DJORGOVSKI: So first, let's review some of the basic definitions and observations of what active galactic nuclei are. This is a picture from Hubble Space Telescope. The bright star-like object is a quasar. And you can see there is some mass going around and that's because it's fueled by the galaxy collisions, which turns out to be a very common thing.

So just as a definition, they are very energetic phenomena in the nuclei of galaxies. And we're now pretty sure that they're powered by an accretion to super massive black holes that form there in the same way that we release energy from material falling onto the stellar mass black holes. But here they're a much larger scale. And their existence has been gradually realized through 20th century. But really only begun 1960s.

And different classification schemes have been adopted just like for galaxies. Hubble first came with morphological classification. So active nuclei have been classified according to their appearance of mostly spectra. But, more recently, people began to realize it's really just one underlying phenomenon with several different flavors. And we look at them from different angles and that's what can account for many of the observed differences between them.

One important thing is that they evolve strongly in time. There are many more in the past than there are here now. And that is because their evolution tends to track that of galaxy evolution. And there is actually real connection there.

So if you look carefully at galaxies in the nearby universe, you find that at least 1/3 show some sort of activity in the nucleus. And only 1% really are traditionally classified as active galaxies. But if you really go deep down, we think that every galaxy at some point has had some sort of quasar like activity. And this is where these black holes come from.

Now quasars are the most luminous of them. And in this neck of the woods maybe one galaxy in a million has a quasar. But they were 1,000 times more numerous when merging galaxies was at its peak.

So this is sort of artist's conception of what the structure of an active galactic nucleus, or AGN, as we call it, looks like. In the middle there is a small black hole colored appropriately. And its surrounded by an accretion disc which is where energy comes, from release of the binding energy of stuff that falls in. This is where most of the emission comes from. There are a lot of gas clouds flying around. We'll talk about that in a sec.

But then the whole thing is surrounded by a torus or maybe warped disc of dusty material which can hide what's happening in the middle if you're looking from the side. That's part of the whole unification scheme. And then some of them, not all, have jets emanating from the middle. They're octagonal from the accretion disc. And they come from magnetic field that's threaded through the disc or through the black hole itself, and accelerate particles to relativistic speeds. So this simple picture can pretty much account for just about everything that we observe.

And what we observe are several different things. First, which is very interesting, that unlike stars they make energy over a very broad range of energies. From radio to gamma rays. And therefore, if you say, pick middle, somewhere in the visible, they're be having ultraviolet, and x-ray excess. They also have radio access. But it's just because they're colors and energy distributions is very different from that of starts.

They have strong emission lines because there is a lot of ionizing radiation present that ionizes the gas that powers the line emission. They can be very luminous. Up to 1,000 times or 10,000 times the luminosities of galaxies. And all that luminosity comes from tiny region that's smaller than solar system. Way smaller, like within radius of Earth's orbit, roughly speaking, which is what made them so interesting.

They are also variable on all different scales because accretion varies and so on. And that right away tells you that in the region is very small. See the time it takes light to come from sun to Earth, or 1 astronomical unit, is a little over 8 minutes. And so quasars have been seen to vary on scales of hours if not minutes. Because their central energy is so small on distances of many megaparsecs or gigaparsecs.

They're completely unresolved. Their point sources just like starts. And that's where the name came from, the quasi stellar radio sources. Not all of them are radio but that's what it meant. And because they're far away we can't see them move in the sky. We can observe proper motions of stars in our galaxy, at least near us, gradually over years. But these are so far away that the tangential motions are completely undetectable.

So each of these properties have been turned around to be used as a method to find them in comparison to other things, like stars. And so here is the schematic outline of what a very broad range of spectral distributions might look like. These are logs access in frequency and in energy per unit logarithmic interval. And it looks pretty flat.

Now stars are more or less black body spectra. And in a black body curve, you come to the half power with maybe a factor of 2 in frequency. Not many orders of magnitude. So a black body of any temperature would be like the very peak little curve up here. And this is what their optical spectra look like. Well, optical and ultraviolet.

There is a very blue continuum. On top of that there are very strong emission lines. Many of them are very broad suggesting motions of thousands of kilometers per second in the rest frame of the object itself.

Some are narrow, a few hundred kilometers per second. And then in far ultraviolet it cuts off. And that's because hydrogen absorbs, very effectively, everything that's blue or in the Lyman continuum limit of 912 angstroms. In many cases also Lyman alpha line 1,216 axis.

And when you ask how many are there in the sky? Well, you count them. We count them as a function of magnitude just like we did galaxy counts. And a good reasonable number to remember is down to some sensible flux limits, like 20 some magnitudes. There are approximately 100 of them per square degree. And there are 40,000 square degrees on the sky. So that tells you that roughly there is about some 10s of millions over the entire sky down to the detectable limits that we have with our technologies today.

Only about 1 or 2 million have been actually cataloged. But we think we could find the others if we wanted to. And there are many more galaxies. So roughly speaking, there's 1 quasar for every 1,000 galaxies. Which is integrated over the entire sky.

So what about classification? The first active nuclei were actually seen in the optical. But nobody really understood it as this is something special going on. And they really attracted attention with the advent of radio astronomy. Where some mysterious cosmic radio sources turned out to be these objects.

And so then, naturally, people divided them in radio quiet and radio loud. If they're radio quiet, it doesn't mean they're radio silent. It could be just a very low power radio. And there's probably a continuum.

And in the optical spectrum, some of them only have narrow emission lines. You don't see those broad Doppler widened lines. And so those that have broad lines called Seyfert 1s or type 1 AGM. And those with only narrow lines are type 2. We now know that that's different just in that for type 2s, the region from which broad lines, the region is obscured by dust from our line of sight.

There is a sequence of luminosities from almost nothing through thousands of times more that the entire galaxy. The really luminous ones are called quasars. Less luminous are called Seyfert. Dwarf Seyfert and so on. There are some special sub types. In particular, remember, there are sometimes radio jets moving out at relativistic speeds.

Well if you happen to be looking right down the jet, then you're going to see some other phenomena as well. And including strong variability. And those are called blazars or BL Lac's. They're named after prototype star called BL Lacertae

And in the olden days, stars were given first Greek names, alpha, beta, gamma and so on. When they ran out of Greek alphabet, they started giving them Roman alphabet names. And double letters were for variables stars. They kind of gave up after that. But now we know stars by the coordinates.

And so, something that is like A, B, and then constellation name will be a variable star in that constellation. So BL Lacertae was a variable star in the constellation of Lacertae. It turned out not to be a star at all. It turned out to be one of these objects. So quasars were actually seen 1920s and nobody recognized them as an interesting phenomenon back then. So some of them are also called optically violently variable. So all these things can kind of go on in parallel.

Now type Seyfert galaxies are prototype. Those are active nuclei in mostly spiral galaxies. Seyfert 1s have spectra just like quasars, these broad lines. Usually broad lines are those of permitted transitions or very abundant elements like hydrogen. And broad lines are very common.

Narrow lines can be from those semi-forbidden or forbidden lines. Which you may recall are called that way because they could not be reproduced in the lab. But they can be easily reproduced in a near vacuum of interstellar space. So, for example, doubly ionized oxygen, denoted as O and Roman three is a very common line in planetary nebulae and star forming regions as well. But here it's ionized by something other than young stars.

And Seyfert 2s, usually stellar spectra of the galaxy. And then just some of those narrow lines. Now we can tell the difference between those that are ionized by one of these accreting black holes and those that are ionized by star formation from the ratios of lines. Some of these lines require so much photon energy to excite that they're simply not produced by stars. You need something other than stars to produce the hard ultraviolet radiation needed for them. And accretion to black holes provides that.

In radio, if you were to superpose radio image onto optical image of a galaxy, you see things like that. A very common phenomenon is double lobe radio sources, a center in the galaxy. There's something in the middle of the galaxy that pumps those out.

And those were first seen in 1950s with the first radio astronomical observations. Very quickly people realized that the amount of energy stored in these radio lobes is of the order of 10 to the 60 ergs and even more. Which is an enormous amount of energy.

And the question is, where did it come from? So now we think, well, that energy came from an active nucleus. From energy of the accretion. Some of which is a [INAUDIBLE] radiation. Some of which is pushed in mechanical energy of accelerating particles and pumping them out. So there is optical as well as mechanical luminosity.

This is a modern map of one of the prototypical radio sources, Cygnus A. First radio sources were given name of the constellation and then A, B, C, depending on the brightness. Very quickly they ran out of letters there. So we don't do that anymore.

And in this case, there's a bright radio nucleus. There's obviously a jet shooting out of both sides. It's brighter on one side because that side is kind of more pointing towards you.

So the speed of the particle boosts the radiation your way as opposed to the other side. And they encounter gas in the intercluster medium. And then the whole thing kind of cause turbulent or hot spots where jets are hitting it. But you can see there's a lot of structure that goes on.

So I mentioned if you happen to be looking right down the jet, then you see what we call blazar. You see a very strong continuum that is boosted by top by relativistic motions of particles in the jet moving towards you. And when the continuum goes down, then you can see all the rest of the emission lines and what have you. So that is the observed variety of properties. And now soon we'll see how we actually explained.