Quark-Gluon Plasma

Daniel: [00:00:00] Hey, Jorge, you're a fan of oatmeal, aren't you? Uh,

Jorge: yeah, I've been done to eat a bowl every once in a while. So how

Daniel: hot do you

Jorge: like your oatmeal? Uh, you know, not too hot, not to cold, you know, maybe in the Goldy

Daniel: Naloxone. So then in physics terms, does that mean like hotter than the surface of Pluto, maybe colder than the surface of

Jorge: the sun?

Yeah, somewhere in there. That's kind of a big range.

Daniel: All right. Let's narrow it down. Maybe hotter than room temperature on earth, colder than room temperature on Venus. Yeah.

Jorge: I'm not sure which one's hotter or colder, but that, that sounds about right. Well, maybe

Daniel: we should use chemistry instead, like hotter than a frozen cube, oatmeal, colder than oatmeal

Jorge: plasma.

I, I'm not sure I should leave you in

Daniel: charge of my breakfast. I'm just trying to come up with creative menus for the Daniel and Jorge.

Jorge: I'm not sure I should leave in charge by lunch either.[00:01:00]

Hi, I'm Jorge a cartoons and the co-author of frequently asked questions about

Daniel: the. Hi, I'm Daniel. I'm a particle physicist and a professor at UC Irvine. And I'm not a fan of menu

Jorge: writing. Oh, have you had to do it several times?

Daniel: No. I mean that, I'm a critic of menu writing and I'm not often impressed, you know, those menus to have things like wild mountain raspberry sauce or, you know, they just keep adding adjective to everything to make it sound more impress.

Oh, I

Jorge: see. You just want, like what food, like , you know, menu options, food and

Daniel: dessert. That sounds pretty good. Yeah. Make it direct. You're like surprise me. None of this flower language. Yes. I'll order

Jorge: dinner, please. Why even have a menu, Daniel? Just go to a restaurant and just have him bring you food.

Daniel: That sounds great.

Actually, I would love to be at the chef's whim. Yeah, you

Jorge: don't have to make any decisions. [00:02:00] In fact, I could just put a tube down your throat and then you'd be out of there in five minutes. Eating is a hassle anyway. But anyways, welcome to our podcast, Daniel and Jorge, explain the universe, a production

Daniel: of iHeart radio in which we serve up the entire menu of all of the mysteries of modern physics and the questions about the nature of reality and our universe.

We serve up the delicious dish of all of our curiosity, about the way things work, how everything came together to form the universe that we know and love and how it may all fall apart in the.

Jorge: Yeah, because we try to nourish you with amazing facts about the universe and fill you up with nutritious and sometimes hot tidbits about our amazing

Daniel: cosmos.

The universe is quite a meal after all. It's more than an appetizer that's for sure. Yeah. It's

Jorge: more like a, a litter or brunch. What do you think? I think it's an

Daniel: all you can eat buffet. I mean, I could just keep going back and back and back until I blow up with physics knowledge.

Jorge: doesn't that violate the law of energy conservation and endless [00:03:00] buffet.

Daniel: Well, as long as the universe keeps expanding and my waistline keeps expanding, then we're all in harmony.

Jorge: Oh man. Wait wouldn't you turn into a black

Daniel: hole. Eventually my plan is to just Redshift my way down to weight loss.

Jorge: I see, right. It's a slimming color. Is that what you're saying?

Daniel: If I'm moving away at high speeds, then technically I have less energy.

Absolutely.

Oh

Jorge: yeah. And there's also like length contraction, right? As you're moving faster, you seem smaller, but only in one direction. So just make sure they get your good

Daniel: side. I'll rely on that when I whizz by the photographer.

Jorge: Right? How do they take your picture of you're going faster than this be of.

Do you actually post before the picture is taken? You know, the whole sequence of events here gets all, you know, relativity confusing.

Daniel: Yeah. I think we're confusing ourselves with physics and PR. I don't think they're a good

Jorge: combination, but it is a pretty wonderful universe full of many options for us to dive into and explore and taste.

I guess it's sort of like, there's a tasting menu and, and this is what this podcast

Daniel: is. Mm-hmm and the universe. So many [00:04:00] mysteries at so many different temperatures, you can study the frozen interior of crazy ice planets. You can study the hot, intense environment at the center of our sun. There are mysteries at all temperatures.

Oh, that's an

Jorge: interesting question. Uh, what is the range of possible temperatures in the roof? Right? Like you could have zero degrees Kelvin that's one extreme. Could you have infinite tempera? On the

Daniel: other side, we did a whole podcast episode about the hottest things in the universe. And another one about the coldest things in the universe.

So check those out if you're interested, but briefly we know that things can't actually get down to zero degrees Kelvin because quantum uncertainty requires things to always be vibrating. A tiny little bit. Quantum fields can never relax to actual zero, but you can get pretty close. On the other side, there is a temperature above which we don't think temperature really makes any.

It's called absolute hot. And it's sort of the maximum temperature you can have in which things sort of stay things above that quantum gravity has to take over. And we don't even really know how [00:05:00] to describe the universe at that crazy high energy density. Whoa,

Jorge: sounds like a vodka brand. Absolute hot . But what does that mean?

It's like when the matter particles are moving it close to the speed of light, it's

Daniel: more than just the particles moving near the speed of light, because velocity is relative. It's about energy D. It's about having things being really compact and also having high speeds. When things get really, really crazy compact, then gravity takes over.

But if you have really small distances, then quantum mechanics is important. And so it's sort of like asking the question, what is the state of matter at the heart of a black hole? We just don't really know and extrapolating to those conditions from our knowledge of the universe, doesn't really even make sense.

So absolute hot is sort of like a statement about, we can't really say anything above this temperature because we're pretty sure our theory would be

Jorge: wrong. Well, that's absolutely

Daniel: interesting. It is. And thermodynamics is very complicated. These connections between density and temperature, some of them break down our ideas of like what temperature is, and if you're interested in those questions and the subtle [00:06:00] connections between energy and density and velocity, check out our episode on what is the hottest thing in the universe.

Jorge: Yeah. So there's how hot things can get in the universe. And then there's how hot are the things that we've seen in this universe and things can get pretty hot as far as we've seen in this

Daniel: universe. Right? That's right. The buffet of our universe offers a lot of different things to explore from the temperature that we are used to sort of like between zero and a hundred degrees Celsius to hotter things inside stars or inside neutron stars, or sometimes even hotter tempera.

Jorge: Whoa, hotter than a star. Isn't a star sort of like the hottest, anything can get, right? Like at the center of the sun or the center of, uh, neutron star.

Daniel: No, it actually turns out that some of the plasma in between galaxies and in between stars can be even hotter because the particles are moving very, very high speeds.

But again, those guys are not very dense. So, if you put yourself in the inter stellar plasma or in the inter galactic medium, then you would freeze really quickly. Cuz there isn't a lot of [00:07:00] heat there, but the particles are moving really, really fast. So technically there are super high temperatures, but the hottest things in the universe are actually things created here on earth by particle physicists.

Wow. They are pretty hot. We are the hottest people in the universe creating the hottest things in the universe. we are too hot to handle. Yeah.

Jorge: I, I think that's what I mean. It's like, if you have a particle out there in space and it's moving it close to the speed of light, wouldn't technically the space around it be super duper hot.

Right. Cause temperature is sort of like about the average, like per particle, kinetic.

Daniel: Yeah. What we talked about in that episode, the definition of temperature is a statistical property. So it's something you can talk about for a set of particles. And most theorists say the temperature isn't defined for a single particle.

Like it just doesn't have a meaning. It's something, as you say, it's about the average motion of these particles, not the specific velocity of one. So what's the temperature of a single particle flying through the universe. It's not defined. Temperature is [00:08:00] something you can only really talk about for a set of

Jorge: particles.

What about, uh, the temperature for a hundred particles moving at the speed

Daniel: of light? I feel like we're gonna have this negotiation and you're gonna ask me what's the smallest number of particles for which you can talk about

Jorge: temperature. At what point can you say something is hot Daniel? So this is

Daniel: thermals and temperature is a macroscopic quantity.

It's something which emerges from the motion. Of microscopic quantities. It's sort of like the concept of value in economics. You know, what is the value of a certain painting? If there's only one person in the world, they can say the value is whatever they want. They have to be able to sell it. They have to be able to transfer it to somebody else.

So value in a market depends on there being like a bunch of people buying and selling something. So you can get a sense for the value. It's sort of the same with temperature. You can't have the temperature of an individual particle. You have to have the temperature of a set of objects. So there's no like fixed threshold where you can define temperature and the concept of temperature sort of loses meaning as the number of particles gets smaller and smaller.

[00:09:00] So what's a threshold. I don't know, a hundred is probably safe, but you're on the

Jorge: edge. Sounds like we need to write a new bestselling book called physics economics. .

Daniel: Sounds pretty freaky.

Jorge: But anyways, we are talking today here about something that is maybe even hotter than the inside of stars, something that is actually made here on earth by physicists.

So today on the podcast, we'll be tackling the question.

What is a cork gluon plasma? Boy, that's kind of a, a wor worth, uh, mouthful to say it is,

Daniel: but it's super fascinating because it lets us explore how the universe looks different at different temperatures. You know, the universe at its smallest scale of made of something we don't know, but as you crank up the temperature.

All sorts of really fascinating and interesting properties emerge, you know, normal matter or gases or plasmas, all these properties sort of arise from how these lower level bits come together. It's really cool to make the universe show you [00:10:00] like a new thing that it can

Jorge: do. Hmm. I think you guys just sit around and, and pair up different, interesting words together.

And then, and then that sets your research. You just like co glue on plasma. Sure. Let's go with that. Yeah.

Daniel: Next we're gonna look for like the cork tiger plasma. That sounds pretty cool.

Jorge: yeah. And maybe a, a hit Netflix show as well. but there's this an interesting state of matter something that's maybe hotter than the insights of neutron stars, which is a little mind blowing, but is usually we were wondering how many people out there tried heard of these three words put together.

Core glue on plasma. So Daniel went out there into the internet to ask people what the core glue

Daniel: on plasma. So thank you very much to those who volunteered to speculate on this question without the chance to Google it. We're very happy to know your thoughts. And if you out there listening right now would like to hear your voice on the podcast for everyone else to appreciate.

Please, don't be shy right to us, to questions@danielandjorge.com.

Jorge: So think about it for a second. What do you think? A qu glue on plasma? [00:11:00] Here's what people had to say. I don't know. I would guess that it has

Daniel: something to do with, for example, pressure or temperature being at such

Jorge: an extreme point that matter

Daniel: with the state of matter changes

Jorge: drastically and becomes something similar to well plasma or

Daniel: both Einstein condensate.

Well, the plasma is probably obtained when you have really high temperatures. So I guess this probably existed. in the early state of the universe. I don't know. Just a guess. A qu gluon plasma is a small unit of blood glued on to an organ to increase the absorption of oxygen. Well, I know the quirks are what make up the, uh, Neutron and proton and the gluons are what bind them together.

Using the strong nuclear force since they can't exist on their own without being closely bound, I would assume it's [00:12:00] the high energy state that. Glue ons are in that kind of bind them together, almost like a

Jorge: liquid adhesive.

Daniel: I'm gonna guess that a cork glue on plasma is when you have a high enough energy

Jorge: state so that the quirks can actually break out of

Daniel: their groups of three and roam around freely with glue ons, passing back and forth between

Jorge: these quirks.

I don't know if this level of energy is

Daniel: possible in our current universe.

Jorge: But maybe it could have been in the very early stages

Daniel: of the big bang. This is something that, uh, I heard it might be inside a Tron star, as far as I know, that's when you have a lot of energy and matter, basically, uh, the, the separation between protons, uh, breaks down and all these quirks just sort of mingle in like a soup.

Jorge: Quirky goodness.

Daniel: Oh, I know that it's a plasma of quirks and gluons really hot.

Jorge: All [00:13:00] right. It sounds like, uh, someone confused blood plasma with physics plasma. right. That's something in your blood, right?

Daniel: Yeah. Plasma is something in your blood, but that's totally different. That's just the same letters. That mean something completely different than sort of physics plasma.

So don't get a physics plasma injection. Next time you go to

Jorge: the doctor. That's for the vampire physic. To, uh, do

Daniel: research out exactly quirk glue on vampires. That's the next crossover event, but some

Jorge: pretty good answers here. I, I think most people sort of associate plasma with something really hot, I guess.

And then it, a lot of people here seem to know it's a state of matter. And so I guess you just kind of put two and two together. And so it's a plasma of quirks and

Daniel: goons. Mm-hmm, , they're on the right track in thinking that it's a new state of matter. Like another thing that matter can do another way the universe can operate.

It's one that really lets us explore deep and fundamental questions about the nature of the universe and the early universe and why we are all here.

Jorge: Yeah. But um, most people [00:14:00] seem to also, um, know that it's associated with temperature. And so that it's something really hot. So let's dive into it. Daniel let's, um, maybe take it back to the basics.

What is the basic definition of a core glue on plasma?

Daniel: So, core glue on plasma is an extension of our idea of states of matter. So you're probably familiar with solids and liquids and gases as different states of matter, you take the same basic objects in this case, atoms, right? Helium, hydrogen, neon, whatever.

And it's just a question of how hot they are and the temperature they are determines how they. So that's what the states of matter are in a solid, the atoms are bound together in a Latice, right? It's like a crystal where they're like not moving and they're squeezed together. As that melts, it becomes a liquid and the particles are free to slide around, but you have sort of constant volume.

And then if he heats up even more, the particles. Loosen up even more and they fly around freely and they're going everywhere beyond that. There's another state of matter plasma that people have probably heard of where you break things up even further. So you take the atom and now you crack it open.

[00:15:00] Instead of just having Adams flying around, you have the constituents of the atoms separating from each other. So the electrons leave the nucleus and go off on their own because there's enough temperature for them to like escape from the energy bonds of the nucl. So now you have charged particles. So plasma is like a gas, but with charged particles instead of neutral particles, which makes it much more complex and intense,

Jorge: right.

I think you sort of hit when you said, uh, that it's something escapes the bonds of something. And so I think that's a big thing in these, this idea of states of matter, right? Because you know, at the, at the end of it, it's all just particles put together in different ways. But there seems to be some sort of like transition points or things that either like stuck together in a certain way or not stuck together or not stuck together at all.

Daniel: Yeah, exactly. Sort of the whole universe is just like particles put together in different ways. And in the end you should be able to describe any configuration using like the most fundamental rules of how those particles work. We don't have those most [00:16:00] fundamental rules. We don't really understand the basic rules of the universe, but what we do have are these effective rules.

Like we say in this configuration, when things are stuck together, the most important thing are these bonds between the atoms and they can be described roughly using this kind of mathematics, fascinating things. As you say that there are these transitions when like things get loosened up and now you can use a different kind of mathematics to describe it.

Like the math of crystals is totally different from the math of fluids, from the math of gases. Right. And it's fascinating that there are these transitions. That's why we even say that we have states of matter, instead of just saying, Hey, look, we got particles and here are the rules. It's because these phenomena emerged just like we were saying earlier, that temperature is an emergent phenomenon at the property of many object.

The whole idea of states of matter of solids and liquids and gases emerges from what's going on underneath. Right.

Jorge: I guess what I mean, it's like, it's not something we're imagining, right? It's not like the universe is actually sort of like a, a continuous grade in between things [00:17:00] that are packed really close together and things that are just out there loose.

It's like the universe really does sort of like click into certain, uh, ways of arranging

Daniel: matter. Ooh, that's really subtle philoso Haval point. Whether this is our interpretation or whether this is inherent to the universe. It really depends on what you think about like the primacy of mathematics, whether it's part of the universe or just part of our thought, you know, we might, for example, meet alien physicists who think that like our definition of phases are nonsense and they have a different way of looking at it because different quantities are important to them.

And so I think it's not clear whether this is like part of the universe or just our description of it, but either way, it's something that's very useful for us. Right, because it's a way for us to simplify things and have like simple mathematical stories that work without having to every time go down to strength theory and do calculations from there.

Jorge: Right. It's not like the universe like actually changes or like the rules of the universe change. Like the, the universe is continues, you know, things don't like suddenly change, but it, there does seem to be sort of this interesting thing where like, when [00:18:00] Adams are sort of close enough to each other, then certain forces become more dominant.

And so then things, for example, click into place as a crystal. But if you sort of exceed some sort of energy level, then other forces are more important. And then the, the particles, the items don't arrange in crystals, they sort of arrange

Daniel: as a liquid. You're exactly right. And that's the most important thing that the universe is following the same basic laws the whole time, whatever those basic laws are.

And we notice these patterns, it's sort of like if you wanted to categorize books in the library, you know, all the books in the library follow the same rules. There's like sequences of words that follow each other. You're like, oh, these are dramas. These are comedies this one on the edge. I'm not really even sure.

Or somebody invented a whole new genre. Right. Where is a genre after all? It's just a way for us to like categorize things that we see patterns that emerge in writing things that work. And so in the same way, like faces that matter are ways for us to simplify a whole set of phenomena in terms.

Simplistic mathematical descriptions. And you might think, well, why can't we just use the most fundamental theory every time? And [00:19:00] you know, the answer is that we just can't do those calculations. It's really complicated. That same reason that you can't like predict hurricanes, even if you understand how drops work, because chaos prevents you from extrapolating from the very small scale.

To the very high scale. And also we don't even know if there is a fundamental theory, like maybe all of our theories, even like the ones about cos and leptons and the standard model. Maybe that's just an effective theory. The same way, like fluid dynamics is, and the ideal gas law, it could all just be like ignoring what's going on underneath because we can't see those details.

Jorge: Right. So, so far we have sort of four basic states of matter. You said, uh, solid one, which is when the atoms are sucked together, kind of in a, a grid liquid when the atoms are moving about, but sliding around with each other and then there's gas, which is when the atoms are flying around freely. But then there's the fourth type of matter, which is when the atoms start to break apart.

Right. And then you sort of have a gas of free flying, um, protons and electrons. Yeah. Protons

Daniel: and [00:20:00] neutrons and electrons. So you have atomic nuclei, you know, for example, if you have hydrogen plasma that is just protons and electrons, there are no atoms. There, there isn't really hydrogen anymore. Instead of every proton, having an electron pair.

Now the protons and electrons are just all flying around on their own. So they're not like confined to each other anymore. They can move freely throughout. And so that's what a plasma is relative to a gas plasma is sort of like a gas of charged particles.

Jorge: Right. But, but the nucleus still stays together.

Or the nucleus breaks apart in these, uh, atoms that are in the plasma,

Daniel: the nucleus still stays together. Like the protons neutrons are still bound together to each

Jorge: other. I see. It's just that the, in the regular plasma. The electrons separate from the nucleus. And so you have nuclei and electrons flying around like a gas mm-hmm

Daniel: Exactly. And that is a gas of charged particles. That's what a plasma is. And it makes sense that a plasma is hotter because in order for that to happen, you have to pump a lot of energy into those electrons so they can climb all the way up that energy [00:21:00] ladder. And eventually basically be. It's like you've given the electrons enough energy to reach their escape velocity from the

Jorge: nuclei, right?

It's like when you give too much sugar to a kid, they start to, you know, separate from their family. at the

Daniel: park. Exactly. They go into really fast orbits and then they're gone. We, but we see plasma in everyday life. It's not just like a weird idea. You know, the sun of course is a huge ball of plasma. So you see it every day, but there's also plasma down here on earth.

Like lightning has plasma. Uh, light bulbs have plasma in them. We create plasma all the time to do fusion research, like a Tomax and stuff like that. So plasma is weird. It's not something you can touch, but it is a part of our everyday life.

Jorge: Yeah. It's what makes up fluorescent lights, right? Like if you work in an office or anytime you go, the, any kind of commercial space, there are fluorescent lights and that's plasma, right?

Daniel: Mm-hmm , that's plasma and plasma is a different kind of state of matter because it doesn't follow the rules of gases. You need different kinds of mathematics. To describe plasma, it's called magni [00:22:00] hydrodynamics, and it combines electrodynamics, you know, the laws of how electrically charged objects, feel each other and push on each other with fluid dynamics hydrodynamics.

So it's massively complicated and it's one of the reasons that fusion research is really complicated. Because charged gases are very unstable and very hard to confine and very hard to do any calculations with as well.

Jorge: Yeah. They're very nasty. They even sound like a marble super villain with those names together.

And so, uh, so then that's when the Adam starts to break apart. So, but you can go even further maybe and break apart the nucleus. Uh, if you keep, I guess, pushing the temperature, pushing the energy of the system. Exactly. And

Daniel: so you can get to the next stage of matter by cranking. The energy even hotter so that you break even more bonds, as you were saying, states of matter are sort of defined by the transitions where you're breaking bonds and different things become dominant.

So the next frontier then beyond plasma is to break, open the nucleus and break, open the protons and neutrons inside

Jorge: of it. All right. Well, let's get to the next frontier of the states of matter [00:23:00] core glue on plasmas. We'll dive into that, but first let's take a quick break.

All right. We're talking about Marvel. Super villains, right? Daniel we're

Daniel: always talking about

Jorge: Marvel. Super villains. Yeah. It seems Marvel should be paying us or at least, um, funding a good part of our podcast. I guess they pay us in movies, somehow entertainment.

Daniel: I suppose so, but everybody else out there, who's not making a podcast is also getting those movies.

Jorge: So, but we, I guess we, we get to talk about it somehow. you go? We get to make like too, hopefully

Daniel: fair use man. Fair use. We get to make good jokes about it. Well, but

Jorge: the latest superhero here we're talking about, uh, is called, uh, core glue on plasma. And we talked a little bit about states of matter and how you can go from solid to liquid, to gas, to plasma.

This kind of plasma is sort of like the next level of a state of matter. If you take plasma and what you heat it [00:24:00] up even more.

Daniel: Yeah. If you take gas and you heat it up even more, then you can break up the next level of confinement. The next thing that's sort of making this up. And so if you take the simplest sort of thing, like protons and electrons and you take those protons and you heat them up, then you can break them open into what's inside them.

Right. And remember that protons are not fundamental objects. They're not point particles. They're actually made of smaller pieces that are inside them. The same way an Adam is made of nucleus and electrons. A proton is made of smaller bits and those bits are quirks held together by glue

Jorge: ons. Mm, but I feel like you skipped a step though, right?

Like we've heard plasma and that was NLE and electrons flying around. And if you heat it up at some point, the nuclei break up into protons and neutrons, is that called anything? Or do we just totally ignore that? Or is that also just a regular plasma?

Daniel: That would also be a regular plasma. That's sort of like vision, right?

You take a big nucleus and break it up into smaller pieces. That's FIS vision. That's something we can do breaking open the proton and breaking open. The [00:25:00] nucleus are related because breaking open a proton means cracking. The bonds between the quirks inside the pro. What's holding the nucleus together anyway.

Like why does a nucleus stick together? Cause it's a bunch of protons and a bunch of neutrons. That's only just charged particles plus charges in zero charges. Why does that any way stick together? It sticks together because of the bonds between the quirks inside them. And so anyway, you can sort of think of a nucleus is sort of like.

A really big quirky particle where all the quirks are held together, not just into protons and neutrons, but also those cos are holding onto the other quirks inside the other protons and neutrons to keep it together. So really what you wanna do to get a colo and plasma is just crack open. All those quirky bonds.

Jorge: Right, but I, I guess there is sort of a, an intermediate step is what I mean. It's like, you know, you have plasma with nucle and electrons and at some point you break open the nucle into protons and neutrons. Is there a state of matter where it's like protons still held together, neutrons and electrons flying around?

That

Daniel: would just be a plasma [00:26:00] there. You've taken heavier NCL and you've broken it down into hydrogen cuz hydrogen is protons.

Jorge: Okay. So then at some point you heat it up so much that the protons then start to break apart. Yeah. Then

Daniel: you can break open those protons. And so protons have three quirks inside held together by glue ons, but these are held together.

Really tightly, the energy of the bonds holding the proton together is much greater than the energy of the bonds holding the electron to the proton. So it takes much higher temperatures to crack open that proton. Yeah.

Jorge: It's a lot of energy. I mean, Even just to break up the nucleus is a lot, right? Like an atomic bomb is basically what happens when you start breaking up nuclear in, in

Daniel: atoms.

Exactly. And so in order to break up the proton into its bits, you need to get up to trillions of degrees. Kel. So five and a half trillion Keman is an estimate for the temperature of the next stage of matter. And that's what a cork Glu on plasma is, is to break open the proton. So the corks and the [00:27:00] gluons inside can now run free.

So just in the same way that a plasma is breaking open and atom. So the electron and then proton can fly free. Now you're breaking open. What's inside the proton so that it can run free. Wow.

Jorge: You're saying like you heat things up and things are moving and crashing into each other. So crazily that it actually like breaks open the protons.

Daniel: Yeah. That's basically like. The melting point of a proton, you heat it up to five and a half trillion, Kelvin, and there's enough energy for the cos to break the bonds of those gluons and to fly around free, you have a bunch of them all together, and you basically get a soup. You get a soup of particles that are not neutral in the strong force.

Right. A plasma is interesting because it's like a gas, but it's not neutral. Electrically. A core glue on plasma is like a gas, but it's not neutral in the strong force. What we call color charge. So you have a gas of colored particles. Whoa.

Jorge: Interesting. Well, you, you got a soup before, [00:28:00] but now you're saying like this, the bits of the super are now they were charged, not just with electromagnetism, but also the strong force

Daniel: color charge.

Yeah, exactly. They're charged in every possible way. They're charged in the weak force. They're charged in electromagnetism cuz they have electric charge and they have color. So they can now move freely. You know, cos are usually confined. They're like stuck inside a particle. Nobody's ever seen an individual cork.

Usually just like trapped inside a proton or neutron or some other kind of particle like a pion or you know, other Maison. But here now the corks can like fly free in the same way. Like electrons and a plasma are now flying freely. They're not trapped to an individual nucleus. The corks in a cork glue on plasma can now move freely all the way around, anywhere inside the plasma,

Jorge: like all by themselves.

Right. That's the idea. That they're not stuck to anything else.

Daniel: They're not stuck to anything else, but they're also not all by themselves. A cork by itself in space, wouldn't be a co glue on plasma. It would just be a cork and corks can't really be by themselves in [00:29:00] space. It would have so much energy. It would just pop all these other particles out of the vacuum.

A cork glue on plasma is when you have all huge density of particles, also all at high temperatures. And so they're sort of like happily living in this frothing vacuum.

Jorge: Mm, I see. Well, I guess maybe, uh, before we go further, just an, um, naming question, like why still call it a plasma? It seems like, you know, this should maybe get its own category of state of matter.

Daniel: well, you call it like a co luon banana.

Jorge: Yeah. Why not? If, I mean, if you're giving me the, uh, naming rights. Sure. , let's go with the bananas state of ma cause it is pretty bananas, right? Like the trillions of degrees, um, CEL suit that's, that's pretty

Daniel: crazy. It is pretty crazy. I like the name plasma because it borrows the concept of the plasma.

We're familiar with that. You're breaking things open and now you have charged objects, but they're just charged in another way. So it sort of like generalizes, the concept of plasma and the plasma we are familiar with should be called. Electric plasma. Um, and so this could be [00:30:00] called like a color plasma or something like that, but, you know, there's a relationship between the plasma we're familiar with and this kind of plasma.

So I think it works, but you know, whatever, I have a

Jorge: name, how about, uh, calling it plasma? Cause you know, it's a quantum cork. Plasma plasma. Yeah. What do you think

Daniel: plasma, that sounds like something that leaks from your wounds when they haven't been treated well

Jorge: but that that's good, right? brings up interesting associations.

I mean, it's better than coming up with a blood association.

Daniel: That's true. That's true. That is pretty weird. But this stuff is also super weird and super fascinating to study, you know, not only would it be really, really hot. It also is super duper. Like a cubic centimeter of this stuff, like a teaspoon, you know, would weigh about 40 billion tons here on earth.

It's incredibly strange stuff. Wait, I

Jorge: guess you're confusing me here bringing in density. Now I, I guess I think what you're saying is that this weird state of PLA, uh, plasma, which I we're [00:31:00] gonna call Cosmo now maybe only happens if you have that much density, right? Like you, the only way to break open a proton is if things are like, Super dense, right?

Because as you said, if you just have a protein out in space, it's not gonna split open. Or if it is split open into cos the corks is just gonna, you know, explode or disappear. So you sort of need this super dense state in order to have

Daniel: a Cosmo. Yeah. And remember that there's a tight connection between temperature and density.

If you can object to a certain temperature and you squeeze it, it gets hot. Right. And so increasing the density also increases the temperature. And so the conditions under which we have created core Glu plasmas are this temperature and this density. And also think in your mind of like that phased diagram, maybe you learned about in school, the transitions between phases are not just temperature dependent.

They're also density dependent, right? They're depend on the pressure. So for example, where water freezes or where it turns into gas, doesn't just depend on the temperature. It also depends on the pressure, the effectively the density of the [00:32:00] material.

Jorge: Mm I see. So when you're saying like, this is a state of matter, that happens when you things get really hot.

That's not quite the whole. Truth. Right? Like you have to get it both hot and dense in order to get Aqua.

Daniel: Exactly. A single proton flying through the universe at very high speeds or even a hundred of them flying at very high speeds. Don't get you Aqua . Yeah.

Jorge: Yeah. That keeps saying it. If you keep saying it it's gonna

Daniel: happen, it's gonna happen.

It's kind of growing on me. It's fun to say Cosma. Yeah, it doesn't make you queasy. no, it doesn't. And you're right. You need density and temperature. And so all of these phase transitions are temperature and density dependent. Mostly we think about them as temperature because that's the dominant effect, but there really is a two dimensional diagram.

You have to keep in mind,

Jorge: right. Or just one dial, which is the bananas dial, right? Like if things get more bananas, You know, as you take a, a solid and, and put it under bananas conditions, it's gonna melt, right.

Daniel: right. Well then the question is because there's a maximum temperature, absolute hot. Is there a maximum bananas?

Can you get to absolute [00:33:00] bananas in the universe? I don't know. You tell me. Is that basically what this podcast is about the search for absolute bananas.

Jorge: the absolute state of bananas. That's the, you know, most major religions are after that state of enlightenment. ,

Daniel: we'll get there one day, another a hundred episodes or so.

Jorge: Yeah. Yeah, it's a journey, but yeah, so aquas that is when things get so bananas that even protons break apart. And so you have this soup and, uh, you're saying that it's so intense that actually, if you try to like grow this or have like a whole sun full of. Cosma. It would be crazy would be like super duper.

You basically maybe even get a black hole.

Daniel: Yeah, I haven't done the calculations, but it would be incredibly intense. And the amount of energy to make a sun size blob of Cosma would be, uh, astronomical. Absolutely. We've only ever made super tiny amounts of it here on our colliders on earth.

Jorge: Mm. All right.

We'll get into whether we've seen it and what it all means. [00:34:00] But I guess, but the main picture you're trying to paint is that it's sort of like a quantum, it's not so much a soup, but like a quantum mechanical soup. Right. Like, because cos can't really be by themselves. So they need to sort of be around.

Gluons kind of for them to stick around. Right. And so it's very sort of quantum mechanical dependent, I guess, is what I mean. It's like, it's a quantum mechanical thing. It's

Daniel: definitely a quantum mechanical thing. And one of the reasons it's super fascinating is that we are forcing the universe to reveal a different kind of thing that it can do, you know, solids and liquids and gases.

These are all just like the dances of lots of tiny particles operating together. And it's incredible what emerges, you know? And so here we have forced the universe to show us another trick that it can pull off how many phases are. We don't know. Right. This is like an idea that came about a few decades ago and we achieved it, improved it and are studying it.

We don't know how many different phases of matter there might be and what each of them might tell us about the most fundamental picture in the

Jorge: early universe. Yeah. And I guess [00:35:00] what I, what I mean is that geek in a Cosma, you can't really keep track of one core. Can you it's like, it's all sort of like.

Bound together in weird quantum mechanical ways, but not as bound as in, uh, in the inside of a proton, but it's still sort of like, you know, it's all sort of entangled, I guess, is what I mean.

Daniel: They're all bound together and sloshing about, and there's a huge amount of energy. So you're constantly creating new quirks and anti quirks and then destroying them as well.

So in that sense, yes, like a frosting pile of

Jorge: these particle. Yeah. And it's hotter than anything that we've seen, right. Even like the inside of a neutron star is not as hot. That's right.

Daniel: It was the champion in our, what is the hottest thing in the universe episode, the neutron star interior might get up to like a hundred billion degrees, Kel, but core glue on plasmas.

So we think reach into the trillions. And so it might actually be the hottest thing in the universe, unless of course. Alien particle physicists are even hotter than we are. And they've reached absolute banana .

Jorge: Maybe they are bananas [00:36:00] which automatically makes them hot, I guess, depending on how hungry you are.

Daniel: Hold on. If aliens are bananas, then what's their favorite snack. Is it podcasters?

Jorge: let's hope not. Maybe they have a whole podcast where, um, they joke around about eating or whatever cartoonists . Yeah. Or physic. Well, I guess then the question is, can you have Aqua a quar glue on plasma naturally out in nature?

Like, are, can you imagine anything having that like, or would you have to like maybe go inside of a black hole for that?

Daniel: Oh, we don't know what's going on inside a black hole. It's possible that you get that kind of thing there. We also don't know what's going on at the heart of neutron stars. It's also very hot and very dense, probably not hot in dense enough to make Corco and plasma.

But still uncertain. However, we do think that there was a moment in the history of the universe when everything was a cork glue on plasma, when that's all there was, and the whole universe was nothing but plasma you mean like at the big bang? [00:37:00] Yes. Very early on. Before there were particles before there were protons before there were bananas, there was plasma.

All right.

Jorge: Well, let's get into more of the big bang and whether or not we've recreated this plasma or core glue on plasma here on. But first let's take another quick break.

All right. We're talking about Cosma, the latest, um, Marvel super villain that we just made up all rights reserve. I think, I think it was one of the infinity stones. Maybe the Cosma stone,

Daniel: the Cosma, the stone. You know, we got a question on Twitter yesterday. About how I laugh at your jokes and whether I'm actually laughing every time, or if I have a button I press over here to just like generate the same chuckle over and over again.

Jorge: because my jokes are so bad. Is that the ideal? I dunno. Oh,

Daniel: I don't know. Or maybe [00:38:00] I just laugh the same exact way every time and it sounds suspicious, like a laugh

Jorge: track. Mm. I see. Well, I have a button right here. It's my whoa button. whenever you say something, mind blowing, I just go, whoa. The same, the same

Daniel: way somebody should sample that and make a song just based on my laughing and your what?

Jorge: Yeah. Yeah. I will not be, uh, listening to that. it makes me very queasy in cosmic. We're talking about quad glue and plasma, which is, I guess, sort of like a fifth state of matter, or would you say it's still part of the fourth

Daniel: state of matter? It's definitely its own state of matter. How many states of matter there are, is another question, you know, like does a Bose Einstein condensate count as a state of matter?

Some people would say yes. So the number of states of matter is a little bit fuzzy, but this is definitely its own thing.

Jorge: Right. And you said that it doesn't happen, or maybe it probably doesn't happen at the center of neutron stars, which get up to, you know, hundreds of billions of Kelvin, which is kind of crazy to me because at neutron star is basically the, like the hottest thing [00:39:00] in the universe right now.

And it's like one step removed from a black hole. So you're saying like a qu glow plasma basically sort of can't really happen naturally in the

Daniel: universe. Yeah. If you think humans aren't natural, then it can't really happen. Naturally. We think that at the heart of neutron stars, there are still neutrons, right.

That the protons and electrons have been squeezed together. So electron is forced inside the proton and basically converts it into a neutron. And then what you have is a very powerful soup of neutrons with very strong forces that we struggle to calculate and to understand the pressure and the density and all that stuff.

We did an episode recently about nicer, which is a telescope, trying to study the interior of neutron stars specifically to answer that question what's going on. And it's so hard because the strong force is really tricky to do calculations. But we don't think that the pressure and temperature inside a neutron star are hot enough to actually break those neutrons up.

So you have like essentially one big object. You can think of a colo plasmas as sort of like a super particle where all [00:40:00] the quirks are all bound together, you know, into one big object, cuz they're all feeling each other or conversely, you could think of like a proton as like a tiny little serving of co glue on plasma.

Jorge: Mm like a little teaspoon of it. What about like in a supernova? Like if a star explodes, could you have a little bit of a, of aquas moment momentarily?

Daniel: Potentially you could get collisions, right? The way to make a core glow in plasma is to recreate super high energy collisions. And we do that here on earth.

And so it's possible that there are core glue on plasmas produced in supernovas. It's also possible that there's tiny amounts of core glue plasma produced. When cosmic rays hit the atmosphere, remember super high energy protons or iron nuclei are hitting the atmosphere all the time. So you strike it just right.

And you might get flashes of co glue on plasma.

Jorge: Whoa. We could be like being rained down upon.

Daniel: By Cosmo. exactly Cosma rain. I think that was a song by prince, right? Yeah. Well, the

Jorge: artist formerly known yes. As prince. Yeah. Just like [00:41:00] Cosma is the state of matter. Formerly known as the core glue on plasma.

Daniel: Exactly. well, we sound

Jorge: so hip. Yeah. So, um, I guess, um, you're saying it happens in collisions and so you make it basically at the particle Collider there in Geneva. We do

Daniel: make it, but you can't make it by just smashing protons together there aren't like. Cos and gluons in there. What you need is really much more like a soup.

So we make it when we collide heavier stuff, our Collider is capable, not just of accelerating protons, but also of accelerating things like lead or gold nuclei. You strip away all the electrons again, just by heating it up. You have like a gold or lead plasma. You take all the positively charged stuff you put into the accelerator, you zip that around a really high speed and you smash it together and you make this crazy soup of quirks and gluon.

All smashed together. And so people have been doing that for decades and trying to see if we can make a cork gluon plasma very briefly in the Collider. Mm.

Jorge: I guess if you just smash protons together, like [00:42:00] if a proton smashes another proton, you will get sort of a, a soup of corks and glues, right. It just, maybe won't last, very long.

Or it'll just fly

Daniel: off. Yeah. There's not really enough there to make the density you need, you can break protons open by smashing them against each other. That's what we do. When you get core quirk interactions directly, you don't really get this new state of matter, the same way. Like, you know, two particles don't make a gas.

To define this state of matter. You need the temperature and you also need the density. And then it has to follow these new rules of this state of matter. There are like equations that define what happens in this state of matter. So quirks can sort of like float around freely. That doesn't happen when you just have two protons smashing into each other and maybe even like trading Coks the Coks don't have a chance to like, Muck around and do all sorts of interesting things that they couldn't otherwise

Jorge: do.

I see cuz when you're smashing, I guess as you smash two protons, you really only have six Coks to play with. And I think what you're saying is that, you know, six QUTs still make a Cosmo.

Daniel: It's sort of like if you have two cars, people can swap cars. And that's what happens when two [00:43:00] protons collide like two corks go over here.

Two Coks go over there. What we're talking about is more like you got two buses and everybody gets off the bus and has a party and that's pretty different than people just like swapping cars. And so it's the physics of that party between the quirks, when the quirks can really fly around free, that makes it a co glue on plasma.

Right.

Jorge: And you're saying that you can do that in the Collider by smashing gold nuclei together. And so what's going on like this nuclei smashing to each other. And all the protons and neutrons inside of those nuclei break apart. And then you have that cork party for a little

Daniel: bit. That's what we think happens, but it's really tricky to figure out if that's what's actually happening.

Because even if you don't get a cork glue on plasma, when you smash two nuclei together, you get a big mess, right? You destroy both nuclei, you get a protons and neutrons and all sorts of other things happening. It's sort of like you have. You know, 80 proton collisions on top of each other, all sorts of crazy stuff is made.

So to figure out whether a cor glue on plasma is made or another big kind of mess was a big challenge and required a lot of subtle [00:44:00] sort of statistical analysis and thinking about like what that cor glue on plasma does for the brief nanoseconds that it exists. And how you can tell

Jorge: that it was there.

Right? That's the other thing about it, cuz it's a little weird that you would call it a state of matter because it basically doesn't last, right? It's not actually a state. It's more like a, like an explosion maybe, or like a crash that you, you know, pause in the middle kind of, because you know, you form, you smash these gold nuclear together, everything SMUs together.

Then the corks are sort of like floating around briefly, but it's so crazy in bananas that it just all flies off and explodes immediately.

Daniel: Almost not quite immediately. We think it lasts for long enough to do some sort of cor gluon plasma E kind of stuff. And that's why we concluded that it's there.

There's a real thing that actually is a state of matter. Cause it lasts long enough to produce effects that you can't otherwise get you're right. That doesn't last very long. And unless it's surrounded by other colo and plasma, it will definitely just expand and cool. And then just turn into a bunch of particle.

Right. So it doesn't last for very [00:45:00] long, but it does last long enough to do unique things. Things you can't see without a core glue on plasma. And that time is short, but not zero,

Jorge: right? Like maybe it's for a brief, you know, nanosecond, it, it follows the rules of Aqua.

Daniel: Exactly. And one of the things that Aqua can do that a plasma can nod is that it seems to have, for example, a very, very low Visco.

Like these things act like sort of super fluids. ORs can like move from one side to the other without facing sort of any resistance at all, which is very confusing because quirks have very strong interactions with each other. And so this is like property that just sort of like emerges when you have all these quirks in this crazy,

Jorge: condition's like a party.

Like everyone becomes more uninhibited they do exactly. You're saying it lasts like a nanosecond. How long does it. When you do it in the Collider,

Daniel: it doesn't last for very long. We're definitely talking about times less than a picosecond the precise lifetime depends a little bit on the energy and on what went in, but we're talking about SuperDuper tiny [00:46:00] amounts of time, less than 10 of the minus 12 or 10 of the minus 15 seconds.

But I

Jorge: guess you could still claim that for that brief amount of time you created a, a. Core Glu on plasma.

Daniel: Yeah, exactly. Because we've seen evidence of it, like they can do calculations and they predict what a co Glu on plasma can do. Like this low viscosity condition or the kind of particles that shoot out of a cork glue on plasma cor Glu, and plasma has its own special density.

And so it tends to like stifle particles from flying out. If you didn't have a Corloo plasma, you tend to see like more particles flying out at weird angles. And if you don't see that it suggests that you probably did see a colo on plasma. It like quenches the emissions of some of these particles. And that's one of the signatures that led them to conclude that they really had created this thing.

At the large hedge on Collider.

Jorge: Mm I see. It's like if, uh, if you didn't have the Cosma, things would just fly off. Like they would just kind of bounce off each other, all this stuff. But if you sort of do click into this new state of matter, at least briefly, it's gonna change [00:47:00] how the things, the thing actually explodes.

Daniel: Exactly. And it does other really weird stuff like changing. Into a new kind of matter changes. Also the temperature of the thing in a really weird way, because remember temperature depends not just on the velocity of the objects inside you, but also on the number of ways that they can wiggle. If you've done any statistical physics, you know, the temperatures related to the number of degrees of freedom, which means like, can you have vibrations?

Can you have rotation? And a Corloo plasma has more ways to wiggle cuz you've broken the particles up into their constituents. And so actually what happens when you create a Corloo plasma is that the temperature goes up briefly because now you have more degrees of freedom, more ways to wiggle.

So the temperature is like has a new definition and it goes up and then of course it very rapidly cools.

So there are these very strange thermal effects of a cork glue on plasma. Whoa.

Jorge: It gets like even more

Daniel: bananas it gets exactly it approaches maximum banana. And in the end, it's something that we want to understand because we do [00:48:00] think that our whole universe came from a cork glue on plasma that in the very early days, the energy density was so great that before protons and neutrons were made, everything was just this big soup of cos and Glu.

And you know, how they came together to make particles really determines how the universe is shaped. Like the reason we have protons and neutrons, the reason the protons and neutrons have the mass that they do is because the power of the strong force to bind them into these particles. So it's something we'd really like to understand.

Something, which will really reveal the whole structure of the matter of the universe that we enjoy.

Jorge: Right. Like I think if you sort of like hit the rewind button on the universe, you start with now, which is like, things are solid and liquid and gas and some plasma here and there. But as you turn back time towards the big bang, closer to the big bang things sort of were all plasma and even closer to the origin of the big bang than things were plasma.

Right. That's I think what you're saying, it's like before there was plasma and stuff and. Planets and things like that. Everything was just, [00:49:00] uh, a big co blue

Daniel: on soup. Yeah. And who knows? What's beyond that, like what's beyond plasma, maybe Bema .

Jorge: There you go. Can we, can we get credit for coining it

Daniel: Bema? I don't know.

It's gonna create a coin, big Bema bigs. That's their new theory of the origin of the. Jokes aside. Yes, exactly. As you crank back time, you go up in temperature. And so you reveal that the universe went through these phase transitions, and we think that there are even more beyond plasma where the rules of the universe are effectively different, right?

In every different temperature regime, the rules of how things work, tend to change. You know the same way that like the rules of solids and gases and liquids are different from plasmas and plasmas and BES, the effective laws of the universe are different. We don't know what the fundamental laws are. If there's like a highest temperature, there's a deepest level.

Or if it's just like an infinite stack of effective laws, but we like to learn what those laws are and understand [00:50:00] them as far back as we.

Jorge: Right, because I think you do have sort of ideas for this asthma, right? Like closer to the big bang is kind of when, like even the quantum fields start to melt together,

Daniel: right?

Yeah, exactly. The very rules of quantum theory change. And for example, the weak force is no longer weak, like aquas exist when there's already a Higgs field that tells the quirks how much mass they have at some time, the very early universe at very, very high temperatures. The Higgs field hasn't even relaxed to its low level.

And so particle masses aren't even well defined at some point, all particle. Have zero mass in the very, very early universe. So the effect of laws of how things work are completely different. That's not something we can achieve in our colliders today. Of course.

Jorge: Well, but it's interesting to think that maybe, you know, right now you're smashing these things together and you're getting to this core glue on Cosma.

Is it possible you think that one day you'll smash things together so much that you'll actually like get to thatas level where even the quantum fields are getting melted together, it's possible

Daniel: because cork could be made of even smaller particles [00:51:00] and they could be bound together by something else. So if one day we can smash open cos and see what's inside them.

Then eventually, maybe we could smash corks together at such high speeds that we could make a plasma of whatever's inside. Cos we have no idea if those particles exist and what energy would be required to make that sort of next level plasma. We don't know, but in theory it's probably possible. And you know, the structure of the universe seems to be hierarchical.

It seems like as you get down to the smaller and smaller pieces, it's always made of something smaller, which is made of something smaller. It's very unlikely. We are now at the smallest level. So it's very likely that quirks are made of some smaller things. So in principle that state of matter can exist and probably did exist in the very early universe.

Well, it must have, right? Yeah. We don't know. We don't understand. And at some point. Our whole theory of quantum mechanics breaks down because gravitational effects start to be important because the energy density's so high. And at that point, you need a theory of quantum gravity, which we just don't have.

And so that's when you get to like absolute hot and beyond [00:52:00] that, we just can't even predict what matter, or, you know, the universe itself would be like,

Jorge: Right, right. You need theory. to peel away at the secrets of the universe to

Daniel: slice it up into your very hot oatmeal, slip it through

Jorge: that, you know, moment of, uh, truth.

And

Daniel: it's really the forefront of particle physics, because it's the thing that we understand the least the strong force is the strongest force, but it's also. The hardest to probe because it's so powerful that almost everything around us is already tightly bound by the strong force. For example, electrodynamics has been tested at like one part in a billion.

The weak force has been tested. Like one part in a few thousand, the strong force has only been tested to like one or two parts in a hundred. So it's the thing that we understand the least, but it's maybe the most important part of the. So cor glow and plasmas is super awesome because it lets us test our understanding of the

Jorge: strong force.

Right? Yeah. It's pretty amazing that like, as humans who are a product of the universe, we've been able to re, or at least you have been able to recreate, you know, [00:53:00] conditions in the universe that are closer to the big bang than anything. It exist in anything, uh, existing out there, basically in the. Like the universe itself, hasn't been able to go back to that state probably, but like humans playing around with, um, some magnets that can, yeah,

Daniel: we think that the cor quo and plasma probably existed at like 10 to the minus 10 seconds after the big bang.

And very briefly, only for like maybe 10 to the minus six seconds. So it's been a long time since the universe has been making this stuff. So, yeah, maybe it's sort of like nostalgic, it's like, oh, I remember that. That was cool.

Jorge: or May's going, what are you doing? you're gonna kill us all one

Daniel: of the two maybe, but we'll learn something

Jorge: along the way.

All right. Well, that's, um, core glue on plasma, which we are calling in this episode. Plasma. Again, we totally made that up. don't go to physics conference with a paper titled co unless you, I guess, give us credit. Yeah, good luck with that. But it is interesting to think about kind of all the different states of, uh, matter that [00:54:00] matter and, and energy in the universe can take.

Right. It's almost like it likes to, um, play around in, in, at different

Daniel: levels. Yeah. And it's sort of another way to explore the universe instead of taking one particle apart and looking inside of it. And then looking inside of that one, it's like, let's make the universe reveal the different kind of dances that it can.

What happens when you take a lot of particles and squeeze 'em together, what mathematics emerges that can describe that in a simple way. It's mind blowing to me that it's even possible. You know, why are there simple mathematical rules to describe how gases work? It should be incredibly complicated. It should be like chaos that emerges from string theory.

It should be impossible, but for some reason, our universe is describable in terms of simple mathematical rules at lots of different levels. And here we have found another.

Jorge: right. Well it's because, uh, these forces have sort of different ranges, right? Like some forces are important at the microscopic level and some forces are more important at the, at the grander level.

And so you, you can have these sort of rules. Describe it right. [00:55:00] You

Daniel: can, but it's not always possible. You know, why are hurricanes hard to describe because it's a chaotic combination of lots of smaller things. Even if there is just one rule describing how drops interact, it's not trivial to describe the motion of billions and trillions of drops all together.

It's chaotic, it's hard to model, but sometimes it's not. Sometimes you can find a simple mathematical story that summarizes the important bits and ignores all the detail. Why that happens is a mystery to me, but I'm glad that it does. Yeah.

Jorge: We'll leave it to the hurricane plasma or harassment physicist to figure.

Daniel: I think we've coined enough terms for today. So we better wrap

Jorge: up yeah, we reach our allowance. our heart's gonna be like, all right guys, wrap it up. All right. Well, the next time you look up at the sky or the night sky, or even the day sky, think about all the craftman that's being maybe formed out there and raining down upon you, showering you with little bits of matter that hasn't existed since the

Daniel: beginning of the universe, and think about all the amazing and crazy things that our universe can [00:56:00] do and all those things that you can taste on the buffet of the universe's.

Thanks

Jorge: for joining us. See you next time.

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