DJOROVSKI: So, that sets the scale of the universe, how big it is and how old is. But now the question is, which of those cosmological model curves it follows. And that requires us to measure other cosmological parameters. And there's two basic paths to this--called standard candles and standard rulers.

Just to refresh your memory, the idea here is you want to find out on which of these different r of t curves do we live. And since you cannot see in the future, all we can do is look along our past light cone and measure redshift gets you the scale factor stretch.

And then, somehow you need to figure out the distance to things that you're looking at. And that determines which model we have been writing so far.

It's a fairly well-established approach and different ways in which we can do this. Again, to remind you, all these tests consist of inverting the expansion diagram, r of t, into well, r of t becomes redshift. And t becomes actually, the distance to something, look-back time, which is fine.

And so in this case, beginning is the big bang, but once you go in the redshift test, well, big bang is a redshift of infinity. And today is a redshift of 0. And less than 0 is the future, right?

Generic behavior that you expect to find is that in the models where there is more deceleration that slows down the expansion, more gravity, higher density, and/or negative cosmological constant, those models will be smaller at any given time. And therefore, things would look brighter, they would look bigger, but the volumes would be smaller.

And the opposite of that is for low-density models, or models in which cosmological constant accelerates the expansion. Objects in those will be further away, they will look smaller, they will look dimmer, but there will be more of them, because larger volume.

Now, it turns out that we actually don't measure absolute distances to anything, even as S-Z clusters, there is some model dependence. But that's OK. Because the scale of the whole thing is outsourced to measurement of the Hubble Constant.

All we need to do is consistent measurements with relative distances to sum set of objects. And since it's all log-log plot, you can shift them. So that's fine. And so, all we need to do is measure relative distances.

And the way we do this is either using relativistic equivalent of inverse square law, for sources of standard brightness, standard candles, or of angular diameter versus linear distance.

Hubble diagram, as you recall, is now not just measure of expansion rate. But once you know the slope, the curvature of Hubble diagram, [? high ?] redshifts will start telling you about geometry of the universes of large scales. And so that requires sources that you think do not change the brightness. Rather, in some instances, are always the same brightness.

And angular diameter test requires you to know absolute size of something on the sky. Source counts are possible because that measures the volume, but we need to have some tracer population that you can see and observe. And you have to be assured that they're actually not changing by number density, and there is no such think.

Now you could, in principal, also measure ages of galaxies by fitting their stellar populations. But there are so many parameters in it, that's not very practical. Now, completely independent of these distance measurements, you can measure density locally, just from dynamics, large-scale structure dynamics. Where cosmological effects are not so important, but overall mean density tells you how much mass is there.

And that can tell you what the matter density is. If you can then measure Hubble Constant age independently, you can constrain combinations of the others. So all of that has been tried. Things to be aware here is that, there is always a selection affect. You're always using some population of tracers-- like galaxies, or supernovae, or clusters, or something-- and there is always limit to your measurements in flux or in angular resolution.

You're always going to be missing a faintest end of the population. And you don't know what you're missing. And so, what you observe is a biased set of [? high ?] redshifts, and so you have to do something to figure out what it must be.

Otherwise, you'll be fitting the wrong model. Because you're only fitting to those sources that you can see, that you can affect.

And this is the generic behavior now you expect for Hubble diagram, as I already mentioned. So there are different things have been tried. Originally, people tried to use brightest cluster galaxies. Well, since galaxies are made of stars, and they merge, galaxies are not standard candles. They evolve in time. So that doomed that approach.

Uncounted nights of Palomar 200 inch time have been spent trying to do this. In fact, people said, well, they built 200 inch to measure q_0, expansion parameter, because they already knew Hubble Constant to 10%. Neither of which was case.

It turns out that now, supernovae of type 1A can be used. And maybe even gamma ray bursts. But before we get into that, let's find out if the universe is actually expanding. Think it's a stupid question, but shh.

It's a legit question. We think the universe is expanding and that's what causes Hubble diagram to appear. But you could have model in which there's one called tired light model, in which photons somehow lose energy. The universe is stationary, but the further away protons travel, the less energy they get. It's going to look exactly the same.

So how can you tell? And there are two typical tests. One is about surface brightness-- Circle Tolman Test-- and the other one is about time dilation-- supernova light years.

The way Tolman test works is that surface brightness, which is flux per unit solid angle-- it's the same thing as luminosity per area. Does not depend on distance in Euclidean space. Right?

But you see there is a ratio square angular diameter distance and luminosity distance-- since they depend on redshift in a different way when you do this, you find out that relative to the Euclidean case, surfers brightness in an expanding, relativistic universe goes down as 1 plus redshift to the 4th power. And it's a unique prediction, right?

So how can you find something has a standard surface brightness? Well this is where our scaling relations come in. And you can express them as surface brightness versus something else. And you look at two clusters and see how much shift there is. And that tells you how much decrement the was due to the expansion.

So it was done for elliptical galaxies in clusters, there was the result. It's amazingly good fit. So we think the universe does expand.

The other test is using supernovae clocks that make one tick. And here, what's shown on the top is a whole bunch of supernova light curves centered on peak brightness. And one case is all of them, the other is [? been ?] the magnitude.

And then, if you don't apply any corrections, you see there's a low spread. Now, if you correct each one of those to be stretched by 1 plus redshift factor, because clocks tick slower there, suddenly they line up beautifully. So this can be done in the opposite sense. And that, too, provides a clear demonstration that yes, the universe is expanding.