HiSPARC

High **S**chool **P**roject on **A**strophysics **R**esearch with **C**osmics

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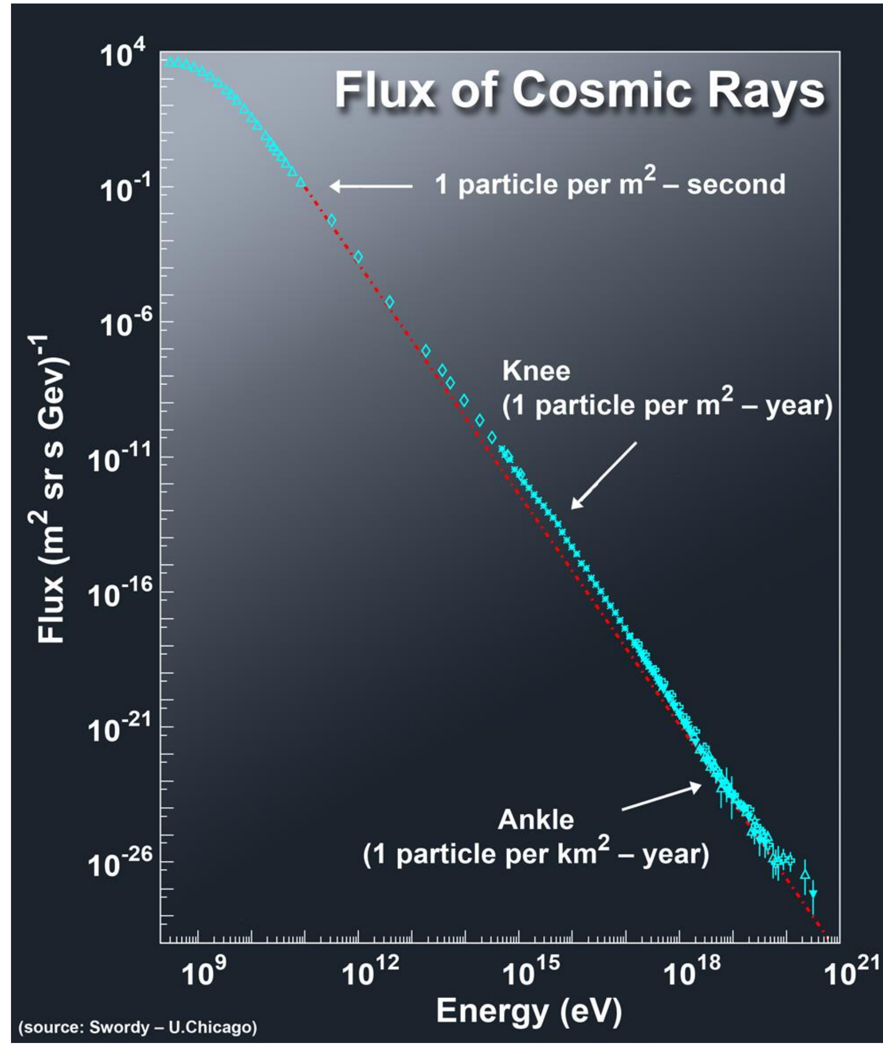
The Ogden Trust
making physics matter

UNIVERSITY OF BIRMINGHAM

Cosmic rays

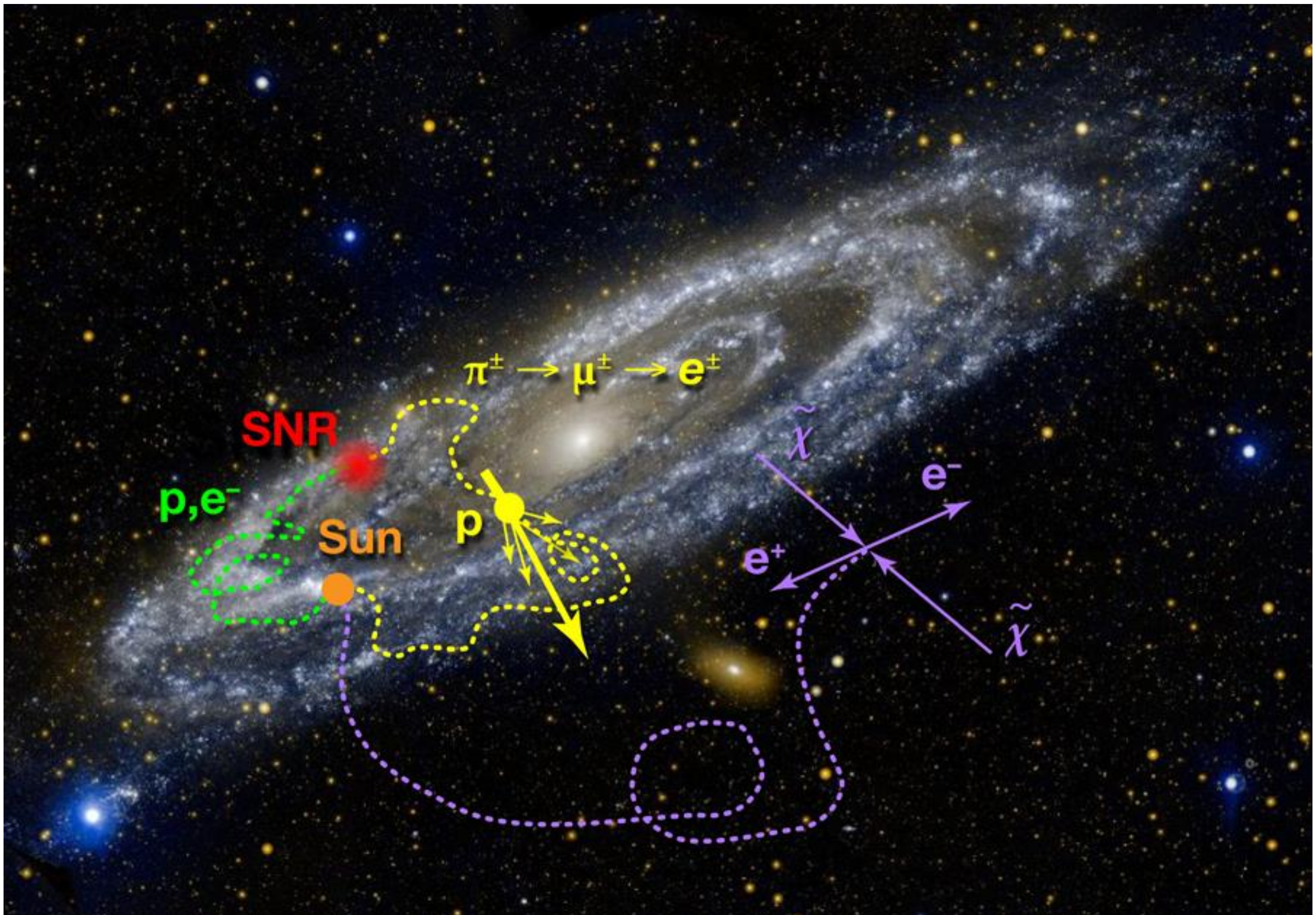
- High energy particles, 10^8 to 10^{20} eV: protons (90%), helium nuclei (9%) and electrons (1%)
- Originate from sun, our galaxy or from further away objects e.g. supernovas, black holes



The big questions

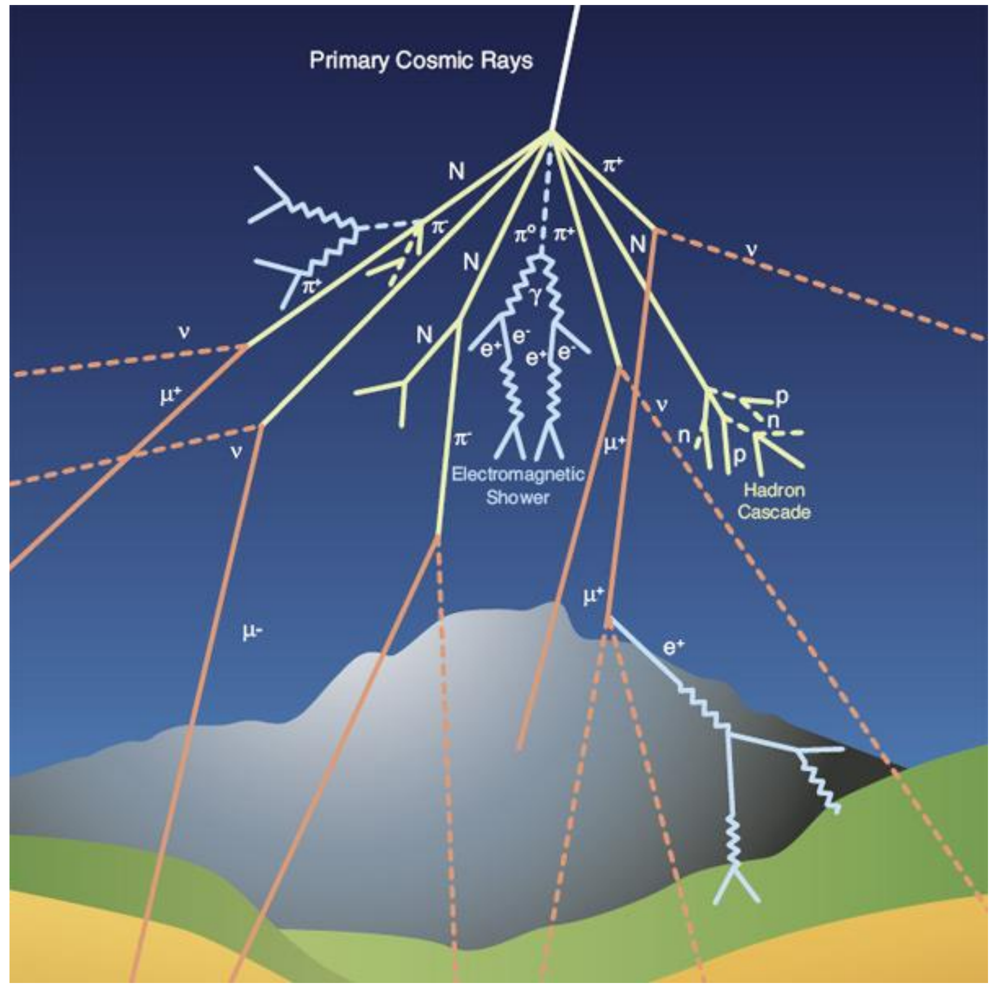
- Lower-energy (up to 10^{15} eV) cosmic rays come from within our own Milky Way Galaxy (possible origin: shock fronts of supernova explosions)
- Do high energy (above 10^{15} eV) cosmic rays have the same origin? ….circumstantial evidence…
- Something extremely energetic is happening in the Universe, but where? and what?

The big problems



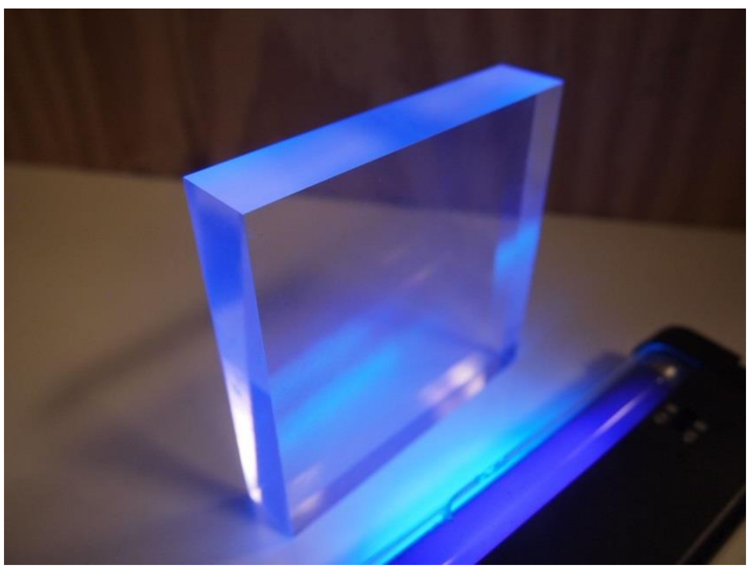
What happens when cosmic rays reach our atmosphere

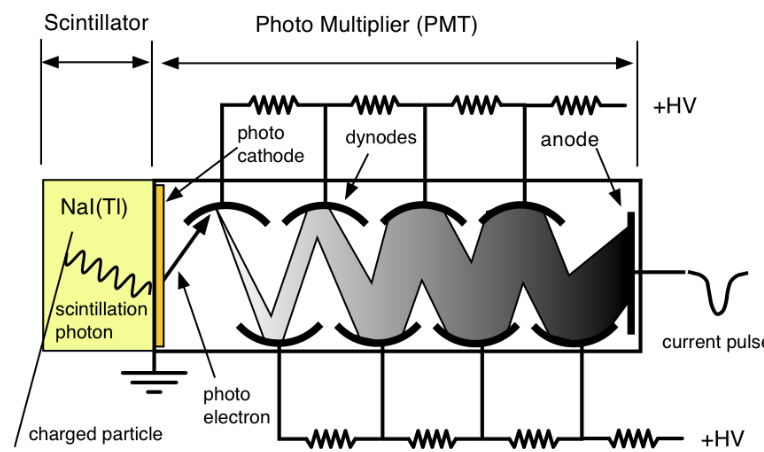
- a shower of particles is generated
- the only particles that finally reach the ground are muons



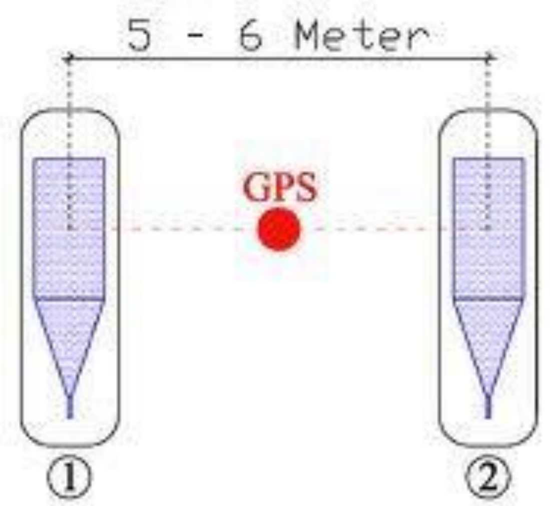
How we detect cosmic rays

the HiSPARC detector detects muons on the ground by converting their energy into light (scintillating plate) and then light into electrical signal

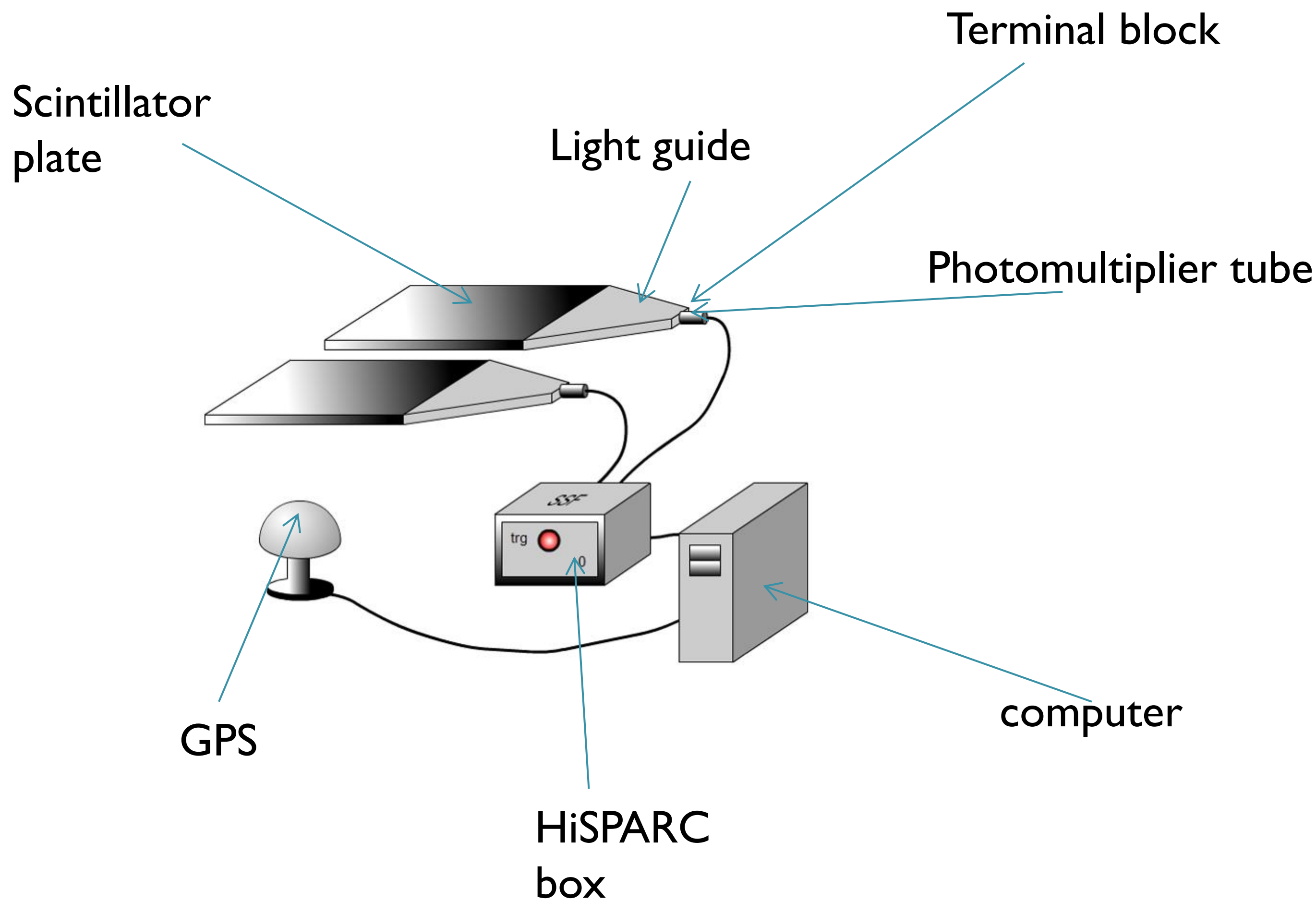




The detector



The detector



Construction Phase 1 (indoors)

- Glue scintillator plate and light guide together
- cover both with aluminium (light produced reflects back on plate)
- Cover both with black liner (no light escapes)

Construction Phase 2 (outdoors)

- Attach aluminium bars on concrete blocks
- Attach ski boxes on aluminium rods
- Attach GPS stand to concrete block

Construction Phase 3

- Attach photomultiplier tube to terminal block
- Cover entire light path with black insulating tape
- Position detector in ski box
- Connect photomultiplier to HiSPARC box
- Check readings for any losses of light

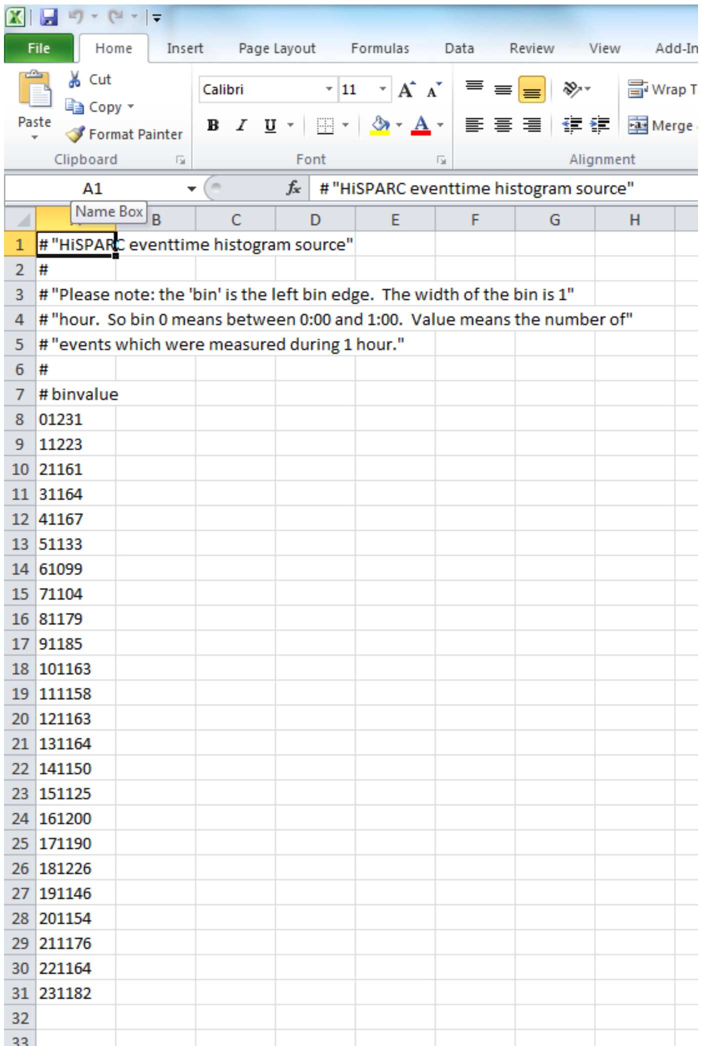
Construction Phase 4 (indoors)

- Software has been installed to computer.
- The first detector has been connected to the HiSPARC box.
- For detector number one, this has had two voltage scans for the photomultiplier tubes in an attempt to find the plateau (region where there is no change in count rate with voltage). One scan was carried out in the dark, the other with the lights on in order to check for light leaks. These scans enable the operating voltages for the detectors to be found.
- On having found light leaks, these were then repaired using duct tape and the above process repeated. The two voltage scans were found to be in fairly good agreement (to within error) and as such may be deemed representative in the current position.
- The detector has had light leaks fixed for the present position only, i.e. lying flat on the floor, but should the geometry change such has been stood up, then it may be expected that other points of entry for ambient light may exist.
- Detector number 2 is now also being checked for light leaks, where above steps have been repeated.
- At the current time, an attempt is being made to use two detectors in coincidence to ensure the software is performing as it should.

How to: download data

- Go to http://data.hisparc.nl/show/stations_by_country/
- Find and choose the Birmingham University detector (station number 14001) and click on its link
- On the right side of the Birmingham detector page, click on a particular day (one in blue font)
- Click the “Source” button above the event histogram graph to download the data file

How to: import data



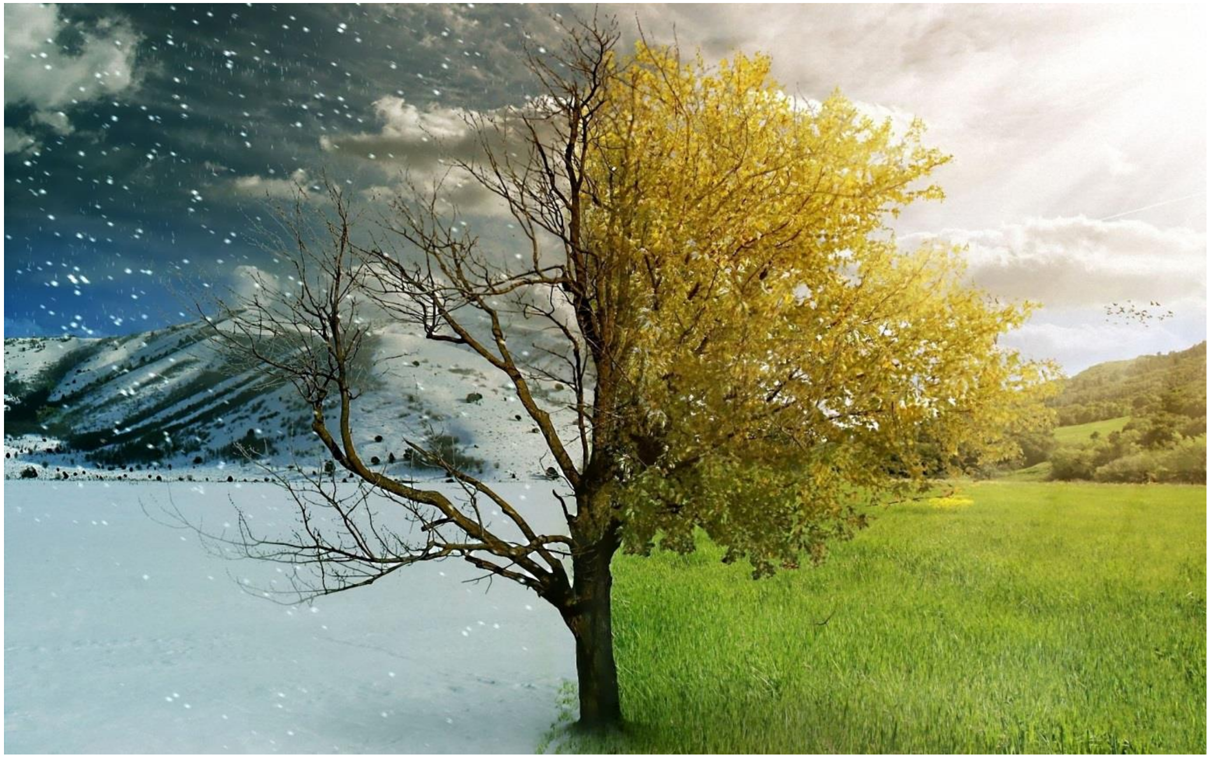
- The data is saved in a tab-separated ASCII files (.csv or .tsv)
- The bin number (time in hours) and its value (number of events per hour) appear in one column, so they need to be separated

How to: separate ‘bin’ from ‘value’

- Open the .tsv file in Excel
- Select ‘Data’ (top menu bar).
- Click on ‘From text’ and select the file you want to import; in this case the file you downloaded.
- Excel will now start a Wizard to import the file.
- Excel will recognise the correct settings. In step one of the wizard choose ‘Delimited’ as file type. In step two make sure that only the option ‘Tab’ is selected. In step three the ‘Column data format’ should be ‘General’.
- After clicking ‘Finish’ you can specify where you want to place the imported data.
- The bin and its value are now in two separate columns

Project 1

Winter-Summer variation of cosmic rays



Investigating the effect of winter and summer on the number of recorded events

- **Observation:** the average number of recorded events during the summer is smaller in comparison to the one during winter.

- **Explanation:** There are many different factors that might be responsible for this variation:

  (i) the difference in the atmospheric temperature between winter and summer,

  (ii) the distance between Sun-Earth during winter and summer,

  (iii) the difference in the atmospheric pressure between winter and summer and

  (iv) the position of the sun relative to the detector during winter and summer.

In order to find out which of the above factors play a major role, each factor should be investigated separately.

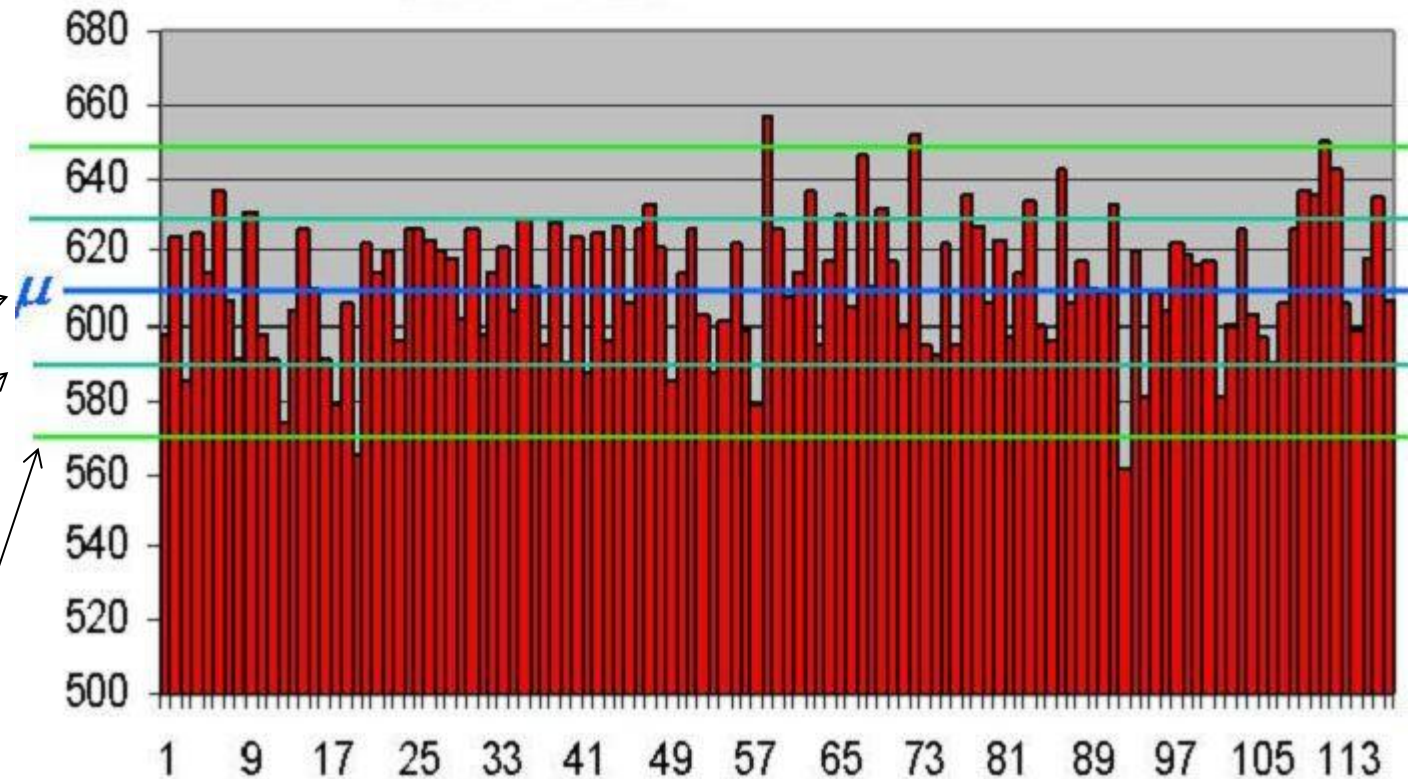
Process:

- Find the days of the winter solstice (21 December 2012) and summer solstice (21 June 2013).
- Download the number of events on a 24 h period over the week around the winter and summer solstices (e.g. from Bristol University station, code 13001).
- Use a spreadsheet and record each day on a separate column; keep winter and summer events apart
- Calculate the SUM of the winter events per day and the SUM of the summer events per day
- Calculate the Average of the winter events per day (μ_1) over the entire week and the Average of the summer events per day (μ_2) over the entire week
- Compare the two averages μ_1 and μ_2

Question: How far apart should the two averages be in order to be recognised as “different”?

Answer: is given by statistical analysis

Number of events



mean

One standard deviation (34.1% from mean)

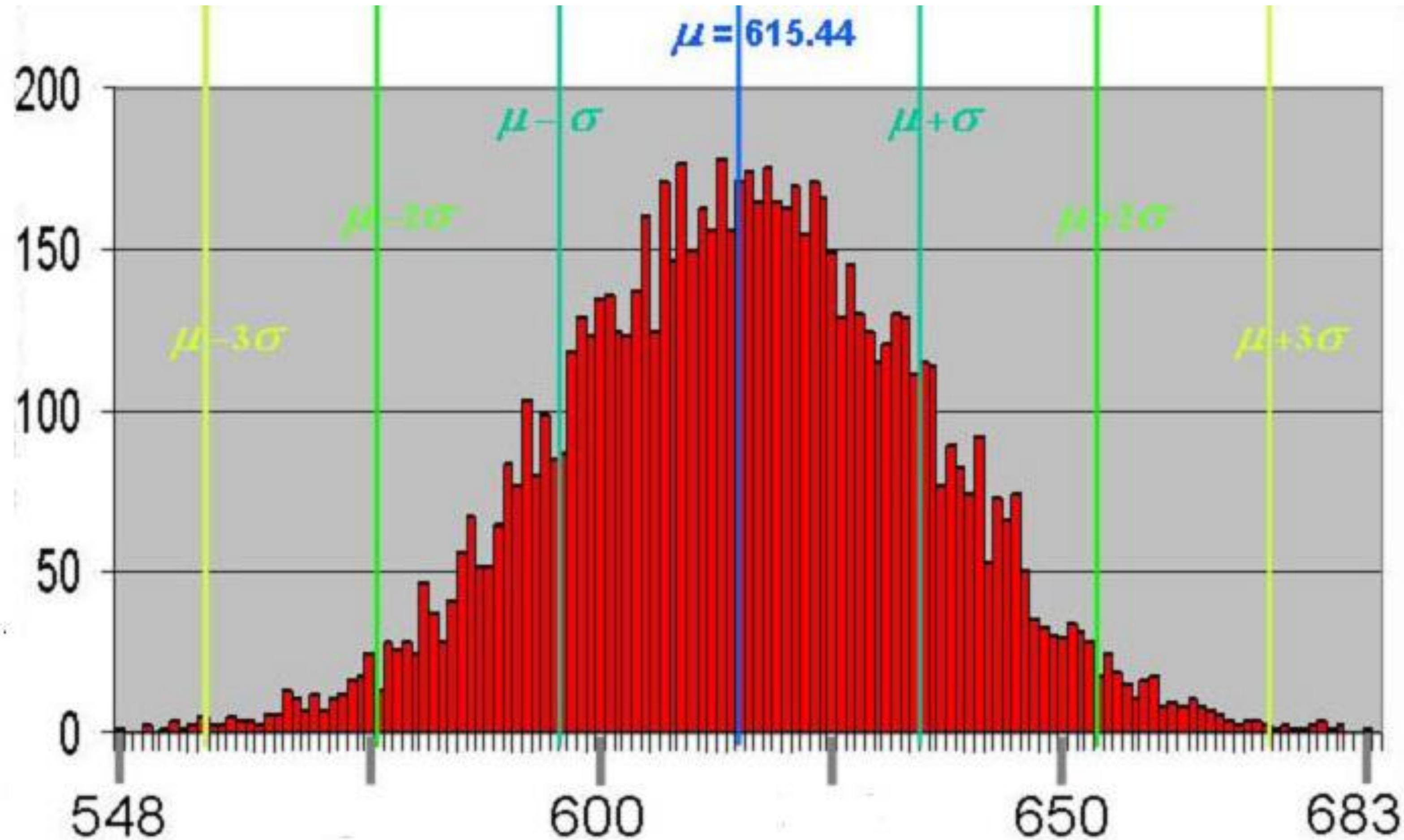
Two standard deviations (13.6% from one stand. dev.)

Time (hours)

mean

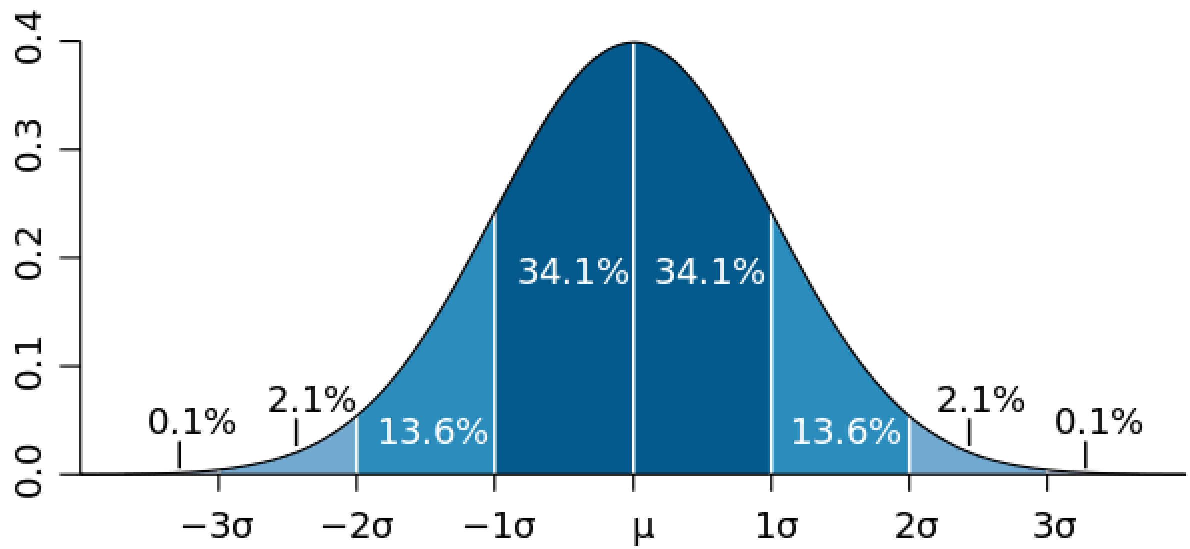
Three standard deviations

Frequency of event number

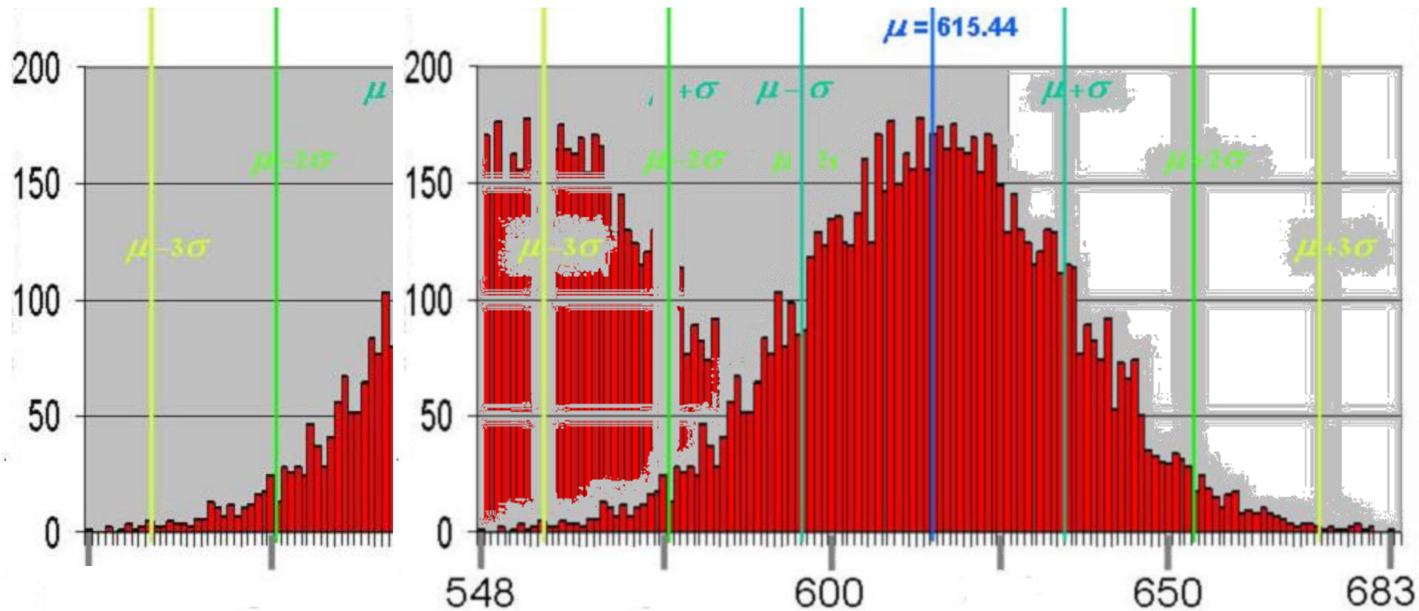


Number of events

Standard deviation



Comparing the mean difference with three standard deviations



Is the difference between winter and summer events statistically significant?

- Calculate the standard deviation of the winter sample (σ_1) and the standard deviation of the summer sample (σ_2), using the function STDEV.P
- Calculate $\Delta N=\mu_1-\mu_2$
- Calculate $\sigma_\Delta = \sqrt{(\sigma_1{}^2 + \sigma_2{}^2)}$
- You will find that $|\Delta N|>5\ \sigma_\Delta$ which means that the variation between winter and summer is statistically significant

Further investigations:

You can now design your own analysis to investigate the contribution of these factors:

- the difference in the atmospheric temperature between winter and summer,
- the distance between Sun-Earth during winter and summer,
- the difference in the atmospheric pressure between winter and summer and
- the position of the sun relative to the detector during winter and summer.

Project 2

Day-Night Variation of cosmic radiation

Investigating the effect of day and night on the number of recorded events

- **Observation:** the average number of recorded events during the day is smaller in comparison to the one during the night
- **Explanation:** Our Sun can protect us from a large part of high energy radiation. The Sun has a large sphere of influence called the heliosphere. Inside this region the magnetic field of the Sun is strong enough to deflect the particles away from us. When the magnetic activity of the Sun is at a maximum, its protective action is also at its strongest.

Process:

- Download the number of events on a 24 h period over several days (e.g. first week in September 2013 from Bristol University, 13001).
- Use a spreadsheet and record each day on a separate column.
- Calculate the number of events during the day, by taking the SUM of events that correspond to 5 hours around mid-day (e.g. from bin 10 to bin 14). Do this for every day of the week.
- Calculate the number of events during the night, by taking the SUM of events that correspond 5 hours around midnight (e.g. bins 0-2 and 22-23). Do this for every day of the week.
- Calculate the Average of the day-events (μ_2) and the Average of the night-events (μ_1)
- Compare the two averages μ_1 and μ_2

Is the difference between day-night events statistically significant?

- Calculate the standard deviation for the day-events (σ_2) and the standard deviation for the night-events (σ_1); use the function STDEV.P

- Calculate the $\sigma_\Delta = \sqrt{(\sigma_1{}^2 + \sigma_2{}^2)}$

- Calculate the difference ΔN between the day and night averages ($\Delta N = \mu_1 - \mu_2$)

- You will find that $|\Delta N| < \sigma_\Delta$ so, based on this particular set of data, we cannot claim that the variation is statistically significant

Further investigations:

- To increase the statistical significance by considering more days (in similar weather conditions)
- To investigate how the outcome is affected by the choice of the time window (5h)
- To establish a correlation with the presence of the sun or clouds
- Does this outcome depend on the season?

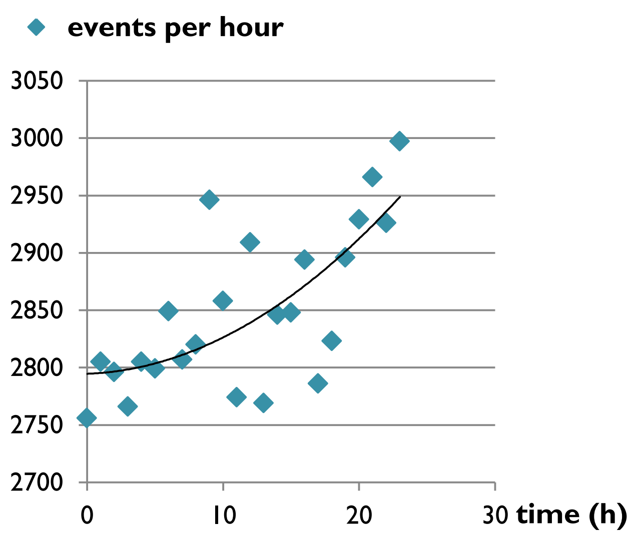
Project 3

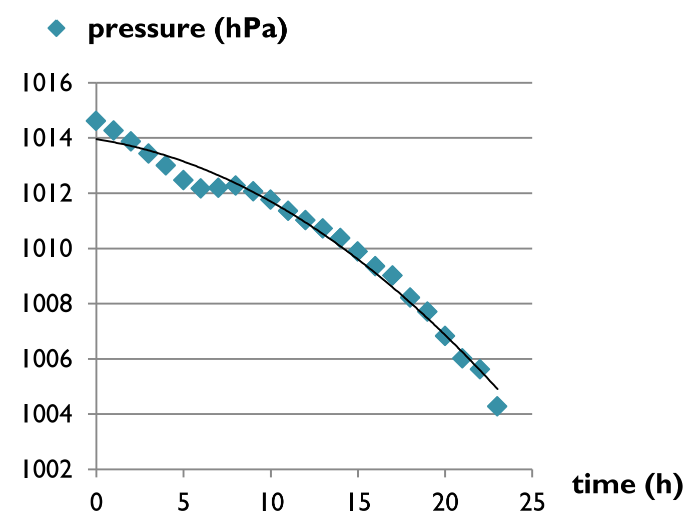
Effect of Pressure on Cosmic Radiation

Investigating the relation between pressure and cosmic radiation

- **Observation:** a decrease in pressure is associated with an increase in cosmic radiation (barometric effect).

- **Explanation:** The atmospheric pressure is a measure for the air mass above the detector. The higher the pressure, the more material there is to stop the development of the shower and consequently, fewer particles are measured at sea level.





Process:

- Download the number of events per hour for the 1st November 2013 from station 501 Nikhef (it includes a weather station)
- Download the barometer data for the same day – time is measured in seconds after 1 January 1970
- Subtract the number of seconds from 1/1/70 so that the barometer time starts at zero; then convert seconds to hours
- Average the pressure readings for every hour so that they can be matched to the events data

Investigating the correlation between pressure and events-per-hour

- Create a spreadsheet with three columns: time, events-per-hour, pressure. Determine the average pressure $\overline{p}$ and its standard deviation σ_p as well as the average events-per-hour $\overline{e}$ and the standard deviation σ_e for the entire time interval e.g. 24 hours.
- Calculate the pressure deviation from the average $(p_i - \overline{p})$ for each reading, i.e. difference between the instantaneous pressure p_i and average pressure for each reading. Place these values in a separate column.
- Calculate the events-per-hour deviation from the average $(e_i - \overline{e})$ for each reading, i.e. difference between the events-per-hour e_i and average events-per-hour for each reading. Place these values in a separate column.
- Multiply the pressure deviation from the average with the events-per-hour deviation from the average $(p_i - \overline{p}) * (e_i - \overline{e})$. Place the result in a separate column.

Calculating the Covariance

- **Covariance**: provides a measure of the strength of the correlation between two sets of variables (in this case pressure and events per hour)

- Calculate the sum of the final column $\sum_{i=0}^{N}(p_i - \overline{p})(e_i - \overline{e})$ and from this, the covariance:

$$\sigma(p, e) = \frac{\sum_{i=0}^{N}(p_i - \overline{p})(e_i - \overline{e})}{N} \text{ (in this case } N = 24\text{)}$$

- You will see that the covariance is a negative number; this means that pressure and events-per-hour are perfectly anti-correlated parameters i.e. when one increase the other reduces.

Calculating the Correlation

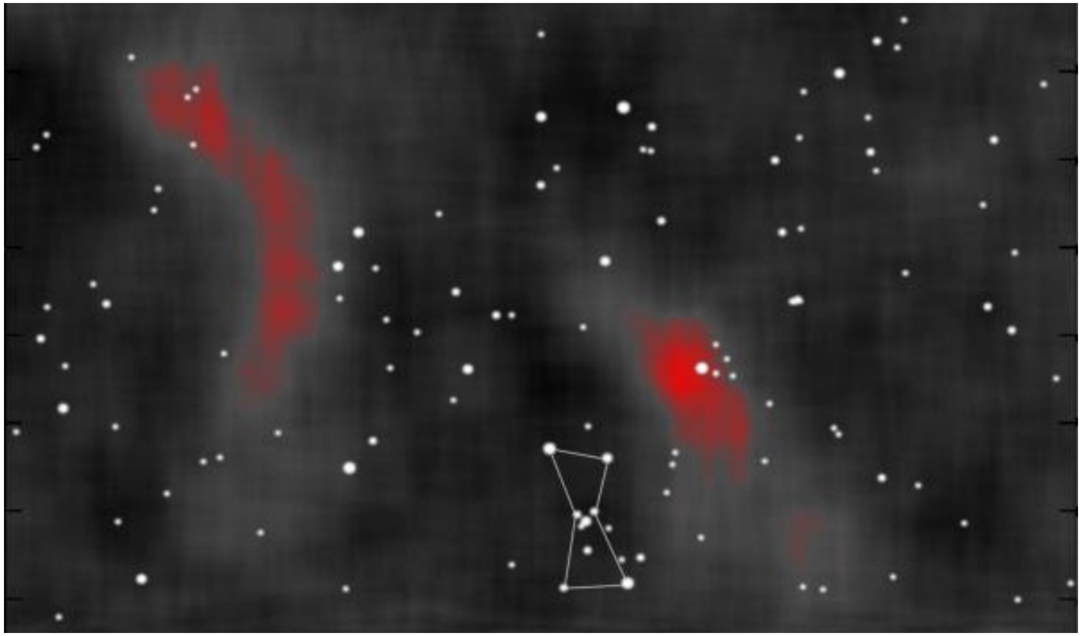
- **Correlation:** the degree to which two variables show a tendency to change together. Perfectly correlated quantities have a correlation of 1; perfectly anti-correlated quantities have a correlation of -1; and independent variables have a correlation of 0.
- Calculate the correlation by dividing the covariance with the standard deviation of pressure and with the standard deviation of events per hour
- You will see that the correlation is -0.7.The closer the correlation is to -1 the greater the statistical significance and thus the confidence that the parameters are anti-correlated.

Further investigations:

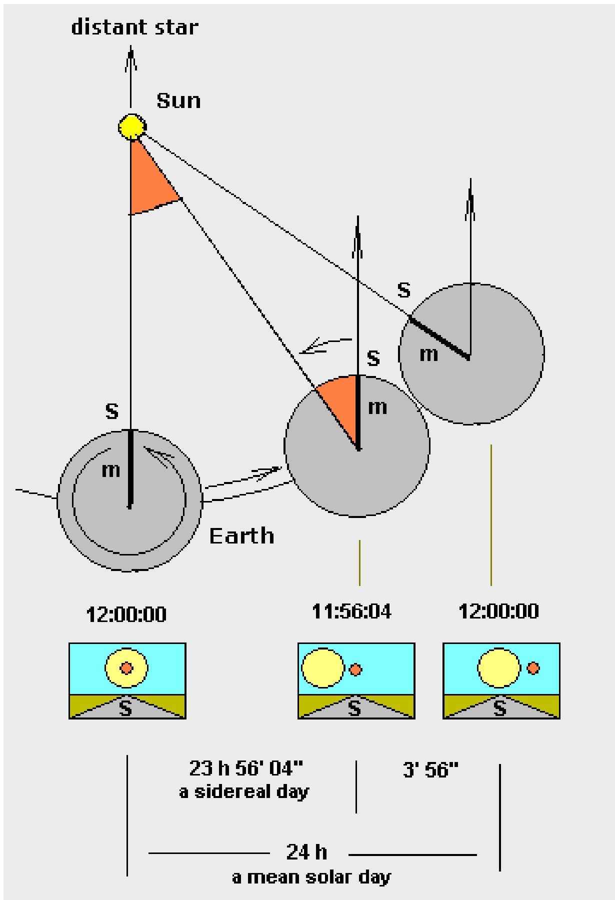
- Try to investigate the same effect from a different station
- Investigate the deviation from the general trend on pressure by correlating with other factors (e.g. temperature)
- Try to find why the number of events is so scattered

Project 4

Locating a Possible Source of Cosmic Radiation

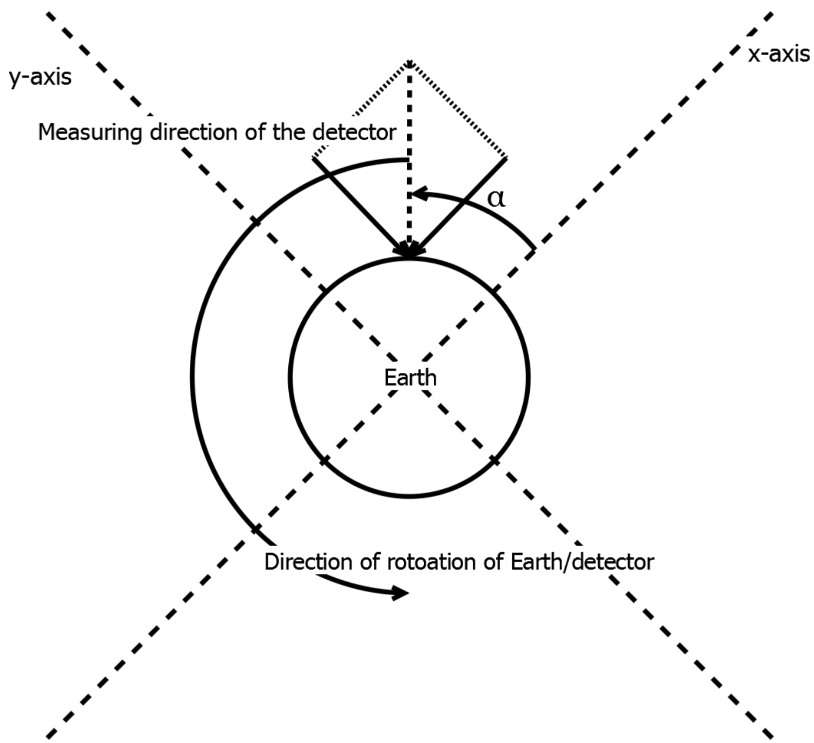


Sidereal day and Solar day



- Sidereal day: (23h 56min 4 sec) the time needed for the earth to rotate 360 degrees around its axis (or the time between successive passages of a distant star across the meridian)
- Solar day (24h) the time between successive passages of the sun across the meridian
- In a solar year there are 365.2422 solar days and 366.2422 sidereal days.

Starting point



- The sky is divided into quadrants and the data is assigned to the quadrant according to the measurement angle α
- Time represents a certain angle **with respect to the stars**. We can switch between time and angle using the following equation:

$$a = \frac{2\pi t}{T}$$

where t is solar time and T is one sidereal day (both in hours)

Initial calculations

The tropical year is the period of time required by the sun to pass from vernal equinox to vernal equinox. It is equal to 365 days, 5 hours, 48 minutes, and 46 seconds, or 365.2422 days.

$$\text{ratio} = \frac{365.2422}{366.2422}$$

Initial calculations

Sidereal day in hours = 24 * ratio

Sidereal day in seconds = 24 * ratio *60*60

Time in sidereal hours = time in solar hours * ratio

Initial calculations

Number of Earth revolutions = time in solar hours/sidereal day in hours

Angle alpha in radians = 2π * number of Earth revolutions

Process:

- Download the number of events on a 24 h period over a week (Bristol University 13001) starting from 12 January 2013; combine all data in three columns (date, time, events per hour)
- Calculate the time in solar hours for the entire week; add this on a new column
- Calculate the time in sidereal hours for the entire week; add this on a new column
- Calculate the angle α for the entire week; add this on a new column

Applying a weighting factor on data

$$weighting\ factor = \frac{1}{2}\left(1 - \cos\frac{2\pi b}{B}\right)$$

where b is the bin number (starting from 1 and increasing by 1 all the way through the whole observational period) and B the total number of bins

- Weighting must be applied due to the Fourier transformation that follows (i.e. frequency-domain representation of the data). Data at the start and end of our data set will count less towards the final answer while the middle part will be treated normally.
- To do: Calculate the weighting factor for the entire week and add this on a new column

Final calculations

- Calculate the weighted data by multiplying the number of events per hour with the weighting factor for the entire week; add this on a new column

- Calculate the *x* and *y* components of the **weighted** Data for the entire week

$$Data\ x = Weighted\ Data * \ \cos a$$
$$Data\ y = Weighted\ Data * \ \sin a$$

and add them on two separate columns

- Calculate the sum of data x ($\sum Data\ x$) and the sum of data y ($\sum Data\ x$) as well as the sum of all weighted data $\sum Data$.

Locating the source of cosmic rays

- Calculate the deviation (what percentage comes from a particular direction)

$$deviation(\%) = \frac{\sqrt{(\sum Data\ x)^2 + (\sum Data\ y)^2}}{\sum Data}\ 100$$

- Find the direction of the source (angle α) using the equation

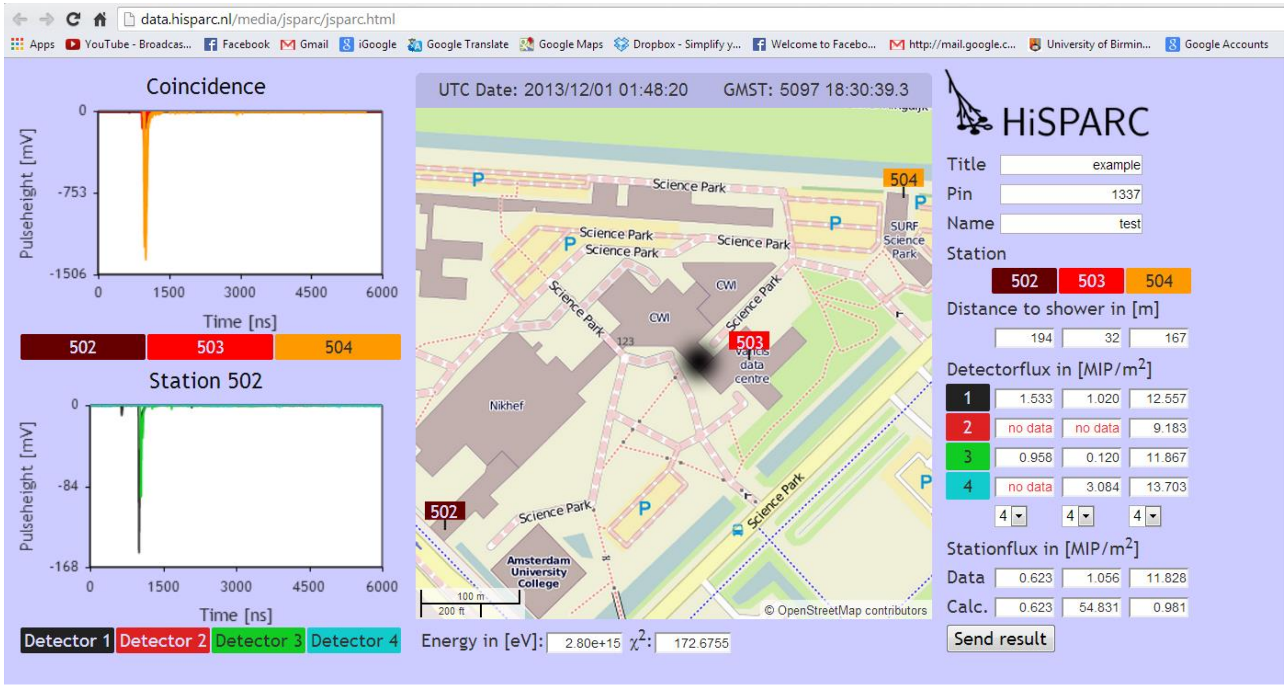
$$\tan a = \frac{\sum Data\ y}{\sum Data\ x}$$

Further investigation: Locating the source in the sky

- Convert the angle α back into solar time
- Use Cartes du Ciel (Sky Chart) or Stellarium with the coordinates of your detector
- Insert the first day of observation as the specified day and the solar time you found as the specified time
- Add the azimuthal grid on your sky chart
- The software will show you the sky on the first day of your observation
- the possible sources of cosmic rays will appear somewhere along the North-South meridian
- Do additional research to decide which one is the most likely source

Project 5

Calculating the Primary Particle Energy and the Location of the Shower Core



Coincidences

- For an event to occur at a station at least two of its detectors must observe particles at the same time.
- **Coincidence**: when three or more stations observe the same event.
- In case of a coincidence multiple stations are hit by the same air shower of particles. In this case, the Primary Particle Energy and the Location of the Shower Core can be calculated

Using the jSPARC software

- Go to

  http://data.hisparc.nl/media/jsparc/jsparc.html

  and click button "Get example".
- **Top left**: graph showing the entire coincidence measured by all stations
- **Bottom left**: graph of coincidence for each individual station (to choose a station, click on station number above graph)
- **Top middle**: map of participating stations; shower core is shown as a black spot that can be moved around
- **Bottom middle**: box showing the calculated energy of the shower core and its error as a χ^2 value (a lower χ^2 value corresponds to a better estimation of the shower core position)

Using the jSPARC software

- Click and drag the black spot on the map.
- Observe how some values on the right rows change while some others stay the same
- **Top right row:** shows the distances between the chosen shower core position and the participating stations
- **Middle right rows:** show the *measured* particle density on all stations
- **Bottom right rows**: the second-to-last row gives the *measured* particle density. The last row gives the *calculated* particle density, with the assumption that the shower core is correctly placed. If the values in the two rows are equal, that indicates that the chosen shower core position might be the *actual* shower core position.

Final calculations

- The best way to estimate the primary particle energy and the location of the shower core is by moving the black spot in the area between the stations with the aim to make the χ^2 value as small as possible.

- Once you have achieved this, compare the ***measured*** particle density with the ***calculated*** particle density. They should have very similar values.

- If the ***measured*** and ***calculated*** value for a particular station do not match, think about reasons why

Analysing data with jSPARC

- Go back to http://data.hisparc.nl/media/jsparc/jsparc.html
- Enter title: Birmingham University224
- Enter pin: 6733
- Enter your name: e.g. MariaPavlidou1
- There are 1900 events to analyse, so keep going !
- During the session we will view the results at:

  http://data.hisparc.nl/analysis-session/birmingham-university224/data

References to pictures

- Winter-summer variation: http://www.gdefon.com/
- Day-night variation: www.wrsc.org
- Standard deviation: http://en.wikipedia.org/wiki/Standard_deviation
- Air Pressure variation: christianevidences.org
- Sources of cosmic radiation: www.universetoday.com
- jSparc: http://data.hisparc.nl/media/jsparc/jsparc.html