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The CN Leo flare census

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Abstract

We investigate the frequency and amplitude distribution of flares on the actice M dwarf CN Leo observed simultaneously in coronal X-rays, chromospheric line emission, and the photospheric optical continuum. We find that most of the larger events are visible in all atmospheric layers, these are equivalent to solar white light flares. Several smaller events are only visible in the chromospheric lines, which corresponds to solar H-alpha flares. One event is very strong in X-rays, but only weak in the chromospheric lines and invisible in the photospheric continuum, indicating a rather large scale height of the flaring loop. We find no obvious correlation of the flare amplitudes and decay times in the different atmospheric layers. We also search for time delays between the different wavelength bands and probe the occurrence of the Neupert effect.

Observations

- 112 ks of data in six XMM-Newton observations (1x May 2004, 2x December 2005, 3x May 2006)
- simultaneous optical photometry and high-resolution spectroscopy with VLT/UVES

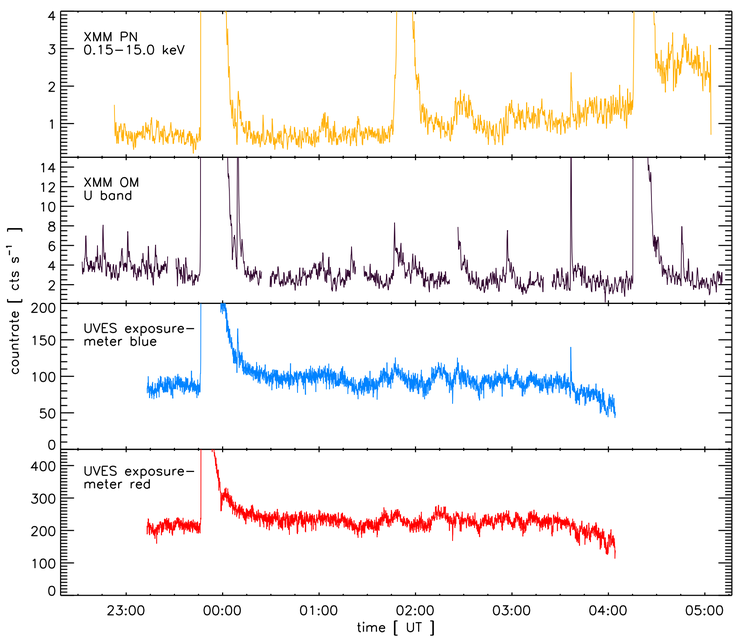


Figure 1: Multiband photometry of CN Leo, 19/20 May 2006.

Three large flares in X-rays in the observation on 19/20 May 2006:

- A giant flare at 23:45 UT (Schmitt et al. 2008; Fuhrmeister et al. 2008; Liefke et al. in preparation)
- A second strong event at 1:45 shows an enigmaticly symmetric X-ray lightcurve with a rise phase slightly longer than the decay (see Fig. 4b) and exhibits comparably weak signatures at optical wavelengths, indicating that the flare does not penetrate deep into the lower layers of the stellar atmosphere.
- A third strong flare is unfortunately not covered by the UVES data anymore.

Flare statistics

Most of the 27 flares observed during the six observations are of short duration ($<$ 1 hour) in X-rays, optical flare durations are even shorter. In Fig. 2 we search for dependencies of the exponential decay times and flux increases from the quiescent level for the blue optical band, the U band, and in X-rays.

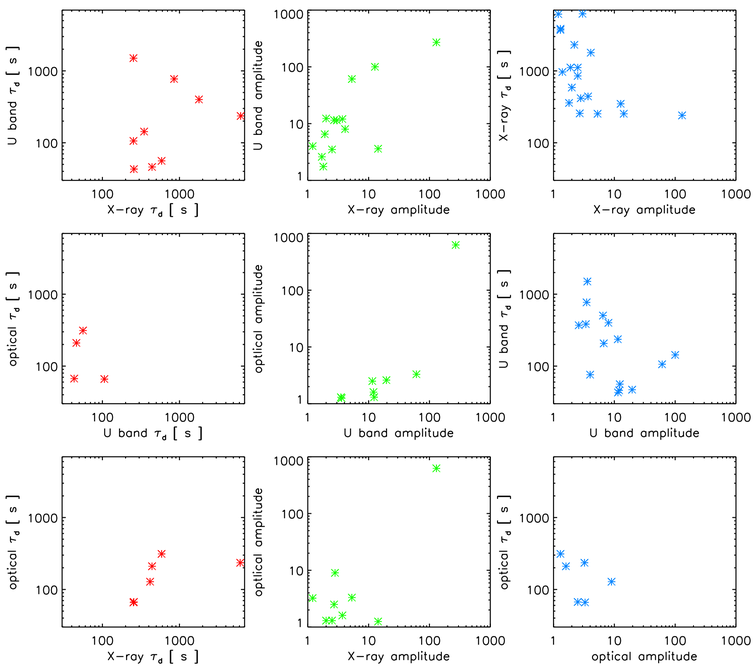
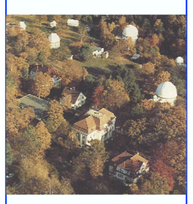


Figure 2: Correlations of flare decay times (first row) and amplitudes (second row) in different spectral bands, and decay times vs. amplitudes (third row).

The quantities show a broad distribution, no tight correlations are found. However, the statistical basis is rather poor for the blue band, and only the giant flare on 19/20 May 2006 is visible in the red band at all.



Flare evolution and loop half lengths

Only the three large X-ray flares on May 19/20 2006 allow time-resolved spectroscopy. Fig. 3 shows the evolution of emission-measure weighted temperature and total emission measure of 2-temperature component APEC models.

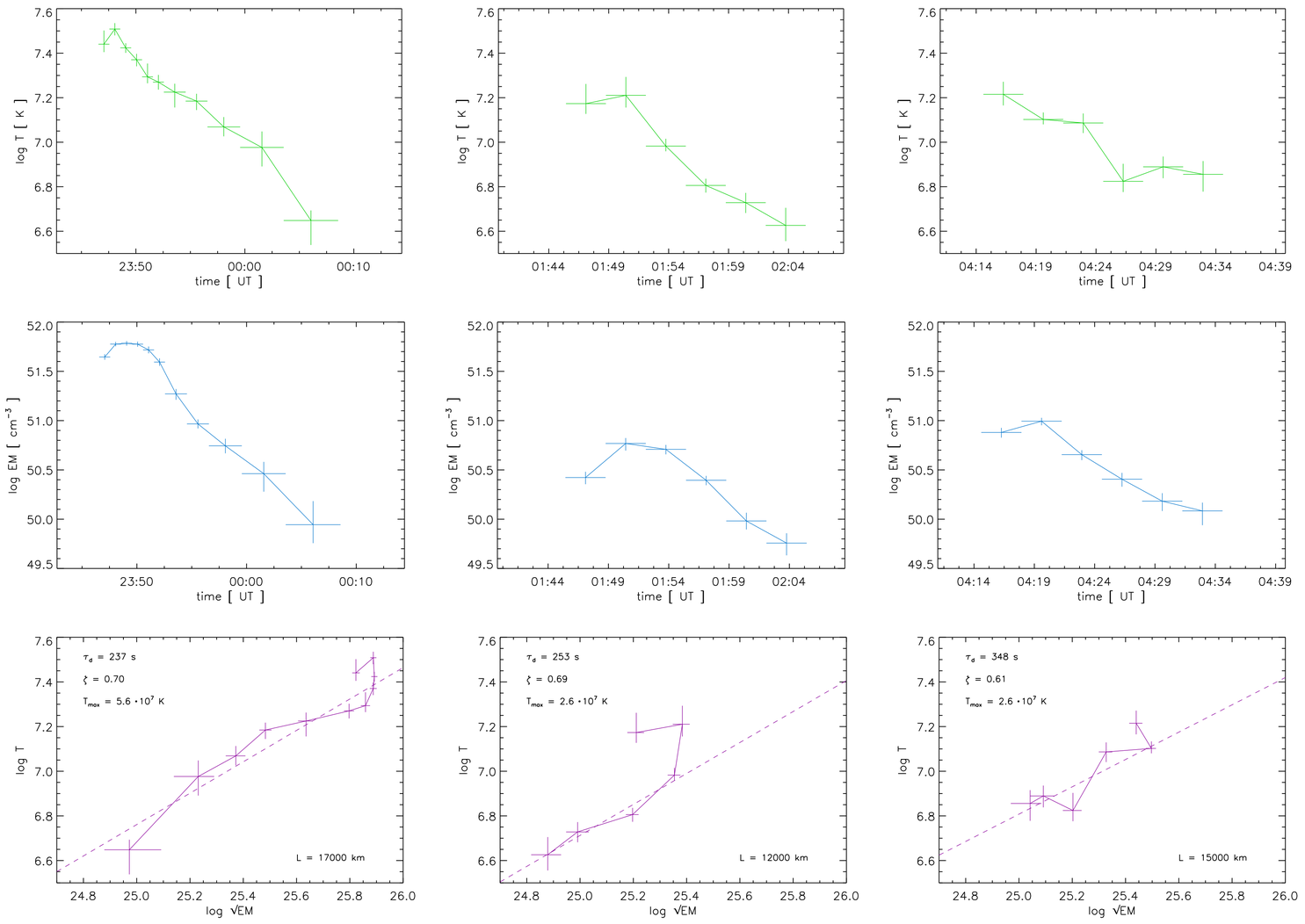


Figure 3: Temporal evolution of flare temperature (first row) and total emission measure (second row), and density-temperature plane (third row) for the giant flare (left column), the “symmetric” flare at 1:45 UT (middle column), and the flare at 4:15 UT (right column).

With $\sqrt{EM}$ as a proxy for n_e, the flare decay can be fitted with a linear slope in the density-temperature plane according to Reale (2007) in order to obtain an estimate of the half length of the flaring loop. The resulting loop half lengths for the three flares are all $\approx 15\,000$ km, comparable to coronal loops on the Sun but corresponding to $\approx 1/10 - 1/4$ of the stellar radius for CN Leo. The fact that very similar loop lengths are obtained for the three flares may indicate that they have their origin in the same loop.

Time lags and the Neupert effect

For the majority of flares we do not observe delays in the onset of optical/U band and X-ray emission at an accuracy of a few seconds. This concerns especially the short and very-short duration events. No obvious trends are visible for the flares where time lags are observed.

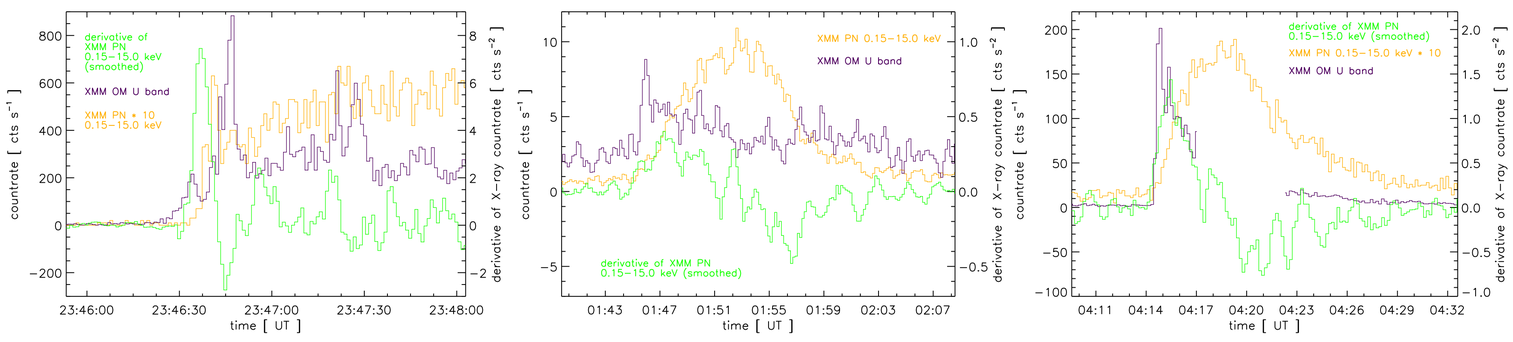


Figure 4: U band and X-ray lightcurves together with the first derivative of the X-ray data for the giant flare (left), the “symmetric” flare (middle) and the the flare at 4:15 UT (right).

For the three strong X-ray flares on on 19/20 May 2006, we test the Neupert effect relation (the time integral of the hard X-ray flux being proportional to the soft X-ray flux). We use the U band emission, which consists mainly of continuum emission (plus chromospheric line emission) which is supposed to be excited instantaneously by the accelerated electrons which cause also the nonthermal hard X-rays, as a proxy. Fig. 4 shows the time derivatives of the X-ray lightcurves together with the U band lightcurves. Only for the third large flare at 4:15 UT the Neupert relation holds.

Conclusions

- We observe 27 flares on the M5.5 star CN Leo in 112 ks of X-ray data and six half nights of mostly simultaneous optical spectroscopy and photometry (19 in X-rays, 15 in the U band, 10 in the optical blue band)
- Average flare durations are 28 minutes in X-rays, 325 seconds in the U band, and 106 seconds in the optical blue band
- The flare decay times and amplitudes in the different spectral bands do not show strong correlations
- We find similar loop lengths around 15 000 km for three larger flares occurring within 4 hours, suggesting that the events originate from the same loop
- Flares of short duration do not tend to show delays in the onset of optical, U band, and X-ray emission
- The Neupert effect is only visible for the last of the three large flares

References

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