Interview with Joel Fajans

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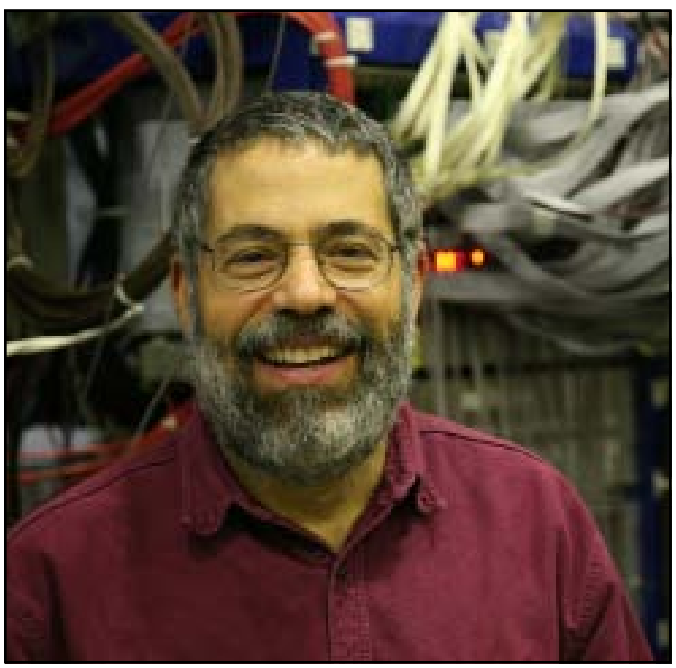
Dr. Joel Fajans' research has recently captured headlines as a part of the ALPHA collaboration at the CERN, Swizerland that created and captured antihydrogen particles in November 2010. That event was named the #1 Physics Breakthrough of the Year by Physics World magazine and since then, the team has worked to store these anti-atoms for longer periods of time, clocking 1,000 seconds in April 2011. After getting his Ph.D. from Massachusetts Institute of Technology in 1985, Professor Fajans joined the physics department as a faculty member in 1988. His lab has since worked on charged plasmas and the occasional paper on gyroscopic motion that speaks to his love of biking. While in Switzerland, Professor Fajans shared his thoughts on the uses of antihydrogen and the future of antimatter research when Berkeley Scientific Journal spoke with him over Skype in the summer of 2011.



BSJ: Because were doing this for our science fiction issue, we were really interested in your anti matter research you are doing at CERN. Can you tell us the goal of your project for what you are doing at CERN Switzerland is right now?

Fajans: Sure. Our goal is eventually to study the properties of antihydrogen atoms. Antihydrogen is a form of antimatter made from an antiproton, which is a negatively charged proton and a positron which is an antimatter electron, a positive electron. There's a substantial theory, called CPT [change, time and parity symmetry] and variance which predicts that aside from these changes in the sign, that hydrogen and antihydrogen are absolutely identical and we'd like to see if that's really true. If it turns out not to be true, then the theory of physics, well CPT, would be overthrown.

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BSJ: What are the consequences of violating CPT? What would happen if you guys found out there was some difference between antihydrogen and regular hydrogen, apart from the charge of those particles?

Fajans: Well, there could be many consequences but the most, the ones were likely to look for first is to look at the color with which antihydrogen glows. You may know that all atoms glow with characteristic colors. You see that in neon signs. Some of the time they're blue. Some are red. It has to do with the gas that's inside the signs – this color is characteristic of the atom, and it turns out that it's something that scientists can measure with extraordinary precision. In principal, we can measure the color of something, more specifically the wavelength, but we'll just call it the color to one part in 1 to the 18th. That is the precision of 1 followed by 18 zeros. Now, that in and of itself may not seem that exciting, but one of the motivating reasons for doing this is because it might help answer on of the grand challenges in physics and

BSJ

in sciences. Mainly, why isn't there more antimatter in the universe? The theory of the big bang, which is a remarkably successful theory, has a small problem with antimatter because it predicts that there should have been just as much antimatter in the universe as matter and when you look around us that appears not to be so. It appears that there's mostly matter, almost entirely matter for that in the universe and very, very little antimatter and nobody knows why. This actually has a name – it's called the baryogenesis problem – and its one of the outstanding critical problems in physics is to try and explain that. Well, even though the connections are sort of subtle, if it turned out that antihydrogen was different from hydrogen, and glowed a different color; this might explain this rather fundamental mystery of how it came to be here.

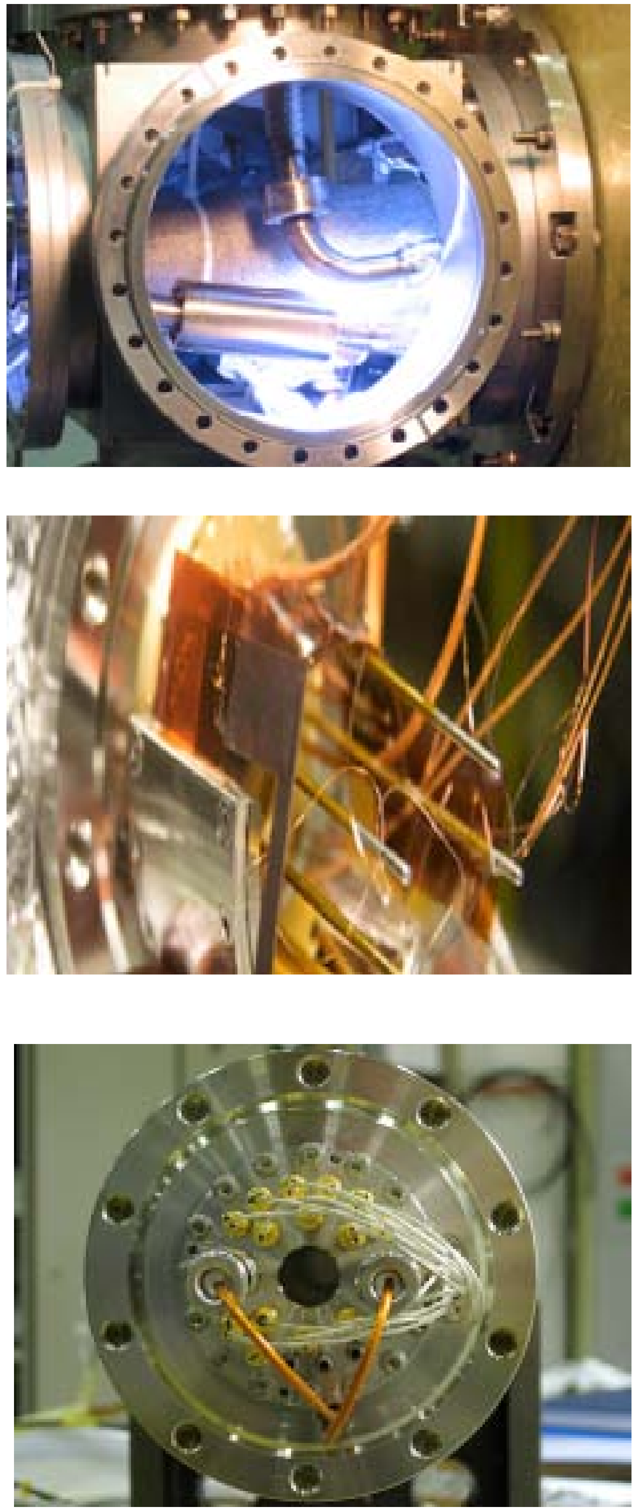

Figure 1. Above a few of components of the ALPHA apparatus, which is designed to trap antihydrogen.

BSJ: In terms of the actual history of this field, I understand that Berkeley is featured quite heavily in the development of anti matter and I think there have been a couple noble laureates associated with it. Can you walk us through how this field has been developed over time and sort of how we've lead up to this sort of culmination project you guys are doing?

Fajans: Well, sure, antimatter was first predicted to exist in a series of vapors in 1930 by a theorist named Dirac and it was an amazing feet of imagination on his part basically he had set up equations which were a more advanced form of quantum mechanics a more advanced form of Schrödinger equations seemed to him to be quite useful and predictive and turned out to be correct equations. They have a problem in which it is possible, in fact necessary that his equations would blow out, that would be mathematical infinities in the problem and he believed in this theory and he believed in his equations, so he invented a way to get rid of those mathematical infinities which was basically to pretend that there were positive electrons in the world and amazingly enough this purely hypothetical prediction was quickly found to be correct by a physicist named Carl Anderson, who detected positrons in the early 1930's. That's where it stood for a while, but then people started to wonder whether or not there were antiprotons, protons that were negatively charged. At the time the biggest accelerator in the world was in Berkeley partially to answer this question. The building in which it was built was just recently torn down. Up until last year you could go up into the Berkeley lab and you could see the building and the remains of the accelerator there called the Bevatron. And the Bevatron had several competing experiments that were looking for antimatter and two of the people there, Segrè and Chamberlain, lead a team of about 5 people in which they discovered the, well they were the first to discover the anti proton. So that's how that came about.

The story basically leaves Berkeley for a while and goes to places like Fermilab and CERN where people further studied the properties of antimatter. I guess to some extent, its come back to Berkeley since I'm a member of the team, there are many members on the team, about 40 people from institutions worldwide. We became the first people to trap neutral antimatter. People have managed to trap an antiproton and positrons before. The goal is to keep the trapped in one place. This isn't so easy to do because matter and

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antimatter, when they touch each other, they explode – they blow up. Physicists call this annihilation. In fact, when antimatter touches matter, all of the mass in the matter and the antimatter gets converted into energy, via Einstein's famous equation E = mc2, which predicts the amount of energy that you get out of all of this mass. If you want to keep antimatter around, you have to make a bottle with no sides. You can't simply put it into, say a glass bottle, because as soon as the antimatter hit the sides they will annihilate and that would be the end of it. So you have to make a bottle that has no sides and the way physicists do this is to use magnetic and electric fields. But it turned out to be particularly tricky for antihydrogen atoms. What we succeeded in doing last year was to finally manage to build a bottle that would contain some antihydrogen atoms.

BSJ: Yes, so we read the paper that you guys wrote regarding you trapped it for, I believe, 1,000 seconds?

Fajans: Right.

BSJ: And that's enough time to perform the spectroscopy and other experiments?

Fajans: Yeah, 1,000 seconds in physics terms is forever. It's sort of boring actually. We had a joke that we could put an atom into a trap and then go out for coffee and then see if was still there when we came back.

BSJ: So have you guys done the spectroscopy?

Fajans: No. That's still some years off. We're trying to do some spectroscopy this year, but it will be relatively crude. It's probably 5-10 years before we can do precision spectroscopy. Maybe less, maybe more – it's hard to say. Right now our goals this year are two-fold. One, we are trying to start to do physics with these atoms – start to do the spectroscopy with these atoms. Second, our other goal is to simply get more of them and make them more easily. It's still a struggle for us to trap – not to make them, it turns out to be fairly easy to make antihydrogen atoms – but it's still a struggle for us to trap the antihydrogen atoms that we've managed to make.

BSJ: How much anti hydrogen can you make? Say in a couple days or something.

Fajans: Well in the terms of atoms we can make quite a few at the moment. We make about 5,000 antihydrogen atoms. Of course we start with ingredients, positrons and antiprotons, about every 15 minutes when we have beam. I will come to that in a second. We can make about 5,000 anti hydrogen atoms. But even on our best days, we only manage to keep one of those atoms around, so we lose 4,999 and we keep one of them entrapped. Our experiment runs 24 hours a day, but there are other experiments with which we share the antiprotons for, and so we run effectively 8 hours of protons a day and with that we can, at 4 times an hour, make 20,000 atoms an hour if things are running well. And we've got 8 hours, so that is 160,000 antihydrogen atoms an hour or something like that. 160,000 antihydrogen atoms a day, but we will only trap a few of them.

> *"160,000 antihydrogen atoms a day, but we will only trap a few of them."*

BSJ: So you mentioned beam?

Fajans: Yes, these experiments have to be done at CERN because, while there are other sources of antiprotons in the world, CERN is the only source of slow antiprotons. You need an accelerator complex to make antiprotons. Antiprotons are made intrinsically with a great deal of energy, but we need the antiprotons to have very, very little energy, so in fact, most of our experimental effort has been extracting energy from these antiprotons. At most accelerator complexes, they simply start out with too much energy for us to be able to trap and successfully, but CERN has a very special facility. CERN, of course, is an accelerator facility, but one of the accelerators at CERN actually works backwards. It's a decelerator, and it takes the antiprotons that are made and created with all this energy and slows them down significantly, reducing the energy by about a factor of a thousand. At that point we can deal with them, because otherwise we wouldn't be able to. For instance, Fermilab, which is in Chicago, actually makes more antiprotons than CERN does, but they're much more energetic and we couldn't use them. I had a shift earlier today that didn't use antiprotons, so I am home for the evening, but at this moment, our collaboration is working and we are trying to improve our traffic. The guy who is running the shift at the moment is a guy named William Bertsche, and he's a former Berkeley graduate student. He is in charge for the evening for us.

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BSJ: So after you have made cold antihydrogen, what is the setup of the trap that the team has built? I mean if it is not heavily focused on magnetic and electric fields to trap charged particles, how exactly do you trap neutral antihydrogen.

Fajans: Well you can't use a electric fields to trap antihydrogen because it is neutral, so it won't be pushed by electrons fields, but we can still use magnetic fields. You certainly know that if you take, say the two south poles of a magnet together they will repel each other.

BSJ: Right.

Fajans: And perhaps you've seen these toys. There's a pretty neat toy in which you take sort of a gyroscope, which has got a magnet in it and spin it over another magnet, a stationary base that has some magnets in it, and it floats in the air. Have you seen this toy?

BSJ: Yeah, yeah. I have.

Fajans: Well that's sort of similar to what we do, but it's a lot harder to do it. Antihydrogen is a small magnet. It is like a tiny, tiny bar magnet – incredibly weak – but nonetheless it has a little bit of magnetism in it. We create a specially designed magnetic field that basically forces antihydrogen into the center of this very special magnet. The design of the magnet we use came from my Berkeley lab. There were proposals for other mechanic systems but we took the standard proposal and modified it somewhat, which is actually how I got into this field. I didn't think that the standard configuration would work very well and proposed a modification to it, and we tested it in Berkeley. There was a Berkeley undergraduate that worked on this with me in terms of proposing this modification and we did experiments, in Berkeley, to show the other standard configuration indeed had problems. So it's a complicated magnet and it's really quite similar to that floating magnet idea that you've seen.

BSJ: Right. So in terms of the progress of the research so far, what has been the most exciting moment that you've been a part of so far at CERN?

Fajans: (laughs) When something catches fire.

BSJ: (laughs) How often do things catch fire?

Fajans: Not to sound facetious, but you know, it's not as if there was one moment where we hadn't caught antihydrogen and there was another where we had because in the very beginning, in 2009 for instance, we thought we had caught, as it turns out 6 antihydrogen atoms, over the course of the year. That doesn't sound like much does it? We thought we had caught them, but we couldn't prove it and it's only in 2010 that we developed the techniques to prove that we had actually prove that we had actually caught antihydrogen. And it turned out, in retrospect, that what we thought we had caught, back in 2009, were indeed antihydrogen atoms, but at the time we just couldn't prove it. So, for a while, when we had only 5 or 10 or 15, the person who happened to be operating the experiment at the moment when that particular antihydrogen atom was named after that person. So we had Will and Nick, maybe Will II. I think for one of them I was operating, so temporarily one was named after me. It's pretty neat, but this has been going on for so long it's not as if there's some moment in which it suddenly succeeds and it all comes together. You don't realize that it's all come together for a while even after it has because things are still uncertain. Well, I've been working on this for a great, a long time and it's really fun to have it work.

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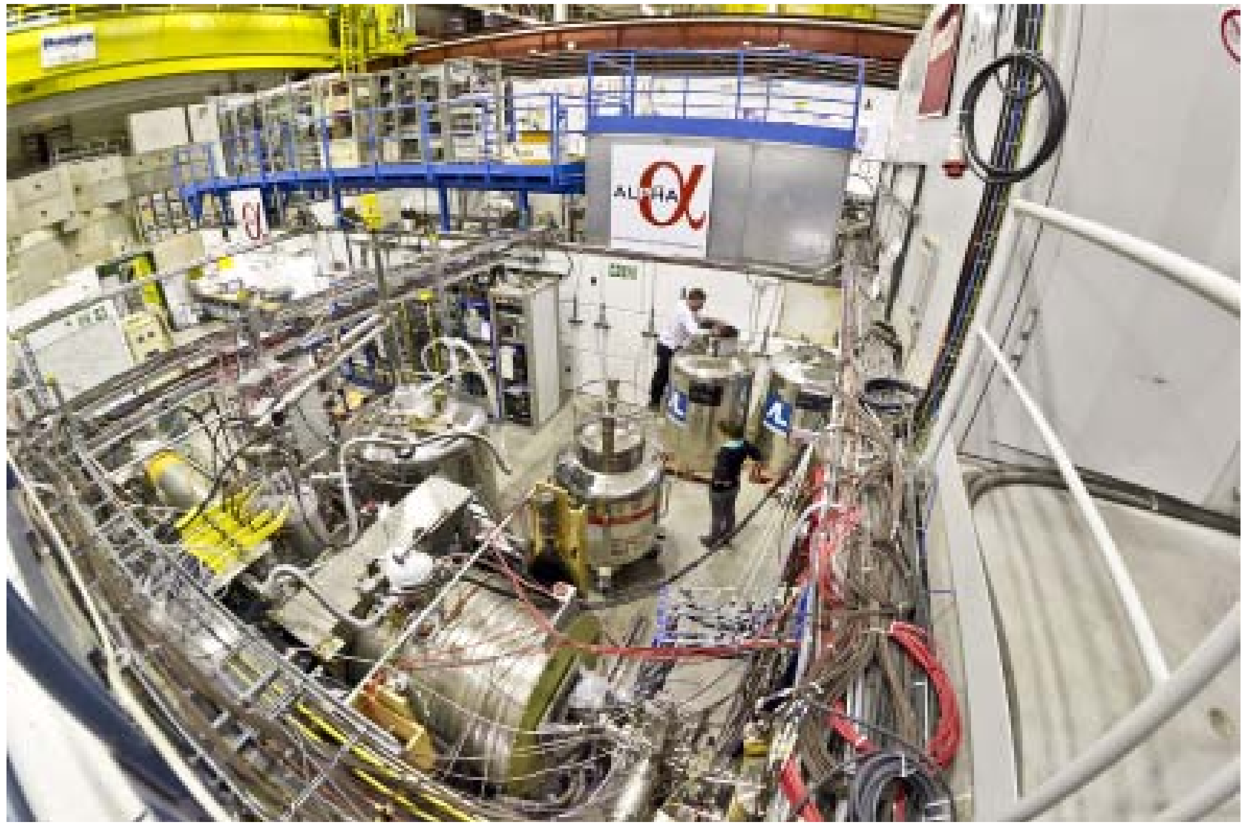

Figure 2. An external view of the ALPHA apparatus.

BSJ: Yeah, of course.

Fajans: And that's great. And when the page paper in Nature came out, we all gathered in our control room and we watched it show up on the Nature website, and then we started watching news stories about it because there was a lot of publicity. It was a great deal of fun, but if you live for those sorts of moments only, then your life is going to be pretty sparse.

BSJ: So were you ever interested in science fiction as a kid? What got you interested in the fields of physics that you study now or that you were studying before you joined CERN?

Fajans: Well actually I am an oddity at CERN; I am probably not the only plasma physicist, though it certainly is not a very common way to get involved in CERN. In the field of plasma physics most physicists work on fusion energy, I have never done that actually, I have always been in one obscure corner of plasma physics, and I kind of almost drifted into this almost by accident because I went to a conference and heard someone talking about how they were going to trap an antihydrogen and what they were telling me just didn't make sense to me. So that is when I started thinking about it, and eventually came up with this proposal for this modification to the idea that they were recounting. But I think, the one sort of thing that marked my entire life, is that I have always liked to build things and make them work. Like when you were talking about what the most exciting thing was, I like getting things to work, building things, designing new and fun things, and that has been most of what I have done in physics: building experiments, and perfecting them, and getting them to work and that is when you get your job day-to-day satisfaction. Not in these brand new things that happen once in a lifetime, or every couple years, unless you really believe, in which case they happen frequently, but that is not the point of my situation.

BSJ: So you mentioned gyroscopes earlier and we were reading through a couple of your catalog of papers and after talking to some of your about students it appears that you really like riding bikes, don't you?

Fajans: Yes, that is true too. In fact I am sitting here in bike clothes because I am biking home from work. But yeah, I do physics, I spend time with my family, I ride bikes. Berkeley is a great place to ride a bike, but CERN is a great place to, so it is fun coming here.
BSJ: That is great, so another thing we were interested about was how such a large team works together at CERN. You have 40 or 50 scientists.

Fajans: Well, I think, it is a complicated thing. We spend a lot of time in meetings. We had a planning meeting this afternoon in which we were talking about rebuilding our device next year, and we were talking about some fiddly details about how it's going to be constructed. People, you know, talking out ideas, argue with each other about one idea being better than the other. In this group there's about 45 collaborators, about 10 of us spend full time on this, there are other people who just come and work on very small and specific aspects of the experiment, some of which are quite critical to our success, but they only spend a limited amount of time and are employed at CERN for a fairly limited amount of time. We have a couple of retired physicists hat come because they want to be involved with a fun experiment, and they spend 3 or 4 weeks here and maybe another month back home. Most of these retired folks are in Canada, and they spend some time at home thinking about our project. But they love physics so much that they can't quite really retire.

BSJ: Yeah and CERN is probably one of the nicer places for a retired physicist to be.

Fajans: Well, except for the current exchange rate of the Swiss frank, it is a lovely place; it is a pretty, pretty area. The weather is good, and the work at CERN, if you're a physicist is really quite exciting. For instance, I am living in a small town, you know. CERN straddles the Swiss Geneva border, and most of the accelerator is actually in France, most of the actual physical hardware. There is a tunnel that is like 17 miles around that is buried underground in the countryside out here. And this summer, my family is here, and we are renting a place in the French town of Prévessin, which sits right in the middle of the accelerator complex. You can't tell, of course, because it is just buried, but if you know where to look there are signs of this giant ring all around in this area, and we're almost pretty close to the center I think.

BSJ: You will be back teaching at Berkeley in the fall correct? Teaching Physics 8B?

Fajans: That is correct

BSJ: Are you going to move everyone back, or is your family going to stay here.

Fajans: We will come back in just two weeks or so. Waiting for the semester to start

BSJ: Cool, so what do you see as the future for antimatter research? This is one step, but after you have done the spectroscopy and the gravity experiments, where do you sort of see this research going in the future?

> "...physicists have this tradition of searching, trying to prove that everybody else is wrong..."

Fajans: Well, I think it depends on whether or not we see an interest in the fact. People will be studying this for a very long time. If nothing shows up, well then, it will be an honorable attempt. Physics is full of this sort of experiments, by the way. There are lots of laws that people believe in that people are testing with greater and greater precision, and this is a part of physics. It rarely turns out that these laws are wrong, but when they are wrong, that can revolutionize people's thinking about a particular field in physics or sometimes physics in general. For instance, there is theory call CPT, which predicts that hydrogen and antihydrogen should be the same. CPT stands for different symmetry, C stands for charge, P stands for something that is called parity, which is like handedness, and T stands for time, and it is a theory about the symmetry of all of these properties. Before there was the CPT theorem, there was the CP theorem that everyone believed in. but it turned out to be true most of the time, but there turned out to be exceptions. That is why people came up with a better theory, the CPT theory. Laws like this are overturned and physicists have this tradition of searching, trying to prove that everybody else is wrong, that these laws are incorrect. It is a very fruitful thing in physics over the years. One has to face the fact that almost always the laws are correct, so that is why I was saying earlier a lot of the satisfaction is, from my personal point of view, trying to get a very difficult experiment to work. It would be foolish of me to think that CPT is wrong; it is unlikely to happen, but there is always a chance. Just like you mentioned gravity, there is always a chance that antihydrogen will fall up, but nobody has ever measured how antihydrogen interacts with gravity. It is very unlikely that it interacts with gravity differently from the way that hydrogen interacts with gravity, but maybe it does, maybe it is antigravity. You asked me earlier if I read science fiction, I wasn't a huge science fiction fan, but I did read a fair amount when I was a kid. For some reason one of the books that always struck me, I don't know why, but it was in the Tom Swift stories. It is the only one I remember now, and it is somewhat ironic because it is the only one that is relevant to me now. I think it was called "Tom Swift and the Antigravity Paint." Well, it is true that if you used antimatter paint, your house would blow up rather than rise, but it is kind of amusing. So I was never really a Star Trek fan. I have of course seen Star Trek every now and then, and of course antimatter torpedoes, and all that is really not my driving influence force.

BSJ: So what actually was your driving force for getting into plasma physics?

Fajans: I think what originally got me excited about plasma physics was fusion energy. Fusion is, as you know, the promise of the infinite source of energy, with essentially no pollution cost. No downside, except for the major downside that people haven't managed to get it to work yet. And they may never get it to work because it is absurdly complicated to get it to work in a laboratory or a power plant, so I think that's what first interested me. But I got sidetracked almost immediately and started working on a type of laser-based on electron beam. It is called a free electron laser and that is what I did my thesis on. And then I got sidetracked again, I signed up as a post-doc to make a crystal out of electrons only, and we never succeeded at that but we did some other rather interesting things with that, this collection of electrons. That is what I did for most of my career at Berkeley, until I got distracted with the antimatter research and started doing that principally.

BSJ: A lot of the literature on the ALPHA collaboration website is postulating some sort of future for the project, and it is mentioning energy. What kind of theoretical potential does antimatter have as an energy source?

Fajans: None, which is why I am surprised to hear you say that it mentions that on the website, unless it would mention it dismissively. The problem with using antimatter as an energy source is that it is incredibly inefficient to make. First you certainly don't get more energy out than you put in, you never would, but on top of that it is incredibly inefficient to make antimatter. Which, in some ways, is a shame because if you had a fistful of antimatter you could make a rocket probe that would go to the stars quickly which would be really fantastic for science, but there is no prospect whatsoever of me making a fistful of antimatter. People have calculated – and some people get one number and other people get another number – that to make a macroscopic quantity of antimatter, say a gram of antimatter, all of the world's energy production, all of the transportation, all the computers, all of the eating and food growing, all of that energy would have to be funneled into making antimatter for some amount of time that various people would say is a thousand years up to a million years. It is an interesting thing, in the history of antihydrogen experiments, a hundred million, perhaps two hundred million, antihydrogen atoms have been made, which sounds like an enormous quantity, doesn't it?

BSJ: Yeah it sounds like a lot but it's not.

Fajans: Yeah it's really nothing; you really need to make a billion billion antihydrogen atoms before you have a macroscopic quantity of this stuff.

BSJ: I see, so I think that is pretty much all of the questions I had, and I'll let you go to sleep now, since it's a bit late over there, but thank you so much for letting me do this interview.

Images courtesy of the Alpha experiment website: http://alpha-new.web.cern.ch/gallery