ECT* WORKSHOP SCIENTIFIC REPORT

Simulating the Supernova Neutrinosphere with Heavy Ion Collisions

7-11 April 2014

ORGANIZERS

C. Horowitz (Indiana University, USA)
J. Natowitz (Texas A&M University, USA)
L. Roberts (Caltech, USA)
H. Wolter (Munich, Germany)

MAIN TOPICS

The idea of this workshop was to explore the feasibility of reproducing supernova neutrinosphere conditions in the laboratory using heavy ion collisions with both stable and radioactive beams. Thus the workshop discussed the following main topics:
1) The equation of state and neutrino opacities of low-density neutron rich matter.
2) Using heavy ions to probe conditions in the supernova neutrino emission region.
3) Light cluster formation in heavy ion collisions and in the supernova neutrino sphere.
4) Neutrino emission and nucleosynthesis in core collapse supernovae.

A special aspect of this workshop was to bring together different communities in nuclear and astrophysics to discuss these questions: heavy ion experimentalists and theorists, many-body theorists, astrophysicists, and neutrino physicists. We succeeded in attracting representatives from most of the important groups currently working in these fields. A list of speakers and the program are provided as an attachment to this report. The intention of the workshop was to initiate a longer-term joint effort on this topic within the communities represented.

SCIENTIFIC REPORT:

Core collapse supernovae (SN) are giant explosions of massive stars that are dominated by neutrino emission. Much of the "action" in these SN occurs at sub-saturation densities near the neutrinosphere. The neutrinosphere is the surface of last scattering for the neutrinos and occurs at densities of 1/1000 to 1/10 of nuclear density and at temperatures near 4-5 MeV. The thermodynamical properties of this medium, in particular the composition, are important for the neutrino opacities, which in turn help determine the spectrum of emitted neutrinos, the composition of the neutrino driven wind, and the resulting nucleosynthesis. In the workshop we discussed how these conditions can be produced in low to intermediate energy heavy ion collisions (HIC), since in the expansion phase of a HIC the composition freezes out at similar densities and temperatures to those of the neutrinosphere, and light clusters such as deuterons, tritons, or alpha particles are formed.

The workshop discussed the validity of a statistical treatment of this freeze-out approximation, ways to measure temperatures and densities in this phase, and how to infer the symmetry energy. Predictions from many-body approaches for the equation of state of warm low-density matter including clusters were critically discussed. In addition we talked about improving procedures to include light cluster formation in transport models used to

simulate heavy ion collisions. Astrophysical simulations of core collapse supernovae were reviewed emphasising the important role of neutrinos, and neutrino interactions and the need for inclusion of the effects of the symmetry energy and of light clusters in modelling neutrino interactions.

RESULTS AND FUTURE PLANS

Neutrino interactions were shown to depend significantly on the symmetry energy of low-density matter and to modify the energy difference between emitted electron neutrinos and antineutrinos. This energy difference in turn helps determine the composition of the neutrino driven wind and is very important for nucleosynthesis. A tremendous amount of very careful work has been performed to extract the conditions of the freeze-out configuration in HIC. However, this analysis has to be done self-consistently using binding energies and volumes of medium modified clusters. Methods using a coalescence approach and correlation functions should be compared. For the treatment of cluster production in transport models different approaches exist which should be compared and checked against each other. Also a direct interface between HIC and supernova simulations is the neutrino response function, which could be directly obtained from appropriate transport models.

Based upon these considerations the workshop suggested a number of action items for future work.

1) Use transport models, that are calibrated to HIC data, to simulate the low density warm matter present in supernovae and calculate the dynamical response functions $S(q,\omega)$. These describe how a neutrino scatters from the medium while transferring momentum q and energy ω.
2) Explore how the composition of light clusters depends on the N/Z ratio of colliding nuclei using both stable and radioactive beams. This will help with informed extrapolations to the very neutron rich conditions of the neutrino-sphere.
3) Check the extraction of freeze out volumes and densities from the two methods used in the interpretation of HIC: correlation functions of various light particle pairs and coalescence methods.
4) Work on the improvement of the description of light clusters in transport models and codes.
5) (Re)analyze additional existing HIC data sets to determine light cluster compositions.
6) Develop a website and WIKI to foster communication among heavy ion and astrophysical communities.
7) Provide a short white paper on the HIC/supernova neutrinosphere physics for the low energy community meeting in Texas in August 2014 and for the next US Long Range Plan for nuclear physics.
8) We should hold a follow up workshop to maintain momentum in about two years, perhaps at the Institute for Nuclear Theory in Seattle or again at the ECT*, which provided a very agreeable atmosphere for this workshop. Such a workshop could be called "Femtonova II" (a Femtonova is a very small new star).

ATTACHMENT:

NUMBER OF PARTICIPANTS: **35**

SPEAKERS:

M.Barbui (Texas A&M, USA)
D. Blaschke (Wroclav, Germany)
A. Bonasera (Texas A&M, USA)
E. Bonnet (GANIL, France)
A.Chbihi (GANIL, France)
T. Fischer (Wroclav, Poland)
C. Froehlich (N. Carolina State, USA)
T. Gaitanos (Giessen, Germany)
K. Hagel (Texas A&M, USA)
M. Hempel (Basel, Switzerland)
E. Lentz (Tennessee, USA)
W. Lynch (MSU, USA)
G. Martinez-Pinedo (TU Darmsdadt, Germany)
G. McLaughlin (N. Carolina State, USA)
B. Mueller (Garching, Germany)
A. Mukherjee (ECT*, Italy)
J. Natowitz (Texas A&M, USA)
P. Napolitani (Orsay, France)
E. O'Connor (Tronto, Canada)
A. Ono (Tohoku, Japan)
A. Raduta (Bukarest, Romania)
S. Reddy (INT Seattle, USA)
G. Roepke (Rostock, Germany)
G. Shen (TU Darmsdadt, China)
S. Shlomo (Texas A&M, USA)
W. Trautmann (GSI, Germany)
S. Typel (GSI, Germany)
G. Verde (Catania, Italy)
S. Wanajo(NAO, Japan)
A. Wuosmaa (U. Connecticut, USA)
S. Yennello (Texas A&M, USA)

Program: Simulating the Supernova Neutrinosphere with Heavy Ion Collisions
ECT* Trento, Italy, April 7-11, 2014
All talks are 30 min long, except as noted.

9:30 to 12:45 Monday morning: Introduction
W. Lynch (MSU): Introduction to heavy ion collisions (HIC) (45 min)
10:45 to 11:15 Coffee break

E. O'Connor (Tronto): Introduction to supernovae (SN) and SN simulations (45 min)
D. Blaschke (Wroclav): Introduction toequation of state (EOS) for supernovae, compact stars, and HIC applications (45 min)

14:30 to 18:00 Monday afternoon: Equation of stateand symmetry energy
G. Verde (Catania): Space-time properties of dynamical sources in Heavy-Ion collisions
A. Bonasera (Texas A&M): (Density and temperature determinations in HIC)
15:40 to 16:10 Coffee break
A.Chbihi (GANIL): Exploring the symmetry energy with isospin effects in heavy-ion collisions
C. Froehlich (N. Carolina State): Neutrinos and supernova nucleosynthesis
Discussion (leader C. Horowitz): Plans for the week, questions/issues for discussion.

9:30 to 12:20 Tuesday morning: SN and probing SN conditions with HIC
E. Lentz (Tennessee): (Supernova simulations)
T. Fischer (Wroclav): Protoneutron star deleptonization - role of the nuclear symmetry energy
10:40 to 11:10 Coffee break
M. Hempel (Basel): EOS effects in core-collapse supernovae
S. Yennello (Texas A&M):Asymmetry dependence of the nuclear caloric curve

14:20 to 18:00 Tuesday afternoon: Probing SN matter with HIC
S. Reddy (INT Seattle): Colloquium: "Supernova Neutrinos: Challenges and its physics potential" (50 min)
15:20 to 15:50 Coffee break
E. Bonnet (GANIL): Vaporization event properties to constrain low-density warm matter
W. Trautmann (GSI): Low-density matter probed in multifragmentation reactions
Discussion: Building nuclear and astrophysics communities

9:30 to 12:20 Wednesday morning: Light clusters in HIC
K. Hagel (Texas A&M): Clusterization and medium effects in low-density nuclear matter
J. Natowitz (Texas A&M): Pastina formation in neutron rich nuclear skins
10:40 to 11:10 Coffee break
A. Ono (Tohoku): Light cluster production in Anti-symmeterized Molecular Dynamics (AMD)
P. Napolitani (Orsay): Fluctuation and fragment production in HIC; Boltzmann-Langevin approach

14:20 to 18:00 Wednesday afternoon: Light clusters in HIC continued
M.Barbui (Texas A&M): Exploring the alpha cluster structure of nuclei using the thick target inverse kinematics technique for multiple alpha decays
S. Typel (GSI): Clustering in dilute matter and equation of state
15:30 to 16:00 Coffee break
A. Raduta (Bukarest): Clusterized nuclear matter in the (proto-) neutron star crust and the symmetry energy

G. Roepke (Rostock):Few-particle correlations in nuclear systems
Discussion (leader H. Wolter): light clusters in HIC and astrophysics

9:30 to 12:20 Thursday morning: SN, neutrino emission, and nucleosynthesis
B. Mueller (Garching): The Role of Neutrinos in Supernovae
G. Shen (TU Darmsdadt): (Neutrino response of warm low-density matter)
10:40 to 11:10 Coffee break
G. Martinez-Pinedo (TU Darmsdadt): Nucleosynthesis in Neutrino Winds
A. Wuosmaa (U. Connecticut):Studying the properties of neutron-rich light nuclei

14:20 to 18:00 Thursday afternoon: neutrinos and nucleosynthesis
G. McLaughlin (N. Carolina State): Neutrinos from black-hole accretion disks
S. Wanajo(NAO, Japan):(r-process in SN and neutron star mergers)
15:30 to 16:00 Coffee break
TBA: Informal talk on SN neutrino oscillations and SN neutrino detection.
Discussion (leader L. Roberts): Neutrinos in SN and nucleosynthesis

9:30 to 12:20 Friday morning: Nuclear structure related to SN and HIC
A. Mukherjee (ECT*): Quantum Monte Carlo calculations for the equation of state with chiral interactions
S. Shlomo (Texas A&M):Modern energy density functional and the equation of state of symmetric and asymmetric nuclear matter
10:40 to 11:10 Coffee break
T. Gaitanos (Giessen): Participant and spectator decay in HIC
Discussion (leaders J. Natowitz + C. Horowitz): A way forward, possible experimental program, and homework assignments

13:00 End of the workshop