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## Abstract

## Full Text

*Astronomy*

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# On the Luminosity of Hot Stars

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As is well known, determining the luminosities of hot stars presents great difficulties, since the main part of the energy is radiated by these stars in the invisible high-frequency region of the spectrum. Usually stellar luminosities are determined under the assumption that the excitation temperature, found from the spectral class, is equal to the effective temperature of the star. More accurately, the luminosity of a star is found by constructing a model of the atmosphere for given values of the effective temperature $T_e$ and the acceleration of gravity $g$, and also for a given chemical composition. Comparison of the calculated spectrum of the star with the observed spectrum makes it possible to determine the value of $T_e$ for the given star.

The spectra of hot stars have been calculated by E. R. Mustel ([1]), Underhill ([2]), and others. With the aid of their results the luminosities of "ordinary" O and B stars can be determined. In the case of "peculiar stars," however, the situation is more complicated. Below we consider the question of determining the luminosities of WR stars and white dwarfs.

**Stars of type WR.** It is generally accepted that from WR stars there is a continuous outflow of matter, leading to the formation of extended atmospheres. The theory of extended atmospheres was first considered by N. A. Kozyrev ([3]). In his theory, however, it is assumed that: 1) the absorption coefficient does not depend on frequency; 2) local thermodynamic equilibrium is established in the atmosphere. A correct theory of the atmospheres of WR stars must be constructed taking into account the fact that absorption is caused by real atoms (hydrogen, helium) and that in the atmosphere high-frequency radiation is transformed into quanta of lower frequencies (in principle the same as in gaseous nebulae).

The emission processes of the envelopes of WR stars were studied in detail several years ago in works by the author ([4]) and V. G. Gorbatskii ([5]). The results obtained in these works can be applied to determining the luminosities of WR stars.

Approximately, we may assume that the star itself (without the atmosphere) radiates according to Planck's law. To determine the temperature of the star, the refined Zanstra method may be used (from the lines of ions with a high ionization potential). To determine the radius of the star, however, it is necessary to take into account that the fluorescence occurring in the atmosphere greatly increases the visible brightness of the star. Theory shows that the influence of the atmosphere on the visible brightness amounts to several stellar magnitudes.

Let us note that B. A. Vorontsov-Velyaminov ($^6$) already proposed, when finding the luminosities of WR stars, taking into account the effect of bright bands. According to his estimates, this effect amounts to several tenths of a stellar magnitude. In reality, however, the influence of the atmosphere on the brightness is considerably greater, since the atmosphere radiates energy not only in lines, but also in the continuous spectrum.

It is interesting that the effect of the radiation of the envelope on the brightness of a star can be approximately found from observations. The point is that in some cases the nuclei of planetary nebulae are WR stars, and in others—O stars. Since the visible brightness of a WR star must be greater than the visible brightness of an O star (at the same temperature), the difference in magnitudes between the nucleus and the nebula in the first case (i.e., in the case of a WR nucleus) should be smaller than in the second. This is indeed the case. The mean value of $M_* - M_n$ for 12 nebulae with WR nuclei from van Pelt' s list ($^7$) turned out to be $1.^m6$. For nebulae with O nuclei, however, it is of the order of $3–4^m$. Thus the effect of the radiation of the envelope of the WR nucleus on the visible brightness is, on average, 2 magnitudes.

By the method indicated above, the luminosity of the WR star belonging to the binary system HD 193576 was determined. It turned out to be of the order of $3 \cdot 10^4 L_\odot$. The mass of this star is $12.4 m_\odot$. These values of $L$ and $m$ approximately satisfy the "mass–luminosity" relation ($L \sim m^4$). Without taking into account the effect of the radiation of the envelope on the brightness of the star, the luminosities of WR stars come out considerably higher.

**White dwarfs.** In the atmospheres of white dwarfs the acceleration of gravity is very large. This leads to two effects: 1) the degree of ionization of atoms in the atmosphere of a white dwarf is lower than in the atmosphere of an "ordinary" star of the same temperature; 2) absorption lines in the spectrum of a white dwarf are strongly broadened by the Stark effect. Therefore the spectra of white dwarfs bear little resemblance to the spectra of "ordinary" stars. For example, in the spectrum of 40 Eridani B only four absorption lines are visible (all of the Balmer series). Nevertheless, observers—by the presence of certain lines in the spectrum and by the color index—still assign white dwarfs a definite spectral type and thence determine effective temperatures as for "ordinary" stars. It is clear that these effective temperatures inspire little confidence.

One may think that white dwarfs are in reality hotter than is commonly believed. The following considerations may be cited in favor of this view:

1) In the spectra of white dwarfs the Balmer jump is absent. As is known, at $T_e \approx 10000^\circ$ (class A0) the jump is very large (the intensity before the limit is approximately 3 times greater than the intensity after the limit), and with increasing temperature the jump diminishes. Therefore

the absence of the jump in the spectra of white dwarfs can be explained by their comparatively high temperature. True, the jump may also be blurred as a result of the high pressure in the atmosphere.

2) The color indices of white dwarfs are strongly affected by absorption in the higher members of the Balmer series. This effect was recently investigated by American astrophysicists ($^8$). From their data it follows that, after correction for the indicated effect, the color indices of white dwarfs should decrease considerably (by approximately 0.3 magnitude).

3) A model of the atmosphere of the white dwarf 40 Eridani B with $T_e = 13800^\circ$ and $\lg g = 7.69$, recently constructed by Greenstein ($^9$), agrees poorly with the results of observations, and one may expect that, with an increase in $T_e$, the agreement will be better.

4) The radius of the white dwarf Sirius B, found from $M_{\text{vis}}$ and $T_e = 9000^\circ$, is more than twice the radius determined from the theoretical relation between radius and mass (for a mean molecular weight ensuring the stability of the star). It has been noted (see ($^{10}$)) that the cause of this discrepancy may be the unreliability of the determination of $T_e$ from the spectrum, since the spectrum of Sirius B is strongly affected by the radiation of Sirius A. The discrepancy is eliminated if one assumes that the effective temperature of Sirius B is not 9000°, but of the order of 25000°.

5) Some white dwarfs have spectra without absorption lines and with weak emission lines. An attempt to explain these spectra

Kuto has recently made this step $^{(11)}$, obtaining, for the stars under consideration, extremely high effective temperatures—of the order of 300 000°.

If the effective temperatures of white dwarfs are usually underestimated, then their luminosities are thereby also underestimated. The question therefore arises whether the known deviation of white dwarfs from the "mass—luminosity" law is not a consequence of this underestimation.

At present there are only three white dwarfs with known masses: Sirius B, Procyon B, and 40 Eridani B. The spectra of the first two of these, owing to the strong influence of the principal components of the systems, are poorly determined; it is therefore very difficult to determine their luminosities accurately as well. Still, it may be asserted that the luminosities of Sirius B and Procyon B quoted in the literature must be considerably increased (both because of the general consideration that $T_e$ must be increased for white dwarfs, and for a number of other reasons). The white dwarf 40 Eridani B, whose spectrum is well determined, is in a better position. For it one obtains $m = 0.45\,m_\odot$, $L = 0.006\,L_\odot$ (for $T_e = 13\,800^\circ$). These values of $m$ and $L$ do not deviate very strongly from the "mass—luminosity" law, and since $T_e$ must apparently be higher, the deviation will be still smaller.

It is possible that the relation between the masses and luminosities of white dwarfs is approximately the same as for "ordinary" stars. In that case the supposition made by us earlier (12) that "ordinary" stars have cores similar in their structure to white dwarfs becomes more probable.

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