Galaxies, part 1: Crash Course Astronomy #38

Crash Course: Astronomy
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We live in a pretty cool neighborhood: the Milky Way Galaxy. We're out in the suburbs, sure, but it's still an interesting place, buzzing with activity: stars, nebulae, stellar clusters of various sorts, the occasional supernova. It's a happening place.

In the earliest part of the 20th Century, astronomers were just starting to figure this all out. But there were a handful of objects that were puzzling. Dotting the sky here and there were faint fuzzies displaying a variety of shapes. Some were round, some elongated, and some even seemed to have spiral arms. Even with big telescopes, they looked smoky, so they were simply called nebulae.

Their existence was puzzling though. What were they? How did they form? Were they big? Small? Near? Far? Eventually, astronomers had uncovered the key to these objects, and in one fell swoop, our universe got a lot bigger. A lot.

(Intro)

In 1920, there were two competing ideas about the universe. One was that our Milky Way was it, and that everything we saw was in it. The other was that these spiral nebulae seen in the sky were also like our Milky Way, island universes in their own right.

Two astronomers debated this controversy in that year. Harlow Shapley argued that the Milky Way was all there is, while Heber Curtis was of the opinion that we were one of many galaxies. It wasn't a debate as such, more of a presentation of ideas, and there was no clear winner. Both sides had fragmentary data and, we now know, some shaky observational evidence that turned out not to be correct.

For example, Shapley noted that one of the spiral nebulae had been seen to rotate, so it must be small. It turns out, that was just wrong. Dead wrong. On the other hand, Curtis noted that if galaxies were as big as Shapley claimed, hundreds of thousands of light-years across, then other galaxies must be impossibly far away. But hello! Galaxies really are that big, and they truly are mind-numbingly distant.

The observation that finally unlocked this mystery was made just a few years later when Edwin Hubble and Milton Humason observed the great spiral nebula M31 in Andromeda, using what was at the time the largest telescope in the world.

They found dozens of pulsating stars in it, literally stars that change their brightness in a regular, periodic fashion. These are called Cepheid variables, and they were critically important because it was known the time it took them to pulse was directly related to their luminosity, how much energy they emitted. That means, if you can measure their period, you can determine how far away they are simply by measuring their apparent brightness. The distance they found to M31 was 900,000 light years, clearly outside even the largest estimates of the size of the Milky Way.

They also resolved swarms of faint stars, cinching the fact that the "Great Andromeda Nebula" was actually the Andromeda Galaxy. At that moment, our understanding of the universe swelled in size, and we've never looked back.

We've learned a lot about galaxies in the ensuing century or so. Each is a collection of at least hundreds of millions, or even trillions, of stars, and most contain some amount of gas and dust. They range in size from tens of thousands to hundreds of thousands of light years across, and they come in a variety of shapes. We use these overall shapes to classify them. Broadly speaking, there are four major types of galaxies: elliptical, spiral, peculiar, and irregular.

Spiral galaxies we've seen, we live in one. These are characterized by broad, flat, rotating disks of stars, gas and dust; a central bulge of older, redder stars, sometimes with a long cylindrical or rectangular bar of stars as well; and a huge extended halo of older stars. Some spirals have large central bulges and some have much smaller ones. Most have bars of stars extending across the central part of the galaxy, our Milky Way does.

The spirals come in a variety of flavors as well. Grand design spirals have magnificent, well-organized spiral arms that extend from the very center out to the visible edge of the galaxy. Others have choppy or patchy arms; these are called flocculent spirals, resembling tufts of cotton. Some spirals have wide-flung arms, while others are tightly wound. Spirals take on wildly different appearances depending on their angle to us.

Some, we see face on, and these may be the most magnificent objects in the entire sky. Huge and sprawling, their structure is obvious and easy to see. Star forming nebulae are laid out like beads on a string, colored pink by the characteristic glow of warm hydrogen. Young, massive, luminous stars blaze blue, tracing the spiral's form. Filigrees of dust clouds align with the arms as well, and the central bulge or bar glows an eerie reddish-yellow, the star formation there long-since ceased. The bluer stars all exploded, leaving only the redder stars behind.

When spirals are more tilted to our line of sight, some of the structure is hidden, and when they're edge-on, we see them as the flat disks they truly are. Dust clouds are tightly restricted to the mid-planes of spiral galaxies and we sometimes see them bisecting the galaxy like a racing stripe right down the middle.

The reason for this is the same reason our Solar System is flat; galaxies probably formed from huge clouds of gas billions of years ago. As a cloud collapses, small eddies in the gas would get amplified and would create an overall spin. This naturally leads to a flattening of the cloud, and by the time the stars in the galaxy were starting to turn on, the overall structure of a flat disk was in place.

Elliptical galaxies are, well, elliptical... kinda. Some are nearly spherical, gigantic cotton balls of billions of stars. Others are more elongated, shaped like cigars or American footballs. They tend to have no overall structure as spirals do. Ellipticals are puffy and they range in size dramatically. Some are what are called dwarf ellipticals just a few thousand light years across, to monsters that hugely out-muscle our own Milky Way.

Besides their shape, ellipticals are characterized by a lack of gas and dust in them, and also are populated with older stars. Apparently star formation in ellipticals came and went eons ago, and all the young massive stars have long-since exploded, leaving less massive redder stars. This makes them similar to the stars in the central bulges of spiral galaxies.

It's not exactly clear how ellipticals form. Current thinking is that they are the products of, and this is mind blowing, galactic collisions. Yes, you heard me, entire galaxies collide. When galaxies collide, it's a train wreck on a cosmic scale. Galaxies are huge structures, and with hundreds of billions of stars in them, their gravity is pretty strong. If two galaxies get close enough together, they can draw each other in and collide.

A galactic collision is a weird event. Even though the collision speeds can be hundreds of kilometers per second, the event plays out over hundreds of millions of years. Remember, we're talking about distances of tens of thousands of light years here.

In the early stages of the collision, tidal effects can be strong. Stars on the side of the galaxy near the other one get pulled toward it more strongly than the stars farther away, so the galaxies can get

stretched, and long tendrils of stars and gas get drawn out.

Generally, collisions aren't head-on, but more of a side swipe so there's some sideways motion. When that happens, the tidal streamer can become curved; a long, graceful arc. Colliding galaxies in this stage form all sorts of bizarre and spectacular shapes. Sometimes the galaxies separate and then fall back together again. When that happens, the main bodies collide.

But this isn't like two cars crashing together. Stars are very very small compared to the space between them, so even though hundreds of billions of stars can be involved, the odds are good that no two stars will ever physically hit each other. Space is weird.

Gas clouds, though, are huge and they do collide. They slam into each other, collapse, and form stars at a furious rate. Colliding galaxies can glow pink and blue as stars are born and light up the hydrogen clouds around them.

Sometimes the two galaxies will collide at a high enough velocity that they pass right through each other. But even then, in most cases they'll slow, stop, and then re-collide. Eventually they merge, their huge energies of motion absorbed by the orbiting stars, puffing them up into vast sweeping orbits. The results, so we think, are elliptical galaxies.

Not all collisions result in galaxies becoming ellipticals. If a big spiral collides with a much smaller galaxy, it can tear apart the interloper and literally absorb it into itself. So galaxies are cannibals. We think most large galaxies grew to their current bulk by consuming smaller galaxies, including our own Milky Way. In fact, we have proof.

We're currently in the process of eating several smaller galaxies right now! Terzan 5 is a small knot of stars that may be the leftover core of a galaxy cannibalized by our own. And two huge, looping streams of stars circling our galaxy are parts of the Sagittarius and Canis Majoris dwarf galaxies being torn apart by the Milky Way.

This brings us to the third type of galaxies: peculiars. These are not shapeless, really, but have a shape that's weird. Peculiar galaxies are essentially all due to collisions. Colliding galaxies clearly have structure, but can be all sorts of odd, distorted shapes.

Sometimes a small galaxy will plunge right through the heart of a much larger galaxy. The gravity of the smaller galaxy draws in stars and then flings them away at the bigger one, like ripples in a pond. The result is a ring galaxy, sometimes with a culprit intruder seen nearby. The famous Cartwheel Galaxy is a fine example of this. Another is Hoag's object, though to be honest, it's not completely clear if this bizarre galaxy is a product of a collision or some other process. It's peculiar either way!

Finally, we come to galaxies that truly are shapeless, called irregular galaxies. These tend to be small, and chaotically shaped. Bigger ones may be victims of collisions, their shapes distorted so much that the structure was lost. Smaller ones may simply be too tiny to collect themselves together into a recognizable shape.

Many galaxies have companion, satellite galaxies. The Milky Way has a couple of dozen such satellites. The two biggest are the Large and Small Magellanic Clouds, visible from the southern hemisphere. Both are irregular in shape, though the Large Magellanic Cloud is barely coherent enough to qualify as a disrupted, though small, barred spiral. Both are riddled with gas and dust. The Large Cloud sports the biggest and most active star forming gas cloud in any nearby galaxy: the Tarantula Nebula. It's producing so many stars that astronomers think it may be in the process of forming a globular cluster!

There are other types of galaxies as well. Some, called active galaxies, pour out far more energy than normal ones. And galaxies aren't just scattered evenly across space; they tend to be found in clusters, some containing thousands of galaxies. We'll get to all that in the next episode.

We now know that the Universe is far, far larger than just our Milky Way galaxy. It's a recurring theme, isn't it? We thought the Earth was the center of creation, and then the Sun, and then the galaxy. But every time we investigate these situations earnestly, and engage in honest debate, we find that we're smaller and farther removed from the action than we thought, or than we thought we deserved. Astronomy is really, really good at putting us in our place. But it's also really good at showing us just how grand and awe-inspiring that place is.

Today you learned that the Milky Way is a galaxy, one of many. Containing gas, dust, and billions of stars or more, galaxies come in four main shapes: elliptical, spiral, peculiar, and irregular. Galaxies can collide, and grow in size by eating each other.

Crash Course Astronomy is produced in association with PBS Digital Studios. Head over to their YouTube channel to catch even more awesome videos. This episode was written by me, Phil Plait. The script was edited by Blake de Pastino, and our consultant is Dr. Michelle Thaller. It was directed by Nicholas Jenkins, edited by Nicole Sweeney, the sound designer is Michael Aranda, and the graphics team is Thought Café.