S. GEORGE DJORGOVSKI: Now let's talk about the stuff between galaxies, which is the intergalactic medium, which is gas. And this is from some simulation. You've seen in those simulations I've shown you early on they get this filamentary, messy structure forming, and that's now known as "cosmic web."

Well, there is dark matter, of course, but there is also gas that hasn't been yet processed in galaxies, so that hydrogen, helium fall into the galaxies, and then provide fuel for more star formation. But then galaxies also expel gas, because of the supernova explosions pushing it out.

And so there is like a whole ecosystem of stuff coming in, and flying out, and chemical evolution happening, and so you have to follow all of this in order to get the fully consistent picture.

Also, turns out there is enough ultraviolet radiation from young stars or from active galactic nuclei to completely ionize all the gas out there. There is almost no neutral intergalactic medium. It's all very highly ionized.

So how do we study that? Well, theories can, of course, give you predictions, but basically you have a random line of sight through the universe, and you need some background source. You observe that source, and you look at absorption lines that's due to the material between you and that source.

Quasars are excellent background sources for this, because they are bright. You can see them far away. They have relatively featureless spectra-- big, broad emission lines, but nothing like stellar spectra. And they have been used to do this-- to probe material in absorption-- so complementary to the normal studies. You take pictures, and you look at things in emission, so this is completely different approach. And so this has been telling us how the stuff evolves in intergalactic space.

So there are several different important types of lines, but most of it is hydrogen. And helium does same thing as hydrogen, but only in ultraviolet, and that's hard to

see. And then there are some what we call "metal" absorption lines. And astronomers call metal everything that's heavier than helium, which is an interesting approximation. But it's usually things like oxygen, carbon, and so on.

And hydrogen comes in a couple different varieties. There is a whole lot of small clouds, which are now called Lyman alpha forest, because a lot of forest of lines, and then there are big absorption chunks of hydrogen, which is in galaxies themselves.

So this is what typical spectrum of a very distant quasar looks like. Most of that jigger is not noise. It's actually absorption by Lyman alpha clouds. Occasionally you see a very deep absorption. That's one of those systems that are really piercing through a disk of some galaxy somewhere. And then there are metallic lines that we can see redward of Lyman alpha.

So if you look through something like the disk of the Milky Way, it's going to leave huge, big absorption line like this. And it's completely saturated. This happens when we have more than 10 to 20 hydrogen atoms per square centimeter, and we can probably interpret these as being due to the galaxies, like Milky Way, that happen to be along the line of sight.

Now, this stuff evolves in time, and here is a dramatic illustration of that. These are spectra obtained from Hubble, so you can look into ultraviolet. The top is a relatively nearby quasar, the first one ever discovered. And you can see that there is some absorption blueward of Lyman alpha line, but not much.

And now, quasar are just like that, but the high redshift suddenly developed this complete mess of forest of lines, so this is not noise. This is actual absorption lines. So these clouds disappear in time. And what happens to them? They probably just fall into galaxies, and then replenish gas supply inside galaxies.

But then galaxies make stars, so stars explode, they kick out some of it, and that's called galactic winds. Just like young, massive stars can drive stellar wind, galaxy can drive galactic wind, which is joint effect of all the supernova explosions. So in

this way, the metals-- the remaining stars-- get back into intergalactic medium, and we observe in there.