FLARES OF M STARS IN THE UPPER SCORPIUS REGION AND FLARES/CMES OF THE ACTIVE M-STAR AD LEO

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Abstract. Using *Kepler K2* data, we studied the flare activity of young K and M stars in the Upper Sco region and found that they have 10000–80000 times as many super-flares with ($E \geq 5\,10^{34} erg$) than solar-like stars. The power-law index for flares is $dN/dE \sim E^{-1.2}$ for K-stars, $dN/dE \sim E^{-1.4}$ for early M-stars and $dN/dE \sim E^{-1.3}$ for late M-stars, which is about the same as for the Sun. We also observed the active star AD Leo.

1 Low-mass planets, flares and CMEs of M-stars

Searching for planets around M-stars has recently become fashionable because it is relatively easy to detect low-mass planets in the so-called habitable zone (HZ) of these stars. However, planets in the HZ of M-stars are exposed to radiation from flares and to Coronal Mass-Ejections (CMEs). A large flare and CME rate could be critical, because the X-ray and UV-radiation from flares together with the CMEs might erode a planetary atmosphere. In less extreme cases, flares and CMEs still affect the photochemistry of the atmospheres. Particularly important are the first few 100 Myrs, which is the main erosion phase of planetary atmospheres. This presentation gave the first result of our study of flares and CMEs on young M stars.

2 Flares on M stars in Upper Scorpius

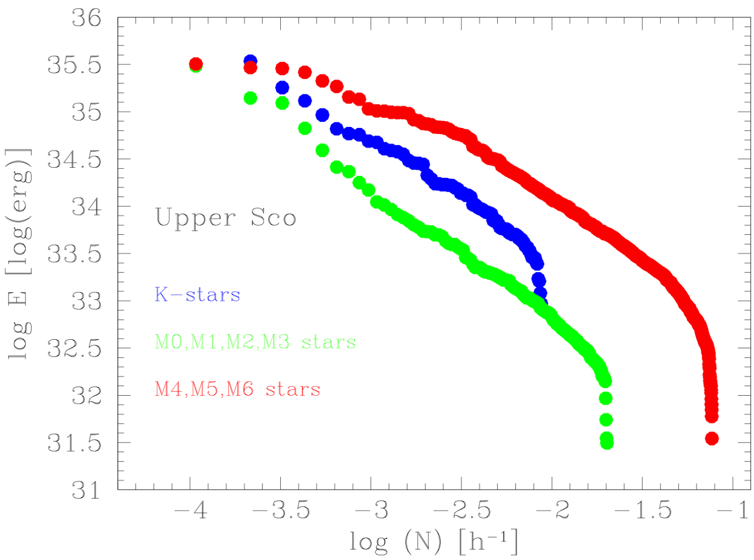

Fig. 1. Cumulative frequency diagram for K and M stars in Upper Sco.

Using light-curves obtained from *Kepler K2* data, we studied the flare activity of M stars in the Upper Scorpius OB association, which has an age of 6–11 Myr (Fang et al. 2017). At that age planets will just have

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formed, and should be in the main erosion phase of their atmospheres. About 100 M stars in Upper Sco have been observed, but we focus here on those 41 stars which we confirmed as being members according to VLT-FLAMES spectra. Of those, 5 are K stars, 17 are early M stars (M0–M3) and 19 are late M stars (M4–M6). One particularly remarkable case is the M1 star 2M161115.3-175721, where we detected 138 flares during the 78 days of monitoring. The radius of this star is 1.30 R_{sun}, and its mass 0.85 M_{sun}. 2M161115.3-175721 will eventually become a late-G or early-K star. Its X-ray brightness is log(Lx) = 30.2 log(ergs^{-1}) and it has a rotation period of 6.03 days. For comparison, the Sun has log(Lx) = 26.4–27.7 log(ergs^{-1}), while the value for solar-like stars in the Pleiades is 29.1–29.6 log(ergs^{-1}) (Giardino et al. 2008). The X-ray flux thus is 300–6000 times larger than that of the Sun. The largest flare emitted $3.3\,10^{30}$ erg in the *Kepler* band (4200–9000 Å), and the smallest one 10^{27} erg.

Summing up the observing times for all stars in each class, we monitored K stars for 9273 hours (1.01 years), early M stars for 31527 hours (3.6 years), and late-M stars for 35236 hours (4.0 years). We detected 81 flares in K stars, 711 in early-M stars and 188 in late-M stars. The power-law index of the distribution was $dN/dE \sim E^{-1.2}$ for K stars (log(E) = 33.8–35.5), $dN/dE \sim E^{-1.4}$ for early M stars (log(E) = 32.4–34.2), and dN/dE $\sim$ E$-^{1.3}$ (log(E)33.2–35.0 log(erg)) (Fig. 1). For comparison the Sun has dN/dE $\sim$ E$^{-1.5}$ for flares (Crosby et al. 1993), and $dN/dE \sim E^{-1.8}$ for nanoflares (Aschwanden et al. 2000). Flares larger than $5\,10^{34}$ erg are usually called super-flares. Compared to solar-like stars, the rate of super-flares was 20000 times greater for the K stars in Upper Sco, 80000 times greater for the early-M stars, and 10000 times greater for the late-M stars (Notsu et al. 2019).

3 The frequency of coronal mass ejections in AD Leo

Coronal Mass Ejections (CMEs) can be detected in stars as blue-shifted components in the spectrum that have velocities larger than the escape velocity of the star. For our study, we selected the M4 star AD Leo, which has an age of 20–300 Myr. The escape velocity from this star is 580 km s^{-1}. We observed it for 222 hours with the echelle spectrograph of the 2-m Alfred Jensch Telescope in Tautenburg, and detected 22 flares. The largest of them emitted $2.9\,10^{31}$ erg in Hα and $1.8\,10^{32}$ erg in $H\beta$. We estimated the XUV-flux to be about $2\,10^{33}$ erg for this flare from the Hα and $H\beta$ fluxes. If M stars have the same CME-to-flare ratio as the Sun, we expect to see a number of CMEs with masses up to $2 - 3\,10^{17}$ g. So far we have not detected a blue-shifted component with $V \geq 600 km\,s^{-1}$, but we did observe velocities up to 200 km/s. It thus looks as though the frequency of CMEs on AD Leo is lower than expected, unless they escaped detection through having a very high velocity.

4 Summary and conclusions

- Young K and M stars have 10000–80000 times as many super-flares ($E \geq 5\,10^{34} erg$) as solar-like stars.
- This enormous activity will certainly affect the evolution and habitability of M-star planets.
- The power-law index for flares was found to be $dN/dE \sim E^{-1.2}$ for K-stars, $dN/dE \sim E^{-1.4}$ for early-M stars and $dN/dE \sim E^{-1.3}$ for late-M stars, which is about the same as that for the Sun.
- We observed AD Leo spectroscopically for 222 hours to search for CMEs. A total of 22 flares was observed, but none showed a clear CME signature.

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