Astronomy Cast Episode 256 for Monday, March 12, 2012: Resolution

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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, Fraser?

Fraser: I'm doing really well. Spring is coming; everything's getting a lot better now.

Pamela: And neither of us experienced horrible storms this week -- and our thoughts are with all of you that had tornadoes, but no, we're all safe here.

Fraser: Yeah, we don't get any tornadoes on the west coast of Canada…everything else.

Pamela: And they went north and south of me, so…

Fraser: Did they actually come close to you?

Pamela: Yeah, yeah.

Fraser: Wow, yeah, I mean, I saw some crazy surveillance footage and things like that -- it's just terrible. So, just a few things to let people know this week: one thing is we've moved the virtual star parties to Sunday nights at 7:00 p.m. Pacific Standard time. This is where we go and connect up as many telescopes as we can into a live Google plus hang-out, and then people can see what it looks like to actually look through the telescopes, and it's really great, I gotta say. We've had some amazing views of all the planets, and at various points, we've had beautiful deep sky objects, just like last night when we're recording, we viewed M51, which is the Whirlpool Galaxy, so if you have any interest in seeing what it looks like to look through a telescope and see different varieties, I highly recommend you check that out and that shows up at 7:00 pm Pacific, 10 p.m. Eastern, 3 a.m. in Greenwich…

Pamela: 3 a.m. GMT, 2 p.m. Sidney.

Fraser: So it's a pretty great time. You can ask us questions; we take requests, so you're like, "Oh, I'd really like to see the Flame nebula." Yeah, no problem -- we move the telescope over and take a look at the Flame nebula, so it's really neat, but we're always looking for new astronomers, and I guess this is the point. So if you have the ability to view from your telescope onto your computer, whether you've got a DSLR connected to your telescope and that's streaming into your computer, whether you've got any varieties of webcams or two-cams or things, you know, astronomy-related cameras, and you can get a view from your telescope onto your computer screen, then we can help you do the rest, which is to get that view into this hang-out and it's a really great time, and you, you know if you're an astronomer and you love to share your view of the sky, it's really worthwhile and rewarding to have all of these people…and you know, we're getting hundreds and hundreds of people watching live as we do this, and it's really exciting. So again, I plead with you, if you're an astronomer who can do this, please drop me an email. So you can email me directly at info@universetoday.com. Just drop me an email and say you'd like to get involved, and I'll just talk you through all the rest and we can try out some practices and do some hang-outs and go from there, and like I said, really rewarding…this is what it's all about.

Pamela: And we're open to people with small hand-guided telescopes and professional observers who are on Keck and want to screen share their professional observations -- so all the range are all welcome.

Fraser: Absolutely, yeah, we've got people with fairly small, couple-of-hundred-dollar telescopes that they're hand guiding until you see the image jiggling around to people who have $20-30,000 set-ups, and everything in between, so no telescope is too low-quality. We really enjoy it because it really gives people that view across all the different telescopes, so yeah. Well, that's out of the way. Why don't we get cracking?

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Fraser: So when it comes to telescopes, astronomers really just care about resolution: how much can you see? Resolution determines how much science you can get done and it depends on your gear, wavelength and viewing conditions -- and putting a telescope in space really helps, too.

Pamela: Yeah.

Fraser: So let's talk about resolution. So when you talk about resolution, or when I say the word "resolution," I'm always thinking of the resolution on my computer screen: 10, 24 x 7, 68…you know, the resolution of the ipad -- whatever. How does that concept of resolution differ from the concept of resolution that astronomers talk about when they're doing their images?

Pamela: So with your computer screen, you can effectively say that the smallest possible thing that you can create is one pixel in size and anything smaller than one pixel just can't exist. With our eye, with optics, with any sort of system that's creating an image, what we talk about is the smallest possible way of taking all of the wavelengths, all of the photons coming off of an object, and putting them together into a defined spot. So that sounds kind of weird, but the way to think of it is if you have a lens and you're focusing all the light from a point source so the light beams are coming through and converging, what is the smallest possible dot you can make, the Airy disk that you can make through that lens?

Fraser: And I mean, I can think of some examples of times when the resolution really came into play. I don't know if you remember…there were some photos of Pluto that were released just a couple of years ago from the Hubble space telescope, and you could see from these dark and lighter sort of blotches on the surface of Pluto, and…but at the same time it was clearly a very pixelated image that there just wasn't a lot of resolution there to be able to see anything in more detail. You weren't seeing craters and chasms and ice fields, and chryo-volcanism. You were seeing: that part's a little bit lighter and that part's a little bit darker, and as Pluto was rotating you could see those lighter and darker parts moving around the dwarf climate, but still, you know, you weren't seeing the resolution, so that's where you really see it, right?

Pamela: Right. So what's happening here is as we try and look at Pluto with, in this case, the Hubble space telescope, you're focusing the light on to a detector, and your ability to resolve an object is limited by two factors:

one is the size of the telescope, and the size of Hubble limits you to being able to see about what's called .05 arc seconds, and this is an angular measurement. So if you've ever played with a protractor, you know it's 180 degrees from left to right, and there's 60 minutes in a degree, there's 60 seconds in a minute and if you pull out a piece of hair (and I'm not going to do that), and you hold it out at arm's length, the width of that normal, standard piece of hair held out at arms' length is one arc second across, and the human eye -- its limiting resolution is about that one second, one arc second hair at arm's length, so with Hubble we're able to see significantly smaller, that .05 arc seconds, but Pluto's kind of tiny, and so that .05 arc second resolution doesn't allow you to see a whole lot of detail.

Fraser: And I guess you can imagine if there was, say, a moon around Pluto, and it was smaller than that .05 arc seconds that Hubble can see, Hubble wouldn't be able to detect that moon.

Pamela: Well, it would be able to detect it because there's still light coming off – so this is one of those things in astronomy that can get confusing at times. You have a light source, it's radiating light, all of that light quite happily hits a pixel, and there's a difference between whether or not you detect it, and whether or not you resolve it, so you're able to detect that light, but you're not able to resolve it into, "well, what does that look like? What's the shape of that?" So we're able to detect things like stars. We can't resolve stars, but we detect them all the time, and so this is the difference between pretty picture, and blob of light -- and mostly we just see blobs of light.

Fraser: Right, all of the…so even with the Hubble space telescope, if you're going to view a distant star, you're just going to get the light coming off of it, but you're not going to resolve the disk. But there's a few cases, right, where the resolution of the detector is good enough that you actually can resolve the disk, right? Hasn't, like, Betelgeuse been resolved?

Pamela: Betelgeuse has been resolved; we've resolved the stars in the Alpha Centauri system, and in all of these cases, it wasn't one single telescope doing the job -- and this is where it gets tricky. The ability of a telescope to resolve an image is based on two different factors (we're going to keep having things that are based on two different factors today): one of those factors is what color of light are you're using. If the color of light you're using has a really long wavelength, well, if your wavelength is longer than the object you're trying to look at, the wavelength isn't going to allow you to resolve the object. So you need to use shorter wavelengths of light to be able to resolve finer details. Now, at the same time, you have to be able to take all of those wavelengths and combine them in a meaningful way, and the more wavelengths you can combine, the better you're going to do, and the more wavelengths you can combine depends on how big is your detector. Now, this starts to work in a kind of screwball way because it's not actually "I have one, two, three, four, five stacked across and I'm collecting all five." It actually has to do with the separation between these two is, well, actually usually 1000s of wavelengths, and I can cut a hole out of the center, or I can actually cut a whole lot of holes out, and we call that the very large array in New Mexico. So the resolution that you get depends on how far apart are the two most extreme wavelengths that you detect in your baseline between the two telescopes, and so that baseline, or the diameter of your single mirror, your single dish -- that defines your resolution in combination with what wavelength you're looking at.

Fraser: And so then, I mean, you were talking about the very long baseline array, and that's a good example, right, where astronomers are putting telescopes really far apart -- in this case radio telescopes -- to give a greater resolution. Is there a down side to that, though?

Pamela: Well, with using lots and lots of telescopes, you're not necessarily going to have the same light-gathering power that you would have, so you can actually take two one-meter mirrors, spread them far apart, and along one single axis get extremely high resolution, but you still only have two one-meter telescopes, so you're going to have extremely high resolution for observing fairly faint objects -- or fairly bright objects, rather. And then there's that it depends on the shape of your baseline, so you can imagine that you're cutting lines across an object, so if you're trying to look at a galaxy, and you only see along north-south and east-west really high resolution, and in all the other directions it's kind of crud because you don't have telescopes along those directions. It ends up leading to you can only get so much improvement, so we tend to use techniques like this for very specific questions where, for instance, we're trying to measure the diameter of an object, where we're trying to do spectroscopy. There's specific applications for interferometry, but if you're trying to build up an entire picture all at once, which radio telescopes don't do, which is why this is so optimal for radio telescopes… if you're trying to build up the entire picture all at once like we do with standard optical telescopes, this starts to get difficult. You also run into problems where we don't usually do this with optical telescopes because the ability to add the light together, well, that gets harder and harder as you deal with shorter wavelengths. You actually need to take the light coming off of each telescope and shift it so that the peaks in the light, the peaks in the phase of the wavelength, line up from each of the telescopes, and there's delays introduced by, well, the starlight hit this telescope first because that part of the planet is a little bit closer to the star (and the differences do matter when you're dealing with wavelengths of light), and this telescope is part of the planet that's a little further from the star…trying to add all of that light together, well, in the radio it's easier; we have really long wavelengths. We can record each telescope separately and add the light together after the fact. You can't do that in optical light. You have to physically use…change the separation between the telescopes using fiber optics and other techniques, and it's difficult and persnickety and the timing has to be correct, and you don't generally do it.

Fraser: Right, we always get this question "Why couldn't we just…couldn't amateurs provide thousands of small telescopes around the world and together those telescopes would act like one big telescope?" But unfortunately, they would still just only act like thousands of small telescopes. They wouldn't be able to combine their light together because you can't synchronize the wavelength so that you're viewing at exactly the right moment with all of those telescopes, or it would just be prohibitively hard. So then what are the factors that define resolution? You know, if you're trying to maximize your resolution, what would you try to do?

Pamela: So the realities are you want to get rid of the atmosphere – can't always do that. I was recently asked, "well, don't professionals have a way of getting rid of clouds when they're observing?" No, no we don't, but we do have space-based telescopes, and that's one way of getting rid of the clouds is you just go above them.

Fraser: So you have this atmospheric distortion, but is it…how is that ruining your resolution?

Pamela: So here you have the light is actually getting moved around as it passes through the atmosphere. So imagine you're looking through a galaxy and the light from two close-together stars ends up crossing back and forth across each other as light passes through the atmosphere, and each set of light rays passes through slightly different pockets of cold and warm air. It blurs your image out. Most of the places on the surface of the planet you go, you set up your telescope, you have typical conditions of about 3-arc-second seeing. You go to the best places in the world and you can a little bit better than one arc second. So you can see a little bit better with your telescope than you can with your eyeball, and that's depressing. Now, we do have ways of compensating for this. The very best telescope for doing this right now (and this is always changing) is the very large telescope down in Chile, and it flexes its mirror to compensate for what the atmosphere does to the light as it comes through, and so they're able in real time to reverse engineer the paths of the light and basically fix the seeing, and they're capable of getting better resolutions, in some cases, than the Hubble space telescope, but that takes advanced technology. If you're just using an everyday telescope, aim for .8 arc seconds, best case.

Fraser: Right, so in the perfect world, you would set up your telescope down in the high plains of Antarctica, where you're above you know any atmosphere, cold, cold sky, you've got a beautiful…

Pamela: Or Atacama's better…

Fraser: Atacama's great, you've got a beautiful view of the sky and nice Chilean food nearby…

Pamela: Not so nearby, it's kind of isolated, but you only get a couple of millimeters of rain a year, and you get "night" every night, which helps.

Fraser: So that is…right you don't get any clouds at all. So step one to improve your resolution is have the best possible seeing conditions that you can. Ideally, just get into space.

Pamela: Right. So beyond that, you want to maximize the diameter of your optical system, and by this I also mean radio, x-ray -- whatever system, whatever light-gathering technique you have, get the greatest diameter possible. If you want to image an object beautifully, use a single mirror or stamp your way across it basically doing one pixel at a time as they do in a lot of radio. And if you really want awesome resolution, you need to step out and use interferometry, which is where you're combing light from multiple sources that are separated because, at a certain point, people are going to get angry at you if you try to make a telescope that big, and there's just not enough resources to support telescopes that have thousands-kilometer diameters.

Fraser: Who would get angry? I think we would all cheer and applaud, you know, attempt to build telescopes 1000s-kilometers across…

Pamela: People have to live somewhere…and think of the miners that would be required, think of the ceramics facilities…it just starts to become intractable at certain sizes.

Fraser: Make the Earth look like the Death Star with the one whole portion of it is carved into a giant telescope. I love it – I think we should get right on that. But the point is you can fake it, you can take multiple radio dishes, set them 1000 km apart, line up the frequencies, or line up the timing, so they are truly observing the same wavelengths, the exact same wavelength, or the time that the light was emitted from that object. And they are essentially providing that resolution.

Pamela: Exactly, and we do this. There are international agreements that facilitate it.

Fraser: Now, how far down…cause I know that as we've said, with things like the very large array, you know, with some of these optical telescopes, you can only have them a few 100 meters apart and they start to get messed up, but in other cases, you can say with radio they can be 1000 km apart and work just fine, so…

Pamela: Well, with radio there's not really a limitation other than the ability to get your clocks in sync, which we're learning is more and more difficult than one would think as we're looking at the CERN results recently, but that's where your limits start to come in is how do you get the data back and how do you synchronize it, so right now with radio telescopes, we're literally limited strictly by the diameter of the planet Earth. And you record the data, you ship it to a single place (this was actually my high school job was finding fringes on data – it was one of the different things I did), and yeah, as long as the timing is correct or mostly correct -- I remember having difficulties with the Russian data because the clocks got off, you can sort it out, you can figure it out, but that's with radio. For optics, right now we're kind of limited to the size of a plateau in the Chilean mountains.

Fraser: Right, right so you can imagine some future super-clocks that would let people stretch those telescopes further apart, but that hasn't…there are no plans in the works. Most people are going with bigger, you know, the overwhelmingly large telescopes they're looking for 10, 20, 30-meter telescopes -- gigantic telescopes, right?

Pamela: And you start to get into limitations of just how do you get all that data back. One of the questions that we seem to get all the time is "Well, when are we going to be able to resolve cities on other planets?" and things like that, and there you start looking at, well, if you try just waiting for the data to come back from opposite ends of the telescopes, starts to be a little crazy, so I actually worked the numbers out on this before we got started on this show, and if you take the planet earth and you put the planet Earth in the Alpha Centauri system, and you just want to resolve the planet Earth, that starts to be something that's almost tractable. You can do that with a telescope that has a diameter of just over 2000 km, so that's not that bad in the grand scheme of things.

Fraser: 2000 km…no, that's a good thing. A 2000-km telescope is great!

Pamela: You want to resolve the size of the Earth at a distance of roughly 10 light years away. There you're starting to look at: you need something that's about 4800 km across – still tractable as long as you're working in the radio. Now, the Earth doesn't exactly give off radio light, and that's frustrating, so I actually ran the calculations imagining we can do this with red light, and interferometry we're able to do infrared right now, so red light isn't too big a stretch. So imagine a future where we're somehow able to get the red light synched-up across these distances. So you have amazing fiber optic detectors, fiber optic cables spanning the diameter of the Earth. They're roughly 5000 km. Now, we often talk about someone in Andromeda looking at the planet Earth would be able to just, if they had magical, non-existent telescopes, they'd be able to make out the earliest men walking on the surface of the planet.

Fraser: Right, two-and-a-half million years ago!

Pamela: So the reason I say make-believe won't happen is to be able to simply resolve the size of the planet -- not the size of a human, the size of the planet -- we need a telescope that is about 100 times the size of the Solar System. That's 8500 astronomical units apart, and that's where you start to worry about how do you get the data back in a sensible way. This is fractions of a light year, meaningful fractions of a light year, and that starts to get a whole lot more challenging.

Fraser: Right. So anyway…but the point being bigger is better.

Pamela: Yeah, and shorter wavelengths is better.

Fraser: And shorter wavelengths is better?

Pamela: Right, because the shorter the wavelength, the smaller the thing you can see. We get in to this with microscopes much more. So if you're working with a normal green light, that's the central light in visual with what you see in your eyes, with the standard visual-light, centered-on-green microscope, the smallest thing you can possibly resolve is 250 nanometers across, and that's way bigger than most molecules.

Fraser: And that's why you push into electron…

Pamela: …or x-ray microscopes. It's actually an x-ray that we get the highest resolution because the x-rays are actually smaller than the electrons. So with x-rays, here you start to be, with the best telescopes we have so far, able to resolve 15 nanometers when you're shining the x-rays through the source. This is still about 5 times bigger than the width of DNA, so we can't yet resolve the DNA helix cleanly. We know it's there, we've figured it out through other methods, but if you're using transmission microscopes, 15 nanometers is currently the limit, and x-rays destroy a lot of samples.

Fraser: So we've talked about the seeing conditions (and I'm just going to assume how well you've polished your mirror, and how good the internal optics are of your telescope)…we've talked about the size of it, and then I guess the third one is just the wavelength, so you're not going to…if all you have is a radio wave that has a wavelength of 5 meters, you're not going to be able to see something that is smaller than 5 meters, right, because it's just passing right by it.

Pamela: And this also starts to give you a hint why radio telescopes are systematically so much bigger than optical telescopes. The wavelengths themselves can be 1000s of times bigger, and so in order to get the exact same resolution between the two systems you have to have extraordinarily large telescopes.

Fraser: Right, and so then, what are the record holders? What are the telescopes…if you needed resolution, if you were going to do a job that needed resolution, like, I'm imagining, say you want to pick out a planet orbiting another star? Optically, you're going to want high resolution so that you can resolve the stars…

Pamela: Yeah, we can't do that right now.

Fraser: No, I understand, I understand, right, but the star…

Pamela: But if you were in infrared, let's go to infrared.

Fraser: Yeah, wasn't that done with Spitzer?

Pamela: So Spitzer on one hand is good, but the very large telescope is actually better if you know exactly when and where to look because here you can start to use…they have an amazing interferometry system where they can tie in their four many-meter telescopes, and they have a bunch of little 1-meter telescopes that they can move out along different baselines, and they're able to actually get down to about .05 arc seconds --no big deal -- and smaller along individual specific baselines.

Fraser: OK, so if you want the highest possible resolution image you can get in optical, what tool would you want to use?

Pamela: So if you just need along one baseline – very large telescope. The entire system, tie all the telescopes, move the little spuds out and bring all the light together.

Fraser: Right, "interferom" them all together.

Pamela¨ Exactly. If you want to take a pretty picture, where the whole picture has the most amazing resolution you can get, then pick a very large telescope, use it with a laser guide star, or an actual guide star, flex the tar out of the mirror to keep up with changes in the atmosphere, and that will get you as good as you can get.

Fraser: So if it were up to you, you would pick the very large telescope over the Hubble space telescope?

Pamela: It actually can get higher resolution because it's that much bigger of a mirror. Now, for tried and true, Hubble consistently does amazing work, and the thing with Hubble that's different (and there's certain science where this really matters) is when you start flexing the mirror, you can't guarantee that the two photons that are now in focus both left the object at the same time, so you're introducing all sorts of weird issues that start to become an issue in certain types of science. With Hubble, you're getting all of the light that was emitted at the same time, hitting your mirror, getting focused together, and you're getting a tried and true, beautiful, well-resolved image from a 2.5-meter telescope.

Fraser: And so then, if you wanted to go to another wavelength, if you wanted to get like a really high resolution infrared, where would you go?

Pamela: Infrared, you can do all of infrared from Spitzer on orbit, you can do some of the infrared depending on what colors get through the atmosphere vs. what colors you're interested in, you can do some of that from the very large telescope. Again, interferometry's awesome. As you start to push into the radio, sub-millimeter…sub-millimeter, wait for Atacama to get built. There's also sub-millimeter array in Hawaii that does a very good job. As you push into the radio, the best you can possibly do is get the whole planet engaged and start looking at things by getting the telescopes in Europe and America and everywhere else working together to do very long baseline interferometry.

Fraser: Is a lot of work done organizing all of those at the same time, or does something really special have to happen to accumulate all those telescopes all at the same time?

Pamela: It's actually a proposal process where it's known this is going to happen. There are agreements that say we're going to pull all of these telescopes together to do a certain amount of science every year. And there are some telescopes that are built specifically for this – the very large baseline array in the United States, for one. And so there's dates that get announced, you're told, "OK, go propose," you propose, they say "yes" or "no," they give you time on specific dates, they tell you which telescopes will or won't be engaged, and then you wait and eventually get your data.

Fraser: And if you wanted to go to the ultraviolet, there's pretty much just Hubble, right? Swift?

Pamela: Yeah, Swift is still up there, and we're going to start to run out of ultraviolet abilities pretty soon, so hang [missing audio] your star up.

Fraser: That's one of the things…a lack of ultraviolet astronomy, so then I guess x-ray, you've really just got Chandra.

Pamela: Well, Swift, I believe, also has some x-ray detections on it. And for gamma rays, you have Fermi,, and you still have parts of Swift.

Fraser: Right, so there's still ways to see…

Pamela: And then there's Chandra. Don't forget Chandra's doing a great job in the x-ray, and it refuses to die. It's manufactured as well as the Mars Rovers -- it's just the telescope that keeps on giving.

Fraser: Yeah, it's a great telescope. Great! Well, thank you very much, Pamela. That was awesome, and we'll talk to you next week.

Pamela: Sounds good. Talk to you later, Fraser.