Welcome Everyone!

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SWUG Team Meeting September 17, 2022

Today's Schedule

This Morning: 10AM to noon

1. Introductions all around
2. Introduction to EOS at UNH?
3. Status of SWUG development
   - Immediate plans
   - Status of deployment engineering
   - Status of the SWUG Data Center
4. Early Deployments
5. Ionospheric Science
6. Very Early SWUG Science

This Afternoon: 1PM to 3PM

1. Deployment discussion
2. Doghouse lesson
3. How does a fluxgate work?
4. Science with the array
   - Ionospheric physics and computer programming
5. Where do we go from here?
6. Future opportunities

The SWUG Data Center and Home Page

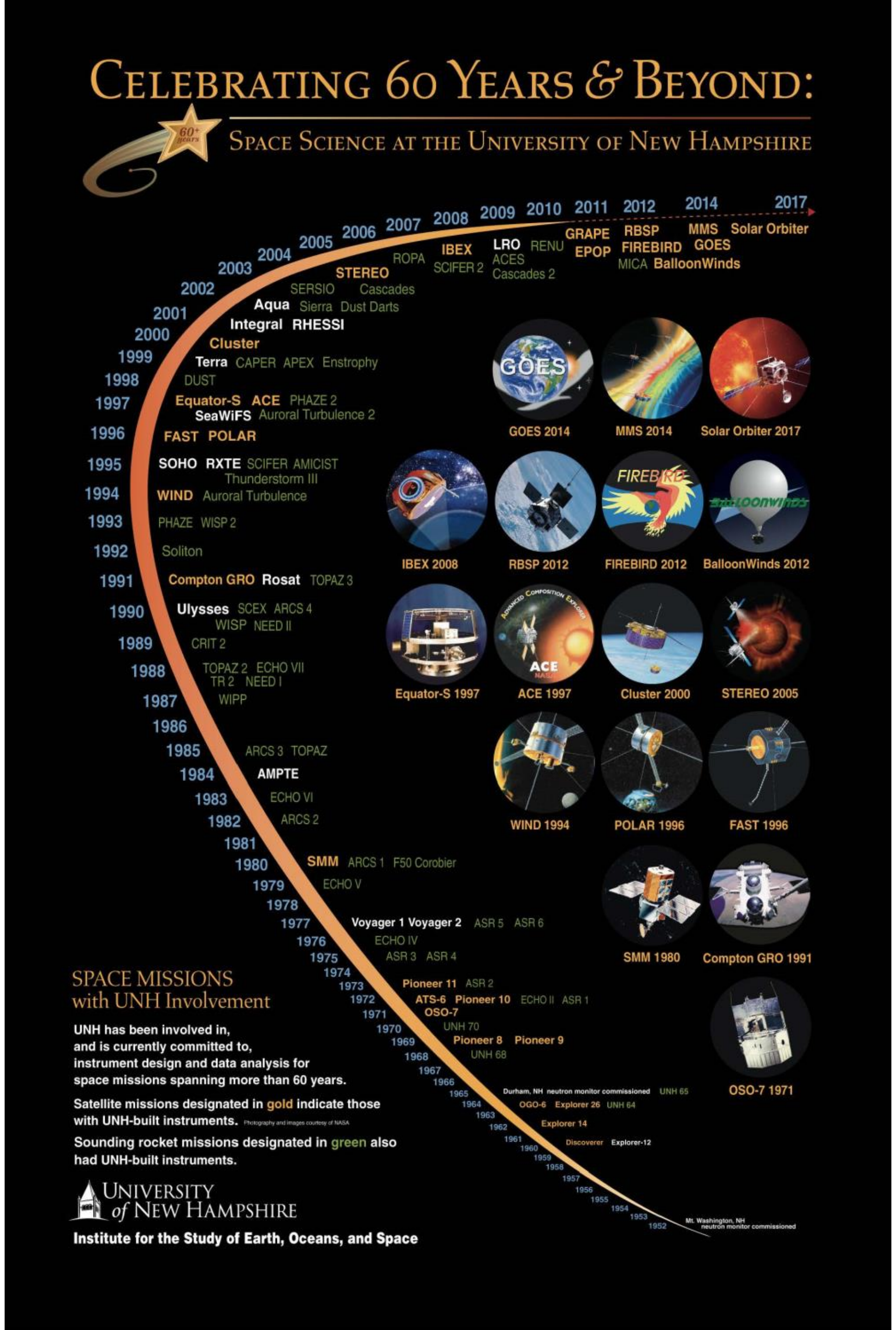
- Space Weather Underground Data Center
  - https://swug.unh.edu/

- Space Weather Underground Home Page
  - https://eos.unh.edu/space-science-center/outreach/space-weather-underground
  - bit.ly/UNHSWUG
  - Is one place that we will post files for you.

Space Science at UNH

- EOS at UNH supports a broad range of space science investigations including:
  - Instruments for ground-based, suborbital, orbital, and interplanetary missions,
  - Analysis of s/c data,
  - Theory and simulation.

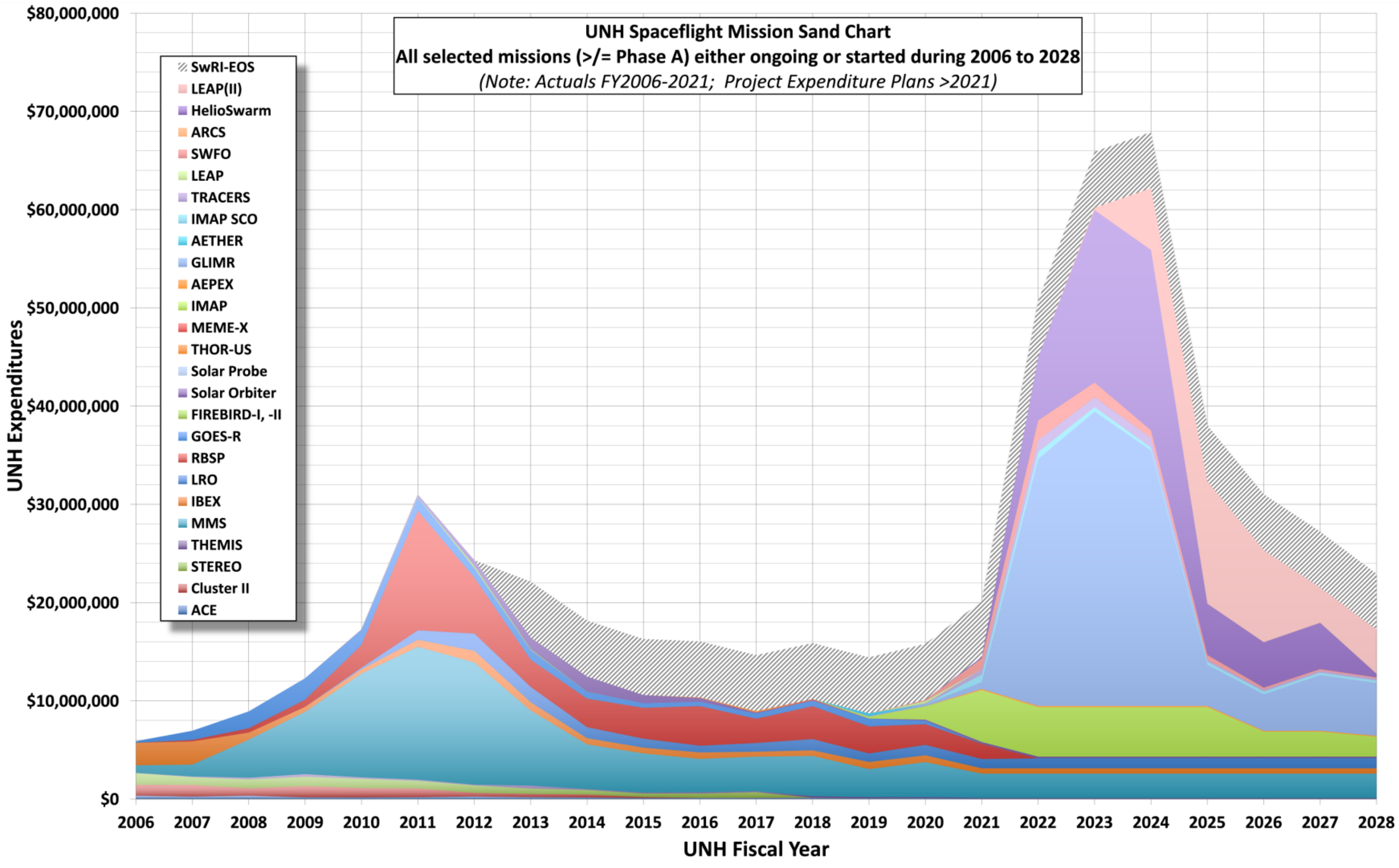
- Our students do real research while they work on their degrees.
  - UNH has the largest Undergraduate Research Conference in the nation.



Spacecraft Involvement at UNH

Since 2006:

Mission	Program	UNH PIs
ACE	LWS	Moebius, Smith
Cluster II	ESA/NASA	Torbert, Mayndard,Kistler, Moebius
STEREO	STP-3	Galvin
THEMIS	MidEx	Raeder
MMS	STP-4	Torbert, Spence
IBEX	SMEX	Moebius, Schwadron
LRO	Planetary	Spence, Schwadron
RBSP	LWS-2	Spence, Torbert
GOES-R	NOAA	Lopate
FIREBIRD-I, -II	NSF CubeSats	Spence
Solar Orbiter	LWS-6	Galvin
Solar Probe	LWS-5	Schwadron, Chandran
THOR-US	MoO	Kucharek
MEME-X	SMEX	Kistler
IMAP	STP-5	Schwadron
AEPEX	NASA CubeSat	Spence
GLIMR	EVI-5	Salisbury
AETHER	ISS TDO	Clemmons
IMAP SCO	Explorer SCO	Lugaz
TRACERS	SMEX	Torbert
SWFO-L1 Mag	NOAA/NASA SpWx	Torbert
LEAP	Astro SMEX MoO	McConnell
ARCS	Helio MIDEX	Kistler
HelioSwarm	Helio MIDEX	Spence
LEAP(II)	Astro MIDEX MoO	McConnell



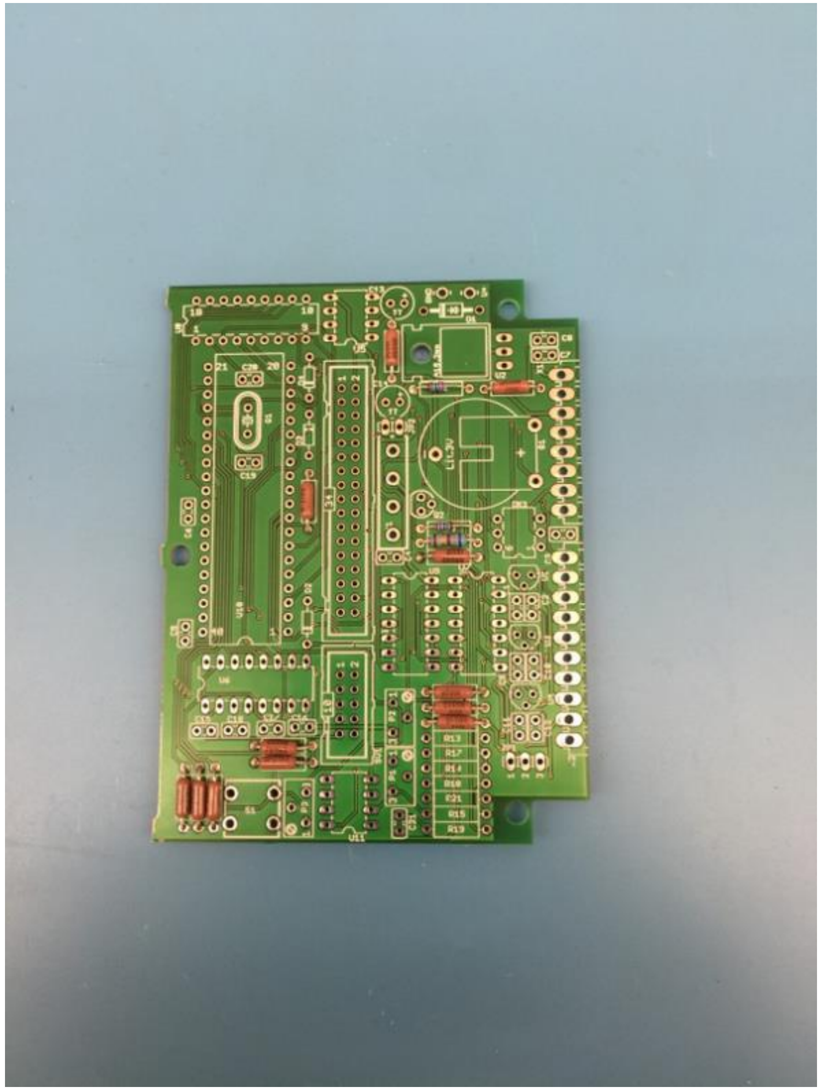
Federal Support for SWUG

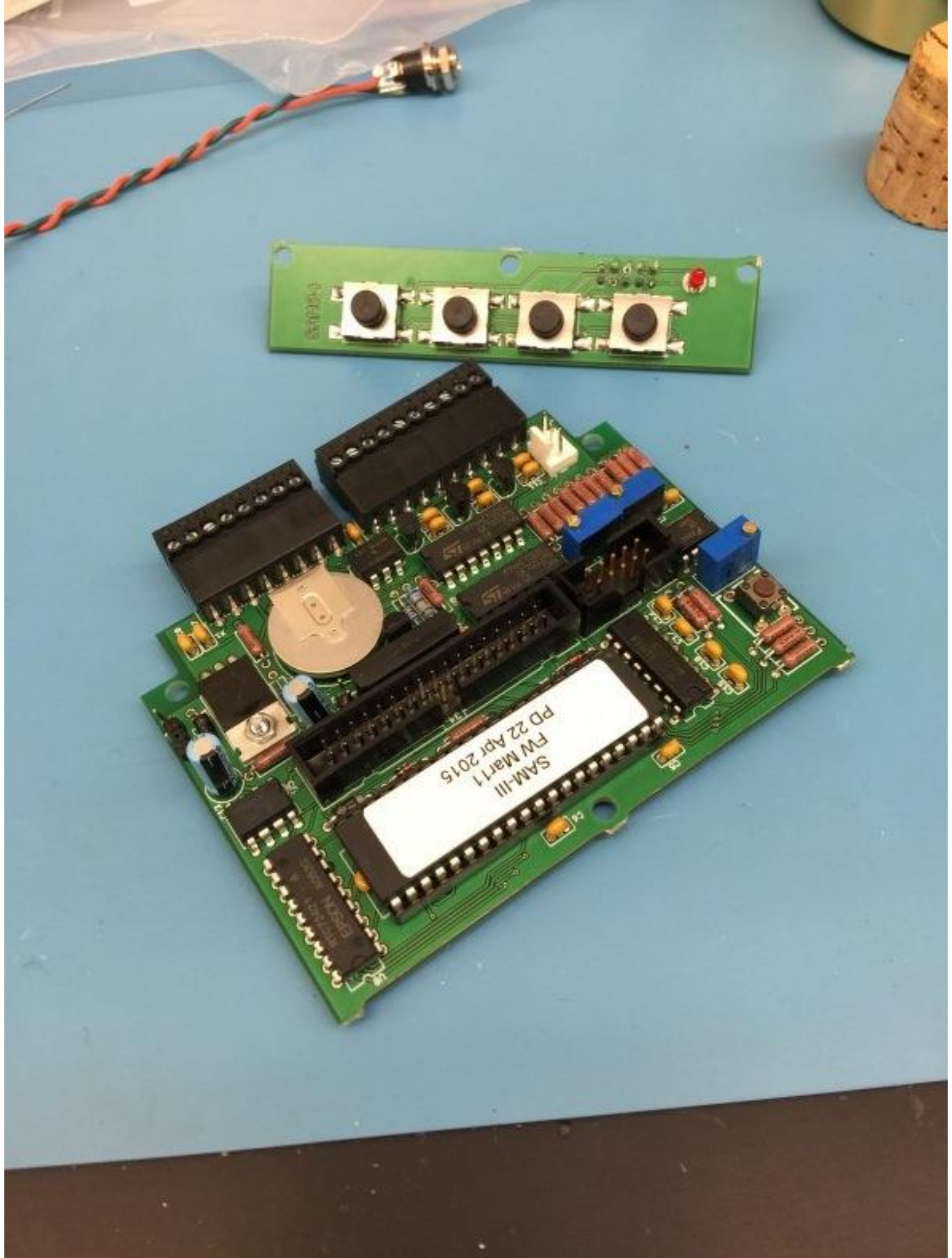
- We have a grant from the National Science Foundation (expires ??).

- We have a grant from the National Aeronautics and Space Administration (expires ??).
  - This inspired Alaska to start an array under the same name.

- We recently obtained earmark funding from Congress (expires ??).
  - This includes funding to develop an array in San Antonio, TX.

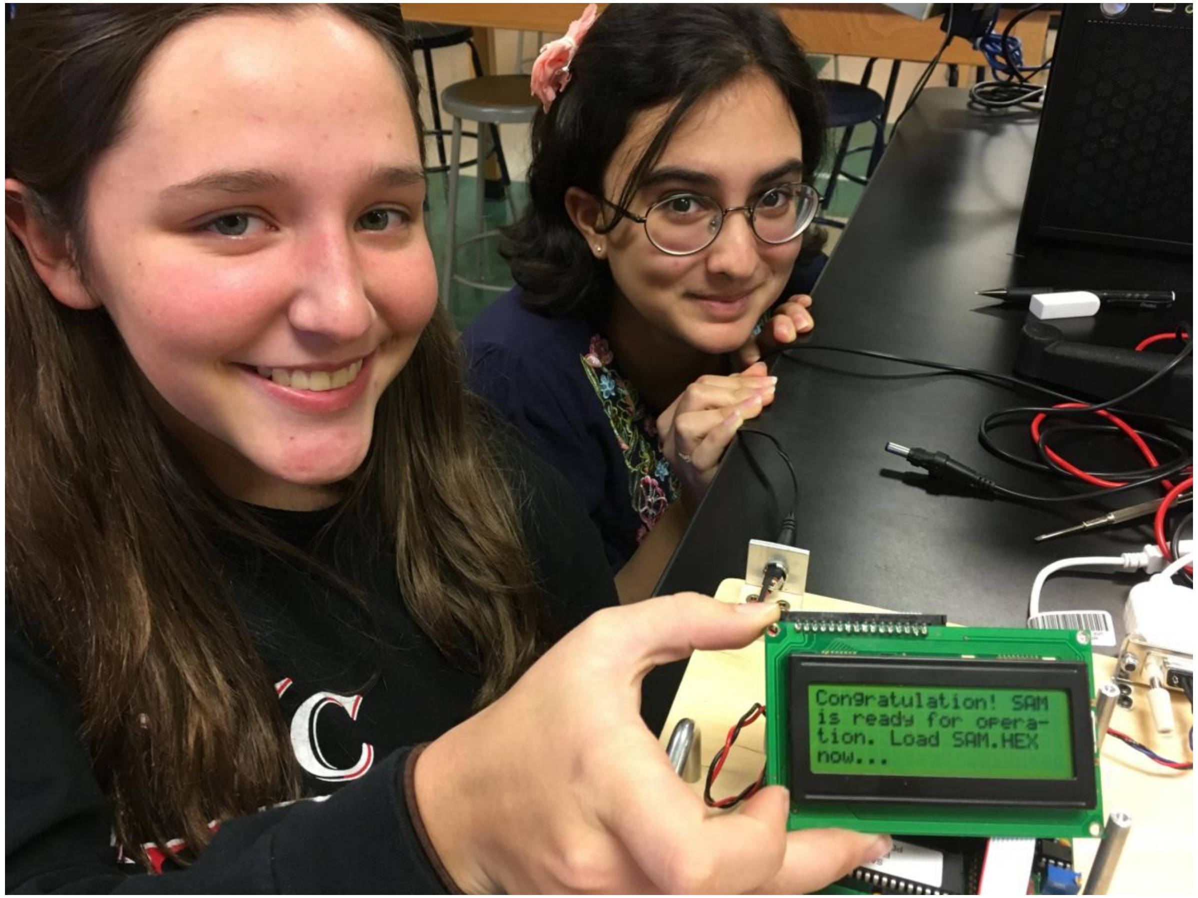
Inexpensive Fluxgate Magnetometers





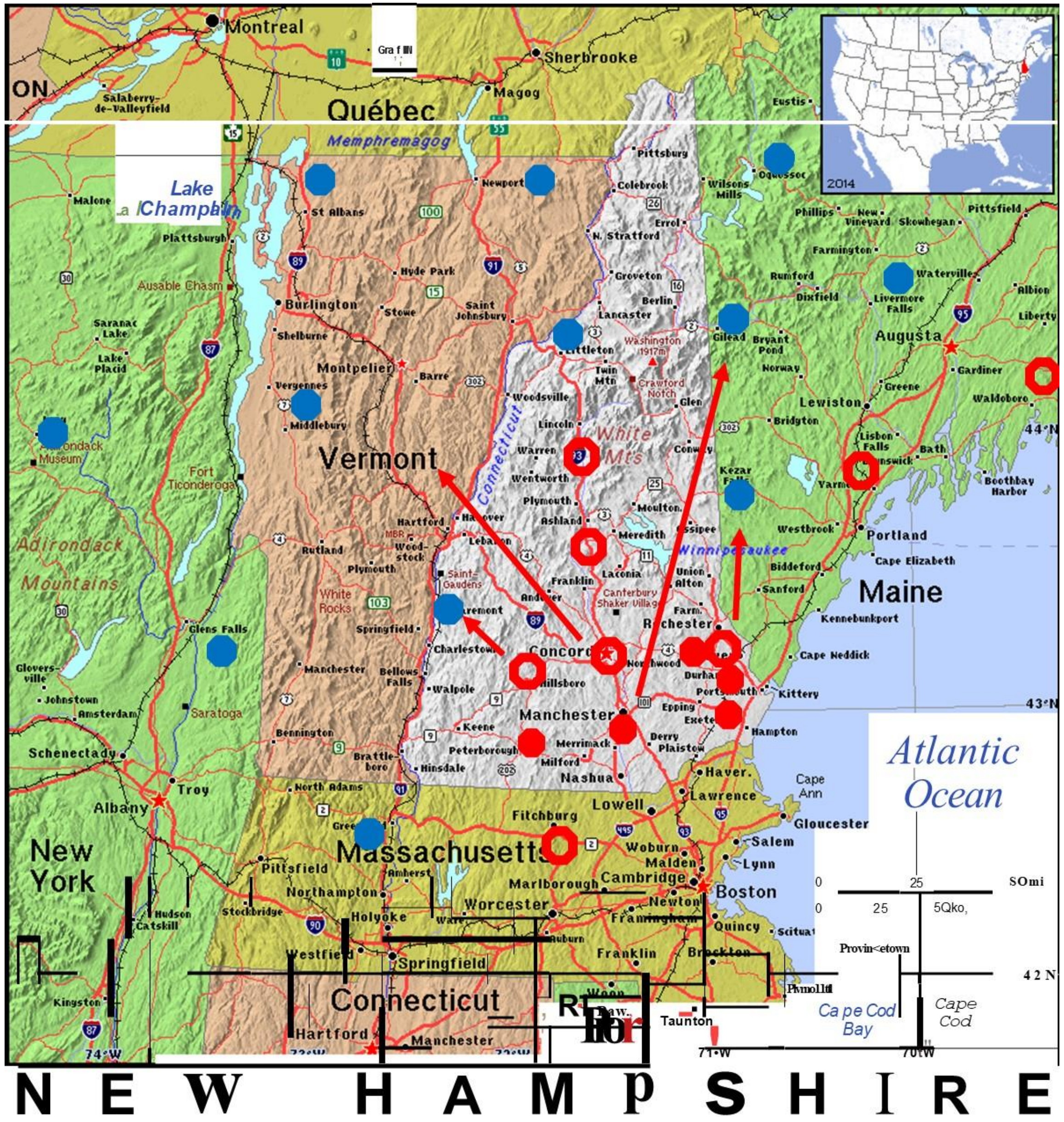
The Goal of the SWUG

- To provide a resource for performing ionospheric physics.
- To give motivated HS students a chance to lean engineering, physics, mathematics, and computer programming outside the classroom.
- Fluxgates are built from kits purchased from Reeve Engineers in Anchorage, Alaska.
  - Sell for ~ $500 each.
  - Deployment is ~ $600 each.



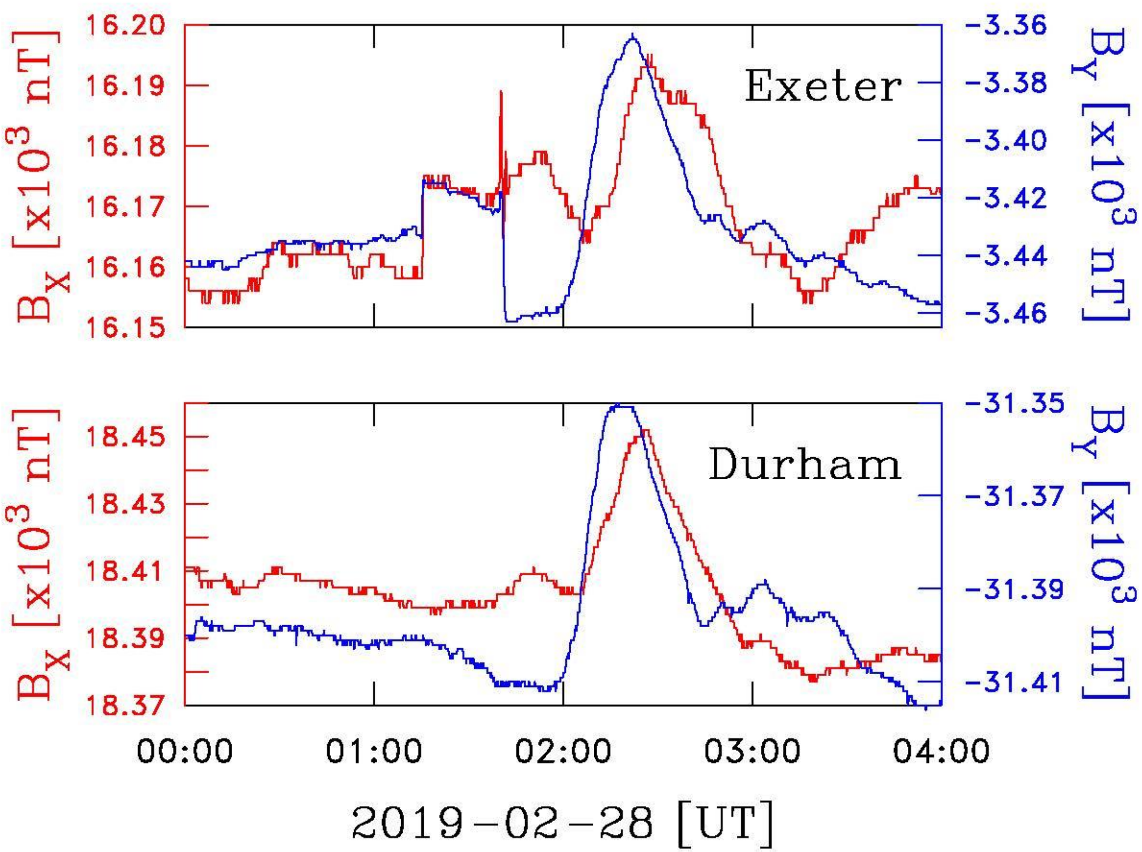
What is SWUG?

- We want to build an array of distributed fluxgate magnetometers across norther New England.
- Ionospheric currents 100 km overhead produce varying magnetic fields on the surface of the Earth.
- By measuring the changing field at multiple locations, we can reconstruct the changing currents overhead.
- Please reach out to your friends!

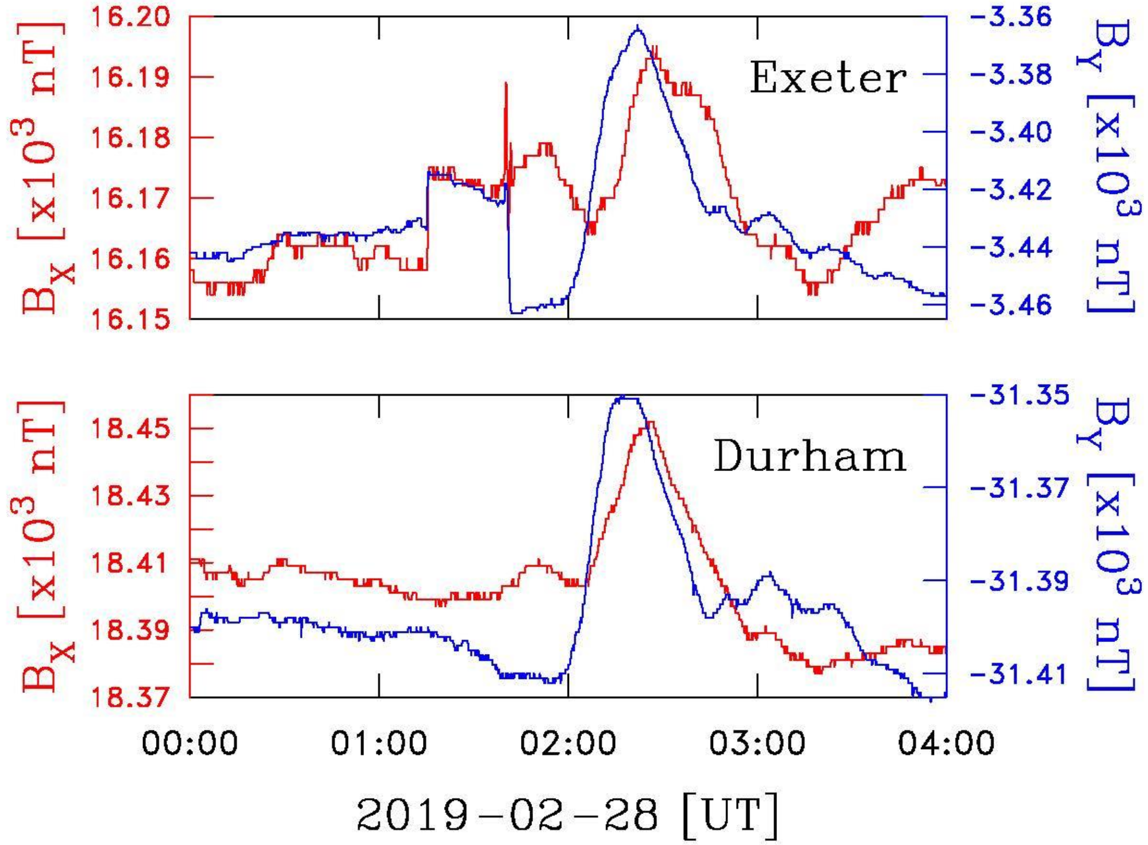


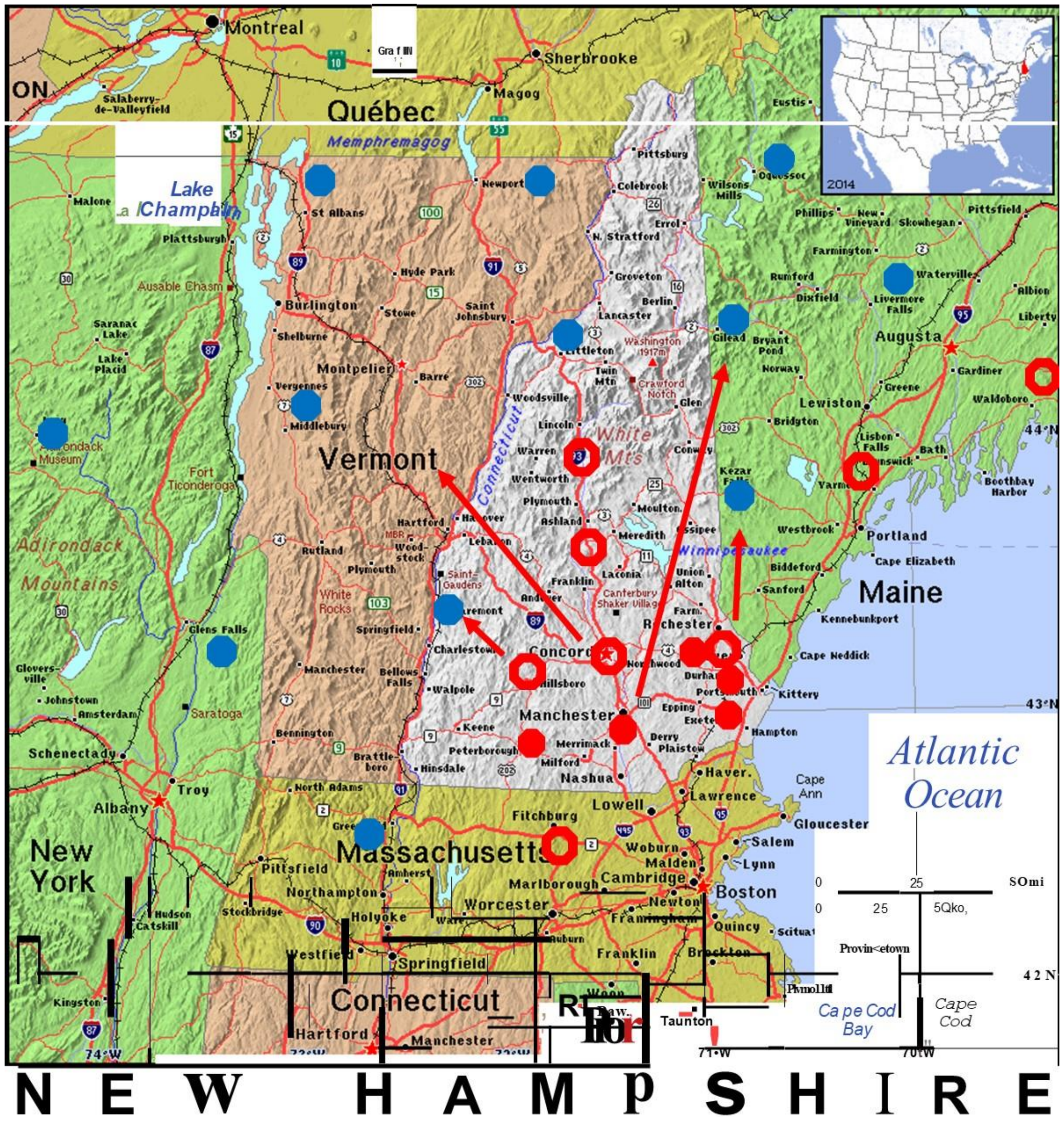
The Goal of the SWUG

- Measurements of the changing magnetic field on the surface are a remote measurement of ionospheric currents.
- Ionospheric currents arise from two sources:
    - Interplanetary transients that originate at the Sun
    - A naturally periodic disruption of the Earth’s magnetosphere



Science Opportunity





SWUG Participants

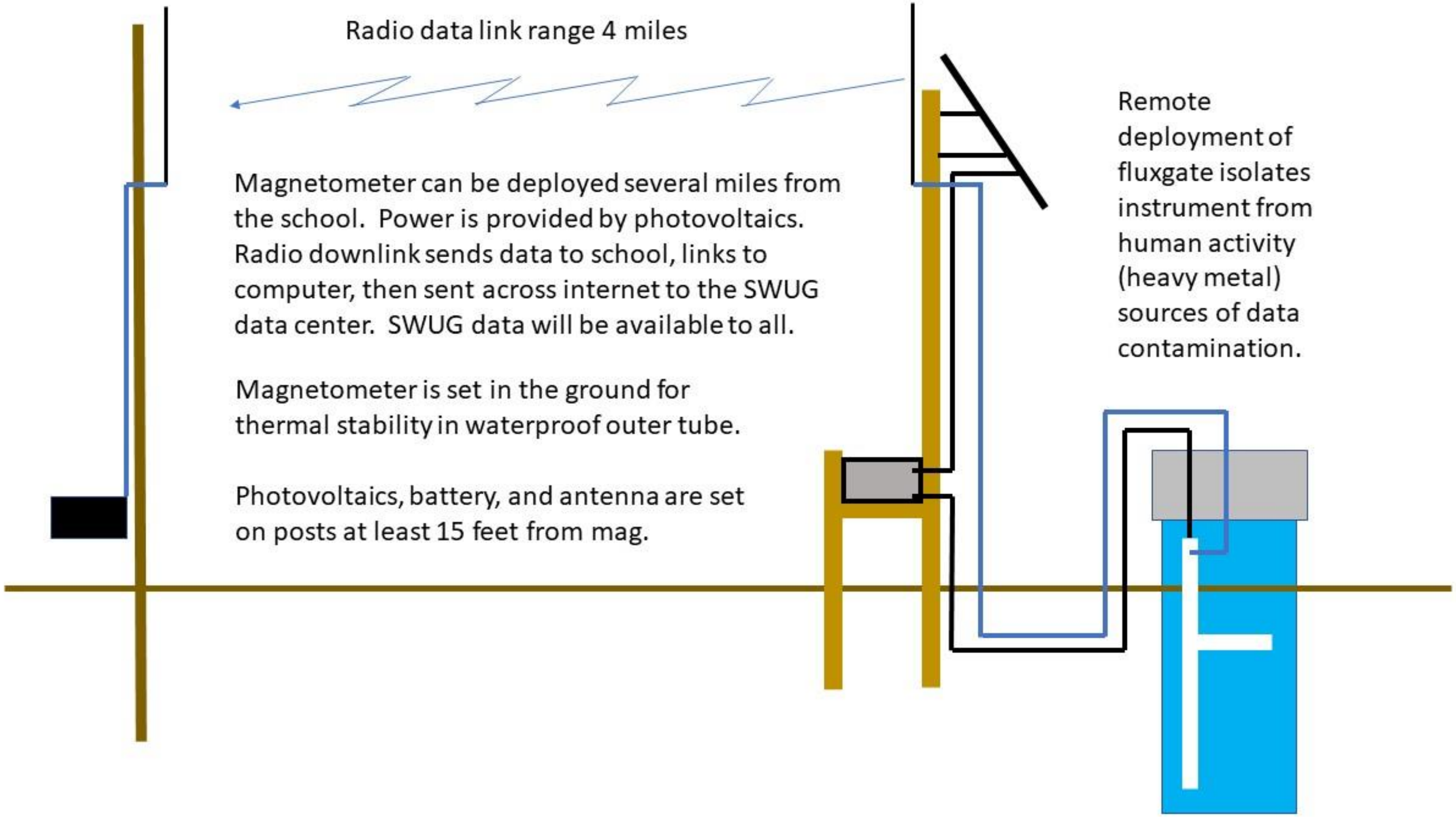
Souhegan backed out this week.

- ✓ John Blackwell, Phillips-Exeter Academy
- ○ Rich Levergood, Londonderry High School
- ✓ Scott & Joanne Goelzer, Coe-Brown Academy
- ✓ Andria Johnson, CONVAL Peterborough High School
- Dave McKenney, Plymouth High School, NH
- Julie Burton, The Bromfield School, Harvard
- Elizabeth England, Winnesquam High School (Tilton, NH)
- Andy Metric, Hillsboro-Deering High School, NH

H-D stalled without students.

- Sara Cathey, Oyster River High School, NH
- Terry Bartick, North Yarmouth Academy, ME
- Carol Coryea, Washington Academy, ME
- Nathan Carle, Souhegan High School, Amherst NH
- Charles Swift, Souhegan High School, Amherst NH
- Stephen Zaffke, Austin High School, Minnesota
- Nick Goeldi, Ripon High School, Ripon, Wisconsin
- Oliver Rygh, Brooklyn Technical High School
- Gregory Fletcher, Southwest Research Institute, San Antonio TX
- Bethany Hayes, Richard Faucett, and Scott Sweeting, Thomas County Central High School, GA
- Abigail Smith, Univ. Maryland Baltimore County, MD

Magnetometer Deployment Concept



The Status of SWUG Deployment

- We have a good deployment scheme, but we are working to improve it.
- The mag needs to stand alone.
- It needs to be remote (in whatever sense that means).
- We want it to be rubust!
- It needs to send data to the SWUG Data Center.
- We want it to have a useful presence in your schools.

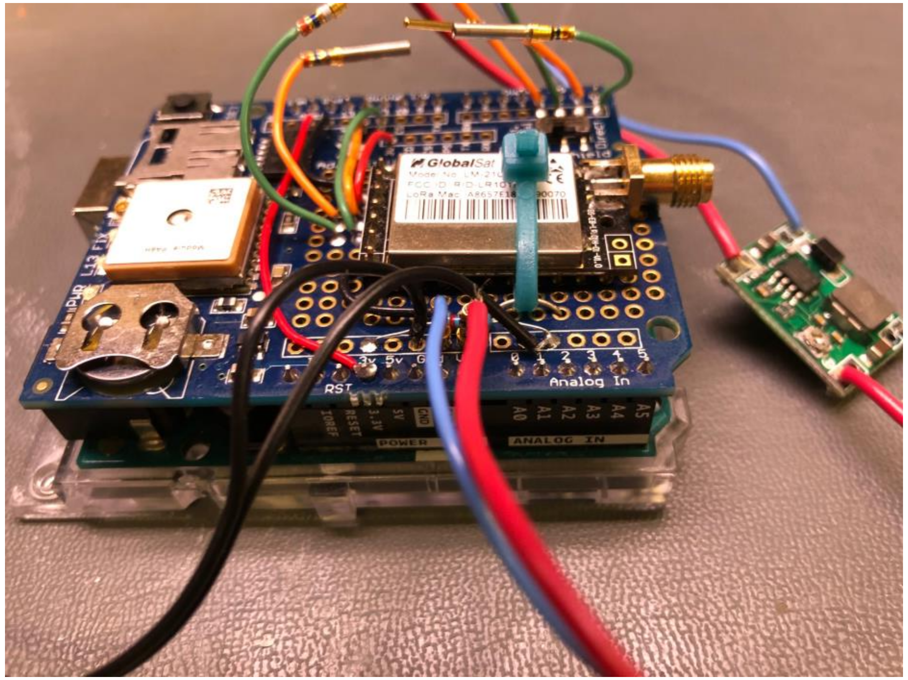
SWUG In-Ground Deployment

- Mags are deployed within PVC tubes.
  - External tube is waterproof.
  - Internal tubes maintain orientation and hold electronics.
- There is a (small) computer screen in the building.
  - Very small!
- We are working on a better representation.
  - Hourly data downloads and ready access on a school monitor.

There Is A Process to This

- Your students build the mag.
- Then like NASA, we take it back to test and calibrate.
  - We can do this with you if you like.
- You build your deployment hardware.
  - Much less likely to fail.
- You dig a hole and sink the outer tube.
- We return and deploy.
- We need outside access to the data receiver.

Deployment Electronics



Arduino-Based Data Logger
+
GPS

Raspberry-Pi Data Storage
+
Internet Download

UNH Is Providing/Paying For:

- The SAM-III mag kits
- The PVC deployment tubes
- The PVC internal tree
- The Arduino data handling hardware
- The Raspberry-Pi data link hardware
- The data link antennae
- Photovoltaics
- The “doghouse”
- Batteries, switches, cables, etc.

UNH Will Provide the Deployment Hardware

- We have 1(?) electronic deployment kits here today for those who are ready.
  - Harald promises a parts list today.
  - We will order and assemble 10 kits in 2 weeks.

- For those within driving distance:
  - I can personally deliver the bulky material (PVC, solar arrays, batteries, etc.)

- For those more remote:
  - We will ship electronics to you and reimburse you for local purchase of bulky products.

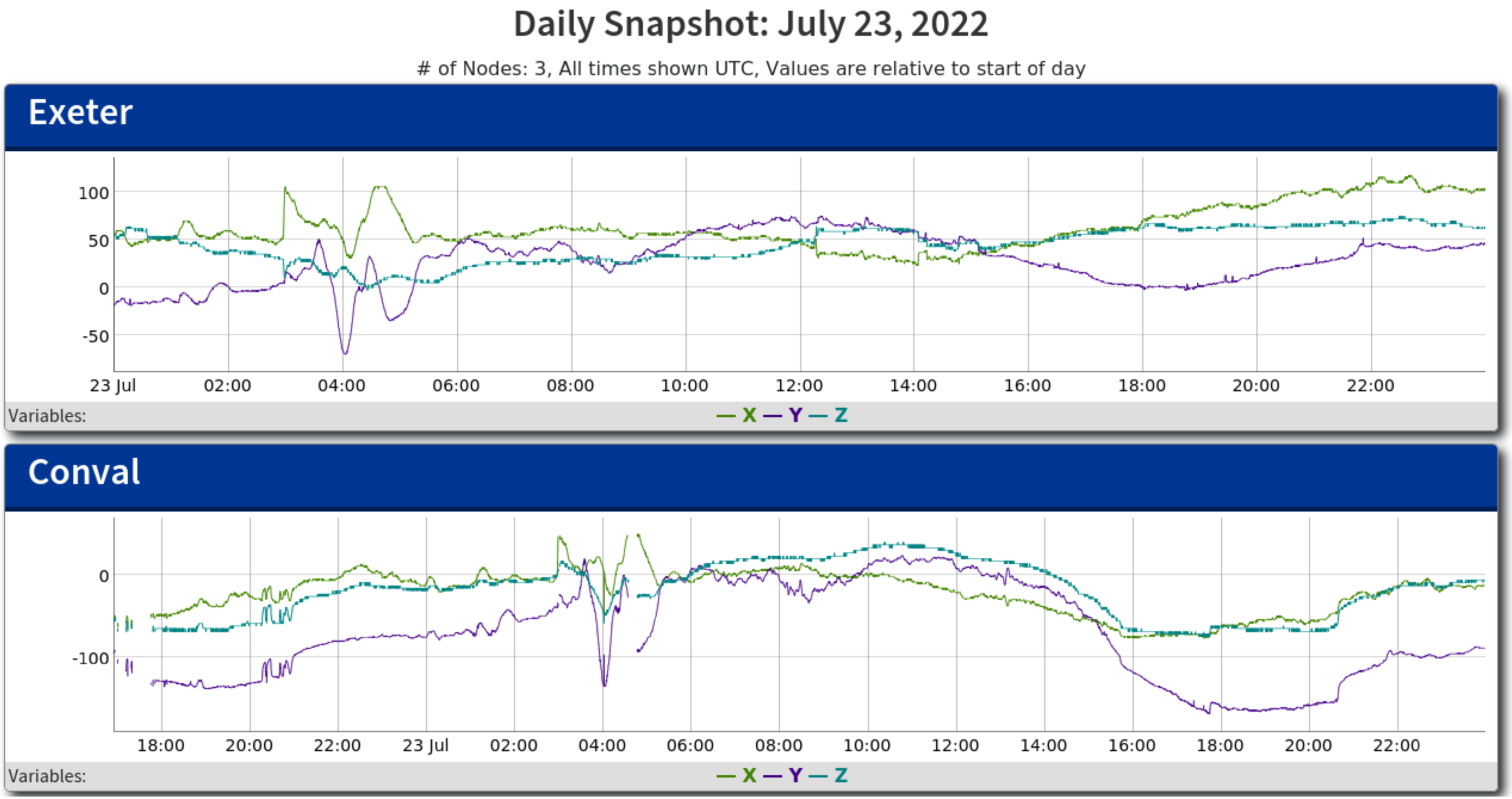
Early Results (not yet science)

Early Deployments

- There are working mags at Coe-Brown, CONVAL, & Exeter.
  - Plus, we have a mag in the lab at UNH that does not post data.
  - Trying to deploy on UNH campus (Oyster River HS mag?).
- These three are basically colinear!
  - We can't do effective timing/triangulation analyses with colinear mags.
  - Plymouth HS would like to do a quick deployment! That is a game changer!
- <u>But we have had problems</u>!
  - Both Coe-Brown and CONVAL failed in mid-winter within 2 weeks.
  - We've had switches fail and minor moisture inside the big tube.
  - We've had cables disconnect due to movement resulting from temperature changes.
  - We are working to refine our deployment scheme.
  - We don't understand the Exeter Z-axis (but we know how to get at it!).

Lessons Learning: Waterproof boxes still develop condensation and cheap switches fail!

Very Early Science / Evolving Lessons

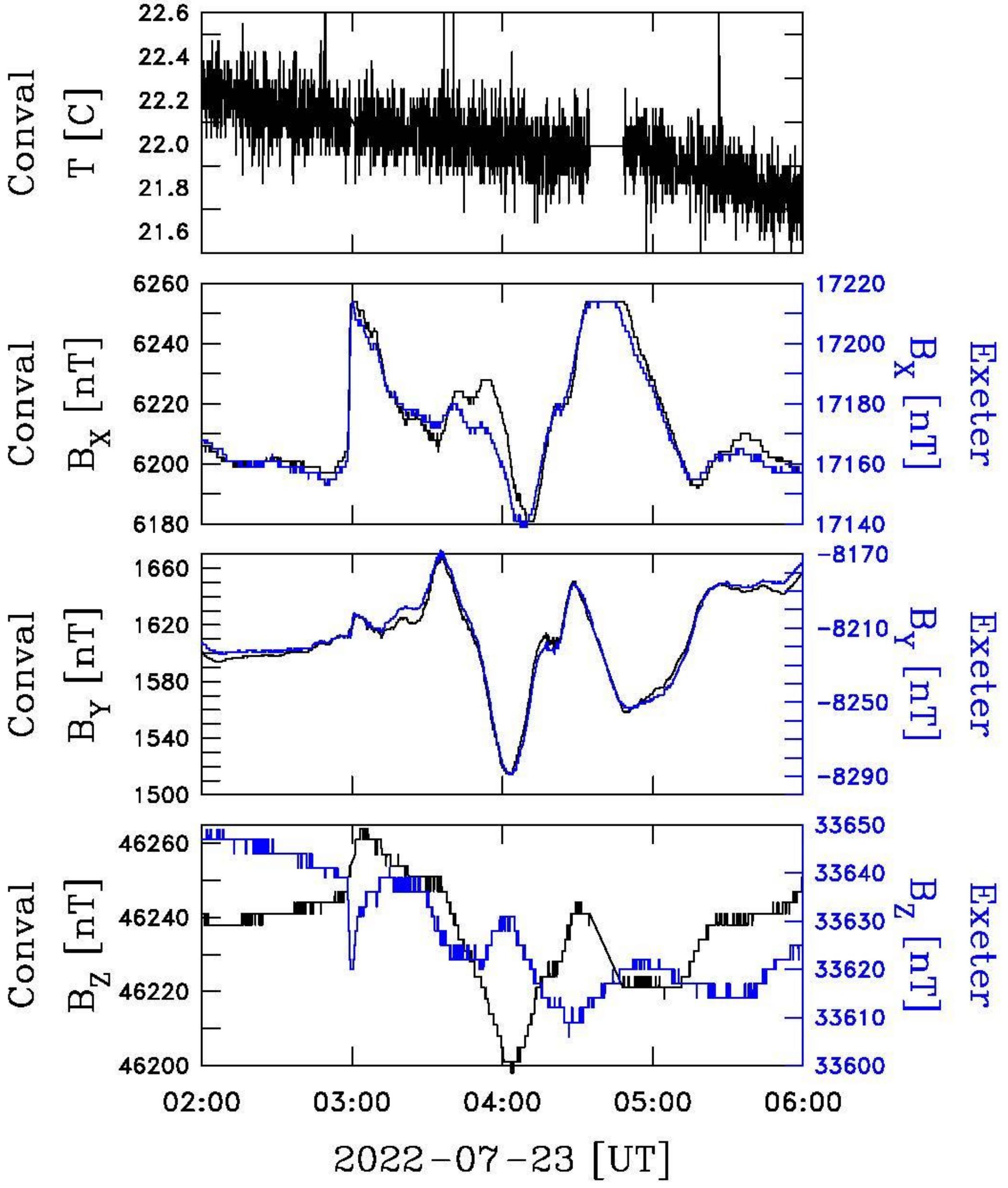


Lesson Learned: We are working to sync our data and plots!

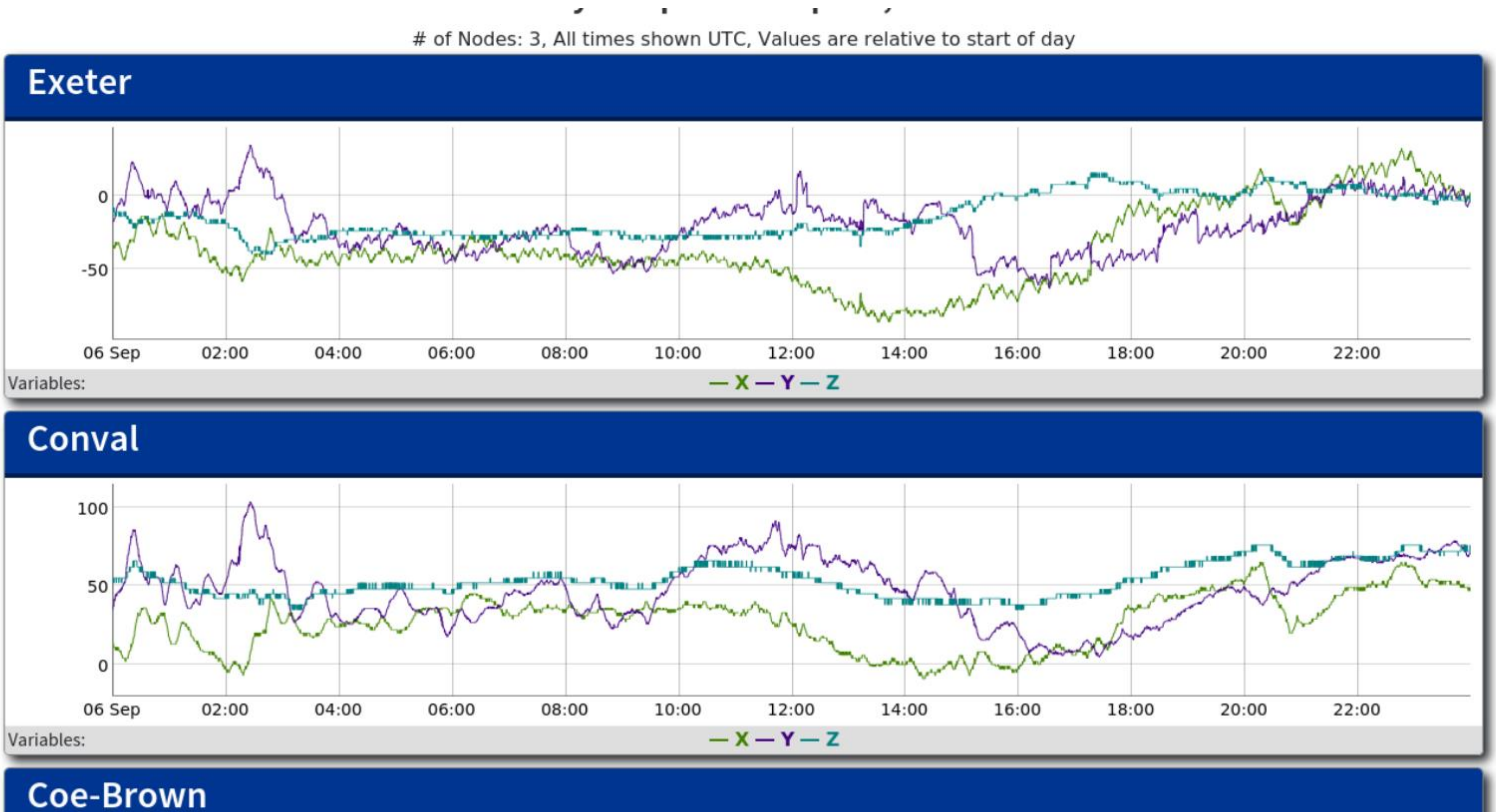
Very Early Science & Evolving Lessons

- We had a nice transient hit the Earth!
- It drove a very nice disturbance overhead.
- Coe-Brown was on the bench for repairs.
- As a demo, we compared CONVAL and Exeter.

Lesson Learned: We need to review our calibration efforts!



September 6, 2022



How Does A Fluxgate Work?

- Fluxgates are driven devices that use the magnetic hysteresis effect to determine the ambient magnetic field.
  - A permeable core is driven to saturation.
  - The remnant magnetization of the core is different at 2 phases of the driver.
- Resultant path separation provides the ambient field.

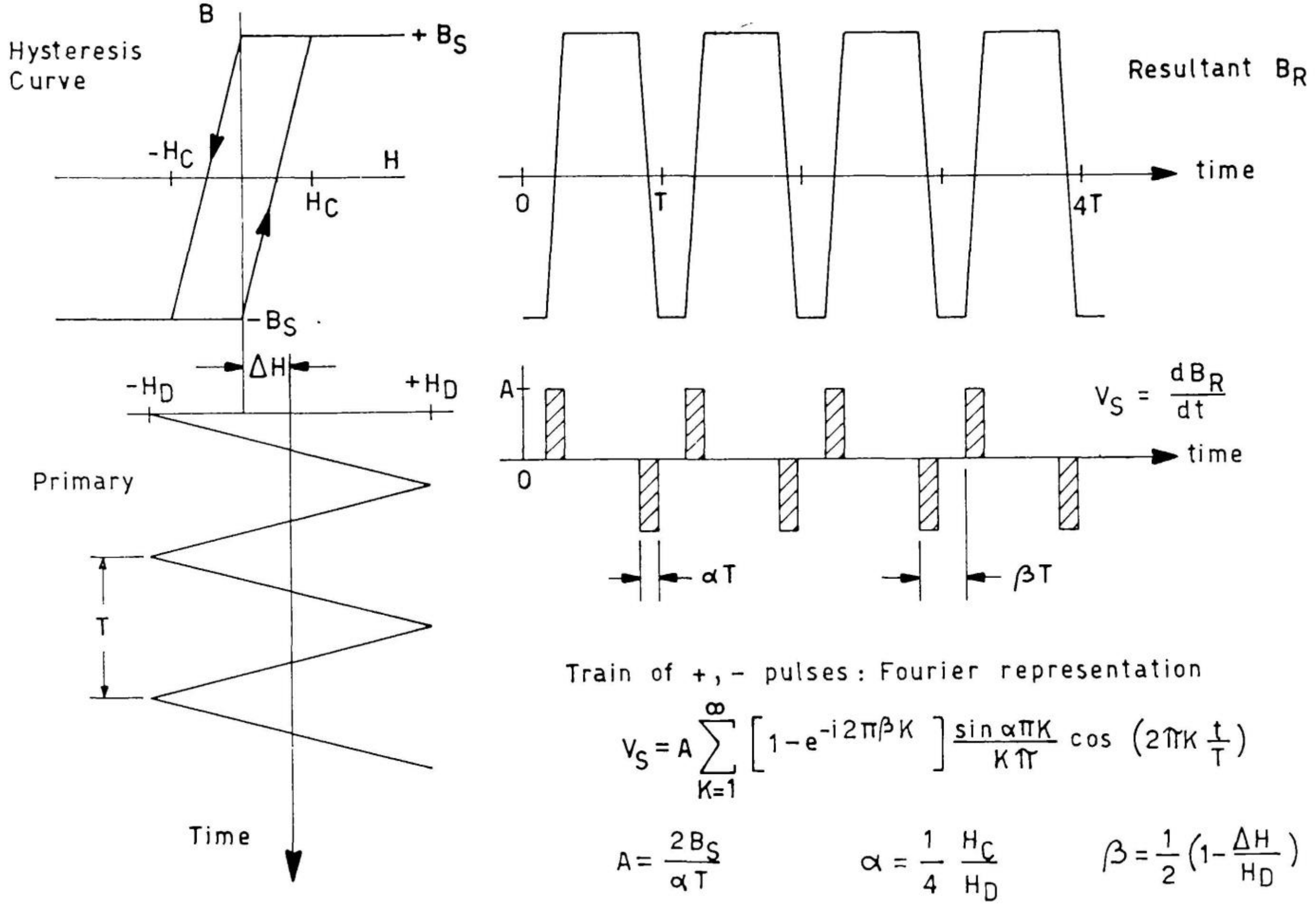


Fig. 7. Diagram illustrating principles of operation of fluxgate magnetometer.

How Does A Fluxgate Work?

- There are a number of different concepts for the measurement of magnetic fields in scientific instruments.
  - Search coil
  - Fluxgate
  - Proton precession
  - Alkali vapor self-oscillating
  - Helium line splitting

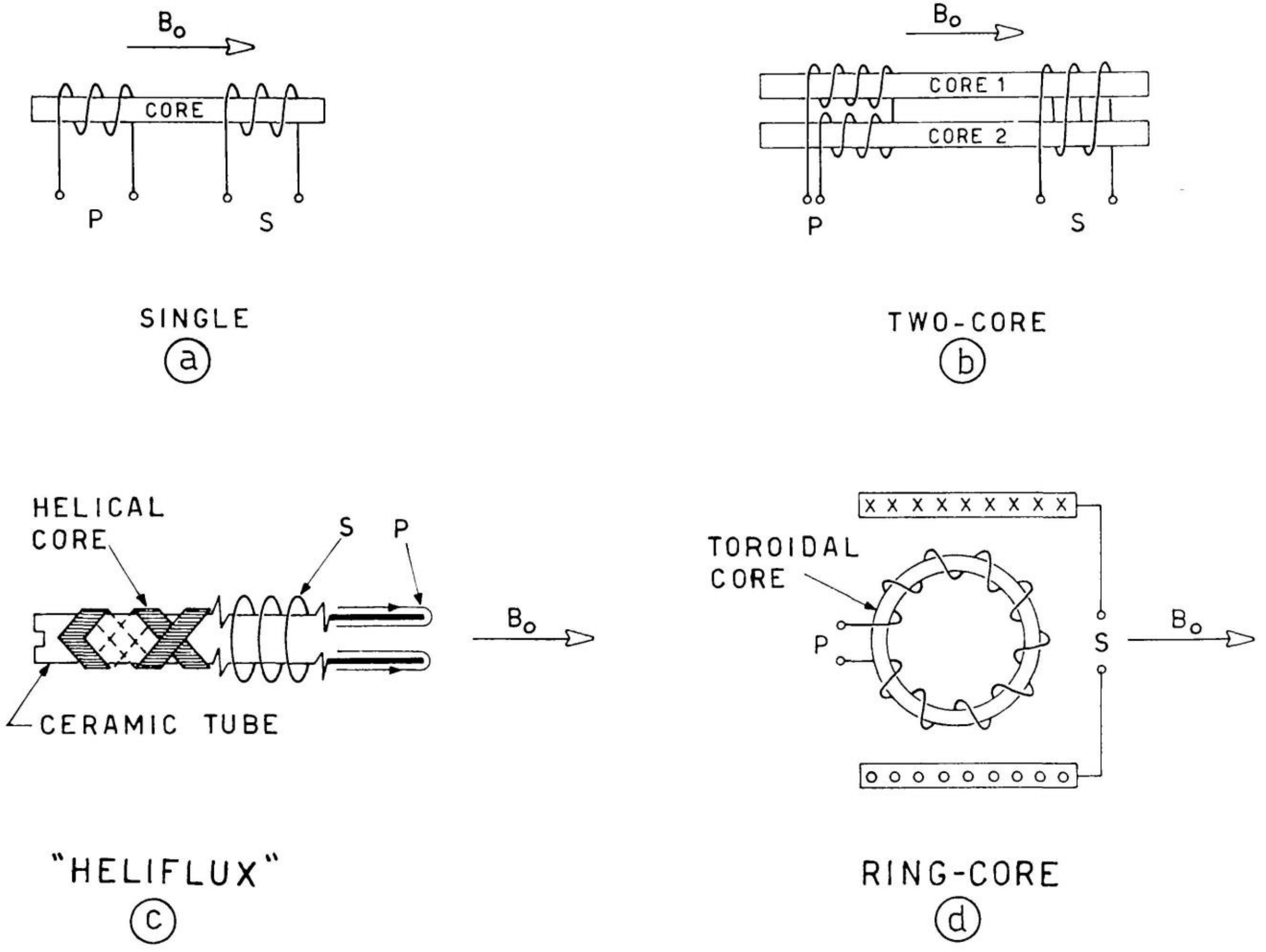
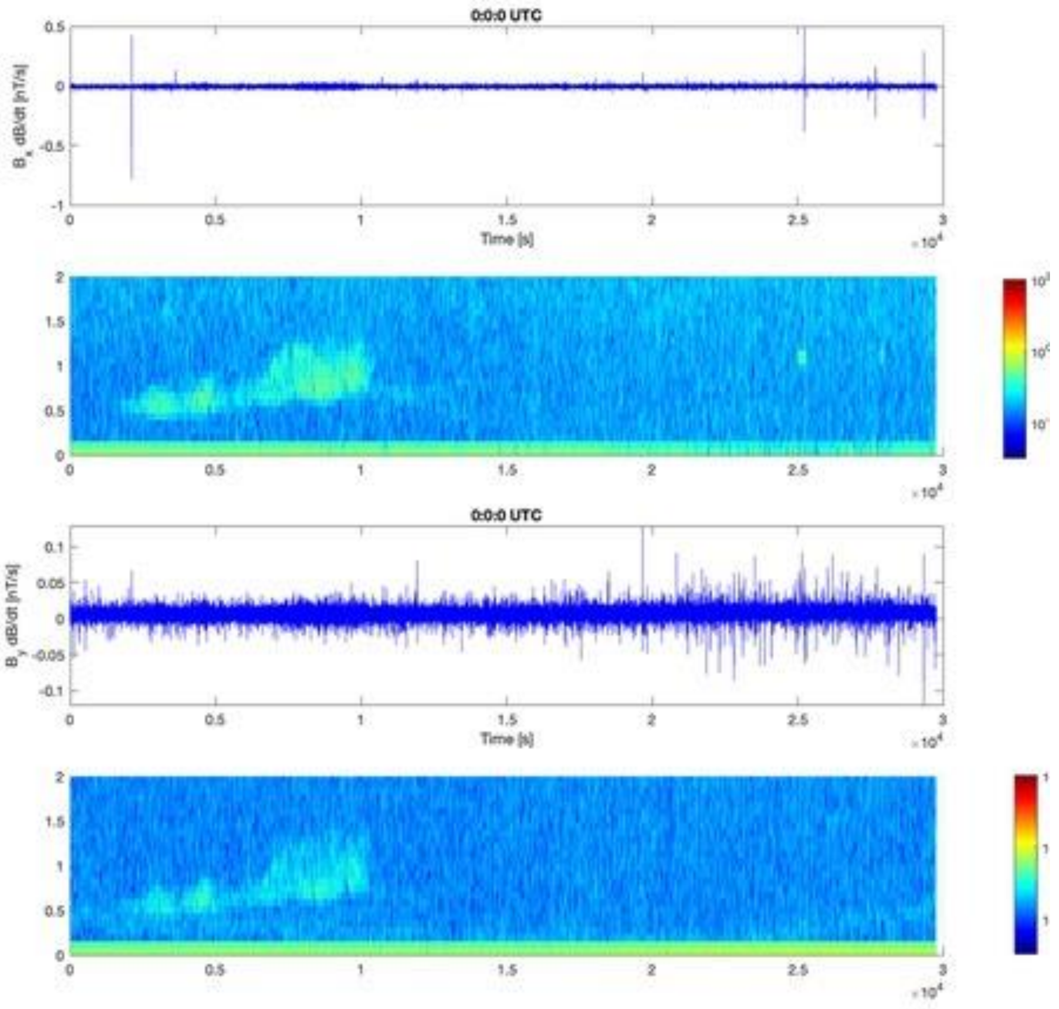


Fig. 9. Various geometries of saturable core sensing elements for fluxgate magnetometers.

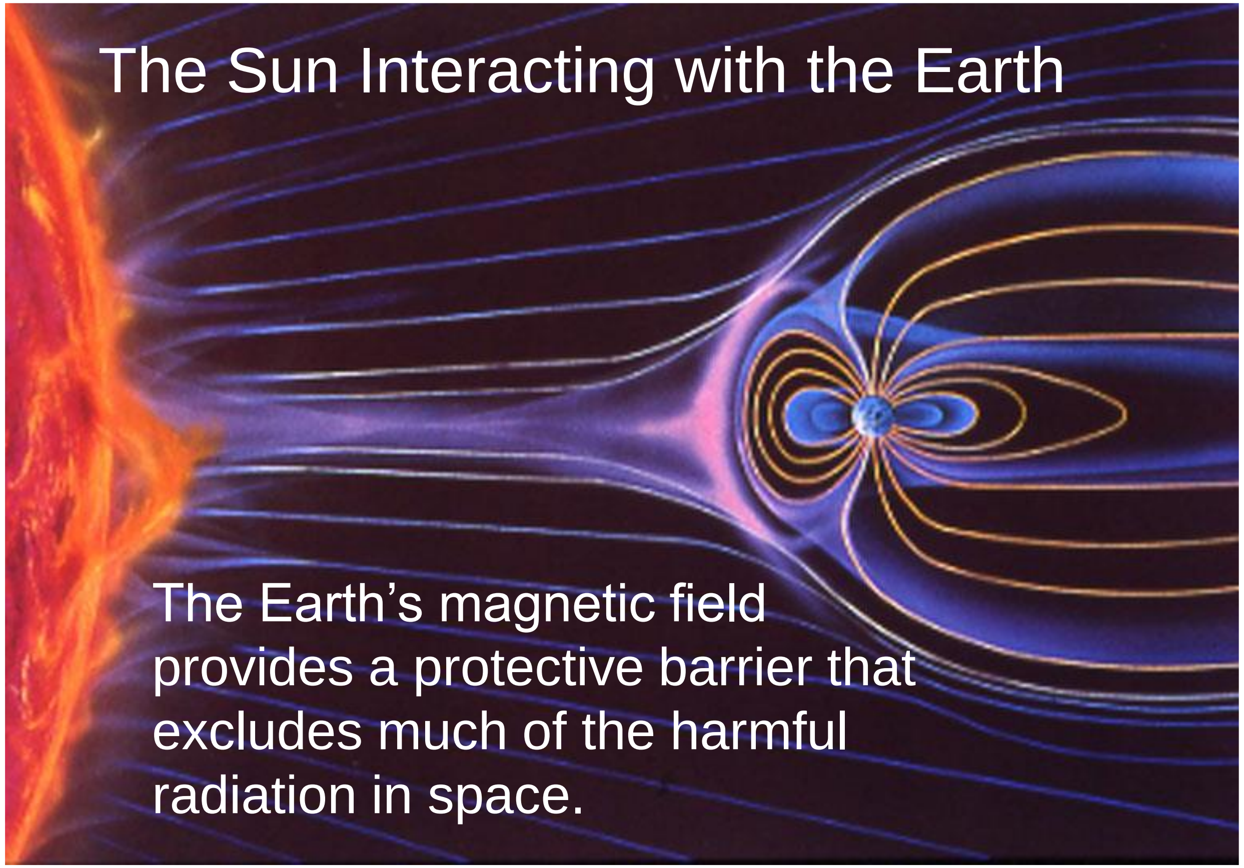
Marc Lessard and Chrystal Moser-Gauthier



- One of the instruments that Marc Lessard specializes in is a search coil magnetometer that provides AC measurements of the changing magnetic field.
  - No DC field values like the fluxgate
  - Coils of wire that use the changing magnetic flux to drive a current
- They deployed their newest search coil mag on Sept 13 and recorded a EMIC wave event on the 2nd day.

Let’s Do Some Science!

The Sun and Solar Wind



- The Sun produces a broad spectrum of light.
  - This is actually the #1 energy product of the Sun.
- It also produces a streaming hot gas of electrically charged particles (mostly p^+ and e^-) and drags the Sun's magnetic field out with it.
- Space is very different from what we commonly hear.
  - It is a highly structured and dynamic environment with physics we do not understand.

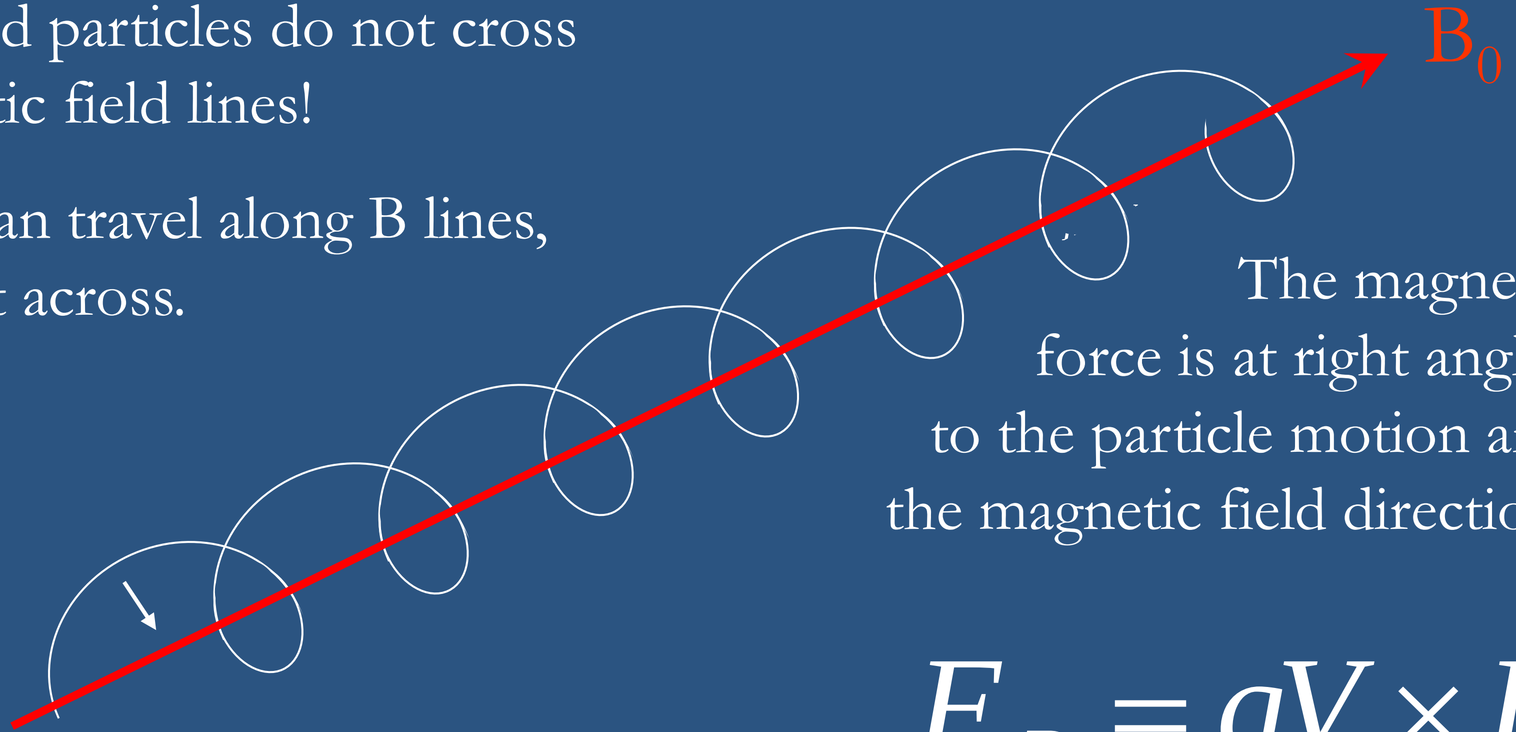
Typical Solar Wind Parameters

- Density $\sim$ 10 p^+ & 10 e^- cm^{-3} @ 1 AU with trace heavy ions
  - Varies as R^{-2}
- Wind speed averages $\sim$ 450 km/s (varies from 250 to 850 km/s).
  - Constant as a function of R!
  - DC is 800 km from here!
- Temperature $\sim$ 10^5 K (180,000 F).
- Magnetic field $\sim$ 10 nT (10^{-4} Gauss).
  - B_{earth} $\sim$ 45,000 nT (0.45 Gauss).

Important Physics

Charged particles do not cross magnetic field lines!

They can travel along B lines, but not across.



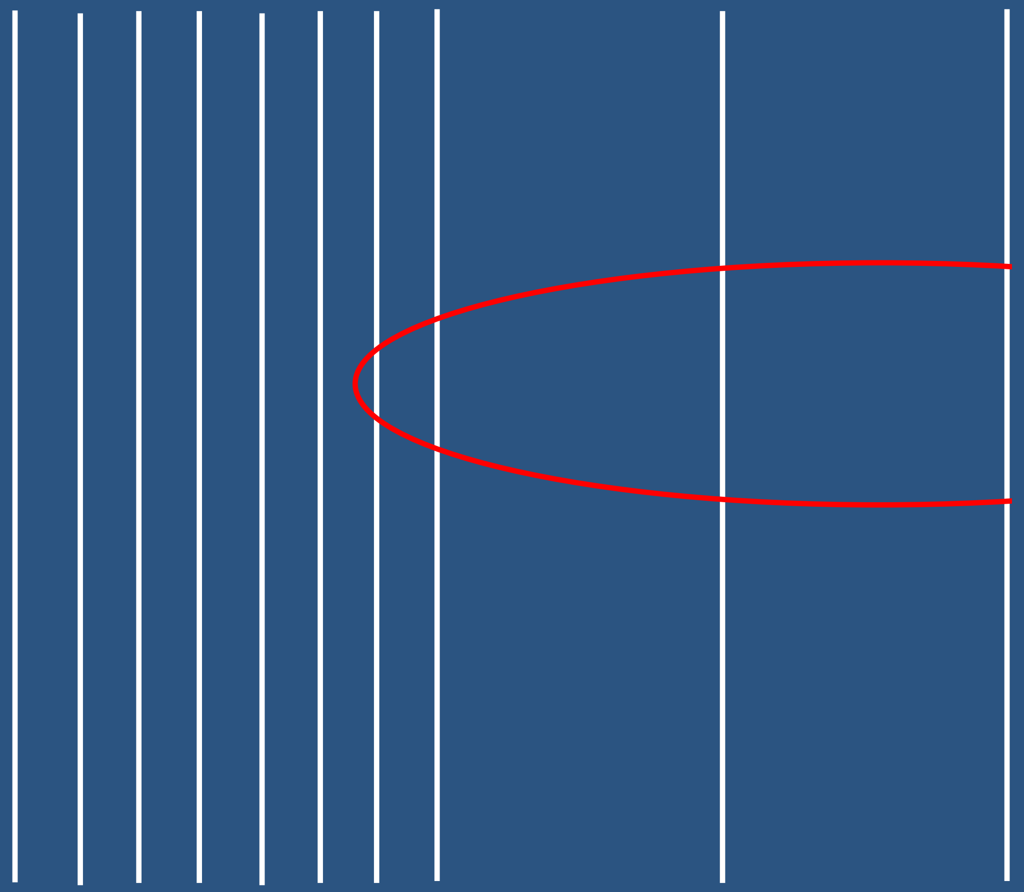
The magnetic force is at right angles to the particle motion and the magnetic field direction.

$$\underline{F}_B = q\underline{V} \times \underline{B}$$

$$\Omega_c = \frac{eB}{mc}$$

$$R_L = \frac{mv_\perp}{eB}$$

Magnetic Fields Exclude Charged Particles



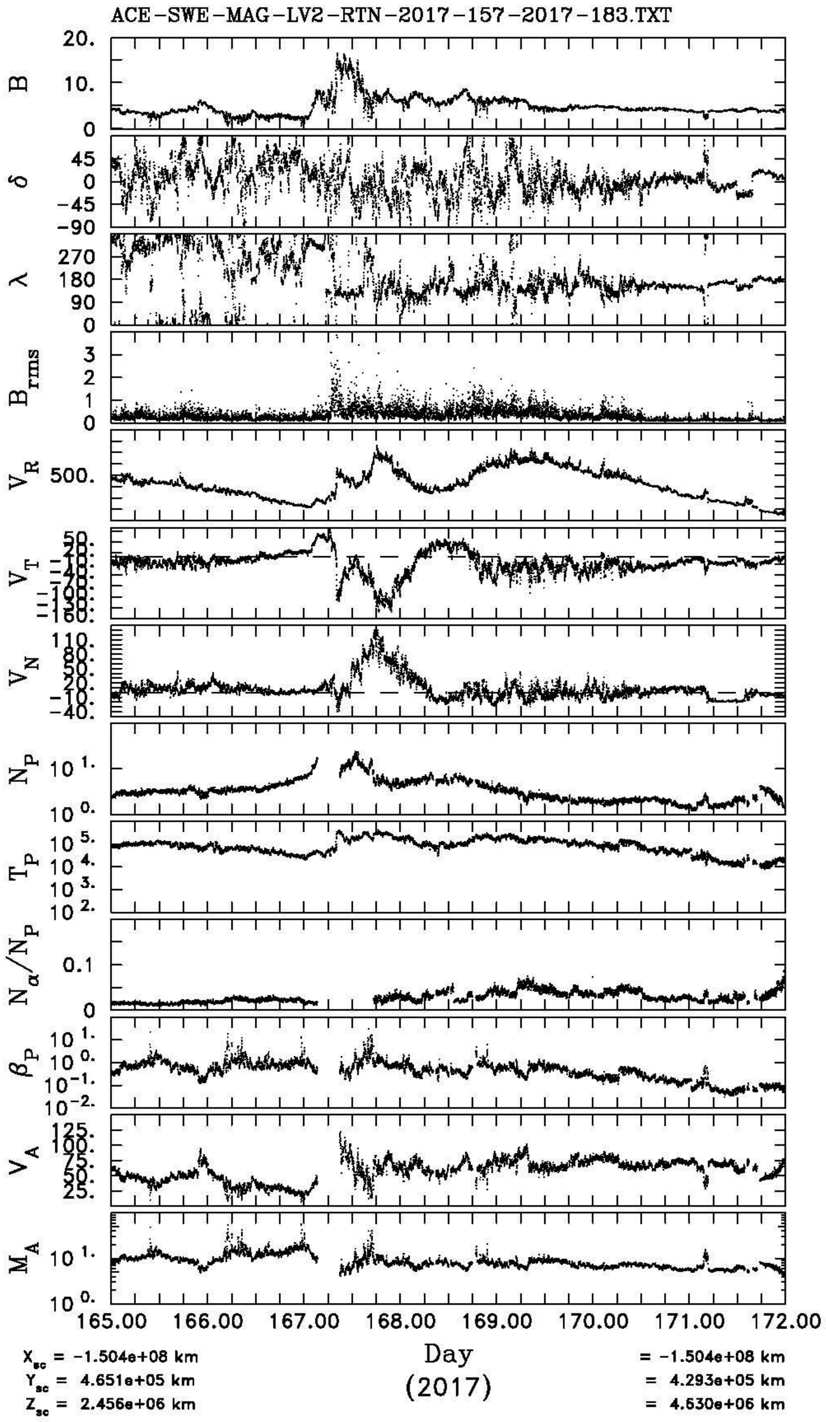
Magnetic fields exclude charged particles by forcing their motions into a smaller gyroradius, thereby expelling the particles back into the region of less intense field.

Particles remain tied to field lines.

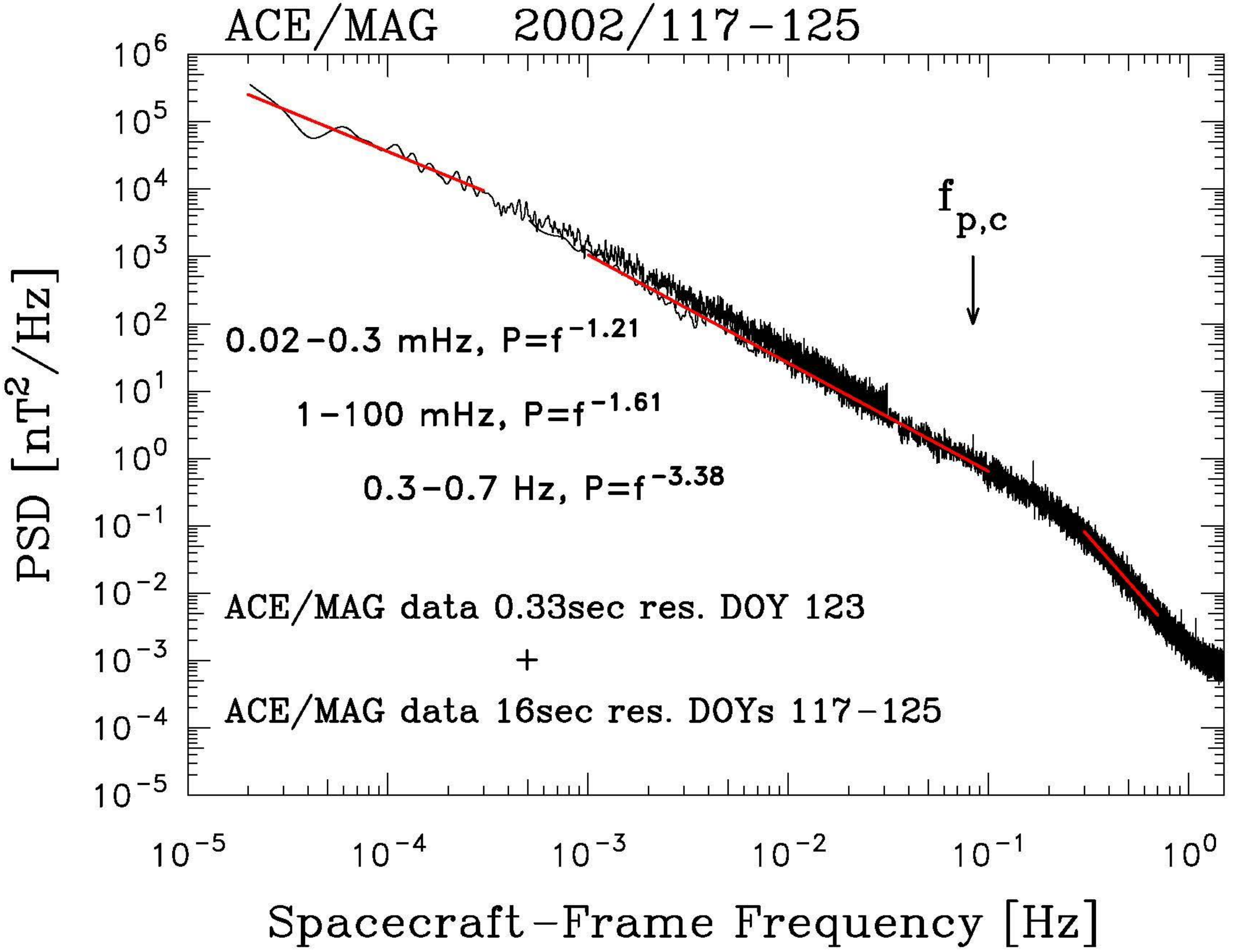
$\Rightarrow$ Magnetic bundles of charged particles behave like collisional fluid elements.

What Do We See in Space?

- We see a dynamic environment flows push against each other, sliding past each other, merging and pulling apart, and constantly driving transient activity.
- The source is not steady.
- The flows interact.
- The interaction drives shocks and rarefactions.
- And everywhere there are nonlinear dynamics called “turbulence”.

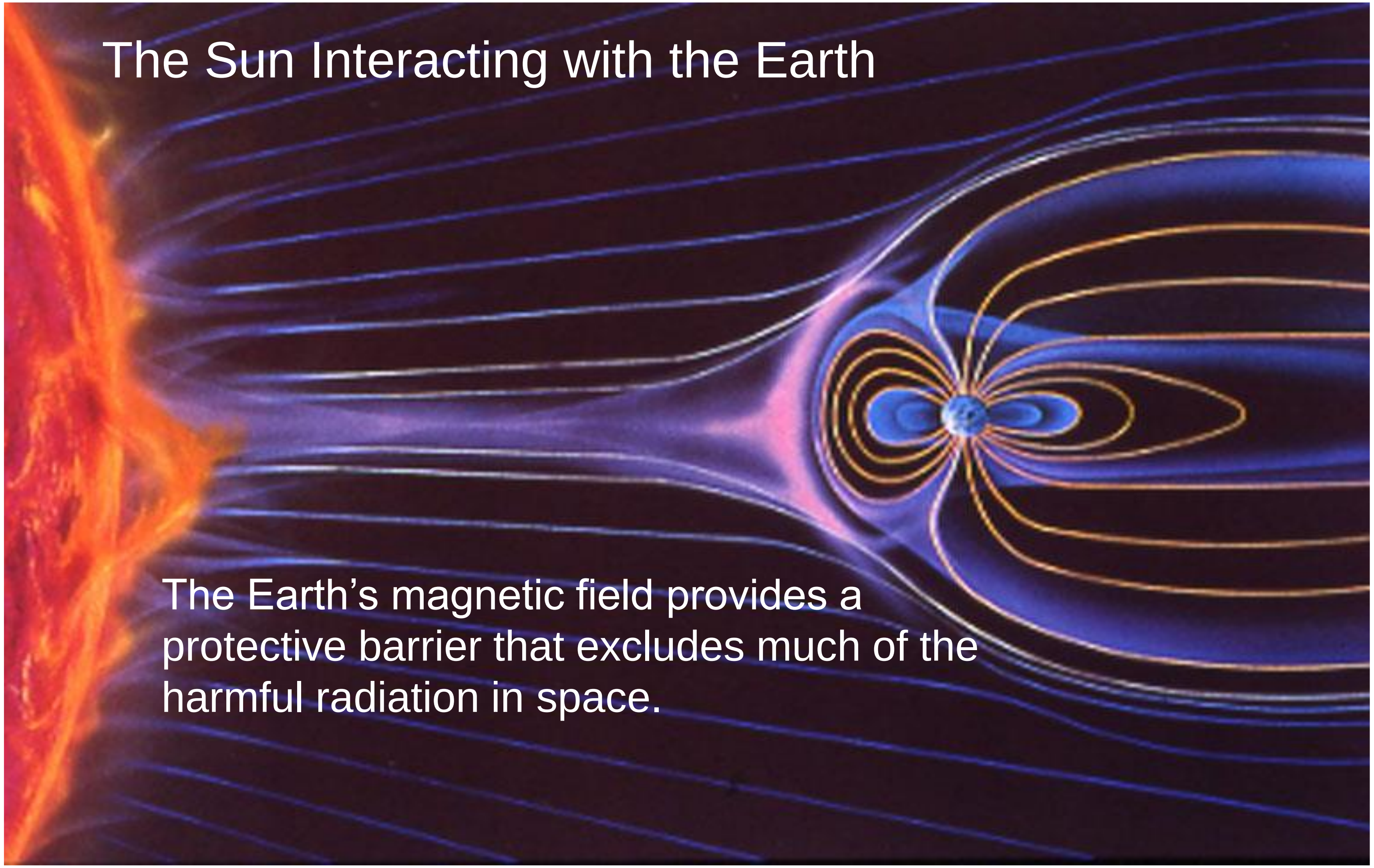


And We See Universal Physics in the Fluctuations



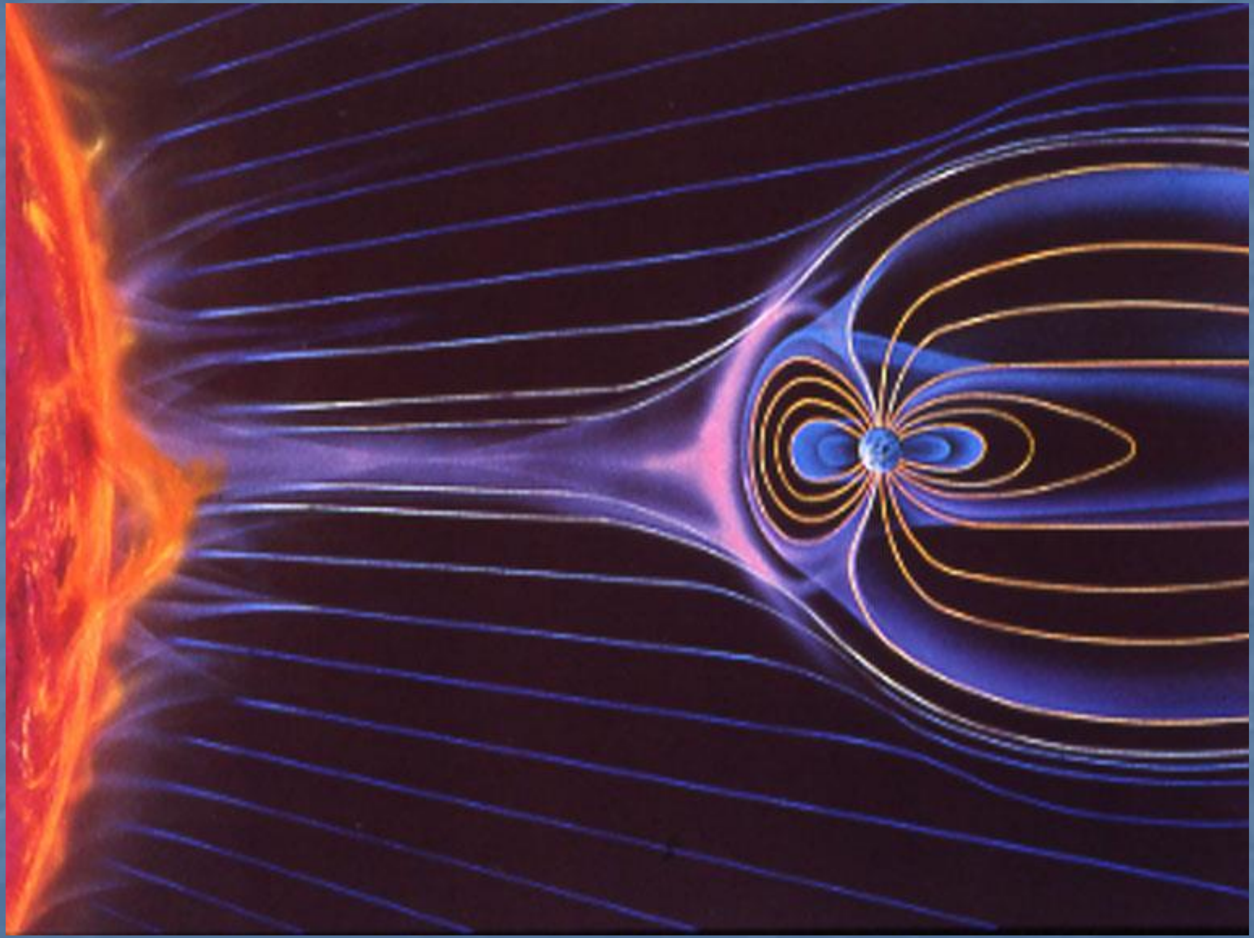
- We see a spectrum of fluctuations from scales associated with solar rotation to the gyroradii of thermal p^+ and smaller!
- It closely resembles hydrodynamic turbulence, but we cannot resolve the nonlinear physics responsible!

The Solar Wind and Earth's Magnetosphere

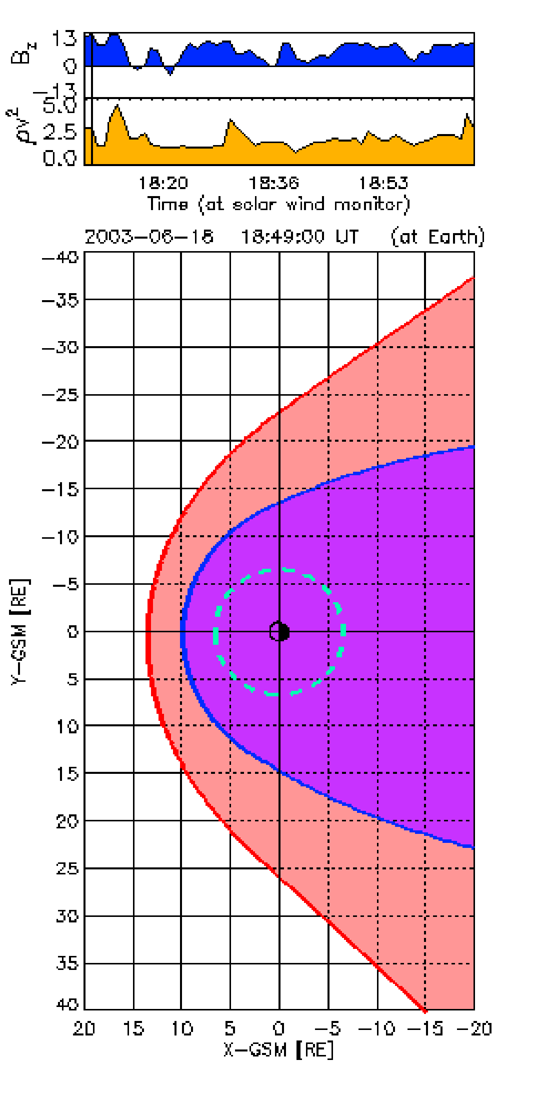


- The Earth is the ultimate immovable object.
- The solar wind collides with the Earth's magnetic field and is forced around.

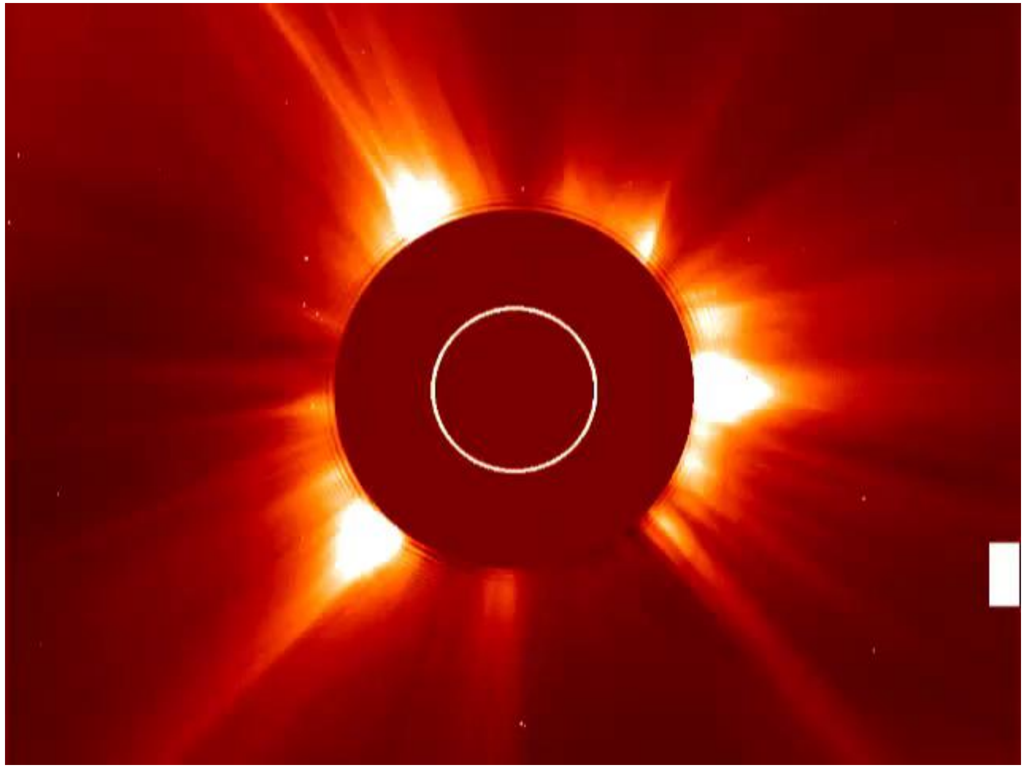
Response of the Earth's Bow Shock

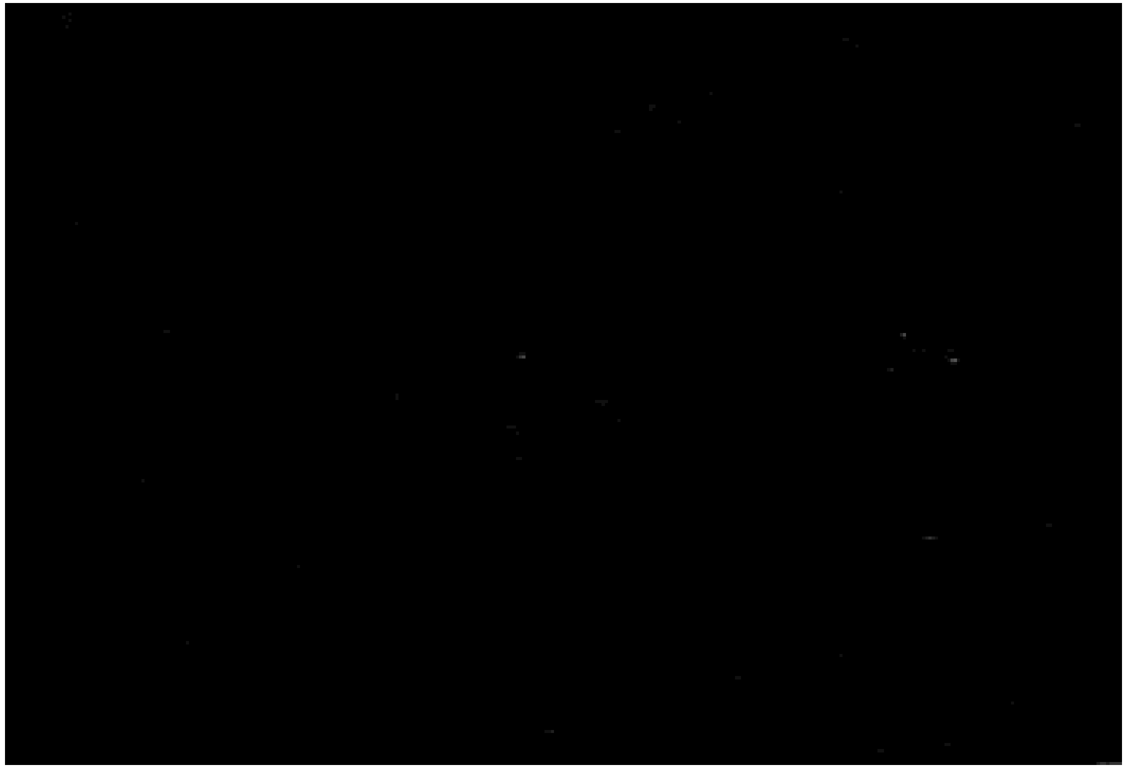


Changing solar wind conditions alter the state of the magnetosphere and its boundary.

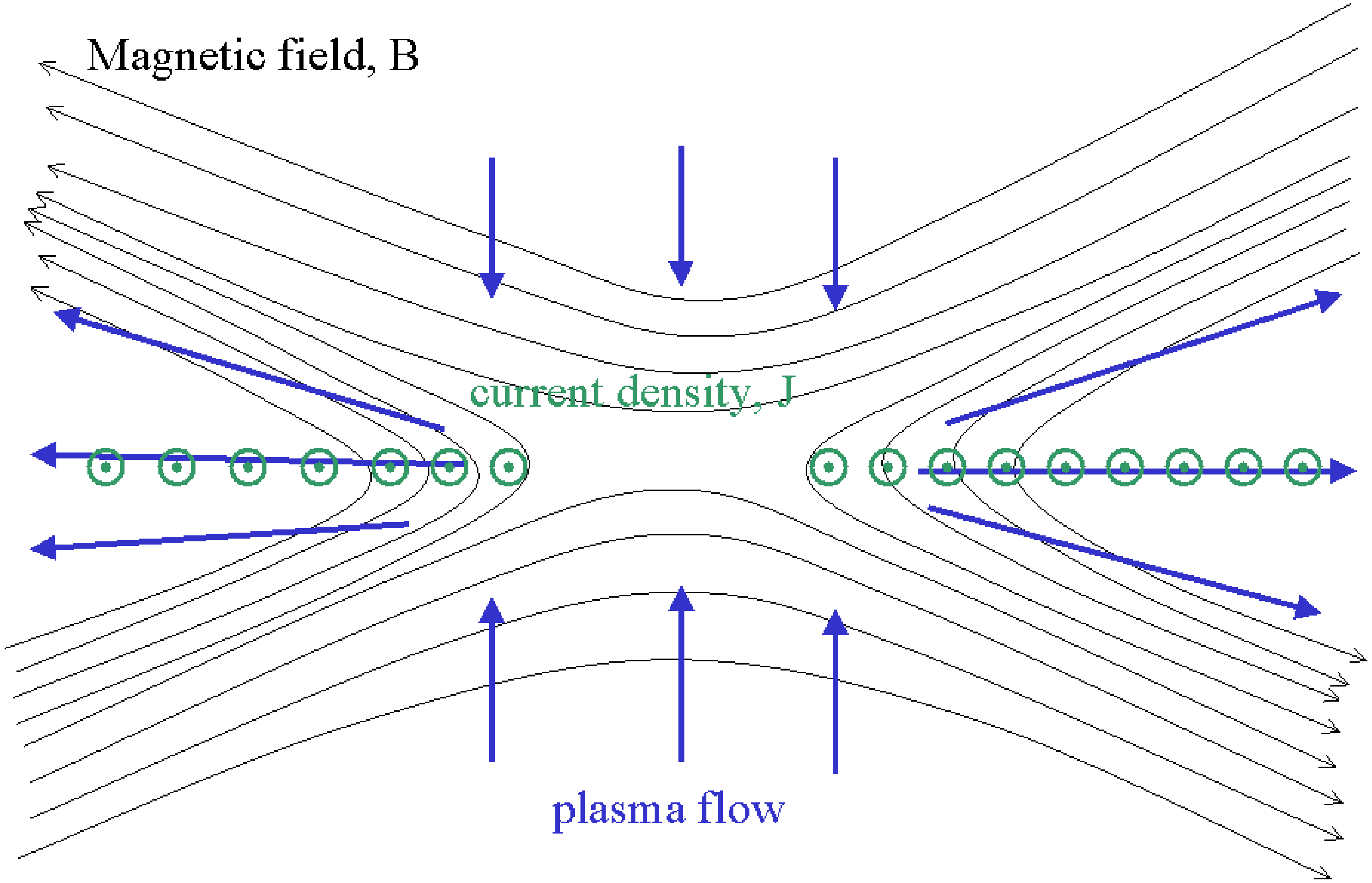


The Magnetosphere and Ionosphere





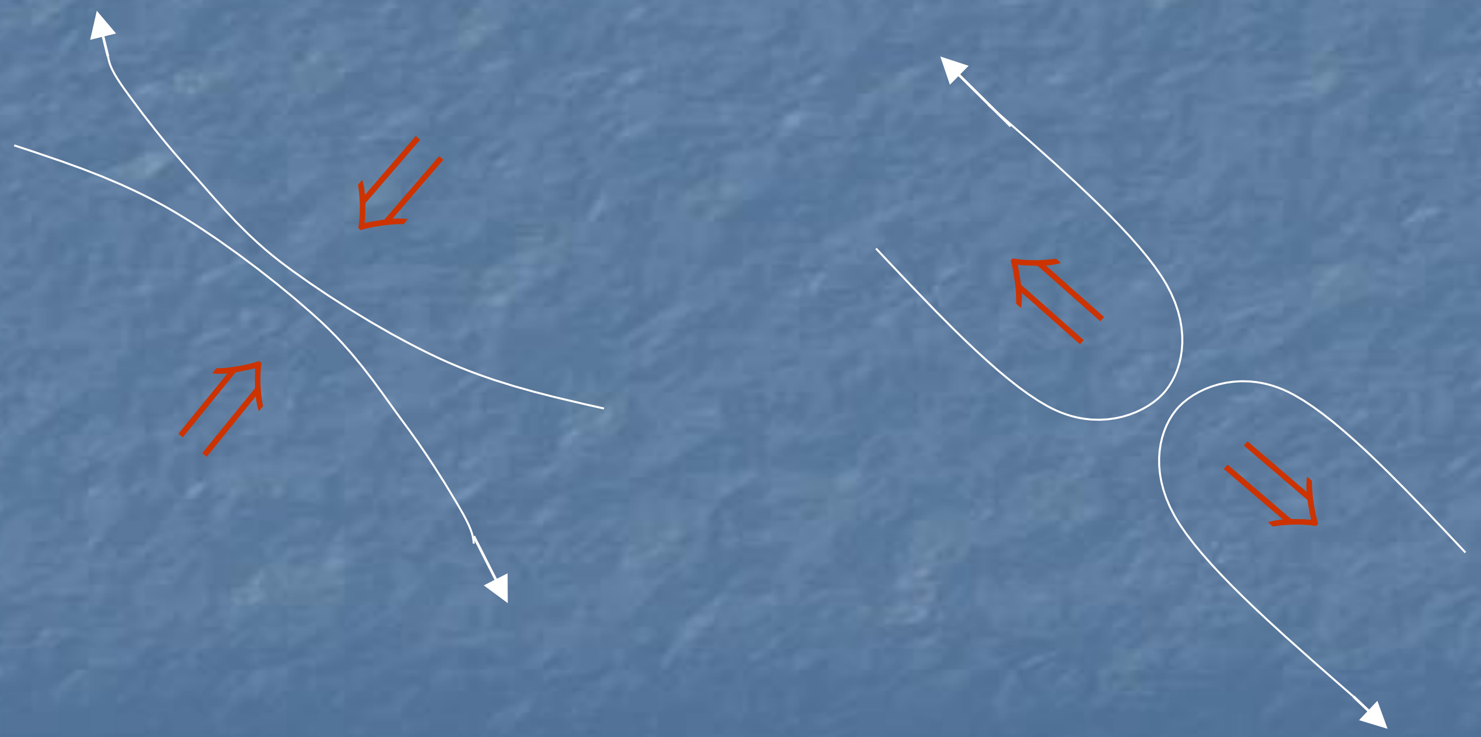
Magnetic Reconnection



- Reconnection occurs when field lines of opposite orientation are forced together and come apart with a different topology.
- This is a frequent occurrence on the nose of the Earth's magnetosphere.

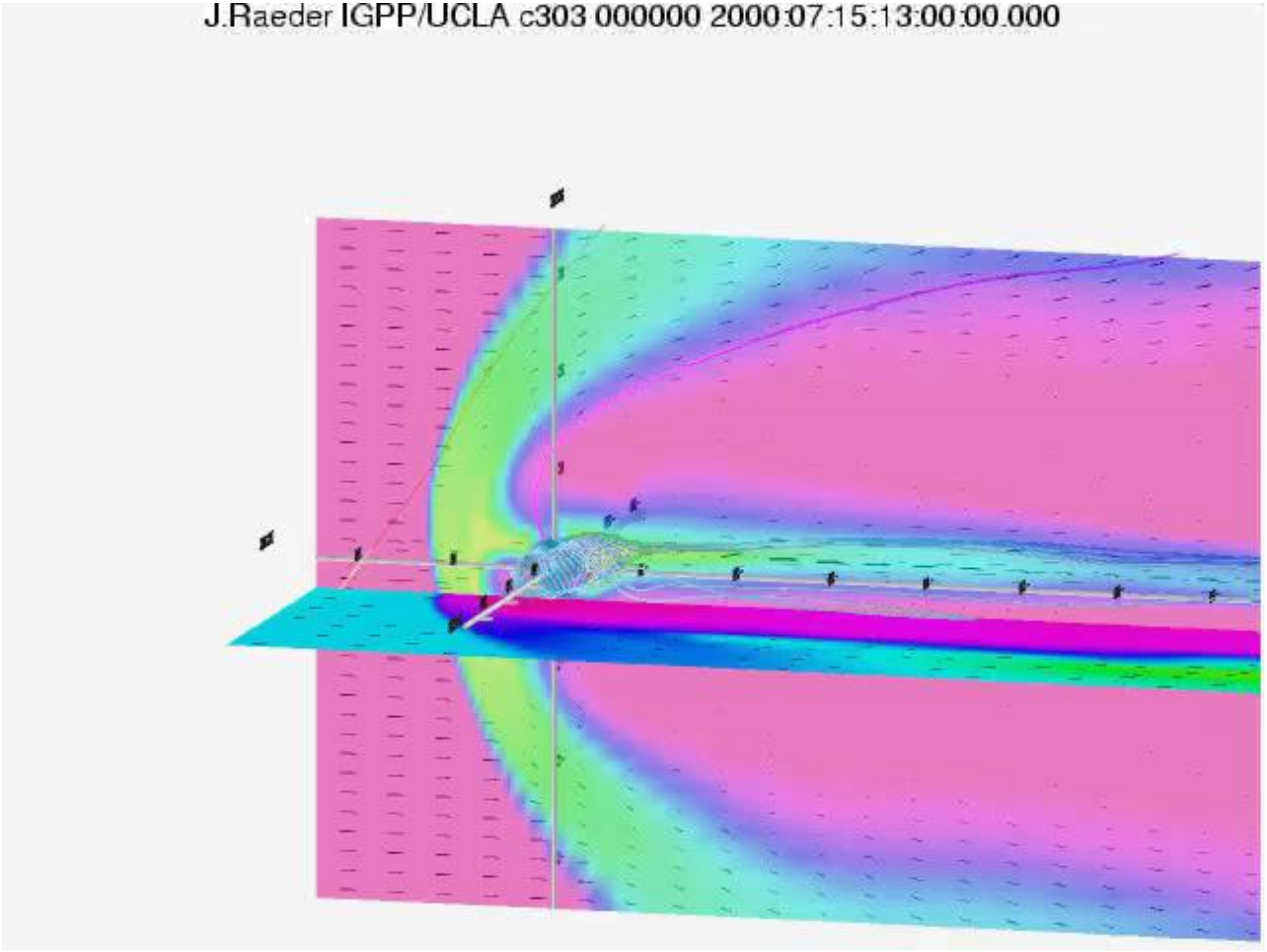
Magnetic Reconnection

A change in the local topology of the magnetic field.

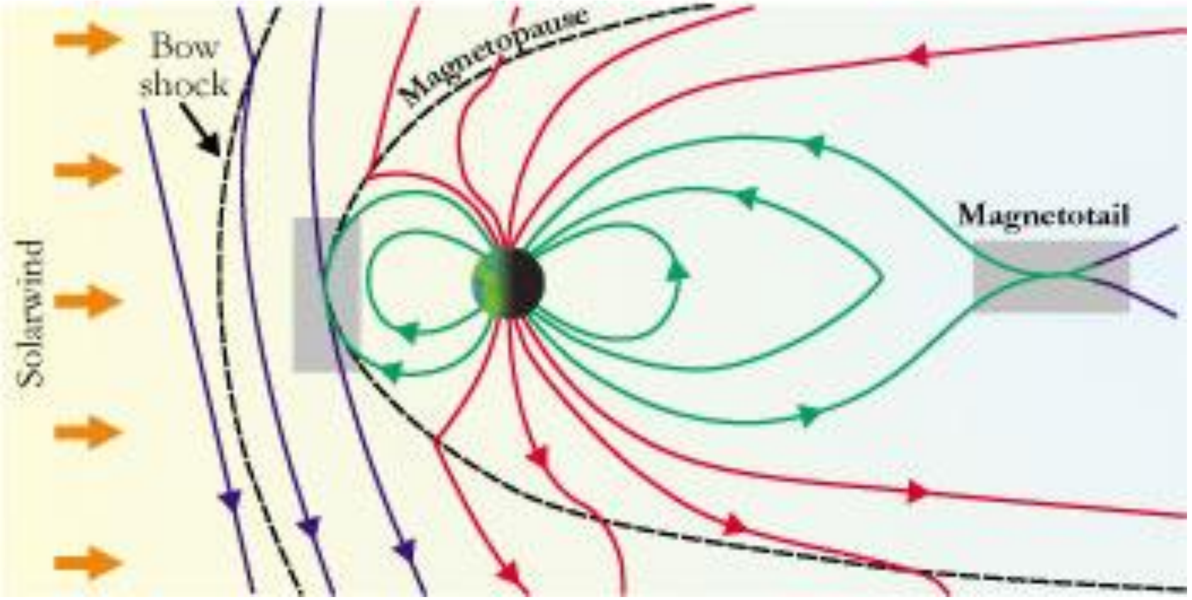


Goes in one way, but comes out another.

The Magnetosphere and Ionosphere



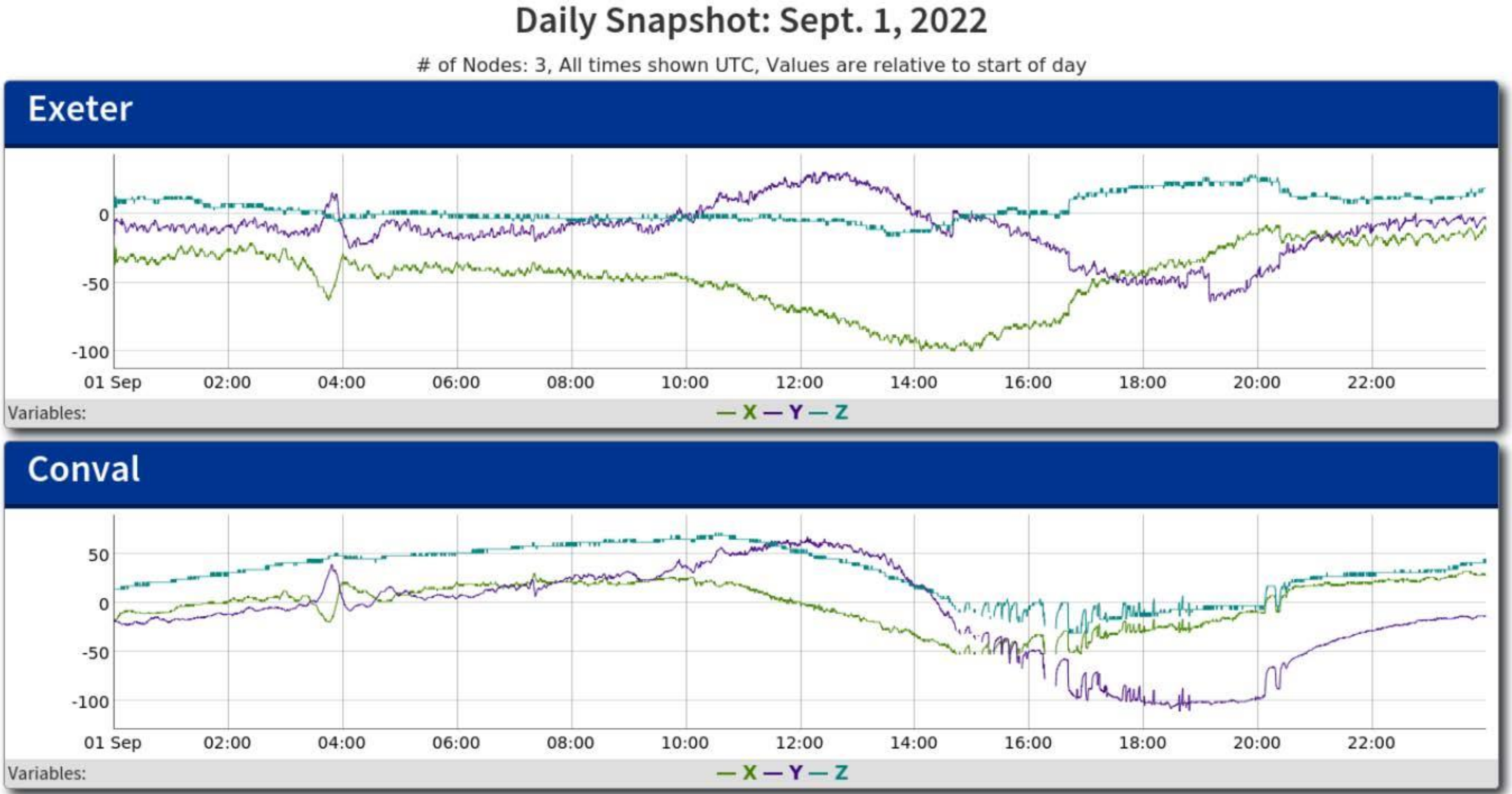
There Is No Static Magnetosphere



There are magnetospheric disturbances driven by solar wind transients and periodic disturbances because the magnetosphere is never in a stable configuration.

- The magnetotail gets drawn out (and energized) until reconnection releases the tension and the field snaps Earthward.
- This causes (some) aurora and ionospheric disturbances.
- There is a quasi-periodicity to this behavior during quiet times in the solar wind.

September 1, 2022



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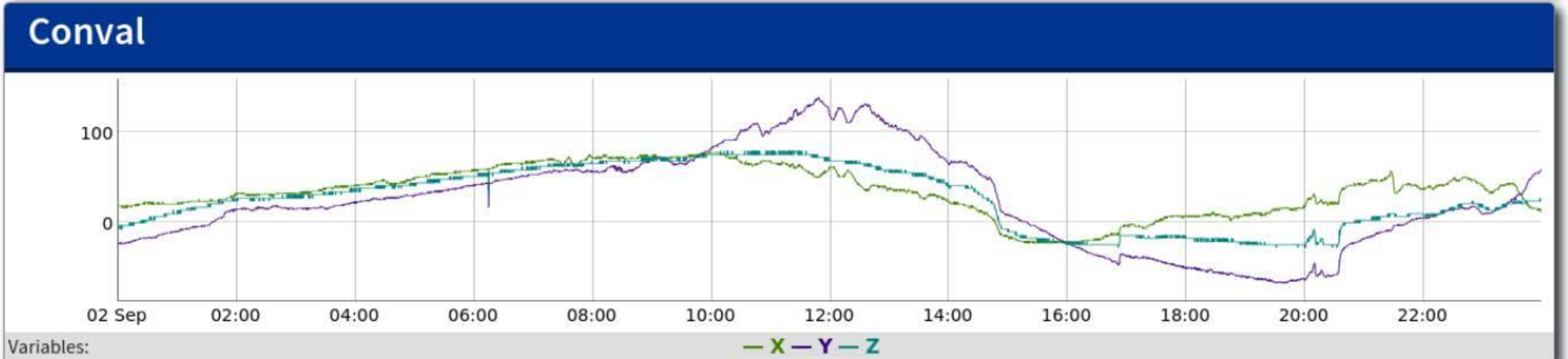
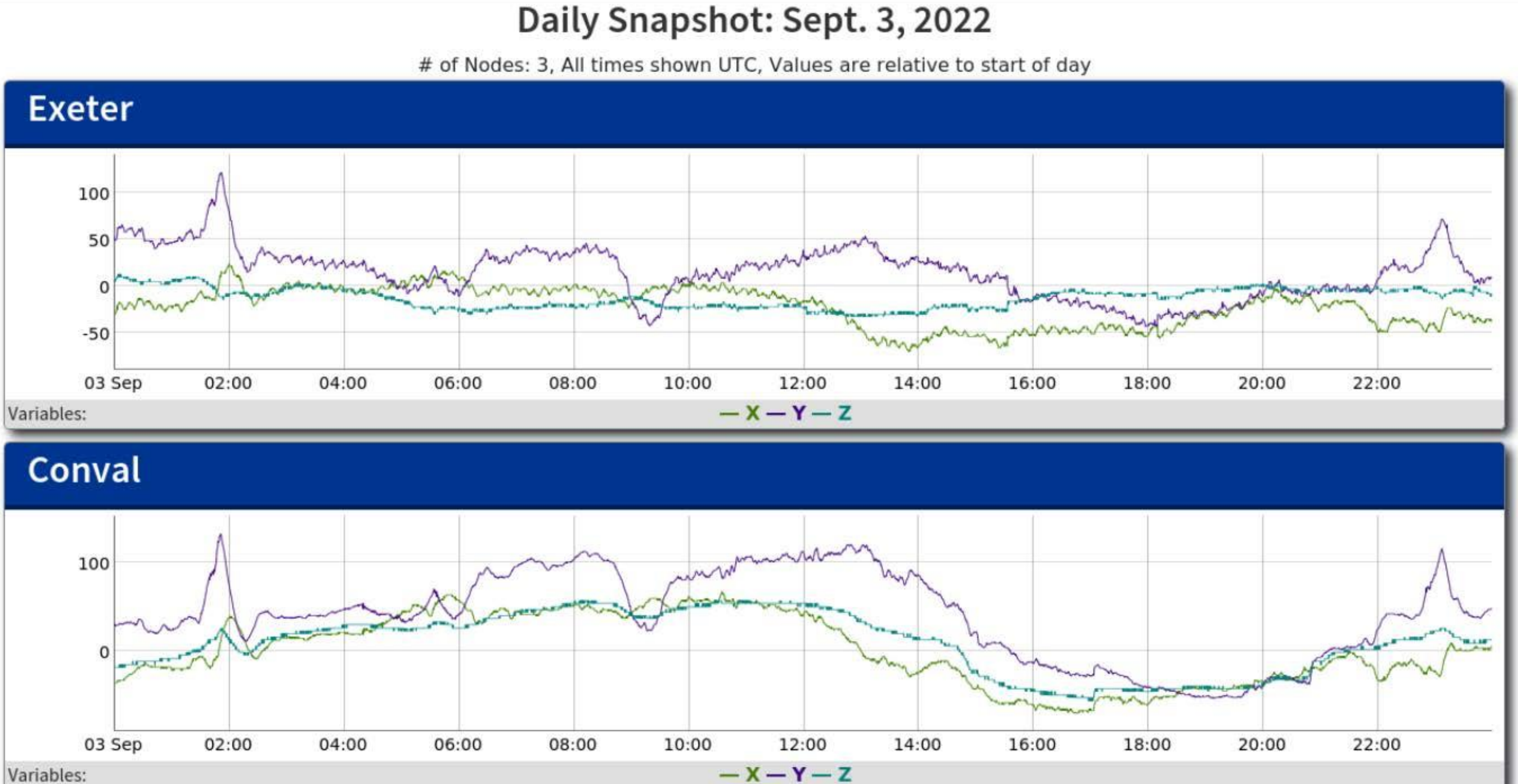


September 3, 2022



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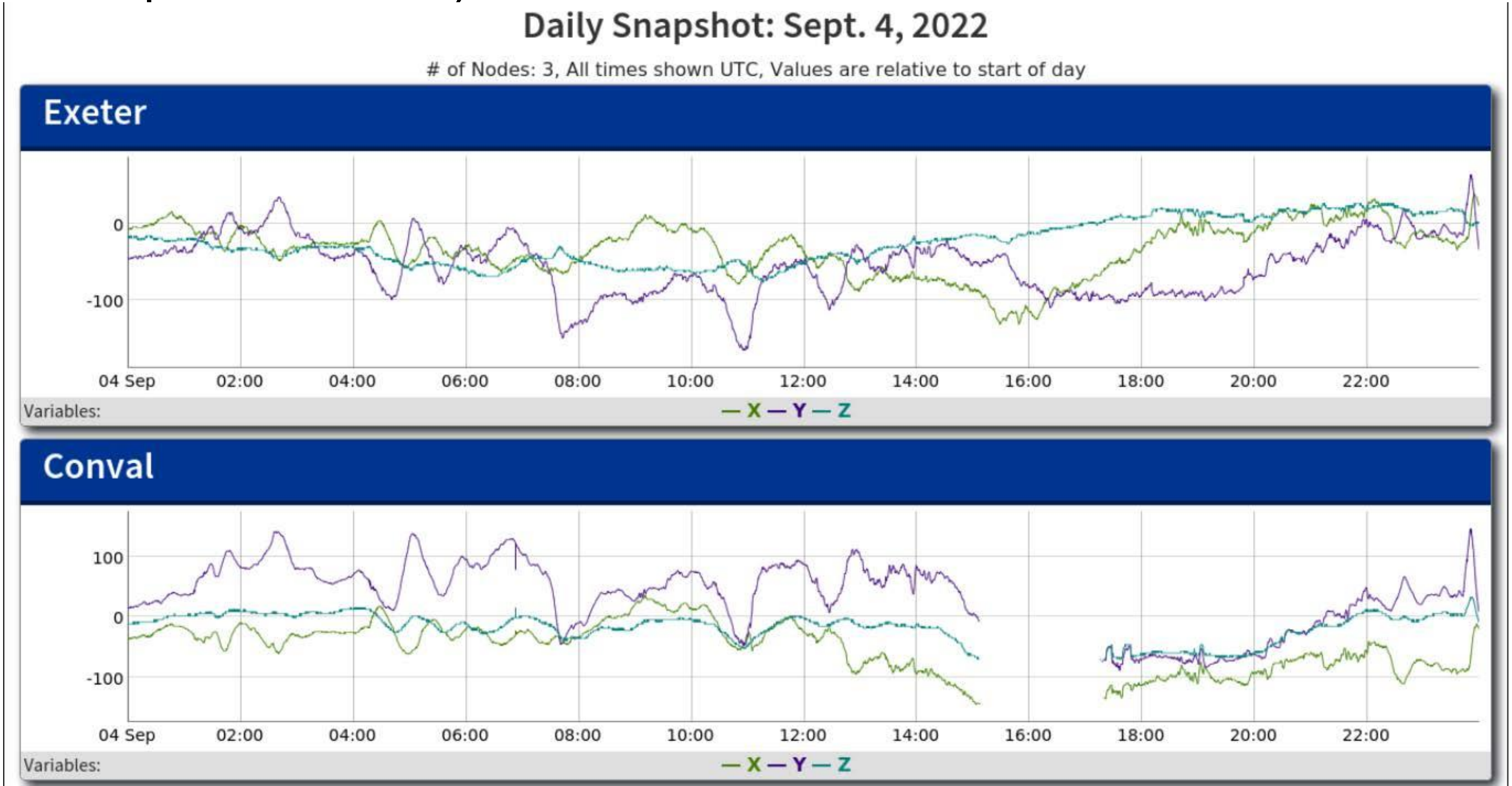

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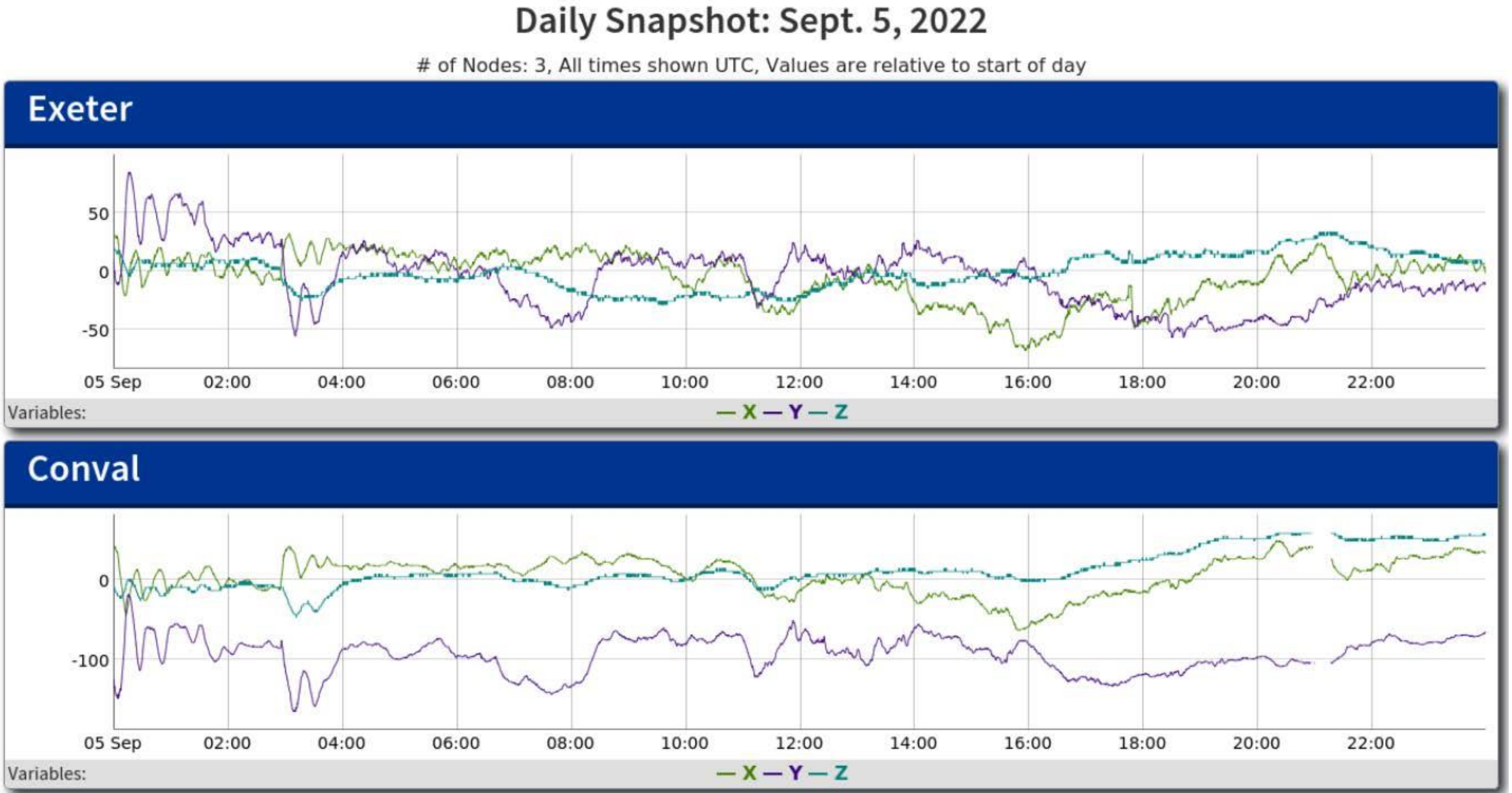

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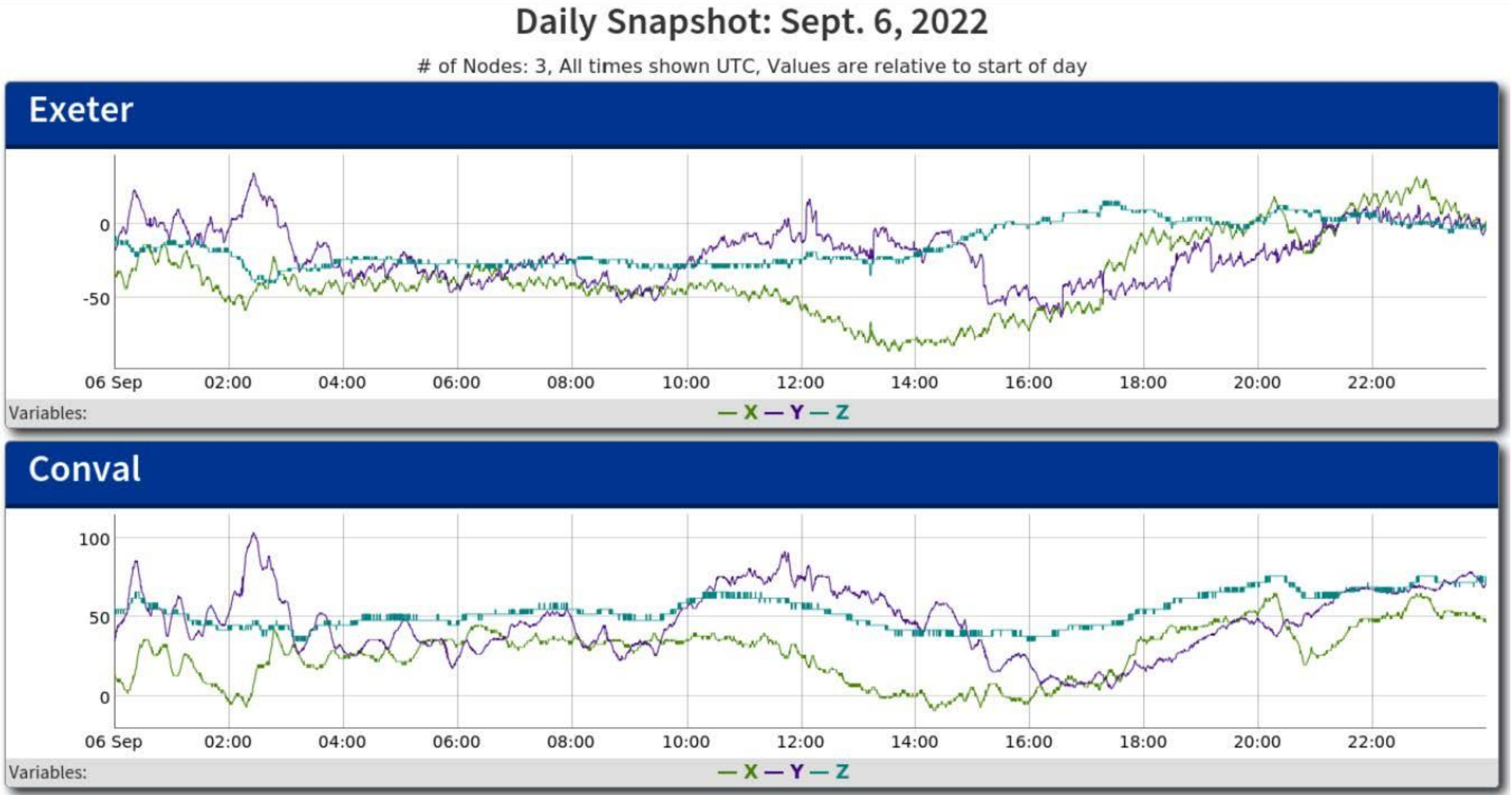

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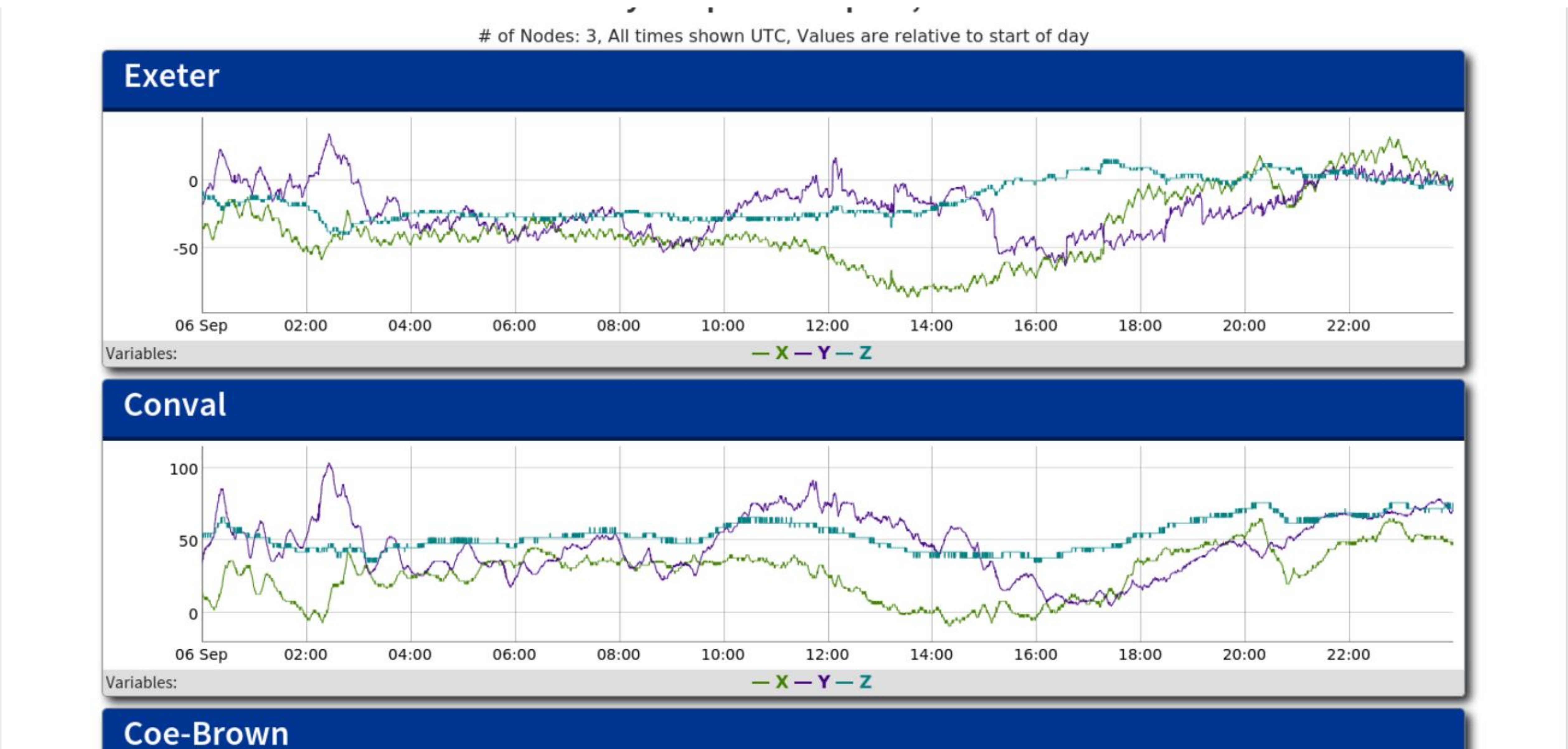

Very Early Science & Evolving Lessons

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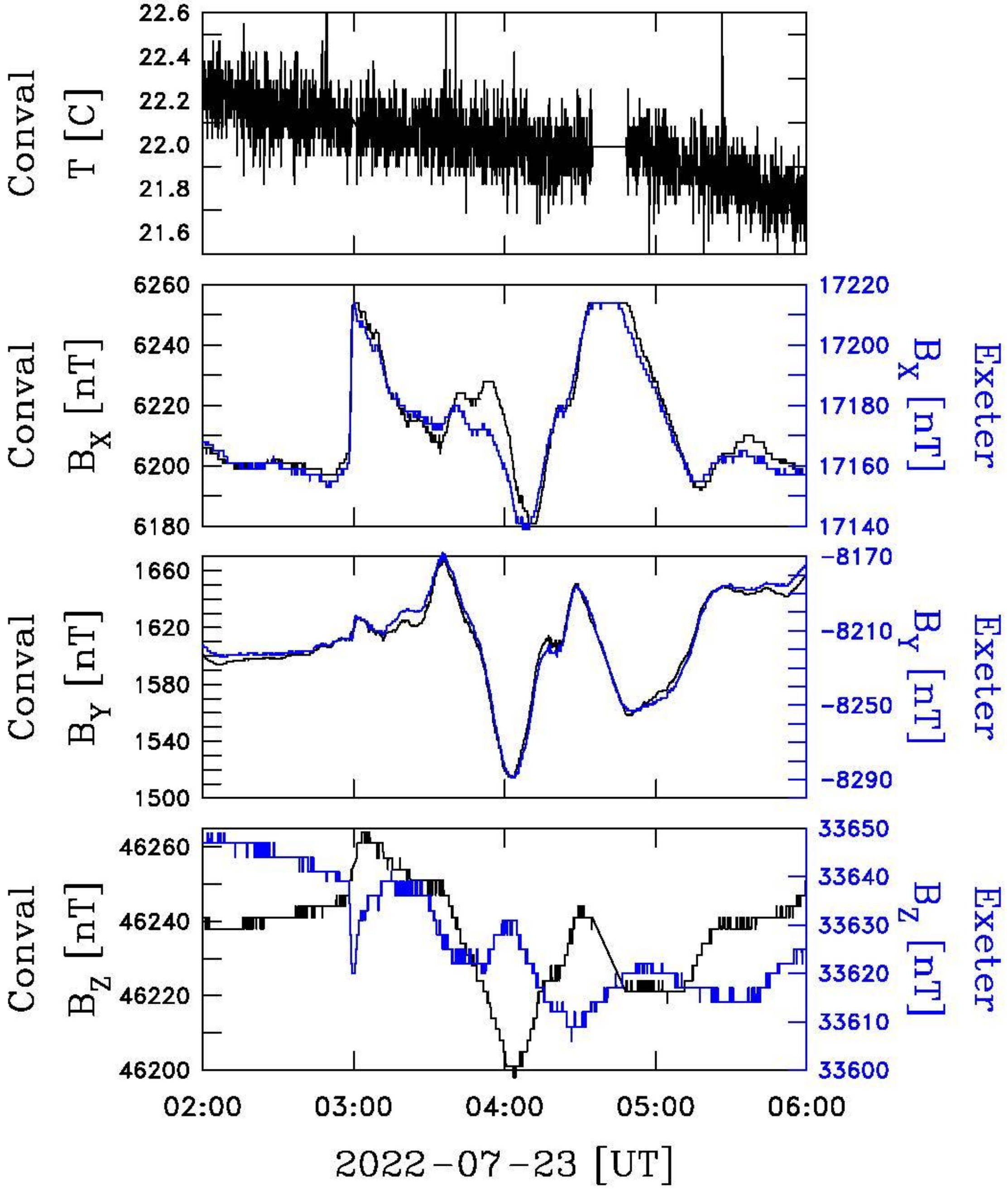
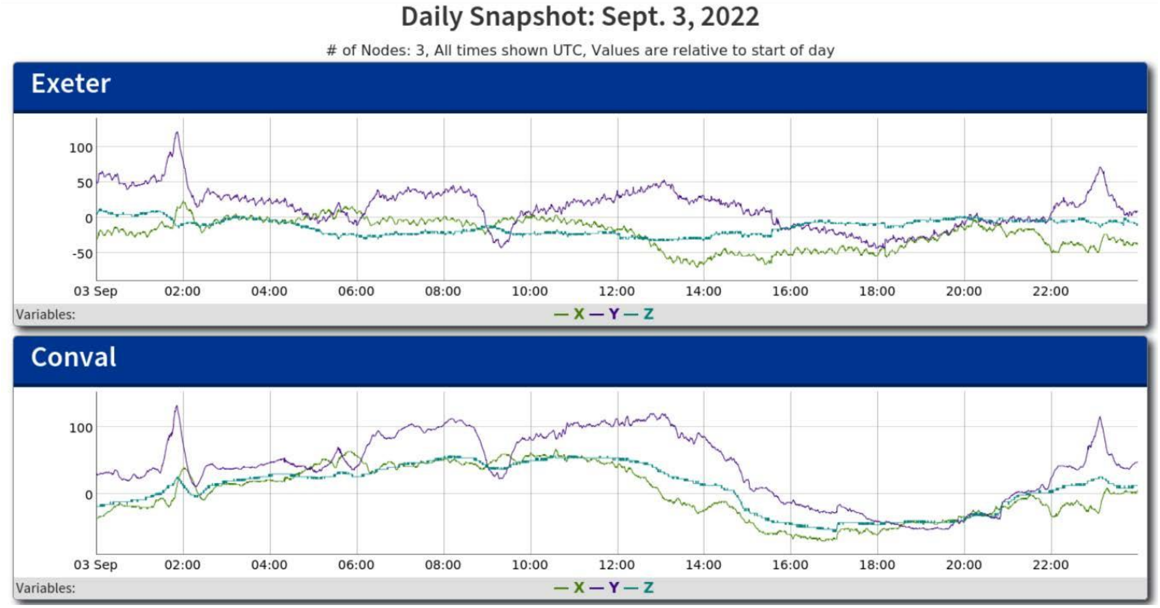
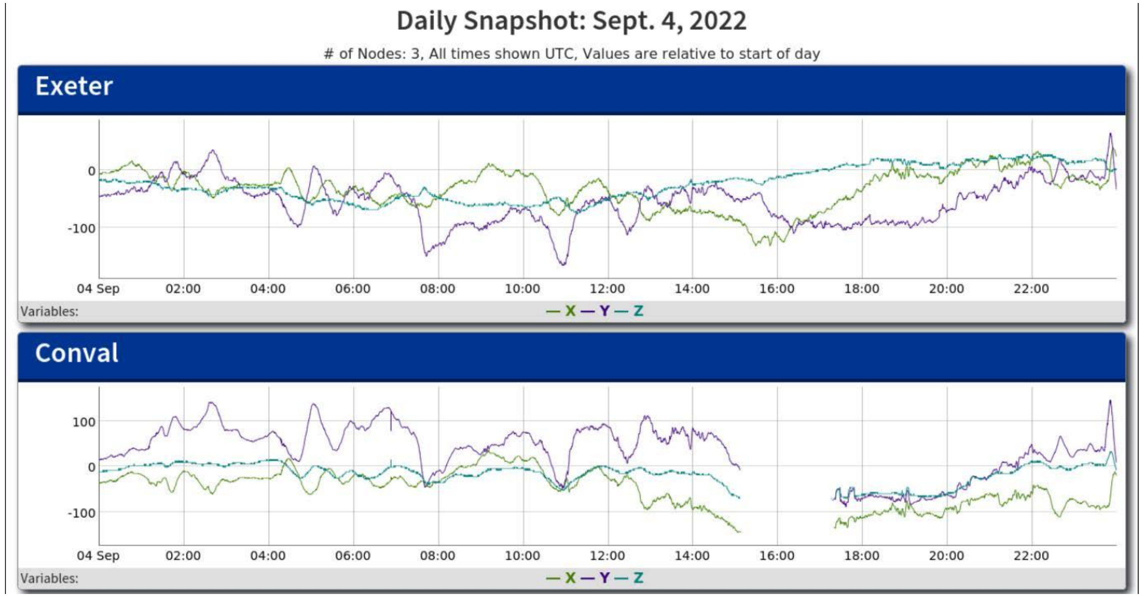
- It drove a very nice disturbance overhead.
- Coe-Brown was on the bench for repairs.
- As a demo, we compared CONVAL and Exeter.

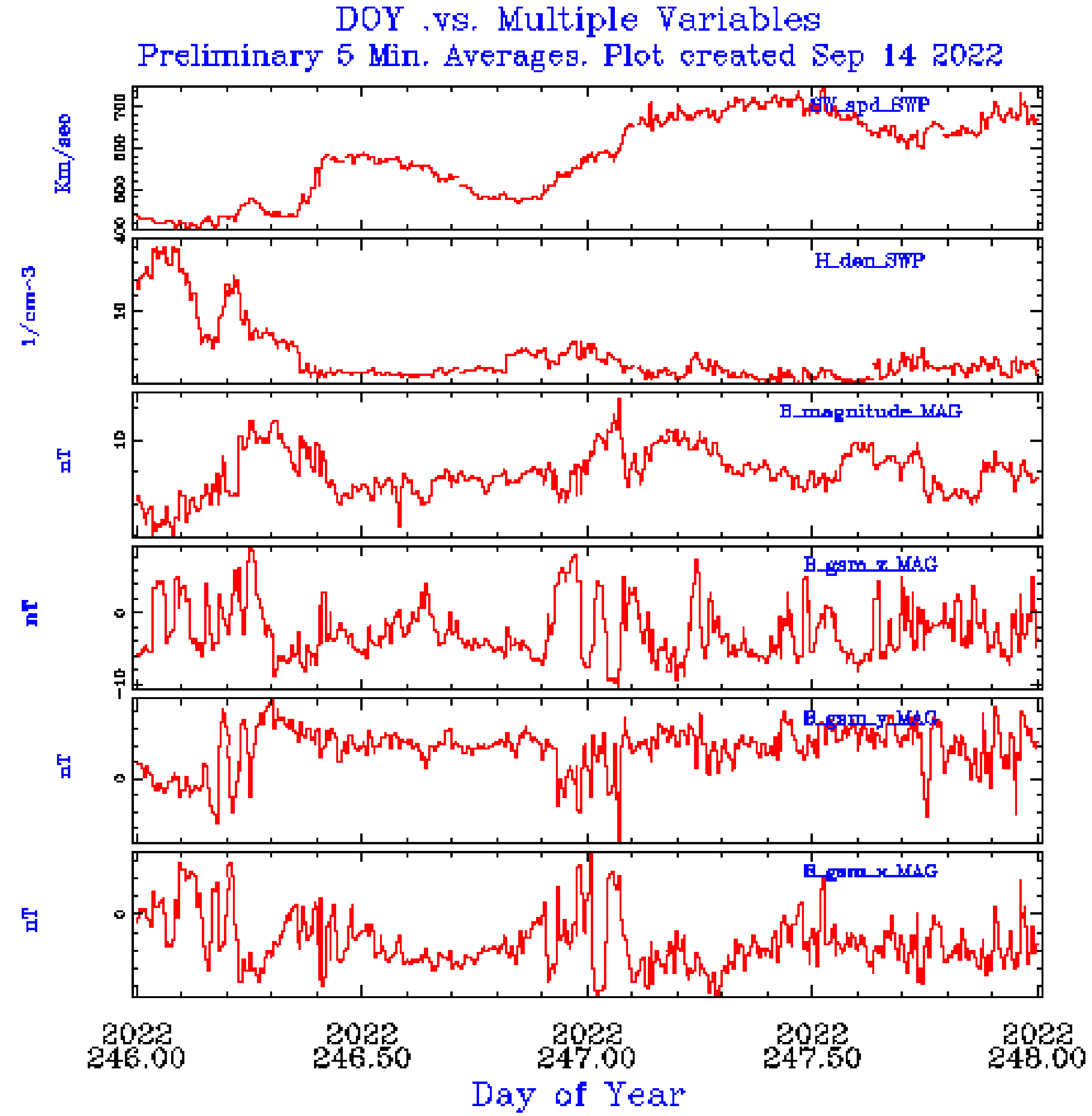
Lesson Learned: We need to review our calibration efforts!



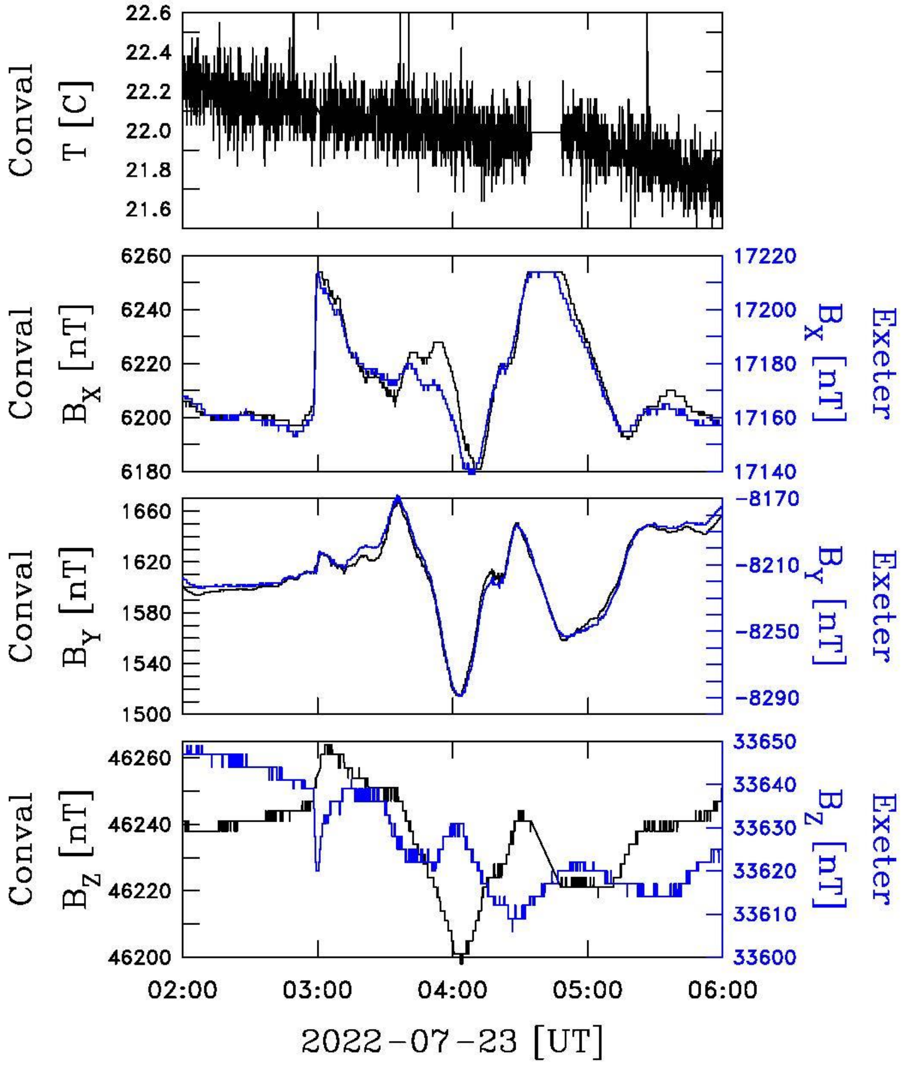
September 3-4, 2022

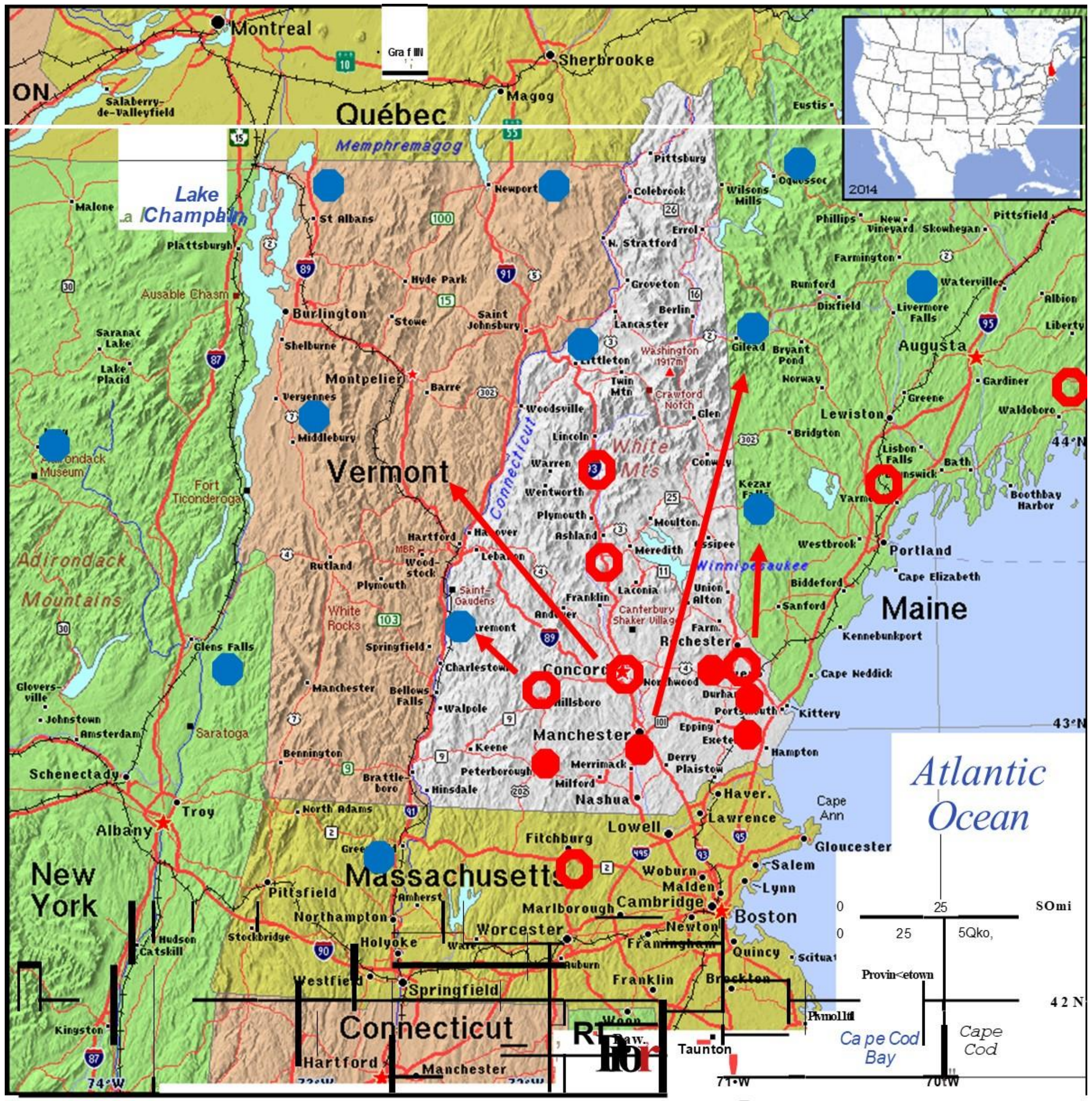






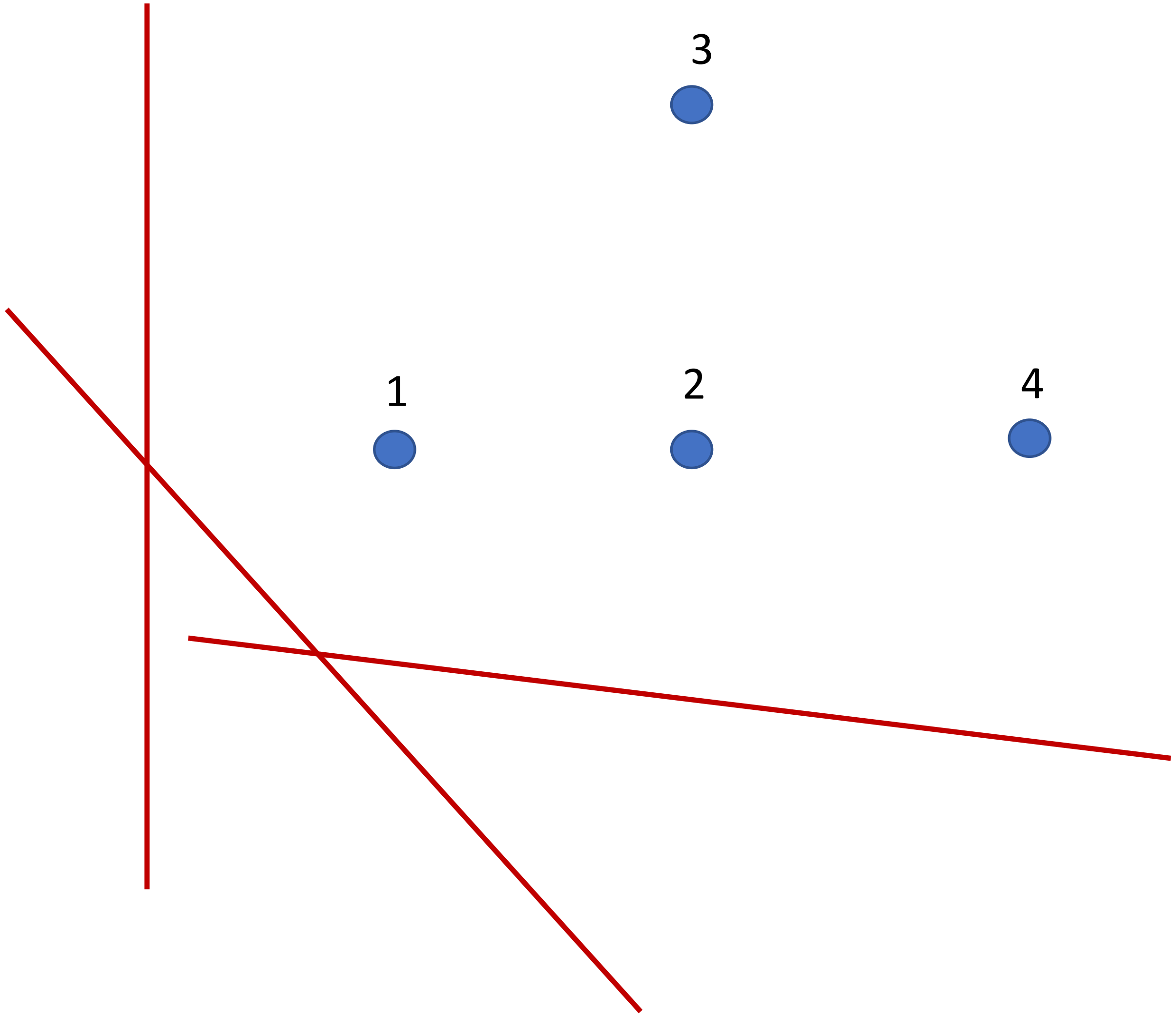
Science Opportunity





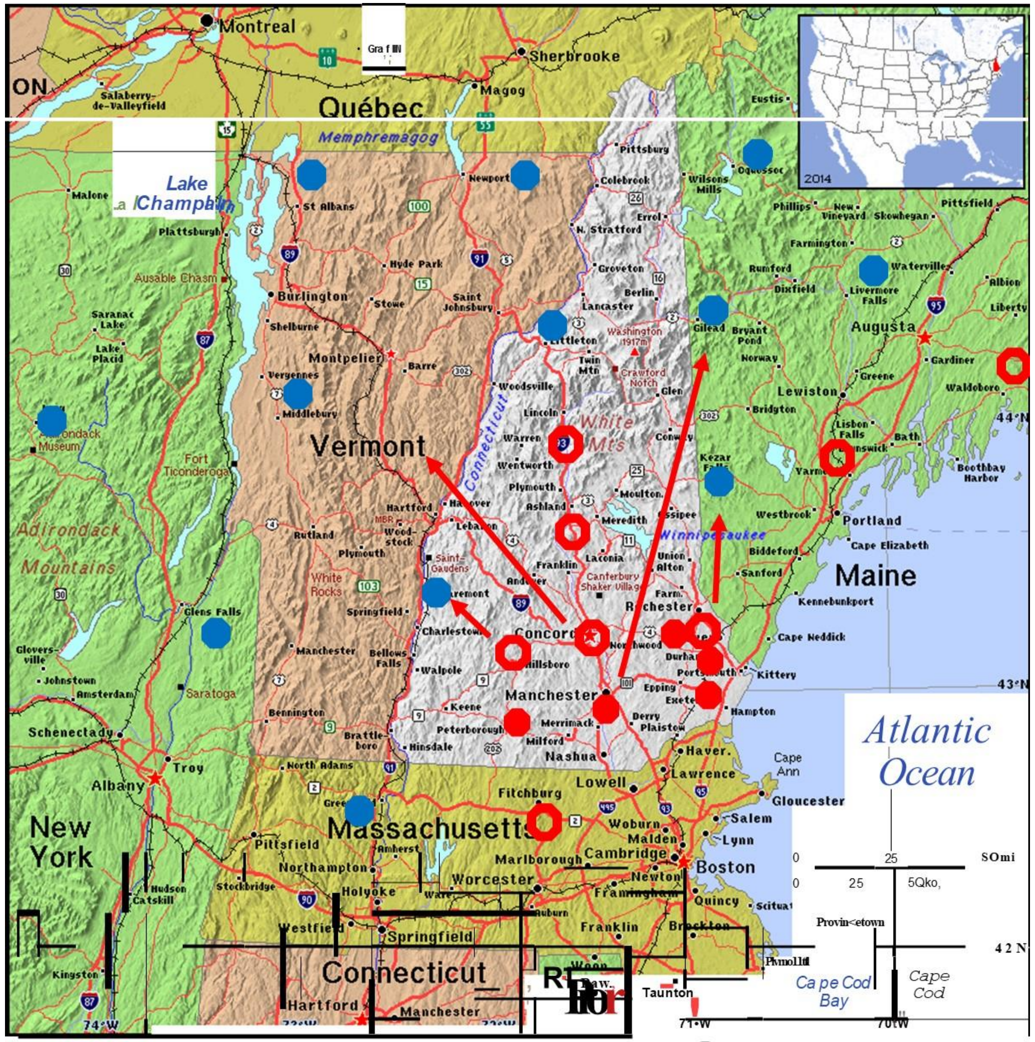
N E W H A M p S H I R E

Three Node Triangulation of Linear Transient



- Three nodes with both north-south and east-west separation are needed to determine the propagation speed and direction of a linear front.
- More than three nodes provides refined uncertainty in the result and indications of curved fronts.
- Larger node separation provides better resolution of timing.
- Smaller separation provides confirmation of transients.

Three Node Triangulation of Linear Transient



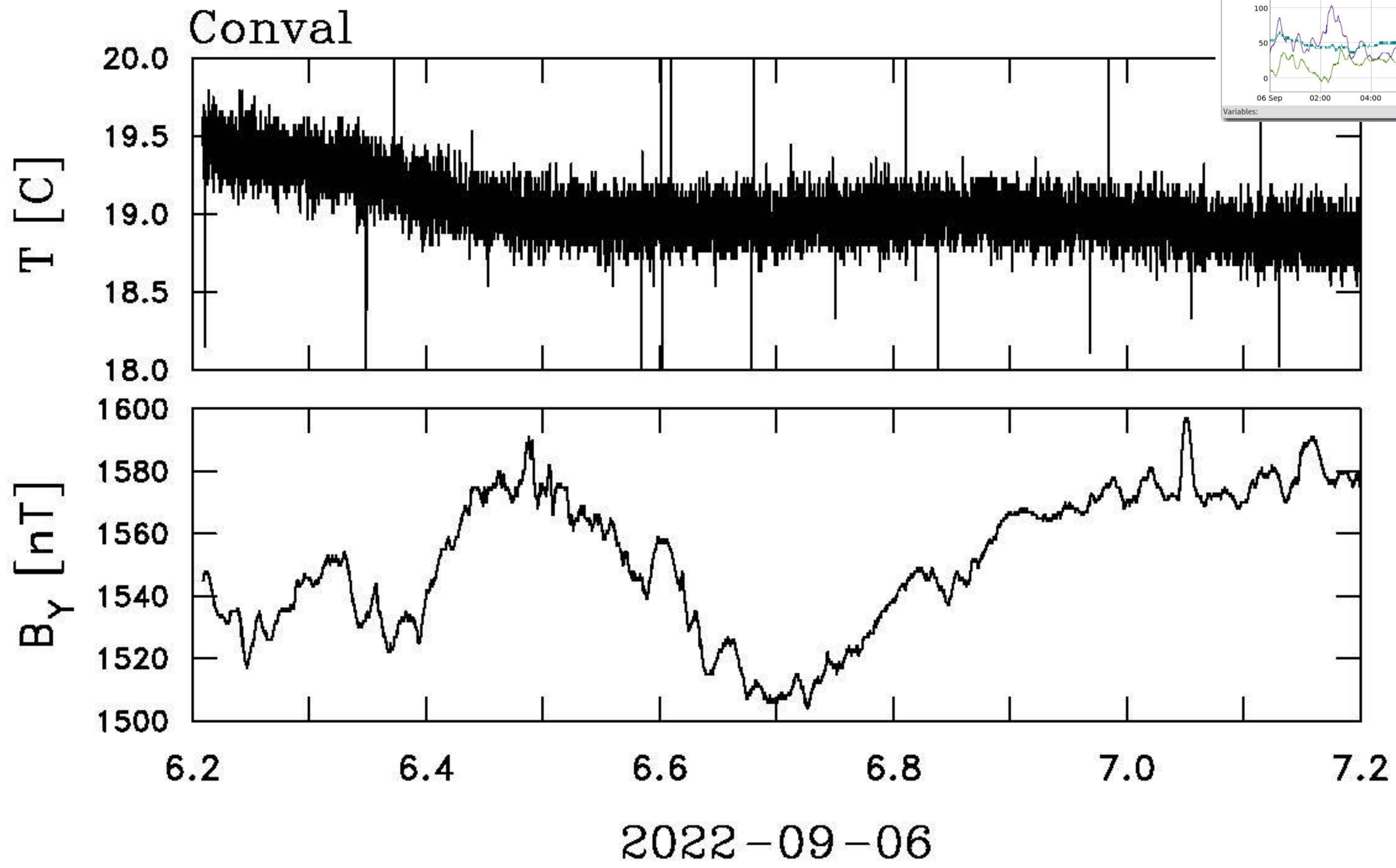
N E W H A M P S H I R E

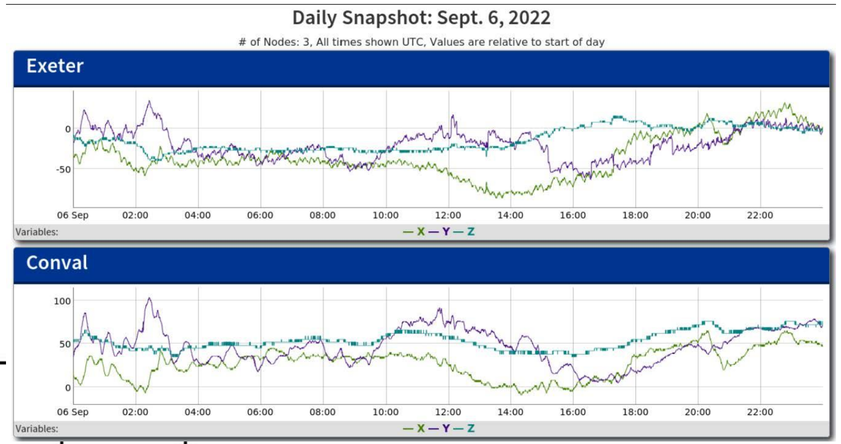
- Direct mathematics
- Computer code that varies parameters in a search toward the optimal solution
- Then we evolve those ideas to include many triangulations.
  - Compute means and variations
  - Discard “poor” solutions
  - Consider curved fronts
- Reconstruct currents overhead

Deployment Problems (All Solvable):

- Our outdoor deployments have both failed in 1 year.
  - They have been fixable, but we can't be fixing 20 instruments annually.
  - We need to review component selections & design.
  - We need a better cable design to facilitate easier deployment.
- We need to perform accurate calibrations (offsets and gains).
  - Easy to do, good thing to do at night.
- We need accurate thermal calibrations.
  - Put mag in a cooler and abuse it.
- We need more deployed magnetometers.
  - We will be speaking at the October NHSTA meeting.
  - Tell your friends about us!

Thermal Sensitivity

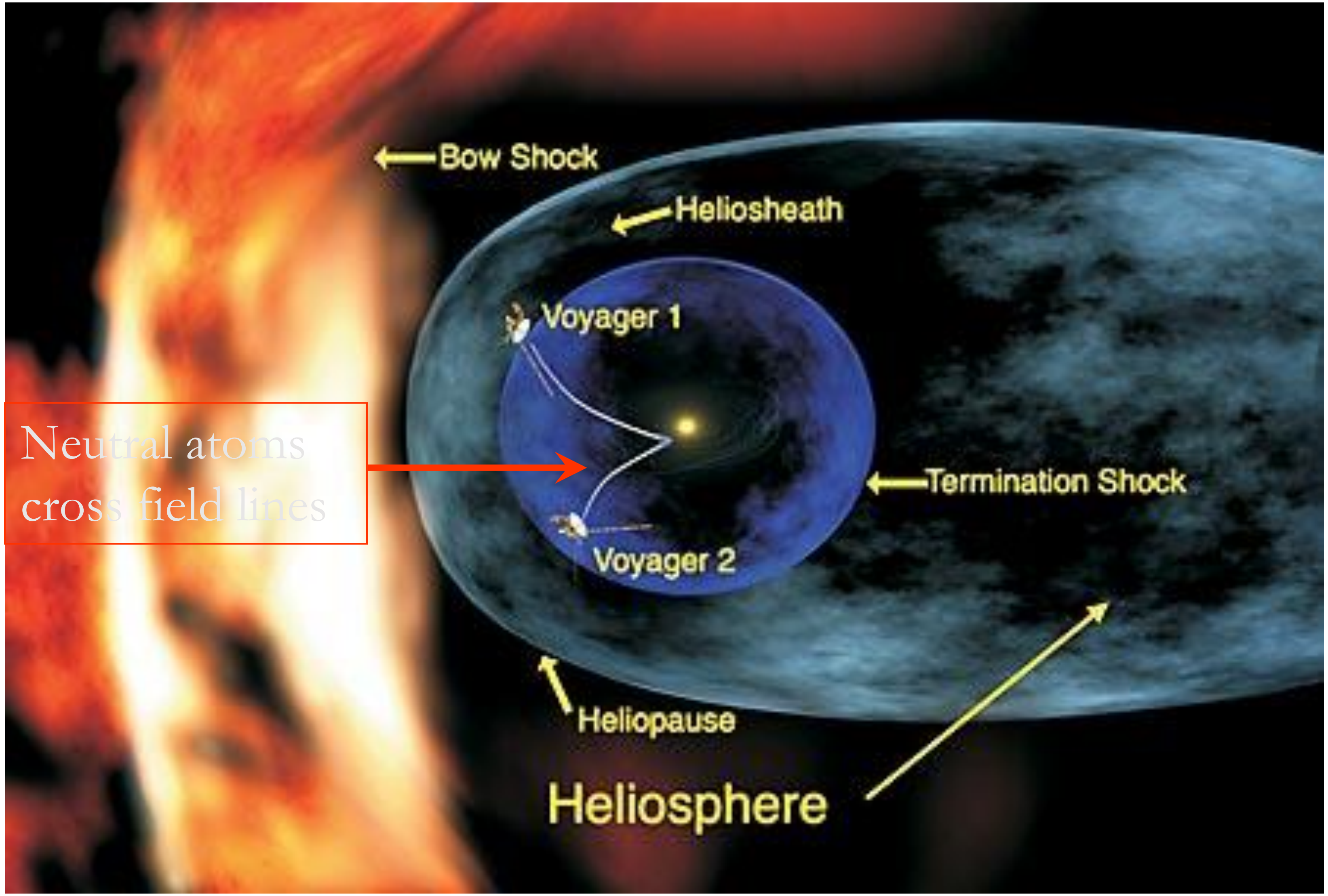




More Deployment Problems (Still Solvable):

- Data files are not user friendly.
  - GPS location is not coming out in data.
    - This actually has additional science value.
  - Excel files do not have seconds on time.
    - I wrote a code to add this, but I’m troubled.
- There are “collisions” costing us data points.
  - Exeter does not have this problem.
- Data files are not coming through as clean days (not Exeter).
  - Start 5 hours into the UT day.
  - This may not be a problem, but we need to be consistent.

Interstellar Space



- Our heliosphere is formed in the same way by an expanding solar wind pushing against the interstellar plasma and magnetic field.
- Voyager has crossed the boundary and that data is available to you!

Where Do We Go From Here?

- We are hoping to deploy ~20 mags across northern New England.
  - More if we can.
  - Additional mags in Alaska, Midwest, Texas, mid-Atlantic, and Georgia.
- They must be robust! We cannot be fixing that many mags.
  - We want a more user-friendly build.
- We hope this becomes a research tool and that your students would like to participate.
- We want you to be able to establish a SWUG presence in your school.
  - This means a monitor that's easy to see and self-explanatory.
- We would LOVE for you to develop lesson plans around any of this science.

Student Experience

- Do real science with real data.
  - Physics, mathematics, and scientific programming
  - Learn subjects that they can understand, but that don’t make it into the HS curriculum.
- Participate in the discussion of science.
  - There are scientific studies to do and papers to write.
  - Attend meetings and present papers
    - AGU has both science and education sessions
  - There are education papers to write.
    - Space science is invisible in most curricula everywhere!
- Scientific programming is the key to unlocking space physics.

Future Opportunities?

- We have applied for support for a 1-week summer program.
  - Opportunity to learn and do space physics.

- We have discussed other builds that could provide similar opportunities for students.

- We also have other ideas for similar student opportunities:
  - Mags under high-tension power lines
  - Mags in the shadow of an eclipse
  - Ground current monitors
  - Environmental monitoring arrays (already have stream monitors)

Extra Slides

The Worst Way Possible to Begin:

- This meeting will contain AT LEAST:

2 apologies
&
3 confessions

- So let’s start now! – I took my eye off the ball!

The SWUG Deployment

- We have a good deployment scheme, but we are working to improve it.
- The mag needs to stand alone.
- It needs to be remote (in whatever sense that means).
- We want it to be rubust!
- It needs to send data to the SWUG Data Center.
- We want it to have a useful presence in your schools.