Astronomy Cast Episode 262 for Monday, April 23, 2012: Solar Sails

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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 great. How are you doing, Fraser?

Fraser: Doing really well. Now, I think we need to give people another reminder that the world is not going to end this year, and we'll be there to celebrate its continued existence.

Pamela: Yes. Yes, so we're going to be going on a "The World is Not Ending" cruise, and you are all invited to join us. It's a cruise that goes out of Miami, leaving December 16, and travels to a bunch of awesome places, to a couple of awesome countries, and we're actually going to spend the day the world is supposed to end at Mayan ruins, and I just…I…I love archaeology, so we're doing this and we're inviting you to do this with us, and if you go to astrosphere.org, which is the non-profit that co-sponsors this particular podcast, there's all the information that you need to sign up. And basically, we're working with a travel agent, her name is Zelda, and when you call up Zelda, just tell her Astronomy Cast sent you, and she'll get you all hooked up with cruise tickets, and an awesome chance to be in on a bunch of private recordings, a bunch of special events, and getting to see me look foolish trying to climb around archaeological sites.

Fraser: And the actual cruise itself has a ton of really interesting stuff on it: David Brin is going to be there, a bunch of astronauts, other astronomers, so it's going to be a very space-focused cruise, and so if that's your thing, we'd love to have you guys join us. So like I said, go to astrosphere.org, there's a link there, and make sure you say that Astronomy Cast sent you, so we will know how many people will be coming to, sort of, participate in the things that we're trying to do.

Pamela: Yeah, and how awesome is it that our travel agent's name is Zelda? That's just part of my favorite.

Fraser: Yeah, the end of the world…it's been prophesied that we will be going to the Mayan ruins by Zelda. Great.

[advertisement]

Fraser: Well, let's get on with today's show. So now, wouldn't it be cool to explore the Cosmos powered only by sunlight caught by your shimmering solar sail? Its sounds like science fiction, but it's serious science. A test sail has even been sent into orbit. It might even be a way to travel from star to star in the far future -- solar sails. I love solar sails! Now, I'm a sailor, so I think it's just a natural fit to turn into solar, you know, to do solar sailing as well, but I do think that the actual reality is that we are going to be a little different for people. I know there's a few surprising things. I remember, you know, even a few years ago, you explained a part to me about solar sailing that completely changed my whole perspective on it, so I will definitely be digging that up for you on this episode. So then, what is the sort of the physics going on? You know, why does a solar sail even seem like a viable way of moving through space?

Pamela: Well, this all goes physically back to that whole $E = mc^2$ part of reality, where light is able to impart momentum. So if you shoot someone with a laser beam, you're actually pushing on them, and when we look at stars we're seeing objects that are very carefully balanced between the forces of light pushing out – light pressure, and the force of gravity pushing in, and we just don't think about this in our day-to-day life, but when it gets to be outer space…it was noted as early as Kepler that there seems to be this force that pushes comet tails so that they're always pointed away from the Sun, and so even before we realized that light was able to exert a pressure, Kepler was thinking this might be a way to actually sail through the Heavens. If the solar wind can push the comet tails in a constant direction away from the Sun, maybe it can also push human beings in great sailing craft away from the Sun as well.

Fraser: Well, but those are kind of different, right? The solar wind and the light pressure form the Sun are two different creatures.

Pamela: Right. So the light pressure from the Sun is literally the pressure of light, and the solar wind includes a lot of particles, a lot of other stuff that's getting blasted off the surface of the Sun, so it does get a little complicated, but it's really the radiation pressure that's exerting the majority of the force, but Kepler, he didn't know any of this stuff. To him, it was all wind.

Fraser: It was all wind. Yeah.

Pamela: It was all wind. And what's kind of awesome is he actually wrote a letter to Galileo in 1610, and I just love this quote. He wrote: "Provide ships or sails adapted to the Heavenly breezes, and there will be some who will brave even that void," and it's just this great, romantic idea of this great Argonaut just sailing between the planets.

Fraser: Now, when we take…I know for a lot of it the analogy holds, I mean, with, you know, sailing here on Earth, you've got the wind that's pushing in a constant direction, and when you're going *with* the wind, it's really the wind is pushing you in the same direction that you're going, and that analogy really holds out in space as well. If you set up some kind of sail, you're going to get pushed in the direction that the light pressure is going, and you're going to be accelerated away from the Sun, but here on Earth when you want to sail *into* the wind, there's sort of a different technique that you have to use, where the boat has a keel, has some sort of dagger board that pushes against the water, and then actually let's you move upwind. But…and I think it's completely possible to move upwind in space, as well, but it's all more about mechanics than it is about actually using some kind of keel.

Pamela: So, where in space you have no drag, you have almost no friction, (unless you're close to the atmosphere of a planet), so that normal idea of dropping your keel, creating the friction, using the water to help you define your direction….in space, you just have to basically say, "OK, there's gravity pulling me over there, let me lessen the amount of force that's pushing on my sail by rotating the sail." You have to try and balance the forces to figure out where you're going, but if you don't have a force where you want to go, you can't go that direction, so it's simply a matter of letting go of the wind and falling into the Sun, or rotating your sail to catch the full light and getting pushed out of the Sun -- hopefully.

Fraser: Right, so let's talk a bit about that, about how you would move through the Solar System. So let's say that we launch a solar sail from Earth, put it into orbit, and now it's in orbit around the Earth (or perhaps in orbit around the Sun) at the same, kind of, roughly orbit that the Earth is going…so how would we move? Let's say we wanted to visit Jupiter. What would we do with our solar sail?

Pamela: We would…first of all, it would be a very, very slow process. That's the first thing everyone needs to understand. This is a slow, slow process. You're looking at maybe a newton of force, and a newton is enough to lift one kg, one meter, and yeah, it's not a lot of force, so you're looking with your very small amount of force, you're going to pivot your sail to catch the sunlight, and you're going to very slowly move into a higher and higher orbit. So you're probably going to do this in a systematic way, such that you always apply the force at the same point in your rotation around the Earth, so you can constantly get higher and higher and higher in a systematic way, just like you might always fire your rockets when you're at the same point to get your orbit larger and larger. Once you finally escape the Earth's orbit, you want to escape such that you're still arcing toward where the object you're trying to get to will be when you get near it so you can gravitationally, hopefully get captured by it. Along the way, you may get lucky and have orbits aligned such that you can use the gravitational assist of objects between here and there, but in general, you're going to, the entire time, just tack your sails to increase or decrease the force that you're getting such that you're accelerating away from the Sun in a way that adjusts your orbit as needed as you move from a planetary orbit to a solar orbit.

Fraser: And if you looked at the orbit, I guess, the path that the solar sail had taken to make this journey, you would see this ever-expanding spiral because you would be, you know…and I think, a great analogy of that is the SMART-1 mission that went to the Moon, and they used an ion engine and what they did is they were orbiting the Earth, and they went around and around and around just in wider and wider orbits until they got captured into the lunar orbit, and then they came the other way and went in and in and in until they were actually orbiting the Moon instead of the Earth, and it's this same situation if you use a solar sail: you're going to be using that power, that acceleration from the Sun to just increase the size of your orbit away form the Sun to put you into higher and higher solar orbit until, I guess, your orbit overlaps Jupiter's orbit, and then you're going to try and get yourself captured by Jupiter.

Pamela: Now we are giving one bad impression with our use of the word "you're" in all of this: this isn't going to be human beings. Solar sails are a wussy, wussy way to accelerate something.

Fraser: Let's use lasers.

Pamela: [laughing] That is a very energy-intensive way of traveling and not practical. So we're really looking here at NanoSat, at CanSats, at spacecraft that make my ipod look heavy. We're not going to be building things that move human beings and their orbital habitats and their life support systems and everything else, simply because it's just not a practical technology for that.

Fraser: Well, this is the part where I'm going to stick my fingers in my ears and say, "La, la, la, I'm not listening," so you can say that if you want and dream about nano-satellites moving to higher orbits, but the reality I know is that we're going to have crude sailing ships plying the spaceways, so…but I think what is really interesting, what is really important about this, I really want to get this into people's brains about the spiraling nature of the orbits because that's the key on how we also descend in the Solar System as well. That's how we go from, say, the Earth to Venus. You may ask yourself if the Sun is pushing outward this whole time, how do we go from the Earth down to Venus…Pamela?

Pamela: So in that case, you simply look to apply the force in a direction that hopefully slows you down somewhat. It's all a matter of angling things, so if you're traveling in a circle around (let's make my microphone the Sun)…if you're traveling in a circle, there's different ways to expand your orbit so that you make it different shapes, and it's tricky because to get a smaller orbit, you do need to slow down, which means you essentially need to figure out how to accelerate in the opposite direction that you're traveling in. Now, the solar sail can really only push you away from the Sun, so it's a matter of figuring out how to do that in a way that adjusts to your orbit such that while you're going further from the Sun on one side of the orbit, you're able to change the angle enough so that, hopefully, you can get closer to the Sun on the other orbit. And it's non-trivial. It's…you're basically looking for something that will gravitationally slow you down because you're not really going to use the solar sail to slow you down. You're going to look forward to adjust your orbit so that gravity can slow you down somewhere.

Fraser: Right. The analogy that I always use is you put your arm out the window of the car while you're driving…you put your hand flat out the window, and then if you tilt your hand up, then you're going to have this lift on your hand, and it's going to want to push you up -- up, up, above, but if you tilt your hand down, now you've sort of got a pressure that's pushing your hand down, and in the case of the solar sails, right, we're tilting the sail so that the pressure from the Sun is going to be decreasing at the speed of your orbit and drop you to lower and lower orbits, right?

Pamela: This is where the whole analogy with real sails actually completely breaks down.

Fraser: No, I know. I know.

Pamela: And the hard part is with a sail, one of the forces that you're dealing with is you have lift, so you have a lifting body, and the physics of lifting bodies is extraordinarily complicated. The truth is wings are not as easily understood as most aerodynamic books will try and make them understood. But solar sails aren't a lifting body, it's simply a force pushing away from the Sun, and you're not going to be able to get any of this getting sucked forward or backwards lifting effect that you get with wind. It's simply a force that always pushes in a straight line away from the Sun, and so that's where it suddenly becomes a "getting near the Sun" means you have to find something else to gravitationally slow you down, and you just let go and fall.

Fraser: Right. Right. Exactly. So let the gravity of the Sun pull you back in using other bodies. So then what kind of material would make sense for a solar sail?

Pamela: This is something that folks have actually been actively struggling with. Many different teams are trying to figure out how to build solar sails. Problems that they're running into is things like struts that are capable of supporting all of the force on a very thin material without tearing or breaking, building things as light as possible, but at the end of the day what we're looking at is plastic films, things like mylars that balloons get made out of and very thin plastics to build the struts. These things basically look like giant kites, giant pinwheels, and it's amazing how big they have to be and how thin they have to be. So we're looking at things that are measured in nanometers, so maybe as thick as 100 nanometers – that's smaller than a hair, and not only are they extraordinarily thin, but then you have to figure out how to pack them up and deploy them without them getting tangled, without them tearing, and so you're building something foldable, fragile, capable of sustaining all of the force against it without tearing, and capable of unfolding in a graceful way while minimizing weight, and it suddenly just becomes this huge, furry deal that we don't always succeed at.

Fraser: I know that origami folders have been called in to this challenge. I know there was actually a folding telescope that was designed with the help of some origami, but I'm sure the same thing is going to happen with creating the solar sails. How do you fold up something that's a kilometer across into a small packet so that you can launch it into space? And then how can you unfold it so all the struts can work properly because we've had problems with solar panels coming out?

Pamela: Right.

Fraser: Where like, oh, the solar panel… Remember the Galileo spacecraft with its fold-out antenna? That sounded like a good idea at the time, but it didn't work.

Pamela: And so, here we are trying to figure out how to build things, well, are 20 meters, that's like 70ish, 65ish feet in width and height -- 20 meters across that fold up into little, tiny spaces, and have struts that safely hold them open and are carrying little, tiny CanSats on them, and so suddenly, it just gets extremely complicated to do this in a safe way. We've used aluminums, we've used plastics, we've used polyimide (which is just a fun word), and they're getting to the point that some of them are deploying, some of them are not, and so far we haven't been able to successfully build one that both deployed and was successful in pushing the spacecraft somewhere.

Fraser: This might be one of the challenges that will be met only by some kind of space-based manufacturing, where you've got these asteroids that we're tearing apart by planetary resources and turning them into solar sails to move material around the solar system.

Pamela: Well, that actually…you're not going to make plastic out of asteroids, so that probably won't happen.

Fraser: That's right. You need dinosaurs for that,

Pamela: You need dead dinosaurs to make solar sails.

Fraser: Yeah, right.

Pamela: [laughing] It's true. It's sad, but true -- solar sails are made from dead dinosaurs converted to plastics. So, I think it's something that we're actually going to figure out soon, but it's one of those things that it hasn't been a primary problem that either NASA, or ESA, or any other organization has been dropping a lot of resources into. We've seen the Japanese try at, we've seen the Russians try at it, we've seen the Europeans try at it, and right now one of the primary efforts is actually coming from the Planetary Society here in the United States, where they're actively working on LightSail I, where they're working to… trying to find what is the most effective way to build this, what is the most effective way to deploy this, and it's something that they will be doing in the near future. So it's just interesting to see that, not only do we have commercial space agencies that are actively working to try and build things like Dragon, but we also have non-profits working to try and solve some real issues in space exploration and build solar sails and CanSats.

Fraser: Yeah, and a quick shout-out to the Planetary Society and our good friend, Emily Lakdawalla, and Bill Nye, the Science Guy…but if this kind of technology is interesting to you, you should join the Planetary Society, give them a donation, help them out with their plans because they've been actually creating solar sails, and actively discovering how hard this is, but I mean, they've actually launched a sail.

Pamela: Well, they have, and it wasn't a complete success, but it's progress. And what's kind of awesome about this is it's a fairly low-cost technology. It's annoyingly difficult technology to work with, but it's a low-cost technology, and as the price of sounding rockets drops, as the price of launches of CanSats drop, it starts to become the type of project that a university engineering class has the potential to work on. This is within reach of working with folks like Kentucky Space (which is another organization to give a shout-out to), so in the near future, this is conceivably a problem that's going to get solved by a bunch of aerospace engineering graduate students, or even undergrads, working hard with a bunch of mylar and aluminum.

Fraser: So let's sort of imagine the near future, or the middle future, you know maybe 10, 20, 30 years down the road when Planetary Society's tests have yielded some success, and Planetary Resources is incorporating, you know, they're launching plastic to be able to build their solar sails, you know. How would a solar sail propulsion system fit into the sort of the various propulsion systems that people will be using to get around the solar System? How would -- when would they choose it?

Pamela: Well, it's definitely something that's an inner Solar System technology, and it's the type of thing where you can imagine you fire something off to one of the inner planets, and you want to send something back, you get it back to orbit and then attach it to a solar sail and use the solar sail to get it back to Earth. So this is a way of getting a free return trip that just requires a great deal of origami, and so these are the nice types of easy projects. Send a couple rocks back. They have to be small rocks, can't carry much mass, but it's a way to get things back to Earth from the inner Solar System. It's also a way to get things perhaps out to the outer Solar System at low cost. You can almost imagine a future where, if you want to send a gift to your relatives on Mars, and it weighs a small enough amount, you send it via solar sail post.

Fraser: How long would that take? Years?

Pamela: A long time…you have to think ahead, but it's not fast. It's not good at sending large amounts of mass, but it's that slow-and-steady-gets-the- job-done-at-a-low-cost.

Fraser: Could you see it as being used as a transfer system between Earth and the Moon? I mean, like sending supplies? You can imagine solar sails making some kind of complicated, orbital mechanics.

Pamela: This is heavy to a solar sail -- not effective for carrying supplies.

Fraser: Not effective for carrying supplies… I think that's just a failure of your imagination, your faith in technology.

Pamela: I think it's a failure of wanting to build something that big. It's just a reality of just how much light we're getting from the Sun. At a certain point, you can't turn up the Sun! And so when the total force exerted on a normal solar sail is enough to lift -- this weighs less than…so big solar sail, you're looking at being able to move a 1-km object ineffectively, and it's simply the limitations of how much pressure we're going to get. The energy that we get -- it's proportional to the energy of the photon divided by the speed of light that gives you the momentum that's the change in energy that you get…we're not going to be able to change the energy of light coming off the Sun, we're not going to be able to change the number of photons coming off the Sun. Between here and the Moon -- we're a high-gravity environment, low Earth orbit, you're dealing with the drag of the Earth's atmosphere. One of the numbers that I've looked up, its estimates are you're looking at 4.57 x 10 to the –6 newtons per square meter of a solar sail.

Fraser: That's small!

Pamela: That's very small, so this is why we need to stress over and over: Not how you're sending supplies!.

Fraser: You are such a buzz kill!

Pamela: There's ion drives! Use ion drives if you want slow and steady.

Fraser: Fine. OK, OK, so the solution to solve this problem is lasers – big lasers. Now, I know that's energy-intensive, but the point being, you can be on Earth, and you can shoot a laser into space, and that's a way get your power from Earth to space and apply a force. Now, can you just shoot a laser at a solar sail and impart force on it?

Pamela: Yes. That's one of the nice things about this.

Fraser: Well, then there's your problem solved right there. Now, obviously, what are the technical constraints of such an energy…?

Pamela: Now, the problem you're going to have with that is laser beams get scattered by the atmosphere. They broaden as they go. When we shoot lasers off the Moon, we're looking at only getting back maybe on a really good firing a dozen photons from that laser beam.

Fraser: And it's a really powerful laser.

Pamela: Yeah, so we're not looking at this being any more effective really. Now, in the future where you can sort of imagine petawatt lasers, lasers that in a single burst use the same amount of electricity as New York City, we're looking at destroying the Earth's resources to be able to push a small object through space – not in favor of that.

Fraser: I can totally imagine that future.

Pamela: [laughing] I love how you're so willing to sacrifice the Earth to use solar sails.

Fraser: Whatever it takes, whatever it takes. We gotta tear apart huge chunks of the Earth and turn them into lasers so we can fire them at solar sails so we can have our 2080 solar system cup -- I'm all for it.

Pamela: Student projects -- this is excellent technology for future student projects. Launching CanSats that are capable of inter-planetary flight…

Fraser: Now, what about the potential for using it as another like a long-term technology to get from star to star? I mean, again, if time is no concern…

Pamela: Right, so this is a way to get you out of our Solar System. To give you a realistic idea of the effects of solar pressure, a spacecraft going from Earth to Mars is going to get displaced 10,000 km by the pressure from the Sun. Now, if you just let that go, if you put that giant sail out, this is going to add up over time, it's going to keep pushing you out. Now, the issue is, at a certain point, you're going to get far enough from the Sun, and everything else that you're no longer expressing, you're no longer experiencing any real noticeable external force due to radiation pressure, the sum of the forces is basically going to add up to zero.

Fraser: But you've got momentum.

Pamela: You have momentum. Tthis is what's carrying the Voyager spacecrafts out, so you use this to carry you very, very, very, very, very slowly out of the solar system. But again, ion drives – much more effective.

Fraser: But, I mean, you've got to carry your fuel, right? And so then you aim at a star, and then you break.

Pamela: But ions don't require all of that much.

Fraser: And then you brake, using the light pressure from the star that you're going towards, right? You've got a way to accelerate yourself, and a way to brake, and you didn't have to carry any fuel -- and it is awesome!

Pamela: And very slow…

Fraser: Man, you just are not…where's your imagination today, Pamela? Come on, come on…

Pamela: I want effective space travel!

Fraser: Alright, alright effective space travel – that's Space-X. Up in your chemical rocket and away you go…

Pamela: Yes.

Fraser: So that's cool. So where do you think this is going to happen? Do you see this being the future of these NanoSatellites? Can you imagine people deploying a lot of really small satellites that have like single-purpose that might be…that might cost hundreds of thousands of dollars?

Pamela: I think this is going to be a really neat, low-cost way to do simple exploration projects. It's going to be the way that we get small cameras doing interesting things. It's going to be the way we collect dust. It's going to be the way lots of little things happen that you don't always need to take the kitchen sink into outer space with you, and this is a great way to do those little, tiny, single-purpose, low-cost spacecrafts once we figure out the technology. It's a technology that's still unproven. Folding those suckers up is turning out to be way more complicated than anyone imagined, but once we figure out how to fold them, once we figure out how to deploy them, once we figure out how high up they need to be before you deploy them so the Earth's atmosphere isn't an issue, I then think that we're going to have a whole new, interesting way to do low-cost, space-based science.

Fraser: Alright, that was kind of inspiring. I'll go with you there. Well, that was great, Pamela. Well, thank you very much, and we will see you in the 2080 Solar System Cup.

Pamela: Sounds great!

Fraser: Alright, see you next week.

Pamela: Yep.