Tracey ([00:00](https://www.rev.com/transcript-editor/Edit?token=JogxBa0LZOlbTOBcuKliqZ7U6pjRBvhxPG13Vvw14eHcakRxJvlJRvrXRA-JbMhXKtzHsVItW__cyFE_53z_C1yQg0w&loadFrom=DocumentDeeplink&ts=0.77)):

Hello, and welcome to NC State's Audio Abstract. I'm your host Tracey Peak. In the early universe, enormous clouds of diffused neutral gases, known as DLAs, served as nurseries of sorts for stars and galaxies as the gases were the fuel for star formation. We're speaking today with Rongmon Bordoloi, an assistant professor of physics here at NC State about the difficulties in studying DLAs, what we know about them and what that might mean for our understanding of star formation in the earliest days of the universe. Welcome, Rongmon.

Rongmon ([00:36](https://www.rev.com/transcript-editor/Edit?token=Yt5TR7X3wolhjsaTGTvGgmr0maQZXesh_bdmHFiXsNcoe7Cqcs-lofaTyXm7xaw4Ymaj08p8RMJTwnyOPOlKR16KeVg&loadFrom=DocumentDeeplink&ts=36.11)):

Hi, thanks for having me.

Tracey ([00:37](https://www.rev.com/transcript-editor/Edit?token=S6RWtfI3IG6D9XLxOlxoWP43d_q3St1WPQFwzpQG3e0zsYTCl6nOL2oD1uE_is7pmesrzXHtB9kvhNr4N62DRFdqEYs&loadFrom=DocumentDeeplink&ts=37.47)):

I am glad you are here. This is a very interesting topic to me. So let's start by kind of defining what we're talking about when we talk about the early universe. This has always been a weird paradox for me how when you look farther into the universe, you're actually kind looking back in time?

Rongmon ([00:56](https://www.rev.com/transcript-editor/Edit?token=2p3p4XbdcOEblcpcLiFhnB4hRFGQRSSPKowz-thnKzo0XQl9oFK2cv3G4Xqth_oTdFcGAR2g46gfoTgg8MZFBInPZlQ&loadFrom=DocumentDeeplink&ts=56.59)):

That is correct. The universe began around 13.5 billion years ago, roughly, and we're today, and if we want to look further away to the early universe, you just have to look at things which are very far away from us. And since light travels with finite speed, so the further an object is, the further back in time you're looking. For example, if you look at the sun, you're not actually seeing what's happening on the sun's surface now. It takes around an eight and a half minute for light to travel from sun to us. So you actually are seeing what the sun was doing eight and a half minutes ago. So if I magically clap my hand and make the sun disappear, you won't feel effect until eight and a half minutes later. So that's what we mean when we say we're actually looking back in time.

Tracey ([01:53](https://www.rev.com/transcript-editor/Edit?token=Ho7hLnXE4n8TvYAi1hqDR89_hVWW7ED0Fzg-ie07E1LC7IXY80QOdXYYLrAPOLmZlV5AEg5-FjOp93UbBaE_uKaiggs&loadFrom=DocumentDeeplink&ts=113.64)):

Let's talk about DLAs. What does DLA stand for first of all?

Rongmon ([02:09](https://www.rev.com/transcript-editor/Edit?token=jIvbo5y1LRTEiiorEFx02gPLIAN47qtbn5SRBfUJUTdzwDrmJLFTpwVTXEjNmBauvO60R3ezuGuBjhei0XCWIwnuaM0&loadFrom=DocumentDeeplink&ts=129.48)):

So DLAs are acronym for Damped Lyman alpha absorbers. It's a very fancy name. But effectively, they are nothing but giant balls of sort of diffuse gas, they're neutral hydrogen atoms, which are pretty diffused and they are existing at a temperature of around let's say 10,000 degrees or so astronomically speaking, they're pretty cool, but they're warm enough that they don't collapse and forms solid stuff like we have here.

Rongmon ([03:01](https://www.rev.com/transcript-editor/Edit?token=ki7nk5ACGbDQmSTGMKCGbXNw4fUXLbTGtUc_NZleDXyiRLIPit8gwuOyykihUc3Rz4AEtsWZj9_Kv7nc2c0aiqSTciU&loadFrom=DocumentDeeplink&ts=181.98)):

So they are kind of moving around in space and they're pretty diffused. They have enough energy to move around, They don't actually emit any light. So therefore it's really hard for us to observe such diffused structure, but these structures are very dense. That is the number of atoms per unit volume is very high. So, when light passes through them, if there is a background star whose light is passing through them, these atoms can absorb that light. So we don't see them in a mission, rather they're seen as lack of light in the spectrum of a background source, which passes through them.

Tracey ([03:41](https://www.rev.com/transcript-editor/Edit?token=7Eqj1hx3mFeMmdL_gMBVvUwNLNTJO-wlryw2PVENldHCFCH0og76Qj4ixU-WDWu8ZvJjuK0Vu4KeV_m9bbwtQD4VuTM&loadFrom=DocumentDeeplink&ts=221.98)):

So if you were to just look out into the universe and you just pretend like you had a completely unobstructed view.

Rongmon ([03:47](https://www.rev.com/transcript-editor/Edit?token=CNTcIRlBUdtnfAqfxSDxgGBa0Pqc36Tnh72i-RK60r552KPuwVY5fEGC90mrRnwUxkgFJHSCU9x41Vygt2ayFTPXiV0&loadFrom=DocumentDeeplink&ts=227.72)):

Yes.

Tracey ([03:48](https://www.rev.com/transcript-editor/Edit?token=1rE-rEn9I5iemXuxo3mjBWyHz1pM8HyleaJn51dAqtrbbLuff0JcyftniAXcSn2ItnEXVQX54NaYZjj5ODc65tieJuI&loadFrom=DocumentDeeplink&ts=228.09)):

All the way back to like 11 billion years ago or there about, you would just see sort of an absence of light, you would see stars and then you would see nothing.

Rongmon ([03:58](https://www.rev.com/transcript-editor/Edit?token=5YG0xXi-gW8301AVVct7isXjb3_NLBDQ_U2KY_kI3wOsorqu17OT5iQTqoivKOtJnhYav9TcaliOT3ncY_AgJ3FQxKM&loadFrom=DocumentDeeplink&ts=238.64)):

Yes. So, the best way to describe it would be you are looking at the silhouette of the gas. So if you are on the beach and sun is setting and a person is walking, you don't see the person, you see the silhouette of the person in the back light of the sun. It's the same sort of a phenomena, but in a atomic level. So we don't see the stuff, the gas itself, rather we see the lack of light because there is a background source, which is very bright. Light is passing through the gas towards us, atoms absorb the wavelength of light, a certain wavelength of light that is corresponding to that atomic transition, so what you see is really lack of light. This method is called absorption line spectroscopy. So it's very dense gas and it's a large volume of gas, therefore we see this huge absorption line signatures in the spectrum of background sources.

Tracey ([05:08](https://www.rev.com/transcript-editor/Edit?token=KkAVRCPsAcaEiNn2Q_C6NpbSOTQyMsKC4uRZNrVyfy2fY58FBSGHgJprgk9O1_y4KtDap1mr33GOVNsiRObb9daoVYo&loadFrom=DocumentDeeplink&ts=308.98)):

Okay. So how did I guess astrophysicists or astronomers first kind of figure out this is what that was?

Rongmon ([05:19](https://www.rev.com/transcript-editor/Edit?token=Aoj1OrezitSKgdC8V90FYZVO1pTffbBXmv_31pL4OcAqLyn0OH0JC41A2vlQperEGGXlNve7cp-T9XqLfli_WDxkq_E&loadFrom=DocumentDeeplink&ts=319.9)):

Yeah. This is kind of an interesting story. So, to understand this, I will take you back on a little journey in time. In the 1950s, we didn't know that you had galaxies 11 billion years ago. We knew the universe was very big. We had a rough idea how old the universe was, but none of those faint sources were detected then. When astronomers were doing some observation, they seemed to see some very, very bright sources on the sky. And they took a spectrum of it. It was a heroic effort in the fifties, and these were sort of starlike point sources, but not quite stars. So we call them quasi-stellar object because they're not quite like stars. When they took the spectrum, they were very confused. What are those? As it turned out, it's a different story, but they are super massive black holes in the heart of a galaxy emitting light.

Rongmon ([06:16](https://www.rev.com/transcript-editor/Edit?token=J_rkSCAzKss86iSqUuQqpe_fBqDLNtDNye-z5iTUNttD88KPUZGRR9fJzbUkd4jEA_msuhubAogsNYyuW4kLkdhj0TE&loadFrom=DocumentDeeplink&ts=376.41)):

But what is interesting is that in those spectrum of faraway galaxy, like super massive black hole spectra, there are a lot of absorption lines, which you could not explain by stuff you see in our atmosphere or stuff you see in our Milky Way. So, some very, very thoughtful astronomers thought about it and they postulated it perhaps we're seeing stuff, which is between us and the galaxies. So this is how this absorption line spectroscopy business began. And it took us another 30 years or so in the 1980s, when people started continuously doing spectroscopy of very far away objects, they started seeing these massive bands of absorption. And this looked exactly like absorption taking place because of neutral hydrogen atoms and this is so big and broad and thick that they call it Damped Lyman alpha absorbers.

Rongmon ([07:20](https://www.rev.com/transcript-editor/Edit?token=raVzrYmTmKTwqR2ZY57yNus_Y0xtjkoHNaf0lgwR72w9iiQLKc3_1f1K3CcBNvfv-36AY5_SxHj2s5jJb5JpIrLO3U4&loadFrom=DocumentDeeplink&ts=440.01)):

Now we knew in the eighties that there are such things as Damped Lyman alpha absorbers detected in background sources and we know that such density of gas should be similar to what you'd see in our Milky Way galaxy's Interstellar Medium. So originally people thought, "Hey, maybe what we are detecting are really fuzzy, faint galaxies very far away." But we had no idea. When people went back and started to look for the galaxies because you should find them, there was nothing. So that was a big puzzle for a very long time that we see these crazy big absorption troughs indicating a lot of diffused, neutral gas, but we don't seem to find anything that is associated with it. So, that was the status for a long time. We knew that they existed. We didn't know how big they are. We didn't know how much stuff there is. And we didn't know if they are actually host galaxies or not.

Tracey ([08:15](https://www.rev.com/transcript-editor/Edit?token=ZWYE3lvfA0XnyK-MB13_N5R1cqzdNS_xastl9jwdGnFwMZYgDeshU_mhWR8lob45iy143GRHK3Fzj_y9ieIBv9Oegts&loadFrom=DocumentDeeplink&ts=495.44)):

As an aside here, when we talk about spectroscopy in astronomy and astrophysics, what is it that you're doing? Because the universe is hugely vast and it's not like you can just turn a light on and really look at it. So, in order to identify these objects that are far, far, far away, you use spectroscopy. So what does that mean exactly?

Rongmon ([08:42](https://www.rev.com/transcript-editor/Edit?token=EVYHckTklHcgardGliUOySGcc5bScrcrfQoNxPArVNv8LhhmFFmXx0_fFOxUINT4yRqRroXdL3kKBxgE7V78q4Dm3sM&loadFrom=DocumentDeeplink&ts=522.41)):

The simplest example I can think of it is when you have sunlight coming towards you, you put a prism in front of it. You see a rainbow of color coming on the floor because the prism basically disperses the light. As the light is passing through, we basically split the light as a function of wavelength because the reflective index of light depends on the wavelength of light. So you can actually disperse the light and study how properties of light vary as a function of its color or its wavelength. And this teaches us many different things. And this is effectively a spectrum of an object, the rainbow of light that you see, and it's important because bluer the light is, more energetic the photon or the light coming towards you it is. So it gives you more information about the internal structure of the source that is emitting the light. If you have lack of light there exactly at the right wave of length where we know an atom should exist, we know that item exists in that source you're observing.

Tracey ([09:54](https://www.rev.com/transcript-editor/Edit?token=XkicS5BjFhhsiOux7tGmLndTG2rz2Crtnyeo1fXETAvWxwbMfZQDzJd_ZSDfAe_dCsvw7-2sdST4S6XD_WcCwk2fO1Y&loadFrom=DocumentDeeplink&ts=594)):

Okay. Even though you can't see it.

Rongmon ([09:55](https://www.rev.com/transcript-editor/Edit?token=iU19EqoI1cdXzeuSBjaVo-dGeTaoiaP1VlrDEXkEXinIQ12g1y39JM308q1a4fBzFV5Aaxd5IuF23ix70ADmhudU0Cg&loadFrom=DocumentDeeplink&ts=595.78)):

Even though you can't see it. So spectroscopy allows you to study the chemical properties of the gas that we see here.

Tracey ([10:01](https://www.rev.com/transcript-editor/Edit?token=CkZdLoz5lzMzcWlABJWHajREKcrh_hCX2mX0uqovTDcC6RmwouJ1Oz18IV0oYrgEdzFETpn1zn1WLnd0lVyMZOdTIs0&loadFrom=DocumentDeeplink&ts=601.81)):

Okay. So that's basically, it's a shorthand for how you identify what's in that giant cloud that just looks like a vast nothing.

Rongmon ([10:10](https://www.rev.com/transcript-editor/Edit?token=f5B6nhhEZwcTv2ApAlWWta4OmlbBIa09Rinq9hg5kiKov5-FbV3XvDv2DJ-NFtnoaPNzII48RetCMnFMVvEt5f8ivBI&loadFrom=DocumentDeeplink&ts=610.81)):

Absolutely.

Tracey ([10:11](https://www.rev.com/transcript-editor/Edit?token=-jp3zLdXKO-Ew1ALopeL9AIHkIkhnS207YqKX2g307AjI4pcx_UC6-EIJBgOEvy8oY7J_YFAF66CjIHKyNscBgqWosE&loadFrom=DocumentDeeplink&ts=611.47)):

Okay.

Rongmon ([10:11](https://www.rev.com/transcript-editor/Edit?token=aLZscmQd57hgzB76a5eKRM5-lrliikjUzbr-qz4Y18M0qAu_QbjfOHXXW_usrgHqw5TayRYIp45BE224-9PjfI7aTs0&loadFrom=DocumentDeeplink&ts=611.78)):

Absolutely, to know what they are made out of. Yes.

Tracey ([10:14](https://www.rev.com/transcript-editor/Edit?token=nM-QG8SzsI6lZzW3NERSY7fqG3sZs17YqpsTU-oqus7huTry1UOPwCHxP0wDfNbKxOGv3Zka1rBr7iJ8-WK53-wLP70&loadFrom=DocumentDeeplink&ts=614.67)):

Right. Okay. So, that's really fascinating that all of this is pretty recent stuff. I guess, it's the technology has caught up with what it is that we're able to do. When did we get the idea that there should be galaxies inside these DLAs?

Rongmon ([10:32](https://www.rev.com/transcript-editor/Edit?token=5sATUBa6KMETmKqCME6txMRzq5ORO78Lpf9um1L88RSqakyulN1JZgZYWWBUJDPdnkSqHQCbhgtgPx1emu9k-QWqNL8&loadFrom=DocumentDeeplink&ts=632.95)):

So, we always suspected that they were, and they were in the nineties and the two thousands, there were hot debates that what are these DLAs? Because that was right about the time when large telescopes started getting commissioned and spectroscopy of these faint sources started getting proliferated. So we started having large surveys which detected thousands and thousands of these DLAs. So people knew they existed. We knew that they are actually a large fraction of the total mass of the universe, but we didn't know what they are. It was still debated hotly. We had our pet theories. Some people thought, "Oh, they're actually a small galaxy. We're hitting a small galaxy. We see them." Some people thought, "No, they're giant clouds of gas that just exist in void." Et cetera. So there are a lot of pet theories. There was no real way to sort of dissect and say that this is the right answer.

Rongmon ([11:32](https://www.rev.com/transcript-editor/Edit?token=K0pQMgfto8kVzWNXeEoxIwuUI95W3BvwUC2GnXwo4mjjmpC1PrQYcm8IJAlvQO1HFgKX490_BHbQ5Q50QwhdvjY7VtQ&loadFrom=DocumentDeeplink&ts=692.52)):

What happened, again, slowly we started getting better and better data. People started seeing that, "Oh, sometimes there are galaxies near these DLAs." So they are not necessarily the galaxies themselves, rather, it could be the halo of the galaxies. So, that was kind of the first breakthrough. We still did not know anything about how big they are. We still didn't know what kind of galaxies are there. It was still a big unknown. So we sort of... we knew that one way to break this deadlock was number one, we had to somehow figure out how big these DLAs are, and number two, we should be able to find a way to actually identify what are the host galaxies associated with it. If they are indeed giant balls of gas which are fueling these galaxies, we should be able to somehow dig in and identify them. So this is where sort of our research comes in.

Tracey ([12:28](https://www.rev.com/transcript-editor/Edit?token=fXfpkB3Z-lvJnaVod8E0cqHlVwimzQXiQhGdonl8m-vZAnInNzOBCQX_e1diiOvGII5V5y2bl5kX6GaAxA87X6MdJaU&loadFrom=DocumentDeeplink&ts=748.06)):

And so you have managed with using another galaxy as kind of a magnifying glass to give you a better look and some better technology.

Rongmon ([12:39](https://www.rev.com/transcript-editor/Edit?token=XBk8ZzxnpGo25xd31-e3odhxOyvfrkH_5T7_tpxErsq2HeDx0Cw58nKD-B6YWF3GzajSOcuFWyOrGDgibGfBM8_Loqc&loadFrom=DocumentDeeplink&ts=759.94)):

Yes.

Tracey ([12:41](https://www.rev.com/transcript-editor/Edit?token=u4QPcjqwQ4rpRl_pAvbnXTgi2lJD4ImQratOSh1Fxy9SgmJqO6LvIovwNJOtq4sYMSPw9JLPaua6R4xrBG8FmfPIhXI&loadFrom=DocumentDeeplink&ts=761.13)):

Figured out that you were able to look at two of these DLAs, in a recent publication, and see that both of them had what you call host galaxies in the center.

Rongmon ([13:40](https://www.rev.com/transcript-editor/Edit?token=b_FpRLv-NHZCas3Dhdkg_ljtZEJJzGgfEN6-qwdRc30zBxW0TzmgqnFpvxMIdKijwyauBnUKE8WK_1GIatgtY2uO7Z0&loadFrom=DocumentDeeplink&ts=820.66)):

So the way to do it is we had to wait until a few years when we started having these new instruments called large integral field spectrographs effectively, what they are they're a fancy camera, which allows you to take a spectrum for every single pixel on that camera. So, it's a 3D instrument which allows us to do a spectrum of every single point on the sky where it's taking an image of. That was a breakthrough and because of this and combination of the natural phenomena called gravitational lensing, which effectively allows us to zoom in on a small part of the sky and kind of magnify it, we are able to do this study.

Tracey ([14:39](https://www.rev.com/transcript-editor/Edit?token=9bwc1rtfAqZhDRcxTEojUaGc2jMALsnRPcb0MxYCGP6Rvx3TNLOHG2QZkJCpnYQ6sG25-7DJPLi0MpCe7FeViPgVczI&loadFrom=DocumentDeeplink&ts=879.65)):

What's happening with these do we think? Are these clouds sort of the, I guess, source material for all of the galaxies that exist currently? Did all of our galaxies develop in this way where these clouds just kind of.. What happens in the clouds, they just kind of swoosh down and make entire galaxies?

Rongmon ([15:07](https://www.rev.com/transcript-editor/Edit?token=DGguc9ouS4LvkELQxi3j0eKDbhywiq-HEV3uaVqxkS1TB08DX4IPv8izNG49xRhm6g3lMFisSYxkyFz_Zz3-86RlJv8&loadFrom=DocumentDeeplink&ts=907.6)):

That's an excellent question. That's what we have been struggling for a very long time to understand. What actually happens? So what you have to understand is that you see a solar system today, which did not exist five billion years ago. So our Milky Way galaxy is very large today, but it didn't start off this way. When galaxies are forming very early in the universe, that is a few hundred million years after the Big Bang, they're tiny, tiny things. They're basically some stars which are initially starting to form and coalesce around them to form a galaxy. They're pretty small. And what happens is the universe is, in those early days, is filled with cool, diffused gas all over the place. And these gases are getting gravitationally attracted to where the stars are because this is where you have the most gravity. So gravity attracts everything. So these gas clouds are coming towards you.

Rongmon ([16:07](https://www.rev.com/transcript-editor/Edit?token=-zb9ptFq_Veit4rC-OEO96vYGXi6-6Ck5kfdpBTkgbkolOAXrK2TxuAPjghUH1YHaMVZHOpUuCxolkCJCs81iWufPuM&loadFrom=DocumentDeeplink&ts=967.49)):

So, they kind of exist in these halos around galaxies where a lot of diffused gas clouds exist and slowly... Slowly, by various phenomena, they start losing their angular momentum and kinetic energy. They start accreting onto the galaxies. Then they get funneled into denser and denser regions where gravity kind of pulls them in more and more and they start forming new stars. And this is how a galaxy grows, one of the ways how a galaxy grows and forms new stars. So this diffused gas cloud that you see around galaxy is actually sort of the fuel tank of the galaxy. So as a galaxy is kind of evolving in its cosmic journey, these gas is accreting onto the disc of the galaxy and forming the next generation of stars. So, for example, the sun did not exist until such accretion of material fell in and gave it enough material for a sun-like star to be born.

Tracey ([17:16](https://www.rev.com/transcript-editor/Edit?token=4BncDnrhpwsvR_S0AZHdXtLJDM4sIbwwuX44g4swJKcuPH9CGqm0N8nd6Qq9d3TWxq7sUqaFYGplxq-ZBV5N4kV05LA&loadFrom=DocumentDeeplink&ts=1036.2)):

Okay. Yeah, that was going to be my next question. Is it a gas cloud, enough of that comes together to make a star and then the rest of it eventually kind of draws in toward it?

Rongmon ([17:40](https://www.rev.com/transcript-editor/Edit?token=-wTRK36zm3gO5t_7bFBHHPZL_VUg5E7pxzkOokHXuU_iY1icqudd3tr1EFW8m7i86M-Q9aYhuvxSZVC1pasFrq7No8M&loadFrom=DocumentDeeplink&ts=1060.3)):

Yes. We definitely think that initially there were no stars when the universe began. Right? And it's a story of how our universe is born, essentially. You initially had a Big Bang when everything was created, including space-time itself, and slowly, the universe is expanding and things are cooling down. And once things are cool enough that the first neutral hydrogen atoms were formed because the universe is cool enough that neutral atoms can form. There were no stars then. But the universe kept expanding and there were small anisotropies in the space time itself. There were regions where you have slightly more matter than the other region. So these regions where you have slightly more matter, a little bit more atom, they had more gravity than the other region. So slowly they started accreting more and more stuff. And that kind of grew until the first stars were born. After that, it's a runaway problem. It's like rich people get more rich. It's like the rich over density regions get more richer. So they attract more and more stuff to them and they kind of form more and more stars, which eventually became galaxies as we see today.

Tracey ([18:50](https://www.rev.com/transcript-editor/Edit?token=pH-NWZ3ckzF1FlGe_0aXAMBEj7fOJmfb1A3Goy7EW253ucgSCmH5RLMsyUz7mx9UUzT-lnhoiUgLAcA4F0SCm_67pLc&loadFrom=DocumentDeeplink&ts=1130.97)):

Okay. So, and just to give people kind of an idea, obviously, if galaxies are forming inside of these DLAs, these DLAs have got to be hugely enormous, vast areas of space. Do we have an idea? I know the research you recently did, you kind of have an idea of maybe how far across one might be that you observed. How big are these things?

Rongmon ([19:17](https://www.rev.com/transcript-editor/Edit?token=fsfZkPq88LcR695GQQUeuFgz5kS5fvP0HNsv1X9-ngJTqGt3-SVGrORprGLJSoH8i-hLxh7pumxWqHfxPxjWhpPXObs&loadFrom=DocumentDeeplink&ts=1157.1)):

So, that's an excellent point. We know that these are massive reservers of gas around galaxies. That's how I would define it. And we think, at least for the objects we studied, where we can measure its size, we actually... we can set a minimum limit how big they are. They could be much bigger than this. And we find that they're at least 17 kiloparsecs across. That in layman's term, I would translate it to around 55 to 56,000 light years across. So, light will take 56,000 years to go from one end to the other.

Tracey ([19:54](https://www.rev.com/transcript-editor/Edit?token=fUX2d11iW0DhBMRLxC03cYJZYgT3A8wESQiuO532FAhkCPVM_Cr7ZyFYX1V8ATLB0i1c4BB2N-QXaWQkfYZoOfSgRFo&loadFrom=DocumentDeeplink&ts=1194.42)):

That's really amazing.

Rongmon ([19:57](https://www.rev.com/transcript-editor/Edit?token=x4tUU_s_ciYZUdxYo2R8hMoZFGJW-uDwDZNEH14NvFyeMDlNp0sKasdyMyMudmjQZPM3k7Hl2teUCNXGtklT1OhmZmw&loadFrom=DocumentDeeplink&ts=1197.66)):

And for context, now, if you take that size, look at our Milky Way galaxy, it's comparable to what the Milky Way galaxy is today. But the difference is, it was 11 billion years ago. So the size of the galaxy was much, much smaller. So the galaxies are factor of five or six smaller. So although you have comparable size in physical size, it's proportionally, it's much bigger, it's factor of five, bigger than how big the host galaxy should be at those redshifts.

Tracey ([20:33](https://www.rev.com/transcript-editor/Edit?token=Ch54xC80-3QGclaAhBEgScGhrsQ6B0AICKFfT0BBSYAMrQWMuv4UuV7Pei9VwHfWOiVI8kEb1zyeA8JWiLlKMkePFG8&loadFrom=DocumentDeeplink&ts=1233.9)):

Okay. So it's like a little tiny seed galaxy in the center of the giant cloud?

Rongmon ([20:37](https://www.rev.com/transcript-editor/Edit?token=3HfB_hyGMVJJvL67XfRPvLY3AdQcWExNEBxNiafBJyxYDpvyvHNXEUwfFD4DkNiLl10NHFdcuz7WKTRvTHmAT8PgACk&loadFrom=DocumentDeeplink&ts=1237.46)):

Yes.

Tracey ([20:37](https://www.rev.com/transcript-editor/Edit?token=hAEN1hYH_IxWNcrkwvZC236X7Yf6de4Ad1b0yhFlFROVze1f5B0_AxlWNZB3vXGCMb8fKFC0r8ZIVBl21OvJBz52Zio&loadFrom=DocumentDeeplink&ts=1237.73)):

And then eventually, the entire galaxy kind of takes up the whole area that the cloud was?

Rongmon ([20:43](https://www.rev.com/transcript-editor/Edit?token=YCkSjYug1z2qstkBByRcnkM0oxnhAMXAjl_1RgnGdg29IP4RD0A31fqI74IAN-Ssazm26SKD5CLZnR8Vq4qFk2C9gOw&loadFrom=DocumentDeeplink&ts=1243.59)):

Yes, at least as big as that. And this is kind of fueling the galaxy, hopefully galaxy grows with it and becomes bigger.

Tracey ([20:50](https://www.rev.com/transcript-editor/Edit?token=10MRicm6gxSFGnehV5Sbsy3AbweKL4SPA3UXr016WO7waH5jN1uS3flGWspTLw-7j-Ps_C59y_Y7AWI1SEZpTASjSsg&loadFrom=DocumentDeeplink&ts=1250.93)):

Now that you've sort of proven the concept that, "Hey, we can use these techniques and we can get much better sort of imaging of these things and kind of dig in and see what's going on, and yes, there were galaxies in the two that we studied and they were similar," correct? It wasn't like they were a bunch of distinct little... Well, you only looked at two, but still, it wasn't like they were really distinct from each other. It was like, "Here's a cloud and here's a little galaxy in the middle of it."

Rongmon ([21:23](https://www.rev.com/transcript-editor/Edit?token=G6wDqwZXox0TQH4Tz7vMOjkz5oiBUHX3Fx3AQ0IyXn9cG2nXNd3v1KbkXvW9vz6eStGrB_aTxV2hGhkHfTNO4n8EzKQ&loadFrom=DocumentDeeplink&ts=1283.02)):

Yes. They are similar in that. The one is a little bit bigger than the other, but on average, they're similar. But you're right, this is just two.

Tracey ([21:30](https://www.rev.com/transcript-editor/Edit?token=5KLp3FrCxvD7RptmTaR_a2CJVtuegd2WdKJ7cgKqkXuwvXXSj1p7jwENU48uLu6mmbakid_MMu9utokv4swrXxwPmOk&loadFrom=DocumentDeeplink&ts=1290.31)):

Yes.

Rongmon ([21:30](https://www.rev.com/transcript-editor/Edit?token=oV2MmKZwRUVplLKJG5T2qiy7eU9vZywvoaIBdsTtDS4LCPb4YZ8dRQiBMN3bKb1svH4j0tpf2-0ICR7FOSz3aWi54kY&loadFrom=DocumentDeeplink&ts=1290.69)):

So we have to ask the question, is it always like this? The answer is we don't know yet. So we are kind of expanding our scope of study. We're trying to get a bigger sample to answer the question. Is it a general trend everywhere? Another question is if indeed there are just extended discs around, we don't even know if it's a completely diffused halo in 3D or it's actually like a pancake extended disc-like structure where gas is core rotating with the galaxy and falling in. We don't know these things. So we have to do additional studies, which would be in higher resolution as well as larger samples to actually nail down those questions.

Tracey ([22:13](https://www.rev.com/transcript-editor/Edit?token=v_ucPfAmquJIFFll0lj3a5351nxW7cKs43xh8ZWpl5ocd0tNarZ8uKIOHoBeV6kqASoVX1I80UH5-wkJvkwzqRns5qI&loadFrom=DocumentDeeplink&ts=1333.58)):

Okay. And what does that mean? Let's say that you can find these wonderful sort of lensed galaxy magnifying glasses here and there, and you can get a look at a bunch of these things. What questions are we trying to answer here about how galaxies form?

Rongmon ([22:45](https://www.rev.com/transcript-editor/Edit?token=slXf0UQYNyLoGY8t2TS-8bijlEARYEBHAm0C8gDBWTOhzq7bmDJ9pL2E5fdprWlpqPj4Y0gEHMC9W1EaYcxTnPPoi1U&loadFrom=DocumentDeeplink&ts=1365.79)):

So there are a couple of big questions that are completely unknown. It's a little bit detailed, but let me put it this way. If you look around us, most of the atoms that you and I are made out of that we see the sun is made out of and the Milky Way galaxy is made out of, if we take it all, we count it up and we try to see, "Okay, we know from the Big Bang theory, how much total matter or baryonic matter like the visible stuff you and I see, how much of this stuff is there? Then we kind of try to count it and see how much of stuff we can actually see. It's a surprising number that a lot of this matter is missing. So, it turns out that more than 83% of the visible matter that you see, the ordinary matter that you see, are not inside galaxies, they're actually outside galaxies. So, this is called a missing variant problem.

Rongmon ([23:42](https://www.rev.com/transcript-editor/Edit?token=dssa6V7_maRowI1PJcKCda5FJqxtQvbp0_DYU1b2bejyeXHmYtIy28snFR1gEzPwuxO2SCT9rbd89PpuGvFQej5g7ic&loadFrom=DocumentDeeplink&ts=1422.57)):

Now we know that in Milky Way-like galaxy, a lot of the stuff is outside galaxies. We also know that at high redshift, a lot of the stuff is even outside galaxies in the intergalactic medium. Now, the question is what fraction of the stuff exists in these halos around galaxies that can fuel star formation in the galaxies that can tell us how big the galaxy will become in a few billion years from where we observe? It can also tell us if you don't have such gas, if you see a galaxy without such a reserver, we know that that galaxy, what we call, would effectively die. It'll stop forming stars. It'll become a dead galaxy. So we can actually ask the question, what makes a galaxy be star forming, become like a Milky Way, versus what makes a galaxy become a different kind of shape? What makes a galaxy red and dead? We see galaxies like this around us, like an elliptical galaxy. Can we actually explain by looking at the reserver gas how a galaxy will evolve with time? That's one of the big questions we're trying to answer.

Tracey ([24:52](https://www.rev.com/transcript-editor/Edit?token=TFGOwddOhhRK5lJELJaMNIZ5Kk85HN2r8UDsYESLICHImBESoe1JXem8aFa7Iheqf6lFpYYm-yBuJ8sntbhAKdQYxzM&loadFrom=DocumentDeeplink&ts=1492.21)):

Wow. That is a big question. That's really cool. I did not know that there were dead galaxies. That they just didn't get the gases, I guess, they don't have the fuel. And they just-

Rongmon ([25:02](https://www.rev.com/transcript-editor/Edit?token=fJm_jyAA4BlaFWC00fnza_2o0k9jb9WYtUfhHlO-JnSMVf6OGaMVWkq0GQA3ycEfMfZdMLnZCTkdCSjwPsbfuAlL2oE&loadFrom=DocumentDeeplink&ts=1502.46)):

They kind of, for whatever reason, they just can't from stars and we don't quite really understand how they actually become the way they are. And the big question is can life actually be sustained in such galaxies? We know that we have a solar system in our Milky Way galaxy, so if you don't have this chemical composition, we don't know that even earth-like planet might exist in those galaxies. We have absolutely no idea.

Tracey ([25:32](https://www.rev.com/transcript-editor/Edit?token=g5cz7LDrpIdgZDq7ue5893TD3EuWS6gvznfeK-nGb-_xVhAA7Je-76B2UO8I9z7llMWc2oy1htTVZV_hf_qej_5Dw0M&loadFrom=DocumentDeeplink&ts=1532.75)):

This also brings me to kind of my last question that I always like to ask people, what brought you into this field of study first of all? Why did you decide, "Hey, I want to look at what makes galaxy form."

Rongmon ([25:53](https://www.rev.com/transcript-editor/Edit?token=t1eYM4i2LzWtJlTefuVpdbztJyZYx495kLCECJRDLzX8VbtoxcUMaXMUWobFlgKgf3GPe5Z5HxqAlKVyyOuWRPWZxwU&loadFrom=DocumentDeeplink&ts=1553.47)):

So, that's an excellent question. As a kid, I always wanted to study astronomy for many reasons. I got inspired by reading a few popular science books, which is kind of corny, but it worked for me and it really inspired me to ask the question... Basically ask what we don't know about how a star is born. What we don't know about how a galaxy is born? Basically to ask the fundamental question. That always inspired me. So I always wanted to have an opportunity to study something new about the universe, and that has been driving me all my life. Just to ask the next question about what can we learn a little bit more about something? And that has sort of led me through this slippery slope of trying to understand what makes a galaxy what it is today? And we're trying to answer this question in many different facets.

Tracey ([26:49](https://www.rev.com/transcript-editor/Edit?token=-8lKNOSKEwh5x0KAFVVnjvTGuvYiSLhFXlbwrvd23axq6PFvpsUTIByvIdVYgRAca8Jwi7gwp7hNJBAflahyjeJnVyA&loadFrom=DocumentDeeplink&ts=1609.48)):

And that said, what is sort of the coolest thing you know, the coolest fact, that you've either discovered or learned about while you were pursuing these?

Rongmon ([27:01](https://www.rev.com/transcript-editor/Edit?token=XzqY8krVtLt6vzlmb-EWJ52hpinG2uoO5LyOo0fiiBKm-ZCJP2l5L41rN79F7l_EgfXO3WG-z82f61fqUBiR_Y7FnTs&loadFrom=DocumentDeeplink&ts=1621.11)):

Oh, there are so many things.

Tracey ([27:03](https://www.rev.com/transcript-editor/Edit?token=ZVz6O0g4BOBrTyncSP0bQ5cDDKwa1AUXj1sqo3wRiU51VBu2NOf5fAhNY0SB-azr7uDQKrGHJtEZ5GySiOWCyCVfERM&loadFrom=DocumentDeeplink&ts=1623.53)):

You can pick the top three if you'd like.

Rongmon ([27:05](https://www.rev.com/transcript-editor/Edit?token=cSm-eSeoYIRRrnIgKGHMzg2IZtHtPM9UdeceOQ5txQgECRFXZGP5hHeE9sxtrrFkuAE1rTgEiNKwUCHOD6HNPcrwIfY&loadFrom=DocumentDeeplink&ts=1625.56)):

I can definitely try and I'll try to include something that we do. So one cool thing I would say is, I don't know if you know this, the universe is filled with something mysterious called dark energy.

Tracey ([27:22](https://www.rev.com/transcript-editor/Edit?token=XXbKVsplsXV5OVBcXw3NAdb2WNMzkG9cMHLs2EnxW7YL2Vf_OQ1l4y-rR-uQiFjoSxIyCHb4F8_j_lznGuDDtwAros4&loadFrom=DocumentDeeplink&ts=1642.1)):

I have heard about dark energy, but I'm not real clear on what that is exactly or what it means.

Rongmon ([27:27](https://www.rev.com/transcript-editor/Edit?token=peT3KdWND9Pdsy7gu_QTJgIqgrUBd2Idcjitr0dBXUjB-R-xj-s7ZayOu5CMdTERX4aolcrj-RxxPw6ZGOvuxR0B_fw&loadFrom=DocumentDeeplink&ts=1647.13)):

Nobody knows.

Tracey ([27:28](https://www.rev.com/transcript-editor/Edit?token=98Hfe2PcU7j8SqvIemrBLyzo1IBg3rMhzs-xp2czVMrwBww7rhWM4CRnEwhgGSxYCZJado6VFrSAEle_r8I2w8uh-ZI&loadFrom=DocumentDeeplink&ts=1648.18)):

Okay.

Rongmon ([27:28](https://www.rev.com/transcript-editor/Edit?token=UbpkyKxBdBwkdv3rY2DKWrpj3S4UTHNHhbgaID-Krv439UQKpldyZ7vES-VUF7qfeoSYiMVpiu_0H79PaDD_X_FDs14&loadFrom=DocumentDeeplink&ts=1648.8)):

But it's effect we can all, at least astronomers, can see and what is happening, recently we discovered, that the universe, as you probably know, the Big Bang theory basically showed and it has been proven that the universe is expanding, but something mysterious is happening recently that the expansion of the universe is accelerating. So, things are kind of moving away from each other at a much faster accelerated rate. So, we think what might be causing it is some sort of weird... weird sort of energy feel, which we call dark energy because we have no idea what that is, which acts something like negative gravity. Gravity attracts you, this kind of repels you. So this is one of the biggest mysteries right now that the universe is accelerating away and we don't quite understand what that is. And if you count up how much energy it is, it's actually around more than 70% of the total energy density of the universe today. So it's the most dominant form of energy in the universe, but we have no idea what that is. That's definitely one of the cool things.

Tracey ([28:42](https://www.rev.com/transcript-editor/Edit?token=SaC-cBjKky8aqmQQShgbnUDDVt07rbtPxJO1bp9YxqpuJ0qh0XBJfQOKFcCRQvQ03Ip6N4BmGVYWMx_TPVfBKSY9yeU&loadFrom=DocumentDeeplink&ts=1722.76)):

70% of what's making up the universe, we don't even know what it is.

Rongmon ([28:50](https://www.rev.com/transcript-editor/Edit?token=VQXf_ZPWPx033f7ylKQSNtSEFKA_LJAfJvqnZne-aIO7Clg-zMmrR871NlFuhSfOm-ew7oUO8nM7m5BniKMBQCjpPNE&loadFrom=DocumentDeeplink&ts=1730)):

We don't even know what that is. We know what it does. I would definitely say the other cool thing we learned and this definitely relates to what we do in our group, and this is a profound realization of our place in the universe, I would argue. So, as I said that our... The stuff, the ordinary stuff that you and I are made out of is only around 13% of the total mass budget of Milky Way galaxy. Every atom that you and I are made out of, we're actually synthesized inside a star. We know that for a long time because the only way we can have heavier elements than hydrogen or helium is because there's nuclear fusion inside stars. So you have carbon atoms that we are made out of. We have nitrogen that our atmosphere is made out of inside the core of a star. Those were regurgitated in supernova explosions and basically that seeded the complex chemicals that our solar system is made out of.

Rongmon ([30:05](https://www.rev.com/transcript-editor/Edit?token=aK2xHcW-FhRVhCxjSUAIxVkdf6XWWI3ufCjJrlNuUK1nBJ8Y6x86SQsBUB2-NG1_JbeqSd3Clg7A3xUXzWL9jiglzNI&loadFrom=DocumentDeeplink&ts=1805.07)):

However that we knew for a while. What we did not know and which, which comes back to those missing variants, is that when supernovas explode, they carry this material outside the galaxies. So we actually figured out that more than 80% of the atoms that you and I are made out of were actually outside our Milky Way galaxy at some point in the last couple of billion years ago. So if you think about it, part of us, part of the atoms that you and I are made out of, were outside our galaxy at some point in the past. So, that's a profound statement that we found actually with our research in the last 20 years.

Tracey ([30:46](https://www.rev.com/transcript-editor/Edit?token=-Ov00WarYQEtAOlD5fD-acEkIQP_rWs9ibMWuB0A3ftzDHQMJRM8BE0tZCzmFnsgIw20ijsyFh212kWF16p2wb_Fsbc&loadFrom=DocumentDeeplink&ts=1846.93)):

Wow. That is really cool. I love astrophysics stuff. It always makes my brain hurt, but I do enjoy it very much.

Tracey ([33:41](https://www.rev.com/transcript-editor/Edit?token=1n9iPnYSC8nMFZnlS4yoEkH_pyla_q9rk7eo1RjYDxu3nnXlVtfs0df_GGny_s3NyQ0KEvVyD8xn5jJ7qlqP4gfBE-A&loadFrom=DocumentDeeplink&ts=2021.42)):

We've been speaking today with Rongmon Bordoloi, assistant professor of physics here at NC state. My name's Tracey Peak. This has been Audio Abstract. Thank you so much for listening.