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 Earth’s magnetic field provides a protective barrier that excludes much of the harmful radiation in space.
Transient Arrival of Bastille Day 2000

Over a week of extensive solar activity, 3 shocks and associated ejecta arrived at Earth. Each resulted in energetic particle enhancements to varying degrees. Each resulted in magneto-ospheric storm activity to varying degrees.
Energy Content of a CME

\( \text{Speed} = 1000 \text{km/s} \)

\( \text{Volume} = [(1000 \text{km/s})(24 \times 60 \times 60)]^3 = 6.45 \times 10^{23} \text{km}^3 \)

\( \text{Density} = 1 \text{P}^+ / \text{cm}^3 = (10^5)^3 \text{P}^+ / \text{km}^3 \)

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

\( (1/2)MV^2 = 5.4 \times 10^{17} \text{Joules} = 1.3 \times 10^5 \text{killotons} \)

\[ \left( \frac{10R_E}{R_{CME}} \right)^2 = \left( \frac{10(6.4 \times 10^3)}{10^3(12 \times 60 \times 60)} \right)^2 = 2.3 \times 10^{-6} \]

So, \( \sim 0.5 \text{ kilo ton} \) 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.

$$\Omega_c = \frac{eB}{mc} \quad \mathbf{F}_B = q\mathbf{V} \times \mathbf{B} \quad R_L = \frac{mv_\perp}{eB}$$
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 constant is 135.3 mWatts/cm².
Radiant solar energy of $\sim 1.4$ GigaWatts/km² ($1.4 \times 10^9$ Watts/km²).

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

Solar wind @ 1 AU:
10 protons/cm³ 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 $2.1 \times 10^{20}$ 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.

Daily Snapshot: Oct. 22, 2022

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 northern 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!

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

Radio data link range 4 miles

Deploy the magnetometer away from human activity (moving metal) like cars, trains, etc.

Fully independent & self-supporting!
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 robust!
- 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 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.
September 1, 2022

Daily Snapshot: Sept. 1, 2022
# of Nodes: 3, All times shown UTC, Values are relative to start of day

Exeter

https://swug.unh.edu/
September 2, 2022

Daily Snapshot: Sept. 2, 2022
# of Nodes: 3, All times shown UTC, Values are relative to start of day

Exeter

Conval

https://swug.unh.edu/
September 3, 2022

Daily Snapshot: Sept. 3, 2022
# of Nodes: 3, All times shown UTC, Values are relative to start of day

Exeter

Conval

https://swug.unh.edu/
September 4, 2022

Daily Snapshot: Sept. 4, 2022
# of Nodes: 3, All times shown UTC, Values are relative to start of day

Exeter

Variables:

Conval

Variables:

https://swug.unh.edu/
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
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

![Graph showing thermal sensitivity over time with data from Conval and Exeter on September 6, 2022. The graphs display temperature (T) and magnetic field intensity (B_y) variations.]
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

The heliosphere is defined as the region of space where the characteristics are defined by the presence of the Sun and wind. It was originally thought to be spherical (as was the magnetosphere, the ionosphere, etc.). Time and study change all these views. The boundary of the heliosphere is set by the interaction of the Sun's wind with the local interstellar medium. Dynamics include wind interfaces, shocks, large-scale current sheets, energetic particle acceleration, etc.
The Heliosphere

- Solar Apex
- Interstellar Winds
- Termination Shock
- Heliopause
- Voyager 1
- Voyager 2
- Earth
- Sun
- Saturn
- Uranus
- Neptune
- Jupiter
- Pluto
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 learn 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

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