DISTANT WORLDS

PETER BOND

MILESTONES IN PLANETARY EXPLORATION

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To Edna,
in memory of a kitchen conversation many years ago

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PREFACE

Until about 500 years ago, the Earth was believed to lie at the center of the Universe, with the Sun and five planets revolving around it. The planets themselves were merely points of light that drifted across the stellar constellations. Then came the invention of the telescope that enabled human eyes to see the planets as colorful disks, each with its own unique characteristics and quirks.

Fifty years ago, the population of the Solar System had swollen to include nine planets, 31 satellites and thousands of comets and asteroids. However, many mysteries remained. As recently as the early 1960s, scientists were still arguing about the existence of canals and vegetation on Mars, or the presence of oceans on Venus.

Today, the number of planets has risen to 10, the tally of satellites has passed 150 and the number of identified small objects is climbing rapidly as increasingly sensitive searches discover thousands of Sun-grazing comets and huge ice balls in the dark regions beyond Neptune.

During the first age of exploration, courageous navigators sailed the seven seas in search of new lands that would bring them fame and fortune. Now, with the exception of the ocean floors, there are few places on Earth that have not been explored. Nevertheless, our thirst for knowledge and desire to understand the unknown—characteristics that make our species unique—remain undiminished.

We are fortunate to be alive during the second great age of discovery, when modern technology is enabling us to construct automated spacecraft and robots that can take our place as explorers and ambassadors, venturing forth into the vast, hostile ocean of space to seek out and study new worlds.

For half a century, robotic spacecraft have been venturing vast distances to examine at close quarters all of the planets in our Solar System, with the exception of Pluto and its recently discovered, larger cousin in the far reaches of the Sun's realm. For the first time, human eyes have been able to see towering cliffs, dust devils, erupting volcanoes, dry river beds and ice formations on dozens of distant worlds, most of them totally alien to our experience here on Earth.

This book recounts the faltering, but inexorable, search for scientific truth and knowledge that, over thousands of years has enabled us to explore beyond the bounds of Earth and understand our place in the Universe.

Inevitably, much of the epic, long-running saga of Solar System exploration and discovery is devoted to the key missions that have unlocked the secrets of these strange worlds. A vast stream of data from a half dozen manned expeditions to the Moon and hundreds of robotic spacecraft has enabled scientists to assemble, piece by piece, a realistic picture of our planetary system.

However, as I have attempted to show in each chapter, long journeys often begin with a few faltering steps. This story of exploration would not be complete without reference to the research and insights of the early pioneers, people such as Aristarchus, Copernicus, Galileo, Kepler and Newton.

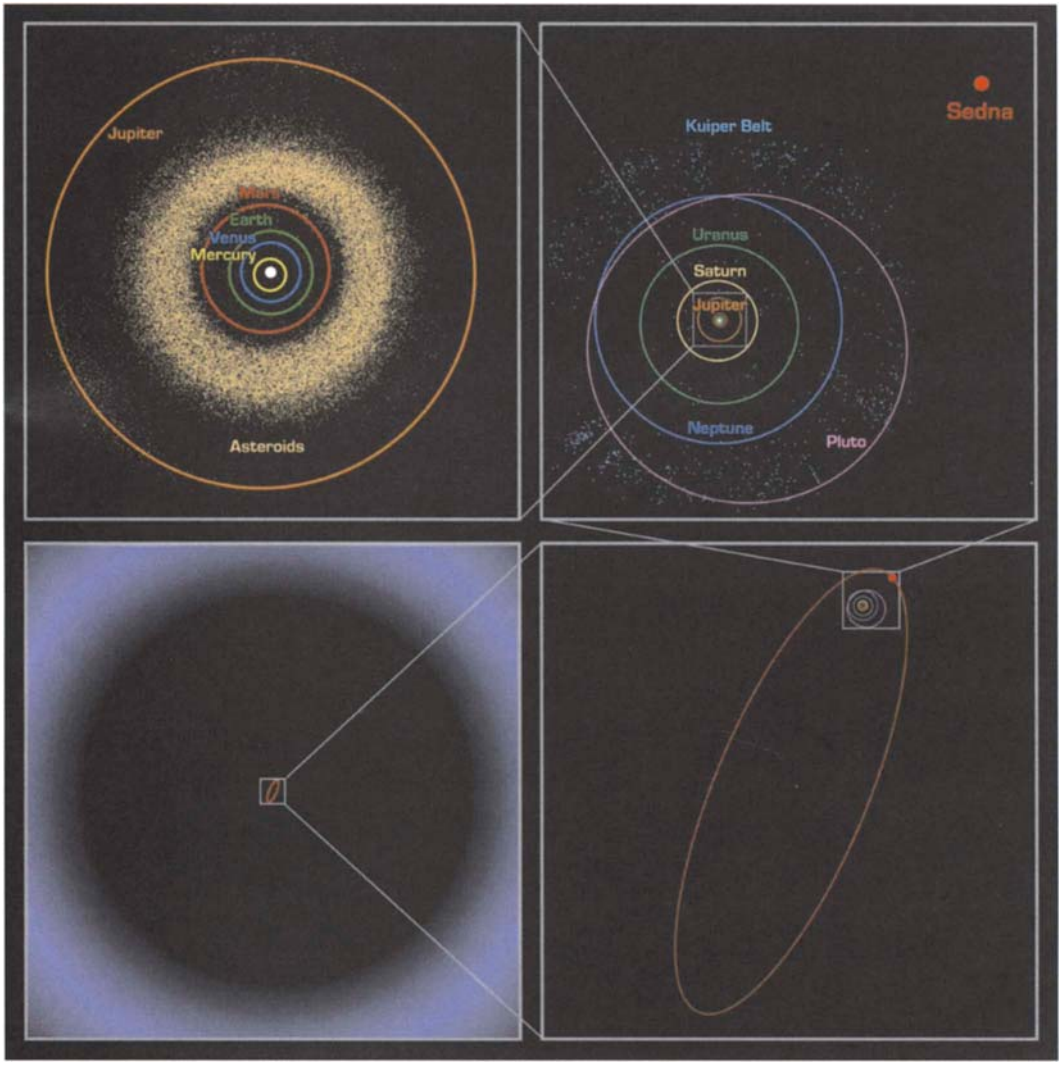
Many years ago, my imagination was captured by books that described the family of distant, alien worlds that circle our Sun. I have been hooked on the planets ever since. It is my hope that readers of this book will be similarly fascinated and inspired.

First considered 20 years ago, this book has eventually reached fruition with the support and encouragement of publisher Clive Horwood. My sincere thanks also go to John Mason for finding the time to read each chapter and make invaluable suggestions for improvement, and to Alex Whyte for his careful editing of the draft text.

Much of the information it contains has been provided by the public information officers and other employees of the major space agencies and companies, assembled over many years. Numerous other scientific sources—many now available on the Internet—are listed in the final pages. I am also very grateful to everyone who helped me to obtain the spectacular images that illuminate this story of outreach and discovery.

Finally, I would like to thank my wife, Edna, whose encouragement and patient forbearance enabled me to achieve a long-lasting ambition.

Peter Bond
Cranleigh, Surrey
September 2005



The Solar System—The scale of the Solar System as we know it today. The first panel (top left) shows the orbits of the inner planets and the asteroid belt between Mars and Jupiter. The second panel (top right) shows the outer planets and the Edgeworth–Kuiper Belt. The third panel (lower right) shows the orbit and current location of Sedna, which travels further from the Sun than any known object in the Solar System. The final box shows that even Sedna's orbit lies well inside the inner edge of the Oort cloud (shown in blue). (NASA/JPL/R. Hurt, SSC–Caltech)

1 DISCOVERING DISTANT WORLDS

If I can see further, it is because I stand on the shoulders of giants.

SIR ISAAC NEWTON

October 7, 1959, marked a new era in the history of humanity. On that day, 29 fuzzy black-and-white images trickled back to Earth from a Soviet spacecraft that had successfully looped around the Moon, venturing some 400,000 km (250,000 mi) from Earth. After staring at the wonders of the night sky for millions of years, technology had enabled human eyes to see an uncharted, extraterrestrial terrain—the far side of the Moon.

Since this first, faltering step, humanity has embarked on a wonderful episode of exploration that has enabled the inhabitants of our little blue world to unveil the secrets of seven planets and hundreds of smaller alien worlds that circle the Sun.

Hundreds of robotic ambassadors have been despatched across the Solar System to establish contact with every corner of the Sun's realm. Their electronic eyes have revealed alien landscapes that are far stranger than anything imagined by our forebears, and helped us to appreciate the fertile oasis in space that is our cradle and our home. Four spacecraft have even overcome the domineering gravitational grasp of our nearest star, carrying messages from Earth as they venture forth on never-ending voyages to distant star systems.

Since the pioneering breakthrough of Luna 3, we have discovered a menagerie of worlds unimagined only half a century ago. The most exotic of these include:

- Mercury—the little "winged messenger" flies around the Sun in just 88 days and, despite a midday temperature of 440°C, it may harbor water ice within its polar craters;
- Venus—a suffocating oven blanketed by sulfuric acid clouds and circled by super-rotating winds;
- Moon—the two-faced satellite that is a product of a cataclysmic planetary collision and innumerable asteroid impacts;
- Mars—an arid, icy world where liquid water once flowed and, perhaps, primitive life evolved;
- Jupiter—the gaseous king of the planets, home of a 300-year-old storm and ruler of more than 60 satellites;
- Io—a violent world of never-ending volcanic eruptions;
- Europa—a smooth ice world hiding a briny ocean;
- Saturn—the lightweight lord of the rings;
- Titan—a smog-shrouded giant where liquid methane takes the place of water;
- Uranus—a toppled giant where summers last for 21 years;
- Neptune—an icy giant dominated by huge storms and fierce, hurricane-force winds;
- Triton—where nitrogen ice is smudged by trails from alien geysers.
- Pluto and Charon—a double planet born in a swam of icy objects on the edge of the Solar System.

In many ways these are the stars of this story of discovery, but, in the words of Isaac Newton, the epic saga of robotic planetary exploration would not have been possible without

the ability of modern scientists and engineers to "stand on the shoulders of giants."

The Wandering Stars

Until the advent of the Space Age, our view of the Universe around us had been severely restricted by the limitations of our vantage point and the difficulty in bridging the vast distances that separate Earth from its so-called neighbors. In the night sky, only our familiar Moon displayed a visible disk, its perfection spoiled by mysterious dark markings.

Seven star-like interlopers drifted among the fixed constellations, changing brightness and sometimes reversing direction. By the sixth century BC it was realized that the brilliant "evening star," known to the ancient Greeks as Hesperus, and the "morning star," known as Phosphorus, were one and the same. The same was true of the two most elusive wandering stars or "planets," Lucifer and Hermes, which always lingered close to the horizon at sunrise or sunset. This brought the number of starlike planets down to five. (A further three planets were subsequently discovered: Uranus in 1781, Neptune in 1846, and Pluto in 1930.)

Simply by studying the sky with the naked eye, it was possible to draw certain conclusions.

Since the Sun and Moon were the two brightest objects, dominating either the day or night sky, they were considered to be more important from a theological or astrological point of view.

It also seemed clear that they were closer to Earth than the planets because they displayed visible disks, and because they traveled across the sky more quickly. At times the Moon could be seen to move in front of a star or planet, thus hiding it from view or occluding it. On rare occasions the Sun could be eclipsed by the new Moon passing in front of it. In these ways the relative distances of the Sun, Moon and planets were established by the time of Aristotle in the fourth century BC.

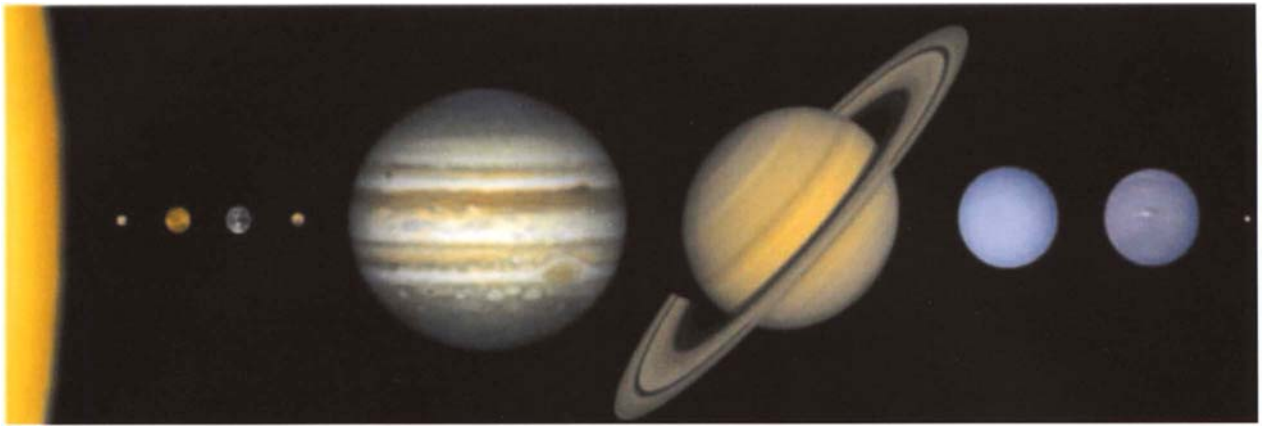
The nearest body had to be the Moon, followed by the rapidly moving Venus and Mercury, which were clearly closely associated with the Sun. Further out were Mars and Jupiter, with Saturn as the outpost of the Solar System.

The absolute scale of the Universe was a major problem. To ancient civilizations the Earth seemed huge compared with all of the celestial objects, and since it was also the home of intelligent life, especially humans, it was assumed that Earth held a pre-eminent position. It also seemed obvious that, with the exception of mountains and valleys, the Earth was flat, while the Sun and Moon were round and the stars and planets were mere points of light.

The first civilizations of the eastern Mediterranean had knowledge of a very limited area, which suggested to them that the Earth was rectangular, though elongated in an east–west direction to allow for the Mediterranean Sea. The early Greek philosophers preferred some sort of flat disk or cylinder, with its rim marked by an expanse of water known as the "Ocean River." What supported this disk or cylinder caused a great deal of debate throughout the ancient world.

The Hindus, for example, believed that the Earth rested on four pillars that were based on the backs of elephants, which in turn stood on the back of a gigantic turtle swimming in a huge ocean. Beyond the ocean they did not go, merely saying that it was wicked to inquire further. Greek myths told of the giant Atlas who rebelled against Zeus and was punished by having to carry the Earth on his shoulders for the rest of time. By the sixth century BC, the Greek philosopher Thales was suggesting that the Earth floated in water.

From this time onward, ideas concerning the Earth began to change radically. Around 550 BC another Greek, Anaximander, proposed that the Earth was curved in a north–south direction, though it took another 100 years to progress to the idea of a spherical Earth. One piece of evidence was the fact that as ships sailed toward the horizon they did not simply appear smaller and smaller, which would be the case on a flat Earth, but they disappeared prow first, with the sails being visible longest. Furthermore, this happened no matter in which direction the ship was sailing. Also, if the Earth was flat, the same stars ought to be visible from anywhere on its surface, but travelers



Sizes of the Planets—The approximate sizes of the planets relative to the Sun. Outward from the Sun (left to right), they are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. Jupiter's diameter is about 11 times that of the Earth, and the Sun's diameter is about 10 times that of Jupiter. Pluto's diameter is slightly less than one-fifth that of Earth. The distances of the planets are not shown to scale. (Lunar and Planetary Laboratory)

reported that different stars appeared above the horizon if they journeyed north or south.

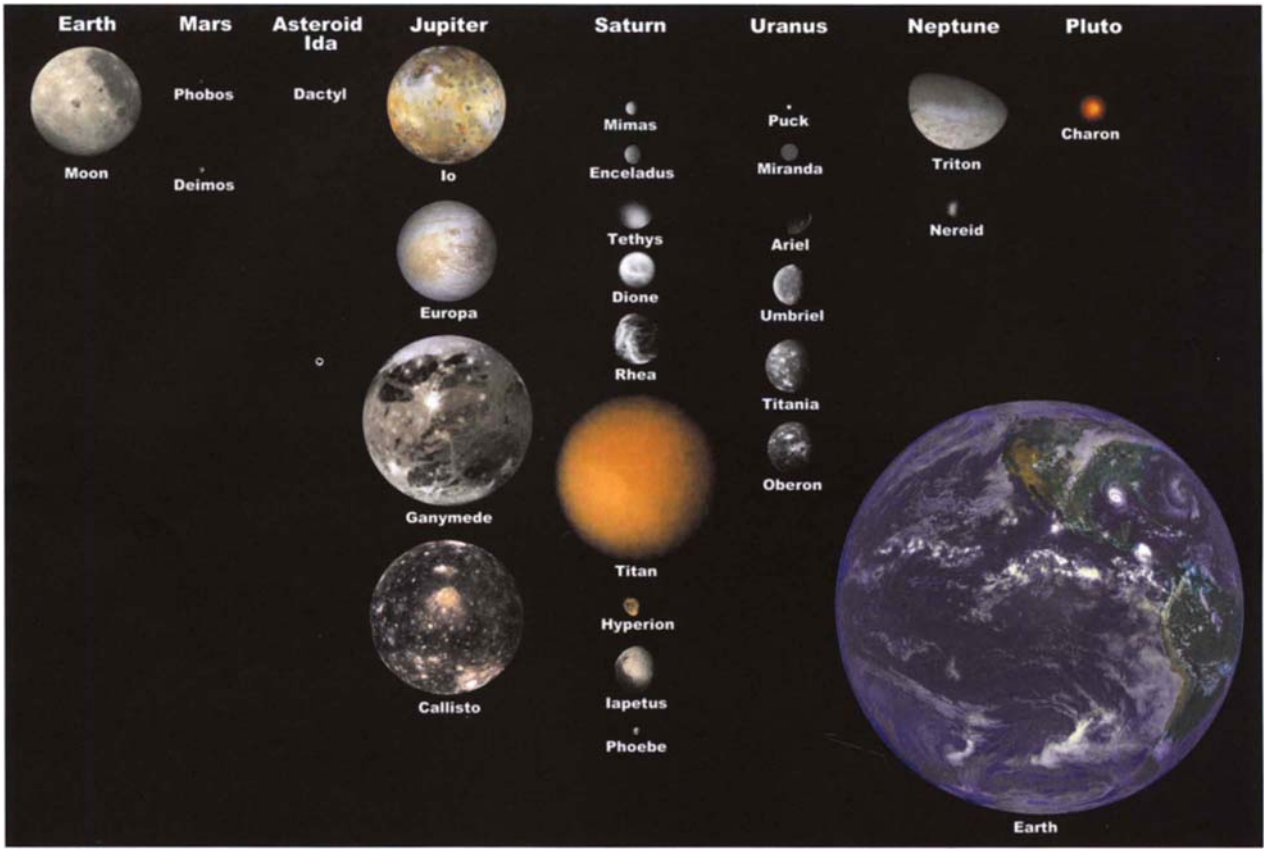
Another convincing piece of evidence involved lunar eclipses, when the full Moon became darker, often turning a deep orange. The Greeks finally realized that this temporary darkening could be explained by the Sun shining on the Earth and creating a shadow through which the Moon passed. Since the shadow always appeared curved in outline, Anaximander's cylinder was not an adequate explanation.

The first to realize that the Earth is a sphere was Philolaus, a follower of Pythagoras, in about 450 BC. Anaximander had already proposed the idea that the Earth was surrounded by empty space and kept its place "because of its equal distance from everything." These two advances in knowledge were tremendously important. The idea of "down" became relative to the observer, since all falling objects move toward the center of a spherical Earth, whether in Britain or Australia, and there is no question of people falling off the edge of the world.

If the Earth was spherical, how large was it? By 250 BC the known world stretched nearly 10,000 km (6,000 mi) from the Atlantic Ocean to the borders of India, yet there was still no sign of the surface doubling back on itself, so it was obviously much larger than this. The actual size of the Earth was eventually calculated by another Greek, Eratosthenes, toward the end of the third century BC. He realized that the Sun was overhead at noon on June 21 (midsummer's day) at the Tropic of Cancer, but a little lower in the sky further north. After comparing the length of the shadow cast at two widely separated places—Syene (modern Aswan) and Alexandria, which lies on the coast of Egypt—he was able to use basic geometry to show that the circumference of the Earth must be about 40,000 km (25,000 mi).

Eratosthenes also knew how to calculate the diameter of the Earth from this and obtained the figure of about 12,500 km (8,000 mi), which is remarkably close to the true figure. Unfortunately, later astronomers revised his figures downward, and so when Columbus set sail for China he believed the voyage would be quite short, with no space available for an intervening continent in the form of America.

Once the size of the Earth had been determined, the next step was to discover the sizes and distances of the Sun and



The Major Moons—The most significant moons in our Solar System are shown alongside the Earth, with their correct relative sizes and true color. Two of them (Ganymede and Titan) are larger than the planet Mercury, and eight are larger than Pluto. Earth's Moon is the fifth largest, with a diameter of 3,476 km (2,160 mi). Most are thought to have formed from a disk of debris left over from the formation of their home planet. However Triton and many of the smallest satellites are thought to be captured objects. Earth's Moon is thought to have formed from the debris ejected when a Mars-sized object collided with the young Earth. (NASA)

the Moon. In the fifth century BC the Greek philosopher Anaxagoras startled the court of Pericles by stating that the Sun was a "great hot stone" the size of Greece, a claim that led to his exile for blasphemy. However, studies of lunar eclipses soon indicated that this was a considerable underestimate rather than an overestimate.

At about the same time that Eratosthenes was working in Egypt, the Greek astronomer Aristarchus was making the first serious attempt to calculate the Moon's distance. By comparing the diameter of the Moon with that of Earth's shadow during a lunar eclipse, he decided that the Sun was 20 times further from Earth than the Moon and seven times

Earth's diameter. These were staggering figures at the time, for they began to suggest that perhaps the Earth was not as important in the Universe as had previously been supposed.

About 150 BC, Aristarchus' methods were refined by Hipparchus, who stated that the Moon's distance was 30 times Earth's diameter. Using Eratosthenes' calculation for the diameter of the Earth, this is very close to the actual figure. So by the mid-second century BC it was known that the Moon orbited the Earth at a distance of about 400,000 km (250,000 mi), and that the Sun was perhaps 8 million km (5 million mi) from the Earth. This meant that the celestial sphere that contained all the fixed stars had to be even further away. Man's horizons were beginning to expand considerably, while at the same time the once dominant Earth was shrinking in importance.

Unfortunately the five planets were posing problems that no one seemed able to solve satisfactorily. From the earliest times it was recognized that they varied in brightness, and it seemed logical to assume that they were brightest when they were nearest to the Earth (the astronomical term is "in opposition"), though this is not actually true in the cases of Venus and Mercury because they are lost in the Sun's glare when at their nearest to us. Such times were specially noted since the planets could be expected to affect human destiny most strongly when they were very bright and close.

After centuries of careful observation these occasions could be accurately predicted, but the planets' intermediate positions defied prediction. The main difficulty arose over the peculiar apparent motions of the planets across the sky. The stars were supposed to be attached to a crystal sphere that revolved daily around a central Earth, and the Sun, Moon, and each planet were also thought to be attached to seven smaller, rotating spheres.

The general movement of the stars was from east to west, while the "superior" planets (Mars, Jupiter, and Saturn) slowly shifted eastward against the background of the different Zodiac constellations. However, at times these planets seemed to come to a halt, then move in a reverse or retrograde direction for weeks or even months before resuming their eastward shift. The overall shape of their paths was a flattened circle or "loop," which was very difficult to explain, especially if the Earth was at the center of the Universe. (One of the few astronomers to question the established beliefs was Aristarchus, but his view that Earth and the planets orbited the Sun was too advanced for the time.)

The Greeks made numerous attempts to explain this phenomenon. The first step was taken in the fourth century BC by Heraclides who realized that the sky only appeared to move slowly from east to west because the Earth is spinning in the opposite direction. However, he retained the Earth in its central position despite correctly placing Venus and Mercury in orbits around the Sun.

Ironically, the excellence of the Greeks as geometers proved a major obstacle to progress because they saw the circle as the perfect figure and, therefore, insisted that the Sun, Moon, and planets should all have circular orbits.

As observations became more accurate, the explanations put forward became increasingly complex and unrealistic. In the fourth century BC Eudoxus resorted to combinations of 30 circles to account for the apparent motions. A little later Aristotle proposed 55 circles. Even this proved inadequate, so that by the time of Hipparchus many more little circles (known as epicycles) had been added to the main circular orbits.

This system was modified by Claudius Ptolemy of Alexandria in about 140 AD so that it gave a reasonably accurate model for explaining the planetary motions, and his version became the universally accepted explanation for well over 1,000 years. Although observations continued during the following centuries, notably by the Arab and Chinese astronomers, no one dared to challenge the pre-eminence of Ptolemy. Until, that is, the science of astronomy was re-awakened by a Polish priest and astronomer named Nicolaus Copernicus.

The Renaissance

Although he was not a great observer, Copernicus gained a reputation as an original thinker. He led the study of