Nature of Dilute and Dense Nuclear Matter and Equation of State

From Earth to Heavens: Direct connection of physics from femto-scale nuclei to Astrophysical objects

- Nucleus-nucleus collisions to recreate dilute and dense nuclear matter from very low ($0.01\rho_0$) to high (~2-3$\rho_0$) density to recreate environment relevant to astrophysics; to probe fundamental nuclear physics questions.
- Collisions at low energy allow study of the supernova neutrinosphere physics and symmetry energy at very low density.
- Structure experiments including masses and skin measurements to probe saturation density region.
- Collisions at around $2\rho_0$ are crucial for the understanding of the n-star properties and dynamics.
Future Plans and Challenges

- **At \( \rho \ll \rho_0 \):** Establish observables to benchmark studies relevant to the neutrino-sphere and clustering effects in low density EoS, and alpha clustering at the nuclear surface of heavy nucleus.
- **At \( \rho \leq \rho_0 \):** Obtain more precise isospin transport, n/p, t/3He ratios, and GR. Run PREXII and CREX measurements.
- **At \( \rho > \rho_0 \):** Determine momentum dependence of symmetry potentials by measuring more relevant data on the ratios of mirror nuclei spectra.
- **At \( \rho \approx 1.5-2 \rho_0 \):** Probe symmetry energy at supra-saturation densities by comparing the energy spectra and flow of isospin multiplets using new TPC detectors.
Theoretical Challenges

Verification and validation of theory and data

- Strong theory support needed to aide in understanding observed phenomenon accessible with current and planned facilities.
- More accurate theoretical modeling of isospin transport, nucleon flow data and GMR excitation energies.
  - Better understanding of cluster formation and alpha clustering in the surface
  - Better understanding of particle production mechanism and threshold effects
  - Better understanding of the connection to neutron star phenomena
- Quantify theoretical uncertainties.
Resources Needed

Multi-Laboratory experimental programs; New Detectors & collaborations

- US RI/stable beam facilities (FRIB, NSCL, TAMU, FSU, JLAB);
- Complementary facility worldwide: Meinz, RCNP, RIKEN, GSI, ....
- High Rigidity Spectrometer (HRS) to detect residues; HRTPC at the HRS for FRIB (but can be used at NSCL now) to access the most neutron-rich beams over a wide range of energies, corresponding to a large range of density and collision asymmetries.
- Updated Instrumentation to measure n and charged particles.
- Need theory support with immediate impact on experimental plans
- Manpower, faculty, postdocs, students, theorists.
- Co-ordinate international effort to study EOS over a range of densities.
- Co-ordinate communications between interdisciplinary fields.