THE ASTRONOMICAL JOURNAL VOLUME 96, NUMBER 4 OCTOBER 1988

LONG-TERM OPTICAL BEHAVIOR OF 144 COMPACT EXTRAGALACTIC OBJECTS: 1969–1988

ANDREW J. PICA,[a] ALEX G. SMITH, JAMES R. WEBB, ROBERT J. LEACOCK, SANDRA CLEMENTS, AND PAUL P. GOMBOLA

Rosemary Hill Observatory, Department of Astronomy, University of Florida, Gainesville, Florida 32611

Received 18 April 1988; revised 16 June 1988

ABSTRACT

Photometric data are reported for 144 extragalactic sources observed during a 19 yr program of photographic monitoring. An additional 22 objects that were classified as optically violent variables (OVVs) have been discussed by Webb *et al.* (1988). The present paper summarizes results for the generally less active sources not included in that earlier publication. Of these, 92 exhibited optical variations at a confidence level of 95% or more. Light curves are presented for 25 of the more interesting objects, three of which displayed OVV activity in the Florida records; another five sources underwent one or more events that approach the OVV level.

I. INTRODUCTION

A program of photographic monitoring of over 200 compact extragalactic objects has been in continuous operation at the University of Florida's Rosemary Hill Observatory since 1969. Earlier summaries of the observations were published by McGimsey *et al.* (1975), Scott *et al.* (1976), Pollock *et al.* (1979), and Pica *et al.* (1980). A recent publication by Webb *et al.* (1988) describes in detail the results obtained for 22 program objects classified at the time of writing as "optically violent variables," or OVVs. The present work summarizes results for 144 additional sources for which there are both extensive observations and reliable comparison sequences. We have consistently followed the criteria delineated by Penston and Cannon (1970) in dividing our program objects into the OVV and non-OVV categories. According to this definition, OVVs exhibit changes in optical intensity of a magnitude or more on timescales of days or weeks.

The methods used to obtain and reduce the data are described in detail in the previous publications, as well as in Pica *et al.* (1987). These earlier papers also include extensive discussions of errors and the steps taken to identify and minimize them. Thus, we present here only a brief summary of protocols. Nearly all exposures were made at the $f/4$ Newtonian focus of the 76 cm reflector, but a few bright objects were at times recorded at the $f/10.5$ Cassegrain focus of the 46 cm telescope. All plates were hypersensitized, and all exposures were made in sealed cassettes in a dry-nitrogen atmosphere. The objects discussed here were photographed on Kodak spectroscopic plates, type 103a–O, in either the Johnson B system (B) or the international photographic system (P), depending on available comparison sequences. Where possible, sequences were obtained from the literature, but in many cases they were established by photographic transfer from nearby Selected Areas, star clusters, or galaxy fields, the objective in each case being to calibrate at least ten reliable comparison stars that were both brighter and fainter than the QSO and within 15 arcmin of it. Readers interested in obtaining any of the sequences can do so by contacting the authors.

Plates were reduced on a Cuffey iris photometer. A Commodore PET 2001 dedicated minicomputer fits a parabolic least-squares curve to the magnitudes and iris readings of the comparison stars, and displays the interpolated magnitude of the QSO. Following Penston and Cannon (1970), we adopt the rms scatter of the comparison stars about the fitted parabola as a measure of error. Based on multiple exposures of the same object made in rapid succession, this error appears to be a conservative estimator of the actual error in the QSO magnitude itself, probably because of increased scatter at the faint end of the comparison sequence. Typical errors are in the range 0.1–0.2 mag. While the formal rms error does not include systematic zero-point errors, our extensive experience in merging RHO data with photoelectric observations suggests that significant zero-point errors are infrequent.

For the purposes of the present paper, all data going back to 1969 were reviewed, and in some cases rereduced to take advantage of improved comparison sequences. It should be noted that our computer programs smooth the sequences, as well as detecting and eliminating comparison stars that are intrinsically variable, so that the sequences improve with time.

II. TABULATED SUMMARY OF RESULTS

The 144 objects in the present study are listed in order of increasing right ascension in column 1 of Table I. For the 123 sources listed by Hewitt and Burbidge (1987), the designation is that given by those authors. Column 2 provides alternative or common names that may be more familiar. Columns 3, 4, and 5 list the inclusive dates of the RHO observations, the total number N of reliable observations, and the color system (B or P) of the observations. The arithmetic average of the N measured magnitudes is shown in column 6, followed by the brightest observed RHO magnitude in column 7. The total observed range of variation, in magnitudes, is listed in column 8; by combining columns 7 and 8, one can, of course, obtain the faintest measured RHO magnitude. Column 9 gives the average of the individual rms errors of the N plates, a quantity that is often a measure of the quality of the comparison sequence. The well-known chi-squared statistical test has been applied to each set of N observations, and column 10 lists for each object the formal probability that the measured fluctuations represent real variations in the source; fuller discussions of this test of significance are given by Penston and Cannon (1970) and by Pica *et al.* (1987). A confidence level of 95% or more has been widely accepted as a good indication that a source is actually variable; it can be seen that many of the objects in Table I display chi-squared probabilities of variation exceeding 99.5%.

[a] Present address: Department of Chemistry and Physics, Salisbury State University, Salisbury, MD 21801.

TABLE. I. Summary of observational data for 144 objects. An asterisk (*) in column 11 indicates an identification from Preston *et al.* (1985). RHO identifications are marked by a double asterisk (**). The remaining identifications are from Hewitt and Burbidge (1987).

SOURCE (1)	ALT. NAME (2)	OBS. DATES (3)	N (4)	COL. (5)	AVG. MAG (6)	MIN. MAG (7)	Δ MAG (8)	AVG. RMS (9)	PROB. VAR. (10)	TYPE (11)	SUB-CLASS (12)
0003+158	PHL 658	10/82-09/86	17	B	15.95	15.70	0.79	0.23	20%	Q	
0007+106	III Zw2	12/77-12/87	62	B	15.23	14.38	1.51	0.17	>99.5	SEY	III
0013-005		09/70-01/86	45	P	18.45	17.72	1.09	0.18	90	RSO*	
0024+349	OB 338	10/69-12/77	16	P	19.62	19.03	0.99	0.20	70	Q*	
0035+121		08/77-01/86	40	B	17.16	16.89	0.83	0.14	>99.5	LAC**	
0048-097	OB-081	11/70-01/88	95	P	16.27	15.30	2.22	0.13	>99.5	LAC	III
0056-001	PHL 923	09/70-01/86	40	P	17.02	16.65	0.67	0.14	3	Q	
0058+019	PHL 938	12/74-09/86	30	B	16.55	16.35	0.60	0.14	75	RQQ	
0109+224		11/76-11/87	56	B	16.41	15.48	1.94	0.18	>99.5	LAC	III
0119-046	4C-04.4	12/69-10/86	56	P	16.47	16.21	0.62	0.15	5	Q	
0128+074	PHL 3375	12/74-01/86	19	B	18.00	17.67	0.63	0.14	98	RQQ	
0130+033	PHL 1027	12/74-11/85	26	B	16.91	16.65	0.68	0.12	70	RQQ	
0133+476	OC 457	02/75-12/80	7	P	17.66	17.00	1.31	0.20	>99.5	Q	
0134+329	3CR 48	09/79-12/85	25	B	16.46	16.17	0.69	0.17	15	Q	
0139+061	PHL 3632	01/75-11/85	22	B	17.80	17.44	0.67	0.13	98	RQQ	
0141+339	DA 58	09/71-11/85	21	P	17.01	16.85	0.30	0.08	50	Q	
0147+089	PHL 1186	12/74-12/87	35	B	17.55	16.50	1.47	0.13	>99.5	RQQ	II
0148+090	PHL 1194	08/75-01/86	28	B	17.83	17.20	1.30	0.13	>99.5	RQQ	II
0151+048	PHL 1222	01/75-01/86	21	B	17.62	17.41	0.42	0.12	5	RQQ	
0151+045	PHL 1226	12/74-01/86	25	B	17.40	17.02	0.76	0.13	>99.5	RQQ	
0159-117	3C 57	12/69-01/86	56	B	16.66	16.01	1.18	0.11	>99.5	Q	I
0202-172		10/69-01/86	50	P	16.99	16.67	0.65	0.12	75	Q	
0219+428	3C 66A	07/74-11/85	46	B	15.58	14.92	1.33	0.14	>99.5	LAC	I
0222-234	MSH 02-27	12/69-01/86	36	P	16.56	15.60	1.48	0.13	>99.5	Q?*	II
0229+131		10/69-01/86	60	P	17.03	16.60	0.74	0.15	75	Q	
0251+189		12/70-01/86	29	P	17.06	16.63	0.74	0.14	10	Q?**	
0301-243		10/77-01/86	21	B	16.63	16.09	0.89	0.16	99	LAC*	
0323+022		09/86-01/87	7	B	17.48	17.45	0.13	0.09	3	LAC	
0333+321	NRAO 140	08/71-01/86	49	P	17.10	16.65	0.75	0.16	1	Q	
0336-019	CTA 26	12/69-01/88	77	P	17.60	16.66	1.46	0.14	>99.5	Q	I
0338-214		10/77-12/86	30	B	16.91	16.25	1.27	0.16	>99.5	LAC*	I
0340+048	3CR 93	11/71-01/86	22	P	17.73	17.27	0.98	0.12	>99.5	Q	
0350-073	3C 94	10/71-01/86	28	B	16.70	16.49	0.37	0.12	20	Q	
0414+009		09/84-01/87	21	B	17.59	17.16	0.93	0.13	95	LAC	
0414-060	OF-024	01/77-02/86	39	B	16.25	16.05	0.57	0.13	80	Q	
0422+004	OF 038	10/76-01/88	51	B	16.05	15.23	2.18	0.15	>99.5	LAC	III
0454-220		10/82-10/86	14	B	15.51	15.10	0.87	0.13	99	Q	
0513-002	ARK 120	02/80-10/86	26	B	13.83	13.55	0.55	0.13	40	SEY**	
0642+449	OH 471	02/75-01/86	31	B	18.42	18.15	1.08	0.17	99	Q	
0711+356	OI 318	11/69-03/86	55	P	18.06	17.40	1.31	0.17	>99.5	Q	III
0723-008		03/80-01/88	39	B	18.19	16.84	2.31	0.17	>99.5	NSO*	II
0725+147	3CR 181	03/71-02/86	66	P	17.68	17.26	0.81	0.12	90	Q	
0736+017	OI 061	11/70-01/88	118	P	16.05	15.45	1.35	0.09	>99.5	Q	III
0738+313	OI 363	02/69-03/86	46	P	16.16	15.85	0.55	0.12	97.5	Q	
0752+258	OI 287	11/80-03/86	20	B	18.41	18.06	1.14	0.17	>99.5	Q	
0754+100	OI 090.4	03/79-01/88	45	B	15.71	15.05	1.56	0.17	>99.5	LAC	III
0802+103	3CR 191	03/72-03/86	28	P	18.19	17.91	0.84	0.12	>99.5	Q	
0805+046	4C 05.34	05/70-03/86	87	P	18.35	17.90	0.70	0.12	>99.5	Q	
0812+020	4C 02.23	03/72-01/86	33	P	16.43	16.12	0.70	0.09	>99.5	Q	
0818-128	OJ-131	11/80-03/86	21	B	17.01	15.77	2.40	0.16	>99.5	LAC	III
0829+046	OJ 049	11/80-01/88	48	B	16.66	14.79	3.19	0.17	>99.5	LAC	I
0829+187		03/69-01/86	22	P	17.47	17.05	0.83	0.10	99.5	GAL*	
0850+140	3CR 208	04/72-12/86	47	P	17.30	16.32	1.67	0.12	>99.5	Q	II
0922+149	4C 14.31	04/72-03/86	30	P	17.38	16.74	1.13	0.14	>99.5	Q	
0945+077		03/72-04/86	46	P	16.69	16.06	1.01	0.09	>99.5	GAL**	II
0953+254	OK 290	02/70-01/88	92	P	17.13	16.59	1.39	0.12	>99.5	Q	III
0957+003	OK 096	03/72-01/86	26	P	17.03	16.36	1.02	0.13	98	Q	
0957+561	A	06/79-04/86	37	B	17.25	16.83	0.77	0.15	75	Q	
0957+561	B	06/79-04/86	37	B	17.35	16.77	1.44	0.15	>99.5	Q	
1004+130	4C 13.41	03/72-01/88	79	P	14.72	14.34	0.79	0.14	>99.5	Q	II
1019+309	OL 333	05/69-03/87	44	P	16.75	16.42	0.65	0.15	>99.5	Q	

TABLE I. (continued)

SOURCE (1)	ALT. NAME (2)	OBS. DATES (3)	N (4)	COL. (5)	AVG. MAG (6)	MIN. MAG (7)	Δ MAG (8)	AVG. RMS (9)	PROB. VAR. (10)	TYPE (11)	SUB-CLASS (12)
1021-006		12/69-01/87	32	P	17.84	17.48	1.00	0.17	99	Q	
1040+123	3CR 245	03/71-01/87	37	P	16.45	16.07	1.00	0.15	>99.5	Q	
1049+215	4C 21.28	02/70-01/87	37	P	17.89	17.46	0.89	0.18	95	Q	
1055+201	4C 20.24	02/72-12/86	54	P	16.25	15.83	0.92	0.19	7	Q	
1101+384	MK 421	04/77-04/87	51	B	13.82	13.35	1.00	0.16	>99.5	LAC	
1116+128	4C 12.39	03/71-01/88	47	P	18.47	17.57	1.68	0.17	>99.5	Q	III
1119+183	OM 133	01/70-02/86	29	P	18.03	17.63	0.78	0.13	99.5	Q	
1123+20B		02/70-05/87	51	P	16.76	15.46	2.19	0.18	>99.5	GAL**	II
1127-145	OM-146	05/70-04/86	16	P	16.74	16.58	0.50	0.14	8	Q	
1147+245	OM 280	03/81-04/86	11	B	16.66	16.41	0.77	0.19	75	LAC	
1148-001	4C-00.47	04/69-03/87	29	P	17.14	16.54	1.08	0.14	>99.5	Q	
1150+497	4C 49.22	02/81-04/87	15	B	17.50	17.31	0.44	0.16	10	Q	
1215+303	ON 325	02/72-01/88	152	B	15.73	14.65	2.00	0.13	>99.5	LAC	III
1217+023	ON 029	04/71-04/87	42	P	15.93	15.36	1.05	0.12	>99.5	Q	
1218+304	RS 4	01/85-05/87	21	B	16.45	15.99	1.04	0.12	>99.5	LAC	
1226+023	3CR 273	01/74-05/87	110	B	13.02	12.59	0.87	0.13	>99.5	Q	I
1229-021	4C-02.55	05/71-04/87	34	P	16.72	16.28	0.94	0.12	>99.5	Q	
1237-101	ON-162	05/70-04/86	19	P	17.22	16.79	0.72	0.12	>99.5	Q	
1246+377	BSO 1	03/75-03/87	24	B	18.25	17.61	0.99	0.16	99.5	RQQ	
1246+346	B 46	05/75-04/87	24	B	18.14	17.82	0.89	0.14	>99.5	RQQ	
1248+337	BSO 2	06/75-03/87	19	B	18.73	18.48	0.85	0.14	95	RQQ	
1252+119	ON 187	06/69-04/87	63	P	16.17	15.86	0.92	0.14	90	Q	
1252+359	B 114	05/75-04/87	20	B	17.46	16.91	1.18	0.17	99.5	RQQ	
1253-055	3C 279	05/71-05/87	56	P	16.84	15.49	2.16	0.15	>99.5	Q	III
1255+353	B 154	06/75-04/86	17	B	18.83	18.50	0.70	0.16	98	RQQ	
1256+357	B 194	06/75-04/87	17	B	18.24	18.00	0.53	0.15	10	RQQ	
1257+346	B 201	05/75-04/87	20	B	16.99	16.58	0.87	0.15	70	RQQ	
1259+344	BSO 6	05/75-04/86	19	B	18.36	18.08	0.57	0.13	80	RQQ	
1304+374	B 312	04/76-04/87	11	B	19.26	18.70	0.75	0.20	35	RQQ	
1311+362	BSO 11	06/75-04/87	15	B	18.82	18.67	0.78	0.16	50	RQQ	
1318+290	Ton 155	06/74-04/87	47	P	16.98	16.39	1.03	0.18	75	Q	
1318+290	Ton 156	06/74-04/87	47	P	16.34	15.81	1.16	0.18	75	Q	
1340+053		05/71-03/87	20	P	16.74	16.45	0.58	0.13	93	GAL**	
1347+214		02/69-04/86	54	P	15.14	14.60	0.89	0.17	75	Q?**	
1354+195	4C 19.44	04/74-07/86	27	B	16.30	15.88	0.95	0.09	>99.5	Q	
1402-012	UM 632	06/71-07/83	23	P	17.16	16.88	0.61	0.13	99.5	Q	
1418+546	OQ 530	05/80-04/87	21	B	15.91	15.12	1.54	0.19	>99.5	LAC	III
1442+101	OQ 172	03/74-03/87	41	P	17.26	16.79	0.97	0.16	50	Q	
1502+036		06/71-07/86	10	P	18.14	17.94	0.60	0.14	75	Q	
1505+012		04/69-07/86	22	P	18.02	17.79	0.51	0.08	99	Q?*	
1510-089	OR-017	06/69-08/87	80	P	16.74	15.58	2.02	0.12	>99.5	Q	III
1526+285		05/83-07/86	11	B	15.70	15.42	0.57	0.16	60	Q	
1532+01E		04/78-04/87	34	B	18.39	17.72	1.31	0.13	>99.5	Q?**	II
1532+01W	1532+016	05/81-04/87	30	B	18.11	17.39	1.38	0.13	>99.5	Q	I
1538+149	4C 14.60	07/79-07/86	26	B	18.31	17.70	1.28	0.15	>99.5	LAC	I
1546+027	OR 078	05/71-07/83	13	P	16.83	16.43	0.93	0.20	>99.5	Q	
1553+113		05/83-04/87	12	B	15.04	14.62	1.03	0.14	>99.5	LAC	
1606+106		04/71-07/86	28	P	16.63	16.06	0.84	0.11	>99.5	Q*	
1611+343	OS 319	03/80-04/87	29	B	17.76	17.08	1.18	0.14	>99.5	Q	
1615+029		06/71-07/86	21	P	17.24	16.68	0.85	0.22	20	Q	
1618+177	3CR 334	05/71-07/86	57	B	16.77	16.37	1.18	0.15	>99.5	Q	III
1645+174		08/69-07/86	48	P	17.86	17.52	0.56	0.17	1	GAL*	
1652+398	MK 501	03/79-03/87	67	B	14.44	14.03	0.90	0.15	90	LAC	
1704+608	3CR 351	03/79-04/87	47	B	16.01	15.64	0.74	0.16	70	Q	
1727+502	I ZW187	05/75-04/87	103	B	16.70	16.15	0.80	0.15	50	LAC	
1749+701		03/79-08/87	39	B	17.39	16.74	1.40	0.19	>99.5	LAC	III
1749+096	OT 081	08/79-08/87	48	B	17.88	16.24	2.65	0.16	>99.5	LAC	I
1831+731		06/76-10/86	72	P	15.39	14.93	0.73	0.13	75	SEY**	
1845+797	3C 390.3	07/73-11/87	100	B	16.42	15.67	2.01	0.16	>99.5	SEY**	III
1901+319	3C 395	03/80-09/86	36	B	17.42	16.71	1.66	0.15	>99.5	Q	II
1921-293	OV-236	06/76-08/87	61	P	16.82	15.47	2.64	0.17	>99.5	Q	III
2059+034	OW 098	06/71-09/86	55	P	18.06	17.36	1.16	0.17	99.5	Q	
2111-259		10/70-09/86	21	P	17.45	16.81	1.33	0.16	99.5	Q*	

TABLE I. (continued)

SOURCE (1)	ALT. NAME (2)	OBS. DATES (3)	N (4)	COL. (5)	AVG. MAG (6)	MIN. MAG (7)	Δ MAG (8)	AVG. RMS (9)	PROB. VAR. (10)	TYPE (11)	SUB-CLASS (12)
2128-123	PHL 1598	07/69-11/86	38	B	15.89	15.49	1.02	0.16	>99.5	Q	
2131-021	4C-02.81	06/71-11/78	20	P	18.73	18.23	1.23	0.14	>99.5	LAC	
2134+004	PHL 61	09/73-11/86	37	B	17.55	17.13	0.62	0.11	20	Q	
2135-147	PHL 1657	06/75-09/86	35	P	15.19	14.92	0.98	0.15	>99.5	Q	
2145+067	4C 06.69	07/69-07/86	81	P	16.27	15.76	0.86	0.15	75	Q	
2155-304		07/79-11/86	28	B	13.58	12.93	1.07	0.15	99.5	LAC	
2201+315	4C 31.63	07/80-07/86	32	B	15.79	15.36	0.77	0.19	5	Q	
2209+080	4C 08.64	08/69-11/85	54	P	18.36	17.92	1.05	0.17	50	Q	
2216-038	4C-03.79	08/69-11/85	28	P	15.72	15.46	0.70	0.12	10	Q	
2223+210	DA 580	07/80-11/86	25	B	18.08	17.75	0.93	0.18	70	Q	
2230+114	CTA 102	08/73-11/87	65	B	17.66	17.26	1.14	0.12	>99.5	Q	III
2251-178		08/78-11/86	25	B	14.79	14.27	0.87	0.16	97	Q	
2254+024	OY 091.3	06/71-10/85	24	P	17.07	16.90	0.42	0.10	75	Q	
2254+074	OY 091	07/79-11/87	43	B	17.03	15.65	2.37	0.15	>99.5	LAC	I
2300-189		08/71-11/85	30	P	17.57	16.44	1.65	0.14	>99.5	GAL*	II
2305+187	4C 18.68	10/82-10/85	8	B	17.92	17.34	1.15	0.19	99	Q	
2335-181		12/69-11/85	44	P	16.55	15.89	1.53	0.17	>99.5	Q	II/I
2349-014	PB 5564	12/69-11/87	91	P	15.63	14.80	1.66	0.16	>99.5	Q	III
2354-117		10/69-10/85	19	P	18.58	18.10	0.79	0.15	75	Q*	
2354+144	4C 14.85	10/69-11/85	42	P	18.10	17.65	0.70	0.14	25	Q	

Column 11 of the table identifies the object as a classical quasar (Q), a BL Lacertid (LAC), a compact galaxy (GAL), a Seyfert galaxy (SEY), a neutral stellar object (NSO), or a red stellar object (RSO). Radio-quiet QSOs are designated as RQQ. These identifications were derived from the literature, with many coming from Hewitt and Burbidge (1987). Sources not listed by Hewitt and Burbidge are distinguished by single or double asterisks. In the case of the single asterisk (*), the identification is that given by Preston *et al.* (1985); double asterisks (**) indicate identifications made at RHO on the basis of available information.

Following the practice in earlier work here (see papers cited in Sec. I) and elsewhere (Dent *et al.* 1974), we have assigned so-called "variability subclasses" to a number of the objects for which adequate runs of data were obtained. Listed in column 12 of Table I, these designations are intended to convey at least a rough impression of the appearance of the light curve. Subclass I shows rapid, nearly continuous "flickering" without major long-term trends. Conversely, subclass II is dominated by slow, long-term changes larger than any brief flickerings. Subclass III is a mixture of short- and long-term fluctuations of comparable amplitudes. In many cases in the present work, the data were insufficient to permit assignment of a subclass with a reasonable degree of confidence. It should also be remarked that in some cases the morphology of a light curve has been found to change markedly with time. For example, prior to 1980, BL Lacertae was the quintessential example of a pure subclass I object. Since 1980, the variations would fall into subclass III (Smith *et al.* 1988).

III. LIGHT CURVES

Initially, light curves were plotted for 42 of the objects listed in Table I. The selection was made on the basis of completeness of the data, activity of the source, and/or morphology of the light curve. From this group, 25 light curves were chosen for reproduction as Fig. 1 of the present paper. Again, the criteria included completeness, overall activity, or unusual interest of the object or its light curve.

Because the RHO program is ongoing, it was necessary for obvious practical reasons to establish cutoff dates for observations to be included in the analysis reflected in Table I. However, for the 25 objects in Fig. 1, special effort was devoted to adding observations made up to the time of writing in early 1988, and for these sources Table I was also updated. Recent magnitudes for most of the objects in the table can be obtained by contacting the authors, who are also prepared to provide tabulated data for any object of interest to a reader.

We now present very brief discussions of each of the 42 sources for which light curves were plotted. The designations used are those of column 1 of Table I. Objects included in Fig. 1 are indicated by an asterisk following the source name.

0007+106*. Known as III Zw 2, this galaxy is classified as a Type I Seyfert. From 1978 to 1981 it declined 0.8 mag, after which it displayed rapid flares of increasing amplitude, brightening 0.92 mag in 27 days in 1984 and fading 0.95 mag in 7 days in November of 1985, approaching the OVV category. The "base level" remained virtually constant near $B = 16$ from 1981 through 1987.

0048−097*. During 18 yr of RHO observations, this BL Lacertid varied 2.22 mag; historical research by Usher *et al.* (1974) disclosed a range of nearly 3 mag. The RHO data show a steady decline of 1.3 mag from 1972 to 1979. During the subsequent 4 yr it gradually regained its original luminosity. Flickering of about 1 mag is superimposed on these changes, although it was never quite rapid enough or of sufficient amplitude to qualify 0048 − 097 as an OVV.

0109+224*. During the initial 4 yr, the base magnitude of this BL Lacertid remained near $B = 16$. In 1979–1980 it dropped over 1 mag, where it remained through 1987 except for a flare in late 1981. Flickering of 0.6–0.7 mag is common.

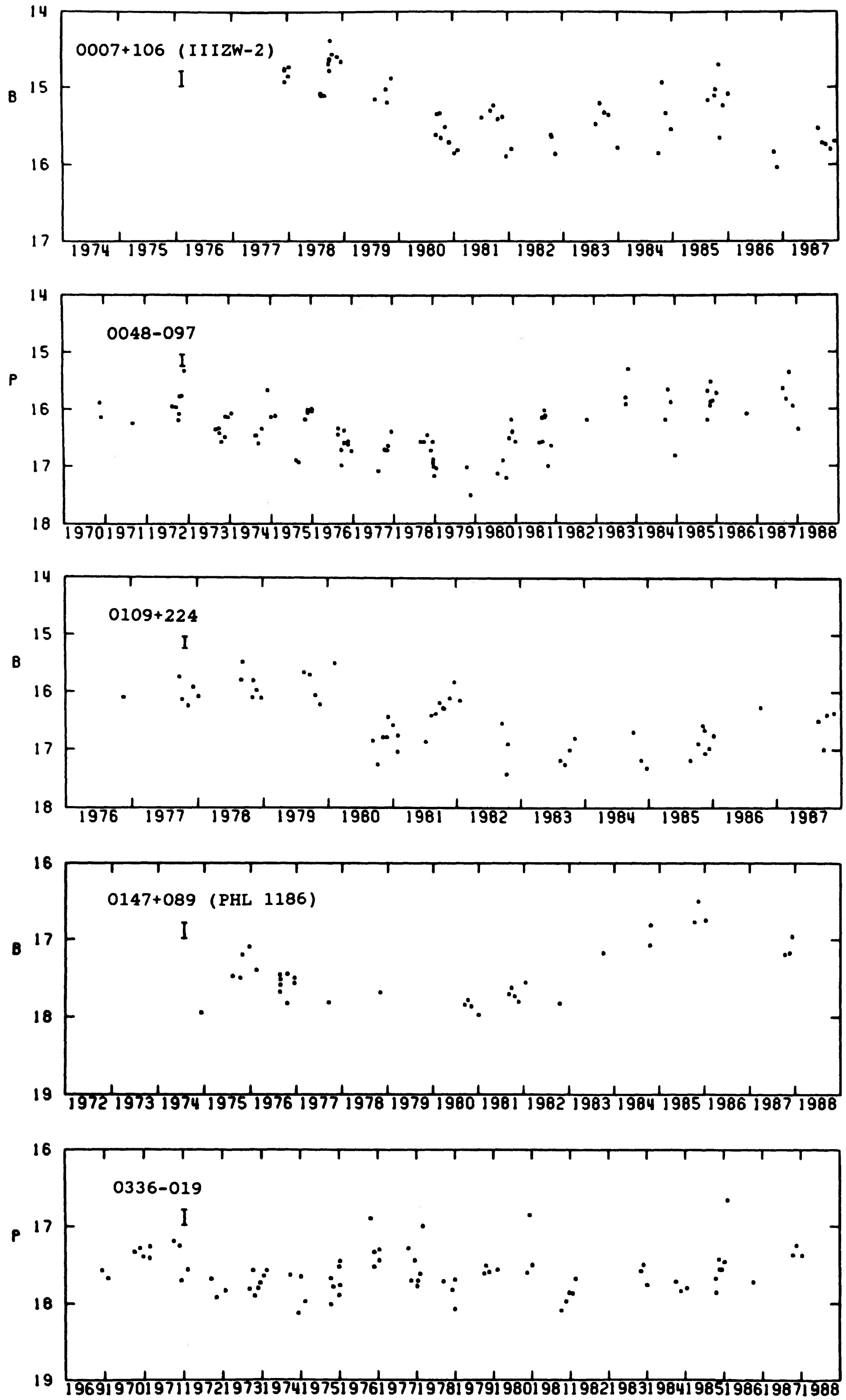

FIG. 1. RHO light curves for 25 extragalactic objects. The vertical axis is labeled in each case to indicate whether the measurements are *B* magnitudes (*B*) or are in the international photographic system (*P*). Note that each magnitude scale has been adjusted to accommodate the observed range of the individual object. The error bar under the designation for each object represents ± one rms deviation (see column 9 of Table I).

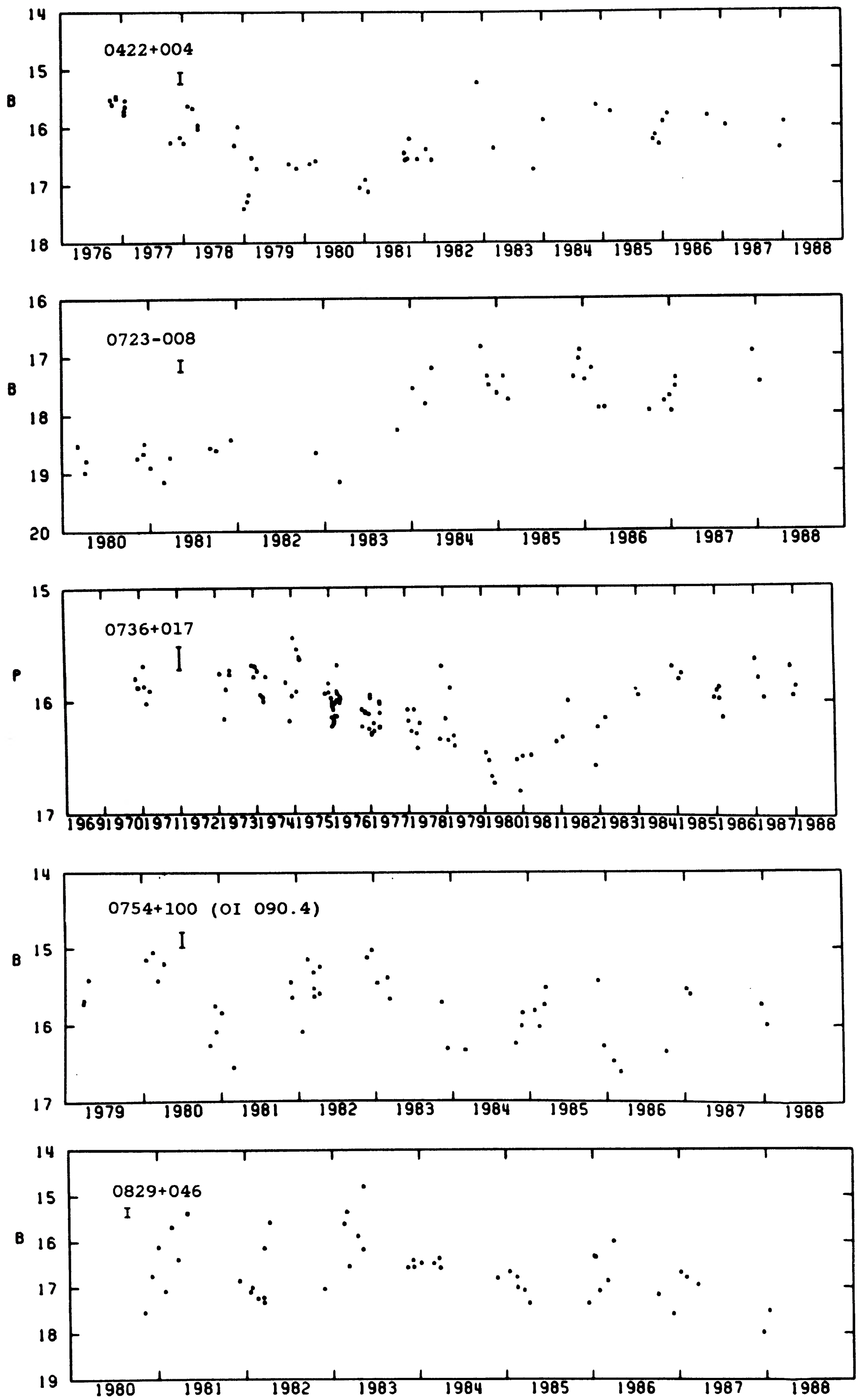

FIG. 1. (continued)

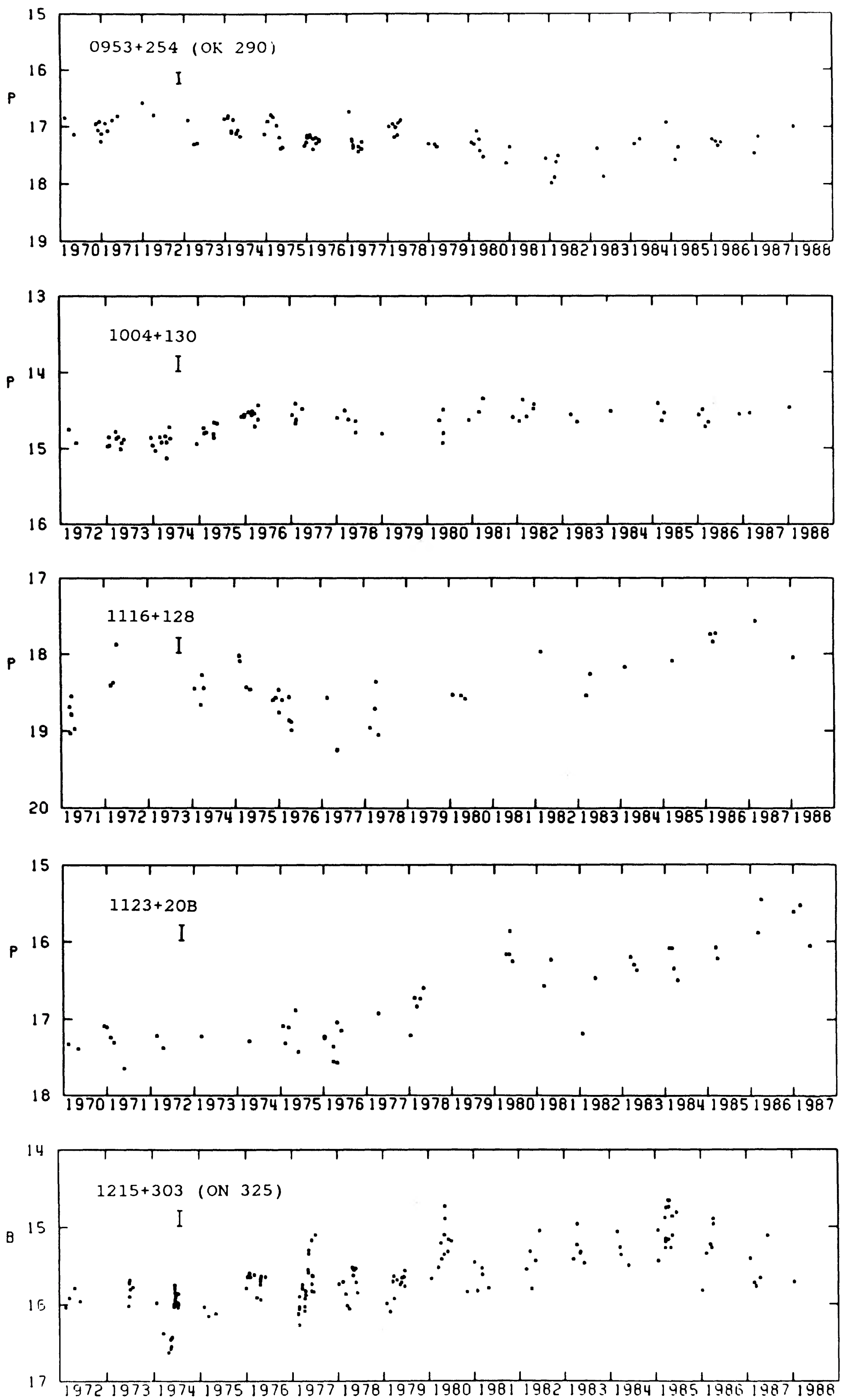

FIG. 1. (continued)

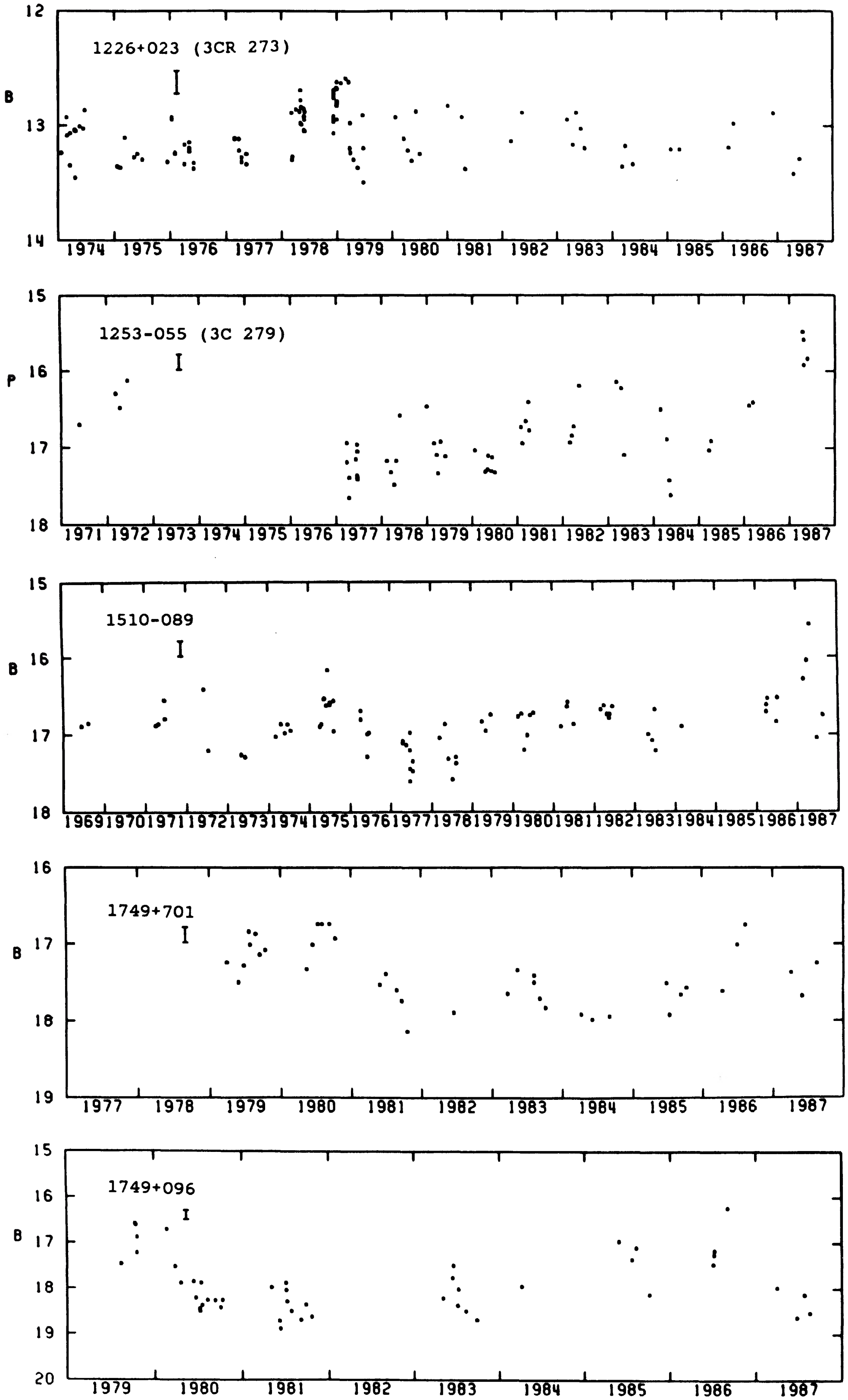

FIG. 1. (continued)

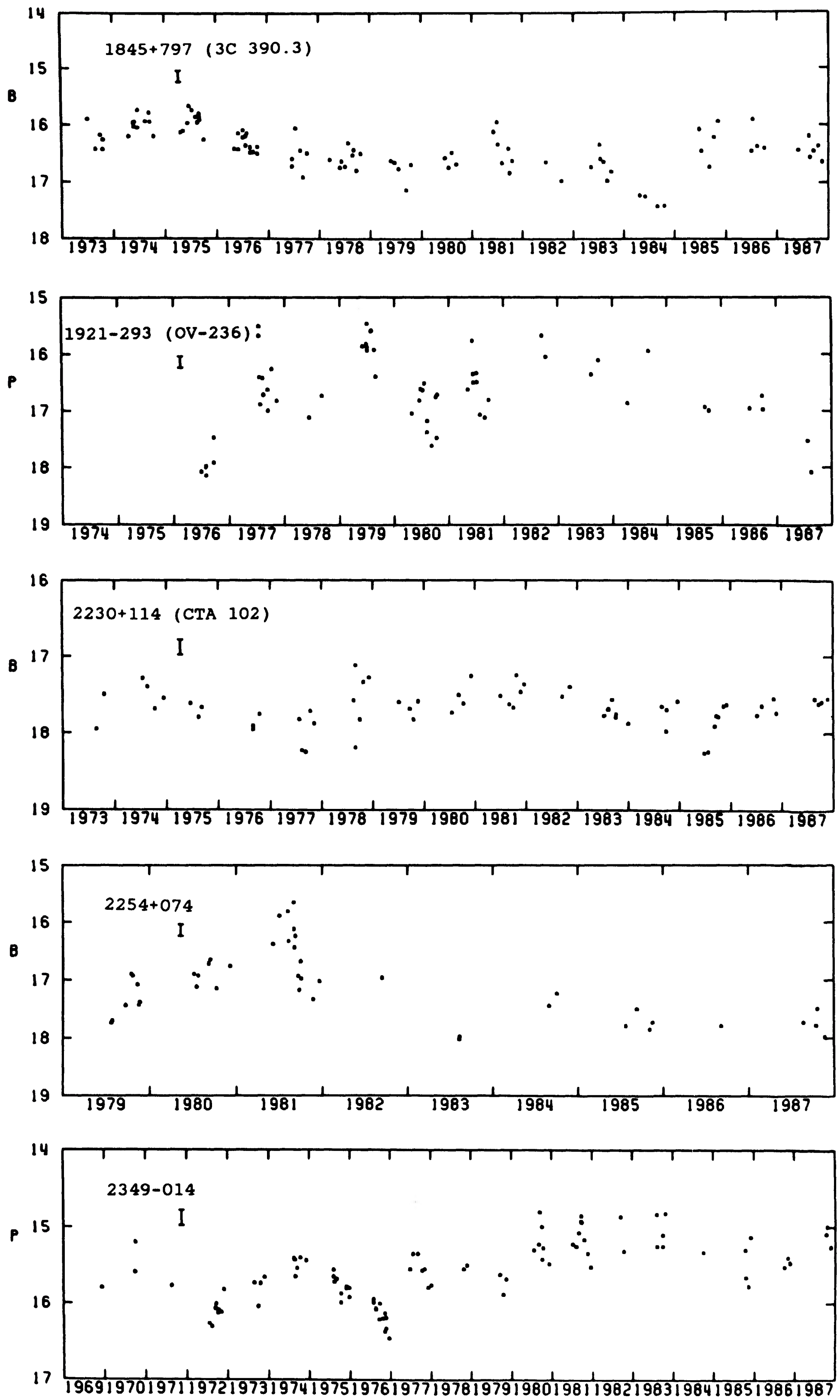

FIG. 1. (continued)

Pica's (1976, 1977) research in the Harvard plate archives revealed a range exceeding 3 mag.

0147+089*. Known as PHL 1186, this object is a radio-quiet QSO. The light curve is dominated by long-term changes with a minimum in 1978–1979, followed by a rise to a maximum in 1985. Except for the initial point in 1974, there is little suggestion of flickering. Recent data indicate a decline from the 1985 peak.

0148+090. Another radio-quiet QSO, PHL 1194, this source displays a light curve strongly resembling that of 0147 + 089. With minimal flickering, a 6 yr decline of 1.2 mag bottomed near 18.5 mag in 1983. All subsequent observations are fainter than 18 mag.

0159−117. For 17 yr, this quasar has flickered ± 0.5 mag about a "baseline" near 16.6 mag. It was most active in the late 1970s.

0219+428. A BL Lacertid known as 3C 66A, this object's light curve resembles that of 0159 − 117, flickering more than 0.5 mag about a mean of 15.6 mag. This base level may have brightened 0.2 or 0.3 mag during 12 yr of observations. Activity peaked in 1979–1980, although coverage has been sparse since 1982.

0222−234. Preston *et al.* (1985) identify this as a possible quasar. From 1971 through 1974 it fell smoothly from 15.7 to 16.7 mag. Since then, it brightened steadily at a rate of 0.07 mag per yr. Any short-term fluctuations scarcely exceed rms measurement errors.

0336−019*. This quasar displays large-amplitude flickering above a base level near 18 mag. On four occasions (1976, 1978, 1980, 1986) it was brighter than $P = 17.0$.

0338−214. RHO monitoring of this Lacertid was only moderately intensive. It resembles 0336 − 019, with rapid events up to 1 mag rising from a base near 17.4 mag.

0422+004*. This BL Lacertid varied 2.18 mag in 12 yr. It reached a minimum of 17.41 mag in late 1978, followed by steady brightening of 0.17 mag per yr. A peak of 15.23 mag was observed in a 1982 flare that is poorly defined because of a paucity of data. The drop of 1.42 mag in 1978 technically qualifies as OVV activity.

0711+356. The base level of this quasar brightened from 18.6 mag in 1970 to 17.8 mag in 1979, after which it declined. There is a good deal of short-term activity, amounting in late 1970 to as much as 1 mag. Monitoring in recent years has been sparse. The object is also known as OI 318.

0723−008*. This source was identified as a galaxy, but Preston *et al.* (1985) describe it as a "neutral stellar object." While it has not been heavily monitored at RHO, the light curve is shown because of its peculiar form. From 1980 to 1983 there was marginal activity about a mean near 18.9 mag. Then, over a year, the mean abruptly shifted to 17.5 mag, where it has persisted for another 4 yr.

0736+017*. This quasar displayed a long-term decline of 0.7 mag from 1974 to 1980, after which it returned to near its original level over the next 4 yr. There has been substantial short-term activity, with two flares of as much as 0.7 mag (late 1974, late 1978).

0754+100*. This BL Lacertid is identified as OI 090.4. Flickering of as much as 0.8 mag is superimposed on longer movements spanning 1 or 2 yr.

0818−128. This sparsely monitored Lacertid was near 16.0 mag in 1980–1981. It then faded, reaching 18.0 mag in 1983–1984, after which it began brightening. There is evidence of flares exceeding 1 mag. In 1982, there were brightenings of 1.03 mag in 3 months and 1.16 mag in 24 days, meeting the technical definition of OVV activity.

0829+046*. This Lacertid exhibited flares of more than 2 mag above a base near 17.3 mag. In 1981 and 1982, there were increases of 1.41 mag in 28 days and 1.76 mag in 25 days. It probably should be classified as an OVV.

0850+140. The light curve of this quasar resembles that of 1004 + 130. Except for a minor event in 1977, there is little convincing evidence of short-term changes. The mean brightened a few tenths from 1972 to 1977, after which it declined smoothly at about 0.05 mag per yr.

0945+077. Identified as a galaxy, this object displays a light curve like that of 0850 + 140. With little evidence of real short-term variations, the mean dimmed almost linearly from 1973 to 1986 at 0.04 mag per yr.

0953+254*. Known as OK 290, this quasar produced no major events. Instead, there is almost constant flickering of 0.5 to 0.7 mag. Between 1973 and 1982, the mean faded 0.7 mag, after which the trend appeared to reverse.

1004+130*. Identified as a quasar, this source has shown a slow, nearly linear increase in brightness of 0.03 mag per yr. A minor surge occurred in 1976–1977, but any other short-term activity scarcely rises above the "noise" of the errors. Jackish (1971) reported no significant optical variability, while a historical study by Grandi and Tifft (1974) showed a range of only 1 mag.

1116+128*. This quasar displays small-amplitude flickering superimposed on long-term changes. After fading below 19 mag in 1977, it began a gradual brightening that reached 17.5 mag in 1987.

1123+20B*. Classified as an N galaxy, this object displays flickering with amplitudes up to 0.7 mag. The mean remained constant near 17.3 mag from 1970 to 1976, after which it began systematic brightening that carried it to 15.5 mag in 1987.

1215+303*. This BL Lacertid is known as ON 325. It varied 2 mag in 16 yr of RHO monitoring, the same range found by Hall and Usher (1973) in historical records. Flares of the order of 1 mag in 1974, 1977, 1980, 1985, and 1986 approach OVV activity. These events are superimposed on a base that brightened from 1974 to 1985 at 0.1 mag per yr, but the recent trend seems downward.

1226+023*. This object is 3CR 273, the archetypical variable quasar. Despite its reputation, it is only mildly variable, spanning a range of 0.87 mag in 17 yr of RHO data. Since its mean appears to have remained stable a little below 13 mag, we assigned it to subclass I. The RHO records show unusual activity in 1978–1979.

1253−055*. Known as 3C 279, this quasar is a noted radio variable. A historical light curve by Eachus and Liller (1975) spanned 6.7 mag with periods of OVV activity; in 1937, it attained $B = 11.27$. RHO monitoring revealed flickering of about 1 mag above a base that brightened from 17.7 mag in 1977 to 16.9 mag in 1982, and then fell back to 17.7 mag in 1984. Since 1984, there has been a steep rise to levels as bright as 15.4 mag in mid-1987. The brightening in 1987 marked the start of a major flare that reached $P = 13.29$ on 3/13/88; by 6/8/88 it had declined to 14.5 mag. Clearly, 3C 279 is an OVV.

1418+546. This BL Lacertid, known as OQ 530, was not followed intensively. In 1980, it dimmed 1.1 mag in 2 months; then, starting at 16.7 mag, it gradually brightened over 1 mag.

1510−089*. The 19 yr light curve of this quasar shows flickering of up to 0.7 mag, as well as long-term variations. The long-term trend was downward from 1969 to 1977, after which brightening at 0.1 mag per yr set in. In 1987, it attained $B = 15.58$, but then fell swiftly below 17 mag, completing the most conspicuous event in the record. Using archival plates, Liller and Liller (1975) found the source had varied 6 mag, from $B = 11.8$ to 17.8 mag, though it has been less active in the past two decades.

1532+01 E, W. A pair of objects 1!'1 apart is listed in the RHO records as 1532 + 01 E and 1532 + 01 W. According to Bolton *et al.* (1976), both show ultraviolet excesses and "continuous or weak-lined emission spectra" (a footnote adds "... some of the spectrograms show an uncertain emission line near 3695 Å"). Positional agreement identifies 1532 + 01 W as the radio source 1532 + 016 listed by Hewitt and Burbidge (1987) as a quasar. 1532 + 01 E is apparently radio quiet and is not listed by Hewitt and Burbidge or Preston *et al.* (1985). The comments of Bolton *et al.* suggest it is a quasar or a BL Lacertid.

The light curve for 1532 + 01E fails to display the activity usually associated with Lacertids, although it is clearly variable. From $B = 18.3$ in 1978 it declined to 19 mag in 1981–1982, after which it recovered to a peak of 17.8 mag in 1985. During 1986–1987 it was once more fading. The only conspicuous short-term event was a change of 0.6 mag in 6 days in 1981. 1532 + 01 W displayed a 1 mag flare in 1981, after which its base rose from $B = 18.6$ to 17.6 mag in 1983. Since then it has fallen to near 18.7 mag in 1987.

1538+149. This BL Lacertid was observed sporadically. It showed short-term fluctuations of 0.6 or 0.7 mag, and it brightened from a low of 19 mag in 1981 to 17.7 in 1983.

1618+177. The base magnitude of this quasar increased almost linearly from near $B = 16.5$ in 1971 to 17.6 in 1979. The trend reversed, and slow brightening occurred at 0.1 mag per yr. Superimposed on these trends is flickering of about 0.6 mag.

1749+701*. In 1979 and 1980, this Lacertid oscillated around a mean of 17 mag. In 1981, the mean faded 0.8 mag, where it remained for 4 yr. Rapid brightening of 1 mag in 1986 was followed by an equivalent drop by mid-1987. The oscillations, typically of about 0.6 mag, are too slow to be described as "flickering," since they span 5 or 6 months.

1749+096*. The RHO records of this Lacertid show marked activity in 1979–1981, ranging from a peak of 16.6 mag to a low of 18.9 mag. The base trended upward from 1983 to 1986, with a flare in 1986 reaching 16.2 mag. In 1987, it was again faint, between 18 and 18.6 mag.

1845+797*. This Seyfert is known as 3C 390.3. Over most of the 15 yr light curve, any short-term variations are scarcely out of the noise. However, distinct events occurred in 1981, 1983, and 1985–1986. The mean fell from 16 mag in 1975 to 17.5 mag in 1984, after which the source brightened and became unusually active. It is interesting that the x-ray luminosity also declined steadily, by an order of magnitude, over a period of 15 yr (Halpern *et al.* 1988).

1901+319. Known as 3C 395, this quasar trended downward from near 17 mag in 1980 to 18.4 mag in 1985–1986, with a drop of 0.9 mag in 6 months of 1985.

1921−293*. This quasar is known as the radio source OV-236. RHO observations, initiated at the suggestion of J. D. Kraus, disclosed optical variations of more than 2.6 mag. In 1977, it faded 1.4 mag in 9 days. It should be classified as an OVV. OV-236 is an active radio source, with Dent and Balonek (1980) reporting it as the most intense quasar in the sky at 31 GHz. In 1987, it was fainter than 18 mag, near its RHO low.

2230+114*. Known as CTA 102, this quasar varied only 1.14 mag in 14 yr. Modest long-term swings occurred around the average of $B = 17.7$. The most significant flare brightened 1.07 mag in 2 days in 1978, this event nearly equaling the overall 14 yr range.

2254+074*. This BL Lacertid exhibited a flare of 1.8 mag in 1981, falling 1.3 mag in 18 days after the peak of $B = 15.65$. Thus, it is capable of optically violent behavior. From 1983 through 1987 the base remained nearly constant near 18 mag.

2300−189. This N galaxy displayed largely long-term variations, with any flickering failing to rise clearly out of the noise. From 1971 through 1976 the mean remained near 17.8 mag. During the next 5 yr, it brightened nearly linearly to 17.0 mag, after which it fell to 17.8 mag in 1983. From 1983 to late 1985 it rose to its brightest RHO magnitude, $P = 16.44$.

2335−181. This quasar was quiescent from 1969 to early 1977, with little short-term activity, although the mean faded from $P = 16.3$ to 16.7 mag. In mid-1977, the source became quite unstable, flaring 0.8 mag before returning to the original level in 4 months. From October 1978 to July 1979 it fell 1.43 mag to its faintest recorded level, $P = 17.42$. Between October 1982 and October 1983, it brightened 1.26 mag. The erratic behavior from 1977 to 1986 is in marked contrast with the earlier uneventful record.

2349−014*. From 1972 through 1976, this quasar displayed a symmetrical brightening and fading of 1 mag. It then brightened from 16.5 mag in 1976 to 15.3 mag in 1983. A small decline in 1984–1985 was followed by brightening throughout 1986–1987. Superimposed on these long-term changes are rapid events of the order of 0.7 mag, especially after 1976.

IV. DISCUSSION

Of the 144 objects in Table I, 88 are identified as "classical" radio-loud quasars. Eighteen belong to a group of radio-quiet quasars selected by Edwards (1981) for a study of this subset. BL Lacertids in the table number 26, while there are four Seyfert galaxies and six compact galaxies. One object is classified by Preston *et al.* (1985) as a red stellar object, and one as a neutral stellar object.

Variability at a confidence level of 95% or greater is displayed by 92 of the objects in Table I (see column 10), representing 64% of the sample. It should be emphasized that the overall sample is in no sense unbiased; most of the objects were selected on the basis of known variability, promising radio spectra, or interesting properties discovered by other observers. Of these 92 sources, all but 20 have confidence levels of 99% or more. The total range of observed variation was as little as 0.13 mag (0323 + 022) to as much as 3.19 mag (0829 + 046).

Three of the objects in the present work probably should be classified as optically violent variables (OVVs); these are 0829 + 046, 1253 − 055, and 1921 − 293. Another five sources displayed one or more fluctuations in the RHO records that technically fall within the usual OVV definition of changes of a magnitude or more on timescales of days or weeks; they are 0007 + 106, 0422 + 004, 0818 − 128, 1215 + 303, and 2254 + 074. That so few objects crossed the boundary between the OVV and non-OVV categories appears to substantiate the view common among workers in the field that the optical OVVs represent a special class of sources, possibly distinguished by relativistic beaming of radiation in the direction of the observer (see, for example, Angel and Stockman 1980). A more recent term, which includes both the BL Lacertids and the classical quasars, is "blazar" (Angel and Stockman 1980). OVVs almost always exhibit high and variable radio and optical polarization, and they are generally strong, compact radio sources which may undergo superluminal expansion. OVVs tend to show flat radio spectra that become quite steep in the optical–infrared region (Rieke 1985). Objects deficient in the foregoing characteristics, in general, display the kind of moderate variability seen in most of the sources in the present paper. Present evidence does not encourage the notion of a continuum of variability bridging the gap between total quiescence and violent activity, although it is as yet unclear to what extent the bimodal distribution of variability is due to the chance orientation of the object relative to the observer (see, for example, Antonucci 1985).

Figure 1 illustrates the wide range of disparate behaviors observed in extragalactic sources. Even within each of the three subclasses (Table I, column 12), there are extensive morphological differences. Three kinds of behavior are perhaps most common. One is a pure subclass I object that displays conspicuous flickering or rapid flaring above a reasonably constant base level, 0336 − 019, 0829 + 046, and 1226 + 023 being good examples. A second archetype is a very slow, long-term change that may take the form of a nearly linear rise or fall in magnitude, with any flickering so inconspicuous as to be hidden in the measurement noise. Such subclass II morphology is well illustrated by 1004 + 130; the curves for 0222 − 234, 0850 + 140, and 0945 + 077 were not included in Fig. 1 because they closely resemble 1004 + 130. A third frequently observed behavior includes significant flickering in the presence of much slower, long-term changes of similar amplitude. Good prototypes of such subclass III activity are 0048 − 097, 0736 + 017, 1215 + 303, 2230 + 114 and 2349 − 014, all shown in Fig. 1.

In Sec. II, the OVV BL Lacertae was cited as an illustration that an object can change abruptly from one type of behavior to another. The quasar 2335 − 181 presents another such example. Prior to 1977, the uneventful light curve would be placed in subclass II. The violent oscillations that begin in 1977 are probably best described as subclass I. Interesting examples of a kind of "bistable" activity are shown by 0109 + 224 and 0723 − 008. In each case, low-level flickering occurs around a rather constant mean. Then, the mean shifts abruptly by over a magnitude (in one case up, in the other down) and the flickering continues about the new mean. The changing, almost infinite variety displayed in the light curves appears to reflect the complexity of the central engine that powers an active galactic nucleus. It is quite possible that we are studying chaotic systems in the sense that minor perturbations in input manifest themselves as major changes in output. Further complications may be introduced by beaming and propagation effects.

The authors are grateful to the National Science Foundation for the long-term support that has made this work possible; the current grant is AST 8516269. Earlier workers who made substantial contributions to the observations include M. Bitran, Patricia Edwards, G. H. Folsom, Karen Hackney, R. L. Hackney, B. Q. McGimsey, J. T. Pollock, and R. L. Scott. Technical support has been provided by Hans Schrader and Don McNeill.

REFERENCES

Angel, J. R. P., and Stockman, H. S. (1980). Annu. Rev. Astron. Astrophys. **18**, 321.
Antonucci, R. R. J. (1985). In *Active Galactic Nuclei*, edited by J. E. Dyson (Manchester University, Manchester), p. 98.
Bolton, J. G., Peterson, B. A., Wills, B. J., and Wills, D. (1976). Astrophys. J. Lett. **210**, L1.
Dent, W. A., and Balonek, T. J. (1980). Nature **283**, 747.
Dent, W. A., Kapitzsky, J. E., and Kojoian, G. (1974). Astron. J. **79**, 1232.
Eachus, L. J., and Liller, W. (1975). Astrophys. J. Lett. **200**, L61.
Edwards, P. A. (1981). Ph.D. dissertation, University of Florida.
Grandi, S. A., and Tifft, W. G. (1974). Publ. Astron. Soc. Pac. **86**, 873.
Hall, D. L., and Usher, P. D. (1973). Nature **241**, 31.
Halpern, J. P., and Filippenko, A. V. (1988). Nature **331**, 46.
Hewitt, A., and Burbidge, G. (1987). Astrophys. J. Suppl. **63**, No. 1.
Jackisch, G. (1971). Astron. Nachr. **292**, 271.
Liller, M. H., and Liller, W. (1975). Astrophys. J. Lett. **199**, L133.
McGimsey, B. Q., Smith, A. G., Scott, R. L., Leacock, R. J., Edwards, P. L., and Hackney, K. R. (1975). Astron. J. **80**, 895.
Penston, M. J., and Cannon, R. (1970). R. Obs. Bull. No. 159.
Pica, A. J. (1976). M. S. thesis, Pennsylvania State University.
Pica, A. J. (1977). Astron. J. **82**, 935.
Pica, A. J., Pollock, J. T., Smith, A. G., Leacock, R. J., Edwards, P. L., and Scott, R. L. (1980). Astron. J. **85**, 1442.
Pica, A. J., Webb, J. R., Smith, A. G., Leacock, R. J., and Bitran, M. (1987). Astron. J. **94**, 289.
Pollock, J. T., Pica, A. J., Smith, A. G., Leacock, R. J., Edwards, P. L., and Scott, R. L. (1979). Astron. J. **84**, 1658.
Preston, R. A., Morabito, J. G., Williams, J. G., Faulkner, J., Jauncey, D. L., and Nicolson, G. D. (1985). Astron. J. **90**, 1599.
Rieke, G. H. (1985). In *Astrophysics of Active Galaxies and Quasi-Stellar Objects*, edited by J. S. Miller (University Science Books, Mill Valley, CA), p. 235.
Scott, R. L., Leacock, R. J., McGimsey, B. Q., Smith, A. G., Edwards, P. L., Hackney, K. R., and Hackney, R. L. (1976). Astron. J. **81**, 7.
Smith, A. G., Leacock, R. J., and Webb, J. R. (1988). In *Active Galactic Nuclei*, edited by H. R. Miller (Springer, New York) (in press).
Usher, P. D., Kolpanen, D. R., and Pollock, J. T. (1974). Nature **252**, 365.
Webb, J. R., Smith, A. G., Leacock, R. J., Fitzgibbons, G. L., Gombola, P. P., and Shepherd, D. W. (1988). Astron. J. **95**, 374.