DJORGOVSKI: Well, let's now take a closer look as to how properties of galaxies change as a function of their morphology and where does it come from. So here is another schematic representation of Hubble sequence with actual real life example pictures to propose on them.

And one thing to notice about this classification is that it has some drawbacks. First of all, it's completely subjective. To some people, the galaxy may look like it's got really prominence spiral arms and other people may not so much.

And anyway, it's based on which filter you take the picture, because if you're using bluer filters, you see more star formation. And if you're redder, you see less. And it's all sort of beauty contest type of assignment. A much better thing is if you can actually measure some numbers and use that as a means of assigning morphology, which is what's now done in modern sky service.

It also missed a very important difference between large galaxies and the small ones. Dwarf galaxies, which there's more than one family, are not just shrunken version of big galaxies. They're very different kind of beasts. And there is different physical process that governs their formation. But if you have eyes in different parts of the electromagnetic spectrum, galaxies would look very different. And so it's sort of a quasi-historical, biological accident that we do it in visible light. But if we had eyes in sense even for infrared, we'll have a completely different kind of classification.

All right. But that's the bad news. The good news is there actually is some meaning to galaxy morphology because that is a product off the overall evolution. And it's useful to think of big galaxies, those in Hubble sequence, as a combination of two basic components-- disks and bulges. Ellipticals will have no disks, traditionally, and the ratio of bulge to disk will define where a spiral is.

And then again, this does not take into account invisible stuff. Dark matter, which totally dominance masses in dynamics of galaxies. But it's very hard to classify morphology with invisible material, so we stick with normal light.

So if you look for properties as they go from ellipticals-- and I smoosh all ellipticals into one group, because it turns out the bar doesn't matter-- and then go along the spiral sequence. And again, it doesn't matter if they have bars or not. Number of interesting things change. Not just the way of stars, and the way stars look, but the dynamics of it.

Ellipticals are supported entirely by random motions of stars in their gravitational potential. Spirals have most of their kinetic energy in an orderly rotation of the disk, like 90%. And there is the dynamical change that corresponds to also gradual change in their stellar populations, from no star formation to a lot of star formation. Therefore from red colors of whole stars, like red giants, to blue colors of blue ultraluminious giants, and so on.

So somehow actual formative processes of galaxies know about all this. They correlate together stellar populations with the dynamics and that is what really poses the question, how and where does this come from. And again, I would note that even though many things do correlate with morphologic types, many others don't. For example if I tell you what's Hubble type of some galaxy you have no idea what luminosity has or role what mass or size. And those are pretty important properties too.

So it is now generally agreed that as far as these observe properties are concerned, that can be all understood in terms of the different star formation histories. Where by ellipticals or orbit types form most of their stars early on where as spirals continue at the more or less uniform pace throughout the age of the universe. And interestingly enough, if you add up all hydrogen that you're seeing in spiral galaxies, add up all-star formation, and ask how much longer do they have to go, how much more fuel they have for making stars, the answer is usually of the order a billion years.

So either we live in a very special time of the universe just before spirals run out of gas, or they somehow get the resupply of hydrogen to build stars. And that's probably what's happening. There is intergalactic hydrogen that is being accreted to the galaxies and then serves as an additional fuel 4 star formation. So this is sort of cartoon version of what the difference might be. That for elliptical galaxies or bulges you do a lot of early start formation. You do it in place.

So you recycle all the supernova products to make next generation star next and within billion years, you might have already hundred generations of stars. This is why these are all methyl rich stellar population, not old methyl four. Whereas to good approximation most this galaxies are more or less constant in their star formation history through the years. So that's as far as stars are concern about how do you connect this with dynamics of galaxies.

Well here is the basic idea. It all depends on when do you make stars verses when do you assemble stuff gas into the bigger galaxies. And if you make stars in small protogalactic pieces like dwarf galaxies and then merge them those stars are mass points. They conserve energy, momentum angular momentum, there's some other combinations of things.

And if there's no dissipation, they will just remain in that motion forever. So they will respond to the global gravitational potential of the newly made galaxy, but they're motions will be random because they came from any direction. So this is why you have elliptical galaxies that schematically supported by random motions, pressure of the stellar gas if you want, not by rotation.

Now on the other hand, if you first put the gas together, it collapses, retains angular momentum, settles into a disk because it doesn't know what to do with angular momentum, then you make stars. Then those stars will remember that they were formed in a thin, cold, rotating disk. And that's exactly what happens. So the sequence of formative events, mergers and star formation, and accretion of gas is what the term is what a galaxy will be most elliptical or mostly disk. And that accounts for a lot of these observed properties.

One other important thing is well, you make stars, big stars explode. They release newly formed chemical elements, what happens to that stuff? Well, if you have a really massive galaxy, the potential well is deep. The supernova shell might expand but then turn around fall back, mix with the rest of the interstellar material used to make new stars.

On the other hand if you had dwarf galaxies, a supernova may put so much kinetic energy in it's expanding shell then that material just leaves the galaxy. And so the galaxy itself does not evolve chemically very much. You expect then dwarfs will be more metal poor, and in fact they really are.

So this mechanism actually can explain a lot of their other properties. By removal of the baryonic material, there is less stuff left to make stars. So in the end, you will end up with very low stellar density systems. Not many stars there, relative to the dark matter that is not affected by supernova shocks at all.

And because you're removing mass altogether the thing will expand slowly and assume even lower dense. So this combination of supernova enrichment of the interstellar medium and kinetic energy actually can explain a lot in terms of differences between a big and small galaxies.