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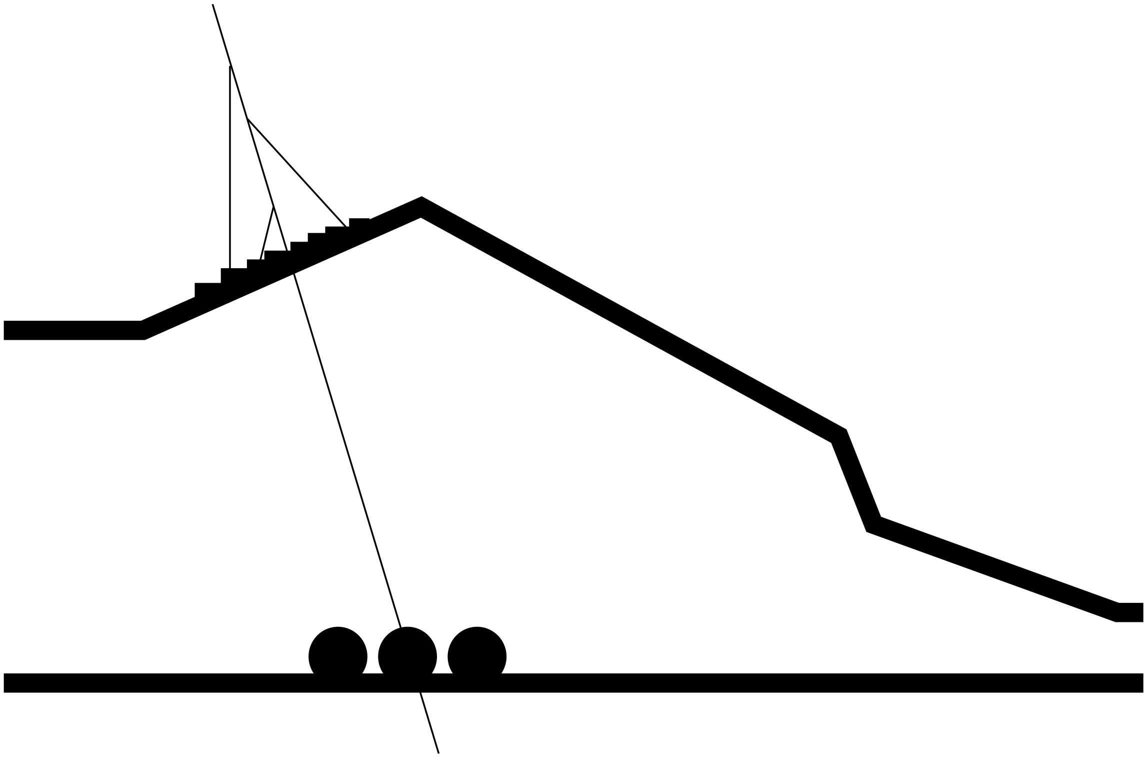

Status of Particle Astrophysics

Report of PANAGIC to IUPAP presented to the meeting of the Council and Commission Chairs of IUPAP - Beijing 6 October - Revised November 2000

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Abstract

The Particle And Nuclear Astrophysics and Gravitational International Committee (PANAGIC) was established by IUPAP in 1998 as an inter-Commission committee.
Its focus is on the emerging interdisciplinary fields of particle astrophysics and gravitational waves, in which activities are related to several Commissions.
This report is divided into two sections. First we briefly review recent developments and future directions in the field. Then we describe the activities of PANAGIC and list its members.

Present PANAGIC Composition

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1 Introduction

The Particle And Nuclear Astrophysics and Gravitational International Committee (PANAGIC) was established by IUPAP in 1998 as an inter-Commission committee. It reports to C4, C11, C12 and C19 with a primary relation to C4 and a connection to AC2. It presently has the status of a Working Group of IUPAP. PANAGIC is analogous to ICFA (International Committee for Future Accelerators). Its focus is on the emerging interdisciplinary fields of particle astrophysics and gravitational waves, in which activities are related to several Commissions.

These interdisciplinary sectors have become a focus of great activity in recent years. Important discoveries have opened new pathways and drive the current experiments and future projects. Some of the new investigations are large enough that they may benefit from co-ordination on an international scale, and it is hoped that PANAGIC may provide a forum for such co-ordination. Scientists from different fields ranging from particle and nuclear physics, to astrophysics, gravitation and cosmology collaborate on experiments and projects. Part of the mission of PANAGIC is to help develop a common culture in this new and rapidly evolving field.

This report is divided into two sections. First we briefly review recent developments and future directions in the field. Then we describe the activities of PANAGIC and list its members. Further information may be found at
http://www.lngs.infn.it/site/exppro/panagic/index.html.

2 THE SCIENCE

Underground laboratories and detectors

Observation of rare, naturally occurring, elementary events, as, for example, a very rare decay, can be an indirect way to explore high energy phenomena even at energies that cannot be reached by present or future accelerators. The high energy frontier is in this situation the low background frontier. To achieve low backgrounds detectors are installed underground, at a few kilometres depth, in pre-existing mines or in especially built laboratories.

Solar neutrinos.

The study of neutrinos produced by nuclear reactions in the core of the sun has been pursued extensively since about 1970. These measurements have the potential to provide information about detailed properties of the sun and of neutrinos themselves. The experiments all involve large detectors which observe neutrino interaction rates of the order of a few per hour or less.

Therefore, they have been sited underground to reduce background from cosmic ray interactions and have also required extreme care with internal radioactivity to reduce backgrounds from these sources. The first experiment to report data was the Homestake detector which used a chlorine compound to detect electron neutrinos from ^{7}Be and ^{8}B branches in the sun, whose flux can be related to solar luminosity through a model of the sun. The observed interaction rate was about a factor of three smaller than that calculated with comprehensive solar models that reproduced other solar properties very well. Nonetheless these predictions were dependent on the values of some of the parameters used in the model.

On the contrary, the flux of the low energy electron neutrinos from the fundamental pp reaction is known from solar luminosity, independently of any solar model. This flux can be detected with a radiochemical experiment using Gallium as the target nucleus and the corresponding rate was measured by GALLEX and by SAGE. GALLEX was also the first to be directly calibrated with an artificial neutrino source and in its chemical process. The Kamiokande experiment, using elastic scattering from electrons in a large water Cherenkov detector, provided real-time measurements of neutrino events from the direction of the sun within the pointing accuracy of the detector, as well as a spectral shape consistent with that expected for ^{8}B neutrinos. These three experiments also observed fewer neutrinos than predicted by solar models by factors of about two.

Superkamiokande, a very large water Cherenkov detector, has provided very accurate measurements of the ^{8}B solar neutrino energy spectrum, directionality and temporal variation of the flux. Studies of helioseismology over the last few years have confirmed the solar models in detail so that solar neutrinos now serve as a beam for studies of neutrino properties, independent of solar models.

At present, the most likely explanation for the observations is considered to be that solar electron neutrinos are changing flavour in transit from the core of the sun, reducing the electron neutrino fluxes detected by the existing detectors. The available parameter space for this process is restricted substantially by the measurements to date.

The experiments which have just begun data acquisition (GNO, SNO) and those being built (Borexino, Kamland) or are under development, taken together, constitute a complementary set of tools that aims to the clear observation of neutrino flavour change and to the definition of the detailed properties of the transitions, including those to either active or sterile species. The GNO experiment uses Gallium for more accurate measurements of the pp electron-neutrino flux. The SNO experiment will study ^{8}B neutrinos with the potential to observe both electron-neutrinos specifically and also the total flux of active neutrino types, through two reactions on deuterium in its heavy water medium. A comparison of the specific ^{8}B electron-neutrino flux with that observed by elastic scattering measurements also has potential to exhibit electron-neutrino flavour change, as the elastic scattering has a sensitivity to both electron and other neutrino types. The Borexino and Kamland experiments will have the potential to make real-time measurements of the low-energy ^{7}Be neutrinos to test for the suppression of neutrinos at various energies produced by specific neutrino flavour changing mechanisms, such as the matter-enhanced process known as the MSW effect.

A number of other experiments are under development, using a variety of processes such as low energy inverse beta decay on stable nuclear targets (LENS), scintillation in a variety of materials including those chosen for low neutrino interaction thresholds, roton production in liquid helium and solid state detectors. These experiments in general have the objective of detecting very low energy solar neutrinos in real time, providing spectral information to provide detailed confirmation of neutrino flavour change and delineate specific properties of the neutrinos such as mass differences and mixing matrix elements. At the same time as the detailed neutrino properties are defined, the detailed spectrum of electron neutrinos produced in the sun will be measured, so that a very accurate test of solar models will be obtained.

⋆ These experiments all require a large underground site and very careful control of radioactivity, as is being provided at underground laboratories around the world. The neutrino flavour change process goes beyond the Standard Electroweak model and these experiments provide otherwise unknown information on neutrino properties. Longer-term operation of existing experiments will enable accurate tests for a number of other neutrino processes including regeneration in the earth and possible evidence for finite neutrino magnetic moments through interaction with solar magnetic fields. The new experiments under development will expand the sensitivity and range of information available on neutrinos and the sun itself.

Atmospheric and accelerator neutrinos

High-energy cosmic rays, when they hit the atmosphere, produce pions and kaons at high altitude. They eventually decay into muons and muon neutrinos. Muons, if their energies are low, decay into electrons, electron neutrinos and muon neutrinos. Kamiokande and then IMB found that the ratio of the number of muon neutrinos to the number of electron neutrinos was not the expected number two but rather close to one. This ratio is to first approximation free from uncertainties in the cosmic ray fluxes and nuclear interactions in the atmosphere, and hence the large discrepancy was considered to be very serious. Super-K later confirmed smallness of the ratio with much higher statistics. Soudan 2 also confirmed the anomaly. Super-K found a second anomaly, namely the number of observed muon neutrinos going upward was almost half of downward-going ones. Electron neutrinos however behaved normally, showing up-down symmetry in the zenith-angle distribution. It is expected that the muon neutrino and electron neutrino fluxes should have up-down symmetry because of the spherical nature of Earth. The observed large up-down asymmetry of muon neutrinos is again insensitive to flux and interaction uncertainties. The results indicate the path length dependence of muon neutrinos. High-energy atmospheric muon neutrinos interact in the rock beneath the detector and produce upward-going muons. They occasionally pass through the detector and are observed. Super-K and MACRO found that the zenith-angle distribution of upward-going muons was steeper than expected, namely they observed fewer muons in the vertically upward direction compared with those going horizontally, again indicating the path length dependence. All these results are reproduced quantitatively by the neutrino oscillation between muon neutrinos and tau neutrinos. The two basic parameters, mass squared difference and mixing angle were determined to be 0.0015 - 0.005 eV^2 and 0.88 - 1.0, respectively (90% C.L.). The large mixing angle is in contrast with a hierarchical order of the mixing angles in the quark sector, namely a very small mixing angle between the second and third generations. It is also concluded that oscillations between muon- and sterile-neutrinos are ruled out.

The only evidence of physics beyond the standard model comes at present from underground experiments on atmospheric and solar neutrinos.

⋆ The oscillation phenomenon discovered with atmospheric neutrinos is reachable with muon neutrino beams artificially produced at an accelerator and directed to a far underground detector. Complementary programs are underway on different continents: K2K from the KEK Laboratory in Tsukuba (Japan) to the Super-K detector (taking data now), NUMI from Fermilab to the MINOS detector in the Soudan mine (Minnesota) (expected to start operation in autumn 2003), the CNGS beam from CERN to a detector in Gran Sasso, OPERA already recommended for approval, ICARUS developing the main prototype (expected to start in spring 2005). K2K has been operational since April 1999 and provided the first result. The number of events observed in Super-K is in good agreement with what is expected from the atmospheric neutrino results, and the K2K data alone disfavours the null oscillation hypothesis at the 95ray experiments on atmospheric neutrinos hence opened a new field in high energy physics.

$\star$ Future accelerator experiments should determine the MNS matrix elements (the mixing matrix in the lepton sector) just as the CKM matrix elements in the quark sector have been and are being measured, including the CP violating phase. The present programs on artificial long base-line neutrino beams must be considered as the first phase of a multidecennial endeavour. New high luminosity neutrino sources are being presently studied, including a new muon neutrino beam from a new high-intensity proton synchrotron, JHF, in Japan directed to SuperK and neutrino factories.

$\star$ A next generation experiment on atmospheric neutrinos has also been proposed, MONOLITH at Gran Sasso, aiming to detect the oscillation pattern and to accurately measure the relevant square mass difference.

Neutrinos from supernovae

Stars with mass larger than eight times the solar mass end their lives with explosion of whole stars, called type II supernovae. Onset of explosion is the gravitational collapse of the central iron core with about 1.4 solar mass. A hot neutron star then forms, which quickly cools down by emitting the enormous number of neutrinos of all types, the characteristic time of cooling being about 10 seconds. In February 1987 a supernova (SN1987A) was found in the Large Magellanic Cloud. It was seen even by naked eye. IMB and Kamiokande observed for the first time the burst of neutrinos from SN1987A, about 160,000 light years away. The number of observed events was only 19. Nevertheless observations revealed that the flux, energy and burst time were in good agreement with the stellar collapse theory. SNO, Super-K, Borexino, AMANDA and the dedicated experiment LVD will provide large statistics in case of an explosion in our Galaxy. These detectors employ different media and different techniques; as a consequence they have different sensitivity to different neutrino flavours and will provide complementary information on neutrino mixing on one side, and on the supernova explosion on the other.

$\star$ A network of early alarm amongst the neutrino detectors is being set up, possibly to be extended to other messenger experiments, gravitational waves and gamma ray bursts.

Proton decay

Grand Unified Theories, GUTs, unify electroweak and strong forces. They also put quarks and leptons in the same multiplet, enabling quarks to change to leptons. This leads to proton decay, namely a proton decays into an anti-lepton and a meson, specifically positron and neutral pion or anti-neutrino and kaon. The water Cherenkov technique, that has reached its maximum sensitivity so far with the 22 kt sensitive mass of Super-K, has given very stringent limits on the proton decay lifetime; on the other hand, the neutrino mass scenario that is emerging may indicate a proton lifetime close to the present limit.

$\star$ A next generation detector for nucleon decay and neutrino physics is being studied; its fiducial volume should be an order of magnitude or more larger than SuperKamiokande.

Dark matter search

The mounting evidence for non baryonic dark matter as a major component of the mass-energy inventory of the universe motivates experiments which seek to identify its nature, either by direct detection in the lab or by indirect evidence from dark matter annihilation in the sun or earth or in interstellar space.

Many experiments on the direct search are taking place in underground laboratories worldwide, employing different techniques. Some of these are mature experiments, while some are still in preliminary R&D phases. DAMA using scintillator techniques and CDMS with cryogenic techniques are at the forefront. Other experiments are active in the field, including EDELWEISS using cryogenic techniques and activity with scintillators in the LSM (Underground Modane Laboratory in France), UK Dark Matter search in the Boulby mine, using scintillators and CRESST at Gran Sasso using cryogenic bolometers.

$\star$ Programs to improve substantially the sensitivity and the performance of the detectors are already going on: CDMS will be moved underground in the Soudan mine with increased sensitive mass (CDMS2), DAMA has developed new techniques to further reduce the background and will double its sensitive mass, CRESST is developing a new technique to detect both heat and scintillation light, GENIUS proposes a 1000 kg Ge detector, that, even in a reduced 100 kg configuration, might be able to explore a large fraction of the parameter space. Further technological developments and larger collaborations will probably be needed for a major step forward.

Majorana neutrinos.

Neutrino oscillations imply that neutrinos are massive particles and that (flavour) lepton numbers are not conserved. The mechanism that gives mass to neutrinos may be very different from that giving mass to quarks or charged leptons. In particular neutrinos may be Majorana particles. This possibility is experimentally accessible via the neutrino-less double beta decay, that presently gives the best limit to the electron-neutrino effective mass (0.4 eV).

$\star$ Large scale detectors have been proposed to reach, with further decrease in the background, the 10 meV region. Based on the Ge technique, the GENIUS project (1 t of enriched ^{76}Ge) has been proposed in 1997 and more recently the MAJORANA project of a similar size, based on cryogenic techniques the CUORE project aims to 600 kg natural Te, while MOON will use ^{100}Mo as double beta active nuclide. Given the uncertainty in the relevant nuclear matrix elements calculations, such a search on different isotopes is mandatory. Technology developments and larger collaborations are also needed.

Underground facilities

The above-mentioned experiments are hosted in underground infrastructures that differ in their sizes, in the support of technology available, in the easiness of access. Gran Sasso National Laboratory is a fully equipped laboratory of the Italian INFN, including external workshops and services and is easily accessible through a freeway tunnel. Similarly the Kamioka laboratory has large halls and its access is through a tunnel. Smaller laboratories, accessible through tunnels are Baksan in Russia, LSM in France and LSC in Spain. SOUDAN and Sudbury are mines with large experiments, while a variety of smaller experiments are carried out in mines at different depths.

- In Europe efforts to improve infrastructures in laboratories located in mines are taking place at Boulby in England and Pyhäsalmi in Finland. The project to enlarge the Gran Sasso Laboratory with two new halls and an independent access tunnel has been approved in Italy.
- In the US there is considerable interest for a fully equipped underground laboratory. A possibility is taking over the site of the Homestake gold mine, that will close soon, as a scientific laboratory (2,600 m deep). An alternative being examined is a waste depository site in New Mexico (WIPP), operated by the Department of Energy, that announced this year that it would welcome underground science experiments. Since the site is not very deep, (700 m cover) the performance of the next generation of double beta decay experiments in such an environment would need to be understood and evaluated.
- In Japan the Kamioka Observatory accommodates experiments in addition to Super-K, including a cryogenic dark matter search, and an R&D experiment on the laser inteferometry for underground gravitational wave detection. Kamioka Observatory works in close collaboration with KamLAND which belongs to Tohoku University and is located only 150 m away from Super-K. Study has begun to foresee a next-generation massive detector beyond Super-K. It is to be used for detailed study of neutrino oscillations with a neutrino beam available from JHF (Japan Hadron Facility) and of course for a search for proton decay.

2.1 Nuclear astrophysics

Many phenomena in astronomy and astrophysics - the mechanism by which core collapse supernovae eject their mantles, synthesising new nuclei and accelerating cosmic rays, the processes governing the light curves of both types II and Ia supernovae, neutron star formation and cooling, neutrino emission from ordinary and explosive stellar environments - are governed in part by nuclear microphysics. Nuclear astrophysics is concerned with modelling such astrophysical environments and exploiting them as possible laboratories for fundamental physics, such as solar neutrino oscillations.

Areas of current activity include:

- The solar neutrino problem has been discussed elsewhere in this report. But one aspect not yet mentioned is the nuclear reaction cross sections crucial to standard solar model predictions. Only in recent years, with LUNA operating in the low-background environment of Gran Sasso, has it been possible to measure some solar cross sections in the Gamow peak, i.e., at the energies typical of solar reactions.
- There remains great interest in understanding the processes by which the lightest elements were created in the first few minutes of the big bang. New measurements of primordial deuterium coupled with the increasing precision of helium abundance have

strained the standard fit to these data.

- The mechanism responsible for Type II supernovae is still unresolved. The standard paradigm, an initial shock wave generated by implosion followed by neutrino heating of the nucleon gas left in the shock's wake, fails numerically to produce a shock. Although full Boltzmann transport has now been implemented in one-dimensional models and two-dimensional models have been explored with simplified transport, two-dimensional models with realistic microphysics and transport are as yet lacking. This is an important "grand challenge" computing task receiving considerable attention in Germany, the US, and Japan.
- Just as the determination of primordial abundances made big-bang nucleosynthesis into a experimental cornerstone of cosmology, observation of the explosive ejecta of a supernova may help theorists solve the supernova puzzle. Remarkable observations made in the last three years showing detailed r-process (or rapid neutron capture process) distributions in early, metal-poor stars (0.1% solar metallicity), identical to solar r-process distributions and thus sugesting that the r-process operated in the early galaxy much as it does today. The r-process produces about half of all nuclei heavier in iron and is believe to occur in the high-entropy ejecta of supernovae.
- A second crucial grand challenge problem is to the understand the mechanism for Type Ia supernovae. This class of supernovae provides an important "standard candle" for distance measurements, and was the basis for the recent conclusion that the cosmological constant is not zero. Such supernovae are believed to arise from nuclear detonations, but no quantitative understanding of SN Ia light curves yet exists.
- There are near-term hopes for establishing quantitative constraints on the properties of neutron stars. New techniques may yield precise mass/radii ratios. Recent observations of coherent oscillations in the emissions from accreting neutron stars by the Rossi X-ray Timing Explorer are being interpreted as a result of the star's spinning. Gravitational wave detectors discussed elsewhere in this report (e.g., LIGO, VIRGO, Tama) may detect wave forms characteristic of neutron star mergers. The details of that waveform provides constraints on possible states of nuclear matter at extreme densities, including mixed phases of quark and ordinary nucleonic matter, kaon condensation, and a colour superconducting QCD phase.
- The transition from a quark-gluon phase to the confined phase occurred in the early universe prior to nucleosynthesis. It is not known whether the transition was sufficiently violent to have consequences, such as the generation of density inhomogeneities that would persist to the time of deuterium formation. The nature of this transition should eventually be clarified by lattice QCD when calculations for nonzero chemical potentials become more feasible. It is also quite possible that the Brookhaven collider RHIC and CERN's LHC might provide relevant experimental constraints.
- There is a rich intersection of nuclear astrophysics and cosmic ray physics involving the acceleration mechanisms for energetic nuclei and their subsequent interactions. One current puzzle is the origin of the light elements Be, B, and Li, which were thought to be produced when energetic cosmic ray protons interact with C and O in the interstellar medium. Yet recent observations show a galactic evolution of these isotopes inconsistent

with this simple picture.

2.2 Cosmic ray physics

Highest energy cosmic rays

Cosmic rays with extremely high energy, above 50 EeV have been observed. At these energies the universe becomes opaque to hadronic radiation, and protons cannot propagate over cosmological distances due to their interactions with the electromagnetic microwave background. This is called GZK limit after the physicists, Greisen, Zatsepin and Kuz'min, who first pointed out that cosmic rays of sufficiently high energy would be attenuated as they propagate through the relic radiation from the big bang. Some dozens of events above this limit have nonetheless been observed, pointing to possible new physics. Two types of detector have led to this discovery. One type consists of large arrays of particle detectors along the lines of the pioneering Volcano Ranch experiment. These include Haverah Park (UK), Yakutsk (Russia) and AGASA (Japan). The other type is fluorescence detector (Fly's Eye) in the USA. The AGASA array, providing the largest statistical sample so far, is still in operation, while the Fly's Eye detector has been superseded by HiRes at the same site.

The basic problem that must be overcome to understand the origin of these ultra-high energy events is their extremely low flux. For example, events with energy above 10^{20} eV occur at the rate of only one per square kilometre per century! In nearly a decade the 100 km^2 AGASA array has accumulated seven events with assigned energies above 10^{20} eV. HiRes should be able to accumulate super-GZK events at a rate several times that of AGASA. To address the problem of low rate, a new gigantic array is now under construction in Argentina by an international collaboration of scientists. The Southern Auger experiment is a hybrid ground array/atmospheric fluorescence detector designed to accumulate these ultra-high energy events at a rate approximately 50 times greater than AGASA.

⋆ Further development of the capability for detecting cosmic rays of extremely high energy is planned for the northern hemisphere with the completion of the Northern Auger project and a very large telescope array (TA) using the fluorescence technique.

⋆ The ultimate air shower detector would be a space-borne telescope observing the atmosphere from above with a field of view approaching or exceeding a million square kilometres. The first detector of this type may be the Extreme Universe Space Observatory (EUSO) planned for the International Space Station in 2005. This may be followed by the OWL project on a free-flyer later in the decade.

Galactic cosmic rays

While the highest energy cosmic rays are generally believed to originate from sources outside the Milky Way, the bulk of lower energy particles have long been associated with galactic supernovae. A primary focus of this field is the energy region from 0.1 to 1000 PeV. The spectrum shows some structure in this range which may be associated with the upper limit of the mechanism for diffusive shock acceleration by supernova blast waves. Magnetic structure of the interstellar medium may also affect the propagation and hence the spectrum in this range energies. The discriminating signature is the energy-dependence of the relative fraction of various groups of nuclei. Air shower experiments of various types around the world, from EASTOP (alone and in coincidence with the underground detectors MACRO and LVD), HEGRA Airobicc and scintillator arrays, KASCADE and ANI in Europe to AKENO in Japan, to CASA-MIA, CASA-BLANCA, DICE and CACTI in the U.S. and the arrays in Tibet and at the South Pole, are giving relevant data. One possibility being considered is that in this high energy region, the observed particles may be the products of only a few, or even a single, cosmic accelerator.

Direct observations of cosmic rays

The observation of cosmic rays outside the atmosphere is complementary to ground-based observations. Direct observations allow precise determination of charge (and in some cases mass) states of individual nuclei, but their reach in energy is limited by the fact that the cosmic-ray intensity decreases rapidly as energy increases. One thrust of experimental activity in this field is to study rare components of the cosmic radiation-antiprotons, positrons and the search for anti-nuclei. Antiprotons and positrons are produced by cosmic-ray interactions in the interstellar medium, but they could also contain contributions from decay or interactions of dark matter particles. Anti-nuclei, though not expected, would be a spectacular signature of large-scale antimatter in the Universe. Measurements of the abundant cosmic ray protons and other nuclei with greater precision and at high energy are also obtained with space-borne detectors, and they provide important information for interpreting the measurements of atmospheric neutrinos mentioned above. Much of our basic understanding of cosmic radiation has come from measurements made with relatively small detectors in spacecraft and somewhat larger detectors carried aloft in balloons. A first version of the Alpha Magnetic Spectrometer (AMS), built by a large international collaboration, was flown abroad of the shuttle Discovery in 1998 collecting hundred millions of cosmic rays.

⋆ AMS-02, with the enhanced resolution made possible by a superconducting magnet, will fly on the International Space Station in 2003. Its primary scientific goal will be the search for antimatter in the cosmos. It will also provide measurements of antiprotons, protons, ordinary nuclei and gamma rays.

⋆ Following an agreement between the Italian INFN and the Russian Space Agency, the PAMELA space experiment is being constructed as part of a Resource satellite to be placed in a sun-synchronous polar orbit at 700 km altitude. The launch is planned for 2002, with measurements of antiprotons, positrons, nuclei and search for anti-nuclei planned.

⋆ The BESS balloon-borne experiment will continue regular flights to measure low energy antiprotons during different configurations of the solar magnetic field, thus using antiprotons as a unique probe of solar modulation, and continuing the search for an exotic component of low energy antiprotons.

A long-held objective has been to study with direct observations the structure in the spectrum of cosmic rays above 1 PeV discovered by ground-based air shower experiments. This feature, known as the knee of the spectrum, may indicate the maximum energy of cosmic accelerators in the galaxy, or a novel feature of propagation that reflects the large-scale structure of the galaxy.

The structure in the knee region and the possible transition to cosmic-rays of extragalactic origin at still higher energy, has been the subject of intense investigation by a variety of ground-based air shower experiments over the past decade.

⋆ The ACCESS project is planned as a follow-on experiment to AMS on the International Space Station. Its objective is to make a direct measurement of the primary cosmic ray composition at energies close to the knee of the spectrum. Although it will not have large enough acceptance to reach the knee, it will have the power to discriminate between different scenarios and to anchor and calibrate the indirect, ground-based experiments.

2.3 Very High Energy Gamma Ray Astronomy

Very-high-energy (VHE) gamma-ray (γ) astronomy is a rapidly expanding research section of particle astrophysics. We refer to measurements made with ground-based instruments with large effective area, which are sensitive to low fluxes characteristic at very high energy. The ground-based detectors are complementary to space gamma-ray telescopes such as EGRET and the proposed GLAST detector, which are sensitive to gamma-rays of lower energy.

The explored energy range extends from about 0.2 TeV to nearly 100 TeV where all instruments run out of sensitivity. Gamma rays, like other long-lived, neutral particles are unaffected by galactic magnetic fields, thus allowing straight extrapolation to the cosmic sources.

Besides being messengers of distant cosmic events, they can also be used to probe cosmological quantities, such as the poorly known infrared (IR) background, through absorption studies. Gamma rays are only a tiny fraction of the total cosmic-ray flux. Therefore their detection and discrimination against the many orders of magnitude larger hadronic cosmic-ray background poses a major experimental challenge. Above about 20 GeV the low flux prevents the detection of even the strongest known γ sources by current satellite-borne detectors. Higher energy gamma rays can be detected - like any other high-energy hadronic cosmic particle - by detectors based on calorimetric principles. When hitting the atmosphere the initial particle generates through electromagnetic and/or hadronic interaction an avalanche of secondary particles.

Depending on the initial energy various components of these air showers can be detected by ground based instruments: Cherenkov light is observed by so-called air Cherenkov telescopes (ACT) or arrays of open photomultipliers viewing the night sky. Shower particles reaching the ground are collected by particle detector arrays, and air fluorescence detectors are used at ultrahigh energies. Up to now nearly all the important discoveries of sources and observations of high energy gamma-rays from the ground have been carried out by ACT's because of their much lower energy threshold compared to other detectors and their potential to discriminate γ-induced air showers from the dominant charged cosmic ray induced air showers. The first high significance observation of a VHE γ source - the Crab nebula - has been reported in 1989 by the Whipple group thus opening a new window for astronomy in the high-energy domain. Since then about, a dozen of

VHE γ sources have been discovered with high significance ($\approx 1/2$ of galactic and $1/2$ of extragalactic origin). For some sources dedicated observations of the light curve and the spectra have been carried out. In particular the long-lasting flaring of the extragalactic source Mkn 501 should be mentioned. This source was observed in the VHE range by 7 instruments. The study of the spectral shape resulted in a new tight limit on the IR background in the 10 μ wavelength range. During the Mkn 501 VHE study observations in other energy bands were carried out simultaneously, revealing that the flaring was by far most violent in the VHE range.

The Crab is now considered as "a standard candle" for northern telescopes while another plerion, PSR 1706-44, could play a similar role for southern telescopes.

The field of VHE γ astronomy is trailing the field of MeV-to- 10-GeV astronomy by about 15-20 years.

$\star$ It is expected that VHE γ astronomy will evolve at a similar pace as the lower energy astronomy carried out by satellite detectors (SAS-2 1972; COS-B 1975-82; Gamma-I 1990-92; EGRET 1991-2000; GLAST 2005-2010).

World wide, one observes a shift from ground-based particle detector arrays to large ACT's. Now about 10 large ACT's and 3 particle detector arrays are operational. One of the main conclusions drawn from current observations is the need for a lower energy threshold and improved sensitivity by better (γ/hadron separation. Therefore many new technology concepts are strongly pursued and a quantum jump in performance is expected from the next generation of detectors - see below.

Physics objectives

The current physics objectives of VHE γ astronomy are rather broad. Originally, the main goal was to find the sources of high-energy cosmic rays. This is a longstanding challenge and still awaits a convincing answer.

Partly based on recent observations the objectives can be classified more broadly.

- Study of γ-ray emission and particle acceleration by supermassive black holes inside active galactic nuclei.
- Search for VHE emission from the violent, extragalactic γ-ray bursts (GRB).
- Study of shell-type supernova remnants, which are considered as plausible sources of cosmic rays.
- Study of plerions, i.e. synchrotron nebulae powered by active pulsars, such as the Crab, to explore relativistic pulsar winds.
- Search for a variety of galactic objects showing sufficient energy release for particle acceleration in shock waves or jets such as accreting binaries, microquasars, cataclysmic variables, etc. More than half the sources detected by EGRET up to a few GeV are still awaiting identification, some of them since 25 years.
- Search for the lightest supersymmetric particle and quantum gravity effects in fundamental physics.
- Constraints on stellar formation at early epochs through measurements of the IR extragalactic radiation field.

Obviously, the first goal in γ astronomy is to establish a broad variety of γ-ray sources and then study various aspects in detail, such as light curves, spectra, acceleration properties (type of acceleration, of particles, etc.), production reactions, connection to observation in other energy bands. Multi-wavelength observations have gained particular importance and will become crucial in the future to clarify many open questions. In this context, the successful launch in 1999 of two long-lived X-ray observatories, Chandra and Newton-XMM, as well as the future launch of hard-X-ray/soft-γ-ray satellites (HETE2 2000, INTEGRAL 2002, SWIFT 2003) will bring important opportunities for co-ordinated observations over many decades in energy.

An important link to another area of particle astrophysics, high energy neutrino astronomy, should be mentioned. It is hoped that future correlated observations of VHE γs and neutrinos will distinguish between cosmic electron and hadron accelerators. This is important to unambiguously identify the sources of the hadronic cosmic rays. Correlated observations of cataclysmic events, such as γ-ray bursts, or flares from accreting systems with gravitational wave detectors are also highly hoped for in the next decade.

Perspectives in the near future

$\star$ Triggered by the recent successes in VHE (astronomy, one observes a world-wide activity to build better detectors, in particular with lower thresholds. There exists an observation gap between, say, 20 GeV and 300 GeV, where fundamental changes in high energy processes must occur. This is highlighted by the observation of nearly 300 γ sources below 20 GeV with detectors of at most 0.1 m^2 detection area and only a dozen sources above 300 GeV with detectors of a few 10^4 m^2 collection area. The activities of closing this gap are concentrating, on the one hand, on new space telescopes - AGILE (2003), GLAST (2005) - and on the other hand, by building ACTs with larger collection mirrors and improved cameras. There are at least 9 new projects either in the test phase or under construction aiming for a sub 50 GeV threshold and an increase in sensitivity at 1 TeV by nearly an order of magnitude.

$\star$ In part, large solar heliostat fields are explored (CELESTE, GRAAL, SOLAR II, STACEE). While the mirrors are readily available, the difficulty lies in building cameras sensitive to subtle differences between γ and hadron induced air showers, a prerequisite for efficient γ - hadron separation. The above mentioned solar array detectors, all located in the northern hemisphere, are already taking test data and have significantly detected the Crab nebula. CELESTE has also recently announced the detection of flares from Mkn 421.

$\star$ The other pursued direction is to build very large telescopes of at least 10 m diameter mirrors, either single very large dishes or arrays of 10 m dishes operated in the so-called stereo mode (CANGAROO III, HESS, MACE, MAGIC, VERITAS) and optimised cameras of fine pixelisation and nanosecond time resolution. CANGAROO III and HESS are located in the southern hemisphere and the other three telescopes in the northern hemisphere. Their position on different longitudes will allow one to have, in case of co-ordinated observations and acceptable weather conditions, up to 12 hours source coverage for monitoring rapidly flaring sources.

$\star$ It is expected that these new projects will be in full operation when the next generation satellite, GLAST, with 1.3 m^2 detection area and large 2.4 sterad field-of-view, is launched in 2005. Designed to detect γ rays up to 300 GeV, GLAST will provide overlap with the

ACTs with well-matched capabilities (comparable angular resolution, reduced sensitivity in space, but wide field-of-view to monitor the highly variable sources for the ACTs).
⋆ Even with all the new projects becoming operational, one has not yet reached full sky coverage for 24h. For example an additional telescope at a northern site on Hawaii and a southern site in the Andes would be very helpful. Also, due to the need of prolonged observation of many candidate objects, it is already now obvious that the number of telescopes under construction is too small, e.g., a strong similarity to the needs for many optical telescopes is visible. A long-standing problem for both space-borne and ground-based instruments is the vital need for highly improved angular resolutions.
⋆ The telescope projects are complemented by a few detectors sensitive to shower tail particles (MILAGRO, Tibet AS and ARGO). In order to reach a low threshold, these detectors have to be set up at high altitudes and require a fully active (or at least high sampling fraction) coverage of a large area (a large water pool in case of MILAGRO, a dense scintillation counter array in TIBET AS and a large area covered completely by RPCs in case of ARGO) .
⋆ The advantage of these detectors is their 24 h up-time, their disadvantages a very modest γ-hadron separation power, strong zenith angle dependence of the thresholds and modest angular resolution. One of their main goals is the search for VHE (γs from GRBs. MILAGRITO may have detected a TeV signal coincident in time and position with a BATSE burst, but the detection of other events is needed to confirm this exciting possibility.
It should be noted that up to now only a few percent of the entire ”TeV sky” has been scanned.
One of the signs of growing interest in this newly developing field is the strong interest of young physicists to participate in the research.
Another indication of the evolution of the field is the intense development of new technologies. Up to a few years ago, experimental techniques developed by high-energy accelerator experiments were used. Nowadays the developments are on the forefront of instrumentation and spin-offs into other areas are visible.
The importance of this evolving area of fundamental research has been recognised by many countries providing increased funding for VHE γ astronomy and allowing many international collaborations to form.

2.4 High energy neutrino astrophysics

Gamma rays are the main messengers for the study of astrophysical sources of very high energies; being neutral, gamma rays point back to the source. But at energies of a few tens of TeV the Universe becomes opaque to gamma rays due to their interactions (pair creation and scattering) by star light and diffuse backgrounds at other wavelengths. Above these energies the only messengers are neutrinos. Large uncertainties exist in the theoretical estimates of the expected fluxes of very high energy neutrinos from astrophysical sources, but at least one point is clear, that the detector size should be enormous, 1 km^3 at least. A neutrino is indirectly observed by detecting the high energy muon produced by its interaction in the detector or close by. At higher energies electron and tau neutrinos may in

principle also be detected by the characteristic large, isolated bursts produced when they interact in a sufficiently large detector. The main background is due to muons produced in the atmosphere over the detector. As a consequence only upward going muons, produced by neutrinos that have crossed the earth are usable for neutrino astronomy with muon neutrinos. Given the enormous value of the ratio down-going/upward-going muons the detector most be screened by a few kilometres of material. Given their size detectors cannot be hosted in an underground hall, they must go underwater or deep in ice.
There are several first generation neutrino telescopes in various stages. AMANDA has deployed linear strings of optical modules at depths from one kilometre down to 2.4 km in the ice of South Pole; atmospheric neutrinos have already been detected. BAIKAL has deployed strings of optical modules at shallow depth in the lake Baikal; the deployment is made relatively easy by doing the operations during the winter when the surface of the lake is frozen. NESTOR is in its R&D phase aiming to deploy "towers" structures, each corresponding to six optical modules strings, pre-assembled and pre-cabled on the surface; NESTOR operates in the Pylos National Laboratory in Greece. ANTARES is an international project aiming to a detector that in the first phase will have a size roughly of a tenth of a km^3 and will be deployed in the Mediterranean sea off the coast of France. NEMO is an Italian project presently devo ted to R&D and to the search for an optimum site in the Mediterranean.
$\star$ Construction of a kilometre-scale neutrino detector is the necessary step to reach the sensitivity at which high energy neutrino astronomy may become feasible. A proposal for an ice detector in Antarctica (ICECUBE) is well advanced while the different projects in the Mediterranean sea will presumably lead to a common proposal.

2.5 Gravitational wave detection

The existence of gravitational waves is a consequence of Lorentz invariance and of the theory relativity. We are just entering into an era were the sensitivity of detectors is reaching the level where direct detection from catastrophic astrophysical events from known sources is anticipated in the coming years, opening up this exciting new field of research. Experimental efforts include advances in resonant bar detectors, a new generation of ground based suspended mass interferometers and an initiative to put a long baseline interferometer into space.
Resonant bars.
Cryogenic resonant mass gravitational wave detectors are designed to detect gravitational waves through the excitation of the quadrupole resonant modes of massive cylinders or spheres of high mechanical quality factor. They evolved from the original ideas and experiments of J. Weber in the 1960s. Since then, the two basic noise sources, the thermal fluctuations in the bar and the final readout amplifier noise, have been reduced, respectively by cooling the few tons bar down to Kelvin and sub-Kelvin temperatures and by using superconducting electronics based either on SQUID magnetometers or superconducting microwave cavities. The total improvement is more than five orders of magnitude in sensitivity.

Currently five detectors operate in Australia, Italy and United States with similar sensitivities, within a factor of four in the energy of a detectable millisecond gravitational wave bursts. The typical sensitivity corresponds to a violent emission of some 0.01 solar masses in the Galaxy. In amplitude of the metric perturbation at the detector, the burst sensitivity is some $h = 5 \times 10^{-19}$ and the spectral strain sensitivity is some $h = 5 \times 10^{-22}$ $\mathrm{Hz}^{1/2}$ over bandwidths of ew hertz around the kHz resonant frequencies. The five bars have been in near continuous operation and are oriented with their axes parallel to each other and each locally orthogonal to a great circle, in order to have all their antenna patterns oriented coherently. The projects exchange data under the International Gravitational Events Collaboration agreement (www.IGEC.lnl.infn.it/igec) to search for coincidences.

The results of the first IGEC search, implemented for short (ms) impulsive signals, shows that the noise in all the detectors is uncorrelated. The false alarm rate, mainly influenced by the non-modelled noise is below 1 event/century for three or more detectors in coincidence. No candidate gravitational wave signal was found over some three months of 3-fold coincidences.

⋆ For the future, all projects have plans for substantial upgrades, to approach the so-called standard quantum limit, and at the same time to open the frequency band to many tens of hertz around the resonances. These improvements are expected on the scale of 2-3 years, which will insure the bars will be complementary to the initial interferometer detectors in the kHz frequency range having very different limitations and background sources.

⋆ On a longer time scale, a number of ideas and preliminary experimental studies have been pursued toward spherical resonators, as well as prototypes of well-matched transducers. The aim is to get a further increase in sensitivity by increasing the cross section and opening up the bandwidth. In addition to all the traditional bar projects, considerable efforts in this direction come also from groups in Brazil, Holland and Spain.

Ground-based interferometers

A new generation of detectors (LIGO, VIRGO, GEO-600 and TAMA) based on suspended mass interferometry promise to attain the sensitivity required to directly observe gravitational waves on the earth's surface. The implementation of sensitive long baseline interferometers to detect gravitational waves is the result of over twenty-five years of technology development, design and construction.

This new generation of detectors is presently in final stages of construction and initial stages of commissioning. TAMA-300 is the furthest along, having locked their interferometer in September 1999 and they have improved sensitivity several orders of magnitude this year. They have taken preliminary data runs, and have already performed a search for galactic neutron star inspiral signals. The Laser Interferometer Gravitational-wave Observatory (LIGO) in the U.S.A. has completed its construction phase and is now entering the commissioning of this complex instrument. Following a two year commissioning program, they expect the first sensitive broadband searches for astrophysical gravitational waves at an amplitude (strain) of $h \sim 10^{-21}$ to begin during 2002. The Geo-600 project in Hannover is beginning commissioning as well and incorporates some advanced techniques that could make it as sensitive as LIGO and VIRGO. The Virgo project with special attention to low frequency response is in the process of major construction and commissioning of the central optics.

The initial searches with these detectors will be the first attempt to detect gravitational waves with a detector having sensitivity that intersects plausible estimates for known astrophysical source strengths. The initial detector constitutes a 100 to 1000-fold improvement in both sensitivity and bandwidth over previous searches. There are eventual plans to correlate signals from all operating detectors as they become operational.

⋆ The facilities developed to support the initial interferometers will allow the evolution of the detectors to probe the field of gravitational wave astrophysics for the next two decades and substantial improvements of sensitivity are envisioned within the next 10 years. Sensitivity improvements and special purpose detectors will be needed either to enable detection if strong enough sources are not found with the initial interferometer, or following detection, in order to increase the rate to enable the detectors to become a new tool for astrophysical research.

⋆ There are a number of proposed new projects, including the Japanese cryogenic project LCGT (Large-scale Cryogenic Gravitational wave Telescope) at the Kamioka mine promising a reduction of thermal noise at low temperatures. This will be ten times more sensitive than the first phase VIRGO and LIGO and comparable to planned improved versions, but with different limiting noise. In addition, there are preliminary proposals for advanced long baseline interferometers in the Southern Hemisphere (Perth, Australia) and a study group has been initiated in Europe to develop a future advanced kilometre-scale interferometer.

Space based Detectors (LISA)

Gravitational waves that can be detected on earth are in the audio band from about 10 to 10 000 Hz. The accessible band in space from 0.1 mHz to 0.1 Hz, which is the goal of the LISA instrument proposed to be a joint ESA/NASA project in space with a launch about 2010, complements the terrestrial experiments. The rates for many sources in space are much higher than on t he earth's surface making the prospect of space based research in this area very attractive. Progress in developing the technology and design for this mission has been significant over the past year or so. The project has been given high rankings in NASA long range planning, a technical review in Europe was successful and R&D on the technically challenging areas is progressing.

3 ACTIVITIES OF PANAGIC

PANAGIC has met three times since its formation, March 1999 in Atlanta (Centennial meeting of the American Physical Society), September 1999 in Paris (in association with the TAUP meeting) and June 2000 at Sudbury, Ontario (in association with Neutrino2000). Minutes are posted on the PANAGIC web site.

The first job of PANAGIC has been to survey the field as indicated above. A web site has been constructed (http://www.lngs.infn.it/site/exppro/panagic/index.html) which describes PANAGIC and its charge and contains links to web sites of current and planned experiments. It includes pages describing the laboratories and the experiments in particle astrophysics.

In order to establish a forum for discussion of issues related to large interdisciplinary projects and to identify opportunities for co-operation, PANAGIC has recommended that the series of TAUP (Topics in Astroparticle and Underground Physics) meetings be expanded in scope. The plan is that each of the biennial meetings of TAUP would feature one of the main topics in the domain of PANAGIC for detailed coverage, while also including overviews of the others. GWIC has similarly recommended the Edoardo Amaldi Conference as the principal series in gravitational waves physics.

The establishment of high level comprehensive school in the field of particle astrophysics is of major importance to help in the development of a common culture. A few options are under consideration. One school has been organised already, the Particle Astrophysics Winter School on Dead Sea, Israel January 7 -14 2001 a second one, School of Cosmic Ray Astrophysics, a NATO ASI, that will take place in Erice from 11^{th} to 21^{st} of November 2000, has been sponsored.

PANAGIC at present has two subcommittees. One is the Gravitational Wave International Committee (GWIC), a pre-existing committee now associated with PANAGIC. The other is the High Energy Neutrino Astrophysics Panel (HENAP), established by PANAGIC to consider international issues related to construction of kilometre scale neutrino detectors.

Membership of PANAGIC

Alessandro Bettini (Italy) Chair
Barry Barish (US)
Massimo Cerdonio (Italy)
Enrique Fernadez (Spain)
Thomas Gaisser (US)
Isabelle Grenier (France)
Wick Haxton (US)
Eckart Lorenz (Germany)
Karl Mannheim (Germany)
Victor Matveev (Russia)
Art McDonald (Canada)
John Peoples (US)
Michel Spiro (France)
Yoji Totsuka (Japan)
Alan Watson (UK)

Activities of GWIC

The Gravitational Wave International Committee continues to be the central co-ordinating body for gravitational wave research. The Amaldi meeting, organised through GWIC, has become the central conference in the field. The next conference will be held in Perth, Australia in July 2001 and has been recommended for sponsorship by GWIC, Panagic and

AC2.
The committee has representation of all major projects in the world - resonant bars; terrestrial interferometers; and space based interferometers. Areas of common R&D have been identified and co-operative projects are being carried out between projects. Agreements between experiments on data exchange are being developed.
http://www.cithep.caltech.edu/~donna/GWIC/GWIC_doc1.html

Membership of GWIC

Barry Barish (U.S.) Chair
Peter Bender (US)
David Blair (Australia)
Alain Brillet (France)
Karsten Danzmann (Germany)
Lee Samuel Finn (US, Seceratay)
Masa-Katsu Fujimoto (Japan)
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James Hough (UK)
Yoshihide Kozai (Japan)
Guido Pizzella (Italy)
John Sandeman (Australia)
Gary Sanders (US)
William Hamilton (US)
Massimo Cerdonio (Italy)

Mandate of HENAP

The Cherenkov detection of high-energy (> 1 TeV) neutrinos in the deep sea or Antarctic ice promises to open an important new window onto the cosmos. The uncertainties in the current neutrino-rate calculations, the fragmentation of the interested community, and the high price tag of the future large size projects have raised a number of questions among scientists, funding agencies, and governments alike. Following the conclusions of the OECD MegaScience workshop of Taormina in May 1997, the PaNAGIC of IUPAP has set up a High Energy Neutrino Astrophysics Panel with the following charge:

- Firm up the scientific justifications: likely sources expected rates and their uncertainties, astrophysical importance of detecting such neutrinos, and connection with other astronomical observations.
- Establish the needed sensitivity and volume and examine the potential justifications for more than one site.
- Identify the needed steps to reach the required detector sensitivity, and establish the scientific milestones that should be reached by the successive generations of instruments, before proceeding to the next step.
- Define with the scientists involved the elements of comparison of the proposed technologies: performance, reliability, maintenance, cost effectiveness etc.
- Identify the opportunity for R&D collaboration between the various projects.
- Define the scientific and technical criteria for the choice of site(s) for a high-energy

neutrino observatory.

- Suggest international collaboration guidelines.
- Examine the potential for involvement of industry.
- Explore the benefit of the facilities for other fields of science.

http://www.lngs.infn.it/site/exppro/panagic/section_indexes/ frame_panels.html

Membership of HENAP

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Steve BARWICK (US)
John CARR (France)
Charles DERMER (US)
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