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A PHOTOMETRIC SURVEY OF THE HYADES FOR δ SCUTI VARIABLES

STEPHEN HORAN
Department of Astronomy, New Mexico State University, Las Cruces, New Mexico 88003
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ABSTRACT

A photoelectric survey of fourteen normal A–F spectral type Hyads within the δ Scuti instability strip has found that 36% of these stars are variable. Taking into account previously discovered variables, the minimum incidence of δ Scuti variability in the cluster is 37%. This is consistent with the results found in other galactic clusters. An additional variable, 60 Tauri, with spectral classification Am was detected during this survey. 60 Tauri lies within the predicted instability strip for Am stars as given by Cox, King, and Hodson (1979). There was found to be no significant differences in the mean rotational velocities between the variable and constant stars of normal A–F spectral type.

I. INTRODUCTION

The study of δ Scuti stars has been greatly aided by surveys of nearby galactic clusters. Partial surveys of the Hyades by Millis (1967) and Breger (1970) were useful in determining the evolutionary stage of the δ Scuti stars and the constancy of the metallic line A (Am) stars. As a result of these surveys, the incidence of δ Scuti variability within the Hyades instability strip has been placed at 13% (Slovak 1978). A new survey was undertaken to have as complete a sample of the Hyades as possible to test the reality of this low incidence of δ Scuti variability. Also, new photometry of 57 Tauri was desired because the variability of this star has been questioned by Eggen (1970).

This paper is a report of the results of a survey of the Hyades instability strip for δ Scuti variability. Cluster membership was determined from the studies of van Bueren (1952) and van Altena (1969). The photometry of Crawford and Perry (1966) and the absolute magnitude calibration of Breger (1974) for the Strömgren indices were used to place cluster members on the H-R diagram. Stars lying within the instability strip defined by Baglin *et al.* (1973) became candidates for the survey. There are twenty-five cluster members of normal and Am spectral classification within the instability strip and two others which, to within the stated accuracy of Crawford and Perry's photometry, cannot be excluded from being within the strip. A total of twenty of these stars were tested for variability as well as seven other cluster members lying near the strip to test the sharpness of its boundaries.

II. OBSERVING METHOD AND DATA REDUCTION

Observations of Hyades cluster members were obtained between October 1978 and February 1979 with the 61-cm telescope at the Blue Mesa Observatory of New Mexico State University. A dry-ice refrigerated 1P21 operating in the pulse counting mode was used as the detector. All observations were made through a Strömgren b filter.

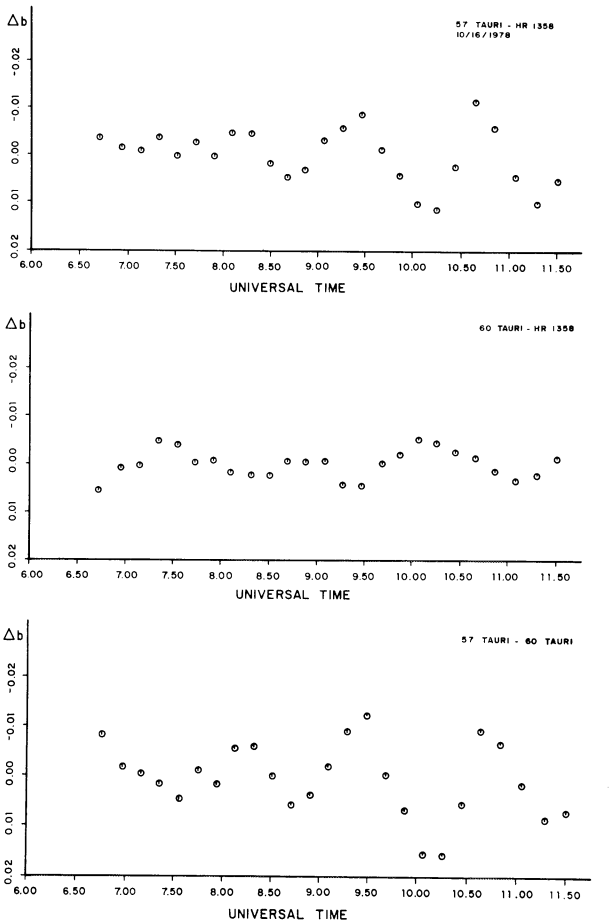

FIG. 1. Variables 57 and 60 Tauri with the comparison star HR 1358 on 16 October 1978.

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TABLE I. Hyads surveyed for variability.

VB	HR (HD)	Name	$b-y$[a]	Mv[b]	Sp T[c]	$v \sin i$[d] km/s	hours	constancy (mag)
30	1351	57 Tau	0.170	2.4	F0 V	100	5	variable
34	1358		0.292	3.6	F6 V	12	9	0.003
37	(27561)		0.267	3.4	F4 V	12	4	0.003
38	1368	60 Tau	0.196	2.6	Am	15	9	variable
45	1376	63 Tau	0.180	2.8	Am	≤12	3.5	0.003
47	1380	64 Tau	0.081	1.6	A7.5 V	35	3.5	0.003
54	1387	65 κ Tau	0.070	1.1	A7 V	90	3	0.004
55	1388	67 Tau	0.149	2.0	A5 n	210	3	0.004
56	1389	68 Tau	0.021	1.5	A3 V	<30	3.5	0.003
60	1392	69 ν Tau	0.165	0.7	A8 Vn	215	3	variable
72	1412	78 θ2 Tau	0.100	1.1	A7 IVn	130	3.7	variable
74	1414	79 Tau	0.114	1.9	A5m:	105	3	0.002
80	1422	80 Tau	0.196	2.5	A6 n	150	13	0.002
82	1427		0.088	1.8	A6 Vn	100	6.7	0.002
83	1428	81 Tau	0.142	2.7	Am	<30	13	0.002
84	1430	83 Tau	0.154	2.4	F0 Vn	140	3	0.002
89	1432	85 Tau	0.215	2.7	F2 Vn	100	4	0.003
94	(28911)		0.277	3.5	F5 V	40	3	0.004
95	1444	86 ρ Tau	0.144	2.3	A8 Vn	95	3	variable
103	1472	89 Tau	0.191	2.4	F0 V	155	3.5	0.003
104	1473	90 Tau	0.067	1.2	A6 Vn	115	3.5	0.003
108	1479	92 σ2 Tau	0.088	1.3	A5 Vn	160	3.5	0.003
111	1507		0.149	2.3	F0 V	75	3.5	0.003
112	1519		0.091	1.7	A2m	<30	3.5	0.003
129	1620	102 ι Tau	0.079	1.1	A7 V	115	3.5	0.003
131	1670		0.149	2.5	A5m	<30	2.5	0.004
141	1394	71 Tau	0.150	1.2	A8 Vn	160	6.7	variable

[a] Crawford and Perry (1966).
[b] Breger's (1974) calibration.
[c] Morgan and Hiltner (1965) except VB 55 and 80 from Crawford and Perry and VB 74, 111, 112, 129, 131, and 141 from Cowley *et al.* (1969).
[d] Treanor (1960) except VB 34, 37, 38, 45, 89, and 94 from Kraft (1965), VB 74 from Abt (1975), and VB 141 from Abt and Moyd (1973).

The Hyades covers a large region of sky making design of the cluster survey similar to that of a survey of a large number of field stars. For this survey, fields of three stars were established which contained at least one Hyad within the instability strip. The choice of field members was based on the following criteria: mutual proximity on the sky, similar brightness, and similar spectral type. Within the field, all stars were treated as "unknowns," including previously detected variables. A minimal observing run of three hours was used per field observed with the typical time to observe each member of the field and sky once being six minutes. A set of ten to twenty-five integrations constituted one observation of a star. Nominal integration times ranged from one to five seconds depending on the brighness of the stars being observed.

Raw magnitudes were corrected for extinction by applying the nightly determined extinction coefficient from the three stars observed. Variability did not significantly affect the determination of the extinction coefficient. The corrected magnitudes were not transformed to the standard system. To determine the constancy of the stars observed in a given field, all possible pairs of magnitude differences were taken among the three stars and then plotted as a function of time. For two constant stars, the typical standard deviation of the magnitude differences about a straight line fit to those differences was 0.003 mag.

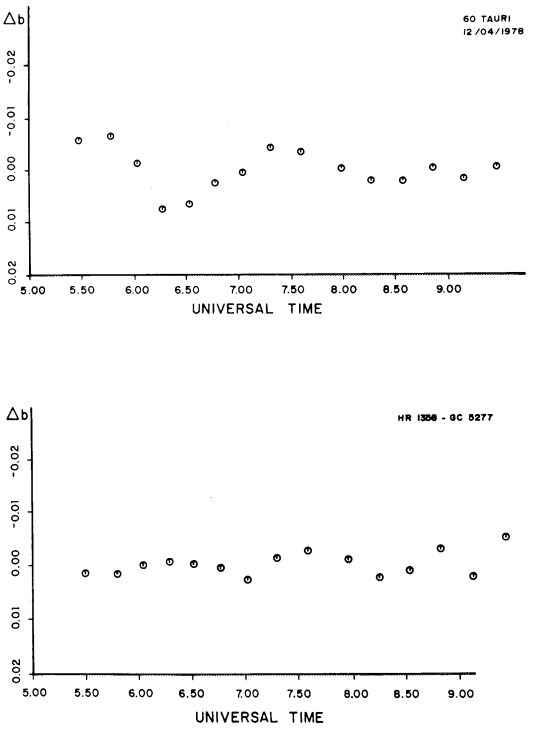

FIG. 2. Variable 60 Tauri minus the mean of the comparison stars HR 1358 and GC 5277 and the comparison stars on 4 December 1978.

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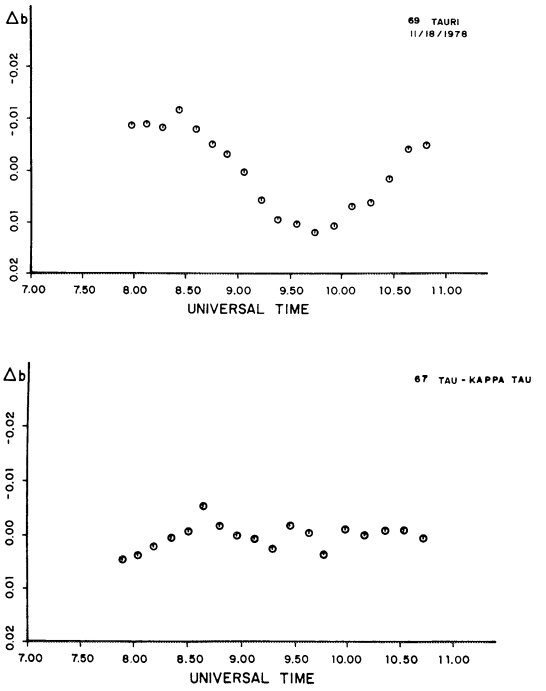

FIG. 3. Variable 69 Tauri minus the mean of the comparison stars 67 and κ Tauri and the comparison stars on 18 November 1978.

III. RESULTS

Of the nineteen normal A-F stars within the Hyades instability strip, fourteen were tested for variability. Among the five remaining stars, there are two known variables, 97 and 58 Tauri (Millis 1967 and Breger 1970) and two stars which were reported to be constant by Millis. A total of twenty-seven Hyads both within and outside of the instability strip were tested for variability during this survey. The observational properties of the survey stars are given in Table I and the light curves for the detected variables are given in Figs. 1–6. For these figures, the variable has been differenced against the mean of the two comparison stars unless otherwise noted and each point on the light curve is the mean of two observations. The curves have been normalized to have a mean magnitude difference of zero. Table II contains the properties of the six δ Scuti variables detected with periods determined using Valtier's (1972) method of fitting a trigonometric polynomial to the data and amplitudes estimated visually. Hyads lying within the instability strip but not surveyed here are listed in Table III. Comments on individual stars follow below.

Fifty-seven Tauri (= VB 30 = HR 1351) was found to be variable on 16 October 1978 and exhibits beats in its light curve. HR 1358 was used as the comparison star. Fifty-seven Tauri lies toward the red edge of the instability strip and was given a spectral classification of F0 V by Morgan and Hiltner (1965). The fundamental period appears to be 1.3 h although the strong beats make period determination difficult based on one run.

Sixty Tauri (= VB 38 = HR 1368) was also found to be variable on 16 October and was confirmed on 4 December 1978. For the first set of observations, HR 1358 was the comparison while for the second set, HR 1358 and GC 5277 were the comparisons. Sixty Tauri lies at the red edge of the instability strip and was classified as Am by Morgan and Hiltner and as A3m by Cowley *et al.* (1969). The fundamental period appears to be approximately 1.5 h, however, 60 Tauri also shows evidence for being excited in more than one mode.

Sixty-nine υ Tauri (= VB 60 = HR 1392) has the highest rotational velocity of any Hyades cluster member. Variability was detected on 18 November 1978 with a period of 3.2 h and an amplitude of 0.025 mag when κ and 67 Tauri served as the comparison stars. The spectral classification of υ Tauri is A8 Vn as given by Morgan and Hiltner.

Seventy-eight θ2 Tauri (= VB 72 = HR 1412) is the most luminous Hyad with a spectral classification of A7 IVn by Morgan and Hiltner. Variability was detected on 15 December 1978 with a period of 1.9 h and an

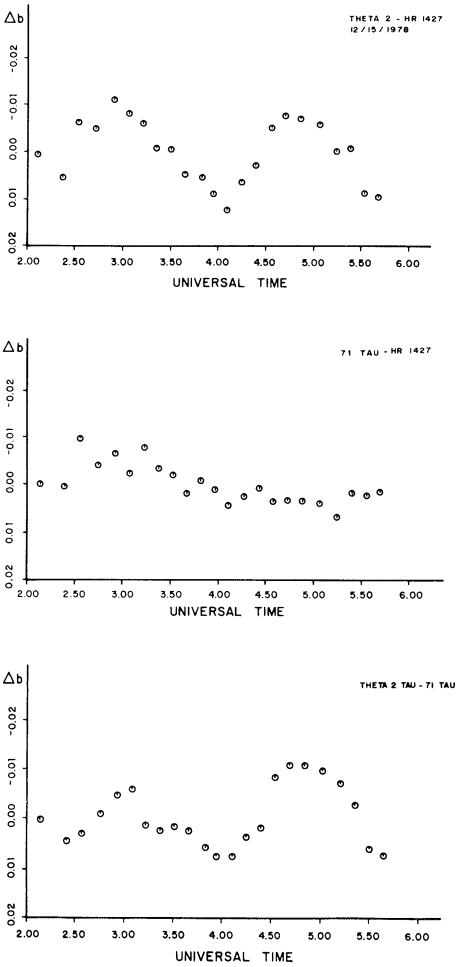

FIG. 4. Variables θ2 and 71 Tauri with the comparison star HR 1427 on 15 December 1978.

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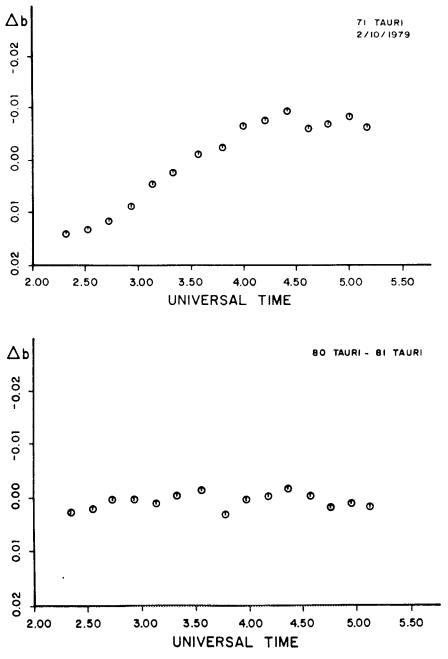

FIG. 5. Variable 71 Tauri minus the mean of the comparison stars 80 and 81 Tauri and the comparison stars on 10 February 1979.

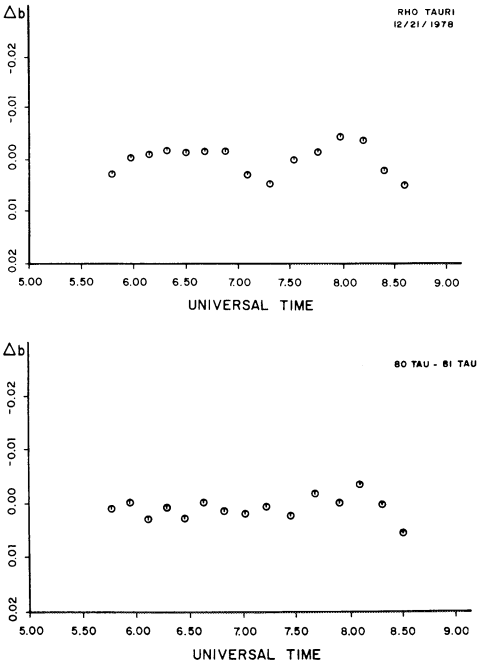

FIG. 6. Variable ρ Tauri minus the mean of the comparison stars 80 and 81 Tauri and the comparison stars on 21 December 1978.

amplitude of 0.025 mag. HR 1427 was used as the comparison for these observations.

Seventy-one Tauri (= VB 141 = HR 1394) was also found to be variable on 15 December and was confirmed on 10 February 1979. HR 1427 was the comparison for the former observations while 80 and 81 Tauri were the comparisons for the latter. The spectral classification of 71 Tauri was given by Cowley *et al.* as A8 Vn. Seventy-one Tauri shows evidence of being excited in more than one mode with a fundamental period of 3.9 h.

Eighty-six ρ Tauri (= VB 95 = HR 1444) is the smallest amplitude variable detected during this survey. The period and amplitude as measured on 21 December 1978 are 1.6 h and 0.01 mag, respectively. Eighty and 81 Tauri served as comparisons. ρ Tauri has been classified as A8 Vn by Morgan and Hiltner.

The variables 57 and θ2 Tauri were discovered previously by Millis (1967) and Horan (1977), respectively. Eggen (1970) has disputed the variability of 57 Tauri. However, the beats present in the light curve could have been responsible for this reported constancy. The variability of θ2 Tauri reported here is similar to that found by Horan and later by Duerbeck (1978).

The variables 60, υ, 71, and ρ Tauri were found by at least one previous investigator to be constant. Millis claimed a possible low amplitude variation may exist in ρ Tauri. The variable amplitudes of 60 and 71 Tauri may explain their reported constancy.

The cluster members κ Tauri and HR 1507 were reported to be possible variables by Millis and Breger, respectively. Neither star exhibited any signs of variability during this survey.

IV. DISCUSSION

The variability in 60 Tauri which has a spectral classification of Am would normally be highly questionable. The exclusion of Am stars from pulsation has been well established in both the field stars and the galactic clusters which have been surveyed. However, Cox, King, and Hodson (1979) have predicted the existence of an in-

TABLE II. Properties of Hyades δ Scuti variables.

VB	Name	Period (h)	Amplitude (mag)	Comments
30	57 Tau	1.3	0.02	Beats
38	60 Tau	1.5	0.01	Multiple periods; Am
60	69 υ Tau	3.2	0.025	
72	78 θ2 Tau	1.9	0.025	
95	86 ρ Tau	1.6	0.01	
141	71 Tau	3.9	0.01–0.02	Multiple periods

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TABLE III. Nonsurveyed Hyads within the instability strip.

VB	HR	Name	$b-y$[a]	V[b]	Sp T[c]	Remarks
24	1331	51 Tau	0.175	5.65	F0 V	
33	1356	58 Tau	0.126	5.26	A9 V	variable (Breger 1970)
67	1403		0.164	5.72	Am	
107	1480		0.150	5.39	A5 V	
123	1547	97 Tau	0.122	5.10	dA5	variable (Millis 1967)
126	1566		0.178	6.37	dF0	
130	1672	16 Ori	0.138	5.43	A2m	

[a] Crawford and Perry (1966).
[b] *Catalogue of Bright Stars* (Hoffliet 1964).
[c] Morgan and Hiltner (1965) except VB 130 from Cowley *et al.* (1969) and VB 107, 123, and 126 from Crawford and Perry.

stability strip for cool Am stars in the region of the red edge of the normal δ Scuti instability strip. Crawford and Perry's (1966) photometry places 60 Tauri within this predicted Am instability strip.

In any survey of this type one has the question of undetected variables. From the typical constancy of the "constant" stars, i.e., 0.003 mag, it can be said that at a 3σ level of detection, any δ Scuti stars with a minimum amplitude of 0.01 mag would have been detected.

The incidence of variability detected among the fourteen normal A-F stars surveyed is 36%. Taking into account the variables 97 and 58 Tauri which were discovered by Millis (1967) and Breger (1970), we can set the minimum incidence of δ Scuti variability at 37% among the nineteen normal spectral type Hyads within the instability strip. This is in agreement with the 30%–35% incidence of variability found in galactic clusters as given by Breger (1975).

Breger (1979) has shown that there is no significant difference in the mean rotational velocities between the variable and constant, non-Am stars in the instability strip. This study confirms that result among the normal spectral type Hyads surveyed. From the data presented in Table I, the mean $v\sin i$ of the variables is 140 ± 49 km/s and of the constant stars is 127 ± 52 km/s.

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