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THE EXTREME OUTBURST OF EX Lup IN 2008: OPTICAL SPECTRA AND LIGHT CURVE

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EX Lup is the prototype of EXors, a class of pre-main sequence eruptive variables, exhibiting unpredictable brightenings lasting some months (Herbig, 1977; Herbig et al., 2001; Herbig, 2007). According to the current picture, eruptions of pre-main sequence stars are caused by enhanced accretion (Hartmann & Kenyon, 1996). In quiescent phase, EX Lup has typically V $\approx$ 13 mag, while in outburst, it may brighten by 1–4 mag. The last known flare-up happened in 2002 (Herbig, 2007). As was announced by Jones (2008), EX Lup has been in outburst again since at least 2008 January 15. Based on visual estimates, the star reached a peak brightness of 8 mag, brighter than at any time before. We started an optical spectroscopic monitoring programme on 2008 January 25. In this paper we present our spectra collected until 2008 February 17, as well as the visual light curve for the same period.

Our spectroscopic observations were carried out during 13 nights in 2008 January and February with the newly installed 0.8 m f/8 Cassegrain telescope, equipped with a DFM Cassegrain Spectrograph and a 1024×1024 pixels Apogee Alta camera, at Florida Institute of Technology. Unfortunately, due to the location of the site, we were constrained to observe at extremely high airmasses (between 2.5 and 3.8). The 5″ slit and 600 l/mm grating yielded a spectral resolution of $\lambda/\Delta\lambda = 730$ in the 4250–6050 Å wavelength range at a dispersion of 1.7 Å/pixel. The S/N for our spectra is typically 5-10. The data were reduced using IRAF *ccdred* tasks and spectra were extracted by using the *twodspec* package. The spectra were traced by a 5th order Legendre function using the *apall* task, and the background was sampled over a 25 pixel range on both sides of the spectra. Wavelength calibration was done using observations of a HgAr lamp. The positions of four identified HgAr lines were fitted by a 3rd order Legendre function with rms around 0.01, to obtain the dispersion axis. The log of observations can be seen in Tab. 1.

In order to increase the signal to noise ratio, we combined all 13 spectra, by first shifting them in wavelength and then by averaging them. The resulting averaged spectrum is plotted in Fig. 1. The spectrum is dominated by emission lines, of which many can be identified as metallic lines (Fe I, Fe II, Mg I, Ti II). In addition, a prominent H_β can be observed, however, H_γ is absent from all our spectra. No absorption lines seem to be present. The identified spectral features are marked in Fig. 1. In order to be able to quantitatively compare our spectra with each other and with others published in the literature, we selected three lines and measured their equivalent widths, see Tab. 1.

Table 1: Log of spectroscopic observations, and equivalent widths of selected emission lines of EX Lup. The first two columns show the date and JD when the exposure started; the third column gives the exposure time in seconds; the fourth column shows the number of spectra taken that night; and the last three columns display the equivalent widths in Å of selected emission lines. The uncertainties of the equivalent widths are about 10% and are dominated by the uncertainties in fitting the continuum level.

Date	JD-2450000	Exp. time	Nr.	H_β	Fe II λ4921	Fe II λ5015
2008 Jan 25	4490.959	600	1	−30.0	−12.1	−11.4
2008 Jan 26	4491.956	900	1	−13.4	−6.0	−5.4
2008 Jan 28	4493.949	900	1	−12.3	−4.7	−4.6
2008 Jan 29	4494.945	900	1	−6.5	−3.2	−3.4
2008 Jan 30	4495.956	600	3	−9.0	−3.9	−3.6
2008 Jan 31	4496.945	900	2	−7.3	−3.6	−3.2
2008 Feb 1	4497.938	900	1	−8.8	−3.7	−3.8
2008 Feb 5	4501.936	900	1	−10.4	−6.3	−6.6
2008 Feb 6	4502.936	900	1	−7.4	−4.2	−4.5
2008 Feb 9	4505.967	900	1	−8.3	−4.8	−5.0
2008 Feb 11	4507.915	600	1	−13.2	−5.8	−6.5
2008 Feb 14	4510.912	900	1	−10.8	−5.7	−5.9
2008 Feb 17	4513.913	900	1	−5.1	−3.1	−3.2

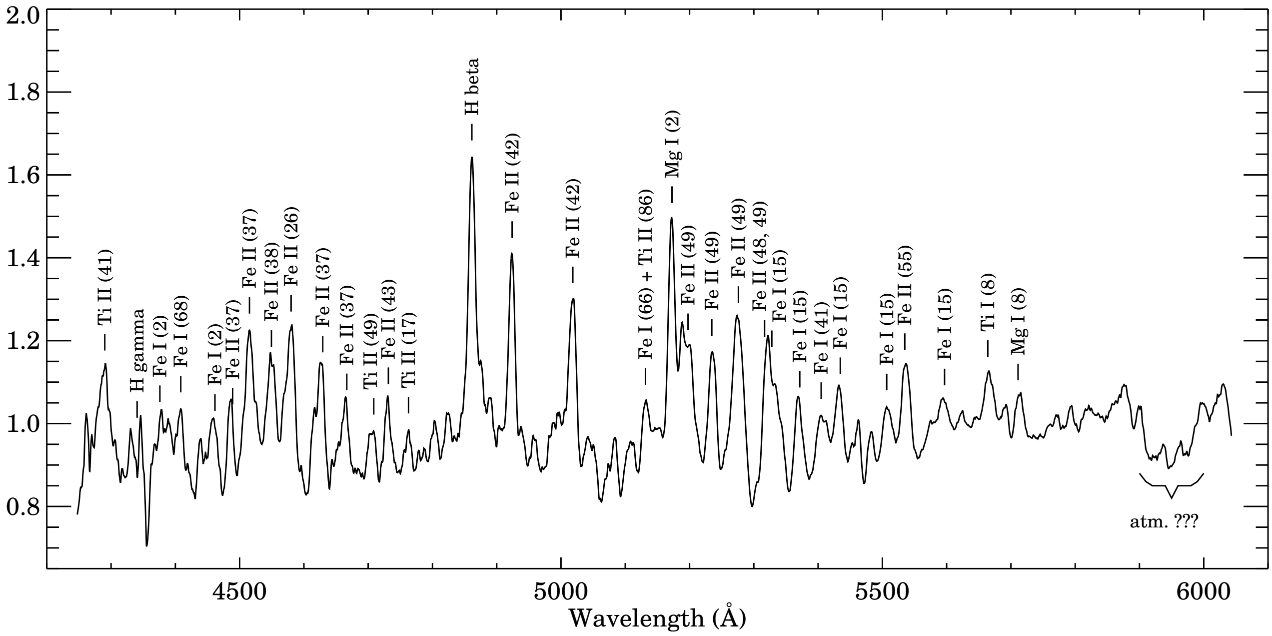

Figure 1. Average of our 13 normalised spectra of EX Lup. Identified spectral lines are marked.

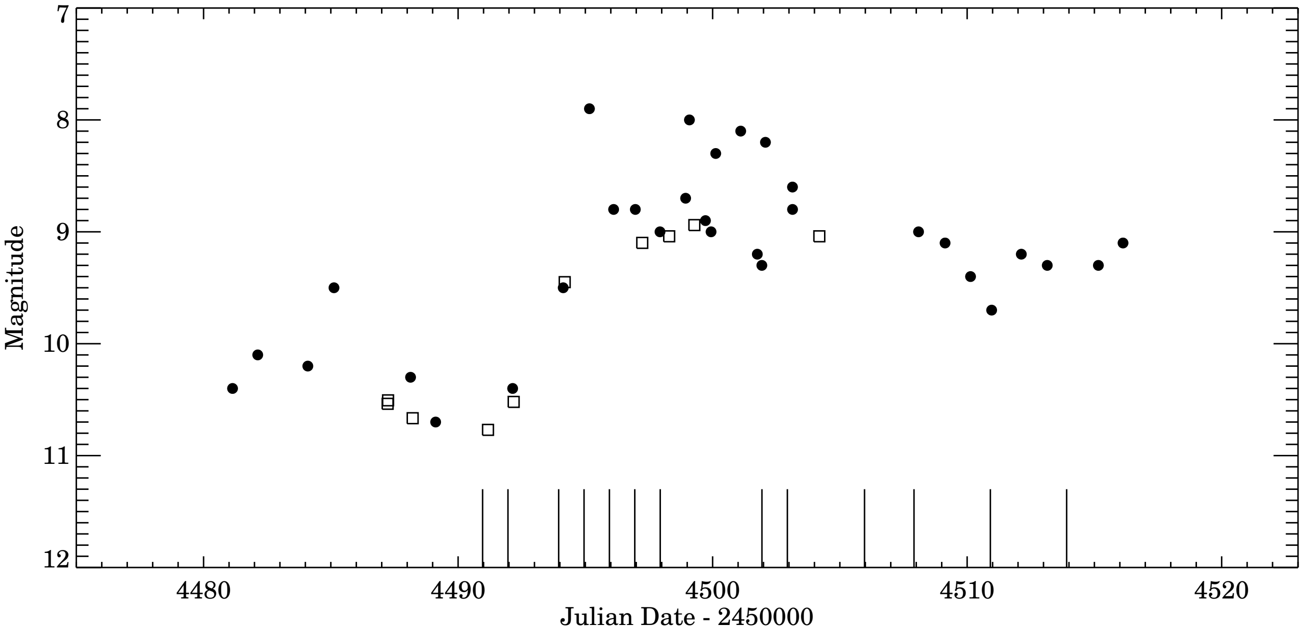

Figure 2. Light curve of EX Lup in the period 2008 January 15 – 2008 February 19. *Filled dots:* visual estimates of A.F. Jones; *open squares:* V-band magnitudes from the AAVSO International Database. The vertical lines at the bottom mark the dates when spectra were obtained.

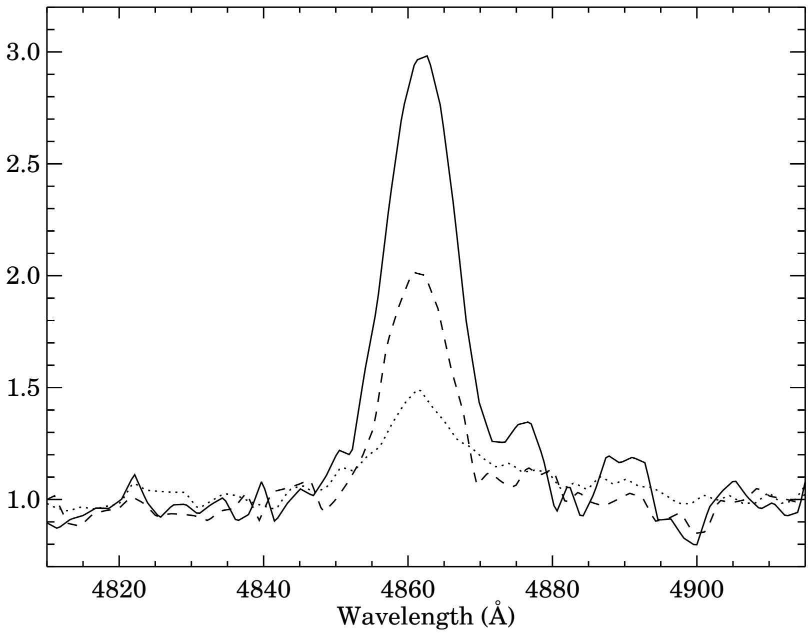

Figure 3. Profiles of the H_β line on 2006 January 25 (solid line), 26 (dashed line), and February 1 (dotted line).

Similar optical spectra were already published for EX Lup both in quiescent and in outburst phases (Appenzeller et al., 1983; Patten, 1994; Lehmann et al., 1995; Herbig et al., 2001; Herbig, 2007). All these spectra show prominent Balmer lines. H_β is clearly visible also in our spectra, and its equivalent width is similar to those published in the literature. Interestingly, H_γ is absent from all our spectra, though it was observed in all the previous studies. Weak He lines were reported in the literature. We found no He lines, but this might be due to our limited spectral resolution (some He lines might be blended with Fe lines). On the other hand, while Fe and other metallic lines were either weak or absent in previous spectra, they are very strong in ours, very likely the strongest ever observed.

Our 13 spectra cover a period of nearly one month around the peak brightness, as shown in the light curve in Fig. 2, which is a compilation of visual and V-band observations. In mid-January, the star already had a visual brightness of ≈ 10 mag, well above the usual quiescent brightness of 13 mag. It soon became even brighter, reaching a maximum of 8-9 mag, then started a slow fading. Checking the equivalent width values in Tab. 1, we found a trend: the equivalent widths were high on the first date, then became significantly reduced between 2008 January 25 and 28, and stayed more or less constant since then (see e.g. the H_β profiles in Fig. 3). The hydrogen and iron lines follow the same trend. Patten (1994) found that the equivalent widths of the Balmer lines did not appear to change much between the outburst and the quiescent phase. This is different in our results. The significant changes in our equivalent widths, however, might be due to the brightening of the object between the dates of our first and subsequent spectra. The lack of absorption features that would normally be present in an M-type dwarf suggests that the increased brightness of EX Lup is not due to variable photosphere but to the addition of a featureless continuum, probably the accretion luminosity.

In summary, our photometric and spectroscopic observations prove that EX Lup is in outburst, exhibiting the highest peak brightness ever observed. The spectra of the present outburst differ significantly from the previous ones in several aspects: the lack of the H_γ and He lines, and the extremely strong metallic features. The increased brightness of the system is probably due to increased accretion. Increased accretion, and consequently increased stellar wind, can also explain the wealth of metallic lines coming from infalling or ejected hot gas, similarly to the case of DR Tau (Beristain et al., 1998).

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