DANIEL KIRKWOOD

THE ASTEROIDS; OR MINOR PLANETS BETWEEN MARS AND JUPITER

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PREFACE

The rapid progress of discovery in the zone of minor planets, the anomalous forms and positions of their orbits, the small size as well as the great number of these telescopic bodies, and their peculiar relations to Jupiter, the massive planet next exterior,—all entitle this part of the system to more particular consideration than it has hitherto received. The following essay is designed, therefore, to supply an obvious want. Its results are given in some detail up to the date of publication. Part I. presents in a popular form the leading historical facts as to the discovery of Ceres, Pallas, Juno, Vesta, and Astræa; a tabular statement of the dates and places of discovery for the entire group; a list of the names of discoverers, with the number of minor planets detected by each; and a table of the principal elements so far as computed.

In Part II. this descriptive summary is followed by questions relating to the origin of the cluster; the elimination of members

from particular parts; the eccentricities and inclinations of the orbits; and the relation of the zone to comets of short period. The elements are those given in the Paris *Annuaire* for 1887, or in recent numbers of the *Circular zum Berliner Astronomischen Jahrbuch*.

DANIEL KIRKWOOD.

Bloomington, Indiana, November, 1887.

PART I.
THE ASTEROIDS, OR MINOR PLANETS BETWEEN MARS AND JUPITER

1. Introductory

PLANETARY DISCOVERIES BEFORE THE ASTEROIDS WERE KNOWN

The first observer who watched the skies with any degree of care could not fail to notice that while the greater number of stars maintained the same relative places, a few from night to night were ever changing their positions. The planetary character of Mercury, Venus, Mars, Jupiter, and Saturn was thus known before the dawn of history. The names, however, of those who first distinguished them as "wanderers" are hopelessly lost. Venus, the morning and evening star, was long regarded as two distinct bodies. The discovery that the change of aspect was due to a single planet's change of position is ascribed to Pythagoras.

At the beginning of the seventeenth century but six primary

planets and one satellite were known as members of the solar system. Very few, even of the learned, had then accepted the theory of Copernicus; in fact, before the invention of the telescope the evidence in its favor was not absolutely conclusive. On the 7th of January, 1610, Galileo first saw the satellites of Jupiter. The bearing of this discovery on the theory of the universe was sufficiently obvious. Such was the prejudice, however, against the Copernican system that some of its opponents denied even the reality of Galileo's discovery. "Those satellites," said a Tuscan astronomer, "are invisible to the naked eye, and therefore can exercise no influence on the earth, and therefore would be useless, and therefore do not exist. Besides, the Jews and other ancient nations, as well as modern Europeans, have adopted the division of the week into *seven* days, and have named them from the seven planets; now, if we increase the number of planets this whole system falls to the ground."

No other secondary planet was discovered till March 25, 1655, when Titan, the largest satellite of Saturn, was detected by Huyghens. About two years later (December 7, 1657) the same astronomer discovered the true form of Saturn's ring; and before the close of the century (1671-1684) four more satellites, Japetus, Rhea, Tethys, and Dione, were added to the Saturnian system by the elder Cassini. Our planetary system, therefore, as known at the close of the seventeenth century, consisted of six primary and ten secondary planets.

Nearly a century had elapsed from the date of Cassini's discovery of Dione, when, on the 13th of March, 1781, Sir William Herschel enlarged the dimensions of our system by the detection of a planet—Uranus—exterior to Saturn. A few years later (1787-1794) the same distinguished observer discovered the first and second satellites of Saturn, and also the four Uranian satellites. He was the only planet discoverer of the eighteenth century.

2. Discovery of the First Asteroids

As long ago as the commencement of the seventeenth century the celebrated Kepler observed that the respective distances of the planets from the sun formed nearly a regular progression. The series, however, by which those distances were expressed required the interpolation of a term between Mars and Jupiter,—a fact which led the illustrious German to predict the discovery of a planet in that interval. This conjecture attracted but little attention till after the discovery of Uranus, whose distance was found to harmonize in a remarkable manner with Kepler's order of progression. Such a coincidence was of course regarded with considerable interest. Towards the close of the last century Professor Bode, who had given the subject much attention, published the law of distances which bears his name, but which, as he acknowledged, is due to Professor Titius. According to this formula the distances of the planets from Mercury's orbit form a geometrical series of which the ratio is two. In other words, if we reckon the distances of Venus, the earth, etc., from the orbit of Mercury, instead of from the sun, we find that—interpolating a term between Mars and Jupiter—the distance of any member of the system is very nearly half that of the next exterior. Baron De Zach, an enthusiastic astronomer, was greatly interested in Bode's empirical scheme, and undertook to determine the elements of the hypothetical planet. In 1800 a number of

astronomers met at Lilienthal, organized an astronomical society, and assigned one twenty-fourth part of the zodiac to each of twenty-four observers, in order to detect, if possible, the unseen planet. When it is remembered that at this time no primary planet had been discovered within the ancient limits of the solar system, that the object to be looked for was comparatively near us, and that the so-called law of distances was purely empirical, the prospect of success, it is evident, was extremely uncertain. How long the watch, if unsuccessful, might have been continued is doubtful. The object of research, however, was fortunately brought to light before the members of the astronomical association had fairly commenced their labors.[1]

On the 1st of January, 1801, Professor Giuseppe Piazzi, of Palermo, noticed a star of the eighth magnitude, not indicated in Wollaston's catalogue. Subsequent observations soon revealed its planetary character, its mean distance corresponding very nearly with the calculations of De Zach. The discoverer called it Ceres Ferdinandea, in honor of his sovereign, the King of Naples. In this, however, he was not followed by astronomers, and the planet is now known by the name of Ceres alone. The discovery of this body was hailed by astronomers with the liveliest gratification as completing the harmony of the system. What, then, was their surprise when in the course of a few months this remarkable order was again interrupted! On the 28th of

[1] The discoverer, Piazzi, was not, as has been so often affirmed, one of the astronomers to whom the search had been especially committed.

March, 1802, Dr. William Olbers, of Bremen, while examining the relative positions of the small stars along the path of Ceres, in order to find that planet with the greater facility, noticed a star of the seventh or eighth magnitude, forming with two others an equilateral triangle where he was certain no such configuration existed a few months before. In the course of a few hours its motion was perceptible, and on the following night it had very sensibly changed its position with respect to the neighboring stars. Another planet was therefore detected, and Dr. Olbers immediately communicated his discovery to Professor Bode and Baron De Zach. In his letter to the former he suggested Pallas as the name of the new member of the system,—a name which was at once adopted. Its orbit, which was soon computed by Gauss, was found to present several striking anomalies. The inclination of its plane to that of the ecliptic was nearly thirty-five degrees,—an amount of deviation altogether extraordinary. The eccentricity also was greater than in the case of any of the old planets. These peculiarities, together with the fact that the mean distances of Ceres and Pallas were nearly the same, and that their orbits approached very near each other at the intersection of their planes, suggested the hypothesis that they are fragments of a single original planet, which, at a very remote epoch, was disrupted by some mysterious convulsion. This theory will be considered when we come to discuss the tabulated elements of the minor planets now known.

For the convenience of astronomers, Professor Harding, of

Lilienthal, undertook the construction of charts of all the small stars near the orbits of Ceres and Pallas. On the evening of September 1, 1804, while engaged in observations for this purpose, he noticed a star of the eighth magnitude not mentioned in the great catalogue of Lalande. This proved to be a third member of the group of asteroids. The discovery was first announced to Dr. Olbers, who observed the planet at Bremen on the evening of September 7.

Before Ceres had been generally adopted by astronomers as the name of the first asteroid, Laplace had expressed a preference for Juno. This, however, the discoverer was unwilling to accept. Mr. Harding, like Laplace, deeming it appropriate to place Juno near Jupiter, selected the name for the third minor planet, which is accordingly known by this designation.

Juno is distinguished among the first asteroids by the great eccentricity of its orbit, amounting to more than 0.25. Its least and its greatest distances from the sun are therefore to each other very nearly in the ratio of three to five. The planet consequently receives nearly three times as much light and heat in perihelion as in aphelion. It follows, also, that the half of the orbit nearest the sun is described in about eighteen months, while the remainder, or more distant half, is not passed over in much less than three years. Schroeter noticed a variation in the light of Juno, which he supposed to be produced by an axial rotation in about twenty-seven hours.

The fact that Juno was discovered not far from the point at

which the orbit of Pallas approaches very near that of Ceres, was considered a strong confirmation of the hypothesis that the asteroids were produced by the explosion of a large planet; for in case this hypothesis be founded in truth, it is evident that whatever may have been the forms of the various orbits assumed by the fragments, they must all return to the point of separation. In order, therefore, to detect other members of the group, Dr. Olbers undertook a systematic examination of the two opposite regions of the heavens through which they must pass. This search was prosecuted with great industry and perseverance till ultimately crowned with success. On the 29th of March, 1807, while sweeping over one of those regions through which the orbits of the known asteroids passed, a star of the sixth magnitude was observed where none had been seen at previous examinations. Its planetary character, which was immediately suspected, was confirmed by observation, its motion being detected on the very evening of its discovery. This fortunate result afforded the first instance of the discovery of two primary planets by the same observer.

The astronomer Gauss having been requested to name the new planet, fixed upon Vesta, a name universally accepted. Though the brightest of the asteroids, its apparent diameter is too small to be accurately determined, and hence its real magnitude is not well ascertained. Professor Harrington, of Ann Arbor, has estimated the diameter at five hundred and twenty miles. According to others, however, it does not exceed three hundred.

If the latter be correct, the volume is about 1/20000 that of the earth. It is remarkable that notwithstanding its diminutive size it may be seen under favorable circumstances by the naked eye.

Encouraged by the discovery of Vesta (which he regarded as almost a demonstration of his favorite theory), Dr. Olbers continued his systematic search for other planetary fragments. Not meeting, however, with further success, he relinquished his observations in 1816. His failure, it may here be remarked, was doubtless owing to the fact that his examination was limited to stars of the seventh and eighth magnitudes.

The search for new planets was next resumed about 1831, by Herr Hencke, of Driessen. With a zeal and perseverance worthy of all praise, this amateur astronomer employed himself in a strict examination of the heavens represented by the Maps of the Berlin Academy. These maps extend fifteen degrees on each side of the equator, and contain all stars down to the ninth magnitude and many of the tenth. Dr. Hencke rendered some of these charts still more complete by the insertion of smaller stars; or rather, "made for himself special charts of particular districts." On the evening of December 8, 1845, he observed a star of the ninth magnitude where none had been previously seen, as he knew from the fact that it was neither found on his own chart nor given on that of the Academy. On the next morning he wrote to Professors Encke and Schumacher informing them of his supposed discovery. "It is very improbable," he remarked in his letter to the latter, "that this should prove to be merely

a variable star, since in my former observations of this region, which have been continued for many years, I have never detected the slightest trace of it." The new star was soon seen at the principal observatories of Europe, and its planetary character satisfactorily established. The selection of a name was left by the discoverer to Professor Encke, who chose that of Astræa.

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