Simulating the Supernova Neutrinosphere with Heavy Ion Collisions

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Abstract:

We propose a one week ECT* workshop to explore reproducing supernova neutrinosphere conditions in the laboratory using heavy ion collisions with radioactive beams. Much of the "action" in core collapse supernovae happens near the neutrinosphere. This surface of last scattering is a warm low-density gas of neutron rich matter. By studying this gas, its composition, correlations, and equation of state in the laboratory, one will be able to make better predictions for supernova neutrino spectra and nucleosynthesis. The workshop will involve heavy ion experimentalists and theorists, many-body theorists, astrophysicists, and neutrino physicists.

Scientific proposal:

The properties of matter near the surface of last neutrino scattering, the neutrino sphere, determine the spectra of neutrinos emitted during core collapse supernovae and can have an important bearing on many aspects of these events. This material is a warm low-density gas of neutron rich matter. Recently several groups have come to appreciate that the neutrinosphere region is not just a free gas of neutrons and protons, but may also contain light nuclei and important correlations. These many-body corrections can significantly impact neutrino opacities and thereby the emitted neutrino spectra. This may be particularly important for nucleosynthesis in the innermost regions of core collapse supernovae.

Remarkably, many properties of the neutrinosphere can be directly reproduced in the laboratory with heavy ion collisions. Temperatures near 5 MeV are easy to achieve, while low subnuclear densities can be studied, for example, by observing intermediate velocity fragments from peripheral collisions. Perhaps the most difficult property of the neutrinosphere to reproduce is the large expected ratio of neutrons to protons. However new radioactive beam machines, such as RIKEN (in operation), FRIB (planned for ~2019), or R3B/FAIR (planned for ~2018) will allow HI collisions involving more neutron rich systems. By comparing results for more proton rich and more neutron rich systems, it should be possible to extrapolate to extremely neutron rich systems.

These laboratory experiments can measure the composition of light clusters and infer the symmetry energy and equation of state of asymmetric matter at very low density. This will motivate and help constrain new microscopic theoretical approaches to warm low-density matter that describe correlations and the formation of clusters in the medium. These approaches should provide robust predictions for the equation of state, composition, and neutrino interactions near the neutrinosphere. As a result, astrophysical simulations will be able to make more accurate predictions of the emitted neutrino spectra and of nucleosynthesis.

We propose a one-week ECT* workshop (during the spring of 2014) that will bring together a broad mixture of neutrino, astro, heavy ion, cold atom, and nuclear physicists to explore neutrinosphere physics. The goals of the workshop are fourfold: (1) to produce better equations of state and neutrino interactions for supernova simulations, and (2) to improve our understanding of light cluster formation in heavy ion collisions, (3) to initiate a new experimental collaboration (NuSphere@RIB) to reproduce neutrinosphere like conditions in the laboratory with heavy ion collisions, and finally (4) to improve communications between this broad range of physicists.

Draft workshop program:

I) Core collapse supernovae.
  a. Overview and introduction.
  b. Multidimensional simulations, the present state of the art.
  c. Neutrino transport methods
  d. Equation of state for SN simulations.

II) Heavy ion collisions at low energies.
  a. Overview and introduction.
  b. Isolating low-density regions.
  c. Cluster formation and experimental observables.

III) Supernova neutrinos.
  a. Neutrino interactions in dense matter.
  b. Predicted neutrino spectra and differences between ν_e and anti-ν_e energies.
  c. Impact of light clusters on neutrino opacities.
  d. Neutrino oscillations.
  e. Supernova neutrino detectors.
  f. Neutrinos and nucleosynthesis.

IV) Cluster formation approaches.
  a. Virial expansion.
  b. Quantum statistical models.
  c. Transport models with clusters.

V) Opportunities with radioactive beams.
  a. Role of symmetry energy.
  b. Asymmetry dependence of fragment yields.
  c. Extrapolation to very neutron rich systems.
  d. Experimental possibilities.
  e. Practical considerations.