
# Stellar Flares by Real-Color Survey

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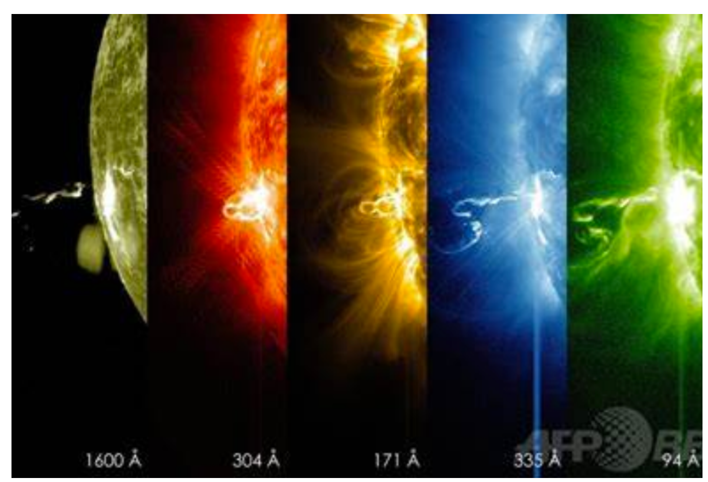
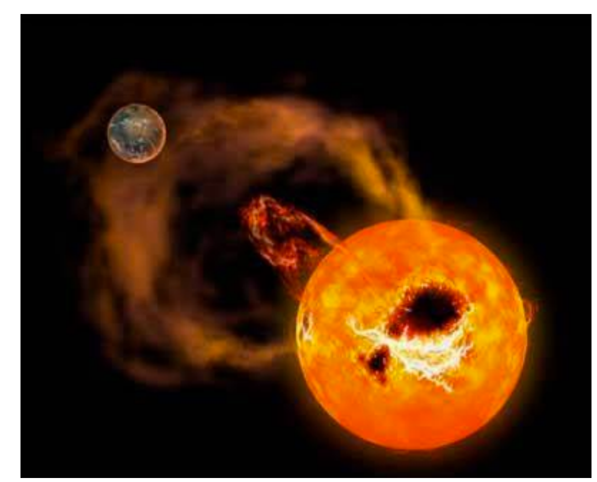


2024/4, SWIFAR-YNU, Kunming

# Mephisto

- The main features of Mephisto can be summarized as follows

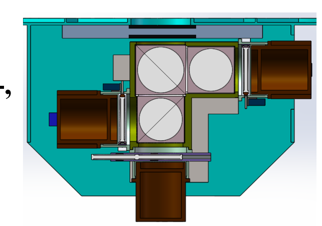
**wide-field** (Survey) **multi-channel** (Real Color)

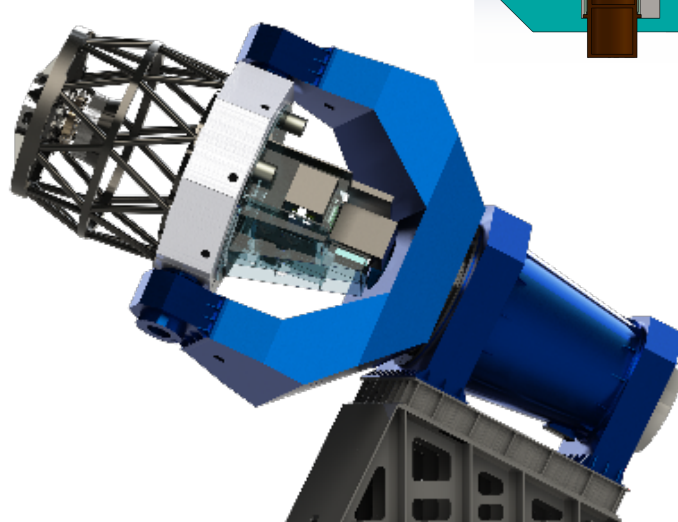
$$\text{Mephisto} = \text{Survey} + \underline{\text{Real}}\ \text{Color}$$

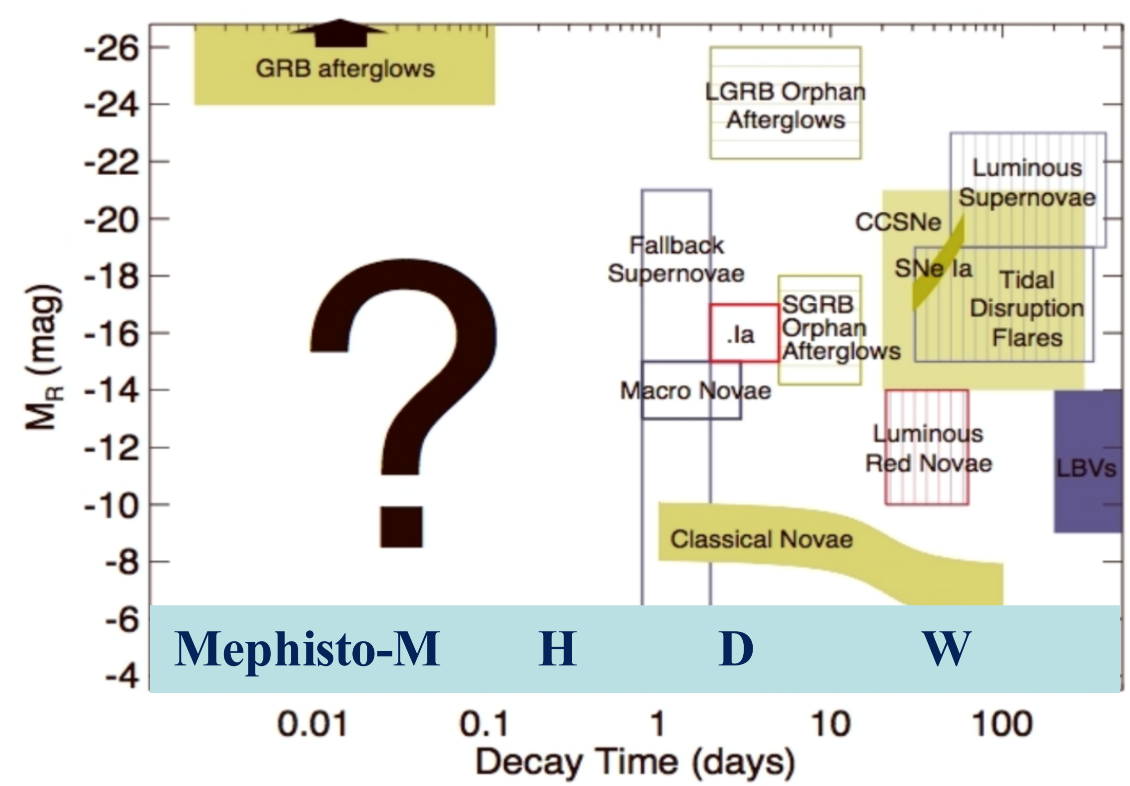
Real → ***<sub-minute***

- Such a characteristic of Mephisto will play an extremely important rule in searching and studying **fast transients with sub-minute durations**, because the time for the time of switching filter is about a few minutes for large optical telescopes.

**3 CCD mosaic cameras** (2×2 e2v CCD-290-99 mosaic) for the blue-, yellow- and red-channels





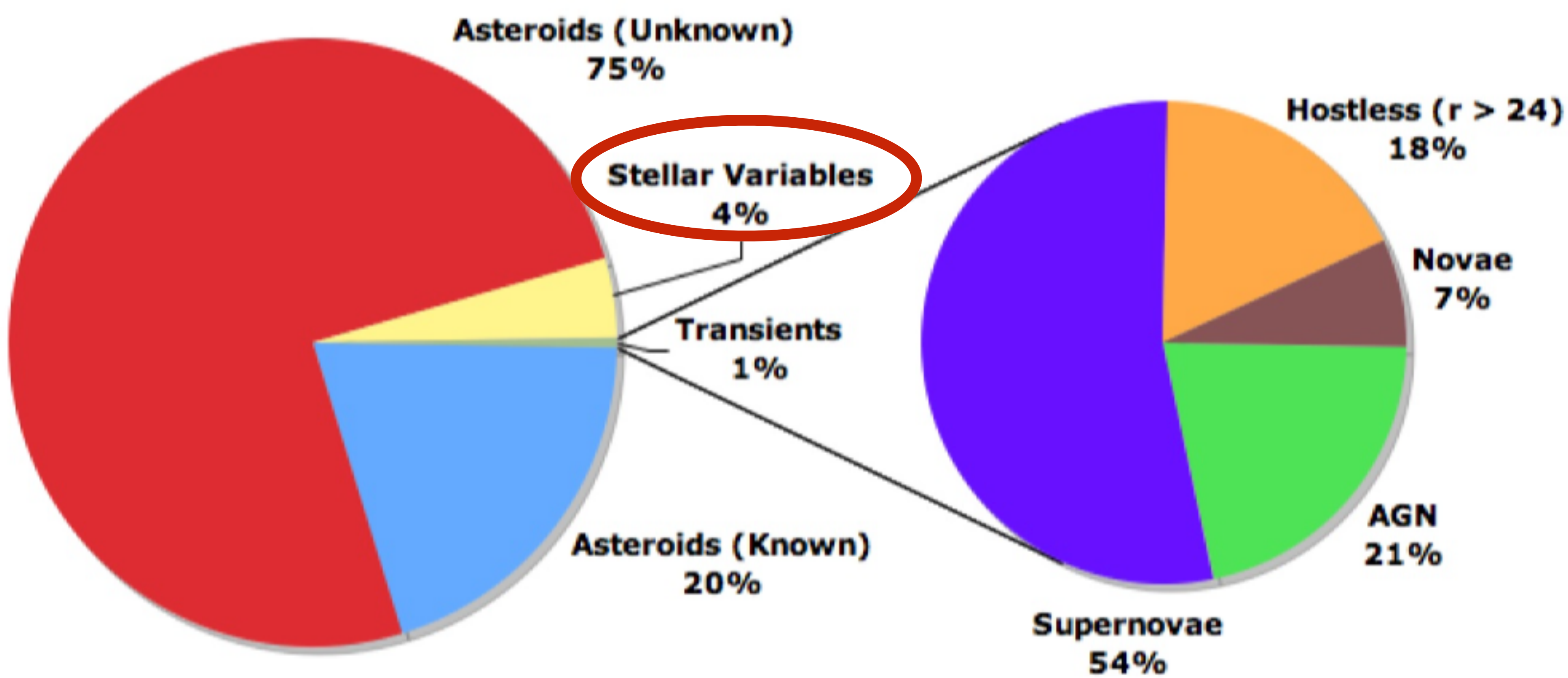


# Transient Survey

- A nightly targeted search of nearby rich clusters (**Virgo, Coma, and Fornax**) using the 3.6-m CFHT-COVET and the 100-inch (2.5-m) du Pont telescopes has revealed **the extensive foreground fog (asteroids, M dwarf flares, dwarf novae)** and **the background haze (distant, unrelated SN)**

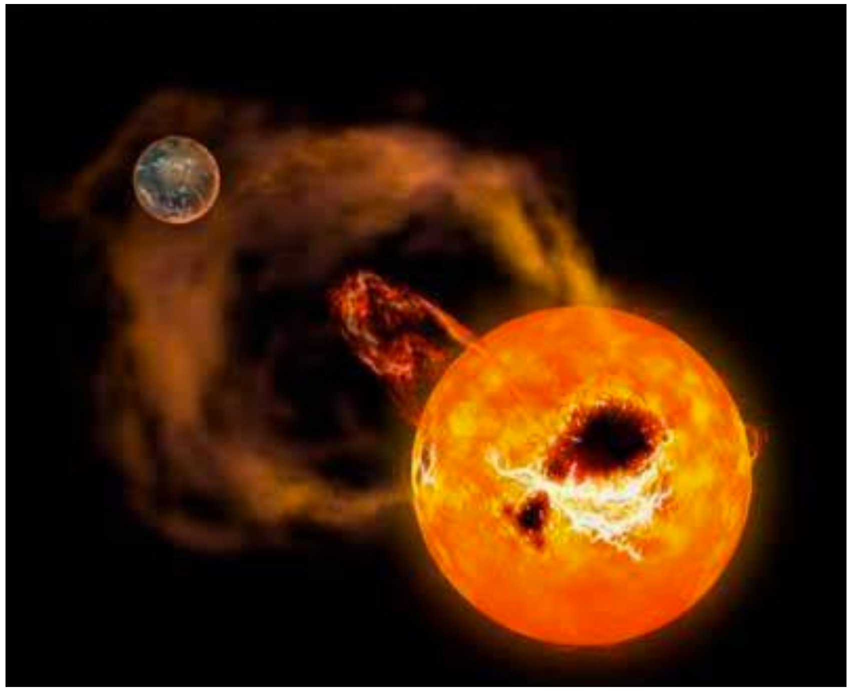
- For example. 28 COVET transients were discovered during a pilot run in 2008A (7 hours). Of the 2,800 candidates, the COVET pipeline automatically rejected 99% as asteroids or Galactic objects.

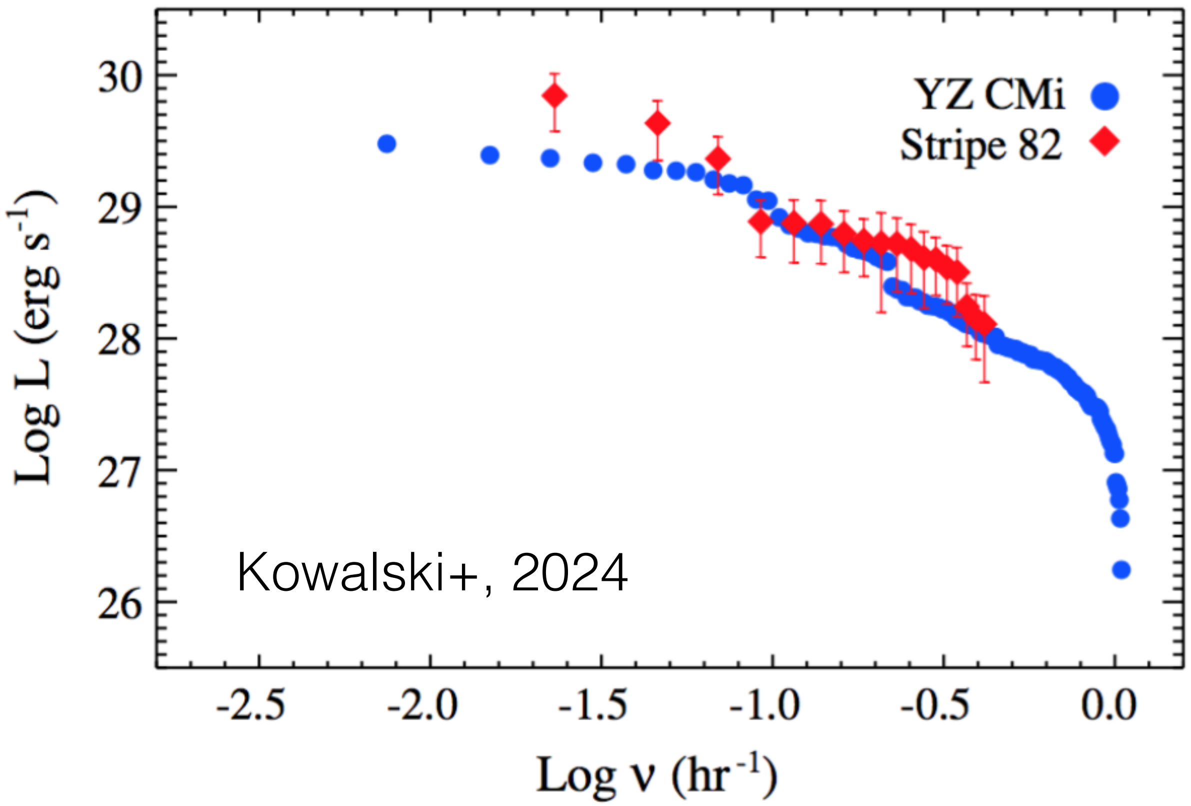
- Stellar variables account for ~ **4% of all events**, and their detection rate is about four times of other astrophysical transients.



# Stellar Flares

- Low mass stars comprise **nearly 70% of stars** in the Galaxy, their flares represent a major source of transient variability in time domain surveys.
- Stellar flares are usually defined as **catastrophic releases of magnetic energy** leading to particle acceleration and electromagnetic radiation accompanied by coronal mass ejections.
- Frequent flaring occurs on stars with **an outer convection zone**, and the timescale of energetic fares is longer than that of less energetic flares. Meanwhile, the larger the flare luminosity, the smaller the flaring frequency.





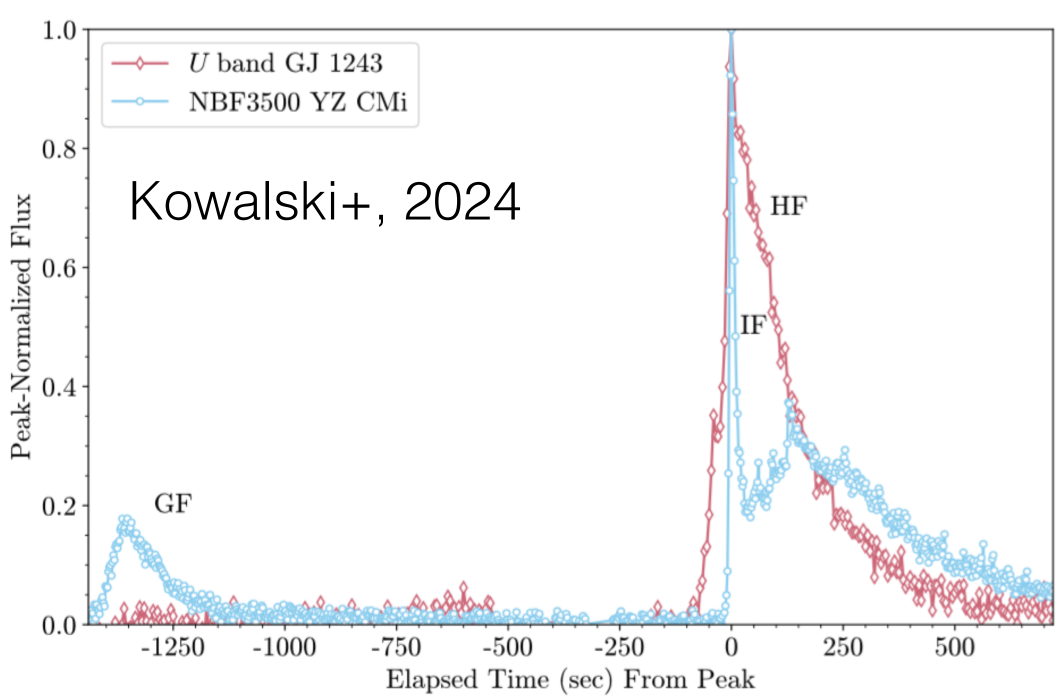
# Light Curves

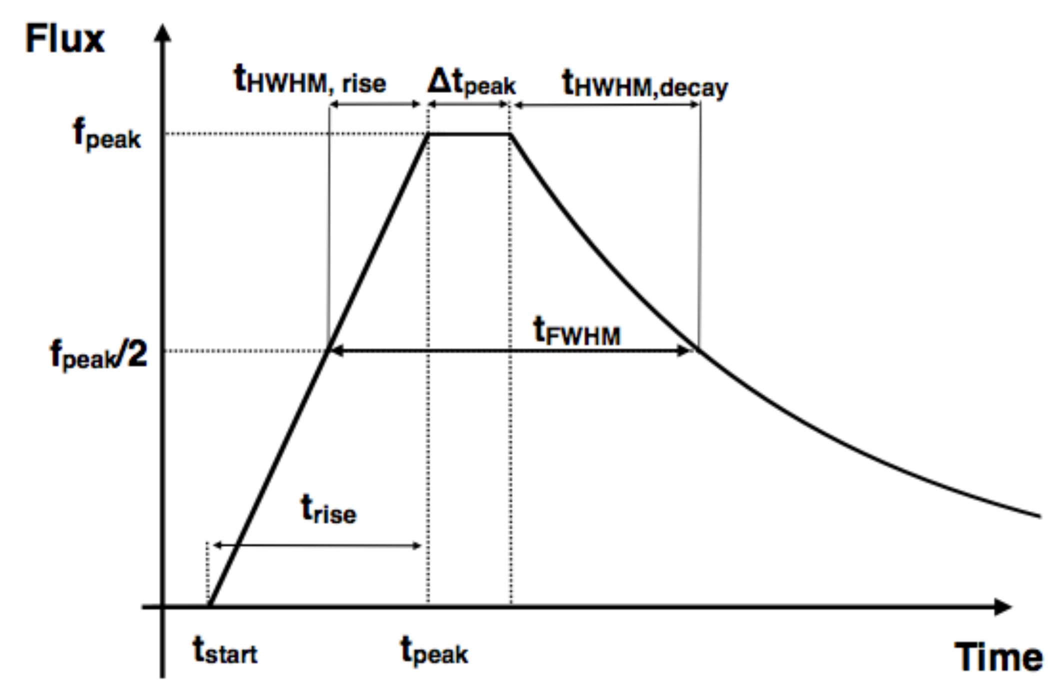
- Over short timescales of **minutes to a few hours**, stellar flares emit energy ranging from 10^23 erg (**nanoflares**) to 10^31 − 10^38 erg (**superflare**). There is relation between the duration and the energy of the stellar flares.

$$\Delta t \sim t_{1/2} \simeq 63 \text{ s} \left( \frac{E}{10^{32} \text{ erg}} \right)^{0.3}$$

- Observations of over 38,000 M dwarfs in the SDSS revealed that the fraction of "active" stars increases dramatically from types M0 to M6, **peaking near spectral type M7-M8**.

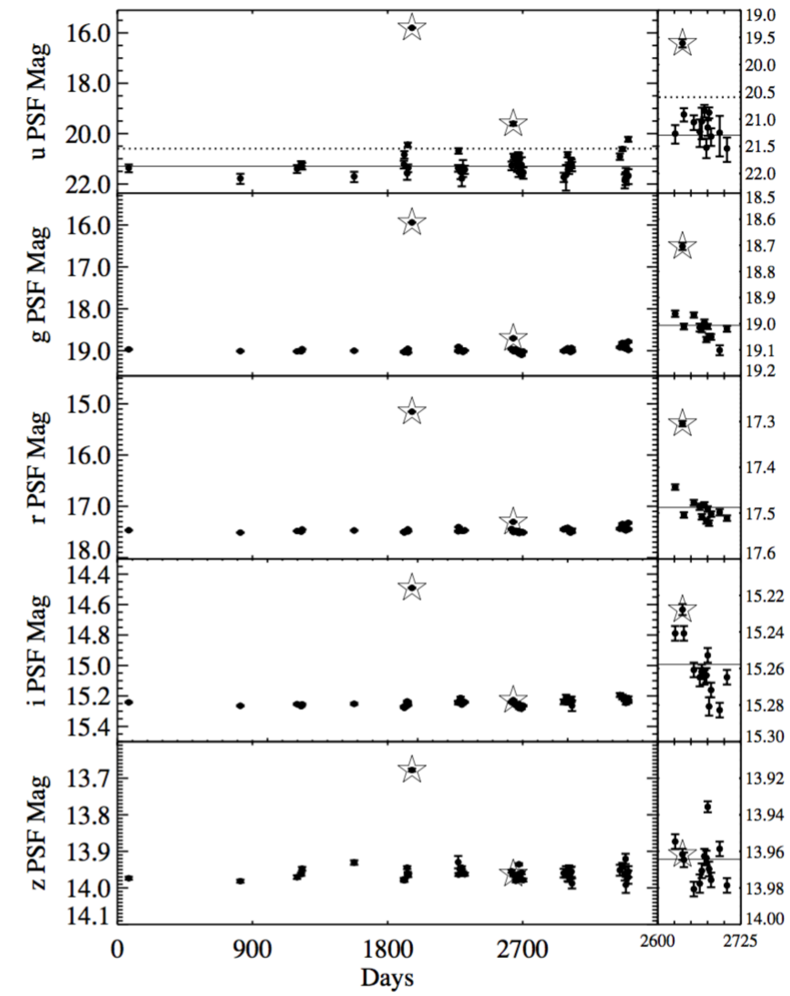
- Flare light curves generally consist of **a sudden increase** in brightness that is most extreme in the near UV and blue optical, followed by **a long tail** as the star gradually returns to its quiescent state.

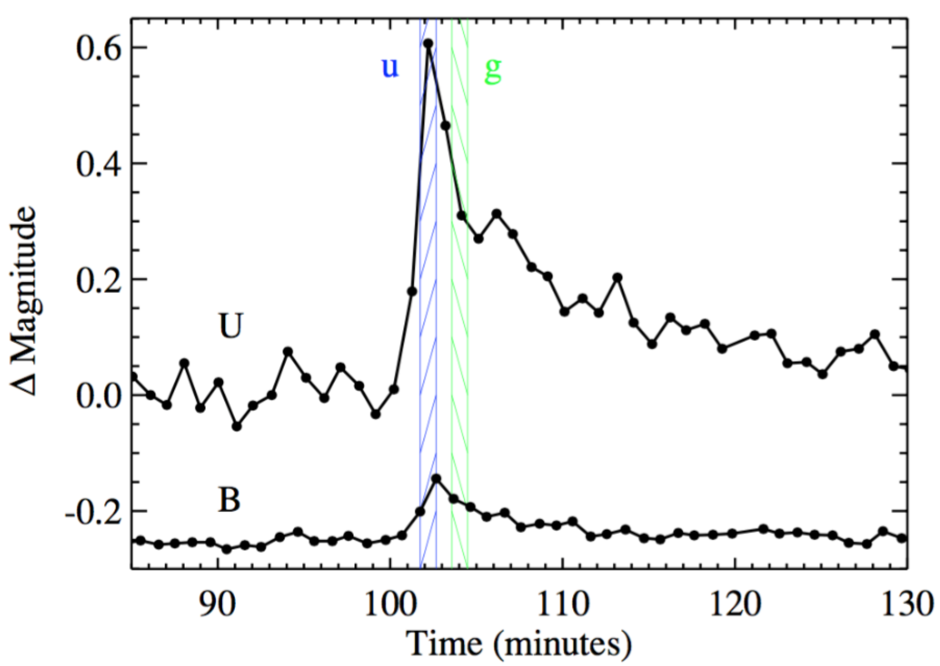


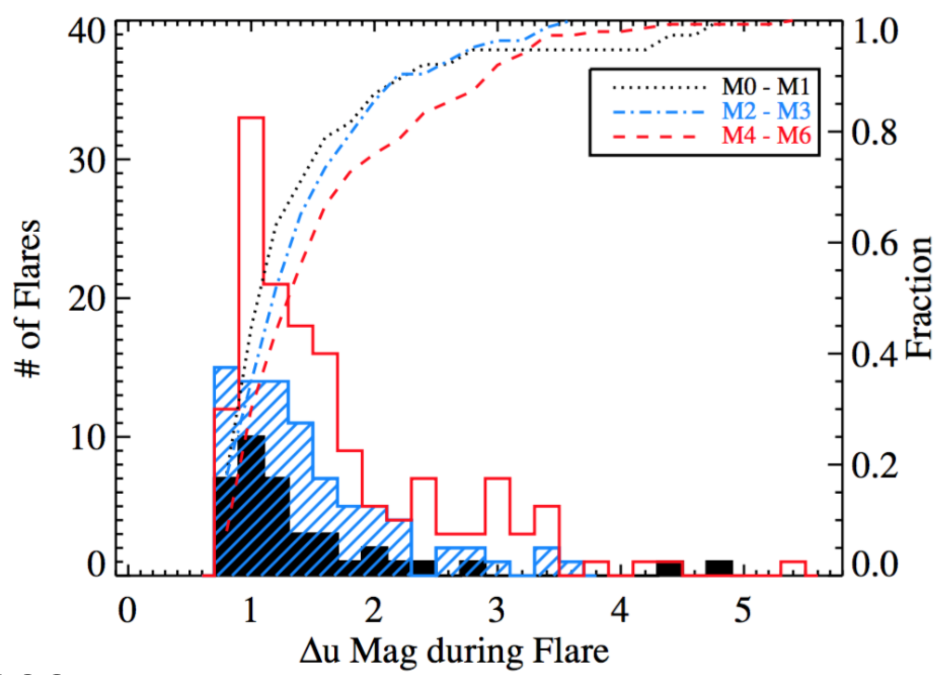



# Survey of Stellar Flares

- Kowalski et al. (2009) presented a flare rate analysis of 50,130 M dwarf light curves in SDSS Stripe 82.
- For stars of spectral types M0-M6 with u<22 mag on Stripe 82, SDSS detected **270 flares with a u-band magnitude change of at least 0.7**
- Flares as large as **Δu ~ 5 mag** were observed in both early and late type M stars, but flares of **Δu < 2 mag** dominate the sample.
- While **the flare contrast is greatest in u**, most flares will be visible (although with a smaller increase in brightness) in g, r, and to a lesser extent in i.




Kowalski+, 2009

# Detection Rate of Stellar Flare

- The observed flare rate is very strongly dependent on the line of sight through the Galaxy 95% of the flaring observations occur on stars that are within 300 pc of the plane, and the flare rate ranges from 0 to 8 flares/hr/deg2 depending on Galactic latitude.
- For the Stripe 82 data, the mean flare rate density is $\Sigma_{S82} \sim 1.3 \text{ flares hr}^{-1} \text{ deg}^{-2}$.
- with a u mag increase of Δu>0.7 as the common flare detection threshold and u<22. The flare rate density for Mephisto could be estimated by

$$\Sigma = 10^{\frac{3(m_u - m_{S82})}{5}} \Sigma_{S82} \sim 0.5 \text{ flares hr}^{-1} \text{ deg}^{-2}$$

**for Mephisto**

- for **m_u=21.3 mag with one minute exposures**

| Spatial Division | Mean # Flares $\text{hr}^{-1}$ $\text{deg}^{-2}$ |
|---|---|
| $23° < \|b\| < 45°$ | 2.0 |
| $45° < \|b\| < 55°$ | 0.9 |
| $55° < \|b\| < 64°$ | 0.7 |
| $45° < l < 90°$ | 1.5 |
| $90° < l < 135°$ | 0.7 |
| $135° < l < 191°$ | 0.9 |

Kowalski+, 2009

# Toy Model for Stellar Flare

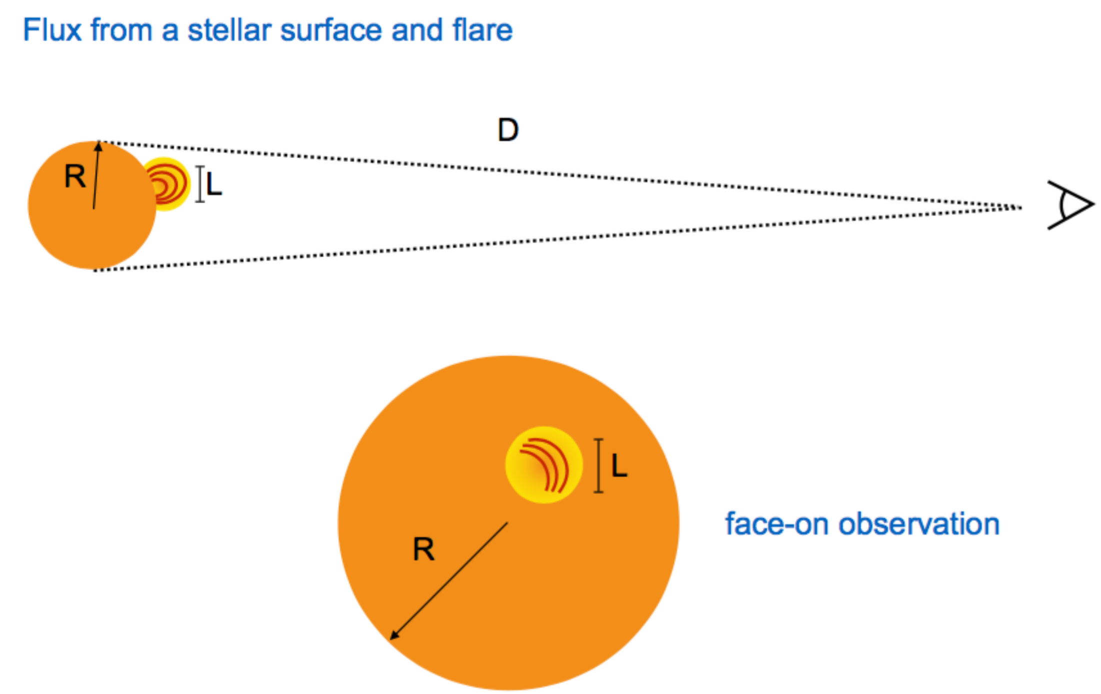
- Assuming that both the star and the flare emit blackt radiation, the total flux during the flare phase could b calculated by

$$F_\nu = \pi \left(\frac{R_s}{D}\right)^2 \left[B_\nu(T_f)x^2 + B_\nu(T_s)\right]$$

**flare** **star**

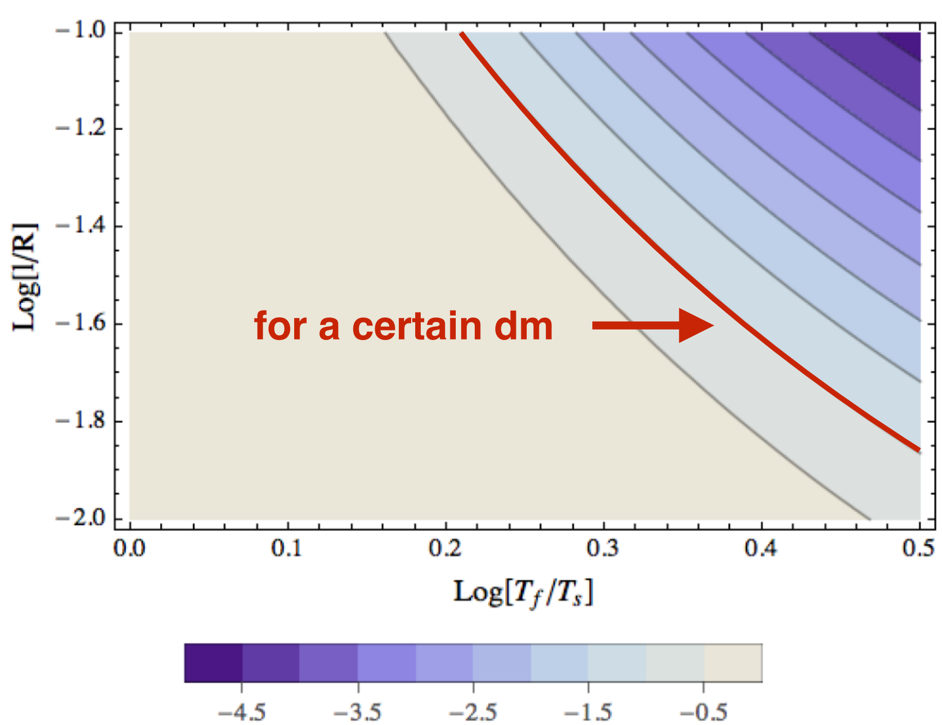
with

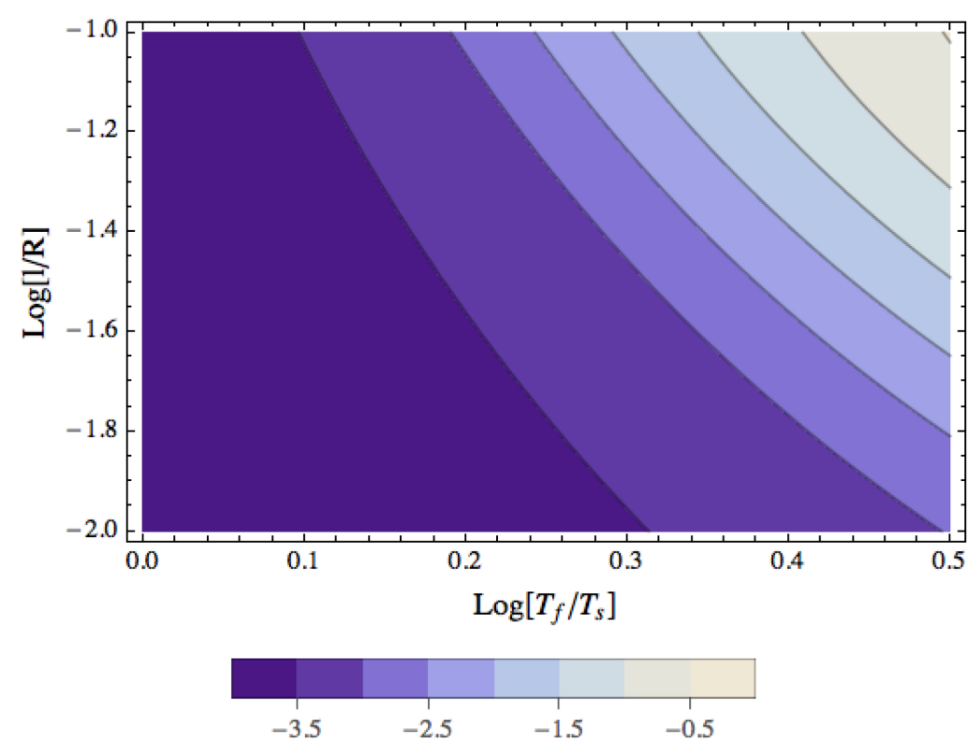
$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{\exp(h\nu/kT) - 1} \quad \text{and} \quad x \equiv \frac{R_f}{R_s}$$




- For a certain frequency, the magnitude difference be tween the flare phase and the quiescent phase as

$$\Delta m \equiv -2.5 \log\left(\frac{F_\nu}{F_{\nu,0}}\right) = -2.5 \log\left[\frac{\exp(h\nu/kT_s) - 1}{\exp(h\nu/kT_f) - 1} x^2 + 1\right]$$



# Simulation

- We consider that a M dwarf and a stellar flare has

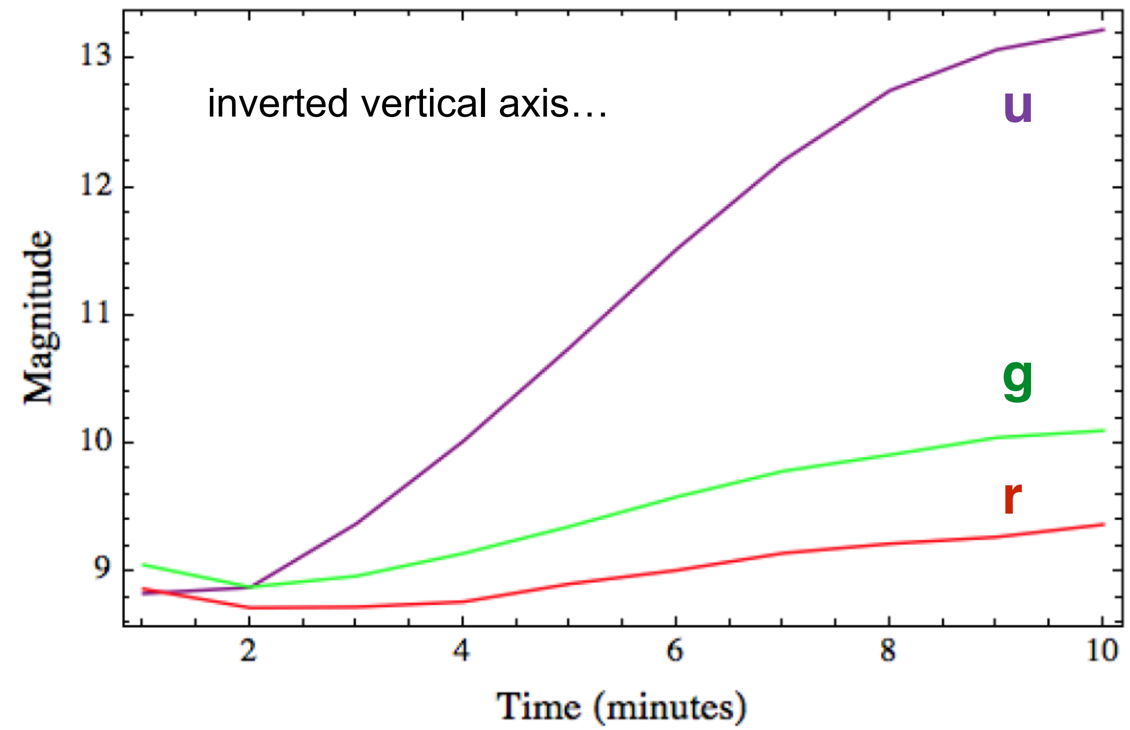
$$R_s = 0.4R_\odot \quad T_s = 3500 \text{ K} \quad d = 10 \text{ pc}$$

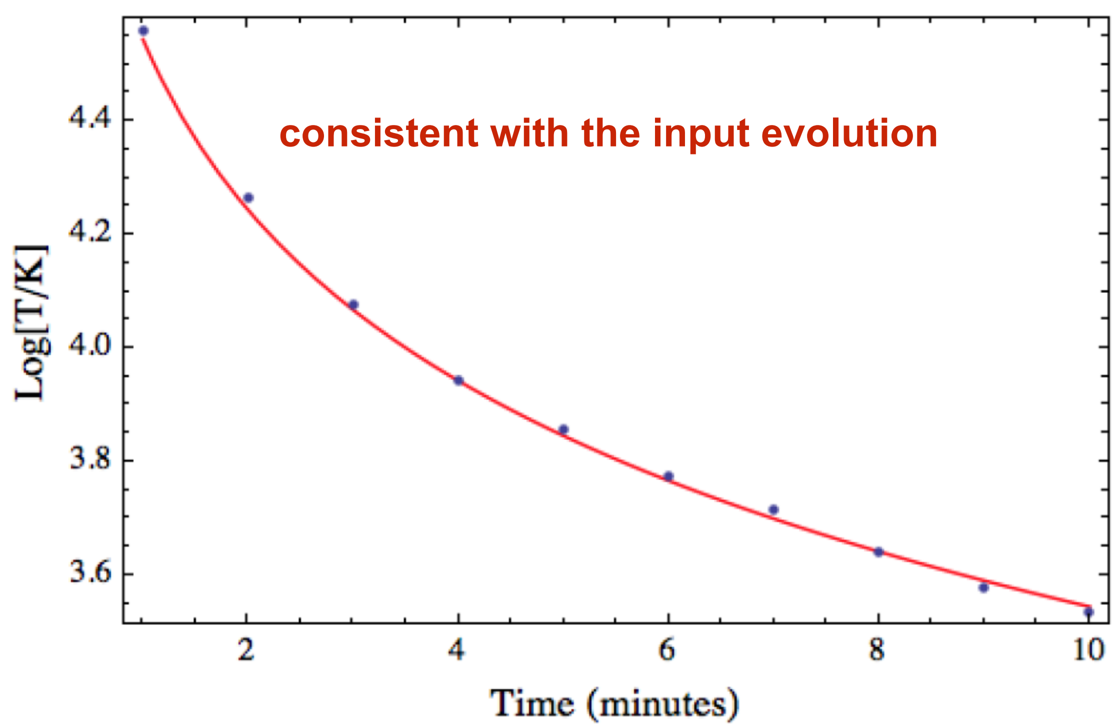
$$R_{f,0} = 10^{-1.5} R_s \quad T_{f,0} = 10 T_s$$

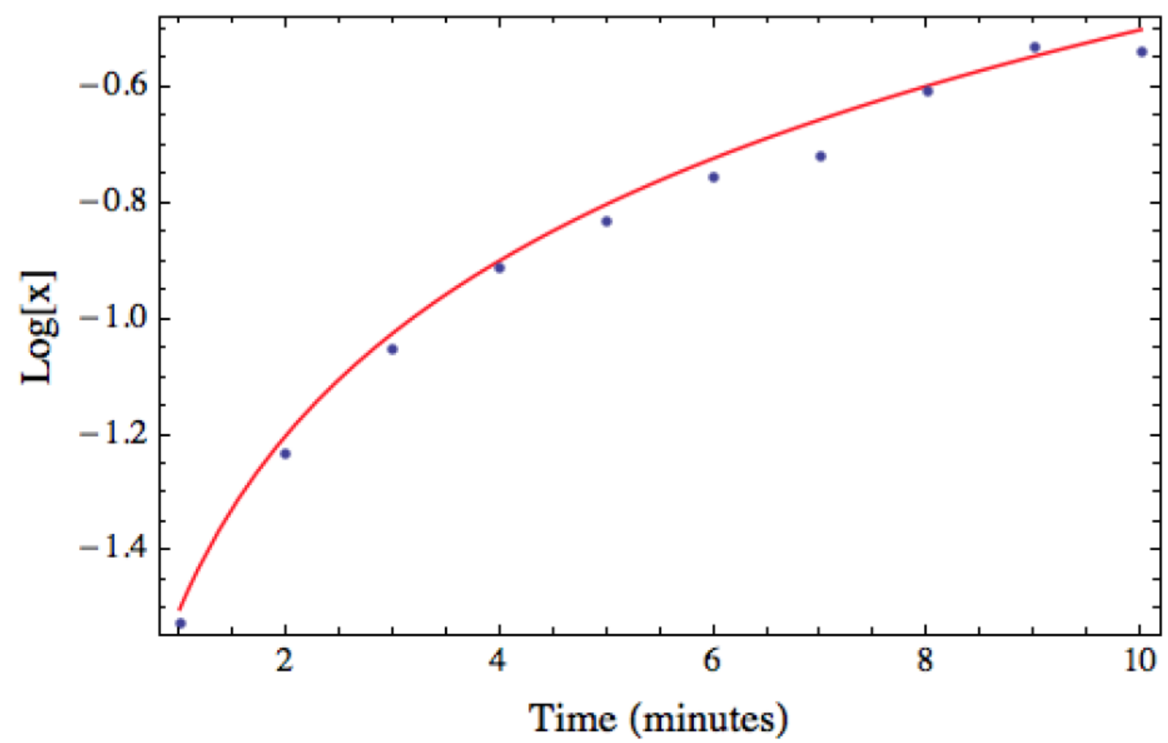
- The evolutions of the scale and effective temperature of the stellar flare may be assumed to be

$$R_f = R_{f,0}\left(\frac{t}{t_0}\right) \qquad T_f = T_{f,0}\left(\frac{t}{t_0}\right)^{-1}$$

- We simulate the magnitudes at different bands based on the flare dynamics and blackbody radiation and add a fluctuation of $\Delta m < 0.05$ mag

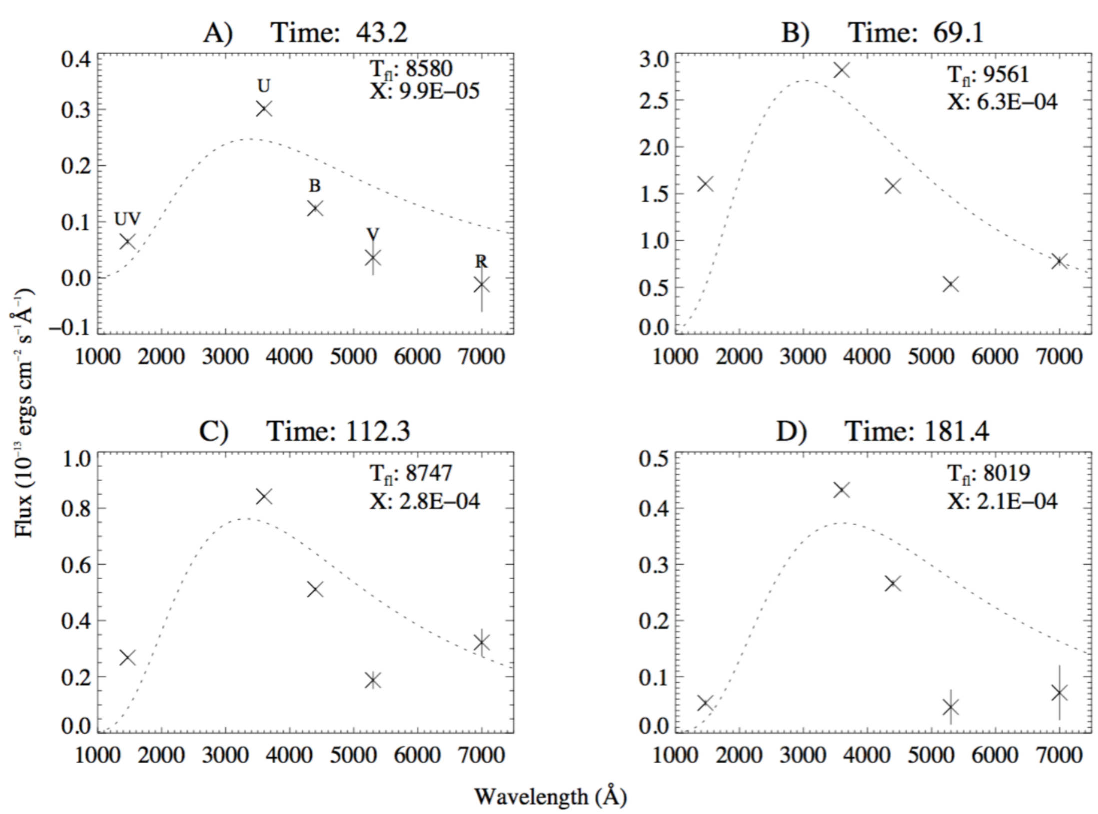


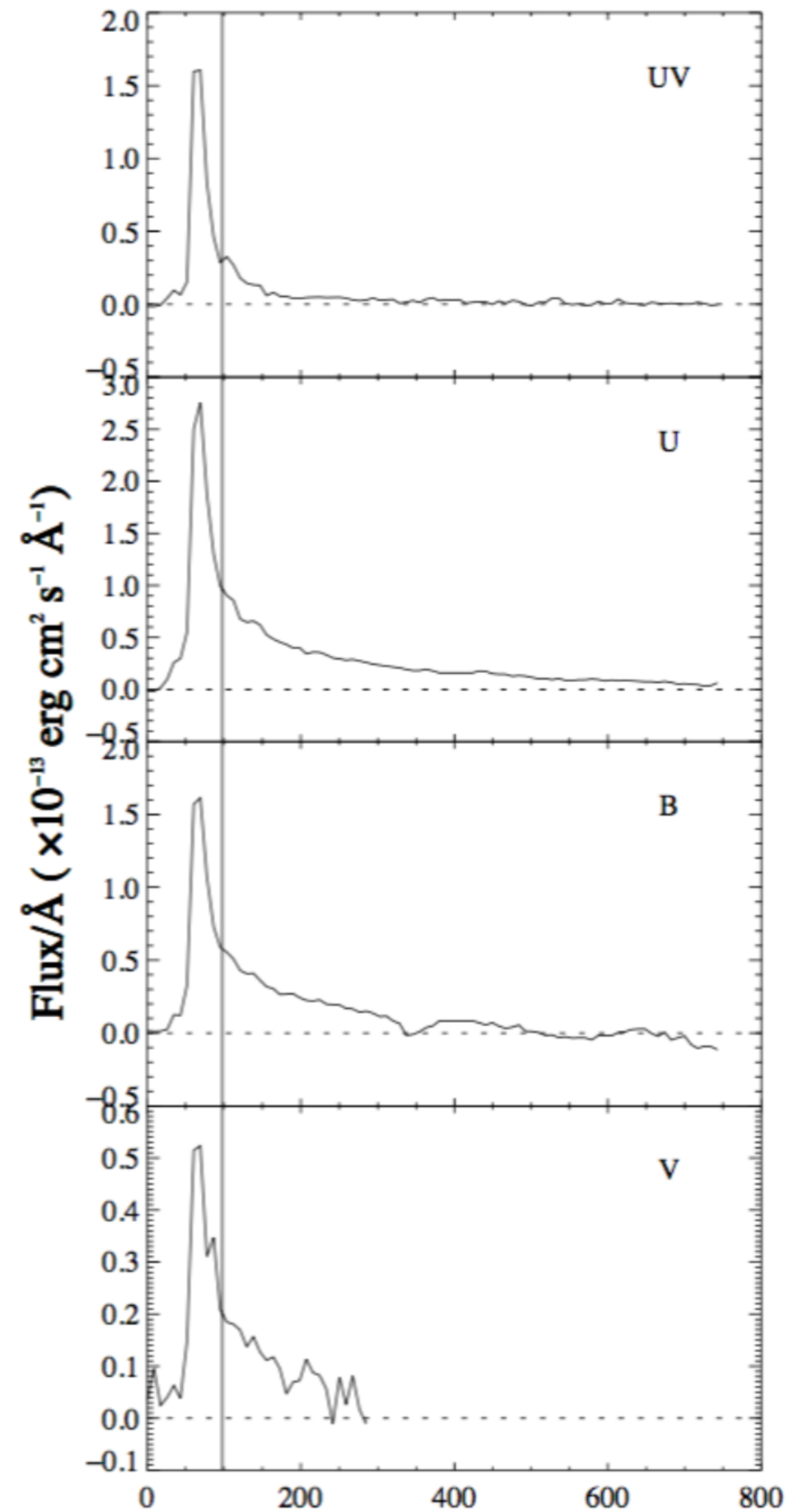



# AD Leo Flaring Star

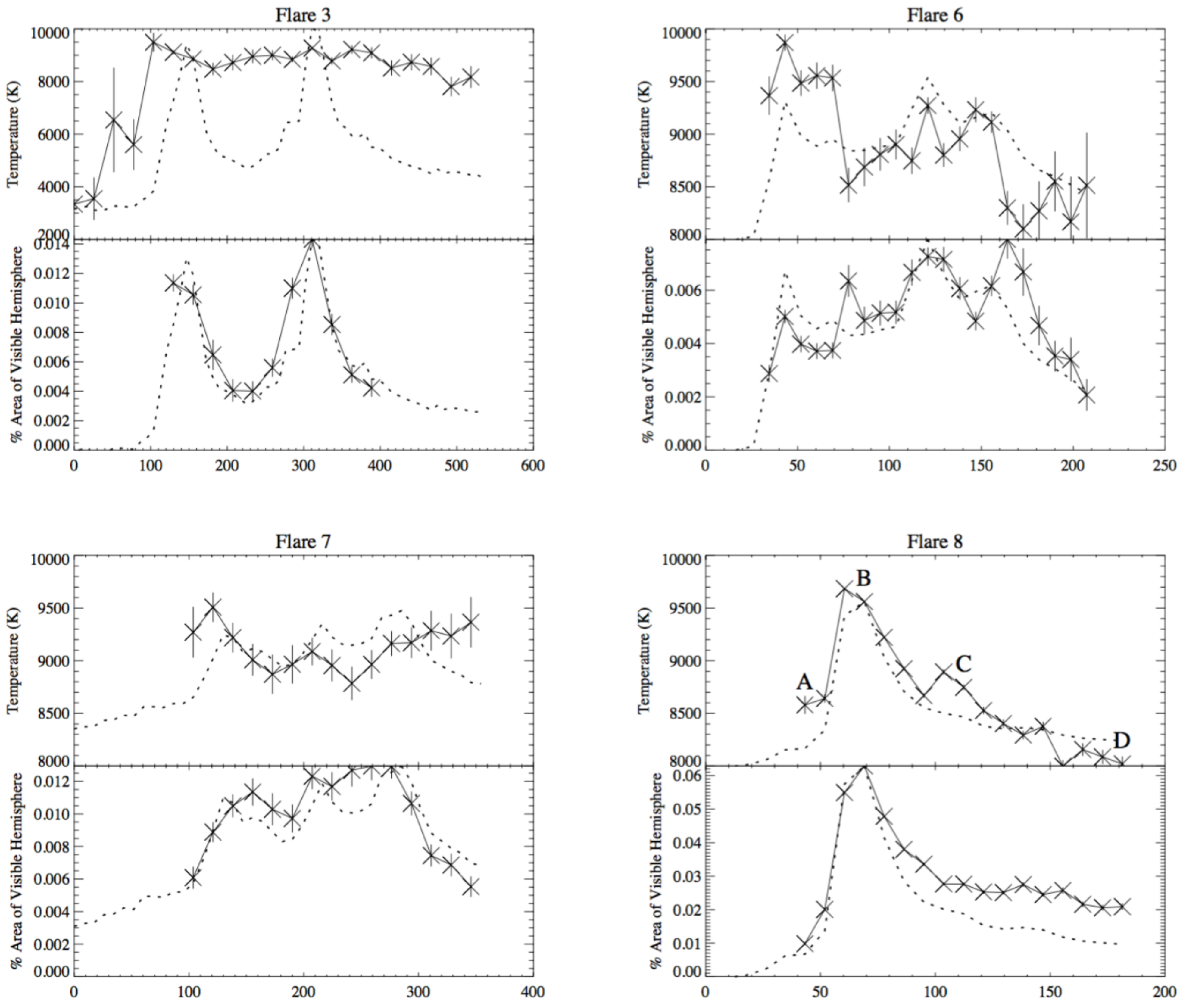
- AD Leo is one of the most active single M dwarfs in the northern hemisphere. In many aspects, flares on AD Leo resemble those on the Sun
- Photoelectric photometry in the Johnson UBVR filters was obtained with the McDonald Observatory 2.1 m Struve telescope equipped with a two-channel photometer
- AD Leo was ob-served with the primary channel, while the second channel monitored the sky conditions
- Integrations of 0.8 s in each filter, combined with 0.2 s for filter rotation, resulted in a 4 s cycle time.




Hawley +, 2003

# AD Leo Flaring Star




Hawley +, 2003

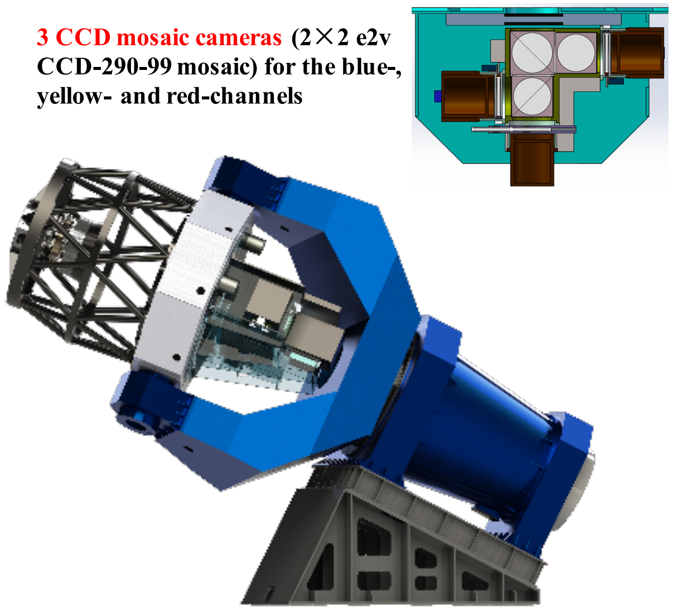
# Summary

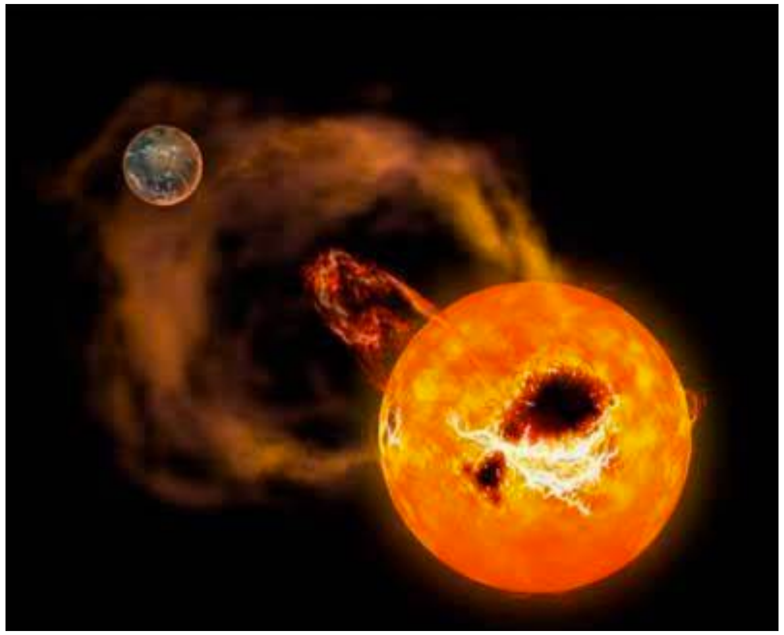
- The main features of Mephisto can be summarized as follows

$$\text{Mephisto} = \text{Survey} + \text{Real Color}$$

- Stellar flares represent a major source of transient variability in time domain surveys.

- Mephisto can provide a large sample of the properties (i.e., effective temperature, flare scale, etc.) during its survey program.



# Thank You!