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Sky and TELESCOPE

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MAY, 1972

COVER: This color picture of Mars was reconstructed from three black-and-white television images taken by Mariner 7 as the spacecraft approached Mars in 1969. The techniques used are described in the adjoining column. Mars pictures from Mariner 9 are reproduced on pages 300 and 301 of this issue, and on page 276 is a discussion of Mars' great dust storm last year. Photograph courtesy Jet Propulsion Laboratory, California Institute of Technology.

About the Cover

EXTRAORDINARY close-ups of Mars, such as those reproduced in last month's issue (page 208), tend to overshadow the successes of previous Mariner missions to that planet. Yet our first detailed look at the solid surface of another planet and proof that the Martian landscape is cratered like the moon's came during the Mariner-4 flyby in July, 1965.

The color picture from Mariner 7 on this month's front cover is another example of earlier achievements. It is a reconstruction from three black-and-white photographs taken through color filters in August, 1969, with the craft's wide-angle camera. The history of this unique portrait has been supplied by Stewart A. Collins of the Jet Propulsion Laboratory.

"After the successful flyby of Mariner 6 on July 31, 1969, it was decided to alter the operating sequence of Mariner 7, due to arrive five days later. Such last-minute reprogramming of a planetary spacecraft had never before been attempted, but our reward was twofold: far-encounter color information and increased coverage of the south polar cap during the near-encounter phase of the mission.

"As part of this modified program, Mariner 7 transmitted photographs as they were taken during the final few hours of approach. This sequence, including the frames for the color picture, began 2⅔ hours before closest approach and lasted for an hour.

"To match the high rate of data accumulation by Mariner's TV camera to the spacecraft's lesser telemetry capability, it was necessary to edit the photographs severely. Only every seventh picture element was transmitted, which greatly reduced the horizontal resolution. Also, the right-hand portion of the image was blanked out to permit transmitting data from other scientific instruments.

"Upon receipt of the pictures, J. A. Cutts of California Institute of Technology computer-processed them, using prelaunch data to obtain photometric calibration. The three frames used to produce the color picture were taken at 84-second intervals. Because Mariner 7's distance from Mars had decreased from 59,577 to 58,377 kilometers between the first and last exposures, it was necessary to unify the scale of the frames and to register them properly. This was accomplished with computer techniques developed by

(Continued on page 289)

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The principal articles are indexed in THE READERS' GUIDE TO PERIODICAL LITERATURE, as well as in the SCIENCE CITATION INDEX.

The Titius-Bode Law: A Strange Bicentenary

STANLEY L. JAKI, *Seton Hall University*

EARLY in 1772, there was published at Hamburg the second edition of a widely read astronomical book by Johann Elert Bode, who was not yet 25 years old. This book, *Anleitung zur Kenntniss des gestirnten Himmels* (Introduction to the Study of the Starry Sky) had first appeared in 1768. Before Bode died in 1826, it went through nine editions, and long afterward it was still being reissued.

But in 1772 one could hardly guess that young Bode was soon to regenerate astronomical studies in his native Germany as director of Berlin Observatory and as editor of the famous *Astronomisches Jahrbuch* (Astronomical Yearbook). His *Anleitung* was not meant to be a scholarly work, but rather a pleasant and informative popularization.

Bode's interests reached well beyond technical astronomy. The science's broader philosophical perspectives clearly fascinated him; otherwise he would hardly have perused the German translation of a philosophical book by a Swiss naturalist, Charles Bonnet. This version, *Betrachtung über die Natur* (Reflections on Nature), appeared in 1766 in Leipzig two years after the French original, *Contemplation de la Nature.* In this book, Bonnet tried to present natural evidence of the wisdom of the Creator, selecting for his first example the planetary system, but he offered only a few generalities about it.

However, when the second edition of the translation appeared in 1772, this part of the text was considerably rearranged. Twenty-two lines on page 7 now appeared as a footnote signed T, clearly indicating that they were not by Bonnet but by the translator. He was Johann Daniel Titius, then 49 and professor of mathematics at Wittenberg. His name also appeared both on the title page and at the end of the dedicatory epistle of the new edition.

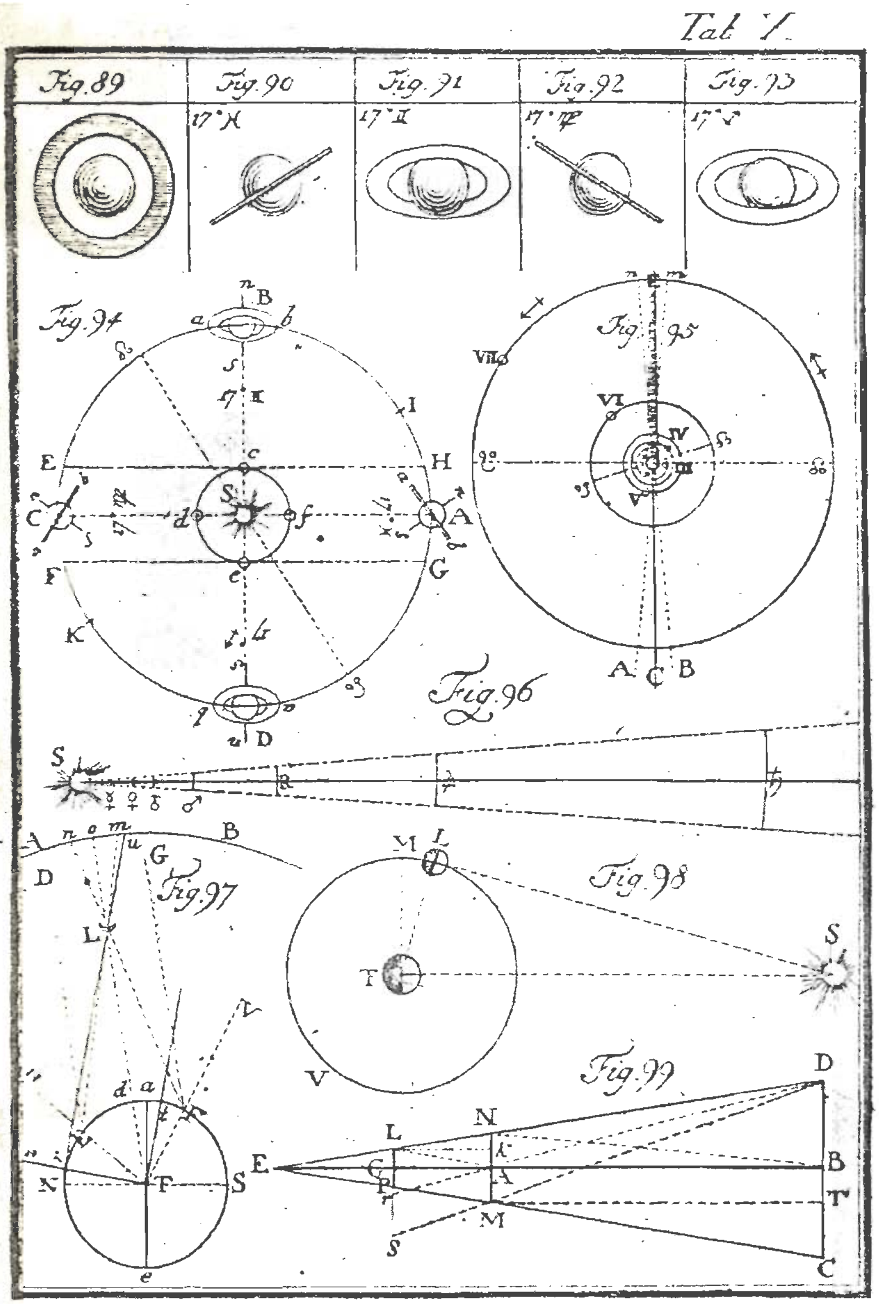
The footnote for which Titius claimed credit was this:

> Divide the distance from the Sun to Saturn into 100 parts; then Mercury is separated by 4 such parts from the Sun; Venus by $4 + 3 = 7$ such parts; the Earth by $4 + 6 = 10$; Mars by $4 + 12 = 16$. But notice that from Mars to Jupiter there comes a deviation from this exact progression. After Mars, there follows a distance of $4 + 24 = 28$ parts, but so far no planet or satellite has been sighted there. . . . Let us assume that this space without doubt belongs to the still undiscovered satellites of Mars. . . . Next to this for us still unexplored space there rises Jupiter's sphere of influence at $4 + 48 = 52$ parts; and that of Saturn at $4 + 96 = 100$.*

Almost exactly the same words appeared in the 1772 edition of Bode's *Anleitung* on pages 462-463. Bode felt that there had to be a planet between Mars and Jupiter, and as a proof he offered "the astonishing relation which the six known planets observe in their distances from the sun":

> Let the distances from the Sun to Saturn be taken as 100, then Mercury is separated by 4 such parts from the Sun. Venus is $4 + 3 = 7$. The Earth $4 + 6 = 10$. Mars $4 + 12 = 16$. Now comes a gap in this progression. After

*For the full English translation of the statements by Titius, Bode, and Wolff, see my article, "The Original Formulation of the Titius-Bode Law," which is scheduled to appear in the *Journal for the History of Astronomy*, June, 1972. My brochure, *Das Titius-Bodesche Gesetz im Licht der Originaltexte*, soon to be published by the Olbers Gesellschaft in Bremen, will give the complete story of the law from 1766 to 1803, with ample documentation from the original material.



In this plate from J. E. Bode's 1778 manual of astronomy, the part labeled Fig. 96 illustrates the Titius-Bode law of planetary distances. A short arc of the orbit of each planet from Mercury through Saturn is shown, with *R* marking the hypothetical planet between Mars and Jupiter. Elsewhere on this plate, Figs. 89-91 explain the varying appearance of Saturn's rings, while Fig. 98 illustrates Aristarchus' method for determining the sun's distance by measuring the angle *MTL*, when the moon is exactly at first-quarter phase. This reproduction is from the first edition of Bode's *Erläuterung der Sternkunde*, Hamburg, 1778.

Mars, there follows a distance [from the Sun] of 4 + 24 = 28 parts, in which no planet has yet been seen. . . . From here we come to the distance of Jupiter at 4 + 48 = 52 parts and finally to that of Saturn at 4 + 96 = 100 parts.

Like Titius, Bode could not believe that Creator of the universe had left empty space between Mars and Jupiter. The difference between the two versions was that Bode did not assign that empty space to some hypothetical satellites of Mars.

Titius did not compare specifically the round numbers 4, 7, 10, 16, 18, 52, and 100 with the actual mean distances of the planets from the sun. In Bode's *Anleitung* the actual mean distances were given in Earth radii: for Mercury, over 8,000; Venus, almost 16,000; Earth, 22,000; Mars, 33,500; Jupiter, 114,000; and Saturn, 210,000. (He also gave them in German miles.) Bode did not compare these figures with the progression, but had he set the earth-sun distance of 22,000 equal to 10, the series of mean distances would have become: over 3.6, almost 7.3, 10, 15.3, 52, and 95.5.

The general agreement of this series with the progression would have appeared undeniable. Of course, remaining differences would have been serious if the progression were regarded as a strict arithmetic sequence embodying, so to speak, a Pythagorean law of nature. Clearly, the actual planetary distances were not exact multiples of the Mercury-Venus distance. But this point was not explored for the next 15 years.

MEAN DISTANCES OF PLANETS FROM SUN

	Titius-Bode Law		Actual*
Mercury	4 + 0 =	4	3.9
Venus	4 + 3 =	7	7.2
Earth	4 + 6 =	10	10.0
Mars	4 + 12 =	16	15.2
(Ceres)	4 + 24 =	28	27.7
Jupiter	4 + 48 =	52	52.0
Saturn	4 + 96 =	100	95.4
Uranus	4 + 192 =	196	191.8
Neptune	4 + 384 =	388	300.6
Pluto	4 + 768 =	772	394.4

*In units of 10 for Earth-Sun distance

During that period, Bode was the only astronomer to mention in print the progression that about a century later became known as the Titius-Bode law of planetary distances. Bode seemed intent on appropriating the law to himself, for he failed to name Titius in the third and fourth editions of his *Anleitung*. Titius was again slighted in 1778, when Bode set forth the progression as a footnote in his scholarly manual of astronomy, *Erläuterung der Sternkunde*.

Titius himself did not seem to care about Bode's use of his idea when in 1774 he sent to press the third edition of his translation of Bonnet. But in the fourth edition (1783), there was a new twist to the situation, for Titius added these words to the footnote:

> The progression and its significance, which Bonnet believed to have been first noted by [Johann Heinrich] Lambert, were already put forward by [Christian] Wolff more than 40 years earlier in his "German Physics."

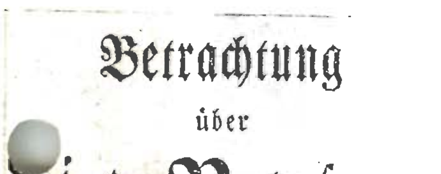
However, this attribution to Wolff is wrong. The "German Physics" of Wolff was his *Vernünftige Gedancken von der Absichten der natürlichen Dinge* (Reasonable Thoughts on the Phenomena of Things of Nature), an elementary German-language treatment of astronomy, physics, and meteorology, which went through five editions between 1724 and 1752. In each edition, Wolff gave the planetary distances as equal to 4, 7, 10, 15, 52, and 95, when the sun-Saturn distance is taken as 95. For Wolff, these numbers were not a mathematical progression but merely an aid for students to recall the approximate distances. Wolff did not invent these numbers, which were the essentially correct values he could have found in almost any astronomy book.

As to Titius' claim that Bonnet had regarded Lambert as the original proponent of the progression, this was rebutted by Bode. In 1784 Bode published a monograph on the planet Uranus (discovered in 1781), in which he expressed his pleasure that the mean distance of Uranus justified the extension of the progression as 4 + 192 = 196. Bode also made public a letter written to him by Lambert on February 3, 1772, expressing his surprise at the progression described in Bode's *Anleitung*. In the same context, Bode also admitted for the first time that he took the progression from Titius' translation of Bonnet's work.

Thus the famous planetary-distance relationship that was originally proposed under Bonnet's name in 1766, then claimed by both Bode and Titius in 1772, sets the stage for a strange bicentenary, which deserves notice for several reasons. First, the usual accounts of its origin need correction. Second, a long-overdue recognition should be given to Titius who, while mulling over Wolff's round numbers for planetary distances, originally realized that a nice progression resulted if the values for Mars and Saturn were changed by one and five, respectively.

Titius' insight, bolstered by the discovery of Uranus, contributed to the finding of Ceres in 1801 and Neptune in 1846. But these were questionable triumphs for the Titius-Bode law. Ceres was followed by a host of other asteroids, which could be explained only by conjecturing that they were fragments of a former planet. In the case of Neptune, both Adams and Leverrier used the so-called law as a guide in predicting its position, but the actual distance of Neptune from the sun is only 30.1 astronomical units, not 38.8 as predicted by the progression. The discovery of Pluto in 1930 gave a still worse discrepancy: actual distance 39.4, predicted 77.2.

For all that, the "law" has continued to influence many speculations about the origin of the planetary system.


Betrachtung

über

die Natur

vom

Herrn Karl Bonnet

Mitgliede der römisch-kaiserl. Gesellschaft der Naturforscher, und der Akademien und Gesellschaften der Wissenschaften zu Petersburg, London, Stockholm, Lyon, München und Bologna; wie auch Correspondenten der königl. Akademie der Wissenschaften zu Paris, und der königl. Gesellschaften zu Montpellier und Göttingen.

Mit Kupfern.

Mit gnädigster Freyheit.

Leipzig,

bey Johann Friedrich Junius, 1766.

The title page of the book in which the Titius-Bode law was originally announced, published at Leipzig in 1766. the German translation by J. D. Titius of Charles Bonnet's *Contemplation de la Nature*. Bonnet (1720-93) was a versatile Swiss amateur scientist. Reproduced from Cornell University Libraries' first edition, courtesy Cornell public information department.

Johann Elert Bode (1747-1826) was in the front rank of the German astronomers of his day. He was director of Berlin Observatory from 1787 to 1825, and prepared 54 annual volumes of the Berlin astronomical yearbook. This portrait has been provided by the History of Science Collection in the University of Oklahoma Library.