DJORGOVSKI: Let's now talk about one of the most important formation processes for galaxies, which is merging. And these are pictures from Hubble space telescope of different galaxy pairs in different stages of merging. Mergers take a couple billion years to accomplish. And so what we can do is find them in different stages, and if we can assemble them in a correct temporal order, that gives us the movie of how galaxies would merge.

And so on the basis of different models-- this is sort of ordered how people think it-- two spirals, they don't know much about each other. They get closer to each other, they distort each other with their own mutual gravity-- making these tidal tails and bridges-- orbit for a while, then smush together and make just one amorphous galaxy that incidentally settles into an elliptical.

Few percent of galaxies today are involved in some sort of strong interaction like this. And that was certainly much more a case in the past. Because first of all, they were closer together-- universe expands, right-- and there were more galaxies around, since the start.

Now, in the early days, people didn't know what to make out of this. So these things look like nothing else on Hubble sequence, so they were called peculiar galaxies. And now, we know there's something peculiar with them. They just happen to be caught in the act of merging with another galaxy somewhere. And there are a number of famous examples-- this one is called Antennae. The spiral colors is imaging from Hubble space telescope, there's a great deal of star formation going on in the mergers of galaxies. And same process must have happened in the early days, when galaxies were first assembled.

And here is a rogues gallery of a number of different types of galaxy mergers. And we're pretty sure that that's what's going on, as we can recover some of these in by dynamical modeling. And notice that there is always-- in the early stages at least-- there is this strange distortion going on. Not spiral arms, but more like a long, long tails stars that are being kicked out.

And this is an intriguing thing. Because if you think in terms of Kepler's Law, Newtons gravity, clockwork, planets go around suns, point masses-- but if you now have a couple 100 billion mass points interacting together, suddenly gravity turns out to be much more interesting. It creates these collective effects of tidal tails and what have you, which you just couldn't possibly predict just knowing Newton's gravity law. And that's all that is going here, just normal gravity.

So sometimes, you see an elliptical galaxy that has dust in it like this. This is the biggest galaxy in the Fornax cluster. And that's just remains of its last meal. It gobbled up this galaxy, and some of the dust clouds are still remaining. Eventually those will dissipate. But Hubble actually noticed some of the dust lines, didn't know what to do with them, kind of ignored them. And now we know this is a normal part of a life of a big galaxy, that it will be just consuming its neighbors.

Now why do galaxies merge? And that is due to the process called dynamical friction. You're all familiar with the regular friction that really comes from the atomic forces of materials, two objects rub against each other. This is different. But it works like viscosity works, but for different reasons.

So imagine there is a large mass, say a galaxy, that's moving through a big sea of stars. Say, going through another galaxy. It will be attracting those stars towards itself. And then it moves on, and those things are still piling up behind it in a wave. And it expands some of the kinetic energy in accelerating those stars towards itself.

So in that way, the bulk kinetic energy of a galaxy, or two galaxies, gets to be translated into the internal degrees of freedom. The kinetic energy has been repackaged to be more within the galaxies themselves. And because of that, if you have two galaxies approaching each other, and they're on parabolic orbit-- that is, not gravitationally bound, maybe even slightly hyperbolic orbit-- they will lose enough energy that they will actually become gravitationally bound. And that will keep going on until they spiral and merge.

So simulations of this have been done for many years now. And this, for example, is what stars might do in a merger of two spirals. So first, there is this dance. A flow of spectacular splatter of stars around. Eventually settles into something like an elliptical galaxy, where now most of the kinetic energy is in random motions. That's the kinetic energy that's being soaked up from the orbital kinetic energy of the two progenitors.

An interesting thing happens when you compare gas to stars. Turns out that the gas loses energy much faster. Stars are mass points, they just get rearranged. But gas can actually dissipate energy. And because of that, it settles to the middle of the merger product, sometimes in a very dense way. What that will do is it will ignite burst of star formation. Or if there is a big block hole, it will feed it and provide fuel for emission.

And so now we have plenty of examples that show that galaxies that seem to be recent mergers, or mergers in progress, do tend to have very luminous bursts star formation in their middle and are also active nuclei. So this dynamical evolution process then explains a number of other observed facts which have to do with star formation, as well as with presence of active nuclei.