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COMPLEMENTARITY BETWEEN PHOTOMETRY AND SPECTROSCOPY

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RESUMEN

Para entender completamente la estructura y comportamiento de las estrellas, es esencial usar toda la información posible. La fotometría, la espectroscopía de alta resolución y el Proceso MK, todo involucra al espectro, pero cada técnica nos proporciona una forma fundamentalmente distinta de descubrir las propiedades estelares. Mientras que cada técnica puede usarse para calibrar a las otras, no existe una correlación única, uno-a-uno que sea válida para todas las estrellas en todo momento. El Proceso MK, con su énfasis en la apariencia del espectro entero y en la comparación con un conjunto de estrellas prototipo, proporciona una referencia útil para estudios basados en la fotometría y en la espectroscopía de alta resolución. Un estudio completo e ideal incluye las tres técnicas. Aunque es verdad que hay errores que pueden descubrirse por medio de comparaciones sucesivas, es importante no suponer automáticamente que todas las diferencias se deben a errores o equivocaciones; a menudo hay indicaciones de peculiaridades interesantes y poco comunes. Cualquiera que sea la causa que origine las diferencias, el uso de estas tres metodologías da información nueva en la intersección. Esto se ilustra con algunos ejemplos.

ABSTRACT

To understand fully the structure and behavior of stars, it is essential to use all the information possible. Photometry, high-resolution spectroscopy, and the MK Process all involve the spectrum, but each provides a fundamentally different approach to the discovery of stellar character. While each can be used to calibrate the others, there are no one-to-one, unique relationships which work for all stars at all times. The MK Process, with its emphasis on the appearance of the entire spectrum and on the comparison with a set of standard stars, provides a useful reference for studies involving photometry and high-resolution spectroscopy. The ideal complete study includes all three approaches. While errors do occur and can be revealed by the inter-comparisons, it is important not to assume automatically that all differences are mistakes; often they are signatures of some interesting and unusual peculiarities. Whatever differences arise from the use of these three methodologies can provide new information at the interfaces. Illustrative examples are given.

Key words: **TECHNIQUES: SPECTROSCOPIC — TECHNIQUES: PHOTOMETRIC**

1. INTRODUCTION

The subject of complementarity is one which is appropriate for a symposium honoring Dr. Eugenio Mendoza, because he has experience in several areas of astronomy, especially spectroscopy and photometry. He started out in the 1950's with W.W. Morgan working on the Pleiades using the tools of MK spectral classification and photoelectric photometry. It has always been my contention that the perspective of spectral classification is very useful for someone working in the field of filter photometry. With this perspective, he went on to discover interesting relationships among stars and to develop useful tools for the study of stars.

When I was a student, it was thought that spectroscopists soon would be phased out, because photoelectri filter photometry was so wonderful and quantitative and precise that it could predict reliably everything th spectroscopists could see. Unfortunately, or fortunately as the case may be, life is never so simple. It turn out that there is not a one-to-one relationship between the photometry and the spectra. Different sizes o interstellar grains and different atmospheric and circumstellar structures for stars mean that various technique give information about different parts of the whole. It is very much like the story of the blind men feelin different parts of an elephant and reporting on the nature of the creature. The interesting result of this is tha there is new information in the interface between the two approaches, information which would be lost if no exploited complementarily. Wise astronomers like Morgan and Strömgren realized this early on, but some o their less far-seeing colleagues were not so perceptive.

2. EXAMPLES

Using the techniques of spectral classification, photometry, and high-resolution spectroscopy in complementary way, one can discover a lot of interesting things. Several examples can serve to illustrat the point.

The discovery of the brightest cataclysmic variable by Garrison et al. (1984) came about because we notice that a star with extremely broad, shallow lines was flickering. We were working on luminous OB stars at th time, with the goal of improving our knowledge of galactic structure in the southern Milky Way. Without th confirmation afforded by the results of both techniques, we might not have been able to suggest that particula interpretation. By exploiting the interface, we were able to draw firm conclusions and compare the observation with other similar stars.

Among the late B-type stars, Hβ photometry is an excellent measure of luminosity, but the interpretatio is always uncertain because of the possibility of a Be star showing emission at Hβ from a circumstellar ring o shell. A complementary spectrum at Hα or Hβ is very useful for determining when there is a shell.

When Hiltner and I were making observations for our massive galactic structure study of OB stars (Garriso et al. 1977), we both simultaneously discovered a pure helium, hot subdwarf. I was taking MK spectra at th University of Toronto Southern Observatory on Las Campanas and he was doing *UBV* photometry of the sam stars at Cerro Tololo. We both noticed that CPD $-31°$ 1 701 was the most unusual star we had ever seen, s we sent urgent notes to each other to observe the star. Our notes crossed paths in the day. He noted that i was the bluest star in the program (no Balmer jump because no hydrogen), whereas I noted that the spectrur did not resemble any star I had ever seen (Garrison & Hiltner 1973). In fact, at first, I thought I had flippe the plate upside down in the darkroom, but I soon discovered that what I had thought were the Ca II H an K lines were actually He II 4686 and He II 4541 and that they indicated a star well below the main sequenc Comparison of He I and He II indicated that the temperature is about equivalent to that of an O8 subdwar It still is the most extreme He star known. The Kiel group have done a fine analysis and confirm that the sta is an O8 subdwarf and that there is virtually no hydrogen; i.e., Y = 1.0 with the predicted temperature an gravity.

The helium-weak stars in Scorpius were discovered first spectroscopically. They have peculiar hydrogen-lin profiles and some anomalous line strengths compared with any of the standards. Photometrically they loo like perfectly normal stars, but with much higher temperatures than the spectra indicate. As it turns out, th temperature is somewhere between the results by the two different techniques; neither gives the true pictur alone. Of course, we now know that they are very strong magnetic stars and are probably the hot relatives c the silicon peculiar A stars.

The helium-strong stars are very obvious spectroscopically, but again they look fairly norm photometrically. These stars, an example of which is σ Orionis E, have stronger helium lines than do sta at the helium maximum at B2.

The star a Centauri (HD 125823) is the most intriguing of all. With a period of 8.8 days, it bounces bac and forth between being a helium-weak star and a helium-strong star. The intriguing thing is that the hydroge lines do NOT change during this Jekyll/Hyde transition. The V magnitude, the $(B-V)$ color and the $(U-B$ color all remain CONSTANT during the wild spectroscopic change. There are several attempts at models i the literature, but none are completely satisfactory. I predict that we will hear more about this awesome sta From the point of view of complementarity, there is plenty of information in the interfaces among the model the spectral appearance, and the photometry. If we were to assume that the whole picture were predictabl from one of the techniques, we would be missing some of the most important information.

Using information in a complementary way, Bruce Campbell and I (Campbell & Garrison 1975) found that the star HD 37321, which looks normal at classification dispersion at the current epoch, was a weak-helium star at the time of the Henry Draper plates. We chose it for our observing program of He-weak stars, because it has an HD type of B8, whereas today it has a modern color corresponding to a B4 star. Imagine our surprise when we discovered that the modern spectrum is clearly B4 V, in perfect accord with its color. I went to Harvard to look at the original plate and found that, indeed, the spectrum was then that of a B8 star. When we analyzed a series of high-resolution plates, we found evidence of a larger than usual number of high-excitation silicon lines as well as a large number of iron lines. These characteristics are inconsistent with one another. This is an excellent example of the complementary use of data from photometry, spectral classification and high-resolution spectroscopy.

Trying to figure out how the Sun compares with other stars also requires the complementary use of many different techniques. To compare the Solar spectrum with that of a star requires integration over the disk of the Sun or reflection of sunlight from another body, effectively integrating the disk. The problem is, of course, that the reflectance spectrum of the other body plays a role, especially in the ultraviolet and the infrared.

In a direct approach, Garrison & Zimmerman (1983) classified spectra of the Solar disk taken at various Solar radii, then discussed the integration. Comparing the "average" (including limb darkening) with stars, the standard type of G2 V was confirmed. It is very difficult to get the color of the Sun, because 1) it is an extended object, 2) it is not observable at the same time as the stars, nor under the same atmospheric conditions. Many attempts to compensate for these problems have led to conflicting results, summarized by Chmielewski (1981). Without going into too much detail, suffice it to say that no one technique can give an unambiguous answer and it has taken many years to sort out all the observational difficulties. The best approach would be to put an aluminum balloon into geosynchronous orbit, calibrate it both from the ground and from the *Hubble Space Telescope*, and observe it from the ground along with other stars. Until we achieve that ideal, the best approach spectroscopically is to observe asteroids, which have their own mineral spectra, but which are point sources and avoid scattering problems. The moon and any of the planets are very poor sources either because of scattering in the spectrograph or because of atmospheres. Finally, we have been able to conclude, using several different techniques wisely and in a complementary fashion, that the Sun has a color of 0.63–0.65, like other G2 V stars.

Chris Corbally and I (Garrison & Corbally 1993) have used photographic colors in a complementary way with low-resolution, objective prism spectra and natural group techniques, to isolate a sample of Solar-type dwarfs in the direction of the Galactic Poles. With slit spectra of MK resolution, we have confirmed that the techniques used together are successful about 90% of the time in predicting true G-type dwarfs in the Halo.

Finally, I would like to discuss Supernova 1987A, which was discovered by Ian Shelton, my assistant at Las Campanas. He used visual inspection of a photographic plate followed by photoelectric photometry. However, from that alone, he could not determine definitively if it was a type II or not. A spectrum taken that same night at the Carnegie 2.5 meter was necessary to see if hydrogen emission were present. Given time, the light curve might have given enough clues, but the complementary use of spectroscopy meant that it could be determined that same night, before it was known by the rest of the world.

3. CONCLUSION

In summary, we should be very skeptical of anyone who claims that his/her technique perfectly predicts the results of the study of a star by other means, either photometry or spectroscopy, either low or high dispersion. They look at different aspects of the elephant, and only by putting them all together (with other information as well) will we understand any individual star.

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DISCUSSION

Keenan: It is more realistic to define the domain of MK System as that spectral region within which the spectrum is formed just above the photosphere. Many late-type stars can be classified with contributions from the red region.

Garrison: I didn't have time to mention that while the MK System refers mainly to the blue-violet region, the MK Process can be applied to the red, infrared, ultraviolet or X-ray. The MK Process is a method, whereby the system is based on a set of carefully chosen standard stars, and then calibrated independently.

I agree that the spectral region used should depend on the problem, and certainly late type stars are most conveniently studied in the red or infrared.

Herbig: I recognized one of the discrepant stars in your plot of HD ptm magnitude vs. modern V magnitude: HD 37061 is embedded in a bright patch of emission nebulosity just north of the Orion Trapezium. Can it be that the HD magnitude was confused by this nebulosity?

Garrison: That may have influenced the visual magnitude estimates and you can see that the standard relation is slightly broadened in that direction, but the magnitude of the discrepancy is much too large for that to be the whole story. HD 37061 is a very peculiar star and in any case obviously HD 37061 is in an extreme position.

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