CHAPTER I

INTRODUCTORY CHAPTER

SURVEY OF THE PROBLEM

The Solar System

1. In 1543 Copernicus published his treatise "De Revolutionibus Orbium Coelestium" in which the apparent motion of the planets was explained by the simple hypothesis that they all described orbits about the Sun at rest. Two thirds of a century later, in the early days of 1610, Galileo first observed the satellites of Jupiter revolving around their primary, and so obtained what amounted almost to direct visual proof of the truth of the Copernican system of astronomy. But in verifying Copernicus' solution of one problem, Galileo had opened up another. For it now became clear that there were at least two systems of almost exactly similar formation in the universe, and a philosophic mind could not but conclude that they had probably originated from similar causes, and would be impelled to conjecture as to what those causes might be.

In this way the problem of scientific cosmogony had its origin. To the modern astronomer the problem is much richer, wider and more definite, in proportion as the mass of observational material within his knowledge is greater than that with which Galileo was acquainted. In the solar system alone, we know that in addition to the eight great planets, there are upwards of 900 minor planets* or asteroids, and all these 908 or more bodies shew the same regularity in their motion. Their orbits are all nearly circular, they are all approximately in one plane, and they are all described in the same direction. If we assume it to be *à priori* an even chance that a planet should move either from east to west or from west to east, then the chance against 908 planets all moving in the same direction would be $2^{907}-1$ to 1. But if we regard the problem from the point of view of statistical mechanics, and calculate the odds against these orbits being all of small inclination and of small eccentricity, then we arrive at odds in comparison with which the previously calculated odds of $2^{907}-1$ to 1 are so small as to look approximately like an even chance.

* At the end of 1916, numbers had been assigned to 826, and orbits computed for 896. Of the 520 earliest discovered planets, 13 are regarded as lost, having been seen at no opposition since their discovery.

A similar uniformity is found in the satellites of the planets. The modern astronomer knows that the system of Saturn as well as that of Jupiter is a small-scale replica of that of the Sun, while the systems of the smaller planets differ only in having fewer satellites. With a few exceptions, it is found that throughout the whole complex system formed by the sun, its satellites, the planets, and the satellites of the planets, the motion is uniformly in the same direction and in nearly circular and nearly coplanar orbits.

The exceptions occur on the outermost edges of the solar system, and on the outermost edges of the systems of Jupiter and Saturn. They are as follows:

Neptune has only one satellite, and this has retrograde motion.

Uranus has four satellites, whose orbits are highly inclined to the plane of the ecliptic.

Saturn has nine satellites*, of which the outermost (Phoebe) revolving at a mean distance of 209 diameters of Saturn, has retrograde motion and high eccentricity of orbit.

Jupiter has nine satellites of which the two outermost move with retrograde motion.

Some of the asteroids also have considerable inclinations and eccentricities. Thus Pallas has an inclination of 34° 43′, and Zerline (531) one of 34° 33′, these being nearly five times the greatest inclination observed among the planets (7° 0′, the inclination of Mercury). Juno has an eccentricity of 0·257 and Pallas one of 0·239, while a few smaller asteroids are supposed, although with less certainty, to have eccentricities of about $\frac{1}{3}$.

Binary Stars

2. We do not know whether uniformity of this kind extends to other systems in space, or whether it is a peculiarity of our own system. When it was first realised that the so-called fixed stars were essentially suns more or less similar to our own, it was natural to conjecture that they also might be the centres of planetary systems similar to that of our sun, but the further growth of knowledge has shewn the need for caution in such conjectures.

Of the nineteen stars whose parallaxes are less than 0·20″—i.e. the nineteen stars which happen at the present moment to be within 96×10^{12} miles of our sun—no fewer than eight, or 42 per cent. of the whole, are quite certainly binary stars†. Although there is no special reason for thinking that these nineteen stars are not likely to be a fair sample of the whole, it is obviously desirable to try to get evidence from other regions of space. Of fifteen stars

* Excluding the tenth (Themis) discovered photographically by W. H. Pickering in 1904, but not seen since.

† Eddington, *Stellar Movements*, p. 41.

examined by Hertzsprung* in the Ursa Major cluster, nine, or 60 per cent. of the whole, are certainly binary, while Frost† finds that in the Taurus cluster the corresponding proportion is 50 per cent. Frost also finds that 40 per cent. of stars of B type are binary, while Campbell‡ finds that out of 1600 stars considered by him, the spectroscopic binaries alone number 25 per cent., a ratio which must of course be increased by the addition of visual and eclipsing binaries. Thus there is every reason to suppose that throughout our universe fully one-third of the stars, and probably more, are binaries.

To an observer who was so far removed from our system that the light from Jupiter was visible while that from the other planets was not, our system would appear to be a binary system. From observations, either spectroscopic or visual, our imaginary observer might be able to determine the ratio of the masses, and would find it to be ·00095. But when in the same way, we determine the ratio of the masses in the binary systems visible to us, this ratio is found never to be very far from unity. Boss§ has found that in ten visual binaries in which the ratio of the masses is well determined, this ratio is never one of greater inequality than 0·33 to 1, the average being 0·69 to 1, while Campbell|| finds for nineteen spectroscopic binaries an average mass-ratio 0·79, the greatest inequality of mass being one of ratio 0·39 to one.

Thus it appears that the binary system formed by our sun and Jupiter is of a very different character from the binary systems observed in other parts of the sky, and the same is true of all the planetary systems inside our solar system. In these latter systems the closest approach to equality of masses of primary and satellite is found in our earth-moon system, in which the ratio is 0·0123 to 1. Next, after a very long interval, come Saturn and Titan having a mass-ratio of the order of 0·0002 to 1, and Jupiter and its third satellite having a ratio of the order of 0·0001 to 1.

Thus, although it may be open to question whether or not our moon stands in a class by itself inside the solar system, there appears to be no question at all that the planetary arrangements inside our system stand in a different class from the binary arrangements outside.

Not only binary but also triple and multiple systems are observed. It is stated by Russell¶ that of the double and multiple stars contained in Burnham's *General Catalogue of Double Stars*, combined with Lewis' catalogue of the Struve stars, about 800 appear to have common proper motion. And of these 74 are triple or multiple, this number being 9·25 per cent. of the whole. The proportion in Jonckheere's more recent *Catalogue and Measures of Double Stars*** which contains 3950 stars is 9·7 per cent. of the whole.

* *Astrophys. Journ.* 30, p. 139.
† *Astrophys. Journ.* 29, p. 237.
‡ *Stellar Motions*, p. 245.
§ *Prel. Gen. Catalogue*, p. 23.
|| *Stellar Motions*, p. 259, or "Second Catalogue of Binary Stars," *Lick Obs. Bull.* 181.
¶ *Astrophys. Journ.* 31 (1910), p. 199.
** *R.A.S. Memoirs*, Vol. 71 (1917).

After allowing statistically for the effects of projection on the celestial sphere, Russell* finds that triple systems consist normally of a close double with a third star revolving at a considerable distance about their centre of gravity, the ratio of the actual separations being about 10 to 1. The bearing of this on questions of cosmogony will be considered later; for the present it is sufficient to notice that the multiple systems observed in the sky shew no resemblance to our own solar system.

Thus we have found a very definite uniformity of arrangement inside our system, and a very definite uniformity of arrangement outside, but the two arrangements are different, and the question of whether there are other systems arranged like our own has to remain an open one. It may perhaps be mentioned that some astronomers believe that there are irregularities in the motion of binary systems which are too definite to be ascribed merely to errors of observation. These may ultimately be found to point to the existence of planetary bodies revolving at a great distance round the central binary system, but the evidence is certainly too vague at present for definite conclusions to be drawn.

Our search outside our own system has, however, disclosed the existence of a second uniformity of structure, namely that of binary stars having masses not far from equal.

Spiral and other Nebulae

3. These two uniformities, namely the planetary formation and the double-star formation, although perhaps the most striking, are by no means the only uniformities which have been discovered by astronomy. Principal among the remaining ones is the spiral nebula formation which appears to be very distinctive and uniform. The characteristic spiral nebula consists invariably of a nucleus with two arms emerging from opposite points; the convolutions of the two arms are similar, the curve of each being approximately an equiangular spiral†. This formation is very freely scattered in space: Keeler and Perrine estimated the number of nebulae easily discoverable with the Crossley reflector to be of the order of half a million, while Keeler found more than half of the nebulae recorded on his plates to be spirals‡. Although the spiral nebulae are only special instances of the more general nebular formations found in the sky, they are nevertheless the most frequent and the most distinctive of these formations known; for cosmogony they are the most interesting because the definiteness of their formation must contain a valuable clue to their origin and condition. Besides spiral nebulae there are other types of nebulae, which are commonly described in the following terms.

* *Astrophys. Journ.* 31 (1910), p. 200.

† v. Pahlen, *Ast. Nach.* No. 4503.

‡ Campbell, *Stellar Motions*, p. 36.

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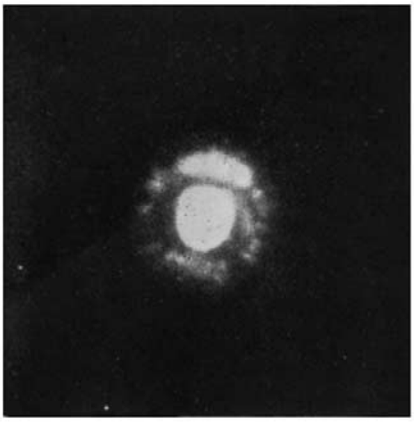
PLATE I



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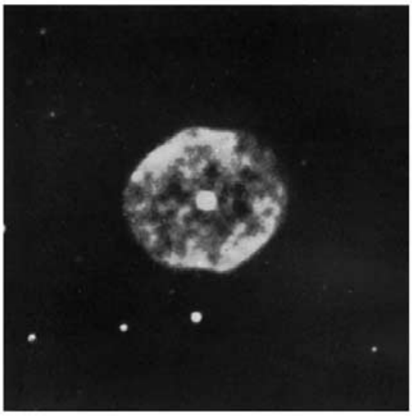

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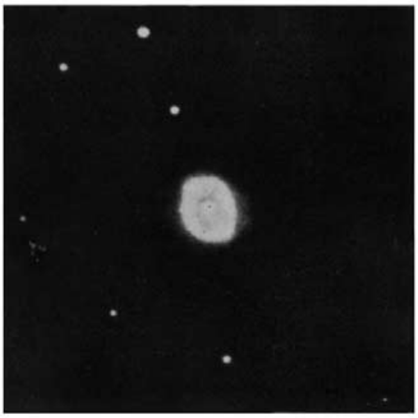

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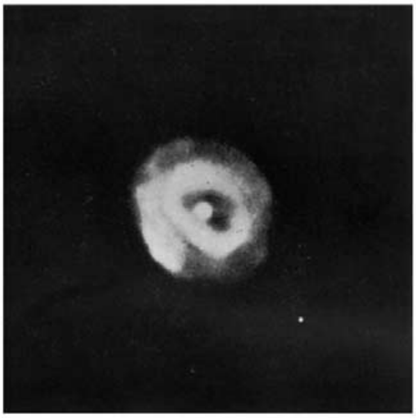

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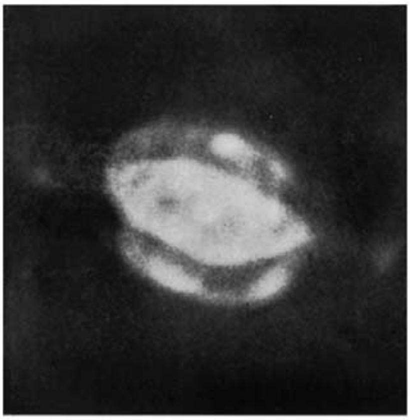

N.G.C. 7009

N.G.C. 6720

Planetary and Ring Nebulae

Mt Wilson Observatory

(1) Irregular nebulae, such as the great nebula in Orion (N.G.C. 1976).

(2) Planetary nebulae, a class of nebulae of apparently spheroidal or ellipsoidal shape, many shewing detailed features and formations in addition. They are few in number, less than 150 having been discovered out of 15000 nebulae so far investigated*. As a rule they shew bright-line spectra, suggesting that they are masses of hot gas, shining by their own light. Some typical examples of Planetary nebulae will be found illustrated on Plate I.

(3) Ring nebulae, such as the well-known nebula in Lyra (N.G.C. 6720). Many astronomers believe that these are not true rings but ellipsoidal shells seen in projection; the reason for this view is mainly that these formations are never seen edgewise or nearly edgewise (see Plate I).

(4) Elliptical, elongated, lenticular and spindle nebulae. These are terms commonly employed to describe the observed shape of nebular masses. A number of nebulae originally classified as spindle-shaped are probably merely spirals seen edgewise, as has been suggested by Slipher† and others. Descriptions, with excellent photographs of these and other types of nebulae will be found in a recent paper by F. G. Pease‡ (see also Plate III).

4. Beyond the information obtainable from their appearance and spectra, we have but little knowledge as to the nature, motions or constitutions of these various nebular systems§. Many of the spirals have velocities in space which are enormously greater than any other class of velocities of which we have any experience, a circumstance which gives some support to the view that they may be regarded as "island universes," each comparable in scale to the universe of stars of which our sun is a member.

Thus for the Andromeda nebula there is consistent evidence of a velocity of approach of about 300 kms a second, Slipher|| determining this velocity as 300 kms a second, Wright¶ as 304 kms a second and Pease** as 329 kms a second. Many spirals have still greater velocities; thus Pease attributes a velocity of recession of about 1180 kms a second to the nebula in Virgo (N.G.C. 4594)†† while Slipher finds a velocity of recession of 1120 kms a second for the nebula in Cetus (N.G.C. 1068)‡‡. The general average velocity is between 300 and 400 kms a second—say twenty times the general average velocity of a star in our universe. Regarding these nebulae as "island universes," it ought of course to be possible to determine the motion of our own galactic system in

* W. W. Campbell, *Science* (1917), p. 521.

† *Lick Obs. Bull.* No. 62.

‡ *Astrophys. Journ.* 46 (1917), p. 24. See also W. W. Campbell, *Science*, 45 (1917), pp. 513—548.

§ A short summary will be found in the *R.A.S. Monthly Notices*, 77 (1917), p. 375.

|| *Lowell Obs. Bull.* No. 58 (1913).

¶ *Popular Ast.* 23 (1915), 36.

** *Journal Royal Ast. Soc. Canada*, Sept. 1915.

†† *Astrophys. Journ.* 46 (1917), p. 41.

‡‡ *Lowell Obs. Bull.* 80 (1918).

space relatively to their centroid. Truman* and Young and Harper† find respectively velocities of 670 kms a second and 598 kms a second.

Not only are large velocities in space revealed by the spectroscope, but also large velocities of rotation. The first discovery of rotation in a nebula was Slipher's‡ discovery in 1914 of the rotation of the nebula in Virgo (N.G.C. 4594§); Pease|| has determined the velocity of rotation to be about 330 kms a second at a distance of 2′ from the centre, the velocity increasing proportionally to the distance from the centre. Velocities of the same order have been found in other nebulae. By a comparison of photographs taken at different dates Van Maanen¶ has found a rotation in the nebula M. 101** in Ursa Major which corresponds to a period of 85,000 years at 5′ from the centre; this nebula does not appear to rotate as a rigid body, the angular velocity being greater near the centre. Van Maanen finds that in this nebula the motion is along the arms and away from the centre, and similar results have been obtained by Kostinsky†† for the spiral nebula in Canes Venatici (M. 51‡‡). Slipher§§ suspects similar motion in the nebula N.G.C. 1068||||.

5. Very large velocities such as we have been considering are a distinctive property of the spiral nebulae. The large irregular nebulae, such as the Orion and Trifid nebulae are found to be almost at rest relatively to the stars of our system as a whole. The planetary nebulae have radial velocities ranging up to 65 kms a second. The average radial velocity of thirteen measured by Keeler¶¶ is 27·7 kms a second. If these velocities are corrected for the solar motion***, their average numerical value is 26·8 kms a second, but their average algebraic value is only 0·9 kms a second. Thus these thirteen planetary nebulae, regarded as a whole, are almost at rest relative to our system, while their individual velocities, although slightly larger than those of ordinary stars, are small compared with the observed velocities of the spiral nebulae.

It must, however, be added that Campbell††† has found quite exceptionally large radial velocities for two planetary nebulae, namely a velocity of approach of 141 kms a second for N.G.C. 4732_2, and a velocity of recession of 202 kms a second for N.G.C. 6644. These velocities are not greater than a few exceptionally high velocities observed for ordinary stars (e.g. 325 kms a sec. for

* *Pop. Astronomy*, 24, p. 111.
† *Journal Royal Ast. Soc. Canada*, 10, p. 134.
‡ *Lowell Obs. Bulletin*, No. 62.
§ See Plate III.
|| *Ast. Soc. Pacific*, 28, p. 191.
¶ *Astrophys. Journ.* 44, p. 210.
** See Plate II.
†† *M. N. Royal Ast. Soc.* 77, p. 233.
‡‡ See Plate II.
§§ *Lowell Obs. Bull.* 80 (1918).
|||| Two fine photographs of this nebula will be found in the paper by Pease already referred to. *Astrophys. Journ.* 46 (1917), p. 24, Plate IV.
¶¶ *Publications of Lick Observatory*, 3, 201.
*** Perrine, *Astrophys. Journ.* 46 (1917), p. 176.
††† *Nat. Acad. Sci. Washington*, 1 (1915), No. 9.

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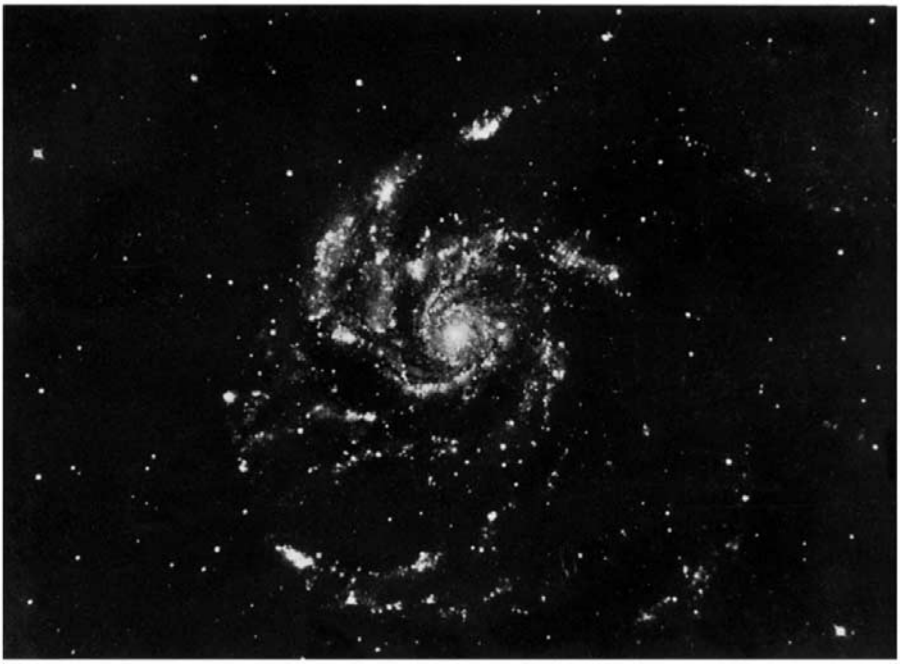
PLATE II



M. 101 (N.G.C. 5457)

M. 51 (N.G.C. 5194—5)

Spiral Nebulae

Mt Wilson Observatory

Lalande 1966 and 242 kms a sec. for Cordoba Z. 5. 243), but regarding the problem as a whole, it is clear that they approach nearer to the velocities of the spiral nebulae than to those of ordinary stars.

With the possible exception of special nebulae such as these last two, it is clear that we may, with good reason, suppose that the irregular and planetary nebulae form a part of our system, and are moving with it, while the spiral nebulae must be supposed to be systems independent of, and outside of, our own system.

Further evidence of this essential difference between the spiral and planetary nebulae is afforded by a study of their positions in the sky. The spiral nebulae are found to be concentrated towards the poles of the milky way, while the planetary nebulae are sparse near the poles of the milky way and shew a very pronounced tendency to collect in the galactic plane. Now there is every reason to believe that our system is of the shape of a coin or watch, our sun being near the middle, and the remote edges being represented by the milky way. Thus the most obvious, although perhaps not the only, explanation of the observed differences of concentration of the spiral and planetary nebulae is this: The planetary nebulae appear to favour the milky way because, being inside our system and intermingled with the other stars of the system, we see most of them in the directions in which we look into the deepest layer of stars, namely directions in the galactic plane. The spirals on the other hand appear to shun the milky way because the absorbing matter of our system blots out or partially obscures such of them as lie in directions near the galactic plane. In confirmation of this view R. F. Sanford* has recently shewn that spirals near the milky way are on the average less bright than those in other parts of the sky. F. G. Brown† has also shewn that the spiral nebulae of larger angular size are in general the brighter, but this is not true of spiral nebulae near the milky way where the visible nebulae are large but faint. All evidence is consistent with the view that the spiral nebulae are uniformly scattered in the sky but are quite outside our system, so that of those which lie in the direction of the galactic plane, the brighter ones are partially, and the fainter ones wholly, obscured by obstructing matter in our own system.

Campbell and Moore‡ have recently found that quite a large proportion of planetary nebulae give spectroscopic evidence of internal motion. Of 33 examined, 16 gave definite evidence of internal motion, 12 gave no indications and the remaining 5 were doubtful. In a previous investigation§ internal motions had been found in the two nebulae N.G.C. 7009 and N.G.C. 6543. The motions are believed to consist in most cases of rotations about

* *Lick Obs. Bull.* No. 297.
† *Monthly Notices R.A.S.* 72 (1912), pp. 195 and 718.
‡ *Nat. Acad. Sci.* 2 (1916), p. 566. § *Lick Obs. Bull.* 9 (1916), No. 278.

axes through the centre, these axes being in general perpendicular to the longest dimensions of the nebulae. In some cases the motion is more complicated than a pure rotation; thus in N.G.C. 6543 the outer portions seem to have velocities much smaller than those of the central parts.

The parallax of the planetary nebula N.G.C. 7662 (Plate I) has been found at Mount Wilson to be 0″·023, from which its diameter may be calculated to be 19 times that of the orbit of Neptune. That of the ring nebula in Lyra, N.G.C. 6720 (Plate I) has been found to be 0″·004, but with a probable error comparable to the whole; the corresponding greatest and least diameters are 330 and 250 times those of the orbit of Neptune*

Star-clusters

6. Further uniformities of formation are to be found in star-clusters. The uniformities are not so definite as those we have just been considering, but are quite definite enough to suggest common origins. There are a great variety of star-clusters, shading often imperceptibly into one another, but they may be classified into three broad types: globular clusters, open clusters and moving clusters†.

The globular clusters are dense aggregates of stars shewing very great condensation towards the centre. They are approximately globular in form, although Pease and Shapley‡ have recently found that out of six supposed globular clusters which it was possible to study in detail, five shewed a pronounced departure from the spherical form, being apparently of a flattened or spheroidal form. A similar absence of complete symmetry in some clusters had been previously noticed by Bailey§. Bailey has also made counts of the stars in some of these globular star-clusters, and it has been shewn by Plummer‖ and von Zeipel¶ that the law of distribution is approximately uniform. The procedure has been criticised by Shapley** on the grounds that only a few of the brightest stars are included in such counts, but however this may be, there is no question that there is a uniformity of some kind. The number of known globular clusters is at most about 100: Bailey†† gives the number of "definitely globular" clusters as 76, while Melotte estimates the number as 82. Practically all of these had been discovered by the time of the Herschels.

* Van Maanen, *Ast. Soc. Pac.* 171 (Oct. 1917).

† Shapley, *Contributions from the Mount Wilson Solar Observatory*, No. 115 (1916), where an excellent summary is given; also P. J. Melotte, "A Catalogue of Star-clusters," *Mem. R.A.S.* 70 (1915), p. 175.

‡ *Nat. Acad. of Sciences*, 3 (1917), p. 96, and *Astrophys. Journ.* 45 (1917), p. 225.

§ *Harvard Coll. Observatory Annals*, 76, No. 4.

‖ *Monthly Notices R.A.S.* 76, p. 107.

¶ *K. Svenka. Vetensk. Acad. Handl.* Bd. 51, No. 5.

** *Observatory*, 39 (1916), p. 452.

†† *Harvard Coll. Observatory Annals*, 76, p. 43.