Study of Cepheid Variables as a Joint Spectroscopy Project

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Introduction

When astronomical spectroscopy moved beyond the limits of the early blue and green orthochromatic emulsions, to the near IR (out to 9000 A., made possible with the new P and R plates of Eastman Kodak), it was quickly learned that strong lines were present due to H, N I, O I, Mg II, and Ca II, and that these were present in widows free from atmospheric absorption. P. Merrill (1934) summarized his findings, using the 2.5-m Hooker telescope on Mt Wilson with a grating spectrograph of 33 A/mm dispersion, noting especially the strength of an oxygen triplet at 7771-7775 A, frequently referred to in the literature as the 7774 feature. This feature was noted as remarkably strong in luminous stars from late **B** to early **G** spectral types, having a combined equivalent width in excess of 2 A in luminosity classes **Ia**. Keenan and Hynek (1950), using the newer I-N plates and a prismatic spectrograph on the new Perkins 1.75-m reflector at only 250 A/mm dispersion, undertook a more detailed study of the triplet feature on about six dozen spectral standard stars spread across the HR diagram.

In 1961 Keenan suggested further study of this feature to one of the authors (KEK) when exploring the use of a new type of imaging detector, an S-1 image converter tube, for quantitative spectroscopy in a direct comparison with I-N and I-Z photographic plates. This was prior to the development of CCD detectors, and was part of the 1960's investments made by NSF in new detectors.

Prior Work on Cepheid Variables

Keenan also pointed out to the student that this region of the HR diagram contained the Cepheid variables, they being **Ib** supergiants, which might be studied by observing how this triplet feature varies during the pulsation cycle of a few days to several weeks, depending on the star. For example, the prototype is *delta Cephei*, which cycles from **F5Ib** to **G1Ib** every 5.366 days, while varying in brightness from +4.37 to +3.48 st mag in this cycle. Fig. 1 is taken from the K&H 1950 paper, and shows the boundaries of luminosity classes vs. the triplet equivalent width. If *delta Cephei* were to remain on the **Ib** trajectory of luminosity, its O I triplet strength could be predicted to vary regularly from about 0.6 A to 1.2 A during each cycle of varying spectral type. Fig. 2, from K&H, shows spectra from **F0** stars from dwarf to supergiants.

Observations were made of the O I feature in *delta Cephei*, both image tube and I-N, during 1962 and 1963, along with the measures of other non-variable stars over a whole range of the HR diagram. The observations of several Cepheids were included, but these were not the main thrust of the investigation, which included stellar and solar spectra extending into the 1.2-micro-meter region, which the S-1 image tube allowed.

Fig. 3, from Kissell's dissertation (1969), shows a plot of data from both I-N (15) and image tube (17) measures of equivalent width of the O I triplet vs. brightness phase of *delta Cephei*, corrected to variable brightness data collected in this same time frame by an AAVSO volunteer* upon my request.

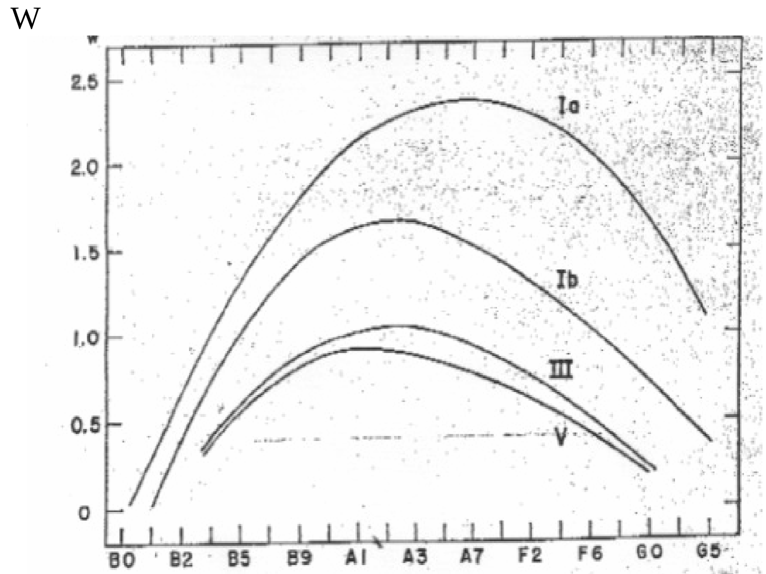
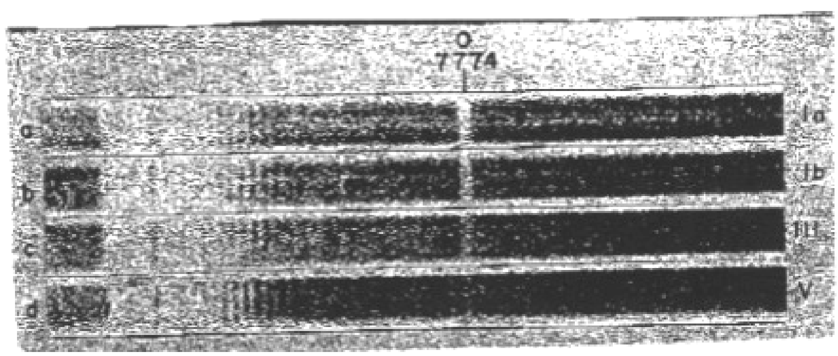


Fig. 1. Luminosity effects in the total absorption of O I 7774 feature.



a)	**ε Aur**	**Ia**
b)	**α Leo**	**Ib**
c)	**ζ Leo**	**III**
d)	**γ Vir**	**V**

Fig. 2. The oxygen lines, 7774 A, in stars of type F0:

As is immediately apparent, the triplet strength shows strong variation with the pulsation of the star, exceeding the expected values plotted also on the figure. Unfortunately the scatter of the data taken at the dispersion used in the Perkins grating spectrograph does not allow confidence in the phase values of the maximum and minimum feature strength. Specific analyses of these data were not part of the dissertation write up (1969) or of other publications. It appears to be long overdue to explore further this interesting feature, now that many amateurs could contribute to it.

* Observations by a Marvin Baldwin, Capt. USAF, who became a very active AAVSO member.

Fig. 4 shows how the brightness, temperature, stellar radius, and radial velocity vary with the phase, zero phase being the brightest. We would like to add O I triplet strength to these plots

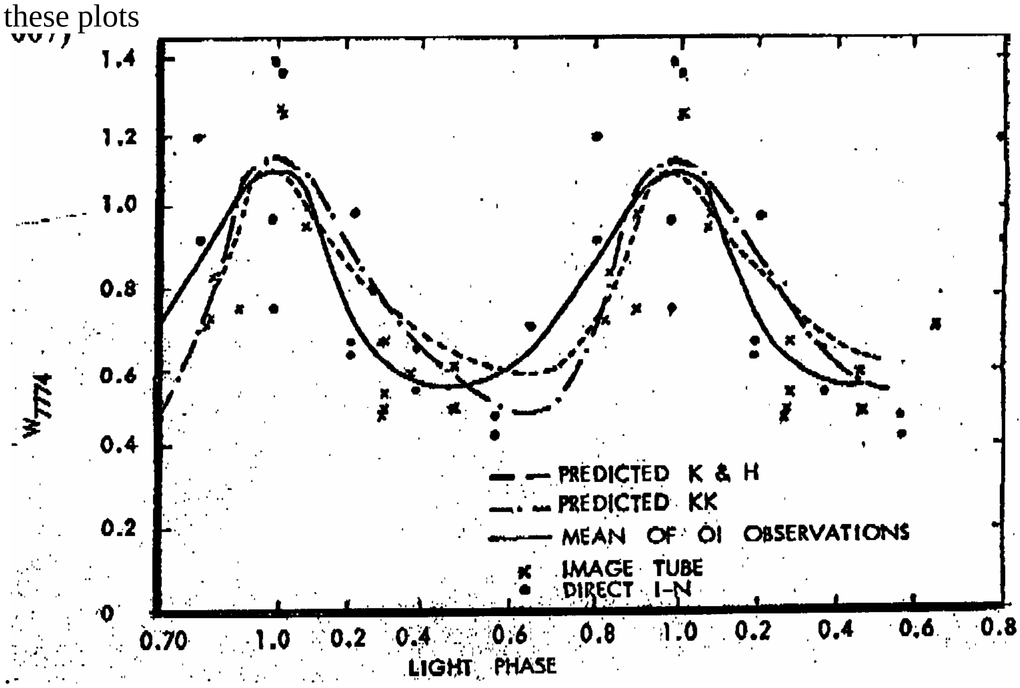


Fig. 3. Variations of O I feature at 7774 A with light phase in delta Cephei. Dashed curves are predictions based on absorption in non-variable supergiants Ib.

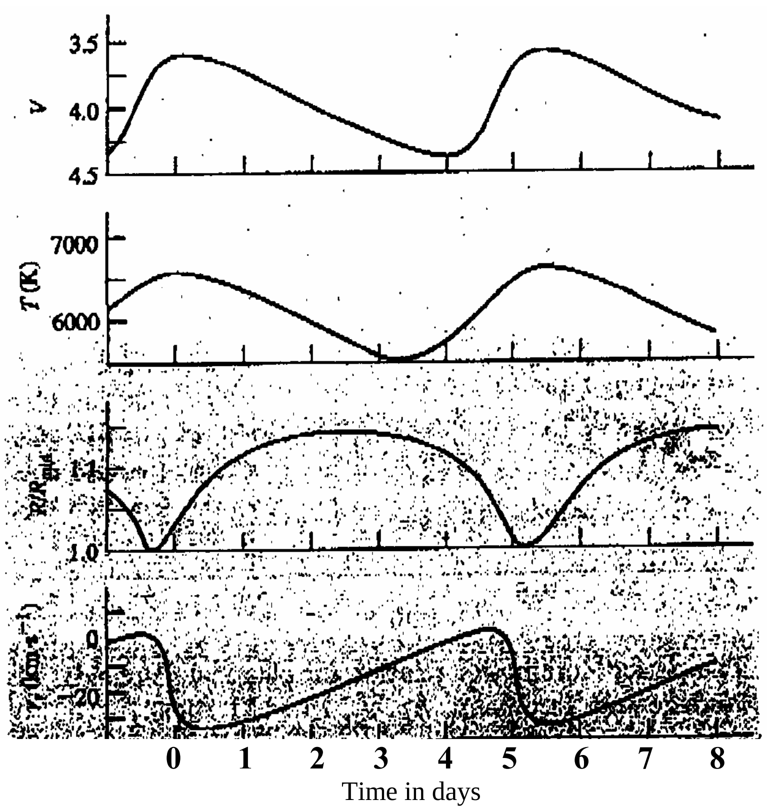


Fig. 4. Observed pulsation properties of delta Cephei.

It is the intention of the proposed study to use current CCD detectors and SBIG grating spectrographs to obtain multiple (nearly continuous) observations at a higher resolution, so as to establish the feature strength and phase on *delta Cephei*, and to collect similar data on several other of the dozen Cepheids both visible in these latitudes and brighter than +7 minimum magnitude. The periods of these candidate stars range from 3.73 to 27.0 days. This study is to 'shed light' on the physics of the triplet feature, which originates from upper levels in the pulsating atmosphere in which normally metastable levels in the oxygen atom have been populated by UV excitation, but remain populated without normal collisional de-exitation.

Table I is a list of Cepheid candidates, taken from the Astronomical Almanac (2007) and it includes an epoch date value for the peak brightness (phase 0.0) from which an observer can reckon the phase at which any spectrum has been taken. We propose to validate the epochs by simultaneous photometry with the spectral collections, either by the observers themselves, or by cooperating participants. In 1963 an offset of 0.05 was needed to phase the predicted peaks to the visual measurements provided by the AAVSO*.

<u>Proposed Future Work</u>

Although the immediate objective of our program is a definitive study of *delta Cephei*, we plan to extend the campaign to nine other Cepheids visible from the d Dark Ridge Observatory, recently relocate to the dark skies of New Mexico, including *eta Aquila*, *zeta Geminorum*, and *T Monocerotis*, all of which were observed for the presence of the O I feature in 1962-63, but not enough to look for their periodicity and phase. These stars will be studied so as to map the equivalent width with phase and spectral type. Equipment to be utilized at the Dark Ridge Observatory include a Meade 14" LX200GPS incorporating an SBIG SGS spectrograph fitted with an 1800 rules/mm diffraction grating.

Another class of variable stars (also of high interest to cosmologists) are the RR Lyras, also pulsating variables but about luminosity class II, and with periods much shorter than the Cepheids, about 0.7 days. The brightest of them is about 4% that of *delta Cephei*. We will explore *RR Lyra* for the O I triplet, but it may be beyond the detailed study with our small instruments. RR Lyras are receiving some rebirth of interest by the Japanese astronomers at the Subaru facility on Mauna Kea.

* Observations by a Marvin Baldwin, Capt. USAF, who became a very active AAVSO member.

References
Keenan, P.C. & Hynek, J.A., Ap.J. 111,1,1950.
Kissell, K.E., “Application of an Infrared Image Tube to Astronomical Spectroscopy”, University Microfilms, Ann Arbor, (1969). Doc. #69-15933.
Carroll & Ostlie, Intro. To Modern Astrophysics, Addison-Wesley (1996), p.546
The Astronomical Almanac, US Government Printing Office (2007)

TABLE I. Cepheid Characteristics for Candidate Program Stars

Name	Right Ascension h m s	Declination ° ‘ “	Magnitude max	min	Epoch (2400000+)	Period d	Spectral Type
T Mon	06 25 37.3	+07 04 52	5.58	6.62	43784.615	27.025	F7Iab-KIIab
RT Aur	06 29 03.0	+30 29 16	5.00	5.82	42361.155	3.728	F4Ib-G1I
ζ Gem	07 04 33.2	+20 33 31	3.62	4.18	43805.927	10.151	F7Ib-G3Ib-G1Ib
X Sgr	17 48 02.0	-29 49 59	4.20	4.90	40741.70	7.013	F5-G2II
W Sgr	18 05 30.0	-29 34 45	4.29	5.14	43374.77	7.595	F4-G2Ib
Y Sgr	18 21 49.5	-18 51 22	5.25	6.24	40762.38	5.773	F5-G0Ib -II
FF Aql	18 58 34.8	+17 22 17	5.18	5.68	41576.428	4.471	F5Ia-F8Ia
η Aql	19 52 51.3	+01 01 31	3.48	4.39	36084.656	7.177	F6Ib-G4Ib
S Sge	19 56 21.7	+16 39 18	5.24	6.04	42678.792	8.382	F6Ib-G5Ib
X Cyg	20 43 41.8	+35 36 54	5.85	6.91	43830.387	16.386	F7Ib-G8Ib
T Vul	20 51 47.4	+28 16 44	5.41	6.09	41705.121	4.435	F5Ib-G0Ib
δ Cep	22 29 27.1	+58 27 13	3.48	4.37	36075.445	5.366	F5Ib-G1Ib
RR Lyr	19 25 42.3	+42 47 57	7.06	8.12	50238.499	0.567	A5.0-F7.0