1. Dawn of Time

When time began, approximately 13.7 billion years ago as we humans reckon time, the Universe was created with a Big Bang, as astrophysics tells us. At that instant, all matter and energy spewed out of an infinitely hot, infinitely dense point. The Universe then expanded from that point in what might be the only perfect adiabatic expansion, which is one in which there is no exchange of energy with anything outside the system in question. Since there's nothing outside the Universe as far as we'll ever know, an adiabatic process is guaranteed. Of course, adiabatic expansion is a little simplistic as a description of the expansion of the Universe because complex subatomic processes were going on during the early moments, but it's descriptive enough for the purpose here. A primary characteristic of an adiabatic expansion is that the system cools as it expands just like a gas cools when it's released from a pressurized can. Sure enough, the Universe has been cooling ever since the moment of creation.

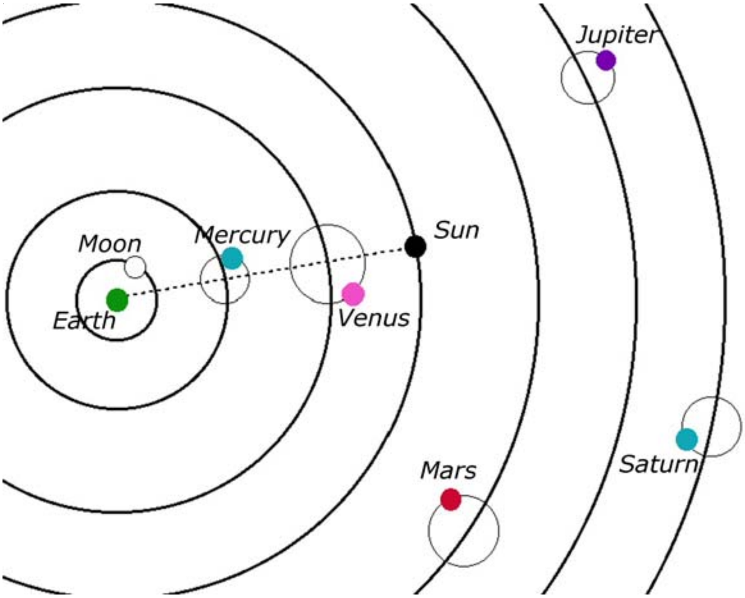
How do we know all this is true? The answer describes a long and difficult study of the Universe in which we live and rules by which it operates, rules that are called God's Laws in these pages because they were created by God at the same instant the Universe was created.

The Ancients

More than two millennia ago, people believed Earth was all there was to the Universe. What we now know to be stars were not recognized as separate bodies beyond Earth but were described as fires of gods or even gods themselves, like the Egyptian god Horus, who pulled the Sun across the sky behind his chariot. Everything circled Earth above the sky in a sort of daily procession that made day and night.

The Greeks recognized stars and planets as individual bodies but kept the ancient belief that they circled Earth as if they were inferior. Stars were believed to be embedded in a crystal sphere above the sky, while the Sun, Moon, and planets were embedded in a succession of crystal spheres between the sky and stars. All these spheres revolved around Earth at various rates. Aristarchus of Samos (c.310 to 230 BCE, Before Current Era) was the only one of the ancients who believed Earth revolved around the Sun; everyone else believed Earth to be stationary and, thus, center of the Universe because they couldn't feel Earth move. That was one of the many times in history when the clamor of the ignorant multitude shouted down the truth. Our knowledge of the cosmos remained Earth centered, with minor refinements, for almost two thousand years.

Early astronomers from Aristotle (384 to 322 BCE) to Claudius Ptolemaeus (c. 100 to 165 AD, or CE, Current Era) wanted to create a theoretical planetary model that would be consistent with planetary motions they observed. (Claudius Ptolemaeus is called Ptolemy, but he is not related to Alexander the Great's general by the same name who inherited the Egyptian portion of Alexander's empire and established a line of Ptolemaic kings of Egypt.) For example, Mercury and Venus never get very far from the Sun; Mercury stays within 28 degrees of it, and Venus never strays more than 47 degrees from it. Another example is that the planets move slowly past the background of fixed stars in a regular way, but then some will reverse course and back up for several weeks. Unfortunately, the ancients were limited by Plato's idea that the circle is the perfect form and by the assumption that any system created by the gods must be perfect. So they were left with the extraordinarily difficult task of describing complex motions of planets with circles. In order to create a circle-based, Earth-centered description of the Universe, they wound up with an awkward system of circles within circles. The search for truth has always been hampered by human assumptions.



Ptolemy's System

The planets move counterclockwise in small circles called epicycles. The centers of these epicycles move counterclockwise along larger circles called deferents. The epicycles of Mercury and Venus move in time with the Sun (illustrated by the line connecting them) because they never get far from it. The main virtue of this system is that it explains why some of the planets sometimes appear to move backwards.

Copernicus to Newton

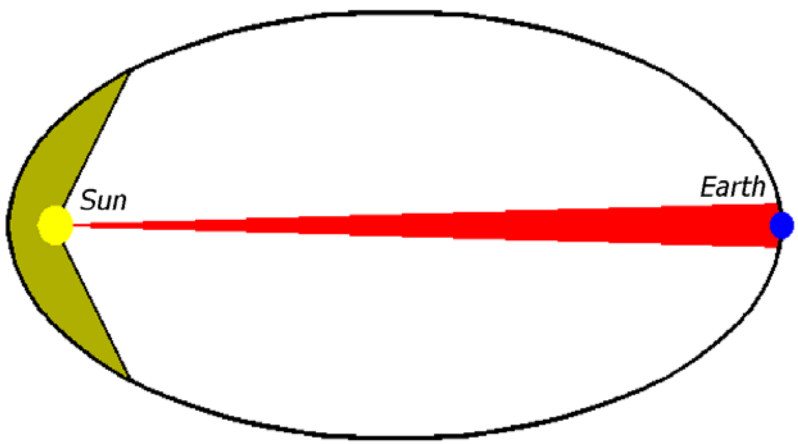
This human-centered view of the Universe was so enthusiastically accepted by the Christian Church that no other theory was proposed until Copernicus (1473 to1543) published his Sun-centered theory in 1543. Copernicus was educated in canon law of the Catholic Church and worked his entire life for the bishops of the cathedral in Frauenberg, Poland. For nineteen hundred years since the time of Aristotle, no advances had been made in our knowledge of the Universe until Copernicus. However, because Copernicus kept the circular paths of the Greeks, his system was not significantly simpler than Ptolemy's, but he did place the Sun at the center of the Universe. That heresy resulted in the Catholic church placing his book on the list of forbidden reading until it was "corrected," and even Martin Luther called him an upstart astrologer who wanted to upset astronomy, noting that scripture says that Joshua commanded the Sun to stand still, not Earth.

Some years after Copernicus died, Tycho Brahe (1546 to1601) was born to a noble family in the town of Skane in what is now Sweden but was then part of Denmark. His parents sent him to live with a wealthy paternal uncle who had no children of his own. Tycho studied at universities in Copenhagen, Leipzig, Wittenberg, Rostock, and Basel. It was at Whittenberg that he lost part of his nose in a duel with a fellow student over who was the better mathematician. For the rest of his life, he wore a metal insert to cover the damage, which was probably the inspiration for Strawn's silver nose in the movie *Cat Ballou*. King Frederick II gave him a small island near Copenhagen and enough money to build the best astronomical instruments of the time. He was able to make the most accurate measurements of planetary motion that had ever been made, but his theory of how the Universe was put together was only a crude amalgam of Ptolemy and Copernicus. Tycho put Earth at the center of the Universe with the Sun and Moon revolving around Earth; Mercury, Venus, Mars, Jupiter, and Saturn revolved around the Sun.

It was left to Johannes Kepler (1571 to 1630) to create a theoretical model of the known Universe that would agree with Tycho's magnificent measurements. (Refinement of theory to encompass increasingly precise measurements is a recurring theme in science, a recent example being Einstein's General Theory of Relativity's refinement of Newton's theory of gravity to explain discrepancies in calculations of the orbit of Mercury. Refined theory then lets scientists predict new measurements that can be made. For example, General Relativity predicts gravity can deflect light, and astronomers have measured these deflections, confirming General Relativity.) The Protestant Reformation had begun during the lifetime of Copernicus, and the Protestant church had considerable influence in the Germany where Kepler was born. Most superior minds of the millennium between the time of the Roman emperor Constantine the Great (c. 280 to 337) and the Reformation were educated by the church, and Kepler was no exception. He studied for the clergy at a Protestant seminary and at the university at Tübingen, but accepted a secular teaching position instead of ordination.

His mathematical talent came to the attention of Tycho, who invited him to be his assistant in 1600. Perhaps Tycho knew his theory was inadequate and wanted a sound mathematician to refine it, but Tycho probably wanted sole authorship. The two men quarreled frequently, and Kepler complained that Tycho would only infrequently share sparse data; Tycho was not simply going to give his life's work to a potential rival. But after Tycho died in 1601, Kepler managed to borrow the data from Tycho's relatives. Since mathematics of the early seventeenth century was inadequate to derive the equations describing planetary motion, he spent several years of trial and error in search of a way to fit those Greek circles to Tycho's data for the orbit of Mars and only with great reluctance eventually abandoned them in favor of ellipses. Once he did, calculations of the orbit of Mars closely agreed with Tycho's observations, and the age of modern astronomy had begun. Kepler published the first two of God's Laws of orbital mechanics (now called Kepler's Laws in honor of their discoverer), the elliptical orbit law and the equal area law, in 1609; the size of the known Universe grew, and our place in it shrank. Kepler was fortunate to have lived in Protestant Germany and not to have suffered the misfortune of his Italian contemporary, Galileo Galilei.

Galileo (1564-1642) began his education with the aim of becoming a physician but developed an interest in mathematics that led him to the

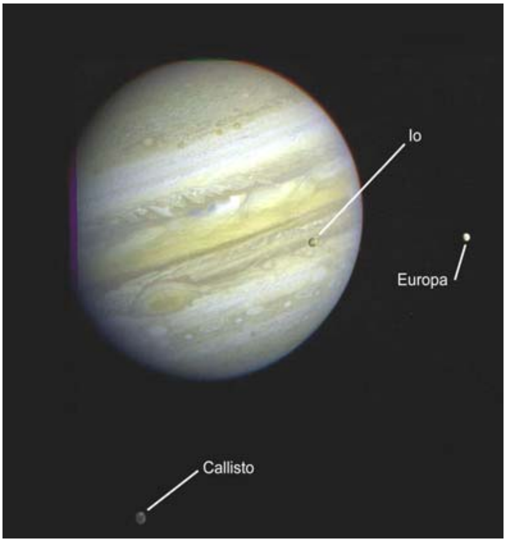


Kepler's Laws

Kepler concluded from Tycho Brahe's measurements that the planets moved in elliptical paths, exaggerated in this figure, with the Sun at one focus (First Law). The planets sweep out equal areas in equal times (Second Law). For example, the crimson area in the figure is equal to the orange area. This means that the planets move slower when they're farther away from the Sun and faster when they're closer to the Sun. These changing speeds make the planets appear to move backward sometimes.

new science of physics. He was studying motion, inclined planes, and machines when he heard of the invention of the telescope in 1609, the year that Kepler published his first two laws. Galileo put aside his other work to build telescopes, and by the end of 1609 he was observing sunspots and lunar mountains. His discovery of four satellites orbiting Jupiter was dismissed until others built their own telescopes and verified the discovery. (The rejection of new ideas until corroborating evidence is presented is another recurring theme of science.) His observations of the phases of Venus led him to believe in the Sun-centered Universe of Copernicus. In 1616, the Pope issued an edict against the Copernican system, an edict that Galileo ran afoul when he published his *Dialog* in 1632 comparing and contrasting Earth-centered and Sun-centered systems. The next year he was called to the Inquisition in Rome for violating the 1616 edict and spent the rest of his life under house arrest. In 1979 Pope John Paul II finally proposed reversing the condemnation.

Galileo died about the same time Isaac Newton (1643 to 1727) was born. Newton's birth is often given as 25 December 1642, but that date is reckoned using the old Julian calendar. In 1582, sixty years before Newton was born, most of the western world adopted the Gregorian calendar devised by Pope Gregory XIII and the astronomer Christopher Clavis (1537 to 1612). The Gregorian calendar corrected a growing difference between the Julian calendar and the seasons and refined the addition of leap days to keep the calendar in tune with the seasons. In the Gregorian calendar, Thursday, 4 October 1582, was followed by Friday, 15 October 1582. Staunchly Protestant England, however, didn't adopt the Gregorian calendar until 1752, and Newton's birthday of 25 December 1642 is according to the Julian calendar used in England at the time. Some references record his birth date as 4 January 1643, which



Jupiter and Three of Its Moons

When Galileo looked at Jupiter through his telescope, he was surprised to find four moons orbiting the giant planet. These four moons, now called the Gallean moons in honor of Galileo's discovery, he named Io, Europa, Callisto, and Ganymede. Only Ganymede is absent from this photo taken by Voyager 1 on February 5, 1979. Io, Callisto, and Ganymede are larger than our moon, and Ganymede is even larger than the planet Mercury. Anyone with good binoculars can see the Gallean moons. They'll appear as small points of light in a line on either side of Jupiter and can be identified as moons rather than stars because they'll change position from night to night compared with the fixed background stars.

corresponds to the Gregorian calendar used everywhere but England at the time.

In 1661, Newton enrolled in Trinity College, one of the group of colleges that make up Cambridge University. Remarkably, he didn't get to study Galileo's new mechanics of motion, inclined planes, and machines; Copernicas's Sun-centered astronomy; or Descartes' new algebra and analytic geometry until his third year because the first two years of education at Cambridge in 1661 focused on Aristotle. When plague closed Cambridge in 1665 and Newton returned to his birthplace in the country, he began one of the most productive 18 months in the history of science. He found that white light was not homogenous, as had been believed since Aristotle, but could be broken into a number of constituent colors by a prism. He found his studies of motion hampered by the inadequate mathematics of the time, so he expanded some ideas of Isaac Barrow, his teacher at Trinity, to create the mathematics called calculus in order to complete them. The results were his three laws of motion. By the time he published *Philosophiæ Naturalis Principia Mathematica* (Latin for "mathematical principles of natural philosophy"), simply called *Principia,* in 1687, he was able to mathematically describe the laws of gravity and motion in one grand system and use this one system to derive Kepler's laws and to describe such various phenomena as orbits of comets, causes of tides, precession of Earth's axis, and the effect the Sun has on the Moon's orbit. Newton had single-handedly forever removed Earth from the central position in the Universe and gave all modern science a sound mathematical basis. Purists enjoy pointing out that the German mathematician and philosopher Gottfried Wilhelm Leibniz developed calculus independently at the same time as Newton. In fact, the modern symbols for the operations of calculus, and even the name "calculus," were introduced by Leibniz. Newton's mathematical notation was cumbersome, and he called the processes "the science of fluxions." But Newton usually gets more credit than Leibniz because he and not Leibniz made wide use of calculus to solve a number of problems in physics and published those studies in *Principia*.

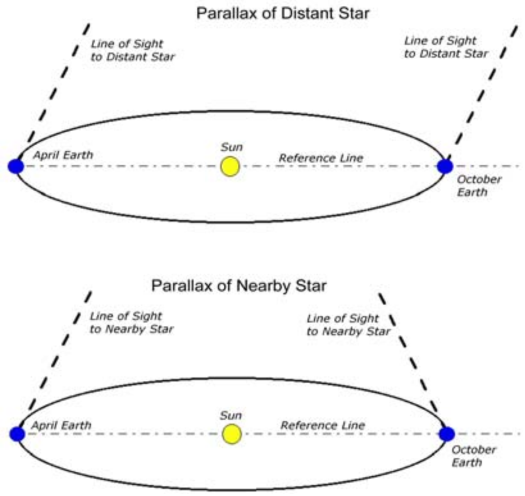
Up to the time of Newton, astronomers had focused their studies on the Earth, Moon, Sun, and planets. Stars were simply points of light even when when viewed with the best telescopes of those times, and astronomers didn't understand what they really were or how far away they were. The British astronomer William Herschel (1738-1822), who had emigrated to England from Germany when he was nineteen, even speculated that the Sun was an inhabited body like Earth but with a luminous atmosphere. Stellar astronomy began with Newton's friend Edmond Halley (1656-1742) of Halley's Comet fame although John Flamsteed (1646-1719), the first director of the Royal Greenwich Observatory, had devoted his life to creating a star catalog. Halley compared star locations recorded by Ptolemy with the latest measurements and concluded that stars have a motion of their own, called proper motion although most proper motion except for Barnard's Star is almost imperceptible.

Stargate

The quality of telescopes continued to improve as decades rolled by, finally enabling the German astronomer Friedrich Bessel (1784 to 1846) to actually measure the distance to a star: in 1838 he was able to get a parallax measurement on a star known as 61 Cygni (which means that it's the 61st brightest star in the constellation of Cygnus, the Swan), and he was then able to calculate the distance to the star. Two years later, Friedrich Georg Wilhelm von Struve, who had emigrated from Germany to Russia when he was fifteen, got a parallax measurement on Vega.

Parallax is the change in the apparent direction of a body when viewed from different places. You can see this effect by holding your finger at arm's length, closing one eye and lining your finger up with a reference point such as a corner of the room. Then look at your finger with the other eye and notice how your finger changes position relative to the reference point. By looking at your finger alternately with your left and right eye, your finger will seem to jump back and forth relative to the reference point. If you try the experiment with your finger closer to your eye, you'll notice that your finger seems to jump a greater span back and forth. The amount of parallax depends on the distance to the object (your finger in this experiment) and the distance between viewing points (the distance between your eyes). Thus, by measuring the parallax angles and knowing the distance between viewing points, distance to the object can be calculated using trigonometry.

Parallax measurements are the most basic way of measuring distances to stars. Stellar parallax measurements are made at two, widely separated times of the year, usually six months apart. For example, angular measure-



Parallax

The angle between the line of sight to a star and a reference line (the Sun line) is measured about six months apart. For distant stars these two angles are the same, and the star is too far away to calculate its distance. However, when a star is nearby, the angles measured six months apart are different (emphasized here), and the distance to the star can be calculated using trigonometry.

ments are made in April and October, and the difference in the two angular measurements (called solar parallax) along with the diameter of Earth's orbit yields distance to the star. This technique is suitable only for nearby stars because solar parallaxes for distant stars are too small to be measured. A distance corresponding to a solar parallax of one arc second of angle is called a parsec (parallax of one arc second). An arc second is an angle measure and is called an arc second to avoid confusion with a second of time. Just like the way we measure time, there are sixty arc seconds in a minute of arc and sixty minutes of arc in a degree.

Beyond the Milky Way

The size of the known Universe got a lot bigger when Bessel and Struve measured the distances to 61 Cygni and Vega, but humankind couldn't begin to get a clear understanding of the true size of the Universe until adequate telescopes were made in the twentieth century. In 1917, American astronomer Heber Doust Curtis (1872 to 1942) was observing an indistinct blob of light that was called the Andromeda nebula. Over centuries of telescope observations, astronomers had charted the position of many objects that appeared to be simply fuzzy patches of hazy light. They didn't know what these fuzzy patches were, so they just called them nebulae. As Curtis watched Andromeda, he spotted a nova (a star that suddenly grows a lot brighter) in it. By comparing the brightness of that nova with others he'd seen, he concluded that the

Andromeda Galaxy

This is a NASA Galaxy Evolution Explorer image of the great spiral galaxy in the constellation Andromeda, which is known as Messier Object 31, M31, and as NGC224. It is 780 kiloparsecs (2.5 million light-years) away and 260,000 light years across and is very similar to our own galaxy but perhaps a bit larger. The stars that fleck throughout the photograph are foreground stars in our galaxy. There is probably someone in Andromeda right now looking at a similar photograph of our galaxy.

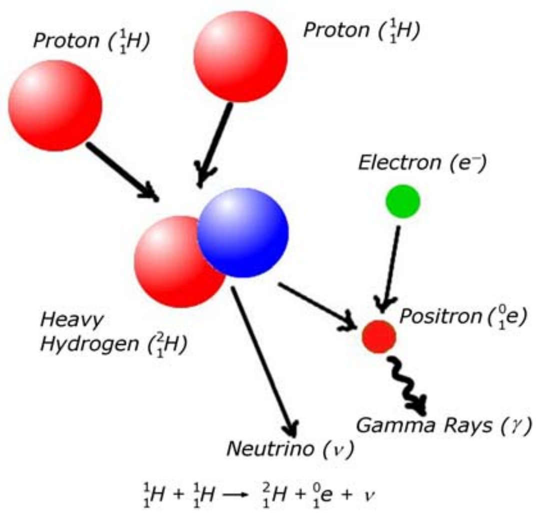
nebula must actually be a galaxy separate from the Milky Way and an incredible distance away. This was later confirmed when larger telescopes were able to identify individual stars in the outer fringes of Andromeda. Andromeda nebula became Andromeda galaxy, and the size of the known Universe suddenly grew enormously.

No one knows who saw the first nova, but Chinese astronomers reported seeing a temporarily, bright star in 185 CE, which is now called SN185 ("SN" designates a supernova, and the number simply refers to the year it was observed.). Chinese and Arabian astronomers recorded detailed observations of SN1006. Tycho Brahe reported one when he observed a new, bright star in the constellation Cassiopeia in 1572 (SN1572) and described it in his book *de Stella Nova* (Latin for "concerning the new star"), giving rise to the name nova. We now know that Tycho actually saw a supernova. Astronomers didn't know what novae were when Curtis saw that one in the Andromeda galaxy because theory (the collection of natural principles that describe how a phenomenon works) hadn't caught up with observation. But theory began to catch up during the twentieth century as George Gamow and Hans Bethe described the energy source that make stars shine. The end result of their research is a description of how novae and supernovae occur.

Gamow proposed in1929 that fusion of hydrogen nucleii was the source of a star's energy, and Bethe published a paper in 1938 that described the physics of hydrogen fusion. This hydrogen fusion idea ultimately led to the description of how a nova occurs. Novae occur only in binary star systems where the two stars are close together. Almost half the stars that we see are actually two or more bodies that orbit one another. For example, the nearest star to the Sun, Alpha Centauri (4.37 light-years away), is a binary system that's composed of an "A" and a "B" star orbinting one another. Alpha Centauri A is about 10% more massive that the Sun, and Alpha Centauri B is about 10% less massive than the Sun. [Alpha Centauri also has a third member, Alpha Centauri C (Proxima Centauri), that's a red dwarf slightly larger than Jupiter and located quite a distance from the other two such that some astronomers think it's not a part of the system at all but is merely a straggler passing through.] In a binary system like Alpha Centauri A and B, one of the two inevitably depletes its hydrogen before the other and becomes a dim burned out star (called a white dwarf because it's a small white hot star about the size of the Earth) composed of carbon and oxygen that the star's high gravity has packed tightly. As the two stars continue to orbit one another, the white dwarf pulls hydrogen off the active one. Eventually, the white dwarf accumulates enough hydrogen to begin fusion again, so it flares up for a few days until it runs out of hydrogen once more. This flare up we see as a nova. If the white dwarf is close enough to its companion, it can possibly nova repeatedly as it continues to suck hydrogen off its active partner. The time between flare ups depends on how fast the white dwarf accumulates hydrogen and generally ranges from 10 to 100 years. Among the novae that have occurred in the past century are T CorB in the constellation Corona Borealis (1866, 1946), WZ-Sag in Sagittarius (1978), TV Corvae in Corvus, RS Ophiuchi in Ophiucus (1898, 1933, 1958, 1967, 1985), and T Pyxidis (1890, 1902, 1920, 1944, 1966).

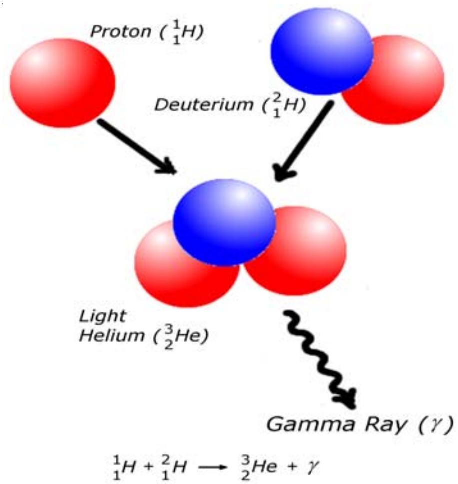
If a nova can be thought of as a rebirth, a supernova is a death: the death of a massive star. By analyzing the chemical signature of light from supernovae, observational astronomers noticed that some involved hydrogen and some didn't, so they called those that didn't involve hydrogen Type I, and those that did were called Type II. Unfortunately, the physics of supernovae (which came later) doesn't fall into such easily discernable types. One type that physics describes, called Type Ia, is the death of a white dwarf that had been a recurring nova. Every time a white dwarf goes nova, it accumulates more mass that it had pulled from its active companion. Eventually, it accumulates exactly the amount of mass necessary to begin a runaway fusion of its carbon and oxygen, detonating the star. The exact mass necessary for this runaway fusion is very specific (1.4 times the mass of the sun, or solar masses) so all Type Ia supernovae have the same detonation profile in terms of light intensity and chemical signature. That's why Type Ia supernova are easily distinguishable and can be used to determine the distances to other galaxies as long as the galaxy is close enough to see the explosion. Although the gravitational force of a white dwarf is high, it's not high enough to contain a supernova. So a Type Ia supernova disintegrates the dwarf, and the shock wave destroys its active companion, leaving nothing behind.

The rest of the supernovae types described by physics are the death of various sorts of very large, active stars. Type Ib is the death of a large star that's had most of its hydrogen and helium blown away by its stellar wind (like our Sun's solar wind), so no hydrogen or helium is involved in its final explosion. Type Ib is very similar to Type Ia, but it appears much dimmer because the gaseous envelope that surrounds an active star absorbs some



Proton-Proton Reaction

This is the first reaction in the proton-proton hydrogen fusion reactions that form helium. Two protons, which are basically hydrogen (H) nucleii (where the superscript in the figure is mass and the subscript is charge. The sums of the masses and charges on the left side of the arrow must equal those on the right.) fuse to form deuterium, also called heavy hydrogen), a positron (positive electron, also sometimes symbolized by e^+), and a neutrino (ν). The positron quickly combines with a free electron (e^-) to form gamma rays (γ). The nuclear equarion is shown at the bottom of the figure.

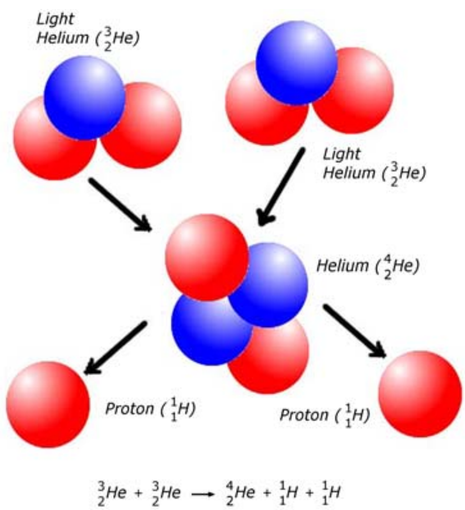


Deuterium-Proton Reaction

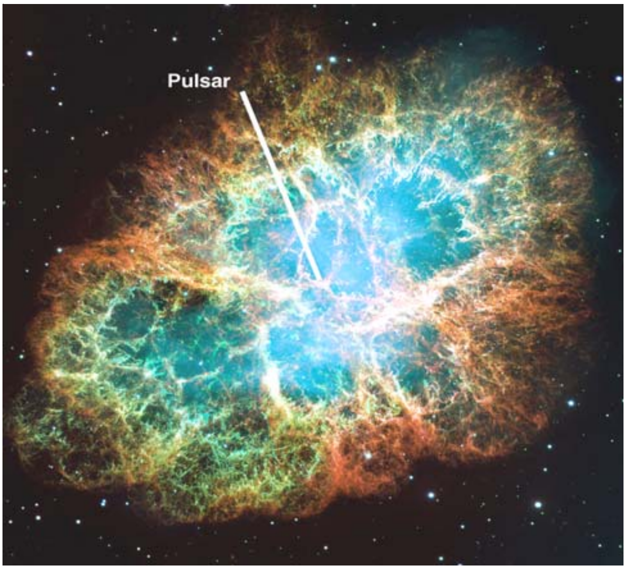
This is the second reaction in the proton-proton fusion reactions forming helium. Another proton fuses with heavy hydrogen from the first reaction to form light helium (so called because it's short a neutron compared with normal helium and is, thus, lighter in weight) and a gamma ray (γ).

Light Helum-Light Helium Reaction

This is the third and final reaction of the proton-proton fusion reactions forming helium. Two light helium nuclei from the second reaction fuse to form helium and two protons. Because two light helium nuclei are necessary to get normal helium, the first two reactions must be done twice, requiring six protons in all, to create helium and two leftover protons in this last reaction. The sum of the masses of the six original protons is greater than the sum of the masses of helium and the two leftover protons. This "lost mass" was converted to an amount of energy determined by Einstein's equation $E = m\ c^2$



of the light. Type II supernovae mark the death of a large active star that still has considerable amounts of hydrogen and helium in its surrounding envelope, so hydrogen shows up in the light's chemical signature. The enormous heat and pressure of Type Ib and Type II explosions causes one final orgy of nuclear fusion as the dying star creates all the chemical elements naturally found in the Universe. Large stars that die by Type Ib and Type II supernovae have a high enough gravitational force to retain some central mass after the explosion, and this central mass will collapse into a neutron star (a moderately large residual central mass) or black hole (a very large residual mass). The blast also ejects an expanding cloud of gaseous debris that's visible through a telescope and that contains the chemical elements created during the blast. This expanding cloud and residual central mass are clearly identifiable for centuries as a supernova remnant, and



The Crab Nebula

In 1054, the star in this Hubble Space Telescope image went supernova (SN1054), becoming extraordinarily bright before fading from sight a year later. The nebula is about 2.0 kiloparsecs (6,500 light-years) from Earth. A neutron star revolving 30 times a second, approximately located in the image, is all that's left of what must have been a very large star. This rotating neutron star has a magnetic field, and from its magnetic poles streams radiation that sweeps through space like a lighthouse beam as the star rotates. The Earth happens to be in the path of this beam, so we see this radiation as pulses as the magnetic poles sweep past us thirty times a second; hence the star is calles a pulsar. The gas cloud in the photograph contains all the elements that may one day be part of life on some future planet.

that's what helped astronomers to identify Tycho's new star as a supernova. But the nova that Curtis saw in Andromeda was too far away to see any remnants and identify whether or not it was a supernova.

By 1925, Vesco Milton Slipher had observed 41 different galaxies and noticed that wavelengths of light from excited hydrogen weren't what they should be. It had long been known that the atoms of all elements, when excited, emit light at distinct wavelengths different from each other (their chemical signature), a discovery made possible by Newton's study of light during that fateful plague year spent in the country. The light coming from Slipher's 41 galaxies had longer hydrogen wavelengths than normal; the light was shifted toward the red end of the spectrum (i.e., the range of frequencies, or wavelengths), and the amount of this redshift was different for each galaxy. The only explanation for this phenomenon is that galaxies are moving away from us, and the redshift is the familiar Doppler shift. In 1929, Edwin P. Hubble found that the amount of redshift is proportional to the distance to the galaxy. The Universe is expanding.

But that's not all. George Gamow predicted in 1949 that radiation from the Big Bang would have cooled as the Universe expanded and should be creating electromagnetic static all over the sky at a specific blackbody temperature. A blackbody is a theoretical perfect absorber and radiator of electromagnetic energy, absorbing 100% of the radiation that falls on it. No blackbody has ever been devised, although soot and carbon black can absorb up to 97% of incident radiation. The radiation spectrum of a black body depends solely on its temperature. Fifteen years after Gamow's prediction, Arno Penzias and Robert Wilson detected Gamow's radiation all over the sky while calibrating a new AT&T horn antenna, and Penzias and Wilson shared the 1978 Nobel Prize in Physics for their discovery. An expanding Universe fits all the data we have and all we know about God's Laws. Unless some new, verifiable data or some new law pops up, everything points to a Universe that's expanding from a point of creation long, long ago.

During the first tiny fraction of the Universe's first second of existence, temperatures were too hot for matter to exist, and the Universe was pure energy. Later in the first second, the Universe had cooled enough that quarks and electrons condensed out of the energy. Current theory of the composition of matter places quarks and electrons among the fundamental building blocks of matter.

Two thousand years ago matter was thought to be composed of various amounts of earth, fire, air, and water according to what type of matter it was. One man, a Greek by the name of Democritus, hypothesized that matter was made of things called atoms that were too small to be seen, but few believed him even though he turned out to be right. Again, as was true in the case of Aristarchus of Samos and has been true of others in the history of other fields, the clamor of the ignorant multitude shouted down the truth.

The atomic theory of matter was revived in the sixteenth and seventeenth centuries by Robert Boyle and Newton and in the nineteenth century by John Dalton and James Clerk Maxwell. In the late nineteenth century, J.J. Thomson found evidence for the existence of electrons, and evidence of the existence of protons and neutrons in the twentieth century led to a complete description of atoms. In the past thirty years, physicists smashed particle beams together and found that protons can break apart if their collisions are energetic enough. That was when physicists first became aware of the existence of quarks. Quarks can only exist when bound up in protons and neutrons; free quarks can exist only when their energy levels are unimaginably high such as at the birth of the universe. Around 1 millionth of a second after the Big Bang, the Universe's temperature cooled to about ten trillion degrees, and all quarks became bound into protons and neutrons. The Universe was too cool for free quarks to exist.

As the Universe continued its expansion, it cooled like a gas does when it's released from a pressurized container. About one hundred seconds into the life of the Universe, its temperature was down to the neighborhood of one billion degrees. The temperature of a system is simply a measure of the average kinetic energy (i.e., energy of motion) of all its particles or, in other words, how fast all of its particles are moving on the average. Some are going fast, some are going slow, but if you add all the speeds together and divide by the number of particles, you get an average speed for all the particles in the system. This is what temperature measures.

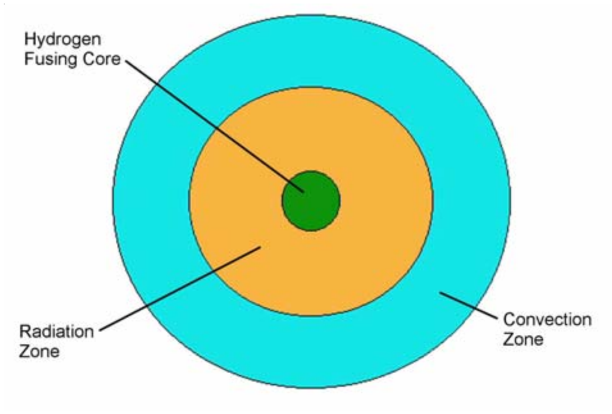
The faster the particles travel, the higher the temperature. A temperature of one billion degrees means the particles are whizzing around at blinding speeds. Thus, after one hundred seconds or so, the Universe was a thick, expanding soup of newly formed, incredibly fast moving protons and electrons. As they flew around, these protons sometimes traveled fast enough that they overcame the natural repulsion of their like electrical charges, smashed into each other, and fused together to form deuterium which, in turn, combined to form helium and, perhaps, a little lithium. These are the reactions illustrated in the figures on pages ten and eleven and are the same reactions that Gamow and Bethe suggested as powering stars.

Around three and a half minutes after the Big Bang, the temperature was down to around three hundred million degrees and synthesis of helium stopped, not because it was too cold, but because particles had become too far apart to find one another. The expanding soup was simply too thin for particles to easily smash into each other.

It took another million years for the Universe to cool to four thousand degrees, the temperaure at which free electrons can combine with nuclei to form atoms of hydrogen (73% of the mass of the measurable Universe), deuterium (trace) and helium (27%). What caused the Universe to cool down? To ask the question another way, what caused all the particles of the Universe flying out in all directions to slow down? The gravitational attraction of all the particles for each other. They all pulled on each other to slow each other down, and all the masses in the Universe are still tugging on one another and had been thought to continue slowing down the expansion. However in the late 1990s, measurements of distant galaxies suggested the the expansion of the Universe is increasing under the influence of a mysterious Dark Energy.

The force of gravity falls off rapidly as the distance between particles increases, so for the first three and a half minutes, when the Universe was a thick soup of protons and neutrons, particles attracted each other strongly and slowed each other down a lot such that the temperature fell by trillions of trillions of degrees, most of that fall happening in the first couple of minutes. As the Universe expanded, the particles attracted each other less and less such that it took a million years for the temperature to fall from three hundred million degrees to four thousand degrees. As time passes, the Universe cools more and more slowly.

For the next 100 million years, the Universe (i.e., space itself) continued to expand although, within this expanding space, hydrogen and helium atoms collected by gravitational attraction into great, nebulous clouds of gas thousands of light-years across. Somewhere in these gas clouds, denser regions gravitationally contracted further, the atoms exchanging potential energy of distance from the collection point for kinetic energy of speed (i.e., temperature); in other words, as the atoms were drawn to the collec-



Structure of a Main Sequence Star

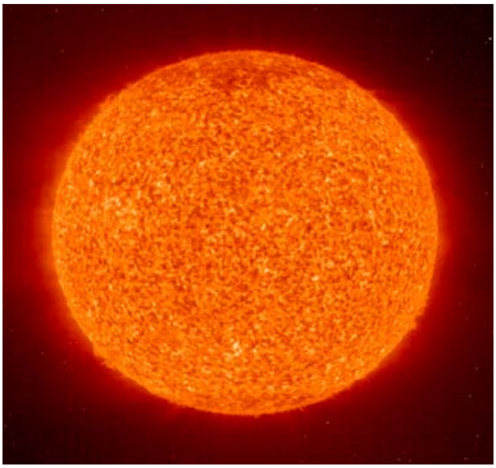
A main sequence star has a central core where nuclear fusion occurs that generates the star's energy. This energy is transported to the surface first through a radiation zone in which the particles of a dense plasma absorb and re-radiate the energy. Then the energy is carried to the surface by the vertical churning of gases in a convection zone. The relative sizes of the three zones shown in this diagram are not at all indicative of those in a typical star.

tion point, they moved faster and faster just as a ball dropped from a tower does. Eventually the temperature of the contracting gas reached 13,000,000 degrees Celsius, hot enough for proton-proton fusion reactions to begin again, making helium the same way it was made at the birth of the Universe.

As described earlier, one of the characteristics of these fusion reactions is that they release energy. Six protons go into the set of reactions, and one helium and two protons come out; thus, a net of four protons is used to make helium. The mass of the four protons that make helium is greater than the mass of the helium made. This "lost" mass is converted into energy. This energy produces an explosive force that is enough to balance the pull of gravity and stop further contraction, establishing an equilibrium between the enormous crush of gravity and the titanic nuclear explosion in the core. In this way, stars are born, and great clouds of gas became galaxies. The first galaxies formed perhaps as soon as 200 million years after the Big Bang.

When hydrogen in a star is fused at such a rate that the released energy exactly balances the crush of gravity, the star is in equilibrium and said to be on its main sequence. Since no direct observations of a star's interior are possible, we can only speculate on how a star is put together, although our speculations are probably pretty accurate because they're based on God's Laws. The structure of a typical main sequence star has been deduced by applying known rules of reality (such as the physics of nuclear reactions) to observations (such as surface appearance) and measurements (such as chemical composition and surface temperature).

Throughout the deep interior, hydrogen and helium gases are so hot that electrons are stripped from their nuclei and the gas mixture exists as a



Mottled Sun

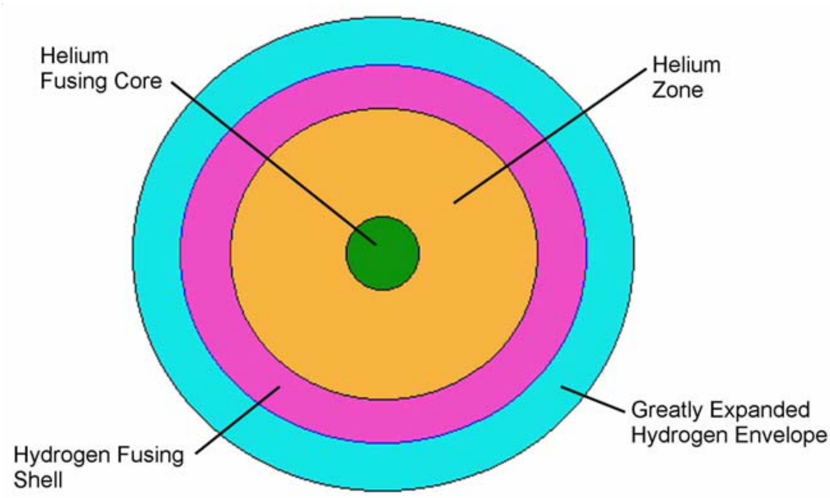
This NASA photograph taken 21 February 2009 clearly shows the Sun's photosphere during a time when it was unusually quiet (i.e., no sunspots or solar prominences). The mottled appearance is caused by the churning of the convection zone bringing bright, hot gas to the surface and returning dark, cool gas back to to be reheated by the radiation zone below.

dense, ionized plasma. The core, where the temperature is at least 13,000,000 degrees Celsius and hydrogen fusion takes place, lies at the center. Beyond the core lies the radiation zone.

Energy created by hydrogen fusion in the core crosses the radiation zone by repeated absorption and re-radiation by particles packed so tightly that each step is only a tiny, tiny fraction of an inch. The tortuous path is estimated to take as long as 100,000 years to complete, so a star generates energy faster than it can get rid of it, causing it to slowly get hotter and hotter. As the energy moves slowly outward, the radiation zone becomes progressively cooler until the temperature drops to 100,000 degrees Celsius where the radiation zone blends into the convection zone above.

Energy is carried outward across the convection zone by a continuous churning of gas up from the radiation zone to the surface where it cools, then sinks back down to the edge of the radiation zone where it's heated again. That's why the surfaces of stars such as the Sun look mottled; they're covered with pools of bright, hot gas boiled up from the interior and other pools of dark, cool gas sinking back down. The visible surface of a star is called the photosphere and is the coolest region, being only 6,000 degrees Celsius for G class stars such as the Sun.

Stars come in different classes depending on their surface temperature, which is essentially a measure of their size (i.e., their gravity) and concomitant core fusion rate. They are classed in order of decreasing temperature as O, B, A, F, G, K, and M; the letters have numbers associated with them that indicates their rank (i.e., temperature) within their class. Small stars have relatively weak gravity, so hydrogen needs only to fuse at a leisurely pace to achieve equilibrium. That's why smaller stars like the Sun can last billions of years before they run out of fuel. Giant stars have incredibly strong gravity, so fusion reactions must take place at a furious rate to produce enough explosive force to balance it. As a result, they shine blue hot and have short lifetimes even though they have a lot of hydrogen to fuse.

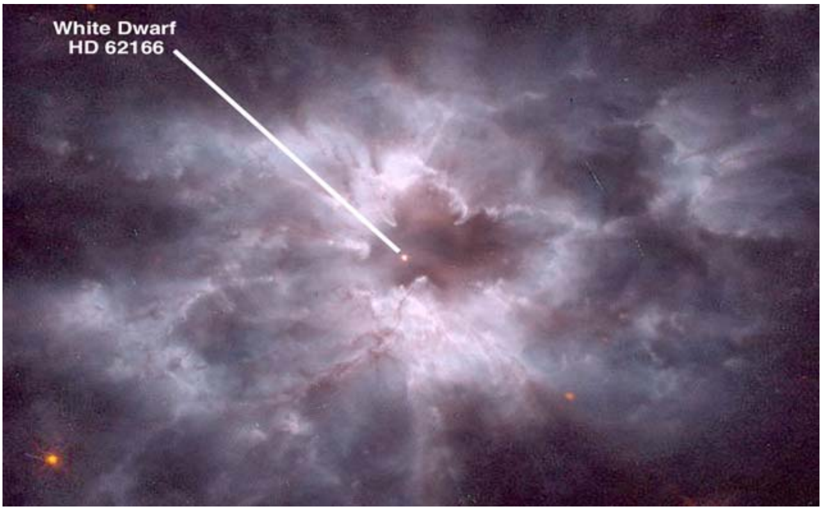


Structure of a Red Giant Star

A red giant star has at least two places where fusion happens. The core fuses helium into heavier elements at very high temperatures (around 100 million degrees), and hydrogen fuses to helium at lower temperatures (about 13 million degrees) in an outer shell. The core of very massive stars can have several layers at increasingly higher temperatures in which heavier elements such as carbon (500 million degrees), neon (1.2 billion degrees), and oxygen (1.5 billion degrees) are fused. The relative sizes of the zones shown in this diagram are not at all indicative of those in a typical star.

Rigel, the bright kneecap of the Orion constellation, is a class B blue giant with a surface temperature of about 11,000 degrees Celsius. Rigel is actually a complex of perhaps four stars that orbit one another. Blue giant stars may fuse hydrogen for only millions of years before they run out of fuel and gravity begins to crush them again as they begins their death throes. As a dying star collapses, its core temperature builds to 100,000,000 degrees Celsius, the temperature at which helium can fuse to form carbon and oxygen. The star then leaves the main sequence and achieves a new equilibrium and new life in a different form: a red giant.

The structure of a red giant is a bit more complex than that of a main sequence star. As temperature in a collapsing star rises, the outer portions eventually reach hydrogen fusion temperature, and the star begins to burn in two places: the core, where helium is fused into carbon and oxygen, and the shell, where hydrogen is fused into helium. Gravity is weaker in the shell than at the core, so hydrogen fusion in the shell can overpower it. The shell then swells, becoming less and less dense until the hydrogen fusion rate is slowed down enough to again balance gravity. As the surface of the star swells, it becomes cooler and, therefore, redder. Depending on the mass of the star, the surface could swell to the size of the orbit of Earth or even Mars. Betelgeuse, the left (as you look up) shoulder of Orion, is a prominent red giant visible in the winter sky. In fact, Betelgeuse is called a supergiant because it is almost the size of Jupiter's orbit. The cores of extremely



A White Dwarf Star

This is a NASA Hubble photograph of white dwarf HD 62166 with its planetary Nebula NGC2440 that it ejected as it reached the end of its red giant phase. The dwarf's surface temperature of 200,000 degrees Celsius is one of the hottest known. When the Sun dies around five billion years from now, it will end up something like this.

massive stars can restructure themselves several times, forming several layers at increasingly higher temperatures in which heavier elements such as carbon (500 million degrees), neon (1.2 billion degrees), and oxygen (1.5 billion degrees) are fused.

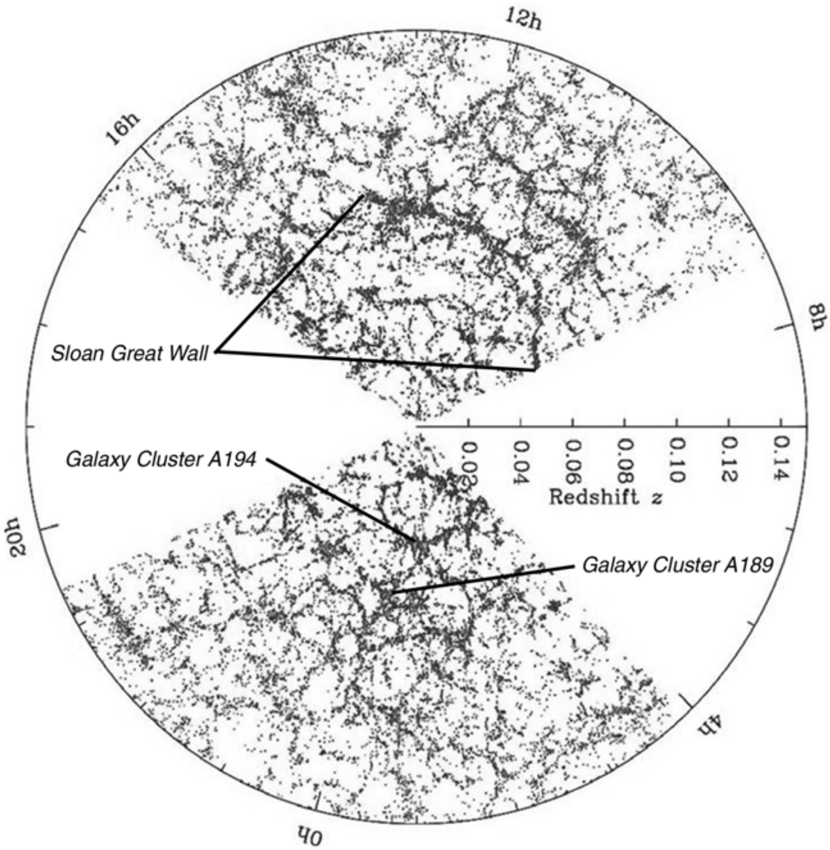
The red giant phase is much shorter than the main sequence phase because the helium supply is, at most, one fourth the original hydrogen supply. A star's death, like its life, depends on how big it is. A small star like the Sun can not get hot enough to fuse nuclei larger than helium; in other words, the carbon and oxygen nuclei, or particles, produced from helium fusion can not move fast enough to overcome the mutual repulsive electrostatic force between their positively charged protons when there are more than two protons in each particle. When small stars like the Sun run out of helium, hydrogen in the tenuous, expanded outer shell will no longer be able to find one another, fusion in the shell stops, and the shell puffs off as a planetary nebula. The core will collapse to a hot white dwarf of carbon and oxygen about the size of the Earth and begin to slowly radiate its heat to space until it eventually becomes a cold, black dwarf.

Large stars several times the Sun's mass collapse with such violence that its electrons and protons combine to form neutrons. The shock wave from the collapse creates a supernova explosion brighter than a hundred suns during which all the chemical elements are forged in one final orgy of creation; these elements are seeded into space by the force of the supernova. The mass that remains determines the star's ultimate fate. A star whose final, residual mass is twice that of the Sun ends up as a neutron star with twice the mass of the Sun squashed into a ball ten to fifteen miles in diameter. Neutron stars rotate and have magnetic fields millions of times more intense than that of Earth. The combination of rotation and magnetic field causes the stars to emit a beam of electromagnetic radiation that ranges in frequency (or wavelength) from radio waves (lowest frequencies, or longest wavelength) to X-rays (highest frequencies, or shortest wavelength) in the direction of their magnetic poles. If, like the Earth, the magnetic poles don't align with the spin axis, this radiation will sweep through space like a lighthouse beam. If the Earth happens to be in the direction of the beam, we detect this radiation as electromagnetic pulses, and the neutron star is called a pulsar. Stars with residual masses greater than three times that of the Sun end up as black holes in which the force of gravity is so great all matter is crushed down to a point.

When the Universe was young and hydrogen plentiful, massive stars and supernova were probably common, so when a gas cloud began to coalesce into the Solar system around 5 billion years ago, supernovae had already seeded the region with all the elements in the periodic table. As material streamed from the galactic disk toward the young protosun, some of it had enough energy to avoid falling directly into the Sun's gravity well and, instead, remained in solar orbit, creating the rotating gas disk from which the planets were formed. Since it was a gas disk and not a rigid disk, it broke into eddies and vortices that tended to accumulate matter.

These eddies accumulated matter the way any vortex does, forming planetesimals that subsequently accumulated to form the planets. Complex interactions between the tidal force of the Sun, chemical reactions in the hot gas disk, and the different freezing points of the various minerals that came from those chemical reactions left the inner planets rocky and the outer planets gas balls. The carbon, oxygen, silicon, phosphorous, calcium, iron, and all the other chemical elements in the gas cloud that formed the inner planets and, ultimately, life on the inner planet we call Earth came from debris the supernovae death of those first stars cast into space. As Dr. Sagan once said, "We are all made of star stuff." This story contrasts markedly with the story of Earth's creation in the early verses of Genesis, but God's Creation itself stands in quiet testimony to the truth of this story rather than Genesis for those humble enough to listen, and humility is largely what these pages are about.

The last two decades of the twentieth century witnessed enormous advances in telescopes like the Hubble Space Telescope, the Keck Observatory on Hawaii's Mauna Kea and the Very Large Telescope at the European Southern Observatory in Chile, for example. In addition, the old photographic film used to record images has been replaced by new types of electronic detectors that use digital technology such as charge-coupled devices (CCDs) like those used as "film" in digital cameras. These technological advances have prompted more than a dozen surveys of the Universe out to billions of light-years distant. These surveys have enabled Astrono-



A Sloan Digital Sky Survey Map

This is a map showing all galaxies in the very tiny part of the sky between 1.25 degrees north latitude and 1.25 degrees south latitude and out to 1 billion light years distant. Each dot is a galaxy typically containing around 100 billion stars. The blank wedges on the left and right are in the plane of the Milky Way; nothing can be seen in those directions because dust in our own Galaxy blocks visible light used in the SDSS survey although galaxies that lie in our Galactic plane can be detected using infrared. The Sloan Great Wall and galaxy clusters identified by the author, so any errors are his.

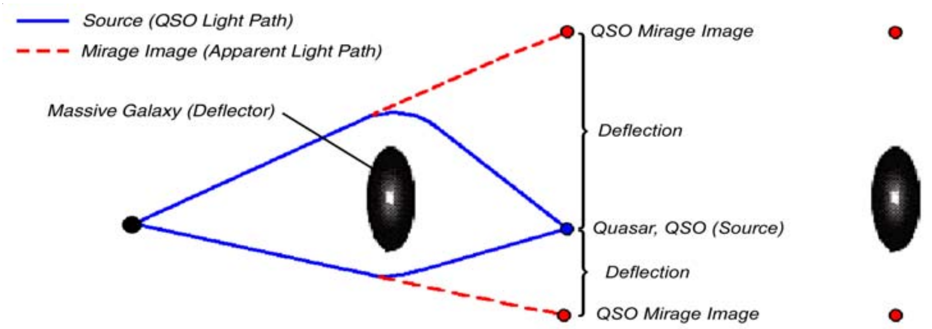
Credit: Sloan Digital Sky Survey (SDSS) Collaboration, http://www.sdss.org

mers to gain a far, far better understanding of the Universe's structure than ever before. The surveys include, among others, the Center for Astrophysics (CfA) redshift survey (which was begun by Harvard University in 1977), the Two Micron All-Sky Survey (2MASS, which was begun in 1997 and completed in 2001), and the Sloan Digital Sky Survey (SDSS, which began in 2000 and is ongoing as of 2017).

The surveys are the culmination of the phenomenal increase in our understanding of the size of the Universe (and our place in it) that has made the twentieth century arguably the Century of Astronomy. As the century opened, we didn't know of any galaxy but our own. For example, Harlow Shapley and Heber D. Curtis debated the size of the Universe in 1920, Shapley arguing that the Universe is only the size of the Milky Way galaxy and Curtis arguing that it was much larger. As the twentieth century closed, we know of a Universe billions of light years broad filled with hundreds of billions of galaxies. We know of filaments of galaxy clusters and superclusters that wind through the Universe like spider webs around vast voids, such as the Virgo and Fornax voids, hundreds of millions of light-years across. We know of great sheets of galaxy clusters such as the Great Wall and Sloan Great Wall that are many hundreds of million light-years long, several hundreds of millions of light-years wide, and tens of millions of light-years thick. The Universe is far, far more immense that our ancestors could have dreamed.

Galaxy clusters were instrumental in the discovery of dark matter, the mysterious substance that seems to form a large part of the Universe's mass. When Einstein published the General Theory of Relativity in 1916, he made the unequivocal prediction that large objects such as the Sun will deflect light, and moreover, he predicted the amount of the deflection for an object with the mass of the Sun. (Unlike psychics, whose "predictions" depend on the proper interpretation of what they've written, scientists make very specific, unambiguous predictions.) For several years, astronomers vied to be the first to make measurements of starlight deflection by the sun during a solar eclipse to verify or refute General Relativity. The measurements had to be made during a solar eclipse when the overwhelming glare of the Sun could be blocked by the Moon, making surrounding stars briefly visible. It was during a solar eclipse in South Africa in 1919 that Arthur Stanley Eddington was able to measure the deflection to be what Einstein predicted, verifying General Relativity.

Because the deflection of starlight by large masses was an essential prediction of General Relativity, Einstein was aware as early as 1912 that a large, massive, relatively nearby object that happened to be directly in line with a far distant object would deflect the light of the distant object (source)



Gravitational Lens

This diagram illustrates the geometry of a gravitational lens (left) and what an astronomer would see in a telescope (right).

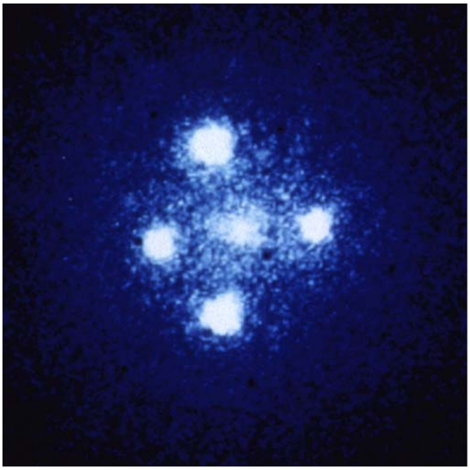
and could conceivably create multiple images (mirages) of the distant source if the alignment was just right. That sort of arrangement is called a gravitational lens. The spacing between the multiple images depends on the mass of the nearby object (the lensing object, or deflector) and the distances to the nearby deflector and the far distant source. But galaxies beyond the Milky Way were unknown at the time General Relativity was developed and the possible candidates for such an alignment were therefore quite limited, so Einstein originally thought such a geometric arrangement to be very unlikely and paid no further attention to the idea.

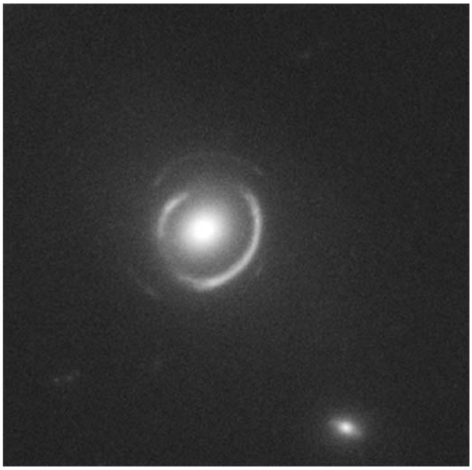
After Heber Doust Curtis and Edwin Hubble proved that what had previously been vaguely called “nebulae” were really distant galaxies separate from the Milky Way, astronomers became aware that the possibility of a gravitational lens alignment of objects might actually be reasonably good. Einstein was finally persuaded to publish a short note in a 1936 issue of *Science*, a publication of the American Association for the Advancement of Science, describing the gravitational lens. Astronomers then carried the idea further than Einstein’s short note. For example, Fritz Zwicky published a paper in 1936 suggesting that galaxies could act as gravitational lenses.

However, the first recorded observation of a gravitational lens didn’t occur until 1979 when astronomers at Kitt Peak National Observatory photographed what was at first called a “twin quasar” called Q0957+561A and Q0957+561B, which was an image of two quasars (now usually called quasi-stellar objects, or QSOs) close together that had the exact same light characteristics (spectrum), hence the term “twin.” Detailed analysis revealed that the twin QSOs were actually a single quasar that was lensed by a giant elliptical galaxy called YGKOW G1 that lies on the line of sight between Earth and QSO Q0957+561.

This, then, is the signature of a gravitational lens: two (or more) images with identical spectra of a far distant source object (usually a QSO) that bracket a large mass (usually a galaxy or galaxy cluster) that’s closer to us than the distant source. Sometimes, the geometry is just right so that four images of the far distant source can be seen, corresponding to deflection of light around the “top,” “bottom,” “left,” and “right” sides of the deflector. The four images are called an “Einstein cross.” On rare occasions, the alignment is so perfect that the images actually form a ring as light is deflected equally all around the deflecting object. This is called an “Einstein ring.”

As modern telescopes and detectors found more and more gravitational lenses, astronomers became aware that measurements of the image deflections (which depend, in part, on the mass of the deflector galaxy) suggested that the intervening deflector galaxies creating the gravitational lenses were much more massive than the intensity of their light indicated. To explain the amount of deflection astronomers see, the deflector galaxies had to be four or five times as massive as they seemed to be judging from the amount of light they put out. The galaxies seemed to have a considerable amount of mass that didn’t emit radiation in any part of the electromagnetic spectrum: no gamma rays, x-rays, ultraviolet radiation, visible light, infrared (heat) radiation, or radio waves. They seemed to have some





Einstein Cross and Einstein Ring

These are Hubble Space Telescope images of an Einstein Cross (left) and an Einstein Ring (right). The left image shows four mirage images of quasar G2237+0305 (8 billion light-years away) lensed by a galaxy called ZW 2237+030 (400 million light-years away) in the center. The right image shows a rare double Einstein ring called SDSS J0946+1006, which is in the constellation Leo. The center object is a galaxy 3 billion light-years away that's lensing two far distant galaxies, one 6 billion light-years and another 11 billion light-years away.

sort of dark matter in addition to the matter that made up stars. The only way we can detect dark matter is through its gravitational interaction with visible matter and light.

Fritz Zwicky first suggested the existence of some sort of dark matter in 1933 when his analysis of the motions of the galaxies that make up the Coma Cluster of galaxies seemed to be inconsistent with the apparent amount of luminous matter in the cluster and could only be explained if there was a lot more mass in the cluster than we could see. No one paid any attention to Zwicky's analysis until the early 1970s when Vera Rubin, using a new spectrograph that was more sensitive than older models, measured the velocities of stars in edge-on spiral galaxies to a greater degree of precision than had ever before been achieved. These measurements showed that the velocity of stars orbiting the central mass of the galaxies is roughly the same no matter how far from the center of the galaxy they are. This is inconsistent with Newton's laws of motion and can only be explained if unseen (hence "dark") matter is distributed throughout the galaxy and in a halo around its perimeter.

As of the beginning of the third millennium, no one knows what dark matter is. Astrophysicists have proposed a new particle, the weakly interacting massive particle (WIMP), as a possible form of dark matter, but no such particle has been detected. On the other hand, galaxies might have more black holes, neutron stars, and brown dwarfs scattered through them than we think. Brown dwarfs are sometimes called failed stars. They're more than five times the mass of Jupiter and, thus, are too big to be planets but are too small to fuse hydrogen into helium and shine like a star. A star has to be at least eight percent of the size of the Sun (80 times the mass of Jupiter, in other words) to fuse hydrogen. Brown dwarfs are hard to see because they're so dim. We didn't find the first brown dwarf in our own part of the Milky Way until 1995, and we only know of a couple dozen, ranging in size from 7 times the mass of Jupiter to around 75 times Jupiter's mass. Detecting them in another galaxy is impossible with current technology. The collection of black holes, neutron stars, and so on have been lumped together under the name massive astrophysical compact halo objects (MACHOs) as a humorous contrast to WIMPs. Galaxies might also have more gas and dust than we can see, and this extra gas and dust together with MACHOs might make up some dark matter. But astrophysicists don't think that this combination can make up nearly enough mass to explain the extra deflection in gravitational lenses or the extra velocity in stars' orbits in their galaxies. No one is sure that dark matter even exists, and it's possible that some new physics of the future will explain the apparent contradictions that gravitational lenses and star velocities have without dark matter. Every time in the past millennia that science has faced a problem it can't explain, a new body of knowledge has been discovered to solve the problem. That's how science has grown.

Dark matter is joined by dark energy as the two major problems in astrophysics. Dark energy is a hypothetical form of energy that permeates all of space, and its story begins with General Relativity as the theoretical description and Edwin Hubble making the observational description. In the early 1920s, the Soviet mathematician Alexander Friedmann solved Einstein's very complicated general equations of gravitation (by making certain simplifying assumptions) and published his solution in the German academic journal *Zeitschrift für Physik* (Journal of Physics). Einstein himself was the journal's peer reviewer of Friedmann's article. Even though the journal was very prestigious and Einstein was the peer reviewer, no one paid much attention to the article. Maybe it was too difficult for most scientists to understand. In 1927, the Belgian astronomy student Georges Lemaître independently found a solution to Einstein's equations similar to Friedmann's and published it in the journal *Annals of the Scientific Society of Brussels*. Both Friedmann's and Lemaître's solutions are theoretical descriptions of an expanding Universe. Of course, mathematical theory is one thing, but observing how the Universe really behaves might be quite another. Enter Edwin Hubble.

Hubble was fortunate to work with what was at the time the world's most powerful telescope, the Mount Wilson Observatory near Los Angeles, and by 1929 he had been accumulating data on "nebulae" for ten years. (The term "galaxy" had not quite replaced "nebula" the year the bottom fell out of the stock market.) He had been able to calculate the distances to 46 galaxies by using Cepheid variable stars. Previously, after measuring the brightness of hundreds of Cepheid variables, Henrietta Swan Leavitt had discovered that there was a very precise relationship between their brightness and their period of variation, and she had published the relationship in the *Harvard College Observatory Circular 173* in 1912. For example, a Cepheid with three-day period has a luminosity of about 800 times that of the Sun, and a Cepheid with thirty-day period is 10,000 times as bright as the Sun. Hubble measured the period of Cepheid variables in nearby galaxies, which told him how bright they were. Then he measured how bright they appeared to be on his photographic plates. Finally, he used the fact that apparent brightness of a star is reduced by the square of the distance to it to work backward and find out how far away the galaxies are. Hubble then compared these distance measurements with velocities that Vesto Slipher had measured of the same galaxies and noticed that distance and velocity were related. The further away a galaxy was, the faster it was moving away from us; the Universe is expanding. In 1929 he published Hubble's law that said galaxies were moving away from us at a recession velocity of 500 kilometers per second for every million parsecs they were distant from us. This is the Hubble constant. Unfortunately, Hubble had made some errors in his distance calibrations (perhaps his measurement of how bright the Cepheids appeared on his photographic plates was a little off), so his value of the Hubble constant was too high. Improved measurements at the end of the twentieth century found the Hubble constant to be between 70 and 75 kilometers per second for every million parsecs a galaxy is distant from us. This value was determined from measurements of galaxies within a billion parsecs of Earth.

That turns out to be just the beginning of the dark energy story. The great improvements in telescopes and detectors at the close of the second millennium has enabled astronomers to see galaxies more than ten billion light-years away. Because the speed of light is limited, a galaxy that's billions of light-years away appears to us as it was billions of years ago, so looking far out into space is like looking back in time. The new telescopes and detectors also enable astronomers to see supernovae in galaxies billions of light-years away, so they can measure the distances to them from the apparent brightness of Type 1a supernovae the same way Hubble used Cepheids to measure distances to nearby galaxies, and they can measure the recession velocity of these far distant galaxies using the Doppler shift in their light. When astronomers looked at the distances and velocities of galaxies billions of light-years away (and therefore billions of years old), the corresponding Hubble constant is less than it is for the nearer (and newer) galaxies. In other words the recession velocity is greater now than it used to be; the Universe is expanding faster now than it was billions of years ago. The only condition that could make something speed up is if energy were added to it, so astrophysicists have proposed that there exists some form of energy that's causing the expansion of the Universe to speed up. They've called this newly discovered energy dark energy.

Originally, the existence of dark energy was inferred solely from Type 1a supernova data. But in the early years of the third millennium, astrophysicists have analyzed data gathered by astronomers on other phenomena such as the microwave background radiation and have discovered that dark energy effects are hidden in those measurements too. So the existence of dark energy is beginning to be supported by a variety of measurements, and programs scheduled to be completed in the first two decades of the third millennium will add considerably to our understanding of this mysterious energy. All we know now is that it's a property of space itself that's only detectable when considering vast stretches of the Universe; we could never detect it if we limit our interest to our own small planet.

As the third millennium of the current era begins, some cosmologists are developing alternative explanations of the Universe's origin, and String Theory is the most promising of them. String Theory grew out of an attempt in the 1960s to describe why, among other things, the nucleus of the atom can stick together even though all the protons there are positively charged and should fly apart. Quantum Chromodynamics proved to be a better theory for that, so String Theory was discarded. Then scientists began to earnestly look for a theory that would marry gravity, the dominant force at large distances, with the theory about how things behave down at atomic distances and create a "theory of everything." Einstein spent the last half of his life trying to find such a grand unification theory, but he was never successful. The search for a grand unification theory became the focus of more scientists when they realized that black holes just might be the place where gravity would meet physics at small distances.

String Theory proposes that all fundamental particles that make up matter are, in turn, made of incredibly small strings of electric charge. These strings can be open like twine or closed like a rubber band. Accumulations of these strings on a scale that would dwarf our universe form membranes which occasionally collide and create universes, and our universe is the result of such a collision.

String cosmology begs the issue of creation, however, because it doesn't propose where the strings come from. This is not defect in the theory but, rather, reflects a limitation of science. Science confines itself to the study of "what is" rather than speculation on where "what is" came from. Science studies phenomena that can be reproduced in order to verify that it's a true description of "what is," and creation can not be reproduced. This is not to say that scientists don't believe in a creation, perhaps by a devine being, as evidenced by Einstein's famous objection to quantum mechanics, "God doesn't play at dice." They simply can't study it.

The other theory of origins is called Quantum Loop Theory. This theory, proposed in the 1990s, says that space is not continuous but, instead, is broken into grains (quantized) that are incredibly small. When scientists run the Universe backward, all theories that assume space is continuous (not quantized) become meaningless as time goes to zero, the time of the Big Bang. However, all theories hold together as time goes to zero if space is quantized. In fact, time can continue past the Big Bang (into negative time) to uncover a universe that's the mirror image of ours but is contracting to form our Big Bang.