# Development and Applications of Novel Instrumentation and Experimental Methods in Astroparticle Physics

## I. Introduction

Astroparticle Physics is a new interdisciplinary field of research on the structure of matter, fundamental interactions and the evolution of the universe. It studies particles that come from sources outside our planet, outside our galaxy, outside the boundaries of the accessible luminous universe. In this research field, Particle Physics converges with Astronomy, with Astrophysics and with Cosmology. Particle Physics focuses on the study of the structure and the fundamental interactions of matter, whilst Astronomy and Astrophysics study the structure of the Universe at large scales and the Cosmos evolution since the Big Bang. Cosmology links the theoretical description of the Nature provided by Particle Physics to that required describing the very early universe. Every achievement in Particle Physics has a direct impact on how we perceive and describe the universe and vise versa, every discovery in Cosmology has fundamental impact on the physical theory of the infinitesimal-microcosm.

Up to the middle of last century, high energy cosmic rays from space was the main source of information upon which the scientific progress concerning the fundamental properties of matter was based. Then, particle accelerators provided the means to experiment with beams of energetic particles and paved the way for enormous achievements concerning our understanding of the structure and interactions of matter. Nowadays, we return to the study of cosmic rays. Indeed, the development of new detection devices and experimental methodology offers the ability to detect cosmic rays, to study phenomena that evolve in energy thousands of times greater than those achieved with ground-based accelerators.

As the field of Astroparticle Physics develops, new windows for observing and studying events that mark the evolution of the universe are opening. The low energy electromagnetic radiation is not anymore the only carrier of information from distant objects in the universe as we started seeing gamma rays in the TeV energy region, ultra high energy cosmic rays and neutrinos. In order to understand many of the phenomena that occur in distant astrophysical objects we need information provided by a wide spectrum of wavelength (or momentum) of various types of messengers (photons, charged particles, neutrinos, even gravitational waves ). Moreover, the cataclysmic events that occur in our accessible universe offer a unique "laboratory" to test our perceptions of the structure and fundamental interactions of matter .

The ambitious research program of Astroparticle Physics could not be realized without the development of theoretical models describing the fundamental interactions of matter and the evolution of the Universe, as well as the development of new detectors and techniques in Experimental Particle Physics and Astrophysics. The current research programs in Astroparticle Physics are challenging the limits of modern technology whilst dealing with experimental difficulties (e.g. uncontrolled experimental conditions, very weak cosmic signal, low probability of interaction of cosmic particles with matter, etc) in extreme environmental conditions. Indeed, the modern facilities of Astroparticle Physics (e.g. the very high energy, very large volume Neutrino Telescopes) should be able to operate in very hostile environments (in the ice of Antarctica or in very deep sea) and must be sensitive enough to record accurately cosmic messengers whilst bombarded by natural background noise that excels by several orders of magnitude the signal they seek. The design, construction and operation of these facilities is a result of the collaborative effort of large, international scientific consortia. Their achievements (e.g. two Nobel Prizes in the last decade) have decisively shaped the modern scientific understanding of our world. Moreover, these extensive infrastructures of Astroparticle Physics offer the platform for collecting a wide-range of observations concerning the environment, the climate, life sciences etc.

In conclusion, Astroparticle Physics is a) a significant scientific research area (where "significant" refers to the promotion of human knowledge regarding the structure and evolution of the universe, the known and unknown mater as well as the known and unknown energy that make our Cosmos), b) a highly interdisciplinary field of research (where the "multidisciplinary" refers to the involvement of Particle Physics, Astrophysics, Astronomy, Cosmology, Detector Instrumentation, Technology of electronic networks for control/data-acquisition/monitor/signal-processing, Material Science, Environmental Sciences as well as Life Sciences) and c) a highly international research area (where the "international" refers both to the structure of the scientific collaborations and the distribution of the research facilities on the globe).
The proposed research program falls in the domain of Neutrino Telescopy (Neutrino Astroparticle Physics) retaining as well a strong link to the multi-messenger approach of Astroparticle Physics. The proposed research aims in developing novel instrumentation and experimental methodology as well as in performing detailed studies for the optimization of large experimental infrastructures and data analysis, in order to

contribute to the international research effort for the detection of neutrinos (of galactic or extragalactic origin) and the discovery of the origin of high energy cosmic rays. In parallel, spin-off applications of the expected results in instrumentation will contribute to the monitoring of environmental parameters and will provide the framework for new developments in Education.

## II. State of the Art and Objectives

Neutrina should be emitted, with high energies, by a wide range of galactic sources (such as SuperNova remnants, pulsars and micro-quasars) and extragalactic sources (such as Active Galactic Nuclei [AGN], γ-ray burst emitters) in the Universe, as products of the interaction of high-energy charged particles with matter. As neutrinos interact weakly with matter, they can escape from inside compact celestial bodies much easier than photons, providing thus the capability of detection and study of phenomena occurring in the Universe and remaining hidden from classical astronomy, γ-ray telescopy, but also from the charged cosmic ray telescopy.
These phenomena could be results either of astrophysical mechanisms described by known physics or of new, yet unknown physical processes. As an example, there are several theoretical models proposed to address open questions in Particle Physics predicting the existence of heavy particles that can form the bulk of the dark matter in the Universe. Searches for new particles, predicted by these mechanisms, constitute main research goals of the large acceleration facilities (e.g. LHC at CERN). The detection of gamma rays produced from the annihilation of dark matter that is gravitationally confined in our galaxy (e.g. as a hello) is one of the goals of the existing and future gamma ray telescopes. However, in case that weak interacting massive particles are gravitationally trapped inside astrophysical objects and annihilate to stable particles, the neutrina will be the only available messenger to reveal this phenomenon, offering thus another important tool, complementary to the accelerator experiments, of discovering the constituents of the unknown dark matter. Moreover, neutrina from cosmic sources will offer strong evidence of charged particle acceleration mechanisms in the Universe and of hadronic production mechanisms of the very high-energy cosmic rays. The detection and study of the diffuse flux of ultra-high-energy neutrina (from unidentified sources or from the interaction of cosmic rays with intergalactic matter and radiation or even with the cosmic microwave background radiation) can offer significant cosmological evidence.

However, the weak interaction of neutrinos with matter renders their detection extremely difficult at the earth laboratories. It has been estimated that a neutrino telescope (that utilizes ice or water as active medium to observe Cherenkov light from the products of the neutrino interaction with the matter surrounding the detector) in order to be able to detect far astrophysical objects should occupy an instrumented volume of the order of several $km^3$. Matter of significant thickness should also surround such a neutrino telescope in order to be shielded from the cosmic radiation background that bombards the earth. Today, after 30 years of pioneering research projects, the international community has focused on the design, construction and operation of two, complementary, large ($km^3$) neutrino telescope infrastructures: IceCube [1] embedded deep in the Antarctic ice and KM3NeT [2] deep in the Mediterranean sea. IceCube has been already completed since the summer of 2010 whilst during the construction period has been partially operated collecting significant amount of data, setting limits to the neutrino emission from known astrophysical objects and falsifying some of the phenomenological models that describe the neutrino production during cataclysmic phenomena (e.g. Gamma Ray Bursts). Although KM3NeT has finished the conceptual and technical design phases (Conceptual Design Report CDR[3], Technical Design Report TDR [4]) there exist several issues concerning important functional parameters[1], the calibration and data analysis procedures to be resolved.

Since the design of IceCube, high-energy gamma ray observatories have revealed several galactic sources exhibiting a hard spectrum of gamma-rays that strongly indicate high energy hadronic interactions. In parallel, large extensive air showers arrays have collected a large amount of ultra-high-energy events establishing the existence of a high energy cut-off (possibly due to the interaction of the UHE cosmic rays with the Cosmic Microwave Background according to the Greisen-Kuzmin-Zatsepin (GKZ)) in the cosmic-ray energy spectrum and revealing a statistically interesting clustering in the arrival direction of extragalactic, ultra high energy cosmic particles. Moreover, space bound gamma-ray observatories have observed very many transient extragalactic gamma-sources, bursting enormous amount of energy in short

[1] Including the prioritization of physics goals, the telescope architecture as a single telescope or a network of underwater infrastructures, the layout, the choice of technological solutions, the construction strategy, and the selection of the deployment site.

time intervals (Gamma Ray Bursts – GRBs), as well as intense fluxes of gamma rays originating from huge "bubbles" above and bellow the galactic plane (Fermi-Bubbles). Although all the above-mentioned phenomena, according to our current understanding of fundamental interactions, should copiously produce high-energy neutrina, no such neutrina of extraterrestrial origin have been observed yet.
IceCube (based on data collected during the construction phase) has already provided significant results (e.g. limits on neutrino fluxes from point-like, extended and transient sources, observation of directional clustering of the galactic cosmic rays etc) on the neutrino emission from astrophysical sources and the origin of cosmic rays. As an example, IceCube has already set limits excluding predictions of several phenomenological models concerning the VHE neutrino production during GRBs. The operation of the completed IceCube detector is expected to offer a higher discovery potential that will provide more exiting results, including searches for neutrina originating from the sun or/and earth's core, which would indicate dark matter annihilation as well as studies of neutrino oscillations based on the enormous statistics of collected atmospheric neutrino events. However, the advances in gamma-ray and charged cosmic-ray telescopy as well as the experimental progress and theoretical effort concerning the nature of dark matter resulted in more accurate estimations of the expected high-energy, galactic and extragalactic neutrino fluxes. These estimations indicate that a neutrino telescope of the size of IceCube (1 $km^3$) could marginally observe high-energy neutrina of extraterrestrial origin in the near future (~ 5 years). Such a fact implies the need of a new design concept and construction strategy for the Mediterranean Neutrino Telescope in order to complement the capabilities of the IceCube and to increase significantly the discovery potential of the Neutrino Telescopy.

The deep water of the Mediterranean offers the necessary shielding from cosmic radiation, exhibiting, in parallel, great transparency and minimal light scattering so that the cosmic neutrino direction can be reconstructed efficiently and with high precision. In addition the geographical position of the Mediterranean is ideal, since the area of the sky that is possible to be observed by a deep-sea neutrino telescope will include the centre of our galaxy and most of the galactic plane where many high-energy gamma-ray sources (potential neutrino emitters) have been discovered. The optical properties of water and the geographical position could elevate a $km^3$ telescope (of the same size as IceCube) to be the most sensitive cosmic neutrino telescope, at least 3 times more sensitive than IceCube for point sources (which, however, observes a different area of the sky). However, the current estimations of the expected neutrino fluxes indicate that a larger neutrino telescope is required to discover cosmic neutrina and study the emission mechanisms. According to studies [5] performed by researchers participating in this proposal (see also the Conceptual and Technical Design Reports of the KM3NeT Collaboration [3, 4]), a Very Large Volume (VLV) Mediterranean underwater neutrino telescope[2] could observe a mean of 1.3 neutrina/year from the most luminous galactic high-energy gamma-ray source (RX J1713.7-3946), on top of a corresponding background of 1 event/year. Furthermore, the neutrino signal in this telescope, corresponding to the expected total neutrino flux from all the high energy galactic gamma-ray sources observed by HESS [7, 5] (assumed to emit as point sources) is 13neutrina events per year on top of 11 background events, indicating that several years of observation are required to detect unambiguously neutrino emission from such sources. This is due to the fact that the gamma ray spectrum of the galactic sources exhibits an energy cut-off of the order of 10 TeV indicating (according to the current phenomenological models that describe the high energy gammas and neutrina as products of the same hadronic interactions at the source) that a similar spectrum should be expected for neutrino fluxes. However, the VLV neutrino telescope layouts, optimized during the KM3NeT Design Study [3,4], exhibit optimal sensitivity in discovering astrophysical sources emitting neutrina with an energy spectrum of $E^{-2}$ and a high (or without any) energy cut-off. Such detectors have lower sensitivity in detecting galactic neutrina in the energy range of 1-10 TeV. Obviously, more studies and the application of more sophisticated experimental and data analysis techniques are needed in order to demonstrate the physics potential of KM3NeT to discover extraterrestrial neutrina providing (on top of the expected results from IceCube) answers to the open questions in Astroparticle Physics (e.g. what is the origin of the galactic and extragalactic cosmic rays? ). These studies fall in the objectives of the proposed research project.

Such strategies are strongly depended on the prioritization of the physics goals and must be studied further taking into account all the systematic effects (e.g. uncertainties concerning the water optical properties

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2 In these studies, we have considered an neutrino underwater telescope of 7 $km^3$ instrumented volume, with 6000 multi-PMT [6] optical modules distributed on 300 vertical structures [strings], with an horizontal separation of 180m between strings and a vertical distance of 50m between optical modules on the same string, deployed in the Ionian see at 3500 m or 4500m depth.

including the particulate scattering, uncertainties in the phenomenological predictions etc) that can affect the results. As an example, previous simulation studies, performed by researchers participating in this proposal, strongly indicate that a further improvement of the telescope's resolution in reconstructing the direction of cosmic neutrinos especially in the 1-10TeV energy region (e.g. introducing a dense detector using strings or towers with extended horizontal structures) does not improve the sensitivity in detecting VHE neutrina (e.g $E^{-2}$ fluxes without energy cut-off, GRBs, cosmogenic GZK neutrina etc) but improves the sensitivity in observing galactic point-like sources, whilst the detection of neutrina from dark matter annihilation requires a very dense detector. On the other hand, a much larger, sparse neutrino telescope has a significant higher sensitivity in detecting VHE neutrina but it is less sensitive to (1-10 TeV) neutrina from the galactic sources, including the bright gamma ray emitters of the galactic plane. Because the sensitivity of a neutrino telescope depends strongly on the size of the instrumented volume and the construction cost grows proportionally to the number of detection units, the optimal density, the telescope layout and the construction strategy should maximize the probability for a significant discovery in near future while keeping the construction cost in realistic limits.

IceCube followed a construction strategy that kept increasing gradually the instrumented volume and keeping constant the string density (with only one exception, that of “Deep Core”) while collecting data during the whole construction period. Simulation studies indicate that a Mediterranean neutrino telescope of 600 strings (15 $km^3$ of instrumented volume at full size) will have the same (or even better) sensitivity if deployed in two identical, autonomous parts. Furthermore, the construction of KM3NeT should follow the available funds provided by the hosts and participating countries while at the same time IceCube will accumulate data (even with lower sensitivity). It is thus important the KM3NeT to maximize the discovery potential in each phase of the construction period and there are simulation results [5] indicating that an increasing density construction strategy (starting for a sparse detector and progressively increase the density, provided that such an approach is technically feasible) offers a better chance. As an example, researchers participating in this proposal have study several deployment scenaria of a 7 $km^3$ underwater detector containing 6000 multi-PMTs on 300 strings. Such a detector could observe 4.2 neutrina/year from GRBs (according to the optimistic model of [21], assuming that 500 GRBs are observed by space born experiments) on top of 0.75 background events per year. Furthermore, according to the same study, a neutrino telescope of the same size but containing the 25% of the optical modules (a sparse detector of only 1500 multi-PMT optical modules) will observe 2.75 neutrino events for gamma ray bursts, on top of 0.6 background events, per year. This expected efficient performance in discovering neutrina from gamma ray bursts is obviously due to the harder energy spectrum predicted by the current phenomenological models and the short time duration of the bursts. Similar efficient performance has been estimated in detecting diffuse fluxes of ultra-high-energy neutrinos from unidentified sources or from the interaction of cosmic rays with intergalactic matter and radiation or even with the cosmic microwave background radiation. Although a sparse detector does not have a chance to discover galactic sources (according to the current models), it retains a significant sensitivity to observe very high energy (VHE) neutrina. Such studies on the evaluation of the sensitivity during the construction phases of a single underwater infrastructure or of a network of two (or three?) telescopes-nodes fall in the objectives of this proposal. These studies will follow the optimization studies and the development of advanced data analysis tools in order to maximize the discovery potential of the infrastructure from the beginning of its (partial) operation.

In optimizing the neutrino telescope architecture, it is also important to utilize in the data analysis the maximum of the experimental information offered by the detection units. Recently, researchers participating in this proposal have demonstrated [8] that by employing in the search strategies information based on the directional resolution and the measured energy of each of the detected muons (produced by the neutrino interaction), improve significantly (up to a factor of 2, depending on the size and the energy spectrum of the source) the discovery potential of the underwater telescope. In addition, simulation studies indicate that the track reconstruction algorithms, when utilise information based on the (known) position of the potential neutrino source, improve significantly (by a factor of 5) the efficiency of detecting neutrina in the 1-10 TeV energy region, whilst suffering of a very low probability to produce fake signal (this has to be studied further). The efficient use of the experimental information can also enlarge the telescope’s field of view. As an example, the IceCube collaboration, recently, published results on searches for point-like and extended neutrino sources demonstrating also the ability of this detector to perform searches above the horizon. KM3NeT has a higher potential to observe high-energy neutrina above the horizon, due to the greater deployment depth and the much better pointing resolution. Researchers participating in this proposal have already published results [5] on the ability of KM3NeT to detect neutrino signal above the horizon, but further studies and developments in data analysis are needed (using the techniques mentioned above and taking into account systematic effects due to the muonic background from EAS) in order to enlarge the KM3NeT potential to discover also neutrino sources at the northern hemisphere, contributing thus directly to the IceCube searches. The performance of such studies and developments are included to the main goals of the proposed research.

As it has been emphasized above, the high pointing resolution and the ability to estimate the energy of the detected muons offer the means to maximize the signal to background ratio and consequently to increase the potential of the telescope to discover astrophysical objects emitting neutrina. In principle, the direction and energy resolution depend on the accuracy in estimating the Cherenkov photons arrival time on the PMTs as well as on "counting" the photons illuminating the PMTs, i.e. they depend on information carried by the waveform of the PMT. It is thus necessary to simulate in details the performance of the digitization electronics, extract the timing and amplitude information from the digitized signals and evaluate the effect on the pointing and energy resolution. As an example, the KM3NeT TDR favours digitization electronics based on the "Time over Threshold" principle but simulation studies (from several groups of the KM3NeT consortium) indicate that a single threshold is not sufficient to provide information on the amplitude of the PMT pulses. This fact also obscures the accuracy in measuring the arrival time of the signal since the pulse amplitude is needed for timing corrections due to the slewing effects, which can reach up to several ns. Researchers participating in this proposal have demonstrated [9] the functional capabilities of digitization electronics based on the PMT-waveform comparison to several (up to 6) predefined thresholds (Multi Time Over Thresholds –MTOT). They have participated in the development (using the HPTDC ASIC of CERN) of prototypes, they have performed tests evaluating the prototype's functional performance and they have studied the use of these devices to digitize PMT signals produced in an underwater neutrino telescope. Their results show that, since the PMT's waveforms are not following a standard shape (due to the delayed photons) more than one threshold (at least 3) are needed for estimating the amplitude, the duration and the integral of the pulse. They have also demonstrated that the information carried by the waveform crossing the three thresholds is sufficient to correct for slewing effects whilst achieving a good resolution (as far as it concerns the muon energy measurement) in estimating the integral of the waveform (proportional to the number of photons illuminating the PMT). A new version of these electronics, which could also be used for other applications, based on a specific ASIC is foreseen to be developed in the framework of this research program. The functional characteristics of the new MTOT electronics must also be described in a detailed simulation and their effect on the pointing and energy resolution must be evaluated in comparison with other technological solutions.

Monte Carlo simulation offers an important tool to perform studies, optimize the experimental parameters and advance methods to estimate physical distributions from the experimental data. However, the simulation description of the neutrino telescope should be compared against experimental measurements and calibration procedures. Researchers participating in this proposal have demonstrated experimental techniques to evaluate the systematic [10] and statistical [11] errors in reconstructing the muon track parameters. As an example, they have demonstrated that the track reconstruction resolution can be measured by comparing the directions of segments of the same track, in real data and simulation. The resolution of this calibration technique depends obviously on the telescope layout as well as on the track parameters (direction and length) and more studies are needed for a complete development of this technique. On the other hand, any systematic effect on the pointing of the neutrino telescope can be accurately evaluated using floating arrays of EAS detectors, on top of the underwater infrastructure, by comparing the direction of an energetic muon (or a muon bundle) detected in the underwater telescope to the direction of an EAS that was detected at the same time by a surface array. Prototype arrays of EAS detectors (developed in the framework of the HELYCON[3] [12] project) have been used to validate the simulation results. In the above mentioned simulation studies each of the floating arrays was used as an autonomous calibration system, without combining information on an event-by-event basis. However several energetic showers are detected by more than one of the arrays even if several hundred meters separate them, providing a better chance to constrain (estimate?) the energy of the energetic muon reaching the underwater detector. Such an information could be used to cross check the energy estimation by the neutrino telescope. The potentiality of this calibration technique should be evaluated with simulation studies whilst the combined operation of several EAS arrays

[3] HELYCON– "HEllenic LYceum Cosmic Observatories Network" is a cosmic ray telescope which utilizes, arrays (stations) of scintillation counters to detect extensive air showers. The telescope, in full deployment, will consist of an extended network of detector stations, installed on roofs of Lyceum and University buildings in the areas of Patras, Thessaloniki, Chios island and Nicosia in Cyprus. The detectors of the telescope are constructed in the Physics Laboratory of the Hellenic Open University in collaboration with scientists from University of Patras, Aegean University, University of Cyprus, National Technical University of Athens, Aristotelian University of Thessaloniki and from the NCSR "DEMOKRITOS".

in the lab could offer the necessary information to trim the simulation description and develop reconstruction algorithms of energetic EAS. It has to be emphasized that, as IceCube observed galactic cosmic ray clusters in the southern hemisphere [13], a Mediterranean deep-sea neutrino telescope, with a much better pointing resolution, can study the directional distribution of energetic galactic cosmic rays in the northern hemisphere, compare with the clustering observed by MILAGRO[14] (especially around the gamma ray source Geminga) and revealing unknown structures in the galactic magnetic field or correlation with diffuse particles flows from nearby astrophysical objects. It is thus important to enhance the detection capabilities of the above described calibration system.

An improvement on the detection capabilities of the above-mentioned EAS arrays is expected by using the MTOT digitization electronics[4] that described previously. Furthermore, researchers participating in this proposal have a significant contribution [15] to the design and construction of micromega detectors. They have proposed the design and construction of large effective area (>0.5 $m^2$) micromegas detectors (MegaMicromegas) that can be “read-out” as a single channel to be used for efficient EAS detection, utilizing the very high sensitivity of micromegas. In parallel, a version of MTOT electronics (with 6 thresholds) could be used for the digitization of the MegaMicromegas signal. The design, construction, functional evaluation and operation of prototype MegaMicromegas with the new digitization system as well as the detailed description of their detection capabilities in simulation are required in order to evaluate the performance of EAS calibration arrays comprise such detectors.

The development of particle showers in the atmosphere (EAS) due to the excess of charge (radio-Cherenkov emission) and / or due to the influence of geo-magnetic-electric (geo-synchrotron radiation) field produces RF radiation. The intensity, polarity and timing of these waves carry information regarding the physical characteristics of the EAS and therefore the primary cosmic particle. In recent years, research activities [24] in Europe and USA aim to develop further this technique for the detection and study of energetic showers. As an example, the R & D that developed in the framework of the Pierre Auger Observatory aims to replace the shower detection technique by scintillation of the atmosphere’s molecules with the detection of radio waves [16]. Moreover, application of this technique is attempted to be used in IceTop [17], the large EAS array on top of the IceCube neutrino telescope. Two research teams participating in this proposal have already started simulation studies on the use of RF antennas in combination with HELYCON detectors, they have install the necessary instrumentation and they currently perform laboratory tests using antenna stations. The proposed research program also includes an R&D project dedicated to the operation of such RF systems in combination with particle counters to detect EAS and estimate the direction and energy of the primary cosmic particle. Laboratory tests and experiments will be used in parallel to simulation studies in order to evaluate the impact of such a detection system to the calibration of the deep-water neutrino telescope.

As it has been emphasized, a very good knowledge of the water optical properties (light absorption and scattering) and their seasonal variation are needed to estimate accurately the discovery potential of an underwater neutrino telescope layout. Although there exist several measurements form the Mediterranean pilot projects (NESTOR, NEMO ANTARES [4]) there is not enough experimental information for a detailed characterization of the water properties at the candidate deployment sites, especially regarding the Raleigh and particulate scattering. Special experiments should be run, for long time periods, at the deployment sites accumulating the necessary information. The design and the sensitivity evaluation of such experiments fall in the objectives of this proposal. As an example, researchers participating in this project have proposed to use the directionality and timing information offered by the 31 PMTs of one of the KM3Net Multi-PMT Optical Module that observes a short laser beam (operating in pulse mode, emitting <ns narrow light pulses) to accurately measure in situ the light scattering characteristics for a wide spectrum of wave lengths (by using several Laser of different wave lengths). Obviously, the realization of such an experiment exceeds the available resources of this project but the proposing collaboration possesses the available expertise and advanced simulation tools to complete the design, develop the data analysis strategies and demonstrate the sensitivity of such an experiment to estimate accurately all the relevant physical parameters from the data.

Contrary to the ice of Antarctica, the water in the Mediterranean Sea contains the radioactive $K^{40}$ isotope, which is a beta ray emitter. Electrons from the beta decays produce Cherenkov light in the vicinity of the photosensitive elements of the undersea neutrino telescopes. Measurements performed by the Mediterranean pilot neutrino projects (NESTOR, ANTARES, NEMO [3,4]) shown a constant optical background noise

[4] Notice that the first version of the MTOT electronics have been developed for the HELYCON detectors and afterwards have been studied as digitizers for the neutrino telescope.

rate of the order of 50kHz per 10" Optical Module. Such a noise does not affect seriously the track reconstruction capabilities of the detector since it is rejected during the filtering and pattern recognition phases of the neutrino telescope data processing. However, it precludes the possibility to use the neutrino telescope as a global counter of low energy neutrino bursts. Although IceCube has the potential to detect supernovae explosions through an observation of an instantaneously (within 10s) increased, spatially uncorrelated, counting rate of the majority of the photosensitive elements of the telescope, a large Mediterranean neutrino telescope does not offer the means for similar detection. On the other had, it has been estimated [18] that Supernova neutrinos can easily be detected by a spherical gaseous TPC detector measuring very low energy nuclear recoils. The expected rates are quite large for a neutron rich target since the neutrino nucleus neutral current interaction yields a coherent contribution of all neutrons (e.g. a typical supernova at 10 kpc, about 1000 events are expected using a spherical detector of radius 4 m with Xe gas at a pressure of 10 Atm). Prototypes of such spherical detectors have been built (in collaboration with researchers participating in this proposal) revealing an excellent energy resolution at low energies. In a recent publication [19], it has been shown that such a detector is able to achieve a very low energy threshold (25 eV) and an excellent energy resolution indicating that indeed such a counter can be used for neutrino detection via neutrino-nucleous elestic scattering. One such prototype is already operated by one of the teams participating in this proposal, as a sensitive neutron radioactivity monitor. The teams participating in this project, in near future, will install two more spherical TPC detectors whilst their operation as neutrino counters and the modelling of the operation of an extensive network of such TPCs for SuperNovae detection falls in the objectives of this proposal. In parallel, there are indications that the $K^{40}$ background in the underwater neutrino telescope could be rejected while retaining sufficient sensitivity in observing SuperNova neutrina by using the small PMTs of the same Multi-PMT OM in local coincidences or applying more sophisticated “causality” filters, on the PMTs contained by the same OM. As an example according to studies performed by researchers participating in this proposal, a coincidence, within 10 ns, between any two PMTs of the same OM reduces the $K^{40}$ background light (produced by Cherenkov emission due to electrons from the beta-decays in the vicinity of the OM) by a factor of more than 350 with respect to the single rates, whilst threefold local coincidences offer an extra rejection factor of 20. On the other hand muons produced by interaction of SuperNova neutrinos around the OMs of the telescope have longer tracks resulting to higher probability in observing multiple local coincidences on the same OM. However detailed simulation studies are needed to quantify the sensitivity of such a technique, which also fall in the objectives of the proposed research.

Often, experimental methods and instrumentation developed in research programs of fundamental Physics find applications in associated Sciences. As mentioned above, researchers participating in this project have operated a small prototype spherical TPC detector as a neutron counter and there are indications that can be used as sensitive U and Pu monitors via the neutrons emitted from spontaneous fission as well as monitors of relativistic atmospheric neutrons (via $Bi^{209}$ fission in the detector). The low energy threshold and the good energy resolution of these detectors indicate that may be used to detect neutrina from nuclear reactors or/and geoneutrina. The exploitation of the potential of these detectors to monitor natural and anthropogenic radioactivity in the environment also falls in the objectives of this proposal. Moreover, the research activities concerning the use of RF antennas with the HELYCON stations distributed over urban areas (for EAS detection) offers the possibility to monitor the non-ionizing electromagnetic, anthropogenic, background. Another significant spin-off application of this research, which also falls in the objectives of the proposed project, refers to the utilization of the EAS detection stations as a platform to develop educational programs for university students, educators, high school students and the general public (Scientific Outreach) contributing to the educational program supported by the HELYCON project (http://www.helycon.gr/HELYCON/HELYCON%40Education.html)

The objectives of the proposed research coincide with the highest priority research challenges in the field of Astroparticle Physics and especially with challenges concerning the deep underwater neutrino telescopy. The participating research teams possess the required knowledge, experience, software tools and experimental infrastructures to bring the proposed project to a successful completion contributing significantly to the instrumentation and methods of Astroparticle Physics. Specifically, a) The VLV Mediterranean Neutrino Telecope (KM3NeT) is the only one of the ESFRI large research infrastructures that Greece has expressed interest to host. The participants in this proposal have contributed very actively to the previous Design Study phases of the telescope. The proposed research comprise the performance of precise studies, the development of innovative experimental and data analysis techniques as well as the development of novel instrumentation. The results of this project will have an important impact to the final design and construction strategy of a Very Large Volume, High Sensitivity, Mediterranean Neutrino

Telecope. They will enhance the telescope's potential to discover, in the near future, phenomena that reveal answers to the open questions of Astroparticle Physics, opening up new horizons in the study of the Universe. Moreover, the success of the proposed project will add scientific value and it will strengthen the Hellenic nomination to host infrastructures of the telescope. b) The proposing scientific team has a strong contribution to R&Ds concerning Micromega detectors as well as to large spherical gaseous chambers. The development of large Micromega detectors (MegaMicromegas) and the development of gaseous detectors sensitive to low energy neutrina consist an entirely novel contribution to detector instrumentation. c) The radio detection of EAS is a new, promising field in Astroparticle experimental Physics. The operation of radio antennas and the long-term operation of HELYCON stations offer a test bench for further developments. d) The participants in this proposal have developed the principles of calibrating KM3NeT using floating EAS detectors and long muon tracks traversing the telescope. The completion of this design and the exploitation of physics possibilities offered by the floating EAS arrays consist a novel contribution to the underwater neutrino telescopy and to multi-messenger approach of Astroparticle Physics. e) The transfer of detector instrumentation to other scientific fields, such as the accurate measurement of environmental radioactivity, is a novel application of experimental techniques of Astroparticle Physics. Also the use of the distributed HELYCON facilities to monitor the ambient electromagnetic background is an important contribution to environment protection. Moreover, the use of research infrastructure as a test bench for the development of novel education programs (as an example see www.helycon.gr) is expected to offer new opportunities and open new horizons to educators and students. Finally the research tools (analysis and simulation methods, digitization electronics) that will be advanced in the framework of the proposed research project may find more general applications to several other scientific fields.

In conclusion, the proposed research program is expected to contribute considerably to the final design, construction, data analysis and calibration of the Very Large Volume, Sensitive Mediterranean Neutrino Telescope (KM3NeT). Furthermore, the main research goal is reinforced by other activities, which aim in the development and operation of other type of particle detectors. These detectors will be used to enlarge the discovery capabilities of the underwater neutrino infrastructure and as calibration arrays to provide the means of external calibration of the underwater neutrino telescope. However, the development of new particle detectors and detection techniques and the operation of a distributed EAS telescope utilizing state to the art detector technology, constitute by themselves significant contributions to the instrumentation and multi-messenger-methods of Astroparticle Physics. In parallel the proposed applications to other scientific fields will also contribute in the safeguarding of the environment and in novel educational developments.

## III. Methodology

The proposed project is organized in Research Activities (RA), which are factorized to Work Packages (WP) with well-defined research targets and deliverables. Work Packages and Research Activities constitute a united research program. As it has been argued in the previous Section, the optimization, of the neutrino telescope architecture and of the discovery strategies require the development of methods, simulation and data analysis tools as well as instrumentation that utilize the maximum of the experimental information in order to detect neutrina in a wide energy spectrum, from low energy SuperNova neutrina to high energy neutrina from galactic and extra galactic sources. Such tools and instruments will be advanced in the framework of the Research Activity A. The Research Activity A contains also WPs dedicated to the hardware development, simulation and studies concerning the spherical TPC counters and the detection of SuperNova explosions through a distributed network of such detectors. The Research Activity B comprises WPs dedicated to the development of simulation and data analysis tools as well as instrumentation (MegaMicromegas, RF antennas and digitization electronics) and experimental techniques concerning the detection of EAS. The results of the above RAs will be utilized in the WPs of the Research Activity C in order to perform precise studies concerning the optimization of the Mediterranean neutrino telescope architecture, to improve the digitization of the PMT waveforms, to advance discovery strategies and estimate the sensitivity of the neutrino telescope to observe extraterrestrial neutrina, to study the directional distribution of energetic galactic cosmic rays, to study construction strategies aiming at early discoveries. Also the Research Activity C includes the design of dedicated experiments in order to measure, in situ, the optical properties of the water (including their seasonal variation) at the deployment site(s) and especially the physical parameters describing the light scattering. Finally the WPs of the Research Activity D correspond to detector instrumentation transfer to associated Scientific Fields as well as to transfer scientific knowledge to education and to society, whilst the two last WPs concern the publicity and the management of the project respectively.

In the following we describe the concepts and objectives of the four main Research Activities whilst the research milestones are described in each work package (WP).

**Research Activity A:** ***Development of detector instrumentation, experimental techniques, simulation and data analysis software for the detection of neutrinos from cosmic sources***. Research teams participating in this proposal contributed significantly to the pilot project in underwater neutrino telescopy, NESTOR, and to the Design Studies of a VLV Mediterranean neutrino telescope in the framework of the KM3NeT international collaboration. They have developed the extensive software package HOURS[20] (HOU Reconstruction and Simulation) which is one of the three main software tools used by the KM3NeT collaboration. As argued in Section II the maximization of the telescope's discovery potential, requires methods and tools that utilize the whole of the experimental information offered by the detector. Such tools and analysis strategies will be integrated in the framework of HOURS, offering the means to perform precise optimization studies and analyze efficiently the experimental information.
Specifically this Research Activity aims at: a) The advance of software tools to simulate in detail (including all the relevant physical processes and the description of the electronic devises functionality) the response of a large underwater telescope to high energy neutrina, the response to low energy SuperNova neutrina as well as the response of the gaseous spherical TPC detectors to neutrina from SuperNova explosions. b) The advance of methods and software tools in order: to process the signals of the above detectors, to reconstruct muon tracks and energetic electromagnetic showers, to estimate the physical properties (direction and energy) of the neutrino, to calibrate and monitor the reconstruction resolution of the telescope and to extract physical information for the neutrino origin (e.g. location of point sources, diffuse fluxes, wimp annihilation in celestial objects etc) as well as to study the directional distribution of the galactic cosmic rays. c) The development of instrumentation relevant to these detectors.

**WP1:** Development and improvements of software packages concerning the detailed simulation of a large underwater neutrino telescope. Improvements and development of new tools within the simulation framework of the HOURS package so that it includes a wide spectrum of event generators and describes accurately the majority of phenomena that they distort the experimental information.

**WP2:** Development and improvement of data processing and selection techniques for large neutrino telescopes. Improvements of reconstruction algorithms, already included in HOURS, particularly with regard to the reconstruction of electromagnetic showers, reconstruction of the neutrino direction at the 1-10 TeV energy region, the accurate estimation of the statistical error matrices and the reconstruction of neutrino interaction topologies.

**WP3:** Simulation studies to develop and improve calibration methods, for a large underwater neutrino telescope, including techniques, which compare the response of different parts of the neutrino telescope, to the same long muon track, in order to estimate the detector resolution.

**WP4:** Development of digitization electronics (modification of the system described in WP9) to be used in recording the PMTs waveforms. Simulation studies[5] have shown that the digitization electronics developed for the HELYCON detectors can be used to record such waveforms. In this WP, the necessary modification to the WP9 electronics will be studied and the modified electronics performance will be evaluated with suitable data form lab tests and simulation studies.

**WP5:** Development of a detailed simulation software package in order to study the response of a large spherical gaseous detector to low energy neutrina, neutrons, alphas and Xrays. Development of signal-processing and analysis techniques. Study of the possibility to determine the neutrino direction.

**WP6:** Simulation study of the performance of an extended network of supernova detectors (as in WP5) in detecting/discovering a supernova explosion. Study of the sensitivity of such a network to neutrina from geological sources, reactors etc

**WP7:** Operation and improvements of a small scale (1m in diameter) spherical gaseous chamber, evaluation (in comparison with results from WP5) of its functional properties. Such a detector has recently started operation at the lab of the AUTH team, which will be used in parallel as a neutron monitor (WP21). Moreover two similar detectors are expected be constructed and installed at the HOU and DEMOKRITOS labs (the instrumentation and consumables are funded through a successful HOU proposal, to the local government of Western Greece, aiming in development of research infrastructures). The prime goal of this WP is the operation of these detectors at high pressure, achieving low detection threshold and high energy resolution.

**Research Activity B:** ***Development of detector instrumentation, experimental techniques, simulation and data analysis software for the detection of Extensive Air Showers. Operation of a network of HELYCON arrays.*** The synchronous detection of EAS by the neutrino telescope and floating detection arrays will be used for calibration purposes but also offers the possibility for novel instrumentation developments. This Activity aims in developing experimental infrastructure and advancing further methods to detect cosmic ray showers in the atmosphere (EAS). The participants in this proposal have already developed instrumentation, simulation and analysis software to detect EAS using the distributed detector-stations array HELYCON[11, 12]. This Research Activity targets in extending the detection methods of HELYCON by employing additional experimental techniques (e.g. the radio detection of EAS) and by developing new particle detectors (of 0.5 $m^2$ effective area) based on the very successful operation principle of the Micromega gaseous chambers. In parallel we will develop a new generation of the HELYCON scintillation counters digitization electronics and we will investigate the possibility (modification) of using them also for the readout of the large MicroMega (MegaMicromega) detectors. Finally the long-term operations of an extensive array of the existing HELYCON scintillation counters and of HELYCON stations equipped with radio and gaseous detectors will provide the experimental data to evaluate the performance of these instruments. In parallel, we will develop all the necessary simulation, data processing and analysis tools in order to support the design, to study the performance of this instrumentation and to improve the reconstruction efficiency and resolution of the detected EAS.

**WP8:** Long term operation of (at least) 18 HELYCON detectors (in 6 stations), data collection and reconstruction of EASs, in order to evaluate the long-term functionality of the system. The majority of the detectors will run with commercial electronics whilst at least 3 detectors will run with the electronics developed in WP9.

**WP9:** Design and development of the second-generation digitization electronics for the HELYCON detectors. This new version of electronics will utilize the "multi time over thresholds" (MTOT) strategy (as in the first version) but integrated in a specific ASIC. The prototypes will be tested and evaluated during the operation that is described in WP8.

**WP10:** Design and construction of large (~0.5 $m^2$) Micromega detectors, which will provide a single output signal corresponding to the global detector response. The performance of the prototypes will be evaluated in the lab and during long term runs integrated in HELYCON stations (WP16).

**WP11:** Development of a readout system for the large effective area MegaMicromega detectors. We will study the front-end modification of the WP9 electronics. The prototypes will be tested as in WP10

**WP12:** Development of simulation software to describe the operation of the large effective area Micromega detectors. Extension of the HOURS package to describe the performance of HELYCON arrays, which include MegaMicromega counters.

**WP13:** Extension of the HOURS EAS-reconstruction software to analyze data from an extended network of HELYCON stations, each consisting of scintillators and MegaMicromega detectors.

**WP14:** Development of simulation tools to describe the emission of radio waves during the development of extensive air showers inside the geomagnetic field. Development of simulation tools to describe the response of radio detectors operating in coincidence with HELYCON particle counters.

**WP15:** Development of reconstruction methods and software for analyzing data collected by HELYCON stations equipped with particle detectors and antennas. This work will utilize the HOURS simulation tools as well as tools developed in WP12, WP13 and WP14.

**WP16:** Combined operation of scintillation counters, MegaMicromega detectors and radio wave detectors in HELYCON stations (in several configurations) in order to evaluate their performance in detecting and reconstructing extensive air showers.

**Research Activity C:** ***Contribution to international research programs and R&D.***

This activity aims in utilizing the results achieved at Activities A and B to: i) the final design of the telescope architecture, the study of construction schemes, the calibration of the neutrino telescope as well as data analysis methods, which enhance the discovery potential of the KM3NeT and ii) the use of a network of large spherical TPCs for low energy neutrino detection in order to enlarge the energy window of the KM3NeT to supernova neutrinos and in parallel to provide the means to detect low energy neutrino fluxes from nuclear sources. Specifically, this Activity includes: a) the utilization of the tools (that will be advanced in Activity A) to perform a detailed simulation study for the final design of the Mediterranean Neutrino Telescope, evaluate the sensitivity in observing neutrino sources and map directional distribution of galactic cosmic rays, as well as to design experiments for measuring the optical properties of the water at the deployment sites, b) the utilization of tools and instrumentations (that will be advanced in Activity B) for the final design of a floating EAS system for the KM3NeT calibration and physics studies and c) the utilization of the results of Activity A to contribute to the design, construction and operation of a large low energy, gaseous neutrino detector.

**WP17:** Optimization of the KM3NeT layout (as a single VLV Neutrino Telescope or as network of two (or three) nodes of underwater infrastructures comprise strings or towers) and of the analysis strategies in order to maximize the discovery potential of the telescope and to enhance its sensitivity in studying the directional distribution of galactic cosmic rays, as described in Section II. Study construction strategies of the telescope that maximize the chance for early discoveries. Simulation studies for the design of an experiment for measuring the water optical properties at the deployment sites.

**WP18:** Final design of the calibration infrastructure using EASs and muon tracks traversing the telescope. We will continue our simulation studies in order to evaluate the performance of floating arrays consisted of MegaMicromega detectors as well as radio detection antennas. We will investigate the possibility of long-term operation of such floating arrays and we will study their physics potential.
**WP19:** Operation of two large HELYCON arrays (including MegaMicromega detectors) close to each other (in order to respond to the same EAS). This experimental set-up will offer the experimental information to cross check the results of our simulation studies (WP18).
**WP20:** Contribution to the development, construction and operation of a large spherical gaseous detector, participating to the R&D for a Dedicated Supernova Detector System (Saclay, Saragosa, AUTH, APC-Paris 7, Ioannina, Sheffield, Demokritos, HOU, INFN Torino). We will use the simulation and analysis tools that will be developed in WP5, WP6 and the instrumentation described in WP7

**Research Activity D:** ***Applications of the Astroparticle Physics instrumentation in environmental measurements, in education and outreach.*** This activity aims in applying the instrumentation and the methods that will be developed in this research to monitor environmental radioactivity and non ionizing radiation as well as in using the HELYCON stations network as a channel to transfer new knowledge and technology to education.
**WP21:** Operation of the WP7 prototype of a spherical gaseous chamber as a neutron, alpha and Xrays detector, evaluating the functional characteristics at different gas pressures, high voltages and for several gas fillings. Evaluation of the sensitivity to detect weak neutron fluxes and the energy resolution in detecting neutrons, alphas and low energy X rays.
**WP22:** Long term operation of three antenna sets in order to monitor the intensity of the ambient electromagnetic noise. Continuous data transmission (through internet) to a central station. Study of the possibility to use the HELYCON network in order to monitor the level of non-ionizing electromagnetic radiation in urban areas.
**WP23:** Development of educational programs, utilizing the HELYCON infrastructure, for training physics teachers in modern Physics and new technologies. Development of educational programs for high school students, aiming in knowledge transfer to the secondary education. Development of laboratory courses for physics students with the possibility to use the HELYCON instrumentation remotely.
**WP24:** Publicity. The results of the proposed research will be published in international scientific journals and conference proceedings, whilst the software tools that will be developed will be available to the community. We expect that the WPs will contribute to scientific publications as follows:
Publication(s) in scientific journal concerning novel simulation and analysis methods (WP1,WP2,WP12,WP13,WP14,WP15)
Publication(s) in scientific journal concerning the design, construction and evaluation of prototype digitization electronics (WP4,WP9, WP11)
Publication(s) in scientific journal concerning the performance of large-spherical-gaseous detectors. Simulation-study of the capabilities of a network of such detectors. WP5,WP6, WP7, WP20, WP21)
Publication(s) in scientific journal concerning the long-term operation of several HELYCON stations, evaluation of the network performance. (WP8, WP13, WP14, WP15, WP16, WP19)
Publication(s) in scientific journal concerning the design and construction of prototypes of large-MicroMega detectors. Evaluation of capabilities. (WP10,WP12, WP16, WP19)
Publication(s) in scientific journal concerning the operation of HELYCON counters with radio antennas. Evaluation of the capabilities. (WP14,WP15, WP22)
Publication(s) in scientific journal concerning the expected sensitivity of an optimized KM3NeT neutrino telescope. Development of construction strategy and design of dedicated experiments. (WP17)
Publication(s) in scientific journal concerning the to design and efficiency of an external calibration system (including RF antennas and gaseous detectors) for the KM3NeT and the long-term operation of calibration arrays (WP18,WP13,WP15,WP16, WP19)
In parallel, the participants will organize a two-day workshop that will include lectures to graduate students, and educators and parallel outreach activities concerning the new developments in Astroparticle Physics. It must be also emphasized that the wide research area spanned by this proposal offers significant possibilities for training young scientists in phenomenological studies, simulation methods, data processing and analysis, detector development, design of readout electronics and experimental methods. The proposed activity of using the research infrastructures to develop training and education provides a channel of transferring new knowledge and technology to education.
**WP25:** This work package concerns the management of the project. The consortium appoints Professor S. E. Tzamarias as Project Coordinator (PC). The PC has the overall supervision of the Activities, chairs the project committees, represents the consortium and he is responsible for the compliance of all documents

relating to the project. The project will be monitored by the Project Management Board (PMB) which comprises the coordinators of each participating research group. For every Action would set an Action Manager (AC). All of ACs constitute the Project Execution Board (PEB). The PEB is responsible for the monitoring of the workpackages progress. Ensuring quality of deliverables will be done through a cycle of internal evaluations, reviews and final approvals. The PEB will appoint two internal referees for each of the workpackages deliverables (technical report, contribution to international conference or publication to an international journal) whilst the final approval is responsibility of PMB .

## IV. Contribution of the Main Team Members and of the External Collaborators to the Proposed Research

The participating research teams will contribute to the work-packages as follows: a) **HOU team**: to the majority of the work-packages (except WP21, WP22), b) **DEMOKRITOS team**: to the work-packages 4-11, 16-21, 23-25, c) **AUTH team**: to the work-packages 5-9, 17-21, 23-25, d) **ATHENS team**: to the workpackages 3, 5-8, 10, 12, 16-20, 23-25, e) **AEGEAN team**: to the work-packages 4, 8-9, 12-19, 22-25. The applicants (and their external collaborators) possess the require knowledge, expertise in experimental Particle and Astroparticle Physics and technological know-how to accomplished the goals of the proposed research. Specifically, the participating teams carry many years of experience in the following fields: 1) **(HOU)** simulation, data analysis, readout electronics, detector design and operation (NESTOR, KM3NeT) as well as experimental techniques for particle and astroparticle physics (neutrino telescopy, EAS), 2) **(DEMOKRITOS)** phenomenological description of physical phenomena, gaseous detectors (MicroMega detectors), readout electronics as well as experimental techniques for particle and astroparticle physics (neutrino telescopy, axion telescopy), 3) **(AUTH)** gaseous detectors (spherical chambers) and dosemetry, large detector design and construction (ATLAS muon spectrometer), data analysis and experimental techniques for particle and astroparticle physics (γ-ray, axion telescopy), 4) **(ATHENS)** design and construction of electronic systems, simulation and data analysis, detector physics as well as experimental techniques. for particle and astroparticle physics (neutrino telescopy, EAS), 5) **(AEGEAN)** simulation and data analysis, electronic design, detector operation (EAS radio detection) as well as experimental techniques in particle and astroparticle physics (neutrino telescopy, EAS)

In the HOU team participate two researchers engaged by another host institution, namely Dr. E. P. Christopoulou (Lecturer at the Physics Department of Univ. of Patras) and Prof. A. Birbas (Department of Electrical Enginnering and Computer Technology, Univ. of Patras).

Dr Christopoulou is an Astrophysicist who collaborates with the HOU team for many years, participates to the KM3NeT Design Study through the HOU team and has contributed significantly to the development of the HELYCON detectors. She is an expert in the construction, operation and signal processing of the HELYCON scintillation counters and she will contribute in all the WPs of the Research Activity B as well as to studies concerning the discovery potential of the KM3NeT to extragalactic neutrina (especially neutrina emitted from Active Galactic Nuclei).

Professor A. Birbas is an expert in Microelectronics and especially in the field of analogue integrated circuits and Microsystems. He has a lot of experience in industrial applications and he will contribute significantly in the instrumentation developments foreseen in this project and especially to the design and construction of the MTOT digitization electronics.

The invited researcher, Prof. P. Razis, is a professor of the Physics Department of Cyprus University and a member of the international Km3NeT consortium. He has a lot of experience in Experimental Particle and Astroparticle Physics (instrumentation and data analysis). Prof. P. Razis and his research team have a high experience in monitoring the ambient electromagnetic radiation and RF noise filtering. His contribution will be very valuable to all the activities of this project and especially to the radio detection of EAS and its applications.

In the AEGEAN team participates also Dr. K. Zachariadou who is engaged in the Technological Institute of Piraeus as an Assistant Professor. Dr. Zachariadou is an Experimental Particle Physicist with a significant experience in data analysis and in data acquisition systems, collaborating since many years with the AEGEAN teams on dta analysis and hardware developments. She will contribute significantly to data selection algorithms and triggers as well as to the simulation and data analysis of RF signals from EAS.

Dr. Papageorgiou, who participated as an external collaboration since the first phase of this proposal, has been appointed as Associated Professor in the Aegean University strengthening further the AEGEAN participation in this project.

The fraction of the main members research effort devoted to the proposed project is shown in the following Table.

| Applicants (main team members) Research Effort Devoted to the Proposed Project | | | | | |
|---|---|---|---|---|---|
| S. Tzamarias | 80% | E. Savvidis | 60% | D. Samsonidis | 30% |
| A. Leisos | 80% | Ch. Petridou | 30% | N. Giokaris | 30% |
| N. Gizani | 70% | Ch. Eleftheriadis | 20% | A. Manousakis-Katsikakis | 50% |
| E. P. Christopoulou | 60% | A. Liolios | 30% | I. Gialas | 50% |
| A. Birbas | 30% | C. Papadopoulos | 50% | K. Zachariadou | 50% |
| G. Fanourakis | 60% | | | P. Razis | 30% |

In the proposed project will also participate four, full time, PhD students, two full time PhD Researchers (Postdocs) and two full time Engineers, who will be funded from the project. One of the PhD Researchers will be Dr. Apostolos Tsirigots. Dr Tsirigotis has significant experience in instrumentation and in experimental methods of Astroparticle Physics (neutrino and cosmic rays telescopy). He has contributed significantly to the NESTOR pilot project and to the KM3NeT Design Studies. He is the main developer of the software package HOURS used for the design of KM3NeT. His contribution will be very valuable in most work packages

The external collaborators participating in the proposed project are scientists with high expertise and significant contribution to Particle and Astroparticle Physics. Several of them are already collaborating with the main teams and their involvement to the research activities will help to the accomplishment of the objectives. Specifically:
Prof. J. Vergados (Emeritus Professor, Univ. of Ioannina): He is a Theoretical Physicist with very important contribution to Nuclear, Particle and Astroparticle Physics. He is one of the initiators of the idea to utilize coherent neutrino nucleus scattering in a gaseous chamber in order to detect very low energy neutrina. He will provide significant help to this research effort, especially regarding to the design of a detector network for SN observation, the detection of low energy neutrina fluxes (e.g. fluxes from reactors or geoneutrina fluxes) and to studies aiming to utilize this TPC instrumentation for dark matter searches.
Prof. I. Giomataris (Director of Research, SACLAY): He is, internationally, well known for his significant contribution to the development of novel particle detectors. He and G. Charpak introduced the Micromega gaseous detectors and he is one of the initiators of the large spherical TPC detectors. He will provide valuable help to the most of the instrumentation R&D's of this project.
Prof. Jean_Pierre Ernenwein (Professor, Aix-Marseille II): He is one of the senior scientists of the ANTARES neutrino program. He contributed significantly to the KM3NeT Design Studies and collaborated with HOU for the design and construction of an EAS calibration system for ANTARES. He will provide valuable help to studies concerning the optimization of the KM3NeT.
Dr. Colas Riviere (Researcher, Aix-Marseille II): He is an active member of the ANTARES team contributing to the data analysis and the construction of the ANTARES floating calibration system. He will offer valuable help to the development of reconstruction algorithms and to searches for point-like neutrino sources.
Sarod Yatawatta (MSc, Engineer of ASTRON-LOFAR): He is an experienced engineer in instrumentation applications in radio-astronomy. He will offer valuable help on technical issues concerning the radio-detection of showers and the monitoring of the ambient non-ionizing electromagnetic radiation.
Ch. Nicolaou (Engineer, Univ. of Cyprous) and Dr. J. Moussa (Researcher, Univ. of Cyprous): Members of Prof. Razis's research group that develop a system of measuring the RF distribution in urban areas. They will contribute to the use of the HELYCON RF system for environmental measurements.
Dr. G. Bourlis (Researcher, HOU): He is an experienced researcher in detector instrumentation, digitization electronics and detection of EAS with distributed scintillation arrays. His help will be very valuable in solving technological problems in several of WPs of this project.
Dr. V. Giakoumopoulou (Researcher, ATHENS): She is a very experienced researcher in Particle Physics, especially in data analysis. She will offer significant help to the simulations of physical processes.
D. Iliadis (AUTH-HOU), M. Zioga(ATHENS), E. Anastasiou(AUTH), I. Katsioulas(AUTH):Doctoral students with experience in data analysis, simulation and hardware constructions. They are expected to help in software development as well as to the operation of detectors and data accumulation..
Prof. S. Pnevmaticos (Univ. of Patras, Director of the Hestia of Science), Dr. E. Pierri (Supervizor of the High School Education of Achaia District), Dr. K. Siori (Educational Consultant of the Peloponnese High Schools), Mr G. Zisimopoulos (MSc, Director of High School Laboratory Center in Achaia District): This is a team of educators, with high expertise to Science Education and technological applications to secondary education. They will offer significant help to use the research infrastructure of HELYCON as a platform to transfer new knowledge to education.

The main team members participating in this proposal are currently active in research projects of Particle and Astroparticle Physics. The HOU team is a very active member of the KM3NeT collaboration and (as mentioned already) has contributed significantly to the KM3NeT Design Study. Currently is contributing to the collaboration effort with simulation and analysis tools as well as with physics studies aiming to strengthen the "physics case" of the project. In parallel the HOU group, in collaboration with other Greek teams, has developed instrumentation for the HELYCON project that provides the test bench for new detector R&Ds. As an example, the development of the digitization electronics proposed in this project is a spin off of the HELYCON R&D, whilst HELYCON detectors are supporting the operation of RF antennas in the Univ. of Aegean, which will be used in the proposed project for advancing shower's radio-detection. Recently, the HOU team succeeded to be funded by the local government of Western Greece, in order to enlarge the research facilities of the Physics Laboratory. The new research facilities comprise a very large computer system (to be part of the HELLAS GRID), hardware infrastructure for the construction and operation of gaseous detectors (including two, large spherical TPCs), digitization and data acquisition electronic systems as well as other specialized electronic units, RF antennas and the corresponding data acquisition electronics. This new computing and hardware infrastructure will support the proposed research. Moreover the AEGEAN team has a long collaboration record with HOU (as an example, they collaborated to develop a KM3NeT calibration system based on the detection of EAS). The AEGEAN team has already (as mentioned above) installed HELYCON detectors and an RF detection system, through a succesfull proposal to the INTEREG program, that recently started operation whilst work is in progress to diminish electronic noise. In parallel the AEGEAN team has secured funds from their local government to support the production of digitization electronics, which will be designed in this project, as well as to enlarge the EAS infrastructure in Chios. The DEMOKRITOS team is an active member of several international R&Ds concerning micromega and migromega-TPC chambers. They are also contributing actively to the design, construction and operation of gaseous detection systems used by Particle and Astroparticle Physics projects (e.g. for the CAST experiment at CERN). The DEMOKRITOS gaseous detector lab is equipped with the required facilities for the design, operation and evaluation of the proposed MegaMicromegas detectors as well as for the proposed large spherical TPCs. In parallel DEMOKRITOS runs an important research program on High Energy Physics Phenomenology, which would offer significant help to the phenomenological needs of the proposed research (e.g. concerning hadronic interaction at VHEs). Currently the AUTH team runs an R&D program, in collaboration with SACLAY, aiming to the development of very sensitive, very large spherical, high-pressured TPCs. The corresponding R&D activity of this proposed research program will be part of the above mentioned international effort, sharing the load of hardware tests and developments that are required to establish high sensitivity in neutrino detection and also contributing with the simulation and analysis tools and with the design of a network for SuperNova detection. Researchers of AUTH who are also active members of the Cherenkov Telescope Array collaboration (CTA) will contribute with their expertise, on high-energy gamma ray telescopy. In parallel, members of the AUTH team are also very active at LHC, to detector physics as well as to physics analysis, and especially to searches for new physics that can explain the nature of dark matter. Finally, the ATHENS team is also very active in CDF at TeVatron and in ATLAS at LHC contributing with novel analysis techniques and searches for new physics. Moreover, they have a significant contribution in detector instrumentation including gaseous particle chambers and photosensitive detectors.

The proposed project is part of the international effort in high-energy neutrino telescopy and in research and developments for low energy neutrina detection, having well defined objectives and methods. As it is emphasized in the previous Sections, the main goals of the proposed research are a) to provide precise results and evaluation regarding an optimal KM3NeT architecture (especially on the issues left by the FP6-KM3NeT Design Study to be resolved by further studies), b) to develop or/and optimize instrumentation, methods, software tools, construction strategies and data analysis, targeting to an efficient operation of a Mediterranean Neutrino Telescope and c) to develop novel particle detector instrumentation with spin-off applications to environmental science as well as to contribute to high quality education. The expected results of this project will be original, important contributions to Neutrino Astroparticle Physics and Detector Instrumentation. The requested funding through this proposal does not cover research activities that are already funded or will be funded by other National or European resources, with the exception of a minor funding (11,000 euro for the period 2008-2012) that has been made available to HOU by European resources for contributing to the FP7 KM3NeT Preparatory Phase.

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