^4$ K) can be observed in Hα (But not always).
- Difficult to detect stellar postflare loops (e.g., Kajikiya+ 2025a, ApJ)



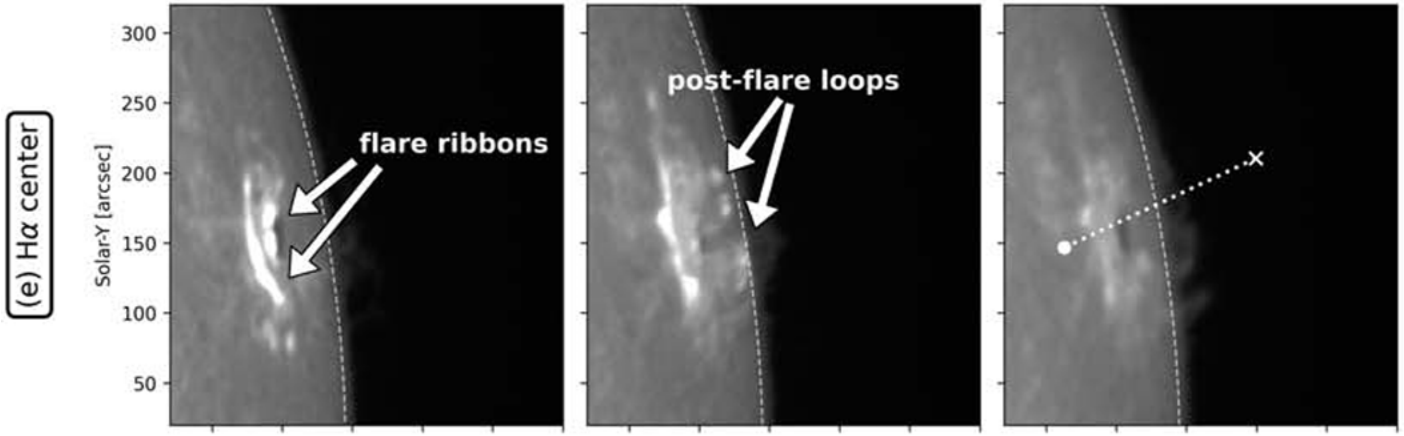
シリーズ現代の天文学　太陽

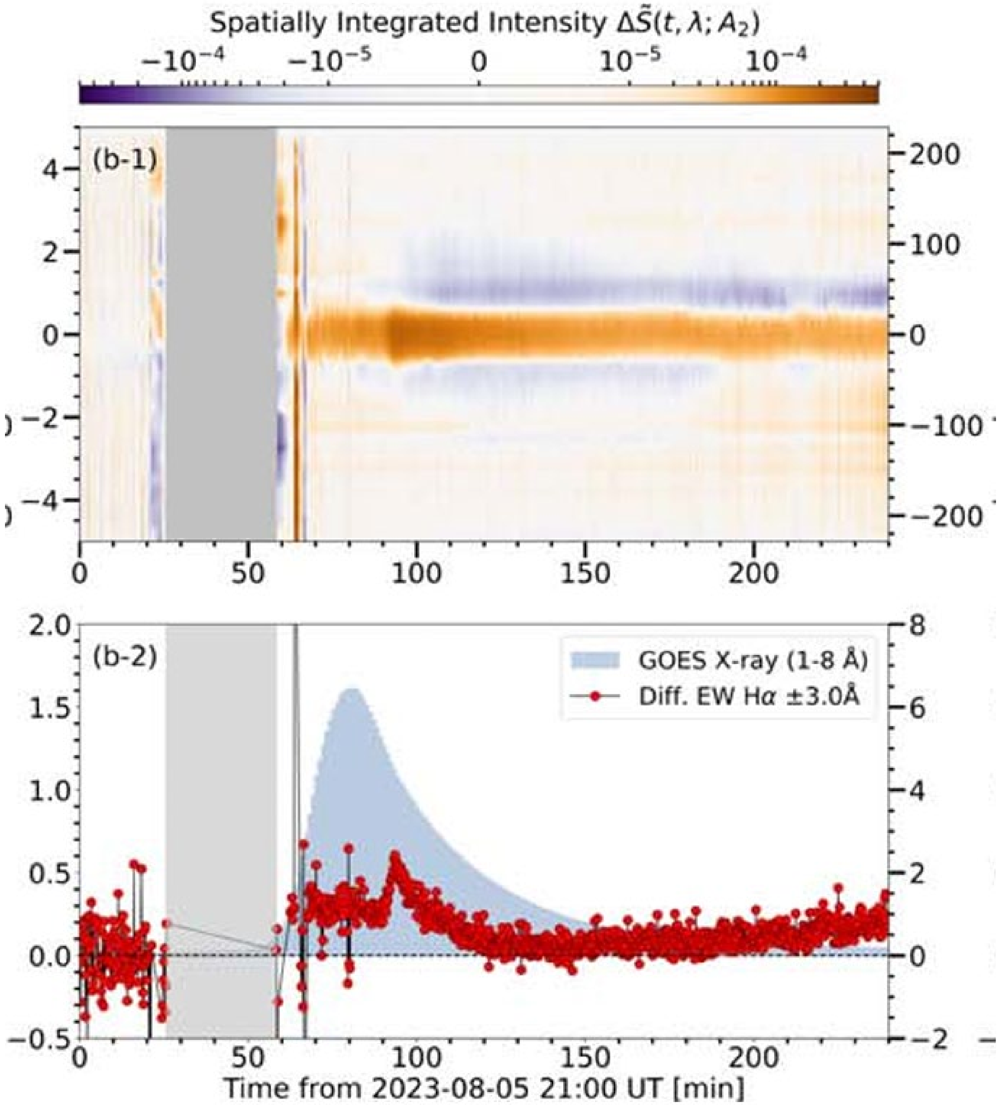
Previous studies about solar postflare loops

Otsu+ 2024 conducted the Sun-as-a-star analysis on X1.6 flare accompanied by postflare loops.

He made the lightcurve and spectra which can be compared with stellar postflare loops

From lightcurve, **delayed bump was detected**





Observations

©NASA

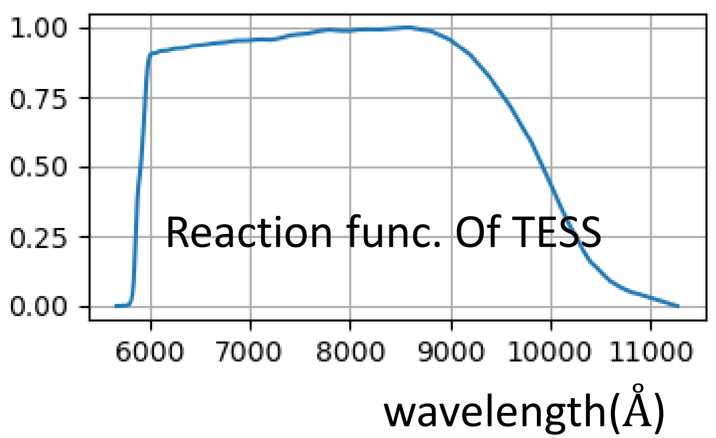
- Phot **TESS**

wavelength	Time cadence
6000-10000Å	2min

- Spec **せいめい望遠鏡 / KOOLS-IFU(VPH-blue)**

wavelength	Time cadence	Resolution
4100-8900Å	～52sec (exp 30sec)	$\lambda/_{\Delta\lambda} \sim 500$

from：SVO Filter Profile Service



target：M-type dwarf(M4.5 Ve) EV Lac

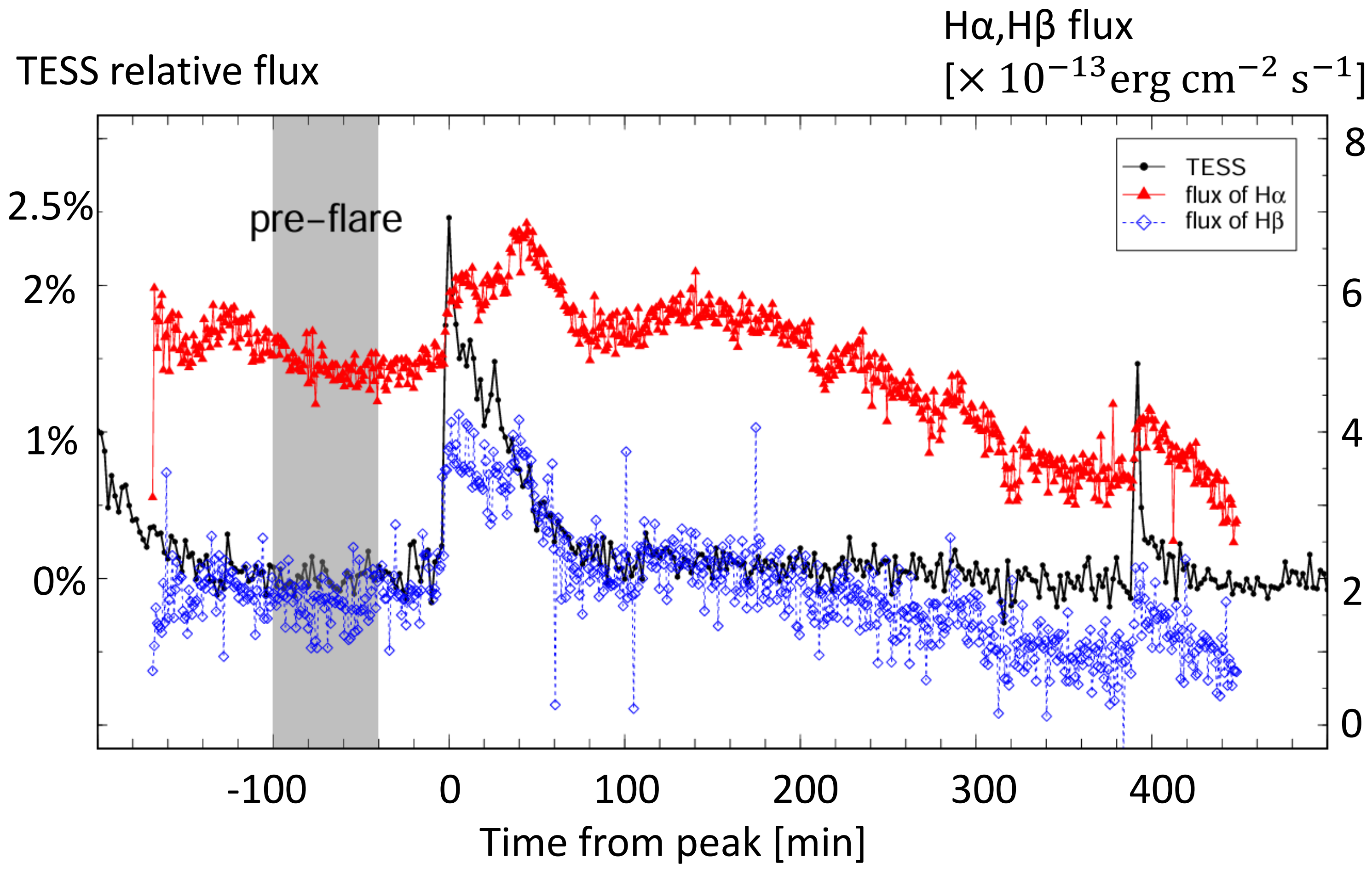
P_{rot}	4.38 day(Pettersen 1980)
Age	125 – 800 Myr(Paudel+ 2021)
T_{eff}	3270±80K (Paudel + 2021)
Flare rate	**~0.4event/h (Schmidt + 2012)**

Observation period more than 8 nights during 2019/09/14-2019/10/04

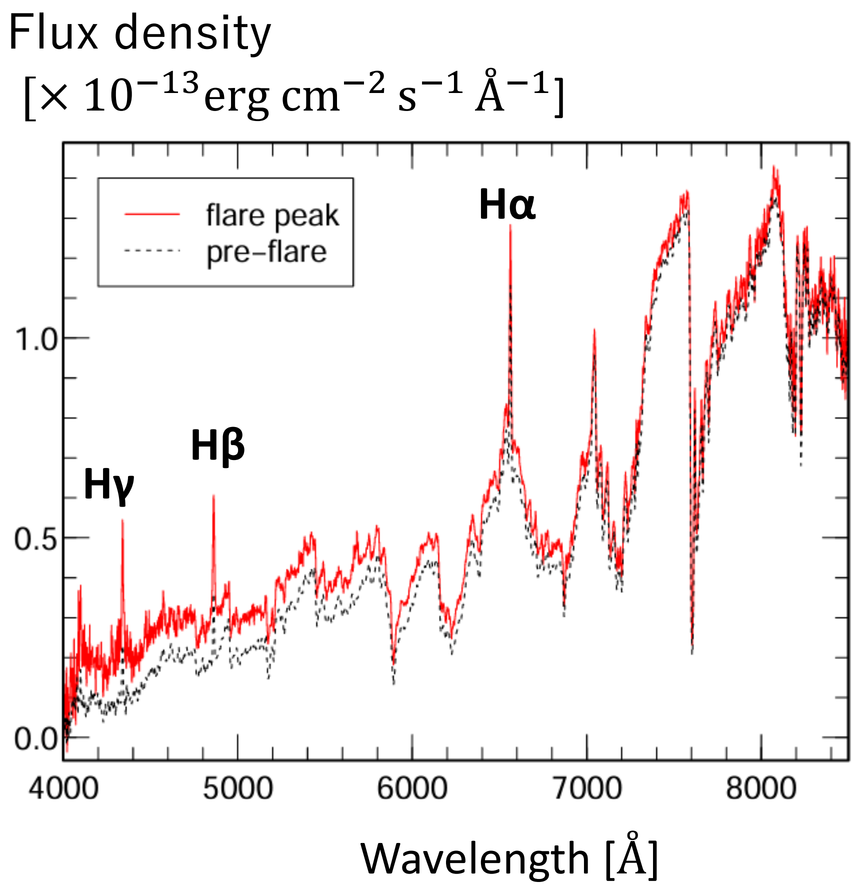
⇨successfully detected one significant flare

Light curves & spectra

Successfully observed a flare with Seimei & TESS simultaneously



Light curves of TESS,Hα,Hβ



Spectra at flare peak & pre-flare quiescence

Estimation of flare temperature

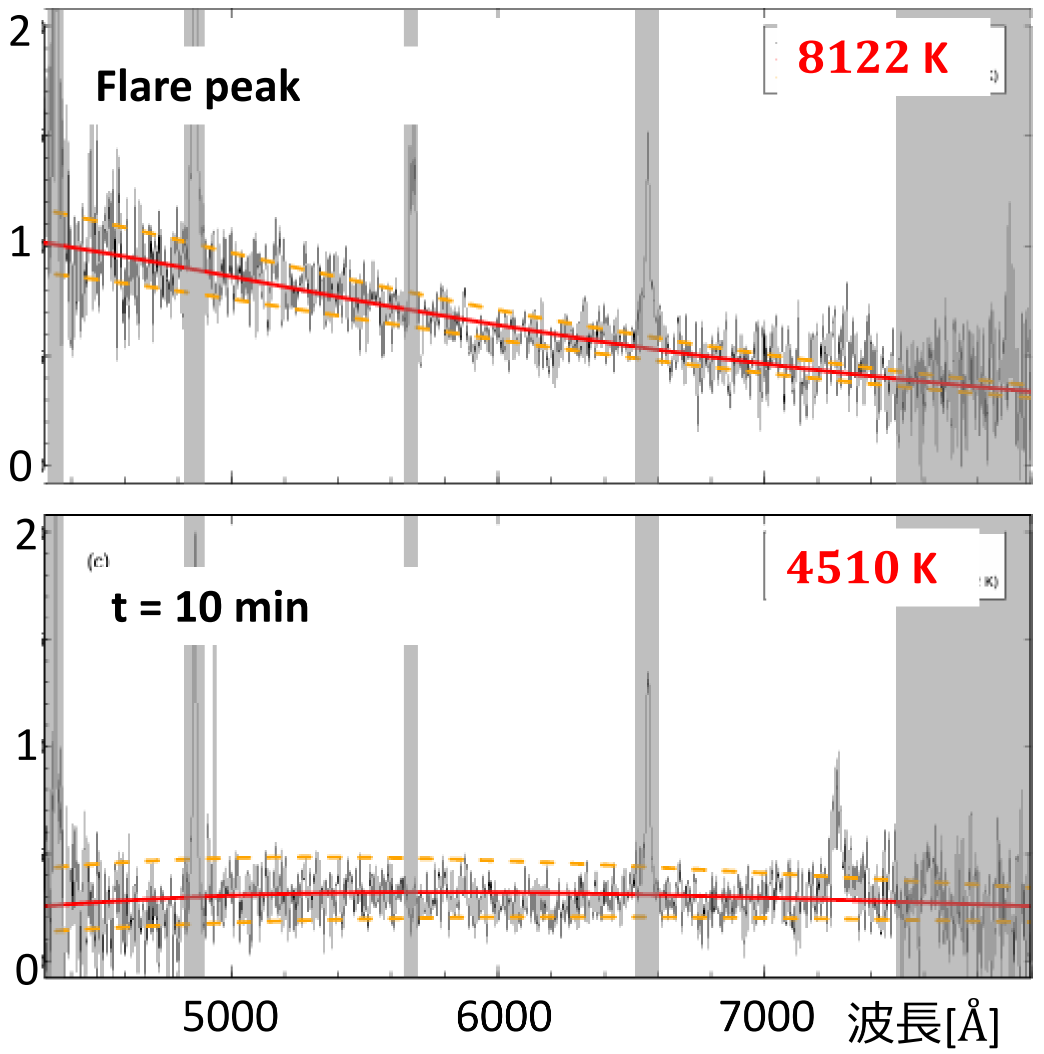
Make the flare component spectrum by subtracting quiescence from peak spectrum. Then, estimate flare temperature assuming blackbody radiation.

$$B_\lambda \propto \frac{A}{\lambda^5} \frac{1}{\exp\left(\frac{hc}{\lambda k_B T}\right) - 1} \quad [\mathrm{erg \cdot cm^{-2} \cdot sec^{-1} \cdot \mathring{A}^{-1}}]$$

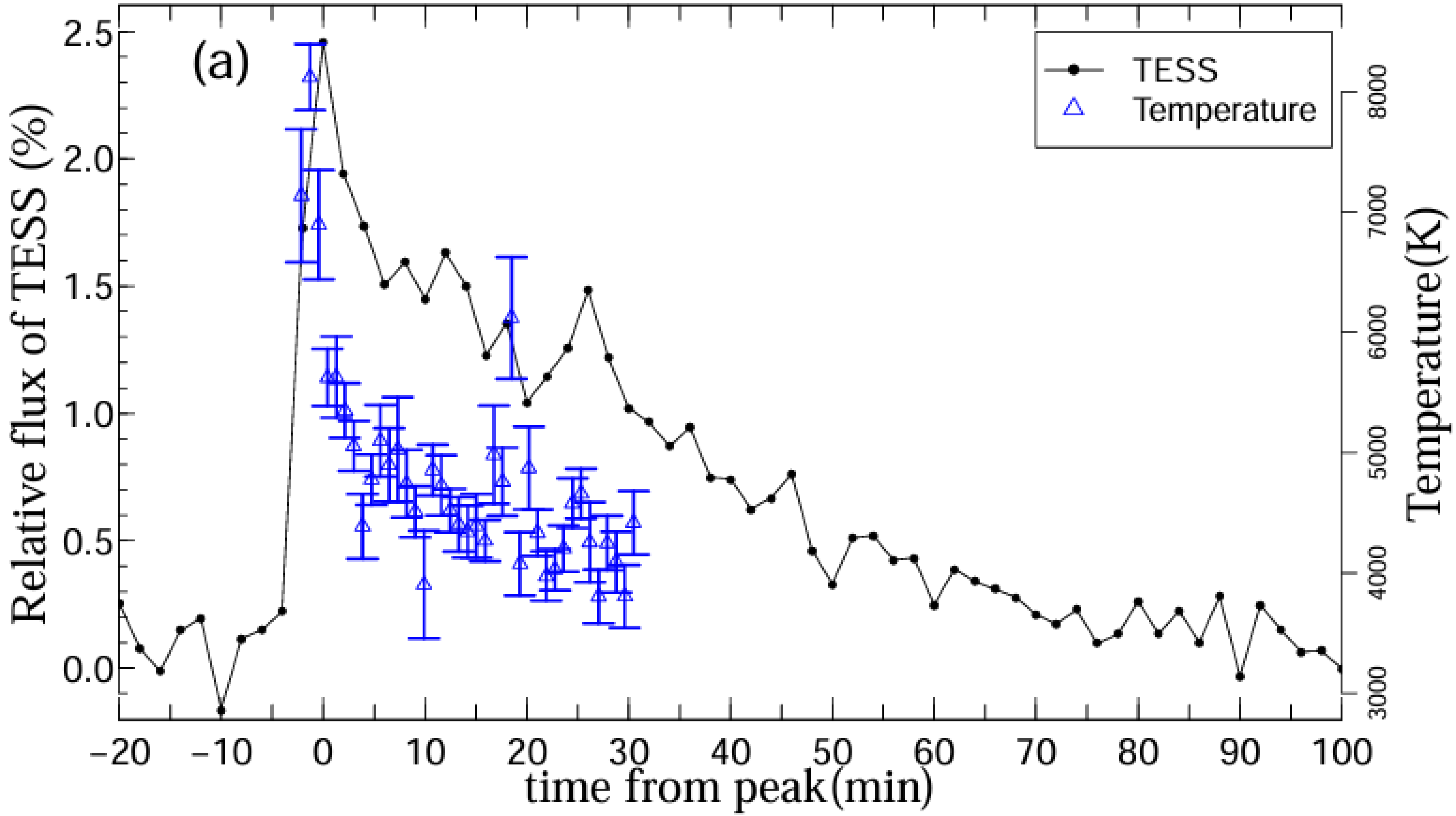
(T and A(scale factor) are free parameter)

➡at flare peak, $\boldsymbol{T_{\mathrm{flare}} = 8122 \pm 273\ \mathrm{K}\ \ (\sigma_T = 91\ \mathrm{K})}$
comparable to previous research

➡10min after the flare peak, $\boldsymbol{T_{\mathrm{flare}} = 4510 \pm 212\ \mathrm{K}}$
Detect the rapid decrease



Time variation of flare temperature



Decay of temperature is more rapid than decay of flux.

E-folding time

T_{flare} ： 2.5 [min]

Flux ： 30 [min]

In previous studies, they estimated the flare energy **by assuming blackbody @T~10^4K(fixed)** so that E_{flare} may be overestimated.

Discussion① エネルギー推定

σ_{SB}	Stefan-Boltzmann 定数
R_{star}	恒星半径 ($0.38R_{\odot}$)
R_{λ}	TESSの応答関数
B_{λ}	T [K]のプランク関数
C'_{flare}	白色光の静穏期からの振幅

Using the method of Shibayama + 13, we calculated radiative flare energy with considering the decreasing flare temperature.
The luminosity is

$$L_{\mathrm{flare}}(t) = \sigma_{\mathrm{SB}}\, \boldsymbol{T}^{\boldsymbol{4}}_{\mathbf{flare}}(\boldsymbol{t})\, A_{\mathrm{flare}}(t)$$

And the area of flare($A_{flare}(t)$) is

$$A_{\mathrm{flare}}(t) = C'_{\mathrm{flare}}(t)\pi R^2_{\mathrm{star}} \frac{\int R_{\lambda}B_{\lambda}(T_{\mathrm{eff}})d\lambda}{\int R_{\lambda}B_{\lambda}(\boldsymbol{T}_{\mathbf{flare}}(\boldsymbol{t}))d\lambda}$$

Then, by integrating $L_{flare}(t)$ in time,

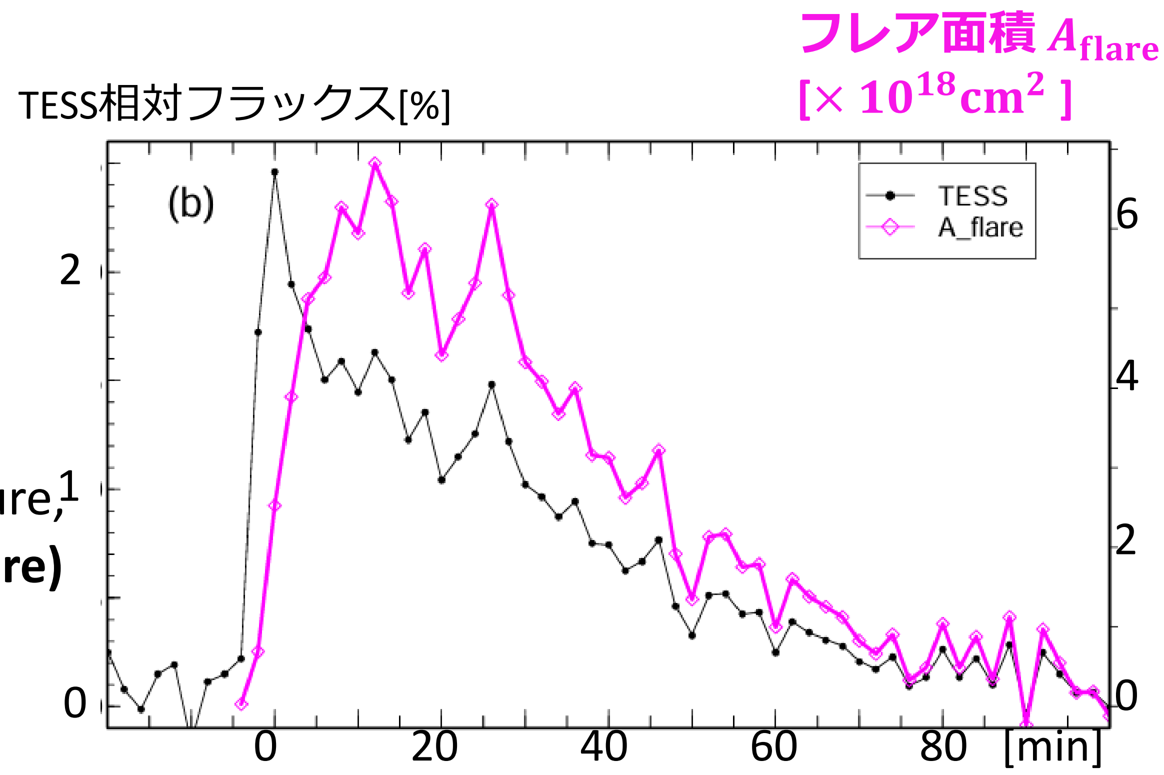
➡$\boldsymbol{E}_{\mathbf{flare}} = \mathbf{4.4 \times 10^{32}}$ erg

If we does not consider the time-evolution of flare temperature,

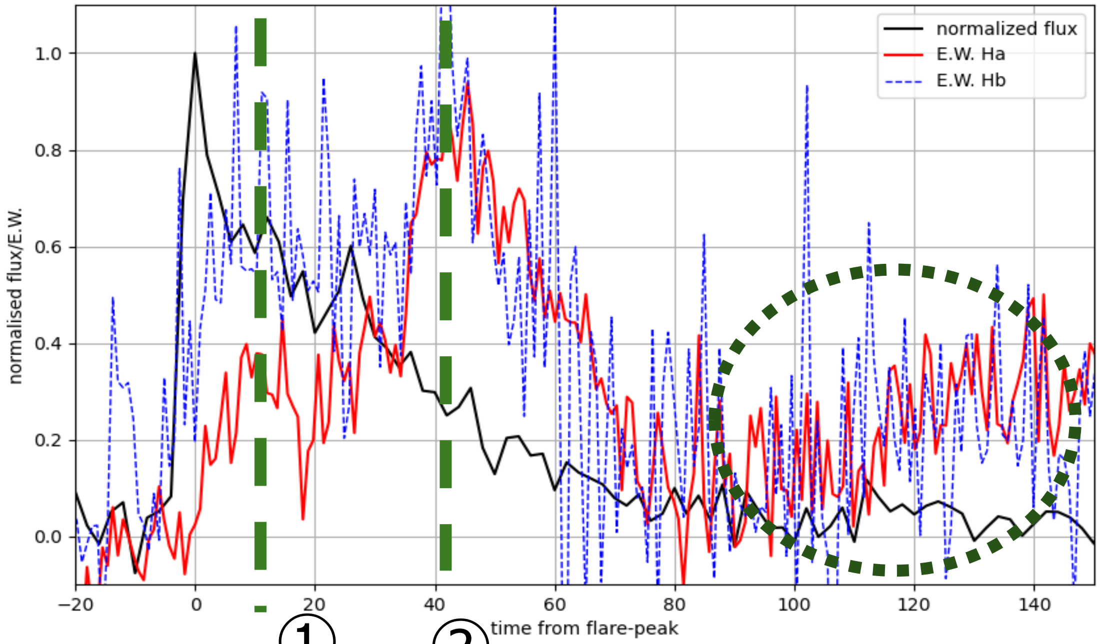
$E_{flare} = 8.9 \times 10^{32}$ erg($T_{flare} = 8122$ K, peak temperature)

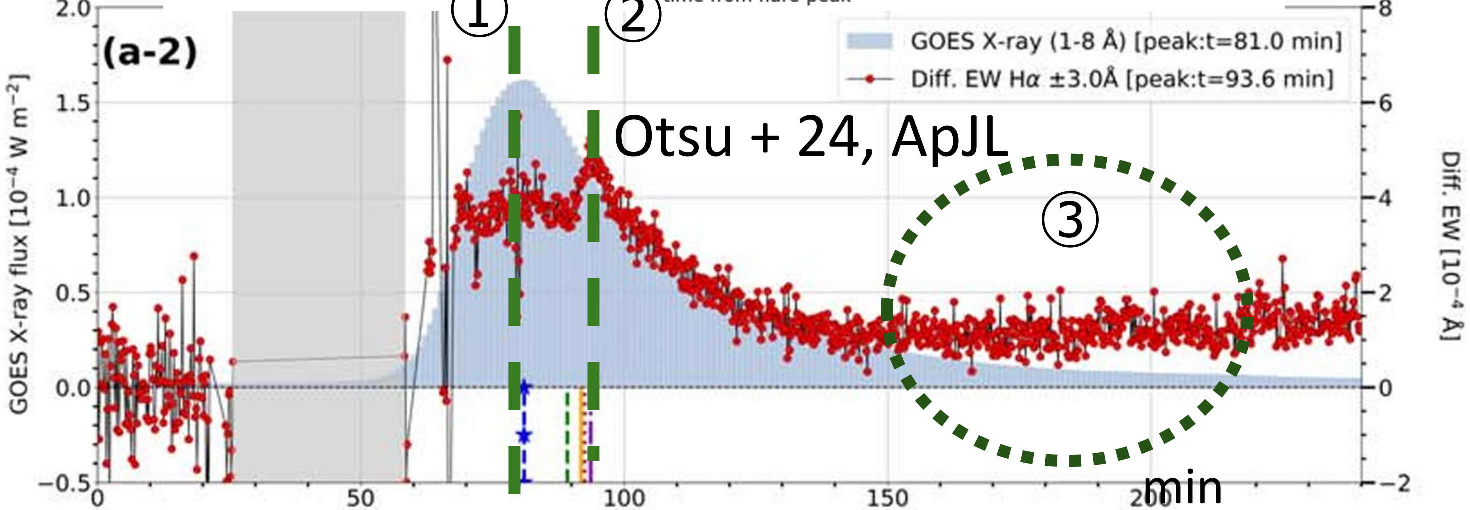
$E_{flare} = 1.2 \times 10^{33}$ erg($T_{flare} = 10000$ K, often used)

➡<u>overestimated by a factor of 2-3 in TESS band</u>



Discussion② Postflare loops on stellar flares





Comparing with the Sun-as-a-star analysis (Otsu + 24, ApJL)

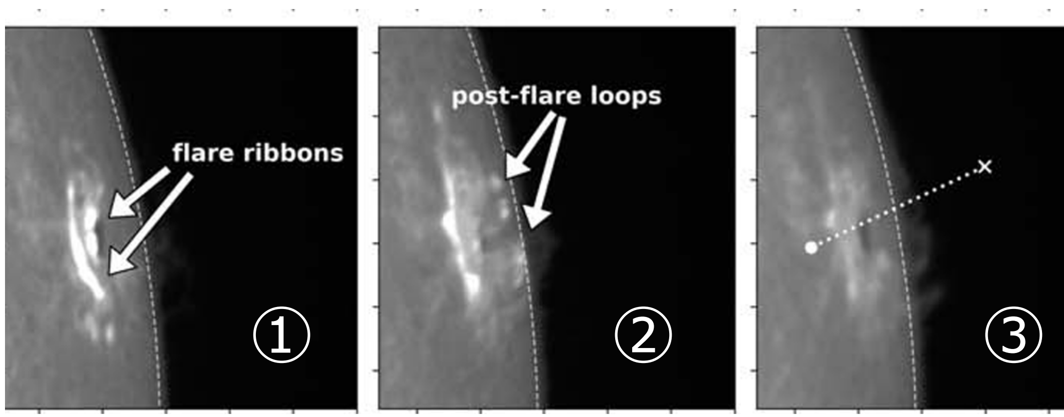
Both data have same 3 features.

①1st increase > two ribbons

②2nd increase > postflare loops

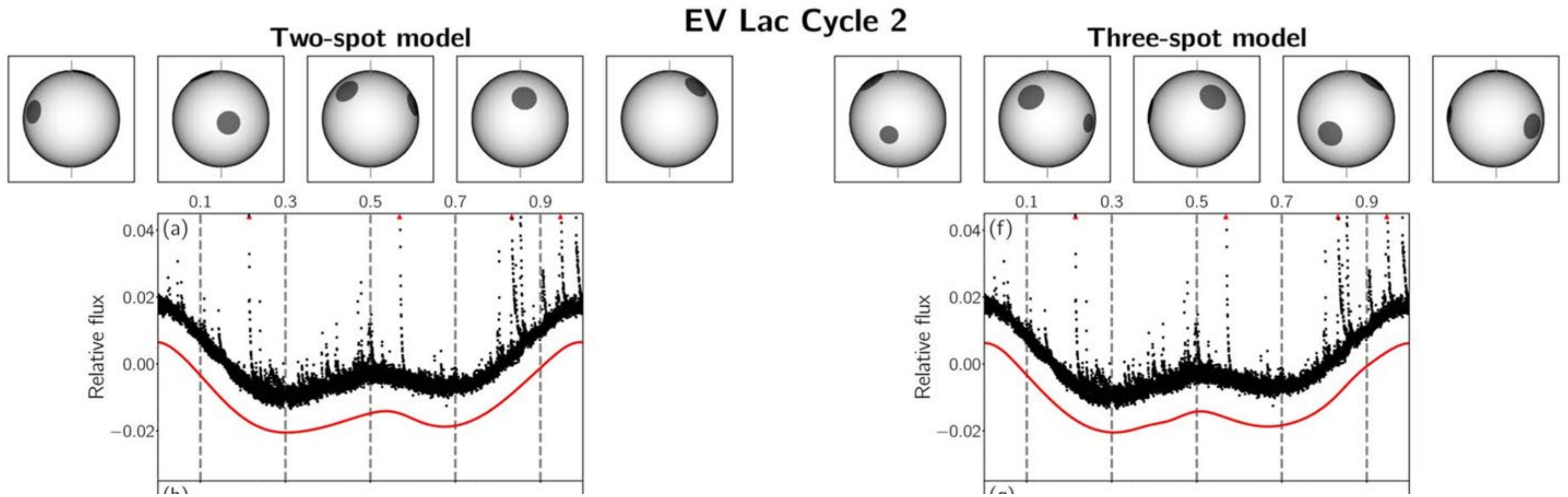
③gradual increase after flare ends

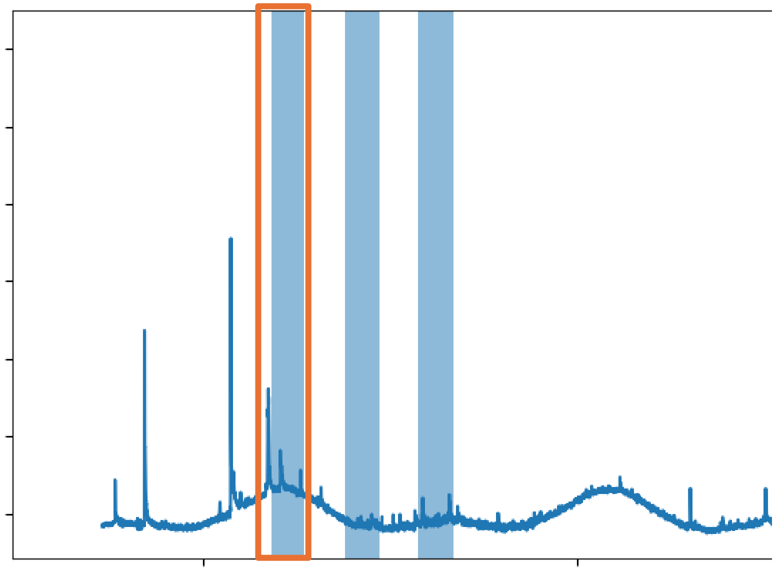
> off-limb postflare loops



Hα line center

Discussion② Postflare loops on stellar flares

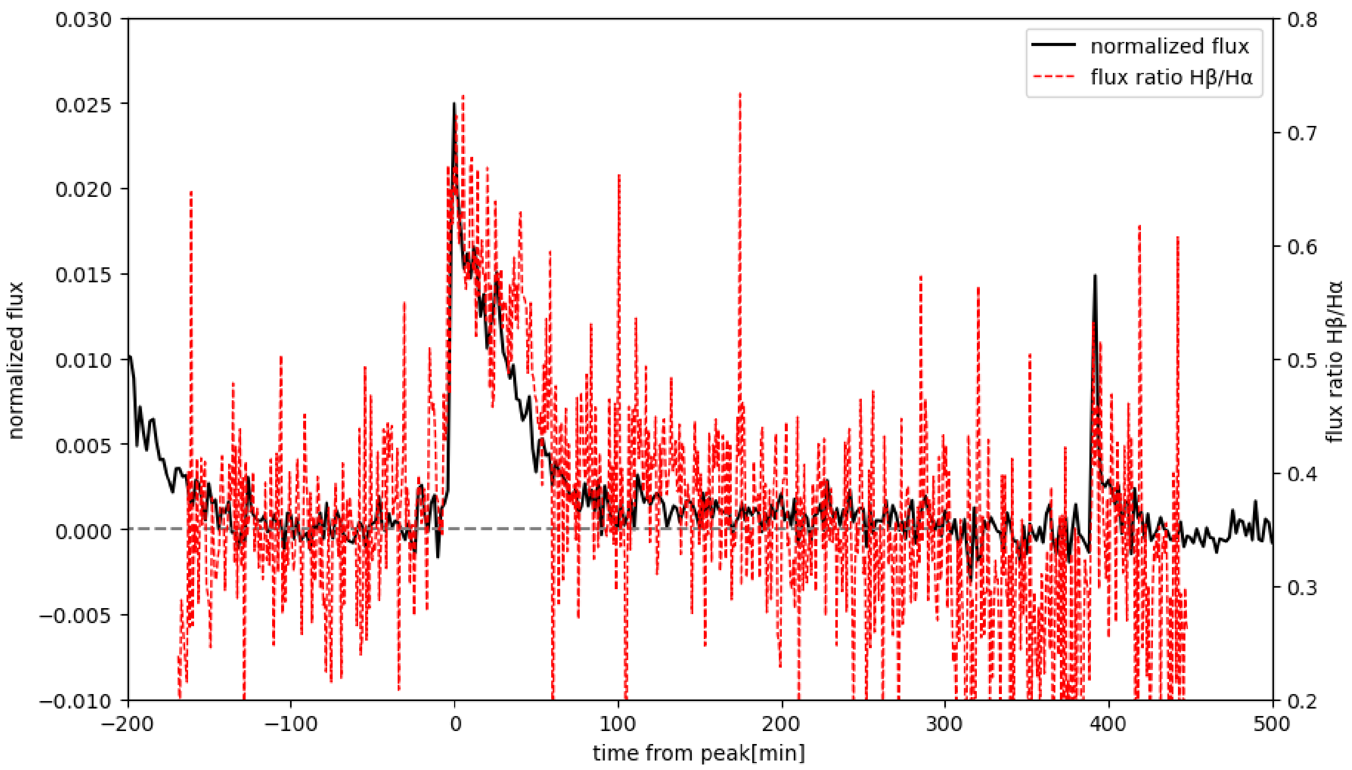




Ikuta+ 2023 conducted 2 or 3 spots mapping with TESS data(same period as this study).

>Around our flare, spot is near the limb.
the size is ~ 6% of stellar disk area (20 times larger than maximum of $A_{flare}(t)$)

Discussion② Postflare loops on stellar flares



Another aspect supporting postflare loops is flux ratio of Hβ/Hα

There is no significant 2nd peak in Hβ/Hα

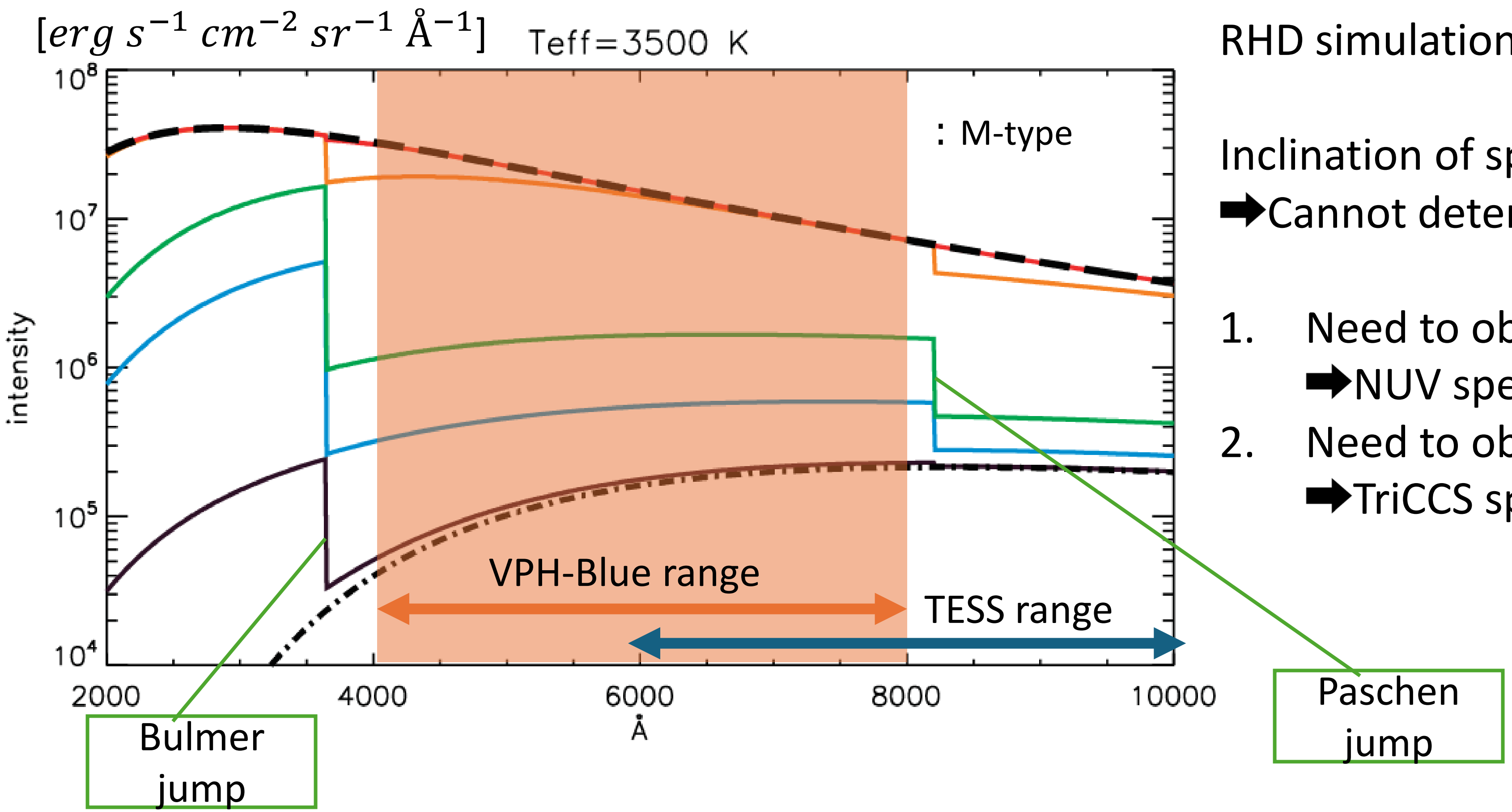
- Hβ is optically thin relative to Hα
  >Hβ is more sensitive to flare heating (flare peak)
- No significant 2nd peak
  >different radiative mechanism
  >possibility of postflare loops

Future work

Time variation of Hβ/Hα is similar to the lightcurve of optical continuum(TESS), but we don't know why.

Future prospect

Figure 1. in Heinzel 2024.



RHD simulation of 1-D slab model (depth= $500\ \mathrm{km}$)

Inclination of spectra is from T_{flare} or n_e?
➡Cannot determine in VPH-Blue range

1. Need to observe Bulmer jump(～3600Å)
   ➡NUV spectroscopy (MAUVE, 行方さん)
2. Need to observe Paschen jump(～8500Å)
   ➡TriCCS spectroscopy mode(前原さん)

Dashed line : blackbody @$10000\ \mathrm{K}$
Dash-dotted line : blackbody @$3500\ \mathrm{K}$ (quiescent)
Color lines : spectra of $n_e = 10^{15},\ 5\times10^{14},\ 10^{14},\ 5\times10^{13},\ 10^{13}[\mathrm{cm}^{-3}]$ (from top to bottom)

Summary

purpose Investigate the detailed time-evolution during white-light flares by observations with Seimei(spectroscopy) & TESS (photometry) simultaneously

obseravtion Observed active M-dwarf EV Lac
➡detected 1 significant white-light flare simultaneously

results

- $\mathbf{T_{flare} = 8122 \pm 273\ K}$（@flare peak）
- $\mathbf{E_{flare} = 4.4 \times 10^{32}}$ **erg** (considering the decreasing temperature)
- Overestimate the energy by a factor of 2-3 with fixed temperature
- Probable postflare loops

Future prospects

- Importance of NUV(行方さん’s talk), NIR > > MAUVE ,TriCCS, and so on..
- Observe with MIDSSAR for detection of moving materials
- Flux calibration is essential in this research.
  ➡More accurate analysis is needed ➡MOFU^2 is good for this research