Astronomy Cast Episode 180
Albedo

Fraser: Astronomy Cast Episode 180 for Monday March 8, 2010, Albedo. 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're you doing?
Pamela: I'm doing well. How are you doing, Fraser?
Fraser: I'm doing very well. So, why are some objects in the solar system bright, while others are dim? Much of an object's brightness is caused by its albedo--or how well it reflects radiation from the sun. If you want to know how big a distant moon, comet, or asteroid is, you gotta know its albedo. Alright Pamela, so mirror, mirror on the wall, which is the brightest thing of them all?
Pamela: Snow! Snow and ice.
Fraser: Snow and ice.
Pamela: Yeah. If you look around our solar system, and you want to find what's the brightest, shiniest thing in our solar system, all you have to do is find the freshest snow pack out there, and that happens to be the little moon Enceladus and its geysers, which are constantly refreshing its surface.
Fraser: And if you could fly out and take a good look at Enceladus, it would just be like a bright white snowball.
Pamela: Yes, it's reflecting almost all of its light. It's up over 90% of the light that's hitting it is getting reflected off because it has such a fresh, snowy surface. And here on our own planet, we find that the amount that we reflect is directly related to how much snow pack there is. As we look around the solar system, we can find other snowy bodies for looking for shiny things. This is part of how we were able to find Eris, this little dwarf planet out on the edge of the solar system is next to Enceladus the second shiniest object, second highest albedo object in the solar system. So it's able to reflect almost all of the light that hits it as well.
Fraser: Alright, so let's sort of transport briefly into your physics classroom, and you've written albedo on the board, what is the kind of textbook astronomer understanding of albedo?
Pamela: Well, it in general is how much incident light on a surface of a given wavelength is reflected off of that surface. And albedo numbers that you find in textbooks typically refer to the amount of light reflected in visual wavelengths all averaged together. How much red light is given off, how much blue light is reflected off... average all that together and that gives you the albedo number for an object. Now, if you get into very technical definitions, you also start worrying about how much light is reflected as a function of the angle the light hits the surface. So for instance with water, if the light hits straight down on the surface, the water's able to absorb almost all of that light and it heats up. But if instead the sunlight hits at a very steep angle just barely grazing and touching the surface, then most of the light is going to be reflected off.
Fraser: Right. And so that's why when we see pictures of the earth as this ball in space there's this spot where we can really see the light glinting from the sun.

Pamela: And that's all about the angle. And when we look out at ocean waves and we see that glint, that's where the fluctuations in the surface, the waves on the surface of the water are able to catch the light. But most of the time, when it comes to oceans, the water is just absorbing and heating up from all of that light.

Fraser: Now we're only including the visible light, so we're not talking about infrared, we're not talking about radio waves, we're not talking about x-rays? Is there some calculation that includes that?

Pamela: Well, you can look up albedo across the different wavelengths, but in general albedo refers to visual light. Different objects actually have completely different albedos in different colors, so you might find that something entirely reflects infrared light while lets visual light pass straight through it. This is actually one of the things that we have to deal with with global warming. You end up with clouds that reflect infrared light that's trying to escape out into space that instead reflect that light straight back down to earth. And so while we're able to get sunlight in visual colors through those clouds down to the surface, they instead are able to reflect IR trying to escape back out back into the earth and warm up the surface of our planet.

Fraser: Right. So the clouds are highly reflective to the infrared spectrum but transparent into the visible spectrum.

Pamela: And what's even worse is invisible things like carbon monoxide in the atmosphere is also capable of doing this. Water vapor in the atmosphere is capable of doing this. Many different chemical compounds all like to reflect the infrared light.

Fraser: And it also plays a role a bit in the ice caps where the ocean water is dark while the snowy ice caps are white. So the thinking goes that the more of the ice that melts of the ice caps, then that's going to cause a bit of an accelerated warming because less of the light is being reflected back away and more is being absorbed by the ocean water.

Pamela: We see this accelerated heating in a lot of different ways. You have as the ice melts and reveals the soil, the soil instead of reflecting the light absorbs the light, heats up, heats up the air around it, drives more melting, and you end up with this runaway melting effect. We also have problems when we build cities, the cement--it just absorbs the heat and you end up with these cities being these extremely hot areas. At the same time though if you chop down a forest, well forests are very good at absorbing the heat and warming up the tropics. Cut them down and instead reveal meadows, instead in some cases let areas become desolate, reveal deserts because you've destroyed the land. Those deserts are then going to be reflecting the sunlight back out, and we're going to have cooling when the forests get cut down. So we have all these strange things going on where in some places by chopping down forests and letting the wrong things happen we end up cooling the areas, but at the same time if you chop down forests and plant farms, a lot of crops that farmers like to plant are even better at absorbing and heating up from the sun than the forests are and you can in some areas raise the year-round average temperature by as much as 3 degrees Celsius just by planting where there used to be a rain forest.

Fraser: Right. So then in terms of astronomy, obviously then it's only the... you called it the incidented...

Pamela: Incident light.

Fraser: That's the reflected light? Is that right?

Pamela: Well, the incident light is how much light hits an object. It's just a fancy way of saying light hits something.

Fraser: Right, so it's like what percentage...

Pamela: Right. What percentage of the light that hits an object... what percentage of the incident light is reflected off gives us the object's albedo.

Fraser: And the percentage that isn't, is absorbed.

Pamela: Is absorbed...yep.

Fraser: It's on a photon by photon basis, right?

Pamela: Right. And so beyond worrying about global warming, albedo is also something that allows us to start guessing at compositions, guessing at sizes. This is one of the things that recently came up looking out at the dwarf planet Quaoar, and one of these days I'm going to have to find out why we were given such an utterly inpronouncable object. But this little rock out in the Kuiper Belt keeps having its size misestimated because when we look out at it, it's just a little bit too small to fully resolve. So in an ideal world, if you want to figure out how big something is, you figure how far away it is, then you measure how far across it appears... how many pixels it takes up on your camera. And then you convert from its angular size and distance to its actual physical size. But when something's one pixel across, that's not useful because it could be a lot smaller than the one pixel... yeah... you just have to start guessing based on how much light you're seeing from the object. You assume that a very bright object that's made out of ice has one size, a very bright object made out of rock is probably a whole lot bigger because rock doesn't reflect light very well. But you have to know something about the composition. Well, with Quaoar, we have this object that we can see. For a Kuiper Belt object, it's fairly bright, so we were able to guess it's fairly big, but it wasn't big enough to directly detect. So, we've been trying to measure its mass, measure its density, by looking at little Weywot, the moon orbiting Quaoar, and Michael Brown, out looking at it, was able to figure out, based on the orbit of this little moon going round and round, that Quaoar is dark, dim, far away and nowhere as big as we thought. It looks like it probably only has a diameter of 1200 kilometers. And that is bigger than we thought, because when we thought it was ice, we guessed smaller. But, it's still really, really tiny.

Fraser: Definitey not bigger than Pluto.

Pamela: No, no.

Fraser: And I know that the consistency of all of these objects in the Kuiper Belt, have actually fairly vastly different albedo values. So it's not like you can say, oh, it's a Kuiper Belt object and they're all snowy ice of a certain number, and so you can just look at it and know how bright it is, and then use that to know how big it is. It took that second calculation it needed to have a moon, and from the moon you can then calculate the mass and get at the diameter that way.

Pamela: Right.

Fraser: And then reverse-engineer the albedo.

Pamela: Right.

Fraser: So it's funny, it's very similar to whole kind of stellar magnitude problem, right? A star can be... you know in the sky, you can see how bright it is, but that doesn't tell you how far away it is. It can be really close and be a dim star, or it can be really far and be a super bright star. So how has that caused people problems in the past?

Pamela: Well, it just means that we have these difficulties in figuring out all these little rocky bodies everywhere. There's lots of asteroids, there's lots of Kuiper Belt objects that their compositions vary from close to pure ice, where they have densities close to 1, to now we know Quaoar has a density that could be up over 5, which would mean solid rock out there hanging out in the Kuiper Belt with almost no ice involved. And, how dense something is is kinda interesting because we can start guessing what it's made of. So we have to try to puzzle out all of these pieces. Now we can also learn interesting things about different features on the surface by looking at changes in albedo. For the objects that we can start to resolve, things that are more than one pixel across, which Pluto is. We can start to look at how its amount of reflected light changes as it rotates, as it goes from day to night. And this allows us to start figuring out, oh... this object isn't just a solid ball of nice shiny ice, or nice dirty ice. It allows us to start sorting out with asteroids in some cases what amount of the asteroid you're seeing as it's rotating. So, if we know it has constant albedo, it constantly reflects the same amount of light, then as we see the amount of light change it means we're going from seeing the broad side of the potato to seeing the skinny end of the potato to seeing the broad side of the potato again. But at the same time it could just be that we have a round object rotating that's going from low albedo to high albedo. Once we can uncouple any of these problems, we can start figuring out oh, this has shiny ice here... oh, this has dark sooty material here, and we can start answering some rather interesting questions about composition.

Fraser: And does that perhaps tell you about... maybe there's surface activity... or things are changing, right? Because if you track the albedo over years... and the same spots aren't dark all the time, then maybe there's, you know, cryo-volcanism...

Pamela: Outgassing...

Fraser: Outgassing, or changing atmosphere or clouds or things like that.

Pamela: And more than just looking at how albedo changes on a given object, because except with comets, that tends to happen very slowly. What it allows us to get at is how old is the ice in some cases. So if you look at a bunch of nice round moons and you find this one's really shiny... well really shiny means fresh ice, fresh snow, you have something going on, like cryovolcanism, that is refreshing the surface. At the same time, if you look at something and it's not highly reflective, that means that you probably have ice that has been dealing with solar wind incident on it, solar radiation incident on it, that's caused chemical processes that make the surface get dingy that cause the albedo to drop, making it reflect less and less light.

Fraser: And so what is the mechanism that an astronomer uses to determine an object's albedo?

Pamela: Well we know how much sunlight is getting radiated by the sun... we can go out and measure that conveniently. Then we figure out... ok, we think we know how big this object is. Based on our estimation of its size, we're able to figure out how much sunlight at its distance hits it. So then you take the amount of light that hits it, the area that it has, and how much light you then receive. And by taking just what is received verses what you know hits it, you can calculate the albedo. The trick is just knowing the size.

Fraser: The only way to know the size is ideally to sort of see how many pixels it covers up in your screen, but if not, to have the mass of a moon that's orbiting it.

Pamela: And that only gives us the mass... that doesn't actually give us the physical size.

Fraser: Right, right... so then what do you do, right? How do you get at the size?

Pamela: Well, often we use Spitzer. Spitzer's very good... it has... yeah... if something's too small, you're stuck. With things like these little Kuiper Belt objects we rely on Spitzer taking images and actually it's more than one pixel across. And when it's not, then you just have to keep getting better and better data until you get data that shows it's more than one pixel across.

Fraser: That's why when an object's first discovered, astronomers will say it's between 1000 and 1500 kilometers across because they just don't know the albedo, and if they knew the albedo, then they would know the answer. There's no way to know unless you can see a number of pixels.

Pamela: And this is where we guess composition. If you know something is ice... and here we can actually get help because looking at reflected sunlight, different chemicals reflect sunlight differently. So if you look at specific colors, you're able to go ah, there's methane ice, ah there's carbon dioxide ice. Once you start to put together known compositions, it allows you to have error bars, but at least you're not completely pulling numbers out of a hat.

Fraser: And there was really interesting research... I did an article about it a couple of years ago, about how astronomers might use the albedo of an Earthlike planet to detect how it reflects on its nearby moons, to determine if it's got clouds, and if so then maybe continents and water and all that kind of thing.

Pamela: Right. There's been some interesting work just looking at the light that reflects off the dark parts of the moon, where you can use Earthshine to start figuring out... ah, this is what's going on on the planet Earth. And we don't think about it because when you look up and don't see the moon, it tends to be out of sight, out of mind... but if you start using careful instrumentation, the moon's still there. It's just not as visible to the naked eye, but all of the light that gets diffused through our atmosphere, all of the light from cities, all of the light that is passing through clouds and getting reflected through our atmosphere from the clouds. All of this is scattering up to the moon. We can measure that and we can start to basically puzzle out what's going on on the surface of our planet that's getting reflected.

Fraser: And one of the interesting things I know is that this Earthshine has been changing over the last few years. So the actual amount of light has been changing from what we've been recording.

Pamela: So this is partially, from what I understand, a reflection of pollutions in the atmosphere that cause light that hits the atmosphere on the sunward side of the planet to get bent through the atmosphere and to come out the other side in slightly different ways than without the pollution or with different types of pollution. And at the same time, the cloud cover on our planet has been gradually changing as we throw up different chemicals into the atmosphere. So we are definitely changing the way our own planet behaves, and we can see that reflected in the Earthshine off of the moon. Now trying to detect this around alien worlds is gonna be difficult, but within our own solar system, at least we're able to say, ah, there's carbon soot over there. One of the interesting things is the composition is not only reflected in the scattered light, but it's also reflected in the types of pollutions that get left on things. So when you look out at a glacier, one of the problems they're having in India is the glacier melt is accelerated by two causes: one... you melt glacier, reveal soil, soil absorbs heat, that heat gets reradiated and melts the glaciers faster. But the other problem you get, is that with all the pollutions we're letting loose into the atmosphere, that pollution first of all affects how much light our atmosphere scatters, but then when the pollution settles out... when it creates a sooty surface... not just on statues and buildings but on the glaciers, well now those glaciers aren't shiny fresh snow and ice anymore. Now they're sooty, nasty, ooky, snow and ice. We've all seen this in cities... well, this is happening to glaciers too. And carbon, of all the substances, has the darkest albedo. Carbon, charcoal, coal are the most absorbing substances we know. And so when you get soot coating a glacier, that can accelerate the glacier's melt by as much as 25%. Now while we produce coal and soot through a lot of industrial processes, you can also get this sent up into the atmosphere through wildfires, you can get this sent up into the atmosphere via volcanism, and so this radical change in albedo, if we were ever able to see it on another world, could reflect some sort of a massive ice age, increasing how much light is reflected, or some sort of horrific wildfire or volcanism causing a planet to suddenly go dark.

Fraser: So, speaking of things that are dark, what is the darkest object in the solar system?

Pamela: Well, exactly what the darkest object is isn't something that's easy to find, because we're finding new rocks everyday. But when you start looking at the big things, Mercury has an albedo of 0.1. This means only about 10% of the light that hits it is getting reflected off. This is one of the darkest objects, and then of course there's lots of asteroids that are in the exact same category of reflecting only about 10% of the light.

Fraser: And so like the surface composition of Mercury is like lava... cooled lava, and...

Pamela: Right...

Fraser: And meteor-blasted ground, so...

Pamela: It's basically a lot of basalts... this is the same stuff that the mare on the moon--the dark parts of the moon--are made of.

Fraser: So it's lava rock everywhere, yeah.

Pamela: Right. So, when you're looking at these and you're looking at carbon-based surfaces, all of this stuff is nice and dark. It's materials like the feldspar in the lunar highlands... these are highly reflective objects. And then like I said... snow and ice... anytime you have snow and ice it just reflects light.

Fraser: And then, brigher than that? Where do we get brighter than that? The moon is actually only a little brighter, though... the moon only has an albedo of 0.14. So it's pretty dark, too.

Pamela: And that's the part of the moon that we're seeing, where again we're seeing a lot of these basalts, we're seeing a lot of these lava-based rock. Where we start to get brighter is as we start to get either gassy planets that are able to... off the clouds... reflect a lot of light. That's another thing that reflects well is clouds. So, when you get cloudy planets, when you have things like Venus... Venus is reflecting all but 35% of its light. It's reflecting 65% of what hits it back so we can see it bright as our evening star. Our own Earth, though it's this mix of clouds, mix of water which absorbs most of the light that hits it, it's a mix of soils and forests and this mixture when we look at the planet Earth, leads to about 40% of the light getting reflected, so it's not quite as bad as Mercury.

Fraser: And we talked about the brightest object in the solar system...

Pamela: So here we're looking for the icy objects, we're looking for things like Eris, like Enceladus, any of these icy moons that are out there. But then again, we also have gassy things. Not up at the 90% level, but Jupiter's out there reflecting 52%. Venus is out there reflecting 65%, so there's a whole continuum of ways that you can get bright objects.

Fraser: Right. And could you imagine if the moon was icy like Enceladus, it would be like almost ten times as bright, I mean eight times as bright.

Pamela: Right, and that would make reading by moonlight far far easier. But unfortunately, as close in to the sun as we are, that just wasn't part of the fate of the moon.

Fraser: Alright, so that wraps up our discussion on albedo... thanks a lot Pamela.

Pamela: My pleasure.

Fraser: Talk to you later.

Pamela: Talk to you later... bye, bye.