Describing EOS Effects in BNS Mergers

Beyond the Tidal Polarizability

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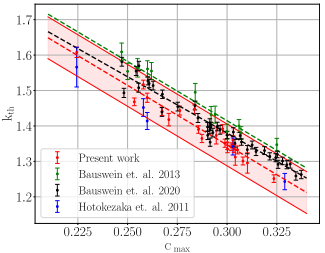
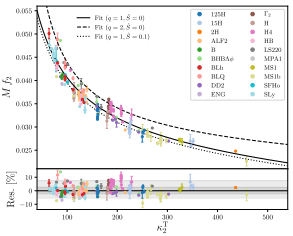
EOS effects in BNS simulation

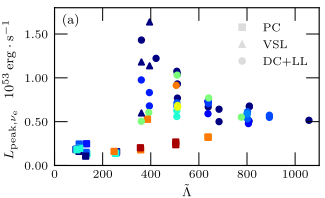
- EOS → major uncertainty in BNS mergers
  - Remnant evolution & fate
  - Inspiral & post-merger GW
  - Ejecta & EM counterpart
- Observation → constrain EOS
- Characterization of EOS effects needed
- Typically single quantity ($\tilde{\Lambda}$, $R_{1.6}^{\rm TOV}$, $M_{\rm max}$, ...)
- Empirical relations
- Small set of EOSs



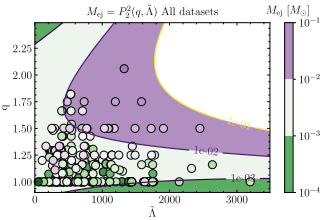
Kashyap+ '22, PRD



Breschi+, Phys. Rev. D 109 (2024)



Cusinato+ '22, EPJA

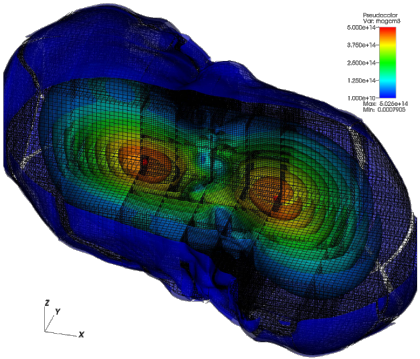


Nedora+ '20, CQG

Rezzolla & Takami 16'; Bauswein+ '16; Kiuchi+ '20; Most & Raithel '21; Gieg '25; Jacobi+ '23; ...

Talks by Albino, David, Tim, Oliver, Peter

GRAthena++



- GRMHD code based on `Athena++`

  Daszutta+ '21, ApJS; Cook+ '25, ApJS

  - Z4c dynamic spacetime
  - Octree mesh structure
  - Task-based parallelism

`computationalrelativity.github.io/grathenacode`

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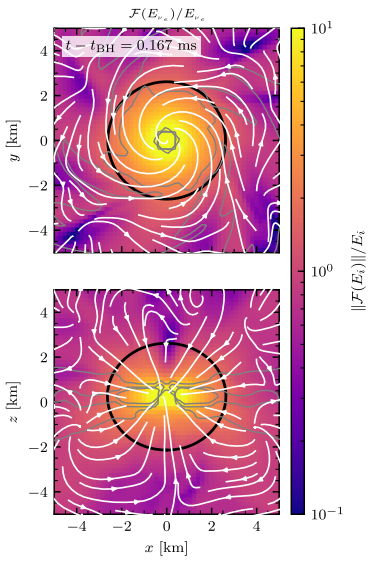


- GRMHD code based on `Athena++`

  Daszutta+ '21, ApJS; Cook+ '25, ApJS
  - Z4c dynamic spacetime
  - Octree mesh structure
  - Task-based parallelism
- M1 neutrino transport

  Daszuta+ '26, *in prep.* (Radice+ '22, MNRAS)

`computationalrelativity.github.io/grathenacode`

`bitbucket.org/andschn/sroeos`

Schneider, Roberts, Ott, Phys. Rev. C 96 (2017)

- Uniform nuclear matter $\rightarrow$ energy density functional

$$e(n,x,T) = \sum_t \frac{\tau_t(n,x,T)}{2m_t^*(n)} - xn\Delta + \sum_{i=1}^{5} \left[a_i + 4x(1-x)b_i\right] n^{\delta_i+1}$$

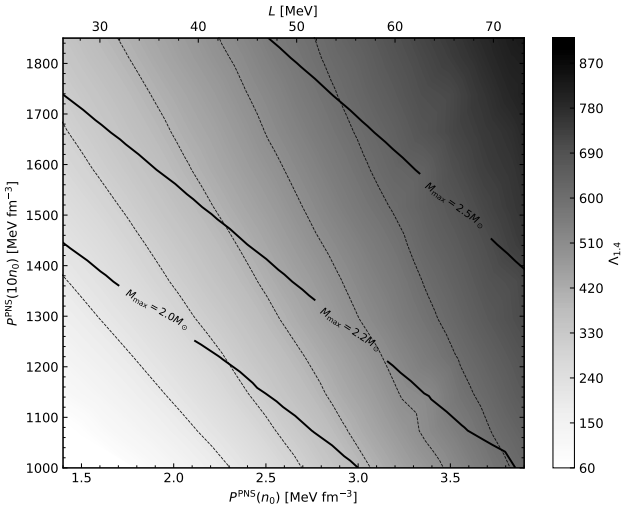
  - $m_t^* = m_t$, $\delta_i = i$
  - 10 free parameters

- SNA $\rightarrow$ non-uniform matter
- NSE $\rightarrow$ low densities

Schneider+ '19, PRC Yasin+ '20, PRL Andersen+ '21, PRC

Fields+ '23, APJL

EOS construction



- Independently vary EOS
  - $P(n_0)$
  - $P(10n_0)$
- Cold β-equilibrium + BPS crust EOS $\rightarrow$ solve TOV

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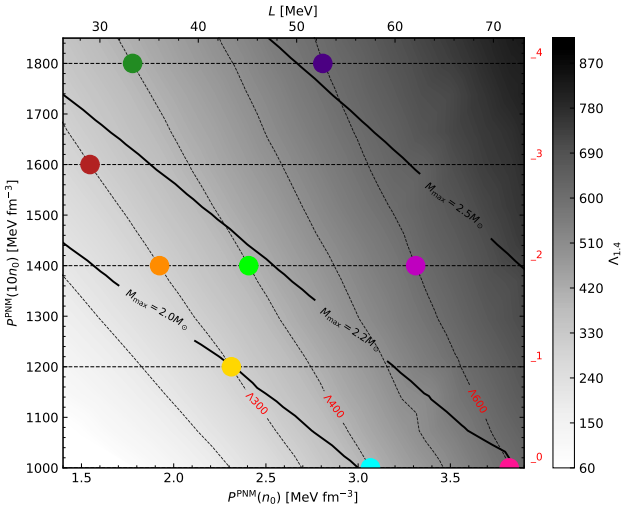

- Independently vary EOS
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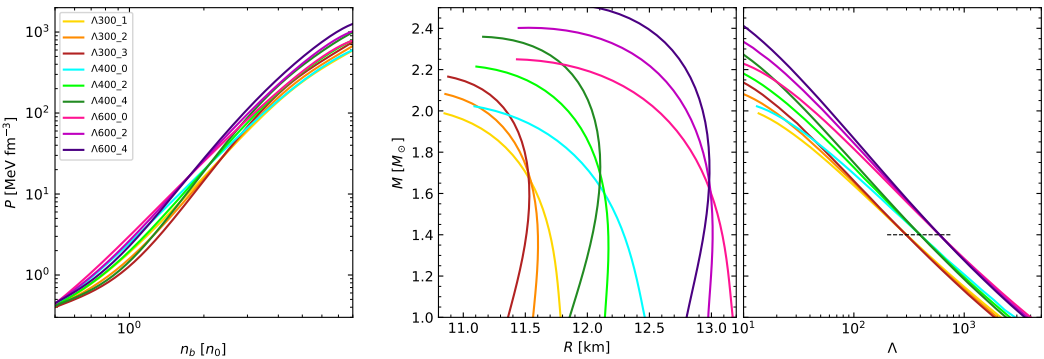
- Cold β-equilibrium + BPS crust EOS $\rightarrow$ solve TOV
- $\Lambda_{1.4} \in \{300, 400, 600\}$
- $P^{\mathrm{PNM}} \in [1000, 1800]\,\mathrm{MeV\,fm^{-3}}$

EOS properties

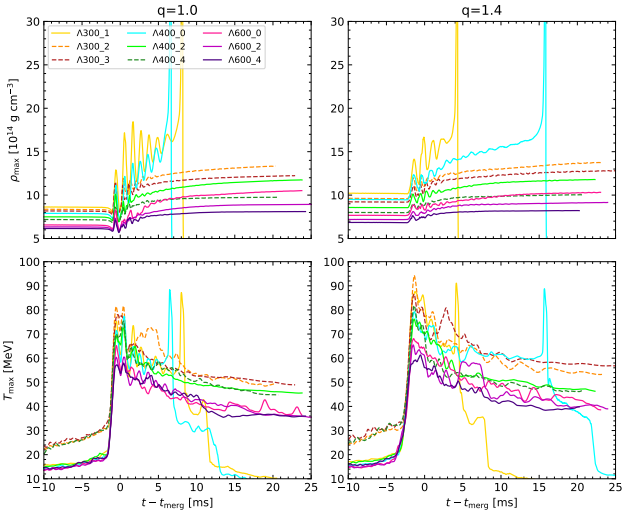


- EOSs with same Λ cross around $n \approx 2n_0$, $P \approx 20\,\mathrm{MeVfm}^{-3}$
- MR diagrams cross around $M \approx 1.6 M_\odot$

Simulation overview

- Simulations with $q \in \{1.0, 1.4\}$
- $\sim 20\,\mathrm{ms}$ evolution
  - dynamical ejecta
  - post-merger waveforms
- EOSs with $L \lesssim 40\,\mathrm{MeV}$
  $\rightarrow$artificial heating in inspiral

  Gieg+ '25, PRD



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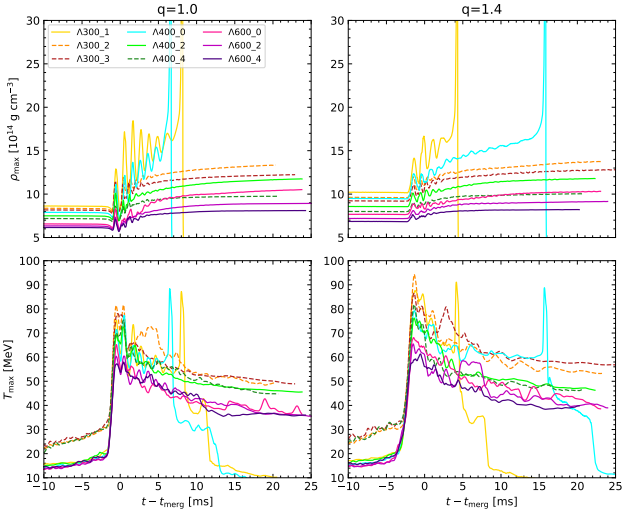
- $T_{\max} \rightarrow$ EOS around $2\rho_0$



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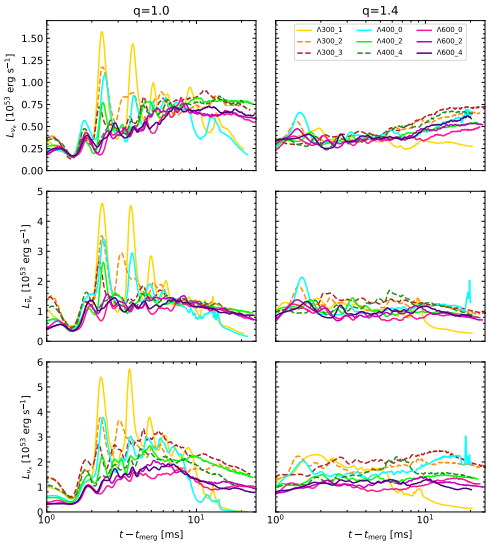

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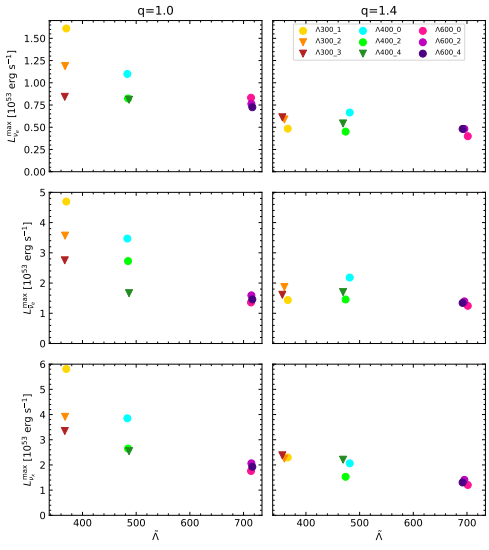
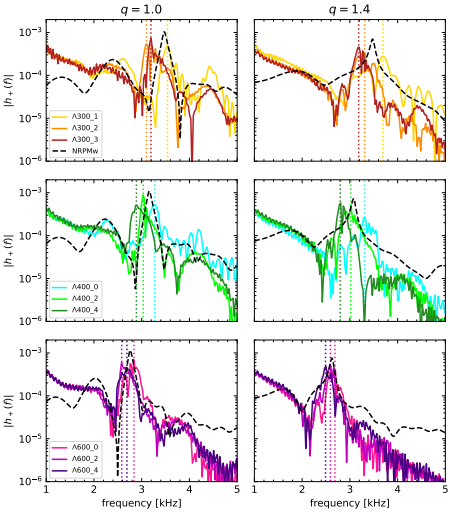
- L peaks correlated to high ρ stiffness Cusinato '22, EPJA



Post-merger Gravitational Waves



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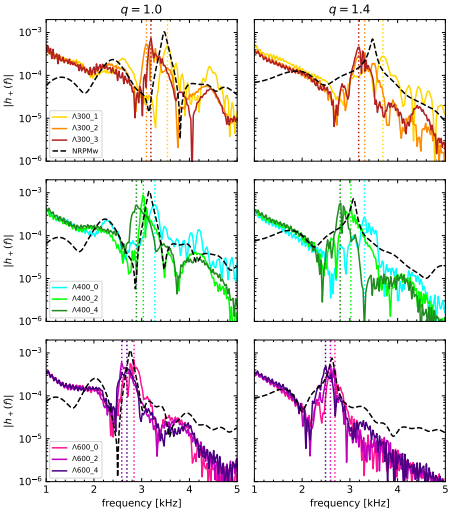

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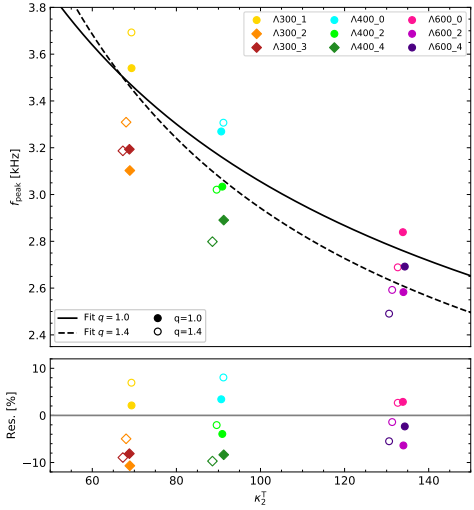
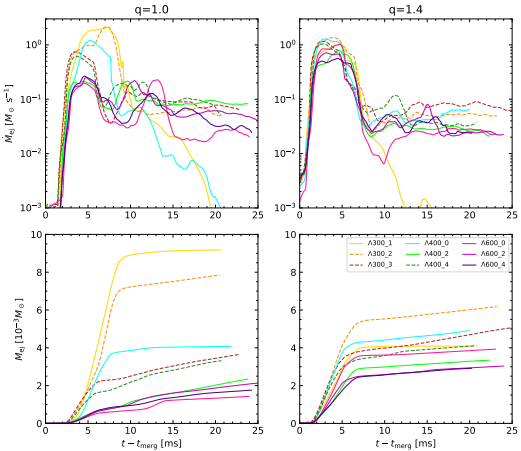


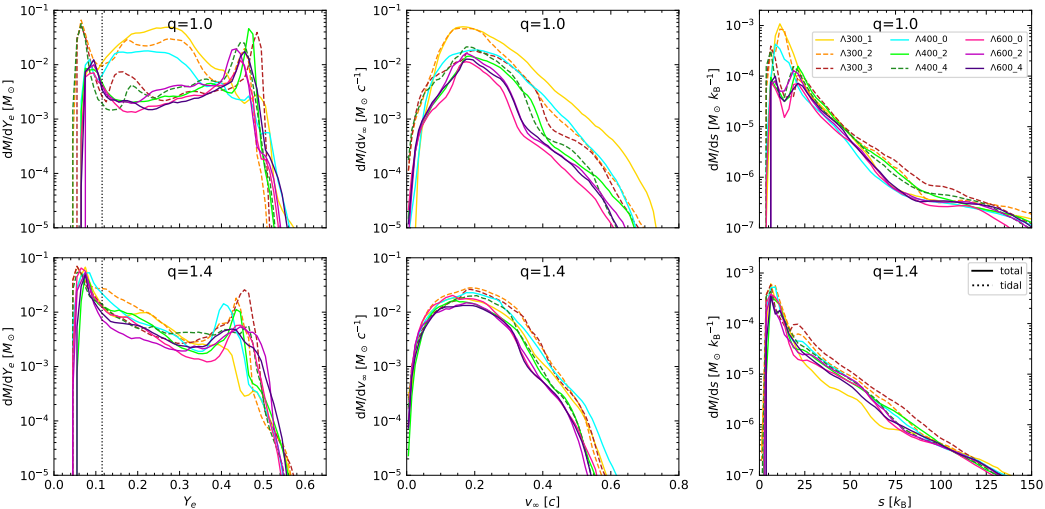
- Residuals correlate with high ρ EOS

Dynamical Ejecta



- Ejecta mass $\sim$ EOS softness
- Extra bounces for soft NS cores
  - enhance $M_{\rm ej}$
- "Hot inspiral" $\rightarrow$ enhanced tidal ejecta

Dynamical Ejecta



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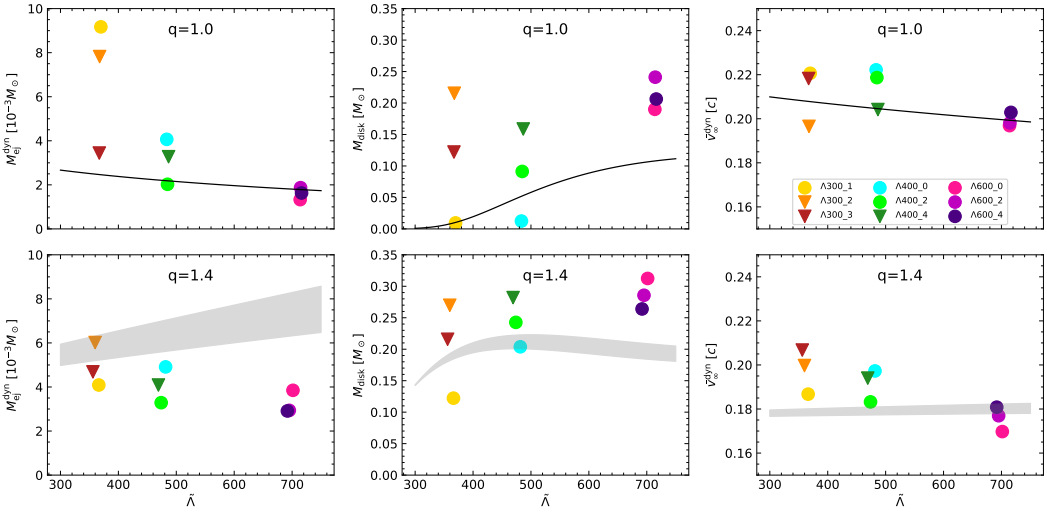

fits from Breschi+ '24, A&A

Outlook

- Systematic EOS samples can improve empirical fits
  - Stiffness at different ρ have different effects
- $\tilde{\Lambda}$ more predictive for stiff EOSs
- EOS effects can be very different for $q > 1$
- Large scale sweep of EOS space would be ideal but expensive
  - GPU codes

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