rio0.png :: LONG TITLE

Hi I'm E A Roy and I'd like to talk to you today about the project that earned me a Master's Degree in Space Physics at the University of Calgary.

My thesis has this long precise and a little bit intimidating title... Investigation of Particle Drift Trajectories in Near Earth Night Side Magnetosphere Using Riometers... but if we go to the next slide you can see...

rio1.png :: SHORT TITLE

This is the short title. I do like this one better, it's much easier to parse. Basically I modelled electrons moving around the Earth.

I'll tell you what that means and why it matters, but first let me give you some context for the field of Space Weather.

rio2.png :: NEAR EARTH SPACE

The Sun outputs a huge stream of charged particles called the solar wind. This solar wind interacts with Earth's intrinsic magnetic field to create a lot of interesting turbulent plasma physics in near-Earth space. This kind of turbulence is called a geomagnetic storm, and the study of it is called Space Weather.

An example of space weather affecting human life is the Carrington Event. This was when a coronal mass ejection, a huge burst of unusually dense plasma came out from the sun and hit Earth. This was devastating for our electrical infrastructure, which in 1859 was mostly just telegraphs. (It melted wires and started fires which does rhyme, but was actually terrible.) If this were to happen today, a huge burst of current running through every wire in every building in every city on the planet... natural disaster doesn't cover it. This is why the study of space weather and geomagnetic storms is so important.

So. Studying geomagnetic storms! When a geomagnetic storm is localized in an area above the surface of the Earth we call that pocket of turbulance a substorm. One of the signifiers of a geomagnetic substorm is the Aurora, or the Northern and Southern Lights. So anywhere you can look up and see Aurora, you know there is some really interesting plasma physics happening right above you.

An earlier substorm signifier, you can think of it like an early warning of Aurora, is a sudden increase in the electron population of the ionosphere – an electron injection. (You're going to hear that phrase a lot.) So when you see a sudden increase of electrons in the ionosphere, you know that a substorm has started. This is why I'm interested in electrons particularly.

rio3.png :: SATELLITES

The go-to method of observing electron injections is in-situ, using electron flux detectors on a satellite. Here's an example of that, from the Van Allen probes of Los Alamos, this is RBSP-A and B.

Time is on our x axis, and electron flux on the y axis. Each coloured line corresponds to a different energy bin, so the red line is showing us flux with respect to time of the lowest electron energy range observable for this equipment.

A dispersed injection event, looking at the bottom panel circled in red, we see the lower energy particles in red and yellow arriving later than the higher energy ones in green and blue.

This means the observation must be some distance away from where these electrons entered the ionosphere, as the lower energy slow moving electrons had time to fall behind the high energy fast moving particles.

To contrast with that, in the top panel circled in green, we have a dispersionless event. You can see all these coloured lines jumping up at once. Every energy channel gets an increase in flux at the same time. Instead of that smooth curve, we see a sharp jump.

Because these electrons all moving at different speed are still bunched up together like this, we can tell this must be close to where they entered the ionosphere together. They haven't had time to spread out. This dispersionless electron injection - as close as we can get to the very second this substorm started - this is what we're looking for.

rio4.png :: RIOMETERS

The cool thing is you don't need satellites to observe electron injections. A riometer, a relative ionospheric opacity meter, is a very simple device that just uses a conductive wire and a voltmeter to observe radio waves. Any change in magnetic field in the ionosphere above them will cause the free charges in a conductive material to move to one side or the other, creating a potential difference we can measure with a simple voltmeter. That's how this really simple device can measure radio waves. I like to affectionately refer to them as coat hangers.

It's at this point in the talk that you'll understand what I mean when I tell you my elevator pitch to non-scientists is “I use coathangers to predict the aurora”.

Here's an example of some typical riometer data, time on the x axis and volts on the y. In the green this nice smooth well ordered curve is the cosmic radio noise, radio sources mostly from our own galaxy. In red is radio waves coming from the sun. In blue is a sweet spot – a discrete deviation from the predictable CRN signal. This is a result of a bunch of electrons appearing in the ionosphere above this riometer and absorbing the radio waves we expect to observe from the galaxy.

The note about Kellerman 2014... I want to point out that while this finding tells us that riometers are most sensitive to injected populations around 60keV, this isn't necessarily the energy of every observation. I'll get back to this later.

We know that riometers can observe electron injections, but satellites also tell us about the energy of these particles. That leads us to ask: Can we use these kinds of riometer observations to talk about the ENERGY of these injected electrons?

rio5.png :: PLAN

Here's the plan. To show how we can use riometers to talk about the energy of these injected electrons, I needed to do two things. First build a model of the magnetosphere. Then use that model to analyze real-world observations of an electron injection drifting around the Earth.

To build a model of our magnetosphere, I'm gonna throw some terms out at you... I used a dipolar magnetic field, the Burke Voland Stern electric potential models. I set the model in the equatorial plane and used guiding center motion approximation, so I don't have to consider things like pitch angle and curvature or polarization drift.

At each step in this program I calculated the EXB and GradB drift velocities that particle would experience as well as its change in energy. Then I numerically integrated the change in position using the vector form of the fourth order Runge Kutta adaptive algorithm.

I used the timing between real world riometer observations as bounds for the model I built, and from that I determined an energy range that these drifting electrons would have to be moving with.

Let me give you a quick look at the model...

rio6.png :: MODEL

Here's an example of how I verified the behaviour of my model. I made a lot of characteristic graphs like this one, showing speed as a function of radial distance, and I compared those to figures of published works, to make sure my model was behaving physically.

I also did a lot of test cases, like you see in the dotted black lines here, I showed what I calculated those speeds should be by hand and compared it to the model's results. If you want to get into the specifics on this calculation I will be putting up a bonus slide getting into the vector calculus behind that result but for now lets move on to the next slide.

rio7.png :: ANALYSIS

So here's what I used my model for.

On the left is a timeline of all of our observations for an event I found I could trace in riometers in Canada all the way to Finland.

The closest observation we had to substorm onset, the most dispersionless event, the sharpest absorption curve, we saw at Rabbit Lake in Canada, and it took 17 minutes for that electron population to be observed in Abisko Finland.

I calculated where in the magnetosphere's equatorial plane would have a footprint at Rabbit Lake. And I dropped a bunch of test particles of different energies into my model to see which starting energy would take 17 minutes to be observed at Abisko.

So from the screenshot I've got here of running these simulations, you can see that the time difference we're looking for of 17 minutes falls right between 150 and 175 keV, kilo electron Volts.

The neat thing here is that this directly contradicts an assumption that my supervisor Emma Spanswick had noticed people in our field were making when she brought me the idea that turned into this project. Because the Kellerman paper in 2014 found that riometers were most sensitive to 60 keV electrons, people had been ASSUMING that all riometer observations were of 60 keV electrons. Which wasn't what that paper had said at all. It's very important to be careful about what a finding actually means.

What I've shown here is that this population of electrons, which was observed by riometers, could not have been drifting across the Atlantic at 60 keV. In order to make it to Finland in the time that it did, it turns out it would need to be about three times more energetic than that.

Now to be precise about it, which you always should... It is possible that these higher energy particles once they arrive at Abisko are causing cascade reactions that result in 60 keV electrons being OBSERVED, but I proved here that there is no way the DRIFTING population could have had that energy.

Of course that is a very nit picky little detail, but it's not the only result of what I've shown you here. Let's talk about...

rio8.png :: IMPACT

Impact! So what does this mean for the field of Space Weather?

Well we don't need satellites to calculate statistics on the energy of injected electron populations. This is great news because satellites are expensive and riometers are cheap. Satellites need to be launched into space, and good luck fixing them once they're up there. But riometers are extremely simple!

Satellites need to be at the right place at the right time but riometers are in the right place ALL the time because they don't move!

It means we can use existing databases of riometer observations to talk about LARGE scale GLOBAL statistics, because have arrays of devices spread out over a huge surface area we can actually watch these injections move across the surface of the Earth. This is something that fast moving satellites simply can't do.

Actually, my next project after this with my co-supervisor Eric Donovan and the CSA, was using predictive algebra to pull out the characteristic shape of a dispersionless injection in riometer data. We were going to teach it to a machine learning algorithm and set it loose on the existing database of riometer observations the UofC has just sitting around gathering dust. So, really interesting, immediately actionable implications here!

So. Not only are riometers more cost effective, they are also much more powerful tools for observing substorm onset.

rio9.png :: SUMMARY

To summarize, I tracked an electron injection with riometers, drifting around the Earth from Canada to Finland.

I built a model of electron drift motion, and used my model with timings of riometer observations to infer the energy of the injection event, and verified my analysis using satellites.

The impact of this result is that we can pull powerful global statistics from existing riometer databases with just a little bit of clever programming.

rio10.png :: REFERENCES

And that's what I have for you today! Here is a list of my references, I'm also including a list with clickable links on this webpage underneath the element playing this audio, and you can get the transcriptions for this audio there as well. Thanks so much for showing an interest in my research and have a lovely day!