A GENERAL STUDY OF DIFFUSE GALACTIC NEBULAE[1]

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ABSTRACT

Suggested classification of nebulae.—Since the time of the Herschels, photography and spectroscopy have revolutionized the study of nebulae. The classification here suggested is based upon the fundamental differences between galactic and non-galactic nebulae. Galactic nebulae are subdivided into planetary and diffuse (luminous and dark), and non-galactic into spiral, elongated (spindle and ovate), globular, and irregular. The characteristics of each are discussed. The belief expressed by Curtis that all non-galactic nebulae are spirals is not justified by the facts.

Distribution of diffuse nebulae.—As shown in Figure 1 these nebulae are concentrated along two belts. One is the Milky Way and the other is approximately the belt of bright helium stars which defines the local cluster. Very few seem to occur in the vast regions between the Milky Way clouds and the local cluster.

Spectral characteristics of galactic nebulae and of associated stars.—(1) *Diffuse nebulae.* Some preliminary results, obtained with slitless spectrographs of various dispersions, are presented for sixty-two nebulae outside the Magellanic clouds, including the twenty-one whose spectra were previously known. They fall into two groups (Tables I and II): Group 1 contains thirty-three, giving predominantly continuous or absorption spectra; and Group 2, twenty-nine, giving predominantly emission spectra. The members of the "continuous" group have generally a smooth, cloudy structure and most of them are found in our local cluster, while those of the emission group are more likely to be filamentous and wispy and to lie in the Milky Way clouds. In the emission spectra the N_1 and N_2 lines are much weaker in comparison with $H\beta$ than in spectra of normal planetaries. (2) *Stars associated with diffuse nebulae* have been studied with slit spectrographs attached to the Mt. Wilson reflectors (Tables III and IV). Stars involved in nebulae having continuous spectra are nearly all of type B1 or later; but stars involved in emission nebulae nearly always have spectra earlier than B1, rarely showing any bright lines. (3) *Stars associated with planetary nebulae* show a corresponding relation. In fact, there is a steady progression in type from the Wolf-Rayet stars involved in small planetaries, through those involved in large planetaries, to the stars of types Oe5–B0 associated with extended diffuse nebulae of Group 1 and the stars of type B1 and later associated with diffuse nebulae of Group 2. A detailed discussion shows that, with the exception of the Cygnus loop and perhaps three other difficult or doubtful cases, each galactic nebula has associated with it one or more stars of a type conformable to its own spectral type. (4) This definite relation between the spectra of the nebulae and of the associated stars suggests that the *source of luminosity of the nebulae* is the radiation from those stars. According to this view, the nebulosity has no intrinsic luminosity but either is excited to emission by light from a star of earlier type or merely reflects light from a star of later type. From a consideration of the nebulosity around Rigel it appears that this luminosity may be excited at a distance of twenty light-years.

Nature of diffuse nebulosity.—From the foregoing results the nebulosity seems to consist of clouds of matter, molecules, dust, or perhaps larger particles, not hot enough to be self-luminous, but visible because of light excited by or reflected from involved or neighboring stars. Nebulae with continuous spectra seem usually more opaque than those giving emission spectra. Whether the association of such stars and nebulae is permanent or temporary is not yet known, but may be determined by studies of the radial velocities.

[1] *Contributions from the Mount Wilson Observatory*, No. 241.

Uncatalogued nebulae.—Five are listed: Table I, Nos. 4, 5, 15, and 21; Table II, No. 15. The third is a bright cometary nebula with a thirteenth-magnitude star at the apex; $\alpha = 6^h 3^m.1$; $\delta = +18°42'$ (1920).

Radial velocities of five stars associated with galactic nebulae.—Results are given for stars associated with N.G.C. 1514, 6514, 6523, and 7635. Of these B.D. $-23°13804$ and Boss 4560 are *binaries*.

CLASSIFICATION OF NEBULAE

The classification of nebulae from visual observations was of necessity based upon resolvability, brightness, size, and form. Thus Sir William Herschel distinguished between clusters and nebulae and devised, for the latter, three classes for brightness, a fourth for definite form, and a fifth for extra large size. It is true that he mentioned in his discussions the terms "milky nebulosity," "nebulous stars," and "stellar nebulae"; that his penetrating genius recognized the existence of nebulous fluid in the nebulous stars and probably in such milky nebulae as the great one in Orion, in contrast to the stellar nebulae or burred stars which he considered as distant clusters; that, in short, he did realize a distinction between planetaries and diffuse nebulae on the one hand and on the other the non-galactic nebulae; but throughout his researches he adhered strictly in catalogues and descriptions to the five classes: bright, faint, very faint, small with definite borders, and exceedingly large. This formal classification was elaborated by the simple system of abbreviation, still in general use, by which each object was described in considerable detail.

Sir John Herschel developed his father's system. His generation had discarded Sir William's idea of a nebulous fluid, as a direct result of the resolution of nebula after nebula by Lord Rosse's great mirrors. Even the Orion nebula, last stronghold of the nebulous fluid advocates, had been announced as resolved by the Parsonstown observers, and the central star in N.G.C. 1514, the great brightness of which as compared to the surrounding nebulosity had led Sir William to his belief in a nebulous fluid, was being explained not as a single star but as an exceptionally compact cluster of stars.

This state of affairs led Sir John Herschel[1] to avoid the discussion of physical distinctions among nebulae and to elaborate his

[1] *Cape Results* (1847), p. 137.

father's formal classification in an ingenious manner. All nebulous objects were divided into regular and irregular, and the latter alone into nebulae and clusters, according to the difficulty of resolving them.

Regular nebulous objects were classified according to magnitude, brightness, roundness, condensation, and resolvability, with five degrees of each expressed by numbers. Thus a bright globular cluster would be 22322, meaning large, bright, round, condensed, and resolved. A small spindle might be classed as 43435, small, faint, elongated, considerably brighter center, irresolvable.

Irregular nebulae were classed as subregular, compact, branching, convoluted, cellular, fissured, and cometic, although Sir John remarks that these objects are so diverse that each one might well represent a separate class. Each subdivision was arranged in five orders of magnitude and brightness.

Here again is a tendency to distinguish between galactic and non-galactic objects, for the regular nebulae, although including the planetaries, for the most part make up the non-galactic nebulae, while the irregular are in general galactic nebulae.

This system of classification did not win a general acceptance because of its very elaboration and also because of the subsequent introduction of spectroscopy and photography. The new methods of research revolutionized the study of nebulae and the basis of nebular classification. Sir William Herschel's ideas were restored in part at least, for the existence of nebulous fluid in the form of gas or dust clouds in the planetaries and diffuse nebulae became a recognized fact. The old question of resolvability is now restricted to spirals and the kindred small non-galactic objects. There has slowly emerged a general recognition of the fundamental difference, hinted at by the Herschels, between planetaries and diffuse galactic nebulosities and the objects, spirals and others, that swarm in regions of high galactic latitude.

Curtis has expressed this new point of view by dividing nebulae into three classes—planetaries, diffuse, and spirals.[1] In explanation of the term "spiral" he states: "It is my belief that all the many thousands of nebulae not definitely to be classed as diffuse or plane-

[1] *Adolfo Stahl Lectures* (1919), p. 98.

taries are true spirals and that the very minute spirals appear as textureless discs or ovals solely because of their small (apparent) size."[1]

His argument for the truly spiral nature of all these non-galactic nebulae is this: "Were the great Nebula in Andromeda situated five hundred times as far away as at present, it would appear as a structureless oval $0\overset{'}{.}2$ long, with very bright center, and not to be distinguished from the thousands of very small round or oval nebulae found wherever spirals are found. There is an unbroken progression from such minute objects up to the great Nebula in Andromeda itself. I see no reason to believe that these very small nebulae are of a different type from their larger neighbors."[2]

This argument is a daring extrapolation and is not justified by our present knowledge of nebular forms. Only a few hundred of the thousands of nebulae photographed show distinct traces of spiral arms. Objects of the most diverse forms, were they removed to the proper distances, would appear as faint "textureless discs or ovals" on the photographic plate. Curtis' extrapolation is not warranted unless all the larger objects examined show positive evidence in favor of, or at least no evidence against, a truly spiral structure.

Now the well-known irregular nebulae, N.G.C. 2366, 4214, and 4449, are unquestionably non-galactic and of considerable size, but by no stretch of the imagination, nor by any orientation, can these objects be termed true spirals. Yet many true spirals are recognized, which have diameters a tenth and less the diameters of these nebulae. It is possible of course to consider the irregular objects as rare exceptions to the general run of non-galactic nebulae.

Stronger evidence of non-spiral forms is found in a class of objects which may be termed globular nebulae. Some of the brighter examples of this type are M 49, 60, 84, 86, and 87, which average about two minutes of arc in diameter.[3] Repeated attempts with the 100-inch reflector under excellent observing conditions, using exposure times from one minute to nine hours, have failed to show any trace or suggestion of spiral structure in the objects mentioned. M 32, the smaller and brighter companion of the

[1] *Publications of the Lick Observatory*, **13**, 12, 1918. [2] *Loc. cit.*

[3] M 60 and M 87 are shown in Plate III.

Andromeda nebula, is a slightly elongated variant of the globular type which also fails to show spiral characteristics under the resolving power of the 100-inch reflector. A long list could be compiled of non-galactic nebulae with diameters over a minute of arc which show no indication of spiral structure under the highest resolving power available. The number is comparable to that of the known spirals. A progression in size of these globular objects can readily be formed running from diameters of over two minutes of arc down to the limits of photographic plates. Toward the lower end of the sequence they merge into the spirals so that the two types become completely indistinguishable (Plate III).

These globular nebulae may be considered as belonging to the same family as the spirals—distribution, velocities, spectra, non-stellar nuclei, and symmetry of form suggest as much—but there is no shadow of evidence for calling them spirals in fact.

Curtis' classification, however, is easily the most significant that has been proposed up to date, and with some modifications would be acceptable as a system the general use of which should be urged. There appears to be a fundamental distinction between galactic and non-galactic nebulae. This does not mean that the latter class must be considered as "outside" our galaxy, but that its members tend to avoid the galactic plane and to concentrate in high galactic latitudes. The distinction seems to be fundamental in a physical sense as well as in distribution. Galactic nebulae are in general associated with stars; even the dark nebulosities are detected by their obscuration of stars. Non-galactic nebulae show no effect on stellar distribution in their neighborhood and have no stars definitely associated with them save those occasional novae which have flared up in a few spirals. The distinction can also be traced in form, texture, velocity, and spectrum, with little if any overlap. In fact, one can say that in no case, except possibly the Magellanic clouds and the similar object N.G.C. 6822, is there any question, from its photographic appearance alone, as to the class to which an individual nebula belongs.

Once this major division is recognized, the subclasses of galactic nebulae follow directly. They are *planetaries* and *diffuse* nebulae. Diffuse nebulae can be divided into luminous and non-luminous or dark nebulae. More detailed classification of these groups will depend upon form, spectrum, and relation to stars, and can well be left to special investigators.

Subdivision of non-galactic nebulae is a much more difficult problem. At present and for many years to come their classification must rest solely upon the simple inspection of photographic images, and will be confused by the use of telescopes of widely differing scales and resolving powers. Whatever selection of types is made, longer exposures and higher resolving powers will surely cause a reclassification of many individual nebulae, although the true spiral once recognized as such will maintain its class with all more powerful instruments, and irregular and globular types are not usually subject to change. Only a very low percentage of nebulae, and these the smaller ones, which appear globular with 24-inch apertures, resolve themselves into spirals or reveal ansae with a 100-inch aperture.

Globular nebulae have already been mentioned. The few known *irregular* nebulae are chaotic forms with non-stellar nuclei and coarse granular texture, and with spectra and radial velocities similar to those of the spirals. Examples are N.G.C. 2366, 4214, and 4449. They are easily distinguished from diffuse nebulae by their non-stellar nuclei and their texture, although analogies have sometimes been drawn between these irregular nebulae and the Magellanic clouds.

The gap between *spirals* and *globular* types is filled with the *elongated* nebulae. There are two distinct varieties of these, the one probably spirals on edge and the other akin to globular nebulae. They may be termed, respectively, spindles and ovate. The former, with sharp nuclei and tapering ansae, are familiar to all observers. The latter deserve some further comment. Examples of the ovate type are M 32 and M 59. They are similar to the globular nebulae in all save their elongated forms. Both are to be described as large and bright, yet even the 100-inch under the finest observing conditions with both long and short exposures reveals no trace or suggestion of spirality in either nebula. Whatever their past or future, their present state is not that of true spirals within the limits set by our observational data.

Spindles and ovate types merge into one another with decreasing linear size of the images on the plates, and the resulting confusion detracts from the value of the distinction for small objects or small-scale photographs. As a matter of fact each system of classification that can be devised for non-galactic nebulae will favor a certain range of resolving powers. The present one favors the largest reflectors. It is a compromise between Curtis' generalization and Wolf's specialization.[1]

Some light on the validity of this classification, and a scale for standardizing results from instruments of various dimensions, for statistical purposes at least, can be derived from photographs of rich fields of nebulae made with telescopes of different apertures and equivalent focal ratios, and with one telescope and differing exposure times. Classification of the nebulae for each exposure will indicate the percentage of objects of each type which are changed from one type to another with increasing exposure and resolving power. Preliminary investigations along this line have already been made, apertures from 10 to 100 inches being used.

The classification proposed for general use, together with typical objects for each class, is as follows:

	Examples
I. Galactic nebulae	
1. Planetary	N.G.C. 7662
2. Diffuse	
a) Luminous	N.G.C. 1976
b) Dark	Barnard 86
II. Non-galactic nebulae	
1. Spiral	M 101 (N.G.C. 5457, 8)
2. Elongated	
a) Spindle	HV 24 (N.G.C. 4565)
b) Ovate	M 59 (N.G.C. 4621)
3. Globular	M 87 (N.G.C. 4486)
4. Irregular	N.G.C. 2366

DISTRIBUTION OF GALACTIC NEBULAE

The distribution, spectra, and radial velocities of planetaries are now well known, due largely to the investigations carried out at the Lick Observatory. Large planetaries are distributed

[1] Wolf's classification of non-galactic nebulae is to be found in *Publicationen des Astrophysicalischen Instituts Königstuhl-Heidelberg*, Band III, No. 5, 1909.

more or less uniformly over the sky, while the small ones concentrate sharply along the Milky Way and are especially numerous between eighteen and twenty hours of right ascension. It is reasonable to suppose that the apparent diameters and nuclear magnitudes are rough indications of distance and that, when real distributions are determined, the vertical deviations from the galactic plane will prove to be relatively small. Radial velocities of ninety-six planetaries corrected for the solar motion average 30 km or about five times the average for B stars. Their spectra are almost purely emission, the continuous spectrum being entirely negligible except for the region on the more refrangible side of the head of the hydrogen series. The ratio of intensities between the N_1, N_2, and $H\beta$ images is 10:3:1, with few exceptions.

Much less is known concerning the diffuse galactic nebulae. Their distribution in the sky is certainly not a simple concentration along the galactic plane. Figure 1 represents the distribution in galactic co-ordinates of all objects of this class, excepting those between galactic longitudes 200° and 300° which are too far south to be observed from Mount Wilson. Two distinct belts are defined —the Milky Way, and a belt inclined at about 20° to the Milky Way. This latter belt has approximately the same nodal points as those of the bright helium stars, although the inclination is considerably greater than that usually given for the stars. The data are not sufficient to determine a value for the dip.

Such a distribution emphasizes the relation between diffuse nebulosity and early type stars. The high inclination of the nebular belt suggests that these objects are comparable in distance with the brightest of the B stars and for the most part lie on the inner side of the ring. There is some evidence that the diffuse nebulae are concentrated in the local cluster and in the Milky Way clouds, and that vast regions between the two are practically devoid of nebulae. If this were not the case, we should expect to find the gaps between the two belts more generally filled, and also a greater dispersion among the galactic nebulae. Perhaps the strongest point in favor of such a distribution is the absence of nebulae with large positive galactic latitudes between longitudes 80° and 200°. In all these 120 degrees of longitude only one diffuse nebula has a latitude greater than $+2°$. This object is B.D. $+23°1301$ at $+3\overset{\circ}{.}5$, announced by Barnard as a nebulous star. The spectrum is B9, photo-visual magnitude 7.0, and hence it is probably relatively near. The greatest deviation from either plane is in the isolated group of dark and luminous nebulosity in Corona Australis, which includes the variable nebula, N.G.C. 6729. The distance of the group is of the order of one hundred parsecs,[1] so that it lies well within the local cluster, and its anomalous position in the sky must be due to perspective. The vertical distance from the galactic plane is about thirty parsecs.

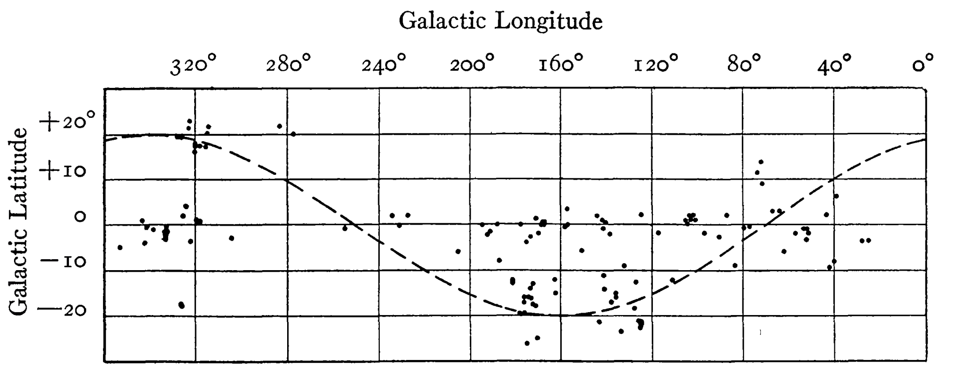


FIG. 1.—Distribution of diffuse nebulae in galactic co-ordinates

There is a decided tendency for diffuse nebulae to cluster. This is more pronounced among nebulae with predominantly continuous spectra than among those with emission spectra, and usually is accompanied by extensive dark nebulosity. Dark nebulae tend to follow the double distribution, although the scattering is greater and the gaps between the two belts are more generally filled than is the case with the luminous diffuse nebulae.

SPECTRA OF DIFFUSE NEBULOSITIES

Published results list emission spectra for thirteen diffuse nebulae as against continuous or absorption spectra for eight.[2]

[1] A distance of three hundred light-years is derived from the luminosity law applied to nebulous stars in the obscured areas, and from movements of luminosity in the nebula N.G.C. 6729 on the assumption that such movements have the velocity of light.

[2] This leaves out of consideration the nebulae in the Magellanic clouds.

This has somehow led to a presumption that an emission spectrum is a general characteristic of diffuse galactic nebulae.

Slit spectrograms of such faint objects will accumulate so slowly that it seems worth while to publish now some results from a preliminary survey with slitless spectrographs. Such instruments readily distinguish spectra which are predominantly emission from those predominantly continuous, although faint emission images on a strong continuous background cannot always be detected. Absorption lines are usually concealed in slitless spectra and the term "absorption spectrum" can be applied in general only to slit spectra. Several such spectra have been reported by Slipher and Pease, so that pure absorption spectra of diffuse nebulosities are as well established in fact as pure emission spectra of others. Indeed, it may be considered as better established, for it is more probable that all bright-line nebular spectra have some faint continuous background than that faint bright lines have been overlooked in absorption spectra of nebulae. The term "emission" will be used in discussing slitless spectra as an equivalent to "bright line" in slit spectra; the term "continuous," where neither bright nor dark lines can be seen; the term "absorption," where dark lines can actually be detected in either slit or slitless spectra. An unbroken series can readily be arranged from the slitless spectrograms, running from emission with no perceptible continuous spectrum to continuous with no emission. There is probably an uncertain number of objects listed as "continuous" in which faint emission images are present and not recognized, but in every case of previously known emission on a continuous background, the slitless spectra show unmistakable irregularities in distribution of density. In view of the uncertainty, however, the method adopted is to list the nebulae as giving predominantly continuous or predominantly emission spectra, and to call attention in notes to combinations of characteristics.

The various instruments employed in the survey are listed below and each is designated by a letter, by which it will be referred to in the course of this paper. It will be noticed that the range in the relation of scale to dispersion is sufficiently wide to accommodate itself to nebulae of all sizes. Seed 30 plates were used throughout with exposures ranging from two to nineteen hours.

A. Focal-plane spectrograph with slit removed, attached to 60-inch reflector, primary focus. Collimator and camera lenses about 6-inch focus. Dispersion, Hβ to Hε = 5.0 mm.
B. 15° objective prism on 10-inch Cooke astrographic lens, focus 45 inches. Hβ to Hε = 5.3 mm.
C. 6° objective prism on 10-inch Cooke lens. Hβ to Hε = 1.8 mm.
D. 39° objective prism on 4-inch lens, 7-inch focus, Hβ to Hε = 4.1 mm.
E. 25° objective prism on 4-inch lens, 7-inch focus, Hβ to Hε = 2.5 mm.
F. 25° objective prism on kinematograph lens F/1.8, 3-inch focus. Hβ to Hε = 1.0 mm.

Results from the survey are collected in two tables, one comprising nebulae which give predominantly continuous, and the other, those which give predominantly emission spectra. Nebulae whose spectra were previously known are included for the sake of completeness and are starred to indicate this fact. One nebula has thus been included which is too far south to be observed from Mount Wilson—N.G.C. 3372, the nebulosity around η Carinae. The two lists should contain all diffuse galactic nebulae for which spectrographic data are available, excepting those in the Magellanic clouds. The tables give in the first column a list number; in the second, the catalogue designation of the nebula; the third and fourth columns give galactic longitudes and latitudes; the fifth column, a rough indication of size on a scale of 1 to 5, the numbers increasing with the size; the sixth column, the instruments employed; the seventh, remarks and references.

Table I contains thirty-three objects having continuous spectra, eight of which were previously known as such. Of the latter, four give pure absorption spectra—the Pleiades, M 78, ρ Ophiuchi, and N.G.C. 7023.[1] N.G.C. 1977 and the two variable nebulae, N.G.C. 2261 and 6729, give faint bright-line images as well, and one, N.G.C. 2245, is known only through an objective prism spectrogram.

[1] Slipher reports that in the spectrum of N.G.C. 7023, "Bright Hβ seems to be present but not so obviously emissive as in the star" (*Publications of the Astronomical Society of the Pacific*, **30**, 63, 1918). The involved star has bright reversed hydrogen lines. Hβ does not show on a spectrogram of the nebula made by Pease.

TABLE I

DIFFUSE NEBULAE WITH CONTINUOUS SPECTRA

No.	Object	Galactic Longitude	Galactic Latitude	Size	Instrument	Remarks
1.	N.G.C. 1333	126°	−21°0	2	C	
2.	I.C. 348	128	−17.5	2	A, B, C,	Also listed as I.C. 1985. B.D. +31°643, involved
3.	Pleiades*	134	−22.0	5	C	See Slipher, *Lowell Bull.*, No. 55, 1912
4.	. . . .	136	−15.5	2	B, C	Uncatalogued nebula, $\alpha=4^h14^m$; $\delta=+28°2'$ (1920)
5.	. . . .	141	−17.0	1	B, C	Uncatalogued nebula, $\alpha=4^h22^m.1$; $\delta=+24°32'$ (1920)
6.	N.G.C. 1579	132	− 9.0	2	C	
7.	I.C. 2087	141	−14.0	1	B, C	
8.	N.G.C. 1788	171	−24.5	2	A, B, C,	
9.	I.C. 2118	175	−26.0	5	B, D, E	Great nebulosity north preceding Rigel
10.	N.G.C. 1977*	175	−19.0	3	B, C	Dark helium and bright hydrogen. See Slipher, *A.S.P.*, **31**, 22, 1919
11.	2023	173	−16.5	1	A, B, C	Nebulosity around B.D. −2°1345
12.	2068*	173	−14.0	2	B, D, E	See Slipher, *A.P.S.* **31**, 212, 1919
13.	. . . .	172	−13.0	5	B, D, E	$\alpha=5^h45^m.5$; $\delta=+1°$ (1920). Brightest portion of great "spiral" in Orion
14.	2183	181	−11.0	1	A, B	
15.	. . . .	158	− 0.5	1	A, B	$\alpha=6^h3^m.1$; $\delta=+18°42'$ (1920). Comet nebula uncatalogued
16.	I.C. 446	168	+ 0.5	1	B, C	Also listed as I.C. 2167
17.	447	168	0.0	2	B, C	Also listed as I.C. 2169
18.	N.G.C. 2245*	169	+ 0.5	1	B, C	See *Ap.J.*, **44**, 196, 1916
19.	2247	169	− 1.0	1	B	
20.	2261*	171	+ 1.5	1	A, B, C	Faint emission on strong continuous spectrum. See *Lowell Bull.*, No. 81
21.	. . . .	193	− 1.5	1	B, C	Uncatalogued nebula about B.D. −12°1771
22.	. . . .	312	+17.0	3	B, F	Nebulosity about π Scorpii
23.	I.C. 4592	322	+23.0	5	B, C, F	Nebulosity about ν Scorpii
24.	4601	323	+21.0	2	B, C	Nebulosity about B.D. −19°4359 and B.D. −19°4361
25.	4603	319	+17.0	4	B, C, F	Nebulosity about B.D. −24°12684
26.	4604*	320	+18.0	4	B, C, F	Nebulosity about ρ Ophiuchi. See *Lowell Bull.*, No. 75, 1916
27.	4605	320	+16.0	2	B, C, F	Nebulosity about 22 Scorpii
28.	N.G.C. 6726, 7	327	−17.5	2	B, C	Nebulosity about B.D. −37°13023 and B.D. −37°13024
29.	N.G.C. 6729*	327	−17.5	1	B, C	Faint emission on strong continuous spectrum. See *Lowell Bull.*, No. 81
30	6914	52	− 4.5	1	B, C	
31.	7023*	72	+14.0	1	B, C	Slipher, *A.S.P.*, **30**, 63, 1918; Pease, *A.S.P.*, **27**, 240, 1915
32.	7129	73	+ 9.0	1	A, B, C	
33.	I.C. 5146	62	− 6.5	2	C	

NOTES

4. Photograph by Barnard, *Astrophysical Journal*, **25**, 219, 1907. This may be I.C. 359 whose position is given as 5^m preceding and 30′ south. No nebulosity is seen in that position.

5. In one of the dark lanes in Taurus.

7. In one of the dark lanes in Taurus. See Barnard, *Astrophysical Journal*, **25**, 218, 1906.

9. Faint extensions of this nebula stretch south and west to end in a faint obscuring cloud more than 35° from the galactic plane.

11. Wolf, *Astronomische Nachrichten*, **180**, 152, 1909, describes this as gaseous emission, but his observations undoubtedly apply to I.C. 434. See note on the latter nebula following Table II.

13. This is the brightest portion of the great loop encircling the belt and sword of Orion.

15. A bright uncatalogued nebula similar to N.G.C. 2245. A thirteenth-magnitude star is at the apex of the cometary form. It is surprising to find that so bright an object has been overlooked by observers.

21. Attention was called to this uncatalogued object in *Union Observatory Circular*, No. 7, 1911.

22. See Barnard's photograph in *Astrophysical Journal*, **23**, 144, 1906.

These nebulae show a decided tendency toward clustering, and can be divided as follows:

	Number
Taurus group	1– 7
Orion	8–14
Monoceros	15–21
Scorpius	22–27
Corona Australis	28–29
Cygnus	30–33

Their distribution in the sky, although affected by this grouping, is clearly not a simple concentration along the galactic plane. In Figure 2 they are plotted in galactic co-ordinates, and it is at

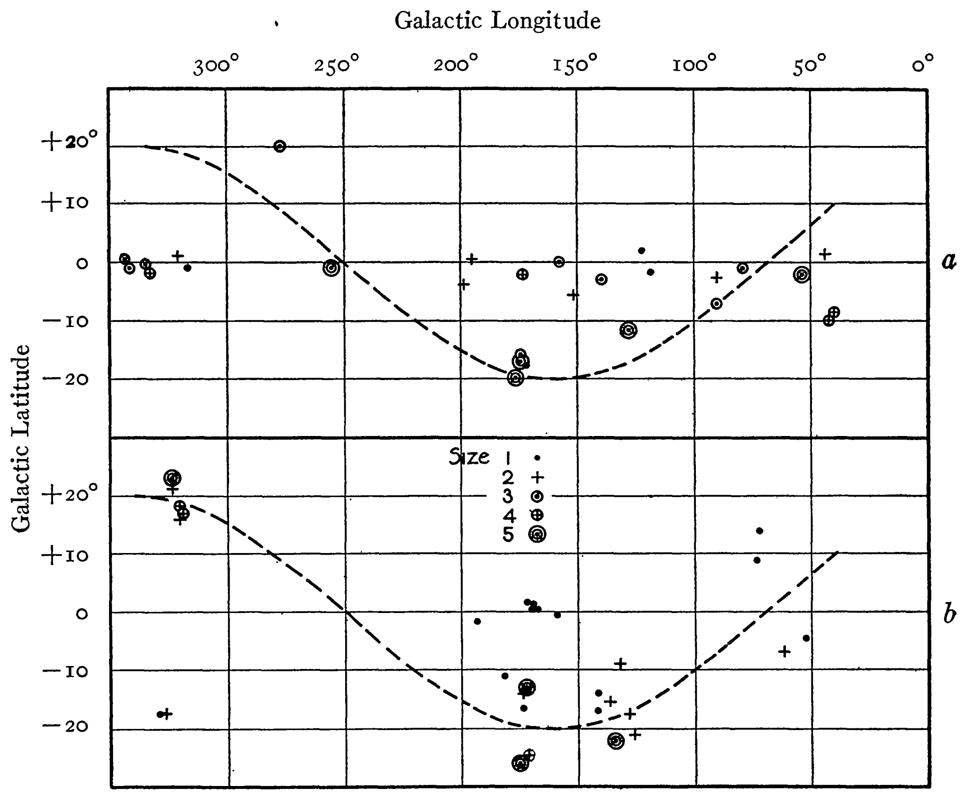


FIG. 2.—Distribution of diffuse nebulae

a. Nebulae with emission spectra

b. Nebulae with continuous spectra

once evident that most of them favor the tilted plane of bright helium stars. The Monoceros group and the isolated pair in

Corona Australis are the only exceptions. The latter, as has been mentioned, is relatively near; in fact, it is among our very nearest nebulous neighbors, and therefore can be properly assigned to the local cluster. The Monoceros group, on the other hand, may be truly galactic as judged by its position, the small size of its components, and the faintness of the stars involved.

Table II contains twenty-nine nebulae with emission spectra, thirteen of which were previously recognized as such. These objects show a greater preference for the galactic plane and less of a tendency to congregate into groups. They all lie close to the Milky Way, except the Cygnus nebula (N.G.C. 6960, 6992), N.G.C. 1499, 5128, and the Orion group. The largest objects in the galactic plane, however, fall at the nodal points of the belt of helium stars and might, from their position alone, be placed in either plane with equal reason. Starting from an assumption of double distribution, it is quite possible to divide the emission nebulae, assigning all five of the largest sizes, five out of thirteen of the graded sizes 4 and 3, and three out of eleven of the two smallest sizes, to the inclined plane. This distribution of sizes fits very well with the known fact that the local cluster of helium stars is nearer than the Milky Way clouds, and with the distribution in sizes of the "continuous" nebulae. Those assigned to the galactic plane have a very small dispersion and a mean galactic latitude of $-1\overset{\circ}{.}6$, which is exactly the latitude of the galactic circle as determined by Nort.[1] So close an agreement was of course unexpected, and lends some justification to the rather arbitrary division of nebulae between the two planes.

A study of the relative intensities of the monochromatic images in Table II leads to the interesting generalization that hydrogen in the extended nebulae as represented by $H\beta$ is much stronger compared to N_1 and N_2 than is the case in the planetaries. Wilson suggested this from the intensities in two extended nebulae, N.G.C. 1976 and 3372, and established the fact that emission nebulae in the Magellanic clouds occupy a position in this respect between the normal planetaries and the extended nebulae.

[1] *Recherches Astronomiques de l'Observatoire d'Utrecht*, 7, 1917.

TABLE II

DIFFUSE NEBULAE WITH EMISSION SPECTRA

No.	Object	Galactic		Size	Instrument	Remarks
		Longitude	Latitude			
1....	N.G.C. 281	90°	− 7°0	3	B, C	One image, $N_1+N_2+H\beta$. Six hours with C much fainter than two hours' direct exposure
2....	I.C. 59–63	90	− 2.5	2	B, C, D	Fan nebulae near γ Cass. D shows three images, $N_1+N_2+H\beta(3)$, $H\gamma(1)$, $H\delta$ (1)
3....	N.G.C. 1491	118	− 1.5	1	C	Strong single image, $N_1+N_2+H\beta$
4....	1499*	128	−11.5	5	B, C, D, E	Spectrum described in *A.S.P.*, **32**, 155, 1920. N_1+N_2 (2), $H\beta$ (2), 4686 (1), $H\gamma$ (2), $H\delta$ (1), $H\epsilon$ (1)
5....	1624	122	+ 2.0	1	C	One image, $N_1+N_2+H\beta$
6....	I.C. 405	139	− 3.0	3	C	Two images, $N_1+N_2+H\beta$ (2), $H\gamma$ (1). Faint continuous spectrum
7....	N.G.C. 1952*	151	− 5.5	2	C	Four images, $N_1+N_2+H\beta$ (5), $H\gamma$ (2), $H\delta$ (0), 3727 (1). Strong continuous spectrum. See *L.O.B.*, **13**
8....	I.C. 423	172	−17.5	1	B	Five images, N_1+N_2 (2), $H\beta$ (2), 4686 (1), 4363 (1), $H\gamma$ (2)
9....	N.G.C. 1976*	176	−19.5	5	B, C, D, E	Orion nebula. See *L.O.B.*, **13**, and *A.S.P.*, **31**, 212, 1919
10....	1982*	176	−19.0	2	B, C, D, E	Orion nebula. See *L.O.B.*, **13**, and *A.S.P.*, **31**, 212, 1919
11....	I.C. 434*	174	−17.0	5	B	Bay nebula south of ζ Orionis. See Wolf, *A.N.*, **180**, 152. Five images, $H\beta$ (5), 4686 (2), $H\gamma$ (4), $H\delta$ (1), 3727 (2)
12....	N.G.C. 2024	174	−16.0	3	B, D	N_1 (1), $H\beta$ (3), 4686 (2), $H\gamma$ (3), $H\delta$ (2), 3727 (2), faint continuous spectrum
13....	2175	157	0.0	3	B, C	N_1 (1) $H\beta$ (3), $H\gamma$ (3)
14....	2237	173	− 2.0	4	B, C, D	N_1+N_2 (2), $H\beta$ (1), $H\gamma$ (1)
15....	....	198	− 4.0	2	C	One image, N_1+N_2
16....	2359	194	+ 0.5	2	B, C	One image, N_1+N_2. Gaseous nature predicted from direct photographs by Pease, *Mt. Wilson Contr.*, No. 132
17....	3372*	255	− 1.0	5	....	See *L.O..B*, **13**
18....	5128	277	+20.0	3	C	$H\beta$ (2) 4686 (1), $H\gamma$ (2), $H\delta$ (1)
19....	6302*	316	− 1.0	1	B	
20....	6357	320	+ 1.0	2	C	One image, N_1+N_2
21....	6514*	334	− 0.5	3	B, C	Trifid. See *L.O.B.*, **13**, N_1+N_2 (1), $H\beta$ (3), $H\gamma$ (2), $H\delta$ (1), 3727 (2)
22....	6523*	333	− 0.5	4	B, C	M 8. See *L.O.B.*, **13**. N_1 (2), N_2 (1), $H\beta$ (4), 4363 (1), $H\gamma$ (3), $H\delta$ (1), $H\epsilon$ (1), $H\zeta$ (1), 3727 (2). Local variation to intensities
23....	6611	343	+ 0.5	3	B	M 16. N_1+N_2 (1), $H\beta$ (3), $H\gamma$ (2). See *Mt. Wilson Contr.*, No. 177, p. 6
24....	6618*	341	− 1.0	3	B	M 17. See *L.O.B.*, **13**, N_1 (4), N_2 (2), $H\beta$ (3), 4686 (0), 4361 (1), $H\gamma$ (3). Local variations
25....	6888	43	+ 1.2	.....	B, C	$H\beta$ (2), $H\gamma$ (1), $H\delta$ (1), 3727 (2)
26....	6960*	40	− 8.5	4	B	See Wolf, *A.N.*, **178**, 379; *ibid.*, **180**, 152
27....	6992*	42	−10.0	4	B	See Wolf, *ibid.*, **178**, 152. Nos. 26 and 27, are really portions of one nebula—an enormous loop in Cygnus
28....	7000*	53	− 1.0	5	B, C	Wolf, *Sitz. Heid. Akad. Wiss.*, **27**, 1, 1910
29....	7635	79	− 1.0	3	A, B, C	$H\beta$ (5), $H\gamma$ (2), $H\delta$ (1), 3727 (4)

NOTES

Campbell and Moore were unable to see bright lines in N.G.C. 2024, 6992, and 7000. N.G.C. 6523, 6618, and 7635 each has at least one image of wave-length shorter than 3727.

7. The continuous spectrum in N.G.C. 1952 is so strong that the nebula might equally well be included in Table I.

11. I.C. 434. This is the remarkable Bay nebula stretching south from ζ Orionis, whose sharp edge on the following side is indented by a dark cloud billowing out from the obscured region bordering on the bright nebula. My plates give an emission spectrum which agrees with that described by Wolf in *Astro-*

nomische Nachrichten, **180**, 152, 1908, and ascribed by him to N.G.C. 2023. N.G.C. 2023, however, is a typical nebulous star, B.D. $-2°1345$, in the obscured region following I.C. 434. The nebulosity around it has a strong continuous or rather an absorption spectrum with no trace of emission. Furthermore, Wolf's remarks "sudlich von ζ Orionis—umittelbar nordlich von die grossen Bucht . . . ." clearly apply to I.C. 434. In view of these facts, I assume the nebula whose spectrum Wolf describes in *Astronomische Nachrichten*, **180**, 152, is really I.C. 434 and so list that nebula as one whose spectrum was previously known. N.G.C. 2023 is listed among those giving continuous spectra which were not previously known.

13. Continuous spectrum fairly strong. Emission spectrum checked by a slit spectrogram.

15. This is an uncatalogued nebula described by Knox Shaw in *Helwan Bulletin*, No. 15. Discovery announced in *Union Observatory Circular*, No. 7, 1911.

28. N.G.C. 7635, formerly known as a nebulous star, appears to be a large planetary immersed in diffuse nebulosity. The brightest portions of the non-planetary nebulosity give the emission spectrum described.

The normal ratio N_1, N_2, and $H\beta$ in the planetaries is 10:3:1. From the observations of Campbell and Moore and of Wilson, data can be gathered for extended nebulae as follows:[1]

	N_1	N_2	$H\beta$
N.G.C. 1976	10	3	5
3372	10	3	5
6514	3	1	10
6523	3	1	10
6618	10	3	5

Table II furnishes data of inferior accuracy, but strongly supporting those listed above.

	N_1+N_2	$H\beta$
N.G.C. 1499	1	2
I.C. 423	1	1
I.C. 434	0	5
N.G.C. 2024	1	3
2175	1	3
2237	2	1
5128	0	2
6611	1	3
6888	0	2
6960, 6992	0	2
7000	0	2
7635	0	5

N.G.C. 1977 and 1982 are connected with N.G.C. 1976, the Orion nebula, and these, together with the outer region of the Orion nebula itself, show a decided weakening of the N_1 and N_2

[1] *Publications of the Lick Observatory*, 13.

lines, as compared to the 10:3:5 relation for the trapezium region. A spectrogram made at Mount Wilson with the slit east-west, just south of the B8 star B.D. $-5°1305$, 12′ south and preceding the trapezium, shows Hβ ten times as strong as N_1 and apparently just stronger than λ 3727.[1] It is interesting to note that the nebulosity condensing about the star shows a pronounced strengthening of the continuous spectrum without affecting the emission lines.

N.G.C. 281, 1491, 1624, 2359, 6357, and I.C. 59, 63, and 405 show such faint overlapping images that they cannot be separated into components for the estimation of relative intensities.

In no case, excepting N.G.C. 1952, is Hβ less than half the intensity of N_1. In this exceptional case, as studied from a slit spectrogram by Sanford, the local variations and overlap of double lines interfere with estimation of relative intensities and the only statement which can be made is that Hβ and N_2 are of about the same order of intensity.

The significance of this generalization is not clear as yet. Of the six giant planetaries[2] only one, N.G.C. 7635, shows the stronger Hβ, and the same ratio holds for small planetaries out of the Magellanic clouds discussed by Campbell and Moore. The most striking examples of these latter, N.G.C. 40, I.C. 418, N.G.C. 4361, and B.D. $+30°3639$, are in no way exceptional in appearance or in their nuclear spectra. The nuclei, however, are unusually bright as compared with the general average.

Among the non-galactic nebulae showing emission lines, two described by Campbell, N.G.C. 1068 and 4151, seem to have the normal planetary ratio, 10:3:1 for N_1, N_2, and Hβ, while three others described by Pease and by Slipher, M 33, N.G.C. 4214 and 4449 show the relatively stronger Hβ.

Tables I and II more than double the number of known emission spectra, and quadruple that of known continuous spectra. The latter now outnumber the former for separately catalogued objects; but in view of the greater tendency to group among the nebulae

[1] "Apparently" in that an ordinary lens and a Seed 30 plate were used. Quartz or U.-V. glass and Seed 23 plates would show λ 3727 as much stronger than Hβ.

[2] The term "giant planetary" is used to describe those with diameter greater than 2′. There are six such planetaries.

with continuous spectra, it is preferable to regard the numbers as about equal. As emission nebulae are much more easily identified for a given surface-brightness because of the discontinuous distribution of light in their spectra, it seems a reasonable extrapolation to assume that continuous spectra are actually more numerous than emission among the diffuse galactic nebulae.

A study of direct photographs fails to give any necessary and sufficient criteria certain for predicting by inspection the nature of the spectrum of a given diffuse nebula. There are several general indications, but each has its exceptions. Filamentary and wispy nebulosity usually has an emission spectrum, as, for example, N.G.C. 1499, 1952, 1976, 2359, 6960, and 6992. This is not a necessary condition and is approximately satisfied in the "continuous" nebulosity about the Pleiades and 22 Scorpii; moreover N.G.C. 1952, the Crab nebula, has so strong a continuous background for its bright-line images that its spectrum could be classed as continuous almost as reasonably as emission. On the other hand, a smooth, cloudy structure is usually confined to "continuous" nebulosity, as in that about ν Scorpii and ρ Ophiuchi, but this again is approximated in the emission nebulae N.G.C. 2024 and the Trifid.

Nebulae with "continuous" spectra are usually associated with greater obscuration than are emission nebulae, although striking exceptions are found in Orion and N.G.C. 7000. It is of course a natural supposition that such vast bodies must be at least partly opaque, and that the "continuous" would be more so than the emission nebulae. Observation shows this to be the case. Obscuration is in fact a universal characteristic of diffuse galactic nebulae wherever the angular areas are large enough to warrant conclusions. The best direct evidence that I have found for transparency in any degree is presented by the helical nebula in Aquarius, N.G.C. 7293, the largest recognized planetary. Photographs made with the 100-inch reflector show three or four small non-galactic nebulae, including one spindle, within the luminous area of the planetary. The great size and galactic latitude of N.G.C. 7293 render it highly probable that the planetary is relatively near, at least nearer than the small nebulae, which, therefore, must be considered as shining through the planetary.

The brightest nebulae have emission spectra; the largest, continuous spectra. In general, however, the two classes mix pretty thoroughly when arranged in order either of size or of brightness. "Continuous" nebulae show a greater tendency to condense around stars, although most of the galactic nebulae have stars involved, and perhaps all have stars associated with them.

SPECTRAL TYPES OF STARS INVOLVED IN DIFFUSE NEBULOSITY

A study of the spectral types of such stars shows that those involved in "continuous" nebulae are of later types than those involved in emission nebulae. This conclusion is based on examination of slit spectrograms made with Cassegrain spectrographs on the 60-inch and 100-inch reflectors. One prism and an 18-inch camera were generally used, although for some of the faintest stars a 7-inch camera was necessary. Table III gives the types of stars involved in 29 of the "continuous" nebulae, which are designated by the list numbers of Table I.

Three cases are exceptional—the faint K8 star in No. 4, around which the nebulosity condenses so strongly and symmetrically that the star must be regarded as involved, and the nuclei of the two variable nebulae N.G.C. 2261 and 6729. V. M. Slipher reports the nuclear spectrum of N.G.C. 2261 as consisting of bright and dark lines agreeing closely with Nova Aurigae in its later stages. He suspected that the nucleus of N.G.C. 6729, R Coronae Australis, was similar, but three spectrograms made with the 100-inch reflector (7-inch camera) show a peculiar G-type spectrum with bright reversed hydrogen and enhanced iron lines. When these three cases are disregarded, the mean type of the other stars is about B4. None is earlier than B1.

There is a decided tendency toward uniformity of stellar type within the various groups. The Taurus group contains nothing earlier than B5. The Orion group is B2 and B3, with one exceptional B1 star in N.G.C. 1977, a nebula giving bright lines as well as a strong continuous spectrum. The stars in the Monoceros nebulae are B1 and B2, and those of the Scorpius group are B2 and B3 as in Orion, excepting the isolated case of I.C. 4601,

TABLE III

STARS INVOLVED IN NEBULAE WITH CONTINUOUS SPECTRA

No.	Nebula	Pv. Mag. of Stars	Spectrum of Stars	
1	N.G.C. 1333	10.6	B8	
2	I.C. 348	8.4	B6	B.D. $+31°643$
		9.8–11.6	B8–A2	9 stars
3	Pleiades	....	B5	Maia and Merope
4	....	12.5	K8	Probably a dwarf
6	N.G.C. 1579	12.0–12.2	A0–B5	2 stars
8	1788	10.0–13.0	B8–B8	2 stars
10	1977	4.6	B1	Boss 1364
11	2023	7.8	B2	B.D. $-2°1345$
12	2068	10.4–10.8	B5–B8	B.D. $+0°1177$
14	2183	14.0	B3	
15	....	13.5	B1	
16	I.C. 446	11.3	B1	
17	447	8.1	B1	B.D. $+10°1159$
18	N.G.C. 2245	10.7	B1	Bright $H\beta$ suspected
19	2247	8.8	B2p	Bright $H\beta$ and $H\gamma$
20	2261	Var.	Pec.	Approximates a nova spectrum
21	....	8.2	B1	B.D. $-12°1771$
22	....	3.1	B2	π Scorpii
23	I.C. 5592	4.2	B2	ν Scorpii
24	4601	7.1–8.4	B8–A0	4 stars
25	4603	7.8	B2	B.D. $-24°12684$
26	4604	5.2–5.9	B2–B3	2 components of ρ Ophiuchi
27	4605	4.9	B3	22 Scorpii
28	N.G.C. 6726, 7	7.2–9.4	B9–B9	2 stars
29	6729	Var.	Gp	R Coronae Australis. Resembles T Tauri
30	6914	9.3–9.9	B5–B5	B.D. $+41°3731$ and B.D. $+41°3737$
31	7023	7.2	B2p	Bright $H\beta$ and $H\gamma$
32	7129	10.2–12.4	B3–B8	3 stars
33	I.C. 5146	10.0	B1	B.D. $+46°3474$

NOTES

4. Nebulous star north following Barnard's nebula.

15. Nucleus of cometary nebula resembling N.G.C. 2245. It is not catalogued.

17. There is a group of six stars in this nebula, some of which are certainly not involved.

24. Boss 4150, visual mag. 6.2, G5 giant, is involved in nebulosity connected with No. 24.

28. B.D. $-37°13017$ and 13018, visual mag. 6.5 and 6.7, B5 and B6, are involved in connecting nebulosity.

29. R Coronae Australis has bright unsymmetrically reversed hydrogen and enhanced iron lines on an absorption spectrum that is approximately a G-type but which has contradictory characteristics. The spectrum resembles that of T Tauri except that it has no bright H and K.

in which are involved four stars, B8 to A0. The Corona Australis group really comprises two double stars in addition to R. The types are B5, B6, B8, and B9, R itself being, as mentioned above, a peculiar later type.

The Monoceros group comprises all the "continuous" nebulae which can be assigned to the galactic plane with any degree of certainty. This distinction is emphasized by the fact that they contain, as a group, the earliest types of involved stars. The only other B1 star (excepting the transitional case of N.G.C. 1977 mentioned above) is central in I.C. 5146, the Cave nebula in Cygnus. This object is so near a nodal point of the inclined plane that it can be placed in either belt with equal justification. These facts raise a question as to whether or not there may be a real difference in type between stars involved in nebulae belonging to the galactic plane as compared with those belonging to the local cluster. The various groups differ so much among themselves, however, that no great weight can be assigned to results from one of their number. Moreover, there seem to be some later-type stars in the cluster around S Monocerotis and possibly in I.C. 447.

The K8 star in No. 4 is not unique. Heretofore it has been thought that all stars involved in nebulosity are B-type or earlier. The following list, which does not include several known cases of A stars, some of which are of the α Cygni type, shows that this is not rigorously true.

1. B.D. $+31°597$	K2 giant
2. B.D. $+28°645$	F8±
3. T Tauri	G peculiar with bright lines
4. No. 4	K8 dwarf
5. Boss 4150	G5 giant
6. R Corona Australis	G peculiar with bright lines

These six objects have all been photographed directly with the 100-inch reflector and, in each case, the nebulosity condenses about the star so obviously that there can be little doubt that the stars are really involved. Some may be cases of stars and nebulosity meeting in the course of the peculiar motions through space, but others, notably T Tauri and R Coronae Australis, must surely be inherently associated with the nebulosity surrounding them. None of them, however, shows any indications of nebulosity condensing into stars.

Absorption spectra of diffuse nebulae are reported by Slipher and by Pease as agreeing with the spectra of the brightest involved stars, as well as could be determined with the small dispersions employed. In this connection it is of interest to mention the following nebulae with predominantly continuous or absorption spectra which have bright-line stars involved.

Nebula	Star
Pleiades	Bright $H\alpha$ in several of the brighter stars
N.G.C. 2247	Bright line B1p
N.G.C. 7023	Bright line B2p
N.G.C. 2261	Approximately a Nova spectrum[1]
N.G.C. 6729	G peculiar with bright hydrogen and enhanced iron lines

The spectrum of the Pleiades nebulosity has not yet been examined in the $H\alpha$ region. No slit spectrogram has been obtained of N.G.C. 2247, and the objective-prism spectra could easily obliterate faint emission images. N.G.C. 7023 and 6729 are suspected, N.G.C. 2261 is definitely proved by Slipher, to have spectra corresponding in detail to the spectra of the stars involved. There is thus no evidence against, and some in favor of, the assumption that nebular spectra that are predominantly "continuous" are the spectra of reflected starlight.

Table IV indicates types of stars involved in nebulae with emission spectra. N.G.C. 3372, the η Carinae nebulosity, is not included because its position is such that no investigation could be made here concerning the question as to which stars are involved and which are not. η Carinae itself is usually accepted as being so involved, and if this is true, it is the one example known of a peculiar bright-line star in emission nebulosity. The Draper *Catalogue* lists two Wolf-Rayet stars within the limits of N.G.C. 3372, but there again the question of their being involved, or simply aligned, requires special investigation that cannot be carried out at Mount Wilson.

[1] *Lowell Observatory Bulletin*, No. 81, 1918.

There are two probable cases of Wolf-Rayet stars associated with diffuse nebulae having emission spectra. These are N.G.C. 2359

TABLE IV

STARS INVOLVED IN NEBULAE WITH EMISSION SPECTRA

No.	Nebula	Pv. Mag. of Stars	Spectrum of Stars	
1	N.G.C. 281	8.6–10.2 10.3–11.6	Oe5 Bo	4 components of B.D. $+55°191$ 3 stars
3	1491	10.6	Bo	
5	1624	13.0–14.0	Oe5	3 stars. Magnitudes estimated
6	I.C. 405	5.8	Bop	Boss 1249
9	N.G.C. 1976	5.4–7.9	Oe5–Bo	4 components of Trapesium
10	1982	6.8	B1p	Bond 734. 4686 strong for type
13	2175	7.5	Oe5	B.D. $+20°1284$
14	2237	7.4–8.2	Oe5	4 brightest stars of the cluster
16	2359	11.0	Od	Magnitude estimated
21	6514	7.8–8.5	Oe5–Bo	2 components of B.D. $-23°338$
22	6523	6.1–6.9	Oe5–Bo	2 brightest stars in M 8. B.D. $-23°13814$–16
23	6611	8.3–9.2	Oe5–Bo	3 brightest stars in M 16.

NOTE

21. B.D. $-22°4510$, pv. magnitude 7.25, A3p (α Cygni type) is central in the northern lobe of the trifid nebula, N.G.C. 6514. The excessive color-index of this star, +0.80 magnitudes, together with the pronounced general absorption of the nebulosity, suggests that the star is actually within the nebula.

and 6888. Photographs of both nebulae have been published by Pease.[1] N.G.C. 2359 shows a ring and tangential streak suggesting the present form of the nebula surrounding Nova Persei No. 2. An eleventh-magnitude Ob star is approximately central in the ring and hence presumably associated with the nebula. N.G.C. 6888 is a segment of an ellipse with the Ob star B.D. $+37°3821$ of magnitude 7.1 near the center of the ellipse. The photograph suggests a ring of nebulosity of non-uniform brightness, inclined to the line of sight. Both nebulae have some resemblance to the planetaries or to a transitional type between planetary and extended forms. Both the nebular forms and types of stellar spectra suggest the possibility that these two nebulae are remnants of former outbursts of novae.

γ Cassiopeiae is probably associated with the emission nebulae I.C. 59 and 63. The star is clearly not involved, but the fan-

[1] *Mt. Wilson Contr.*, No. 186; *Astrophysical Journal*, **51**, 276, 1920.

shaped masses of nebulosity pointing toward that star suggest an intimate association. If this is true, γ Cassiopeiae is the one known case of a bright-line B-star associated with emission nebulosity. The type is called Bo peculiar.[1] ζ Orionis can with equal justification be considered as associated with N.G.C. 2024. In fact, all the belt stars of Orion might be thought of as associated with emission nebulosity, for the faint cloud in which they are immersed brightens in the portion known as I.C. 434, the bay nebula south of ζ Orionis, sufficiently to permit its spectrum to be identified as emission. These stars are of the Bo type.

Another feature of the table is the marked tendency of Oe5 stars to form clusters in emission nebulae. Examples are N.G.C. 281, 1624, 2237, and 6611. Definite data are restricted to the brighter members of these clusters, but small dispersion spectrograms suggest that the fainter members are of somewhat later types and that the brighter ones alone determine the spectrum of the nebulosity.

N.G.C. 6618 (M 17) has no stars obviously involved, but there are indications of a cluster on its southern border. Two of the brightest of these are B8 and two fainter ones are Bo. General indications from focal-plane slitless spectrograms are that the two stars mentioned are the only late B-type stars in the group. A reasonable conclusion is that the two B8 stars are merely aligned, and that the group of fainter stars, if they are connected with the nebula, are of the usual type—Bo. The B8 stars are B.D. $-16^\circ4827$ and $-16^\circ4828$.

The main features of Table IV are the close limitation of the stars within the types Oe5 and Bo—at least for the brighter stars in each nebula—and the relatively rare occurrence of bright lines. These are four probable cases of emission nebulae associated with bright-line stars, but in no case do the spectra of star and nebula agree. The fact is well established that in the case of emission nebulae, the nebular spectrum and the spectra of stars involved or associated do not agree. This recalls Wright's remarks on the

[1] B.D. $-10^\circ1848$ may be another case, but the spectrum of the nebulosity is so confused on my plates that the statement cannot be made definitely. The star is Bop with bright hydrogen lines.

rare agreement between nebular and nuclear spectra among the planetaries.

The progression in stellar type from gaseous to "continuous" nebulae seems to be definitely established. There is no overlap save in N.G.C. 1982, which shows marked transitional characteristics in its spectrum. The sequence is well illustrated in the Orion nebulae of which the spectra have been investigated by Slipher and by Campbell and Moore.

N.G.C. 1976 gives a typical nebular emission line and a weak continuous spectrum. The trapezium stars are of type Oe5 and B0.[1]

N.G.C. 1982 gives a transitional spectrum. It is predominantly emission, but has a very considerable continuous background which intensifies in a marked degree about the involved star Bond 734. This is a B1 star, with λ 4686 unusually strong for the type. It might be called an early B1.

N.G.C. 1977. The spectrum is predominantly continuous with bright hydrogen and dark helium lines. No nebulium can be seen. The involved star, Boss 1364, is of type B1.

N.G.C. 2023. The spectrum is continuous with dark hydrogen and helium lines, and that of the involved star, B.D. $-2°1345$, is B2.

N.G.C. 2068 (M 78). The spectrum is continuous with dark hydrogen and helium lines and was classed by Slipher as probably late B. The stars involved are classed as B3 and B5, but subject to a rather large uncertainty. My own plates tend to place the nebular spectrum as not later than B5.

N.G.C. 2237 in Monoceros might be placed at the head of this sequence as it gives a pure emission spectrum with no continuous background perceptible. The four brightest stars involved, which have been investigated, all show fine Oe5 spectra.

SPECTRA OF PLANETARY NUCLEI

The progression is so pronounced that it seemed advisable to investigate the possibility of extending it into the other type of galactic nebulae, the planetaries. Wright has shown that some

[1] It has been previously mentioned that "continuous" nebulosity condenses strongly about the B8 star B.D. $-5°1305$ in the outer region of N.G.C. 1976, while the emission lines of the nebula are not affected by the star.

planetary nuclei have bright lines or bands, and that others do not. Where emission does occur it is probably of the Wolf-Rayet type. He has not published results for any of the nuclei of giant planetaries, and, as these seem to have the closest affinity to extended nebulae, their spectra have been observed at Mount Wilson.

As an arbitrary division, those planetaries whose mean diameter exceeds two minutes of arc are called giants. There are six such, all within reach in this latitude.

N.G.C. 246	N.G.C. 6853 (Dumbbell)
1514	7293 (Helix)
3587 (Owl)	7635

Two of them have central stars bright enough for the Cassegrain spectrograph with one prism and an 18-inch camera on the 100-inch reflector. These are N.G.C. 1514 and 7635, whose central stars are, respectively, B.D. $+30^\circ 623$, 9.4 photo-visual magnitude, and B.D. $+60^\circ 2522$, 8.7 photo-visual magnitude. Their spectra are similar and of a type not covered by the Harvard classification. They show no bright lines or bands. The following dark lines are present.

Hβ	Hδ	4200[1]	4686 faint and hazy
Hγ	4542[1]	4026[1]	4471 just perceptible

To these may be added λ 4481 in B.D. $+30^\circ 623$ nearly as strong as λ 4542, and in B.D. $+60^\circ 2522$, λ 4147 stronger than λ 4471, and H and K faint and sharp. With these exceptions, the spectra could be described as Od with the bright lines suppressed to the extent of a trace of absorption in λ 4686. Their position is intermediate between the Wolf-Rayet type and Oe5. Radial velocities for four plates of each are $+35.4$ km for B.D. $+30^\circ 623$ and -34.5 km for B.D. $+60^\circ 2522$.

A single slit spectrogram of the central star in N.G.C. 246 made with one prism and a 7-inch camera shows a spectrum similar to B.D. $+60^\circ 2522$, the central star in N.G.C. 7635. In all three objects, the line λ 4542 is the strongest except the hydrogen lines.

By way of comparison, a spectrogram of the nucleus of the smaller planetary I.C. 2149 was obtained, using one prism and

[1] The lines $\lambda\lambda$ 4542, 4200, and 4026 are those discovered by E. C. Pickering in the spectrum of ζ Puppis, for which he employed the designation Hγ', Hδ', and Hϵ', respectively.

an 18-inch camera on the 100-inch reflector. This nucleus is one for which Wright reported a continuous spectrum with no bright lines. An exposure of eight hours gave a legible spectrum in spite of very poor seeing conditions. The rather faint continuous spectrum of the nucleus holds up unusually well toward the violet, and is crossed by the bright lines of the nebula, so sharp and narrow that their source is unmistakable. Only three dark lines can be detected. $H\beta$ and $H\gamma$ are very faint and hazy and almost obliterated by the strong bright nebular lines superposed. The third dark line is λ 4542, exceedingly faint, but free from any nebular line. No trace of λ 4686, either bright or dark, can be seen. Thus the nuclear spectrum, freed from the bright lines due to the nebula, is rather similar to a weak spectrum of the three central stars discussed above.

Slitless spectra have been obtained for the nuclei of all six of the nebulae. The dispersion is small, about 5.0 mm from $H\beta$ to $H\epsilon$, and conclusions based on them are not as certain as one would wish. All six are essentially similar; at least no difference could be made out on the small-dispersion plates. No bright lines or bands are seen, and all show the well-known strength in the ultra-violet which Wright first reported. This similarity of slitless spectrograms, together with the results of a detailed study of three higher-dispersion spectra taken with a slit, permits the assumption that we have in these central stars a class of objects intermediate between stars involved in extended emission nebulae and in the smaller planetaries.

Wright himself published observations of only two planetaries with mean diameters greater than one minute of arc. These are N.G.C. 4361 and 6720. In both cases the nucleus gave a continuous spectrum with no bright lines. His fifteen nebulae whose nuclei show no bright lines have a mean diameter of about 30″ as against 20″ for the fifteen whose nuclei do show bright lines, probably of the Wolf-Rayet type.[1]

The evidence, as far as it goes, points to a progression in spectral type of central or involved stars from the small planetaries to the large ones, and this progression joins immediately on to that of the

[1] *Publications of the Lick Observatory*, 13, 252, 1918.

extended nebulae. The complete sequence of stars involved in galactic nebulae can be represented as follows:

Small planetaries	Wolf-Rayet
Large planetaries	Intermediate between Wolf-Rayet and Oe5
Extended emission nebulae	Oe5 and B0
Extended "continuous" nebulae	B1 and later

The overlap is surprisingly small and for the most part confined to nebulae with unusual forms or spectra. No conclusions have been formed as to the end of the sequence, although it may be significant that the stars of latest type seem to favor faint nebulosity and pronounced obscuration. N.G.C. 2359 and 6888, on the assumption that the Ob stars are truly associated, fall out of place. In both cases, however, there is evidence of a ring structure that suggests a nova origin or at least an affinity with the planetary type.

ASSOCIATION OF GALACTIC NEBULOSITY WITH STARS

This intimate relation between spectral type of nebula and of involved stars raises a presumption that one is a consequence of the other. It seems more reasonable to place the active agency in the relatively dense and exceedingly hot stars than in the nebulosity, and this leads to the suggestion that nebulosity is made luminous by radiation of some sort from stars in certain physical states. The necessary conditions are confined to certain ranges in stellar spectral type and hence are possibly phenomena of effective temperature. The nebulous material itself must be in a physical state sensitive to the stellar radiation, and close enough for the density of radiation to be effective. The abrupt transition from emission to "continuous" nebulosity between stellar types B0 and B1 suggests a critical point in the spectral sequence or possibly effective temperature below which stellar radiation is incapable of exciting nebulous material to emission luminosity. From thence down the spectral sequence the luminosity gives a continuous spectrum and probably partakes more and more of the nature of reflected light.

A theory of nebular luminosity built on these lines meets a first obstacle in the necessity for locating stars conspicuously associated with each galactic nebula, of the required spectral type, and properly placed to energize the nebulosity. Planetaries offer no great difficulty. There is doubt in some cases as to whether the nuclei are truly stellar, but there is usually a condensed center which may well conceal a star or take the place of a star as a center of radiation. In several extended nebulae, however, there is a conspicuous absence of any obviously dominating star or group of stars. Such of those as give continuous spectra show pronounced obscuration in and surrounding the nebulosity, and offer the possibility that stars capable of playing the required rôle are present but entirely or partially obscured. Nos. 4, 5, 6, and 7 in Table I are examples.

Emission nebulosity exhibits much less general absorption, possibly because the matter is in a more highly dissociated state. Here the assumption of obscuration generally fails, and the radiation centers must be sought among the multitude of stars always found within, or near to, the nebulosity. Such stars need not be apparently bright, for the apparent surface luminosity of nebulae is independent of the distance. Furthermore, several of the giant planetaries, for instance, N.G.C. 3587, 6853, and 7293, have bright nebulosity with central stars of the thirteenth to the fourteenth magnitude. Such objects then as N.G.C. 1499 and the nebula in Cygnus, N.G.C. 6960 and 6992, might, with no great stretch of the imagination, be considered as receiving affective radiation from some of the neighboring stars, after the manner in which N.G.C. 2024 probably receives its energy from ζ Orionis.

These suggestions may be applied to the nebulae considered in this paper. Table I contains only six nebulae with continuous spectra, which have no stars obviously involved or conspicuous on direct photographs for location and brightness. They are Nos. 4, 5, 6, 7, 9, and 13. The first four fall in the Taurus group and lie in regions of complete obscuration. Involved stars would need to lie on the near side or very close to the nearer surface of the nebulae in order to be seen at all. In two of these four cases, Nos. 4 and 6, faint stars are present which are almost certainly dimmed by intervening nebulosity. It is possible and even reasonable to assume that bright stars may be involved or associated with all four of these objects, but partially or completely hidden by the obscuring clouds.

No. 9 is the nebulosity north of and preceding Rigel. The form of the nebula approximates an arc with Rigel at the center. Moreover, several fan-shaped details are present which in each case point toward that star. In short, the nebula shows a considerable degree of radial symmetry with Rigel as the point of convergence. The spectral type of Rigel, B8p, and the absolute magnitude, -5.5 according to Kapteyn, are significant. The nebulosity extends to a distance of $2^{\circ}5$ from the star which, in terms of actual distance across the line of sight, is of the order of twenty light-years at the distance of Rigel. This seems an enormous distance over which to assume stellar radiation to be effective in illuminating nebulosity, but a comparison with the better-known Pleiades nebulosity indicates that the two cases are comparable, and Hertzsprung's[1] discussion of the Merope nebula lends considerable weight to the suggestion that reflected starlight can account for the whole of the nebular luminosity in that particular case. In terms of absolute magnitudes Rigel is about 4.7 magnitudes brighter than Merope and hence will have the same illuminating power at 8.7 times the actual distance of similar nebulosity from Merope; or since Rigel is about 1.5 times as distant as Merope from the earth, to an angular distance of about 5.8 times as seen from the earth. Nebulosity comparable in brightness to the nebulosity near Rigel exists nearer to Merope than to any other of the bright stars of the Pleiades, and it extends to a distance considerably more than 1/5.8 times its angular distance.

Inclusion of all the Pleiades stars will not entirely destroy the analogy. According to Trumpler's list of cluster stars, the equivalent brightness of the Pleiades cluster is of the order of magnitude 1.3 or about -3.7 absolute, and the center of the cluster is about $6'$ west of Alcyone. Rigel then is 1.8 magnitudes brighter than the entire cluster and would have equal illuminating powers on nebulosity at about 1.4 times the angular distance of equivalent nebulosity from the center of the cluster. The equivalent distance in the Pleiades cluster is about $100.'$ The actual nebulosity is rather sharply divided into bright inner clouds involving the more luminous stars and extending in parts to about $50'$ from the center, and

[1] *Astronomische Nachrichten*, **195**, 449 (No. 4679), 1913.

very faint exterior clouds extending to 3° or $3^{\circ}.5$ from the center. The position of the nebulosity near Rigel would seem to fall between these extremes. This discussion disregards inclinations to the line of sight of the direction from star to nebulosity, and hence leaves an element of uncertainty in the conclusion. It does seem plausible, however, to regard the relation of Rigel to its neighboring nebulosity in the same category as the relation between stars and nebulosities in the Pleiades cluster.

No. 13, the great loop, sometimes called the spiral, around the belt and sword of Orion, offers difficulties of another sort. The belt stars and the general aggregation of fainter stars in the vicinity are sufficiently bright to account for the nebular luminosity on the same basis as in the case of Rigel and the Pleiades, but the continuous spectrum of the nebulosity does not fit the Bo spectral types of the brighter belt stars. These same stars appear to produce an emission type of illumination in nebulosity immediately adjacent to them, N.G.C. 2024, I.C. 434, etc.; yet if they truly do illuminate the more distant loop, it is with a different light altogether. It may be that the physical state of the loop nebulosity is different from that in the closer objects—that the physical state of all nebulosity depends upon distance from, and spectral type of, associated stars. Or, again, the ability of stellar radiation to produce emission luminosity may be restricted to certain limits of distance which in this case are exceeded.[1]

The facts seem definite—the nebulosity close to the belt stars gives emission spectra while that far away gives a continuous spectrum. Several nebulae giving continuous spectra, as, for example, N.G.C. 2023, are nearer to the belt than is the loop, but they lie on the near side of an obscuring cloud which seems to veil them from the influence of the belt stars and permits them to shine by the undisturbed action of their own involved stars. Slipher suggested that spectra of the Orion nebulosities change from emission to continuous or rather to absorption, as one proceeds outward from a center—probably the great nebula around

[1] The brightest portion of the loop is nearest the belt stars. The distance across the line of sight to the nearest belt star—ζ Orionis—is about forty light-years.

θ Orionis, and these new observations may be but another application of some law. However this may be, the loop in Orion, if it does receive its light from the group of stars that includes the belt, is the one known example of a nebula giving a predominantly continuous spectrum, having as the brightest stars associated with it those of a type earlier than B1.

The result of this examination is as follows: twenty-six out of thirty-three nebulae giving predominantly continuous spectra have prominent stars obviously involved in the nebulosity; in six of the remaining cases more or less plausible means can immediately be suggested to account for the absence of dominating stars within the nebulae; and in the last case, exceptional in many respects, there exists at least possible means of accounting for the nebular illumination as originating in stars.

The case of the emission nebulae is nearly as strong. Among those listed in Table II the following do not have early type stars actually within their borders:

Nos. 2, 4, 7, 8, 11, 12, 25 (26 and 27), 28.

No. 2, I.C. 59, 63—the fan-shaped nebulae near γ Cassiopeiae. That star is obviously associated with, although not involved in, the nebula. The very form of the nebulosity seems determined by radiation or repulsive action from the star which lies at a center of radial symmetry with respect to the fans. The spectral type of γ Cassiopeiae, Bop with bright lines, conforms to the rule previously established concerning the relation between stellar and nebular spectra.

No. 4, N.G.C. 1499—ξ Persei is the brightest neighboring star. The nebula lies on a rough arc, concave to ξ Persei, which can readily be considered as occupying the center of the arc. The star is of type Oe5 and hence conformable to the nebular spectrum. No other star in the vicinity brighter than ninth magnitude has a spectrum earlier than B3.

No. 25, N.G.C. 6888—a long segment of an ellipse, of which B.D. $+37^{\circ}3821$ occupies the center. The stellar type is Ob, hence the star and nebula seem to resemble N.G.C. 2359. No other star in the neighborhood has a spectrum earlier than B5. The only brighter star near is of K-type.

These three cases offer positive evidence of association of star and nebulosity. In each, one definite external star appears to dominate the nebula, its position approximating a center of radial symmetry, its spectral type conforming to the established rule. No rival claimants can be found for any of the positions.

No. 12, N.G.C. 2024—ζ Orionis, B0, a sort of super-giant with an absolute magnitude of -4.17 according to Kapteyn, is conveniently located to energize the nebula. Direct photographs give an instant impression that this star illuminates the nebula, although the details of nebulosity do not show such marked radial structure as is found in the three cases cited above.

No. 11, I.C. 434—the Bay nebula south of ζ Orionis. This seems part of a cloud involving the belt stars and σ Orionis. In this particular portion, both ζ and σ can be considered as sources of illumination, both from position and from spectral type.

No. 8, I.C. 423—a small loop between δ and ϵ Orionis, nearer the former. Both these stars from their spectral types can be considered as the energizing agents. Their positions bear no obvious relation to the figure of the nebula, but their distances are within reason unless greatly distorted by projection.

These three cases do not offer such definite evidence as the first three discussed. They pass from positive in No. 12 to suggestive in No. 8.

The last three cases, Nos. 7, 28, and 26 and 27, offer more serious difficulties. One indeed, 26 and 27, seems flatly to defy explanation on any observational basis.

No. 7, N.G.C. 1952, the Crab nebula, has two faint stars about centrally located. The brighter is of about 15.5 photographic magnitude and the other only slightly fainter. The nebular spectrum is strongly continuous with widely doubled bright lines. Curtis includes the nebula among the planetaries, although he calls it a doubtful classification. Exposure-ratio plates made at Mount Wilson indicate a decided negative color-index for the brighter star at least, and this, together with their approximately central position, permits the assumption that one or both are involved in or associated with the nebula. There are no bright stars in the neighborhood which can be considered as sources of energy, either from position or spectral type.

The question, then, is whether or not the faint central star or stars can dominate the nebula. The best answer is another analogy, this time with the Helical nebula in Aquarius, the giant planetary, N.G.C. 7293. This nebula has a diameter about three times that of the Crab and a central star about two magnitudes brighter. The relation between stellar magnitude and square of the radius are of the same order. If the Crab were at three times the distance of the Helical nebula the two objects would be comparable in size and brightness of their central stars. If the planetaries are energized by their central stars, then one may assume as a possibility that the same is true of the Crab nebula.

No. 28, N.G.C. 7000—the North America nebula. This object gives a considerable continuous spectrum with faint emission. Several stars from sixth to ninth apparent magnitude are involved, and heavy obscuration is evident around the borders, especially in the southern portion. The nebulosity is cloudy and devoid of filamentous detail. In a general way it recalls the appearance of the Trifid. The spectrum also has some resemblance to that of the Trifid, although this latter nebula has a stronger emission and a weaker continuous background. The stars involved in N.G.C. 7000 are all later than B1, and hence can account for only the continuous portion of the nebular spectrum.

Inspection of small-scale photographs of this nebula, for instance, those made by Barnard with the 6-inch Willard lens, suggests that α Cygni may be associated. The Trifid nebula offers a possible analogy, for in the north lobe of that object is a star of the same enhanced A-type as α Cygni. The star is B.D. $-22^{\circ}4510$, photo-visual magnitude 7.2, with a spectrum remarkably similar to that of α Cygni. The star has a color-index of about 0.8 magnitude and hence is regarded as involved in the nebulosity. The Trifid nebula gives an emission spectrum on a continuous background. The emission portion can be attributed to the Oe5 star B.D. $-23^{\circ}338$ in the southern lobe, but the lack of pronounced strengthening of continuous spectrum immediately contiguous to the star in the northern lobe suggests that the latter star may be responsible for part at least of the emission spectrum. The enhanced α Cygni type of stellar spectrum is so unique that unusual properties may be suggested for such stars without prejudice to the existing data. If the star, B.D. $-22^\circ 4510$, does produce some emission luminosity in the Trifid, then α Cygni can be considered a possible source of illumination in N.G.C. 7000.

α Cygni is some 5.5 magnitudes brighter than B.D. $-22^\circ 4510$; hence, if we assume the same absolute magnitude for both stars, α Cygni would have equal illuminating powers at about thirteen times the angular distance, or by figuring from the dimensions of the Trifid, to just under 2°. The nebulosity in N.G.C. 7000 actually does extend from $2^\circ.5$ to $3^\circ.5$ from α Cygni so that, disregarding inclinations to the line of sight, and remembering that nebulosity need not be similarly distributed in these objects, we can regard the distances in the two cases as roughly of the same order. It is necessary to emphasize that this discussion does not explain the luminosity of N.G.C. 7000, and that it does not even make out a strong case. The most that can be said is that a possibility is offered which derives some weight from analogy and which must receive some consideration before it can be definitely dismissed.

Nos. 26 and 27, N.G.C. 6960 and 6992, are portions of an enormous loop in Cygnus. This nebula apparently is the one absolute exception to the suggestion that all galactic nebulae have associated with them stars of spectral types conformable to the type of nebular spectrum. The spectrum of the loop in Cygnus appears to be almost purely emission, yet no stars earlier than B3 nor any stars of the enhanced α Cygni type can be located, which have any probable connection with the nebula. In fact no stars at all, brighter than 9.5 magnitude, can be suggested as associated with the nebulosity.

This discussion of emission nebulae indicates that seventeen out of the twenty-six objects in Table II have stars of conformable spectral types within and obviously associated with the nebulosity. Of the remaining nine objects, three give positive evidence of association with external stars, three suggest such association, two offer possibilities of association, and one seems flatly to contradict the idea of association.

Combining the results from Tables I and II there is one clear exception and three difficult or doubtful cases out of the sixty-two nebulae. Examination of an observing list of some one hundred and twenty-five extended galactic nebulae, all the known objects of this class north of -40° declination, shows no other exception and only one or two doubtful cases. The evidence then, with the single clear exception of the Cygnus loop, is very strongly in favor of the view that all galactic nebulae have associated with them stars of spectral types conformable to the types of the nebular spectra.

CONCLUSIONS

The general conclusion of this discussion is that all galactic nebulae are associated with stars and that the spectra of nebulae and associated stars have a definite relation. This suggests that galactic nebular luminosity has its source in stellar radiation. The phenomena are not simply those of reflected starlight, for in general the emission spectra of nebulae do not agree with the spectra of the associated stars. The reverse is true for diffuse nebulae with continuous spectra. In these cases the reflection theory appears to offer a reasonable explanation, or at least a working basis for further investigation. The mechanism of emission luminosity will probably find its explanation in the fact that it is always associated with the very hottest types of stars.

It is very doubtful whether or not a mass of diffuse nebulosity isolated in space and with no stars involved could hold together and at the same time shine by light generated by collisions of molecules. At temperatures corresponding to intensity-distribution or width of lines in nebular spectra, the average speeds of molecules would be so high compared to the velocities of escape that the nebulosities would probably dissipate rapidly. On the other hand, if molecular speeds were sufficiently small to admit of cohesion in the mass, the nebulosity would probably be too cold to radiate light. This argument suggests that diffuse nebulosity is not intrinsically luminous, but is rendered so by external causes. The only obvious external sources of energy are the stars actually involved in or neighboring to the nebulosity, and definite relations have now been found to exist between the radiations of such stars and nebulosity.

The resulting conception of diffuse galactic nebulae is that they are clouds of material (molecules, dust, or larger particles) illuminated by neighboring stars. The question as to whether the association is temporary or permanent can be answered by a comparison of radial velocities of stars and nebulae. Unfortunately the large majority of such stars are binaries which require a great deal of labor for determining the velocities of the systems. This is especially true of the Oe5 and B0 stars which are associated with the diffuse emission nebulae whose velocities are best determined.

The meager data available at present are indeterminant. Radial velocities are given by Campbell and Moore for six diffuse nebulae as follows:

N.G.C. 1976 (Orion)	+17.5 km
3372	+ 6.0
6514 (Trifid)	+11.0
6523 (M 8)	− 3.0
6618 (M 17)	+ 7.0

The brighter stars in N.G.C. 1976 are all binaries for which no velocities for the systems have been determined. The stars in N.G.C. 6618 are faint and no measures have been published as yet.

η Carinae, in N.G.C. 3372, gives for the hydrogen lines velocities differing from those of other emission lines. The mean of four spectrograms measured by Sanford[1] gives +33.8 km for hydrogen and −22.8 km for the other emission lines. It is just possible that the mean, +5.5 km, may have a significance when compared to the nebular velocity, +6.0 km.

The three brightest stars in N.G.C. 6514 have been observed at Mount Wilson. They are:

B.D. −22°4150, A3p	− 1.5 km, 3 plates
B.D. −23°13804 (brightest comp.), Oe5	− 4.7 km, 4 plates, range 26 km
B.D. −23°13804 (second brightest comp.), B1	+17.3 km, 3 plates, range 20 km
Mean	+ 2.9 km

The two brightest components of B.D. −23°13804 are undoubtedly binaries and the mean of the seven measures for the

[1] *Lick Observatory Bulletins*, **8**, 134, 1916.

two, $+6.3$ km, is suggestive, but by no means conclusive, on the question of agreement between stellar and nebular velocities. B.D. $-22^\circ 4510$ is definitely not in agreement. Its high color-excess[1] may mean that it is seen through the entire nebula.

One star in N.G.C. 6523 has been measured—Boss 4560, Oe5, magnitude 6.1. The spectrograms give a velocity of $+12.6$ km. As the range is 33 km, the star must be considered a binary.

Further data on this question are very desirable. A casual inspection of diffuse nebular structure and configurations of involved stars suggests that the association is for the most part temporary. This may be one fundamental distinction between diffuse nebulae and planetaries, for in the latter the central stars must be permanently associated with the surrounding nebulosity; otherwise their central positions could not in general be maintained.

Mount Wilson Observatory
May 1922

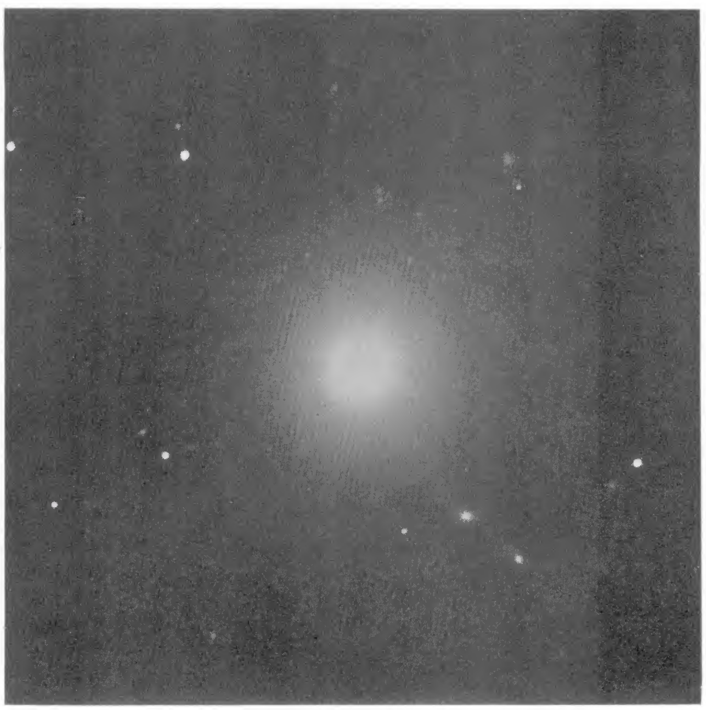
[1] The color-index is 0.8 magnitudes. See *Mt. Wilson Contr.*, No. 187, p. 15; *Astrophysical Journal*, **52**, 22, 1920.

1922ApJ....56..162H

PLATE III

North

a



b

Globular Nebulae

a. M 60, N.G.C. 4649 Globular 1 mm = 4″.2
N.G.C. 4647 Spiral
b. M 87, N.G.C. 4486 1 mm = 5″.2

Photographed with the 100-inch Hooker reflector