Simultaneous Multi-site, Multi-wavelength, and Multi-messenger Monitoring of the Nearby Red Dwarf GJ 3147

Tai, Chen-Yu [1], Chen, Wen-Ping [1], Tsai, AL [1], Lalchand, B [1], Sharma, T [1],

Hu, SM [2], Wu, H [3], Zheng, J [3], Zhou, AY[3], Wei, JY[3], Wang, J [3], Bai, JY [3] ,

Qian, SB [4],Zhu, LY [4], Liu, JZ [5] , Hojaev, A [6], Panwar, N[7]

[1] Institute of Astronomy, National Center University, Taoyuan City, Taiwan; [2] Weihai Observatory, Shandong, China; [3] Xinglong Observatory, Hebie, China; [4] Gaomeigu Observatory, Lijiang, China; [5] Nanshan Observatory, Xinjiang, China; [6] Maidanak Observatory, Tashkent, Uzbekistan; [7] ARIES, Nainital, India

Graduate Institute of Astronomy, NCU
國立中央大學天文研究所

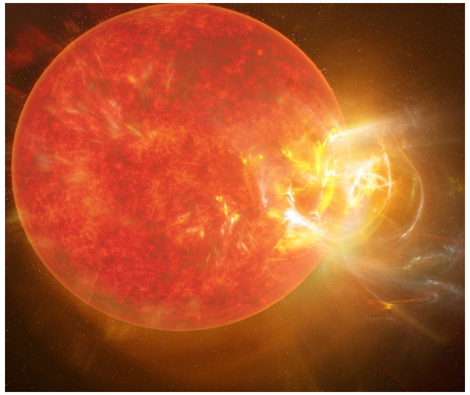
Email: m1129005@gm.astro.ncu.edu.tw

Stellar Flares

- Reconnection of surface magnetic field lines can produce flares. (Benz and Güdel 2010)

- Late M-type Stars:

  low-mass, fully convective dynamos, and magnetically active



Credit: S. Dagnello, NRAO/AUI/NSF

➢ The detailed mechanism uncertain

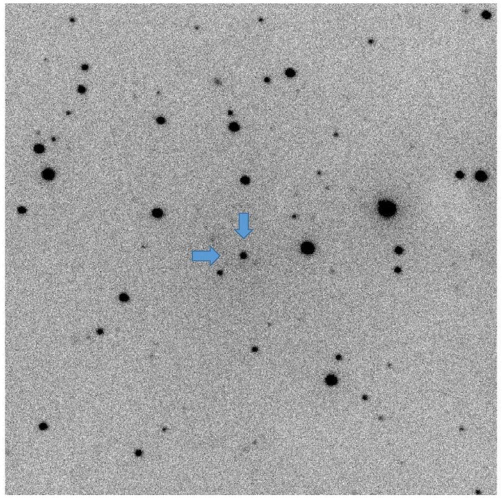
- We are interested in the heating and cooling processes of the stellar flares.

$\Longrightarrow$ A campaign to observe stellar flares by:

1. Different sampling functions $\rightarrow$ **Underlying flare profile**.
2. Different wavelengths $\rightarrow$ **Flare temperature**.

Monitoring Campaign

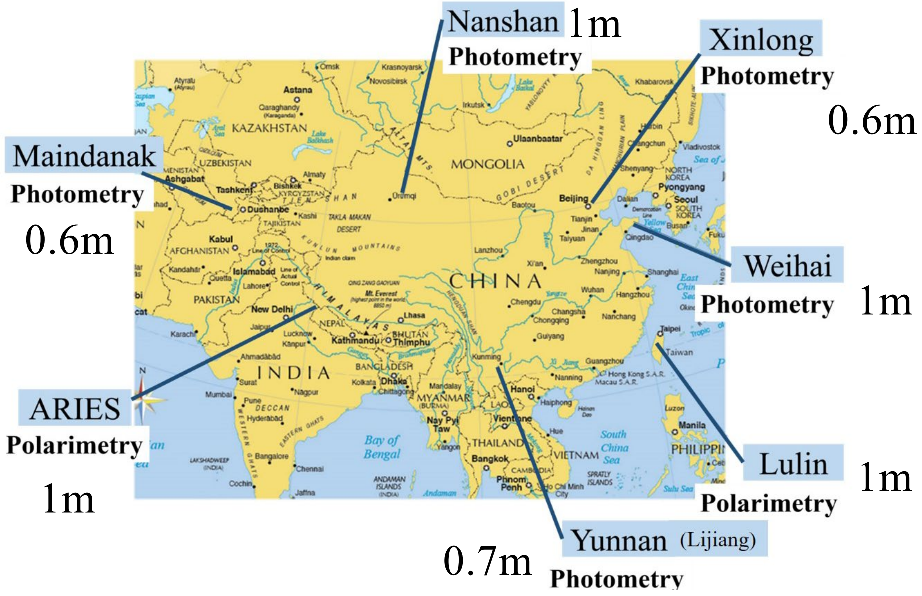
- Target: **GJ3147** (LP245-10)
  - R.A. = 02:1710.02 DEC. = +35:26:32.54 J2000, Spectral Type: **M7V**
  - Parallax: 96.7355 ± 0.0475 [mas], Distance ~ **10.34 [pc]** (Newton et al 2014)



GJ3147 2021.11.03 @Xinglong 60 cm; R band120 s

- Campaign:
  - 2021 November 11th to 17th
  - **7 East- to Mid-Asian observatories**
  - 100 data hours

  → detected **3 major** + numerous minor flares



- Simultaneous observations in **photometry** and **photopolarimetry**

Detection of a giant flare

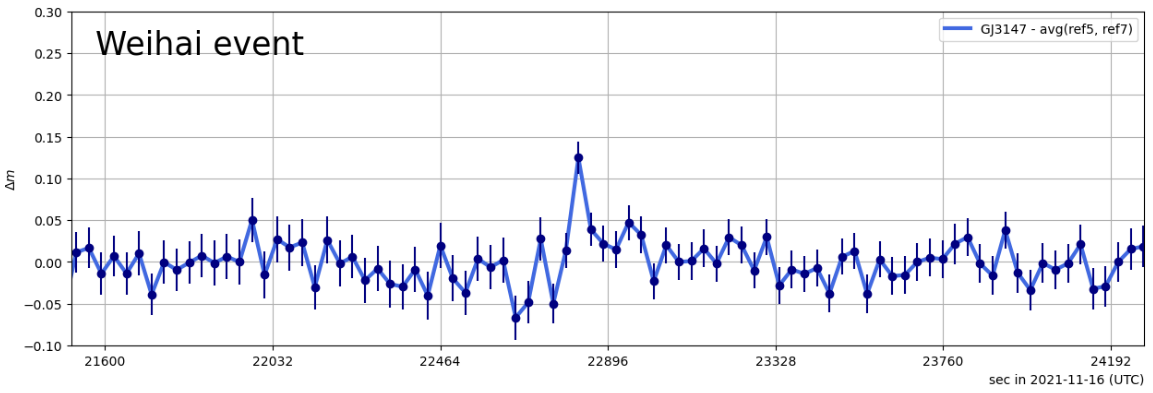
- The 2021 November 16 major flare was detected by four telescopes.
- Photometry: Weihai, Lijiang, and Nanshan
- Photopolarimetry: Lulin

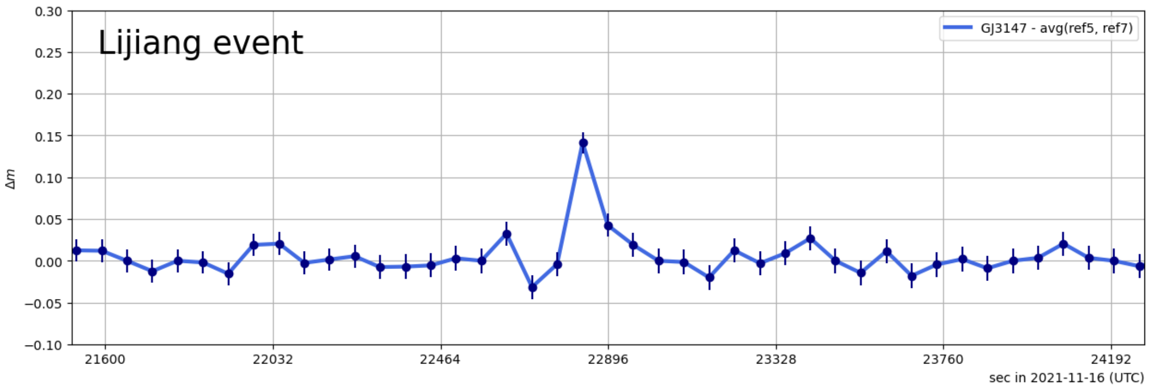
$\Delta R \sim 0.\mathbf{12}$ [mag] by **Weihai** at 22820.0 s

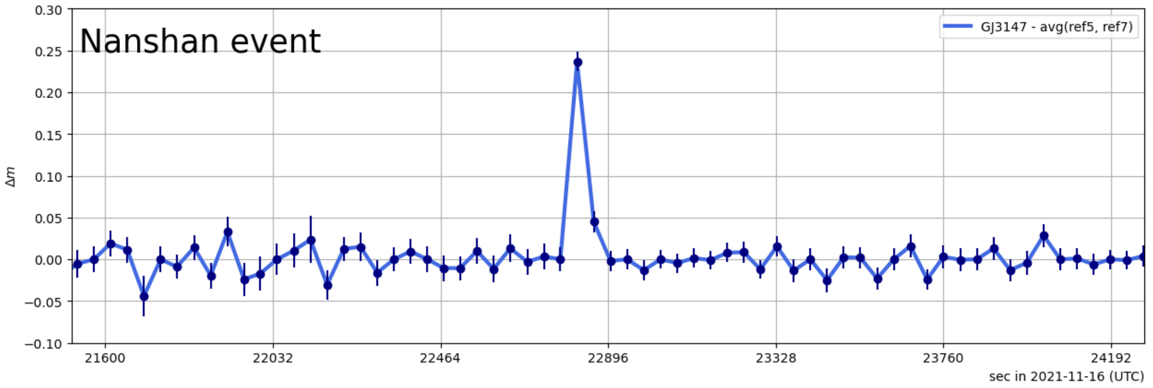
$\Delta R \sim 0.\mathbf{14}$ [mag] by **Lijiang** at 22812.0 s

$\Delta R \sim 0.\mathbf{24}$ [mag] by **Nanshan** at 22819.0 s

$\Longrightarrow$ **Intrinsic flare parameters**







Derivation of the underlying profiles

- We assume an impulse flare.

$$f(t)\begin{cases} = 0 & ,t < t_1 \\ = A & ,t = t_1 \\ = Ae^{-(t-t_1)/\tau} & ,t > t_1 \end{cases}$$

t_1: The peak time,
A: Peak amplitude
τ: decay time constant

$t_1 = (22464..\ 23328, \Delta t = 0.1s)$
$A = (0.1..\ 5.0, \Delta A = 0.01)$
$\tau = (1 \times 10^{-4}..10 \times 10^{-4}, \Delta\tau = 1 \times 10^{-4})$

$\Longrightarrow$ Over 40 million simulated light curves

- Calculated Light Curves $\leftrightarrow$ Observed Light Curves

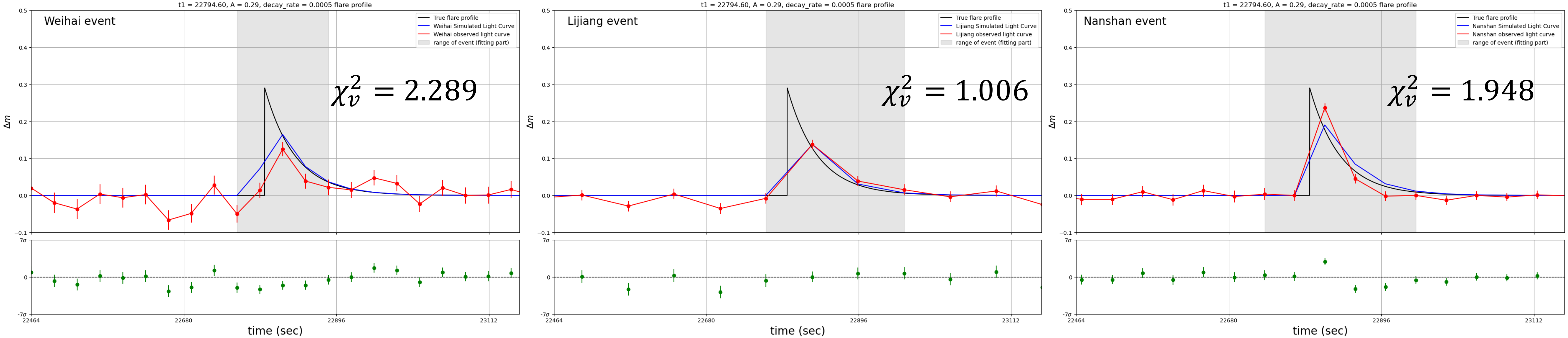
- Combine reduced χ_v^2 = conditional probability of the parameters

$\Longrightarrow$ **the underlying profiles**

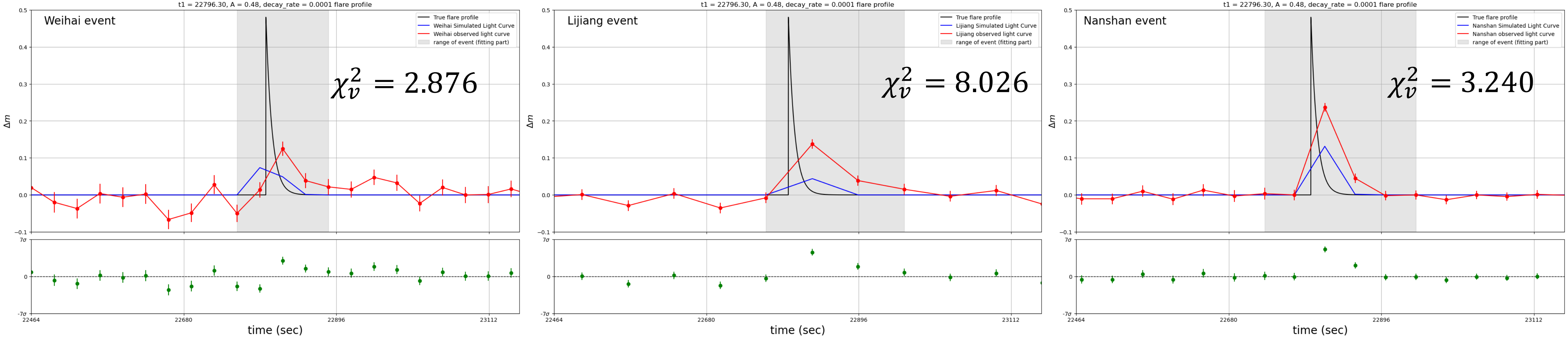
Best-fitting Profile vs. Poorly-fitting Profile

Best-fitting: $t_1 = 22794.6s, \Delta A = 0.29, \tau = 5 \cdot 10^{-4}$ $(\widetilde{\chi_v^2} = 1.649)$

Duration ~ 2 m 46 s



Poorly-fitting: $t_1 = 22796.3s, \Delta A = 0.48, \ \tau = 1 \times 10^{-4}$ $(\widetilde{\chi_v^2} = 4.213)$



The Same Flare but with Photopolarimetry

- Lulin Observatory provided polarization and simultaneous photometry at g', r', and i'.
- Flare peak:

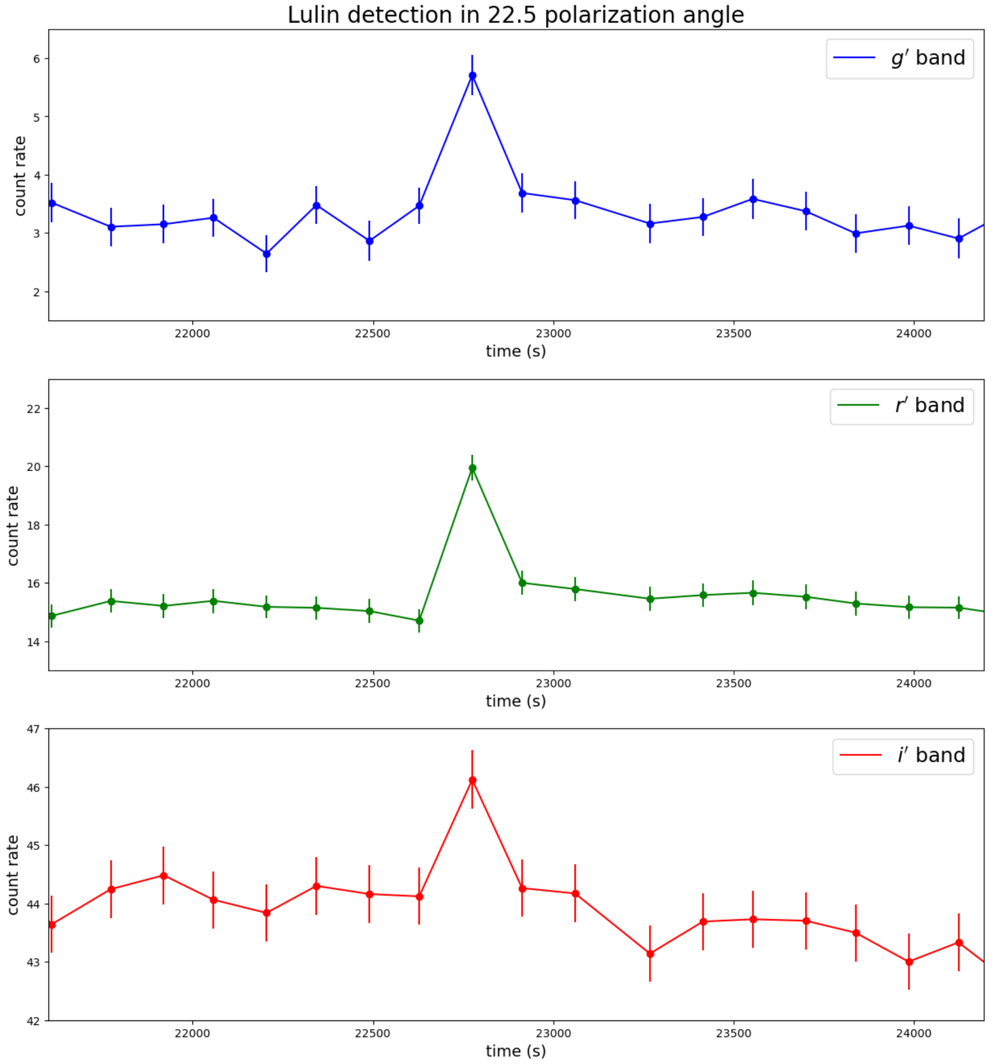
$$\frac{\Delta F}{\tilde{F}} = 69\% \text{ in } g'$$
$$\frac{\Delta F}{\tilde{F}} = 28\% \text{ in } r'$$
$$\frac{\Delta F}{\tilde{F}} = 5\% \text{ in } i'$$

$\Longrightarrow$ **Flare temperature estimation**

$\Longrightarrow$ **Linear polarization detection** (quiescent)

5.8% at g' , 2.0% at r' , and 0.5% at i'

It might be due to scattering in an inhomogeneous, dusty, and cold atmosphere or prolonged shape due to fast rotation. (Zapatero Osorio et al. 2005, ApJ, 621, 445)

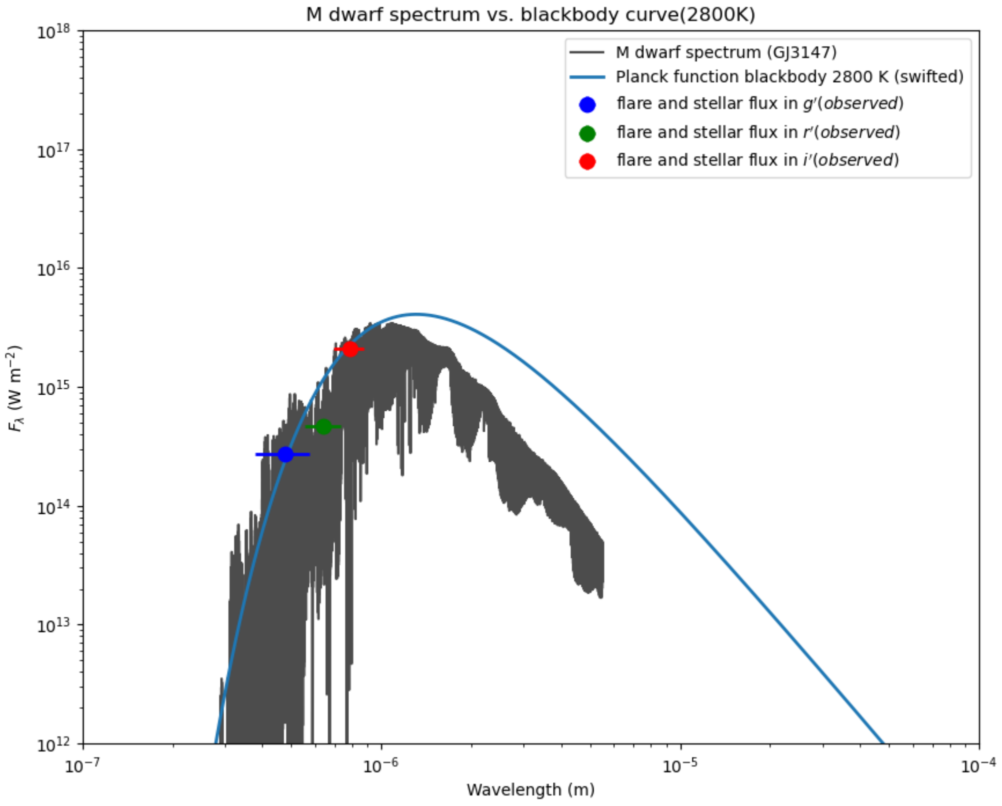


Same sampling function = Same flux rate

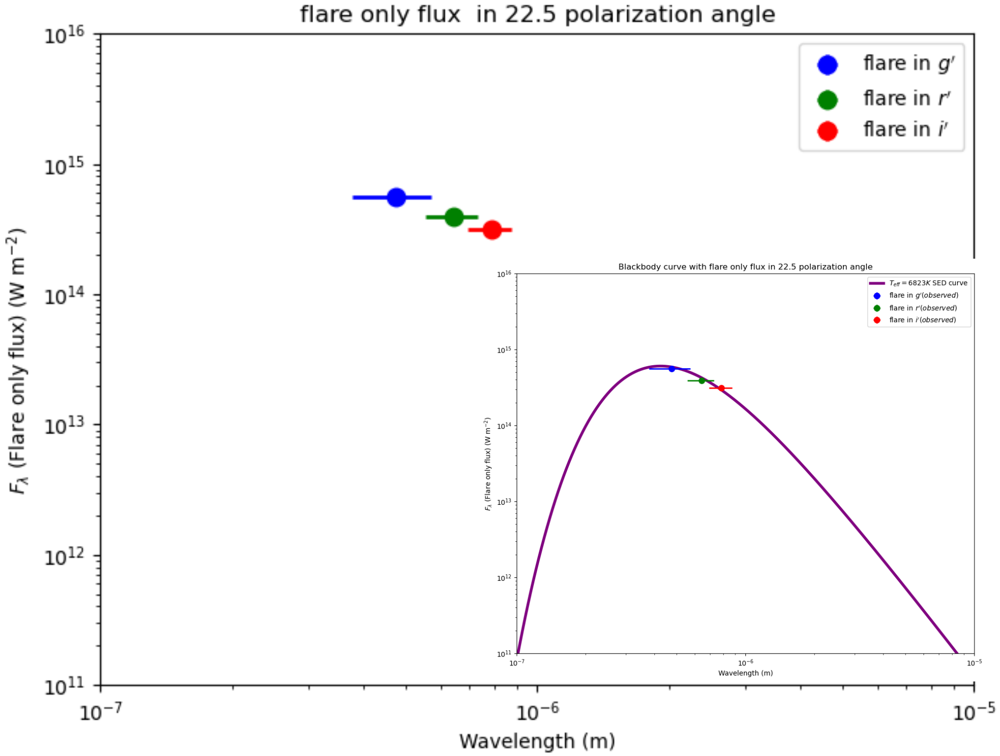
Flare Temperature Estimation

- Phoenix M7 atmospherical model (Husser et al. 2013)⟶ Flare only flux
- We assume the flare to be a blackbody.

⟹ Flare temperature = 6800 $\pm$ 300 K



Subtracting stellar flux



Conclusion

- We report a successful multi-site, multi-wavelength, and multi-messenger campaign for GJ3147 from November 11th to 17th, 2021.

- Multi-site $\Longrightarrow$ Intrinsic flare parameters
  - To get the 'True' heating and cooling time scales.

- Multi-wavelength $\Longrightarrow$ flare temperature (6800 ± 300K)
  - Sampling effect will NOT affect temperature estimation due to flux ratio.

- Multi-messenger $\Longrightarrow$ photometry and polarimetry

Backup slides

Combine Reduced χ_v^2 of the Simulated Light Curves

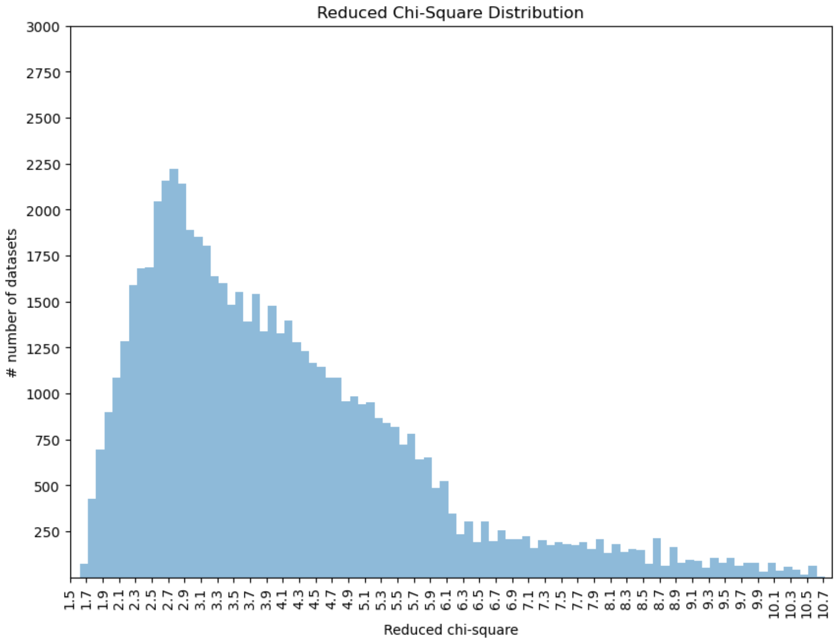
Well-fitting parameters

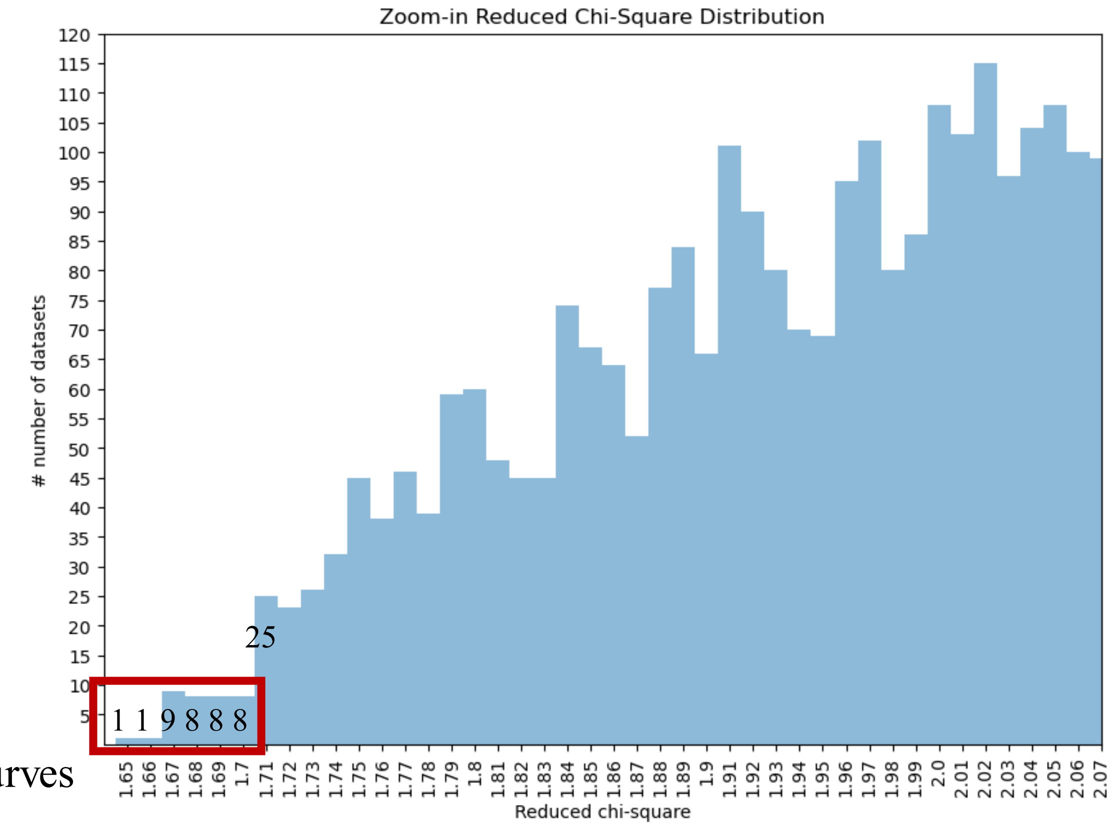
Polarization Detection in Lulin

Spectrum Model Introduction

Combine Reduced χ_v^2 of the Simulated Light Curves

- Three telescopes observed the flare event which means there will be three reduced χ_v^2 in each simulation.
- We find out that both geometric and arithmetic mean will reveal the same best-fitting parameter. However, we use the geometric mean on this research.

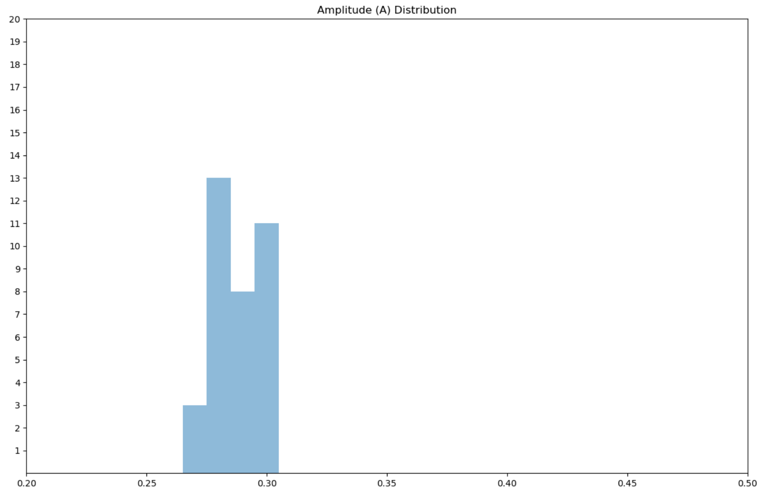


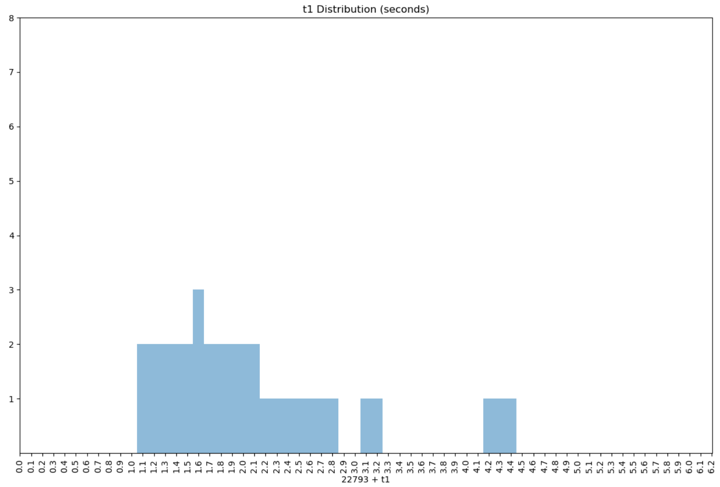


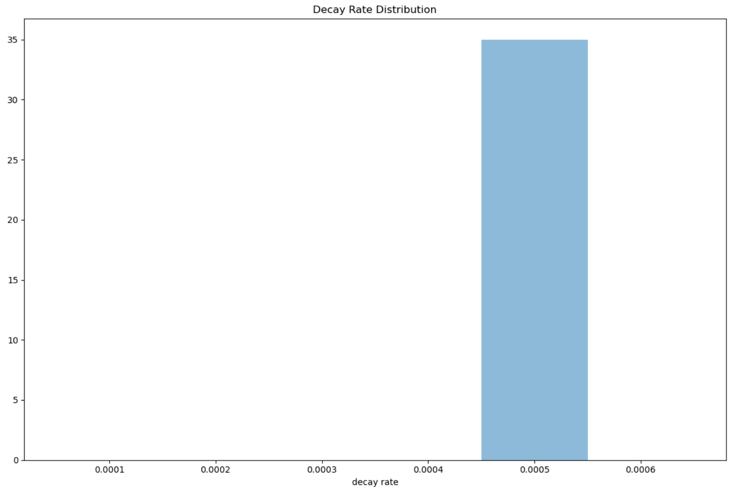
total 35 light curves

Well-fitting parameters

- After selecting the 35 light curves, we checked the parameter distributions and decided on the ranges.
- Results: $\Delta m\ = 0.29 \pm 0.01,\ t_1 = 22795.1 \pm 0.9,\ \tau = 5 \times 10^{-3}$



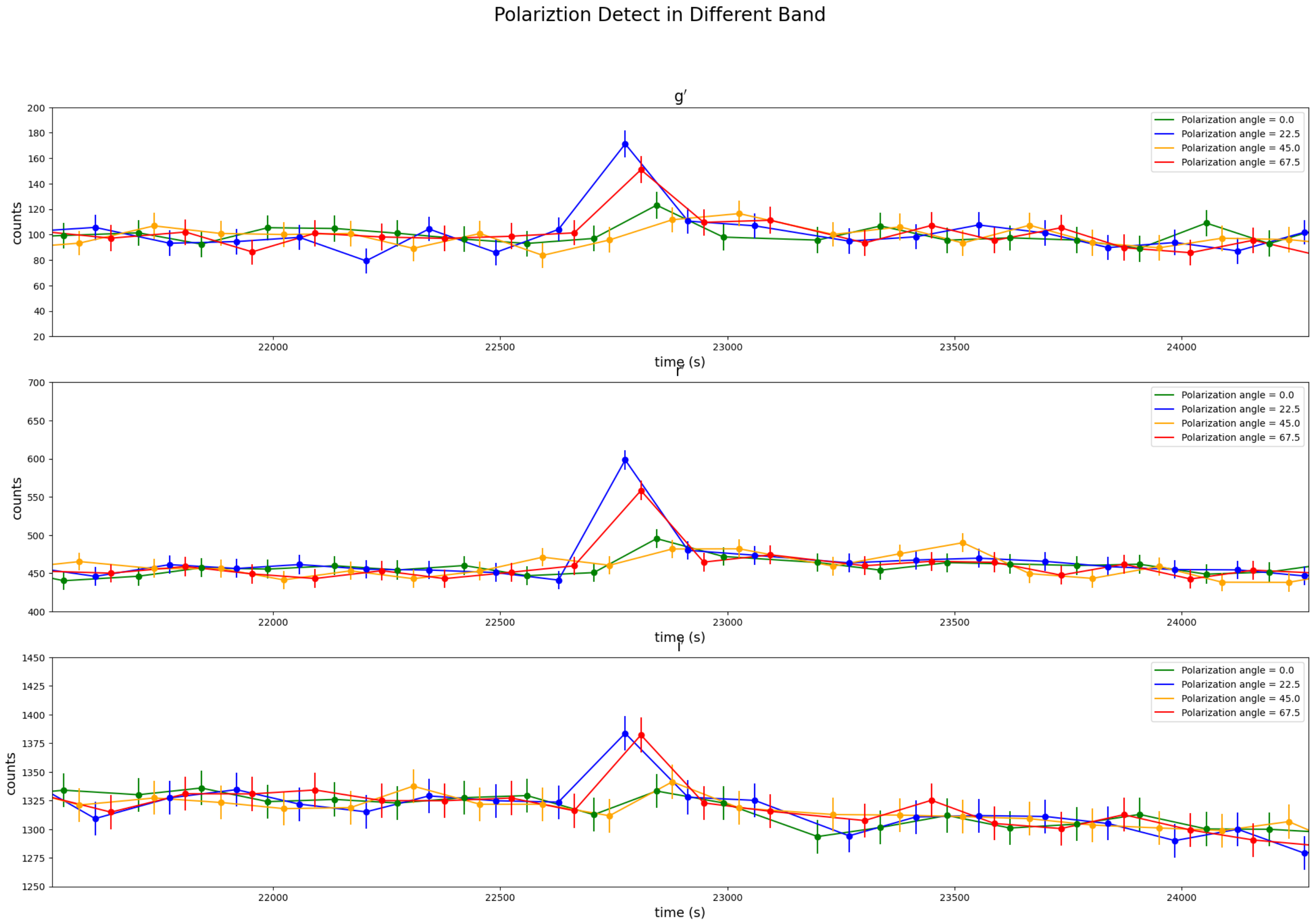




The histograms showed the distributions of Δm, t_1, and τ.

Polarization Detection in Lulin

- In Lulin, the polarization detections weren't simultaneous, so we can only detect the star polarization information in quiescent states.

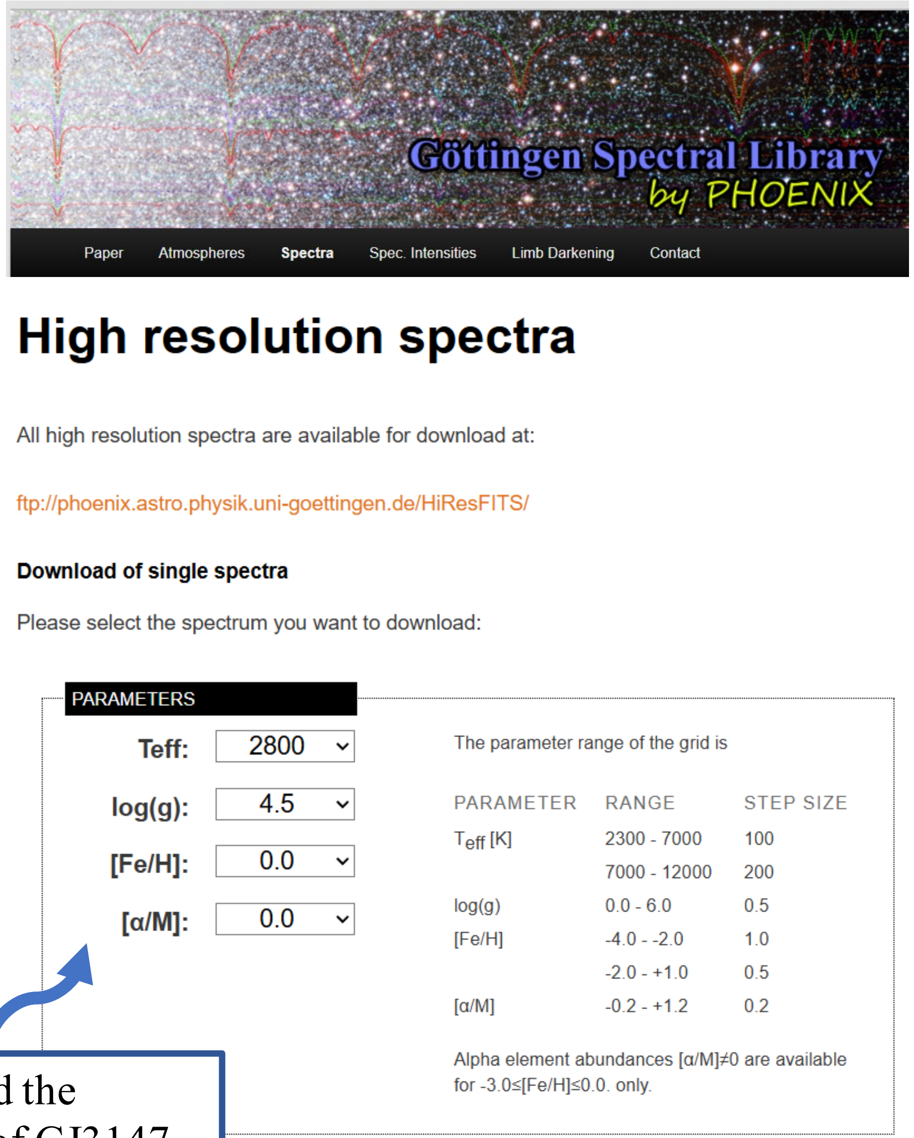


Spectrum Model Introduction

- By Husser et al. from Germany.
- In this model, they considered more newly discovered atomic and molecular lines. (like alpha elements eg.: Mg, Ti, Si, Ca, S)
- The table below is the parameter space of the model.

Variable	Range	Step size
T_{eff} [K]	2300–7000	100
	7000–12 000	200
$\log g$	0.0–+6.0	0.5
[Fe/H]	−4.0–−2.0	1.0
	−2.0–+1.0	0.5
[α/Fe]	−0.2–+1.2	0.2

Notes. Alpha element abundances [α/Fe] $\neq$ 0 are only available for 3500 K $\leq T_{\mathrm{eff}} \leq$ 8000 K and $-3 \leq$ [Fe/H] $\leq$ 0.



We imported the parameters of GJ3147.