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Optical photometric monitoring of γ-ray loud blazars.*

I. Observations from November 1994 to November 1995

M. Villata[1], C.M. Raiteri[1], G. Ghisellini[1], G. De Francesco[1], S. Bosio[2], G. Latini[2], B. Bucciarelli[1], M. Chiaberge[2], G. Chiumiento[1], A. Cora[1], L. Lanteri[1], M.G. Lattanzi[1], G. Massone[1], A. Peila[2], F. Racioppi[1], R.L. Smart[1], F. Scaltriti[1,], and E. Anderlucci[1,**]**

[1] Osservatorio Astronomico di Torino, Strada Osservatorio 20, I-10025 Pino Torinese (TO), Italy
[2] Istituto di Fisica Generale dell'Università, Via Pietro Giuria 1, I-10125 Torino, Italy

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Abstract. The results of the optical monitoring between November 1994 and November 1995 of twenty γ-ray loud blazars included in the Torino blazar monitoring program are presented. All data were taken with the 1.05 m REOSC astrometric telescope of the Torino Astronomical Observatory, equipped with a 1242×1152 pixels charge-coupled device (CCD) camera. Observations have been carried out in the standard B, V (Johnson), and R (Cousins) bands. Source magnitudes are calculated with respect to reference stars in the same frame. For half blazar fields it was possible to perform a photometric calibration through the observation of Landolt's fields during photometric nights. In the other cases either photometric sequences from the literature were adopted or, when lacking, magnitudes were simply normalized to their minimum value. Most of the monitored objects show a more or less pronounced brightness variability on both short and long time scales. In a few cases also noticeable intranight variations were detected. Data simultaneous to pointings of the Compton Gamma Ray Observatory (CGRO) are present in our light curves: when the γ data are available they will provide a useful information in order to understand the possible correlations between the optical and γ-ray emissions. For one source (PKS 2254+074) we performed also photopolarimetry, deducing magnitudes, amount of polarization, and position angle in the $UBVRI$ bands.

Key words: quasars: general — gamma rays: theory

Send offprint requests to: M. Villata (villata@to.astro.it)

* Tables 4–48 are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

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1. Introduction

The Compton Gamma Ray Observatory (CGRO) satellite has recently discovered that highly variable and radio-loud quasars are also strong γ-ray emitters (Fichtel et al. 1994; von Montigny et al. 1995; Thompson et al. 1995). The power released by such objects above 100 MeV can overcome that in the other bands by even two orders of magnitude (see e.g. Dondi & Ghisellini 1995).

Many theoretical models have been proposed in order to explain this phenomenon and observational constraints are the only tool that can operate a choice among them. According to a group of models, the γ-ray emission can be due to inverse Compton scattering of optical photons on relativistic electrons inside a jet. In turn, the seed photons may either be produced by the same relativistic electrons through synchrotron process (Maraschi et al. 1992) or come from some external region (e.g. from the accretion disk, as in the model by Dermer & Schlickeiser 1993, or from the broad line region illuminated by the accretion disk, as in the model by Sikora et al. 1994).

Through the optical observation of strong γ-ray emitting blazars it is thus possible to obtain information about the mechanisms that rule the production of the seed photons for the γ radiation. In particular, optical monitoring simultaneous with γ observations can confirm the expected temporal correlation between the two emissions and constitutes a crucial test for the theoretical predictions. Indeed, in the case of seed photons produced by the same relativistic electrons which are responsible for the γ radiation, besides a simultaneous variability in the two bands, larger amplitude variations in the γ one are expected, since any increase in the relativistic electron number contributes twice to the γ emission. If, on the contrary, the seed photons were produced outside, the γ-ray emission intensity would vary more or less linearly with the optical one. A non-simultaneous variability would be a problem for both the models.

For the above reasons, an optical monitoring campaign has been started at the Torino Observatory since November 1994 with the aim of following the optical behaviour of a list of γ-ray loud blazars. The observations were intensified, when possible, during CGRO pointings. Collaborations with other institutes were started on some sources: as for OJ 287, 3C 66A, and AO 0235+164 we joined the OJ-94 Project (e.g. Sillanpää et al. 1996; Takalo et al. 1996a,b; Villata et al. 1996), while for OF 038, S5 0716+714, PKS 0735+178, S4 0954+658, and ON 231 a national collaboration with the Roma and Perugia groups was set up (Massaro et al. 1996; Ghisellini et al. 1996; Latini et al. 1996; Fiorucci et al. 1996; Tosti et al. 1996). In this paper we present the results of the optical monitoring of the remaining twenty blazars in the Torino program list. In Sect. 2 a description of the instrumental equipment and data reduction procedure is given and the list of the observed sources is presented. Section 3 contains, for each source, a brief summary of previously published data in the optical (and γ) band and the presentation and description of the light curves we obtained within the period from November 15, 1994 to November 7, 1995. For the BL Lac object PKS 2254+074 we show the results of $UBVRI$ photopolarimetry too. Photometric sequence calibrations are also given for ten sources. Finally, the main conclusions of this work are drawn in Sect. 4.

2. Observations and data reduction

The blazar optical monitoring program was started at the Torino Observatory in November 1994. The data have been obtained with the 1.05 m Cassegrain REOSC telescope equipped with a 1242×1152 pixels charge-coupled device (CCD) camera. The scale of the CCD is 0.47 arcsec per pixel. In order to collect images of as large a number of sources per night as possible while preserving some spectral information, we initially chose to observe in the R (Cousins) and B (Johnson) bands only. More recently we have decided to observe in the V (Johnson) band too in order to get a more complete spectral picture and to make our data more easily comparable with those of other astronomers. Exposure times in the R band range from 180 s for the brightest objects (like Mkn 421 and 3C 273) to 600 s for the faintest ones (e.g. PKS 0528+134). Flat field frames are taken against the sky both at sunset and at dawn, when possible; each time three or four frames per filter are made and then the median is calculated for the images correction. The bias level is checked several times along the night and then subtracted from the images. No dark current correction is necessary.

The data reduction is performed with a mixture of the MIDAS and Robin procedures. This latter was developed at the Torino Observatory by L. Lanteri: the point spread function is fitted by means of a circular gaussian, the background being subtracted by fitting it with an inclined plane. This method has proved to be faster than the MIDAS integrated aperture photometry and to give stabler results.

The blazars magnitude and corresponding uncertainty are derived by comparison with 3–4 reference stars in the source frame. If available, we have chosen stars included in already published photometric sequences, evaluating again, when possible, their magnitudes through the observation of Landolt's fields (Landolt 1992) and adopting our own calibration. This was performed with the SNOPY general purpose photometric reduction program contained inside the MIDAS software package. The maximum error allowed in the passage from the instrumental to the standard magnitudes is 0.05 mag.

When photometric sequences in the literature were missing, we chose reference stars of various magnitudes. In this way the brightest two objects usually allow to calculate the source magnitude with a minimum error, while stars of brightness comparable with that of the source can be used to obtain reliable error estimates (see Sect. 3). In several cases (0109+224, 0420−014, 0528+134, 1101+384, 1641+399, 1739+522, 2230+114, 2251+158, 2254+074, 2356+196) we could neither calibrate the reference stars nor find photometric sequences in the literature, so that we shall present the data as magnitude differences with respect to the minimum magnitude registered during the observational period.

In Table 1 the list of the monitored objects is presented, including their identification features (name, right ascension and declination, redshift, classification, and reference for the finding chart).

Table 2 gives information on the source emission properties at different wavelengths: in Cols. 2–4 published radio (5 GHz), X-ray (1 keV), and γ-ray (> 100 MeV) fluxes are indicated; Cols. 5 and 6 show the minimum and maximum magnitudes in the R and, when available, in the B band derived from our data (or the maximum variations ΔR and ΔB in case of no calibration); in Col. 7 the absorption coefficient in the V band is reported; finally, Col. 8 gives a list of reference numbers for the bibliography (see Table 3) relative to the quoted fluxes and A_V.

3. Results

In this section, all the observed sources are briefly introduced by quoting the main observational information available in the optical (and γ) band and the corresponding journals of observations are presented. Tables and plots of the light curves are shown, where the source magnitude is given as the average between those derived with respect to the two reference stars presenting the smallest variations in their magnitude difference: the deviation from the mean magnitude difference is shown in the figure subsets. In case that at least one of the two

Table 1. List of the monitored blazars

Source	Name	RA (2000)	Dec. (2000)	z	Class.	Finding chart
0109+224	S2	01 12 05.71	+22 44 39.2		BL Lac	Miller et al. 1983
0420−014	PKS	04 23 15.80	−01 20 33.07	0.915	HPQ	Bolton & Wall 1970
0528+134	OG 147	05 30 56.42	+13 31 55.15	2.07	LPQ	Condon et al. 1977
0827+243	OJ 248	08 30 52.09	+24 10 59.82	2.05	LPQ	Hazard et al. 1968
0836+710	4C 71.07	08 41 24.37	+70 53 42.17	2.172	LPQ	Kühr et al. 1987
0906+430	3C 216	09 09 33.45	+42 53 45.96	0.668	HPQ	Penston et al. 1971
1101+384	Mkn 421	11 04 27.25	+38 12 31.7	0.031	BL Lac	Craine 1977
1156+295	4C 29.45	11 59 31.77	+29 14 43.61	0.729	HPQ	Smith et al. 1985
1226+023	3C 273	12 29 06.70	+02 03 08.60	0.158	LPQ	Smith et al. 1985
1229−021	PKS	12 32 59.99	−02 24 05.30	1.045	LPQ	Craine 1977
1253−055	3C 279	12 56 11.17	−05 47 21.52	0.538	HPQ	Sandage & Wyndham 1965
1510−089	PKS	15 12 50.46	−09 06 00.12	0.361	HPQ	Craine 1977
1611+343	DA 406	16 13 41.06	+34 12 47.91	1.404	LPQ	Grueff & Vigotti 1972
1633+382	4C 38.41	16 35 15.41	+38 08 04.42	1.814	LPQ	Pauliny-Toth et al. 1973
1641+399	3C 345	16 42 58.81	+39 48 37.00	0.595	HPQ	Craine 1977; Smith et al. 1985
1739+522	4C 51.37	17 40 36.7	+52 11 43.3	1.379	HPQ	Cohen et al. 1977
2230+114	CTA 102	22 32 36.41	+11 43 50.91	1.037	HPQ	Sandage & Wyndham 1965
2251+158	3C 454.3	22 53 57.67	+16 08 53.40	0.859	HPQ	Craine 1977
2254+074	PKS	22 57 17.30	+07 43 12.31	0.19	BL Lac	Craine 1977
2356+196	PKS	23 58 45.9	+19 55 18	1.066	LPQ	Shimmins et al. 1975

Table 2. Emission properties of the monitored blazars

Source	$F_{\rm R}$ (Jy)	$F_{\rm X}$ (μJy)	F_γ ($10^{-7}\,{\rm cm}^{-2}\,{\rm s}^{-1}$)	R	B	A_V	References
0109+224	0.70	0.15	< 0.6	$\Delta R = 1.10$	15.46–16.52	0.27	19; 14; 8; 7
0420−014	3.72	0.52	4.5 ± 1.0	$\Delta R = 2.64$	$\Delta B = 2.64$	0.59	19; 17; 8; 6
0528+134	4.3	1.59	8.4 ± 1.0	$\Delta R = 0.56$		5.28	19; 33; 12; 33
0827+243	0.672	0.0967	1.8 ± 0.4	16.05–17.23		0.068	10; 31; 8; 18
0836+710	2.57		2.1 ± 0.4	16.65–16.77		0.083	13; 23; 18
0906+430	1.80	0.16	3.2 ± 0.9	18.25–19.05		0.029	22; 1; 23; 18
1101+384	0.73	19.6	2.36 ± 0.76	$\Delta R = 0.36$	$\Delta B = 0.41$	0.11	9; 32; 25; 20
1156+295	1.65	0.87	6.3 ± 1.5	14.03–15.78	14.78–16.59	0.10	9; 21; 24; 20
1226+023	44.6	21	2.38 ± 0.45	12.47–12.51	12.85–12.91	0.16	13; 27; 25; 26
1229−021	1.07	0.08	1.2 ± 0.4	16.39–16.46		0.03	22; 31; 8; 18
1253−055	16.10	0.63	28 ± 4	14.61–16.63	15.66–17.75	0.045	30; 32; 11; 18
1510−089	3.35	0.84	2.7 ± 0.6	16.61–17.24	17.43–18.06	0.43	13; 21; 23; 21
1611+343	2.67	0.05	3.3 ± 0.6	17.00–17.48	17.71–18.29	0.1	4; 1; 24; 2
1633+382	4.08	0.08	10	14.96–17.67	16.98–17.80	0.069	5; 2; 29; 2
1641+399	12.4	0.7	1.3 ± 0.6	16.86–17.53	17.44–17.93	0.046	3; 32; 28; 16
1739+522	1.98		3.6	$\Delta R = 1.19$	$\Delta B = 0.22$	0.098	22; 29; 18
2230+114	3.61	0.43	2.7 ± 0.4	$\Delta R = 0.63$		0.36	22; 31; 8; 7
2251+158	23.3	5.5	13.17 ± 2.07	$\Delta R = 0.36$	$\Delta B = 0.37$	0.39	30; 15; 25; 20
2254+074	1.19	0.15	< 0.8	$\Delta R = 0.60$		0.32	22; 32; 8; 7
2356+196	0.709		1.7 ± 0.4	$\Delta R = 0.11$		0.068	10; 23; 18

Table 3. References for Table 2

1	Biermann et al. 1987
2	Bloom & Marscher 1991
3	Brown et al. 1989
4	Browne & Murphy 1987
5	Browne & Perley 1986
6	Elvis et al. 1989
7	Falomo et al. 1994
8	Fichtel et al. 1994
9	Gear et al. 1994
10	Gregory & Condon 1991
11	Hartman et al. 1992
12	Hunter et al. 1993
13	Kühr et al. 1981
14	Ledden & O'Dell 1985
15	Makino 1989
16	Malaguti et al. 1994
17	Maraschi et al. 1986
18	NASA/IPAC Extragalactic Database (NED)
19	Perley 1982
20	Pian & Treves 1993
21	Sambruna et al. 1994
22	Stickel et al. 1994
23	Thompson et al. 1993
24	Thompson et al. 1994
25	Thompson et al. 1995
26	Ulrich et al. 1980
27	Unwin et al. 1985
28	von Montigny et al. 1993
29	von Montigny et al. 1995
30	Wall & Peacock 1985
31	Wilkes et al. 1994
32	Worrall & Wilkes 1990
33	Zhang et al. 1994

objects has a brightness comparable with that of the source, these deviations can be assumed as reliable error estimates. In practice, errors are calculated as the maximum between the above deviation and a given value (from 0.02 to 0.15 mag) corresponding to the typical uncertainty for the considered source and filter. For intranight variability, the lower limit to the error may be diminished.

In the following, finding charts with identification of the reference stars are also shown for those sources for which the calibration of a new, unpublished photometric sequence was performed. The relative star magnitudes in the R, V, and B bands are given in Table 4 (see footnote to the title).

Usually, the best sampled light curves are those in the R band and the worst ones are those in the V band. When the number of observations in the V band was lower than four, they have been collected in Table 5.

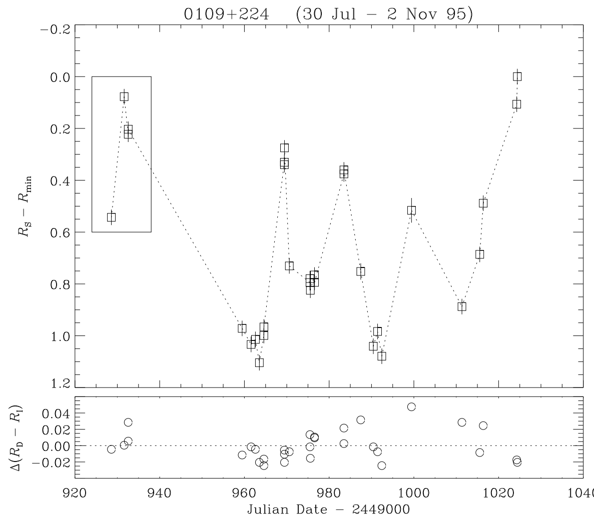

Fig. 1. Light curve of S2 0109+224 in the R band; the box indicates the EGRET pointing period

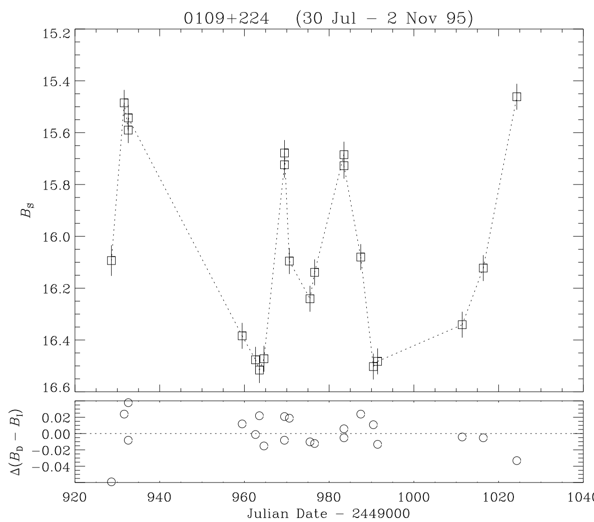

Fig. 2. Light curve of S2 0109+224 in the B band

3.1. S2 0109+224

The most impressive optical variation of this source was registered in 1943 when, after an outburst, its brightness decreased by 3.07 mag in 1 year (Pica 1977). The object was monitored by Pica et al. (1988) from 1976 to 1988. During the first 4 years it showed a B magnitude around 16; in 1980–1981 its luminosity decreased by 1 mag and maintained this value until 1987, except for one flare in fall 1981. A flickering of 0.6−0.7 mag characterized the whole observational period. The total variability range was $\Delta B = 1.94$, with minimum and maximum values of 15.48 and 17.42 mag. In their optical monitoring program, Xie et al. (1994) found brightness variations in the period from 1985 to 1991 between 16.78 and 15.26 mag in the V band and from 17.36 to 15.68 mag in the B band, with a flare of 0.49 mag in V and 0.68 mag in B registered in

70 minutes on December 9, 1985. Other observations of 0109+224 were performed by Sillanpää et al. (1991) from 1985 to 1989, showing a variability range of about 0.8 mag in the V band, and by Valtaoja et al. (1993) from 1990 to 1992, who registered a V magnitude oscillating between 16.32 and 15.05.

Our data in the R, V, and B bands (see Tables 6-5 and 7, respectively, and Figs. 1 and 2) confirm the oscillating behaviour of this source, with a maximum variation of 1.10 mag in the R band, where we have no calibration of the field comparison stars. In the B band, by using the photometric sequence by Miller et al. (1983), the brightness varies between 16.52 and 15.46 mag, showing values comparable with those of the previous campaigns. The box in Fig. 1 shows the pointing period of the Energetic Gamma Ray Experiment Telescope (EGRET) on board CGRO, during which the optical data reveal a sensible variation, slightly wider in the B band (see Fig. 2). Another different behaviour between the two bands can be found in the last data: on $\overline{\mathrm{JD}} = 1016$ ($\overline{\mathrm{JD}} = \mathrm{JD} - 2449000$) the source was relatively fainter in B than in the other two bands ($B - V = 0.74$), as can also be deduced by comparing the following brightening $\Delta B = 0.66$ with $\Delta V = 0.39$ and $\Delta R = 0.38$, leading to $B - V = 0.47$ on $\overline{\mathrm{JD}} = 1024$. Moreover, in the last night we have the only sensible intranight variation: $\Delta R = 0.11$ in 3.5 hours.

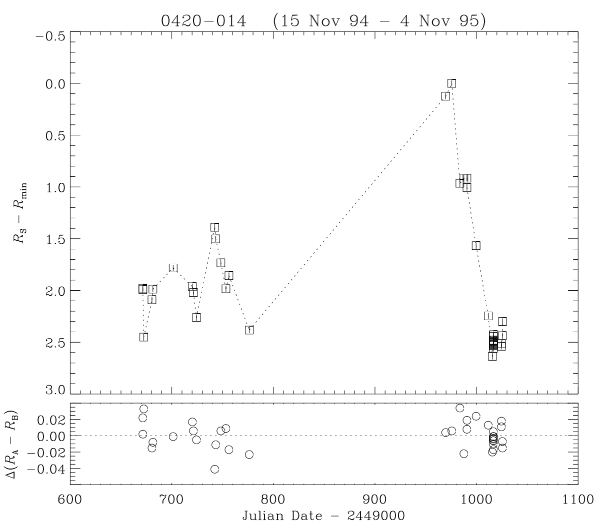

Fig. 3. Light curve of PKS 0420 − 014 in the R band

3.2. PKS 0420−014

This quasar has revealed a strong variability in the optical band. Webb et al. (1988) present its light curve from April 1969 to January 1986: the source is very active and exhibits variations up to 2 mag on a few year time scale. A noticeable flare was detected in late 1979, when a 1.3 mag increase in 5 days was registered, followed by a 1.7 mag

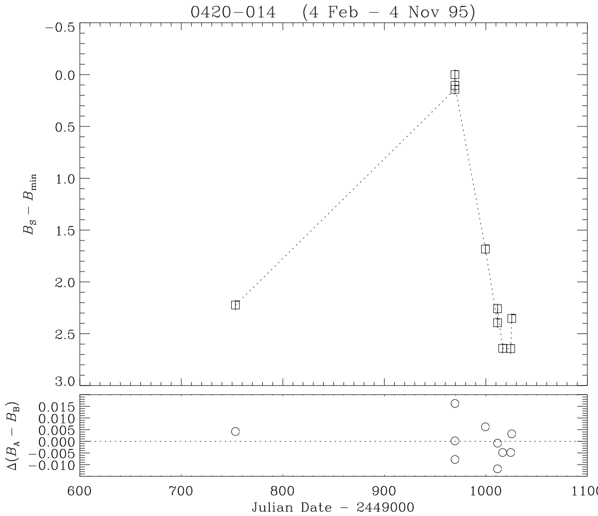

Fig. 4. Light curve of PKS 0420 − 014 in the B band

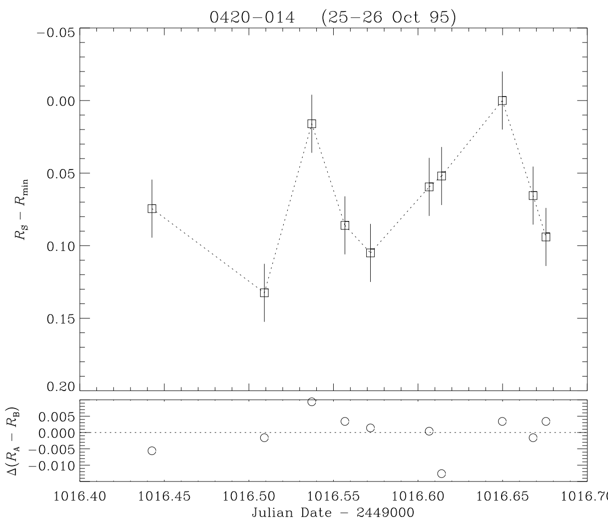

Fig. 5. Intranight light curve of PKS 0420−014 in the R band

decrease in 23 days. A strong variability also comes out from the 20 year light curve (from 1970 to 1990) reported by Smith et al. (1993). Their data, in the photographic band, show a maximum magnitude variation of 2.8 and three maxima at the beginning of 1975, 1978, and 1982. Other three maxima were observed at the beginning of 1990, 1991, and 1992 by Wagner et al. (1995), who also noticed fast flux variations with time scales of the order of 1–10 days. The flare of February–March 1992 was the highest optical state observed until then (14.6 mag in the R band); in that period EGRET registered the highest γ flux density. Moreover, since low fluxes or non detections at γ energies correspond to low optical states, a direct correlation between the optical and γ emissions was suggested.

We have no calibration of the field comparison stars of this source; consequently, in Tables 8–10 and in Figs. 3–5 the source magnitude is given as the deviation from the minimum value registered during the monitoring period. Our data confirm the strong variability; the most noticeable variation was the fall of 2.64 mag in 40 days observed from September 15 to October 25, 1995 in the R band. A rough calibration leads to the estimate $R = 14.2$ for the peak registered on September 15, 1995 ($\overline{\text{JD}} = 975.6$), which would thus represent the highest optical state ever seen.

We also checked for microvariability in the R band on October 25–26, 1995 ($\overline{\text{JD}} = 1016$): the steepest variation detected was 0.12 mag in 40 minutes (see Fig. 5).

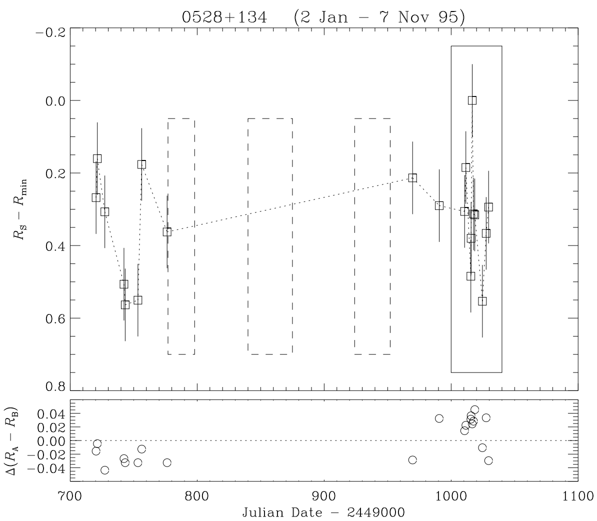

Fig. 6. Light curve of OG 147 in the R band; boxes indicate EGRET pointing periods

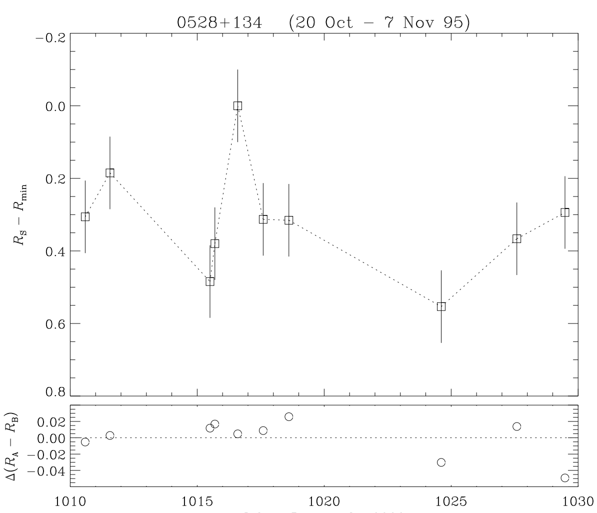

Fig. 7. Enlargement of the solid box shown in Fig. 6, including data simultaneous with the EGRET pointing of October 17–31, 1995

3.3. OG 147 (0528+134)

The peculiarity of this quasar is that the density of the neutral hydrogen column derived from X-ray observations is very high, so that its optical emission must be strongly absorbed, probably by the host galaxy and/or by a galaxy on the line of sight (Zhang et al. 1994). The source has been pointed by EGRET several times, revealing a very intense, strongly variable, γ-ray emission and a steep spectrum. This latter feature is confirmed by the COMPTEL detection (Collmar et al. 1994).

Because of its optical faintness we took images of OG 147 in the R band only, with exposure times of typically 600 s. No calibration of the reference stars was available. The results are shown in Table 11 and in Figs. 6 and 7, where the source magnitude is normalized to its minimum value. During the observational period, the maximum variation of the source brightness was 0.56 mag, while the fastest one was an increase of 0.48 mag in 1 day ($\overline{\text{JD}} = 1015-1016$). In Fig. 6 the dashed boxes indicate pointing periods by EGRET in which we have no data because of the solar conjunction, while the solid box includes data that we took around the EGRET pointing of October 17–31, 1995 ($\overline{\text{JD}} = 1008-1022$). These data are better shown in Fig. 7: in the middle of the EGRET period we detected both the fastest variation and the highest source brightness.

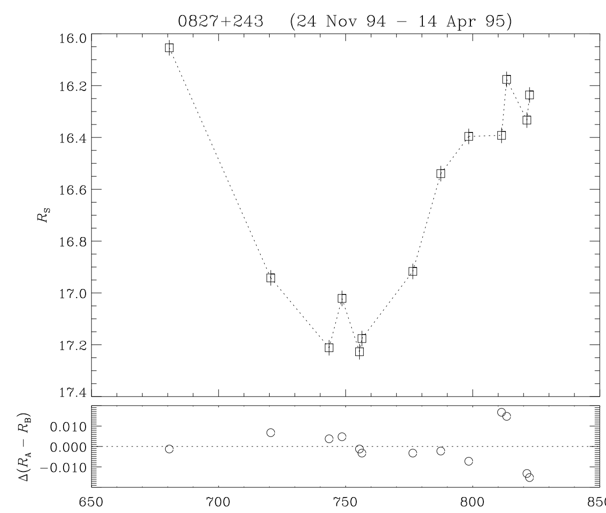

Fig. 8. Light curve of OJ 248 in the R band

3.4. OJ 248 (0827+243)

There is not much information on this source in the literature. Previous data in the V band give magnitudes of 17.26 (Hewitt & Burbidge 1987) and 17.5 (Maoz et al. 1993). Nothing was known about possible flux variations. Redshift estimates from the emission lines have produced

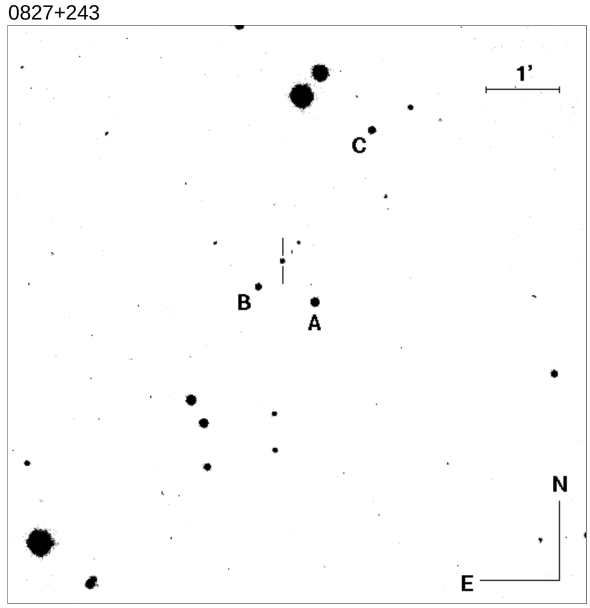

Fig. 9. Finding chart of OJ 248

different results: on one side Hewitt & Burbidge (1987) obtained $z = 0.939$ (which is close to the value of 0.941 derived by Steidel & Sargent (1991)), while Véron-Cetty & Véron (1987) got $z = 2.05$.

The results of our monitoring campaign in the R band are shown in Table 12 and Fig. 8, while two data in the B band are presented in Table 13 and the only observation in the V band in Table 5. The photometric sequence that we chose is shown in Fig. 9 (see footnote to the title) and the corresponding stellar magnitudes are given in Table 4. The source has revealed a noticeable variability, with a decrease of 1.16 mag in the first 63 days and a subsequent increase of 1.05 mag in 58 days.

3.5. 4C 71.07 (0836+710)

The interesting features of this quasar are the strong γ-ray emission and fast optical variability of small amplitude. Its optical monitoring has been started in 1989 by Wagner and coworkers (Wagner et al. 1990), who found variations in the R band below 3%, inside the errors. An optical flare was detected in February 1992, with an increase $\Delta R \gtrsim 0.5$ and a maximum brightness $R = 16.54$ (von Linde et al. 1993). After that, and up to mid 1993, the source magnitude has remained more or less constant around $R = 16.6$ (Schramm et al. 1994). The source was observed by EGRET just before and just after the flare, showing a doubling of the flux and a steep spectrum (Thompson et al. 1993).

Tables 14 and 15 and Fig. 10 show our results from November 16, 1994 to April 14, 1995. One observation in the V band is reported in Table 5. The mean magnitude

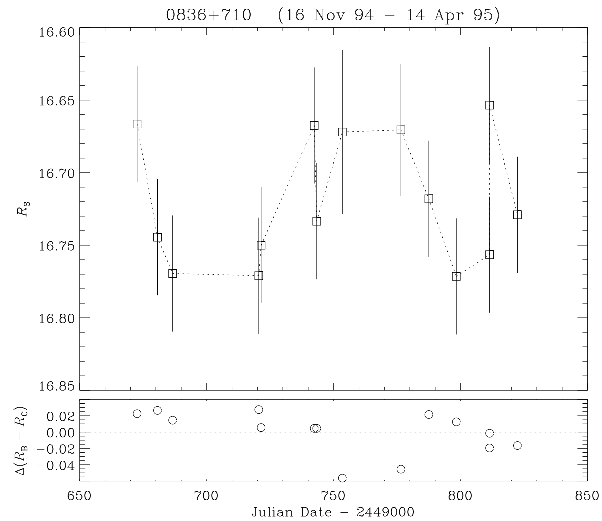

Fig. 10. Light curve of 4C 71.07 in the R band

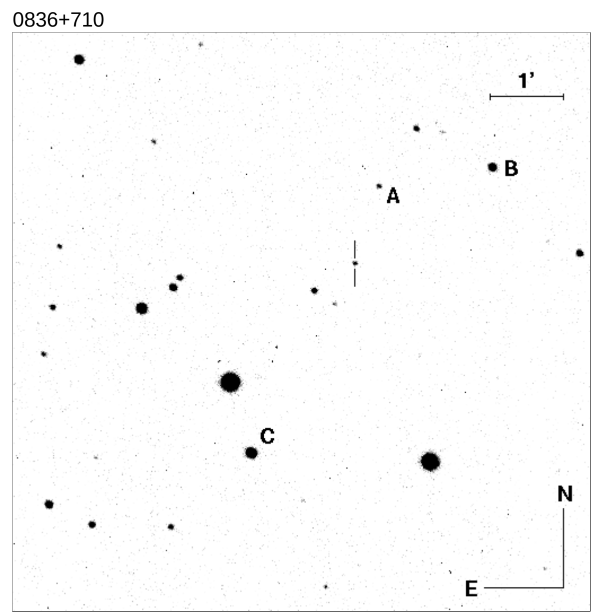

Fig. 11. Finding chart of 4C 71.07

in the R band was ~ 16.7 and no appreciable brightness variations were detected. The source magnitude calibration was performed by adopting the photometric sequence presented in Fig. 11 and in Table 4.

3.6. 3C 216 (0906+430)

This was one of the first quasars to be discovered; its classification is controversial, since 0906+430 presents some typical features of BL Lacertae objects (high and variable optical polarization) as well as those of highly polarized quasars (HPQ) (strong emission lines). According to Fejes et al. (1992) the source must be considered an

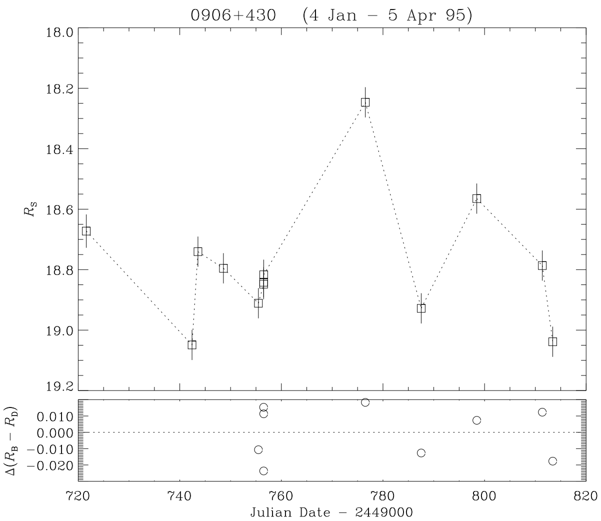

Fig. 12. Light curve of 3C 216 in the R band

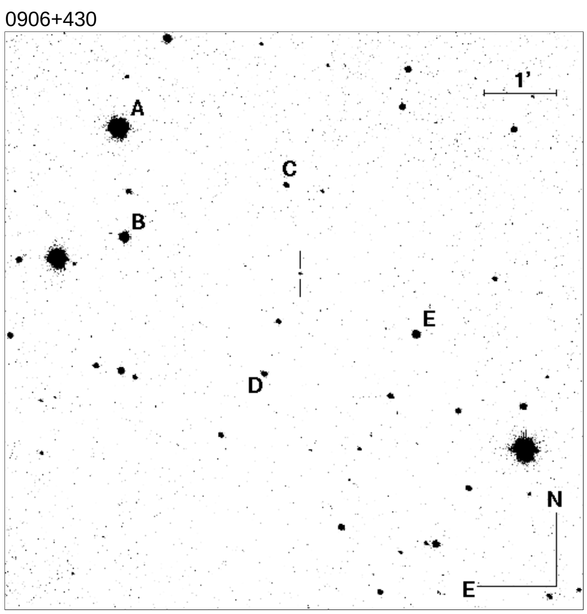

Fig. 13. Finding chart of 3C 216

optically violent variable (OVV), i.e. an active galactic nucleus (AGN) with violent optical variations and high polarization, but monitoring studies have been lacking so far, hence it is not known whether the source is strongly variable or not.

The light curve of 0906+430 that we obtained (in the R band) is plotted in Fig. 12 and the corresponding data are given in Table 16. Fig. 13 shows the field of 3C 216; the estimated magnitudes of the four reference stars we have adopted are given in Table 4. One of them (Star B) has been already calibrated by Penston et al. (1971), who found $V = 14.02$ and $B = 14.93$. The other star calibrated by the above authors, Star A in Fig. 13, was not used for the analysis since it often saturates the pixel capacity in our R frames. During our observational period the source has always been faint, with a maximum magnitude variation of 0.80.

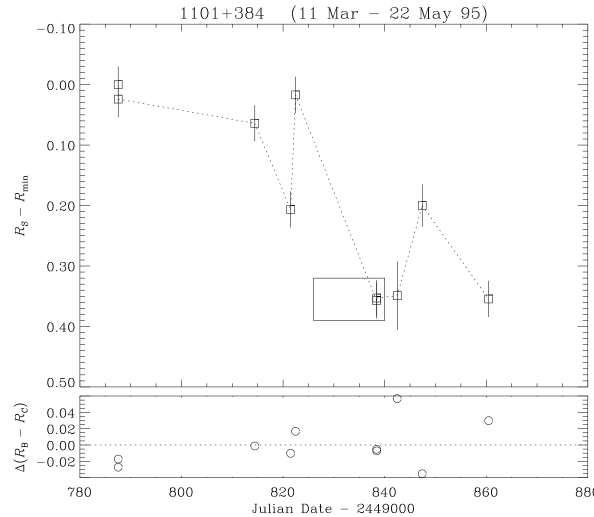

Fig. 14. Light curve of Mkn 421 in the R band; the box indicates the EGRET pointing period

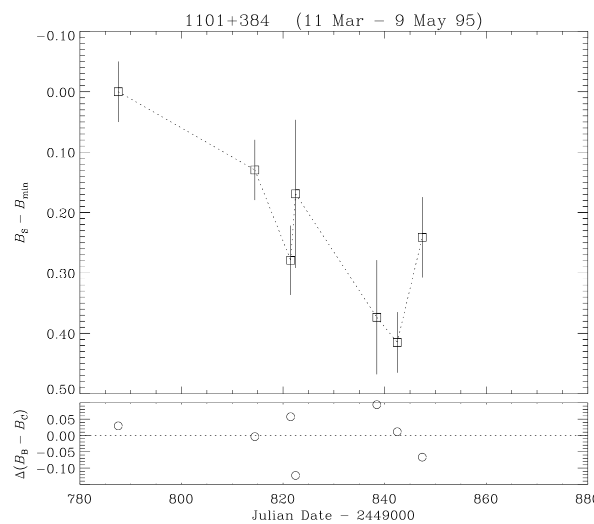

Fig. 15. Light curve of Mkn 421 in the B band

3.7. Mkn 421 (1101+384)

Miller (1975) reports the light curve of Mkn 421 in the B band from 1899 to 1975. The main features are: the presence of a luminosity maximum on January 19, 1934, when the source reached $B = 11.6$; the high luminosity state shown in 1901, 1916, and 1936, with $B < 12.5$; the fast brightness decline of 1.6 mag in 16 days observed in January 1942. The maximum magnitude variation over the considered period was $\Delta B = 4.7$. According to Xie et al. (1988), a variability time scale of 2.5 hours can be inferred (on January 13, 1986 a 1.4 mag increase in the B band was registered in that time), from which the authors estimate the mass of the Mkn 421 black hole to be about $1.810^7\,M_\odot$. More recently, another flare was announced by Hurst (1992), who observed a 0.9 mag increase in the V band in about 40 days. Mkn 421 was the first BL Lac object to be revealed in the γ band; its γ flux is however weak. It is also the only AGN, besides Mkn 501, that was detected at TeV energies by the Whipple Observatory High Resolution Atmospheric Cerenkov Camera (Kerrick et al. 1995). In particular, a flare at TeV energies was registered in May 1994; in the same period the ASCA satellite detected a high X-ray flux, while EGRET did not observe a flux change and the International Ultraviolet Explorer (IUE) satellite measured a normal ultraviolet (UV) flux. Another multifrequency campaign was performed in April–May 1995 when observations by the Whipple and ASCA observatories showed a high state in both the energy bands (Takahashi et al. 1995; Buckley et al. 1995).

A photometric sequence was calibrated by Véron & Véron (1975) in the B band, but all their stars (except Star 1) are too far from the source to be included in our frames. Therefore, the data in Tables 17 and 18 and in Figs. 14 and 15 are expressed as magnitude differences with respect to the minimum value registered.

The maximum magnitude variation that we detected is about 0.4 in both the R and B bands, the steepest variation being 0.19 mag in 1 day (R band). The box in Fig. 14 shows the EGRET pointing period.

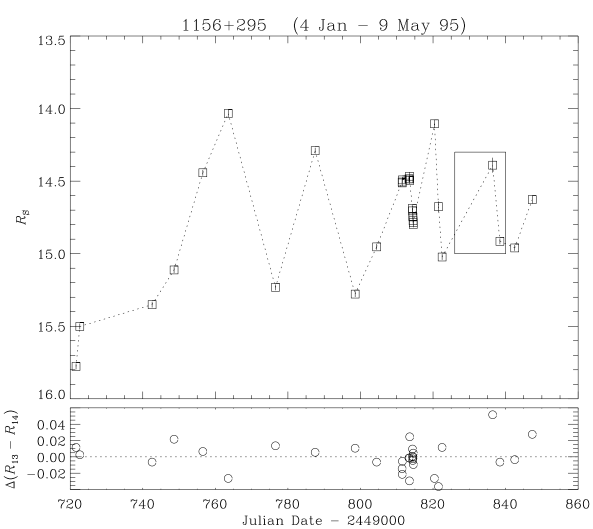

Fig. 16. Light curve of 4C 29.45 in the R band; the box indicates the EGRET pointing period

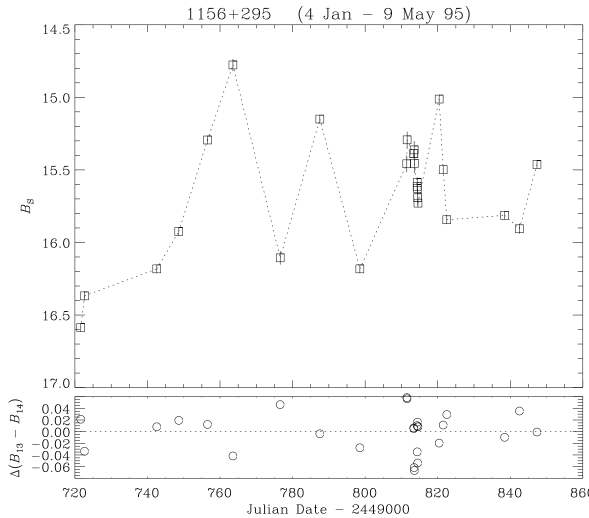

Fig. 17. Light curve of 4C 29.45 in the B band

3.8. 4C 29.45 (1156+295)

This quasar has been recognized to be an OVV (Stockman 1978). After many years of inactivity followed by a few years of slowly increasing activity, in spring 1981 a strong outburst was detected by Wills et al. (1983). The brightness increase was ~ 5 mag and the high activity state lasted about 1 year; in this period the optical light curve revealed a small amplitude variability on half an hour time scale. Another big outburst of ~ 2.5 mag was observed in 1985 (Webb et al. 1988). More recently, activity in the γ-ray, optical, and millimeter bands has been reported (Webb et al. 1995), the EGRET data revealing a flare in the γ-ray emission of several $10^{-6}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ (hence about one order of magnitude greater than the previous detection in 1991 and one of the highest fluxes ever observed in an AGN) on April 27, 1995.

The journals of our observations in the R and B bands are shown in Tables 19 and 20, respectively; the corresponding light curves are plotted in Figs. 16 and 17. One observation in the V band is included in Table 5.

For magnitude calibration we used the stars of the photometric sequence by Smith et al. (1985), but adopted our magnitude estimates (see Table 4), which are in good agreement with the values derived by the above authors.

The source has always been actively variable over all the monitoring period (see also Raiteri et al. 1996), showing a maximum oscillation amplitude of about 1.8 mag in both the R and B bands; the steepest variation was a decrease $\Delta R = 0.91$ in 2 days ($\overline{\mathrm{JD}} = 820-822$). A not negligible intranight variability was seen on April 7: a quasi linear decrease having a slope comparable with that of the above steepest drop.

The box in Fig. 16 indicates the period of EGRET pointing: unfortunately we have only a couple of data and in particular no data simultaneous with the γ flare occurred on April 27, but one observation on April 28 reveals a high optical state.

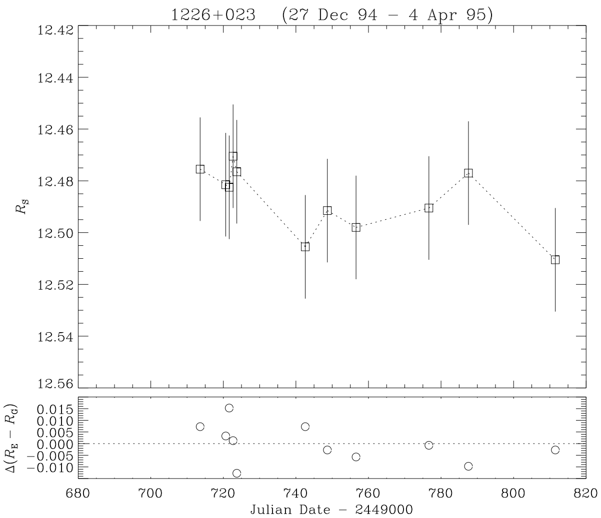

Fig. 18. Light curve of 3C 273 in the R band

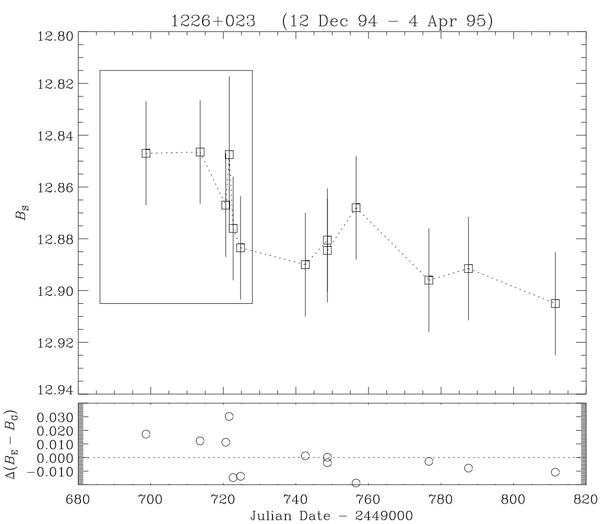

Fig. 19. Light curve of 3C 273 in the B band; the box indicates the EGRET pointing period

3.9. 3C 273 (1226+023)

This is a very bright and consequently very famous quasar. Among its main features one can quote the optical jet and the existence of a UV excess (blue bump) in the spectrum, whose luminosity is comparable with or even greater than the γ one. The source does not show a high optical activity: variations less than 1 mag were reported after several years of observations. An optical flare was detected at the beginning of 1983 (Sadun 1985; Sillanpää et al. 1988), the visual magnitude reaching 12.17. The first detection of 3C 273 at γ energies was obtained by the COS B satellite in July 1976 and then in June 1978. Subsequently, it was observed by the instruments OSSE (50 keV – 10 MeV), COMPTEL (1–30 MeV), and EGRET (30 MeV – 20 GeV) on board CGRO. This allowed to reconstruct the spectrum of the quasar in the γ band (Johnson et al. 1995).

The results of our monitoring campaign for 3C 273 are presented in Tables 21–23 and in Figs. 18 and 19. For the magnitude calibration we have adopted the field comparison stars chosen by Smith et al. (1985). Our photometric calibration in the R and B bands (see Table 4) gave results in good agreement with those determined by the above authors. The box in Fig. 19 shows the period of EGRET pointing. We have not observed significant variations in the source brightness during all the considered period.

3.10. PKS 1229−021

There is not much information about this quasar in the literature. Pica et al. (1988) report on 34 observations in the photographic system relative to the period from May 1971 to April 1987: the average magnitude is 16.72 and the minimum one is 16.28, the total observed range of variation being 0.94 mag. Wilkes et al. (1994) quote $B = 17.23$ and $V = 16.75$ from the catalogue of Véron-Cetty & Véron (1987).

Figure 20 shows the comparison stars we chose in the field of PKS 1229−021; their magnitudes are reported in Table 4. Our data in the R band are given in Table 24; one observation in the V band is included in Table 5. As can be seen, we found a mean magnitude in the R band of 16.42 with no significant variations, and a value of 16.75 mag in the V one, in agreement with published data.

3.11. 3C 279 (1253−055)

This is a very active quasar, showing flares at all wavelengths. It has been classified as an OVV by Webb et al. (1990), who present its historic light curve from 1927 to 1990. In the period before 1951, a series of flares with $\Delta B = 3$−4 are discernable, as well as a very violent outburst in 1938, when the source brightness rose from $B \sim 18$ to $B = 11.27$ in about 1.5 years. After 1951 the object is less active, flares exhibiting a smaller amplitude ($\sim$ 2 mag). A big outburst was observed in 1988, when the magnitude $B = 12.13$ was reached, with an increase from $B = 14.00$ to the maximum brightness in 24 hours. Other two flares were detected in 1989 and in 1992, this latter being of particular interest since simultaneous observations in the γ and UV bands were made (Netzer et al. 1994). In general, the γ emission of 3C 279 appears very variable, with a typical time scale of about 1 day. It has been detected by both EGRET and COMPTEL on

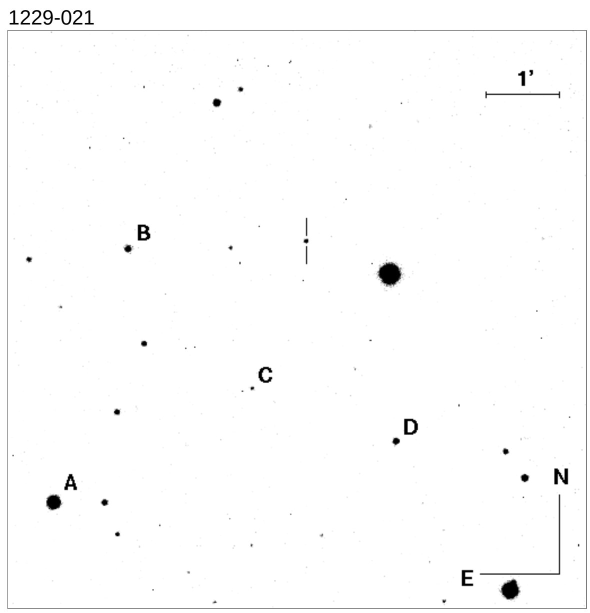

Fig. 20. Finding chart of PKS 1229−021

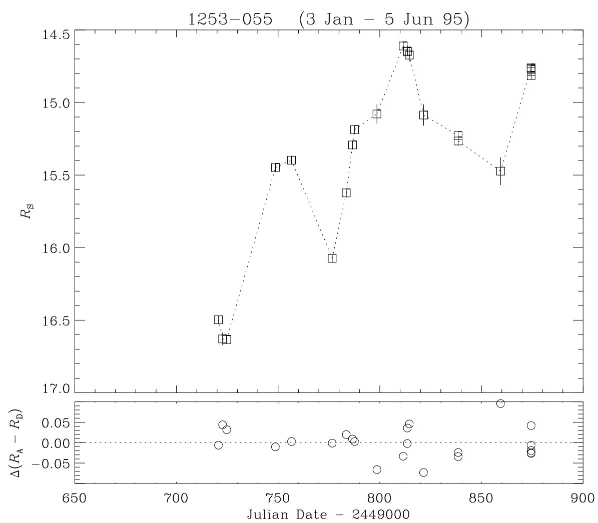

Fig. 21. Light curve of 3C 279 in the R band

board CGRO, allowing the spectrum at γ energies to be derived.

The results of our observations are given in Tables 25–27 and in Figs. 21 and 22. Our data confirm the large variability of the source brightness: we registered an overall 2 mag variation in both the R and B bands. The box in Fig. 22 shows the EGRET pointing period: a fall of 1.09 mag was observed at that time.

The field reference stars that we chose for magnitude calibration are shown in Fig. 23; their magnitudes are given in Table 4. We have to notice that Star B is actually a variable object with a peculiar spectrum, presenting fast

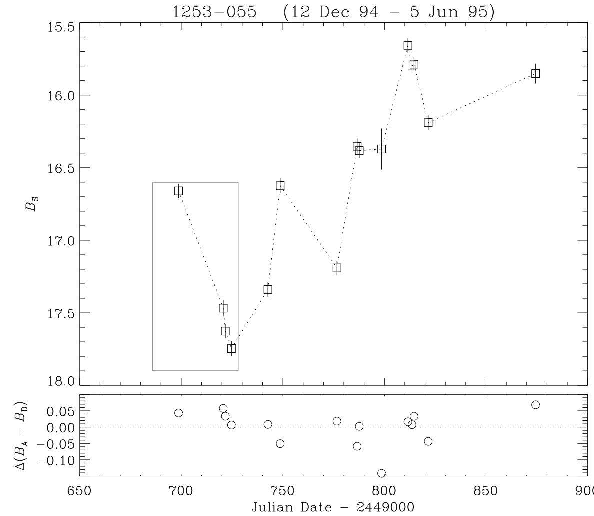

Fig. 22. Light curve of 3C 279 in the B band; the box indicates the EGRET pointing period

variations especially in the B band (up to about 1 mag in 1 day), and thus it cannot be adopted as comparison star.

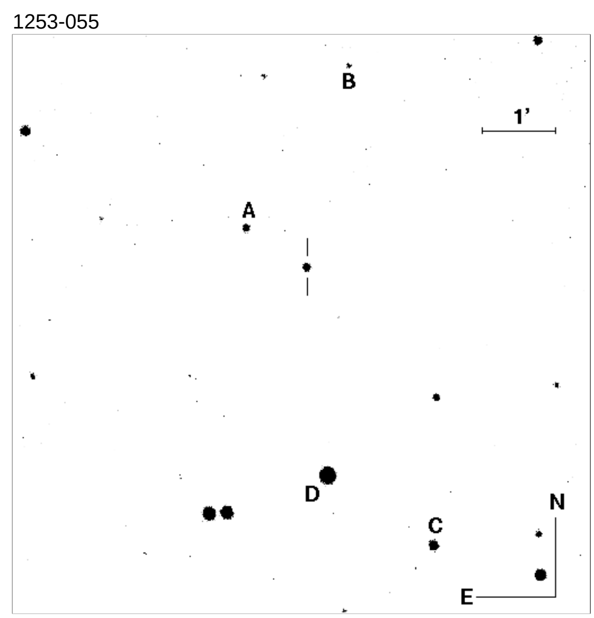

Fig. 23. Finding chart of 3C 279

3.12. PKS 1510−089

This quasar presents strong spectral analogies with 3C 273: in both sources a pronounced UV excess, a very flat X spectrum, and a steep γ spectrum are found. From the analysis of observational data from 1933 to 1952 Liller & Liller (1975) report a maximum brightness variation

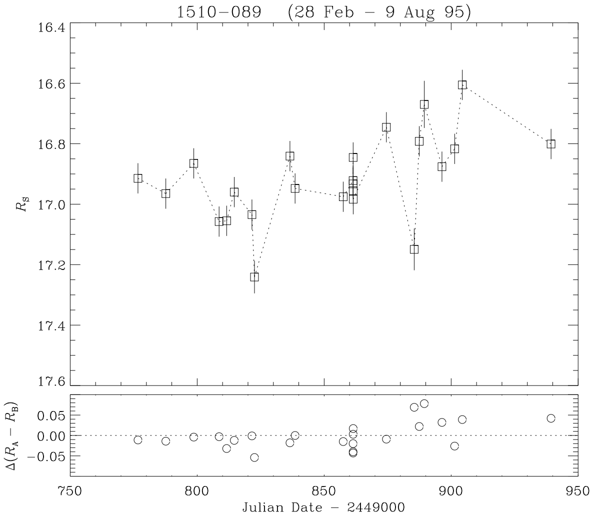

Fig. 24. Light curve of PKS 1510−089 in the R band

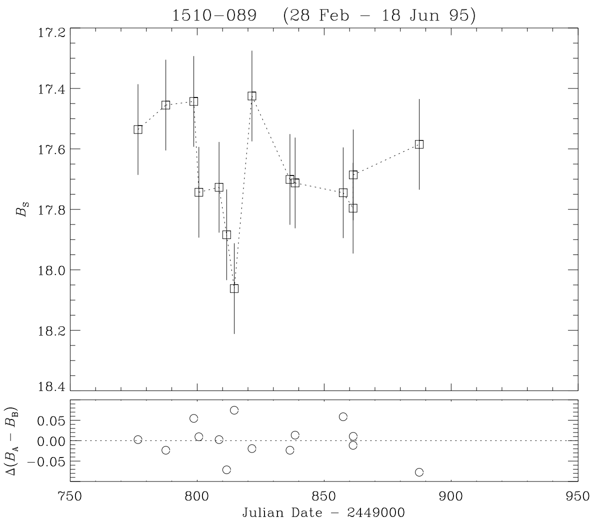

Fig. 25. Light curve of PKS 1510−089 in the B band

of 5.4 mag in the B band. Between 1935 and 1945 the mean magnitude is $B \sim 15.5$; during 1946 the brightness increases and stabilizes around $B = 14.8$ during 1947. In 1948 the quasar undertakes a period of intense activity, during which two maxima separated by 57 days are observed: in one of these the source magnitude reaches $B = 11.8$. Later on the brightness decreases down to $B = 15$ in 1952. Between 1968 and 1977 a further slow decrease is seen. After a maximum in 1987.3, the quasar luminosity rapidly falls again (Pica et al. 1988).

The data we collected during our monitoring campaign are presented in Tables 5, 28, and 29, and in Figs. 24 and 25. The comparison stars adopted are shown in Fig. 26; their magnitudes are given in Table 4. Small amplitude oscillations are visible on short time scales, the total maximum variation being 0.63 mag in both the R and B bands. A peculiarity of this source is the evidence

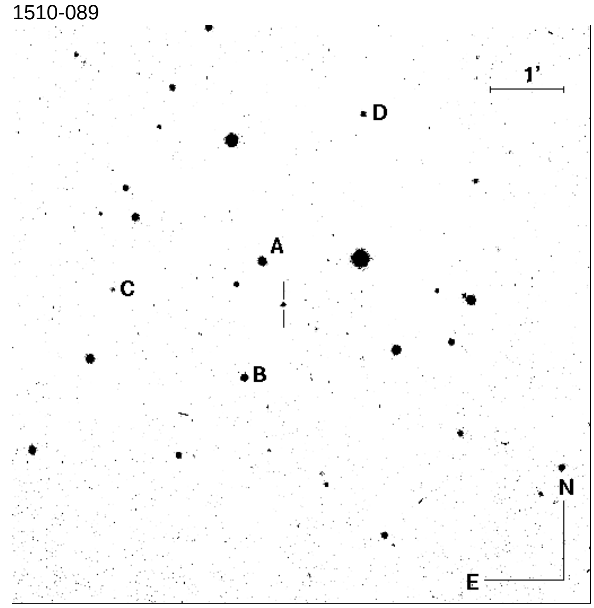

Fig. 26. Finding chart of PKS 1510−089

of a sensitively different trend of the R light curve with respect to the B one.

3.13. DA 406 (1611+343)

Pica et al. (1988) have been observing this source sporadically between 1980 and 1987, detecting a mean magnitude $B = 17.76$ and a maximum variation $\Delta B = 1.18$. A more intense monitoring was performed by Smith et al. (1993) from 1980 to 1991: their light curve can be described as the superposition of fast flares on a slow growth. The minimum and maximum magnitudes registered are $V = 16.8$ and $V = 18.3$. Tornikoski et al. (1994), in their study of possible correlations between the radio and optical emissions, report optical fluxes ranging from 0.27 to 0.7 mJy in the period 1983–1991.

The finding chart of this source is shown in Fig. 27, where field comparison stars are indicated; the calibrated magnitudes of two of them are given in Table 4. Our data in the R and B bands are shown in Tables 30 and 31 and in Figs. 28 and 29, while the only datum in the V band can be found in Table 5. As in the case of PKS 1510−089, wider luminosity variations are found on the shortest rather than on the longest time scales.

3.14. 4C 38.41 (1633+382)

This quasar has also been classified as an OVV (Mattox et al. 1993) because of its strong optical variability. Barbieri et al. (1977) report the source light curve in the B band from May 1969 to May 1976; wide variations are visible on both long and short time scales. In particular, a brightness

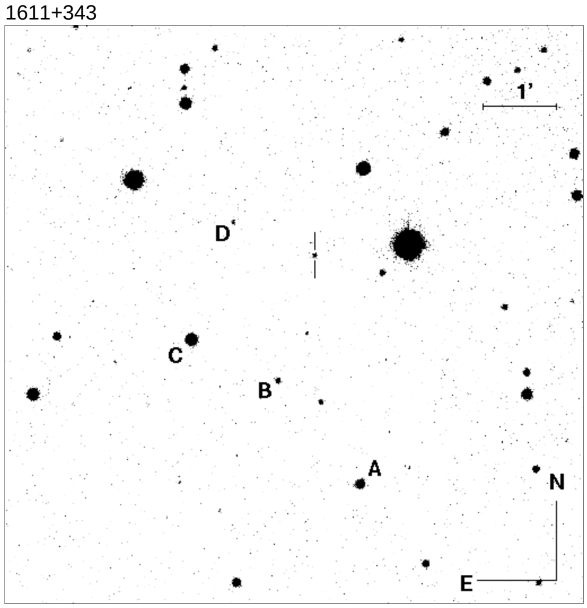

Fig. 27. Finding chart of DA 406

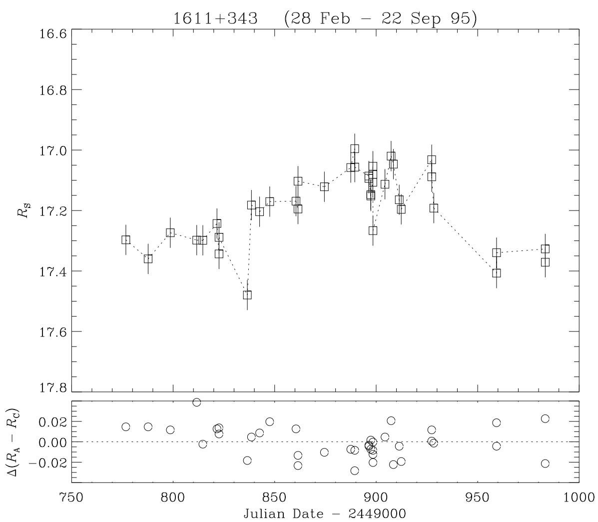

Fig. 28. Light curve of DA 406 in the R band

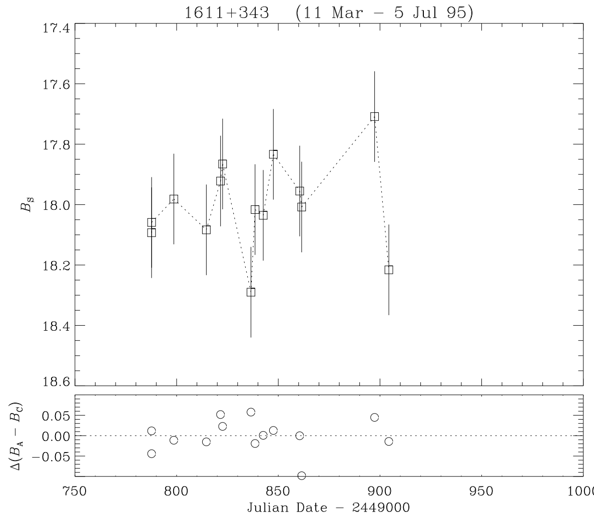

Fig. 29. Light curve of DA 406 in the B band

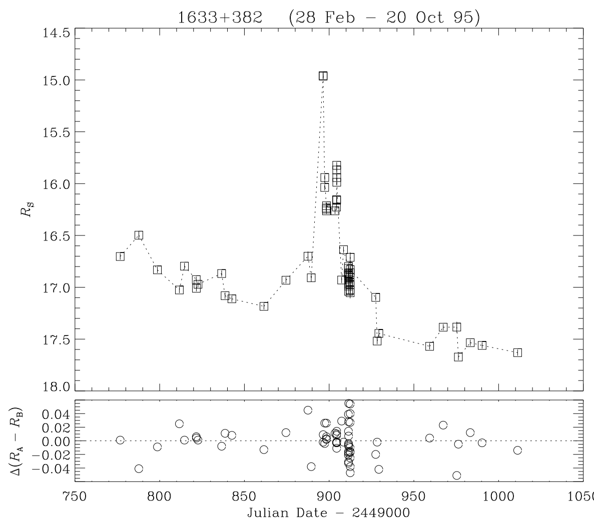

Fig. 30. Light curve of 4C 38.41 in the R band

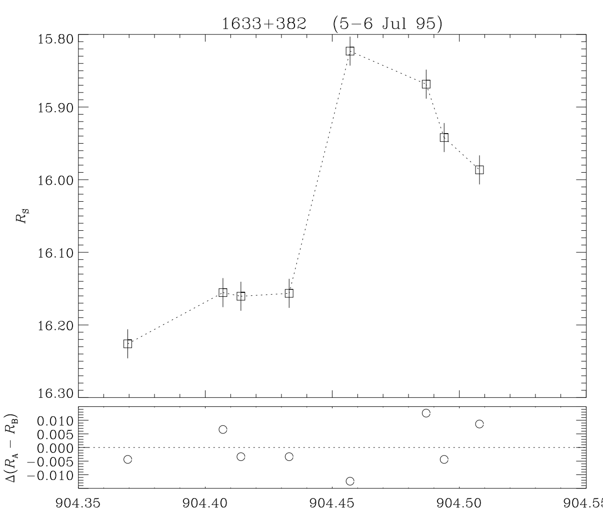

Fig. 31. Intranight light curve of 4C 38.41 in the R band

decrease (from the peak at $B = 15.85$ observed on May 27, 1971) of 3.15 mag in 4.02 years was registered, while the maximum variations observed on shorter time scales were the rise to and the drop from the same peak: 1.55 mag in 11 and 20 days, respectively (see also Bozyan et al. 1990). As for its γ emission, 4C 38.41 is one of the most powerful sources detected by EGRET.

The violent optical variability of this source is confirmed by our data in Tables 32 and 33 and in Fig. 30. As can be seen from the data in the R band, after a period of quiet emission an outburst was detected with a brightness increase of 1.95 mag in 7 days, when, on June 27, 1995, the magnitude reached 14.96. These are the maximum

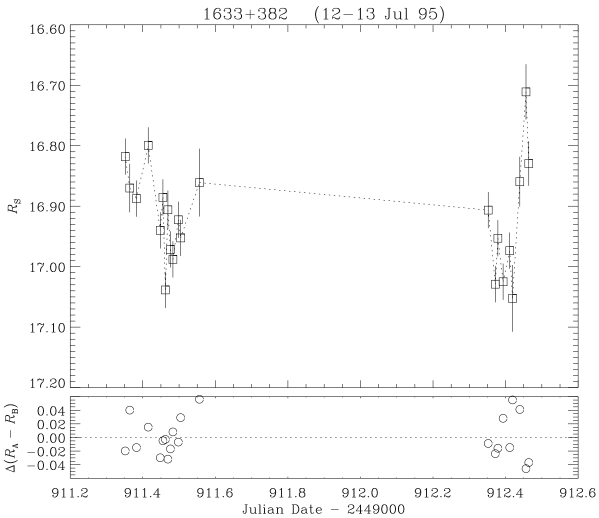

Fig. 32. Microvariability of 4C 38.41 in the R band

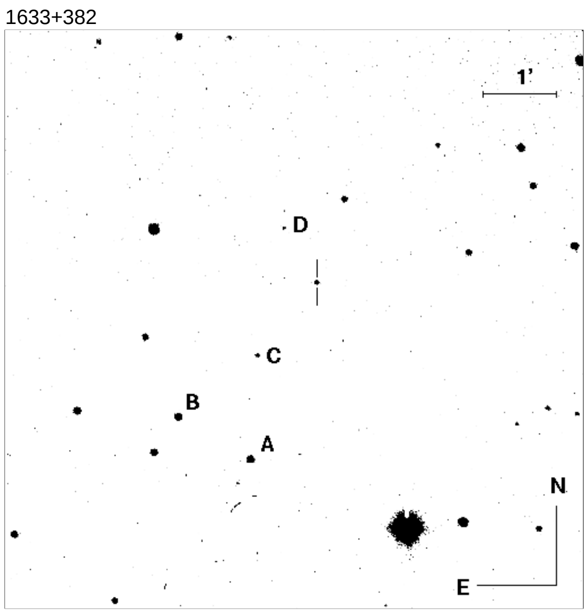

Fig. 33. Finding chart of 4C 38.41

brightness (comparable with that of the above quoted peak) and the steepest big variation ever observed for this quasar (see also Bosio et al. 1995; Raiteri et al. 1996). The subsequent dimming phase was extremely rapid too: a first decrease of 1.08 mag was registered in 21 hours, followed later by another one of 1.11 mag in 2.9 days, with which the brightness returned to its "normal" levels. Between these two drops, we were able to detect also a noticeable intranight variability, as is shown in Fig. 31 for $\overline{\mathrm{JD}} = 904$, when an increase $\Delta R = 0.34$ was registered in 35 minutes. Other examples of microvariability are presented in Fig. 32, where the data collected during $\overline{\mathrm{JD}} = 911$ and $\overline{\mathrm{JD}} = 912$ are plotted: again one can see an increase of 0.34 mag, this time in 53 minutes.

The reference stars that were adopted for the photometric calibration are reported in Fig. 33 and the magnitudes of three of them are listed in Table 4.

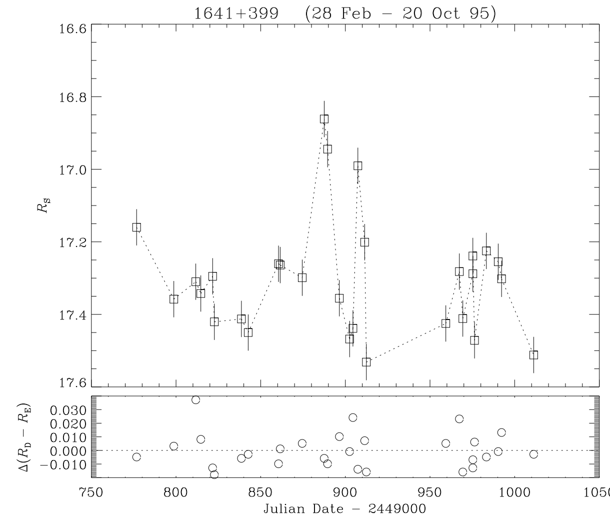

Fig. 34. Light curve of 3C 345 in the R band

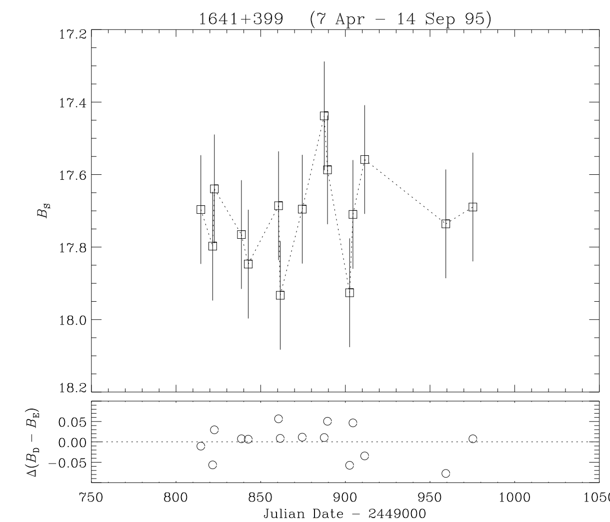

Fig. 35. Light curve of 3C 345 in the B band

3.15. 3C 345 (1641+399)

This quasar was recognized to be an OVV by Penston & Cannon (1970). Bregman et al. (1986) show optical data from 1965 to 1984 and notice two kinds of variation: the first one is a flickering with oscillations up to 1 mag on a few week time scale, the second one being represented by long term trends such as the 1 mag increase in the mean brightness between 1972 and 1982. Moreover, four outbursts are visible in 1967, 1969, 1971, and 1982 (see also Schramm et al. 1993). In the period from 1971 to 1984 the variability range is about 2 mag in both the B and U bands, while in the V band it is about 2.5 mag. This discrepancy is explained by the authors as possibly due to the effect of the 3000 Å bump on the B and U bands and of the strong Mg II line on the B one.

Observations reported by Schramm et al. (1993) show that after 1986 the optical flux decreases, with no evidence of flares, until it reaches $B \gtrsim 18.0$ in May 1989. The above authors present data in the B, V, and R bands taken at Calar Alto from 1988 to 1992. Until fall 1990, 3C 345 is in a low optical state (an historical minimum is reached in May 1990, with $B = 18.66$ (Kidger & Takalo 1990)). In the period 1990–1992 three rapid bursts are observed, with an overall brightness variation of 3 mag. A multiwavelength study of the 1991 outburst was performed by Webb et al. (1994).

Microvariability was checked by Kidger & de Diego (1990) during one night in May 1989: ten frames were taken in 1 hour, revealing a variation of half a magnitude.

The results of our monitoring are presented in Tables 34 and 35 and in Figs. 34 and 35; one observation in the V band is included in Table 5. The source magnitudes have been calculated with respect to Stars D and E in the sequence given by Smith et al. (1985). Our light curves confirm the presence of small amplitude oscillations on short time scales (1−3 weeks); in particular, an increase of 0.45 mag in 3 days was observed in the R band between $\overline{\rm JD} = 904$ and $\overline{\rm JD} = 907$, followed by a decrease of 0.33 mag in 1 day ($\overline{\rm JD} = 911-912$). The maximum magnitude variation over the whole monitoring period was 0.67 in the R band and 0.49 in the less sampled B one.

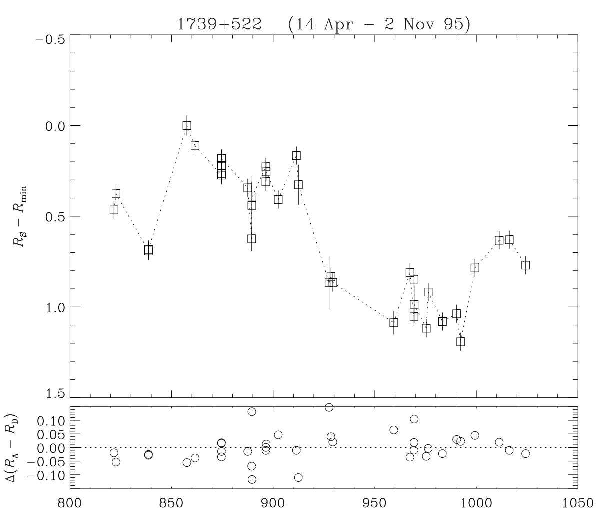

Fig. 36. Light curve of 4C 51.37 in the R band

3.16. 4C 51.37 (1739+522)

Apart from the identification of the radio source 4C 51.37 with a quasar of photographic magnitude 18.5 (Kühr 1977), the optical information about this source is very poor in the literature (Cohen et al. (1977) give $R = 18.5$ and $B = 18.7$). Impey & Tapia (1990) found an optical polarization of 3.7%. This object was detected in the γ band by EGRET, with a maximum flux of $3.6\,10^{-7}\,{\rm cm}^{-2}\,{\rm s}^{-1}$ (von Montigny et al. 1995).

Without calibration of the reference stars, our data are presented in Tables 36 and 37 and in Fig. 36 as magnitude differences with respect to the minimum value. The maximum variation in the monitoring period was $\Delta R = 1.19$. Some intranight variation can be distinguished on $\overline{\rm JD} = 889$ and $\overline{\rm JD} = 969$.

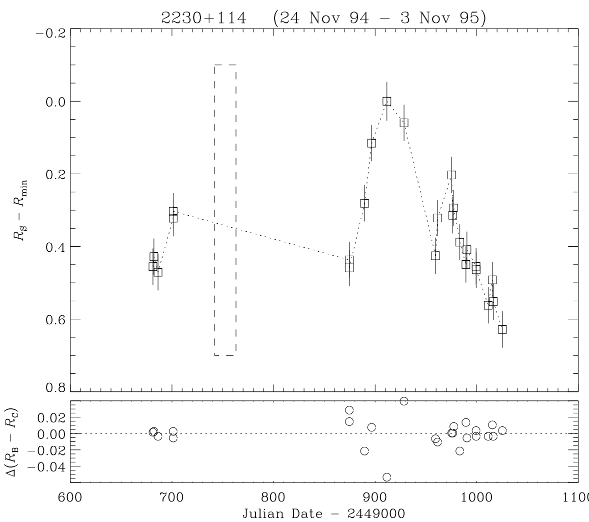

Fig. 37. Light curve of CTA 102 in the R band; the dashed box indicates the EGRET pointing period

3.17. CTA 102 (2230+114)

There are not many data in the literature about the optical behaviour of this source. Pica et al. (1988) refer about 65 observations in the B band from August 1973 to November 1987: the average magnitude is 17.66, the minimum value 17.26, and the variation range observed is 1.14 mag; the most significant flare was registered in 1978 and led to a 1.07 mag brightness increase in 2 days. Wilkes et al. (1994) report $B = 17.75$ and $V = 17.33$ from Véron-Cetty & Véron (1987).

We observed this object in the R band only; data are presented in Table 38 and Fig. 37 as differences with respect to the minimum magnitude observed. The dashed box in Fig. 37 indicates the period of an EGRET pointing, when the source was in the diurnal sky; another pointing was scheduled from November 28 to December 12, 1995, just after the monitoring period covered by the present paper. The overall brightness variation was $\Delta R = 0.63$.

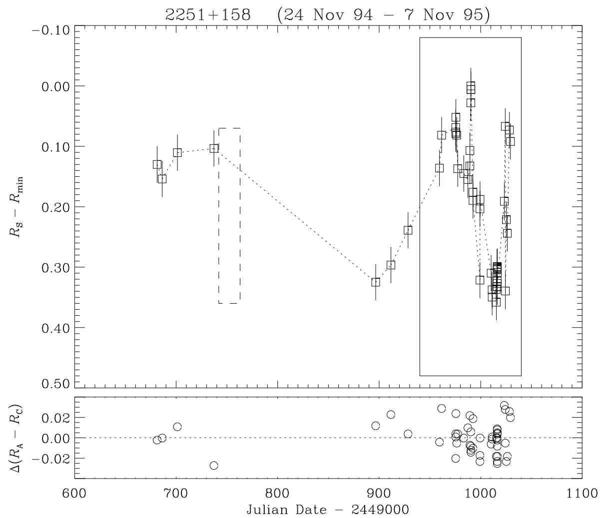

Fig. 38. Light curve of 3C 454.3 in the R band; the dashed box indicates the EGRET pointing period, the solid one is enlarged in Fig. 39

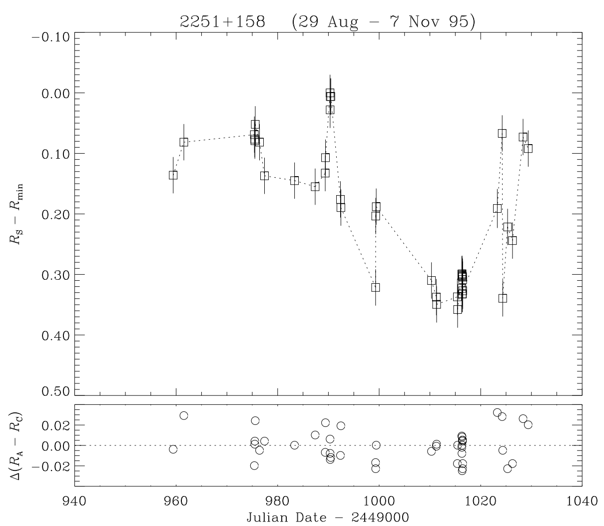

Fig. 39. Enlargement of the solid box shown in Fig. 38; the period coincides with that of the B light curve in Fig. 40

3.18. 3C 454.3 (2251+158)

The light curve of 3C 454.3 in the B band from 1966 to 1979 is reported by Lloyd (1984). The mean brightness is seen to decrease from $B = 16.4$ in 1966 to $B = 17.25$ in 1971. The source remains in a low optical state from 1971 to 1979, when it suffers a 1.4 mag flare. Data in the B band from 1971 to 1985 are presented by Webb et al.

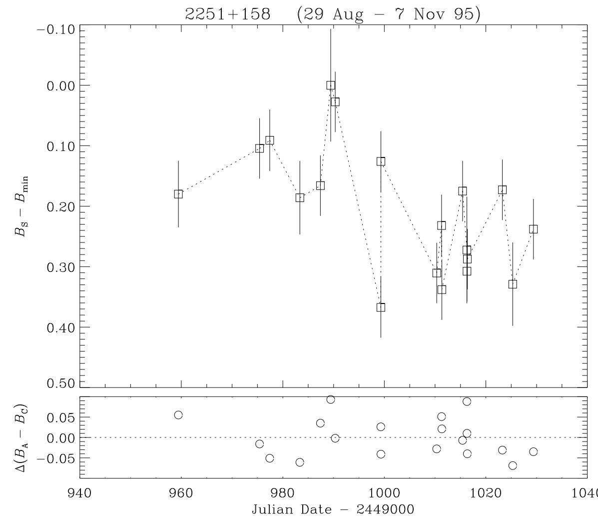

Fig. 40. Light curve of 3C 454.3 in the B band

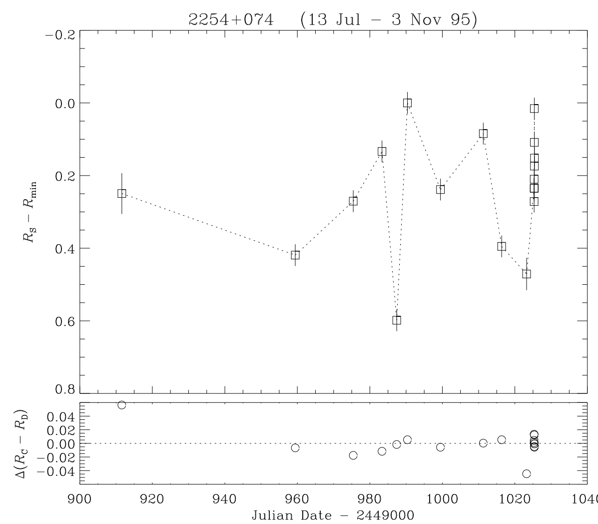

Fig. 41. Light curve of PKS 2254+074 in the R band

(1988); the above flare in fall 1979 is reported as a variation of 1.28 mag in 63 days. Subsequently, the flux slowly decreases for about 3 years, showing small and fast variations similar to those observed before 1979. A general flux increase is evident from 1983 onward. Between November 1986 and January 1987, the average B magnitude of the source is 16.56, with a variation of 0.92 mag in 44 days (Corso et al. 1988). A more recent study on the correlation between the radio and optical emissions of PKS 2251+158 from 1980 to 1992 shows a big increase of the optical flux at the end of 1988, followed by an increase of the radio one with a few month delay (Tornikoski et al. 1994).

As for the γ emission, this is one of the few blazars to have been detected by COMPTEL, together with PKS 0528+134, 3C 273, and 3C 279: all these objects show a spectral maximum at MeV energies (Blom et al.

1995). Detections with EGRET and OSSE were obtained too.

The results of our monitoring program are shown in Tables 39–41 (R, V, and B bands, respectively) and in Figs. 38, 39 (R band), and 40 (B band). No calibration of the reference stars has been performed so that magnitudes are normalized to the minimum value. In the R light curve of Fig. 38 the dashed box refers to an EGRET pointing; we have no data in that period because of the solar conjunction. The solid box in the same figure indicates the best sampled period (preceding the EGRET pointing of November 28 – December 12, 1995, out of the monitoring period we present in this paper), which has been enlarged in Fig. 39 and corresponds to that of the B light curve in Fig. 40. Some behaviour difference can be seen between the two bands; moreover, the noticeable intranight variation on $\overline{\rm JD} = 999$ is not confirmed by the V data. Another fast variation of 0.27 mag in 2.6 hours ($\overline{\rm JD} = 1024$) can be found only in the R curve, this time for the lack of data in the other two bands. In any case the source has presented only small, short term variations, within a total range less than 0.4 mag.

3.19. PKS 2254+074 (including photopolarimetric data)

This source shows a very variable flux in the optical band. In November 1990 Xie et al. (1994) observed a fall of 0.69 mag in 41 minutes, when the source reached the minimum brightness $B = 18.38$. However, a steepest variation was registered by the same authors in November 1987: a decrease of 1.0 mag in 40 minutes.

A flare of 1.8 mag was observed by Pica et al. (1988) in 1981: the peak magnitude was $B = 15.65$, followed by a brightness decrease of 1.3 mag in 18 days. A maximum variation of 2.37 mag in 1.39 years is found in their 43 point light curve in the B band from July 1979 to November 1987 (see also Bozyan et al. 1990).

Our data in the R band are shown in Table 42 and in Fig. 41. Since calibration of the reference stars was not performed, the source magnitude is given as deviation from the minimum value. No trends on long time scales are recognizable, while some fast variations were detected. The maximum variation in the observational period was 0.60 mag, and it occurred in 3 days. On November 3, 1995 intranight variations were also observed, the steepest one being an increase of 0.21 mag in 10 minutes.

On this source we carried out also $UBVRI$ (Johnson-Cousins) photopolarimetry using the equipment (see Scaltriti et al. 1989) attached to the 2.15 m reflector of Complejo Astronomico El Leoncito (Argentina). The photopolarimeter allows to perform linear and circular polarization measurements in the $UBVRI$ bands simultaneously. The design of the polarimeter is such that the sky background polarization is directly eliminated; this has been found especially valuable in the observations of faint objects and when there is moonlight. Moreover, photometric light curves were obtained in each band.

The observations were taken during eight nights in the period July 23 – August 1, 1995. The $UBVRI$ photometric light curves are shown in Fig. 42 (left panels), where nightly means are plotted against Julian Date; the corresponding data can be found in Tables 43–47. The maximum error is 0.11 mag on $\overline{\rm JD} = 923$ (B and I bands), when the object was found particularly faint; the mean error in the nightly means is 0.04 mag. The light curves show noticeable night to night changes, up to more than 1 mag in 1 day, reflecting thus the fast variability already noticed in both our monitoring and literature data. Also the spectrum appears to change, as is evident by comparing the various light curves. In particular, this is visible in the drop between $\overline{\rm JD} = 922$ and $\overline{\rm JD} = 923$, more pronounced in the U and B bands (1.22 and 1.27 mag, respectively) in comparison with the other ones (0.49−0.77 mag).

The results on linear polarimetry (polarization P and position angle PA) are shown in Tables 43–47 and in Fig. 42 (centre and right panels), where nightly means are plotted. Taking into account the observational errors, P does not change appreciably in the whole run, except the bump in the V band observations obtained on $\overline{\rm JD} = 926-928$; the increase of P is not visible in the other bands. Analogously, no significant trend can be seen in PA, except for the U band, where PA shows an abrupt increase, again on $\overline{\rm JD} = 926-928$, when, on the contrary, a slight decrease can be distinguished in the other bands.

The mean polarization values during the observing run are P_U =5.4%, P_B =8.9%, P_V =9.7%, P_R =9.8%, and P_I =7.5%; previous values range from 8.8% to 21% (Kinman 1976; Kühr & Schmidt 1990; Wills et al. 1992). Excluding the three values of about 100° (U band), the average value of position angle in the whole run and for $UBVRI$ is 32.5°; previous findings are 133.4° by Kühr & Schmidt (1990) and 48° by Wills et al. (1992). No evident correlation exists between the photometric and polarimetric data.

3.20. PKS 2356+196

Wills & Wills (1976) report $V = 18.0$ for this source. No information about its optical behaviour is available in the literature. EGRET detected a maximum γ flux of $2.9\ 10^{-7}\ {\rm cm}^{-2}\ {\rm s}^{-1}$ (Thompson et al. 1993).

Our data in the R band are shown, without calibration, in Table 48 and in Fig. 43, where the box indicates the EGRET pointing period. No significant variation has been observed.

4. Conclusions

We have presented the results of the first year monitoring campaign on the optical behaviour of twenty γ-ray loud blazars out of the 28 ones included in our program. Most

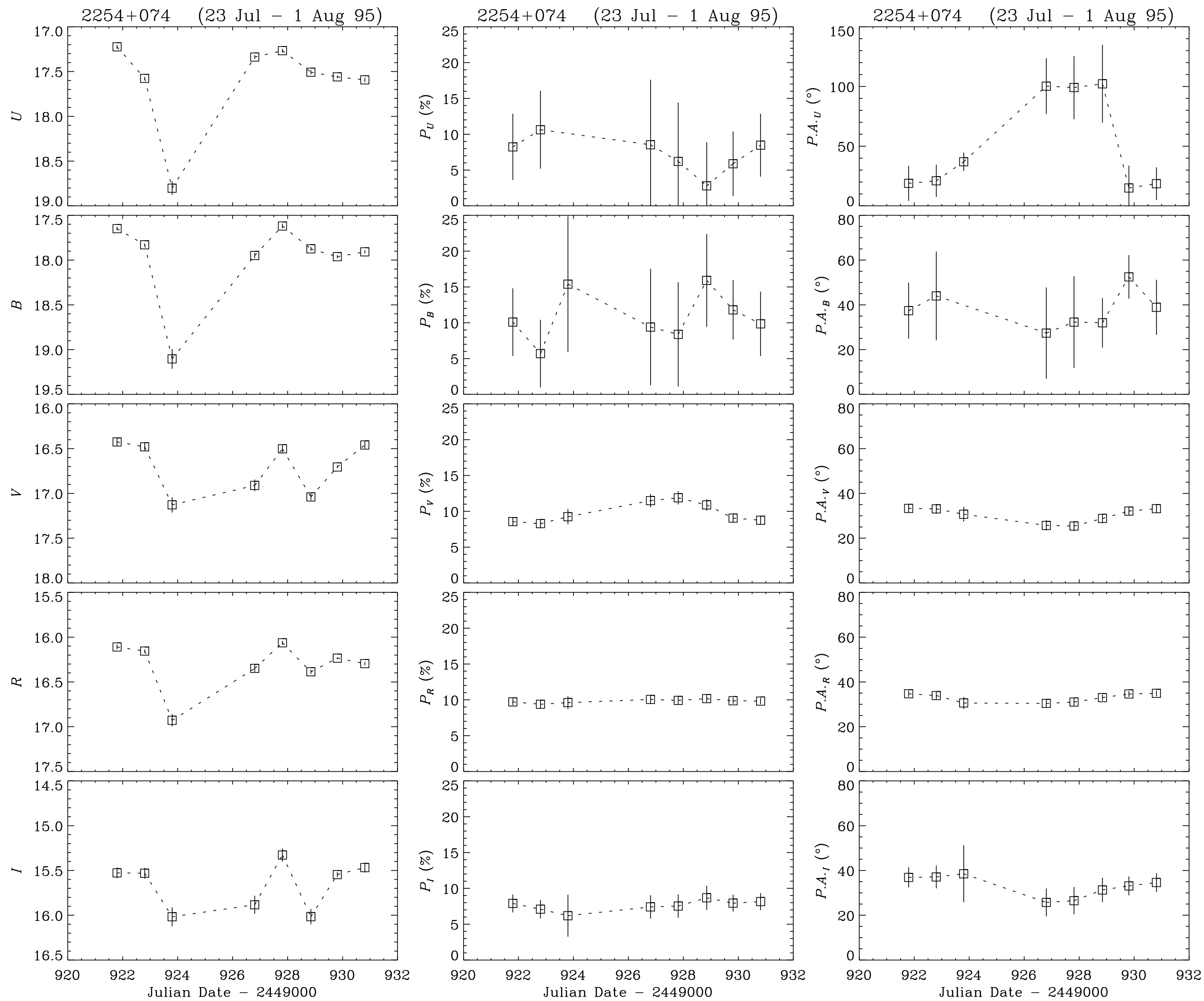

Fig. 42. Photometric light curves (left), linear polarization (centre), and polarization angle (right) of PKS 2254+074 in the $UBVRI$ bands

of the sources presented a more or less pronounced variability on both short and long time scales; for some objects noticeable intranight variations were observed too. We detected the maximum ever registered brightness for two quasars (PKS 0420−014 and 4C 38.41) and, in general, our light curves have a satisfactory time resolution, in many cases much better than those obtained with previous sporadic observations; for some sources they represent the first ever published ones. Moreover, we could obtain optical data simultaneous with EGRET pointings, thus providing a very useful information for all those models which try to explain possible correlations between the optical and γ emissions. Notwithstanding this, in several cases we lament the lack of information in wide periods, mainly due to unfavourable atmospheric conditions, added to the fact that we share the use of the telescope with other observational programs. This stresses the necessity of performing optical monitoring in collaboration with other observatories, as we have started to do for the other eight sources of our program, whose results are presented elsewhere (see Sect. 1). Some other sources are now included in these collaborations and we hope to further on extend this kind of monitoring, which has already shown itself to be very profitable, providing very well sampled light curves, indispensable for the understanding of these still largely unknown objects.

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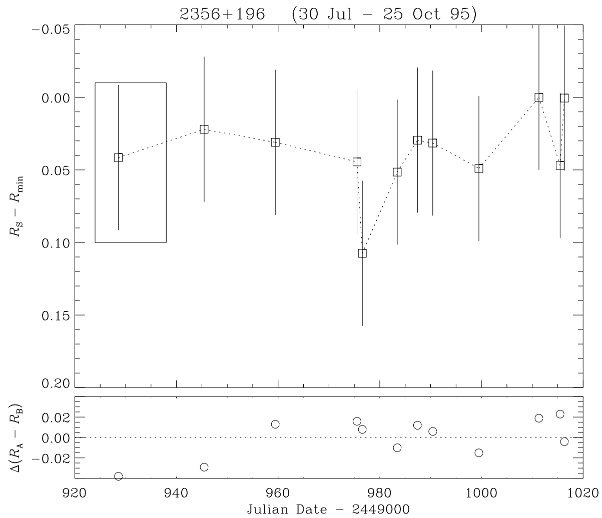

Fig. 43. Light curve of PKS 2356+196 in the R band; the box indicates the EGRET pointing period

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