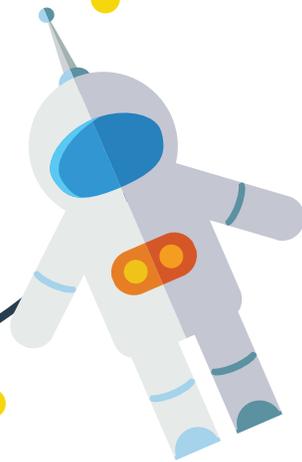


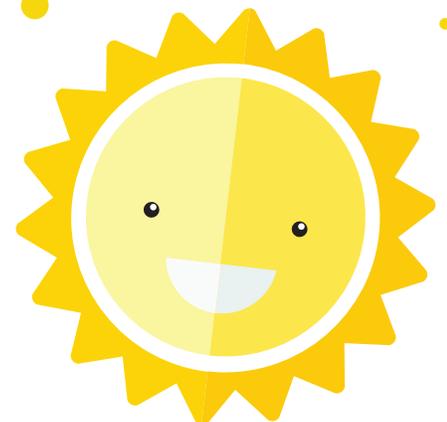
# AMS-02 ACTIVITY

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

*V. Bindi, C. Consolandi, C. Corti, K. Whitman*



Check for some other awesome  
physics stuff on our website!  
[www.phys.hawaii.edu/ams02/outreachnsf/](http://www.phys.hawaii.edu/ams02/outreachnsf/)



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

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## Goal of Activity

In this activity, you will use the proton rate (i.e. the number of protons per second arriving at Earth) measured by the Alpha Magnetic Spectrometer (AMS-02) to explore how cosmic rays are influenced by the Sun, an effect called solar modulation.

AMS-02 is located in space, above the Earth's atmosphere, so it can measure cosmic rays directly. In this activity you will use measurements of protons with different energies to investigate whether solar modulation affects particles of all energies in the same way or if it is an effect that varies with energy.

## Background Info: AMS-02

AMS-02 is a state-of-the art particle detector located in space which was installed onboard the International Space Station (ISS) on May 19th, 2011. It measures particles and photons with energies between 500 MeV ( $5 \times 10^8$  eV) to a few TeV ( $1 \times 10^{12}$  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!

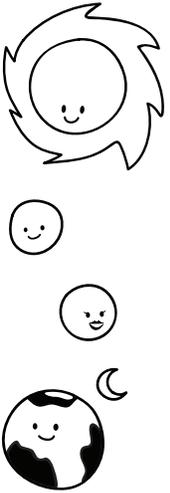
<http://www.n2yo.com/space-station/>

## Cosmic Rays

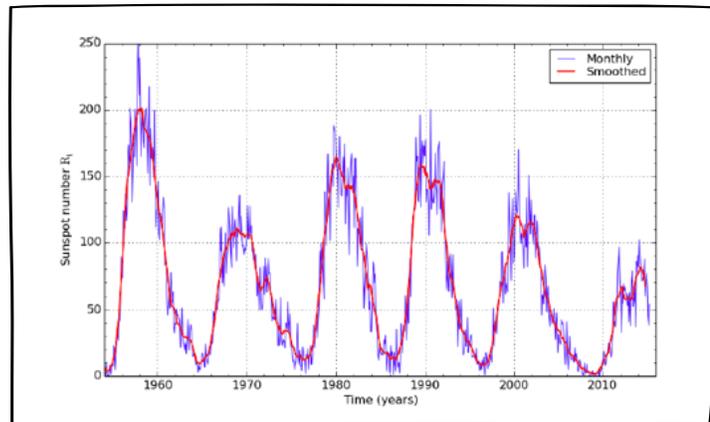
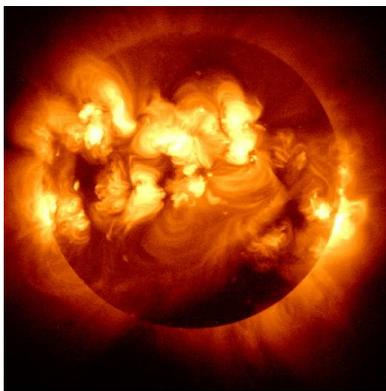
Cosmic rays are charged particles in space, like electrons, protons, and ions (like He, Carbon and Iron atoms positively charged because they have lost electrons, that travel at very high speeds close to the speed of light. These particles are accelerated in extremely energetic environments like supernova 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, shown in the picture below (left). 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. 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, which in turn, changes the amount of cosmic rays measured at Earth. 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>

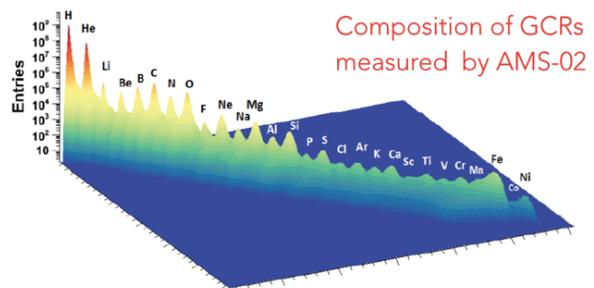


## Look for Solar Modulation on Cosmic Rays Using AMS-02

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.



Composition of GCRs measured by AMS-02

## Make predictions

How do you expect the Sun will influence cosmic rays that reach Earth?

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During which part of the solar cycle would you expect the **least** amount of cosmic rays to reach Earth?

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## Team Members

your group  
number is:

## Start your Investigation **SECTION 1**

In this section you will learn how to make graphs of the proton rate data collected by AMS-02 at 5 different energies using Google spreadsheets.

- 1 Open Google Drive and login with the information given to you by your instructor.
- 2 Select the spreadsheet corresponding to your group number.  
The spreadsheet has 5 different data sets, corresponding to a different kinetic energy. Each data sets contains the data collected from Jan to Oct 2012 and the Normalized Proton Rate per each day.

Date	Normalized Proton Rate				
1/24/2012	0.961312943				
1/25/2012	0.865795788				
1/26/2012	0.907331378				
1/27/2012	0.940922421				

☰	0.59 GeV ▾	1.33 GeV ▾	2.37 GeV ▾	4.29 GeV ▾	8.53 GeV ▾	Slope vs. Energy ▾
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▶ Data Sets

### **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**

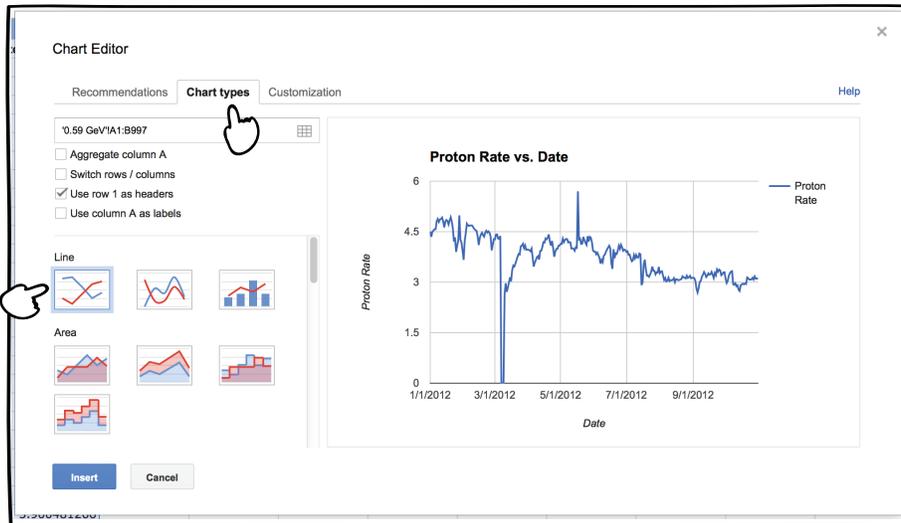
*The resolution is the capability to distinguish between one value and another. A detector has in general a finite resolution because it is impossible to distinguish all the infinite values between one quantity and the other.*

### **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  $1.6 \times 10^{-19}$  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.*

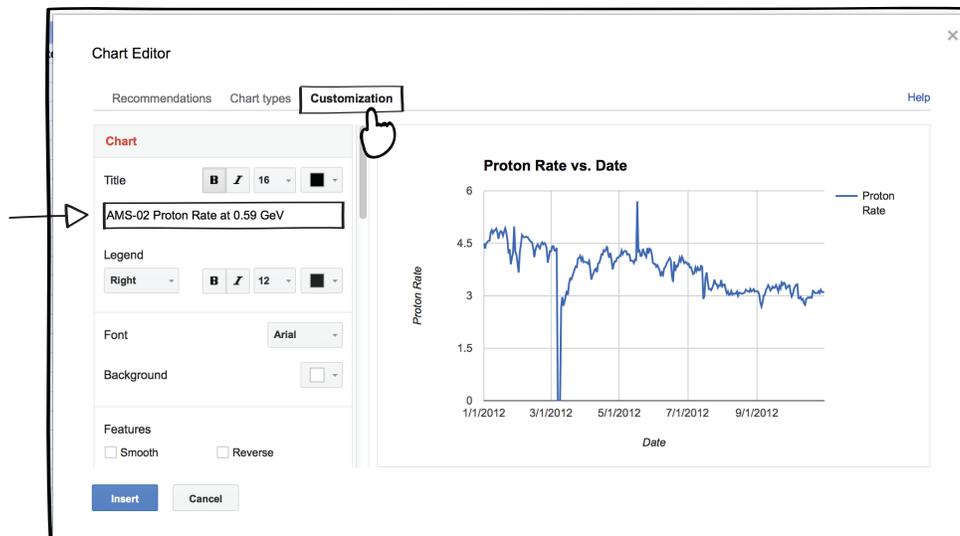
- 3 Select a Data Set.
- 4 Highlight the Date and Normalized Proton Rate columns. Click on **Insert** and **Chart**. The Chart Editor will appear in a pop up window.

- 5 In the Chart Editor window, click on the **Chart types** and choose **Line**.



## Customize your Chart

- 6 In the Chart Editor window, click on the “Customize” tab and write:  
Title: AMS-02 Norm Proton Rate for **## GeV** where the **##** indicates the energy on the bottom tab of your sheet.  
Scroll down and find the drop down menu titled **Axis**. Select and name each axis (if they do not already have the correct names).  
Horizontal Axis: **Date** - Vertical Axis: **Proton Rate**



- 7 Finally, click **Insert** to insert your chart into your sheet.

## Discuss With Your Partner

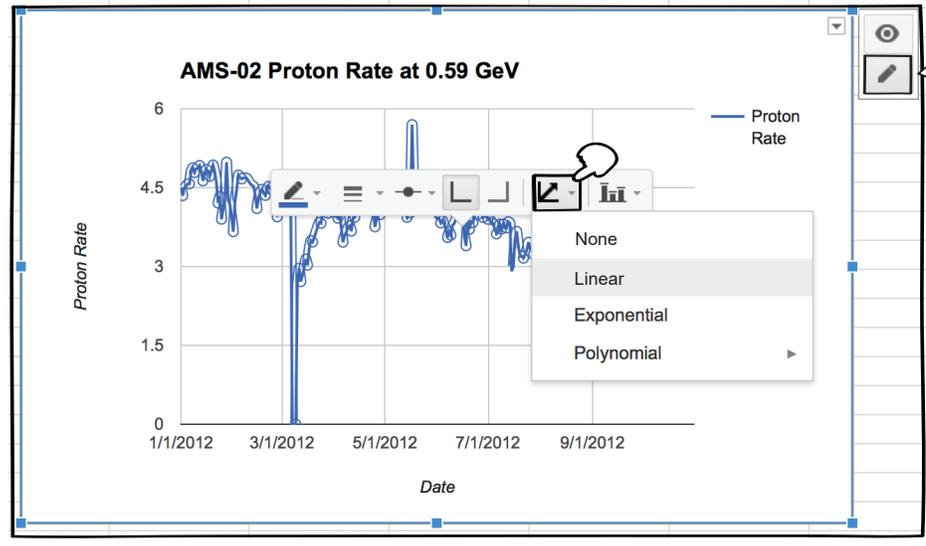
*Looking qualitatively at your chart, do you see an overall change in the normalized proton rate measured over time? Does the proton rate increase or decrease?*

# Analyze Your Data SECTION 2

In this section, you will investigate whether solar modulation impacts the rate of cosmic rays and if the particles at all energies are affected the same way. You will do this by fitting a line to your data, in the chart you just created, and reporting the slope of the line for the 5 different energies (Data Sets).

## Make a Linear Fit

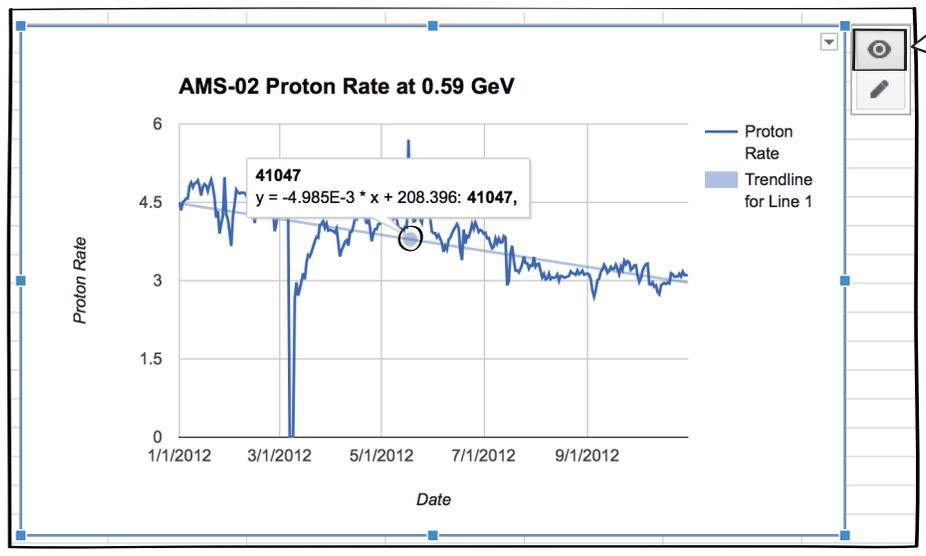
- 8 Click on the data (the blue curve) in your graph so that it is highlighted, then click on the icon that shows a graph with an arrow. Select "linear".



- 9 Google will fit a line to your graph using the equation  $y=mx+b$ , where  $m$  is the slope and  $b$  is the y-intercept. You can look at the slope of the line by clicking on the eye icon at the top right of the graph, then place your mouse over the fitting line.

### 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 ( $\Delta y$ ) divided by the amount that  $x$  changes ( $\Delta x$ ) 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: Slope of Linear Fit to Proton Rate

⑩ Report the slope measured for the energy, then repeat steps from ③ to ⑩ for all the energies.

Energy (GeV)	Slope (m)	y-Intercept (b)
0.59		
1.33		
2.37		
4.29		
8.53		

*Discuss with your partner: What the slope  $m = 0$ ,  $m > 0$  and  $m < 0$  means?*

## And Now Interpret The Results SECTION 3

By comparing the slopes you measured at different energies, answer the following questions.

Does solar modulation affects the rate of Cosmic Rays? Justify your answer.

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By comparing the particles at which energies are influenced by solar modulation?

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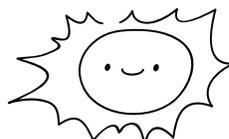
Which energy was **most affected** by solar modulation? And the **least affected**?  
Justify your answer.

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Nice job!



## What did you learn after this activity?

## Glossary Index in alphabetic order

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