II. INSTABILITY IN THE HOT STARS OF LOW LUMINOSITY AND IN THE NOVAE

7. EVIDENCE FOR INSTABILITY AMONG SUB-LUMINOUS STARS

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A programme of spectroscopic study of sub-luminous stars has been in progress at Palomar, using the coudé spectrograph. Various types of objects have been studied and some preliminary results are available. Certain other programmes will, when completed, be relevant to the subject-matter of this Symposium. A survey of possible velocity variations in sub-dwarfs of spectral types A to G is in progress. So far I can report that no emission lines have been found, and that there are very few spectroscopic binaries in this group. In another programme, the depth of the late-type absorption lines in the composite spectra of SS Cygni stars will be used to estimate the luminosities of the hot components near their minima. Spectra of old novae are also being obtained with a dispersion of 38 Å/mm. Plates obtained thus far show that complex structure still exists in the emission bands.

I wish to report some results on the spectra of white dwarfs and hot subdwarfs. As far as I know, light variations have not been found in the white dwarfs. In view of the results of photo-electric studies (H. L. Johnson and D. L. Harris) of the colours and magnitudes, it is probable that any light variation is small. The spectra of white dwarfs have now been found to show considerable variety, and the evidence for or against instability takes different forms dependent on the type of spectrum.

(1) Twelve white dwarfs with strong hydrogen lines have been studied spectrophotometrically. There is a wide range of line strength, colour and probably temperature; equivalent widths of Hγ range from 2 to 40 angstroms. In *no* case has peculiar spectral features been noted, nor has variability been suspected. Radial velocities are too poor to be useful. For the sharp-lined star L 532–81, my velocity $+57 \pm 8$ km./sec. agrees perfectly with that determined at the McDonald Observatory. But for a broad-lined star, W 1346, I find $+38 \pm 7$ km./sec.; from low dispersion the Mount Wilson result was $+101$ km./sec. and the McDonald $+26$ km./sec. Popper in his detailed study of 40 Eri B found no significant velocity variations.

(2) One strong-lined white dwarf HZ 9 (=L 1239–16) is a member of the Hyades cluster; its absolute magnitude is near +12. There are emission lines in its spectrum: $H\gamma$, $H\delta$, $H+H\epsilon$, K, λ 3905 of Si I and $H\zeta$. The hydrogen emissions are seen at the bottoms of the strong absorption lines, but K and λ 3905 are superposed on the continuous spectrum and must be intrinsically quite strong. The emission lines are slightly asymmetric with an absorption feature at velocity +40 km./sec. The centre of the emission, which is 250 km./sec. wide, lies near +70 km./sec. The velocity of the cluster is about +36 km./sec., so that this displacement could be interpreted as an Einstein shift in the emission, which disappears in the outer absorbing material. However, asymmetric self-reversal is so common in Be stars that the velocities should not be over-interpreted. While this discovery of emission is very unexpected, an alternative explanation is possible. The colour indices of the star were measured photo-electrically by D. L. Harris who kindly communicated his results: $B-V=+0{\cdot}33$, $U-B=-0{\cdot}69$. Such a $B-V$ colour makes it the reddest of his normal A-type white dwarfs, while the $U-B$ corresponds to a rather hot white dwarf. He interprets the star as a composite of a dM5 star and a hot white dwarf. Luyten had previously suspected the star to be bright on an infra-red photograph. In the blue the white dwarf would be 2·2 magnitudes brighter, in the ultra-violet 4·1 magnitudes brighter than the dM star. While this analysis explains the colour indices, the strength of the emission lines is surprisingly high, if they are ascribed to the red star. For example, λ 3905 would be thirty times the strength of the dM continuum.

(3) There are few late-type white dwarfs known, but in two out of the three wF stars so far examined, an unexpected shell-like phenomenon was found in the H and K resonance lines of Ca II. Relatively sharp cores are superposed on strong, pressure-broadened lines. The star L 745–46 gave core velocities of $+24\pm25$ and -18 ± 15 km./sec. from two plates. No other lines were measurable. The star R 640 has stronger lines, and the exposure was insufficient to reach cores, if they are present. The most detailed investigation has been made of Van Maanen 2 (=W 28). This object has very greatly broadened Fe I lines in the ultra-violet, and broad H and K with superposed sharp cores. It is probable that the 'shell' or core-producing region is variable in velocity and extent. Five old low-dispersion Mount Wilson plates had given a catalogue velocity of +263 km./sec. No recent plate approaches this value, the range of measured velocities being from about +30 to +140 km./sec. Table 1 includes a journal of the recent measures.

Only one day elapsed between the dates of N 203 and N 205, and between those of Pe 1821 and 1824. It is probable but not certain that the velocity is variable; a sharp core might be superposed with a relative negative displacement on a broad line from the reversing layer. An increase of plate density, or more probably of the intensity of the core, could explain a reduced velocity. Setting on the centre of the broad line is impossible at high dispersion, in the presence of a deep core. The older low-dispersion work might give an average velocity. However, even with this as a tentative possibility, the apparent structure of the lines and the present velocity cannot be understood without an extended stellar envelope possessing a velocity gradient. The envelope or shell need not be detached. With a velocity of escape of 4000 km./sec., the forces producing ejection or distention must be very powerful. I can mention magnetic fields, rotation or internal instability as possibilities. Incidentally, the lower positive velocity now found makes the galactic orbit of this star less peculiar than that resulting from the catalogue value, and obviates the need for an improbably large red shift.

Table 1. *Velocity Measures in Van Maanen 2*

Plate	Dispersion (Å/mm.)	Velocity (km./sec.)	Probable error (km./sec.)	Remarks
N 203	192	+ 21	±60	Dense, core only
N 205	192	+239	40	Thin, whole width
Pd 548	18	+122	30	Very thin, whole width
Pd 1203	18	+ 48	4	Whole width
Pe 1258	38	+ 31	15	Core only
Pe 1301	38	+ 28	18	Core
		+137	18	Whole width
		+300	—	Red core? H only
Pe 1821	38	+ 54	5	Thin; cores complex?
Pe 1824	38	+ 71	±30	Thin, whole width

(4) Hot sub-dwarfs and white dwarfs with strong helium lines exist in considerable number. The very blue star +28° 4211, closely related to the white dwarfs, shows strong He II and H, and no peculiar spectral features. Two white dwarfs with very strong, broad He I lines, found by Luyten, have extraordinary spectral characteristics which indicate ejection or an extended envelope. They are very blue, about apparent magnitude 15, and have $M \approx +11$. No hydrogen lines are seen. The He I lines are extraordinarily strong, and some of the $2^3P^\circ - n^3D$ lines show relatively sharp centres. But the absolutely metastable lines, λ 3888, $2^3S - 3^3P^\circ$ and λ 3964, $2^1S - 4^1P^\circ$ have very much sharper and deeper cores. In fact, the sharp λ 3888 line is the strongest feature of the spectrum to the eye, although the broad shallow lines like $\lambda\lambda$ 4471, 4026 actually have twice

the equivalent width. It should be remembered that λλ 3888, 3964 appear in absorption in the spectra of stars in the Orion Nebula, a few other diffuse nebulae, and in 30 Doradus. The metastability of the lines under nebular conditions of the dilution of radiation is well established theoretically; however, they would be enhanced with respect to other He lines even if the radiation is only slightly dilute. The cores are not completely sharp, and may show velocity broadening. If the optically thin envelope region had a radius 10 or 100 times that of the white dwarf, any initial random mass motion with velocity near that of escape would be substantially reduced by gravity.

The spectra so far obtained are few in number, since at 38 Å/mm. a 15th magnitude star is a difficult object even with the 200-inch Hale reflector. The star L 930–80 shows, on two plates, cores at a displacement of −15 km./sec., as compared to a stellar velocity of −2 km./sec. Weak displaced components are also suspected in five He I lines, on different plates, at a velocity of −320 km./sec. The star L 1573–31 has a velocity of +45 ± 3 km./sec., from five good spectrograms. The cores of λλ 3888, 3964 are at +34 ± 7 km./sec., and sharp components of λ 3888 are suspected on two plates at −140 and −310 km./sec. It is surprising that the strong cores are so near zero velocity. The highly displaced lines are weak and not seen on all plates, but are probably real. More observations are needed, but are difficult since the star is near magnitude 15. My opinion is that both helium-rich white dwarfs have extensive envelopes.

(5) Among the faint blue stars a considerable number of very interesting O-type sub-dwarfs have been studied, for example HZ 1, 3, 44 and a brighter object found by G. Münch, HD 127493. These stars have weak H, strong He I and He II, and many sharp lines of N II, N III, Si IV, etc. Their luminosities can only be estimated; pressure and Stark broadening is large, but interstellar lines are weakly seen in the magnitude 13 objects. Most of the sharp lines, due to N III and Si IV, arise from non-metastable, highly excited levels, so that the pressure is lower than in white dwarfs but is high enough to broaden He I lines. Probably the absolute magnitudes are between +1 and +5. All four stars have sharp cores in λλ 3888 and 3964, as well as traces of cores in the less metastable He I lines of the 2^3P° series.

The existence of the cores apparently demonstrates that low-pressure envelopes exist with a considerable dilution of radiation. However, there are only very small velocity shifts. HD 127493 has been studied at dispersions of 10 Å/mm. and 18 Å/mm. The largest line shift found is −6 ± 2 km./sec. for λ 3964, and the mean shift of the metastable lines is −3 km./sec. In HZ 44, observed at 18 Å/mm., the mean shift is barely significant, -5 km./sec. The fainter stars, HZ 1 and HZ 3, have a non-significant shift of -3 km./sec., measured at 38 Å/mm. The stars of this O-sub-dwarf group are at moderate to high galactic latitudes, and have a velocity dispersion, as a group, slightly larger than do the ordinary B stars. HZ 3 has the highest radial velocity ($+43$ km./sec.), but correction for normal solar motion leaves a radial component of the space motion of only $+25$ km./sec.

In conclusion, the helium-rich white dwarfs and sub-dwarfs show no evidence of a large velocity gradient from the reversing layer upwards, but all have sharp cores in most metastable lines. No astrophysical explanation for the sharp core lines exists except a very large pressure gradient in the atmosphere, and the relative enhancement of the cores of the most metastable lines would suggest that the atmosphere is large compared to the star. Observations designed to detect possible short-period light variability would be desirable.