Astronomy Cast Episode 98:
Quasars

Fraser Cane: Last week we talked about Galaxies in general and hinted at the most violent, energetic ones out there. Active Galaxies, specifically Quasars have been a mystery for more than half a century. What kind of object could throw out more radiation than an entire Galaxy?

A Black Hole, it turns out with a mass of hundreds of millions of suns can do this feat. Let's trace back the history of Quasars and find out exactly what they are.

So Pamela, I actually find the history of Quasars really interesting because it was this amazing discovery and they had no idea what was causing it.

Dr. Pamela Gay: Well you're exactly right. This is one of those things that really confused people for a while. Back in the 1950s we started looking at the skies through radio telescopes. We started to realize that even objects like Jupiter emit light in radio waves and if you tune a radio dish to the right color of radio light and look around the sky you can find all sorts of cool objects.

One of the common wavelengths to look at is about 20 centimeters. But there is everything from millimeters to many meters long that we look at as we try to gain more information about these objects. In one of the surveys that is now affectionately referred to as the "Three C Catalog", they found all of these little point sources of radio light around the sky.

They started following them up with progressively larger telescopes and found that some of these points of radio light were actually associated with points of optical light. But they were fairly faint so they started looking with spectrographs. They were questioning what they were seeing. What type of star were they looking at?

When they looked at them, they saw emission lines. They saw patterns of lines that didn't match any known type of star and there was a lot of head scratching. There were a few people who made early claims that it was just something at really high red-shifts. It took awhile before someone was able to look at these lines and recognize the pattern of hydrogen.

Fraser: Right but to say something was at really high red-shifts when what they were seeing was something moving away very quickly, right?

Pamela: Yes, that's exactly right. Astronomers like to sometimes confuse our terminology. It's not really very friendly of us. When we say something is at high red-shift, what we mean is that it is moving away from the planet Earth at an extremely large velocity. As a result of its motion we see that the color appears to change and appears to move toward the red.

This reddened light is just part of the Doppler shift. It's the same thing that affects sound when a fire truck passes your house and you hear the pitch appear to change.

With Quasars, these are objects that are billions of light years away and some of them are red-shifted sixteen percent. This means that the color is sixteen percent of what it should be. Some of these objects are moving 37, 38 or more percent of the speed of light as you look at things further and further out into the Universe.

Fraser: So Astronomers noticed all of these points that look like stars but when they analyzed the spectra of them, they were moving like a Galaxy really far away.

Pamela: And at the time, we still weren't consistently able to find Galaxies at that high of a distance. This is one of the things that really confused us. Here are these points of light that seem to correspond to the edge of the Universe and they were so bright. They looked like stars and they didn't have morphologies that looked like any type of Galaxy we've ever seen.

There was a lot of head scratching. It wasn't until about 1962 that we figured out that these lines are the spectral lines of hydrogen. These are objects that are moving more than 40,000 kilometers per second away from us and this is some sort of new Physics, some sort of a new object.

It was only in the 1980s that we started to build big enough telescopes to look at these points of light and see that the point was just the center of a very distant Galaxy. It now appears that at some point in their history probably just about every type of large Galaxy could have been a Quasar.

Fraser: And the term Quasar comes from?

Pamela: It's actually an abbreviation. These things were found in the radio. They looked like stars. But they weren't so we called them Quasi-stellar Radio Sources. But that's a pain to write out so a fellow by the name of Hong-Yee Chiu pointed out this is a lot of words to write so let's abbreviate it to Quasar.

Some of these objects don't actually give off radio light so we call those QSOs – Quasi-stellar Objects, which isn't nearly as much fun to say. So the name Quasar is the one that is most frequently used.

Fraser: So with the advent of more powerful telescopes Astronomers were able to actually see that these weren't just really bright star-like objects in the sky but they actually were at the heart of a Galaxy.

Pamela: These were the cores of distant spirals. They were the cores of distant ellipticals. These were just regular Galaxies that for whatever reason had an angry monster in their centers.

Back before we even knew for certain that Galaxies actually had super-massive Black Holes in their centers; we knew that there was some sort of angry physical entity that was rapidly spewing out more energy than anything else in the known Universe.

Fraser: And just to give some amounts out, a Quasar can put out as much energy as the rest of the Galaxy, right?

Pamela: It can put out more energy than the rest of the Galaxy. That's one of the cool things about it. Take all of the energy in the Galaxy, up the ante a little bit, and you start to get the brightest of Quasars.

Fraser: Wow. Okay, so they're starting to realize that there is some kind of exotic object, something at the middle of the Galaxy that is pouring out all of this energy. When did the Black Hole connection finally come back?

Pamela: People started to make guesses about that in the 1980s once we started to realize that these were objects at the center of Galaxies. But the first super-massive Black Holes weren't confirmed until the mid-90s. There were a lot of talks between the mid-80s and mid-90s where Astronomers stood up there and talked about the angry monster and that was actually the phrase that was usually used in scientific talks: "The Angry Monsters in Centers of Distant Galaxies."

They talked about how you could generate this with the Black Hole. There are actually a lot of different pieces of evidence coming out from many different directions. In the most distant parts of the Universe we had Quasars with enormous brightness. Sometimes these objects would be a hundred times the brightness of the Milky Way all compacted into the center of a distant Galaxy.

The other thing that we knew was they were capable in some instances of varying in brightness very rapidly. When you have rapid variation that means you can't be dealing with a large object.

One of the things that happens is if you take a light and you embed it the center of a media and you turn the light on and off, the light is traveling both toward you and backwards through the media. It's going to reflect off of it and come back at you later.

The first light that you get is from when the light is originally turned on and it starts propagating straight towards you. Now you turn the light off and you're still going to keep getting light for a while. The last bit of light that you get is the light that comes from the furthest back edge of that object that hit the back edge of the object and then reflected back towards you.

Fraser: I understand, you've got almost like a ball around the center and you see the light coming down from the front side of it. You're also going to see reflections off of the back of that imagined like some sort of silver ball. So the last amount of light that you will see is the light that is bouncing off the back of that.

Pamela: So the shortest flicker you can possibly see is defined by the size of that object. With these active Galaxies we see flickering that seems to indicate we are dealing with an object maybe only the size of the Solar System.

So you have something that is roughly Solar System sized and is also giving off huge amounts of life. This is really confusing and pretty much the only way to do this is to cram a Black Hole in there, it's the only thing dense enough, put an Accretion disc around it (a disk of dust and gas and other material that is streaming in towards the Black Hole) and try to jam that material into the Black Hole so quickly that the Black Hole gets jammed up and magnetic fields form.

You start jetting the material out the rotational axis of the Accretion disc. If you put all of these pieces together, you start to get the things that we identify with Quasars. You start to get the amazing amount of luminosity. You start to get the fact that these things don't look the same at all angles.

Some of these give off radio light while others don't, which is probably an effect of the angle we are looking at them. If you're looking at a system straight down the jet, straight down toward the Accretion disc such that the Accretion disc would appear like a plate down at the base of this jet, then you will get all the radio emission.

If instead you are looking at the system sideways, such that the radio jet goes straight up and straight down on your image of the sky, the rest of the Galaxy will probably block the central radio emission. That's how you end up without getting radio luminosity as you look at it. It's all different affects of angle and of how much feeding is going on.

The other clue that these might be something unique to the edge of the Universe that fits with our cosmological models is Galaxies had more dust and gas when they were younger. Over time this gas and dust clearly fell into Black Holes. It also was wrapped up into star formation.

So as we look at the nearby Universe we don't see any Quasars. We also don't see systems that have a lot of gas and dust down in the centers of the Galaxies. This fits with the model where early in the Universe we had these Galaxies forming and they had too much gas and dust and all of this material fell in towards the center of the system and lit up an angry monster, an angry super-massive Black Hole that was feeding. This created these radio jets, dense regions of emission that flickered and changed over time and that we now see as these highly variable objects.

Fraser: There is one last really important piece of data that was uncovered in our own Milky Way, right?

Pamela: Yeah, as we look out and start looking at the high-energy gas around our own system, we see shock waves that look like sometime in the past our own Milky Way was indeed a Quasar. Echoes of this angry history are still out there being discovered.

You can almost imagine this amazing period in the Universe when all of the Galaxies were lit up like Quasars and everywhere you looked all of the Galaxies were these bright shining nuclei of jets and radio, and gamma ray and x-ray emission. Once going through this terrible Quasar phase everything calmed down to the normal Galaxies that we see today.

Fraser: So let's talk a bit about the phases then. I know that the thinking right now is that the super-massive Black Hole and the Galaxy kinda seem to grow together.

If you have a big Galaxy it has a big super-massive Black Hole and if you have a smaller one then it has a smaller Black Hole. And so the Black Hole goes through phases, right? What sets it into an active feeding phase when we see the Quasar?

Pamela: It needs to be eating something. This is one of the cool things about looking around the modern Universe. We may not see these things that have two trillion times the energy output of our Sun, but we do see Galaxies that have active Black Holes in the center that are giving off radio emission.

These systems are often irregular systems that are in the process of consuming things, or that sit in the very center of Galaxy Clusters, places where they are getting extra gases and dust from somewhere.

What seems to dictate the anger – to abuse an adjective I shouldn't – of a super-massive Black Hole what seems to dictate the luminosity of the Accretion disc in the jettison material it is giving off is the rate at which it is consuming material.

Today we don't have as much stuff to feed a super-massive Black Hole. However, you can imagine a point in the future where when Andromeda and the Milky Way collide.

What gas and dust is left in our two systems will be shocked into both forming stars and plunging into the two system's central massive Black Holes and as it does that our two different super-massive Black Holes are going to come to life. They are going to become active. There will be bright nuclei in the centers of our two Galaxies that over time are going to coalesce and over time those Black Holes are going to coalesce.

We can see this as we look out at other emerging Galaxies – the Mice for instance. They have active Black Holes in their centers, bright cores of light in what's left of their two nuclei. It's a whole range of objects. "Active Galactic Nuclei" is the parent term. It incorporates everything from M87, a Galaxy in the center of a cluster that is giving off amazing radio jets. It is an elliptical Galaxy whose central Black Hole is angrily feeding on gas and dust and it sits in the center of a high-energy x-ray emitting cloud of gas.

There are other systems such as BL Lac a Galaxy that was originally thought to be a star that was a variable. It's a Galaxy that has amazing jets that are pointed almost directly at us and we see the center of the Galaxy flicker and change with light over time as the Accretion disc fluctuates with time.

There's a whole range of objects. We have too many different names because we originally didn't know these were all the same thing. For instance there are two different types of systems called Seyfert One and Seyfert Two.

Early on when I was in graduate school people made a big deal about how these were two different systems and one had only narrow emission lines, bright thin spikes in their rainbow where one particular color was given off more than any other. Seyfert Ones had these bright narrow spikes but they also had bright broad spikes. You get narrow lines when something isn't moving that fast. You get broad lines when something is moving extremely fast.

The Seyfert Twos didn't have these broad lines. They only had the narrow lines. People made a big deal about how these were different systems with different physics. But then slowly a picture began to emerge where we realized that the broad lines, this was when we were looking at material that was close in to the super-massive Black Hole, material that was moving extremely rapidly and the stuff on the left edge would be moving rapidly toward us and the stuff on the right edge would be moving rapidly away from us.

We would see this line, this particular color of light get both red-shifted and blue-shifted depending on where it was in the center of the Galaxy. Whereas the narrow lines came from looking at material that wasn't moving quickly, material that was further out. So you only got both broad and narrow lines when you could see all the way down into the center.

Fraser: So, you've gone over this a few times but if you can imagine a Galaxy with a super-massive Black Hole at the center and the super-massive Black Hole is rapidly spinning, it has magnetic fields around it that are interacting with all of the gas and dust that it is feeding on. Then around that there is like a ring or a donut of dust that obscures the Galaxy, right?

So if we see it, and I know that the angle can really matter on what we think we're looking at right? If we see right down into the Black Hole then we don't see that obscuring donut of gas and dust around it. It's like we're seeing it almost directly, right?

Pamela: The model that gets used a lot is actually one of these foldout Christmas or party decorations you can get. They're fan-shaped with a pivot point in the center. We'll put a link to one of these things on our website so you can buy one at the local party store if you want.

When you fan them out, they have a very narrow center and then they get wider out towards the middle, as in middle of the distance from the center to the edge. Then they get thinner out towards the edge.

So, you have this three-dimensional disk. The center of the disk is basically a few millimeters thick. Out halfway from the center to the edge it is many millimeters thick. Then it gets thinner again.

If you hold this thing you can tilt it such that the thick part that is near you blocks you from being able to see the very center, the thinnest point of the disk. You can still see some of the stuff back beyond it.

It's this three-dimensional shape that is thinnest in the center and then gets wider as you move away from the center that we think represents the Taurus of the center of one of these Galaxies.

So, you have the gas and dust of the main part of the Galaxy that obscures your ability to see in toward the center. The Accretion disc itself has structure so you're basically looking at this disk of random distribution of matter in it. It's a disk. It has spiral arms and it all depends on how things are lined up what part of the core you're able to see.

Fraser: But we can look right down the throat of it and see the Black Hole pouring out the radiation or we can see it from the side where this disk is completely obscuring the Black Hole.

Pamela: It's the angles in-between that make life interesting.

Fraser: Right, but isn't that where the classifications come from, whether it's a Seyfert Galaxy or a Quasar or I know they have some other names as well.

Pamela: Well, Seyfert One and Seyfert Two seem to come from what angle you look at it. Quasar is something that is feeding at an enormous rate. Quasars are sort of taking any of the other active Galaxies, turn up the mass consumption level, and you can turn them into a Quasar.

Turn down the mass consumption level and you start to get things like the Seyfert Ones and Seyfert Twos, which are generally spiral Galaxies or irregular Galaxies. You also end up with just plain active Galaxies like M87. It's an elliptical with jets. It's a radio Galaxy.

We try to make the definitions we use based on physics. The physics that we're looking at for things like this are if you call something a Blazar. That is something that you're looking straight down the throat of the jet. You're looking straight in at the Black Hole. If you call something a Seyfert One or a Seyfert Two, you're talking typically about a spiral or an irregular Galaxy that you're able to see varying amounts of the center and that changes the definition of what you're looking at.

The energy matters, whether it has radio emissions or not does matter. We have dozens of words that we use to describe these things and put them into little tiny, tiny bins.

The important part is Quasars have lots of luminosity, active galactic nuclei that includes the Quasars but most of the time you are talking about things that are a little less violent.

Fraser: The measurement is just how much material is being consumed today.

Pamela: Yeah.

Fraser: And if you could look back in the past things might be Quasars a million years ago but not be Quasars today. Or, things might become Quasars in the future. It just depends on when things happen to fall into the center of the Galaxy. And it often happens after you have these collisions.

Pamela: This is what keeps the Universe interesting. It hasn't always looked the same. So as we look at more distant objects, we see more Quasars. As we look around today we still see the radio Galaxies.

They're close enough that we can start to get a detailed view of the basics of what's going on. They're not quite as violent today as they used to be. The Universe is a bit more peaceful today.

Fraser: Now if our super-massive Black Hole at the heart of the Milky Way went into an active feeding phase what would we see?

Pamela: Well the Sagittarius Constellation would sure light up a lot. We'd see it as a combination of different things. There would first of all be a whole lot more optical luminosity.

We'd also see what is called synchrotron emission, which is a type of radio light that comes from accelerating electrons. We would see x-rays and gamma rays from all the material being heated up in the Accretion disc.

All of these different things would also light up the dust and gas in the center of the Milky Way making it pretty much impossible to see through to the other side as everything was lit up more and more.

We'd be safe. Luckily we're in the disk of the Galaxy so any jets that happen to have formed would be pointed in other directions. It would certainly be an amazing light show.

Fraser: Right. I know that we get little hints of it every now and then when something even fairly small like asteroid-sized chunks of material drop into the super-massive Black Hole let off so much energy.

Pamela: Yeah, there's definite x-ray flickering that we see and occasionally you'll see reports of planet-sized objects falls into center of Milky Way….

Fraser: Yeah, it's almost like they're tracking them now. They can report that something this big fell in on Thursday [Laughter] and they will see reflections. They can even know when larger things happened hundreds of years ago because as we talked earlier, you get these reflections coming off of the gas around the super-massive Black Hole.

So, you'll see almost like light beams moving through this material and you think oh yeah, that was like 200 years ago when that burst happened. It's quite amazing.

Pamela: We can keep track of the destruction of things in this way and watch the flickering. It is really amazing how much we can learn about the center of our Galaxy today by looking at the material around it and by looking at how materials orbit around it.

There are some amazing videos out there online. A lot of them are by a woman named Andrea Dupree who has been tracking the motions of stars in the inner part of the Milky Way for well over a dozen years now.

She can see these objects in their quick turn around motions around a central object that has to be exceedingly small to explain the closeness that the stars are able to get to it.

We know there's a super-massive Black Hole there. There's no longer any observational doubt. Nothing else could fit into so small of a space. We watch the x-ray flickering.

Our first hint that our Galaxy had a super-massive Black Hole was this anomalous x-ray object that we call the Sagittarius A*. We now know that it's coincident with the object that Andrea is able to see in her observations.

Fraser: And so we're absolutely safe from our super-massive Black Hole? Even if it turns into a Quasar?

Pamela: Well, I don't see it turning into a Quasar. We don't exactly have that much gas and dust hanging out. We should be safe.

Fraser: All right, good. I think next week we're going to take a look at another Galaxy our own home Galaxy – the Milky Way.

This transcript is not an exact match to the audio file. It has been edited for clarity.
Transcription and editing by Cindy Leonard.