

Scientific Report

ESF Exploratory Workshop on

How to Constrain the High Density Symmetry Energy - HiDeSymEne

Zagreb (Croatia), 16-18 October 2009

Convened by:
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Executive summary

The main building blocks of the visible matter in the Universe, the neutron and proton, slightly differ in their fundamental properties. This difference is described by the isospin-dependent term of the nuclear interaction. The isospin nature of the fundamental strong interaction determines properties of the asymmetric nuclear matter (unequal number of protons, Z , and neutrons, N , usually $N > Z$) 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.

The behaviour of the nuclear medium as a function of density is of fundamental importance to both nuclear physics and astrophysics and deals with the question of hardness of nuclear medium to compression. This bulk feature of nuclear medium is usually referred to as a (nuclear) equation of state (EOS). Its properties govern the energetic collisions of heavy nuclei in the laboratory experiments and the supernova explosion dynamics and the neutron star properties in the astrophysical domain. 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 and determines the properties of the (isospin) symmetric nuclear matter (medium made of equal number of protons and neutrons, $N=Z$). The isospin asymmetric term can be expressed as $E_{\text{sym}}(\rho/\rho_0) \cdot x^2$, 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 nuclear matter densities. The density dependent function $E_{\text{sym}}(\rho/\rho_0)$ is termed the Symmetry Energy and represents the difference between the energy of neutron matter and of symmetric matter. As of today, no satisfactory constraints on the density dependence of symmetry energy exist, requiring extensive experimental investigations.

Undeniably, our understanding of the nuclear EOS is limited, largely due to our poor knowledge of the density dependence of the nuclear symmetry energy. Heavy-ion reactions induced by neutron-rich nuclei, especially radioactive beams, have a crucial role to play in this field. While considerable progress has been recently made in determining the symmetry energy around and below the normal nuclear matter density ρ_0 much more work is still needed to probe its high-density behaviour. Besides an urgent astrophysical need for constraining the symmetry energy at supra-normal densities the interest for this topic is largely enhanced by the recently announced perspective of the high intensity neutron-rich radioactive beams of relativistic energies to be available at the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany. Due to rather weak isospin signal choice of observables is very delicate and the sensitivity crucially relies on the isospin content of the nuclear system under study. This is even more so because of the quadratic dependence of the nuclear EOS on the isospin asymmetry $x=(\rho_n-\rho_p)/\rho$, where ρ_n , ρ_p and $\rho=\rho_n+\rho_p$ are, respectively, the neutron, proton and total nuclear matter densities. Therefore, one expects that FAIR will provide an improvement step forward in measuring isospin-sensitive observables.

A dedicated experiment, ASY-EOS, aimed at constraining the symmetry energy at supra-normal densities has been recently approved at GSI facility in Darmstadt. This Workshop brought together twenty six scientists and doctoral students from both the experimental and theoretical nuclear physics and astrophysics communities with the aim of stimulating an interdisciplinary collaborative effort, and identifying common objectives in this expanding research topic. Nevertheless, the pivoting axes of the meeting was the discussion of the future experiment, the already approved ASY-EOS but also beyond it, aiming at performing the best possible choice of observables and detection instruments, yet available or under development and construction, in Europe and US in view of realizing the most pertinent measurement of isospin-sensitive observables at the supra-normal nuclear densities. In addition, one of the key aims of the workshop was to expose experimentalists to the recent advances and opportunities existing in the most recent theoretical investigations on the symmetry energy from the point of view of both nuclear physicists and astrophysicists, and to provide a broad outlook of future developments. At the same time, the workshop was an occasion to present to the theoreticians the current status of the laboratory experimental research on the Workshop topic. Further common objective was to identify fundamental issues that both nuclear and astrophysics communities could benefit from current and future research and to discuss the creation of a Research Networking Programme (RNP), a framework for an integrated interdisciplinary approach comprising experiments, theory and numerical modelling relevant to the study of the symmetry energy. In that context the workshop also served as a platform to discuss funding issues at a European and international level.

The outcome of the workshop was very encouraging and positive. The following key points were highlighted in the discussions:

- The need for increased exchange of information at the European level.
- To define the boundaries of the research field on European and world level.
- The state-of-the-art of the field in Europe and worldwide.
- To provide an outlook for the next three to five years comprising close interaction with experts from the US and Japan.
- To discuss funding issues at the European level.

Finally, the draft proposal to the open ESF RNP call was discussed at length. In the meantime, as it was agreed during the Workshop, the convenor of the Workshop submitted the Constraining the Symmetry Energy (CoSymE) RNP proposal.

Scientific content

Heavy-ion reactions, in particular those induced by neutron-rich nuclei, especially radioactive beams, are a unique tool for obtaining information on the symmetry energy in the laboratory. A considerable activity is presently devoted to the symmetry energy at the sub-normal density regime resulting in a substantial progress in constraining the symmetry energy in the range of nuclear matter density $\rho/\rho_0 \sim 0.3-0.6$, where ρ_0 is the so-called normal nuclear density. Much more work is still needed to probe high-density behaviour of the symmetry energy. 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 subject of the Workshop was the isospin dependent term of nuclear equation of state, i.e. the Symmetry Energy with emphases on the problem of constraining the value of the symmetry energy by laboratory experiments at high densities (case of highly compressed nuclear matter). The sub-topics of the Workshop are:

- I. Reviewing the contemporary knowledge on the symmetry energy;
- II. Constraints of the symmetry energy at sub-normal densities (case of diluted nuclear matter);
- III. Information on the symmetry energy from the ground state properties of ordinary and exotic nuclei;
- IV. Astrophysical aspects of the symmetry energy problem;
- V. New observables to probe the symmetry energy at high densities;
- VI. Modelling nuclear EOS and isospin-sensitivity at low, normal and high densities;
- VII. Choice of the most appropriate experimental setup to infer the state-of-the-art information on the symmetry energy at high densities

The workshop topics were covered by 19 talks. Besides very animated discussions after most of delivered talks the Workshop offered several opportunities (round table discussions) for an ample exchange of opinions on how to best approach the very hard problem of constraining the value of the symmetry energy at high densities in a laboratory experiment. The most appropriate physical observables and the best suited detection apparatus were discussed at length. The necessary interaction with theorist was particularly addressed underlying a necessity for a new generation of transport codes which would greatly help the task of extracting the properties of the nuclear EOS in a broad range of densities. It is worth underlying that the Workshop excursion turned out to be a particularly well suited forum for informal contacts and very animated exchange of ideas and views on multifold facets of the symmetry energy problem.

In brief, the presentations covered the above mentioned topics as follow:

The symmetry energy at the so-called normal nuclear densities i.e. of ordinary and exotic nuclei at their ground state or at low excitations close to the ground state was discussed by P. Danielewicz and N. Paar. The symmetry energy of diluted nuclear matter (at sub-normal densities) was presented by R. Bougault and A. Chbihi. V. Foehr discussed the role of momentum dependence of the nuclear mean field on the symmetry energy. Most of talks were devoted to the high density symmetry energy problem both experimentally (B. Jakobsson, Y. Leifels, J. Lukasik, W. Trautmann, P.Z. Wu and M. Zorić) and theoretically (D.M. Cozma, M. Di Toro, P. Russotto and H.H. Wolter). B.-A. Li and in particular J. Aichelin addressed a serious problem of predictive limits of contemporary transport codes largely used in extracting the physical information from heavy-ion reaction dynamics and in particular of the symmetry energy fingerprints on dynamical observables. B. Jakobsson, P. Pawlowski and P. Russotto presented possible experimental solutions to the problem of constraining the high density symmetry energy. D.B. Blaschke delivered a review talk on the symmetry energy problem seen from the Astrophysics-of-Compact-Stars point of view.

More details on the HiDeSymEne ESF Exploratory Workshop may be found at the Workshop website URL <http://www.irb.hr/users/mkis/> where an interested reader may find all delivered presentations.

Assessment of the results and the future direction

The workshop was very useful for establishing new interactions between the participants and strengthening existing ones. The experimental physicists were able to learn more about the recent advances in theoretical description of the symmetry energy problem from both nuclear and astrophysical viewpoint. On the other hand, theoreticians got a better insight into the existing experimental capabilities and those becoming available in the near future. The participants came to the conclusion that the best preparation for the future tasks in this flourishing topic can be achieved via strengthening already existing efforts in both communities by carrying on the networking activities. In fact, practical steps in that direction were undertaken several months before the Workshop. A kind of steering committee has been established which by exchanging information via e-mail started a work on effectuating the common wish to pursue the activity on constraining the symmetry energy term of nuclear EOS on a more formal and durable grounds. Besides the formation of a new collaboration around the recently proposed high-energy heavy-ion experiment at the GSI facility, Darmstadt, Germany named ASY-EOS we decided to submit a proposal for networking activities offered on an annual base by the ESF. Since the deadline for the ESF Research Networking Programme (RNP) submission was shortly after the Workshop a broad discussion took place on how to on the best way present this proposal. To that aim the workshop excursion turned out to be a particularly well suited forum of informal discussions. As agreed during the Workshop the convenor of the Workshop took the responsibility of the proposal contact person and submitted the RNP proposal Constraining the Symmetry Energy (CoSymE). The proposal is registered under reference number 09-RNP-069 (see attached page).

APPLICATION

Ref. Number

5 257

Submission date

19/10/2009

PROPOSAL DETAILS

Domain

PESC

Additional Domain(s)

Proposal Title

Constraining the Symmetry Energy

Acronym

CoSymE

Duration (months)

60

Budget Req.

575000 €

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.

Information on previous 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 and expansion of the activities launched by the HiDeSymEne.

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PROGRAMME

Thursday, 15 October 2009

Afternoon	<i>Arrival</i>
19.00	<i>Dinner</i>
21.00	<i>Get-together at the hotel lobby</i>

Friday, 16 October 2009

09.15-09.30	Welcome by Convenor with a Presentation of the European Science Foundation (ESF) Instruments Z. Basrak (IRB, Zagreb, Croatia)
09.30-12.45	Morning Session I: Recent View on the HiDeSymEne (I) (Chairman: B. Jakobsson)
09.30-10.15	"Symmetry Energy in Nuclear Ground State" P. Danielewicz (MSU/NSCL, East Lansing, USA)
10.15-10.45	"Isotopic Flows in Au+Au at 400 A MeV" W. Trautmann (GSI, Darmstadt, Germany)
10.45-11.15	<i>Coffee / Tea Break</i>
	Morning Session II: Recent View on the HiDeSymEne (II) (Chairman: J. Aichelin)
11.15-12.00	"Current Theoretical View on the High Density Symmetry Energy Problem" B.-A. Li (TA&M, Commerce, USA)
12.00-12.45	"Constraints on the Asymmetry Energy Term of Nuclear Equation-of-State from Astrophysical Observations" D.B. Blaschke (ITP, Wroclaw, Poland)
12.45-14.30	<i>Lunch</i>
14.30-18.30	Afternoon Session I: Recent View on the HiDeSymEne (III) (Chairman: P. Danielewicz)
14.30-15.00	"What one has Learned on the Asymmetry Energy Term of Nuclear Equation-of-State in the FOPI Experiments" Y. Leifels (GSI, Darmstadt, Germany)
15.00-15.30	"Isotopic Effects with INDRA@GSI" J. Lukasik (IFJ-PAN, Krakow, Poland)
15.30-16.00	"High-Precision Momentum Measurements of Fragmentation Residues from $^{112}\text{Sn}+^{112}\text{Sn}$ and $^{124}\text{Sn}+^{124}\text{Sn}$ Collisions at 1 AGeV" V. Foehr (GSI, Darmstadt, Germany)
16.00-16.30	<i>Coffee / tea break</i>

Afternoon Session II: Towards Better Constraints of the HiDeSymEne (I) (Chairman: B.-A. Li)

- 16.30-17.00 **"On the Influence of the Asymmetry Energy on the Dynamics of High Energy Nucleons"**
J. Aichelin (Subatech, Nantes, France)
- 17.00-17.30 **"Isospin Effects on Particle Production, Flows and Phase Transitions at High Baryon Density"**
M. Di Toro (INFN-LNS, Catania, Italy)
- 17.30-18.00 **"Symmetry Energy Effects in Particle Production"**
H.H. Wolter (Univ. of Munich, Munich, Germany)
- 18.00-18.30 **"Status of the UrQMD Predictions"**
P. Russotto (INFN-LNS, Catania, Italy)
- 18.30-19.00 **"Dependence of Flow Observables in Heavy-Ion Collisions on the Isospin Dependent EoS of Nuclear Matter"**
D.M. Cozma (NIPNE, Magurele/Bucharest, Romania)
- 19.30 *Dinner*

Saturday, 17 October 2009

- 08.00-16.30 Workshop Excursion with Lunch Included Providing an Ample Opportunities for Discussion**
- 16.30-19.00 Afternoon Session: Towards Better Constraints of the HiDeSymEne (II) (Chairman: H.H. Wolter)**
- 16.30-17.00 **"What Interferometry May Bring to the Study of High Density Symmetry Energy"**
B. Jakobsson (Lund Univ., Lund, Sweden)
- 17.00-17.20 **"Study of the Symmetry Energy with Isotopic Distributions"**
A. Chbihi (GANIL, Caen, France)
- 17.20-17.40 **"Sideward Wall Detector for the ASY-EOS Experiment"**
P. Pawlowski (IFJ-PAN, Krakow, Poland)
- 17.40-18.00 **"The Nuclear Equation of State and the Symmetry Energy"**
P.Z. Wu (OLL, Liverpool, United Kingdom)
- 18.00-19.00 **Discussion**
- 19.30 *Dinner*

Sunday, 18 October 2009

- 09.00-12.30 Morning Session I: Recent View on the HiDeSymEne (IV) (Chairman: M. Di Toro)**
- 09.00-09.30 **" $^{136,124}\text{Xe} + ^{124,112}\text{Sn}$ INDRA Experiment and SMF Results"**
R. Bougault (LPC, Caen, France)
- 09.30-10.00 **"Density Dependence of the Symmetry Energy Close to Normal Density from Neutron Skin Thickness and Dipole Excitations"**
N. Paar (Univ. of Zagreb, Zagreb, Croatia)
- 10.00-10.15 **"Energy and Isospin Dependence of Elliptic Flow – An Alternative Analysis of the LAND-FOPI Data"**
M. Zorić (IRB, Zagreb, Croatia)

10.15-10.45	<i>Coffee / Tea Break</i>
	Morning Session II: Towards Better Constraints of the HiDeSymEne (III) (Chairmen: Y. Leifels and G. Verde)
10.45-12.30	Round Table Discussion and Recommendations (Test experiment outcome, main beam time preparation, etc.)
12.30-14.00	<i>Lunch</i>
14.00-16.00	Afternoon Session: Futur of the HiDeSymEne: Discussion on Follow-up Activities/Networking/Collaboration (Chairmen: Z. Basrak, D. Blaschke and W. Trautmann)
16.00	<i>End of Workshop and departure</i>

List of Participants

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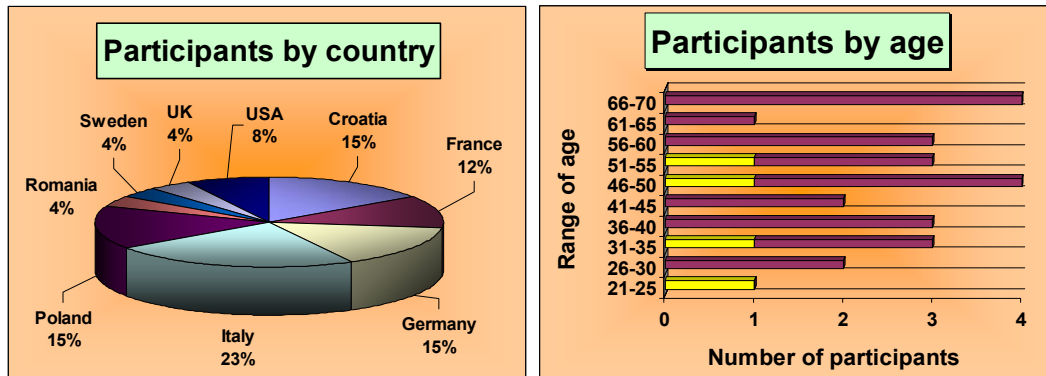
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Statistical information on participants

The workshop has been held with 26 attendees from 8 European countries (each an ESF member state) and the United States. Number of participants from a single country ranged from one to 6 (on the average 2.9 participants per country, see the pie-type graph below).



The age of participants has been distributed more or less regularly and ranged from doctoral students to professors close to the retirement age (see the bar-type graph above). Among participants there were 4 ladies physicist (in the bar-type graph above bars colored yellow) and 22 men physicist (bars colored violet). It should be noticed that two ladies (Dr. A. K. from GSI, Germany and Dr. M. C. from Univ. of Liverpool, UK) had to cancel their participation due to the pregnancy. Also, 7 other participants could not attend the Workshop some of them in the very last moment (Prof. Q. L. from China due to visa problem, Profs. T. A. from Germany, J. B. from Spain, J. B. from Poland, C. H. from France and A. P. from Italy due to urgent meetings and Dr. R. L. from UK due to baby delivery of his wife). Only some of them could be replaced by other participants so that number of participants from the planned 30 dropped to 26.