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SEARCHING THE OPEN CLUSTER NGC 6939 FOR VARIABLE STARS

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Small radial velocity variations in red giants were discovered by Walker et al. (1989) suggesting that corresponding photometric variations might be detectable. Edmonds and Gilliland (1996) discovered photometric variations in the red giant stars in the globular cluster 47 Tucanae, using the Hubble Space Telescope in the ultraviolet. We observed NGC 6939 in an attempt to observe similar variations in an open cluster in the visible part of the spectrum.

Our sixteen nights of observations were made using the 0.5 meter telescope, Cousins R filter and CCD camera of the University of Victoria (Robb and Honkanen 1992). This is an automated system, which will observe a single field all night, keeping a star on the same pixels. Each frame was bias subtracted and flat fielded using IRAF.[1] To isolate merged images the point-spread-function-fitting routines in DAOPHOT (Stetson et al. 1990) were used to find the magnitudes. An ensemble was formed from the brightnesses of the brightest stars and each star was compared with the ensemble to form a differential magnitude, ΔR in the sense of the star minus the ensemble.

The red giant stars measured in common with Mermilliod et al. (1994) are listed in Table 1 with our star identification numbers, Kustner's (1923) identification numbers, the V and B−V found by Mermilliod et al. (1994), the ΔR and the night to night standard deviation.

Table 1: Brightness, color, ΔR, and its precision for the red giants.

Id	K Id	V	B−V	ΔR	StD.	Id	K Id	V	B−V	ΔR	StD.
s1	212	12.03	1.69	2.867	0.002	s3	133	12.27	1.51	3.187	0.005
s4	121	12.53	1.54	3.448	0.003	s6	135	12.58	1.11	3.740	0.002
s8	190	12.73	1.36	3.840	0.005	s9	182	12.92	1.37	3.835	0.003
s10	053	12.86	1.30	3.894	0.004	s11	134	12.95	1.29	4.020	0.004
s12	230	12.90	1.32	4.051	0.005	s13	170	13.13	1.34	4.041	0.003
s15	145	13.05	1.31	4.086	0.002	s18	214	13.00	1.27	4.185	0.006
s19	130	13.10	1.25	4.184	0.003	s20	294	13.19	1.34	4.209	0.012
s24	58	13.32	0.89	4.568	0.002	s26	279	13.73	0.96	4.918	0.010

[1]IRAF is distributed by National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract to the National Science Foundation

Brightness variations during a night were measured by the standard deviation of the differential magnitudes of that night, which ranged from $0^{\rm m}_{\cdot}004$ for bright stars on a good night to $0^{\rm m}_{\cdot}100$ for the faint stars on poor nights. The standard deviation of the sixteen nightly means is a measure of the night to night variations. The high precision of these data can be seen from the standard deviation of ΔR for the bright stars. The fainter stars have the expected larger standard deviation. Plots of the standard deviation versus brightness were made and all outliers were checked for variability.

To find the variable stars the differential magnitude of each star was plotted against the time of day. For each star the sixteen nights were plotted in a four by four array with the brightness and time scales chosen to be the same for all nights. At a glance we could then see both the variations during a night and also from night to night. We checked all 215 stars in this manner and surprisingly found no ambiguity in whether or not a star was variable.

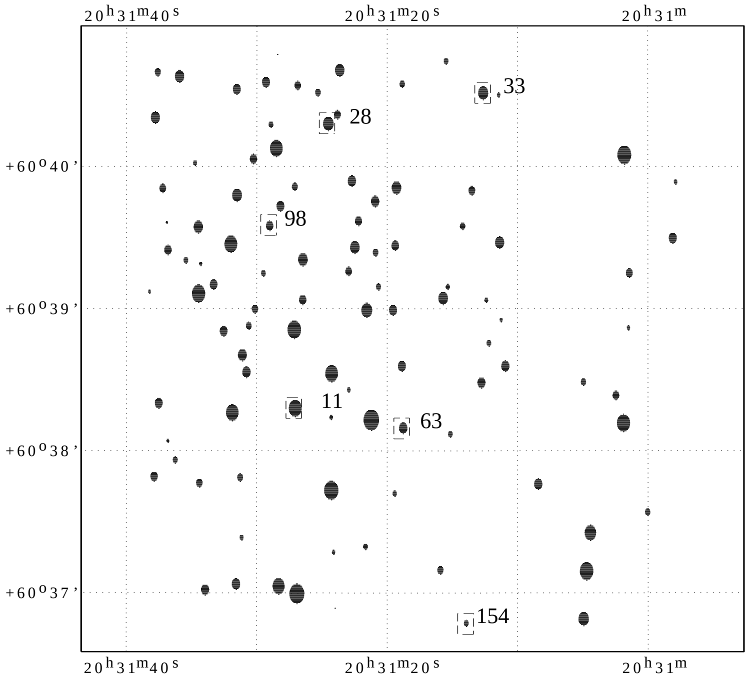

Figure 1. Finder chart labeled with our identification numbers

A finder chart based on our frames is shown in figure 1 with the variable stars marked with our id numbers. Table 2 gives our star identification numbers, Kustner's (1923) id numbers, coordinates (J2000) and magnitudes measured using the Hubble Space Telescope Guide Star Catalog (Jenkner et al., 1990), the period, the epoch with the uncertainty in the final digit in parentheses and the type of epoch.

Each variable star's differential magnitudes were fit to a sine curve of various periods and the χ^2 was used to estimate the best period. Light curves were then plotted at these periods and the aliases and multiples were checked. All the periods are very secure except that of star s11 where the period finding program also found an alias of 1.165 days that was nearly as likely.

The data were binned by JD four points to a bin. The mean magnitudes of each star are plotted against phase in Figure 2 using the period and epoch given in Table 2. The

Table 2: Variable stars discovered in the field of NGC 6939.

Id. No.	Kustner Id	R.A. J2000	Dec. J2000	Mag.	Period [days]	Epoch Helio JD	Epoch Type
s11	K134	$20^h31^m27^s$	$+60°38'18''$	13.3	7.4(6)	2450657.5(7)	max
s28	K125	$20^h31^m25^s$	$+60°40'18''$	14.2	1.30(2)	2450655.75(9)	max
s33	K80	$20^h31^m13^s$	$+60°40'31''$	14.4	10.5(20)	2450654.4(9)	max
s63	K95	$20^h31^m19^s$	$+60°38'10''$	15.1	4.954(3)	2450653.8079(5)	min
s98	K147	$20^h31^m29^s$	$+60°39'35''$	15.6	3.598(3)	2450654.0244(8)	min
s154	-	$20^h31^m14^s$	$+60°36'47''$	16.6	0.3550(6)	2450656.432(5)	min

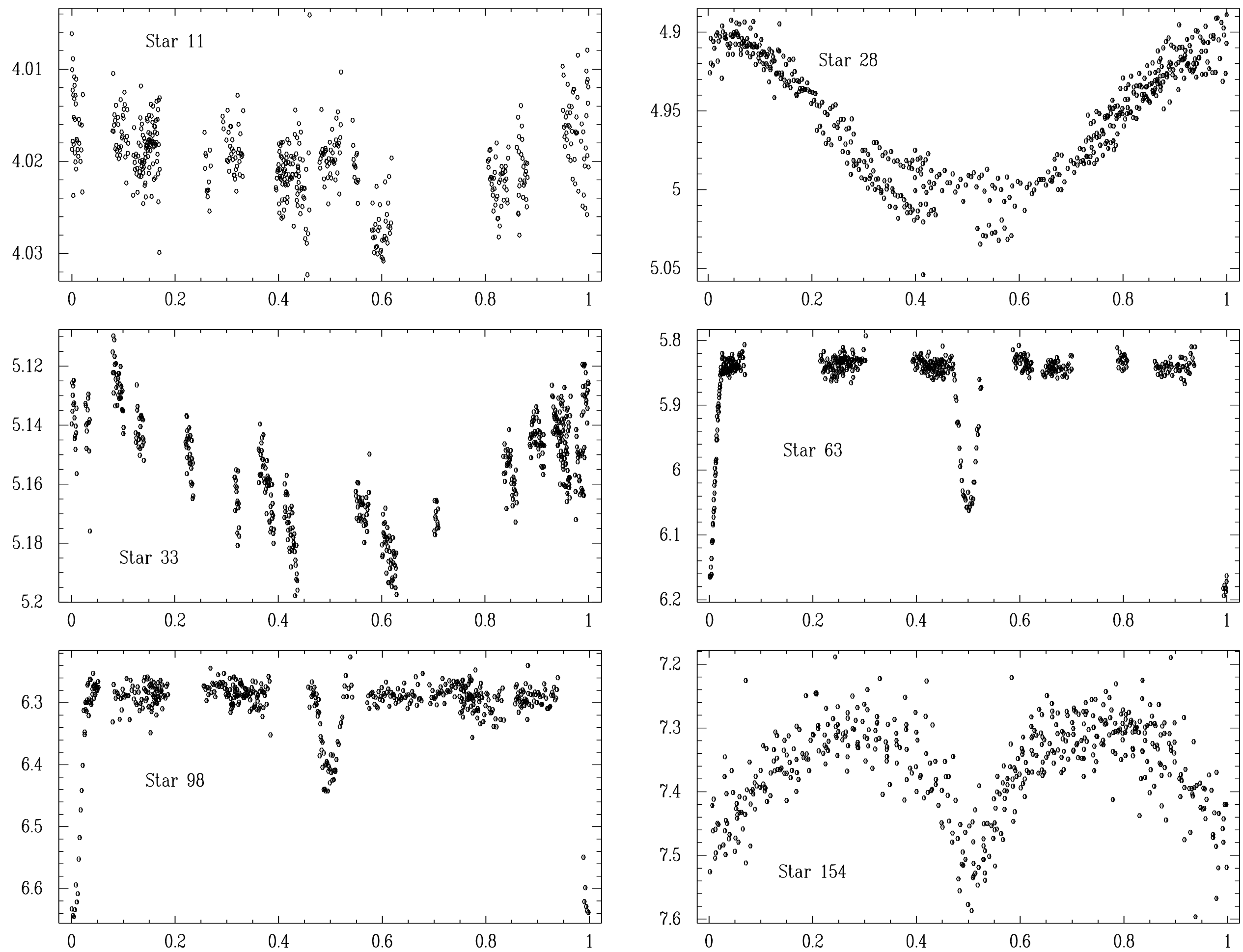

Figure 2. R band light curves of the variable stars in NGC 6939 plotted according to phase.

stars s11, s28 and s33 all lie in the red giant part of the HR diagram but s33 is probably a field star (Cannon and Lloyd 1969). Of the 16 red giants measured by Mermilliod et al. (1994) and ourselves, we find that one is variable (s11), 13 have a standard deviation of $0\overset{m}{.}005$ or less from night to night and the other two were at the extreme corner of the CCD and have a standard deviation of about $0\overset{m}{.}01$. This is in contrast to Jorissen et al. (1997), who propose that all late type stars are variable. S11 was observed for radial velocity by Milone (1994) who found it to have the largest scatter among those stars not considered variable.

Obviously from the light curves the stars s63 and s98 are eclipsing binaries. Using the method of Kwee and van Woerden (1956), heliocentric Julian times of secondary minimum were found to be 2450695.9169(5) for star s63 and 2450691.8036(8) for star s98. From the light curve of s154 we classify it as a contact binary. From our period and the relations of Rucinski (1997) and assuming a reddening of $E_{(B-V)} = 0.43$ (Mermilliod et al. 1994), this W UMa star's apparent brightness is consistent with it being a member of the cluster.

These data show that the K giant variable stars can be observed from the ground in the visible light and that not all red giant stars are variable at the level of accuracy of this work. The two eclipsing binary stars are near the turnoff point of the cluster and so are deserving of more observations especially radial velocity measurements to find the masses of the stars.

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