

## THE VARIABLE NEBULA N.G.C. 2261

By EDWIN P. HUBBLE

Recent astronomical research has been especially fruitful in the study of nebulae—a study which has now extended into the realms of dynamics. The spectroscope, with its disregard for the vast distances involved, has reaped, first—radial velocities of planetary, irregular, gaseous, and spiral nebulae; it has also shown internal motion in the great nebula of Orion, and rotation in both spiral and planetary nebulae. Patiently accumulated photographs are just beginning to be of service, as witness the proper motions of nebulae lately announced by Wolf of Heidelberg.

A striking instance of actual change in form has been found<sup>1</sup> in the case of the nebula N.G.C. 2261 (R.A.  $6^{\text{h}}32^{\text{m}}$ , Dec.  $+8^{\circ}51'$ , Epoch 1860.0, H. IV  $2=h\ 399=G.C. 1437$ ), one of the few real examples of cometary form in the sky and easily the finest of them. Photographically it is well defined and has almost the form of an equilateral triangle with a sharp stellar nucleus at the extreme southern point. There are faint extensions from the northern portion of it. One long streamer which projects from the northern edge extends almost due north.

Plates taken by the writer in the past winter with the 24-inch reflector of this observatory, when compared under the blink comparator with an unusually good plate taken with the same instrument by F. C. Jordan in March 1908, show changes of outline and displacements of the structural details of the nebula.

These changes, though striking, seemed improbable on account of the short interval—less than eight years—and raised a suspicion as to whether the changes could be real and were in the nebula itself or whether they might not be due to some peculiar photographic action. But repeated plates taken under different conditions of seeing, exposure time, aperture, etc., verified the changes beyond question. One of these tests was to make three successive

<sup>1</sup> A preliminary notice was published in the *Proceedings of the National Academy of Sciences*, 2, 230, 1916.

exposures of half, double, and the full normal time. These, when compared among themselves, did not show any change except that due to the regular building up of the image. Each of these, however, when compared with the early plates, confirmed the curious changes.

Notwithstanding the excellence of Jordan's plate, its perfectly round star-images and clear-cut nebular details, it became of first importance to find another early plate for confirmation. A reproduction was found in *Knowledge*, 24, 181, 1901, of a photograph taken at Starfield, January 27, 1900, by the late Dr. Isaac Roberts, with his 20-inch reflector of 100 inches focal length. At the request of the director of this observatory, Mme Dorothea Roberts had the great kindness to prepare and send both positive and negative copies of this invaluable piece of evidence. Long exposure had burned out some of the finer details, but happily sufficient were in evidence to fully confirm the shifts already observed. In the *Lick Observatory Bulletin No. 248*, H. D. Curtis described a photograph of this nebula which he had taken on January 31, 1913, with the 36-inch Crossley reflector with an exposure of two hours. Director Campbell has very kindly loaned us the original negative. It is of remarkably fine quality.

An attempt was made to photograph the nebula with the 40-inch refractor, but the disadvantages of a small focal ratio, 1 to 19, and a visual color-filter, were so great that an exposure of four and three-quarter hours on a brilliantly clear night registered only the nucleus and a trace of the bright band just above. Again at the request of our director, Professor Schlesinger, director of the Allegheny Observatory, very kindly had a plate taken with an hour's exposure with the 30-inch Thaw photographic refractor. The plate was taken by F. C. Jordan, and has sufficient scale to show the brighter details in their true form—coiled streamers running out from the condensed nucleus.

The nucleus of the nebula has long been known as an irregular variable star, R Monocerotis, for which a range from magnitude 9.5 to 13 has been reported. Lassell states that it is not a star, but a true nucleus, such as that of the great spiral in Andromeda, and Barnard has confirmed this opinion by visual observations

with the 40-inch refractor. The longer exposures, especially that of the Lick plate, show a very considerable nebulosity about the nucleus.

The photographs show no indication of variability of the nucleus. The writer has taken eighteen plates which cover a period of five months in the winter of 1915-1916, and three others were taken in 1900, 1908, and 1913, respectively. Small changes might easily be masked by the surrounding nebulosity and the short focus of the reflector, but there are no large differences on the dates mentioned. Such an investigation, however, belongs properly to the field of visual observation or of instruments with a long focus, and the foregoing negative results cannot be considered as conclusive. It is unfortunate that data on so interesting an object should be so scanty. Observations made at Harvard by Leon Campbell and others in the years 1904-1910 indicate a variation through two magnitudes, from 10.0 to 12.0.

Photographically, the nucleus has been about seven-tenths the way from star No. 44 to No. 73 on the Hagen chart; photographically, about one-third the way from No. 44 to No. 62, or 10.8 on Hagen's scale and 12.0 on the Harvard scale.

For a study of details in the nebula itself, five negatives were employed (Table I). All save the last were made with reflectors. Negative copies were made of Nos. 1, 3, and 5, reduced to the scale of the 24-inch Yerkes reflector, and the entire set was compared in the blink comparator.

TABLE I

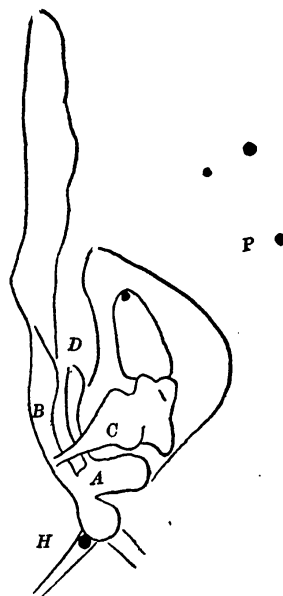
	Date	Aper- ture	Focus	Ex- posure	Observatory	Taken by	Notes
1	1900 Jan. 27	in. 20	in. 100	90 <sup>m</sup>	Starfield (England)	I. Roberts	Copies, details blurred
2	1908 Mar. 20	18	93	60	Yerkes	F. C. Jordan	Good
3	1913 Jan. 31	36	210	120	Lick	H. D. Curtis	Good
4	1916 Mar. 8	18	93	70	Yerkes	E. P. Hubble	Good
5	1916 Mar. 11	30	556	60	Allegheny	F. C. Jordan	Weak

The most striking change was what at first appeared to be a transverse shift of the bright band across the nebula just north of the nucleus, and marked *A* on the sketch. A careful examina-

tion showed that the following end of *A* is coincident on plates 1 and 2, and also on plates 3, 4, and 5, but between the two sets there is a difference of about  $4''.5$ , in the sense that between 1908 and 1913 an extension appeared on the following edge of the band. The phenomenon is very conspicuous, and is evident in Plate V accompanying this article. Plates 3 and 5 with their larger scales show that this is due rather to the sudden appearance of a mass of nebulosity than to motion of the band itself. This new mass is apparently separated from the band, and is situated about the same distance from the nucleus, on the narrow streamer which connects the head to the body of the nebula. A new branch continues from this mass to meet the point of *C*, and another curves up and to the left, eventually mingling with the streamer which forms the following edge of the nebula, marked *B* on the sketch.

There are several other differences between the negatives which seem to be changes in the nebula itself. On the Starfield plate the north following corner of the triangle is much denser than on the others, and this apparently progresses in the sense that *B* and *D* are shifting their center of density toward the head. Considerable faint nebulosity shows around the north preceding corner and steadily drifts, as one proceeds from plate to plate, toward the center in a south following direction. The preceding end of *A* is coincident on plates 1 and 2, but from 2 to 3, and more markedly from 2 to 4, it shifts along the band toward the east.

The fainter extensions to the north of the triangle show no certain changes, nor do two extremely faint streamers running from the head to the southeast and south by southwest, respectively. In the southeast streamer, however, is a tiny mass of nebulosity, marked *H* on the sketch, so small that it appears on the short-focus plates as a star of about the sixteenth magnitude,



which exhibits a decided and irregular motion. It is very near the nucleus and seems to be covered on plate 1 by the large image of the nucleus. On plate 2 it appears clearly, just on the edge of the image of the nucleus. On plate 3 it has moved in toward the nucleus some  $2''.5$  of arc, so that on plate 4 it lies within the image. Plate 5 has a larger scale and shows it clearly, but apparently coincident with the position on plate 2. That is, this curious bit of nebulosity moved in toward the nucleus just when the new masses appeared in the body; viz., between 1908 and 1913. When the nebula comes around into position this winter, some further light may be thrown on the subject by long exposures with instruments of long focus.

It would seem from the data at hand that  $H$  has moved not less than  $0''.5$  per year between 1908 and 1913, and possibly much more. From the relation of parallax to proper motion and linear velocity, it follows that the parallax of this object is about  $\frac{2.5}{V}$ , where  $V$  is expressed in kilometers per second. Any velocity, therefore, up to 100 kilometers per second would suggest a sensible parallax, especially as the sharp stellar nucleus permits of accurate measurement. It is to be hoped that the nebula will find a place on the program of some of the instruments suited for such work. Careful measurements of the plates at hand fail to show any appreciable proper motion of the nucleus.

Several possibilities suggest themselves when one is seeking an explanation of the changes. The nebula may be rotating as a whole, bringing new features into view. An objection to this is that the changes are more evident at the edges, whereas a simple rotation would show its greatest effect in the middle. Further, many of the markings in various parts of the nebula show no change whatsoever, and a rotational effect should show a regularity of distribution.

Another possibility is that of local brightening and fading of stationary matter. This would satisfy most of the data, but for certain points, such as  $H$ , actual motion is too evident to be disregarded. Among these considerations is the current suggestion that a variable nebula might shine by light reflected from the

nucleus and the variation of the two would be directly related. In the case of this nebula, the nucleus is already believed to be irregularly variable, and the nebula might shine by reflected light, but any effects of variability of the nucleus should show a regularity that is entirely absent from the observations. One would be forced to conceive of only certain portions of the nebula being affected.

The most plausible explanation would seem to rest on actual motion of portions of nebulosity relative to the nebula as a whole. The plates indeed suggest a discharge of matter from the nucleus, northward along the following edge, where the band *A* joins to the head. However, the data at hand are too meager for conviction and the explanation must await further study of the nebula with large telescopes.

The position in the sky of N.G.C. 2261 seems highly significant. It lies in, and near the end of, a dark lane which leads up to the nebulosity around 15 Monocerotis, indicating that the nebula is nearer to us than the mass of stars blotted out by the obscuring matter in the lane. This portion of the Milky Way is rich in diffuse nebulosity, nebulous stars, and dark, obscured regions. There is another cometary nebula, N.G.C. 2245, just over two degrees north preceding, again in a dark lane, and so obviously connected with it and with the nebulous cluster, that no great stretch of the imagination is required to place the two cometary nebulae in the same category. They have so much in common that it would not be surprising to find them similar in their peculiarities, and it is to be regretted that we have no old plates of N.G.C. 2245 to compare for change.

The case is strengthened by the data from other variable nebulae. Hind's variable by T Tauri (N.G.C. 1555) is the most famous. Its remarkable career has been carefully investigated by Barnard in two papers published in *Monthly Notices*, 55, 442, 1895, and 59, 372, 1899. Some sixty years ago, it was a conspicuous object in a small telescope. Today it is barely discernible with the best instruments. Recent long-exposure photographs show an exceedingly faint, fan-shaped wisp of nebulosity, close to and pointing toward the variable T Tauri, which Burnham and Barnard saw as a small condensed nebula. It also is situated in a dark lane.

Schmidt, at Athens, discovered in 1861 a small nebula just beside the variable star R Coronae Australis. It is now known as N.G.C. 6729. He later announced it as a variable nebula, and Innes at the Cape in 1890 confirmed Schmidt's observations. Very recently Knox-Shaw at Helwan made a study of the nebula and removed any doubts as to its variability by photographic evidence. In this case also there is a fan-shaped wisp with a variable star at the tip. Again the variable lies in a very pronounced dark region south following the globular cluster N.G.C. 6723. Knox-Shaw read a paper on the subject before the British Astronomical Association, which is reported in the *Journal* of that association for June 1916. He affirmed that the nebula varies from week to week both in brightness and in shape. No definite period has been found for either star or nebula.

There are two other cases of variability within nebulae. Just north preceding N.G.C. 6729, and in the very heart of the dark region, is a wide double star, each component of which is the nucleus of a considerably large and bright mass of nebulosity. Innes, in a recent circular of the Union Observatory, announced that one of the nuclei is variable. The other case is that of the planetary N.G.C. 7662, the nucleus of which Barnard has observed to vary through several magnitudes. The nebula, of course, is gaseous, but the nucleus gives a strong, continuous spectrum. As a planetary, it differentiates itself from the fan-shaped nebulae.

Several plates of N.G.C. 2261 were taken here with a  $15^\circ$  objective-prism on the Zeiss U. V. camera. The nebula gives a strong, continuous spectrum, in which no lines were to be seen, but which, as compared with the neighboring stars of early type, weakened toward the violet, after the fashion of a spectrum of the solar type. This explains why the nebula photographs so readily with a visual color-filter: for while, with a visual color-filter and a Cramer Instantaneous plate, the usual equivalent exposure with the 24-inch reflector is about five times that for a free exposure with a Seed 30 plate, in the case of this nebula, about two and a half times the normal free exposure sufficed to give a strong image through the color-filter. N.G.C. 2245 was in the camera field and also gave a good continuous spectrum. This latter nebula is so

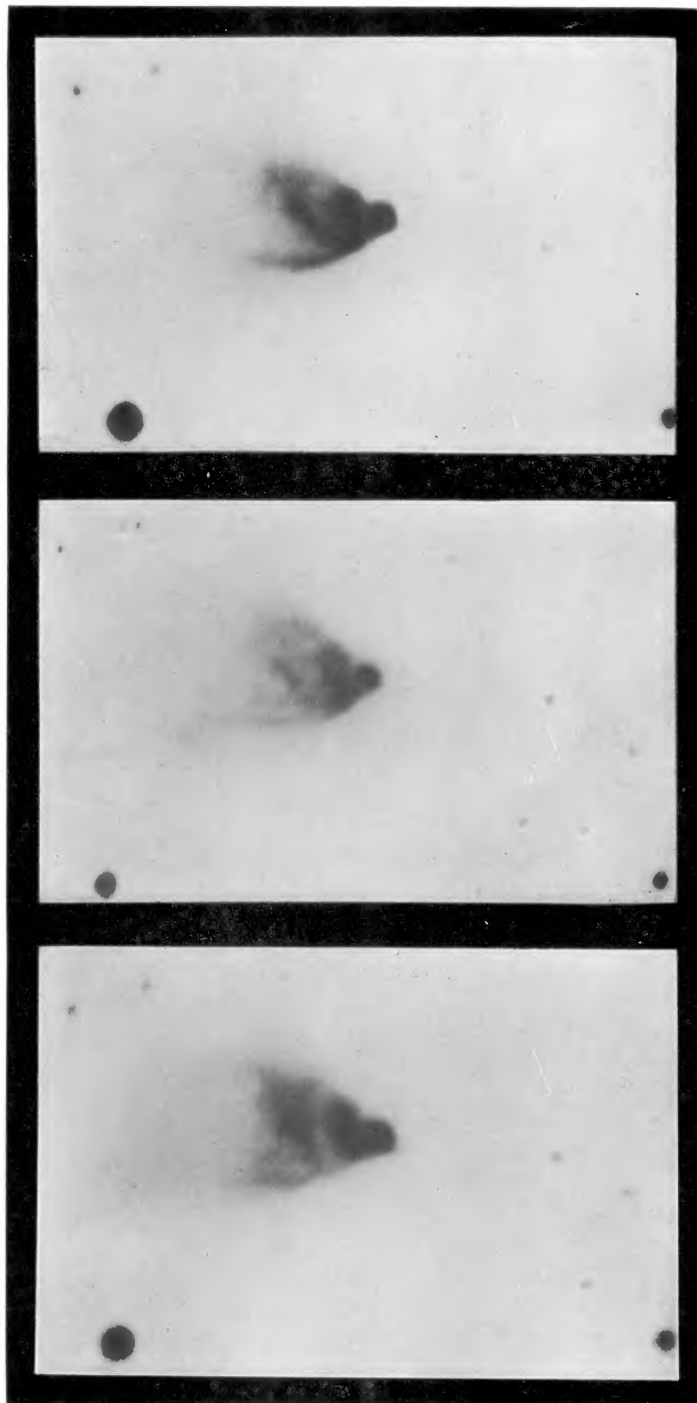
obviously connected with the nebulosity around the cluster, Dreyer Index Cat. 2169, that it is a fair inference to suppose that nebulosity also has a continuous spectrum. This is borne out by the speed with which it registers through the visual color-filter. The variable nebulae would seem to form a family group, characterized by the shape more or less of a fan, with a condensed variable nucleus at the tip, and having some connection with dark regions in the sky. It would be of interest to determine the nature of R Coronae Australis, whether it is not in reality a nucleus rather than a true star.

North of the nucleus of N.G.C. 2261 about  $97''$ , and preceding it by  $4''.4$ , is a fifteenth-magnitude star, marked *P* on the sketch, which has a proper motion of  $27''$  per century in a direction  $164^\circ$ . North following  $9'$  and  $10'$ , respectively, are two variable stars whose maxima are at about 15.5 mag. There is still another variable some  $17'$  north preceding the nucleus, with a range of at least from magnitude 11 to 17.

YERKES OBSERVATORY  
September 14, 1916

PLATE V

Scale: 1 mm = 3".0



1916 March 8  
Yerkes 24-inch Reflector  
Enlarged 24 times

1913 January 31  
Lick 36-inch Crossley-Reflector  
Enlarged 9 times

1908 March 20  
Yerkes 24-inch Reflector  
Enlarged 24 times

N.G.C. 2261