# Space Science

## (Concepts and Elements)

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# Space Science

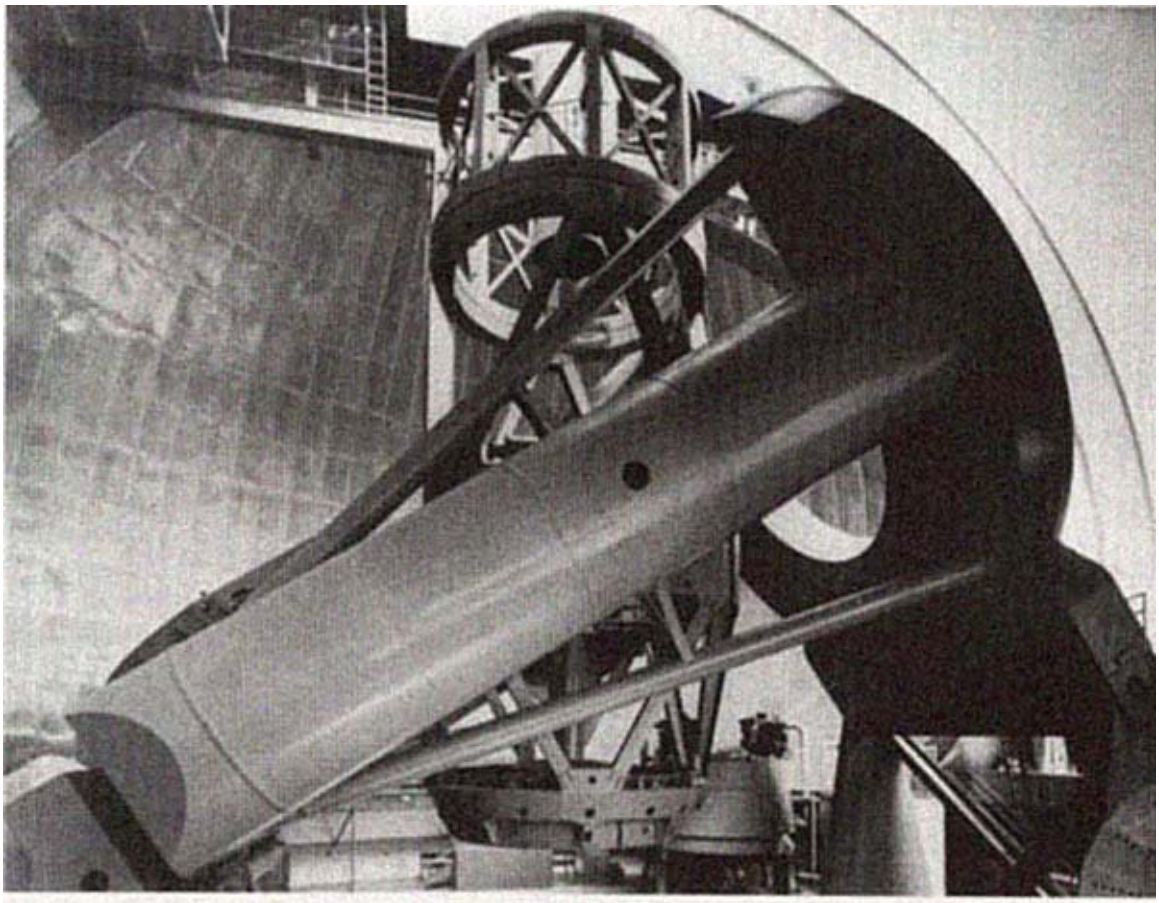
A picture showing part of the Milky Way

**Space science** is an all-encompassing term that describes all of the various science fields that are concerned with the study of the Universe, generally also meaning "excluding the Earth" and "outside of the Earth's atmosphere". Originally, all of these fields were considered part of astronomy. However, in recent years the major sub-fields within astronomy, such as astrophysics, have grown so large that they are now considered separate fields on their own. There are eight overall categories that can generally be described on their own; Astrophysics, Galactic Science, Stellar Science, non-Earth Planetary Science, Biology of Other Planets, Astronautics/Space Travel, Space Colonization and Space Defense. The Library of Congress and Dewey Decimal System have a major classification "Descriptive Astronomy" which they use instead of placing

descriptive works into their huge "Geography" collections. Space science should not be confused with space research and space exploration.

# Astronomy

## Astronomical methods



*Mt. Palomar's 200-inch Hale Telescope, pointing to the zenith, as seen from the east side.*

Palomar Telescope.

Astronomical methods are the equipments and techniques used to collect data about the objects in Space. Galileo's first astronomical method was to find and buy the best telescope of the time and then point that telescope to the heavens. Methods can be categorized according to the wavelength they are attempting to record.

Radio astronomy includes radio telescopes; devices that receive and record radio waves from outside the Earth. They record cosmic microwave background radiation resulting from the Big Bang, Pulsars and other sources. Optical astronomy is the oldest kind of astronomy. X-ray observatories include the Chandra X-ray Observatory and others. gamma ray includes the Compton Gamma Ray Observatory and others. Neutrino astronomy observatories have also been built, primarily to study our Sun. Gravitational wave observatories have been theorized.

A space telescope is a telescope orbiting or travelling from the Earth, such as the Hubble space telescope. RXTE is Long Exposure Time Astronomy used to study millisecond pulsars and pulsar deceleration.

Spectroscopy

**Astronomy teaching tools** include Planetariums and others.

## Descriptive astronomy

Galileo's second astronomical method was to describe what he saw in the telescope. Descriptive Astronomy is the highest sub-category of Astronomy used by the Library of Congress and Dewey Decimal systems to classify any knowledge related to describing celestial objects. Because we are seeing today portions of the Universe as they actually looked millions or billions of years ago we should have a historical section within Descriptive astronomy: **History of The Universe** includes the size, shape and structure of the historical universe), **Cartography of The Historical Universe**, Early Universe and others. **The Current Universe** includes size shape and structure of the current Universe, cartography of the current Universe and others.

**Cartography of Space Bodies**. Recording photographic or similar images of the Earths surface from space is a well developed science, yet still expanding because of advances in the actual resolution of images taken from space or atmosphere and because of advances in digitizing and manipulating the images. Most of these advances are being applied to the cartography of space-located bodies, even though acquiring the original images of those bodies is extremely complicated and expensive, usually requiring long distance probes to carry the cameras.

Visible matter in the universe is apparently organized geographically into structures with large amounts of space between them; either the space between planets, the space between stars or the space between galaxies. Even galaxies themselves are not spread uniformly but appear to be located in filaments. Therefore The Universe can be divided geographically into regions that follow this structure. **The Filaments of Galaxies** are the furthest visible structures.

Those filaments are made of superclusters, tending to line up in filaments. Our Milky Way Galaxy is a galaxy in what is called **Our Supercluster of Galaxies** by the National Geographic Society. Some 150 million light-years across, Our Supercluster is a great

aggregation of perhaps thousands of smaller clusters of galaxies. The largest of these smaller clusters is called the Virgo Cluster. According to National Geographic, The Virgo Cluster contains the center of mass of Our Supercluster. Although The Milky Way Galaxy is a part of Our Supercluster, it is not a part of the Virgo Cluster. Our Milky Way Galaxy is part of a cluster called the Local Group. Gravitationally, our Local Group plays a small role in Our Supercluster because it is a small and distant cluster from the center. A much larger cluster within in Our Supercluster is the Ursa Major Cluster. The following objects are located within Our Supercluster but not within the Local Group; they are objects 100,000,000 light-years to 10,000,000 light-years from the Sun: M49, M51, M58, M59, M60, M61, M63, M64, M65, M66. National Geographic magazine has produced a very good drawing of this region in its Map of the Universe Supplement, October 1999 issue.

**Local Group**: Our Milky Way Galaxy is one of about 30 galaxies called the Local Group. The Local Group is about 4 million light-years across. In the Local Group our Milky Way Galaxy plays a large gravitational part because our galaxy is the second largest galaxy in our Local Group, second only to the Andromeda Galaxy. All of the other galaxies in our Local Group are gravitationally bound either to the Andromeda Galaxy or to our Milky Way Galaxy. Inside of our local group but outside of our Galaxy are objects 4,000,000 LY to 1,000,000 LY from the Sun: M31, M32, M33.

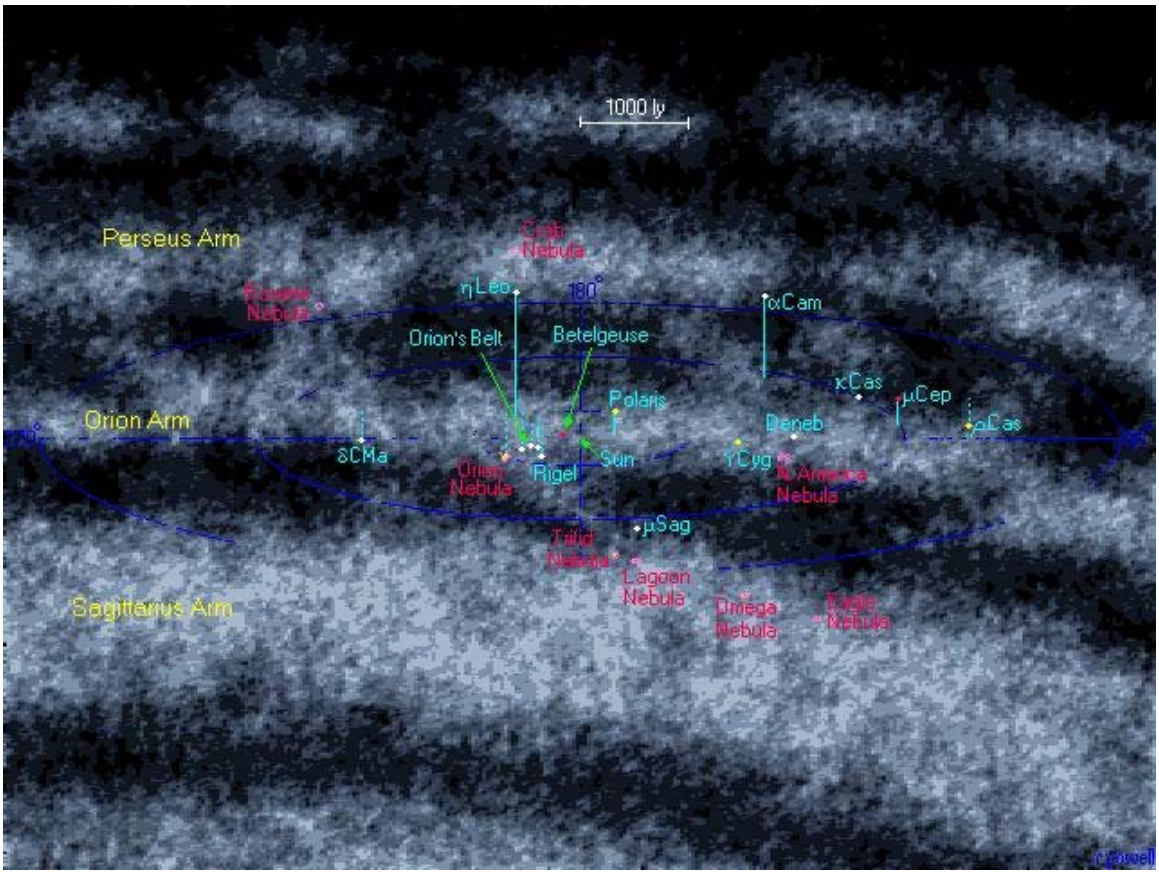



Image of the Orion and neighbouring arms

**Milky Way Galaxy**: Our Milky Way Galaxy is a massive mass-containing structure 100,000 light-years across and 30,000 light-years tall. Most of its billions of suns are organized into several structures called "arms". Our Sun is located in what is called the "Orion Arm". The next arm outside of us is called the "Perseus Arm". The Crab Nebula M1 is located in the Perseus Arm. The arm outside of the Perseus Arm is called the Outer Arm. Palomar 1 is located in the Outer Arm. The next arm inside of us is called the Sagittarius Arm. The Ring Nebula M57 and the Carina Nebula (NGC 3372) are located in the Sagittarius Arm. The next arm inside of the Sagittarius Arm is called the Crux Arm. The inner arms are much shorter, obviously from being shifted by gravitational forces. Arms beside each other today may have at an earlier time been one.

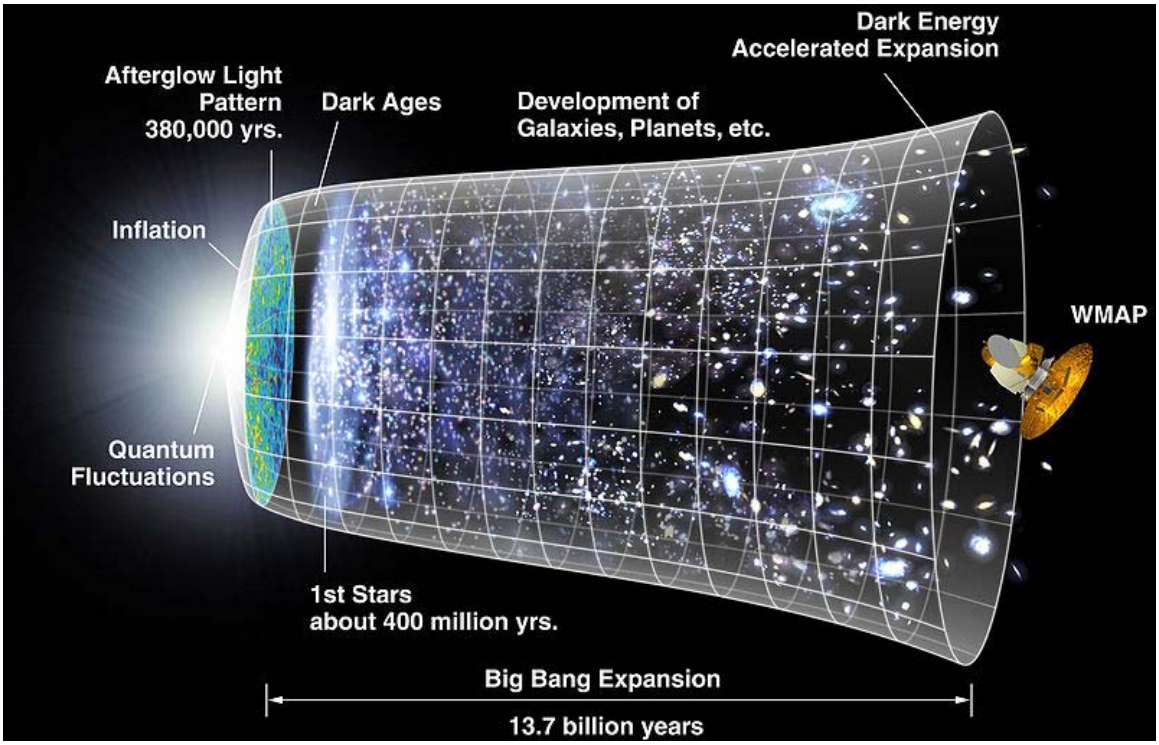
**Orion Arm**: The Orion Nebula M42 is located in our Arm. **Celestial Objects 1000 LY to 100 LY from the Sun**: M39, M44, M45. **Celestial Objects 100 LY to 16LY From the Sun**. **Celestial Objects less than 16 LY from the Sun**: List of nearest stars

**Nearby-Stars Solar Systems**: By measuring the extremely small movements of nearby stars astronomers have been able to prove that there are planets going around these Suns, therefore these suns have become "Solar Systems".

Solar system includes **Scientific Study of Solar System Planets**, Venus, Mercury, Saturn, Jupiter, Uranus, Neptune, Mars, and Moon

Further reading can be found in the Library of Congress Classification QB495-903 Descriptive astronomy (Dewey 523) Galileo's second astronomical method was to describe what he saw in the telescope.

# Physics of the universe / Astrophysics




Timeline of Origin of Space.

After first looking at the planets, then second describing what he saw, Galileo's third astronomical method was to theorize about the reasons for what he saw in the telescope, specifically to theorize that the Earth goes around the Sun. The Physics of the Universe can be divided into several broad categories:

**Astrophysical Theory** includes general relativity and others.

**Astrophysical Processes** includes baryonic and others.

**Physical Processes, General** includes Mechanics, Electromagnetism, electromagnetic forces, Statistical Mechanics, Thermodynamics, Quantum Mechanics, relativity, gravity and others.

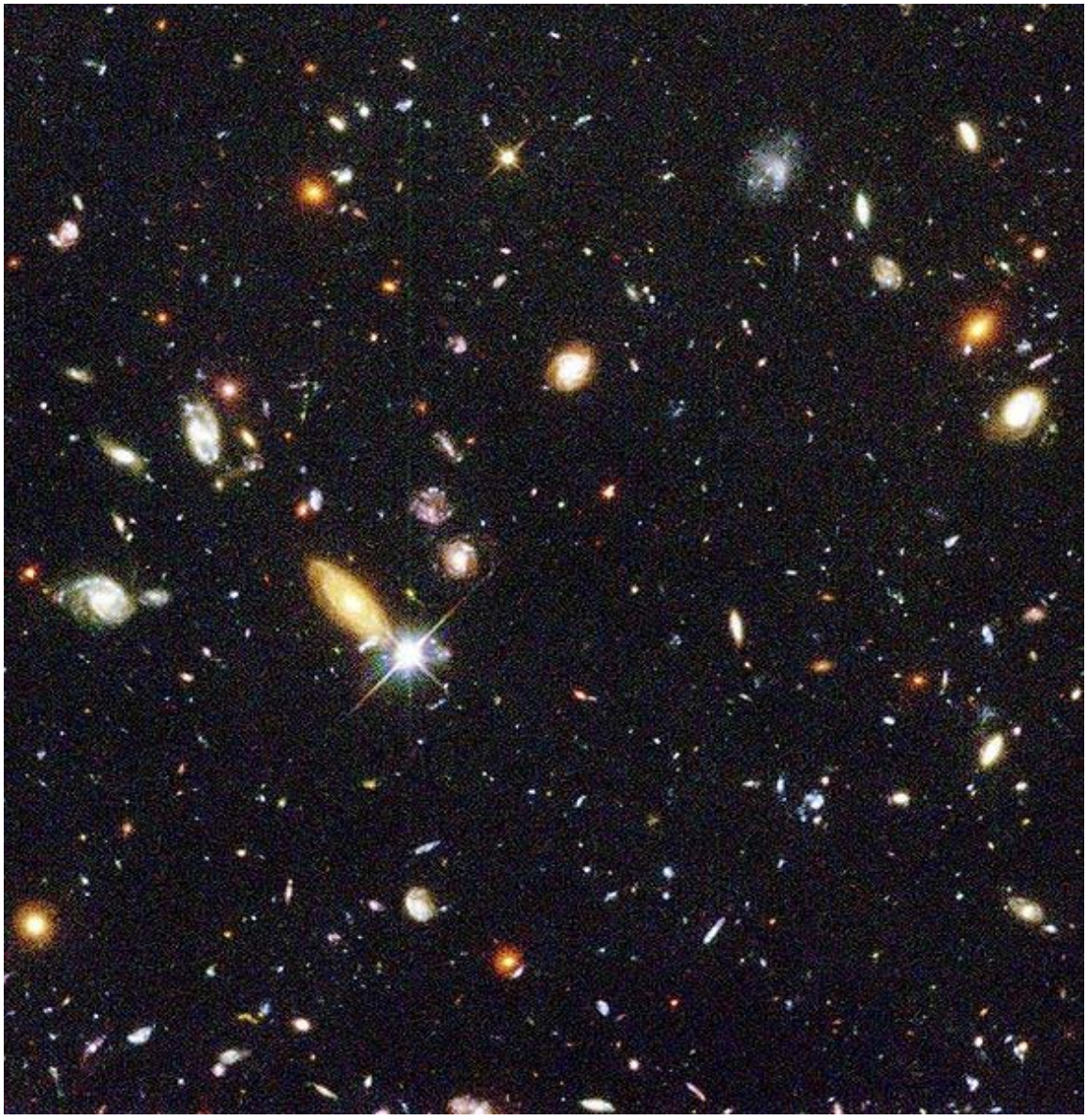
**Origins Of The Universe** Universe Theories of the Origins of the Universe, Big Bang Theory, Early Universe, Evidence, Cosmic Microwave Background, Dark Ages, **Interstellar Medium** , voids, Filaments of Galaxies, galaxy clusters and others.

**Astrophysical Plasma** includes plasma and *quasineutrality* and others.

**Cosmic Plasmas Between Stars, (Diffuse Plasmas)** includes intergalactic space, intergalactic medium, interstellar medium, interplanetary medium, heliospheric current sheet, interplanetary medium, Solar wind and others.

**Cosmic Plasmas Inside Stars, (Dense Plasma)** includes Stars, plasma physicists, active galactic nuclei, fusion power, magnetohydrodynamic, X-rays , bremsstrahlung, Cosmology , reionized, ambipolar diffusion, Particle Physics and others.

# Cosmology



Galaxies in the Hubble Deep Field.

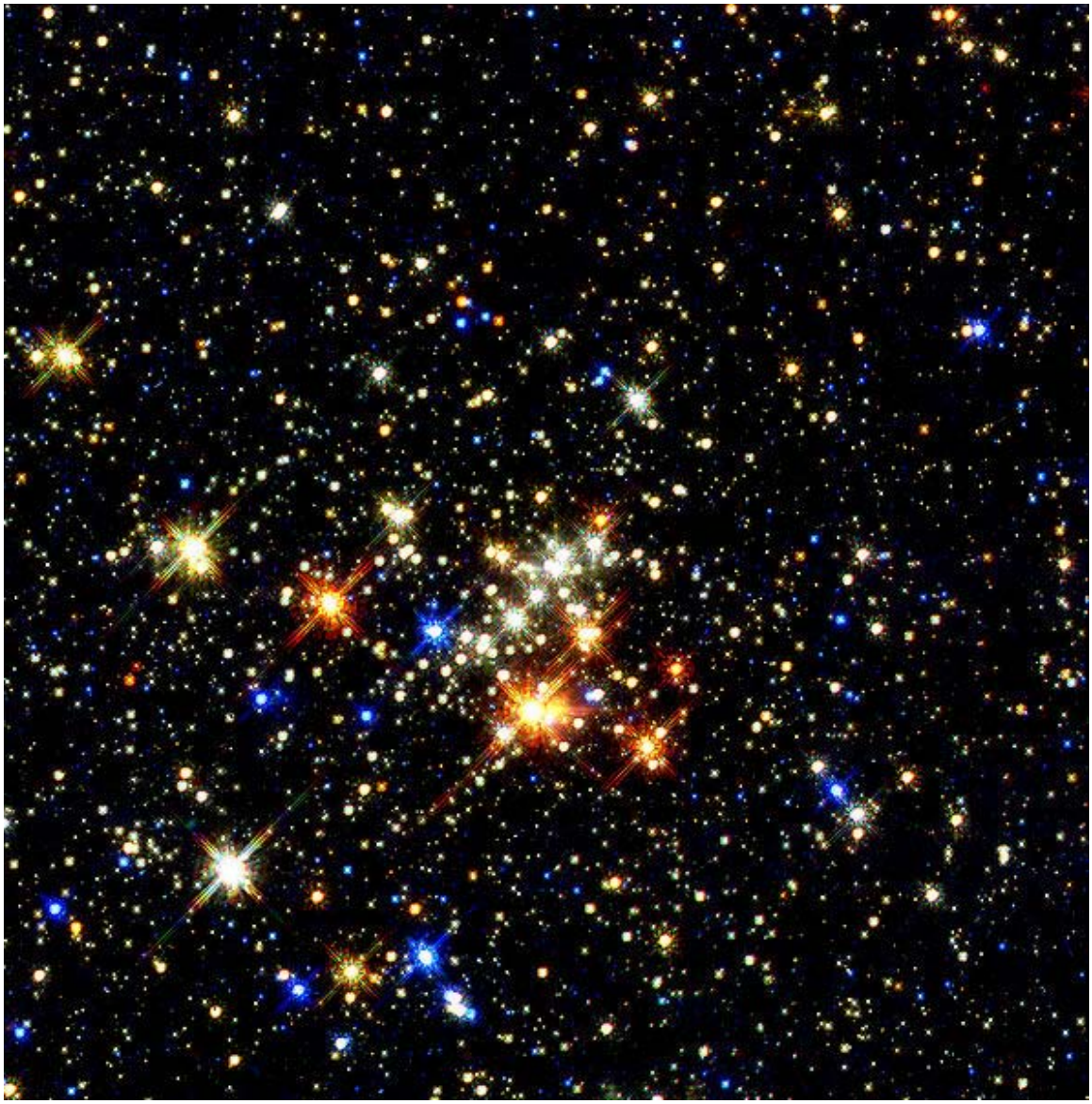
Physics can explain the underlying physical science of any galaxy, yet many aspects of galaxies are not best described through their physics. **Galactic physical science** is the general term for all physical sciences that can be applied to any galaxy in the Universe or to a particular galaxy.

**Galaxy Formation and Evolution** includes Galaxies, elliptical galaxies Giant Galaxies, **Spiral Galaxies**, M31 The Andromeda Galaxy and others.

**Intra-Galaxy Processes, General** includes Black Hole, Globular Clusters, Satellite Galaxy, Retrograde Rotation, Halo stars, High Velocity Clouds, Monoceros Ring, **accretion disc**, Gravitation, Angular momentum, Centripetal force, tidal effects, Viscosity, orbital momentum, Accretion disk, Active galactic nuclei, Protoplanetary discs, Gamma ray bursts and others.

**Milky Way Galactic Physical Science** is the overall science containing all the physical sciences related directly to the Milky Way Galaxy: Halo stars, Milky Way High Velocity Clouds, Milky Way Monoceros Ring, Milky Way **accretion disc**, Milky Way Gravitation, Milky Way Angular momentum, Milky Way Centripetal force, Milky Way tidal effects, Milky Way Viscosity, Milky Way orbital momentum, Milky Way event horizon, Milky Way black hole and others.

# Stellar science



Quintuplet Cluster- Very young and near the Galactic Center.

Physics is the underlying physical science of any star, yet many aspects of stars are not best described through their physics. **Stellar science** is the general term for ALL physical sciences that can be applied to any star in the Universe or to a particular star. **Solar science of the Sun** Sun is the overall science containing all of the physical sciences related directly to our local Sun.

**Stellar-Processes, General** Stellar dynamics, stars, Stellar Evolution, event horizon, black hole, x-rays, nuclear fusion and others. In astronomy, **stellar evolution** is the sequence of changes that a star undergoes during its lifetime; the hundreds of thousands, millions or billions of years during which it emits light and heat. Over the course of that time, the star will change radically.

Stellar evolution is not studied by observing the life cycle of a single star—most stellar changes occur too slowly to be detected even over many centuries. Instead, astrophysicists come to understand how stars evolve by observing numerous stars, each at a different point in its life cycle, and simulating stellar structure with computer models.

**Stellar evolution** begins with a giant molecular cloud (GMC), also known as a stellar nursery. Most of the 'empty' space inside a galaxy actually contains around 0.1 to 1 particle per $cm^3$, but inside a GMC, the typical density is a few million particles per $cm^3$. A GMC contains 100,000 to 10,000,000 times as much mass as our Sun by virtue of its size: 50 to 300 light-years across.

Very small protostars never reach temperatures high enough for nuclear fusion of hydrogen to begin; these are brown dwarfs of less than 0.1 solar mass. Brown dwarfs heavier than 13 Jupiter masses ($M_J$) do fuse deuterium, and some astronomers prefer to call only these objects brown dwarfs, classifying anything larger than a planet but smaller than this a sub-stellar object. Both types, deuterium-burning or not, shine dimly and die away slowly, cooling gradually over hundreds of millions of years. The central temperature in more massive protostars, however, will eventually reach 10 megakelvins, at which point hydrogen begins to fuse by way of the proton-proton chain reaction to deuterium and then to helium. The onset of nuclear fusion leads over a relatively short time to a hydrostatic equilibrium in which energy released by the core prevents further gravitational collapse. The star thus evolves rapidly to a stable state.

New stars come in a variety of sizes and colors. They range in spectral type from hot and blue to cool and red, and in mass from less than 0.5 to more than 20 solar masses. The brightness and color of a star depend on its surface temperature, which in turn depends on its mass.

A new star will fall at a specific point on the main sequence of the Hertzsprung-Russell diagram. Small, cool red dwarfs burn hydrogen slowly and may remain on the main sequence for hundreds of billions of years, while massive hot supergiants will leave the main sequence after just a few million years. A mid-sized star like the Sun will remain on the main sequence for about 10 billion years. The Sun is thought to be in the middle of its lifespan; thus, it is on the main sequence. Once a star expends most of the hydrogen in its core, it moves off the main sequence.

**Maturity**After millions to billions of years, depending on its initial mass, the continuous fusion of hydrogen into helium will cause a build-up of helium in the core.

The later years and death of stars:

**Low-mass star** Some stars may fuse helium in core hot-spots, causing an unstable and uneven reaction as well as a heavy solar wind. In this case, the star will form no planetary nebula but simply evaporate, leaving little more than a brown dwarf. But a star of less than about 0.5 solar mass will never be able to fuse helium even after the core ceases hydrogen fusion. There simply is not a stellar envelope massive enough to bear down

enough pressure on the core. These are the red dwarfs, such as Proxima Centauri, some of which will live thousands of times longer than the Sun. Recent astrophysical models suggest that red dwarfs of 0.1 solar masses may stay on the main sequence for almost six trillion years, and take several hundred billion more to slowly collapse into a white dwarf. (S&T, 22)

**Mid-sized stars** Once a medium-size star (between 0.4 and 3.4 solar masses) has reached the red giant phase, its outer layers continue to expand, the core contracts inward, and helium begins to fuse into carbon. In stars of less than 1.4 solar masses, the helium fusion process begins with an explosive burst of energy generation known as a helium flash.

Helium burning reactions are extremely sensitive to temperature, which causes great instability. Huge pulsations build up, which eventually give the outer layers of the star enough kinetic energy to be ejected as a planetary nebula. At the center of the nebula remains the core of the star, which cools down to become a small but dense white dwarf, typically weighing about 0.6 solar masses, but only the volume of the Earth.

**White dwarfs** -White dwarfs are stable because the inward pull of gravity is balanced by the degeneracy pressure of the star's electrons. (This is a consequence of the Pauli exclusion principle.) With no fuel left to burn, the star radiates its remaining heat into space for thousands of millions of years. In the end, all that remains is a cold dark mass sometimes called a black dwarf. However, the universe is not old enough for any black dwarf stars to exist.

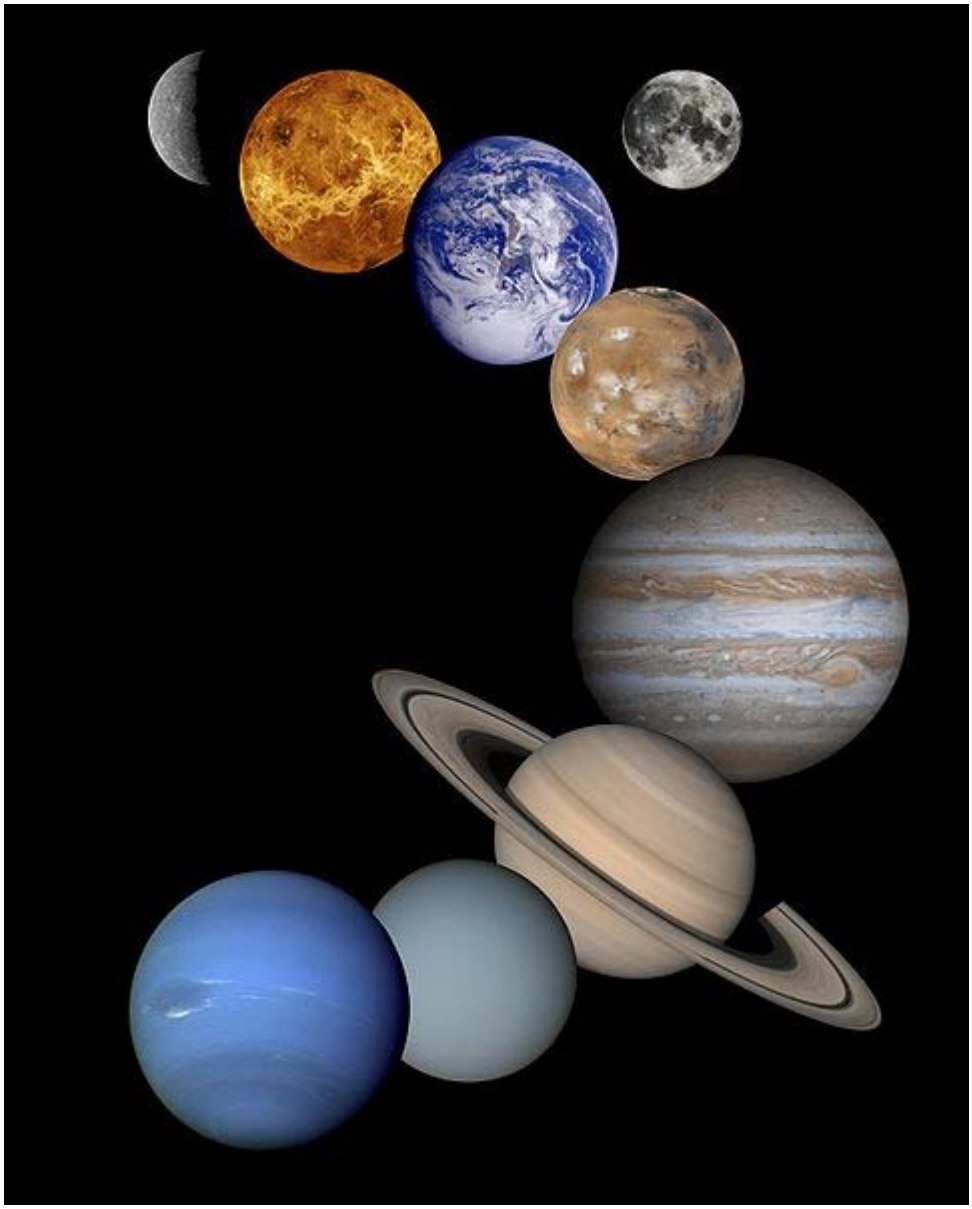
**Supermassive stars** After the outer layers of a star greater than five solar masses have swollen into a gigantic red supergiant, the core begins to yield to gravity and starts to shrink. As it shrinks, it grows hotter and denser, and a new series of nuclear reactions begin to occur. These reactions fuse progressively heavier elements, temporarily halting the collapse of the core.

**Neutron stars**

It is known that in some supernovae, the intense gravity inside the supergiant forces the electrons into the atomic nuclei, where they combine with the protons to form neutrons. The electromagnetic forces keeping separate nuclei apart are gone (proportionally, if nuclei were the size of dust motes, atoms would be as large as football stadiums), and the entire core of the star becomes nothing but a dense ball of contiguous neutrons or a single atomic nucleus.

**Black holes** - It is widely believed that not all supernovae form neutron stars. If the stellar mass is high enough, the neutrons themselves will be crushed and the star will collapse until its radius is smaller than the Schwarzschild radius. The star has then become a black hole.

# Non-Earth planetary science



Solar System Planets.

**Planetary Processes, General** includes Planetary science, Planets, Extrasolar Planet, Dwarf Planets, Comets, Asteroids and others.

**Geophysics** is the study of the Earth by quantitative physical methods, especially by seismic, electromagnetic, and radioactivity methods, therefore **Planetary Geophysics** is the study of the planets by quantitative physical methods, especially by seismic, electromagnetic, and radioactivity methods. It includes the branches of: Seismology (earthquakes and elastic waves), planetary gravity, geodesy, Tectonophysics (geological processes in the planets), Mineral Physics and others. Geophysics can be both a part of physics and a part of Geology.

**Geodesy of The Solar System**, also called **geodetics** of the solar system, is the scientific discipline that deals with the measurement and representation of the planets of the Solar System, their gravitational fields and geodynamic phenomena (polar motion in three-dimensional, time-varying space. The science of geodesy has elements of both astrophysics and planetary sciences. The shape of the Earth is to a large extent the result of its rotation, which causes its equatorial bulge, and the competition of geologic processes such as the collision of plates and of vulcanism, resisted by the Earth's gravity field. These principles can be applied to the solid surface of Earth (orogeny; Few mountains are higher than 10 km, few deep sea trenches deeper than that because quite simply, a mountain as tall as, for example, 15 km, would develop so much pressure at its base, due to gravity, that the rock there would become plastic, and the mountain would slump back to a height of roughly 10 km in a geologically insignificant time. Some or all of these geologic principles can be applied to other planets besides Earth. For instance on Mars, whose surface gravity is much less, the largest volcano, Olympus Mons, is 27 km high at its peak, a height that could not be maintained on Earth. The Earth geoid is essentially the figure of the Earth abstracted from its topographic features. Therefore the Mars geoid is essentially the figure of Mars abstracted from its topographic features. Surveying and mapping are two important fields of application of geodesy.

Physics is the underlying physical science of any planet, yet many aspects of planets are not best described through their physics. **Planetary science** is the general term for ALL physical sciences that can be applied to planets in the Universe or else to a particular planet. **Planetary science of the Earth** is the overall physical science containing all the physical sciences related directly to our Earth. Planetary Science can be broadly divided into several major sciences: Geology, Oceanography and Atmospheres.

**Geology of Solar System Planets** contains Geology of Mercury, Geology of Venus, Geology of the Moon, Geology of Mars, Geology of Jupiter, Geology of Saturn, Geology of Uranus Geology of Neptune, Geology of Pluto

**Geology of Other Planets** Planetary geology (sometimes known as Astrogeology) refers to the application of geologic principles to other bodies of the solar system. However, specialised terms such as *selenology* (studies of the Moon), *areology* (of Mars), etc., are also in use. Most of the geological sciences related to the Earth can be directly applied to the study of non-Earth planets: **Geology Fields or related disciplines** Structural geology, Geomorphology., Economic geology, Mining geology, Geodetics, Geomorphology, Geophysics, Historical geology, Hydrogeology or geohydrology, Mineralogy, Paleoclimatology, Sedimentology, Seismology, Stratigraphy, Structural geology, Volcanology,**Hydrology**. Geothermometry (heating of the earth, heat flow, volcanology, and hot springs), Hydrology (ground and surface water, sometimes including glaciology).

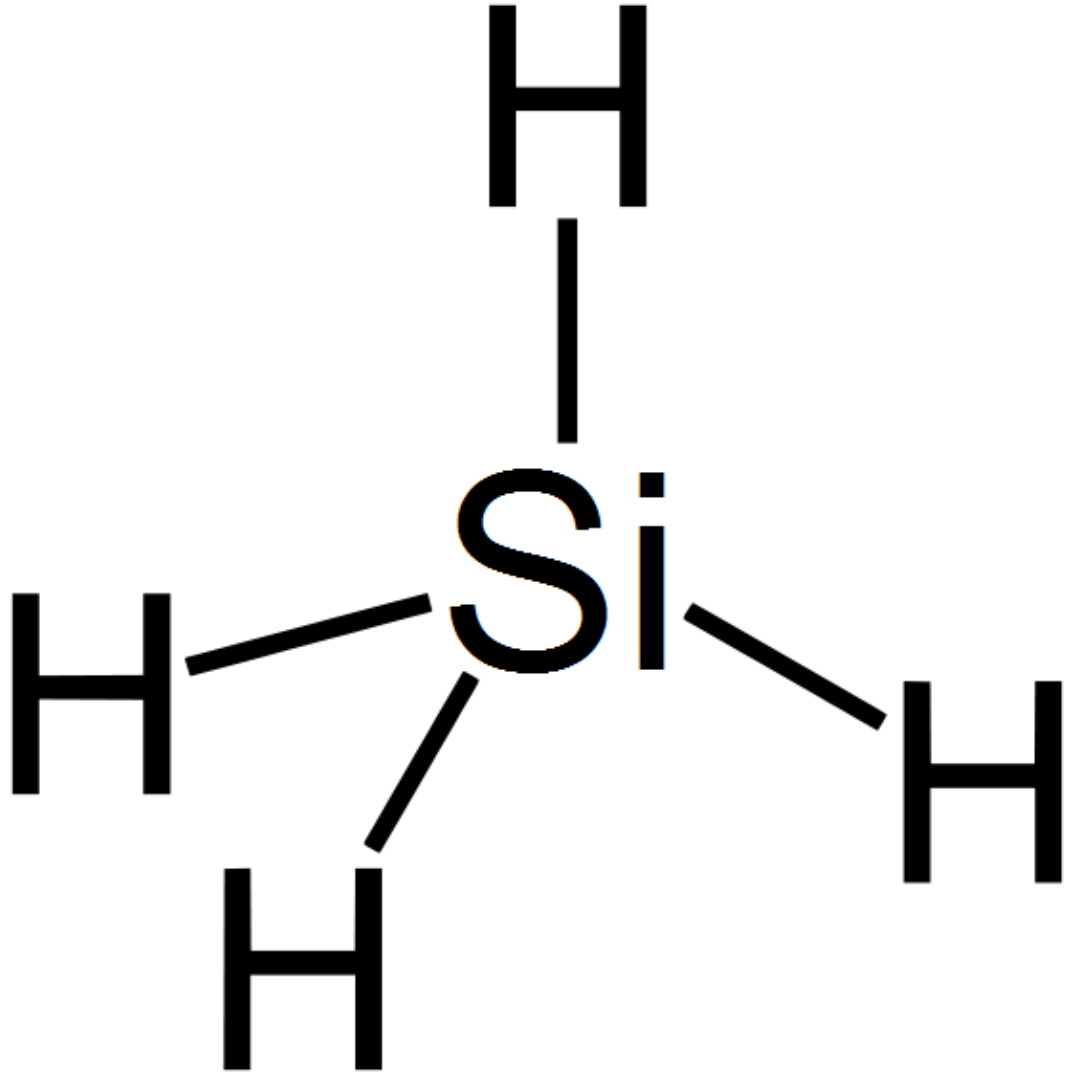
**Extrasolar Geology** is currently a young science because only recently have extrasolar planets been found.

**Atmospheres of Solar System Planets** refers to the application of meteorological principles to other bodies of the solar system including the application of: Atmospheric

electricity and terrestrial magnetism (including ionosphere, Van Allen belts, telluric currents, Radiant energy, etc.), Meteorology and Climatology. Aeronomy the study of the physical structure and chemistry of the atmosphere.

**Atmospheres of Extrasolar Planets** is currently a young science because only recently have extrasolar planets been found. Astronomers are currently theorizing that the recently discovered extrasolar Jupiter-sized planets have continuous surface winds of many thousands of miles per hour caused by their highly elliptical orbit which brings them close to their parent star.

## Exobiology / Extraterrestrial life




Silicon Based Life. A picture of silane, the silicon-based analogue of methane.

Earth telescopes can resolve some surface features of the nearby planets and so far, no life can be seen through the telescopes. However, Earth telescopes cannot resolve the surface features of any planet outside the solar system, so the search for life on other planets continues. While no incontestable evidence has been found for life outside of Earth, the scientific study of the theoretical basis for life on other bodies is progressing. Some scientists are trying to theorize which kinds of stars would have planets that hold life. Because life has overall fragile parameters for survival the general consensus is that only older stars would have planets circling them with life. From this they theorize which sections of our Milky Way Galaxy would most likely hold life. Other scientists theorize the quantity of civilizations that might exist in a galaxy and others are actually listening for the possible radio chatter of extraterrestrial technical civilizations. These sub-sciences of exobilogy can be categorized as follows:

**Habitable Zone Astrobiology** is discussed in Galactic Habitable Zone and Solar System Habitable Zone.

**Astrobiochemistry** Exogenesis Most scientists hold that if extraterrestrial life exists, its evolution would have occurred independently in different places in the universe. An alternative hypothesis, held by a minority, is panspermia, which suggests that life in the universe could have stemmed from a smaller number of points of origin, and then spread across the universe, from habitable planet to habitable planet. These two hypotheses are not mutually exclusive. **Alternative biochemistry** includes **Alternative Carbon Biochemistry** where water is not the Solvent of Carbon Chains: Life forms based in ammonia rather than water are also considered, though this solution appears less optimal than water. Also included is **Alternative Non-Carbon Biochemistry**: Non-carbon based chemistry Silicon is usually considered the most likely alternative to carbon, though this remains improbable. Silicon life forms are proposed to have a crystalline morphology, and are theorized to be able to exist in high temperatures, such as planets closer to the sun.

**Astrobiosphere** is the entire area of a planet that supports life and includes Biosphere, Theory of Biosphere, Planetary Habitability Extrasolar planets Astronomers also search for extrasolar planets that would be conducive to life, especially those like OGLE-2005-BLG-390Lb which have been found to have Earth-like qualities.

**Plants On Other Planets** includes Extremophiles, Theoretical Astrobotany, Life On Jupiter, Life on Mars scientific theory, Independently in 1996 structures resembling bacteria were reportedly discovered in a meteorite, ALH84001, thought to be formed of rock ejected from Mars. This report is also controversial and scientific debate continues.

**Humanoids-On-Other-Planets** includes Humanoids-On-Other-Planets Origins-Speculations And Scientific Theory Panspermia. Extraterrestrial life along with the biochemical basis of extraterrestrial life, there remains a broader consideration of evolution and morphology.

**Humanoids-On-Other-Planets Technical Civilizations** includes Humanoids-On-Other-Planets Technical-Civilizations, Speculation And Theory.

**Humanoids-On-Other-Planets Technical-Civilizations, Migrations** Most scientists hold that if extraterrestrial life exists, its evolution would have occurred independently in different places in the universe. An alternative hypothesis, held by a minority, is panspermia, which suggests that life in the universe could have stemmed from a smaller number of points of origin, and then spread across the universe, from habitable planet to habitable planet.

**Humanoids-On-Other-Planets Technical-Civilizations, Quantity of** Drake Equation

**Humanoids-On-Other-Planets-Civilizations On Local Stars** includes Search For Humanoids-On-Other-Planets-Civilizations On Local-Stars, SETI

# Space exploration through space travel

Orion approaching the ISS.

Astronomy is exploration of space through instruments based on Earth. Space Exploration through space travel is exploration of space by travel through it, either in person or by drone. Closely associated with Space travel is Space Station, either manned or unmanned. All man-made satellites are a form of unmanned or manned space stations.

**Unmanned Space travel** includes the sciences of Spacecraft Propulsion, Rocket launch technology, Rocket, Astrodynamics, Unmanned space missions, and others.

**Manned Space travel** further includes the sciences of Microgravity environment, Space transport, Manned space missions, Interplanetary travel, Interstellar travel and Generation ship.

## Unmanned space station

There are Astronomical satellites, Biosatellites, Communications satellites, Miniaturized satellites, Navigation satellites, Reconnaissance satellites, Earth observation satellites, Earth observation satellites and others. There are many different kinds of orbits possible for these devices.

**Manned Space Station** includes the sciences of Space Station and Floating cities.

## Space colonization

Space colonization is a colossal science that includes all of the scientific disciplines needed to be able to build colonies on non-Earth planets and planetoids.

**Space Colonization Justification** includes the sciences of Space and survival.

**Space Colony Research And Development** Man can practice living on other worlds by building permanently inhabitable cities in extremely hostile environments of the Earth: The poles and the deserts. This is discussed in the Biosphere 2 and BIOS-3. Currently manned Earth hostile-environment stations include Amundsen-Scott South Pole Station, Devon Island, Mars Arctic Research Station, Mars Desert Research Station, climate, underwater structures for planets with oceans or very heavy atmospheres and others.

**Space Colony Location** is the science of figuring out the best planets and the best locations on those planets for colonization. Because water is such a necessity for human survival most searches are for locations close to some kind of water. These issues and other related issues are discussed in the Colonization of Mars, Mars Society, Colonization of Mercury, Colonization of Venus, Venusian terraforming, Colonization of the Moon, Artemis Project, Europa, Phobos, Colonization of the asteroids and others.

**Space Colonization Habitat** science includes Space habitat, Human adaptation to space, Manmade closed ecological system, Planetary habitability, Domed city, Ocean

colonization, Underground city and other sub-sciences. Further reading is available at Space Industrialization Dewy 629.44.

**Space Colonization Health** (Space Medicine Dewey 616.9)

**Space Colonization Agriculture** includes Biosphere 2 and BIOS-3 and others.

**Space Colonization Food Processing** includes Space food and others.

**Space Colonization Housing** includes International Space Station.

**Space Colonization Clothing** includes Space suits

**Space Colonization Construction** includes Orbital Megastructures, station-keeping, Amundsen-Scott South Pole Station, Devon Island, Mars Arctic Research Station, Mars Desert Research Station, climate, underwater structures for planets with oceans or very heavy atmospheres and others.

**Space Colonization Transportation** includes Lunar rover

**Space Colonization Materials** includes Recycling

**Space Colonization Energy** includes Renewable energy

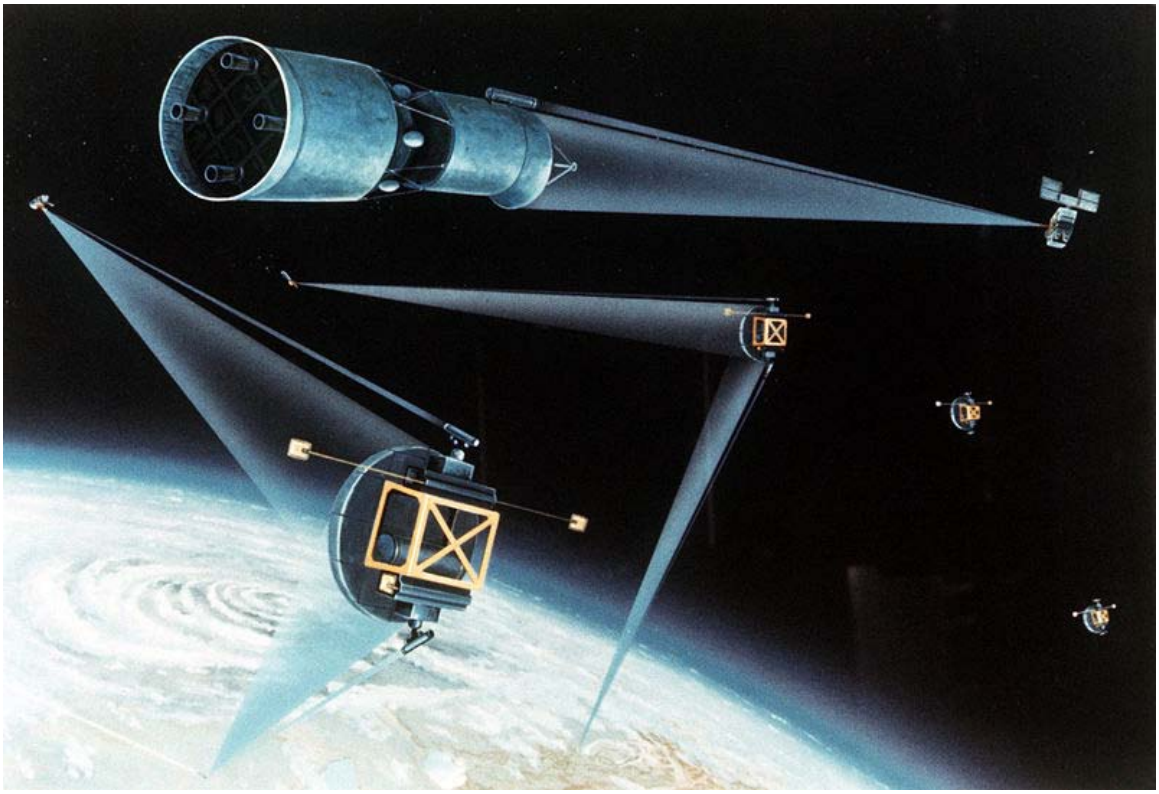
**Space Colonization General Manufacturing** includes Space Manufacturing

**Space Colonization Economics** includes Space Frontier Foundation , Private spaceflight and space tourism, solar power satellites, Asteroid mining, space manufacturing,

**Space Colonization Operations** includes space agencies, Space advocacy, Colonize the Cosmos, Artemis Project , National Space Society, Planetary Society, robotic exploration , search for extraterrestrial life, Space Settlement Institute, Students for the Exploration and Development of Space, NASA, ESA, Project Constellation

'*Space Colonization Law and Protection* includes Space Law

# Space defense

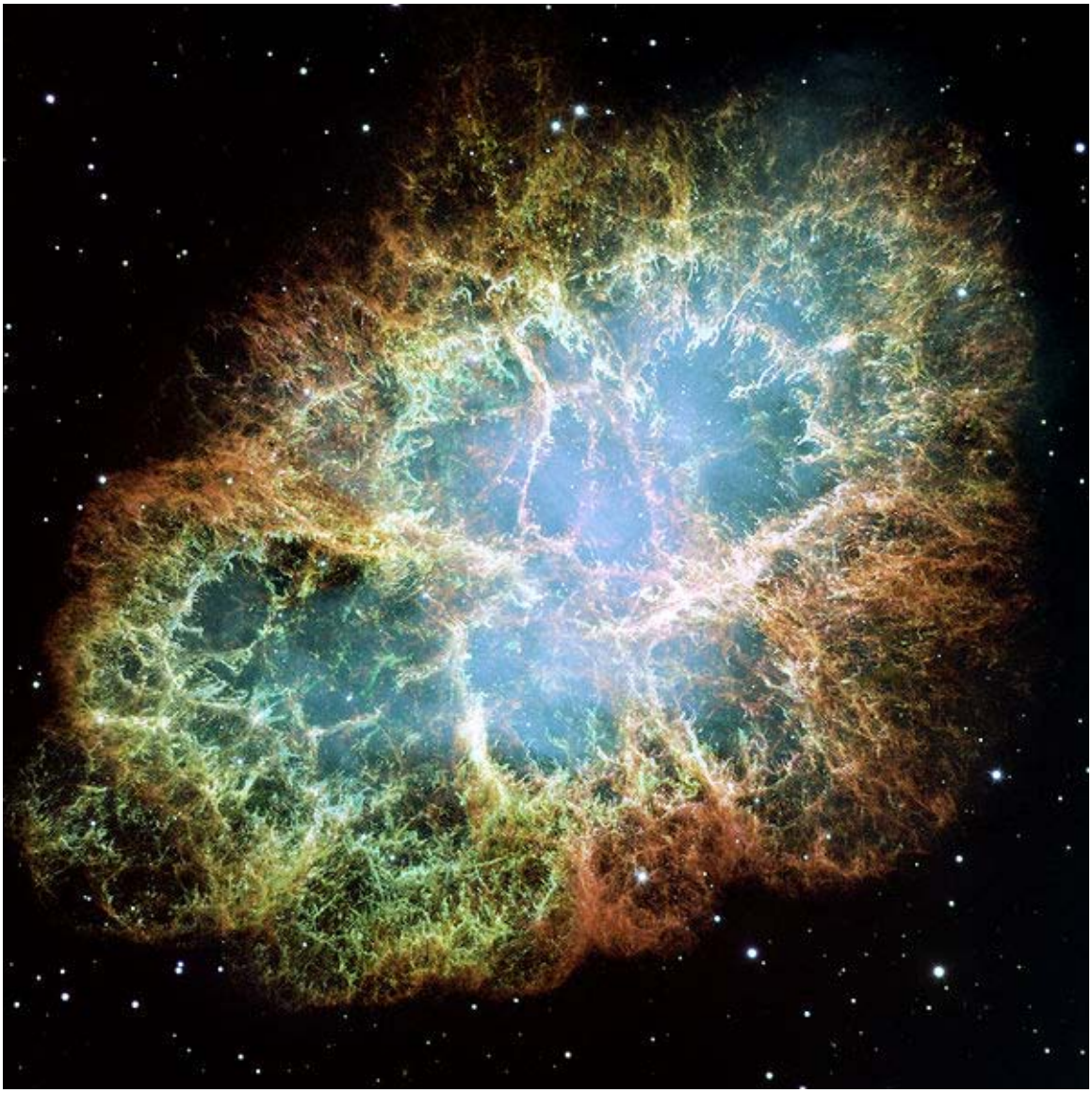


Space Lasers.

Space Defense is the science of defending the Earth from natural or unnatural threats from Space. Natural threats include Near Earth Asteroids and similar. Other issues are discussed in Missile Defense Command, United States Army Space and Missile Defense Command, Department of Defense Manned Space Flight Support Office, European Aeronautic Defense & Space and Joint Defense Space Research Facility.

**Chapter- 2**

# Astronomy



A giant Hubble mosaic of the Crab Nebula, a supernova remnant

**Astronomy** is a natural science that deals with the study of celestial objects (such as stars, planets, comets, nebulae, star clusters and galaxies) and phenomena that originate outside the Earth's atmosphere (such as the cosmic background radiation). It is concerned with the evolution, physics, chemistry, meteorology, and motion of celestial objects, as well as the formation and development of the universe.

Astronomy is one of the oldest sciences. Prehistoric cultures left behind astronomical artifacts such as the Egyptian monuments and Stonehenge, and early civilizations such as the Babylonians, Greeks, Chinese, Indians, and Maya performed methodical observations of the night sky. However, the invention of the telescope was required before astronomy was able to develop into a modern science. Historically, astronomy has included disciplines as diverse as astrometry, celestial navigation, observational astronomy, the making of calendars, and even astrology, but professional astronomy is nowadays often considered to be synonymous with astrophysics.

During the 20th century, the field of professional astronomy split into observational and theoretical branches. Observational astronomy is focused on acquiring data from observations of celestial objects, which is then analyzed using basic principles of physics. Theoretical astronomy is oriented towards the development of computer or analytical models to describe astronomical objects and phenomena. The two fields complement each other, with theoretical astronomy seeking to explain the observational results, and observations being used to confirm theoretical results.

Amateur astronomers have contributed to many important astronomical discoveries, and astronomy is one of the few sciences where amateurs can still play an active role, especially in the discovery and observation of transient phenomena.

Ancient astronomy is not to be confused with astrology, the belief system which claims that human affairs are correlated with the positions of celestial objects. Although the two fields share a common origin and a part of their methods (namely, the use of ephemerides), they are distinct.

# Lexicology

The word *astronomy* (from the Greek words *astron* (*ἄστρον*), "star" and -nomy from *nomos* (*νόμος*), "law" or "culture") literally means "law of the stars" (or "culture of the stars" depending on the translation).

### Use of terms "astronomy" and "astrophysics"

Generally, either the term "astronomy" or "astrophysics" may be used to refer to this subject. Based on strict dictionary definitions, "astronomy" refers to "the study of objects and matter outside the Earth's atmosphere and of their physical and chemical properties" and "astrophysics" refers to the branch of astronomy dealing with "the behavior, physical properties, and dynamic processes of celestial objects and phenomena". In some cases, as in the introduction of the introductory textbook *The*

*Physical Universe* by Frank Shu, "astronomy" may be used to describe the qualitative study of the subject, whereas "astrophysics" is used to describe the physics-oriented version of the subject. However, since most modern astronomical research deals with subjects related to physics, modern astronomy could actually be called astrophysics. Various departments that research this subject may use "astronomy" and "astrophysics", partly depending on whether the department is historically affiliated with a physics department, and many professional astronomers actually have physics degrees. One of the leading scientific journals in the field is named Astronomy and Astrophysics.

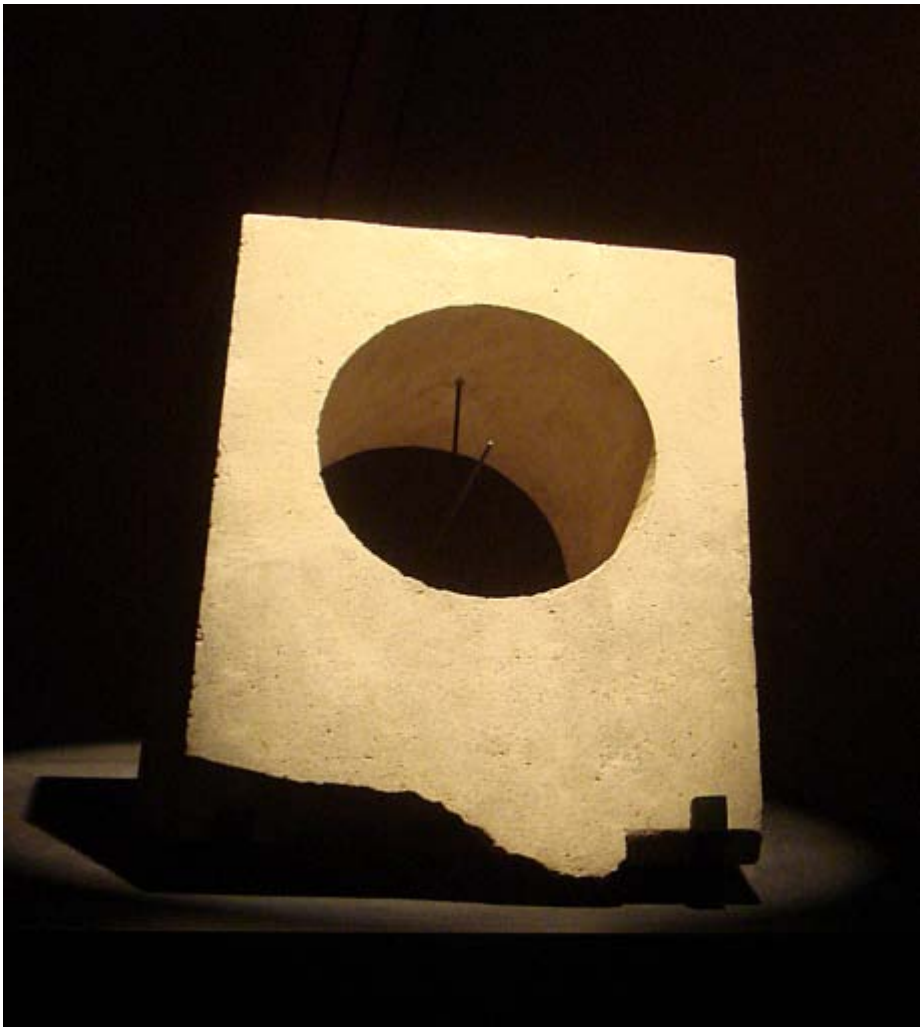
# History

A celestial map from the 17th century, by the Dutch cartographer Frederik de Wit.

In early times, astronomy only comprised the observation and predictions of the motions of objects visible to the naked eye. In some locations, such as Stonehenge, early cultures assembled massive artifacts that likely had some astronomical purpose. In addition to their ceremonial uses, these observatories could be employed to determine the seasons, an important factor in knowing when to plant crops, as well as in understanding the length of the year.

Before tools such as the telescope were invented early study of the stars had to be conducted from the only vantage points available, namely tall buildings and high ground using the naked eye. As civilizations developed, most notably in Mesopotamia, China, Egypt, Greece, India, and Central America, astronomical observatories were assembled, and ideas on the nature of the universe began to be explored. Most of early astronomy actually consisted of mapping the positions of the stars and planets, a science now referred to as astrometry. From these observations, early ideas about the motions of the planets were formed, and the nature of the Sun, Moon and the Earth in the universe were explored philosophically. The Earth was believed to be the center of the universe with the Sun, the Moon and the stars rotating around it. This is known as the geocentric model of the universe.

A particularly important early development was the beginning of mathematical and scientific astronomy, which began among the Babylonians, who laid the foundations for the later astronomical traditions that developed in many other civilizations. The Babylonians discovered that lunar eclipses recurred in a repeating cycle known as a saros.

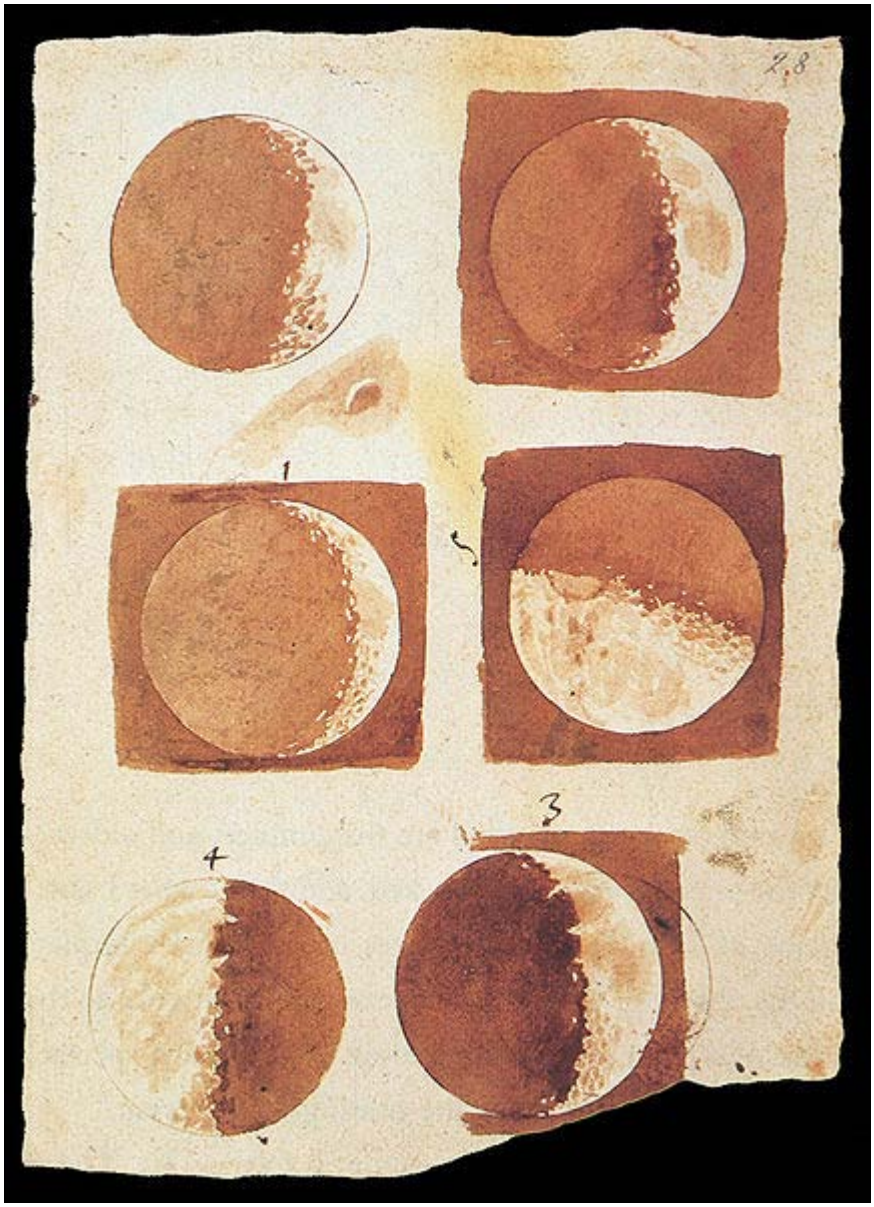


Greek equatorial sun dial, Alexandria on the Oxus, present-day Afghanistan 3rd-2nd century BCE.

Following the Babylonians, significant advances in astronomy were made in ancient Greece and the Hellenistic world. Greek astronomy is characterized from the start by seeking a rational, physical explanation for celestial phenomena. In the 3rd century BC, Aristarchus of Samos calculated the size of the Earth, and measured the size and distance of the Moon and Sun, and was the first to propose a heliocentric model of the solar system. In the 2nd century BC, Hipparchus discovered precession, calculated the size and distance of the Moon and invented the earliest known astronomical devices such as the astrolabe. Hipparchus also created a comprehensive catalog of 1020 stars, and most of the constellations of the northern hemisphere derive are taken from Greek astronomy. The Antikythera mechanism (c. 150–80 BC) was an early analog computer designed to calculating the location of the Sun, Moon, and planets for a given date. Technological artifacts of similar complexity did not reappear until the 14th century, when mechanical astronomical clocks appeared in Europe.

During the Middle Ages, astronomy was mostly stagnant in medieval Europe, at least until the 13th century. However, astronomy flourished in the Islamic world and other parts of the world. This led to the emergence of the first astronomical observatories in the Muslim world by the early 9th century. In 964, the Andromeda Galaxy, the nearest galaxy to the Milky Way, was discovered by the Persian astronomer Azophi and first described in his *Book of Fixed Stars*. The SN 1006 supernova, the brightest apparent magnitude stellar event in recorded history, was observed by the Egyptian Arabic astronomer Ali ibn Ridwan and the Chinese astronomers in 1006. Some of the prominent Islamic (mostly Persian and Arab) astronomers who made significant contributions to the science include Al-Battani, Thebit, Azophi, Albumasar, Biruni, Arzachel, Al-Birjandi, and the astronomers of the Maragheh and Samarkand observatories. Astronomers during that time introduced many Arabic names now used for individual stars. It is also believed that the ruins at Great Zimbabwe and Timbuktu may have housed an astronomical observatory. Europeans had previously believed that there had been no astronomical observation in pre-colonial Middle Ages sub-Saharan Africa but modern discoveries show otherwise.

## Scientific revolution




Galileo's sketches and observations of the Moon revealed that the surface was mountainous.

During the Renaissance, Nicolaus Copernicus proposed a heliocentric model of the solar system. His work was defended, expanded upon, and corrected by Galileo Galilei and Johannes Kepler. Galileo innovated by using telescopes to enhance his observations.

Kepler was the first to devise a system that described correctly the details of the motion of the planets with the Sun at the center. However, Kepler did not succeed in formulating a theory behind the laws he wrote down. It was left to Newton's invention of celestial dynamics and his law of gravitation to finally explain the motions of the planets. Newton also developed the reflecting telescope.

Further discoveries paralleled the improvements in the size and quality of the telescope. More extensive star catalogues were produced by Lacaille. The astronomer William Herschel made a detailed catalog of nebulosity and clusters, and in 1781 discovered the planet Uranus, the first new planet found. The distance to a star was first announced in 1838 when the parallax of 61 Cygni was measured by Friedrich Bessel.

During the 18–19th centuries, attention to the three body problem by Euler, Clairaut, and D'Alembert led to more accurate predictions about the motions of the Moon and planets. This work was further refined by Lagrange and Laplace, allowing the masses of the planets and moons to be estimated from their perturbations.

Significant advances in astronomy came about with the introduction of new technology, including the spectroscope and photography. Fraunhofer discovered about 600 bands in the spectrum of the Sun in 1814–15, which, in 1859, Kirchhoff ascribed to the presence of different elements. Stars were proven to be similar to the Earth's own Sun, but with a wide range of temperatures, masses, and sizes.

The existence of the Earth's galaxy, the Milky Way, as a separate group of stars, was only proved in the 20th century, along with the existence of "external" galaxies, and soon after, the expansion of the Universe, seen in the recession of most galaxies from us. Modern astronomy has also discovered many exotic objects such as quasars, pulsars, blazars, and radio galaxies, and has used these observations to develop physical theories which describe some of these objects in terms of equally exotic objects such as black holes and neutron stars. Physical cosmology made huge advances during the 20th century, with the model of the Big Bang heavily supported by the evidence provided by astronomy and physics, such as the cosmic microwave background radiation, Hubble's law, and cosmological abundances of elements.

# Observational astronomy

The Very Large Array in New Mexico, an example of a radio telescope

In astronomy, the main source of information about celestial bodies and other objects is the visible light or more generally electromagnetic radiation. Observational astronomy may be divided according to the observed region of the electromagnetic spectrum. Some parts of the spectrum can be observed from the Earth's surface, while other parts are only observable from either high altitudes or space. Specific information on these subfields is given below.

## Radio astronomy

Radio astronomy studies radiation with wavelengths greater than approximately one millimeter. Radio astronomy is different from most other forms of observational astronomy in that the observed radio waves can be treated as waves rather than as discrete photons. Hence, it is relatively easier to measure both the amplitude and phase of radio waves, whereas this is not as easily done at shorter wavelengths.

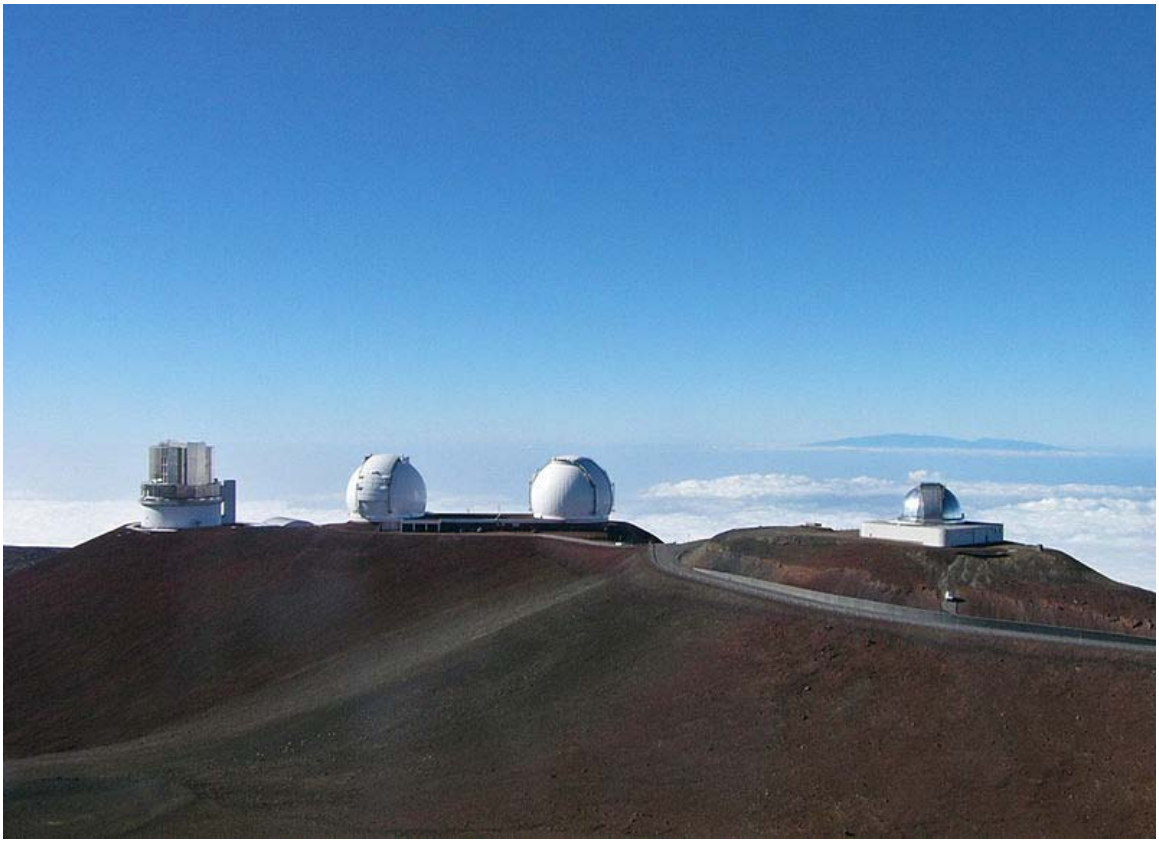
Although some radio waves are produced by astronomical objects in the form of thermal emission, most of the radio emission that is observed from Earth is seen in the form of synchrotron radiation, which is produced when electrons oscillate around magnetic fields. Additionally, a number of spectral lines produced by interstellar gas, notably the hydrogen spectral line at 21 cm, are observable at radio wavelengths.

A wide variety of objects are observable at radio wavelengths, including supernovae, interstellar gas, pulsars, and active galactic nuclei.

## Infrared astronomy

Infrared astronomy deals with the detection and analysis of infrared radiation (wavelengths longer than red light). Except at wavelengths close to visible light, infrared radiation is heavily absorbed by the atmosphere, and the atmosphere produces significant infrared emission. Consequently, infrared observatories have to be located in high, dry places or in space. The infrared spectrum is useful for studying objects that are too cold to radiate visible light, such as planets and circumstellar disks. Longer infrared wavelengths can also penetrate clouds of dust that block visible light, allowing observation of young stars in molecular clouds and the cores of galaxies. Some molecules radiate strongly in the infrared. This can be used to study chemistry in space; more specifically it can detect water in comets.

## Optical astronomy



The Subaru Telescope (left) and Keck Observatory (center) on Mauna Kea, both examples of an observatory that operates at near-infrared and visible wavelengths. The NASA Infrared Telescope Facility (right) is an example of a telescope that operates only at near-infrared wavelengths.

Historically, optical astronomy, also called visible light astronomy, is the oldest form of astronomy. Optical images were originally drawn by hand. In the late 19th century and most of the 20th century, images were made using photographic equipment. Modern images are made using digital detectors, particularly detectors using charge-coupled devices (CCDs). Although visible light itself extends from approximately 4000 Å to 7000 Å (400 nm to 700 nm), the same equipment used at these wavelengths is also used to observe some near-ultraviolet and near-infrared radiation.

## Ultraviolet astronomy

Ultraviolet astronomy is generally used to refer to observations at ultraviolet wavelengths between approximately 100 and 3200 Å (10 to 320 nm). Light at these wavelengths is absorbed by the Earth's atmosphere, so observations at these wavelengths must be performed from the upper atmosphere or from space. Ultraviolet astronomy is best suited to the study of thermal radiation and spectral emission lines from hot blue stars (OB stars) that are very bright in this wave band. This includes the blue stars in other galaxies, which have been the targets of several ultraviolet surveys. Other objects commonly observed in ultraviolet light include planetary nebulae, supernova remnants, and active galactic nuclei. However, as ultraviolet light is easily absorbed by interstellar dust, an appropriate adjustment of ultraviolet measurements is necessary.

## X-ray astronomy

X-ray astronomy is the study of astronomical objects at X-ray wavelengths. Typically, objects emit X-ray radiation as synchrotron emission (produced by electrons oscillating around magnetic field lines), thermal emission from thin gases above $10^7$ (10 million) kelvins, and thermal emission from thick gases above $10^7$ Kelvin. Since X-rays are absorbed by the Earth's atmosphere, all X-ray observations must be performed from high-altitude balloons, rockets, or spacecraft. Notable X-ray sources include X-ray binaries, pulsars, supernova remnants, elliptical galaxies, clusters of galaxies, and active galactic nuclei.

According to NASA's official website, X-rays were first observed and documented in 1895 by Wilhelm Conrad Röntgen, a German scientist who found them quite by accident when experimenting with vacuum tubes. Through a series of experiments, including the infamous X-ray photograph he took of his wife's hand with a wedding ring on it, Röntgen was able to discover the beginning elements of radiation. The "X", in fact, holds its own significance, as it represents Röntgen's inability to identify exactly what type of radiation it was.

Furthermore, according to the website, in some German speaking countries, X-rays are still sometimes referred to as Röntgen rays, in honor of the man who discovered them.

## Gamma-ray astronomy

Gamma ray astronomy is the study of astronomical objects at the shortest wavelengths of the electromagnetic spectrum. Gamma rays may be observed directly by satellites such as the Compton Gamma Ray Observatory or by specialized telescopes called atmospheric Cherenkov telescopes. The Cherenkov telescopes do not actually detect the gamma rays directly but instead detect the flashes of visible light produced when gamma rays are absorbed by the Earth's atmosphere.

Most gamma-ray emitting sources are actually gamma-ray bursts, objects which only produce gamma radiation for a few milliseconds to thousands of seconds before fading away. Only 10% of gamma-ray sources are non-transient sources. These steady gamma-ray emitters include pulsars, neutron stars, and black hole candidates such as active galactic nuclei.

## Fields not based on the electromagnetic spectrum

In addition to electromagnetic radiation, a few other events originating from great distances may be observed from the Earth.

In neutrino astronomy, astronomers use special underground facilities such as SAGE, GALLEX, and Kamioka II/III for detecting neutrinos. These neutrinos originate primarily from the Sun but also from supernovae. Cosmic rays, which consist of very high energy particles that can decay or be absorbed when they enter the Earth's atmosphere, result in a cascade of particles which can be detected by current observatories. Additionally, some future neutrino detectors may also be sensitive to the particles produced when cosmic rays hit the Earth's atmosphere. Gravitational wave astronomy is an emerging new field of astronomy which aims to use gravitational wave detectors to collect observational data about compact objects. A few observatories have been constructed, such as the *Laser Interferometer Gravitational Observatory* LIGO, but gravitational waves are extremely difficult to detect.

Planetary astronomers have directly observed many of these phenomena through spacecraft and sample return missions. These observations include fly-by missions with remote sensors, landing vehicles that can perform experiments on the surface materials, impactors that allow remote sensing of buried material, and sample return missions that allow direct laboratory examination.

## Astrometry and celestial mechanics

One of the oldest fields in astronomy, and in all of science, is the measurement of the positions of celestial objects. Historically, accurate knowledge of the positions of the Sun, Moon, planets and stars has been essential in celestial navigation and in the making of calendars.

Careful measurement of the positions of the planets has led to a solid understanding of gravitational perturbations, and an ability to determine past and future positions of the planets with great accuracy, a field known as celestial mechanics. More recently the

tracking of near-Earth objects will allow for predictions of close encounters, and potential collisions, with the Earth.

The measurement of stellar parallax of nearby stars provides a fundamental baseline in the cosmic distance ladder that is used to measure the scale of the universe. Parallax measurements of nearby stars provide an absolute baseline for the properties of more distant stars, because their properties can be compared. Measurements of radial velocity and proper motion show the kinematics of these systems through the Milky Way galaxy. Astrometric results are also used to measure the distribution of dark matter in the galaxy.

During the 1990s, the astrometric technique of measuring the stellar wobble was used to detect large extrasolar planets orbiting nearby stars.

# Theoretical astronomy

Theoretical astronomers use a wide variety of tools which include analytical models (for example, polytropes to approximate the behaviors of a star) and computational numerical simulations. Each has some advantages. Analytical models of a process are generally better for giving insight into the heart of what is going on. Numerical models can reveal the existence of phenomena and effects that would otherwise not be seen.

Theorists in astronomy endeavor to create theoretical models and figure out the observational consequences of those models. This helps observers look for data that can refute a model or help in choosing between several alternate or conflicting models.

Theorists also try to generate or modify models to take into account new data. In the case of an inconsistency, the general tendency is to try to make minimal modifications to the model to fit the data. In some cases, a large amount of inconsistent data over time may lead to total abandonment of a model.

Topics studied by theoretical astronomers include: stellar dynamics and evolution; galaxy formation; large-scale structure of matter in the Universe; origin of cosmic rays; general relativity and physical cosmology, including string cosmology and astroparticle physics. Astrophysical relativity serves as a tool to gauge the properties of large scale structures for which gravitation plays a significant role in physical phenomena investigated and as the basis for black hole (*astro*)physics and the study of gravitational waves.

Some widely accepted and studied theories and models in astronomy, now included in the Lambda-CDM model are the Big Bang, Cosmic inflation, dark matter, and fundamental theories of physics.

A few examples of this process:

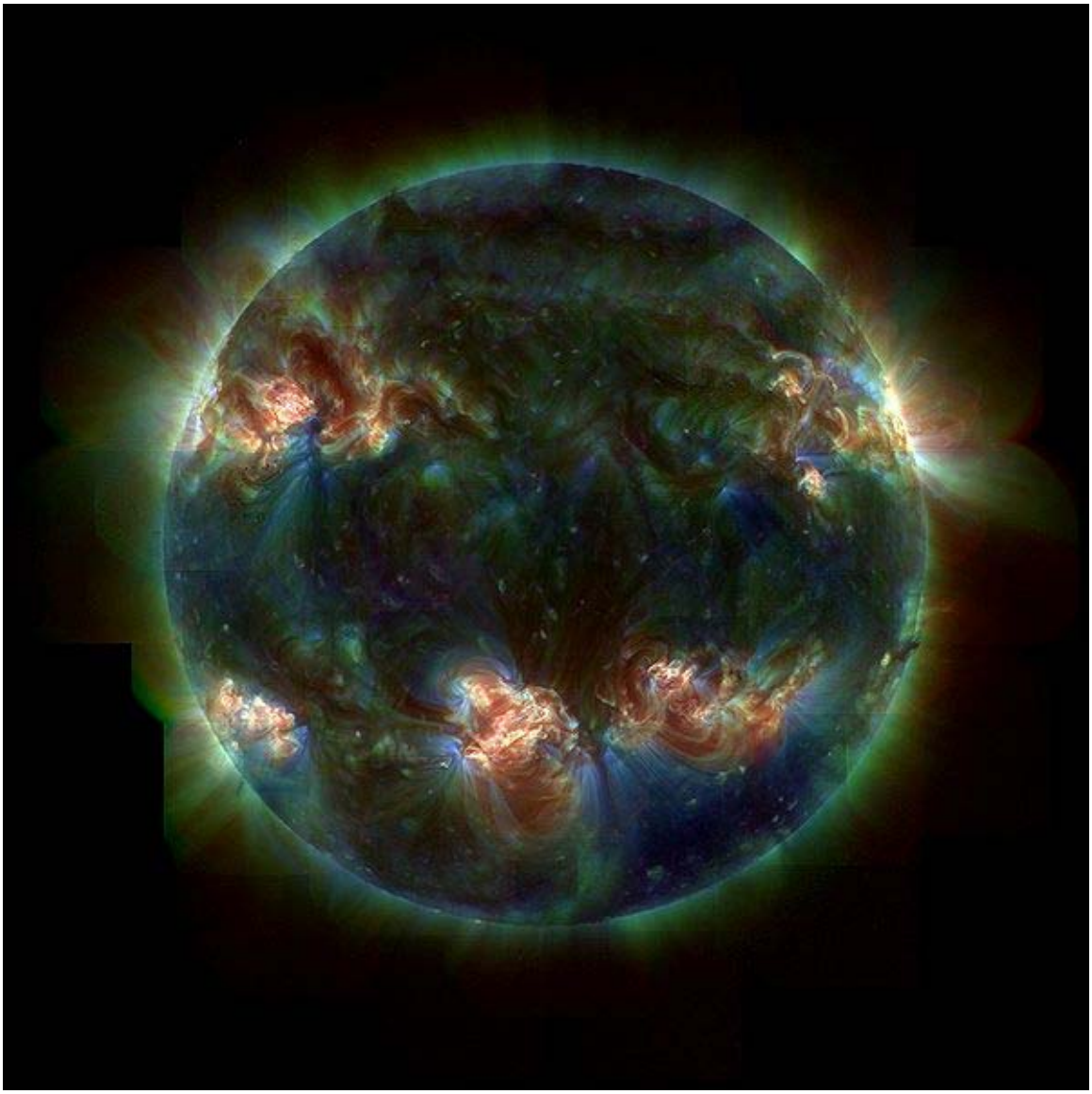
| **Physical process** | **Experimental tool** | **Theoretical model** | **Explains/predicts** |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Gravitation | Radio telescopes | Self-gravitating system | Emergence of a star system |
| Nuclear fusion | Spectroscopy | Stellar evolution | How the stars shine and how metals formed |
| The Big Bang | Hubble Space Telescope, COBE | Expanding universe | Age of the Universe |
| Quantum fluctuations | | Cosmic inflation | Flatness problem |
| Gravitational collapse | X-ray astronomy | General relativity | Black holes at the center of Andromeda galaxy |
| CNO cycle in stars | | | |

Dark matter and dark energy are the current leading topics in astronomy, as their discovery and controversy originated during the study of the galaxies.

# Specific subfields

### Solar astronomy



An ultraviolet image of the Sun's active photosphere as viewed by the TRACE space telescope.

At a distance of about eight light-minutes, the most frequently studied star is the Sun, a typical main-sequence dwarf star of stellar class G2 V, and about 4.6 Gyr in age. The Sun is not considered a variable star, but it does undergo periodic changes in activity known as the sunspot cycle. This is an 11-year fluctuation in sunspot numbers. Sunspots are regions of lower-than- average temperatures that are associated with intense magnetic activity.

The Sun has steadily increased in luminosity over the course of its life, increasing by 40% since it first became a main-sequence star. The Sun has also undergone periodic changes in luminosity that can have a significant impact on the Earth. The Maunder

minimum, for example, is believed to have caused the Little Ice Age phenomenon during the Middle Ages.

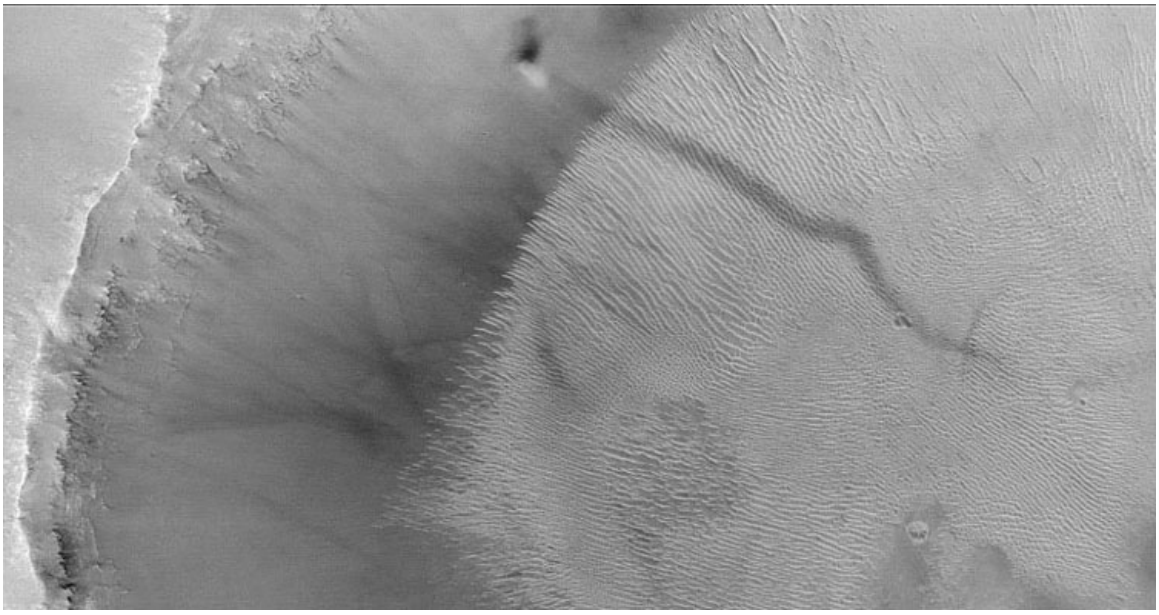
The visible outer surface of the Sun is called the photosphere. Above this layer is a thin region known as the chromosphere. This is surrounded by a transition region of rapidly increasing temperatures, then by the super-heated corona.

At the center of the Sun is the core region, a volume of sufficient temperature and pressure for nuclear fusion to occur. Above the core is the radiation zone, where the plasma conveys the energy flux by means of radiation. The outer layers form a convection zone where the gas material transports energy primarily through physical displacement of the gas. It is believed that this convection zone creates the magnetic activity that generates sun spots.

A solar wind of plasma particles constantly streams outward from the Sun until it reaches the heliopause. This solar wind interacts with the magnetosphere of the Earth to create the Van Allen radiation belts, as well as the aurora where the lines of the Earth's magnetic field descend into the atmosphere.

## Planetary science

This astronomical field examines the assemblage of planets, moons, dwarf planets, comets, asteroids, and other bodies orbiting the Sun, as well as extrasolar planets. The solar system has been relatively well-studied, initially through telescopes and then later by spacecraft. This has provided a good overall understanding of the formation and evolution of this planetary system, although many new discoveries are still being made.



The black spot at the top is a dust devil climbing a crater wall on Mars. This moving, swirling column of Martian atmosphere (comparable to a terrestrial tornado) created the long, dark streak.

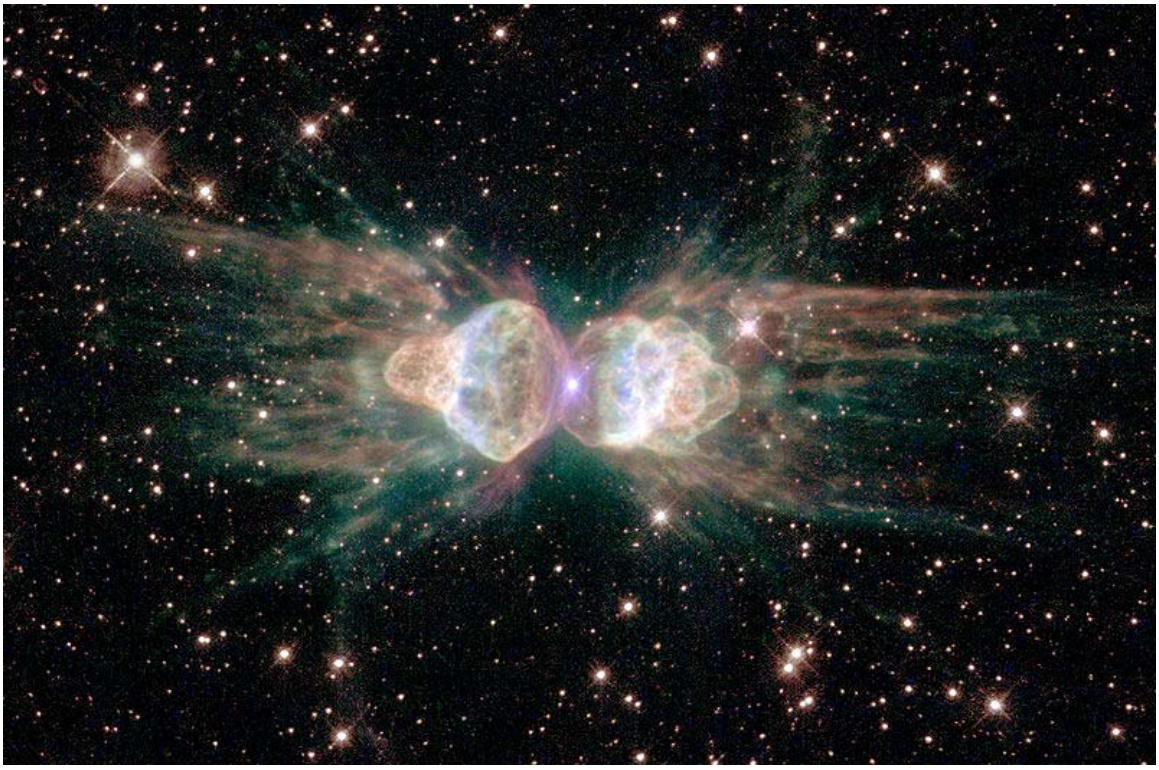
The solar system is subdivided into the inner planets, the asteroid belt, and the outer planets. The inner terrestrial planets consist of Mercury, Venus, Earth, and Mars. The outer gas giant planets are Jupiter, Saturn, Uranus, and Neptune. Beyond Neptune lies the Kuiper Belt, and finally the Oort Cloud, which may extend as far as a light-year.

The planets were formed in the protoplanetary disk that surrounded the early Sun. Through a process that included gravitational attraction, collision, and accretion, the disk formed clumps of matter that, with time, became protoplanets. The radiation pressure of the solar wind then expelled most of the unaccreted matter, and only those planets with sufficient mass retained their gaseous atmosphere. The planets continued to sweep up, or eject, the remaining matter during a period of intense bombardment, evidenced by the many impact craters on the Moon. During this period, some of the protoplanets may have collided, the leading hypothesis for how the Moon was formed.

Once a planet reaches sufficient mass, the materials with different densities segregate within, during planetary differentiation. This process can form a stony or metallic core, surrounded by a mantle and an outer surface. The core may include solid and liquid regions, and some planetary cores generate their own magnetic field, which can protect their atmospheres from solar wind stripping.

A planet or moon's interior heat is produced from the collisions that created the body, radioactive materials (*e.g.* uranium, thorium, and $^{26}Al$), or tidal heating. Some planets and moons accumulate enough heat to drive geologic processes such as volcanism and tectonics. Those that accumulate or retain an atmosphere can also undergo surface erosion from wind or water. Smaller bodies, without tidal heating, cool more quickly; and their geological activity ceases with the exception of impact cratering.

## Stellar astronomy



The Ant planetary nebula. Ejecting gas from the dying central star shows symmetrical patterns unlike the chaotic patterns of ordinary explosions.

The study of stars and stellar evolution is fundamental to our understanding of the universe. The astrophysics of stars has been determined through observation and theoretical understanding; and from computer simulations of the interior.

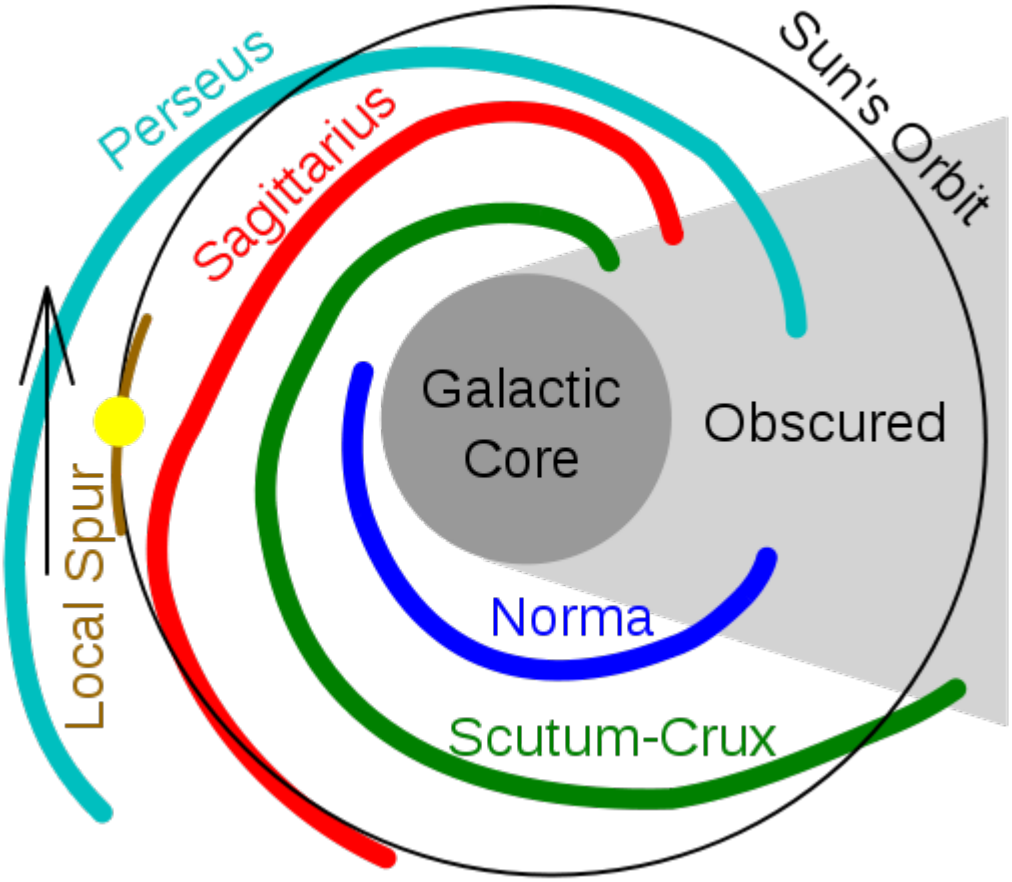
Star formation occurs in dense regions of dust and gas, known as giant molecular clouds. When destabilized, cloud fragments can collapse under the influence of gravity, to form a protostar. A sufficiently dense, and hot, core region will trigger nuclear fusion, thus creating a main-sequence star.

Almost all elements heavier than hydrogen and helium were created inside the cores of stars.

The characteristics of the resulting star depend primarily upon its starting mass. The more massive the star, the greater its luminosity, and the more rapidly it expends the hydrogen fuel in its core. Over time, this hydrogen fuel is completely converted into helium, and the star begins to evolve. The fusion of helium requires a higher core temperature, so that the star both expands in size, and increases in core density. The resulting red giant enjoys a brief life span, before the helium fuel is in turn consumed. Very massive stars can also undergo a series of decreasing evolutionary phases, as they fuse increasingly heavier elements.

The final fate of the star depends on its mass, with stars of mass greater than about eight times the Sun becoming core collapse supernovae; while smaller stars form planetary nebulae, and evolve into white dwarfs. The remnant of a supernova is a dense neutron star, or, if the stellar mass was at least three times that of the Sun, a black hole. Close binary stars can follow more complex evolutionary paths, such as mass transfer onto a white dwarf companion that can potentially cause a supernova. Planetary nebulae and supernovae are necessary for the distribution of metals to the interstellar medium; without them, all new stars (and their planetary systems) would be formed from hydrogen and helium alone.

**Galactic astronomy**




Observed structure of the Milky Way's spiral arms

Our solar system orbits within the Milky Way, a barred spiral galaxy that is a prominent member of the Local Group of galaxies. It is a rotating mass of gas, dust, stars and other objects, held together by mutual gravitational attraction. As the Earth is located within the dusty outer arms, there are large portions of the Milky Way that are obscured from view.

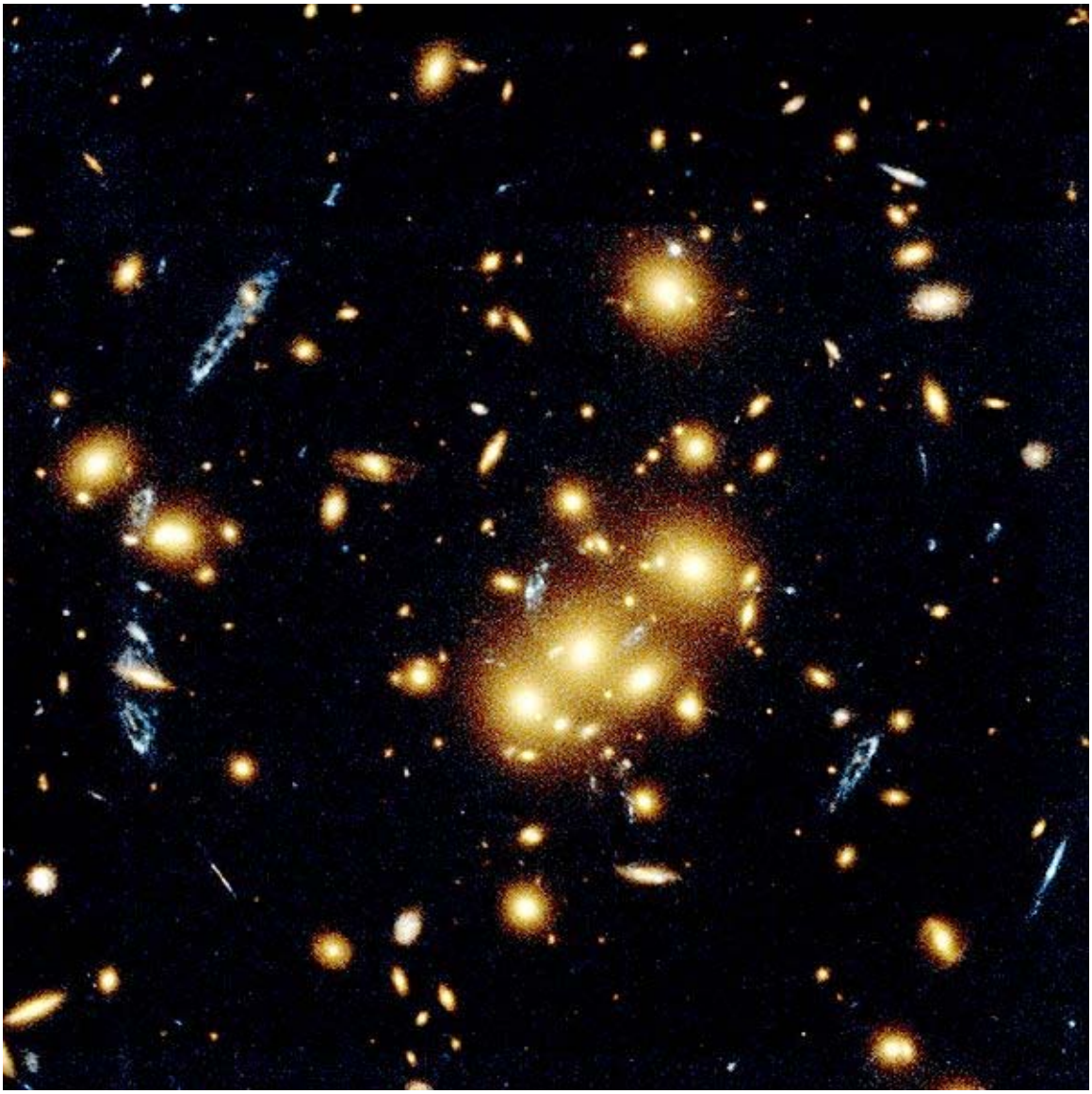
In the center of the Milky Way is the core, a bar-shaped bulge with what is believed to be a supermassive black hole at the center. This is surrounded by four primary arms that spiral from the core. This is a region of active star formation that contains many younger, population I stars. The disk is surrounded by a spheroid halo of older, population II stars, as well as relatively dense concentrations of stars known as globular clusters.

Between the stars lies the interstellar medium, a region of sparse matter. In the densest regions, molecular clouds of molecular hydrogen and other elements create star-forming regions. These begin as a compact pre-stellar core or dark nebulae, which concentrate and collapse (in volumes determined by the Jeans length) to form compact protostars.

As the more massive stars appear, they transform the cloud into an H II region of glowing gas and plasma. The stellar wind and supernova explosions from these stars eventually serve to disperse the cloud, often leaving behind one or more young open clusters of stars. These clusters gradually disperse, and the stars join the population of the Milky Way.

Kinematic studies of matter in the Milky Way and other galaxies have demonstrated that there is more mass than can be accounted for by visible matter. A dark matter halo appears to dominate the mass, although the nature of this dark matter remains undetermined.

## Extragalactic astronomy



This image shows several blue, loop-shaped objects that are multiple images of the same galaxy, duplicated by the gravitational lens effect of the cluster of yellow galaxies near the middle of the photograph. The lens is produced by the cluster's gravitational field that bends light to magnify and distort the image of a more distant object.

The study of objects outside our galaxy is a branch of astronomy concerned with the formation and evolution of Galaxies; their morphology and classification; and the examination of active galaxies, and the groups and clusters of galaxies. The latter is important for the understanding of the large-scale structure of the cosmos.

Most galaxies are organized into distinct shapes that allow for classification schemes. They are commonly divided into spiral, elliptical and Irregular galaxies.

As the name suggests, an elliptical galaxy has the cross-sectional shape of an ellipse. The stars move along random orbits with no preferred direction. These galaxies contain little or no interstellar dust; few star-forming regions; and generally older stars. Elliptical galaxies are more commonly found at the core of galactic clusters, and may be formed through mergers of large galaxies.

A spiral galaxy is organized into a flat, rotating disk, usually with a prominent bulge or bar at the center, and trailing bright arms that spiral outward. The arms are dusty regions of star formation where massive young stars produce a blue tint. Spiral galaxies are typically surrounded by a halo of older stars. Both the Milky Way and the Andromeda Galaxy are spiral galaxies.

Irregular galaxies are chaotic in appearance, and are neither spiral nor elliptical. About a quarter of all galaxies are irregular, and the peculiar shapes of such galaxies may be the result of gravitational interaction.

An active galaxy is a formation that is emitting a significant amount of its energy from a source other than stars, dust and gas; and is powered by a compact region at the core, usually thought to be a super-massive black hole that is emitting radiation from in-falling material.

A radio galaxy is an active galaxy that is very luminous in the radio portion of the spectrum, and is emitting immense plumes or lobes of gas. Active galaxies that emit high-energy radiation include Seyfert galaxies, Quasars, and Blazars. Quasars are believed to be the most consistently luminous objects in the known universe.

The large-scale structure of the cosmos is represented by groups and clusters of galaxies. This structure is organized in a hierarchy of groupings, with the largest being the superclusters. The collective matter is formed into filaments and walls, leaving large voids in between.

## Cosmology

Cosmology (from the Greek κόσμος "world, universe" and λόγος "word, study") could be considered the study of the universe as a whole.

Observations of the large-scale structure of the universe, a branch known as physical cosmology, have provided a deep understanding of the formation and evolution of the cosmos. Fundamental to modern cosmology is the well-accepted theory of the big bang, wherein our universe began at a single point in time, and thereafter expanded over the course of 13.7 Gyr to its present condition. The concept of the big bang can be traced back to the discovery of the microwave background radiation in 1965.

In the course of this expansion, the universe underwent several evolutionary stages. In the very early moments, it is theorized that the universe experienced a very rapid cosmic

inflation, which homogenized the starting conditions. Thereafter, nucleosynthesis produced the elemental abundance of the early universe.

When the first atoms formed, space became transparent to radiation, releasing the energy viewed today as the microwave background radiation. The expanding universe then underwent a Dark Age due to the lack of stellar energy sources.

A hierarchical structure of matter began to form from minute variations in the mass density. Matter accumulated in the densest regions, forming clouds of gas and the earliest stars. These massive stars triggered the reionization process and are believed to have created many of the heavy elements in the early universe which tend to decay back to the lighter elements extending the cycle.

Gravitational aggregations clustered into filaments, leaving voids in the gaps. Gradually, organizations of gas and dust merged to form the first primitive galaxies. Over time, these pulled in more matter, and were often organized into groups and clusters of galaxies, then into larger-scale superclusters.

Fundamental to the structure of the universe is the existence of dark matter and dark energy. These are now thought to be the dominant components, forming 96% of the mass of the universe. For this reason, much effort is expended in trying to understand the physics of these components.

# Interdisciplinary studies

Astronomy and astrophysics have developed significant interdisciplinary links with other major scientific fields. Archaeoastronomy is the study of ancient or traditional astronomies in their cultural context, utilizing archaeological and anthropological evidence. Astrobiology is the study of the advent and evolution of biological systems in the universe, with particular emphasis on the possibility of non-terrestrial life.

The study of chemicals found in space, including their formation, interaction and destruction, is called astrochemistry. These substances are usually found in molecular clouds, although they may also appear in low temperature stars, brown dwarfs and planets. Cosmochemistry is the study of the chemicals found within the Solar System, including the origins of the elements and variations in the isotope ratios. Both of these fields represent an overlap of the disciplines of astronomy and chemistry. As "forensic astronomy", finally, methods from astronomy have been used to solve problems of law and history.

# Amateur astronomy

Amateur astronomers can build their own equipment, and can hold star parties and gatherings, such as Stellafane.

Astronomy is one of the sciences to which amateurs can contribute the most.

Collectively, amateur astronomers observe a variety of celestial objects and phenomena sometimes with equipment that they build themselves. Common targets of amateur astronomers include the Moon, planets, stars, comets, meteor showers, and a variety of deep-sky objects such as star clusters, galaxies, and nebulae. One branch of amateur astronomy, amateur astrophotography, involves the taking of photos of the night sky. Many amateurs like to specialize in the observation of particular objects, types of objects, or types of events which interest them.

Most amateurs work at visible wavelengths, but a small minority experiment with wavelengths outside the visible spectrum. This includes the use of infrared filters on conventional telescopes, and also the use of radio telescopes. The pioneer of amateur radio astronomy was Karl Jansky, who started observing the sky at radio wavelengths in the 1930s. A number of amateur astronomers use either homemade telescopes or use radio telescopes which were originally built for astronomy research but which are now available to amateurs (*e.g.* the One-Mile Telescope).

Amateur astronomers continue to make scientific contributions to the field of astronomy. Indeed, it is one of the few scientific disciplines where amateurs can still make significant contributions. Amateurs can make occultation measurements that are used to refine the orbits of minor planets. They can also discover comets, and perform regular observations of variable stars. Improvements in digital technology have allowed amateurs to make impressive advances in the field of astrophotography.

# Major problems

Although the scientific discipline of astronomy has made tremendous strides in understanding the nature of the universe and its contents, there remain some important unanswered questions. Answers to these may require the construction of new ground- and space-based instruments, and possibly new developments in theoretical and experimental physics.

- What is the origin of the stellar mass spectrum? That is, why do astronomers observe the same distribution of stellar masses – the initial mass function – apparently regardless of the initial conditions? A deeper understanding of the formation of stars and planets is needed.
- Is there other life in the Universe? Especially, is there other intelligent life? If so, what is the explanation for the Fermi paradox? The existence of life elsewhere has important scientific and philosophical implications. Is the Solar System normal or atypical?
- What caused the Universe to form? Is the premise of the Fine-tuned universe hypothesis correct? If so, could this be the result of cosmological natural selection? What caused the cosmic inflation that produced our homogeneous universe? Why is there a baryon asymmetry?
- What is the nature of dark matter and dark energy? These dominate the evolution and fate of the cosmos, yet their true nature remains unknown. What will be the ultimate fate of the universe?
- How did the first galaxies form? How did supermassive black holes form?
- What is creating the ultra-high-energy cosmic rays?

# International Year of Astronomy 2009

During the 62nd General Assembly of the UN, 2009 was declared to be the International Year of Astronomy (IYA2009), with the resolution being made official on 20 December

2008. A global scheme laid out by the International Astronomical Union (IAU), it was also endorsed by UNESCO – the UN body responsible for Educational, Scientific and Cultural matters. IYA2009 was intended to be a global celebration of astronomy and its contributions to society and culture, stimulating worldwide interest not only in astronomy but science in general, with a particular slant towards young people.

Chapter- 3

# Observational Astronomy

Mayall telescope at Kitt Peak National Observatory

**Observational astronomy** is a division of the astronomical science that is concerned with getting data, in contrast with theoretical astrophysics which is mainly concerned with finding out the measurable implications of physical models. It is the practice of observing celestial objects by using telescopes and other astronomical apparatus.

As a science, astronomy is somewhat hindered in that direct experiments with the properties of the distant universe are not possible. However, this is partly compensated by the fact that astronomers have a vast number of visible examples of stellar phenomena that can be examined. This allows for observational data to be plotted on graphs, and general trends recorded. Nearby examples of specific phenomena, such as variable stars, can then be used to infer the behavior of more distant representatives. Those distant yardsticks can then be employed to measure other phenomena in that neighborhood, including the distance to a galaxy.

# Telescopes

Galileo Galilei was the first person known to have turned a telescope to the heavens and to record what he saw. Since that time, observational astronomy has made steady advances with each improvement in telescope technology.

A traditional division of observational astronomy is given by the region of the electromagnetic spectrum observed:

- Optical astronomy is the part of astronomy that uses optical components (mirrors, lenses and solid-state detectors) to observe light from near infrared to near ultraviolet wavelengths. Visible-light astronomy (using wavelengths that can be detected with the eyes, about 400 - 700 nm) falls in the middle of this range.
- Infrared astronomy deals with the detection and analysis of infrared radiation (this typically refers to wavelengths longer than the detection limit of silicon solid-state detectors, about 1 μm wavelength). The most common tool is the reflecting telescope but with a detector sensitive to infrared wavelengths. Space telescopes are used at certain wavelengths where the atmosphere is opaque, or to eliminate noise (thermal radiation from the atmosphere).
- Radio astronomy detects radiation of millimetre to dekametre wavelength. The receivers are similar to those used in radio broadcast transmission but much more sensitive.
- High-energy astronomy includes X-ray astronomy, gamma-ray astronomy, and extreme UV astronomy, as well as studies of neutrinos and cosmic rays.

Optical and radio astronomy can be performed with ground-based observatories, because the atmosphere is relatively transparent at the wavelengths being detected. Observatories are usually located at high altitudes so as to minimise the absorption and distortion caused by the Earth's atmosphere. Some wavelengths of infrared light are heavily absorbed by water vapor, so many infrared observatories are located in dry places at high altitude, or in space.

The atmosphere is opaque at the wavelengths used by X-ray astronomy, gamma-ray astronomy, UV astronomy and (except for a few wavelength "windows") far infrared astronomy, so observations must be carried out mostly from balloons or space observatories. Powerful gamma rays can, however be detected by the large air showers they produce, and the study of cosmic rays is a rapidly expanding branch of astronomy.

## Optical telescopes

For much of the history of observational astronomy, almost all observation was performed in the visual spectrum with optical telescopes. While the Earth's atmosphere is relatively transparent in this portion of the electromagnetic spectrum, most telescope work is still dependent on seeing conditions and air transparency, and is generally restricted to the night time. The seeing conditions depend on the turbulence and thermal variations in the air. Locations that are frequently cloudy or suffer from atmospheric turbulence limit the resolution of observations. Likewise the presence of the full Moon can brighten up the sky with scattered light, hindering observation of faint objects.

For observation purposes, the optimal location for an optical telescope is undoubtedly in outer space. There the telescope can make observations without being affected by the atmosphere. However, at present it remains costly to lift telescopes into orbit. Thus the next best locations are certain mountain peaks that have a high number of cloudless days and generally possess good atmospheric conditions (with good seeing conditions). The peaks of the islands of Mauna Kea, Hawaii and La Palma possess these properties, as to a lesser extent do inland sites such as Llano de Chajnantor, Paranal, Cerro Tololo and La Silla in Chile. These observatory locations have attracted an assemblage of powerful telescopes, totalling many billion US dollars of investment.

The darkness of the night sky is an important factor in optical astronomy. With the size of cities and human populated areas ever expanding, the amount of artificial light at night has also increased. These artificial lights produce a diffuse background illumination that makes observation of faint astronomical features very difficult without special filters. In a few locations such as the state of Arizona and in the United Kingdom, this has led to campaigns for the reduction of light pollution. The use of hoods around street lights not only improves the amount of light directed toward the ground, but also helps reduce the light directed toward the sky.

Atmospheric effects (astronomical seeing) can severely hinder the resolution of a telescope. Without some means of correcting for the blurring effect of the shifting atmosphere, telescopes larger than about 15-20 cm in aperture can not achieve their theoretical resolution at visible wavelengths. As a result, the primary benefit of using very large telescopes has been the improved light-gathering capability, allowing very faint magnitudes to be observed. However the resolution handicap has begun to be overcome by adaptive optics, speckle imaging and interferometric imaging, as well as the use of space telescopes.

Astronomers have a number of observational tools that they can use to make measurements of the heavens. For objects that are relatively close to the Sun and Earth, direct and very precise position measurements can be made against a more distant (and thereby nearly stationary) background. Early observations of this nature were used to develop very precise orbital models of the various planets, and to determine their respective masses and gravitational perturbations. Such measurements led to the discovery of the planets Uranus, Neptune, and (indirectly) Pluto. They also resulted in an erroneous assumption of a fictional planet Vulcan within the orbit of Mercury (but the explanation of the precession of Mercury's orbit by Einstein is considered one of the triumphs of his general relativity theory).

## Other instruments

In addition to examination of the universe in the optical spectrum, astronomers have increasingly been able to acquire information in other portions of the electromagnetic spectrum. The earliest such non-optical measurements were made of the thermal properties of the Sun. Instruments employed during a solar eclipse could be used to measure the radiation from the corona.

With the discovery of radio waves, radio astronomy began to emerge as a new discipline in astronomy. The long wavelengths of radio waves required much larger collecting dishes in order to make images with good resolution, and later led to the development of the multi-dish interferometer for making high-resolution aperture synthesis radio images (or "radio maps"). The development of the microwave horn receiver led to the discovery of the microwave background radiation associated with the big bang.

Radio astronomy has continued to expand its capabilities, even using radio astronomy satellites to produce interferometers with baselines much larger than the size of the Earth. However, the ever-expanding use of the radio spectrum for other uses is gradually drowning out the faint radio signals from the stars. For this reason, in the future radio astronomy might be performed from shielded locations, such as the far side of the Moon.

The last part of the twentieth century saw rapid technological advances in astronomical instrumentation. Optical telescopes were growing ever larger, and employing adaptive optics to partly negate atmospheric blurring. New telescopes were launched into space, and began observing the universe in the infrared, ultraviolet, x-ray, and gamma ray parts of the electromagnetic spectrum, as well as observing cosmic rays. Interferometer arrays produced the first extremely high-resolution images using aperture synthesis at radio, infrared and optical wavelengths. Orbiting instruments such as the Hubble Space Telescope produced rapid advances in astronomical knowledge, acting as the workhorse for visible-light observations of faint objects. New space instruments under development are expected to directly observe planets around other stars, perhaps even some Earth-like worlds.

In addition to telescopes, astronomers have begun using other instruments to make observations. Huge underground tanks have been built to detect neutrino emissions from

the Sun and supernovae. Gravity wave detectors are being designed that may capture events such as collisions of massive objects such as neutron stars. Robotic spacecraft are also being increasingly used to make highly detailed observations of planets within the solar system, so that the field of planetary science now has significant cross-over with the disciplines of geology and meteorology.

## Observation tools

The key instrument of nearly all modern observational astronomy is the telescope. This serves the dual purposes of gathering more light so that very faint objects can be observed, and magnifying the image so that small and distant objects can be observed. For optical astronomy, the optical components used in a telescope have very exacting requirements which require great precision in their construction. Typical requirements for grinding and polishing a curved mirror, for example, require the surface to be within a fraction of a wavelength of light of a particular conic shape. Many modern "telescopes" actually consist of arrays of telescopes working together to provide higher resolution through aperture synthesis.

Large telescopes are housed in domes, both to protect them from the weather and to stabilize the environmental conditions. For example, if the temperature is different from one side of the telescope to the other, the shape of the structure will change, due to thermal expansion, pushing optical elements out of position, and affecting the image. For this reason, the domes are usually bright white (titanium dioxide) or unpainted metal. Domes are often opened around sunset (pointed east, of course!), long before observing can begin, so that air can circulate and bring the entire telescope to the same temperature as the surroundings. In order to prevent wind-buffet or other vibrations affecting observations, it is standard practice to mount the telescope on a concrete pier whose foundations are entirely separate from those of the surrounding dome/building.

In order to do almost any scientific work, telescopes must keep track of objects as they wheel across the visible sky. In other words, they must smoothly compensate for the rotation of the Earth. Until the advent of computer controlled drive mechanisms, the standard solution was some form of equatorial mount, and for small telescopes this is still the norm. However, this is a structurally poor design and becomes more and more cumbersome as the diameter and weight of the telescope increases. The world's largest equatorial mounted telescope is the 200 inch (5.1 m) Hale Telescope, whereas recent 8-10 m telescopes use the structurally better Altazimuth mount, and are actually physically *smaller* than the Hale, despite the larger mirrors. As of 2006, there are design projects underway for gigantic alt-az telescopes: the Thirty Metre Telescope , and the 100 m diameter Overwhelmingly Large Telescope

Amateur astronomers use such instruments as the Newtonian reflector, the Refractor and the increasingly popular Maksutov telescope.

The photograph has served a critical role in observational astronomy for over a century, but in the last 30 years it has been largely replaced for imaging applications by digital

sensors such as CCDs and CMOS chips. Specialist areas of astronomy such as photometry and interferometry have utilised electronic detectors for a much longer period of time. Astrophotography uses specialised photographic film (or usually a glass plate coated with photographic emulsion), but there are a number of drawbacks, particularly a low quantum efficiency, of the order of 3%, whereas CCDs can be tuned for a QE >90% in a narrow band. Almost all modern telescope instruments are electronic arrays, and older telescopes have been either been retrofitted with these instruments or closed down. Glass plates are still used in some applications, such as surveying, because the resolution possible with a chemical film is much higher than any electronic detector yet constructed.

Prior to the invention of photography, all astronomy was done with the naked eye. However, even before films became sensitive enough, scientific astronomy moved entirely to film, because of the overwhelming advantages:

- The human eye discards what it sees from split-second to split-second, but photographic film gathers more and more light for as long as the shutter is open.
- The resulting image is permanent, so many astronomers can use (and argue over!) the same data.
- It is possible to see objects as they change over time (SN 1987A is a spectacular example).

The blink comparator is an instrument that is used to compare two nearly identical photographs made of the same section of sky at different points in time. The comparator alternates illumination of the two plates, and any changes are revealed by blinking points or streaks. This instrument has been used to find asteroids, comets, and variable stars.

The position or cross-wire micrometer is an implement that has been used to measure double stars. This consists of a pair of fine, movable lines that can be moved together or apart. The telescope lens is lined up on the pair and oriented using position wires that lie at right angles to the star separation. The movable wires are then adjusted to match the two star positions. The separation of the stars is then read off the instrument, and their true separation determined based on the magnification of the instrument.

A vital instrument of observational astronomy is the spectrograph. The absorption of specific wavelengths of light by elements allows specific properties of distant bodies to be observed. This capability has resulted in the discovery of the element of helium in the Sun's emission spectrum, and has allowed astronomers to determine a great deal of information concerning distant stars, galaxies, and other celestial bodies. Doppler shift (particularly "redshift") of spectra can also be used to determine the radial motion or distance with respect to the Earth.

Early spectrographs employed banks of prisms that would split the light into a broad spectrum. Later the grating spectrograph was developed, which reduced the amount of light loss compared to prisms and provided higher spectral resolution. The spectrum can be photographed in a long exposure, allowing the spectrum of faint objects (such as distant galaxies) to be measured.

Stellar photometry came into use in 1861 as a means of measuring stellar colors. This technique measured the magnitude of a star at specific frequency ranges, allowing a determination of the overall color, and therefore temperature of a star. By 1951 an internationally standardized system of UBV-magnitudes (*U*ltraviolet-*B*lue-*V*isual) was adopted.

Photoelectric photometry using the CCD is now frequently used to make observations through a telescope. These sensitive instruments can record the image nearly down to the level of individual photons, and can be designed to view in parts of the spectrum that are invisible to the eye. The ability to record the arrival of small numbers of photons over a period of time can allow a degree of computer correction for atmospheric effects, sharpening up the image. Multiple digital images can also be combined to further enhance the image. When combined with the adaptive optics technology, image quality can approach the theoretical resolution capability of the telescope.

Filters are used to view an object at particular frequencies or frequency ranges. Multilayer film filters can provide very precise control of the frequencies transmitted and blocked, so that, for example, objects can be viewed at a particular frequency emitted only by excited hydrogen atoms. Filters can also be used to partially compensate for the effects of light pollution by blocking out unwanted light. Polarization filters can also be used to determine if a source is emitting polarized light, and the orientation of the polarization.

# Observing

Astronomers observe a wide range of astronomical sources, including high-redshift galaxies, AGNs, the afterglow from the Big Bang and many different types of stars and protostars.

A variety of data can be observed for each object. The position coordinates locate the object on the sky using the techniques of spherical astronomy, and the magnitude determines its brightness as seen from the Earth. The relative brightness in different parts of the spectrum yields information about the temperature and physics of the object. Photographs of the spectra allow the chemistry of the object to be examined.

Parallax shifts of a star against the background can be used to determine the distance, out to a limit imposed by the resolution of the instrument. The radial velocity of the star and changes in its position over time (proper motion) can be used to measure its velocity relative to the Sun. Variations in the brightness of the star give evidence of instabilities in the star's atmosphere, or else the presence of an occulting companion. The orbits of binary stars can be used to measure the relative masses of each companion, or the total mass of the system. Spectroscopic binaries can be found by observing doppler shifts in the spectrum of the star and its close companion.

Stars of identical masses that are formed at the same time and under the similar conditions will typically have nearly identical observed properties. Observing a mass of

closely associated stars, such as in a globular cluster, allows data to be assembled about the distribution of stellar types. These tables can then be used to infer the age of the association.

For distant galaxies and AGNs observations are made of the overall shape and properties of the galaxy, as well as the groupings in which they are found. Observations of certain types of variable stars and supernovae of known luminosity, called standard candles, in other galaxies allows the inference of the distance to the host galaxy. The expansion of space causes the spectra of these galaxies to be shifted, depending on the distance, and modified by the doppler effect of the galaxy's radial velocity. Both the size of the galaxy and its redshift can be used to infer something about the distance of the galaxy. Observations of large numbers of galaxies are referred to as redshift surveys, and are used to model the evolution of galaxy forms.

**Chapter- 4**

# Astrophysics

NGC 4414, a typical spiral galaxy in the constellation Coma Berenices, is about 56,000 light-years in diameter and approximately 60 million light-years distant.

**Astrophysics** (Greek: *Astro* - meaning "star", and Greek: *physis – φύσις* - meaning "nature") is the branch of astronomy that deals with the physics of the universe, including the physical properties (luminosity, density, temperature, and chemical composition) of celestial objects such as galaxies, stars, planets, exoplanets, and the interstellar medium, as well as their interactions. The study of cosmology addresses questions of astrophysics at scales much larger than the size of particular gravitationally-bound objects in the universe.

Because astrophysics is a very broad subject, *astrophysicists* typically apply many disciplines of physics, including mechanics, electromagnetism, statistical mechanics, thermodynamics, quantum mechanics, relativity, nuclear and particle physics, and atomic and molecular physics. In practice, modern astronomical research involves a substantial amount of physics. The name of a university's department ("astrophysics" or "astronomy") often has to do more with the department's history than with the contents of the programs. Astrophysics can be studied at the bachelors, masters, and Ph.D. levels in aerospace engineering, physics, or astronomy departments at many universities.

## History

Although astronomy is as ancient as recorded history itself, it was long separated from the study of physics. In the Aristotelian worldview, the celestial world tended towards perfection—bodies in the sky seemed to be perfect spheres moving in perfectly circular orbits—while the earthly world seemed destined to imperfection; these two realms were not seen as related.

Aristarchus of Samos (c. 310–250 BC) first put forward the notion that the motions of the celestial bodies could be explained by assuming that the Earth and all the other planets in the Solar System orbited the Sun. Unfortunately, in the geocentric world of the time, Aristarchus' heliocentric theory was deemed outlandish and heretical. For centuries, the apparently common-sense view that the Sun and other planets went round the Earth nearly went unquestioned until the development of Copernican heliocentrism in the 16th century AD. This was due to the dominance of the geocentric model developed by Ptolemy (c. 83-161 AD), a Hellenized astronomer from Roman Egypt, in his *Almagest* treatise.

The only known supporter of Aristarchus was Seleucus of Seleucia, a Babylonian astronomer who is said to have proved heliocentrism through reasoning in the 2nd century BC. This may have involved the phenomenon of tides, which he correctly theorized to be caused by attraction to the Moon and notes that the height of the tides depends on the Moon's position relative to the Sun. Alternatively, he may have determined the constants of a geometric model for the heliocentric theory and developed methods to compute planetary positions using this model, possibly using early trigonometric methods that were available in his time, much like Copernicus. B. L. van der Waerden has interpreted the planetary models developed by Aryabhata (476-550), an Indian astronomer, and Abu Ma'shar al-Balkhi (787-886), a Persian astronomer, to be heliocentric models but this view has been strongly disputed by others.

In the 9th century AD, the Persian physicist and astronomer, Ja'far Muhammad ibn Mūsā ibn Shākir, hypothesized that the heavenly bodies and celestial spheres are subject to the same laws of physics as Earth, unlike the ancients who believed that the celestial spheres followed their own set of physical laws different from that of Earth. He also proposed that there is a force of attraction between "heavenly bodies", vaguely foreshadowing the law of gravity.

In the early 11th century, the Arabic Ibn al-Haytham (Alhazen) wrote the *Maqala fi daw al-qamar* (*On the Light of the Moon*) some time before 1021. This was the first successful attempt at combining mathematical astronomy with physics, and the earliest attempt at applying the experimental method to astronomy and astrophysics. He disproved the universally held opinion that the moon reflects sunlight like a mirror and correctly concluded that it "emits light from those portions of its surface which the sun's light strikes." In order to prove that "light is emitted from every point of the moon's illuminated surface," he built an "ingenious experimental device." Ibn al-Haytham had "formulated a clear conception of the relationship between an ideal mathematical model and the complex of observable phenomena; in particular, he was the first to make a systematic use of the method of varying the experimental conditions in a constant and

uniform manner, in an experiment showing that the intensity of the light-spot formed by the projection of the moonlight through two small apertures onto a screen diminishes constantly as one of the apertures is gradually blocked up."

In the 14th century, Ibn al-Shatir produced the first model of lunar motion which matched physical observations, and which was later used by Copernicus. In the 13th to 15th centuries, Tusi and Ali Qushji provided the earliest empirical evidence for the Earth's rotation, using the phenomena of comets to refute Ptolemy's claim that a stationary Earth can be determined through observation. Kuşçu further rejected Aristotelian physics and natural philosophy, allowing astronomy and physics to become empirical and mathematical instead of philosophical. In the early 16th century, the debate on the Earth's motion was continued by Al-Birjandi (d. 1528), who in his analysis of what might occur if the Earth were rotating, develops a hypothesis similar to Galileo Galilei's notion of "circular inertia", which he described in the following observational test:

The small or large rock will fall to the Earth along the path of a line that is perpendicular to the plane (*sath*) of the horizon; this is witnessed by experience (*tajriba*). And this perpendicular is away from the tangent point of the Earth’s sphere and the plane of the perceived (*hissi*) horizon. This point moves with the motion of the Earth and thus there will be no difference in place of fall of the two rocks.

After heliocentrism was revived by Nicolaus Copernicus in the 16th century, Galileo Galilei discovered the four brightest moons of Jupiter in 1609, and documented their orbits about that planet, which contradicted the geocentric dogma of the Catholic Church of his time, and escaped serious punishment only by maintaining that his astronomy was a work of mathematics, not of natural philosophy (physics), and therefore purely abstract.

The availability of accurate observational data (mainly from the observatory of Tycho Brahe) led to research into theoretical explanations for the observed behavior. At first, only empirical rules were discovered, such as Kepler's laws of planetary motion, discovered at the start of the 17th century. Later that century, Isaac Newton bridged the gap between Kepler's laws and Galileo's dynamics, discovering that the same laws that rule the dynamics of objects on Earth rule the motion of planets and the moon. Celestial mechanics, the application of Newtonian gravity and Newton's laws to explain Kepler's laws of planetary motion, was the first unification of astronomy and physics.

After Isaac Newton published his book, *Philosophiæ Naturalis Principia Mathematica*, maritime navigation was transformed. Starting around 1670, the entire world was measured using essentially modern latitude instruments and the best available clocks. The needs of navigation provided a drive for progressively more accurate astronomical observations and instruments, providing a background for ever more available data for scientists.

At the end of the 19th century, it was discovered that, when decomposing the light from the Sun, a multitude of spectral lines were observed (regions where there was less or no light). Experiments with hot gases showed that the same lines could be observed in the

spectra of gases, specific lines corresponding to unique chemical elements. In this way it was proved that the chemical elements found in the Sun (chiefly hydrogen) were also found on Earth. Indeed, the element helium was first discovered in the spectrum of the Sun and only later on Earth, hence its name. During the 20th century, spectroscopy (the study of these spectral lines) advanced, particularly as a result of the advent of quantum physics that was necessary to understand the astronomical and experimental observations.

# Observational astrophysics

The majority of astrophysical observations are made using the electromagnetic spectrum.

- Radio astronomy studies radiation with a wavelength greater than a few millimeters. Example areas of study are radio waves, usually emitted by cold objects such as interstellar gas and dust clouds; the cosmic microwave background radiation which is the redshifted light from the Big Bang; Pulsars, which were first detected at microwave frequencies. The study of these waves requires very large radio telescopes.
- Infrared astronomy studies radiation with a wavelength that is too long to be visible to the naked eye but is shorter than radio waves. Infrared observations are usually made with telescopes similar to the familiar optical telescopes. Objects colder than stars (such as planets) are normally studied at infrared frequencies.
- Optical astronomy is the oldest kind of astronomy. Telescopes paired with a charge-coupled device or spectroscopes are the most common instruments used. The Earth's atmosphere interferes somewhat with optical observations, so adaptive optics and space telescopes are used to obtain the highest possible image quality. In this wavelength range, stars are highly visible, and many chemical spectra can be observed to study the chemical composition of stars, galaxies and nebulae.
- Ultraviolet, X-ray and gamma ray astronomy study very energetic processes such as binary pulsars, black holes, magnetars, and many others. These kinds of radiation do not penetrate the Earth's atmosphere well. There are two methods in use to observe this part of the electromagnetic spectrum—space-based telescopes and ground-based imaging air Cherenkov telescopes (IACT). Examples of Observatories of the first type are RXTE, the Chandra X-ray Observatory and the Compton Gamma Ray Observatory. Examples of IACTs are the High Energy Stereoscopic System (H.E.S.S.) and the MAGIC telescope.

Other than electromagnetic radiation, few things may be observed from the Earth that originate from great distances. A few gravitational wave observatories have been constructed, but gravitational waves are extremely difficult to detect. Neutrino observatories have also been built, primarily to study our Sun. Cosmic rays consisting of very high energy particles can be observed hitting the Earth's atmosphere.

Observations can also vary in their time scale. Most optical observations take minutes to hours, so phenomena that change faster than this cannot readily be observed. However, historical data on some objects is available spanning centuries or millennia. On the other

hand, radio observations may look at events on a millisecond timescale (millisecond pulsars) or combine years of data (pulsar deceleration studies). The information obtained from these different timescales is very different.

The study of our own Sun has a special place in observational astrophysics. Due to the tremendous distance of all other stars, the Sun can be observed in a kind of detail unparalleled by any other star. Our understanding of our own sun serves as a guide to our understanding of other stars.

The topic of how stars change, or stellar evolution, is often modeled by placing the varieties of star types in their respective positions on the Hertzsprung-Russell diagram, which can be viewed as representing the state of a stellar object, from birth to destruction. The material composition of the astronomical objects can often be examined using:

- Spectroscopy
- Radio astronomy
- Neutrino astronomy (future prospects)

# Theoretical astrophysics

Theoretical astrophysicists use a wide variety of tools which include analytical models (for example, polytropes to approximate the behaviors of a star) and computational numerical simulations. Each has some advantages. Analytical models of a process are generally better for giving insight into the heart of what is going on. Numerical models can reveal the existence of phenomena and effects that would otherwise not be seen.

Theorists in astrophysics endeavor to create theoretical models and figure out the observational consequences of those models. This helps allow observers to look for data that can refute a model or help in choosing between several alternate or conflicting models.

Theorists also try to generate or modify models to take into account new data, In the case of an inconsistency, the general tendency is to try to make minimal modifications to the model to fit the data. In some cases, a large amount of inconsistent data over time may lead to total abandonment of a model.

Topics studied by theoretical astrophysicists include: stellar dynamics and evolution; galaxy formation; magnetohydrodynamics; large-scale structure of matter in the Universe; origin of cosmic rays; general relativity and physical cosmology, including string cosmology and astroparticle physics. Astrophysical relativity serves as a tool to gauge the properties of large scale structures for which gravitation plays a significant role in physical phenomena investigated and as the basis for black hole (*astro*)physics and the study of gravitational waves.

Some widely accepted and studied theories and models in astrophysics, now included in the Lambda-CDM model are the Big Bang, Cosmic inflation, dark matter, dark energy

and fundamental theories of physics.Wormholes are examples of theories which are yet to be proven.

## Chapter- 5

# Star Formation

**Star formation** is the process by which dense parts of molecular clouds collapse into a ball of plasma to form a star. As a branch of astronomy star formation includes the study of the interstellar medium and giant molecular clouds (GMC) as precursors to the star formation process and the study of young stellar objects and planet formation as its immediate products. Star formation theory, as well as accounting for the formation of a single star, must also account for the statistics of binary stars and the initial mass function.

## Stellar nurseries

Hubble telescope image known as *Pillars of Creation,* where stars are forming in the Eagle Nebula.

## Interstellar clouds

A spiral galaxy like the Milky Way contains stars, stellar remnants and a diffuse interstellar medium (ISM) of gas and dust. The latter consists of about 0.1 to 1 particles per $cm^3$ and is typically composed of roughly 70% hydrogen by mass, with most of the remaining gas consisting of helium. This medium has been chemically enriched by trace amounts of heavier elements that were ejected from stars as they passed beyond the end of their main sequence lifetime. Higher density regions of the interstellar medium form clouds, or *diffuse nebulae*, where star formation takes place. In contrast to spirals, an elliptical galaxy loses the cold component of its interstellar medium within roughly a billion years, which hinders the galaxy from forming diffuse nebulae except through mergers with other galaxies.

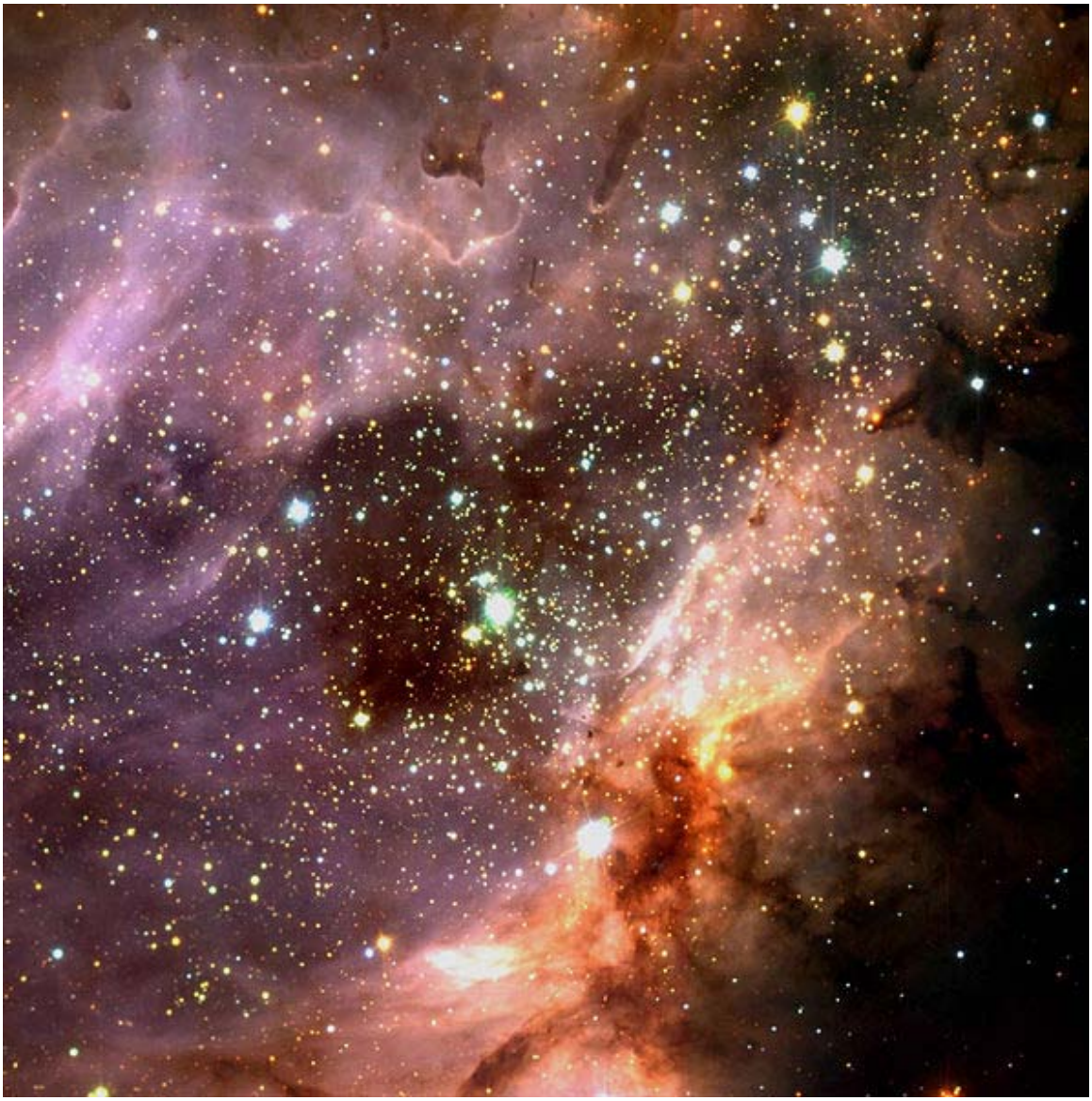
In the dense nebulae where stars are produced, much of the hydrogen is in the molecular ($H_2$) form, so these nebulae are called molecular clouds. The largest such formations, called giant molecular clouds, have typical densities of 100 particles per $cm^3$, diameters of 100 light-years ($9.5\times10^{14}$ km), masses of up to 6 million solar masses, and an average interior temperature of 10 K. About half the total mass of the galactic ISM is found in molecular clouds and in the Milky Way there are an estimated 6,000 molecular clouds, each with more than 100,000 solar masses. The nearest nebula to the Sun where massive stars are being formed is the Orion nebula, 1,300 ly ($1.2\times10^{16}$ km) away. However, lower mass star formation is occurring about 400–450 light years distant in the ρ Ophiuchi cloud complex.

A more compact site of star formation is the opaque clouds of dense gas and dust known as Bok globules; so named after the astronomer Bart Bok. These can form in association with collapsing molecular clouds or possibly independently. The Bok globules are typically up to a light year across and contain a few solar masses. They can be observed as dark clouds silhouetted against bright emission nebulae or background stars. Over half the known Bok globules have been found to contain newly forming stars.

## Empty space

A discovery by the infrared telescope Herschel in conjunction with other ground based telescopes, determined that black patches of space in certain areas encompassing a star formation were not dark nebulas but actually vast holes of empty space. Such is the case of the area NGC 1999 and its star V380 Orionis. The exact cause of this phenomenon is still being investigated, although it has been hypothesized that narrow jets of gas from some of the young stars in the region punctured the sheet of dust and gas, as well as, powerful radiation from a nearby mature star may have helped to create the hole. This was a previously unknown and unexpected step in the star-forming process.

## Cloud collapse



Stellar cluster and star-forming region M 17.

An interstellar cloud of gas will remain in hydrostatic equilibrium as long as the kinetic energy of the gas pressure is in balance with the potential energy of the internal gravitational force. Mathematically this is expressed using the virial theorem, which states that, to maintain equilibrium, the gravitational potential energy must equal twice the internal thermal energy. If a cloud is massive enough that the gas pressure is insufficient to support it, the cloud will undergo gravitational collapse. The mass above which a cloud will undergo such collapse is called the Jeans mass. The Jeans mass depends on the temperature and density of the cloud, but is typically thousands to tens of thousands of solar masses. This coincides with the typical mass of an open cluster of stars, which is the end product of a collapsing cloud.

In *triggered star formation*, one of several events might occur to compress a molecular cloud and initiate its gravitational collapse. Molecular clouds may collide with each other, or a nearby supernova explosion can be a trigger, sending shocked matter into the cloud at very high speeds. Alternatively, galactic collisions can trigger massive starbursts of star formation as the gas clouds in each galaxy are compressed and agitated by tidal forces. The latter mechanism may be responsible for the formation of globular clusters.

A supermassive black hole at the core of a galaxy may serve to regulate the rate of star formation in a galactic nucleus. A black hole that is accreting infalling matter can become active, emitting a strong wind through a collimated relativistic jet. This can limit further star formation. However, the radio emissions around the jets may also trigger star formation. Likewise, a weaker jet may trigger star formation when it collides with a cloud.

As it collapses, a molecular cloud breaks into smaller and smaller pieces in a hierarchical manner, until the fragments reach stellar mass. In each of these fragments, the collapsing gas radiates away the energy gained by the release of gravitational potential energy. As the density increases, the fragments become opaque and are thus less efficient at radiating away their energy. This raises the temperature of the cloud and inhibits further fragmentation. The fragments now condense into rotating spheres of gas that serve as stellar embryos.

Complicating this picture of a collapsing cloud are the effects of turbulence, macroscopic flows, rotation, magnetic fields and the cloud geometry. Both rotation and magnetic fields can hinder the collapse of a cloud. Turbulence is instrumental in causing fragmentation of the cloud, and on the smallest scales it promotes collapse.

# Protostar

LH 95 stellar nursery in Large Magellanic Cloud.

Composite image showing young stars in and around molecular cloud Cepheus B.

N11, part of a complex network of gas clouds and star clusters within our neighbouring galaxy, the Large Magellanic Cloud.

A protostellar cloud will continue to collapse as long as the gravitational binding energy can be eliminated. This excess energy is primarily lost through radiation. However, the collapsing cloud will eventually become opaque to its own radiation, and the energy must be removed through some other means. The dust within the cloud becomes heated to temperatures of 60–100 K, and these particles radiate at wavelengths in the far infrared where the cloud is transparent. Thus the dust mediates the further collapse of the cloud.

During the collapse, the density of the cloud increases toward the center and thus the middle region becomes optically opaque first. This occurs when the density is about $10^{-13}$ g $cm^{-3}$. A core region, called the First Hydrostatic Core, forms where the collapse is essentially halted. It continues to increase in temperature as determined by the virial

theorem. The gas falling toward this opaque region creates shock waves that further heat the core.

When the core temperature reaches about 2000 K, the thermal energy dissociates the $H_2$ molecules. This is followed by the ionization of the hydrogen and helium atoms. These processes absorb the energy of the contraction, allowing it to continue on timescales comparable to the period of collapse at free fall velocities. After the density of infalling material has dropped below about $10^{-8}$ g $cm^{-3}$, the material becomes sufficiently transparent to allow radiated energy to escape. The combination of convection within the protostar and radiation from the exterior allow the star to contract in radius. This continues until the gas is hot enough for the internal pressure to support the protostar against further gravitational collapse—a state called hydrostatic equilibrium. When this accretion phase is nearly complete, the resulting object is known as a protostar.

Accretion of material onto the protostar continues partially through a circumstellar disc. When the density and temperature are high enough, deuterium fusion begins, and the outward pressure of the resultant radiation slows (but does not stop) the collapse. Material comprising the cloud continues to "rain" onto the protostar. In this stage bipolar flows are produced, probably an effect of the angular momentum of the infalling material.

When the surrounding gas and dust envelope disperses and accretion process stops, the star is considered a pre-main sequence star (PMS star). The energy source of these objects is gravitational contraction, as opposed to hydrogen burning in main sequence stars. The PMS star follows a Hayashi track on the Hertzsprung-Russell (H-R) diagram. The contraction will proceed until the Hayashi limit is reached, and thereafter contraction will continue on a Kelvin-Helmholtz timescale with the temperature remaining stable. Stars with less than 0.5 solar masses thereafter join the main sequence. For more massive PMS stars, at the end of the Hayashi track they will slowly collapse in near hydrostatic equilibrium, following the Henyey track.

Finally, hydrogen begins to fuse in the core of the star, and the rest of the enveloping material is cleared away. This ends the protostellar phase and begins the star's main sequence phase on the H-R diagram.

The stages of the process are well defined in stars with masses around one solar mass or less. In high mass stars, the length of the star formation process is comparable to the other timescales of their evolution, much shorter, and the process is not so well defined. The later evolution of stars are studied in stellar evolution.

## Observations

The Orion Nebula is an archetypical example of star formation, from the massive, young stars that are shaping the nebula to the pillars of dense gas that may be the homes of budding stars.

Key elements of star formation are only available by observing in wavelengths other than the optical. The protostellar stage of stellar existence is almost invariably hidden away deep inside dense clouds of gas and dust left over from the GMC. Often, these star-forming cocoons can be seen in silhouette against bright emission from surrounding gas; they are then known as Bok globules. Early stages of a star's life can be seen in infrared light, which penetrates the dust more easily than visible light.

The structure of the molecular cloud and the effects of the protostar can be observed in near-IR extinction maps (where the number of stars are counted per unit area and compared to a nearby zero extinction area of sky), continuum dust emission and rotational transitions of CO and other molecules; these last two are observed in the millimeter and submillimeter range. The radiation from the protostar and early star has to be observed in infrared astronomy wavelengths, as the extinction caused by the rest of the cloud in which the star is forming is usually too big to allow us to observe it in the visual part of the spectrum. This presents considerable difficulties as the atmosphere is almost entirely opaque from 20μm to 850μm, with narrow windows at 200μm and 450μm. Even outside this range atmospheric subtraction techniques must be used.

The formation of individual stars can only be directly observed in our Galaxy, but in distant galaxies star formation has been detected through its unique spectral signature.

### Notable Pathfinder Objects

- MWC 349 was first discovered in 1978, and is estimated to be only 1,000 years old.
- VLA 1623 -- The first exemplar Class 0 protostar, a type of embedded protostar that has yet to accrete the majority of its mass. Found in 1993, is possibly younger than 10,000 years.
- L1014 -- An incredibly faint embedded object representative of a new class of sources that are only now being detected with the newest telescopes. Their status is still undetermined, they could be the youngest low-mass Class 0 protostars yet seen or even very low-mass evolved objects (like a brown dwarf or even an interstellar planet).
- IRS 8* -- The youngest known main sequence star, discovered in August 2006. It is estimated to be 3.5 million years old.

## Low mass and high mass star formation

Stars of different masses are thought to form by slightly different mechanisms. The theory of low-mass star formation, which is well-supported by a plethora of observations, suggests that low-mass stars form by the gravitational collapse of rotating density enhancements within molecular clouds. As described above, the collapse of a rotating cloud of gas and dust leads to the formation of an accretion disk through which matter is channeled onto a central protostar. For stars with masses higher than about 8 solar masses, however, the mechanism of star formation is not well understood.

Massive stars emit copious quantities of radiation which pushes against infalling material. In the past, it was thought that this radiation pressure might be substantial enough to halt accretion onto the massive protostar and prevent the formation of stars with masses more than a few tens of solar masses. Recent theoretical work has shown that the production of a jet and outflow clears a cavity through which much of the radiation from a massive protostar can escape without hindering accretion through the disk and onto the protostar.

Present thinking is that massive stars may therefore be able to form by a mechanism similar to that by which low mass stars form.

There is mounting evidence that at least some massive protostars are indeed surrounded by accretion disks. Several other theories of massive star formation remain to be tested observationally. Of these, perhaps the most prominent is the theory of competitive accretion, which suggests that massive protostars are "seeded" by low-mass protostars which compete with other protostars to draw in matter from the entire parent molecular cloud, instead of simply from a small local region.

Another theory of massive star formation suggests that massive stars may form by the coalescence of two or more stars of lower mass.

Chapter- 6

# Neutron Star

A **neutron star** is a type of stellar remnant that can result from the gravitational collapse of a massive star during a Type II, Type Ib or Type Ic supernova event. Such stars are composed almost entirely of neutrons, which are subatomic particles without electrical charge and a slightly larger mass than protons. Neutron stars are very hot and are supported against further collapse because of the Pauli exclusion principle. This principle states that no two neutrons (or any other fermionic particle) can occupy the same place and quantum state simultaneously.

A typical neutron star has a mass between 1.35 and about 2.0 solar masses , with a corresponding radius of about 12 km if the Akmal-Pandharipande-Ravenhall equation of state (APR EOS) is used. In contrast, the Sun's radius is about 60,000 times that. Neutron stars have overall densities predicted by the APR EOS of $3.7\times10^{17}$ to $5.9\times10^{17}$ $kg/m^3$ ($2.6\times10^{14}$ to $4.1\times10^{14}$ times the density of the Sun), which compares with the approximate density of an atomic nucleus of $3\times10^{17}$ $kg/m^3$. The neutron star's density varies from below $1\times10^{9}$ $kg/m^3$ in the crust increasing with depth to above $6\times10^{17}$ or $8\times10^{17}$ $kg/m^3$ deeper inside. This density is approximately equivalent to the mass of the entire human population compressed to the size of a sugar cube.

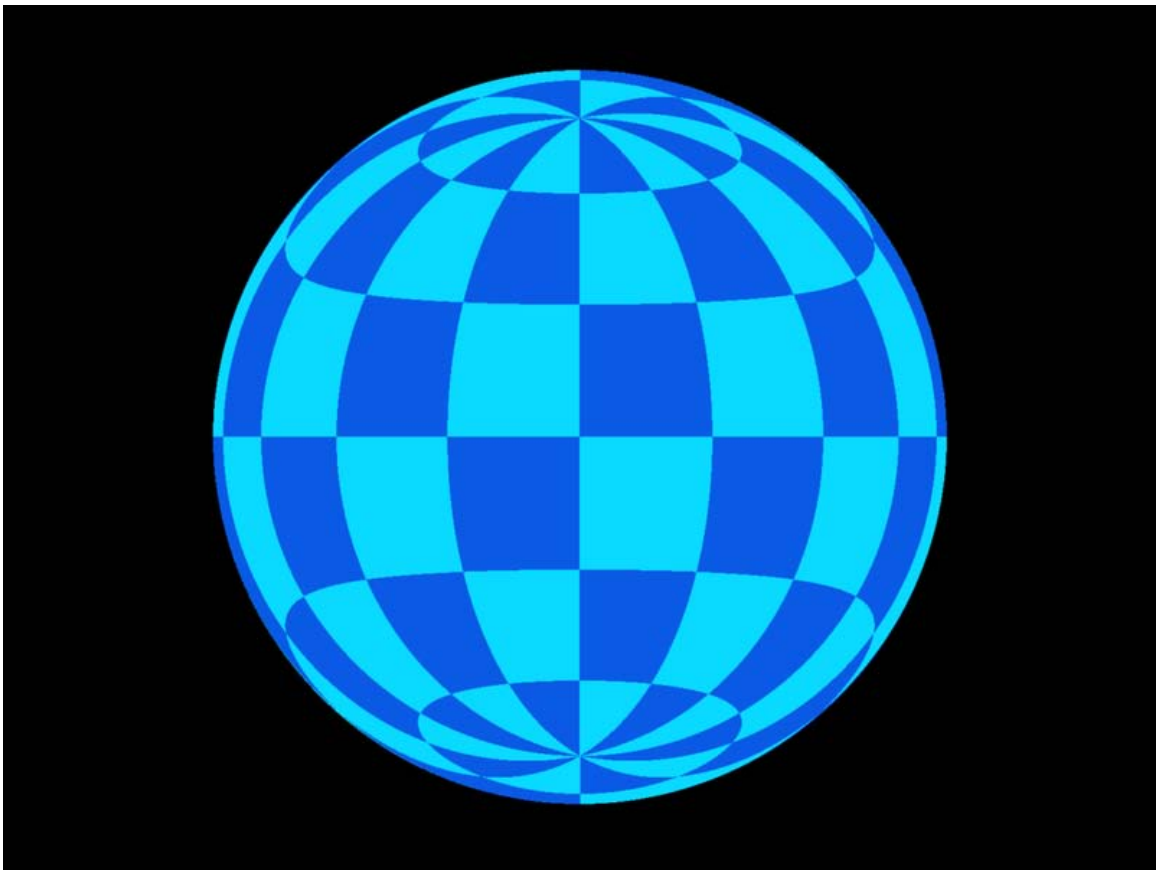
In general, compact stars of less than 1.44 solar masses – the Chandrasekhar limit – are white dwarfs, and above 2 to 3 solar masses (the Tolman-Oppenheimer-Volkoff limit), a quark star might be created; however, this is uncertain. Gravitational collapse will usually occur on any compact star between 10 and 25 solar masses and produce a black hole.

## Formation

As the core of a massive star is compressed during a supernova, and collapses into a neutron star, it retains most of its angular momentum. Since it has only a tiny fraction of its parent's radius (and therefore its moment of inertia is sharply reduced), a neutron star is formed with very high rotation speed, and then gradually slows down. Neutron stars

are known to have rotation periods between about 1.4 ms to 30 seconds. The neutron star's compactness also gives it very high surface gravity, up to $7\times10^{12}$ m/s² with typical values of a few $\times10^{12}$ m/s² (that is more than $10^{11}$ times of that of Earth). One measure of such immense gravity is the fact that neutron stars have an escape velocity of around 100,000 km/s, about a third the speed of light. Matter falling onto the surface of a neutron star would be accelerated to tremendous speed by the star's gravity. The force of impact would likely destroy the object's component atoms, rendering all its matter identical, in most respects, to the rest of the star.

## Properties



Gravitational light deflection at a neutron star. Due to relativistic light deflection more than half of the surface is visible (each chequered patch here represents 30 degrees by 30 degrees). The mass of the star depicted here is 1 and its radius 4, in natural units from a geometrized unit system such that it has double its Schwarzschild radius of 2.

The gravitational field at the star's surface is about $2\times10^{11}$ times stronger than on Earth. The escape velocity is about 100,000 km/s, which is about one third the speed of light. Such a strong gravitational field acts as a gravitational lens and bends the radiation emitted by the star such that parts of the normally invisible rear surface become visible.

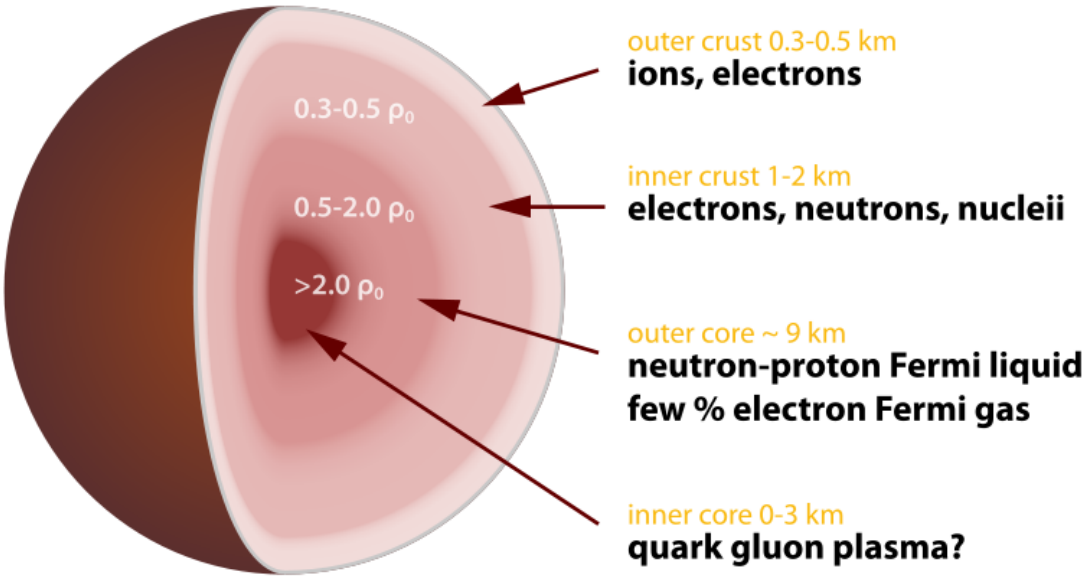
The gravitational binding energy of a neutron star with two solar masses is equivalent to the total conversion of one solar mass to energy (from the law of mass-energy equivalence, $E = mc^2$). That energy was released during the supernova explosion.

A neutron star is so dense that one teaspoon (5 milliliters) of its material would have a mass over $5.5 \times 10^{12}$ kg, about 900 times the mass of the Great Pyramid of Giza. The resulting force of gravity is so strong that if an object were to fall from a height of one meter it would only take one microsecond to hit the surface of the neutron star, and would do so at around 2000 kilometers per second, or 7.2 million kilometers per hour.

The temperature inside a newly formed neutron star is from around $10^{11}$ to $10^{12}$ kelvin. However, the huge number of neutrinos it emits carries away so much energy that the temperature falls within a few years to around $10^6$ kelvin. Even at 1 million kelvin, most of the light generated by a neutron star is in X-rays. In visible light, neutron stars probably radiate approximately the same energy in all parts of visible spectrum, and therefore appear white.

The equation of state for a neutron star is still not known. It is assumed that it differs significantly from that of a white dwarf, whose EOS is that of a degenerate gas which can be described in close agreement with special relativity. However, with a neutron star the increased effects of general relativity can no longer be ignored. Several EOS have been proposed (FPS, UU, APR, L, SLy, and others) and current research is still attempting to constrain the theories to make predictions of neutron star matter. This means that the relation between density and mass is not fully known, and this causes uncertainties in radius estimates. For example, a 1.5 solar mass neutron star could have a radius of 10.7, 11.1, 12.1 or 15.1 kilometres (for EOS FPS, UU, APR or L respectively). All EOS show that neutronium compresses with pressure.

## Structure




Cross-section of neutron star. Densities are in terms of $\rho_0$ the saturation nuclear matter density, where nucleons begin to touch.

Current understanding of the structure of neutron stars is defined by existing mathematical models, but it might be possible to infer through studies of neutron-star oscillations. Similar to asteroseismology for ordinary stars, the inner structure might be derived by analyzing observed frequency spectra of stellar oscillations.

On the basis of current models, the matter at the surface of a neutron star is composed of ordinary atomic nuclei crushed into a solid lattice with a sea of electrons flowing through the gaps between them. It is possible that the nuclei at the surface are iron, due to iron's high binding energy per nucleon. It is also possible that heavy element cores, such as iron, simply drown beneath the surface, leaving only light nuclei like helium and hydrogen cores. If the surface temperature exceeds $10^6$ kelvin (as in the case of a young pulsar), the surface should be fluid instead of the solid phase observed in cooler neutron stars (temperature $<10^6$ kelvins).

The "atmosphere" of the star is roughly one meter thick, and its dynamic is fully controlled by the star's magnetic field. Below the atmosphere one encounters a solid "crust". This crust is extremely hard and very smooth (with maximum surface irregularities of ~5 mm), because of the extreme gravitational field.

Proceeding inward, one encounters nuclei with ever increasing numbers of neutrons; such nuclei would decay quickly on Earth, but are kept stable by tremendous pressures.

Proceeding deeper, one comes to a point called neutron drip where free neutrons leak out of nuclei. In this region, there are nuclei, free electrons, and free neutrons. The nuclei become smaller and smaller until the core is reached, by definition the point where they disappear altogether.

The composition of the superdense matter in the core remains uncertain. One model describes the core as superfluid neutron-degenerate matter (mostly neutrons, with some protons and electrons). More exotic forms of matter are possible, including degenerate strange matter (containing strange quarks in addition to up and down quarks), matter containing high-energy pions and kaons in addition to neutrons , or ultra-dense quark-degenerate matter.

# History of discoveries

The neutron subatomic particle was discovered in 1932 by Sir James Chadwick. By bombarding the hydrogen atoms in paraffin with emissions from beryllium that was itself being bombarded with alpha particles, he demonstrated that these emissions contained a neutral particle that had about the same mass as a proton. In 1935 he was awarded the Nobel Prize in Physics for this discovery.

In 1934, Walter Baade and Fritz Zwicky proposed the existence of the neutron star, only a year after Chadwick's discovery of the neutron. In seeking an explanation for the origin of a supernova, they proposed that the neutron star is formed in a supernova. Supernovae are suddenly appearing dying stars in the sky, whose luminosity in the optical light outshine an entire galaxy for days to weeks. Baade and Zwicky correctly proposed at that time that the release of the gravitational binding energy of the neutron stars powers the supernova: "In the supernova process mass in bulk is annihilated". If the central part of a massive star before its collapse contains (for example) 3 solar masses, then a neutron star of 2 solar masses can be formed. The binding energy $E$ of such a neutron star, when expressed in mass units via the mass-energy equivalence formula $E = mc^2$, is 1 solar mass. It is ultimately this energy that powers the supernova.

In 1965, Antony Hewish and Samuel Okoye discovered "an unusual source of high radio brightness temperature in the Crab Nebula". This source turned out to be the Crab Nebula neutron star that resulted from the great supernova of 1054.

In 1967, Iosif Shklovsky examined the X-ray and optical observations of Scorpius X-1 and correctly concluded that the radiation comes from a neutron star at the stage of accretion.

In 1967, Jocelyn Bell and Antony Hewish discovered regular radio pulses from CP 1919. This pulsar was later interpreted as an isolated, rotating neutron star. The energy source of the pulsar is the rotational energy of the neutron star. The majority of known neutron stars (about 2000, as of 2010) have been discovered as pulsars, emitting regular radio pulses.

In 1971, Riccardo Giacconi, Herbert Gursky, Ed Kellogg, R. Levinson, E. Schreier, and H. Tananbaum discovered 4.8 second pulsations in an X-ray source in the constellation Centaurus, Cen X-3. They interpreted this as resulting from a rotating hot neutron star. The energy source is gravitational and results from a rain of gas falling onto the surface of the neutron star from a companion star or the interstellar medium.

In 1974, Antony Hewish was awarded the Nobel Prize in Physics "for his decisive role in the discovery of pulsars" without Jocelyn Bell who shared in the discovery.

In 1974, Joseph Taylor and Russell Hulse discovered the first binary pulsar, PSR B1913+16, which consists of two neutron stars (one seen as a pulsar) orbiting around their center of mass. Einstein's general theory of relativity predicts that massive objects in short binary orbits should emit gravitational waves, and thus that their orbit should decay with time. This was indeed observed, precisely as general relativity predicts, and in 1993, Taylor and Hulse were awarded the Nobel Prize in Physics for this discovery.

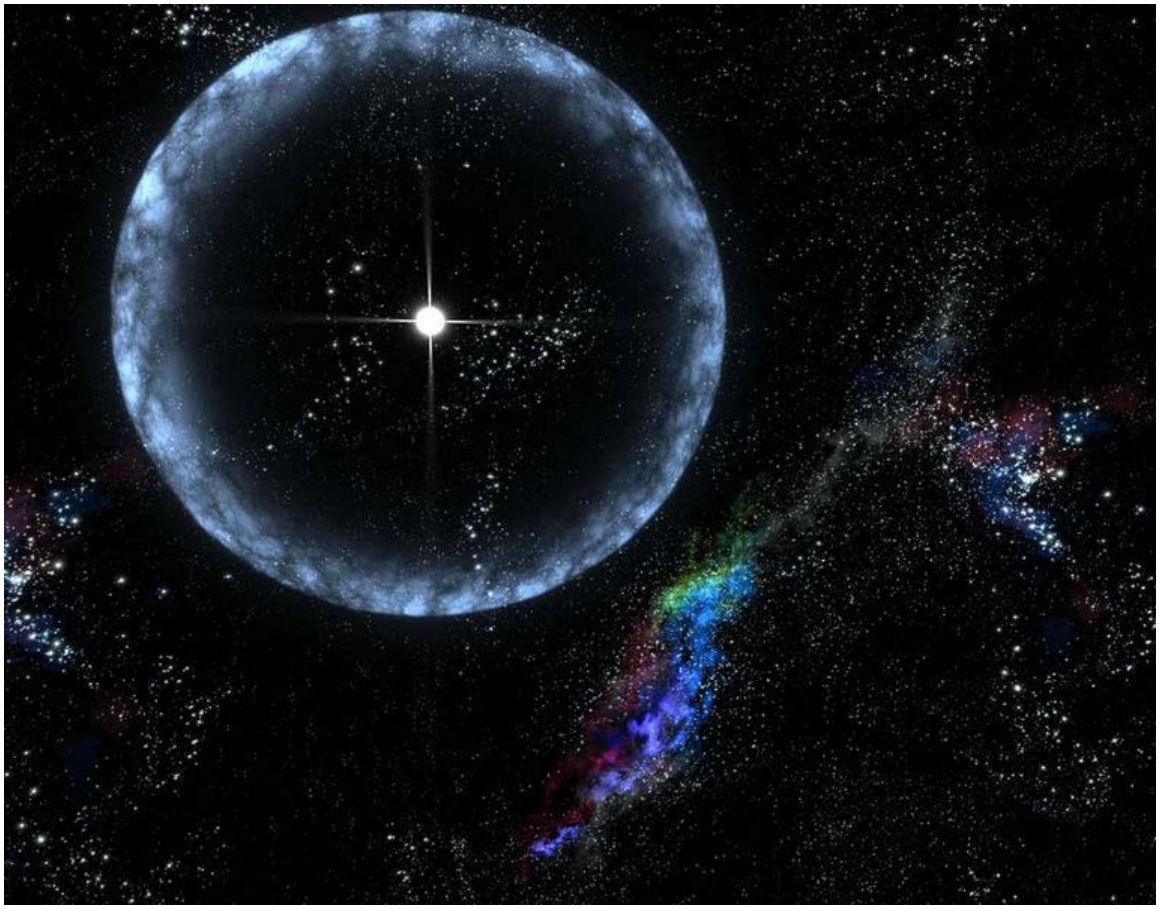
In 2010, Paul Demorest and colleagues measured the mass of the millisecond pulsar PSR J1614-2230 to be 1.97+-0.04 solar masses, using Shapiro delay. This is substantially higher than any other precisely measured neutron star mass (in the range 1.2-1.45 solar masses), and places strong constraints on the interior composition of neutron stars.

# Rotation

Neutron stars rotate extremely rapidly after their creation due to the conservation of angular momentum; like spinning ice skaters pulling in their arms, the slow rotation of the original star's core speeds up as it shrinks. A newborn neutron star can rotate several times a second; sometimes, the neutron star absorbs orbiting matter from a companion star, increasing the rotation to several hundred times per second, reshaping the neutron star into an oblate spheroid.

Over time, neutron stars slow down because their rotating magnetic fields radiate energy; older neutron stars may take several seconds for each revolution.

The rate at which a neutron star slows its rotation is usually constant and very small: the observed rates of decline are between $10^{-10}$ and $10^{-21}$ seconds for each rotation. Therefore, for a typical slow down rate of $10^{-15}$ seconds per rotation, a neutron star now rotating in 1 second will rotate in 1.000003 seconds after a century, or 1.03 seconds after 1 million years.



An artist's conception of a "starquake", or "stellar quake".

Sometimes a neutron star will *spin up* or undergo a *glitch*, a sudden small increase of its rotation speed. Glitches are thought to be the effect of a starquake - as the rotation of the star slows down, the shape becomes more spherical. Due to the stiffness of the 'neutron' crust, this happens as discrete events as the crust ruptures, similar to tectonic earthquakes. After the starquake, the star will have a smaller equatorial radius, and since angular momentum is conserved, rotational speed increases. Recent work, however, suggests that a starquake would not release sufficient energy for a neutron star glitch; it has been suggested that glitches may instead be caused by transitions of vortices in the superfluid core of the star from one metastable energy state to a lower one.

Neutron stars have been observed to "pulse" radio and x-ray emissions believed to be caused by particle acceleration near the magnetic poles, which need not be aligned with the rotation axis of the star. Through mechanisms not yet entirely understood, these particles produce coherent beams of radio emission. External viewers see these beams as pulses of radiation whenever the magnetic pole sweeps past the line of sight. The pulses come at the same rate as the rotation of the neutron star, and thus, appear periodic. Neutron stars which emit such pulses are called pulsars.

The most rapidly rotating neutron star currently known, PSR J1748-2446ad, rotates at 716 revolutions per second. A recent paper reported the detection of an X-ray burst oscillation (an indirect measure of spin) at 1122 Hz from the neutron star XTE J1739-285. However, at present this signal has only been seen once, and should be regarded as tentative until confirmed in another burst from this star.

# Population and distances

At present there are about 2000 known neutron stars in the Milky Way and the Magellanic Clouds, the majority of which have been detected as radio pulsars. The population of neutron stars is concentrated along the disk of the Milky Way although the spread perpendicular to the disk is fairly large. The reason for this spread is that neutron stars are born with high speeds (400 km/s) as a result of an imparted momentum-kick from an asymmetry during the supernova explosion process. One of the closest known neutron stars is PSR J0108-1431 at a distance of about 130 parsecs (or 424 light years). Another nearby neutron star that was detected transiting the backdrop of the constellation Ursa Minor has been catalogued as 1RXS J141256.0+792204. This rapidly moving object, nicknamed by its Canadian and American discoverers "Calvera", was discovered using the ROSAT/Bright Source Catalog. Initial measurements placed its distance from earth at 200 to 1,000 light years away, with later claims at about 450 light-years.

# Binary neutron stars

About 5% of all neutron stars are members of a binary system. The formation and evolution scenario of binary neutron stars is a rather exotic and complicated process. The companion stars may be either ordinary stars, white dwarfs or other neutron stars. According to modern theories of binary evolution it is expected that neutron stars also exist in binary systems with black hole companions. Such binaries are expected to be prime sources for emitting gravitational waves. Neutron stars in binary systems often emit X-rays which is caused by the heating of material (gas) accreted from the companion star. Material from the outer layers of a (bloated) companion star is sucked towards the neutron star as a result of its very strong gravitational field. As a result of this process binary neutron stars may also coalesce into black holes if the accretion of mass takes place under extreme conditions.

# Subtypes

- Neutron star
  - Protoneutron star (PNS), theorized.
  - Radio-quiet neutron stars
  - Radio loud neutron star
    - Single pulsars–general term for neutron stars that emit directed pulses of radiation towards us at regular intervals (due to their strong magnetic fields).
      - Rotation-powered pulsar *("radio pulsar")*

        - Magnetar–a neutron star with an extremely strong magnetic field (1000 times more than a regular neutron star), and long rotation periods (5 to 12 seconds).
            - Soft gamma repeater (SGR)
            - Anomalous X-ray pulsar (AXP)
    - Binary pulsars
        - Low-mass X-ray binaries (LMXB)
        - Intermediate-mass X-ray binaries (IMXB)
        - High-mass X-ray binaries (HMXB)
        - Accretion-powered pulsar *("X-ray pulsar")*
            - X-ray burster–a neutron star with a low mass binary companion from which matter is accreted resulting in irregular bursts of energy from the surface of the neutron star.
            - Millisecond pulsar (MSP) *("recycled pulsar")*
                - Sub-millisecond pulsar
- Exotic star
    - Quark star–currently a hypothetical type of neutron star composed of quark matter, or strange matter. As of 2008, there are three candidates.
    - Preon star–currently a hypothetical type of neutron star composed of preon matter. As of 2008, there is no evidence for the existence of preons.
    - Q star–currently a hypothetical type of heavy neutron star with an exotic state of matter. As of 2008, there is no evidence for their existence.

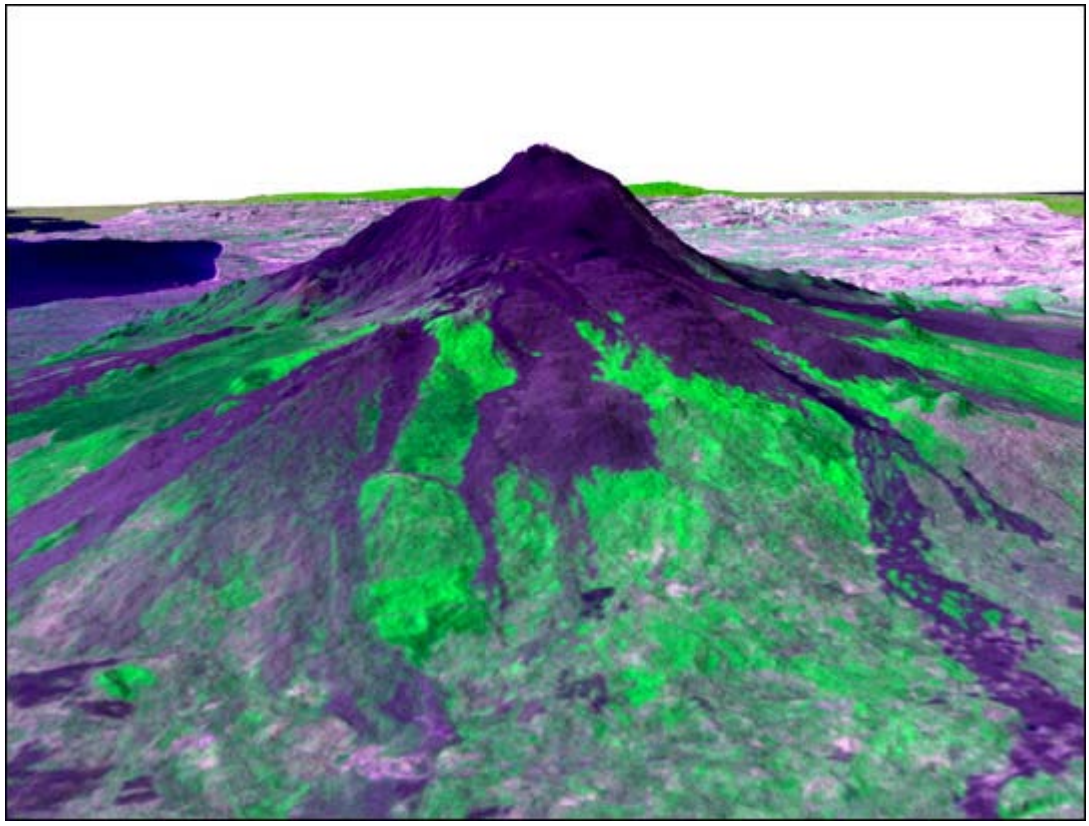
# Giant nuclei

A neutron star has some of the properties of an atomic nucleus, including density, and being made of nucleons. In popular scientific writing, neutron stars are therefore sometimes described as giant nuclei. However, in other respects, neutron stars and atomic nuclei are quite different. In particular, a nucleus is held together by the strong force, while a neutron star is held together by gravity. It is generally more useful to consider such objects as stars.

Chapter- 7

# Space Science Experiments

# Advanced Spaceborne Thermal Emission and Reflection Radiometer



ASTER image draped over terrain model of Mount Etna

**ASTER** (**Advanced Spaceborne Thermal Emission and Reflection Radiometer**) is a Japanese sensor which is one of five remote sensory devices on board the Terra satellite launched into Earth orbit by NASA in 1999. The instrument has been collecting surficial data since February 2000.

ASTER provides high-resolution images of the Earth in 15 different bands of the electromagnetic spectrum, ranging from visible to thermal infrared light. The resolution of images ranges between 15 to 90 meters. ASTER data are used to create detailed maps of surface temperature of land, emissivity, reflectance, and elevation.

## ASTER Bands

ASTER image of Rub' al Khali (Arabia's Empty Quarter).

| Band | Label | Wavelength (µm) | Resolution (m) | Nadir or Backward | Description |
|---|---|---|---|---|---|
| B1 | VNIR_Band1 | 0.520–0.600 | 15 | Nadir | Visible green/yellow |
| B2 | VNIR_Band2 | 0.630–0.690 | 15 | Nadir | Visible red |

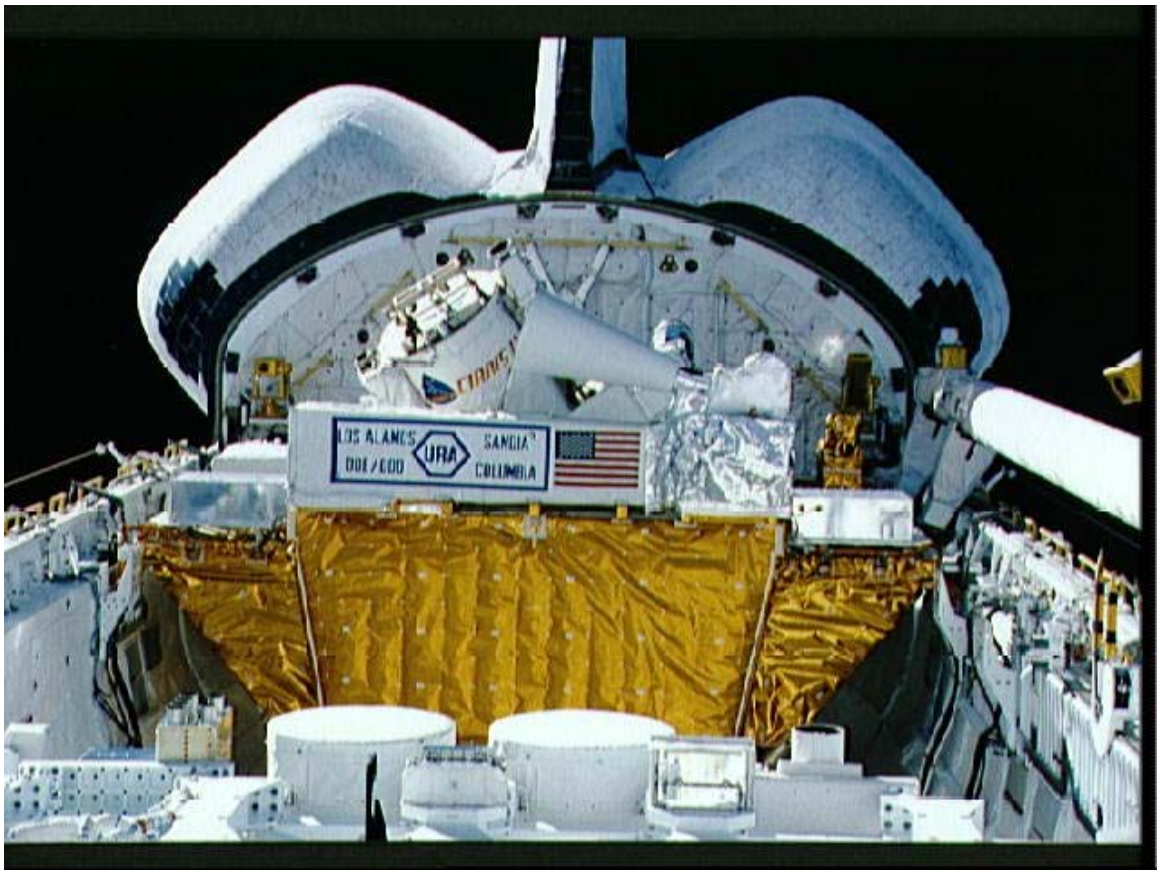
| | | | | | |
|---|---|---|---|---|---|
| B3 | VNIR_Band3N | 0.760–0.860 | 15 | Nadir | Near infrared |
| B4 | VNIR_Band3B | 0.760–0.860 | 15 | Backward | |
| B5 | SWIR_Band4 | 1.600–1.700 | 30 | Nadir | Short-wave infrared |
| B6 | SWIR_Band5 | 2.145–2.185 | 30 | Nadir | |
| B7 | SWIR_Band6 | 2.185–2.225 | 30 | Nadir | |
| B8 | SWIR_Band7 | 2.235–2.285 | 30 | Nadir | |
| B9 | SWIR_Band8 | 2.295–2.365 | 30 | Nadir | |
| B10 | SWIR_Band9 | 2.360–2.430 | 30 | Nadir | |
| B11 | TIR_Band10 | 8.125–8.475 | 90 | Nadir | Long-wave infrared or thermal IR |
| B12 | TIR_Band11 | 8.475–8.825 | 90 | Nadir | |
| B13 | TIR_Band12 | 8.925–9.275 | 90 | Nadir | |
| B14 | TIR_Band13 | 10.250–10.950 | 90 | Nadir | |
| B15 | TIR_Band14 | 10.950–11.650 | 90 | Nadir | |

# ASTER Global Digital Elevation Model

On 29 June 2009, the Global Digital Elevation Model (GDEM) was released to the public. A joint operation between NASA and Japan's Ministry of Economy, Trade and Industry (METI), the Global Digital Elevation Model is the most complete mapping of the earth ever made, covering 99% of its surface. The previous most comprehensive map, NASA's Shuttle Radar Topography Mission, covered approximately 80% of the Earth's surface, with a global resolution of 90 meters, and a resolution of 30 meters over the USA. The GDEM covers the planet from 83 degrees North to 83 degrees South (surpassing SRTM's coverage of 56 °S to 60 °N), becoming the first earth mapping system that provides comprehensive coverage of the polar regions. It was created by compiling 1.3 million VNIR images taken by ASTER using single-pass stereoscopic correlation techniques, with terrain elevation measurements taken globally at 30 meter (98 ft) intervals.

Despite the high nominal resolution, however, some reviewers have commented that the true resolution is considerably lower, and not as good as that of SRTM data, and serious artifacts are present. Some of these limitations have been confirmed by METI and NASA, who point out that the current version of the GDEM product is "research grade".

# AFP-675




The AFP-675 experiment pallet in the cargo bay. The Uniformly Redundant Array (*horn shape*) and CIRRUS 1A (*drum that reads CIRRUS*) expirements can be seen atop the pallet.

**AFP-675** (Air Force Program-675) was a Space Shuttle experiment package that was carried into orbit on *Discovery* as part of STS-39.

AFP-675 consisted of six experiment packages mounted on a pallet in the *Discovery's* cargo bay. The total weight of the package was 5,080 kilograms (11,200 lb). The objectives of the project were:

1. To obtain data in several wavelength regions to support the development of Department of Defense (DOD) systems
2. To validate technologies for DOD applications
3. To validate the use of man as an autonomous experimenter in space
4. To demonstrate the cost effectiveness of performing DOD experiments on reusable systems.

# The experiments

Mission Specialist Charles L. Veach monitors the AFP-675 panel on *Discovery's* aft flight deck.

## Cryogenic Infrared Radiance Instrumentation for Shuttle

The Cryogenic Infrared Radiance Instrumentation for Shuttle (CIRRIS 1A) experiment was designed to measure the spectral, spatial, and temporal properties of the Earth's limb (edge). The primary instruments in this experiment were a Michelson spatial interferometer and a spatial radiometer. Infrared radiation was collected through a cryogenically cooled telescope that was controlled from the flight deck. The principal investigator (PI) for the instrument was Dr. Robert R. O'Neil of the Phillips Laboratory.

## Far Ultraviolet Cameras

The Far Ultraviolet Cameras experiment was to capture imagery and photometry of naturally occurring and man-made emission phenomena such as airglow and diffuse aurora. Secondary missions were to study interplanetary and interstellar objects (such as comets and stars) and to make atmospheric density measurements by stellar occultations. The instrument consisted of two imaging cameras and a low-light-level TV camera

mounted on the same base. Like CIRRIS, they were controlled from the flight deck. Dr. George R. Carruthers, then working for the United States Naval Research Laboratory, was the PI for this experiment.

### Uniformly Redundant Array

The Uniformly Redundant Array conducted a technology demonstration of coded aperture imaging in space and the capability to form images without stabilization. The instrument was a wide field-of-view, photon-counting imaging device. Edward E. Fenimore of the Los Alamos National Laboratory was PI for this experiment.

### Gamma Ray Advanced Detector

GRAD was another technology demonstration program to test the suitability of bismuth germanate in gamma-ray detectors, the suitability of n-type, high-purity germanium gamma-ray detectors for space, the performance of an advanced gamma-ray spectrometer and to study the gamma ray background around the shuttle, as well as the gamma-ray spectrum of the sun and the Galactic Center. The instrument is non-steerable and is pointed by moving the Shuttle. Dr. C. Rester from the University of Florida was the PI.

### Horizon Ultraviolet Program

The Horizon Ultraviolet Program demonstrated the ability to measure the spatial and spectral characteristics of the Earth's horizon in the vacuum ultraviolet wavelength. The sensor was an Ebert-Fastie spectrometer telescope. F. S. Leblanc of the Phillips Laboratory was PI.

### Quadrupole Ion Neutral Mass Spectrograph

The Quadrupole Ion Neutral Mass Spectrograph was designed to support the CIRRIS 1A experiment by providing positive ion and neutral contaminant species identifications, concentrations, and temporal variabilities. The sensor package was made up of an electron impact ion source, an ion-focusing grid system, a set of quadrupole rods, and an electron multiplier. Dr. Edmond Tryczinski of Phillips Laboratory was the PI.

# Faint Object Spectrograph

The Faint Object Spectrograph (FOS). This picture was taken after FOS was brought back to the Earth again.

The **Faint Object Spectrograph** (FOS) was a spectrograph installed on the Hubble Space Telescope. It was replaced by the Space Telescope Imaging Spectrograph in 1997, and is now on display in the National Air and Space Museum in Washington DC.

# FOS facts

- **Instrument type**: Spectrograph
- **Wavelength range**: 115 to 850 nm

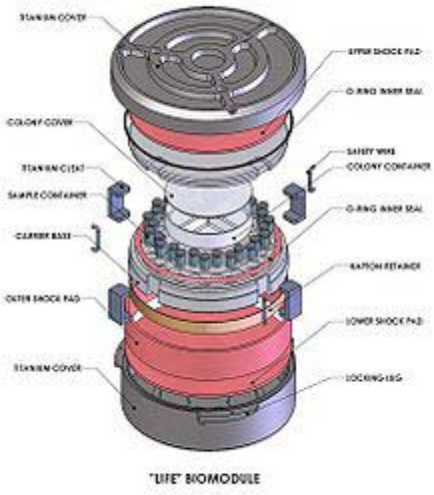
A technical description of the construction and operation of the FOS can be found in NASA technical report CP-2244. The instrument used two digicon detectors, 'blue' and 'red', and had a spectral resolution of about 1300 over the 115nm to 850nm range. It had a number of apertures of varying size, but the aberration of the HST mirror meant that, until COSTAR was installed, the smallest apertures suffered very serious loss of light; even the largest 4.3-arcsecond aperture collected only 70% of the light from a point source.

The digicons suffered from inadequate magnetic shielding, which meant that a static image was smeared over several pixels; the red digicon suffered most from this. Also,

either the blue detector or one of the mirrors in the system was contaminated in such a way as to remove sensitivity below 150nm; this was a serious problem since it makes the Lyman-alpha line at 121.6nm inaccessible.

# Living Interplanetary Flight Experiment

## Living Interplanetary Flight Experiment




'LIFE' Bio-Module

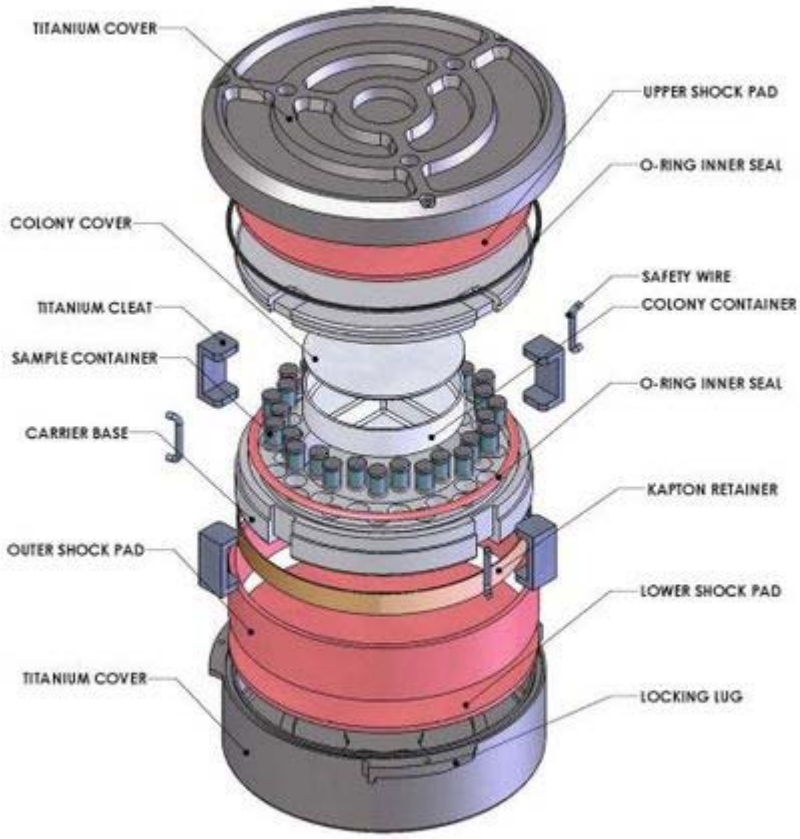
| | |
|---|---|
| **Operator** | The Planetary Society |
| **Major contractors** | Roskosmos and NPO Lavochkin |
| **Mission type** | Astrobiological experiment on board the Fobos-Grunt spacecraft. |
| **Launch date** | 2011 |
| **Launch vehicle** | Zenit rocket |
| **Mission duration** | 3 years round trip. |
| **Mass** | 100 grams or less |

The **Living Interplanetary Flight Experiment (LIFE)** is an interplanetary mission being developed by the Planetary Society. It will consist of sending selected microorganisms on a three-year interplanetary round-trip in a small capsule aboard the Russian Fobos-Grunt spacecraft in 2011, which is a sample-return mission to the Martian moon Phobos.

The goal is to test whether selected organisms can survive a few years in deep space by flying them through interplanetary space. The experiment will test one aspect of transpermia, the hypothesis that life could survive space travel, if protected inside rocks blasted by impact off one planet to land on another.

# The experiment

The project is planned to include representatives of all three domains of life: bacteria, eukaryota, and archaea. The Planetary Society anticipates transporting 10 types of organisms in 30 self-contained samples, i.e., each will be flown in triplicate for better science results. In addition, one or more natural native soil samples will be flown in their own self contained capsule. The Phobos-Soil sample return mission is the only scheduled mission that will return to Earth from deep space, far beyond the protection of Earth's magnetic field; sending biological samples through deep space is therefore a much better test of interplanetary survivability than sending the samples on a typical Earth-orbiting flight.




"LIFE" BIOMODULE

The project is being done in collaboration with the Russian Space Research Institute, the Institute for Biomedical Problems of the Russian Academy of Sciences, the Moscow State University, the American Type Culture Collection (ATCC), and the Institute for Aerospace Medicine in Germany.

## Specimens

Three fundamental guidelines governed the selection of the organisms: First, the organisms selected would represent the three domains of life – eukaryote, bacteria, and archaea. Second, the organisms should be very well studied (e.g., having their genome sequenced and studied in many other experiments) to make it possible to accurately assess the effects of the long exposure to space. If they had already been studied in space

conditions so much the better, since it would enable researchers to pinpoint precisely how organisms were affected by the years-long exposure to the interplanetary environment. Finally, a strong preference was given to organisms that appear to stand the best chance of surviving the journey. These are extremophiles, organisms that thrive in conditions that would kill the vast majority of Earthly creatures.

The 10 'passenger' organisms selected are listed below:

Bacteria

- *Bacillus safensis*
  - Discovered in JPL's 'clean' room: Spacecraft Assembly Facility . Might already be on Mars with Spirit and Opportunity .
- *Deinococcus radiodurans*
  - Is extremely resistant to radiation, will survive a dose of 5,000 Gy.
- *Bacillus subtilis*, strain MW01
- *Bacillus subtilis*, strain 168
  - Very well known from other experiments. Flew to the Moon with Apollo and had multiyear exposure in low Earth orbit .

Archaea

- *Haloarcula marismortui*
  - If Mars had an ocean, it would have been very salty. *H. marismortui* is halophilic.
- *Methanothermobacter wolfeii*
  - Mars Express has discovered methane in the Martian atmosphere. *M. wolfeii* is a methane-producing organism.
- *Pyrococcus furiosus*
  - *P. furiosus* thrives at about 100°C, it will act as a maximum temperature indicator.

Fungus

- *Saccharomyces cerevisiae* (yeast)

Plantae

- Seeds from *Arabidopsis thaliana* ('mouse-ear cress')
  - Flew to the Moon with Apollo .

Animalia

- Tardigrades ('water bears')
  - Have survived vacuum and radiation in low Earth orbit.

## Capsule design

The mass of the Bio-Module on board the Fobos-Grunt spacecraft, will be 100 grams or less. The current design is a short cylinder. The bio-module will provide 30 small tubes (3 milimeter in diameter) for individual microbe samples. It will also accommodate a native sample of bacteria—derived from a permafrost region on Earth -- within a cavity 26mm in diameter.

## Current status

The LIFE experiment is accepted for flight on the Fobos-Grunt mission. The module has passed stress tests including a shake test with vibrations at frequencies to 1,100 Hz and an impact test of 4,000 G, designed to simulate the potential impact of the capsule on Earth.

The Fobos-Grunt mission was originally scheduled for launch in October, 2009. During the year, officials admitted that the schedule was very tight, but still hoped until the last moment that a launch could be made. On 21 September, it was officially announced that the mission would be delayed to the next launch window in 2011.