In My Own Words

Exploring the Dark Side of the Universe

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When Dr. Risa Wechsler looks up at the night sky, she sees more than stars. She sees a universe full of sweeping changes wrought over billions of years, a sky full of data useful for answering big questions. Her love of these big questions led her to physics and cosmology, and she now spends her days studying galaxy evolution to reveal the nature of dark matter and dark energy.

The scientist as a middle schooler
In middle school I liked math, but other topics, too. I attended summer programs at the Center for Talented Youth, where I took classes in math, of course, but also in world geopolitical structures and archaeology. Although I had broad interests, I had a pretty clear idea from middle school on that I wanted to be a scientist. I just wasn’t sure what type of science I was interested in.

Finding my niche
When it came to choosing a college, I was looking for a place where I would be challenged, have great peers, and have opportunities to do research. At MIT, a lot of students get involved in research quite early, so that was a good fit. The intensity of life at MIT was also very good preparation for a career in research. I was always interested in fundamental questions and originally thought about going into particle physics. But the big questions in cosmology—What’s the universe made of? How did it evolve?— appealed to me. I shifted my focus to cosmology toward the end of college and continued to pursue that interest in graduate school.

Numbering the darkness
When I started graduate school, we didn’t have a clear picture of what the universe is made of, but we did know that the universe as we know it couldn’t be explained solely by gravity acting on the visible mass. We now know that most of the universe is made up of something we can’t see with our eyes at all.

The Earth is made mostly of oxygen and silicon, and the atmosphere is made mostly of oxygen and nitrogen. But the universe is made up of something completely different. Normal matter—consisting of all the elements on the periodic table—makes up only about 5% of the universe. Everything else is different from what you learned about in your standard chemistry class and from what you interact with in your daily life. Most of the mass in the universe is dark matter, and it’s called “dark” because it doesn’t emit or absorb light. We know by looking at the movement of stars in our own galaxy and the way the universe has evolved that there has to be more mass than we can see. Dark matter is pervasive in the universe.

There was some evidence of the existence of dark matter in the 1930s, but it wasn’t widely accepted until the 1980s. Even then, we really didn’t know how large a contribution it made to the total contents of the universe. It’s only in the last 10 years or so that we’ve gone from dark energy and dark matter being hypothesized to where we have measurements of these various constituents accurate to the few-percent level. Dark matter makes up approximately 25% of the universe, and dark energy, a mysterious form of energy that might explain why the universe is expanding, about 70%.

A perspective measured in billions
I’m working on figuring out how the universe works, including learning exactly what dark matter and dark energy are and how they act. Because we can’t see them, I study the cosmological structures they act on: galaxies, clusters of galaxies, and the universe as a whole.

After the Big Bang, matter was evenly distributed in the universe. Today, though, stars and planets are not evenly distributed, and even galaxies are clustered because gravity pulls them together. Measurements of cosmic microwave background radiation have given us a very clear picture of fluctuations in the density of the universe, starting from about 400,000 years after the Big Bang. That’s the time frame I study: the last 13.2 billion years.
Modeling the universe
The main tools I use in my research are computer simulations. The first types of simulations—of the evolution of the universe—are on a massive scale. Since there are hundreds of billions of galaxies in the universe, these simulations are naturally very large and complex. It’s a nice physics problem, though, because we have a pretty good handle on the initial conditions of the universe, and we know that most of the physics that is important is gravity. Gravity isn’t the only important force, but on large scales, gravity dominates. Because dark matter makes up about 85% of the mass of the universe, what happens on a large scale is dominated by dark matter and gravity’s effect on it.

In these simulations, we can start with the very small fluctuations in the smooth early universe, add in gravity, and then predict how we expect dark matter to be distributed. We think there is a galaxy at the center of every “clump” of dark matter in the universe.

A biographer of galaxies
Figuring out how the distribution of dark matter is related to what we see with a telescope is much more challenging. In order to do this, I combine simulations of the evolution of mass in the universe with theoretical models for how individual galaxies form in the dark matter skeleton of the universe. You have to factor more physical processes into these models: how gas cools, how stars form, how stars eject energy into the surrounding gas when they explode. All these processes affect the subsequent evolution of the galaxies. It’s truly challenging to model the physics of an individual star-forming region while taking into account all these local and regional forces.

Model, meet data
We compare our models to the actual state of the universe by using observations from massive telescopes. The more closely the models match the data, the more likely the underlying parameters we set in the simulation are to explain our own universe. We use data from a lot of sources, including deep-sky surveys that can observe galaxies formed more than 12 billion years ago. One of the most important current datasets is the Sloan Digital Sky Survey (SDSS). The largest survey ever of the local universe, the SDSS lasted 10 years and was just completed. It mapped out positions of about a million galaxies in almost 3D and got pictures of about a hundred million galaxies. When I make predictions about how galaxies should be distributed in space, I can then compare them with these observations and go back and refine my models.

A day in the life
When I was an advanced graduate student and post-doc, I was already doing computer simulations of the formation of the universe, so for the most part I spent my days writing code and programming the models. I also developed theoretical models for the formation of galaxies and larger structures. I still get to do a bit of this, but now I typically spend my time in meetings with my graduate students and post-docs discussing and planning our research. Or I spend time writing and editing papers and proposals.

Cosmology is a field that relies on international collaborations, so I go to several international meetings a year, and some of the large projects I’m on have researchers from 10 countries involved. I travel a lot in the United States as well to give talks and to meet collaborators. That’s one thing I didn’t fully anticipate going into this field—just how much travel there would be. I find it fun and stimulating to talk to colleagues from around the world.

Looking back to leap forward
Telescopes can probe the universe now at greater distances and with greater precision than ever before, and that’s good news for cosmologists. I just came back from a meeting of the Dark Energy Survey, which is going to start collecting data in the next six months and will collect data for five years. The SDSS surveyed about a quarter of the sky and focused on galaxies that formed in the last billion years. The DES will go much deeper, tracing galaxies over the last 7 billion years, measuring the history of cosmic expansion. Our hope is that studying these galaxies formed so long ago will help scientists figure out what dark energy is, and why the expansion of the universe is accelerating.