Principles of

Astronomy

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Publisher's Note

Grey House Publishing is pleased to add *Principles of Astronomy* to its Salem Press collection, the third of four titles in the *Principles of* series: Chemistry, Physics, Astronomy, and Computer Science. This new resource introduces students and researchers to the fundamentals of astronomy using easy-to-understand language, giving readers a solid start and deeper understanding and appreciation of this complex subject.

The 140 entries range from Ablation to Quarks to XMM-Newton, and are arranged A to Z, making it easy to find the topic of interest. All entries include the following:

- Related fields of study that illustrate connections between various branches of astronomy, such as sub-planetary astronomy, theoretical astrophysics, astrochemistry, and planetary astronomy;
- Brief summary of the topic and how the entry is organized;
- Principal terms fundamental to the topic and to understanding the concepts presented;
- Illustrations, diagrams, and charts that clarify difficult topics such as solar systems, white dwarf and red giant stars, orbital plotting, rocket propulsion, and near-Earth objects;
- Star charts and photographs taken from space observatories;
- Photographs of significant contributors to the study of physics;
- Further reading lists that relate to the entry.

Ancient Greeks and Romans lent their names to many of the planets, stars, and constellations we study. Entries related to these celestial bodies explore how they were named, as well as the significance these figures held in the ancient world. Astronomy in the modern era has more to do with math and physics than with deities and myth. What we know about Black holes, Blazars, Quarks, and Supernovas is due to the work of the world's most renowned mathematicians and physicists, including Charles Messier, whose catalog is used to this day to describe and categorize objects visible in the sky, Edwin Hubble and his ground-breaking work in the discovery of universes beyond our own, and Albert Einstein and how his theory of general relativity elegantly describes the way that gravity can affect space and time.

This reference work begins with a comprehensive introduction by editor Donald R. Franceschetti, PhD, that discusses the significance of naked eye observations by the earliest astronomers; the use of optical, radio, and neutron telescopes; and the contributions derived from space probes, manned missions, and space stations. The goal of this material is to advance our understanding of our own planet, the celestial bodies around us, and the ways in which astronomy and physics have become intertwined.

The book's backmatter is another valuable resource:

- Nobel Notes explain how prizes awarded in areas such as chemistry and physics have advanced work in the area of astronomy;
- List of important figures in astronomy, including Ptolemy, Copernicus, Newton, and Hubble;
- Timeline of important advances in the field of astronomy;
- Timeline of space exploration;
- Glossary;
- General bibliography;
- Web Resources, and
- Subject index.

Salem Press extends its appreciation to all involved in the development and production of this work. The entries have been written by experts in the field, whose names follow the Editor's Introduction.

Principles of Astronomy, as well as all Salem Press titles, is available in print and as an e-book. Please visit www.salempress.com for more information.

Editor's Introduction

Astronomy is the oldest of the natural sciences, and human beings have looked to the skies since before recorded time for answers to some of their most important questions. It is believed that the first people to observe the skies and make calculations based on the movement of the stars were priests, so it is natural that they would associate heavenly bodies with gods and the divine, as well as with the events in nature which they associated with the stars—night changing to day, the procession of seasons, the tides, and annual weather events from rains to winds to floods.

One of the earliest practical tasks of astronomy was to set the length of the year and determine when the sun would pass from the northern to the Southern hemisphere. Over the last ten to twenty years, archaeologists have determined that those priests were quite sophisticated when it came to applying their skills as observers and as mathematicians. They devised both lunar (moon-based) and solar (sun-based) calendars that allowed them to determine such important events as planting seasons. Some of these early calendars date back as far as 4000 BCE. It was the need to improve the calendar and better determine the dates of religious feasts that led Copernicus to first suggest that the sun be treated as the center of the solar system.

Early on, though, it was also taken as truth that one's horoscope, based on the precise position of the stars and planets at the moment of one's birth, held all the details of one's fate. Since the sky might not be clear enough to "read" when important personages like kings or emperors were born, it was important to have some device for predicting the positions of the heavenly bodies. Ptolemy's book of tables, the *Almagest*, was the first of these; it was used for 2000 years, though it became inaccurate over time. While today, we draw a clear distinction between astronomy and astrology, at first there was no distinction between the activity of the stars and the activities of the gods or spirits thought to rule over men, which meant that astrology–an attempt to decipher how the positions, movements, and properties of the stars can affect human beings–was not truly distinct from astronomy. In fact the names of the stars and constellations shows quite clearly the powerful influence this believe in the connection between deities and spirits on human destiny.

Naked Eye Observations

Despite the fact that the ancients may have had a more "mystical" approach to some of their observations, the fact remains that they were intent upon observing the behaviors of the bodies they saw in the sky. They built structures known as observatories specifically to observe the heavens, including one of the earliest known observatories, Stonehenge, located on Salisbury Plain in England. Researchers have demonstrated that Stonehenge is aligned quite precisely with sunrise on the summer solstice and sunset on the winter solstice. The pyramids in Egypt also represent important astronomical observatories; they are thought to be aligned with the pole star. Chinese astronomers created star charts and used their recorded observations to predict the movements of the stars as well as lunar and solar eclipses, and also to set the dates and times for important festivals. All of these observations were made with the naked eye, well before the invention of the telescopes used by modern astronomers.

Telescopes and a Model of the Solar System

While Galileo did not invent the telescope, he was one of the first scientists to turn the telescope skyward rather than using it solely as a way to keep track of sailing vessels. He discovered marvelous things: The moon was covered with craters; the planet Venus went through phases just like the moon; the planet Saturn had rings which disappeared when viewed edge on; and the planet Jupiter had its own little solar system of at least four moons. All of these discoveries contradicted the prevailing Aristotelian orthodoxy. The story of Galileo's battles with the Pope are legend—his treatment at the hands of the Church and the fact that he died under house arrest discouraged scientists in the Catholic countries of Europe from following in his footsteps. Espousing the understanding that the Earth revolved around the Sun was considered heresy and led to the persecution of such important figures as Galileo and Copernicus, and even Frederick Kepler.

Tycho Brahe (1546-1601) was the last of the naked eye observers of astonomy. He was renowned for the precision and accuracy of his observations, made from an observatory built for him by by King Frederick of Denmark, on the island of Hven, where he recorded planetary positions night after night. It was Brahe's observations that led to geocentric (Earth centered) understanding of our solar system, with Earth at the center and the stars and sun revolving around Earth. It took many years for a different system to come into wide acceptance. Although there were errors in some of the transciptions of these records by scribes and students who flocked to work with Brahe, the data concerning the movements of the planet Mars were accurate enough to allow Johannes Kepler to devise his laws of planetary motion. Kepler's mathematical models of the movement of the planets and stars were able to join physics with astronomy and so became the basis of Newton's more general laws of motion.

Newton, a Protest and Non-Conformist in religion, completed the work of dismantling of Aristotle's mechanics. His three laws of motion did away with the distinction between celestial and terrestrial motion, as well as the need for a divinity to set things in motion. His law of universal gravitation explained why things seemed to be attracted to the center of the Earth, stating that every mass in the universe attracted every other mass with a force proportional to the product of the two masses and inversely proportional to the square of the distance between them. Thus, there was nothing physically special about the Earth.

By the nineteenth century, the Copernican model of the solar system had been general accepted. The question then became how accurately did Newton's laws predict the time evolution of planetary positions? Astronomy turned to computational mathematics for the answers. In classical physics there are generally no exact solutions for systems of three or more interacting bodies. To handle the solar system with its many interacting bodies, one approach was to begin with the solution for two interacting bodies, the sun and Jupiter for instance, and to treat the effects of the additional bodies as perturbations on a readily solvable problem.

DISCOVERING NEW PLANETS

William Herschel built Observatory House in Slough, England, to house his 48-inch reflector. In 1791, he discovered the planet Uranus, the first new member of the solar system to be discovered since classical times and the first to be located on the basis of Newton's laws and mathematical computations. Then, after 50 years of observation, it became apparent that Uranus was deviating from the orbit predicted by Newton's laws, so it was hypothesized there might be another planet whose gravitational effect had not been taken into account. Two pairs of mathematicians, one in Berlin and the other in Paris, computed the coordinates of the new planet—Neptune—which was eventually found just where it was expected to be. The situation was repeated in 1930 when observations of Neptune led to the discovery of Pluto. In recent years, observations of the motions of nearby stars have made possible the identification of some 2000 objects outside the solar system.

Newton's theory of gravitation provided a framework for understanding the structure of the universe. Before Newton, celestial objects were thought to move in circles because circular movement was considered perfect. Newton's theory meant that objects were understood to respond to the gravitational force and, therefore, one could extract from the motion of any object the vector sum of all the other objects influencing it. Gravitation is one of the fundamental forces in the universe, and certainly the weakest of the long-range forces. Nonetheless planets have been identified through their gravitational effects on other planet's orbits. Neptune was first identified this way and then in 1930, Pluto.

The optical telescope, which gathers and focuses light from visible light from electromagnetic spectrum, (with wavelengths between 400 and 750 nm) has been used since before Galileo and is still used up to the present day by astonomers and star-gazers alike. The optical telescope reached its high point with the construction of the 200-inch Hale telescope in 1939, set atop Mt. Palomar in CalTech's Palomar Observatory. This telescope, augmented by radio telescopes and then adaptive optics programs that can rapidly change the mirror's shape, make it possible to correct for atmospheric distortions so that it can produce images comparable to those received by space telescopes taking direct images of extra-solar objects.

Radio astronomy is the study of the universe through the analysis of radio emissions from celestial objects. The first radio telescope was built in 1937. Radio telescopes are capable of capturing information from the microwave region of the electromagnetic spectrum that ranges between a meter and a centimeter in wavelength. Radio telescopes typically involve a large reflector and a detector at the focus of the reflector. Many radio telescopes operate at a wavelength of 21 cm, which is associated with a proton spin-flipping transition in atomic hydrogen.

Gravity and General Relativity

Astronomers have studied the orbit of Mercury for centuries. This planet, nearest to the sun, describes an elliptical orbit, as all planets do, but its orbit appears to move ever so slightly in space. Even allowing for the orbit being perturbed by the gravitational pulls of other planet, Mercury's perihelion (point of closest approach to the sun) precesses by about 43 seconds of arc per century. This residual precession inspired the search for a planet within the orbit of Mercury, given the tentative name of Vulcan, but no such planet was found.

The explanation was found in the general theory of relativity put forth by Albert Einstein in 1915 just over a hundred years ago. The sun is massive enough to distort space by a slight amount in the vicinity of Mercury and this small deviation from Euclidean geometry was just enough to account for the precession. In a similar way the sun's gravity should result in a slight deviation of starlight when it passes near the sun's surface. This deviation should be observed during a solar eclipse and was captured on photographic plates by a British expedition in 1919 as predicted. It was at this point that Albert Einstein became famous world-wide. Since that time small perturbations in the orbits of the sun's nearer neighbors have led to the discovery of about 2,000 extra-solar planets with more discoveries expected each year. The search not only demonstrated the validity of the laws of physics far from the Earth, but also led to new discoveries

Once it was understood that interstellar distances could extend for hundreds or thousands of light years, astronomers began to wonder whether the Milky Way galaxy was in fact the entire universe or whether it was just one of a great many objects at incredible distances from the Earth. Interestingly, a number of cloud like objects had been cataloged by Charles Messier as a aid to comet hunters at the end of the eighteenth century. Harlow Shapley, noted the presence of large variable stars in such clouds. Their size put them beyond our galaxy. That fact meant that the universe was larger than anyone had thought.

Heinrich Olbers is often given credit for pointing out that the darkness of the sky at night is itself a clue to the distribution of matter in the universe. The basic argument is that if the sky were full of stars, randomly distributed, then looking in any direction, the line of sight would sooner or later end on a stellar surface. If the stars had been shining forever then the night sky should be ablaze with light. That it was not implied that the stars had finite lifetimes or were not randomly distributed or both.

While it is now common knowledge that the stars shine because they are releasing their mass energy, this was not known at the beginning of the twentieth century. Edwin Hubble used the Doppler shift of the hydrogen lines in the spectrum of other galaxies to determine how rapidly and in which direction they were moving. Hubble's conclusion was that galaxies were moving away from each other at a speed that roughly increased with distance. If you were to "run the movie backwards," all the galaxies would converge at a single point about 13 billion years ago, indicating that the universe had not existed forever but rather had begun in a cosmic explosion: the big bang.

Examining Einstein's work on general relativity, astronomers realized that Einstein's equations allowed for an expanding or contracting universe. The expansion was ongoing but slowing down. The open question was then: Is there enough matter that, at some time in the future, the universe would begin contracting? It turned out that the answer to this question was much more involved than anyone might have guessed.

Confirmation of the big bang cosmology would come not from astronomy but from communications engineers. Arno Penzias and Robert Wilson were working for the Bell Telephone system, developing a microwave horn antenna to communicate through the earth's atmosphere. They found a mysterious signal which they could not attribute to any source. Eventually they realized that it was a radiation residue from the big bang, now cooled to 2.7 kelvins.

The Space Age

The "space-age" began in October 1958 when, to the great surprise of the American public, the first artificial earth satellite, *Sputnik I,* was launched by the Soviet Union. The satellite epoch was ushered in by rocket-launched, space-based telescopes, which offered two advantages over the terrestrial variety: Far more accurate images and the ability to function in frequency regions in which earth's atmosphere was opaque.

Since 1958 some thousands of space vehicles have been launched. Some of those probes include telescopes that can make observations in the microwave, infrared, ultraviolet, and x-ray regions. Prominent among them is the Hubble astronomical telescope, an optical telescope launched at a cost of over one billion dollars. This telescope afforded earth-based observers a factor of 10 improvement in resolution. Images from the Hubble provided evidence that not only was the universe's expansion continuing, it seemed to be accelerating. Further measurements of galactic rotational speeds indicate that galaxies have much more mass than would be estimated on the basis of their luminosity. Estimates of the amount of dark matter in the universe vary but may exceed 50 percent.

As we review the various epochs of astronomy fron naked eye observations to optical telescopes, radio telescopes, and neutrino telescopes, we can see our understanding of the universe grow, starting with Ptolemy's world, through the computational models of Copernicus and on to the period where the Milky Way was the "island" universe, to Hubble and Shapley's world of many hundreds of galaxies, and into Einstein's world, where we cannot uniquely separate space and time, and ultimately, into the highly speculative worlds of the far future.

DETERMINING LOCATIONS OF ASTRONOMICAL BODIES

One perennial challenge to astronomers was to locate the various astronomical objects, that is, determine their distance from us. The absence of parallax of the stars was one of the strongest arguments against the heliocentric model of Copernicus. Stellar parallax is quite small, only 0.76 seconds of arc for the nearest star Centauri, and the first accurate determination of stellar parallax was not made until 1828 when parallaxes could be determined for only the closest stars.

Herzsprung and Russell provided the next clue for determining interstellar distances. They found that stars could be classified by their optical spectra, which itself was a clue to the chemical composition of the stellar atmosphere. Determining the spectrum of a star let the astronomers classify it. They found that for the vast majority of stars the brightness correlated with their spectral type. Thus from the spectrum we would know in absolute terms how bright a star is and thus how far away it is.

Next came the realization that for certain variable stars, the period of their variation was directly related to their luminosity. Finding some of these stars in nearby galaxies led Shapley to the conclusion that the some of the nebulae were in fact galaxies like our own, but millions of light years older.

It is a truism that in spite of our ability to map out the universe, the human race has been to one planet and one moon—both ours. Everything else has been learned by observation.

Since 1958 space probes have surveyed the solar system, visited all of the planets and returned pictures, Rocket observations have also been made of the sun, planets, and a comet and space probes have only just departed into deep space.

Some of the strangest of astronomical instruments include the neutrino telescope and the gravitational wave observatory. Our principal source of information about all but our immediate neighborhood in space is the electromagnetic radiation we receive although we are able to draw some inferences from other forms of radiation and materials on Earth of extraterrestrial life.

The neutrino was proposed by Wolfgang Pauli in 1930, and given its current name in 1934 by Enrico Fermi. The particle only interacts via the nuclear weak force and presumably gravitation. As a result neutrinos are very hard to detect. The basic event of neutrino emission from the care of stars remained conjectural until the 1950's. Every time four protons in the sun core combine to form a helium nucleus two neutrinos are released into space. Most neutrino detectors are based on the weak force driven reaction

Proton + electron → **neutron** → **neutron** + neutrino

Thus if a chlorine nucleus absorbs a neutrino, it becomes a nucleus of the inert gas argon. Technology now exists that can cycle a gigantic tank of CCl4 and count the number of argon atoms that have been created in this way. Neutrinos from the Sun have been detected in this way in a neutrino "telescope" in an abandoned gold mine in Lead, N.D. In 1987 two supernovas were recorded in the Magellenic clouds, satellites of our own Milky Way galaxy, Analysis of the detector fluid was done and the results confirmed a detectable increase in neutrino flux.

The only problem with neutrino detectors is that the number of neutrinos detected is about only one-third of the number that was expected from the known energy output of the sun. Current theory says that the neutrino released in solar physics actually oscillated between three different neutrino species. The seven-minute journey was enough to allow the beam of neutrinos to become an equal mixture of electron neutrinos, muon neutrinos, and taon neutrinos. This implied that, rather than being massless particles traveling at the speed of light, neutrinos actually had a small rest mass.

Conclusion

As this essay is being written, on February 11, 2016, the National Science Foundation has just announced that on September 14, 2015, the Laser Interferometer Gravitational Wave Observatory (LIGO) with detectors in locations in the United States—one in Louisiana and one in Washington—detected gravitational waves coming from the collision of two black holes. In what can only be described as an observational tour de force, this confirms Albert Einstein's 1915 prediction that detectable waves in the gravitational field could come about from a sufficiently violent cosmic collision. The detector is basically a pair of massive tuning forks, some 2000 miles underground. By looking for vibrations of the forks in phase with each other, one can identify their response to the collision. It is worth noting that there is still some uncertainty as to the source of the universe's cosmic expansion. In fact, there are quite a few mysteries associated with gravitation so, after all, there is still much work to be done.

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