S. GEORGE DJORGOVSKI: So let's now take a look at how does this phenomenon appear at high energies, X-rays and gamma rays? And what's shown here is X-ray picture of the Moon from ROSAT satellite. And you can actually see that there is Moon's little line, this is reflecting solar X-rays. Actually see the terminator. Ironically, the first X-ray observations in astronomy were done trying to detect the Moon, and they didn't. But much later, with satellite, they took this picture.

So the beginning of X-ray astronomy was one rocket flight in 1962, lead by Ricardo Giacconi. Here he is. And he got the Nobel prize for this 40 years later. And in this one rocket flight, they discovered first cosmic X-ray sources, other than the Sun, and also uniform background of X-rays coming from everywhere, which is now called the cosmic X-ray background.

And it turns out that that cosmic X-ray background has 50% energy of the integrated starlight over the universe. And that's a few percent of the cosmic microwave background. But this was discovered at the same time, or actually a little before, the cosmic microwave background.

And as soon as we understood there are such things as quasars and so on, it was thought that this background must be due to integrated emission of many, many, many active nuclei over the entire universe. And that's, in fact, the case. But there was an issue with the spectrum. In gamma rays, this is definitely the case.

So now if I expand picture of what's the spectrum of the universe over 13 or so orders of magnitude in frequency or wavelength, well, you have a very narrow Planck function in the radio or microwaves. That's the cosmic microwave background from cosmology. And then you have actually two bumps, in optical and far infrared, which is the starlight. And then at high energies, you get, again, almost flat, but not really completely flat, cosmic X-ray background and gamma ray background.

So that bump was what was puzzling people for a long time. This does not look like a spectrum of an active galactic nucleus. This is measurements from many different satellites combined. Instead of that, it actually looks like X-ray spectrum of hot gas. The brems travel in the radiation, just like the hot gas in clusters of galaxies.

But we knew that the universe is not filled uniformly with hot X-ray gas, because we have isolated sources. And so the answer was, in the end, that this is a combination of X-ray emission received directly from active nuclei, just as I was telling you earlier, and also reflected X-rays. Because, remember, there is that dusty torus. And so X-rays do go through a lot of stuff. But some fraction of them can be reflected off of dust particles. And that has its own spectrum. So if you have a proper combination of things, you can add up something over a whole different metrics to something that looks like this.

So now we think that, in fact, all of the X-ray background is due to a combination of mostly active nuclei, with some star formation thrown in. And the way we know this is people looked at very deep fields. So just like optical astronomers had some deep fields, like Hubble Deep Field, and Ultra Deep Field, and super-duper deep field, whatever. And then added a lot of integration together to see as deep as possible, X-ray astronomers do the same thing. And they did it, again, in the same fields. So that there is an optical counterpart for every X-ray source that is found.

And they do have a variety of properties. Some are near enough that you can see a host galaxy. So it looks star-like. Those are quasars, far away.

And when you add them all up and extrapolate a little bit to what you cannot see as individual sources, that can pretty much account for both soft and hard X-ray background, at least like 90% of it. And it's easy to assume that the rest of it is due to the sources that are too faint for us to the detect. So the origin of the X-ray background seems to be reasonably well understood today.

So even though that's only just a few percent of starlight, the reason it's as much as a few percent of starlight is that accretion to black holes is so much more efficient that thermonuclear reactions. Thermonuclear reactions convert much less than a percent of rest mass energy, as mass, into the energy. With black holes you can do

10%. And so there are many fewer of resources, but they're much more efficient in producing energy. And the gamma ray sources are believed to be almost all beamed active nuclei, blazars. We're looking down a jet.

This is a picture of the gramma ray sky from Fermi satellite. There's over five years. In the galactic plane, you have all matter of other stuff, supernova remnants and whatnot. At high latitudes, there are some pulsars and mostly some of these beamed active nuclei, looking at us.

This is not 100% clear by now. But it's pretty close. And so this is a reasonable thing to assume. So you have these cosmic accelerators pointing at us, sending us high energy photons, also probably high energy cosmic rays.

And so when you put it all together, this is what spectrum of the universe looks like. And each part has different contributions. In radio, it's mostly AGN from synchotron emission. There is some star formation at the regions. Then microwaves, it's cosmic nucleosynthesis in the early universe. And then from submillimeter to ultraviolet, it's mostly stars. And then accretion in black holes accounts for pretty much all the rest, at very high energies.