The Prediction of the New Planet —A Classic of Science

Astronomy

MEMOIR ON A TRANS-NEPTUNIAN PLANET, by Percival Lowell. Memoirs of the Lowell Observatory, Vol. 1, No. 1. Lynn, Mass. 1915.

1. Ever since celestial mechanics in the skillful hands of Leverrier and Adams led to the world-amazed discovery of *Neptune* a belief has existed begotten of that success that still other planets lay beyond, only waiting to be found. Leverrier himself, with the far-sight of genius, was firmly of this view, though unfortunately oversanguine of the happy date of its demonstration. In consequence since his time many attempts have been made to indicate the position of one or more of these unknowns, attempts for the most part of no scientific value because not founded on rigorous mathematical investigation. For so complicated is the problem that all elementary means of dealing with it lead only to error. The sole road to any hope of capture lies through the methodical approach of laborious analysis.

Not only are all summary processes worse than useless, engendering false ideas in their conclusions, even a supposed proximate analysis proves not to be approximate in its results. Thus the simplifying of the problem by the assumption of a circular orbit for the unknown, originally suggested by Tisserand and worked out in the present case with all due reserve by M. Gaillot, and more or less likewise by M. Lau, betrays intrinsic evidence of inadequacy. For M. Gaillot reduces the mean of the outstanding squares of the residuals only from 1.04 to 0.88, which, considering that the admission of a disturbing body must necessarily reduce them is self-confessedly hardly a satisfactory solution.

Still more questionable is the attempt to explain planetary irregularities on the supposition of two unknowns, both traveling in circles; as we have no guarantee that the habit of either body is of this obliging simplicity. In fact, there is a distinct antecedent probability that it is not.

2. To any real solution, the problem must be attacked analytically with all the rigor possible. Before entering upon such an investigation it is well to state the problem generally, showing the data upon which it rests and the limitations to which it is necessarily subject. For lack of appreciation of these points has led to mistaken ideas of what is or is not possible.

3. The theory of a planet cannot in the nature of things be exact; and this for three reasons:

(1) the observations on which it is founded are necessarily more or less in error; (2) the theory itself may be more or less imperfect; (3) an unknown body may be acting of which perforce no account has been taken. The latter is a particularly insidious pitfall inasmuch as the greater part of the disturbance it causes can be concealed by suitable changes of the disturber's elements in the following way:

Since the biggest terms in the perturbation are those arising from terms of long period or terms having nearly the period of the disturbed body, these can in large part be thrown upon the mean motion, the epoch, the eccentricity and the place of the perihelion of the disturbed body. For a long period term in the perturbation has for a century or so nearly the same effect as an alteration in the mean motion or in the epoch or both; while one having nearly the period of the perturbed planet may similarly be represented by altering the supposed eccentricity or perihelion place of the latter. Not only may these terms so be accounted for; by the process of solution adopted they must necessarily be. For the corrections of the elements are obtained from the observational equations themselves by the method of least squares.

Consequently the residuals left by the theory are not at all the outstanding perturbations, but only such small part of them as cannot be got rid of by suitable shuffling of the cards. We have then no guarantee that our supposed elements are the real ones, but only the best attainable under the assumption *that no unknown exists.* Every theory of a planet is thus open to doubt, seeming more perfect than it is. It has been legitimately juggled to come out correct, its seeming correctness concealing its questionable character.

4. The test of the existence of an unknown body thus left out of account lies in the substantial reduction of the outstanding residuals of the theory by its subsequent admission. The reduction must be substantial to be indicative, because a slight betterment necessarily follows the introduction of another factor among the adjustable quantities. . . .

8. At the present time no such simple problem confronts us. We cannot use *Neptune* as a finger-post to a trans-Neptunian as *Uranus* was used for *Neptune* because we do not possess observations of *Neptune* far enough back. A disturbed body must have pursued a fairly long path before the effects of perturbation detach themselves from what may be well represented by altering the elements of the disturbed. *Neptune* has not been known long enough to do this. Analysis of its residuals, made in the course of this investigation, yielded no rational result.

Secondly, in 1845 the outstanding irregularities of *Uranus* had reached the relatively huge sum of 133″. To day its residuals do not exceed 4″.5 at any point of its path.

9. Adams' method was direct and masterly; Leverrier's, equally original, was simpler and more complete. . . .

10. Originally the above course [Leverrier's] was pursued in the present investigation, but with extensions in the number and character of the terms calculated in the perturbation in order to render it more complete. The residuals used were those of Leverrier's theory of *Uranus* of 1873, brought up to 1906 by the Greenwich observations. The outcome was very satisfactory, indicating an unknown body in

longitude 244° at 1912.0

11. In 1912. the subject was continued by solving again with Gaillot's residuals in place of Leverrier's. Gaillot's theory is to be found in the *Annales* of the *Paris Observatory,* Vol. 28, and in addition to its general excellence has two qualities which specially commend it. The first is that the adopted masses of the several planets concerned are probably the best we possess today, having been taken with great judgment by M. Gaillot. The full merit of this can be appreciated only by those familiar with most works on celestial mechanics, in which, after excellent analytical solutions, values of (*Turn to page* 182)

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the quantities involved are introduced on the basis apparently, of the respect due to age. Nautical Almanacs abet the practice by never publishing, consciously, contemporary values of astronomic constants; thus avoiding committal to doubtful results by the simple expedient of not printing anything not known to be wrong.

His second mark of merit is in giving the residuals between his theory and observations.

With Gaillot's residuals, values for the longitude came out, according to the terms included in the perturbations, changed elimination equations, etc., as

209° and 203° for Jan. 1, 1912;

on the whole, a corroboratory result.
. . .

In the present case, it seemed advisable to pursue the subject in a different way, longer and more laborious than these earlier methods, but also more certain and exact; that by a true least-square method throughout. When this was done, a result substantially differing from the preliminary one was the outcome. It both shifted the minimum and bettered the solution. In consequence, the whole work was done *de novo* in this more rigorous way, with results which proved its value.

14. This investigation we shall now give in detail. The work was done in duplicate, and as a further check, wherever possible, the functions involved were plotted so that any important deviation from their proper curves could be detected at sight. Besides the outcome from the standpoint of accuracy, the procedure disclosed the fact that points of commensurable period introduce no discontinuity into the perturbative function. . . .

[There follow 90 pages of tables, formulae and computations.—Ed.]

Conclusions

62. Assembling the various solutions, got by considering such diverse terms and in such different ways, we are first struck by the general concordance the results exhibit. This is significantly displayed in the several sets of elements, in the comparatively close resemblance of the excentricities, masses, perihelion places and mean longtitudes of the epochs deduced. Even the resulting heliocentric longitudes of the unknown for a given date, July 0, 1914, come out in rather striking accord. . . .

That they are not more so will perhaps be one's second thought. But when we look into the matter more closely, we begin to realize some reason for this. Even in his problem Leverrier discovered that his preliminary solution was entirely altered by the omission of two apparently trifling terms. Much more then should this be the case in the present investigation where we are perforce obliged to neglect terms, the coefficients of which we know to be large. . . . We should rather expect, then, disheartening discordance from the second order results; but such is not the case. . . .

65. That Leverrier's solution gave him limits which were erroneous shows how necessary to a full comprehension of the problem is the rigorous and more complete method of solution. This does not detract from the great analytical skill displayed by both Adams and Leverrier in their mastterly attack on the problem. That alone deserved success. Why it attained it is nevertheless a cause for some surprise, for Leverrier left out terms bigger than two he retained. The explanation would seem to lie in the nearness of *Neptune* and the near circularity of its orbit. *Neptune* turns out to have been most complaisant and to have assisted materially to its own detection.

How important the circularity or non-circularity of the orbit is to the finding the unknown may be seen from Gaillot's circular solution which, although it gives a major axis for *X* (45 astr. units) not inconsistent with that from the elliptical one, is entirely discordant (295°) with the latter when it comes to assigning the present position of the perturbing body.

66. It becomes pertinent here to note what both Leverrier and Adams considered a satisfactory betterment of the *Uranian* residuals, and which in view of the then relatively imperfect theories of the other planets it certainly was. The sum of the squares of the residuals left by Adams' theory was 348, and by Leverrier's, 615. This was an enormous improvement on Bouvard's, or even on Bouvard's corrected by Leverrier. Yet both are much larger than the sum with which we at present start as our initial data.

The solutions indicate the place of the perturbing matter supposing it represented by a single body which is the only practical and workable supposition. For though other bodies doubtless exist beyond, their effect is not likely, owing to distance, to be such as seriously to modify the primary solution. If the matter should be distributed in an asteroidal ring, although the theory would remain correct, the matter itself would escape recognition.

Finally it is vital to notice how it is the far residuals that give us information of the presence of an unknown not the near ones. These have been made small by proper shift of the elements of the perturbed body and can always be so minimized. It is only the distant ones which cannot be thus reduced and which therefore constitute our guideposts in the case.
. . .

68. But that the investigation opens our eyes to the pitfalls of the past does not on that account render us blind to those of the present. To begin with, the curves of the solutions show that a proper change in the errors of observation would quite alter the minimum point for either the different mean distances or the mean longitudes. A slight increase of the actual errors over the most probable ones, such as it by no means strains human capacity for error to suppose, would suffice entirely to change the most probable distance of the disturber and its longitude at the epoch. Indeed the imposing "probable error" of a set of observations imposes on no one familiar with observation, the actual errors committed, due to systematic causes, always far exceeding it.

In the next place the solutions themselves tell us of alternatives between which they leave us in doubt to decide. If we go by residuals alone, we should choose those solutions which have their mean longitudes at the epoch in the neighborhood of 0°, since the residuals are there the smallest. But on the other hand this would place the unknown now and for many decades back in a part of the sky which has been most assiduously scanned, while the solutions with epoch around 180° lead us to one nearly inaccessible to most observatories, and, therefore preferable for planetary hiding. Between the elements of the two, there is not much to choose, all agreeing pretty well with one another.

Owing to the inexactitude of our data, then, we cannot regard our results with the complacency of completeness we should like. Just as Lagrange and Laplace believed they had proved the eternal stability of our system, and just as further study has shown this confidence to have been misplaced; so the fine definiteness of positioning of an unknown by the bold analysis of Leverrier or Adams appears in the light of subsequent research to be only possible under certain circumstances. Analytics thought to promise the precision of a rifle and finds it must rely upon the promiscuity of a shot gun after all, though the fault lies not (*Turn to page* 190)

ELEMENTS OF CHEMISTRY

By Harry N. Holmes, Professor of Chemistry, Oberlin College, and Louis W. Mattern, Head Teacher of Chemistry, McKinley Technical High School, Washington, D. C.

The authors maintain that an intelligent appreciation of the industrial life of the nation and of the foundations of world power is no longer possible without some knowledge of chemistry. Hence, in this elementary textbook, they set out to convince the student that his own personal comfort, safety, pleasure, health, and well-being are dependent upon chemical reaction. By the use of "Problems Yet to Be Solved" the subject matter is given spice and interest with the lure of the unknown and the conviction of the wonderful service that chemistry can give to the world.

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Prediction of the Planet—*Continued*

more in the weapon than in the uncertain bases on which it rests. But to learn of the general solution and the limitations of a problem is really as instructive and important as if it permitted specifically of exact prediction.

For that, too, means advance.

Summary

69. This investigation establishes the following:

1. By the most rigorous method, that of least squares throughout, taking the perturbative action through the first powers of the excentricities, the outstanding squares of the residuals from 1750 to 1903 have been reduced 71% by the admission of an outside perturbing body.

2. The inclusion of further terms yielded solutions in accordance with the first.

3. Solutions taking the years 1690-1715 also into account agreed substantially with those from the years 1750-1903.

4. So did those in which the additional years to 1910 were considered.

5. The second part of the investigation, in which the solutions were made for the second powers of the excentricities as well, gave conformable results.

6. When the probable errors of observation were reckoned, the outstanding squares of the residuals of theory excluding an outside planet proved to have been reduced by its admission from 90% to 100% nearly, the solutions seeming to confirm one another. . . .

7. Though this would indicate an absolute solution of the problem, it must be remembered that the actual as against the probable errors of observation might decidedly alter the result; and so might the terms above the squares in e and e' necessarily left out of account.

8. The investigation disclosed two possible solutions in each case, one with the mean longtitude of the epoch around 0°, one with it around 180°; and that this duality of possible place would necessarily always be the case.

9. On the whole, the best solutions for the two gave: mean longitude of epoch around 0°: epoch 22°.1; semi-axis 43.0; mass 1.00; excentricity .202; place of perihelion 203°.8 heliocentric longitude July 0, 1914—84°.0: mean longitude of epoch around 180°: epoch 205°.0; semi-axis 44.7; mass 1.14; excentricity .195; place of perihelion 19°.6; heliocentric longitude July 0, 1914—262°.8: the unit of mass being 1/50,000 the mass of the *Sun*.

10. It indicates for the unknown a mass between *Neptune's* and the *Earth's;* a visibility of the 12-13 magnitude according to albedo; and a disk of more than 1" in diameter.

11. From the analogy of the other members of the solar family, in which excentricity and inclination are usually correlated, the inclination of its orbit to the plane of the ecliptic should be about 10° This renders it more difficult to find.

12. Investigations on the perturbation in latitude yielded no trustworthy results. This is probably because the excentricity as well as the planet's other elements enter as data into the latitude observation equations.

13. The perturbative function is not discontinuous at the commensurability of period points, a fact hitherto in doubt.

14. That when an unknown is so far removed relatively from the planet it perturbs, precise prediction of its place does not seem to be possible. A general direction alone is predictable.

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New Comet

BEYER'S comet, discovered on March 11 by an astronomer at the Hamburg Observatory in Germany, has been observed by Prof. George Van Biesbroeck, at the Yerkes Observatory, Williams Bay, Wis. This announcement was made by the Harvard College Observatory.

Prof. Van Biesbroeck observed it on the night of March 13. Then it was in the constellation of Auriga, the charioteer, now high in the southwestern evening sky. Astronomically, its position was 6 hours 5 minutes 10 seconds right ascension and 33 degrees 25 minutes and 14 seconds north declination. It is still moving northwards, and is of the tenth magnitude, visible only in a medium-sized telescope.

According to word received at the Harvard Observatory from Europe, it has been found that photographs of this part of the sky made by Prof. Prager at the University of Berlin's Observatory also showed the comet, though it was not recognized until Dr. Beyer's discovery. These early positions, however, will greatly aid in calculating the comet's path. Three separate observations are required to compute an orbit, and the farther apart they are, the more accurate is the result.

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