INTERVIEW

OF

DR. CHRISTOPHER RUSSELL

Conducted by Troy Cline

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P R O C E E D I N G S

MR. CLINE: Okay. If you could just tell us your name and your title, what you do.

DR. RUSSELL: I am Troy Cline --

MR. CLINE: Hahaha. Wow, that's awesome.

DR. RUSSELL: Okay. Should we try that again?

MR. CLINE: I could fill in a few stories for you.

DR. RUSSELL: Okay. I am Chris Russell and I am Professor of Space Physics at the University of California, Los Angeles, and I've had the fortune to be involved in a lot of the early discoveries after the beginning of the space age.

MR. CLINE: Okay. Thank you. And the first question we have for you is if you could tell us what your primary area of research interest is.

DR. RUSSELL: Okay. My primary area of research interest is the physics of magnetized plasmas, especially flowing plasmas.

I am interested in dynamos and how the magnetic fields of the solar system are generated. I am interested in reconnection, which is a process whereby magnetic fields get coupled together and enable the transfer of energy from one region to another, and they also can enable the annihilation of magnetic fields and the release of that magnetic energy into other forms of energy.

I am interested in the formation of magnetic ropes. These are twisted bundles of ropes, especially ropes that can twist in such a way as they are self balancing. So they push outwards and pull inwards at the same time, and form just a rope very much like a rope that you might tie something up with.

I am also interested in magnetic barriers of different types, and boundary layers that enable the pressure of say, the solar wind, to be transmitted to the Earth's magnetosphere.

I am interested also in shocks, which are a non linear phenomena where the magnetic field changes very rapidly, and the plasma conditions change very rapidly, and there's a lot of dissipation of energy in these boundaries. And that's very important for a plasma because it makes very highly energetic particles.

And I'm also interested in waves. Both -- the shock is a wave itself, but there are also smaller waves that transmit energy. They do heating and they change the space environment in many ways.

MR. CLINE: Okay. What I'm going to do -- let me pause this for just a second.

(Pause in recording.)

MR. CLINE: Okay. And I am un-paused. So we will back up just a few statements and cut out the door slamming.

DR. RUSSELL: Okay. I am interested in magnetic barriers and boundary layers. They enable the transmission of both force and pressure to various regions in the plasma, like the Earth's magnetosphere being pushed on by the solar wind.

I am interested in shocks where there is a nonlinear interaction. The shock is a very strong wave. It heats the plasma and slows the plasma down and compresses it, and is a very efficient way of energizing particles.

I am interested in waves themselves. The smaller, nonlinear waves that will interact with the plasma, heat the plasma, scatter the plasma, and cause a lot of dissipation that is important to the space environment.

MR. CLINE: You may have actually already touched on this second part of the question about what do you like about it? If there is like a personal interest that you take in some of these areas, you might want to just touch on that.

DR. RUSSELL: Well, if you say, what was my involvement in all of those things --

MR. CLINE: Uh-huh.

DR. RUSSELL: That each one of them, I've done a little bit of work on and pushed the field in a little way. So I feel some involvement in each one of these topics, but just like I have a couple of children and I try not to favor one over the other, even though one's -- no -- haha -- no, I try not to favor one topic over the other. I am interested in all of them.

MR. CLINE: That's a great answer, actually. I like that. Now -- so you talked -- the second question is with what, and when, were you involved in space weather research?

DR. RUSSELL: Well, I was very fortunate at the time that I graduated. I got my bachelor's degree and I just applied to the government for a summer job. I said, "You know, you've got this program for summer jobs for college students. Just put me someplace."

Well, they put me on a space program, and so my first summer job was studying solar radio waves from an ionospheric satellite that could also receive the radio emissions from the sun. So I got to learn about solar physics right from the get go when I got my bachelor's degree.

I then left -- you know, after my summer job -- and I went off to UCLA where I was going to major in just ordinary physics, maybe high energy physics -- and -- but I got interested in space by my summer job.

So when I got to UCLA, I looked around and I said, "Is anybody here involved in the space program?" And I found a professor who was in geophysics, rather than the physics department, and then I transferred over to geophysics and I became a graduate student with Professor Holzer and he was involved in the OGO series, the satellites -- that's the Orbiting Geophysical Observatories -- and they had just launched, the year before, the first of the OGO's -- OGO-1 -- aptly named.

And I got a chance to work on that particular spacecraft with some other graduate students who were already in the group. I was the third student, so I actually got to work on OGO-3.

Now, in those days -- they were the glory days of space because we were launching an OGO spacecraft every year. Okay? So when the first one had a problem and spun up when it was supposed to be 3-axis stabilized, they just -- you know, they said, "Okay, what went wrong?" And then they fixed it on the next one, and the next one worked better, and when that got to a failure mode, they figured out what went wrong, then they'd fix that on the next one.

So each one was better than the others, okay? So I got number three, and that introduced me to the magnetopause, then the bow shock and the outer magnetosphere, and also the waves within the magnetosphere. So I also felt that I was especially blessed because I got to work on an eccentric orbiting spacecraft that went way out.

There were two types of OGO's. They were in polar circular orbit, and then an eccentric orbit, and if you are working on an eccentric orbiter, you got to go through every region of the magnetosphere.

You know, so we went out into the solar wind. We went into the bow shock. We went into the magneto sheath, the magneto pause, the outer magnetosphere, and in the tail, and so we got to explore all of the various regions of the magnetosphere where things were happening, and then we got a better sort of perspective of the whole magnetosphere than somebody who's just in one little spot and had to understand one little piece of the system. So I always felt blessed by that experience. So I like odd numbers now.

And then, finally, after I graduated I changed jobs just ever so slightly. I had been working on the search coil magnetometer on the spacecraft, and I switched to a flux gate magnetometer, which would measure the entire Earth's field. And so I got a chance to do a few things that we weren't able to do with just the search coil magnetometer.

And, in particular, we started looking at the motion of the magnetopause, and that led us to understanding the effect of the interplanetary magnetic field on the magnetosphere, and got me into studying the process we call reconnection.

So, the erosion of the magnetosphere is a situation where the magnetic field in the interplanetary medium in the solar wind comes up to the Earth and it's southward. And the southward field is opposite of the Earth's magnetic field, and it reconnects or joins, or annihilates the Earth's magnetic field, and then the magnetopause, because it's been eaten away by this anti- parallel field, moves inward.

People had a hard time with that. They could understand pressure pushing the magnetopause in, but they didn't understand erosion. So there's a little bit of, you know, paradigm changing sort of friction there. People do not like to have their paradigm's changed on them, and they resist as long as they can until they find out that this new paradigm explains more than the old paradigm did.

So, then I got into the semiannual variation of geomagnetic activity. There was a whole bunch of silly ideas about why the aurora and geomagnetic activity was stronger at the equinoxes than it was at the solstices, and they didn't make good physical sense to me, but I understood that there was this erosion process associated with reconnection, and I figured out how that might end up being modulated by the time of year, just the pointing of the Earth's dipole would do it. And so I came up with that and that got me a little bit more notoriety.

And then there was another phenomena, the ring current that also was modulated by reconnection, and so we explained how geomagnetic storms were just a process in which the coupling with the solar wind became greater for a period of time, energy flowed in to the magnetosphere, and then gradually decayed with time. And you could explain it with just a few simple parameters -- how geomagnetic storms worked. So that got us a little bit more notoriety.

Then, I thought -- well, I was about 29 years old -- what was I going to do with my life? So I sent a proposal in to NASA to build a couple of magnetometers for a new spacecraft called ISEE, the International Sun Earth Explorer, and there are two spacecraft in the same orbit -- and that's really very useful, co-orbiting spacecraft, because the magnetosphere is a very dynamic place and the magnetopause is moving in and moving out, moving in and moving out -- the bow shock does the same thing.

And if you could just measure how fast these boundaries were moving back and forth, then you could figure out how thick they were because we didn't know on the OGO spacecraft -- it was just a one at a time spacecraft -- that -- you know, how fast these boundaries were moving. We made some models, but it wasn't as good as actually measuring it.

And so that was good. NASA said sure, Chris, and so I became a magnetometer PI, and sure enough there are a whole bunch of things that were unexpected. Whenever you do something new you might get the explanation for what you were expecting, but sometimes a whole bunch of new things come up.

And in this particular case, we found flux ropes. These were essentially bundles of magnetic field rolled up that were on the magnetopause, and we see those now on Mercury -- we see them not only on the Earth, but we also see them at Jupiter. So they are a common magnetopause phenomena and they are associated with reconnection, but we didn't necessarily solve it perfectly the first time, we just understood its general terms. It's still being worked on and even today new models -- or at least old models are being tested, and it looks like maybe it's multiple reconnection points on the magnetopause simultaneously.

I wasn't satisfied with just sending in one proposal. The next year I sent in another proposal to study Venus, and when we got to Venus we saw flux ropes again, but Venus didn't have intrinsic fields so that puzzled us somewhat.

And then we started to understand the

macroscopic cause of these geomagnetic storms that we had explained in terms of energizing the magnetosphere. We found out that the sun was doing something -- making magnetic clouds -- and these magnetic clouds also were wrapped up in ropes so that the sun was sending out giant magnetic ropes at the Earth, and that was what was causing these storms.

So magnetic ropes in a lot of forms, from the sun, then the Venus ionosphere, and also at the Earth's magnetopause, have influenced my thinking and my research quite a bit.

MR. CLINE: I've learned quite a bit. I haven't actually heard a lot about the magnetic ropes that you're talking about, especially at the magnetopause, and I know that MMS hopefully will be seeing a lot of that.

DR. RUSSELL: I expect so. We're trying to aim at the right spot.

MR. CLINE: I hope so. Yeah. I am thinking what I'm going to do is pause...

(Pause in recording.)

MR. CLINE: All right. We're recording, so we'll start that again.

DR. RUSSELL: Okay. Let me take you back to 1908 when we discovered that the sun was magnetic. Now, I wasn't around at that particular time, but it was a very important time for my research because it helped explain to the community, eventually, why the sun does influence the Earth's magnetic field.

And it's the interaction of the solar magnetic field with the Earth's magnetic field that allows us to have all the beautiful aurora and other phenomena that occur on the sun -- or occur on the Earth because of the sun. But it was very controversial and very difficult to understand because people did understand a little bit about plasmas, and especially magnetized plasmas, and could not understand one particular important point, and that is how fast the sun can release that energy.

The sun can build up the energy in its magnetic field with its internal dynamo and building up magnetic constructs on the surface, but it has a way of getting rid of that energy in a hurry and then launching it off towards Earth. And that became a very controversial subject.

There were a couple of people in the field. One was Giovanelli an Australian researcher, and another was Jim Dungy (ph,) who became his post doc after Jim Dungy's graduation from college -- or getting his PhD in England. And so Jim went off to Australia, joined Giovanelli, and they started looking at what process could launch this energy quickly, and they came up with neutral points and centered their study around the physics of magnetic regions in which the magnetic field went to zero, and you had anti-parallel fields coming into this point.

That turns out to be what I consider the very breakthrough idea. However, other people, like Sweet and Parker, were trying to get rapid energization out of sheets of anti-parallel magnetic field, rather than points of anti-parallel fields, and they were unable to get the same speed as Giovanelli and Jim Dungy were aiming at. However, eventually -- we understand it much better now and we understand the geometry of the situation that is all very important.

Now, there was one other important

breakthrough that Dungy is associated with, and that was realizing how that process of reconnection that they were studying, because of its solar implication, could be used to power the aurora at Earth.

And Jim tells the story that he was invited to give a seminar in Paris, and he was sitting there, you know, at a coffee cafon the streets of Paris, and they're trying to think what the heck he could say in this seminar. And he realized that the anti-parallel fields, when they reached the Earth's magnetosphere, would set up a circulation pattern. They would reconnect with the Earth's magnetic field, transport a flux over the pole, and come in and cause circulation from a neutral point in the tail that would cause the flow to come back at the magnetosphere and set up this overall circulating pattern of flows within the magnetosphere.

And so the rest is history, but it took many years for Dungy's ideas to be accepted. Dungy was a person who had very -- you know, off the mainstream -- out of the mainstream -- ideas, and he wasn't always appreciated because of his personality and because of his, you know, odd way of thinking out of the mainstream.

And so it was many years. That was 1961. I came along doing my work in this particular area in the regime of about 1968 to '73, approximately, and we were - - we knew the name that Dungy had been using for this effect, "Reconnection," but when we started publishing papers in support of these ideas -- that were consistent with his ideas -- we didn't use "Reconnection." In fact, embarrassingly enough to say, we didn't even reference Dungy, but eventually we proved Dungy to be right.

One of the first concepts that supported Dungy was the erosion of the magnetopause. That's where the interplanetary field turns southward, the solar wind pressure doesn't increase, but this magnetopause moves in because flux is being transferred to the tail.

It was an amazing --

MR. CLINE: I am going to pause now.

(Pause in recording.)

DR. RUSSELL: Okay. Let me say a little bit about the erosion of the magnetopause and how that supported Dungy's model -- that we found that when the interplanetary field turns southward, opposite the direction of the Earth's magnetic field at the forward magnetopause, that the two fields merged or joined together, and that eroded or pulled flux from the day side to the night side, and then later we found how that returned.

Now, people didn't accept that right away because they understood that a pressure could move the magnetopause, but they didn't understand how this magnetic force, that magnetic stress that was being applied to the magnetopause, would work.

Fortunately, there were some bright theoreticians around who were able to understand that and explain it, but that erosion of the magnetopause was a key observation for us that Dungy was right.

I'm a little embarrassed to say that we did not give Dungy the proper credit at that particular time. His ideas were known, but they weren't very much accepted, but eventually we got Dungy the credit that he deserved.

Then the spacecraft -- it was an --

(Interruption in recording.)

MR. CLINE: There we go.

DR. RUSSELL: OGO-5, which we were using to study the erosion of the magnetopause -- six months after it was on the day side it was on the night side of the Earth, because the Earth goes around the sun and the orbit stays fixed in inertial space.

And so we started to measure what was happening in the geomagnetic tail, and we could then see that these dynamic features were also happening in the tail of the Earth, that were returning the flux from the tail -- that had been transferred to the tail -- into the Earth's magnetosphere.

That gave us the idea that there was a neutral point, like Dungy had predicted, but that neutral point was much closer to the Earth. Now, we call that neutral point now a plasmoid, but that's what -- basically the plasmoid is centered around or formed by the neutral point that Dungy had proposed many years ahead of time.

That was very important in putting together an overall phenomenology of what we call a substorm, and that's the standard explanation of the substorm today. And in fact, I think at the present time I can say that there is very little controversy now about the origin of a substorm, that people held out until the recent THEMIS mission, but when the THEMIS mission went off a few years back now, then the opposition to that finally died away.

But the acceptance of Reconnection at the front of the magnetosphere took not just the magnetic energy -- evidence -- but it also took us to demonstrate that there were flows of the plasma, so that the nice thing that the ICEE spacecraft had that the OGO spacecraft didn't have were detectors that could look along the field line and see the plasma that was accelerated flow away from the equatorial regions.

And when the flow measurements came, then we were brave enough to use the word "Reconnection" in the title of our article. And so the nature paper that discovered these flows said "Evidence for Reconnection" in the title, and we were brave finally.

We had won in the paradigm fight.

(Whereupon, the interview was concluded.)

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I, ANNMARIE WASKO, do hereby certify that this transcript was prepared from audio to the best of my ability.

I am neither counsel for, nor party to this action nor am I interested in the outcome of this action.

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ANNMARIE WASKO