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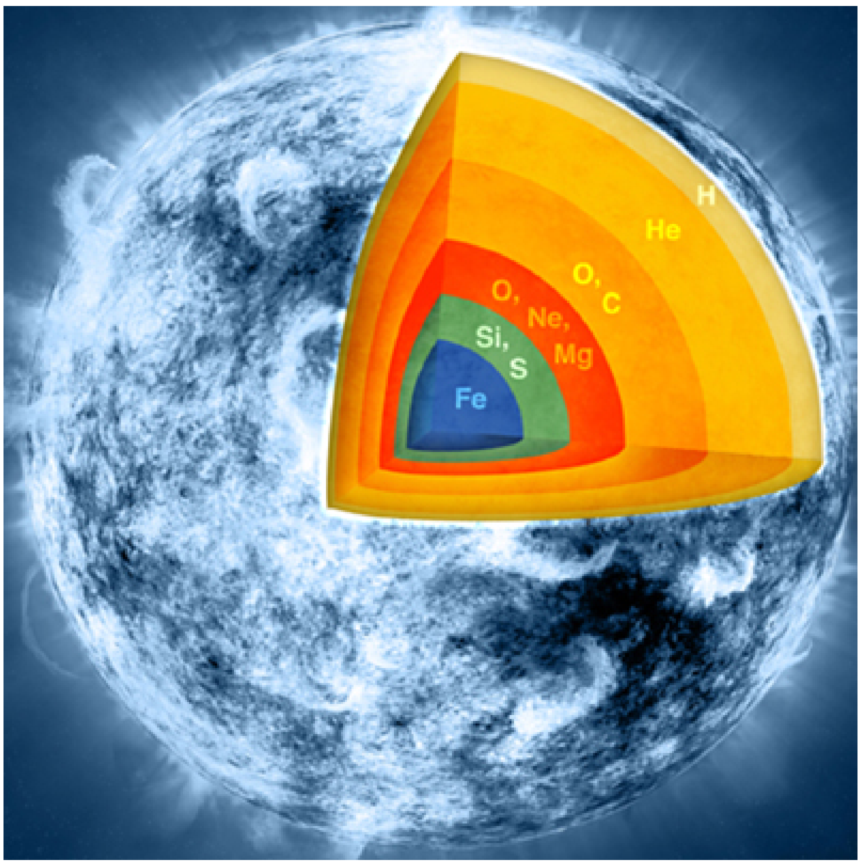
NuSTAR telescope takes first peek into core of supernova

February 19 2014, by Robert Sanders



Stars fuse hydrogen (H) and helium (He) into heavier elements to produce energy, but once the reactions reach iron (Fe), fusion stops and the star implodes, creating a compact object – a neutron star or black hole – and blowing off the star's outer layers in a supernova explosion. The explosion seeds the galaxy with elements like carbon (C) and oxygen (O) essential to life. Credit: NASA image.

(Phys.org) —Astronomers have peered for the first time into the heart of an exploding star in the final minutes of its existence. The feat by the high-energy X-ray satellite NuSTAR provides details of the physics of the core explosion inaccessible until now, says team member Steven Boggs of UC Berkeley. NuSTAR mapped radioactive titanium in the Cassiopeia A supernova remnant, which has expanded outward and become visible from Earth since the central star exploded in 1671.

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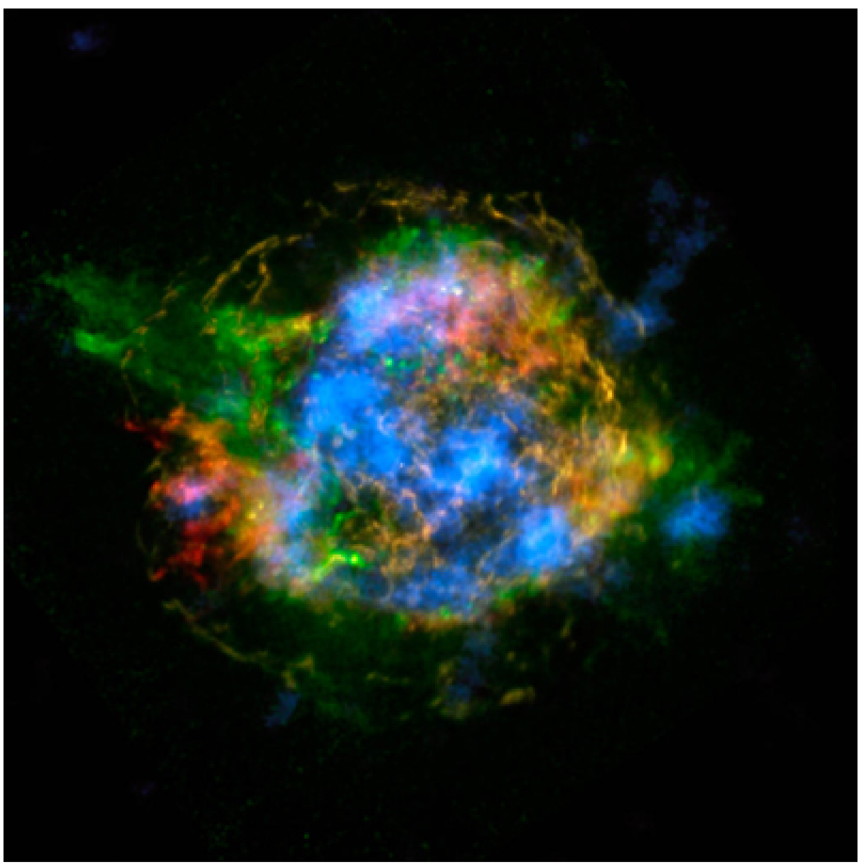
The feat is one of the primary goals of NASA's NuSTAR mission, launched in June 2012 to measure high-energy X-ray emissions from exploding stars, or supernovae, and black holes, including the massive black hole at the center of our Milky Way Galaxy.

The NuSTAR team reported in this week's issue of the journal *Nature* the first map of titanium thrown out from the core of a star that exploded in 1671. That explosion produced the beautiful supernova remnant known as Cassiopeia A (Cas A).

The well-known supernova remnant has been photographed by many optical, infrared and X-ray telescopes in the past, but these revealed only how the star's debris collided in a shock wave with the surrounding gas and dust and heated it up. NuSTAR has produced the first map of high-energy X-ray emissions from material created in the actual core of the exploding star: the radioactive isotope titanium-44, which was produced in the star's core as it collapsed to a neutron star or black hole. The energy released in the core collapse supernova blew off the star's outer layers, and the debris from this explosion has been expanding outward ever since at 5,000 kilometers per second.

"This has been a holy grail observation for high energy astrophysics for decades," said coauthor and NuSTAR investigator Steven Boggs, UC Berkeley professor and chair of physics. "For the first time we are able to image the radioactive emission in a supernova remnant, which lets us probe the fundamental physics of the nuclear explosion at the heart of the supernova like we have never been able to do before."

"Supernovae produce and eject into the cosmos most of the elements are important to life as we know it," said UC Berkeley professor of astronomy Alex Filippenko, who was not part of the NuSTAR team. "These results are exciting because for the first time we are getting information about the innards of these explosions, where the elements are actually produced."



Superimposed images of the Cas A supernova remnant taken by NASA's Chandra and NuSTAR orbiting telescopes. Red and green are X-ray emissions detected by Chandra of heated iron and silicon/magnesium, respectively, while blue shows NuSTAR's map of the distribution of titanium produced in the core of the explosion 340 years ago. Credit: NASA/NuSTAR image.

Boggs says that the information will help astronomers build three-dimensional computer models of exploding stars, and eventually understand some of the mysterious characteristics of supernovae, such as jets of material ejected by some. Previous observations of Cas A by the Chandra X-ray telescope, for example, showed jets of silicon emerging from the star.

"Stars are spherical balls of gas, and so you might think that when they end their lives and explode, that explosion would look like a uniform ball expanding out with great power," said Fiona Harrison, the principal investigator of NuSTAR at the California Institute of Technology. "Our new results show how the explosion's heart, or engine, is distorted, possibly because the inner regions literally slosh around before detonating."

Expanding supernova remnant

Cas A is about 11,000 light years from Earth and the most studied nearby supernova remnant. In the 343 years since the star exploded, the debris from the explosion has expanded to about 10 light years across, essentially magnifying the pattern of the explosion so that it can be seen from Earth.

Earlier observations of the shock-heated iron in the debris cloud led some astronomers to think that the explosion was symmetric, that is, equally powerful in all directions. Boggs noted, however, that the origins of the iron are so unclear that its distribution may not reflect the explosion pattern from the core.

"We don't know whether the iron was produced in the supernova explosion, whether it was part of the star when it originally formed, if it is just in the surrounding material, or even if the iron we see represents the actual distribution of iron itself, because we wouldn't see it if it were not heated in the shock," he said.

The new map of titanium-44, which does not match the distribution of iron in the remnant, strongly suggests that there is cold iron in the interior that Chandra does not see. Iron and titanium are produced in the same place in the star, said UC Berkeley research physicist Andreas Zoglauer, so they should be similarly distributed in the explosive debris.

"The surprising thing, which we suspected all along, is that the iron does not match titanium at all, so the iron we see is not mapping the distribution of elements produced in the core of the explosion," Boggs said.

He and his UC Berkeley colleagues also launch balloon-borne high-energy X-ray and gamma-ray detectors to record the radioactive decay of other elements, including iron, in supernovae to learn more about the nuclear reactions that take place during these brief, catastrophic explosions.

"The radioactive nuclei act as a probe of supernova explosions and allow us to see directly into densities and temperatures where nuclear processes are going that we don't have access to in terrestrial laboratories," Boggs said.

NuSTAR continues to observe radioactive titanium-44 emissions from a handful of other supernova remnants to determine if the pattern holds for other supernovae as well. These supernova remnants must be close enough to Earth for the debris structure to be seen, yet young enough for radioactive elements like titanium – which has a 60-day half-life – to still be emitting high-energy X-rays.

More information: Study paper: dx.doi.org/10.1038/nature12997

Provided by University of California - Berkeley