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THE CLASSIFICATION OF NEBULAE.

The Primary Division

The primary division of nebulae into galactic and non-galactic is sharp and fundamental. The classes are mutually exclusive and uncertain objects are extremely rare. A casual inspection of the photographic image is in almost every case sufficient for this primary differentiation.

Galactic nebulae are best described by the subdivisions into which they naturally and unavoidably fall. They are (a) Planetaries and (b) Diffuse nebulae the latter being either luminuous or dark. Non-galactic nebulae are the spirals, spindles and small, structurless objects that crowd the regions of high galactic latitude.

These primary classes are characterised by certain groups of criteria, no single unit of which is sufficient for precise definitions and delimitations. Scarcely a statement can be made concerning an individual criterium to which obvious exceptions do not exist.

Galactic nebulae tend to concentrate in low galactic latitudes while the non-galactic favor high latitudes.* The conspicuous overlapping in apparent distribution is attributed to the effect of perspective, modified by such minor group traits as the tendency of the diffuse nebulae toward the inclined belt of bright B stars[1], and of spirals toward the hemisphere complementary to that favored by globular clusters.[16]

Stars are actually involved in or conspicuously associated with galactic nebulae, while the non-galactic show no relation to individual stars except in the rare phenomena of novae in spirals.[1] Stars are probably the source of luminosity of galactic nebulae,

* The Magellanic clouds with their nebulae of the galactic type are exceptions to this statement.

and excerise a considerable influence in determinign their form[2]. Even the angular extent of the luminosity is a function of the magnitude of the associated stars[2]. Dark nebulosity is of course exceptional in these respects but it is probably the same sort of material as luminous diffuse nebulosity and is known only by its effect on apparent star distribution. Non-galactic nebulae show no effect whatsoever upon star distribution.

Galactic nebulae have early type spectra while non-galactic nebulae have late type spectra.* Spectra of the former are emission, or, if continuous or absorption, of the B type.[1,2,3] Hydrogen, Helium and Nebulium produce the characteristic lines. Non-galactic nebulae have absorption specgra of types ranging from F to K, with occasional emission lines of Hydrogen and Nebulium as minor features.[6] The earlier typefound by Slipher for the spiral N G C 278 is a marked exception.[5] 3034 etc

Galactic nebulosity is never granular, while non-galactic is often conspicuously granular. Galactic nebulosity can be described as wispy, filamentous, or smooth and cloudy. Non-galactic nebulosity is smooth and cloudy or granular as in the arms of many spirals. The designation smooth and cloudy is replaced in this report, by the shorter term amorphous which is used in the geological sense of being undifferentiated, and signifies that nebulosity of this type shows no indications of being resolved by the greatest optical powers at present available. The granular type appears as stellar or semistellar condensations in an amorphous matrix.

It is extremely difficult to differentiate precisely between the characteristic forms of galactic and non-galactic nebulae. This is due in a large measure to the fact that planetaries and non-galactic nebulae both furnish strong evidence of radial and rotational symmetry, in the former type of object about a star and in the

* If the diffuse nebulae with continuous spectra are shining by reflected star-light we may expect occasionaly to find late type absorption spectra. The case of Messier 33 suggests the possibility that when emission lines are observed in non-galactic nebulae spectra, they are localized in a particular part or feature of the nebulae.(11)

NGC 4449 & 4214

latter, about a non-stellar but highly condensed nucleus. The simplest method will be to proceed immediately to summarize the characteristic groups of features, including forms, pertaining to each of the classes previously mentioned. This will eliminate a long and necessarily involved discussion on form which is of theoretical rather than of practical importance.

The classes commonly distinguished are Planetaries, Diffuse and the non-galactic objects.

Galactic Nebulae.

Planetaries are recognized by four characteristics.#

a. Emission spectra of the nebulosity.

b. Central Star.

c. Symmetrical distribution of the nebulosity about the star.

d. Sharply defined edges.

The first is a necessary condition. The emission spectrum consists of lines due to Nebulium, Hydrogen, and Helium, with occasional faint traces of Nitrogen and Carbon.[4] In most cases the N_1 line is the strongest in the photographic region, the usual intensity relation of N_1, N_2 and $H\beta$ being 10-3-1.[3,4]. The continuous spectrum where present at all is extremely weak.[4]

The normal form of the planetary is a well defined disc or a pattern of concentric rings, not necessarily coplanar, about an accurately centered star.[9] The star cannot always be detected, but the data available on luminosity relations between nebulosity and stars raises a strong presumption that the difficulty in such cases is a mechanical one of resolving and light gathering power.[2] Exceptional cases are known in which one or both of the criteria c and d are lacking either apparently or actually, and in two or three cases the data are sufficiently discordant to render the classification uncertain or questionable.*

* Messier I, the Crab nebulae in Taurus is the most striking exception. Each condition is fulfilled but to a rather wide approximation.

\# J. H. Reynolds summarizes the principal characteristics as three — an emission spectrum, a central star, and a definite circular, elliptical or compound elliptical outline (MN vol 80 p 200 1919)

In apparent distribution, the planetaries concentrate towards and define the galactic plane.[9] The ocasional individuals found in high galactic latitude are exceptionally large and hence presumably near. The small planetaries are most numerous in the portion of the Milky Way between R. A. 18 and 20 hours, the general direction of the ~~cluster~~ center of the galactic system as observed from the earth.

<u>Diffuse Nebulae</u>

Luminous diffuse nebulae show wisps, filaments or amorphous clouds apparently oriented in fields of force originating in particular stars or groups of stars which are either involved in or conspicuously associated with the nebulae.* Evidence of rotational equilibrium, so conspicuous among many of the plantearies, is absent from the diffuse nebulae, and radial symmetry, while generally indicated, is less prominent than in the former class.

The spectra of diffuse nebulae are emission, continuous (or absorption)# or a mixture of the two, apparently depending upon the spectral types of the associated stars[1]. In emission spectra the lines are much the same as in the planetaries although N_1 and N_2 are weaker, N_2 never being so bright as Hβ. The continuous or absorption spectra so far observed are not later than the type B.

Dark diffuse nebulosity is detected by its obscuration of stars or portions of luminous nebulosity. Many of the luminous diffuse nebulae fade gradually into dark nebulosity (Messier 20, Messier 42) and indeed can be readily considered as local illumination of dark clouds in the neighborhood of particularly bright stars.[1] Dark nebulae may be semitransparent or entirely opaque, both types being well represented by the lanes in Taurus. Prolonged ~~exposures often indicate an extremely feeble luminosi~~ty

* The form and orientation appear to be due to a combination of attractive and repulsive forces among which gravitiation and radiation pressure are obviously important. There is considerable evidence for the theory that the luminsoity of galactic nebulae has its origin in the associated stars.[1]

\# The nature of the spectra of several diffuse nebulae is known only from slitless spectrograms. These furnish fairly reliable data on the presence or absence of strong emission lines but cannot in general reveal the presence of absorption lines. The term continuous as applied to nebular spectra signifies a continuous spectrum in which no absorption lines have been detected although they are probably present.

exposures often indicate an extremely feeble luminosity and often too, the eye at the telescope can distinguish a dull grayish quality in the field of view distinctly different from the normal background of the sky. The "black drop" in Sagittarius, Barnard No. 92, is an example. There is good reason for supposing that dark diffuse nebulosity is the same sort of material as the luminous, indeed that the latter is but a special case of the former which consititutes the great proportion of diffuse nebulosity in the Galactic system.

In the matter of distribution also the luminous and dark diffuse nebulosities are similar. They concentrate along two planes, the galactic plane and the inclined plane of the brighter B stars.[1] In these respects they are regarded as galactic objects in the same sense as are the B stars.

The relation between luminous and dark nebulosity is so intimate that a division for the purposes of classification is an arbitrary matter depending largely upon selected standards for observing conditions. Some diffuse nebulae are predominantly luminous and others are predominately dark, but all stages between these two states are readily found on the photographic plates. Precise numerical grades are extremely difficult to establish and relatively unimportant for most purposes. The simplest procedure will be to classify the diffuse nebulae as predominantly luminous, predominantly dark or conspicuously mixed. These classes can then be designated for cataloguing as L for diffuse luminous, O for diffuse dark and LO for the mixed sort.* If a precise boundary between L and O is desireable the Franklin-Adams charts or better still the original plates from which the charts were made suggest themselves as a suitable standard for reference.

O already used for stellar type and so why not use another letter, D?

III Non-Galactic Nebulae

In general, the non-galactic nebulae have relatively bright, central,

* The term obscure with its abreviation O calls attention to the feature by which dark nebulosity is recognised, saves a repetition of letters in the cataloguing symbol, and satifies the requirements for an international nomenclature.

non-stellar nuclei from which the nebulosity fades away indefinately. The nebulosity is symmetrically distributed with respect both to the nucleus and to a plane through the nucleus. The asymmetry appears to be of the rotational type. The forms can be represented as the projection of objects ranging from globular through various degrees of flattening to thin discus shaped figures tilted at all angles to the line of sight. Spiral arms springing out from the central regions are conspicuous features of amny of disci, and it is in these arms that the granulation or condensation in the amorphous matrix is generally found. Local obscuration is a general phenomenon in spirals[8] and is most frequently, though by no means always, found in the outer regions of the nebulae. It is occasionaly found in non-galactic nebulae which are clearly not spirals.

The spectra of non-galactic nebulae are normally absorption spectra ranging from late F to K.[5,6] A very few areknown to contain bright lines of Nebulium and Hydrogen, which in one case at least, Messier 33, are localized in a particular portion of the nebula.[11] All emission lines recorded to date are in nebulae in which granulation is conspicuous. The data however, is too meagre to justify a definite conclusion. V. M. Slipher reports one nebula with an early absorption spectra-NGC 278[5]. At present this must be considered as a remarkable exception, although more extended observation may change accepted views.

A very few objects (NGC 2366, 4449 etc.) are exceptional in that they show no dominating nucleus, asymmetry of form, or evidence of rotation, yet their high galactic latitude, their late type spectra, and their granular texture place them unquestionably in the non-galactic class.

The details of distribution of non-galactic nebulae are known only in vague terms. Generally speaking they"avoid the milky way" and their numbers increase with increasing galactic latitude. Reynolds however, has shown that distribution in galactic longitudes is equally important for the spirals at least.

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which, again speaking generally, are mutually exclusive with the globular clusters. There seems no reason at present for distinguishing the spirals from other non-galactic nebulae regarding their distribution. They are however very rarely found in galactic latitudes less than 15° and thus, considering the hundreds of thousands in the higher latitudes, they justify the term non-galactic.

Preliminary Classification

The remainder of this report will concern itself for the most part with the further classification of non-galactic nebulae. The preceeding paragraphs are thought to contain very little of a new or controversial nature, and can be summarized in a tabular form.

All nebulae are divided into

	Designation
I Galactic	
A. Planetary	P
B. Diffuse	D
1) Luminous	D L
2) Obscure	D O
3) Mixed	D L O
I Non-Galactic	

For D use A?

This table amounts to the classification made by H. D. Curtis with a slight rearrangement and a change in nomenclature.[10] The nomenclature requires some comment. Planetary and Diffuse are terms established by long usage, and are without serious rivals. There is no good reason for ~~abending~~ abandoning them. Furthermore they are international in that similar terms are current in the astronomical literature of many foreign languages. Finally, the initial letters, in their capital forms, are not already preempted for cataloguing pruposes.

Planetaries and Diffuse nebulae are commonly spoken of as galactic objects in the same sense as Wolfe-Rayet, N stars, novae etc. In contrast, the other nebulae are non-galactic. No other criterium of nebulae classification is more distinctive of the two classes, nor lends itself so well to a balanced nomenclature. The terms are distincitve, concised and balanced, are already current with similar connotations, and are international in their roots. The terms galactic and non-galactic do not immediately suggest suitable cataloguing symbols, but this is not a serious defect. Galactic nebulae will certainly all be catalogued by the subclasses as P or D and an analogous procedure should be followed for the non-galactic. It will be understood that non-galactic refers to apparent distribution only, and has no reference whatsoever to that highly controversial issue, the island universe theory of spirals.

The term "obscure" rahter than dark has been used as a complement to "luminous" for practical reasons. It transfers more readily into other languages and saves a repetition in the cataloguing symbol.

The galactic nebulae are limited in number and fairly well known. There are about 130 planetaries and 150 luminous diffuse nebulae on record, and future additions to these lists are expected to be unimportant. Special investigators can carry them all in mind and discuss them as groups without serious uncertainties arising from incomplete data. Even the obscure diffuse nebulae, although uncatalogued, are pretty well known in a general way by all students of milky way structures. The result is that further subdivision of the galactic nebulae is not an immediately pressi pressing concern. Moreover it would require more detailed knowledge of the individual objects than we possess at present, and hence should wait upon the special investigator who will confine his attention for the time to a single group.

Further Classification of Non-Galactic Nebulae

The non-galactic nebulae present an entirely different sort of problem. Hundreds of thousands of these objects are known to be within reach of existing telescopes. They possess a few traits in common but also many variations. A reasonably thorough knowledge of these variations and, if possible, a physically significient classification is the first step in the study of these nebulae as a group.

No such classification exists at present. The result is confusion in the literature and widely differing interpretations are placed upon similar terms. Curtis' suggestion that all non-galactic nebulae are really spirals,[7] cannot be maintained[15, 1]. However his recognition of the Ø shaped or barred spirals as a distinct subdivision is a contribution of permanent significance.[7] Wolf's classification[12] is merely what it claims to be, a scheme for 'pigeon-holing' data awaiting further study. It is too arbitary and depends too largely upon mere orientation to be the basis for a significant classification.

The published suggestions of J. H. Reynolds are thoroughly sound, but they have not been worked into a complete and organized system. He[15] and Knox-Shaw[13] were the first to discuss the globular nebulae recognizing that many of those round or nearly round non-galactic objects, condensing sharply toward the center, show no traces whatsoever of spiral structure. Reynolds introduced also the term amorphous, emphasizing the unresolvable character of much of the nebulosity in non-galactic objects.[14,17] He pointed out that in spirals the amorphous nebulosity favors the nuclear regions while the granular type is largely confined to the outer portions of the arms, and that the granular arms build up at the expense of the amorphous nuclei.

Following these lines of progress, Reynolds[17] has formulated seven classes of true spirals, rather cautiously excluding the so called spindles although he considers them as undoubtedly spirals seen edgewise. The first five classes represent a series with increasing degree of condensation in the amorphous matrix of the outer arms, and the last two represent, the one an exceptional type in which the condesnation starts in an intermediate zone of the arms, the other, objects in which symmetrical lines of development have not been followed at all.

This classification, although incomplete, is well founded and very suggestive. The criticisms are of a minor character. For instance the first class, spirals consisting entirely of amorphous nebulosity, is rather problematic. The two examples he names are unfortunate, NGC 205 is not a spiral and NGC 3623 (M65) is not entirely amorphous, falling rather into its sixth class. Perhaps NGC 4762 would more nearly fulfill the condition. Curtis's ø-shaped spirals are ignored or possibly put into the class of irregulars, although they are fairly numerous and present a development parallel to and fully as symmetrical as the logarithmic spirals. Finally, as he states, the wholly amorphous non-spirals, globular and elongated, are not included in the classification.

Jeans in his Problems of Cosmogany recognises as separate types Irregular, Planetaries, Rings, Spirals, and a group including nebulae termed elliptical elongated, lenticular and spindle, an undetermined percentage of which are spirals seen nearly on edge. This obviously is not an attempt at a formal classification and need not be criticise as such. The noteworthy feature is that, following Reynolds, he does not consider all elongated non-galactic nebulae as spirals on edge, and this conclusion forms a considerable part of the observational justification for his theory of the origin of spirals.

Jeans' investigation however is truly theoretical-deductions from very general assumptions-and observational data are mentioned merely to illustrate the soundness of his conclusion. Therefore the observer may well look to Jeans' theory for the thread of physical significance that shall vitalize a system of classification of non-galactic nebulae. In the scheme presently to be proposed, a conscious attempt was made to ignore the theory and to arrange the data purely from an observational point of view. The analogy however was so suggestive that at several points where approximately even choices were offered, there was no hesitation in accepting the one favored by Jeans' theory of spirals.

REQUIREMENTS FOR A SYSTEM OF CLASSIFICATION

An acceptable classification of non-galactic nebulae should satisfy the following conditions.

a) It should be based upon simple inspection of photographic images. All but a very few of these nebulae are too faint for reliable visual or spectrographic observations. The vast majority can be studied only through the medium of photographic plates. In addition to their range and definition these plates furnish permanent records, the intercomparison of which may be expected to determine the criteria of classification. This procedure reduces the possible criteria to form, structure and texture.

b) It should apply to instrumental powers of a reasonable range. Since the criteria are to be found in photographic images, the scales, speed and resolving powers of telescopes, exposure affect the problem to a considerable degree. A lower limit in brightness and size, and hence an upper limit to the number of classifiable objects, is set by the dimensions of the instrument, the exposure times and the plates employed. Beyond these limits all sorts of objects appear as hazy patches which practically defy classification. These difficulties are inherent and unavoidable. The simpler the criteria, however, the greater the usable range in instrumental equipment.

There appears to be a more or less general agreement that the proper instruments for investigations of forms of nebulae are reflectors or camera lens of apertures from about 20-inches up and focal ratios on the order of 1 to 5. Fast plates, such for instance as the Seed 30, ~~the~~ and minimum exposures of from one to two hours with these instruments should furnish the reasonable range conformable to which the criteria should be chosen.

c) It should be independent of the orientation of the nebulae in so far as this is possible.

Whatever the possibilties it offers for studying the relations of spirals to the rest of the universe, of planes to the direction of motion, of galactic fields of force, oreāntation must be recognised as an irrelemant accident in so far as it concerns simple classification. The so called spindles in which any structure whatever can be discerned are almost certainly spirals on edge, and the slight possibility of their being strange non-rotational figures doesnot justify the creation of a sepperate sub-division.*

Any of marked sym. Spindle shapes are practically true Spirals on edge for we have no sym. nebulae that is not spiral more or less doubtful.

d) The sub-classes should form a sequence if possible.

e) The system should permit further division without destroying the balance of the classification.

f) The systen shodld reduce exceptions to a minimum.

g) The nomenclature should be builded on roots common to several languages and capable of symbolic representation by single Latin letters or short combinations of letters not already in general use with specific connotations. These conditions are for the purpose of avoiding confusion and of economical cataloguing.

Footnote

*Two or three elongated objects are known which are probably neither spiral nor other figures of rotation. Examples are NGC 3034. (M82) and NGC 4756. However there is every reason to suppose that the numbers of such nebulae are neglible. The simplest procedure is to presume that all elongated nebulae which show any structure are spirals, and to admit an object exceptional only on the basis of strong evidence.

DATA OF OBSERVATION.

The study of photographs establishes the following data on the general appearance of non-galactic nebulae.

a) Central, highly condensed nucleii are almost invariably present. The least condensed which the writer has observed is that of

NGC 4649, (M60), which on the shortest exposures recording it on Seed 30 plates with the 100-inch reflector, measures about 5" of arc in diameter. NGC 221 and 224 (M32 and 31) have nuclei which are sensibly stellar. Visual observations with the 100-inch do not show sharp stellar images, but the higher the magnification employed, the closer these nuclei approximate to the appearance of star images. No nucleus has ever been observed as a true star.

b) Symmetry of a rotational type with respect to the nucleus is a general characteristic.

This statement is to a certain extent an extrapolation, for the imagination must be exercised in eliminating the probable effects of orientation and projection. Moreover a few objects must be recognised as irregular in this particulars and, significantly, in the absence as well of a dominating nucleus. An example is NGC 4449. The number of these objects is negligible and they may be treated as actual exceptions in a system of classification.

c) Three disticet forms can be recognised, structurless discs or ellipses, logarithmic spirals, and barred or ø shaped spirals. This division attempts to interprete the elongated nebulae showing internal structure as projections of spirals arising from orientation. It involves the usual assumption that spirals are normally thin discus shaped figures. The structureless elliptic nebular images cannot be freed from the effect of projection by any known simple criteria. They are termed structureless although they do possess some small claim to structure in that the luminosity fades smoothly away from the nucleus.

d) The nebulosity is of two types, amorphous and granular. The term amorphous is to be interpreted as unresolvable with the optical powers available. By indirect methods alone we can hope to determine the nature of such material whether it consists of gas, dust, meteorites or stars. The term granular can be described as semi-stellar condensations in an amorphous matrix.

The elliptical nebulae consist entirely of amorphous nebulosity. In the spirals, bith types of nebulosity are often found, but, as Reynolds has remarked,[14,17] the granular favors the outer regions of the arms, while the nuclear regions are usually amorphous.

e) Areas of obscuration are characteristic features of logarithmic spirals. They are foten found in the barred spirals as well, but are rarely seen in the elliptical nebulae. The phenomenon is very probably due to actual material, but its significance is not well understood. In a general way it favors granular nebulosity and the outer regions of nebulae, although it is sometimes found about the very nucleus itself. If the course of evolution in non-galactic enbulsoity is assumed to be from amorphous to granular, the phenomena of observation may be correlated with the stage of development and be regarded as a symbol of age.

The critteria of classification must be chosen from these general traits of the photographic images. The persistent feature is that of rotational symmetry about a dominating non-stellar nucleus. One group shows internal structure of a general spiral character and another group shows no structure save that of luminosity smoothly fading from the nucleus outward. This immediately suggests a first division of non-galactic nebulae into spirals and elliptic nebulae. Since the latter are entirely amorphous while the former shows more or less granulation and obscuration, there is some justification in considering the elliptical nebulae as representing an earlier stage of evolution, and placing them first in the order of subdivisions.

(The amorphous being smaller than the granulated spirals to be also younger than the granulated would be equivalent to saying that such nebulae are expanding.)

ELLIPTICAL NEBULAE

This type, comprising about one third of the brighter non-galactic nebulae, consists entirely of amorphous nebulosity. The surface brightness of the projected images diminished smoothly from relatively bright and condensed nuclei to indefinite borders. To several hours at least, the linear dimensions are a function of the exposure time. In form the individual nebulae range from round to spindle, the latter being most simply interpreted as thin discus shaped figures projected on planes perpendicular to the axis of rotation. All the figures can be represented as various stages of an originally globular mass condensed toward the center, flattening under the influence of increasing rotation.

The actual orientation is established only in the case of the spindles. In other cases, the form may be the projection of an ellipsoidal figure of any eccentricity inclined at the necessary angle to the line of sight. There is no simple method of determining the two unknowns in the individual case, and it is possible that they may be incapable of separation by direct observation. The ratios of axes of the projection images permit the application of statistical methods of investigation and, indeed, are the only criteria that can readily be derived from photographic plates.

The round or nearly round nebulae are clearly more numerous than can be accounted for by random orientation of thin disci, hence the existence of globular or nearly globular forms is probable. The suggestion is both obvious and reasonable that all forms from globular to thin disci are represented in the elliptical nebulae. The matter bears directly on nebular evolution and therefore cannot well be ignored. Since the final solution of the question will take the form of a statistical analysis of the ratios of axes of the images, these data are highly desirable.

The simplest procedure would probably be to express the ratios of axes by numerical postscripts, denoting a circular image by E1. and a much elongated image by say E3. In actual practise, however, the gradations in figure easily distinguished by the eye or not evenly spaced in such a system. For instance the difference between ratios 1.0 and 1.2 is about as conspicuous as that between ratios 2.5 and 3.5.

The excentricity offers a more uniform scale for eye estimates and has about the proper number of steps in the first significant figure. Elliptical nebulae have no definite borders and excentricities more accurate than can be expressed by one significant figure can be obtained only by such refined methods as microphotometry. For practical classification the simplest and most rapid method that has been devised consists in eye comparisons of the nebular images with a series of ellipses of excentricities 0.0, 0.2, 0.4, 0.6 and 0.8, sketched roughly on coordinate paper. The accuracy is fully as great as that of any ordinary method of measurement. For cataloguing purposes the decimal can be neglected and the excentricities can be expressed by single digits. Thus Eo would desiginate a circlar disc and E8 a very much elongated image.

SPIRAL NEBULAE

In general, all those non-galactic nebulae are spirals in which internal structure can be seen other than a steady decreases in luminosity away from the nucleus. There are two exceptions in this statement. In a very few of the elliptical nebulae small patches of obscuration are outlined against the amorphous nebulosity near the nucleus. An example is NGC 205. A few non-galactic nebulae, about 3 % of the several hundred examined by the writer, are quite irregular and form exceptions in any simple system of classification. Examples are NGC 2366,   and 4449. A few of these objects will doubtless be included among the spirals, since all edge-on nebulae showing structure are presumed to be spirals until proven otherwise, but the number will be negligible. Likewise a number of faint spirals with relatively bright amorphous nuclear regions will doubtless be inclosed among the elliptical nebulae. This will be serious only when near the limits of classification set by the instrumental powers employed.

The various classes of spirals are provisionally estimated to include about 60% of the brighter non-galactic nebulae. Difficulties arising from orientation are eliminated by the assumption, commonly accepted, that all spirals are thin disci, at least that the arms determine ~~the~~ a plane. The form obviously involves rotational symmetry about a more or less conspicuous nucleus. Granular texture and local obscuration are frequently found, especially in the outer regions.

Two extreme types are conspicuous. The one has a relatively large amount of amorphous nebulosity immediately about a bright condensed nucleus. From this central region spring closely coiled spiral arm in which are little or ~~mere~~ no granulation. On very short exposures, the nuclear region alone is seen, rather similar to the elliptical nebulae both in form and luminosity distribution. The other type has a fainter almost stellar nucleus surrounded by very little amorphous nebulsoity . The spiral arms approach much closer to the nucleus, are more open — unwound as it were – and are conspicuously granulated. Examples are NGC 4594 for the former and NGC 5457 (M101) for the latter. The gap between the two extreme forms is well filled and a series is readily constructed in which the granular spiral arms seemingly grow at the expense of the amorphous nuclear region, unwinding as they grow.

Carrying the series from the second stage toward the first, the increasingly amorphous central region and the diminishing relative importance of the spiral arms logically lead to the thin discus shaped and wholly amorphous elliptical nebulae. Likewise assuming the existance of the series among the elliptical nebulae ranging from globular to discus shapes, an extrapolation, made easy by Jean's theoretical discussions, leads to the first form of the spiral. There is thus some grounds for using the terms early type and late type spirals and considering the elliptical nebulae and spirals as a single evolutional sequence.

In the great majority of spirals, the arms start from the outer portion of an ellipsoidal amorphous central region, and wind outward in the form of equiangular logarithmic spirals. Most of the well known objects, such for instance as Messier 31, 51, 81, and 101 are of this type. There is a relatively small group, however, that assumes a different characteristic form. The arms probably follow the logarithmic spiral, but they spring abruptly from the extremeties of a bar of nebulosity running diametrically across the nucleus. This type has been described by Curtis and named by him the ø type spiral. Messier 95 is an example. "Its main characteristic" to quote Curtis,[7] "is a band of matter extending diametrically across the nucleus and inner parts of the spiral. Frequently the whorls in this type appear to begin at the ends of this cross arm. The general appearance is that of the Greek letter ø and I have termed such objects ø-type spirals for lack of a better name." He lists 23 examples out of some 513 non-galactic objects. In every case examined by the writer, the arms begin at the ends of the cross bar and hence the appearance suggests the Greek letter θ rather than ø. This distinction has some significance, for it is much more difficult to imagine physical causes of such a nature as would produce the ø shape with the bar extending beyond the arms than to account for the θ shape. However the interests of economical printing urge abandoning altogether the use of Greek letters for cataloguing symbols, and suggest some equivalent designation in Latin script. "Barred Sprials" might serve the purpose.

This type once formed appears to develop in a manner analogous to that of the logarithmic spirals. The early members are composed entirely of amorphous nebulosity. Their appearance, especially on short exposures, approximates a ring, or series of rings, concentric to a strong condensed nucleus with the relatively bright bar running across the full diameter of the inner ring Greater resolving power and longer exposures establish the rings as close spirals of of amorphous nebulosity springing from the ends of the bars. These objects are found tilted at all angles to the line of sight. When seen on the edge or nearly so, they present a rather curious pattern of an elongated nebula with a bright nucleus and a short bright minor axis perpendicular to, or at large angles to, the elongation. A series in order of increasing tilt is furnished by NGC 3384, 1023, 4754 and 2859.

NGC 3351 (M95) presents an advanced stage in the development with the spiral arms "unwinding" and granulation beginning to appear in the outer regions. The last stages of the series are represented by the S-shaped spirals such as NGC 7479 and 3187. In these the granulation has reached the nucleus and the greater part of the arms has faded away. The S shape is formed by the bar and the beginnings of the spiral arms. Reynolds was the first to call attention to the close relation between the barred and the S-shaped spirals.[15]

Classification of Spirals according to the Stage of Development

The observational evidence is very strong for parallel lines of development among the various types of spirals. There is clearly a progression from amorphous to granular type of nebulosity, with the unwinding of the spiral arms; clearly too, the arms build up at the expense of the amorphous nuclear regions. Both of these facts are readily explained in the assumption that spirals develop out of amorphous elliptical nebulae, and could furnish criteria for subdividing the spirals into stages of development. The progression during the spiral stage however is not so smooth and uniform as to permit the ready classification into mutually exclusive groups. Unknown factors, such possibly as mass, internal composition and external forces, seem to cause considerable variation from the normal progression of evolution. Reynolds,[17] for instance, has recognised a small but striking group of spirals in which the arms are well developed but the granulation appears near the nucleus instead of the edge, and seems to be accompanied by considerable obscuration. Examples are NGC 4736 (M94) and 4826 (M64).*

Again, NGC 3031 (M81) has a large proportion of amorphous nebulosity in the nuclear region, but its arms are thin, rather open and coarsely granulated. NGC 224 (M31) on the contrary, with a relatively small proportions of its material in the amorphous nuclear region, has thick, closely woven arms in which the granulation is very fine. It is difficult, if not impossible, to decide which of these objects represents the latter stage of development. Numerous other points of a similar nature could doubtless be cited by every investigator, but those mentioned demonstrate that our present state of knowledge is insuffigient for minutely subdividing the spirals into significant stages of development.

However, the distinction between early and late, roughly between amorphous and granular, is too conspicuous to be entirely disregarded. For the present, it seems sufficient to recognise the distinction and to cover the gap by a middle class. The three groups, termed vaguely, early, middle and late, could be represented by arbitrary postscripts a, b, and c to the spiral symbols which would serve to describe catalogued spirals very concisely and to a fair approximation.

Summary of Classification of Non-Galactic Nebulae

The photographic features of non-galactic nebulae can be fairly represented and catalogued by a classification, the main lines of which are as follows.

* NGC 4826 (M64) is an interesting nebula with an elusive identity. Reynolds, in commenting upon its structure, calls it NGC 4286 (MNv.80 p.753) and refers to Jeans (Problems of Cosmogony p. 215) who calls it NGC 4828.

NON-GALACTIC NEBULAE — SYMBOL

A. Elliptical Nebulae — E

These wholly amorphous and structureless objects are to be further described by numerical postscripts expressing the excentricities of figure.

B. Spiral Nebulae — S

1. Logarithmic Spirals — S

Includes the great majority of spirals and hence can be termed the normal spiral.

a. Early — Sa

b. Middle — Sb

c. Late — Sc

2. Barred Sprials

A small but distinctive sub-group of spirals — S B

a. Early — S B a

b.Middle — S B b

c. Late (the S shaped spirals) — S B c

C. Irregular Nebulae — I

This includes the very few exceptional non-galactic nebulae which cannot be classified either as elliptical or spiral.

NOMENCLATURE

"Elliptical" is chosen as describing the approximate form of the photographic images of wholly amorphous nebulae with no structure excepting a decreasing brightness from the nuclei outward. The term is an arbitrary compromise and open to some objection. It is short, however, and the corresponding symbol E is not too widely used in current classifications. The numerical postscript describes the ellipse and supplies data for statistical analysis.

"Spiral" is so generally used and so appropriate that no discussion is necessary. The symbol S is already used for a small class of stellar spectra but the dangers of confusion in these cases are too slight to warrent the substitution of an arbitrary, meaningless symbol for the spirals.

"Logarithmic" and "Barred" are descriptive, and direct attention to the most conspicuous features of each group. They are not balanced, for the former describes the shape of the arms which is probably the same sort of mathematical curve in both groups, and the latter emphasizes the points of origin of the arms which are different in the two groups.

The procedure is perhaps justifiable on the grounds that the barred spirals form a relatively small sub-group of the general class of logarithmic spirals, differentiated chiefly by the unique points of the origin of the arms. This state of affairs is more clearly represented by the symbols. Thus S signifies spirals in general which are also logarithmic spirals, while SB signifies the sub-group of logarithmic spirals which are distinguished by the fact that their arms spring from the ends of a diametrical bar across the nucleus.

Early, late??

The terms early, middle and late are compromises and suggest as an hypothesis a theory that is perhaps controversial. Therefore they are appropriately represented by the arbitrary symbols a, b, and c. The sequence which clearly exists cannot be accurately described as progressing uniformly from anorphous to granular nebulosity nor from closely coiled to open arms. It is a combination of these two roughly parallel ~~courses~~ criteria, judged from the general appearance of the nebula as a whole, that ~~the~~ best determines ~~its~~ the position in the sequence.

"Irregular" calls particular attention to the lack of rotational symmetry, the chief obstacle to the normal classification of these objects. The term has often been applied to diffuse the galactic nebulae, and is thus open to some objection. The latter usage, however, has not been universally adopted and indeed has been steadily replaced in the literature by the term diffuse. Moreover, the term "irregular" has been frequently used to denote the class to which it is here applied, and no other term has been widely employed for this class.

> I see no good reason why "Irregular" should not be used in both Galactic & Non-G. classes.

The letter p, denoting peculiar, is unfortunately necessary to most classifications of natural objects. It is added to the symbol expressing the class which contains the general features, and calls attention to some particular variation which is not common enough to justify a separate subdivision.

THE COMPLETE CLASSIFICATION

The complete scheme of nebular classification is as follows.

	Symbol	Examples	
I Galactic Nebulae			
A. Planetaries	P	7662, 3587 (M97)	
B. Diffuse	D		
1. Luminous	DL	6618 (M17)	
2. Obscure	DO	Barnard 92.	
3. Mixed	DLO	7023	
II Non-Galactic			
A. Elliptical	En	3379	Eo
n= Excentricity		4221 (M32)	E2
		4621 (M59)	E4
		3115	E7
B. Spirals	S		

> Gaseous & otherwise

> Irregular seems a better term than diffuse, which applies to texture rather than form, whereas Planetary refers to form.

> The Spiral family to my mind, includes the great majority of Non-galactic nebulae, and since this is the common feeling it would be well to begin the N-G. classification with Spirals.

Is not "Logarithmic" a too definite a term?

Early & Late are terms of evolutional significance, that the present state of our knowledge hardly warrants our attempting to use. A purely descriptive term seems better.

Inclination should be given

1. Logarithmic Spirals	S	
a. Early	Sa	4594
b. Middle	Sb	2841
c. Late	Sc	5457 (M101)
2. Barred Spirals	SB	
a. Early	SBa	4754
b. Middle	SBb	3351 (M95)
c. Late	SBc	7479
C. Irregular	I	2366, 4449
D. Unclassified	U	

Note: Non-galactic nebulae so small and faint that they cannot be classified with the instrumental equipment employed, are to be designated by the Symbol Q. This procedure will be discussed in the following paragraphs.

No separate symbol is necessary for Galactic nebulae as a group. Each object can be catalogued as P or as D. The half dozen or so which present any considerable uncertainty can be indicated as peculiar in the usual manner. Or if one does not wish to choose between P and D, these symbols can be combined into PD which very clearly indicates the uncertainty in the classification of a definitely galactic nebula. The nova Aquila nebula and the present one about Nova Persei may be termed Pp, while the temporary nebulosity about the latter, now completely faded out, would have been called Dp. NGC 1952 (M1), 2359 and 7635 could probably be termed either Pp or Dp, although the former classification is preferable because all of the characteristic features of the planetaries are approximated. The great loop in Cygnus of which NGC 6960 and 6992 are diametrically opposite arcs, may be called Dp for the present, although this character is by no means definitely established. The R Aquarii nebulosity is truly galactic in its nature. Its spectrum, definite form and galactic latitude suggest the temporary designation as Pp. No other difficult case has come to the writer's attention.

Non-galactic nebulae require a group symbol because many thousand of them are known to exist which are entirely beyond the limits of classification for any instrumental powers at present available. These objects appear as small blurs on the photographic plate, merging into the faintest star images at the limits of resolution. Max Wolf employed a most appropriate term when he called them "Nebelflecken". Large numbers will appear in catalogues of nebulae and the only physical fact known concerning them will be that they are non-galactic. - - - - - - - - The interests of economical printing suggests that this fact be designated by a single symbol rather than a combination such as ES or ESI.

The term non-galactic does not lend itself to a convenient initial. Both N and G have too many present usages, and there is no reason for choosing any other particular letter in the term. The selection must therefore be more or less arbitrary. About the only guiding principle involved is, that letters in general use for other purposes should be avoided. The letter Q suggests itself as a convenient symbol, at least it connotes the questionable nature of the objects to which it would be applied. Upper limits of angular size and brightness for the Q nebulae will naturally vary with the instrumental powers employed, and doubtless with the conservativeness of the observer.

The proposed system of classification has been actually tested by applying it to some two hundred non-galactic nebulae which have been photographed at Mt. Wilson and also to a list of about four hundred non-galactic objects including the Mt. Wilson photographs, photographic reproductions from other institutions and published descriptions of nebulae from photographs. The data are not homogeneous but the results may indicate the general order of distribution to be expected.

Type	Mt. Wilson	All
E	41 %	31 %
S	41	56
SB	15	10.5
I	3	2.5

The distribution of eccentricities among 125 elliptical nebulae is as follows:

Eo	27 %
E2	28
E4	19
E6	14
E8	12

These results are obviously different from these to be expected from an assumption that elliptical nebulae are all discus shaped figures tilted at random to the line of sight.

References

1. Hubble, Mt. Wilson Contr. No. 241. Astrophysical Journal 56, 162, 1922.

2. " " " " No. 250 " " 26, 400, 1922.

3. W. W. Campbell and J. H. Moore Lick Observatory Publications 13, Part IV 1918.

4. W. H. Wright " " " 13, Part VI 1918.

5. V. M. Slipher Popular Astronomy 30, 35, 1921.

6. " " " Publications of the American Astronomical Society 3, 98, 1914.

7. H. D. Curtis, Lick Observatory Publications 13, Part I, 1918.

8. " " " " 13, Part II, 1918.

9. " " " " 13, Part III, 1918.

10. " Adolph Stahl Lectures p. 98 1919.

11. F. G. Pease, Publications of the Astronomical Society of the Pacific 28, 33, 1916

12. Max Wolf, Publicationes des Astrophysicalischen Instituts Konigstuhl-Heidelberg Band III No. 5, 1909.

13. H. Knox-Shaw, Helwan Obs. Bulletin No. 15 1915.

14. H. J. Reynolds, Observatory 39, 174, 1916.

15. " " " 43, 377, 1920.

16. " " Monthly Notices of the R. A. S. 83, 147, 1922.

17. " " " " " " " 80, 746, 1920.