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.

Donald R. Franceschetti, PhD

A

ABLATION

FIELDS OF STUDY

Astrophysics; Astronautics

SUMMARY

Ablation is a phenomenon during which material vaporizes, sublimates, melts, or otherwise erodes from a surface. In space science, it refers to a cooling effect by mass transfer during aerodynamic heating. A famous example of ablation is a meteor or spacecraft entering Earth's atmosphere. Ablation has important implications for humans, including the way it protects Earth from large meteors.

PRINCIPAL TERMS

- **ablation shield:** the material on spacecraft that is meant to ablate to protect the craft during reentry.
- **sublimation:** the process of a frozen solid becoming a gas without passing through the liquid phase.

Fundamentals of Ablation

Ablation is a phenomenon during which materials are eroded from the exterior of an object. This may occur through sublimation, vaporization, melting, chipping, or other processes. In the context of space, ablation is a form of cooling through mass transfer.

Examples of Ablation

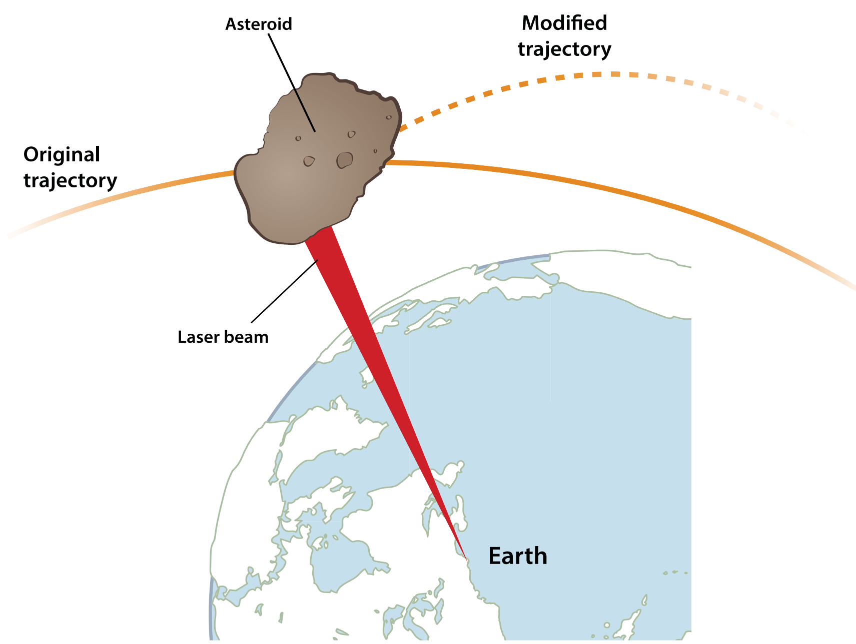
Many different examples of ablation exist. One of the most common examples is that of meteors that enter Earth's atmosphere. Friction ablates the surface of the falling meteor, and the eroded particles form a tail behind the object.

Another example of ablation is the ablation shield on some spacecraft. Scientists have designed shields made from special material that is meant to ablate upon reentry into Earth's atmosphere. This helps keep the spacecraft cooler while it enters the atmosphere. Such shields are not reusable.

Implications of Ablation

Ablation has important implications for humans on Earth. The natural ablation of meteors in the atmosphere helps protect Earth's surface from large impacts. As meteors ablate, they become smaller. Most disintegrate completely before reaching the surface. Without ablation, meteor impacts could devastate life on Earth.

Another way in which ablation is important is its use in aerospace technology. Ablation shields, commonly called heat shields, allow astronauts to land



A high-intensity laser impacting with an object, such as space debris or a near-Earth asteroid, causes vaporization of surface material. This vaporization is called ablation, which produces thrust and can change the trajectory of the target object.

safely back on Earth, making space exploration possible. Ablation may also provide protection from asteroids large enough to pose a threat to Earth. Near-Earth objects have impacted Earth's surface in the past, and similar objects will likely impact it in the future. However, some scientists believe they can deflect such threats using laser ablation. This process would use solar-powered lasers to sublimate an asteroid's surface. The gas created by the sublimation could propel the asteroid enough to change its course so it does not impact Earth.

—Elizabeth Mohn

Further Reading

"Ablation." *Cosmos.* Swinburne University of Technology, n.d. Web. 17 Mar. 2015.

"Ablation Shield." *Oxford Index.* Oxford University Press, 2014. Web. 17 Mar. 2015.

Angelo, Joseph A. "Ablation." *Encyclopedia of Space and Astronomy.* New York: Facts On File, 2006. Print.

Cammorata, Nicole. *Words You Should Know 2013: The 201 Words from Science, Politics, Technology, and Pop Culture that Will Change Your Life This Year.* Avon: Adams, 2013. Print.

"Investigating Heat Shield Physics May Improve Design of Space Capsules." *Aerospace Engineering and Engineering Mechanics.* Cockrell School of Engineering, University of Texas at Austin, 13 Apr. 2013. Web. 20 Mar. 2015.

Jones, Daniel C., and Iwan P. Williams. "High Inclination Meteorite Streams Can Exist." *Advances in Meteoroid and Meteor Science.* Ed. J. M. Trigo-Rodríguez. New York: Springer, 2008. Print.

"Sublimation." *Cosmos.* Swinburne University of Technology, n.d. Web. 17 Mar. 2015.

ACCRETION DISKS

FIELDS OF STUDY

Astrophysics; Observational Astronomy; Sub-planet Astronomy

SUMMARY

Accretion disks are relatively flat, rotating collections of debris and gas that form around black holes, young stars, or other large celestial objects with great gravitational force. Accretion disks can produce large amounts of energy and light, and they are one way scientists can identify the location of a black hole.

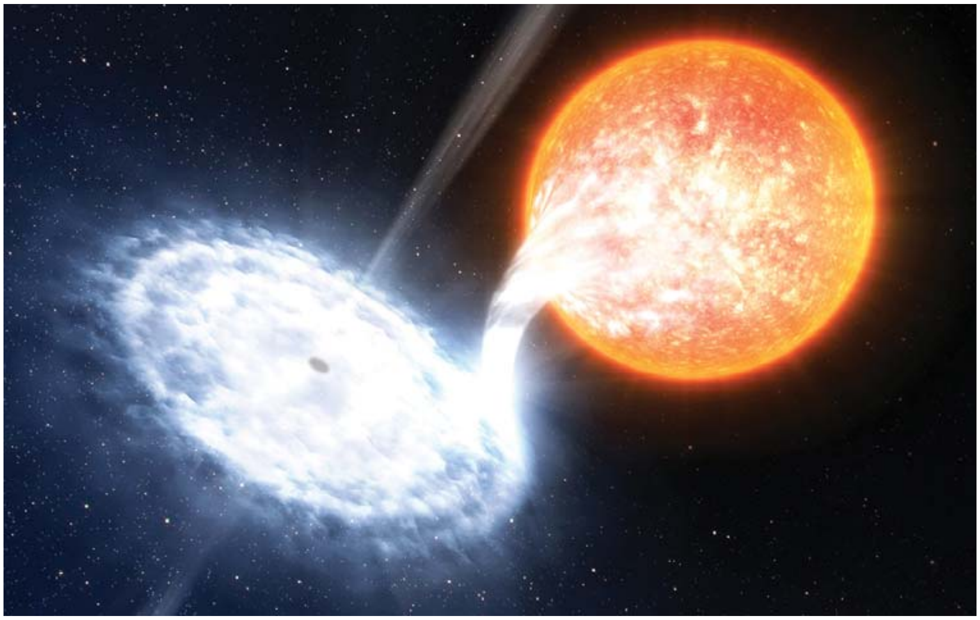
PRINCIPAL TERMS

- **angular momentum:** the momentum, or force of motion, of a rotating object or system, determined by the object's mass, speed, and distance from the point about which it is rotating.
- **binary star:** two stars that orbit around a common center of mass.
- **black hole:** a region of space with a gravitational pull so strong that even light cannot escape it.
- **galactic nucleus:** the center of a galaxy, relatively small but with a high concentration of stars.
- **quasar:** short for "quasi-stellar"; an extremely bright celestial object that produces very large amounts of energy.
- **white dwarf:** a small, very dense star that has exhausted nearly all of its fuel and is nearing the end of its life cycle.
- **x-ray:** high-energy electromagnetic radiation with a very short wavelength.

Black Hole Markers

Accretion disks are one way that scientists detect the presence of black holes. Some black holes form when a massive star dies in a supernova explosion and then collapses in on itself. For a star to collapse into a black hole, its mass must be about twenty times that of the sun or greater. Other black holes are formed by the collision of dense objects, such as neutron stars. The tremendous gravitational power of a black hole is the result of a massive amount of matter being compressed into a relatively small area. The very center of a black hole is called a "singularity." A singularity is a point in space where mass density, and thus gravitational force, is essentially infinite.

The enormous size and power of a black hole pulls in everything within range, including light. Because of this, scientists cannot locate or study black holes



An artist's rendition of an accretion disk with a black hole at its center and a star, similar to the sun, orbiting it; the GX 339-4 binary system. By ESO/L. Calçada (eso.org), via Wikimedia Commons.

directly using any of the usual instruments that detect electromagnetic radiation. Instead, they look for objects and phenomena that accompany black holes. One such object is an accretion disk. Accretion disks are made up of the dust, gas, and other debris that massive objects such as black holes attract. Because of the law of conservation of angular momentum, this material continues to orbit the massive object as it approaches, following a spiral path and forming a flat, rotating mass. The friction produced by this rotation causes the material in the accretion disk to heat up and generate x-rays. The x-rays then propagate through space. Scientists look for these x-rays in order to identify the probable location of a black hole.

Other Accretion Disks

The largest black holes can be more than a billion times as massive as the sun. These supermassive black holes are believed to be at the center of the galactic nuclei of most massive galaxies, including the Milky Way. If the accretion disk of a supermassive black hole produces enough friction, it generates a tremendous amount of heat and light, more than is produced by the rest of the galaxy combined. This phenomenon is called a quasar. The term "quasar" comes from "quasi-stellar radio source," as quasars were first thought to be individual starlike objects that emitted strong radio waves. In fact, a quasar is a type of active galactic nucleus (AGN), which is a galactic nucleus that emits more radiation than can be produced by the stars it contains. Quasars are believed to be the brightest objects in the universe. They are often more than a hundred times brighter than their surrounding galaxies. Quasars last as long as there is matter in the accretion disk to fuel them.

Accretion disks also form around young stars as they exert their gravitational forces on the space around them. Some of the material in such a disk may eventually form planets that orbit around the new star. On the other end of the stellar life span, accretion disks can also form when a white dwarf, a type of dying star, is one half of a binary star. The white dwarf compresses and grows both smaller in size and heavier in mass, increasing its gravitational power. This can cause it to draw material from its partner in the binary system, forming an accretion disk.

Bringing Accretion Disks into View

In 2011, scientists at the National Aeronautics and Space Administration and the European Space Agency were able to use the Hubble Space Telescope to study a quasar accretion disk. Because quasars are at the center of distant galaxies, too far to study in detail with even the most powerful telescopes, the scientists developed a new technique: they used a galaxy between Earth and the quasar as a gravitational lens. When the stars in this galaxy passed in front of the quasar, their gravitational fields amplified the quasar's light and made it easier to see. This was the first time scientists were able to gather direct information about a quasar and its accretion disk instead of relying on theoretical data.

—Janine Ungvarsky

Further Reading

"Angular Momentum." *Cosmos: The SAO Encyclopedia of Astronomy*. Swinburne University of Technology, n.d. Web. 30 Mar. 2015.

"Binary Star." *Cosmos: The SAO Encyclopedia of Astronomy*. Swinburne University of Technology, n.d. Web. 30 Mar. 2015.

"Black Holes." *NASA Science*. NASA, 30 Mar. 2015. Web. 31 Mar. 2015.

"Galactic Nuclei." *Cosmos: The SAO Encyclopedia of Astronomy*. Swinburne University of Technology, n.d. Web. 30 Mar. 2015.

"Hubble Directly Observes the Disc around a Black Hole." *ESA Science & Technology*. European Space Agency, 4 Nov. 2011. Web. 31 Mar. 2015.

Lemonick, Michael D. "Winds Blasting from Black Holes Shut Down Star Growth." *National Geographic*. Natl. Geographic Soc., 19 Feb. 2015. Web. 31 Mar. 2015.

Wanjek, Christopher. "Ring around the Black Hole." *Solar System Exploration*. NASA, 21 Feb. 2011. Web. 6 Mar. 2015.

AEROSPACE DESIGN

FIELDS OF STUDY

Aerospace Engineering, Astronautics; Space Technology

SUMMARY

Aerospace design is crucial to the development and manufacturing of aircraft and spacecraft. Since the introduction of aircraft in the nineteenth century, aerospace design has led to the production of countless flight vehicles, including spacecraft used for space exploration. Aerospace design involves a design process, which may take several years to complete. The phases of this process typically are system/mission requirements, conceptual design, preliminary design, and critical design. With spacecraft, the design generally includes major components such as the mission payload and the platform. The design of the Space Shuttle is one good example.

PRINCIPAL TERMS

- **attitude control:** the process of obtaining and sustaining the proper orientation in space.
- **mission payload:** the extra equipment carried by a craft for a specific mission. For a launch vehicle, payload usually refers to scientific instruments, satellites, probes, and spacecraft attached to the launcher.
- **platform:** all parts of a spacecraft that are not part of the payload; also known as the bus.
- **telemetry:** the process of transmitting measurement data via radio to operators on the ground. Telemetry is used to improve spaceflight performance and accuracy. It provides important information about standard operational health and status of a craft as well as mission-specific payload data.
- **thermal control:** the system aboard a spacecraft that controls the temperature of various components to ensure safety and accuracy during a mission.
- **tracking and commanding:** tracking takes account of a craft's position in relation to the ground base with transponders, radar, or other systems. Commanding refers to the ground station sending signals to a craft to change settings such as ascent and orbit paths.

Learning to Fly

The term "aerospace" refers to Earth's atmosphere and the space beyond. Aerospace design or aerospace engineering is the branch of science and technology that focuses on creating and manufacturing effective aircraft and spacecraft. Aerospace design is divided into two subfields: aeronautic design and astronautical design. Aeronautic design refers to the creation of machines that fly in Earth's atmosphere. Astronautical design deals with designing and developing spacecraft and their launch vehicles, generally powered by highly powerful rockets. The aerospace industry caters to military, industrial, and commercial consumers.

The history of aerospace design begins with the history of aviation. The first powered lighter-than-air craft existed as early as the 1850s. Jules Henri Giffard (1825–82) invented a steam-powered airship in 1852. Ferdinand von Zeppelin (1838–1917) introduced rigid airships in 1900; they came to be known as "zeppelins" and later as "blimps." Brothers Orville (1871–1948) and Wilbur Wright (1867–1912) designed a heavier-than-air, piloted airplane that is generally credited as the first of its kind to execute a successful powered flight, in 1903. Air flight designs continued to progress throughout the twentieth century, paving the way for the development of rotary winged aircraft such as helicopters, which use revolving wings or blades to lift into the air. Powerful air flight engines that fuel modern aircrafts did not emerge until the mid-twentieth century.

At the same time that engine design was advancing, aerospace engineers also began developing machinery that would take humans to the upper atmosphere and into space. Konstantin Tsiolkovsky (1857–1935), known as the Russian father of rocketry, was a pioneer of astronautics with his insightful studies in space travel and rocket science. American engineer Robert Goddard launched the first liquid-fueled rocket in 1926. Goddard continually improved his rocket design over the years. His calculations contributed to the development of other rocket-powered devices such as ballistic missiles. Tsiolkovsky and German scientist Hermann Oberth (1894–1989) independently made similar breakthroughs in the same time period.

During World War I and World War II, aerospace design saw rampant progress as military engineers pursued higher performance aircraft design. In particular, advances in rocket research during World War II laid the foundation for astronautics. Continued advances in aerospace design were spurred by the Cold War and the space race between the United States and the Soviet Union. The competition to reach outer space led to the launch of the first spacecraft, *Sputnik I*, by the Soviet Union in 1957. The United States established the National Aeronautics and Space Association (NASA) in 1958. Aerospace engineers designed a wide range of spacecraft to explore space, incorporating new technologies and capabilities as they became available. For example, in 1969, an American-made spacecraft successfully sent astronauts to the moon, which marked the first time humans landed on the moon. Many other spacecraft have been used to carry out missions elsewhere in the solar system. Artificial satellites have proven critical to twenty-first-century communications systems and become widespread with a variety of designs and functions.

Design Process

The design process of a spacecraft generally occurs in the following phases: system/mission requirements, conceptual design, preliminary design, and critical design. Some of these phases can take years to complete. In the system/mission requirements phase, the requirements of the spacecraft are addressed. The type of mission the spacecraft will be used for helps determine these requirements, as specific tasks may dictate certain design elements. For example, a deep space probe would require a significantly different design than a weather monitoring satellite.

The conceptual design phase deals with several possible system concepts that could fulfill the requirements of the mission. These concepts are first conceived and then analyzed. After the most suitable concept is chosen, costs and risks are examined and schedules are made.

The preliminary design phase involves several tasks. Variations of the selected concept are identified, examined, and improved. Specifications for each subsystem and component level are identified. The projected performance of the systems and subsystems is analyzed. Documents are composed, and an initial parts list is put together. This phase may run for several years depending on the novelty and complexity of the mission.

Lastly, the critical design phase, or detailed design phase, takes place. During this phase, the detailed characteristics of the structural design of the spacecraft are established. Equipment, payload, the crew, and provisions are all taken into account. Plumbing, wiring, and other secondary structures are reviewed. Various tests involving design verification are performed, including tests of electronic circuit models and software models. Design and performance margin estimates are improved. Test and evaluation plans are settled. Like the preliminary design phase, the critical design phase may take several years to complete.

Once the design process has been completed, the spacecraft can finally be built. It is then tested before being delivered for use.

Typical Components

Most spacecraft share two key components: the mission payload and the platform, or the bus. The mission payload includes all of the equipment that is specific to the mission, such as scientific instruments and probes, rather than general operation. The platform comprises all other parts of the spacecraft, used to deliver the payload. It consists of several subsystems, including the structures subsystem, thermal control subsystem, electrical power subsystem, attitude control subsystem, and telemetry, tracking, and commanding (TT&C) subsystem.

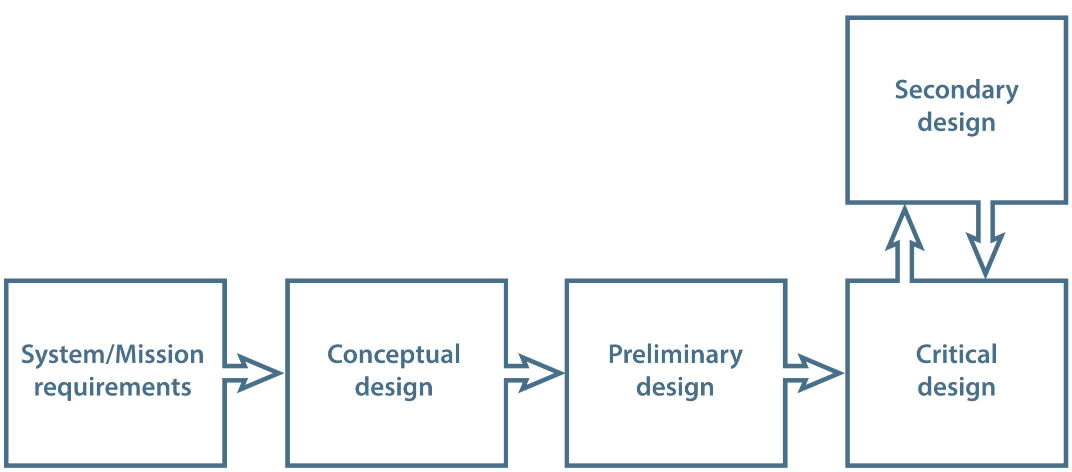
The structures subsystem serves various functions such as enclosing, supporting, and protecting the other subsystems, as well as sustaining stresses and loads. It also provides a connection to the launch vehicle. Two main types of structure subsystems exist: open truss and body mounted. The open-truss type typically has the shape of a box or cylinder, while the body-mounted type does not have a definite shape. The choice of structural materials is an important consideration in aerospace design. Light, durable, and heat-resistant materials, such as aluminum, titanium, and some plastics, are typically used.

The thermal control subsystem regulates the temperature of the spacecraft's components. This helps guarantee that the components function properly throughout the mission. Different components require different temperatures. Thermal control systems may be active or passive. Active thermal control involves the use of electrical heaters, cooling systems, and louvers. Passive thermal control includes the use of heat sinks, thermal coatings and insulations, and phase-change materials (PCM). With passive thermal control, electrical power is not needed and there are no moving parts or fluids.

The electrical power subsystem provides the power the spacecraft needs for the duration of the mission, which can last for years. In most cases, the subsystem includes the following components: a source of energy; a device that converts the energy into electricity; a device that stores the electrical energy; and a system that conditions, charges, discharges, distributes, and regulates the electrical energy. The source of energy is generally solar radiation, nuclear power, or chemical reactions.

The attitude control subsystem deals with the process and hardware necessary for obtaining and sustaining the proper orientation in space, or attitude. It has several functions, including maintaining an orbit (station keeping), adjusting an orbit, and stabilization. That subsystem typically includes navigation sensors, a guidance section, and a control section. As with thermal control, the attitude control may be either active or passive. Active attitude control uses continuous decision making and hardware that are closed loop. This includes the use of thrusters, electromagnets, and reaction wheels. Passive attitude control uses open-loop environmental torques to sustain attitude, such as gravity gradient and solar sails.

The telemetry, tracking, and commanding (TT&C) subsystem involves communication with operators on the ground. Telemetry uses a radio link to



The process of designing aerospace technology begins with reviewing system and mission requirements. From this a conceptual design is developed. This phase is followed by the preliminary design phase in which concept designs are refined and preliminary parts are identified. The critical design phase follows and identifies finer details of the design. During this stage preliminary structure details are finalized and secondary structures are evaluated for inclusion in the critical design.

transmit measurement data to those operators. It is typically used for improving spacecraft performance and for monitoring the health of the spacecraft, including the payload. Tracking and commanding deals with the spacecraft's position. Tracking is used to report the spacecraft's position to the ground station, while commanding is used to change the spacecraft's position. Some common tracking methods are the use of a beacon or a transponder, Doppler tracking, optical tracking, interferometer tracking, and radar tracking and ranging. Commanding is achieved through coded instructions that the ground station sends to the aircraft.

Practical Example

A good example of aerospace design is that of the Space Shuttle, officially called the Space Transportation System (STS). In 1969, US president Richard Nixon established the Space Task Group to study the United States' future in space exploration. Among other things, the group envisioned a reusable spaceflight vehicle. It was not long before NASA, along with industry contractors, began the design process of such a vehicle. The process involved numerous studies, including design, engineering, cost, and risk studies. Some of the studies focused on the concepts of an orbiter, dual solid-propellant rocket motors, a reusable piloted booster, and a disposable liquid-propellant tank.

In 1972, the design of the Space Shuttle was moved forward. It would feature an orbiter, three main engines, two solid rocket boosters (SRBs), and an external tank (ET). The orbiter would house the crew, the SRBs would provide the shuttle's lift at the beginning of its flight, and the ET would hold fuel for the main engines. All of the components would be reusable, except for the ET, which would be jettisoned after launch. Refinements continued to be made as the project continued and systems were tested.

The first orbiter spacecraft, named *Enterprise*, was completed in 1976 and underwent several flight tests. However, *Enterprise* was merely a test vehicle and was not used for any actual space missions. In 1981, the first Space Shuttle mission took place. *Columbia* lifted off from the Kennedy Space Center and became the first orbiter in space. Over the next several decades, several shuttles successfully performed many space missions.

—*Michael Mazzei*

Further Reading

Aerospace Design Lab. Stanford U, Dept. of Aeronautics and Astronautics, 28 July 2013. Web. 9 June 2015.

Garino, Brian W., and Jeffrey D. Lanphear. "Spacecraft Design, Structure, and Operations." *AU-18 Space Primer.* Air U, 2009. Web. 9 June 2015.

Lucas, Jim. "What Is Aerospace Engineering?" *Live Science.* Purch, 4 Sept. 2014. Web. 9 June 2015.

"Part I. Historical Context." *Space Transportation System.* Denver: Historic American Engineering Record, Natl. Park Service, US Dept. of the Interior, Nov. 2012. PDF file.

"Space Shuttle History." *Human Space Flight.* NASA, 27 Feb. 2008. Web. 9 June 2015.

"Spacecraft Design, Structure, and Operations." *AU Space Primer.* Air U, 2003. *Air University.* Web. 9 June 2015.

NOBEL NOTES

While there is no Nobel Prize designated specifically for astronomy, quite a few of the Physics Prizes and at least one of the Chemistry prizes have some connection with one of the following areas: observational astronomy, the big bang theory, or the ultimate fate of the universe.

The Nobel Prize for Physics in 1936 was split equally between Carl D. Andersen, for his discovery of the positron, and Victor F. Hess, for the discovery of cosmic rays.

In 1967 the prize went to Hans Albrecht Bethe for his analysis of the hydrogen fusion reaction that powers most stars.

Mention should be made here of the 1971 Chemistry prize to Gerhard Herzberg, a spectroscopist, who studied the electronic structure of highly reactive species, many of which could only exist in the near vacuum of space. Using a variety of innovative techniques he was able to determine the absorption spectra of these highly reactive species.

The Nobel Physics prize was shared in 1974 by Sir Martin Ryle and Anthony Hewish for their investigation of radio sources.

In 1978, the Nobel Prize for Physics went to Arno Penzias and Robert Wilson for identifying the cosmic ray background, the isotropic radiation background reflecting a black body temperature of 2.7 K, confirming the large scale expansion of the universe as proposed by Hubble. This was the first Nobel Award for cosmology, the study of the universe as a whole.

In 1983 the Nobel Prize in Physics was split between Subramanyan Chandrasekhar and William H. Fowler. Chandrasekhar had established the maximum size possible for a white dwarf star and contributed to the theory of colliding black holes. Fowler, an experimental nuclear physicist, had clarified the sequence of reactions that powered the sun and other stars.

In 1993 the Prize was awarded jointly to Russell A. Hulse and Joseph H. Taylor Jr. for the discovery of a binary neutron star which appeared to be losing energy due to gravitational radiation, a prediction of Albert Einstein' general theory of relativity.

The Nobel Prize in 1995 honored two investigators in neutrino physics. Martin Perl was honored for the discovery of the tau lepton, which completed the set of 6 leptons in parallel to 6 quark flavors while Frederick Reines was honored for the actual detection of neutrinos in a water tank near a nuclear reactor.

In 2002, the Nobel Prize for physics was shared by three investigators: Raymond Davis, Jr. and Masatoshi Koshiba, for the detection of neutrinos from cosmic sources, and Riccardo Ginacconi for identifying cosmic x-ray sources which are most likely the result of matter falling into a black holes.

The Nobel committee returned to cosmology in 2006 with an award to John C. Mather and George F. Smoot for confirming that the cosmic background radiation was of the form of a black body spectrum and for the first determination of the anisotropy of the radiation. Physicists can now look to the development of that isotropy is the earliest moments of the universe to determine how it gave rise to the current distribution of galaxies arose.

The Nobel Prize in Physics for 2015 was awarded to Takaaki Kajita and Arthur B Macdonald for the discovery of neutrino oscillations. If the three known families of neutrinos are allowed to have a slightly different amounts of rest mass, then it could be argued that the flux of electron neutrinos from the sun would in the eight minutes it took to reach the earth turned in to a roughly equal mixture of electron, muon, and tauon neutrinos, accounting for the fact that only one third of the neutrinos expected are found among the solar neutrinos.

If we examine the Nobel Prizes that touch on Astronomy and Cosmology, we can readily identify a number of important trends. The establishment of the big bang cosmology is certainly one. Tying together advances in particle physics with their astrophysical consequences is certainly another. Enrico Fermi's "little neutral one," the *neutrino*, is continuing to surprise us. The next few chapters in the history of astronomy are still to be written.

George Hale (1868-1938, American). Discovered that sunspots have localized magnetic fields, He founded three important observatories: Yerkes, Mt. Wilson, and Palomar.

Henrietta Swan Levitt (1868-1921, American). Another member of "Pickering's Women" who discovered that a particular type of variable star known as a Cepheid could be used as a distance marker. This discovery made it possible to determine astronomical distances to objects.

Ejnar Hertzsprung (1873-1967, Danish). One of the inventors of the Hertzsprung-Russell diagram, showing the relationship between the absolute magnitude and the spectral type of stars. He determined the distance to the Small Magellanic Cloud, a galaxy visible from Earth's southern hemisphere.

Karl Schwarzschild (1873-1916, German). The first to study the theory of black holes. The Schwarzschild radius is the distance from a black hole at which bodies would have an escape velocity exceeding the speed of light and therefore would be invisible. He wrote on the curvature of space, based on Einstein's theory of relativity.

Henry Russell (1877-1957, American). One of the inventors of the Hertzsprung-Russell diagram describing the spectral types of stars. He measured the parallax of the stars photographically, allowing them to be properly placed on the H-R diagram.

Albert Einstein (1879-1955, German). His special theory of relativity, proposed in 1905, extends Newtonian mechanics to very large speeds close to the speed of light and describes the changes in measurements of physical phenomena when viewed by observers who are in motion relative to the phenomena. In 1915, Einstein extended this further in the general theory of relativity to include the effects of gravitation. According to this theory, mass and energy determine the geometry of spacetime, and curvatures of spacetime manifest themselves in gravitational forces.

Arthur Eddington (1882-1944, British). Proved observationally that Einstein's prediction of light bending near the extreme mass of a star is scientifically accurate. He also explained the behavior of Cepheid variables, and discovered the relationship between the mass of a star and its luminosity.

Edwin Hubble (1889-1953, American). Discovered that faraway galaxies are moving away from us. Known as Hubble's Law, the theory states that galaxies recede from each other at a rate proportional to their distance from each other. This concept is a cornerstone of the big bang model of the universe.

Jan Oort (1900-1992, Dutch). The first to measure the distance between our solar system and the center of the Milky Way Galaxy and to calculate the mass of the Milky Way. He proposed a large number of icy comets left over from the formation of the solar system, now known as the Oort Cloud

George Gamow (1904-1968, Russian-born American). First to put forward the idea that solar energy comes from the process of nuclear fusion.

Karl Jansky (1905-1950, American). Discovered that radio waves are emanating from space, leading to the science of radio astronomy.

Gerard Kuiper (1905-1973, Dutch-born American). Discovered a large number of comets at the edge of the solar system beyond Pluto's orbit, known as the Kuiper belt as well as several moons in the outer solar system and the atmosphere of Saturn's moon, Titan.

Clyde Tombaugh (1906-1997, American). Discovered Pluto, which he found photographically in 1930, using the telescope at the Lowell Observatory in Arizona.

Subramanyan Chandrasekhar (1910-1995, Indian-born American). Made important contributions to the theory of stellar evolution. He found that the limit, now called the Chandrasekhar limit, to the stability of white dwarf stars is 1.4 solar masses: star larger that cannot be stable as white dwarves.

James Van Allen (1914-, American). Discovered the magnetosphere of the Earth and gave his name to the belts of radiation surrounding the planet, the Van Allen belts, which moderate the amount of solar radiation hitting Earth.