AirSpace Season 5, Episode 3 - Reflektor

Music in and under

Emily: Welcome to AirSpace from the National Air and Space Museum, presented by Olay. I'm Emily.

Nick: I'm Nick.

Matt: And I'm Matt.

Nick: The start of season five has us feeling reflective. So we're going to kick things off with a gaze at the mirrors that power telescopes, large and small.

Matt: Now you're listening to the AirSpace podcast. So we're going to guess that at some point you've looked through a telescope and maybe you even own your own telescope, but the process to make those telescopes and the really big telescopes that allow scientists to study things very far away are both very different and very similar.

Emily: Today. We're going inside a lab that makes some of the biggest telescope mirrors in the world, and into a much smaller lab that makes telescopes you could use at home. Even some that you could make yourself. That's ahead on AirSpace.

Music up and out

Emily: So, if you follow along with space exploration, you've probably heard of the next latest, greatest space telescope called the James Webb Space Telescope. But if you're in the know all the cool kids call it JWST and it's meant to be launched this fall. So that got us thinking about telescopes in general, because they're really cool. Sometimes they're in space. Sometimes they're here down on earth. They're the thing scientists use, but they're also the thing that amateur astronomers use. And frankly, just people who think space is kind of cool and thought it might be fun to look through a telescope.

Matt: Do either of you own a home telescope?

Nick: I have looked through a telescope, but honestly, probably only on one occasion before I came to the museum. So, no. I have never owned one. And when I got here, I asked some of our astronomers whether I should buy one and they said, "You should buy binoculars. Binoculars are much easier to get started."

Nick: Which is to say telescopes are for everyone, they're not intimidating, but they're deep.

Matt: They're deep.

Emily: They're deep.

Nick: They're not hard to use, but the hobby is really engaging and it can take you down rabbit holes. And we're going to learn some of that today.

Emily: Yeah. So we were inspired to do this episode because of JWST, but that's not really what we're talking about. In part, because JWST is a space telescope, rather than a telescope that's going to be installed here on earth. The mirrors in JWST aren't made from the same kind of stuff we make mirrors out of for regular telescopes. So JWST's mirrors are made out of beryllium, which is a really light metal. That's not what we use here on earth. So we want to talk about all the, kinda, cool telescopes that we have here on earth, including some of the really big ones.

Nick: So I've got a pair of binoculars, celestial binoculars. They're great, I lay on my back and gaze up at the sky. Closest I've ever come to a telescope is like a pirate spyglass. I went through a pirate phase as a kid. Didn't we all? So, like, let me, let me ask you a question. There are mirrors in telescopes?

Emily: Yeah. So this is mirrors in telescopes, versus lenses in telescopes. There are two kinds of telescopes, those that use mirrors and those that use lenses, the ones that use lenses are called refractors. Those that use mirrors are called reflectors. They both have their uses, but the telescopes we're talking about today are mostly reflectors, the ones with mirrors in them, but refractors are where it all started.

Nick: So the refractors are what you would use to look for enemy galleons on the horizon or maybe [crosstalk].

Emily: *laughs* Sure, if you were a pirate.

Matt: Yeah, no, it's true. The refractors are the original telescopes. In the early 1600s rumors reached Italy. Right, this is the famous story that the Dutch had invented. Basically the pirate spyglass that you were talking about, Nick, but not a very great magnifying power. It was mainly treated as kind of a curiosity and rumors got to Galileo about this device and someone told him, one of his mentors told him essentially, "Hey, you could make some money. If you could refine this thing, give it better magnifying power and then sell it to the military." And so that's what he did.

And, you know, you have to realize that the science of optics at that time was so primitive that when Galileo designed his first telescope, he basically used a cut and try method of grinding lenses at different angles, different powers until he finally got one that worked properly. He didn't really know the math behind how it would all work, he more kind of just, sort of, played around until he got it right. And eventually he did. And he made his very famous discoveries about the Moon’s surface, then also about the moons that were orbiting around Jupiter,

which we did a little bit of an episode about before. Emily's, One of Emily's favorite moons is out there at Jupiter.

Emily: So what I love about talking about telescopes or the history of telescopes is the fact that we both get to mention Galileo and Newton, because if you're going to talk about space science, you really just got to talk about both of them. So Galileo really pushed the bounds of the refractor, the telescope that uses a lens. But what Newton did was he managed to make the refractor using lenses into the reflector, which uses mirrors. And so if you've ever heard of a Newtonian telescope, that's a kind of telescope that uses these mirrors.

And it's getting into this mirror technology that I think is really what gets us to the point where we can start building the enormous telescopes that we're talking about today and that we use in modern space exploration from the ground here on earth. So Newton plays a really important role in this story, but since we're not doing an episode on the history of telescopes, we just want you to be really into the fact that Galileo and Newton played a part in this. You should go find a book about that later, but Newton is the one who gets us into the reflector realm of telescope styles. And I think that's really cool that you get to, kind of, link this story between these two scientists using telescopes.

Matt: Yeah, and I mentioned that Galileo's optics, his mathematics were very primitive in trying to figure out how to build a better, more powerful telescope. When you look at Newton, Newton's, everybody knows Newton's Principia, right? That's what everybody's a big fan of Newton for is laying out those-

Emily: Sure, everybody knows it. *laughs*

Matt: Those laws of gravity, but his optics were equally influential in his day. He invented a whole new form of calculus or one of the first forms of calculus and was able to actually figure out, you know, the mathematics of optics. And that's why he was able to make so many advances in that area.

Emily: So all of these, all of these telescope technologies are really getting advanced in the 1600s, but that's where it kind of gets started, and I think in, I don't want to say it's snowballs, because I think there was probably a bit of a lag in there, but we're kind of at this point now where we can let technological developments snowball in a way that scientists have continued to push the bounds of technology to get better and bigger telescopes because when it comes to telescopes, you really need big mirrors, the bigger your mirrors, the more light you can collect, the more information you can collect, the more stuff you can see deeper into space. So that's part of what's cool about this story is that some things haven't changed. Scientists are still pushing that envelope.

Nick: Yeah. And this big acceleration it's not a metaphor, it was the renaissance. This was a big part of the advances in technology and science and understanding and philosophy

Emily: So like all really cool scientific equipment, a lot of it you can't just go, like, buy out of the catalog. You need to have it custom made for your custom needs. So if you're going to talk about really big telescopes, you've got to talk about how you make really big telescopes. And since we're talking about optics a lot today, we've got to make really big mirrors if we want really big telescopes. And so you gotta go to a place that makes really big mirrors and I'm sure you'd be shocked to find that there's not a lot of places that do this.

Nick: But there is one in Arizona.

Matt: Arizona. Woo,

Emily: Woo, woo.

Matt: It’s a dry heat.

Buddy Martin: Okay. My name's Buddy Martin, I'm the project scientist for mirror polishing at The Richard F. Caris Mirror Lab at The University of Arizona. We're part of the Department of Astronomy, but we're not in the same building with the rest of the department. The university needed a large area to make big mirrors in and the best large area available was under the stands of the football stadium.

Nick: So, whoa boy, there's a giant telescope laboratory underneath a football stadium.

Emily: There's a mirror fabricating laboratory under the football stadium at The University of Arizona.

Nick: Ahhhhh

Emily: I mean, it's not totally different Nick, but it's not exactly the same.

Nick: No, no, no. And precision is important

Emily: Well, for here- [crosstalk] Absolutely. It turns out that when you're looking at really big things really far away, precision is even more important in a way. So right now, what the lab is working on is a series of seven, eight and a half meter mirrors that are going to be part of The Giant Magellan Telescope. And The Giant Magellan Telescope is sometimes called the GMT. If you're with the cool kids in the know, and it's going to be placed at the Las Campanas Observatory in Chile, that's scheduled to open to do science in 2029, but I've actually had the opportunity to go to the mirror lab under the football stadium at The University of Arizona. It was a total fluke opportunity before I knew I was going to be a space scientist when I grew up, although I was hanging out with the space kids at the time. So, there might have been an influence there, like any scientific laboratory. It's really impressive for what it does, but sometimes you're sort of like, "Really, that's, that’s how you do that?" Like, "Who figured that out?" And

you kind of go down there and I don't think we fully got an appreciation of the scale of the space. Football stadiums are really big, but when you're talking about making mirrors that are 8.4 meters. So if you're not somebody who works in meters, multiply that number by three, and then you have that sort of in feet.

If you're making multiple of those at the same time, all of a sudden it becomes really hard to maneuver those things around. It's a lot of concrete and powder coated steel, is the way I remember it. And you've got these big round furnaces, which is where they melt the glass to make the mirror.

Buddy Martin: We do make these mirrors essentially from scratch. We buy the glass from a Japanese company, Ohara. They send it to us in blocks that weigh a few pounds each. So the first thing we have to do is build this mold and this takes four months or so. It's a big tub, 8.4 meters diameter, but it contains 1,700 hexagonal boxes that will form the cavities in the honeycomb. When the glass melts, it flows around these boxes to leave the cavities and to leave a continuous layer of glass on top that's 28 millimeters thick.

So much of the time is spent building the mold. Once it is built, we pile the glass on top, weighing it as we put the blocks in, so we'll get the right amount. Then we assemble the furnace around the mold, heat it over a few days to about 1,200 degrees C.

At that point, the glass has a consistency like molasses and it flows slowly into the mold, it flows around the hexagonal boxes and after three or four hours, it has completely filled the mold. And it has that honeycomb shape that we want. We achieve that concave surface by spinning the furnace while the glass is molten. Now, it's also true that the mold has this concave shape so that when the furnace spins and the top surface of the liquid glass takes on that concave shape, you'll have a uniform thickness of glass on top of the mold.

So we continue the spinning as long as the glass is liquid. Once it gets down below about 900 degrees C, then it's solid. It's not going to change its shape anymore. And then we have to cool it very slowly down to room temperature over a period of three months in order to minimize stress in the glass.

Nick: This is, this is, kind of, a mind blowing process. Like even hearing it described. I'm bowled over by the complexity, the scope, the time and the scale of this. You've got 28 foot furnaces spinning like a record player, but since they're 28 feet across instead of 12 inches, they go, what, five times around per minute?

Emily: Yeah. So it's not, it's not as fast as you might think it would be, but that's kind of the sweet spot to get those centrifugal forces to sort of push that glass out into the edges.

Matt: So now that the mirror has its basic shape, it still has to go through several rounds of grinding and then polishing to get the final shape so that it can actually be as precise as possible.

Emily: Yeah. And this was a question I had asked because I was really curious how much of this was done by human hands and how much of this was done by robot hands because there's benefits and disadvantages to each one of them. And it's really, it turns out it's a process that's really driven by humans, directing machines to do the grinding and then the polishing. Right? So you have to go through all those phases of grinding before you even contemplate the idea of polishing because you can't polish until it's been ground properly. And so it's the machines that are doing all of that physical labor sort of at the direction of humans. So it's teamwork, you know.

Buddy Martin: That's a long, iterative process. We don't just grind it and polish it and then show that it's accurate to 25 nanometers. We go through many cycles of grinding and measuring and grinding some more and measuring. And then once it's close enough, we switch from grinding to polishing where the surface becomes shiny and transparent, but it's still this long iterative process. Something like 50 cycles of polishing, measuring, polishing, measuring, hoping for some significant improvement in every cycle, hoping that after 50 or so cycles, it's good enough in all respects and accurate on average to about 25 nanometers.

Emily: So the grinding and polishing is really there to make the mirror as accurate as possible. Any imperfections in that glass in terms of roughness on the surface is going to affect how that mirror captures and focuses light, and therefore the picture that you're trying to create.

Nick: So if the mirror is the size of the continental United States, the imperfections, the hills and valleys of a 3,000 mile theoretical mirror at this level of precision, are two thirds of an inch. So we're talking-

Emily: That's just insane.

Nick: Extraordinarily, insanely flat.

Emily: So you need this level of precision. You need this of smoothness of the mirror so that it can be accurate enough to see what you are trying to see. And the analogy for the sort of level of accuracy that these mirrors are trying to achieve is to imagine that the telescope with that sized mirror is in Washington D.C., you would be able to see a softball in the hand of a pitcher standing in San Francisco.

Nick: So this is big. It's an awkward size load. It's probably pretty heavy.

Emily: It's not flat.

Nick: It's not flat. It's made of glass like woo, super duper made of glass and you can't scratch it. So all ground based mirror telescopes in that one stadium, because they can't take them anywhere or, or is there a way to get these up a mountain in Chile, for instance?

Emily: Oh, there's ways. Oh, there's ways. But you know, like everything you ship it.

Buddy Martin: So the process to get a mirror from Tucson, to a mountaintop in Chile is first, it goes onto a special support frame, that's built just for transport that attaches to the mirror at a large number of points, in the ballpark of a hundred points using these same interfaces that are bonded to the mirror for use in the telescope. And that frame contains several layers of suspension, isolation from vibrations and shocks. And then a steel box is built around that frame.

The whole thing is loaded onto a flatbed trailer, which also has special suspension to give a smooth ride. And it then goes on the ordinary streets. We have to get special permits to take it through the streets of Tucson and sometimes we have to do that in the middle of the night. But once it's on the interstate highway, it's an ordinary wide load and the mirrors that are going to Chile will probably go to port in or around Houston and then onto a freight ship taken through the Panama Canal to a port in Chile and then back onto a similar flatbed trailer and up the mountain.

Emily: Yeah. And this was something that was really two really big surprises to me. One, they don't coat it until it's on site, which I thought was bananas because if you're going to spend this much time grinding and polishing, you're going to put the mirror, the shiny mirror coating on it, once you get it up on the mountainside and that's for a couple reasons. But I thought that was really surprising, the other thing that was really surprising to me is that the coat goes on the front of the mirror, not the back of the mirror. So unlike-

Matt: Oh! I totally assumed the opposite.

Nick: Yeah

Emily: Right. Because all the mirrors that we deal with in our day to day are like the bathroom mirrors. They all have that shiny coating on the back side of the glass. But if you think about it, you spend all this time grinding and polishing this mirror if it was on the back of the glass, the light would have to go through that glass before it gets reflected back and that's where the there's more technically there could be more imperfections that could distort that light. So the mirrors get coated on the front and they get coated on site and they get re-coated on site every few years because those mirrors are open to the elements frequently.

Nick: So not only is this thing probably pretty expensive, takes four or five years to make, has to be shipped very carefully through the Panama Canal and up mountains, and then they leave it outside!?

Emily: Well, you've seen telescope domes, right? Everybody's seen domes, they're all under domes, but anytime those mirrors are going to be used for observing those domes have to be open and that's usually during nighttime. So yeah, they are open to the elements when they're being used. And for these kinds of telescopes, there are really special pieces of scientific equipment that need to be used. And so the people who are managing these telescopes are constantly balancing the needs of scientists with the equipment and they want that equipment to be used as much as possible. So those things are open to the elements for really long stretches of time.

Music button

Emily: Yeah. So I'm, I'm not the only one who has made it into a mirror lab. So I had the opportunity of course to go see these really giant, eight and a half meter mirrors get made under a football stadium, but there's lots of other folks who are out there making telescopes and our Producer Jen had the opportunity to go hang out with someone who's making their own telescope mirrors, but on a much smaller scale.

Matt: And we get to hang out with Jen all the time, but now we're going to introduce her to you and, bring her in to tell us about this experience.

Nick: I can't tell you how excited I am. I've been trying to get our star producer in front of the microphone and on the show forever and now is our moment.

Jen: Umm, so I went out to not a giant lab under a football stadium, but to a small row house in D.C and I was there at the same time as what I've been calling The Cicada-pocalypse, which was this time in parts of the United States, where there were just cicadas, literally everywhere, screaming from the trees. And that's the kind of worrying sound that you're going to hear in the background of all of this tape.

Emily: But a special kind of cicadas because well we are the Air and Space Podcast, it is important to understand that this is brood 10, which comes out every 17 years. So this is a really big deal if you're listening to this far in the future.

Nick: Yeah. And we've got entomologists friends within the Smithsonian and they are awesome and now is their moment. And cicadas might be scientifically interesting, but they are so loud. And man, I am done with them landing on me.

Cicadas up in background

Guy Brandenburg: Okay. Come on in. Okay.

Jen: And so I went up to this ordinary looking house and a guy let me in and we went down a skinny kind of old school set of stairs to a very well organized basement.

Guy Brandenburg: My name's Guy Brandenburg. I'm a D.C. native. I was a teacher in D.C. public schools for about 30 years, taught math at mostly the middle school, some high school level. I am an interested person in telescope making. I've been actually leading the D.C. area telescope making workshop at the Chevy Chase Community Center for about 20 years now.

Jen: And he has a pretty ordinary looking workbench. Anyone who's ever seen someone who does like woodworking in their basement or something like that, it was very similar to that type of thing. He's just making mirrors.

Matt: So, I mean, I think we've all visited our uncle's wood shop at some point. Right? And seen them working on those. But I mean, how is a mirror lab, a small scale mirror workshop different from your traditional wood workshop or tinkerer's workshop, like, what's going on in there?

Jen: So it's not really all that different at all, it's just the kind of the tools and how they're used. And so Guy actually doesn't normally work in his basement either, he normally works in a workshop that I didn't get to see because it's closed down because of COVID. He works at the Chevy Chase Community Center where he runs workshops, where he teaches other people to make telescope mirrors. So not only is he making telescope mirrors, he's teaching other people how to do it as well.

And most amateur telescope makers aren't making their own glass. So like these really big facilities that we've been talking about, they're actually casting their own glass, but amateur makers don't really do that. So they buy glass blanks from suppliers and then they do a bunch of math. And Guy is actually a retired math teacher, so he was really excited to find a hobby that he was able to use the math that he was teaching.

Though probably higher level because he was teaching middle school math so I don't think that the middle schoolers were doing, like, trigonometry. So they do some math and figure out what the curvature needs to be and then they start with grinding.

Guy Brandenburg: Okay. So I put some grit down there and I'm going to put some water on it because you don't want to get silicosis. *grinding noise* So in any case, this is what I'm doing here is I'm doing a grinding. And I'm grinding the top one against the bottom one and I'm going to make it here. This is a little unusual. I'm using a very much undersized tool to grind out a hole in the middle. You do that until you've got the depth that you want. You've done some calculations hopefully beforehand and you have some way of measuring how much is the curvature.

Emily: So it sounds like, Jen, that the process in making these huge eight meter mirrors, minus the casting of the actual glass, isn't all that different from making these much smaller, say, let's say eight inch mirrors that Guy is making.

Jen: Exactly. So he has a roughly eight inch blank. And once you have that blank, it's that same process of grinding and measuring and grinding and measuring. And then once you get to where you're close enough, then you start and do polishing and measuring and polishing and measuring until you get that contact lens shape that you're looking for.

Emily: Since Guy doesn't have robots doing this work for him, he's doing this all by hand. Can you describe what he's grinding with and how that's different from what he's polishing with?

Jen: Yeah. So he had a couple different things that he was using, but the beginning of the grinding is done with a weight and some grit. So this grit looks like it kind of looks like sand, but it's like gray and sparkly.

Guy Brandenburg: Okay, so this one is what we call 60 grit and let's see, what should I say, it looks like. *whispers* Diamond dust.

Jen: And it comes in different sizes. And then he pours a little bit on his mirror that is sitting on wet newspaper so that it doesn't move around so much. So for the grinding it's on just on newspaper and then his glass blank. And then he puts the grit on and puts a little bit of water on so that the grit doesn't turn into dust that he's then breathing in. And then he takes, he has like half of a five pound dumbbell weight that he cut in half. And it's just meant to be kind of like a mallet, I guess.

Emily: Like a mortar and pestle.

Jen: Exactly, exactly like that. And he just like uses these different motions, used a couple different motions. One was kind of around and then one was like a back and forth kind of motion to grind that out. And then once you're done with the grinding, you go through different levels of grit. And once you're done with that, then he had a couple of different polishing stones.

Guy Brandenburg: So that is a pitch lap. And a pitch lap basically is pitch like from trees or from tar. This stuff I think is from trees and they boil it down and they treat it just right.

Jen: And it's rough on the top. It kind of reminded me of, like, reptile scales.

Guy Brandenburg: It would go kind of like this. You cannot hear very much can you? What you mostly hear is a click, click of my brand new polishing stand, polishing merry-go-round, or Lazy Susan sort of thing.

Jen: So then, once you switch to polishing, instead of moving the thing that you're using to polish on top of the glass, you flip it. So then you're polishing stone is being held by, he's got this wooden thing that holds it in place, and then you rub the glass on top of it.

Matt: Oh, so now you're moving the glass instead of the [crosstalk]

Jen: Yeah. So you go from moving the polisher to moving the glass.

Emily: So it sounds like between the newspaper and the cut off five pound weights, that there's a lot of highly specialized equipment used in this process.

Jen: For sure, for sure.

Matt: And it sounds like a lot of muscle memory, right? Like this is a very tactile process.

Jen: It is. Yeah. And it sounds really cool. I was excited to be able to get that sound because as an audio producer, I'm very concerned with how things sound and the noises that they make.

Matt and Emily laugh

Emily: So what happens after the polishing phase? Right, like when we were talking about the eight and a half meter mirrors, the ones that are going to Chile for the GMT, they don't get coated in their shiny aluminum coating to be reflective until they get on site in Chile. What does Guy do once he's finished polishing? Does he coat them himself? Does he send them out for that process? How does that work?

Jen: So some amateurs do have to send them out, but the group that Guy is a part of that's based out of the Chevy Chase Community Center they actually have their own aluminizer that they got through a series of surplussing said originally was military and now is at the community center so they can aluminize their own mirrors. And it's a somewhat chemical process and since the community center is so close I didn't get to see that process. So I don't actually know what that looks like, but he showed me a finished mirror and it looks all pretty and shiny and like a mirror. And since, you know, you don't have to carry your eight inch amateur mirror up and down the mountain you don't really have to worry about doing it on site because, I mean, he carries them around and the very sophisticated container of Tupperware.

All laugh

Matt: And so he must also have built some telescopes also, not just the mirrors. Did you get to see some of the telescopes that he's built for these?

Jen: I did, yeah. So he keeps the telescopes once they're done in his, he has one in his garage and then one is in his office.

Guy Brandenburg: All right, so I guess that's pretty much, unless you want to see some homemade ones?

Jen:(In tape) Sure

Jen: And they are made out of a big cardboard tube.

Emily: Like a concrete form?

Jen: Yeah, exactly. His was painted green on the outside, not on the inside and the mirror goes at one end and they have like an eye piece at the other, the lights coming into the concave mirror that you spent all that time making and it bounces off of that into the flat mirror that bounces it into your eye piece and that is which is what you can see.

Guy Brandenburg: So I made, this is my second telescope. That's an eight inch. So I had so much fun on the first one I decided making the second one.

Jen: It's about four and a halfish feet tall and they move around and they have handmade wooden umm, *pauses*

Emily: Rocker boxes?

Jen: Yeah.

Emily: So it could be if it's a Dobsonian style telescope, which is based off of a design invented by John Dobson, who called himself the sidewalk astronomer. So he felt like astronomy should be accessible to everybody. So he came up with these telescopes that you could make out of concrete forms, um, and all kinds of things that you could get at the hardware store. And so part of the beauty of his design is this thing called the rocker box, which lets it sit on the ground and you can move it all around. So if you ever get the opportunity to come to the museum and look through some of the telescopes that are staff set out for the public to use, one of them is a John Dobson OG Dobsonian Telescope, just saying, and they have a rocker box. That was my story. The end.

music up and under

Emily: The D.C area amateur astronomers is one group and a huge network of amateur astronomy clubs across the country and around the world. And many of them have members who make their own telescopes, make their own mirrors and if you're interested in learning how you can contact your local group.

Matt: AirSpace is from the Smithsonian's National Air and Space Museum. It's produced by Katie Moyer and Jennifer Weingart mixed by Tarek Fouda AirSpace is presented by Olay and distributed by PRX.

Music up and out

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