Equation of State Effects on Neutron Star Mergers

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QCD Phase Diagram:

- results from CMF model (without mixture of phases)
CMF (Chiral Mean Field) Model:

- extended non-linear realization of SU(3) sigma model
- uses pseudo-scalar mesons as parameters of chiral transformation
- includes baryon octet (+ leptons) and quarks
- fitted to reproduce nuclear, lattice QCD and astrophysical constraints
- effective masses

\[
\begin{align*}
    m_b^* &= g_{b\sigma}\sigma + g_{b\delta}\tau_3\delta + g_{b\zeta}\zeta + \delta m_b + g_{b\Phi}\Phi^2 \\
    m_q^* &= g_{q\sigma}\sigma + g_{q\delta}\tau_3\delta + g_{q\zeta}\zeta + \delta m_q + g_{q\Phi}(1 - \Phi)
\end{align*}
\]

- 1\textsuperscript{st} order phase transitions or crossovers (order parameters $\sigma$, $\Phi$)
- potential for $\Phi$ (deconfinement)

\[
U = (a_0 \, T^4 + a_1 \, \mu^4 + a_2 \, T^2 \mu^2)\phi^2 + a_3 \, T_0^4 \, \ln (1 - 6\phi^2 + 8\phi^3 - 3\phi^4)
\]
Neutron Star Matter: Local vs Global Charge Neutrality:

- absence / presence of mixture of phases: surface tension ???
- “mixed” quantities like \( \rho_B = \lambda \rho_B^Q + (1 - \lambda) \rho_B^H \)
Non-congruent Phase Transitions:

- more than one globally conserved charge within 2 macroscopic phases within a Coulomb-less model: baryon #, electric charge
- local concentration of a charges vary during phase transition
- same chemical potential (assoc. to charge) in both phases ($\mu_q$)
- very different from symmetric matter liquid-gas (LGS)
Proto-Neutron-Star Matter:

- charge neutral with $Y_l = 0.4$

- more than one conserved charge (baryon #, electric charge, lepton fraction): non-congruent phase transition!

\[ \tilde{\mu} = \mu_B + Y_l \mu_l \]
Perturbative QCD:

- 3-flavor QGP at zero temperature including β-equilibrium and charge neutrality
- Bag model failure!
Perturbative limit at $T=0$

- Chiral EoS until central density of most massive star ($\sim 2 \, M_{\text{Sun}}$)
- no vector interactions for quarks
Perturbative limit at finite temperature

- Chiral EoS limits from PQCD

\[ \begin{align*}
T &= 0: & \mu_B &= 1411.04 \text{ MeV} \\
T &= 45 \text{ MeV}: & \mu_B &= 1419.76 \text{ MeV} \\
T &= 100 \text{ MeV}: & \mu_B &= 1356.87 \text{ MeV} \\
T &= 0: & \mu_B &= 1421.69 \text{ MeV} \\
T &= 45 \text{ MeV}: & \mu_B &= 1429.09 \text{ MeV} \\
T &= 100 \text{ MeV}: & \mu_B &= 1364.08 \text{ MeV}
\end{align*} \]
Conclusions and Outlook

- more investigation of high density part of phase diagram is required (including comparisons with PQCD)!
  Signature for 1\textsuperscript{st} order phase transition from astrophysics?
- better understanding of congruent/non-congruent deconfinement phase transitions: finite temperature description, unified EOS (used for L-G transitions) and that provides particle population
- we already have a 3D star merger hadronic EoS table available online at CompOSE (Publ. Astron. Soc. Aust. 34 (2017) e066)
- we are testing the effects of quarks on star mergers using a 3D table
- we are about to include magnetic field and quark pairing effects