DJORGOVSKI: All right. So let's then put this all together, and ask the question, what was the history of star formation in the universe that is converting of primordial gas into stars, which then create light? I mentioned earlier that we can be seeing unobscured, young stars or they can be shrouded in dust, and then the energies are radiated in far infrared.

So if you take a dusty, star-bursting galaxy, like M82 here, indeed its spectrum shows two humps. There is a quasi-black body in ultraviolet, that's protospheres of young stars, and there is a bigger quasi-black body in far infrared, which is hot dust, that's been heated by stars you cannot see. And so the same thing would apply through the universe. And there are different ways of measuring this.

One of the best ways was with the Spitzer Space Telescope, which is the one right up here. That's the building next door. And here is some quasi-round place in the sky, and the panels are labeled. So in the visible light, which is upper right, you don't see anything. And then, if you go to near infrared, you begin to see something, that's lower left.

And then go to middle infrared, which is what Spitzer does, you see a very prominent source. So there are some sources out there which are too red to be seen at all in visible light because they've been extinguished by dust. But if you can observe them at frequencies where they actually emit their energy, which would be far or mid infrared, there they come.

So you can add up all this and plot it as a function of redshift and ask, what's the local density of star formation as a function of redshift, which is such a lookback time? And it looks something like this. As you go deeper in the past, it climbs up. There was more star formation going on in the earlier days. And that flattens out.

That means for some period of time, something like half of 2/3 of the age of the universe, there was roughly equal amount of star formation per unit volume. And then, since about redshift of one, which is roughly 1/3 of the edge of the universe lookback time it drops substantially. So galaxies are now aging. And all the action has already happened.

You can plot that as a function of time, looks a little less steep. And again, you can see what, for the first half or so, or 1/3 of the edge of the universe, it was more or less constant and then declined. Now more recently, this has been extended, with some extrapolation, to even further out. Because galaxies of redshifts like 8 or 10, or something, we can't measure those. Those are way too faint.

Their infrared, from their broadband measurements, and some model fitting, so there's some inherent uncertainty there. Statistically, this is probably correct. You get some of them wrong, but the bulk will probably be right. And we'll have to wait for the 30-meter telescope to really get redshifts of those faint things out there, and really make sure.

So you see that there is now a decline once you go sufficiently deep in the past. And that means, well, first you start with nothing, there is no galaxies. They build up galaxies, and then, for a few billion years there is a lot of activity going on, and then it declines. So this is exactly what you expect. First there is a rise in star formation density rate, broad maximum, now decline.

You can translate this into the assembly of the mass in stars, not dark matter. And this is by fitting stellar population models, which tell you how you convert mass into light. And indeed, this is what you expect. Very far away, there was relatively little mass in stars. And then, as you approach present day, it grew up, and now it leveled off. Still growing a little bit.

And so even if you push this to the most distant things we infer, at least reasonably from the Hubble Space Telescope, the trend continues. And this makes, again, perfectly good sense. At first you don't have any galaxies, there's no stars. You start making stars, and this eventually grows, and comes to present day volume.

So what does this add up to? And this is an interesting question. How much energy was ever made by stars? And that will be an integrated diffuse background, all light from all galaxies in the universe. So there is a number given there, but the interesting thing is the spectrum of it. And it's two humps, again. Just like the spectrum of the starburst galaxy in M82, and for the exact same reason.

You see integrated distribution of unobscured starlight, or not visible. And you see integrated distribution of processed energy from dust grains. And all together, they're about the same. So that tells you there is about same amount of obscured and unobscured star formation in the universe. If you just look at visible light, you're missing half of it.

So it varies slightly with redshift, but this is a good number. And incidentally, that adds up to only a few percent of the energy density in the cosmic microwave background, which is the remnant of the Big Bang.