Organisation for Economic Co-operation and Development (OECD)

Global Science Forum

Working Group on Astroparticle Physics

Interim Report to the Global Science Forum

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Section 1: Background and Rationale

Astroparticle physics stands on the threshold of a new era of discovery. The scientific scope of the field extends over vast distance scales – from the realm of subatomic particles to the outer reaches of the observable universe. It marks the intersection of cosmology, astrophysics and particle and nuclear physics. Major research challenges fall within the realm of astroparticle physics, notably, understanding the properties of dark matter and dark energy, and exploring the potential unification of the fundamental forces of nature. Researchers are addressing these challenges by studying some of the rarest and most violent phenomena in the Universe (via the detection of high energy gamma rays or non-electromagnetic messengers such as ultra high energy cosmic rays, neutrinos and gravitational waves), searching for the limits of the stability of the proton, or exploring the cosmological and astrophysical role of neutrinos.

A new generation of instruments (located underground, underwater, on the Earth‘s surface, and in space) promises to deliver important results based on enhanced sensitivity and resolution. While these prospects are exciting, it is important to ensure that the scientific potential is fully realised via a corresponding endeavour in the domain of science policy. That is, to make sure that, during the next 10-15 years, progress in astroparticle physics will be a globally coherent, affordable response to the scientific challenges, using an optimal set of national, regional, and international projects. Accordingly, in October 2008, the OECD Global Science Forum established the Working group on Astroparticle Physics, based on a proposal from the Delegation of France. The Working Group comprises government-nominated representatives of eighteen countries (Argentina, Australia, Belgium, China, France, Germany, India, Italy, Japan, Korea, the Netherlands, Norway, Poland, the Russian Federation, Spain, Switzerland, the United Kingdom, and the United States), two Observer organisations (an intergovernmental organization (CERN)) and an independent scientific organisation (PaNAGIC)) and invited experts. The Appendix contains the list of members of the Working Group. The Working Group is chaired by Dr. Michel Spiro, Director, *Institut National de Physique Nucléaire et de Physique des Particules (IN2P3)*. The Group held two meetings in 2009 – in Paris, France, and Kraków, Poland. This interim report, which was mandated when the Working Group was created, presents the results of the consultations to date, and makes the case for further work, which is described in Section 5.

Astroparticle physics experimental and theoretical endeavours are seeking answers to a set of basic questions:

1) What is the form of matter and interactions at the smallest scales or equivalently the highest energies? In particular:

    a. Do forces unify and therefore can we detect the decay of the proton?

    b. What can we infer for the physics at the highest energies from the knowledge of neutrino properties (mass and mixings)?

    c. Which mechanism broke matter-antimatter symmetry?

2) What is the Universe made of? In particular, what is the nature of dark matter and dark energy?

3) How does the sky appear at extreme energies? In particular:

    a. What can we learn about the origin and acceleration mechanisms that produce high energy cosmic rays and gamma rays.

    b. What can we learn about the interior of cosmic bodies and violent phenomena using neutrinos?

    c. What can we learn about violent processes and the nature of gravity using gravitational waves?

The answers to these major questions will provide important clues for understanding the genesis and

evolution of the Universe and the cosmic structures within it. We need to understand a) the physics of the highest energy scales in order to approach theoretically the origin of the Universe, b) the nature of dark matter and energy in order to understand the formation and evolution of large-scale cosmic structures and the ultimate destiny of the universe,
c) the physics of violent phenomena, since they play a regulating role in the formation and evolution of key cosmic structures (stars and galaxies), can also help us understand and study the types of phenomena can create such high energy particles and waves and can test the violation of fundamental laws.

The advancement of knowledge in the above fields will have of course a great impact beyond cosmology, to particle physics and astrophysics.

Although the themes of astroparticle physics have much in common with cosmology, astrophysics and particle physics, the experimental methods used are, for the most part, different. For example, one tries to determine particle properties but one does this by studying rare decays and interactions in underground laboratories and not at accelerators; symmetrically, although one studies the sky, one does this by using high-energy photons and charged particles, neutrinos and gravitational waves.

Astroparticle physics has emerged rapidly, in a span of 20 years, from a field of charismatic pioneers transgressing disciplinary frontiers using risky and innovative detection techniques, to a fully-developed global science activity involving thousands of researchers and hundred million or billion dollar scale projects. The need for global coordination is felt both from within the scientific community and the funding agencies.

The GSF Astroparticle physics Working Group believes that the field has reached a high degree of autonomy, and that therefore an independent strategic vision for the field and its worldwide coordination should be developed. The scope of the study includes astroparticle physics science as well as the facilitlies and detectors used in the investigations.

Some science topics and their associated facilities that are considered astroparticle physics are already being globally coordinated by other bodies. These are described in this report but will not be in the scope considered for coordination by the Working Group.

Due to the interdisiplinarity of the field, many of the experiments and facilities have capabilities in a wide range of science topics outside of the scope of what the Working Group is considering astroparticle physics. These capabilities and science topics will be described but are not in the scope considered for coordination by the Working Group.Given the interdisciplinarity, and the quite recent emergence of the field, differences of nomenclature arise in what is considered astroparticle physics, or particle astrophysics, in different parts of the world. A major challenge for this document is to recognize the links to other branches of science and further, recognize that different countries and agencies have different ways of defining the boundaries of various scientific domains. In the discussion below, we attempt to identify the central links that exist.

It should be noted that the compartmentalisations are fluid. For example, considering neutrino oscillations, the first suggestions came from particle physics theory, the discovery came from core astroparticle studies of the Sun and cosmic rays and they have now become a central part of mainstream particle-physics accelerator and nuclear reactor-based programs. A critical aspect of this strategy document will be the provision for such dynamical evolution of the field.

While the report takes a broad perspective on astroparticle physics, it does not cover some closely related fields. For example, nuclear astrophysics is a field in which astronomical events such as novae are understood by measurements of critical reaction rates in the laboratory. The systems studied are somewhat lower in energy or temperature than those explored in astroparticle physics but there is no clear dividing line. We do not include this field in the report because essentially all agencies treat this as a core part of nuclear physics and the facilities used for the study are largely separate from those of astroparticle physics.

Section 2: Principal Scientific Challenges of Astroparticle Physics

The following paragraphs describe what can be considered as ―core” challenges for astroparticle physics, the large infrastructures needed to tackle them, and the many links with neighbouring fields. The order of exposition follows the major questions of the field.

What is the form of matter and interactions at the smallest scales (highest energies)?

Grand Unified Theories (GUTs) of particle physics predict that the proton has a finite lifetime. The discovery of proton decay would be one of the most fundamental discoveries for physics and cosmology. The related physics may be closely linked to the physics of the Big Bang; it would determine the scale of Inflation and eventually the cosmic matter-antimatter asymmetry.

Neutrinos appear in three species: electron, muon and tau neutrinos. The discovery that neutrinos have mass can be considered as one of the greatest discoveries of astroparticle physics and points towards physics beyond the standard model of particle physics. Furthermore the large gap between the masses of the neutrinos and those of the other leptons indicates that the mechanism producing their mass is more complicated than the mechanism responsible for the mass of the other fundamental constituents and that therefore may involve high energy scale physics, inaccessible to current accelerators. Last but not least, asymmetries in the neutrino decays may trigger matter-antimatter asymmetry. These eventualities make the measurement of the neutrino mass and properties together with the proton lifetime sensitive probes of the unification scale energies.

Proton decay: Data from the Super-Kamiokande water Cherenkov detector constrain the proton lifetime to be larger than 10^{34} years, tantalizingly close to predictions of certain ―supersymmetry” GUT versions. At 50 kilotons, this facility in Japan is the largest underground detector in the world. A sensitivity improvement of an order of magnitude would require water-filled detectors on the Megaton scale or detectors filled with scintillating liquid or liquid argon on the 100 kiloton scale. Different projects for the construction of a megaton scale detector are currently in progress in Japan (Hyper-Kamiokande) under study in the US (using the proposed Deep Underground Science and Engineering Laboratory (DUSEL) as well as other facilities) and under design in Europe (LAGUNA) and China.

Neutrino properties (mixing): In the Standard Model of particle physics, neutrinos should have no mass. This assumption was questioned when electron neutrinos were shown to disappear on their way from the Sun to the Earth (Homestake mine, Ray Davies, Nobel Prize 2001). As we know today, the electron neutrinos change their identity to one of the other species, the latter escaping detection. The first measurements that proved that this is the case, independent of the models of the Sun, were done in the Sudbury Neutrino Observatory (SNO) in Canada. A similar effect appeared in Earth‘s atmosphere: neutrinos produced by cosmic rays change their species during their trip to the detector. It was first detected in the Kamiokande and Super-Kamiokande Water Cherenkov —proton decay” detectors in Japan. Experiments at nuclear reactors and accelerators have confirmed these findings and also provided independent knowledge about the strength by which the three neutrino species mix with each other. The above changes are dubbed neutrino oscillations, or mixings, and can occur only if neutrinos have a mass. Therefore, oscillations herald first physics beyond the Standard model.

Matter-antimatter symmetry breaking: The fact that the Universe is predominantly made of matter, while our theories would naively predict a matter-antimatter symmetry, is one of the major questions of Cosmology today. The so-called charge-parity decays of a heavy neutrino are among the prime suspects of the generation of this asymmetry. They would generate a lepton-antilepton asymmetry (leptogenesis) which through its interactions with nucleons (baryons) would induce a matter-antimatter asymmetry (baryogenesis). One can use the large underground detectors as targets using accelerator beams, in long baseline oscillation experiments, to probe the mixing angles responsible for these charge-parity violating decays.

Low energy neutrino astronomy: Large underground water and scintillator detectors (Super-Kamiokande, SNO, Kamland, Borexino) were able to use neutrinos as probes of the Sun and Earth (geoneutrino) physics. The earliest detectors designed to search for proton decay (Kamiokande together with IMB in the US) were also able to make the serendipitous detection of a Supernova explosion (1987A) through its neutrino burst (Masatoshi Koshiba, Nobel Prize 2001), together with the Baksan scintillator telescope, which had established earlier best limits on proton decay.This event is considered to be the inaugural event of the –new” era of astroparticle physics.

As seen from the above, large underground detectors occupy a pioneering and historical role in the development of astroparticle physic. Nevertheless after the first indications, the determination of neutrino mixings has been established by a mix of accelerator-based experiments and non-accelerator measurements. Neutrino oscillation experiments are currently becoming mainstream accelerator physics with major projects proposed or underway in Japan, the US and Europe while there has been renewed interest in the reactor-based experiments with major projects in China and France. There is a planning mechanism for the accelerator-based experiments through ICFA but there remain strong links to astroparticle physics because of the use of shared infrastructure such as the detectors also serving astroparticle goals (e.g. Super-Kamiokande, the proposed DUSELin the US, the future Indian Neutrino Observatory (INO), and several European sites.) and underground laboratory space.

Presently, large underground, water, scintillator or argon detectors are in the design phase so that beyond the search of proton decay they are sensitive to neutrino parameter measurements and low energy neutrino astronomy and astrophysics (Japan, US, Europe, China, India, Russia). Furthermore, they can be used as long baseline targets of high power neutrino beams to study neutrino parameters and in particular the charge-parity violation mixing angle believed to be at the origin of the matter-antimatter asymmetry through leptogenesis.

***Since the large underground detectors beyond their particle astrophysics potential (proton decay, neutrino astrophysics) have also a major potential for detecting neutrinos from accelerators sources, , it appears that some kind of joint planning between ICFA and the particle astrophysics communities is essential.* The large underground detectors are also by their sheer volume and cost clearly global scale projects and will have to be constructed by world type collaborations.**

Neutrino properties (mass): Neutrino oscillations are unable to provide us with the values of these three masses: we know «only» the differences between the squares of any pair of them. How can we determine the absolute values of neutrino masses, rather than just the mass differences? In the traditional method, one measures the electrons from tritium beta decay, where a neutron inside a nucleus transforms into a proton, an electron and an antineutrino. From these experiments we know that the heaviest of the three neutrinos is lighter than 2.3 eV; the next-generation experiment KATRIN in Germany will probe the 0.2 eV level, with an intermediate step taken by the Troitzk experiment in Russia aiming at 0.8 eV. Similar masses will be probed indirectly through the current generation microwave cosmological background satellite PLANCK.

In normal beta decay, a neutron inside a nucleus transforms into a proton (which stays bound in the nucleus), an electron and an antineutrino. Let two neutrons in a nucleus decay simultaneously, releasing two electrons and two antineutrinos. Then you have a rare process called double beta decay. In its neutrino-less version, only electrons are released, no antineutrinos; this process is only possible if neutrinos are their own anti-particles (Majorana neutrinos) and if they have a mass. The consequences of a possible Majorana nature of neutrinos would be fundamental. It is, for example, the condition that leptogenesis leads to the observed dominance of matter over antimatter in the Universe. Detectors containing 100 kg to one ton of double beta decay enriched isotopes are needed to increase by an order of magnitude the sensitivity of the searches for the neutrino mass and to probe the largest part of the so-called ―inverse hierarchy” of neutrino mass spectrum. Design studies and R&D towards this goal are in progress in many regions (Europe, US, Japan, Russia). The scale of the current neutrino-less double beta decay experiments can be accommodated in regional dimensions, and in fact it is the case given the multiplicity of current efforts. Nevertheless, an overall coordination and avoidance of duplication, especially in the domain of procurement of enriched isotopes would clearly be beneficial to this field.

Neutrino mass determination cuts across the fields of nuclear, particle physics and astrophysics. The work is mainly carried out in deep underground laboratories whose overall purpose is largely astroparticle physics. Due to these reasons as well as the increasing scale of the experiments, this science should be treated as a core part of the astroparticle physics.

What is the nature of dark matter and dark energy that make up the bulk of the Universe?

There are clear indications coming from astrophysics (type 1a supernova explosions, star velocities, galaxy distributions, microwave background studies, gravitational lensing and microwave background studies) that visible matter appears to be a minority component (one sixth) of the total mass of the Universe and that the visible matter makes up only 5% of the matter-energy content of the universe, with the rest consisting of dark matter and dark energy

Dark matter: How does one detect dark matter? From a technical point of view, the question can be tackled in three ways, each exploiting the tools of nuclear and particle physics.

For particle physicists, the hunt for dark matter is closely connected with the search for new particles. These particles would not only provide important clues in understanding the early Universe, but are also suggested, and well motivated, by particle physics. The prime suspect of most experts is a weakly interacting particle, much heavier than the proton: a WIMP (Weakly Interacting Massive Particle). Such a particle is also suggested by super-symmetric theories of particle physics. The second-prominent candidate demanded by particle theory is the axion.

―Direct methods" look for signals from nuclei kicked on by a WIMP. Since WIMPs interact rarely and the signals are feeble, the detectors are operated deep underground, well shielded against noise and ambient radioactivity which may mimic WIMP signals. ―Indirect methods" look for particles such as neutrinos, gamma rays or antiparticles that would emerge from WIMP annihilations in celestial high-density regions, like the Sun or the centre of the Galaxy. These indirect methods form part of the programme studying violent phenomena using new messengers, presented in detail in the next chapter.

Finally, dark matter particles may also be produced in high-energy particle interactions at the Large Hadron Collider (LHC), which starts operations at CERN soon The searches for supersymmetric particles at high energy colliders is of course, closely linked scientifically but is administratively part of accelerator-based high-energy physics. A positive identification either in the accelerator experiments or in the non-accelerator sectors would have a profound impact on the direction of the field as a whole. In any case, a discovery in one field would have to be complemented with a discovery in the other, in order to fully measure the properties of the candidate particles.

Concerning the direct method of detection, it is well established by now, that in order to obtain the sensitivity needed to detect the candidate particles one needs to construct a detector containing above one ton of sensitive material, operating in conditions of very low cosmogenic background in an underground laboratory. Currently, there are two promising technologies for the construction of such a detector: the first uses bolometric material such as Germanium and the second employs noble liquids.
Major efforts using direct method techniques are in progress in US, Europe, Japan and Korea. The next-generation detectors, if not constructed in a global context, should be embedded in a global programme with sufficient complementarity and effort to avoid duplication.

The direct search for cosmogenically produced particles that might make up the dark matter through their interaction with detectors is a core part of astroparticle physics. Searches for WIMP dark matter, or axion searches are core to the field.

Dark energy:

That the universe is expanding has been known since the 1930's. What came as a surprise a decade ago (1998) is the fact that the Universe presently appears to be in a state of accelerated expansion. What is the motive power of this expansion is a matter of debate. Is it a new kind of particle physics field? Do we need to change the equations of General Relativity or some of the assumptions of our cosmological model? Is it simply an effect of the presence of the ―cosmological constant" in the equations of Einstein? This effect has been dubbed dark energy and a rich experimental programme is in development for addressing the above theoretical issues.

The most developed methods for studying the nature of dark energy is, through large telescopic surveys at the optical and the infrared. These surveys permit the measurement of dark energy parameters using the luminosity of distant supernovae, baryonic acoustic oscillations, the effects of weak gravitational lensing and galaxy clustering. Looking beyond existing instruments, a next generation of cosmology missions is already in preparation. Projects that may get under way in the near future include the proposed Large Synoptic Survey Telescope, LSST (US), large surveys at the SUBARU telescope (Japan), the European

Extremely Large Telescope, ELT (and other optical telescopes of the 30/40 metre class), and proposed space based missions in the US (JDEM) and Europe (Euclid). Other methods using radio surveys are planned for the future (Square Kilometer Array, SKA).

I think this should be removed. Studying dark energy via gravity waves is one of those methods that are pretty hypothetical at this point,. Instead, talk about this in the gravity wave section!

The large observatories of the future relevant to dark energy, on the ground and in space, will have a scale in complexity and cost demanding global coordination.

Astroparticle physicists have been engaged in the field of dark energy since the beginning. They contributed with their experience in developing methods to detect and measure large numbers of supernovae, handling large data sets and with cutting-edge technologies. Many of the experiments support a variety of standard astronomical tasks and are not limited to dark energy surveys. As a result of the above, the construction of future instruments – large telescopes and space missions – depends on choices of many agencies beyond the single field of astroparticle physics and may not be appropriate to consider as scope of the global coordination effort. Nevertheless, given the profound implications for fundamental physics, dark energy missions find the strongest support from the astroparticle physics community and are included in its core mission.

How does the sky appear at extreme energies?

Most of the visible cosmic matter is in a state of ―thermal equilibrium”; that is characterised by a certain temperature. The prime cosmic example is our Sun: analysing its spectrum, we can conclude that its surface temperature is about 6000 Kelvin. The spectra of hotter stars, extending far to the ultraviolet or the X-ray range, indicate temperatures up to 50000 Kelvin. In the X-ray range, some strange objects begin to appear on astronomer‘s sky-maps; they do not fit into the equilibrium scheme but emit considerably more energetic particles than expected for a body with a well defined temperature.

It is here that the realm of the ―non-thermal” or violent Universe of extremely high energies begins: supernova explosions or their remnants, pulsars, black holes at the centre of galaxies, gamma ray bursts, mergers of black holes or neutron stars. It is the realm of cosmic accelerators; they emit high-energy photons, high-energy charged particles, neutrinos and gravitational waves. These particles and waves can be used, in association with more standard optical, X-ray or radio signals, as messengers bringing crucial information on their site of emission and the galactic and intergalactic medium where they propagate. The use of new messengers for the study of the sky has recently achieved tremendous progress either in the number of sources detected or in the increase of the sensitivity of the instruments.

There is mounting evidence that these non-thermal or ―violent” phenomena serve as regulators of the genesis and evolution of the cosmic structures from galaxies to stars. Their understanding impacts the understanding of the history of our cosmos. Furthermore, as happened in the case of the Sun and the neutrino, a better understanding of e.g. galaxy astrophysics would help disentangle the eventual presence of dark matter annihilation and decay products among the cosmic radiation. Extragalactic sources can be used either as cosmic markers giving information on the expansion rate of the Universe, or one can study deviations from fundamental laws through the propagation effects on the emitted radiation.

Charged Cosmic Rays**:** The flux of charged cosmic rays varies by 32 orders of magnitude from MeV energies to the very highest energies ever recorded. At 100 GeV, one charged particle per square metre per second bombards the atmosphere. At one million GeV it is only one particle per square metre per year. And in order to catch one per year of the ten billion GeV type, one needs a full square kilometre.Where are they accelerated? What happens during their propagation through the galactic and intergalactic space? What is in detail their composition? Are there dark matter decay or annihilation products among them? Some of these are by now century old questions. Since the 1930s, supernova remnants have been the prime candidate sources of low- to medium-energy cosmic rays, but this attribution still remains to be confirmed. Recent studies suggest that active galactic nuclei can generate the highest energy cosmic rays. Further work is needed to pinpoint exactly the type and number of sources that produce the broad cosmic ray spectrum and their acceleration mechanisms.

Much can be learned at GeV energies with detectors on balloons and satellites like e.g. ATIC, CREAM, PAMELA and, in the very near future, the Alpha Magnetic Spectrometer (AMS), scheduled for launch and deployment on the International Space Station (ISS) in 2010. There is, for example, the continuing search of abnormal traces of antimatter in the cosmic rays. They would point to either a) regions of antimatter in the nearby Universe or b) decays of dark matter particles. Only recently, PAMELA, ATIC in conjunction with the satellite Fermi Gamma-ray Space Telescope (FGST) and the ground Cherenkov telescope H.E.S.S., presented tantalising evidence of anomalous electron and positron spectra of astrophysical or cosmological origin.

Going higher in energy, the KASCADE detector (Germany) and the Tibet-AS-gamma experiment (a Japan-China collaboration) have provided new insight into galactic cosmic rays of up to 1017 eV. Several major experiments such as the TALE in the US, HEAT/AMIGA in Argentina and Tunka in Russia are in progress.

There is finally a lot of research on the very highest energies, likely to be entirely of extragalactic origin. This is the domain of the terrestrial Pierre Auger Observatory, covering with detectors a 3000km2 in Argentinean pampa, Telescope Array in Utah, USA (a US/Japan/Korea/Russia collaboration) and space based detectors (e.g. the Japan led JEM-EUSO collaboration, scheduled for ISS installation in 2015) monitoring huge volumes of the atmosphere for traces of high energy particles.

AMS, Auger and JEM-EUSO are already global scale projects; any new large project in the field will have to be built on a global scale by world-type collaboration.

Cosmic ray studies are a core, indeed quintessential, astroparticle physics activity. Its centenary tradition predates the re-emergence of the interest for cosmic messengers with particle physics methods. It uses ground as well as balloon and satellite instruments. Future efforts are becoming larger and need global coordination.

High Energy Gamma Rays: The last decade has witnessed the birth of a new field of astronomy – Very High Energy (VHE) gamma ray astronomy – expanding wavelength coverage of astronomical instruments by another 10 decades towards the highest energy radiation. These gamma rays are produced when high-energy cosmic rays collide with interstellar gas, for example, near the cosmic accelerators. Unlike charged cosmic rays, the gamma rays travel on a straight path and point back to the point in the sky where they were produced. Apart from serving as tracers of the origin of cosmic rays, some VHE gamma rays may result from annihilation or decays of dark matter particles.

VHE gamma-ray astronomy is also becoming part of mainstream astronomy with surveys of the Galaxy revealing dozens of VHE gamma-ray emitting cosmic-ray accelerators. Objects discovered include supernova remnants, binary systems, pulsars, stellar associations and different species of active galaxies, hosting super-massive black holes at their centres.

VHE gamma rays interact in the Earth‘s atmosphere, creating a cascade of secondary elementary particles, most of which never reach the ground.

Satellite instruments detect gamma rays before they enter the atmosphere. The field owes a lot to the pioneering instrument EGRET on the satellite Compton Gamma ray Observatory (CGRO, 1991-1999) that has produced the first full-sky map of the VHE gamma ray Universe. Currently, its successor, the satellite Fermi Gamma-ray Space Telescope (FGST) is operating and (NASA, with DOE partnership on the primary instrument as well as European and Japanese participation), is releasing extremely interesting results and providing extraordinary insights into the non-thermal Universe.

Orbiting observatories are too small to capture enough of the highest energy gamma rays. The Imaging Atmospheric Cherenkov telescope ground-based detection technique pioneered by the American Whipple telescope and perfected by the H.E.S.S./MAGIC/VERITAS/CANGAROO instruments (Europe, US and Japan) has brought important breakthroughs during the last five years. These telescopes collect and image an effective area of a few 10000 m^2, compared to the m^2 area of satellite detectors.

Cherenkov telescopes are flanked by detectors recording the shower particles which reach the ground, like the Chinese-Italian ARGO/YBJ detector in Tibet, the American MILAGRO instrument and its planned successor HAWC or the Japanese-Chinese Tibet ASgamma experiment and its planned successor Tibet AS+MD in Tibet. Although inferior in sensitivity for individual sources, they provide an important complement in that they continuously monitor large parts of the sky and allow the study of extended cosmic sources, including the band of the Milky Way.

There are proposed projects for constructing new large arrays of Cherenkov telescopes in Europe (CTA), US (AGIS), India and China with a dramatic increase in sensitivity and in the number of accessible sources. A global coordination of the next-generation observatories is a major challenge for the field.

Very High Energy gamma ray physics addresses fundamental astrophysics goals as well as the search for dark matter and the detection of fundamental law violations. It thus constitutes a core activity of astroparticle physics, with strong ties to Astrophysics and to Astronomy. Future efforts are becoming larger and need global coordination.

<u>High Energy Neutrinos</u>**:** Solar neutrinos and burst neutrinos from the supernova SN1987A, at energies of the order of 10's of MeV, have been detected in proton decay detectors as presented above. Measurements of neutrinos in this energy range – MeV to GeV – would be vastly improved in a next-stage proton decay detector.

As of today, the sky-map of extraterrestrial even higher energy neutrinos is still empty – a challenging terra incognita. Such neutrinos must be emitted as a by-product of high-energy collisions of charged cosmic rays with matter. Since they can escape much denser celestial bodies than light, they can be tracers of processes that stay hidden to traditional astronomy. Undisturbed by anything, they reach us from the remotest regions of the Universe and may let us probe deeper into the universe than with any other messenger. Nevertheless, at the same time their extremely low interaction probability makes their detection extraordinarily difficult. Detectors for solar neutrinos are buried deep underground in order to shield them against noise which could mimic their rare interactions. Only neutrinos can penetrate deep enough to reach these devices undisturbed. In order to detect the low fluxes from the suspected distant sources of higher energy neutrinos, immense detectors of cubic kilometre volume are required. They cannot be arranged underground but only in deep oceans, lakes or glacial ice where space is available.

Finding the cosmic sites where protons are accelerated is one of the major challenges of the next years for the field. The presence of neutrinos emitted from a certain cosmic site would be the telltale signature that protons are indeed accelerated there; it would be a key ingredient for the final resolution of the century old enigma of the origin of the charged cosmic ray spectrum. Galactic source candidates are Supernova Remnants, binary systems or pulsars; they are the main focus of neutrinos telescopes observing the Southern sky from the Northern hemisphere. Neutrinos from Active Galactic Nuclei (AGN) and collisions of ultra-energetic protons with the 2.7 Kelvin cosmic microwave radiation (marked GZK) will also likely be detected by neutrino telescopes in the next decade.

There are currently 2 global scale projects: the US-led project IceCube with large European participation, under construction in the Antarctic, and the KM3NeT project in the Mediterranean Sea. A third experiment with somewhat lower sensitivity, GVD, is under preparation in Lake Baikal, Russia. They are complementary covering the Southern and Northern hemispheres and there is a rich programme of exchanges and coordination between the three collaborations.

The programme of high-energy neutrino telescopes is clearly a core programme of astroparticle physics. Future efforts are becoming larger and need global coordination.

Gravitational Waves**:** Theory predicts that gravitational waves should be emitted by the coalescence of two orbiting compact objects like neutron stars or black holes, by the falling of a star into a giant black hole, by the collapse of a massive star, by rapidly spinning pulsars, and by the violent motion of the big Bang itself. The observation of gravitational waves from binary mergers out to extreme distances would strongly impact astroparticle physics.

First attempts to detect gravitational waves used very massive metallic cylinders and aimed to measure the tiny vibrations caused by gravitational waves. Although these instruments may be able to detect a nearby supernova, they cannot compete with a technique using interferometers. In these devices, light waves are split, propagate along extended, perpendicular arms, are reflected back by large mirrors, and finally superimposed at the splitting spot. A gravitational wave passing the device would compress the space along the two arms in a different way, leading to a flickering of the interference pattern. Longer arms, higher light power and better noise suppression are the keys to improving the sensitivity of the interferometer. Progress with light power and noise suppression has been tremendous in recent years.

There is a worldwide collaboration between the leading sensitivity antennas: LIGO in the US, Virgo and GEO in Europe and the Japanese antennas TAMA and CLIO. In particular LIGO, Virgo and GEO have reached a high level of coordination including: common and synchronised data taking, common signature of publications, coordinated running etc, thus enhancing their sensitivity and the robustness of detection. LIGO and Virgo have begun construction of advanced versions that should begin operations in 2014 and should reach the sensitivities necessary for the first detection of gravitational radiation (although this cannot be excluded for the current detectors). The Japanese LCGT project has the same goals and, by using cryogenic technology, paves the way for future generations of such detectors. There are also plans for similar antennas in Australia and Japan. A third-generation antenna (provisional name ―Einstein Telescope") beyond the advanced LIGO/Virgo phase is in the planning process as a global project. Third-generation antennas would be located underground so as to reduce the seismic noise and extend the frequency coverage. They will employ new technologies like non-classical interferometry and squeezed light being currently tested with prototype interferometers and in GEO. It is hoped that the third-generation antennas will achieve event rates that place gravitational wave observations firmly into routine astronomy.

The coalescence of super-massive black hole binaries, the spiralling of stars into black holes, stochastic backgrounds from the early universe and Big Bang quantum fluctuations should emit waves in the milli-Hertz range. This is the realm of the space-based interferometers. The first ambitious project among them is the proposed ESA/NASA mission LISA, consisting of three satellites separated by millions of kilometres and forming a huge orbiting interferometer. The LISA Pathfinder mission in 2011 will be a key test of technologies, with the start of LISA itself being envisaged for 2018. LISA would provide high signal to noise ratio observations of massive black holes out to cosmological distances. In Japan, a space project (DECIGO) aiming at the intermediate frequency range (around one Hertz) is currently under study and a technology precursor, DPF, has been proposed.

The nano-Hertz range of signals from supermassive black holes is the target of pulsar timing efforts using arrays of pulsars as gravity wave detectors like the European Pulsar Timing Array (EPTA), the Parkes Pulsar Timing Array (PPTA), the North American NANOGrav, and a Chinese group on its way with FAST.

The gravitational wave detection community has a high degree of internal coordination, as demonstrated by the operation since a few years of the GWIC (Gravitational Wave International Committee), an IUPAP working group, that has published recently a global strategy for the gravitational wave community. Their pioneering effort for a common strategic vision is highly recommended and encouraged by the GSF Working Group.

Detecting gravitational waves (and utilising them to study the sources of the radiation) is a core goal of astroparticle physics. Both the current ground-based and future space-based facilities are considered to be within the scope of the Working Group's activities (while recognising that, in many countries, space-based efforts are planned and managed by agencies and coordinating bodies other than those that have traditionally been responsible for astroparticle physics).

Tentative conclusions and guidelines for the work to come

While coordination in some middle scale projects can be concentrated in specific topics, e.g. procurement and avoidance of duplication; in other cases coordination is required by complementarity, e.g. the complete coverage of the sky. There are finally projects that by sheer volume and cost demand to be thought from the start as global projects. The largest projects have also strong links to neighbouring fields, e.g. proton decay detectors to accelerator neutrino beams, dark energy to astronomy and of course the large space projects for dark energy and gravitational wave detection to the overall space programme. The detailed classification and proposed specific measures will be the subject of the work during the next year.

Section 3: Benefits to Society

Even though astroparticle physics involves the pursuit of pure knowledge ―for its own sake,” there are significant benefits to society in the domains of culture, education and technological innovation. Some of these benefits are described below. A quantitative analysis of the economic, technological, and educational benefits of particle astrophysics doesn‘t exist and a professional study would have value in providing an assessment and impact of the field.

Cultural Benefits

Astroparticle physics, in connection to particle physics and astronomy, satisfies humankind‘s quest/curiosity to understand the Universe, how it came to be, how it works and where it is going. Seeking answers to big questions drives basic research, appeals to our deepest human nature and provides a culture of learning and discovery to society. It also provides a sense of pride to the countries involved in the research while keeping them in the forefront of scientific discovery and technological excellence. The field is international in scope, with scientists and funding agencies around the globe cooperating to design, build and carry out the experiments needed to uncover the mysteries of the Universe. Astroparticle physicists continue the culture of particle physics and astronomy concerning large-scale science: large scale characterises not only the size and complexity of detectors but also those of scientific collaborations. The scale and scope of the scientific collaborations and experiments have had and will have transformative effects on society. The international scientific collaborations in this field lead to cross-cultural interactions in many areas. The research facilities bring researchers and engineering, computing and technical teams from disparate areas to study and exchange ideas. In short, the scientific challenges are global and they demand global answers. As will be explained below, the technological spinoffs of astroparticle observatories are also important for the other high priority global challenges of mankind: climate, energy and risk prevention.

Educational Benefits

Education and outreach activities are of growing importance in basic research. Astroparticle physics piques the students and public‘s curiosity and fascination and leads to a better understanding of science and science methods which may eventually transform into public, financial and political support for research.

Astroparticle physics also grooms the workforce of tomorrow. In addition to training the scientists of tomorrow, it also provides training and opportunities in education for engineering, technology and computing. No specific study on astroparticle physics graduates has been done yet, since the field is quite recent, but one can safely extrapolate from a neighbouring field with the same scientific and technological culture: particle physics where only one sixth of those completing doctoral degrees ultimately pursue careers in high-energy physics research; the rest find their way to diverse sectors of the economy such as industry, information technology, medical instrumentation, electronics, communications, biophysics, defence and finance — wherever the workforce requires highly developed analytical and technical skills, the ability to work in large teams on complex projects, and the ability to think creatively to solve unique problems.

Students are the top target groups of educational activities, but more and more there is an effort to reach the teachers and to help them understand what is going on in the field and how scientific research is done. For instance, since cosmic rays are ubiquitous (some 300 charged particles traverse our body per second) there is a world-wide educational programme in providing instrumentation for its detection at schools. It permits the familiarisation of teachers and pupils with the principles of measurement, electronics and data analysis. In some cases it also encourages networking activities, such as putting in coincidence detectors in neighbouring schools to detect large cosmic ray air-showers (—AUGER@school”).

Most particle physics education programs (e.g. QuarkNet in US or EPPOG in Europe) started out with activities on the LHC and Tevatron but have expanded to areas of astroparticle physics and astrophysics. Other traditional means of outreach that are used in this field are open houses at underground labs, telescope observatories, universities and other facilities.

The Einstein@Home project brings gravitational wave research directly into 200,000 homes worldwide by using the idle resources of private laptops for doing gravitational wave data analysis on real detector data. The LIGO/LSC outreach program and Scienceface.org are pioneers in bringing exotic science to high-school and university students. And the LIGO outreach/education centre at Hanford, Washington is probably unique to the astroparticle physics field.

Technological Benefits

The majority of the goals of astroparticle physics require the detection of cosmic radiation through large distributed networks of sensors deployed in hostile environments (desert, sea, ice) or the detection of rare decays and interactions in underground sites protected from the background of cosmic radiation. The geosphere (atmosphere, earth and the ocean or the poles) is thus used as a target and detecting medium that needs to be known and monitored continuously with a dense grids of detectors. In parallel the techniques of high radiopurity underground detectors provide the necessary sensitivity to detect subtle time-tracers for the study of the evolution of many geological processes or the study of the human impact on the environment. There is therefore a natural synergy of many astroparticle physics detection techniques with the techniques used in geosciences, geo-engineering, environmental and biological studies as well as risk monitoring and homeland security issues.

Astroparticle physicists were the first to install a high bandwidth continuous link with the ocean bottom or deep ice, instrument a very large desert area with a dense sensor grid and develop underground laboratories of unprecedented radiopurity. Satellite and balloon-borne experiments are also used for astroparticle physics measurements in obvious synergy with atmospheric and monitoring studies. Few people know that cosmic ray research was the driving force for balloon development in the beginning of the 20th century, and continues to be an important driver in the beginning of the 21st (NASA long duration balloon flights).

There are also large technological benefits related to data analysis and data mining issues, since, for example, the next generation dark energy studies require large sky surveys in the optical and infrared that will challenge computing and storage models currently used even for such demanding projects as the analysis of LHC data.

Examples of technological spinoffs of astroparticle physics detectors: The astroparticle physics experimental programme exhibits certain recurrent characteristics in the detection methods: one finds the ubiquitous presence of photodetectors, cryodetectors and charge gain amplification devices, research and development of new materials (from crystals to noble liquids/gases), radio-purification techniques and state-of-the-art optical elements for gravitational antennas or large sky surveys. One also finds R&D on low power electronics or low radioactivity cryogenic electronics. On the acquisition side one finds the instrumentation of large areas or volumes in hostile environments, using ―intelligent” and, sometimes, autonomous detectors. More specifically:

Photodetectors are a basic and critical building block for nearly all experiments in the field of astroparticle physics. Observatories detecting high energy cosmic radiation such as gamma rays, neutrinos, and charged particles, or studying neutrino properties use techniques based on measuring Cherenkov or fluorescence light induced by particles or particle showers in different media: atmosphere, water/ice and other liquids. It is fair to say that astroparticle physics experiments have driven the technology improvement of photodetectors for these types of observations. There are of course many spinoffs for nuclear medicine, state-of the art molecular biology or national security.

Cryodetectors are central elements for dark matter search and neutrino physics, although significant development efforts are also focusing on building matrices of detectors in cosmology (matrices for cosmological background polarisation) and infrared and X-ray space-based astronomy. Here too there are many applications in homeland security.

N**oble gas liquid detectors** (xenon, argon, germanium …) are currently used in the fields of direct dark matter searches and neutrinoless double beta decay. In addition, large scale liquid argon detectors are under study for proton decay studies. The ability to use liquid noble gases as dense, high sensitivity gamma counters with good position reconstruction and low threshold also lends these types of targets to medical imaging.

Liquid-scintillator detectors feature high energy resolution and low energy detection threshold combined with efficient means of background reduction. As scintillators can be based on relatively cheap organic solvents, the large volumes needed for neutrino detection or rare decays are affordable. They have many applications for the monitoring of nuclear proliferation and homeland security.

Rare Isotope production plays a crucial role for the experiments of astroparticle physics. Large amounts of isotopically enriched materials will be necessary for future experiments on double beta decay and dark matter searches. A strategic effort is in progress to organize the requested enriched isotope production through different techniques (centrifugal, laser enrichment or ion cyclotron resonance). There could be many spinoffs for the streamlining of the production of medical isotopes needed in nuclear medicine. Here again astroparticle physics can be the technology driver.

Large sensor arrays deployed in the desert or the bottom of the sea as well as the future large underground facilities have in common the distribution of sensors around a large volume, or surface, the large amount of data to be reduced and partially processed locally, and the need to rely on standard technology that can be easily upgraded after some years. All these requirements are fulfilled in ***smart sensor architectures*** where each sensor is seen as a node with embedded processing power in a standard Ethernet network. This is a technology pioneered by astroparticle physics with several observatories operating in over a thousand node configurations.

Gravitational wave detectors have been a venue for the development of innovative advanced technologies. Laser frequency stabilization has been an important technology for gravitational wave detectors. Radio Frequency (RF) reflection locking (Pound-Drever) for lasers developed for gravitational wave detectors has become standard stabilization method for obtaining low line widths for spectroscopic and frequency standards applications. Cryogenic sapphire optical cavities and room temperature stabilization cavities have found applications in metrology and in the development of optical clocks. The development of high power single frequency 1.06 micron lasers has been driven by the gravitational wave field, and is preparing the ground for new lasers for free space communication. A laser of this type is, for instance, in operation on the TerraSAR spacecraft testing a long range laser link for optical communication. Both space-based and ground-based projects have stimulated the development of fibre-based laser systems that eventually will benefit laser technology for remote sensing and coherent laser radar applications. High quality wave front testing developed for gravitational wave detector optics may become relevant for other field of optics. For instance high performance Hartmann sensors ($< \lambda/10000$) may be used in optometry and optical diagnostics for both technology and science. Other devices that may find relevant applications are moderate scale (35 cm diameter) optics with $\lambda/1000$ polishing, coating and metrology. Computer-intensive data analysis required by gravitational wave research has driven grid computing research in a number of directions such as workflow planning, workflow management and execution, volunteer computing, data replication and data placement for computation. Projects within the U.S. include GriPhyN, iVDGL, Open Science Grid, while in Europe, EGEE - Enable Grid for E-Science - is an EU-funded project to develop a large scale eScience infrastructure for Europe, all essentially driven from the LHC eforts.

Astroparticle technologies for the monitoring of the environment and risk prevention

There are natural synergies between astroparticle physics and the geosciences, environmental monitoring and risk prevention. In the following we review three fields of application: ocean floor monitoring, atmospheric monitoring, underground monitoring.

Underwater monitoring: The underwater world has not yet been exhaustively explored. Current technology allows autonomous vehicles or remotely operated vehicles (ROVs) to carry out scientific experiments at great depths only for relatively short periods requiring costly support ships. The envisaged large deep-sea neutrino telescopes will provide abyssal multidisciplinary observatories for deep sea science that will offer a unique opportunity to explore the properties of deep sea sites over a period of many years.

The current pilot projects, in the process of constructing deep-sea neutrino telescopes in the Mediterranean Sea, are pioneering the development of such permanent undersea observatories. These facilities already provide real-time, high-bandwidth transmission of continuous measurements of oceanographic (current velocity and direction) and environmental (temperature, conductibility, salinity, pressure, natural optical and acoustic noise from sea organisms) parameters from sensors installed on the neutrino telescope. The installation of specialized instrumentation for seismology, gravimetry, radioactivity, geomagnetism, oceanography and geochemistry provide data highly attractive for long-term measurements of interest to a wide field of sciences including biology, environmental sciences, geology, geophysics and oceanography. Similar studies are performed in Lake Baikal.

Deep sea observatories also have the potential to play a key role in the assessment and monitoring of global warming, climate change and geo-hazards. Many of Earth‘s most seismogenic zones and most active volcanoes occur along continental margins plate boundaries like South Europe. Continuous measurements are required with the ability to react quickly to episodic events, such as earthquakes and volcanic eruptions.

Atmospheric monitoring: The astroparticle experiments in the field of cosmic rays and gamma rays are based on observation of large volumes of the atmosphere. The high energy cosmic ray and photon observatories represent a new generation of devices capable of measuring the fluorescent or Cherenkov light emitted by cosmic rays or gamma rays with unprecedented precision. However, the experimental teams also have to perform —new generation” atmospheric monitoring to meet their scientific objectives. For example, the difference between the positions of shower maxima for different cosmic ray nuclei is comparable to differences caused by seasonal variations of the atmospheric profile. Similarly, the aerosol distribution and their attenuation properties are crucial factors in the energy determination of the detected cosmic gamma ray.

Large-area detectors for cosmic ray studies are a useful tool of monitoring the intensity of cosmic rays and its long-term variations. Short disturbances of this intensity during extreme solar events and thunderstorms are of great importance for studying solar-terrestrial links and physics of the atmosphere and to understand the role played by cosmic rays as seed and triggering particles in thunderstorm phenomena (Baksan air shower array).

The R&D activities in atmospheric monitoring are enabled by these infrastructures, and are already producing very useful data. The atmosphere and its contents are monitored with classical meteorological instruments, radio-sounding, dedicated IR cloud cameras but also LIDAR scans, ultra-violet monitoring and star-light attenuation. Astroparticle observatories are notable for state-of-the-art Raman LIDAR detectors that produce data which are essential for the development and validation of atmospheric models.

A second point of convergence with atmospheric science is located in the technologies developed for the purposes of the observatories. For instance, Auger has deployed a relatively dense grid (spacing of 1.5 km) covering a very large area (3000 km^2) with autonomous (solar powered), intelligent (local processing) and synchronised (GPS) sensors. Powerful data acquisition systems have been developed that are robust to the changes of geometry and number of nodes of the network. This system exhibits a series of technological solutions with large application potential to networks developed for ground and underwater seismic monitoring (e.g. Earthscope, Neptune in the US, EPOS and EMSO in Europe and large sea networks in Japan).

Underground laboratories in synergy with geosciences: The existence of a set of well-equipped underground facilities developed for astroparticle physics searches, allows the development of an interdisciplinary platform in order to develop synergies with environmental sciences and geo-sciences.

In Europe and elsewhere a vigorous R&D programme is in progress, with special attention to radioactive tracers for environmental science and hydro-geological issues. The very sensitive astroparticle detectors measuring ultra-low radioactivities for material selection are now used for environmental measurements, radiochronology and the control of the origin of products. The determination of ultra low traces of radionuclides is becoming more and more interesting to physics of the atmosphere, of the environment, geology and hydrology; radioactive contamination in soil, water, ice and atmospheric dust can trace transportation phenomena, erosion and sedimentation. Innovative underground networks of sensors, monitoring the deformation phenomena in the laboratories induced by natural and anthropogenic factors, in combination with environmental radioactive background, neutron fluxes and information from surface networks permit the geophysical imaging of groundwater resources and the study of the complex interactions between tectonic stresses, seasonal infiltration and fault-zone hydro-mechanical stability. Arrays of muon detectors attempt to detect the movements of water or lava inside mountain complexes and volcanoes. Ambitious R&D for the detection of feeble magnetic signals in correlation with seismic phenomena and ionosphere perturbations is also in progress.

In the US, the white paper studies of the proposed DUSEL (Deep Underground Science and Engineering Laboratory) have shown that the underground facilities will play in the future an important role in addressing key questions in biology, geoscience and engineering. In particular in the words taken from these studies :

―Although half of the earth‘s biomass lives below the earth‘s surface, some of it in the hot, dark, rock-bound environment at depths of five kilometres or more, underground life remains largely unknown. How do these microbes live in conditions that, from our surface perspective, would seem to make life improbable? How have they evolved, isolated for millennia from surface organisms? How do they alter the geology and chemistry of the subsurface? What can they tell us not only about life at the extremes here at home, but about life as it might exist on other planets? Underground labs give to the biologists sustained access to deep pristine environments, uncontaminated by mining operations and with the best possible control of drilling operations, to discover the nature of life at the underground extreme.

Microorganisms in the deep subsurface degrade petroleum to carbon dioxide at rates that are at least a million times slower than the rates of surface microbes. Such a glacial pace of life suggests that an individual microbe may be anywhere from 100 to 100,000 years old. Using the low-level counting facilities constructed underground by physicists, biologists may be able to determine the age of underground microbes. By coupling physicists‘ photon detector technologies with the bioluminescence molecules used by biologists, underground researchers could develop the next generation of life-sensing technologies to examine subsurface microbial processes at natural rates and in their natural habitats.

Geoscientists, in turn, see sustained access to large volumes of deep subterranean rock as an opportunity to address central questions in modern earth science. Can we understand and predict catastrophic natural events, especially earthquakes? How do material properties control processes in the earth‘s crust? Similarly, underground engineers anticipate that building and working in a dedicated underground laboratory will take them far in their quest to develop a —transparent earth,” whose now-opaque mass might one day become transparent to observers. The increasing strategic value of underground space to meet the needs of our shrinking planet gives urgency to their efforts.”

According to the DUSEL study, deep underground experiments can yield important societal benefits. Underground construction, resource extraction, management of water resources, environmental stewardship, mine safety and national security are prominent examples. Furthermore, the interdisciplinary link between biological science, hydrogeology and geochemistry is another key synergy. Each depends on carefully controlled access to uncontaminated environments, and microbial populations are strongly influenced by the flow paths of water and solutions. Similarly, studies in rock mechanics, fracture propagation, fracture permeability, fluid flow, rock failure, and geophysical imaging of fractures are all closely intertwined.

In Japan, there is already a strong synergy being exploited between the underground CLIO gravitational wave detector prototype in the Kamioka mine and a parallel laser strain meter of the same baseline set up and used by geophysicists.

Section 4: Science Policy Considerations

The Global Science Forum authorized the establishment of the Astroparticle Physics Working Group based on the rationale in the proposal that was submitted by the Delegation of France: ―the main reason for engaging the Global Science Forum is to ensure that the scientific potential is fully realised via a corresponding endeavour in the domain of science policy. That is, to make sure that, during the next 10-15 years, progress in astroparticle physics will be a globally coherent response to the scientific challenges, using an optimal set of national, regional, and international projects." To fulfil this mandate, the Working Group examined, during the course of 2009, the key scientific challenges of the field, and it reviewed the scale and scope of research efforts around the world. The Working Group's relevant findings in these areas are described in Sections 2 and 3 of this report. In this Section, the Working Group presents additional findings about the methods and processes that are currently in use for planning, prioritizing, funding and managing research in the field, and it offers recommendations for future desirable actions including, notably, those to be undertaken by the Working Group itself during 2010, with the continuing support of the OECD Global Science Forum.

Section 4a: A review of existing planning mechanisms

During the two meetings that were held in 2009, and in the preparation of this report, information was solicited from the representatives of the participating countries about the processes through which national and regional decisions are made. This material can be summarised as follows:

Argentina	Research in astroparticle physics started in Argentina in early 1950. The current responsibility in the field lies within the Ministry of Science, Technology and Innovative Production (MINCyT) and the National Atomic Energy Commission (CNEA). In October 2008, MINCyT formed a ―Comisión de Astronomía y Ciencias del Universo" with the aim of elaborating a broad ―roadmap" (with the inclusion of astroparticle physics) of projects in which Argentina could participate. This Comisión encompasses both prominent members from the scientific community and from the Agencies. Cooperation at the global level is highly encouraged and favoured. This partly follows from the successful implementation of the Pierre Auger Observatory, an international endeavor of 15 countries for the study of ultrahigh energy cosmic rays which has finished the first

	construction phase and undertaken the second phase. The panel conclusions are expected by October 2010.
Australia	In Australia, astroparticle physics is funded mainly through the Australian Research Council, the body responsible for all non-medical scientific research. The field is relatively small in Australia, though the groups involved have strong international links. Coordination comes via the decadal plans of the National Committee for Astronomy (a committee of the Australian Academy of Science), which set forward visions for the future optical, radio and high energy astrophysics. These plans provide background for funding decisions, but generally proposals in astroparticle physics are funded based on the merits of the proposal in competition with others from the full range of fundamental and applied science.
Belgium	In Belgium, astroparticle physics is mainly funded by the F.R.S.-FNRS (Fonds de la Recherche Scientifique) and the FWO (Fonds Wetenschappelijk Onderzoek-Vlaanderen). Some temporary positions (PhD and Postdoc) are financed by the Belgian Federal Science Policy Office (BelSPO). Both the F.R.S.-FNRS and the FWO are member of the Astroparticle Physics European Coordination group (ApPEC) and of the EC funded ASPERA-2 ERA-NET. The experimental activities are mainly oriented on indirect search for dark matter, high energy cosmic rays as well as high energy gamma and neutrino astronomy.
China	In China, responsibility for astroparticle physics research lies within the Ministry of Science and Technology, National Nature Science Foundation of China and Chinese Academy of Sciences. While the identity and significance of the field are acknowledged, decisions about specific projects and programs are taken within a broader context of planning and management of fundamental research in the physical sciences, where HEP and astronomy, are considered together. In 2007-2008, a major review of programs in these areas was carried out by a group of prominent scientists appointed by the three founding agencies.
France	In France there are 3 research institutions funding astroparticle physics : CNRS (Centre National de Recherche Scientifique), CEA (Commisariat

	d‘Energie Atomique) and CNES (Centre National d‘etudes Spatiales). The recently created ANR (Agence Nationale de Recherche) has also funded some smaller scale astroparticle physics projects through open annual ―Blue Sky” calls. Within CNRS, astroparticle physics research is funded through its two institutes IN2P3 (Institut National de Physique Nucléaire et Physique des Particules) and INSU (Institut National des Sciences de l‘Univers). Since 1999, there has been a CNRS interdisciplinary programme funding ApP research, as well as a Very Large Infrastructure budget line funding the gravitational wave antenna Virgo and the high energy gamma ray observatory H.E.S.S. There are also laboratories of the Institute of Physics performing astroparticle physics research. On the CEA side, research teams working on astroparticle physics belong to IRFU (Institut pour la Recherche des lois Fondamentales de l‘Univers), a department of the matter science division (DSM/CEA). The research activities in astroparticle physics are mainly performed by 31 laboratories (15 IN2P3, 15 INSU and 1 IRFU) that are ‗joint ventures‘ between Universities and CNRS, and sometimes, CEA. There are also 3 research platforms related to astroparticle physics in France: the Underground Laboratory of Modane LSM at Fréjus, the Antares neutrino Observatory south of Toulon and the LMA Laboratoire des Matériaux Avancés) related to Virgo, in Lyon. The total ApP budget for 2006 was of the order of 40 M€ including salaries The total number of FTE in ApP research in 2006 was 552 (CNRS) + 56 (CEA) or 608 in total. Some observatories (ANTARES) or platforms (LSM) also receive regional support. IN2P3 and IRFU conduct common roadmap exercises, while INSU conducts its own. The last exercises were conducted in 2003-2004. The two institutional roadmap processes interact on astroparticle physics through the establishment of common committees. Both CNRS and CEA participated to the ASPERA and ASTRONET European networks and the corresponding roadmap exercises.
Germany	The German funding landscape is described by the federal system and the different responsibilities of the Federal Government and the 16 Länder. The major source of funding for basic research in Germany is the German

	Research Foundation (DFG) that provides support for individual or coordinated research programs (including astroparticle physics) at universities and other publicly financed research institutions. Non-university institutions relevant in the field of astroparticle physics are operated by the Helmholtz Association of German Research Centres (HGF) and the Max Planck Society (MPG). Both organisations are commonly funded by the Federal Government and the Länder. The Länder are also in charge of the public universities that accordingly are institutionally funded by the Länder. When national or international large scale research infrastructures are concerned and large investments are required, the Federal Ministry of Education and Research (BMBF) may complementother avaliable sources of national funding. Indeed, the BMBF is involved in funding the construction and operation of a variety of large research facilities in essentially all fields of basic research. To justify large investments in construction or upgrade of research infrastructures it is of equal importance for the BMBF to ensure the optimal use by German researchers. Therefore, especially university groups in Germany are supported via the BMBF collaborative research programme called ―Verbundforschung". Since 1999 astroparticle physics has been recognized as an own field of science within this funding scheme. It is worthwhile to mention that space-related experiments – also astroparticle phyics – are funded by the Federal Ministry of Economics and Technology (BMWi) via the German Aerospace Center (DLR). To support German researchers in their leading role in many of the current astroparticle physics projects, BMBF is a member of the Astroparticle Physics European Coordination group (ApPEC) and also actively participating in the EC funded ASPERA ERA-NET and its successor ASPERA 2, a network of European funding agencies in astroparticle physics. The BMBF is currently defining a national roadmapping process with the aim to connect Germany's position with the European roadmapping effort in order to meet the demands for global coordination.
India	In India, basic research in high-energy physics, nuclear physics, astronomy & astrophysics including astroparticle physics are mostly

	funded through Department of Science & Technology (DST) and Department of Atomic Energy (DAE), Government of India. The science and technology base in India has now reached a stage where it can plan to take up mega science projects in the country and also participate in similar projects being implemented by consortia of nations. Both DST and DAE are now working synergistically to raise India's research capabilities in the above mentioned areas. In 2006 , DST and DAE jointly organised a vision meeting for drawing roadmap for high-energy, nuclear physics and astroparticle physics research. Several recommendations of this roadmap meeting are currently being implemented. Some of the mega science projects in which India is currently participating are the LHC project at CERN, FAIR project in GSI Germany and India-Based Neutrino observatory project to be set up in the country.
Italy	In Italy, astroparticle physics (APP) is a well-defined domain of the experimental and theoretical research in physics. Searches for dark matter, proton decay, gravitational waves, antimatter in the space and studies of the neutrino properties (including oscillations), of the high energy cosmic rays as well as high energy gamma and neutrino astronomy make part of the mission of the Istituto Nazionale di Fisica Nucleare (INFN), a Public Research Institution (PRI), in a specific scientific line named ―astroparticle physics”. Other Italian PRI‘s - like Agenzia Spaziale Italiana (ASI), Istituto Nazionale di Astrofisica (INAF) - play a role in some APP fields. Most of the Academic Staff involved in APP research is associated to the INFN structures. The above-written PRI‘s operate on the basis of their own three-year plan of activities. The plans define the objectives, the research programs, and the expected socio-economic results and include the human and economical resources needed.
Japan	In Japan, the researches of basic sciences are supported mainly by Ministry of Education, Culture, Sports, Science, and Technology (MEXT). Universities and research institutions receive yearly grants for running costs and salary of permanent positions. Competitive research funds are available mainly through Grant-in-Aid for Scientific Research

	and the Special Coordination Funds for Promoting Science and Technology for short term projects up to five years. Japanese science policies are planned and controlled by Council for Science and Technology Policy. Many astroparticle researches in Japan are hosted by the Institute of Cosmic Ray Research (ICRR), the University of Tokyo, in collaboration with the universities, though they are also done by the universities and the research institutions. ICRR, as an inter-university research institute, supports many small-and middle-range researches of the universities. Future plans in astroparticle field are discussed in ad-hoc committee organized by ICRR in cooperation with Cosmic Ray Research Congress (CRC) organized by by cosmic-ray researchers. Space missions (including missions aboard the international space station), sounding rocket programs, and balloon-borne missions are conducted by JAXA (Japan Aerospace Exploration Agency) under the collaboration with universities and research institutes. Scientific missions are proposed by ad-hoc working groups organized under the Space Science Steering Committee of the Institute of Space and Astronautical Science (ISAS), JAXA. Missions that will use the Japanese Experiment Module "KIBO" of International Space Station are reviewed and evaluated by—KIBO” utilization promotion committee, JAXA.
Korea	Not yet available
Netherlands	In the Netherlands, the budget for scientific research is provided mainly by the ministry of Education, Culture and Science (OC&W). Some large research infrastructures (LOFAR) are financed by the ministry of finance or economy. The universities receive a yearly grant for running cost, permanent positions and education. Most temporary positions (PhD and Postdoc) are financed through project grants from FOM or personal grants from NWO. NWO is the umbrella organisation for all scientific research in the Netherlands and FOM is the funding agency that specifically manages the budget for fundamental research in physics. Astroparticle physics is considered part of FOM. Astroparticle physics research is mainly carried out at Nikhef (the national institute for sub-atomic

	physics). Nikhef is one of three institutes of FOM. The budget for astroparticle physics research has become 14% of the total annual budget in 2008 (from 0% in 2000) compared to 50% for particle physics. Some activities in astroparticle physics are carried out at the universities of Amsterdam, Groningen, Nijmegen and Leiden and the institutes KVI (Groningen) and IMAP (Nijmegen). Technical developments in radio astronomy (LOFAR, SKA, JIVE) are pursued at ASTRON. FOM financed a joint programme for the scientific exploitation of both Antares and Auger (3 Meuro) in 2007. A reqeust for funding the participation in Virgo has been submitted. NWO financed in 2008 a programme for KM3NeT (9 Meuro investment).
Norway	In Norway, the universities receive a yearly grant for running cost, permanent positions and education form the Ministry of Research and Education. While most postdoc and PhD positions are financed by the Norwegian Research Council (Norges Forskningsrad, NFR), university and private funding is also present. Funding for astroparticle physics is provided primarily by NFR, however there are no specific calls in astroparticle physics. So far funding came via calls in space physics, CERN-related physics, –free calls” where all areas of research can apply for quite limited funding and private funding agencies (Melzer grants, Trond Mohn grants). So far astroparticle physics activities has been nearly exclusively limited to theoretical astrophysics and astroparticle physics phenomenology with some experimental engagement in PLANCK. Three universities are active in the area : University of Oslo (theoretical astrophysics, astronomy and cosmology), University of Bergen (astroparticle phenomenology), Norwegian Technical University in Trondheim (astroparticle phenomenology). A recent grant from private funding agency will allow to establish an experimental astroparticle physics group at the University of Bergen in the near future.
Poland	In Poland, the system of financing of large infrastructures is changing now and this description should be updated within a time scale of a year or

	two. Responsibility for astroparticle physics research lies within the Ministry of Science and Higher Education, where all principal decisions are elaborated. However, after a decision is made further supervision and financing of individual project will proceed through an independent state agency National Centre of Research and Development ("NCBiR"). In recent years, when considering participation in large projects, the Ministry has attached increasing importance to (and has actively participated in) the European ESFRI process, and some ASPERA activities. Following the ESFRI road map the Ministry is in a final phase of preparation of the analogous Polish roadmap for large scientific infrastructures. It is expected to be followed with decisions about long time financing of Polish participation in the roadmap projects. Increasing Polish activity in the field of astroparticle physics is mostly contained within the European efforts.
Russian Federation	In Russia, scientific planning in the field of astroparticle physics is done through the Scientific Councils of the Russian Academy of Sciences (RAS), including the Council on Neutrino Physics and Neutrino Astrophysics, the Council on Cosmic Ray Physics and the Council on Elementary Particle and Fundamental Nuclear Physics. There is also Scientific Council on Physics in the Cosmos under ROSCOSMOS (State Cosmic Agency). Research in astroparticle physics carried out in Institutes belonging to the RAS and ROSATOM is funded by RAS and ROSATOM, respectively. Research in the Moscow State University and St.-Petersburg State University is funded directly from the State budget. Research in other universities and the Kurchatov Institute is funded through the Ministry of Education and Science. Decisions on major projects are made by the Government of the Russian Federation. The Ministry of Education and Science and its Agency ―ROSNAUKA” as well as Russian Foundation for Basic Research provide funding of a limited number of projects in astroparticle physics via a grant system. The Ministry of Science and Education is the major funding agency for

	international collaboration in astroparticle physics outside Russia.
Spain	In Spain, responsibility for astroparticle physics research lies within the Ministry of Science and Innovation (MICINN). The National Plan for Scientific Research, Development and Technological Innovation (I+D+I) is structured, since 2008, in a set of 5 transversal funding instruments, namely: Human Resources, Research Projects, Scientific and Technological Infrastructures, Usage and Transfer of Knowledge, and Articulation and Internationalisation of the Research. The instrument funding Research Projects in practice is organised in a set of specific areas for different research lines like for instance "Particle Physics and Accelerators (FPA)", "Astronomy and Astrophysics (AyA)" and "Space Science" among many others. The astroparticle physics field is not recognised as an independent area, and decisions about specific projects and programmes in astroparticle physics are taken within an open competition framework in those three specific areas mentioned above mainly, being nevertheless "FPA" the one with the highest relevance for most of the astroparticle physics projects (the only exceptions so far are the participation in ground-based gravitational wave detectors and the participation in space missions relevant to astroparticle physics). The funding for research follows a quadrennial plan which at present covers the period from 2008-2011. Since the structure in the aforementioned 5 funding instruments was a new concept first applied in 2008, this year (2009), a major review of these funding instruments by Ministry-appointed groups of experts and prominent scientists is taking place. In recent years, when contemplating potential participation in larger projects, the MICINN has attached increasing importance to (and has actively participated in) the European ESFRI process, and the continuing ASPERA roadmapping effort. It is expected that these will continue to play a major role, although cooperation at the global level is also seen as highly desirable. A research infrastructure in Astroparticle Physics is the Canfranc Underground Laboratory (LSC), which is funded on multi-annual basis

	jointly by the MICINN and the Aragon Government and is part of the System of Scientific and Technological Structures (ICTS) co-ordinated by MICINN.
Switzerland	In Switzerland, R&D is publicly support by the Federal Government and the Cantons. The Federal Government supports the research according to guidelines and goals of the Education, Research and Innovation system (ERI) and through FP7. The basic funding of the 10 Cantonal Universities comes from the Cantonal Parliaments, with some contributions from the Federal Government provided by the State Secretariat for Education and Research (SER). The Swiss National Science Foundation (SNF) receives its budget from SER. It allocates funding mostly for investigator-driven research, but it also funds targeted research in the form of National Research Programmes. Funding of EIROforum Organisations' membership is provided separately by SER. When contemplating potential participation in larger projects, SER attaches increasing importance to the European ESFRI process, and the continuing ASPERA road mapping effort. Cooperation at the global level is also seen as highly desirable. APP activities in Switzerland form one of the three pillars of the CHIPP (Swiss Institute of Particle Physics) Roadmap. The funds for APP projects allocated by the SNF are increasing since about 10 years, with respect to particle and nuclear physics, as well as physics in general.
United Kingdom	Within the UK, responsibility for astroparticle physics research lies with the Science and Technology Facilities Council (STFC). While the importance of astroparticle physics research in answering many key scientific questions in physics is recognised, funding for astroparticle physics projects, and their exploitation, is tensioned against similar activities in astronomy, particle physics and nuclear physics and STFC's support for domestic and international facilities. The STFC conducts regular reviews of its programme priorities, the most recent being in 2008. The next review is currently underway and will be completed in January 2010. STFC works closely with other UK Research Councils in developing a UK strategic view of the future provision of large research infrastructures in the UK and internationally. STFC's vision is to

	maximise the impact of its investments for the benefit of the UK and its people. International engagement through ESFRI, joint programming and global coordination of major investments are seen key components in realising this goal.
United States	In the US, the Department of Energy (DOE), NASA and the National Science Foundation (NSF) provide most of the funding for Astroparticle Physics Research. Proposals for both individual investigator support and construction and operations funding are subject to peer reviews. The High Energy Physics Advisory Panel (HEPAP) provides advice to DOE and NSF on the high energy physics (particle physics) program, and the Astronomy and Astrophysics Advisory Committee (AAAC) provides advice to DOE, NASA, and the NSF on activities in which their programs overlap. NASA gets advice from its Astro Physics Subcommittee (APS). The agencies also get advice from program planning committees, subpanels of HEPAP and/or AAAC such as P5, DMSAG, NuSAG and PASAG and the National Academies of Science panels (such as Astro2010 and the Beyond Einstein Program Assessment Committee (BePAC) and the EPP2010). Many projects are co-reviewed by more than one agency and subsequent funding is also provided by more than one agency.

ASPERA/ApPEC	The consortium ASPERA comprises the majority of funding agencies and program managing organisations funding Astroparticle Physics in Europe (15 countries) . Historically ASPERA arose from the existence of ApPEC. ApPEC (Astroparticle Physics European Coordination) is an interest grouping of national funding agencies that came into being in 2001 when six European scientific agencies took the initiative to coordinate and encourage Astroparticle Physics in Europe, an emergent field not covered by adjacent disciplines. Broadly the aims of ApPEC are to a) develop long term strategies and offering advice to national funding agencies or other organisation as appropriate, b) express the views of European Astroparticle Physics in international forums, c)

	establish a system of peer review assessment. Since then, ApPEC has grown to fifteen agencies representing thirteen European countries. It comprises two bodies. Its executive body is the Steering Committee (SC), where each country participates with its leading scientific executive and also representatives of CERN, ESA end ESO with observer status. Its strategic advisory body is the Peer Review Committee (PRC) composed of scientific experts in Astroparticle Physics nominated ―ad personam". By 2005 ApPEC realised the identity of its goals with those of the EU ERANET scheme and therefore coordinated the submission of the proposal for ASPERA-1 to the EU. ASPERA-1 started in July 2006 and was funded by the EU with a budget of 2.5 M€ for a 3 year period. Three work packages formed the core of the ASPERA-1 work programme: a) chart the status of Astroparticle Physics funding schemes in Europe, b) establish a roadmap and action plan, c) link the existing platforms of observation, establish the best legal schemes for future infrastructures and find ways to commonly fund and manage the new large programs. A transversal work-program developed a high-level electronic infrastructure for the consortium and an extensive outreach activity. It is recognised, that the EU funded ASPERA-1 program was a tremendous boost to the European convergence of the domain, since it permitted a census of the field, the establishment with the help of a priority roadmap, linking agreements of European underground laboratories and the launching of pan-europan calls for joint funding of astroparticle physics related R&D. The successful ASPERA-1 is currently continued with ASPERA-2 (2009-20012). The goals of this second installment of ASPERA are the implementation of the roadmap through further common calls, establishment of pan-european evaluation and follow-up committees, increase of the links with industry and adjacent fields, preparation of an upgraded ApPEC legal form and participation in a global coordination process in the context of the OECD Megascience forum.

Section 4b: Scope and Scale of Astroparticle Physics in Participating Countries

Study in progress …

Annual Funding*	Lab Operation	Investment	Salaries	Other	**Total**
Europe	26	50.6	90.35	10	176.95
US (incl. DOE-HEP, DOE-NP, NASA and NSF-PHY)	9.9	34.9	56.3	2.1	119.2
Canada					
Argentina					
Mexico					
Brazil					
Russia (in Million $)	3.5	2.5	6.0	0.5	12.5
India					
China					
Japan					
Korea					
Australia	0.3	0.3	1.4	0	2.0
TOTAL	39,4	88	154,05	12,6	310,65

*In Million Euros, Dollars or Okuyen, without exchange rate applied

PERSONNEL (FTE)	Permanent*	Postdocs	Graduate Students	Other	**TOTAL**
Europe	1021	269	439	197	1926
US US (incl. DOE-HEP, DOE-NP, NASA and NSF-PHY)	269	135	220	68	692
Canada					
Argentina					
Mexico					

Brazil					
Russia	500	60	50	100	710
India					
China					
Japan					
Korea					
Australia	6	4	20	0	30
TOTAL	1790	468	729	365	3358

* Scientists and Engineers

The review of existing processes was an important exercise for the Working Group, since any new recommended actions must not duplicate (or interfere with) mechanisms that are already in place. Furthermore, the OECD Group did not want to be perceived as carrying out lobbying on behalf of any particular project that is already being considered by recognised authorities.

Section 5: Recommendation, and Notional Work Programme for 2009/2010

Having reviewed the existing national and regional processes for planning and priority setting, the Working Group considered the essential question: are these processes sufficient to ensure the desired optimal evolution of the field as seen from a global perspective? In formulating the answer to this question, the Working Group took into account the many past and current mechanisms, both formal and informal, through which the plans and priorities of other countries and regions are incorporated into national decision-making. This is especially significant in Europe, where, in many countries, national decisions are now strongly anchored in the ApPEC/ASPERA process. The Working Group also took note of the community-based foresight exercises, notably those under the aegis of GWIC//PaNAGIC/IUPAP on gravitational wave detection. Following considerable debate, the Working Group concluded that the existing processes should be augmented by an additional new effort whose outcome should be the development of a consensus international strategic vision[1] of astroparticle physics for the next 10-15 years. This new work would not duplicate or interfere with existing national and regional efforts, but would complement them by helping to avoid unnecessary duplication, promoting the sharing resources and expertise, and identifying opportunities for the joint establishment and exploitation of new research infrastructures.

The Working Group proposes to oversee the preparation of the first version of the strategic vision during 2010. Its elements are enumerated below. If deemed successful, it is expected that the vision would be further updated as developments warrant, even after the OECD group has finished its work.

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[1] The Working Group adopted the term —strategic vision”, as opposed to —roadmap”, because the former implies a desired level of prescriptive detail and completeness. A roadmap normally enumerates (and, implicitly, endorses) specific projects or programmes. The OECD Working Group does not have the authority (or intention) to assess or endorse individual projects. Moreover, the Working Group wishes to focus on a limited subset of future projects, i.e., those large infrastructures that could benefit from extensive international involvement by national funding agencies.

Elements of an international strategic vision for astroparticle physics

This section of the report describes, in generic terms, the anticipated result of the work that the OECD Working Group proposes to perform in 2010, including the methodology and schedule. The strategic vision would be presented in the form of a policy-level document of some 20 pages, containing the following elements:

1) Science Goals

It has already been stated in this report that the international scientific community of astroparticle physicists is very well connected, and that a broad consensus exists about the principal scientific challenges. There are a number of reports where these challenges are described in detail, and Section 2 of this report is an abbreviated version of these. Accordingly, this element of the strategic vision should not be difficult to realise, but the renewed effort will be important for at least two reasons. Firstly, it will clearly define the boundaries of astroparticle physics that are being assumed, in the context of neighbouring fields and the overall scientific enterprise. This will make it clear whether the presence or absence in the final report of certain research issues (and the related research instruments and infrastructures) is due to the way that the boundaries of the field are defined, or is due to priorities that were assigned based on an analysis of scientific and policy issues. Secondly, the listing of science goals will establish a baseline that will, with the passage of time, be superseded as new scientific results and insights are obtained by researchers in the fast-moving field. This will be important when applying the report for policymaking purposes, and will be useful when determining whether the strategic vision needs to be updated.

2) An enumeration of research tools that are needed to achieve the science goals

More than most research domains, astroparticle physics is characterised by an enormous diversity of instruments and technologies that are utilised by researchers. In most cases, multiple methods exist for addressing a particular scientific challenge. For planning and foresight purposes, it will be useful to compile – using a uniform set of standards and formats – a taxonomy/inventory of existing and potential future techniques, instruments, detectors and facilities. This will be a generic enumeration, focussing on needs and capabilities, rather than specific proposed projects. In each instance, the following topics will be addressed in some detail:

- The current state of technological maturity, the scientific and technological options for achieving the desired performance/cost/reliability objectives, the likely scope and scale of needed R&D efforts.

- In the case of medium- and large-scale infrastructures, the advantages and disadvantages of duplication, diversification and complementarity of projects (for example, to independently verify difficult measurements, to improve detection likelihood using coincidence methods, to explore different properties of the same physical phenomenon, to provide directional coverage of the entire sky).

- The infrastructure and siting needs (for example: shielding from cosmic rays underground, orbiting far from the Earth).

- When appropriate, a time schedule of implementation, contingent on other results being obtained, or progress being made in related disciplines.

It is expected that the preparation of this list will be the subject of considerable debate (and even a measure of controversy) among members of the scientific community, since the exercise will be subject to a constraint of financial realism. That is, the goal will be to define an optimal global-scale experimental capability, in which historical funding patterns are expected to persist or expect a reasonable increase. Inevitably, difficult choices will have to be made about the future value of alternative techniques, and the prospects of achieving desirable performance and cost goals. The ambitions of countries, institutions and individuals will need to be subordinated to the overall interests of the field. In cases where such choices cannot be reliably made at this time, a clear statement of the relevant arguments will need to be provided.

3) An exploration of the potential role of international coordination and collaboration.

As indicated above, most of the planning and implementation of projects and programmes in astroparticle physics takes place at the national level, sponsored in each case by the appropriate national funding agency. The European ApPEC/ASPERA process is a notable exception to this generalisation in the domain of strategic planning. This section of the report will analyse and describe the potential role of various forms of international cooperation, culminating with a short list of major projects that could be considered for implementation, at some future date, as purely international undertakings. A variety of international modalities will be considered:

- Joint R&D projects for feasibility studies and development of instrumentation, without necessarily assuming future joint implementation.

- Research partnerships and international participation in national projects, ranging in scale from simple involvement by individual researchers and university teams, to major in-kind contributions of equipment and manpower to national projects.

- At the policy (agency) level the creation of new planning and prioritisation processes (or the modification of existing ones). This could involve changing the scope or timing of planning exercises, so as to take into account similar work being done in other countries or regions. Corresponding adjustments could be made at the level of the organised scientific community (i.e., PaNAGIC and its working groups).

- The potential establishment of a new mechanism for the regular sharing of information and coordination of polices and plans by the funding agencies that are responsible for supporting research in astroparticle physics. Any such initiative would require careful consideration of the impact on related scientific fields, notably astronomy/astrophysics, elementary particle physics and nuclear physics. As an example one can cite the special relationships that astroparticle physics in Europe has with CERN and to some extent with ESO, or the interdependence of the different sub-domains and their different respective weight in the US agencies .

The strategic vision of astroparticle physics will include an analysis of the prospects for realising a small number of major projects on a purely international basis; that is, projects whose planning, organisation, management, funding, construction and exploitation would not be the responsibility of any single country, but would be undertaken jointly based on an appropriate international agreement. Currently, the Pierre Auger Observatory is an example of such a project, as are ALMA and ITER.

The following notional work programme for the Working Group on Astroparticle Physics is proposed for review and approval by the Global Science Forum at its 21st meeting in October 2009:

1	Fall/Winter 2009	Finalise work plan. Convene regional subgroups in three scientific domains: - Non-accelerator particle physics or underground science: dark matter, neutrino mass and proton decay (convenor D. Sinclair)

		- High-energy cosmic rays including gamma rays and neutrinos (convenor C. Spiering) - Dark Energy (convenor C. Baltay) (NB: the Gravitational Wave International Committee has published its global roadmap, so that it is not necessary to reconvene the GW community)
2	January 15/16 2009	3rd meeting of the Working Group Tata Institute, Mumbai, India
3	Early to Mid 2010	Subgroups hold regional –town meetings” of members of scientific community
4	Summer 2010	Working Group reviews scientific community input and begins formulating policy recommendations
5	September 2010	4th and final meeting of the Working Group North America
6	October 2010	Preliminary final report to the 23rd GSF meeting in Amsterdam
7	End 2010	Final report submitted to Global Science Forum

APPENDIX

OECD Global Science Forum

WORKING GROUP ON ASTROPARTICLE PHYSICS

Nominated delegates

(as of July 30, 2009)

Chairman	Michel Spiro	Institut National de Physique Nucléaire et de Physique des Particules (IN2P3)	mspiro@admin.in2p3.fr	+33 1 44 96 47 53
Argentina	Alberto Etchegoyen	Pierre Auger Project	etchegoy@tandar.cnea.gov.ar	+54 11 6772 7062
Australia	Bruce Dawson	University of Adelaide	bruce.dawson@adelaide.edu.au	+61 8 8303 5275
Belgium	Daniel Bertrand	Université Libre de Bruxelles	daniel.bertrand@ulb.ac.be	+32 2 629 3213
China	Hesheng Chen	Institute of High Energy Physics, Chinese Academy of Sciences	chenhs@ihep.ac.cn	+86 10 88235164
France	Stavros Katsanevas	CNRS IN2P3	katsan@admin.in2p3.fr	+33 1 44 96 47 57
	Philippe Chomaz	Institut de Recherche sur les Lois Fondamentales de l‘Univers, CEA	philippe.chomaz@cea.fr	+33 1 69 08 24 02

Germany	Thomas Berghöfer	Projektträger DESY (PT-DESY)	thomas.berghoefer@desy.de	+49 40 8998 2537
	Guido Drexlin	Forschungszentrum Karlsruhe GmbH	guido.drexlin@kit.edu	+49 7247 82 3534
	Karsten Danzmann	Max Planck Institute for Gravitational Physics	karsten.danzmann@aei.mpg.de	+49-511 762 2356
India	Naba Mondal	Tata Institute of Fundamental Research	nkm@tifr.res.in	+91 22 2278 2227
Italy	Benedetto D'Ettorre	Istituto Nazionale di Fisica Nucleare (INFN)	dettorre@presid.infn.it	+39 06 684 0031
	Alessandro Marini	INFN Laboratori Nazionali di Frascati	alessandro.marini@lnf.infn.it	+39 06 940 32799
Japan	Toshikazu Ebisuzaki	RIKEN Computational Astrophysics Lab.	ebisu@postman.riken.jp / t-ohata@riken.jp	+81 48 467 9414
Korea	Doo Jong Song	Korea Astronomy & Space Science Institute	djsong@kasi.re.kr	+82 42 865 3215
Netherlands	Maarten de Jong	NIKHEF Institute	maarten.de.jong@nikhef.nl	+31 20 5922000
Norway	Anna Lipniacka	University of Bergen	anna.lipniacka@ift.uib.no	+47 555 82803
Poland	Michał Ostrowski	Jagiellonian University in Krakow	mio@oa.uj.edu.pl	+48 12 425 12 94
Russian Federation	Victor Matveev	Russian Academy of Sciences	matveev@inr.ac.ru	
Spain	Manel Martinez	IFAE Barcelona	martinez@ifae.es	+34 93 5811309
Switzerland	Maurice Bourquin	Swiss National Science Foundation	maurice.bourquin@unige.ch	+41 22 379 6276
	Martin Steinacher	State Secretariat for Education and Research	martin.steinacher@sbf.admin.ch	+41 31 324 23 82

United Kingdom	Janet Seed	Science and Technology Facilities Council (SFTC)	janet.seed@stfc.ac.uk	+44 1793 442 561
	Deborah Miller	STFC	deborah.miller@stfc.ac.uk	+44 1793 442 004
United States	Kathy Turner	US Department of Energy	kathy.turner@science.doe.gov	+1 301 903 1759
	Gene Henry	US Department of Energy	gene.henry@science.doe.gov	+1 301 903 3613
	Vernon Jones	National Aeronautics and Space Administration	w.vernon.jones@nasa.gov	+1 202 358 0885
	Stephen Murray	Smithsonian Astrophysical Observatory	ssm@head.cfa.harvard.edu	+1 617 495 7205
	Vernon Pankonin	US National Science Foundation	vpankoni@nsf.gov	+1 703 292 4902
	James Whitmore	US National Science Foundation	jwhitmor@nsf.gov	+1 703 292 8908
PaNAGIC (Observer)	David Sinclair	Carleton University	sinclair@physics.carleton.ca	+1 613 520 7536
CERN (Observer)	Felicitas Pauss	CERN	Felicitas.Pauss@cern.ch	+41 22 767 1330
OECD	Stefan Michalowski	Global Science Forum secretariat	stefan.michalowski@oecd.org	+33 1 45 24 92 89
Invited Experts	Charles Baltay	Yale University	charles.baltay@yale.edu	+1 203 432 3386
	Christian Spiering	DESY	csspier@ifh.de	+49 33762 77218
	Jay Marx	LIGO / Caltech	jnmarx@ligo.caltech.edu	+1 626 395 2065
	Benoit Mours	Laboratoire d'Annecy-le-vieux de Physique des	benoit.mours@lapp.in2p3.fr	+33 4 50 09 55 87

		Particules (LAPP)		
	Yoichiro Suzuki	Institute for Cosmic Ray Research, U. of Tokyo	suzuki@suketto.icrr.u-tokyo.ac.jp	
	Roger Blandford	Kavli Institute for Astrophysics and Cosmology	rdb@slac.stanford.edu	+1 650 926 2606