A NEW KIND OF HR DIAGRAM?

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When the system of correlations between stellar parameters that we know as the HR diagram was discovered, the physical basis for them was unknown and remained essentially unknown during four decades of eager application.

Two years ago Thomas Barnes and I found a relationship which we dare to hope may have a similar history. A parameter related to the visual surface brightness of stars is expressible as

$$F_V = \log T_{eff} + 0.1C = 4.2207 - 0.1V_o - 0.5 \log \phi'$$

where T_{eff} = effective temperature, C = $M_{bol} - V_o$ = bolometric correction, V_o = apparent visual magnitude corrected for extinction, and ϕ' = angular diameter of the star in arc milli-seconds. The formula is equivalent to one given in Russell, Dugan and Stewart (Vol. II, p. 738, 1927 edn). Barnes and I found that F_V was extremely closely related to the Johnson $(V-R)_o$, (and not to any other color index), that it is almost completely immune to the effects of interstellar extinction, and independent of luminosity class (Barnes and Evans, 1976; Barnes et al, 1976). The relation started from a consideration of occultation angular diameters but went on to include all determinations. In the latest version to be published by Barnes, Evans and T.J. Moffett (1978) there are 92 measures of angular diameter by all methods and much new photometry. The result shown in Fig. 1 is closely similar to a theoretical black body color index computed for 550 nm and 700 nm with non-trivial deviations between types A and early M, suggested to be due to the effects of negative hydrogen ions. It seems unlikely that it will be much changed by the

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addition of new data.

It invites applications, though the first that struck me was one of the least obvious. Two of the points refer to (speckle measures) of Mira at different phases and it was conjectured that variable stars stayed on the relation during pulsation. George Wallerstein (1977) disbelieved the result on the ground that the radial velocity variations of Miras in the visual were too small but is apparently convinced by the much greater velocity range found by Hinkle (1977) in the near infrared.

The relationship allows us to calculate angular diameters from photometric observations and, if the conjecture is correct, for a Cepheid at any phase. The angular diameter variation from photometry ought to match the linear diameter variation calculated from radial velocity measures at each phase, with the scaling factor giving the distance of the Cepheid. Tom Barnes and I put our variable star class to work on this and, with Sidney Parsons as consultant, produced distances for the nine Cepheids for which suitable data were available (Barnes et al, 1977). The results are practically unaffected by the assumed values of interstellar extinction and reproduce the Fernie-Hube distance scale within a few per cent. This has occasioned criticism from theoretical quarters as being inconsistent with the new Hyades distance. The distance results are critically dependent on the adopted slope of the relation and when we apply the revised version it seems likely that the scale, at least for all except the longest period Cepheids will be expanded by a few per cent. We should know by early in the New Year. So far this seems a reliable technique for the determination of true geometrical distances up to possibly 2000 parsecs, but once established it should go vastly further.

Energetic application to the RR Lyrae stars and dwarf Cepheids by Barnes, Tom Moffett and Wayne van Citters indicates that we are on sure ground there. Practical difficulties have got in the way of meeting the ideal of simultaneous photometric and spectroscopic observations of RR Lyraes and we proceed with caution before committing ourselves to definitive statments in the critical area of RR Lyrae absolute magnitudes.

Although white dwarfs have degenerate interiors they must radiate through an outermost layer which is normal. We have tried an application here with apparent success (Moffett et al, 1977) judged by consistency with results by other methods. New photometry mainly by Barnes and Moffett covered a limited number of white dwarfs but the realization that old photometry could be transformed to the Johnson (VR) system extends the coverage to 71 stars. The mean radius of DA stars with known parallaxes is

0.0132 ± 0.0005 solar radii with only a small scatter, and adoption of this figure identifies 14 new cases which should be within 25 parsecs. Other topics include the computation of the mean density of 40 Eridani B as near 2×10^5 g cm^{-3}, in reasonable accord with the observed gravitational redshift.

Preoccupied with variables, we failed to notice the fact that any star for which a linear radius (in kilometers) is known can yield a distance, while for any star with a good parallax the linear radius can be found. Claud Lacy had the wit to realize this and has produced a preliminary paper (Lacy, 1977a) dealing with the distances of nine eclipsing binary systems--a number he hopes to increase to 500-- and a paper in press (Lacy, 1977b) dealing with the radii of 150 nearby stars. He finds an intriguing radius deficiency of 25% for M dwarfs as compared with theoretical models, and presents independent evidence in support of this conclusion.

The number of possible applications seems very large, ranging from estimation of the distance of a nova by Barnes (1976), new estimates of effective temperature, direct determination of the sizes of spots on M-dwarfs and even the estimation of the dimensions of stellar flares (Evans and Lacy, 1977). I am sure that we have nowhere nearly exhausted the possibilities and are happy to see others making use of the relationship.

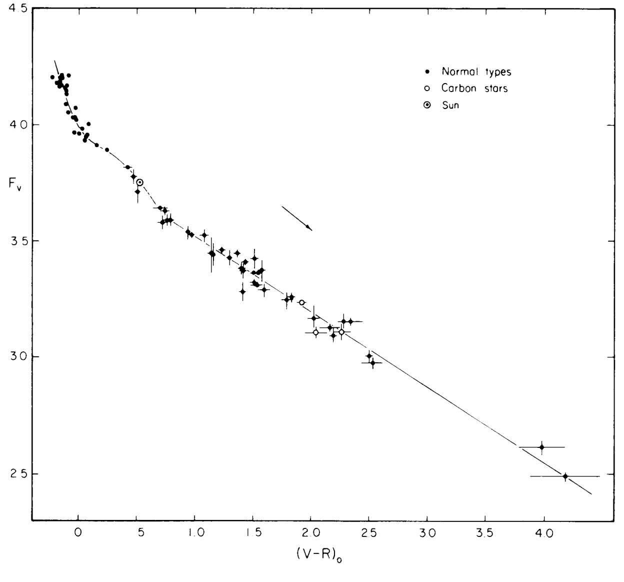

Fig. 1. The Visual Surface Brightness Relation. The arrow showing the effect of one magnitude of visual extinction is almost parallel to the curve.

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DISCUSSION

WEIDEMANN: Does it not all boil down to the fact that (V-R) is taken as a (single valued) measure of effective temperature? It works in the white dwarf case since the gravity scatter is small. But in principle (V-R) will depend not only on T_{eff} but also on surface gravity.

D. EVANS: It is somewhat more complicated than that since for much of the range bolometric corrections are large, but this certainly plays some part.

BELL: Have you included limb darkening corrections in your angular diameter data e.g., in the first slide that you showed?

D. EVANS: Yes. These have been included for all the angular diameter data using results from Hanbury Brown and studies for later type stars, part theoretical and part from double reductions assuming uniform disk and full darkening. The range in values comes out at about 12% between the two extremes.