MARK HARTMAN: If there were no compact object over there, nothing that produced a gravitational force, this companion star, if it was just going this direction, it would continue to just go up. If there was nothing over there and this star was just moving through space, it would go in a straight line.

So let's say this is the compact object. This is the companion star. We're going to talk about how do they move. So if there was no compact object, the star would move in a straight line. If anybody's taken physics before and has talked about Newton's laws of motion, an object in motion tends to stay in motion. So if there is no other outside force that's acting on this object, it's just going to travel in a straight line.

So if no compact object, we're going to say, the companion star moves in a straight line. So it would look like this. This would be the velocity if there was no compact object. It would just move in a straight line.

But if there is a compact object, if there is a compact object, then gravitational force pulls the two together. So what would that change about this object's motion? Steve, you had a question.

AUDIENCE: Yes, I [INAUDIBLE] the compact object, like includuing the [INAUDIBLE].

MARK HARTMAN: So that's what we're going to talk about right now. So if there is a compact object, the gravitational force pulls the two together. So what that means is this object feels a force. So we're going to say this is gravitational force.

If it's moving upwards but then it feels a force this way, which direction is it going to start to move? It goes up a little bit, but then it gets pulled that way. So it kind of gets pulled over a little bit. But now, we know that the gravitational force always acts to pull things together.

So if we up here, now the force is going to pull us this way. So then we turn a little bit more and we move forward. Up here, the force on this object is now going to be pulling down a little bit. So we're going to turn a little bit more and keep going.

So this gravitational force that's always pulling these two together ends up curving the path of this object around the other object. That's the simple, nice, easy explanation of why is it that gravity causes one thing to orbit around another thing. It kind of takes this straight-line path,

and it pulls it, and it pulls that straight-line path to always be around the compact object. Steve.

AUDIENCE: What was the [INAUDIBLE] the other star goes directly to the [INAUDIBLE]

MARK HARTMAN: So there are no planets on the board. We just have our companion star, and we have our compact object, which is still a collapsed neutron star, a black hole. This is the simple picture.

So I'm just going to say, if there is-- whoops. If there is a compact object, gravitational force pulls the two together. The companion orbits the compact object. I'm going to deal with your question in just a second here, Steve-- compact object. When we say orbit, we just mean travel in a circle around.

This is the simple version. This is what we're going to stick with. And in fact, whoever does the X-ray binary project is going to learn a little bit more about how can you actually calculate things about forces.

But, in reality, these two objects, it's not that this one's just getting pulled. This one is getting pulled too. So gravity always acts to pull two things together. So the actual motion is a little bit more complicated.

And I think on the very first resource that you'll find on the [? expert ?] project wiki, there's a little picture. Actually, [? Pierre, ?] would you mind pulling up the picture of the binary orbit? It's in the very first resource on the second page for the [? expert ?] project under X-ray binary star systems.

Because in reality, they both kind of pull each other together. So they really orbit around each other. It's not that one is fixed at the middle.

Let's see. Under that one, yeah. Let's take a look here. Go to page two. So if you look here, our simple model was there was one thing at the middle, and the other was going around the outside. Ooh, there we go.

But in this case, it's that each of these objects pull on each other. So they're kind of orbiting around each other. It's a little bit more complicated, but you can see that this object still goes in a circle, or something close. It could be an ellipse, kind of an elongated oval. And this one also goes in a circle.

It just depends on how massive each one of those is. If you've got a very massive object in the

middle, it's not going to move around a lot as the other one moves around. If you have objects that have the same mass, they're actually going to both move a lot.

But the simple picture and the one that we're going to keep in mind is this one over here. We're going to assume that our compact object is nice and heavy, has a lot of mass. And then this star is going to be the one that actually goes around it. It's going to make it a little bit easier for us to think about.

This also helps us to think about accretion, right, because we said accretion is when mass is transferred from one object to another. Well, if this star is over here the, outer layers of this star are held together by the gravity of that object. If this star gets close to the compact object, the gravitational force between two objects depends on how close they are.

If you have a big object and a big object, there's going to be lots of force. If you have a big object and a big object and a small distance, what do you think is going to happen to the amount of force that pulls them together if you bring two things close?

AUDIENCE: They're going to combine.

MARK HARTMAN: OK. If you bring two things really close together, the force actually gets stronger. If you've ever done kind of a similar thing with magnets-- if you take magnets and they're far apart, it's kind of easy to pull them further apart. But as you get them closer and closer together, you have to hold them back harder and harder and harder because the magnetic force between the two gets stronger and stronger as your distance gets smaller.

We can actually write, and some of you may have seen-- the expression or the equation for how much force this gets pulled together with is going to be the force is equal to this number g, which is a constant, times the mass of one object-- this is going to be the mass of the other object-- divided by the distance between them squared. And this is the distance.

So that means if one of these objects gets bigger, the force gets bigger. If the other object gets bigger, the force gets bigger. If the distance between them gets smaller, this number gets smaller. So if you take something divided by a smaller number, you get a bigger number. That makes sense.

And in fact, let's look at what [? Island ?] wrote over here. She said, "the faster the orbital speeds, the stronger the gravitational force gets, which enables gas and stars to be held in the orbit." Let's think about that. If we were orbiting out here, we could go slow, and the force

would be enough to hold us together.

But if we were in here, orbits happen faster when you're closer to the object. And if you have a faster orbital speed-- there's actually a subtle detail here that isn't quite right. It's not that the faster you go, the stronger the gravitational force gets. It's the faster you go, the stronger the gravitational force you need to enable the gas and stars to be held in their orbit.

So remember, if we look at this equation, force has nothing to do with how fast it's going. It just has to do with how far away it is. And if the object's really close, that force is going to be really strong. So you can go really fast and not fly away.

So we don't really need to know all of these details. But if you're interested in exactly how this works, this is what you'll work on with the X-ray binary project. For right now, though, what I want you to think about is we've got our compact object at the center. We have our companion star going around the outside.

And a simple way to think about, well, OK, what does all this have to do with flux-- what does all this have to do with the brightness-- we are going to look at both the X-ray luminosity, and we're going to look at the visible light luminosity. What do we mean when we say X-ray luminosity and visible light luminosity? What do you think? What is luminosity? Steve.

AUDIENCE: When you talk about X-ray luminosity, you mean the X-ray-- like, an object that produces X-ray [INAUDIBLE] flux of the object, and then [INAUDIBLE] flux of the X-ray [INAUDIBLE]. And then visible light, you mean the [INAUDIBLE] flux of the object.

MARK HARTMAN: OK. [? Ezeke, ?] you want to--

AUDIENCE: So luminosity--

MARK HARTMAN: Nice and loud.

AUDIENCE: Luminosity is the light given by the source. Flux is what we receive.

MARK HARTMAN: OK, luminosity is the light given by the source. So if I say X-ray luminosity--

AUDIENCE: It's [INAUDIBLE] that's given off by the source.

MARK HARTMAN: How much energy does that object put out as X-ray light, versus visible light luminosity, how much light does that object put out invisible light photons. Because remember, our detector is

only sensitive to one or the other. It's not both.

So what we have here-- the X-ray luminosity for our compact object, which one of these objects is going to produce more X-rays?

AUDIENCE: The bigger one.

AUDIENCE: The compact.

MARK HARTMAN: The what?

AUDIENCE: I said the one in the middle, the compact.

MARK HARTMAN: OK, you're saying compact. You're saying the bigger one.

AUDIENCE: [INAUDIBLE]

MARK HARTMAN: OK. So be careful when you say bigger. Do you mean bigger mass? Do you mean bigger in size? What do you mean?

So this compact object, the neutron star or the black hole, the X-ray luminosity is high. It's putting out lots of light in X-rays. Why? And again, this is where you guys should write these things down.

Over here on this board that [? Shekeeb ?] is currently taking pictures of-- no, go ahead. In the bottom, it says-- and this one also got a lot of stars, so you should write this down too. The heat of accretion produces X-rays.

From this star, we have material that's kind of being pulled off. Sorry, this diagram's getting a little bit messy. But you've got material that's being pulled off here and formed into an accretion disk, which is the thing that's swirling around that compact object. If you look in your pictures, here again, we have this swirling stuff that's swirling around the compact object.

So the accretion disk gives off X-rays because it's very, very hot. It's because all of that gas, as it's swirling around in the accretion disk, is rubbing against each other. The inner parts of the gas orbit fast. The outer parts orbit slower, and so they rub past each other.

And since they're spinning around and rubbing past each other so hard, it heats things up. So our accretion disk gives off lots of X-ray luminosity because the heat of accretion produces X-rays. If this was less hot, it wouldn't give off X-rays.

What kind of a spectrum do you think we should try to fit if we were looking at an accretion disk? Any ideas? If something is giving off light because it's hot--

AUDIENCE: A black body?

MARK HARTMAN: So Chris says is a black body. If this accretion disk is thick, which means that you can't see through it, then it would give off a black-body spectrum. So try and make those connections back and forth through the things that we looked at before.

Let's finish filling in this table, and then we'll take a break. So we've got the compact object, neutron star/black hole, has high X-ray luminosity. Would something that is this hot give off lots of visible light?

AUDIENCE: Kind of. Sort of.

MARK HARTMAN: Kind of? Sort of? We're going to say, for these compact objects, most of the light comes out as X-ray luminosity.

AUDIENCE: Most.

MARK HARTMAN: Most. So we're going to say the visible light luminosity is low. Over here, for the companion star, if this is just a regular star, it's not hot enough to produce X-rays. We saw that regular stars produce mostly visible light.

So the X-ray luminosity here is going to be low for our companion star. So I want everybody to put that in. And then the visible light, it's going to give off a higher luminosity. We'll expect to see this star in visible light, but not in X-ray light.

So let's take a look at this. We are going to-- here's an example. Here, I'm going to say this is my compact object, my X-ray-emitting object. Because we still never answered the question, what does this have to do with flux?

Most of you guys already have this model up here, so I hope this makes sense. If we had a low-mass X-ray binary system which has a neutron star, we're going to say that this light coming out is X-ray light. So this is our compact object, which has a high X-ray luminosity.

AUDIENCE: [INAUDIBLE]

MARK HARTMAN: Yeah. And then this is our companion star. Now, in this case, if you look, it says this could be a white dwarf star. If I have my white dwarf star and I orbit around this star-- let me put this down at your eye level. I want you to tell me what happens to the flux that your eye receives from this X-ray object if I make this go around in a circle. So it might help if you close one eye.

AUDIENCE: [LAUGHS]

[INAUDIBLE]

MARK HARTMAN: OK. Now if instead of that, I had a massive X-ray binary, I have a bigger star here. It's still orbiting around. But now, this is a slightly bigger size. If I put this one and I move it around, again, what happens to the flux that you receive? What happens? Somebody describe it. [INAUDIBLE].

AUDIENCE: It's smaller when you orbit it around the light source. It didn't block out that much light. If you do this, it blocks out light for a longer time if the object's massive.

MARK HARTMAN: If the object is, well, not necessarily massive, but in this case, it has to do with the size. If the object is bigger, it blocks off the light from getting to you for a longer amount of time. So when we're talking about X-ray binary systems as an explanation for changing flux, what we really mean is this idea, that we block some of the flux as we go by.

But let me ask you one more quick question before we take a break. What if I did it this way? Let me do it like this. If I went like this and made this orbit around-- actually, [? Shekeeb, ?] can you come and hold this for me?

AUDIENCE: Like this?

MARK HARTMAN: Yeah, just like that, just like that. Good. Now if I do this, what do you see, Steve?

AUDIENCE: The same thing. I see the same flux.

MARK HARTMAN: OK. And Bianca, what do you see?

AUDIENCE: When the star passes in front [? on ?] this side, it's blocked out [INAUDIBLE].

MARK HARTMAN: OK. So you don't always get a change in flux when you have an X-ray binary system. It depends on what angle you're looking at it from, because Juan is also going to see that flux get blocked-- well, kind of. Maybe it's getting blocked by his hand. But then Steve and Chris

are still not going to see this thing get blocked.