GEORGE DJORGOVSKI: So let's talk about the other kind of supernovae. Supernovae who come from the collapse of very massive stars at the end of their thermonuclear life. And the remnants always look like these nice shells. They're expanding.

So to freshen your memory, thermonuclear evolution of really massive stars proceeds by going from lighter elements to heavier. First hydrogen to helium, then helium to carbon and oxygen, and going to silicon and iron. And at that point you can no longer do thermonuclear fusion, because it's endothermic reaction. And you have to put in extra energy. So massive stars, if they're massive enough, can reach central densities and temperatures to create chemical elements, all the way up to iron. And that's it.

But then you have this steel structure. You have, say, silicone burning into iron into core, surrounded by shell that burns silicon and so on. All the way you get into lower density, lower temperature layers. Burning hydrogen to helium in the end. And there is still normal stellar envelope left above that. This is way hydrogen indeed in supernova remnant comes from.

OK. So what happens when you can no longer burn stuff in the core? You just created enough iron. There is no silicon left to burn. And it's the equivalent of why stars leave main sequence and climb through a Giant Branch.

Well in this case, there is no way to create any more energy that will support star against its gravity. Essentially thermonuclear fire stops in the middle. And because of that, the core collapses.

Strong gravity produces strong pressure, and two different things can happen. Iron can photodissociate gamma rays. And you can also have inverse beta decay, if you have sufficiently energetic particles. Note is that the process releases two things, neutrons and electron neutrinos. And they're both important, because neutrons will end up as the building material of what's left. A neutron star. Neutrinos fly away, carry most of the energy.

So these two processes take away the energy further. The core collapses, you get the shock wave. There's usually balance of the shock wave, and that balance can actually explode the star. The physics of this is fairly complicated, and not entirely fully understood. People who do numerical simulations of exploding stars have only recently managed to build-- have a full convincing simulation of how stars explode.

One interesting tidbit about this is that neutrinos can be an important agent of this explosion. Now neutrinos hardly interact with matter at all, but they do interact. Now if you put a lot of particles, protons and neutrons, in their way, such as you have in a massive star, then there is a reasonable probability for these neutrinos of actually interacting with that material. And so you have a neutrino win. Pushing the star involved out.

At least that's the theoretical model. So the collapse of the core releases binding energy that's created. That creates a shock that goes out. That shock is what explodes the star.

And that's again indicated here. So the energy of the supernova comes from the release of the binding edge. That suddenly you're packing a substantial fraction of star's mass, at least two stellar masses, more if possible, into a tiny remnant that's kilometers in size. And that binding energy is then converted into kinetic energy and luminosity, in both electromagnetic and neutrinos. And this is where the supernovae come from.

Now theory says that 99% of the energy will be actually emitted in neutrinos. And until 1987 that was just a theory. But then supernova exploded in one giant cloud. And several of those deep underground neutrino detectors, which are usually built to detect solar neutrinos, captured neutrinos coincident with this optical explosion.

And the amount of energy in those neutrinos, and it's like a dozen of them, was exactly right. Exactly what theory predicted should be the neutrino flux here on earth from something in the giant cloud. So that was a very powerful demonstration. That we really actually do understand why massive stars-- how massive stars explode.

And finally let's talk about supernova remnants. So you have this envelope of the star is now being pushed out by the shock wave. And it's pushed out at speeds that at first actually exceed 10,000 kilometers per second. Eventually they slowdown.

Within it is all the newly synthesized material, products of nucleosynthesis. There is some of which is done in star before it exploded. Some of which is done during the explosion. And this is how interstellar medium is enriched by heavy elements.

So every atom in your body of elements heavier than, say, oxygen comes from a supernova explosion. Think about that. It's pretty cool. We're all built out of stellar ashes.

And these remnants can last hundreds of thousands of years. They fade out slowly, and they emit in all different frequencies. Because along with stellar envelope, there are magnetic fields that are being trapped in the plasma and are carried out.

Then there are all kinds of interactions, just like you have in solar atmosphere. Interaction of magnetic field and plasma can produce nice little flares that accelerate electrons. And so these things are observable in a variety of ways. And there is a large number of these in Milky Way only few really are in visible light. But many can be seen in radio or x-rays.

And they look like this when they're young. This is the famous Crab Nebula, of course. Remnant of a supernova that exploded. At least as we've seen the light from, in the year 1054.

And it's probably the most famous supernova, or supernova remnant. It was well studied by Chinese astronomers, also Japanese, Koreans. It was also seen by the North American Indians. And they're famous pictographs in Chaco Canyon showing this new star.

And it was brighter than Venus for many weeks. So couldn't miss it. Right? And until recently there were no records whatsoever of the supernova in the European records. Now it could not have been cloud over the entire Europe for few months in a row. Especially this was in the summer.

And the explanation was that, well. This kind of clashed with church's teaching that the heavens are perfect and nothing new can happen. Cannot be changed, therefore, this thing could not be happening. And so nobody dared write anything down. There were some that were recently found. And they thought this was a sign of pope so and so dieing and going to heaven, but-- Interesting. Right?

So even today this nebula is expanding at high speed. These nice filaments are the beauties in plasma. That is very turbulent. There is magnetic field mixed with lots of free electrons. It emits in x-rays and everything. And it's also home to the Crab Nebula Pulsar. First pulsar that was discovered. And we'll talk about pulsars next time.

And finally here is one called Cassiopeia A. And it got its name because it was the first and brightest source, a radio source, seen in the constellation of Cassiopeia. Because it's pretty big, it was easy to identify. This is the remnant of a supernova that exploded in 1658.

I think Tycho, certainly Kepler, have seen it. The picture here is composite of the infrared optical and x-ray images from different satellites.