

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

1

INTERVIEW
OF
DR. CHRISTOPHER RUSSELL

Conducted by Troy Cline
Thursday, March 21, 2013

Adnet Systems, Inc.

NASA GSFC

Code 672

Greenbelt, Maryland 20771

Phone: 301-286-1359

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

2

1 P R O C E E D I N G S

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

4 DR. RUSSELL: I am Troy Cline --

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

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

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

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

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

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

21 I am interested in dynamos and how the
22 magnetic fields of the solar system are generated. I

1 am interested in reconnection, which is a process
2 whereby magnetic fields get coupled together and
3 enable the transfer of energy from one region to
4 another, and they also can enable the annihilation of
5 magnetic fields and the release of that magnetic
6 energy into other forms of energy.

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

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

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

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

4

1 particles.

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

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

8 (Pause in recording.)

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

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

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

22 I am interested in waves themselves. The

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

5

1 smaller, nonlinear waves that will interact with the
2 plasma, heat the plasma, scatter the plasma, and cause
3 a lot of dissipation that is important to the space
4 environment.

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

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

12 MR. CLINE: Uh-huh.

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

21 MR. CLINE: That's a great answer, actually.
22 I like that. Now -- so you talked -- the second

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

6

1 question is with what, and when, were you involved in
2 space weather research?

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

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

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

18 So when I got to UCLA, I looked around and I
19 said, "Is anybody here involved in the space program?"
20 And I found a professor who was in geophysics, rather
21 than the physics department, and then I transferred
22 over to geophysics and I became a graduate student

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

7

1 with Professor Holzer and he was involved in the OGO
2 series, the satellites -- that's the Orbiting
3 Geophysical Observatories -- and they had just
4 launched, the year before, the first of the OGO's --
5 OGO-1 -- aptly named.

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

10 Now, in those days -- they were the glory
11 days of space because we were launching an OGO
12 spacecraft every year. Okay? So when the first one
13 had a problem and spun up when it was supposed to be
14 3-axis stabilized, they just -- you know, they said,
15 "Okay, what went wrong?" And then they fixed it on
16 the next one, and the next one worked better, and when
17 that got to a failure mode, they figured out what went
18 wrong, then they'd fix that on the next one.

19 So each one was better than the others,
20 okay? So I got number three, and that introduced me to
21 the magnetopause, then the bow shock and the outer
22 magnetosphere, and also the waves within the

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

8

1 magnetosphere. So I also felt that I was especially
2 blessed because I got to work on an eccentric orbiting
3 spacecraft that went way out.

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

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

19 And then, finally, after I graduated I
20 changed jobs just ever so slightly. I had been
21 working on the search coil magnetometer on the
22 spacecraft, and I switched to a flux gate

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

9

1 magnetometer, which would measure the entire Earth's
2 field. And so I got a chance to do a few things that
3 we weren't able to do with just the search coil
4 magnetometer.

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

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

19 People had a hard time with that. They
20 could understand pressure pushing the magnetopause in,
21 but they didn't understand erosion. So there's a
22 little bit of, you know, paradigm changing sort of

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

10

1 friction there. People do not like to have their
2 paradigm's changed on them, and they resist as long as
3 they can until they find out that this new paradigm
4 explains more than the old paradigm did.

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

16 And then there was another phenomena, the
17 ring current that also was modulated by reconnection,
18 and so we explained how geomagnetic storms were just a
19 process in which the coupling with the solar wind
20 became greater for a period of time, energy flowed in
21 to the magnetosphere, and then gradually decayed with
22 time. And you could explain it with just a few simple

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

11

1 parameters -- how geomagnetic storms worked. So that
2 got us a little bit more notoriety.

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

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

20 And so that was good. NASA said sure,
21 Chris, and so I became a magnetometer PI, and sure
22 enough there are a whole bunch of things that were

1 unexpected. Whenever you do something new you might
2 get the explanation for what you were expecting, but
3 sometimes a whole bunch of new things come up.

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

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

22 And then we started to understand the

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

13

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

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

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

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

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

21 (Pause in recording.)

22 MR. CLINE: All right. We're recording, so

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

14

1 we'll start that again.

2 DR. RUSSELL: Okay. Let me take you back to
3 1908 when we discovered that the sun was magnetic.
4 Now, I wasn't around at that particular time, but it
5 was a very important time for my research because it
6 helped explain to the community, eventually, why the
7 sun does influence the Earth's magnetic field.

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

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

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

15

1 very controversial subject.

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

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

22 Now, there was one other important

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

16

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

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

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

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

17

1 his, you know, odd way of thinking out of the
2 mainstream.

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

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

19 It was an amazing --

20 MR. CLINE: I am going to pause now.

21 (Pause in recording.)

22 DR. RUSSELL: Okay. Let me say a little bit

1 about the erosion of the magnetopause and how that
2 supported Dungy's model -- that we found that when the
3 interplanetary field turns southward, opposite the
4 direction of the Earth's magnetic field at the forward
5 magnetopause, that the two fields merged or joined
6 together, and that eroded or pulled flux from the day
7 side to the night side, and then later we found how
8 that returned.

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

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

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

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

19

1 Then the spacecraft -- it was an --

2 (Interruption in recording.)

3 MR. CLINE: There we go.

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

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

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

22 That was very important in putting together

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

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

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

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

21

1 We had won in the paradigm fight.

2 (Whereupon, the interview was concluded.)

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

22

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

CERTIFICATE OF TRANSCRIBER

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.

ANNMARIE WASKO

Capital Reporting Company
 Russell, Dr. Christopher 03-21-2013

<hr/> <p style="text-align: center;">1</p> <hr/> <p>1908 14:3 1961 17:3 1968 17:5</p> <hr/> <p style="text-align: center;">2</p> <hr/> <p>2013 1:9 20771 1:19 21 1:9 29 11:3</p> <hr/> <p style="text-align: center;">3</p> <hr/> <p>301-286-1359 1:20 3-axis 7:14</p> <hr/> <p style="text-align: center;">6</p> <hr/> <p>672 1:15</p> <hr/> <p style="text-align: center;">7</p> <hr/> <p>73 17:5</p> <hr/> <p style="text-align: center;">A</p> <hr/> <p>ability 22:5 able 9:3 18:15 accelerated 20:16 accept 18:9 acceptance 20:9 accepted 16:19 18:21 action 22:7,8 activity 10:6,8 actually 5:5,21 7:9 11:19 13:13 Adnet 1:13 age 2:14 ahead 19:21</p>	<p>aim 13:18 aiming 15:19 allows 14:10 already 5:5 7:8 am 2:4,10,11,21 3:1,7,13,17 4:9,12,17,22 5:19 13:19 17:20 22:7,8 amazing 17:19 Angeles 2:12 annihilates 9:15 annihilation 3:4 ANNMARIE 22:3,11 answer 5:21 anti 9:17 15:11 anti-parallel 15:16,17 16:9 anybody 6:19 applied 6:5 18:13 appreciated 16:22 approximately 17:5 aptly 7:5 area 2:17,18 17:4 areas 5:8 article 20:20 associated 10:11 12:10 16:1 audio 22:4 aurora 10:7 14:10 16:4 Australia 15:7 Australian 15:3</p>	<p>away 9:17 18:9 20:8,16 awesome 2:5</p> <hr/> <p style="text-align: center;">B</p> <hr/> <p>bachelor's 6:4,13 balancing 3:10 barriers 3:13 4:13 basically 19:19 beautiful 14:10 became 6:22 10:20 11:21 14:22 15:4 beginning 2:14 best 22:4 better 7:16,19 8:14 15:20 bit 5:14 9:22 10:15 11:2 13:11,12 14:14 17:22 blessed 8:2,17 boundaries 3:21 11:14,18 boundary 3:14 4:13 bow 7:21 8:9 11:12 brave 20:19,22 breakthrough 15:14 16:1 bright 18:14 build 11:5 14:18 building 14:19 bunch 10:6 11:22 12:3 bundles 3:8 12:5</p> <hr/> <p style="text-align: center;">C</p> <hr/>	<p>cafon 16:7 California 2:12 case 12:4 cause 5:2 13:1 16:13,14 causing 13:7 centered 15:9 19:19 CERTIFICATE 22:1 certify 22:3 chance 7:6 9:2 change 3:19 4:5 changed 8:20 10:2 changes 3:18 changing 9:22 children 5:17 Chris 2:10 11:21 CHRISTOPHER 1:4 circular 8:5 circulating 16:16 circulation 16:11,13 Cline 1:8 2:2,4,5,8,15 4:6,9 5:5,12,21 13:12,19,22 17:20 19:3 closer 19:17 clouds 13:4,5 Code 1:15 coffee 16:7 coil 8:21 9:3 college 6:7 15:5</p>
--	--	---	---

Capital Reporting Company
 Russell, Dr. Christopher 03-21-2013

<p>comes 9:12 coming 15:12 common 12:9 community 14:6 compresses 4:20 concepts 17:13 concluded 21:2 conditions 3:19 Conducted 1:8 consider 15:13 consistent 17:9 constructs 14:20 controversial 14:13 15:1 controversy 20:4 co-orbiting 11:9 counsel 22:7 couple 5:16 11:5 15:2 coupled 3:2 coupling 10:19 credit 18:19,21 current 10:17 cut 4:10</p> <hr/> <p style="text-align: center;">D</p> <hr/> <p>day 18:6 19:6 days 7:10,11 decayed 10:21 degree 6:4,13 demonstrate 20:12 department 6:21 deserved 18:22 detectors 20:14</p>	<p>died 20:8 different 3:14 difficult 14:13 dipole 10:14 direction 18:4 discovered 14:3 20:21 discoveries 2:13 dissipation 3:20 5:3 doc 15:4 done 5:14 door 4:11 DR 1:4 2:4,6,10,18 4:12 5:10,13 6:3 13:17 14:2 17:22 19:4 Dungy 15:4,19 16:1,19 17:6,11,12,14 18:17,19,21 19:16,20 Dungy's 15:5 16:19 18:2 dynamic 11:10 19:11 dynamo 14:19 dynamos 2:21</p> <hr/> <p style="text-align: center;">E</p> <hr/> <p>early 2:13 Earth 9:13 11:7 12:8 13:7 14:12,22 16:4 19:7,12,17 Earth's 3:16 4:15 9:1,14,15 10:13 13:10 14:7,9</p>	<p>16:10,12 18:4 19:14 eaten 9:17 eccentric 8:2,5,6 effect 9:7 17:7 efficient 4:20 embarrassed 18:18 embarrassingly 17:10 emissions 6:11 enable 3:3,4,14 4:13 energetic 3:22 energization 15:16 energizing 4:21 13:2 energy 3:3,6,20 4:4 6:16 10:20 14:17,18,21 15:8 20:11 England 15:6 entire 9:1 environment 4:5 5:4 equatorial 20:16 equinoxes 10:8 eroded 18:6 erosion 9:10,21 10:11 17:14 18:1,16 19:5 especially 2:20 3:8 8:1 13:14 14:15 essentially 12:5 eventually 14:6 15:19 17:11 18:21</p>	<p>evidence 20:11,21 expect 13:17 expecting 12:2 experience 8:17 explain 10:22 14:6 18:16 explained 10:18 13:2 explains 10:4 explanation 12:2 20:2 explore 8:12 Explorer 11:7</p> <hr/> <p style="text-align: center;">F</p> <hr/> <p>fact 17:10 20:3 failure 7:17 fast 11:13,17 14:17 favor 5:17,19 features 19:11 feel 5:15 felt 8:1,17 field 3:18 5:14 9:2,8,11,13,14,1 6,17 12:6 14:7,9,19 15:2,11,17 16:12 17:15 18:3,4 20:15 fields 2:22 3:2,5 12:20 15:12,17 16:10 18:5 fight 21:1 figure 11:15 figured 7:17 10:12 fill 2:8</p>
--	---	--	---

Capital Reporting Company
 Russell, Dr. Christopher 03-21-2013

<p>finally 8:19 20:8,22</p> <p>first 2:15 6:9 7:4,12 12:11 17:13</p> <p>fix 7:18</p> <p>fixed 7:15 19:8</p> <p>flow 16:15 20:16,18</p> <p>flowed 10:20</p> <p>flowing 2:20</p> <p>flows 16:16 20:12,21</p> <p>flux 8:22 12:4,19 16:13 17:17 18:6 19:12</p> <p>force 4:14 18:12</p> <p>form 3:11</p> <p>formation 3:7</p> <p>formed 19:20</p> <p>forms 3:6 13:8</p> <p>forth 11:14</p> <p>fortunate 6:3</p> <p>Fortunately 18:14</p> <p>fortune 2:12</p> <p>forward 18:4</p> <p>friction 10:1</p> <p>front 20:10</p> <hr/> <p style="text-align: center;">G</p> <hr/> <p>gate 8:22</p> <p>general 12:12</p> <p>generated 2:22</p> <p>geomagnetic 10:6,7,18 11:1 13:1 19:10</p>	<p>geometry 15:21</p> <p>Geophysical 7:3</p> <p>geophysics 6:20,22</p> <p>getting 14:21 15:6</p> <p>giant 13:6</p> <p>Giovanelli 15:3,7,18</p> <p>glory 7:10</p> <p>government 6:5</p> <p>gradually 10:21</p> <p>graduate 6:22 7:7</p> <p>graduated 6:4 8:19</p> <p>graduation 15:5</p> <p>great 5:21</p> <p>greater 10:20</p> <p>Greenbelt 1:19</p> <p>group 7:8</p> <p>GSFC 1:14</p> <hr/> <p style="text-align: center;">H</p> <hr/> <p>haha 5:18</p> <p>Hahaha 2:5</p> <p>hard 9:19</p> <p>haven't 13:13</p> <p>heard 13:13</p> <p>heat 5:2</p> <p>heating 4:4</p> <p>heats 4:19</p> <p>heck 16:8</p> <p>held 20:5</p> <p>helped 14:6</p> <p>hereby 22:3</p> <p>high 6:16</p>	<p>highly 3:22</p> <p>history 16:18</p> <p>Holzer 7:1</p> <p>hope 13:19</p> <p>hopefully 13:15</p> <p>hurry 14:21</p> <hr/> <p style="text-align: center;">I</p> <hr/> <p>ICEE 20:13</p> <p>idea 15:14 19:15</p> <p>ideas 10:7 16:19,21 17:8,9 18:20</p> <p>I'm 4:2,6 13:20 18:18</p> <p>implication 16:3</p> <p>important 3:21 5:3 14:5,16 15:21,22 19:22</p> <p>Inc 1:13</p> <p>increase 17:16</p> <p>inertial 19:8</p> <p>influence 14:7</p> <p>influenced 13:10</p> <p>interact 5:1</p> <p>interaction 4:18 14:8</p> <p>interest 2:17,19 5:8</p> <p>interested 2:21 3:1,7,13,17 4:2,12,17,22 5:19 6:17 22:8</p> <p>internal 14:19</p> <p>International 11:7</p> <p>interplanetary 9:7,12 17:15</p>	<p>18:3</p> <p>Interruption 19:2</p> <p>interview 1:2 21:2</p> <p>intrinsic 12:20</p> <p>introduced 7:20</p> <p>invited 16:5</p> <p>involved 2:13 6:1,19 7:1</p> <p>involvement 5:11,15</p> <p>inward 9:18</p> <p>inwards 3:10</p> <p>ionosphere 13:9</p> <p>ionospheric 6:10</p> <p>ISEE 11:6</p> <p>it's 9:13,17 12:12,14 14:8</p> <p>I've 2:12 5:13 13:12</p> <hr/> <p style="text-align: center;">J</p> <hr/> <p>Jim 15:4,5,6,19 16:5</p> <p>job 6:5,9,14,17</p> <p>jobs 6:7 8:20</p> <p>joined 15:7 18:5</p> <p>joins 9:15</p> <p>Jupiter 12:8</p> <hr/> <p style="text-align: center;">K</p> <hr/> <p>key 18:17</p> <p>knew 17:6</p> <p>known 18:20</p> <hr/> <p style="text-align: center;">L</p> <hr/> <p>later 18:7</p>
---	--	---	---

Capital Reporting Company
 Russell, Dr. Christopher 03-21-2013

<p>launch 15:8 launched 7:4 launching 7:11 14:22 layers 3:14 4:13 learn 6:11 learned 13:12 least 12:13 led 9:6 life 11:4 line 20:15 linear 3:18 little 5:14,15 8:15,16 9:22 10:15 11:2 14:14 17:22 18:18 20:4 long 10:2 Los 2:12 lot 2:13 3:20 5:3 13:8,13,16</p> <hr/> <p style="text-align: center;">M</p> <hr/> <p>macroscopic 13:1 magnetic 2:22 3:2,5,7,13,18 4:13 9:8,11,14,16 12:5 13:4,5,6,8,13 14:3,7,9,19,20 15:10,11,16 16:12 18:4,12 20:10 magnetized 2:19 14:15 magneto 8:10 magnetometer 8:21 9:1,4 11:21</p>	<p>magnetometers 11:6 magnetopause 7:21 9:6,16,20 11:11 12:6,9,15 13:10,15 17:14,17 18:1,5,11,13,16 19:5 magnetosphere 3:16 4:15 7:22 8:1,7,11,13,15 9:8,10 10:21 11:10 13:3 16:10,15,17 19:14 20:10 mainstream 16:20,21 17:2 major 6:15 March 1:9 Maryland 1:19 may 5:5 maybe 6:16 12:14 measure 9:1 11:13 19:9 measurements 20:18 measuring 11:19 medium 9:12 Mercury 12:7 merged 18:5 mission 20:6 MMS 13:15 mode 7:17 model 18:2 models 11:18 12:13 modulated</p>	<p>10:12,17 months 19:5 motion 9:6 move 18:10 moves 9:18 17:17 moving 11:11,12,14,18 multiple 12:15</p> <hr/> <p style="text-align: center;">N</p> <hr/> <p>NASA 1:14 11:5,20 nature 20:20 necessarily 12:11 neither 22:7 neutral 15:9 16:14 19:16,17,18,20 nice 20:13 night 18:7 19:6 non 3:18 nonlinear 4:18 5:1 nor 22:7 notoriety 10:15 11:2</p> <hr/> <p style="text-align: center;">O</p> <hr/> <p>observation 18:17 Observatories 7:3 occur 14:11 odd 8:18 17:1 OGO 7:1,11 11:16 20:14 OGO-1 7:5 OGO-3 7:9 OGO-5 19:4</p>	<p>OGO's 7:4 8:4 okay 2:2,6,10,15,18 4:6,9,12 7:12,15,20 14:2 17:22 old 10:4 11:4 12:13 one's 5:18 opposite 9:14 18:3 opposition 20:7 orbit 8:5 11:8 19:8 orbiter 8:6 orbiting 7:2 8:2 ordinary 6:16 origin 20:5 others 7:19 outcome 22:8 outer 7:21 8:10 outwards 3:10 overall 16:16 20:1</p> <hr/> <p style="text-align: center;">P</p> <hr/> <p>paper 20:20 papers 17:8 paradigm 9:22 10:3,4 21:1 paradigm's 10:2 parallel 9:17 15:12 parameters 11:1 Paris 16:6,7 Parker 15:15 particles 4:1,21 particular 7:7 9:5 12:4 14:4,16 17:4 18:19</p>
--	---	---	---

Capital Reporting Company
 Russell, Dr. Christopher 03-21-2013

<p>party 22:7 pattern 16:11,16 pause 4:7,8 8:10 13:20,21 17:20,21 people 9:19 10:1 14:14 15:2,14 18:9 20:5 perfectly 12:11 period 10:20 person 16:20 personal 5:7 personality 16:22 perspective 8:14 ph 15:4 PhD 15:6 phenomena 3:18 10:16 12:9 14:11 phenomenology 20:1 Phone 1:20 physical 10:9 physics 2:11,19 6:12,16,21 15:10 PI 11:21 piece 8:16 plasma 3:19,22 4:15,19 5:2 20:12,15 plasmas 2:20 14:14,15 plasmoid 19:18,19 point 14:16 15:12 16:14 19:16,17,18,20 pointing 10:13</p>	<p>points 12:15 15:9,17 polar 8:5 pole 16:13 post 15:4 power 16:4 predicted 19:16 prepared 22:4 present 20:3 pressure 3:15 4:14 9:20 17:16 18:10 primary 2:17,18 problem 7:13 process 3:1 9:9 10:11,19 15:8 16:2 professor 2:11 6:20 7:1 program 6:6,8,19 proper 18:19 proposal 11:5 12:18 proposed 19:20 proved 17:12 publishing 17:8 pull 3:10 pulled 18:6 push 3:10 pushed 4:16 5:14 pushing 9:20 putting 19:22 puzzled 12:21</p> <hr/> <p style="text-align: center;">Q</p> <hr/> <p>question 2:16 5:6</p>	<p>6:1 quickly 15:8 quite 13:11,12</p> <hr/> <p style="text-align: center;">R</p> <hr/> <p>radio 6:9,11 rapid 15:15 rapidly 3:19,20 rather 6:20 15:17 reached 16:10 realized 16:9 realizing 16:2 really 11:8 receive 6:10 recent 20:6 reconnect 16:12 reconnection 3:1 9:9 10:11,17 12:10,15 16:2 17:7,10 20:9,19,22 reconnects 9:15 recording 4:8 13:21,22 17:21 19:2 reference 17:11 regime 17:5 region 3:3 8:7 regions 4:15 8:12 15:10 20:17 release 3:5 14:17 research 2:17,19 6:2 13:11 14:5 researcher 15:3 resist 10:2 rest 16:18</p>	<p>returned 18:8 returning 19:12 rid 14:21 ring 10:17 rolled 12:6 rope 3:11,12 ropes 3:8,9 12:5,20 13:5,6,8,13 Russell 1:4 2:4,6,10,18 4:12 5:10,13 6:3 13:17 14:2 17:22 19:4</p> <hr/> <p style="text-align: center;">S</p> <hr/> <p>satellite 6:10 satellites 7:2 satisfied 12:17 saw 12:19 scatter 5:2 search 8:21 9:3 second 4:7 5:6,22 seeing 13:16 self 3:9 semiannual 10:5 seminar 16:6,9 sending 12:17 13:6 sense 10:10 sent 11:5 12:18 series 7:2 sheath 8:10 sheets 15:16 shock 4:3,18 7:21 8:9 11:12</p>
---	---	--	---

Capital Reporting Company
 Russell, Dr. Christopher 03-21-2013

<p>shocks 3:17 4:17 silly 10:7 simple 10:22 simultaneously 12:16 sitting 16:6 situation 9:11 15:21 six 19:5 slamming 4:11 slightly 8:20 slows 4:19 smaller 4:3 5:1 solar 2:22 3:15 4:16 6:9,12 8:8 9:12 10:19 14:8 16:3 17:16 solstices 10:9 solve 12:11 somebody 8:15 someplace 6:7 somewhat 12:21 sort 8:14 9:22 southward 9:13 17:15 18:3 space 2:11,14 4:5 5:3 6:2,8,17,19 7:11 19:8 spacecraft 7:7,12 8:3,22 11:6,8,9,16,17 19:1 20:13,14 speed 15:18 spot 8:16 13:18 spun 7:13 stabilized 7:14</p>	<p>standard 20:2 start 14:1 started 9:5 12:22 15:7 17:7 19:9 statements 4:10 stays 19:8 stories 2:8 storms 10:18 11:1 13:1,7 story 16:5 streets 16:7 stress 18:12 strong 4:18 stronger 10:8 student 6:22 7:9 students 6:7 7:8 studying 6:9 9:9 16:3 subject 15:1 substorm 20:1,2,5 summer 6:5,6,9,14,17 sun 6:11 11:7 13:3,6,9 14:3,7,11,12,17, 18 19:7 support 17:8 supported 17:13 18:2 supposed 7:13 sure 11:20,21 surface 14:20 Sweet 15:15 switched 8:22 system 2:22 8:17</p>	<p>Systems 1:13 <hr/> T <hr/> tail 8:11 16:14 17:18 19:10,12,13 talked 5:22 talking 13:14 terms 12:12 13:2 tested 12:14 Thank 2:15 that's 2:5 3:21 5:21 7:2 11:8 17:14 19:18 20:2 THEMIS 20:6 themselves 4:22 theoreticians 18:15 there's 3:20 9:21 they'd 7:18 they're 16:8 thick 11:15 third 7:9 Thursday 1:9 tie 3:12 title 2:3 20:20,22 today 12:13 20:3 topic 5:19 topics 5:16 touch 5:9 touched 5:6 towards 14:22 TRANSCRIBER 22:1 transcript 22:4</p>	<p>transfer 3:3 transferred 6:21 17:18 19:13 transmission 4:14 transmit 4:4 transmitted 3:15 transport 16:12 Troy 1:8 2:4 try 2:6 5:17,18 trying 13:17 15:15 16:8 turns 15:13 17:15 18:3 twist 3:9 twisted 3:8 types 3:14 8:4 <hr/> U <hr/> UCLA 6:15,18 Uh-huh 5:12 unable 15:18 understand 8:16 9:20,21 12:22 14:13,14,16 15:20 18:11,15 understanding 9:7 understood 10:10 12:12 18:10 unexpected 12:1 University 2:11 un-paused 4:9 useful 11:9 <hr/> V <hr/> variation 10:5 various 4:14 8:12</p>
--	---	---	--

Capital Reporting Company
Russell, Dr. Christopher 03-21-2013

Page 7

<p>Venus 12:19,20 13:9</p> <hr/> <p style="text-align: center;">W</p> <hr/> <p>WASKO 22:3,11</p> <p>wasn't 11:19 12:17 14:4 16:21</p> <p>wave 4:3,19</p> <p>waves 4:2,4,22 5:1 6:9 7:22</p> <p>ways 4:5</p> <p>weather 6:2</p> <p>we'll 14:1</p> <p>We're 13:17,22</p> <p>Whenever 12:1</p> <p>whereby 3:2</p> <p>Whereupon 21:2</p> <p>whole 8:14 10:6 11:22 12:3</p> <p>who's 8:15</p> <p>wind 3:15 4:16 8:9 9:12 10:19 17:16</p> <p>won 21:1</p> <p>work 5:14 7:6,9 8:2 17:4 18:13</p> <p>worked 7:16 11:1 12:12</p> <p>working 8:6,21</p> <p>Wow 2:5</p> <p>wrapped 13:5</p> <p>wrong 7:15,18</p> <hr/> <p style="text-align: center;">Y</p> <hr/> <p>you've 6:6</p> <hr/> <p style="text-align: center;">Z</p> <hr/>	<p>zero 15:11</p>		
--	--------------------------	--	--

(866) 448 - DEPO