THE ASTROPHYSICAL JOURNAL, **269**:253–257, 1983 June 1

A PROPOSED NEW WHITE DWARF SPECTRAL CLASSIFICATION SYSTEM

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Received 1982 August 9; accepted 1982 November 18

ABSTRACT

The lack of temperature distinctions among the hydrogen-dominated and helium-dominated spectral sequences of white dwarfs, the discovery of hybrid composition white dwarfs, and the many composition subclasses further complicated by variability, polarization, and other observable indicators of magnetism all speak to the need for a new system of white dwarf spectral classification. We propose and define such a new scheme. It retains a link with the present system but introduces a better description of what the spectrum actually exhibits and provides quantitative temperature information. These changes are consistent with the expressed needs of investigators in the field. The combination of symbols will consist of (1) an uppercase D for degenerate; (2) an uppercase letter for primary spectroscopic type in the optical spectrum; (3) an uppercase letter for secondary spectroscopic features, if present; and (4) a temperature index from 0 to 9 defined by $10 \times \theta_{\rm eff}$ ($= 50{,}400/T$).

Subject headings: stars: spectral classification — stars: white dwarfs

I. INTRODUCTION

The number of newly observed white dwarfs and the volume of observational and theoretical research on the origin and evolution of these stars has greatly increased in the past ten years (cf. Greenstein 1976, 1983; Green, Schmidt, and Liebert 1983; Liebert 1980). With improved spectral resolution and instrumental technology, new spectroscopic and spectrophotometric observations have led to several revisions in our understanding of the spectra of degenerate stars. The discovery of hybrid composition white dwarfs, the many composition spectral subgroups further complicated by variability, polarization, and magnetism, and most importantly, the lack of temperature distinctions between hydrogen-dominated and helium-dominated white dwarf spectral sequences all speak to the need for a new, less unwieldy, more physical white dwarf spectral classification. A number of investigators in the field have expressed dissatisfaction with the present system. In response to these needs, we propose a new system, which will replace the old spectral types listed under the spectral class entry in the first edition of the *Catalogue of Spectroscopically Identified White Dwarfs* (McCook and Sion 1977). The new system will be introduced in the second Villanova Catalogue.

II. PROBLEMS WITH THE PRESENT SYSTEM

The present system of spectral classification for white dwarfs (Greenstein 1960) is shown in Table 1. This system is an elaboration of that proposed by Luyten (1952). Kuiper (1941) appears to have been the first investigator to systematically attempt classifying white dwarf spectra. When these earlier systems were developed, it was not fully realized that such a diversity of atmospheric compositions exists among the white dwarfs. Hence, this scheme is based upon visual inspection of the photographic spectra but lacks a quantitative basis and inadequately describes degenerate stars having spectra that are not monoelemental or which belong to a spectral group that extends over a wide color range. For example, white dwarfs have been discovered ranging from the colors (and temperatures) of O stars through K stars, and a few with early M colors have recently been found. These divide spectroscopically into (*a*) the "DA" sequence with hydrogen lines covering

TABLE 1

THE PRESENT SYSTEM

Symbol	Characteristics
DC	Continuous spectrum; no lines deeper than 10%
DO	He II strong; He I and/or H present
DB	He I strong; no H
DA	H present; no He I
DA, F	H sharper and weaker; Ca II weak
DF	Ca II, Fe I, no H
DK	Weak Ca II
DM	Ca II; Ca I weak; TiO?
λ4135	Broad "Minkowski" bands, unidentified
λ4670	Broad bands at $\lambda\lambda$4670, 5165; probably C_2
C_2	Same as definition of λ4670 stars
Subscripts:	
p or P	polarization; also sometimes used for peculiar
wk	weak
e	emission
s	sharp
ss	very sharp
n	diffuseness
PEC	peculiar

nearly the full range in color and (*b*) the non-DA or generally helium-rich types also covering the full temperature range of white dwarfs. Currently this latter group includes types DB, DC, DF, DG, λ4670, and the two original classes DK and DM (which no longer apply to any definite stars). There is no distinction, however, between DA or non-DA stars of 7000 K and 75000 K. Since the derivation of white dwarf temperature from measured colors is a fundamental indicator of luminosity, it is highly desirable to incorporate a temperature indicator or index into a new scheme.

The fascinating variety of white dwarf stars, a variety which lends considerable richness to their study, also creates problems for classification schemes. In the old system, these phenomena have shown up in a concatenation of letters which are appended to the basic class of a star. These letters may denote weakness, strength, diffuseness or sharpness of spectrum lines, as well as polarization and variability. In addition, some of the original classifications have turned out to be less useful. There is still only one "λ4135" star, Grw +70 8247 (= EG 129, WD 1900+70), and the DK and DM classifications now may consist of an empty set or have no more than one or two members.

With improved spectral resolution and sensitivity, weak line features have been found in many spectra, resulting in reclassification or in the development of hybrid classifications such as DBA. The recent recognition of composition classes that extend beyond the DA and non-DA groups, concisely illustrated in Figure 1 of Liebert (1980), makes the present system cumbersome.

III. THE PROPOSED NEW SYSTEM

A new spectral classification system is proposed which preserves a strong link with that presently in use but introduces a better description of what the optical spectrum actually exhibits and directly incorporates effective temperature as a numerical index. The combination of symbols proposed consist of (1) an uppercase D for degenerate; (2) an uppercase letter for primary or dominant spectroscopic type in the optical spectrum; (3) an uppercase letter for secondary spectroscopic features, if present *in any part of the electromagnetic* spectrum; and (4) a temperature index from 0 to 9, defined by $10 \times \theta_{\rm eff}$ $(= 50{,}400/T)$. Symbols will be presented for polarized magnetic stars and for peculiar or unclassifiable spectra.

a) *Composition Dependent Symbols*

The first uppercase letter D is identical to the first letter in the present system to indicate a degenerate star. The second uppercase symbol uses most of the same letters as the system now in use, except for the introduction of two new letters defined for stars with metal lines only and stars with carbon (C_2) bands. The spectral types are defined in Table 2. The class DQ represents any star showing carbon features, either atomic or molecular, in any part of the electromagnetic spectrum. Only for the DQ stars are nonoptical spectra used to define the primary symbol. The letter Q is chosen in order to conform with the other letters rather than using the designation C_2 or DC_2. The letter S, suggested by Landstreet (1979) after the Swan bands of carbon, is avoided because of its possible association with the S type red giants. The class DZ, for white dwarfs with metal lines only, would replace DF, DG, and DK, with Z chosen for its widespread astrophysical connotation with metal abundance and because adopting DM has an unavoidable connotation with main-sequence dwarfs and very low temperature degenerate stars. Merging the old DF and DG types into the new DZ class has the disadvantage that there is a potential information loss since DF and DG stars do differ spectroscopically. However, many of these objects are peculiar on an individual basis, and it is difficult to define clearcut subdivisions for this small number of objects at the present time.

The second uppercase letter would denote weaker or secondary spectroscopic features, *if present in any part of the electromagnetic spectrum.* For example, a DB white dwarf showing Ca II would be classified DBZ, a DB star with weak Balmer lines would be classified DBA, a star with Balmer lines dominant but with weak Ca II would become DAZ, a DO star whose ultraviolet spectrum shows N V (λ1240) would become DOZ, and so on. With

TABLE 2

DEFINITION OF PRIMARY SYMBOLS: PRIMARY SPECTRAL

Spectral Type	Characteristics
DA	Only Balmer lines; no He I or metals present
DB	He I lines; no H or metals present
DC	Continuous spectrum, no lines deeper than 5% in any part of the electromagnetic spectrum
DO	He II strong: He I or H present
DZ	Metal lines only; no H or He
DQ	Carbon features, either atomic or molecular, in any part of the electromagnetic spectrum

the exception of the DQ stars, nonoptical spectra will only be considered in adopting the secondary symbol, not the primary.

b) *The Temperature Index*

The surface temperature of white dwarfs, derived from color, is the most important information that we can now derive. Following the secondary letter and any additional symbols, a quantative temperature index from 0 to 9 will be used, defined by 10 times θ ($\theta = 5040/T$). This quantity $50{,}400/T$, given as an integer, will be a temperature and luminosity indicator. For a white dwarf of average temperature and luminosity, say 15,000 K, this index will be 3. All objects cooler than 5500 K would have the symbol 9 for temperature. If many cooler stars are ever found, a two-digit temperature indicator could be used in the future. For white dwarfs at very high temperatures, one can use the computer-generated symbol for zero. The index will be generated from correlation tables of temperature and color indices for each photometric and spectrophotometric system used for white dwarfs. Formulae based upon color index-temperature correlations using grids of model atmospheres allow a temperature calculation for any white dwarf with measured colors. Temperature-color index correlations using model atmospheres for DA and non-DA stars are already available for multichannel spectrophotometric colors $(g-r)$; Strömgren colors $(u-b,\ b-y)$; and broad-band *UBV* colors $(B-V,\ U-B)$. Temperatures derived in different ways are generally very consistent (cf. Koester, Liebert, and Hege 1979; Shipman and Sass 1980; Greenstein 1979). The color transformations employed for the temperature determinations will be based upon Tables 1 and 2 and equations (9) and (10) of Shipman (1979). The transformation relations for non-DA stars are

$$(B-V) = 0.334 + 0.836\ (g-r)$$

and

$$(b-y) = 0.286 + 0.553\ (g-r)\ .$$

For DA stars the color transformations are

$$(B-V) = 0.3336 + 0.5906\ (g-r)$$

and

$$(b-y) = 0.2197 + 0.4485\ (g-r)\ .$$

If, in the future, large revisions to the white dwarf effective temperature scale are found, this temperature parameter would still be based upon the photometric colors and spectral scans described above, rather than requiring the need for a new definition of this quantity.

c) *Additional Symbols*

It is proposed that following the symbol for secondary spectroscopic features, the uppercase letter P be adopted as a symbol only for polarized magnetic stars, H for magnetic stars showing no detectable polarization, X for peculiar or unclassifiable spectra, and an optional V to denote the ZZ Ceti stars or any other variable degenerate star. In Table 3, twelve examples of the proposed new system are listed with both the present spectral type and new spectral type tabulated.

IV. CONCLUSION

Adopting the system proposed here will enable an observer or theoretician to know, from the assigned spectral type, the dominant or primary spectroscopic features in the optical spectrum, weaker or secondary spectroscopic features in any part of the electromagnetic spectrum, the approximate surface temperature and luminosity of the white dwarf based upon temperature/color correlations, and self-consistent symbols for

TABLE 3

EXAMPLES OF THE PROPOSED NEW CLASSIFICATION

Example	Old	New
1. A white dwarf with only H I lines; $T_e = 30{,}000$ K (e.g., EG 157)	DA	DA1
2. A white dwarf with only He I lines; $T_e = 15{,}000$ K (e.g., L1573−31)	DB	DB3
3. A white dwarf with no lines deeper than 5% in any part of the electromagnetic spectrum; $T_e = 8000$ K (e.g., EG 1)	DC	DC6
4. A DB Star with Ca II; $T_e = 14{,}000$ K (e.g., GD 40)	DBPEC	DBZ4
5. A polarized magnetic white dwarf with helium and hydrogen, but with helium dominant; $T_e = 20{,}000$ K (e.g., Feige 7)	DBAP	DBAP3
6. A cool white dwarf with Ca II, Fe I; $T_e = 6000$ K (e.g., vMa 2).............	DG	DZ8
7. A DA, F star; $T_e = 7400$ K (e.g., G74−7)	DA, F	DAZ7
8. A peculiar metallic line white dwarf with H; $T_e = 8500$ K (e.g., Ross 640)	DFPEC	DZA7
9. A DA star with weak He II (λ4686); $T_e = 50{,}000$ K (e.g., HZ 34)...........	DA	DZ01
10. A peculiar magnetic white dwarf; unidentified composition with no detectable polarization; $T_e = 25{,}000$ K (e.g., GD 229)	DXP	DXH3
11. A cool white dwarf showing C_2 bands in the optical and C I lines in the ultraviolet; $T_e = 8500$ K (e.g., L879−14)	C_2	DQ6
12. A DO white dwarf with N V (λ1240) $T_e = 70{,}000$ K	DO	DOZ1

magnetic field/polarization, variability, and spectral peculiarities. Thus, this classification system will convey more physical information in a more consistent manner than is available from the currently used system.

The principal reason for introducing a new, more physical system is the ease with which it can be used in selecting stars of interest for particular observational or theoretical programs from, say, the approximately 1500 stars in the forthcoming second edition of the *Villanova Catalogue of Spectroscopically Identified White Dwarfs* or from discovery lists in the literature. Someone working in the ultraviolet or at higher photon energies could, say, select the hottest stars (temperature index 0 or 1). Someone seeking ZZ Ceti candidates could isolate the relevant temperature range in a similar way. A theorist, seeking to analyze all the stars with observed metallic lines, could immediately locate the appropriate stars. These are not the only applications of the proposed system but also serve to illustrate the ways in which the proposed system can serve the needs of the investigators in a way that the present system does not. The selection of stars in the ways mentioned above would not be possible with the present system.

It can be argued that a stellar spectral classification should be constrained by two fundamental conditions: (1) that the system should be based only on visual inspection of the spectrum, and (2) that the system should depend on one consistent observational technique. These criteria have been used in defining spectral classifications for main-sequence stars (e.g., Morgan, Keenan, and Kellman 1943) and in other astronomical classification schemes. But changes in technology now make it impossible to apply criterion (2) since people at different observatories often obtain a spectrum of a white dwarf suspect, the discovery spectrum which results in the star's classification, with different resolutions and different signal-to-noise ratios. The variety of people who have searched for white dwarf stars using a variety of techniques and telescopes make it necessary to violate the criterion of uniformity; we doubt that there is any photometric or spectroscopic system which has been applied to all known white dwarf stars.

A more basic philosophical difficulty involves the first criterion, the idea that classification must be based on the visual appearance of the spectrum rather than on quantitative information, which our temperature index requires. This notion of classification has a long and honorable tradition, both in astronomy and in biology, the science in which the art of classification is refined to the highest degree. But degenerate stars present a fundamental difficulty: the spectrum of a hot DA1 (new classification) or DAwk (old classification) star like HZ 43 resembles, in visual appearance, the spectrum of a very cool star like L870−2, classified DA7 (new system) and DAwk (old system). There is no classification scheme which could distinguish these two stars from the appearance of the spectrum alone. Yet in almost all conceivable uses of a classification scheme, it is very useful to distinguish stars on the basis of temperature. Because of the unique astrophysical problems presented by various types of degenerate stars undergoing accretion, convective mixing, gravitational and thermal diffusion, and thermal cooling, we believe that a temperature index is an essential part of a viable classification scheme. We recognize that classifications of individual stars may change as new observations and model atmosphere calculations supersede older efforts, but the quantitative nature of this classification scheme is not soly responsible: the classification of individual objects in other, more descriptive systems also changes with the passage of time.

In summary, we have outlined and defined a new classification scheme for white dwarf stars. This scheme will be used in the second edition of the *Villanova Catalogue of Spectroscopically Identified White Dwarfs*. The class of a white dwarf star provides information on its basic chemical makeup, its temperature, and other properties which it might possess (e.g., magnetism, variability, and obvious spectral peculiarities).

The spectral classification scheme developed here first emerged in outline form from informal discussions held during IAU Colloquium 53, "White Dwarfs and Variable Degenerate Stars" held at the University of Rochester, 1979 July 30–August 2, and was further developed through private communication. Most of the refinements were discussed at the First Delaware Workshop on White Dwarf Stars which was supported by the Unidel Foundation of the University of Delaware. We thank Drs. R. J. P. Angel, R. A. Bell, K. H. Böhm, R. Green, P. M. Hintzen, M. P. Savedoff, and H. M. Van Horn for useful discussions and for comments which have helped us develop the classifications outlined here.

The authors thank the National Science Foundation (grants AST 78-13396-A02) (E. M. S.), AST 77-09191 (J. L. G), AST 76-22273 (J. L.), AST 78-24355-A01 and AST 81-15095 (H. L. S.), and AST 82-19474 (G. L. W.), and the John Simon Guggenheim Memorial Foundation (H. L. S.) for financial support.

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