Where do giant flares occur on small (spectral type ≥M5) stars?

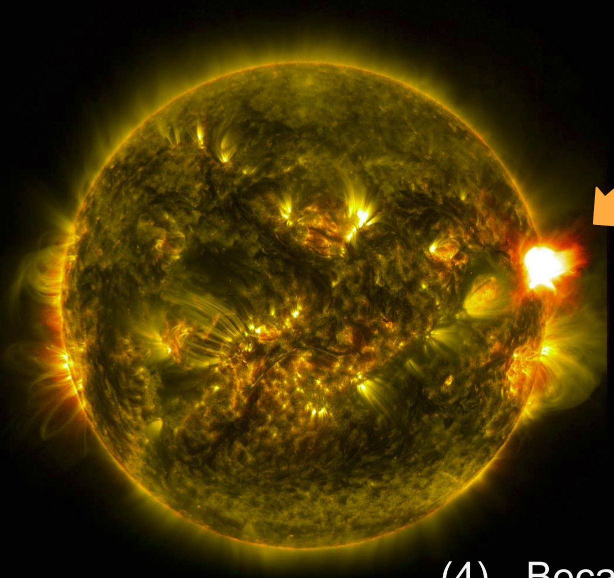
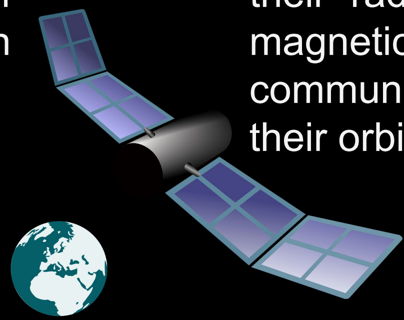


Image Credit: NASA/SDO
Last Updated: Aug. 7, 2017
Editor: Sarah Loff
SDO bands: 17.1 nm and 13.1 nm

(1) Flares are giant explosions that occur on the surfaces of stars. We can observe them in great detail on the Sun.

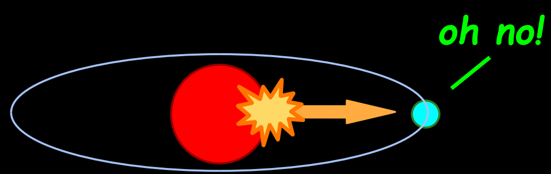


(2) If they are sufficiently intense, their radiation can stir up Earth's magnetic field, disturbing satellite communication and dragging on their orbits.

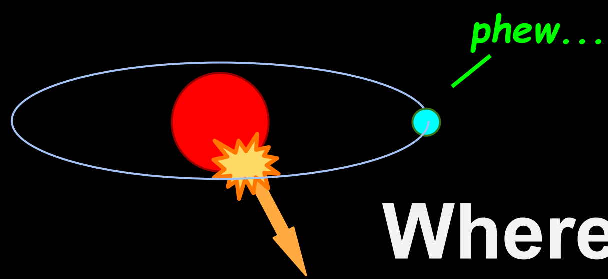
(3) What about other stars? In fact, small, red stars have strong magnetic fields that cause flares far more intense than anything we have ever seen on the Sun.

(4) Because these stars are much cooler than the Sun, their habitable-zone planets are found in orbits very close to the star, so that repeated flare radiation impact could potentially strip the planet's entire atmosphere.

(5) On the Sun, flares occur in a belt around the equator. Most flares will radiate close to the ecliptic plane, where Earth's orbit resides.



(6) But if the same flare occurred closer to the poles, an orbiting planet would receive much less radiation because most emission would be directed out of the plane.



Are these planets doomed?

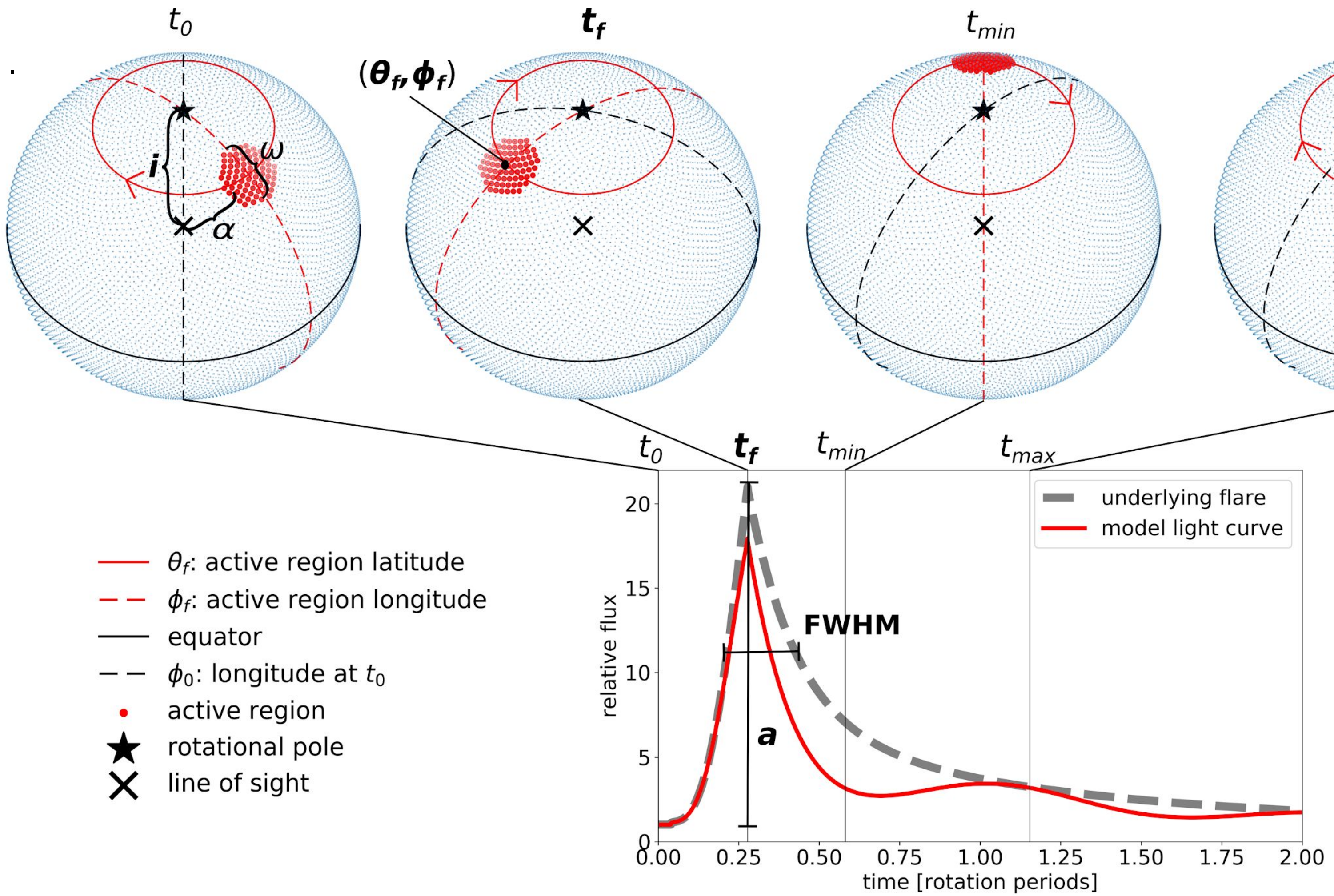
Maybe not!

Where do giant flares occur on small (spectral type >M5) stars*?

***and brown dwarfs?**

(1) In general, this is hard to tell, because we cannot resolve the stellar disk like we resolve the Solar disk.

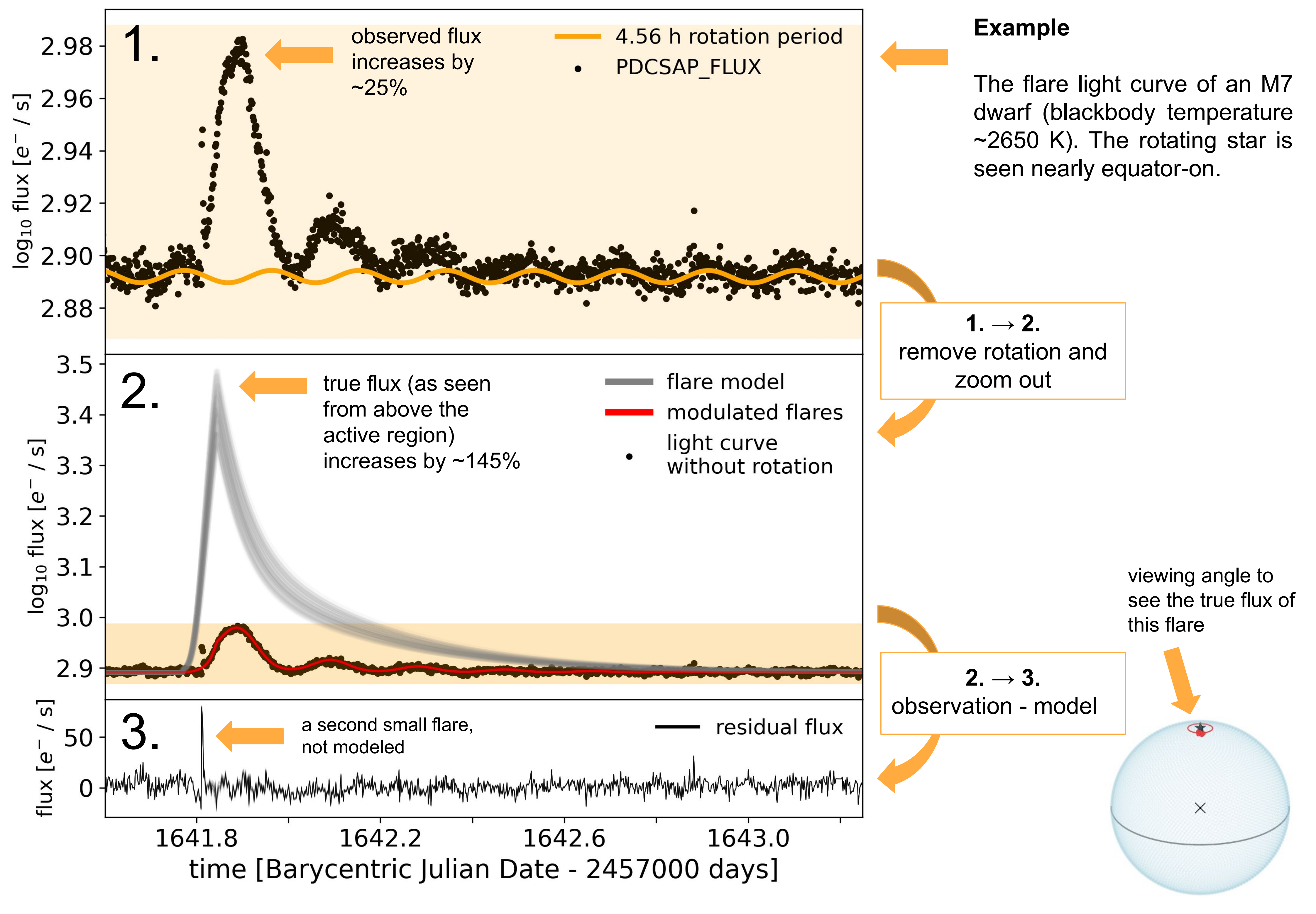
(2) However, in a lucky find in the archives of the **Transiting Exoplanet Survey Satellite** we found light curves that allowed us to determine the latitude of the flaring regions on four late-type (M6-L1) dwarfs **without the need to resolve them spatially**.



(3) The stars we studied rotate rapidly with rotation periods <12h (Sun: 25 days). They released **gigantic flares** that were visible throughout multiple rotations.

The model on the left shows how we used this information to locate the flaring region when the inclination of the rotation axis *i* was known.

Flare modulation model. From left to right, the top row shows a clockwise rotating star (blue dots) with a flaring region (red dots), from the start of observation at t_0 to the peak flare time t_f, and further to local minima and maxima of the rotational modulation. Note that these do not correspond to the minima and maxima of the observed flux (red line in the bottom panel). The angular distance between the rotational pole (black star ★) and the intersection of the line of sight with the center of the star *O* (black cross **x**) is the inclination *i*. The depicted configuration results in the observed light curve (red line) in the bottom panel. The underlying empirical flare model from Davenport et al. (2014) is shown as grey dashed line in the same panel.



Example
The flare light curve of an M7 dwarf (blackbody temperature ~2650 K). The rotating star is seen nearly equator-on.
1.
observed flux increases by ~25%
4.56 h rotation period
PDCSAP_FLUX
1. → 2.
remove rotation and zoom out
2.
true flux (as seen from above the active region) increases by ~145%
flare model
modulated flares
light curve without rotation
2. → 3.
observation - model
3.
a second small flare, not modeled
residual flux
viewing angle to see the true flux of this flare
log10 flux [e− / s]
flux [e− / s]
time [Barycentric Julian Date - 2457000 days]
2.88
2.90
2.92
2.94
2.96
2.98
2.9
3.0
3.1
3.2
3.3
3.4
3.5
0
50
1641.8
1642.2
1642.6
1643.0

Main result:

Flares on four late-type ultrafast spinning dwarfs occurred much closer to the poles (>45°) than typical flares on the Sun (<30°).

Table of results below: SpT - spectral type. i - inclination of the stellar rotation axis. θ_f - flaring region latitude. E_f - flare energy in erg. For comparison: the largest known flare on the Sun, the famous Carrington event, released about 5×10^{32} erg (Cliver & Dietrich 2013).

SpT	i [deg]	θ_f [deg]	E_f [erg]
M7	87	$82.1\pm^{0.4}_{0.5}$	$3.2\cdot10^{34}$
M6	33	>70	$2.2\cdot10^{33}$
M5	21[1]	$58.5\pm^{0.3}_{0.6}$	$8.6\cdot10^{34}$
L1	57[2]	$46\pm^{12}_{14}$	$3.3\cdot10^{32}$

[1] Kraus et al. (2014) [2] Gizis et al. (2013)

Contributing authors:

Ekaterina Ilin[1,2,*], Katja Poppenhäger[1,2], Sarah J. Schmidt[1], Silva Järvinen[1], Mahmoud Oshagh[3,4]

[1]Leibniz Institute for Astrophysics Potsdam (AIP),
[2]University of Potsdam
[3]Instituto de Astrofísica de Canarias (IAC)
[4]Departamento de Astrofísica, Universidad de La Laguna (ULL)
*email: eilin@aip.de

Conclusions

Flares happen where strong magnetic fields emerge on the stellar surface. Surface magnetic fields on fully convective stars have so far been mostly studied using spectroscopy, and spectropolarimetry of atomic and molecular lines. Only a handful of magnetic maps exist for these spectral types.

While our technique relies on serendipitous observations of large flares in optical light curves, we expect that the Transiting Exoplanet Survey Satellite mission (Ricker et al. 2015) alone will collect 1-5 such events per year of observation, which will allow us to consolidate or revise the trend that megaflares occur at high latitudes in fully convective ultrafast rotators.

Multi-period flares put important constraints on dynamo models for fully convective stars, and the loci bear noteworthy implications for the impact of flaring activity on exoplanets in their orbits.