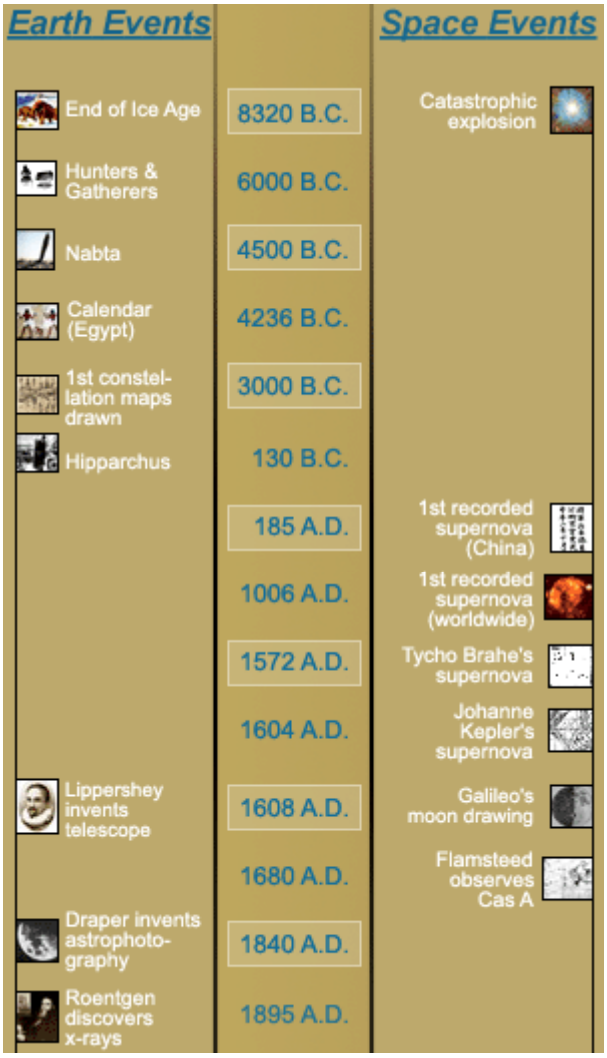
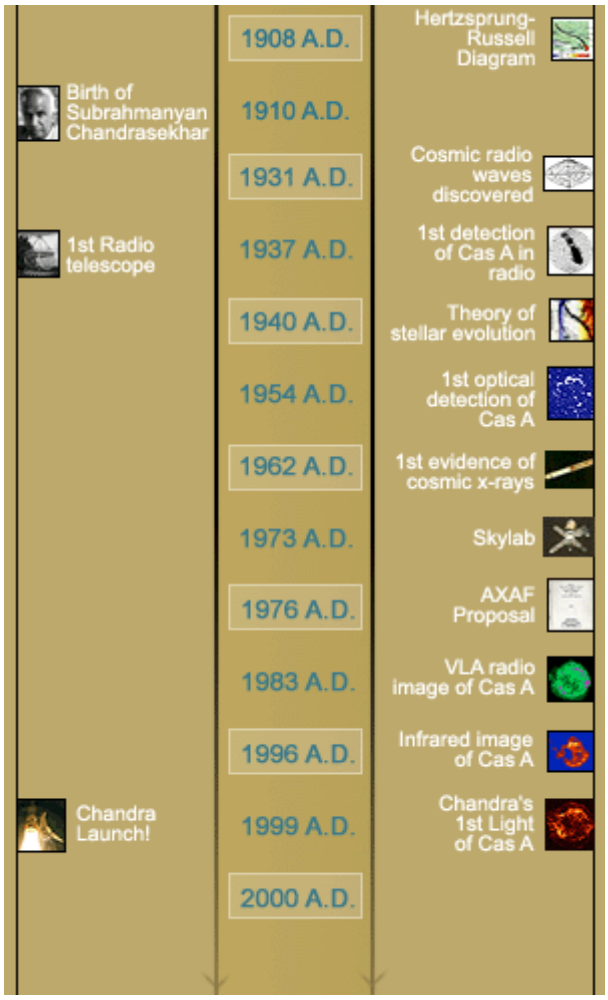
Cassiopeia A
The Death of a Star



Ten thousand, three hundred and twenty years ago and sixty trillion miles away, a giant star was dying. More than ten times more massive than our Sun, the star had existed for more than ten million years. Now the star was running out of hydrogen, the fuel necessary to keep its nuclear fires burning. The radiation pressure pushing outwards from the nuclear fires in the core of the star stopped. Without the radiation pressure, there was nothing to balance the relentless inward pull of gravity and the star began to collapse. The star, which had existed since the evolution of mammals on Earth, finally lost its battle with gravity. The complete and total destruction of the star followed in a catastrophic **explosion**. On Earth, the year was 8320 BC and the glaciers had finally finished receding, ending the last great **Ice Age**. Small bands of hunter-gatherers had crossed the Bering Strait and were spreading throughout North and South America. A paleo-Indian culture was flourishing in the region of the Rio Grand Valley in New Mexico.

Prehistoric cultures had already turned their eyes to the sky above them. The repeating patterns of the motions of the Sun, Moon and stars had become a calendar, clock, and compass. The sky told them when the game herds would migrate, the direction in which to travel, and eventually when to plant and harvest their crops. They believed that human events and cycles were part of larger cosmic events and cycles, and that the night sky was part of that cycle. Maybe the first stirrings of human consciousness were born in the contemplation of the mystery and beauty of the night sky. The steady progression of the changing pattern of motions must have seemed calm and eternal and comforting. It was, however, an illusion. The stars in the sky are not eternal; they are born from nuclear fires, they live, and ultimately die. Some die violently, tearing themselves apart with catastrophic explosions. These ancient skywatchers did not know about the death of the star in the sky above them so

very far away. However, ten thousand, three hundred and twenty years into the future, the brilliant death of the star would become known.



The star had left behind the story of its destruction. The energy released in the violent collapse of the star traveled through the interstellar space surrounding the star in the form of photons. The interstellar medium between the stars is so thin and tenuous that it is nearly a perfect vacuum. The few atoms and molecules that comprise the medium inhabit a frigid environment with a temperature of nearly absolute zero, having so little kinetic energy that they barely move. Light travels through the silence and the darkness and the cold, carrying its messages to and from distant galaxies, stars, and planetary systems thousands and millions of light-years apart. Light is the ultimate cosmic voyager, traveling for hundreds, thousands, millions, and billions of light-years to deliver ancient messages from the stars to those with the ability to read them. Within the radio, infrared, visible, and x-ray photons now radiating into space in all directions was a message, waiting to be read by those who had the ability to decode the story of the death of the star.

The **hunter-gatherers** were making sophisticated stone tools. Metals had not yet been discovered and the Bronze Age was still 2000 years in the future. In Europe, Africa, Asia and the Americas crops were planted and animals were domesticated. The motions of the sky were watched and recorded with rock and stone monuments or alignments, rock art and notches inscribed into bones, antlers and tusks.

Sometime around 4500 BC in the Sahara Desert in Egypt, stone slabs nine feet high were dragged over a mile to create **Nabta**, the oldest known astronomical alignment of megaliths in the world. Predating Stonehenge by more than one thousand years, the stones are aligned with the summer solstice horizon. The descendants of this mysterious and complex culture may have eventually constructed the first pyramids along the Nile. In 4236 BC the Egyptians invented the first **calendar** based on 365 days. The first day of the Egyptian year started with the day that Sirius the Dog Star in the constellation Canis Major rose in line with the Sun in the morning and coincided with the annual flood of the Nile. While ancient cultures on Earth were using the stars to

track the passage of the seasons, the light carrying the story of the death of another star had now been traveling through spacetime for four thousand and eighty four years.

Early observers organized stars into easily recognizable patterns that resembled the objects, animals, and people important to their culture and religion. Knowledge of the sky was necessary for survival. One of the oldest recognized patterns in the sky is the Big Dipper, part of the constellation of Ursa Major. Archaeological evidence suggests that the stories about this constellation date back to the Ice Age. At that time, cultures in both Siberia and Alaska shared a common heritage as people moved across the Bering Strait. In 3000 BC, the first **constellation maps** were drawn by ancient astronomers. The constellation of Cassiopeia, in the direction of the dying star, had not yet been named. However, one day in the future the star would be named for the constellation it appeared to be in – Cassiopeia. The light from CAS A had been traveling for six thousand, three hundred and twenty years from a part of the sky not yet drawn on constellation maps.

Hipparchus of Nicaea, a Greek astronomer, compiled the earliest known star map and catalogue of 1,080 stars in 130 BC. The star catalogue itself has long since been lost or destroyed and is only known by references to it from later astronomers. The Almagest (Arabic for The Greatest) was completed in 140 AD by Ptolemy of Alexandria. Two of the thirteen chapters were a Catalogue of Stars that gave the positions of 1.022 stars. Ptolemy's star catalogue was used for the next seventeen hundred years. The light from CAS A, unknown and not in the star catalogue, had now been traveling towards Earth for eight thousand, two hundred years.

In the year 185 AD the **Chinese** observed a "guest star", mostly likely a supernova, in the constellation Centaurus, which remained visible for 20 months. The Chinese also recorded other possible "guest stars" in 369 AD, 386 AD, and 393 AD. Then, in **1006 AD** a supernova or "guest star" was reported in China, Japan, Europe, and the Arab lands. The new star remained visible for several years. The supernova of 1006 was the first supernova event observed worldwide. The light from CAS A had now been traveling for nine thousand, three hundred and twenty six years, and will not reach Earth for another six hundred and seventy four years.

On November 11, 1572 Tycho Brahe was walking home from his lab just after sunset. He was contemplating the stars and noticed a new and unusual star directly over his head in the constellation of Cassiopeia where he had never seen a star before. For two weeks the star outshone every other star in the sky, and could be seen in full daylight. At the end of November it began to fade and change colors and finally faded from sight in March of 1574, having been visible to the naked eye for 16 months. There were no telescopes then; however Tycho’s account of the light changes and his position measurements form a valuable record of the event. **Tycho's supernova** event occurred in the same constellation as CAS A, however the exploding star was much closer to

Earth and the information reached Earth first. Brahe's apprentice, Johannes **Kepler** who would later formulate the three laws of planetary motion, carefully studied the next observed supernova event that occurred in 1604.

The light from CAS A had been traveling for nine thousand, nine hundred and twenty eight years when, in 1608 AD, **Hans Lippershey**, a Dutch spectacle maker invented the first telescope. **Galileo Galilei** used the new invention to look at the sky in 1609 and opened a new era in Astronomy. Instruments were developed and attached to telescopes that would aid in the measurement of the velocity of light and the distances to stars. The development of the spectrometer allowed Frauhofer to provide a detailed description of the chemical composition of the Sun. By now there was a worldwide interest in the field of astronomy.

After traveling through interstellar space for more than ten thousand years, the light carrying the story of the death of CAS A finally reached Earth in the year 1680. By this time there was a keen interest in astronomy in Europe and a large number of telescopes were being used. Though two previous supernova events had been observed from Europe (1572 and 1604) it was though that no record existed anywhere on Earth that the CAS A event was observed. This was a mystery since Cassiopeia is a circumpolar constellation and located outside in Milky Way in a dark section of the sky. However, it now appears that one man did observe CAS A. The British astronomer **John Flamsteed** observed a star that was near the position of CAS A which was not seen by anyone else and was never seen again. Was John Flamsteed the only person to actually observe the light from CAS A as it sped past Earth?

In 1840 AD, **John William Draper** used the recently invented technology of the camera to take a photograph of the Moon. This was the first application of photography to astronomy. The light from the initial explosion of CAS A had now traveled one hundred and sixty years beyond the orbit of the Earth, continuing to tell the story of the death of a star more than ten thousand years in the past. On the day that Draper took the first picture of a celestial object and invested astrophotography, the information passing Earth told the story of the events that happened during the 160th year of the dying star. And still, only one man had noticed the CAS A supernova event.

On November 8, 1895 **Wilhelm Roentgen** was working in this laboratory at the University of Wurzburg in Germany. His attention was drawn to a glowing fluorescent screen on a nearby table. Roentgen immediately determined that the fluorescence was caused by invisible rays originating from the tube he was using in his study of cathode rays (now known as electrons.) Surprisingly, these mysterious rays penetrated the opaque black paper wrapped around the tube. Roentgen had discovered X-rays. He was completely unaware that X-rays carrying the story of the death of a far-away star were at that very moment speeding past the Earth. His discovery would assist future astronomers in their quest to understand supernova remnants and the catastrophic

collapse of massive stars. In 1901 Roentgen received the first Nobel Prize in physics for his momentous discovery. By that time, the scientific community had gained a better understanding of the electromagnetic spectrum, the nature of light, stellar distances, and the chemical composition of stars.

In 1908 a Danish astronomer named Hertzsprung started describing giant and dwarf stars. He and an American astronomer named H.N. Russell independently developed the **Hertzsprung-Russell Diagram**. The diagram is a graph that plots the relationships among mass, intrinsic brightness and temperature for stars. Theories about the evolution of stars were beginning to appear.

On October 14th, 1910, **Subrahmanyan Chandrasekhar** was born in Lahore, British India. In later years he would become known to the world simply as Chandra. He did not know that 89 years into the future and 5 years after his death, an orbiting X-ray observatory would be named after him. Chandra was interested in stellar evolution, and calculated the mass limit of a star that would evolve into a white dwarf. The light from CAS A had now been traveling for ten thousand, two hundred and forty three years.

Karl Jansky, an engineer at Bell Labs, discovered **cosmic radio waves** in the 1930's. He found that not only was the Milky Way an emitter of radio noise, but that sources in deep space emitted as well. One of the powerful radio sources was in the region of Cassiopeia and was named CAS A. Finally! CAS A had been "rediscovered".
The radiation from CAS A, composed of all wavelengths of the electromagnetic spectrum, had been traveling through spacetime and past Earth for more than ten thousand years and had remained unnoticed. No one had decoded the message, and no one knew the story. Now Earth was starting to record information from the cosmos in wavelengths other than the visible part of the spectrum. In 1937 an amateur radio operator named Grote Reber built the **first true radio telescope**. Reber plotted radio intensity maps of several sources, including the first detailed **radio map of CAS A**. It had been two hundred and fifty seven years since John Flamsteed's single and nearly forgotten observation of a newly visible star in the constellation of Cassiopeia.

In 1940 a Russian astronomer, George Gamow, described giant red stars and formalized the **theory of stellar evolution** and the creation of elements in massive dying stars. Gamow understood that the explosive death of a giant star produced elements that later became part of nearby clouds of gas and dust, and eventually became incorporated into newborn stars. In 1954, two German-American astronomers were conducting a survey to locate the optical counterparts of the bright radio sources that had been discovered. The two astronomers, Rudolph Minkowsky and Walter Baade, found the **CAS A optical remnant** associated with its radio counterpart. Earth now could start to decode pieces of the story of CAS A; however some very important chapters were still missing.

The first rocket flight that successfully detected a **cosmic source of X-ray** emissions was launched in 1962. The Aerobee 150 rocket rose 80 miles into the atmosphere and opened the window on its detector for 5 minutes and 50 seconds and discovered a very bright X-ray source. The source was named Scorpius X-1 (SCO X-1), because it was the first X-ray source found in the constellation of Scorpius. X-ray telescopes were constructed to track down the sources for cosmic X-rays. In 1973 the first orbiting X-ray telescope was transported to **Skylab**. The orbiting space station took thousands of X-ray images of the Sun. However, there were so few solar X-rays compared to other wavelengths that it was not thought that there were many X-rays in the universe. X-ray astronomers did not think there was much of a future for them. They had nothing to worry about! It turns out that the universe it full of catastrophic events that send silent X-ray screams of death and destruction through interstellar space. Several orbiting X-ray telescopes were built and launched, including Einstein, EXOSAT, and ROSAT.

In 1976, after the success of the Einstein mission, a group of X-ray astronomers proposed a larger, more powerful orbiting X-ray telescope to NASA. It was called **AXAF** (the Advanced X-ray Astrophysics Facility.) For the next 13 years scientists worked with NASA and Congress to get the funds to build AXAF. In 1989 they received a go-ahead to build the first set of X-ray mirrors. In the next 10 years, AXAF was built while it survived funding cuts that resulted in fewer mirrors and scientific instruments. While the remaining mirrors and instruments and the observatory were constructed, more finely revolved images of CAS A were build produced in optical, **radio**, and **infrared**. In 1999 NASA held a contest to rename the X-ray observatory. AXAF became known as Chandra and it was decided that Chandra's first "light image" would be CAS A.

After two aborted attempts due to a hydrogen leak and the weather, Chandra was successfully **launched** at 12:31 EDT on July 23, 1999 on board the space shuttle Columbia. Chandra was deployed from the shuttle Columbia and after several maneuvers established it's highly elliptical orbit which carries it more than one third of the distance to the Moon. On August 19th, the Chandra X-Ray Observatory pointed towards the supernova remnant CAS A for its **first light** image. Not only was the remnant seen in incredible detail, the probable neutron star at the core of the star was seen for the first time! Finally, after the light from CAS A had been traveling towards and beyond Earth for ten thousand, three hundred and nineteen years, CAS A began to reveal its innermost secrets. And not by one unnoticed observer: this time CAS A was seen by the world. The story of a star that had been born in nuclear fires while mammals were evolving, began to run out of nuclear fuel during the emergence of Homo Sapiens, and died a catastrophic explosion at the end of the Ice Age was now becoming known on Earth.

The light from CAS A will traverse the universe forever, possibly encountering other planets and other civilizations with the ability to decode the message and learn the story. CAS A is a part of the endless stellar cycle of formation and destruction. During the dying process elements created deep within the interior are blown into the interstellar medium, and caught up in condensing clouds of gas and dust that will give birth to other stars. The death of CAS A created and scattered the elements necessary for planets to form and life to evolve. The cycles of life and death for living organisms on this planet is possible because of the cycles of formation and destruction of stars – we are all part of the continuing story of cosmic evolution.