Astronomy Cast Episode 270 for Monday, June 18, 2012: Inertia

Fraser: Welcome to Astronomy Cast, our weekly facts-based journey through the Cosmos, where we help you understand not only what we know but how we know what we know. My name is Fraser Cain; I'm the publisher of Universe Today, and with me is Dr. Pamela Gay, a professor at Southern Illinois University – Edwardsville. Hi, Pamela. How are you doing?

Pamela: I'm doing well. How are you doing, Fraser?

Fraser: Doing great. So actually, again -- warping space and time -- this is the second episode that we're recording on this day, which is actually in July, moments before the announcement of the Higgs-Boson! But as we're catching up shows…so we're actually only a couple of episodes behind. We will be caught up this week, I think.

Pamela: Maybe Wednesday, maybe Friday we can record?

Fraser: Yeah, we will be caught up, and then we will…I won't say that we'll never fall behind because we absolutely will because that's just the reality. Now, we had a couple of people who posted sad reviews in iTunes because Astronomy Cast was a little bit late, and they took away some stars from us, so we're really sorry for all of you who felt that us being late detracted from the Astronomy Cast experience. We understand that keeping this show coming out on a very regular basis is really important to you, and it's important to us, and we will absolutely focus our energy on getting this show out as regularly as we can. Now, if you do love Astronomy Cast, or you know feel like you need to give an honest review, the iTunes reviews are a great place to do that. So you can just do a search for Astronomy Cast on iTunes and give us a review -- be honest! But it's great; those reviews are wonderful, and we really appreciate them so…

Pamela: And we do read them and take them to heart.

Fraser: We absolutely do, and in fact the funny thing is because I'm in Canada, I see a tiny version of the number of reviews and I only thought we had a few reviews, and then I was able to switch my country to pretend like I was in the U. S., and there were like thousands or 1500 reviews or something like that. It was quite overwhelming to see all of these at the same time. The other thing that is really important to know is Google Plus (Google), recorded a documentary about the virtual star parties that we do, which is really cool. So they actually flew a team of film makers out to all across north America to our friends in North Carolina, and in your house, Pamela, and my house here on Vancouver Island, and down in Los Angeles to meet with Gary, and they recorded this really moving documentary about the star parties that we do, and it's on YouTube, and you can get it from…you know, I'm sure we'll put it into the show notes, but if you haven't seen this, it is unbelievable it is really cool, and I highly recommend that everybody watch it. It is really neat, and if you want, remember we always do our virtual star parties every Sunday night from when it gets dark on the west coast for about an hour/hour-and-a-half, and we bring in a live view of telescopes, so we're trying to use all of the different media in the appropriate ways so people can appreciate astronomy as much as we do. Alright! Well, let's get recording.

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Fraser: So an object at rest tends to stay at rest. An object in motion tends to stay in motion. Isaac Newtown dismantled the traditional idea that objects would tend to slow down over time, and describe the concept of inertia, the amount an object will resist changes to its motion: inertia. Alright, Pamela, so then I think this is where we really kind of need to go back in history and get an idea. The traditional, the ancient Greeks, the medieval scientists (if you can call them that)…what did they think about the way motion worked?

Pamela: Well, the initial ideas go all the way back to Aristotle, and he thought that an object in motion would, over time, just stop, and he explained the motion of things like projectiles through the air as the median that they were flying through, so in this case the air was providing that extra something that was needed to keep them in motion while they flew. Now, this…

Fraser: Whoa! Whoops! I didn't understand that. Hold on. What? The air was…

Pamela: The air was somehow going, "Keep moving, keep moving, keep moving," and so his idea was if you were able to create a vacuum, objects wouldn't move through vacuums, which is a really weird concept.

Fraser: So the air provided a way to propel objects forward?

Pamela: It kept them in motion somehow.

Fraser: It kept them in motion -- somehow, but not accelerating. They would still slow down.

Pamela: Well, and that was the crazy thing was an object falling through air is clearly accelerating. A projectile goes up, arcs, and then accelerates back down, so somehow the air was responsible for all of this craziness.

Fraser: Oh! So in other words…

Pamela: …force.

Fraser: No, I understand. So in other words, you go and you take an object up to the top of a cliff, and you drop it, the air is going to be accelerating it towards the ground until it runs out of air and hits the ground.

Pamela: And so there's something clearly funky going on…the idea that in a vacuum things aren't moving. People who started thinking about the idea of a Sun-centered solar system had a [gag sound] reaction to this, and so it was actually Galileo who initially started doing the hard experimental work to overturn this idea. Now, he wasn't the first one. So we had well before that we had Lucretius (Titus Lucretius Carus), who was working in the last century B. C., who was trying to say the default state of stuff isn't to be at a dead stop, which was Aristotle's idea, that if you left anything in motion it would come to an eventual stop. He decided that this probably didn't make sense. John Philoponus and said the idea of the median keeping things going…there were issues with it, and that void probably wouldn't limit motion.

Fraser: Was this the impetus theory? Was this the…

Pamela: Well, the impetus theory is all tied into it, and the impetus theory finally came out in the 14^{th} century B. C., and this was an idea that air is somehow pushing, and that when you give something energy -- when you push it, when you accelerate it -- you're giving it an impetus, and then that can get dissipated in to the surrounding…well, this is where friction comes in, but they didn't have friction yet. Galileo's the one who really came up with a solution for this, and one of the big problems they had was they didn't have clocks, and Aristotle's thinking…and Aristotle did not believe in experimentation; Aristotle believed in *thinking*, and that a true understanding of the Universe could come from *thinking*.

Fraser: This is one of those Classic examples, right, where you had these ancient scientists, you know ancient Greeks who would argue about the number of teeth that a horse had, right, and somebody would go out and say, "Well, I'll just count them," and they were like, "No! Don't do that!"

Pamela: And what's funny is sometimes it seems like there's very little difference between particle physics today and regular physics back then. [laughing] Sorry.

Fraser: Zing! Zing! You think people missed that? That was Pamela zinging the particle physicists. Send any letters to Pamela Gay, starstryder@gmail.com.

Pamela: So you had all these people philosophizing about how things move, and they actually believed that acceleration of a falling object was a linear process, so you go a distance, you accelerate an amount, you go twice that distance, you accelerate twice as much. And the reality is that it's a square relationship. So your acceleration: go one unit of time, you go one unit of distance; go two units of time, it's going to be, so…let me actually do one and two units of distance: two units of time, four units of distance (that does the math a little bit easier), and so you have this square relationship going on, and you have to have a clock to figure that out. And it was Galileo who didn't solve the clock problem, but figured out a circumvention of it with what's called the water clock. If you have a very large surface area on a container, the rate at which the water level falls for small amounts is fairly linear over time, so you're getting a constant stream of fluid coming out, so every beat of the clock is a set of volume of water coming out. So what he did was he built this drum of water that had a system with water coming out the bottom that he could turn on and off, and he would very carefully weigh the amount of water that came out after a ball had gone a certain distance. And the one thing, the one miscalculation that's in this is an object that's rolling has slightly different physics than an object that is sliding down, but it's such a small correction that it didn't affect the physics in this course.

Fraser: Right, but this was a way that Galileo could slow down time. Essentially, he could make an object fall as quickly or as slowly as he needed to be able…

Pamela: …using an inclined plane.

Fraser: …using an inclined plane, right, so that he could say, "Well, it's too fast for me to measure this stuff just dropping it, so let's use an inclined plane then I can measure this stuff in a much more slow…" you know, everything unfolds in slow time. Brilliant! Absolutely brilliant! Do you do that experiment with your physics students?

Pamela: I don't do it at SIUE. When I was at Harvard we did this, and we did everything to stay similar to what he did while not killing ourselves. So what he did is he actually used a many-meters-long inclined plane made out of a carved groove, he lined it with parchment to decrease the friction absolutely as much as possible, he created the water clock, he marked off the distances going down the inclined plane, measured how long it took it to go one unit of distance, to go two units of distance, and so on all the way down. Well, what we did because, well, wood weighs a lot is we used PVC pipe because that starts out nice and parchment-smooth, and so we had things going down a half-tube of PVC pipe that students used grease pencils to mark. And we did build our own water clocks using surgical hosing, and those big old buckets that you get when you're tarring your driveway.

Fraser: So then, what is the relation to inertia, though? How does this play into the story that we're telling?

Pamela: Well, what he figured out, as he decreased friction as much as possible, is that when you send something going down the inclined plane, it would just keep going down the other side if it was flat, but if he ended up with two back-to-back inclined planes, and decreased the friction as much as possible, it would go up to basically the same starting height. So he was able to take how much potential energy -- and he didn't have these concepts, it took Newton to get to gravity, but he could start it off at the top, it would accelerate down, and then it would decelerate up, and as he lowered the plane, it went further and further and further, and so he was able to say whatever was needed to go up that incline precipitated the motion, but if there was no force, if there was no "something" acting on the object, it would keep going forever. And he actually…in writing about this, trying to explain the concept of friction, he had some great discourses where he was basically…he had different characters arguing over what friction was, and this is where the little demons argument comes in where there were people basically saying there were little demons out there stopping things, and getting them to stop moving, and that when you smooth something off, you're clearing the demons off, and things like that.

Fraser: Smoothing things off to clear the demons off.

Pamela: It's a brilliant…if you ever have a chance to read the discourses that Galileo wrote, they're brilliant, and you can instantly see why he got himself in so much trouble with the Pope.

Fraser: Yeah. If people haven't read these, they absolutely should. I'm sure it's all available open-source out there somewhere.

Pamela: It should be. There's a great source of Galileo-related everything at Rice University.

Fraser: And he wrote in a very accessible style, and he was clearly poking fun at the people who disagreed with him, who also happened to be very powerful people who were able to put him in jail, but that's a whole separate show that we've already done on Galileo. So Galileo gets to the point that he's created this, he's figured out that there is some kind of inherent motion that is accumulated by the object rolling down the hill, which it then dissipates again as it goes back up -- so how did this sort of carry the concept of inertia forward?

Pamela: So we went from an "Aristotilian" view of the Universe, in which an object in motion comes to a stop to a way of looking at it of: an object in motion will stay in motion unless friction, or something else, acts on it to eventually…when Newton came along, the idea of: we finally started to get friction, we finally started to get gravity, we finally started to get all of these things mathematically described, and it became: an object in motion stayed in motion unless acted upon by an external force. So suddenly, everything got quantified, and here you have: things stay in motion in straight lines unless they're worked on by an external force as well, and this was one those things that folks really struggled with because with Galileo's view of: they keep going in a straight line -- but why do the planets keep orbiting? That was a serious challenge that Newton had to figure out how to address, and that's where gravity became such an important part of understanding inertia, basically.

Fraser: Right, and so if Aristotle had really just thought a bit, and looked up and noticed that the planets are flying though space…of course, he didn't know that there was no air up there, right? They thought it was like some kind of ether, I guess.

Pamela: Well, and he had them embedded on spheres.

Fraser: On spheres…OK. Never mind. See? He never would have figured it out, but the point being that you've got the situation where you've got these objects, they're moving, and yet they're going in a circle. Why don't they stop? Why don't they spiral outward? Why don't they spiral inward? What's going on, right?

Pamela: And this is where we had to understand that the force of gravity connects two points at their center of mass. And if my microphone here is the planet Earth, and this rock is the Moon, then what's happening is if the Moon had no velocity, gravity would pull it straight into the Earth, and that would be a very bad thing, but because the Moon has a velocity that's trying to carry it forward, the force of gravity is constantly pulling it in, causing it to constantly arc inward, but it has enough velocity so that it never actually hits the Earth. So it's trying to go straight, gravity is trying to pull it down, and the result is an almost circular motion.

Fraser: Right, so you've got this situation where you've got these planets that are moving, that nothing is slowing them down, they're not spiraling outward, they're not spiraling inward -- what is the force? Why are they kept going in this circular orbit around the Earth? And this is this concept of gravity and inertia, so…

Pamela: And so this is where, for a while, there were actually people thinking that inertia wasn't just an object in motion stayed in motion in the same way, but an object in motion could either stay in motion in a curve or in a straight line. Well, today we now know that an object in motion will stay in motion with the same vectoral motion that it had to begin with unless acted upon by an outside force. And a vector defines both its speed and its direction.

Fraser: But in the case of the planets, of course, they're orbiting in a circular vector? I mean they've got multiple forces pulling on them, right?

Pamela: No, that's…so the thing is vectors are straight lines, but then you can define them across…well, a vector's something that has multiple characteristics. So velocity is something that only has a speed and a direction. The planets are actually accelerating, which means their exact velocity is constantly changing because that direction is constantly changing. Now, if an orbit's a perfect circle, then its speed is constant at all times, but its velocity is constantly changing as that direction changes.

Fraser: Right. Right. OK, so then where did Newton's main discovery come in?

Pamela: Well, the story, as frequently told, is he was sitting under a tree and saw an apple fall, and saw the Moon in the sky, and had this epiphany that a falling apple and a falling moon are the exact the same thing except the moon is missing the planet. And the analogy that often gets used is if you had a cannon, you put the cannon on a hill, when you fire the cannon ball, if you have it with sufficiently low velocity, it lands on your foot (assuming you're standing right in front of the cannon). If you hit it with larger force, it goes a larger distance. If you hit it with larger and larger force, it goes a larger and larger distance, and it always arcs down to the planet, though, as it falls because gravity's constantly trying to pull that cannon ball back to Earth. Well, if you use enough force to fire that cannon ball, it's going to gain sufficient velocity that Earth's pull only succeeds in bringing it around so that you hit the butt of the cannon. Now, if you hit it with even more force, you can actually start to hit escape velocities, and this is what we do with rockets, in which case the force of gravity is insufficient to change the initial velocity sufficiently to get the cannon ball to return to the planet.

Fraser: So then, I mean, he also…he really famously coined that phrase, right, that "a body in motion tends to stay in motion, and an object at rest tends to stay at rest."

Pamela: "…unless acted upon by an external force."

Fraser: "…unless acted upon by an external force." Right. Exactly. So how did this sort of change people's understanding of the objects moving around them?

Pamela: Well, it was a sudden epiphany that everything is connected by forces, and that when we see something happen, one of two things has to be true: there's either a force acting on the system, or we're looking at a system that's undergoing acceleration, and this is where we start to get into inertial and non-inertial frames of reference. So if you're in an accelerating car, that's a non-inertial frame of reference, so that when you look at the hanging dice hanging from your 1970s vintage automobile's rear view mirror, you'll see the dice don't hang straight down toward the center of mass of the planet Earth. As you're accelerating, they will actually sway backwards, and that's because it's an accelerating frame of reference. An inertial frame of reference is one in which there's no acceleration taking place.

Fraser: And this is why as you go around a corner, you feel pushed up against the side of the car, right, because you tend to want to stay in the motion that you were going, which in this case, you wanting to move straight forward, but the car is now exerting an external force on you, on your left shoulder, that is pushing you around the corner with it, and so your body is pushing back against the side of the car, and that's what you feel.

Pamela: Well, this is where crazy frictional forces come into play because as your car whips around that corner, as little kids in the backseat always know because you try to purposely smush each other into the door...

Fraser: Wheeee! Yeah, yeah...

Pamela: …you feel like you're getting forced to the outside of the car, but the actual force is towards the center of the circle. So this is why when you have a ball on a string, the ball stays on the end of the string. It's because the force is going toward the center of the circle. Now, there's a sudden, "Wait! Hold on, but the kids are flying outwards!" No, the kids are simply trying to go in a straight line, and the car is getting in the way of that straight line, and so you're experiencing this frictional force on your butt. Your body's trying to keep going straight forward, and as the car curves, you're getting caught by friction, basically, and that's: you want to go in a straight line, you're failing to go in a straight line, the car's preventing you from going in a straight line, you feel like you're getting flung outwards. The reality is the real force is towards the center of the circle.

Fraser: Now, this is all fine and good, and you know, completely changed everyone's thinking about the Universe, and the motion, and physics, and you know, how things [missing audio], and all these great technological advances (Thanks, Isaac Newton!), but this was all sort of thrown out the window again when Einstein came along.

Pamela: Well, it wasn't so much thrown out the window as it was changed. So as we're trying to figure out frames of reference, as we're trying to figure out what is an inertial frame, suddenly, in a relativistic situation, things started to become much more curious. So suddenly, when you're looking at your frame of reference, you realize everyone has their own frame of reference, you start to realize everything's in motion, you start to realize there is no such thing as a truly inertial frame of reference. I mean we can pretend that we have a non-accelerating frame of reference. If you're standing next to a railroad train, and a railroad train goes by, and you see someone drop a ball in the window, relative to the moving train that ball falls straight down; relative to you, you'll see it starts falling here it lands over here because the whole window moved sideways. So within the train, it seems to be a non-accelerating inertial frame of reference. You can go back and forth between the two frames of reference, but you're on the surface of a planet going in a circle, which means you're actually constantly changing velocity as you stay adhered to the surface of the planet. But over small distances, we're able to make these assumptions, but when we start looking at larger and larger distances, we start having to worry about things like Coriolis force, we start having to worry about the effects of the fact that the planet is rotating underneath you, and all of these things start to come together and life gets more and more complicated. Now, add to that the effects of time contraction, add to that all of the relativistic effects, and suddenly defining inertial frames is a nightmare because they don't totally really exist, and every observer is their own observer.

Fraser: And that's where the headaches start to set in.

Pamela: Yeah.

Fraser: Yeah, but of course, the predictions made by Einstein perfectly match the measurements that are made in space to a level of accuracy that Newton could have only dreamed about, and so…

Pamela: And one of the beauties of all of this was this realization that whenever we're dealing with things, the proper way to think of them isn't: an object of a given mass moving at a given velocity, it's to think of it as an object with a set amount of momentum because it's the momentum that things carry with them that has the true impact (just to be unintentionally punny). And so the example I use in class a lot is you can imagine a three-year-old and a Sumo wrestler on roller skates. If that three-year-old starts going as fast as it can skating toward the Sumo wrestler, it's carrying a set amount of momentum that it's going to impact into that Sumo wrestler, who, assuming no friction, no inelastic parts of the collision, they're going to bounce off each other, and the Sumo wrestler's going to be basically unaffected, and the three-year-old is going to go flying off in the opposite direction. Now, if you instead have two Sumo wrestlers doing this, you're going to end up with, perhaps if you get a second equal-mass Sumo wrestler coming along and hitting at the same velocity as that small child was, well that big other Sumo wrestler's now going to take all that velocity and start going in the same direction, and that first dude will stop cold just like a pool ball will.

Fraser: Yeah, talk about that pool ball example, right, which is a wonderful example of this transfer of inertia. You have a ball sitting on the table...

Pamela: Transfer of momentum.

Fraser: Transfer of momentum, sorry…and you shoot your cue ball at that ball, your cue ball (in a perfect world) stops perfectly, and now that second ball is moving.

Pamela: And the key to achieving that perfect world is to have the two centers of mass completely line up so that when it hits, all of its force goes straight into an impulse on the other one, and all of the momentum gets cleanly transferred. Now, the reality is that most of the time when you hit pool balls together, it's not that perfect center of mass, and you end up hitting slightly off-center, and so this is where you hit it and it veers off.

And if you get good, you can actually hit something with a glancing blow and cause it to go off at close to a right angle.

Fraser: That was really cool. Alright, well, I think we made our way through this episode of inertia. So once again, thank you very much, Pamela, and we will see you next week.

Pamela: We'll see you next week, and hopefully the internets will be with us.

Fraser: Yes, right.