Specification and Prediction of the Coupled Inner-Magnetospheric Environment (SPeCIMEN)

J. Bortnik[1] **and Craig J. Rodger**[2]

1. Dept. of Atmospheric and Oceanic Sciences UCLA, United States of America.

2. Physics Department, University of Otago, Dunedin, New Zealand.

AOS UCLA

UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo
NEW ZEALAND

6th VERSIM Workshop 2014
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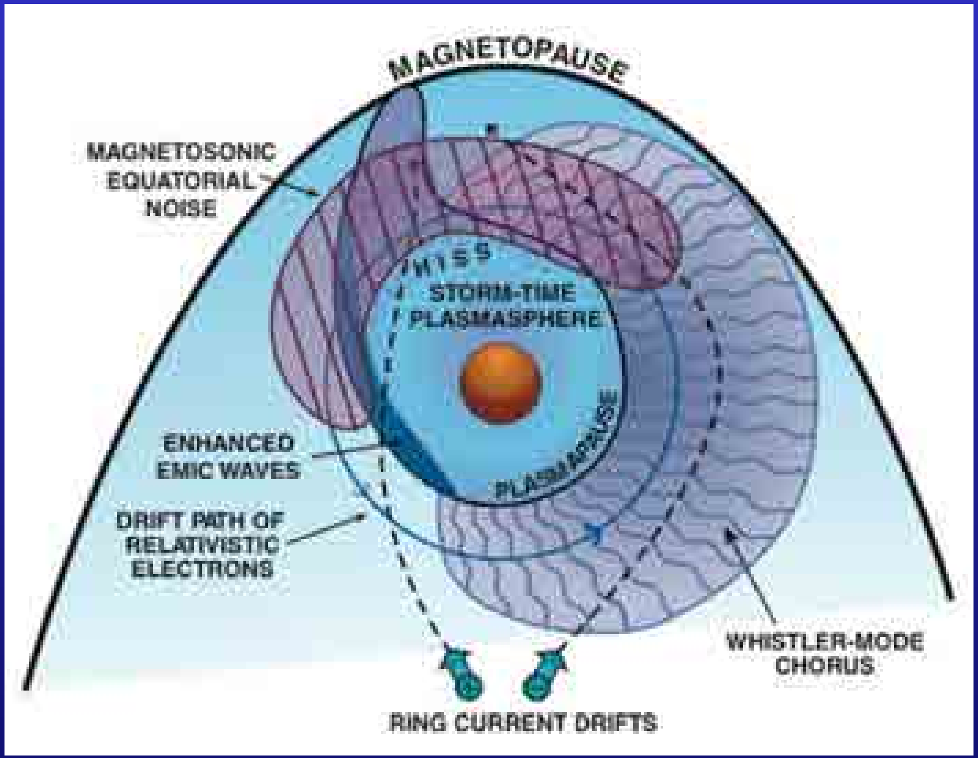
Dunedin, New Zealand

SPeCIMEN Objective

Prediction and specification of the Earth's inner magnetospheric environment

1. To high accuracy,
2. Based on inputs from the Sun and solar wind,
3. Employing a combination of physical and statistical predictive modeling.



Thorne [2011] GRL "frontiers" review

In just 10-years (the "Dst mistake")

Reeves et al. (2003), *Geophys. Res. Lett.*, 30(10), DOI: 10.1029/2002GL016513.

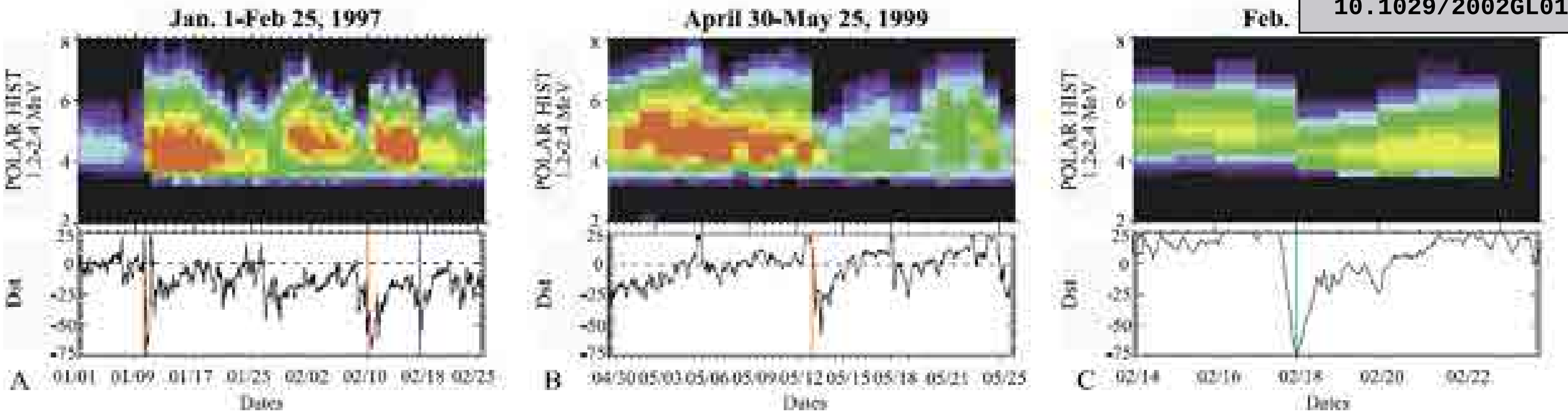


Figure 2. Details of three types of responses. (A) A strong increase of relativistic electron fluxes in response to the January 1997 geomagnetic storm. (B) A dramatic and permanent loss of electrons throughout the outer belt in May 1999. (C) A −100 nT storm in February 1998 with peak fluxes after the storm very similar to peak fluxes after the storm.

Not so long ago the community was struggling to understand or predict what happened to radiation belt fluxes after big storms.

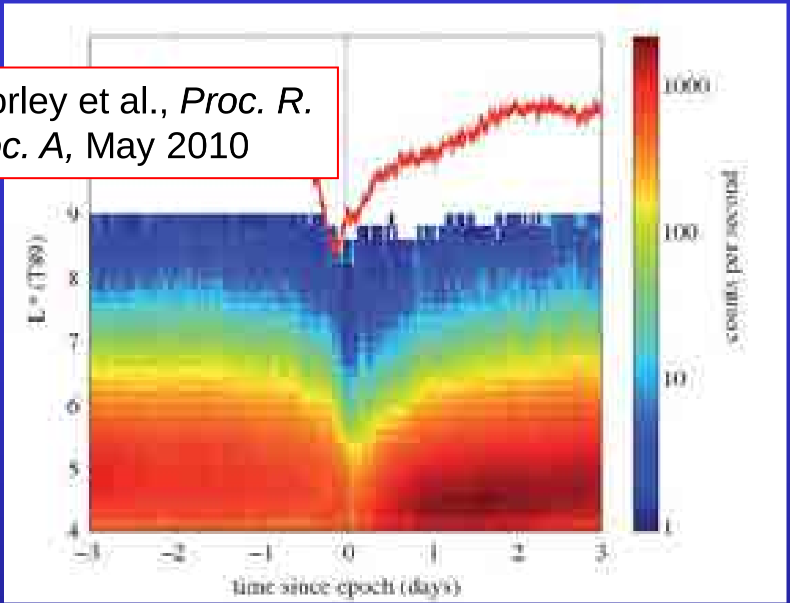
Ten years ago Geoff Reeves (LANL) looked at measurements after big storms (Dst<-50nT) and found a lot of different behaviour after these storms.

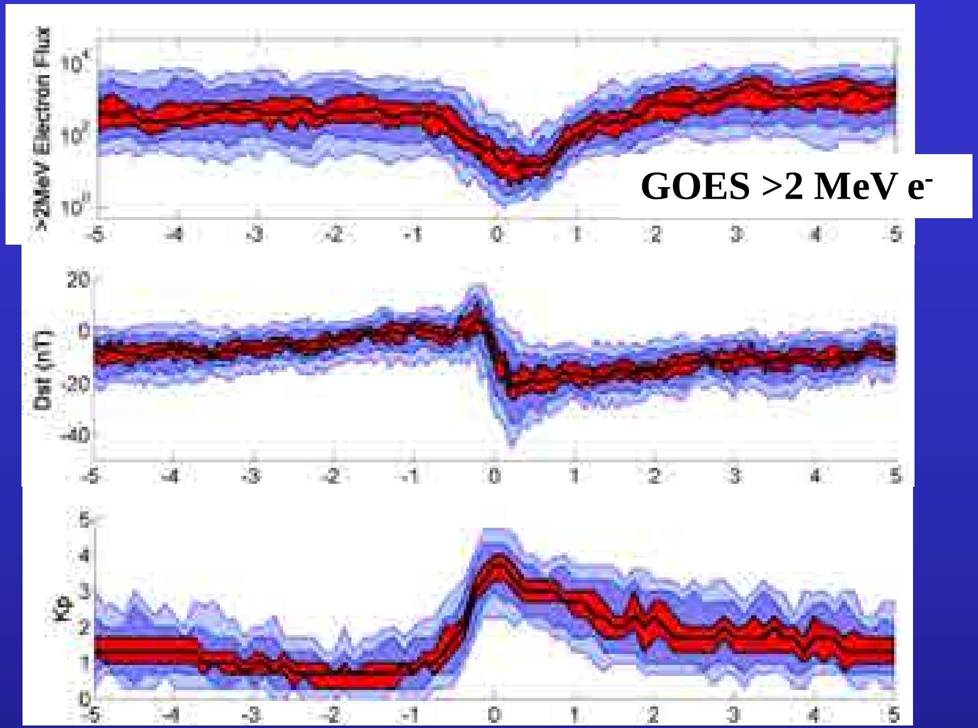
Half led to increases in flux, 20% to decreases, and 30% to no-change.

A view was developing that "if you had seen one storm" you had only seen one storm - they were each unique (like a snow-flake). This made it hard to understand the detailed physics in each event, or build predictive models, as there was no consistent response.

But that was then (now, after the "Dst mistake")

Morley et al., *Proc. R. Soc. A*, May 2010





By 2007 (or so) the community was coming to realise that continued classification of geomagnetically disturbed intervals by Dst alone did not work so well, and one could find examples of consistent physical processes occurring storm after storm. This initially started by looking at changes around high speed solar wind stream interfaces and smaller geomagnetic storms (which consistently led to large radiation belt increases).

If you saw one of these storms, you could describe the others!!

Example from Steve Morley of dropouts after high speed solar wind streams followed by an enhancement in fluxes - a process which is highly repeatable.

What's the Physics here?

There is now growing understanding of the linkages which are taking place, and how the inner magnetosphere responds, consistently. It appears that the same physics occurs around each one of these events (at least to first order). Various people have been explaining the physical thinking here. One example is that below:

High Speed Solar Wind Stream

↓

"Continuous" substorms

↓

Injection of "low-energy" protons and electrons & convection

↓

ELF/VLF waves stimulated

↓

Acceleration of RB electrons to relativistic energies

I want to give credit to **Yoshi Miyoshi (STELAB, University of Nagoya)** who gave a particularly clear set of talks at the Japan Geosciences Union meeting in 2012 – he laid out this process, and provided experimental and/or theoretical evidence for the steps. This helped my understanding a great deal.

The improving physical understanding puts is in a good position to be able to **specify** and then **predict** the evolution inside the **Inner Magnetosphere** (**SPeCIMEN**).

Why now?

1. Space weather- lots of expensive/ critical space assets.
(it <u>should</u> be done)

2. Lots of data: Recent RBSP mission launched, and more to come (plus the ground).
(we have lots of observations)

3. Theoretical tools, numerical techniques and computational power.
(we have the tools needed)

Space weather

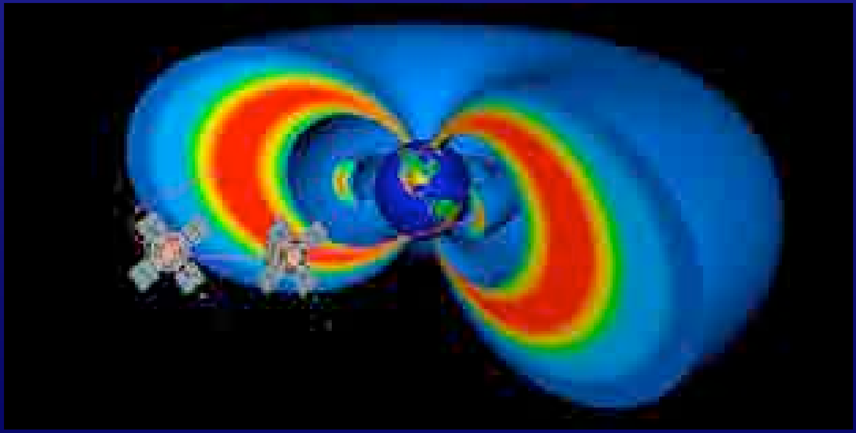
Roughly 450 operational satellites in GEO.

- MeV electrons: internal charging; 0.1-100keV: surface charging; MeV ions: SEU
- ¾ satellite designers said that internal charging is now their most serious problem, 2001 ESA study [*Horne*, 2001]
- Examples: Intelsat K, Anik E1 & E2, Telstar 401, Galaxy-4, Galaxy-15
- Costs: ~$200M build, ~$100M launch to GEO,
  3%-5%/yr to insure; e.g., in 1998 $1.6B in claims, but $850M in premiums

Data: Van Allen Probes/RBSP

1. Discover which processes, singly or in combination, accelerate and transport radiation belt electrons and ions and under what conditions.
2. Understand and quantify the loss of radiation belt electrons and determine the balance between competing acceleration and loss processes.
3. Understand how the radiation belts change in the context of geomagnetic storms.

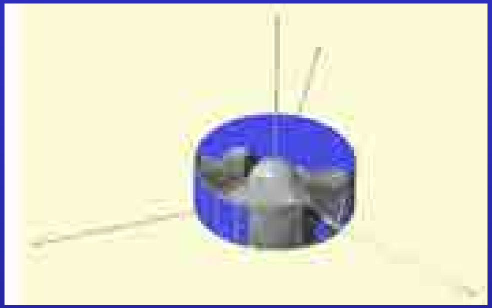
- NASA Living With a Star
- Launched 30 August 2012
- 2 probes, <1500 kg for both
- ~10° inclination, 9 hr orbits
- ~500 km × 5.8 Re

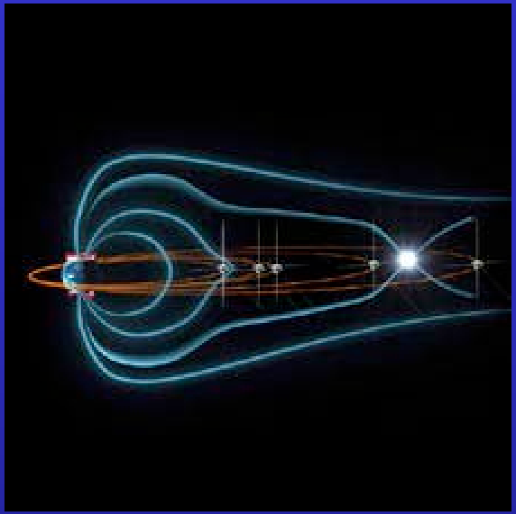


Yet More Relevant Missions (just a few)

BARREL (NASA)
Launch 2012/13 & 2013/14
2 campaigns, ~20 balloons each

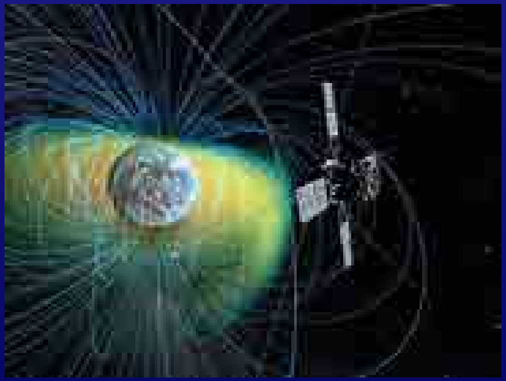
RESONANCE (Russia)
Launch ~2014, 4-spacecraft
Orbit:1800 × 30,000km, ~63° incl.

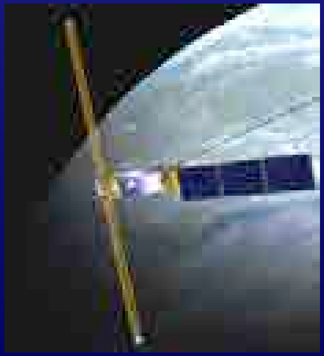




THEMIS (NASA)
Launch Feb 17, 2007
5 identical probes (now 3)

ERG (Japan)
Launch ~2015, GTO





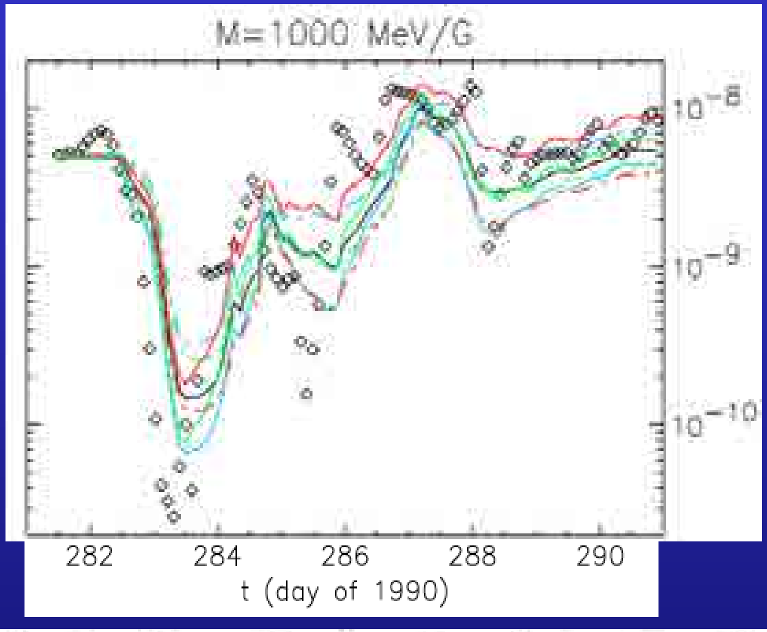
DSX (US AFRL)
Launch ~2014-2015
MEO, wave/particle

Theoretical tools

A large number of theoretical tools have become available in the past decade. These provide physical insight, but its hard to capture all physics.

Diffusion modeling (theory: cross-terms, 3D diffusion matrix)

Test-particle based modeling (nonlinear phenomena in wave-particle interactions, drift-resonant interactions)

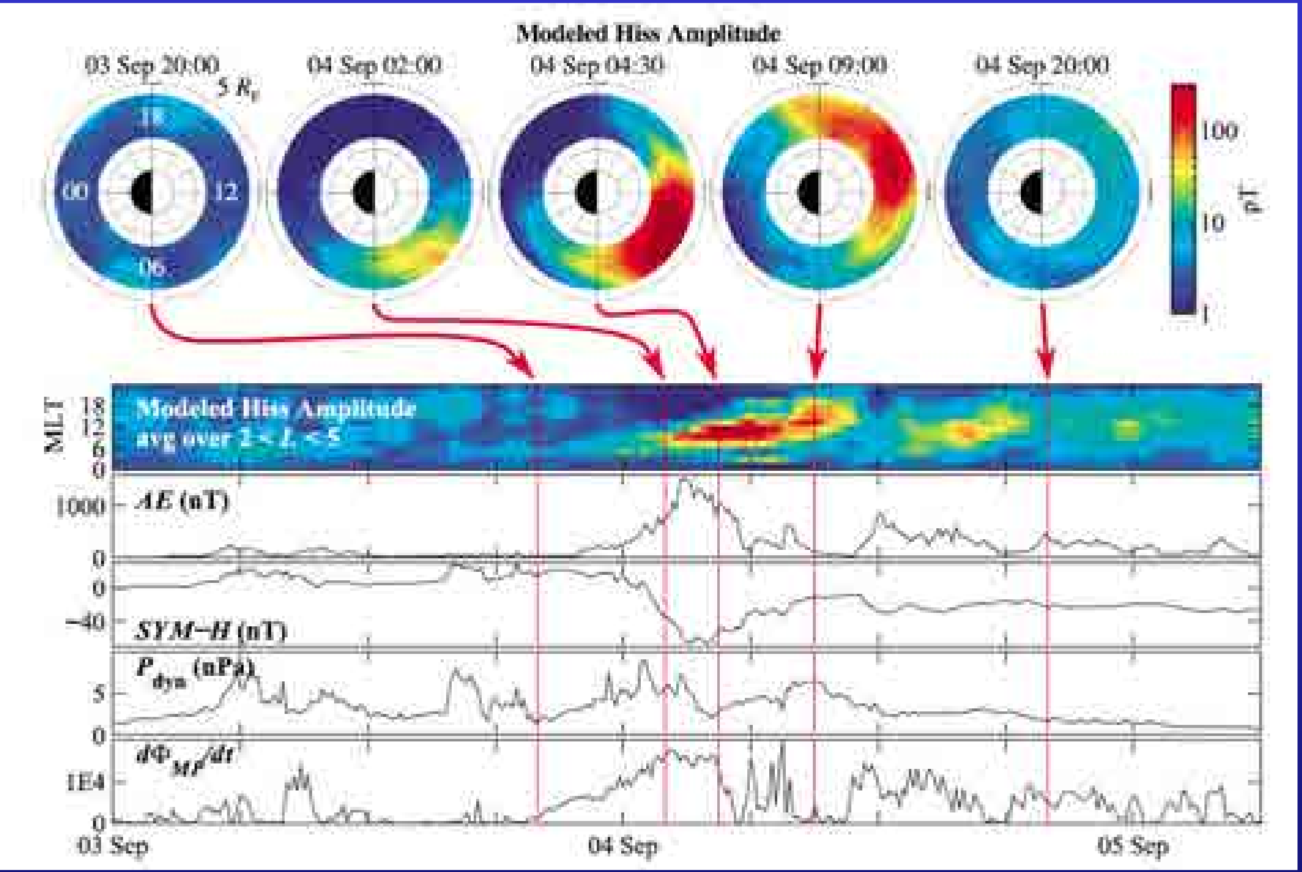


$$\frac{\partial f}{\partial t} = \frac{1}{G}\frac{\partial}{\partial \alpha_0} G\left(\frac{D_{\alpha_0\alpha_0}}{p^2}\frac{\partial f}{\partial \alpha_0} + \frac{D_{\alpha_0 p}}{p}\frac{\partial f}{\partial p}\right) + \frac{1}{G}\frac{\partial}{\partial p} G\left(\frac{D_{\alpha_0 p}}{p}\frac{\partial f}{\partial \alpha_0} + D_{pp}\frac{\partial f}{\partial p}\right) + L^2 \frac{\partial}{\partial L}\frac{D_{LL}}{L^2}\frac{\partial f}{\partial L},$$

Albert et al. [2009]
3D modeling

3.2 Numerical techniques

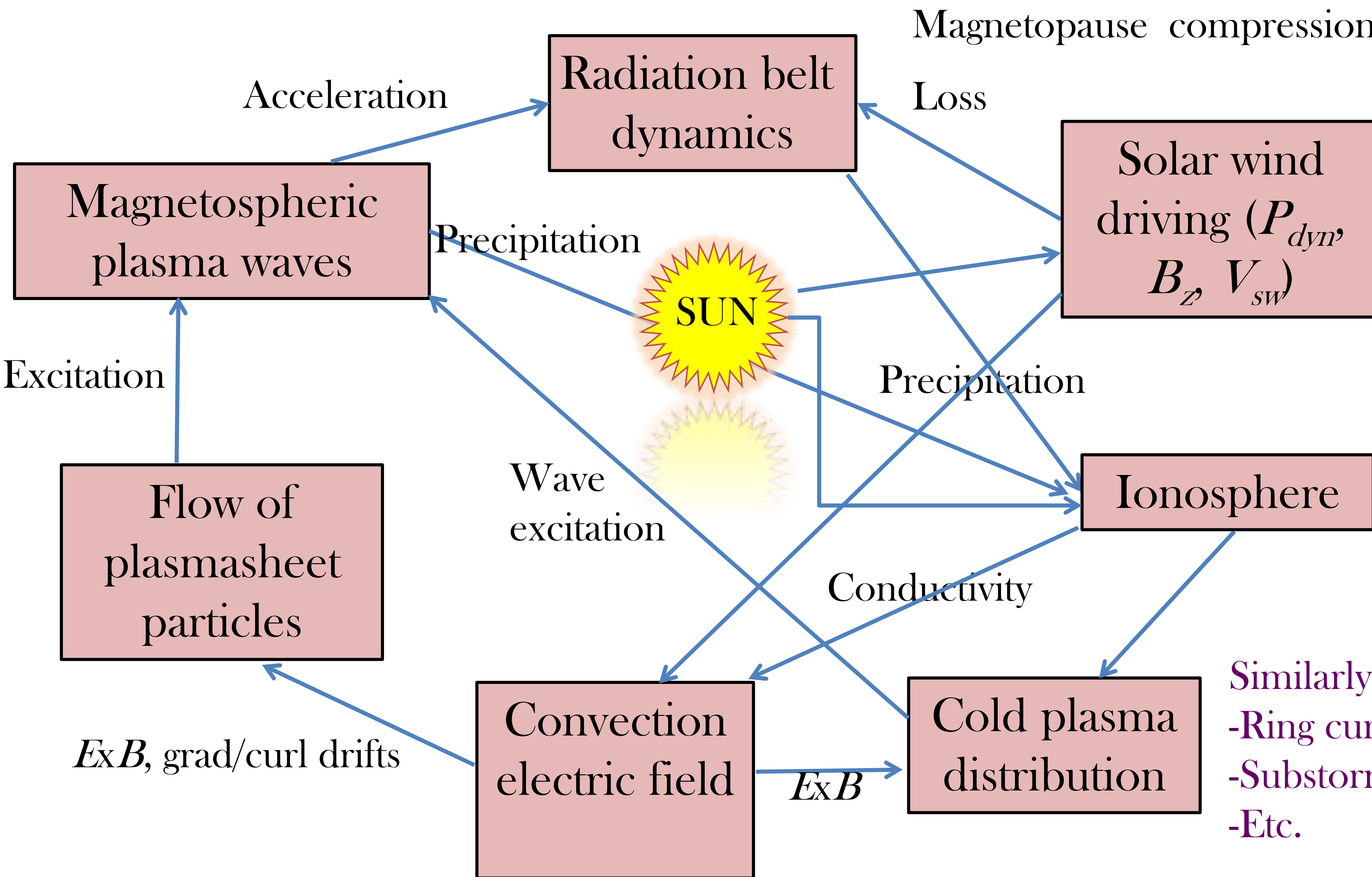
Golden et al. [2012]
Multiple linear regression



Numerical "learning" models: capture details, but no physical insight
Multiple linear regression; data assimilative; NARMAX; "mutual information and cumulant based cost"

It's a complex system!

And understanding it will require a lot of people with different knowledge and different backgrounds (remember, we span ~6-orders of magnitude in Energy).



Similarly:
- Ring current
- Substorms
- Etc.

SPeCIMEN Approach

Large scale collaboration between physical modelers, predictive modelers, and observationalists.

Four temporal phases (spanning roughly the 4-5 year project):

1. Improvement of predictive models & further development of theoretical models, with a view to integration
2. Fusion of predictive and physical models
3. First generation 'complete' model development, comparison with multiple data streams
4. Feedback and refinement

All of these phases must be informed by observations! Tools are being developed to help share and visualise experimental observations.

White paper team - from proposal stage

Jacob Bortnik (USA)
Craig Rodger (NZ)
Richard Thorne (USA)
Mark Clilverd (UK)
Richard Horne (UK)
Yoshi Miyoshi (Japan)
David Shklyar (Russia)
Ian Mann (Canada)
Eric Donovan (Canada)
Ioannis Daglis (Greece)

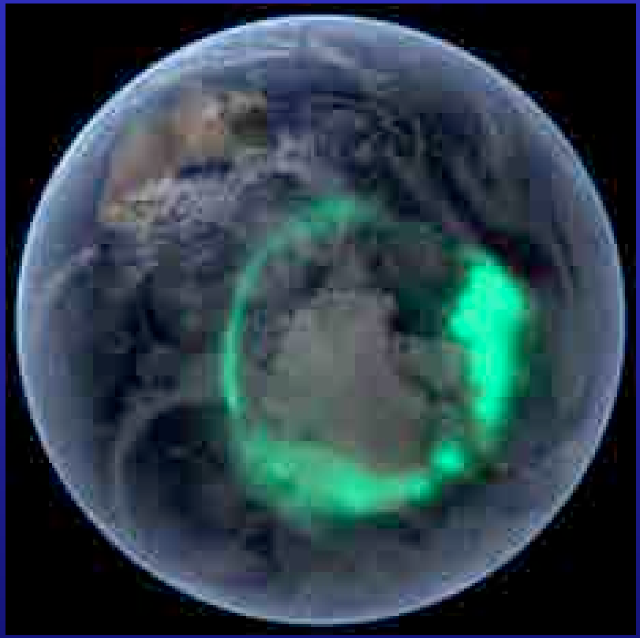


IMAGE satellite, 11 Sep 2005

SCOSTEP's SPeCIMEN Project 2014-2018 in VarSITI SUMMARY

Specification and Prediction of the Coupled Inner-Magnetospheric Environment (SPeCIMEN)

Schedule outline: We will aim to have 2 in-person meetings per year for the duration of the SPeCIMEN scientific program, 2014-2018. One meeting will be a dedicated project meeting, and the other will be attached to an already existing meeting, that a large proportion of the SPeCIMEN team is already planning to attend.

2014

- session at **Geospace Environment Modeling (GEM) workshop** in Portsmouth, Virginia, USA (15-20 June 2014)
- two sessions at the **URSI General Assembly and Scientific Symposium** in Beijing, China (16-23 August 2013)
- **Geospace Revisited Conference** in Rhodes, Greece (15-20 September 2014)

SCOSTEP
Scientific Committee on Solar-Terrestrial Physics

We are preparing an e-mail discussion list to send out announcements!

SPeCIMEN - Specification and Prediction of the Coupled Inner-Magnetospheric Environment

Through SPeCIMEN we seek to produce a frame-work where international scientists can work collaboratively on inner magnetospheric physics.

Think about joining us.

SCOSTEP's SPeCIMEN Project Summary (2014-2018 inside VarSITI)

Specification and Prediction of the Coupled Inner-Magnetospheric Environment (SPeCIMEN)

Goals and objectives: The quantitative prediction and specification of the Earth's inner magnetospheric environment based on Sun/solar wind driving inputs.

Questions: How does the inner magnetosphere respond as a coupled system to Sun/solar-wind driving?

Data/theory/modelling: A combination of physical and statistical (machine learning) modelling, theory, and observations from various platforms – both satellite & ground.

Anticipated outcome: A series of coupled, related models that quantitatively predict the dynamical evolution of the inner magnetospheric state (radiation belts, ring current, cold plasma distribution, plasmasheet, convection electric field, and so on).

SCOSTEP
Scientific Committee on Solar-Terrestrial Physics

Co-Leaders:
Jacob Bortnik
(UCLA, USA)
Craig J. Rodger
(U. Otago, New Zealand)

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Jacob Bortnik

Dept. of Atmospheric and Oceanic Sciences

UCLA

Craig J. Rodger

Department of Physics

University of Otago

Dunedin

Thankyou!