**DJORGOVSKI:** And now let's talk about dark energy. It's probably the single most outstanding mystery of physical science, because we have no idea what's it's from. The basic observation, really, is micro background fluctuations, which tells us that the universe is flat to an amazing precision. And in order for it to be flat with observed dynamical amount of mass that we see, there has to be an exact complement of unity that matches.

Today we're in the regime where it accelerates the expansion of the universe. You can think of this as an elastic force. The elasticity of physical vacuum. So the spring-- the force is bigger the more you compress it or stretch it. So think of it as a negative spring. The more you stretch it, the more it pushes.

And it can affect growth of the density perturbations but it's unlike the gravity that you know and love, that's inversely proportional to the distance squared. This one is actually proportional to the distance. The further away you look, the bigger effects you see. And this is why it's only really perceptible on cosmological observations.

I've been carelessly mixing cosmological constant and dark energy. And dark energy is a more general term. Whatever is is, that's filling up the universe, but it need not be constant. Cosmological constant is exactly what the name says. It's the constant uniform energy density or mass density that's distributed through space. Since space expands, this is yet another example how energy is not conserved in relativistic universes. Because you get more space, but energy density stays the same.

Now the first attempt to understand this was due to Soviet physicist Yakov Zeldovich. Now in Einstein's day, vacuum was vacuum. But then quantum physics taught us that, actually no, vacuum is filled with virtual particle, anti-particle pairs that appear and disappear, obeying Heisenberg's uncertainty principle. And while they exist for a very short period of time, they can count as an energy density.

And so in principle, you could create energy density of a vacuum from this. But we don't know how to do this. Because we need the quantum theory of gravity in order to make this computation properly.

This is now being used also in inflation. That's exactly the same with the inflation tells you. Vacuum goes from a high energy state to a lower energy state. But, anyway. So we don't have a theory but people try yet. And so they tried and made the worst prediction ever.

Since the only natural units they could think of for this would be Planck units, they get essentially Planck's density prediction, which is a few times 10 to the 92 grams per cubic centimeter. And that's 123 orders of magnitude off from what's measured. And now that's called a fine-tuning problem. Because you have to somehow get rid of this bulk of potential vacuum energy to 1 part in 10 to the 123. But this could be just a completely wrong reasoning.

So since obviously the universe wasn't Planck times old, it didn't have this density, then the only natural value is zero, right? So whenever you're doing a problem set and you just can't figure out the answer, zero is always the best answer because then you don't have to worry about units.

Not a very reliable way to go about the fate of the universe. And so people ignored this for a while until observations show that it's there.

So now, we're pretty sure it's there from variety of different lines of evidence and the question is, what it is? And there are multiple papers written on this every day, literally. There are many thousands of papers being written about the possible nature of dark energy. And I think everybody agrees that we really don't know. Not yet. I mean, some models look more interesting that others, but so far this is the biggest uncertainty.

And all kinds of crazy stuff has been proposed, including the so-called multiverse with a landscape that there are 10 to the power of 500 different universes, each one of them has different values of constants including this one, and so on.

It's very hard to say much more about it since we only measure one number. That's what is density today, and forever actually. And the only other possibility that we may have is that if the density was actually changing in time. If it wasn't constant. And so that is done by expressing it through the equations of state , which you may remember is the parameter of w which connects pressure with density. And the generic equation of state is written there.

So if w is equal to minus 1, then rho is constant. And one thing that some people worry about is that it seems weird that we just happen to live in the time where matter and dark energy are about comparable. I personally don't see this as a problem because it's been this way for the past 10 billion years or so, but some people worry about it.

So the version of dark energy that changes in time is called quintessence. And again, nobody has any idea what it could be. But different models make different predictions in terms of how it changes in time. So then the path towards understanding what's going on here is to measure if the energy density is changing in time. And so far, all of the measurements from all different kinds of observations, zero in on w minus 1.

Everything so far, is consistent with it being constant. Since the recombination until the present day. So I would say that the chances are pretty good that it really is constant. Or constant with such a high precision that it really doesn't matter. And so it remains an outstanding problem for physics.