Physics Enrichment Session

Wed, 8/18 1:50PM • 1:50:02

SUMMARY KEYWORDS

dark matter, mass, particle, atoms, force, gravity, electromagnetic force, interact, objects, question, universe, galaxy, wimp, big, turns, chat, star, matter, squared, physics

10:10

Hi everyone, good afternoon. I'm just going to give it a few minutes for everyone to join. That's all right.

10:55

Thank you for everyone joining out, let me give it another 30 seconds or so. People who are still yet to come. Okay, while we're waiting, can I just remind everyone to please not have their full name and assume name so if you could kind of replace your surname with your first initial, that will be garbage just for safeguarding reasons. Thank you. Okay, I reckon. Let's get started if that's alright with Hannah.

11:43

Yeah, yeah. Okay. Hi everyone, my name is Hannah and I am doing a PhD in theoretical physics here at the University of Cambridge, and I am super excited to be here with all of you today because I'm going to be sharing something which I think is really cool. And hopefully you guys will also think is really cool, and you may have had to go if you did do the preparation reading Iset, you may have had a little, you may have an idea of what I'm going to talk about if you, if you haven't, don't worry. You'll have plenty of time in the session today to get to grips. So the idea of today is to introduce you to something cool, give you practice of using some kind of techniques in physics and maths that will hopefully help you get prepared and ready for when you start studying your A levels. Okay, so the first thing I'd like you to do is just take a look around you and think about what you can see, okay. Now, everything you can see, in my case, pretty boring like cotton. Everything that you can see, the reason you can see it is because light has reflected off that object and entered your eyes okay so everything that you're saying, has interacted with the light around you. Now, it turns out that 85% of matter in the universe. Can't do that. Which means we can't see it. Okay, which is really really quite bizarre. And this has led to the concept of something known as Dark Matter. And you may be thinking, Well, okay, what is this dark matter then why can't we see it, why can't Why can we see normal stuff on why can't we see this dark matter and that's something which we are going to talk about today. So it turns out that when things interact with light when stuff reflects off light, what I mean. So when light reflects of objects. What I mean is that light is actually interacting with the object that's what an interaction is okay interaction is just some, I don't know how you explain it interaction without using the word interaction and interaction is just some interaction between two things, okay. And so this dark matter. Not only do we know that it's out there, but we don't know what it is. Okay, so any of you that are sitting there thinking, okay, you've told us this stuff that's there that we can't see what we don't. What is it, well, you're absolutely right because even the top scientists in the world today do not know what this dark matter is. And this is kind of our job as physicists to try and find find out what this is. So, you may be thinking, Okay, so we've got you're telling me this stuff's here. Well, How do I know it's there. And how can I try and work out what this stuff is. And this is all boils down to interactions. Okay, another word for interactions in physics is force. So when I say that two things interact. All I'm saying is that they're able to put forces on each other. Okay, so for example I can interact with a table by pressing it. I'm able, that just means I'm able to exert a force on the table. Okay. When I say that an object, interacts with light. For example, it's able to reflect light, all we're doing, all we're thinking of is that object is causing the light to change direction okay something changes direction, it's got to have a force acting on it, hopefully you've done Newton's laws in a GCSE and you should know that things will be moving things move in a straight line unless they have a force acting on them, okay, if there's a force acting on an object, then it will change direction. Okay, so when we're talking about things reflecting light, we're talking about being able to exert a force on like so it sounds like forces are going to be quite useful in our study today so we need to think a bit more carefully about what forces are okay, in physics, physics we can kind of think of physics, as

16:09

well I always think of physics, as a way of describing what we can see around us with Maths. But on a more fundamental level physics is basically just the study of forces in energy. Okay, so we're gonna have a little think more about what we mean by force. And it turns out, you probably used to dealing with forces in a GCSE is right, you probably your teachers telling you, oh this is a frictional force. This is a gravitational forces and the electric force, your teachers, actually, are absolutely right. But it turns out that all of these forces that you you've been used to thinking of like buoyancy force friction air resistance, everything like that. They can all be classified as one of four fundamental forces. So in the universe there are actually only four very fundamental forces and these forces are electromagnetism, what's known as the strong force, the weak force, and the gravity and gravity, and you're probably thinking strong and weak well I'm pretty bad maybe So as you'll see today physics, physicists, physicists are actually really bad at naming stuff, but we will get more onto that, as we get through today. But anyways, we've got these four forces and actually everything that you're used to. Friction buoyancy, all of them. They're all class at one of these four types, now it actually turns out that everything that you've heard of in your kind of normal like day to day life or even a GCSE physics, apart from gravity, they're all actually just a type of electromagnetic force so things like friction. That's just electromagnetic. Okay, so it's actually the same. It has the same is the same fundamental force that causes friction like when you rub your hands together, but it's causing. For example, two positive ions to repel each other. It's actually the same force. And it turns out that if force, if things want to interact fire a certain force. They have to have the right passcode. Okay, so when you reuse the idea that if you've got two charged objects, they will attract or repel each other, but they won't attract or how a natural object right so the neutral object is unaffected by. It won't be attracted or repelled by a charged object, okay. And so the neutral object doesn't have like the past code for the force, okay. So it turns out if objects want to be affected by the electromagnetic force, then they need to have charge anything that's completely neutral won't be affected by the electromagnetic force. Similarly, I don't need to worry too much about this, but if you wanted to be affected by the strong force or the weak force, then you would need to have what we call strong charge on which charge. And last but not least, if we want to be affected by gravity. Then we have to have mass. Okay, so these are the only four fundamental forces in our universe so every every kind of force has to be one of these types. And as I've said every kind of force that you guys are familiar with, is actually a type of electromagnetic force. So when light is reflecting off a wall, that's actually just part of the electromagnetic that's actually just an electromagnetic force, and you may be thinking, Come on Hannah you've told me only things that have charged are able to interact by the electromagnetic force are able to exert these forces, but my wall isn't charged so Why can the wall reflect light. Well, anyone got any ideas about why the wall can reflect light, even though it's not like Nuke, even though it's neutral overall. Anyone got any ideas you can either post in the chat or just shout out.

20:32

What's the wall made of, yes correct yes someone's getting that electrons are transferred, not quite electrons, but the wall contains electrons. Yes, fantastic. Well done, brilliant yet this is brilliant. You guys are great. Okay, yes. So what's happening is our wall is made up of positive and negative charges. So because everything around us is made of atoms. These atoms contain charges, and it's actually the charges which are causing light to reflect. So, we have come to the conclusion, and this is something I want you to hold in your minds really carefully today, that only things that contain charges are able to reflect light. Okay, so that means if I'm telling you there's something out there, something that we can't see. What do I know about the charge of that object who can post that in the chat, or just shout out. What is charged that object if I can't see it, it's neutral yeah fantastic brilliant. You guys are scientists who are making deductions based on evidence yeah this is brilliant. So, um, yeah, so this is the idea I want you to keep in your head, the only thing so this is a really key point only things that are able that are neutral, are able to interact with life as only things that are charged are able to interact with light, and at a fundamental level. We call that the electromagnetic force. Now scientists, as we're about to find out today have come up with the conclusion that there must be stuff out there in the universe, that doesn't have this property. Okay, so it's at a fundamental level it's neutral, and that means it can't be built from atoms, right, because if it was contained atoms, just like our wall is able to reflect light, then we'd be able to see it. And you may well we think, Well, how do we know that this stuff is out there, if we can't see it. So anyone have any other ideas about what how we might be able to do that, how we might be able to detect is there. Gravity Yeah Oh, you guys perfect Yeah, interact with other forces brilliant Yes, this is perfect so you're right, so we've said that it's not able to exert a force on light so we can't reflect light, but it can exert a force on other objects, and it can interact with. Well, we think it interacts with gravity, fantastic so remember that our password for gravity is mass we said that anything that can save mass can interact gravity. And we think that this stuff out there has mass, so it's able to exert a force on stuff we can see yeah this is brilliant. So the idea is, although we can't see it directly, we can see the effect that this stuff has. But we can see the gravitational effect that this has on normal matter. Very good. So it's all to do with its gravitational interaction. Okay, fantastic. Right. I'm sorry I just want to keep it in, keep also keeping your wine. The probably in the room with you right now. There's some kind of other matter there with you that you can't see. And not only can you not see it, but you can't touch it. You can't taste it, feel it, smell it, because all of these senses all of these ways that we have perceiving objects is all to do with electromagnetic interactions okay so every time you smell something every time you touch something that's all electromagnetic interaction. So, We can't physically sense or the texts, these, this this dark matter. So even though it's there, we don't know it or feel it. And you may think, well you've told me we can sense it by gravity, but the force of gravity between me and the amount of dark matter in the room is not big enough to have a, like,

24:58

an effect that we could see but we'll see. See only start to see it on big scales which is what we'll get onto now. Okay, fantastic. Um, please please please if I'm talking too fast or not making sense, can you just shout out, or post stuff in the chat like questions, like I love getting questions so, so do ask the question as many questions as you want. Okay. Brilliant. So, what is this dark matter. Well, as I said physicists are really bad at naming stuff. So dark matter is pretty much what it is that does on the tin. Okay, so the word doc, that just means that it can't interact with light. Pretty obvious right. So that means basically part interact for the electromagnetic force and as you guys deduced from earlier. that means it must have no electric charge. And then we have the second word matter. Well what does matter mean well matter just means something has mass, and if something has mass, then that's the right passcode to interact with gravity so dark matter, although it can't interact with the electromagnetic force it is able to interact with gravity. So going back to our table of fundamental forces. If I can get back that is okay. We know that definitely can't interact with this one, because otherwise we'd be able to see it, or we'd be able to, at some point was upset. We know that it does interact gravity, and we can't. The moment we don't know about these strong and these weak forces now these are the forces that we tend to think of on a particle level. In fact, you do you guys have come across with the weak force because the weak force that's responsible for like beaters okay so when particles decay, radioactive decay. It's actually the weak force that causes that, so we only really think about the weak force and strong balls when we're thinking about particle physics. They're not really macroscopic forces so we don't think of them as treating, we don't really think of them acting on bulk objects that we deal with in everyday life. Okay fantastic right so we're now going to look at how exactly we have managed to deduce that dark matter is out there, um, as you guys have already told me it's all to do with gravity. So we're gonna start thinking a little bit about gravity and you're all familiar with gravity is what's keeping you on the ground right now, we're going to look in it. We're going to begin, start looking at gravity and the way that you guys are going to, you will look at it at your a level so. What is gravity. Okay So gravity is just an attractive force between any two objects that have mass. So, me, my pencil. We are actually exerting a gravitational force on each other, right now. Okay. And, in fact, everything you guys are exerting a gravitational force on every object that's in your room. And not only are you exerting a force on that object but there, that object is exerting gravitational force back on you. So if you've got two objects. They actually attract each other with equal and opposite forces so you look at this picture, we've got on the right here we've got a little mass mass, a mass m, and a big mass of mass big M. And these things are attracting each other with equal and opposite forces. Now, there's a very clever chap, Isaac Newton, you may well have heard of him. He's the guy that the apple fell on his head. In fact, I think it was here in Cambridge or we've certainly got the true Trinity College, they've got this tree and they claim it's Newton's apple free so they go come to Cambridge because that's why Newton was. And Newton told us the exact formula, between the masses of objects, and that distance. Somebody has asked me, Can gravity ever be repulsive very good question no gravity has to be attractive gravity's, it's a force which is only attractive. So, all that means is if you've got two objects, they only ever exert a force along the direction between the two objects so again if you look at these pink and blue walls, you'll see that the pink ball is exerting a force on pay towards the paintballs. So, the force of a OB is towards the people, whereas the force of B on A is towards the blue. So these forces are yeah they're always attractive they're always in the direction of to itself, like interior to itself rather than the way. And Newton.

29:53

Very good. So Newton said that when you've got to point objects are two things that you can treat as point objects. For example, me and a pen, we exert according to this formula. Okay so, F equals g m over d squared. Okay, so what is this telling us, well this is telling us that the force between the objects the strength of the force between the objects, depends on the masses of the objects, and the distance between them, and also on this thing G now G is just a constant. And it's constant known as the gravitational constant you're going to get practice on seeing what exactly what that is in a second. But something I want to really really highlight at this point is that the force which I'm exerting on my pen. Okay, is exactly the same as the force. The pen is exerting on me. Okay. So, that force is just equal to some constant times the product of our masses, divided by the distance between us. Okay. And someone's asked a brilliant question in the chat, which is how close to objects have to be until no gravity is felt. Now this is a very, very good question. So, you'll see that the size of the force depends on the masses so how close they'd need to be would depend on the two objects that you had the size of the masses, but it would also depend. So what we mean by felt is basically I guess I felt you mean motion. Okay, kind of, so I want to just go I'm just going to move on, I'll come back to this question. But actually my next slide is going to cover this. But how do we, what, how do we sense a force, how do we know a force is that well the reason the no force is there is because, again, down to Newton. Newton tells us that forces cause things to move, and the way that they do that is they cause objects to accelerate so when someone says, How do we feel gravity. Well, what we're actually really feeling in a physical sense is we're feeling that the acceleration, okay. So, all Newton's law, second law is telling us that if you've got a force acting on an object so my pen is exerting a force on me. I'm going to accelerate. But you can see that my acceleration is going to be the force divided by my mass, okay so the amount of acceleration that I'm going to experience will depend on my mass. So now that your question, how know, we not only need to know the masses of the two objects, so it's going to depend on on the masses of the two objects, but also on my, on my last one mean I'm being attracted right so. So essentially, the mass of the two objects is what's going to determine it. So as we've got here. So we've got these two objects. The big mass and the small mass they're attracting each other with equal and opposite forces, but is their acceleration going to be the same. Well, no, not unless their mass is the same so this is why we typically get cases. For example, if you think our solar system, we think of all the planets going around the sun. We might think well if the force of attraction is equal and opposite. Why does the Earth go around the sun, and not the sun go around the earth. Well the reason for that is all down to Newton's second law so as you can see here. So we have the acceleration on objects. A. That's just the force, this force which we said is the same f A on B, divided by the mass of this smaller object m. Okay, but the acceleration be experiences is going to be equal to the force divided by its mass which is big. Okay, big M, so we can see that if big M is much, much bigger than small bam, m, then the acceleration that the big object feels is actually much, much less than the acceleration, the small object feels so get this okay. The sun is attracting the Earth with the same strength but the earth is attracting the sun. Okay. But the acceleration that the our sails is much much greater than the acceleration, the sun feels because the mass of the Earth is much smaller. Okay, so, actually. Our Sun is accelerating, due to the acceleration of the Earth's gravitational field so our Sun technically is doing a little

34:49

over it. But that all is so small, because the acceleration of the mass of the sun is so big that actually the sun's orbit is actually within the radius of the sun itself so it's just kind of like wobbling. So yeah, so actually our son and our Earth are attracting each other with the same strength, but we only see one of them moving. Okay, so let's think a little bit more, so we've we've come up with all these good points about gravity, I've been very impressed with you guys, your guys intuition. We're just gonna think a little bit more about our solar system, and the planets that are orbiting it. Now, planets in our solar system are moving in circular orbits around the Sun pretty much circular orbits okay they're elliptical but we're gonna approximate those circles today. And it turns out that if something is moving in what we call circular motion. And again this is something you'll cover when you do a level, we say that it's what's causing that circular motion because remember, if something is moving in circular motion, it's always changing direction. What does Newton's law tell us if something is changing direction, it has to have a four successes on it. So there must be something which is causing something to move in a circle. And what is the force which causes our planets to move around the sun can we post that in the chat or shout out what forces it gravity yeah fantastic gravity Yep. So, any force like in general we call the force which is causing things to move in a circle, a centripetal force, or a centripetal acceleration. Okay, So keep that in mind in new words entropy to let just mean something which is causing something to move in a circle. And therefore, if we've got a planet that's an orbit around the sun. What the thing that's providing that centripetal force is gravity. And it turns out, This is another key equation for you today. But you can relate the, the acceleration that an object in circular motion feels to the distance it's orbiting and its velocity via this equation. So a equals v squared over d, and this is just what's known as the equation for centripetal acceleration, okay. So this is a really really key equation. So now it's time for a bit of a challenge for you guys so hopefully you've got pen and paper nearby you, if you haven't, like don't really worry you can try and do it in your heads. But what I would like you to do is I'm going to be a couple of minutes to do this. We're going to use this equation for Newton's law, and we're going to assume there's a planet that's moving as the fee in a circular orbit, a distance d from a star. so imagine the earth moving around the sun. I want you to find an expression for the star M in terms of and you're only allowed to use, you don't need to use all of them but you have to use these V d G and M. Okay, so the equations, you're going to be using are, what the gravity between two objects is, but you're also going to need to use Newton's second law. And also,

38:17
this

38:20
equation for centripetal acceleration you salute everyone able to see the slide if I do that,

38:28
hopefully, okay, well I'm going to give you guys a couple of minutes just have a go if anyone's really stuck, you can message in the chat, or just shout out, and I'll give you help but this is really, I wanted to see how you guys are able to take new equations and be able to manipulate them to find out find out new stuff.

39:00
When you if you guys get an answer, just so I know how long's give you do you think you could, like, give me a thumbs up in the chat or something like that, or a just, just put a thumbs up or something, indicate in the chat you've done it.

41:34
Anyone managed to get there or make a stall, maybe done. Okay, that's looking good, looking good. Okay, it's tricky.

41:54
I'm gonna give you one more minute and then I'll go through it. But the are just some, just some hints so you know what the centripetal forces. Okay. And you know the centripetal force is going to be able to form an A. But you know what A is. So you know A is v squared over d. So hopefully you should be able to equate some equations.

42:40
Yeah, I think people are getting that fantastic yeah I'm gonna I'll go through it now this is the good guys. Okay, I'm going to stop sharing the screen, and I will just do it on the whiteboard. I'm really impressed that you guys have done this actually okay right so what do we know. Where's my penguin. She just holding it and that's gone. Ah, Sorry, okay right so we know that f is equal to. And, and g d squared. Okay, but what do we know about F well we know that we can always write f as M A. So we have Ma is equal to m g over d squared. Right. This is using Newton's second law. So all I can do is I can cancel out my M's. And I can write my acceleration as V squared over D. Ah, so hopefully, when I do that, the G d squared. So you can see the n is just going to be V squared d over g. Brilliant. So well done to those of you who go m equals v squared over m equals v squared d of G, which looks in the chat that a lot of you do get that so I'm really really impressed so that's brilliant. News, I'm fantastic. Okay, I'm right. I'm right, Okay, yeah, um, what I need to do is just share my screen again. Sorry, I didn't realize it stopped sharing. So why is this useful. Well it turns out is useful in many many different ways. The first thing I'm going to do is just give you guys a bit of a quiz so I'd like you to just either scan the QR code, or go to HTTPS, our slides.com, hope that's

45:08
clear.

45:10
So if you just go to that website. We are going to do a bit of a quiz, just to see how much you guys have picked up on gravity. Let me just, okay, um, right. Are you guys able to see the question. Okay. All right, so I have the force of gravitational attraction between a planet of mass m, which is orbiting a star of mass big M. At a distance d, and we're going to call that f. And we're going to replace our star with another star of mass to double the mass. If the distance the planet remains the same. What happens. Lots of people are posting something in the chat. Join because there's too many people, or no. Okay, I'm not sure why that is. Okay. Right. What I'm going to do is, can you. Ah, right. Okay, just think about what the question would be, I'll share I'll say what I'll share my screen. I'll share a new screen so you can all see the questions, maybe you can just put like a, okay we do this in the chat so if you post like a B or C for what you think the answer is. Okay, right. Can we see this question. So, um, yeah. So we've got the the force that we're looking for the force of gravitational attraction between a planet, and a mass. And what I would like you guys to do is say, how you think the force is going to be affected.

Okay. So looks like we get a lot of votes and if you're unable to join it on the charts, I'm sorry if you're unable to join it, please just post on the chat.

47:38
Just give me like 30 seconds more. Everyone's getting to us yeah really impressed guys yep so we see from our formula g equals m over d squared that if we increase the mass, then it's going to increase. What about. So now looking at the second question. If they're in, if they're both in circular orbits, is the planet now going to be orbiting at a same speed faster speed, or a slower speed if this star is is bigger.

48:26
Okay, getting a bit of conflict here I'm getting some slurs in the chat but some Foster's on the thing so remember we've now got our son is now bigger is the planet going to be moving slower, so we can go back to our formula, remember V, sorry. So, n equals v squared d over g. So that tells me that v squared is proportional to m. Okay. So the bigger the masses, the bigger the mass of the stores, the faster it's going to be moving very good. Okay. Awesome, right. You guys are really liking these funny faces on the, the game. okay right brilliant next question. Um, question number three so now in this case. So, we're calling it f, but now instead of replacing star, I'm going to replace the planet. So I'm going to replace the the planet with a mass of a half. So what's going to happen is it now going to be naught point five F two F F or four. If we have the mass of the planet.

49:46
Everyone's got it yeah, fantastic, it's no point 5x Now, last question, you probably guess what it is. What is it, so so well we have the planet of mass m, and the planet of mass nought point five M, if they're both in a circular orbit at the distance d, Which one is going to be moving faster.

50:15
Think carefully. So let's go back to our formula. Our formula was that, m equals v squared dy over g so let's think about what that's telling us. So our V, remember, is just going to be the square root of g m over D. Okay, so that means, what we're sorry we're m is the mass of the Sun, the star. Okay, so our star is the same mass. But we have the mass of the planet. Does anyone want to change that answer, given the equation that I've just told you,

51:07
changes. So that's how I think again. So we said that at Big M capital M, the mass of the star is the same. Okay. But we said the speed of the little planet, the speed of the planet only depends on the big mass m, the distance D, and G. Okay, so does any of that change when I change the, the mass of the small mass. No fantastic right yes so I think people are getting there now so we should find that they're moving at the same speed. And the reason for that. Fantastic, well don't just watch that on the the question. So the reason for that is, although the force of gravity is half the acceleration is double. Okay, so the force of gravity is half, but the acceleration is double so actually the mass cancels out, as we saw when we did that calculation. So actually it's independent of the mass of the star that's orbiting so that's something that I want you guys, again, to keep in mind so well done, so those of you that got those questions right. You may well be thinking, Okay, so we've done with this. But what has this got to do with dark matter. Well it turns out that it's actually really really key piece of evidence for dark matter.

So, this is a galaxy. This is what's one galaxy a spiral galaxy known as the Andromeda Galaxy, and it's actually the nearest galaxy to the Milky Way to our galaxy in fact it's gonna actually collide with the Milky Way, but not for billions of years so no need to panic about that yet. But if we just look at this the picture of this galaxy. You'll see what it looks like you'll see that we've got this very central luminous bit. And then we've got stars outside. Now we call the central luminous fit the core of the galaxy. Okay, and the core of that galaxy is very very very luminous, and it's got lots of stars concentrated in the center there, but the stars that are further out stars as we go further out we have other stars and it's a little bit like our solar system and that the stars that are further out are actually in orbit around the center of the galaxy, and their orbital speed again is going to depend on the mass of whatever is interior to them. Okay. Right, so, um, that was a very, very clever astronomer there Ruben, and what she did was she started observing Andromeda. And she was looking she managed to measure the speed of stars that were in orbit around the center of this galaxy and she measured how fast they were moving, and she then used our formula. The formula that you guys just derived and equals v squared d over g. And she used that to predict the mass of the galaxy, okay the mass of this, this bright center.

54:27
And

54:31
what she also did was she calculated so they that's known as the orbital method the method of getting the gravity, sorry the method of calculating the mass. You guys just derived m equals v squared dy over g. And you can also measure it via a brightness method okay. But when they did this they found out they got, they've got a value that was much much less. So that's telling us that the mass of luminous matter is much less than the total mass of matter. Okay, so what do I mean by a brightness method basically all they do is they look at the amount of light that's coming out of the galaxy. And we know roughly how much light, a given star gives off, and we know roughly what the mass of an average star is so you can get an estimate of the mass contained within the stars in this luminous center so they got a brightness method they have a brightness method for determining the mass, but they also have this velocity method. And when they did this they found they had this big discrepancy. Now, not only did Vera Rubin do this for like one star, and calculate the mass but she actually did it for lots of stars and she fact she did it for lots of stars at different distances. Now, when you look at the pitch of this galaxy. You can see that most of the matter in the center. Most of the sorry, most of the light is concentrated in the center. So this actually looks like a very similar picture to our solar system. So in our solar system. More of the light, and supposedly all of the mass are concentrated in the center. And what do we find well we find that as we go further out what happens to the speed on my planets using the formula to further out, as I increase the distance what happens to the speed of the planets to get faster or slower will stay the same.

56:42
getting some responses now in the chat. It's looking good. They go slower yes So the further planet out is, the slower it's moving so again this just comes back from that formula that you derived so remember you derive that v squared dy over g is equal to m, so just rearranging that you'll find that V squared is equal to g d over BM, sorry g m over D. Okay, so you'll see that as you increase d, that's increasing the denominator of this fraction, and therefore decreasing the result so we find that the further out our

planet is the slower that it's moving. So because she thought, Okay, well, galaxies just look like our solar system, she expected them to decrease so if you look at this graph in the bottom right hand corner, she's expecting the speed decrease as we look further out. But what she actually found was that the speed remained the same. Okay, so this was a real puzzle because if you've got objects where one's concentrated in the center, then they should have this decreasing tendency, Okay, but it didn't. So these two observations, led her to come to a very important conclusion, and that conclusion was one. Not only are stars orbiting much quicker than expected. So, from the amount of luminous matter, okay so we found that because we found out that there was this discrepancy in the mass of the galaxy that we calculate. So not only must there be more mass there. But we can't be able to see that mass because if we could see it. Then, Not only would it be included in our estimate of the luminous part of the galaxy. But also, we know that the luminous mass of the universe is concentrated, so we know the luminous mass of a galaxy is concentrated in the center, because we can see it, but this result, the fact that we have what's known as a flat rotation curve is telling us that instead of being concentrated in the center, there must be mass that's all around the galaxy. Does that make sense. So instead of being like, our solar system where we have the sun, like the mass of our solar system is concentrated in the center, and that's what causes the speed of the planets to decrease. Actually in galaxies, there must be mass, that's all around, that's causing stars that are further out to move at the same speed as ones that are farther in, okay. And we call this a dark matter Halo, and it turns out that we think that every galaxy is surrounded by what's known as a dark matter Halo so in fact our Sun. We're actually in also in a spiral galaxy, we're in orbit around the Milky Way. And we're actually moving through the dark matter halo of the Milky Way, so at the moment there's loads and loads of dark matter actually hitting us in fact we kind of think of it as being like a dark matter wind.

59:59

Okay, brilliant, fantastic. So that's a little bit about one reason why we know that dark matter exists just going to quickly tell you about another couple, and then we'll get onto another activity. So it turns out it's not only the velocities of things that we care about Einstein, another very, very clever, scientists came up with the idea of what's known as General Relativity, and basically general relativity in a nutshell, is just that whenever you have a mass, whenever you have some kind of mass it's actually bending space around it, so you can kind of think of this is like if you, if you've ever, like jumped on a trampoline, you'll know that when you stand on the trampoline the trampoline bends right. And it's kind of exactly the same way so if you put shotput in a trampoline you'd see the trampoline band around the shotput is exactly the same in space so whenever we have a big mass in space for example, the Galaxy space actually bends around it. Now, this affects the light. Okay so if like, we know you guys all know that light travels in straight lines. But if space itself is curved. That means that the light will be bent. Okay, so this means that if you wanted to look at faraway galaxy. So, imagine this is me, and I'm looking at this what's known as a quasar which is just basically a faraway galaxy, but there's some mass in between. Now this mass in between is bending the space between me and the galaxy that I'm looking at. And it means that when light travels from this galaxy to me, it has to go along this bend, and it means that the image that I see if the Galaxy what I see, will no longer look how it actually does. Okay, so it would have been bent. So in the same way that those of you that wear glasses when light passes through your glasses it's bent. Okay. Um, and we call it lens for when you look for a magnifying glass again the light is bent and it's what causes it to look bigger. In the case of a magnifying glass. So it turns out that the galaxy that's between me and what I'm observing acts like a lens, and it actually causes distortion to my image so instead of seeing objects which look like points, I actually see them looking like curves these kind of I don't know if you can see these arcs here and Einstein's theory tells us that the amount of distortion that we see depends on the mass, the intervening mass of this galaxy. So what people can do is they can go away and they can measure the amount of distortion they see and they can use that distortion to calculate the mass. That must be in between them and what they're looking at. But when they calculate the mass. It turns out the mass that they calculate is much much much bigger than the amount that then the amount that they estimate from the brightness of the intervening object. So again this is real indication that there must be something out there that we can't see. Now, there is a lot more evidence as well. And that evidence also begins to come from cosmology so cosmology is basically the study of the universe from the Big Bang to the present day. And I just want to, hopefully, ask you guys some questions, and just talk a little bit about it because actually this is one of the reasons. The only reason we exist is because of dark matter which I think is pretty cool. So, we think the universe began with the Big Bang. Okay. And ever since the Big Bang. So, the point of Big Bang, The universe was like a point, it was really really hot, it was really really dense, but ever since then it's been expanding and cooling, okay. Now what happens to atoms, when they're really really hot. Who can tell me that what happens is atoms when they're really hot.

1:04:13
Or when they've got lots of energy. They do move faster. What happens to the constituents of the atoms, what happens the electrons within the atoms. If we heat up a gas, they release actors Yes, brilliant guys yes, that ionized. Okay, so we've got really really hot matter. Instead of being a neutral atom, we have an iron. Okay, something which is charged and hopefully you're thinking back to what we were talking about earlier, and I was saying anything that's got charge is going to interact really strongly with light. Okay, so I've got, um, things interacting strongly with light. In the early universe so in the very early universe, the Big Bang, I had all these charged particles fighting about. I also had photons a photon is just what we call a light particle, so it turns out that actually you can think of life as particles rather than waves but anyway so we've got these particles. And we call anything that's built of atoms, what's known as a baryon okay it's a new word for you, anything that's built from baryons we call anything was built from atoms we call a barium. So cool, got all of these, this matter that's interacting. Now, what does that mean well, we want to know how structures form in the universe so at the moment we've just got like single particles floating about. We want to know how do we form a galaxy well the way that you'd form a galaxy is all that matter starts to come together under gravity it starts to cluster, because it's attracted by gravity. Now if you can imagine you've got to, I don't know, particles, like, at atoms or anything. Trans come together and trying to collapse under gravity so to know to ions right so say that they're going to collapse under gravity. Now they can't do that because anytime they try and get close, what happens is a pesky photon comes along and blast them part. So in the very early universe is something I really want you guys to keep in mind, nothing that's made from atoms could come together and form structures. Okay. Because these photons kept blasting it apart. But, um, it gets to a point when the universe becomes neutral. And we call this the era of decoupling, where something known as the cosmic microwave background was emitted, don't worry too much about that at all. But basically this is when the first light was emitted in the universe because before that, again, light was just traveling on such a scattered path that no one could see anything or not there was anyone there but you wouldn't be able to say anything. So when atoms became neutral, because these were no longer as charged. Because there are no longer any free electrons. And this meant that

matter could suddenly start to come together because it could no longer interact strongly with the photons. So, the matter started to cluster and clump together. Now, I just want you to have a thing. Okay, so every everything that we see around us, the fact that we can see galaxies, the fact that we can see stars the fact that you and I exist. That means that you no matter has had to come together, okay and we see if you think about it, we actually see quite a lot of structure if you can imagine, just the universe being like single particles is taken a lot of collapsing and condensing for it's a form of a structured thing that we observed today.

1:07:52
And

1:07:55
we can actually estimate how long it would take these structures to form so I'm just going to go here and we can estimate how long it would take to see the pattern of structures that we would see. And it turns out it's far, far longer than the amount of time, but normal matter has been clustering from. Okay, so we know that normal matter atoms could only start clustering and building structures, no matter could only build structures. During this period, but this period isn't long enough. So what does that telling us what it's telling us that there must be some other stuff, which is able to cluster. Okay, and it's able to cluster before this period of decoupling Okay so before the universe became neutral. So I was able to Costa before then, what mustn't it be doing. Who can tell me in the chat. If it's able to cluster if it's not being blasted part by, by photons, what must it be able to do. Brilliant. I love this, you guys are brilliant yeah no electromagnetic interaction it mustn't be able to interact with photons, okay. So this is telling us that there must be something that during this early part of the universe was able to cross that. And it was unable therefore to interact with the photons, it was unable to interact with light. Okay, so this is really clear evidence that there is something here that actually, it's not just because it's too far away, that's not the reason we can't see it. The reason we can't see it is because at a very, very fundamental level it's unable to interact with light. Okay. And because of that, it can't be built from atoms, okay. So we say that dark matter is non baryonic okay I want you to keep that word in your head because it's really really clear so non baryonic means it's not built from atoms, okay right so I've talked a lot. I think it's time for you guys to do another activity. So what I'd like you to do is hopefully this will allow you to. I don't mean to send that out what's going on. Sorry, I don't know what I was trying to copy a link but it seems to be just copying my PowerPoint. Let me just try that again. What's going on. Okay, all right, Maybe the link is our billing sir. Okay, right. Let me copy this link. Okay, I'd like you to go to this link on Doc's domain. Um, you might need to copy it directly into your browser if it's not. I always have trouble. Copying directly from zoom chat for some reason. So what I'd like you to do is go to this website. There we go. I don't know. Yeah, people able to get on that. What I'd like you to do is you may need to just put in your name or your initials. What I'd like you to have a think about is, we've looked at various bits of evidence. We said that dark matter can't be built from atoms we want to find out we want to think we therefore thing, because we know dark matter can't be ruled from atoms, we think it must be built from some kind of new particle. Okay. Um, and, therefore, we want to know what properties this new particle might have. Okay. So what I'd like you to do is go on to the link on adopt storming link dot storming storming link. I'd like you to post what properties you think, dark matter, well what do we know about dark matter based on the evidence that we've looked at so for example, we know because dark matter interacts with it, it causes things to move faster than expected. We know that dark matter has

mass, so we know that our particle has mass, okay. And if you see someone, if you if you agree with someone you should be able to just like vote that you like that answer. So what I like to do is just add a card. So I'm going to add a card now that says, dark matter must have mass. So dark matter particles must have mass. If you agree with me, then you can like it if you don't, then you can dislike it I guess. But I want you guys to think about what else, what other properties can we tell from the, from the evidence that we've looked at.

1:12:56
So try and get a bit of discussion going on here. What other properties do we know to think about the bits of evidence we've talked about, we've talked about it, causing things to move. We've talked about the structure formation, what did I say about the structure formation, what was that telling me have a little think about that.

1:13:30
What properties, does it have what forces does it interact with shouldn't need a password. If anyone is struggling then just post it in the chat, and I will post your comments. There's the link again. That should be an actual link. So be great to see some more cards going up is anyone unable to access it.

1:14:37
Okay, some people are needing passwords okay well don't worry too much about this then. All right, let's, let's leave this, and I would like to just post in the chat so okay right so don't don't go on the link. Um, okay so if dark matter is able to cluster, before the time of decoupling, what does that tell me about the property, it's not very on it yes oh my gosh, I'm so pleased okay someone, someone's got it, it's non baryonic can it interact with electromagnetic force, what do you think. No, okay, brilliant. I still will we still see the effects of dark matter today. Okay, so there's still dark matter out there today, but we also know there was dark matter out there right at the beginning of the universal near the beginning of the universe, what does that tell me about the dark matter. Any ideas. The fact that it's still around, what hasn't happened to it. It's not being destroyed close. What do we call it, non react Yes, it's not been decay Yeah, fantastic. So we actually say dark matter must be a stable particle. So what we're doing now is we're trying to invent a new particle, and we know that it's got to have mass. We know that it can interact with the electromagnetic force. And we know that it is stable so it doesn't decay. Um, what about its interactions with other forces. If it was able to interact a lot, would we have detected it by now, do you think, like if it was able to interact via the weak force or the strong force we would have detected it Yeah, so we can also tell the fact that we haven't detected dark matter. We still don't know what it is. We must know that it can't interact very much at all. And so this is kind of what scientists do particularly theoretical physicists like me so they look at the evidence that they've got, and they're trying to come up with a new scenario that fit fits it, and I'm loving this someone is saying, undiscovered subatomic particle yes that's kind of exactly what we're talking about. So I'll share my screen again. So they can't with lots of different candidates with dark matter, and every candidate that they come up with, as I said, has to match the properties that we've observed. Okay, so let me just share the screen again. And it turns out that like the most popular candidate, the Beyonce of all candidates is, again, they have very, very bad. They have very, very bad. Um, just lost my train of thought. They have very bad naming things so they have said that the most generic particle which meets all of the criteria is what's known as a wimp. Okay, so what does the word mean well it just does on it, it is basically what it says on the tin

so it means weakly interacting massive particle. So that means something which is interacting for the weak force. Okay so it's only able to interact by the weak force. And it isn't able to interact with light. So that tells us it must be neutral, right can't interact with the electromagnetic force. Um, so it can't be built from atoms. Okay, so it's got to be some kind of new particle exotic particles someone said, We know that it's got mass it's heavy. And we also call it cold, which just means it moves slowly and an example of this is a particle known as the neutralino, which is, comes from a theory known as supersymmetry, you don't need to worry too much about that but basically supersymmetry is the idea that every particle in the universe has like a mirror twin that's undetected. And there's a particle in our universe known as the neutrino and its mirror particle is the neutralino, which comes from supersymmetry. Someone's posted Great question which is, could you not try and detect it from a gravitational wave interferometer in space. Yes, like gravitation gravitational wave interferometry. You need some kind of source of gravitational waves so dark matter. You'd need like to, if you wanted to do that you need like two concentrated sources that were like going to collide so so you have to and people are looking into this this is a very good questions, there's a bit more exotic, but so gravitational waves, the ones that we detect for example it would be like two black hole. black holes colliding, or two neutron stars orbiting each other and spiraling into each other. Um, so if you had to,

1:19:41

for example, it may well be the case that we have dark matter, which is able to like clump and form what's known as Dartmouth star. And again, this is like right, cutting edge research so it's really, really, really out there but if there were such dark matter kind of neutron type stars, it could be very well but you could detect it. But the difficulty will be distinguishing its signal from normal neutron stars but it is something which is kind of being considered at the moment so it's really cutting edge research, we'll have to see in future years whether this gravitational garment gravitational waves does become interesting for dark matter. But yeah, this is the most likely candidate that the wimp. And it turns out that was we can't really use gravitational interaction yet, there are various different ways that we can hunt for wimps. And you can kind of summarize them in three ways. I'll have a little rhyme, which is, shake it, break it and make it, okay. So, direct detection is basically you have physical matter. So, for example, me, and it may well be that because there's dark matter around us, occasionally, that dark matter may actually interact. Okay, so those that it doesn't interact very much only interacts by the weak interaction, it may be. And again, there's very, very low probability of this happening but occasionally it might actually collide with a normal thing. And it may well be that we could detect it that way. The other method. The next method is break it, which is where there may be dark matter and again we said dark matter is like stable, but there may be situations that would cause it to decay. Okay, maybe that we can induce it to decay in some ways, and it may well be that we could look for excess radiation produced from these decays, or annihilations even, which is when a dark matter particle and a dark matter anti particle come together and form, convert their mass into energy. And the last way is we can try and look for it at colliders like the Large Hadron Collider. So I want to just focus a bit on this direct detection method so this is the idea that we have no matter out there. And it's the idea that occasionally these dark matter particles will come along and they'll collide with normal atoms. And although we can't see the dark matter, hit the atom. We will see the atom recoil. Why does things recoil and collisions, you can tell me that.

1:22:37

Why do things require what what is there a fundamental, what must be conserved when we have a collision, conservation of momentum yeah fantastic Yeah, and momentum just depends on the mass and the velocity. Okay, so if you've got two like billiard balls colliding. We can always work out. We know that their momentum in the collision must be conserved. Now it turns out these types of collisions where you've got dark matter colliding with atoms. And it turns out, we'd also expect these to be what we call elastic collisions. Does anyone know what an elastic collision is.

1:23:23
So an elastic collision is one which conserves kinetic energy. Okay, so when the kinetic energy before the collision is the same as the kinetic energy. After the collision, we call that an elastic collision, and we assume. Dark Matter collisions with recording Nicholas's are elastic. So basically the idea is, and what scientists are actually doing at the moment and there's a big UK involvement in this is they put these massive fats, of like heavy nuclei, deep deep deep underground, and what they do is they basically sit there and wait to see the atoms recoiling without being hit, basically. So, does anyone want to suggest why this might be difficult, why, why is it difficult to look for dark matter in this way,

1:24:30
limps in this way, not massive enough, not that it's not messy they're actually interacting via the weak interaction, so they're not interacting via gravity they're interacting by the weak interaction. And you cannot predict when it will happen yes there's a lot of time and money Yes, fantastic. What other, think about. Yes, it's hard to measure things, why do they need to be underground.

1:25:02
Yeah, very good. So there are other reasons why something could appear to move without being hit. So for example, if there was something known as a cosmic ray or a neutrino for example, they would also cause the atom to appear to move without being hit. And that means you couldn't be able to tell whether what hit your atom was a wimp, or it was like one of these cosmic rays. So they need to keep them very very very very very well shielded, so it's difficult because one, you need to show them like really really really really really hard to, you need to sit around and wait for ages. And the reason that is is because, obviously, Dark Matter doesn't interact very much, but there are several of these big detectors out there, and what they're doing as I said is they're basically looking for the energy of a recoil, and just to give you guys a brief idea of how this works, I'd like you to have a little goat this question here. So, what we can see is we've got a, an atom geranium. Okay. And I've got a wimp. And this is the mass of my wimp. And this is the speed of the wimp, which is colliding with a stationary atom. Okay, and the wind is deflected and its speed reduces okay so you guys can hopefully, we want to shoot that as nastic collision. I want you to work out how much energy is transferred to the nucleus. And remember that we can't see the wind, or we can't ever detect the energy of the wind, but we can check the change in energy of this geranium. A wind is a weakly interacting massive particle and it's what our best candidate for dark matter is. So it's basically just a particle which interacts only via the weak interaction, and gravity, its massive, and it's neutral. Okay so this is like a dark matter particle. So, if people could have a little go at doing this, and remember that the equation for kinetic energy is a half m v squared. So I'd like you to see if you can work out how much energy is transferred to this geranium. And also then it says how many times will resist and the energy required to lift a grain of

sand. So it tells you how much energy that's needed, that is, so if you could then have a go at working out how many times that is so hopefully you guys have got calculators.

1:28:00
Yeah, just give me a couple of minutes to have a quick guard up. Again, any questions please post them in the chat. Someone asked a good question earlier in the chat I haven't answered is how could Dark Matter of fact, space travel and research in the future. Well, dark matter is really underpinning. What is one of the biggest unanswered questions in the universe, the fact that we know that 85% of the, the mass of the universe. We don't even know what it is we're just suggesting that it could be a wimp, but we don't know anything about these worms, we don't know what their masses. We don't know how much like how much how strongly they interact via the weekend direction, we don't even know whether it is a wimp. And there are all of these experiments out here searching for wimps like this big. These CDMS experiments like the direct detection experiments you guys are doing the calculation of now that there's experiments out there and they've been going on for years but we're yet to detect anything. So it may well be that dark matter is not actually a whim, maybe it's some kind of other particle maybe it's something which is really really really really light known as an axiom. So there are lots and lots of different candidates for dark matter, and the WinPE is just the most popular one, it's the most possibly the most likely one, but it's by no means the most probable one so when people are doing these detections, when they're trying to detect dark matter. They're trying to actually uncover what it is. So research is really really moving towards trying to really find out what this dark matter is so we know that it's there because of gravity. We've never detected it by any other interaction vibe, other than gravity so we need to do that. And if we do manage to do that if we do manage to see these signals that will allow us to find out more about the properties of this worm so for example about its mass about its charges, things like that. Because remember, as you guys will see the mass of the wind is going to affect how much energy is deposited. So this detector. Okay, so if anyone does have any other questions please do post them.

1:30:46
And if you could stop posting your answers when you start getting them. Be careful about your units guys, what units are you working in. So you've got two different answers on the chat. One of them is correct. The other one is kind of correct but I think you've used the wrong unit somewhere.

1:32:01
Yeah, that's a good so you should have the way that you'd approach this question is before the collision. You know what the kinetic energy is it's just the kinetic energy of the, sorry, it's just the kinetic energy of the WIMP so we're looking for a half times the mass of the WIMP times the velocity of the wimps squared. Okay so again you want the mass in kilograms and the velocity in meters per second squared. And you should get it as big, like 2.8, times 10 to the minus 15 joules. And after the collision, it's reduced in speed and its new kinetic energy is three times 10 to the minus 16 joules. So, the amount of energy that's transferred to the nucleus is just going to be the energy before, minus the energy after. And if you do that you get 2.5 times 10 to the minus 15 joules, so I was on to all of you that got that. Did anybody work out how many times more is than the energy needed to lift a grain of sand. Yeah, fantastic, Yeah, we're getting about 14 million. Okay, so the amount of energy that this when this dark matter particle would

1:33:26
like

1:33:28
affect the, the atom and are detected by is 40 million times less than the amount of energy needed to lift a grain of sand by one millimeter. And so hopefully that just gives you just an idea of how difficult it is to detect dark matter and how sensitive, our detectors and instruments need to be. Okay. So, to detect dark matter, people are doing these these direct detection experiments, as I mentioned, they're also looking for dark matter annihilations in the case they're looking for. Excess radiation. So they're looking for radiation in places that you wouldn't expect it. So access gamma rays, they can look for access cosmic rays X rays neutrinos, these could all be possible signatures of dark matter. Another thing they're doing is at colliders, they are smashing protons together at really really really really high energies. And the idea is that when you do that, you could actually produce dark matter directly. And if you did do that. Then you'd actually see so you know how much energy you put into your, into your collision, you'd start seeing what's known as missing energy because you wouldn't be able to tap dark matter. Dark matter would escape undetected through your, your detectors and these collisions. So if you have more energy at the beginning than you have at the end that can be indicative indication that dark matter has been produced, okay right so in the last five minutes, I really just want to have a home that the main take home message which is that as we can see that is gravitational evidence lots of evidence that there's, there's gravity, sorry there's loads of evidence from gravity, that 85% of the matter in our universe is invisible, it can't interact with the electromagnetic force. However, we are yet to know our particle level, what this dark matter is so we know that it's there, but we don't know what it is and we've got an idea. We think it's probably a weakly interacting massive particle is a wimp. But we really don't know anything about the properties of it, and scientists around the world are racing to try and uncover what these properties are and this is one of the biggest unanswered questions in science and it's something which is, you know, it's got a real international effort at the moment and it's something which if those, those if any of you do ever want to go into particle physics or cosmology or anything like that in the future. It may well be a problem which you guys help to solve. So in the last four minutes, I'd really just like to answer any questions if any of you have any questions, some of you did have fantastic questions earlier so I'm hoping that some more of you have questions. Now, it can either be on dark matter or kind of anything for succeed really or on any questions about physics or physics at university. So if you do have any questions please post them in the chat, or just shout out. Or I can just keep talking about physics if you want. Anyone got any questions. Okay. Um, I have a question what did your PhD research work, focus on. Okay, fantastic. Yeah, my PhD research is actually very much on dark matter so I'm looking at coming up with these new theories, so I've said that a wimp is like the beyond several theories, but it's very much not a, it's very much not the only theory. And as he said there are all these experiments, which didn't haven't detected it yet so it may well be the dark matter isn't a wimp so my PhD is about coming up with new theories which better fit the experimental evidence that we have for things like dark matter. Another question is dark matter is spread evenly across the whole universe. No, and it does actually in the same way that we have structures in our universe, it sorry it was real matter. There's also structures of dark matter in the sense that every galaxy is

1:38:04

surrounded by Dark Matter Halo so in the same way but matter, tends to come together because of gravity, dark matter also comes together under gravity so we actually do have a distribution of dark matter in the universe, and you can actually measure that distribution of dark matter. Using the cosmic microwave background but yeah, Very good question. It's not spread, spread evenly it is distributed. What do you want to do after your PhD, I would love to stay in research. I would love to go and work so I like sound like that the Large Hadron Collider, and carry on. Getting to think about what's out there. Not everyone that's doing a PhD will want to go on with research. And I will say that now just so that you're aware that if any of you do want to go and do a degree in physics, and then do a PhD, you don't need to stay in research, you can go into lots and lots of other careers if you go and do a degree in physics, pretty much any career is open to every every sector, you know, finance, advertising consultancy there's so much out there that you can do so don't feel that if you do a physics degree you have to go and do a physics job afterwards. Not at all. There are so many people out there and they literally do lap up physics students. Did you do your undergrad at Cambridge. No, um, I lived in London, and I wanted to stay living in London. So I did my undergrad at Imperial College. I did physics there and then I came to Cambridge and did a master's in theoretical physics, and then I stayed here for my PhD. Um, yeah, so that's that's kind of me any other questions anyone at all, is dark matter all the same stuff that was created at the start or is more of being created out very good question, and it was actually created in the early Universe, and it's the same way that matter. So, if you think about it. Mmm, matter is created when you've got very high, sorry, Einstein's theory of relativity tells us the energy and matter can convert. So if you have a matter particle and an anti matter particle, it turns out that they can annihilate each other, but it also turns out the energy can be converted into mass. So if you had a very very very very energetic source like a gamma ray that gamma ray could actually produce a new particle, and its anti particle power so it could produce an electron and a positron which is the electrons anti particle, okay. Again, it's possible that a gamma ray could produce if dark matter was a wimp. It's possible that a very high energy gamma ray could produce like just now somewhere. A dark matter and I don't matter path. However, Most of the most of like, so most of matter, like, although technically we still get the conversion between matter and energy. Now, most of that happened when there was a lot of very, very high energy radiation around which was in the very early universe when the when the temperature of the universe is very very very hot. So yeah most dark matter we think was, was produced very early on in the universe's history, again we know that it must have been there before the coupling, because that's what was clustering to form the structures but excellent question. Another question, you mentioned the weak force was involved in beta decay, please explain further. Okay so, any process or any interaction is occurring due to a force, and at a fundamental level forces are not actually

1:42:02

forces a car because of passwords being exchanged, so actually turns out that if you think about an electromagnetic interaction so imagine you had two electrons that were repelling each other. What's actually happening is these electrons are exchanging what's known as a force carrying particle. And they exchange, a force carrying particle of the electromagnetic force and the force current particle of the electromagnetic force is the photon, which is why we say that only things that can interact with the electromagnetic force interact with the photon. So, if you can imagine that you and I are on an ice rink, and I threw you a basketball. If it was a totally frictionless ice rink, when I threw the basketball to you, we would probably move apart. Okay, and we move part due to conservation of momentum. Now, even though I haven't actually touched you. We've moved apart, and it's kind of the same way so the way that, so it looks like you've experienced a force, even though I haven't touched you. But it's because I have thrown a basketball at you. So you can imagine two electrons repelling each other, what is actually happening is they're exchanging a photon. Um, and it turns out that in beads decay, what's actually happening is the path, the particles that make up so it turns out that neutrons and protons are not actually found fundamental particles that don't have fundamental particles known as cool so quarks I'm, I realized this is a lot of new stuff so you're doing really well if you're following. But basically we have these quarks that are inside the proton and the neutron, and what's actually happening is, again, there's being an exchange of particles. I'm sorry again in beta decay, you have a neutron, decaying into a proton. So what's actually happening is that neutron is, um, well it's actually a dunk walk within the neutron is actually changing into an art cork, by giving off what's known as a W bows on and the W bows on is the force carrying possible for the week for so in the same way that when things interact via the electromagnetic force they have to be exchanging photons, when things interact via the weak force they have to exchange a weak bows on or weak force carrying particle, which is the web goes on and that's what's going on in BTK there's a W boson being being transferred and that allows a neutron to convert to a proton in the quantum multiverse if it exists with dark matter exists in equal amounts, well, no one knows. But, excellent, excellent idea. So actually, one of the biggest another theory for dark matter. So, we talked about one theory for dark matter which was wimps. But there is because as I said best there are all these experiments out there, and we haven't detected dark matter yet, it may well be that dark matter is not a wimp. It may well be dark matter is, for example, another theory of dark matter is what's called mirror world dark matter. So it's the idea that instead of what as well as every particle in our universe. There is like a dark matter pair, a dark matter version so we'd have like a dark proton, a dark neutron, a dark electron. And the idea is that these dark particles interact in exactly the same way as normal particles, but why are their own analogous forces so we have like dark electromagnetism, we'd have dark weak force dark strong force for example. So in that case there will be a whole other universe out there a whole dark universe. But we would never ever be able to interact with it, because we only interact via the normal strong force, normal weak force, and the normal electromagnetic force, but that we don't have the passcode for any of the dark forces, and likewise, maybe it's the dark forces don't have the passcode for any of our forces, and therefore we'll never be able to interact. So that's, yeah led to the idea of a whole kind of mirror well it's called Mirror well dark matter. Acts Excellent question. Does that match your Bay Conservation Laws and how would you prove this. Very good again. So we know that it obeys conservation of energy in its gravitational interactions as to its other interactions.

1:46:48

We are unsure as to. So it turns out that every force has its own conservation rules. And that comes from your theory, because we don't know what the underlying theory for dark matter is we don't know what the conservation rules are. So for example, baryon number has to be conserved and lepton number has to be conserved in certain interactions. Again, don't worry about these words. But that comes from, from knowing about the force of dark matter was interacting via some kind of new force, we wouldn't know the conservation laws but again this is all something which we're really struggling to pin down and really trying to pin down. And last question, if more matter is produced and galaxies continue to move away from us. Surely we will get to a point where we can no longer see anything in space. Yeah, excellent. And it's not really that more dark matter is produced, but you are right that galaxies are so the universe is expanding so yes you're right that eventually, you wouldn't be able to see anything within your visible horizon. However, I would say that we are looking. Also, when you look out at things you're looking back in time. Because which I think is really cool because light takes a finite amount of time to reach us. So when you are looking at a star. If that star is one light year away. That means that the star that you're viewing now you're not actually viewing it now you're viewing the star as it was a year ago. If a star is 40 light years away, you are viewing that star as it was 40 light years ago, and we do actually get things that are like, hundreds and 1000s of light years ago that we can still we see hundreds and 1000s of light years away, that we can see. So that means we're looking at them not as they were now but as they were hundreds and 1000s of years ago, which I think is really really quite cool. So I hope that answers all of your questions. It's been lovely to, to be with you guys today you've had some great questions you've been really interactive. I hope you enjoyed it a bit. I'm sorry about the links not working. Um, but yeah if you do have any questions in the future about any of this or the future, please do feel free to. I don't, I don't think you have my contact details directly but I'm sure that Hayley could pass on any questions if you do have any about anything. Otherwise, I hope you enjoyed it and I hope you enjoy the rest of your summer.

1:49:35
Thank you so much. I know that was. Yeah, I really enjoyed following along, I'm not satisfied, but that was absolutely fascinating. Thank you. And yeah, like you said, if you pass on any questions for Hannah to me and then I can forward them on to Hannah that's probably the best way to go about it. Um, but yeah, thank you so much and I hope you enjoy the rest of your day everyone. Take care. Thanks everyone, bye.