DJORGOVSKI: OK. Let's switch now to wavelengths. And this is the beginning of radio astronomy. This fellow, his name is Karl Jansky. And the strange contraption there is the first radio telescope, which he built in cornfield somewhere in Illinois or someplace like that.

He did this just before War II. He detected radio waves from the Milky Way galaxy, as well as sun. And is widely regarded as a father of radio astronomy. The Very Large Array telescope in New Mexico has now been named in his honor, a Jansky Very Large Array.

Now simplest radio telescopes are big dish antennae, like a satellite dish. And, again, you want a big dish because it have a large collecting area, bounces radio waves into the receiver, which is in the focal point. The two biggest ones that are worth thinking about are Arecibo, which is a dish that's inside a crater in Puerto Rico, so it doesn't move. So you move the receiver so it kind of captures things as it makes transit. And there is the Green Bank Telescope, which does move. And it's currently the largest, operational, movable radio dish.

But even the biggest radio telescopes-- it's kind of hard to make them much bigger-- and a few hundred meters that can't move. And let's think what is the angular resolution. Let's say you are looking at a wavelength of 21 centimeters, which is good transition of neutral hydrogen.

And let's say you have time on a 100-meter radio telescope. What is the angular resolution that you're getting? That's 0.2 divided by 100. It's 2 times 10 and minus 3. 2 times 10 to the minus 3 radians is more like 400 arc seconds. So it's like several arc minutes. That's a pretty lousy angular resolution.

So this is why single-dish telescopes-- this is how radio astronomy may have started, but they're only used when you really want to collect lots of signal. They are not good for making pictures. To make radio images, we use interferometers. And has a VLA on the top, which is probably one of the most productive ones ever.

There is also our very own interferometer-- well, this is obsolete picture. It's now CARMA. Used to be OVRO, Owens Valley Radio Observatory. And there you have multiple individual radio telescopes. And their signals are combined in a way that I'll explain in a second to give you higher resolution.

The latest and the bestest of this sort is so-called ALMA Interferometer, for Atacama Large Millimeter Array . And that tells you that it's in Atacama Desert in Chile. And it's pretty large, and it operates on millimeter wavelengths. It's an international project that involves US, Europe, Japan -- I don't know who else as a large number of antennae with really top-notch receivers and so on.

And any individual radio telescope would work, just like your satellite dish if you have one. And it will collect radio waves. Bounce them to focal point. There is a receiver, those tend to be very high quality things these days. Signal is amplified. Somehow it's recorded. When Jocelyn Bell discovered pulsars, that recording was done on a chart recorder with ink. Nowadays it's all done very much digitally and much more precisely.

So this is how we can measure brightness intensity in radio waves in the sky. But again, not with a very good angular resolution. However, if you can connect your individual dishes in a coherent fashion and you can find things exactly, then you can achieve the angular resolution that corresponds to the largest separation you can have. And those are called baselines.

So if you can spread your radio antennae over tens of kilometers, this is as if you had a radio telescope of that size. You're still limited by same collecting area, sum of all individual antennae, but the angular resolution that can be achieved corresponds to the biggest baselines. Now you can move them around or let planet Earth turn your radio telescope around slowly so you can sample different baselines. Some processing is done, and pictures reconstructed.

The ultimate end of this game is using the whole planet Earth as your radio telescope. And that's called a very large baseline interferometry, where they have antennae spaced by thousands and thousands of kilometers. And this is the most precise angular measurements we can do today -- so much so that people are actually talking about resolving a black hole in the galactic center.

Now interferometry is now being carried to shorter wavelengths, like optical. That is an extremely, technically-demanding thing, because you have to control the separation of individual detectors by a small fraction of the wavelength. And so if your effectors are, say-- telescopes are 100 meters apart, and you don't want to move, you have to know their separation within-- oh, let's say-- 50 nanometers.

This is very serious meteorology, because Earth shakes, people passing by, trucks, there are earthquakes and so on. Actually, with Keck Interferometer in Hawaii on the top of Mauna Kea, just 4.2 kilometer-high mountain, one of the biggest sources of noise was surf from the beach. Just teeny, tiny seismic waves from water waves hitting the shore. So you really have to do extremely precise arrangement.

The ultimate end of this is so-called Square Kilometre Array, which does not exist yet. It's been planned. It will actually exist in two pieces, one in South Africa and one in Australia. Those are among the most radio-quiet regions on the planet Earth. And it will be a whole lot of mass-produced, individual dishes of different sizes, and so on, plus fields of dipoles, and so on, that can be combined in some way.

And the square kilometer pertains not to the area over which they are spread, but by the total collecting area of all of the antennae. And they'll be spread over tens or hundreds of kilometers in each one of those sites. And the sites will be a few thousand kilometers apart.

So this is a project that everybody's looking forward to. The construction hasn't started yet. Actually, it hasn't been fully funded. But it's moving along. And sometime in 2020s, this will probably be the single most powerful astronomical instrument ever.