Quark-Gluon Plasma in the NDL Equation of State for Supernova Simulations

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Core-Collapse Supernovae Simulation

Routine Components

- Hydrodynamics
- Neutrino Transport
- Equation of State
Core-Collapse Supernovae Simulation

Routine Components

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Equation of State Archetypes

Commonly Used
- Liquid Drop Model
  - Lattimer & Swesty
- Relativistic Mean Field Theory
  - Shen et. al.

Ours
- Density Functional Theory
  - NDL EoS
Regimes

Low Density

NSE

n, p, 4He, 12C, 16O, 20Ne, 24Mg, 28Si, 56Ni

α, <A>

NSE

Not in NSE

Hadrons

n, p

Pions

n, p

π⁺, π⁻, π⁰

Quark Gluon Plasma?

Nuclear Saturation Density
Mixed Phase Transition

Volume Fraction:
\[ \chi \equiv \frac{V_Q}{V_H + V_Q} \]

Conserve:
- Pressure
- Charge
- Baryon Number
Pure Quark-Gluon Plasma

Grand Potential Function

\[ \Omega = \Omega_q^{(0)} + \Omega_g^{(0)} + \Omega_q^{(2)} + \Omega_g^{(2)} + BV \]

3 flavors of quarks

strong coupling \( \propto \alpha_s \)

\[ P = - \left( \frac{\partial \Omega}{\partial V} \right)_{\mu,T,Y_e} \quad ; \quad S = - \left( \frac{\partial \Omega}{\partial T} \right)_{\mu,V,Y_e} \]
Phase Diagram

Temperature (MeV) vs. Baryon Number Density (fm$^{-3}$) for different values of $Y_e$.
Collapse: $\Gamma < \frac{4}{3}$
EoS Prediction:
Neutron Star Mass vs. Radius Relation

![Graph showing the relationship between neutron star mass and radius for different EoS models.](image-url)
EoS Prediction:
Neutron Star Mass vs. Radius Relation
Mixed QGP cores not excluded!
Varying the Bag Constant

Mixed QGP cores not excluded!
Future Work

- Supernovae simulation runs, with and without QGP phase, for various B and $\alpha_s$
- Neutrino spectrum from Blackhole Formation
Questions?