

## Glossary

**absolute magnitude** | The apparent magnitude an object would have if it were at a distance of 10 parsecs. cf magnitude.

**absolute zero** | An idealized temperature at which there is no energy left in a given system. 0 Kelvin is absolute zero, which is  $-273.15^{\circ}\text{C}$ , or  $-459.67^{\circ}\text{F}$ . Modern quantum physics precludes real systems from reaching absolute zero.

**absorption** | The process by which light or other electromagnetic radiation is absorbed by an atom, giving its energy to the atom in the process.

**absorption line spectrum** | A spectrum showing dark lines in some narrow color regions (wavelengths). The lines are formed when atoms absorb the light at specific wavelengths.

**accelerate** | A change in uniform motion, either from slowing down or speeding up, or changing direction.

**accretion disk** | A disk of matter that forms when material is transferred to a small gravitating body, such as a black hole or protostar. For black holes, the disks form outside the event horizon. For other objects, such as neutron stars or protostars, the disks can extend down to the stellar surfaces. Friction (collisions) within the disks heat them and allow material to flow inward while angular momentum flows outward. Accretion disks often emit a wide range of different types of electromagnetic radiation including infrared, UV, and x-rays.

**accuracy** | In science, the closeness of a measurement of some quantity to its true value. This differs from precision.

**active galaxy** | A galaxy with a very bright, energetic nucleus. The evidence suggests that they are powered by the release of gravitational energy as material falls onto a central black hole. The range in mass from several million to several billion times the mass of the Sun. Sometimes active galaxies are called AGN, for active galactic nuclei.

**alpha radiation** | A type of radiation emitted during radioactive decay, an alpha particle is a  ${}^4\text{He}$  nucleus

**anti-particle** | The antimatter complement to a particle, mostly having identical properties to the particle, but with opposite electric charge.

**apparent magnitude** | How bright an object appears as seen by an observer. cf magnitude.

**arcminute** | A measure of angular size based on a circle. A full circle has  $360^{\circ}$ , which can be divided into 60 equal parts, each part being 1 degree. An arcminute, in turn, is one sixtieth ( $1/60$ ) of a degree.

**arcsecond** | One sixtieth ( $1/60$ ) of an arcminute.

**asteroid** | A rocky object in space that can be a few meters to hundreds of kilometers wide.

**astronomical unit** | The average distance between Earth and the Sun, equal to 149,597,870.7 kilometers. Abbreviated AU.

**atom** | A basic physical building block of matter in the Universe, which is composed of electrons, protons, and neutrons.

**atomic number** | Indicates the number of protons in the nucleus of an atom. The atomic number defines a chemical element.

**AU** | See Astronomical Unit.

**background counts** | Sources of light detected by a CCD that are extraneous to the celestial object being studied.

**band-pass** | A specific range of electromagnetic frequencies, often used to describe a satellite's viewing capabilities.

**BBN** | See Big Bang Nucleosynthesis.

**beta radiation** | A type of radiation emitted during radioactive decay, an electron or a positron is emitted

**Big Bang Nucleosynthesis (BBN)** | The processes in the early Universe that created the lightest chemical elements. Also, the period of time over which these processes were active.

**Big Bang Theory** | The theory that suggests that the Universe at early times was compressed into an extremely hot, dense state. Then, for reasons currently unknown, the universe expanded and cooled to its present condition, and it continues to expand and cool at the present time.

**big chill** | An end-of-Universe scenario where galaxies continue to move away from each other and the temperature of the universe continues to cool.

**big crunch** | An end-of-Universe scenario where gravitational attraction causes galaxies to eventually start moving toward each other.

**big rip** | An end-of-Universe scenario where dark energy becomes so strong that the expansion rips apart galaxies, even at the atomic level.

**binary** | The word binary simply means there are two of something. When applied to a star system, it means that two stars orbit their common center of mass.

**binary star system** | A system of two stars, very close to each other, that orbit around their common center of mass. Such systems are quite common.

**binding energy** | The energy required to break up an atomic nucleus into its constituent protons and neutrons.

**black hole** | A region of space within which the force of gravity (space-time curvature) is so strong that nothing, not even light, can escape from it.

**blackbody** | A theoretical object that is a perfect absorber and emitter of electromagnetic radiation. Such an object would emit so-called blackbody radiation.

**blackbody radiation** | Radiation produced by a blackbody. The intensity at each wavelength follows a distribution that depends on the temperature of the object.

**blackbody spectrum** | The spectrum of the radiation emitted by a blackbody depends upon the temperature of the black body. cf. blackbody radiation.

**blueshift** | An apparent shift of spectral lines in the radiation emitted by an object toward shorter wavelengths. Often caused by motion of the object toward the observer, or vice versa. See also Doppler effect.

**brightness** | The amount of light an observer sees emitted from an object like a star. Brightness is measured in watts per square meter ( $\text{W}/\text{m}^2$ ).

**brown dwarf** | A cosmic object that is too small to be a star and too large to be a planet. Brown dwarfs have the same composition as stars, but because of their low mass are unable to sustain nuclear fusion at their cores (assuming that they ever manage to get fusion started).

**bulge** | The central region of a spiral galaxy.

**causality** | the idea that some events are the direct cause of other events, and that the cause must precede its effect.

**CCD** | See charge-coupled device.

**chameleon particles** | A hypothetical particle which is postulated as a dark energy candidate. The particle is chameleon-like in that its mass can change.

**charge-coupled device (CCD)** | An instrument that can act as a camera sensor. It works by converting the light that falls onto it into electrical signals in individual picture elements (pixels), which are generally arranged in a square array.

**chronometer** | A watch that has been specifically designed to keep very accurate time.

**coefficient** | A number that multiplies another number or expression.

**coma** | The cloud-like ball of gas and dust surrounding a comet's nucleus.

**comet** | Dusty bodies of ice that orbit a star. We typically imagine comets with their characteristic tails, but the tails only form when comets approach close to a star. Comets have three distinct tails: the dust tail is composed of dust pushed out by radiation pressure from the star, the ion tail is composed of particles evaporated by solar winds and pushed back, and a tail of sodium escapes from the dust. The sodium tail is not visible to the naked eye. These tails point in slightly different directions but always away from the star.

**concordance model** | Our currently accepted and most commonly used cosmological model.

**conservation of energy** | a physical law that says that energy cannot be created or destroyed. Because of this law, any naturally occurring physical process can only transfer energy from one part of a system to another part; the total energy must remain the same.

**constellation** | A region in the sky that has been officially defined by the International Astronomical Union. Constellations are used by astronomers to designate a region in the sky, similar to the way countries are used to designate regions on Earth. Most constellations, especially in the Northern Hemisphere, have historical origins related to the myths of Ancient Greece.

**continuous spectrum** | A spectrum that is an unbroken range of wavelengths. An object emitting some light in every wavelength, such as a blackbody, produces a continuous spectrum.

**continuum** | See continuous spectrum.

**convergence point** | The point on the horizon where parallel lines seem to converge. In astronomy, it is the point to which an extended object such as a star cluster seems to converge as it moves away from the observer. If the motion is toward the observer, then the object seems to expand away from the convergence point.

**cosmic distance ladder** | A hierarchical process used by astronomers to determine the distances to very distant astronomical objects based on known distances of similar objects that are closer.

**Cosmic Microwave Background (CMB)** | This is the radiation left over from the big bang. It was produced early in the age of the universe, when the average density and temperature were much higher than today. The expansion of the universe has cooled the radiation to its current temperature of about  $2.7^{\circ}\text{K}$ .

**cosmic rays** | high-energy charged particles from outer space. These include protons, neutrons, atomic nuclei, and subatomic particles.

**cosmology** | The astrophysical study of the history, structure, and evolution of the universe.

**critical density** | A special value of density that causes the Universe to have zero curvature.

**dark current** | The small but detectable charge that accumulates in a CCD, even when it is not exposed to light. This is a source of noise in astronomical instruments that must be removed.

**dark energy** | a hypothetical form of energy or property of space that causes the expansion rate of the universe to accelerate.

**dark matter** | Making up approximately 80% of the matter in the Universe, dark matter does not appear to radiate or absorb any light and is only detectable indirectly by the effect its gravity has on visible objects.

**dark nebula** | cold, relatively dense clouds of interstellar gas and dust

**data** | The factual information a scientist collects that is related to the hypothesis he or she is testing. Data can be direct measurements of properties, for example, the height of plants one month after seeds have been planted. Data can also be observations of patterns, for example, the behavior of animals when they encounter a predator. To determine whether a particular measurement or observation is a rule rather than an exception, a scientist will often repeat measurements or observations to gather additional data.

**degeneracy** | A combination of values having the same properties.

**density** | A measure of how much matter is packed into a given volume. High-density objects have more material packed into a given volume than low-density objects.

**detector** | A device, or devices, used to capture photons, or in some cases, other particles like protons, electrons, etc.

**diffraction grating** | Parallel slits or grooves etched on an optical surface that cause light to bend and create an interference pattern after passing through the grating. This spreads the light out into a rainbow of colors.

**disk** | A thin, roughly circular plane in which the majority of stars, gas, and dust of a spiral galaxy are contained.

**distance** | The length of space between two objects.

**Doppler effect** | The Doppler effect is the apparent change in the wavelength and frequency of sound or light depending on whether the source is moving toward or away from you. The faster you or the source is moving, the more profound the impact. You may have experienced an example of this with sound waves if you have ever heard a higher pitch sound from a car moving toward you, and a lower pitch noise when it is moving away.

**Doppler shift** | The shift in the frequency or wavelength of a wave due to the Doppler effect.

**dust** | mixture of molecules, such as silicates, graphite, iron, and other compounds

**dwarf galaxy** | A galaxy that contains somewhere around several billion stars, as opposed to the hundreds of billions of stars found in a large galaxy like the Milky Way.

**dwarf planet** | An astronomical object that orbits its parent star and that has enough mass for gravity to make it spherical in shape, but has not cleared its orbital path of debris.

**ecciptic** | The name given to the plane in which the Earth travels as it orbits the Sun.

**electromagnetic (EM) radiation** | Another term for light, including visible light and invisible forms from radio up through gamma-rays. See electromagnetic spectrum.

**electromagnetic (EM) spectrum** | This is the continuum of waves of light, which range from very low-frequency and low-energy radio waves to very high-frequency and high-energy gamma rays. The kind of light we are familiar with is visible light, which is a tiny sliver in the middle of the EM spectrum.

**electromagnetic force** | The electromagnetic (or EM) force is one of the four known universal forces, along with gravity and the strong and weak nuclear forces. The EM force holds all the molecules and cells in your body together and is the result of interactions between charged particles (protons and electrons) within the atoms and molecules.

**electromagnetic waves** | Another term for light. Light waves are fluctuations of electric and magnetic fields in space.

**electron** | A fundamental subatomic particle that is commonly found in the outer regions of an atom and is negatively charged. Electrons are a type of lepton.

**electron cloud** | The region around the nucleus of an atom that the electrons occupy.

**electron volt** | A unit of energy.  $1 \text{ eV} = 1.602 \times 10^{-19}$  joules. It is the energy gained by an electron (or a proton) falling through an electrical potential difference of one volt. Visible light photons have energies of about one electron volt.

**element** | A substance that is composed of a single type of atom.

**elementary particle** | A particle which is not made up of any other particles or substructure, such as quarks and leptons.

**elliptical galaxy** | These galaxies range in shape from nearly spherical to flattened disks. They are characterized by an old population of stars and have very low rates of star formation, meaning very few stars are being born in them. Ellipticals contain little or no cool gas or dust.

**emission** | The production of light, or more generally, electromagnetic radiation, by an atom or other object.

**emission line spectrum** | A spectrum consisting of bright lines at certain wavelengths separated by dark regions in which there is no light.

**emission nebula** | clouds of hot interstellar gas that emit light

**energy** | Energy is the ability to do work. The SI unit for energy is the joule (J), where  $1 \text{ J} = 1 \text{ kg (m/s)}^2 = 1 \text{ N m}$ . The eV (see electron volt) is another common unit of energy:  $6.242 \times 10^{18} \text{ eV} = 1 \text{ J}$ . Joules are also related to watts (W), the SI unit for power, via:  $1 \text{ W} = 1 \text{ J/s}$ . One exploded ton of TNT is equivalent to  $4.2 \times 10^9 \text{ J}$ , or  $2.6 \times 10^{28} \text{ eV}$ .

**entropy** | a physical measure of the disorder of a system, often computed by measuring the number of possible configurations of the system.

**error ellipse** | A region on a plot that covers all allowable values for the specified cosmological parameters given the measurement uncertainties.

**escape speed** | The minimum speed required to escape the gravitational pull from a massive object.

**eV** | See electron volt.

**event** | in special relativity, an event is a location (t, x, y, z), in spacetime, that describes the position and time of an occurrence.

**event horizon** | The region near a black hole where the escape speed becomes the speed of light. Anything that crosses the event horizon cannot escape the gravitational pull of the black hole.

**evolve** | To change over time.

**excited state** | An energy state in a quantum system that lies above the lowest available state, or ground state. In an atom, an electron that has gained energy and moved from its lowest state into a higher energy state is said to be in an excited state. The atom must release energy, often by emitting a photon, for the electron to return to the ground state.

**exponent** | The value to which a base number is raised. For example, in the number  $10^4$ , the 4 is the exponent, 10 is the base.

**extra-solar planet** | A planet that orbits a star other than the Sun and is therefore not within our Solar System.

**field bosons** | Fundamental particles of integral spin (0,  $\pm 1$ ,  $\pm 2$ , etc) that carry force between other particles. Sometimes called *field bosons*. One example is the photon, which carries the electromagnetic force. Another is the gluon, which carries the strong nuclear force.

**filter** | A device that can be placed in front of a camera that lets certain wavelengths of light pass through and blocks other wavelengths.

**flux** | A measure of the amount of energy given off by an astronomical object per unit time per unit area. Because the energy is measured per time and area, flux measurements make it easy for astronomers to compare the relative energy output of objects with very different sizes or ages.

**frame (of reference)** | in physics, a frame of reference refers to the coordinate system used to conduct measurements, actual or imagined. These coordinates could be fixed to a laboratory that is stationary on Earth, or they could be on a moving object like a plane flying through the air. They could even be on some other planet, or even on an imagined spaceship that travels between the planets or stars. All measurements are only meaningful if referred to some standard of measure in some frame of reference.

**frequency** | A property of a wave that describes how many wave patterns, or cycles, pass by a point in a given time. Frequency is often measured in hertz (Hz), where one hertz is one cycle per second.

**fusion** | The process of merging multiple objects into one. In nuclear fusion, light atoms are forced together to form heavier atoms. For instance, hydrogen can be fused to form helium. Helium in turn can be fused into the heavier atom carbon, and so on. This process releases large amounts of energy and is what powers stars. However, fusion requires very high temperatures. That is why a tube of hydrogen or helium gas in a laboratory will not spontaneously undergo nuclear fusion.

**galaxy** | A gravitationally bound system of stars, their satellites, dust, gas, and dark matter that contains a supermassive black hole at its center. There are three general types of galaxies; spiral, elliptical, and irregular.

**galaxy cluster** | A group of two or more galaxies that are bound by gravity.

**galaxy halo** | A spherical distribution of stars, with very low density, in which galaxies are embedded. Different than dark matter halo.

**gamma** | The factor in special relativity by which time and space are stretched or compressed by relative motion. Also, the ratio of the energy of a particle to its rest energy. The gamma factor depends on the relative velocity between reference frames approximately equal to  $x$  for small angles  $x$  (when  $x$  is measured in radians).

**gamma rays** | The very highest energy end of the electromagnetic spectrum, with the shortest wavelengths. Gamma rays typically have energies a few hundred times larger than low-energy x-rays and wavelengths shorter than a few hundred picometers (pm,  $10^{-12}$  m).

**gas** | atoms and small molecules, primarily hydrogen

**gas giant** | A planet that is at least five times as massive as Earth and comprised mostly of gases, such as hydrogen and helium.

**Gedankenexperiment** | German, “thought-experiment.” These are illustrative scenarios used to guide one’s thinking when considering physical situations, especially when thinking about relativistic systems. These were often employed by Albert Einstein when developing his physical intuition regarding problems related to relativity.

**GeV** | Gigaelectron volt, or 1 billion electron volts.

**Giga (prefix)** | A billion,  $10^9$ . Denoted as G, e.g., GeV.

**globular clusters** | Exceptionally dense, spherical clusters of old stars that are gravitationally bound, located in galaxy halos.

**gluon** | A subatomic particle that carries the strong nuclear force between quarks.

**gravitational constant** | See Universal Constant of Gravitation.

**gravity** | The universal force of attraction between all matter.

**Great Red Spot** | A giant cyclone that has existed on Jupiter for at least 300 years. It is not known whether it will ever disappear.

**greatest elongation** | When the Sun, Earth and a planet interior to Earth’s orbit are positioned such that the planet appears as far as possible from the Sun in the sky as seen from Earth. Only Venus and Mercury can attain such a configuration.

**ground state** | The ground state is the lowest energy state available in an atom or other quantum system.

**H-R diagram** | See Hertzsprung-Russell diagram.

**half-life** | The average time required for half of a sample of radioactive atoms to decay

**halo** | See dark matter halo or galaxy halo.

**helium-3** | A form of helium that has 2 protons and 1 neutron. He-3, which is used in nuclear fusion research, is rare on Earth.

**hertz** | Abbreviated “Hz”. The derived SI unit of frequency, defined as cycles per second.

**Hertzsprung-Russell diagram** | A plot of the brightness of stars versus their surface temperature or spectral class. Abbreviated to H-R diagram.

**histogram** | A graph that displays the density of data, generally the frequency of occurrence of a range of events, such as the frequency of photons of specific wavelengths striking a detector per second (example histogram below). A familiar use of a histogram is the “bell curve” used to show the distribution of grades on a test, for example.

**HST Key Project** | Hubble Space Telescope (HST) had several chief missions, called Key Projects. One such mission was to accurately determine the extragalactic distance scale, beginning with galaxies in the Virgo Cluster.

**Hubble’s Law** | The relationship between the recession velocity of a galaxy and its distance from the observer. The farther away a galaxy is from an observer, the faster it is moving away. The law is named for Edwin Hubble, who first published it in 1929 (Proc. Nat. Acad. of Sci, Vol 15, March 15, 1929).

**hydrostatic equilibrium** | The state in a fluid, such as the gas in a star, or the atmosphere or ocean of a planet, in which the compressional force of gravity is everywhere offset by the outward force of pressure in the fluid.

**Hz** | See hertz.

**image processing** | The process by which data gathered from a CCD or other electronic imaging detector are converted into images that can be interpreted by an astronomer.

**imaging** | Scientific technique that results in photographic or computerized representations of data.

**imprecision** | Lack of precision or repeatability. cf. precision.

**inertial frame** | a frame of reference that moves at constant velocity. An inertial frame does not change its speed or direction.

**infrared light** | Abbreviated “IR”. The band of the electromagnetic spectrum intermediate between optical and microwaves, with wavelengths in the micron ( $\mu\text{m}$ ,  $10^{-6}\text{m}$ ) range. Infrared is correspondingly more energetic than microwaves, but less energetic than optical.

**intensity** | See flux.

**International System of Units** | Abbreviated SI Units, also called the metric system, it is the scientific standard of carefully defined units of measurement. The SI unit of length is the meter, of time is the second, and of mass is the kilogram. Many other units are used to measure other quantities.

**invariance (invariant)** | see Principle of Invariance.

**Inverse Square Law** | A relationship that states that the flux, or apparent brightness, of an object decreases as the inverse of the square of its distance to the observer.

**ionization** | The process of stripping electrons from an atom.

**ionized gas** | see Plasma.

**irregular** | A galaxy that does not fit into any of the other categories (spiral or elliptical).

**isotopes** | Atoms with the same number of protons but different numbers of neutrons.

**jovian planets** | Jupiter-like planets that do not have solid surfaces. They are composed primarily of helium and hydrogen. They typically have radii larger than 10,000 km (6,213.7 miles) with a mass over  $1 \times 10^{25}$  kg. These gaseous planets also have rings and many moons.

**k** | See kilo.

**K** | See Kelvin.

**Kelvin** | The SI unit for temperature. The temperature at which water freezes on the surface of Earth is 273.15 kelvin, and the temperature that water boils is 373.15 kelvin. Zero on the Kelvin scale is the theoretical point where all motion ceases in classical thermodynamics (absolute zero). The name honors the 19th century Scottish physicist William Thomson, who is more commonly known as Lord Kelvin.

**keV** | 1 kilo electron volt is equal to 1,000 electron volts, and is a unit of energy convenient for describing x-ray energies.

**kg** | See kilogram.

**kilo (prefix)** | A thousand;  $10^3$ . Denoted as k, e.g., keV.

**kilogram** | Abbreviated “kg”. The SI unit of mass. The kilogram is the only SI unit still maintained by a physical artifact (a platinum-iridium bar) kept in the International Bureau of Weights and Measures at Sevres, France. One kilogram is equivalent to 1,000 grams or about 2.2 pounds; the mass of a liter of water.

**kilometer** | A unit for measuring length, one thousand meters. Abbreviated km.

**Kuiper belt** | The region of the solar system past Neptune, from approximately 30 AU to 100 AU. Objects in this region are called Trans-Neptunian Objects (TNO).

**length contraction** | the distortion of measured lengths between inertial frames. Observers in different inertial frames will measure distances along the direction of relative motion between their frames to be longer in their own frame than in any frame moving with respect to their own.

**lepton** | A fundamental particle with little mass, or possibly no mass in some cases. Electrons, muons and taus are all leptons, as are their associated neutrinos.

**light speed** | See Speed of Light.

**light-hour** | The distance that light travels in a vacuum in one hour, approximately equal to one billion kilometers ( $1 \times 10^9$  kilometers).

**light-minute** | The distance that light travels in one minute, which is approximately 18 million kilometers ( $1.8 \times 10^7$  km).

**light-year** | The distance that light travels in one year, which is about 10 trillion kilometers ( $9.45 \times 10^{12}$  km). Light-years are a convenient unit of measure for most astronomical distances.

**lookback time** | The delay of time, due to the finite speed of light, required for light to travel from its source to its observer. The lookback time for terrestrial objects is negligible, but for astronomical objects, it grows with their distance, from about 8 minutes for light from the Sun to billions of years for distant galaxies.

**luminosity** | The amount of energy an object, like a star, radiates per unit time. This is usually measured in watts, just like a light bulb.

**magnification** | The process of enlarging the appearance of an object through various optics and lenses.

**magnitude (astronomy)** | A measure of brightness. Counterintuitively, the brighter an object is, the lower its magnitude. A first magnitude star is about 2.5 times as bright as a second magnitude star, and so on. The brightest object in the sky is, of course, the Sun, with a magnitude of -26.73. The full moon is -12.6, and with the naked eye, we can see all the way down to about a magnitude of 6. The brighter stars in the sky are around magnitude zero, with the brightest, Sirius, having a magnitude of about -1.5.

**magnitude system** | See magnitude.

**main sequence** | Abbreviated “MS”. The region of a Hertzsprung-Russell diagram, running diagonally from hot and bright to cool and dim, stars that appear in this region derive their energy solely from hydrogen fusion. The MS contains roughly 90% of all stars.

**main sequence fitting** | Determining cosmic distances by comparing the main sequence regions in H-R diagrams of different star clusters.



**main sequence star** | A star that is actively fusing hydrogen into helium in its core. The inward gravitational force due to the mass of the star is balanced by the outward thermal pressure generated by nuclear fusion.

**main sequence turn-off point** | Refers to the point at which stars leave the main sequence in the H-R diagram as they exhaust the hydrogen in their core.

**mass number** | The total number of protons and neutrons in an atom.

**masses** | A measure of the inertia of an object and also of the strength of its gravitational interactions, with larger masses having greater inertia and stronger gravitational interactions. Mass is related to how much “stuff”—in the form of protons and neutrons—an object is made of, and is only changed by changing the amount of this stuff.

**meteor** | The flash of light we see when a solid object falls into our atmosphere and disintegrates. These objects vary in size from as small as sand to many meters in diameter. The largest reach the ground before burning up and create impact craters when they land. The pieces of rock or metal that remain are called meteorites.

**meteor shower** | When we see a large number of meteors in a relatively short time, created when Earth passes through a cloud of dust left over from the pass of a comet. For example, during its peak, observers might notice one or two meteors a minute from the Perseid meteor shower that occurs each year around August 12.

**meter** | Abbreviated “m”. The fundamental SI unit of length, defined as the length of the path traveled by light in vacuum during a period of  $1/299,792,458$  s. A unit of length equal to about 39 inches. A kilometer is equal to 1000 meters.

**metric system** | See International System of Units. The metric system uses Celsius rather than Kelvin for temperature, but is otherwise the same as the International System of Units.

**MeV** | Megaelectron volt, or 1 million electron volts.

**micro (prefix)** | One-millionth;  $10^{-6}$ . Denoted as  $\mu$  (Greek lowercase mu), e.g.,  $\mu\text{m}$ .

**microwave** | A region of the electromagnetic spectrum between infrared and radio. The energy of microwaves is a bit higher than radio waves. Their wavelengths are therefore shorter and are typically measured in centimeters (cm or  $10^{-2}$  m).

**Milky Way** | Common name for the galaxy in which our Solar System is located.

**milli (prefix)** | One-thousandth;  $10^{-3}$ . Denoted as m, e.g., mm.

**model** | A simplified explanation of how a natural system works that is based on empirical evidence and logic. To be useful, a model should make testable predictions. See also theory.

**molecular cloud** | A giant region of diffuse gases that can be several hundred light years across. They are composed mostly of molecular hydrogen, with helium and a few other elements dispersed throughout. Internal gravitation in colder denser regions of the cloud can trigger collapse and star formation. In addition to molecular hydrogen, molecular clouds contain molecules like CO, CH<sub>4</sub>, NH<sub>3</sub>, HCN, CH<sub>2</sub>O and others.

**molecule** | Two or more atoms held together by chemical bonding.

**moon** | A celestial body that orbits a planet or smaller body. See also satellite.

**moving cluster method** | A method for determining the distances to clusters of stars that employs geometry and trigonometry to determine the cluster distances. This method would be useful just outside the boundary of using the parallax method.

**multi-wavelength astronomy** | The study of the Universe in all ranges of the electromagnetic spectrum, from radio waves to gamma rays.

**muon** | a subatomic particle similar to, but more massive than, an electron.

**natural satellite** | See moon.

**nebula** | Plural, nebulae. Interstellar clouds of dust and gas, from the Greek, for *cloud*.

**nebulae** | Singular, nebula. Interstellar clouds of dust and gas, from the Greek, for *cloud*.

**neutrino** | An elementary particle that has an extremely small mass and only very weakly interacts with matter. The neutrino is part of the lepton family of particles. The majority of neutrinos detected on Earth come from the Sun.

**neutron** | One of the particles that makes up the nucleus (center) of atoms and has no charge. Neutrons are composed of three quarks.

**neutron star** | The collapsed core of a massive star, composed mostly of neutrons. Neutron stars are very small, with a diameter of about 10 kilometers. They have an enormous mass for their size, ranging from 1.4 solar masses to a bit more than twice that.

**Newton’s constant** | See Universal Constant of Gravitation.

**nuclear fission** | The process by which heavy elements split apart into lighter ones. For instance, uranium nuclei can be split into two nuclei, each of which is roughly half the mass of the original uranium nucleus.

**nuclear fusion** | The process by which lighter elements like hydrogen and helium fuse together to make heavier elements like lithium, carbon, oxygen, etc.

**nuclear reaction** | The process by which the nucleus of an atom gains or loses neutrons and protons.

**nuclei** | Singular, *nucleus*. The central core of an atom, composed of neutrons and protons.

**nucleus** | Plural, nuclei. The central core of an atom, composed of neutrons and protons.

**observatory** | A facility that includes a telescope, either on the ground or in space.

**Oort cloud** | A region of space where long period comets originate, approximately 50,000 AU from the Sun.

**open cluster** | Loosely associated stars, numbering in the hundreds, that have formed together in the same cloud, but have not yet had time to drift apart.

**open universe** | A universe with no dark energy that does not contain enough mass to counteract its expansion; Omega is less than 1.

**optical** | The band of electromagnetic radiation that we can see with our eyes. It is intermediate in terms of energy and wavelength, between ultraviolet and infrared. Wavelengths range from approximately 400 to 750 nm, and energies are about one eV.

**orbit** | The path followed by a moon, planet, artificial satellite or other body, as dictated by gravity.

**cosmological constant** | A constant term that can be added to Einstein’s equations; works in the opposite direction to the gravity due to mass-energy; causes space to expand rather than contract.

**oxidation** | The combination of a chemical element with oxygen.

**parallax** | The apparent shift in position of a relatively nearby object compared to a more distant background as the location of the observer changes. Astronomically, it is half the angle that a star appears to move as Earth orbits from one side of the Sun to the other.

**parsec** | A unit of distance used by astronomers. An object one parsec away will exhibit a parallax of one arcsecond. One parsec equals about 3.3 light-years.

**particle** | See subatomic particle.

**period** | Time required for cyclic motion to repeat. For instance, the period of Earth to turn once around its axis is 24 hours, while the period for Earth to travel once around the Sun is 365 days. We would say that Earth has a *rotation period* of 24 hours and an *orbital period* of 365 days.

**photo-excitation** | The process by which an electron in an atom absorbs the energy from a photon and is excited to a higher energy state.

**photoelectric effect** | An effect whereby materials are induced to emit electrons when light shines onto them. The effect was explained in 1905 by Einstein by employing a particle theory of light.

**photometry** | The measurement of the brightness of astronomical objects. A standard result of photometry is the light curve (a plot of brightness versus time).

**photon** | A quantum (particle) of light or electromagnetic energy. Photons have zero rest-mass and no electric charge.

**pico (prefix)** | One-trillionth;  $10^{-12}$ . Denoted as p, e.g., pm.

**Planck spectrum** | See blackbody spectrum.

**Planck’s constant** | A fundamental physical constant denoted by  $h$ . It has the value  $6.626196 \times 10^{-34}$  J s.

**planet** | Meaning “wanderer” in Greek, a celestial body that is massive enough for its own gravity to form itself as a spheroid but is not massive enough to begin thermonuclear fusion. Planets orbit a star or stellar remnant and have cleared their orbital paths of debris.

**planetary nebula** | Plural, nebulae. The expelled outer layers of low-mass stars, ionized by the ultraviolet radiation of a central white dwarf.

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**plasma** | A gas that contains charged particles. It is composed of electrons that have been stripped from atoms, and the resulting positively charged particles called ions.

**precision** | The expected range of uncertainty of a physical measurement. Repeatability of that measurement. Precision differs from accuracy.

**Principle of Invariance** | this principle states that the spacetime separation of two events is a constant in Special Relativity, or in other words, that it is the same for all inertial frames of reference.

**proper motion** | The angular change in position of an astronomical object over time as seen from Earth. Measured in arcseconds per year.

**proton** | One of three subatomic particles that make up an atom. Protons are positively charged and located in the nucleus of an atom. Protons are composed of three quarks.

**protostar** | A young star that is still accreting matter from an accretion disk and that is enshrouded in a cloud of gas. A protostar is the earliest stage of a star's life, before it has even grown large enough to start nuclear fusion in its core.

**pulsar** | A type of magnetized spinning neutron star that emits a flash of light from a bright spot, like a lighthouse. Since the bright spot on the star's surface only points at us some of the time, it looks to us like it is pulsing on and off, hence the name pulsar.

**Pythagorean Theorem** | a theorem that relates the sides of a right triangle, stating that the square of the hypotenuse of the triangle (the side opposite the right angle) is equal to the sum of the squares of the other two sides. The theorem takes its name from the Ancient Greek philosopher and mathematician Pythagoras.

**quantized** | Discrete. For example, electrons in atoms, rather than having continuous energies, can only have a set of discrete or quantized energies, but not others.

**quantum** | Plural, quanta. A discrete minimal unit that is valid for physical systems. Photons, for example, are quanta of light.

**quantum mechanics** | The branch of physics that deals with the properties and behaviors of atoms and subatomic particles.

**quantum system** | A system that must be analyzed using quantum mechanics.

**quark** | A type of elementary particle that combines to make neutrons, protons and other types of particles. There are six types of quarks, along with their anti-particle pairs. Three quarks combine to make neutrons and protons.

**quintessence** | A hypothetical form of non-constant dark energy postulated as an explanation of the observation of an accelerating rate of expansion of the Universe; involves a decaying energy field.

**radial velocity** | The velocity of an object along the observer's line of sight.

**radian** | A unit of angular measure, 1 radian = 57.3 degrees.

**radiation** | Energy emitted in the form of waves (example: light) or particles (example: electrons).

**radio waves** | The name given to the lowest energy region of the electromagnetic spectrum. Radio waves have wavelengths of meters (m), or even kilometers (km).

**radioactive** | An atom that is unstable and will break apart to become a new element, releasing energetic particles.

**radioactivity** | The natural or artificial process by which the nucleus of an atom is unstable and thereby breaks apart (decays) to become a new element. The decay process is accompanied by emission of energetic particles.

**redshift** | This is the name given to the apparent change in the wavelength of light due to the Doppler effect. Scientists know what the regular spectrum of a galaxy should look like (based on the spectrum of light emitted from known elements). If the light waves from a galaxy appear to have shifted towards higher frequency (blue), it is moving towards us, and if they have shifted toward a lower frequency (red), it means the object is moving away.

**redshift (cosmological)** | This is the name given to the apparent change in the wavelength of light due to the expansion of the Universe. The cosmological redshift is denoted by the letter  $z$ , and it is defined such that the Universe has expanded by an amount  $1+z$  over the time the light has traveled to us. So an object with redshift  $z=1$  is seen when the Universe was half its present size (it is twice as big as when the light was emitted), if  $z=2$  the Universe is three times bigger than when the light was emitted, if  $z=3$  the Universe is four times bigger, and so on.

**reference frame** | see frame.

**relativistic** | systems in which relativity is important, generally because the velocities are an appreciable fraction of the speed of light.

**relativistic gamma** | The factor in special relativity by which time and space are stretched or compressed by relative motion. Also, the ratio of the energy of a particle to its rest energy. The gamma factor depends on the relative velocity between reference frames approximately equal to  $x$  for small angles  $x$  (when  $x$  is measured in radians).

**resolution** | The fine-ness of a measurement. For example, a camera with a high resolution has the capability of capturing a more detailed image than a camera with a lower resolution.

**rest energy** | See rest mass.

**rest energy** | the energy a particle has in its rest frame, which depends on the particle's mass and the speed of light.

**rest frame** | a frame that is not moving with respect to an observer making measurements in it. We say that the observer is at rest in such a frame.

**rest mass** | The mass of an object measured when it is at rest relative to the observer measuring it.

**rotate** | turns on its own axis

**satellite** | A natural or man-made object that orbits a planet or other object.

**scale** | A ratio between the measurement of an object or event and its representation within a model. The scale can be represented as  $1:X$ , where one is "one unit on the model" and is equal to  $X$  units in the actual system. On some maps, there is a scale that reads "one inch equals 10 miles" or something similar.

**scientific notation** | Using base-ten exponential form, e.g.  $2.04 \times 10^4$  kg for 20,400 kg, to write numbers, especially very large or very small numbers.

**second** | Abbreviated "s". The fundamental SI unit of time, defined as the period of time equal to the duration of 9,192,631,770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium-133 atom. There are 60 seconds in each minute and 3600 seconds in each hour of time.

**Second Law of Thermodynamics** | a physical law that says that the total entropy of a system must always increase.

**SI Units** | Abbreviated SI Units, also called the metric system, it is the scientific standard of carefully defined units of measurement. The SI unit of length is the meter, of time is the second, and of mass is the kilogram. Many other units are used to measure other quantities.

**singularity** | A place in the center of a black hole where the equations describing the mass density and gravitational force become infinite.

**sky brightness** | Extraneous light in the sky that is a result of scattered light from ground sources, light emitted from the atmosphere itself (perhaps due to its reaction with cosmic rays), and light from unresolved background sources.

**small angle approximation** | A mathematical approximation which amounts to  $\tan(x)$  and  $\sin(x)$  being approximately equal to  $x$  for small angles  $x$  (when  $x$  is measured in radians).

**small angle formula** | See small angle approximation.

**SNR** | See supernova remnant.

**solar wind** | The term given to the stream of charged particles that are ejected from the Sun's atmosphere. One of the effects of the interaction of solar wind and Earth's atmosphere is a creation of beautiful light patterns in sky known as auroras.

**solar/star system** | Defined as a system of celestial objects such as planets and asteroids orbiting one or more stars. When capitalized (Solar System), indicates the system associated with Earth and the Sun.

**sources of error** | Factors that can introduce errors into measurements and experiments. One of the most common sources of error originates in the instruments themselves.

**spacetime** | the four-dimensional system employed in special relativity that merges three spatial dimensions with one dimension of time and describes all events as points in that system:  $(t, x, y, z)$ . Three coordinates,  $x, y$ , and  $z$  describe the position of an event in space, and one,  $t$ , describes its position in time.

**spacetime diagram** | a simplified schematic representation of spacetime that generally shows the time axis as vertical with one axis of space being horizontal. The other two spatial dimensions are usually suppressed for simplicity. The diagrams are useful for understanding the relationship between events as seen by different observers in special relativity.

**Special Theory of Relativity** | Commonly called special relativity, the theory that predicts the behavior of objects moving at speeds close to the speed of light. One assumption of Special Relativity is that the speed of light in a vacuum is always constant.

**spectra** | Singular, *spectrum*. The distribution of intensity (i.e., number) of photons as a function of energy. Equivalently, it could be photon intensity distribution versus either wavelength or frequency.

**Spectral Class** | See stellar spectral classification.

**spectrograph** | Scientific instrument used to measure a spectrum.

**spectroscopy** | The scientific technique in which the intensity of light of different colors or wavelengths is measured. Comparing the measurements at different wavelengths can help to determine, for example, which elements are present in the light source.

**spectrum** | Plural, spectra. The distribution of intensity (i.e., number) of photons as a function of energy. Equivalently, it could be photon intensity distribution versus either wavelength or frequency.

**speed** | The distance ( $d$ ) covered by a moving object in a given time ( $t$ ). Mathematically, speed,  $s$ , is given by  $s = d/t$ . Differs from velocity in that velocity takes account of direction, not just how fast something moves.

**speed of light** | In a vacuum, denoted as " $c$ ", the speed of light is 299,792,458 m/s in all frames of reference, regardless of their relative states of motion.

**spin** | The quantum mechanical property of a particle that is analogous to the classical angular momentum (like a spinning top). For particles, the spin is always quantized and is either integral (for bosons) or half-integral (for fermions).

**spiral arms** | See spiral galaxy.

**spiral galaxy** | A galaxy whose primary feature is a flattened disk with long spiraling arms that extend out from a central core or bulge. The arms contain many massive young stars, a sign of high rates of star formation there.

**standard candle** | A celestial object that has a known inherent luminosity. Because these objects have a known luminosity output, their distances can be measured using their apparent brightness and the fact that brightness of an object falls as the inverse-square of distance from the object.

**standard ruler** | An astronomical object whose physical size is known. Using the known size and the small angle approximation, it is possible to determine the distance to the object.

**stellar nurseries** | Giant molecular clouds in galaxy, in which the density and temperature of the gas are such that parts of the clouds collapse under their own gravity to form new stars.

**stellar spectral classification** | A system in which stars are given a classification of O, B, A, F, G, A, K, or M based on their pattern of spectral absorption lines, which is related to their surface temperatures. O stars are the hottest and M stars are the coolest.

**strong nuclear force** | The force between quarks that keeps protons and neutrons bound within the nucleus. The force is also responsible for binding the nuclei themselves.

**subatomic particles** | Particles smaller than an atom, such as neutrons, protons and electrons, as well as other smaller particles like quarks, neutrinos, etc.

**supermassive black hole** | A black hole with mass on the order of millions or billions of solar masses. There is strong evidence that all large galaxies contain such black holes in their cores, including our own Milky Way, which contains a 4-million solar mass black hole at its center.

**supernova** | Plural, *supernovae*. The explosive collapse of the core of an evolved star. In massive stars, this collapse forms a neutron star or black hole. Under some circumstances low mass stars can also undergo supernovae as the result of the explosion of a particular type of white dwarf.

**supernova remnant** | The gas expelled during a supernova explosion, as well as the material swept up by that gas.

**supernovae** | Singular, *supernova*. The explosive collapse of the core of an evolved star. In massive stars, this collapse forms a neutron star or black hole. Under some circumstances low mass stars can also undergo supernovae as the result of the explosion of a particular type of white dwarf.

**tangential velocity** | In astronomy, the velocity of a star perpendicular to our line of sight, i.e., its velocity in the plane of the sky.

**telescope** | Optical instruments used to see great distances. Although originally telescopes were handheld, today they include both ground- and space-based varieties. Some examples are 10-meter motor-driven optical instruments, such as the Keck telescopes in Hawaii; the 27 antenna Very Large Array (VLA) radio observatory in New Mexico; and the orbiting Fermi Gamma ray Space Telescope some 550 km above Earth.

**temperature** | Most commonly a measure of the average energy of a particle in a system. Measured in kelvin (K) in the SI system.

**Tera (prefix)** | A trillion;  $10^{12}$ . Denoted as T, e.g., TeV.

**terrestrial** | “Earth-like” planets. They are made mostly of rock, have solid surfaces, and typically have a mass comparable to Earth’s. They generally have only one or two moons, if any. From the Latin, *terra*, meaning Earth.

**theory** | A conceptual framework that has explanatory and predictive power related to some aspect of the world. Theories generally encapsulate many experimental results and observations of the world into a coherent logical structure that makes testable predictions about related phenomena. For instance, Newton’s theory of gravity explains the motions of the moon and falling objects on Earth, and makes predictions about the motions of other planets in the solar system as well as stars and galaxies.

**time** | A measure of how long it takes something to happen (an event’s duration).

**time dilation** | The slowing of clocks that are in motion relative to an observer when compared to clocks at rest with respect to the observer. Predicted by Einstein’s Special Theory of Relativity.

**time dilation** | the distortion of time between inertial frames. Observers in different inertial frames will measure time to pass more quickly in their own frame than in any inertial frame moving relative to their own.

**Trans-Neptunian Objects** | Trans-Neptunian Objects—Minor planets that orbit the Sun interior to the Kuiper Belt.

**transit** | When a planet passes in between Earth and the Sun such that the planet is seen to cross the face of the Sun. Only Mercury and Venus can undergo transits. Also, the passage of an extrasolar planet across the face of its star.

**turbulent flow** | Chaotic or disorganized motions within a fluid.

**Type 1A supernova** | The explosion of a carbon-oxygen (C-O) white dwarf that has accumulated enough material from a companion star to exceed the Chandrasekhar mass limit.

**ultraviolet (UV) light** | Electromagnetic radiation intermediate between the blue/violet end of visible light and x-rays. Ultraviolet radiation is more energetic than visible light but less than x-rays. Ultraviolet wavelengths are typically about 100 to 3800 nanometers (nm,  $10^{-9}$  m).

**uncertainty** | The range of likely errors based on measurements of a given quantity, generally denoted as plus/minus ( $\pm$ ) error-range and depending upon the experiment and measurement techniques. For example, a measurement listed as  $6 \pm 1$  mm might be expected to have a true value of anywhere from 5 to 7 mm.

**uncertainty principle** | The position and the velocity of an object cannot both be known to perfect precision simultaneously; similarly, the energy and lifetime of virtual particles cannot both be known to perfect precision simultaneously.

**uniform motion** | Moving with a constant speed and direction.

**Universal Constant of Gravitation** | Denoted as capital G. The constant of proportionality in Newton’s law of universal gravitation. It plays an analogous role in Einstein’s general relativity. It is equal to  $6.67428 \times 10^{-11} \text{ m}^3 / \text{kg} \cdot \text{sec}^2$ .

**Universe** | Everything that exists, including Earth, planets, stars, galaxies, and all that they contain; the entire cosmos.

**vacuum energy** | The energy content of “empty” space; one possible explanation for the cosmological constant.

**variable** | A value that can change. For instance, the brightness of a pulsar changes depending on whether or not its beam of light is pointing toward us when we are looking at it, so its brightness is variable. Often in mathematical expressions, some parameters are allowed to change, and are thus variable.

**velocity** | How fast an object moves in a given direction, i.e., the speed of an object in a given direction. Velocity differs from speed because speed is how fast something moves without regard to direction.

**visible light** | Electromagnetic radiation at wavelengths which the human eye can see. We perceive this radiation as colors ranging from red (longer wavelengths;  $\sim 700$  nanometers) to violet (shorter wavelengths;  $\sim 400$  nanometers.) Also called optical light.

**wavelength** | The distance between adjacent peaks in a series of periodic waves. Also see electromagnetic spectrum.

**worldline** | The path taken by a particle through spacetime. This line connects all the events in the particle’s history and future.

**x-ray** | High-energy electromagnetic radiation. X-rays are more energetic than ultraviolet light but less energetic than gamma rays. The energy of x-rays ranges roughly from 1 keV up to a few hundred keV. Their wavelengths are from about 10 nm down to about 10 pm.

$\pm$  | “Plus/Minus,” indicates the range of uncertainty of a value, e.g.  $10.2 \pm 0.4$  kg indicates the mean value of the experiment was 10.2 kg, but there is a possibility that the true mass lies somewhere between 9.8—10.6 kg.