Student questions: SESE Graduate Students Colloquium

3/3/21

Gregory Vance: "Asymmetric Supernovae and the Elements They Create"

How accurate would you say your simulations for supernovas are?

It's difficult to answer this question breifly because accuracy is a broad subject. Every real supernova and every supernova simulation are a bit unique and chaotic, so I don't think you'll ever see perfect matches. One of the big goals of our work is starting to quantify the amount of variabilty present in supernova models, which many authors don't address in their work. We can definitely compare some of our yields numbers to observations, but I don't think astronomers currently have the ability to look at a supernova remnant with a telescope and easily measure yields for more than a few elements. We can gain some level of insight by merely comparing our models to each other, like I did in my talk. There are certainly some places in our simulations where we use approximations or shortcuts to improve computational efficiency, but that's true of every physical simulation. It's best to take as few as possible when we have the option.

Taking information from past supernovas and using them to simulate what supernovas explode, what do you take into account when making a simulation?

There are some supernova modelers who focus on the complex question of which stars will and will not explode. That isn't the focus of my own work, so I'm not sure I'm prepared to discuss it at length. The models I work with are not generally based on any specific historical supernovae. Our models are sometimes inspired by remnants like Cassiopeia A or G292.0+1.8, but we aren't often trying to reproduce a particular explosion as closely as possible. At most, we'll use the star's mass, metallicity, and the type of circumstellar medium that surrounded it.

Many times simulations were mentioned, what was used to run these simulations?

We use a variety of different pieces of code, some of which I did mention in my talk. The initial star models use the stellar evolution code Tycho. When the stars reach core collapse at the end of their lives, we use a Lagrangian code to handle the core collapse itself, and then we map the explosion into three dimensions since the previous two codes are both 1D radial models. At this point, we impose any asymmetries we want and follow the explosion hydrodynamics using the SNSPH code. Once SNSPH is done running, we do post-processing of the simulation to calculate the nuclear yields. Previously, we used a code called Burnf for that, but out newer models use PRISM. Our models were run on computing clusters at Los Alamos National Lab and the clusters available here at ASU.

Are we able to predict when and where supernovae will occur?

Not precisely, no. Most of the time when we see them observationally, it's because someone was pointing a telescope at the right galaxy at the right time. A great example of our inabilty to predict supernovae is the nearby star Betelgeuse. We know that Betelgeuse is a red supergiant very late in its evolution and it will likely explode any day now. But "any day now" in stellar terms means "some time in the next million years." Definitely look up Betelgeuse if you want to look into this question more.

What causes the hole seen in the top right corner of the convective velocity model?

There was probably a lot of mixing of material taking place in that bit of the star when the explosion took place. The "hole" is an apparent gap in the oxygen-rich layer of the star, so it was likely the result of that oxygen mixing into the surrounding layers of the star.

Are there other alternatives in the literature for target isotopes with the presence of radioactive decay (such as 44Ti and 56Ni mentioned during the presentation) that could be indicative of the mechanism of supernovas?

There are likely a few others (I can't think of any off the top of my head), but those two have a good combination of features. They originate from near the star's core, they produce photons at observable energies when they decay, and they have human-friendly decay half-lives. Titanium-44 in particular is also very sensitive to the conditions deep in the explosion. The amount of titanium-44 produced varies with the temperatures and densities from the explosion. Iron is decently important, since it can be observed and all of the nickel-56 winds up as iron.

What are the implications of a depletion/reduction in the quantity of Cu compared to other metals with lower atomic Z such as Co (during the presentation a figure indicated an excess of Co in a simulation)?

I haven't yet had a chance to investigate it in detail for that simulation, but I expect it has to do with differences in how those elements are produced. It's not unusual for nucleosynthesis to pile up at the iron peak around $Z = 26$ because of the atomic binding energies involved. However, it seems that the effect is more pronounced in the new convective velocity model than in the others. At this time, I can't speculate about why.

Does gas in space just flow everywhere or does it need some sort of gravitational force?

There's a variety of forces that affect interstellar gas. In the midst of a supernova, the sheer energy of the explosion is obviously driving most everything outwards from the collapsed core of the star at high velocity. If material gets too close to the collapsed core of the star, gravitational forces can cause it to be accreted onto that object. In the abscense of a supernova, a big cloud of gas is mostly subject to pressure and its own gravity. If the temperature is low enough, then gravity might overcome the pressure and collapse the cloud to form a star. Gas that is ionized also has to worry about magnetic fields affecting it.

Is it possible that supernova had elements that we haven't discovered yet, and if it is, would this fundamentally change the simulation's parameter?

It's not likely. As I said in my talk, the material that formed our Solar System was at one point processed by supernovae. Any stable elements produced in supernovae would exist in trace amounts here on Earth, where we would have the opportunity to discover them. It is possible that some of the super-heavy nuclei off the end of the periodic table that we haven't yet been able to synthesize in a laboratory are produced in supernovae. However, all of those are the sorts of nuclei that are unstable with nanosecond decay half-lives, so none of them would stick around long enough to be observed. They certainly would not be abundant enough to have a big effect on the supernova.

Is there a level of spontaneity to supernova that makes them particularly difficult to model?

There is definitely some degree of chaos to the way they evolve. The explosion is mainly a hydrodynamics simulation, so much of the structure results from fluid instabilities like Kelvin-Helmholtz or Rayleigh-Taylor that grow out of very small imbalances. The nucleosynthesis is mediated by nuclei at extreme temeperatures and pressures running into each other in a largely random manner, but that can be modeled statistically.

Are there particular stars or solar systems that are "hot spots" for super novas?

Probably the best place to find core-collapse supernovae are OB associations and superbubbles. These are clusters of young, high-mass stars that will live comparatively short lives and die as supernovae. Those high-mass stars are the key, so you'll find the most supernovae wherever you have the most high-mass stars.

Why only choose the 44Ti and 56Ni isotopes to focus on?

Those isotopes have a particular combination of features that make them useful. They can be observationally measured in supernova remnants because of their radioactivity, they originate from deep within the star (so they can probe the conditions near the collapsing core), and titanium-44 in particular is very sensitive to the temperature and density in the explosion.

This might be an easy question but, how do you know if a supernova has occurred in the past to study it? How would you go about identifying a past supernova?

Supernova remnants are pretty identifyable when observing the sky at a certain wavelengths because they're so energetic, and they generally stick around for many centuries after the star explodes. They eventually diffuse into the interstellar medium, but there are historical records of "new stars" appearing in the sky 1,000 years ago in spots where we now see supernova remants.

What benefit do you think will develop from studying supernovae?

Since ourselves and our planet are essentially made from supernova material, there are tenuous ways to connect this sort of study to almost anything. That's a very philosophical way to look at the benefits of this research. However, it also connects more directly to a variety of other scientific fields. It helps us understand how planets form, interpret the origins of grains in meteorites, understand the cosmological history of matter in the universe, and understand the origins of radioactive heating in the Earth.