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John Heavisides
University of New Hampshire - Main Campus

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Higher Levels of Confusion: Rocket Sensors in the Northern Lights

—John Heavisides (Editor: Elsa Lindgren)

Since February 2012, I have been part of the Magnetosphere-Ionosphere Research Laboratory at the University of New Hampshire (UNH), which often participates in launches of small rockets into the *aurora borealis*, the Northern Lights, to gather data about that beautiful and mysterious phenomenon. Because I was only a freshman physics major at the time, I was nervous about the kind of work I would have to do in the lab run by my advisor, Dr. Marc Lessard, an associate professor in the Space Science Center. Before I began at the lab, I received a piece of advice from one of my professors: "You will be very confused at first," he warned, "And even after a lot of work, you will still be confused. But you will be confused at a higher level." I have always found those words worth bearing in mind. During my very first week in the lab, I was surprised to find that most of the lab members, along with Dr. Lessard, were away on a mission to launch a small rocket from a base just north of Anchorage, Alaska. (The rocket mission was known as the Magnetosphere-Ionosphere Coupling in the Alfvén Resonator, or MICA.)

Two years later, in the summer of 2014, data about electron temperatures gathered from that very mission would be the focus of an International Research Opportunities Program (IROP) grant that I received from UNH's Hamel Center for Undergraduate Research, a grant that would take me both to the University of Oslo in Norway, and to the very highest levels of confusion.

The rocket is launched into the aurora (Courtesy of Terry E. Zaperach, NASA).

Studying the Northern Lights using Rocket-Based Sensors

The Northern Lights are native to the cold, polar parts of the world. To physicists, they are the aurora, the visible effect of particles from the sun being scooped up by Earth's magnetic field and slammed into the upper atmosphere. When the particles hit the air, they release their energy in distinctive bands of green and red. As the light is created, the atmosphere around these displays is turned into a plasma: a super-hot state of matter beyond gas.

In this plasma, untold trillions of electrons swarm. Electrons are the particles responsible for electricity, and in many ways this electrically charged part of the atmosphere works like the wiring inside your house, if your house were hundreds of miles wide. Quite a bit is still unknown about how the electrons behave in the aurorae, leaving the origin of the

Assembling the MICA rocket in Alaska (Courtesy Ian Cohen).

phenomena still something of a mystery. Learning how electrons move would deepen our knowledge of how the sun affects the Earth's magnetic field. Furthermore, aurorae are some of the most visible results of a solar storm hitting the Earth. Solar storms, an astronomical event where the sun ejects a huge amount of energy in one outburst, could theoretically make satellites inoperable and destroy electrical transformers. Because the aurorae are so connected to these events, large efforts are being made to understand these beautiful, but potentially devastating phenomena.

Unfortunately, the upper atmosphere is a difficult place to study. One of the most effective ways to see what is happening is to actually go there and take measurements, a tall order for humans but the perfect job for a small rocket. Due to the expense and complexity of rocket launches, research groups from around the world collaborate on missions, sharing the expense of the rocket which carries sensors relevant to their investigations.

For the MICA mission, my lab had joined with Dartmouth College, Cornell University, and the University of Oslo to build sensors for the launch of a small rocket. The goal of the mission was to study the conditions inside the aurora as the rocket flew through it. If successful, the data gathered would provide insight on the energy and density of the electrons, as well as how they were moving in the upper atmosphere. My lab contributed a small device with a productive flight history named ERPA that would record the electron temperatures. ERPA had a counterpart sensor, designed and built by the group from Oslo, which would take electron density measurements.

Improving the Rocket's Efficiency

During preparation for the launch, the head of the Norwegian team, Professor Jøran Moen, noted that our two universities had similar sensors. In fact, their similarities might mean that one sensor could be used to predict (and essentially measure) the data of the other. The possibility that one sensor could do the work of two was enticing; the rockets flying through the aurora are relatively small, and can carry only a limited amount of weight. Frequently, needed data goes uncollected because a sensor was too heavy to fit on the rocket.

If the mission team were able to eliminate an entire sensor from the final payload, it would mean that future missions could collect even more data for little extra cost, allowing more science to be done without needing a larger budget. Even better, older data from prior missions could be reviewed, somewhat like retroactively adding an extra sensor on a mission that had flown years ago. The main obstacle to creating a dual-use sensor from our two sensors was that no one on our two teams had any idea how to use one set of data to predict the other set. Someone was going to have to look at the data the two sensors collected and try to make that connection. That person was also going to have to work very closely with the other team, more closely than simple e-mails or Skype calls could accommodate. As fortune would have it, I was selected to be that person.

The author (with coffee) at his workspace at the University of Oslo.

I arrived at the University of Oslo in mid-May, 2014, and started to settle in. Before even finding my room, however, I made my way to the physics laboratory. It was exciting to meet my Norwegian counterparts. Despite several thousand miles between me and Durham, I encountered an atmosphere I was already familiar with. Language wasn't a problem; people in the lab came from all over the globe, and English was the common tongue. In what must be a universal tradition, I was quickly introduced to the coffee machine and shown how to use it, mirroring perfectly my first day in the lab back at UNH. Feeling immediately comfortable with my surroundings, I was eager to get to work.

Finding a Relationship between Temperature and Density

During the first few days, I looked at what we already knew about the problem. A graduate student in the lab at UNH had taken an early stab at correlating the data sets using some established equations, but the work remained incomplete. After discussing this with the Oslo team, I decided to look at the code he had written to run the data analysis, and see what could be improved. Although I had experience with the programming language (Interactive Data Language, or IDL) that we were using for the project, the first answers that were returned didn't seem to make any sense whatsoever. There were evidently some bugs that needed to be worked out, so my next few days in the lab were spent examining every line of code that had been written.

Much to our chagrin, the code didn't seem to be flawed. We decided that our approach must have been wrong, so we backtracked and tried to develop a new approach to the model we had been using. There were lots of discussions, many pages of paper with equations furiously scribbled all over them, and very little actual progress over the span of nearly a week. Despite a few years of research experience, this was the first time I really understood how messy real research can be. It is possible to have all the tools and formulas at your disposal, but the data will stubbornly do its own thing, resisting all attempts at being understood.
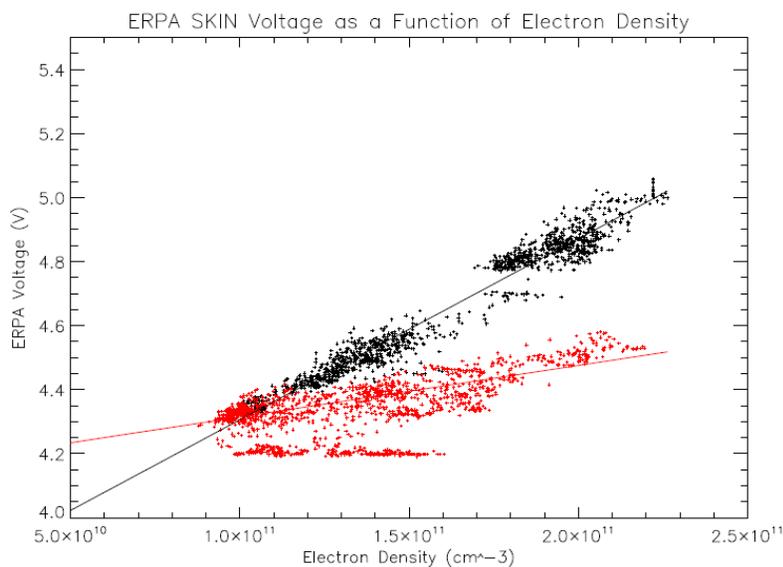

Figure 1: The correlations show two distinct trend lines for the two sensors.

In frustration with this theoretical approach, I decided to simply plot the data sets against each other. To our great astonishment, the results actually looked reasonable. (See Fig. 1) There was a strong, linear-looking correlation between the data we had from ERPA and the recorded density—the exact kind of relationship we were interested in. The mixture of emotions from the team could be felt in the air. On the one hand, we had something we could really work with; but on the other, there was very little justification for what we were doing. No theory as we understood it made the data behave this way. I had been working primarily with two people: a physicist who interpreted the data, and the engineer who designed the density sensor. The physicist shook his head, concerned that the use of "magic numbers" was not a well-grounded approach. The engineer shrugged his shoulders and figured that, so long as the results were okay, a suitable theory would appear somewhere.

Further Frustrations

Science, when carried out properly, demands that results be reproducible. This is even more important if the results are suspect. I decided to test our methods and "magic numbers" against another data set from a launch several years prior to the MICA mission, where a different sensor had measured electron density. Work shifted to incorporating that data set into the existing code. Once that work was completed, I was eager to look at the output.

Confusion immediately set in. The results were nonsense. How could a method that worked so well on one data set be so wrong on the next? I fiddled with the equations. I tried different ways of managing the data. I rewrote the code from scratch in an attempt to weed out errors. Nothing. Time was ticking, months shrinking to weeks and then to days. Most frustrating was that there was no way the first data set matched so well simply by accident. I sent for more data sets, only to learn that there were no more available that had come from UNH's sensor. No answers, no theories ever presented themselves.

And, like that, I had to pack my bags and return. I could almost smell the scent of failure in the air. Was I a bad scientist? Instead of helping to clear up a little the problem of creating a dual-use sensor, it seemed that my work had only muddied the waters. Had I wasted everyone's time? I was nervous about meeting with my advisor and telling him that I really didn't have much to show for my nine-week absence.

Returning to UNH

When I met with Dr. Lessard, however, my understanding of the situation changed. Instead of disappointment, I was met with congratulations: "These are some really tantalizing results," he remarked. The advice I had received years earlier came flooding back. Real science is a messy thing that likes to avoid giving direct answers. Did I have a definitive result? No, but in science that is an answer in its own right. The next person to pick up this task can start at "maybe," instead of "nobody knows." Like me, they would be confused, but they would be confused at a higher level.

As for myself, I have settled back into my final year at UNH. I have a few different projects going on around the lab, and my work with all of them has been better informed from my time in Norway. I would like to think that I am a better scientist because of it. I have learned that questions are often more valuable than answers. As I move forward with my studies and my work, I am learning to be comfortable with my confusion. The goal is not necessarily to have made sense of it all, but rather to keep working until you reach that next level. Answering questions with yet more questions might feel frustrating, but that is how we know that we are making progress.

The work I have been privileged to do in this project has been possible only through the incredible generosity of many people. I would like to thank my mentor, Dr. Marc Lessard, for providing me with unlimited guidance, insight, and opportunity to do the things I have always dreamed of. I will be forever grateful to the Hamel Center staff for the support and confidence they have given me, and for the selfless contributions from my donors, Frank and Patricia Noonan and Sam and Sarah Paul. I cannot thank the team at the University of Oslo enough for their overwhelming hospitality and friendship. Finally, I would like to thank everyone who has helped me reach this point in my life and career. I will never forget the kindness you have shown me.

Author and Mentor Bios

John Heavisides will graduate in May 2015 with a bachelor of science degree in physics. From Goffstown, New Hampshire, John decided to attend the University of New Hampshire after he learned that UNH had something called the Space Science Center, which offered numerous resources and opportunities for students. He credits the television shows he watched growing up, like *Star Trek,* for initially piquing his interest in science and space. John decided to study physics because he likes to "understand how everything works at the most fundamental level." In addition to receiving the International Research Opportunities Program (IROP) award for his research in Oslo, Norway, John's team was also a finalist for the 2014 Social Venture Innovation Challenge for their "Food to Fuel Project," which proposed using food waste to "produce clean fuel sources and fertilizers, thereby reducing its contribution to climate change and landfill space." In the future, John is considering research in a new area—not space, but the ocean. He is interested in applying his physics knowledge to either oceanography or ocean engineering.

Dr. **Marc Lessard** is an associate professor in the Department of Physics and Space Science Center at the University of New Hampshire. He has been at UNH for ten years. His research focuses on the ionosphere, specifically on the question of how energy from the solar wind finds its way into the ionosphere. Dr. Lessard has served as a mentor for many undergraduates and has worked with students abroad on three different IROP projects, including John's. "This [project] turned out great," he said, indicating the results will contribute to a research paper to be published later this year. He encourages his students to work on their writing skills. In physics, he said, "writing to a wide range of audiences is very important."

Dr. **Lasse B. N. Clausen** is a research associate in the Department of Physics at the University of Oslo. He studies various aspects of the solar wind-magnetosphere-ionosphere interaction, from the dynamics of large-scale current systems over wave-particle interactions, down to small-scale ionospheric turbulence. He was the local contact person for John, helping set him up in the lab and discussing with him the details of his project and possible aspects to explore. Dr. Clausen said he was very impressed with John, "because he chose to cross the Atlantic in order to live and work in a foreign country for over two months.

Professor **Jøran Moen** is the head of the Department of Physics at the University of Oslo and was a co-investigator on the MICA rocket. He helped arrange John's summer work.