Season 3, Episode 3

Tammy Ma: Fusion Ignition and Beyond

SPEAKERS
Jennifer Granholm, Sarah Webb, Tammy Ma

Jennifer Granholm 00:00
Last week at the Lawrence Livermore National Laboratory in California, scientists at the National Ignition Facility achieved fusion ignition. And that is creating more energy from fusion reactions than the energy used to start the process. It's the first time it has ever been done in a laboratory anywhere in the world. Simply put, this is one of the most impressive scientific feats of the 21st century.

Sarah Webb 00:37
That was United States Secretary of Energy Jennifer Granholm speaking at a press conference on December 5, describing a long-awaited milestone in fusion energy research. I'm your host, Sarah Webb. And in this episode of Science in Parallel, we'll be talking about what's next and how supercomputing supports fusion energy research. You'll hear from Tammy Ma, a plasma physicist at the National Ignition Facility known as NIF. She was an important figure among the fusion ignition research team and also leads Livermore's Inertial Fusion Energy Initiative, pursuing the difficult questions that could help this science move from lab experiments to power plants.

Sarah Webb 01:25
Tammy's scientific expertise is doing experiments rather than simulations. But in her current role, she considers all parts of the fusion puzzle. She's at the forefront of one of science and society's grand challenges. Can we produce clean, sustainable fusion energy on the scale needed to power our planet? I asked Tammy to talk about computing's role in understanding and optimizing fusion reactions, and how computing's crossroads could shape fusion energy's future.

Sarah Webb 02:00
Tammy, it's great to have you on the podcast.

Tammy Ma 02:03
Thank you so much, Sarah. It is a pleasure to be here.

Sarah Webb 02:05

Give me a little context for your interest in fusion research. How did you get interested in this work? Why did you get interested in fusion?

Tammy Ma 02:14
Fusion is one of the great grand challenges of science and technology. It is this incredibly difficult problem that scientists have been thinking about and dreaming about for decades. And the potential benefits if we can get it to work. If we can harness fusion energy, it could be a clean, limitless energy source for mankind. So that enormous challenge is what makes it so exciting. And what partially brought me into the field. The other thing was I love working on big science projects with big teams, big facilities, things that, in some cases, only national labs can really harbor and make happen. And so here, I was really lucky to get to combine the two.

Sarah Webb 02:57
So let's talk about the ignition finding in December. As you were saying, it took decades to get here. What were the key innovations that got us from near ignition in 2021?

Tammy Ma 03:09
This is something that we've been working for decades on. And soon after the laser was invented, and one of our early lab directors came up with the idea like, Hey, you could use a laser to drive a fusion reaction. Imagine 60 years ago coming up with that idea. And then we had to go through and build successively bigger and bigger lasers to make this happen. And so in 2021, we had a pretty big breakthrough already, where we were able to get burning plasma, meaning enough fusion reactions going that it could feed back on itself and really start propagating burn and making more fusions happen. But we had yet to get more energy out than we put in with the lasers, what we call ignition.

Tammy Ma 03:47
And so in the intervening year, we were able to turn up the laser energy about 8% more, and we're always trying to improve the laser anyway, put in improvements: make it more precise, more energetic. We improved the target. So the little fuel capsule that holds the deuterium-tritium fuel has to be nearly perfect with very little nicks, bumps, divots on that surface of the capsule. So that was an improvement there. And then a few design changes by turning up the laser energy, we can make the wall of that capsule, the thickness of the capsule a little bit thicker, that makes it a little more stable as you're driving it in. And so if you combine all of those things together, that's what got us to ignition in 2022.

Sarah Webb 04:28
So talk to me a little bit about the role of computing in those advances. How do computers work into all of this refinement?

Tammy Ma 04:37
So in any one of our experiments, there's over 10,000 different physics parameters that can be changed on every shot. You can change the laser energy you put in, the laser pulse shape, meaning the power output as a function of time. The target: You can change the thickness of the capsule wall, the materials, exactly where the lasers point. And so like how do you know from experiment to experiment, what to change? 10,000 parameters is too much for the human mind to figure it out on its

own. So computing plays an enormous role; we have to use our high fidelity simulation tools to try to do our best to model the entire reaction. And some of these 3D simulations where we model everything we can every bump every divot on that capsule, exactly how the laser is delivered. We put that into the simulation codes, and then grind and go to see what the final result is and see if we can match what came out of the experiment.

Tammy Ma 05:30
And, of course, the computers never exactly get it right. The simulations are only as good as the data we feed it. And so we take the data from the last experiment, put it back in, and then try to improve the code and then run it again on the next experiment. So these two things, the experiments we do in the computers and the simulations are really a step-by-step process helping each other get better. Our team of computer modelers and simulators is as big as the experimental side of the house, because that's how important it is. With fusion in general, it could potentially be a clean, very abundant, almost limitless energy source, because in that fusion reaction, there's no carbon that you're generating. The fuel that we would use, deuterium and tritium: Deuterium is naturally occurring in seawater; tritium, we know how to breed. It's environmentally sustainable. If you can get a lot more energy out of the reaction than you put in, you can use that energy to keep running your power plant and feed it out to the grid.

Tammy Ma 06:30
And so fusion could be the holy grail— if we can make it work. Because it's so abundant, it not only helps us with climate security, it also helps us with energy security. The U.S. wouldn't be reliant on external energy sources; we wouldn't be fighting wars over energy. It could be deployed around the world to bring up standards of living everywhere. So that is the potential of fusion energy. Now, inertial fusion specifically means in this case, we're using lasers to actually compress and hold that fusion field together long enough to get it to actually fuse. You're relying on the inertia of the target itself. And it's difficult because anywhere in the world we've done it just once so far. Now we're working on trying to replicate that.

Tammy Ma 07:13
So we're obviously still very much in the early R&D stages trying to understand and figure out the reaction beyond that to turn this into a power plant. There is so much more R&D that we have to do. It's envisioned you would have to repeat the reaction 10 times a second. Right now on the NIF we do a shot every four to eight hours. You need materials, blankets and walls for your reactor that can handle those huge fluxes of energy and particles. You need tritium handling; you need recycling; you need thermal conversion out to turn your energy into heat. So all of these different subsystems that pulling in resources from across the U.S. from across the DOE complex, and all that expertise to make it happen, it's going to be something that takes a little while to because we have to develop all of these technologies. But when I talk about having to shoot at like 10 Hertz, repeating the reaction 10 times a second, this is where the computers come in again. And as we watch the technologies evolve, how do we bring all of these new emerging technologies to bear to feed into this problem and actually make it doable?

Sarah Webb 08:18

Another big fusion technology out there is magnetic confinement fusion. And I guess I wanted to sort of get your perspective on inertial fusion versus magnetic confinement fusion, and how those two technologies might come together toward this future fusion energy problem.

Tammy Ma 09:23
So magnetic fusion has also been researched for several decades. Now, the idea is you would use these huge, very strong magnets to hold your plasma together long enough that it can also fuse and get you more energy production than you put in to actually run it. Both concepts have a very different technology development paths, different risks that you would have to try to overcome and solved. But, that being said, they both have a lot of potential. And because we are working with fusion plasmas, in both cases, you can imagine there's a lot of overlap as well. In magnetic fusion, one of the big challenges that you have is as you're using this magnet to hold your plasma, you're trying to keep the plasma from touching the wall, right. So this plasma is zooming around super energetic. If some of it touches the wall, it crunches and you have what we call it disruption and then all of the sudden, it'll break basically, and the reaction will stop. We can use machine learning and AI to try to figure out what the conditions need to be in real time.

Tammy Ma 09:43
Plasmas never behave. That's the story of life-- plasmas do not behave right. So all you can try to do is like work with them and do your best to control them. But if you can understand that what the plasma is doing in real time, you can change your magnetic fields strength; you can change the temperatures. You can change things within your magnetic reactor to control things and keep it from disrupting. And it's a really hard problem because again, there's all these different parameters simultaneously interacting with each other that you need to control. So that's where the AI and machine learning comes in.

Tammy Ma 10:16
And then similarly, on the inertial side, we have similar issues where we want to control the plasma in real time. And so you can imagine, like, you've got these little target pellets that you're dropping into your reactor and shooting at 10 times a second, and not every pellet is going to be perfect just from typical fabrication. So if you know what your pellet looks like, before you shoot it, you can adjust the laser in real time so that you can optimize the reaction. So in both cases, we're talking about using machine learning and AI for feedback loops, so that you can do the best experiment that you can in real time, we definitely try to work together from magnetic and inertial fusion, to trade ideas, to trade techniques, trade applications, and see how we can all help each other.

Sarah Webb 11:02
Computing itself is also growing and changing; the systems are bigger. There's more and more emphasis on AI and machine learning and new technologies and a lot of questions about where the computational science space is going. Where do you see those transitional edges in computing intersecting with fusion energy’s future? What are the kinds of tools that you're envisioning needing, from the computing folks that are emerging that might help you do the work that you're planning to do?

Tammy Ma 11:34

One of the things that DOE has been just phenomenal in pushing really is something we call predictive capability. That is not just oh, something happens in the universe, you observe it, and then you run a code to try to understand it afterwards. And if you're running a simulation code, you can always turn knobs to get it to match something. Where you validate whether you really understand what's going on is if you can predict it before it happens. And again, that can only come through really good computational tools. But you have to have experiments alongside it. One thing that's important for fusion going forward is to continue to improve their predictive capability, you want to make better simulation codes, so not only improve the physics that is in your simulations, but how the physics talks to each other across multifidelities and multiphysics.

Tammy Ma 12:28
So what I mean by that is, if you're trying to run a physics simulation of a reaction, you might start at the very atomic scale, we're talking about plasmas, so the ions are separate from electrons, everything's moving separately in an atomic code. You're going to try to model the atoms at that very scale, however, your plasma is all moving together. So then you need a hydrodynamics code to actually model how this plasma moves as a wave or moves together with its collective effects. And then you want to step it up to the next piece of things, which is okay, so maybe I can understand what the fusion plasma is doing. But in my simulation I also have to model the lasers coming in, right? And so it's a whole different component. And then how do we combine together all of those different physics codes, which are each one alone amazing, so that you get a full picture.

Tammy Ma 13:17
And so the next frontier-- Well, okay, I'm not a computational scientist. So, you know, what's important for us on the fusion side of things is really combining codes across different scales and then also combining experiments at these different scales. And so bringing in knowledge and data from maybe experiments we do on very small lasers looking at the atomic physics, but all the way up to these integrated experiments using the biggest lasers in the world like NIF. Right? So combining the data across all different scales, the computational aspects across all different scales, and then across the complex as well, right? There's many different DOE labs and universities and private industry even that does research in this area. So how do we combine all of the knowledge that we have and leverage it all to build up a big full picture. And that's another thing that DOE is amazing at. This interconnectedness, this network that we have to draw across to bring it all together, and that that can only happen now because supercomputers are getting so much better that they can handle all this information. And so that's one of the big frontiers for us going forward.

Sarah Webb 14:28
I want to zoom out a little bit philosophically from a science perspective. All of this fusion research is super-exciting, but I'm curious, what are the key questions that get you out of bed in the morning?

Tammy Ma 14:41
Well, I think what gets me up in the morning gets me really excited is the fact that we're doing something that hasn't been done before. And we really get to chart that path, not just the scientific questions to be asked, but how do you bring together a program and how do you work with DOE and government as well and players across the U.S. to help realize how important fusion energy is, and

bring together the people to really build a new program for the U.S. I guess what I'm trying to get to is, is science is not just sitting in front of the computer necessarily analyzing data. There's also a huge policy aspect to it as well, where scientists we have a responsibility to help move society and help move our country in the direction that we think is best based on scientific knowledge.

Tammy Ma 15:39
For me, fusion energy is so important for our future-- for clean energy, for climate, for energy security-- that it is something that we need to invest in, put in the real effort, the R&D, that will take a long time. But move that forward, because it could be such an important potential solution. And we have to work it on, not just the scientific front and continue to make advances there to demonstrate to the world the potential, but for science to actually be done requires a huge amount of support, a huge amount of buy-in from your legislators, from DOE and the national lab system. And so what excites me is this aspect of bringing it all together and learning new things. Every day, I get to learn something new, and I get to grow.

Sarah Webb 16:28
Along those lines, what piece of advice would you pass along to early career researchers at this point?

Tammy Ma 16:36
I think my advice is a bit generic, but it's really just: Stick with it because science by definition is hard. You're trying to do things that have not actually been done before. And so inherent in that is a lot of risk. There's a lot of unknown; there's gonna be a lot of failure. And that's okay, everybody goes through that. But hopefully you have a team to do it with. And so just stick with it. And just know that you're not alone.

Sarah Webb 17:05
Is there anything that we haven't talked about that you think is important to mention about fusion, about computing, about this time that we're in?

Tammy Ma 17:14
When people ask me like, why is it so important now? Like, what is the difference? What is this moment in time? And a lot of it comes down to all of these new technologies and advances that we've had in different areas that we can bring to bear in fusion, and computing is absolutely one of the most important parts. It helps us to understand our fusion plasmas better than ever before. It sets us on a path to increased understanding, faster development. And the other really exciting thing though, is when you combine fusion and computation, it's not just fusion energy. It's also there's all these other spinouts. And it helps with the national security mission for the U.S. as well, because the same simulation codes that we are testing on our fusion plasmas are the ones that underline the safety, security reliability of our nuclear stockpile. They're the same high-performance computing techniques that we apply to some very difficult problems around the complex. When I give NIF tours, I always pause and point out to everybody coming through that there's a supercomputer that you can see out the window and NIF would not exist without that supercomputer. And so it's essential.

Sarah Webb 18:29

To learn more about Tammy Ma, inertial confinement fusion and the path to fusion power, please check out our show notes at scienceinparallel.org.

Sarah Webb 18:41
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