Article 1

Big Bang - the birth of our universe. The universe we can observe is finite. It has a beginning in space and time, before which the concept of space and time has no meaning, because spacetime itself is a property of the universe. According to the Big Bang theory, the universe began about twelve to fifteen billion years ago in a violent explosion. For an incomprehensibly small fraction of a second, the universe was an infinitely dense and infinitely hot fireball. A peculiar form of energy that we don't know yet, suddenly pushed out the fabric of spacetime in a process called "inflation", which lasted for only one millionth of a second. Thereafter, the universe continued to expand but not nearly as quickly. The process of phase transition formed out the most basic forces in nature: first gravity, then the strong nuclear force, followed by the weak nuclear and electromagnetic forces. After the first second, the universe was made up of fundamental energy and particles like quarks, electrons, photons, neutrinos and other less familiar particles.

About 3 seconds after the Big Bang, nucleosynthesis set in with protons and neutrons beginning to form the nuclei of simple elements, predominantly hydrogen and helium, yet for the first 100,000 years after the initial hot explosion there was no matter of the form we know today. Instead, radiation (light, X rays, and radio waves) dominated the early universe. Following the radiation era, atoms were formed by nuclei linking up with free electrons and thus matter slowly became dominant over energy. It took 200 million years until irregularities in the primordial gas began to form galaxies and early stars out of pockets of gas condensing by virtue of gravity. The Sun of our solar system was formed out of such a pocket of gas in a spiral arm of the Milky Way galaxy roughly five billion years ago. A vast disk of gas and debris swirling around the early Sun gave birth to the planets, including Earth, which is between 4.6 and 4.5 billion years old. This is -in short- the history of our universe according to the Big Bang theory, which constitutes today's most widely accepted cosmological viewpoint.

Article 2

What speaks in favor of the Big Bang theory?

A number of different observations corroborate the Big Bang theory. Edwin Hubble (1889-1953) discovered that galaxies are receding from us in all directions. He observed shifts in the spectra of light from different galaxies, which are proportional to their distance from us. The farther away the galaxy, the more its spectrum is shifted towards the low (red) end of the spectrum, which is in some way comparable to the Doppler effect. This redshift indicates recession of objects in space, or better: the ballooning of space itself. Today, there is convincing evidence for Hubble's observations. Projecting galaxy trajectories backward in time means that they converge to a high-density state, i.e. the initial fireball.

If two intelligent life forms in two different galaxies look at each other's galaxy, they perceive the same thing. The light of the other galaxy appears redshifted in comparison to nearer objects. This is caused by ballooning space that stretches the wavelength of emitted light. The magnitude of this effect is proportional to the distance of the observed galaxy.
According to the Copernican cosmological principle, the universe appears the same in every direction from every point in space, or in more scientific terms: The universe is homogeneous and isotropic. There is overwhelming evidence for this assertion. The best evidence is provided by the almost perfect uniformity of the cosmic background radiation. This observed radiation is isotropic to a very high degree and is thought to be a remnant of the initial Big Bang explosion. The background radiation originates from an era of a few hundred thousand years after the Big Bang, when the first atoms where formed. Another piece of evidence speaking in favour of Big Bang is the abundance of light elements, like hydrogen, deuterium (heavy hydrogen), helium, and lithium. Big Bang nucleosynthesis predicts that about a quarter of the mass of the universe should be helium-4, which is in good agreement with what is observed.

Article 3

Big Bang

In the Beginning

The Big Bang model of the universe's birth is the most widely accepted model that has ever been conceived for the scientific origin of everything. No other model can predict as much as the Big Bang model can.

A common question that people ask is "What happened before the Big Bang?" The phrase "in the beginning" is used here to refer to the birth of our universe with the Big Bang. In the creation of the universe, everything was compressed into an infinitesimally small point, in which all physical laws that we know of do not apply. No information from any "previous" stuff could have remained intact. Therefore, for all intents and purposes, the Big Bang is considered **the** beginning of everything, for we can never know if there was anything before it.

History of the Big Bang Model

The Big Bang model had its beginnings with Edwin Hubble's discovery in 1929 that, on large scales, everything in the universe is moving away from everything else. The only explanation for this was that the universe was expanding in every direction, and it was taking galaxies along with it.

The next step towards the Big Bang model was to take this process in reverse - that is, to go back in time. If the universe is "blowing up" like a balloon as time progresses, then what would happen if you were to run the timeline backwards? What was the universe like in the past?

If the universe is currently growing, then the universe was smaller in the past. There must have been some point in time when the universe was half its current size. Then there must have been a time when it was half that size. If you continue to run time backwards, there must have been a time when the universe was an infinitesimally small point*.

This is the basic idea behind the Big Bang. All matter and energy existed in an infinitely small point of infinite density a long time ago, and has since been expanding as our universe. One important note here is that the Big Bang was not an explosion **in** the universe, but rather it is an explosion **of** the universe. Therefore, there is no "center" of the universe from where the Big Bang started.

Article 4

Main Evidence

The Big Bang is the leading theory that almost all astrophysicists believe explains the origin of the universe. This is because all observations so far made support the Big Bang theory; there are four main lines of evidence that are most-often used.

The first was discussed above: The expansion of the universe. The universe is expanding now, so in the past it must have been smaller. If it were smaller in the past, then there probably was a time when it was infinitesimally small. One could ask why don't we think that it might be expanding now but it could have been shrinking before and we just don't know about it. The answer is that there is simply no mechanism that we know about that could accomplish this transition on a universal scale.

The second line of evidence is the Cosmic Microwave Background Radiation (CMB) that was discovered in 1965 by Arno Penzias and Robert Wilson from Bell Labs. They were working with a microwave receiver, but were getting noise from every direction they pointed the receiver. It was coming from all over the sky at what seemed to be exactly the same frequency. This was the first evidence for the CMB, and they later shared a Nobel Prize for this discovery.

The CMB is an "echo" left over from when the universe was approximately 300,000 years old, as predicted by the Big Bang model. As something becomes compressed, as matter was when the universe was young, it becomes hot. The actual "heat" comes from particles' movements - the faster they move, the more energetic they are, and so the more heat we see. The universe was so hot before it was 300,000 years old that atoms could not form. Because of this, *photons* - particles of light - could not move around, for they kept reacting with *electrons*.

Therefore, during this period, the universe was effectively opaque. Once the universe had reached 300,000 years old, atoms could form, and electrons were now bound to a *nucleus*. Once this happened, photons could move about freely. This "first light" is the CMB, and its existence is a very strong indication that the Big Bang occurred.

The third major pillar of the Big Bang theory lies in the abundance of the different elements of the universe. The theory predicts that certain amounts of hydrogen, helium, and other elements should be made. Observations have shown almost exactly the amounts that are predicted.

The fourth piece is that the Big Bang theory is the only one that comprehensively lays down a framework for the eventual evolution of the universe as we observe it today.

Article 5

Big Bang Cosmology

The Big Bang Model is a broadly accepted theory for the origin and evolution of our universe. It postulates that 12 to 14 billion years ago, the portion of the universe we can see today was only a few millimeters across. It has since expanded from this hot dense state into the vast and much cooler cosmos we currently inhabit. We can see remnants of this hot dense matter as the now very cold cosmic microwave background radiation which still pervades the universe and is visible to microwave detectors as a uniform glow across the entire sky.

General Relativity

The first key idea dates to 1916 when Einstein developed his General Theory of Relativity which he proposed as a new theory of gravity. His theory generalizes Isaac Newton's original theory of gravity, c. 1680, in that it is supposed to be valid for bodies in motion as well as bodies at rest. Newton's gravity is only valid for bodies at rest or moving very slowly compared to the speed of light (usually not too restrictive an assumption!). A key concept of General Relativity is that gravity is no longer described by a gravitational "field" but rather it is supposed to be a distortion of space and time itself. Physicist John Wheeler put it well when he said "Matter tells space how to curve, and space tells matter how to move." Originally, the theory was able to account for peculiarities in the orbit of Mercury and the bending of light by the Sun, both unexplained in Isaac Newton's theory of gravity. In recent years, the theory has passed a series of rigorous tests.

The Cosmological Principle

APM Survey fo a 30 deg. swath of the sky, showing about 1 million galaxies out to a distance of almost 2 billion light years.After the introduction of General Relativity a number of scientists, including Einstein, tried to apply the new gravitational dynamics to the universe as a whole. At the time this required an assumption about how the matter in the universe was distributed. The simplest assumption to make is that if you viewed the contents of the universe with sufficiently poor vision, it would appear roughly the same everywhere and in every direction. That is, the matter in the universe is homogeneous and isotropic when averaged over very large scales. This is called the Cosmological Principle. This assumption is being tested continuously as we actually observe the distribution of galaxies on ever larger scales. The accompanying picture shows how uniform the distribution of measured galaxies is over a 30° swath of the sky. In addition the cosmic microwave background radiation, the remnant heat from the Big Bang, has a temperature which is highly uniform over the entire sky. This fact strongly supports the notion that the gas which emitted this radiation long ago was very uniformly distributed.

Article 6

The Life Cycles of Stars

I. Star Birth and Life

Imagine an enormous cloud of gas and dust many light-years across. Gravity, as it always does, tries to pull the materials together. A few grains of dust collect a few more, then a few more, then more still. Eventually, enough gas and dust has been collected into a giant ball that, at the center of the ball, the temperature (from all the gas and dust bumping into each other under the great pressure of the surrounding material) reaches 15 million degrees or so. A wondrous event occurs.... nuclear fusion begins and the ball of gas and dust starts to glow. A new star has begun its life in our Universe.

So what is this magical thing called "nuclear fusion" and why does it start happening inside the ball of gas and dust? It happens like this..... As the contraction of the gas and dust progresses and the temperature reaches 15 million degrees or so, the pressure at the center of the ball becomes enormous. The electrons are stripped off of their parent atoms, creating a plasma. The contraction continues and the nuclei in the plasma start moving faster and faster. Eventually, they approach each other so fast that they overcome the electrical repulsion that exists between their protons. The nuclei crash into each other so hard that they stick together, or fuse. In doing so, they give off a great deal of energy. This energy from fusion pours out from the core, setting up an outward pressure in the gas around it that balances the inward pull of gravity. When the released energy reaches the outer layers of the ball of gas and dust, it moves off into space in the form of electromagnetic radiation. The ball, now a star, begins to shine.

New stars come in a variety of sizes and colors. They range from blue to red, from less than half the size of our Sun to over 20 times the Sun’s size. It all depends on how much gas and dust is collected during the star's formation. The color of the star depends on the surface temperature of the star. And its temperature depends, again, on how much gas and dust were accumulated during formation. The more mass a star starts out with, the brighter and hotter it will be. For a star, everything depends on its mass.

Throughout their lives, stars fight the inward pull of the force of gravity. It is only the outward pressure created by the nuclear reactions pushing away from the star's core that keeps the star "intact". But these nuclear reactions require fuel, in particular hydrogen. Eventually the supply of hydrogen runs out and the star begins its demise.

Article 7

II. Beginning of the End

After millions to billions of years, depending on their initial masses, stars run out of their main fuel - hydrogen. Once the ready supply of hydrogen in the core is gone, nuclear processes occurring there cease. Without the outward pressure generated from these reactions to counteract the force of gravity, the outer layers of the star begin to collapse inward toward the core. Just as during formation, when the material contracts, the temperature and pressure increase. This newly generated heat temporarily counteracts the force of gravity, and the outer layers of the star are now pushed outward. The star expands to larger than it ever was during its lifetime -- a few to about a hundred times bigger. The star has become a red giant.
What happens next in the life of a star depends on its initial mass. Whether it was a "massive" star (some 5 or more times the mass of our Sun) or whether it was a "low or medium mass" star (about 0.4 to 3.4 times the mass of our Sun), the next steps after the red giant phase are very, very different.

III. The End

A. The Fate of Sun-Sized Stars: Black Dwarfs

Once a medium size star (such as our Sun) has reached the red giant phase, its outer layers continue to expand, the core contracts inward, and helium atoms in the core fuse together to form carbon. This fusion releases energy and the star gets a temporary reprieve. However, in a Sun-sized star, this process might only take a few minutes! The atomic structure of carbon is too strong to be further compressed by the mass of the surrounding material. The core is stabilized and the end is near.

The star will now begin to shed its outer layers as a diffuse cloud called a planetary nebula. Eventually, only about 20% of the star's initial mass remains and the star spends the rest of its days cooling and shrinking until it is only a few thousand miles in diameter. It has become a white dwarf. White dwarfs are stable because the inward pull of gravity is balanced by the electrons in the core of the star repulsing each other. With no fuel left to burn, the hot star radiates its remaining heat into the coldness of space for many billions of years. In the end, it will just sit in space as a cold dark mass sometimes referred to as a black dwarf.

Article 8

The Fate of Massive Stars: Supernovae! and Then...

Fate has something very different, and very dramatic, in store for stars which are some 5 or more times as massive as our Sun. After the outer layers of the star have swollen into a red supergiant (i.e., a very big red giant), the core begins to yield to gravity and starts to shrink. As it shrinks, it grows hotter and denser, and a new series of nuclear reactions begin to occur, temporarily halting the collapse of the core. However, when the core becomes essentially just iron, it has nothing left to fuse (because of iron's nuclear structure, it does not permit its atoms to fuse into heavier elements) and fusion ceases. In less than a second, the star begins the final phase of its gravitational collapse. The core temperature rises to over 100 billion degrees as the iron atoms are crushed together. The repulsive force between the nuclei overcomes the force of gravity, and the core recoils out from the heart of the star in an explosive shock wave. As the shock encounters material in the star's outer layers, the material is heated, fusing to form new elements and radioactive isotopes. In one of the most spectacular events in the Universe, the shock propels the material away from the star in a tremendous explosion called a supernova. The material spews off into interstellar space -- perhaps to collide with other cosmic debris and form new stars, perhaps to form planets and moons, perhaps to act as the seeds for an infinite variety of living things.

So what, if anything, remains of the core of the original star? Unlike in smaller stars, where the core becomes essentially all carbon and stable, the intense pressure inside the supergiant causes the electrons to be forced inside of (or combined with) the protons, forming neutrons. In fact, the whole core of the star becomes nothing but a dense ball of neutrons. It is possible that this core will remain intact after the supernova, and be called a neutron star. However, if the original star was very massive (say 15 or more times the mass of our Sun), even the neutrons will not be able to survive the core collapse and a black hole will form!

Article 9

More about the Stellar Endpoints

A. White/Black Dwarfs

A star like our Sun will become a white dwarf when it has exhausted its nuclear fuel. Near the end of its nuclear burning stage, such a star expels most of its outer material (creating a planetary nebula) until only the hot ($T > 100,000$ K) core remains, which then settles down to become a young white dwarf. A typical white dwarf is half as massive as the Sun, yet only slightly bigger than the Earth. This makes white dwarfs one of the densest forms of matter, surpassed only by neutron stars.

White dwarfs have no way to keep themselves hot (unless they accrete matter from other closeby stars); therefore, they cool down over the course of many billions of years. Eventually, such stars cool completely and become black dwarfs. Black dwarfs do not radiate at all.

Many nearby, young white dwarfs have been detected as sources of soft X-rays (i.e. lower-energy X-rays); soft X-ray and extreme ultraviolet observations enable astronomers to study the composition and structure of the thin atmospheres of these stars.

B. Neutron Stars

Neutron stars are typically about ten miles in diameter, have about 1.4 times the mass of our Sun, and spin very rapidly (one revolution takes mere seconds!). Neutron stars are fascinating because they are the densest objects known. Due to its small size and high density, a neutron star possesses a surface gravitational field about 300,000 times that of Earth.

Neutron stars also have very intense magnetic fields - about 1,000,000,000,000 times stronger than Earth's. Neutron stars may "pulse" due to electrons accelerated near the magnetic poles, which are not aligned with the rotation axis of the star. These electrons travel outward from the neutron star, until they reach the point at which they would be forced to travel faster than the speed of light in order to still co-rotate with the star. At this radius, the electrons must stop, and they release some of their kinetic energy in the form of X-rays and gamma-rays. External viewers see these pulses of radiation whenever the magnetic pole is visible. The pulses come at the same rate as the rotation of the neutron star, and thus, appear periodic. Neutron stars which emit such pulses are called pulsars.

C. Black Holes

Black holes are objects so dense that not even light can escape their gravity and, since nothing can travel faster than light, nothing can escape from inside a black hole. Nevertheless, there is now a great deal of observational evidence for the existence of two types of black holes: those with masses of a typical star (4-15 times the mass of our Sun), and those with masses of a typical galaxy. This evidence comes not from seeing the black holes directly, but by observing the behavior of stars and other material near them!

Galaxy-mass black holes are found in Active Galactic Nuclei (AGN). They are thought to have the mass of about 10 to 100 billion Suns! The mass of one of these supermassive black holes has recently been measured using radio astronomy. X-ray observations of iron in the accretion disks may actually be showing the effects of massive black holes as well.

Article 10

Small Stars

Stars less than about eight times the mass of our Sun are considered medium and small size stars. The production of elements in stars in this range is similar, and these stars share a similar fate. They begin by fusing hydrogen into helium in their cores. This process continues for billions of years, until there is no longer enough hydrogen in the star's core to fuse more helium. Without the energy from fusion, there is nothing to counteract the force of gravity, and the star begins to collapse inward. This causes an increase in temperature and pressure. Due to this collapse, the hydrogen in the star's middle layers becomes hot enough to fuse. The hydrogen begins to fuse into helium in a "shell" around the star's core. The heat from this reaction "puff up" the star's outer layers, making the star expand far beyond its previous size. This expansion cools the outer layers, turning them red. At this point the star is a red giant.

The star's core continues to collapse until the pressure causes the core temperature to reach 100 million Kelvin. This is hot enough for the helium in the core to fuse into carbon. Energy from this reaction sustains the star, keeping it from further collapse. Nitrogen is fused in a similar way. After a much shorter period of time, there is no more material to fuse in the core. The star is left with carbon in its core, but the temperature is not hot enough to fuse carbon. However, if the star has a mass between 2 and 8 times the mass of the sun, fusion of helium can take place in a shell of gas surrounding the core. In addition, fusion of hydrogen takes place in a shell on top of this. The star is then known as an Asymptotic Giant.

Motion of the gas between these shells and the core dredges up carbon from the core. The helium shell is also replenished as the result of fusion in the hydrogen shell. This occasionally leads to explosive fusion in the helium shell. During these events, the outermost layers of the star are blown off, and a strong stellar wind develops. This ultimately leads to the formation of a planetary nebula. The nebula may contain up to 10% of the star's mass. Both the nebula and the wind disperse into space some of the elements created by the star.

While the star is an Asymptotic Giant, heavier elements can form in the helium burning shell. They are produced by a process called neutron capture. Neutron capture occurs when a free neutron collides with an atomic nucleus and sticks. If this makes the nucleus unstable, the neutron will decay into a proton and an electron, thus producing a different element with a new atomic number.

In the helium fusion layer of Asymptotic Giants, this process takes place over thousands of years. The interaction of the helium with the carbon in this layer releases neutrons at just the right rate. These neutrons interact with heavy elements that have been present in the star since its birth. So over time, a single iron 26Fe56 nucleus might capture one of these neutrons, becoming 26Fe57. A thousand years later, it might capture another. If the iron nucleus captures enough neutrons to become 26Fe59, it would be unstable. One neutron would then decay into a proton and an electron, creating an atom of 27Co59, which is higher than iron on the periodic table. During this Asymptotic Giant phase, conditions are right for small stars to contribute in this way to the abundance of selected elements from niobium to bismuth.

After the Asymptotic Giant phase, the outer shell of the star is blown off and the star becomes white dwarf. A white dwarf is a very small, hot star, with a density so high that a teaspoon of its material would weigh a ton on Earth! If the white dwarf star is part of a binary star system (two stars orbiting around each other), gas from its companion star may be "pulled off" and fall onto the white dwarf. If matter accumulates rapidly on the white dwarf, the high temperature and intense gravity of the white dwarf cause the new gas to fuse in a sudden explosion called a nova. A nova explosion may temporarily make the white dwarf appear up to 10,000 times brighter. The fusion in a nova also creates new elements, dispersing more helium, carbon, oxygen, some nitrogen, and neon.

In rare cases, the white dwarf itself can detonate in a massive explosion which astronomers call a Type Ia supernova. This occurs if a white dwarf is part of a binary star system, and matter accumulates slowly onto the white dwarf. If enough matter accumulates, then the white dwarf cannot support the added weight, and begins to collapse. This collapse heats the helium and carbon in the white dwarf, which rapidly fuse into nickel, cobalt and iron. This burning occurs so fast that the white dwarf detonates, dispersing all the elements created during the star's lifetime, and leaving nothing behind. This is a rare occurrence in which all the elements created in a small star are scattered into space.

Article 11

Stars

As the Universe continued to expand and cool, the atoms formed in the Big Bang coalesced into large clouds of gas. These clouds were the only matter in the Universe for millions of years before the planets and stars formed. Then, about 200 million years after the Big Bang, the first stars began to shine and the creation of new elements began.

Stars form when the giant clouds of gas, light-years across and consisting mostly of hydrogen, begin to contract under their own gravity. First, clumps of denser hydrogen gas form, which over millions of years eventually combine to form a giant ball of gas hundreds of thousands of times more massive than the Earth. The gas ball contracts under its own gravity, creating enormous pressure at the center. The increase in pressure causes an increase in temperature at the star's center. It becomes so hot that the electrons are stripped from the atoms. What's left are hydrogen nuclei, moving faster and faster as the ball of gas contracts and the temperature at the center continues to increase. Once the temperature reaches 15 million Kelvin, the hydrogen nuclei are moving so fast that when they collide they fuse together. This releases a great deal of energy. The energy from this nuclear fusion pours out from the center of the ball of gas and counteracts gravity's relentless inward pull. The ball of gas is now stable, with the inward pull of gravity exactly balanced by the outward pressure from the exploding fusion energy in the core. This energy flows out through the star, and when it reaches the surface, it radiates off into space. The ball of gas begins to shine as a new star.

Stars come in a variety of sizes, anywhere from one-tenth to sixty (or more) times the mass of our Sun. At their hearts, all normal stars are fueled by the energy of nuclear fusion. Depending on the size of the star, however, different elements are created in the fusion process.

Article 12

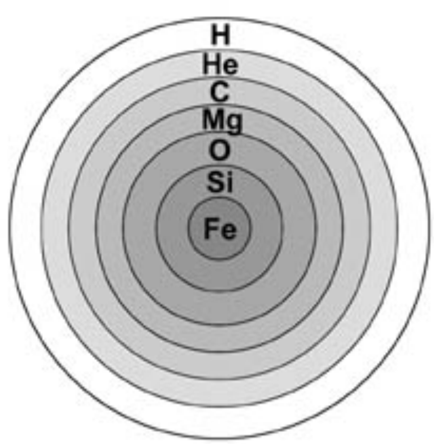
Large Stars

Stars larger than eight times the mass of our Sun begin their lives the same way smaller stars do: by fusing hydrogen into helium. However, a large star burns hotter and faster, fusing all the hydrogen in its core to helium in less than 1 billion years. The star then becomes a red supergiant, similar to a red giant, only larger. Unlike red giants, these red supergiants have enough mass to create greater gravitational pressure, and therefore higher core temperatures. They fuse helium into carbon, carbon and helium into oxygen, and two carbon atoms into magnesium. Through a combination of such processes, successively heavier elements, up to iron, are formed (see Table 1). Each successive process requires a higher temperature (up to 3.3 billion kelvins) and lasts for a shorter amount of time (as short as a few days). The structure of a red supergiant becomes like an onion (see Figure 3), with different elements being fused at different temperatures in layers around the core. Convection brings the elements near the star's surface, where the strong stellar winds disperse them into space.

Fuel	Main Product	Secondary Products	Temperature (billion K)	Duration (years)
H	He	N	0.03	1 x 107
He	C, O	Ne	0.2	1 x 106
C	Ne, Mg	Na	0.8	1 x 105
Ne	O, Mg	Al, P	1.5	0.1
O	Si, S	Cl, Ar, K, Ca	2.0	2
Si	Fe	Ti, V, Cr, Mn, Co, Ni	3.3	0.01

Table 1 - This table shows the nucleosynthesis reactions that occur in successive stages in large stars. The table summarizes the chief reactions and their products (including other elements that are produced in trace amounts), the temperature at which the reaction occurs, and how long it takes to use up the available input fuel.

Figure 3: The "onion shell" model of a red super giant.



Fusion continues in red supergiants until iron is formed. Unlike the elements before it, iron releases no energy when fused. This is because iron has the most stable nucleus of all the elements. Elements lighter than iron generally emit energy if fused, since they move from a less stable nuclear structure to a more stable one. By contrast, elements heavier than iron emit energy if they undergo fission, that is, by losing nucleons (i.e. protons and/or neutrons). Again, they go from a less stable to a more stable nuclear structure. This is illustrated in greater detail by the "Binding Energy Per Nucleon" chart (Figure 4). The number of nucleons in the nucleus, plotted along the x-axis, is equivalent to the atomic weight of the atom. "Binding energy per nucleon" represents the amount of energy necessary to break the nucleus apart into separate protons and neutrons. The plot shows how this binding energy changes with increasing atomic weight. The stability of the iron nucleus is represented by the fact that it requires the most energy to break apart.

Another reason fusion does not go beyond iron is that the temperatures necessary become so high that the nuclei "melt" before they can fuse. That is, the thermal energy due to the high temperature breaks silicon nuclei into separate helium nuclei. These helium nuclei then combine with elements such as chlorine, argon, potassium, and calcium to make elements from titanium through iron.

Large stars also produce elements heavier than iron via neutron capture. Because of higher temperatures in large stars, the neutrons are supplied from the interaction of helium with neon. This neutron capture process takes place over thousands of years. The abundances of selected elements from iron to zirconium can be attributed to this type of production in large stars. Again, convection and stellar winds help disperse these elements.

Article 13

Supernovae
We see how stars produce many of the elements on the periodic table. Solar winds, planetary nebulae, and occasional novae liberate a fraction of these elements - too little, though, to account for the amounts we see in the Universe today. Is there another way these elements are made or dispersed? And what produces the remaining elements on the periodic table?

Look again at what happens in large stars. As red supergiants, they fuse many elements, finally producing iron in their cores. Iron is the end of the line for fusion. Thus, when the core begins to fill with iron, the energy production decreases. With the drop in energy, there is no longer enough energy to counteract the pull of gravity. The star begins to collapse. The collapse causes a rise in the core temperature to over 100 billion Kelvin and smashes iron's electrons and protons together to form neutrons. Because of their smaller size, the neutrons can pack much closer together than atoms, and for about 1 second they fall very fast toward the center of the star. After the fall, they smash into each other and stop suddenly. This sudden stop causes the neutrons to violently recoil. As a result, an explosive shock wave travels out from the core. As it travels from the core, the shock wave heats and accelerates the surrounding layers. In addition, neutrinos (elementary particles with very little mass) arise from the formation of the neutrons. The energy from the neutrinos causes the majority of the star's mass to be blown off into space, in what is called a supernova. Astronomers refer to this as a Type II supernova.

Supernovae often release enough energy that they shine brighter than an entire galaxy, for a brief amount of time. The explosion scatters elements made within the star far out into space. Supernovae are one of the important ways these elements are dispersed into the Universe.

As it moves through the original onion layers of the star, the shock wave also modifies the composition of the layers (particularly the C, Ne, O, and Si layers) , through explosive nucleosynthesis. This contributes to the production of elements from Si to Ni, with many elements below iron being made from the Si shell.

The tremendous force of the supernova explosion also violently smashes material together in the outer layers of the star before it is driven off into space. Before it is expelled, this material is heated to incredible temperatures by the power of the supernova explosion, and undergoes a rapid capture of neutrons. This rapid neutron capture transforms elements into heavy isotopes, which decay into heavy elements. In seconds or less, many new elements heavier than iron are created. Some of the elements produced through this process are the same as those made in the star, while others come solely from the supernova process. Among the elements made only from supernovae explosions are iodine, xenon, gold, and most of the naturally occurring radioactive elements.

Article 14

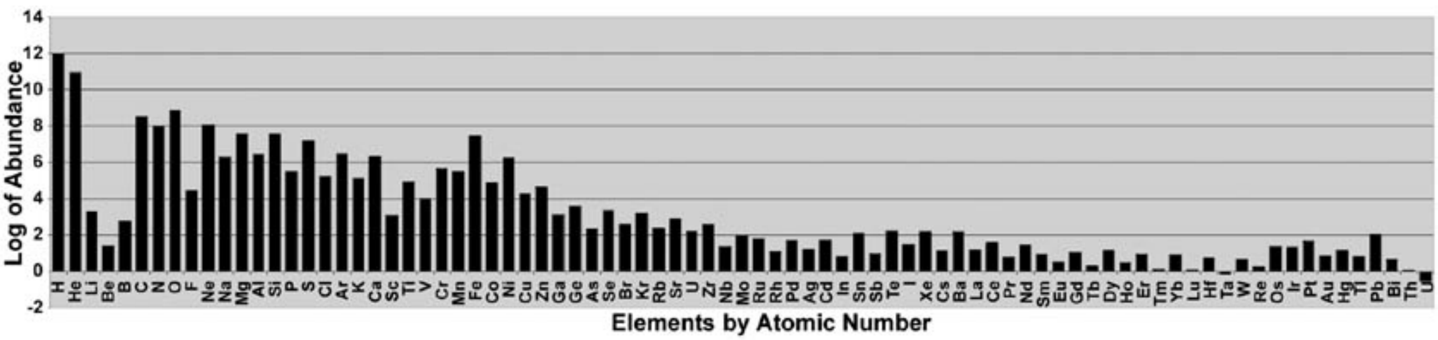


Figure 7: The elemental composition of the solar system. The abundance of hydrogen is arbitrarily set to 1012 so that the smallest abundance in the graph is about 1. (Click on image for larger version.)

III. Composition of the Universe

A. What It is, and How do we Know?

Astronomers seek to understand what the universe is made of. In practical terms, this means determining the relative abundances of the different elements. However, there is no direct way to measure the composition of the Universe as a whole. This is because different objects in the universe have different compositions. The different compositions reflect the different environments in which these objects are formed and their different histories. Matter clumps together in the form of stars, gas clouds, planets, comets, asteroids and meteors. So astronomers determine the composition of those objects, and ultimately attempt to deduce the overall make- up of the universe.

The composition of the universe is not static. We've seen that the universe started with just hydrogen and helium, and that heavier elements are made through fusion in stars and the explosive power of supernovae. So the first generation of stars was made only of hydrogen and helium. Thus, this first generation of stars could not be accompanied by rocky planets. As the universe aged, more light elements were turned into heavy elements. After the first generation of massive stars went supernova, they enriched space with heavy elements, allowing later generations of stars to have rocky planets.

The change in the elemental composition also happens at different rates in different places. Star formation is much faster in the dense cores of galaxies, so there will be more heavy elements there than in the slower-paced outskirts of the galaxies.

Composition is usually determined via spectroscopy. Each element gives off a unique signature of specific wavelengths of light, which are observed as bright lines in its spectrum. By measuring the relative intensities of these "emission lines" from different elements, it is possible to determine the relative abundances of the elements. When interstellar gas absorbs light, we see absorption lines, evidenced as dark lines in the spectrum. These lines can be used to tell us the composition of the gas cloud. The spectrum of a star shows the elements in the star's outer layers. The spectrum of a planet shows the elements on its surface and in its atmosphere. Meteorites found on earth, lunar samples, and cosmic rays are the few pieces of the Universe in which the elements can be directly separated and measured chemically.