MITOCW | Investigation 4, Part 3

MARK HARTMAN: This morning, we're going to learn a new skill. OK, so we're going to say a new skill, and that's going to be comparing quantities. Comparing quantities is really important. We've already done it a couple of different times. We compared the angular size of our expert project objects with the angular size of the sun. We compared the flux that we got from the sun to the flux that we would expect to get from our expert project objects.

We've also been talking a lot about distances, to the nearest star, distances to the center of the galaxy. So when we dealing with a bunch of these really large numbers that we use for scientific notation, we also want to be able to compare them, and this is the way that we're going to do it. So I first have a question to ask you, which is if I took this solar system-- we're going to talk about size scales right here.

We're going to talk about comparing sizes as an example of how to compare quantities. We're going to learn about how to compare quantities using ratios. So I have a question for you. If I took the whole solar system-- which is the sun at the very, very center-- and then I shrunk it down-- the sun with all the planets, all the way out to Pluto, right, Pluto's orbit.

If I shrunk the whole solar system down until it was the size of a quarter-- and, actually, does anybody have a quarter? I don't think I have a quarter on me. I promise you'll get your quarter back. Whoever's first.

SHAKIB AHMED: [INAUDIBLE]

MARK HARTMAN: Aw, Shakib's first. Thanks, man.

All right, so this is the quarter. The sun would be a tiny, tiny, tiny, little dot that you couldn't even see at the middle, and the outside is the orbit of Pluto, right, that's the edge of the solar system. If I shrunk the solar system-- and I'm just going to abbreviate that SS-- to the size of a quarter, where would the next star be?

Where would the next star or the next nearest solar system? I want you to talk with your group, and I want you to make a prediction. If I held the solar system right here, where would the next star be? Where would the next solar system be? OK, like how far away would it be?

AUDIENCE: How many solar systems can a galaxy have?

MARK HARTMAN: We're going to get there. So just a quick estimate, talk about it for just a minute, and come up with one answer. And I'm going to have you guys share them, rapid fire. I think what we will do, we'll just pour them out into different buckets. Everybody will have a little bucket of M&Ms, and they get to choose the right color.

SIMBA KOL: Because he said 30 a color, so I'm like, that's 150 M&Ms.

MARK HARTMAN: No, no, we just have to say, each one of these represents a certain energy. And then in a little cup, we have a bunch. And they'll just have those with them and say, OK, this is one.

SHAKIB AHMED: Last time I had to do 30.

MARK HARTMAN: Yes.

AUDIENCE: Forgot your $0.50.

MARK HARTMAN: So if you put a $0.50 piece next to it. So estimate it in terms of centimeters or inches or something, like if you put it right there, it would maybe be like an inch away, a couple of inches away, something like that.

AUDIENCE: Two inches.

MARK HARTMAN: It's close. Whatever.

SHAKIB AHMED: No, it's not.

MARK HARTMAN: OK, here's the solar system. Ooh.

[SIDE CONVERSATION]

AUDIENCE: I'd say like three and four inches.

MARK HARTMAN: OK, let's go around the room. Have you guys had a chance to decide? Make a decision. Who would like to go first? Who would like to volunteer their answer first? How about that group?

AUDIENCE: A foot.

MARK HARTMAN: A foot. How far is the next star in this model? One foot. So here's the solar system. The next star would be like there. All right, what about this group?

AUDIENCE: $0.50. I mean, like two quarters.

MARK HARTMAN: Like two quarters width.

AUDIENCE: That would be like two inches.

MARK HARTMAN: Like two inches. So one foot, two inches-- OK, how about this group?

AUDIENCE: One foot.

MARK HARTMAN: One foot. OK, we'll just put a check next to this one. What about this group? Don't let other people influence your decision.

AUDIENCE: To the dome.

MARK HARTMAN: To the MIT dome, right? You mean the one that was on top, that we took a picture of?

AUDIENCE: Yeah.

MARK HARTMAN: OK, the one in the next building over.

AUDIENCE: One mile.

MARK HARTMAN: OK, so let's say to the next building, which is maybe, yeah, like maybe a quarter mile, maybe 1,000 feet, something like that.

AUDIENCE: It's far.

AUDIENCE: Wow.

MARK HARTMAN: OK, so you're all wrong. The next star would actually be on the other side of campus.

AUDIENCE: We were close.

MARK HARTMAN: So it's about six football fields away. So that's 600 yards, which is about 2000 feet. Well, no, that's wrong, yeah. Six football fields, each football field is 100 yards. So 600 times 3, 1800 feet. OK, so maybe we are close, right. Maybe not to that dome, the little one outside, but has anybody been to the infinite corridor yet?

AUDIENCE: No.

AUDIENCE: Where is it?

MARK HARTMAN: A couple of people have taken picture of the infinite corridor. That's the one with the big MIT dome on it, which is about four or five or six buildings that way. So space is mostly empty space. Between our solar system and the very next star is that far. Have we gone to the next nearest star besides the sun? No, the furthest any human piece of technology has ever been are the Voyager spacecrafts, which are just right beyond the edge of this quarter.

AUDIENCE: Really.

MARK HARTMAN: Yeah, so right now they're just right beyond the edge of Pluto.

AUDIENCE: How far it is?

MARK HARTMAN: We're going to talk about that in just a minute. So our next nearest star is actually about, let's say, six football fields.

AUDIENCE: That's far.

MARK HARTMAN: That's going to be about 2000 feet, or about a half a mile away. All right, well, Juan, what was the question that you asked just a couple of minutes ago? How many--

AUDIENCE: Oh, how many solar systems can a galaxy have?

MARK HARTMAN: How many solar systems or how many stars with planets orbiting around are fit in a galaxy or make up a galaxy? Because we know there's the solar system, and then we also live in a galaxy. And there's a picture of one right over there. That is a cartoon of what we think our galaxy looks like. That's the Milky Way galaxy, a cartoon. We can't actually-- you know, if we've only gone this far, we can't go outside and see the galaxy.

So my next question is, on this scale, if our solar system was a quarter, how big is the galaxy? Is it going to be bigger or smaller than the--

AUDIENCE: It's going to be like 100 blocks.

MARK HARTMAN: It's going to be bigger than this. So, again, I want you guys to predict, if now knowing that the next nearest star is a half a mile that way, how big is the whole galaxy? So think about it for just a minute.

AUDIENCE: Boston.

MARK HARTMAN: Got. How big is the galaxy if the solar system is a quarter? This group.

AUDIENCE: About the size of Boston.

MARK HARTMAN: About the size of Boston. Size of Boston.

AUDIENCE: Including the suburbs.

MARK HARTMAN: Which is maybe-- including the suburbs-- OK, fine, maybe like 15 or 20 miles. OK, next group.

AUDIENCE: As big as Massachusetts.

MARK HARTMAN: As big as Massachusetts.

[SIDE CONVERSATION]

OK, this group.

AUDIENCE: The size of the Northeastern United States.

MARK HARTMAN: OK, so New England.

[SIDE CONVERSATION]

So that's like all the way up to Maine, all the way down to Rhode Island and Connecticut. OK, last group.

AUDIENCE: From here to Mars.

MARK HARTMAN: From here to Mars. From here, this place on Earth, all the way to Mars. OK.

[SIDE CONVERSATION]

AUDIENCE: To Mars.

MARK HARTMAN: To Mars. All right, Jaylen.

AUDIENCE: Isn't the galaxy like infinity?

MARK HARTMAN: No, no, no, no, talk out loud to all of us.

AUDIENCE: Wait, we don't how big the galaxy is, right?

MARK HARTMAN: Can you hear him, is he--

AUDIENCE: What? No.

MARK HARTMAN: No, talk to them. I'm just the person writing things down. You guys are the ones who are figuring things out.

AUDIENCE: We don't know how big the galaxy is right?

MARK HARTMAN: We're talking about how big the galaxy is, yep.

AUDIENCE: Yeah, but we don't know big it is, right?

AUDIENCE: We're just predicting how big it is.

MARK HARTMAN: Do we? You're confusing the galaxy with the universe. The galaxy is all of the stars that are close to us in space. We'll talk about other galaxies. The galaxy itself is not infinite. It's not infinitely large, OK?

All right, we're going to move on, but keep that question in mind as we go. What is this? Hmm. Think about when you heard that, OK, and then we'll get back to that, especially when we start talking about cosmology, which is the study of the whole universe all together.

So to Mars is wrong. That's too far. If the solar system was the size of a quarter, the size of the galaxy would be the size of North America. So Shakib, can you come stand over here?

AUDIENCE: Serious? Wow.

AUDIENCE: You said that, half of the US.

MARK HARTMAN: So that's wrong, wrong, wrong. You guy said New England. Now New England is like that big. Half of the US is like that. So can you put that just over there on the board-- Northeastern part. So the galaxy would be the size of North America.

AUDIENCE: That seems crazy.

AUDIENCE: [INAUDIBLE] are really good. [INAUDIBLE].

MARK HARTMAN: Ah-ha, so--

AUDIENCE: Or Mexico.

MARK HARTMAN: So we actually-- let's just make it a little more New England-centric-- we would be somewhere, I forget, I think we're above Pennsylvania somewhere. We're out here on this side. Well, it's kind of round anyway.

But if you wanted to create a scale model of our galaxy, you would take $200 billion quarters. And you would drive around all of North America. And you would put them about a half a mile apart each. And you would put them up to-- I forget exactly how tall it is-- but probably up to about 10 miles in the sky.

The galaxy is about 100 times wider than it is thick. So if you think about a CD, a CD is about 100 times wider than it is thick. So the galaxy is a very flat thing, all right. So it doesn't have a whole lot of thickness. But its width is actually really large.

So you'd have to drive around in a bus or 17 buses full of these quarters. Close, actually, it would probably be more than that. And you would have to put these quarters at about that far apart. Except, here in the middle of the US, you'd put them much closer together. Instead of being a half a mile apart, maybe they would be from this quarter to the other side of the room.

AUDIENCE: Let's do it.

MARK HARTMAN: That would be a good summer CAI project. It would take a long time.

AUDIENCE: Let's call [INAUDIBLE].

MARK HARTMAN: So that gives you a sense of the fact that the galaxy where we live is so much bigger than our solar system. And we'll come back to this discussion when we talk about other galaxies and talk about where they are in the universe. OK, we'll do this thing again.

But now that we have this idea in our mind, let's think about how could we represent this mathematically? If I wanted to say-- and, actually, did you take pictures of these? OK, could you take a picture of that real quick? So I'm going to put this over here.

So if we're comparing sizes-- I just had asked you, how far is it to the next star? How big is the galaxy if the solar system was shrunk to the size of a quarter? So, in general, we're going to want to answer questions like-- and then put this in your notes down below-- the galaxy is how many times bigger-- well, let's say larger because bigger, I mean, it could be mass; it could mean volume-- how many times wider than the solar system?

All right, another question could be, my object is how many times more luminous than the sun? Or I have two stars, how many times larger is one star than another? So if we have a sentence that's like this, we can rewrite this in mathematical language. And we can say, so the galaxy is how many times wider than the solar system?

I just write this as math. I can say the diameter because that's the width of the galaxy. We said it was kind of round shape like a CD. So we're going to say, the diameter of the galaxy is-- that means equals, in terms of talking about math-- how many times-- well, that's like the thing that we're looking for, so we'll call that x-- is how many times, x times, wider than the solar system?

Well, now we're going to say times the diameter of the solar system. Can everybody see this over here? You may have to crane your head around a corner a little bit. So what we're really looking for is, how many times bigger is the galaxy than the solar system? If we wanted to solve this equation for x, that number, how many times bigger is it, how would we do that? Nicky.

AUDIENCE: Divide the diameter of the solar system into the galaxy.

MARK HARTMAN: OK, so I want to divide both sides by the diameter of the solar system, right? Now I can simplify because these two cancel out. And then I'll just rewrite underneath. I can now write the diameter of the galaxy over the diameter of the solar system is equal to this number. It's equal to some number that tells me, how many times wider is it?

So let's check our model, right? I just kind of told you that this is what the model would be. Let's actually put in the diameter of the galaxy and the diameter of the solar system and see what we get. So the diameter of the galaxy is about 9 times 10 to the 20th meters. Remember yesterday, we had said that the center of the galaxy is about 2 times 10 to the 20th meters away from Earth.

So let's look on our chart here. If we're out here 2 times 10 to the 20th meters is like that. So 9 times that is going to be maybe 4 times wider-- 1, 2, 3, 4, that's about right. OK, so 9 times 10 to the 20th meters over the diameter of the solar system in reality is 4.4 times 10 to the power of 12 meters.

All right, so we just simplify this. I'm going to take this up and put it over here. We simplify this by saying 9 over 4.4. We just gather the numbers together. And then we gather the powers of 10 together. 10 to the 20th divided by 10 to the 12th. And then we gather the units together, and we have meters over meters. And that still equals x, this number that we're trying to find out.

Let's simplify that again. 9 over 4.4 is about 2. Remember how we do division of powers of 10. That's 10 to the power of 20 minus 12. And then meters over meters cancels out. So our number doesn't have any units because it's just how many times bigger is it, equals x.

So we simplify 2 times 10 to the power-- what's 20 minus 12-- 8. So 2 times 10 to the 8. Let's write that out. That's 2 with eight 0s after it-- 1, 2, 3, 4, 5, 6, 7, 8. So that means the galaxy is 200 million times bigger than the solar system.

Now, I could have done that first, and you would have been like, ooh, wow, 200 million, that's a lot. But it doesn't make as much-- it doesn't give as much gut reaction as when you say, well, here's a quarter and the size of the galaxy would be the size of North America, which is why we talked about that first. So let's--