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The Hamburg quasar monitoring program (HQM) at Calar Alto.* III. Lightcurves of optically violent variable sources

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Abstract. — HQM is an optical broad-band photometric monitoring program carried out since September 1988. We use a CCD camera at the MPIA 1.2 m telescope. Fully automatic photometric reduction relative to stars in the frames is done within a few minutes after each exposure, thus interesting brightness changes can be followed in detail. The typical photometric error is 1–2% for a 17.5 mag quasar. We here present lightcurves of 14 known violently variable sources and compare them with literature data. For two BL Lac objects, 1E 1229+645 and 4C 56.27 (1823+568), this paper is the first variability study. We have also carried out POSS photometry to obtain indications for variability on a longer timescale.

Key words: quasars: general

1. Introduction

In this paper, being the third one in a series, we show some lightcurves for quasars which were known to be optically violent variables (OVVs) prior to our program or which were identified as BL Lac objects due to their optical spectra so that violent variability can be assumed. We *define* an object as an OVV if it shows variations $\gtrsim 0.5$ mag with gradients $\gtrsim 5\,\mathrm{mag\,yr^{-1}}$ in the quasar restframe. We show only those lightcurves for which measurements exist sufficiently spread over a time-span $\gtrsim 2$ yr. The OVV class which is possibly equivalent to the blazar class has sometimes (e.g. Kayser et al. 1986; Schneider & Weiss 1987) been proposed to contain good microlensing candidates. Our intention was to test this hypothesis by comparing the high quality lightcurves of our program with simulated microlensing lightcurves. A detailed physical discussion of the flaring characteristics of the OVVs in our sample will appear in a subsequent publication (see also Borgeest & Schramm 1992).

For HQM, we use a CCD camera which was equipped with different chips, in 1988 with an RCA 15μ chip (640×1024, pixel size 0.315″) and later various, but similar, coated GEC 22μ chips (410×580, pixel size 0.462″). We measure the quasar fluxes through a standard Johnson R broad-band filter relative to stars included in the frames. The data reduction is carried out automatically, immediately after the observation, on a μVAX 3200 workstation. The software package "HQM" has been developed in Hamburg (for a short description see Borgeest & Schramm 1994, hereafter Paper I); it is much faster than standard image processing software. A 0.01 mag accuracy (in relative photometry) in the lightcurve of a $\sim$ 17.5 mag quasar can be reached in this way also for "non-photometric" conditions with a typical exposure time of 500 s. One of the most interesting OVVs in our sample is 3C 345; a detailed discussion of possible variability mechanisms can be found in a separate publication (Schramm et al. 1993; cf. also Borgeest & Schramm 1992 and Schramm & Borgeest 1992). For another three objects, we already published or are preparing separate papers: 0836+710 (von Linde et al. 1993) and PKS 0420-014 (Wagner et al. 1993) which have both been found to be highly luminous in the γ-ray waveband as well as PKS 1510-089 (Valtaoja et al. 1993) for which we have obtained simultaneous mm-radio data. In Paper I and in Schramm et al. (1994, Paper II) we have plotted lightcurves of weakly variable objects.

Extensive monitoring programs which contain violently variable quasars have been carried out by several investigators: Lightcurves of many bright quasars have been obtained from the Harvard historical plate collection (e.g. Angione 1973) spanning periods of up to 100 years. Monitoring data obtained until 1973 are reviewed and critically discussed by Grandi & Tifft (1974). Lloyd

*Based on observations collected at the German-Spanish Astronomical Centre, Calar Alto, operated by the Max-Planck-Institut für Astronomie (MPIA), Heidelberg, jointly with the Spanish National Commission for Astronomy

Table 1. Properties of the HQM-quasars discussed in this article. Following the name, we have listed the emission redshift, the absolute visual magnitude and the radio flux at 6 cm (all from Véron & Véron-Cetty 1991). In the following columns redshifts and restframe equivalent widths (together for both lines) of MgII-absorption line systems are given. The next columns list properties of foreground galaxies, $\theta_{\rm gal}$ is the angular separation and $r_{\rm gal}$ the physical ($H_0 = 50$, $q_0 = 0$) distance of the galaxy from the sight-line, $\theta_{\rm a}$ is the approximate radius of a galaxy on a POSS blue print. The next column lists the variability classification. In the last column we give the results of our POSS photometry; a "+" indicates that the quasar became brighter in recent years. Following abbreviations are used: med: medium, nd: not detected

Object	Name	$z_{\rm em}$	$-M_V$	S_6 [Jy]	$z_{\rm abs}$	$W_{\rm r}$ [Å]	Ref	$z_{\rm gal}$	$\theta_{\rm gal}$ [″]	[$\theta_{\rm a}$]	$r_{\rm gal}$ [kpc]	$V_{\rm gal}$	Ref	Var	Ref	ΔR_{40} [mag]
0007+106	IIIZw2	0.089	23.3	0.42	–			–						OVV	2	$-0.15 \pm 0.50^{\triangleright}$
0215+015	PKS	1.715	30.0	0.36	1.345	3.2	3	–						OVV	4	–
0219+428	3C 66A	0.444	27.2	1.04	–			0.021	145	4.9	90	15.4	5	OVV	6	$+0.56 \pm 0.20$
0235+164	AO	0.934	28.7	1.94	0.524	4.8	7	0.524	0.5		3.6	20.1	8	OVV	4	$+2.36 \pm 0.25$
									2			20.9				
								0.525	6		9.0	21.9				
					0.852	0.9										
0735+178	PKS	>.424	>26.0	1.99	0.424	2.8	9	–						OVV	4	-0.34 ± 0.44
0836+710	4C 71.07	2.17	30.1	2.57	0.914		10	–						nd	11	-0.09 ± 0.10
0851+202	OJ 287	0.306	26.0	2.61	–				3			21	1	OVV	4	-1.14 ± 0.24
								)*					1			
1219+285	ON 231	0.102	22.7	0.72	–			–						OVV	4	-0.44 ± 0.14
1229+645	1E	0.164	23.0	0.042	–			0.009	81	2.0	21	14.2	12	–		$-1.00 \pm 0.31^{\triangleright}$
								)$^\sharp$					1			
1253−055	3C 279	0.538	25.1	15.34	–			–						OVV	13	$+1.67 \pm 0.50^{\triangleleft}$
1308+326	B2	0.996	29.1	1.59	0.879	0.4	14		5.4			21	1	OVV	4	$-1.17 \pm 0.36^{\triangleleft}$
1638+398	NRAO 512	1.66	29.4	1.16	–			)$^\sharp$					1	OVV	4	-0.87 ± 0.27
1641+399	3C 345	0.595	27.1	5.65	–				4.5				1	OVV	15	–
									6.6							
1749+701	W1	0.76?	26.7	1.09	–			–						med	16	-0.59 ± 0.21
1823+568	4C 56.27	0.66?	25.0	1.67	–			–						–		–
2223−052	3C 446	1.404	27.1	4.07	0.847		17	–						OVV	4	$+1.40 \pm 0.17$

$^\sharp$ Faint galaxy/galaxies within few arcsec
* There is a number excess of faint galaxies inside 30″
$^\triangleleft$ There are only less than five stars in the CCD frames which are useful for POSS photometry
$^\triangleright$ All stars useful for POSS photometry are fainter than the quasar

(1984, hereafter L84) reports on lightcurves of 36 radio sources from the Herstmonceux Optical Monitoring program for the period 1966-1980. At the Rosemary Hill Observatory more than 200, mostly radio-selected quasars have been monitored since 1968, although not all objects over the total period (Pica et al. 1980, hereafter PPSL; Pica & Smith 1983, hereafter PS83; Smith et al. 1993, hereafter SNLC, and Refs. therein); more recent data on OVVs can also be found in Webb et al. (1988). Another program was carried out at the Asagio Observatory (e.g. Barbieri et al. 1979, hereafter BRZ) over the period 1967 to 1977. Moore & Stockman (1984) have collected a catalog of the observational properties of 239 quasars, including variability data. A more recent monitoring program of BL Lac objects and quasars, starting in the early '80s, is carried out at the Tuorla Observatory, Finland (Sillanpää et al. 1988a, 1991).

2. Discussion of the lightcurves

Some interesting properties of the quasars under consideration are given in Table 1; we also give there the results of a POSS photometry for which we used our CCD frames to calibrate red POSS prints (for a short description see Paper I). The given values are variations with respect to the reference magnitude R_0 indicated in each lightcurve. All lightcurves are shown with the same time and magnitude scale in Fig. 1. Those parts of the lightcurves which are better sampled are plotted with higher time resolution in Figs. 2−8. In this section we also discuss literature data; however, we concentrate only on a few publications for each object. A more complete list of references can be found in Hewitt & Burbidge (1987, 1989).

III Zw 2 (0007+106). This type-1 Seyfert galaxy was included in the early Rosemary Hill sample; PPSL found only marginal variability, comparable to our HQM data.

Table 2. References for Table 1

1.	This work
2.	Lloyd 1984
3.	Gaskell 1982
4.	Webb et al. 1988
5.	Monk et al. 1986
6.	Pica et al. 1980
7.	Wolfe & Wills 1977
8.	Stickel et al. 1988
9.	Peterson et. al. 1977
10.	Stickel & Kühr 1992
11.	Wagner et al. 1990
12.	Stocke et al. 1987
13.	Eachus & Liller 1975
14.	Bergeron & Boissé 1984
15.	Schramm et al. 1993a
16.	Arp et al. 1979
17.	Perry et al. 1978

Violent variability with a total amplitude of 1.7 mag was recorded by L84.

PKS 0215+015 is a BL Lac object with a very high redshift. WSLF have monitored this object since 1981 and detected variations over a 3.5 mag range. Our data indicate violent variability, too; however, both observed time-span and amplitude are smaller.

3C 66A (0219+428) is another BL Lac object at medium redshift. It was included in the early Rosemary Hill sample; PPSL detected variability with a total range of 1.2 mag in their highly undersampled lightcurve. Miller & McGimsey (1978) searched for intraday variability, with a negative result. Eight photometric data points obtained in the early '80s by Corso et al. (1986) yielded a 0.42 mag range of variability. In the Tuorla programme (Sillanpää et al. 1991), the authors found a variability range of 1.4 mag caused by an outburst in Oct. 1985. Our HQM lightcurve is well sampled in some parts, it shows one sharp peak at the end of 1989; the curve is relatively smooth compared to other BL Lac objects. On our CCD frames there is a number excess of relatively bright galaxies inside $2'$.

AO 0235+164. This BL Lac object has sometimes been proposed as a very good microlensing candidate (Kayser 1988; Stickel et al. 1988) since it has two foreground galaxies at small angular separations (see Table 1). WSLF present a lightcurve spanning from 1975 to 1986; they measured a 5 mag outburst in 1979 which was of similar shape than an outburst in 1975; another strong event occurred in 1986/87. The HQM lightcurve shows very rapid, large amplitude variations; two parts of it are shown in Figs. 2 and 3 with higher resolution. The most rapid variation is displayed in Fig. 2 where the object brightened by 1.60 mag within 47.5 hours between Feb. 20 and 22, 1989. On Feb. 15, 1989 the object faded by 0.68 mag within 18.5 hours. Another rapid brightening of 0.67 mag within 28.5 hours occurred between Feb. 23 and 24, 1991 (Fig. 3). Making use of the photometric sequence of McGimsey (1976) and Smith et al. (1985), we were able to determine the reference magnitude of our lightcurve, $R_0 = 16.23$.

PKS 0735+178 is a BL Lac object with an unknown redshift. The Rosemary Hill data reported by WSLF suggest long-term trends with amplitudes of about 2 mag with more rapid flares of $1-1.5$ mag superimposed. The historical lightcurve of Pollock (1975) shows a 2.2 mag total range of variability. The HQM lightcurve shows one flare in early 1991; the preceeding state has been monitored with higher resolution and is shown in Fig. 5. Making use of the photometric sequence of McGimsey (1976) and Smith et al. (1985), we were able to determine the reference magnitude of our lightcurve, $R_0 = 15.24$.

4C 71.07 (0836+710). The HQM lightcurve has been discussed in detail in von Linde et al. (1993). The lightcurve shown in Fig. 1 includes some more recent data points indicating that the object has reached roughly the same brightness stage than before the flare which occurred in Feb. 1992 nearly simultaneously with the detection of this object by the GRO γ-ray observatory. The reference magnitude is $R_0 = 16.84$.

OJ 287 (0851+202) is one of the best studied OVVs of BL Lac type. The Rosemary Hill data reported by WSFL have a 5 mag range of variability. Sillanpää et al. (1985) who compared the 1972 and 1983 outbursts found a similar morphology. The historical lightcurve, combined with more recent data, was collected by Sillanpää et al. (1988b); it starts 1894 and exhibits 7 outbursts with a possible periodicity and a period of $\sim 11{,}5$ yrs. Our HQM lightcurve is clearly undersampled in most parts; in winter 1992, however, the increasing wing of a flare (see Fig. 4) could be recorded with sufficient resolution. Making use of the photometric sequence of Smith et al. (1985), we were able to determine the reference magnitude of our lightcurve, $R_0 = 15.13$.

W Com (1219+285). The Rosemary Hill data reported for this BL Lac object by WSFL show 2 mag outbursts occurring with a relatively high frequency. The HQM lightcurve is well sampled only in February 1991 (see Fig. 5); we did not detect any dramatic event.

1E 1229+645. There exist to our knowledge no variability studies in the literature for this BL Lac object. Our HQM lightcurve clearly indicates variations but up to now no OVV behaviour. In about $3''$ from the quasar there is another object, unresolved even on good seeing CCD frames.

3C 279 (1253−055). The Rosemary Hill lightcurve of this BL Lac object plotted in SNLC is as undersampled as the HQM curve; however, a flare occurring in 1989 is represented by more data points. Another flare with the peak value 4 mag above the average base level appeared

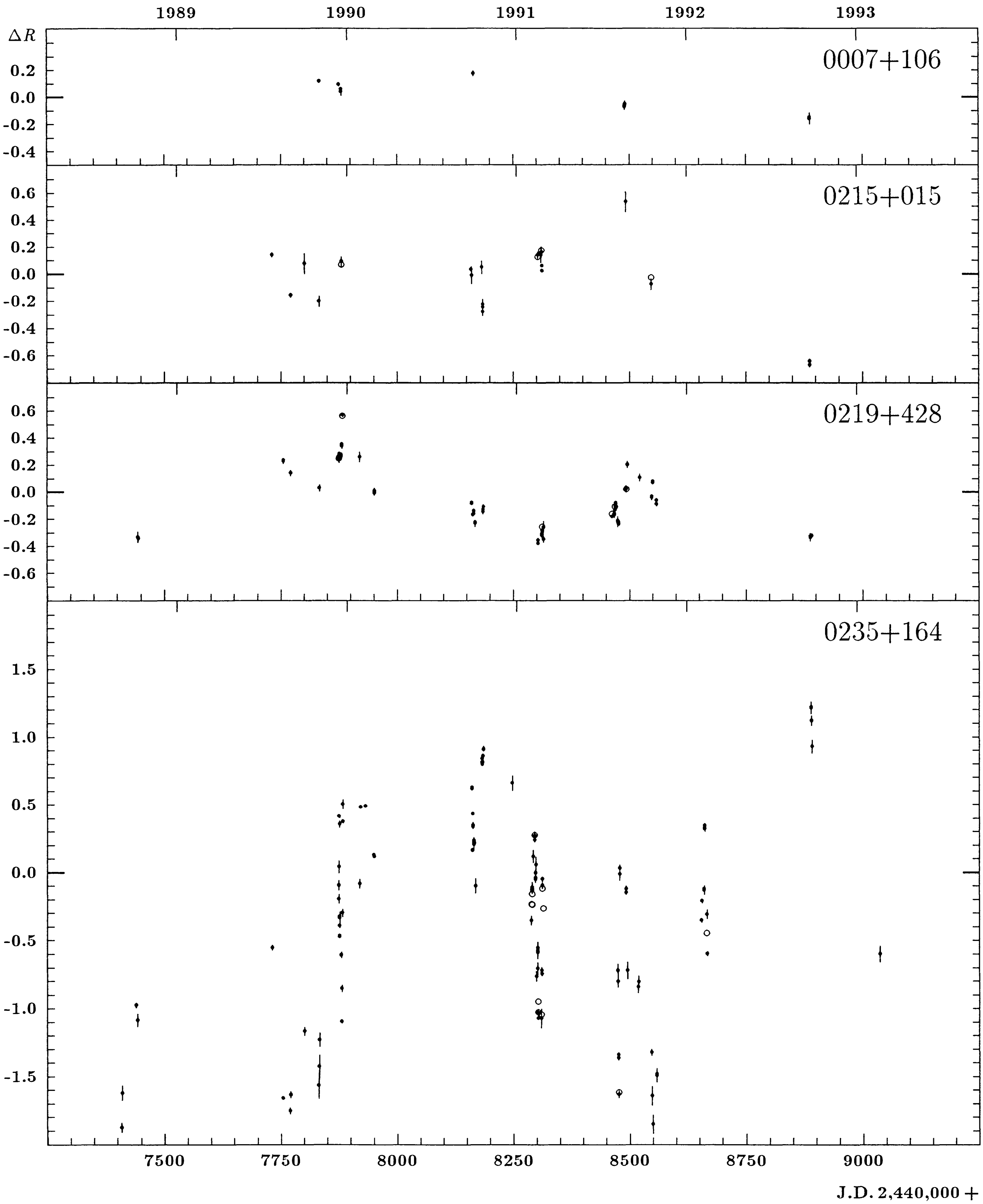

Fig. 1. HQM-lightcurves in the Johnson-R band. Plotted are variations $\Delta R = R_0 - R$; the reference magnitude R_0 is indicated by thick dashes; it was not possible to determine R_0 for all quasars, see text. Measurements obtained with too short exposure time or under bad atmospheric conditions or those with only one reference star are shown by open circles; reliable error bars can in these cases not be given

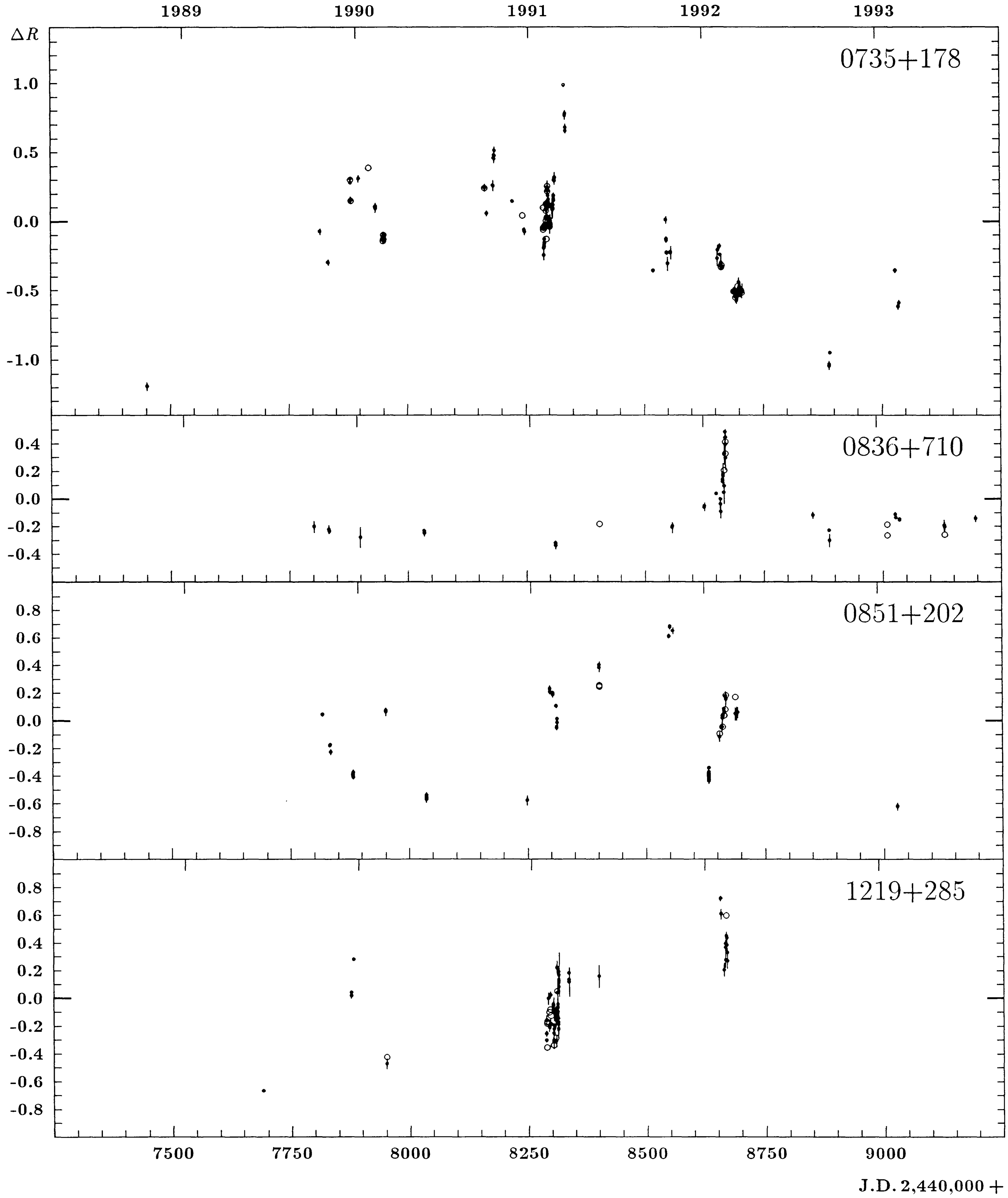

Fig. 1. continued

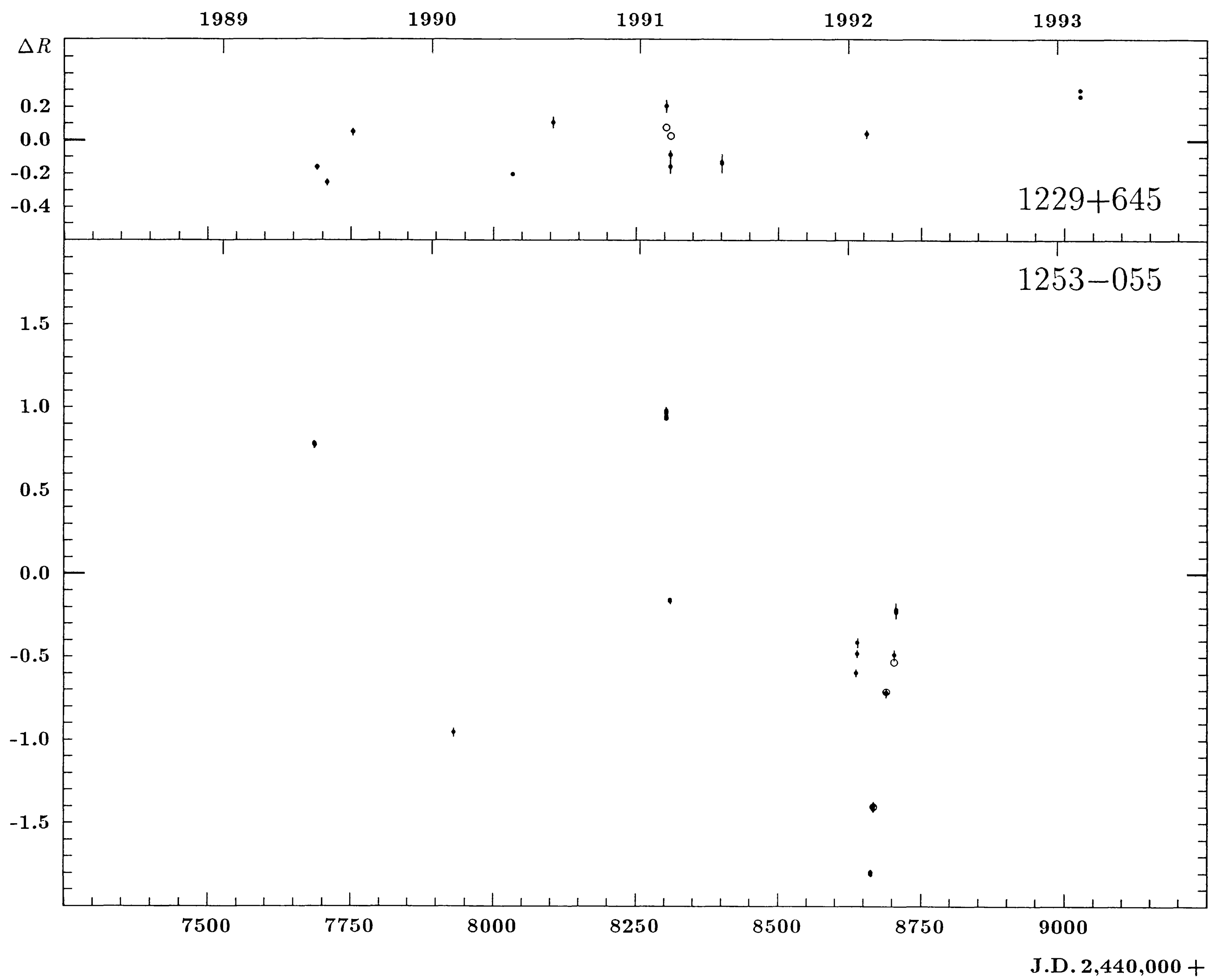

Fig. 1. continued

one year before. From 1971 to 1986 the object did not show OVV behaviour. Very impressive is the historical lightcurve measured by Eachus & Liller (1975); the object reached 11.27 ± 0.07 mag in 1937 April and thus showed a 6.7 mag total range of variability. The most rapid variation was a 2.2 mag change in 13 days in 1936.

B2 1308+326. The lightcurve shown by WSLF covers the time between 1976 and 1986; it displays a 3.0 mag total range of variability with several flares recorded. WSLF note an overall decline in the lightcurve and report that the BL Lac object was at a very faint state in early 1987. Our HQM lightcurves seems to indicate that the object is brightening again. A series of data is shown with higher time resolution in Fig. 6. We have obviously covered the peak of a "mini-flare". On our CCD frames there is a number excess of relatively bright galaxies inside $2'$.

NRAO 512 (1638+398). The Rosemary Hill lightcurve plotted in SNLC includes only three data points for the period of our observations; it shows, however, a series of flares in the early '70s and a 3.2 mag total range of variability. The HQM lightcurve shows an isolated data point in the second half of 1988 which is 1.5 mag above the average base brightness; a few 0.5 mag events are covered by more data points; see also Fig. 7. Making use of the photometric sequence of Smith et al. (1985) for 3C 345, we were able to determine the reference magnitude of our lightcurve, $R_0 = 19.31$.

3C 345 (1641+399). The Rosemary Hill lightcurve plotted in SNLC is not well sampled since 1988. All other literature data and the HQM lightcurve have been discussed in detail in Schramm et al. (1993). The lightcurve shown in Fig. 1 includes some more recent data points,

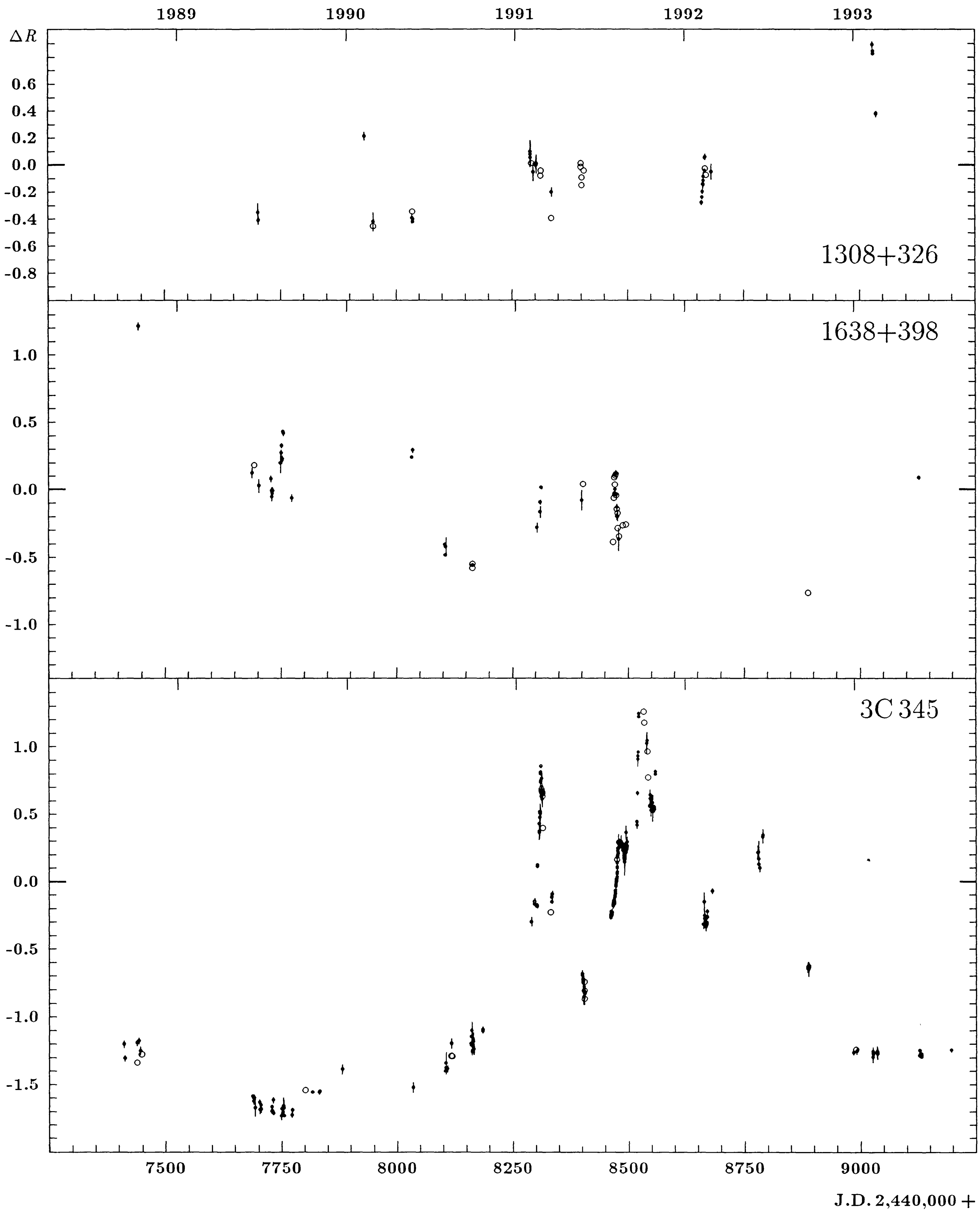

Fig. 1. continued

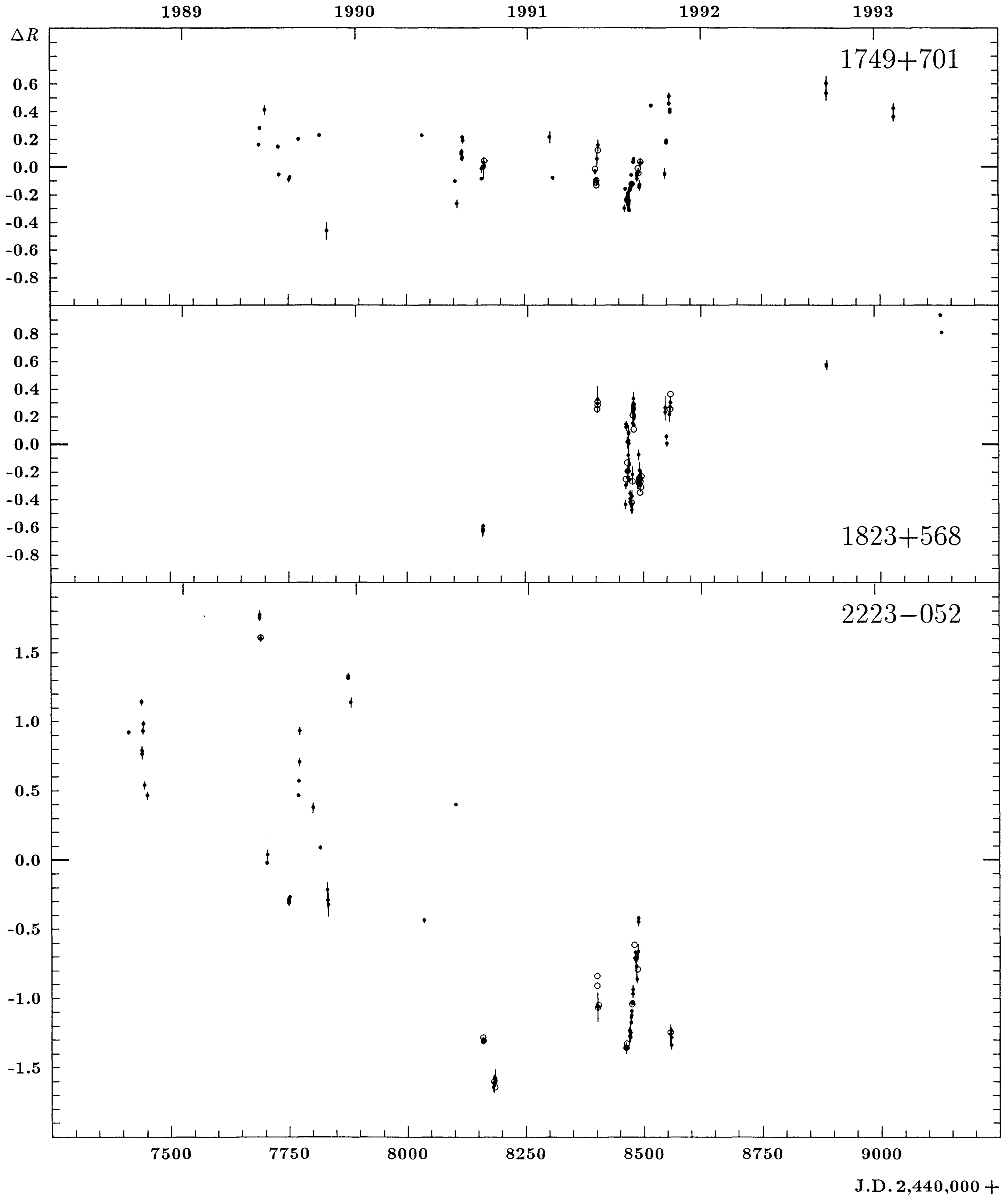

Fig. 1. continued

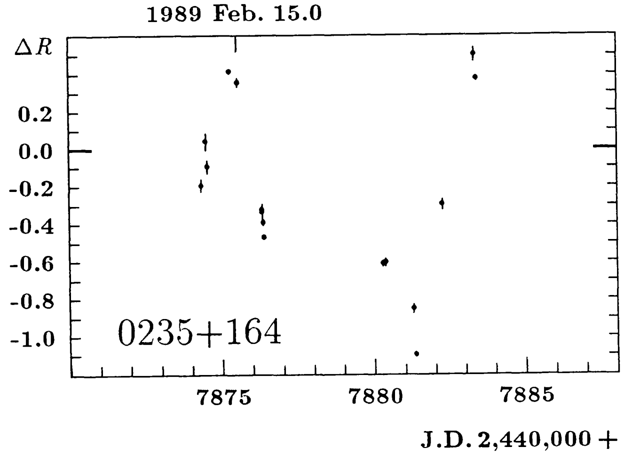

Fig. 2. Lightcurve of AO 0235+164 in February 1989. Between Feb. 20 and 22, a 1.60 mag brightening occurred within 47.5 hours

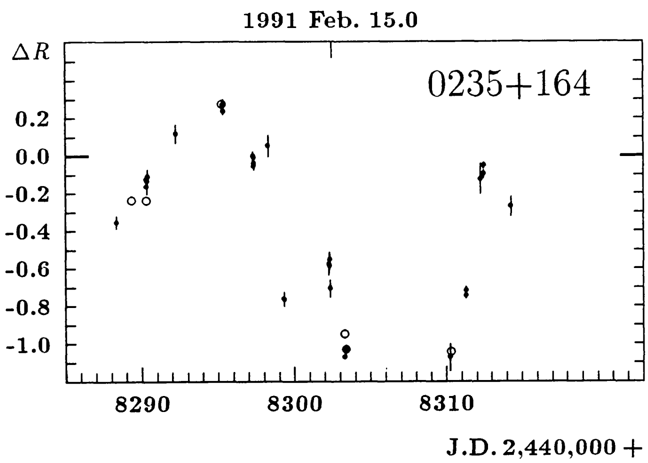

Fig. 3. Lightcurve of AO 0235+164 in February 1991

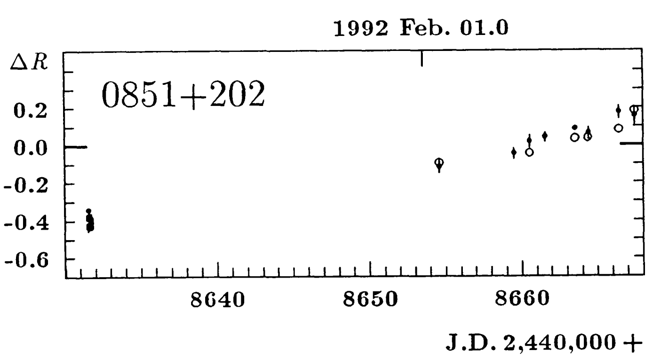

Fig. 4. HQM-lightcurve of OJ 287 (0851+202) in winter 1992

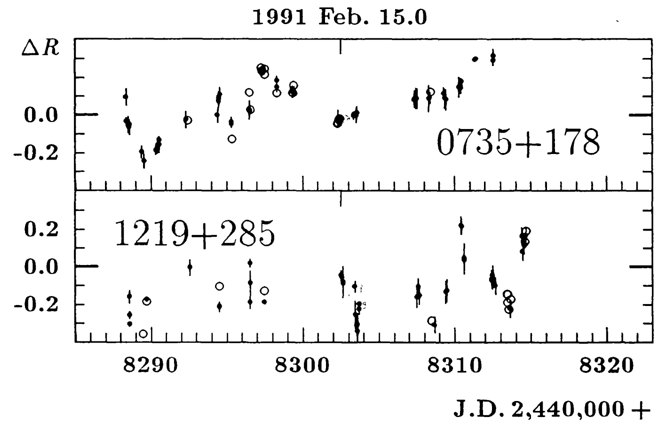

Fig. 5. Lightcurves of PKS 0735+178 and W Com (1219+285) in February 1991

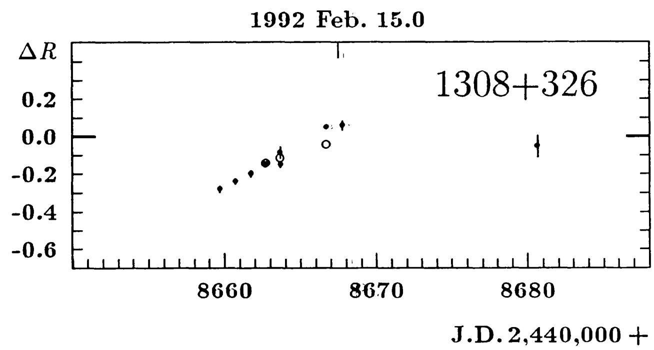

Fig. 6. HQM-lightcurve of B2 1308+326 in February 1992

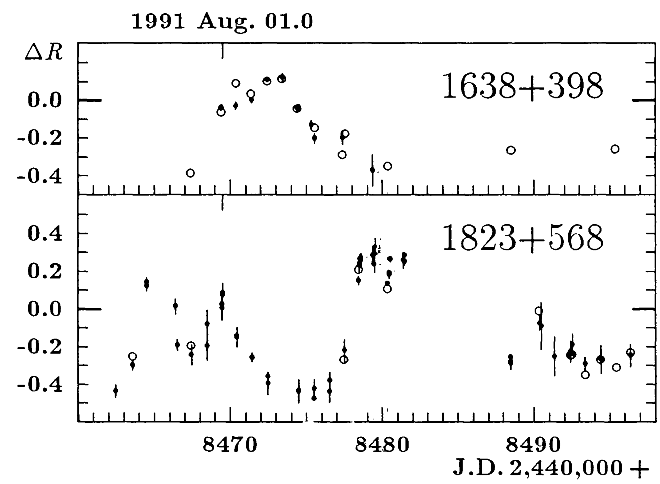

Fig. 7. Lightcurves of NRAO 512 (1638+398) and 4C 56.27 (1823+568) in August 1991

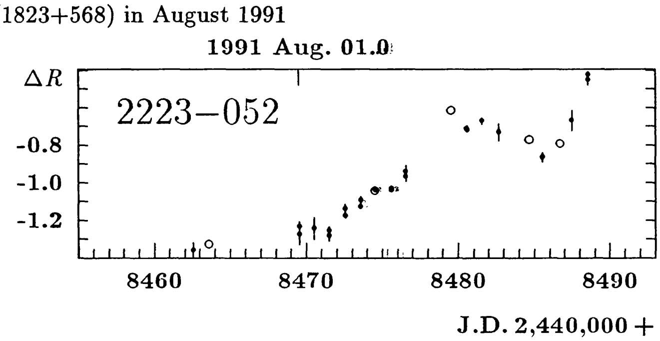

Fig. 8. Lightcurve of 3C 446 (2223−052) in August 1991

partly obtained with a 0.7 m telescope at the Landessternwarte Heidelberg by J. Heidt. The reference magnitude is $R_0 = 15.67$. The new measurements indicate that the object has reached again a state nearly as faint as prior to the 1991/92 outburst. This differs from the predicted lightcurve of Schramm et al. but does not contradict the model of a "lighthouse effect"; the new data probably indicate that the opening of the jet sets in at a shorter distance from the core (for more details see Borgeest & Schramm 1993, Camenzind 1993 and Sillanpää & Valtaoja 1993).

W1 1749+701. There is only one publication concerning variability of this BL Lac object: Four measurements obtained by Arp et al. (1976) in 1975 indicate a 0.5 mag range of variability. The HQM lightcurve has a total range of 1.0 mag and shows rapid brightness changes of a few 0.1 mag.

4C 56.27 (1823+568). There exist to our knowledge no variability studies in the literature for this BL Lac object. The HQM data have a total range of 1.2 mag. The lightcurve obtained in August 1991 is shown with higher resolution in Fig 7; some rapid brightness changes $\gtrsim 0.5$ mag occurring within a few days are obvious.

3C 446 (2223−052). The Rosemary Hill lightcurve as shown in WSLF covers the time from 1971 to 1985; data collected between 1964 and 1974 are plotted in BRZ. This BL Lac object exhibits strong, spikelike flares and slow, large-amplitude variations. Since 1984 the object showed an almost monotonic decline. The HQM lightcurve exhibits very rapid, large amplitude variations; one part, collected in August 1991 is shown in Fig. 8 with higher resolution. The most rapid variation occurred in early summer 1989 (Fig. 1) where the object faded down by 1.50 mag within 12 days. Making use of the photometric sequence of Smith et al. (1985), we were able to determine the reference magnitude of our lightcurve, $R_0 = 19.31$.

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