

The Classification of Spiral Nebulae.

IN *The Observatory* for June 1927, Mr. J. H. Reynolds has criticised a classification of nebulae which I published recently as a preface to some rather general statistical investigations*. Mr. Reynolds is a friend whose acquaintance with nebulae is very extensive and whose criticisms I shall always welcome. Many of his comments are certainly well founded, but there are a few which I believe should be answered.

THE CLASSIFICATION.

The classification under discussion arranges the extra-galactic nebulae in a sequence of expanding forms. There are two sections in the sequence, comprising the elliptical nebulae and the spirals respectively, which merge into one another. The elliptical nebulae range from the globular E₀ to the lenticular E₇, the cypher indicating the ellipticity of the image (omitting the decimal point) as derived from the ratio of the axes. The spirals might possibly be treated in the same way, but the ratio of the axes is insensitive as a criterion and is replaced by conspicuous structural features. Of these there are three which determine positions in the sequence: (1) the relative size of the unresolved nuclear region, (2) the extent to which the arms are unwound (the openness or angle of the spiral), (3) the degree of condensation in the arms. These three criteria are quite independent, but as an empirical fact of observation they develop in the same direction, and can be treated as various aspects of a single process. This correlation leads directly to the sequence as a basis for classification †. The criteria are not always consistent, it is true, but the combined evidence usually serves to establish general positions without much uncertainty. The "spread," in short, is reasonably small compared to the "length" of the sequence.

The sequence of the spirals is subdivided into three sections of approximately equal "length," termed "early," "intermediate," and "late," respectively. This is an arbitrary procedure, and is adopted merely because it is possible to distinguish the middle section from the two ends. The nomenclature, it is emphasized,

* *Mt. Wilson Contr.*, No. 324; *Astrophysical Journal*, lxiv. p. 321, 1926.

† The "barred spirals," a distinct type, were arranged in a similar subordinate series. Their numbers are a small fraction of the numbers of normal spirals.

refers to position in the sequence, and temporal connotations are made at one's peril. The entire classification is purely empirical and without prejudice to theories of evolution—comparison with theories will be the more significant for this very reason. Moreover, since the classification was devised primarily for statistical studies, the orientation of nebulæ was ignored in so far as this was possible.

In actual practice the system works very well. Among upward of a thousand spirals which I have examined, not more than a dozen have refused to fit into the sequence, and in less than ten per cent. has there been any considerable doubt as to their general position. Since reading Mr. Reynolds' criticisms I have reclassified the 290 spirals listed in the paper on which he comments. In only eight cases do the revised types differ from those originally assigned, and some of these are obvious mistakes in the latter. Even admitting an unconscious bias on the part of the author, this is satisfactory for statistical purposes.

Finally, a statistical investigation of Holetschek's nebulæ, including all the brighter and a representative collection of the fainter ones down to a definite limiting magnitude over about three-fifths of the sky, has furnished quantitative results which justify the classification in a very evident manner. The sequence, which was derived from structural features alone, presents a smooth progression in mean surface brightness and in diameters for a given total luminosity. Moreover, among the nebulæ of a given type, or stage in the sequence, the mean surface brightness is constant, since the total luminosity varies with the square of the diameter. As a result of these numerical relations, the extra-galactic nebulæ can be reduced to a standard type and treated statistically as a homogeneous group. There are residuals of course, and at times they are considerable, yet the correlations are evident and, in the opinion of the author, fully justify the general scheme of the classification.

THE CRITICISMS.

(1) Mr. Reynolds disagrees with this conclusion, declaring that "the classification of the spirals is altogether too simple for the great range in types to be found. . . ." A great range in structural details is admitted, and for this very reason a first general classification should be as simple as possible. In actual practice, however, three separate criteria were employed. That the three combine to establish a general sequence is an observational fact

and the reason for choosing the sequence as the basis of classification. Other possible criteria were examined, and discarded because they exhibited no apparent correlations among themselves.

Mr. Reynolds' objections, I suppose, can be stated in another way—that the residuals about the path of the sequence are so large as to destroy the significance of the sequence. This involves quantitative tests, and considerable data may be found in the paper under discussion. Mr. Reynolds does not comment upon the actual results; he criticizes the method by which they were derived, questioning the validity of combining Holetschek's visual magnitudes, measured with a 6-inch refractor, with angular diameters measured on photographs with large reflectors.

The essential features of the investigation were a homogeneous list of diameters and a homogeneous list of magnitudes. Since the distribution of luminosity over the images varies continuously throughout the sequence of types from the compact globular nebulæ to the open spirals, it was necessary to use total luminosities in order to treat all types in a uniform manner. Holetschek's list contains the best approximations to total luminosities which we possess in large numbers, and no systematic errors are known that are large enough to invalidate the general order of results of statistical analysis. His values compare favourably, for instance, with the photographic ones which Shapley and Miss Ames derived from Harvard plates for some 60 nebulæ in the Virgo Cluster*, among which are represented all stages in the sequence of types. Even where the bulk of the luminosity is confined to the nuclear region, the measured values are still fair approximations to the total magnitudes. I see no reason why this list should not be combined with a list of diameters derived from a moderately homogeneous group of photographic plates. If this conclusion is admitted, the residuals from the correlation curves become significant, and in a general way they justify the classification, at least as a basis for preliminary statistical studies.

(2) Mr. Reynolds, after mentioning only one of the criteria used in my classification of spirals, the degree of condensation, continues:—"There are at least two other criteria which should be taken into account in any classification which is to be used statistically, as Hubble has done in the paper mentioned. No classification would be complete unless the development of the

* *Harvard Circular*, No. 294, 1926

spiral form itself were taken into consideration." On this last we would seem to agree, for I have devoted the first two of my three criteria to it.

Mr. Reynolds, however, has something else in mind, for he adds:—"It (the development of the spiral form) is to a certain degree an indication of age, as a spiral developed through two revolutions of the spiral with many subsidiary arms must have taken longer to develop than the rudimentary examples developed only through half a revolution. It by no means follows that this criterion is in agreement with the development of condensations. . . ."; and he mentions M 33 as a "condensed" spiral developed through a little over half a revolution. Certainly the number of revolutions shows no pronounced correlation with the degree of condensation in the arms. In fact it is not conspicuously correlated with any of the other general features of spirals (except perhaps the thinness of the arms), and for this reason was rejected as a criterion of classification in favour of the openness or angle of the arms. The infrequent cases where the arms can be traced through two revolutions are found among the spirals most similar to the lenticular nebulæ, as well as among those most dissimilar.

Mr. Reynolds' statement concerning the age of spirals appears to be an intuitive judgment, and as such has little bearing on an empirical investigation. In the same spirit, however, the openness of the spiral arms might be suggested as a criterion of age with fully as much justification as the number of revolutions—and there is no obvious correlation between the two. There is no need to labour over the point. The number of revolutions is a feature of interest, and eventually it may prove to be of critical importance. At present, however, the significance has not been established, and in the absence of correlations with other general features, it does not seem profitable to use it as a major criterion of classification.

(3) The other criterion which Mr. Reynolds wishes to include and which he feels to be of still greater importance, is the "general apparent mass of the spiral." He differentiates, it will be remembered, between the "massive" spirals, such as M 33, and the "filamentous," such as M 74*. I believe that this is a very significant distinction which may lead to quantitative criteria of absolute dimensions when it is worked out in detail. Its position in a general classification, however, will then be similar to that of

* *Monthly Notices of the R. A. S.* lxxxv. p. 142, 1924.

absolute magnitudes in the sequence of stellar spectra. It will serve to subdivide the general classes, and will be taken into account by subscripts to the class symbols. If this view is correct, the significance of "apparent mass" will be admitted and welcomed without prejudice to the sequence of types.

I hope Mr. Reynolds will continue his investigations along these lines and develop the criterion in a quantitative manner. So far as one can judge from the stars involved in spirals, and these are at present the only indications we have as to distances of individual nebulæ, the "massive" spirals are indeed larger systems than the "filamentous." M 31 and M 101 represent about the extreme range in total luminosities of which we are reasonably certain. As yet we have only glimpses of the general luminosity function of extra-galactic nebulæ, although the objects whose distances are established, the differences in luminosity between nebulæ and their brightest stars, and the frequency distribution of luminosities in a half dozen clusters of nebulæ, all indicate a range of the order of perhaps five magnitudes. Further investigations, I venture to believe, must proceed along statistical lines, and a classification adapted to that type of research is very desirable.

(4) Finally, Mr. Reynolds believes that the edge-on spirals are not adequately dealt with in my classification. He urges that they be incorporated into a separate class and further described according to the ratio of the axes and pattern of the absorption. Some precision is certainly sacrificed by including the edge-on objects on the same footing as the others, but the amount can easily be exaggerated. The early-type spirals are readily identified, and most of the difficulty is confined to distinguishing between the intermediate and the late types. Even among these latter, a considerable proportion can be placed with some confidence on the basis of the degree of condensation in the arms and the distribution of luminosity over the image. The heavy peripheral belts of absorption which sometimes obscure the condensations are for the most part confined to the earlier types, where the classification can be estimated on other criteria. Among the 290 spirals classified in the paper under criticism, less than a dozen gave trouble because of their orientation. In these cases the uncertainties were but moderate fractions of the run of the sequence, and, in general discussions of spirals, the errors should tend to cancel out. The difficulties, I believe, are scarcely sufficient to warrant the introduction of an arbitrary class which would destroy the homogeneity

of a classification suitable for statistical discussions of numerical data.

This last aspect of the question seems to me to be of considerable importance. A simple homogeneous system has been formulated which classifies the great majority of nebulae in a fairly definite manner and which, by quantitative tests, has proved to be suitable for statistical investigations. Other systems may handle these matters in a more effective or significant manner, but, until they are formulated and tested, I see no reason for abandoning the present scheme, even though it does ignore some interesting details of structure.

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1927, July.

The Satellite Question.

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At an extraordinary meeting of the Solar Branch of Celestial Bodies, Ltd., the proposed Satellites Disputes Bill came up for discussion.

The Sun having occupied the focus, the minutes of the last meeting were read by the secretary (Mercury) and duly approved.

The Sun rose and said he wished to call their attention to the unsatisfactory conduct of certain of the satellites. These, he complained, were in the habit of interposing periodically between their primaries and himself, with the result that he suffered eclipse and lost prestige and dignity. This eclipse policy, he continued, had been deliberately adopted by the Satellites' Union. There could be no excuse for it, as, with the whole of the heavens at their disposal, satellites might easily arrange their orbits so as to avoid this annoyance.

He wished to make his own position as luminous as possible. His business was to provide central heating and lighting for the whole solar system. He endeavoured to give satisfaction. Personally he resented any attempts, whether organised or not, to interfere with the execution of his duties. He would instance the total eclipse programme which had been attempted on June 29th. He had recently received many complaints from the Earth that on that planet they were not receiving their due quota