Prof. Melville P. Ulmer (00:14):

Okay. Thank you very much for attending. The basic need for a technology is that for, I don't know how many years, 20, 30, 40 years, you can find articles, conferences saying, "Gee whiz. We would like membrane mirrors to work. We would like these to work because we can fold them up like umbrellas, have them launched, and then deploy." Since that need has been there for, it seems like forever, we can then deduce, "This must not be easy. Otherwise, it'd already be done, and we wouldn't be having this conversation." I'll give you a lot of background and then give you some particulars about my technology which, if I can get the thing to work completely, I'm amazed at how well it works already, but we're definitely not there yet. If we can get that to work, it could be a paradigm shift.

Let's go on to the next slide here. What is the basic technological issue that we're trying to solve with these so-called membrane mirrors? Collecting area is the obvious one. If you have more collecting area, then everything goes faster and you can see fainter, etc. But if you know a little bit about physics and optics, you know that the larger the diameter of your mirror, if the mirror has a perfect shape, as you increase the diameter, your defraction limit improves. Guess what? You get better image quality. We have two things working for us as we increase the area, speed, but also image quality. But only if, as you increase the diameter, you maintain figure integrity.

As I paraphrase down here in this last line, our comedians might say today, "Give me enough money and I can image anything. I can make a really big telescope in space." One of the main goals or the main goal, if you will, is to reduce the cost, where we want less cost per unit area than what we know how to do right now. Along with cost, we have another thing which is mass. If you read the literature on membrane mirrors, the holy grail is one kilogram per square meter, which translates into making a mirror out of ice that's one millimeter thick. That's pretty challenging. We're not there yet, but we do keep in mind mass. This poor animal was hoisted into the air when they put too much mass on the cart.

This picture I got from a ground base telescope white paper called... The telescope was a project by the European Southern Observatory. It was called Owl. Owl stood for Overwhelmingly Large Telescope. The point was even on the ground, you worry about mass. But the other implicit thing here is if you're going to have an overwhelmingly large telescope, you better be able to pay the price. Then when [inaudible 00:04:48] looked at ESO, the European Southern Observatory, they looked at the price tag. They said, "Oops." Now Owl is a shelf project. But mass also matters for the James Webb space telescope, which we'll look at in the next slide.

This tells us how we're accomplishing one of the goals of our membrane mirrors, which is to have a larger diameter mirror than what fits into the rocket faring that you can get if you go to the aerospace equivalent of ACE hardware store, in other words, the standard diameter rocket faring or nose cone can accommodate a monolithic mirror that's about four meters in diameter. You have something here, this image is six and a half meters from here to here. Six and a half meters doesn't fit into four meters unless you fold it up. This thing folds down the way you might on the leaves of some dining room table, and then it fits inside. You notice that these hexagons look rigid, and they are. They're made out of beryllium, and beryllium is chosen because it's got the highest ratio of stiffness to mass. This is lightweight as about you dare. They've managed to polish this beryllium down to a high shine.

If you get angry that, "Hey, NASA's flying gold-plated telescopes mirrors." The amount of gold, it turns out, that if you were to scrape this all off and roll it up into a ball, it would be the size of a golf ball. The gold involved is not what runs up the price of this approximately now $10 billion project. What do we have? You notice kind of for scale, you have people here. You want to make your telescope look bigger, make sure you have a vertically challenged person standing next to it. You can't see that very well here, but that's one of the few things I got out of one of my graduate classes, pick the right kind of person to stand next to your telescope. We need to fold things up. Now you ask the question, "What about after James Webb's space telescope? Have we maybe solved this membrane problem?" The answer is, "Not to anybody's satisfaction or confidence because if you look at the white papers for the next generation beyond James Webb, they're stopping at about somewhere between nine and 12 meters. The reason is they're still sticking with this design of solid rigid segments."

Once this thing gets up there and gets deployed, we are going to need to use actuators to tip, tilt these things to get everything just right. That's where we are now. I'm just going to talk a little bit about what other people have done, just so you get some idea of what other people have done. Then we'll segue into my technology. Historical context, why bother? Why hasn't this been solved already with the Piezo electric effect? It turns out that Piezo actuators, which work by putting a voltage across material, and then that material expands, turn off the voltage, and the material collapses down. You can imagine you can adjust the height depending on how you situate these things that tip, tilt back and forth and so forth, and adjust your figure. But we know because this is not what anybody's planning for the next generation James Webb space telescope, that this hasn't been solved by the Piezo approach.

I'm just going to give you some relatively old references here. This is from JPL. You can see it looks good, looks very plausible. But again, by observation, we know it can't be that great because nobody has bought into this, at least that I've read, for the next generation. One of their several weaknesses to this approach, not that mine is perfect by a long shot, but one of them is discussed on this next slide, which is you need your mirror itself to be thin enough so it can be folded up and deployed, and also thin enough so that the Piezo patches, which aren't infinitely strong, can push, pull the substrate to the amount needed. What this study said was at least the way they looked at things, their so called print through.

You glue the patches to the back, you go around and look at the front, and you can see the pattern that you glued on the back. It's called print through. Just to allow you to visualize here, this is pulled from some carbon fiber company webpage, where you can see the pattern of the carbon fiber, even though it's kind of shiny, you can still see that pattern printing through. The bottom line is the Piezo approach has been thought about, is a standard idea. There are different kinds of these patches. This is not even the only way people are approaching getting large areas up there. But it's the most mature when you're talking about much, much smaller mirrors, mirrors that are used in a different application. Even there, they're not meeting the specs that we would like for the next generation, but that's another story.

Let's move along and talk about the physics behind the technology I'm using. It's called magnetostriction. If you look down here on the right where my cursor is now, holy cow, this was known, discovered by Joule, the famous Joule, in 1840. It's been almost 200 years and we still haven't managed to apply this effectively so that we have membrane mirrors up there that are as good as Hubble, but say 20 times the diameter. Therein lies, you might say the devil in the details. What's going on here is that if you have a fair magnetic material, there are domains which are shown here by the North and South poles. This arrow here, we've got a fairly strong magnetic field that's going parallel to this rectangle, and it's causing these domains to line up. You can imagine when they line up, the material expands a little bit. Let's see if we can go back here.

As the arrow goes back and forth, these domains rotate. One of the things that's cool about this effect is you have, not only the knob of the size of that arrow, if you will, to turn, but the direction of the arrow. We can get all kinds of control on the substrate on this film. It turns out you don't need a thick material. You can get away with two to three microns film. Remind you, your hair is about somewhere between 50 and 100 microns. Two to three microns is pretty tiny. The idea is let's take some material, and there's material that was developed by the Naval Ordinance Laboratory for sonar in the '60s called [inaudible 00:14:29]. That material has a giant or super response to a magnetic field. You coat the back of your substrate with this, you apply a magnetic field, and you will generate a strain, which then generates the stress and changes the shape of your mirror. We hope for the better, not the worse. We'll come into one other little detail related to that in a minute, but this is enough for now.

Let's take this basic physics to the extreme and imagine we've made this all work. This is a demo put together by University of Illinois, Urbana Champaign, but quite a few years ago now, already. Here we've deployed the mirror. This is our primary mirror. This is our secondary mirror. This bar here holds the traveling electromagnet. You can see one of the advantages of this technology is you don't have to have a wire to every darn place on the mirror that you need to apply correction to. You don't need the power on all the time. Those are good advantages. Here's a little demo. It's fun. Make sure you have your sound on. We'll listen to how this goes. Now we're deploying.

When these [inaudible 00:16:24] deploy, when the mirror membrane deploys, the whole issue is that we don't know how to get a high fidelity figure just by deployment. There are going to be errors in the figure. There's several science fiction things about this demo. One of them is that there's only one flaw in the mirror, that we know exactly where that flaw is. Then we know exactly what current to run through the electromagnet to affect the desired change and the shape. But here it works just great. You might be asking a question, which is, "What happens when I turn off the electromagnet?" I told you that this was used for sonar. Sonar is a speaker that's generating sound waves. If you don't have something to hold that magnetic field in after you off the electromagnet, you are in trouble. I'll show you, we have another approach as well.

But what we've found is this actually works. Here's a configuration. We've got our reflective coding of choice. We use a polyimide that's fairly stable so it doesn't creep after you apply a stress to it, CP one, and we're using this [inaudible 00:18:20] and this MSM stands for Magnetic Smart Material. Here we've got our magnetic storage layer, which we're using right now of nickel cobalt. That actually works. These are all details about the electromagnet we used, but those details aren't that important. Let's just move on.

Here's the other substrate we've generated so far just in the last month or so for testing. We're in the process of making a different one. But the key here is that we're using instead of a polyimide or what we might call high price saran wrap, we're using Ni-Ti or nitinol. This is a shape memory alloy. What's so cool about this, and I'll show you a little video of it being rolled up and being deployed, is instead of when you deploy it, instead of being off by 100 microns or so, it's only off by one micron. Now we have a much easier task in terms of push, pull. It turns out we've got some other problems, which is why we've got this [inaudible 00:19:43] nickel coating on the top, which Ni-Ti, by itself looks as matte as the laptop on my Mac laptop here, which is not very good if you're trying to make a mirror to image the sky.

This is what our setup looks like. The main thing you want to get out of this is this little blue gizmo here, where my arrow is going, is what's called a wavefront sensor. The wavefront sensor shines a laser beam onto the test substrate we're working on. Then the light gets reflected back up through some magic system. Then that image that bounces off the test substrate is compared to a reference image. We take a shot of the surface, store that as a reference, turn on the electromagnet, turn it off, and then look for the difference. For the CP one, I've got a nice clean image. For the N-Ti or nitinol, I don't have such a nice clean image because we're still working on it. But I'll give you the bottom line of both of those in a minute. We're almost done, which is good, I think.

What we see here is rotating the magnetic field in two different directions, as you can see by the red arrows down here at the bottom of each plot. You can see here from the bottom to the top of this right hand one, where [inaudible 00:21:31] achieved a 10 micron deflection. We only used 150 magnetic field that we could get or use before things get saturated. We only used about 1/5 of the thickness. It turns out the strain actually doesn't go linearly with the thickness of the film. All in all, I feel confident we can get somewhere between 100 and 200 microns stroke with this technology. This is held in for two days. I was amazed somebody, a former collaborator who now has left the country, left the field completely, he patented the idea. I wasn't sure it would work. You turned off the electromagnet, and you think everything was going to go boom. But it didn't. It stayed. This is really cool. Now let's look at the shape memory alloy deploy.

This is a piece. You can see it's been heated up to about 50 C, not a crazy temperature. There you go, it's gone pretty flat. We could roll this up like a cigar, then deploy it like this, and come back to a micron. This is our first try at doing this. All these holes give you an idea that no, there aren't holes in the piece. It wasn't eaten by a moth, but it's because the reflectivity is not great. This is not a really high quality surface, but it was just barely good enough. If you go from bottom to top here, or even from here to here, we're getting more than a micro. This has held for a couple of days, at least. Again, the bottom line is either way works in principle.

What we need to do is go to the next step of finding a generous sponsor to demonstrate that we can make a mirror better. Then eventually go to maybe a small launch first, a so-called CubeSat, and then work our way up to these 16 to 30 meter diameters. You heard about that here. End up with a slide from our famous architect in Chicago, [inaudible 00:24:12]. They have no magic. All right. But remember, when you stir people's enthusiasm, they're going to ask you how much. That's the bottom line or takeaway, if you cost too much, nobody's going to buy. That's our challenge. Thank you very much. I'll stop there.

Speaker 2 (24:40):

Thank you so much, Dr. Melville Ulmer. if anyone has questions, you should be able to unmute yourself now. You may also submit questions in the chat. One of our hosts for this talk will read your question. Please complete the short poll that should pop up on your screen at this time.

Speaker 3 (24:58):

We already have a question in the chat. This is from a student. "This might be a bit off topic, but when the telescope is deployed in the vacuum of space, before it opens up, how is cold welding prevented between the folded parts?"

Prof. Melville P. Ulmer (25:18):

I hope it is, but seriously, nothing is put together that tightly that you would get vacuum welding or cold welding. I've worked on a mission where we had a moving part in space vacuum. It tilted off and on where it was pointed every two minutes for 10 years. Cold welding is... We break out into a sweat about lots of things, but cold welding is not very high on the list.

Speaker 3 (26:03):

Thank you. Then we have another question. "How do the substrates differ when using the different technologies, Piezo and magnetostriction? Can they use the same kind of substrates?"

Prof. Melville P. Ulmer (26:21):

Yes and no. I claim that the magnetostriction is more universal, if you will, because we can put it on membranes, and it's not going to print through. Whereas, the Piezo patches do print through. The Piezo patches have been used quite effectively for what they call the formidable mirrors for exo plan and imaging. Those mirrors are only about five centimeters in diameter, the requirements are quite a bit different, and those substrates tend to be stiffer and more robust, so you don't have the print through.

Speaker 3 (27:14):

Okay. Thank you.