Stars

We have all gone outside, glanced up at the sky and seen the many points of light that spread across our view like a giant dark carpet sprinkled with glitter. Most of the time, especially if you live in a city like most people do, these lights look like white points of light that are all pretty much the same size and color.

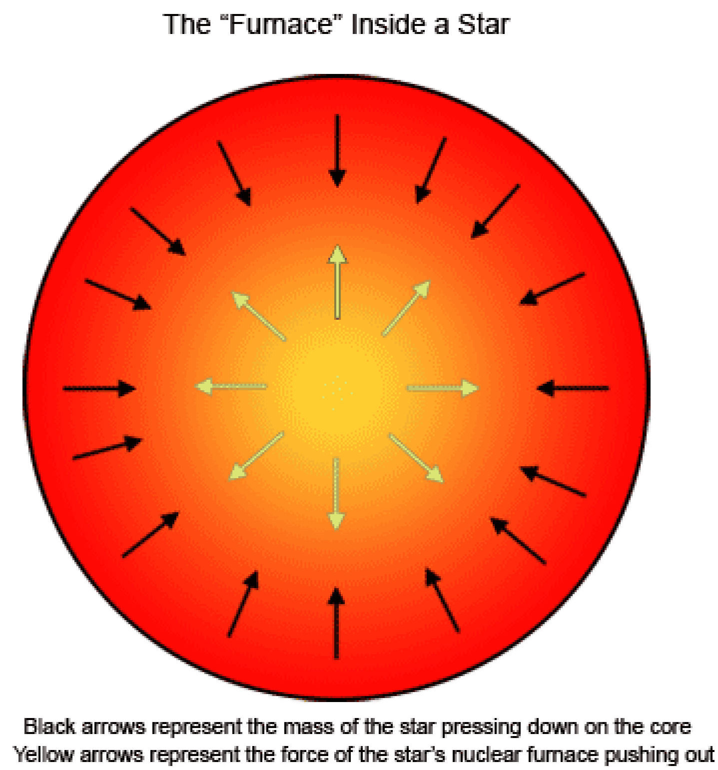
If you take the time to get several miles away from the city, the view changes dramatically. After giving your eyes about half an hour to adjust to the changed light, a whole new sky seems to magically appear above you. Now the sky is filled with thousands of twinkling lights of different sizes and colors. Some stars are noticeably brighter than others and many of them are different colors as well. Most of the stars still appear to be pretty much white, but some of them are "whiter" than others, some of them appear to have a faint orange-yellow tint and a few are as red as a stop light. If you have never seen the sky when there are no distracting lights of civilization, you owe it to yourself to make the trip away from the city. The view is absolutely amazing.

You are, or should be, asking yourself, "Why are the stars different colors and sizes?" The answer is that stars, like people, come in different sizes and colors. The size and color of a star tells us a lot about it, including how hot it is as well as how old it is. What you will learn in this section of the site is what the different sizes and colors tell us as well as many other interesting things about all those lights in the sky.

A Star's Internal Furnace

A Furnace that Generates Light and Heat

A star gives off light and heat as a result of the thermonuclear "furnace" burning at its core. The center of a star is an amazingly hot area as a result of the constant thermonuclear explosions. This "furnace" generates all the light and heat, as well as other forms of energy, that a star gives off. The temperature at the center of a star is in the hundreds of millions of degrees and the pressure is almost unimaginable.



A star gives off light and heat as a result of the thermonuclear "furnace" burning at its core.

Why Doesn't the Star Blow Up?

You may be asking yourself "Why doesn't the star blow up?" After all, everyone knows that thermonuclear reactions, like the ones in thermonuclear weapons, are very destructive and release massive force when they go off. The answer is that even though the reactions inside the star's furnace are very powerful, the star has so much mass that it contains the force of the explosions like we have shown in the above diagram. As long as there is enough mass in the star to contain the explosions, the star will generate light and heat instead of self-destructing. As you might guess, this is a very delicate balancing act.

Eventually, though, the star will burn up all the available hydrogen. When this happens, the balance between the central furnace and the mass of the star is destroyed and the star starts to die. This is also when the star goes off the Main Sequence in the H-R diagram.

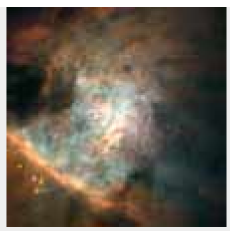
The Life Cycle of a Star

Stars have a life cycle just like everything else in the universe. From the humble beginnings of a few atoms of matter, stars grow into large stellar furnaces that provide the beautiful points of lights that we see in the sky. Our own Sun, which is a yellow dwarf star, also provides heat and, directly or indirectly, all other forms of energy to those of us living on Earth.

After a star is born, it goes through its adolescence and adulthood until it finally gets old and dies. The death of a star can either be quiet and calm, or dramatic and violent, which is what happens when what is called a supernova occurs.

A Star is Born

From the humble beginnings of a few atoms of matter, stars grow into large stellar furnaces that provide the beautiful points of lights that we see in the sky. Our own Sun, which is a yellow dwarf star, also provides heat and, directly or indirectly, all other forms of energy to those of us living on Earth.



Stars are being born in the Orion Nebula right now.

If you've done much reading about space, you have probably read that most of space is empty, with just a few atoms of matter, mostly hydrogen and helium, scattered around here and there. If most of space is empty, where do stars, planets and everything else come from? That is a very good question.

The answer is that matter is not spread evenly throughout space. There are places in space where, for a variety of reasons, more atoms and molecules have accumulated. If enough gas and dust particles have accumulated in a single area of space, the force of gravity will cause them to clump together in a cloud. If enough gas and dust are present the cloud can start growing on its own by attracting other gas and dust particles. This can turn into a kind of "snowball effect" where the cloud gets larger and larger, which, in turn, causes the cloud to attract even more and more matter.

As the matter in the cloud accumulates, the force of gravity causes the cloud to compress, or get smaller in size. When this gas is squeezed, the atoms are closer together which causes the temperature of the cloud to go up. As the cloud accumulates more and more matter, the gas gets squeezed closer together and the temperature gets even hotter. If the cloud accumulates enough matter, the molecules are squeezed so tightly together that they start a process called "fusion". When this process happens, the molecules are squeezed together so tightly that the hydrogen atoms start joining, or fusing, together to form helium. When hydrogen atoms are fused together to form helium, a tremendous amount of energy is released and the brand new star begins to shine. A star has just been born.

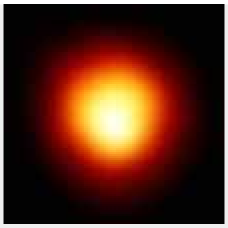
The Next Phase

What happens to our newborn star during the rest of its life depends on the mass, or amount of matter the cloud had accumulated before the new star ignited. This determines how long the star lives and what happens to it when it dies.

A Star Grows Up

From the humble beginnings of a few atoms of matter, stars grow into large stellar furnaces that provide the beautiful points of lights that we see in the sky. Our own Sun, which is a yellow dwarf star, also provides heat and, directly or indirectly, all other forms of energy to those of us living on Earth.

An Adult Star



A picture of the supergiant red star Betelgeuse in the constellation Orion.

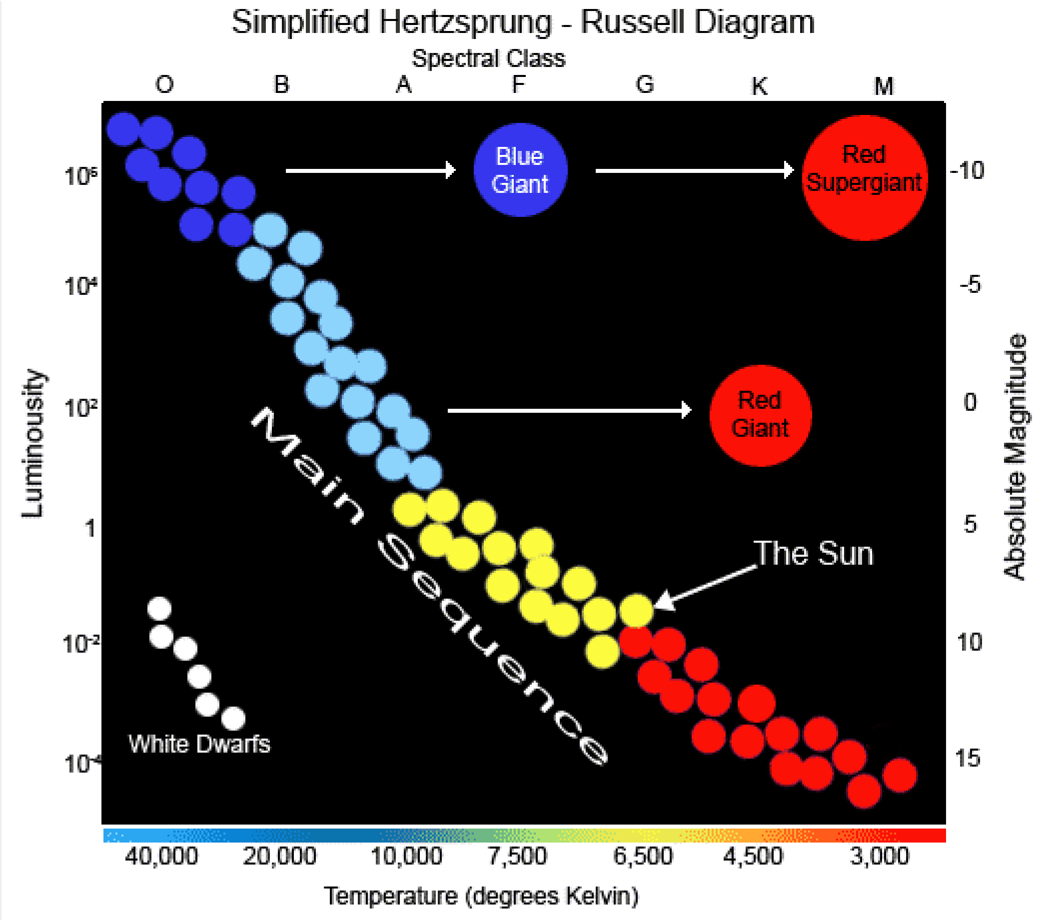
As we mentioned in A Star is Born, the adult phase of a star's life is determined by the star's mass, or how much matter it contains. This determines how hot a star is. For example, a star with relatively low mass will be cooler than a star with a higher mass. The color of a star is very important, as astronomers can determine the temperature of a star by observing its color. One of the things that some people find a little confusing is that red stars, like Betelgeuse and Antares are much cooler that blue stars like Sirius.

Most of us have grown up using phrases like "red hot" to indicate that something that glows red, like the burner on an electric range, is really hot. To us humans, a red burner on a electric range is really hot. When we are talking about stars, though, a star that is red is relatively cool, with a surface temperature of "only" a few thousand degrees on the Kelvin scale. The really hot stars like can have a surface temperature that is tens of thousands of degrees. This may be a little easier to remember if you think about watching a movie that shows how steel is made. When hot liquid steel comes of out the furnace, it glows almost white and then gets redder as it cools down.

What Kind of Star are You?

Stars come in a variety of sizes, masses and colors just like people do. The color of a star, which is called its spectral type, tells astronomers how hot it is. As we mentioned earlier, stars that are blue or blue-white in color are much hotter than stars that are red. The luminousity, or absolute magnitude, of a star depends on its size. Scientists use a combination of a star's temperature and luminousity to determine the type, size and age of a star. After all the information about a star has been gathered, astronomers can place the star on the Hertzsprung-Russell diagram, which is a tool used by astronomers all over the world to classify stars.

Hertzsprung-Russell Diagram



Scientists use the Hertzsprung-Russell diagram to classify stars.

While a star is going through its adult phase, or on the "main sequence", of its life, the thermonuclear "furnace" at its core continues to "burn" by fusing hydrogen atoms into helium atoms. This process can go on for many millions or billions of years. Eventually, though, the star will run out of its hydrogen fuel and the star will start to die. When a star dies, it can die quietly by just getting dimmer and dimmer or it can die in spectacular fashion by becoming a supernova or one of several other ways.

The Death of a Star

Stars can have a lifespan anywhere from several million to many billions of years. To us humans, this is a very long time indeed. Eventually, though stars must die like everything else in the universe. A star begins to die when the furnace at its center runs out of hydrogen fuel.

The death of a star is part of the life cycle of the universe. When a star dies, the hydrogen and helium atoms that are left behind can become parts of new stars that are born later. When larger stars die, their death creates the heavier elements like iron, carbon and silicon that are used to create new planets and their inhabitants. It is recycling on a cosmic scale.

A Star's "Engine" Runs out of Gas

In the stellar furnace, we explained that the explosive energy created at a star's center is contained by the mass of a star. When a star's furnace has burned up most of the hydrogen in the star, it no longer produces enough energy to "hold up" the mass of the star and the star begins to collapse in on itself. When this happens, the star begins to die. What happens next depends, like everything else in the life of a star, on how much mass the star has.

Small Stars

When very small mass red dwarf stars, like Proxima Centauri, die it is a relatively quiet, peaceful process. Stars like this are about half the size of our Sun and when their furnace runs out of fuel the star simply collapses and the star goes dark. It will eventually turn into a brown dwarf star. Brown dwarf stars are very plentiful in the universe, but we haven't been able to see any yet because they are so small and dim.

Medium Stars

When a medium mass star, like our Sun, dies its death will be a complicated. During the star's life, the furnace at the core of the star is fusing hydrogen atoms into helium atoms and photons. When the star begins to collapse, its larger mass causes the helium in the star's center to fuse together creating heavier elements like iron. At the same time, the outer layers of the star expand greatly and the star becomes a red giant. The outer part of the star also starts to come apart and the gas that is expelled is called a planetary nebula. Eventually the star will be unable to fuse any more helium and the final collapse will take place. The star shrinks down in size until it becomes what is called a white dwarf. Stars like this are no larger than Earth, but are very dim and extremely dense.

Giant and Supergiant Stars

Stars that are several times more massive that our Sun are destined to die in a violent and spectacular fashion. The start of the death of a giant star is a lot like that of a medium mass star. The star begins to collapse on itself and hydrogen fusion takes place and the star swells in size. The additional mass of a supermassive star, though causes the temperatures at the center of the star to go even higher, into the hundreds of millions of degrees. When this happens, the star begins to create elements even heavier than iron like silicon and other elements.

This fusion process continues until all that is left at the center of a star is a core made up almost entirely of iron with traces of the heavier elements. When this happens, the star collapses almost instantly in a giant explosion called a supernova. Supernovas are so bright that they are usually brighter than all the other stars in a galaxy combined! The explosion generates tremendous amounts of energy in the form of gas jets, X-rays and other radiation.

After the supernova explosion, a small part of the original star will be left behind. Scientists tell us that this remnant can be one of two things, depending on how much mass the star had originally:

A Neutron Star

When the star collapses in a supernova explosion, the force of the collapse is so great that what is left behind isn't what we normally think of as atoms. All of the atoms of the star have been crushed together so tightly that what remains is essentially just the centers, or nuclei, of the atoms. This is a very small, about the size of a city here on Earth, but are incredibly heavy. A teaspoonful of this matter weighs several billion tons! The tiny neutron star also spins around very rapidly. Neutron stars also emit a lot of energy as they spin around. When we detect this energy, the star is called a "pulsar" and appears to be a cosmic lighthouse that blinks on and off many times a second.

A Black Hole

If the original star was even more massive, it would collapse even more than a neutron star into a black hole. The center of the star is crushed together with so much force that it becomes even smaller and more dense than a neutron star. The force of gravity of this object is so great that anything that that comes near it, including light, gets sucked into it and disappears forever.

Basic Star Types

As you learn more about the stars, you will run across stars being described as "black dwarfs", "supergiants" and so on. Here is a listing of the more common types of stars as well as a brief description of each. The classification of stars is actually a lot more detailed than this short listing, but these are the most common types of stars you will encounter.

Black Dwarfs

Black dwarf stars are stars that we aren't even positive really exist in the universe, but computer simulations tell us will probably exist many billions of years from now. Black dwarfs are so old that they have burned up all of their hydrogen fuel and as a result are completely dark and cold. Computer simulations have told us that it would take longer for this to happen than the universe has existed.

Brown Dwarfs

Brown dwarf stars are stars in the technical sense, but they have so little mass that nuclear fusion is not occurring at their core. It is a lot like a car that won't quite start. Brown dwarfs can occur either when the cloud that the star came from isn't quite big enough to get nuclear fusion started or they can happen when a star dies.

Red Dwarfs

Red dwarf stars are the most common stars in the universe. They are very small, much smaller than the Sun and are very cool relative to other stars. A red dwarf star appear at the lower right of the H-R Diagram. Since red dwarf stars burn their hydrogen fuel at such a slow rate, they can live for many billions, or even trillions, of years.

Yellow Dwarfs

Yellow dwarfs are moderately bright, medium-sized main sequence stars that are very common in the universe. Our Sun is a yellow dwarf star. Yellow dwarf stars live for about ten billion years and then die by swelling up into red giants and then collapsing into white dwarfs.

White Dwarfs

White dwarf stars are formed when a star dies. They are what is left over after a star has collapsed onto itself. They are much hotter than the other dwarf stars. Our Sun will become a white dwarf when it dies billions of years from now.

Red Giants

Red giant stars are very large, but relatively cool, stars that are created when a medium-sized star, like our Sun dies. When a mid-sized star dies, it swells up tremendously in size and cools off before it finally collapses into a white dwarf star.

Red Supergiants

Red supergiant stars, like Antares in the constellation Scorpius are the most massive stars in the universe. They are many hundreds of time larger than our Sun and are formed when a very massive star begins to die. Red supergiant stars die in a very spectacular explosion called a supernova and then finally collapse into a neutron star or a black hole.

Special Stars

There are trillions upon trillions of stars in the universe and all of them are very special when you think about what it takes for a star to be born. Some, however really catch our eye because of their brightness, size or the amount of energy they produce. We have only started to learn about all of the amazing types of stars and here is an introduction to a few of them.

Binary Stars

Binary stars are very common in our night sky, but you can't see them using just your eyes.

A picture of Sirius A and B from the Chandra Observatory.

Scientists believe that many, or even most, stars live together as couples in binary systems, bound together by gravity and orbiting each other in a type of cosmic dance that goes on for the life of the stars. When two stars are in a binary system, the larger of the two stars is called "A" and the smaller one is called "B", like Sirius A and Sirius B in the sidebar at right.

There are also special binary stars that actually have three stars, all orbiting each other, but these are still called binary stars.

Beautiful and Practical

When seen through a telescope, binary stars are, as you might guess, very beautiful. They are also useful for learning more about the universe we live in. Scientists can determine the mass of binary stars by timing how long it takes for them to complete an orbit around each other and their distance from each other. Using these two facts, the mass of the stars can be calculated.

There are binary pairs of stars that are so far away or so dim that they cannot be seen using a standard telescope. If the pair of stars is aligned in such a way that one passes on front of the other during their orbit, scientists can detect the pair by studying the light output of the more massive star. If the light from the larger star dims regularly, there is a vary good chance that the dimming is caused by the smaller star passing in front of it. A pair like this is called an "eclipsing binary".

A Very Dangerous Dance

Most binary stars live together peacefully for their entire life. If a star is unfortunate enough to be paired with an incredibly dense neutron star, however, it could face a slow but certain death.

Since neutron stars are incredibly dense, their immense gravity can actually suck matter from their companion star. If this process continues long enough, the unfortunate partner of the neutron star will eventually lose enough mass that it ceases to exist.

Black Holes

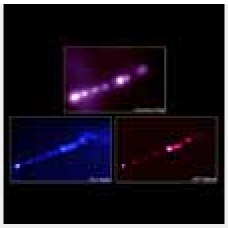
Black holes are created when a supermassive star dies. The star collapses onto itself, which results in a massive explosion called a supernova. After the explosion, the what is left of the original has collapsed into an object that is so dense that the force of its gravity traps everything that falls into its grasp and makes it disappear. Nothing, including light, can escape from a black hole.

A picture of a galaxy with a black hole in the center.

Since even light cannot escape from the grip of a black hole, we can't see them and we don't have any pictures of them. All we can do is observe what happens to the area around them. The effects of a black hole on its surroundings are truly amazing and terrifying at the same time.

What happens When an Object Falls into a Black Hole?

Every black hole has a kind of border around it called the "event horizon", which varies in size depending on the mass of the black hole. As long as you stay at least that far away from the black hole, everything is fine and you won't even notice that it's there. It is invisible, after all.



Three views of the jets of energy that stream from a black hole.

Once any object wanders inside the event horizon certain destruction awaits. The gravity of the black hole is so very strong that no amount of energy can provide an escape. The unfortunate object would be inevitably drawn towards the black hole. As the object is inevitably drawn to the center of the black hole, it becomes more and more stretched out. When it finally falls into the black hole, its matter is ripped apart and it disappears forever into the black hole. When the object's matter is ripped apart, the ripping process creates streams of amazingly powerful and fast moving jets of many kinds of energy that stream away from the black hole.

What About Wormholes?

Wormholes are a concept that has been popularized in science fiction movies and books for many years. The concept behind a wormhole is that if a black hole is infinitely dense, which they seem to be, where is the bottom of it? It is a very interesting question that we don't have an answer for right now.

One popular theory is that the bottom of the black hole goes on for an incredibly long distance, possibly to the other side of the galaxy or even the other side of the universe. It is kind of like digging a hole in Earth that is so deep that you come out on the other side.

It would be very handy if we could travel from one side of the universe to the other by using a wormhole shortcut. The real answer to this question, like so many others, is that we have no real idea. The current theory is that there are no wormholes, but that could easily change at any time. In the meantime, it is a very fascinating topic.

Neutron Stars & Pulsars

Neutron Stars

Neutron stars are created in the final phase of the death of a star that is much more massive than our Sun, but not quite massive enough to become a black hole.

After the star explodes in a supernova, what remains is a very small, but incredibly dense object that is made up almost entirely of the centers of the atoms, called the nuclei, of the original star. Scientists tell us that neutron stars are very small, no larger than a medium-sized city.

What neutron stars lack in size, though, is more than made up for by their density. Since what is left of the original star has been crushed down into nuclei, what is left is incredibly heavy. Just a teaspoonful of the matter that makes up a neutron star can weigh several billion tons!

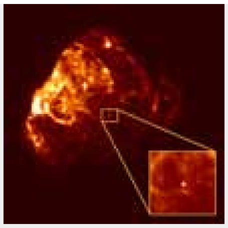
Pulsars

All stars spin on their axis and a neutron star is no different. When a neutron star is created, it spins faster and faster as it becomes smaller and smaller. Neutron stars rotate on their axis at a speed that can very anywhere from once every few seconds to many hundreds, or even thousands of times per second. The pulsar at the heart of the Crab Nebula, for example rotates at a speed of thirty times per second.

In addition to their very high rotation speed, neutron stars also generate tremendous amounts of energy that streams away from the star at amazingly high speeds. The energy that the star generates "pulses" with each rotation of star, which it what gives pulsars their name.

If the star is aligned to Earth in a certain way, we can detect these pulses of energy, which makes that star appear to be blinking like a cosmic lighthouse.

A picture of the Crab Nebula with the pulsar at its center.



An x-ray image of the Puppis supernova remnant and the pulsar at its center.

Supernovas

Supermassive stars, like Antares in the constellation Scorpius, die in spectacular fashion. When the star begins to die, it starts swelling up in size until it becomes many hundreds, or even thousands, of time larger than our Sun. When a star gets to this phase of of its death, it is called a red supergiant star. When the star cannot expand any more, which is caused when it can no longer create enough energy to support its mass, the star collapses completely and explodes in a giant explosion called a supernova.

The final collapse and explosion takes place in seconds and is incredibly bright. A supernova is so bright that it can outshine all the other stars in a galaxy combined!

An Unimaginably Massive Explosion

A picture of the remnants of a supernova.

A Cosmic Energy Source

Supernovas are not just incredibly bright. They also create amazing amounts of energy in many forms. The force of the explosion sends shock waves speeding away from the dying star at amazing speeds. In addition, a supernova generates jets of energy that can be in the form of gas jets, x-rays, radio signals and plasma. These jets of energy can stream away from the dead stars at speeds of thousands of miles per second.

A picture of the jets of energy created by a supernova.

Supernovas also help create new stars. When the expanding shock waves run into other gas clouds in the universe, they can help trigger the formation of brand new stars, which start the stellar lifecycle all over again.

In addition to helping create new stars, supernovas are also the source of all the elements in the universe that are heavier than oxygen. The heat and pressure of a supernova explosion help create atoms of silicon, carbon and many others. These atoms can go on to become new stars, planets and the basis for life forms on the new planets. As Carl Sagan once said, we are all starstuff.

On July 4th, in the year 1054, people all over the world witnessed an amazing event On that date, a supernova occurred in the constellation Taurus. The event was recorded by scientists in Europe, Japan and China and was apparently drawn on cliff walls in the American west by Anasazi Native Americans.

The explosion was several times brighter than Venus and was so bright that it could be seen in broad daylight for twenty-three days.

The Supernova of 1054 AD

A picture of the Crab Nebula.