DJORGOVSKI: Well, let's move on then. Creating white dwarfs can do even more spectacular things. So let's talk about supernovae-- cosmic explosions. This is an artist's conception. We don't see them like that.

And first, let us discuss what kind of supernova there are. There are just two basic types, and then there are many subtypes. I'll talk about this in a second. And phenomenologically, what happens is the star of some brightness suddenly, over periods of days or weeks becomes vastly brighter-- reaching luminosity comparable to that one of the entire galaxy-- and then slowly declines.

Now that's just the tip of iceberg. 1% or less of the total energy. Bulk of the energy generated in supernovae-- we can't see. It's in form of neutrinos. But we have detected them from one supernova, from the Magellanic cloud. And then there is a kinetic energy that actually explodes the star which is comparable to the amount of energy that's shown away in light.

The expansion of the shell of the exploding star is some fraction of the speed of light, typically of the order of tens of thousands of kilometers per second, then slows down. And so what is left is one of those beautiful supernova remnant, plus a compact remnant in the middle, which is neutron star or a black hole, depending on the mass of the progenitor star. There is a new kind of supernovae, called pair-instability supernovae, which do not leave a remnant. We'll talk about them in a sec.

So the basic classification of supernova is Type I, Type II. And first, they were empirically classified on the basis of their spectra, whether or not they have lines of hydrogen in their spectrum. Hydrogen being by far the most common element, you expect it to be present. But Type I supernovae have no hydrogen. And now we know why. It's because they come from white dwarf progenitors, and their envelopes have been shed away. What was left is core composed of carbon and oxygen, maybe some helium.

Type II do have hydrogen in their spectra. And a good rough number to remember is you get one supernova per galaxy per century, roughly speaking. Of course, depends on how many stars is making and that kind of stuff. But this is a reasonable number.

So in the historical times in the Milky Way, we've seen three. There was the Crab supernova, there was the one seen by Tycho, and one seen by Kepler. And we haven't seen others, but we know that there were others. They were just in hidden parts of the Milky Way hidden by the dust. People have found some of the radio remnants, which probably are supernovae exploded one or two centuries ago.

But we can see them in outer galaxies easily. And so today, several thousand of supernovae have been found. More everyday, literally. Right. And we have a reasonably good understanding of the phenomenon.

These two types correspond to two different mechanisms. Now they have subtypes, which, again, depend on some variation of the spectral properties, and then they're one of a kind, and so on. And then there is this possible new type, Type-- well, they don't have a name, yet. The appearance, the beauty supernovae, where the massive star is so massive, so dense and hot, that you create electron-positron pairs in its core. They annihilate and explode the star.

So these are examples of supernova spectra, right. The one in the middle is called Type II, and you can see arrows are pointing to the Balmer lines. The one on the top is-- well, and the others are not. They do not have hydrogen. They have all kinds of other stuff.

You'll also notice that the lines are very broad. The reason for this is that there are high velocities involved. The supernova is expanding at speeds of thousands of kilometers per second, and therefore, the lines will be broadened by a comparable amount.

If you look carefully, you'll see that many of the lines have this specific form that's first, there is an absorption, and then there is an emission. And that's called a P-Cygni profile. The origin of this is that you have an expanding shell. The inner part is hot, the outer part is cooler. The emission from the inner part would be creating emission line. But then, some of that would be absorbed by the cooler material in the front. And so, it will remove some of the light from the emission turned into absorption line. Those are called P-Cygni profiles. They're also characteristic of sources where there is stellar wind or things like that.

The spectra evolving time, there are people who studied this in great and gory detail and deduced the physics and nuclear synthesis that happens inside supernova and so on.

This is how light curves look like. The Type Ia-- Used to be just Type I, but now there are subtypes-- are supernovae with no hydrogen. They come from exploding white dwarfs. The Type II are those that come from exploding massive stars at the end of their thermonuclear life. And they do differ in peak luminosities and shapes. There is some variety. But always, what happens is, when you wait long enough, the light curve becomes exponential. This is log luminosity plotted versus linear time, so exponential is a straight line.

This is a signature of radioactive decay. In the supernova explosion, sufficient energies and densities are created with enough flux of neutrons that you build elements heavier than iron. Some of those are unstable. In particular, those which have same atomic number as iron are produced in copious numbers-- nickel and cobalt. They decay radioactively. The energy from their radioactive decay is absorbed by the expanding supernova remnant, converted into luminosity. So it's just if you were doing nuclear physics lab, if you plot Geiger counter rate versus time, if you do it logarithmically, you'll see a straight line. That's exactly the same thing.

So let's talk about Type Ia supernovae. Those are made by white dwarfs. What happens is that a white dwarf somehow acquires extra mass that pushes it over Chandrasekhar limit. Typically this could be it's in a binary with another star, and it keeps accreting and accreting. Once it goes above Chandrasekhar limit, the star can no longer sustain itself. Its core has to collapse. That releases enough energy to explode the star.

Alternative mechanism that people talk about is that you have a white dwarf binary. Used to be a binary of two low-mass stars, both end up as white dwarfs. White dwarfs orbit each other, but they lose energy, because they are rising tides on each other. So that means they will spiral in slowly. Once they come close enough to merge-- so instead of 1 or 1.4 solar masses, you have twice that much. The same thing happens, the thing explodes. It's not clear at this point which of these two dominates are both playing different ways and so on.