THE SATELLITES OF MARS: PREDICTION AND DISCOVERY

OWEN GINGERICH, Smithsonian Astrophysical Observatory and Harvard College Observatory

The remarkable prediction of the two satellites of Mars contained in Jonathan Swift’s *Gulliver’s travels* has perplexed astronomers for nearly a century. Swift’s eighteenth-century satire appears to have anticipated Asaph Hall’s actual discovery of Phobos and Deimos in 1877 by almost exactly 150 years. According to Swift, the scientists of Laputa had “discovered two lesser stars, or satellites, which revolve about Mars; whereof the innermost is distant from the center of the primary planet exactly three of his diameters, and the outermost five; the former revolved in a space of ten hours, the latter in twenty-one and a half; so that the squares of their periodical times, are very near in the same proportion with the cubes of their distances from the center of Mars; which evidently shews them to be governed by the same law of gravitation, that influences the other heavenly bodies.”

The most uncanny part of the prediction is a very short (10-hour) period for the inner satellite—considerably shorter than the period of any of the ten satellites known in Swift’s day, and at least qualitatively borne out by the eventual discovery.

<table>
<thead>
<tr>
<th>Mars’s satellites</th>
<th>Actual a/d 3° P(hrs)</th>
<th>Swift’s predictions a/d 3° P(hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phobos</td>
<td>1·4 7·6</td>
<td>3 10</td>
</tr>
<tr>
<td>Deimos</td>
<td>3·5 30·3</td>
<td>5 21 1/2</td>
</tr>
</tbody>
</table>

A closer look at Swift’s numbers, however, shows that he was not so clairvoyant as a first glance suggests. A choice of three and five planetary diameters for the distances of the two satellites very nearly matches corresponding distances for Jupiter’s Io and Europa. The correspondence with the Jupiter satellite system and also the similarity to Saturn are shown in Table II, where the distances are expressed in terms of planetary diameters. Swift probably realized that our moon is anomalously large compared to its parent body, and particularly remote. Had a similar situation prevailed for Mars, its satellites would have already been discovered.

<table>
<thead>
<tr>
<th>Jupiter</th>
<th>a/d 2</th>
<th>P(hrs)</th>
<th>Saturn</th>
<th>a/d T1</th>
<th>P(hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Io</td>
<td>3·0</td>
<td>42</td>
<td>Tethys (1684)</td>
<td>2·5</td>
<td>45</td>
</tr>
<tr>
<td>Europa</td>
<td>4·8</td>
<td>85</td>
<td>Dione (1684)</td>
<td>3·2</td>
<td>66</td>
</tr>
<tr>
<td>Ganymede</td>
<td>7·8</td>
<td>172</td>
<td>Rhea (1672)</td>
<td>4·5</td>
<td>108</td>
</tr>
<tr>
<td>Callisto</td>
<td>13·6</td>
<td>400</td>
<td>Titan (1655)</td>
<td>10·5</td>
<td>383</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Japetus (1671)</td>
<td>30·6</td>
<td>1900</td>
</tr>
</tbody>
</table>

More puzzling is the choice of ten hours for the period of the innermost satellite. Even if Jupiter had been chosen as the paradigm for satellite spacing, the periods would not follow by direct analogy. Further calculations are required. If Mars had the same density as the Earth, then the first satellite at 3

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planetary diameters should have a period of roughly one day; if the density were more like that of a Jovian planet, the period should be closer to two days. Newton’s work had already provided the basis for such a calculation, so that we can only suppose that 10 hours was chosen as a convenient guess. However, Swift’s choice leads to an absurdly high density for Mars. Given the distances and one of the periods, the other follows from Kepler’s harmonic law, succinctly stated by Swift in the quoted passage. This law was well-known by 1726, and that Swift used it correctly should occasion little surprise; some commentators have suggested, however, that Swift had professional help.

In Swift’s day the idea that Mars should have two satellites was firmly rooted in analogy with the adjacent planets in the solar system. Mercury and Venus had no known satellites, the Earth one, Mars an unknown number, Jupiter four, and Saturn five. Voltaire confirmed this line of reasoning in his Micromegas (1752), where he states, “[the voyagers] would see the two moons which belonged to this planet, and which have escaped the searches of our astronomers. I know quite well that P. Castel has written, and even rather pleasantly, against the existence of these two moons; but I am in agreement with those who reason by analogy. The best philosophers know how difficult it would be for Mars, which is next from the sun, to have less than two moons.”

Much earlier Fontenelle had also discussed the matter in his Conversation on the plurality of worlds. The pupil argues,

> Because Nature hath given so many Moons to Saturn and to Jupiter, it is a kind of proof that Mars cannot be in want of Moons. I should have been very well satisfied that those Worlds, which are removed at a distance from the Sun have them, if Mars did not interfere, in order to make a very disagreeable exception. Ah! truly, replied I, if you mix Philosophy with every thing you do, you will soon accustom yourself to make exceptions to the best systems. Some things always agree very well, others never will agree, do all we can, so that they must be left as found, otherwise we may despair of ever attaining the end proposed.

Quite possibly the inspiration for two Martian satellites derived from Kepler, who repeatedly argued from archetype principles based on harmony or analogy. In a letter to Galileo, Kepler wrote “I am so far from disbelieving in the discovery of the four circumjovial planets, that I long for a telescope, to anticipate you, if possible, in discovering two round Mars (as the proportion seems to require), six or eight round Saturn, and perhaps one each round Mercury and Venus.”

Kepler’s belief in the possibility of a pair of Martian satellites led him into a curious trap in his correspondence with Galileo. Shortly after publishing his Sidereus nuncius, Galileo made yet another discovery that was announced to the world in the form of an anagram consisting of the series of letters: smaimulmepletalumibunenugtauiras. Few riddles can have been more challenging to Johannes Kepler, who waited in Prague with eager expectation for word of the new astronomical discoveries from Florence. Kepler transposed the letters to read:

> Salve umbistineum geminatum Martia proles.

Hail, twin companionship, children of Mars.

Kepler’s remarkable and erroneous deciphering hinged on the word umbistineum,
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apparently a Latinized German word such as unbeistehn. But in fact, Galileo's anagram had nothing to do with the discovery of two satellites of Mars. In a letter dated 13 November 1610 Galileo rearranged the letters to form

Altissimum planetam tergeminum observavi.10

I have observed the most distant of the planets to have a triple form.

Thus Galileo was signaling the peculiarities of Saturn that we now understand to be its ring system.

Kepler’s false decoding of the anagram was published in the preface to his Dioptrice. The second edition of this work was published in London in 1653 along with Gassendi’s Institutio astronomica and Galileo’s Sidereus nuncius; yet another edition appeared in 1683, so that Kepler’s fancy with respect to the Martian satellites was probably better known to the English audience than were many of his other ideas. While this does not prove that Swift got his inspiration for the Laputan discovery of two Martian satellites from Johannes Kepler, yet the evidence indicates that the idea must then have been “in the air”.

Neither the original announcement of Asaph Hall’s discovery of Phobos and Deimos during the particularly favourable opposition in August of 1877, nor the subsequent discussions, give any clue that the detection of the satellite was more than a routine piece of sharp-eyed observing. Nor do the record books for the U.S. Naval Observatory 26-inch refractor, the “Great Equatorial”, give any indication to the contrary. The observations on 11 August 1877 began with routine measurements of the satellites of Saturn, followed by an examination of Mars. The notes indicate “seeing good for Mars. The edge of the white spot has two notches near the center of its outline. (A faint star near Mars).” A later note has been inserted by Hall: “This proves to be satellite 1. See Aug 16 and seq.”, that is, Deimos.

The following nights were cloudy and on 15 August the seeing conditions were very poor. On 16 August Hall’s first observation was a rough measurement of the “Star near Mars”. Two hours later he succeeded in obtaining a more precise series of chronometer measurements.

On the following night the first page of the record book closes with the remark that “The Mars Star observed tonight is a fixed star and not the object observed last night.” It is plain from this remark that Hall is already convinced that his object was a new satellite. Later the same night he recorded for the first time two satellites, each ambiguously labelled “Mars Star”. The pages for 17 August close with the remark that “Both the above objects faint but distinctly seen both by G. Anderson and myself” (see Plate I).

The situation clearly changed by the following night, for Hall was joined in the dome by D. P. Todd, Simon Newcomb and William Harkness, all of whom made measurements, and in the course of the observing the expression “Mars Star” becomes “Mars-Satellite”. The first remark is in Hall’s hand: “Images very poor at 9h 40m, but saw the satellite immediately.” This is followed by four lines signed by D. P. Todd: “Seeing extremely bad: still I saw the companion without any difficulty. ‘Halo’ around the planet very bright, and the satellite was visible in this halo.”11

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That Professor Hall's search was deliberate and guided in part by theoretical consideration becomes somewhat more apparent in a brief monograph prepared the following year, where he refers to an article by d'Arrest in the *Astronomisches Nachrichten.* This line of argument is presented by Hall with still more clarity and force in a hitherto unpublished letter to E. C. Pickering. The letter contains in addition a remarkable comment about the actual circumstances of the discovery; consequently, the letter is quoted here in full, with the permission of the Harvard University Archives:

1888 Febr. 14

Professor E. C. Pickering
Director Harvard College Obs'y

My Dear Sir:

In the Spring of 1877, when I began to think of searching for a satellite of Mars, a little rough calculation convinced me that this planet could have no moon even at half the distance D'Arrest assumes as a limit. If Mars is at the geocentric distance 0.52, the elongation 70' would make the distance of the satellite from Mars = 1.000 000 miles, nearly, = 0.0108108, in terms of Earth's dist. from sun. Mars dist. from sun is 1.5236914 the disturbing force of the sun on a satellite is the difference of its action on the planet and on the satellite. When the satellite came between Mars and the sun its dist. from the sun would be 1.5128806. Computing the forces by the expression \( \frac{\mu}{r^2} \), \( \mu \) being the mass of the sun, or of the planet, I found the disturbing force of the sun more than twice as great as the attraction of the planet on the satellite. Hence, we would at once reduce the elongation to 30', and this being a *limit* the probable elongation would be much less. A little trial, and the analogy of other planetary systems, led me to search very near the planet. My calculation made me think that D'Arrest did not intend to be very exact in his statement A. N. Bd. 64; and that he reasoned rather from analogy. In the case of any planet I should compute the forces as I did before.

In the case of the Mars satellites there was a practical difficulty of which I could not speak in an official Report. It was to get rid of my assistant. It was natural that I should wish to be alone; and by the greatest good luck Dr. Henry Draper invited him to Dobb's Ferry at the very nick of time. He could not have gone much farther than Baltimore when I had the first satellite nearly in hand.

Will you give me some information in photography. Capt. Phythian proposes to photograph the solar Eclipse of next Jan. on the Pacific coast. What photographic lenses would you recommend, and what plates. Professor Harkness is inclined to retain old methods, but I presume you have made improvements.

Yours truly,

A. Hall

The assistant Hall so much desired to get rid of was none other than Edward S. Holden, a young protégé of Simon Newcomb. (Newcomb was in charge of the Nautical Almanac Office and, for all practical purposes, the scientific director of the Naval Observatory.) Newcomb's enthusiasm for Holden may have waned
in later years after his former assistant became president of the University of California and then in 1887 director of the Lick Observatory. Describing Holden as a "much-hated man", Newcomb relates in his autobiography that "The term of Holden's administration extended through some ten years. To me its most singular feature was the constantly growing unpopularity of the director."  

Holden's own interest in possible Martian satellites was described by Hall many years later in a letter to [Seth] Chandler, dated 7 March 1904:  

There are several points about the discovery of the satellites of Mars that have not been noticed. Thus Newcomb and Holden had the 26 inch Telescope for the first two years and they tried to make discoveries. W. Herschel said he had seen six satellites of Uranus; and only four are known. Somebody, perhaps Lassell, reported a second satellite of Neptune. After two years Newcomb got tired of the night work and offered the instrument to me. He had made good determinations of the masses of Uranus and Neptune. Procyon had been examined very carefully for the disturbing companion. Of course one of the first things I did was to find out what my predecessors had been doing. I found in a drawer in the Eq. room a lot of photographs of the planet Mars in 1875. From the handwriting of dates and notes probably Holden directed the photographer, but whoever did the pointing of the telescope had the satellites under his eyes. All that was needed was the right way of looking, and that was to get rid of the dazzling light of the planet. The satellites might have been found at Harvard in 1862 very easily.  

Hall's suspicions that Holden would try to get into the act were quickly confirmed. On 28 August Holden wrote from Dobb's Ferry that he and Dr Henry Draper had detected a third satellite of Mars on 26 and 27 August. A letter of 9 October from Hall documents yet another Holden discovery: "Prof. Holden has observed a fourth satellite of Mars since Sept. 24th: but I think it will turn out that the Draper-Holden moon and the recent Holden moon do not exist. Another satellite of Mars may be found at Melbourne but these are fictitious."  

Simon Newcomb also took a share of the credit for himself; according to the New York Tribune of 20 August 1877, Hall hardly recognized his great discovery until Newcomb had worked out the period from the preliminary observations. In spite of a clarification published shortly after in Nature, a misunderstanding between Newcomb and Hall must have lingered for years. This was at least partially cleared up in 1901 when Hall read the manuscript for the following account in Newcomb's Reminiscences:  

One morning Professor Hall confidentially showed me his first observations of an object near Mars, and asked me what I thought of them. I remarked, 'Why, that looks very much like a satellite.'  

Yet he seemed very incredulous on the subject; so incredulous that I feared he might make no further attempt to see the object. I afterward learned, however, that this was entirely a misapprehension on my part. He had been making a careful search for some time, and had no intention of abandoning it until the matter was cleared up one way or the other.  

In returning the manuscript to Newcomb, Hall wrote, "I thank you for your letter of the 21st inst. It puts you in a different light from what I have seen you
for the last 24 years.” And in a later paragraph he adds, “After the excitement
was over I could see that you and Holden must naturally feel a great deal of
disappointment and I should have felt the same had we changed places.”¹⁹

But three years later, in the letter to Chandler already quoted, Hall was more
severe: “Newcomb was greatly excited over my discovery. Holden was away,
and he and Draper made a blunder, and afterwards Holden behaved very well,
Newcomb felt disappointed and sore, and something is to be allowed for
human nature under such circumstances. He was always greedy for money and
glory . . .”

After Hall’s death in 1907, his biographers lauded him as a great observer.
Yet, as this episode attests, the greatest observations are spurred on by theory.
Asaph Hall’s discovery of the two satellites of Mars cannot be written off
simply as the good luck of a keen observer, for the record is firm that his search
was deliberate and guided by gravitational theory. This is reinforced by a second
letter from Hall to Pickering, sent immediately after the first:⁰⁰

1888 Febr. 14

Professor Pickering

My Dear Sir:

After mailing my letter yesterday I saw that the method I followed is clumsy.
Although you no doubt see the easier way I will put it down:—If the sun’s mass
be unity, \(m\) that of the planet, \(a\) the distance of planet from sun, and \(x\) the distance
of satellite from planet; we have for equal attraction forces on the satellite,
neglecting its mass,

\[
\frac{1}{(a-x)^2} = \frac{m}{x^2}
\]

a very simple equation for \(x\). I will not answer for the numerical exactness of the
numbers I sent you, but they served for my purpose.

Should you think of photographing regions around the planets I ask your
attention to a paper by Marth on the satellite of Neptune in the Monthly Notices
a year or two ago. The irregular changes in the node and the inclination are
remarkable, and tho’ it may be possible that these are produced by systematic
errors in the orbits it does not seem probable. The gaps in the distances of the
satellites of Saturn are worthy of notice.

Yours truly
A. Hall

Acknowledgments

I wish to thank Lyle Boyd for pointing out the Asaph Hall letters at Harvard to
me; Barbara Welther for her assistance in tracing some of the literary sources;
Alfred H. Mikesell for providing photographs of the 26-inch refractor record
books at the U.S. Naval Observatory; and Marion Hall Fisher for providing
information collected largely by her cousin Llewellyn Hall about their grand-
father, Asaph Hall, including a privately-printed biographical sketch by Percival
Hall.
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REFERENCES


2. See Marjorie H. Nicolson and Nora M. Mohler, "The scientific background of Swift's Voyage to Laputa" reprinted in Nicolson's *Science and imagination* (Cornell, 1956); Lyle Boyd's "The provenance of Swift" in *The graduate journal*, vii (1965), 235–43, provides the whimsical explanation that Swift was a Martian transported to earth.


5. Voltaire, *Micromegas* (1752), ch. 3. Father Louis-Bertrand Castel (1668–1757) was a prolific and determined critic of the new Newtonian science, who looked back to Descartes and Kircher for inspiration (see Donald S. Schier, *Louis Bertrand Castel, Anti-Newtonian scientist* (Cedar Rapids, Iowa, 1941)). A rapid examination of Castel's principal work, *Traité de physique sur la pesanteur universelle des corps* (1724) has failed to locate the argument cited by Voltaire, although I have found a series of curious propositions based on a theory of vortices, such as "109—if the moon is destroyed, it is possible that Mars would take its place; it is possible that Venus and the earth would change places; it is possible that the earth would be overpowered by Venus, or Mars, or Mercury and become its satellites". Perhaps an explicit denial of the existence of Martian satellites is found in one of his 50 articles on the theory of vortices written between 1724 and his death.

6. Bernard le Bovier de Fontenelle, *Entretiens sur la pluralité des mondes* (1866); the quotation here is from p. 211 of an anonymous translation published in London in 1767, but an English translation by Glanvill was already available in 1702.


10. The original letter is unknown except for its publication in Kepler's *Dioptrice* (Augsburg, 1611), 15–16; see F. Hammer's note in *Johannes Kepler Gesammelte Werke*, iv (Munich, 1941), 515.

11. The order of the observations is given explicitly here because of the light it sheds on a statement written by Todd about 30 years later for the *Cosmopolitan magazine* of 11 March 1908, p. 343: "So mine was the first eye that ever saw Phobos recognizing it as a satellite."


14. I am indebted to the Hall family for allowing me to quote a portion of this letter; it is currently in the possession of Nancy Hall Denio. Asaph Hall further described his observing method in an unindexed letter in *Monthly notices of the Royal Astronomical Society*, xxxviii (1877), 203–8: "I began to examine the region close to the planet, and within the glare of light that surrounded it. This was done by keeping the planet just outside the field of view, and turning the eye-piece so as to pass completely around the planet."

15. Holden to Rear Admiral John Rogers, Superintendent of the Naval Observatory, Dobbs Ferry, New York, 28 August 1877; the letter is presumably at the U.S. Naval Observatory.

16. Hall to Arthur Searle, Washington, 9 October 1877, in the Harvard University Archives; Hall's greatest potential competition was from the great 48-inch Melbourne reflector, especially since Mars was better placed for southern observers.


19. Hall to Professor Newcomb, South Norfolk, Conn., 23 August 1901, in the Simon Newcomb papers in the Library of Congress.

20. Hall to E.C. Pickering, quoted with permission of the Harvard University Archives.