A SOURCE BOOK
in
ASTRONOMY

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NORMAN LOCKYER[1]

Stellar Evolution

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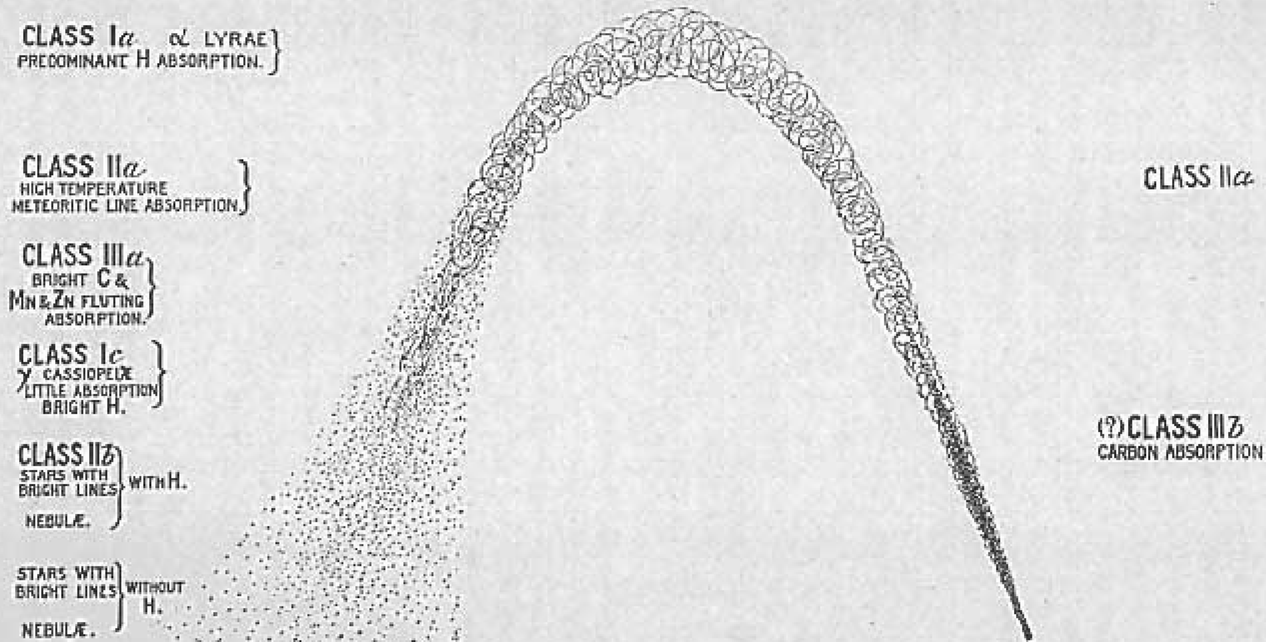
Having, then, gone over the various classifications of stars according to their spectra, I now proceed to consider the question of the classification of celestial bodies from a more advanced point of view. I pointed out in the year 1886 that the time had arrived when stars with increasing temperatures would require to be fundamentally distinguished from those with decreasing temperatures, but I did not then know that this was so easy to accomplish as it now appears to be; and, as I have already stated, when we consider the question of classification at all, it is neither necessary nor desirable that we should limit ourselves to the stars; we must include the nebulæ and comets as well. Stellar variability should not introduce any difficulties, seeing that as a rule in its extremest form it is the passage from one spectrum to another, even if of a different type, owing to sudden changes of temperature.

In the first classification on these lines, which is certain to be modified as our knowledge gets more exact, it is desirable to keep the groups as small in number as possible; the groups being subsequently broken up into sub-groups, or, even into species, as the various minute changes in spectra brought about by variations of temperature are better made out.

For the purpose of making clear what follows, I here introduce the "temperature curve," on which is shown the distribution of nebulæ, comets, and of stars as divided into classes by Vogel, on the two arms of the curve.

[1] Sir Joseph Norman Lockyer (1836–1920), pioneer English astrophysicist. He made important advances in the field of solar and stellar physics, and is responsible for naming the element helium, for emphasizing the two-branch theory of stellar evolution, and (jointly with Janssen) for the method of observing solar prominences without an eclipse. Lockyer's scheme of stellar development has been modified in many important details, but its basic principle, of both rising and falling temperatures in the life history of a star, is the central idea of our present theories of stellar evolution.



Temperature curve, showing the relative temperatures of the different orders of celestial bodies. The top of the curve represents the highest temperatures, and the bottom of each arm the lowest. On the left arm, the temperatures are increasing, on the right they are decreasing. The diagram shows the relative temperatures of Vogel's classes.

On one arm of this we have those stages in the various heavenly bodies in which in each case the temperature is increasing, while on the other arm we have that other condition in which we get first vaporous combination, and then ultimately the formation of a crust due to the gradual cooling of the mass, in dark bodies like, say, the companion of Sirius. At the top we of course have that condition in which the highest temperature must be assumed to exist.

To begin, then, a more general classification with the lowest temperatures, it is known that the nebulæ and comets are distinguished from most stars by the fact that we get evidence of radiation alone, or almost alone so far as we know. Absorption has been suspected in the spectra of some nebulæ, and has been observed beyond all doubt in some comets. But there are some stars in which we also get radiation, accompanied by certain absorption phenomena. But there is no difficulty in showing that nebulæ and comets are more special on account of their bright lines than on account of their absorption bands. I have already shown that in all probability the stars with bright lines are most closely allied with nebulæ. Indeed, it seems as if they are very nearly akin to those condensations in nebulæ, showing an undoubted olivine and hydrogen spectrum, which gave them the appearance of resolvability. It seems, also, highly probable that future observations with instruments of great light-collecting power, will show that in nebulæ, the spectra of which are recorded as continuous, lines including the remnants of some of the carbon flutings, which there is good reason to believe have already been traced in the spectra of bright line stars, are also present. From this point of view, the various recorded observations of regions of different colour in certain nebulæ acquire an additional interest. It is also clear that since the only real difference between comets and other meteor swarms of equal denseness is that the former are in motion round the centre of our system, comets whether at aphelion or at perihelion will fall into this group. We may, therefore, form the first group of bodies which are distinguished by the presence of bright lines or flutings in the spectrum.

The great distinction between the first group and the second would be that evidences of absorption now become prominent, and side by side with the bright flutings of carbon and occasionally the lines of hydrogen we have well-developed fluting absorption.

The second group, therefore, is distinguished from the first by mixed flutings as well as lines in the spectrum.

The passage from the second group to the third brings us to those bodies which are increasing their temperature, in which radiation and fluting absorption have given place to line absorption.

At present, the observations already accumulated have not been discussed in such a way as to enable us to state very definitely the exact retreat of the absorption—by which I mean the exact order in which the absorption lines fade out from the first members to the last in the group. We know, generally, that the earlier bodies will contain the line absorption of those substances of which we get a paramount fluting absorption in the prior group. We also know, generally, that the absorption of hydrogen will increase while the other diminishes.

The next group—the fourth—brings us to the stage of highest temperature, to stars like α Lyræ; and the division between this group and the prior one must be more or less arbitrary, and cannot at present be defined. One thing, however, is quite clear, that no celestial body without all the ultra-violet lines of hydrogen discovered by Dr. Huggins can claim to belong to it.

We have now arrived at the culminating point of temperature, and now pass to the descending arm of the curve. The fifth group, therefore, will contain those bodies in which the hydrogen lines begin to decrease in intensity, and other absorptions to take place in consequence of reduction of temperature.

One of the most interesting problems of the future will be to watch what happens in bodies along the descending scale, as compared with what happens to the bodies in Group III, on the ascending one. But it seems fair to assume that physical and chemical combinations will now have an opportunity of taking place, thereby changing the constituents of the atmosphere; that at first with every decrease of temperature an increase in the absorption lines may be expected, but it will be unlikely that the coolest bodies in this group will resemble the first one in Group III.

The next group—the sixth—is Secchi's type IV, and Vogel's Class III*b*, its distinct characteristics being the absorption flutings of carbon. The species of which it will ultimately be composed are already apparently shadowed forth in the map which accompanies Dunér's volume, and they will evidently be subsequently differentiated by the gradual addition of other absorptions to that of carbon, while at the same time the absorption of carbon gets less and less distinct.

To sum up, then, the classification I propose consists of the following groups:

Group I.—Radiation lines and flutings predominant. Absorption beginning in the last species.

Group II.—Mixed radiation and absorption predominant.

Group III.—Line absorption predominant, with *increasing* temperature. The various species will be marked by increasing simplicity of spectrum.

Group IV.—Simplest line absorption predominant.

Group V.—Line absorption predominant, with *decreasing* temperature. The various species will be marked by decreasing[1] complexity of spectrum.

Group VI.—Carbon absorption predominant.

Group VII.—Extinction of luminosity.

It will be seen from the above grouping that there are several fundamental departures from previous classifications, especially that of Vogel.

The presence of the bright flutings of carbon associated with dark metallic flutings in the second group, and the presence of only absorbing carbon in the sixth, appears to be a matter of fundamental importance, and to entirely invalidate the view that both groups (the equivalents of III*a* and III*b* of Vogel) are produced from the same mass of matter on cooling.

This point has already been dwelt upon by Pechüle.

Another point of considerable variation is the separation of stars with small absorption into such widely different groups as the first and fourth, whereas Vogel classifies them together on the ground of the small absorption in the visible part of the spectrum. But that this classification is unsound is demonstrated by the fact that in these stars, such as γ Cassiopeiæ and β Lyræ, we have intense variability. We have bright hydrogen lines instead of inordinately thick dark ones; and on other grounds, which I shall take a subsequent opportunity of enlarging upon, it is clear that the physical conditions of these bodies must be as different as they pretty well can be.

It will be seen that, with our present knowledge, it is very difficult to separate those stars the grouping of which is determined by line absorption into the Groups III and V, for the reason that so far, seeing that only one line of temperature, and that a descending one, has been considered, no efforts have been made to establish the necessary criteria. I noted this point in the paper to which I have already referred in connexion with the provisional curve.

[[1] Presumably this should read "increasing complexity."]