AstronomyCast Episode 255 for Monday, March 5, 2012:

Observing Hydrogen

Fraser: Welcome to AstronomyCast, 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 really well … having fun recording another episode of AstronomyCast with all of our closest friends here on Google plus, so if you want to watch us live record the show, which we know not many people can actually do because they have jobs, and lives, and things like that, but yeah, you can just go to CosmoQuest.org/hang-outs and you'll see a list of all of the shows that we do. We do a ton on astronomy-related content and science with us, and Phil Plate, Emily Lakdawalla from Planetary Society, and Alan Boyle from MSNBC, so we got lots of space friends and we're doing a lot of really good content, so you should come and check it out, and that's at CosmoQuest.org/hang-outs. We also…we embed the shows there so you can watch them live, you can participate in the conversations, and then, of course, if you can't watch it live, we do try and mix everything and feed it into the AstronomyCast feed, and actually, I realized we've been putting the weekly space hang-out into the AstronomyCast feed and didn't warn anybody, so…[laughing].

Pamela: [laughing] You suddenly have new content!

Fraser: Yeah! So if you've noticed now that you're getting like an extra hour of audio content every week, that's this weekly space hang-out that we're doing on Google plus. No one's complained, but no one has also said "Hey, thanks for putting that in there. I really appreciate that!" So I don't know whether people are deleting them, or what. But if you're getting those and you're happy, that's great; if you're getting them and you're sad, then also let me know because we could also just break it up. You know, it's pretty interesting, it's the kind of content that people always asked us to do, but we never did, which is talk about the news and the current events and analysis of that kind of stuff, which is totally different from AstronomyCast, so anyway, that's all in there. Sorry about that; hope you're OK with that. Please let us know if you're not. Alright, well, why don't we get cracking then?

[advertisement]

Fraser: So hydrogen is the most common element in the Universe, formed at the beginning of everything in the Big Bang. It's the raw material of stars, gathering together through mutual gravity into vast nebulae. Astronomers can learn so much looking for hydrogen in the Universe. Well, here's why and how they do it. Now, we wanted to, sort of, when we first sort of set up this show, I was like "OK, so the topic is hydrogen!" And you were like "No, no, no, that's too big, that's too much. Let's just observe hydrogen."

Pamela: It's like 70% of the Universe. There's a whole lot of stuff going on and…let's keep focused.

Fraser: Like chemistry, and fusion, and powering cars, and things like that, so…but at least I think we should just have a brief conversation just about the formation of hydrogen and where it all came from, and then I promise we won't go into the detailed chemistry of it.

Pamela: Well, so hydrogen -- talking about its formation is somewhat silly. You take energy, you leave it on a shelf, it becomes protons probably (or other particles), and if it's enough energy to become a proton, well, one proton that counts as ionized hydrogen, let it near a neutron, you now have a slightly more interesting hydrogen atom. Give it an electron -- you now have a neutral hydrogen atom, so basically, hydrogen is that stuff that just formed when the Universe's energy cooled off enough to start forming particles. Everything more complicated than hydrogen, you have to have some sort of nuclear fusion reaction take place in order to get to it, so hydrogen is just that simple thing that comes out of energy.

Fraser: And so back when the…during the Big Bang, when everything was just too hot, you just had raw energy…

Pamela: Yes.

Fraser: And then as things cooled down, that raw energy turned into protons, and…

Pamela: Protons, neutrons, electrons…

Fraser: …and electrons, and you just, you know, you just gather them together in the simplest possible way and that's hydrogen. Obviously, we talked about it in a few episodes where you had this moment where the entire Universe was in this state of a star, and the hydrogen atoms were being fused into helium, and that's where we get the helium from, but really, and then the expansion continued and now we're just left with all this hydrogen, just this raw material, the building block of the entire Universe, so…and then why is it, then, I guess, important, then, for astronomers to observe hydrogen?

Pamela: Well, it's not so much that it's important to be able to observe hydrogen so much as we can't *help* but observe hydrogen. It's out there, and it's causing us a whole variety of good things, and bad things, so on one hand, every time we're looking at a star, we're observing an excited hydrogen atmosphere. Every time we look at a beautiful nebula, we're observing a cloud that's rich in hydrogen gas that's usually glowing red. When we start trying to look through the galaxy in radio light, we find all of the cold parts of space permeated with what's called the 21-centermeter line of hydrogen. It's just everywhere. Even when we look at high red-shift galaxies, we find in the spectra of these galaxies all of these places where intervening hydrogen gas has sucked the light out of the spectra of these distant galaxies, so if you study astronomy you're just going to over and over come across the vocabulary of hydrogen. It can get a bit overwhelming, and that was actually part of the inspiration for this show. We've been doing live star parties, and I realized last night we're talking , "H-II" -- all of these different terms, and no one knows what the heck we're talking about.

Fraser: Right, so hydrogen is the most abundant element in the Universe, so you just can't help but see it everywhere you look.

Pamela: Yes.

Fraser: And so we might as well understand what it is that we're looking at. Is it almost like all astronomers are pretty much hydrogen astronomers, you know? Like, a certain percentage of the time is just dealing with the hydrogen in everything they're looking at?

Pamela: Yes, and one of the hazing rituals of getting a physics degree is learning all of the Quantum Mechanics of the hydrogen atom, and so by the time you finish getting even an undergraduate degree, you are intimately aware of the inner workings of hydrogen at levels you may not want, and you know how to find it all over the Universe.

Fraser: But you're going to spare us the Quantum Mechanics today.

Pamela: I'm going to spare you the Quantum Mechanics today.

Fraser: OK – good, good. Alright, so then let's talk about the different flavors of hydrogen that astronomers will observe out in the Universe.

Pamela: Well, the most common way that we confront hydrogen just as we peer through the sky with a pair of binoculars, or with a telescope is what's called Hydrogen Balmer Lines, so when you look out, you'll see particularly what's called either Hydrogen Balmer Alpha Line, or just hydrogen-alpha because we get lazy. This is that bright red color that is associated with most nebulae, and it comes from the fact that the hydrogen's energy levels are such that that one lone electron it's got – it can jump between, well, it's lowest energy level, to its second energy level, and transitions in and out of that lowest energy level. Those occur in the ultraviolet where we don't see them with our eyes, so those are probably the most common transitions, but the ones we don't see because ultraviolet gets blocked by our atmosphere. Now, go up one set of energy levels, and look at the transitions in and out of the second energy level. Well, there we have what's called the 3 to 2 – from the third energy level to the second energy level transition -- and that's at this beautiful, red color that we see in "Open" signs at the local deli, and we see in all of these nebula that are all through the sky, so that red color associated with nebulosity – that is the lowest transition in and out of the second energy level of hydrogen, and this transition was discovered by a dude named Balmer, so it's called the Balmer energy set, and alpha is for the lowest one, so 3 to 2 is alpha, then if you went 4 to 2 that would be beta, and so on through the list.

Fraser: And just to be clear, I think we talked about this in previous shows as well, right? This is that transition, that energy transition, right? When an atom of hydrogen, where it's got its proton, it's got its neutron, and then it's got this electron, and that electron jumps up or down a level, you can get like a release of energy, and we're seeing the photons streaming away from these nebula as these electrons are being released.

Pamela: So to get this to happen, you have to have a cloud of gas that's getting heated up by something. So there's either a bright star embedded in the cloud, there's a whole bunch of bright stars embedded in the cloud, and the light from the stars is exciting the hydrogen so that it's making this transition.

Fraser: Now, sorry, when you say just…I'm trying to be kind of precise here. So when you say exciting, you mean photons are streaming off of this star…

Pamela: Those photons are getting absorbed by the hydrogen atom.

Fraser: Right.

Pamela: And the hydrogen atom in response to absorbing this photon, the electron is jumping to a higher energy level, and it might actually jump a whole bunch of energy levels, depending on what energy it gets hit with, and this actually has a neat effect where if the geometry is such that you look out, you look at the cloud and the star that you're looking at is on the other side of the cloud, when you look at the cloud, you'll actually see the hydrogen alpha light, that red light, removed from the colors that you're looking at. Now, if instead, the star is off to the side and not precisely lined up, then you see that color that red energy from the star is getting absorbed by the hydrogen, re-radiated in all directions, and so you end up seeing the nebula as red.

Fraser: Right, but the point is (and this is where the whole concept of Quantum comes from, right?) that there is this very discreet, very specific step that these electrons take as they jump up the energy levels, and with it there is the corresponding release that comes out in a very specific color, and it's that color of radiation that we see with our telescopes, and that astronomers are really specifically looking for. They're actually…they're limiting the entire spectrum that they could see down to that exact, specific light.

Pamela: And this is actually something that anyone out there listening can experience for themselves. A lot of gag stores, a lot of novelty stores will sell these prism glasses that create rainbows when you look through them. Well, if you get one of these pairs of rainbow glasses, and you walk up to your local deli, you walk up to your local pub, whatever, and you look through these glasses at the neon signs, you'll see the discreet, specific lines given off by the atoms in that sign, so if you look at a red "Open" sign, you're going to see this bright red line that comes from the hydrogen alpha, but you'll also see this gap, and then this bright (they call it "cyan," to me, I'd call it turquoise)…this bright turquoise line, and that's hydrogen beta. Then a little bit over to the side from that is hydrogen gamma – this is the 5 to 2 transition (and this is like Crayola blue, or that 00255 if you work in RGB colors), and so you'll then start seeing closer and closer-spaced, deeper shades of blue as you look at the spectra of that red "Open" sign, and then you'll see a completely different set of fingerprints if you look at a green sign, or a purple sign, but that red "Open" sign has this distinctive spectra through the novelty rainbow glasses that's the Hydrogen Balmer series.

Fraser: Right, so I guess what astronomers are doing, right, is they're filtering out every color of light except for that specific, sort of, in the frequency range that they're trying to see. The equivalent of putting those crazy glasses on…

Pamela: If we use a hydrogen-alpha filter, yeah.

Fraser: Right, and so that's the point, right? Astronomers will have a collection of these filters. They'll have one for hydrogen alpha…how many hydrogen-related filters will astronomers use?

Pamela: So at a certain point, you stop using filters and you start doing imaging spectroscopy, so it's not too uncommon to have a H alpha filter, a Lyman-alpha filter if you're working in the ultraviolet, or what will also happen is since these lines are given off by galaxies at different red-shifts, people will actually create special filters tuned to only detect, say, Lyman-alpha. This is the 1 to 2 transition in hydrogen that if it's nearby we can't see because it's UV, but if a galaxy is far away, and its light is getting shifted into the red, that color that's usually so blue we can't see it – it gets moved a little bit redder, a little bit redder, a little bit redder until we can see it, and they'll create filters tuned to see the Lyman-alpha of galaxies that are moving at specific velocities.

Fraser: And I guess this is part of the thing where the amount of that frequency is so tight that if it is red-shifted, you've got to push it up and down the frequency. So astronomers know that they want to see this specific kind of frequency of light, and they've got the tools to be able to see it, but what does seeing it tell them? Why do they want to do this?

Pamela: Well, it's… it depends on what you're doing.

Fraser: Trying to do science.

Pamela: [laughing] And so the thing is there's lots of different science that you could be doing. For instance, when we're looking at different nebulae locally, we're often trying to figure out what is the distribution of temperature in a cloud of gas, what is the density of the gas, and so when we're looking at the hydrogen alpha light, when we're looking at the light in all of these different energy levels of hydrogen, what we're trying to do is figure out just how hot is that gas. And this is where we start talking about things like H-II regions. So an H-II region…the crazy notation we use in astronomy is a letter from the periodic table is clearly the abbreviation for the atom, if it has a Roman numeral "I" next to, that's something that hasn't been ionized at all -- it's completely neutral. If it has a "II" next to it, that means we've yanked off one electron. If it has a "III" next to it, we've yanked off two electrons. So take the number, subtract one, and that's how many electrons we've removed from the atom. So when we're talking about the H-II region, we're talking about a region of space filled with hydrogen gas, and that gas is ionized one time to remove that one electron. Now in these H-II regions, this is a cloud of gas that is typically being heated up by really hot, bright stars, so when you look at the Orion nebula with all of it's O-giant stars embedded in the gas, you're looking at an H-II region, and in these regions the hydrogen atoms will periodically glom on to one of these free electrons, and as they glom on to the free electron, the electron will cascade down through the different energy levels, and it will give off hydrogen alpha, it will give off hydrogen beta, it will give off all these different parts of the spectrum, and by looking at that, and looking at the ratios of how many of the atoms appear in the different energy levels, we can start to get at the density of the material and the temperature of the material.

Fraser: Now, you mentioned a couple of other things as well. And there's neutral hydrogen, and cold hydrogen, and those are useful for astronomers to observe as well, right?

Pamela: Right, and so another one of the things that we look at is what's called the 21-centimeter line of hydrogen, and this is perhaps one of the harder things to try and explain. It's actually something that when we teach it, we talk about this is something that was originally referred to as "Not going to happen, never going to be observable…" and it's because it's a process that takes a long, long time for it to happen, so if you take a hydrogen atom, its proton in the center has what we call in Quantum Mechanics a "spin," and the spin is either spin up or spin down, and its orbiting electron has the same thing. It either has a spin up or a spin down, and ideally the two little bits -- they want to be lined up the same, and so what you'll have is if you leave hydrogen alone long enough, and it's not in its lowest possible energy, you'll end up getting that "spin-flip" and the energy given off in this flip is energy that corresponds to light with a wavelength that's 21 centimeters long. Now, the probability, in most cases, is that before the atom has a chance for that flip to take place (because it takes a long time for the atom to finally get around to flipping probabilistically), it's probably going to undergo a collision, it's probably going to undergo and excitation – something's going to happen to it. The only way that you're going to consistently get this spin-flip is if you have a whole bunch of gas, it's really cold, and thus not moving, so all the little atoms are just sort of going, "not moving, moving very slowly…" and it's very diffuse gas as well, so you need cold, diffuse gas.

Fraser: Well, that's kind of interesting though, right, because there's a way…like, you wouldn't think if it's out there, just super-cold in space, just sitting there, not interacting, you would think there'd be nowhere to see it, it would just be invisible, but because there's this crazy Quantum effect, they just randomly spin-flip, you get a release of radiation that's very subtle, but it's there and let's you detect it.

Pamela: And so this is one of the ways we're able to measure the rotation rate of our galaxy out to extremely high radii. So what we do is we use radio telescopes, and this is actually the type of thing that undergrads can do, or any amateur who builds their own at-home radio dish, and you can get kits to do that. This is an experiment you can do is identify where the clouds of cold gas are out in the outer wings of the arms of the Milky Way, take a look at them, and measure the Doppler shifting of that 21-centimeter line, and from the Doppler shifting you can get the rate at which the cloud is moving forward and backward in that direction in the sky, and you can use geometry then to start to then get at the orbital velocity of this gas and at the end of the day, this gives you the rotation curve for our galaxy that shows that everything is moving at about the same velocity as you move out toward the outer parts of the galaxy, and thus, you can demonstrate for yourself there is something gravitationally changing. This is dark matter.

Fraser: Well, I think that should be everyone's homework for this week, then. So everyone should go out and observe the 21-centimeter line, and calculate the Doppler shifting, use geometry to determine the motion, the rotational motion of our position within the Milky Way.

Pamela: Completely elementary!

Fraser: Completely elementary – everyone, get on that! So what are these cold…? I mean, OK, so we can use these cold clouds of gas as weigh points, as places to determine position, but I mean, aren't these future nurseries of stars?

Pamela: Not necessarily. The thing is that in order to get a star-forming region, you have to have dense gas that has sufficient mass that when you collapse it down and things start forming, you get enough mass leftover to form a star, and some clouds of gas just aren't massive enough that they're ever going to form anything meaningful, and in other cases, the clouds of gas as they are right now are so diffuse and so stable that we don't see star formation in their immediate future. Now, spiral arms do help trigger star formation because what ends up happening is as these clouds of material orbit around the Milky Way, they get pulled in on the one side to the spiral arm, and then as they try and orbit out the other side of the spiral arm, they get slowed down, and as they linger in the spiral arm, there's a good chance that there's going to be collisions, there's going to be compressions, there's going to be shock waves from supernovae, and all of these effects may cause some of these otherwise far-too-diffuse clouds of gas to have star formation, but in general, our galaxy's only about 1% effective at transforming gas into stars.

Fraser: So astronomers don't see…like, don't really do a lot of searching for great, big clouds of future nurseries. It's more like waiting until the…you know, I guess it moves into to that hydrogen alpha phase, where you're actually starting to see the light coming off the nebula that you start to identify these star-forming regions?

Pamela: Well, there's lots of things that we do look at, and we're like, "THAT is forming stars right now," and this is where people who work in the radio and the millimeter, they actually start mapping out some of these clouds. So there are certain, what are called "bok globules." These are extremely dense, often molecular hydrogen regions, so this is the other form of "H-two" that when you're doing an audio show, it makes no sense. So you have "H-Roman numeral II," which is ionized hydrogen, and you have "H-subscript 2," which is molecular hydrogen, and when you look at these dense, black regions on the sky (Horsehead Nebula isn't a bok globule, but it's an example of one of these dense, black regions on the sky)…when you look at these dense, black regions in the sky in the optical, they just look like the never-ending story, "Great Nothing," ate a part of the Universe, but when you start to look at them instead in millimeter wavelengths, you start to see they're knots of thermally-radiating areas. These are areas where the gas has begun to contract, and as the gas squishes down, the atoms start hitting each other and this process radiates away, basically, warmth. So this is infrared; this is millimeter to light. You can sort of think of this as if you rub your hands together, it's going to generate heat, and if you had an infrared camera, you could actually hold your hands up and see that change in temperature from rubbing your hands. Now, when the gas starts colliding like that, you start initially giving off in the radio light. Now, you wait as it continues to collapse, stars start to form, starts to light up in the infrared, and eventually it brings itself all the way into the bright blue UV when you get the youngest stars actually igniting, but so we look for those dark, molecular clouds that are high-density, and those…yeah, they do probe those for star formation, but not every blob of gas is necessarily going to form stars.

Fraser: Can we look for places where, like, hydrogen is absorbing light? You know, like we look for places where certain elements are actually blocking, right?

Pamela: And so when we look at nebula, we talk about there being reflection nebula, we talk about there being emission nebula, and the truth is it's just a matter of geometry. So if it's star-cloud-observer, that cloud is going to absorb out the hydrogen lines. If it's cloud in front of us, star off to the side, then we see emission lines, and so there's lots of different ways, and it's all about geometry that controls what we're able to see.

Fraser: And I think as we've been really experiencing with doing these live star parties, and we have one person, we have Gary, who has got this just phenomenal 14-inch telescope, but he's in this really polluted area -- he's in Los Angeles -- and yet he seems to be able to pull together these really sensitive images of nebula. So, why does this hydrogen look so crisp and clear even when you've got really bad polluted skies?

Pamela: So he's cheating in a way. If you've ever had one of those kids' toys, or cereal boxes where you get the little red filter, and you look at this scrambled mess on the side of the cereal box, and then when you put the red filter in front of it you suddenly see a message. Well, what's happening is, in that case, is you have all this visual noise, and that visual noise gets removed when you put the red filter in front of it -- and Gary's doing the exact same thing. In his case, he's in the Los Angeles basin, and there's for the most part sodium lights (those are the yellow parking lot lights that make the sky glow this raspberry color on a cloudy night), and then there's also…now we're getting more and more fluorescent lights which are giving off their blue UV light, and all of this is scattering skyward. Sometime it's because they're using stupid light fixtures that point the light upwards, or they're illuminating buildings and it points the light upwards.

Fraser: Hate those people…

Pamela: Right, and sometimes it's just a matter that you're shining light down on cement, and the cement reflects the light back up; however, the light's getting upwards, it's primarily consisting of the sodium light from the sodium light fixtures, and white light that's peaking off in the UV from the fluorescents or peaking off towards the UV, not actually in the UV, and what he's doing is he's saying, "OK, I'm going to look at the sky, and I know that most of the sky is being brightly lit up by the atmosphere reflecting the sodium, and all of this white stuff that is peaking towards the blue. I'm going to try and get rid of as much of that as possible, and I'm going to focus in on one line of light – the hydrogen alpha light that's in the red, as opposed to the blue, and the sodium's yellow…" and by focusing on just that one color, well, suddenly, his background goes to black again because these street lights aren't giving off hardly anything at all in , so suddenly the light pollution for the most part has been filtered out the same way all that visual noise was filtered out on the cereal box, and what's left behind is only the hydrogen alpha light. Now, the crazy thing is if he actually went to a dark site, he'd get even more amazing images if he was able to use broader-band filters that were letting in more light all at once, but he does what he can, and he's found a way to do really good astro-photography in a very light-polluted part of north America.

Fraser: Yeah. So there's hope for all of us.

Pamela: Yeah, there is.

Fraser: Cool. Well, I think that about wraps it up for this week, so thanks a lot, and we'll talk to you next week.

Pamela: That sounds great. Talk to you later, Fraser.