Binary neutron star mergers of quark matter based equations of state

Atul Kedia

University of Notre Dame
akedia@nd.edu
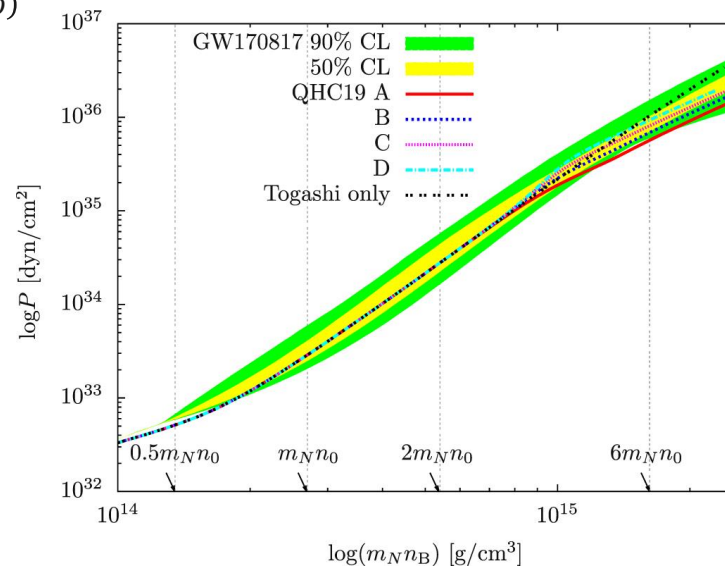
Collaborators: Grant Mathews[1], Hee Il Kim[2], In-Saeng Suh[1]
[1] University of Notre Dame, [2] Sogang University

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Dense matter Equation of State

Equation of state (EoS) in the form of Pressure v. density $P(\rho)$

Baym, Furusawa, Hatsuda et al. *ApJ* (2019) 885:42

Dense matter Equation of State

Equation of state (EoS) in the form of Pressure v. density $P(\rho)$

Quark-Hadron Crossover (QHC19A-D) EoS
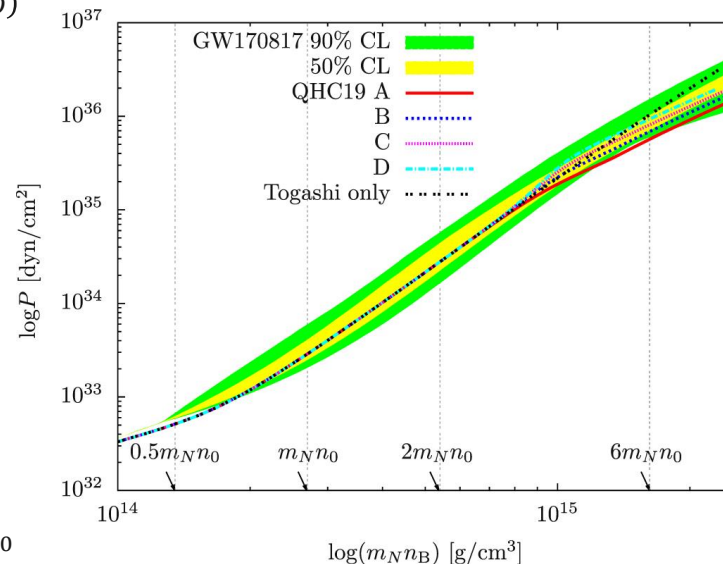*Baym et al. 2019, 2018,* Other's by Kurkela et al. *ApJ* (2014) 789:127

Cold EoS ($T = 0$)

Hadronic EoS: Togashi EoS (extension of APR) for densities
$$< 2n_0 \approx 5.4 \times 10^{14} \, gm/cm^3$$

Quark EoS: Nambu-Jona-Lasinio model
$$> 5n_0 \approx 1.3 \times 10^{15} \, gm/cm^3$$

Smooth fitting in the intermediate Crossover region: $2n_0 - 5n_0$

Baym, Furusawa, Hatsuda et al. *ApJ* (2019) 885:42

Piecewise polytropic fitting scheme

Fitting conditions:
- Pressure-density relation: $P(\rho) = K_i \rho^{\Gamma_i}$

- Internal energy density $\epsilon = a_i\, \rho + \frac{K_i}{\Gamma_i - 1}\, \rho^{\Gamma_i}$

- Continuity of pressure, internal energy is imposed.

Read, Lackey, Owen, Friedman *PRD* (2009) 79, 124032.

3 piece piecewise scheme (high density) capture all essential structure of the EoS, + SLy EoS at low densities.

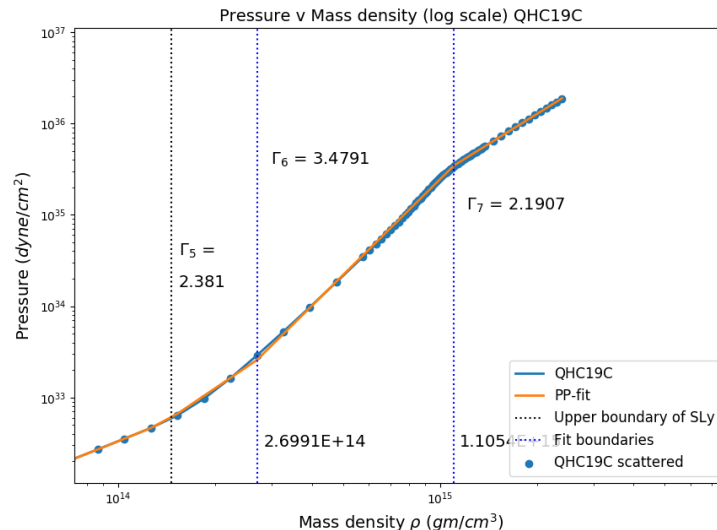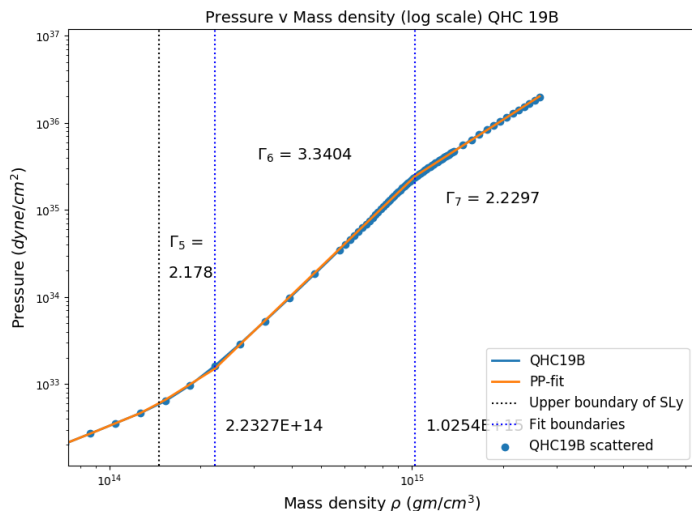Non-zero temperature corrections by $\Gamma_{thermal}$ contribution.
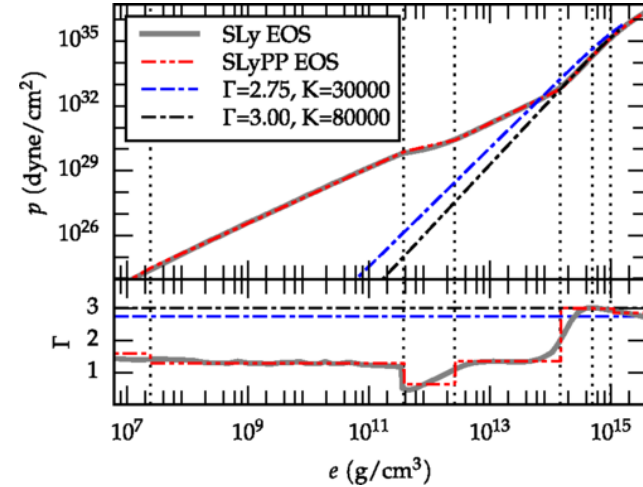
Pietri, Feo, Maione, Löffler *PRD* (2016) 93, 064047
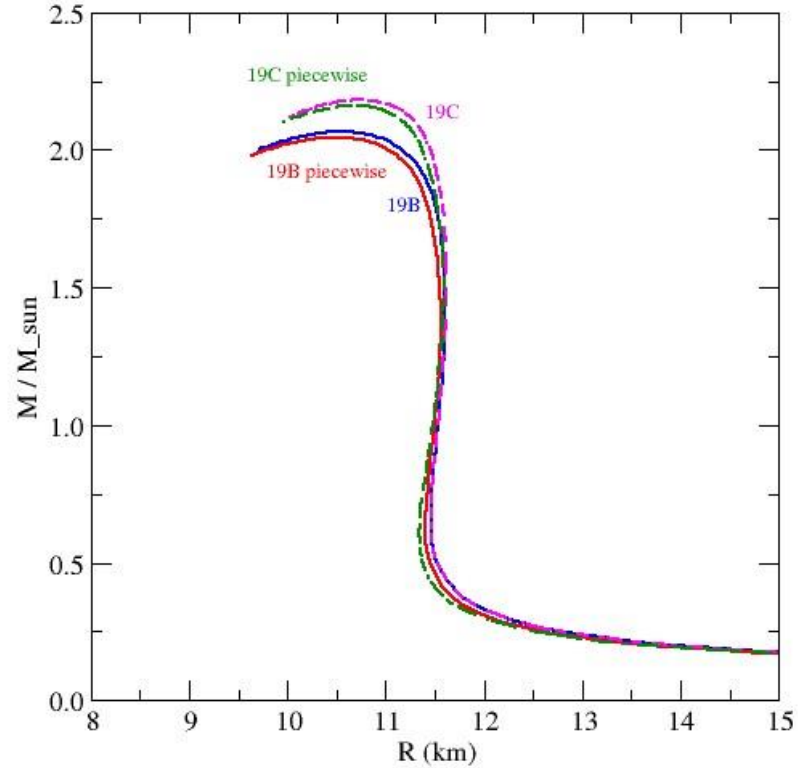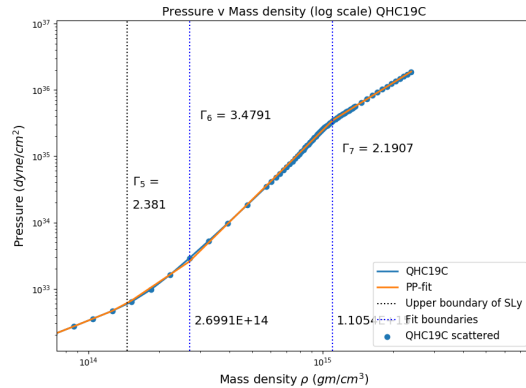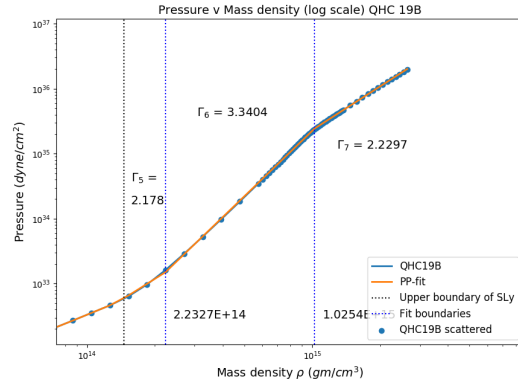
Parameterized QHC EoS piecewise

We fit the High density QHC region using this scheme and obtain the EoS Pieces:

Degrees of freedom in fitting $(\Gamma_5, \rho_5, \Gamma_6, \ \rho_6, \ \Gamma_7)$

RMS Residual = $\sqrt{\frac{1}{m} \ (\sum_{i \ (Pieces)} \sum_{j (Densities)} (\log P_j \ - \ \log K_i - \Gamma_i \ \log \rho_j)^2)} = 0.014$ i.e. $\log P = 35 \ \pm \ 0.014$.
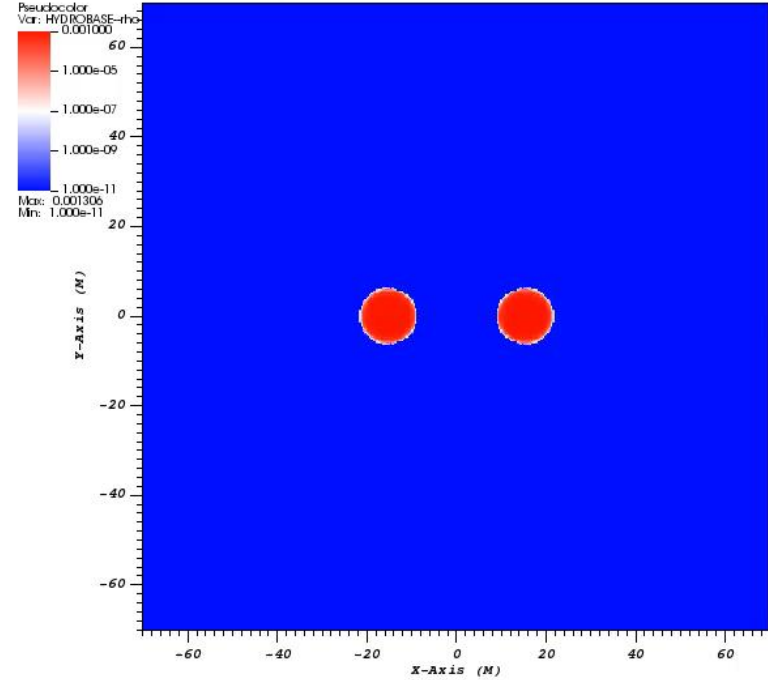
Mass-Radius relations of QHC19
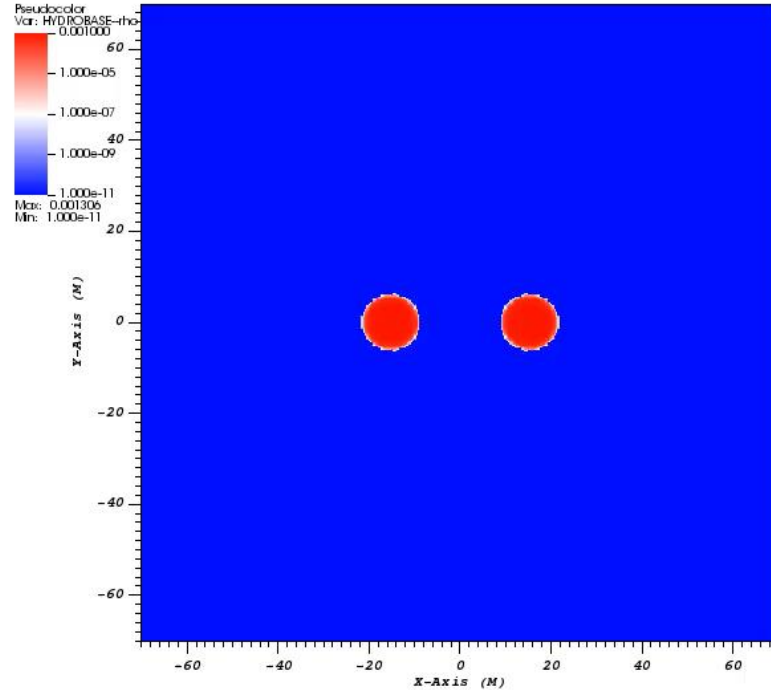
Pressure v Mass density (log scale) QHC 19B

$\Gamma_6 = 3.3404$

$\Gamma_7 = 2.2297$

$\Gamma_5 = 2.178$

2.2327E+14   1.0254E

- QHC19B
- PP-fit
- Upper boundary of SLy
- Fit boundaries
- QHC19B scattered

Pressure v Mass density (log scale) QHC19C

$\Gamma_6 = 3.4791$

$\Gamma_7 = 2.1907$

$\Gamma_5 = 2.381$

2.6991E+14   1.1054

- QHC19C
- PP-fit
- Upper boundary of SLy
- Fit boundaries
- QHC19C scattered

19C piecewise

19C

19B piecewise

19B

Merger for QHC19C

Mergers of 19B v 19C
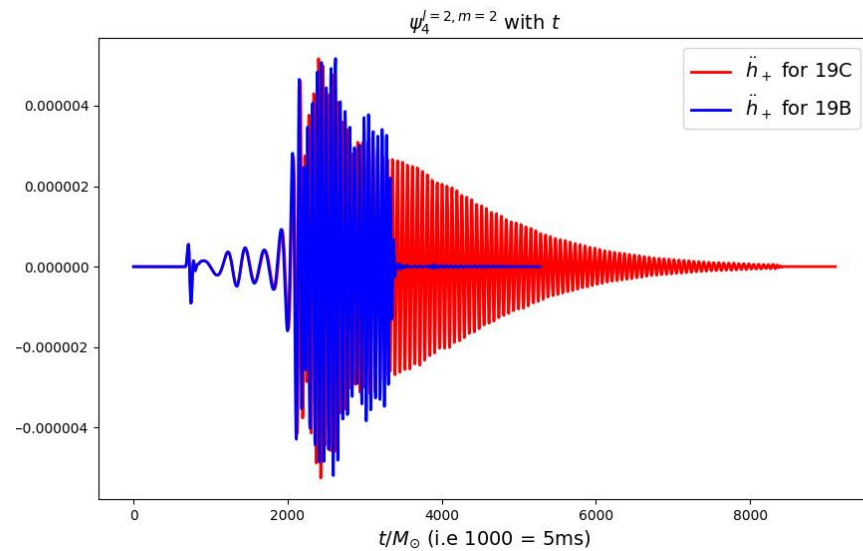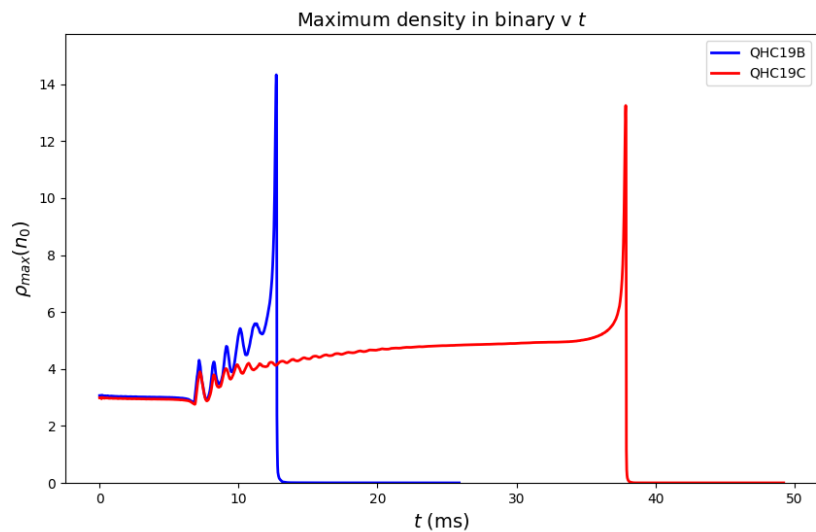
Convergence and Spectrum of 19B
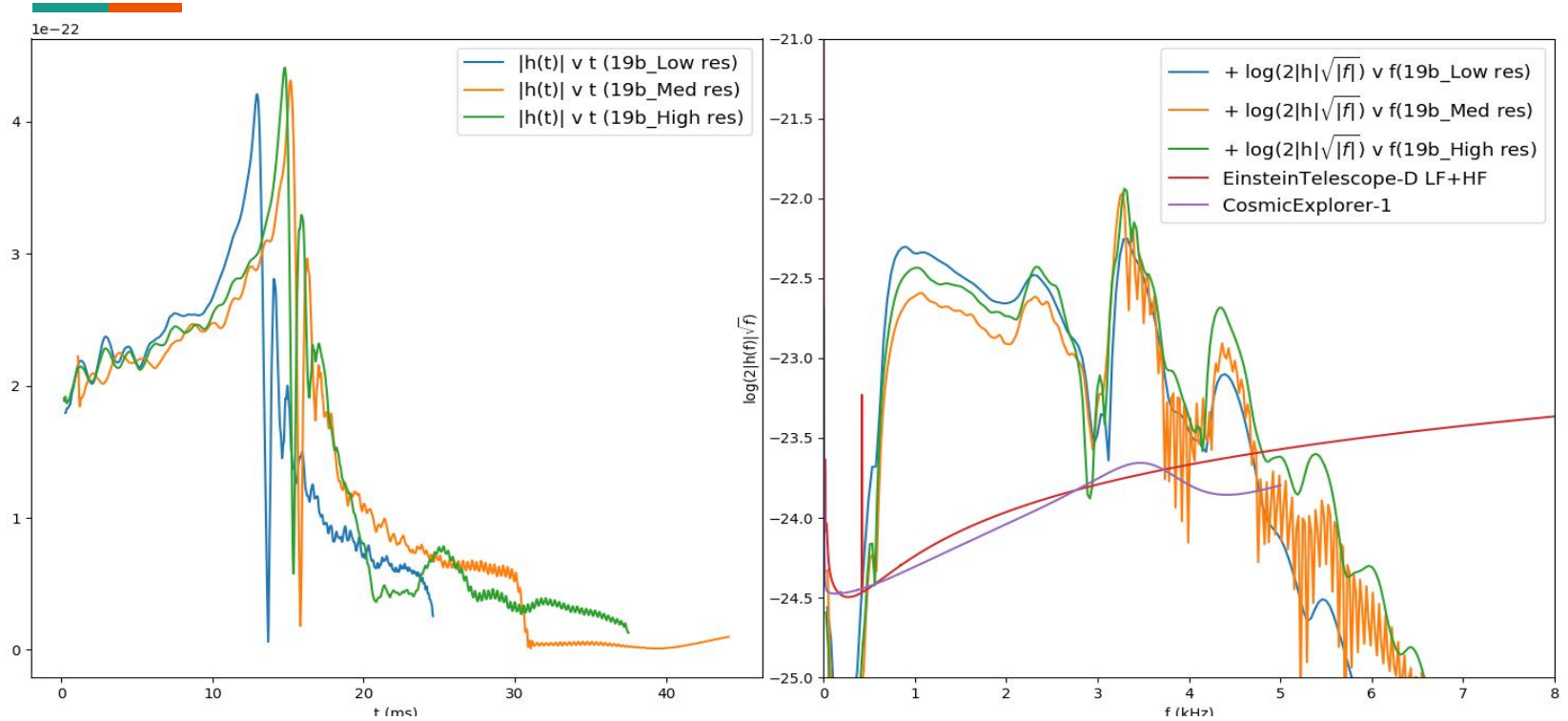
Summary and Conclusion

Summary :
- The high density EoS is uncertain, and can be studied via BNSMs.
- QHC19 EoS endeavors to explain the behaviour at the phase transition and quark matter state.
- We parameterized the QHC19B-C EoS and performed mergers to see stark differences in the post merger evolution.

Future work :
- Convergence tests for the evolution for massive NS simulations.
- Detailed Gravitational waves analysis.
- Evolutions of all four QHC19A-D

Thank you! Questions?

Email: akedia@nd.edu