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Excerpt
More information

1 It's a small world

Then I felt like some watcher of the skies
When a new planet swims into his ken;

John Keats, On first looking into Chapman's Homer

TRAIN STATION SIX

On the evening of October 6, 2008, Richard Kowalski was monitoring the search results of hundreds of images he and others routinely take each clear night with the 1.5 m Mt. Lemmon telescope. It is one of three telescopes used for the Catalina Sky Survey, an effort funded by NASA to discover new asteroids and comets. As on many other nights, a faint speck in the images, one of thousands, caught his attention – a new asteroid. After checking to see that it was not already known, it was dutifully given the cryptic provisional designation 8TA9D60 and reported to the Minor Planet Center in Cambridge, Massachusetts, the clearinghouse for all new asteroid and comet discoveries. Other observatories in Arizona and Australia were notified and quickly observed it. Dozens of new images were taken, giving enough information to calculate orbital elements and announce the discovery through a Minor Planet Electronic Circular. All of this happened within eight hours of the initial discovery and, by then, the object had a new name – 2008 TC_3. Why the rush? Preliminary orbital calculations at the Minor Planet Center showed a 100% chance of impact in less than twelve hours.

In the eight hours between discovery and announcement, astronomer Steve Chesley at NASA's Jet Propulsion Laboratory (JPL) had been flagged and confirmed the initial assessment: the orbit of 2008 TC_3 would intersect the Earth on 2008 Oct 07 02:46 UTC (Universal Time), less than twelve hours from the announcement, with an impact point over northern Sudan. In a stunning display of rapid international collaboration by professional and amateur astronomers around the world, hundreds of additional observations were made in the remaining hours and, one hour prior to impact, Paul Chodas – a colleague of Chesley's at JPL – reported a refined atmospheric entry time of 2008 Oct 07 02:44:28 UTC ± 15 seconds, with an impact time of 02:46:20 UTC ± 40 seconds.

The William Herschel telescope in the Canary Islands was quickly pressed into action to acquire the only telescopic spectra that would be taken in the short window of opportunity. Those spectra showed the asteroid to be most like an F- or B-type asteroid, depending on which classification scheme was used. These are darker asteroids, reflecting only a small percentage of the light that hits them, and their spectral signature is so featureless that little can be reliably gleaned about their composition.

Based on its distance from Earth and apparent brightness, astronomers estimated 2008 TC_3 to be a small asteroid – only a few meters in size. Objects like this hit the Earth on a yearly basis and generally do not survive atmospheric entry. Most of them decelerate so rapidly that they catastrophically disrupt. They put on a good show during entry, blazing across the sky with the brightness of the noonday Sun, but come apart tens of kilometers above the Earth's surface with a glorious airburst. Some of the mass is vaporized because of the intense frictional heat generated, and what survives is usually blasted into dust and hangs in the upper atmosphere for days afterward. If lucky, a few of the more coherent fragments survive intact and fall to the ground in an ellipse-shaped region, called a **strewn field**, which is often tens to hundreds of square kilometers in area.

The fateful hour came and went. Scientists were anxious for any reports and began to check images and data from a variety of sensors. The European weather satellite Meteosat-8 caught a glimpse of the entry over Sudan, as did US defense satellites. Infrasound detectors in Kenya, set up to monitor low-frequency sounds from illegal nuclear weapons testing, showed explosions equivalent to a couple of tons of TNT occurring at the correct time. And a KLM pilot and cockpit crew flying over Chad from Johannesburg to Amsterdam caught some flickering lights in the direction of the reported entry, more than 1000 km from their flight path. But for days afterward, there were no reports of visual sightings or meteorites collected. This region of Sudan is open desert, and there are few inhabitants.

Some weeks later, Dr. Peter Jenniskens of the SETI Institute in California and Dr. Muawia Shaddad of the University of Khartoum organized a joint expedition to search for eyewitnesses and fragments. They set out in early December, using the satellite imagery to help narrow the search area. The expedition traveled south from Khartoum through the desert and obtained eyewitness accounts whenever possible. The entry occurred early in the morning local time, so many were awake and beginning their day. A few had even captured pictures of the dust trail that lingered after the fireball exploded.

Finally, near Train Station Six, one of ten train stations that run through the desert from Khartoum to Wadi Halfa, they reached the area they felt most likely to contain fallen fragments. Nearly four

FIGURE 1.1. Smoke trails taken shortly after asteroid 2008 TC_3 entered the atmosphere above Sudan.
Credit: Dr. M. Shaddad.

dozen scientists, staff, and students from the university formed a wide line – with only a few meters between neighbors – and walked the desert, visually scouring the sand for possible meteorites. The first fragments were found within hours. Over the next few days, they collected 15 meteorites weighing a total of half a kilogram (one pound). A second five-day expedition around Christmas yielded another 32 fragments and brought the total mass to 4 kg (10 lbs). Subsequent expeditions brought in another 570 fragments and nearly tripled the mass found. For perspective, the asteroid that entered the atmosphere was estimated to be 83 ± 25 tons and the recovered fragments represent only 0.005% of the initial mass.

Following the rule for naming meteorites after the location of their recovery, this fall was called *Almahata Sitta*, which translates as "Station Number 6." Analysis by meteoriticists around the world showed it to belong to a relatively rare meteorite group called

FIGURE 1.2. Faculty, staff, and students from the University of Khartoum line up to comb the desert for fragments of Almahata Sitta. Credit: Dr. P. Jenniskens.

urelites. For the first time ever, scientists could directly link a telescopically observed asteroid to meteorite fragments from it.

It required more than 200 years of work by scientists from around the world to get to this intellectual point. If Newton stood on the shoulders of giants, those involved in this discovery were standing on a human pyramid. This book will trace their story and look in some detail at what we know about asteroids and their meteorite progeny, and how we know it. How are they found, named, classified, and studied? And what does all this tell us? Where does their study fit in the larger intellectual edifice of science? As I hope to show, they take us back to our own beginnings.

In this chapter, we look at the discovery of the asteroids, take a survey of their locations, and briefly touch on how they are numbered and named.

KEPLER, BODE, AND THE GAP

One might reasonably call the great German astronomer Johannes Kepler (1571–1630) a mystic. He was almost religiously obsessed with the arrangement of the six known planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn). What determined their distance from the Sun? Why had God placed them where he had? Kepler was a devoutly religious man and, like a scientific Janus, represented a figure on the threshold of an old and a new way of looking at the world. Carl Sagan famously called him "the last scientific astrologer" and the "first astrophysicist." The old was astrology and biblical exegesis as a way of explaining the world. The new was the modern method of observation, model, and testing. Kepler blended them both and looked for pattern and order, convinced that it would bring him closer to the mind of the creator. The title of his first major publication leaves little doubt of his feelings and motivation: *Mysterium Cosmographicum*. He saw order in the spacing of the planets, but boldly, he also saw flaws:

> Between Jupiter and Mars I placed a new planet, and also another between Venus and Mercury, which were to be invisible on

> account of their tiny size, and I assigned periodic times to them. For I thought that in this way I should produce some agreement between the ratios, as the ratios between the pairs would be respectively reduced in the direction of the Sun and increased in the direction of the fixed stars... Yet the interposition of a single planet was not sufficient for the huge gap between Jupiter and Mars; for the ratio of Jupiter to the new planet remained greater than is the ratio of Saturn to Jupiter.

Note the phrase "the huge gap between Jupiter and Mars." These gaps irritated Kepler, for they marred an otherwise elegant pattern that he perceived in planetary spacing.

The gap between Mars and Jupiter became more pronounced and problematic with the discovery of a mathematical relationship between planetary distances that would later be referred to as "Bode's Law" or sometimes the "Titius–Bode Law." But neither is it a law nor did it entirely originate with either Messrs. Titius or Bode. The first hint of this pattern of distances can be traced to a treatise on *The Elements of Astronomy* (published in 1715) by David Gregory (1659–1708), a professor of astronomy at Oxford:

> ... supposing the distance of the Earth from the Sun be divided into ten equal parts, of these the distance of Mercury will be about four parts, of Venus seven, of Mars fifteen, of Jupiter fifty-two, and that of Saturn ninety-five.

In other words, the distances can be placed into integer ratios of "parts." Today, we divide Dr. Gregory's parts by 10 and call them **astronomical units** (AU), originally *defined* as the **semi-major axis** (roughly the average radius) of the Earth's orbit about the Sun, but which is now defined to be precisely 149,597,870,700 km. So the Earth is 1 AU from the Sun, Mercury is 0.4 AU, etc. From Dr. Gregory, this pattern is borrowed, paraphrased, and footnoted by a variety of people including Christian Wolff (1679–1754), a leading German philosopher of his day, Johann Daniel Titius (1729–1796), a

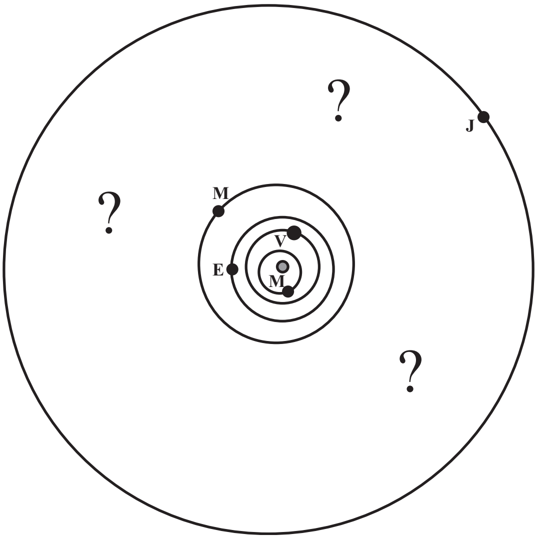

FIGURE 1.3. The solar system as known to Johannes Kepler, up to Jupiter (Saturn was known but is not shown). The large gap between Jupiter and Mars is at odds with the regular of spacing of the inner planets. Credit: M. Shepard.

German astronomer and professor at Wittenberg, and finally Johann Elert Bode (1747–1826), a German astronomer who would eventually become Director of the Berlin Observatory. Of these, though, Titius would be the first to note that these integer ratios could be approximated by a simple mathematical algorithm.

Start with the sequence 0, 3, 6, 12, … doubling each time. Add 4 to each number (which gives Gregory's parts) and then divide the sum by 10 to get distances in astronomical units. The planets are associated with these numbers in order of their solar distance, so Mercury corresponds to the first number, Venus to the second, and so on. As you can see from Table 1.1, the correspondence with modern measurements is quite close.

Here again, the gap persisted, marring an otherwise tidy relationship so beloved by scientists, for you must skip the predicted planet distance at 2.8 AU, before coming to Jupiter. In 1786, the discovery of a new planet, Uranus, would bring it into sharp relief.

Table 1.1 *Bode's Law versus actual planetary distances*

Planet	Mercury	Venus	Earth	Mars	???	Jupiter	Saturn
Bode's Law (AU)	0.4	0.7	1.0	1.6	2.8	5.2	10.0
Measured (AU)	0.39	0.72	1.0	1.52		5.20	9.54

THE GAP WIDENS

The British astronomer William Herschel (1738–1822) was originally born and raised in Germany. At this time, though, the reigning British monarch, George II, was also from the German House of Hanover, so the ties between Germany and England were strong. Herschel came from a musical family and, as a teen, was sent to England as a member of the Hanover Military Band. Later recalled to Hanover during a war with France, Herschel fled to England in 1757 at the urging of his father after the regiment to which he was attached was defeated and scattered. Although a minor, he was labeled a deserter. He was pardoned in 1782 by George III, but had made England his home and would remain there for the rest of his life.

Herschel's first career was as a musician, and he is known to have composed more than 20 symphonies, along with numerous other works. But in his mid-thirties, he became fascinated by astronomy and spent his remaining years, not to mention days and nights, split by the two cultures. He became famous for his self-made reflecting telescopes with mirrors cast and ground from speculum metal, an alloy of copper and tin that could be polished to make a highly reflective surface. He made a number of them, including one giant of 49.5 inch (1.26 m) diameter with a 40 foot (12.2m) focal length. For a time, it was the largest telescope in the world.

Herschel was a meticulous observer and, with his sister Caroline, made a systematic survey of the sky, generating catalogs of thousands of double stars, star clusters, and nebulae. While observing in March 1781, he stumbled upon a new planet, although in his initial descriptions he refers to it more cautiously as a "comet." Only after repeated observations by others showing its orbit to be nearly circular and lacking any of the usual accoutrements of comets, such as a fuzzy head or tail, was he willing to agree that it was a planet. He attempted to name the planet after the reigning monarch, George III, but Bode suggested Uranus, in accord with the conventions of naming the other planets after Roman gods and goddesses. (One wonders what role the naming of this planet by Herschel might have had in his pardon by the King in 1782!) Other European astronomers were more inclined to Bode's suggestion than Herschel's and Uranus eventually became official.

The most intriguing aspect of this new planet was its distance – right around 19 AU; the Titius–Bode Law predicts 19.6, and this did not escape Bode's attention. The excellent correspondence of the distance of a previously unknown planet with the rule convinced Bode of its rightness and predictive power. This made the gap at 2.8 AU even more glaring, and Bode called for the search of an overlooked object in that space.

PIAZZI PLUGS THE GAP

How exactly does one go about searching for a missing planet at a given distance? Even if the object can be seen, its distance cannot – only its movement. But Kepler had found in his Third Law of Planetary Motion that there is a relationship between the orbital distance of a planet and its period, or apparent movement, around the Sun. So one must look for an object that moves relative to the fixed stars at a particular rate. This was challenging in the eighteenth century. Photography had not been invented, so any subtle movement could be detected only by visually comparing the many stars in a field-of-view over a number of consecutive nights. And telescopes were quite modest by our standards – a well-equipped amateur astronomer today has far better instrumentation. But perhaps the biggest problem was that the sky had not yet been mapped thoroughly, and a significant amount of modern astronomy at that time consisted of the precise measurement and plotting of stars onto charts.

This was the exacting task that Giuseppe Piazzi (1746–1826), Director of the Palermo Observatory in Italy, had set for himself. To accurately place a star on a star chart, one must measure its *right ascension* and *declination*. These are the equivalent of celestial longitude and latitude, respectively; in fact, declination is the projection of the Earth's latitude lines onto the celestial sphere. The celestial equator is defined to have declination 0°; points north of the celestial equator have a positive declination and points south a negative. Right ascension is the equivalent of longitude and is measured eastward from the **vernal equinox**, the position of the Sun on the first day of spring when it crosses the celestial equator.

To conduct this exacting work, Piazzi had commissioned a special telescope from the best instrument maker in Europe, Jesse Ramsden (1735–1800) of London. The telescope, known as the Palermo Circle, was of modest aperture – only 7.5 cm (3 inches) – but sat on a state-of-the-art altazimuth mount. To measure angles accurately, one needs lots of divisions on the angular scale. The easiest way to do this is to make the scale large, so that the 360° can be divided into degrees, and these subdivided into tenths of degrees, and these further subdivided as far as mechanically possible. The Palermo Circle had an altitude scale, for measuring up and down, with a 5 foot (1.5 m) diameter and an azimuth scale, for measuring east and west, with a 3 foot (1 m) diameter. To make the measurements as precise as possible, Ramsden had also placed microscopes on each scale so that measurements accurate to better than 0.01° were possible. This was truly a state-of-the-art instrument. But Piazzi wasn't looking for a missing planet. He was using his new instrument, night after night, making countless positional measurements of stars for a new star catalog he was working on. Each star had to be observed four or more nights to insure the highest positional accuracy. For those unfamiliar with the life of a scientist, this is how 99%