

# What are Cosmic Rays?!

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# X-Rays: Siblings of Cosmic Rays

Have you ever had an X-ray examination at the hospital? In 1896, a German physicist, W. C. Röntgen, astonished people with an image of bones captured through the use of X-rays. He had just discovered the new type of rays emitted by a discharge device. He named them X-rays. Because of their high penetration ability, they are able to pass through flesh. Soon after, it was found that excessive use of X-rays can cause harm to bodies.

In that same year, a French scientist, A. H. Becquerel, found that a uranium compound also gave off mysterious rays. To his surprise, they could penetrate wrapping paper and expose a photographic film generating an image of the uranium compound. The uranium rays had similar characteristics as those of X-rays, but were determined to be different from them.

The emission of rays was also found in thorium by G. C. Schmidt in Germany and M. Curie in France in 1898. The term "radioactivity" was given to this mysterious phenomenon. M. Curie made the spectacular discovery of radium. Radium began to be used for radiation research because of its intense radiation. It was found to be a few tens of thousands times stronger than uranium.

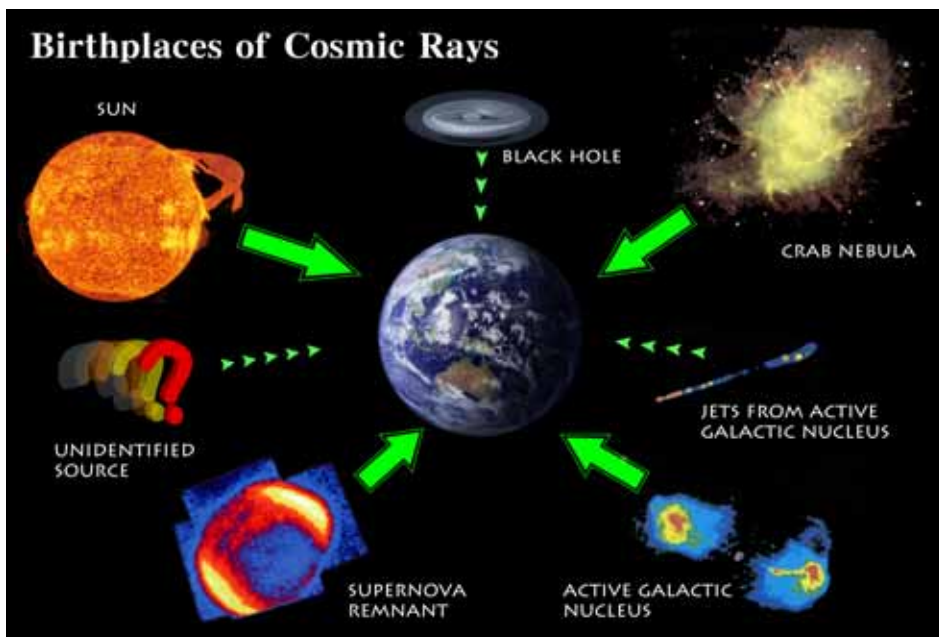
Scientists identified three types of radiation: positively-charged alpha particles, negatively-charged beta particles, and uncharged gamma rays. In 1903, M. Curie along with her husband, P. Curie, and Becquerel, won the Nobel prize in physics. Furthermore, M. Curie was awarded the Nobel prize in chemistry in 1911.

Certain types of radiation including X-rays are now used for many medical purposes including examining inside the body, treating cancer, and more. Radiation, however, could be harmful unless the amount of radiation exposure is strictly controlled.

The work with radium by M. Curie later led to the breakthrough discovery of the radiation coming from space. These cosmic rays were discovered by an Austrian physicist, V. F. Hess. Although cosmic rays have high-penetration ability, they do not affect humans because the Earth's atmosphere makes them harmless.

Outside the atmosphere, however, cosmic rays become a threat to astronauts! They have to be protected from the harmful effects.

Now, what are cosmic rays? In this booklet, you will find the answer with the help of your friends Mol and Mirubo.



<Sources: Sun, Earth - NASA; Crab Nebula - Hale Observatories; Jets from Active Galactic Nucleus, Active Galactic Nucleus - National Radio Astronomy Observatory; Supernova Remnant - ISAS/JAXA>

*Tiny mysterious particles are coming all the way through space to Earth.*

*They are cosmic rays!*

Hooray,  
I got it!

Robotic  
dog, Mirubo.

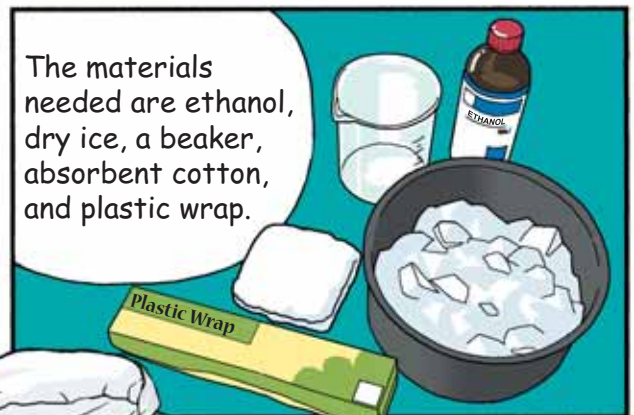
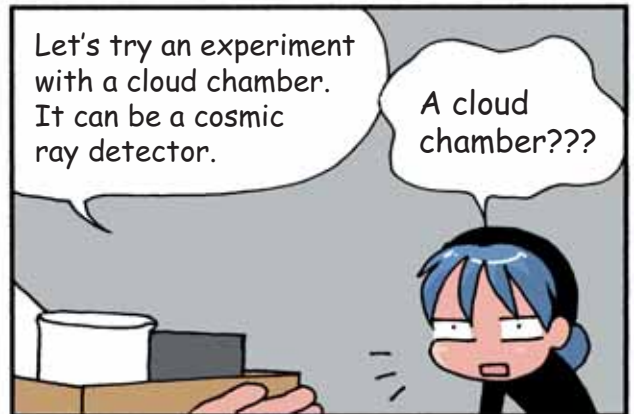
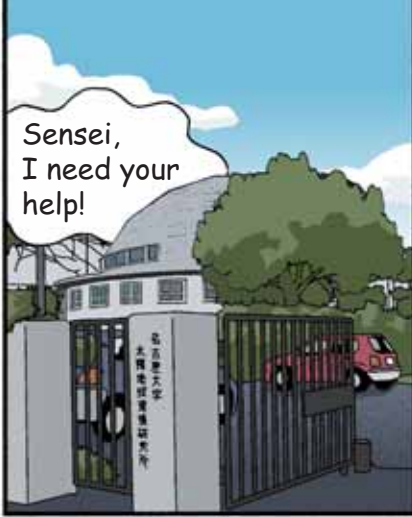
What are you  
looking at,  
Mirubo?

Cosmic  
rays!

Mol, science-  
loving girl.



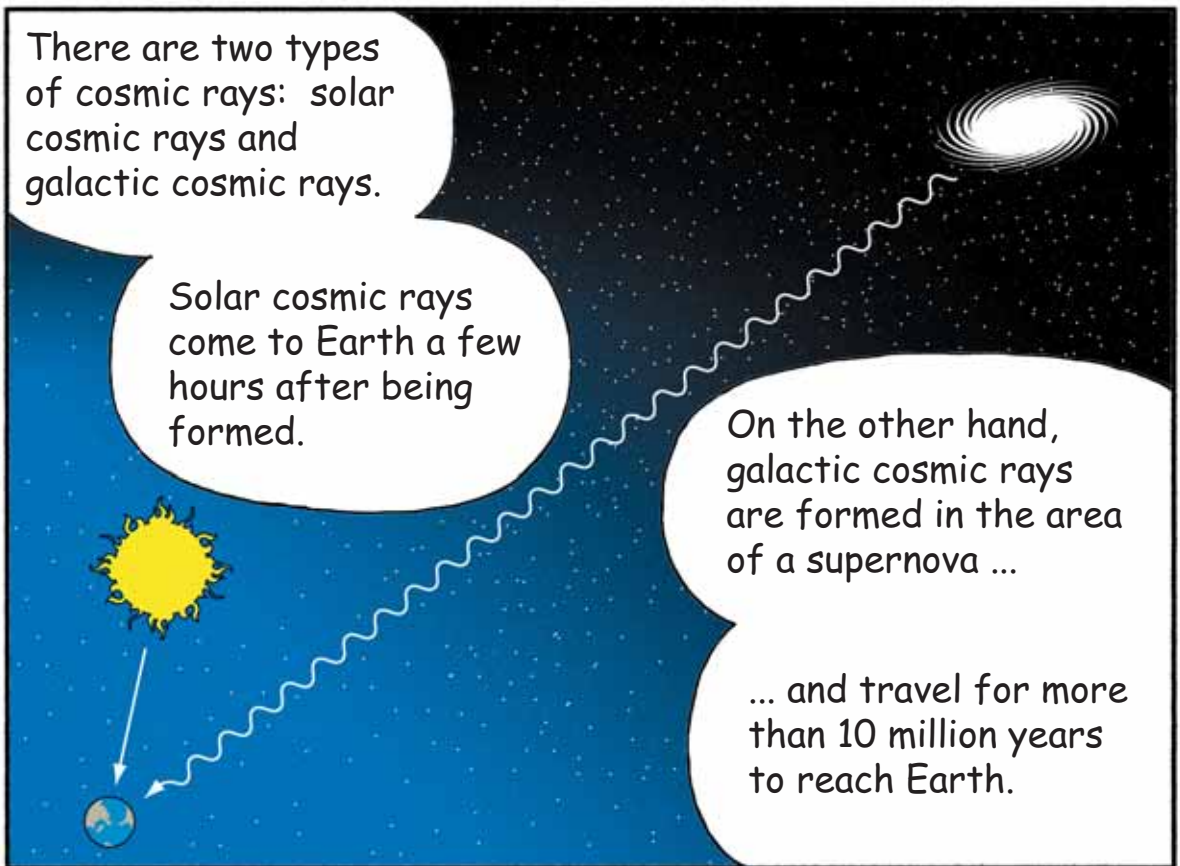




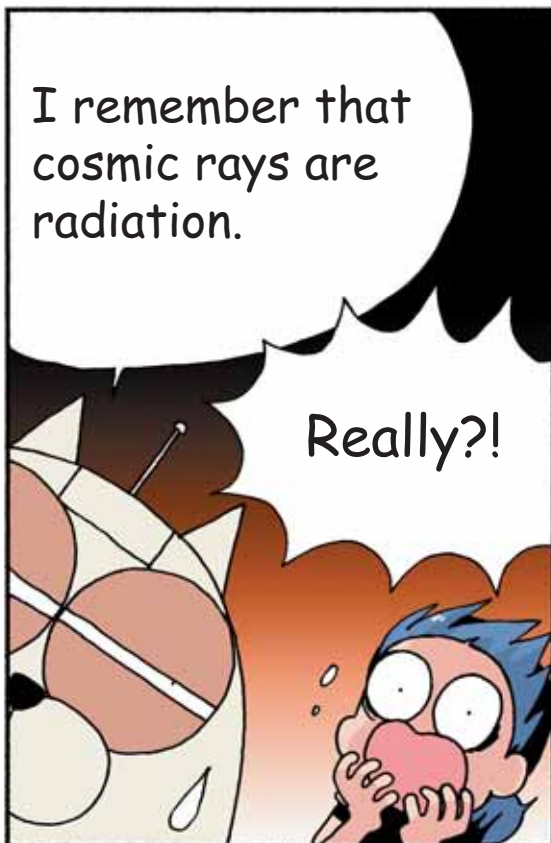
CAUTION: Dry ice must be handled with care. Do not touch it directly.









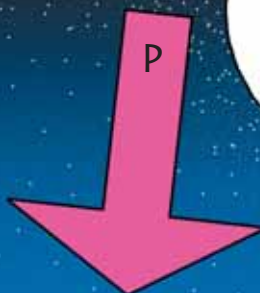




What do cosmic rays consist of?  
What particles do they have?



Primary cosmic rays, the cosmic rays coming from outer space, are mostly protons.



**PRIMARY  
COSMIC RAYS**

They collide with the Earth's atmosphere and decay into secondary cosmic rays.

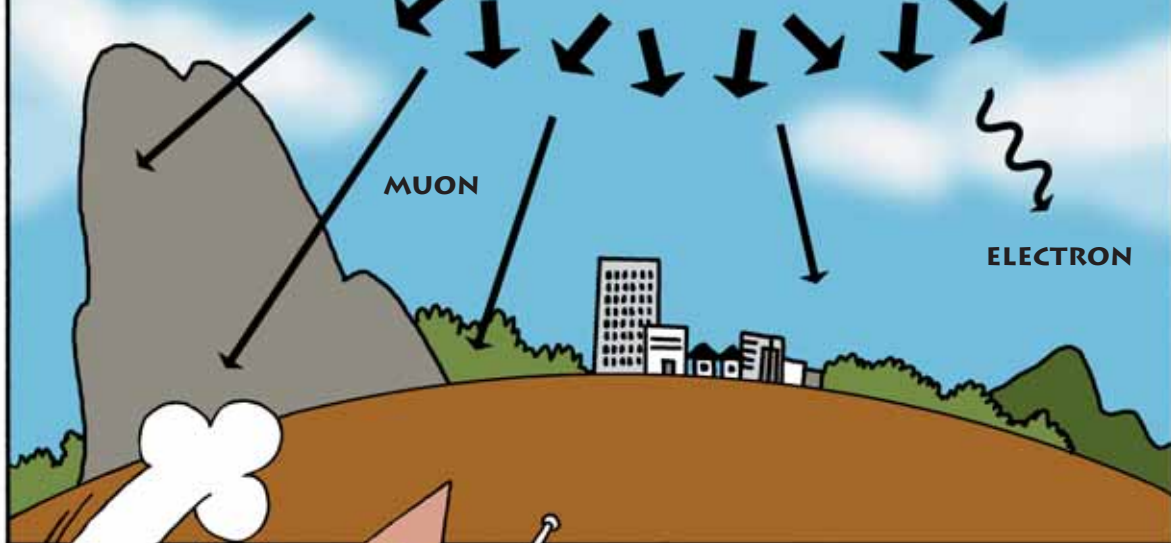
**PION**

**GAMMA RAY**

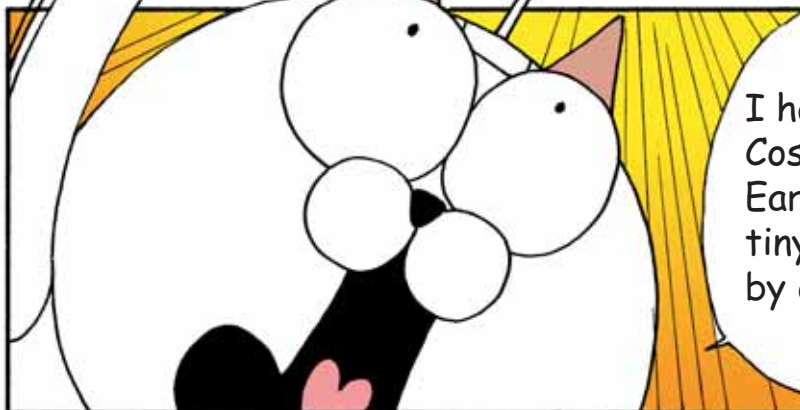
**SECONDARY  
COSMIC RAYS**

**MUON**

**ELECTRON**



I have got it!  
Cosmic rays on the Earth's surface are tiny particles produced by energetic protons.



Exactly. They are tiny but have exceedingly high energy!

How high is that?

Let's take a familiar example, a fluorescent light commonly seen at school and home, ...  
... to compare its energy to that of cosmic ray particles.

Inside a fluorescent tube, atoms in a high-energy state return to the ground state by emitting the extra energy in the form of light.

The energy is equal to 2 electron volts (eV).

Now, an individual cosmic ray particle has the energy of...

...  
**1 billion eV!!!**

**Aiiiee!!**

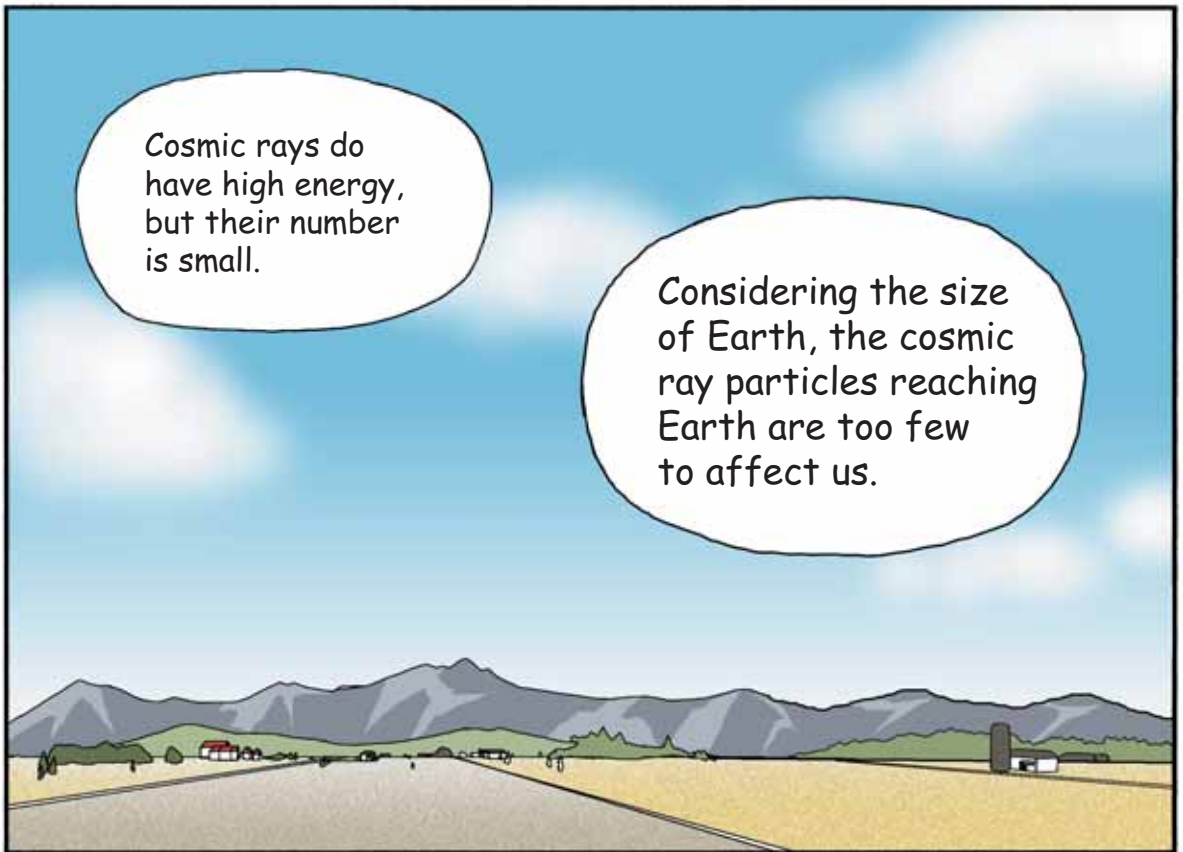
If we were hit by those particles, ...

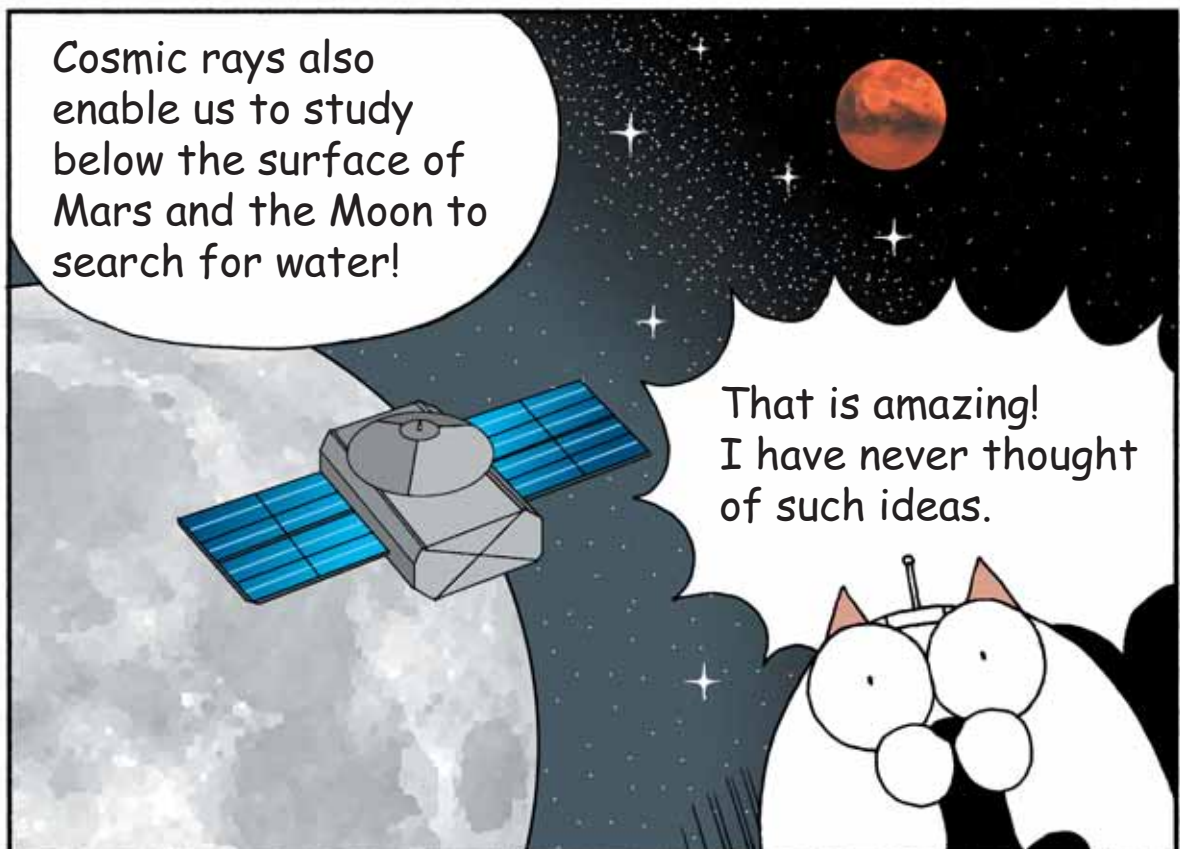
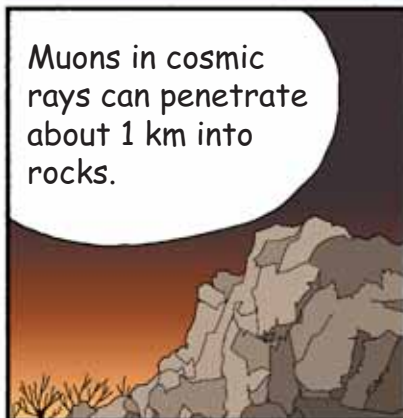
... we would get a huge shock!

Wait! I have never heard of these dangerous particles.

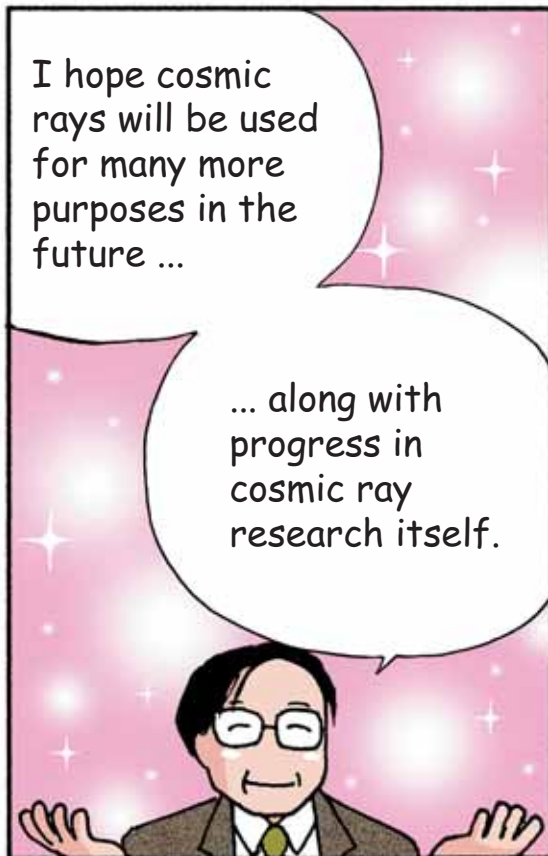
Why doesn't anyone care about them?











# What are Cosmic Rays?!



I am excited to learn about cosmic rays. First of all, how high is the energy of cosmic rays?



The energy of cosmic rays is over 1,000 times higher than that of other types of natural background radiation. Sometimes it becomes 10 trillion times higher for ultra-high-energy cosmic rays.



Wow, what gives them such high energy?



Good question, Mol. Cosmic rays obtain energy through repeated collisions with other particles.



Where do they come from?



The Sun, distant stars, and distant galaxies outside ours are their birthplaces.

Cosmic rays are produced in solar flares and from star explosions.



Are they visible? How about color, shape, and smell?



I can see them, but do not know the color and smell. At least they carry no savory aroma of roasted meat.



Cosmic rays are very small particles and cannot be seen even with a microscope. They have no color or smell. There is a device called a cloud chamber to make cosmic rays visible!

They are coming from space at nearly the speed of light and showering onto Earth.



Do they hit the Moon and Mars, too?



Definitely. Mars has a thin atmosphere, and so it is believed that only half as many cosmic rays reach Mars as compared to the Moon.

Cosmic rays are a great threat to humans travelling in space, but I believe it is not for you, Mirubo.



Harrumph! I am well-designed.



You are lucky, Mirubo. Sensei, would you tell me how they can search for water on Mars and the Moon through cosmic rays?



Cosmic rays can penetrate 40 cm deep into the surface of Mars and the Moon, and reach ice that may be lying beneath the dust. Cosmic rays would be reflected by hydrogen nuclei, just like billiard balls. We then have to measure the reflected rays via satellite.

When the rays that are reflected by hydrogen increase, we are able to pinpoint an area which could have water.



How about oxygen? Water ( $H_2O$ ) is made up of oxygen (O) and hydrogen ( $H_2$ ). How do you know that there is oxygen?



That is a good question. To prove the presence of water, for example, drilling should be conducted at the lunar pole where the level of the reflected cosmic rays is high.



Does the Earth emit cosmic rays like the Sun does? Could I find the answer if I went to the Moon?



Radiation from rocks on the Earth is so weak that it is absorbed in the atmosphere.

Meanwhile, low-energy gamma rays and X-rays emitted from auroras and thunderstorms could be measured from the Moon because they are released high in the thin atmosphere. Their energy is too low to be called cosmic rays, and could be named "Earth rays," instead.



Earth rays?! How nice!!



I will try to make my performance more powerful so I can go to the Moon and see "Earth rays" with my own eyes!!



# The Higher We Go, the More We Learn



Measurements of cosmic rays are usually made on high mountains. Do you know why? It is because the Earth is surrounded by an atmosphere.

A French scientist B. Pascal made important discoveries about air pressure. The unit for atmospheric pressure, hectopascal, came from his name. One hectopascal is equal to 100 pascal. You may have heard a weather forecaster on TV saying that the typhoon's atmospheric pressure is, say, 910 hectopascal. That is a very strong typhoon. The atmospheric pressure at the center of the typhoon is 10% lower than the normal pressure.

Atmospheric pressure becomes even lower at the top of high mountains. For example, our Solar Neutron Telescope on Mt. Norikura is located at 2,770 meters above sea level, where the air pressure becomes 25% lower than that at sea level. On the top of Mt. Fuji, it lowers to 60%.

The Chacaltaya Observatory in Bolivia is located at 5,250 meters above sea level. The air there is half as thick as at sea level. If you have ever seen a video of mountain climbers attempting to climb Mt. Everest, you can easily imagine how

difficult it is for humans to be in this thin air.

However, thin air becomes advantageous for observing cosmic rays, because they collide in the atmosphere and are absorbed. A change of 200 g/cm<sup>2</sup> in atmospheric weight changes the concentration of cosmic radiation as much as 10 times. In other words, comparing an observatory on Mt. Chacaltaya with the one on Mt. Norikura, observational equipment at the former could be 10 times smaller than that at the latter. Furthermore, the former is able to obtain more accurate data when the same equipment is used.

Do you understand why the higher we go, the more we are able to learn about cosmic rays?



Solar Neutron Telescope on Mt. Norikura.



Chacaltaya Observatory <Courtesy of the Brazil-Japan Emulsion Chamber Group, Chacaltaya Observatory>

#### CAWSES: A SCOSTEP Program 2004–2008

##### Solar Influence on Climate



##### Space Weather: Science and Applications

##### Atmospheric Coupling Processes



##### Space Climatology



## Climate and Weather of the Sun-Earth System (CAWSES)

CAWSES is an international program sponsored by SCOSTEP (Scientific Committee on Solar-Terrestrial Physics) and has been established with the aim of significantly enhancing our understanding of the space environment and its impacts on life and society. The main functions of CAWSES are to help coordinate international activities in observations, modeling and theory crucial to achieving this understanding, to involve scientists in both developed and developing countries, and to provide educational opportunities for students at all levels. The CAWSES office is located at Boston University, Boston, MA, USA. The four science Themes of CAWSES are shown in the figure.

<http://www.bu.edu/cawses/>

<http://www.ngdc.noaa.gov/stp/SCOSTEP/scostep.html>



## Solar-Terrestrial Environment Laboratory (STEL), Nagoya University

STEL is operated under an inter-university cooperative system in Japan. Its purpose is to promote “research on the structure and dynamics of the solar-terrestrial system,” in collaboration with a number of universities and institutions both in Japan and abroad. The Laboratory consists of four research Divisions: Atmospheric Environment, Ionospheric and Magnetospheric Environment, Heliospheric Environment, and Integrated Studies. The Geospace Research Center is also affiliated to the Laboratory to coordinate and promote joint research projects. At its seven Observatories/Stations, ground-based observations of various physical and chemical entities are conducted nationwide.

<http://www.stelab.nagoya-u.ac.jp/>

## はやのん Hayanon

Graduated from the Department of Physics of Ryukyu University, Hayanon, a writer and cartoonist, has contributed a number of serials in popular magazines on the basis of her strong background in science and computer games. Her consistent writing style, expressing a love for science, is well accepted.

<http://www.hayanon.jp/>

## 子供の科学 Kodomo no Kagaku (Science for Kids)

Kodomo no Kagaku, published by the Seibundo Shinkosha Publishing Co., Ltd. is a monthly magazine for juniors. Since the inaugural issue in 1924, the magazine has continuously promoted science education by providing various facets of science, from scientific phenomena in everyday life to cutting edge research topics.

<http://www.seibundo.net/>

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