FUNDING APPLICATION FOR
EXPLORATORY RESEARCH PROJECTS - PN-II-ID-PCE-2011-3
Section 3

Exotic super-massive particles in Neutrino Telescopes

Project leader: Dr. V. Popa (CS1)

Project team: Dr. L.A. Popa (CS1), G.E. Pavalas (CS3), M. Rujoiu (CS3)

Institute for Space Sciences

B. Project leader

B1. Scientific visibility and prestige (maximum 2 pages)

B.1.1. *Main research results*

The project leader. Dr Vlad Popa (VP) joined the astroparticle community after obtaining the PhD degree at the University of Bucharest, 1993. His thesis dealt with multiquark states produced in hadronic interactions [1-3]. VP started a long lasting collaboration with the Bologna Section of INFN (Istituto Nazionale di Fisica Nucleare) and with the Bologna University, initially in the frame of the MACRO (Monopole, Astrophysics and Cosmic Ray Observatory) at Gran Sasso, Italy [4]. He contributed to the construction and calibrations (experiment EMU-18 at CERN-SPS [5]) of the track etch sub-detector of MACRO. As a byproduct, relativistic lead fragmentation cross sections were measured [6]. After the completion of the detector, VP activated mostly in the MACRO Rare Particle Group, that he coordinated between 1998 and 2000. VP studied the interactions of magnetic monopoles (MM) and Q-balls in the MACRO detectors and in the Earth [7, 8], and introduced the search for nuclearites in the MACRO scientific program. MACRO produced the lowest (yet) flux limits for GUT MMs [9] and nuclearites in the penetrating cosmic rays (CR) [10]. MACRO measured (simultaneously with Super-K) the parameters of atmospheric neutrino oscillations [11, 12], a first breakthrough behind the Standard Model. VP extended the MACRO neutrino oscillation analysis searching for Lorenz invariance violating mechanisms [13]. VP organized and led a number of small experiments looking for possible neutrino radiative decays during total solar eclipses: in Romania (1999), Zambia (2002) and Libya (2006). A complete model of such an experiment was published in Ref. [14]. The 2006 experiment yielded to the best lower lifetime limits obtainable with this technique [15, 16]. The experience gained with the MACRO track etch sub-detector allowed VP to be among the proposers of the SLIM (Search for Light Monopoles) experiment. SLIM was deployed at the Chacaltaya CR Lab. (Bolivia) and a smaller part on the K2 massif, Pakistan. Due to the high altitude, SLIM allowed the search for exotic particles at lower masses than MACRO [17, 18]. In 2001 VP joined the ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch) Collaboration, focusing on the search for massive exotic particles [19]. Presently, ANTARES is fully operational on the bottom of the Mediterranean Sea, and various analyses start reporting important results. After its return to ISS, VP successfully applied in on behalf of the Institute for full membership in ANTARES (September 2006). The active contribution of the Romanian ANTARES group, lead by VP, made possible the ISS access in the KM3NeT Collaboration, in May 2007. KM3NeT will be a multi-cubic kilometer neutrino telescope, to be deployed in the Mediterranean Sea starting 2013 [20, 21]. VP is one of the proposers of the MoEDAL experiment at CERN – LHC, based on the MACRO and SLIM track etch detectors experience. MoEDAL, to be deployed in the next winter, will look for exotic particles produced in pp interactions at the LHC energies [22]. VP was the director of the ROCOSMICS project (PN2) that prepared the deployment in Romanian high schools of a network of educational CR detectors [23]. One such prototype, operated at ISS, is included in a pilot European network [24].

B.1.2. *The visibility of the scientific contributions.*

Invited talks to international conferences:

- V. Popa, *Ricerca di Monopoli Magnetici Supermassivi al Gran Sasso*, LXXXII Congresso Nazionale SIF, Verona, 23-28 Settembre 1996 (Relazione su invito)
- V. Popa, , *Search for Neutrino Decay during the 199 Solar Eclipse*, 8 UN/ESA Workshop on Basic Space Science: Sientific exploration from Space, Mafraq, Jordan, March 1999 [25]
- V. Popa, *Search for Magnetic Monopoles and Nuclearites with the MACRO Detector*, 8 UN/ESA Workshop on Basic Space Science: Scientifc exploration from Space, Mafraq, Jordan, March 1999 [26]
- V. Popa, *Some results from the NOTTE experiment*, 9 UN/ESA Workshop on Basic Space Science, Toulouse, June 2000
- V. Popa, *Limits on radiative decays of solar neutrinos from measurements during a total eclipse*, X UN/ESA Workshop on Basic Space Science Reduit, Mauritius, June 2001 [27]
- V. Popa, *KM3NeT: Present status and potentiality for the search for exotic particles* 2 Roma Int. Conf. on Astroparticle Physics (RICAP), Frascati 2009 (invited lecture) [28]
- V. Popa, *KM3NeT: The Birth of a Giant*, Exotic Nuclei And Nuclear/Particle Astrophysics (III): From Nuclei To Stars 20 Jun - 3 Jul 2010, Sinaia, Romania, 2010 (invited lecture) [29]

Membership in collaboration leading bodies:

- ANTARES Institute Board
- KM3NeT General Assembly (FP6) and Strategic Board (FP7)
- Physics coordinator of the MoEDAL Collaboration

Lections on astroparticle physics for Master and PhD students, Bologna University, academic year 2005-2006

International referee for the National Science Fund of Bulgaria (2009, 2010).

External PhD referee for the Oujda University, Morocco, and COMSATS, Islamabad, Pakistan.

Referee for *Astroparticle Physics* and *Romanian Reports in Physics*.

B2. Curriculum vitae *(max. 4 pages)*

a) Education, degrees and diplomas:

1976 - 1980, University of Bucharest, Romania - undergraduate student.

1980, Diplomat Physicist, University of Bucharest, Romania. Diploma Thesis on an original model for hadron-nucleus interactions at intermediate and high energies.

1980 - 1981, University of Bucharest, Romania - graduate student;

1981, MSc in Nuclear Physics, University of Bucharest, Romania. Specialization Thesis on the derivation of the geometric characteristics of hadronic distribution inside nuclei from hadron-nucleus cross section data.

1989 - 1993, University of Bucharest, Romania - PhD Stage. Adviser: Prof. Clin Beliu, Subject: The production of exotic multi-quark states in relativistic nuclear reactions.

1993, PhD in Physics, High Energy and Nuclear Physics Dept., University of Bucharest, Romania.

b) Professional experience, former employers:

1981 - 1983: physics teacher, Industrial High School No. 1, Mangalia, Romania

1983 - 1986: research assistant, Institute for Space Sciences Bucharest, Romania (I.S.S.)

1986 - 1995: researcher, Institute for Space Sciences, Bucharest, Romania

1995 - 1999: 3 senior researcher, Institute for Space Sciences, Bucharest, Romania

1999 - May 2001: 2 senior researcher, Institute for Space Sciences, Bucharest, Romania

From May 2001: 1 senior researcher, Institute for Space Sciences, Bucharest, Romania.

From January 2002: scientific secretary of I.S.S.

December 2002 - December 2004 researcher at INFN - Bologna (art. 23 - temporary assignment).

February 2005 - February 2006: *Primo ricercatore* at INFN - Bologna (art. 23 - temporary assignment).

April 2006 - May 2006: Invited professor at the *Facoltà di Scienze Matematiche, Fisiche e Naturali, Università degli Studi di Bologna*.

From June 2006: Scientific secretary, Institute for Space Sciences, Bucharest, Romania

International projects won as project director:

-„NOTTE", NATO-CN.SUPPL 974683 (1998)

-„ NOTTE-1", NATO-PST.CLG977691 (2001)

- "Experimental and phenomenological contributions to astroparticle physics", poz. 17 in The Scientific and Technological Cooperation Agreement betweem Italy and Romania

Director of 2 ORIZONT2000 projects and 1 PN2 project (ROCOSMICS, Contract 91070)

c) List of (most recent) publications

1. Aguilar JA, Al Samarai I, Albert A, ..., V. Popa et al., A fast algorithm for muon track reconstruction and its application to the ANTARES neutrino telescope, Astropart. Phys. **34**, 652-662 (2011)

2. Popa V., KM3NeT: Present status and potentiality for the search for exotic particles, Nucl. Instr. and Meths. in Phys. Res. A **630**, 125-130 (2011)

3. Aguilar JA, Al Samarai I, Albert A, ..., V. Popa et al., Time calibration of the ANTARES neutrino telescope, Astropart. Phys. **34**, 539-549 (2011)

4. Aguilar JA, Al Samarai I, Albert A, ..., V. Popa et al., Search for a diffuse flux of high-energy nu(mu) with the ANTARES neutrino telescope, Phys, Lett. B **696**, 16-22 (2011)

5. Aguilar JA, Al Samarai I, Albert A, ..., V. Popa et al., AMADEUS-The acoustic neutrino detection test system of the ANTARES deep-sea neutrino telescope, Nucl. Instr. and Meths. in Phys. Res. A **626** 128-143 (2011)

6. Cecchini S, Centomo D, Giacomelli G, ..., V. Popa et al., New lower limits on the lifetime of heavy neutrino radiative decay, Astropart. Phys. **34**, 486-492 (2011)

7. Popa V., KM3NeT-The Birth Of Giant, AIP Conference Proceedings **1304**, 291-299 (2010)

8. Aguilar JA, Al Samarai I, Albert A, ..., V. Popa et al., Performance of the front-end electronics of the ANTARES neutrino telescope, Nucl. Instr. and Meths. in Phys. Res. A **622**, 59-73 (2010)

9. Aguilar JA, Al Samarai I, Albert A, ..., V. Popa et al., Zenith distribution and flux of atmospheric muons measured with the 5-line ANTARES detector, Astropart. Phys. **34**, 179-194 (2010)

10. Aguilar JA, Al Samarai I, Albert A, ..., V. Popa et al., Measurement of the atmospheric muon flux with a 4 GeV threshold in the ANTARES neutrino telescope, Astropart. Phys. **33**, 86-90 (2010)

11. Aguilar JA, Al Samarai I, Albert A, ..., V. Popa et al., Performance of the first ANTARES detector line, Astropart. Phys. **31**, 277-283 (2009)

12. Cecchini S, Cozzi M, Ferdinando D, ..., V. Popa et al., Results of the search for strange quark matter and Q-balls with the SLIM experiment, European Phys. J. C **57**, 525-533 (2008)

13. Cecchini S, Chiarusi T, Giacomelli G, ..., V. Popa et al., Fragmentation cross sections of Fe26+, Si14+ and C6+ ions of 0.3-10 A GeV on polyethylene, CR39 and aluminum targets, Nucl. Phys. A **807**, 206-213 (2008)

14. Balestra S, Cecchini S, Cozzi M, ..., V. Popa et al., Magnetic monopole search at high altitude with the SLIM experiment, European Phys. J. C **55**, 57-63 (2008)

15. G.E. Pavalas, V. Popa, Nuclearite detection with the ANTARES neutrino telescope, AIP Conf. Proc, **972**, 511-515 (2008)\

16. Ageron M, Aguilar JA, Albert A, ..., V. Popa et al., Studies of a full-scale mechanical prototype line for the ANTARES neutrino telescope and tests of a prototype instrument for deep-sea acoustic measurements, Nucl. Instr. and Meths, in Phys. Res. A **581**, 695-708 (2007)\

17. Ageron M, Aguilar JA, Albert A, ..., V. Popa et al., The ANTARES optical beacon system, Nucl. Instr. and Meths, in Phys. Res. A **578**, 498-509 (2007)

18. Balestra S, Cozzi M, Giacomelli G,..., V. Popa et al., Bulk etch rate measurements and calibrations of plastic nuclear track detectors, Nucl. Instr. and Meths, in Phys. Res. B **254**, 254-258 (2007)

19. Aguilar JA, Albert A, Ameli F, ..., V. Popa et al., The data acquisition system for the ANTARES neutrino telescope, Nucl. Instr. and Meths, in Phys. Res. A **570**, 107-116 (2007)

20. Aguilar JA, Albert A, Ameli F, ..., V. Popa et al., First results of the instrumentation line for the deep-sea ANTARES neutrino telescope, Astropart. Phys. **26**, 314-324 (2006)

21. Popa V., Very large volume neutrino telescopes as magnetic monopole and nuclearite detectors, Nucl. Instr. and Meths, in Phys. Res. A **567**, 480-482 (2006)

22. Balestra S, Cecchini S, Giacomelli G, ..., V. Popa et al., Search for nuclearites with the SLIM detector, Czechoslovak J. Phys. **58**, A221-A230 (2006)

23. JA, Albert A, Ameli F, ..., V. Popa et al., Study of large hemispherical photomultiplier tubes for the ANTARES neutrino telescope, Nucl. Instr. and Meths, in Phys. Res. A **555**, 132-141 (2005)

24. Battistoni G, Becherini Y, Cecchini S, et al., Search for a Lorentz invariance violation contribution in atmospheric neutrino oscillations using MACRO data, Phys. Lett. B **615**, 14-19 (2005)

25. Popa V., Search fo, r neutrino radiative decays during the 2001 total solar eclipse, Nucl. Phys. B (Proc Suppl.) **143**, 512-512 (2005)

26. Becherini Y, Ceechini S, Chiarusi T, ..., V. Popa et al., Time correlations of high energy muons in an underground detector, Astropart. Phys **23**, 131-155 (2005)

27. Aguilar JA, Albert A, Amram P, ..., V. Popa et al., Transmission of light in deep sea water at the site of the ANTARES neutrino telescope, Astropart. Phys. **23**, 265-272 (2004)

28. Ambrosio M, Antolini R, Baldini A, ..., V. Popa et al., Search for stellar gravitational collapses with the MACRO detector, European Phys. J. C **37**, 265-272 (2004)

29. Ambrosio M, Antolini R, Bakari D, ..., V. Popa et al., Measurements of atmospheric muon neutrino oscillations, global analysis of the data collected with MACRO detector, European Phys. J. C **36**, 323-339 (2004)

30. Aglietta M, Alessandro B, Antonioli P, ..., V. Popa et al., The cosmic ray proton, helium and CNO fluxes in the 100 TeV energy region from TeV muons and EAS atmospheric Cherenkov light observations of MACRO and EAS-TOP, Astropart. Phys. **21**, 223-240 (2004)

31. Cecchini S, Centomo D, Giacomelli G, ..., V. Popa et al., Search for possible neutrino radiative decays during the 2001 total solar eclipse, Astropart. Phys. **21**, 183-134 (2004)

32. Cecchini S, Centomo D, Giacomelli G, ..., V. Popa et al., Monte Carlo simulation of an experiment looking for radiative solar neutrino decays, Astropart. Phys. **21**, 35-43 (2004)

The complete list of publications (from which **94** listed on the Web of Science) may be found at http://www.spacescience.ro/~vpopa/vlist.pdf

d) Hirsch index and the total number of citations, according to Web of Science

Hirsch index = 25, total number of citations = 2293, number of citations excluding auto-citations = 1252

e) The address of the researcherid.com profile: **C-3470-2011**

B3. Scientific contributions from the period 2001-2011

Articles (10 most cited):

1, Ambrosio M, Antolini R, Auriemma G, ..., V. Pops et al., Matter effects in upward-going muons and sterile neutrino oscillations, Phys. Lett. B **517**, 59-66 (2001), 185 citations

Abstract: The angular distribution of upward-going muons produced by atmospheric neutrinos in the rock below the MACRO detector show anomalies in good agreement with two flavor neutrino-mu ==> neutrino-tau oscillations with maximum mixing and Delta m**2 around 0.0024 eV**2. Exploiting the dependence of magnitude of the matter effect on oscillation channel, and using a set of 809 upward-going muons observed in MACRO, we show that the two flavor neutrino-mu ==> neutrino-sterile oscillation is disfavored with 99% C.L. with respect to neutrino-mu ==> neutrino-tau.

2. Ambrosio M, Antolini R, Bakari D, ..., V. Popa et al, Measurements of atmospheric muon neutrino oscillations, global analysis of the data collected with MACRO detector, European Phys. J. C 36, 323-339 (2004), 97 citations

Abstract: The final analysis of atmospheric neutrino events collected with the MACRO detector is presented. Three different classes of events, generated by neutrinos in different energy ranges, are studied looking at rates, angular distributions and estimated energies. The results are consistent for all the subsamples and indicate a flux deficit that depends on energy and path-length of neutrinos. The no-oscillation hypothesis is excluded at ~ 5s , while the hypothesis of n_m ® n_t oscillation gives a satisfactory description of all data. The parameters with highest probability in a two flavor scenario are $\sin^2 2q_m$ = 1 and Dm^2 = 0.0023 eV^2 . This result is independent of the absolute normalization of the atmospheric neutrino fluxes. The data can also be used to put experimental constrain on this normalization.

3. Ambrosio M, Antolini R, Bakari D, ..., V. Popa et al, Atmospheric neutrino oscillations from upward throughgoing muon multiple scattering in MACRO, Phys. Lett. B **566**, 35-44 (2003), 85 citations

Abstract: The energy of atmospheric neutrinos detected by MACRO was estimated using multiple coulomb scattering of upward throughgoing muons. This analysis allows a test of atmospheric neutrino oscillations, relying on the distortion of the muon energy distribution. These results have been combined with those coming from the upward throughgoing muon angular distribution only. Both analyses are independent of the neutrino flux normalization and provide strong evidence, above the 4 sigma level, in favour of neutrino oscillations.

4. Ambrosio M, Antolini R, Auriemma G, ..., V. Pops et al., Final results of magnetic monopole searches with the MACRO experiment, European Phys. J. C **25**, 511-522 (2002), 62 citations

Abstract: We present the final results obtained by the MACRO experiment in the search for GUT magnetic monopoles in the penetrating cosmic radiation, for the range $4\times 10^{-5}< \beta < 1$. Several searches with all the MACRO sub-detectors (i.e. scintillation counters, limited streamer tubes and nuclear track detectors) were performed, both in stand alone and combined ways. No candidates were detected and a 90% Confidence Level (C.L.) upper limit to the local magnetic monopole flux was set at the level of 1.4×10^{-16} cm^{-2} s^{-1} sr^{-1}. This result is the first experimental limit obtained in direct searches which is well below the Parker bound in the whole β range in which GUT magnetic monopoles are expected

5. Ambrosio M, Antolini R, Auriemma G, ..., V. Pops et al., Neutrino astronomy with the MACRO detector, Astrophys. J. **546**, 1038-1054 (2001), 56 citations

6. Aguilar JA, Albert A, Ameli F, ..., V. Popa et al., First results of the instrumentation line for the deep-sea ANTARES neutrino telescope, Astropart. Phys. **26**, 314-324 (2006), 49 citations

7. Aguilar JA, Albert A, Amram P, ..., V. Popa et al., Transmission of light in deep sea water at the site of the ANTARES neutrino telescope, Astropart. Phys. **23**, 131-155 (2005), 47 citations

8. Aglietta M, Alessandro B, Antonioli P, ..., V. Popa et al., The cosmic ray primary composition between 10(15) and 10(16) eV from Extensive Air Showers electromagnetic and TeV muon data, Astropart. Phys. **20**, 641-653 (2004), 47 citations

9. Aguilar JA, Albert A, Ameli F, ..., et al., The data acquisition system for the ANTARES neutrino telescope, Nucl. Instr. and Metds. Phys. Res. A **570**, 107-116 (2007), 43 citations

10. Ambrosio M, Antolini R, Assiro R,, ..., V. Popa et al., The MACRO detector at Gran Sasso, Nucl. Instr. and Metds. Phys. Res. A **486**. 663-707 (2002), 39 citations

C. Project description (max. 10 pages).

C1. *Scientific context and motivation*.

The goal of this project is to define, develop and implement the search for super-massive, Slowly Moving exotic Particles (SMPs) as GUT magnetic monopoles (MMs), nuclearites and Q-balls with very large volume neutrino telescopes (VLVnT): ANTARES in present and KM3NeT in the future. The present experimental lowest flux limits for SMPs are reported by MACRO [9, 10].

Experimental searches for MMs were triggered by the Dirac historical paper [30] that demonstrated that the quantification of the electric charge may be explained by the existence of monopoles. There was no mass prediction, but masses of the order of few GeV/c^2 were expected. In 1974 t'Hooft and Polyakov independently demonstrate that MMs are natural solutions of Grand Unified Theories (GUT) [31, 32].This type of MM may catalyze the proton decay through the Rubakov – Callan mechanism [33, 34]. GUT MMs should be very massive ($M > 10^{16}$ GeV/c^2), they could be produced only in the Early Universe, and cannot be accelerated by astrophysical magnetic fields to relativistic velocities. No VLVnT reported yet a search for GUT MMs, as VLVnTs are based on the detection of the Cherenkov light emitted by ionizing relativistic particles. One of the objectives of this project is to realize such a search, speculating the proton decay signature [28]. Intermediate mass (10^7 – 10^{10} GeV/c^2) monopoles (IMMs) could be produced in subsequent phase transitions [35, 36]. IMMs may be relativistic, and all VLVnTs (Baikal, AMANDA, IceCube and ANTARES) searched for them, trough the Cherenkov light emitted in water or ice by them or by the knock – off electrons [37 – 39]; thus IMMs are not of interest for this project. Light MMs ("Dirac" MMs) are also possible, but they cannot reach the depth of VLVnTs. They are searched at accelerators; MoEDAL is such a dedicated experiment at LHC [22]. The flux of MMs in the Galaxy is limited by the survival condition of the galactic magnetic field, the Parker bound, $\Phi < 10^{-15}$ cm^{-2} s^{-1} sr^{-1} [40]. A stronger, but more speculative upper limit is the so called "extended Parker bound" [41].

If Strange Quark Matter (SQM) is the ground state of Quantum Chromodynamics (QCD) [42], nuggets of SQM ("nuclearites") have to be present in penetrating cosmic rays [43]. They could be produced in the Early Universe, or in violent astrophysical processes as binary strange star collapses [44]. The only phenomenological bound to the nuclearite flux in the galaxy is derived from the Dark Matter density [43]. The nuclearite detection in VLVnTs is possible trough the black body emission from their over-heated path in water [28]. This search is ongoing in ANTARES, being performed by the Romanian group [45, 46].

Q-balls appear in theories where scalar fields carry a conserved quantum number Q as nontopological solitons stabilized by global charge conservation [46]; in some supersymmetric theories they are absolutely stable [47]. From the point of view of their detection in VLVnTs, Q-balls exhibit properties similar to those of GUT MMs and nuclearites [28]. Protons (or nuclei) could penetrate the squark core of neutral Q-Balls, yielding to “proton decay” – like events. Such processes should be inhibited in the case of positively charged Q-balls; in all cases, as extended objects, Q-balls interact with matter trough elastic collisions with the atoms in their path, as nuclearites.

The very large effective area of VLVnTs ensures sensibilities to SMPs much larger than MACRO. ANTARES sensitivity is about one order of magnitude better (in one year of data tacking) than that of MACRO, in its full life time (about 8 years), ensuring a considerable discovery potential in the field.

ANTARES is fully deployed since June 2009, south of Toulon (France) at a depth of 2500 m, and taking data. Our commitment is to keep ANTARES working at least till the next Mediterranean VLVnT (KM3NeT) will be able to take its place, as being the only very large neutrino telescope in the Northern hemisphere (IceCube, is at the South Pole). The first major ANTARES results are going to be published in the next future.

KM3NeT will be a 6 km^3 instrumented volume neutrino telescope, to be deployed starting 2013 or 2014. It is included in the ESFRI priority list, and among the “7 Magnificent” of the ASPERA roadmap. The technical convergence achieved [21], decisions concerning the site(s) and the footprint on the sea bed are still to be taken, before the completion of the FP7 Preparatory Phase Project (end February 2009).

Any positive result from the above searches could have major impact on GUT theories, QCD or supersymmetric theories. The discovery of SPMs in penetrating cosmic rays would be also of great relevance for cosmology. Even negative results may be of interest, yielding to restrictions in the parameter space of such theories.

C2. *Objectives*.

The main objective of this project is the search for SMPs (Slowly Moving exotic Particles) using the ANTARES neutrino telescope, preparing the extension of the search to the KM3NeT neutrino telescope. Exploiting the obtained results in terms of physics beyond the Standard Model and cosmology will be also considered. The main objective is naturally divided in 3 objectives: O1, O2 and O3, while bridging with cosmology and theoretical physics is considered as O4. A supplemental objective, O5, depends on the future evolution of the KM3NeT project (site and footprint choices): the inclusion of the simulation and analysis software resulting from the achievement of O1 – O3 in the SeaTray software package to be used by the collaboration.

O1. Search for GUT magnetic monopoles with the ANTARES neutrino telescope with extension to KM3NeT. The discovery of the GUT MM would have huge impact on physics. It would represent the check of GUT theories, and provide them with the missing parameters concerning GUT MMs: their mass and the proton decay catalysis intrinsic cross section. The observation of the MM induced proton decay would be of great significance for particle physics and QCD, while the flux measurement would bring essential information for cosmology (as GUT MMs are strongly correlated with inflation) and the astrophysics of galactic magnetic fields. A negative results, considering that the resulting flux limit will be much lower than the extended Parker bound, would seriously question the validity of GUT theories or our knowledge on the galactic magnetic fields. It could also have significant consequences on the inflation scenarios in cosmology. The existing flux limits (as well as the Parker bound) make MMs not to be significant candidates for Cold Dark Matter (CDM).

O2. Search for nuclearites with the ANTARES neutrino telescope with extension to KM3NeT. Nuclearites reaching undersea telescopes should be heavier than few 10^{13} GeV/c^2, and are expected to travel in the galaxy with velocities of about 300 km/s. Their discovery will confirm the QCD prediction on the SQM stability, and could complement the expected discovery of nuclear mass nuclearites ("strangelets") at LHC. The flux and mass spectrum of nuclearites would offer valuable information on the presence of binary strange stars in the galaxy, on the interactions in the intergalactic medium, but also on the nucleosynthesis cosmological phase, and on the CDM composition. It would also offer essential input for the relativistic nuclear physics, on the quark – gluon plasma parameters. A negative result, assuming the discovery of strangelets at colliders, would question our knowledge of massive star physics. A combined negative result (nuclearites and strangelets) would seriously impact on QCD.

O3. Search for Q-balls with the ANTARES neutrino telescope with extension to KM3NeT. Q-balls are predicted by some supersymmetric theories, and their existence and stability is demonstrated by a set of them. Their discovery in cosmic rays would be a strong confirmation of supersymmetric scenarios behind the SM, with major implication for particle physics, astrophysics and cosmology. A negative result would yield important bounds on those theories.

O4. Investigation of the impact of the project results on physics beyond the Standard Model

and cosmology. This objective will ensure the bridging between the ANTARES and KM3NeT activities in the search of SMPs, and other physics related domains. It will allow the tuning of the O1 – O3 subordinated activities in function of the progress in field theory and cosmology, and will ease the exploitation of the obtained results.

O5. Compatibility of the developed software with SeaTray. SeaTray is a software frame, developed in ANTARES by adapting the IceCube IceTray package. It is meant to integrate all simulation and analysis codes in a user friendly package, allowing users to make their research by combining simple scripts and obtaining results in a standard format, easily accessible to other users. O5 will allow a fast conversion of the software developed for ANTARES in O1 – O3 to the KM3NeT conditions.

C3. *Method and approach*.

The ANTARES (and KM3NeT) data acquisition philosophy is an "all data to shore" one. All data from the detector Optical Modules (digitized waveforms from the photomultipliers) are send to the shore station and processed in the local computer farm. Data (most of it is background due to ^{40}K radioactivity and bioluminescence) are filtered by software triggers, conceived to identify events compatible to the Cerenkov cones produced by the passage of relativistic charged particles. In those conditions, the search for slow moving particles (velocities of few 100 km/s) is a very delicate task. This explains why no VLnT (except our analysis ongoing in ANTARES) did attempt to look for SMPs. Our approach is to speculate the fact that the light yield of SMPs (trough specific mechanisms identified in [19, 28]) is isotropic, so we expect long "trains" of fast triggers to signal their passage. This analysis is actually based on the peculiar trigger combinations that such particles would produce. In ANTARES, if a trigger occurs, two "snapshots" of data (50 μ s in total) are registered. The passage of a SMP in ANTARES will last 100 μ s – 1ms, depending on its trajectory with respect to the detector, so we have enough information to try to individuate it. If events will survive our cuts, the easiest reconstruction strategy is to use the space-time distribution of the center of the collected charge distribution (or of the hit rates, which is nearly equivalent), Such a reconstruction could give hints on the velocity and direction of the particle, then the final reconstruction might be done trough a Monte Carlo technique, selecting between various hypothesis using a likelihood criterion., If convincing events will be found, we intend to implement a dedicated trigger, asking the record of about 1 ms of the whole detector activity.

The objectives of the present project are limited to this step. The physics analysis in the case of validated events requires a different approach, and ways to perform it will be find if this will be the case.

The activities related to this project assume:

theoretical description of the interaction mechanisms and energy losses of slowly moving exotic particles in matter, focusing on the light yield in water,

Monte Carlo simulation of SMP propagation and detection in ANTARES (and KM3NeT in a latter phase) and the definition of the analysis cuts using standard triggers (optimization trough the Feldman – Cousins approach),

blind analysis (on 15 % of real data, using the MC results),

full analysis of experimental data,

projecting dedicated software triggers and reconstruction algorithms, in the case of candidates surviving the cuts.

The work will be organized such that all intermediate results are crosschecked by at least two team members. After consistency checks, the results (theoretical calculus, MC codes, search strategies, data analysis, event analysis, etc.) will be presented to the Collaboration When completed, codes and analysis abstracts will be added in the ANTARES internal wiki page.

The task structure and the milestones in achieving Objectives **O1**, **O2** and **O3** are similar. In the following list, # stands for 1, 2 or 3, corresponding to the objective number.

T#.1: Model the propagation of the SMP in matter. (Theoretical computation and Monte Carlo (MC) simulation).

T#.2: Simulate the energy loss and the light yield produced by the SMP in water. Milestone **M#.1**: check that the light yield allows a search in a VLVnT. (Monte Carlo - MC)

T#.3: Determine the geometrical acceptance of ANTARES to the SMP. (MC)

T#.4: Simulate the answer of the ANTARES triggers to the passage of the SMP. (MC)

T#.5: Define analysis cuts to optimize the efficiency and reduce the background of the search. Milestone **M#.2**: check of the experimental sensitivity to the passage of the SMP. (MC)

T#6: Perform a blind analysis (using the MC cuts defined in T#.5 on 15% of the real data and understanding the surviving events). Task ends with the unblinding request to the ANTARES Institute Board. Milestone **M#.3**: Unblinding approval. (MC + data analysis)

T#.7: Perform the analysis on the real data, prepare the results for publication. Milestone **M#.4**: The presence of candidate events. (Data analysis)

T#.8: Reconstruction strategy (based on the weight center of the photomultipliers collected charge and/or the trigger rate space and time distributions) and the design of a dedicated software trigger. (MC and data analysis)

Tasks T2.1 –T2.6 are already completed, they are not considered in this project. The achievement of Objective O3 depends on the results of O1 and O2; the corresponding activities will be delayed consequently. In all activities regarding O1 and O3, the involved participants are VP, GEP and MR (see the cover page of the Funding Application). Remaining tasks of O2 will be completed by VP and GEP. The effort is estimated to 20 fte (O1), 14.5 fte (O2) and 14.8 fte (O3).

O4 is an integration objective; the activity will be achieved by LAP that will participate to the project accordingly (about 2 fte). This activity will be centered around the project milestones, and will be intensified if significant discoveries in related fields occur.

T4.1: Bridging the main project activities with particle cosmology: suggestions and feedback. (Theoretical analysis, consulting)

O5 is a technical objective. Its achievement is conditioned by the evolutions inside the KM3NeT Collaboration. The implied personnel are: VP, GEP and MR. The estimated effort is 11.2 fte.

T5.1: Adapting the produced software to the SeaTray requirements, according the KM3NeT specifications.

T5.2: Validation of the software inside SeaTray.

Work plan: Arrows represent the duration of every task (dashed arrows refer to tasks that are conditioned by the obtained results). Stars mark the milestones, as defined in the text. The data in the "start" line are the starting data of each trimester, assuming the project starts in October 1, 2011. Numbers in each line are the full time equivalent of the predicted effort, considering that participants are involved also in other projects.

Start Task	01/10 2011	01/01 2012	01/04 2012	01/07 2012	01/10 2012	01/01 2013	01/04 2013	01/07 2013	01/10 2013	01/01 2014	01/04 2014	01/07 2014
T1.1	3.0											
T1.2		1.5	M1.1									
T1.3			1.1									
T1.4				2.5								
T1.5						1.3	M1.2					
T1.6							1.6	M1.3				
T1.7									M1.4	6.0		
T1.8											3.0	
T2.7	M2.4					9.0						
T2.8							5.5					
T3.1			1.2									
T3.2				2.0	M3.1							
T3.3					1.0							
T3.4						1.5						
T3.5							1.5	M3.2				
T3.6								2.0	M3.3			
T3.7										M3.4	4.0	
T3.8											1.6	
T4.1						2.						
T5.1									6.4			
T5.2											4.8	

Reporting to the Funding Agency will be periodically done: 15/12/2011, 15/12/2012 and

15/12.2013 – Progress Reports, and 01/10/2014 Final Report, or as it will be stipulated in the Funding Contract.

The convergence of the human resources is granted as the team demonstrated its efficiency in previous projects. If it will be needed, the team could be extended with a new young researcher, without modifying the overall balance. The achievement of the objectives does not request material resources other than normal consumables. The project leader will coordinate the activity of the two young researchers, including the crosschecking of the intermediate results. He will also ensure an equitable distribution of the mobility funds, stimulating them to participate to Collaboration meetings in order to straighten their relation with the other Collaboration members and directly benefit of their experience and advices. Some rather unlikely risk factors may be: a major technical problem of the ANTARES telescope (but during the years it demonstrated its reliability), or the abandon of the KM3NeT Project (hard to happen, considering its high level of priority at European level).

C4. *Impact, relevance, applications*.

The search for slowly moving particles could have impact on other science domains. As one of the main background sources is the bioluminescence, the analysis of candidate events could give important information on bioluminescent activity as time scales less than the millisecond. Both ANTARES and KM3NeT have a “sea and Earth sciences” component, including marine biologists. Very massive nuclearites could create seismic signals; ANTARES could detect them in coincidence with the submarine seismic station attached to the telescope. The acoustic signals produced by SMPs in water are another interesting byproduct, considering the presence of hydrophones both in ANTARES and KM3NeT.

The projects results will be published in scientific journals with large impact factor, and presented to major international conferences (ECRS 2012, ICRC 2013, RICAP 2013 and/or others). Younger researchers will be encouraged to participate. Results obtained independently on the ANTARES and KM3NeT Collaborations (not using unpublished material of the collaborations) will be signed by the contributing members, in alphabetical order; other publications will follow the ANTARES and KM3NeT rules (full list of collaborators in alphabetical order, internal peer review and approval of the results by the whole collaborations). In all cases, the financial support from ANCS will be properly acknowledged. Dissemination to the general public is considered as an obligation of the research team. It will be realized in cooperation with the Romanian mass media. Special attention will be dedicated to educative actions, targeted on high school and undergraduate students, as

"Science Fest", "Open Days" and so on, based on the experience acquired in the ROCOSMICS project. This could contribute to change the public perception of the realities of the Romanian research, and motivate young people to choose a scientific or technical education and career.

The project will consolidate the Romanian position in ANTARES and KM3NeT. This will increase our credibility, allowing us to involve Romanian industry in the building effort of KM3NeT. The possible industrial partners will benefit on the access to state of art technologies, and would themselves improve their visibility abroad.

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