Galaxies, part 2: Crash Course Astronomy #39

Crash Course: Astronomy
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===== Intro (0:00) =====

Hey Astronomers! Phil Plait here.

In our last episode I talked about galaxies - vast collections of gas, dust, and upwards of hundreds of billions of stars. We live in one, The Milky Way, a gigantic disk galaxy with sprawling spiral arms. Other galaxies are elliptical or irregular or peculiar, but those are classifications based on shape.

We also classify galaxies on their behavior, and sometimes even on their location and mass. To understand why, we have to take a step back and look at the environments in which galaxies sometimes find themselves. And if you thought galaxies were big and powerful, well, I'm about to crush your brain again.

(Intro)

===== Active Galaxies (0:52) =====

In the 1960s, a peculiar object was found called 3C273. Through optical telescopes it looked like an unassuming blue star, but through a radio telescope it was seen to be ablaze with light - a luminous powerhouse. Stars didn't blast out that much radio radiation, so this was baffling. The mystery deepened when spectra of 3C273 were taken. It wasn't a star; it was an entire galaxy, and not just any galaxy, but one very very far away - well over 2 billion light years.

Far from being some dim thing, 3C273 revealed itself to be the most luminous object in the universe ever seen at that time. It blasts out over 4 trillion times the energy the Sun does. And yet it appears star-like, a mere dot in the sky. Because of this, it was dubbed a "quasi-stellar radio source," which is pretty underwhelming for the most powerful energy source in the entire cosmos.

Happily, the name was shortened to "quasar," which you'll admit, is way cooler. Once 3C273 became known, lots more such objects were found. With the advent of x-ray observatories launched into space, even more energetic point sources were found, which is amazing. X-rays are a very high-energy flavor of light, and it takes a lot of power to make them.

Eventually, galaxies like these were even found to be blasting out gamma rays, the very highest energy kind of light. Clearly, these were no regular galaxies. Astronomers gave them the generic name *active galaxies* and classified them into various sub-categories depending on how they emitted their light and what kind of spectra they had.

But what could power these immensely energetic galaxies? It turns out, to create that kind of energy, you need to have an object with a lot of gravity. And what kind of object has a lot of gravity? (sinister laugh)

In the 1980s, astronomers were getting suspicious that all large galaxies had very massive black holes in their cores. In fact, one of the reasons the Hubble space telescope was built and launched was to explore this idea and characterize (that is, find out as much as it could about) these black holes.

Over time, we found this idea is absolutely correct. Every big galaxy we see appears to have a huge black hole in its heart. Even the smallest is a monster, with millions of times the Sun's mass, and some tip the cosmic scale at billions of solar masses.

We now think that these supermassive black holes form at the same time galaxies do. As the material coalesces to create a galaxy, some falls to the center and feeds the black hole there. It grows as its host galaxy does.

But I can hear you thinking, "Hey Phil, don't black holes suck down everything, even light itself? How could they power active galaxies, the brightest objects in the universe?" Ah, you can't escape from a black hole once you fall all the way in. Just outside the black hole's event horizon things can still get out.

If a black hole is sitting all by its lonesome out in space it's, well, black. But if matter (like gas, dust, or even whole stars) falls into the black hole, it can be shredded by the fierce gravity. This material forms a flat disk called an *accretion disk*, the matter swirling madly at ferocious speeds before falling in, like water down a bathtub drain.

Stuff closer to the black hole orbits faster than stuff farther out. This means material in the disk rubs together and heats up, just like rubbing your hands on a cold day warms them up via friction. But around a black hole, the orbital speeds are near the speed of light. Try rubbing your hands together at a couple of hundred thousand kilometers per second and see how much heat you make.

So friction and other forces heat the material falling in to millions of degrees - so hot that it blasts out light across the electromagnetic spectrum, and that's what powers active galaxies. The black hole is the energy source, but the matter falling into it is the actual light bulb. Active galaxies are so bright, they can be seen clear across the universe.

Not only that, but some active galaxies have jets. Magnetic fields coupled with the incredible rotation of the accretion disks can launch twin beams of matter and energy directly away from the black hole along the poles of the disk. These beams pack a huge wallop, traveling for hundreds of thousands of light-years. Eventually they slow down as they ram through the thin material between galaxies, but when they do they puff up. They look like huge cotton swabs, which glow in radio waves.

Active galaxies can look pretty different from each other, and we now think that's due to our viewing angle on their accretion disk. When we see it edge on, the thick dust in the disk blocks the intense highest-energy light, but we do see lots of infrared as the radiation from the disk heats up clouds of dust around it. If the accretion disk is tipped a bit to our line of sight, we see more optical and high-energy light from it. And if the poles are aimed right at us, all that ridiculously energetic x- and gamma ray light can be seen.

The Milky Way has a supermassive black hole in its heart too, with a mass of over 4 million times the Sun's. That might sound huge, but remember, the galaxy has hundreds of billions of stars in it. The black hole is only a teeny tiny fraction of the total mass of the Milky Way. Our black hole is *quiescent* (that is, not actively feeding) so we're not an active galaxy. Every now and again we'll see a flare from it as it swallows down a gas cloud or something like that, but nowhere near what's needed to switch it fully on. Happily, we appear to be safe from any tantrums it might throw. But that may not always be the case.

One way to flip such a black hole from milquetoast to monster is through galactic collisions. When two galaxies collide, a lot of gas can be dumped into their centers where it can be gobbled down and heated up. We do see a lot of evidence that active galaxies are disturbed, as if they recently collided. So, could that happen to us?

Yes, yes it can. In fact, it will, but not for a few billion more years. To understand that, we have to take a small step back. Well, actually a huge step back - a few million light years - and take a look at where

galaxies live.

===== Local Group (6:45) =====

Our Milky Way isn't alone. It's part of a small knot of galaxies we call (in long, boring astronomical nomenclature tradition) the *Local Group*. It consists of a few dozen galaxies, most of which are small and dim, so faint that we're still discovering them. Two galaxies completely overpower the group: the Milky Way and the Andromeda Galaxy. The Local Group is elongated, almost dumbbell-shaped, with the Milky Way on one side and Andromeda on the other.

In the past, the Local Group probably had lots more galaxies, but over the eons the two big galaxies ate them all, growing huge. Andromeda is bigger than we are and has more stars, but honestly we're both pretty big as galaxies go. And someday, we'll be bigger.

The Andromeda Galaxy is about 2.5 million light years away, close enough that it can be seen by the naked eye on dark nights - the most distant object easily seen without aid. Spectra taken of Andromeda reveal an interesting fact. It's headed right for us!

Its spectrum is blue-shifted, meaning it's approaching us, and it's doing so at quite a clip - about 100 km per second. That's fast, but 2.5 million light years is a long way. The collision is inevitable, but it won't happen for several billion years.

When it does, both galaxies will stretch out due to galactic tides, forming long curving streamers of stars. They may pass by each other during the first pass, but over the next few hundred million years, they'll slow, fall back toward each other, and merge. They'll then form one much larger galaxy, probably an elliptical which astronomers have called "Milkomeda." I know that's awful, but if you can come up with a better name, let us know.

Anyway, although this won't happen for billions of years, that's still long before the Sun dies. The Earth may still be around when the galaxies collide. It's not clear what will happen to us. The Sun may continue to lazily orbit the core of the new galaxy, or it may move farther in toward the center, or farther out in the galactic suburbs.

And here's another fun fact: Andromeda has a gigantic black hole in its core too, which has 40 million solar masses - ten times the mass of ours. When the galaxies merge, the two monsters will probably go into orbit around one another. Not only that, but any gas and dust left over from star formation during the collision may fall toward the center of Milkomeda where the two black holes will gobble them down, and may turn the galaxy into an active one. Hopefully any death rays launched from that will miss Earth. But that won't happen for like 4 billion years anyway. I'm not too concerned over the fate of the Earth at that point.

===== Galaxy Clusters and Superclusters (9:14) =====

I feel that right now is a good time to give you a heads up. We're about to take a very VERY big step. Up to this point in the series, we've talked about some very big distances, millions or billions of kilometers to the planets, trillions of kilometers to the stars, and then jumping to thousands of light years (quadrillions or quintillions of kilometers) when talking about the galaxy itself.

But those distances are as nothing when you start talking about intergalactic trips. We're about to venture out into the greater universe, and things are about to get very large.

When we step outside our Milky Way, we find that a few galaxies have clumped together to form the Local Group. But as we look farther out into the universe, we see that galaxies tend to clump together on larger scales as well. Many are in small groups like ours, but sometimes they aggregate into much larger *galaxy clusters*. A typical galaxy cluster is a few tens of millions of light years across and can contain thousands of galaxies.

The nearest one to us is the Virgo Cluster located about 50 million light years away in the direction of the constellation Virgo. It has well over a thousand galaxies in it, maybe twice that much. It may have as many as a quadrillion stars in it.

Like star clusters, galaxies and galaxy clusters are bound to the cluster by their own mutual gravity, and move through the cluster on long orbits that can take billions of years to complete. Thousands of clusters are known, and they contain every kind of galaxy imaginable: spirals, ellipticals, irregulars, peculiars, active galaxies.

In many clusters, a huge elliptical galaxy sits right at the very center. This is probably the result of collisions between smaller galaxies. When they smack into each other, their velocities through the cluster tend to cancel out, like two cars hitting head-on and stopping, so they fall to the center. As more mass falls to the center, the galaxy there grows huge. As mind-boggling as this all is, we're not done.

Surveys of the sky have revealed that not only do galaxies clump together in clusters, but clusters themselves fall into even bigger groups called *superclusters*.

A supercluster usually has several dozen clusters making it up and are hundreds of millions of light years across. Our Local Group is near the Virgo Cluster, and both are part of the Virgo Supercluster. Recent observations indicate the Virgo Supercluster is actually only an appendage of the even larger Laniakea Supercluster, which may have 100,000 galaxies in it, stretching across 500 million light years.

This new result is a bit controversial. I mean, it's hard to know exactly how big such a structure is, especially when we're inside it. But it gives you an idea of the vast sizes and distances we're talking about here.

Superclusters themselves aren't just randomly distributed through the universe either. They appear to fall along tremendously long, interconnected and intersecting filaments, making the universe appear almost foamy on the biggest scales, like a sponge. In between the filaments are vast regions relatively empty of galaxies called *voids*.

This cosmic, large-scale structure - its size, shape, distribution of matter, and more - holds clues to some of the biggest questions we can ask: What is the universe made of? How did it start? What is its eventual fate? These are questions we'll get to in future episodes very soon, and I promise you they'll stretch your mind like nothing you've ever encountered before.

===== Hubble Deep Space (12:28) =====

But before we wrap up, there's one more thing I want you to see. When you look at all these pictures of galaxies, of clusters, of superclusters, a question pops up: How many galaxies are there? Can we count them all?

To help answer that question, back in the 1990s, astronomers used the Hubble Space Telescope. They pointed it toward the emptiest

part of the sky they could, a spot with little or no stars, nebulae or galaxies in it. They then let it stare, simply collecting light from whatever it could see, letting light accumulate until incredibly faint objects could be detected.

And what did it find? Wonder. Pure simple wonder. Oh yeah, and THOUSANDS of galaxies.

This is the Hubble Deep Field. Mind you, the area of sky you see here is roughly the same as the apparent size of a grain of sand held in your palm with your arm outstretched. And yet, in that tiny section of sky, there are thousands of galaxies. Essentially everything you see in that image is a galaxy - a huge collection of gas, dust, and billions of stars.

The Deep Field was repeated in different parts of the sky, and the result was always the same - crowds of galaxies, jostling for position, crammed together even in a tiny slice of the heavens. You can count all the galaxies in these deep fields, and then use them to extrapolate to the entire sky, giving you the total number of galaxies in the universe. And what do you get? Well, give or take, 100,000,000,000 galaxies. A hundred billion. And each with billions of stars.

The universe is mind-crushingly huge, and yet here we are a part of it, learning more about it all the time. It's easy to think the universe is too big to comprehend, and makes us seem tiny and insignificant in comparison. To me, the opposite is true; it's our curiosity about this enormous cosmos that makes us significant. We yearn to learn more, to seek out knowledge. that doesn't make us small, it makes us vast.

===== Recap (14:24) =====

Today you learned that active galaxies pour out lots of energy due to their central supermassive black holes gobbling down matter. Galaxies tend not to loners, but instead exist in smaller groups and larger clusters. Our Milky Way is part of the Local Group and will one day collide with the Andromeda Galaxy. Clusters of galaxies also clump together to form superclusters - the largest structures in the universe. In total, there are hundreds of billions of galaxies in the universe.

===== Credits (14:50) =====

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.