OBSERVATION OF THE SPECTRA OF STARS IN THE SAME PHOTOMETRIC BOXES

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ABSTRACT

We have started at the OHP observatory an observing program for classifying stars in Golay's boxes of photometrically identical stars. So far 380 stars have been observed at 80 Å/mm dispersion, covering the range from B0 to G8. The main result is that stars belonging to the same box are spectroscopically identical at this dispersion if one considers classifications taken from different well experienced observers. This remains true within the current errors of spectral classification. The problem presented by the Ap and Am stars is discussed in detail.

In the lecture of Prof. Hauck we have heard about the different attempts to correlate spectroscopic and photometric data. Among the most fruitful recent approaches to the problem we have Golay's idea of star boxes, which we think is one of the ideas of the future.

The boxes are defined as elementary cells in a n-dimensional color index space, where n is the number of different color indices measured in a given photometric system. The length of the elementary cell (box size) is chosen in each color as being equal to $a \cdot \varepsilon$ where $1 < a < 3$ and ε is the observational error of the color index. If n could be very large and the colors could cover the complete spectrum of the stars, we could state safely that all stars in a box are identical (within the errors implied by the ε). Since however we neither cover the whole stellar spectrum (but only the region $3100 < \lambda < 6900$ Å) nor is n very large ($n < 10$), the identity of the stars in the same box is something reasonable, but it has to be demonstrated. A good counter example is given by those stars which are

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normal in the visual, yet are abnormal in the infrared or in the ultraviolet-like the Be stars in the infrared or the "λ 2360" stars in the ultraviolet.

When we specify the spectrum of a star by means of a few color measurements obviously we can not hope that all parameters which characterize a star are equally reflected in its radiation spectrum. Although magnetic fields, for instance, are important for the structure of a star, up to now no photometric system has been found sensitive to this effect. From what we know colors in the optical wavelength range are sensitive to

1 - surface temperature
2 - surface gravity
3 - binarity
4 - rotation
5 - chemical composition
6 - interstellar reddening

Therefore $\underline{n}$ should be at least equal to six; if one considers systems with smaller $\underline{n}$ one can be sure that not all of these parameters can be determined.

If one considers on the other hand spectral classification as embodied in the Yerkes system, a discussion of low dispersion spectra provides information equivalent to points 1 and 2 of the previous list and gives also some idea about points 4 and 5. Therefore a partial answer to the general problem of the identity of the stars belonging to the same box can be obtained through an examination of the spectral classification of the stars belonging to the same box. We expect that stars in the same box do share the same spectral classification. Obviously this is a necessary but not a sufficient condition, since stars having the same classification could still differ for instance in properties 3 and 6, to which spectroscopy is less sensitive.

The most immediate approach to the question would be thus to compare published spectral types to published boxes. This was done by Golay, Peytremann and Maeder (1969). They selected stars with identical colors in the Geneva system (six color indices) and compared them with published spectral types. The box size considered were $0^m\!.01$ and $0^m\!.02$ (a box size of $0^m\!.01$ implies that all stars in the box differ by less than $0^m\!.01$ - in all colors - from those of the central star; a similar definition applies to the $0^m\!.02$ boxes). Their conclusions, for the $0^m\!.01$ boxes were -

a.. for 83% of the stars, the maximum difference between spectral types for the stars in the same box is 0.2 spectral class or less;

b. in 73% of the boxes, the difference in luminosity is one class or less.

For the $0^{m}_{\cdot}02$ boxes the results are slightly worse:

a. passes from 83% to 81%;
b. passes from 73% to 61%.

Such a result is rather discouraging, since it implies either that the stars are not identical or that very large errors exist in the spectral classification. If we accept that the random errors are normally distributed, we expect that the difference of two classifications is also normally distributed. We would expect 84% of the stars to disagree less than 0.2 class if the dispersion of each normal distribution were 1.4 tenths of a spectral type. For the luminosity classes we infer similarly σ = 0.7 classes.

The dispersion of the spectral types is unexpectedly high, a fact which has surely to do with the selection of the spectral types.

In order to have a statistical basis to compare with what we report later on, we have repeated the statistics reported. We have considered also boxes in the six color Geneva system, of the $0^{m}_{\cdot}01$, but the classifications were taken from the "Catalog of Selected Spectral Types". The result for sixty boxes is:

- in 84% of the boxes the maximum disagreement between stars was one tenth of a spectral type;
- in 89% of the boxes the maximum disagreement between stars was one luminosity class or less.

This certainly constitutes progress, which is due to the better selection of the classifications used. If interpreted along the lines proposed before, we arrive at

σ (spt) ~ 0.7 tenths of a spectral type
σ (lum) ~ 0.6 classes

which is in line with previous findings about the precision of the MK classification (Jaschek and Jaschek 1965).

Since these previous results suggest that better classification imply more coincidences for the box stars, it would be obviously worthwile to redo the problem with a set of homogeneous classifications derived from spectra taken specially for this purpose, and that is what we did.

The spectra were obtained at the Haute-Provence Observatory,

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with the 152 cm telescope and the Pediscou spectrograph which gives a dispersion of 80 Å/mm. The spectra were widened 0.6 mm and thanks to the exposuremeter the density of all spectra was very similar. We have taken up to now about four hundred spectra, of standards and box stars.

Since we have the spectral classifications at our disposal, we can consider what happens when we put the stars into boxes defined in different ways in different photometric systems.

We start with UBV boxes. The first difficulty one finds is to chose the box size. According to Nicolet (1978) the error of a good quality observation is

$$\sigma\ (B-V) = 0.011 \quad p.e.\pm 0.008$$
$$\sigma\ (U-B) = 0.021 \quad p.e.\pm 0.015$$

Therefore a reasonable box size would be $0\overset{m}{.}02$. However it is easy to show that even in boxes of $0\overset{m}{.}01$ length one finds inconsistencies, as can be seen in the following three boxes

Box A: A 1 V, A 2 V, A 0 V (two MK standards)
Box B: A 4 IV, A 5 IV, A 4 III, A 7 V
Box C: A 2 V, A 3 V, A 2 IV

The explanation resides simply in the fact that the standard deviation of each observation is larger than the box, so that we observe a very "smeared out" distribution. This is confirmed by Nicolet (1978) who has examined a list of 300 stars having both UBV and Geneva photometry. Stars belonging to the same $0\overset{m}{.}01$ box in the Geneva system scatter widely in UBV. We thus dismiss the UBV system from further consideration in the present discussion.

We consider next the Geneva photometry. Golay has defined two different kinds of boxes, namely those in which all color differences are less than $0\overset{m}{.}01$, except in U, where differences of $0\overset{m}{.}02$ are permitted. We will call them the "non strict $0\overset{m}{.}01$" boxes. The second kind of boxes he considers are the "strict $0\overset{m}{.}01$ boxes" in which all color differences are less than $0\overset{m}{.}01$.

We consider first the "non strict $0\overset{m}{.}01$ boxes. We have used 50 boxes with an average of more than three stars per box. The results can be summarized in the following way:

a. in general stars in boxes tend to have equal spectral type
b. in general stars in boxes tend to have the same luminosity class, but there are some exceptions with differences of one luminosity class

c. normal, peculiar and metallic line stars can coexist in the same box. For instance in one box one finds a normal star, three Am's and one Ap star of the Sr-Cr-Eu type.

We pass now to the "strict $0^{m}.01$ boxes", which is thought to be the most severely selected sample. We have studied 75 boxes covering the range of B0-G2 and some additional boxes up to M0. The coverage in luminosity class is less extensive because of the difficulty of having boxes of high luminosity stars due to the differences in interstellar reddening. In fact we have covered only luminosity classes III-V. The average number of stars per box is three, with a range between two and six.

Our most important conclusion can be stated as follows: if stars in the same box are normal - i.e. non peculiar - their spectra are identical. This rules applies to all boxes.

The interpretation of this finding is that the surface temperature and gravity of the box stars are identical. This is however not true as far as rotation is concerned, since frequently one finds in the same box a slow rotator and a rapid rotator. Because of our dispersion, "slow" means here 80 Km/sec. In boxes where Vsini is known for both components, we find identical spectral classifications, despite differences of the order of 200 Km/sec. However we have had as yet no boxes with extremely rapidly rotating stars.

If we consider next stars which are not normal, we find as a rule that non normal stars appear in boxes together with normal stars only if the peculiarity is not very pronounced - for instance, Mn-Hg stars, mild Si stars and mild Am stars. (We call "mild Am" a regular Am star in which the differences between the Ca, the H and the metallic line type are small, let us say less than two tenths of a spectral type). When the difference between metallic line type and hydrogen line type of an Am star is very large, the star is found in a box of all Am's.

The fact that boxes contain Am stars and normal stars is disturbing and we have examined the possibilities of separating them. The problem cannot be regarded as entirely solved, and we propose to observe a larger number of boxes with Am stars. With this reservation in mind we can describe the situation as follows:

a. When Am stars and normal stars lie in the same box, the hydrogen type of the Am stars corresponds to the spectral type of the normal stars. This confirms our earlier results (Jaschek and Jaschek 1959) of the important role played by the H-type for the Am stars.

b. We have tried to single out the Am stars in the mixed boxes with several photometric parameters. We have tried the

(B_2-V_1) vs. m_2 of the Geneva photometry
(B_2-V_1) vs. d of the Geneva photometry
$(B-V)$ vs. $[m_1]$ of the Strömgren photometry

Somewhat paradoxically the one which works best is the $[m_1]$ parameter. Systematically the stars with the largest $[m_1]$ index in the boxes are Am's, and a line can be drawn separating normal and Am stars.

In conclusion our results appear to confirm the possibility of using the Geneva six color photometry for a purely photometric stellar classification.

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DISCUSSION

Nandy: You have not used the ultraviolet colors which are now available for about 1000 stars. I demonstrated in the last I.A.U. General Assembly that there is a one-to-one correlation between the reddening-free ultraviolet parameters (which I denoted as PHI and PSI) and MK spectral types of Nancy Houk.

My impression is that if you increase the number of color-indices, the deviation from what you call a standard star may systematically increase.

C. Jaschek: We did not use the ultraviolet colors here because they are less accurate than those in the 3500-6500 Å interval, but we will include them in our future work. I agree completely with you on the second point.

Gratton: I am not very familiar with photometric boxes but I am suspicious about the question of peculiar and normal stars. After all it may become difficult in some cases to say when a star is normal and when it is not, and it may be a vicious circle to assign a star to the class of "peculiar" because of some photometric criteria and then find out that all stars remaining in the box according to them are normal.

How do high velocity stars fit into these rules?

C. Jaschek: When you are working in the frame of any classification system (in this case the MK system) "peculiar" means only "not fitting into the scheme." In photometry it means that at least one color has a different value than in "normal" stars. So if our conclusion, that stars in the same Geneva photometric box are spectroscopically identical in the MK system, is correct we have learned something new.

As regards high velocity stars we have not yet observed them.

Mendoza: You have stated that two stars in the same box have the same temperature (spectral type) and gravity (luminosity class). Next you have said that Ap and Am stars are in different boxes. Would you please clarify this?

C. Jaschek: To be in the same box is a sufficient, not a necessary condition for having the same spectral type. In this case of Am and Ap stars you have to deal with a third factor, namely chemical composition.

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Hauck: The "strong" Ap stars are not in the same boxes as stars with the same M_V and T_{eff} because of an effect present with the filter V1. It is possible also to have in the same box stars which are very peculiar. For example, you have a box containing ApSiCr stars (HD 9393, HD 133029), both with a large value of the parameter of peculiarity $\Delta(V1 - G)$. Stellar boxes are perhaps the way to determine photometrically the kind of peculiarity which characterizes the Ap stars.

McCarthy: I would like to suggest to you and to Dr. Houk that a more uniform terminology could be proposed to the I.A.U. General Assembly in Montreal for the host Commissions of this Colloquium, Comm. 25 and 45. It would be a help to avoid confusion.

C. Jaschek: If Houk agrees, we shall certainly do that.

McCarthy: Why do you have difficulties with boxes after G0? I would think of blanketing.

Jaschek: No, it is just that stars after G0 tend to be faint and we go first after the brighter ones.

Lesh: Have the colors used in forming your boxes been corrected for interstellar reddening? If not, I am surprised that you find as many coincidences as you do, because I would expect many giants and even main sequence stars, as well as supergiants, to be affected by reddening.

C. Jaschek: The Golay "boxes" are not corrected for reddening. Therefore you find in boxes mostly unreddened or slightly reddened stars. Highly reddened stars have less chance to fall into boxes.

Garrison: I am impressed by your comment that "If the stars are normal, than the spectra are identical." In fact, I am too impressed. I would not expect, a priori, a one-to-one correlation between the photometric parameters and the spectral type. There will be a general correlation, but these are, in my experience, stars which are normal and identical spectroscopically as determined by both Morgan and me which have different colors and vice versa. My question from this is: Did you do the classification truly independently or did you know the correct "photometric" box beforehand? This is extremely important, as I am sure you know, but in view of the accuracy you claim, I had to ask the question at least.

C. Jaschek: We took the usual precautions and classified the stars independently from their box. I would like to add that you are forcing two stars to be identical in all colors of the Geneva system (within $0^m.01$), so that it is perhaps not too surprising that stars do have similar spectra. From our present results, based on a rather small number of boxes, our conclusion is that they are identical; we shall see if we confirm this with a larger number of boxes.

Houziaux: Do you have any relatively faint B stars in your program? You can have two such stars in the same n dimensional box with $0^m.01$ accuracy without correcting for reddening but this would certainly not be true if you included ultraviolet colors.

C. Jaschek: Yes we do have some, but not very many because the different interstellar reddening for faraway stars "disrupts" the boxes. By adding more colors into the definition of the box, you are enhancing the chances of having identical stars in it.

Houziaux: I think it should be clearly stated that there is no one-to-one correlation between a spectral box and physical parameters characterizing the outer layers of the star, such as effective temperature, gravity, hydrogen to helium ratio, etc. Do you agree?

C. Jaschek: Although I think you are right, I really cannot answer your question, because we are dealing only with colors and spectral classification and not with the underlying parameters.