

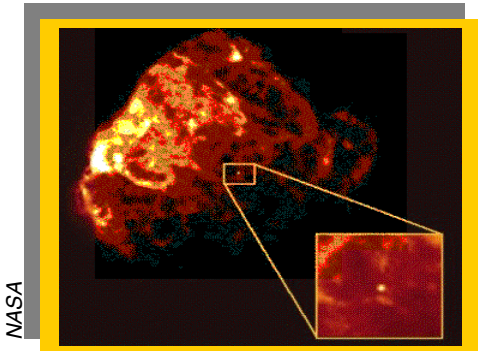
Neutron Stars

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A **neutron star** is one example of a stellar remnant: something left behind by a star at the end of its lifetime. Stars are what they are because they burn hydrogen gas. In reality, they fuse the hydrogen nuclei (the cores of the atom) together into helium nuclei. This nuclear reaction releases much more energy than any kind of ordinary fire. In addition to making a star a source of light and heat, the nuclear reaction also generates a great deal of pressure. For most of its life, the star exists due to a balance between this outward pressure and the contracting force of its own gravity. What happens when the hydrogen runs out? The balance of pressure and gravity is destroyed and the star collapses. Between that point, and the very end of the story, several interesting things may happen. There may be brief periods (only a million years or so!) when other types of **fusion** occur. The star may shed some of its matter, making a kind of nebula. The color and nature of the star may vary wildly. But if the star has the right mass (medium large, but not too large), the final collapse results in a big explosion when everything crunches into the center and rebounds. This is one type of **supernova**. If conditions are just right, there will be a compact object left behind, made of very different material than normal stuff and a product of the enormous forces of the supernova explosion.

What is this stuff? To answer that, we have to switch the scale of our thinking from huge objects, like stars, and think about things smaller than **atoms**. Inside an atom, the **nucleus**, or core, is essentially made up of particles called **protons** and **neutrons**. The protons have a positive electric charge, and the neutrons are electrically neutral. Together, they account for most of the **mass** of an atom. Buzzing around outside the nucleus are the **electrons**. They are much lighter (about 2000 times lighter), and have a negative charge. In between the nucleus and this “cloud” of electrons is a lot of empty space. In fact, a normal atom is composed mostly of empty space! Without getting into the details, powerful nuclear forces keep the electrons separate from the core, maintaining the atom’s structure.



NASA
Supernova Remnant with close-up view of young neutron star

The exotic thing that happens in the heart of a supernova is that the force of the blast (which from the outside is an explosion, but from the center is an implosion) is so strong that it overpowers these normal nuclear forces. In a manner of speaking, the positive charges (the protons) and the negative charges (the electrons) are “squeezed” together into neutral particles (more neutrons). The atoms are no more. Their structure is gone, along with all of that empty space. All that is left is a “sea” of neutrons. This is a neutron star.

With all of that empty space gone, the matter in a neutron star is much denser than any “normal” matter could ever be. A typical neutron star will have more than 10 billion times as much mass as our sun, yet it will only be about 10 kilometers in size (our sun is more than a million kilometers across). A centimeter cube of neutron star material one would weigh more than a billion tons here on Earth, and thus would probably sink down through concrete, steel, rock, or anything else, to punch through to the center of the planet.

A neutron star is very hot because the hot core of the “regular” star it came from never had a chance to cool. And the pressures of the supernova explosion, and the “packing down” into neutron degenerate matter, heats things up even more. But since the neutron star is so compact, there isn’t much surface area, so it cannot radiate much energy away. This makes a neutron star dim and hard to see. Yet astronomers have located a number of neutron stars, and an explosion that creates a new one is quite easy to see. One of them happened in 1054 AD in the constellation of Taurus, and was well documented by Chinese astronomers. We can still see the remains of that explosion today. It is known as the Crab Nebula.