

Ancient man beginning with one important and two minor free metals acquired by heat tin and iron giving him an acquaintance with five metals. Modern man has freed 52 more, knows 85 elemental substances and predicts the eventual discovery of several others.

¹Rollain, A., *Scories de fer antéhistoriques.*, *Bull. Soc. Anth.*, Paris, 4 s, 1899, p. 318. Discussion by M. Lionel Bonnemère.

ON THE OBSERVED ROTATIONS OF A PLANETARY NEBULA

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The geometric forms of certain classes of nebulae are such as to suggest that they are in rotation about axes passing through their effective centers. We refer especially to the spiral nebulae and to those so-called planetary nebulae which are of ring, circular, or elliptical form with relatively condensed or stellar nuclei.

In the latter part of 1915 we tested several planetary nebulae by means of observations made with the Mills 3-prism spectrograph and obtained positive evidences of rotation, as Doppler-Fizeau effects.

The planetary nebula No. 7009 in Dreyer's New General Catalogue, right ascension 20h. 58m., illustrated herewith, was submitted to the test of four spectrograms. In each case the slit of the spectrograph was placed centrally across the image of the nebula and made slightly longer than the diameter of the elliptical outline of the nebula, and the condensed nucleus of the nebula was kept central in the slit during the exposures. In two exposures the slit was placed upon the longer axis of the nebular image, parallel to the slender rectangle drawn above the nebula in the illustration to represent the slit in length and direction. In a third exposure the slit was placed east and west across the image. On these spectrograms the bright lines of nebulium (4959 and 5007A) and of hydrogen (H Beta), comprising the recorded nebular spectrum, were inclined to the 'zero' direction, as indicated by the comparison spectra of hydrogen, helium and titanium on the same plates. This inclination of the lines is illustrated (exaggerated) by the direction of the bright line on the diagram of the slit in the upper part of the figure. The section of the lines corresponding to the western parts of the nebula are displaced to the violet, and the sections corresponding to the eastern parts, to the red. Interpreted as Doppler-Fizeau effects, the western parts of the nebula are approaching us and the eastern parts are receding from us by virtue of the rotation of the nebula. The fainter ends

of the lines do not maintain the inclination of the bright central section of the lines but turn backward slightly. We interpret this to mean that the corresponding faint outer strata of nebulosity do not rotate with speeds proportional to the radii of the strata—relatively to the speeds of the bright inner strata—but that they ‘lag behind.’

The maximum displacements of the nebular lines correspond to points in the nebula 9 or 10 seconds of arc west and east of the central nucleus, and the observed component of rotational speed is of the order of 6 km. per second.

On a fourth spectrogram, with the slit upon the minor axis of the elliptical image, the nebular lines are not inclined to the ‘zero’ direction, and they therefore fail to indicate any components of rotational motion in the plane passing through the minor axis of the nebula and the observer—a result in accord with expectations.

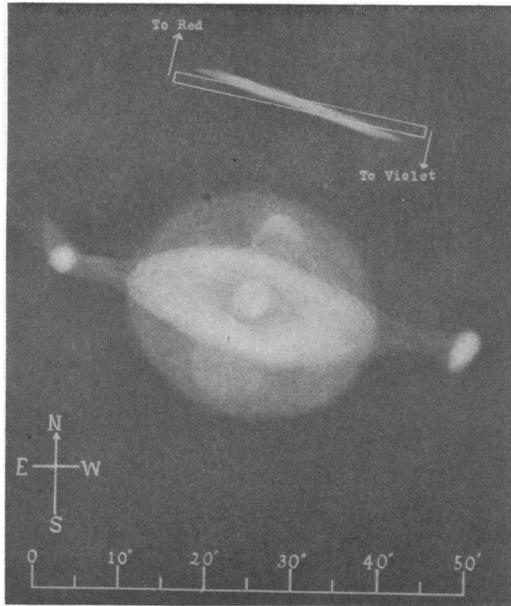
The observations which we have described, considered in connection with the geometrical form of the nebular image as photographed, leave essentially no room for doubt that the nebula is rotating about an axis through the central nucleus approximately at right angles to the plane passing through the observer and the major axis of the image, the nebular materials lying nearest to us being carried from west to east by the rotation.

Measures of the rotational velocity of the nebula enable us to draw some interesting conclusions concerning its mass. If we assume that the axis of rotation is located as described above, then the orbital speed of the nebular materials lying at a distance of 9 seconds of arc from the center is about 6 km. per second. If we provisionally assume the mass of the central nucleus to equal that of the Sun, Kepler’s law connecting the periodic time with the distance from the nucleus tells us definitely that the nebula is distant from us only 8.9 light years. This must be regarded as an improbably small value, in view of other evidence bearing on the question. For assumed distances of 100 and 1000 light years, which we have reason to believe are more probable orders of nebular distance, the masses of the nebula would be respectively 11.3 and 113 times that of the Sun, and the corresponding periods of rotation 1371 and 13,710 years. From these considerations it seems certain that the mass of the planetary nebula N. G. C. 7009 is several times that of the Sun. The nebula is therefore competent, from the point of view of its mass, to develop into a system more pretentious than is our solar system.

A few speculations concerning this nebula may not be without interest and value.

The faint extensions to the east and to the west of the elliptical fig-

ure suggest an encircling ring of materials whose principal plane, passing through the nucleus, passes also near our (the observers') position in space. These extensions terminate in condensed nuclei at equal distances from the nucleus and on exactly opposite sides of the nucleus. The faint extensions and condensations may be and probably are largely the effect of the edge-wise projection of such a ring, as in the case of Saturn's rings when the observer is in the plane of the rings. The forms of the two terminating condensations, and especially the wing extending up and out from the east condensation, suggest that we are not precisely in the plane of the assumed ring.



PLANETARY NEBULA N. G. C. 7009 (COMPOSITE DRAWING, FROM CURTIS'S PHOTOGRAPHS OF THE NEBULA MADE WITH THE CROSSLEY REFLECTING TELESCOPE. THE SCALE IS IN SECONDS OF ARC)

The form of the main nebula appears to be ellipsoidal and not chiefly elliptical.

The space immediately surrounding the central nucleus appears to be relatively vacuous. Aside from the nucleus, the principal mass of visible nebulosity exists in the brilliant ring, roughly elliptical as to its inner and outer boundaries, which occupies the region about midway between the nucleus and the outer edge of the nebular structure. The brilliant ring is probably in reality an ellipsoidal shell: the projection of such a shell upon a plane at right angles to the line of sight would nat-

urally show a relatively dark central area, but the projection principle may not be the only one involved.

If this nebula is in process of development into a solar system, the indications are for a system having certain resemblances to our solar system. Our four outer planets have a combined mass 225 times as great as that of the four inner planets. Similarly in N. G. C. 7009, there is apparently a paucity of material to form planets near the nucleus and an abundance of material for planets at greater distances from the nucleus.

In the course of our determinations of nebular velocities in the past three years we have noted a relatively large number of ring forms among the planetaries, and we have observed no extremely-elongated or highly-elliptic gaseous nebulae, and no such forms of gaseous nebulae as would result from thin rings seen edge-wise. According to the probabilities of the case, if the apparent ring nebulae are really of ring form in space, we should have expected to see a number of very elongated elliptic rings and a certain number of relatively long and narrow nebulae. We are accordingly led to question whether the ring nebulae are true rings or whether they are in reality ellipsoidal shells of nebulosity, which appear to be rings wholly or in part by virtue of their projection upon the plane of sight.

Students of cometary orbits in the past five years have apparently established the Kantian view, that comets are bona fide members of our solar system. The observed fact that comets approach the Sun without marked preference for any direction of origin has seemed to be difficult to account for on the more prominent hypotheses of the evolution of the solar system. If the planetary nebula N. G. C. 7009 and other planetaries which involve the ring form have in reality three principal dimensions and are developing into solar systems, the more or less uniform distribution of cometary matter in space of three dimensions does not seem to call for surprise.

A SHORT PERIOD CEPHEID WITH VARIABLE SPECTRUM

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The most suggestive indication that the stars actually develop from one physical condition represented by a definite spectral type into other closely allied conditions, if it is not in fact the only direct observational evidence of stellar evolution, is afforded by the spectra of certain short