University of New Hampshire Space Weather UnderGround

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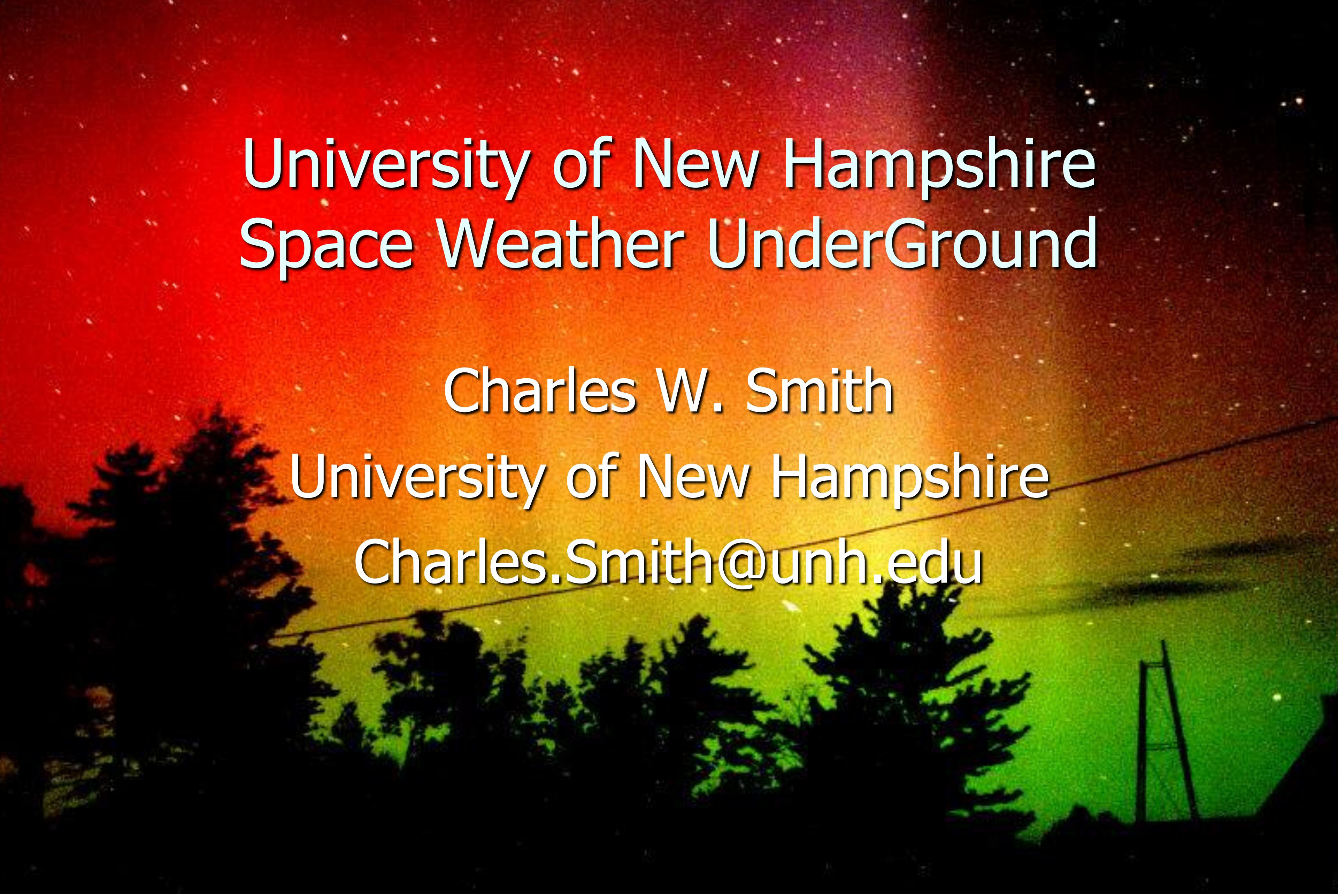
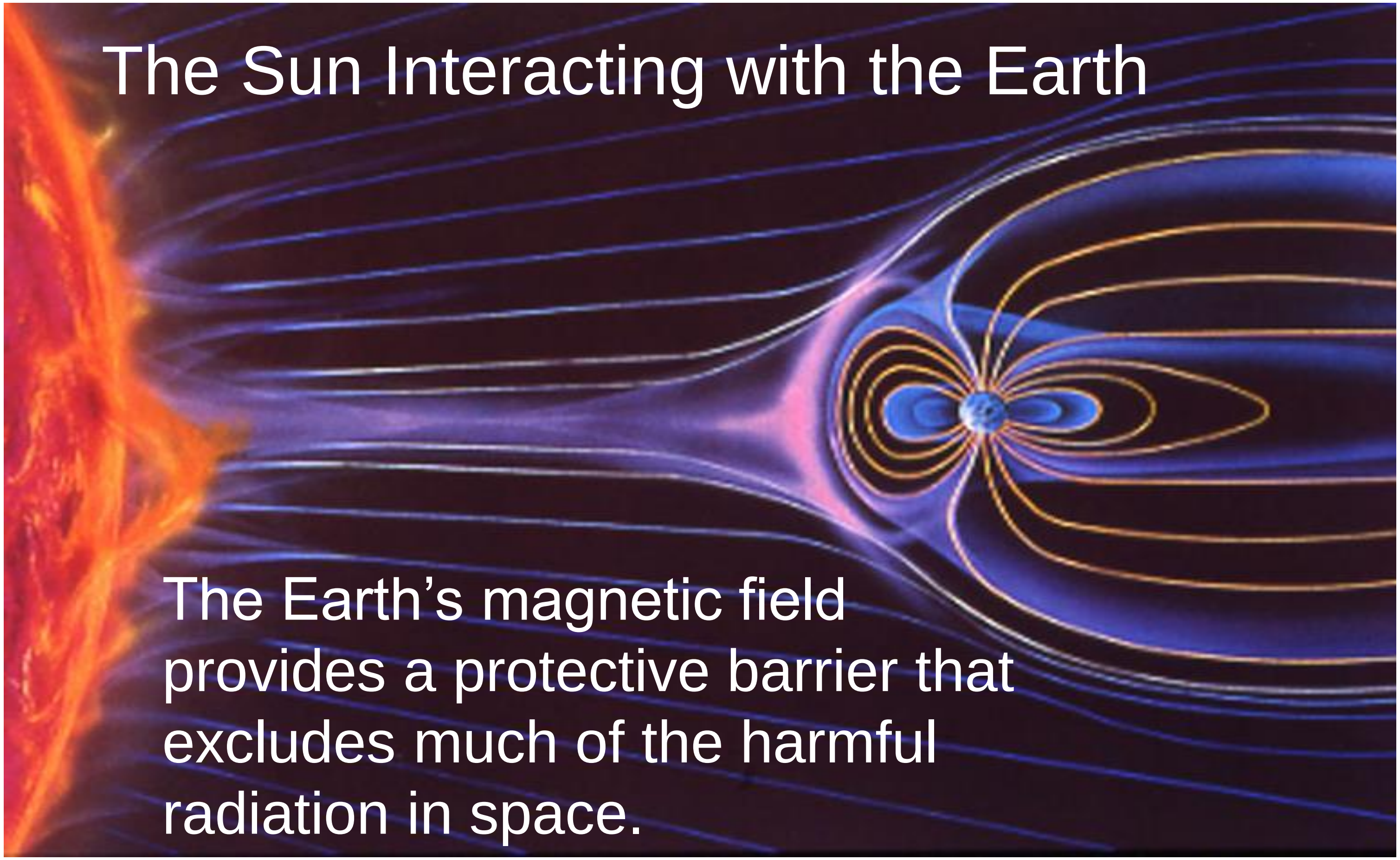


Aurora over Springfield, VT (Halloween 2003).

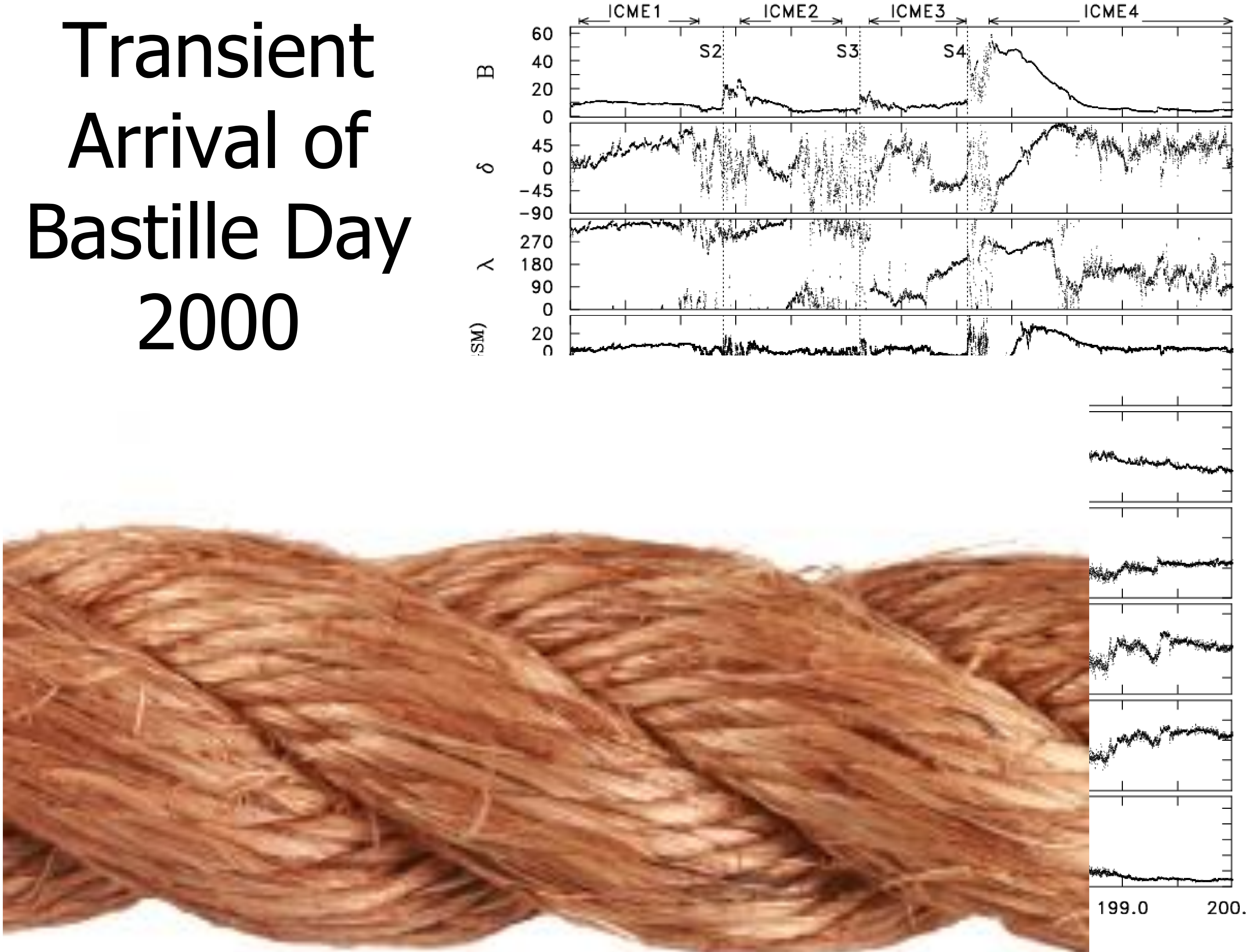
What is Space Weather?

- It is the prediction of electromagnetic and radiation disturbances as a result of solar activity.
- Better predictions prevent disruption of power grid and communication, reduced satellite lifetimes, and threats to astronauts.

The Solar Wind and Earth's Magnetosphere



Transient Arrival of Bastille Day 2000



Energy Content of a CME

$$Speed = 1000 km/s$$

$$Volume = \left[(1000 km/s)(24*60*60)\right]^3 = 6.45x10^{23} km^3$$

$$Density = 1P^+/cm^3 = (10^5)^3 P^+/km^3$$

$$Mass = (1.67x10^{-27} kg/P^+)(10^{15} P^+/km^3)(6.45x10^{23} km^3)$$

$$(1/2)MV^2 = 5.4x10^{17} Joules = 1.3x10^5 killotons$$

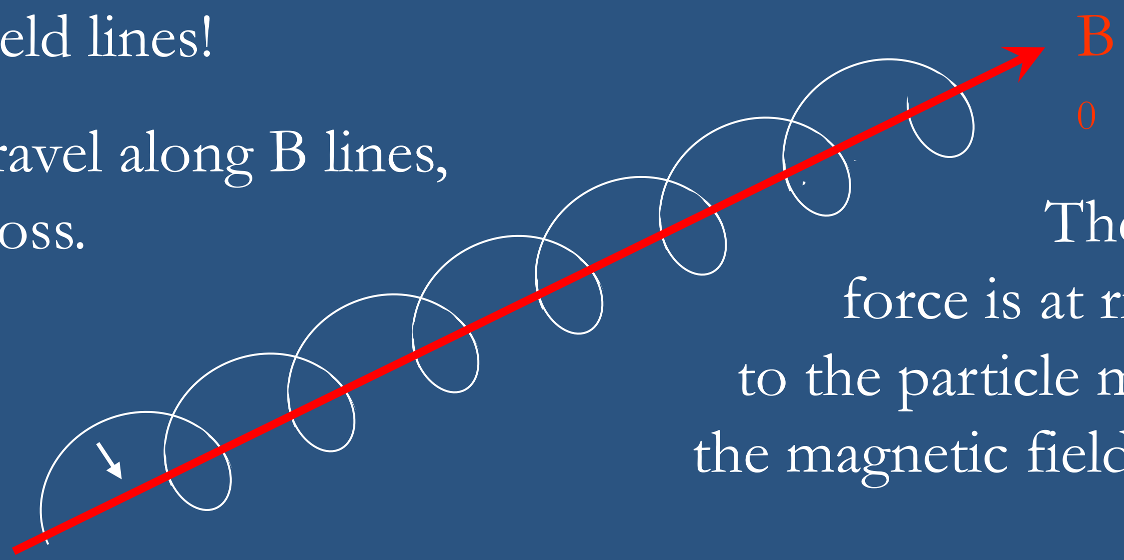
$$\left[\frac{10R_E}{R_{CME}}\right]^2 = \left[\frac{10(6.4x10^3)}{10^3(12x60x60)}\right]^2 = 2.3x10^{-6}$$

So, ~0.5 kilo ton hits the magnetosphere.

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.

$$\Omega_c = \frac{eB}{mc} \qquad \underline{F}_B = q\underline{V} \times \underline{B} \qquad R_L = \frac{mv_\perp}{eB}$$

Solar Energetic Particles

Solar flares on Bastille Day 2000 marked the eruption of coronal magnetic fields and associated plasma.

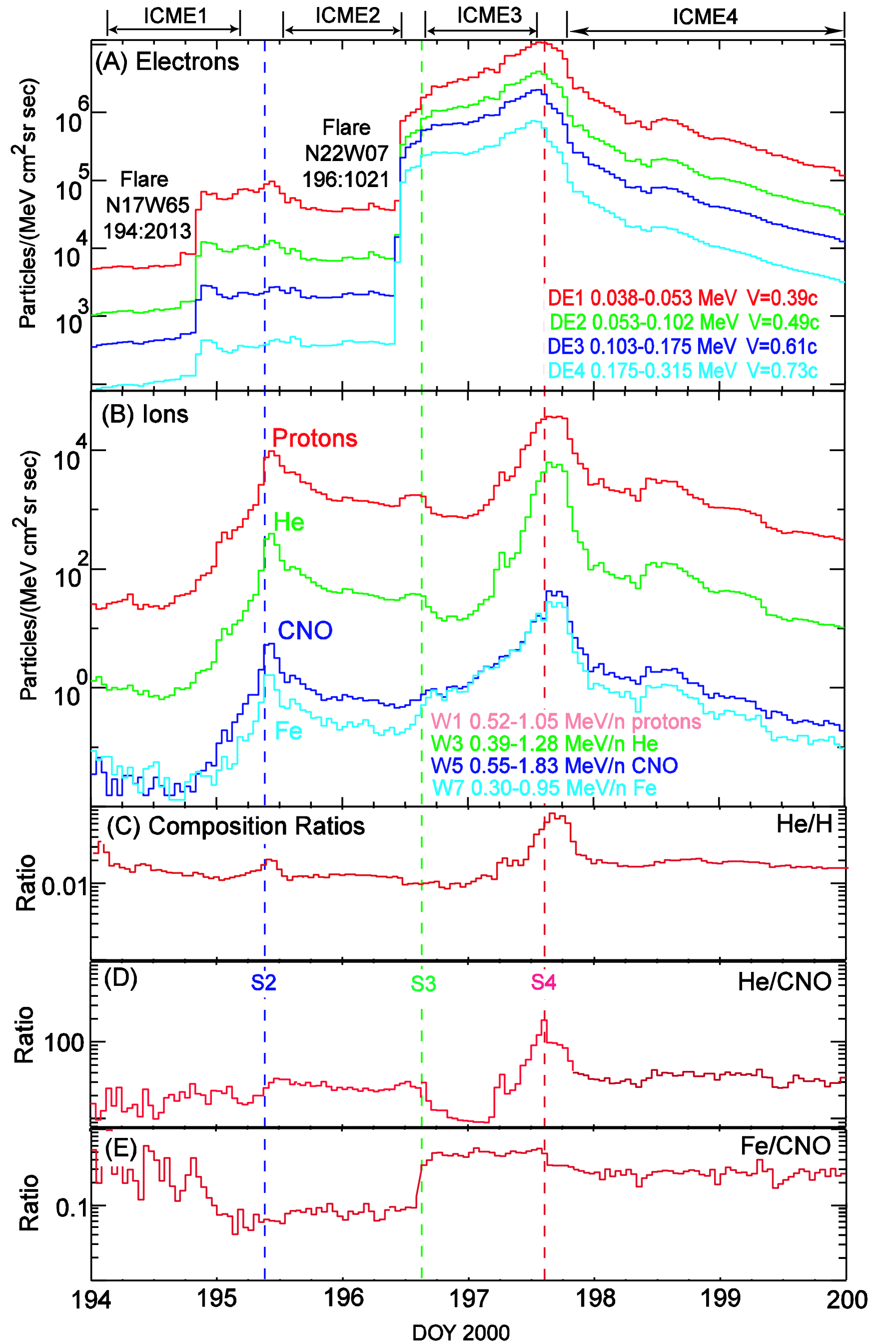
This ejection resulted in the acceleration of ions and electrons via mechanisms still under study.

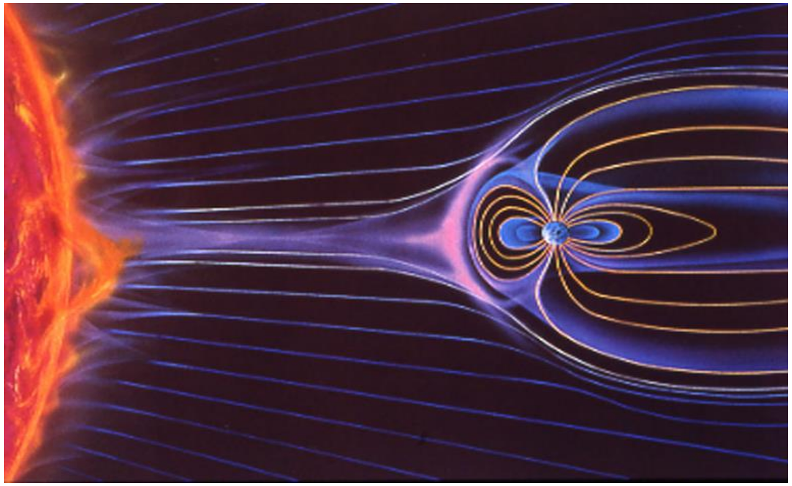
ACE observed the energetic particles arrived at Earth several days ahead of the ejecta.

Orbiting spacecraft were damaged or destroyed.

Loss of electrical power was threatened.

Astronauts were endangered.





The Solar Output

The solar constant is 135.3 mWatts/cm^2.
Radiant solar energy of ~1.4 GigaWatts/km^2 (1.4×10^9 Watts/km^2).

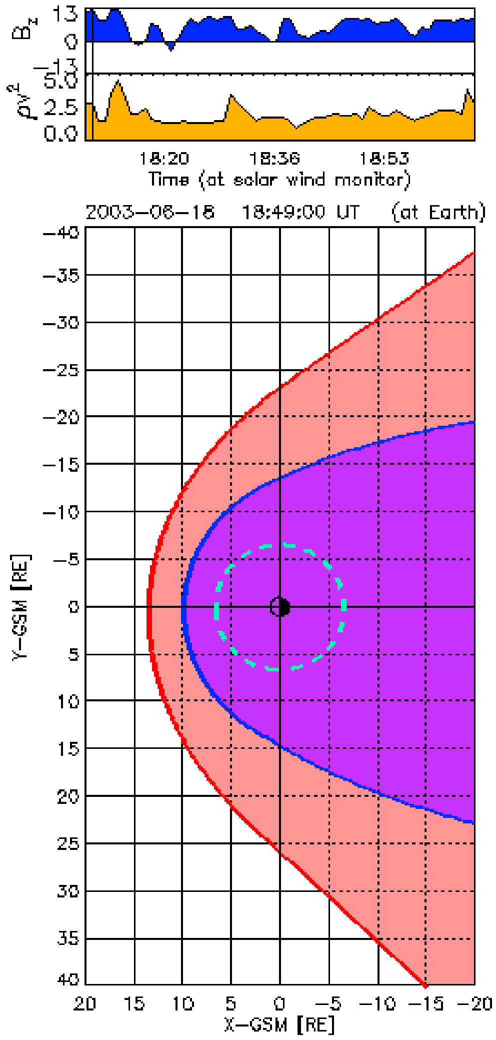
Multiplying by area of sphere 1 AU = 1.49×10^8 km in radius ($4\pi R^2$)
$\Rightarrow$ solar output of light energy at 3.9×10^{26} Watts.

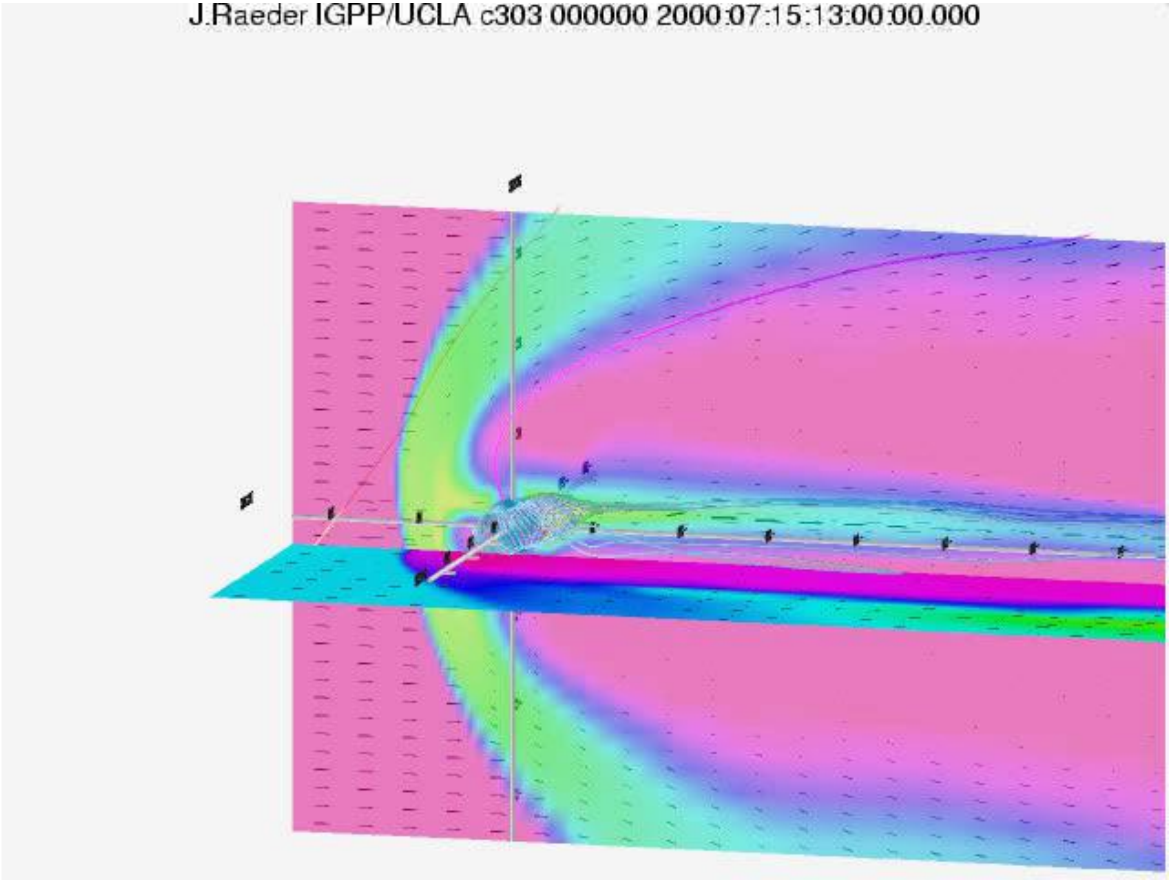
Solar wind @ 1 AU:
10 protons/cm^3 traveling at 450 km/s has an energy flux density of…

$$(1/2)\,(M_P\, N_P\, V_{SW})\, V_{SW}^2 = 7.6 \times 10^2 \text{ Watts/km}^2$$

Integrating over a 1 AU sphere, the solar wind is 2.1×10^{20} Watts.

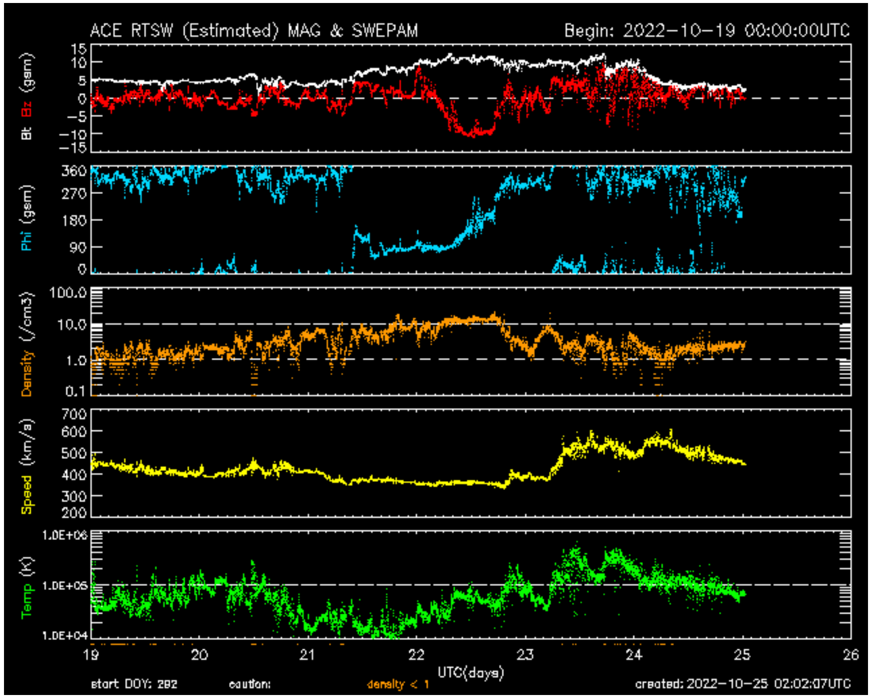
Global Simulation of the Magnetosphere





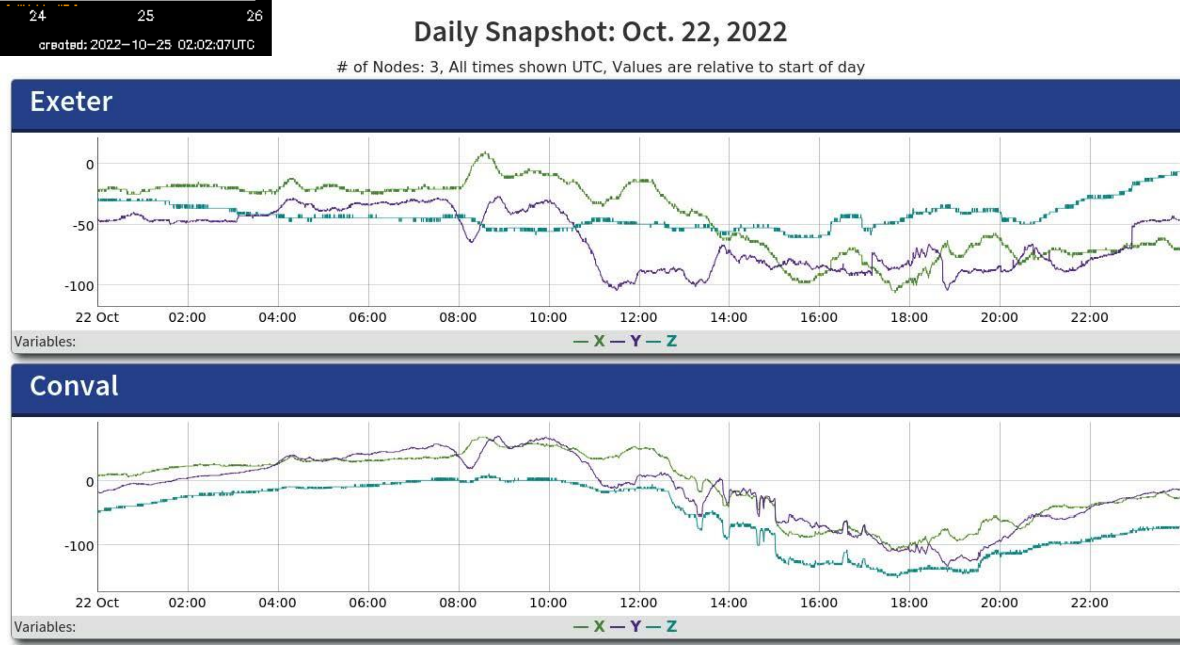
Simulation by Prof. Jimmy Raeder

Space Weather



ACE sees an interesting disturbance on 10-22-2022.

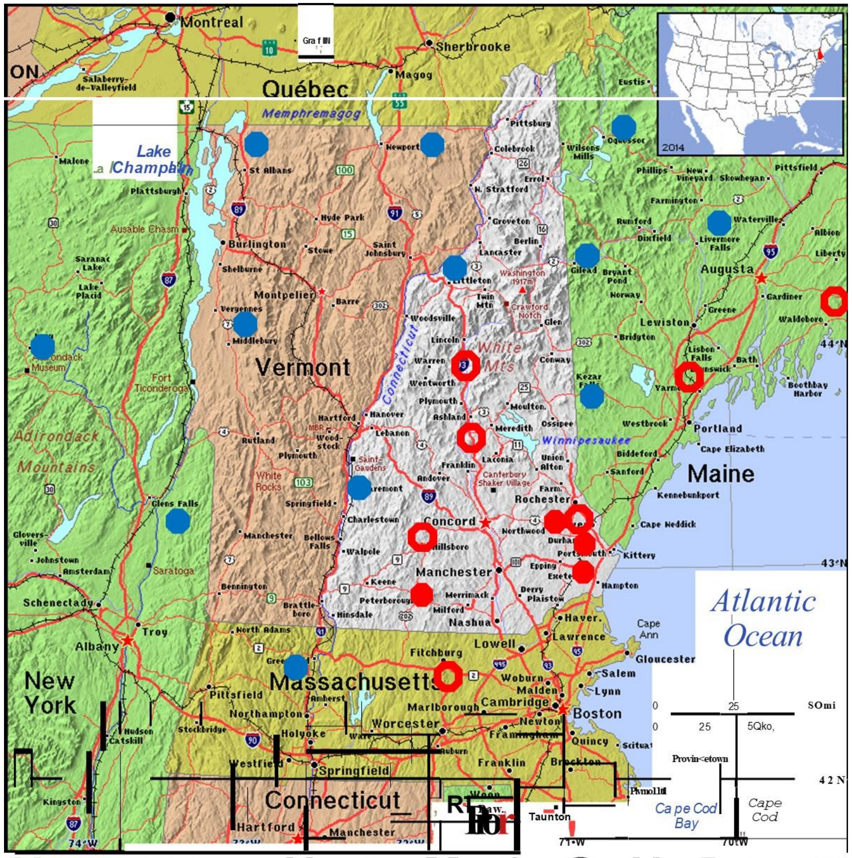
SWUG sees the resulting disturbance over New Hampshire.



https://www.swpc.noaa.gov/products/ace-real-time-solar-wind

What is Space Weather UnderGround?

- We want to build a distributed array of 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!

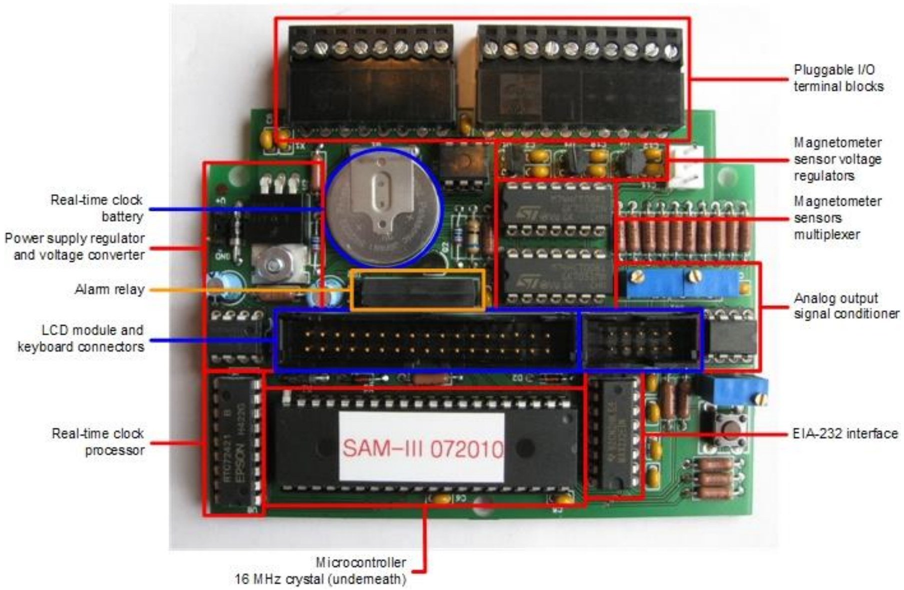


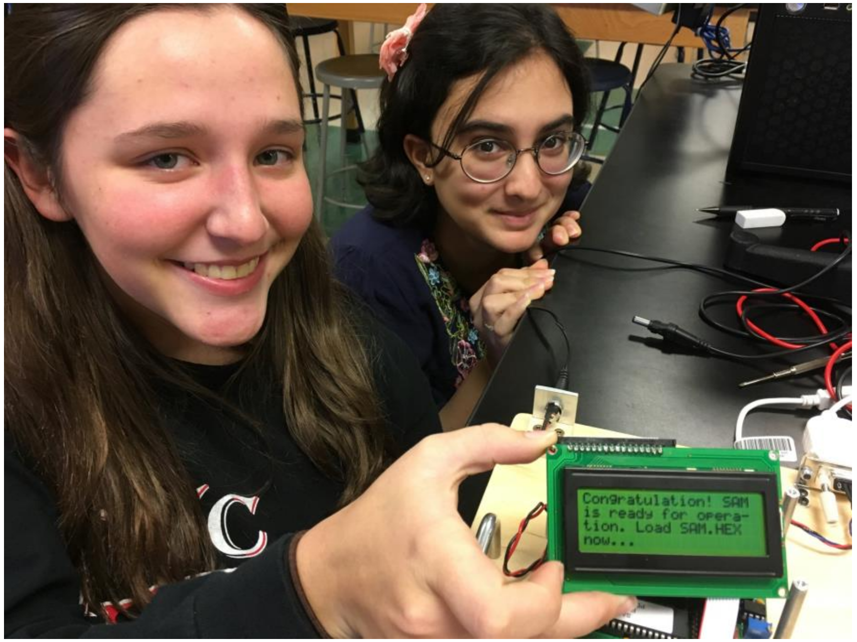
N E W H A M P S H I R E

https://eos.unh.edu/space-science-center/outreach/space-weather-underground

bit.ly/UNHSWUG

The Fluxgates are Purchased as SAM-III Kits from Reeve Engineers in Alaska



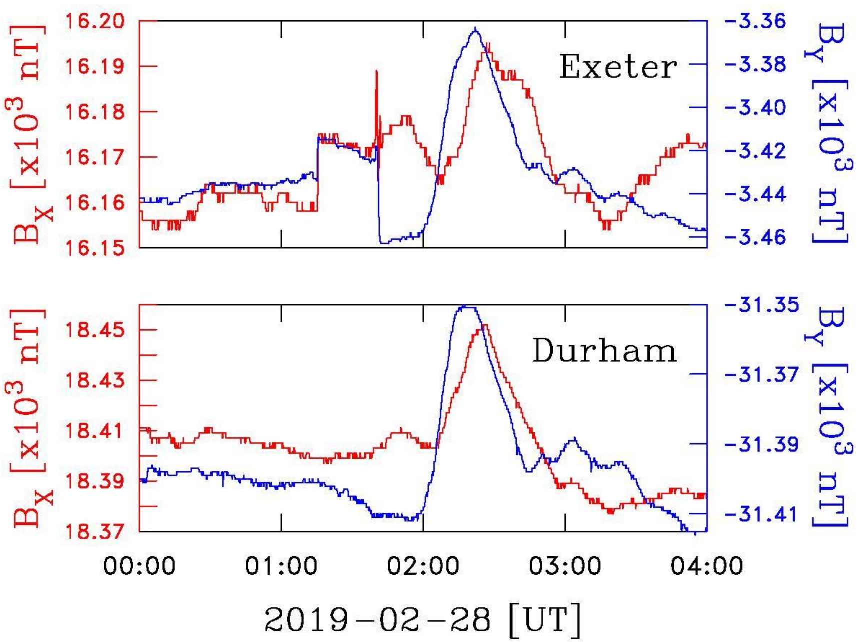


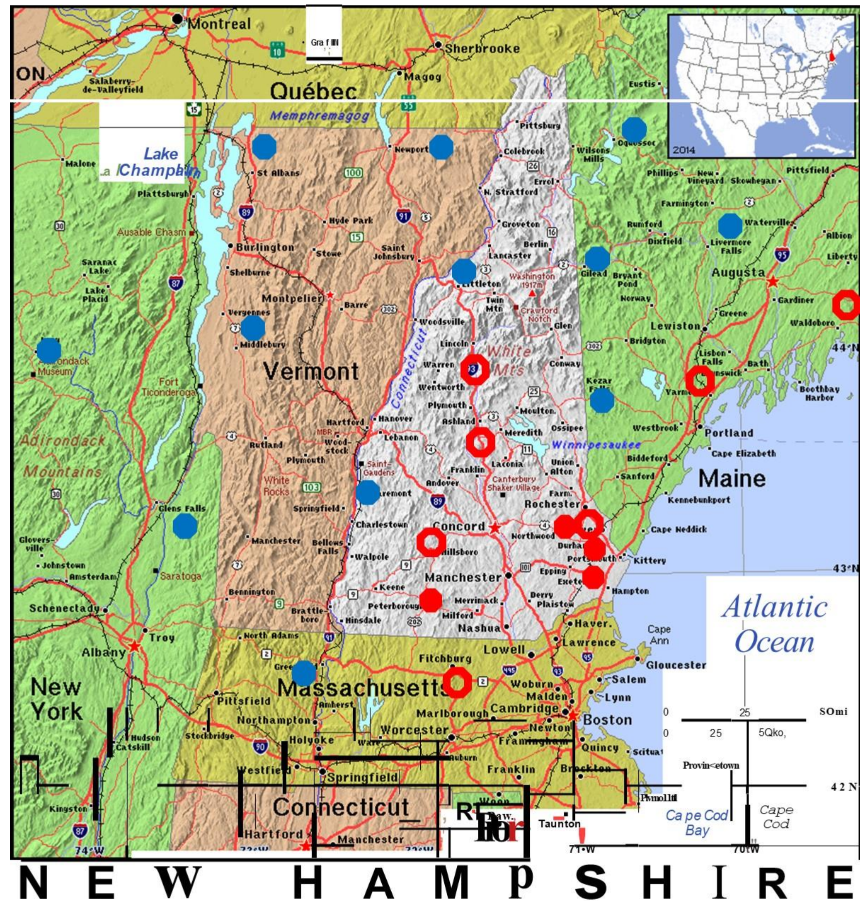
https://www.reeve.com/SAMDescription.htm

SWUG Participants

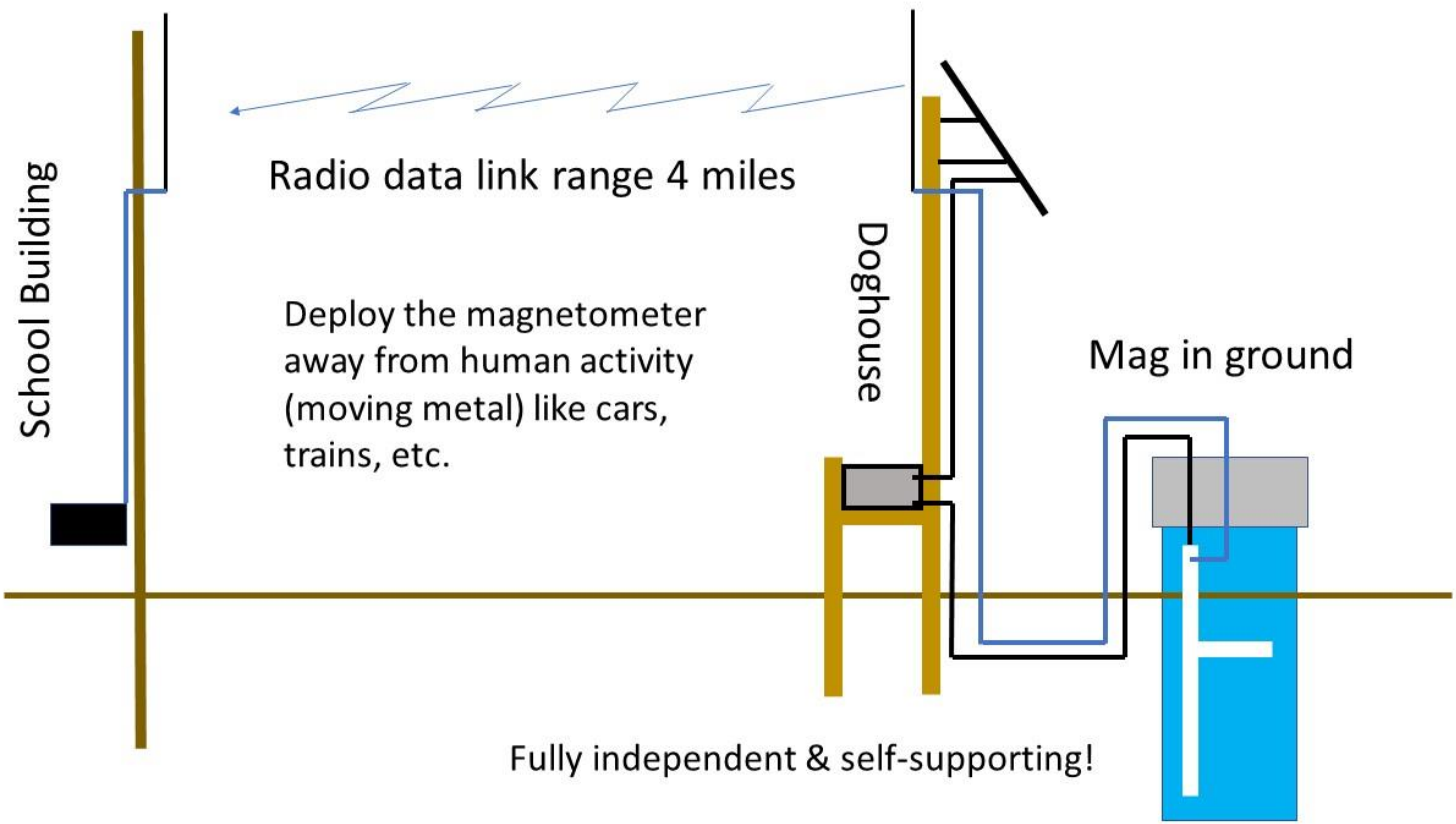
- John Blackwell, Phillips-Exeter Academy
- Rich Levergood, Londonderry High School
- Scott & Joanne Goelzer, Coe-Brown Academy
- Andria Johnson, CONVAL Peterborough High School
- Dave McKenney, Plymouth High School, NH
- Julie Burton, The Bromfield School, Harvard
- Elizabeth England, Winnesquam High School (Tilton, NH)
- Andwar Heliovore, Hillsboro-Deering High School, NH
- Sara Cathey, Oyster River High School, NH
- Carol Coryea, Washington Academy, ME
- Terry Bartick, North Yarmouth Academy, ME
- 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

Science Opportunity





Magnetometer Deployment Concept



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.

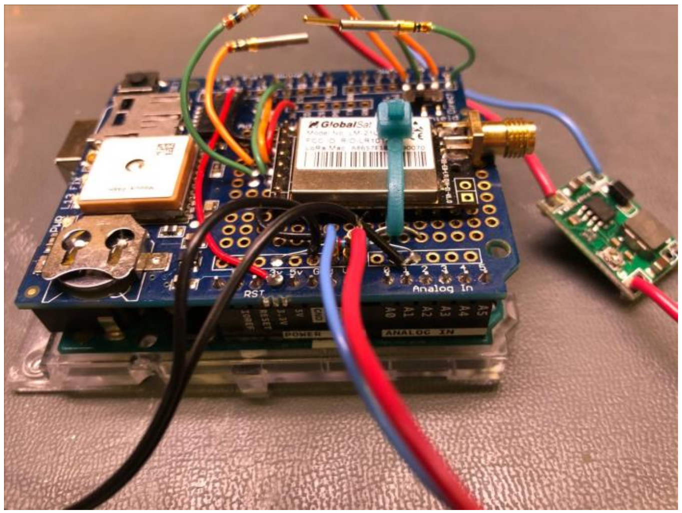
SWUG In-Ground Deployment

- 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



Arduine-based data handling with GPS chip for accurate time and radio downlink

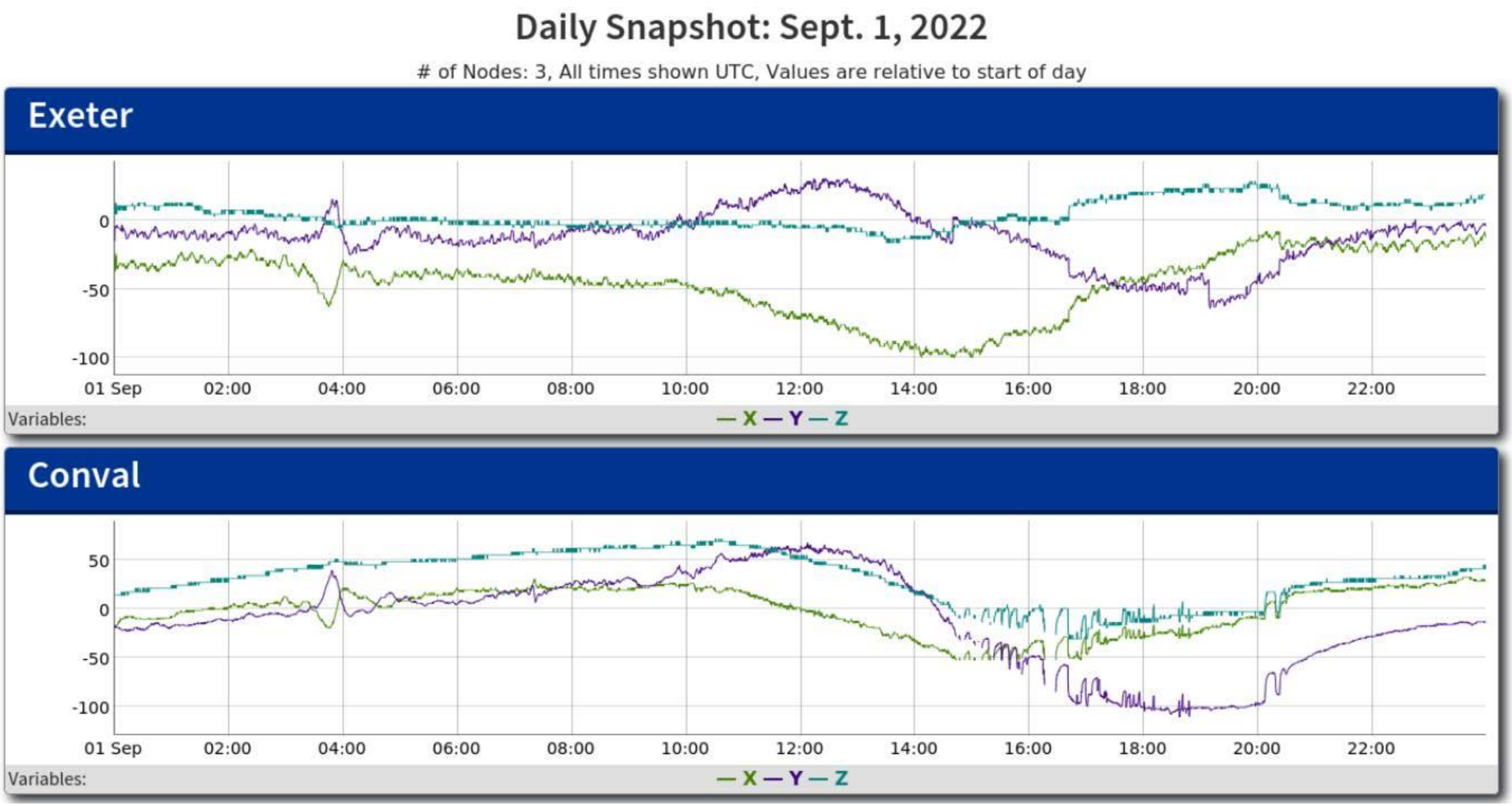
Raspberry-Pi based data storage, radio link receiver, and internet download

UNH Is Providing/Paying For:

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

Space Weather Underground Project: Magnetometer Installation Prototype at Coe-Brown Northwood Academy May 16th 2021

September 1, 2022



https://swug.unh.edu/

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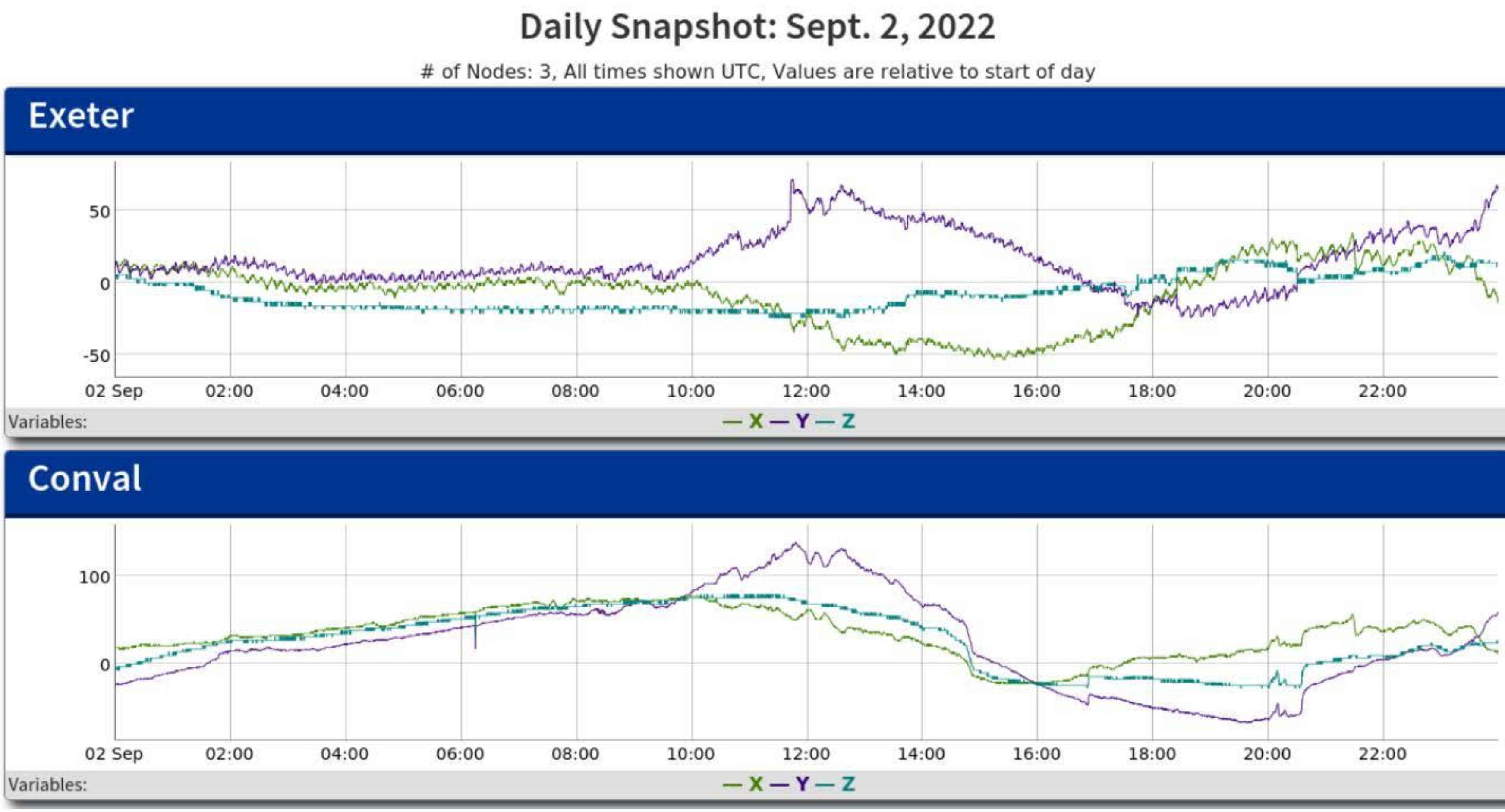

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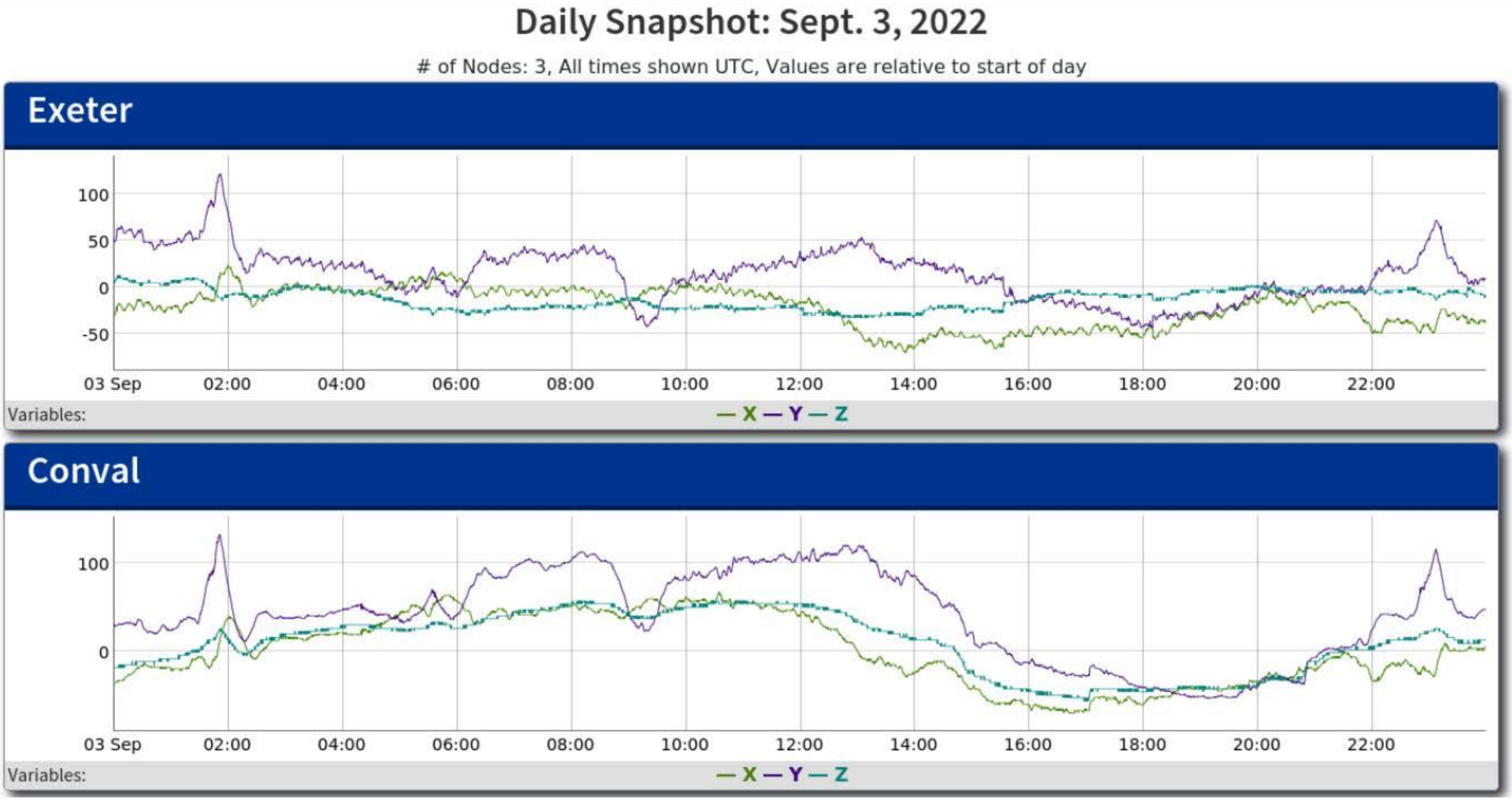
September 3, 2022



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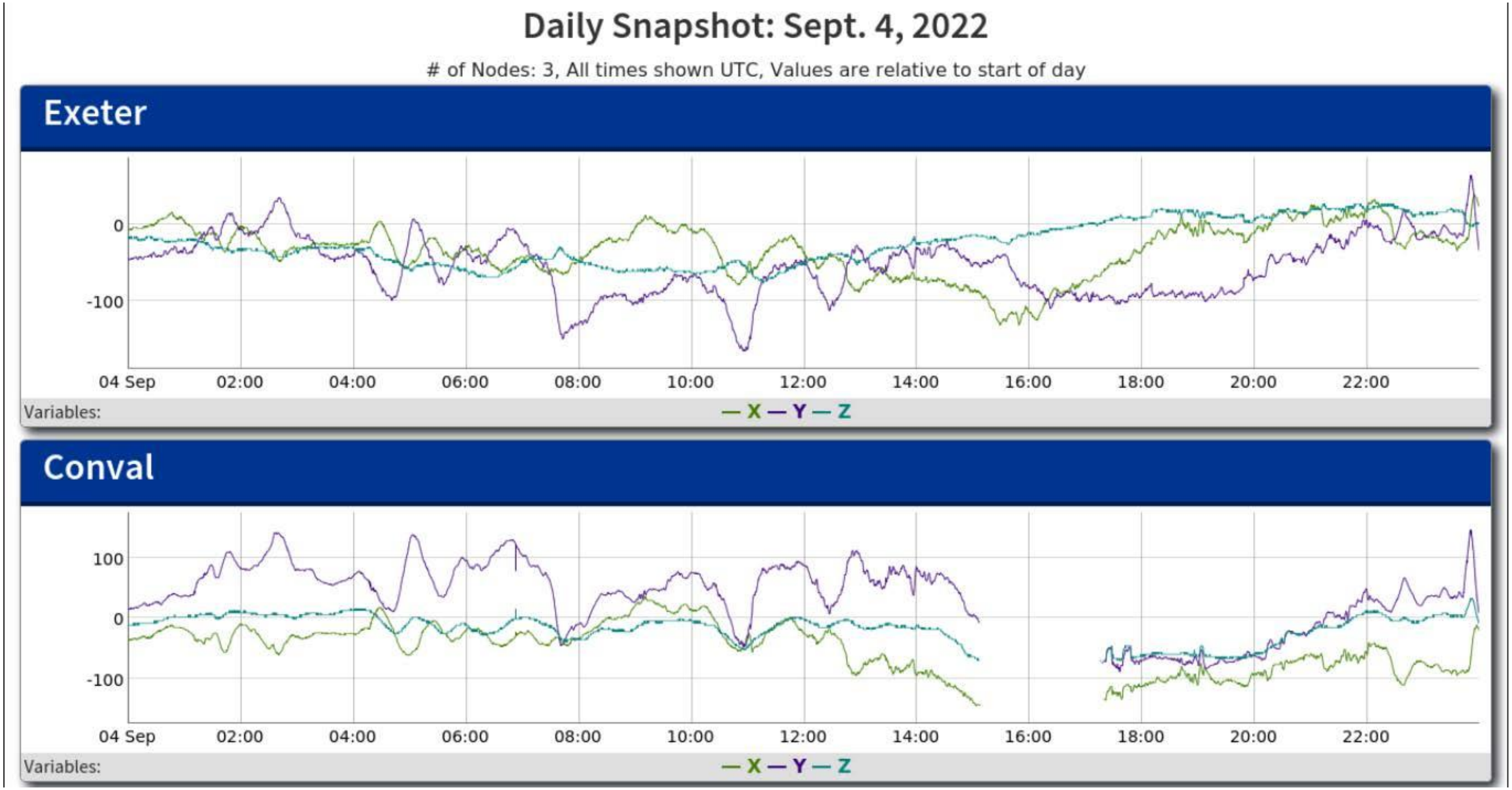
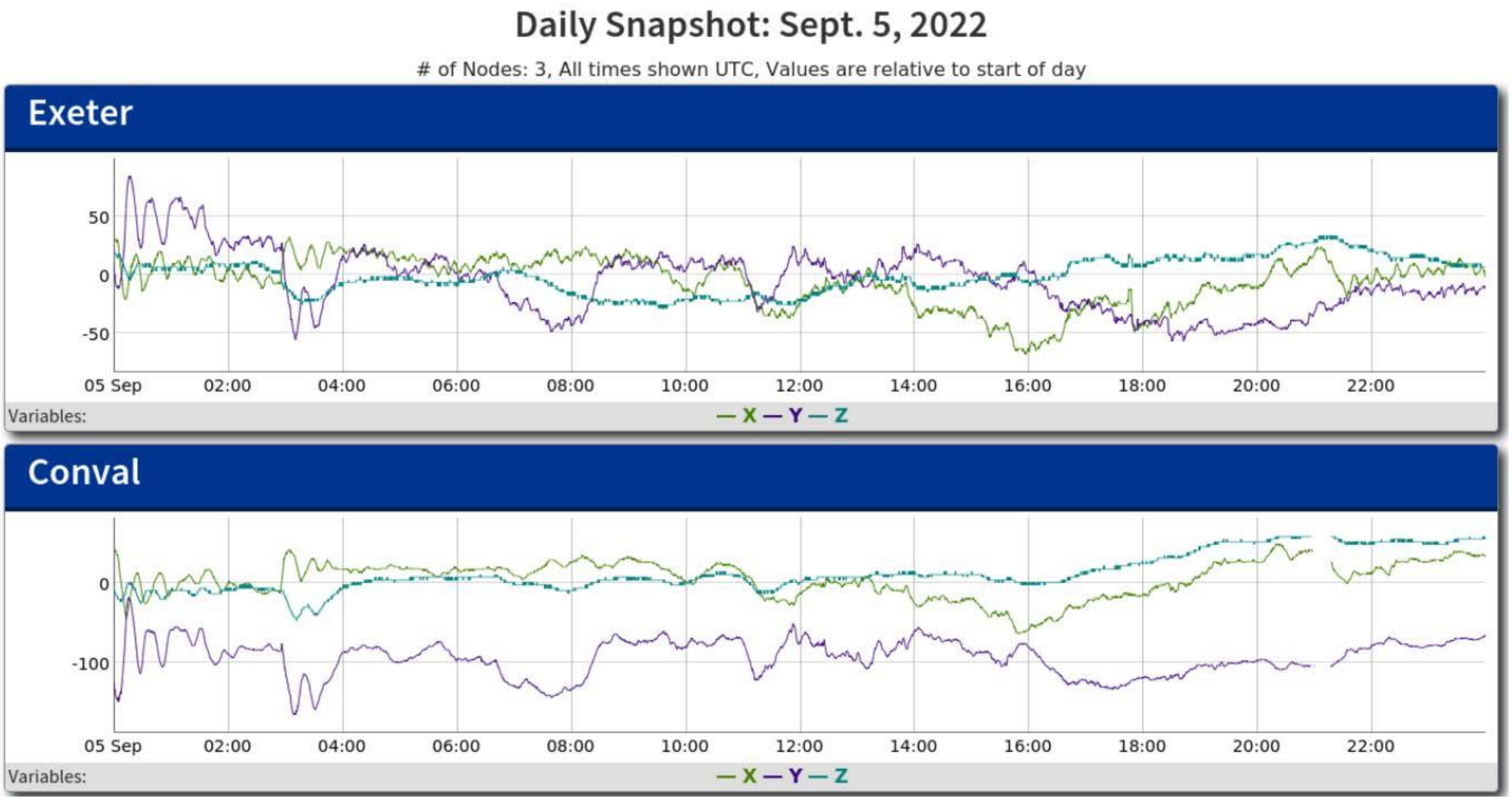
September 4, 2022



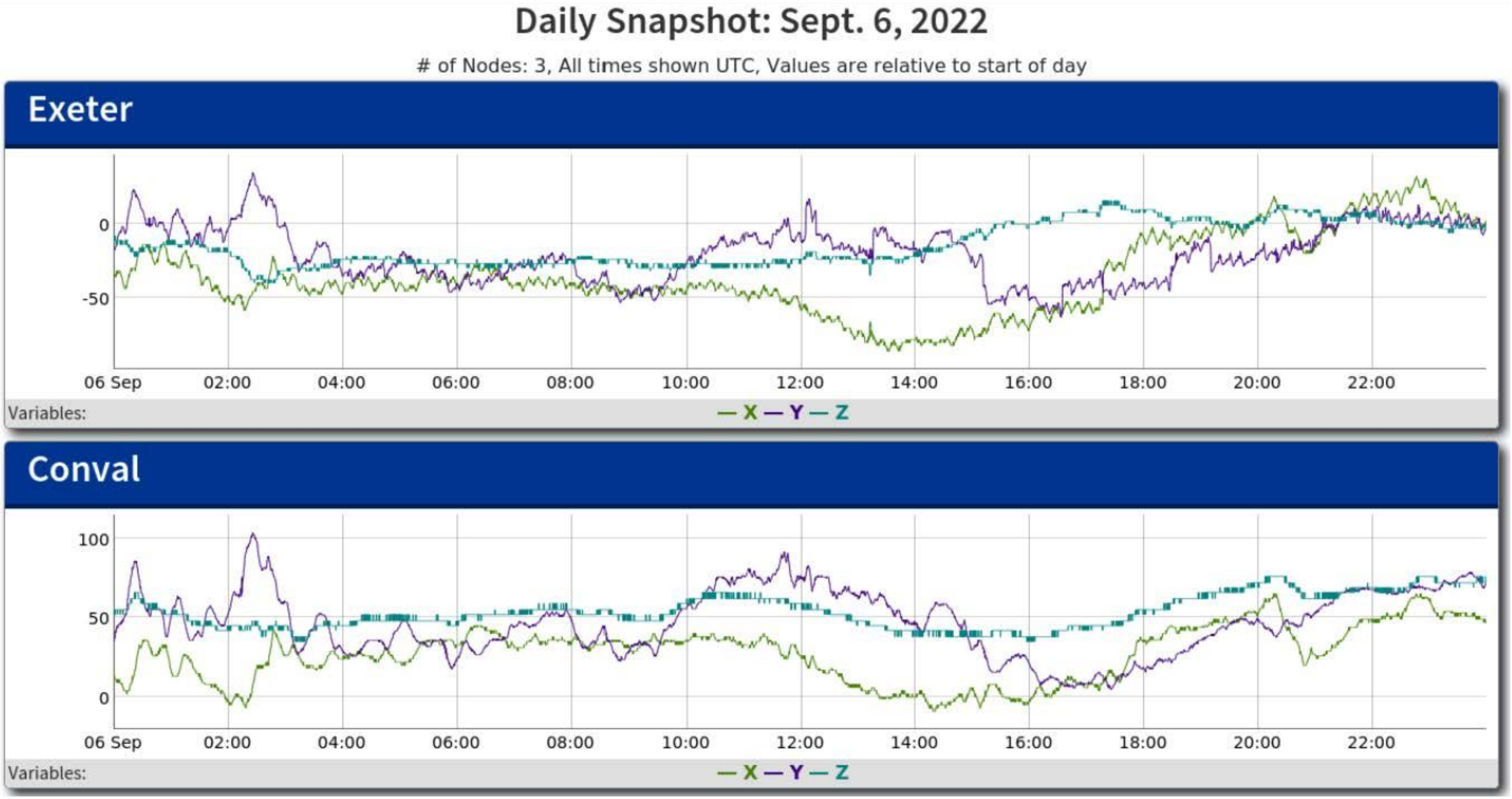
https://swug.unh.edu/

September 5, 2022



https://swug.unh.edu/

September 6, 2022



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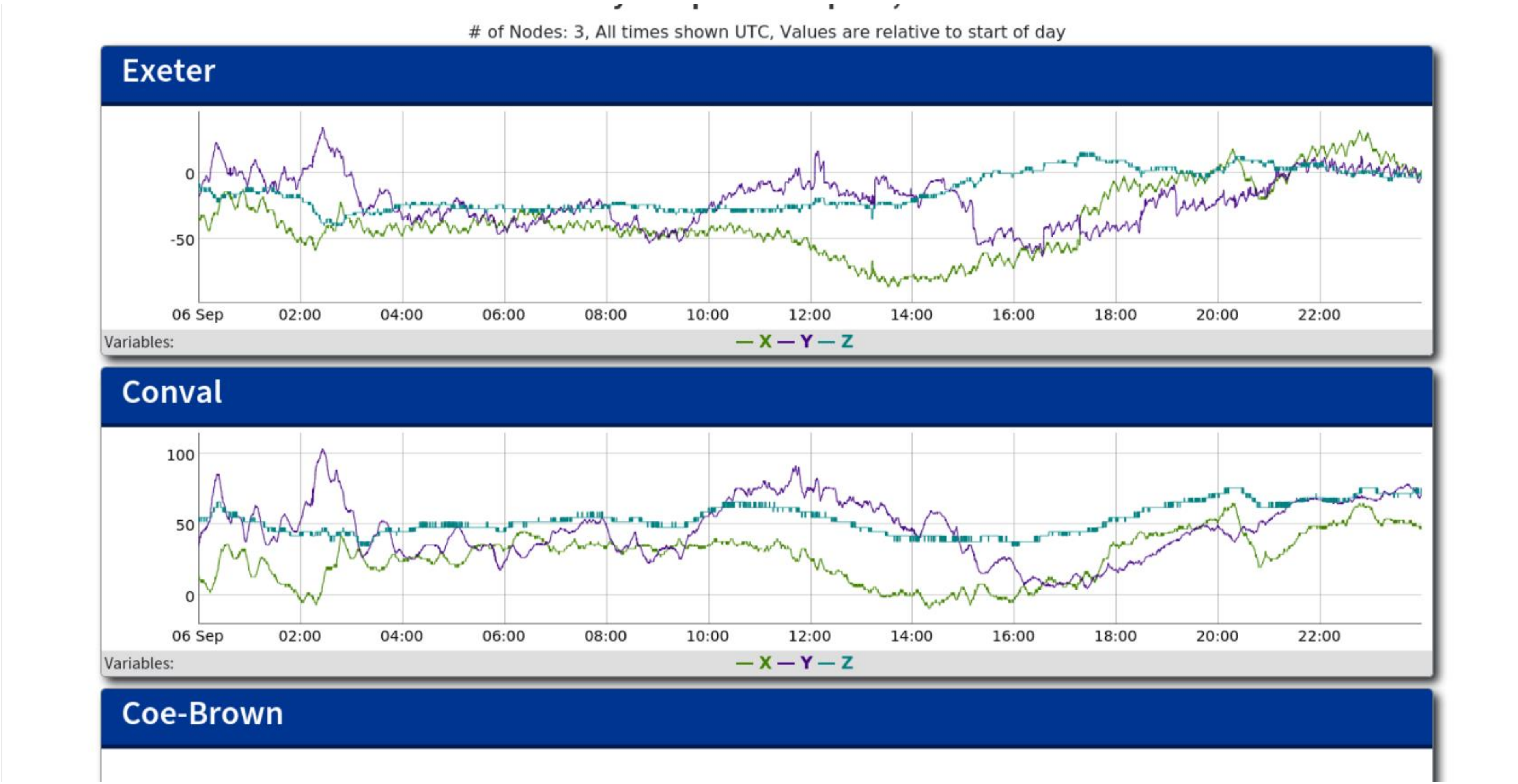
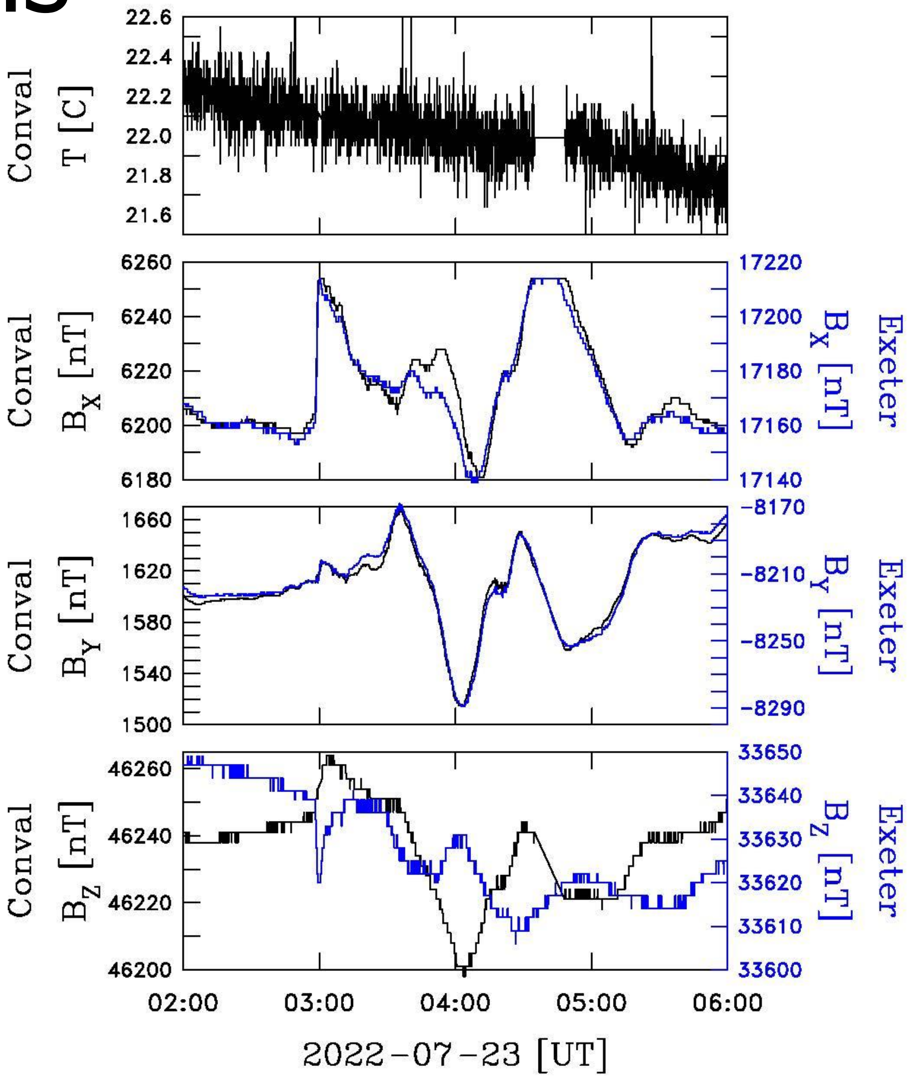
September 7, 2022



https://swug.unh.edu/

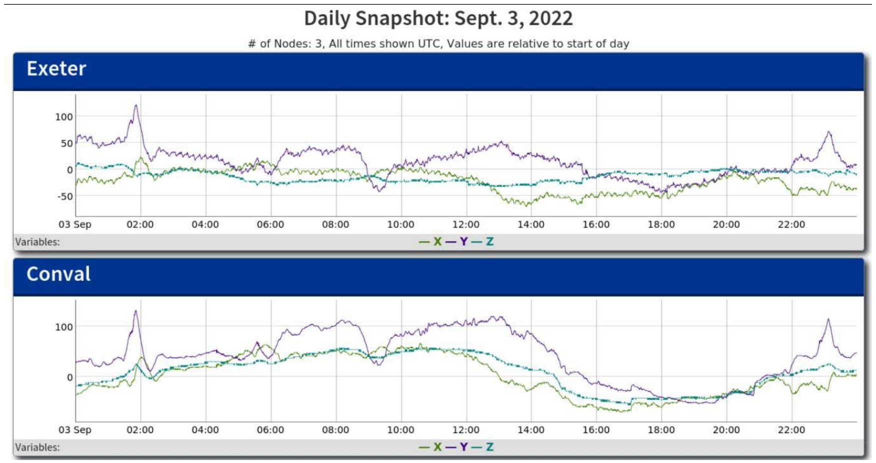
Very Early Science & Evolving Lessons

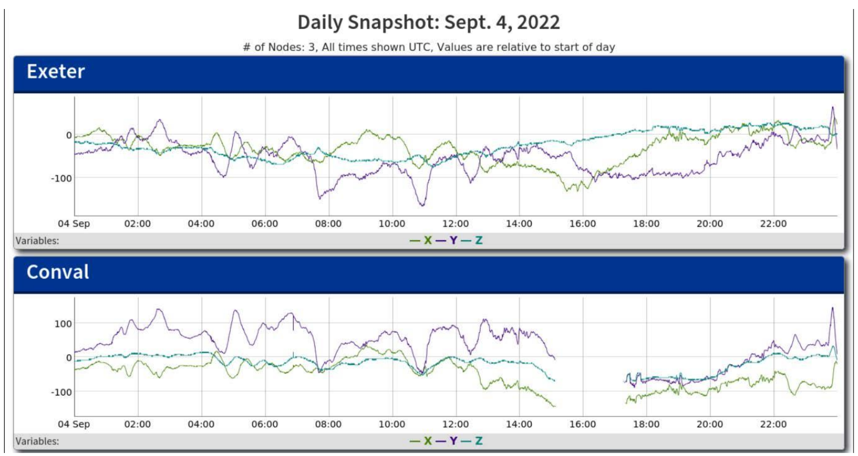
- We had a nice transient hit the Earth!
- It drove a very nice disturbance overhead.
- Coe-Brown was on the bench for repairs.
- As a demo, we compared CONVAL and Exeter.

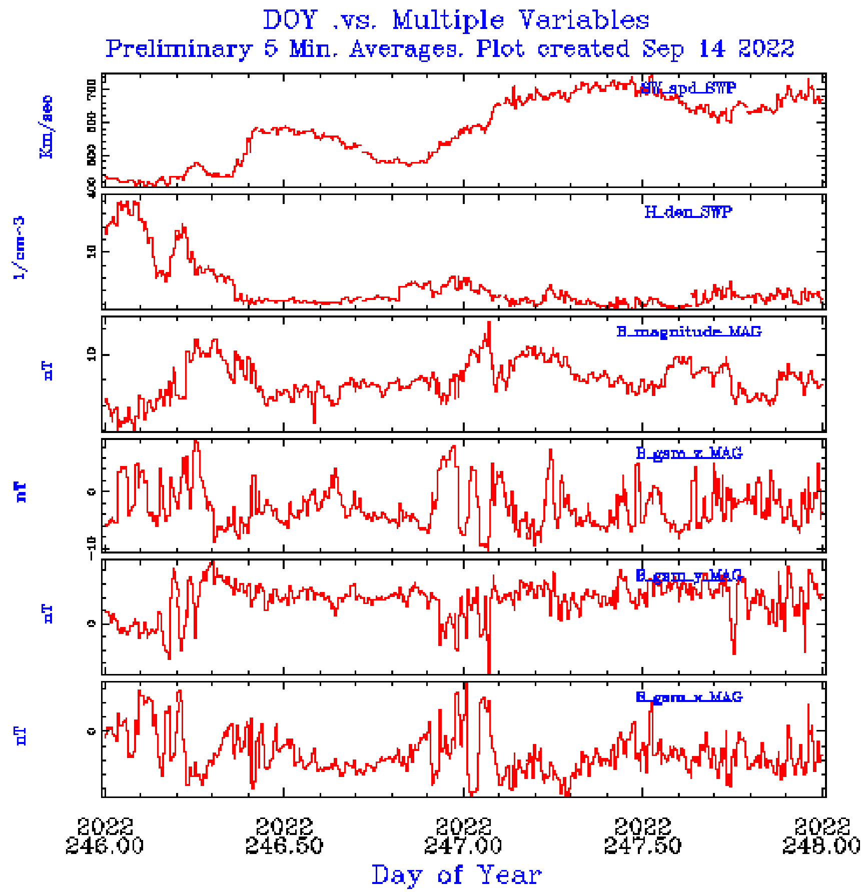


Lesson Learned: We need to review our calibration efforts!

September 3-4, 2022



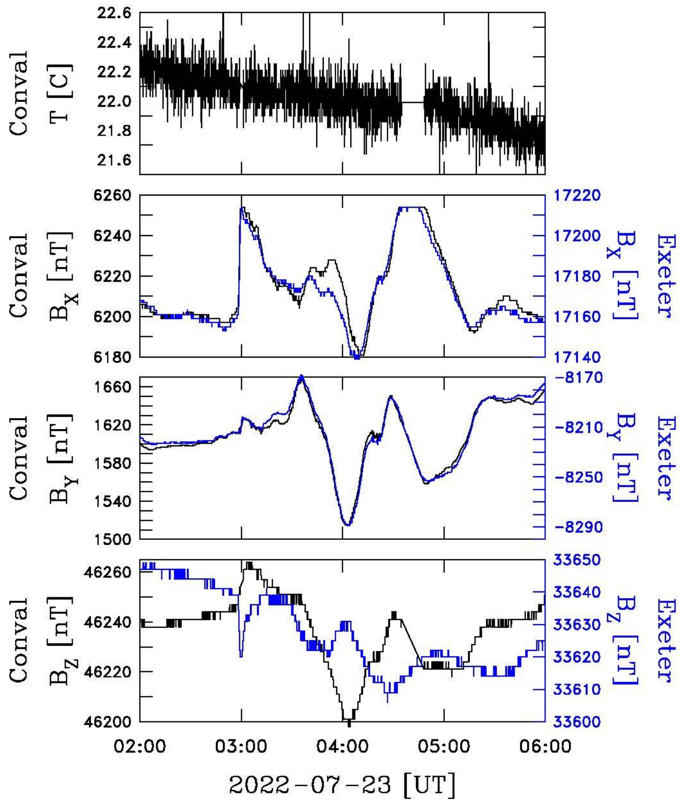


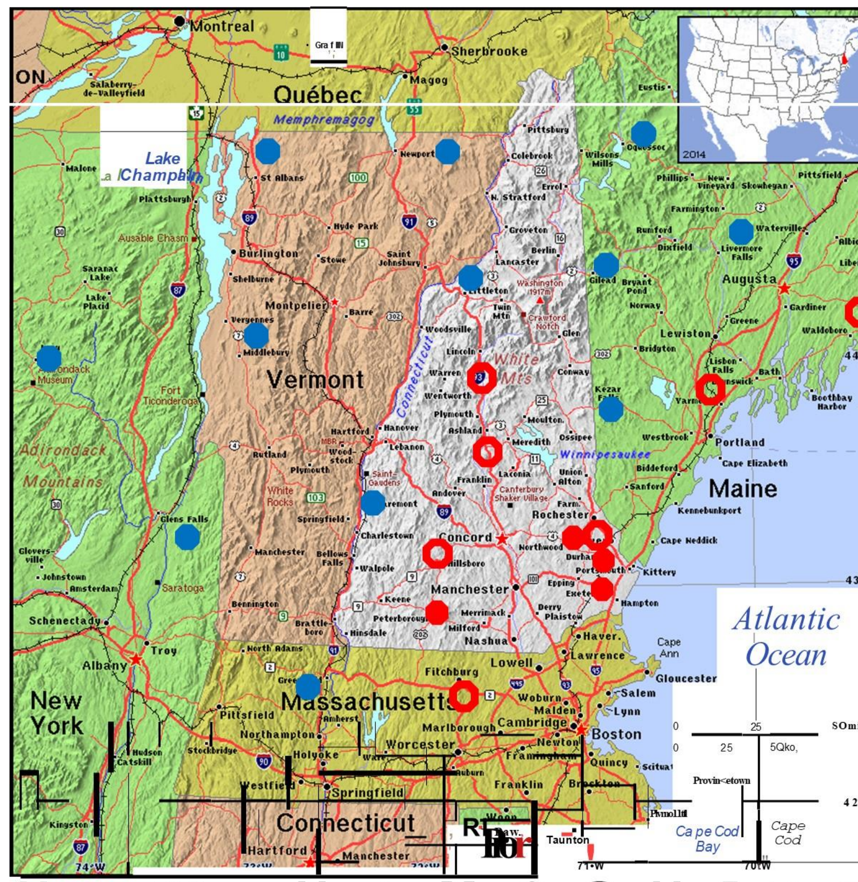


https://swug.unh.edu/

https://izw1.caltech.edu/ACE/ASC/

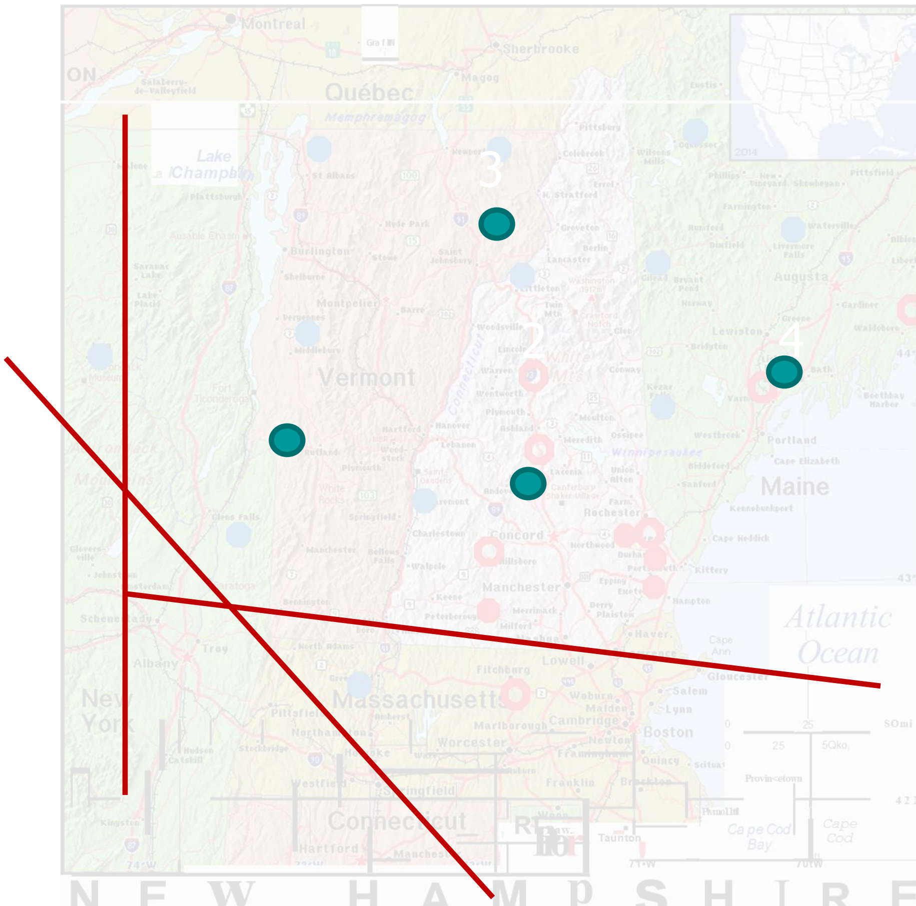
Science Opportunity





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

Three Node Triangulation of Linear Transient

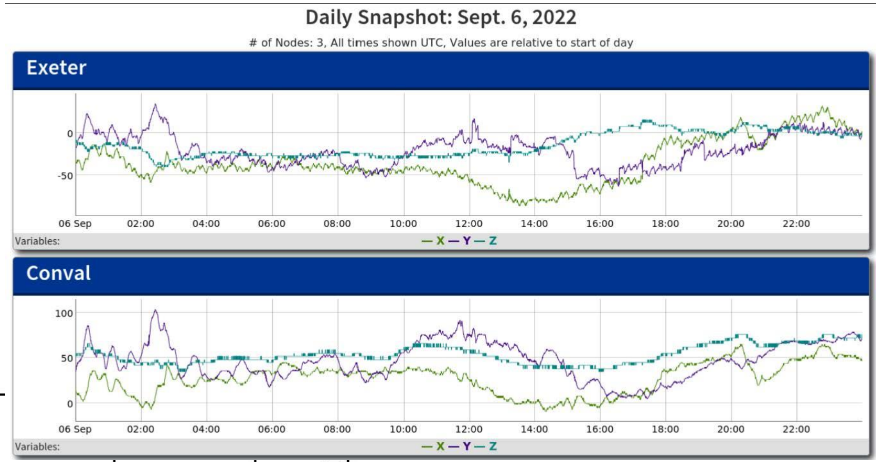


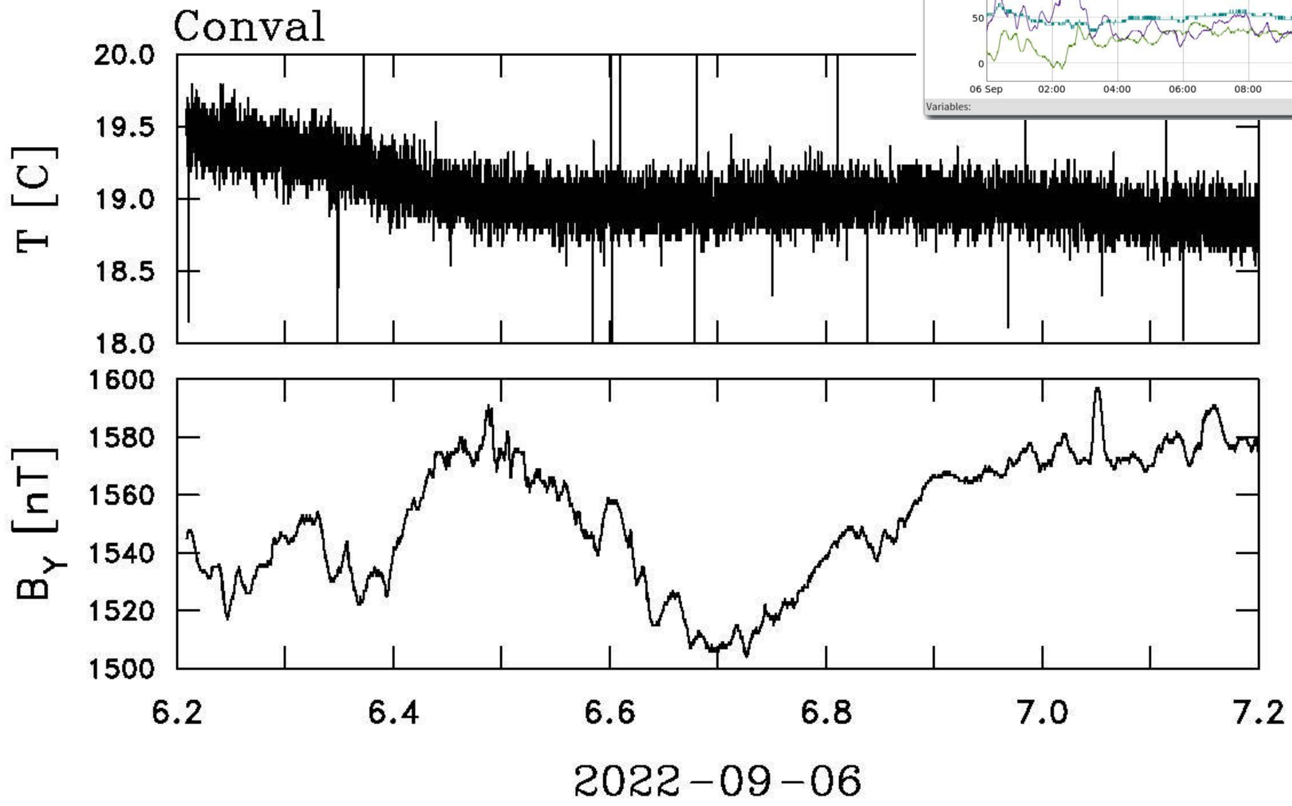
- Three nodes with both north-south and east-west separation are needed to determine the propagation speed and direction of a linear front.
- More than three nodes provides refined uncertainty in the result and indications of curved fronts.
- Larger node separation provides better resolution of timing.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

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.

Here Is the Great Unkept Secret!

- The data from every NASA spacecraft (including NOAA) is online and available to the public free of charge!
  - Solar wind missions like Advanced Composition Explorer, New Horizons, Pioneer 10 & 11, Parker Solar Probe, Solar Orbiter, Ulysses, Voyager 1 & 2, WIND, etc.
  - Earth missions like Geotail, Van Allen Probes, Themis, etc.
  - Planetary missions like Pioneers including Pioneer Venus, Voyagers, JUNO, Messenger, etc.
  - and the Omnitape joint data.

Relevant Web Pages

- Space Weather Underground Data Center

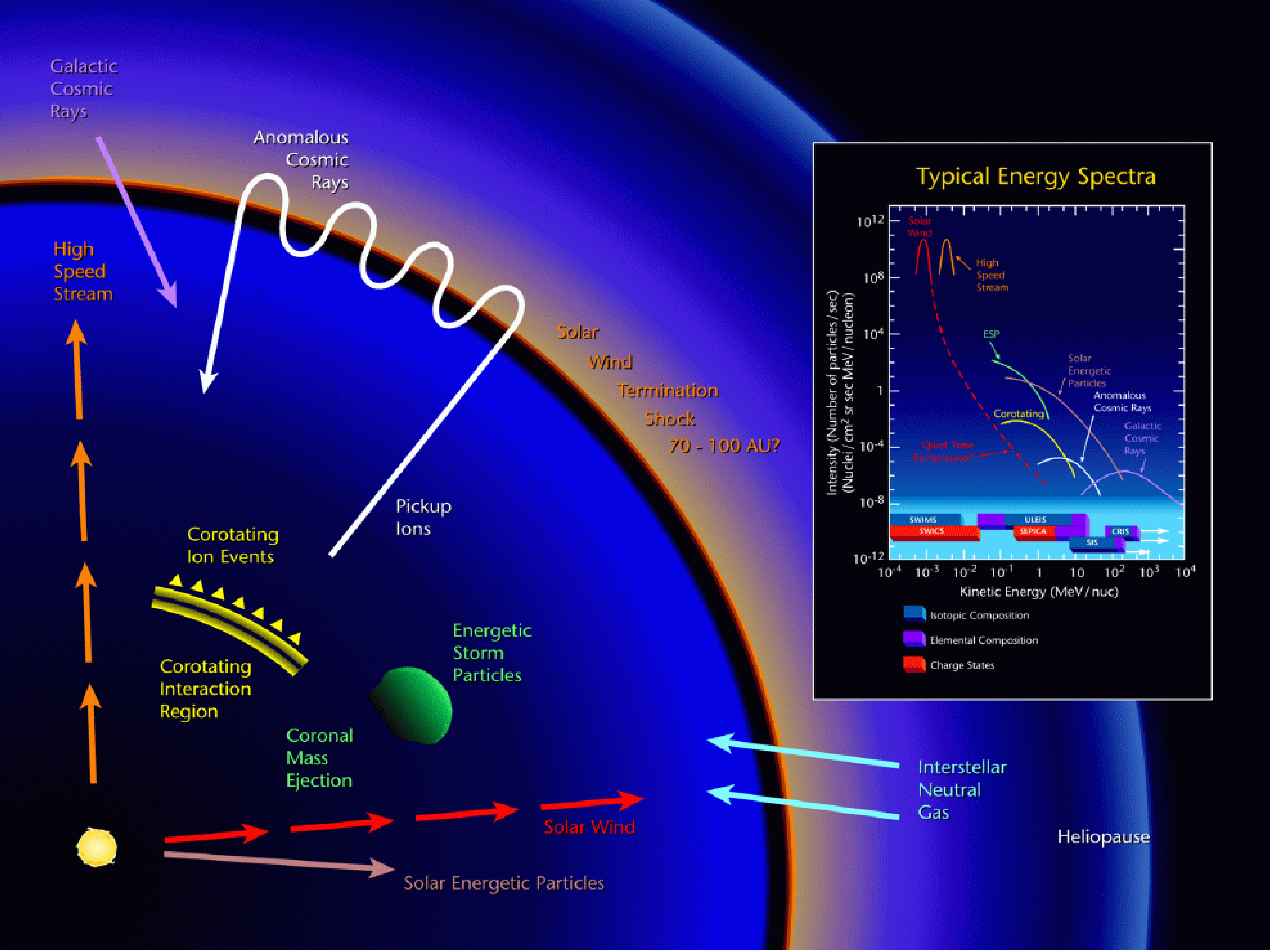
  https://swug.unh.edu/

- Space Weather Underground Web Page

  https://eos.unh.edu/space-science-center/outreach/space-weather-underground

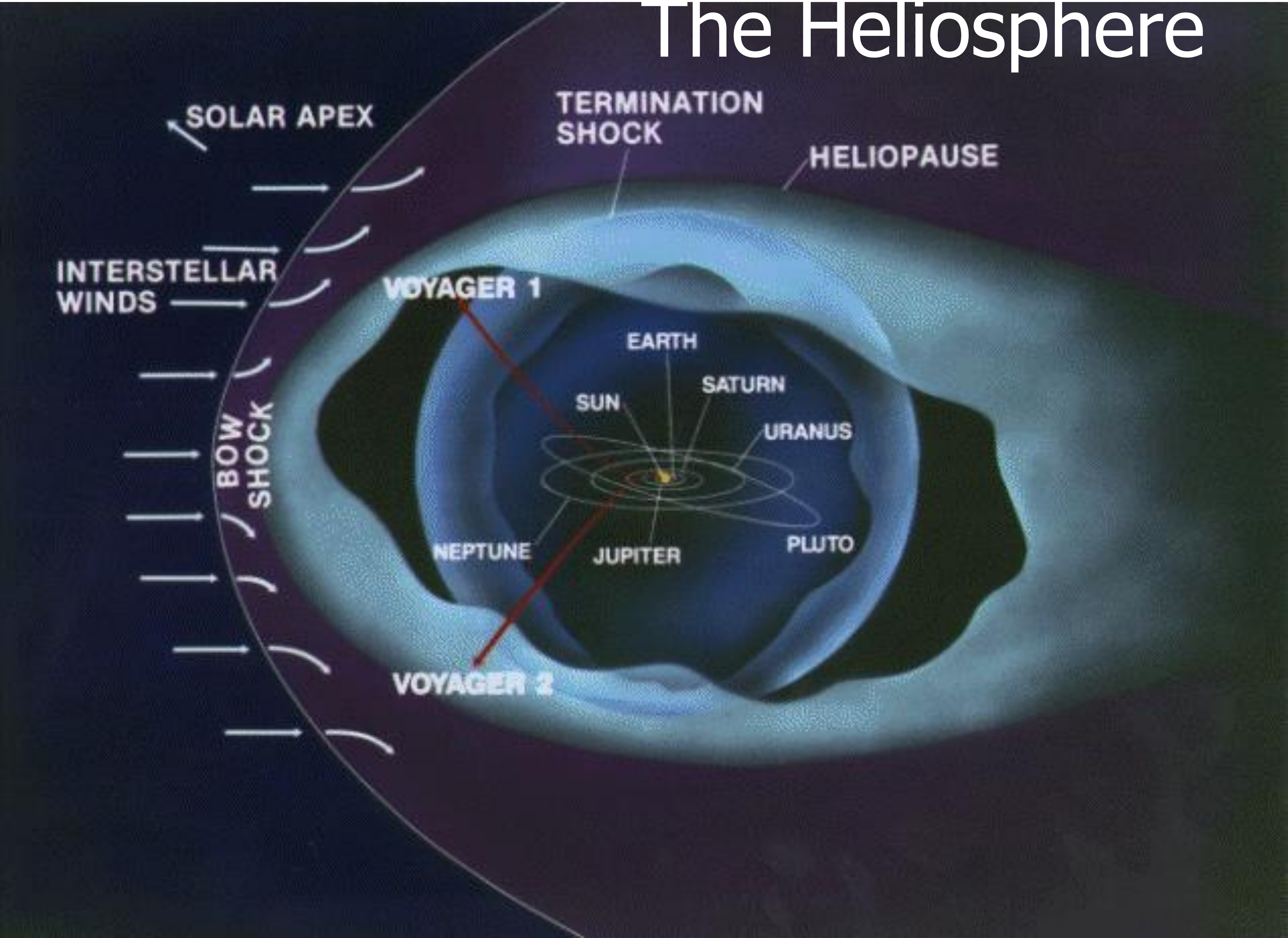
  bit.ly/UNHSWUG

- https://www.swpc.noaa.gov/products/ace-real-time-solar-wind



Galactic Cosmic Rays
Anomalous Cosmic Rays
High Speed Stream
Solar Wind Termination Shock 70 - 100 AU?
Pickup Ions
Corotating Ion Events
Corotating Interaction Region
Energetic Storm Particles
Coronal Mass Ejection
Solar Wind
Solar Energetic Particles
Interstellar Neutral Gas
Heliopause
Typical Energy Spectra
Intensity (Number of particles / sec) (Nuclei / cm^2 sr sec MeV / nucleon)
Kinetic Energy (MeV / nuc)
Solar Wind
High Speed Stream
ESP
Solar Energetic Particles
Anomalous Cosmic Rays
Corotating
Galactic Cosmic Rays
Quiet Time Background?
SWIMS
SWICS
ULEIS
SEPICA
SIS
CRIS
Isotopic Composition
Elemental Composition
Charge States

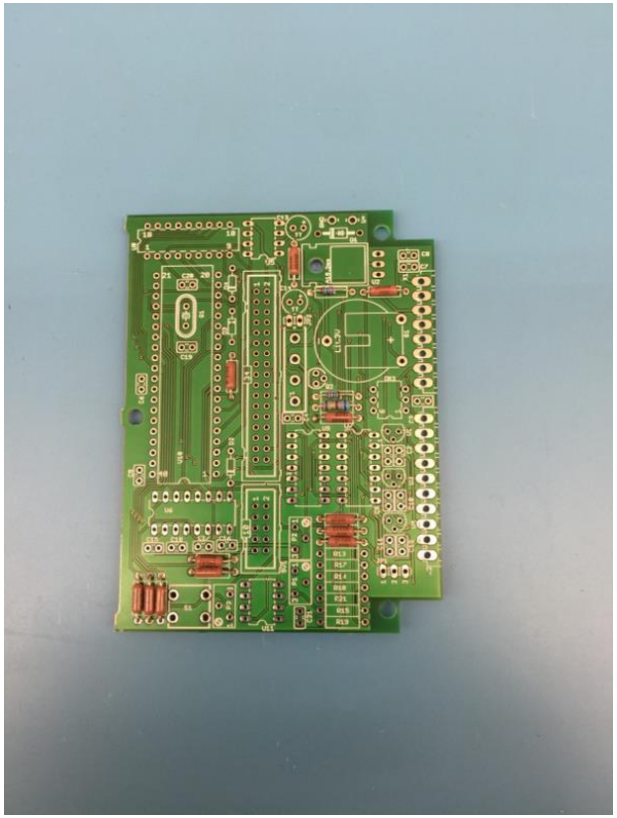
The Heliosphere

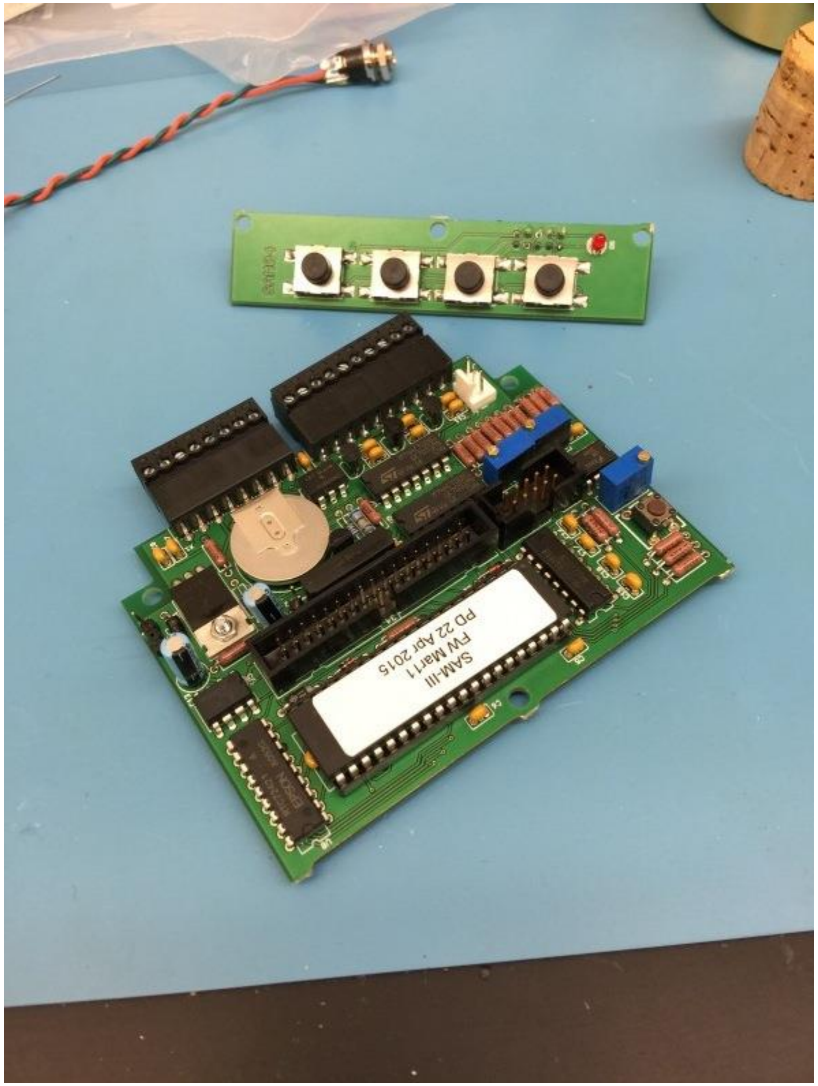


Thank You!

Extra Slides

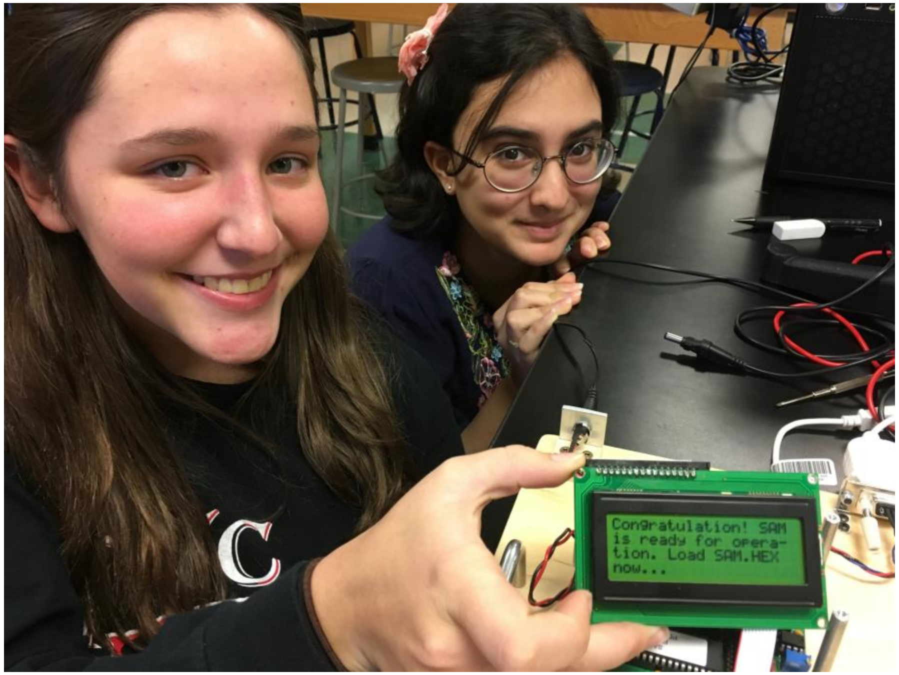
Inexpensive Fluxgate Magnetometers



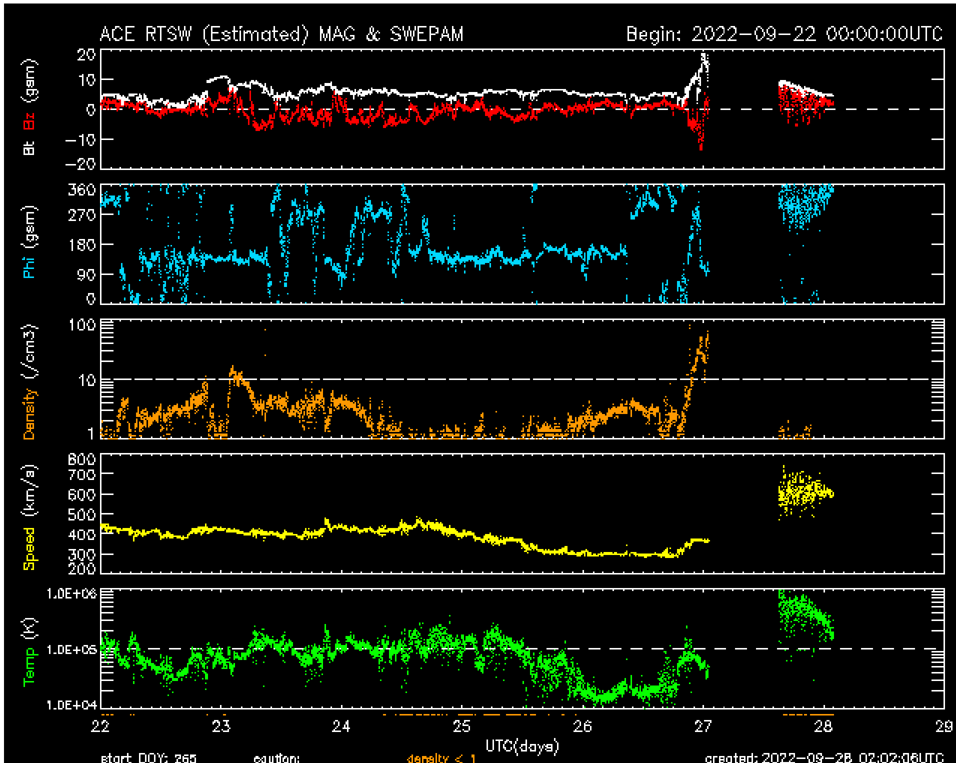


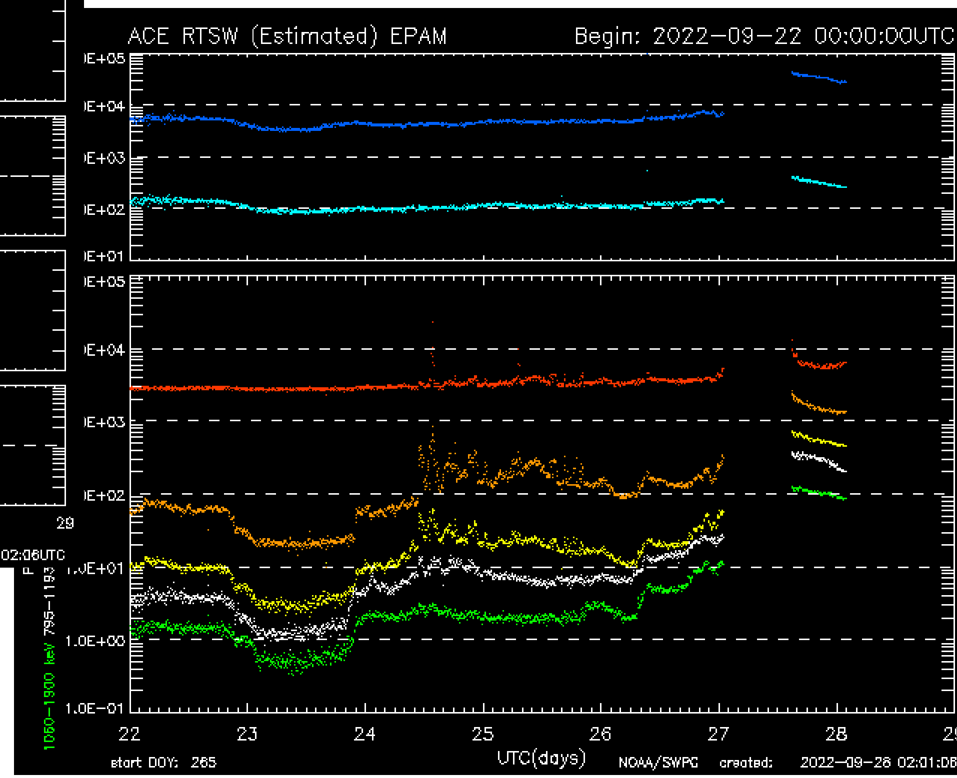
The Goal of the SWUG

- 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.



Space Weather





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