Speaker 1: [00:00](https://www.rev.com/transcript-editor/Edit?token=IK1W7JwXNM1PUv22990p-6bbZA8gUdpyOO9pBja-KbhKLOAKJW5Em9GRFyNN8TK-ytnvp6reoaFRSBkZ6_fUfdo8IGQ&loadFrom=DocumentDeeplink&ts=0.72) All right, here we go.

Tracey: [00:03](https://www.rev.com/transcript-editor/Edit?token=WMPnhVJDp90qDdo5vWlHODinKXCrXMCKxa3OGFZ5Stau3PZyT_6JFJvPc_pHusSenIu3H-z1bwS1K_xeHulEztsb2Xg&loadFrom=DocumentDeeplink&ts=3.36) Hello and welcome to NC State's Audio Abstract. I'm your host Tracey Peake. If the big bang heralded the beginning of the universe, what could bring about its end? We're speaking today with Katie Mack, assistant professor of physics here at NC State and author of a new book entitled The End Of Everything, about how the universe might end, what that might look like and how astrophysicists figure out these scenarios in the first place. Hello Katie, how are you?

Katie Mack: [00:03](https://www.rev.com/transcript-editor/Edit?token=b9MYO_k9U8nclvz2hyLZtaADcZguAHsXaYfO8o6qtdyeHSaQjAhSct6B-i2sy5Y9MroixfdusZrjgIAF7BWR-BhuUCw&loadFrom=DocumentDeeplink&ts=3.36) I'm good. How are you doing?

Tracey: [00:35](https://www.rev.com/transcript-editor/Edit?token=XvWBMmORGvIZUP83wRAZKL5Pg19T4zrk8r7Uq71PkLceAPC4N3--RrE4uRToBEcfSXnsXA3BTw2nlph9hSz0NBXb6vM&loadFrom=DocumentDeeplink&ts=35.11) I'm doing great. Let's start with some background. You're a cosmologist and a theoretical astrophysicist. So what drew you to this field, first of all, and how do you go about studying things we can't actually see like nuclear particles and gravity?

Katie Mack: [00:55](https://www.rev.com/transcript-editor/Edit?token=2rfbh4V6Q4P1b5tcUb_-BgyJBTyPgWti8G6s0tcwgwV8q06mHkexCWtkZo0CphPbTQt4PRXCMW85alZas7otycuq6mw&loadFrom=DocumentDeeplink&ts=55.51) So I've been interested in space and physics since as long as I can remember. When I was a little kid, I was always trying to take things apart and put them back together to figure out how they worked. And at some point, I started reading about black holes and the big bang and space-time and all that. And I thought that was amazing. I wanted to know how that worked too. And I figured out that the people who study that are called cosmologists and I figured, "Okay, that's what I want to do in my career." And so I studied physics and astrophysics and ended up working in theoretical cosmology.

Tracey: [01:34](https://www.rev.com/transcript-editor/Edit?token=udyx5uUHh9cxxzUjYi5mBZq4HA14CVqUNvEYLXLmrwAVQm6I77knsB8vBx-slM5NWhWQ9xnrLPr101_JKKtMYsanIws&loadFrom=DocumentDeeplink&ts=94.91) So for lay people, when you think of theoretical cosmology, what that kind of boils down to in a lot of ways is math, right?

Katie Mack: [01:48](https://www.rev.com/transcript-editor/Edit?token=ohW0zuYHn4y74Al83I4P0oOAdh6VPVd8Vk5giQzpuA9J58QYIlfNGrncMZzSo3OqCSc3i5a_dTOFNyKQ9K9L7B9pKBo&loadFrom=DocumentDeeplink&ts=108.35) Yeah. Yeah. So mathematics is what we use to kind of make models of the universe. In the sense of, we take data about how things work, how planets move around stars, how particles interact when they collide with each other in experiments, all of that. And we create mathematical kind of maps to talk about how that all works. And we use equations to describe those interactions, to describe what's happening. And that allows us to make a sort of picture of all this in a mathematical structure. And then that allows us to make predictions about what will happen if we do the experiment again, or if we do another observation. And as long as the mathematical models we put together still fit the data, fit all the data we take, then we figure that's a pretty good model. And that's why we use math in these scenarios, because it's something that seems to work. It's something that can be used to make predictions, to describe what we see. And it seems that the way the universe works fits pretty well with the kind of mathematical structures that we can write down in our equations. So it's a useful tool really, to describe what we see in the universe.

Tracey: [03:10](https://www.rev.com/transcript-editor/Edit?token=IVwnrnc_gK-UmHw-bORHE9iLM3KSurxBAcdrjMSBBwacnFudcoYIRf-bjrGUCZJvv-6S9pBS-nYrZXivIhz-DyTAzyU&loadFrom=DocumentDeeplink&ts=190.93) It's kind of hard to run, I guess, a real time simulation of the universe. That's not really a thing.

Katie Mack: [03:20](https://www.rev.com/transcript-editor/Edit?token=zvHbHTiigfWhdcdj7MxgSffys5pvP0PajJ6rq8m5zBRG3bUfatLcsb8bKDpjvUR3MMS4WETodUTCaCC1Jsgd5VwI68g&loadFrom=DocumentDeeplink&ts=200.07) Yeah. but we can use simulations to explain what we see in the cosmos. So we can do a simulation where we tell a computer we have a certain number of particles in a certain amount of space and they're moving in a particular way and they have gravity and we can let those particles come together and create galaxies and so on in the computer. And then compare that to what we see in the sky, and find out if we're sort of on the right track with our mathematical models. And that's how we refine these things. And when it comes to things that we can't see, you mentioned nuclear particles and so on, what we can do is, we can use mathematical structures to describe how these particles are interacting and then figure out, okay if that were happening, what would the interactions with our experiments look like? What kind of data would we get? And then, that way we can test our models of what's happening below the surface, where we can't see it.

Tracey: [04:11](https://www.rev.com/transcript-editor/Edit?token=s5wCahB6RX9umE58YYa9TiwgWi_keShB37duhbGo0uwAluxXheKNhp72oRWAmxdaMsL87nYKxCI0NmHepUXvi8iPYoI&loadFrom=DocumentDeeplink&ts=251.1) So now that we know we can make sort of models about how the universe works and test them, so that we know that our math is kind of the right math, is the universe's demise inevitable?

Katie Mack: [04:30](https://www.rev.com/transcript-editor/Edit?token=yYR-ZFQKGz2bNnpdR6u3yPdou4PNHjjfxfBRjCUdcwMx5mGYF5yfudPXrls0cYL3N-zwtWV4jStUFzKovM8GEjMVN94&loadFrom=DocumentDeeplink&ts=270.35) Well, this is something that I've been looking into a lot since working on this book. And just since being curious about the universe in general, one of the things we really see very clearly in our observations of the universe is that it's changing. We know that the universe is expanding, that galaxies are getting farther apart from each other all the time, the empty space in the universe is getting bigger. And we can look far into the distance of the universe and see what it looked like when it was younger. Because when we look far away, we're looking back in time. So we can see what was happening billions of years of the past in the universe. And we can see that the universe was hotter and denser and smaller in the past.

And they had this big bang, this event where the universe went from being a hot, dense space, to being the sort of expanding universe we see today. And so the thing we learned from that is that the universe is evolving, is changing. And as we follow that evolution into the future, it sort of necessarily leads to a situation where everything that we know about the universe, all the things in the universe are kind of in some way going to end up sort of falling apart, or decaying away in the very, very far distant future. I mean, right now our universe is kind of very habitable sort of place. We have stars forming. We have galaxies interacting with each other, making new stars, but in the far future if the universe keeps expanding the way we see it expanding now, then those processes will slow down. There'll be fewer stars. And then fewer structures kind of in the universe in general.

And there are a few possibilities for what can happen as that carries forward. And there are some very dramatic possibilities for how the universe might end, but there's really no serious suggestion in the cosmological literature that everything will just kind of carry on just fine as it is now. The universe is changing, is evolving and it's evolving into someplace that's going to be more and more diffuse, and less and less capable of harboring structures like what we see out there now. And so there are various possibilities for what could happen next, but a kind of steady state universe was really ruled out early on in the '60s and '70s.

Tracey: [07:04](https://www.rev.com/transcript-editor/Edit?token=s8dBj2gC5T535jmDtv2dKyLvPO2ebc154_1JqHKgrM6B4tEH2a0EcxNHcOhVIHpVp-Vjx6SolxWS6ahCp7hfeygbdBE&loadFrom=DocumentDeeplink&ts=424.86) Well, as a citizen of the universe, that's kind of a bummer.

Katie Mack: [07:08](https://www.rev.com/transcript-editor/Edit?token=n-TXCij0CSb0XjLu6WbUIoWY9tPm7HEmhdEc3dw0KyRngUKsbTu-flf9a84f_6x1-wbXbuIZtxDrQnS47PK5ZT4j1es&loadFrom=DocumentDeeplink&ts=428.23) Yeah. Well, we've got to make the most of the time we have, right?

Tracey: [07:13](https://www.rev.com/transcript-editor/Edit?token=sDK3Cgt5dGK4wO0wM7Z2mCJZKyCWzAiFUsKVATk_8ljhIxfY5bMVBvXoYKdy-dCWs5VB0gPb5-EzBnu5B97g1xEBFV0&loadFrom=DocumentDeeplink&ts=433.17) Hopefully that's billions of years, right? So in your book, you outlined five potential universe ending scenarios.

Katie Mack: [07:22](https://www.rev.com/transcript-editor/Edit?token=GzXcRqgbPY8O6Cqh1okKN6vSflAmqKcbyEeXboEwx8n45Nw7nhyAn2M0MGtzQsgb1PerJml8erpCAY3xJGiyNITo4zY&loadFrom=DocumentDeeplink&ts=442.13) Yes.

Tracey: [07:22](https://www.rev.com/transcript-editor/Edit?token=Zb5BGHj3t3bHPjiiPg7ePxX0HQGgvKMXSs_8dIxgqlBFfc7Cb6ZH4sCy2JfW3dvd1bYHqhr-4vtcRZDSxHC9UnYrp1k&loadFrom=DocumentDeeplink&ts=442.61) So of those five ways the universe can end, which one is your favorite?

Katie Mack: [07:28](https://www.rev.com/transcript-editor/Edit?token=ZA8c_IgrIYhv_Pw6My34U507iGg5rjralXENTwA1_7Gw8jbiBxh6pLzk3zSA4eB9DBmAANibylUp5FQhkfcZz2MMdZU&loadFrom=DocumentDeeplink&ts=448.73) So I should make a distinction between my favorite and the one I think is most likely, because the one that's most likely is what we call the heat death. That's the one where the universe just keeps expanding and expanding, and things get farther away from each other and stars stop forming, and everything kind of fades into black basically. The universe sort of decays away into this cold, dark, empty space. That seems to be the most likely based on the data we have now on how we think about the equations and so on. But it's not the most exciting. A lot of people think it's a little bit depressing, this idea that the universe just kind of fades away.

The one that I think is the most interesting is called vacuum decay. And that's where basically you can have a kind of quantum event happen somewhere in the universe. And that event will create a bubble of a different kind of space. And that bubble can expand out at the speed of light and destroy everything in the cosmos. Now there's some subtleties as to why that could happen and how that could happen. It's very unlikely to happen anytime soon, if it were going to happen, and we're still not at all convinced that it can. But there are certain pieces of the data that sort of point in the direction that our universe is not entirely stable. And it has this instability built in, where that kind of bubble of this new kind of space, what we call a true vacuum, could form and could sort of expand and destroy everything.

And so the idea of this very sudden, very violent event is kind of fun to think about. As somebody who studies things that generally happen over time scales of billions of years, the idea that you can have this bubble form and expand at the speed of light and just destroy everything, is an exciting prospect, as much as it's also a very destructive one. But I should emphasize that even if that's possible, we think that it wouldn't be something that would happen for so many trillions of years that it's not even worth thinking about. But it is, as a physicist, worth doing calculations about. And so that's some of the work that I've been doing recently has looked at that possibility, and what we can learn about physics and about cosmology, by thinking about the possibility that the universe could be unstable to this sort of decay process.

Tracey: [10:02](https://www.rev.com/transcript-editor/Edit?token=yjiUolsrWulMnDG3ZvsqO9HrQB1B6HnIoxnv-Ni9O2fmZEzbRJ9ifigLgu7BsC3RVZc9so_TJ6t3UI1I5OBlJq9gHDY&loadFrom=DocumentDeeplink&ts=602.28) That would be such a bummer. I mean...

Katie Mack: [10:04](https://www.rev.com/transcript-editor/Edit?token=L1MpyROZTV1E7WfEtNWIKarSW3pzG0DY8T-jEyscKVWKiHKoVw9Bcg7NkXa0X0EBotNKK-j6lcKxu3pCVjNXSwZC8wQ&loadFrom=DocumentDeeplink&ts=604.08) You wouldn't notice it though. You wouldn't see it coming because if it happens at the speed of light, you can't see it approach. So you don't see it coming. You don't feel it because your nerve impulses don't travel that fast. So even if the bubble hits you, you don't know. So in some ways it kind of doesn't matter, because nobody knows it happens if it does. And it's a very humane process in that sense.

Tracey: [10:27](https://www.rev.com/transcript-editor/Edit?token=aOTy3Z_IQs8DWUAn2jLCsxWWVCaVv0Q0fKV-buIsi0Cj-rS6Aa7E1hJrgQ8iBmkuyn-fYWX2GHnjjkHxFxkAlI1Jd_4&loadFrom=DocumentDeeplink&ts=627.85) Universe euthanasia. Yeah. In some ways it's even worse though. You just wink out.

Katie Mack: [10:36](https://www.rev.com/transcript-editor/Edit?token=qbAWHJKFnkk_-HQTrDGVxUIz1iAJAWLTY5py8JojJ-JODePrZetla9rESl-C9dEioXrC9mDywyuV2zmo89vrHbMP98k&loadFrom=DocumentDeeplink&ts=636.08) I mean, it's like, I don't know, people have different opinions about which of these are most or least pleasant to think about.

Tracey: [10:46](https://www.rev.com/transcript-editor/Edit?token=dUhK6kFjae9GZ3e0XgRGivLK7TIzoqrgYevT3-E1Hr4oZcGdQxFBZM14t0skyW_V8DaktuflmjNJW23w0ncllbhkVWs&loadFrom=DocumentDeeplink&ts=646.75) So a long slow, sad process or boom, done. People like to have doomsday scenario timelines, right?

Katie Mack: [10:58](https://www.rev.com/transcript-editor/Edit?token=cyV8MM5nusrhKjzw0-P5fnumVWOz3n60c3uCaSptEBzL5K59wPBQdw8igoo_UYn4Vytf5ZxHoodCXtDE0I2YMCXqXmk&loadFrom=DocumentDeeplink&ts=658.27) Yeah.

Tracey: [10:58](https://www.rev.com/transcript-editor/Edit?token=OaGkuCC-oXJYWCT7j8rshcTgbuehiXDjXT_peiNDHNLzqOQx0J-QN3u96tEsyGr9uFk0m3yT9_JTxELRDwsGrQ7QAbs&loadFrom=DocumentDeeplink&ts=658.82) So all of these scenarios you're describing are like how far in the future do they think that will happen?

Katie Mack: [11:14](https://www.rev.com/transcript-editor/Edit?token=Db6ZY6a3KpEM6MBxw3sd-_6KsfnYIOi7yZt29COczdWqqdXQIEiLklvT-Whkl0SLwD07ErqttPfbTVNuy4xORGWrcYY&loadFrom=DocumentDeeplink&ts=674.27) Well, so it depends. So in the book I talk about five different possibilities. The heat death is kind of the farthest into the future one, because really, I mean it depends on how exactly you define heat death ultimately, because there's a sort of final state where the universe just totally decays into waste heat and there's really no structure left at all. And that process takes so long that we don't really have words to describe it. Even mathematically, it's hard to put enough exponents on what you're talking about to get to that number of years. But in the process of the heat death, there are a number of things that happen, like in 100 billion years, everything is so far away from everything else that we don't see other galaxies in our sky anymore. And you know, after a few hundred billion years, most of the stars are going to be dead and there aren't going to be new ones forming.

And so, you have these various degrees, these processes. After 10 to the 60 something years, the black holes that we know about in our sort of local space are going to evaporate away. And then maybe 10 to the 40 something years, that's the minimum lifetime of protons so that the particles would be decaying already by that time. So there are a number of sort of milestones you can write down, but we're talking about numbers that are so big that we don't really have a concept of them. But there are other possibilities that could be in principle sooner. So one of the things I talk about in the book is the big rip, which is this possibility that instead of the kind of gentle expansion we have now that is speeding up, but really just moving things apart from each other, not messing with things that are already sort of bound structures like galaxies. The big rip proposes a different kind of dark energy, where dark energy is what's making the universe expand faster, and this dark energy would be able to rip galaxies apart, rip solar systems apart.

And we think that's probably not what's going to happen, but we can put a minimum life span on the universe if we assume that that's where we're headed, and we get something like around 200 billion years, at least, before that could possibly happen. So there's still a reasonable amount of time, right? There's still... Already by then stars are dying out. There's not a whole lot going on. And then there are a couple of other scenarios where, because they're sort of less studied or less favored, we don't have such strict time scales on them.

So there's the big crunch, which we think is very unlikely to happen, where the expansion of the universe would turn around. Everything would smash back together, and we can't come up with any mechanism where that would happen within tens of billions of years. But we also don't think it's going to happen at all. So timescales on that are a little bit complicated. And then with bouncing cosmology scenarios, where you go kind of big crunch, big bang, or colliding universes or various things like that, those all depend on which scenario you're talking about. And again, the timescales on that are also a little fuzzy. But in general, we're talking many billions of years. And even with vacuum decay, even though it could technically happen at any moment based on the mathematics, estimates of the time scale on that are like 10 to the 100 years. So we still have a lot of time for that one too.

Tracey: [14:45](https://www.rev.com/transcript-editor/Edit?token=Q24lfUADq1HH8_BlRGuf5mBiw_rnIuKoFaRONfsfIdw7mxFDawPwEIZhQOpapmvSyAlwbzO3NJuZ3Z0gMS0vjzWSrR0&loadFrom=DocumentDeeplink&ts=885.05) So in other words, continue to fund your retirement plans.

Katie Mack: [14:49](https://www.rev.com/transcript-editor/Edit?token=_0ltIJ5PMpqSjH2h324OFGTY6Pfta9GOqnoxEHxUbgngCs3PX4n7tTCq1sKxjhqNu-O93ZmTior7c3DquHorqeLhh7E&loadFrom=DocumentDeeplink&ts=889.19) Yeah, yeah, yeah. You still got to take out the trash, even though the universe is going to end someday.

Tracey: [14:55](https://www.rev.com/transcript-editor/Edit?token=gY5lfQvyYVaus1Vp3VNK6oEhHqSe4JQvGrJu-c3Xfb8uLVvbrBvXV0jRmUN2WWVFKKjO0Jx4btrx5kjxkPlKxaXFuBk&loadFrom=DocumentDeeplink&ts=895.13) That's good to know. I'm also really a fan of the terms for all of these cataclysmic scenarios. The big crunch.

Katie Mack: [15:06](https://www.rev.com/transcript-editor/Edit?token=Jol-3tXvCnb_jPwTsKBvSYdK5msCl6-y-Qsw6DQBoZfUb-HCyvCOB5k1aQkmKA9r02yltcH7LKBeNJW_waFRUD_2Dxg&loadFrom=DocumentDeeplink&ts=906.27) Yeah. Astronomers, we don't usually come up with fancy names for things.

Tracey: [15:10](https://www.rev.com/transcript-editor/Edit?token=C7dFw3qiPY-Jz0YBloVXLqxAtqIGvqzTcjYczt1cJZFkQPIWHeQAkGQ1fCezgyk_XfdNYK4cNKVOZurafE2xSkoPZT8&loadFrom=DocumentDeeplink&ts=910.89) Yeah. I like it though. It's simple. It's direct. You kind of know what's going to happen. You can visualize this.

Katie Mack: [15:16](https://www.rev.com/transcript-editor/Edit?token=ZvlmY1mPuQwDbhFqBWqtht7LFVOmA2jE1suwrbQhq_CYnKiWfhZxu9jQV_qY0JszX_2pzf8E97AujS_h5HYwydAaRco&loadFrom=DocumentDeeplink&ts=916.81) Yep.

Tracey: [15:18](https://www.rev.com/transcript-editor/Edit?token=8BUaCCaVS5uOaYKuj6KJj1Fsq4gPVERsRXoREsIvpcy9_M2svEUY-wIz28SWPG36iTwSQ4jo9HIHL1OeapcmkjS65es&loadFrom=DocumentDeeplink&ts=918.66) What is the coolest thing you know about the universe?

Katie Mack: [15:23](https://www.rev.com/transcript-editor/Edit?token=ou_zoJ6mMsUcRMz1fr-LkYF5it5P5aHQpYKHlFxKkossvHhUMDlhf7mgVuPt6rZKRHOlGaUH7pm61gwbasfj6aGpetY&loadFrom=DocumentDeeplink&ts=923.1) I think the coolest thing about the universe is that we can see its beginning, so we can see the big bang. When we look out into the universe and we look at a distant galaxy, we're looking at the universe as it was when it was younger, because we're looking at something that's so far away, the light took a long time to get to us. And if we look beyond those distant galaxies, if we look far enough away, we can look at parts of the universe that are about 13.8 billion years into the past. Right? So from our perspective, like the light has taken 13.8 billion years to get to us. So we see them as they were in the very first million years of the universe. And we can see light from the time when the whole universe was this sort of cosmic fireball state, when it was this hot dense state of the big bang where the space itself was filled with this hot plasma and everywhere in the universe...

And during the big bang, the whole universe was hot and dense. It wasn't like a single point. It was everywhere in the universe was hot and dense, and it's filled with this glowing plasma. And then after a while, the universe expanded and that plasma cooled down. But we can see parts of the universe that are so far away that from our perspective, they are still on fire. And so when we look out into the cosmos, we see this background light coming from the most distant reaches of the universe. And that background light is the fading of that cosmic fire from the very, very first moments. I mean, it's lasted for 180,000 years, which is a tiny amount of time in the history of the universe. So we can see that from the first 380,000 years of the cosmos.

And so, we see that light from the very beginning, the sort of afterglow of the big bang. And we can use that to study how the conditions for galaxies and clusters of galaxies and so on were set up. We can see that there are little fluctuations in that background light. And those little fluctuations were little places where there's a little bit more density here in that sort of roiling, cosmic fire, and a little bit less density over there. And the places where there's more density, those are the places where you eventually get galaxies forming. And the places with less density, that's where you get voids forming. We can actually put the observations we see from this background light into computers and run that evolution forward and end up with the universe like what we see today, with galaxies distributed across the sky.

And I think that's amazing. I think that's the coolest thing I know about the universe, that we can see the past very directly. We see it because we're looking into the past and we look into the distant cosmos. We see the last stages of the big bang, and we can calculate exactly what that means for the evolution of the cosmos. And it matches what we see in the sky.

Tracey: [18:17](https://www.rev.com/transcript-editor/Edit?token=QdTDYSw-63DvLQsqjWOcYuJsO9enumsATKA1_ITujd2uOuGibxO--nb_qWEeHjhwlhxsaWYN9G3KWIw4mlhTv9dvKhs&loadFrom=DocumentDeeplink&ts=1097.67) That is the coolest thing, it's the closest thing we have done at a time machine, I guess.

Katie Mack: [18:23](https://www.rev.com/transcript-editor/Edit?token=ZkJR33WKK6XEaoi7hSshQB0Z4yYv_rRrnPvmFvTgYWgWx7hsnn0O-n-l62yfM769x02_J7Qxe8d1hyouokx09JkMwm8&loadFrom=DocumentDeeplink&ts=1103.59) Yeah, absolutely. Yeah. And then we can learn about what the universe is made of from that and how it's going to evolve over time, and all of this information we get from being able to look at the past directly.

Tracey: [18:36](https://www.rev.com/transcript-editor/Edit?token=GiNDCbQgfg-oFpgByTb03zlqUkjOU0iwEzFw9ra60Ek1_XycMFqVM2AbYIbmY6LBEppXLa7boJ8ZVOx3jtbb07HJ7Rg&loadFrom=DocumentDeeplink&ts=1116.48) That is amazing. That really is.

Katie Mack: [18:38](https://www.rev.com/transcript-editor/Edit?token=xu4gYl_dP5Ij7MQj9zV-jh8mVdCKyNXpQjHAebCwgVTgivFaouljeR5jmdlR3VSN6W5GpHoptX4X60RwoCSJg4_zYCw&loadFrom=DocumentDeeplink&ts=1118.42) Yeah.

Tracey: [18:39](https://www.rev.com/transcript-editor/Edit?token=l_X-Jfn42KlhgiY-IZ_V8ZbySZfMYvjDjLB0UjOqD_IoSGVAKKGKHCxeggm64rHg-SnuV-HbAoZcswigyczBolMBNT0&loadFrom=DocumentDeeplink&ts=1119.31) Well, Katie, thank you so much for being here with us today.

Tracey: [18:44](https://www.rev.com/transcript-editor/Edit?token=u__xAMl-2nwztIqYWgQ1siebZWGbNjFyAtO8jXgoUy2ypXdzsFkjYlgM6Ue5C3oKNg4jzLLUGK1QmAQvF8E1tNrkI7k&loadFrom=DocumentDeeplink&ts=1124.13) It's been great.

Katie Mack: [18:46](https://www.rev.com/transcript-editor/Edit?token=ket8ncYHoK-lIp844Lkvqsb9lldXtj05-aWrx1QKtpEwyWM-R5c3srJjgR7nVp7m7ny99gx8ztt0BThdyDxFTo6kCLc&loadFrom=DocumentDeeplink&ts=1126.74) Yeah. It's always great to talk about the end of the universe.

Tracey: [18:53](https://www.rev.com/transcript-editor/Edit?token=PWXVZGOEt7ZzC7Y6hpF9zM7VyFRCipDm4k5-AaUM5npgjvMtUJ9IoDa68MYp7y8Hpa4Pr55GbfwmxZVrfIux9KDF-VE&loadFrom=DocumentDeeplink&ts=1133.58) We've been speaking today with Katie Mack, an assistant professor of physics here at NC State. This has been Audio Abstract. I'm your host, Tracey Peake. Thank you so much for listening.