DJORGOVSKI: Now let's turn to explain away the amazing morphology that you see in the galaxy-- the spectacular spiral arms.

This is a Hubble Space Telescope picture of M101-- cartwheel spiral. It's pretty.

And so, in fact, spiral arms are a defining feature of spiral galaxies, or just galaxies. And for a long time it wasn't clear where they come from.

There are some clues. They're only seen in disks that contain gas, not so-called S0 disks. And they're best outlined with young stars-- luminous blue stars or star forming regions. And so their lifetime at any given place must be less than the galactic rotation. Although, as a pattern, it could be moving.

Now, first question you think is, which way are they going? Are they going in intuitive direction like you think-- like a cyclone? Or like water going down the sink? Or the other way around?

STUDENT: It says that [INAUDIBLE]

DJORGOVSKI: Both statements are actually true. If you ask in the absolute sense, they're going in the way that your intuition tells you-- winding up. However, they're only going at 1/2-- exactly 1/2-- of the angular speed of the stellar disk. So relative to the disk in which they reside, they're going in the opposite way-- like scooping up the stars. And we understand why that is.

Now because this is a differentially rotating disk, you think, well, this is easy. If you somehow line up stars, or star forming regions radially-- some explosive event-- and just let go-- because the inner parts rotate faster than the outer parts-- you're going to generate spirals naturally-- immediately.

And then as the galaxy keeps turning on and on, it's going to wind up in what? It looks like the old LP record. And that's not the case. This is not how they form. Because we've never seen them super tightly wound. And they obviously last a long time.

Now, a hint here is that if you have stars that are in elliptical orbits and each orbit can be decomposed into two circular motions-- circle around the galactic center. And then there is point in that circle and go around that circle like epicycles. Then there will be resonances.

And stars could be in these nested ellipse orbits. And if you have ellipses twist around just a little bit as you go out, the pile up of the density will be such that you generate nice two-arm spirals.

This actually turns out to be part of the solution. Now if you are going to pile up the density in some regions like this, they will be attracting material. So say other clouds would come in, collide with, say, interstellar clouds that are already there, that can push them over the edge and they can make stars. This is why you would see it outlined in a form of luminous young stars or star clusters.

And so that, indeed, is what's going on. You expect that the pattern that we see, which we now know is a density wave in a differentially rotating stellar disk. Like if you had steady disk, you create gravitational perturbations, you are going to have a symmetric wave go out.

Now if you have differentially rotating disk and create perturbation, that perturbation is going to be distorted into a spiral pattern. So spiral arms are not material objects. They're just waves of density that go through the disk-- just goes denser or less denser. It keeps going around.

But how do they do this? Now remember the scooping up material. Then molecule clouds will collide, start making stars, and as wave passes, you have freshly made star forming regions. And then they'll go away.

And then, because these massive young stars will only last a few million years and a galaxy rotational period is a couple hundred million years, they'll die out soon enough. So the signature of the passage of that spiral arm there will fade out. But now the arm's already moved somewhere else. And you see that pattern somewhere else.

So that explains everything. So generic expectation then is if you look at spiral arms, on the inner part you're going to start seeing the dust lanes. Because this is where it's compressing the interstellar medium gives the dust clouds.

Then as you go across the arm, you're going to see star forming regions and then luminous blue stars. And then they're going to go away.

And this is what real galaxies look like. Look carefully. Inner side-- that's where you see the dust lanes. And then you see blobs of star formation and then fade out on the outer ends of the spiral arms.

So spiral density waves stimulate star formation in disks. You can have star formation without them but this is a good way to keep grinding out stars. And indeed the theory seems to work really well.

So they're essentially created by the gravitational attraction, or density perturbation. And stars and gas go through the pattern. They're not carrying on with the arms.

There will be star forming regions, in any case, because there is gas. But this certainly organizes it. It makes it more interesting.

So this is what explains what they call a grand design spiral. Those are the photogenic galaxies that you see pictures of all the time.

There are other galaxies that don't look so pretty. They're called flocculent or amorphous spirals, where you don't see spiral arms but you still see star formation.

So this is one of the textbook examples of what the grand designs spiral is. It's M81 near Virgo. And you see several arms. There is a nice bulge in the middle-- some dust lanes. This is what most people think of as spiral galaxy or galaxy, period.

But then there are galaxies like this where you can't really tell that there is any spiral pattern. There is also a patchy star formation. There are little elongations that could be due to this winding business of differential rotation. But that, too, works. These are in minority, I think.

And one last pattern to talk about are galactic bars. I told you the Milky Way has one. And this is actually common. Some large fractional spirals-- half of them have one of these.

That there is this elongated feature made up of all stars mostly and then spirals arms begin from its tips usually. They're flattened ellipsoids. And unlike everything else in the disk, bars rotate like solid bodies. Stars actually do take a ride together. And this is why this is not found in spiral.

So it really is a self-gravitating object like an elongated elliptical galaxy that spins around and tumbles at constant speed. And that creates gravitational perturbation that can be exciting these density waves. So this is why some of the spiral arms then begin at the tips of the bars.

There also turns out to be a very good way to funnel gas to the middle because of the way that orbit instability works.

And if you have an active galactic nucleus-- a gigantic black hole in the middle, this would be an excellent way to feed it. And there is some evidence that, indeed, nearby spirals with active nuclei do have all bars. But it's a messy business.