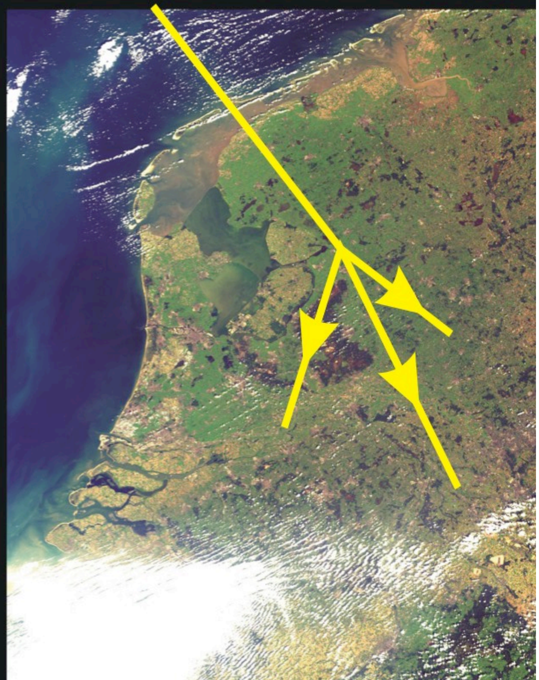
Strategic Plan for **Astroparticle Physics** in the Netherlands



Commissie voor de
Astrodeeltjesfysica
in Nederland (CAN)

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Outline

Executive Summary

A new interdisciplinary research domain is emerging at the interface of physics and astronomy with important inputs from cosmology, e-science and space research. This field of research, which is known as *astroparticle physics*, is addressing issues that may revolutionize our scientific and philosophical views on the origin of the universe. While so far most scientific endeavours have addressed the nature of normal matter, of which stars, planets and human beings are composed, one of the key subjects of astroparticle physics is the nature of unknown types of matter and energy which are labelled *dark matter* and *dark energy*. In fact, recently it has been established that dark matter comprises about 23% of the total energy content of the universe, while another 73% appears in the form of *dark energy*. Hence, only about 4% of the universe consists of normal matter. The adjective *dark* that labels the new forms of matter and energy is used to demonstrate our lack of knowledge, and the fact that no visible manifestations of these new forms of matter and energy have been discovered so far. They betray their presence by their influence on the motions within galaxies and in clusters of galaxies, and by their influence on the evolution of the universe.

In astroparticle physics experimental techniques and theoretical insights from both astronomy and physics are combined to investigate fundamental questions, such as those pertaining to the nature of dark matter and dark energy. Related questions that are being pursued in this new interdisciplinary research field concern the origin of cosmic rays with energies in excess of 10^{16} eV – including the highest-energy particles known to date – , the contribution of neutrinos to dark matter, and the existence of gravitational waves. Research in astroparticle physics distinguishes itself from the traditional approaches used in physics and astronomy by the use of expertise from both fields in addressing the questions mentioned above. Examples include the construction of neutrino telescopes, in which the detection technologies developed in physics and observational techniques from astronomy are combined, and the radio observations of cosmic rays with the associated atmospheric air showers, where techniques developed for astronomical purposes are applied to a physics research topic.

Internationally, astroparticle physics represents an important growth area in fundamental research. Many leading European countries have already allocated substantial budgets to this new interdisciplinary research field. In the US several dedicated institutions for astroparticle physics research have been recently established. It is the purpose of the present document to initiate an astroparticle physics research program in the Netherlands and request funding for this important new research field.

In 2004 a number of leading researchers in the Netherlands, originating from astronomy, physics and space research, have started to investigate the opportunities for a well-structured research program in the field of astroparticle physics. As a result of this effort a strategic plan has been developed that is described in the present document. The most important recommendation of this plan is to study the fundamental scientific issues addressed in astroparticle physics by means of a *multi-messenger approach*, in which the same subjects are studied by means of radio, neutrino and gravitational-wave detectors. Accordingly, the strategic plan is centred

on three major research initiatives that were chosen because of their scientific potential and the availability of unique Dutch expertise in each of these domains:

- radio detection of cosmic rays;
- deep-sea neutrino detection;
- gravitational wave detection.

Moreover, by building upon important previous Dutch investments (LOFAR[1], ANTARES and MiniGRAIL) in these research areas, the environment is created for a full exploitation of these instruments, which – at the same time – forms the starting point for a prominent participation in three large international research collaborations (the Pierre Auger Observatory, KM3NeT and LISA). A strong theoretical research effort and an equally important outreach program will supplement the chosen research topics. Taken together the choices made should result in a strong and internationally visible research program on astroparticle physics research in the Netherlands, thereby ensuring an active role of the Netherlands at this new frontier of science.

The proposed interdisciplinary research program in astroparticle physics will run from 2006 to 2015 with a total estimated budget of about 70 M€, of which 40 M€ will be provided by the participating universities and research institutes (NIKHEF, SRON, KVI, and ASTRON). Hence, additional resources – increasing from 1.5 M€ in 2006 to 3.2 M€ in 2008 and later years – are needed to realize this challenging research program.

[1] It is realized that funding for the completion of the LOFAR instrument and its technical exploitation are – at the time of this writing – not yet fully secured. In the framework of the present strategic plan for Astroparticle Physics in the Netherlands it is assumed that these resources come available, and that LOFAR is fully completed and operational. Hence, only resources for the *science exploitation* of LOFAR (and the other instruments that are part of the proposed strategy) are included in the present strategic plan.

Recommendations

The key recommendations of the *Strategic Plan for Astroparticle Physics in the Netherlands* are summarized below:

- It is recommended to initiate a new interdisciplinary research program in the Netherlands on the subject of astroparticle physics.

  The enormous discovery potential of this emerging field stems from the fact that for the first time experimental and theoretical techniques have been conceived that enable the investigation of forefront questions on the nature of dark matter and dark energy, the origin of the highest-energy cosmic rays, the large-scale structure of the universe and the exploitation of gravitational waves as a probe of the very early universe.

- It is recommended to address the fundamental questions of astroparticle physics by means of a multi-messenger approach, in which the same subjects are studied by means of radio, neutrino and gravitational wave detectors.

  In the last couple of years scientists in the Netherlands have developed unique detection concepts – concerning the radio detection of cosmic rays, the all-data-to-shore concept for neutrino detectors and the inertial sensor control and readout of gravitational wave detectors – that put the Dutch scientific community in a unique position to play a leading role in several frontline international experiments in astroparticle physics.

- It is recommended to focus the research effort in astroparticle physics on studies of the origin of cosmic rays.

  Radio detection of cosmic rays (with LOFAR), measurements of the cosmic neutrino spectrum (with ANTARES and KM3NeT) and the exploration of the highest energy cosmic rays (with Auger) all address different aspects of this issue. As it is commonly believed that cosmic rays originate in very energetic compact objects (such as Active Galactic Nuclei, Black Holes, Supernovae or relics from the early universe), it is very important to study the same objects also with different means. This will be done with the gravitational wave antennas (MiniGRAIL and LISA) that are presently being developed.

- It is recommended to launch a strong research effort in theoretical astroparticle physics.

  For the proper interpretation of the anticipated data, the development of links between the various "messengers", and the independent development of novel theoretical ideas, dedicated theoretical astroparticle physics research efforts at various Dutch universities and research institutions need to be initiated. The theoretical effort must be sufficiently strong that research of the highest quality can be realized. It is vital that the relevant funding agencies continue to support related areas in Theoretical Physics and Astronomy to provide the necessary embedding for this program.

- It is recommended to carry out astroparticle physics research in a truly international fashion, where the new research program operates as a stepping stone for prominent Dutch participations in the highest-level international experiments that are leading in their field.

  The price tag of frontline astroparticle physics projects is such that most *experiments or observatories can only be realized by forming international collaborations. By focussing the Dutch involvement in those international collaborations through the proposed research program, and limiting the Dutch participation to those projects where the Netherlands – because of proven expertise – can have a prominent position, the highest level research is realized.*

- It is recommended to appoint new faculty in the area of astroparticle physics at the science departments of Dutch universities.

The success of the Dutch research institutions ASTRON, NIKHEF and SRON, which are the home bases of the three unique detection concepts mentioned above, needs to be accompanied by university groups that play a crucial role in attracting and training students, and analysing the data. Through such collaborations optimal use is made of Dutch involvements in international experiments. So far only limited knowledge of radio detection of cosmic rays and deep-sea neutrino detection is available at single Dutch university groups, and hardly any expertise on gravitational wave detection is available. This needs to be changed.

- It is recommended to accompany the proposed research program by well-organized teaching efforts and outreach activities.

- It is recommended to include the necessary computing infrastructure in the long term strategic plan of the Dutch foundation for "Nationale Computer Faciliteiten" (NCF) that will encompass all infrastructural computing needs of the major research initiatives in the Netherlands.

- It is recommended that additional resources are provided at an annual level of 1.5 M€ in 2006 increasing to 3.2 M€ in 2008 and later years. In this way it will be possible to realize the objectives of the present strategic plan on astroparticle physics in the Netherlands.

The proposed interdisciplinary research program in astroparticle physics, which will run from 2006 to 2015, has a total estimated budget of about 70 M€, of which 40 M€ will be provided by the participating universities and research institutes (NIKHEF, KVI, ASTRON and SRON).

A healthy scientific program is well-focused and organized, but leaves plenty of room for the unexpected, i.e. serendipity. The multi-messenger approach outlined in the recommendations listed above will offer such opportunities now that – for example – instruments such as KM3NeT and Auger turn out to have a serious chance to observe dark matter constituents, even though neither of these facilities was designed for that purpose. This example illustrates that there is a tantalizing future ahead of us in astroparticle physics research. The Netherlands must be part of that future!

1. Introduction

In recent years astroparticle physics has emerged as a highly promising interdisciplinary research field that brings together expertise developed in physics and astronomy with the objective of addressing a number of key questions in science:

- What is the nature of dark matter?
- What is the nature of dark energy?
- What is the origin of the highest-energy cosmic rays?
- What is the origin of the large-scale structure of the universe?
- Can gravitational waves be directly observed, and what do they tell us?

A conclusive answer found to any of these questions, or even a partial one, will represent a major break-through at the frontier of scientific investigations. Identifying one or more constituents of dark matter, a field-theoretical explanation for dark energy, a source of the highest-energy cosmic rays or the first unambiguous direct detection of gravitational waves, will each mark the beginning of an entirely new field of research ranging from 'Dark Matter Physics' to 'Gravitational Wave Astronomy'. Moreover, astroparticle physics – by combining techniques from both astronomy and physics – gives access to the study of the laws of physics under conditions that cannot be reproduced in terrestrial experiments. Examples include the extreme conditions which are believed to have existed in the early universe, in supernova explosions, in the vicinity of black holes or in the core of neutron stars.

It is obvious that astronomers and physicists alike are using their traditional tools (telescopes and accelerators) in trying to find answers to the questions listed above. The distribution of dark matter in the universe, for example, will be further mapped by astronomers using optical, infrared and radio telescopes, while physicists will search for the possible production of dark matter particles at their highest energy particle accelerators. The distinguishing feature of astroparticle physics, however, is that techniques of both fields (often together with those of cosmology, space research and e-science) are used when addressing the central scientific questions of this field in an entirely novel approach. The study of high-energy cosmic rays with radio detection techniques can be mentioned as an example of such an approach. It combines radio techniques developed in astronomy with physics ideas on the nature of cosmic rays, while the massive amount of data produced by such a radio telescope requires data processing techniques developed in e-science. Such cross-disciplinary activities are typical for astroparticle physics research.

In recent years many international projects have been initiated in astroparticle physics to address the fundamental scientific questions listed above. At the European level this has been accompanied by the establishment of the Astroparticle Physics European Coordination (ApPEC) committee, in which many funding agencies and national laboratories are represented in an effort to streamline and prioritize the various initiatives. Although individual Dutch scientists participate in some of these international projects and committees, no coherent astroparticle physics research program exists in the Netherlands. This is unfortunate, as the fundamental nature of the issues addressed in this new interdisciplinary field appeal to both the scientist and non-scientist alike. Moreover, as astroparticle physics has an enormous discovery potential and is being pursued in a highly international context, the presence of active and visible astroparticle physics groups in the Netherlands will be very attractive for prospective first-year students in physics and astronomy at the universities.

In order to change this situation a group of physicists and astronomers has started to organize a series of national astroparticle physics symposia. The first two of these took place in 2004, in April at NIKHEF in Amsterdam, and in September at the Radboud University in Nijmegen. A third one was held in January 2005 at Leiden University. For 2005 two more such symposia are planned (in Groningen and Utrecht). At the same time a Committee for Astroparticle physics in the Netherlands (CAN) was formed with representatives from almost all research groups that are interested in the development of astroparticle physics in the Netherlands[2]. This committee has made an inventory of the research opportunities and ambitions for astroparticle physics in the Netherlands[3]. On the basis of this inventory and through active consultation of the entire astroparticle physics community in the Netherlands, a strategic plan has been formulated that is contained in the present document. The main goal of the plan is to develop a strong research program in astroparticle physics in the Netherlands in the coming years. The proposed research program is centred around the third of the 5 key questions mentioned above, i.e. the study of the *origin of the highest-energy cosmic rays*. This question will be studied using a so-called *multi-messenger approach*: use is made of the complementary nature of data obtained from very-high energy muons, radio signals, neutrinos and gravitational waves[4] Given the available Dutch expertise in each of these domains, a highly visible contribution to astroparticle physics research can be realized in this way. Moreover, the plan also includes an active theoretical research program and a crucial outreach component. The entire research program will involve about 30 junior scientists (PhD students and postdocs) every year, and will run from 2006 to 2015.

This document is organized as follows. In section 2 it is explained how the key questions listed in the beginning of this document translate into explicit research projects. In section 3 the actual strategic plan for future astroparticle physics research in the Netherlands is presented; the selected projects are identified and the considerations – strategic and otherwise – that have led to the selection of these projects are discussed. The remainder of the document is devoted to a number of accompanying measures that require attention when developing a successful research program: teaching aspects (section 4), outreach (section 5), computing (section 6), application perspective (section 7) and finances and management (section 8). The document is concluded with a number of appendices containing supplementary information.

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[2] The present membership of the "Commissie voor de Astrodeeltjesfysica in Nederland" (CAN) is listed on the inside of the cover page of this document.

[3] The result of this inventory is described in appendix 1.

[4] Because the defining science issues of astroparticle physics are in many cases intimately related (as will be explained in section 2), the chosen focus will also yield partial answers to some of the other questions mentioned above – more in particular to the first (dark matter) and fifth question (gravitation).

2. Astroparticle Physics

In order to explain how the fundamental questions introduced in section 1 are investigated in astroparticle physics, they are discussed in somewhat more detail in separate subsections below. In each case the emphasis is on the relation between the basic question and the specific (international) research projects that are at present under development to address this question. This provides us with a (not necessarily complete) inventory of international astroparticle physics projects that form the input for the strategic choices that are discussed in section 3.

2.1 The nature of dark matter

Evidence for the existence of large amounts of dark matter in the universe comes - amongst others – from the measured rotational dynamics of – and velocity dispersion in – galaxies, observations of the relative velocities of galaxies in a cluster, and gravitational lensing in clusters of galaxies. In fact, all current estimates, including those derived from satellite-based observations of the cosmic microwave background radiation, indicate that dark matter constitutes about 23 ± 4 % of the total energy content of the universe. It has been suggested that a large fraction of dark matter consists of the so-called *lightest supersymmetric particles*. These hypothetical particles (also known as neutralinos) would be a manifestation of *supersymmetry,* a theoretical framework – that goes beyond the Standard Model of particles and fields[5] – in which bosons and fermions are treated on equal footing. In order to find evidence for the existence of neutralinos various methods have been introduced in the last couple of years:

- At the highest-energy particle accelerators (such as the Tevatron in the US and – in the nearby future – the LHC in Europe) neutralinos and other supersymmetric particles can be directly produced. So far, searches of neutralinos in production experiments of this type have yielded a lower limit for the neutralino mass of 30 GeV, which is well below the large neutralino mass that is theoretically expected. These searches, which will be continued at the LHC, will not be further considered here, as the techniques employed entirely belong to main stream particle physics.

- In direct searches it is tried to measure the recoil energy deposited by a passing cosmic neutralino in a well shielded (underground) detector. The neutralino – as part of the galactic halo – has a modest velocity, leading to low recoil energies which do not lead to a well-defined signature in the spectrum. Experiments of this type are known by their acronyms as DAMA, CDMS, CRESTT, Edelweiss, and ZEPLIN (among others).

- In satellite-based searches gamma rays, positrons or antiprotons are observed originating from the annihilation of a pair of neutralinos in a large celestial body such as the sun. This will result in the emission of gamma rays, electrons, positrons, anti-protons or neutrinos. This method has led to first (unconfirmed) claims for the existence of a 50 - 200 GeV neutralino using

[5] Existing observations of neutrino oscillations have already demonstrated that the Standard Model is incomplete.

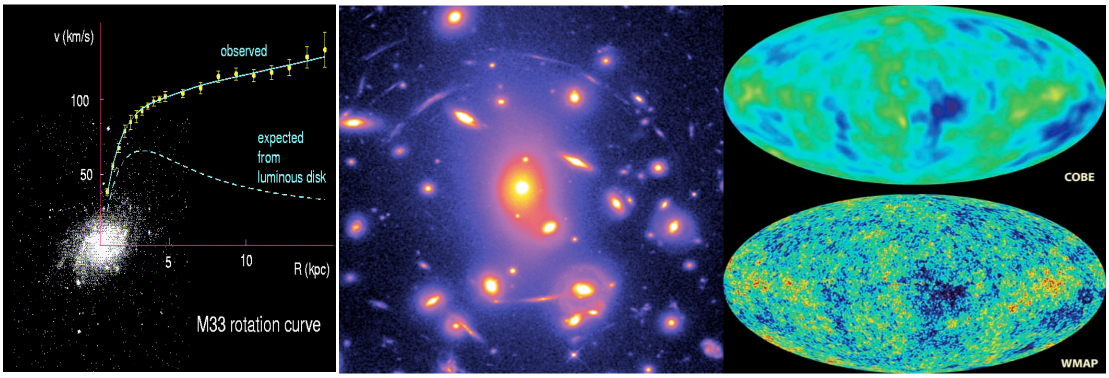

Fig. 1. Three pieces of observational evidence supporting the existence of dark matter in the universe. On the left the discrepancy between the observed and expected rotational light curves is displayed, in the middle a picture of gravitational lensing is shown, while on the right the temperature fluctuations occurring in the cosmic microwave background are shown.

data obtained by the EGRET (γ's), BESS (e^+'s), HEAT and AMS-02 (antiprotons) satellites. However, in this case significant uncertainties still exist as the signals are diluted by huge backgrounds that need to be modelled.

- In an indirect search it is hoped to detect the neutrinos that are emitted in the decay of W-bosons, which in turn have been produced in the annihilation of a pair of neutralinos. This method has the advantage that high-energy neutrinos need to be observed, which clearly stand out above the low-energy background of atmospheric neutrinos. Moreover, by making use of the directional sensitivity of the new deep-sea (or ice) neutrino detectors such as AMANDA, ANTARES[6], IceCube and KM3NeT[7] an independent measure of the background can be obtained by also taking data at large angles with respect to the solar direction or that of the galactic centre.

It should be realized that several alternative scenarios for dark matter candidates have been proposed. These scenarios include the possible existence of a very heavy right-handed neutrino (the neutrinos of the Standard Model are left-handed), or other weakly interacting heavy particles that are relics of the Big Bang. In heavy-neutrino models that form the basis of such scenarios usually relations are established between the mass of the Standard-Model neutrino (ν_e) and its newly proposed heavy partner. For this reason, there is considerable interest within astroparticle physics to carry out a direct measurement of the ν_e mass, or obtain a more constrained upper limit. A value of the ν_e mass will also further constrain the analysis of the temperature variations of the cosmic microwave background and the formation of large-scale structure, thus resulting in more precise values of the amount of dark matter in the universe. At present, the most promising experiment that is being developed to measure or further constrain the ν_e mass is the KATRIN experiment in Karlsruhe[8].

6 The ANTARES project is described in more detail in appendix 1.

7 Of the four new neutrino telescopes the AMANDA project is already producing data; ANTARES and IceCube are under construction, while KM3NeT is in the design phase. More information on the European KM3NeT project can be found in appendix 2.

8 More information on the KATRIN project can be found in appendix 4.

This experiment aims at measuring $m_{\nu e}$ directly, or instead at deriving an upper limit for its mass as low as 0.2 eV.

Another process that is sensitive to the mass of the neutrino is the so-called neutrinoless double-beta decay. While in normal beta decay, the atomic nucleus emits an electron accompanied by an anti-neutrino, in neutrinoless double beta-decay the two electrons are emitted simultaneously without the emission of anti-neutrinos. When this process occurs in nature it proves that the neutrino and the anti-neutrino are identical (i.e. that they are Majorana particles), and that the neutrino has mass. Moreover, the decay rate for neutrinoless double beta-decay provides a direct measure of $m_{\nu e}$. While there is one controversial claim for observing this process (in the Heidelberg-Moscow experiment), the upper limit of 0.37 eV for $m_{\nu e}$ derived from the same experiment is commonly accepted as the best upper limit obtained so far from measurements of this kind. It should be realized, however, that this limit becomes somewhat weaker if a large mixing between the three mass eigenstates of the neutrino (m_1, m_2, m_3) is considered. The result of the Heidelberg-Moscow experiment then corresponds to $\Sigma\, m_i < 3.2$ eV, while the WMAP analysis (see section 2.4) gave $\Sigma\, m_i <$ 1 eV. Nevertheless, new independent double beta-decay experiments of this type are needed, also – as was mentioned above – to further constrain the cosmic microwave background analyses. Such experiments have been started among others in France (NEMO in the Modane underground research laboratory) and Italy (CUORICINO, Majorana and CUORE in the Gran Sasso underground research laboratory).

2.2 The nature of dark energy

The primary evidence for the existence of dark energy comes from observations of distant type-Ia supernovae that appear dimmer than they would be if the expansion of the universe was decelerating under the pull of gravity alone. Other evidence for the existence of dark energy comes from the number density of galaxy clusters, from the large-scale density fluctuations and from the observed number of strong gravitational lenses. By combining information derived from the redshifts of distant type-Ia supernovae (which – to be precise – gives a value for the *difference* between the amount of dark energy and dark matter) and the data obtained on the temperature fluctuations of the cosmic microwave background as obtained by the COBE and WMAP satellites (which gives a value for the *sum* of the amount of dark energy and dark matter), it is found that dark energy constitutes an astonishing 73% of the total energy content of the universe. Taking into account that dark matter – as was mentioned before – represents about 23% of the universe's energy content, this implies that only 4% of the universe consists of normal (baryonic) matter. In order to make progress in understanding the nature of dark energy several research projects have been initiated:

- Cosmological arguments imply that the relative amount of dark energy and dark matter is changing while the universe is expanding. To verify this prediction, it is of importance to measure the redshifts of type-Ia supernovae out to very large distance scales (i.e. redshifts). Such programs, known as GOODS and ESSENCE, have been started but as the techniques involved are traditional optical techniques in astronomy they are not further considered here. There is also a satellite project, SNAP, which is designed to measure

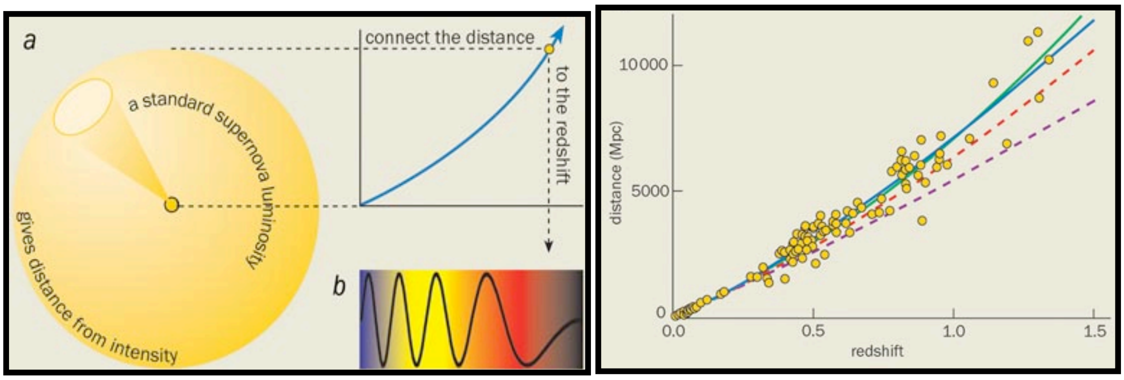

Fig. 2. As the luminosity of type-Ia supernovae is well known, the apparent luminosity gives a measure of the distance (plotted on the y-axis) which can be compared to the redshift (plotted on the x-axis). While the left panel illustrates the concept, the right panel shows the actual data in comparison to various model calculations that include an accelerated expansion of the universe. The dashed purple line has no accelerated expansion included.

redshifts of about 2000 type-Ia supernovae per year at cosmological distances. This project should provide definite evidence of the acceleration of the expansion of the universe, and the evolution of its equation of state.

- The measurements of the cosmic microwave background, as performed by the COBE and WMAP satellite, and several ground-based and balloon-based experiments, have (together with the type-Ia supernova redshift measurements) played an essential role in establishing dark energy as the dominant component of the present universe. New cosmic microwave background measurements with a hitherto unattainable precision will be performed by the PLANCK satellite that is presently under construction. With PLANCK the temperature fluctuations will be measured to a relative precision of 10^{-6} at an angular resolution of 5 arc minutes. Such data will allow probing the predicted evolution of the amount of dark energy in the universe with time. (PLANCK will also provide other cosmological data, as will be discussed in section 2.4.)

- A possible source of dark energy is the energy that – according to quantum mechanics – is contained in the vacuum. Unfortunately, simple estimates of this vacuum energy density, based on summing vacuum fluctuations up to the Planck scale, result in a value that is some 120 orders of magnitude larger than the (dark) energy observed in the universe. Theoretical questions that emerge are whether the Higgs field (that is invoked to generate the mass of the elementary particles of the Standard Model) or supersymmetry (the previously mentioned theoretical framework that goes beyond the Standard Model) is able to resolve this discrepancy. Hence, *theoretical astroparticle physics* research is needed with inputs from particle physics, cosmology and astronomy.

2.3 The origin of the highest-energy cosmic rays

The atmosphere of the Earth is continuously bombarded by gamma rays, neutrinos,

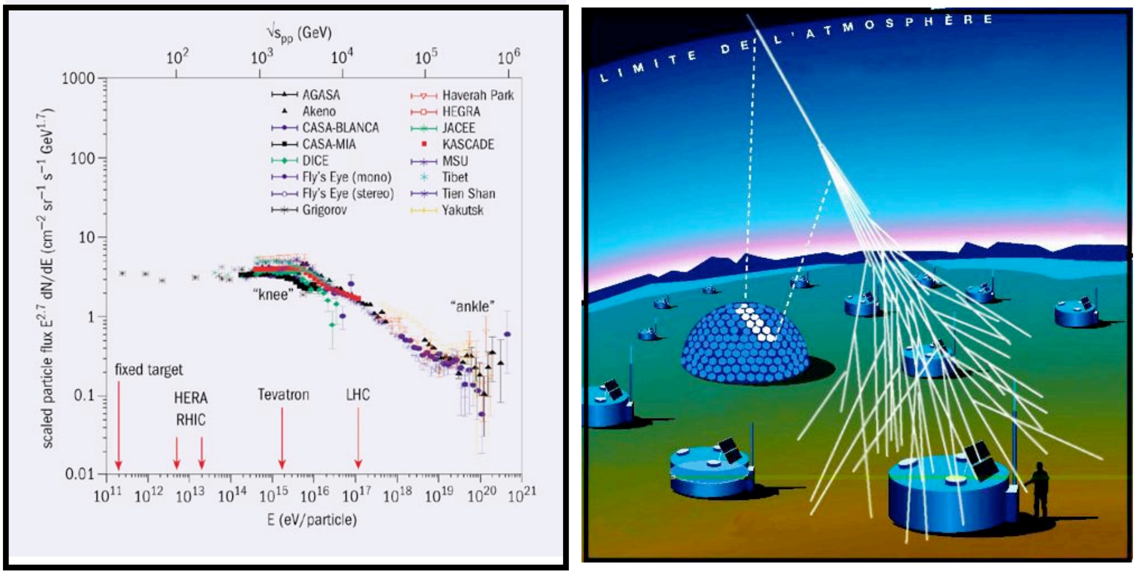

Fig. 3. In the left-hand panel the energy spectrum of cosmic rays above 10^{11} eV is shown. The spectrum is scaled by a power of 2.7 in order to highlight the various features of the spectrum. The data above the GZK limit ($5{\cdot}10^{19}$ eV) are not fully consistent. In this domain new data with much better statistics will be collected by the Auger project, of which a schematic picture is shown in the right-hand panel.

electrons, protons and heavier atomic nuclei. These so-called cosmic rays are causing air showers of secondary particles. The extent of the air showers, i.e., the spatial spread of the secondary muons reaching the surface of the Earth, is used to determine the energy distribution of the original cosmic rays hitting the Earth. The measured cosmic-ray energy spectrum extends to energies well in excess of the highest energies that can be produced in present-day particle accelerators (see figure 3 – left panel). In fact, cosmic rays are the only observed ultra high-energy (UHE) particles on Earth. While the steeply falling spectrum has been measured by a number of experiments up to energies of more than 10^{20} eV, many questions remain:

- What is the origin of cosmic rays with energies in excess of 10^{16} eV? What is the nature of the cosmic acceleration mechanism(s) that give rise to such high energies? Are these acceleration mechanisms related to the most energetic sources in the universe such as Active Galactic Nuclei (AGNs) and the intense streams of matter (jets) they generate, Gamma-Ray Bursts (GRBs), Magnetars, Micro-Quasars (involving stellar mass black holes) or Supernova remnants?

- Does the cosmic ray spectrum extend beyond the highest possible energy a proton can maintain over large distances in the universe due to collisions with the cosmic microwave background radiation (which will result in the production of pions at, and above such energies)? If a large flux of cosmic rays is indeed observed above this so-called GZK (Greisen, Zatsepin and Kuzmin) limit, can they be attributed to entirely novel phenomena such as relatively nearby cosmic accelerator mechanisms that are operating relatively nearby, or relics of heavy dark matter particles?

- What is the chemical composition of the cosmic rays hitting the upper layers of the atmosphere of the Earth?

Fig. 4. One the left-hand side one antenna of the LOFAR prototype radio telescope LOPES is shown. The prototype antenna is placed at the KASCADE cosmic ray particle detector array in Karlsruhe. An overview of the KASCADE set-up is shown on the right.

In order to answer these questions more detailed experimental information on the nature of cosmic rays must be obtained. Moreover, such new data need to be confronted with the latest theoretical ideas on cosmic acceleration mechanisms, and on the type and energy of the particles that are expected to be ejected by the most explosive events in the universe such as AGNs and GRBs. Progress in this field thus requires a coherent research program containing the following subprojects:

- The shape and amplitude of the cosmic ray spectrum needs to be verified with independent experiments, in which outreach projects such as HiSparc can play a role (see section 5).

- Unambiguous experimental data on ultra-high energy cosmic rays need to be obtained in order to establish beyond doubt whether or not the GZK limit is violated. For this type of measurements the Pierre Auger Observatory – usually and henceforward referred to as the Auger project – that is presently under construction in Argentina on the southern hemisphere, offers the best opportunities as it has the potential of obtaining up to 20 events per year in the energy domain beyond 10^{20} eV (see fig. 3). While the construction of Auger is progressing, initial data taking has already started with a subset of the detectors. The full observatory is expected to be completed in 2006 (see appendix 3).

- The information that is presently available on high-energy cosmic rays is largely limited to the observation of muons in extended air showers reaching the surface of the Earth, and the detection of fluorescence radiation from excited molecules in the atmosphere of the Earth. In order to investigate the origin and propagation of extended air showers, alternative probes are needed that can provide us with independent information on the development of the air shower. Such information can be obtained from radio observations of air showers, a new concept developed by scientists at ASTRON and Radboud University. Moreover, radio detection of cosmic rays offers many new opportunities in this field:
  (i) the energy dependence of the development of extended air showers can be measured over many orders of magnitude;

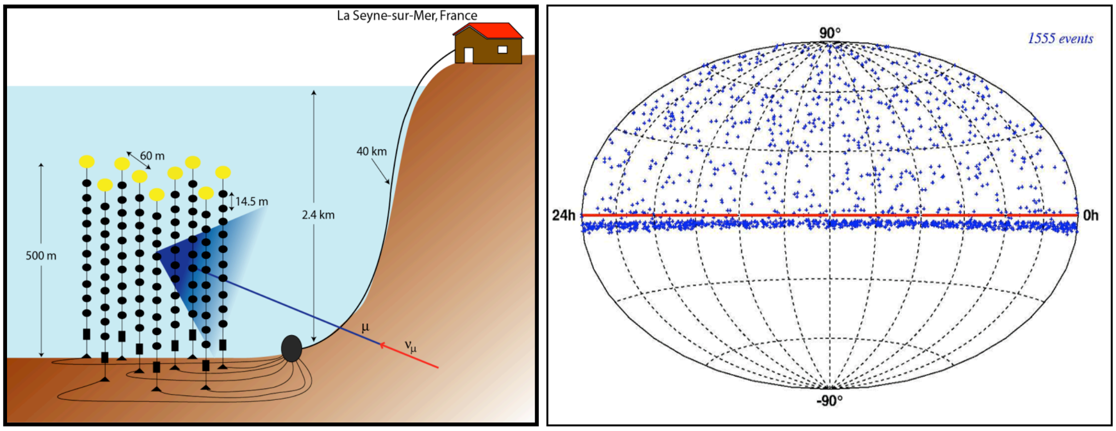

Fig. 5. Left: schematic drawing (from M. Bouwhuis, PhD Thesis University of Amsterdam, 2005) of the ANTARES deep-sea neutrino telescope, as it is presently under construction in the Mediterranean Sea near La Seyne-sur-Mer, in France. The effect of an upcoming muon neutrino that leads to the production of a muon after a charged-current interaction in the earth is schematically shown. The produced muon generates Cherenkov light in the sea, which can be observed by a neutrino telescope. Right: first sky-map obtained with the AMANDA deep-ice neutrino detector in Antartica, which is based on a similar principle of operation.

(ii) the directional sensitivity of radio detection will make it possible to measure possible anisotropies (as has been so successful in the case of the cosmic microwave background radiation);

(iii) the ability to reconstruct the air showers makes it possible to study - under special conditions – cosmic neutrinos including possibly tau neutrinos.

Projects that have recently been developed to carry out measurements of this type include CODALEMA (Cosmic ray Detection Array with Logarithmic Electro-Magnetic Antennas) in Nançay, RICE (Radio Ice Cherenkov Experiment), the balloon-based ANITA (Antarctic Impulse Transient Array) – the latter two based in the Antarctic – and LOFAR, which is presently under construction in the North-Eastern part of the Netherlands and described in appendix A1.1. A small-scale prototype of LOFAR (known as LOPES illustrated in figure 4) has already obtained first results, which are also discussed in appendix A1.1. It is has also been proposed to use salt domes for radio detection of cosmic rays, which has led to the SALSA and ZESANA projects (see appendix 4) which are in the conceptual design phase.

- The interpretation of the high-energy charged particles that are causing air showers in the atmosphere of the Earth is sometimes complicated by the known existence of intergalactic magnetic fields. Hence, it is difficult, if not impossible, to identify individual astrophysical sources that can be associated with such high-energy cosmic rays. These difficulties are circumvented if the corresponding flux of cosmic neutrinos can be observed. Hence, the development of neutrino telescopes (such as AMANDA, ANTARES, ICECUBE and KM3NeT – see figure 5 and appendices A1.2) offers an entirely new window on the sources of high-energy cosmic rays. As these detectors have or will have an angular resolution of 0.2 to 2.0 degrees, it will

Fig. 6. One of the four telescopes representing the first phase of the High Energy Stereoscopic System (HESS) in Namibia. During daytime, the mirrors are normally parked looking down, with the "camera" protected in its shelter. (Taken from Cern Courier, Jan/Feb. 2005)

be possible to search for neutrino point sources. If such sources are identified, the observed rates can be used to study the validity of astrophysical models that predict the emission of high-energy neutrinos by AGNs, GRBs and Micro-Quasars.

- The direct observation of high-energy gamma rays (E > 1 TeV) has similar advantages as the observation of high-energy neutrinos, although intergalactic absorption still plays a role. In this respect it is encouraging that the recently commissioned HESS telescopes (see figure 6) reported some of the first high-energy gamma sources near the end of 2004. These high-energy gamma rays seem to originate from various compact objects close to the galactic centre. The HESS telescopes measure cosmic gamma rays in the energy range above 100 GeV with unprecedented sensitivity and resolution. They achieve this by detecting the Cherenkov light that is emitted when a high-energy gamma ray is absorbed in our atmosphere, resulting in a cascade of electrons and positrons rushing through the air at speeds close to that of light. The initial success of HESS nicely illustrates the discovery potential of instruments that open up a new window in either wave length or particle type.

- To complement the new measurements described above theoretical modelling is needed of extended air showers, and of the relation between radio, muon and neutrino observations. In addition, astrophysical modelling of the sources of these highly energetic particles and of the production mechanisms operating in these highly energetic sources is needed.

2.4 The origin of the large-scale structure of the universe

It is commonly assumed that the universe has evolved from an initial super dense and hot phase, the so-called Big Bang. While matter was distributed to a very high accuracy homogeneously in the early universe, the stars, galaxies and clusters of galaxies we observe today – 13.7 billion years later – must have been formed later from minute density fluctuations that have occurred almost from the beginning. In the process of galaxy formation massive black holes may have played an important role. Also, the observed dominance of matter over antimatter requires the existence of some asymmetric processes in the early phases of the universe. These issues are traditionally studied in cosmology. However, as there is both experimentally and theoretically a growing overlap with questions emerging in (theoretical) particle physics (such as those related to CP violation) some of these issues are now addressed by astroparticle physics:

- In section 2.1 the measurements of the temperature fluctuations of the cosmic microwave background by the satellites COBE and WMAP were already introduced. Such measurements do not only provide information on the amount of dark matter and dark energy in the universe, but also strongly constrain the age of the universe, its curvature, expansion rate and several other cosmological parameters. More importantly, the successor of WMAP, the PLANCK satellite, will – because of its improved angular resolution and capability to measure the polarization of the cosmic microwave background – be able to probe the effects of a period of exponential inflation of the universe. While inflation is successful in explaining the global properties of the universe (such as the statistics of the initial density fluctuations, its flatness, horizon and smoothness), it has no firm theoretical foundation in physics. On the other hand, there are many models of inflation (some of them embedded in particle physics models of grand unification) that provide a successful implementation of cosmic inflation. What is needed is the experimental means to distinguish between such models. By probing the relics of the inflation era and by measuring the polarization of the microwave background caused by primordial gravitational waves, the PLANCK satellite has the potential of providing such data, and thus causing a break-through in this field.

- In the last decade work in theoretical high-energy physics has led to several ideas that may have a direct impact on our understanding of the origin of the large-scale structure of the universe. These ideas include the development of string theory leading to the prediction of extra dimensions, the development of concepts related to quantum gravity (see section 2.5), the matter-antimatter asymmetry in the universe and cosmic defects. A central issue at stake is whether these newly developed concepts provide an understanding of inflation in terms of the underlying physics. Moreover, these ideas need to be confronted with the new data that will be produced by – among others – the PLANCK mission.

- Another important cosmological parameter is the fraction Ω_b of baryonic matter in the universe. While the nature of the baryonic matter is well understood, its origin is just as mysterious as the origin of dark matter. It may well be that at the electroweak phase transition neutralinos dominated the generation of the asymmetry between matter and antimatter, thus explaining one of the coincidences of the Standard Cosmological Model ($\rho_{DM}/\rho_b \sim 5$). Such models are testable by combining the information expected from the next generation of particle physics experiments (at the LHC collider, for instance) and astroparticle physics experiments (with the PLANCK mission, for instance). While the present best measurement of Ω_b (=0.044 ±0.004) has been obtained by WMAP, the new microwave background measurements from PLANCK are expected to measure Ω_b with a significantly improved accuracy. When taken together with the anticipated results from LHC, *baryogenesis* models will be further constrained.

Studies of the origin of the large-scale structure of the early universe are often – but not necessarily – closely related to studies exploiting the extreme conditions that are believed to have existed in the early universe. As such conditions cannot be reached in Earth-based laboratories, they offer the opportunity to investigate the validity of the laws of physics and astronomy under extreme conditions. Experiments of this kind make use of radio signals, high-energy photons (in the MeV – TeV range), neutrinos or gravitational waves.

2.5 The observation and use of gravitational waves

Gravitation plays a central role in the evolution of the universe. It is well-described by general relativity, but it is unclear how general relativity acts at the quantum level (which has an immediate impact on models of the early universe). One of the – as yet only indirectly confirmed – predictions of general relativity is the existence of gravitational waves. Hence, the question emerges whether we can actually observe gravitational waves, and – if so – whether their observation can be exploited to address open questions in astroparticle physics. Assuming a positive answer to the first part of the question, the second question is addressed in the subsequent paragraphs.

In the first place, gravitational waves can be used as a diagnostic to probe the evolution of compact binaries, supernovae and the formation of black holes. This information is entirely independent of any observation in the electromagnetic spectrum, and is therefore likely to lead to unique information on such compact (and usually energetic) objects. Moreover, because of the weakness of the interaction of gravitational waves with anything they encounter (which also explains why it is so hard to discover their presence in the first place) they propagate unperturbed through essentially the entire universe. This makes it in principle possible to use gravitational waves to probe the early universe even beyond the timescales probed by the PLANCK satellite. As the spectrum and amplitude of gravitational waves from inflation sensitively depends on the details of the inflationary fields, such data – if feasible – will represent the first direct test of models of inflation. As an aside – and in relation to the previous section – it is of interest to note that gravitational waves also generate temperature fluctuations that contribute to the large-scale anisotropy (above the horizon at recombination) in the Cosmic Microwave Background, which can also be measured with the PLANCK satellite.

Hence, if gravitational waves are observed directly – which in itself would be a major success – it not only proves the validity of the framework of general relativity, but it also opens up a window to 'Gravitational Wave Astronomy'. In fact, it is widely believed that gravitational waves – once detected – will have a discovery potential comparable to that of the cosmic microwave background in recent years. Experiments designed to observe (and hence discover!) gravitational waves come in three types:

- *Resonant detectors* have specific dimensions (in the form of a bar or a sphere), and are therefore only sensitive to the passage of gravitational waves having a frequency component that falls in a very narrow band in the kHz range. At present several resonant gravitational wave detectors are operational:

ALLEGRO, AURIGA, EXPLORER, NAUTILUS, NIOBE, MARIO SCHENBERG and the Dutch experiment MiniGRAIL in Leiden (see appendix 1).

- *Interferometers* usually consist of 2 or 3 very long arms. A laser pulse is split and travels a number of times up and down each arm after which it creates an interference pattern with the other pulse. A change in the path length due to a passing gravitational wave can be deduced from a change in the interference pattern. This principle is used in a large number of gravitational wave observatories, AIGO, GEO600, LIGO, TAHA300 and VIRGO. The frequencies to which these gravitational wave detectors are sensitive depend on the length of the arms, and range from a few kHz down to 1 Hz. Gravitational waves at kHz frequencies are expected to be emitted by neutron star mergers, supernovae, rapidly spinning neutron stars in X-ray binaries and at somewhat lower frequencies by supermassive black holes in Active Galactic Nuclei (AGNs).

- *Satellite-based interferometers* will be able to probe the earliest cosmological time periods. This is illustrated in figure 7 for the very promising satellite-based interferometer project, LISA. In the framework of this project three satellites are positioned in orbit around the sun, trailing the Earth by some 20 degrees. The range of sensitivity of LISA is expected to reach down to 10^{-4} Hz. This will enable the observation of the coalescence of massive black holes and mergers of white dwarf stars. At the upper end of its sensitivity (near 1 Hz) LISA might just be able to observe the primordial gravitational waves produced during the inflation era. Follow-up satellite projects such as the proposed Big-Bang Observatory will be most sensitive in the relevant 1 Hz range. From the above it is clear that projects such as LISA are of fundamental importance for the development of gravitational wave astronomy.

It should be noted that the effects of strong gravitational fields may also be studied in different ways. In X-ray binaries – or any other binary system consisting of heavy compact objects – the effect of gravity is very much higher than can be observed anywhere in the vicinity of the Solar system. The observation of such systems (by other means than gravitational waves) makes it possible to verify the validity of the laws of gravity, such as they are encoded in the framework of general relativity, under conditions that differ widely from any previous test of this framework. A second example of an indirect way of studying gravitation follows from a new (theoretical) development according to which there is a coupling between gravitational waves and magneto-hydrodynamic waves at the source. This may lead to the opportunity to detect gravitational waves indirectly with the low-frequency radio telescope LOFAR[9] (see section 2.3).

Apart from the experimental work mentioned above, theoretical activities are needed in parallel. As an example, the evolution of white dwarf binaries needs to be modelled in order to be able to predict the number of galactic sources that can be observed by

[9] It is presently expected that the future Square Kilometre Array (SKA), which can be considered as a kind of super-LOFAR project, will be able to indirectly observe low-frequency gravitational waves from rapidly spinning pulsars on the basis of the same principle (see http://www.skatelescope.org/pages/science_key_ pulsars.htm).

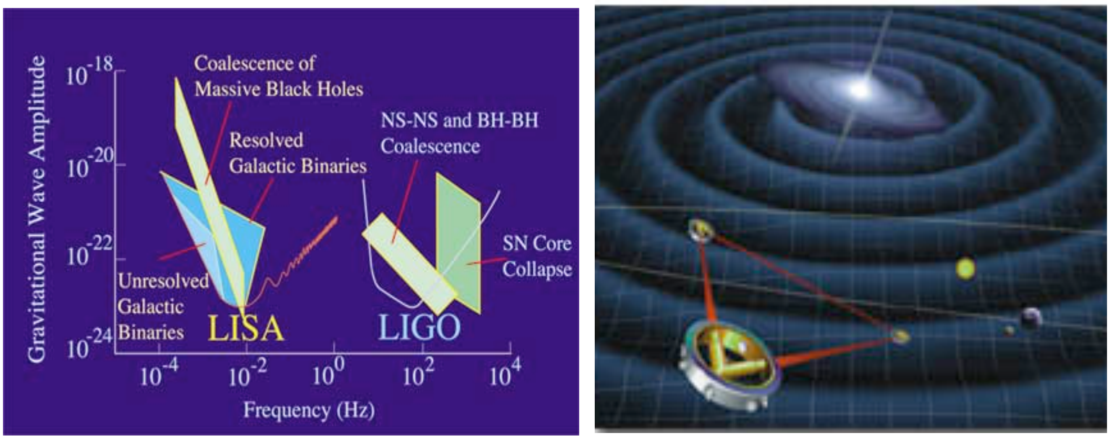

Fig. 7. In the left-hand panel the estimated amplitudes of gravitational waves emitted by various astrophysical sources are plotted as a function of the frequency of the gravitational wave. This amplitude or sensitivity corresponds to twice the relative length change (ΔL/L) of a given detector (arm) due to the detection of the gravitational wave. The red (blue) curve gives the lower sensitivity limit of LISA (LIGO). In the right-hand panel the configuration of the three satellites constituting the LISA gravitational wave observatory is schematically shown. The relative distance between the three satellites is approximately 5 10^6 km.

LISA. This will contribute to the further definition of the parameters of the system. Furthermore, a proper understanding of the tidal interactions in binaries needs to be available for a fruitful comparison between LISA data and predictions. Clearly, other potential sources of gravitational waves, such as black hole mergers, need to be studied as well. However, important obstacles such as the lack of adequate numerical computational schemes need to be overcome.

3. Proposed astroparticle physics research in the Netherlands

In section 2 it was shown that astroparticle physics is a rapidly developing international field of research, which addresses a number of the most challenging scientific questions of our time. Although some Dutch activities in astroparticle physics exist (see appendix 1), the absence of resources for interdisciplinary research of this kind jeopardizes the further development of these research efforts. In order to coordinate the national research effort in astroparticle physics and increase its momentum the Dutch committee for astroparticle physics (CAN) has been formed, as was described in section 1. Based on the inventory of research projects described in sections 2 (and appendix 1) and a number of general considerations, which are discussed in section 3.1, the committee has developed a coherent plan for astroparticle physics research in the Netherlands. This strategic plan is presented in section 3.2. In section 3.3 the relevance of the chosen strategy for the key scientific issues introduced in section 1 are discussed, while the international aspects of the plan are presented in section 3.4.

3.1 Considerations

In preparing and discussing the strategic choices for astroparticle physics in the Netherlands the committee used several considerations:

- Excellence. Fundamental research in the Netherlands should be of the highest quality: innovative, creative, visible and productive. Hence, only those projects are considered that can be qualified as excellent, either because it concerns an international project that has been subject to peer review or because it is expected to pass a round of peer review easily as the project addresses central questions in astroparticle physics using proven (or soon to be proven) techniques.

- Focus and mass. In order to strengthen the community of astroparticle physicists in the Netherlands, it is important that the various groups involved work together on a small number of internationally recognized research topics. The nature of the theoretical or experimental project should be such that it clearly belongs to astroparticle physics. (Searches for neutralinos with the new LHC detectors at CERN do not fulfil this requirement as this is part of the normal experimental high-energy physics program.) Because of the small distances in the Netherlands, a well-focussed research effort can then be initiated which is of a sufficiently large mass to ensure that a coherent research effort emerges.

- Investments & expertise. As is described in appendix 1, several investments have been made for the construction of astroparticle physics detectors in the Netherlands: LOFAR, ANTARES and MiniGRAIL. These projects have led to an internationally recognized level of expertise. In selecting future projects it is desirable to ensure that we can profit as much as possible from previous investments and previously acquired levels of expertise.

- International context. The size of most research projects in astroparticle physics is such that the investments involved have to be carried by a large number of countries. In order to also profit from the emerging European Research Area[10] it is specifically desirable to participate in EU-based projects. Hence, it is clear from the beginning that astroparticle physics research in the Netherlands can only be conducted in a highly international context.

- Fast access to new data. In a healthy research community there should be a proper mixture of data analysis, theoretical modelling, and development of future instruments. This is of particular importance for the PhD students in the program (see section 4). At the same time, when setting up a new research program there is the danger that the emphasis is on the construction of instruments only. To avoid such a situation and be able to participate at the forefront of astroparticle physics from the outset, it is highly desirable to join a running (or almost running) experiment as well.

- Theory. In order to address the defining questions of astroparticle physics a theoretical effort is required in parallel to the experimental/observational projects. As experimental and theoretical aspects of astroparticle physics are closely related, the new interdisciplinary research program needs to support several theoretical activities as well. However, at the same time it should be realized that the development of a strong and independent theoretical astroparticle-physics program goes beyond the scope of the present plan which is mainly focussed on experimental and/or observational work (see section 3.2).

- Outreach. The subject of astroparticle physics is ideally suited for outreach activities (see section 5). These activities are expected to result in an increase of the enrolment in physics and astronomy at the universities. The financial means for outreach activities are therefore included in the strategic plan.

3.2 Strategic plan

Based on the considerations discussed above, it is proposed to study the fundamental scientific issues addressed in astroparticle physics by means of a *multi-messenger approach*, in which the complementary nature of radio, neutrino and gravitational-wave detectors are fully exploited to make progress in this new research field. In practice, this means that the following three research themes are selected as the basis for the development of astroparticle physics in the Netherlands:

- Radio detection of cosmic rays. The full exploitation of LOFAR for radio detection of cosmic rays is foreseen. Moreover, it is proposed to export this technique to the Auger project[11] which will give instant access to the study of cosmic rays of the highest possible energies.

- Deep-sea neutrino detectors. The full exploitation of ANTARES as the first fully operational deep-sea neutrino detector is foreseen. Moreover, the

[10] The Astroparticle Physics European Collaboration (ApPEC) committee has submitted a proposal for the EU 6th Framework Program to develop a European Research Area (ERANET) in the domain of astroparticle physics. The Netherlands participate in this so-called ASPERA project through NIKHEF. This is further discussed in section 3.3.

[11] A description of the Auger project can be found in appendix 3.

expertise developed in this framework ("all-data-to-shore") will be used for the large km^3 sized neutrino telescope[12] (KM3NeT) that will open the era of neutrino astronomy in the Northern hemisphere as IceCube[13] will do in the Southern hemisphere.

- Gravitational wave detectors. The full exploitation of MiniGRAIL is foreseen. At the same time the expertise developed for the LISA-Pathfinder project will be used for an active Dutch role in the construction of the LISA gravitational wave satellite system, and development of analysis techniques that can be used to observe gravitational waves and use them as probes of compact objects.

Each of the chosen projects has passed the test of *excellence* in a recognized peer-review procedure. The first two subjects *focus* on different aspects of the same basic question regarding the unknown origin of the highest-energy cosmic rays. Moreover, as high-energy cosmic rays are commonly believed to be originating from compact objects such as AGNs, GRBs, supernova remnants and micro quasars or from relics of the early universe, which are all expected to be the source of detectable gravitational waves as well, it becomes clear that the three research themes are intimately connected. In fact, observing the universe with cosmic rays, neutrinos and gravitational waves illustrates the "multi-messenger approach" that was chosen as a central theme of the proposed astroparticle physics research program. The three projects have sufficient national *mass* to ensure international visibility of Dutch astroparticle physicists. Furthermore, it is emphasized that most projects mentioned in section 2 are *not* a part of our strategic plan, while the few subjects that have been selected do profit from existing Dutch *investments* and *expertise*. In addition, the projects mentioned above are all carried out in an *international context*. The ANTARES and KM3NeT projects are entirely European, and both LOFAR and MiniGRAIL have a strong European involvement. At the same time, participation in the worldwide Auger and LISA projects will be organized through a cluster of European countries. *Fast access to new data* is ensured by the proposed participation in the Auger project, which is being commissioned right now (2004 – 2005) and already collecting first data[14], and the existing small-scale involvement in the analysis of the AMANDA/IceCube data (see appendix 1). As can be seen from table 1 (on page 26) each of the chosen research topics will involve typically 3 to 4 university groups and/or institutions. Each one of the groups involved has expressed support for the entire strategy outlined in this section.

As argued in section 3.1, the experimental/observational projects mentioned above need to be accompanied by an independent project on *theoretical astroparticle physics.* Theoretical research is essential to ensure the full exploitation of the proposed experimental projects, and to infer and interpret the implications of the anticipated new observations. A similar approach – in which theoretical and experimental projects are conducted in parallel – has been successfully employed for LEP at CERN and the Hubble Space Telescope, for instance. Successful theoretical work does not require the formation of large collaborations. Hence, the proposed funding for theoretical astroparticle physics is of a different nature than that proposed

[12] More information on the KM3NeT project is given in Appendix 2.
[13] At Utrecht University a group is involved in the analysis of data collected by IceCube (see Appendix 4, p. 69); this effort will contribute to the successful design and exploitation of the KM3NeT project.
[14] As was already mentioned before, more details on the AUGER project are presented in appendix 3.

for the experimental projects discussed above.

Table 1. Foreseen involvement (in 2006) of tenured senior scientists in the selected observational and/or experimental projects that are part of the present strategic plan.

Research Area	Institute	Scientific Staff	Research Interests
Radio Detection of Cosmic Rays	UvA - Amsterdam	RAMJ Wijers S. Markoff	LOFAR; compact objects (GRB, AGN)
	ASTRON - Dwingelo	H Falcke (& RU)	LOFAR, Auger
	KVI - Groningen	JCS Bacelar AM van den Berg MN Harakeh J Messchendorp HJ Wörtche	LOFAR, Auger, Westerbork, extended air showers
	RU - Nijmegen	P Groot SJ de Jong J Kuijpers Ch Timmermans (new UD astron.)	Expertise centre for LOFAR/cosmic rays Auger
Deep-sea neutrino detection	NIKHEF - Amsterdam	M de Jong P Kooijman G vd Steenhoven E de Wolf	ANTARES, KM3NeT
	UvA - Amsterdam	RAMJ Wijers	ν-astronomy; GRBs
	KVI - Groningen	MN Harakeh N Kalantar H Löhner	ANTARES, KM3NeT
	UU/SRON – Utrecht	A Achterberg N v Eijndhoven J Heise	ν-astronomy; GRBs AMANDA/IceCube analysis; KM3NeT
Gravitational wave detection	NIKHEF - Amsterdam	H vd Graaf FL Linde	LISA electronics and analysis
	VU - Amsterdam	JFJ vd Brand Tj Ketel	LISA simulation and analysis
	LU - Leiden	G Frossati	MiniGRAIL
	RU - Nijmegen	J Kuijpers	GW-astronomy
	SRON - Utrecht	A Selig M Smit	ISTM for LISA Pathfinder, LISA
Outreach	VU - Amsterdam	HJ Bulten	HiSparc
	NIKHEF - Amsterdam	B van Eijk JW van Holten	HiSparc
	KVI - Groningen	J Messchendorp	HiSparc
	LU - Leiden	P van Baal	HiSparc
	RU - Nijmegen	Ch Timmermans	HiSparc LOFAR@School
	UU – Utrecht	J Kortland GJL Nooren	HiSparc

In this case it is sufficient – and even desirable – to define a flexible funding scheme with annual allocations and to identify a number of central research topics. The chosen theoretical astroparticle physics research subjects are largely based on the available expertise in the Netherlands, as presented in table 5 (page 58). The five main subjects are listed below, followed by some key words in each case:

- *Dark Matter*: supersymmetry, sterile neutrinos, neutrino mass;
- *Matter-Antimatter*: CP violation, baryogenesis;
- *Cosmic Rays*: radio detection, neutrinos, ultra-high energy, shower development;
- *Cosmology*: phase transitions, inflation, early universe, large-scale structures, topological defects, string theory;
- *Compact Objects*: GRBs, AGNs, acceleration mechanisms, jets, gravitation, magneto hydrodynamics, neutron stars, quark stars.

3.3 Relevance for key scientific issues

The relevance of the chosen experimental and/or observational projects for the main scientific questions of astroparticle physics as discussed in sections 1 and 2 is illustrated in table 2. From the table, it can be seen that the proposed experimental research efforts for astroparticle physics in the Netherlands are focused on questions related to the unknown origin of high-energy cosmic rays. At the same time, because of the versatility of the instrumentation that will be used for that purpose, it will be possible to address questions related to the nature of dark matter and the detection of gravitational waves. As was already explained above, the foreseen theoretical astroparticle physics research in the Netherlands will have a broader coverage.

It should be noted that a large number of international projects, in which Dutch scientists were invited to participate and for which they have expressed their interest, have not been selected. Examples include the KATRIN experiment in Karlsruhe, aimed at measuring the neutrino mass or – at least – reducing the existing upper limit to 0.2 eV, the AMS-02 experiment that will fly on the International Space Station with the aim of discovering antimatter and/or dark matter candidates, and the IceCube neutrino observatory which is presently under construction at the South Pole and which is aimed at searching for cosmic neutrino point sources. This illustrates the spirit of collaboration and focus which characterizes Dutch astroparticle physics. A brief outline of some of these alternative projects is given in Appendix 4.

The chosen strategy for the development of astroparticle physics research in the Netherlands is partly based on technological expertise available at the Dutch research institutions ASTRON, NIKHEF and SRON, where the three unique detection concepts mentioned above have been conceived. This technological expertise needs to be accompanied by university groups that play a crucial role in attracting and training students, and analysing the data. However, at present the knowledge of radio detection of cosmic rays, deep-sea neutrino detection and gravitational wave detection is only available at very few single Dutch university groups. Fortunately, theoretical expertise in astroparticle physics is much more widely available at the Dutch universities. Nevertheless, additional faculty needs to be hired to create (or expand) experimental or observational astroparticle physics groups at the participating universities. As an example of the urgency of such measures, the LISA space mission can be mentioned. This is one of the most expensive purely scientific ESA/NASA missions ever with a budget of approximately 2000 M€. In order to realize a visible Dutch contribution in LISA it is important that the Netherlands has both high-level technological expertise and an internationally appealing scientific user community. In fact, the prospects for SRON to acquire a mission-critical hardware project in LISA will significantly improve if support from university-based groups specialized in the analysis and use of gravitational-wave detection data is available.

Table 2. Relation between the proposed experimental projects for astroparticle physics research in the Netherlands and the key scientific issues discussed in section 1. A cross indicates that a given project will contribute to the answer of the corresponding question.

	LOFAR	**Auger**	**Antares**	**KM3NeT**	**MiniGRAIL**	**LISA**
1. Dark Matter						
neutralinos			X	X		
heavy relics		X	X	X		X
neutrino mass						
2. Dark Energy						
high redshifts						X
equation of state						
3. HE Cosmic rays						
acc. mechanism	X	X	X	X		
compact objects	X	X	X	X	X	X
GZK limit	X	X		X		
4. Large-scale struct.						
CMB						X
inflation						X
5. Gravitation						
direct detection					X	X
GW-astronomy	X				X	X
extreme gravity						

3.4 International aspects.

There are a few more international aspects to astroparticle physics that need to be mentioned here, as they further illustrate the strong European involvement in astroparticle physics and the role of Dutch researchers in (new) European collaborations on astroparticle physics.

- The Astroparticle Physics European Coordination (ApPEC) committee, which is one of the specialist advisory committees of the European Science Foundation, has been formed several years ago in response to the growing amount of astroparticle physics research in Europe. ApPEC is in the process of reviewing plans and setting priorities to the large number of astroparticle physics initiatives in Europe. Most importantly, ApPEC has prepared a proposal for the formation of a European Research Area (ERANET) that has been submitted to the 6th Framework Program of the European Commission.

Such a European Research Area will facilitate the development of astroparticle physics in a truly European fashion by developing funding schemes and a common EU roadmap for the field. Two members of the Committee for Astroparticle Physics in the Netherlands are active within the framework of ApPEC: F. Linde serves on the Steering Committee.

- The European 6th Framework also offers the possibility for submitting International Infrastructure Initiatives (I3 programs). In the first round the ILIAS (*Integrated Large Infrastructures for Astroparticle Science*) program was approved. The ILIAS program aims at bringing together all the researchers who can contribute to the optimal operation of the different infrastructures in astroparticle physics and to gain maximum benefit from the many common features in the technical problems to be overcome and in the ultimate scientific goals. The three main scientific topics are: physics in deep underground laboratories, gravitational wave detection, and theoretical astroparticle physics. From the Netherlands the Leiden group is actively participating in the IDEA (Integrated Double β Decay) and STREGA (Study on Thermal Noise Reduction in Gravitational Wave Detectors) activities of the project, while theory groups from Amsterdam, Groningen, Leiden and Utrecht are involved.

- As ILIAS does not cover all aspects of the rapidly growing field of astroparticle physics in Europe, a second I3 proposal has recently been submitted to the 2nd round of the European 6th Framework Program. This new proposal carries the name HEAPNET (*High Energy Astrophysics Net*) and includes so-called Joint Research Activities (JRAs) in the fields of photo-detection and radio-detection of high-energy cosmic rays and neutrinos. Networking Activities in the area of multi-messenger analyses and high-energy astrophysics with neutrinos, high-energy gamma rays and cosmic rays are also part of the proposal. The Netherlands is represented by astroparticle physicists from NIKHEF, KVI, ASTRON and the Radboud University in this I3 proposal.

The examples given above do not only show the rapid development of astroparticle physics in Europe, but – at the same time – give evidence of the growing Dutch involvement in these activities. By developing a strong Dutch program, as proposed here, that is firmly embedded in European research networks the Netherlands is positioning itself as a prominent player in this newly emerging interdisciplinary research field.

4. Training aspects

As the proposed research program in astroparticle physics will involve many graduate students (up to almost 30 per year if the program has been fully developed), it is crucial to ensure that a proper training is available for each one of them. In this section a brief outline is given of the training requirements for graduate students who will carry out their research work in the field of astroparticle physics in the Netherlands. Fortunately, many aspects of the proposed training scheme can be shared with existing Dutch graduate schools in astronomy (NOVA), particle physics (OSAF) and nuclear physics (FANTOM). Moreover, certain graduate schools or lectures series can be carried out in an international framework[15]. The key issue here is that although practical arrangements may differ for each astroparticle physics group in the Netherlands, each student who is supported by the proposed new interdisciplinary research program will be monitored by the program management to verify that the requirements presented below are fulfilled.

The training of graduate students in astroparticle physics should consist of a combination of introductory courses, topical lectures and an advanced research school:

- Once a year a research school of about one week should be attended that is partly dedicated to introductory lectures in the field of astroparticle physics. Subjects covered may include elementary particle physics, astronomy, gravitation, cosmology, neutrino physics, cosmic background radiation, star models, data acquisition etc. Part of the time will also be spent on preparing, presenting and reviewing student lectures on recent papers that have appeared in the astroparticle physics literature.

- During every year the students will be asked to also attend a series of *topical lectures*, hosted by one of the participating institutions. These lectures, which will be presented in just a couple of days including some practical training, will go beyond the introductory approach adopted at the research schools.

- Senior graduate students (in their 3rd or 4th year) should attend an advanced school on astroparticle physics. Such a school will typically have an international character, and thus be open to students from outside the Netherlands as well. Within the Netherlands such a school will be organized every two years. Excellent lecturers from both inside and outside the Netherlands are invited to present the most advanced developments in the field. Moreover, modern educational techniques will be used in the afternoon to train the students in defending and reviewing research proposals in a competitive fashion. Experience with such an advanced school was obtained in 2003, when the first Nijmegen school on Astroparticle Physics was organized (chaired by P.J.G. Mulders). This type of school was highly appreciated by students and lecturers alike[16].

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[15] In early 2005, several Dutch groups have been approached by astroparticle physics groups from Germany (Erlangen and Wuppertal) to participate in a joint German-Dutch "International Research Training Group", which could – if approved – be integrated in the presently proposed training structure for astroparticle physics graduate students in the Netherlands.

[16] The preparations for the 2nd Nijmegen school on Astroparticle Physics, which is scheduled for early

As was already mentioned above, the students should also be part of a monitoring system. Such a system should involve, for instance, a monitoring committee ("MC") consisting of the direct supervisor, the formal PhD advisor, and an external member. The committee meets the student at least once a year to discuss results obtained, possible problems encountered and plans for the coming period. A brief report is made of these formal MC meetings, which will be kept on file. The meetings will serve as milestones for the graduate students, and enable the identification of serious problems at an early phase such that appropriate actions can be taken. Such actions may include a change of subject, additional training, or anything else that is deemed necessary to successfully complete the PhD thesis.

As a last element of the training the national astroparticle physics symposia should be mentioned. Twice a year all scientists that participate in the new research program meet in a national symposium, which will be the continuation of the already initiated national astroparticle physics symposia[17]. Graduate students will be encouraged to present the results of their work at these meetings such as to give them experience in presenting scientific results to a broad audience.

September 2006, have already started. The organizing committee is composed of J. Kuijpers (RU), P.J.G. Mulders (VU), G. van der Steenhoven (NIKHEF/RuG – chair) and R.J.G. Timmermans (KVI).

[17] This series of astroparticle physics symposia has already been initiated in 2004, when symposia were organized in Amsterdam (April '04) and Nijmegen (Sept. '04). The 3rd and 4th "APP" symposia are hosted by Leiden (Jan. '05) and Groningen (April '05).

5. Outreach

Outreach activities are of growing importance in society because of two reasons. On the one hand the general public needs to be (and wants to be) informed about the exciting developments at the forefront of research; on the other hand the continuous demand for well-educated young researchers with a PhD in science, makes it increasingly important to convince young people to start studying physics, astronomy or a related subject at the university. Research in astroparticle physics is particularly suited for outreach activities as the developments in this field are related to very basic questions concerning the origin of matter, energy and the universe, which appeal to a broad audience. In fact, one of the most successful outreach programs in the Netherlands (or Europe for that matter) is based on astroparticle physics: HiSPARC.

In 2002 Dr. Charles Timmermans of the Radboud University, initiated the *Nijmegen Area High School Array* (NAHSA) project. Within the framework of this project scintillator detector arrays were constructed, which were subsequently placed at the roofs of a number of local high schools to observe extended air showers. In 2003, Prof. Bob van Eijk (NIKHEF/UT) and Prof. Jan-Willem van Holten (NIKHEF/VU) took the initiative to extend this idea beyond Nijmegen by developing a country-wide network of such cosmic ray detectors. This project, which carries the name HiSPARC (*High School Project on Astro*[*particle*] *physics Research with Cosmic rays*), is designed as an open network enabling other schools and academic institutions to join. Presently, between 20 and 30 high schools are involved, clustered around 6 universities, and the number is growing. HiSPARC is mainly an educational project, but the spatial distribution of the various schools in the network makes it possible to observe extended air showers with a spread of a few kilometres, which correspond to cosmic rays of ultra-high energy (i.e. in excess of 10^{18} eV). The observation of ultra-high energy cosmic rays is certainly of scientific interest as well, and fits in very nicely with the main theme of the presently proposed research program.

The goal of HiSPARC is to involve high-school students directly at all stages of scientific research. The project provides them with first-hand experience in scientific measurements and teamwork. As a first step, the high-school students construct their own (scintillator) detector under supervision of a scientist at one of the participating universities or institutes. Next, the detectors are tested and calibrated, whereafter they are put into operation on the roof of their school. The individual systems at each school are connected via internet to a central computer that collects all data, which are freely available to all participants.

All schools, universities and research institutions involved contribute to the project by providing students, teachers, technical staff and scientific staff. In addition universities, scientific societies, industry, private organizations and schools have supported the project financially. In 2004 HiSPARC has won the Altran Foundation Award 2004 in a pan-European competition under the theme: *Discovering, understanding and enjoying science through innovation.*

In practice all students, teachers and scientists involved are extremely enthusiastic about this project. Science is brought to the high schools; students become increasingly interested in research and are increasingly attracted by science in general.

The development of astroparticle physics as a new interdisciplinary research effort in the Netherlands will profit from a continuation and expansion of the HiSPARC project. The first symposia on astroparticle physics in the Netherlands already gained active participation of several high-school teachers, and the success of the HiSPARC project starts to attract students into physics and astronomy. Moreover, the first observation of extended air showers corresponding to energies beyond 10^{18} eV implies that the project has scientific potential as well. For all those reasons, the present strategic plan includes the following outreach activities:

- HiSPARC. More and more schools are interested to participate in this project. Resources are needed for the national supervision and management of the emerging network of cosmic ray detection systems. Apart from the construction of new detector systems, new analysis tools need to be developed that provide direct access to the data for the high-school students involved.

- LOFAR@SCHOOL. One of the LOFAR 'beams' can be reserved for educational purposes. Furthermore, the possibilities to install relatively simple LOFAR radio antennas on high schools will be explored. Combining HiSPARC and LOFAR stations would increase the possibilities for high-school based research projects even further. At present, a pilot project of this type is being developed at Nijmegen (under the name 'LORUN').

- MASTER CLASSES. Professional scientists will give master classes at high schools on challenging astroparticle physics topics, explaining as simply as possible the origin and challenge of the key scientific questions that implicitly define astroparticle physics (on dark matter, dark energy, cosmic rays, the structure of the universe, gravitation and changing constants of nature). Such classes supplement the hands-on activities mentioned above.

6. Computing

The computing needs for the proposed astroparticle physics projects in the Netherlands are very significant. The LOFAR radio telescope, for instance, produces data at a rate of 20 TByte/s, while the planned KM3NeT deep-sea neutrino telescope will yield some 10 GByte/s. The rates for LOFAR are of such a size that advanced data handling techniques need to be developed to extract the desired scientific information from the data streams. Although the KM3NeT rates are substantially lower, these rates are still very large considering the fact that this data stream has to be retrieved from a hostile deep-sea environment. The issue is further complicated by the fact that both telescopes operate as a "virtual observatory", or – phrased differently – as a software telescope. The raw (unprocessed) data are transported to a central computing facility where searches are carried out for certain directions, bandwidths or other specific features of the data. In the past such searches were implemented in hardware by defining certain electronic hardware triggers, or – in the astronomy case – by actually directing the telescope in a certain direction.

The solutions considered for the computing requirements of the two projects mentioned above[18] are somewhat different. While in both cases use is made of multi-bandwidth data transport from the individual detector units to the central data collection station through optical fibres[19], the processing of the main data stream is handled differently:

- At LOFAR all data are directed to one of the largest central computers in the world, the IBM "Blue Gene" computer, which is hosted by the University of Groningen. In this computer the basic synthesis of the individual radio signals is applied to the data, reducing the amount of data to several Gbits/s. Further processing of the data is still needed, which can be carried out at major computing centres such as the proposed "TIER-1" facility in Amsterdam[20].

- At KM3NeT the 'all-data-to-shore' concept developed for the ANTARES project implies that all data are channelled to a large computing farm in the local shore station of the detector. In the PC farm several search algorithms are being applied to the data. However, with the expansion of the research program of the deep-sea neutrino telescopes many searches need to be carried out simultaneously. One solution is to transport the data to a range of local computing facilities spread out over Europe, each one of them focussing on a different type of search. In such an approach modern GRID technologies (i.e. for distributed computing) can be used.

From the brief description above it is clear that the most advanced techniques developed in e-science for the distribution, storage, services, and processing of very large data sets need to be used in astroparticle physics research. These needs are not

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[18] In this section no attention is given to the computing needs for the Mini-GRAIL and LISA projects, as they are substantially less demanding than those of LOFAR and KM3NeT.

[19] Optical data transmission technology employing the so-called Dense Wavelength Division Multiplexing (DWDM) concept is currently providing about 100 colour channels per optical fibre with which transmission speeds of 10 Gb/s and more can be achieved.

[20] The TIER-1 facility in Amsterdam was primarily designed for processing particle-physics data produced by the LHC experiments at CERN, but now other applications are considered as well.

unique for astroparticle physics, as similar challenges are encountered in astronomy, particle physics, bio-informatics, meteorology, and other disciplines. Obviously, a close collaboration between these fields is mandatory in order to maximally profit from the necessary infrastructure. For that reason it has been decided NOT to include a separate request for computing infrastructure in the financial paragraph of the present plan (see section 8). Instead the local infrastructure and computing needs for astroparticle physics in the Netherlands will most likely be included in the strategic plan (2006 – 2010) of the Dutch foundation for "Nationale Computer Faciliteiten" (NCF). This strategic plan, which is presently being prepared, will encompass all computing needs for a number of sciences in the coming years.

For the present proposal it suffices to mention that the astroparticle physics community in the Netherlands strongly supports the systematic development of the most advanced computing facilities together with the necessary high-speed and high-bandwidth connections. At the European level the further improvement of the connectivity needs to be advanced as well. For the European exploitation of Dutch infrastructures such as LOFAR, and for the distribution of raw ANTARES (or KM3NeT) data throughout Europe high-bandwidth connections capable of operating at rates in excess of several GByte/s need to be realized.

7. Application perspective in industry, other disciplines or society

The presently proposed interdisciplinary research program is of immediate interest to neighbouring disciplines such as physics, astronomy and cosmology, for which the origin and nature of dark matter and dark energy, for instance, forms an equally large and challenging research topic. However, there is another aspect to experimental astroparticle physics research projects that is highly relevant for many other scientific areas and society at large. This is the concept of a *sensor network*. Essentially all projects included in the proposed research program (with the exception of MiniGRAIL) consist of a collection of individual detectors interconnected by high-bandwidth signal connections. While LOFAR, for example, consists of a very large number of relatively simple radio receivers, KM3NeT will consist of a large number of photomultiplier tubes. Such sensor networks can be used for other detection systems – relevant for other sciences – that make use of the same infrastructure. Examples include seismic detectors that can provide information on movements of the ground or the bottom of the sea, respectively.

Some details on the application perspective of the detector projects singled out for the present proposal are briefly described below:

- Radio detection of cosmic rays. In the original proposal advocating the construction of LOFAR, it is already mentioned that the LOFAR sensor network will also be used for geophysical research (long-term monitoring of movements underground, which will provide information on the lowering of the surface, the local water management and possible resources such as natural gas), ICT research (data mining, data visualisation, coupling to distributed computing systems – GRID, etc.) and agricultural research (optimization of production processes through wireless sensor networks).

- Deep-sea neutrino detection. The operation of a deep-sea neutrino detector has generated the interest of marine biologists, as it enables continuous monitoring over very long periods of time of light-emitting (bio-luminescent) life forms that inhabit the depths of the seas. Such biological studies are – among other subjects – focused on the impact of these life forms on the CO_2 balance in the oceans. As the operation of deep-sea neutrino detectors also involves the generation, transport, storage and analysis of relatively large amounts of data (at least for data originating from the bottom of the sea) there is a potential common interest with groups involved in developing intensive computing and grid technologies (e-science). Moreover, long-term measurements of oceanographic (current velocity and direction) and environmental (temperature, conductivity, salinity, pressure) parameters will be possible for the first time.

- Gravitational wave detection. The miniaturized inertial-sensor control & readout electronics developed by SRON (and Dutch SME) will also be applied in the next generation Earth gravity missions. This mission is known as the Laser Doppler Interferometry Mission (LDIM), which will perform ultra-precise measurements of the time variable gravity field of the Earth for the determination of mass displacements; examples includes patterns in sea level variation, hydrology and geodynamics. This type of mission will make use of laser interferometry between inertial sensors of the LISA type. Such measurements are thus of immediate relevance for other fields of science such oceanography, hydrology and geodynamics. The same miniaturized design can also be applied to future Mars gravity gradiometers and/or lander seismometers. The latter technique is included in the Dutch national platform for planetary research (NPP) coordinated by the SRON program bureau and NIVR, the Netherlands' Agency for Aerospace Programs. Moreover, there also are very good opportunities for Dutch industry to participate in the LISA mission: TNO Science and Industry (for laser metrology, pointing mechanisms and the caging mechanism), Bradford Engineering (for cold gas micro propulsion techniques) and Dutch Space (for real-time system test beds and simulations, and the caging mechanism together with TNO S&I). Recently, SRON signed a (non-exclusive) cooperation agreement with TNO S&I and Dutch Space aimed at the coordination of future applications of their respective technologies in the DARWIN and LISA space missions. While TNO S&I is specialized in ultra precision optic mechanical systems, Dutch Space is the Netherlands largest space industry. This agreement should facilitate the preparation of national programs.

It is concluded that many application horizons exist for the technologies used – or proposed – in the framework of the present plan. It is emphasized, however, that the present strategic plan for astroparticle physics in the Netherlands does not include requests for the resources needed for the full development of the applications listed above.

8. Finances and management

In this section the financial requirements and the management structure of the proposed research program are described. In subsection 8.1 the annual budget of the program is presented including the somewhat more specific budget needs for each of the main themes of the research proposal. The investments needed to carry out the proposed research are discussed in the next subsection, while subsection 8.3 presents the proposed management structure of the program.

8.1 Annual running budget

To launch a new research program on astroparticle physics both senior and junior manpower is needed. As a first step in evaluating the total resources needed for a successful research program of the type described in section 3.2, an inventory has been made of the expenses for senior and support staff (engineers) that are already working on astroparticle physics research or have agreed to do so in the near future. The result of this exercise is shown in the columns labelled “2006” of table 3. It is emphasized that the budgets (and numbers of FTEs) listed do not include any junior staff, EU-support, or any other incidental support that groups sometimes have already been able to acquire[21]. According to table 3 the total amount of money that will be spent annually on paying permanent staff in astroparticle research in the Netherlands already adds up to about 3.2 M€ for 2006. Assuming that the proposed plan for astroparticle physics research is realized, a larger number of faculty members at the universities, and staff members and engineers at the institutions will start working on astroparticle physics. This increased commitment of university groups and institutes to astroparticle physics is represented by the last columns of table 3, which are labeled “2010”. In this case the total amount of money is estimated to add up to about 4.5 M€. In order to properly assess these numbers it should be realized that (a) these amounts are estimates only; (b) this commitment requires no major additional investments; (c) these numbers do not include costs for hiring graduate students or postdocs, travel money, or any other material costs; and (d) the large amount of manpower involved in the construction, commissioning and hardware maintenance of LOFAR is not included in these numbers.

Apart from the baseline funding contained in table 3, additional resources are needed for hiring graduate students and postdocs, travel money, contributions to the operational budgets of the selected experiments or observatories, special fees, minor material expenses and some contingency. Below an estimate is given of the required additional budget for each main activity of the proposed research program. The following nominal amounts have been assumed (which include the full employer costs):

- Graduate student: 41 k€ (salary) + 15 k€ (travel, etc.) = 56 k€ per year;
- Postdoc: 58 k€ (salary) + 15 k€ (travel, etc.) = 73 k€ per year;
- Engineer: 50 k€ (salary) + 5 k€ (travel, etc.) = 55 k€ per year.

[21] Two remarks are in order: (i) the amount of incidental support acquired for astroparticle physics research in recent years is discussed in appendix A1.6 with some numbers given in table 6; (ii) as the various institutions use different calculation models for evaluating the overhead costs, the budget figures provided by each group can only be globally compared.

Other costs, such as contributions to the annual operation costs of the experiments and *Table 3. The total amount of resources committed to astroparticle physics research in the year 2006. The numbers only include permanent scientific staff, engineering staff and overheads (20 – 40%, depending on case) that the university groups and national research institutions are planning to spend on this type of research. No junior manpower or materials are included. For the year 2010 rough estimates are given of the same numbers, based on the present planning of the various institutes and research groups.*

Institute	Contact	FTEs '06	Budget '06	FTEs '10	Budget '10
UvA-astro.	RAMJ Wijers	1.7 FTE	140 k€	1.7 FTE	140 k€
UvA-phys.	J Smit	1.0 FTE	110 k€	1.0 FTE	110 k€
ASTRON	H Falcke (/RU)	3.0 FTE	230 k€	3.0 FTE	230 k€
RuG-astro.	R vd Weygaert	0.5 FTE	55 k€	0.5 FTE	55 k€
RuG-phys.	E Pallante	0.5 FTE	55 k€	1.0 FTE	110 k€
KVI	AM vd Berg	4.6 FTE	560 k€	6.2 FTE	750 k€
UL	A Achúcarro	2.2 FTE	265 k€	1.2 FTE	135 k€
RU	J Kuijpers	2.5 FTE	398 k€	3.8 FTE	525 k€
NIKHEF	FL Linde	7.0 FTE	830 k€	19.0 FTE	1.630 k€
SRON[22]	AM Selig	5.2 FTE	280 k€	6.0 FTE	400 k€
UU-astro.	A Achterberg	0.5 FTE	55 k€	0.5 FTE	55 k€
UU-phys.	T Prokopec	1.2 FTE	133 k€	1.2 FTE	132 k€
VU-phys.	PJG Mulders	1.0 FTE	110 k€	2.0 FTE	220 k€

fees to be paid upon joining an experiment, differ from case to case. Benchmark fees or overheads are included at the level of 10%, although it is realized that arrangements are different for each university group or institute. Including all these considerations we arrive at the following budget description (and estimates) for each one of the proposed research activities in astroparticle physics in the Netherlands:

- Radio detection of cosmic rays. This part of the scientific program requires a fairly large number of graduate students and postdocs, as it involves the development of radio detection of cosmic rays at Auger including radio detection in the horizontal direction to observe neutrinos – for which LOFAR is not sensitive – and related measurements. For LOFAR[23] it is assumed that about 6 PhD students and 2 postdocs will be hired, while for Auger an additional 3 PhD students and 1 postdoc will suffice. Material expenses are assumed to peak in 2008/9 at 50 k€ being somewhat less before and after that time. Starting from 2007 an annual contribution of 300 k€ to the operation of LOFAR is included in the budget. The foreseen hardware investment in the Auger experiment (estimated at 200 k€) and the annual contribution to the

[22] The base-line budget for SRON in 2006 is based on the known contribution to the LISA-Pathfinder mission. The estimate for 2010 represents the anticipated contribution to the LISA mission itself as financed by SRON itself. The total annual effort from SRON for LISA is expected to be about 19 FTE and 950 k€. The difference with the amounts quoted in the table for 2010 is expected to come from other sources such as ESA.

[23] Note that "Ultra-high energy cosmic rays" is one of the four key programs of LOFAR. It is assumed that the funding of the "Development & Commissioning of LOFAR for Astronomy (DCLA)" has been secured. In the present budget request no contribution is asked for the DCLA; only an annual contribution to the scientific operation of LOFAR is included in table 4.

common fund have also been added to the budget A build-up of 2 PhD students and 1 postdoc per year is assumed in constructing the budget profile. Moreover, participation to the Auger project is assumed for 5 years (2006 – 2010), while the involvement in LOFAR is assumed to cover the entire duration of the program. The annual expenses reach about 1050 k€ in 2008, while they are down to about 800 k€ in 2012 and beyond.

- Deep-sea neutrino detection. The full development, commissioning and exploitation of the proposed deep-sea neutrino telescopes require typically 6 graduate students and 2 postdocs. As the exploitation of the ANTARES project and the development and construction of the KM3NeT project are intertwined (and very much related) no distinction is made between students working on either project. In evaluating the annual costs for these activities it has to be realized that the exploitation costs of the deep-sea telescopes are very high because of submarine operations. For that reason the annual contribution to the operation of the experiment is estimated at 180 k€. Moreover, the specific development work needed for KM3NeT requires the hiring of additional support staff (1 postdoc and 1 engineer) for 3 years in the period 2007 – 2010. Obviously, this results in year-to-year differences, but on average an annual budget of about 700 k€ is needed for this part of the program with a peak of about 850 k€ in 2009.

- Gravitational wave detection. University-based research in gravitational wave detection will be built up during the initial years of the proposed research program. Physics and astronomy departments in Amsterdam (VU), Leiden (LU) and Nijmegen (RU) have expressed interest in developing such research groups. Moreover, in view of the explorative nature of the research work for LISA (and LISA pathfinder) initially postdocs need to be hired. In fact, a relatively slow increase in the number of postdocs and graduate students is foreseen. Also, supplemental engineering support staff (based at SRON) will be needed in the years 2007 – 2012 for the full realization of this advanced satellite based experiment. In the early phase of the program 1 postdoc and 1 graduate student will be hired for the exploitation of the MiniGRAIL experiment. The annual budget is expected to reach 550 k€ in 2008 and level off to 450 k€ in later years.

  Theoretical astroparticle physics. As has been argued in section 3, experimental and observational work in astroparticle physics needs to be accompanied by theoretical activities. Theoretical work needs an entirely different organization, involving many smaller groups throughout the country. It also needs a flexible structure to adapt itself to new developments and research directions. For this purpose 9 positions for PhD students are created at a rate of 3 positions per year during the start-up of the program. A description of the major research subjects around which the theoretical research will be centred can be found in subsection 3.2. The positions are allocated by management of the program ("DBA" – see subsection 8.3) upon advice of the scientific advisory council ("ROAD" – see subsection 8.3). The *annual budget* will increase from 200 k€ in 2006 to 550 k€ in 2009.

- General costs. Two main budget categories are included under this heading:

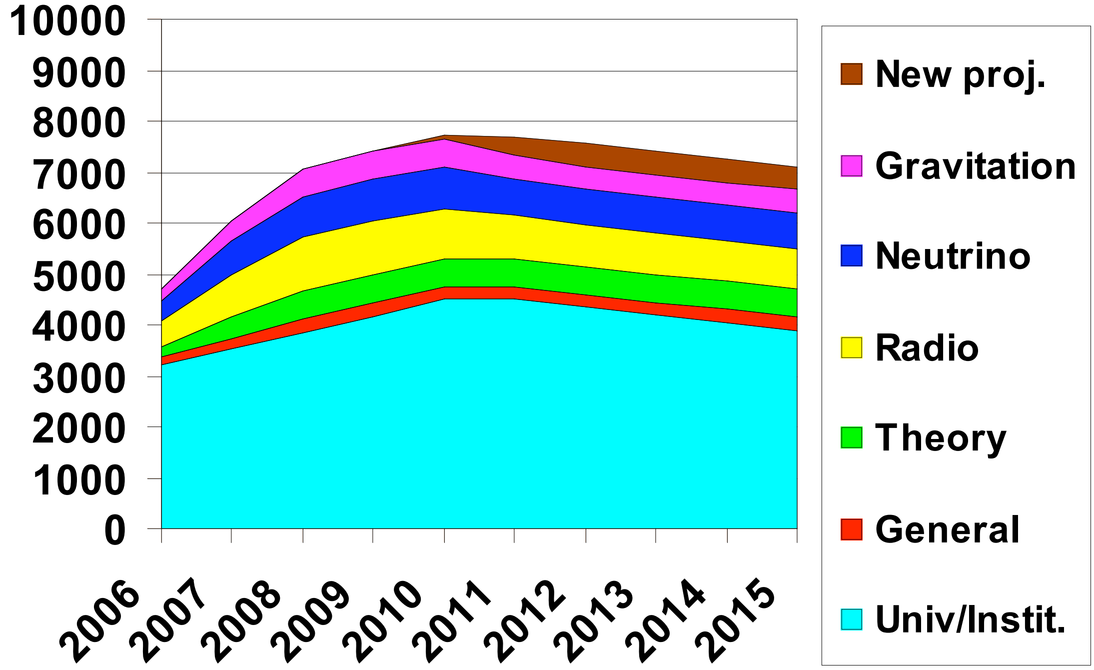
Table 4. Overview of the additional (i.e. not covered by the existing resources at the participating institutions) expenses of the proposed research program in astroparticle physics. For each of the planned research activities the annual expenditures shown include junior staff, travel, operational costs and overheads (and are expressed in k€'*s).*

Activity	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
RADIO	500	850	1050	1050	1000	850	800	800	800	800
NEUTRINO	400	650	800	850	800	700	700	700	700	700
GRAVITAT.	250	400	550	550	550	500	450	450	450	450
THEORY	200	400	550	550	550	550	550	550	550	550
NEW PROJ	-	-	-	-	100	350	450	450	450	450
GENERAL	150	200	250	250	250	250	250	250	250	250
TOTAL	1500	2500	3200	3250	3250	3200	3200	3200	3200	3200

- *Outreach.* High-schools participating in the outreach projects HiSPARC and LOFAR@SCHOOL are in most cases able to generate their own funds for purchasing the necessary equipment. However, for the national coordination of the project, including the development of new outreach initiatives one physicist at the postdoc level needs to be hired. Moreover, some teachers need
  to be supported temporarily, and materials need to be purchased for new initiatives. *Annual budget: 150 k€.*

- *Management.* The management structure of the program, as described in subsection 8.3, needs financial support. The estimated costs include 50% of the salary of a senior faculty or staff member, costs for administrative support and financial support services. *Annual budget: 100 k€.*

The result of these budget estimates is listed in both table 4 and figure 8 (next page). In the figure the budget profile also includes the estimated base funding allocated for astroparticle physics by the universities and institutes. It is observed that the total annual budget of the proposed research program increases from slightly more than 4.7 M€ in 2006 to about 7.7 M€ per year in 2010. Almost 60% of this budget is provided by the universities and institutes, while the additional budget requested to realize the objectives of the present research program increases from 1.5 M€ in 2006 to about 3.2 M€ in 2009. As was mentioned before, these additional resources are primarily needed to hire junior scientific staff, i.e. graduate students and postdocs. Given the potential of the research field it is to be anticipated that after a couple of years new astroparticle physics initiatives will be taken. Hence, by proposing a fixed additional annual budget of 3.2 M€ for the years after 2010, financial room for such new initiatives becomes available in those years. This has been indicated in table 4 and figure 8. The subject of such a new initiative, its selection and the progress with the ongoing research efforts will be discussed at a *mid-term review* evaluation that will be scheduled at about the same time. It is noted that the peaking of the base funding at the universities and institutes is largely generated by development and construction work for the LISA project.



The proposed interdisciplinary research program in astroparticle physics, which will

Figure 8. The budget profile, showing a time-line of the requested funds for the proposed research program in astroparticle physics. The annual budget is given in k€, while the legend on the right-hand side identifies the budget each band represents.

run from 2006 to 2015, has a total estimated budget of about 70 M€, of which about 40 M€ will be provided by the participating universities and research institutes (NIKHEF, KVI, ASTRON and SRON). With an initial budget allocation of 15 M€, the proposed research program can be fully developed for the first 5 years, where after a new allocation needs to be requested to cover the second part of the program. From the project descriptions given above it is concluded that after a couple of years the newly proposed research program will employ an estimated 28 graduate students, 8 postdocs and 4 engineers. With such an effort the visibility and impact of the Netherlands in the new interdisciplinary research field of astroparticle physics is ensured.

8.2 Investments

The construction of the large instruments that are needed for astroparticle research requires significant investments. As the presently proposed research program makes use of several instruments which are under construction – or which have recently been completed – the required capital investments are limited to three projects:

- Auger. The construction of the Pierre Auger Observatory in Argentina is being realized by foreign (but mostly European) funding agencies, not involving any previous Dutch investments. When joining the Auger collaboration at this stage, some contribution (in hardware for instance) is expected from the Dutch groups. For this reason a budget of 200 k€ has been added to the 'Radio' budget of the present program for 2006 listed in Table 4. Part of this money can be used to partly equip Auger with radio antennas similar to the LOFAR antennas but now sensitive to horizontally incident cosmic rays as well. The full cost for equipping Auger with radio antennas is estimated to be 5 M€, which will be realized as a new – fully international – investment in the experiment. A more detailed budget estimate is expected to be available in 2008, which will be based on further development work in this direction foreseen in the framework of the present strategic plan. Future extension of the Auger project may also involve the design and construction of Auger North, which will most likely be built in the United States. The Auger North project is expected to start in the year 2007.

- KM3NeT. While for the design of the large deep-sea neutrino telescope KM3NeT European support is available (at a level of approximately 10 M€), its full construction – which is foreseen to begin in 2009/2010 – will require a total pan-European investment of about 200 M€. Assuming that about 4% of this investment needs to be supplied by the Netherlands, which is fairly common for European projects of this size, an investment of 8 M€ will be needed. This amount of money has not been included in the present proposal. When the design of KM3NeT is finalized and a better estimate can be given of the total budget of the project and the type of equipment that will be developed in the Netherlands, a separate request will be submitted to the '*NWO-Groot*' scheme. Such a proposal can be anticipated in 2009.

- LISA. Part of the technology that is needed for the successful operation of LISA will be tested by the LISA-Pathfinder mission, in which SRON is investing about 1250 k€ (spread out over 5 years). This will result in the delivery of the Inertial Sensor Test Module (ISTM) and associated software in 2006. The quoted investment includes manpower for system-level test support and flight data analysis. In the nearby future SRON will apply for additional support in order to be able to contribute to the development and construction of the LISA satellite mission as well. The corresponding investment (which is estimated at 7 M€) is likely to be part of a national plan for aerospace development, which is jointly set up by the ministries of economic affairs, public health, and education, culture and science. It is not foreseen that additional funds are requested from one of the NWO investment schemes. The resources requested in the present proposal for gravitational wave detection are to a large extend aimed at complementing the technical developments for LISA at SRON by supporting university-based groups that are planning to become involved in the analysis and interpretation of the data of the first gravitational wave observatory.

It is concluded that relatively modest investments (as discussed in this subsection) and annual costs (discussed in the previous subsection) give access to a range of high-tech, very expensive astroparticle physics instruments that have a price tag that exceeds the possibilities of the Dutch budget for fundamental research in physics and astronomy by a considerably. As the participation in these projects – for which Dutch scientists are often approached in view of their expertise – gives access to all data that are produced by these instruments, the proposed research program is effectively supported by large international resources coming from outside the science budget available in the Netherlands.

8.3 Organization and management

A research program of the size presently proposed requires a transparent organization and management structure. Also, the chosen organizational structure needs to reflect the inter-disciplinary character of the research program. Taken these considerations into account the following formal organizational structure is proposed[24]:

- The daily scientific and financial management of the research program is carried out by the "*Dagelijks Bestuur van het onderzoeksprogramma Astrodeeltjesfysica* (DBA)" which consists of a program director, and four program leaders. The program director chairs the DBA and carries the full executive responsibility, while each program leader is responsible for one of the four main activities of the research program: (1) radio detection of cosmic rays; (2) deep-sea neutrino detection; (3) gravitational wave detection and (4) theory. The DBA members are appointed for the duration of the program. For each main activity, research plans, monitoring systems, budget profiles and allocations per participating institution have to be set up.

- The DBA reports to a *Steering Group* (SG), which will be put together by the funding agencies supporting the proposed research program. It is up to the funding agencies to decide on the composition, name and mandate of this body.

- All institutes and university groups participating in the proposed research program are represented in the "*Raad voor Onderzoek in de Astro-Deeltjesfysica* (ROAD)". The ROAD is an advisory council to the DBA. This council gives advice on scientific issues, symposia and research schools. The members are appointed by the participating institutes and universities[25].

- Support with administrative, organizational, financial and human resource matters is given by the research institution hosting the management of the program (for a nominal fee). Typically, but not necessarily, the home institution of the program director (called the *host institution*) will be asked to take on these duties.

Depending on the way the financial support for the proposed astroparticle physics program will be structured, the funding agencies (in consultation with the DBA) will set up a system for the distribution of the financial resources over the various participating groups and institutions. It is noted that the allocation of resources among the various theory groups may have to be organized somewhat differently as compared to the other three main activities of the program. Also, the funding agencies (again in consultation with the DBA) will define a peer review system – involving mid-term reviews etc. – to be able to monitor the scientific progress achieved by the proposed research projects.

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[24] Depending on the way the financial support of the proposed research program is realized, the structure of the organization and management of the program may have to be adapted.

[25] This advisory body could be the natural successor of the 'Commissie voor de Astrodeeltjes-fysica in Nederland (CAN)' and may also serve as an interdisciplinary scientific network as recognized by the participating funding agencies.

The entire Dutch community of astroparticle physicists will meet twice a year at the *astroparticle physics symposia.* As was mentioned before, the first set of such national symposia has already taken place. This successful meeting series will be continued. At these symposia important results and developments are presented, international experts are invited for review talks, graduate students and postdocs are given the opportunity to present their results at a national level, and the community can discuss issues of common interest.

Appendix 1: Existing astroparticle physics projects in the Netherlands

Research in astroparticle physics in the Netherlands dates back to the nineties, when first ideas were developed to build a spherical gravitational wave detector, known as GRAIL. Later, one of the particle physics experiments at CERN (the L3 experiment, see figure 9) was equipped with additional scintillators to be able to measure the cosmic ray spectrum, which led to several PhD theses on the subject and the start of the NAHSA project[26]. More or less at the same time, nuclear physics reactions that are relevant for the understanding of supernovae and gamma-ray bursts were studied at the cyclotron AGOR at the KVI in Groningen, and – again somewhat later – a small group at Utrecht University got involved in the AMANDA project exploring the possibility to search for high-energy cosmic neutrino sources. It should also be mentioned that the cooling system of the Alpha Magnetic Spectrometer (AMS-02), which was constructed with the aim of searching for direct evidence of anti-matter and dark matter on board of the International Space Station, was designed at NIKHEF in Amsterdam.

After these early initiatives, the various funding agencies in the Netherlands gave support to four different projects that are described one by one in the following subsections. At present, each of these projects is either under construction or has entered the commissioning phase. However, because of the interdisciplinary character of these four projects regular funding is not secured, and it is not clear whether any of these projects can be adequately exploited in the future. This issue is discussed in

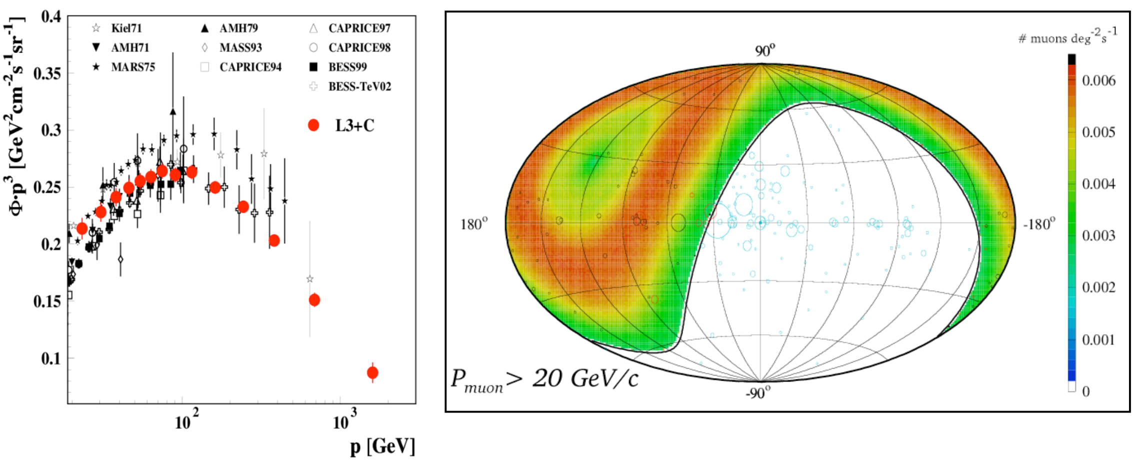

Fig. 9. In the left-hand panel the worlds best muon spectrum at sea-level (red dots) is shown. The data are derived from measurements by the L3+C collaboration at CERN (H. Wilkens, PhD Thesis, Radboud Universiteit, Nijmegen, 2003). On the right-hand side the absence of correlations between the muon fluency above 20 GeV/c as measured with L3+C at CERN and the positions of the unidentified Gamma-Ray sources as reported by EGRET is shown. The blue circles represent the calculated fluency (M. van den Akker, PhD Thesis, Radboud Universiteit, Nijmegen, 2005) for some of these sources.

[26] The Nijmegen Astrophysics High-School Antenna (NAHSA) project was the local predecessor of the national HiSPARC project, the Dutch astroparticle physics outreach project that is further explained in section 6 of this document.

section 3, while the present appendix continues – in subsection A1.5 – with an overview of ongoing theoretical work in the field of astroparticle physics in the Netherlands. It should be noted that no significant resources are available for the development of theoretical activities in this field either. This appendix is concluded in subsection A1.6 where a quantitative summary of the present Dutch involvement in astroparticle physics is presented.

A1.1 Cosmic ray detection with LOFAR

Radio astronomy is currently undergoing a major revolution with the introduction of digital phased arrays, of which LOFAR is the first. LOFAR (Low-Frequency Array) is an array of a large number of cheap radio antennas that are combined to form a giant and very sensitive radio telescope with hitherto unknown possibilities. Early digitisation and the processing of the radio signals in supercomputers, lead to an extremely flexible, real-time software telescope. This new type of telescope makes it possible to explore the universe in a largely uncharted frequency domain. The new data that will be collected with LOFAR will provide information ranging from the earliest phases of the universe to the most violent explosions in space and down to relativistic particles hitting the Earth. LOFAR is the first radio telescope that will observe radio signals from the entire overhead sky, on all time scales, and at a large range of frequencies. By making use of data buffering techniques LOFAR will be able to store the full data stream for a couple of seconds, which is important for searches initiated from an external sources such a satellite signalling the observation of a Gamma Ray Burst.

So far telescopes have always looked in pre-defined directions on the sky. Transient signals that occur unexpectedly from an unknown direction on the sky that last for only a very short period of time are impossible to detect with conventional radio telescopes. LOFAR, however, has antennas that simultaneously receive signals from the *entire* sky. After digitization of the signals, a central computer synthesizes a virtual radio telescope with a number of directed beams. In this way a radio image of the sky in a specific direction is constructed. Hence, it is the main goal of LOFAR to survey and monitor the entire sky. It is hoped that this will lead to the observation of the so-called “Epoch of Re-ionisation”, and the first generation of black holes and galaxies in the universe.

One of the other key programs of LOFAR is the study of high-energy cosmic rays in the range 10^{15} -10^{20} eV. The foundation for this program is the geo-synchrotron effect: coherent synchrotron radiation, emitted by the e^-/e^+ cascade in an extensive air shower that is created when a primary cosmic ray hits the terrestrial atmosphere. LOFAR can detect this emission, and is expected be able to determine the direction of the primary cosmic ray as well as its energy. The primary can be a hadron (including neutrons from galactic sources), a very high-energy gamma ray, or a neutrino arriving horizontally.

To test this new approach, a LOFAR Prototype Station (LOPES) has been installed at the “Forschungszentrum Karlsruhe” in Germany next to the cosmic ray detector array “KASCADE Grande”. Using the first LOFAR antennas, the experiment now regularly measures the radio emission from extended air showers induced by cosmic rays. It has

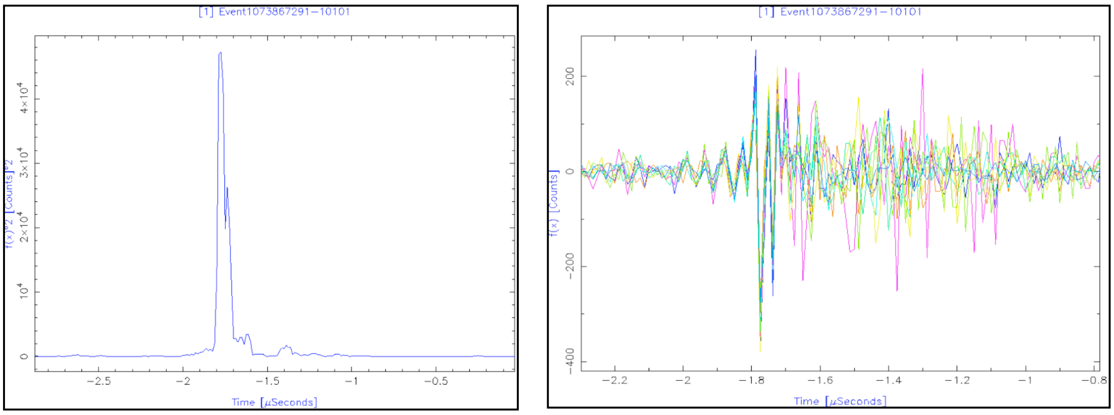

Fig. 10. One of the first results obtained with the LOPES test set-up. On the left-hand side a beam-formed signal obtained with 8 antennas is shown. The relative strength of the electric field amplitude is displayed versus time (in microseconds). This event, collected in January 2004, represents one of the many events that were simultaneously observed with the KASCADE particle detector (see figure 4). It demonstrates that radio emission coming from high-energy cosmic ray air showers can be observed. On the right-hand side the same event is shown, but now the total signal measured by LOPES is plotted.

thus confirmed the geo-synchrotron effect, and provides a first cross-calibration between conventional arrays and LOFAR.

Radio detection of high-energy cosmic rays offers a new, efficient method that is complementary to particle detectors at the Earth's surface. As compared to fluorescence detectors, for instance, radio detection is 100% efficient. Unique features of studying high-energy cosmic rays with LOFAR are:

- The physics of the electromagnetic part of the extended air shower can be unravelled by determining the location of the maximum of the shower.
- Cosmic rays with energies above $2 \cdot 10^{14}$ eV can probably be observed with LOFAR. This will allow the study of anisotropies in the distributions of the arrival directions of high-energy cosmic rays, their propagation and source origin.
- Above energies of 10^{15} eV, the composition of cosmic rays can be studied through the Gerasimova-Zatsepin effect, i.e. by observing simultaneous pairs of air showers that are separated by distances up to several 100 km. In 1960 Gerasimova and Zatsepin first argued how photo-disintegration of cosmic rays may occur in the solar radiation field leading two distinct air showers. By comparing the energy and direction of these two showers information on the original composition of the cosmic ray can be obtained.
- Galactic neutron sources for cosmic rays with energies above 10^{18} eV can be discovered.

The search for ultra high-energy cosmic-rays by means of radio signals will already be explored by making used of the Westerbork Synthesis Radio Telescope (WSRT) in the Netherlands. In this so-called *New Moon* project, a joint initiative of KVI and ASTRON, the moon is used as a huge target. If a high-energy cosmic-ray (or neutrino) is hitting the moon, the induced electromagnetic shower will traverse the dielectric lunar regolith at the speed of light. This will result in the emission of strong radio signals along a Cherenkov cone. In the New Moon project the low-frequency and broadband acceptance of the WSRT array is used to search for extremely high energy (> 10^{20} eV) cosmic rays (or neutrinos) hitting the surface of the Moon. Such experiments will probe the cosmic ray spectrum beyond the GZK limit. The advantage of the low-frequency domain is that the Cherenkov cone becomes very wide, which together with the broadband acceptance and the signal synthesis from the 14 WSRT dishes increases the sensitivity for detection by several orders of magnitude compared to earlier experiments like GLUE. Initial tests have already been performed, while a first full run is foreseen for later in 2005, followed by a full exploitation of this concept with LOFAR. The facilities WSRT and LOFAR are at present the only ones in the world providing the necessary low frequency band together with a fast sampling of the incoming data.

It is noted that the LOFAR program aimed at the observation of transient phenomena is also of interest for astroparticle physics. For instance, a changing (or transient) radio signal from an Active Galactic Nucleus (AGN) – or any another compact object – observed by LOFAR gives important information on the properties of a likely source of high-energy cosmic rays. Hence, such measurements may help in further unravelling the origin of the high-energy cosmic ray spectrum.

The LOFAR Phase-1 baseline consists of 7500 Low Band antennas (30-80 MHz) and 7500 High Band antennas (120-240 MHz), which are distributed over a core (2 km x 2 km) with half the number of antennas and 40 outlying stations with the rest. The maximum baseline between stations in the Phase-1 configuration is 100 km. Future extensions towards other European countries are envisaged.

LOFAR is under construction and, presently, the core is being rolled out in Borger-Odoorn (the Netherlands) with the first 100 antennas. The core is planned to be operational late 2006. Completion of the entire array will follow two years later. Data taking has started already with an initial test station consisting of 60 antennas.

Funding: a total of 104 M€ has been secured for LOFAR, of which 52 M€ has been obtained through the BSIK infrastructure funds of the ministry of education, culture and science (OCW), and the remainder has been supplied through various matching schemes, participating universities and other organizations. For the operational costs one has to distinguish between (i) commissioning costs, i.e., the resources needed to get the instrument fully operational (including all software development); (ii) the annual costs, i.e., the resources that are needed every year to operate and maintain LOFAR as an observatory; and (iii) the science exploitation costs, i.e. the money needed to hire graduate students and postdocs, and related expenses. Operational costs have not yet been secured, but plans are being developed (see footnote on page 40). The present strategic plan for astroparticle physics in the Netherlands only includes the science exploitation costs for LOFAR as a cosmic ray detector and a small fraction of the annual operation costs (see discussion on page 40).

A1.2 The ANTARES neutrino telescope

The primary aim of a deep-sea neutrino telescope is the search for neutrino point sources. Such searches could possibly lead to the observation of the predicted diffuse flux of high-energy neutrinos as well, which should help in identifying the unknown origin of high-energy cosmic rays. The observation of neutrino point sources will elucidate the acceleration mechanism of extreme astrophysical objects such as Micro-Quasars, Active Galactic Nuclei (AGNs) and Gamma-Ray Bursts (GRBs). Moreover, measurements of high-energy cosmic neutrinos can be used to search for dark matter candidates, and exotic particles such as magnetic monopoles, strangelets, and mini-black holes.

At this time three projects are underway in the Mediterranean Sea, ANTARES (in France, see Fig. 5), NESTOR (in Greece) and NEMO (in Italy) in an effort to demonstrate the proper functioning of a deep-sea neutrino telescope. Each of these neutrino telescopes will be positioned at the bottom of the Mediterranean. Atmospheric muons have already been seen with prototype set-ups by both the ANTARES and NESTOR collaborations[27]. The ANTARES project, in which the Netherlands is involved, is expected to yield the first scientific results on cosmic neutrino searches on the Northern hemisphere with its relatively large active volume of 0.05 km^3. The project serves as a precursor to a full-scale deep-sea neutrino telescope with a sensitive volume of about 1 km^3, which is known under the name KM3NeT. In the KM3NeT project, which is described in more detail in appendix 2, each one of the three Mediterranean neutrino collaborations is involved.

The principle of deep-sea (or deep-ice) neutrino telescopes is the use of the Earth as gigantic converter target in which incident neutrinos interact with any subatomic particle through a so-called charged-current interaction producing a high-energy muon. If such a (charged) muon is produced in the vicinity of water (or ice), the propagation of the highly relativistic muon will generate Cherenkov light that can be detected in the water (or ice) by means of photomultiplier tubes (PMTs). The volume of water (ice) equipped with PMTs has to be located as deep as possible to shield the detector from downward-going muons that are generated in the atmosphere by cosmic rays. The feasibility of this concept was demonstrated by the AMANDA collaboration, which succeeded in observing for the first time upward-going neutrinos[28] using a collection of PMTs that were melted into the Antarctic ice at a depth of 1500-2000 m.

The most important feature of the ANTARES project as compared to the AMANDA project (or its successor IceCube) is the complementary sky coverage. While the ANTARES telescope will cover the Southern hemisphere, AMANDA covers the Northern hemisphere. This complementarity is crucial for the development of neutrino astronomy. Other features of the Mediterranean and Antarctic neutrino telescope projects are compared below:

- In both cases the energy threshold is about 100 GeV. This is particularly relevant while searching for dark matter candidates and other exotic particles such as monopoles, a possible heavy relic produced during the Big Bang.
- The angular resolution of ANTARES will be about 0.2 degrees for neutrinos with energies larger than 10 TeV, increasing to 0.8 degrees for 100 GeV

[27] A. Kouchner (ANTARES Collaboration), Proceedings of "Les rencontres de Moriond". March 2000, Les Arcs, France (2000); and NESTOR Collaboration, Astroparticle Physics 23 (2005) 377.
[28] The observed rate of upward-going neutrinos was consistent with the rate expected from high-energy cosmic rays impinging on the other side of the earth producing atmospheric neutrinos. The AMANDA results have been published in Phys. Rev. D66 (2002) 012005 and Phys. Rev. Lett. 92 (2004) 071102.

neutrinos. For AMANDA the corresponding range in angular resolution is 2.0 – 2.5 degrees, which will be improved to < 1.0 degrees for IceCube. A good angular resolution is important for the identification of neutrino point sources.

- The galactic centre can only be viewed by detectors that are not too far away from the equator such as ANTARES, while it is not visible from Antarctica. This is of particular interest in view of the newly discovered high-energy gamma sources near the galactic centre (as described in section 2.3). It should be noted, however, that for the highest energy neutrinos (beyond 10^{17} eV) the galactic centre can be viewed by both ANTARES and AMANDA/IceCube by making use of downward going neutrinos.

The detection technique employed by ANTARES involves the deployment of many strings of photomultiplier tubes (PMTs) in the Mediterranean. Use will be made of 12 strings carrying a total of 900 PMTs. The strings will be located at a depth of about 2400 meters below see level off the coast of France, near Toulon.

The operation of large deep-sea (or deep-ice) neutrino telescopes requires the use of many thousands of photomultiplier tubes. In order to limit the large amount of data from so many individual tubes initially local electronic triggers were implemented in the design of neutrino telescopes. As a result the energy threshold of such detector systems turned out to be relatively high, i.e. about 1 TeV[29]. In ANTARES, instead, the all-data-to-shore concept was introduced. In such a system, conceived at NIKHEF, essentially all data from the photomultiplier tubes are brought to the shore station using advanced DWDM fiber optic techniques. On shore, further – easily changeable – filtering procedures can be applied to the data. This has enormous advantages. It will not only be possible to reduce the energy threshold of the neutrino telescope by more than an order of magnitude for neutrino point sources, but it will also be possible to change the actual trigger budget of the telescope on a daily basis. This will make it possible to respond to a trigger of a Gamma-Ray Burst satellite, for instance, and – more generally – make a true telescope program based on the decisions of a time-allocation committee. In short, it becomes possible to operate a deep-sea neutrino detector as a true observatory.

ANTARES is presently under construction and, in the course of 2005 the first strings will be deployed. The remaining strings will be deployed in 2006. Completion of the entire detector will follow in 2007. Data taking will started as soon as the first couple of strings have been put into operation.

Funding: a total of about 20 M€ has been invested in the construction of the ANTARES deep-sea neutrino telescope, of which the Netherlands has contributed 3.6 M€ through a dedicated "NWO-Groot" investment grant. The other international partners of the ANTARES collaboration have supplied the remainder. Operational costs will be shared among the member states of the ANTARES collaboration. Until 2006 operational costs are covered by the Dutch 'Stichting FOM'. Additional resources are needed in the Netherlands for a full exploitation of this neutrino telescope after 2006.

A1.3 The LISA pathfinder project

[29] In IceCube this threshold turned out to be only 0.2 TeV due to the relatively low noise rate.

Gravitational waves are space-time distortions caused by celestial bodies that are accelerated or disturbed. The waves propagate through space-time, distorting other bodies in their path as well as the space between them. The resulting motions and distortions have extremely small amplitudes but can in principle be detected with laser interferometry and resonant detectors.

Indirect evidence for the existence of gravitational waves has been obtained by Hulse and Taylor (Nobel Prize 1993) from the observation of the time-dependence of a signal from a binary pulsar. Since then the direct detection of gravitational waves and the development of gravitational wave telescopes is a high-ranking goal in science. However, despite several years of data taking by a number of ground-based experiments, no direct gravitational wave signal has been discovered so far. It has become clear that the direct detection of gravitational waves will require worldwide cooperation. Coincident measurements by a network of detectors are needed to give confidence in a claimed detection.

The scientific impact of gravitational wave detection will be enormous. It will tell us about the physics of supernova explosions, neutron star and black hole collisions or mergers. It will also be a major step forward in cosmology, since gravitational radiation can give information on the earliest stages of the Universe (inflation), even before the Cosmic Microwave Background was emitted (see section 2.5). Moreover, Einstein's Theory of Relativity will be tested in regimes where it has not been tested before. Dutch research on astrophysical sources of gravitational waves takes place in Amsterdam, Leiden, Nijmegen and Utrecht (compact binary systems involving neutron stars, white dwarfs and/or stellar mass black holes, as well as super-massive black holes in galactic nuclei).

Future international plans are focused on the space-based laser interferometer LISA (Laser Interferometer Space Antenna, an ESA/NASA mission with a target launch in 2013). LISA will operate at a low-frequency band, which is not accessible to ground-based detectors, and therefore both types of detector are complementary. LISA relies on completely new technology that cannot be tested from the ground and will be tested in space by the LISA Pathfinder precursor mission, in which a team from SRON participates.

One of the technologies to be tested with LISA Pathfinder is the Inertial Sensor system. This system comprises a cubic, conducting proof mass and a surrounding system of electrodes that capacitively measures minute displacements of the proof mass relative to the spacecraft. Inertial Sensors cannot be fully tested on the ground, due to the Earth's gravitational pull on the proof masses in the laboratory. SRON is therefore developing special test equipment – an "Inertial Sensor Test Module (ISTM)" – that will be used to simulate the Inertial Sensor read-out electronics with realistic sensing signals during on-ground tests of the LISA Pathfinder system. In fact, the read-out and control electronics of the ISTM therefore have an even better performance than the in-flight electronics. SRON is also contributing to detailed software models of the Inertial Sensor, which are included in the industrial "End-to-End Simulator" being developed at EADS Astrium (Germany).

Funding: the work of SRON on the ISTM represents the official Dutch contribution to the payload of the LISA Pathfinder mission. The total investment of SRON in this project (manpower and materials) amounts to 1250 k€ up to the delivery of the Inertial Sensor Test Module to the consortium "EADS-Astrium". It includes manpower for system-level test support and flight data analysis. The ministry of OC&W has reimbursed 400 k€ of the total investment.

A1.4 The MiniGRAIL project

The Netherlands is also involved in the construction and use of the resonant gravitational wave detector MiniGRAIL at the University of Leiden. The first of its kind (developed in collaboration with Twente), MiniGRAIL operates in conjunction with two cylindrical bar detectors, run by the INFN in Italy, thus providing coincidence measurements. Its primary target is the observation of gravitational radiation from non-axisymmetric instabilities in rotating single and binary neutron stars, and the radiation from mergers of small black holes or neutron stars**.**

MiniGRAIL is a 68 cm diameter spherical antenna with a resonant frequency of about 3 kHz cooled to ultra-low temperatures. A resonant detector of spherical symmetry has isotropic sky coverage and – in principle – the capability to determine the source direction and the tensor character of the incident wave. Such detectors will have the potential to identify the source location in the sky and to measure the wave polarization state. At the moment, MiniGRAIL is equipped with three capacitive transducers coupled to one single stage and two double stage SQUID amplifiers. MiniGRAIL will be upgraded to 6 transducers and so become omni-directional in the course of 2005. The highest sensitivity that was reached up till now was $1.5\times10^{-20}/\sqrt{Hz}$ and is expected to be improved in the near future to a few times $10^{-22}/\sqrt{Hz}$.

In order to reduce the influence of noise when trying to observe gravitational waves, it is desirable to require a coincident observation of signals in two independent resonant detectors. With this purpose in mind a collaboration has been formed with the Italian "Rivelazione di Onde Gravitationali" **(**ROG) team, which has two bar detectors in continuous operation: the EXPLORER project (cooled to 2.5 K) at CERN, and the NAUTILUS project (cooled to 3.2 K at the Frascati National Laboratory). The collaboration between ROG and MiniGRAIL involves the complete implementation of the readout system and data acquisition systems and the joint analysis of the data. The aim is to operate the MiniGRAIL detector with sensitivities comparable to or better than the operating bar detectors. The coincident observation of a signal in two detectors has the additional advantage that information on the direction of the passing gravitational wave can be obtained, which is more precise than that derived from a spherical detector alone.

Funding: the MiniGRAIL project receives support from the Dutch "*Stichting Technische Wetenschappen*", the Italian "*Rivelazione di Onde Gravitationali*", Leiden University and the EU Framework 6 project "*Ilias*" (which is further discussed in section 3.3). In total about 1.2 M€ has thus been secured for the initial phase of the project. Operational costs are covered by Leiden University.

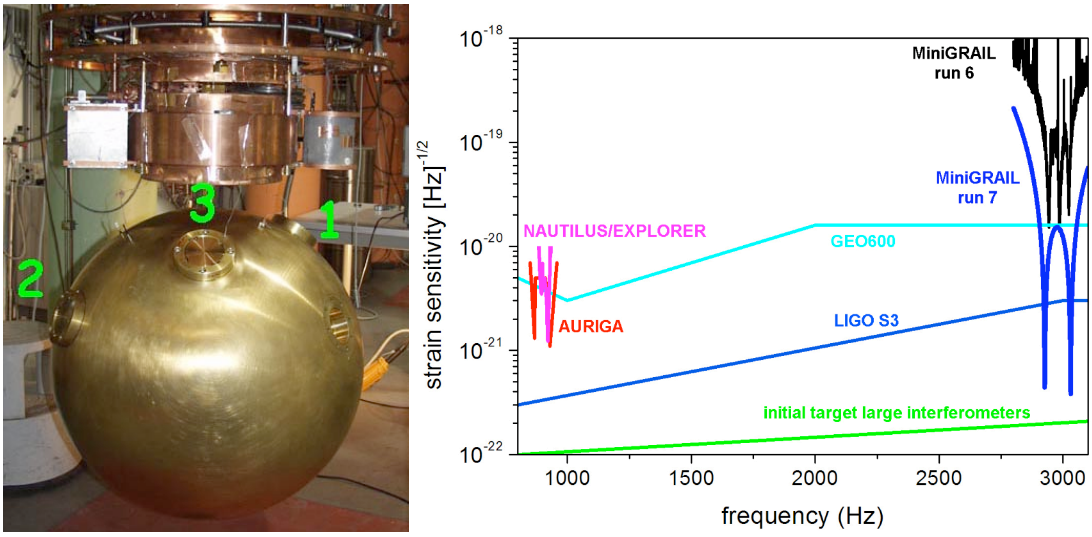

Fig. 11. The MiniGRAIL detector (left panel) is a cryogenic 68 cm diameter spherical gravitational wave antenna made of CuAl(6%) alloy with a mass of 1400 Kg, a resonance frequency of 2.9 kHz and a bandwidth of about 230 Hz, possibly higher. The location of three transducers is indicated. The quantum-limited strain sensitivity dL/L is expected to be ~4x10^{-21} (right panel). The antenna will operate at a temperature of 20 mK. Another similar detector is being built in São Paulo (Brasil), which will strongly increase the chances of detection by looking at coincidences.

A1.5 Present theoretical activities in astroparticle physics in the Netherlands

Theoretical astroparticle physics in the Netherlands is addressing a similar set of fundamental questions as was already mentioned in section 1. Theoretical research in this area is fuelled by the new observations that have become available, and by the prospects offered by observational facilities – several of which were introduced in section 2 – that will become available in the near future.

Broadly speaking, existing research theoretical astroparticle physics in the Netherlands focuses on a number of areas:

Cosmic accelerators and fundamental interactions at very high energies

Astrophysical particle accelerators routinely produce particles with energies far beyond the maximum energy that can be achieved in man-made accelerators. Presently, a number of fundamental questions remain that are the subject of vigorous research:

- What is the origin and composition of ultra-high energy cosmic rays?
- Are Gamma Ray Bursts and Active Galactic Nuclei observable point sources of cosmic neutrinos?

High-energy cosmic rays, gamma rays and neutrinos offer important insights into the mechanisms operating in astrophysical accelerators. Astrophysical particle acceleration is associated with the presence of *strong shocks* in tenuous astrophysical plasmas. Such shocks have been observed in Supernova Remnants and in the energetic outflows (jets) associated with the massive black holes in the nuclei of

Active Galaxies and (micro-) Quasars, and are believed to be present in the sources of Gamma Ray Bursts. The energetic particles produced near these shocks generate secondary particles: electrons generate photons through synchrotron and inverse-Compton emission, while nucleons generate pions in inelastic collisions with other nuclei and photons. These pions decay into gamma rays or into muons and neutrinos. In this way the particle emission, photon spectrum and the secondary gamma rays and neutrino's all contain information about the physical conditions inside the source.

The recent detection by HESS (see section 2.3) of diffuse high-energy gamma-rays from several galactic supernova remnants confirms this general picture in the case of galactic cosmic rays ($E < 10^{16}$ eV). In the case of the ultra-high energy cosmic rays the picture is less clear. The question of their sources and the production mechanism(s) remains open, and it is unclear if the conventional scenario sketched above can explain the observations.

The detection of neutrinos from cosmological point sources (as opposed to the diffuse atmospheric neutrino flux resulting from cosmic-ray interactions at the upper layers of the Earth's atmosphere) would be an important new tool to constrain models of astrophysical particle acceleration and the associated radiation processes. The small (weak interaction) cross section of neutrinos allows us to probe the inside of sources when (and where) they still are opaque to photons. Neutrinos have already played a similar role in our understanding of solar nuclear fusion and the fundamental properties of neutrinos (the solar neutrino problem and neutrino mixing).

Cosmology and the physics of the early universe

There has been an enormous advance in our knowledge of the fundamental parameters of the universe over the last decade. Nevertheless, the detailed composition of the universe is largely unknown, and the following questions form an important area of research:

- Is there a background of massive, weakly interacting relic particles (e.g. massive neutrinos) left over from the Big Bang that created our universe?
- What caused the matter-antimatter asymmetry after the Big Bang?
- What are the properties of the fluctuations in the Cosmic Microwave Background radiation, i.e. the afterglow of the Big Bang?
- Which processes govern the formation of large-scale structures in the universe?

Observations of the temperature fluctuations in the Cosmic Microwave Background allow us to constrain the fundamental parameters governing the evolution of the universe, such as the question of flatness or curvature, the spectrum of primordial density fluctuations and the presence of a universal background of primordial gravitational waves, as predicted by the theory of inflation, which postulates that the near-flatness of the universe is the result of an episode of rapid expansion in the distant past.

Together with the simulations and observations of large-scale structures, the filamentary distribution of visible matter in the universe, the CMWB observations allow us to strongly constrain the properties of both *hot* dark matter (e.g. massive neutrinos) and of *cold* dark matter.

Fundamental physics: the Standard Model and beyond

The extreme temperature of the Hot Big Bang, the extreme energy of ultra-high energy cosmic rays, the extreme density found in the cores of compact objects such as neutron stars and the violent collapse of dying stars create circumstances that can never be achieved experimentally. One is investigating the theory of fundamental interactions in such extreme circumstances in the hope to answer the following questions:

- What will the dark matter particles tell us about the nature of interactions that go beyond the Standard Model of particles and fields, such as supersymmetry?
- Does the phase structure of the Standard Model (involving both QCD and electro-weak transitions) have consequences for the early universe?
- What is the relation between String Theory and inflation and the possible existence of extra dimensions and cosmological defects?
- What generated the baryon asymmetry in the early universe? Was it a form of electro-weak baryogenesis or did it take place via leptogenesis?
- What is the role of the strong interaction (and strange quarks) in the core of neutron stars, and could quark stars be formed?
- Does the observed cosmic ray spectrum at the highest energies show any evidence for the breaking of Lorentz-invariance?
- What are the sources of gravitational waves?

The strong interaction sector of the Standard Model finds several direct applications in astroparticle physics. Examples are hadronic scattering parameters at low energy involving not only nucleons but also strange baryons. This becomes important for modeling the processes that take place in the cores of neutron stars. Other investigations study the consequences of the possible formation of quark stars. Strong interaction physics (Quantum Chromo-Dynamics - QCD) is being studied through lattice methods or in effective theories. The phase structure of QCD plays a role in the final evolutionary stages of massive stars.

Theoretical investigations of physics beyond the Standard Model are focusing on several mechanisms that may affect leptogenesis and baryogenesis. In particular, our understand-ing of the neutrino sector, with the possibilities of sterile neutrinos and C-violation, may affect our present-day views. These investigations require the study of basic questions, such as how to deal with quantum fields out of equilibrium. This is also important for the description of processes such as cosmic inflation. Supersymmetric extensions of the Standard Model are relevant for dark matter studies.

Finally, gravitational waves contain evidence about the violent processes that take place in the final stages of stellar evolution and in the evolution of close binaries (see figure 11), and about the processes that occur in the nuclei of active galaxies and quasars containing a massive black hole. These processes include the core collapse of massive stars, and the formation of black holes in binary systems, and in the dense stellar environment in the nuclei of galaxies.

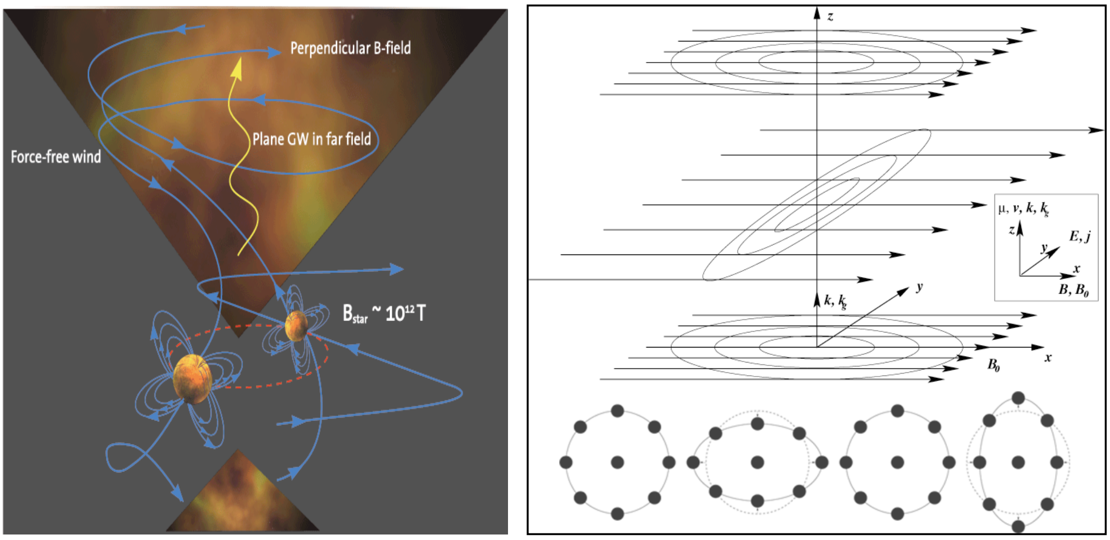

Fig. 12. On the left a schematic drawing illustrates the geometry of gravitational wave emission in an existing electron/positron jet from a merging neutron-star binary (J. Moortgat and J. Kuijpers – 2003). The drawing on the right gives a sketch of the interaction between a gravitational wave and a magnet ohydrodynamic fast mode wave, both propagating in the z-direction across an ambient magnetic field (top), and the tidal effect of a gravitational wave in the x-y plane (bottom). The gravitational wave induces periodic compressions and rarefactions of the ambient magnetic field and thus couples to a MHD wave (J. Moortgat and J. Kuijpers – 2003).

Theoretical investigations in Cosmic Accelerators, String Theory, Cosmology and Gravitation are part of the fast worldwide developments in this field. The field provides the challenging ideas that drive the proposed experimental projects in astroparticle physics research, such as the topology of cosmic defects, presence of extra dimensions and the understanding of inflation. The fact that the questions addressed by the theoretical astroparticle physics community in the Netherlands are so closely linked to the observational facilities, illustrates the importance of a strong theoretical effort in this newly emerging field.

In order to get an overview of all theoretical activities in this field, table 5 below lists all the (university) groups that are presently active in this field, including the leading scientists and the major topics that they are working on. These topics are identified by a few words only with reference to the text above for a brief explanation of these topics.

Several of the university groups listed here have an on-going cooperation with institutes such as NIKHEF (ANTARES: neutrino point sources), SRON (on the possible participation in the LISA gravitational wave detection mission) and ASTRON (LOFAR: cosmic ray detection and the detection of transient phenomena).

It should be noted that part of the theoretical projects mentioned above are supported by the NIKHEF theory program and the FOM research programs "Fundamental Interactions" and "String Theory and Gravity". Together they form the Network for

Table 5. Present involvement of tenured senior scientists in theoretical astroparticle physics research in the Netherlands. The names of the scientists involved are listed in the2nd column. The 3rd column lists the primary research interests of each group.

Research group	Staff members	Theoretical astroparticle physics subjects
UvA-astronomy	Wijers	GRBs and their environment, implications for stellar evolution and cosmology
UvA-physics	Smit, de Boer	Nonequilibrium and finite-temperature field theory and phase transitions in cosmology, sterile neutrino dark matter, baryogenesis; string theory & cosmology
VU-physics	Mulders, Boer	QCD phase transitions in the early Universe and in neutron and quark stars
NIKHEF-theory	Van Holten, Koch, Schellekens	Inflation and CMB density fluctuations, neutrino astrophysics and GRBs, relativistic fluids, string cosmology, dark energy, quantum cosmology
RuG-astronomy	Van de Weijgaert	theory and simulations of the formation of large scale structures in the universe
RuG-physics	Bergshoeff, de Roo, Pallante	CP violation in hadrons on the lattice, string theory and cosmology, extra dimensions
KVI-theory	Timmermans, Scholten	CP violation outside the Standard Model, ν-mass matrix, cosmic-ray shower development
UL-physics	Achucarro	the early universe, topological defects
RU-astronomy	Kuijpers, Falcke (& ASTRON) Groot	cosmic-ray generated atmospheric radio emission; theory of energetic jets associated with AGNs; radio detection high-energy cosmic rays
UU-astronomy	Achterberg, van Eijndhoven	ultra-high energy cosmic rays, extreme relativistic plasmas and neutrino astrophysics
UU-physics	Loll, Prokopec, ‘t Hooft	baryogenesis, neutrino oscillations, inflation, quantum cosmology, alternative theories of gravitation and cosmology, dark energy

Theoretical High Energy Physics.

A1.6 Present Dutch involvement in astroparticle physics

In this subsection the present Dutch involvement in astroparticle physics projects is summarized. First, a quantitative overview is given of all active scientists, where after the key areas of expertise are discussed. More quantitative information, i.e. an overview of the actual financial resources available, is presented in section 8.

In table 6 the Dutch manpower involved in astroparticle physics research in 2005 is summarized. For each group the senior and junior manpower that is active in this field of research is listed. It is noted that most of the junior positions included in table 6 are paid from ad-hoc fellowships or grants, as no structural positions for this type of research are available in the Netherlands. The fact that, despite this limitation, a considerable number of students and postdocs are active in this field illustrates the strength of astroparticle physics in competitive research schemes.

Over the last years Dutch scientists have developed several innovative ideas that are

Table 6. Present involvement of tenured senior and junior scientists in astroparticle physics research in the Netherlands. The names of the contact person for each group are listed in the 2nd column. The 3rd, 4th and 5th columns lists the (effective) number of faculty members, graduate students and postdocs that are working on astroparticle physics research in the year 2005.

Institute	Contact	Senior (FTE's)	PhD's	Postdocs
UvA-astronomy	RAMJ Wijers	1.7 FTE	3	2
UvA-physics	J Smit	1.0 FTE	1	-
ASTRON	H Falcke	1.0 FTE	1	-
RuG-astronomy	R vd Weygaert	0.5 FTE	3	1
RuG-physics	E Pallante	0.5 FTE	-	-
KVI	AM vd Berg	4.6 FTE	1.5	-
UL	A Achúcarro	2.2 FTE	4	3
RU	J Kuijpers	2.5 FTE	3	2
NIKHEF	FL Linde	5.5 FTE	6	1
SRON	AM Selig	2.0 FTE	-	-
UU-astronomy	A Achterberg	0.5 FTE	2	-
UU-physics	T Prokopec	1.2 FTE	1	1
VU-physics	PJG Mulders	1.0 FTE	1	-

considered to be crucial for the future of astroparticle physics research. These ideas are described one by one below, but please note that the discussion is limited to the observational and/or experimental efforts as the groups that are active in theoretical astroparticle physics have already been listed in table 5.

- The geo-synchrotron effect. The idea to use a low-frequency radio telescope for the detection of coherent synchrotron radiation emitted by the e^-/e^+ cascade of an extensive air shower was developed by Dr. Heino Falcke of ASTRON and Radboud University. Detection of high-energy cosmic rays with LOFAR is now one of the four key programs of this new telescope. The LOFAR cosmic ray science centre is hosted by the Radboud University because of the existing expertise on cosmic ray detection. The successful demonstration of the validity of this concept at the LOPES test set-up in Karlsruhe has generated considerable international interest. As a result the Netherlands have been invited to join the collaboration that is developing and beginning to exploit the Auger cosmic ray observatory in Argentina, with the objective to implement this concept at Auger as well.

- All-data-to-shore. The idea to transport as many data as possible from all (the very many) photomultiplier tubes of a deep-sea neutrino detector to the shore station was introduced and developed by Dr. Maarten de Jong of NIKHEF. As a result, the physics output of the detector and its flexibility are enormously increased. In fact, this idea is essential for using deep-sea neutrino telescopes for dark matter searches. The ANTARES collaboration has adopted this Dutch concept immediately, and for the same reason the Netherlands have been invited to lead the information technology aspects of the design of the future km^3 sized neutrino telescope in Europe, known as KM3NeT.

- Inertial-sensor control & readout electronics. Within SRON, the Netherlands institute for space research, control and readout electronics for inertial sensors are being developed for the ISTM project of the LISA Pathfinder mission, which was described in section A1.3. In parallel, SRON – with Dutch SME as industrial subcontractor – is carrying out a development program for miniaturized read-out and control electronics (by means of mixed-signal ASIC technology) which is focused on high resolution (24 bit) low frequency AD/DA conversion. This technique will be primarily applied in inertial sensors for future space flights, but also e.g. in phase meter read-out systems. This development is part of a national program supported by the NIVR, the Netherlands Agency for Aerospace Programs.

Given the large international interests and the enormous scientific potential of astroparticle physics, many research groups and institutions in the Netherlands have already embarked in this direction. This is to a certain extent illustrated by table 1 (shown and discussed in section 3.2), in which the foreseen involvement (in 2006) of tenured staff members in astroparticle physics projects is summarized. Although the table concerns 2006, many – if not most – of the mentioned staff members are already involved in astroparticle physics research since a couple of years. It should also be noted that the overview presented in table 1 is limited to the experimental and/or observational projects only. Despite the considerable number of ongoing activities in astroparticle physics (as can also be gathered from the discussion in section 8.1), the interdisciplinary nature of astroparticle physics (which falls in between the disciplines represented by GB-E and GB-N/FOM within NWO) presently precludes a concerted effort such as is required to exploit the scientific potential and international impact of the Netherlands in the area of astroparticle physics.

Appendix 2: The KM3NeT project.

The KM3NeT project is a joint European project set up by the existing ANTARES, NEMO and NESTOR collaborations. These collaborations are aimed at developing the technology for a large deep-sea underwater neutrino telescope in the Mediterranean Sea.

The KM3NeT project was launched in 2003 with the aim of building a large neutrino telescope with a volume of at least 1 cubic kilometre (having 20 times the active volume of the ANTARES detector). For this purpose a design study was proposed to the EU 6th Framework Program, which was recently approved and will receive funding at the level of (approximately) 10 M€ for a period of 3 years starting in 2006. Near the end of the design study, which includes the selection of the site in the Mediterranean Sea, an international proposal for the construction of KM3NeT will be prepared. The expected total costs amount to 200 M€, of which typically 4% will be put up for funding by the Netherlands. The construction of the neutrino telescope can start in 2009-2010, enabling first observations in 2010. Measurements with the complete telescope will take place from 2012 onwards.

The start of operations of KM3NeT is expected to be several years later than the anticipated starting date of the IceCube neutrino telescope, of which the first string has already been deployed and which is expected to be fully operational in 2010. IceCube is being constructed in the Antarctic ice at a depth ranging from 1450 to 2450 meters. The IceCube project is an international collaboration in which a roughly similar number of North-American and European institutes participate. As was already discussed in appendix A1.2 deep-sea and deep-ice neutrino detectors have similar characteristics. In short, the IceCube project has the advantage of time – being operational before the start of operations of the KM3NeT, while the KM3NeT project has a better angular resolution – giving it a better sensitivity to neutrino point sources. The timing advantage of the IceCube project is exploited by the Utrecht group; their participation in the IceCube analysis effort will provide the Dutch community with important experience that will be used when the observations with KM3NeT start.

KM3NeT will address scientific questions which are similar to the questions addressed by ANTARES, but now have an extended reach because of the largely increased size of the telescope. As an example, with ANTARES only a few neutrino point sources are expected to be observable, while many more (i.e. 10 – 100) are expected to be visible with KM3NeT. More in particular the following scientific issues will be addressed by KM3NeT:

- Measuring the diffuse cosmic neutrino flux
- Searches for neutrino point sources (such as micro quasars, AGNs, GRBs)
- Searches for exotic particles such as neutralinos, monopoles, strangelets, etc.
- Searching for ultra high-energy cosmic neutrinos (GZK limit)
- Neutrino oscillations (by observing tau neutrinos).

KM3NeT is an international collaboration with groups from many European countries. The Dutch involvement in the design study is significant (mainly concerning the working package on information technology). The combined efforts of the NIKHEF and KVI groups will ensure a high and visible level of involvement during both the construction and exploitation phases of the large neutrino telescope.

The KM3NeT project offers good opportunities for technical and scientific departments of the institutes involved in astroparticle physics research in the Netherlands. To be more specific, one can consider contributions in the field of data acquisition and analysis, detector simulations, electronic designs for low-power systems, precision time to digital converters, and mechanical designs for submarine structures. The establishment of a test site for large submarine telescope parts with a major engagement in development, production and test in the Netherlands offers a great (inter)national visibility and opportunities for students. Such a local test site would require (apart from financial investments) the involvement of up to 100 FTE engineering support spread out over a about 6 to 7 years.

The KM3NeT project is truly European enjoying already financial support of the EU within the FP6 framework. Within the Netherlands, NIKHEF and KVI are planning to participate in the project. In addition, Dutch astronomers and astrophysicists have expressed their support to this project. Being a new and exciting field of science, this project will attract bright students. These students will be given a chance to work on the challenging physics subjects mentioned above and gain hands on experience with sensitive photon detectors, high speed signal transmission, low-power electronics, simulation of complex detector systems and data filter and analysis methods.

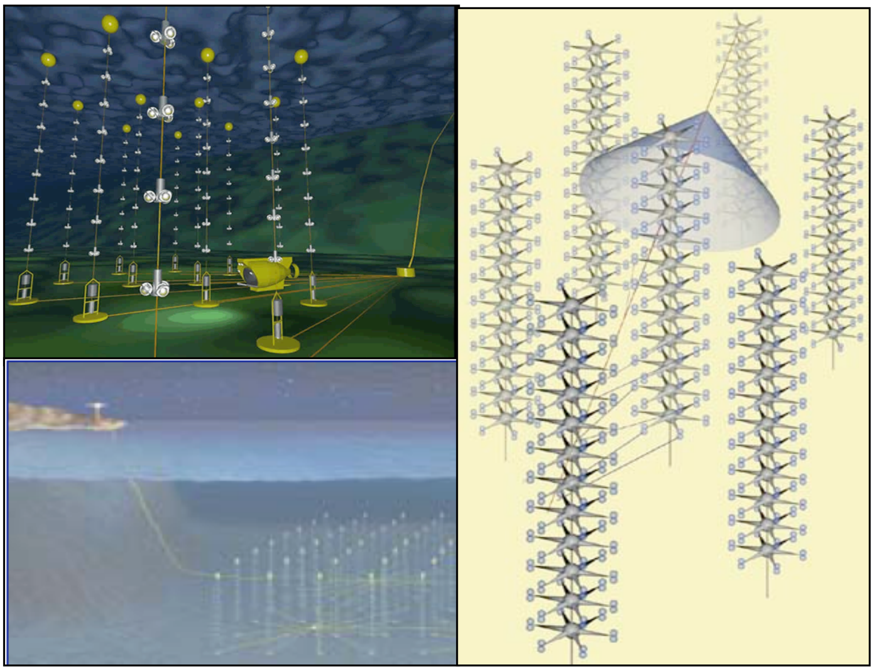

Fig. 13. In this figure the three pilot projects on which the KM3NeT deep-sea neutrino telescope is based are shown. In the top-left panel an artist impression of the ANTARES project is shown, in the bottom-left sketch of the NEMO project is displayed, while the basic structure of the NESTOR project is shown on the right.

Appendix 3: The Pierre Auger Observatory.

The Pierre Auger Observatory (or Auger project in short), which is presently under construction (and reaching completion) in Argentina, is a huge, innovative detector array which combines two hitherto successful methods: particle detectors and fluorescence detection. The full array will be ready in 2006, and is operated by a worldwide collaboration involving more than 200 scientists.

In the first part of the detection system, 1600 particle detector stations will form a giant regular array, or grid, covering about 3000 square kilometre, an area that is similar to that of the Dutch province of Utrecht. The detector stations will be about 1.5 km apart, each one an 11,000-liter (3000-gallon) tank filled with 12 tons of pure water. Each station will be self-contained and will operate on solar power. For events seen in both the surface detectors and the fluorescence detectors, about 5000 extended air showers will be observed for energies larger than $3 \cdot 10^{18}$ eV, while only 10 showers are expected for energies above $1 \cdot 10^{20}$ eV. If only the surface detectors are used the expected rates increase by an order of magnitude because the low duty cycle (10%) of the fluorescence detectors does not reduce the observed rates any longer.

A second detection system will make use of the faint glow caused by the collisions of shower particles with air molecules during cosmic ray air showers. A collection of light sensors pointing at the sky in all directions observes an air shower as a trace of light across the sky. The total amount of light depends on the number of particles in the shower and, in turn, on the energy. The shape and direction of the light trace helps to determine the cosmic ray's direction and indicate what kind of particle the original cosmic ray might have been. The fluorescence detectors can measure cosmic ray showers in more detail than the giant array but can only observe fluorescence on dark nights. Because the large surface array is active all the time, it measures 10 times more events.
The surface array working alongside the fluorescence detectors will make a very powerful instrument for capturing the rarest, most interesting, and most puzzling high-energy cosmic rays.

One third of the ground detectors and more than one half of the fluorescence detectors have already been completed. So far several ten thousands of cosmic ray events have been measured and during 2005 the Auger project will have reached a total event rate equal to all previous experiments, making Auger the biggest and most important cosmic ray detector in the world.

Complementary to LOFAR it has been suggested to install radio antennas collocated with the Auger cosmic rays detector array in Argentina on the Southern hemisphere. Adding radio antennas to the Auger project has several major advantages. First of all, Auger is the only cosmic ray array with significant event rates at energies up to 10^{20} eV. Hence, a cross-correlation between radio and conventional particles detectors for the highest energies is only possible at this site. This cross-correlation will be very important for making reliable measurements with LOFAR up into this energy range. In addition, there is nice complimentarity between LOFAR and Auger, as LOFAR will observe in the Northern hemisphere supplementing the radio observations of Auger South.

Moreover, it is quite likely that the combined study of ultra-high energy cosmic rays with particle and radio detectors improves energy and composition determination of the primary particles. As fluorescence detectors only work during 10% of the time, an expansion of Auger South with LOFAR radio antennas to obtain significantly enriched data is a very attractive option. Given the current advantage of the Dutch groups with this technique, equipping Auger with radio antennas would provide a well visible and significant Dutch contribution.

In anticipation of a possible role of the Netherlands in the Auger project, initial contacts have been established. On the basis of these contacts and in view of the prospects of implementing part of the Auger detectors with radio antennas similar to those developed in the framework of the LOFAR project, the Auger collaboration has granted preliminary membership to a group of Dutch scientists. This group comprises representatives from ASTRON in Dwingelo, KVI in Groningen, Radboud University in Nijmegen and NIKHEF in Amsterdam, and is known as the *Netherlands UHE Cosmic ray Collaboration* (NUCC). The establishment of NUCC is a direct consequence of the strategic and focussing activities of the *Commissie voor de Astrodeeltjesfysica in Nederland* (CAN).

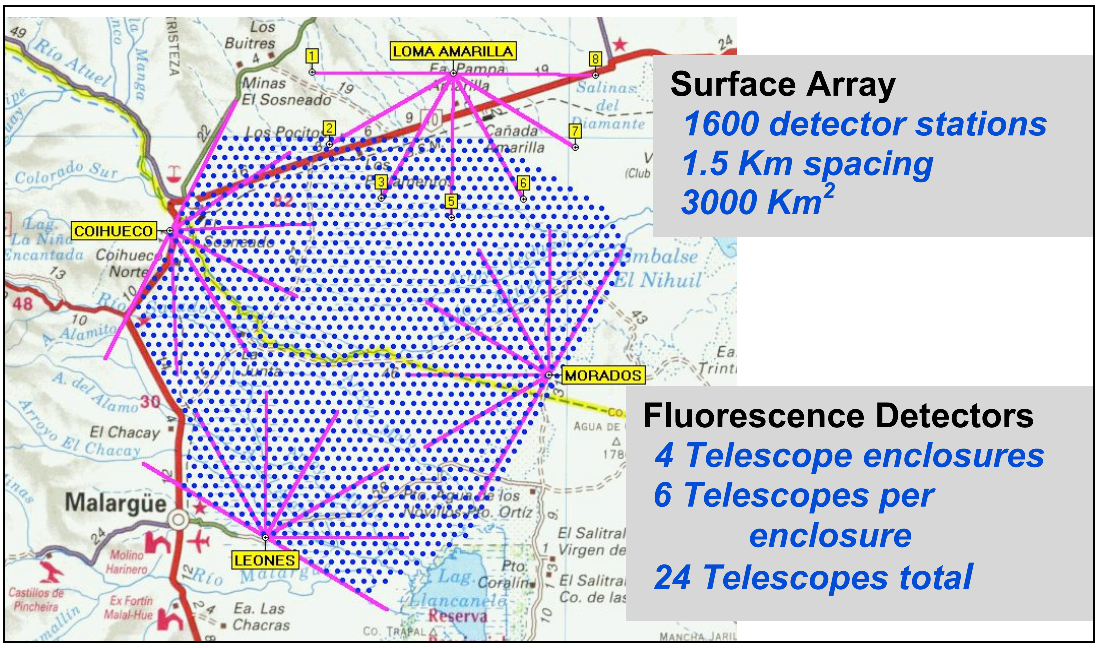

Fig. 14. Layout of the Auger Project near Malargue in Argentina. Each (blue) dot represents one of the 1600 individual detector stations. The four fluorescence detectors are represented by 7 straight magenta lines centered at a hill with a name labelled in a yellow box.

Appendix 4: other opportunities in astroparticle physics

While reviewing the various options for future astroparticle physics research projects in the Netherlands, a fairly large number of experiments has been discussed. In this appendix information is given on some of these alternative projects. Here, only those projects are listed that were actually initiated by one of the Dutch research institutions, and those projects in which Dutch scientists were invited to participate because of their expertise. It is of relevance to describe these projects, as they further illustrate the potential strength of astroparticle physics research in the Netherlands. It has to be realized that these projects were not omitted from the present program because of lack of scientific quality, but – mainly – because they could not serve as a good starting point for a major research activity and/or because they would endanger the coherence of the program. At the same time, some of these projects are certainly suitable for small-scale proposals that can be submitted to the various open competition programs of the Dutch funding agencies. An incidental PhD student or postdoc financed independently from the present strategic plan can thus serve as an enrichment of the entire astroparticle physics program in the Netherlands.

- AMS-02 is an astroparticle physics experiment in space. The purpose is to perform accurate, high statistics, long duration measurements of energetic (up to multi-TeV) primary charged cosmic ray spectra in space. One of the main physics goals is the search for dark matter. Collisions of dark matter in the galactic halo could produce antiprotons, e^+-s or gamma-s. The antiproton, e^+-s and gamma-s from these collisions will produce deviations from the smooth background spectra. Therefore, precision measurements of antiproton, e^+ and gamma spectra could make it possible to establish whether SUSY particles are a key constituent of dark matter. AMS-02 will collect 10^9 nuclei and isotopes (D, He, Li, Be, B, C, and up to Fe) in three years. Other interesting science issues include: an accurate determination of the ratio of boron to carbon over a wide range of energies, which provides crucial information on the propagation of cosmic rays in the galaxy. In particular, the ratio of ^{10}Be to the stable ^{9}Be isotopes will provide important information on the understanding of cosmic ray propagation. AMS-02 will be installed on the International Space Station, most likely in 2008. The cooling system for AMS-02 has been designed at NIKHEF (on a full cost basis). The AMS-02 collaboration has invited NIKHEF to join the collaboration.

- EARTH (Earth Anti-neutRino Tomography) aims at developing directional sensitive low-energy antineutrino detectors, that will be combined to a modular system of sensors placed into arms of an underground antenna. For Earth tomography about ten of such antennas will span the globe. In addition, there are applications of these detectors for fundamental and astrophysics as well as a basis for tools monitoring nuclear power plants and illicit nuclear explosions. EARTH has the potential, for instance, to be the first detection system to measure the subdominant mixing angle θ_{13}, the size of which determines whether CP violation in the lepton sector is detectable. A successful θ_{13} experiment will define the direction of neutrino research for the next decade and beyond. Being specific to antineutrinos, EARTH has a clean window for supernova antineutrinos and given the granularity of the detector yielding fast response timing, the worldwide antenna system may be linked to the Supernova

Early Warning System (SNEWS). Besides these fundamental physics aspects and its capability to detect supernova antineutrinos, directional sensitive detection of low-energy antineutrinos up to about 50 MeV provides a unique opportunity to observe antineutrinos from the Sun. These antineutrinos could be created by a combination of spin flavour precession (SFP) and neutrino flavour oscillations. EARTH will have less background than previous experiment such as KamLand, and will have directional sensitivity. Also in its application to the tomographic mapping of radiogenic heat sources and its potential in non-proliferation issues such as detection of nuclear explosions with a high location potential (50 km at a distance of 1000 km) EARTH is a unique project. The concept of EARTH was developed by KVI.

- ICECUBE is a neutrino observatory located at the South Pole. It consists of a surface array (IceTop) and sensors buried at a depth ranging from 1450 to 2450 m in the deep Antarctic ice (IceCube). The IceCube detector will represent a cubic-kilometer sized successor of the AMANDA detector, which has been in operation since 1997. It will consist of 4800 10-inch diameter photomultiplier tubes (PMTs), arrayed on 80 strings. Each string comprises 60 optical modules (OMs) spaced vertically by 17 meters. In the horizontal plane the strings will be arranged in a triangular pattern such that the distances between each string and its up-to-six nearest neighbours are 125 m. A significant improvement compared to the AMANDA detector is that each IceCube OM will house electronics to digitise the PMT pulses, so that the full waveform information is retained. The waveforms will be recorded at a frequency of about 300 MHz in 4 channels with different gain settings to provide a large dynamic range. The IceCube array will be complemented by IceTop, a surface air-shower array consisting of 160 frozen-water tanks containing 2 OMs each, comparable to the ones used by the Auger project. The tanks will be arranged in pairs, separated by a few meters, one on top of each IceCube string. Apart from the usual measurement of air-shower parameters, combination with the signals from the deep-ice sensors provides a new measure of the primary cosmic ray composition up to an energy of 10^{18} eV. Furthermore, data from IceTop will serve as a veto for air-shower induced background in IceCube and will enable cross checks for the detector geometry calibration, absolute pointing accuracy and angular resolution. In addition, the energy deposited by tagged muon bundles in air-shower cores will be an external source for energy calibration. Currently one complete IceCube string and four IceTop tanks are operational at the South Pole together with the existing AMANDA detector. The full setup will be completed in the austral summer of 2009. Based on data obtained with AMANDA and recently also with IceCube, an angular resolution of about 0.5 degrees is expected for reconstructed high-energy muon tracks and a lower energy threshold of about 100 GeV. This will make the device a very suitable tool to investigate neutrino point sources as well as the expected diffuse neutrino flux. Based on existing experience with data analysis techniques and modelling of relativistic shock wave acceleration, a small group from Utrecht University was invited to join the IceCube collaboration, which was realised in 2003. The Utrecht group focuses on high-energy neutrino signals correlated with transient cosmic events (e.g. GRBs and flaring AGNs).

- KATRIN. The Karlsruhe Tritium Neutrino Experiment (KATRIN) is the only planned project which is sensitive enough to constrain or measure model independently the electron neutrino mass down to 0.2 eV. This precision is an improvement of about one order of magnitude compared to results obtained by an earlier generation of beta-decay experiments. Interestingly, a model-dependent but controversial neutrinoless double-beta decay study (the Heidelberg-Moscow Germanium experiment, also mentioned in section 2.1) claims a neutrino mass of about 0.4 eV, which falls within the sensitivity range of KATRIN. On the other hand, an upper limit of 0.2 eV would imply that neutrinos do not contribute significantly to the total mass of hot dark matter and indicate that the different neutrino flavours are degenerate in mass. As a method, the KATRIN experiment will measure the end point of the tritium beta decay spectrum, from which the neutrino mass can be determined. In the Netherlands, KVI has been approached to join the KATRIN collaboration.

- XEUS. Observations with gamma rays satellites such as INTEGRAL have lead to the suggestion that gamma rays originating from the centre of the galaxy are possibly the result of the decay of light dark matter particles. Moreover, gamma-ray observations of the Crab nebula, its high-energy synchrotron radiation, have prodded some groups to infer constraints on quantum gravity (i.e. upper limits on deviations from the equivalence principle.) Such issues will be addressed by the XEUS mission, which is the successor of ESA's Cornerstone X-Ray Spectroscopy Mission (XMM-NEWTON). XEUS will be the best X-ray observatory to date. It will be a permanent space-borne X-ray observatory with sensitivity comparable to that of the most advanced planned future facilities such as JWST, ALMA and Herschel. XEUS will be about 200 times more sensitive than XMM-NEWTON, and is expected to be launched in 2014.

- ZESANA (ZEchstein SAlt Neutrino Array). This project aims at building radio detectors in halite (salt domes) to develop innovative neutrino detection techniques. By building large relatively cheap arrays in underground salt domes it is hoped that a cost effective detector for ultra-high energy neutrinos can be constructed. With such a detector system the existence of neutrinos below and above the GZK-limit (at $5 \cdot 10^{19}$ eV) can be investigated. Crucial aspects of the project are the attenuation length for radio waves in halite and the ability to develop ultra-sensitive radio receivers. For both items national and international collaborations need to be initiated. ZESANA can be located near LOFAR and together they might provide in a system tailored for simultaneous detection of both cosmic rays and neutrinos. The Dutch concept for ZESANA – developed at KVI – is based on a proposal made by Askaryan, which was recently also taken up by Salzberg and Gorham for the construction of a similar detector system in the US, known under the name of SALSA. KVI has been invited to join the SALSA collaboration.

Appendix 5: list of senior scientists supporting the present proposal

1.	A. Achterberg	UU
2.	A. Achucarro	UL
3.	P. van Baal	UL
4.	F.A. Bais	UvA
5.	J.C.S. Bacelar	KVI
6.	S. Bentvelsen	UvA/NIKHEF
7.	A.M. van den Berg	KVI
8.	E. Bergshoeff	RuG
9.	D. Boer	VU
10.	J. de Boer	UvA
11.	J.F.J. van den Brand	VU/NIKHEF
12.	H.J. Bulten	VU/NIKHEF
13.	H.R. Butcher	Director ASTRON
14.	R.H. Dijkgraaf	UvA
15.	M. Duvoort	UU
16.	B. van Eijk	NIKHEF/UT
17.	N. van Eijndhoven	UU
18.	H. Falcke	ASTRON/RU
19.	G. Frossati	UL
20.	K.J.F. Gaemers	UvA
21.	H. van der Graaf	NIKHEF
22.	P. Groot	RU
23.	M.N. Harakeh	Director KVI
24.	J. Heise	SRON/UU
25.	L.O. Hertzberger	UvA
26.	Tj. Ketel	VU/NIKHEF
27.	E.P.J. van den Heuvel	UvA
28.	J.H. Koch	NIKHEF/UvA
29.	J.W. van Holten	NIKHEF/VU
30.	G. ’t Hooft	UU
31.	P. Hoyng	SRON
32.	M. de Jong	NIKHEF
33.	S.J. de Jong	RU/NIKHEF
34.	N. Kalantar-Nayestanaki	KVI
35.	P.M. Kooijman	UvA/NIKHEF/UU
36.	J. Kuijpers	RU
37.	E.L.M.P. Laenen	NIKHEF/UU
38.	F.L. Linde	Director NIKHEF
39.	H. Loehner	KVI
40.	R. Loll	UU
41.	J.G. Messchendorp	KVI
42.	P.J.G. Mulders	VU
43.	GJL Nooren	NIKHEF/UU
44.	E. Pallante	RuG
45.	Th. Peitzmann	UU
46.	T. Prokopec	UU
47.	M. de Roo	RuG
48.	A.N. Schellekens	NIKHEF/RU

49. O. Scholten	KVI
50. A. Selig	SRON
51. J. Smit	UvA
52. M. Smit	SRON
53. G. van der Steenhoven	NIKHEF/RuG
54. J. Templon	NIKHEF
55. R.G.E. Timmermans	KVI
56. Ch.W.J.P. Timmermans	NIKHEF/RU
57. M.J.G. Veltman	Univ. Michigan/NIKHEF
58. K. Wakker	Director SRON
59. R. van de Weygaert	RuG
60. R.A.M.J. Wijers	UvA
61. H.J. Woertche	KVI
62. E. de Wolf	UvA/NIKHEF