S. GEORGE DJORGOVSKI: So let's now see how's clustering evolving the universe. And that introduces interesting phenomenon called galaxy biasing, which I hinted already. And what's meant by this is exactly what we imply, that you can observe structures in light, some differential density amount, excess of a deficiency divided by the mean. So the relative variations in density of light are somehow related to the relative variations and density of mass.

And the simplest thing to say is there is just direct proportionality, and if constant is equal to 1, then they're fair tracer. So that little constant, b, is called a bias factor. And it turns out that in fact b squared is the number that connects the observed two-point correlation function with the light with the underlying mass. So because b could be different, like if galaxies are clumped more strongly than the mass, b would be greater than 1. That's what proportionality is.

And say b is 2 or 3 or 5, then galaxies will not be a fair tracer of mass. There will be a biased tracer of mass. They would be favoring the densest spots. And so that was the basic idea. And it turns out that some of that is actually happening. And the simple model for this is, let's assume that in the very distant universe, when you start forming galaxies, you require them to be above certain density threshold for stuff to fall together and ignite a star formation.

Now, remember density field can be interpreted as a superposition of waves of different wavelengths and amplitudes. So you have small waves riding on top of large waves. Now if you impose a threshold, then you are naturally going to select first the small peaks that are riding on top of big waves. And so, in this picture, first galaxies will form in first clusters, and then star formation will spread out.

An equivalent of that, will be say, if you look at the snow line on planet earth, you will see that it's only the peaks of the highest mountains that are covered. Or even if you're just to say let's ask, where is the earth's surface as a function of elevation? Well, first you see just whole bunch of correlated spots in the Andes, and Rocky mountains, and Himalayas, and as you lower down the threshold eventually, all of the surface of the earth is encompassed.

So in galaxy formation, the idea is that you start with the densest spots, and then eventually spread further out as you have more time. And this is an illustration of this from a numerical simulation, one of those simulations of structured formation, showing both what gas and stars do, and what the dark matter does. And people who did simulation know exactly where the particles are, and then they ask, what are the 1 sigma deviations from the mean and cut? What are 2 sigma? 3 sigma? And then they run out of volume.

And you can see the higher threshold of contrast you demand, the more clustered will those spots be. So this also explains why clusters of galaxies are clustered more strongly than galaxies themselves, which was very puzzling, until Nick Kaiser came up with this idea. All right. So those bias depend on something. Well remember, two-point correlation function was different for bright galaxies and faint galaxies and red and blue, and so on. That is simply reflecting bias factor.

The more luminous, more massive galaxies, are higher bias factors, so they looks more strongly curled. So this has now been measured, and seems to fit theoretical models just fine. What about evolution in time? Well, generically you expect that clustering grows stronger in time, because the density field slowly collapses upon itself, galaxies, dark hills, coagulate. They creak more.

So you expect that there is less clustering in the past, than there is here now. So you expect weaker clustering at larger edges as you go far away. And sure enough, that is what you see. This is plot of the strength of correlation function on the sky as a function of depth in survey. And the deeper you go, the weaker it gets. This is what you naturally expect. And this goes all the way up to about redshift of one, when the earth was half its present size.

But then beyond that, something weird happens. It turns around. Then, as you go deeper in the past, clustering seems to grow stronger, which makes no sense whatsoever, because you couldn't just collapse things, and then let them fly apart.

So how's this possible? And the answer is the bias itself evolves. This was already sensed in these redshift histograms from deep pencil beam surveys. I told you how we seem to be encountering same kind of structures no matter how far we go, for all filaments and so on. And now we think we know why this is. And so look at this.

Consider say just behavior of the highest contrast fluctuations, 5 sigma fluctuations. Those will be the densest, and then will start collapsing first. And those will be the first one to turn on galaxy formation. Then you go to lower threshold, say 3 sigma fluctuations. They'll be falling, but with some time delay, and so on, down to lowest fluctuations.

So if you impose a threshold, then the highest peaks would reach it first, and those of the only galaxy that you can see. So because those are the most biased spots in the density field, you'll see the galaxy clustering was stronger in the past. Instead of that, you're not actually seeing behavior gambling mass. For underlying mass, they're all growing time, only growing time. But the illuminated peaks, which once that changes, and that explains the observations.

And so now we can ask the question, how's that involving in time again for very deep surveys? And you can see that near us, at low redshift bias factories, about one, just as I told you before. But then as you keep going to higher and higher redshifts, it keeps climbing. And in fact, when time galaxies were forming, maybe 5 sigma peaks or 6 sigma peaks were the ones to first go on linear and ignite.