> *What is dark energy?*

> *What does dark matter consist of?*

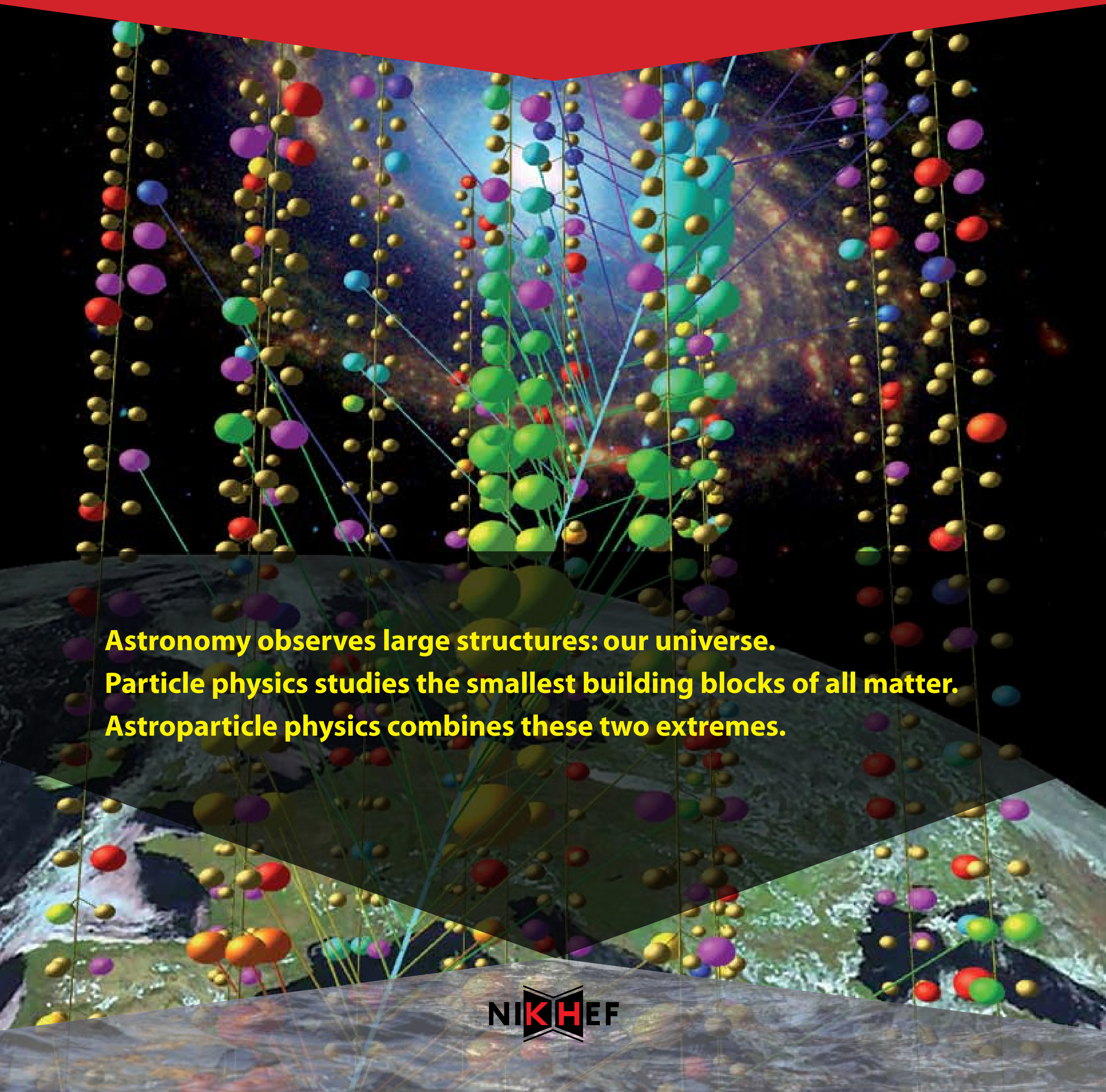
> *What are cosmic rays and what is their origin?*

> *How did the large-scale structure of the universe evolve?*

> *What are gravitational waves and how can you measure them?*

> *Do astroparticle physicists know the answers to such questions?*

Astroparticle physics

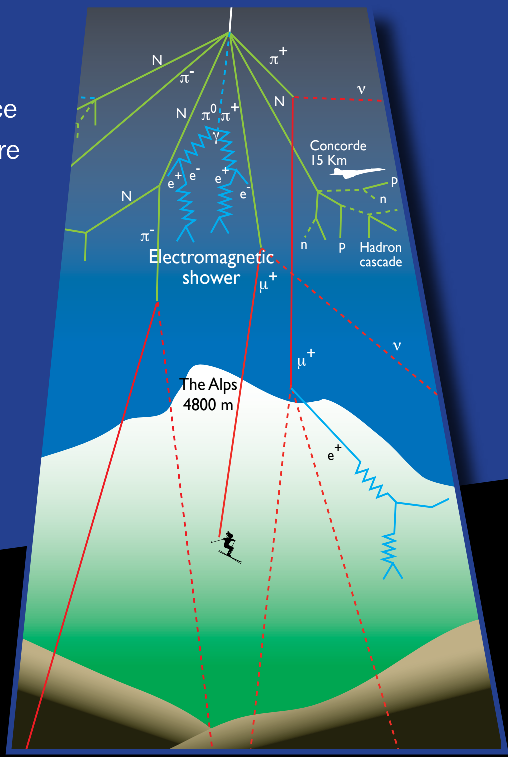


**Astronomy observes large structures: our universe.
Particle physics studies the smallest building blocks of all matter.
Astroparticle physics combines these two extremes.**

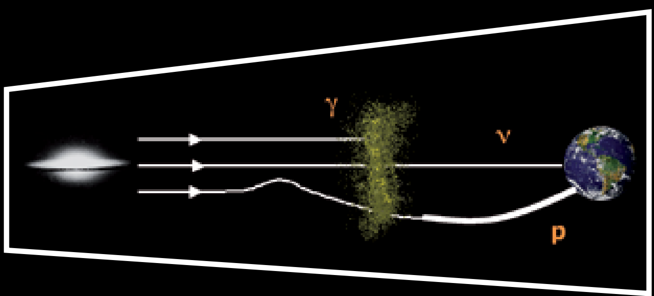
NIKHEF

What are cosmic rays and what is their origin?

Our Earth is continuously being bombarded by particles from outer space. A small fraction of these particles was unexpectedly found to carry a lot of energy. To discover where such particles, and the source of their energy, come from, new particle detectors are needed that are suitable for observing neutrinos and protons with a very high energy. That is difficult because the particles concerned are very rare and, moreover, they normally fly unnoticed through detectors.

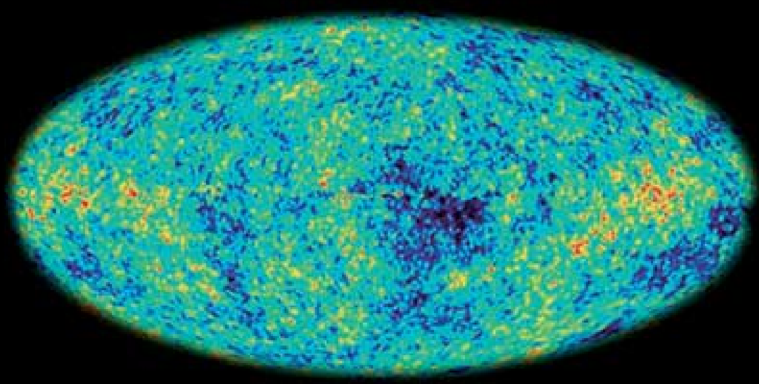


Upon colliding with the atmosphere, cosmic particles cause a cascade of all kinds of elementary particles onto the Earth. >



< *Neutrinos are very important for the research because their direction indicates exactly where they came from. This is not the case for other cosmic particles, such as protons which are bent in magnetic fields or photons that are absorbed, for example, by interstellar gas clouds.*

Questions about the large-scale structure of the universe are not studied here on Earth but in satellites orbiting the Earth. The COBE satellite (1989-1993) was the first to do this successfully, and in 2006 the American physicists George Smoot (photo right) and John Mather received the Nobel Prize for this work. With the WMAP satellite (2001-2009) many accurate results are being obtained.



One of the results of several years of measurement is illustrated here. The colour differences in the photo indicate small temperature differences in the early universe. This observation is an indirect indication for the existence of large quantities of dark energy and dark matter in the universe. >

Scientific research at school

Just like real detectives school pupils and scientists are together searching for high-energy cosmic rays. They would like to know more about these mysterious particles that are constantly falling on us. In **HiSPARC** more than 40 schools and institutes together form a country-wide network of detectors that capture as many particles as possible.

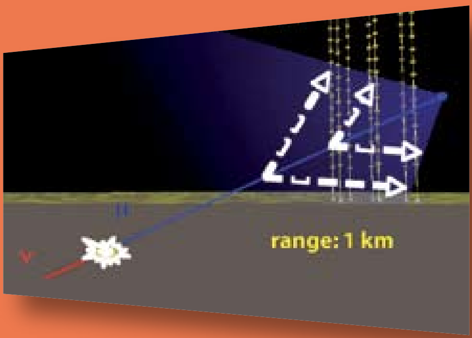
> HiSPARC

When cosmic particles enter our atmosphere, they encounter various obstacles; collisions will occur with atomic nuclei and the processes that play a role in this can be studied here on Earth with the aid of particle accelerators. Depending on the energy of the primary particle, an increasingly broader cascade of secondary particles will be formed. The larger the energy, the larger the surface of the Earth that will be hit by the avalanche. The measuring points at schools that participate in **HiSPARC** provide a wealth of information. This project brings pupils into contact with real scientific research and also allows them to contribute to it. As the data are available to all participants, each pupil can do his or her own research, for example into the influence of the weather and air pressure on the number of cosmic particles measured. They also learn a lot about the use of technical facilities such as computer-guided data reading and exact time and position determination with the help of GPS. - www.hisparc.nl

> How exactly are neutrinos detected?

ANTARES is a neutrino telescope in the Mediterranean Sea, 40 km off the coast of Toulon (France). Twelve vertical lines (cables) have been sunk at a depth of 2.5 km over an area of 20,000 m^2. Each line is packed with 75 phototubes, which are mounted in groups of 3 every 15 m along the cable.

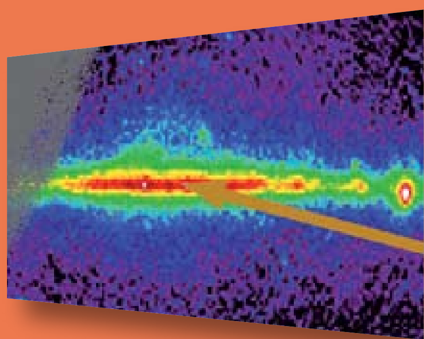
ANTARES simultaneously uses the Earth as both a filter and a detector. High-energy neutrinos (>10^{10} eV) that pass through the Earth, very occasionally collide with matter and react with it. In such cases a muon is created, which moves forward in the same direction as the original neutrino. If the muon travels in water, it emits radiation in the form of Cherenkov light. That light can be observed with phototubes. Phototubes (photomultiplier tubes or PMTs) are a sort of light bulb in reverse: they convert light into electrical currents.



*< **ANTARES** detects muons: A cosmic neutrino (red) flies with a high energy straight through the Earth. If such a neutrino collides with an atomic nucleus in the Earth it forms a muon (blue). During such a journey through seawater, the muon emits Cherenkov light that is detected by the light-sensitive phototubes attached to the detector lines of **ANTARES.***

By observing just the muons emerging from the seafloor, therefore from the southern sky, other cosmic particles are not measured: they are filtered out by the Earth. Another disruptive phenomenon is also present, namely bioluminescence. Light-emitting algae and fish are responsible for a background of light flashes. All signals from the phototubes, in other words the arrival time and the intensity of the Cherenkov light, are transmitted to a coastal station via an optic fibre connection. On the basis of these signals, fast computers at the coastal station calculate the direction and energy of the muon and further selection processes are used to determine whether or not a cosmic neutrino has been observed. Nikhef scientists and technicians designed and built the extremely complex optical fibre connections, computers and software that are necessary for this.

ANTARES is a prototype for the neutrino telescope ***KM3NeT***, which will be 20 times as large. This ***KM3NeT*** project is also currently under preparation. Scientists hope to use this device to observe neutrinos from sources located much further away.



*Both **ANTARES** and **KM3NeT** will investigate for the first time whether the centre of our Milky Way (the red area) is a source of high-energy neutrinos as scientists suspect.. >*

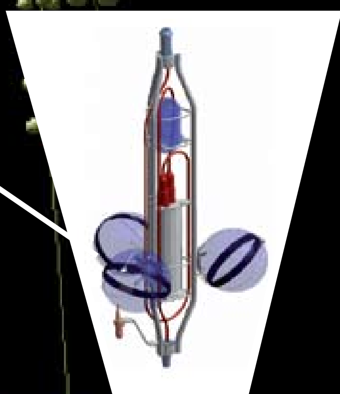
"The idea of simultaneously using the Earth as a filter and a detector is really smart. Yet it is also strange that the particles we measure have come from the other side of the Earth!"

Mieke Bouwhuis, researcher at Nikhef

Detector lines with phototubes

One set of three light-sensitive tubes during the sinking operation of the detector lines with phototubes for ANTARES.

Drawing of an optical module which besides the three phototubes (in the glass spheres) also contains a cylindrical module with all of the read out electronics.



Pierre Auger Observatory

In the middle of the Argentinean Pampas ***the Pierre Auger Observatory*** is building a very different type of detector - one that consists of 1600 water basins distributed over an area of 3000 km^2. In the water basins, the Cherenkov light is measured from the cascade of muons that is created when a cosmic particle hits our atmosphere. Additionally, extra information is obtained about the particle cascade by searching for fluorescence and radio signals from the cosmic particles. By combining these different techniques the scientists obtain better measurement results.

^ *At the Pierre Auger Observatory, the energy and direction of the cosmic particles are calculated by combining the signals from all of the water basins that have been hit.*

"I really enjoy doing research here with all of these water basins stretched out across the Argentinean pampas, with herds of cattle as company!"

Charles Timmermans, scientist at Pierre Auger/Nikhef and initiator of the school pupils' project HiSPARC

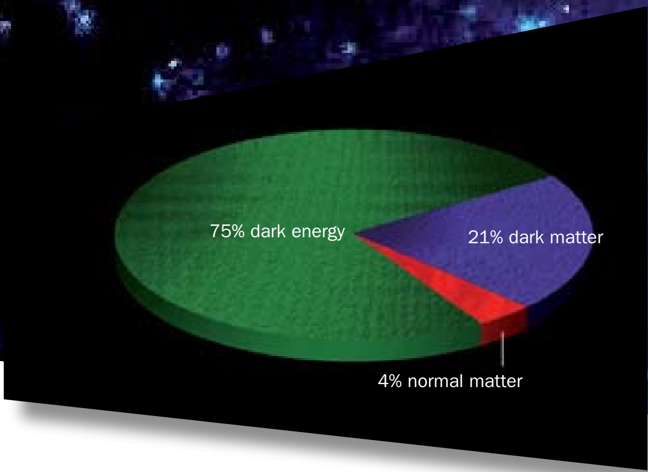
< Another detector, named ***Virgo***, tries to observe so-called gravitational waves that can provide indirect information about the sources of cosmic rays in the universe. Scientists think that gravitational waves and cosmic rays are emitted by the same sources. In the future, a special system of three satellites will also be launched ***(LISA)***, which will search for gravitational waves that are thought to have been released during the Big Bang. In about 10 years time the satellites will be put into an orbit around the Sun at a distance of about five million kilometres from each other.

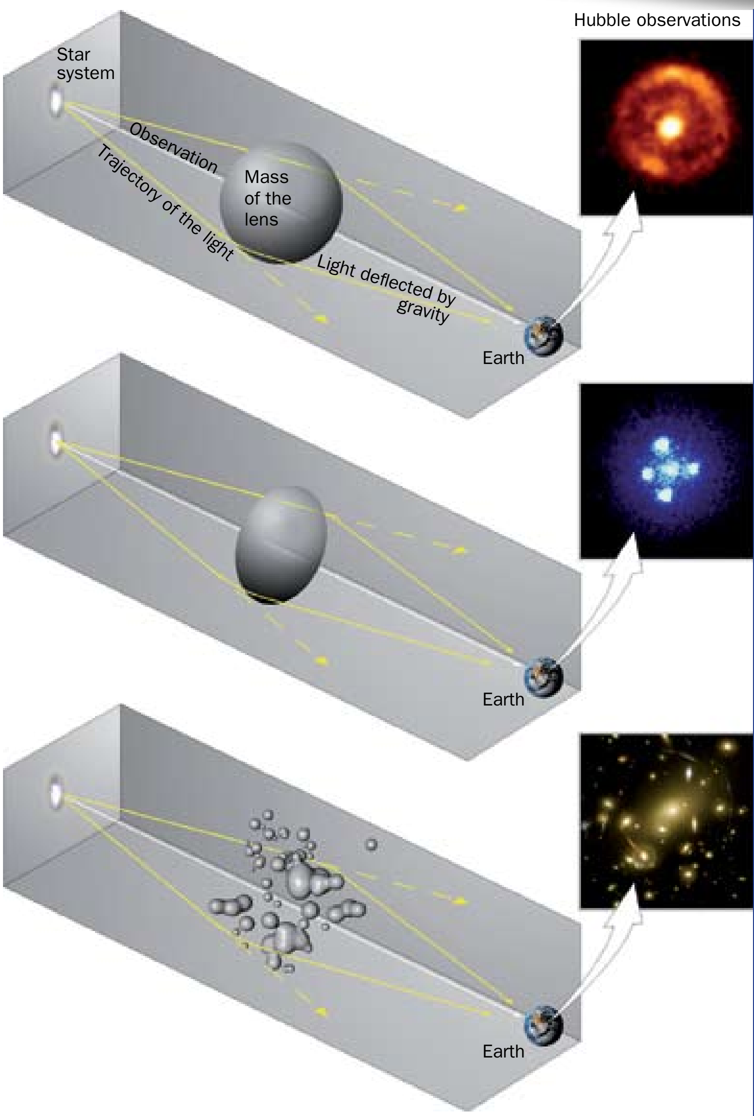
What are gravitational waves and how can you measure these?

Gravitational waves are ripples in space. Einstein's general theory of relativity predicts the existence of gravitational waves; the movement of two heavy masses around each other results in energy being emitted in the form of gravitational waves. This is at the expense of the energy available for the orbit of the masses and so gradually the masses move closer together. These masses can be two stars but equally well two black holes. Space-ripples around matter under the influence of gravity. The gravitational waves emitted can be measured by observing very small movements of mirrors between which laser light is repeatedly reflected forwards and backwards. The measurement accuracy can be made appreciably better by observing so-called interferences between two laser bundles, as is the case at the ***Virgo*** observatory in Pisa. ***Virgo*** has two 'arms' with a length of 3 km in between which the laser light is reflected many times.. This set-up is sensitive to the passage of a gravitational wave. It can detect movements with a size smaller than a millionth of the diameter of an atomic nucleus (10^{-22} metres) This project is indirectly contributing to the first question as well: where do cosmic rays come from? The objects in the universe observed by ***Virgo*** are possibly the same as those emitting cosmic rays. Therefore, information from the Virgo detector and the Pierre Auger Observatory could form a highly promising combination.

What is dark energy and what does dark matter consist of?

The boundaries of our knowledge are clear. Recent astronomical observations have revealed that 96% of the universe consists of unknown forms of matter and energy, which are therefore referred to as ‘dark’. So there is still a lot to discover in the field of physics. v





∧ *Mass deflects light. Observations with the Hubble telescope have led scientists to conclude that there is more mass in the universe than we can see.*

How do we know that there is so much (96%!) unknown mass and so many unknown forms of energy present in the universe? Measurements of the deflection of light that originates from distant sources in space can be used to calculate how much matter is necessary for the deflection concerned. That appears to be far more than the quantity of matter in the form of stars that emits light. This unknown form of matter is termed dark matter, which appears to constitute 23% of our universe. Theoreticians only have a vague idea as to what this dark matter could consist of.

The universe evolved from a Big Bang and continues to expand. That process is accelerating and at a faster than expected rate, as was discovered 10 years ago. Since then physicists have performed countless calculations: what lies behind this acceleration? Only a large quantity of extra energy in the universe can explain this phenomenon and this unknown energy form is termed dark energy. Under the influence of this unknown energy, matter moves further apart as if subject to an **anti-gravitational force**. Dark energy appears to constitute 73% of our universe.

Working together on astroparticle physics

The National Institute for Subatomic Physics (***Nikhef***) is a research institute in the area of particle and astroparticle physics. ***Nikhef*** investigates the smallest building blocks of matter on both the Earth and in cosmic processes with the help of telescopes and detectors. ***Nikhef*** is a partnership between the Foundation for Fundamental Research on Matter (***FOM***) and four universities: Universiteit van Amsterdam (***UvA***), VU University Amsterdam (***VU***), Radboud University Nijmegen (***RU***) and Utrecht University (***UU***) - www.nikhef.nl

Only by means of cooperation can the Netherlands participate in the research projects for which these large detectors and telescopes are necessary. There is now a Dutch network of researchers in astroparticle physics, represented by the Committee for Astroparticle Physics in the Netherlands (***CAN***). This committee facilitates cooperation and long-term planning in this new area within the Netherlands - www.astrodeeljesfysica.nl

In Europe, various research organisations (such as FOM in the Netherlands) have jointly taken the initiative to draw up a plan for the future of astroparticle physics. ***ASPERA*** is the name of this partnership supported by the European Union (EU) - www.aspera-eu.org

"If we had sensitive radio eyes, we would see the sky sparkle with radio flashes."

quote of Heino Falcke, chair CAN

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