Search for Solar Energetic Particles with the AMS-02 detector on the International Space Station

TEACHER NOTES

DESCRIPTION

In this activity students are challenged to identify particles accelerated by the Sun, called Solar Energetic Particles (SEP), as recorded in data from the Alpha Magnetic Spectrometer (AMS-02). AMS-02 is a particle detector flying on board the International Space Station (ISS). Since it is located in space above the Earth's atmosphere, it can measure cosmic rays directly. Normally, AMS-02 data is dominated by galactic cosmic rays because the energy of particles in the Solar Wind is below the energy threshold of the detector. However, massive solar flares or Coronal Mass Ejections (CME) can accelerate particles up to the energy range of AMS-02. These will show up as a short-term increase in the flux observed by AMS-02 over a particular energy range.

Each team will be provided with AMS-02 data from a different time period during which SEPs occurred. Students will create a variety of plots to analyze their data, as well as use internet databases for investigating the solar flare or CME that produced the SEPs that they observed in their data.

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

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.

The data will look like this:

fx | Energy

	A	B	C	D	E	F	G	H	I
1	Energy (GeV)		18-Jan-12	19-Jan-12	20-Jan-12	21-Jan-12	22-Jan-12	23-Jan-12	24-Jan-12
2	0.131441		462.834	459.8	464.593	478.075	439.989	855.261	438.643
3	0.145141		458.1	458.204	480.45	474.474	442.137	801.636	467.239
4	0.160173		463.018	462.821	473.695	477.638	439.88	742.307	437.036
5	0.176646		465.969	462.169	468.65	463.546	441.548	705.1	451.657
6	0.19468		463.383	476.072	470.878	468.466	440.769	641.515	440.644
7	0.214397		463.443	461.575	473.353	472.616	443.345	575.101	433.177
8	0.23593		466.842	475.61	468.156	482.944	446.669	535.45	421.493
9	0.259414		482.938	471.71	472.924	476.439	452.382	508.601	428.298
10	0.284995		464.768	469.723	482.047	479.046	446.978	485.426	424.965
11	0.31282		468.478	467.697	472.666	473.69	443.664	460.299	422.703
12	0.343046		470.587	469.821	474.572	474.269	446.129	441.301	428.493
13	0.375834		467.856	459.161	467.643	461.805	438.586	417.977	411.784
14	0.411352		449.181	453.771	459.53	452.09	429.689	403.315	406.069
15	0.449773		442.712	446.494	451.799	443.698	422.695	383.327	399.999
16	0.491277		428.51	430.474	444.239	429.711	407.699	367.428	386.494
17	0.536049		414.918	416.365	419.513	418.101	396.636	358.851	376.409
18	0.584279		403.358	400.374	405.401	407.812	382	342.208	363.323
19	0.636168		384.412	386.284	388.783	391.062	369.271	333.181	351.479
20	0.691918		372.537	371.528	369.33	373.221	352.364	315.574	338.138
21	0.751741		350.731	350.276	353.018	352.15	332.258	301.118	319.811
22	0.815859		328.918	330.618	331.235	332.658	318.573	283.421	302.694
23	0.884497		310.399	312.283	311.568	312.664	296.103	268.506	285.516
24	0.957892		291.078	290.788	292.215	292.088	278.464	252.444	270.038
25	1.03629		273.69	272.855	271.921	274.525	260.71	241.793	252.834
26	1.11995		250.23	251.54	252.881	250.376	241.405	223.261	232.782
27	1.20914		231.626	235.789	236.695	231.834	224.077	208.18	215.497
28	1.30414		214.195	215.729	216.445	215.068	205.394	192.955	200.513

Feel free to allow your students to use any plotting program they are familiar with. Here is some guidance if you are doing it directly in Google Docs:

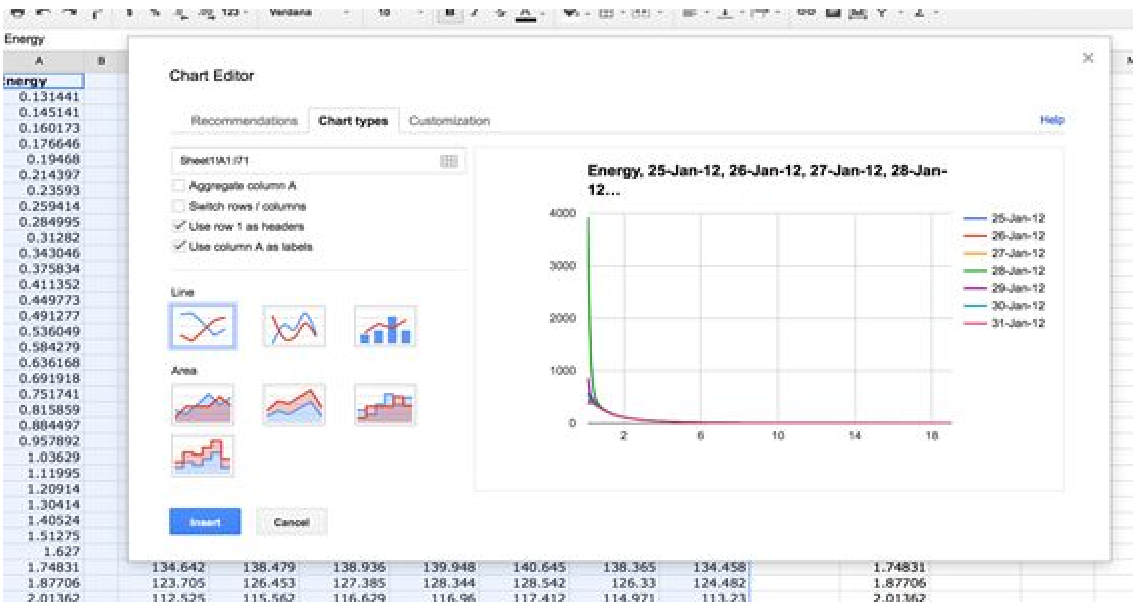
Plotting proton rate as a function of energy for each of the seven days:

Double click on your team's excel spreadsheet and click on Open at the top, to open it in Google Sheets.

Highlight all of the Energy and Date columns all the way down to the very last numbers in the columns. Do NOT include the rightmost 'Energy and SEPs' columns.

Click on Insert and choose Charts.

When the Chart Editor pops up with the Recommendations, use the default chart type (top left selection).



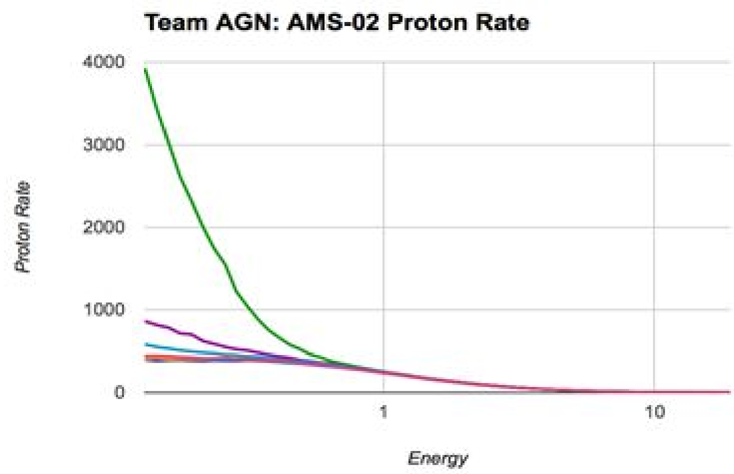
Click on the Chart Types tab and use the defaults: "Use row 1 as headers" and the top left line chart should already be selected. Also select "Use column A as labels".

Now edit the axes and titles. Select the Customization tab in the Chart Editor.
Change the Title to Team AGN: AMS-02 Proton Rate (of course, write your own team name).

Scroll down to the Axis box. Set the X-axis (horizontal) title to Energy (GeV), and the Y-axis (left vertical) title to Proton Rate.

Select the Horizontal axis again from the drop down menu. Scroll down and click on the box that says Log Scale.

Click on Insert to put the chart into your spreadsheet.



Plotting the SEPs: this could be a challenging activity for your students. After allowing some time for them to brainstorm and try out ideas for how to extract the SEP rate by subtracting out the cosmic ray "background", you may need to provide additional guidance:

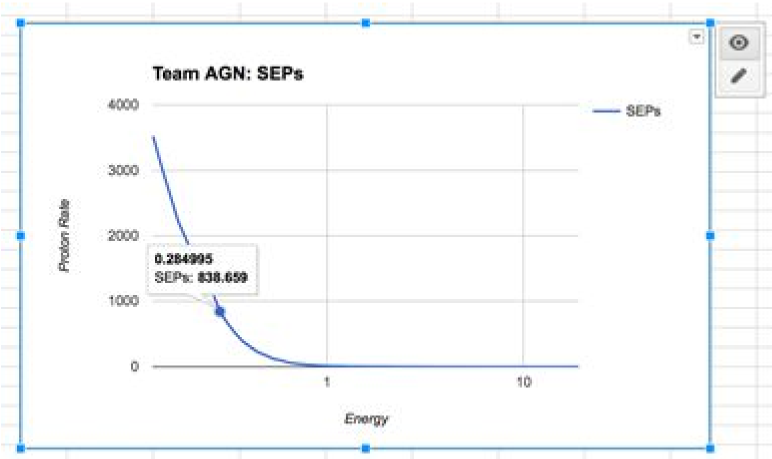
> ***On days without solar activity, the proton rate is due only to cosmic rays (CR) and can be written mathematically as:***
>
> ***Total Protons = CR***
>
> ***For a day during an SEP event, the proton rate is due to both cosmic rays and SEPs and can be written mathematically as :***
>
> ***Total Protons = (CR + SEPs)***
>
> ***In order to get the SEP signal, we need to subtract the background cosmic ray protons:***
>
> ***(CR + SEPs) - CR = SEPs***
>
> ***That is:***
>
> ***(Proton rate on day with SEPs) - (Proton rate on day before SEPs) = SEP proton rate***
>
> ***This calculation can be done in the rightmost Energy and SEPs columns of the excel sheet. Write the equation as shown below. In the example, column F is the day of an SEP event and column C is a day of only cosmic rays and no SEP signal.***
>
> ***After you hit enter, drag the little blue box in the corner of the cell down to the bottom of the column to fill in the SEPs values automatically.***

K	L
Energy	SEPs
0.13144	=F2-C2
0.145141	
0.160173	
0.176646	
0.19468	

K	L
Energy	SEPs
0.131441	3529.722
0.145141	
0.160173	
0.176646	
0.19468	

Now highlight the red Energy and SEPs columns, and insert a line char, setting up the formatting as before. This time, your title should read: Team AGN: SEPs.

Your plot should look like this one. After you have inserted the graph into your spreadsheet, click on the graph and then click on the eye. Put your cursor on the plot to see the values for each data point.



WRAP UP

After each group has finished their analysis, facilitate a comparison of plots and results between the groups.

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
What are solar energetic particles and how can the Alpha Magnetic Spectrometer (AMS-02) be used to study them?

Objectives

In this activity you are challenged to identify particles accelerated by the Sun, called Solar Energetic Particles, recorded in data from the Alpha Magnetic Spectrometer (AMS-02). Each team will be provided with data from AMS-02 covering a different time period during which SEPs occurred. After you have found and analyzed your SEP event, you will compare it with other teams' events to discover which SEP event is the most intense, which has the highest energy SEPs, and more.

AMS-02 is a particle detector flying on board the International Space Station (ISS). Since it is located in space, above the Earth's atmosphere, it can measure cosmic rays directly. Your challenge is to identify SEP events in the data recorded by AMS-02, which is dominated by galactic cosmic rays.

Each team will be provided with data from a different time period during which SEPs occurred. After you have found and studied your SEP event, you will compare it with other teams' events to discover which SEP event is the most intense, which has the highest energy SEPs, and more.

Record your team name:____
Team Members: ____

Your team is named after an astrophysical object that accelerates cosmic rays.
Do a quick internet search and write down a short definition of your team's name:
____
____

As you already know, galactic cosmic rays consist of a variety of charged particles and nuclei, called ions. The most common cosmic ray particle is the proton and the data that you will be provided consists of a table of average daily proton rates as detected by AMS-02.

Your data table will be organized as follows: Column 1 is a list of energy levels; the central energy for each rate bin (energy in GeV). Columns 2 through 8: for each energy bin, the average daily proton rate (# of protons/second averaged over a 24 hour period) is provided for each day over a week.

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 eV) to a few TeV (1x10 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/

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.

Solar Energetic Particles
The Sun experiences many explosive events, such as flares and coronal mass ejections (CMEs). This is called solar activity, which is known to vary on an eleven year cycle. Normally, the energy of the particles in the solar wind is too low to be measured by AMS-02. However, the largest and most energetic of these explosive events can accelerate charged particles up to energies measured by

AMS-02.

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.

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.

Locate AMS-02

1. Do you know where ISS and AMS are now? Go find out on the website and check its location with the rest of the class! http://www.isstracker.com/

Location:
____

Latitude:
____

Longitude:
____

Date:
____

Time:
____

At home: check when the International Space Station is visible from your home town! https://spotthestation.nasa.gov/sightings/

Your Prediction

Before continuing, write down your predictions. If SEPs appear in the AMS-02 data, how will you tell? How can you figure it out using the data you will be provided?__________________________
____
____
____
____

Plan your Investigation

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

____
____
____
____
____
____

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

Once the facilitator is satisfied that you have a workable plan, you will be provided with the login information to access the data from our Google Drive account. The files that you need are in the folder "AMS02ForTeachers", in the subfolder "Search for SEPs." Choose your team's spreadsheet. Each spreadsheet contains one week of data. Each column is labeled with the date of when the data was collected.

Carry out your investigation using Google Plots or any plotting program of your choice.

Looking qualitatively at your plots, describe any trends that you see in the data. Compare and contrast rates your observations at different energy levels and on different days.

____
____
____
____
____
____

Analyze your Data

Quantitatively analyze your data. Ensure that your plots are properly labeled, including the axes and a title. Also ensure that it is easy to read and ready to share. Using a log-scale on one or more axes may improve readability.

Date Range Analyzed: ____

Which date(s) show an increase in proton rate due to a Solar Energetic Particle event? How can you tell?____

____
____

What is the energy range of your SEP event? ____

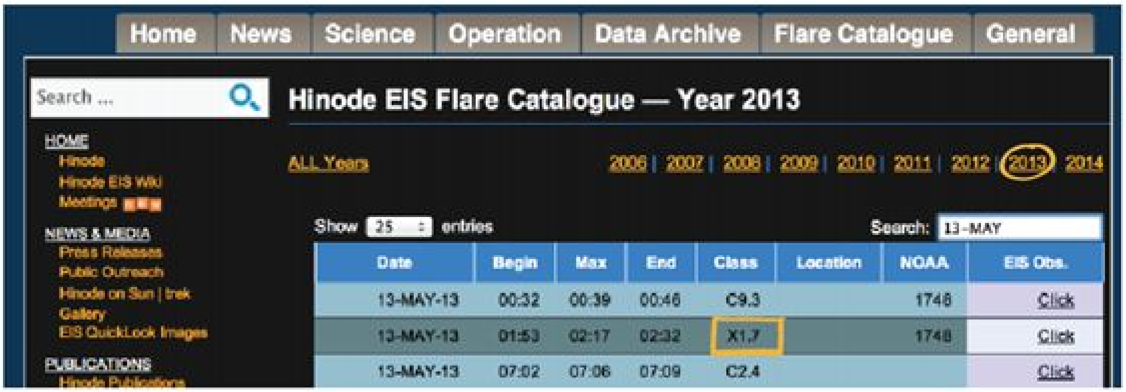
How does the SEP rate compare to the daily rate of galactic cosmic rays? ____________________
____

Can you think of a way to get only the SEP signal? **Create a plot that shows just the flux of solar energetic particles as a function of energy for the date of the event.** In other words, consider the SEPs your *signal* and the galactic cosmic rays your *background*. Subtract out the estimated background. *Hint: on the day of your SEP, the proton rate is due to the sum of cosmic rays plus SEP. On a day without an SEP event, the proton rate is due to cosmic rays.*

And now interpret the results

If the signal is real, there should be X or M class flares and a fast coronal mass ejection in the 24 hours prior to the first day of the SEP event:

> Search the Hinode/EIS catalogue for strong flares on the day of or the day before your possible SEP event: http://solarb.mssl.ucl.ac.uk/SolarB/eisflarecat.jsp
>
> Click on the year of your event and then enter the date following the format: 13 - MAY
> Look for an M or X class flare in the table.



Solar Flare

A solar flare is a sudden flash of light observed near the Sun's surface. It involves a very broad spectrum of electromagnetic emissions. Flares are often, but not always, accompanied by a coronal mass ejection.

SOLAR FLARE INFORMATION

Date: ________________________________
Begin Time: _____________________________
Class: ________________________________
Location (if available): ____________________

Coronal Mass Ejections

A coronal mass ejection (CME) is the release of a huge amount of plasma and magnetic fields from the sun. CMEs often follow solar flares. This expanding ball of plasma can be observed by coronagraphs as it moves outwards into space and consists primarily of electrons, protons, and other ions. CMEs typically move at speeds between 400 - 3000 km/s. They move so fast compared to the material around them that they create shocks and it is believed that these shocks accelerate SEPs.

See what a CME looks like: https://www.youtube.com/watch?v=uecMk8ZZ1uE.

Search the NASA CDAW CME Catalog to look for a very fast halo CME associated with the solar flare you identified above. http://cdaw.gsfc.nasa.gov/CME_list/

The First Appearance Time should be close to the flare time that you found in the flare catalogue, the Central PA should be HALO, and the Linear Speed should be greater than 800 km/s. Feel free to click on the links to see the videos and plots associated with the CMEs.

CME INFORMATION

Date: ____
Time: ____
Central PA: ____________________________________
Linear Speed: __________________________________

Are you convinced that your proton rate increase is associated with solar activity and is a real SEP event? justify your answer using your plots and the results of your database investigations.

____
____
____
____
____
____
____
____
____

SEP Event Characteristics

By moving your cursor along the data points, find the last point were the SEP proton rate is greater than 10. The energy of that data point is the maximum SEP energy.

What is the maximum SEP energy that you measured? ___________________________________

What is the largest value of the SEP proton rate? This is the maximum SEP intensity.____________

Is there anything strange, unusual or confusing that you would like to note about your SEP proton rate? ____
____
____

Compare with the other group's SEP plots to see if yours looks similar or different. ____
____
____
____

SEP Event Summary

Report the characteristic of your SEP event.

Date Observed by AMS-02	
Duration of SEP Event (# of Days)	
Date of Solar Flare Time of Solar Flare Solar Flare Class	
CME Linear Speed (km&s)	
SEP Maximum Energy (GeV) SEP Maximum Intensity (Proton Rate) Was there a Forbush Decrease?	

STUDENT REPORT

If required by your instructor, write-up your investigation in the following report format.

Research question:
____
____

Reason (why is this interesting):
____
____

Physics principles:
____
____

Hypothesis and reasoning:
____
____
____
____
____
____

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!