Vol. 37 (2006) *ACTA PHYSICA POLONICA B* No 7

PRESENT AND FUTURE OF ASTROPARTICLE PHYSICS IN EUROPE

Christian Spiering

DESY, Platanenallee 6, 15738 Zeuthen, Germany

(Received May 29, 2006)

This talk reviews the status of european astroparticle experiments and sketches elements of a roadmap over the next decade. It is mostly based on work towards an ApPEC strategy paper which is presently underway and planned to be finished in Summer 2006.

PACS numbers: 14.69.Pq, 95.35.+d, 95.85.Ry, 95.90.+v

1. Introduction

This talk reviews the status of astroparticle experiments in Europe or with European participation, respectively. It also sketches elements of a strategy for the next decade. A roadmap paper is presently being prepared by the ApPEC Peer Review Committee (PRC) [1]. ApPEC stands for Astroparticle Physics European Coordination.

Astroparticle Physics has evolved as an interdisciplinary field at the intersection of particle physics, astronomy and cosmology. It will not come as a surprise, that the borders of a field overlapping with its neighbours are somewhat fuzzy, and assignment of certain types of experiments to either astroparticle physics, or particle physics or cosmology sometimes appear to be debatable. Rather then wasting efforts in endless discussions on definitions, the Roadmap Committee adopted the assignments grown historically and being practiced in most European countries, and will formulate its recommendations by addressing a set of basic questions:

1. What is the Universe made of?
2. Do protons have a finite life time?
3. What are the properties of neutrinos? What is their role in cosmic evolution?

4. What do neutrinos tell us about the interior of Sun and Earth, and about Supernova explosions?

5. What is the origin of cosmic rays? What is the view of the sky at extreme energies?

6. What is the nature of gravity? Can we detect gravitational waves? What will they tell us about violent cosmic processes?

An answer to most of these questions would mark a major break-through in understanding the Universe and would open an entirely new field of research by its own. The following sections address the questions in detail and reflect the recommendations of the ApPEC PRC (at the time of writing this report being still preliminary).

2. What is the Universe made of?

2.1. Dark Matter

Only 4% of the Universe is made of ordinary matter. 73% of the cosmic energy budget seems to consist of "dark energy" and 23% of Dark Matter. The simplest solution to the Dark Matter problem assumes Weakly Interacting Massive Particles (WIMPs), thermally produced in the Early Universe. The most notable WIMP candidate is the lightest super-symmetric particle, the neutralino. These particles can be searched for in LHC experiments, although evidence for super-symmetric particles in accelerators does not imply their existence as Dark Matter. Their presence as the main component of our Milky Way halo can be detected with both direct and indirect methods [2].

Direct methods search for recoil products from WIMPs interacting in deep underground detectors. Annual modulation of the rate of possible signals (due to the movement of the Earth) is one of the smoking guns for the WIMP character of the signal, the others being a directional signature (due to the movement of the Sun through the galactic halo) and the A-dependence of signal rate and shape. Actually, an annual modulation of event rates has been reported by the DAMA group in Gran Sasso. The DAMA signature by itself is model independent. However, interpreting the signal as a standard neutralino would lead to contradictions with limits obtained by other experiments. An upgraded version, DAMA/LIBRA is presently taking data; another ongoing experiment at a different site (the ANAIS project in Spain) might provide a valuable cross check.

Cryogenic detectors of nuclear recoils with a threshold of few keV, excellent background suppression, and a mass of order one ton, can cover an important fraction of the parameter space of existing models and eventually be sensitive to WIMPs with an interaction cross section as low as

10^{-10} pb. Present best limits are at a few 10^{-7} pb (CDMS in the USA) and are expected to improve to 10^{-8} pb within the next two years. The two most advanced European efforts, CRESST (Gran Sasso Laboratory) and EDELWEISS (Fréjus Tunnel), use also bolometric techniques and eventually will converge to a single project on the scale of a few hundred kg to one ton (EURECA). Another approach is based on noble liquid techniques: ZEPLIN (Boulby mine, UK) and XENON (to be installed in Gran Sasso) use Xenon; WARP (Gran Sasso) and ArDM explore the feasibility of Argon. Noble liquid techniques could provide a complementary path to reach detectors with a ton-scale and should also converge towards a single proposal for a large-scale facility with 10^{-10} pb sensitivity.

A possible scenario would result in one or two low-background experiments on the ton scale with a European lead role. A 1-ton DAMA type detector (10 times larger than the original DAMA but much cheaper than 1-ton cryogenic detectors), is an additional option when first conclusions from DAMA/LIBRA have been drawn. As mentioned above, one of the smoking guns for the direct detection of WIMPs would be directional dependence. The case for a massive directional device would be provided by the detection of a clear signal by non-directional, large mass detectors. Further development of this technique (the DRIFT project in the Boulby mine) is therefore important.

The progress made over the last few years is impressive, and extrapolating to the future one concludes that there is a significant chance to detect WIMPs in the next decade — provided the progress in background rejection can be realized and the considerable funding (on the 50–100 milion € scale for 1-ton projects) is provided.

Indirect evidence for WIMPs can be obtained with the help of gamma telescopes, space based cosmic ray detectors and neutrino detectors. This attempt is complementary to the direct methods, for some parts of the supersymmetric parameter space even superior.

WIMPs can come in diverse incarnations — s-neutrinos and Kaluza–Klein particles are just two examples of many. The other theoretically well motivated candidate for cold Dark Matter, beside WIMPs, is the axion, searched *e.g.* by the CAST project in CERN. Continued searches for other Dark Matter candidates like the axion should be continued. This also includes searches for those exotic particles which may contribute to Dark Matter at best at a subdominant level. Examples include magnetic monopoles, supersymmetric Q-balls, or nuclearites, all searched for by detectors with other primary goals, like *e.g.* neutrino telescopes.

2.2. Dark energy

The nature of dark energy is one of the most important problems in physics and cosmology today. So far, dark energy can primarily be explored through its influence on cosmic evolution. Observations in this area traditionally use astronomical techniques which have been outside particle physics, but particle physicists, both experimentalists and theorists, have joined this new field and are playing a major role. There is growing activity in the astroparticle physics community in Europe in this area, and initiatives to address this question together with the astrophysics and cosmology communities are welcome. The roadmap committee feels, however, that detailed recommendations on dark energy missions are beyond its charge and its competence.

2.3. Antimatter

The key for the obvious asymmetry between matter and antimatter in the Universe comes from the very early phase of the Big Bang. This makes the search for antimatter particularly important. The most notable projects on antimatter search are PAMELA (to be launched in fall 2006) and AMS which is much delayed due to the notorious space shuttle problems, but (still) foreseen to be operated on the International Space Station.

3. Do protons have a finite lifetime?

Grand Unified Theories (GUTs) of particle physics predict that the proton has a finite lifetime. Actually, proton decay is one of the generic and best testable implications of GUTs. The physics of proton decay is closely linked to the physics of the Big Bang and the matter–antimatter asymmetry in the Universe. The discovery of proton decay would be one of the most fundamental discoveries for physics and cosmology.

An improvement of an order of magnitude over the existing limits explores a physically relevant range of lifetimes. The design for a detector with this capability appears possible, but requires careful studies to optimise the methods and choice of the most promising technology. The Roadmap Committee recommends envisaging a new large European infrastructure, as a future international multi-purpose facility on the 10^5–10^6 ton scale, for improved studies of proton decay and of low-energy neutrinos from astrophysical origin (see the review [3] in these proceedings). The three detection techniques being studied for such large neutrino detectors in Europe, Water–Cherenkov (like MEMPHYS), liquid scintillator (like LENA) and liquid argon (like GLACIER), should be evaluated in the context of a common design study which should also address the underground infrastructure and the possibility of detecting neutrinos from future accelerator beams. This design study should take into account worldwide efforts and converge, on a time scale of 2010, to a common proposal.

4. What are the properties of the neutrinos? What is their role in cosmic evolution?

Neutrinos have provided the first reliable evidence of phenomena beyond the Standard Model of particle physics. In the Standard Model, neutrinos have no mass. A major breakthrough of the past decade is the discovery that neutrinos, in contrary, are massive. This evidence has been obtained from the observation that neutrinos can change their identity and oscillate between different states. From the oscillation pattern, the mass differences between different neutrino states but not the absolute values of the masses and the form of the hierarchy can be inferred. Dedicated experiments are sensitive to the absolute value of the mass. Another class of experiments searches for "neutrino-less double beta decay" and may tell us whether the neutrinos are their own antiparticles — a discovery going much beyond the precision measurement of their absolute mass. Another important issue for particle physics and cosmology is the precise way how neutrinos oscillate from one state to another. Information on the "mixing matrix" is obtained from measurements with neutrinos from the Sun, supernovae or the Earth's atmosphere. Moreover, the question is addressed by dedicated experiments with artificially produced neutrinos. Massive neutrinos and their mixing have likely played a role in the genesis of the matter–antimatter asymmetry of the Universe and in the formation of large scale cosmic structures.

4.1. Direct measurement of the neutrino mass

The measurement of beta-decay spectra near the endpoint allows a direct kinematical determination of the neutrino mass, without model assumptions. The key experiment on this sector is KATRIN (Karlsruhe), which will start full operation of its huge 10-m diameter main spectrometer in 2010 and aims to increase the sensitivity by one order of magnitude below the present limits of $2.2\,\mathrm{eV}/c^2$ (obtained by spectrometers in Troitzk/Russia and Mainz/Germany), down to $0.2\,\mathrm{eV}/c^2$. A positive effect would mildly violate limits obtained from present precision cosmology and would certainly challenge more rigid upper limits like those expected from the PLANCK satellite (launch in 2007).

Bolometric techniques to measure the electron spectrum do not suffer from the principal limitations of the KATRIN technique but have not yet reached their technological limit. They may eventually go beyond the projected sensitivity of KATRIN; therefore their potential should be further explored.

4.2. Mass and nature of neutrinos from neutrino-less double beta decay

A clear signal of neutrino-less double beta decay [4] would establish that neutrinos are the only fermions being their own antiparticles ("Majorana particles"). Establishing a possible Majorana nature of neutrinos would be a fundamental discovery. Neutrino-less double beta decay would also constrain the absolute scale of the neutrino mass. There are three possible mass ranges. Two of them (corresponding to the "degenerate" and the "inverted hierarchy" scenario, respectively) are accessible with present methods. The third one ("normal hierarchy") cannot be addressed with present technologies.

Existing experiments like CUORICINO and NEMO-3 are exploring masses of the order of ≥ 500 meV, belonging to the range of the first of these mass intervals: They could address (but not fully disprove) a recent claim on a positive observation derived from data taken with the Heidelberg–Moscow detector.

The European next-stage detectors are GERDA, CUORE, Super-NEMO and possibly COBRA (mass range 50–100 meV). With these detectors, Europe will be in the best position to improve sensitivity and maintain its leadership in this field. These experiments also could clearly prove or disprove the mentioned claim.

Only future detectors of the then following stage, with an active mass of order of one ton, good resolution and very low background, can cover the second possible mass range (inverted mass hierarchy) and reach the level of 20–50 meV. Different nuclear isotopes and different experimental techniques are needed to establish the effect and extract a neutrino mass value. Europe should play a leading role in one or two of the follow-up detectors.

A key element of double beta searches is a better knowledge of nuclear matrix elements, with present uncertainties being a factor two to four. A vigorous program, based on both theoretical and experimental investigations, is necessary to assess and to reduce the uncertainty of nuclear matrix elements, at least for a few key nuclei.

4.3. Study of neutrino mixing parameters

The structure of the neutrino mass matrix, describing the mixing between different neutrino flavours, has a great impact on particle physics and cosmology. Future measurements with neutrinos from the Sun, supernovae or other astrophysical objects, coupled with those generated in the Earth's atmosphere will not only provide a deeper understanding of their sources, but also improved information on the neutrino mixing and fundamental properties. Precision data on neutrino mixing, in particular the mixing angle θ_{13} and the CP-violating phase δ, are expected from dedicated experiments with neutrinos generated in reactors and in accelerators (with those at accelerators not covered by the ApPEC Roadmap). The "Double CHOOZ" experiment at a French nuclear power reactor appears to be the most advanced project to measure θ_{13}. However, the discovery window of Double CHOOZ is only a few years, since accelerator experiments like T2K in Japan are expected to reach a better sensitivity in θ_{13}. In order to make use of this window of opportunity, Double CHOOZ must be built as soon as possible.

5. What do neutrinos tell us about the interior of Sun and Earth, and about Supernova explosions?

In 2002, Ray Davis and Masatoshi Koshiba were awarded the Nobel Prize in Physics for opening the neutrino window to the Universe, specifically for the detection of neutrinos from the Sun and a Supernova. However, so far only the high energy tail of solar neutrinos, a small fraction of the total, has been studied in detail [5]. Precise measurements of the low-energy part of the solar neutrino spectrum would test our understanding of neutrino oscillations, would allow fine-tuning of picture of nuclear fusion deep inside the Sun and would give hints on long-term variations of the Sun [6]. Another source of neutrinos are Supernova collapses. The 23 neutrinos detected from Supernova SN1987-A have yield a rich harvest for particle physics and impressively confirmed astrophysical expectations on the collapse process. A galactic Supernova would result in thousands of neutrinos in existing or planned large neutrino detectors. The neutrino signal would give detailed insight in the mysterious way how the early explosion process of supernovae is sustained. Moreover, it would turn the Supernova into a fantastic laboratory for particle physics and provide the best sensitivity to many intrinsic properties of particles like neutrinos, axions and others. First evidence for the detection of neutrinos from the interior of the Earth have been reported recently. These neutrinos can provide unique information on the way of heat production inside our own planet.

With GALLEX/GNO (Gran Sasso), Europe has played a strong role in establishing solar neutrino oscillations. European groups have also played a significant role in developing other technologies for low energy neutrino detection. With GNO closed, there will be no running solar neutrino experiment in Western Europe until BOREXINO will start data taking. After many unfortunate delays, BOREXINO now must be completed and start operation as soon as possible, Also, the technical and personal support needed to ensure full operation must be provided.

After the dismantling of MACRO, the presently running detectors with good Supernova detection capability and European participation are LVD (Gran Sasso), AMANDA and SNO. Russia is running two relevant detectors in its Baksan laboratory: SAGE for solar neutrino detection and the same scintillation detector for Supernova detection which already has recorded three neutrinos from SN-1987. Russians plan to upgrade the latter detector, but are also thinking about a much larger scintillation detector (5 ktons or so), with the aim to study neutrinos from Sun, Earth and supernovae.

Any major neutrino experiment with a mass on the scale of Super-Kamiokande or larger should be multi-purpose and thus discussed in a larger context than low-energy neutrinos. This context should include proton decay, solar, atmospheric and Supernova neutrinos, and possibly accelerator neutrinos — see also Section 2 on proton decay. The committee ranks such a detector (respectively, two of them worldwide) very high and recommends that Europe plays a leading role in at least one of them, including the preparation of the corresponding infrastructure in Europe.

6. What is the origin of high energy cosmic rays? What is the view of the sky at extreme energies?

Cosmic rays have been discovered nearly a century ago. Later, it turned out that some of these particles have energies a hundred million times above that of terrestrial accelerators. The observation of particles with such breathtaking energies raises several questions: How can cosmic accelerators boost particles to these energies? What is the maximum energy for galactic sources like Supernova remnants or micro-quasars? What is the nature of the particles? How do they propagate through the Universe? Does the cosmic ray spectrum extend beyond the maximum energy a proton can maintain when travelling over large cosmic distances but eventually colliding with the omnipresent microwave background? A large flux above this energy limit must likely be attributed to entirely new cosmic phenomena. The mystery of cosmic rays is going to be solved by an interplay of detectors for high energy gamma rays [7,8], neutrinos [9] and charged cosmic rays [10].

6.1. High-energy cosmic rays

The "knee region" between a few 10^{14} and a few 10^{16} GeV has been studied by many air-shower experiments, most notably KASCADE in Karlsruhe. Obvious gaps remain below and above this region. The first of them extends down to experiments recording primary cosmic rays above the atmosphere, *e.g.* balloon experiments like TRACER and CREAM and satellite detectors like PAMELA and AMS. This gap should be bridged by large-aperture, long duration flight missions above the atmosphere and/or by ground detectors with sufficient particle identification placed at highest altitudes. The second, less severe gap extends towards Auger-energies ($\sim 10^{18}$ eV) and will be partially covered by square kilometre air shower detectors like KASCADE-Grande, TUNKA-133 (Siberia) and IceTop (South Pole).

The study of ultra-high energy cosmic rays addresses important physics problems and requires a sustained long-term programme. The present flagship of this field is the Southern Pierre Auger Observatory, with a 50% European contribution. The interplay of source distribution, energy spectrum and propagation through background radiation and magnetic fields requires both detailed theoretical modelling and a careful study of the arrival directions of cosmic rays with full-sky coverage. This is the main idea behind a Northern Auger Observatory, the second being an extension to ten times the Auger-South area and measuring to even higher energies. European groups should play a significant role to establish the scientific case, and, should it be warranted, make a significant contribution to the design and construction of Auger-North.

6.2. High energy neutrinos

The physics case for high energy neutrino astronomy is obvious: neutrinos can provide an uncontroversial proof of the hadronic character of the source; moreover, they can reach us from cosmic regions which cannot be escaped by other types of radiation. European physicists have played a key role in construction and operation of the two pioneering large neutrino telescopes, NT200 in Lake Baikal and AMANDA at the South Pole. These detectors have approached tantalisingly close — but did not yet enter! — a sensitivity region with high discovery potential. Europeans are also strongly involved in AMANDA's successor, IceCube. With the projects ANTARES, NEMO and NESTOR as seed, another strong community has grown over the last decade, with the goal to prepare the construction of a large underwater telescope in the Mediterranean. An EU-funded 3-year study (KM3NeT) has been approved to work out the technical design of this future installation. Prototype installations (NESTOR, NEMO) and an AMANDA-sized telescope (ANTARES) are expected to be installed in 2006/2007.

A complete sky coverage, in particular of the central parts of the Galaxy with many promising sources, requires a cubic kilometre detector in the Northern Hemisphere complementing IceCube. Resources for such a detector in the Mediterranean should be pooled in a single, optimised large research infrastructure "KM3NeT". Start of the construction of KM3NeT has to be preceded by the successful operation of small scale or prototype detector(s) in the Mediterranean. I note that there also exist Russian plans to extend the NT200+ detector in Lake Baikal to Giga-ton scale, although at present without foreign partners.

The construction of IceCube with its early high discovery potential is planned to be completed in 2010/11. European partners have been playing a strong role in AMANDA/IceCube since long and will need the necessary support in order to ensure the appropriate scientific return, as well as a strong contribution to the considered extension of IceCube.

6.3. High-energy gamma-ray astronomy

European instruments are leading the field of ground-based high-energy gamma ray astronomy. The rich results from current instruments (in particular H.E.S.S. and MAGIC) show that high-energy phenomena are ubiquitous in the sky; in fact, some of the objects discovered emit most of the power in the gamma-ray range and are barely visible at other wavelengths. With the experience gained from these instruments, the need for a next-generation instrument is obvious, and its required characteristics are well understood.

To further explore the diversity of galactic and extragalactic gamma ray sources, construction of a next-generation facility for ground-based very-high-energy gamma ray astronomy is recommended with high priority. This Cherenkov Telescope Array (CTA) must both boost the sensitivity by another order of magnitude and enlarge the usable energy range. The technology to build arrays of highly sensitive telescopes is available or under advanced development, and deployment of CTA could start around 2010, overlapping with the operation of the GLAST satellite.

CTA is conceived to cover both hemispheres, with one site each. While low-threshold capability is of interest for both, a southern site of the facility should also provide improved detection rate at very high energies, given the flat spectra of galactic sources; this aspect may be less crucial for a northern site concentrating more on extragalactic physics. The instruments should be prepared by a common European consortium and share R&D, technologies and instrument designs to the extent possible. Cooperation with similar efforts underway in the US and in Japan should be explored.

6.4. New technologies

The field of high-energy cosmic radiations is particularly rich on innovative detection techniques. Examples include radio Cherenkov detection in ice or in salt domes, in the atmosphere or in the moon crust, or acoustic detection of neutrino interactions. Another example is radio detection of air showers. The impetus of present R&D and prototype activities should be maintained and ongoing coordinated R&D work should be strongly supported.

6.5. Multi-wavelength and multi-messenger studies

For virtually all topics, multi-wavelength coverage of radiation sources is a key issue; in particular information at radio, X-ray and lower-energy gamma-ray wavelengths is crucial for the understanding of the processes in the sources. GLAST — serving as an all-sky monitor at lower energies — is an essential element in a multi-wavelength approach towards gamma-ray astronomy. The next decade will likely open the possibility to extend the classical multi-wavelength approach towards a true multi-messenger approach, including charged cosmic rays, photons from radio to TeV energies, neutrinos and gravitational waves. The realization of this potential requires close collaboration between the high and low energy gamma communities both experimentalists and theorists.

7. What is the nature of Gravity? Can we detect gravitational waves? What will they tell us about violent cosmic processes?

Gravitation governs the large scale behaviour of the Universe. Weak compared to the other macroscopic force, the electromagnetic force, it is negligible at microscopic scales. The main prediction of a field theory is the emission of waves. For electromagnetism it has been established by the discovery of electromagnetic waves in 1888. The emission of gravitational waves from accelerated masses is one of the central predictions of the Theory of General Relativity. The confirmation of this conjecture would be fundamental by its own. Moreover, gravitational waves would provide us with information on strong field gravity through the study of immediate environments of black holes, and they would be a first rate cosmological probe, in particular to test the evolution of dark energy.

The tools for gravitational wave detection include interferometers with broad-band sensitivity as well as resonant detectors [11]. At present, the world's most sensitive interferometer is LIGO (USA), the other interferometers are GEO600 in Germany, TAMA in Japan and VIRGO in Italy.

The Gravitational Wave field has a huge discovery potential but is still awaiting the first direct detection. Therefore, the effort must be balanced between the quasi-continuous observations and the upgrade of the existing detectors as well as the design and construction of new one(s).

The European community should continue the effort towards integration and should focus its resources on the projects with the largest discovery potential. In the short term, the European ground interferometers (GEO and VIRGO) should turn to observation mode with a fraction of their time dedicated to their improvement (GEO-HF, VIRGO+ and Advanced VIRGO). A continued operation of resonant detectors is desirable in order to limit the effect of the down time of the interferometer network. The design study of a large European third-generation interferometer facility should start im the nearest future.

Gravitational wave observations complementary to those of the ground interferometers will be provided by the LISA project. Covering the sub-Hz frequency range, it will enable the exploration of a wealth of sources, both of galactic and cosmological origin.

8. Summary

The European astroparticle community has a lead position in many fields. This happens in a period when most of these fields have moved from infancy to maturity: the past 1–2 decades have born the instruments and methods for doing science with high discovery potential. We observe an accelerated increase in sensitivity in nearly all fields — be it neutrino-less double beta decay, Dark Matter research, search for high energy neutrinos, gamma rays and cosmic rays, or to gravitational waves — just to mention a few.

The long pioneering period to prepare methods and technologies is expected to pay off over the next 5–15 years. This will not only need substantial investment in large detectors but also in the necessary infrastructures — underground laboratories (providing the infrastructure to perform, *e.g.*, the search for double beta decay, "direct" searches for Dark Matter, investigation of neutrinos from the Sun or supernovae, or detectors searching for proton decay) and telescopes/observatories (like neutrino telescopes underwater and ice, telescope arrays for gamma rays or the largest detectors for air showers from charged cosmic rays).

The price tag of frontline astroparticle projects requires international collaboration, as the realization of the infrastructure does. Cubic-kilometre neutrino telescopes, large gamma ray observatories, Megaton detectors for proton decay, or ultimate low-temperature devices to search for Dark Matter particles or neutrino-less double beta decay are in the 50–500 million € range. Cooperation is the only way (a) to achieve the critical scale for projects which require budgets and manpower not available to a single nation and (b) to avoid duplication of resources and structures.

A process of coherent approaches in Europe has started in 2000, when the major national agencies funding astroparticle programmes have formed ApPEC. ApPEC successfully helped to launch ILIAS, an Integrated Infrastructure Initiative which leading European infrastructures in Astroparticle physics. ILIAS covers experiments on double beta decay, Dark Matter search and gravitational wave detection as well as theoretical astroparticle physics. The projects within ILIAS have made excellent progress in the first two years of the initiative and the growth in cooperation between the subfields and the interaction between the various programmes is significant. Also, the Design Study proposal for the Mediterranean KM3NeT neutrino telescope was supported by ApPEC and accepted by the European Commission. KM3NeT is just one of several examples for a project on the price scale of 100 million € or above, which are supported by a large and multi-national community and should be realized in 2010–2015. CTA, the advanced facility for ground-based high-energy gamma ray astronomy as next generation observatory after H.E.S.S. and MAGIC, is another example. The large ultra-low background cryogenic facility to detect Dark Matter particles and extremely rare events, EURECA, is a third example, and the next generation gravitational antenna a fourth.

Let us assume that the process of cooperation and coordination convergences to the following large (cost larger then 30 million €) next-stage projects:

(a) construction and operation of two 1-ton Dark Matter experiments,

(b) construction and operation of two double-beta experiments, the one basically European, the other shared to equal parts with US physicists,

(c) start of construction of one large infrastructure for proton decay and low energy neutrino astronomy (possibly also accelerator neutrinos),

(d) construction and initial operation of KM3NeT,

(e) construction and operation of Auger-North,

(f) construction and operation of CTA,

(g) construction of a third generation gravitational wave interferometer.

Assuming that 90% of the funding available for astroparticle physics is focused to these projects, one arrives at an oversubscription of about a factor 2 when compared to present funding. The prospects of astroparticle physics merit such an increase. The ApPEC roadmap paper is intended to make the case for these increased efforts, to the physics community as well as to funding agencies. Discoveries lay ahead — it is up to us to take the chance offered by the next decade!

I am indebted to my colleagues in the ApPEC Roadmap Committee for fruitful discussions and work on the roadmap paper. Parts of the text of this paper have been taken from our draft for the recommendations. I am also grateful to Agnieszka Zalewska, who invited me to the nice and stimulating Epiphany Symposium.

REFERENCES

[1] Members of the ApPEC Peer Review Committee are: F. Avignone, J. Bernabeu, P. Binetruy, H. Blümer, K. Danzmann, F. von Feilitzsch, E. Fernandez, J. Iliopoulos, U. Katz, P. Lipari, M. Martinez, A. Masiero, B. Mours, F. Ronga, A. Rubbia, S. Sarkar, G. Sigl, G. Smadja, N. Smith, C. Spiering (Chair), A. Watson. Permanents guests: T. Berghöfer, L. Bezrukov.

[2] See for a recent review Laura Baudis, astro-ph/0511805.

[3] S. Katsanevas, *Acta Phys. Pol. B* **37**, 2115 (2006), these proceedings.

[4] K. Zuber, *Acta Phys. Pol. B* **37**, 1905 (2006), these proceedings.

[5] A. McDonald *et al.*, *J. Phys. G* **29**, 843 (2003) [astro-ph/0303068].

[6] J. Bahcall, *Phys. Scripta* **T121**, 46 (2005) [hep-ph/0412068].

[7] T. Weekes, astro-ph/0508253.

[8] H. Voelk, astro-ph/0401122 and astro-ph/0603501.

[9] C. Spiering, *Rev. Sci. Inst.* **75**, 293 (2004) [astro-ph/0311343].

[10] A. Watson, astro-ph/0511800.

[11] J. Hong, S. Rowan, B.S. Sathyaprkash, gr-qc/0501007.