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BVR photometry of comparison stars in selected blazar fields

I. Photometric sequences for 10 BL Lacertae objects

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Abstract. We present photometric sequences in the Johnson's *BV* and Cousins' *R* bands in the fields of 10 BL Lacertae objects (BL Lacs) monitored at the Torino Astronomical Observatory. Data were taken during 14 photometric nights from February 1995 to May 1997. The 56 calibrated stars are brighter than $V = 16$ and can be used as comparison objects in order to derive the BL Lac magnitudes. Finding charts are included for the stars identification.

Key words: galaxies: active — BL Lacertae objects: general

1. Introduction

BL Lacertae objects (BL Lacs) are radio-loud active galactic nuclei (AGNs) characterized by a very variable emission at all wavelengths. They belong, together with a subset of radio-loud quasars, to the class of blazars (Urry & Padovani 1995).

Optical monitoring represents the possibility of following their optical emission behaviour with the aim of understanding the mechanisms of such variability. In the last years many efforts have been spent to organize international monitoring campaigns in order to improve the monitoring efficiency. Moreover, simultaneous observations at different wavelengths are demanded, since the discovery of possible correlations among the emissions in different bands can be an important key to clarify the radiation processes. The operation of several satellites for astronomical researches, such as the Compton Gamma Ray Observatory (CGRO) and the Satellite per Astronomia X "Beppo" (BeppoSAX), has recently brought much excitation on this kind of research.

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The Torino monitoring group was formed in fall 1994 with the aim of observing γ-ray loud blazars and of providing the optical counterpart to the CGRO pointings. From then on, the object list has been extended to include other interesting sources, many of which belonging to the BeppoSAX programs. For further information on our monitoring activity and collaborations we refer to Villata et al. (1997); Massaro et al. (1996); Ghisellini et al. (1997); Raiteri et al. (1998a); Tosti et al. (1998).

In this paper we present *BVR* calibration of 45 stars and *VR* calibration of 11 stars in the fields of 10 BL Lacs that are part of our observational list. Photometric sequences for 9 quasars will be published in a forthcoming paper (Raiteri et al. 1998b).

2. Observations and data reduction

The observations were done with the 1.05 m REOSC telescope of the Torino Astronomical Observatory, equipped with a 1242×1152 pixel CCD camera (EEV) and standard Johnson's *BV* and Cousins' *R* filters. Data were taken during 14 photometric nights, from February 1995 to May 1997.

Frames were reduced by the Robin procedure locally developed, which includes bias subtraction, flat fielding, and circular gaussian fit after background subtraction.

Calibration was obtained through observations of Landolt's fields (Landolt 1992) and other standard stars during each night. The Calib procedure was written to transform instrumental magnitudes into standard ones; the relevant equations are

$$V = v_0 + \zeta_v + \epsilon(V - R), \quad (1)$$

$$V - R = \psi\,(v_0 - r_0) + \zeta_{vr}, \quad (2)$$

$$B - V = \mu\,(b_0 - v_0) + \zeta_{bv}, \quad (3)$$

where ζ are the zero-point constants; ϵ, ψ, μ are the transformation coefficients; and v_0, r_0, b_0 are the instrumental magnitudes corrected for atmospheric extinction:

$$v_0 = v - k'_v X, \quad (4)$$

Table 1. List of the BL Lacs for which photometric sequences are derived

Source	Name	RA (2000)	Dec. (2000)
0048−097	PKS 0048−09	00 50 41.32	−09 29 05.2
0502+675	1ES 0502+675	05 07 56.20	+67 37 24.0
0716+714	S5 0716+71	07 21 53.45	+71 20 36.4
0737+746	MS 0737.9+7441	07 44 05.12	+74 33 58.1
1028+511	1ES 1028+511	10 31 18.50	+50 53 36.0
1101+384	Mkn 421	11 04 27.31	+38 12 31.8
1133+704	Mkn 180	11 36 26.41	+70 09 27.3
1517+656	1ES 1517+656	15 17 47.58	+65 25 23.3
1652+398	Mkn 501	16 53 52.22	+39 45 36.6
1959+650	1ES 1959+650	19 59 59.85	+65 08 54.7

$$r_0 = r - [k'_r + k''_r(v - r)]\,X, \quad (5)$$

$$b_0 = b - [k'_b + k''_b(b - v)]\,X, \quad (6)$$

where v, r, b are the instrumental magnitudes, k' and k'' represent the principal and second-order extinction coefficients, and X is the air mass.

In one night V observations were lacking so that we had to base the transformation to the standard system on the B and R bands only; the resulting magnitudes were in agreement with those obtained in the other nights.

3. Results

The blazars in the fields of which photometric sequences were obtained are listed in Table 1, where their coordinates at the 2000 equinox are given.

The comparison stars are indicated in the finding charts shown in Figs. 1–10 (they are $10'$ wide; north is up and east is on the left). Their calibrated magnitudes are reported in Table 2, together with the estimated uncertainties (σ) and the number of observations (N) done in each band. In general, the given magnitude represents the median value among the observations; when only two observations are available, the weighted mean is given. The reported uncertainty corresponds to the maximum between the standard deviation on the weighted mean and the uncertainty of the mean defined as $\sigma_\mu = (\sum 1/\sigma_i^2)^{-1/2}$, where σ_i are the uncertainties of the single data.

3.1. S5 0716+71

This is one of the best measured fields, with 8 observations in the B and R bands, and 4 observations in the V one.

A standard sequence was published by Ghisellini et al. (1997), with errors ranging from 0.04 to 0.08 mag; their Stars A, B, C, and D correspond to our Stars 2, 3, 5, and 6, respectively. By comparing our results with theirs, we see that magnitudes are in agreement within the errors, with the only exception of the R magnitude of Star 2.

Star 5 of the present photometric sequence was also calibrated by Takalo et al. (1994; their Star 2), whose derived magnitudes are in accordance with ours.

A comparison among the results of the different authors is performed in Table 3.

3.2. MS 0737.9+7441

Two comparison stars in the field of MS 0737.9+7441 were already calibrated by Smith et al. (1991); their Stars A and B are our Stars 1 and 4 and the respective magnitudes agree inside the errors.

Notice in Fig. 4 the presence of another AGN (MS 0737.0+7436) to the south–west of the BL Lac.

3.3. Mkn 421

Star 1 of our photometric sequence corresponds to that calibrated in the UBV bands by Véron & Véron (1976); while the V magnitudes are in agreement, we find a B magnitude which is fainter by 0.10 mag.

3.4. Mkn 180

Four stars were calibrated in the field of Mkn 180; Star 3 is just below the source, and in Fig. 7 is not distinguishable from it. In our frames instead it is well separated from the BL Lac.

3.5. Mkn 501

Stars 1 and 2 of our photometric sequence have already been calibrated by Véron & Véron (1976; their Stars 3 and 2) in the UBV filters and by Smith et al. (1991; their Stars A and B) in the $UBVRI$ bands. We confirm the results of the above authors in the BVR filters. Standard VRI magnitudes for Stars 1, 4, and 6 were published by Fiorucci & Tosti (1996); also in this case there is accordance among their data and ours. A comparison among calibrations is shown in Table 4.

4. Conclusions

In this paper we have presented photometric sequences in the fields of 10 BL Lacs that are part of the object list of the Torino monitoring group. Standard magnitudes have been determined in BVR for 45 stars and in VR for 11 ones. All stars are brighter than $V = 16$ and can be used by observers to derive the BL Lac magnitudes.

Table 2. BVR magnitudes of the comparison stars

Blazar	Star	B (σ)	N_B	V (σ)	N_V	R (σ)	N_R
PKS 0048−09	1			12.77 (0.04)	3	12.47 (0.04)	3
	2			13.86 (0.02)	3	13.33 (0.03)	3
	3			14.12 (0.03)	3	13.55 (0.02)	3
	4			15.00 (0.02)	2	14.60 (0.04)	2
1ES 0502+675	1	14.12 (0.03)	2	13.08 (0.03)	2	12.60 (0.04)	2
	2	15.19 (0.04)	2	14.18 (0.03)	2	13.69 (0.05)	2
	3	15.07 (0.04)	2	14.28 (0.03)	2	13.89 (0.04)	2
	4	15.24 (0.04)	2	14.51 (0.03)	2	14.16 (0.04)	2
	5	15.95 (0.04)	2	14.82 (0.03)	2	14.31 (0.03)	2
	6	16.64 (0.04)	2	15.19 (0.03)	2	14.49 (0.03)	2
S5 0716+71	1	11.54 (0.01)	8	10.99 (0.02)	4	10.63 (0.01)	8
	2	12.02 (0.01)	8	11.46 (0.01)	4	11.12 (0.01)	8
	3	13.04 (0.01)	8	12.43 (0.02)	4	12.06 (0.01)	8
	4	13.66 (0.01)	8	13.19 (0.02)	4	12.89 (0.01)	8
	5	14.15 (0.01)	8	13.55 (0.02)	4	13.18 (0.01)	8
	6	14.24 (0.01)	8	13.63 (0.02)	4	13.26 (0.01)	8
	7	14.55 (0.01)	6	13.74 (0.02)	3	13.32 (0.01)	7
	8	14.70 (0.01)	8	14.10 (0.02)	4	13.79 (0.02)	8
MS 0737.9+7441	1	12.54 (0.04)	3	11.66 (0.02)	3	11.19 (0.03)	3
	2	13.99 (0.03)	3	13.13 (0.02)	3	12.66 (0.03)	3
	3	14.16 (0.05)	3	13.54 (0.03)	3	13.17 (0.02)	3
	4	14.75 (0.04)	3	14.24 (0.03)	3	13.92 (0.03)	3
	5	16.20 (0.05)	3	15.65 (0.03)	3	15.36 (0.03)	3
1ES 1028+511	1	13.91 (0.03)	2	13.20 (0.02)	2	12.93 (0.03)	2
	2	14.93 (0.03)	2	14.29 (0.03)	2	14.04 (0.03)	2
	3	15.02 (0.03)	2	14.40 (0.03)	2	14.18 (0.03)	2
	4	15.05 (0.05)	2	14.40 (0.03)	2	14.17 (0.03)	2
	5	15.75 (0.04)	2	15.03 (0.03)	2	14.75 (0.03)	2
	6	15.66 (0.03)	2	15.06 (0.03)	2	14.87 (0.04)	2
Mkn 421	1	15.02 (0.03)	5	14.36 (0.02)	7	14.04 (0.02)	7
	2	16.20 (0.04)	5	15.57 (0.05)	7	15.20 (0.03)	7
	3	16.69 (0.03)	4	15.77 (0.03)	7	15.24 (0.03)	7
Mkn 180	1	14.49 (0.02)	5	13.98 (0.02)	5	13.73 (0.02)	5
	2	15.36 (0.03)	3	14.80 (0.02)	3	14.41 (0.02)	3
	3	16.13 (0.04)	5	15.49 (0.04)	5	15.13 (0.02)	5
	4	16.55 (0.03)	2	16.00 (0.03)	3	15.66 (0.04)	3
1ES 1517+656	1	13.45 (0.05)	3	12.88 (0.03)	3	12.54 (0.02)	3
	2	14.29 (0.02)	3	13.70 (0.02)	3	13.42 (0.02)	3
	3	14.40 (0.05)	3	13.73 (0.02)	3	13.35 (0.02)	3
	4	14.94 (0.04)	3	14.27 (0.02)	3	13.85 (0.03)	3
	5	14.89 (0.07)	3	14.31 (0.03)	3	13.90 (0.02)	3
	6	15.33 (0.07)	3	14.56 (0.02)	3	14.07 (0.03)	3
	7	15.34 (0.07)	3	14.70 (0.02)	3	14.26 (0.03)	3
Mkn 501	1	13.55 (0.03)	3	12.61 (0.02)	4	12.11 (0.02)	4
	2	14.10 (0.03)	3	13.23 (0.02)	4	12.79 (0.02)	4
	3	15.98 (0.04)	3	15.24 (0.02)	4	14.80 (0.02)	4
	4	16.05 (0.05)	3	15.30 (0.02)	4	14.96 (0.02)	4
	5	16.27 (0.04)	3	15.51 (0.02)	4	15.08 (0.02)	4
	6	16.82 (0.05)	3	15.67 (0.04)	4	14.99 (0.04)	4
1ES 1959+650	1			12.67 (0.04)	2	12.29 (0.02)	2
	2			12.86 (0.02)	2	12.53 (0.02)	2
	3			13.18 (0.02)	2	12.27 (0.02)	2
	4			14.53 (0.03)	2	14.08 (0.03)	2
	5			14.54 (0.03)	2	14.00 (0.02)	2
	6			15.20 (0.03)	2	14.78 (0.03)	2
	7			15.24 (0.03)	2	14.79 (0.03)	2

Table 3. Comparison among different calibrations in the field of S5 0716+71

This work				Ghisellini et al. (1997)				Takalo et al. (1994)			
Star	B (σ)	V (σ)	R (σ)	Star	B (σ)	V (σ)	R (σ)	Star	B (σ)	V (σ)	R (σ)
2	12.02 (0.01)	11.46 (0.01)	11.12 (0.01)	A	12.07 (0.06)	11.51 (0.04)	11.21 (0.04)				
3	13.04 (0.01)	12.43 (0.02)	12.06 (0.01)	B	13.06 (0.08)	12.48 (0.05)	12.12 (0.05)				
5	14.15 (0.01)	13.55 (0.02)	13.18 (0.01)	C	14.17 (0.08)	13.58 (0.06)	13.18 (0.05)	2	14.10 (0.05)	13.50 (0.02)	13.21 (0.02)
6	14.24 (0.01)	13.63 (0.02)	13.26 (0.01)	D	14.25 (0.05)	13.66 (0.04)	13.27 (0.04)				

Table 4. Comparison among different calibrations in the field of Mkn 501

This work				Fiorucci & Tosti (1996)			Smith et al. (1991)				Véron & Véron (1976)		
Star	B (σ)	V (σ)	R (σ)	Star	V (σ)	R (σ)	Star	B (σ)	V (σ)	R (σ)	Star	B	V
1	13.55 (0.03)	12.61 (0.02)	12.11 (0.02)	A	12.61 (0.03)	12.15 (0.03)	A	13.55 (0.01)	12.61 (0.01)	12.11 (0.01)	3	13.53	12.65
2	14.10 (0.03)	13.23 (0.02)	12.79 (0.02)				B	14.08 (0.01)	13.22 (0.01)	12.76 (0.01)	2	14.06	13.23
4	16.05 (0.05)	15.30 (0.02)	14.96 (0.02)	C1	15.30 (0.07)	14.91 (0.07)							
6	16.82 (0.05)	15.67 (0.04)	14.99 (0.04)	C2	15.68 (0.08)	14.97 (0.08)							

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References

Fiorucci M., Tosti G., 1996, A&AS 116, 403
Ghisellini G., Villata M., Raiteri C.M., et al., 1997, A&A 327, 61
Landolt A.U., 1992, AJ 104, 340
Massaro E., Nesci R., Maesano M., et al., 1996, A&A 314, 87
Raiteri C.M., Ghisellini G., Villata M., et al., 1998a, A&AS 127, 445
Raiteri C.M., Villata M., Lanteri L., Cavallone M., Sobrito G., 1998b, A&AS (in press)
Smith P.S., Jannuzi B.T., Elston R., 1991, ApJS 77, 67
Takalo L.O., Sillanpää A., Nilsson K., 1994, A&AS 107, 497
Tosti G., Fiorucci M., Luciani M., et al., 1998, A&AS (in press)
Urry C.M., Padovani P., 1995, PASP 107, 803
Véron P., Véron M.P., 1976, A&AS 25, 287
Villata M., Raiteri C.M., Ghisellini G., et al., 1997, A&AS 121, 119

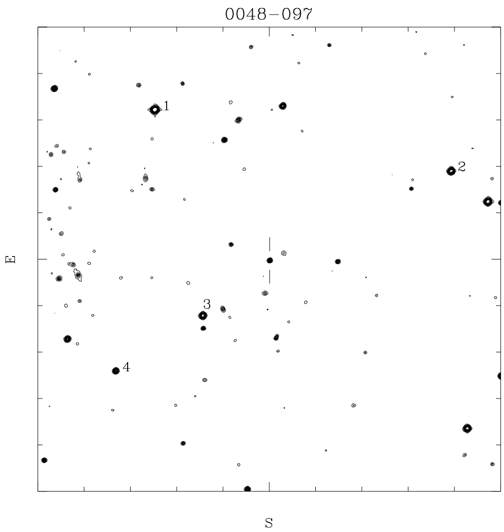

Fig. 1. Finding chart of PKS 0048−09

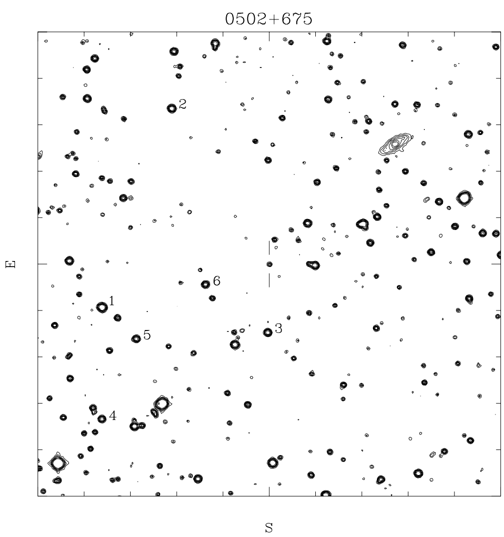

Fig. 2. Finding chart of 1ES 0502+675

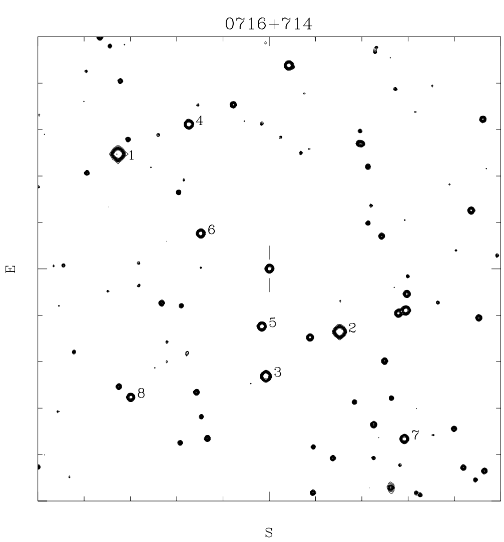

Fig. 3. Finding chart of S5 0716+71

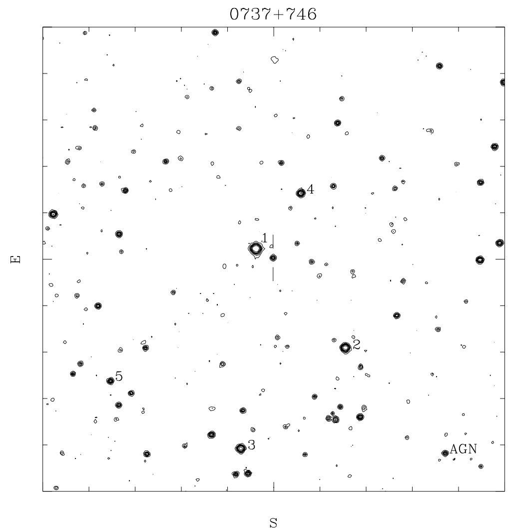

Fig. 4. Finding chart of MS 0737.9+7441

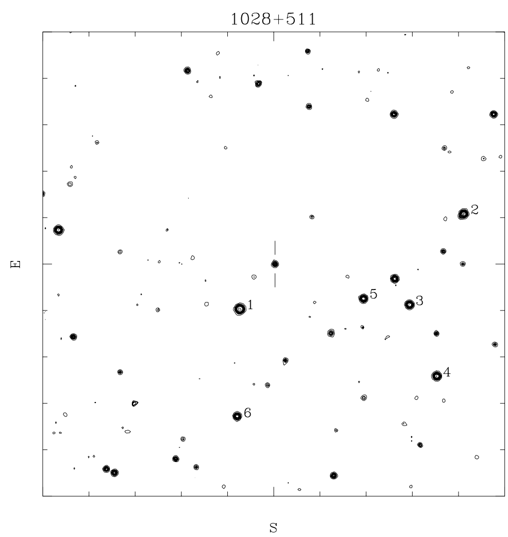

Fig. 5. Finding chart of 1ES 1028+511

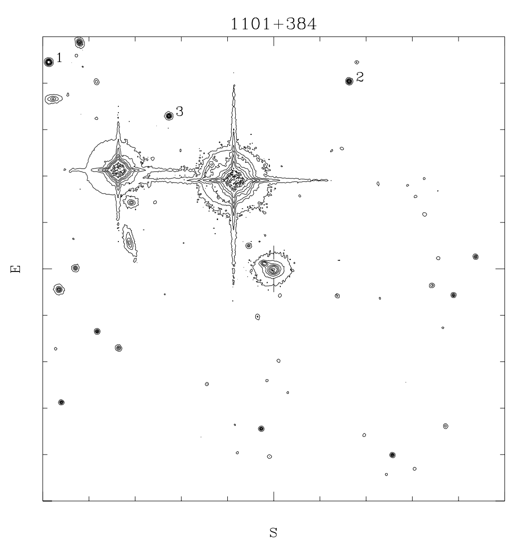

Fig. 6. Finding chart of Mkn 421

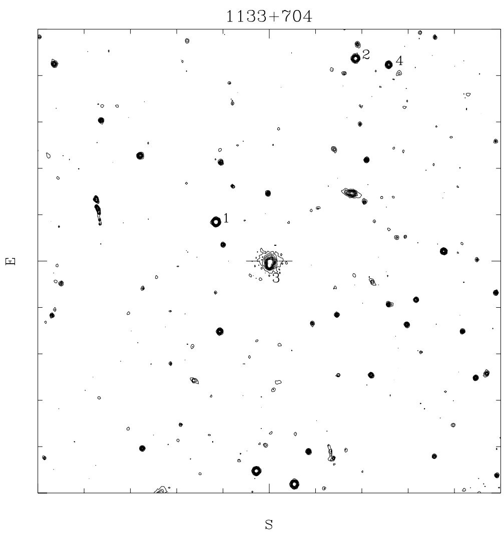

Fig. 7. Finding chart of Mkn 180; Star 3 is just below the BL Lac

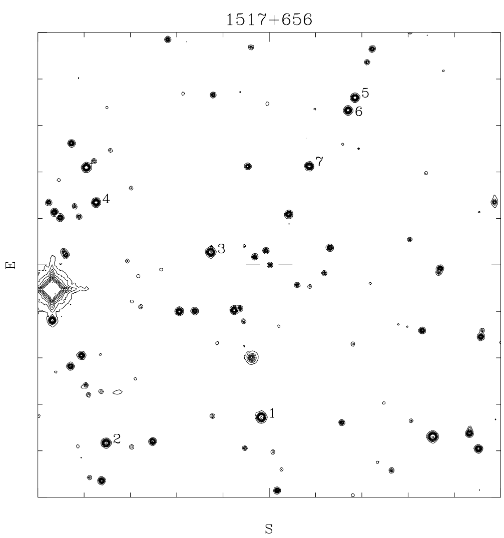

Fig. 8. Finding chart of 1ES 1517+656

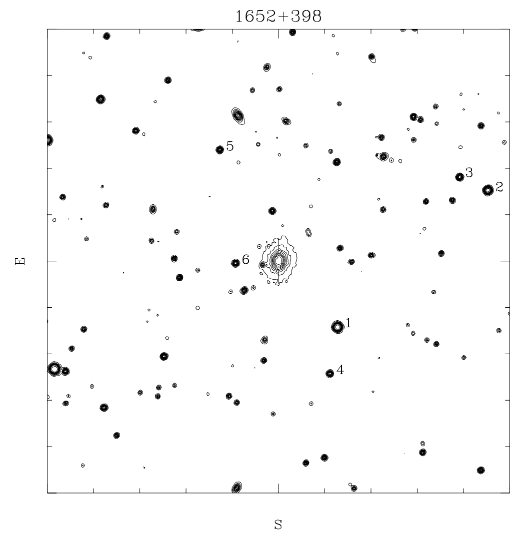

Fig. 9. Finding chart of Mkn 501

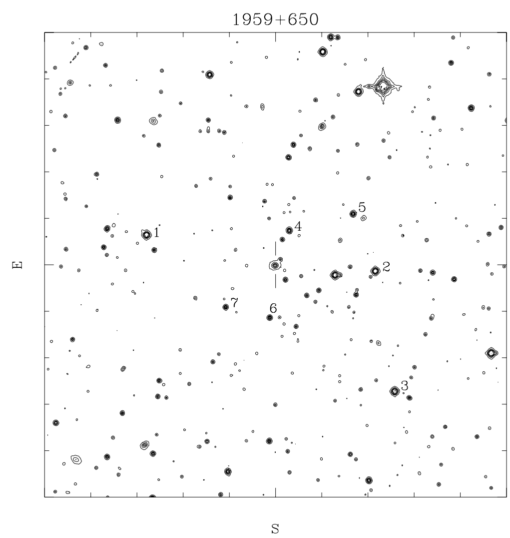

Fig. 10. Finding chart of 1ES 1959+650