Recent Researches on Nebulæ.[1]

By MAJOR WILLIAM J. S. LOCKYER.

THE latest volume (No. xiii.) in the series of Publications of the Lick Observatory, situated on Mount Hamilton, California, is completely devoted to a series of well-laid-out investigations of the study of the forms, distribution, velocities, and spectra of the nebulæ. The volume is one of extreme interest and importance, and will become a classic for a considerable time on those interesting objects scattered throughout the heavens.

In these days, when the study of the evolution of the stars is occupying a position in the front rank, the more detailed information of the nebulæ, their composition, structure, and movements, is of fundamental importance, for these bodies are criteria in the evolutionary stages of stars.

Considerations of space will not permit here more than an outline of the contents of this substantial volume, which includes six separate contributions, each devoted to a special research, and a large number of beautifully reproduced plates.

Part i. is contributed by Mr. H. D. Curtis (pp. 11–42), and deals with the descriptions of 762 nebulæ and clusters photographed with the Crossley reflector. It comprises all photographs of these objects which have been taken with this instrument since the year 1898, when systematic work was commenced, forming, therefore, a valuable homogeneous research.

It is interesting to note the types of the 762 entries, which Mr. Curtis divides as follows: 513 spiral, 56 diffuse, 36 globular, 24 sparse, 78 planetary, 8 dark, and 47 unclassified. Mr. Curtis is led to believe that all the many thousands of nebulæ not definitely to be classed as diffuse or planetary are true spirals, and that "the very minute spiral nebulæ appear as textureless discs or ovals solely because of their size."

In estimating the probable total number of the spiral nebulæ, Mr. Curtis concludes that at least 700,000, and very probably 1,000,000, small spirals are within the reach of large reflecting telescopes. A chart showing the distribution of regions on which small nebulæ were counted indicates also the position of the galactic plane, and the paper concludes with reproductions of a few typical nebulæ.

The second part, by the same author, is devoted to a study of occulting matter in the spiral nebulæ (pp. 45–54), and its object is to show that the occurrence of such dark bands running down the length of spiral nebulæ seen edgewise is a relatively common feature. While a description of these appearances is not necessarily satisfactory to those who have not had occasion to observe them or to see the original photographs, Mr. Curtis includes seventy-seven reproductions. By the kindness of Prof. W. W. Campbell, reproductions of some of these spirals are here given (Figs. 1, 2, and 3).

References are made to other evidences of occulting matter in the sky, such as the cutting off in the number of stars round a nebula, "coal sacks" or starless regions, dark nebulæ, etc. (see Fig. 4). The fact that many spectroscopic binaries indicate a constant radial velocity for the H and K lines, different from the periodic shift of the other lines in the spectrum, suggests, according to the author, the interposition between us and the binary of a cloud of non-luminous matter, though, as he says, there are some difficulties in this hypothesis. The subject of the peculiar grouping of the spiral nebulæ about the galactic poles is also mentioned.

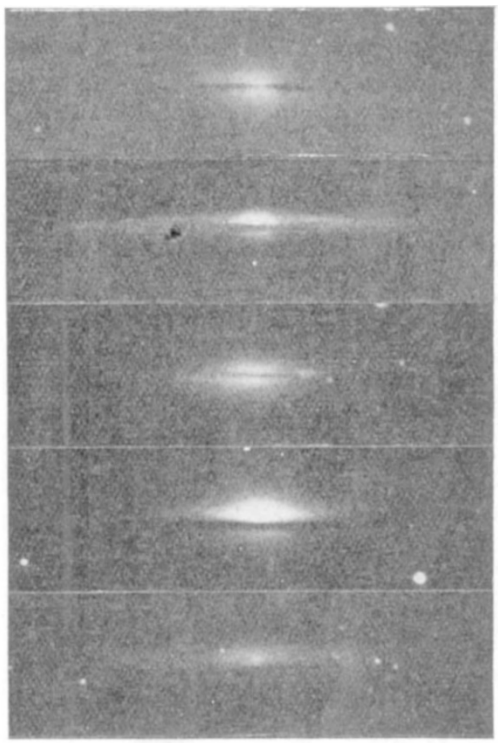

FIG. 1.—Spiral nebulæ seen almost exactly edgewise and showing indubitable evidence of dark lanes. (H. D. Curtis.)

Part iii. is entitled "The Planetary Nebulæ," and in it Mr. Curtis brings together the results of a research on a series of photographs of all the planetary nebulæ north of 34° S. declination. Seventy-eight of these objects are dealt with, and they are all reproduced either by photographs or by drawings (with scale). Drawings were resorted to only when the objects were so small that they could not be reproduced by the process of photo-engraving, or when great differences in brightness between the central and the faint outlying portions were encountered, which

[1] University of California Publications. Publications of the Lick Observatory. Vol. xiii. Pp. 268+50 plates. (Berkeley: University of California Press, 1918.)

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prevented an adequate representation of all the details of the nebula (Fig. 5). This collection of illustrations, showing the forms assumed by the planetary nebulæ, will throw considerable light upon the structure and life-history of these bodies. An important addition to the illustrations is that the exposure for recording a selected portion of the Orion nebula has been used as a standard, and the time necessary for recording the brightest portion of a planetary nebula is given in relation to that standard. Thus

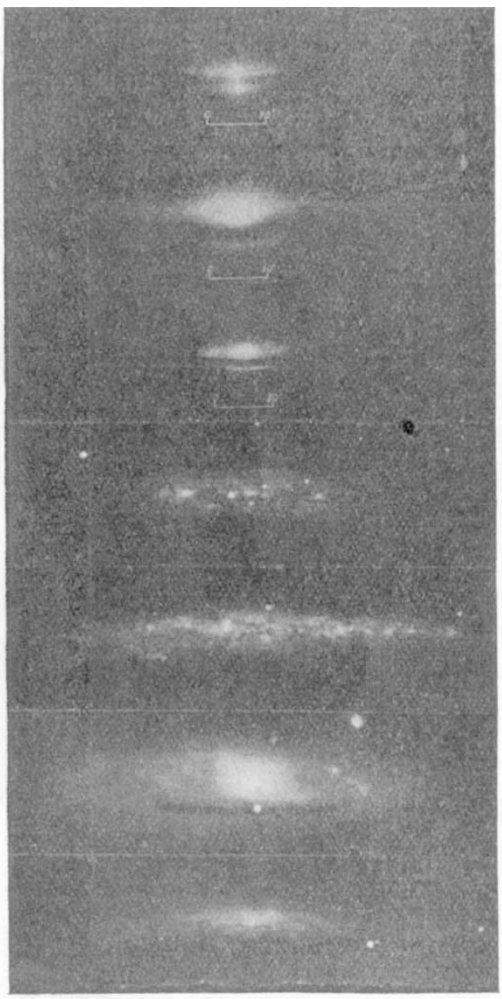

FIG. 2.—Spiral nebulæ seen almost, but not exactly, edgewise, and some the planes of which make a small but appreciable angle with the line of sight, showing clear evidence of dark lanes. (H. D. Curtis.)

an approximation to the relative brightness of the planetary nebulæ is secured.

With regard to the distribution of these nebulæ in space, an interesting diagram of which is given, Mr. Curtis finds that the smallest objects are almost invariably in, or very close to, the Milky Way, while the larger planetaries, "the giants of the class," somewhat more frequent in the vicinity of the galactic plane, are, "on the whole, fairly uniformly distributed over the entire sky." It is concluded, therefore, that these giants may be in the Galaxy, but the nearest to us, and, therefore, would only appear outside, and he suggests their inclusion in parallax programmes, as many of them have central stars sufficiently bright for that purpose.

Further reference cannot be made here to this interesting paper except to add that the author classifies the planetary nebulæ according to their appearances, and then discusses these forms in relation to homogeneous oblate spheroidal or

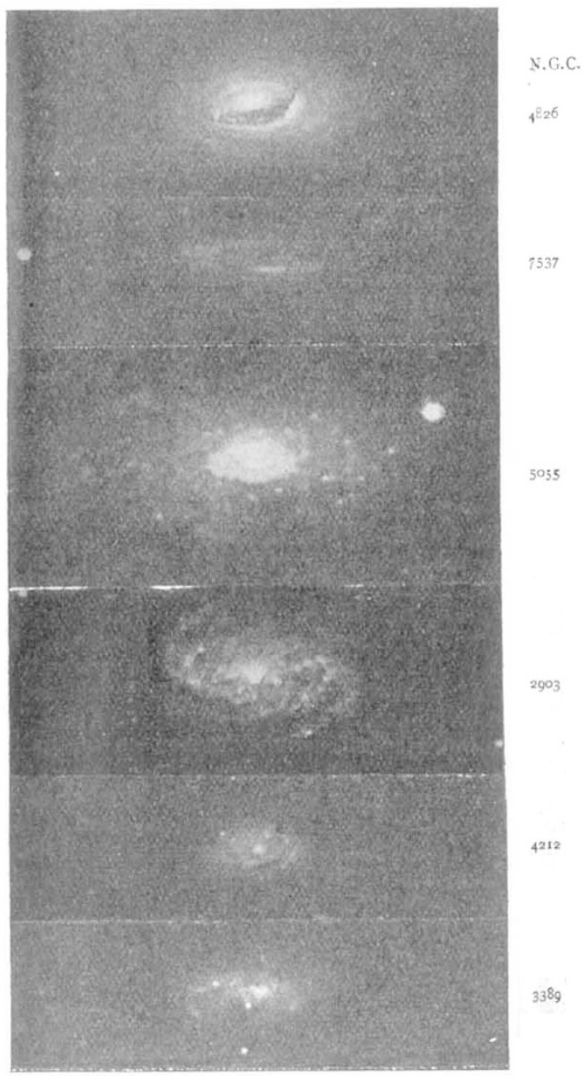

FIG. 3.—Spiral nebulæ making a much greater angle with the line of sight, showing clear-cut dark lanes (2903, 4212), and a lane absolutely black and cutting across a whorl at the right end (4826). (H. D. Curtis.)

homogeneous truncated spheroidal shells under various conditions.

Prof. W. W. Campbell and Mr. J. H. Moore are the authors of part iv., which is devoted to the spectrographic velocities of the bright-line nebulæ (pp. 77–183). The observations are a combination of those made with the 36-in.

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refractor at Mount Hamilton and with the 37-in. Mills reflector at Santiago, Chile, and they were commenced in the year 1913. The list includes 138

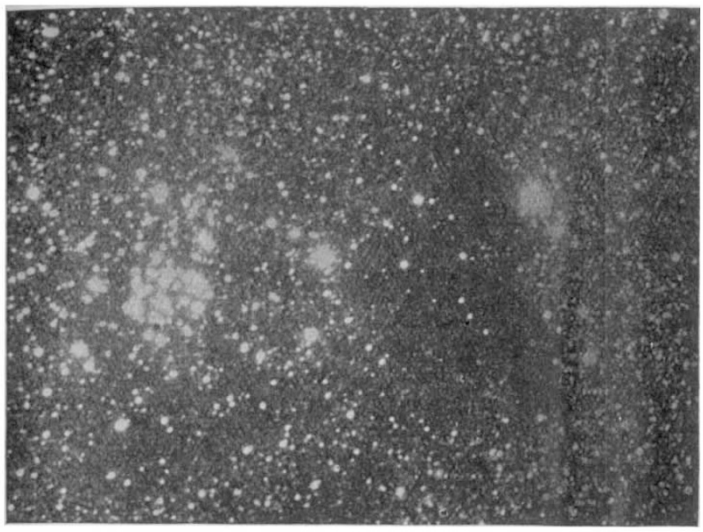

FIG. 4.—A "dark nebula" (17h. 57m., −27°50′) visible through its projection upon the background of stars, and not considered to be "a hole" in the Milky Way. Note the circular protuberance at the south-west corner, as clear-cut as an ink-drop and perfectly dark. (H. D. Curtis.)

nebulæ with bright lines in their spectra. In the earlier part details are given with respect to the spectroscopes employed, the probable errors of the results, and a description of the observations made at the two stations.

The detailed results of each object are then given in the order of right ascension. Attention may be directed to the fact that the lengths of the slits of the spectroscopes employed were in most cases more than sufficient to cover the width of the images of the objects photographed, so that the spectra of the central and outlying portions of the nebulæ should both be recorded.

In a further table the final deduced radial velocities of each object observed are given. The observations recorded are evidence of most extensive and arduous work, and the numerous observations of each object considerably emphasise

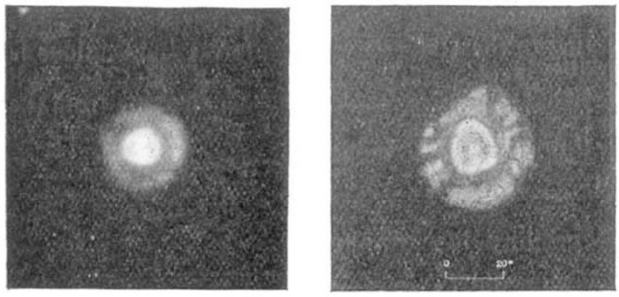

FIG. 5.—On the left a photograph of N.G.C. 2392, a double-ring planetary nebula; and on the right a composite drawing of the same made from several photographs to show details of the structure not attainable from any single photograph. (H. D. Curtis.)

this fact. The accompanying illustration (Fig. 6) shows a photograph of the chief nebular line in N.G.C. 2392, and exhibits the kind of structure displayed from which the internal motion of the nebula was deduced.

The average magnitudes of the derived values for the velocities are as follows: Calling the nebulæ less than 5 secs. in diameter "stellar," and those greater than 5 secs. "non-stellar," the mean velocity for thirty-one "stellar" nebulæ is 28 km. per sec., and for sixty-five non-stellar nebulæ 31 km. per sec. with reference to the stellar system. For evidence of rotation or internal motion in the planetary nebulæ, the lines in the spectra of forty-six such objects have been examined in detail and are here discussed. Of these, twenty-five gave evidence of internal effects, while nineteen, and possibly two more, indicated rotations about axes roughly perpendicular to the line of sight. It is worthy of note that the most elongated planetary nebulæ showed the highest rotational speeds.

The study of the radial velocities of numerous parts of the Orion nebula shows a range in velocities from +9·7 km. to +24·9 km., and, as the authors state, the results do not favour the hypothesis of a rotation as a whole, but the observed differences appear to be local or regional in character.

Mr. R. E. Wilson contributes part v. of this volume (pp. 187–90), which deals with the radial velocity of the greater Magellanic cloud. In 1914 it was pointed out that several gaseous nebulæ in this region exhibited very large and approximately equal radial velocities, so Mr. Wilson presents the esults of his study f the cloud as a hole. The author pholds this view fter his survey, for e finds that, observ- ng seventeen planet- ry nebulæ in this egion, the radial elocities lie between -251 km. and +309 km., an average of +276 km. Correcting this mean for solar motion, the mean velocity is +261 km. per sec. This average, compared with the mean velocity deduced in part iv. for other planetary nebulæ, points to

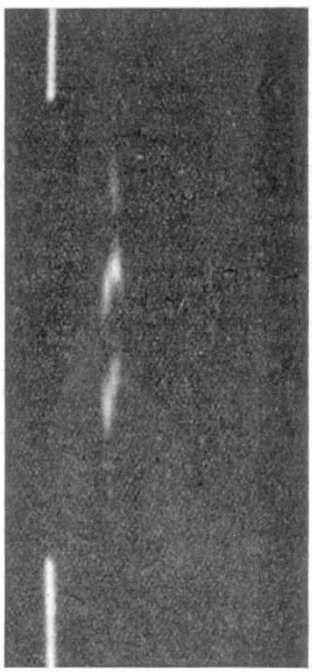

FIG. 6.—A photograph of the chief nebular line in N.G.C. 2392. The slit of the spectroscope was placed along the major axis of the nebula. (W. W. Campbell and J. H. Moore.)

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exceptional conditions in this region. Mr. Wilson refers to the spiral appearance of this great cloud and to the high velocities observed in spiral nebulæ, nebulæ which may be considered as isolated island universes similar to our Milky Way system, suggesting that the great cloud may afford an opportunity for the study of detailed characteristics of spiral nebulæ.

Part vi., the last of the series of the important contents of this volume, is contributed by Mr. W. H. Wright, and deals with the subject of the wave-lengths of the nebular lines and general observations of the spectra of the gaseous nebulæ (pp. 193–268). The matter falls under three headings: (1) The measurement of wave-lengths and the intensities of the nebular lines; (2) the study of the nebular nuclei; and (3) the investigation of the distribution of nebular radiations throughout the nebulæ; and is accompanied by a series of plates, which demonstrate, more than text can do, the fine definition and great scale of the photographs of the spectra of the nebulæ which served as his data. Fig. 7 is an illustration of the spectrum of N.G.C. 6818, taken with the slitless spectrograph with an exposure of four hours. It does not seem that the statement could be contradicted that the wave-lengths and intensities of the nebular lines deduced will be used as a standard in this branch of physical astronomy for some time.

This research is very opportune, because more detailed facts were required to help in the unravelling of the relationships between nebulæ as such, nuclei of nebulæ, and bright-line stars such as Wolf-Rayet stars. As the whole problem of the nature of stellar evolution is that of the solution of the relationship between nebulæ and stars, the study of the question is of vital importance. The idea of a falling temperature continuing throughout the whole life-history of a star has more recently given place to the hypothesis, apparently a very natural one, of a star in its early career increasing in temperature, reaching a maximum of development and temperature, and afterwards cooling until the invisible stage is reached. In the light of these hypotheses Mr. Wright, as the result of his research, expresses his view as follows:—

> There are at present two general conceptions as to the nature of stellar evolution, one of which assumes a falling temperature throughout the period of a star's development, while the other predicates a rise to maximum and a subsequent decline; both of these views assume the nebula as the primordial state. As between these two hypotheses, the present observations undoubtedly favour the first, since they add to the proof that the gaseous nebulæ are associated only with the hot stars.

While the above is one of the main conclusions derived by Mr. Wright from this research, there are many other points of particular interest to which limitations of space forbid reference in this article.

It is interesting to compare a direct photograph of a nebula with its spectrum taken with a slitless spectrograph. Nebulæ when photographed with the latter instrument present remarkable varieties of form and size corresponding to different nebular lines in the spectrum, while the direct photograph shows only a form resulting from the integration or the fitting together of the component images of the different forms and sizes. The prismatic images afford a means, therefore, of detecting the differences in distribution of the component gases of the nebula, and indicate that the view of a nebula in a telescope or on a direct photograph is not the best means of studying the complex structure of these bodies.

In conclusion, it may be stated that this addition to the University of California Publications is a valuable contribution, and sustains the high standard of the researches which emanate from the Lick Observatory under the able directorship of Prof. W. W. Campbell.

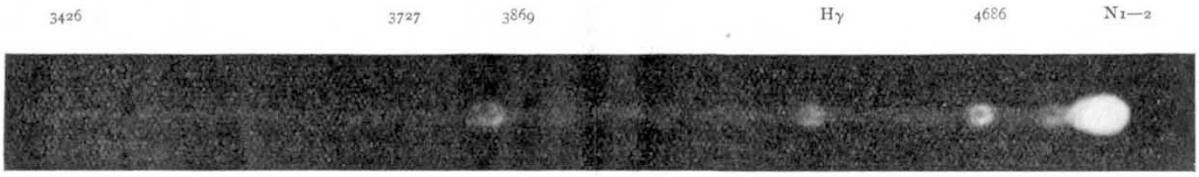

FIG. 7.—The spectrum of N.G.C. 6818, which records images of a variety of shapes and sizes, most of them having the appearance of a horse-shoe, the open end of the shoe lying to the north. Some of the images show mottlings or condensations scattered along the shoe or ring. (W. H. Wright.)

The Importance of Meteorology in Gunnery.

By DR. E. M. WEDDERBURN.

AT the commencement of the war the knowledge of the effect of wind and of the density of the air on the flight of a shell was elementary. It was assumed by the gunners that the wind was of the same direction and strength at all heights reached by the projectile, and that the density of the air decreased with altitude according to an artificial convention. The corrections for wind and density which the gunner was taught to apply were supposed to be referable to the meteorological conditions observed by him at the battery, but he was not taught how

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