Rare Isotope Time Trial Gives Insight to Neutron Star Heat Source

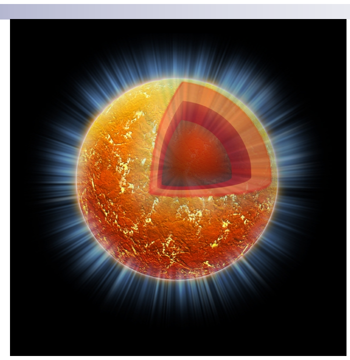
The recent measurement of the mass of the short-lived rare isotope manganese-66 has made it possible for JINA nuclear astrophysicists to pin down the underlying heating elements of one of the universe's most fantastic phenomena—accreting neutron stars.

Out in the cold depths of space, billions of the densest objects known to man sit quietly while their nuclear cooling processes play out. But some of them are hungry. Some neutron stars sit close enough to a neighboring star for its gravity to begin pulling matter from its neighbor onto itself burning it via thermonuclear reactions in the process.

But sooner or later, the fuel for the neutron star is exhausted and it begins to cool rapidly. Through observations of this cooling process and measurements taken at nuclear physics laboratories such as the National Superconducting Cyclotron Laboratory (NSCL), scientists can deduce the inner workings of neutron stars.

In the recent experiment at NSCL led by JINA postdoc Milan Matos and JINA graduate student Alfredo Estrade, JINA researchers from MSU, ND, and LANL measured the mass of manganese-66, which sits right next to iron-66 on the nuclear chart. Based on the newly discovered mass and previous measurements of iron-66, scientists can determine where in the crust of a neutron star the layer of iron-66 lies, which is one of two heating elements in neutron stars.

"On earth, iron-66 is a rare short-lived isotope with a half-life of about 400 ms," said Hendrik Schatz, nuclear astrophysicist at NSCL and Principle Investigator for the Joint Institute for Nuclear Astrophysics (JINA). "However, it also is part of a deep layer in the crust of accreting neutron stars, where it becomes stable due to the high density. Eventually however, iron-66 heats the crust by capturing electrons and that process depends on the mass difference to manganese-66."



This is an artist's impression of the neutron star at the center of the Cassiopeia A supernova remnant. Illustration: NASA/CXC/M.Weiss

Scientists at NSCL calculated the mass of manganese-66 by doing a time-of-flight experiment. 86-krypton was accelerated up to 40% of the speed of light and smashed into a thin foil of beryllium. Some of the ions shattered after hitting other nuclei in the foil, creating a smorgasborg of new isotopes and particles. The facility then filtered out about 100 desired types of isotopes, some of which they wanted to measure and others that they used for calibrations.

The filtered isotopes traveled down the beamline where they were caught by a detector that identified which isotope was which. Due to their different masses, the different isotopes took different amounts of time to complete their journey. By identifying manganese-66 and measuring the time it took to run the course, the scientists could determine its weight to within one part in 100,000.

The resulting mass was different than what theorists had predicted for the rare isotope, which changes the models of how neutron stars are structured. The result was a bit of a surprise.

"The mass difference between iron-66 and manganese-66 allows us determines the depth needed to induce the heating reactions and therefore the location of the heat source associated with this reaction inside a neutron star," explained Schatz. "With this new measurement, all of the critical heat sources now can be located within a neutron star. The heat source turns out to be located much closer to the surface than was assumed before based on theoretical predictions of the mass difference between iron-66 and manganese-66."

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