Juan Manfredi

Starstruck

BY JUAN MANFREDI

The first moments of our universe still are mysterious, but we know that in the beginning there was the Big Bang. We also know that after a millionth of a second, protons (hydrogen atoms) and neutrons formed. Two hundred million years later, these particles began condensing into massive balls of plasma, commonly called stars.

Inside stars' nuclear furnaces, protons and neutrons fuse to form the two-proton atom helium, slightly heavier than the single-proton hydrogen. As stars produce more helium, it reacts with other neutrons and protons to make even heavier elements, like carbon. After a few billion years, stars explode as supernovae, firing up their internal nuclear combustion engines enough to create heavier elements (like gold, titanium, lead, calcium, and many others we can't imagine living without). Over the eons, myriad supernovae have spread these particles across the universe, where they became the seeds for planets and more stars. Nuclear reactions, in other words, tell the story of the cosmos.

Stars, light-years away, do not make for an ideal laboratory setup. Here on Earth we do our best to simulate their internal conditions on a smaller scale. I do my research at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University, where we accelerate nuclei to half light speed before smashing them to pieces against a foil target. (Many of these pieces are rare nuclei that naturally exist only in the thermonuclear guts of stars or supernovae.) From there, magnets transport the nuclei to any of several experimental stations, where scientists reproduce and analyze the actual reactions that form and destroy stars. These reactions often produce nuclei that decay so quickly we can detect only their remains. Just as collecting debris from a car accident can help determine what the vehicles originally looked like, the products of a nuclear reaction or decay can help us piece together the structure and behavior of the rare parent nucleus. Specifically, we can deduce its weight, how it decayed, and how the protons and neutrons were arranged inside it. This information then helps us determine where, when and how quickly such reactions occur in the cosmos.

To probe stars' inner workings further, my thesis project studies fission – splitting heavy nuclei into two smaller chunks. An important example of this process is uranium fission, a reaction that has powered every nuclear plant in the country for decades and that scientists have studied for even longer. The breakup of heavy, exotic nuclei (which have a remarkably high or low ratio of neutrons to protons) taking place in stars is much more complicated than splitting uranium. There are lots of theories on how fission in this region works, but we need data to test them.

In pursuit of such information, my thesis experiment at NSCL next year will study lead-196, one of many exotic fissionable nuclei within our lab's reach. By measuring its products, we'll reconstruct the parent lead-196 nucleus and determine its fission barrier – how much energy is needed to split it. We'll compare that with the fission barriers of more common lead isotopes to see how fission changes for rare nuclei.

Although experiments like this are exciting and full of possible discoveries, more powerful equipment is needed to truly understand the way fission of heavy exotic nuclei works. The Facility for Rare Isotope Beams (FRIB, also at Michigan State) will be complete in 2022, allowing scientists to explore questions about this special type of fission. FRIB will accelerate nuclei to 57 percent of light speed, allowing for the production of more than 1,000 new isotopes. My thesis project will be the first experiment in an international campaign to study exotic fissile nuclei. This program will continue once FRIB opens, expanding the fission frontier into unexplored territory. FRIB also will collect unused isotopes for medical treatment and research as well as generate thousands of construction jobs and an estimated local economic impact of $1 billion over 20 years.

But there lies a deeper, more instinctual drive behind nuclear astrophysics, one going beyond intellectual curiosity and the practical benefits. Studying reactions that create basic elements answers the question of where we and our planet came from. It's as grand an origin story as humanity has ever seen: In the blazing fires of exploding stars, components of life were forged and launched across the universe. These scattered components clumped together into stars and planets, including Earth, where humanity emerged as a way for the universe to study itself. The same sense of wonder that for thousands of years drove humans to look up and ask why inspires scientists to look inward and ask how. In this evolving quest for answers, we are finally on the verge of fully simulating and studying our true birthplace: the stars.

The author is a second-year fellow at Michigan State University. "Starstruck" won first place in the 2014 SSGF Essay Slam.