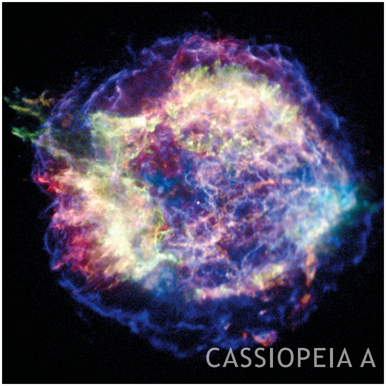
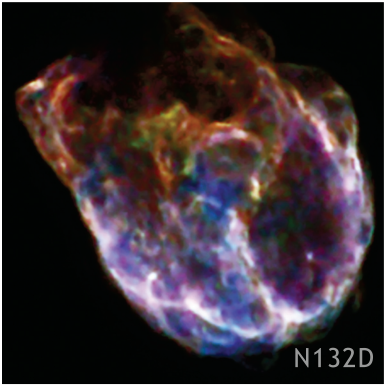
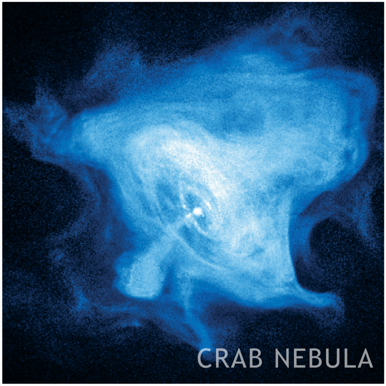
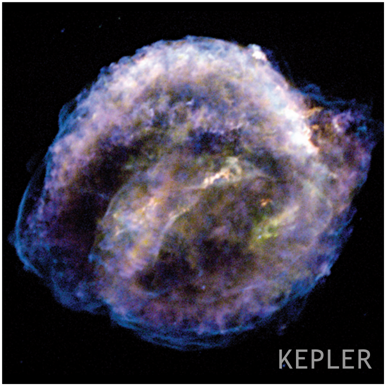
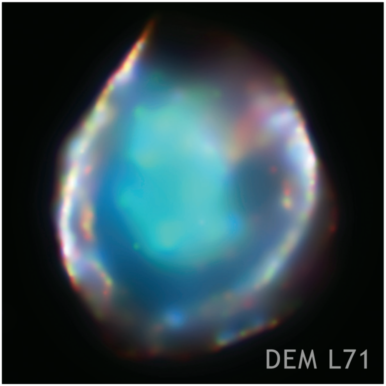
CELESTIAL FIREWORKS: SUPERNOVA REMNANTS


CASSIOPEIA A

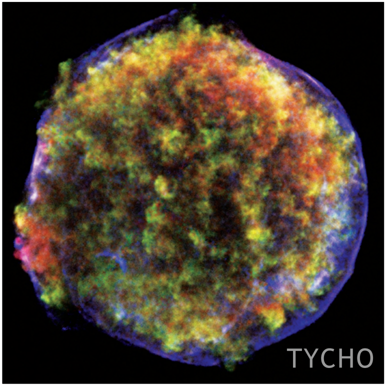

N132D

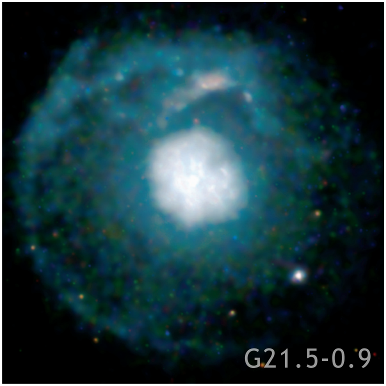

CRAB NEBULA


KEPLER


DEM L71


W49B


TYCHO


G21.5-0.9

Supernovas that signal the end of massive stars are some of the most dramatic events in the cosmos. With its unique mirrors and instrumentation, Chandra has captured these celestial explosions in spectacular X-ray images. These titanic events send shock waves rumbling through space and create giant bubbles of multimillion-degree Celsius gas.

Chandra's X-ray images enable astronomers to determine the energy, composition, and dynamics of these explosions. In the centers of many of these bubbles, Chandra has revealed the presence of pulsars—rapidly rotating, highly magnetized neutron stars—that are pumping wave after wave of extremely energetic matter and antimatter particles into space.

A LOOK AT SUPERNOVA REMNANTS WITH THE CHANDRA X-RAY OBSERVATORY

Every 50 years or so, a massive star in our Galaxy blows itself apart in a supernova explosion. Supernovas are one of the most violent events in the Universe, and the force of the explosion generates a blinding flash of radiation, as well as shock waves analogous to sonic booms.

There are two types of supernovas: Type II, where a massive star explodes; and Type Ia, where a white dwarf collapses because it has pulled too much material from a nearby companion star onto itself.

The general picture for a Type II supernova goes something like this. When the nuclear power source at the center or core of a star is exhausted, the core collapses. In less than a second, a neutron star (or black hole, if the star is extremely massive) is formed. As infalling matter crashes down on the neutron star, temperatures rise to billions of degrees Celsius. Within hours, a catastrophic explosion occurs, and all but the central neutron star is blown away at speeds in excess of 50 million kilometers per hour. A thermonuclear shock wave races through the now expanding stellar debris, fusing lighter elements into heavier ones and producing a brilliant visual outburst that can be as intense as the light of several billion Suns!

The matter thrown off by the explosion plows through the surrounding gas producing shock waves that create a shell of multimillion degree gas and high energy particles called a supernova remnant. The supernova remnant will produce intense radio and X radiation for thousands of years.

In several young supernova remnants the rapidly rotating neutron star at the center of the explosion gives off pulsed radiation at X-ray and other wavelengths, and creates a magnetized bubble of high-energy particles whose radiation can dominate the appearance of the remnant for a thousand years or more.

Eventually, after rumbling across several thousand light years, the supernova remnant will disperse. Supernovas heat the interstellar gas, seed it with heavy elements, and trigger the collapse of giant clouds of cool dust and gas to form a new generation of stars. It is probable that a supernova led to the formation of our solar system some five billion years ago and provided the chemical elements necessary for life on Earth.

The cloud that collapsed to form the Sun and its planets was composed mostly of hydrogen and helium, but it was enriched with heavier elements, among them carbon, nitrogen, oxygen, silicon, sulfur, and iron. These elements are manufactured deep in the interior of massive stars and would, for the most part, remain there if not for the cataclysmic supernova explosions.

Astronomers are using Chandra data to compile detailed maps of supernova remnants that show the variations in temperature of the hot gas, the total energy of the shock wave, and the quantity and location of various elements. Chandra has also been used to observe recent supernova events. These observations will allow astronomers to refine and test theories of the explosion and the events leading up to it.

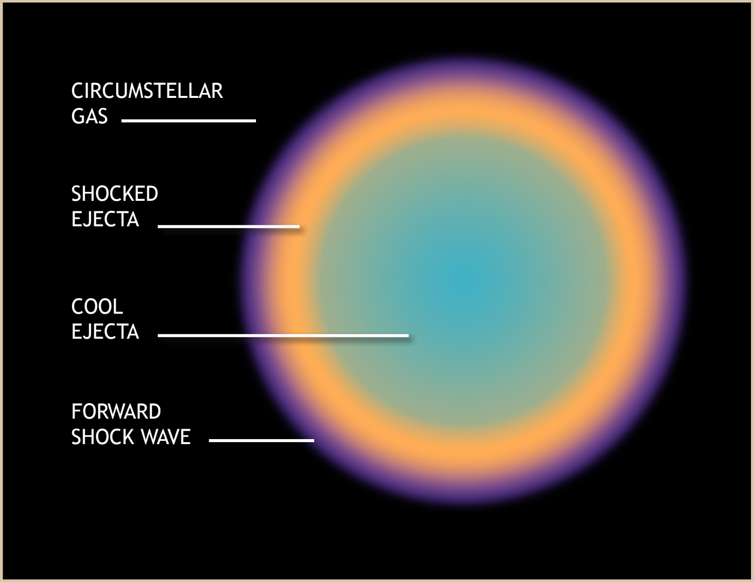
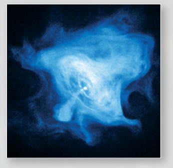
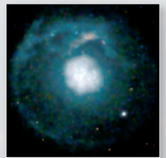


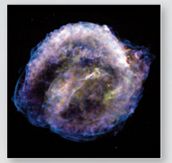
ILLUSTRATION OF SHOCK WAVES IN SUPERNOVA REMNANTS: The expansion of the ejecta into the circumstellar gas from a supernova explosion generates a forward shock wave that speeds ahead of the ejecta. Like an extreme version of sonic booms produced by the supersonic motion of airplanes, the forward shock wave produces sudden, large changes in pressure and temperature behind the shock wave (purple). The hot, high pressure gas (purple) behind the forward shock expands and pushes back on the ejecta, causing a reverse shock that heats the ejecta (orange). Eventually, the reverse shock wave will traverse the cool ejecta (blue) and heat it.



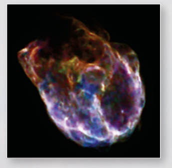
CRAB NEBULA: The Crab Nebula was first observed by Chinese astronomers in 1054 A.D., and this stellar debris left behind from a supernova explosion has since become one of the most studied objects in the sky. This image from Chandra provides a dramatic look at the activity generated by the pulsar (white dot near the center of the image) in the Crab Nebula. The inner X-ray ring is thought to be a shock wave that marks the boundary between the surrounding nebula and the flow of matter and antimatter particles from the pulsar. Energetic shocked particles move outward to brighten the outer ring and produce an extended X-ray glow. The jets perpendicular to the ring are due to matter and antimatter particles spewing out from the poles of the pulsar.



G21.5-0.9: This image, made by combining 150 hours of archived Chandra data, shows the remnant of a supernova explosion. The central bright cloud of high-energy electrons is surrounded by a distinctive shell of hot gas. The shell is due to a shock wave generated as the material ejected by the supernova plows into interstellar matter. Although many supernovas leave behind bright shells, others do not. This supernova remnant was long considered to be one without a shell until it was revealed by Chandra.

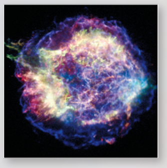


KEPLER'S SUPERNOVA REMNANT: In 1604, Johannes Kepler was among those who witnessed a "new star" in the western sky. Four hundred years later, Chandra is helping unravel the mysteries of the expanding remains of what is now called Kepler's supernova. Modern astronomers know that Kepler's supernova is a fast moving shell of iron-rich material from the exploded star, about 14 light years across, surrounded by an expanding shock wave that is sweeping up interstellar gas and dust. Chandra's X-ray vision allows astronomers to analyze regions where high-energy particles glow due to their multimillion-degree temperatures.

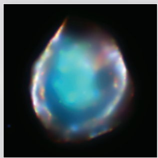


N132D: Chandra's image of N132D shows a beautiful, complex remnant of the explosion of a massive star. The horseshoe shape of the remnant is thought to be due to shock waves from the collision of the supernova ejecta with cool giant gas clouds. As the shock waves move through the gas, they heat it to millions of degrees Celsius, producing the glowing X-ray shell. N132D is about 180,000 light years from Earth in the Large Magellanic Cloud, a small companion galaxy to the Milky Way.

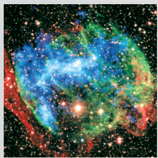
MORE ABOUT CHANDRA'S SUPERNOVA REMNANTS...



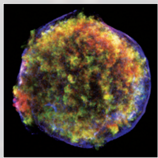
CASSIOPEIA A: This extraordinarily deep Chandra image shows Cassiopeia A (Cas A, for short), the youngest supernova remnant in the Milky Way. Analysis of Cassiopeia A shows that this supernova remnant accelerates electrons to enormous energies. The blue, wispy arcs reveal the acceleration is taking place in an expanding shock wave generated by the explosion that destroyed the progenitor star. This acceleration is close to the theoretical limit and provides strong evidence that supernova remnants are key sites for generating cosmic rays, mysterious high-energy particles that bombard the Earth.



DEM L71: Astronomers consider DEM L71 to be a textbook example of what happens when a star explodes and ejects matter at high speeds into the surrounding interstellar gas. Chandra's X-ray image of DEM L71 reveals a 10-million-degree inner cloud (aqua) of glowing iron and silicon, which is surrounded by an outer ring of 5-million-degree gas. An analysis of the Chandra data identified the inner cloud as the remains of a white dwarf star that exploded. The white dwarf pulled matter from a nearby companion star onto itself until it became unstable and blew apart in a thermonuclear explosion. Like N132D, DEM L71 is located in the Large Magellanic Cloud.



W49B: This is a composite Chandra X-ray (blue) and Palomar infrared (red and green) image of the supernova remnant known as W49B, which lies some 35,000 light years from Earth. The data reveal a barrel-shaped supernova remnant consisting of bright infrared rings around a glowing bar of intense X-radiation. These X-rays are produced by jets of 15-million-degree gas that is rich in iron and nickel. These features indicate that W49B could have been produced when the core of a rapidly rotating massive star collapsed to form a black hole, triggering the ejection of high-energy jets of material.



TYCHO'S SUPERNOVA REMNANT: Chandra's image shows a bubble of hot gaseous supernova debris (green and red) inside a more rapidly moving shell of extremely high-energy electrons (blue). These features were created as the supersonic expansion of the debris into interstellar gas produced two shock waves—one that moves outward and accelerates particles to high energies, and another that moves backward and heats the stellar debris. The relative expansion speeds of the hot debris and the high-energy shell indicate that a large fraction of the energy of the outward-moving shock wave is going into the acceleration of atomic nuclei to extremely high energies. This finding strengthens the case that supernova shock waves are an important source of cosmic rays, high-energy nuclei which constantly bombard Earth.

Credits — Crab Nebula: NASA/CXC/SAO/F.Seward et al.; G21.5-0.9: NASA/CXC/U.Manitoba/H.Matheson & S.Safi-Harb; Kepler's SNR: NASA/CXC/NCSU/S.Reynolds et al.; N132D: NASA/CXC/NCSU/K.J.Borkowski et al.; Cassiopeia A: NASA/CXC/MIT/UMass Amherst/M.D.Stage et al.; DEM L71: NASA/CXC/Rutgers/J.Hughes et al.; W49B: X-ray: NASA/CXC/SSC/J.Keohane et al.; Infrared: Caltech/SSC/J.Rho & T.Jarrett; Tycho's SNR: NASA/CXC/Rutgers/J.Warren & J.Hughes et al.; Illustration: CXC/M.Weiss

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