Proposal for an ESF Research Networking Programme – Call 2009

Section I:

Programme title: Constraining the Symmetry Energy

Programme acronym: CoSymE

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Keywords: Nuclear equation-of-state; Symmetry energy; Neutron star; Isospin; Dense nuclear matter

Abstract:

The equation of state of asymmetric nuclear matter is an essential ingredient in nuclear physics and astrophysics but, as of today, insufficiently constrained by experiment. The symmetry energy, i.e. the difference between the energy of neutron matter and of symmetric matter, and its dependence on density are important for the modelling of neutron stars and supernova explosions as well as for isospin phenomena in nuclear reactions and nuclear structure.

Heavy-ion reactions are a unique tool for obtaining information on the symmetry energy in the laboratory, and a considerable activity is presently devoted to its low-density behaviour. The study of the symmetry energy at supra-saturation densities requires high-energy reactions capable of compressing the colliding nuclei and suitable probes sensitive to these early reaction stages. Several probes have been proposed and new experiments are expected to take place during the next few years, in Europe as well as worldwide.

The relevant information will not be possible to deduce without the close collaboration with reaction theorists. Transport theory with full isovector dynamics is required for the interpretation of the new data. Astrophysics with observational results on neutron star properties can provide important and complementary limits for the equation of state of neutron-rich matter. Therefore, close networking between these scientific domains will be essential to guarantee coherent progress in the field.

The proposed network is intended to generate a forum for the close collaboration of the leading scientists and groups in these fields and for the direct exchange of information with particular emphasis on the involvement and scientific growth of young scientists. It is, furthermore, intended to provide the means for imbedding the European efforts at GANIL/SPIRAL, GSI/FAIR, and INFN/LNS into the worldwide activities which are expected to take place during the coming years.

Previous or concurrent applications to the ESF:

ESF Exploratory Workshop on How to Constrain the High Density Symmetry Energy - HiDeSymEne, EW08-124. Workshop was convened by Zoran Basrak and took place in Zagreb, Croatia from October 16th – 18th 2009 (see http://www.irb.hr/users/mkis/). The present proposal is a continuation end expansion of the activities launched by the HiDeSymEne.

Section II:

Status of the relevant research field; scientific context, objectives and envisaged achievements of the proposed Programme:

Protons and neutrons are the main building blocks of the atomic nucleus and account for more than 99% of the mass of directly observed matter in the Universe. A small asymmetry in neutron and proton fundamental properties results in the isospin-dependent term of the nuclear interaction. The isospin nature of the fundamental strong interaction determines the properties of the equation of state (EOS) of asymmetric nuclear matter and represents a challenging topic in nuclear physics and astrophysics. The fingerprints of the asymmetric nuclear matter are observed either in laboratory experiments in static and dynamic properties of nuclei and their interactions, or indirectly, via astrophysical observations. In this proposal, we focus on laboratory studies.

Description of nuclear matter via EOS is alike to thermodynamic description of ordinary molecular matter. In fact, forces and potentials are similar although nuclear matter deals with objects having sizes of the order of few femtometres. Consequently, it is possible to describe different phases of nuclear matter where e.g. a nucleus in its ground state represents a (Fermi) liquid and a neutron star represents a (Fermi) gas. Some features of the nuclear EOS are well known, whereas others, like its density and isospin dependence need more investigations.

The nuclear EOS can be expressed as the sum of a symmetric term and an asymmetric term. The symmetric term has been largely explored in the last decades [Dan02,Sto04,And06] and determines the properties of symmetric nuclear matter (N=Z). The isospin asymmetric term can be expressed as $E_{sym}(\rho/\rho_0)\cdot x^2$ [Lat00,Lat01, Lat04,Li08], where $x=(\rho_n-\rho_p)/\rho$ and ρ_n , ρ_p and $\rho=\rho_n+\rho_p$ are, respectively, the neutron, proton and total matter densities. The density dependent function $E_{sym}(\rho/\rho_0)$ is termed the Symmetry Energy (SE). Figure 1 shows predictions for the EOS of asymmetric nuclear matter for different neutron/proton asymmetries (N/Z=1-1.5 corresponds to known stable nuclei, N/Z=2-3 to neutron rich nuclear systems and infinity to the limit of pure neutron matter). Altering the asymmetry N/Z strongly modifies the EOS. That is due to the quadratic dependence on the nuclear asymmetry x which makes the effects of the SE more and more important as N/Z asymmetry increases. Figure 2 shows some examples of predicted density dependences of SE, commonly termed as "Soft" and "Hard". As of today, no satisfactory constraints on the density dependence of SE exist, requiring extensive experimental investigations.

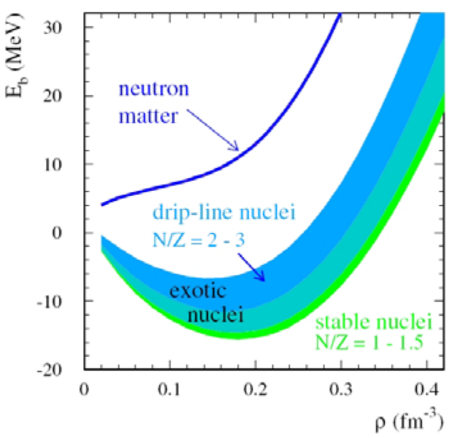


Figure 1: The nuclear equation of state (binding energy per nucleon E_b vs. nucleon density ρ) for neutron-to-proton ratios ranging from symmetric nuclear matter (N = Z) to pure neutron matter (Z = 0) [Jon98].

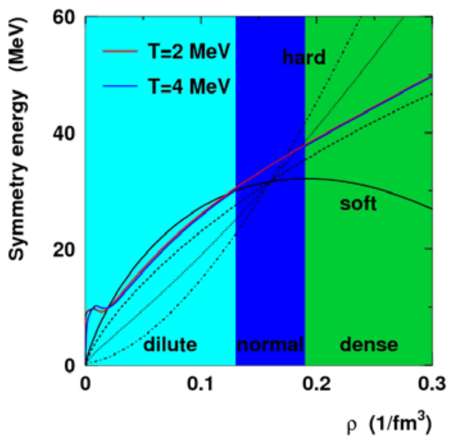


Figure 2: Predictions for the density dependence of the symmetry energy in various models differ considerably from each other [Bla09].

Besides its importance in nuclear physics (structure of exotic nuclei and dynamics of nuclear reactions) several aspects of neutron star physics and supernovae collapse rely on the density dependence of the SE. Among them we mention the nature of various phases coexisting within a neutron star [Ste08], the feasibility of direct URCA cooling processes [Tod05], proto-neutron star cooling rates [Lat04,Ste05], the composition [Ste08] and the thickness of its inner crust, the frequencies of its crustal vibrations and neutron stars radii [Lat04]. These properties are currently being investigated with ground-based and satellite observatories.

Large efforts have been undertaken by both the nuclear structure and heavy-ion reaction communities over the last three decades [Dan02] to constrain the EOS of symmetric nuclear matter. The incompressibility at saturation density $\rho_0 \approx 0.16\ \mathrm{fm}^{-3}$ has been determined to be $K_0=231\pm5$ MeV from nuclear giant monopole resonances [You99]. The EOS at densities $2\rho_0<\rho<5\rho_0$ has been constrained by measurements of collective flows [Dan02,And06] and of sub-threshold kaon production [Stu01,Fuc06] in relativistic nucleus–nucleus collisions. It has been also pointed out [Dan02,Col04, Pie04] that residual uncertainties in the determination of both K_0 and the EOS of *symmetric* nuclear matter are mainly governed by the uncertainties in density dependence of *SE*.

Theoretical studies of the SE have been based on different many-body theories using various two-body and three-body forces or interaction Lagrangians as well as various numerical implementations. However, because of our poor knowledge about the isospin dependence of in-medium nucleon–nucleon interaction and the difficulties in solving the nuclear many-body problem, predictions of the SE based on the three main concepts, such as the microscopic many-body approach the effective-field theory and the phenomenological approaches differ widely. The absence of strong constraints on the SE engenders major theoretical uncertainties: the above mentioned well established theoretical approaches disagree in predicting the ρ dependence of the SE among them but also within the same approach. Indeed, different parameterisations capable of describing available nucleon scattering data, lead to strong discrepancies in the ρ dependence of the SE within the same model.

In the dependence of the SE on ρ, three distinct regions can be identified (Fig, 2): a) Around the so-called normal or saturation nuclear density ρ_0; b) diluted matter at sub-saturation densities ($\rho<\rho_0$); c) compressed matter at supra-saturation densities ($\rho>\rho_0$). Constraints on the density dependence of the SE from terrestrial laboratories are mainly provided by heavy-ion reactions (HIR) at intermediate and relativistic energies. In these reactions, several experimental probes are proposed

- $\rho<\rho_0$: multifragmentation, isoscaling, isospin fractionation, isospin diffusion, isobaric nuclei production ratios, single and double neutron-proton differential flow, neutron-proton correlation functions at low relative momentum, neutron/proton relative pre-equilibrium energy spectra, etc.
- $\rho\approx\rho_0$: nuclear giant monopole resonance, neutron skin, isovector giant dipole resonance, electron scattering, proton-nucleus elastic scattering, neutron to proton ratio of pre-equilibrium nucleons, etc.
- $\rho>\rho_0$: neutron to proton (double) ratio (especially at mid-rapidity), neutron-proton (double) differential transverse/elliptic flow (especially at high transverse momenta), π^-/π^+ ratio, K^+/K_0 ratio, light isobaric nuclei production ratios, isospin transparency, deconfinement precursors, etc.

Experimental investigations are required to explore the above-listed density regimes. Results from nuclear structure studies have been successful in studying nuclear matter at $\rho\approx\rho_0$ (see the most recent works [Kli07,Li07]). A large number of these projects have been carried out in European laboratories thanks to the availability of the first generation of radioactive beam (RIB) facilities.

Experimental studies of the SE at $\rho<\rho_0$ are currently being carried out both in USA [Tsa01-9,Che05,Fam06,Igl06,She07,Li08] and in Europe [Amo09,Chb07]. These studies are aimed at providing a consistent description of several astrophysical and HIR observables and constrain model parameters (cf. [Li08] and Fig. 3 [Tsa09]). At supra-saturation densities different many-body theories provide very different predictions. No experimental constraints on the SE at higher densities are available at present. The only relevant data may be found in Refs. [Lei93,Ram00,Lop07,Rei07], although these experiments have not been specifically designed to constrain SE. The collected data provide contradictory results: while π^+/π^- yield ratio data for Au+Au collisions in a broad energy range [Rei07] predicts a vanishing SE at $\rho \approx 3\rho_0$ [Xia09], n-p squeeze-out data from Au+Au collisions at E_{beam}/A=400 MeV [Lei93] predicts a steady rise of the SE [Tra09] for $\rho > \rho_0$ (Fig. 3). Unfortunately, the statistical accuracy of the present n-p elliptic flow data is somewhat marginal. Therefore, unambiguous constraints on the high density behaviour of SE from HIR are urgently needed. These constraints are important to also understand the interior of neutron stars.

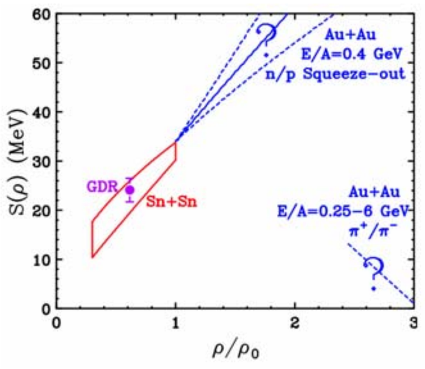


Figure 3: SE obtained from HIR. The limits to the enclosed region at sub-saturation nuclear matter density are obtained from Sn+Sn collision data assuming S_o=30.1 and 33.8 MeV. The dotted line in the lower right corner represents initial constraints obtained from the measurements of π^+/π^- yield ratio data from Au+Au collisions over a range of energy from E/A=0.25 to 6 GeV [Rei07,Xia09]. The upper solid lines enclosed by two dashed lines is the density dependence obtained by analyzing the neutron and proton squeeze out flow from Au+Au collisions at E/A=400 MeV [Tra09]. (from [Tsa09])

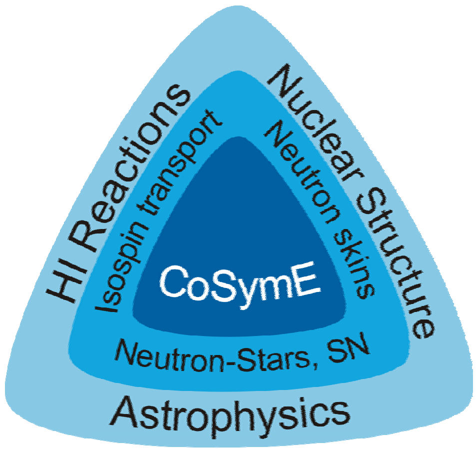
Some recent European experiments will provide important information on the SE both below and above the saturation nuclear density: a) An experiment recently performed with INDRA/VAMOS at GANIL to study isotopic distributions of complex fragments produced in ^{40,48}Ca+^{40,48}Ca collisions at E_{beam}/A=35 MeV [Chb07]. b) A recent measurement of the relative competition between incomplete fusion and binary deep inelastic collision mechanisms in ^{40}Ca+^{40,48}Ca,^{46}Ti reactions at E_{beam} /A=25 MeV [Amo09]. c) An experiment to study neutron/proton elliptic flow in Au+Au collisions at E_{beam} /A=400 and 800 MeV has been recently approved by the GSI Programme Advisory Committee and will be performed next year [Lem09]. The first two experiments explore the SE at low densities, while the third experiment is expected to be one of the first explorations of the SE at high densities.

Understanding HIR data requires taking into account the contributions from bulk and surface components to the SE [Sat01,Dan03,Ste05] as well as in-medium modifications of elementary scattering processes [Fuc06a,Dit06]. In addition, improved microscopic transport models, describing the collision dynamics, are mandatory in order to link the measured quantities (which reflect the last stage of the reaction) to their initial values probing the high density regime ($\rho > \rho_0$). Furthermore, finite size effects have to be taken into account in order to realistically extrapolate measured quantities to nuclear matter properties.

The effects induced by the SE need to be amplified because they are generally weaker than those induced by the nuclear isoscalar potential at the same density. An obvious approach to enhance isospin signals consists of using very N/Z asymmetric reaction systems. The focus on constraining the SE via HIR is currently emphasized by the next-generation of RIB in Europe (Spiral2 and its post-acceleration, SPES, Hie-Isolde, FAIR) as well as in Japan (RIKEN) and in USA (FRIB). The expected RIB luminosities (e.g. at FAIR and Hie-Isolde) will allow performing dedicated experiments to constrain the SE at very large values of neutron/proton asymmetries. These facilities may include also ion-storage rings as colliders or highly asymmetric target nuclei.

Isospin physics with HIR is a fast growing field as it is demonstrated by the existence of several contributions in the literature. The main aim of the present proposal for a Research Networking Programme (RNP) consists of creating a framework to allow experimentalist and theoreticians to exchange experts and students. Meetings will be organized in order to discuss the above-mentioned research topics, involving researchers from different fields: nuclear reaction dynamics, astrophysics, nuclear structure and particle physicist as well as experimental and computing infrastructure developers. These meetings should become a forum to debate fundamental and technical issues relevant to advancing our knowledge of SE through encountering researchers from ESF and non-ESF countries such as USA and Japan. The scientific goal and its achievement requires joint and complementary efforts on a global level. This motivates the global character of the present RNP. The relevance of the proposed efforts is strongly emphasised by a clear need for new ideas prior to the advent of new-generation radioactive beam facilities.

As outlined in Ref. [Li08] the most important theoretical challenges are i) the high density behaviour of nuclear symmetry energy, ii) the momentum dependence of isovector potential and the associated neutron–proton effective mass splitting in asymmetric matter and iii) the isospin-dependence of the in-medium nucleon–nucleon cross sections in asymmetric matter. Progress on the topics listed above is hindered by the lack of relevant experimental data and, in some cases, by the lack of yet inappropriate theoretical tools.



To conclude, we schematically illustrate the interdisciplinary objectives and the main lines of information flow intended with the proposed CoSymE Research Networking Programme in the inset diagram. The central research goal of the participating groups is constraining the symmetry energy with laboratory experiments (dark blue). Investigations of isospin transport and dynamics in heavy-ion reactions will be carried out at intermediate and relativistic energies, giving access to density ranges $\rho \approx 0.3\rho_0$–$0.8\rho_0$ and $\rho > 2\rho_0$, respectively. The obtained results are of importance for other fields (light blue), astrophysics, nuclear structure, and heavy-ion reactions, with whom we like to interact more closely and more directly. The mediators and main topics of information exchange between fields are indicated in-between (normal blue). Reaction theory with a full treatment of isospin transport is indispensable in order to interpret the experimental results. It will in turn benefit from the opportunities of precisely testing the predictions. In this direction, longer-term exchanges of active scientists will be the most effective means of reaching these goals. The relation with the other two fields is less technical and more on the result level. The symmetry energy governs the thickness of the neutron skin of neutron-rich heavy nuclei and other isotopic phenomena in nuclear structure and is essential for modelling neutron stars and supernova dynamics. The study of these phenomena is expected to provide independent information and limits for the strength of the symmetry energy. A close exchange of results is necessary in order to exploit these complementary aspects. It will be the goal of the proposed network to respect these complementary aspects, strengthen the indicated lines of information flow, and to contribute to reaching a consistent result for the symmetry energy as a function of density.

Bibliography:

[Amo09] F.Amorini et al., Phys. Rev. Lett. 102 (2009) 112701.
[And06] A. Andronic et al., Eur. Phys. J. A 30 (2006) 31.
[Chb07] A. Chbihi et al., Exploring the symmetry energy with isospin effects in heavy-ion collisions, GANIL experiment E503.
[Bla09] D.B. Blaschke, ESF Exploratory Workshop on How to Constrain the High Density Symmetry Energy (http://www.irb.hr/users/mkis/presentations.html).
[Che05] L.W. Chen, C.M. Ko, B.A. Li, Phys. Rev. Lett. 94 (2005) 032701.
[Col04] G. Colo et al., Phys. Rev. C 70 (2004) 024307.
[Dan02] P. Danielewicz, R. Lacey, W.G. Lynch, Science 298 (2002) 1592.
[Dan03] P. Danielewicz, Nucl. Phys. A727 (2003) 233.
[Dit06] M. Di Toro et al., Eur. Phys. J. A 30 (2006) 153.
[Fam06] M.A. Famiano *et al.,* Phys. Rev. Lett. 97 (2006) 052701.
[Fuc06a] C. Fuchs and H.H. Wolter, Eur. Phys. J. A 30 (2006) 5.
[Igl06] J. Iglio et al., Phys. Rev. C 74 (2006) 024605.
[Jon98] F. de Jong, H. Lenske, Phys. Rev. C 57 (1998) 3099.
[Kli07] A. Klimkiewicz et al., Phys. Rev. C 76 (2007) 051603.
[Lat00] J.M. Lattimer and M. Prakash, Phys. Rep. 333 (2000) 121.
[[Lat01] J.M. Lattimer and M. Prakash, Ap. J. 550 (2001) 426.
[Lat04] J. M. Lattimer and M. Prakash, Science 304 (2004) 536.
[Lei93] Y. Leifels, et al., (LAND-FOPI Collaboration), Phys. Rev. Lett. 71 (1993) 963.
[Lem09] R.C. Lemmon, P. Russotto et al., Constraining the Symmetry Energy at Supra-Saturation Densities with Measurements of Neutron and Proton Elliptic Flows, GSI experiment S394.
[Li07] T. Li et al., Phys. Rev. Lett. 99 (2007) 162503.
[Li08] Bao-An Li et al., Phys. Rep. 464 (2008) 113.
[Lop07] X. Lopez et al., (FOPI Collaboration), Phys. Rev. C 75 (2007) 011901 (R).
[Pie04] J. Piekarewicz, Phys. Rev. C 69 (2004) 041301.
[Ram00] F. Rami et al., (FOPI Collaboration), Phys. Rev. Lett. 84 (2000) 1120.
[Rei07] W. Reisdorf et al., (FOPI Collaboration), Nucl. Phys. A781 (2007) 459.
[Sat01] W. Satu, R. Wyss, Phys. Rev. Lett. 86 (2001) 4488; W. Satu, R. Wyss, Phys. Rev. Lett. 87 (2001) 052504; Phys. Lett. B 572 (2003) 152.
[She07] D.V. Shetty et al., Phys. Rev. C75 (2007) 034602; D.V. Shetty et al., Phys. Rev. C76 (2007) 024606.
[Ste05] A.W. Steiner et al., Phys. Rep. 411 (2005) 325.
[Ste08] A.W. Steiner, Phys. Rev. C 77 (2008) 035805.
[Sto04] G. Stoicea et al., (FOPI Collaboration), Phys. Rev. Lett. 92 (2004) 072303.
[Stu01] C. Sturm et al. Phys. Rev. Lett. 86 (2001) 39.
[Tod05] B.G. Todd-Rutel and J. Piekarewicz, Phys. Rev. Lett. 95 (2005) 122501.
[Tra09] W. Trautmann et al., Proceedings of the XLVII International Winter Meeting on Nuclear Physics, Bormio (Italy), Jan. 26-30, 2009, arXiv:0907.2822.
[Tsa01-9] M.B. Tsang et al., Phys. Rev. Lett. 86 (2001) 5023; M.B. Tsang, et al., Phys. Rev. Lett. 92 (2004) 062701; M.B. Tsang, et al., Phys. Rev. Lett. 102 (2009) 122701.
[Tsa09] M.B. Tsang, 2nd Int. Conf. on Nuclear Fragmentation, NUFRA2009, Kemer (Antalya), Turkey.
[Xia09] Zhigang Xiao et al., Phys. Rev. Let. 102 (2009) 062502.
[You99] D.H. Youngblood et al., Phys. Rev. Lett. 82 (1999) 691.

Facilities and expertise which would be accessible by the Programme:

Isospin physics has made a decisive step forward through studies of exotic nuclei. As a result of the leading role of European laboratories in the R&D of first generation radioactive ion-beams (RIBs produced either by the projectile fragmentation or the ISOL-isotope separation on-line methods) European laboratories have, and continue to largely contribute in this research. Of equal importance is the leading European effort in designing and building advanced detector arrays for such measurements.

Researchers from different European laboratories and universities gathered in this RNP are leading both experimental and theoretical research into the nuclear equation of state and its isospin-dependent component, the symmetry energy. They have been involved in providing the best sets of experimental data and the theoretical predictions in both the sub- and supra-saturation density regions. Together with experimentalists, the list of participants in the proposal includes well known nuclear theorists and astrophysicists, with expertise vital to interpret the experimental results.

At the disposal of the researchers of the RNP will be strong computing resources such as large computing clusters at GSI and elsewhere, the computing centre of IN2P3 in Lyon etc. Several collaborating institutions are user facilities (GSI, GANIL, INFN-Catania) and are unique experimental facilities worldwide by their performance both technologically (accelerator and experimental detection equipment) as well as by their human resources of internationally recognized researchers and its technical staff. GSI and GANIL are certainly among the most distinguished European large scale facilities for nuclear physics.

The proposed RNP will provide the collaborating researchers and early-career scientists opportunities to use the unique equipment (state-of-the-art detector systems and electronics), ion-beams and data analysis procedures (simulation and computing) of the premier radioactive ion beam facilities in Europe and worldwide as well as the full support of leading theoreticians from various interlaced research topics. The success of this project requires the utilization of multiple resources in our partner institutions. The results of the project will provide guidance to the future research directions at RIB facilities worldwide, including FAIR, Spiral2 with post-acceleration and Eurisol in Europe. This investment is vital to maintain European scientific leadership in the study of the equation of state of asymmetric nuclear matter, and to prepare for the studies at above mentioned RIB facilities in the near future.

Expected benefit from European collaboration in this area:

To ensure continued leadership of Europe within nuclear physics research, the high-intensity RIB facilities FAIR, Spiral2 with post-acceleration and Eurisol will be built. This proposal aims to ensure an adequate networking support and organisational framework to prepare the methods, techniques and equipment needed to study asymmetric nuclear matter at these new European RIB facilities. It will also train and prepare young scientists for international leadership in this field. Nuclear science is an international effort where many advances require the cooperation of scientists across both the national as well as scientific discipline borders. This is particularly true because of the significant infrastructure demands of large accelerators and advanced detection systems. Moreover, many of the theoretical advances are complex and benefit significantly from close collaboration with experimental groups. This exchange of researchers and collaborative work has been for many years the necessary approach in attacking the complex problems in nuclear physics which demand large resources and man power. The effort needed to constrain the density dependence of the SE is such that the European collaboration in isolation is not fully sufficient. Therefore, this RNP has a global character and involves collaborators from the USA and Japan.

European context

The ESF expert committee for Nuclear Physics NuPECC in its Long-Range Plan 2004, “Perspectives for Nuclear Physics Research in Europe in the Coming Decade and Beyond”, (LRP2004, http://www.nupecc.org/pub/lrp03/long_range_plan_2004.pdf) aiming at maintaining a leading position of Europe in nuclear physics research, recommends investigation of nuclear matter properties with the objective to understand the nature of neutron stars and nuclear matter (see LRP2004, p. 14,15 and Chapter 5). In a more recent NuPECC document “Roadmap for Construction of Nuclear Physics Research Infrastructures in Europe” (www.nupecc.org/pub/NuPECC_Roadmap.pdf) aiming at paving infrastructural support for realisation of its LRP2004 recommendations via “new large infrastructures and novel experimental techniques and equipment” which “have to be developed and realised to maintain the opportunity to pursue future research at the cutting edge” the top priority is given to new facilities for high-intensity RIBs: FAIR (uses in-flight fragmentation – IFF method) and EURISOL (uses isotope-separation on-line – ISOL method) which are complementary in their performances and are both expected to enter into operation in years 2016-20.

Our main concern and motivation for this proposal is to pave the road towards the new opportunities offered by these new European RIB facilities in studying asymmetric nuclear matter. (We mention here that research on the Symmetry Energy has been identified explicitly as one of the most outstanding questions in the 2007 US Nuclear Physics Long Range Plan by the NSF/DOE Nuclear Science Advisory Committee [http://www.sc.doe.gov/np/nsac/docs/Nuclear-Science.Low-Res.pdf]. The study of asymmetric nuclear matter and its relation to neutron star physics will form a research priority and highlight of the new NuPECC Long-Range Plan 2010, which is currently under preparation.)

The R3B project (reactions with Relativistic Radioactive Beams), part of the Nustar collaboration at FAIR, was a part of a European Commission FP5 project as well as part of the infrastructural FP6 I3 project Eurons (task RHIB). The study of asymmetric nuclear matter, and in particular the density dependence of the symmetry energy, via nuclear structure and heavy-ion investigations forms a central topic of the scientific programme of R3B. This RNP will provide essential guidance to this part of the R3B scientific programme.

The CBM collaboration at FAIR also offers overlaps with the CoSymE objectives but at densities beyond $3\rho_0$ at which one expects new phenomena at QCD level on SE. The CBM was a part of FP6 I3 project HP and is currently in its continuation as FP7 I3 project HP2.

A running ESF RNP “The New Physics of Compact Stars (CompStar)” chaired by David Blaschke is complementary in several aspects to the present proposal and common actions are foreseen. We foresee attendance of our early-career scientists in astrophysics schools organized by the CompStar as well as formative stays of the CompStar young theoreticians in our experimental groups. On the experts level exchange of leading scientist as lecturers is welcome for both RNPs.

Overlap with the recently proposed ESF CORE project EuroGENESIS is less obvious but some common actions may and should be realized.

Although it might be seen out of context, we find it important to mention that the partner countries include new EU countries (Poland and Romania) as well as an EU candidate country (Croatia) which will naturally facilitate scientific and cultural integration of Europe. With that aim, graduate students and postdoctoral fellows will be encouraged to participate in the language and culture programs organized and often offered for free by the host institution (introductory language courses and similar activities).

Proposed activities, key targets and milestones:

The main aim of the proposed RNP is to advance our understanding of the equation-of-state of asymmetric nuclear matter, i.e. to constraint the Symmetry Energy (SE) in the nuclear density range $0.4\rho_0 \leq \rho \leq 3\rho_0$. The **key targets and milestones** are:

- Create a forum for physicists working on experimental, theoretical and simulation topics relevant for the SE problem
- Design of topical heavy-ion experiments dedicated to further constraining the SE
- Provide the best conditions for the education of young nuclear physicists through international cooperation

These targets will be achieved by the following **activities**:

- Organize or contribute in organization of an annual triangular conference of a global nature which will move cyclically among Europe, USA and Japan
- Organize or contribute in organization of at least one topical workshop per year in the collaborating countries,
- Exchange of experts between collaborating organizations by 16-24 short visits per year.
- Exchange of students and young scientists between collaborating organizations on the basis of 12-16 months per year.

The activities of the RNP are strongly interlaced with the dynamics of dedicated isospin sensitive experiments mentioned above in the description of the physics-case of CoSymE. These experiments should provide constraints on i) SEmodel parameters, ii) effective nucleonic masses (m_n^*, m_p^*) in asymmetric medium and iii) in-medium modifications of NN cross sections (σ_{nn}, σ_{pp}, σ_{np}) due to scattering in an asymmetric medium.

An important CoSymE activity consists in organizing visits of graduate students (GS) and postdoctoral fellows (PD) in simulations, computing, experiments, development of state-of-the-art detector systems, technical and electronics developments including an enhanced education in nuclear reactions, nuclear astrophysics and nuclear detectors. The extended visits of GS and PD will be hosted by collaborators working on research central to the focus of the proposal and one of the senior scientists will serve as their mentor. Mentoring by foreign near-peer scientists will forge a network of life-long collaboration between junior scientists at home and abroad. In addition, stays in foreign countries offer early-career scientists the opportunities to experience international collaboration in large scale projects. Upon completion of their stay abroad, GS and PD will be required to write a report detailing their experiences. These reports will be posted on the CoSymE web site and will provide a knowledge repository for future programme participants. Moreover, GS and PD will be expected to prepare presentations for the annual CoSymE meetings.

The CoSymE activity will conform to the rules of good scientific practice and train doctoral students and postdoctoral fellows in these regulations.

Besides the official knowledge dissemination via publishing and the CoSymE web-site the GS and PD will be encouraged to state-of-the-art internet communication tools to disseminate their experiences and knowledge they acquire to a broader audience. The available communication technology to transcend national boundaries will be extensively used to strengthen the human networking developed during the visits to advance the research and expand our students' ability to compete and work in the global environment.

All the activities will be coordinated and approved by the Programme Steering Committee (PSC). We took care on composition of the provisional PSC regarding age and sex of its members. The PSC will meet once a year. However, modern communication and videoconferencing technology will be used whenever needed to strengthen the coordination issues.

To ensure that the best scientific ideas and results will come out of the experiments and simulations, the CoSymE Network plans to elect a scientific director whose tenure will rotate among the collaborators to oversee the scientific direction of the collaboration. The scientific director will chair the steering committee. To monitor and coordinate the progress toward project goals and project outcomes the PSC will undertake evaluation and assessment activities. In that way PSC will continuously control CoSymE achievements as well as timely prepare the Programme progress reports. The main evaluation and assessment objectives are publication of and talks given on research results, enhancement of international collaboration of diverse groups, progress in young scientists for future studies/careers, etc.

Duration: 60 months

Budget estimate (in €) by type of activities and per year of the Programme

Budget Justification

The total budget requested is **575 kEMU** over five years. The amount is modest considering the impact of the Programme on research to address one of the main questions identified in the NuPECC Long-Range Plan 2004. Besides the important interplay of the Programme with the neutron star and supernovae astrophysics we emphasize its impact on nuclear science education both for graduate students (GS) and postdoctoral fellows (PD). Indeed, over one third of the resources are exclusively devoted to the early-career scientists (see the pie chart). Most of the results from this project, such as the global education and research experiences provided to students and postdoctoral fellows, the education components and the science guidance to FAIR, Spiral2 with post-acceleration and Eurisol research, will outlast the duration of the proposal. Owing to its global character travel expenses are to some extent higher because trips to the USA are twice and to Japan about three times more expensive than in Europe. One has to bear in mind that the main GS and PD hosting institutions (GSI, INFN-Catania and GANIL) are user facilities; they have regular infra-structure resources for visitors such as affordable housing and office space. All the host institutes provide opportunities for the RNP participants to engage in outreach activities.

RBI will also provide admin-istrative resources to help the Programme coordinator with Programme managing, effort tracking and provide equipment to host video and telephone conferences.

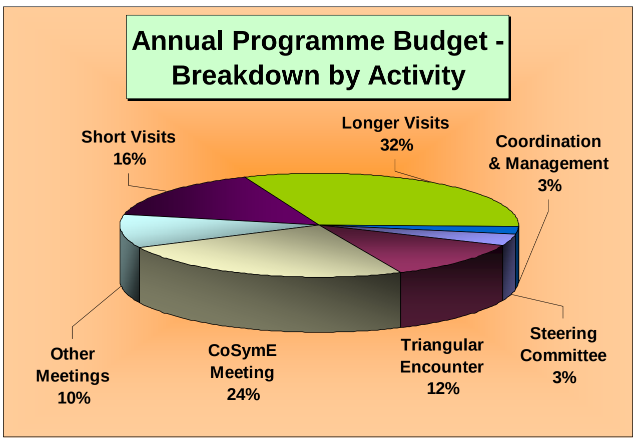


Table II. Breakdown by activity of annual Programme budget

	Activity	kEMU
1	**Steering Committee meeting** 10 participants (may be organized jointly with other activity thus reducing travel costs)	**4**
2	**Main annual meeting** ("triangular annual encounter" **-** EU/USA/Japan) 12 - 16 attendees in the year meeting is held in EU 8 - 12 attendees in the year meeting is held in USA 6 - 10 attendees in the year meeting is held in Japan	**14**
3	**RNP CoSymE annual meeting** (2-3 days) 40-50 attendees	**28**
4	**Other relevant meetings/workshops** (organized by this RNP or by other organizers)	**12**
5	**Short visits** (duration up to 1 week) 16 - 24 visits on the basis of 70 EMU daily allowance and use of the host institution "guest house"	**18**
6	**Longer exchanges intended for students** (duration up to 3 months) 12-16 months on the basis of 70 EMU daily allowance (2100 EMU/months) and use of the host institution "guest house".	**36**
7	**Coordination and management** (dissemination and communication cost and administrator fee)	**3**
Total		**115**

Section III:

Envisaged Steering Committee members

1. **Croatia**: Zoran Basrak, Ruđer Bošković Institute, P.O.Box 180, Zagreb
2. **France**: Abdelouahad Chbihi, GANIL, CEA/DSM-CNRS/IN2P3, Caen
3. **Germany**: Yvonne Leifels, GSI, Plankstrasse 1, Darmstadt
4. **Italy**: Giuseppe Verde, INFN – Sezione di Catania, Catania
5. **Poland**: Jerzy Lukasik, IFJ-PAN, Krakow
6. **Romania**: Mihai Petrovici, NIPNE, Bucharest / Virgin Baran, Bucharest
7. **Spain**: Jose Benlliure, University of Santiago de Compostela, Santiago de Compostela
8. **Sweden**: Bo Jakobsson, Faculty of Science, Lund University, Lund
9. **United Kingdom**: Roy Lemmon, STFC Daresbury Laboratory, Warrington, Cheshire

Programme collaborators

1. **Croatia**:
   Department of Physics, University of Split, Split
   Department of Physics, University of Zagreb, Zagreb
   Ruđer Bošković Institute, Division of eperimental physics, Zagreb
2. **France**:
   GANIL, CEA/DSM-CNRS/IN2P3, Caen
   LPC Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, Caen
   Subatech, EMN-IN2P3/CNRS-Université de Nantes, Nantes
   Institut de Physique Nucléaire, IN2P3-CNRS, Orsay
3. **Germany**:
   GSI Helmholtzzentrum fur Schwerionenforschung GmbH, Darmstadt
   FIAS, Universitat Frankfurt, Frankfurt am Main
   Institute for Theoretical Physics, University of Giessen, Giessen
   Institute for Theoretical Physics/Astrophysics, University of Heidelberg, Heidelberg
4. **Italy**:
   Dipartimento di Fisica, University of Catania, Catania
   CSFNSM, Catania
   INFN – Sezione di Catania, Catania
   INFN-LNS, Catania
   Kore University, Enna
   INFN – Sezione di Milano and Dipartimento di Fisica, Milano
   INFN – Sezione Napoli and Dipartimento di Fisica, Napoli
5. **Poland**:
   Institute of Physics, University of Silesia, Katowice
   Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, Krakow
   IFJ-PAN, Krakow
   A. Soltan Institute for Nuclear Studies, Swierk/Warsaw
   Institute of Experimental Physics, Warsaw University, Warsaw
   Institute for Theoretical Physics, University of Wroclaw, Wroclaw
6. **Romania**:
   NIPNE, Bucharest
   University of Bucharest and IFIN-HH, Bucharest
7. **Spain**:
   University of Santiago de Compostela, Santiago de Compostela
8. **Sweden**:
   Department of Fundamental Physics, Chalmers University, Göteborg
   Faculty of Science, Lund University, Lund
   School of Technology, Malmo University, Malmo
9. **United Kingdom**:
   STFC Daresbury Laboratory, Warrington, Cheshire
   University of Liverpool, Liverpool

Global dimension

The importance of constraining the density dependence of the symmetry energy is equally recognized in the US and in Japan. Scientific programs in this direction are either underway or proposed and significant contributions have already been made. In particular, the MSU group (M.B. Tsang et al.) has collected several data sets from cross bombardments of ^{112,124}Sn nuclei at 50 MeV per nucleon. Their analysis has led to considerable progress in the sub-saturation domain where isospin diffusion and neutron-to-proton yield ratios have been identified as suitable observables.

The MSU group plans a long-term involvement in projects aiming at constraining the symmetry energy at sub-saturation but also at supra-saturation density by, e.g., measuring particle ratios. A proposal has been submitted at Riken, Japan, and has found positive response. At Riken, funding has been obtained for a large-acceptance dipole magnet, SAMURAI, which can serve as the central instrument in such experiments, possibly with exotic secondary beams.

Because of the differences in available beams, energies, and intensities and in the different observables chosen for these programs, these projects for overseas laboratories have to be considered as complementary parts in a global effort to achieve the desired goal with a variety of means. To achieve this goal, collaborations and regular contacts between the leading scientists will have to be established. It will, in particular, also be important that our European network has access to the latest results and developments.

Plans exist for long-term research activities, jointly with our colleagues from the USA and Japan. American scientists are part of the accepted proposal for experiments at the GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany, and European scientists are, jointly with the US and Japanese groups, proposing an experimental program to be conducted at the NSCL (National Superconducting Cyclotron Laboratory) at Michigan State University and the Nishina Centre for Accelerator-Based Science of RIKEN facility at Wako-Tokyo, Japan.

The networking proposal of our US partner, after being selected in the first round of pre-selection by the NSF (National Science Foundation) Partnerships for International Research & Education (PIRE) award committee, has been submitted under the direction of M.Y. Betty Tsang of NSCL-MSU (e-mail: tsang@nscl.msu.edu) on 18th of September this year. The NSF-PIRE proposal is entitled “Determination of the Equation of State of Asymmetric Nuclear Matter: International collaborative research between US, Japan and Western Europe”.

Our Japanese partners will also seek funding to provide in-kind support for participation in the activities organized by our ESF Research Networking Programme. The contact person representing the Japanese colleagues involved in these programmes is Hiroyoshi Sakurai (e-mail: sakurai@ribf.riken.jp) from Radioactive Isotope Physics Laboratory, Nishina Centre, RIKEN.