The Crab Nebula

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Abstract

The Crab Nebula is a vast cloud of gas and dust located about 6,000 light years from Earth. This nebula results from a supernova star explosion that was observed and documented in AD 1054. The supernova remnant continues to expand outward today, more than nine centuries later. At the center is a neutron star, or pulsar, with a rapid rotation of 30 cycles per second. The Crab Nebula is an intense emitter of radio waves, x-rays, and gamma rays. Thousands of research papers, books, and symposiums have appeared on this well-known object. The history of the Crab Nebula and current research findings provide several insights and research opportunities for creationist astronomy.

A Brief History of the Crab Nebula

In the year AD 1054, over nine centuries ago, stargazers noticed an unusual event in the night sky. A bright new star suddenly appeared in the constellation Taurus. The light brightened rapidly over a three-week period, and then slowly faded away over the following two years. This temporary light show was a deep mystery to early astronomers, but we now recognize the 1054 observation as a supernova star explosion. Certain massive stars become violently unstable during the latter stage of their nuclear energy production. The star disintegrates and its outer layers are blasted into surrounding space. For a period of several months, the resulting light and energy output may exceed that of an entire galaxy of one hundred billion stars.

The 1054 event was recorded by observers in many lands, particularly across Asia. Chinese, Japanese, and Korean observers described the "guest star" in existing records. Reckoning from the Julian calendar places the initial appearance of the celestial fireworks around July 4 of that year. There are intriguing clues that this supernova event also was noted by Native Americans, probably the Anasazi (a Navajo word for the "ancient ones") (Mitton, 1978). Throughout the southwest United States are many petroglyphs, also called pictographs or rock paintings. Some of them may commemorate the unusual bright light in the heavens. The location of the star explosion lies close to the moon's path across the sky. In fact, the crescent moon would have passed within 2 degrees of the bright star. Several petroglyphs appear to picture an unusual light source in the vicinity of a crescent moon (Figure 1). This interpretation is subjective because of uncertainties in the dates and meanings of the Indian art. However, one can be certain that early Americans closely watched the skies by night. (The fascinating search for astronomy connections with ancient records is called archaeoastronomy.)

At the site of the 1054 supernova explosion is a resultant expanding nebula (Latin for "cloud") of star debris. The nebula was first reported by British amateur astronomer John Bevis in 1731. Decades later, the famous comet hunter Charles Messier prepared a catalog of about 100 nebula and star clusters to avoid their misidentification with comets. The Crab Nebula prompted the catalog and is the first item in the list, today known as M-1, or Messier object number one. The New

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Figure 1. Drawing of a petroglyph painting on a sandstone overhang. The star, moon, and hand figures are each about six inches in size. This drawing is in Chaco Canyon, New Mexico. Chaco was a major center of Indian culture from AD 850–1250.

General Catalog system identifies the Crab Nebula as NGC 1952. In 1844, Irish nobleman and stargazer Lord Rosse noticed clawlike gas filaments around the object's border and first called it the Crab Nebula.

Moving forward two centuries, a neutron star or pulsar was detected within the Crab Nebula in 1968. This extremely compact, rapidly spinning type of star results from the implosion or collapse of the inner regions of the original disintegrating star. Pulsars had been discovered a year earlier by Cambridge graduate student Jocelyn Bell-Burnell. Her advisor, astronomer Antony Hewish, won the Nobel Prize in Physics for working out the model for pulsar behavior. The emitted pulses of radiation from such stars are so regular that they were initially thought to be signals from other civilizations. Hundreds of pulsars are now known to exist in the Milky Way. The Crab Nebula continues to receive active study by many astronomers. Some of the related historical dates are summarized in Table 1.

Table 1. Some historical dates related to the AD 1054 supernova event.

Date	Event
1054	The supernova is observed worldwide.
1731	The gaseous nebula of star debris is discovered by John Bevis.
1780	Charles Messier lists the Crab Nebula in his published catalog of sky objects.
1844	Lord Rosse refers to the crablike appearance of the nebula.
1892	The first photograph is taken of the Crab Nebula.
1913–15	Initial spectroscopic studies of the nebula are carried out by Vesto Slipher.
1968	A pulsar is detected in the Crab Nebula using the Aricebo Radio Telescope, located in Puerto Rico.
1969	An optical or visible flash from the Crab Nebula pulsar is observed.

Supernova Mechanism

The theoretical details of a supernova event have been explored in recent decades with supercomputers (Clayton, 1984). The following description is a model that may be near or far from reality: A star such as the sun produces its energy by the nuclear fusion of hydrogen to helium. As the internal hydrogen is exhausted, additional fusion reactions occur in the star's core as helium fuses to carbon, then oxygen and heavier elements. Finally the element iron builds up in the core. However, nuclear fusion reactions of elements beyond iron absorb rather than produce energy. Iron is the "end of the nuclear road" and the production of energy by nuclear fusion thus ceases. As a result, such a star may slowly contract to become a small, hot, stable star called a *white dwarf*. If the initial star is larger, however, at least

1.4 times more massive than the sun, its eventual collapse is far from tranquil. As the nuclear fusion fire is extinguished by the formation of atomic iron in the core, the inward gravity force on the outer portions of the star is too great to be supported by its interior. In mere seconds the outer layers of the star collapse inward catastrophically. This extreme dynamical motion results in internal temperatures reaching billions of degrees. The collapsing star then rapidly rebounds with an outward shock wave, and star wreckage bursts outward in a cataclysmic supernova explosion. This dramatic description is for Type II supernovae, which mark the death of heavyweight stars. Massive stars need not necessarily reach the iron core stage before exploding. A supernova observed in the Large Magellanic Cloud in 1987, called SN 1987A, was found to be deficient in heavy elements such as iron. It appears that the star simply exhausted its internal fuel supply, collapsed, and then disintegrated. Most astronomers consider the AD 1054 event to have been a Type II supernova (Hester et al., 2005). There is also a Type I category of supernova, somewhat rarer and less energetic, which results either from mass transfer in binary star systems or else variations of the Type II process. There are further supernova subcategories based on their atomic spectra, including types Ia, 1b, 1c, II-P, and II-L.

Heavy atomic elements beyond iron will form by nuclear fusion in the outer regions of the star during its final death throes. These elements are then flung outward across space. In the evolutionary model of the universe, the iron atoms in our blood, the gold in jewelry, and the uranium within Earth rocks originated in the destruction of ancient stars. This is a poetic, but unbiblical, idea that we are made of stardust, and to stardust we will eventually return.

During a supernova event the center portion of the original star may be crushed inward to form a neutron star. This star matter resembles a giant atomic nucleus with all of its component protons and electrons combining to form neutrons. The detailed internal structure of neutron stars is not known. Models variously predict the presence of elementary particles, a solid crystal lattice of neutrons, and superfluid neutron layers. Neutron stars are only about 6 miles (10 km) in diameter, more than 100,000 times smaller than the sun. Neutron stars have an extreme density of 10^{14} grams/cm^3 and a surface gravity 200 million times that of the earth. One teaspoon of this extraordinary "stardust" weighs as much as Mount Everest. Most, if not all, neutron stars are also pulsars. The star is spun up to an extremely high rotation rate during its collapse. As nearby material falls onto the star, intense and continuous beams of radiation are emitted from the pulsar's magnetic poles. These beams shine outward from the turning star like searchlight beacons in space. The resulting pulses of radiation reveal the star's rotation rate, as great as one thousand rotations per second. Neutron stars may emit visible light or other components of the electromagnetic spectrum.

For supernovae involving the largest stars, those with a mass greater than about 4 solar masses, current theory predicts an even stranger destiny. During the supernova process, the interior portion of the star collapses inward without limit, and becomes a black hole. This ultimate concentration of mass is called a *singularity*, with infinite density and gravity.

Supernovae are relatively rare within a galaxy. There are six known supernova events in the Milky Way from the last millennium (Table 2). No supernovae have been observed in the Milky Way Galaxy since the invention of the astronomical telescope, popularized by Galileo in 1609–1610. Dozens of earlier supernovae remnants also are observed in our galaxy such as the Veil Nebula in Cygnus. Of all the known supernova

Table 2. Six historical supernovae in the Milky Way galaxy. The distances are averages from many sources and are uncertain by at least ten percent. The last supernova was not recorded by observers and its exact date is uncertain.

Date	Distance Estimate (light years)	Constellation Location
AD 1006	6500	Lupus (Also the Wolf), near Libra. Documented in Oriental Arabic records. This is thought to be the brightest supernova in historic times.
1054	6000	Taurus
1181	10,000	Cassiopeia. Observed by Chinese and Japanese observers. The Crab Nebula.
1572	10,000	Cassiopeia. Called Tycho Brahe's star.
1604	13,000	In Ophiuchus. Called Johann Kepler's star.
1680(?)	10,000	Cassiopeia A. This supernova remnant was discovered in 1947.

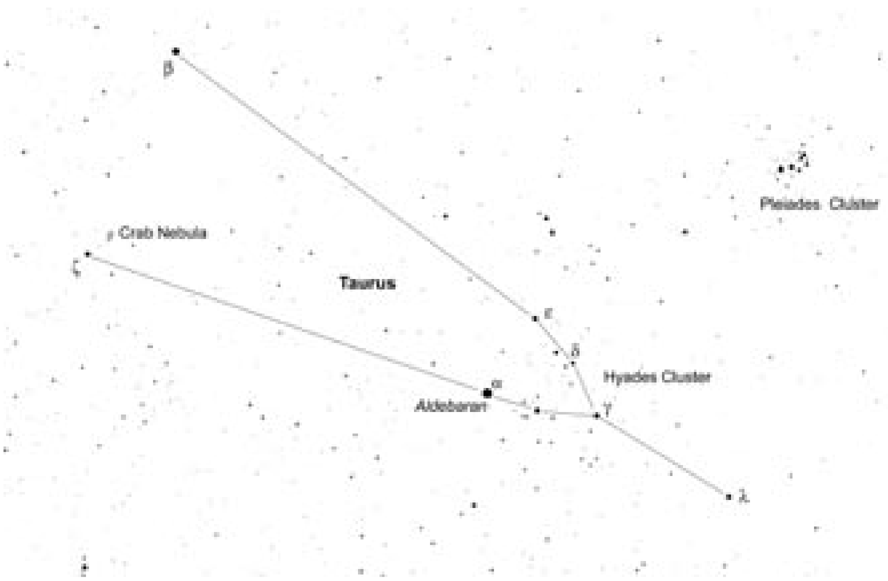

Figure 2. The Taurus constellation, which is visible in the northern hemisphere in winter. The location of the supernova of AD 1054 and its resulting Crab Nebula are indicated just inside the open top of the V shape. This drawing is adapted from the website of the Jodrell Bank Observatory in England.

remnants, the Crab Nebula remains the brightest and best known.

On a smaller scale, the term *nova* (Latin for "new") is given to the temporary brightening of certain stars. This may occur in binary systems when matter from the larger member, perhaps a red giant star, falls on its white dwarf companion. The flare-up typically lasts several months and is probably recurring. Nova events are observed 30 to 40 times each year within the Milky Way. A nova explosion increases a star's brightness about 10,000 times. In contrast, the increase in supernova light or luminosity is at least 10,000 times greater still. The chief nova-supernova distinction is the scale of the energy output. A nova does not result in a restructuring of the entire star, as is the case for a supernova.

Description of the 1054 Event

Taurus the Bull is one of the twelve zodiac constellations. This means that Taurus is positioned close to the ecliptic, the plane of the solar system. The constellation has a V-shape arrangement of bright stars with Aldebaran, the brightest, as the eye of the bull. The open star cluster Hyades is part of Taurus, positioned at the bottom of the V, and the Pleiades cluster is also nearby (Figure 2). The 1054 supernova occurred just inside the open top of the V as indicated in the figure. The right ascension and declination coordinates are 05 hr 35 min and +22°. In the northern hemisphere the Crab Nebula is faintly visible during winter months under good conditions using a small telescope. Its apparent magnitude is 8.4 and its absolute magnitude is about -3.

The maximum brightness of the supernova is estimated to have been -16 to -17 on the absolute magnitude scale. This means the explosion was nearly a billion times brighter than the sun. At its great distance from Earth, however, the explosion would have appeared as a bright star with an apparent magnitude of -5, outshining the planet Venus. As with Venus, the supernova would have been visible during the daylight hours for several weeks. The bright light then gradually faded out of sight over the following two-year period.

The Crab Nebula today is about 10 light years across (Figure 3). This is 7,000 times the size of the entire solar system. The nebula has an angular spread of 4-6 minutes of arc, about 10 times less than the moon's diameter. The stellar cloud is roughly spherical in nature, but it appears from our perspective as two dimensional and somewhat circular. Extrapolating back 950 years gives an average outward speed for the nebular gas of 50 million miles per day, or nearly 600 miles per second (1000 km/sec). This is one of the highest rates of expansion measured for any supernova remnant. The angular spreading of the nebula is 0.2 seconds of arc (0.000055°) per year, noticeable on photographs that are compared over several decades. A clear comparison of Crab Nebula photographs taken 28 years apart is available. See the Astronomy Picture of the Day (APOD) reference.

A neutron star or pulsar is located at the center of the Crab supernova remnant where it illuminates the surrounding gas cloud. Its rotation rate is measured at 30 rotations per second; the precise period is 0.033089 seconds. The assigned name of the pulsar is PSR0531+21. Distinct radiation pulses are detected across the entire electromagnetic spectrum including radio, visible, x-ray, and gamma ray wavelengths. The Crab Nebula pulsar is among the brightest objects in the sky at nonvisible light wavelengths. Optical or visible light pulses were first observed in 1969. If we could see the pulsar with its rapid rate of blinking, it would appear to our eyes as a steady light. A slight slowdown in the pulsar rotation has been measured in recent years due to a gradual loss of its energy and angular momentum.

Crab Nebula Mysteries

The Crab Nebula is one of the most studied objects in the heavens. Neverthe-

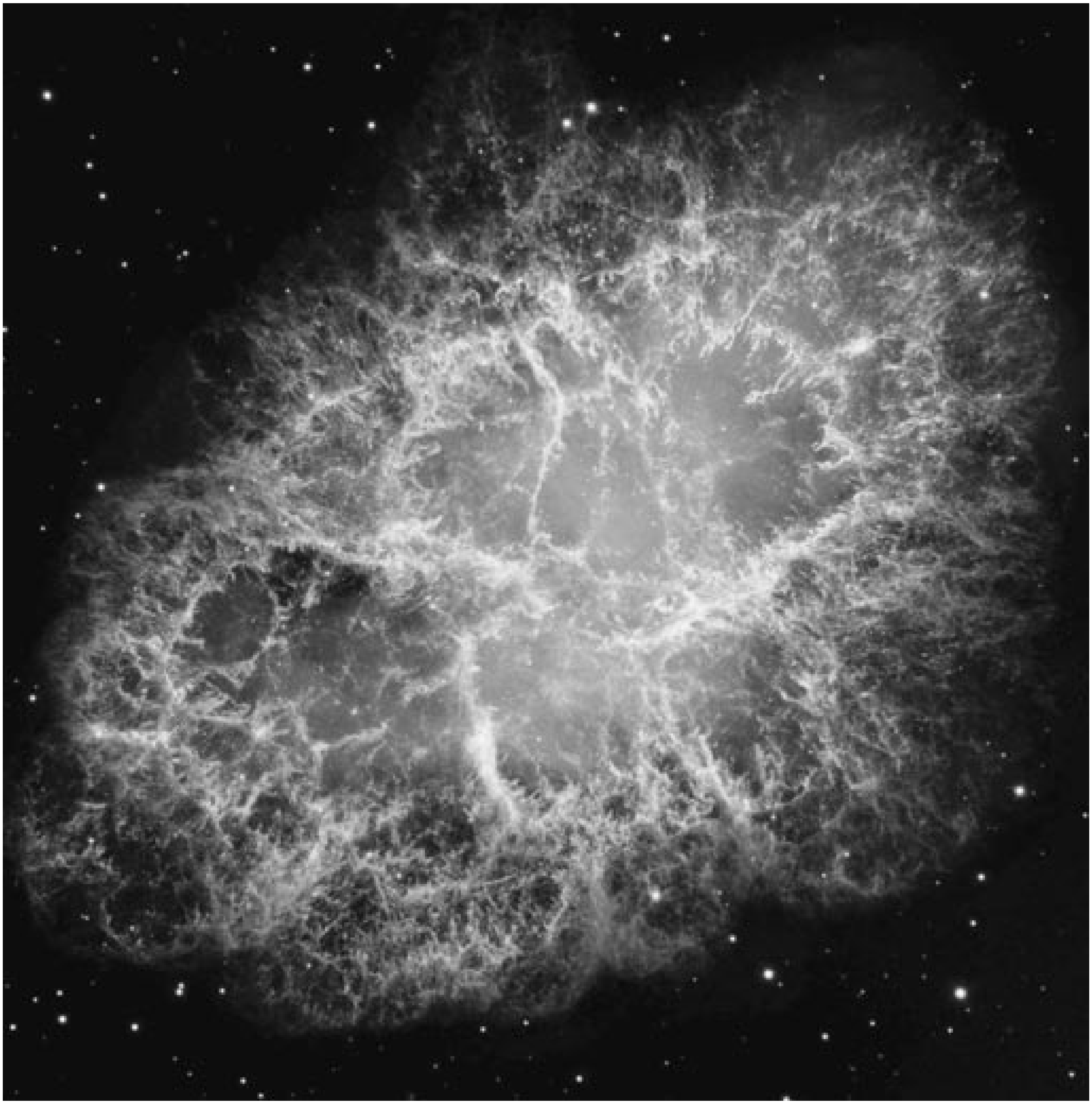

Figure 3. A Hubble Space Telescope photograph of the Crab Nebula. The cloud of gas and dust results from the supernova of AD 1054. The nebula is about 10 light years in size and is 6000 light years from Earth.

less there are several unsolved mysteries, and three will be mentioned here. The first concerns historical observations of the 1054 supernova. As described earlier, stargazers worldwide recorded the unusual event. However, there is no known mention of the supernova by European observers at its time of occurrence. Surely the bright supernova was noticeable to Western observers as it was elsewhere. Some have suggested that the Catholic Church later expunged all records of the supernova. The theory is that church authorities had proclaimed the bright light as a sign of the end times, and then they were embarrassed when the light faded away. There is no evidence to back up this typical "religion bashing" theory. Furthermore, there also are no known Arabic records of the 1054 supernova event. The unanswered question is "Why not?"

A second mystery involves data that shows that the overall Crab Nebula expansion is not gradually slowing, as expected, but is instead accelerating outward (Burnham, 1978). This finding is similar to the much grander observation that the entire universe appears to be accelerating in its outward expansion. These unexplained motions show how little is understood about the dynamics of the cosmos.

A third mystery relates to the total number of known supernovae. Table 2 lists six historical supernovae that have occurred in the Milky Way. Because of the "bunching" of these events in past centuries, supernova frequency within a particular galaxy is usually stated as once every 25 to 50 years. However, the Milky Way has not experienced a known supernova for over three centuries, 6 to 12 times as long. It would appear that we are long overdue for a new supernova event in our galaxy. One might suggest a possible theological connection. The supernovae listed in Table 2 actually occurred sometime before their signals arrived on Earth. Depending on distance uncertainties, several may actually have occurred nearly simultaneously. Is it possible that an era of frequent supernova activity coincided with events such as the Creation, the Fall, or the Flood? As an analogy, recent research has found tentative evidence for a universal acceleration of radioactive decay at multiple times during history (DeYoung, 2005). Further exploration is needed of the possible theological reasons for the temporary acceleration of various rates on a cosmic scale.

If accelerated nuclear decay did indeed occur in the realm of the stars, large-scale changes in stellar energy models would result. Many implications would then follow. For example, smaller mass stars could become unstable and subject to supernova events. The possibility of rapid nuclear decay is a topic for future theoretical creation research in astronomy.

Observing Supernovae in a Young Universe

Spectroscopic studies of the Crab Nebula give a distance of about 6000 light years, or 33 thousand trillion miles. The precise distance is not known, and published estimates vary between 5500-6500 light years. Using uniformitarian reasoning, the supernova light thus traveled about 6000 years before its detection on Earth in AD 1054. These numbers imply that the supernova actually occurred about 7000 years ago, in conflict with the 6000-year model of creation. Many other supernovae remnants give a much greater time conflict. For example, consider supernova SN 1987A, which was observed two decades ago. It is located in the Large Magellanic Cloud, one of our nearest galaxies at a distance of 180,000 light years. Several additional supernova events are observed each year in more distant galaxies. The question is how such supernovae can be seen in a young universe? How does their light reach us on a short timescale? This topic of seeing distant starlight has been much discussed in the creation literature. The vast distances in space are real and cannot be reduced to just thousands of light years. Also, evidence is lacking for a gradual, historical decrease of light speed. Russell Humphreys has suggested the existence of different clocks on the earth and in deep space (Humphreys, 1994). This theoretical model is called *white hole cosmology*. The details of this model have not yet been worked out for objects in our relatively near vicinity of space such as the AD 1054 event.

Let us consider further possibilities for seeing distant starlight. First, the speed of light may have been infinite at the very moment of its origin on day four of Creation week when the heavens were supernaturally filled with galaxies, stars, planets, and moons. In this case distant, created starlight from deep space would arrive at earth instantaneously. Then, light speed may have been set immediately to its present constant value of 186,000 miles per second, or 300,000 km/sec. Where do supernova explosions fit into such a picture? Consider some alternatives. God may have greatly accelerated the aging process of stars during their creation. Thus the starlight reaching Earth on the fourth day would have a built-in appearance of age or maturity. This is entirely consistent with the creation of our first parents Adam and Eve, the Garden of Eden, and the entire earth. The idea is also consistent with the conclusion from recent research that radioisotope decay was accelerated a billionfold during Creation and also during the Flood (DeYoung, 2005). In addition, this mature creation of space objects matches observations that show fully formed galaxies at remote distances (Cowen, 2005). These remote, "adult" galaxies are in conflict with the assumption of their gradual formation long after the big bang event. In contrast, the mature galaxies are consistent with a fully functioning creation. It is recognized that the mature creation model expressed here, also called the "light-in-transit" model, faces theological challenges (Humphreys, 1994). The multiple physical connections between accelerated decay, light speed, and stellar decay need further exploration.

If the preceding discussion of a mature creation does not appeal to the reader, there is a second option. The entire cosmos may have been reprogrammed at the time of the Fall of Genesis 3 with a resulting appearance of age. I would suggest that in some ways we read too many physical changes into the Curse, but in other ways we read far too few. Romans 1:20 states that the whole creation, including the heavens, feels the impact of the Fall. Also, all of creation, including deep space, eagerly awaits an eventual renewal.

Other Creation Implications

Our location in the Milky Way Galaxy appears to be providential for our survival. The solar system is positioned two-thirds of the distance outward from the center of the galaxy. In this outer region the stars are relatively sparse or widely spread. If the earth were instead positioned at the center of the galaxy, among the densely populated stars, we would probably experience a greater number of nearby supernovae events. This situation would be dangerous since a supernova occurring within several light years of Earth would spray us with lethal radiation and destroy the ozone shield, if not life itself (Ward and Brownlee, 2000).

Some of the largest and most complex experiments in physics involve particle accelerators. These machines typically constrain charged particles—protons, electrons, and their antiparticles—to move in a circle while they are accelerated to near light speed. Collisions and interactions with these ultra-fast particles then provide information on the fundamental building blocks of matter. The large particle ring at Fermi Laboratory in Illinois, for example, has a radius of 1 km and a circumference of 6.28 km, or 3.9 miles. A large particle accelerator also is nearing completion in Geneva, Switzerland by the European Center for Nuclear Research (CERN). The larger the particle accelerator, the closer the atomic particles can approach light speed. This high-energy physics research is limited by machine size and budget constraints. Meanwhile, the Crab Nebula may provide the ultimate particle accelerator. Electrons are detected in the nebula moving at speeds far beyond our capabilities on Earth, extremely close to light speed. As a result their relativistic mass is increased by 100 million times. A light gray haze is noticed in the core of the Crab Nebula, due to synchrotron radiation given off by these ultra high-speed electrons (Figure 3). The electrons follow a cycloid path around lines of magnetic field existing within the nebula. The radii of their circular paths are several billions of miles. The Crab Nebula therefore is a natural particle accelerator on a scale billions of times larger than any man-made device. The extraction of data from the moving electrons remains a challenge because of their remote location. Nevertheless, it appears that physicists are provided with a no-cost cosmic laboratory to explore creation details.

Creationists have pointed out the rarity of observed Milky Way supernova remnants (SNRs), which contrasts with predictions assuming a long age for the universe (Davies, 1994). Some statistical estimates predict thousands of SNRs on a long timescale. However, only about 200 SNRs are known in the Milky Way, in apparent agreement with a young universe. Rebuttals to this young-universe evidence are not convincing (Isaak, 2005). Although this argument is on the side of the young-earth view, it remains tentative. Table 2 shows that the observed supernova occurrence is nonuniform over time. Also, due to intervening matter, it may be that only a small percentage of supernovae and resulting SNRs in our Milky Way galaxy are actually observed.

Conclusion

Photographs of the Crab Nebula reveal a beautiful structure of glowing gas and dust in outward motion. Its center is host to a spinning, blinking pulsar. The nebula provides ongoing mysteries for both creationist and evolutionary interpretations. Perhaps the most fundamental lesson to be learned from the Crab Nebula is that the universe is temporary. Stars do not originate by themselves but were created on day 4. Likewise, stars do not live forever, as illustrated by supernova explosions. Sooner or later, the heavens will need refurbishing as described in 2 Peter 3:13.

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