Long Term Solar Modulation with the AMS-02 detector on the International Space Station

TEACHER NOTES

DESCRIPTION

In this activity, students explore whether solar activity impacts the flux of galactic cosmic rays reaching the inner solar system. This effect is called Solar Modulation. Students also investigate the energy dependence of this effect. First, students will develop a hypothesis. Then, they will construct an analysis by figuring out how they will analyze data from the Alpha Magnetic Spectrometer (AMS-02). Finally, they will carry out their analysis by constructing plots of the AMS data and making conclusions based on their plots.

The data that students are provided is the daily average proton rate (i.e. the number of protons per second arriving at Earth) as measured by AMS-02 over a period of ten months. These measurements are provided in five different energy bands to allow evaluation of the energy dependence. Students will also need to know the solar activity over this time period (whether it is rising or lowering). However they are expected to recognize the need for this additional information on their own and then to ask for it or locate it on the internet.

STANDARDS

Next Generation Science Standards

Science and Engineering Practices

3. Planning and carrying out investigations
4. Analyzing and interpreting data
6. Constructing explanations
7. Engaging in arguments from evidence

Crosscutting Concepts

1. Observed patterns . . . guide organization and prompt questions.
2. Cause and effect . . . investigating and explaining causal relationships

Common Core Literacy Standards

Reading

9-12.3 Follow precisely a complex multistep procedure . . .
9-12.4 Determine the meaning of . . . domain specific words . . .
9-12.7 Translate quantitative or technical information . . .

Common Core Mathematics Standards

MP2. Reason abstractly and quantitatively.
MP5. Use appropriate tools strategically.
MP6. Attend to precision.

ENDURING UNDERSTANDING

When addressing initial thinking, we use comparison data to make a claim about whether or not the idea is correct. Claims are made based on data that comprise the evidence for the claim.

LEARNING OBJECTIVES

Students will know and be able to:

- Develop a hypothesis
- Construct an analysis and carry out analysis using data from the Alpha Magnetic Spectrometer (AMS-02) to test their hypothesis

BACKGROUND MATERIAL

Before the activity, students should receive an introduction to: cosmic rays; the differences between solar, galactic, and extra-galactic cosmic rays (different sources, energy regions, flux levels); solar activity: the solar wind and the 11-year sun spot cycle; the motion of charged particles in a magnetic field; the structure of the Sun's heliosphere.

PRIOR KNOWLEDGE

Students will need to know how to use a plotting program and create scientific plots comparing dependent and independent variables.

RESOURCES/MATERIAL

http://www.phys.hawaii.edu/ams02/outreachnsf/for-teachers.html

more……..

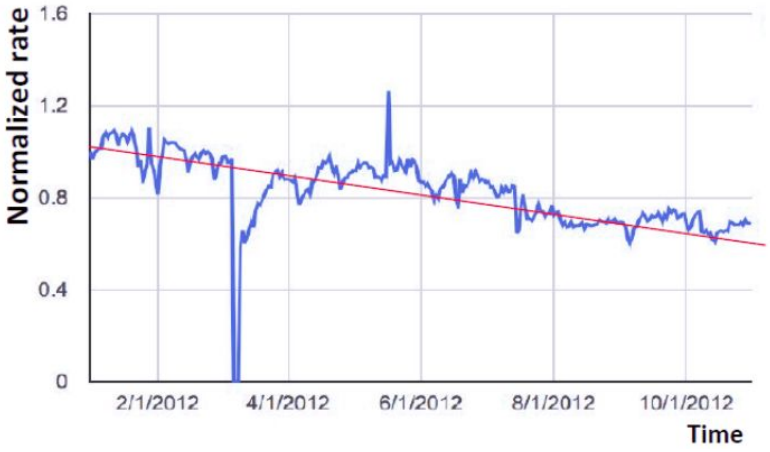
IMPLEMENTATION

After each group of students develops an appropriate hypothesis and data analysis plan, provide that group with the information to access the AMS-02 data:

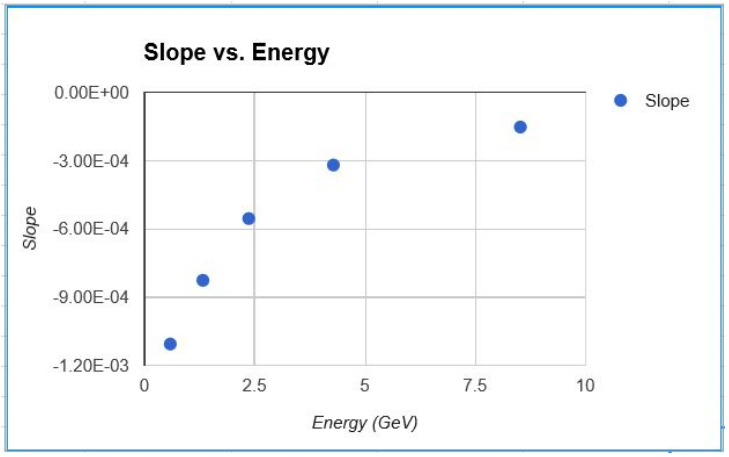
1. If you are logged into your own google account (e.g. gmail), log out
2. Go to https://www.google.com/drive/ and click on the button "Go to Google Drive"
3. Select "Add Account" and/or log in using the following credentials - Username: ams02forteachers@gmail.com, PW: AMS3duc@t10n
4. Once you have logged into Drive, click on "Shared with Me"
5. Go into the folder "AMS02ForTeachers"
6. Go into the folder "Solar Modulation" and use the spreadsheet matching your group number.
7. Select the spreadsheet corresponding to your group number. The spreadsheet has 5 different data sets, corresponding to different proton kinetic energies. Each data sets contains the data collected from Jan to Oct 2012 and the Proton Rate per each day.

A typical analysis plan is as follows:

(1) Plot the proton rate versus date then fit a straight line to the result. A sample plot is below:



(2) Do this for for each of the five energy regions.
(3) Record the slope for each energy region and create a plot of slope versus energy:

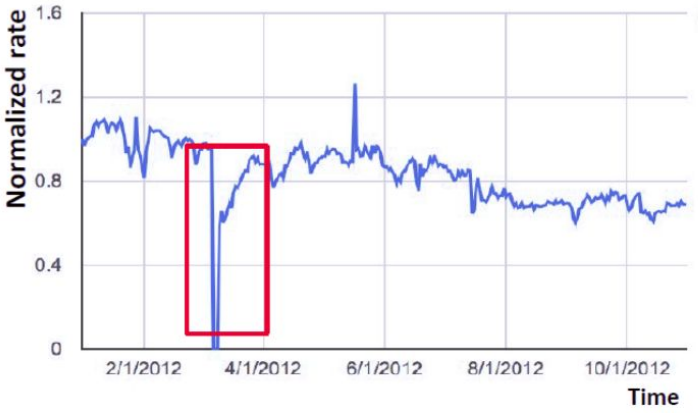


WRAP UP

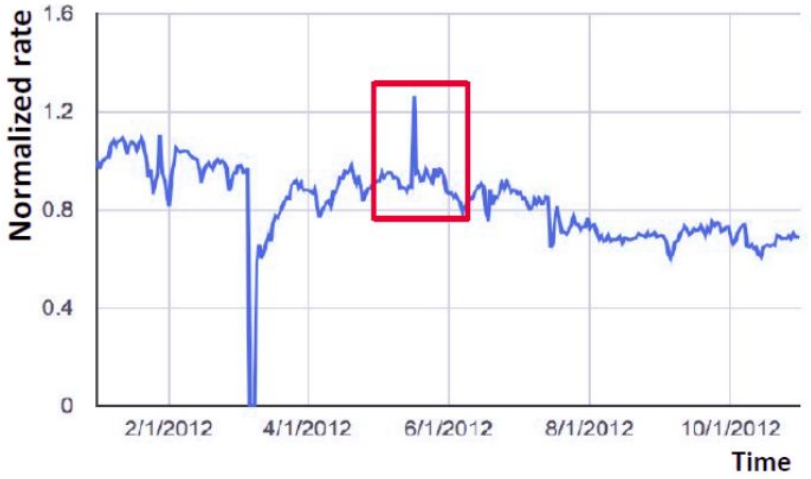
After each group has finished the analysis (they may or may not be done with the "Student Report" if that is to be completed later), discuss the following:

(1) Interpretation of their plots
(2) Whether their hypothesis is supported or refuted
(3) Energy dependence of solar modulation
(4) Additional information in the plots, such as short time-scale solar activity:

Coronal Mass Ejection (CME). When the Sun emits CME, the solar wind is stronger than normal and the galactic cosmic rays (GCR) may suddenly decrease for a short period of time. This is known as a Forbush decrease.



Solar Energetic Particles (SEP). During intense activity, the Sun may accelerate particles up to the energies of GCRs. SEPs can be observed as an excess of particles over the normal GCR spectrum.



ASSESSMENT

Depending on the specific goals of the teacher and time allowed for the activity, the assessment can be based on (1) the graphs created and the student answers to the questions in the analysis section alone, or (2) can also include a student report in the format of the "Student Report" section below.

STUDENT GUIDE

Question

Does solar activity impact the flux of galactic cosmic rays reaching the inner solar system? If so, in what way? Does the effect depend upon the energy of the galactic cosmic rays?

Objectives

In this activity, you will develop your hypothesis, construct an analysis, and carry out your analysis using data from the Alpha Magnetic Spectrometer (AMS-02) to test your hypothesis. AMS-02 is located in space, above the Earth's atmosphere, so it can measure cosmic rays directly. You will use the proton rate (i.e. the number of protons per second arriving at Earth) as measured by AMS-02 to explore whether cosmic rays are influenced by the Sun, an effect called solar modulation. Measurements of proton rates over a period of ten months will be provided to you, in five different energy bands.

Before continuing, write down your hypothesis:

_____

_____

If solar activity does affect the flux of galactic cosmic rays reaching the inner solar system, how can you use the energy dependence of your data to support or further investigate your result?

Is there any data, in addition to the AMS-02 data mentioned above, that you will need?

Background Info: AMS-02

AMS-02 is a state-of-the art particle detector located in space which was installed on board the International Space Station (ISS) on May 19th, 2011. It measures particles and photons with energies between 500 MeV (5x10 8 eV) to a few TeV (1x10 12 eV). AMS-02's primary mission is to search for Dark Matter, new types of matter that don't exist on Earth, antimatter, make precision measurements of galactic and extragalactic cosmic rays (GCR), and measure the highest energy solar energetic particles (SEPs) generated by the Sun. Because AMS-02 is in space, it makes direct measurements of the actual cosmic rays that arrive at Earth, which is an advantage over ground-based detectors that can only observe reactions caused by incoming particles when they slam into the atmosphere.

ISS - International Space Station

Year of launch: 1998
Speed: 4.8 miles per second (7.66 km per sec)
Altitude: 259 miles (416 km)
Orbital period: 92.69 minutes
The Space Station is as big as a football field: 360 ft long (109 mt)

AMS - Alpha Magnetic Spectrometer

Date of Launch: May 2011
Launch vehicle: Space Shuttle Endeavour
Mass: 14,809 lb (6,717 kg)
About 1,000 cosmic rays are recorded by the instrument per second, generating about one GB/sec of data
Check out the web site: http://www.ams02.org/

Do you know where ISS and AMS are now? Go find out on the website and check with the rest of the class! http://www.n2yo.com/space-station

Cosmic Rays

Cosmic rays are charged particles in space, like electrons, protons, and ions (like He, Carbon and Iron atoms) positively charged because they have lost electrons, that travel at very high speeds close to the speed of light. These particles lost their electrons and became charged when they were accelerated in extremely energetic environments like supernova explosions, active galactic nuclei (AGN), colliding galaxies, and black holes. Cosmic rays are generated inside of our Milky Way galaxy and in other galaxies, then travel long distances before they are observed by particle detectors at Earth. Because cosmic rays are charged particles, they do not travel in straight lines. Rather, they follow curving and looping paths through the magnetic fields within our galaxy.

Sun and Solar Modulation

The Sun influences the space environment in the solar system on both short and long timescales. The primary long-term change that the Sun experiences is its approximately 11-year solar activity cycle. During solar minimum, the Sun is quiet, with very few sunspots, a reduced amount of solar activity, and a magnetic field that looks much like a dipole (similar to the magnets on your refrigerator). During solar maximum, the number of sunspots increases, solar activity like flares and coronal mass ejections (CMEs) become more frequent, and the solar magnetic field becomes twisted and complicated. These changes on the Sun affect the heliosphere, i.e. the region of space influenced by the Sun (pictured below). The heliosphere grows during solar maximum and shrinks during solar minimum. It is essentially a big magnetic bubble that expands and contracts, and the magnetic fields inside this bubble act as a shield that blocks incoming cosmic rays. The Sun's effect on cosmic ray flux due to the solar cycle is called long-term solar modulation.

More details about solar modulation can be found at:
http://www.phys.hawaii.edu/ams02/outreachnsf/for-teachers.html

Look for Solar Modulation on Cosmic Rays Using AMS-02

You will look at AMS-02 measurements of proton rate (number of protons per unit time) from January to October 2012.

Proton Rate

The proton rate is obtained by counting the number of protons that pass through our detector for each second. The system of units is [particles/sec] or [Hz] the same as the frequency.

Make Predictions

How do you expect the Sun will influence cosmic rays that reach Earth?
During which part of the solar cycle would you expect the least amount of cosmic rays to reach Earth? How will the energy of the galactic cosmic rays alter the effect?

_____
_____
_____
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_____

Energy Bin

In nature cosmic rays are emitted in a continuum at all kinetic energies. Because of finite detector resolution we cannot distinguish between all the infinite values of kinetic energies but we can

group them in discrete intervals called bins.

Detector Resolution
The resolution is the capability to distinguish between one value and another. A detector has in general a finite resolution because it is impossible to distinguish all the infinite values between one quantity and the other.

eV and GeV
An electron volt (eV) is the amount of kinetic energy an electron has after it has been accelerated by an electric potential of 1 volt. Because an electron is so small, an eV is a very small amount of energy that is equivalent to 1.6x10^(-19) joules. A giga electron volt (GeV) is 1 billion (10^9) eV. An electron with a kinetic energy of 1 GeV is traveling at 99% the speed of light.

Plan your Investigation - Section 1

Describe how you will analyze the AMS-02 data, including any graphs you will create:
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_____
_____
_____
_____
_____

How does your plan take advantage of the data in different energy bins?
_____
_____
_____

What additional data will you need?
_____
_____

Discuss your plan with the activity leader, who will then provide you with access to the data.

Carry out your Investigation – Section 2

Now, carry out your investigation. Use Google Plots or any plotting program of your choice.

Looking qualitatively at your plots, do you see an overall change in the proton rate measured over time? Does the proton rate increase or decrease?
_____
_____
_____

Analyze your Data - Section 3
Quantitatively analyze the impact of solar modulation on the rate of cosmic rays and whether the particles at all energies are affected the same way. What sort of relationship exists? Note that there will be daily random fluctuations in the data that you will have to smooth over some how. Are there fitting functions in your plotting program that you can use to analyze the relationship between cosmic ray flux and time and also the energy dependence of this relationship?

Slope

A line is described by the equation y = mx + b, where x is the independent variable, y is the dependent variable, b is the y-intercept of the line, and m is the slope of the line.
The slope is defined as the amount that y changes (Δy) divided by the amount that x changes (Δx) from one point on the line to another: m = $\Delta y / \Delta x$, often referred to as the rise/run. The slope is a measure of how much y changes when x changes. If the slope is positive, then y increases when x increases. If the slope is negative, then y decreases when x increases. If the slope is zero, then y doesn't change at all when x changes. A slope of zero means that y doesn't depend on x.

Results:

Create a data table and record the results of the line-fits to your data for each energy range. What does slope m = 0, m > 0 and m < 0 mean? Create a plot of "slope" versus "energy band".

Energy Band	Slope of Rate vs. Time plot

And now interpret the Results – Section 4

Does the data support or refute your hypothesis? Justify your answer.

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_____
_____
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By comparing the slopes you measured at different energies, answer the following questions.
Does solar modulation affect the rate of Cosmic Rays the same at each energy range? Justify your answer.

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Which energy was most affected by solar modulation? And the least affected?
Justify your answer.

_____
_____
_____

STUDENT REPORT

Research question:

_____
_____

Reason (why is this interesting):

_____
_____

Physics principles:

_____
_____

Hypothesis and reasoning:

_____
_____
_____
_____
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_____

Claim:		**Evaluate the accuracy of your hypothesis as an answer to the research question.**
Evidence:		**2-3 pieces of evidence (data, observations, calculations) that support the claim**
Questions to consider: How did we test the hypothesis? What data supports the claim?		

Reasoning:		**Justify how and why the evidence backs up the claim. Use scientific principles to explain *why* you got this data. Use and explain relevant scientific terms.**
Questions to consider: Why does the data compel this claim? Is anything left out?		

Sources of Uncertainty in Measurement:		**How much do results vary in calculation? Why? Are their outliers? Why?**
Question to consider: Why and to what extent can we trust your results?		

Practical Applications:		**What is the value of what you learned?**
Questions to consider: How might this information be useful to NASA when planning missions to Mars?		

Now, write your formal scientific conclusion statement. Combine your ideas from the previous pages into two or three well-constructed paragraphs that include the research question, your hypothesis, your evaluation of the hypothesis (claim, evidence and reasoning), possible sources of uncertainty (specific to your data) and practical applications for your discovery. Spelling and grammar do count; be thorough and persuasive!