Upper limits on the CME frequency of solar-like stars

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Abstract

In the last years efforts have been made to determine parameters of stellar coronal mass ejections (CMEs), on the one hand via acquiring dedicated observing time at telescopes and on the other hand via searching data archives. Here we present a search for CMEs on solar-like stars using optical spectroscopic data from the Polarbase and ESO HARPS Phase 3 archives. For detecting stellar CMEs we use the signature of filaments/prominences being ejected from a star, which is Doppler-shifted emission/absorption occurring on the blue side of Balmer lines, as filaments/prominences are very pronounced in Balmer lines. Using more than 3700 hours of on-source time of 425 stars we aim for a statistical determination of CME parameters, such as projected velocity, occurrence frequency, and mass. The target stars are nearby objects and consist of F-K main-sequence stars of various ages. We find no signature of CME activity and a very low level of flaring activity (10 out of 425 stars). Comparing this to results from the Kepler mission, the fraction of flaring stars is more or less consistent. Comparing extrapolated Hα flare rates to the sparse detection of flares reveals that we could have detected more flares. We therefore determined the full-disk Hα signal of one of the strongest solar flares in the last solar cycles. This showed that we would have needed data with higher S/N to detect such a flare in our data. Finally, we compared the observed upper limits of CME rates of our target stars to modelled CME rates. The modelled CME rates are mostly below the observationally determined upper limits, indicating that most on-source times per star were too short to detect stellar CMEs with this method. The sparse detection of flares and the non-detection of CMEs may be explained by biases naturally introduced by using archival data, as well as a a low level of activity of the target stars. We conclude with a short report on ongoing and future activities of the search for stellar CMEs.

1. Idea, data, approach, and target sample

The knowledge of stellar CMEs is still poor after already a number of recent attempts using signatures of solar CMEs in the radio domain, as well as using the direct signature of mass being ejected from a star at X-ray and optical wavelengths [6]. To explore further possibilities and to focus on solar-like stars we aimed at exploring the data archive of the High Accuracy Radial velocity Planet Searcher (HARPS) on the 3.6m telescope in La Silla of the European Southern Observatory (ESO) together with the Polarbase archive hosting observations from the Echelle Spectro Polarimetric Device for the Observation of Stars (ESPaDOnS) instrument installed on the 3.6 m Canada-France-Hawaii Telescope (CFHT) and the Narval instrument installed on the 2.0 m Telescope Bernard Lyot. Solar-like stars have yet not been the focus of CME investigations. We use the well known approach of identifying spectral asymmetries appearing in emission/absorption being the signature of erupting prominences/filaments if ejected with velocities being larger the star's escape velocity.

In both archives we find data of 425 stars of spectral types ranging from F to K. The majority is of spectral type K (56%), followed by G (37%) and F (7%), the sample has no restriction on age and includes therefore young and old solar-like stars. The observations result in a total on-source-time of more than 3700 hours. All spectra are available in already reduced form.

2. Flares and CMEs

Although the amount of analysed data is large we identfied only 11 flares, either identified from the typical shape of flare light curves built from extracted Hα pseudo equivalent widths (2Å wide window centered on Hα) or from deviations $>5\sigma$ from the mean of the light curve of the corresponding star. Accordingly we derive flare incidences of 1% for K-stars, 3% for G-stars and 10% for F-stars (being of low significance due to a small F-star sample). Comparing those incidences with those derived from Kepler data, our derived values are within the incidences given in [2], [8], and [9], but keeping in mind that Kepler observations are broad-band observations and we have constructed very narrow-band light curves.

Moreover, comparing these very low flare rates to the flare power-law given in [1], constructed from stellar EUV observations, our derived flare rates and upper limits are well below those predictions. Ofcourse, flares are more pronounced at shorter wavelengths, therefore we constructed from the power-law by [1] an Hα equivalent making it more realistic to compare. Based on the formulation in [1] we used the Balmer decrement as well as a relation of X-ray and Hγ flare luminosities [4, 3]. As those relations were obtained from data covering different wavelength ranges than the one from [1] we introduced additional correction factors (for details see [5]) which finally result in a relation of daily flares with energies $> 10^{32}$erg in Hα and the XUV domain (see Eq. 1, Fig. 1), dependent on the flare power law index α and a conversion factor c which needs to be larger than 1 (therefore the relation gives upper limits only):

$$\frac{N_{\mathrm{H}\alpha}(E > 10^{32}\ \mathrm{erg})}{N_{\mathrm{XUV}}(E > 10^{32}\ \mathrm{erg})} = (c \times 37.9)^{1-\alpha} \tag{1}$$

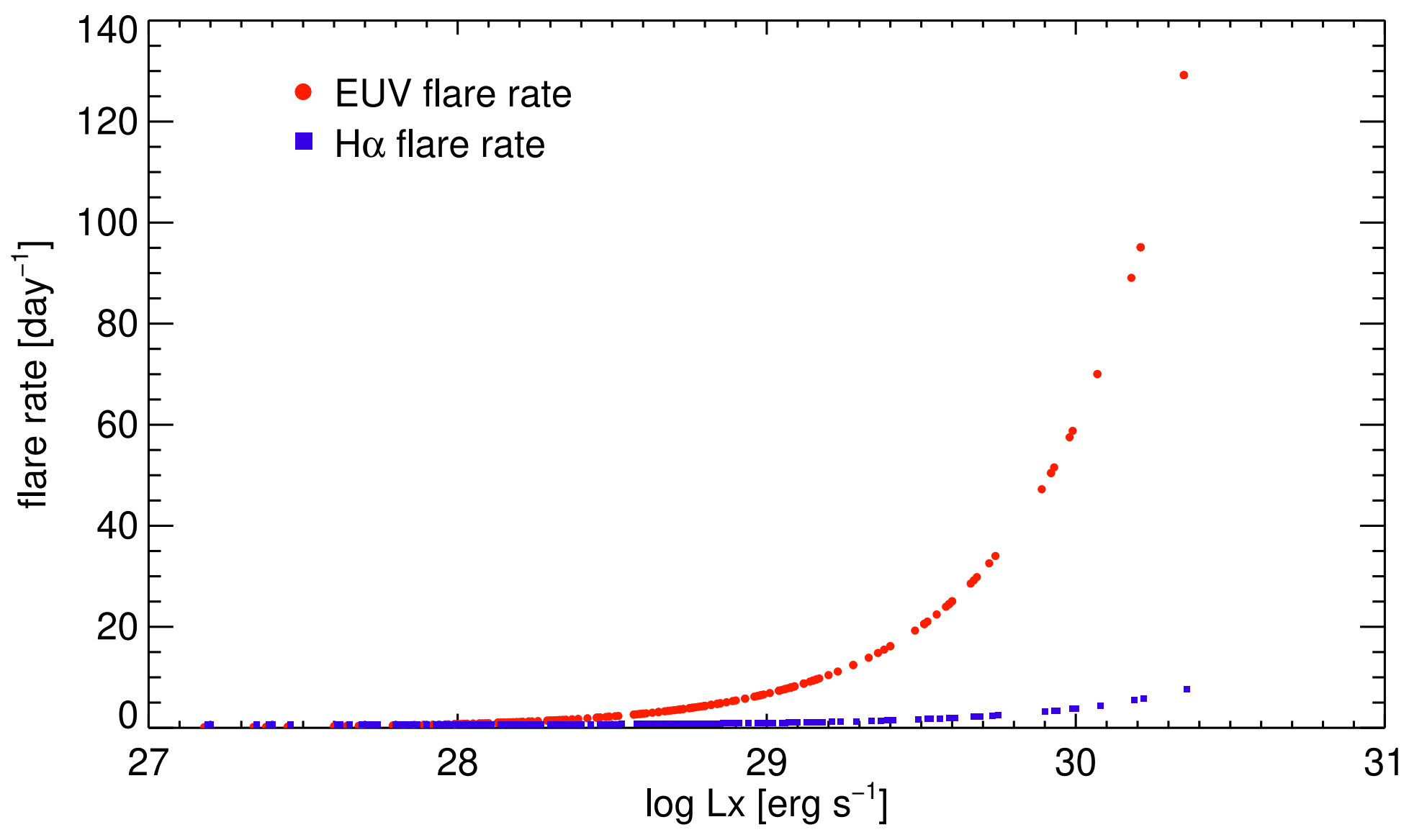

Figure 1: *Flare rates of the target stars predicted from [1] (red dots) derived from stellar EUV observations and from Eq. 1 (predicted Hα flare rates.)*

To see if one of the strongest solar flares (we selected the 4th November 2003 event) would have been detectable in the used observations we examine its flare enhancement and find it to be 2.25mmag, deduced from Big Bear Solar Observatory (BBSO) observations. In Fig. 2 we plot signal to noise (S/N) versus flare enhancement in mmag. As one can see the detection of an equivalent of the 4th November 2003 solar flare would have required a much higher S/N.

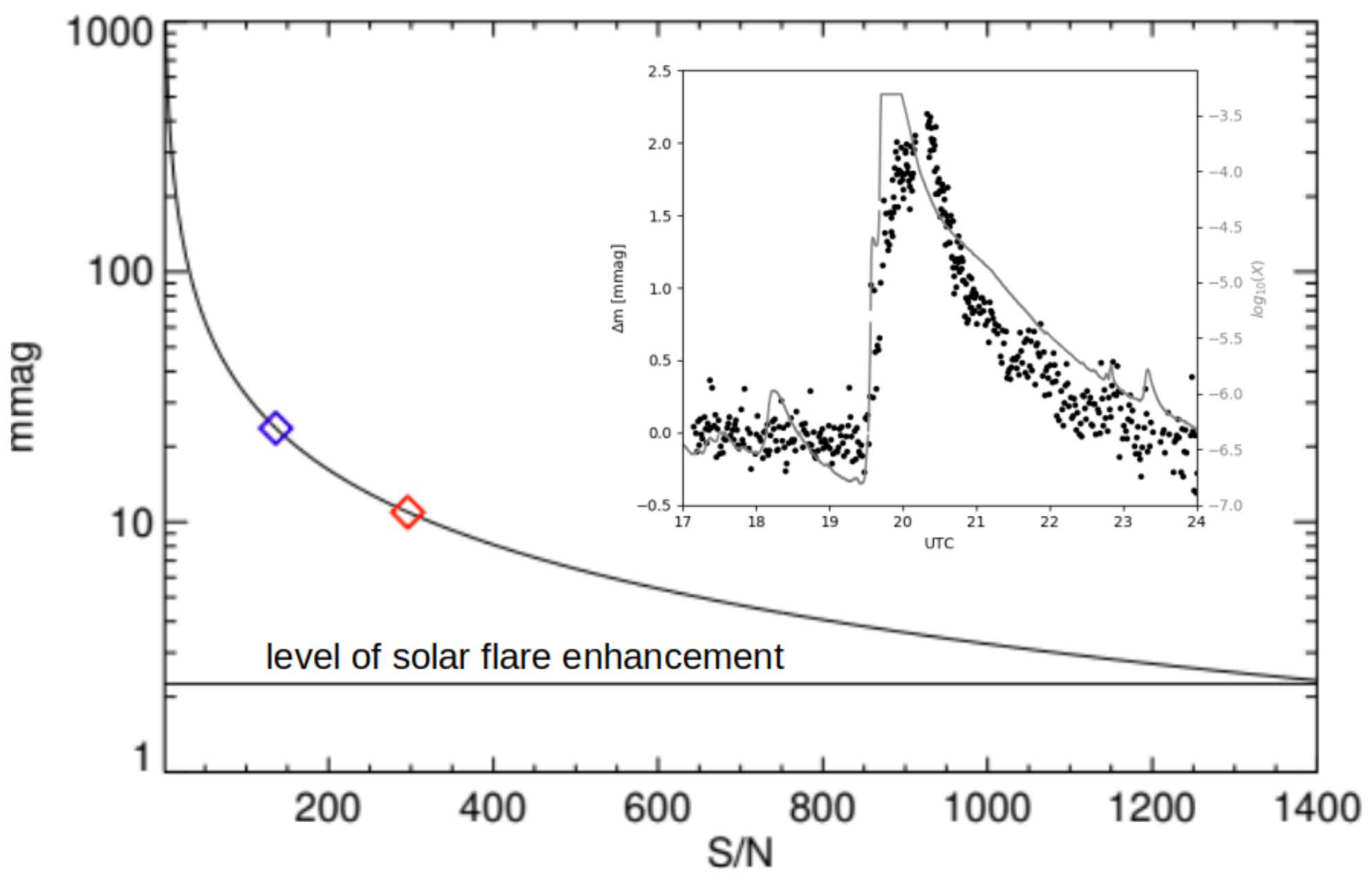

Figure 2: *S/N versus flare enhancements in Hα. The blue and red diamond symbols denote the mean S/N values of the HARPS and Polarbase data. Also shown is the BBSO Hα lightcurve (black dots) of the solar flare from 4th November 2003, overplotted with the GOES X-ray lightcurve (grey solid line, arbitrarily shifted to match the Hα quiet level).*

As we found no signatures of stellar CMEs, i.e. no extra emissions/absorptions occurring on the blue side of Hα we calculate upper limits of the CME rates only. We further compare the observed upper limits to predicted CME rates from [7]. In Fig. 3 we plot on-source time versus CME rate [day^{-1}]. The grey shaded area denotes the upper limits derived from this study whereas the black dots denote the maximum observable CME rates of the target stars using the model of [7]. As one can see, most of the predicted CME rates are well below the observational upper limits, only for 11 stars we could constrain the CME predictions from [7].

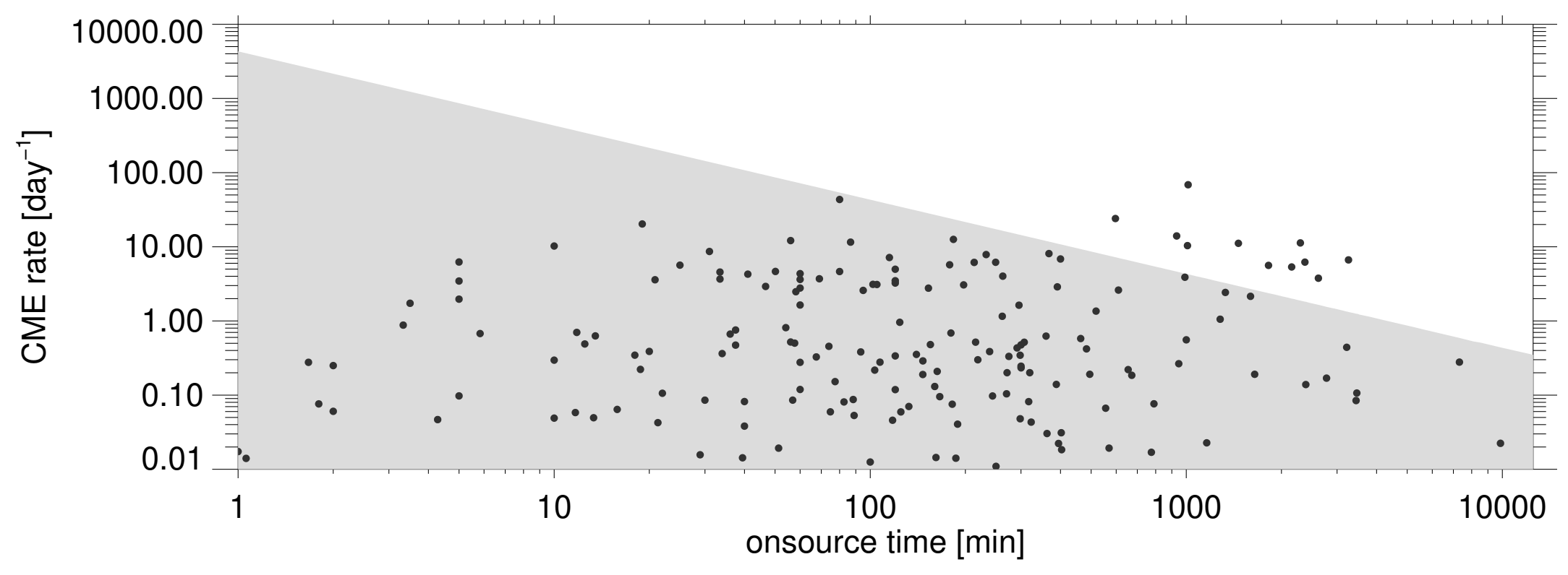

Figure 3: *On-source time versus stellar CME rate. The grey shaded area denotes the observational upper limits. The black dots denote maximum observable CME rates obtained from modelling [7].*

3. Conclusions and future perspectives

Although we found no stellar CMEs, the upper limits give important insights in the CME activity of solar-like stars. With the S/N of the HARPS and Polarbase data we could have detected stellar CMEs with masses of the upper solar CME mass distribution (10^{17}g) or above. What can not be ruled out using the method of Doppler shifted emission/absorption is ionization of ejected plasma (the sooner it gets ionized the less we see in excited hydrogen), Doppler dimming, a phenomenon affecting moving clouds, as well as projection effects. Moreover, the target selection as well as the observational parameters (mainly S/N) may have an additional influence on the results.

What can be finally concluded from our study is that massive CMEs are probably rare on solar-like stars and Hα flaring regions need to be much larger than their solar counterparts to be seen in stellar Hα spectroscopy.

An observational approach which is lacking so far in conjunction with the Doppler shifted method to detect stellar CMEs is long term monitoring of selected stars. Since few years we run an observing project on CME detection on bright solar-like stars (e.g. π^1 UMa, χ^1 Ori, etc.) at the Observatory Lustbühel Graz (OLG) using its 0.5m telescope together with moderate resolution spectroscopy. With this setup we are also able to catch massive CMEs only.

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