# Astronomy Cast Episode 268 for Monday, June 4, 2012:

# Energy

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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 today, Fraser?

Fraser: Doing really well. So once again, we are recording this episode of Astronomy Cast as a live Google Plus hang-out. We do this every Monday at noon, so if you ever want to, like, see what Pamela and I look like, you can. And you can also…what's cool is we'll record the main show, and the people watching the show will give us their comments and questions and feedback and ideas, and then…but at the end we'll stick around for about a half an hour and just answer questions from people. So we sort of lost our questions show a few…like maybe about a year ago, a year-and-a-half ago because we're so busy...

Pamela: More than that.

Fraser: …because we're just so busy, but we love the questions show, and so this is the way that we're feeding the questions show back into the show, so if you want to come and watch that -- and everything is all archived on Youtube as well, you can access it all from…if you go to our Astronomy Cast site, all of the episodes are available in full, the video on the pages of the various episodes, so if just listening to us isn't enough and you want to improve the experience, then you can go and check it out. Lots of different places, so just want to let people know that you can do that. Alright. Are you…should we get cracking then? Did you have any more announcements?

Pamela:  I think the most important thing I can say is if you want to look *with your eyes* at images of the Apollo 15 landing site as seen by the Lunar Reconnaissance Orbiter, those images right now are in the MoonMappers project at cosmoquest.org -- so cosmoquest.org/mappers/moon.  We're trying really hard to release some new science about this region of the Moon that has actually had humans walking on it!  And so we'd love it if you'd help us do science, as well as learning science, by listening to the show.

Fraser:  Yeah, we plan to turn you from passive listeners into active scientists.

Pamela:  Yes.

Fraser:  So this is the process.  Alright.  Well, let's get rolling.

[advertisement]

Fraser:   So our entire civilization depends on energy:  getting it, converting it, burning it, and conserving it, but how do physicists think about energy?  How do they measure and quantify it?  And what is energy's special relationship with mass (which is going to be the topic of next week's show because they're really one in the same…might as well just be talking about the same thing)?

Pamela:  They are, but you do deal with mass in a different, not direction – different, distinct way.

Fraser:  Yeah.  Absolutely.

Pamela:  I generally don't worry about the energy of my body; I do worry about what that scale says.

Fraser:  So I can remember, actually, I remember being in high school and learning about energy and how we think about different kinds of energy, and how they convert from one to the other -- how potential turns into kinetic, and it was really a revelation to me to see all that stuff, and to see how it converted from one form to another.  So how do you sort of begin your explanation of energy when you bring that up?

Pamela: Well, unfortunately, you do have to start with math, and the math for work and energy is force exerted over a distance on an object, and a force is how you change an object's velocity, and how you change its direction of motion, so you have to be able to exert a force on an object and get that sucker to go somewhere in order for there to be work, or energy, that takes place.

Fraser: So energy is measured of output with time.

Pamela: Yes. Well, work over distance, work times distance.

Fraser: Work over distance, and so if you're going to raise an object up off the planet, you're going to be doing work on that object over the distance of what it's going to take to raise it.

Pamela: So it's force times distance equals work, just for all of you trying to keep track of things.

Fraser: People love the math.

Pamela: Yeah.

Fraser: Yeah, so OK, and so how is energy interchangeable? How are there different kinds of energy?

Pamela: Well, it's a matter of…

Fraser: Was that a tough one? Did I ask you a killer question?

Pamela: This is one of those concepts that just hurts, and so I'm trying to figure out how to make it not hurt, and my brain froze for a moment because it just hurts. It's one of these things where, for instance, when you're walking along, holding a weight, and it's your arms that are holding the weight, and you're moving forward, well, your arms are just holding that weight in place, and so it's not moving relative to the force that your arms are exuding to keep that weight up, and so your arms aren't actually doing any work in the math sense that we just discussed. But then there's chemical reactions going on in your arms that are contracting those muscles, that are causing the weight to get to stay out, and there's all sorts of chemical processes that are going on, and so when you look at the full chain of energy that went into this event, what you have is:  Sun released light, light hit plant, plant took in light, had chemical reaction, human ate plant, more chemical reactions occurred, sugars or other forms of energy were carried to muscle, muscle used this to do twitchy things that muscles do that allowed you to hold up the mass that you're now carrying -- and it's your body carrying it forward across a distance that is the work that you're doing.

Fraser:  And to even roll that back further, you know:  Big Bang happened, gravity sucked in all of the particles together to form the star, the compression of the star converted the hydrogen into heavier elements releasing energy…it's energy, energy, energy, energy.  Each one is just this conversion from one thing to the other thing.

Pamela:  And you have to worry about all sorts of different energies in this because you have, down at the molecular level, you have the energy in the vibrations of the molecules.  So molecules can switch between different vibrational states.  They're also rotating, so you have different rotational energies in the molecules, and the atoms themselves have electrons that can be in a variety of different energy levels, and so you have all of these different atomic level energies that you have to track using quantum mechanics.  Then when you have the chemical reactions going on, some chemical reactions pull energy from the environment.  Those, when they occur, create a cold solution in your cup, if you're doing a chemical reaction, where you can see the frost forming on the reaction-containing container.  Then there are some reactions that they push energy out to the environment, and in this case, you may see a flash of light, you may feel infrared radiation -- that's warmth.  When you feel warmth, that's infrared radiation that you're sensing through your skin, so you have that sort of chemical reaction going on.  And it's also…you have to deal with collisions at all different scales, so you can have atoms colliding into each other, in which case the force of the impact can cause something to happen over the distance of the impact, and depending on how that interaction takes place, you can end up with things shooting off in different directions, things bonding together and flying together -- so car wrecks and gas molecules colliding in the atmosphere have very, very similar physics, and it's all transfer of energy.

Fraser:  And I guess that's the key is that transfer of energy, that energy turns from one thing into another thing, so what exactly is going on? When we say energy is transferred, when we turn say potential into kinetic or kinetic into potential, what is actually going on?

Pamela: Well, when you have potential energy, this is, for instance…

Fraser: Lift a book up on the…

Pamela: I'm looking for something I can drop without causing pain, so I have a spool of thread right here, and right now I'm exerting a force on it that is holding it above the surface of my desk. I'm not doing work on it because the sucker isn't moving, but I'm exerting a force on it that causes it to stay still, and potential energy is locked up in anything that requires a force to prevent that energy from escaping, so if I remove my hand, suddenly the potential energy that was tied up in the spool of thread that I was holding up (and those of you that are listening are just going to have to believe me), and as that object fell, it gained velocity because the force of gravity from the planet Earth was pulling the spool of thread toward the center of the planet, and then that energy from the fall, that kinetic energy, when it hit the table, it created sound waves, so in that case, the energy from the fall got transferred to the table, caused vibrations in the table. The table, if I had high enough ability to capture thermal properties, I would have been able to see the table heated up, the air around it heated up from the sound waves going through it, then that energy from the compression waves, that sound (compression of the air moving through the air) hit my ear, energy was transferred to my eardrum that got translated into a neurological signal that my brain picked up on.

Fraser: So much energy being dissipated from that drop…but I know that a certain amount of energy is always getting lost, right?

Pamela: Yes. Well, so lost is the wrong way to…

Fraser: Not lost, yeah.

Pamela: The Universe conserves energy.

Fraser: Unusable, unusable…a certain amount of that energy is getting lost to us.

Pamela: Right, right, so within any given system that isn't perfectly sealed (and, like the Earth is not perfectly sealed by a long shot), energy over time does end up going into places where we may not be able to access it. So

Mars, I think, is the better example. Mars has an atmosphere that when sunlight hits it, it gets heated up, excited, and the collisions between the atoms in the atmosphere can periodically cause things to fly away. Now, you add in high-energy particles coming from the Sun, they hit the atmospheric particles on Mars, and the energy contained in that molecule gets swept away from Mars, so Mars is slowly losing energy.

Fraser: Right, but if you take…I mean, just for an example, if you take a ball and you put it on the end of a rubber band, and you stretch that ball down and you let go of it, the ball's going to bounce up, and then it's going to bounce back down, but it's not going to bounce back up as high as it did the first time.

Pamela: Oh, you're getting at friction.

Fraser: Yeah, yeah, exactly -- that there is a certain amount of energy that is lost through friction to heat.

Pamela: To that system...yes.

Fraser: To that system, and that heat is then, you know, the whole concept of heat is really that it's this energy that's being lost to us from that system, and eventually the whole Universe is going to be heat, and it will be all the same temperature and not usable. It's these differences in heat that we can exploit, but yeah, that always sort of …when you drop something and it doesn't bounce quite up as high as it did the time before, but when you start out it's potential energy at the top, you let go of it, it drops, it bounces, right before it hits the ground it's all kinetic energy, and then it converts back into potential energy as it rises back up, and then…but each time it's less and less.

Pamela: And the realities are that when we drop a real ball onto the table, energy gets lost to two major processes: one is when the ball hits the table, the act of compressing the ball, there's frictional forces in there, so when the ball uncompresses and springs back up, it's lost some energy, and it also loses energy to making sound. In order for a ball to bounce all the way back to where it started, it would have to be a soundless bounce. I mean, imagine a basketball game where you couldn't hear the ball bouncing, but the amount of force that you put to that first dribble causes it to always dribble the same amount, so you're basically walking around hovering your hand over the ball to give slight side to side forces to steer it, but that’s all you’d have to do.

Fraser: And I guess the point then is that the basketball player, as they’re dribbling, is injecting energy back into the system…

Pamela: Exactly.

Fraser: They’re actually pushing the ball every time they hit it.

Pamela: And that’s the exhausting part of dribbling the ball is that you just have to keep adding force, adding force, adding force, otherwise it’s not going to make it back up to your hand the next time.

Fraser: And so then how do physicists measure energy?

Pamela: It depends on the system we’re looking at. We don’t like to do things just one way. That’s one of the hard things about science is energy’s everywhere. There’s lots of different ways to deal with it, so we look at energy in terms of what is the temperature of something because that speaks to the kinetic energy that’s in the motions of the particle. We look at how much mass is there because, well, the mass that’s tied in that holds its own energy in its ability to…a neutron can decay and release energy, lots and lots of particles actually can decay and release energy, and if you get fission and fusion going on, depending on where you are on the atomic table, that’s another way to release energy from mass. So then we also start looking at: OK, what are the forces that are acting on something that are causing it to have potential energy locked up in the system as well? In general, what we’re looking at can pretty much always be broken down into the activation energy available from molecular reactions, the nuclear energies that are tied up in potential decay processes, the kinetic energy in the system, which is from all the different varieties of motions, and the potential energy from any other external forces that are acting on the system.

Fraser: Now what about the gaining and releasing of energy? Is there some way to measure how fast things are getting rid of energy? Is there a limit to how fast something can get rid of energy, or gain energy?

Pamela: Well, the limit really has to do with the ability of the surrounding materials to transfer that energy. So for instance, if you have a copper box and you put a piece of dry ice into that copper box (I don't know why you would do this, but we're going to pretend for a moment)…so say you have copper box, and you stick a piece of dry ice into it, and you leave it out in perfect darkness, but in a 100-degree oven. Well, very quickly the dry ice is going to melt, and try to explode your box because the dry ice gas is bigger than the solid dry ice, and it's trying to take up space inside the box. Now, if you, instead of having copper, which transfers heat very readily and allows the heat from the outside (heat is a form of energy) to go inside and change…use that energy to change the state, in this case, of the carbon dioxide. If instead of having copper, which facilitates that transfer of energy, you have something like Styrofoam, that doesn't want to allow energy to transfer, then the ability of the energy to flow from that hot oven to that cold dry ice and facilitate that state change, the energy can't flow so that is a slowing-down effect. You also have to look at: how effective is a particular molecular transfer? Is it something that readily changes? Is it something that you need a lot of energy to encourage the change? So there's rates involved that change with temperature as well. So melting ice, the ice is going to melt faster if you're on a copper substance at a much higher temperature that's readily transferring in the energy, than if you're on Styrofoam at a 35-degree temperature -- 35 degrees Fahrenheit, just a couple of degrees Centigrade.

Fraser: So…and I'm going to ask you one of those four-year-old questions, which is: where did all of the energy come from? What was…like, right at the Big Bang, and we've got all this energy in the system, what were the earliest states of it [missing audio] what we have today?

Pamela: Well, we can't say where all the energy came from. If we could do that, I could tell where the Universe came from.

Fraser: No, I understand that, but I'm talking about the actual…right after the Big Bang, when all of the energy of the entire Universe was injected, was there…?

Pamela: So initially everything was in the form of light energy. Everything was basically photons, and then the color of the photons, which is a measure of the energy, so red is a lower energy than blue, which is a lower energy than x-ray, which is a lower energy from gamma ray (and all the really high stuff we just refer to as gamma rays), so when the Universe first formed, everything was light -- and I actually love the poetry of our Universe started as pure light, and then the mass separated from the light as the Universe expanded and cooled, and hit the temperature where suddenly the light was allowed to solidify out to mass.  Mass is just solid light.

Fraser:  Yeah, I was going to get into that…so for a while there, all the energy in the Universe was essentially just super-high energy gamma radiation?

Pamela:  Pretty much.

Fraser:  That was it -- that was the only kind of energy there was in the Universe?

Pamela:  Yeah, kind of sad…

Fraser:  And yet, let's…

Pamela:  Well, there was actually a point where even light -- the forces hadn't split if you go back far enough. So you go back far enough and it was just stuff we can't really speak about in a sensible way.  Not even the forces had separated, so without electromagnetism by itself, you can't really say the Universe was pure light, but that split up so quickly, we're going to ignore those fractions of a second.

Fraser:  Right, OK.  But then, let's compare and contrast that to the far, far future of the Universe.

Pamela:  So the far, far future…the kind of neat thing is what was once pure light will, assuming protons decay, will again be pure light, so what we have is a far distant future, again, assuming protons decay – we don't know if they do, we actually have limited to…they seem to be stable for at least 10 to the 34 years, which is a lot of years, so assuming that they actually do decay, then eventually all of the black holes will have time to evaporate. Even the big suckers will eventually start evaporating once they no longer have cosmic microwave background energy to suck in, so as the black decay and the particles themselves start to decay, we'll end up with diffuse energy everywhere, and in this case it's not a matter that the energy…that it's too hot and too dense to form mass.  It's a matter that the mass has had time to turn back into pure energy, and the energy is spread out so much that there isn't enough in a small enough space to form a particle again.

Fraser: And so you would end up with the whole Universe being very long, assuming, I guess, dark energy is still acting, and still accelerating the expansion of the Universe, you would end up with a whole Universe that is rapidly expanding. I guess, wavelength-stretching radio waves at the very low end of the electromagnetic spectrum, you would end up with photons of light that could have a wavelength that could be light years across.

Pamela: Eventually, if you expand the Universe long enough, that's just a matter of letting your clock run out, and it's…

Fraser: Yeah, you need a clock that will never run out.

Pamela: And that's the other thing we don't know is when you start talking about the end of the Universe, for all we know, we're eventually going to merge with another universe, so there's a lot of "what ifs" involved in the ending of things, but in the beginning, I feel safe in saying that at the beginning, it was originally so dense, so hot that even all the forces were the same sucker. Over time, Universe cooled, forces split out, everything became pure energy. Over time Universe cools, got lower in density, and mass was able to start forming, and then eventually we even reached the point where neutral atoms were able to start forming, and that happened about 300,000 years after the Big Bang.

Fraser: So where do the -- and I think we probably need to do a whole show on the laws of thermodynamics if we haven't already -- where do these play into this concept of energy?

Pamela: Well, it's…I mean zero is two thermometers that read the same temperature, experiencing the same thing, that's just a matter of making the science so you can communicate from one person to another. The idea that heat travels from high-energy heat to cold energy, that's a matter of everything basically equaling out. So you can imagine the gravitational way of thinking of this in terms of if you have a flat surface, and you have a cup of water, and you suddenly remove the walls from the cup, the water's going to spread out so that it has an equal potential everywhere. Well, energy, in the same way, if you have a hot room and cold room, subtract the wall, the energy from the hot room is going to equilibriate between the two rooms. So cold is a lack of energy, and so the hot -- the energy will spread out so that it's equal everywhere.

Fraser: And I mean, I know there's more laws of thermodynamics.

Pamela: There's more laws, but then you start getting into things like entropy and stuff like that, so [missing audio]…

Fraser: But in this case, yeah, I mean entropy -- definitely that's a whole show on its own as well actually…but right. This whole concept of equilibrium -- the fact that the energy is looking to balance itself between different situations, that balls are looking to roll downhill, that ice cubes are going to melt, that rubber bands want to be snapped back together, that this is the…this always looking for this equilibrium…

Pamela: And things are always trying to get down to the lowest allowed energy state as well. So you don't have a room where suddenly all of the energy in the room goes to making a certain number of the atoms at the highest possible energy level they can be at. Things are going to try to equalize out to the lowest possible energy across the population, and it's the population stuff that really starts to look interesting.

Fraser: What do you mean by that?

Pamela: So, again, we can look at Mars' atmosphere as a great example. You have a whole bunch of different types of atoms in all of our atmospheres. So here on Earth we have oxygen, we have nitrogen, we have carbon dioxide, carbon monoxide -- all of the other nasty pollutants out there, and each of these different molecules and atoms has their own mass. Now, they're trying to equalize to spread out energies that are equilibriated between the different populations, and this means that the heavier mass molecules are going to be moving slower than the lighter weight molecules as they spread out the energies across all the populations. Now, you're always going to have a few things that are moving a lot faster, and a few things that are a lot slower, but this Bell curve distribution of the velocities…and the height of that Bell curve is going to depend on the mass of the things that you're looking at.

Fraser: Is there a way…is there like a minimum measurement for energy? I know that, for example, there's like a Planck length version of measuring energy.

Pamela: The idea of measuring energy is the idea of absolute zero. This is when you take an atom and you remove all energy from it, such that the electrons are not moving, all vibrations have stopped, it's frozen, but we can't get there. There seems to be the Bose-Einstein condensate is as far as we've gotten, and there always seems to be some minimum vibration in the system, some quantum noise.

Fraser: So we can try to get closer to that absolute zero, but it is theoretically impossible to actually reach it, or practically impossible to actually reach it.

Pamela: It's practically…and here the issue becomes: how do you perfectly isolate something to remove all the energy of it when the reality is that energy always wants to flow down to that lowest energy state and equalize everything out? And so we do all sorts of crazy manipulations of magnetic and electromagnetic fields, of magnetic and electric fields rather, we remove all other molecules so that you don't get any collisional excitations, we do everything we can to stop that motion, but at the end of the day, the Universe wants to equalize everything, and in fact, our own planet Earth is constantly radiating away energy that's trapped in the planet as we try to freeze out to equalize with the Universe around us.

Fraser: That is really cool. Alright, well, I think we're running out of time for this week, but I know that next week we're actually going to connect the dots. We're going talk about how mass is actually, as you said, frozen light, and we'll talk a bit about how those discoveries were made, and just how mass works out, and talk a bit about the new discoveries that have been made about the Higgs boson -- although that's probably a separate show.

Pamela: And we'll bring in things like how radioactive decay keeps the Earth warmer than the Sun alone can do, and things like that.

Fraser: And what's the difference between mass and weight.

Pamela: Yeah, that one confuses everyone.

Fraser: Yeah, absolutely. Great! Well, thank you very much Pamela, and we'll talk to you next week.

Pamela: My pleasure.