Physics Seminar

February 11, 2019

>>DR. GARRISON: All right. So I guess we'll get started.

All right. So first off, I guess you guys notice that we had a change in cast today. The speaker who was regularly scheduled, he couldn't make it. So, you know, this is normally the part where I'd be introducing the speaker. So I'm just going to introduce myself. I'm really proud to be here. You know, I'm really happy that I was invited to be here, although I'm a little disappointed that that was my second choice, so -- you've just got to go with what you've got.

So, you know, I wanted to give you guys a little bit of background on some research that I'm doing. And I thought that this was, you know, somewhat interesting, which is why I brought it up. And so I hope you guys enjoy this.

This is essentially some research about what we call the Biermann battery. And the Biermann battery is something that I found out about a while back. Let me just take you back a little bit.

So a few years ago, I had spent several years developing this numerical relativity code. The basic idea is that this code can solve Einstein's equations and plasma physics equations simultaneously. You know, which I thought that's pretty cool. But that also brought up a really interesting question: Well, what can you do with that? So I started looking at problems with cosmology because I've been interested in gravitational waves. And so my first thought was, I want to look at gravitational waves from the early universe, and that's still a big focus of this research.

But along the way, I realized that, you know, if you have this powerful code, you should be able to do more than just one thing with it. So I happened to -- I had gone to a conference. I gave a talk on some stuff that I was doing involving gravitational waves from the early universe, and I met this guy who was a researcher at Johns Hopkins. And he invited me, next time you're in Baltimore, come in to Johns Hopkins and we'll talk. So I went one summer I was there, and I went up to the Space Telescope Institute and met with him. And, you know, just as a chance to just talk and come up with other ideas on different research projects.

So I meet with him and it was interesting because, you know, after being at UHCL in a small physics program, I meet up with him and the first thing we did, we went to lunch. And there was another guy who was also visiting with him from Dartmouth. And there was also, you know, we're going through the cafeteria to get our lunch and there are two other guys joined us and they were both particle physics people. And so it was an interesting experience because, you know, this is -- I was surrounded by physicists in this cafeteria. If anyone can remember a scene from the Big Bang Theory, it's probably like that.

And then one thing that you do know or that you will realize as you go further in physics is that you can tell when you're in a room full of physicists because it's just the level of the conversations going on in the background are completely different than what you run into if people are into education or humanities or art or whatever.

And, you know, so there was sort of a focus, an intensity, and these guys were talking to me about general relativity and gravitational waves like people who had been focusing on that for their whole lifetime and they were really particle physics people, who after I had been talking to them, I recognized them from that documentary about the large hadron collider. These are those guys sitting next to me talking about Einstein's equations.

So after lunch we went back to the office and the guy from Dartmouth just happens to have this thesis that he pulls out written by a guy named Miller who had graduated the year before. And he had graduated and went into a job in industry and wasn't doing physics research anymore. But he had this idea where he looked at this Biermann battery and he studied it. And from that, he gave me a copy of the thesis, said this is something you can look at because I saw this thesis and I thought there's some room for improvement here. And so that's where this project really came from.

And, you know, just to give you that background because you never really know where the inspiration for the good ideas are going to come from, and they -- and there are a lot of smart people out there that can give you these great ideas that you will just never even see coming.

So with that, I like to start at the beginning. And I always like to start at the beginning with the cosmology talk because the beginning is really literally the beginning. And so in the beginning, you know, people would look up at the sky and, you know, this is just something universal throughout human history. We all look up at the sky at some point and we all ask the same question -- where the heck did all that come from? I mean you see all these lights in the sky, they're out there every night except in Houston when it gets so cloudy. But for the rest of the world, they see these lights and they see where they come from and you start to notice little things. You'll see patterns there and you'll see lack of patterns there. And, you know, where there's a cluster of stars here and not there and so on. And in this case you can see this whole big belt in the middle, but it's not completely neat.

And so what people did was they wanted to understand all this stuff in the sky and all these stars so they started building observatories. The first one here is Stonehenge. I think people know this was an ancient observatory. And the neat thing about it -- especially if you ever get to visit it, it's really fascinating -- is that these were some incredibly large rocks that just seem like they were in a place where there should not be really large rocks, and they're arranged in a perfect pattern so that on the summer and winter solstice, the light goes right through in a certain way. And it basically gives them a way of telling time. Like, that they could tell what time of year it was without GPS satellites, without digital clocks, without the Internet or anything. And this was really fascinating because it was also very useful. Because if you know what day it is, then you know when you can plant your crops, you know when you can harvest your crops.

And so they spent time studying the cycles of moon and they would study when the sun was in certain positions in the sky, and coming up with ideas about how the universe actually works. And then over time the technology got better and better. So you can see you've got tiny telescopes like what Galileo might have used and you've got space telescopes like the Hubble. And so the further out you look, instead of things getting clearer, more mysteries just keep showing up. And one of those is the mystery I want to talk about today.

So you take all these observations and ideas from different people and you start putting it together. And putting all these ideas together, that's where astrophysics come from and cosmology comes from. It's the basic, fundamental, let's put all these things together into some reasonable theory. And, of course, not everybody understands it. So you can see here -- I like this cartoon. You can imagine Kepler explaining his theory. So you see the orbit of the planet is elliptical. And the first guy says what's an orbit. And the next guy is, like, what's a planet? And the third one is, like, what's elliptical? So this is kind of how you feel when you're explaining physics to your nonphysics major friends. So we can all kind of appreciate that.

So what I want to do is I want to kind of break it down and just look at different parts of this theory in order to explain what the heck that is in the sky.

So right here I've got basically a picture of the entire history of the universe and the way I like to read this is to start at the top and work our way down. And you can see at the top you've basically got humans looking out at the stars in the present. And you can see that here are the stars. There are some galaxies. They're really far out.

And as you look through your telescope and you look further and further out, you're actually looking back in time because the speed of light is finite. And so it takes longer for the light to get to you. So that light has been traveling since earlier in the universe and if you look further and further out and this takes special equipment, then you'll see that the stars that were younger back then. And you can learn things about how the stars developed over their lifetime.

And you go back a billion years, and that's when the first galaxies were forming. So if you could actually look back a billion years or past a billion years, you don't even see galaxies. You go back even further -- sorry, that's a billion years after the beginning of the universe. So it's about 13 billion years ago. And you would not even see galaxies.

You go back further, and eventually you'll get to a place when the universe was about half a million years old. And that is really where the cosmic microwave background radiation comes from. You hear about the cosmic microwave background radiation all the time and they say we study this, so we know about inflation and we know about the early universe and we can tell everything about the universe from the cosmic background microwave radiation. That's not true. That's kind of a secret within science.

The general public doesn't really get that because that cosmic background microwave radiation was half a million years old or somewhere between three and 500,000 years old.

When something is 300,000 years old, that's not early or young. Okay? So relative to the rest of the universe, that's pretty early. But we can do better than that.

And so what happens is before that 500,000 years, everything we know about the universe had to be based on our knowledge of physics. Everything since 500,000 years could be based on actual observations. But if you want to actually go earlier, you have to use physics, you have to do some calculations and you're basing everything on what our theories are saying. So maybe it's true, maybe not. You know, depends on whether our physics is right.

So tradition with astronomy goes from today back to 500,000 years. Before that, if we start applying physics, we get to an era of nuclei. And that was when just the nuclei of atoms were around. There were particles flying around. And to what's really a plasma. You know, just like you would see plasma inside the sun or what they're trying to do a nuclear fusion. That's basically everything in the universe. And it was so thick that light could not pass through it. So all the light that's coming out since then, all the light that came out before that was scattered, and it all scattered off of something. All the light since then has come directly from the cosmic microwave background. So it's a little bit different.

Then if you can back to when the universe was only three minutes old and at three minutes, before that you get to the era of nucleosynthesis. You would have protons and neutrons, but you would not have protons and neutrons combined into a nucleus. So it's even more simple than that, it's and even hotter plasma. More energetic. So much more stuff is going on.

If you go before that, you get into the (inaudible), where there weren't even nuclei of atoms or even, you know, fundamental -- what we think of as fundamental articles like protons and neutrons. They were just quarks. And so these elementary particles were flying around and it has so much energy that you actually need to correct for Einstein's equations in order to understand what's going on. Like if you think about thermodynamics, you learn that thermodynamics is energy in the particles and what happens is if you get the stuff hot enough, that kinetic energy is so much, it translates into velocity squared and at velocity squared, it's relativistic velocity. They will experience time dilation because they're moving so fast. And that completely changes your picture of physics.

And then before that, there was this thing called electroweaker, where the electricity and weak forces were united into one force. So there was not an electromagnetic force and a weak force. They were combined. And before that you get into the grand unification and before that, you get into God nose what. Literally, this is the point where physics breaks down and you can't even say what was going on because our physics can't even handle it.

So the trick, we want to really understand, is we'd love to understand all of this stuff. But we're going to try to understand little pieces of it. Like you could see here that this little cone got a lot smaller around here. That was when inflation happened and the universe just expanded several orders of magnitude in a fraction of a second. What happened around here, this electroweaker, there was actually an event that happened here, the electroweak phase transition. Everybody's heard about Higgs Boson. That was the point in the universe where these Higgs Boson were everywhere. They didn't necessarily all decay all at once. But when they went through the phase transition, they froze out, they decayed and there was a huge mixup in the universe.

So it's really neat because we can go back and we can try to understand the physics and thanks to our computers, we can actually model some of the stuff going on in these different eras. And that's what I want to get into.

So, my focus here is on primordial magnetic fields. And the thing about these primordial magnetic fields is we tell there are these magnetic fields out there in the universe. There are magnetic fields that cross entire galaxies out there. We know they exist. We know about how strong they are now. But we don't know where they came from. Or when they came into existence. And that's a mystery.

And it's a real mystery because magnetic fields, you know, can play a big role in a physical system. So if you know when they came into existence and how strong they were and all this other stuff, you can tell a lot about the system. And so we believe that these primordial magnetic fields were seeded by large scale magnetic fields at the mega parsec field sometime earlier in the universe and I mean sometime between now and the beginning of the universe. So we've got about 13 billion years to work with. Somewhere in there the magnetic fields all formed.

And the thing about this that's hard is you can't directly observe a magnetic field. You can observe the effects of the magnetic field somewhat. But observing actual magnetic fields is, you know, not really very practical. And also these magnetic fields were formed in an event we call magnetogenesis. Where something happened, the first fields were created, and then they amplified the magnetic fields and even we got what we have today.

So the way we model this is we actually want to look at this thing called a 3D could you be. And you can imagine a donut as a good example. Where if you move around any example on a donut, you come back to the same point. So we try to model the code so it's periodic in the same direction. And if anybody wants a simple example of that, go back and play Pacman. You'll notice if you go through a tunnel you come out the other side. It's exactly like that.

And the reason this works for what we're doing is it's like we can take a little cube chunk of the universe and we can pretend that it is exactly like every other cube-sized chunk of the universe and that, if we model statistics on that, it will be the same statistics on the next one. And we don't have any boundary conditions we worry about because everything flows through the boundaries. It's like when something shows up, it's like it just came from the next cube. So it works pretty well when you're trying to model a homogenous system to use these periodic boundaries.

Also, because there's no boundary conditions to worry about, we could focus on the physics of the turbulence that's occurring and, you know, turbulence means everything is being shaken up. And so we can think about this as a surrogate for a fluid, because we want to focus on one little area in the universe.

And so what we're going to do is we're going to be modeling these things, I'm calling these the GMTDR equations. The longest word you will hear all night.

And these are essentially the Navier-Stokes equations. But the difference is Navier-Stokes is designed for a fluid like water and what these do is they also model magnetic fields. Now, in the traditional MTD equations, they're talking about a nonrelativistic fluid. But it's basically Navier-Stokes but they add some magnetic terms in there.

What we're doing is we've got a relativistic system and it's got to take into account all this relativistic stuff, like including the curvature of space time. Which is neat, because this code not only models this physics going on but it can also model the gravitational waves that will produce.

We can model both the three metric and the four metric where the four metric is all four dimensions of space time. The three metric is just the space part. If you can think about it as if you're watching a movie and you just see one clip at a time and that's the three metric. And the laps here represents how these little time chunks relate to each other. So, like, going from a clip now to a clip in the future and then another one in the future and so on.

You can also find -- you also can replace the properties of the fluid with this stress energy tensor. I'm not sure if you guys have talked about that much in your classes, but the idea is a stress energy tensor, it's a tensor which contains all the information about density and pressure and, you know, a lot of the other, you know, physical properties of the fluid. And so that ends up showing up in our equations, too.

And then we also have things like four velocity, where we know about three dimensions of velocity, you know, the X, Y, and Z components of velocity. But what happens in Einstein's relativity is that time is this fourth dimension and you can think of something like a moving object as if it's tipping its direction with respect to space and time, so you actually get a time component to something like velocity. And we keep track of that, too.

So these are the variables that I'm actually going to evolve. And as you can see, in a room full of physics majors, I can show these equations and nobody gets scared. If this were more of a general audience, I wouldn't be doing this because then people would be running out of the room afraid. But you can see here, this is the main things that I'm going to evolve. And the first one is called conserved mass density. And you notice it's basically taking the standard mass density but then multiplying it with some relativistic stuff and that's the three metric and the temporal part of the velocity of the four velocity.

And then I've got the momentum density, which is actually involved. The first term with the conservation of mass, that's kind of like evolving mass in a fluid dynamic system. The momentum density evaluation is like (inaudible) in the equation. In the Navier-Stokes equations, you're basically just evolving the density and the velocity of a fluid. So you'd be done after those two.

The next term is the energy density and you can see the zero, zero component and that represents the energy part of the stress energy tensor. And you can see that that term is the (inaudible), which is being evolved, and then there's the magnetic field and the magnetic field evolution looks a lot like it. And then we have the three velocity, which is the velocity we would observe as real people, and that falls in the evolution.

And then the next equations basically show you how you get that fourth component of velocity and the bottom equation is talking about where pressure comes in. So we can actually -- in this case pressure is actually calculated. And it is a function of density. And then this term epsilon is actually the specific energy of the system where if you take a density and you multiply it by a specific energy, then you get the energy density of a system.

And then we use this gamma law equation of state which means that pressure depends on this term gamma minus one, and gamma in this case is four thirds. So this would basically say that the pressure is equal to one-third the energy density. And we just assume that that's true through everywhere.

So these are the actual equations that the computer is solving. I left out the part where it might actually solve gravity -- (mic cut out).

(No audio).

(End of class)