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Letter to the Editor

The extraordinary optical outburst of ON 231 (W Com) in spring 1998

E. Massaro[1], **M. Maesano**[1], **F. Montagni**[1], **R. Nesci**[1], **G. Tosti**[2], **M. Fiorucci**[2], **M. Luciani**[2], **L.O. Takalo**[3], **A. Sillanpää**[3], **S. Katajainen**[3], **P. Keinänen**[3], **T. Pursimo**[3], **M. Villata**[4], **C.M. Raiteri**[4], **G. De Francesco**[4], **G. Sobrito**[4], **Y.S. Efimov**[5,6], **and N.M. Shakhovskoy**[5,6]

[1] Istituto Astronomico, Unita' GIFCO Roma-1, Universita' "La Sapienza", Via Lancisi 29, I-00161 Roma, Italy
[2] Osservatorio Astronomico, Universitá di Perugia, Via A. Pascoli, I-06100 Perugia, Italy
[3] Tuorla Observatory, Tuorla, FIN-21500 Piikkio, Finland
[4] Osservatorio Astronomico di Torino, Strada Osservatorio 20, I-10025 Pino Torinese, Italy
[5] Crimean Astrophysical Observatory, 334413, Nauchny, Crimea, Ukraine
[6] Isaac Newton Institute of Chile, Crimean Branch

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Abstract. The BL Lac object ON 231 (1219+285, W Com) had an exceptional outburst phase in April-May 1998 and reached the most luminous state, observed at least since the beginning of the century. In this paper our multiband photometric light curves and polarimetric measurements of this event are presented. In the maximum phase the magnitude of ON 231 was R(Cousins)=12.2 and the optical spectral distribution was the flattest ever observed. Our data indicate that the main features of this burst can be explained by the presence of some emission components having different polarisation states and variability time scales ranging from 1 day to several months.

Key words: galaxies: BL Lacertae objects: general – galaxies: BL Lacertae objects: individual: ON 231

1. Introduction

ON 231 (1219+285) was one of the first radio sources classified as a BL Lacertae object (Biraud 1971; Browne 1971). The optical counterpart was already known as a variable star since the beginning of this century (Wolf 1916), when it was in a very bright state. The historic light curve (Tosti et al. 1999a) shows that the mean source luminosity is increasing after a minimum in the early seventies. Since 1994 we are carring out an optical monitoring whose results up to June 1997 are described by Tosti et al. (1998). In that period ON 231 was very active and showed in each season a bright maximum in which its R_C (Cousins) magnitude reached the level of about 13.4. In 1998 the activity of ON 231 was even stronger than in the past years; in particular, the source had an extraordinary outburst in April 1998 and reached the highest brightness level ever recorded since the Wolf's discovery.

Send offprint requests to: E. Massaro (massaro@astro.uniroma1.it)

We performed during this prominent burst many optical photometric and polarimetric measurements. The most relevant results are presented in this paper while all the data tables, the instruments and the data reduction techniques are described in a couple of separate papers (Efimov & Shakhovskoy 1998, Tosti et al. 1999b), retrivaible from an electronic data journal at the *Web* site *http://bldata.pg.infn.it*. Our observations triggered also two ToO pointings of the X-ray satellite BeppoSAX in May and June 1998: in the former ON 231 showed a very unusual spectrum with a clear excess at energies greater than 4 keV (Tagliaferri et al. 1998).

2. Light curves and time scales during the 1998 outburst

The historic light curve of ON 231 in the Johnson B band after 1970 is shown in Fig. 1: from these data the change of the source activity after 1995 and the extraordinary outburst of April-May 1998 are very evident. The lowest states of ON 231 were observed in 1972–74, when the flux was only 0.5 mJy (B=17.4) (Webb et al. 1988); afterwards the flux increased but always showing fluctuations with a typical amplitude of 1–1.5 mag. Since 1994 ON 231 was on the average brighter than in the past, but with the same fluctuation amplitude. Unfortunately, the lack of data in the period from 1986 to 1994 does not allow us to know exactly when the present active phase started on. In the very strong burst of 1998 ON 231 was about 3 times brighter than in the previous years and a factor of 60 than the minimum of 1972.

The light curves from December 1997 to May 1998 in the V and R_C bands, which are the best sampled, are shown in Fig. 2: we have measurements in 71 days over a total span of 176 with a mean separation of about 2.5 days, which decreases to 1.9 after February 15th. Photometric measurements were performed with different telescopes equipped with CCD cameras; the standard stars used in the data reduction were the same and their calibration was accurately verified to make all the data sets

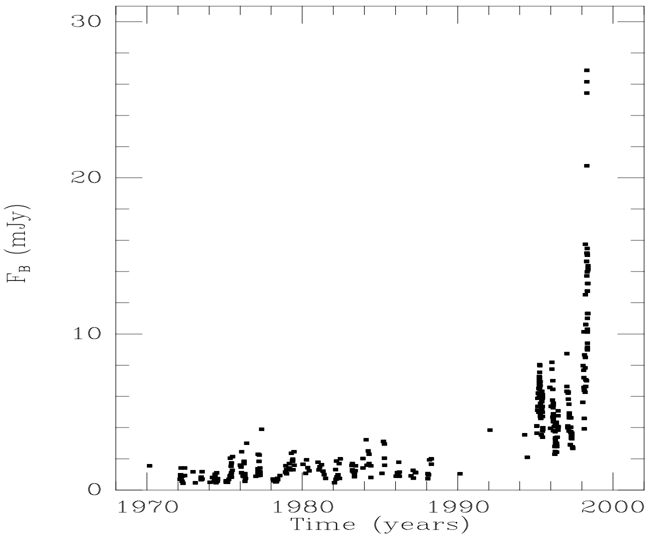

Fig. 1. The historic light curve of ON 231 in the B band after 1970. The data up to the spring of 1997 are taken from Tosti et al. (1998), while those of 1998 are given in Tosti et al. (1999b). Fluxes are not corrected for the interstellar reddening.

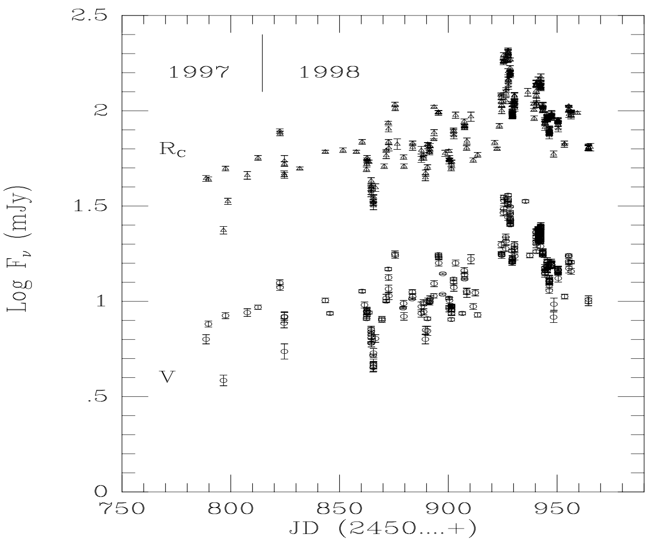

Fig. 2. The light curves of ON 231 from December 1997 to May 1998 in the V and R$_C$ bands. A constant value equal 0.7 has been added to the logarithm of the R$_C$ fluxes to avoid the superposition with the V points.

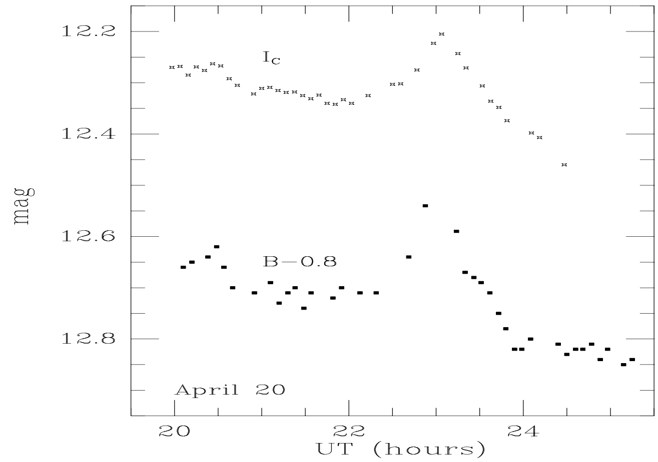

Fig. 3. Intranight variations of ON 231 in the I_C and B bands observed on 1998 April 20. The B data points have been shifted by 0.8 mag to plot the points in a clear scale. Typical magnitude errors are 0.02 in I_C and 0.04 in B, respectively.

homogeneous, as described by Tosti et al. (1998) for the earlier observations.

A mean increasing brightening trend is evident throughout all the period, particularly after February 1998, but from April to the end of May the mean luminosity of ON 231 increased by about 0.5 mag. In the same period the source continued its intense flaring activity and during one of these flares it reached the greatest brightness (April 23, $R_C = 12.2$). Another prominent flare occurred on May 1, but it is not well described because we have only one photometric point in the V band. Typical durations of the rapid flares were not longer than two-three days and the amplitudes during the maximum phase were comparable to those of the previous periods. Notice also that the variation amplitude in the V band is systematically greater than in R_C.

Flux changes on a few hour time scales were detected in some intranight observations. An example is shown in Fig. 3, where two simultaneous light curves in the I_C and B bands, obtained with two telescopes are plotted in the same scale: a synchronous small flare around 23 h is clearly evident: again the amplitude is greater in the B band with variation rate of about 0.3 mag/hour. The same rate was again observed on April 23 when the source had the maximum luminosity.

3. Spectral evolution

Photometric data can be used to study also the spectral evolution of ON 231 during the outburst. It is well known from previous works (Lorenzetti et al. 1990, Tosti et al. 1998) that ON 231 shows a clear spectral hardening when its luminosity is increasing. Such a behaviour is fully confirmed by the 1998 observations. In Fig. 4 we plotted the spectral distributions of ON 231 in four different luminosity states derived from BVR_CI_C photometric meaurements performed with a very short time separation and using the same telescope. The spectral index, computed from the zero magnitude fluxes by Mead et al. (1990), varied from -1.40$\pm$0.06 (February 20) to -0.52 $\pm$ 0.05 (April 24, during the maximum phase). This change corresponds to a variation of the peak frequency in the νF_ν spectrum from the near infrared in the lowest state to the B band (or beyond) in the highest one. We stress that a spectrum as flat as that of April 24 is really exceptional and was never observed in the previous years: Tosti et al. (1998) report only two values of the spectral index greater than -1.0 over a set of 143 data in 1994-1997 and the greatest one was -0.87.

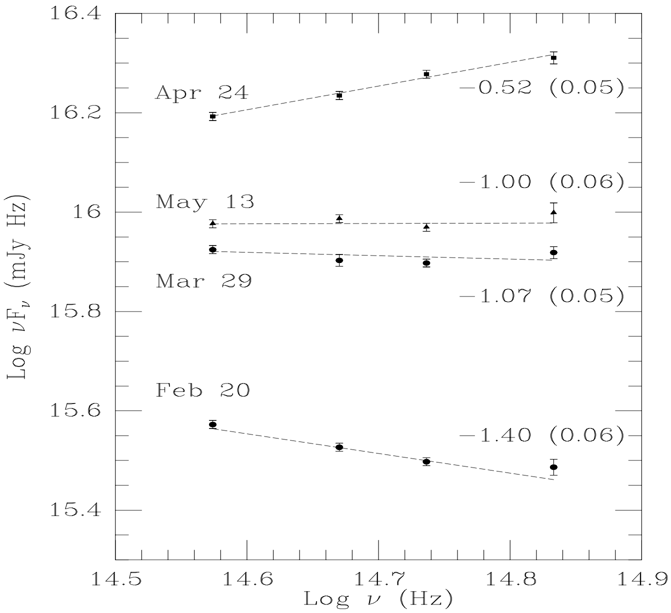

Fig. 4. Four points spectral distributions of ON 231 in different luminosity states during the outburst. A reddening correction with A_V=0.11 was applied to the measured magnitudes. The dashed lines are the power law ($F_\nu = K\nu^\alpha$) best fits whose α values are indicated.

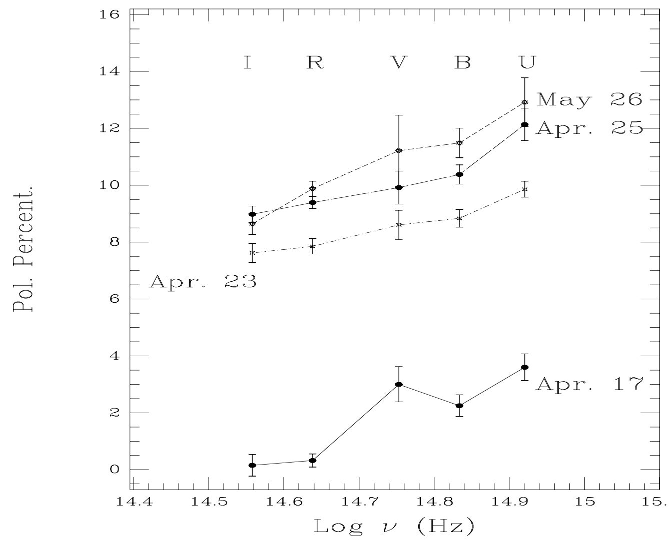

Fig. 5. Frequency dependent linear polarisation of ON 231 observed in April and May 1998.

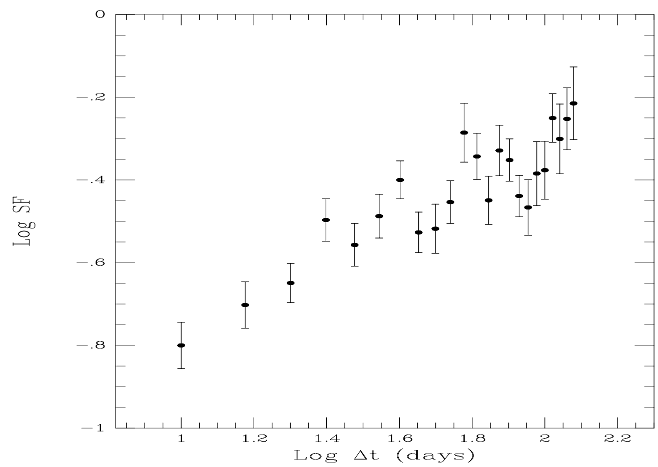

Fig. 6. Double logarithmic plot of the structure function of the light curve of ON 231 in 1998, with time steps of 5 days.

4. Polarimetry

Multiband polarimetric observations were performed just before and during the brightest phase (April 17-25) and after one month when the luminosity of ON 231 was about a factor of 3 weaker than the maximum. On April 17 (V=13.6) the polarisation percentage was very low in all the bands: between 2.3±0.4% and 3.6±0.5% in U, B, V and practically not detected (i.e. less than 0.4%) in R_C and I_C. Three days after, when the V magnitude of ON 231 was 13.10, we measured the mean polarisation around 8% and a comparable level was also found on April 23 (V=12.64). Higher levels were measured on April 25, when the source brightness decreased to V=13.42 and one month later (May 26), when it was at the level of V=13.71.

A clear dependence of the polarisation fraction upon the frequency was also evident: it was greatest in the U band, ranging during the outburst from 9.9±0.5% to 12.9±0.7%, and lowest in I_C (from 6.6±0.3% to 9.0±0.3%). These results are shown in Fig. 5. Polarisation angles were the same in all the five photometric bands and changed with time, but only in a 35^o range: on April 23 the PA was 162^o±2, after two days 128^o±2 and on May 26 it was 142^o± 1.

5. Discussion

The observational results presented in the previous sections are the first detailed description of the optical activity of ON 231 in a very bright state and are useful in understanding the physical processes responsible of such high variability.

We searched for possible recurrent features in the light curve of Fig. 2 for time intervals longer than ten days by computing the first order structure function averaging the data over time intervals of 5 days. The result is shown in Fig. 6: the structure function is quite smooth with a mean slope of 0.44 and only a swallow minimum around 90 days. A direct inspection of the light curve suggests that the main phenomena can occur at least on three possible time scales. The longest of the order several months (or years) corresponding to the long term trend, an intermediate scale of about 3 10^6 s (month) corresponding to the duration of the ouburst and a third one of about 10^5 s (1-2 days) associated with the flaring activity. The longest time scale could be produced by structural modifications of the source, the second one could be related to the acceleration and radiative cooling of relativistic electrons in the synchrotron source, and the third one to the development of short living instabilites or fast shocks inside the emitting region. A more complete analysis, however, is necessary to achieve a better description of the variability pattern useful to unravel the relations among the main parameters of a physical model, but it is not the aim of this paper.

The data on frequency dependence polarisation in different luminosity states are also very useful to understand the physics of the source. The polarisation fraction had a large increase at the same time of the onset of the ouburst and remained high without great changes of the polarisation angle, indicating that the field orientation was rather stable. Ballard et al. (1990) showed that a frequency dependent polarisation can be explained by the combination of two components: an unpolarised one with power law spectrum superposed to a highly polarised one having a flatter spectrum with a cut-off frequency, where the resulting polarisation is maximum. A luminosity decrease of the latter component cannot imply a lower polarisation degree if also the cut-off frequency decreases.

We stress, finally, some similarities between this outburst of ON 231 and that of BL Lacertae in summer 1997. In both cases a rapid flaring activity, with typical rates of about 0.2 mag/hour (Nesci et al. 1998, Speziali & Natali 1998), superposed to an increase of the mean luminosity was observed (Tosti et al. 1999c), The overall durations of both outbursts were on the month time scale. During the bursts the spectral distributions were harder than in quiescent phases and also significant enhancements of the X-ray luminosities were observed (Makino et al. 1999, Tagliaferri et al. 1998). All these analogies suggest that these intense outbursts of both sources are likely produced by the same physical processes.

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