Astronomy Cast Episode 168
Enrico Fermi

Fraser: I think we've got one interesting announcement for the new year, which is that we now have another organization that we fall underneath, right?
Pamela: Right, so for the past year and a half, since right before the International Year of Astronomy started, we kinda realized that there's a lot of us doing new media projects that well, it would be good if we all had one home, one umbrella that we could fit under, so you and I, along with Phil Plait and the U.S. Single Point of Contact for the International Year of Astronomy, Doug Isbell, and one of our local faculty members, Tom Foster, and with help from Chris Lintott who does Galaxy Zoo, we established a new non-profit called Astrosphere New Media which anyone can learn about at astrosphere.org and this is a new way to get your donations to making new media happen tax-deductable, and your donations will help this show and there's also links to 365 Days of Astronomy, to the IYA Second Life island, and to a number of other projects that we're involved with.
Fraser: Yeah, I mean I think we're still recovering from the dizzying amount of bureaucracy and paperwork that was required to actually make this happen, and now we can move on to the actual fun part where we come up with projects and get involved. I mean I think we're both really committed to helping people learn about astronomy, giving people who've never had a chance to look through a telescope... helping them learn more and just kind of taking the word out and showing people why we think astronomy is great and so we've got Astronomy Cast, we've got Astronomy 365, we've got other projects that we're going to be working on, and this is sort of a way to kind of keep it all held together, and a way that people can donate and get involved, so stay tuned!
Pamela: And this is just one more way that we're going to keep the International Year of Astronomy's legacy maintained into the future and I cannot explain how good it is to have that experience behind me.
Fraser: Yeah, that's great, what a year.... I can't believe it. And so today's episode of Astronomy Cast is about another famous astronomer--Enrico Fermi. We've already taken a look at one of Fermi's most famous ideas: the Fermi Paradox, or "Where are all the aliens?" Let's meet the man behind the ideas, the namesake for the new Fermi mission, and we're going to do this a little differently, or, I think you might like this, this is Pamela's big idea... we're going to do the person... the man... and then for the next episode we're actually going do the mission. So, we got the new Fermi mission, we're going to do that, and then we've got some others... Kepler, Herschel, they also have missions named after them as well, so... if only we'd thought about that for Hubble, but ok, so Fermi... who is this guy?
Pamela: Well, he was an Italian, he was born in 1901 in Italy which is where most Italians tend to come from, he was one of these amazing genius people, he just did things at a young age that kind of boggled the mind. So, his essay when he applied for college, he sat down to solve the wave equations for waves on a string, and he did this using partial differential equations and Fourier analysis, which I have to admit is one of those things I was asked to do as graduate school homework assignment that left me thoroughly intimidated. I got through it, but I was a graduate student. The person who marked his

college entrance essay which was this horribly hard problem said that it was a fine piece of work that would have been considered a fine piece of work for a doctoral student.
Fraser: And this is what he did just getting into college...
Pamela: Just getting into college, yes... and he managed to complete all of his college degrees Bachelors, doctoral degree, all of it in just 4 years.
Fraser: Wow.
Pamela: Yes.
Fraser: So they knew... I guess they must have really known they had a pretty special guy here, and helped him get access to the classes and the teachers and speed things along...
Pamela: The system was a little bit different back then, and so I think it was much more a matter of Fermi came up with ideas and he just did them and he was able, yes, he did have the people advising him but I think when you have a mind that amazing in front of you, you just kind of get out of the way and give them the things they need to run as fast as they can. His first major paper came out his third year of college. When he left the university in 1922, he went on to spend semesters at some of the most prestigious universities all across Europe. One of the things he did shortly after finishing the university was he worked with Dirac on the ever-so-simple project of figuring out what are the energies of all of the particles in a gas of all fermions, all particles that have to obey the Pauli Exclusion principle. This is one of those things that had been baffling scientists, they couldn't figure out how electrons in metals behaved, why they would flow like current but wouldn't heat up in expected ways. Just shortly after finishing his PhD, Fermi sat down with Dirac and the two of them solved this project.
Fraser: So where did he start? I mean when I think of Fermi, it's where the Fermi Paradox comes from, but where did he really kind of make his biggest hit in science?
Pamela: He wandered back and forth between quantum mechanics and nuclear physics. His work with Dirac was purely quantum physics, but he also did a lot of work in particle physics where, in fact he got the Nobel prize at the age of 37 for sorting out what happens when you bombard the cores of atoms with neutrons and how you can induce radioactivity. He opened up an entirely new field of science in many ways. By taking careful looks at problems and one of the most powerful things he did was in sorting out problems. He figured out what is the most simple way to approach this. Instead of doing a "well we have to take into consideration this, and we have to take into consideration that, and we need to have the exact number for this," Fermi was an expert at estimation. He was an expert at cutting things down to the minimal required information for a parameter. This is where Fermi problems come from. How do you estimate the number of blades of grass in a football field? He was able to look at problems such as neutron bombardment and use that to sort out "ok, so if I take a stack of uranium and mix it with cadmium-coated rods and build it in this way, I can build a sustained nuclear reaction."
Fraser: Right. And so was this the experiment that he got the Nobel prize... can you go into more detail on that?
Pamela: No, it was actually just for figuring out that you can induce radioactivity that he got the Nobel prize. It was later on in his career that he went on to create the first chain reaction of nuclear materials in the United States. It was after that that he went on to work with the Manhattan project. Figuring out that you could bombard things with neutrons

and make them radioactive was just the beginning of everything he did and he got the Nobel prize for the point at which he started, which is pretty amazing.
Fraser: Ok, so then that's... you're hinting at sort of the next major path in his career and life was his involvement in the Manhattan project, so how did that come about?
Pamela: Well, when he got the Nobel prize in 1938, he pretty much went straight from Stockholm to the United States. He and his wife emigrated. One of the problems with 1938 Italy was it was under the rule of Mussolini, and World War II was gearing up to get pretty awful. And there were starting to be restrictions on Jews in Italy, and his wife was Jewish, and many of his lab assistants were Jewish and he decided to get out while he could like so many scientists did. And so in 1938 he emigrated to the United States and went to Columbia where he began work. While he was there was able to collaborate with Niels Bohr who had a lectureship at Princeton. He was able to meet with a number of other people and they built on work done by others that had discovered that, well if you get together a bunch of uranium you can end up with sustained nuclear reactions. And they decided to build the first nuclear reactor here in the United States. They didn't do it in New York City, instead they did it with collaborators at the University of Chicago. Enrico Fermi went to Chicago, and in an old squash court underneath the then-not-in-use football field, they built their first, what was then not called a nuclear reactor but a nuclear pile. This was all done in 1938 and 1939, and it was in December of 1939 that they got the first fission experiments to work. This was Chicago pile number one. It was a pile of uranium that had interlaced within it graphite and they used cadmium rods to control the rate at which the reactions were occurring.
Fraser: Wow. Did he get a dose of radiation? He must have...
Pamela: Well, what's kind of amazing is he must have been exposed to radiation pretty much his entire career and this was back when we didn't fully understand all the side effects of radiation. So here he was at Columbia University where he was working in the lab to induce radioactivity through bombarding things with neutrons, then he goes to Chicago, he builds the very first nuclear pile there, then he was there for the Trinity experiment outside of Los Alamos. He actually was able to estimate the power of that explosion by dropping shredded bits of paper into the air just as the blast wave approached to see how much the blast wave moved those little pieces of paper he dropped. His entire life he was constantly in the heart of all of these radioactive experiments. The truth is, he ended up dying in his early 50s of stomach cancer. You can't prove definitively that the reason he got this was because due to his work with radiation, but he was still a young man in many ways when he passed away.
Fraser: And so he was, you know, pretty deeply involved in getting the first nuclear weapons built.
Pamela: Right. So, he was one of the people that figured out what is required for a chain reaction, he was one of the people that worked on defining the shapes that are needed, he was never, at least not that I've found documentation of, one of the people who pushed to get nuclear weapons built, but he did move to Los Alamos National Labs during the later stages of the Manhattan project to work as a general consultant. He was there when all of these things began to happen. He was there when the Hanford B reactor first went critical in 1944, and interestingly enough also became a citizen of the United States at the same time as he was working at the Los Alamos National Laboratory.
Fraser: Yeah, I'm sure his citizenship was fast-tracked.

Pamela: Probably just by a little bit... but the focus of his work was never developing nuclear weapons. The focus of his work was understanding particle physics, understanding how to solve problems. He is known as perhaps the best person at doing both experimental and theoretical physics to have lived during his century. He was the type of person that wasn't daunted at all by mathematics, but given the choice of solving long complicated equations or going down to the lab and throwing some things together and building a very complicated and meticulous experiment, he was comfortable doing either, but he always selected the most straightforward route to the solution.
Fraser: That's interesting, that's a very valuable skill. I think a lot of scientists... as you said they can be very mathematically inclined and sit down and really think through the equations and, you know, and maybe like string theory where they're making... they're coming up with mathematical models that can never be experimentally tested, but... and on the flip side you've got experimenters who have a limited range of the things they're able to do... it almost sounds like he was very practical, you know, that he was only interested in the kinds of ideas that he could demonstrate with the skills that he had, and he probably had a very rapid turn-around, being able to come up with an idea, head down to the lab, smash things together, see if it worked, come up with another idea, and, as you said, that being able to strip away an idea right down to its bare essentials. That's a pretty great skill to have.
Pamela: And it allowed him to make a lot of progress on difficult projects that required statistical thinking during the time when we didn't have computers that could readily chew through every possible option. His ability to employ statistics to understand sample theory, for instance, led to whole new ways of looking at what was likely to happen in particle physics. Particle physics--you're dealing with a whole lot of "ok, so we have this many (ten to the "a lot") of this at this temperature with these characteristics and we know within this they're going to have this distribution of energies and they're going to have this distribution of motions." And it's very easy to quickly, in today's world, take all of that and say, "ok, I'm going to build a simulation within my computer that contains ten million particles," set it loose and see what happens. Well, they couldn't do that during the 1940s, and Fermi had the ability to say, "ok, so let's look at calculations of the distribution. Let's look at statistical sampling methods. Let's look at sitting down and just chewing through hard core page after page of doing this sample of this group over here, this sample of this group over here. What was amazing in many ways about this was he had no problem sitting down when he had to do the meticulous calculations we now do with Excel and chewing through them one after another after another, doing the same calculation the hundreds of times that might have been needed for a hundred different cases. So, he's happy to do the boring tedious work, but he had the intellectual flexibility to say, "I can just use statistics, I can just use samples." And that fluidity made him powerful.
Fraser: So then after the Manhattan project, what happened next?
Pamela: Well, he kept working on different ways to do nuclear reactions, he kept working on studying particle physics. He was one of the people who stepped back and said, look, the nuclear bombs that you're looking at building--you just can't do that. It requires prohibitive amounts of tritium, it's just not a fusion reaction that can be propagated. So he actually stood up against Edward Teller and said you have to rethink your plans. But he also went on to do work studying the unstable pions and muons.

Nuclear particles that get created during a variety of different reactions and are very hard to study because they very quickly decay to other things. He was also a professor and one of the things he had a habit of doing was coming up with whole lists of projects. He'd hand them out to students, and one of the myths is that he'd give these amazingly complicated problems to students, and he had amazing students, and they'd go off and they'd work very hard, and he would've already solved things because he was bored and wanted to know the solution. But, he'd let the students keep full credit for what they did. So, as a mentor he was a pretty amazing person as well.
Fraser: So he'd actually give them the kinds of things that someone might write a paper about if they solved the problem.
Pamela: Right. And the problems that he'd give them were extremely complicated problems that hadn't been solved, but he'd just get impatient and solve them off on the side, then wait for the student to come back with the published solution.
Fraser: Right, but I think half of the challenge of this is knowing which questions to ask. That's where you get that practical sense where someone could say, well, this is a good question to ask because it's achievable and tells us something interesting. It's not impossible... it's doable. And those are some of the best questions that you can ask, you know, the ones that you can actually find the answer to. Which is great... I love this guy!
Pamela: He's the type of person that you can't help but be inspired by. He and Chandrasekhar I think are... and they were both at the University of Chicago at overlapping points in time... they are two scientists that you have to respect them for not just their brilliance, but their style with which they worked. Fermi kept detailed notes of everything he did... walking around with notebooks everywhere and recording his thoughts, recording problems, recording solutions. He was famous in later life for... people would come to him with complicated projects, complicated mathematical problems relating to physics, and he'd flip through his notebooks to find where he'd worked on similar problems in past years earlier in his career, and he'd pull together the pieces to solve the modern-day problems. So he, in many ways, was creating his own body of work that he could forever build on to solve new problems in new ways. I don't know how many times I've personally have had a conversation in my office with myself along the lines of "ok, I know I did something similar to this, where did I put it?" I don't personally keep the types of volumes of notebooks that Fermi was able to keep... and that clearness of writing as well as of thought as well as of recordkeeping allowed him to always move in a forward direction and not have to cycle back like so many of us have to do.
Fraser: And so then at the end of his life, you say, he died of stomach cancer.
Pamela: He died of stomach cancer at 54, he's known for having, even towards his death... Eugene Wigner wrote that "ten days before Fermi died he told me I hope it won't take long." He knew when it was over and he accepted that and so for him it was just always a motion forward.
Fraser: So what would you say... I mean this is Astronomy Cast so what would you say were Fermi's biggest contributions to the field of astronomy? And next week we're going to get into the mission that's named after him.
Pamela: His theory of induced radiation which got him the Nobel prize and all of his work on nuclear bombardment helped us understand how particles both decay and how they build. In supernovae, this is something that happens on a regular basis. Supernova

goes off, and you have a flash of neutrons and neutrinos that head out from all of the nuclear reactions that are going on during the star's collapse. And this bombardment of neutrons on elements that are in the shell of material that's given off by the supernova. These neutrons cause what are called the fast process, the r-process which, very quickly, you take some fairly normal atom and you bombard it with neutrons, bombard it with neutrons, bombard it with neutrons, and these neutrons collapse down and become protons, turning that atom into a heavier and heavier element. Because of him, we have a better understanding of how you're able to build elements during supernovae. It also gives us a better understanding of the processes by which decay can happen in any radioactive material. Beta decay, the process by which neutrons are either formed or destroyed converting back and forth from protons with either positrons being emitted or electrons being emitted, this beta decay process was something that Fermi helped define which defines the creation of nuclear elements in stars and supernova explosions.
Fraser: And of course, and we've already done a whole show on this, but you can give a little reminder of his paradox.
Pamela: So one of the things that bears his name is what are called Fermi problems. This is where you look at something and you say ok, how can I solve this by the most straightforward method. As I mentioned earlier, the "how many blades of grass are there in a football field?" And one Fermi problem that he had was "Where are all the aliens?" If you do a quick "back of the envelope" calculation of how long it would take a civilization to send out space probes to the nearest star, that from there they send off two to the nearest two stars, and each of those send off two to the nearest two stars, you very quickly can populate the entire galaxy with little space probes that are going forth and basically communicating "hey we've got life over here" to life elsewhere in the galaxy. And we haven't seen this definitive proof that life's out there. And the fact that we haven't seen this definitive proof is referred to as Fermi's paradox.
Fraser: Right. Even the most conservative estimates for the amount of intelligent life there must be in the galaxy would still have the solar system crawling with probes.
Pamela: And the only way to get around Fermi's paradox is to either say that the life out there doesn't care and isn't out there spreading the word that they exist, or that we're alone.
Fraser: Or the distances are just too vast. That there is some almost physical wall that is preventing us from being able to reach out from world to world, which is a pretty sad and depressing thought, too.
Pamela: Right, and it's the one that technologically is the hardest to understand, because even at our early stage of development as a civilization, we've managed to fling things out beyond the edge of our solar system.
Fraser: In a mere 70,000 years, Voyager will have arrived at the nearest star. So, we did it... why can't the aliens do it? So... yeah, if you haven't already, listen to the episode... we've done a whole show on the Drake equation and Fermi's paradox, and they're both... what a great question... it's a puzzler that I often have to think about... and wonder...
Pamela: And it shows the clarity of how he looked at the universe, just a nice straightforward... well statistically he's not someone I'd ever want to get in any sort of an argument with... But he's remembered for so many different things that have his name on it... There's Fermi-Dirac statistics that I think has broken every student who's ever taken quantum mechanics on at least one homework problem, there's Fermi problems that are

done by school children to teach them estimation, there's even a computer that he developed. One of the very first computers to be able to do Monte Carlo simulations was an analog computer that Fermi built. So there's a FERMIAC computer bearing his name. And then of course element 100 on the periodic table is named after Fermi.

Fraser: Well, thanks Pamela. And next week we're going to talk about the mission that's named after him which is now in space, helping to look at some of the ideas that he thought about, so... that'll be great. We'll talk to you next time.

Pamela: Sounds good, Fraser.