DJORGOVSKI: Well, let's move on to slightly related subject of cosmic gamma ray bursts. You can think of them as supernova deluxe. And they're really interesting phenomenon that puzzled scientists for many, many years.

So they're first discovered in 1970's by these Vela Satellites. They were military satellites that were launched to look for gamma ray flashes from nuclear explosions on planet earth to enforce the Nuclear Test Ban Treaty. And they've seen gamma ray flashes all right, but they weren't coming from Soviet Union. They were coming from outer space.

And after they assured themselves that, indeed, this has nothing to do with earth and politics, but something in the universe, this was published. And nobody knew where these things were coming from. They had been studied for a long time with different space missions, like Compton Gamma Ray Observatory here.

The problem was they don't last very long. A second maybe. And they're gamma rays. As you probably remember, you cannot focus gamma rays because they're shorter wavelength and intergalactic spacing for any terrestrial material.

Now if you could take neutronium and make mirrors of neutronium, that'll work. But we don't have that. And so gamma rays could not be easily focused, and only we could get very rough direction using all manner of tricks where the bursts are happening. Maybe tens of degrees of uncertainty. There are way too many things in a circle that's tens of degrees, so you have no idea which one could have been.

And this is what they look like. These are from detectors and satellites. I think one was Geiger counters. And usually there is a pulse, and there is a cay. Sometimes there are many, many pulses. They come in two varieties. There are short ones which have hard exospectra. Somewhat longer ones, softer spectra. And typically, the overall flux per unit area integrated over a pulse is of the order of 10 minus 6 ergs per square centimeter.

Now if you plot them on cosmological distance, that will be giga parsecs away. and that will be something like 10 to 29 centimeters 4 pi r squared multiply with fluence. You find out that energies emitted, if they're isotropic, will be all your 10 to the 52, 10 to the 54 ergs.

How does that compare with the rest mass of the sun? Let's do mc squared. What's the mass of sun in grams? Anybody? OK. 2 times 10 to the 33. What's the speed of light? In CGS units. 3 times 10 to the 10. C squared will be 10 to the 21. 10 to the 30-- that'll be 10 to the 54.

So these things will correspond to annihilate the entire star in a space of milliseconds. What turns out that's not actually the case. They're beam just like pulse's are beam, but we didn't know that for a while. And again same reasoning as before. Their short durations imply very small regions, so black bodies could not be that luminous at all. So there had to be some sort of non-thermal mechanism.

So for about 30 years people didn't know what these things were. And the resolution came in 1997, in satellite called BeppoSAX, which had hard x-ray camera. And they can actually take pictures of gamma ray bursts, but in hard x-rays, which we know how to focus. And so suddenly, it was possible to tell whether we can arc minutes which is much, much easier.

And that led to the discovery of the optical counterparts, then later radio. And once you have optical counterpart, you can take spectrum, and try to figure out where it is and done that. In fact this was done right here at Caltech. And so establish that gamma ray bursts are, indeed, at cosmological distances. They're not say, neutron stars in the halo of the milky way, which was another possibility.

There are all kinds of crazy theories, 150 theories at one point, and if most one of them is right, so you find that 49 are wrong, found that 50 are probably wrong. Well, actually it turns out some of the theories are right on the money.

And this is what it looks like. This is the actual sky picture and then picture taken right after gamma ray burst happened, and you can see there is an extra star pointed by the arrow. And then they fade according to the power.

The physics of this is really well understood from synchrotron radiation theory and so on. And then when we looked, where are they? They turn out to be in galaxies all right, and they tend to like star forming regions of galaxies. So they're related to star formation in some way. So that went well with models, so they are probably related to supernovae in some fashion. And now I think that's most generally believed.

And there are basically two possible mechanisms. One is you can take neutron binary or neutron black hole or black hole and white dwarf or something, merge them together, the release of that orbital kinetic energy can create a gamma ray burst. We now think that probably the short hard variety of gamma ray bursts come from this mechanism.

Another one is you have a massive star that explodes as a supernova, leaving a black hole remnant. But it's not so simple. The idea is that the collapsing core makes a black hole. There is consideration of angular momentum. You get an accretion disk inside the star, really dense material, neutronium basically, that is now creeping in to that black hole so as far as that stuff's concerned, star doesn't exist.

And because there is a spin axis and magnetic field involved, you generate a jet which drills through star as it's exploding, as a supernova. The shock waves of that collide with material outside, convert energy into gamma rays, and if we're looking from the right direction, we see gamma ray bursts.

This is now being established with very high degree of confidence, and these things have been studied to great extent while it was happened here at Caltech. Actually the most distant objects, for which we're pretty sure we know how far they are in the universe, are these because they've seen what are likely gamma ray bursts from popsicle population three stars in the early universe.