DJORGOVSKI: Well, let's first begin by going over some of the global properties of our galaxy. This is actually about an artist's illustration of what it might look like seen from the top on the basis of the modern data, and I'll tell you more about it in a second. But first, a little bit of history. It was thought that the milky way was the universe, and the fuzzy little patches and nebulae, nobody knew what they were.

Although people like Immanuel Kant and Thomas Wright did speculate that those are island universes, just like our own, but there was no real data for it. The data started coming with star counts, first with William Herschel. He counted stars in all different directions, and then plotted stellar density as a function of-- well, as he moved that corresponding, supposedly, to the radio.

And it looked like we're in the middle of this irregular patch of stars. And now we know that in fact, he was counting just the local vicinity. It was limited by the galactic extinction, and so didn't all count stars correctly to the large distances. In the 20th century, people did a lot more of this, and Jacobus Kapteyn was the first one to do a little better job on this. But they still thought that the Milky Way is relatively small, and they were very close to the middle.

Until Harlow Shapley started looking at the distribution of globular clusters, postulated correctly that they're probably distributions centered on the galactic center, and somewhere in the constellation sagittarius. And from that he deduced that, indeed, we're actually far from the center the Milky Way.

And finally, the discovery of interstellar extinction persuaded people that, indeed, we got the scale completely wrong, and we're just off to the side. Still, people didn't know whether other galaxies are actually galaxies like our own. There was a famous debate between Shapley and Heber Curtis from Lick Observatory. Shapley actually thought that the Milk Way was all there is. That's the universe.

And he was wrong. Curtis was right. But that was still in indirect arguments which were a result when Edwin Hubble resolved stars in Andromeda from Mt. Wilson observations, and detected variable stars, cepheids, which gave him the distance. And all of a sudden, the size of the universe went up by many, many orders of magnitude. This was the first time that Hubble became famous.

The second move was when he discovered expansion of the universe. Well, rather, got credit for it. But at that point, essentially, our modern astronomy was born. The next important development happened after the World War II, with the advent of radio astronomy.

And it was realized by several people, Schplosky in the Soviet Union, Jan Oort in the Netherlands, and others that you can use that spin flip transition of neutral hydrogen, 21 centimeter line to map the galaxy, because there's plenty of hydrogen, and radio waves go through the dust unaffected. And so suddenly we could map the entire disk of our galaxy regardless of the extinction.

The missing cones here are parts of the sky that couldn't be seen from the Netherlands, but you can already see that there's some hints of spiral arms. Some of the first maps. So the modern picture of our galaxy, and many others, is that there is a disk of stars. There's a bulge of stars in the middle, and then there is a much more extended region of halo that contains stars, and gas, and most of all, dark matter. And I'll tell you about their properties shortly.

So here is the actual picture of the Milky Way. This is all sky image in eta projection, just wrapped on the outside, centered on a galactic center. It's a mosaic done by this astronomer, Andrew Mellinger, and then here is the same thing in near infrared. And it looks different because here you can see that there are large areas that are obscured by dust, whereas in near infrared, most of it's gone.

There's still a layer of dust right in the middle of the plane, and you can see that the voltage bulge is kind of peanut shaped, which is now understood to be a signature of a stellar bar superposed on a spherical bulge. So nowadays we can observe the Milky Way in all different wavelengths, from radio to gamma rays. And here is a collection of slices along the galactic plane in different wavelengths.

And if you look carefully you'll see that there are real differences, that some stuff is distributed much more close to the galactic center. Other things, on the other hand, seem to correspond more to regions of star formation, and so on. So a cartoon version of what our galaxy might look like was produced by Robert Hurt here at the IPAC, and this was based on modern observations.

So this indicates the scale. We are about 27 or so thousand lightyears from the center. Eight kiloparsecs. There is the bulge in the middle. There is also a bar that's inclined relative to us, and there are several spiral arms, which have names like-- well, there is Cygnus Arm, Perseus Arm, Crux-Scutum and Norma. And there's probably also one more.

And they're just given by the name in which consolation we see it tangentially onward. We are actually not in a spiral arm, per say. We're in a little spur off to the side. It's called the Orion arm. It's not really an arm. And there is an Orion star forming complex there. So a step in the understanding of our galaxy and others was done in the 1940s by Walter Baade, maybe early '50s.

And he noticed that actually, not all stars are equal. I mean, stellar populations are not equal. And he divided them into two populations. Population one, which were stars like in the disk of the Milky Way. There's a lot of star forming regions. There's young stars, ol stars, stuff like that. And what he called population two, which were the old stars, like in a galactic bulge, in globular clusters, and stellar halo.

There is not much star formation, there are no massive stars left. They've all evolved and exploded. And Baade thought they were all metal-poor, which is true for the halo, but not for the bulge. Nowadays we actually have a little finer division of things. There are these subsystems inside galaxies, which consists of stars, gas, and dark matter, and each of them has their own characteristics in terms of age distribution, and metalicity and kinematics.

Are they supported by rotational kinetic energy, or by random kinetic energy? Because they're all sharing the same potential well. And they can be nested inside each other. Of course, in fact, they are. So people still talk about population one, population two. Population one is reasonably well defined, pop two really is not, because it gets together all manner of different parts of the history of our galaxy.

But we can distinguish, at least geometrically, about several different components. There is the disk, which actually has three parts to this. There is the thin disk of stars, in which the sun belongs, and that's where a lot of young stuff is. And then there is a thicker, fluffier, less dense disk, inside of which this thin disk exists, which is consisting of middle age or older stars.

Both of them have exponential density distributions, both in radius and vertical from the plane, meaning if you were to squish it all in the galactic plane and plot the density as a function of radius, it'll be declining exponentially with e folding length of three kiloparsecs.

And likewise, if you were to go straight up from the galactic plane and count the density, it'll decline exponentially with e folding length that ranges from maybe 100 parsecs to 1,000 parsecs, depending on how all the stars are. The older they are, the fluffier they are. And inside all of this, there is a thinner yet disk of interstellar medium. Gas, dust, stars. This is where star forming regions are. That's where clouds are.

The other component has at least three parts. There is bulge, the quite spheroidal part of the middle. It contains maybe like, 10% of the mass of the galaxy, or the luminosity of the galaxy. There is a bar, which is sort of like elongated, ellipsoid superposed on the spherical bulge. And then there is halo, which contains several different things. There's stars and globular clusters. They're parts of the same stellar component.

There is gas, which unlike the gas in the disk of the milky way, which is cold, tens to hundreds of Kelvin where stars are forming, or maybe 10,000 Kelvin in those beautiful HIII regions, this one is up to a million degrees. And this turns out to be the kinetic temperature that corresponds to the velocities needed to have protons and electrons zip up there, tens of kiloparsecs out.

And the biggest and most important component is dark matter, about which we know very little. But that's what kind of dominates dynamically our galaxy and others. Now, we do have some idea where these things come from. Actually, a pretty good idea. So thin disk stars clearly are being generated out to the gaseous disk in the galactic plain, the thin disk.

They're forming star forming regions, which you've seen. Those star clusters, freshly made star clusters are then dissipated because of dynamical encounters with other giant molecular clouds, and the newly formed stars essentially evaportate into the thin stellar disk. It's just like the atmosphere on planet Earth, if you go directly up, the density is going to decline more or less exponentially. Not exactly, but close.

And so the same thing is you can think of stellar disk as an atmosphere of stars on the galactic plane. Then the thick disk, there are several mechanisms, but basically, they all come down to that somehow what was a thin disk got dynamically heated up, converted some of the rotational kinetic energy into the random motions.

And a good way to do this is by merging a lot of small galaxies, which kind of disturb the nice, orderly rotation. And that happened in the early phases of the galaxy, so now they're older stars. The bar, we think, forms out of the disk. There is a dynamical instability that happens in rotating stellar disks, and if you don't have enough stabilizing mass in the halo, it will naturally form this kind of structure that will tumble around.

It will also funnel all the gas to the middle, and that's why there is no more star formation. So superficially it looks like the same stuff the bulge is made out of, but really isn't. Stellar halo, now, we think, is made out of grinding up of little dwarf galaxies in globular clusters in processes of dynamical friction tidally operation that we talked about earlier.

And essentially every star in the galactic halo came from a globular cluster or dwarf galaxy at one point. That hot gas? That is almost surely generated by supernova as they explode. You may remember, they put 10 to the 51 ergs of kinetic energy into the expanding shell. That's enough to kick some of the gas way out above the galactic plane. The kiloparsecs, a thousand kiloparsecs out.

And that mechanisms is called the galactic fountain. Because it kind of squirts gas up. And of course, then, there is the dark halo, which we think is the primordial thing. Dark matter, about which more in a moment, we don't know what it is, but pretty sure it comes out of the early big bang.

Fluctuations in density of the dark matter collapse and make proto halos. Regular stuff pours in, and then makes stars. So we can think of the dark matter halos as containers within which you build galaxies.