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LONG TERM VARIABILITY IN DWARF M STARS

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ABSTRACT

Broadband *VRI* observations for 43 dwarf M stars have been made over the period 1980–1991, and 21 of them, including eight *UBV* standard stars, show long term variability at the 95% confidence level. While it undoubtedly exists, periodic behavior cannot be demonstrated from these data except perhaps in the cases of GL 213 and GL 876 which appear to show periods of 2.7 and 2.9 yr, respectively. Substantial short term variations in the light of GL 277A (=VV Lyn) are also noted.

I. INTRODUCTION

The subject of activity cycles in stars other than the Sun received substantial impetus from the pioneering investigation of Wilson (1978) who monitored chromospheric activity in 91 F, G, and K stars through the measurement of fluxes in the cores of the H and K lines. The project, and its continuation (Baliunas & Vaughan 1985), requires substantial amounts of observing time on large telescopes. For monitoring broadband fluxes a much smaller instrument can be used, but for solar type stars the amplitudes of long term variations in broadband light are usually rather small and require observations of an accuracy significantly greater than that usually associated with routine broadband photometry, as has been successfully demonstrated by Lockwood *et al.* (1993).

Many dwarf M stars are known to display sizable short term brightness variations as a consequence of either flaring activity or rotational modulation due to variable spotting. Since these manifestations of magnetic activity can affect the short term brightness variations of M dwarfs much more markedly than for solar type stars there is reason to suppose that magnetic activity cycles can also affect the long term brightness variations more substantially for M dwarfs and to a degree that would allow their detection with broadband photometry of only average accuracy.

During the period 1980–1991 more than 40 dwarf M stars were observed as primary and secondary "standards" in connection with a number of programs of photometry of late dwarf stars carried out at the Kitt Peak National Observatory. Although the standards were not observed with a study of long term variability in mind, the data have proved to be useful toward that end.

2. OBSERVATIONS

Observations in the *V*, *R*, and *I* passbands were obtained at the Kitt Peak National Observatory during 20 observing runs over an 11 year period. The 0.9 m telescope was principally used, although for a few runs the 1.3 m was employed. A GaAs photomultiplier tube and Cousins-type filters were used for all observations, but it was not possible to ensure that the same tube and filter set were used for every observing run. Each observing run (hereafter referred to as a season) was typically of seven or eight nights duration although, of course, it was not always possible to obtain useful observations on each night. Thus, the seasonal mean value of a photometric quantity may involve anywhere from one to eight observations, with three or four observations being typical.

Each season the observations were reduced to the Johnson *V* and Kron *R*,*I* systems using the same procedures and resulting in similar, but not identical, extinction and transformation coefficients. Customarily, variable star observations are reduced relative to a comparison star and one or two check stars. In the present case each star is reduced relative to an ensemble mean of the subset of 25 or so other standards which may be observable in a given season, many of which are themselves significantly variable. Because of this and the fact that the equipment used was not always exactly the same it is probable that significant systematic differences will arise from one season to the next. To reduce the systematic problems somewhat the following *ad hoc* procedure was employed. Starting with the originally reduced values of the photometric quantities, seasonal and overall mean values were computed for each star, and residuals formed from the differences between seasonal and overall mean values were studied for each season as a function of color, mean airmass of observation, and right ascension. Where significant trends were found, compensating corrections were applied. These corrections to the seasonal mean values for each star were usually small (60% were less than 0.005 mag), but a small fraction were larger than 0.015 mag, and these are indicated by larger symbols in Fig. 1. Certainly significant errors and

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systematic problems remain, but there are a number of stars for which the dispersion of seasonal mean V magnitudes is 0.005 mag or less which indicates that the remaining systematic errors are not much larger than this.

3. DISCUSSION

For each of the 43 dwarf M stars the run of seasonal mean V magnitude versus time is given in Fig. 1. The stars are identified by their numbers in the catalogues of Gliese (1969) and Gliese & Jahreiss (1979) and, if they are named variables, by that designation as well. Each error bar represents the estimated mean error of the mean magnitude. For a given star we shall denote by σ_a the average mean error of a seasonal mean magnitude (averaged over all seasons) and by σ_b the dispersion of the seasonal mean magnitudes about the overall mean. These quantities are

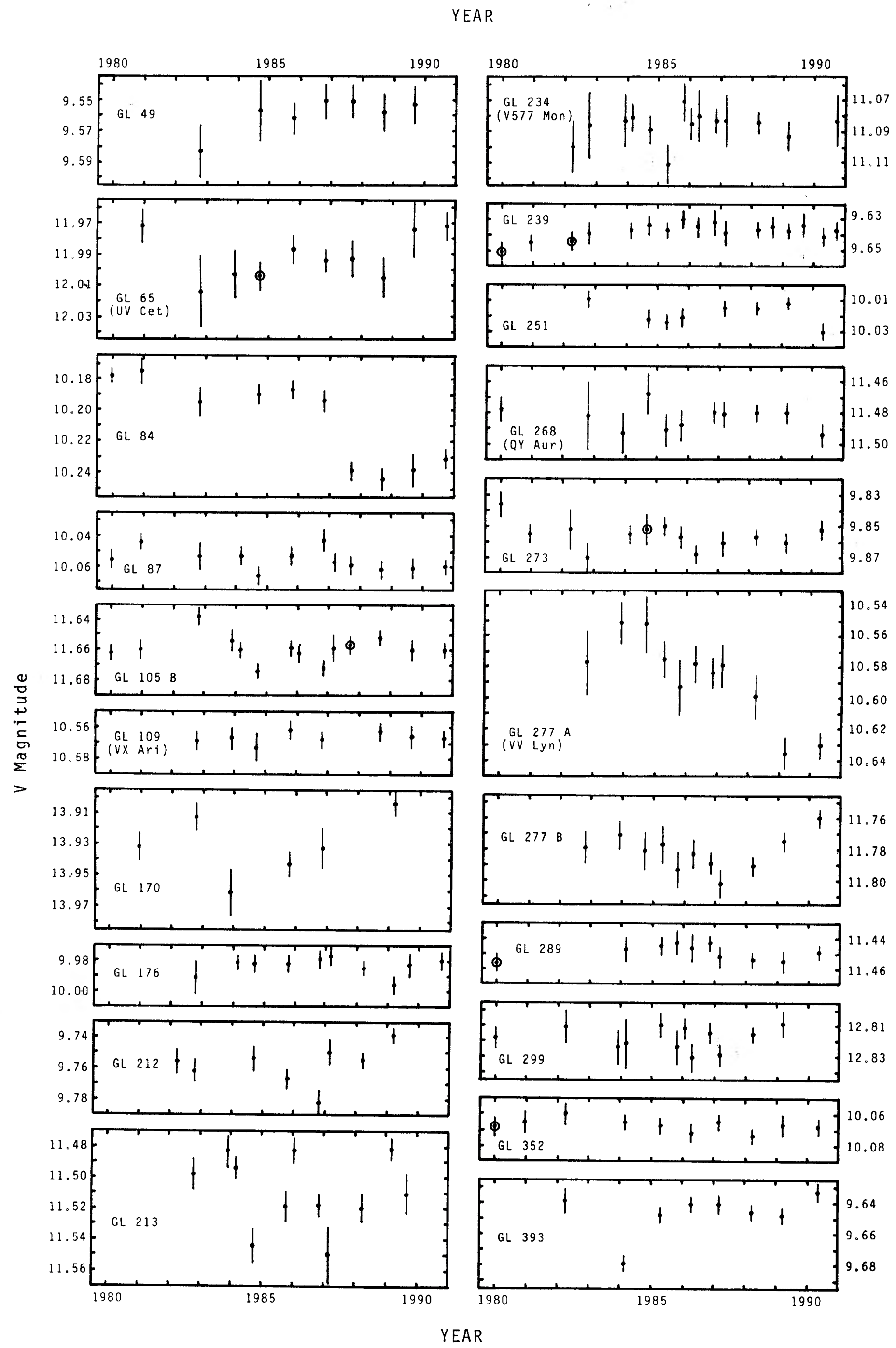

FIG. 1. Seasonal mean V magnitudes vs time for 43 dwarf M stars. The larger symbols denote points for which the corrections discussed in the text amount to more than 0.015 mag.

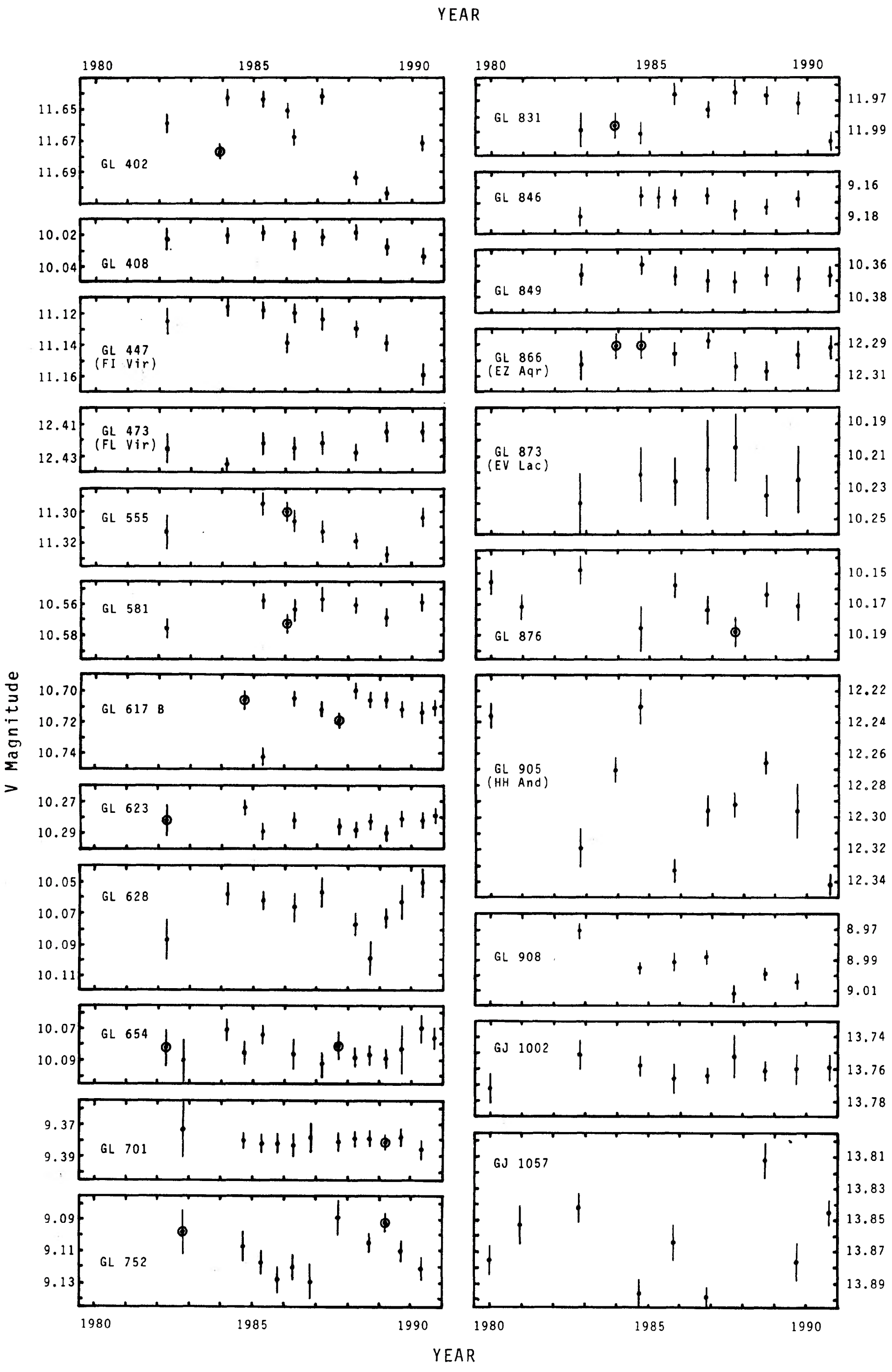

FIG. 1. (continued)

given in Table 1 for *V*, *R*, and *I*. The quantity σ_a will depend on short term variability and error while σ_b depends mainly on long term variability and error. It may be noted that when σ_a or σ_b is greater than 0.010 mag in *V*, the corresponding values in *R* and *I* are nearly always smaller. This is another way of saying that the stars are bluer when brighter and redder when fainter, as one would expect. When σ_a or σ_b is less than 0.010 mag in *V* this effect is largely masked by observational error.

Also listed in Table 1 are spectral types (*e*=Hydrogen line emission) taken from Joy & Abt (1974) and measures of Hα equivalent width (+=emission) taken from Stauffer & Hartmann (1986), Herbst & Layden (1987), and Herbst & Miller (1989). For two of the stars, GL 176

TABLE 1. Data for 43 dwarf M stars.

	Mean Values							σ_a			σ_b			
GL/GJ	V	V-R	R-I	N	n	SpTp	Hα	V	R	I	V	R	I	P
49	9.56	1.08	0.89	7	17	dM2	- 3	13	10	10	11	10	10	67 I
65AB	11.99	2.06	1.69	10	37	dM6e		13	11	10	15	14	16	99 I
* 84	10.21	1.19	1.02	10	42		- 2	7	8	9	27	22	17	99 V
* 87	10.06	1.03	0.86	12	53	dM2.5	- 4	6	7	7	7	6	6	75 V
* 105B	11.66	1.43	1.25	14	62	dM4.5	- 1	6	6	6	8	9	8	99 V
109	10.57	1.25	1.08	8	29	dM3.5	- 2	6	8	7	3	4	5	16 I
170	13.93	1.66	1.41	6	21			10	8	8	21	8	9	99 V
176	9.98	1.15	0.97	10	26	dM2.5e	- 3	6	8	8	6	7	8	37 V
212	9.76	1.04	0.82	8	18	dM1	- 3	7	7	6	13	12	10	99 V
213	11.51	1.46	1.27	11	31	sdM4.5	- 2	10	10	9	24	16	12	99 V
234AB	11.09	1.60	1.36	14	39	dM4.5e	+36	13	11	12	10	7	8	10 V
* 239	9.64	0.98	0.73	17	65	dM1	- 4	6	7	7	5	7	7	78 R
251	10.02	1.29	1.11	8	25	dM3.5	- 3	5	5	6	7	7	8	93 V
268	11.48	1.61	1.36	11	35	dM5e	+19	10	10	10	8	6	6	17 V
* 273	9.86	1.39	1.21	13	53	dM4	- 1	7	7	7	9	7	8	82 V
277A	10.59	1.23	1.07	11	38	dM3.5e	+13	14	12	11	27	21	14	99 V
277B	11.78	1.38	1.22	11	38	dM4.5e	+21	9	7	7	12	9	8	93 V
289	11.45	1.08	0.89	10	33			7	6	5	5	5	4	29 I
299	12.82	1.52	1.31	12	34	dM5		9	9	7	8	8	6	40 R
* 352AB	10.07	1.22	1.05	10	36			6	8	9	4	4	6	10 V
* 393	9.65	1.14	0.96	8	36	dM2.5	- 3	6	6	5	14	10	7	99 V
402	11.67	1.47	1.25	10	37	dM5	- 2	5	6	6	22	16	13	99 V
408	10.02	1.21	1.04	8	32		- 4	5	5	5	5	4	5	48 V
447	11.13	1.59	1.33	9	35	dM4.5	0	6	7	8	14	11	9	99 V
473AB	12.42	1.93	1.62	8	32	dM5.5e		6	6	7	7	6	6	59 V
555	11.31	1.49	1.28	8	32			7	7	6	11	8	8	99 V
* 581	10.56	1.30	1.10	8	32	dM4	- 3	6	6	6	7	8	9	97 I
617B	10.71	1.24	1.08	11	35		- 3	5	6	6	11	11	7	99 V
623	10.28	1.17	1.03	11	35	dM3	- 2	5	6	6	5	7	4	86 R
* 628	10.07	1.38	1.20	10	31	dM4.5	- 3	9	10	9	15	12	12	99 V
* 654	10.08	1.06	0.91	14	51	dM3	- 4	9	9	9	7	6	6	20 V
* 701	9.38	1.06	0.85	12	44	dM2	- 4	7	7	8	3	4	4	2 R
* 752A	9.11	1.18	1.02	11	34	dM3	- 3	9	9	10	14	13	12	99 V
831	11.98	1.58	1.33	9	37	dM5e	+14	7	6	6	12	11	8	99 V
846	9.17	0.99	0.75	8	26	dM0	- 5	6	7	6	5	6	5	37 V
849	10.37	1.27	1.11	8	30	dM3.5	- 4	7	7	7	3	6	7	68 I
866	12.30	2.09	1.68	9	38	dM5.5e		8	7	7	7	6	11	98 I
873	10.22	1.38	1.19	7	23	dM4.5e	+35	20	17	13	11	9	10	28 I
* 876	10.17	1.42	1.22	9	38	dM4.5	- 2	9	9	9	13	9	6	98 V
905	12.29	1.90	1.56	10	40	dM5.5e		9	7	7	38	23	17	99 V
* 908	8.99	1.03	0.85	7	20	dM2.5e	- 4	5	7	6	13	14	14	99 V
1002	13.76	1.99	1.63	9	34			8	7	8	7	7	5	54 R
1057	13.86	1.77	1.48	9	22			10	10	8	28	23	19	99 V

* = standard star of UBV system (Johnson & Harris, 1954)
GL/GJ = number in catalogs of Gliese (1969) and Gliese & Jahreiss (1979).
N = number of seasons.
n = number of observations.
Hα = equivalent width of Hα (unit = 0.1A, + = emission).
σ_a = average mean error of a seasonal mean magnitude (unit = 0.001 mag.)
σ_b = dispersion of seasonal mean magnitudes (unit = 0.001 mag.)
P = estimated probability of long term variability (unit = 0.01). Letter indicates passband of maximum probability.

and GL 908, the observations are conflicting, with Joy and Abt reporting H line emission while the more recent measures of Hα show the line in absorption. In an earlier paper by Joy (1947) H line emission is not noted for GL 176. It seems likely that single dMe stars may experience periods of relative quiescence, and for purposes of this discussion GL 176 and GL 908 will be taken to be dM stars at the present epoch. Of the ten stars in Table 1 taken to be dMe stars, all except GL 277A, 277B, and 873 have $R-I>1.3$. For six of the stars the status of H line emission is unknown, although GL 170, GJ 1002, and GJ 1057 are quite late and are very likely to be dMe stars. Figure 2 shows a plot of σ_b vs σ_a for the V magnitude data, which roughly corresponds to a plot of long term versus short term variability somewhat complicated by observational error. It may be seen that the two variables are not strongly correlated, in contrast to the results reported for solar type stars by Radick *et al.* (1990) using more accuate observtions. In Fig. 2 the dMe stars tend to show more variability than the dM stars although this is not consistently true. On the basis of these data, hydrogen line emission appears to be a somewhat better predictor of short term variability than of long term variability.

Under the crude assumption that, for stars which are intrinsically nonvariable, the quantity $(N-1)\ \sigma_b^2/\sigma_a^2$ is distributed like χ^2, it is possible to estimate the probability of long term variability. The probability was estimated from, successively, the V, R, and I data, and the largest proba-

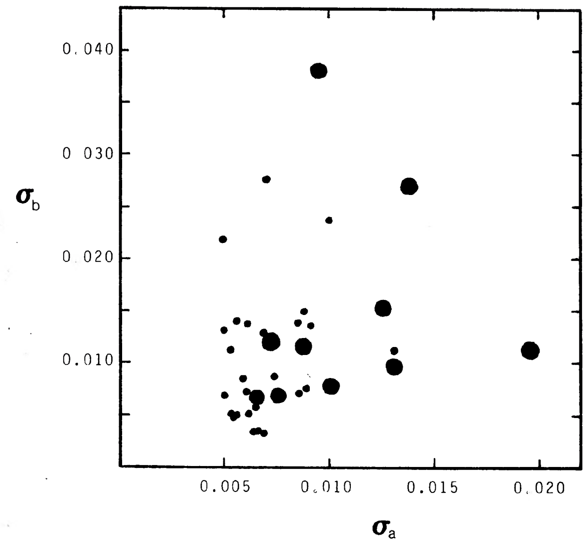

FIG. 2. σ_b vs σ_a in magnitudes for most of the stars in Table 1. This is roughly a plot of long term vs short term variability. Large symbols and small symbols denote dMe and dM stars, respectively.

bility of the three is entered in Table 1 for each star along with a letter indicating the data that were used. About half of the stars show long term variability at better than the 95% confidence level, but for two of the stars, GL 393 and GL 617B, the high probability is the consequence of one discordant season and thus perhaps ought to be viewed with suspicion. As indicated by asterisks in Table 1, 14 of the stars are standard stars of the *UBV* system (Johson & Harris 1954), and eight of them show long term variability at better than the 95% confidence level. It will be understood that stars for which long term variability cannot be demonstrated from these data might show such variability with more accurate data, and that stars which shows little or no variability at the current epoch may do so at a later time in a manner analogous to the Maunder minimum of the Sun as discussed by Baliunas & Jastrow (1990). It should be noted that a comparison of the standard *V* magnitudes with the mean values given in Table 1 for the UBV standards indicates that the *V* magnitudes of this paper are systematically 0.01 mag too faint relative to the standard system.

Beyond a mere demonstration of long term variability one would like to see evidence of periodicity in that variability. Given that the errors and sampling intervals are larger than one would wish and that the observations cover no more than 11 years (and only seven years for many stars), it is difficult to make a convincing case for cyclic variability from the present data. Inspection of the light curves in Fig. 1 reveals possible cyclic variability for GL 213 and GL 876 with periods of 2.7 and 2.9 yr, respectively. These periods are quite short for stellar activity cycles but not unprecedented since Baliunas & Vaughan (1985) have demonstrated a 2.6 yr period for HD 190406. GL 213 has a space motion greater than 100 km/s, and a spectrum classified as subdwarf by Joy & Abt (1974). While GL 213 may not actually be a subdwarf, it is likely to be numbered among the oldest stars in Table 1. This reinforces the notion, formed from the observation of a large amplitude magnetic cycle in the metal poor subdwarf HD 103095 by Baliunas & Jastrow (1990), that substantial long term variability is not the exclusive province of youth. The 2.7 and 2.9 yr periods may also be found from a periodogram analysis following the procedure outlined in Horne & Baliunas (1986) from which one may compute formal false alarm probabilities of 0.24 and 0.13 for GL 213 and GL 876, respectively. Thus, these periods are not particularly convincing. Furthermore, the periodograms show additional periods with comparable spectral power of 38.4 and 27.8 days for GL 213, and 28.7 and 20.2 days for GL 876. These periods are much shorter than the sampling interval, and thus not much may be said about them, but it is possible that one of the short periods is real and the long period merely an alias. The question can not be resolved from these observations.

Referring again to the light curves in Fig. 1, the star GL 752A would appear to show cyclic behavior with a period of about five years, but one would like to see another cycle or two to be convinced. The variability of GL 905 might appear to have a period of about 4.2 yr, but this interpretation of the data does not take into account the 0.06 mag variation with 120 day period reported by Kron (1950) which would greatly complicate the long term picture. A weak periodicity of 121 days may be found in these data, but five other periods of equal or greater spectral power may also be found between 60 and 291 days, so the 120 day period of Kron can not be confirmed from these observations. As for the rest of the stars, either the amplitudes are too small relative to the noise or the sampling interval too large to allow anything convincing to be said, although certainly in looking at the light curves in Fig. 1, some of the patterns are suggestive of possible cyclic variation.

It should be mentioned that photometrically unresolved pairs with the component stars differing in brightness by less than about one magnitude will present a more complicated picture than single stars. One imagines that, in general, the two stars would have activity cycles of differing period and amplitude which would be out of phase with each other much of the time producing long periods of slight and irregular variation. The only such pairs known among the stars of Table 1 are GL 65, 352, and 473 (for GL 234 the brightness difference is more than 3 mag). Marcy & Benitz (1989) report double lines in the spectra of GL 268 and GL 289, so perhaps they should be included as well. We note that of the five stars only GL 65 shows significant evidence of long term variability from these data.

Although this study is primarily concerned with long term brightness variations, some mention must be made concerning the remarkable short term variations observed in the case of GL 277A. Brightness variations on a time scale of days have been noted for this star by Bopp & Espenak (1977) on the basis of which it was designated a variable star (VV Lyn) of the BY Draconis type. McMillan & Herbst (1991) observed the star on 17 nights

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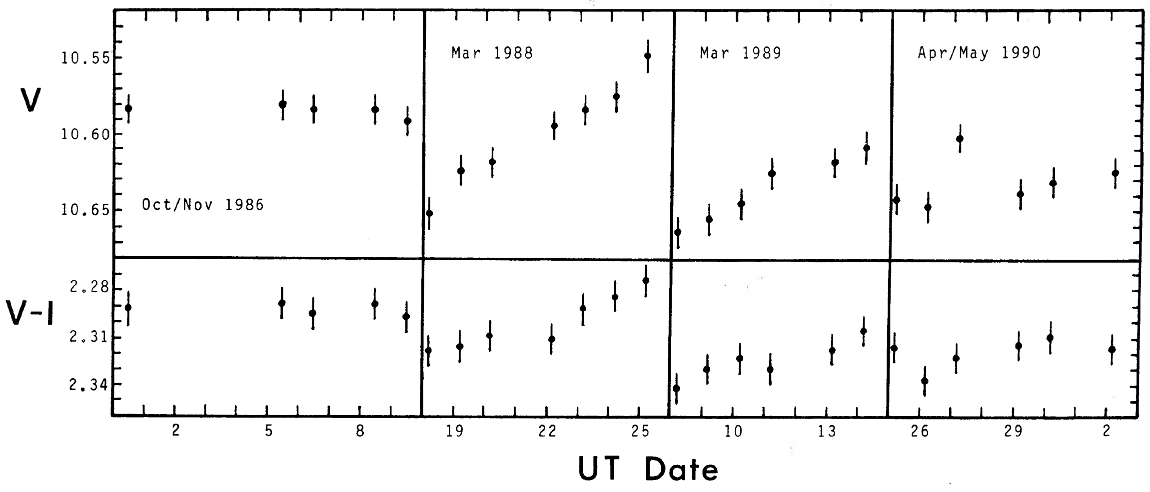

FIG. 3. *V* magnitude and $V-I$ color vs UT date for GL 277A during four observing seasons.

during the first three months of 1990 without seeing any particularly noteworthy variations in the visual light. In Fig. 3 are shown the nightly observations in *V* and *V-I* for each of the four seasons during which the star was observed on more than three nights. The observations for the fall of 1986 are essentially constant, but during the spring of both 1988 and 1989 the star displayed a sudden increase in brightness over a period of about a week with the color becoming correspondingly less red. The 1990 observations are not particularly remarkable except that the discordant observation may have occurred during or shortly after a flare event. The 1988 and 1989 observations may be interpreted as resulting from a particularly large and longitudinally asymmetric spot grouping on a star rotating with a period of either about two weeks or slightly more or less than one day (or half a day, etc.). Since the star has hydrogen line emission the larger period seems less likely. On the other hand, radial velocity measures have been made by a number of observers without any mention made of broad lines, so perhaps the period near one day is most likely.

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REFERENCES

Baliunas, S. L., & Jastrow, R. 1990, Nature, 348, 520
Baliunas, S. L., & Vaughan, A. H. 1985, ARA&A, 23, 379
Bopp, B. W., & Espenak, F. 1977, AJ, 82, 916
Gliese, W. 1969, Veroff. Astr. Inst. Heidelberg, No. 22
Gliese, W., & Jahreiss, H. 1979, A&AS, 38, 423
Herbst, W., & Layden, A. C. 1987, AJ, 94, 150
Herbst, W., & Miller, J. R. 1989, AJ, 97, 891
Horne, J. H., & Baliunas, S. L. 1986, ApJ, 302, 757
Johnson, H. L., & Harris, D. L. 1954, ApJ, 120, 196
Joy, A. H. 1947, ApJ, 105, 96
Joy, A. H., & Abt, H. A. 1974, ApJS, 28, 1
Kron, G. E. 1950, AJ, 55, 69
Lockwood, G. W., Skiff, B. A., & Thompson, D. T. 1993, in Stellar Photometry: Current Techniques and Future Developments, IAU Colloquium No. 136, edited by J. Butler and I. Elliott (Cambridge University Press, Cambridge) (in press)
Marcy, G. W., & Benitz, K. J. 1989, ApJ, 344, 441
McMillan, J. D., & Herbst, W. 1991, AJ, 101, 1788
Radick, R. R., Lockwood, G. W., & Baliunas, S. L. 1990, Science, 247, 39
Stauffer, J. R., & Hartmann, L. W. 1986, ApJS, 61, 531
Wilson, O. C. 1978, ApJ, 226, 379