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FLARES ON AD Leo IN 1973 AND 1983

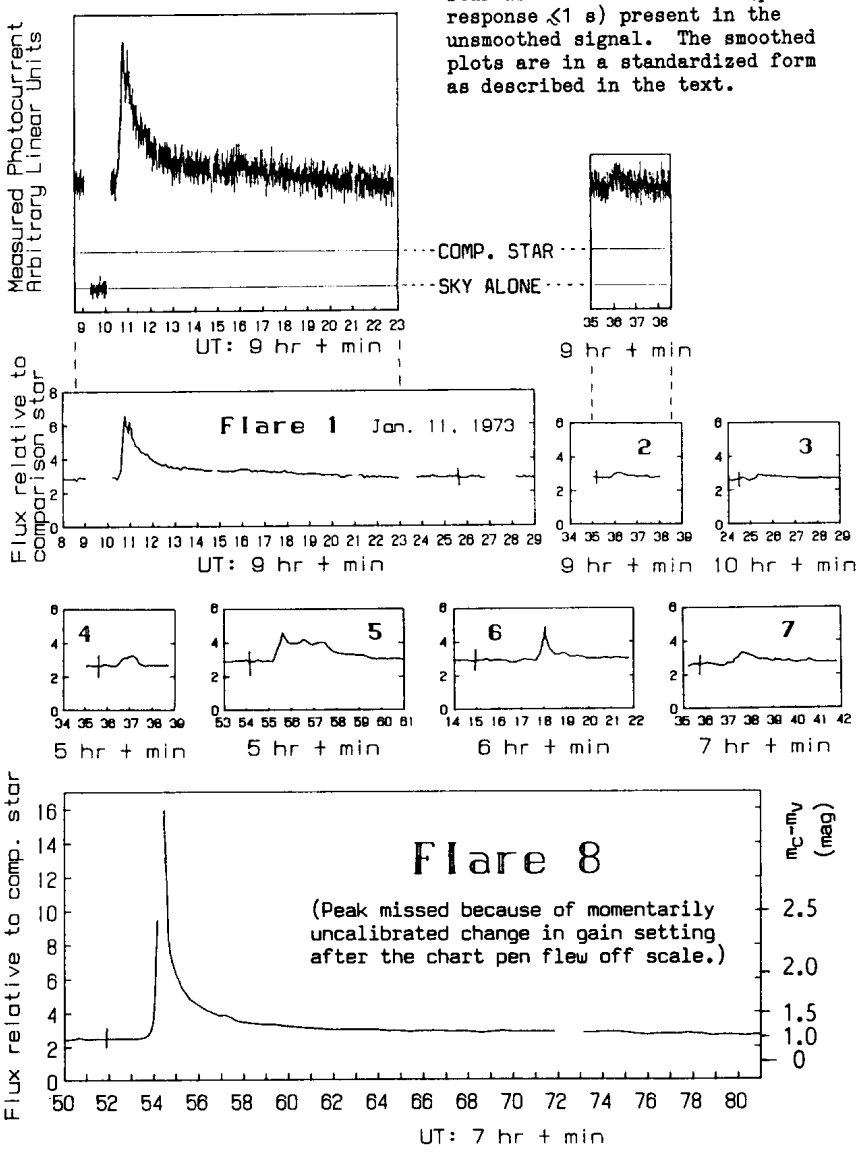
Since 1968, undergraduate students at the University of Delaware have participated in our continuing program of flare-star monitoring with the 24-inch cassegrain at Mt. Cuba Observatory. Except for the possible slow deterioration of equipment, supervising professor, and atmospheric conditions, the instrumental system has remained the same since IBVS 329.

Previously unreported are 21.5 hours of ultraviolet photoelectric monitoring of AD Leonis by a special-project class during January, 1973. To this we have added 5.9 hours of observations in the spring of 1983. To facilitate comparisons, we present both seasons in this combined report. The distribution of times is given in Table II in which gaps greater than one minute are explicitly shown.

Differential measures of the ultraviolet magnitude of AD Leo with respect to the comparison star were made at times of supposed quiescence. From Table III it may be noted that AD Leo averaged 0.07 mag brighter in 1983 than in 1973; however, as might be expected for so active a flare star, this difference is not statistically significant. Standard deviations in 1973 and 1983, respectively, were 0.05 mag (25 points) and 0.08 mag (13 points). In March-April 1982 (IBVS 2426) 17 measures also showed AD Leo brighter than in 1973; the average then being 0.11 mag (0.07 s.d.) brighter.

That the signal-to-noise ratio in 1973 is notably better than in 1983 is due largely to a dark-moon run of excellent weather in January 1973. Less time is now available for such work at the Mt. Cuba telescope; and, consequently, some of the 1983 monitoring was done on lower quality nights. Concern that the system had deteriorated during the decade was relieved by noting that on the two nights when AD Leo was briefly monitored through the same Johnson U filter in 1971 (IBVS 597), the signal-to-noise ratios were as low (5.5 to 8.7) as in 1983.

Fig. 1. Flares in January, 1973. See Table I. The upper plots for flares 1 and 2 are tracings from the original photometer chart to show the interpolated reference levels for the background sky and the comparison star as well as the noise (pen response $\lesssim$1 s) present in the unsmoothed signal. The smoothed plots are in a standardized form as described in the text.



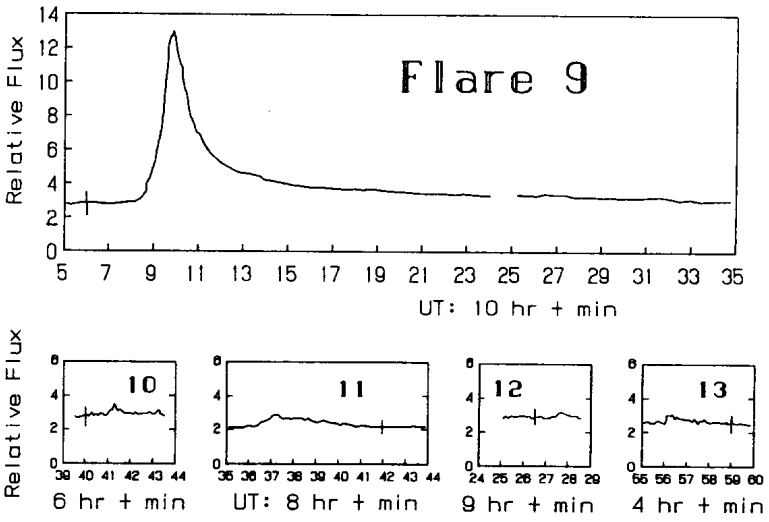


Fig. 1 cont'd. Flares of AD Leo observed in January, 1973.

Table I. Ultraviolet Flares of AD Leonis*

No.	Date yr mo da	UT max h m	t_b min	t_a min	Δ m mag	P min	Air Mass	JD 244 0000+
1	1973 1 11	09:10.6	0.3	17.	0.94	2.26	1.11	1693.88236
2	1973 1 11	09:35.8	0.4	1.2	0.12	0.09	1.14	1693.89986
3	1973 1 11	10:25.3	0.1	1.5	0.15	0.12	1.26	1693.93424
4	1973 1 12	05:36.8	0.2	0.8	0.24	0.17	1.23	1694.73389
5	1973 1 12	05:55.6	0.4	7	0.55	1.16	1.18	1694.74694
6	1973 1 12	06:18.1	0.2	3.5	0.55	0.33	1.14	1694.76257
7	1973 1 12	07:37.7	0.9	2.5	0.24	0.28	1.06	1694.81785
8	1973 1 12	07:54.4	0.7	21	>1.56:	>7.7:	1.06	1694.82944
9	1973 1 12	10:09.9	1.4	33	1.68	10.0	1.22	1694.92354
10	1973 1 13	06:41.4	0.3	4	0.24	0.09	1.10	1695.77875
11	1973 1 13	08:37.3	0.9	9	0.44	0.71	1.08	1695.85931
12	1973 1 13	09:27.7:	0.3:	1:	0.13	0.05	1.14	1695.8942
13	1973 1 30	04:56.3:	0.2:	4	0.22	0.28	1.16	1712.7058
14	1983 3 17	03:50.5	3.5	20+	1.34	15.6+	1.06	5410.66007
15	1983 3 17	05:44.6	1.6	6.4	0.32	2.20	1.18	5410.73931
16	1983 3 17	06:05.3	0.5	23 ?	>2.3	12 ?	1.24	5410.75368
17	1983 5 10	05:27.5	0.2:	-	>3	>20 ?	2.79	5464.72743

* where t_b and t_a are the durations before and after maximum,
Δ m is the change in magnitude of AD Leo (quiescent to maximum),
P is the equivalent duration of the flare.

Flares that we observed are numbered in Table I. Examples of the light curves for both major and uncertain flares are provided in the figures, on which flares are identified by their numbers in Table I. Breaks in the light curves are moments when the background sky and/or comparison star were measured. In a few cases, shown by a fragmented line, the break was caused by a passing cloud (see Flares 15 & 16).

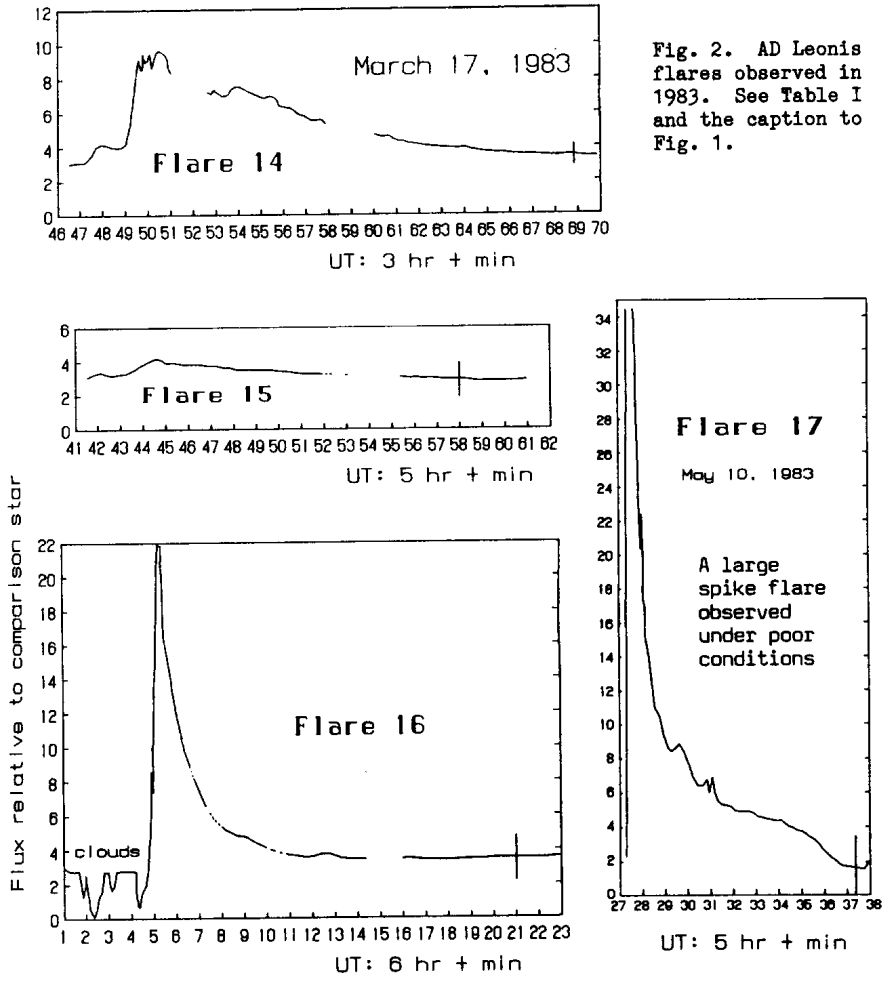


Fig. 2. AD Leonis flares observed in 1983. See Table I and the caption to Fig. 1.

Tracings of all the flares were digitized and plotted in units of the flux of the comparison star. This provides a coordinate reference that is more consistent than the quiescent level of AD Leo, which varies with background activity over the visible hemisphere of the flare star. Also, this plot facilitates estimating when a flare has ended. Note that the ordinate of these graphs may be converted to astronomical magnitudes by taking its logarithm and multiplying by 2.5. For convenient general comparison with Table III, a magnitude scale has been added on the right hand side of the flare-8 figure.

Because this analysis suppresses high frequencies, we have included in Figure 1 faithful reproductions of the original chart recordings for flares 1 and 2. Here may be seen the full photometric noise down to the instrumental time constant of approximately 1 second as well as any potentially real stellar flashes. A peak-to-peak measure of this higher frequency noise has been made near each flare, translated to the relative flux units and included as a vertical "error bar" on the graphs. These represent approximately six standard deviations of the high frequency noise as tabulated in the signal-to-noise ratio in Table III.

The astrophysical importance of the rotation periods of dMe stars has been pointed out by Marcy, Lindsay, and Wilson (1987). Photometric determinations based on the star's nonuniform surface brightness require analyzing a large number of samples because of the inherent variability. Pettersen, Coleman, and Evans (1984) report that Sandmann deduced a rotation period of 2.7 days from starspot modulation of AD Leo. Our UV data is not sufficient to confirm or negate this result, although, on the four consecutive days at the beginning of the 1973 run, such a period is possible if the amplitude at that time was less than 0.03 mag. Quiescent ultraviolet flux, as indicated by the magnitude differences in Table III, averages 2.77 times that of the comparison star. This may be compared directly to the levels portrayed in the figures.

Table II. AD Leo Flare Monitoring: Coverage in 1973 & 1983.

Date	U.T. in hours and minutes
1973 Jan. 10	9:53.9- 9:58.1, 10:02.1-10:15.1, 10:17.4-10:32.5, 10:36.4-10:49.0, 10:51.2-10:58.7.
Jan. 11	8:57.8- 8:58.8, 9:00.7- 9:09.0, 9:10.2- 9:26.9, 9:28.2- 9:45.0, 9:47.7- 9:59.5, 10:00.6-10:13.8, 10:15.6-10:29.0, 10:32.5-10:44.0, 10:46.0-10:49.5, 10:51.9-10:55.0.
Jan. 12	5:11.6- 5:13.7, 5:16.9- 5:20.8, 5:23.8- 5:30.2, 5:31.8- 5:38.8, 5:40.2- 5:46.9, 5:48.4- 6:10.5, 6:13.7- 6:49.8, 6:51.2- 7:07.4, 7:08.8- 7:24.9, 7:26.2- 8:11.8, 8:13.2- 8:23.9, 8:25.2- 8:26.7, 8:29.0- 8:30.0, 8:31.8- 8:37.0, 8:38.3- 9:00.7, 9:02.2- 9:13.7, 9:15.1- 9:28.5, 9:30.2- 9:38.6, 9:42.5-10:24.1, 10:25.3-10:40.6, 10:42.5-11:00.0.
Jan. 13	3:10.4- 3:19.1, 3:25.2- 3:36.4, 3:38.2- 3:54.4, 3:55.8- 4:02.2, 4:03.1- 4:10.8, 4:12.6- 4:15.4, 4:16.5- 4:30.4, 4:33.5- 4:48.9, 4:50.7- 4:59.7, 5:54.8- 5:56.3, 6:02.1- 6:14.6, 6:15.2- 6:22.0, 6:23.6- 6:38.0, 6:39.5- 6:43.6, 6:44.8- 6:49.0, 6:51.2- 6:56.8, 6:58.9- 7:11.1, 7:12.5- 7:34.0, 7:35.5- 7:51.0, 7:51.9- 7:59.4, 8:11.2- 8:21.7, 8:22.8- 8:25.9, 8:28.1- 8:44.8, 8:46.7- 9:03.0, 9:04.2- 9:28.6, 9:30.4-10:02.4, 10:04.2-10:18.6, 10:19.8-10:34.4, 10:36.3-10:42.0.
Jan. 26	4:32.5- 4:35.1, 4:37.1- 4:43.8, 4:46.0- 4:57.6, 4:58.8- 5:21.2, 5:23.6- 5:39.2, 5:40.4- 6:02.1, 6:03.6- 6:12.0, 6:14.3- 6:31.9, 6:34.0- 6:51.0.
Jan. 30	1:57.4- 1:59.4, 2:03.7- 2:11.0, 2:12.8- 2:17.4, 2:20.7- 2:33.9, 2:35.4- 2:46.7, 2:49.5- 3:01.8, 3:07.8- 3:23.8, 3:29.2- 3:44.4, 3:47.6- 3:58.2, 4:00.6- 4:01.9, 4:05.8- 4:22.6, 4:25.0- 4:42.0, 4:47.2- 5:01.8, 5:04.1- 5:08.3, 6:05.6- 6:21.0, 6:23.4- 6:37.4, 6:38.5- 6:53.0, 7:02.6- 7:19.2, 7:21.2- 7:38.0, 7:40.5- 7:56.6, 7:58.0- 8:16.2, 8:19.1- 8:26.2, 8:27.0- 8:35.0, 8:36.6- 8:51.7, 8:54.2- 9:08.8, 9:10.5- 9:27.0, 9:29.6- 9:44.4, 9:47.0-10:02.9, 10:05.2-10:22.6.
1983 Feb. 22	4:43.5- 4:49.0, 4:51.8- 4:58.0, 5:00.9- 5:06.1, 5:12.2- 5:16.0.
Mar. 3	3:04.0- 3:08.0, 3:12.8- 3:20.6, 3:27.0- 3:34.0, 3:42.2- 3:50.0, 3:54.0- 3:59.0, 4:02.8- 4:09.6, 4:15.8- 4:23.0, 4:27.6- 4:35.0, 4:38.1- 4:44.8, 4:46.0- 4:54.1, 4:56.6- 5:02.5.
Mar. 17	2:55.1- 3:01.0, 3:05.2- 3:10.6, 3:12.1- 3:17.6, 3:19.7- 3:27.9, 3:29.4- 3:35.6, 3:38.7- 3:45.0, 3:46.3- 3:51.1, 3:52.6- 3:57.8, 4:00.0- 4:10.3, 4:32.0- 4:39.0, 4:41.2- 4:50.0, 4:53.4- 4:59.6, 5:02.2- 5:10.1, 5:12.6- 5:20.8, 5:22.9- 5:30.0, 5:31.8- 5:39.6, 5:41.5- 5:52, 5:55.4- 6:14.4, 6:16.0- 6:23.2, 6:25.0- 6:31.0.
Mar. 24	5:34.6- 5:43.0, 5:45.5- 5:52.6, 5:55.9- 6:04.3, 6:06.6- 6:15.8, 6:21.5- 6:32.0, 6:36.1- 6:48.2, 6:50.5- 7:00.8.
May 10	5:05.0- 5:12.9, 5:15.5- 5:24.0, 5:27.3- 5:40.0, 5:42.8-5:51.

Table III. Ultraviolet magnitude differences between the comparison star and AD Leo during moments of apparent quiescence, and estimates of the unsmoothed signal/noise for AD Leo.

Date	Time hr min	JD 2440000+	$m_c - m_v$	$\frac{I_o}{\sigma}$	Air Mass
1973					
Jan. 10	10 33	1692.9396	1.04	13.0	1.27
Jan. 11	9 00	1693.8750	1.08	-	1.09
"	9 47	1693.9076	1.07	17.1	1.16
"	10 31	1693.9382	1.10	-	1.27
"	10 51	1693.9521	1.08	14.3	1.34
Jan. 12	5 48	1694.7417	1.12	11.5	1.20
"	7 08	1694.7972	1.10	14.1	1.08
"	9 30	1694.8958	1.06	13.4	1.14
"	10 41	1694.9451	1.10	11	1.32
Jan. 13	4 31	1695.6882	1.25	6.9	1.46
"	6 50	1695.7847	1.08	15.9	1.09
"	8 28	1695.8528	1.07	15.6	1.07
"	9 29	1695.8951	1.10	15.9	1.14
Jan. 26	4 36	1708.6917	1.16	-	1.24
"	4 45	1708.6979	1.14	14.2	1.22
"	5 22	1708.7236	1.01	14.8	1.14
"	6 03	1708.7521	1.07	-	1.09
"	6 33	1708.7729	1.03	16.0	1.07
Jan. 30	2 18	1712.5958	1.08	9	1.97
"	3 28	1712.6444	1.00	11.7	1.44
"	4 44	1712.6972	1.02	14.6	1.18
"	6 22	1712.7653	1.03	16.5	1.07
"	7 39	1712.8188	1.06	16.3	1.09
"	8 53	1712.8701	1.05	15.6	1.21
"	10 03	1712.9188	1.15	14.5	1.46
1983					
Feb. 22	4 55	5387.7049	1.09	4.0	1.07
Mar. 3	3 47	5396.6576	1.11	6.4	1.08
"	4 19	5396.6799	1.15	6.1	1.07
"	4 42	5396.6958	1.16	5.8	1.06
Mar. 17	3 43	5410.6549	1.22	9.2	1.06
"	4 57	5410.7062	1.23	7.2	1.10
"	5 07	5410.7132	1.05	7.5	1.12
"	5 18	5410.7208	1.11	8.8	1.13
"	5 37	5410.7340	1.18	7.4	1.17
"	6 21	5410.7646	1.32	7.7	1.28
Mar. 24	6 00	5417.7500	1.16	4.3	1.31
"	6 41	5417.7785	1.16	4.7	1.49
May 10	5 20	5464.7222	1.02	5.6	2.62

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