DJORGOVSKI: This is a picture of the core of the Virgo cluster. This is the so-called Markarian's chain of galaxies. It's only 15 to 20 megaparsecs away from us. And so clusters are certainly-- it's a little bit of an editing problem there. Clusters are very prominent parts of the large scale structure. They're the first one to be seen. And only a small fraction of all galaxies in the clusters. Most of them are in groups. But interesting things happen in clusters or galaxies.

So how did it look like? This is Virgo Cluster, the closest one to us, center local super cluster. The picture on the left is an X-ray image. You can see the individual bright galaxy superimposed on the overall cluster X-ray emission. On the right is a map of where optical galaxies are. It follows the same structure. There is of the order of a couple 1,000 galaxies, almost all of them are dwarfs. Only few tens of really big galaxies. So Virgo is not a very interesting cluster. It's a very poor cluster as clusters go.

Coma Cluster is more like a real thing, and that's 100 megaparsecs away. And here you can see X-ray and optical pictures and their superposition. And this turns out to be fairly typical of what clusters might look like. They're very prominent X-ray sources, and that's important in finding them.

And another important nearby one is so-called Perseus Cluster. This is somewhere in between Virgo and Coma in terms of overall mass and density. The brightest galaxy there, and you see 1265 is actually housing one of those obscure quasars. And if it wasn't for obscuration, may be even visible by naked eye. Fortunately, or unfortunately, it is obscured.

And so the same thing carries on. As you keep pushing out in red shift, the galaxies become harder and harder to see. But X-ray gas is easily detectable. There's very little else that can be confused with. I mean, they're quasars, but they're all point sources, as opposed to clusters, which are well resolved blobs of gas. And even the most distant clusters that we now know, which are now of the order 2/3 of the look back time to the Big Bang are following a similar kind of behavior.

So, I think there's a problem with the Powerpoint on this laptop. So there are several ways in which clusters can be found. In the optical, we can look just for overdensity of galaxies. Sometimes we can use colors to look for elliptical galaxies. But then you're vulnerable to superposition of structure different red shifts. In X-rays, it's much easier because it's very distinctive. There's very little confusion. And that's by far the best way now to find clusters.

A new method is so-called Synyaev-Zeldovich effect. I'll explain it in a moment. And also, you can use gravitational distortions, or gravitational lensing, to look for those. That's very hard to do.

There are several important trends that you see. One is that clusters range from very symmetric, well-relaxed looking that are elliptical galaxy rich to very loose, fluffy, irregular ones that are mostly spiral galaxy rich. And the former more is limited X-ray sources. So it's all understood in terms of clusters just coming together and galaxies plowing through the extra gas.

Spiral galaxy, this could lose their gas and become S0's eventually merge with ellipticals. And so we see clusters in different dynamical stages of formation. The most relaxed ones, or the ones full of elliptical galaxies, are the oldest. And those which are irregular, still full of spiral galaxies, are the youngest. Remember that free fall time scale is a few billion years for a cluster. So you expect clusters to be still forming.

So the X-ray gas is interesting. And it's millions or tens of millions of degrees. Some of it came out of galaxies through stellar winds, supernova winds. They're pushed out. Some of which is just pristine has that came in from the universe that was never in galaxies.

We know that some of it was in galaxies because it's not pure hydrogen and helium. Its metallicity is about 1/3 solar, so that is likely to come out of elliptical galaxies. And X-ray luminosity correlates with all other important properties, masses and what have you.

It also has substructure. And some of it is due to clumps of galaxy groups falling in. Some of it is due to active nuclei, those jets disturbing the gas. So they're not perfect, uniform X-ray sources. But they contain interesting signatures of past history.

I mentioned Synyaev-Zeldovich effect, and this is what this is. Here's a cluster, some blob effects for gas, hot gas, electrons. And behind it is cosmic micro background. So those low energy photons for micro background come through this hot gas and do inverse contour scattering on those fast electrons, which boosts their energies at the expense of the energy of electrons.

And so now cosmic micro background looks a little hotter right against the cluster. Not due to temperature of cluster, due to this energy exchange process. And at the bottom, you see the radio map of one of those clusters that shows bumpy microwaves that corresponds to the same distribution of X-rays.

Now, since you're not looking at source itself-- source is the micro background. This is redshift independent. Source is always in the same redshift. So this effect, unlike everything else, does not depend on distance. So you can find clusters using this technique very, very far away. And now this is a very popular way of finding clusters for cosmological purposes with blank satellites and others.

We talked already about dark matter in clusters. And just to refresh your memory, the idea here is that X-ray particles, those test particles in gravitational potential, if it's in variable equilibrium, temperature is related to kinetic energy. You go through the numbers, you find out that clusters have hundreds of times more mass that can be accounted by divisible material.

This is being actually demonstrated very clearly with gravitational lensing signal. They can map amount of mass due to the lensing of the background galaxies. And what's shown here is a so-called bullet cluster, where blue blobs are the dark matter distribution from lensing, pure gravity.

Red stuff is hot X-ray gas superposed on optical picture. So what happens when you have two clusters, they collide. Dark matter clouds go through each other because they're collisionals.

But gas collides. Gas stays. So you have now dark matter has passed out, and the gas remains in the middle. Eventually, those two blobs of dark matter will come back, and they will settle into virial equilibrium. But you're encountering this merger of two clusters right after the first passage.

Several other cases of this have been found now. That's seen as one of the important pieces of evidence that indeed the reason why we think there's dark matter there is correct, because it's confirmed by this gravitational lensing as well as this dynamical process.

I mentioned that spiral galaxies, as they fall into these X-ray atmospheres of clusters, will get stripped away of their hydrogen. And therefore, star formation then will be depressed. So evolution of galaxies would be strongly dependent on where they live. Spirals in dense cluster environments will get snuffed out very quickly. And those in view, like Milky Way, will just keep making stars at uniform pace.

A very nice illustration of this is-- this is a combination of radio maps and neutral hydrogen of spiral galaxies in Virgo Cluster. The center is M87 galaxy in Virgo cluster, central Virgo cluster. You can see that spiral galaxies are smaller closer to the middle and bigger on the outskirts. And that's exactly what you expect. Those on the outskirts haven't really been stripped yet. Those that fell through only have the innermost parts left.

And the same kind of thing then is seen in so-called intracluster light. As galaxies pass by, they distort each other, these tidal tails, be little splatter of stars all over it. And there will be diffused light of stars that now belong to the cluster, not to every galaxy. That's sort of accumulated as a result of all these galaxy interactions.

And in order to see them, you have to look at very, very low surface brightness level. So people who have done that do this for Virgo Cluster. And the missing holes are where the bright objects are. You can see that there are galaxies and there are very extended envelopes. And there are tidal tails and features, all of which are due to the past dynamical interactions. So stars now belong to the cluster potentially more than they belong to the host galaxies themselves.