PART II

HR DIAGRAMS, THE SOLAR NEIGHBORHOOD

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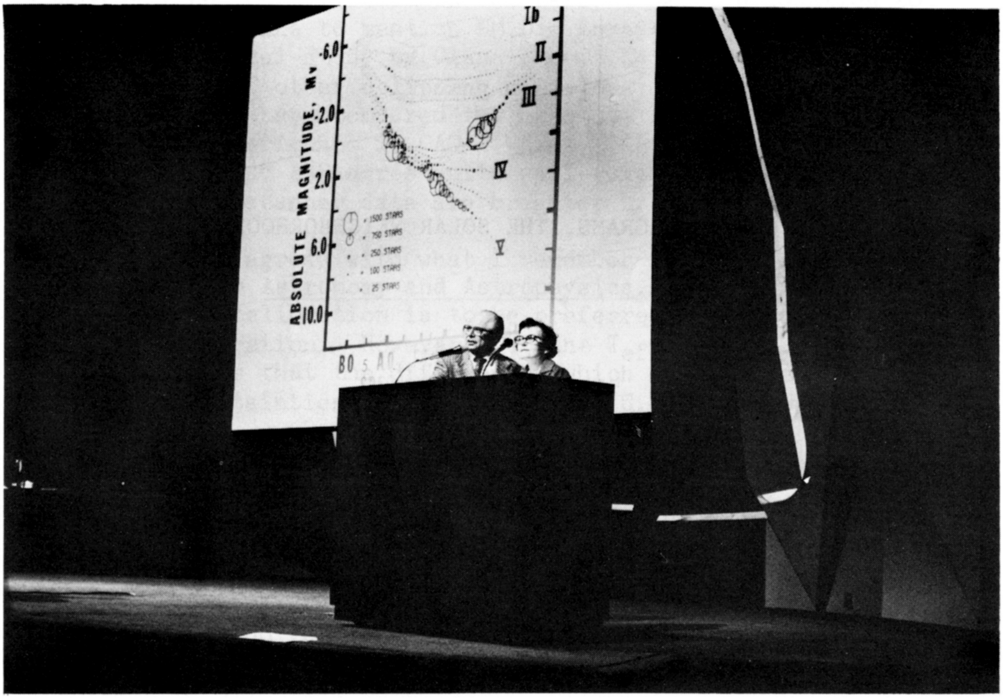

Jesse Greenstein and Nancy Houk on stage.

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HERTZSPRUNG-RUSSELL DIAGRAMS AND COLOR-LUMINOSITY DIAGRAMS FOR THE STARS NEARER THAN TWENTY-TWO PARSECS

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1. DATA AVAILABLE IN 1977

Observational data for stars in the solar neighborhood received before January 1969 were included in the Catalogue of Nearby Stars (Gliese, 1969) which contains more than 1800 objects, single stars and components of binaries, nearer than 22 pc. Since then more than 8 years have gone by and many new data have been published, especially new trigonometric parallaxes as well as photometric distance determinations. Today we know more than 2000 stars with parallaxes measured to be greater than 0$\overset{m}{.}$044. But many of these distances are still very uncertain and for a considerable number of objects, especially the faint ones, spectral classificiation is lacking or the photometry is still not satisfactory.

A discussion of relations between luminosity and other physical properties must be restricted to stars with parallaxes determined trigonometrically since this is the only primary stellar distance indicator we have. In 1977 we know nearly 1500 such objects with $\pi_t > 0\overset{''}{.}044$ but their distances and their absolute magnitudes have been determined with very different accuracies. The numbers of these stars whose absolute magnitudes are known with standard errors between given limits is shown in Table I. The numbers of spectroscopic binaries or objects with large dispersion in their radial velocity data are given in brackets. They have been excluded from the stars in the diagrams shown in this paper. However, the number of detected spectroscopic binaries is still incomplete even in the solar neighborhood. Detailed investigations among F and G dwarfs and subgiants by Abt and Levy (1976) have implied that single stars are rare.

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We learn from these numbers that MK types have been obtained only for somewhat more than 600 stars, mostly F, G and K dwarfs, whereas broad-band (B-V) photometry is available for about 1300 of these objects. Joy and Abt (1974) have published a classification of red dwarfs from dM0 to dM6.5 for nearly 300 of our stars. The 55 degenerates in this sample can be easily included in a (M_V,B-V) diagram.

2. EFFECTS OF THE OBSERVATIONAL ERRORS

The effects of uncertain observations on a color-luminosity diagram are demonstrated by a comparison between Fig. 1 and Fig. 2 which show the (M_V,B-V) diagrams for several hundred nearby stars. The large dots represent the stars with well-known absolute magnitudes (s.e. up to $\pm 0\overset{m}{.}12$). The open box at $M_V = +4\overset{m}{.}85$ gives the position of the Sun. The small dots in Fig. 1 show the stars with somewhat more uncertain data (s.e. of M_V from $\pm 0\overset{m}{.}13$ to $\pm 0\overset{m}{.}30$). Among them there is an insignificantly larger spread along the main sequence but no remarkable systematic difference between the regions with large and with small dots. In Fig. 2, however, the small dots represent the objects with very uncertain luminosities. Their standard errors exceed half a magnitude and, as photoelectric data are available, they are caused mainly by errors in the trigonometric parallax determinations. A striking phenomenon is the large number of small dots lying below the main sequence, especially between the limits $+0\overset{m}{.}5<(B-V)<+1\overset{m}{.}3$ which is the region of the G and K stars. Obviously, this population does not appear in the sample of stars with accurate data.

The difference between the distribution of the stars in the two diagrams is due to the well-known systematic effects of the accidental errors in parallax measurements. The use of a lower limit to the parallaxes in this investigation produces a preference for objects with positive parallax errors and, consequently, the number of stars with apparently too low luminosities is greater

TABLE I

NUMBERS OF NEARBY STARS ($\pi_t > 0\overset{''}{.}044$) WITH DIFFERENT STANDARD ERRORS OF THEIR ABSOLUTE MAGNITUDES

Standard errors	Number of stars (SB)	Standard errors	Sp. types MK	Sp. types Joy	Colors (B-V)	Colors (R-I)
up to $\pm 0\overset{m}{.}12$	126 (12)	up to $\pm 0\overset{m}{.}30$	216 (30)	154 (23)	525 (52)	303 (40)
±0.13 to ±0.30	428 (42)					
±0.31 to ±0.50	496 (48)	exceeding ±0.3	400 (45)	137 (11)	807 (64)	240 (7)
exceeding ±0.5	436 (45)					
Sum	1486 (147)		616 (75)	291 (34)	1332 (116)	543 (47)

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than that of the objects measured to be too bright. Statistical corrections to eliminate this phenomenon vary as σ^2 where σ is the average mean error of a parallax determination in a group of objects. Therefore, this effect remains negligible for the series of stars with small errors in Fig. 1 but it is pronounced in the luminosities with standard errors exceeding half a magnitude. Conclusions drawn from the second diagram would not therefore be reliable. Further discussions in this paper are restricted to objects with standard errors in M_V not greater than $\pm 0^m.30$.

3. HR DIAGRAMS

The HR diagram for 186 nearby stars and for the Sun is shown in Fig. 3. The spectral types are MK classifications. Stars of luminosity classes III to VI are present: giants, subgiants, dwarfs and three subdwarfs of type G. The M-dwarf region is still sparsely populated with MK types. The scale of the abscissa has been dilated from M0 onwards so that the steepness of the main sequence remains nearly constant until M4.

The few giants, α Boo, both components of α Aur, and β Gem (HD 124897, 34029 and 62509) do not allow us to make any conclusions about luminosity class III. The diagram confirms that there is no clear dividing line between the classes IV and V, especially in the region of the early F stars.

The scatter along the main sequence shows a thickness of about one magnitude in M_V in the classes A to K. This spread is partly due to the observational errors in the trigonometric parallaxes, but a smaller part also is due to the spectral classifications (s.e. = $\pm$0.6 tenths of a spectral class; C. Jaschek and M. Jaschek, 1973; Gliese, 1973) and a small additional component is introduced by concentrating the objects only at discrete points on the abscissa. Furthermore, the material may contain some undetected spectroscopic binaries.

Even if all these effects could be eliminated a real scatter in the luminosities of main-sequence stars of the same type would be observed. The fine structure of the HR diagram of nearby F, G and K stars has been investigated by Perrin, Hejlesen, Cayrel de Strobel and Cayrel (1977) using 138 stars with fairly reliable observational data. They studied the state of evolution by means of theoretical ($\log T_{eff}$, M_{bol}) diagrams corresponding to the actual chemical composition of the stars. They concluded that the differences in metal content can account for the thickness of the observational main sequence for stars of effective temperature under 5500 K whereas the evolutionary effects become predominant for stars of effective temperature over 6000 K.

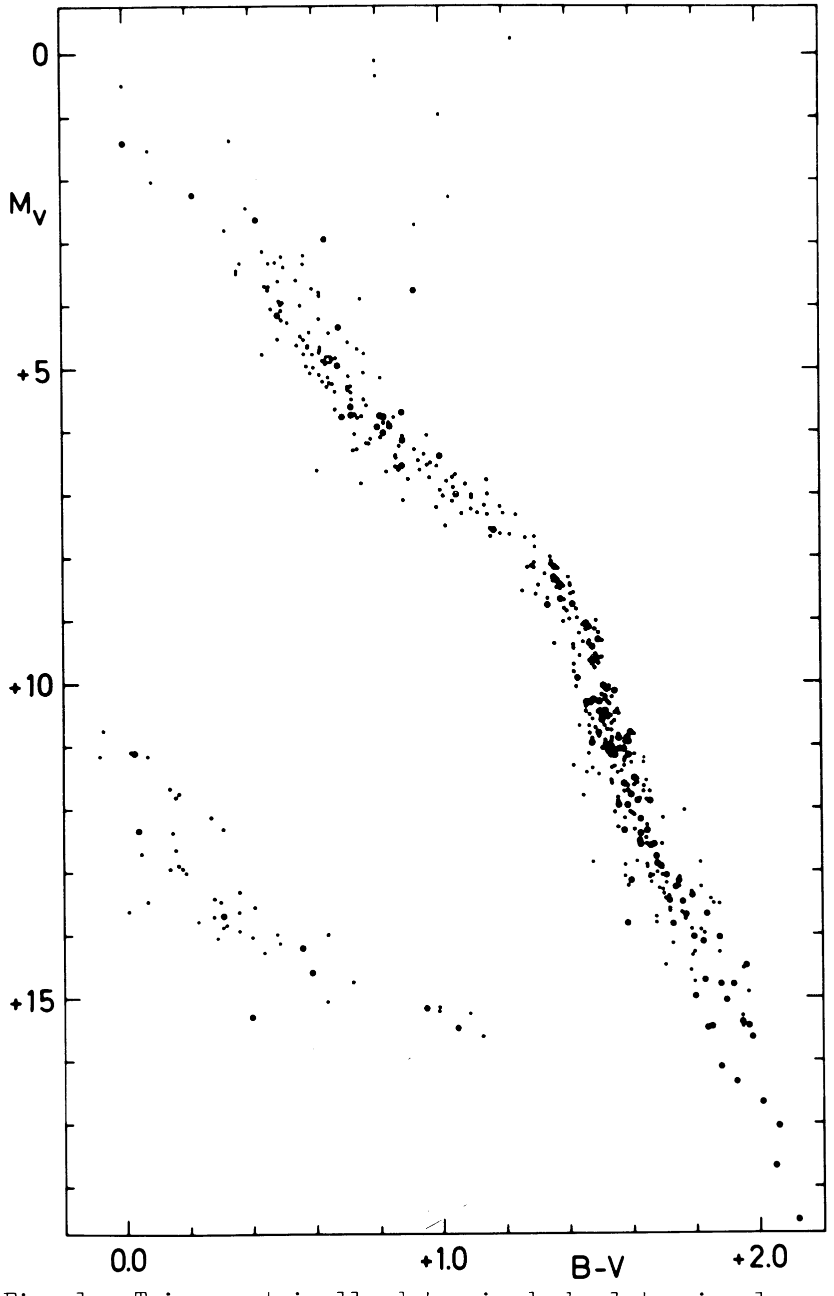

Fig. 1. Trigonometrically determined absolute visual magnitudes M_V of nearby stars <u>vs.</u> (B-V) colors. The large dots represent the stars with s.e. (M_V) up to $\pm 0\overset{m}{.}12$, the small dots represent the stars with s.e. (M_V) from $\pm 0\overset{m}{.}13$ to $\pm 0\overset{m}{.}30$.

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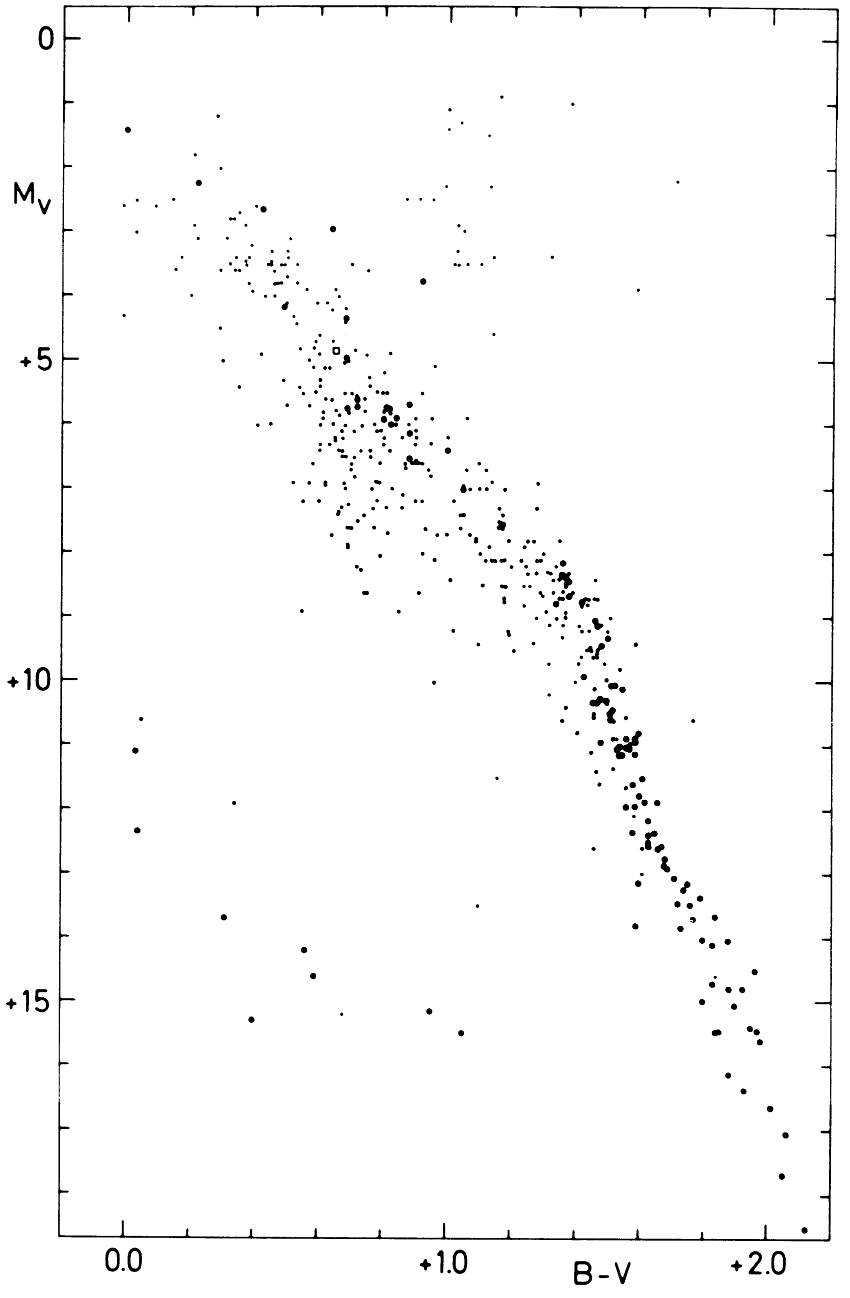

Fig. 2. Trigonometrically determined absolute visual magnitudes M_V of nearby stars vs. (B-V) colors. The large dots represent the stars with s.e. (M_V) up to $\pm 0^m.12$, the small dots represent the uncertain data with s.e. (M_V) exceeding $\pm 0^m.5$.

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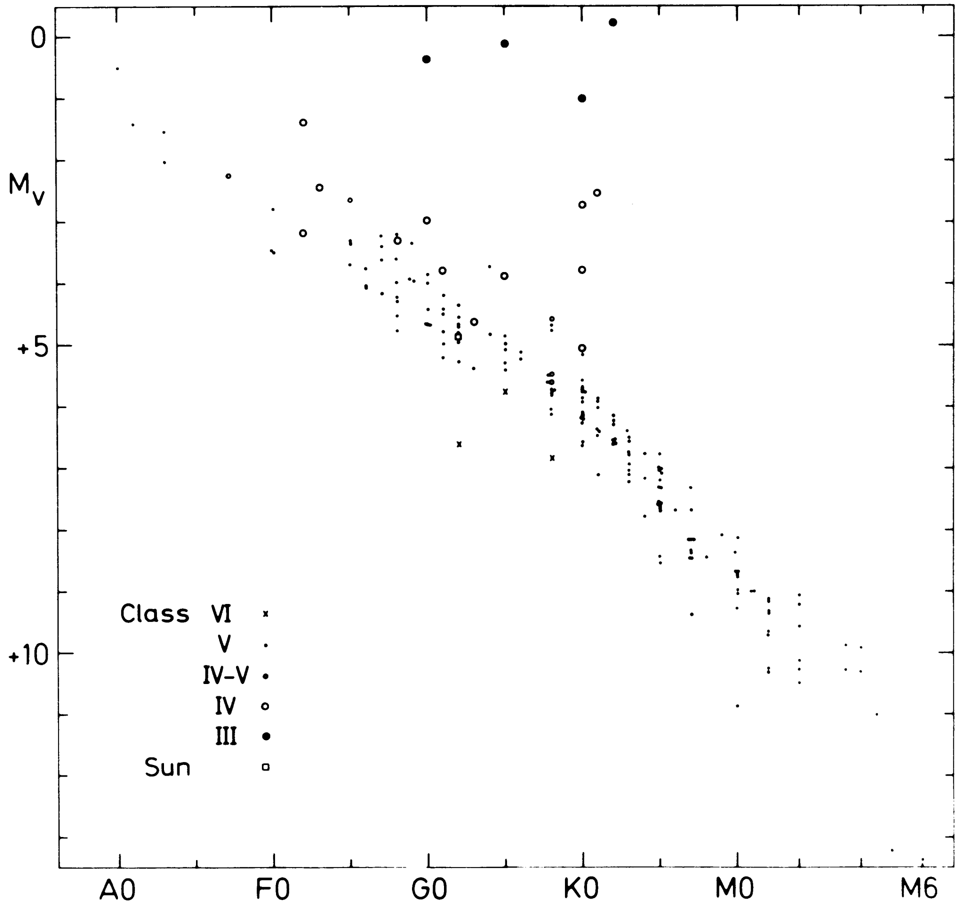

Fig. 3. Observational HR diagram for stars with trigonometric parallaxes >0".044 and with MK classification. All stars with s.e. (M_V) exceeding $\pm 0^m.30$ have been eliminated.

Observational data for such a detailed investigation are available only for a limited number of bright stars. For the red stars in the HR diagram Fig. 4 shows the main sequence based on the classification by Joy (Joy and Abt, 1974). Open circles represent the dMe stars with hydrogen emission. CaII emission can be detected in the H and K lines of nearly all M dwarfs (Wilson and Woolley, 1970) but with a large scatter in intensity. Therefore, all objects without H emission have been classified as "dM". They are plotted as dots. It is known that the CaII emission intensity is correlated with age and with the velocity dispersion of a group of red dwarfs (Wielen and Jahreiss, 1974; Wielen, 1974). Barnard's star and Ross 47 have been classed as sdM4.5; they are marked as crosses. From Fig. 4 only one conclusion can be drawn: There is an increase in the percentage of dMe stars among the latest spectral types.

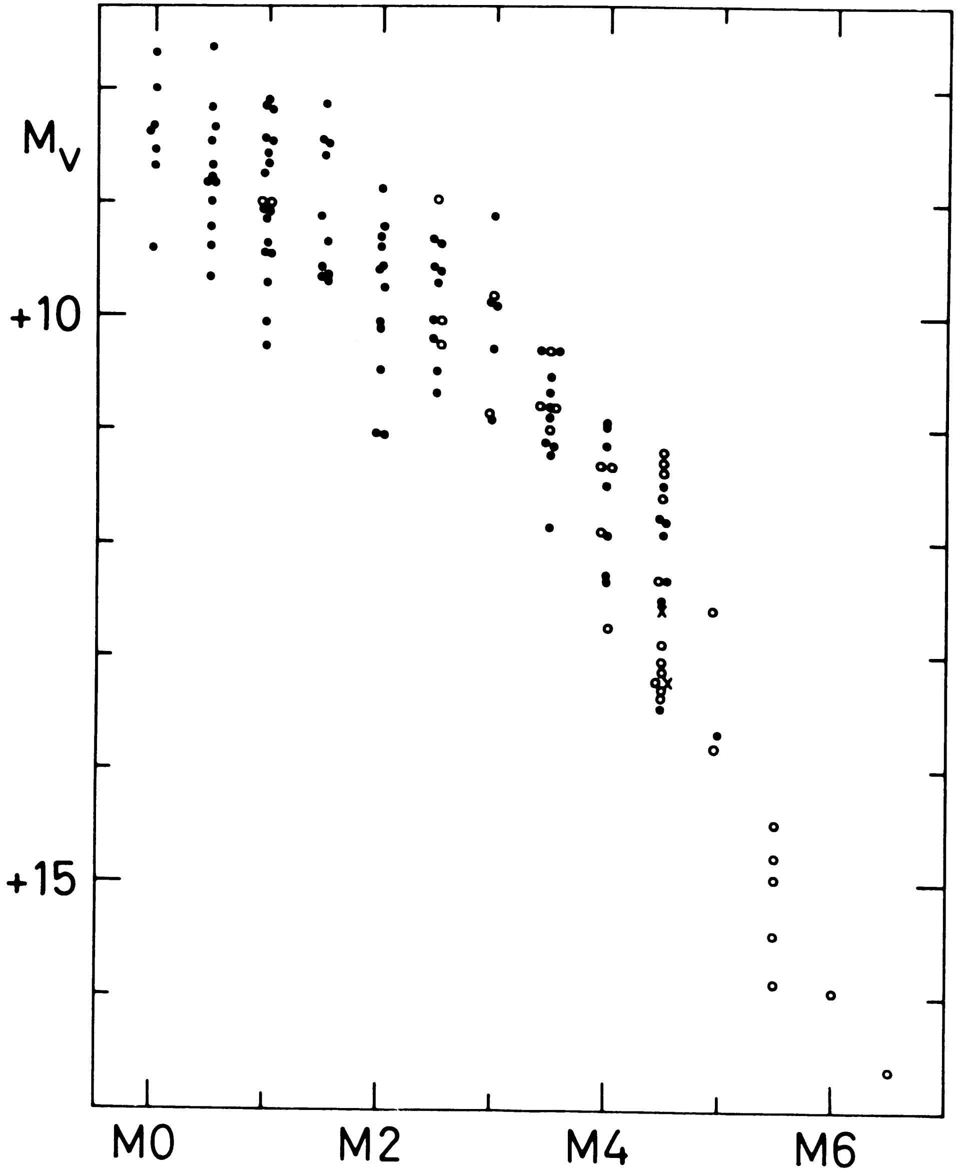

Fig. 4. Observational HR diagram for nearby red dwarfs classified by Joy (1974). The open circles represent the stars with hydrogen emission; the dots represent the other dM stars. All stars with s.e. (M_V) exceeding $\pm 0^m.30$ have been eliminated.

Many of these objects have proved to be flare stars; more dMe stars have been detected as flare stars as time goes on. There is a disagreement in the literature concerning their positions in a HR diagram or in various color-color diagrams. Do they deviate from the average of the other M dwarfs or not?

A detailed discussion of the luminosities and temperatures of M dwarfs has been published by Veeder (1974) who has done infrared photometry of more than one hundred objects. Various diagrams showing "absolute bolometric magnitude versus (V-K) color" have been constructed to examine whether or not there exist systematic displacements between some groups of nearby M dwarfs, such as halo stars, disk and young disk members, hydrogen emission stars, calcium emission stars, and others. There is a considerable overlap due to the scatter of stars in each group with the result that the average displacement is not very dramatic. Halo stars are subluminous by about $0^m.2$ on the average; stars with hydrogen emission lines average about $0^m.3$ bolometric magnitudes brighter than M dwarfs without emission lines. But what is the effect of still undetected spectroscopic binaries? Do they occur more frequently among emission-line red dwarfs? Bopp and Fekel (1977) have found only four single stars among 13 BY Dra variables.

4. COLOR-LUMINOSITY DIAGRAMS

It is not possible in this short review to mention all the detailed investigations published in the last few years. MK classifications, Joy's data, UBV photometry are not sufficient for discussing all special problems. Other photometric systems have been chosen and constructed by their authors to satisfy the requirements of a well-defined problem. However, refined parameters have been measured only for relatively small groups of stars and detailed investigations have been restricted to limited regions in the HR diagram.

Today, the most extensive survey of the HR diagram in the solar neighborhood can be made by the (M_V,B-V) diagram shown in Fig. 1. It includes nearly 500 objects with fairly reliable absolute magnitudes (s.e. of the M_V not exceeding $\pm 0^m.30$). Normally, the errors in (B-V) are small, of the order $\pm 0^m.02$. Between some of the UBV series used here there may be small systematic differences.

Additional to the HR diagram of the MK types in Fig. 3 the (M_V,B-V) diagram also includes the white dwarf sequence. These objects are fairly frequent from (B-V)= $-0^m.10$ to $+0^m.70$. The search for red degenerates has not yet succeeded in detecting objects of (B-V)> $+1^m.13$ with one exception: LP 701-29 with the data ($16^m.11$ $\pm 0^m.12$, $+1^m.88$) which means that this red"white dwarf" lies on the main sequence in the (M_V,B-V) diagram (Dahn et al., 1976).

Multichannel spectrophotometry of white dwarfs with the 5 m Hale reflector by Greenstein (1976) has shown that their colors are highly correlated with their luminosities. The most useful color is that from $1/\lambda = 2.12$ to $1.25\mu^{-1}$. It appears that most white dwarfs of a given color lie in a narrow band of luminosity.

This short review could not be complete. There are many more possibilities for drawing color-luminosity diagrams. More precise measurements are required for the nearby stars. But parallax programs have been very successful in the last few years and the steady increase of photometric data of nearby objects is noteworthy.

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DISCUSSION

D. EVANS: Because the intensity of Balmer line emission in dMe stars frequently varies with time one can envisage the possibility that some stars might at one time be classed as dMe and at another dM. I am not al all convinced that we ought to consider them separately.

GLIESE: You may be right, but the detailed discussion of the flare star phenomenon among dM or dMe stars has taken already whole sessions in variable star colloquia without solving all the problems. Certainly, it exceeds our possibilities here.

GREENSTEIN: When will the next edition of your valuable catalog appear?

GLIESE: I am just compiling a preliminary list of another 250 stars which have been observed since 1969 with parallaxes exceeding 0."044. The publication of the final Third Catalogue of Nearby Stars is planned for 1980 or 1981.

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