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GAUSS AND THE DISCOVERY OF CERES

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On the evening of 1 January 1801, the celebrated Italian astronomer Giuseppe Piazzi (1746–1826) observed what appeared to be a new star of the eighth magnitude in the constellation Taurus. When he checked this observation on the following evening, he found a slightly different value for the angular distance between this and a neighbouring star which made him doubt the accuracy of his former observation. However, after a further attempt to determine its position during the evening of 3 January, he became convinced that it exhibited a retrograde motion and therefore could not be a star as he had originally supposed; and he was not long in establishing its daily variation in right ascension as 4′ and in declination as 3′30″. Although this was a chance discovery made in the course of constructing his great star catalogue, one should not fail to note Piazzi's comment: "If I had not been in the habit of observing the stars four, five, six times, and even more, I should certainly not have discovered my present one".[1] Indeed, at that time he had already spent nine years at his observatory in Palermo making observations with his 5-foot radius transit circle (constructed for him by the well-known London instrument-maker Jesse Ramsden), and had recorded the equatorial co-ordinates of well over six thousand stars to within an accuracy of only a few seconds of arc.

Piazzi, naturally excited by his discovery, transmitted an account of it on the 23 January to his fellow-astronomers Barnaba Oriani, Johann Elert Bode, and Baron Franz Xavier von Zach, having failed in the interim, on account of the poor weather conditions, to obtain further observations of this new celestial object. In these communications, he gave merely its apparent positions on the 3 and 23 January, pointing out that the motion must have changed from being retrograde into being direct on 10 January. He also informed his correspondents that his "star" would be named *Ceres Ferdinandea* in honour of King Ferdinand of Sicily who had founded the observatory at Palermo.[2] An unpublished letter in the archives of the Royal Greenwich Observatory would appear to imply that it was not he, but von Zach, who chose to designate it by ⚳ on the ground that "The symbol of Saturn ♄, represents a scythe, so the symbol of ceres ⚳ may represent a sickle, as Ceres is the goddess of corn and tillage".[3]

Shortly after dispatching his letters, Piazzi began to suspect that the object may have been a comet, since it appeared smaller in size and in brightness than at first. He therefore made several computations, but arrived at inconsistent results which indicated that his working hypothesis was wrong. A circular orbit proved, in fact, to yield a better fit, but his own observations did not cover a sufficiently long time-span to decide this question.[4] Nevertheless, the agreement between theory and observations was sufficient to establish the fact that he was observing a planet rather than a comet. It was in answer to requests for the rest of his observations, and not because of a fear of being deprived of the glory attached to his discovery, that Piazzi sent these data in April 1801 to Joseph de Lalande in Paris, to Oriani in Milan, and to Bode in

Berlin. This was particularly necessary since Ceres had been masked by the rays of the Sun before any of these observers had had the opportunity of observing it, and there was no sure means of knowing precisely when and where it would reappear. Oriani replied on the 25 July, giving Piazzi details of the results of his calculations and those of "some other Astronomers" whom he did not name.[5]

An anecdote[6] relates that Gauss's attention was first directed to the challenging problem of devising a new practical method for determining the orbit of Ceres in the course of a conversation with his patron, teacher and friend Eberhard August Wilhelm Zimmermann, Professor of mathematics, physics and natural history at the *Collegium Carolinum* in Brunswick where the former was then engaged on fundamental research in the theory of numbers. By November 1801, Gauss had succeeded in developing a method quite different from any that had been used before, which involved no pre-supposition regarding the form and character of the assumed (unperturbed) orbit, other than that it had to be a conic section.[7] With the aid of Piazzi's observations, which he received from von Zach,[8] Gauss made the necessary calculations for Ceres on the basis of his theory and, despite the fact that these data had not been reduced for the effects of proper motion and instrumental errors,[9] found that the assumption of an elliptical orbit produced an exceptionally close fit between theory and observation.

The orbital elements which Gauss was adopting at this time were as follows:[10]

Epoch of 1801	67°36′34″
Aphelion	326°27′38″
Node	81° 0′44″
Inclination	10°36′57″
Eccentricity	0·0825
Maximum equation of centre	9°27′41″
Maximum distance	2·7673
Daily heliocentric and tropical motion	12′50″·914
Periodic time	1681 days (= 4 years 7 months).

Burckhart, another undefatigable calculator who worked upon the assumption that the orbit was elliptical but used no novel theory to obtain his results, announced in an article "Sur la nouvelle planète"[11] a value for the periodic time which was $5\frac{1}{2}$ months less than Gauss's value. He put the eccentricity at 0·0825047, the epoch for 1801 as 77°36′34″, and the common logarithm of the semimajor axis as 0·4420527. In communicating these figures to the English Astronomer Royal Nevil Maskelyne on 2 January 1802, Burckhart remarked that according to calculations by Joseph de Lalande, Gauss's elements for Ceres yielded predictions which were 1° greater than the corresponding values observed by Heinrich Wilhelm Olbers. According to the calculations of von Zach, however, Burckhardt's own elements would have yielded values of 4° less than observations.[12] The mean distance of Ceres was in excellent agreement with the value of 2·8 assigned to the hypothetical planet which Johann Elert Bode in 1772 had claimed should exist between the orbits of Mars and Jupiter,[13] and in this respect the former harmonized admirably with the arrangement of the seven planets known at that time. The inclination of its orbit, on the other hand, was much steeper than any of the known planets; and William Herschel's micrometric measurements of its angular diameter[14] led him to infer that its

linear diameter was only 161 miles, a figure which was excessively small in comparison with the dimensions of the other planets.

There can be little doubt that Herschel's investigations were made as a direct response to the request in the second paragraph of the following letter which Gauss sent to him from Brunswick on 20 February 1802:[15]

Ich hoffe, dass Sie, verehrungswürdigster Herr Doctor, die Freiheit die ich mir nehme, Ihnen eine kleine Ephemeride unsers neuen Planeten früher als Sie sie sonst erhalten würden, mitzutheilen, gütig aufnehmen werden. Diese Ephemeride ist nach bereits einmal verbesserten Elementen berechnet, und wird wie ich hoffe im Merz und April keine Minute fehlen; sie trägt daher vielleicht etwas bei, die Beobachtung dieses so licht-schwachen Sterns zu erleichtern. Die Elemente selbst erscheinen im Merz Heft der v. Zachschen Monatl. Correspondenz; sie werden freilich noch merklicher Verbesserung bedürfen: allein mit den bisher gemachten und den künftig bis zur nächsten Conjunction noch zu machenden Beobachtungen hoffe ich Ihnen schon einen grossen Grad von Praecision geben zu können, und es muss sich dann bald entscheiden, ob die Ceres Ferdinandea eben das Schicksal gehabt hat wie der Uranus Georgius, schon früher gesehen aber nicht erkannt zu sein.

Ich bin sehr neugierig ob Ihre Beobachtungen uns schon diesmal mit Ceres Trabanten oder andern physischen Merkwürdigkeiten dieses Planeten beschenken werden, und es würde mir äusserst schmeichelhaft seyn, wenn Sie mich in diesem Falle mit einigen Nachrichten darüber beehren wollten.

Ich verharre mit der inningsten Hochachtung und Verehrung

Ihr
ergebenster Diener
Gauss

Apart from three minor changes,[16] the accompanying ephemeris was the same as that which Gauss communicated to Maskelyne when he wrote on 20 February 1802 requesting the latter's co-operation in providing him with "some exquisite observations" made with the instruments of "unparalleled excellence" at Greenwich.[17] The results of comparing Maskelyne's observations of Ceres between 4 February and 3 July 1802 with Gauss's ephemerides during that five-month interval are shown in Table I. The calculated figures are linear interpolations from these ephemerides for the times between 6 March and 20 June to which the Greenwich measurements refer, and take account of Gauss's own estimate of 42^m56^sE ($\equiv 10°44'$E) for the longitude of his observatory at Seeberg.[18] Considering the various sources of error which are necessarily inherent in this comparison, the high level of agreement testifies to the accuracy both of the observations and of the computations.

Maskelyne's own awareness of this remarkable order of accuracy undoubtedly explains why he was so ready to co-operate with Gauss by exchanging his observations for the latter's ephemerides, contrary to Olbers's expectation.[19] Indeed, a personal memorandum now preserved among Maskelyne's unpublished papers at the Royal Greenwich Observatory, dated 17 February 1802,[20] proves that even before receiving Gauss's letter he had already decided to adopt his elements for Ceres's orbit in preference to those of Burckhardt—despite the fact that he knew nothing of Gauss's method nor of the reports

TABLE I

A Comparison between Maskelyne's Observations and Gauss's Calculations of the Minor Planet Ceres

1802		Right Ascension: Observation (Maskelyne)	Right Ascension: Calculation (Gauss)	Diff. (″)	Declination: Observation (Maskelyne)	Declination: Calculation (Gauss)	Diff. (″)
		° ′ ″	° ′ ″		° ′ ″	° ′ ″	
March	6	185 49 2·6	185 48 42·2	+20·4	16 3 49·5	16 3 56·1	−6·6
	14	184 15 3·8	184 15 35·1	−31·3	16 52 0	16 53 1·8	−61·8
	18	183 24 30·8	183 25 1·2	−30·4	17 14 10·6	17 14 15·2	−4·6
	25	181 54 18·8	181 54 39·0	−20·2	17 43 49·8	17 44 5·4	−15·6
April	6	179 28 22·8	179 29 8·2	−45·4	18 9 10·2	18 9 29·2	−19·0
	21	177 13 37·2	177 13 26·0	+11·2	17 51 41·4	17 52 8·9	−27·5
May	1	176 26 1·2	176 26 34·2	−33·0	17 12 34·7	17 12 26·6	+8.1
	4	176 19 5	176 19 29·7	−24·7	16 57 7·7	16 56 53·0	+14·7
	11	176 15 48	176 16 15·4	−27·4	16 12 41·8	16 15 4·2	−142·4
	13	176 18 6·9	176 18 45·8	−38·9	16 1 48·6	16 1 49·6	−1·0
June	20	181 2 7·8	181 1 15·7	+52·1	10 26 15	10 26 47·2	−32·2

Mean diff. in R.A. = 30″ Mean diff. in Decl. = 21″

Note: The anomalous result for Ceres's declination on 11 May 1802 would appear to be due to an error in either the transcription or reduction of the observational value; it has therefore been discounted in estimating the mean difference.

which had been appearing in von Zach's *Monatliche Correspondenz. . .* for 1801.[21] In the course of the next three years Maskelyne wrote no fewer than seven letters to Gauss containing observations not only of Ceres itself but also of the minor planets Pallas and Juno which had been discovered in the interim. The original letters are all preserved in the Göttingen University Library,[22] and have recently been published by the writer along with five others from Gauss to Maskelyne written during the same period.[23] Internal evidence in this correspondence indicates that Gauss wrote a further six letters to Maskelyne dated 19 May, ? July, 29 July, ? November 1802, 11 September 1803, and 25 October 1804. However, since those are not preserved in any of the London or Cambridge libraries, nor among Maskelyne's papers at the Royal Greenwich Observatory, one must conclude that they are lost, if not destroyed.

REFERENCES

1. The quotation, along with the rest of the information in this paragraph, is taken from an English translation of Piazzi's memoir entitled: "Results of the observations of the new star discovered on the 1st of January 1801 at the Royal Observatory of Palermo", to be found among Maskelyne's manuscripts at the Royal Greenwich Observatory (P.R.O. Ref. 285).
2. The first reliable and exhaustive report of these circumstances appeared under the title: "Über einen zwischen Mars and Jupiter längst vermutheten, nun wahrscheinlich entdeckten neuen Haupt-planeten unseres Sonnen-Systems" in von Zach, *Monatliche Correspondenz zur Beförderung der Erd- und Himmels-Kunde*, iii (1801), 592–623.
3. Von Zach to Maskelyne; Seeberg, 30 March 1802 (R.G.O. MSS, P.R.O. Ref. 249).
4. Von Zach, *op. cit.* (ref. 2), 608–9.
5. Cf. ref. 1, Appendix.
6. This is referred to by G. Waldo Dunnington, *Carl Friedrich Gauss: Titan of science* (New York, 1955).

7. This result was a direct consequence of his adoption of the inverse-square distance law of gravitational attraction. Gauss's original method, referred to here, was first published in von Zach, *Monatliche Correspondenz*, xx (1809), 147–192.
8. These were published in von Zach, *Monatliche Correspondenz*, i (1801), 279–83.
9. It was subsequently found, however, that these errors amounted to only 3″ or less in the values of the right ascension. Cf. ref. 1, Appendix; also, von Zach, *Monatliche Correspondenz*, iv (1801), 573.
10. Rough notes, in Maskelyne's hand, in: R.G.O. MSS, P.R.O. Ref. 249.
11. *Moniteur*, Quartidi 4 Pluvoise An 10, 24 January 1802.
12. *Loc. cit.* (ref. 10).
13. The original suggestion of the harmonic progression in the planetary distances with which Bode's name has come to be associated actually stems from Professor Johann Daniel Titius, who wrote a note about it in the German translation *Betrachtung über die Natur*. . . (Leipzig, 1772) of the second edition of Charles Bonnet's *Contemplation de la Nature* (Amsterdam, 1768).
14. William Herschel, "Observations on the two lately discovered celestial Bodies", *Philosophical transactions of the Royal Society*, cxxii (1802), 213–32; 218.
15. This is preserved among the Herschel papers in the Royal Astronomical Society library, London.
16. These are: an increase of 1′ in the right ascension of Ceres for 10 March, an increase of ½′ in its declination for 18 April, and a decrease of ½′ in its declination for 6 April.
17. Gauss to Maskelyne; Brunswick, 20 February 1802 (*loc. cit.* (ref. 10)).
18. This value is cited at the head of an ephemeris of the equatorial co-ordinates of Ceres from 21 April to 29 June 1802 enclosed with Gauss's letter to Maskelyne of 3 April 1802 (*ibid.*).
19. Olbers to Gauss; Bremen, 16 March 1802, remarks: "So wenig kommunikabel er sonst auch mit seinen Beobachtungen ist, so wird er sie Ihnen doch gewiss nicht abschlagen". See C. Schilling, *Wilhelm Olbers sein Leben und seine Werke*, ii (Berlin, 1900), 15.
20. *Loc. cit.* (ref. 10).
21. Maskelyne to Gauss; Greenwich, 1 October 1804 (cf. ref. 22). Maskelyne states: "I have, however, never seen Zach's Journal. . .".
22. *Cod. Ms. Gauss 102.*
23. Eric G. Forbes, "The Correspondence between Carl Friedrich Gauss and the Rev. Nevil Maskelyne (1802–1805)", *Annals of science*, xxvii (1971), 213–237.