M-dwarf flares in the Zwicky Transient Facility data and what we can learn from it

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07 march 2024, Voloshina Anastasiia

M-Dwarfs

Temperature: **2500 K to 3800 K**

Lifetime: **10's billion to 10's trillion years**

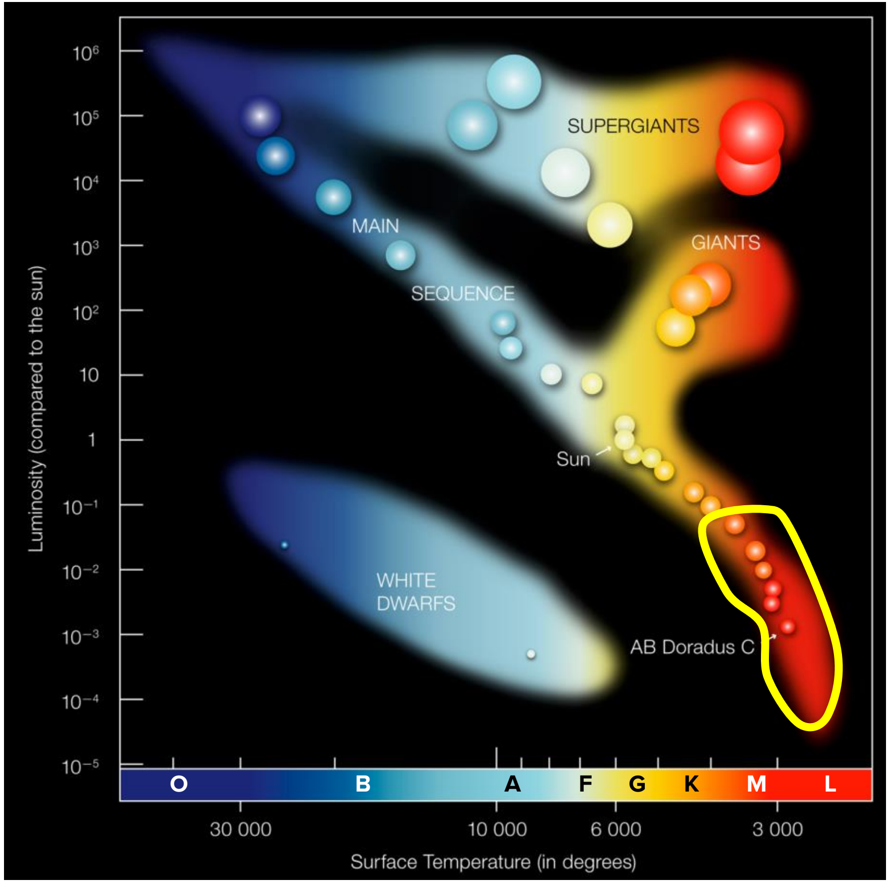
Luminosity: **0,0001 $L_\odot$ to 0,075 $L_\odot$**

Mass: **0,075 $M_\odot$ to 0,47 $M_\odot$**

The closest star to the Earth, Proxima Centauri is an M dwarf!

Spectral class represents the temperature of the star.

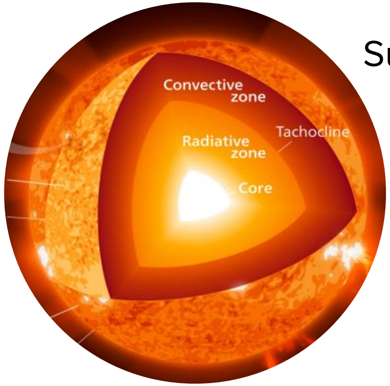
Hertzsprung-Russell diagram



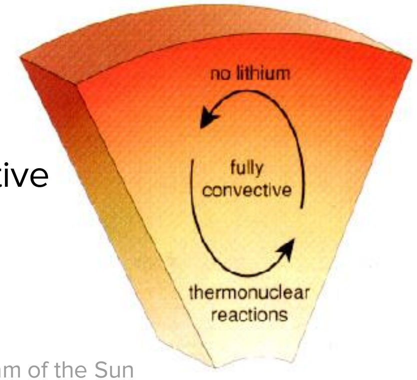
Red, dim, cold, small stars that live extremely long

ESA/Hubble & NASA, New shot of Proxima Centauri
ESO, Hertzsprung-Russell Diagram

Magnetic activity

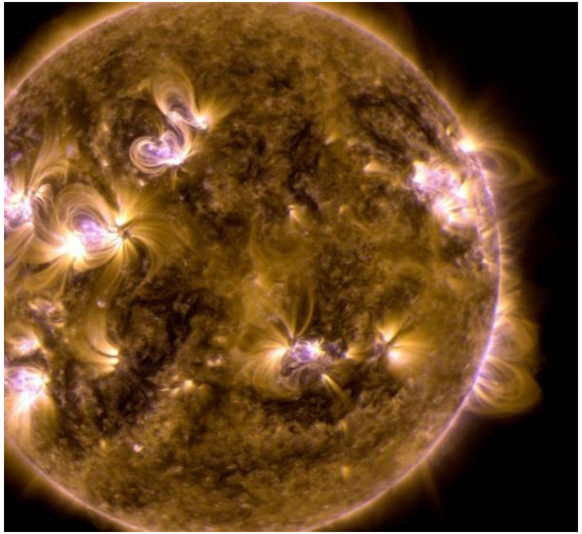


Sun-like star

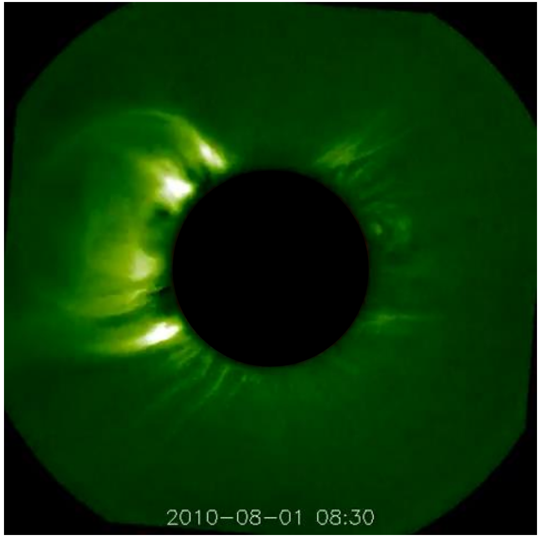


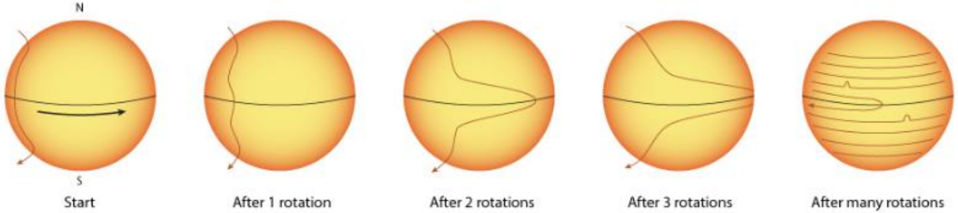
Fully convective M-dwarf

Magnetic activity cause...



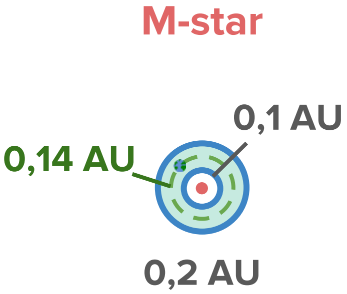
... flares!

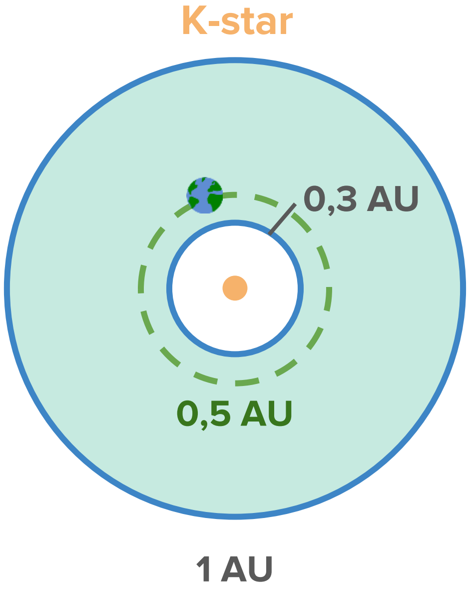


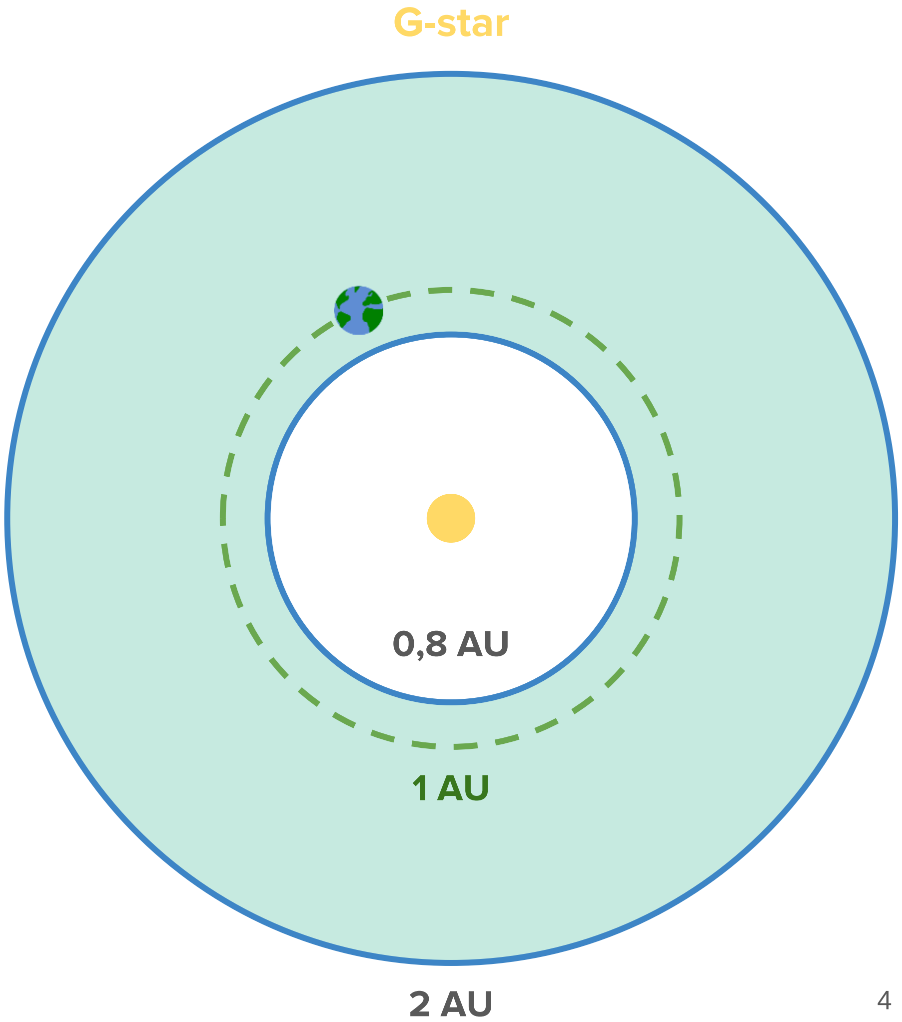


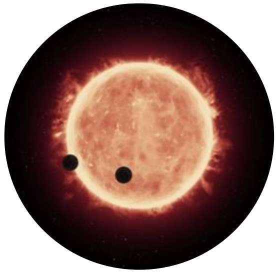
Kelvinsong, Wiki, Diagram of the Sun
SDO Gallery, Sun
NASA video, coronal mass ejections captured by the STEREO COR1
NASA / IBEX

Habitable Zone









ESA/Hubble, artist’s impression of the dwarf star TRAPPIST-1

Resume:

- M-dwarfs are **red, dim, cold, small** stars that **live extremely long**
- Their **magnetic activity is surprisingly efficient** (sunlike) for their size, and it is driven by another mechanism, so it has to be fully studied
- **Flares** – one of the markers of magnetic activity
- Flares are **transients**, that last from a few minutes to several hours
- To study **magnetic activity** of M-dwarfs and **potential habitability** of their systems we should collect **big statistics** (different spectral subtypes, rotational periods, ages, positions, distances) and find **extreme cases** (brightest, shortest, etc. flare events).

NASA, ESA and STScI, Hubble

ZTF

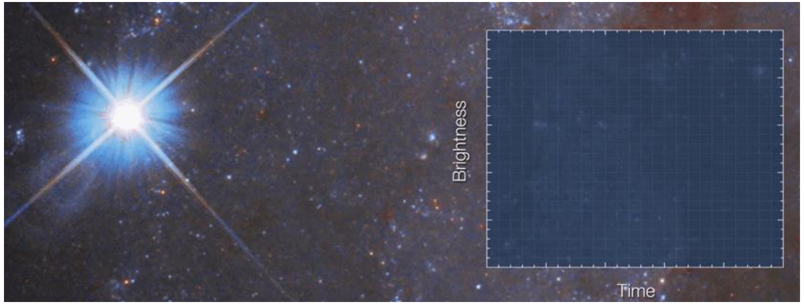
The Zwicky Transient Facility

Wide sky astronomical survey

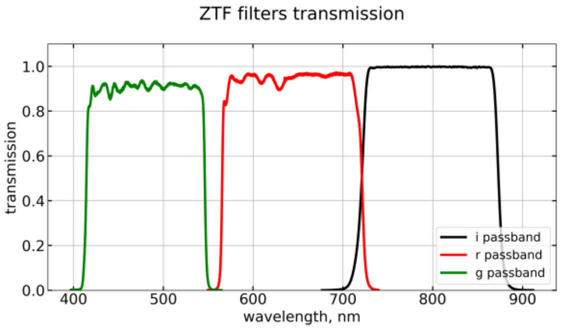
Uses a 1.22 m telescope
Field of view: 47 sq. degrees
Scans the entire northern sky

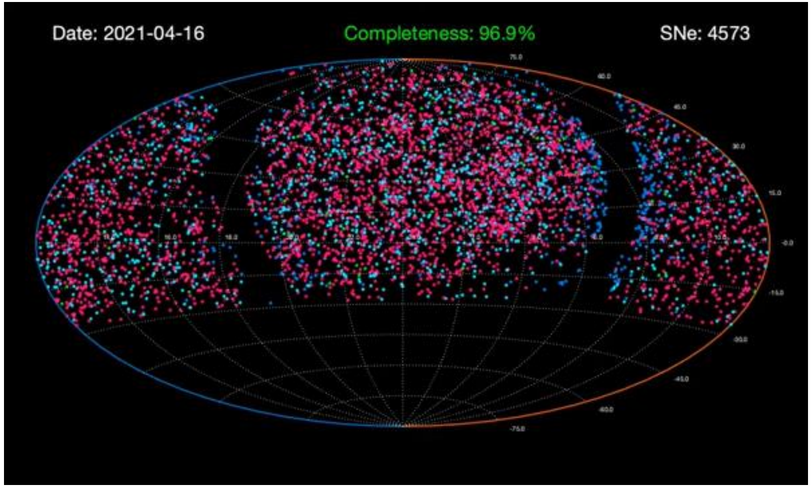
DR8

March 17, 2018 – September 3, 2021
Cadence: 1-3 days, ~ 40 sec



Example of a transient

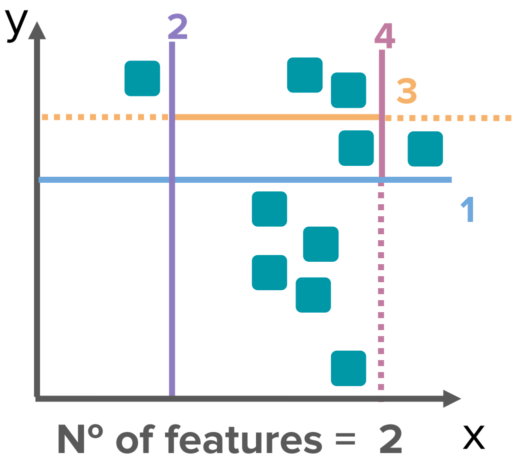


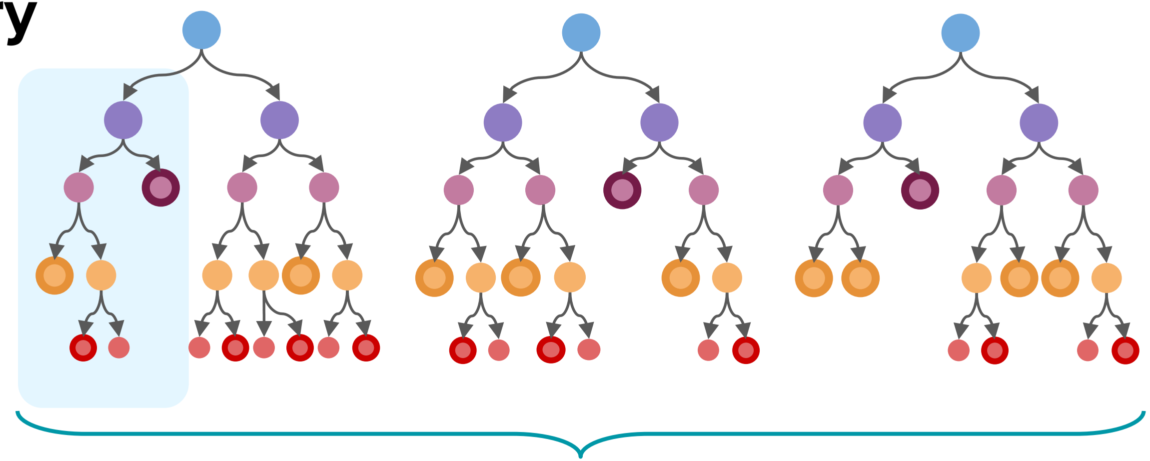


Night sky coverage

ESA/Hubble & NASA, M. Kornmesser, M. Zamani, A. Riess and the SH0ES team

Active Anomaly Discovery



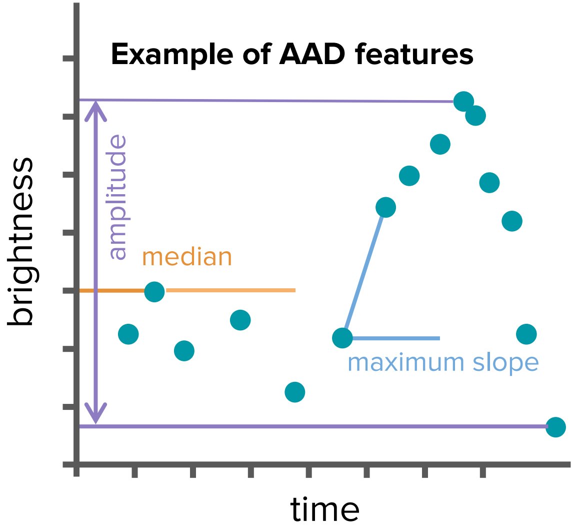


Isolation forest

Anomaly score

AAD

N° of features = 40



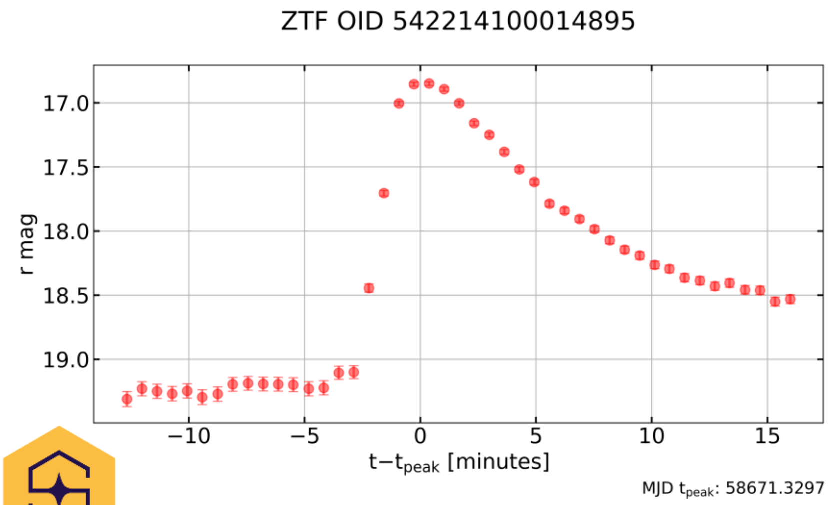
“YES”
“NO”

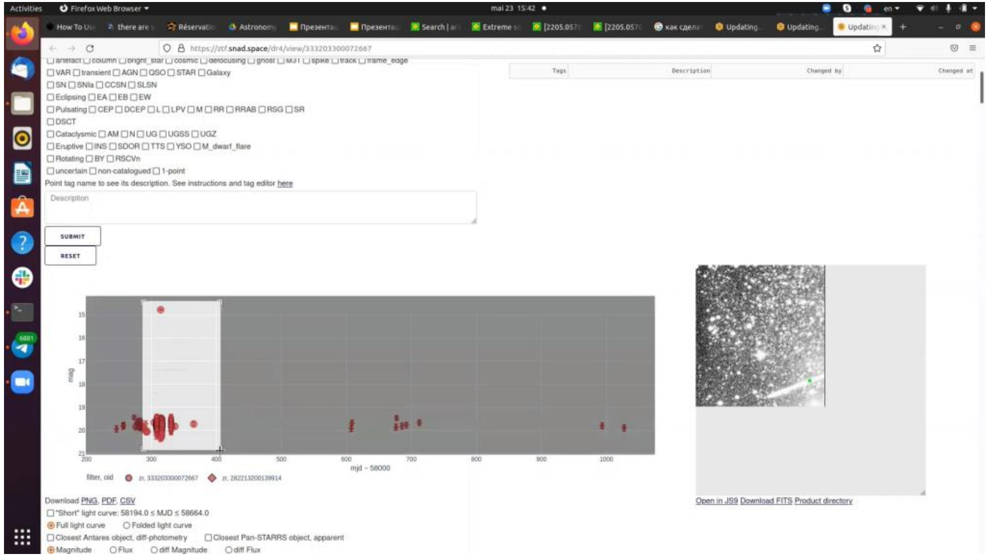
Shows to the expert

AAD flare search

An expert considered as anomaly light curves like this, taking into account the image of the object, the cross-match with other catalogs, and said “YES” only to objects like this

Initial data set: **21.5 million objects**
Visually inspected: **860 objects**
Expert said “YES”: **35 objects**

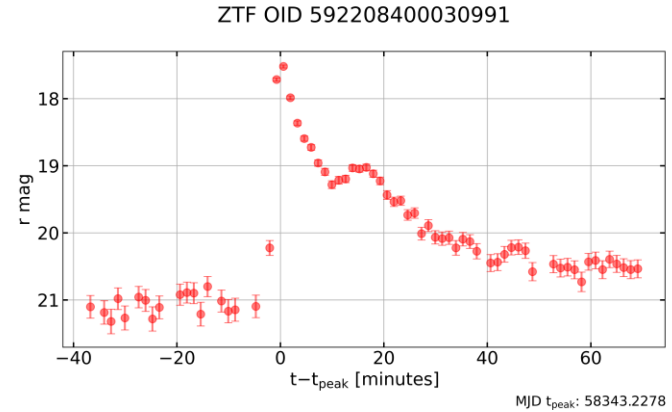


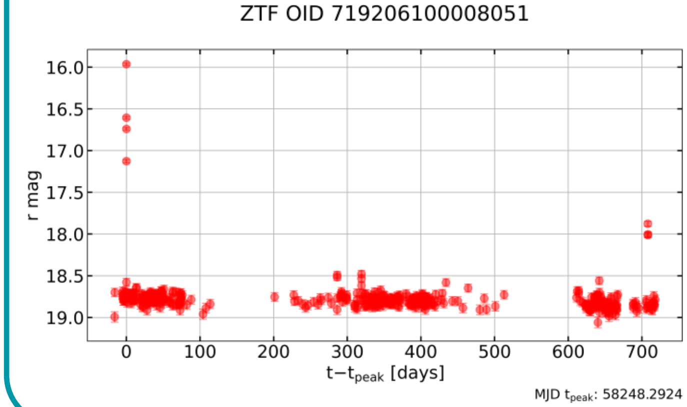


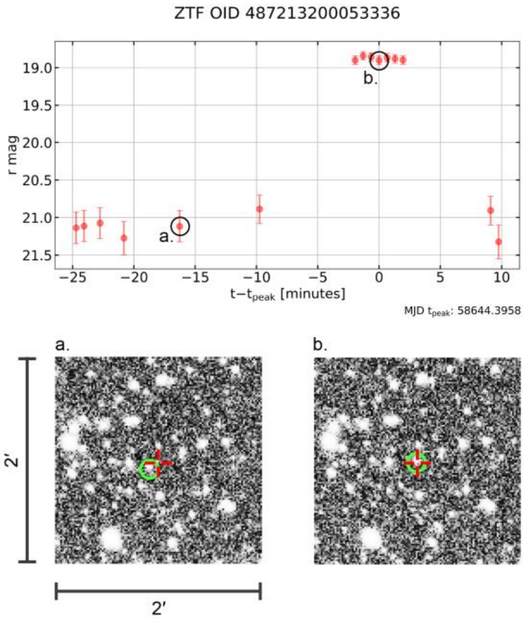
Example of the work of an expert: he said “NO”

Examples

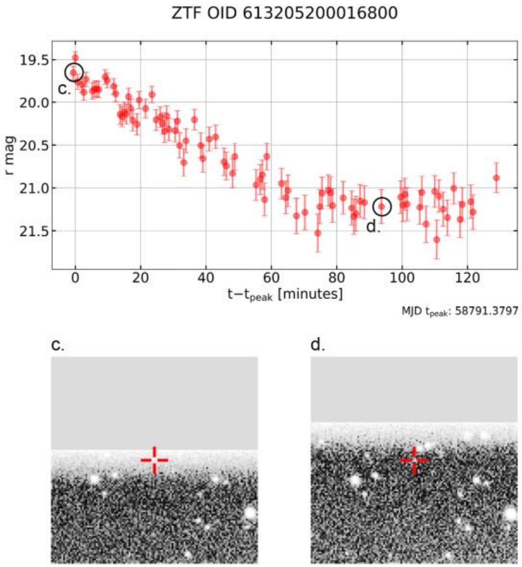
Other types of "transients"







Asteroid

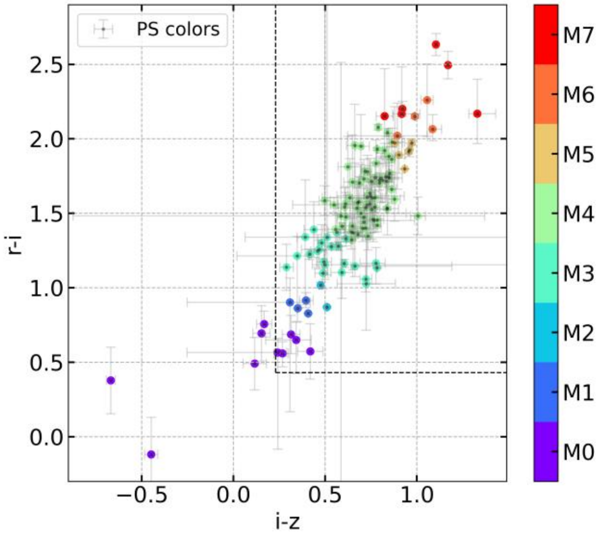


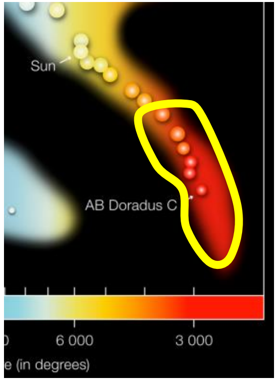
Edge of the frame

Expert said "YES"

Physical parameters

Spectral subtype





Proves that these stars are M-dwarfs.
This estimations can be used to study their distribution over Spectral classes, galactic latitude etc.

Flare energy

oid	E ×1e33 [erg]
257209100009778	$45.19\pm^{13.37}_{7.14}$
385209300066612	$26.31\pm^{14.40}_{14.96}$
412207100011243	$57.73\pm^{11.83}_{8.70}$
436207100033280	$19.13\pm^{4.52}_{3.88}$
437212300061643	$162.62\pm^{15.15}_{14.06}$
540208400015276	$11.57\pm^{4.09}_{2.59}$
542214100014895	$10.90\pm^{0.42}_{0.42}$
592208400030991	$10.49\pm^{0.91}_{0.81}$
615214400005704	$464.87\pm^{139.97}_{107.99}$
726209400028833	$28.16\pm^{0.82}_{0.76}$
768202400043820	$4.48\pm^{1.81}_{1.10}$
768211400063696	$10.17\pm^{3.20}_{4.16}$
771216100033044	$122.91\pm^{14.89}_{14.79}$

Table 1. Bolometric energy estimations for the subsample of 13 candidates for the flaring events. The upper and lower uncertainties of the bolometric energies are defined according to the uncertanties of estimation of photogeometric distances in Gaia EDR3.

ESO, Hertzsprung-Russell Diagram

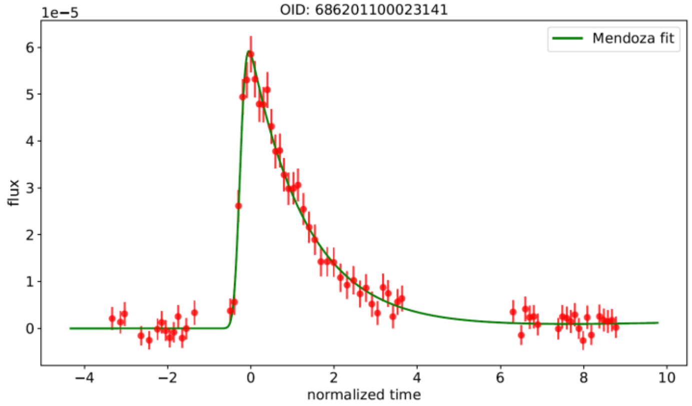
Other methods

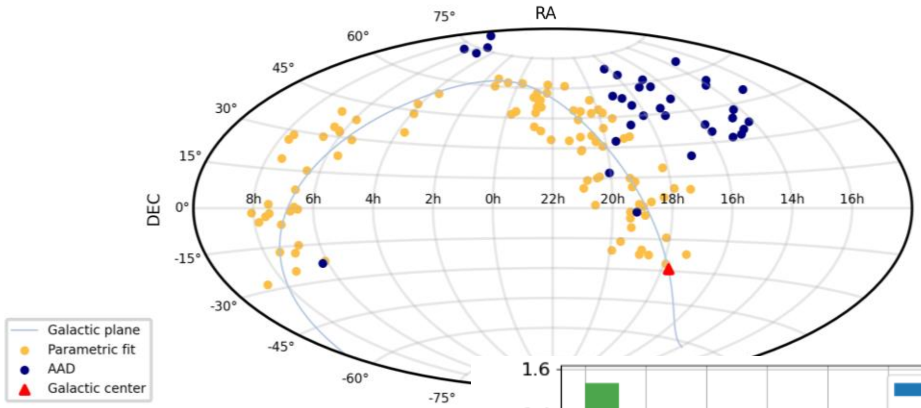
Parametric fit search

$$f(t) = f^* + \frac{\sqrt{\pi}AC}{2} \times \left(F_1\, h(t,B,C,D_1) + F_2\, h(t,B,C,D_2)\right),$$

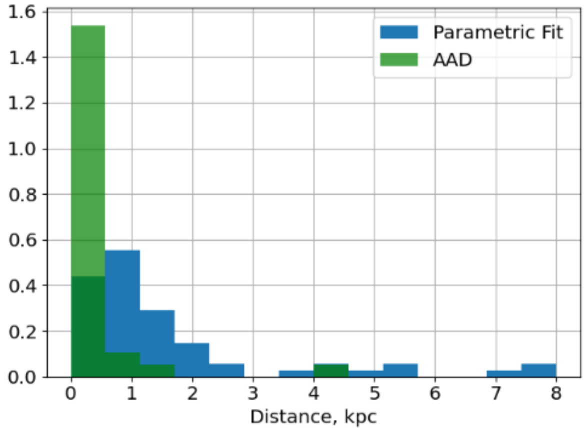
$$h(t,B,C,D) = \exp\left(\alpha CD\right) \times \operatorname{erfc}(\alpha),$$

$$\alpha(t,C,D) = \frac{B-t}{C} + \frac{1}{2}CD,$$





The spatial distribution of flaring M dwarfs



Normalized histogram of distances to M dwarfs

Data cut

High Cadence: < 30 min between observations

Duration: > 2 hours (long duration sample)

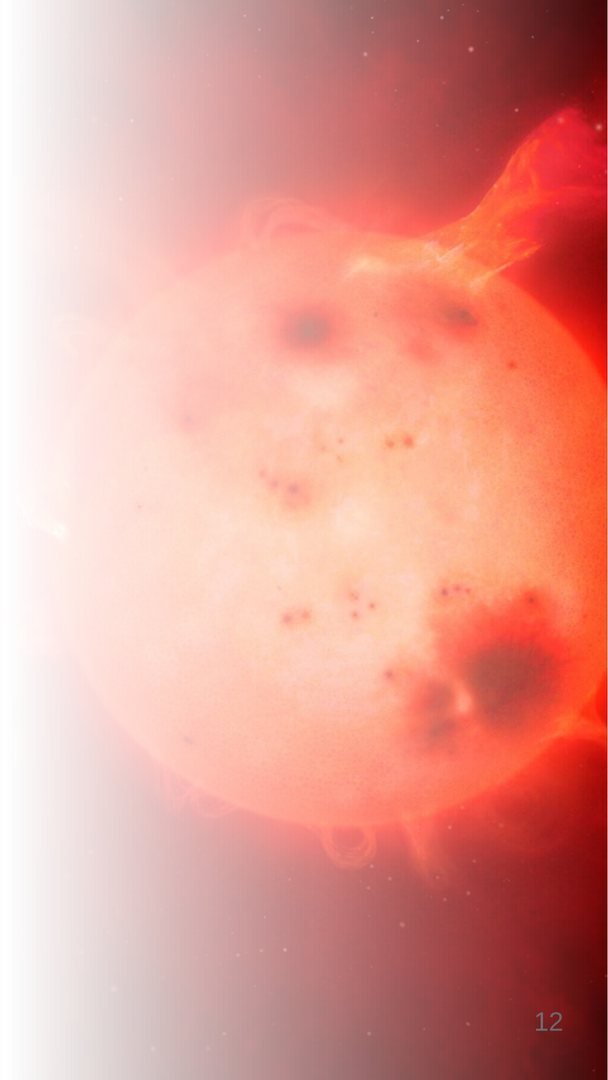
> 30 minutes (short duration sample)

- Different methods – different sky zones
- AAD let us find short distant flares, recurrent flares, the brightest one
- Parametric fit let us find dim, long-distance flares

Mendoza G. T. et al. 2022, AJ

Summary

- 126 flaring M-dwarfs were found using both, AAD and Parametric Fit methods
- Active Anomaly Discovery algorithm can be used in astronomical studies, and allows to find the chosen class of astronomical objects, if we consider them as “anomalies”
- It covers the amount of objects, that haven’t been found by standard astronomical method, and have different features such as distance, recurrence, brightness
- ZTF survey has a potential to discover a large amount of new flaring events which will have a great impact on the current research of flares’ distribution depending on evolutionary stage



University of Warwick/Mark Garlick