BUFFALO ASTRONOMICAL ASSOCIATION INC.
BUFFALO MUSEUM OF SCIENCE
HUMBOLDT PARKWAY
BUFFALO NEW YORK 14211

the Spectrum

Editor: Ernst E. Both

M A Y - J U N E 1975

MAY MEETING: Our meeting on May 9, 1975 (8:00 p.m. EDT, Club Room, Buffalo Museum of Science) will feature Dr. Frederick R. West in a lecture entitled "THE SOLAR NEIGHBORHOOD." A member of the B.A.A. for the past five years, Dr. West is a professional astronomer who specializes in binary stars, particularly spectroscopic binaries. In his lecture Dr. West will discuss the stars and star systems nearest the Sun. It is our pleasure to WELCOME OUR OWN DR. WEST!! * * * At the same meeting there will be an exciting BAKE SALE (proceeds to go to the observatory fund), featuring many delicious items - so please come prepared and support this worthwhile endeavor!!!! ************

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TOTAL LUNAR ECLIPSE: As reported in the last issue, there will be a total lunar eclipse during the early morning hours of Sunday, May 25, 1975. The Moon will begin to enter the Earth's shadow around midnight, Saturday the 24th. Totality begins at 1:03 a.m. on Sunday, and the Moon will leave the Earth's shadow at 3:30 a.m. The museum's Kellogg Observatory will be open for viewing from 11;30 p.m. on Saturday, until 3:30 a.m. on Sunday. B.A.A. members are encouraged to come and bring their telescopes if they wish. We are still looking for members to help with this event. ****************

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THE ASTEROIDS: The Bode-Titius Law and Resonances. By Dr. Frederick R. West

The story of the asteroids or minor planets can be considered to begin with the discovery of the planet Uranus by Sir William Herschel in 1781. A few years aerlier, in 1772, the Bode-Titius Law had been published. This law can be written as

$$a = 0.3 \times 2^n + 0.4 \qquad (1)$$

where n is an integer (whole number). In tabular form, the Bode-Titius law becomes:

n	$-\infty$	0	1	2	3	4	5	6	7
0.3×2^n	0.00	0.30	0.60	1.20	2.40	4.80	9.60	19.20	38.40
a	0.40	0.70	1.00	1.60	2.80	5.20	10.00	19.60	38.80
a_{pl} a.u.	0.38	0.72	1.00	1.52		5.20	9.54	19.18	30.06
Planet	Mercury	Venus	Earth	Mars		Jupiter	Saturn	Uranus	Neptune

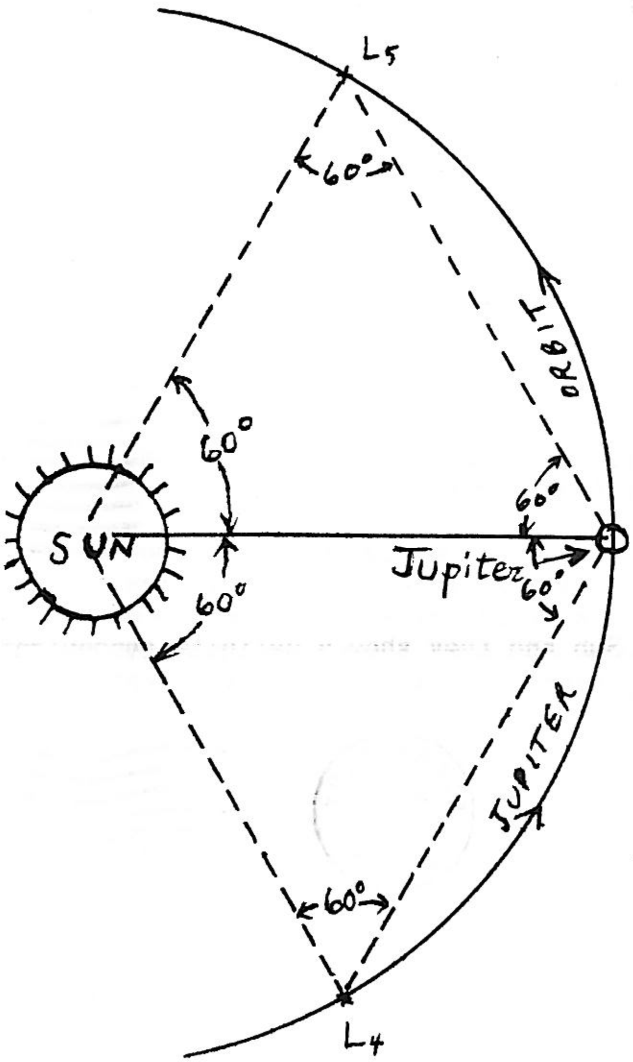
which shows that the n values of $-\infty$, 0, 1, 2, 4, and 5 produce values of a that approximate the mean distances from the Sun (a_{pl}) in astronomical units (a.u. = 1.496×10^8 km = 92, 957, 000 miles) of the planets Mercury, Venus, Earth, Mars, Jupiter, and Saturn respectively. Until 1781 Saturn represented the outermost known limits of the solar system. The actual mean distance of Uranus from the Sun and that predicted by the Bode-Titius law are in remarkably good agreement.

After the discovery of Uranus, it appeared that the Bode-Titius law might be a fundamental law of planet distribution in the solar system. However, inspection of its tabular form shows a gap at n=3 or a predicted distance of 2.8 a.u. from the Sun, whereas no planet between Mars and Jupiter was known. Thus after the distance of Uranus from the Sun was found, a search was begun for a small planet or its remains between Mars and Jupiter to fill the gap in the Bode-Titius law. The search was rewarded with the discovery of Ceres by Piazzi on January 1, 1801, but Ceres was lost in the evening twilight before he could make many observations of Ceres' position. Karl Friedrich Gauss used Piazzi's observations in his newly derived method of orbit calculations to predict the future positions of Ceres, which led to the re-observation of it on December 31, 1801; otherwise, Ceres might have been lost. Loss of briefly observed asteroids has been a difficulty even to the present day. Ceres was found to have a mean distance of 2.77 a.u., close to the value predicted by the Bode-Titius law.

Other asteroids were then discovered, slowly and sporadically for the next 90 years, then when photography was used in asteroid searches with modern wide field, photographically fast telescopes, much more rapidly. Today more than 5,000 asteroids are known and orbits have been determined for about 2,000 of them. To illustrate the advantages of photography for discovery and keeping track of asteroids, the author recalls that while he was an asteroid observer for the Indiana University asteroid patrol project, whose main purpose was to keep track of faint asteroids with known orbits, a plate of one hour exposure with the 10-inch Cooke triplet asteroid telescope, covering a $4^\circ \times 5^\circ$ sky field showed 29 asteroids, including perhaps 2 that were unknown. Most asteroids have orbits between Mars and Jupiter, with most mean distances from the Sun found between 2.1 and 3.3 a.u. and which form a statistical distribution around an average mean distance from the Sun not far from the predicted 2.8 a.u. Meantime, however, the Bode-Titius law was found to break down beyond Uranus with the discovery of Neptune in 1846 at a mean distance of 30.06 a.u., much less than the predicted value for $n=7$, which is almost the mean distance found for Pluto (=39.44 a.u.). Unlike the comets, all the asteroids known have direct (counterclockwise as seen from the North Ecliptic Pole) revolutions around the Sun and they show a definite concentration to the plane of the ecliptic, although not as much as for the major planets. Asteroid orbits average, in addition, somewhat higher in eccentricity than the major planets. Present asteroid discoveries lead to an estimate of about 100,000 asteroids with diameters of one mile or greater, but the sizes and masses of the known and predicted asteroids sum to a total mass of less than 1/10 that of the Moon. At present Vesta is thought to be the largest asteroid with a calculated diameter of 1,000 km; Ceres, Pallas, Juno, Bamberga and a few others have diameters estimated between 200 and 700 km. The other known asteroids range in size down to a mile or less in diameter. Clearly the known asteroids cannot compare in mass to the smallest known major planets.

The true significance of the Bode-Titius law, which we now see to be an interesting approximation of the mean distance distribution of most of the known major planets and the average of the mean distances of the asteroids from the Sun, is still unclear. Any satisfactory theory of the origin and development of the solar system must account for its existence. Recent research indicates that parts of the Bode-Titius law can be built up by resonances (simple fractions) between the orbital periods of some of the major planets around the Sun. The planet Jupiter with its large mass and the fairly close situation of its orbit to most of the asteroids would be expected to have important effects on their orbits. Already in the last century the astronomer Daniel Kirkwood of Indiana University found, after construction of a histogram of the number of asteroids in different ranges of their periods of revolution around the Sun, not a continuous distribution, but a distribution with gaps (almost no asteroids, now called "Kirkwood gaps") at orbital periods that are simple fractions (1/4, 1/3, 2/5, and 1/2) of Jupiter's orbital period around the Sun (11.86 years). This phenomenon is caused by the cumulative effect of the perturbing pull of Jupiter which, for an asteroid with such an orbital period, asts in the same direction every fourth, third, fifth or second revolution around the Sun, and in a few thousand years moves the asteroid into a larger or shorter orbital period where the perturbations due to Jupiter are not as cumulative.

As the number of known asteroid orbits has increased, other gaps (at 1/6, 1/5, and 2/3 the orbital period of Jupiter) have been detected. A stable concentration of asteroid orbits, the Hilda group, seems to exist at orbital periods slightly less than 2/3 that of Jupiter. In Jupiter's orbit there are two concentrations of asteroids known as the Trojan asteroids. Lagrange, in 1772, found a stable solution for the 3-body problem in celestial mechanics, with only 5 points of stability (hence known as the restricted 3-body problem). The two most stable points in the Sun-Jupiter-asteroid configuration are the points L_4 and L_5 in Jupiter's orbit but behind and preceding Jupiter by 60° (see adjacent diagram; L for Lagrangian point. This point may be thought to orbit the Sun, while the asteroids oscillate or librate around this point). Each of the two points forms an equilateral triangle with the Sun and Jupiter. In 1906 Max Wolf of Heidelberg, one of the most successful asteroid hunters of the time, found an asteroid at one of these stability points. By 1962 there were 17 known and 4 suspected Trojans, while a recent survey by Gehrels and others of the sky near L_5 with the 48-inch Palomar Schmidt telescope has allowed detection of 45 additional Trojan asteroids. On the basis of statistical arguments, Gehrels predicts that about 700 Trojan asteroids brighter than opposition mag. 20.9 might be associated with L_5. Finally, the outer 8 satellites of Jupiter may be asteroids which the planet has captured into its gravitational field.



In addition to these now evident effects of Jupiter on the asteroids, it is very possible that Jupiter's strong gravitational field has shaped the evolution of the entire asteroid belt. Jupiter may have 1) prevented the formation of a major planet between Mars and Jupiter during the early years of the solar system, and 2) by increasing the relative velocities between the asteroids, increased the number of high-velocity (2 km/sec or greater) collisions between asteroids, which fragment the colliding asteroids and which will send some of the fragments outside the asteroid belt. Although most asteroids are between Mars and Jupiter, we now know the asteroid Icarus which at perihelion comes closer to the Sun than Mercury ever does, and Hidalgo, which at aphelion reaches Saturn's orbit. Theory predicts that asteroids which cross the orbits of the major planets will collide with a planet and be added to the planet's mass within a few tens of millions of years, which is a short time, cosmically speaking. Such a collisional process sustained by Jupiter's gravitational perturbations could have reduced a mass of asteroids that 4 billion years ago was comparable to that of a terrestrial planet (Mercury, for example) to the present estimated total mass.

About 36 asteroids are known whose perihelia are situated inside the orbit of Mars. These are divided into two groups: the Amor group whose perihelia are between the orbits of the Earth and Mars, and the Apollo group with perihelia closer to the Sun than the Earth; thus these asteroids cross the Earth's orbit. To the latter group belong the asteroids Icarus, Apollo, Toro, Geographos, Adonis, 1948 EA, and 1971 FA, which have been or are considered capable of being re-observed, and Hermes (which passed less than 500,000 miles from the Earth in 1937), 1947 XC, 1950 DA, and 1959 LM which have been lost in spite of fairly accurate orbital elements. In recent years, resonances of several Apollo asteroids with the Earth and Venus have been found. Most famous of these is the resonance of Toro, whose orbital period is nearly 1.60 years. Thus 5 revolutions of Toro, 8 revolutions of Earth, and 13 revolutions of Venus are nearly equal. This "3-body resonance" is maintained by alternate close passages of Toro first near Earth, then near Venus. Detailed calculations forward and back in time show that this resonance seems unstable and may not last even 10 million years; Mars, whose orbit Toro crosses but with which Toro has no resonance, may eventually move Toro out of this interesting resonance. Geographos may show a very high-order resonance with the Earth, where 18 revolutions of Geographos nearly equal 25 of Earth's. Still less likely are resonances of Icarus with Earth, where 8 orbital periods and 9 sidereal years, and 17 orbital periods and 19 sidereal years both differ by less than 0.05 sidereal year. Since Icarus passed less than 6,500,000 km from Earth in 1968, it will again be quite close to Earth in June 1977 and June 1987. Among the Amor group, resonances with Earth are found for Eros, which passed less than 24,000,000 km from Earth on January 23 of this year, making four revolutions in slightly more than seven sidereal years. Thus Eros will be close again in 1982, 1989, and 1996.

These resonances, if they are stable beyond a million years, may prolong the lifetimes of the resonating asteroids; while in the above resonances, we find that Toro cannot collode with the Earth, which over tens of millions of years becomes a very probable occurence for non-resonating asteroids in similar Earth-crossing orbits.

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At the NEXT INSTRUMENT SECTION meeting on May 23, 1975 (8:00 p.m. Buffalo Museum of Science) Ed Lindberg will be actually silvering a mirror, an art which only few people still master. So don't miss this exciting demonstration./***/ We now have 103 members - 20 new members since September. More about the membership in the July-August issue. JUNE MEETING: Friday, June 13, 1975 (8:00 p.m.), general business meeting - reports.

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