DJORGOVSKI: Let's talk about supernova standard candles and how do we use them in Hubble diagram? Supernovae bright, this is really what makes them useful for cosmological measurements. And you recall there are two types, 1a, which are detonating white dwarfs, and type 2, which are thermonuclear bombs, so massive stars.

It turns out that those type 1a can used with standard candles. By themselves, the peak brightness of 1a's has a substantial scatter. But it turns out that scatter correlates with the width of the light curve, how long it takes the supernova to get brighter and dimmer. And when you correct for that effect, you get superb, almost constant standard candle to better than 10 percent. And it looks like this.

So the light curves on top is a whole bunch of independently measured ones. And then you can see that there is a spread, both in width and in the amplitude. So you correct for the spread in the amplitude by using function of the width. And suddenly they all collapse onto one standard candlelight curve. Since the width is something that does not depend on cosmology-- it follow the light curve-- you can measure that. You can correctly observe light curve and compare it to what you got here.

So this was actually very transformative measurement. First it was done to figure out what Hubble constant was. But then it was carried out into far field cosmology. And this is what it looks like.

The top diagram shows you, if you just plot peak brightness of a type 1, a supernova, versus redshift the other way, there is considerable scatter. You make a correction, and the scatter goes down to measurement course. Beautiful.

So for nearby supernovae, relatively nearby, you get Hubble diagram. This is now log redshift, or log velocity, versus log of flux. And it's almost perfect straight line. So locally, you can use this to measure the expansion rate, the slope of this line. Then, as you go to higher redshifts, meaning larger look-back times, cosmic geometry effects come in and possibly volitionary effects.

So two groups in 1998, the Supernova Cosmology Project and High Redshift Supernova Team did this. They used nearby sample supernovae to anchor their Hubble diagram. Then they looked at the very distant ones. And the idea here is that up priory, this spot would be standard candle because it depends on fundamental physics of stellar evolution to intersect our mass. And that's what makes them standardized.

You push towards intersect or limit, thing explodes. And that's been tested, actually is a good assumption. And so they got really high-precision Hubble diagrams. And they both found the same thing, that the best fit models for supernovae Hubble Diagram candles imply the existence of cosmological constant.

They tried every kind of correction, anything you can think of to get rid of this. And they just couldn't find it. All the selection effects going the other way.

Remember, all models of cosmological constant make things look dimmer. So it's not like you're losing them. If they found the opposite effect, they only see the bright ones, then you worry about selection effect. But this is in the opposite direction.

So this result has stood test of time. Many groups have done this now with many, many more objects. And everybody gets the same result. So that's very encouraging.

So the leaders of the two groups, Riess and Schmidt on one side and Perlmutter on the other, shared Nobel prize for physics. And well-deserved I should say. There is a lot of interesting background stories to this, which I will not tell you. But it was really a milestone that finally physicists understood that there is such a thing as cosmology constant. And this is today one of the major outstanding mysteries of physics.

So this is what happens when you plot these things on the normal RFT diagram, inverting Hubble diagram back. And so all of the observed data points are now in the past. They're telling you on what curve we sit and extrapolate to the future. And essentially it says, the universe is open and will expand forever. Well, it's flat, but it will expand forever.

And this is fairly recent version, just couple years old. You can see now there are many, many, many more data points have been added. And the results been holding up. And now we see supernovae with Hubble space telescope all the way to about redshift 1 and 1/2. And everything works beautifully.