Astronomy Cast Episode 41:
Rise of the Supertelescopes

Fraser Cain: I'm so excited about this topic! I think this was one of the first ideas that I had for a topic way back when, and now we're going to do it. It took a lot of research, so thank you Pamela.

Dr. Pamela Gay: No problem.

Fraser: The last decade has been the golden age of astronomy, with new observatories and space telescopes pushing out our understanding of the Universe. We can see billions of light years away, watch dynamic events unfold in almost real-time, and see into every corner of the electromagnetic spectrum. Just you wait; things will only get better. Here come the supertelescopes!

All right – don't you giggle! We worked on that!

Let's set the stage for this episode. What is state-of-the-art in observatories right now?

Pamela: It's a matter of are looking on orbit or are you looking on the planet Earth? State of the art in space is mid-80s technology where we have the Hubble Space Telescope that was launched when I was still in high school. Then we also have the other great observatories joining it: the Compton gamma ray observatory, the Chandra x ray observatory, the Spitzer infrared observatory. These are all telescopes that are roughly the size of a school bus, which as far as telescopes go, is actually kind of small. The Hubble Space Telescope has a mirror that's only 2.4m across.

In space we're a bit behind the times, we're a lot kind of small… but…

Fraser: But they're in space!

Pamela: But they're in space.

Fraser: That's not easy!

Pamela: It's not easy, and they were limited by having to fit into the space shuttle's cargo bay which is the size of a school bus (thus their size being the same as a school bus). On the planet, we're not limited in size by what fits on top of a rocket or into the space shuttle.

So here on planet Earth, state of the art today we have the South African Large Telescope, which has an 11m segmented mirror. We have the Keck observatories, Keck 1 and 2 which sit side by side. They each have 10m mirrors that are single cast mirrors that were spun to their enormous size and then gotten via ship and then via giant truck to the top of Mauna Kea in Hawaii.

Then we sort of work our way down, and it's only once you get to 6m that we start finding lots and lots of telescopes. So, there's large telescopes scattered around the planet between about 6m and 9m in size.

Fraser: I know there are technologies that allow multiple telescopes to work together.

Pamela: Currently working toward its first light is the Large Binocular Telescope. It's a pair of 8.4m mirrors. These are mirrors that won't fit in the average American bedroom. Two of them partnered up side by side make this telescope work as a single large collecting surface, just like using binoculars (where you're sending the light to each set of eyes), this telescope is combining the light from these two mirrors to look at a single object.

We have other telescopes that are also made with segmented mirrors. SALT, like I said – it's made out of segmented mirrors. There's also the Hobby-Eberly Telescope, the third largest telescope in the world, with a 9.2m mirror. Again, these are basically small mirrors, a metre-ish in size, often hexagon shaped that are arranged on a tress. They're moved together to shape out the correct shape that you need to view what you're looking at. Depending on their design they are parabolas or spherical in curvature.

These combined mirrors get very carefully moved by little pistons on the back. They have sensors on the edge that help them figure out how they're aligned in relation to the mirrors next to them. This is actually a really complicated way to try and build a telescope because every time the temperature changes the mirrors are going to try and go out of alignment. Every time the humidity changes the mirrors are going to try and go out of alignment. So you're constantly fighting every little environmental parameter, whereas with a single solid mirror, it just sits there going, "yeah, I'm a parabola." It's much easier to deal with, but much more expensive to cast a single 10m diameter mirror, versus a bunch of little 1m diameter mirrors.

Fraser: What difference does the size of the mirror make? How much better is a 10m telescope than an 8m telescope? (or some amount)

Pamela: You're looking at two different things. The size of the mirror determines how much light you can get. With every doubling in size you're able to get that much further away in space and adding one or two metres to an 8m telescope is not going to be a huge difference, but it might be the difference between barely glimpsing a galaxy at the edge of the Universe and being able to see it stand out against the background glow of the sky.

What really starts to kick in is the resolution you can get with these different telescopes. We're limited by our atmosphere. The Earth's atmosphere has lots of different pockets of different temperatures, different humidities… all these slight variations in the atmospheres cause light to bend and dance. When you see a star twinkling, what you're actually seeing is the atmosphere causing the star's light to dance around. It's good for a romantic night, not so good for trying to do an imaging run.

In order to counteract the atmosphere we do lots of things involving bending and reshaping mirrors to correct for what the atmosphere is doing in real time. If you can make these corrections, then your ability to resolve an object is directly related to how big your mirror is or how far apart are the most extreme sections of your light correcting area.

Fraser: Right, I've done a few stories on this. These are the adaptive optics systems where they fire a laser beam up into the atmosphere to make a star that they know, and then they actually warp the mirror in real time to smooth out the atmosphere distractions, right?

Pamela: Exactly. A strange way to think of it that makes it understandable to me is: imagine looking at something outside through old glass that's slightly non-flat (just because they couldn't make old glass really well). As you're looking out that window, trees might not appear to be straight. As you move your head, things appear to dance and move in ways that are strictly due to that non-flatness of the glass. If you took a different piece of glass that was warped in just the right opposite set of ways, you could make it so when you looked through the warped glass, the entire outside world always looks crystal clear and non-deformed.

What they're doing with these giant mirrors is they're actually actuating the mirror; changing its shape in real time to account for deformities in their image caused by the changing atmosphere. It's not like just making a single piece of glass to correct for a window that's always wrong in the same way. They have to constantly update their model (sometimes multiple times a second), to account for what our atmosphere's doing.

Fraser: So those are the observatories, and these are the technologies that are being used to clarify the images. Let's set a bit of a yard-stick here. What would be a way we could measure the power of existing telescopes, and what's going to come in the future?

Pamela: We can start by using the Hubble Space Telescope (which is probably the best-known telescope on the planet) as our light-collecting yard-stick.

Fraser: So we'll be measuring in "Hubbles"

Pamela: We'll be measuring in Hubbles. So just for comparison, the 10m Keck telescope is 17.4 times the light collecting area of Hubble. It's like using 17.4 Hubbles to collect light from the sky.

Fraser: Right, but it suffers because it's got to deal with the atmosphere.

Pamela: It suffers because it has to deal with the atmosphere. On the best days, both Keck and the Very Large Telescopes down in Chile are able to use their adaptive optics to get to about the same level as Hubble. We're starting to get to the point that we can build giant telescopes, actuate their mirrors, and achieve Hubble's resolutions.

Fraser: That's still amazing that a telescope that has 17 times the power of Hubble can only match it, because it's here on Earth.

Pamela: It's our atmosphere.

Fraser: Okay, so what's coming then?

Pamela: There are some truly crazy things out on the horizon.

Fraser: Let's start with the less crazy stuff then. We'll get into bizarre at the end.

[laughter]

Pamela: Perhaps one of the more realistic ones is the giant Magellan telescopes. This is a plan to build a telescope that has segmented mirrors, where the segments, instead of being 1m in size, are actually 8.4m in diameter. SO you take the 5th largest telescope in the world today, multiply it by seven and glue (well, not glue, but bolt) those pieces together, and you can build yourself a mirror that's 24.5m in diameter.

Fraser: So it would be arranged in a hexagonal shape, right?

Pamela: Yes.

Fraser: But instead of being one, it's one with six around it.

Pamela: Yes.

Fraser: Right, okay – and it's going to be the equivalent of a 25m telescope.

Pamela: Yes. So, it's huge, it's still in the planning stages, but they're hoping to have this thing built by 2016.

Fraser: Where would it go?

Pamela: Currently they're looking to put it out at Las Campanas, which is in Chile. It's where a lot of the major telescopes of the world are currently getting built, and one of the locations for the Magellan telescopes.

We're looking at where in the entire world do we have the best skies, and we're taking our technology there. In this case, it turns out the Attacama desert is one of the best places in the world for astronomy.

Fraser: That's a place that doesn't get any rain, ever, right?

Pamela: Right, it's measured in millimetres – like, less than 10mm per year, often. It's really high, it's really dry, and when you have water in the atmosphere, the water actually absorbs light. If you can go somewhere extremely dry, like a desert, you have more transparent skies.

Fraser: All right, so give me the Hubbles!

Pamela: [laughing] In this case we're looking at 104.2 Hubbles in light-collecting area.

Fraser: Wow.

Pamela: Kinda cool.

Fraser: I wonder if our calculations start to get wonky here because, with the Keck Observatory at 17 times the light-collecting ability… I'm just wondering… it won't be 100 times as good as Hubble, but it will still be crazy…

Pamela: It will still definitely be crazy-good.

Fraser: And this is the beginning?! Keep going.

[laughter]

Pamela: Now we start getting into the really big, scary… "plans are on the books but we're not sure they're actually going to happen" telescopes.

There are a whole series of telescopes that have the last three words "extremely large telescope". Two of them are the European Extremely Large Telescope, and the California Extremely Large Telescope (which, depending on who you talk to, actually goes by different names because there are funders involved who aren't in California). These two telescopes are slated to be 42m in diameter for the European telescopes, and 30m in diameter for the California telescope. They're both slated to be, again, opening somewhere in the 2015-2020 category. These are things that aren't too far off in the distance – off 10 years in the future, which for a big project means they're starting to consider where all the money comes from.

Fraser: But the money for one of these mega-observatories is fairly reasonable when you compare it to the cost of, say, the Hubble Space Telescope. You're looking at hundreds of millions of dollars, or in the low billions as opposed to… what Hubble cost.

Pamela: That's true, but it's still hard to get all the money together. There are so many of these different projects going on right now that it's little pockets of money going to this telescope, little pockets of money going to that telescope… and so far we're only talking about projects that are in the optical. The sky has light coming at the Earth in all different wavelengths, so we have to take our funding and spread it across the gamma ray spectrum, the optical spectrum, the infrared telescopes, the radio telescopes. Then we also have to consider things that are really better seen if you go to them, like Pluto.

We also have money that's going to build spacecraft that travel to objects within our solar system.

Fraser: All right, let's go bigger!

Pamela: Okay. So now we have the Overwhelmingly Large Telescope.

Fraser: I love these names!

[laughter]

Crazy-Big Telescope; Biggest Telescope We Could Possibly Build…

All right, so the Overwhelmingly Large Telescope…

Pamela: It started out as a European plan to build a 100m class telescope.

Fraser: 100m telescope.

Pamela: That's way bigger than a football field.

Fraser: Do you have some Hubbles for me?

Pamela: That's 625 Hubbles.

Fraser: Oh God…

Pamela: Sorry, that's for the abbreviated version. They changed their mind and brought it back to only 60m, they think that's a more reasonable size.

Fraser: Oh okay.

Pamela: For their current 60m plans, that's 625 Hubbles in size.

Fraser: And what would that be?

Pamela: This is a giant, segmented mirror with, like, 20m-ish secondary mirror. So when you look at a standard scientific telescope, they're what are called reflecting telescopes. They have the big mirror at the base of the telescope, light comes in through the top, hits the primary mirror at the bottom, gets reflected back up to either a camera or a secondary mirror that's part-way up the tube, and then it either gets recorded by the camera or shot back out by a hole in the primary mirror.

The secondary mirror, the one up toward the top of the tube, they're looking at that being over 20m for this telescope. This is just all huge, lots and lots of segments, they'll build it bringing a few segments online at a time.

There's questions like what do you house something this big in? There's some amazing animations on the European Southern Observatory website (which we'll link to in our show notes). They're really thinking "let's take science fiction and make it reality" and the sky's the limit in what they're designing.

Fraser: Okay, so then let's talk about some… you mentioned some of the other spectrums. What are some other large projects that are being done in other parts of the electromagnetic spectrum?

Pamela: Now that I've just finished talking about these tens of metre telescopes, I'm going to return back to the smaller observatories. On the more reasonable side of things, we have the upcoming James Webb Space Telescope

Fraser: But now we're going to space!

Pamela: Now we're going to space. We're now looking at launching something 6.5m in the diameter (for the mirror) into space, out beyond where the space shuttle can get to. Now we're increasing to 7.3 Hubbles in light-gathering ability.

This telescope's going to work primarily in the infrared. So all these really pretty, optical and ultraviolet pictures that we get from the Hubble Space Telescope, we're no longer going to be able to get. That's okay, because we have all these ground-based telescopes that are starting to get Hubble-level results.

Fraser: This is going to be like Spitzer's big brother.

Pamela: Exactly.

Fraser: As opposed to Hubble's big brother. I think people are calling it the successor to Hubble, but it's more Spitzer.

Why are they not planning to do an optical telescope?

Pamela: It's all a matter of what questions are there, and how do we best answer those questions. A lot of the questions that people are asking today are best answered using infrared telescopes. If you want to study planets around other stars, they're going to be mostly just warm. "Warm" is something we can best detect in the infrared. Spitzer is used to try and image new planets. James Webb will also have this ability to start looking for planets.

There's also things like trying to look at the very first galaxies. The light from the first galaxies to form has been shifted by the expansion of the Universe. We call this redshifting. So you take the light of a bright, blue, star-forming, hot galaxy, and you redshift it, and you keep redshifting it, and you redshift it some more (because it's at the end of the Universe) and suddenly you're in the infrared.

Fraser: Oh I see, so this is the same process that happened with the Cosmic Microwave Background Radiation that at one time was visible light, but it's so far away, and so much Universe has expanded in between us and that radiation, that's been shifted out to the microwave spectrum, same thing. You have some really distant galaxies that would once have been visible, but now they're just off in the infrared.

Pamela: It's similar. The Cosmic Microwave Background has some other things. The wavelengths literally get expanded by the expanding cavity they're within. But the basic idea that something is so far away that its light has been stretched by the expansion in the process of getting here is exactly the same.

Fraser: So many new, many future telescopes – infrared is going to be the place they go.

Pamela: There's so many cool objects in the infrared that we're just starting to learn about. M dwarfs, the little dwarf stars that we're now finding quite often have planets. Brown dwarfs – no one really understands brown dwarfs. What's the difference between a brown dwarf and a planet? Don't know – still figuring it out.

James Webb will help us be able to answer all these different questions.

Fraser: When's it due for launch?

Pamela: That's kind of a moving target. Somewhere in the next five years.

Fraser: Okay. So what's next, then, for space-based observatories?

Pamela: We also have GLAST, which is one of the next gamma ray telescopes that's going up. It's going to help us figure out gamma ray bursts, and all the high energy events: supernova, active galaxies. You can't really put a diameter on a gamma ray telescope, because gamma rays really avoid reflecting politely. You sort of funnel them through different layers of material trying to get them to your detector. It's going to be significantly more sensitive than the current Compton gamma ray telescope. It's the next big thing for people interested in the high energy Universe.

We're starting to expand our questions away from the optical, and look both to the more high energy part of the Universe, and look both to the more high energy part of the Universe, with GLAST, and to the colder part of the Universe, with the James Webb.

Fraser: All right, keep going.

[laughter]

Pamela: Those are the biggest things that are out there. The one thing we haven't really touched on is radio telescopes. I have to admit – I couldn't find that many really, scary big things to talk about in the radio part of the Universe. We already are all familiar with the Very Large Array, that was in the *Contact* movie. It's an array of 27 different 'scopes that each have a 25m dish that looks a lot like your cable television station's radio dishes.

Fraser: Isn't there a planetary-wide network of radio telescopes that are used for some things?

Pamela: There's also the Very Long Baseline Array, which has 10 different telescopes that are spread out (mostly across the United States, in this case) and those are 82m dishes. But there's lots of random dishes around the world. For different projects, they'll get all these different random radio telescopes from Jodrell Banks in England, to Arecibo in Puerto Rico… all of these telescopes working together on single projects, where we can get half the globe at a time looking at a single celestial object.

So that's a lot more ad-hoc, but a lot more cool in some ways because you're dealing with all of the politics, all of the technology differences and language differences, and we still pull it off on a regular basis.

Fraser: So there are no large radio projects in the works?

Pamela: There are some projects. There's LOFAR, which is still in the process of being built, it's the Low Frequency Array. It's going to be basically a one square kilometre total collecting area. Currently they're looking to build it across the Netherlands and northern Germany. A bunch of small dishes, and it's going to be out there collecting as many photons as possible, trying to be able to do new, deeper studies of the sky.

Fraser: So they're going to be acting like a single observatory that's a kilometre across.

Pamela: Exactly.

Fraser: But it's only in the radio spectrum, not visible light.

Pamela: It's only in the radio spectrum. They're going to be looking a lot at continuum transitions (which is basically the gas in galaxies is emitting light in radio all of the time). They're going to be looking for that radio light and mapping out the sky, looking for things like – star-forming galaxies give off radio. Galaxies that have active black holes in their centres give off radio light. They're going to be probing the sky for all these different things.

Fraser: All right. Were there anymore space missions? I know there are a bunch – stop hiding them!

[laughter]

Pamela: Space missions are always a bit of a moving target, because you're not sure up until right before launch that they're a certainty. One of the things that is looking fairly certain right now is DARWIN. It's a set of three scopes that are each about 3m in diameter that are going to be launched by the European Space Agency, and their goal is to go out and look for planets.

So, that's another project, next 5-10 years, hopefully it will be go. It's following on the COROT mission, so this is a set of sister missions that are going to feed off of one another's successes. That's looking like a really neat project that will actually happen.

Then there's also this one mission that really fascinates me because I've never seen anything quite like it before, and the last project that fascinates me is the New Worlds Imager. Here what they're planning to do is go out and block the light of stars so that telescopes – and they're going to move the shade around, not the telescopes, so this can work with different telescopes – so that telescopes can hopefully see the light of faint planets next to bright stars.

This is sort of like if you've ever gone outside into a parking lot and held your fist out at arms length over a streetlight to look at the stars around the streetlight. This sun shade/star shade is going to work like your fist at arms length. But they had to design it using a really weird flower-looking design to make sure that all the light rays from the star cancelled out exactly right. A lot of really cool mathematics went into designing this flower-shaped star shade that may someday go into orbit.

Fraser: Right, the problem being that telescopes may be powerful enough to see planets around other stars, but the light of the stars is so bright it just washes out the planets. They need some kind of technology to get rid of the light from the star.

Pamela: And this star shade will do that.

Fraser: Right. Now we're talking speculation here.

Pamela: This is speculation. It's not funded. It has a really cute website out of Colorado with a really neat animation of how this will look when it's in action… but it's pure speculation.

Fraser: Now I read some stories that people are considering the Moon as a base for an observation.

Pamela: The neat thing about the Moon is if you put a telescope on there, the Moon's gravity is a lot less, so your telescope isn't going to go through the mechanical stress, the mechanical twisting you get here on the planet Earth. You can start to build really big things, and one of the things that's being considered (again, this is speculative) is building a liquid telescope on the Moon.

There's currently a liquid telescope in your neck of the woods, up in British Columbia, where they have a 6m basically, dish of mercury that they spin to look at objects that are going straight over the telescopes at the very peak of the sky. This is called a transit telescope. It only looks at things at zenith. There's a lot of scariness about building a telescope involving liquid mercury. You have to worry about the environmental impact if you accidentally spill some. This is solid cement everything around the telescope. You have to worry about people breathing vapours off the mercury too much. You put it on the Moon, you can build it bigger and you don't have to worry about these environmental impacts the same way.

Fraser: You can also put it so it's on the far side of the Moon, and then doesn't get any of the electromagnetic noise from the Earth, right?

Pamela: For an optical telescope (which is what a mercury telescope is) that's not as big a concern. There've always been people talking about putting radio telescopes on the backside of the Moon, because your cell phone signal interferes with telescopes, your microwave interferes with telescopes. The iridium satellites, which are used for satellite cell phone communications really mess up radio telescopes. All this noise can be avoided if you go to the back side of the Moon because all of the signals are (more or less) directed at the Earth, and those that do escape off into space will get shadowed by the Moon.

Fraser: Was there anything else? I think you covered it pretty well here.

Pamela: It's a world where I'm sure there are new ideas out there that I haven't found the information about yet, but these are the ones that have so far landed on my radar and really got my imagination going.

Fraser: We'll definitely try and come back and discuss any of them if some of the stuff moves forward. There are some really interesting ideas.

This transcript is not an exact match to the audio file. It has been edited for clarity.