Danielle Ho (00:14):

Hi, my name is Danielle Ho and I will be your host for today's space talk. Welcome to the IllinoisX Space Technology Talks presented by Illinois Space Grant Consortium, University of Illinois at Urbana-Champaign and Northern Illinois University. Today, we have Dr. Sonny White and Christopher A. Miller. I would like to now introduce our first speaker, Dr. Sonny White.

Dr. White received his Bachelor's of Science in Mechanical Engineering from University of South Alabama, his Master's in Mechanical Engineering from Wichita State University, and his PhD in Physics from Rice University. Dr. White has accumulated over 19 years of experience working in the aerospace industry with Boeing, Lockheed Martin, NASA, and now with the Limitless Space Institute. He currently serves as the Director of Advanced Research and Development at LSI. In this role, he leads all research and development work for LSI, establishes priorities and recommendations for investigators and expenditures. Dr. White obtains grants and other resources in support of R&D efforts, markets LSI to major benefactors to increase resources and related R&D efforts and conducts, arranges, and schedules events, ensures appropriately related well-known individuals are involved. Today, Dr. Sonny White will give an overview on the Limitless Space Institute and talk about advanced power and propulsion to enable interstellar flight.

Dr. Sonny White (02:01):

Thank you, Danielle. I appreciate the very kind introduction. I really like your headphones. It's very cool. Very neat to have those kinds of things to express yourself. I love it. Thanks everybody for joining today. I'm going to share my screen real quick. Can everybody see my screen before I continue on?

Danielle Ho (02:20):

Yes, we can.

Dr. Sonny White (02:22):

Great. I'm going to give you guys an overview of what we're doing here at Limitless Space Institute. As Heidi said, I previously spent some time working at NASA from 2000 and 2019, doing a lot of work on advanced power propulsion and trying to integrate that into human space flight. I had an opportunity very recently to help stand up this nonprofit, Limitless Space Institute. After a lot of thought and prayer, it really seemed like a very good step for me to take. I've been very excited to be involved with them since December of 2019, certainly made a lot of progress in the very short period of time. But just to give you a quick overview, there'll be a little bit of highlights of the technical things that we're doing. It should be a pretty interesting talk for you guys.

Our mission at Limitless Space Institute is to inspire and educate the next generation, to travel beyond our solar system, to support the research development of enabling technologies. Our pinnacle objective, our north star, if you will, is to work, to try and enable interstellar travel by the turn of the century. That is, by no means, an easy task, very, very challenging. When you talk about space exploration, I mean, we're currently talking about sending humans back to the surface of the moon, and we just had very recently, NASA landed a Rover on the surface of Mars, and we've gotten some great video and pictures back from that, a little helicopter that's flying on Mars. Sometimes, when we think of space exploration, those are the things that we think about. But if we want to do something like send humans to someplace in the outer solar system, let's just say we wanted to send human beings to Saturn and we wanted to get them there in 200 days, the amount of energy that's necessary to make something like that possible is extremely large compared to anything that I just talked about.

The energy that's required to send humans to Saturn in 200 days is an order of magnitude higher than the energy it takes to get a payload from the surface of the earth into lower earth orbit. It's significantly more challenging. Chemical propulsion will not close this type of emission. It's not practical. You can't do it. These types of objectives, they require significant improvements in power and propulsion, if you will, and just the little coffee cup saying that we've come up with here, is we have to develop the ability to go incredibly fast, because it's all about this time distance problem. How would we do that? I mean, how do we even begin to try and tackle some kind of a problem like that? This slide is our capability slide. It provides a synopsis of ways that we could potentially tackle this type of a challenge, starting with what we know on the left in the context of physics and engineering and working, to what we don't know on the right in terms of physics frontiers, and unknown engineering.

On the left, we could potentially, based on known physics and known engineering, we could implement something we call nuclear electric propulsion, NEP. That is where we have a fusion reactor that is coupled to some electric thrusters, if you will, like some haul thrusters or an iron engine. There's lots of other types, but you have this persistent power source providing electrical power to these electric thrusters. This type of a system has the right combination of power and propulsion, where we could, if we're in the megawatt level range of power, we could potentially send humans to every destination in the outer solar system. This has been discussed in the literature and it's well understood. We could also enable what I call interstellar precursors. You'll see a little thing there that says a thousand AU, that's astronomical units.

That's like the distance from the earth to the sun, if that's a meter stick, if you will, if you lay that to one after another a thousand times, that's a common interstellar precursor that we talk about, but that's not interstellar. Interstellar, getting to Alpha Centauri, that's 270,000 astronomical units. NEP really can't do that in a practical timeframe. Now, if we move a little bit into the unknown, into this middle swim lane, if you will, instead of fidgeting material, if we fusion material, like we burn a plasma, deuterium-Tritium plasma or something, we could change the power source from a nuclear reactor to a fusion reactor, where the fusion reactor would simply replace the fission reactor and provide power to the same types of thrusters. It would probably be overall higher power levels. Fusion has the potential to be larger power. Alternately, we could use something we call direct fusion. And I'm moving my mouse on the screen, and you guys can see that, correct?

Danielle Ho (07:15):

Yes, we can see it.

Dr. Sonny White (07:16):

Great. Direct fusion is where we would potentially have a reactor that's just open to space, if you will. And so the fusion process provides the power for the reaction and the thrust all at the same time. Now, switching to this approach, this is known physics. We understand this from a physics perspective, but we don't quite have the engineering worked out. But this type of approach would enable fast human exploration of the solar system. If you think about the TV show Expanse, this is I think the propulsion scheme that they use a lot in that particular TV show. By the same token, fusion is discussed in the literature as being one of the techniques that we've discussed for the paper studies to try and figure out how to send a probe to, whether it's Bernard's Star or Proxima Centauri. Those have typically been fusion propulsion systems to try and get there.

The only downside is it takes decades to the larger fraction of a century to be able to get to those locations. Now, we could potentially move into the frontiers of physics, if you will. Physics today, if you were to envision it as a Venn diagram, there's two circles on the Venn diagram. One circle on the

Venn diagram has the word quantum mechanics and that represents our understanding of the microscopic world, and that gives us that gives us cell phones. And then the other circle would have the words general relativity in it, and that helps us understand the macroscopic world. And we use global positioning satellites, if you will, to be able to use our phones, to navigate somewhere, to go see somebody at a new location, if you will.

And so just that level of understanding of physics touches our lives every day. But the Venn diagram, those two circles do not overlap, right? So the two circles do not overlap. So that tells us there is a more generalized understanding for us to try and decode. And in the process of trying to decode that math and physics, that invariably will provide us potentially new ways of doing things that we haven't considered before. Maybe that will eventually lead to giving us the ability to implement something like a space drive. Can we find some way to interact with the fabric of space time itself, to be able to tractably push and pull off of it so that we can generate a force on a spacecraft? Can we interact with the quantum vacuum in some way that we can impart momentum onto the vacuum field and move a spacecraft as a result of that? The idea of a space warp and a wormhole, these things are mathematically possible in the context of general activity, but we don't exactly know what to physically build to try and manifest something like that.

And so in the process of exploring the frontiers of physics, maybe we could figure that out. And then with these types of insights, maybe we could definitely do things that we couldn't do with just the known physics and engineering that we have today. And maybe we can enable fast interstellar, right? Being able to get to another star system in a handful of years as opposed to the larger fraction of a century.

Now this slide goes through and shows the things that we're doing at Limitless Space Institute, as we're trying to pursue this pinnacle objective. We are a doing organization. And so we are very active right now in research and development and engaging academia and students. We have research that we conduct internally through our lab we call Eagleworks.

We are currently funded by DARPA defense science office. We have a million dollar grant to pursue a frontiers of physics model that we're working with called the dynamic vacuum model. I'll talk a little bit more about that in a second. We also fund external work through our interstellar initiative grants, and I'll go through the grant winners that we funded as part of that grant program. We were partnered with Texas A and M and the Breakthrough Foundation in the process of implementing and administering those grants. We sponsor university partnerships where we directly fund universities to do work related to those three swim lanes, if you will. We're currently partnered with Texas A and M to work on a compact nuclear reactor, and I'll talk just a little bit more about that. We also have the student programs where we can have interns here in the lab, all these research and development programs that we have students involved in every single one.

And we are commissioning a class that we will be teaching this summer aimed at STEM students to help introduce and go through all the mathematics and engineering and physics that would be related to the principle of interstellar studies, if you will. So it'll be a week long class. So if you have any interest in that kind of a thing, I'll be checking back with our website. We'll be uploading some of the information very shortly for that. That's in partnership with the Initiative for Interstellar Studies. They'll be teaching that. They're developing that class for us, and they'll be teaching that week long class. This goes through and shows the partnerships that we already have. And these are formal partnerships that we already have in place. We're partnered with 17 universities and a number of companies in just our short period of time.

We intend to grow this list as we move forward. There's a lot of interest to work in this domain. And so we're continuing to dialogue with people. There's a lot of opportunity. So we're definitely very excited about that. And I'll just spend a few seconds talking about the research that we're conducting and funding in a little bit more detail, and then I'll be finished and I can take some questions. The work that we're doing for DARPA is this frontiers of physics work, that third swim lane, if you will. We're trying to figure out in terms of the Venn diagram, maybe there's a more generalized understanding that we can develop, that we can then think of some ways to making technology that might be useful for the pinnacle objective. And so right now, we're trying to develop some customized Casimir cavities.

You see from this little picture, this is a scanning electron microscope image of some of our three dimensional structures that we've been able to make to date so far. We're definitely on the leading edge of nano manufacturing, because we're fabricating three dimensional structures. So this is very, very challenging, but we're making good progress. And there's some potential implications from this. Even though it's basic research exploring the scientific side of things, it does have some technological implications for power, maybe the ability to increase something we call a negative vacuum energy density. This is the thing that's necessary to make the idea of a space warp work. There may be some communications and some sensors implications. We'll be exploring that. And there may actually be the ability to import thrust on a spacecraft. Very small, but to non-zero thrust on a spacecraft.

And so we'll be exploring all of that as we continue to move forward. We've got these customized typologies that we're looking at. Now, we use some pretty hairy analysis to do this kind of research. We have to try and study how the quantum vacuum response, these custom Casimir cavities, it requires a lot of computational capability. We routinely have to make runs with about a thousand or more CPUs in the runs that we do with our customized code. And you see a nice little picture here of how we predict the quantum vacuum responds to this plate pillar structure. If you just look at that central pillar where I'm moving my mouse right now, these white lines represent the walls. And this is a top down view. And this is showing how the quantum vacuum responds to that particular system.

We were trying to make sure that the pillar, the vacuum field in the pillar was representative of the stuff that's in the far field. And so this was very useful for us to see that we should be able to observe some of the structure that we think exists in these cavities. Now, the interesting thing about doing leading edge research like this is you don't always know where it's going to lead, and sometimes you just find things that you had no intention of looking for, but it was just something that fell into your lap in the process of doing the work. And so looking at that plot that I just showed you, that plate pillar, the previous plot was a log plot. This is a linear plot. You see these yellow regions represent this negative vacuum energy density that's predicted to exist in the quantum vacuum for this plate pillar, plate system.

And this two dimensional plot looks very similar to this two dimensional plot of the energy density requirements for something called the Alcubierre warp metric. So in terms of a space warp, in general relativity, this is a model that's been published in the peer reviewed literature and discussed at length where in order to get the space time to expand and contract in a way that's useful for this idea of a space warp, you have to have this ring, if you see my little cartoon this [inaudible 00:16:13] ring that's filled with exotic matter or negative vacuum energy density, and it'll cause space time to respond in such a way that you could make this trick manifest itself.

Now, this qualitative similarity was interesting to us, but the difference is this plot is pillar-like. It's prismatic. The pillars are long like a tree or something like that. And so these lenticular shapes are just long prismatic shapes. So it's not a one to one, because three dimensionally, this is not a [inaudible 00:16:43], whereas this is a [inaudible 00:16:45]. So we modified our model. We looked at a scenario where we have a four micrometer cylinder with a one micrometer sphere in the center. And then we looked at how the quantum vacuum is predicted to respond to this system. And it's very nearly a one to one match with the Alcubierre warp metric. And so what this told us is that we can propose to the scientific community that there is a structure that one could build that is predicted to perturb the quantum vacuum in such a way that it will manifest a real nanoscale warp bubble.

Now, before anybody gets excited, let me be clear. This is not going to go anywhere. It's not going to do anything, but just as a matter of precedence, it may be a very significant finding. So we've got a paper and peer review right now, and we'll try and work that, but there may be some ways to do some experimentation to study some of the optical implications of these little nanoscale warp bubbles. They would be in a sense like a broadband metamaterial. So they may have some very useful optical properties that we could potentially use long before they could ever be something that we would use in some kind of a space application. But the thing I want you to take from this chart is that sometimes when you're doing fundamental research, things just come up that you weren't looking for to begin with. So there's value in working on the frontier, if you will.

And I'll talk just very little bit about the ice grid grants. This is a program we stood up to fund research externally to the Institute. We anticipate this as being a program will conduct every two years. There'll be two different award categories for a 12 month period of performance. One category, we call a tactical grant. That's envisioned to be a paper study, if you will, maybe some experimentation if the program has other funding. And we have a strategic grant category that's meant to allow for empirical aspect to the grant. And so in terms of the proposals that we funded, we got proposals from all over the world. We picked nine proposals for funding, covering things like beamed energy propulsion, relativistic solar sails. We funded four fusion propulsion concepts, two space drives, and a team that's working on worm holes. So I'll just step through those real quickly.

We funded a team at UC Santa Barbara to work on beamed energy propulsion, and they want to work on developing where they have three beaming stations that are beaming to a remote collector at some large distance, external to the lab. They've done a lot of work in the lab to date. And so they want to look at doing something external, where they have much larger distances. We've also put them in contact with one of our contacts at Intuitive Machines to look at an experiment where maybe they could put a phasing beacon on Nova C and they could have a 10 meter sparse array of these beaming stations on the surface of the earth that could lock with the spacecraft on the surface of the moon.

While they would not be able to beam power to it, there's not enough elements at 10 meters, but they could potentially heat the regolith and an infrared camera would see this polka dotted defraction pattern of heating on the [inaudible 00:19:59]. So that might be a neat experiment to conduct.

We funded professor Richard Norte at Delta University of Technology to work on relativistic solar sails. They're the world's expert at making photonic crystals, large photonic crystals. This is almost five centimeters by five centimeters with very, very small features. So it's a lot of good work they've been doing, and we're paying them to try and expand this approach to incorporate characteristics and make this solar sail compatible with being able to have beamed power sent to it as it continues to accelerate to a speed such that relativistic shifts become important. And so you need to make sure your sail is very reflective throughout the entire velocity range that it's anticipated to be going whenever you're trying to do some kind of an interstellar mission like breakthrough star shot.

We've funded Professor Ray Sedwick at University of Maryland to work on a centrifugal confinement, direct drive fusion concept. This uses some E cross B shear flow stabilization. And so we're paying for the development, taking the model to the next level of maturity to continue to explore the viability of this approach. It'll be interesting to see what happens with this particular technique. We're funding Professor Jason Cassibry at the University of Alabama Huntsville for a pulse breakeven infusion concept. They've got some experimental equipment that they have in their laboratory, and they have, if you look at this little puddle plot over here on the left, this yellow region is where the physics coefficient and performance for the system would be greater than one. And then this blue region, of course, is less than one. And they have the ability to explore everything below where my mouse is. They have the ability to detonate targets up to that region. And so they want to figure out where are they in this blue section and what type of scaling do they need to be able to get into the yellow section?

We funded Kelvin Long from the Interstellar Research Center to develop some high fidelity code, to model some inertia confinement fusion processes with fuel capsules. And so he'll be using that to also look at some of the historical missions that have been documented in the literature to confirm their performance predictions. And then LSI can use that to also look at future missions. So it'll be some in-house code that we can make use of to continue to explore interstellar missions using fusion.

We funded Helicity Space, it's partnership with the Cal Tech and the University of Maryland into Baltimore County. They have a new fusion propulsion concept where they're using this thing they call a plectoneme. If you see from the little picture on the top left, a plectoneme is a plasma rope type of configuration, like a twisted donut, if you will. And this is a very stable condition. And so they have this scenario where they have several different plectoneme guns combining the plasma, and this combining process heats the plasma as the magnetic fields reconnect, that causes a lot of heating in the plasma here. And then the part that we are funding is this external portion of the peristaltic magnetic nozzles. So it charges those coils in sequence. And so they squish the plasma pulse and compress it to a point where it initiates fusion. And so we're covering the model development and hardware development of this peristaltic magnetic nozzle portion of the concept.

We're funding a Professor John Bush at MIT. He's doing some work on a frontiers of physics type of model, not unlike the dynamic vacuum model that we're working on. He's trying to expand some of his work on a model he calls his hydrodynamic quantum field theory model from two dimensional space into three dimensional space. And in the process of developing those models, can he find ways to generate a force by interacting with this medium, if you will, that's responsible for some of the stochasticity that we see when we consider quantum mechanics?

We're also funding Charles Chase at UnLAB and Professor Yuval Dagon at Technion Israel Institute of Technology. They're working on trying to explore some implications of a asymmetric potential in a resonant tunneling diode. If you look at how the quantum vacuum responds to the presence of this asymmetric potential, it predicts a non-zero asymmetric force. And so they're trying to figure out, can they come up with a manufacturable RTD where they can generate a force that one can actually observe in the lab. And this might be something that we can consider for some type of form of in-space propulsion.

And then finally, we funded Professor Remo Garattini at University of Bergamo to do some development on wormholes. He's very well published in literature in this domain. He's trying to explore are there's some alternative Casimir configurations that he can implement along with superconducting to increase the magnitude of negative vacuum energy density that he can manifest. And then he is also wants to look at some different mathematical profiles to try and find maybe more benign traversable worm holes.

And then finally, our university partnership with Texas A and M on a micro nuclear reactor. This is potentially a nuclear reactor that would fit in a 40 foot Conex container. The power level would be in the one to 10 megawatt electric range. So very, very small compared to typical terrestrial nuclear reactors. We want the weight of this thing to be a little bit lighter than what people might typically consider for terrestrial reactors, something that would be forward compatible for space use.

But this effort is being very purposeful about trying to align with the DOD Pele program. So the Department of Defense is also looking at micro nuclear reactors to be able to be used to charge electric vehicles in different locations around the world. And so we want to try and see, in the process of trying to meet those objectives for terrestrial applications, can you come up with a design that is reasonably forward adaptable for use in space? So can we find some ways so that terrestrial needs can help pay for the design and development and testing of a concept so that we don't have to bear all that burden when we look at to trying to apply it for some type of application in space? And so we'll be doing that over the next 12 months with Texas A and M nuclear engineering department.

So with that, that's everything I have. I think at this point, I can stop talking and just take questions. So thank you guys.

Danielle Ho (26:59):

Thank you so much, Dr. Sonny White. If anyone has any questions you should be able to unmute yourself now.

Heidi Bjerke (27:06):

We did have a comment in the chat that Jason, and I'm probably going to mispronounce his last name. Cassibry that you had mentioned. He was a UIUC aerospace engineering alumni.

Dr. Sonny White (27:19):

Oh, wow. Cool.

Heidi Bjerke (27:21):

So he has connections here with us.

Dr. Sonny White (27:24):

Awesome. Very good. Yeah, he's a great guy, good investigator, has a lot of good ideas, certainly very passionate about trying to push back the darkness, if you will. So it's been really a pleasure to get to know him a little better through watching the work that he's doing and being able to sponsor him directly too. That's really great. We had a tri-agency fusion workshop a week ago, and out of all the teams that were talking about to compact fusion, three of them were from our ice [inaudible 00:28:02] grants team. It was really neat to see that in the process of NASA, Department of Defense and Department of Energy pulling together this workshop, as they were surveying the different people, three of the people that they pulled to come in and give talks were three of our grant winners. So I was very sure to point that out when I finished up the day and gave my talk.

Heidi Bjerke (28:23):

Yeah, definitely. Would you mind telling students a little bit more about the summer course that you're going to offer? I know you mentioned it's a week long.

Dr. Sonny White (28:32):

Yes. It'll be a week long class with a very thematically focused on interstellar studies, if you will. It'll actually cover all the different types of systems that would be integral with some type of a mission to the outer solar system or one day on to the stars. And so there'll be a lot of technical grit, a lot of great, interesting things that'll push you and challenge you and also be very interesting and entertaining, if you will, if this is an area that you're interested in. So I think the class is going to have 30 slots. So just be looking for that, when that comes out. And if you're interested in that, go ahead and register. The cost that we're going to charge for the class is $200. We're just trying to basically cover the cost of paying the [inaudible 00:29:27] for administering the class for us.

Heidi Bjerke (29:30):

Okay. Yeah. When I see that pop up, I'll make sure to send that out to anybody that's interested if they let me know they're interested. But I'll also post it on our website and things too. I don't know if anybody else has any other questions. They can unmute if they like.

Courtney Bradley (29:46):

Hi, my name is Courtney Bradley. I'm a student at NIU. I just had a question about the nuclear reactors, the [inaudible 00:29:53] you were talking about. I just wanted little clarity. Did you say that they were added as payload, or are they going to be just brought into space to stay, to be used for spacecraft missions, maybe intermediate, not Mars, but I guess they're trying to do a lot of infrastructure there. So would it be there? Would they would just be an added load to stay with the spacecraft that it's being used on?

Dr. Sonny White (30:24):

Yeah. Thank you, Courtney, for your question. The compact nuclear reactor in terms of how we would envision using it in space, you can use nuclear power as a persistent power source for the surface of the moon. That's already being discussed at the agency. They have a solicitation, I think, that they'll be coming out in a couple months. You know, the lunar night is really long. It's 15 days, and that's a long time to not have any sun and the batteries that you would have to have would be very, very large. You need some type of way to provide power. And so nuclear power is how you get persistent power when you don't have a lot of sunlight.

The Rover that's on Mars has a radio isotope thermal generator, so it's using plutonium to provide electricity to the Rover, to allow it to continue to operate. Sunlight, when you get out tomorrows, sunlight's getting diffused. It's maybe about getting to be one quarter of the power density, power flux, if you will, for solar panel, when you're at it to one and a half AU, as opposed to one AU.

I would also envision that we would use nuclear reactors as a way to provide power to thrusters. When you talk about some of the things that I mentioned about going to Saturn, or to Pluto or interstellar precursors with human beings, you can't use chemical propulsion. You have to use electric propulsion. So instead of using liquid oxygen and liquid hydrogen, and combining those and using the specific heat of combustion that causes the exhaust propellant to have a lot of energy, and it hits the sides of the rocket nozzle, and then goes out the back of the rocket and generates thrust, that provides a lot of thrust, but it's not very fuel efficient.

So if you think about a car, the miles per gallon for that are low, whereas an electric propulsion, you can ionize a gas like Xenon, for example, is a very common gas that's used in electric thrusters. So you use electric and magnetic fields to ionize and then accelerate the propellant so that it has much, much higher velocity when it comes out of the back of the rocket. And so that makes it much more fuel efficient. The miles per gallon for that are much better, if you will.

That really helps with making the propellant tanks much smaller. And so that's why electric thrusters are very appealing as a form of in space propulsion, but they have to have a power source. And so that's where nuclear becomes so important, not only for the fact that it provides power, but it's persistent power no matter where you're at in the solar system. So if you go out to Saturn at five astronomical units, the amount of sunlight you would get out there is just entirely impossible to be able to power anything. So you'd have to have something that wouldn't care about how far it is from the sun. So a nuclear reactor, or a fusion reactor, those are the types of things that we'd have to have to send humans out that far.

Courtney Bradley (33:31):

Okay. Thank you.

Mona Fang (33:33):

Well, I have a question. So I am also an undergraduate student studying aerospace engineering. I'm really fascinated by this field, but what intimidates me is that I know I don't want to get into the research space. Is there any ways to get involved within this kind of work, maybe either through startups or more business senses. What are your thoughts on entering into this?

Dr. Sonny White (33:55):

Yeah. Great question, Mona. In terms of ways to get involved where maybe you don't want to get right on the leading edge on being like a principal investigator on a research proposal or something, there are a lot of companies that make electric thrusters, haul thrusters. [inaudible 00:34:16] makes haul thrusters. [inaudible 00:34:19] makes haul thrusters. There are a couple of startups that make very small forms of electric propulsion that they're looking to use in cube sets, to allow cube sets to have very fuel efficient capabilities. And they can be used for lots of interesting missions. So there are companies out there that you could potentially try and look towards joining and helping them develop these technologies in a much nearer term way, if you will. SpaceX, all those satellites that they put on orbit for their communications network, if you will, those all have haul thrusters on them and they design those haul thrusters in house.

There's probably a number of other companies that are also thinking about that. So there should be a lot of opportunities for you to work in this domain without having to get onto just the purely R and D side of things. And by the same token, power. Commonwealth Fusion is a commercial company up in Boston, a spinoff company from MIT that's looking at doing terrestrial fusion, but those things also have some space applications that may come up in the near term at some point. So I think there's a lot of opportunities for you.

Mona Fang (35:36):

Thank you.

Dr. Sonny White (35:36):

Sure.