1, Physics in Supernova

- Equation of State (EOS)
  - Stiffness
  - Pressure, entropy, nuclear composition, etc.
  - Calculation: minimization of free energy density under baryon and charge conservation
  \[ f = f_{\text{nu,n}} + \sum_{AZ} n_{AZ}(E_{AZ}^{\text{kin}} + M_{AZ}) \]

- Weak Interactions
  - Neutrino-absorption
  - Neutrino-emission, e.g. Electron Capture (EC)
  - Neutrino-scattering rates, e.g. (N,Z) + ν → (N,Z) + ν

- Hydrodynamics

- Neutrino Transport

2, Roles of Input Physics in Core-Collapse Supernovae

- Core-Collapse of Massive Stars
  - \((\rho, T, Y_e): (10^{10} \text{ g/cc}, 0.5 \text{ MeV}, 0.46)\)
  - Iron group nuclei ⇒ Which nuclei?
  - Core deleptonization (decrease \(Y_e\)) is sensitive to Nuclear weak interactions at \(\rho \sim 10^{11-12} \text{ g/cc}\).

- Energy Sources of Explosion & Neutrinos
  - Release of gravitational energy
  \[ \Delta E_{\text{gra}} = G M_{\text{PNS}}^2 / r_{\text{PNS}} \sim 10^{53} \text{ erg} \]

- Impact of Input Physics (EOS and Weak Rates)
  - Structure of proto neutron star (PNS)
  - Energy of supernova explosion \(E_{\text{SN}}\)
  - Neutrino emission \(L_\nu\)

3, Equations of State [1]

- Statistical Equation of State
  - Input: \(\rho, T, Y_e\)
  - Output: pressure, entropy, nuclear composition, etc.
  - Calculation: minimization of free energy density under baryon and charge conservation

- In EOSs and EOS Model List
  - Bulk properties: \(f_{\text{nu,n}}\) and nuclear bulk energies
  - Mass data: masses of neutron-rich nuclei at \(T=0\)
  - Partition function: function of temperature modifications

- Ratio of Exiting States to Ground State

- Figure: \(\frac{f_{\text{nu,n}}}{f_{\text{nu,n}}+f_{\text{p,n}}}\)

- Figure: Partition functions are quite different at core-collapse temperatures.

4, Which Nuclei Appear? What Determines It? [1,2]

- Core-Collapse \(\rho, T, Y_e\)
  - Center of core-collapse of 15\(M_{\odot}\) \(\nu\) Juodagalvis+10

- Average Mass & Proton Numbers \(A,Z\)
  - Sensitive to partition functions
  - Stiffness a little reduces \(A\), \(Z\)
  - Coherent scattering rates \(\sigma(A^2)\) would change.

- Entropy \(s_B\)
  - Sensitive to partition functions
  - \(T, Y_e\) during collapse would change.

- Mass Fraction in Nuclear Chart

- Figure: 


- Setup of supernova simulations
  - 1D Supernova Simulations of 1.2 \(M_{\odot}\) based on Full-Boltzmann neutrino transport code [6]
  - Soft EOS (red lines) [7] based on AV18 and UXII nuclear potentials or Stiff EOS (black lines) [4] based on RMF with TM1
  - Lower EC rates (dashed lines) of data by Juodagalvis+10 or higher EC rates (solid lines) of data consistent with EOSs [1]

- Impact of Input Physics
  - Softer EOS ⇒ More compact PNS ⇒ More electron-antineutrinos
  - Higher EC rates ⇒ Less compact stellar structure & More neutrino absorptions ⇒ Less electron-antineutrinos
  - Neutrino observables may constrain on the nuclear properties (EOS & EC).