8. HIGH FREQUENCY STELLAR OSCILLATIONS

IV: *Photoelectric Monitoring of Southern White Dwarfs*

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Abstract. Time-series data for 14 stars in the list of Eggen and Greenstein have been used to compute their power spectra, which confirm previously found quiescency in the 4 to 700 sec period range. Additionally, characteristics of the continuous power spectra are considered.

1. Introduction

Late in 1968, we undertook at the Cerro Tololo Inter-American Observatory an extension of the program begun at Princeton University to survey observationally the features of the power spectra of representative degenerate stars. While our primary motivation was to reobserve the central stars of planetary nebulae, for which the Princeton results were somewhat inconclusive, we did observe a much broader sample of about 50 stars thus including white dwarfs, central stars of planetary nebulae, old novae, U Gem stars, and other objects (see, e.g. Lasker and Hesser, 1970). The discussion for 14 stars selected from the list of white dwarfs compiled by Eggen and Greenstein (1965) is given here; those results for the planetary nebulae will be presented shortly.

2. Observations

Our data-collection and analytical techniques closely resemble those previously discribed (Hesser, Ostriker and Lawrence 1969; hereinafter referenced as HOL); only departures from those procedures are discussed further here. The observations were obtained with the 60-, 36- and No. 2 16-inch telescopes on Cerro Tololo; a standard one-channel, 1P21, offset-guiding photometer was used. The typical data set consists of UBV photometry (for identification purposes) followed by about two hours of continuous monitoring in integrated light with 2-second integrations; the UT of every seventh data point was also recorded. A 12.5″ or 27″ diaphragm was normally used, and guiding was done to better than 1″. Sky measurements were acquired at random intervals of approximately 45 min for constant and dark skies and more frequently under less favorable conditions. The white dwarf observations, viewed in

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the context of our program, were generally intended to serve as standards of quiet objects and multiple observations of the same star were seldom obtained. Furthermore, such stars were more often observed when, for some reason, conditions were suspect. Despite such reasons for expecting that the observations of white dwarfs reported here will not reach the ultimate limit of which the techniques are capable, we have attained, on the average, an improved limit on the 'noisiness' of these stars.

The University of Michigan's data system, being extremely compact, was transported to Chile by one of us (B.M.L.) for this program, and was used to register all data. This apparatus consists principally of Solid State Radiation pulse amplifiers, LeCroy 50 MHz scalers, and various micrologic control circuits. The scaler is gated by a precision crystal-controlled timer. In the monitoring mode, this system repeatedly makes an integration, loads the count into a punch buffer in 90 μsec, and begins another integration cycle while punching the previous count. The 30 frame/sec speed of the paper-tape punch permitted outputting 0.1 sec integrations with no data loss, but normally 2 sec integrations were used to minimize tape consumption. For facility in analysis, all paper tape was converted to magnetic tape at the end of the observing run. The observations, together with certain analytical parameters discussed below, are summarized in Table I, the format of which is nearly identical to that used in HOL.

3. Analysis and Results

Our computations of the power spectrum for each data-set of Table I were performed by the standard techniques (see, e.g. Blackman and Tukey (1958), Bingham *et al.* (1967), and HOL). For all spectra a window nearly the total width of the data-set was used, and calculations were made for all frequencies from the Nyquist frequency to the reciprocal length of the data set. The resultant spectra were examined for evidence of harmonic activity in the original data sets; this, of course, would manifest itself as a delta-like function in the power spectrum. The amplitude of the largest local maximum, A_{max}, and its associated period, $T(A_{max})$, are given in Table I for each data set. With the exception of G44-32 (EG 72), our results are consistent with those of HOL: white dwarfs are quiescent in the period range from 2 to 700 sec. Furthermore, we note that the generally superior sky conditions at Cerro Tololo enable us to reduce the mean values of the noise statistic, Q (see HOL), and A_{max} from the Princeton values by a factor of about 2 (see Table II). G44-32, whose recently discovered variability has been discussed elsewhere (Lasker and Hesser, 1969, Warner *et al.*, 1970), is seen to stand apart from the other stars in Table I in all three parameters: Q, A_{max}, and x, the slope of the low frequency portion of the power spectrum (see below).

In addition to examining the local behaviour of power spectra for evidence of harmonic activity, inspection of the overall properties of the spectra for continuous trends is of some importance. Here, for example, is where the effects of flickering would appear. From log-log plots of $P(f)$ it is clear that the power spectra generally consist of two parts: a flat component due to the photon statistics of observing, and a component decaying with frequency due to various aperiodic fluctuations in the

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TABLE I

Summary of white dwarf observations†

Designation Discover	EG	Mag.	Sp. T.	Date	Time (UT)	Tel.	N	$A_{\max}$(mag)	$T(A_{\max}$; sec)	Q	x
LB3303	21a	11.2	(DA)	01/05–06/69	02:20:02	36	3627	0.0008	6.3	0.004	−0.01
L587-77A	22*	13.9	DAs	01/06–07/69	01:17:11	36	3681	0.009	455	0.038	−1.47
θ^2 Eri B, C	33*	9.52	DA	12/31/68–01/01/69	02:30:35	36	3695	⩾0.008	120	0.004	−0.04
L879-14	41	14.10	4670	01/19–20/69	01:45:04	16	4051	0.016	178	0.029	−0.66
L1244-26	46	13.40	DA	01/08–09/69	04:34:28	36	2715	0.003	482	0.006	−0.81
L745-46A	54	12.98	DF	12/28–29/69	04:38:06	36	1147	*	*	*	*
L97-12	56	14.5	DC	01/30–31/69	06:35:00	36	3140	*	*	0.012	*
L532-81	62	12.0	DA, Fs	12/30–31/68	04:49:14	36	5461	0.004	607	0.008	−0.76
				12/31/68–01/01/69	05:38:57	36	3975	0.0008	293	0.005	−0.18
				02/05–06/69	04:22:58	16	2729	0.002	5.3	0.008	−0.29
LDS275 AB	66*	15.0	DC	01/22–23/69	04:34:00	36	3175	0.002	67.7	0.011	−0.43
L825-14	70*	12.97	DAn	01/15–16/69	05:12:23	16	3633	0.003	57.7	0.013	−0.24
G44-32	72*	16.55		01/24–25/69	07:34:06	36	2071	0.016	14.0	0.026	−0.15
				02/20–21/69	05:15:29	60	10795*	0.034	862	0.029	−1.16
				02/21–22/69	06:53:18	60	4916*	0.036	315	0.023	−1.42
				04/11–12/69	04:48:12	50*	5041	0.035	420	0.016	−1.04
				04/12–13/69	04:11:28	50*	6706	0.023	630	0.026	−1.39
F46	81*	13.24	DO-B	01/21–22/69	06:23:36	16	4137	0.005	6.1	0.023	+0.01
L145-141	82	11.44	4670	01/06–07/69	06:58:13	36	2365	0.0009	315	0.004	−0.31
L845-70	122	14.30	DC?	04/12–13/69	09:12:25	50*	~7200	*	*	*	*

Notes:

† Where an asterisk (*) appears next to the EG number or in the body of the table, a note pertaining to that star follows. Unless otherwise noted below, data were acquired using no filter and 2 sec integration times.

EG 22. Both stars included in diaphragm; second star is sdM3, V = 15.6, B − V = +1.7. Noisiness of record due to guiding difficulties and Moonlight interference. Q, $A_{\max}$, and x-values not used in forming means.

EG 33. Both stars B and C were in diaphragm; V filter used.

EG 54. Automatic features of editing program failed due to shortness of run; inspection of analog record indicates that the object is non-variable in the higher frequency range.

EG 56. B filter used with an integration time of 1.060 sec. Error in computation of power spectrum occurred which does not allow us to compute $A_{\max}$ or x from present spectrum.

EG 66. Double white dwarf system; both stars taken with cautious guiding to keep third star out of diaphragm.

EG 70. Dramatic change in seeing occurred during run, as well as several guide errors.

EG 72. None of the derived parameters for this star are included in the means discussed in text. The February data were acquired with 1 sec integration times. The April data were obtained with the Kitt Peak National Observatory 50-inch telescope.

EG 81. U filter used to minimize effect of faint companion star. Eggen and Greenstein note that F 46 may be a sdO star.

EG 122. Analysis of automatically recorded data have not been performed to date; inspection of analog record indicates that the object is non-variable and it is included here for completeness. KPNO 50-inch telescope. Possibly a λ 4670 star.

TABLE II

	Princeton				Cerro Tololo			
	No. Obs.	M	σ_i	σ_m	No. Obs.	M	σ_i	σ_m
Q	42	0.019	0.016	0.002	12	0.011	0.008	0.002
$A_{\max}$	38	0.012	0.009	0.001	12	0.004	0.004	0.001

Notes: M is the mean, σ_i is the standard deviation of an individual datum and σ_m is the standard deviation of the mean (Poisson statistics assumed).

light (see, e.g., Figure 1). As the individual log-log plots contain too much information of dubious significance to justify publication, we have chosen to characterize the decaying part of the power spectrum by the parameter x, where $P(f) \propto f^x$. The results for x given in Table I were obtained by a least squares fit for periods from

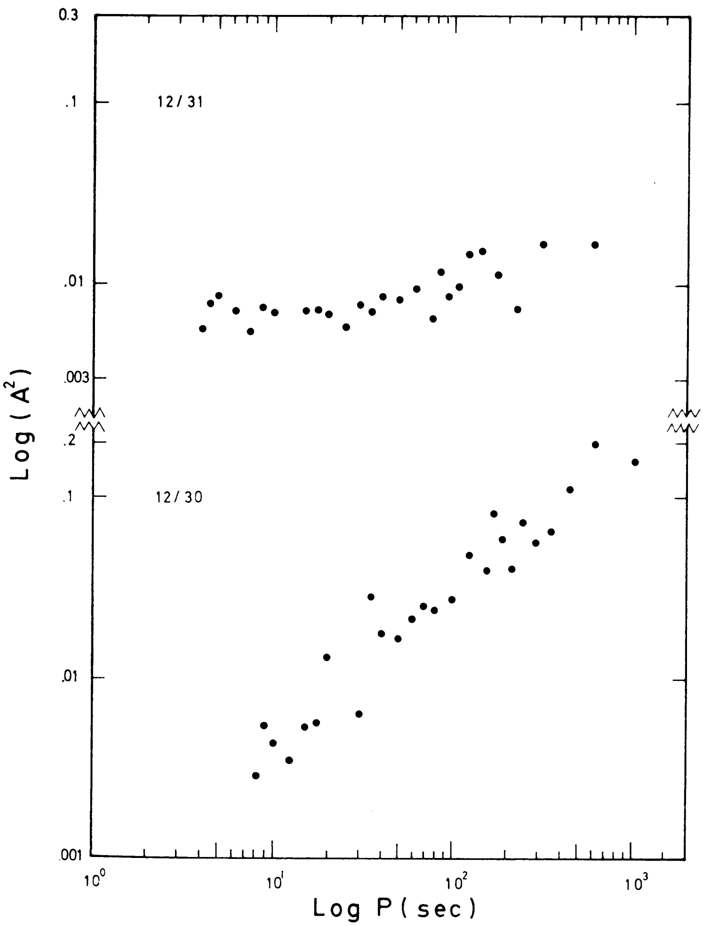

Fig. 1. Smoothed spectra computed from high resolution spectra of L532-81 (EG 62). Ordinate is amplitude squared in relative units normalized such that unity is the approximate amplitude of the 1 % calibration peak introduced in the analysis and corrected for sky contributions.

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$T/10$ to $T/83$, where T is the record length. The mean value of x for observations of 11 stars is -0.34 ± 0.09 (standard deviation). Unfortunately our data were not secured, nor have they been analyzed, in a fashion that lends greatest reliability to the continuum behaviour at the lowest frequencies, in that point-to-point sky subtraction has not been made experimentally (for a description of the analytical formalism used see HOL). Furthermore, a cursory examination of the astronomical literature on seeing and scintillation (Mikesell, 1955; Stock and Keller, 1960; Rozhnova, 1966; and references cited therein) does not provide a ready comparison from either observation or theory. It will nonetheless be interesting to compare the mean white dwarf result with those obtained from other classes of objects, where the data were acquired and analyzed under similar conditions; we shall report upon that comparison in future papers.

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