A FAR-ULTRAVIOLET FLUX DIFFERENCE BETWEEN HYADES AND PLEIADES STARS

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Abstract. Four ultraviolet fluxes measured in U_2 (centered at λ_{eff} 2300 Å) by the Celescope experiment aboard OAO 2, reveal an important flux difference between Pleiades and Hyades stars. Available blanketed stellar models show that the difference is too large to be understood as a blocking effect for admissible metal overabundance in Hyades stars. Known rotation and presence of Ap and Am stars in the Hyades and Pleiades apparently cannot account for the discrepancy.

One of the important assumptions of the cluster-fitting method is that two main-sequence stars of the same spectral type or intrinsic colour have the same absolute magnitude. I wish to show that Pleiades and Hyades stars of the same spectral type or $b-y$ colour differ by a factor of 2 in their 2000 Å ultraviolet fluxes, and so presumably differ also in their absolute visual magnitudes.

The data for this paper were acquired as part of the Celescope sky-mapping experiment aboard the successful OAO 2 satellite. The Celescope package incorporated four ultraviolet-sensitive television scanners, or Uvicons, which, in conjunction with four filter sets, provided stellar fluxes at four wavelength bands between 1200 and 3000 Å. I should like to present results obtained with the U_2 filter, which, because of its high peak transmission and broad bandpass, yielded the greatest amount of data. The U_2 filter has a bandpass of 1000 Å centered at approximately 2300 Å. Reduction of the Celescope pictures has been completed under the direction of Dr R. J. Davis, Dr W. A. Deutschman and Mrs K. Haramundanis and will be discussed in the final printed catalog. The rms deviation of a single observation has been assessed, from repeated observations of various stars, to be $\sigma_{\mathrm{rms}}=0.15$ mag.

Strömgren four-colour and Hβ photometry from Crawford and Perry (1966) and from other unpublished data by Crawford was used to analyze the ultraviolet photometry. The Hyades were assumed to be unreddened, and the Pleiades were dereddened by using the calibrations and procedures outlined by Crawford and Perry (1966), with a value of 4.75 used for the ratio of $E(U_2-V)/E(B-V)$ (Haramundanis and Payne-Gaposchkin, 1972). Because reddening of the Pleiades stars is almost zero, essentially none of the conclusions of this paper is likely to be an artifact of the reddening corrections.

Figure 1 shows the comparison of U_2-V fluxes of the Hyades stars and all Pleiades members having $(b-y)_{\mathrm{o}}\geqslant 0.1$. In this graph we see a clear separation between the two clusters.

Several points must be made concerning the validity of the difference between Pleiades and Hyades stars, as seen in Figure 1. Because the Pleiades and Hyades are close in the sky and because the Pleiades measurements were made between several sets of Hyades measurements, it is very unlikely that small orientation or time-

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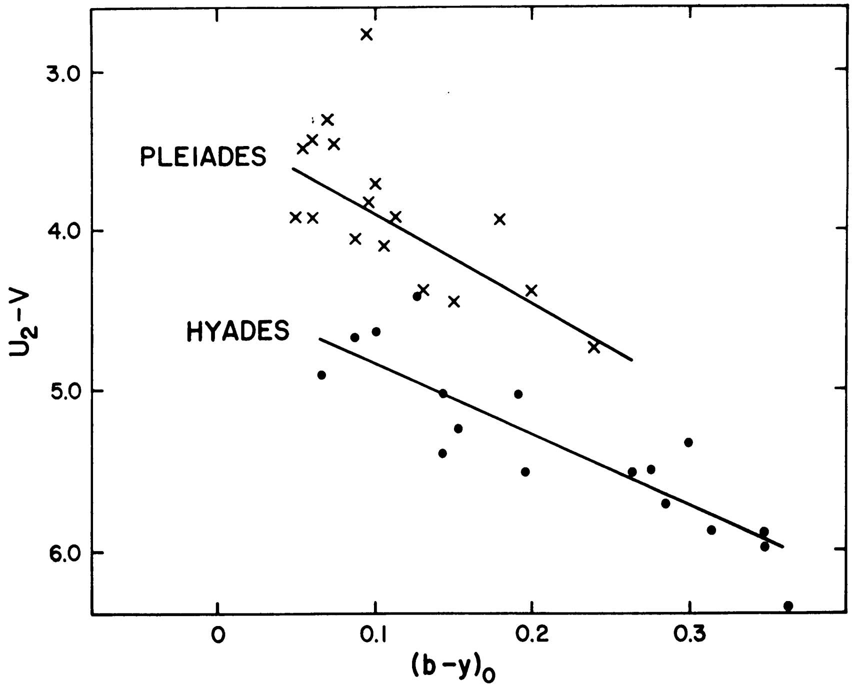

Fig. 1. Two-colour diagram showing $U_2 - V$ as a function of $(b-y)_0$, with reddening of Pleiades stars corrected for by use of a $\beta-(b-y)$ diagram. Data for hotter Pleiades stars are not shown, because the dereddening procedure can no longer be applied. Data for Pleiades stars redder than $b-y=0.1$ may be affected by completeness, since observations were continued to a magnitude limit in U_2.

variable calibration effects caused the observed difference. The Pleiades data may be affected by completeness, especially for $b-y \geqslant 0.15$; however, the mean Pleiades relation in Figure 1 can be seen to be a smooth continuation of the $U_2 - V$ relation for hotter Pleiades stars and for hotter stars in the θ Car cluster.

Some differences between the Pleiades and the Hyades stars have previously been noted in the literature. Chaffee *et al.* (1971) pointed out that Hyades stars have 50% higher metal abundances than do Pleiades stars and the Sun. The Hyades are known to have many metallic-line stars, and Struve (1945) has shown the Pleiades to have significantly higher mean projected rotational velocities.

Before considering the effects of abundance and rotation on the ultraviolet fluxes, we might ask how field stars compare to the mean Pleiades and Hyades relations. In Figure 2, we have plotted $U_2 - V$ against spectral type, since four-colour photometry is not available for a significant number of field stars having Celescope photometry. We see from the figure that the A stars in the field have far-ultraviolet fluxes similar to the Hyades stars, whereas the F stars are, if anything, fainter in the ultraviolet.

Now we can consider the effects of abundances on the far-ultraviolet and visible fluxes. I have reviewed the models of Chaffee *et al.* (1971) to determine the effects of metal overabundance on the U_2 and V fluxes. In Figure 3, the far-ultraviolet fluxes for 25% and 50% metal overabundances are plotted; the 50% overabundance is the value adopted by Chaffee *et al.* For a 50% overabundance, these models predict that the ultraviolet fluxes in U_2 will be depressed by $0\overset{m}{.}21$ while the V magnitude will be increased by $0\overset{m}{.}025$. If we extrapolate these results, we would need a factor of 2.5 overabundance of metals in Hyades and field stars relative to the sun and Pleiades stars in order to account for the Hyades (and field star!) ultraviolet deficiencies. Such large metal overabundances seem precluded by direct abundance determinations. We note that even such a large amount of ultraviolet line blocking, interpreted as an overabundance effect, appears to cause no more than an $0\overset{m}{.}1$ increase in the V magnitude at constant T_{eff}. This is because the V magnitude is also strongly affected by blocking, and much of the radiation escapes in the infrared.

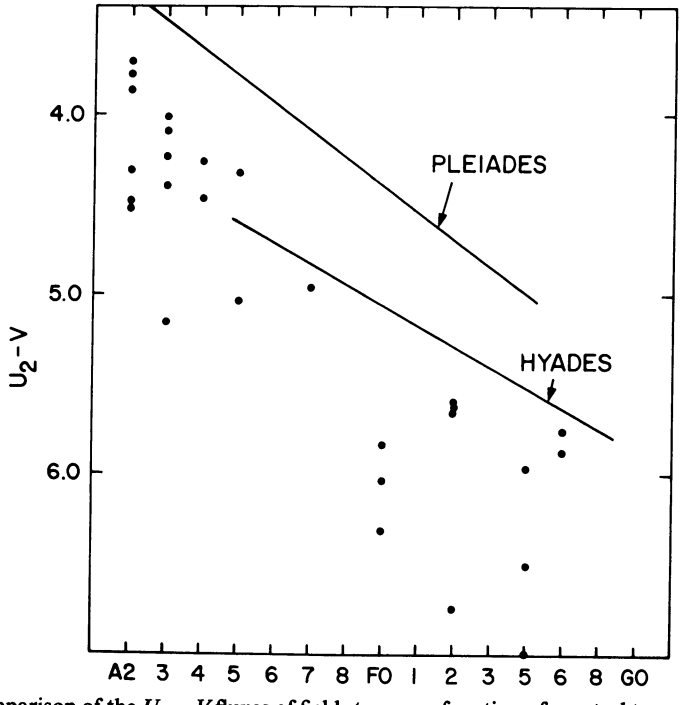

Fig. 2. A comparison of the $U_2 - V$ fluxes of field stars, as a function of spectral type, with the mean Pleiades and Hyades relations. Not only are the field stars fainter at U_2, but the scatter is much greater than for stars in coeval groups.

We conclude that if the Hyades ultraviolet deficiency is an effect of line blocking due to metal overabundance, the visual magnitudes are not likely to be affected by more than $0\overset{m}{.}1$; however, a metal overabundance sufficient to depress the ultraviolet as observed should have been easily detected in direct abundance determinations from coudé spectra.

We next consider the possibility that differences in rotation cause the observed

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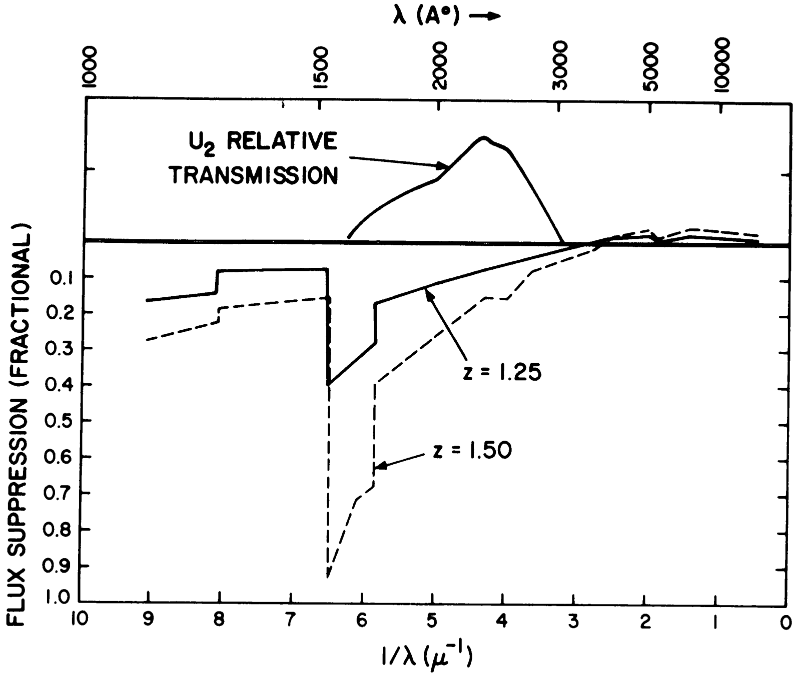

Fig. 3. Ultraviolet-flux suppression as a result of metal overabundance in a $T_{\mathrm{eff}} = 7500$ K main-sequence star. The two curves show the suppression computed for 25% ($z = 1.25$) and 50% ($z = 1.50$) metal overabundances relative to the Sun. Note that the curves change sign in the visible and near infrared, showing that the flux escapes the star in these spectral regions.

differences in ultraviolet flux. Hardorp and Strittmatter (1968) have computed energy distributions of nonrotating and critically rotating stars. We note their result for a $T_{\mathrm{eff}} = 8600$ K star: Compared to a nonrotating star, a pole-on star rotating at 99% of breakup velocity is only $0\overset{\mathrm{m}}{.}06$ bluer in $U_2 - V$. Of course, both the pole-on star and the rapid rotator have sharp spectral lines. Relative to the sharp-lined stars, the critically rotating stars seen equator-on are $0\overset{\mathrm{m}}{.}6$ *fainter* in $U_2 - V$. Thus, whereas rotation can produce large changes in the ultraviolet fluxes, the sense is wrong to account for the fact that the apparently more rapidly rotating Pleiades stars are brighter in the ultraviolet than are the Hyades and field stars.

It is well known that there are a relatively greater number of Am and Ap stars in the Hyades than in the Pleiades. Since the Am stars are binaries, could the presence of binary components cause the Pleiades-Hyades difference? For example, if secondary components contribute to the V magnitude, then the binaries will be fainter in $U_2 - V$.

We must conclude that binary secondaries do not cause the observed Pleiades-Hyades differences in ultraviolet flux, for the following reasons:

(i) From the amount of the effect, essentially all the binary systems would have to have equally luminous components.

(ii) The known spectroscopic binaries and Am stars are not displaced from the nonbinaries in Figure 1.

(iii) The nonbinary Hyades are redder in $U_2 - V$ than the Pleiades spectroscopic binaries.

We conclude that the ultraviolet faintness of the Hyades relative to the Pleiades measured in Project Celescope does not have a simple explanation in abundance, rotation, or spectrum peculiarity. As we have seen, for the observed ultraviolet faintness of the Hyades to be an abundance effect, the metal abundance would have to be so high as to have been detected on coudé spectra. Suppression of the ultraviolet by rotation effects is in the wrong sense for the known difference in projected rotational velocities between the Pleiades and the Hyades. And the identification of the stars in Figure 1 known to be spectroscopically peculiar shows them not to be responsible for the effect. Until the origin of this ultraviolet difference is understood, the method of cluster fitting based on the Hyades must be applied with caution.

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DISCUSSION

Jaschek: Apparently, from the two communications, one has to conclude that the difference between theory and observation in the case of the Hyades can only be explained in two ways:

(1) by changes in the bolometric corrections,

(2) by having a large number of undetected binaries which affect the total magnitudes of the stars.

Could any one of the speakers comment upon this?

Schild: My answer can be brief; my observations, since they are reported as colour-colour diagrams, are independent of bolometric corrections. Similarly, undetected binary secondaries are likely to be so much fainter, and redder, that it is hard to imagine their contributing significantly to the far ultraviolet fluxes.

Pecker: The Pleiades vs Hyades diagram $U_2 - V$ vs $b - y$ is essentially characteristic of atmospheric properties. If we exclude Jaschek's good suggestion for double-star phenomena affecting the measurements, we must consider that a large difference in abundances cannot be excluded (as said by Schild) on the basis of *differential* curves of growth, as the atmospheres themselves may have a definitely different structure (possibly connected to deeper convective regions which, according to Demarque's comment, are coming in the picture). Differential methods have to be strongly criticized in such problems.