Quasi-Equilibrium Configurations of Compact Binaries Composed of Two Fluids

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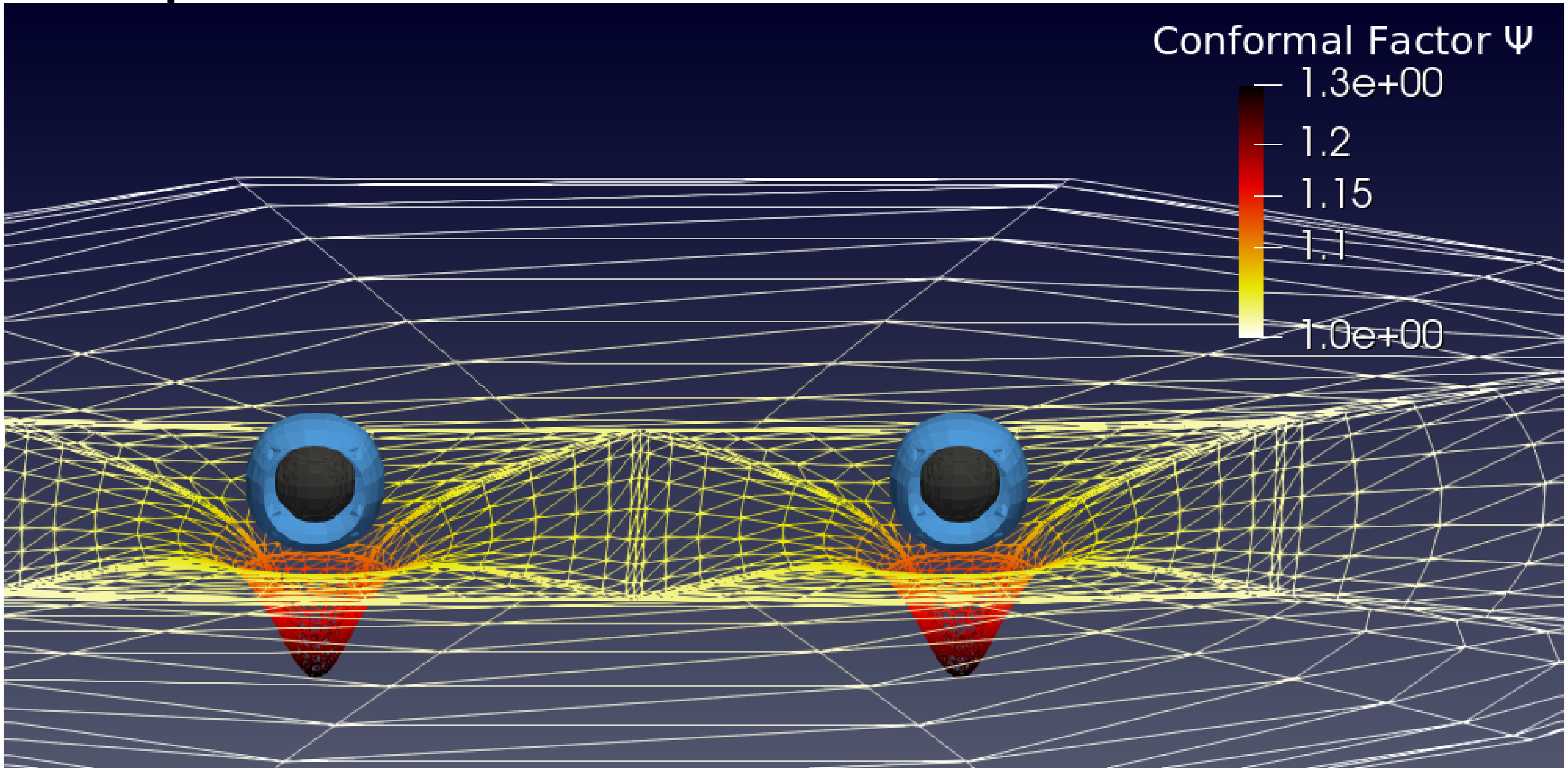
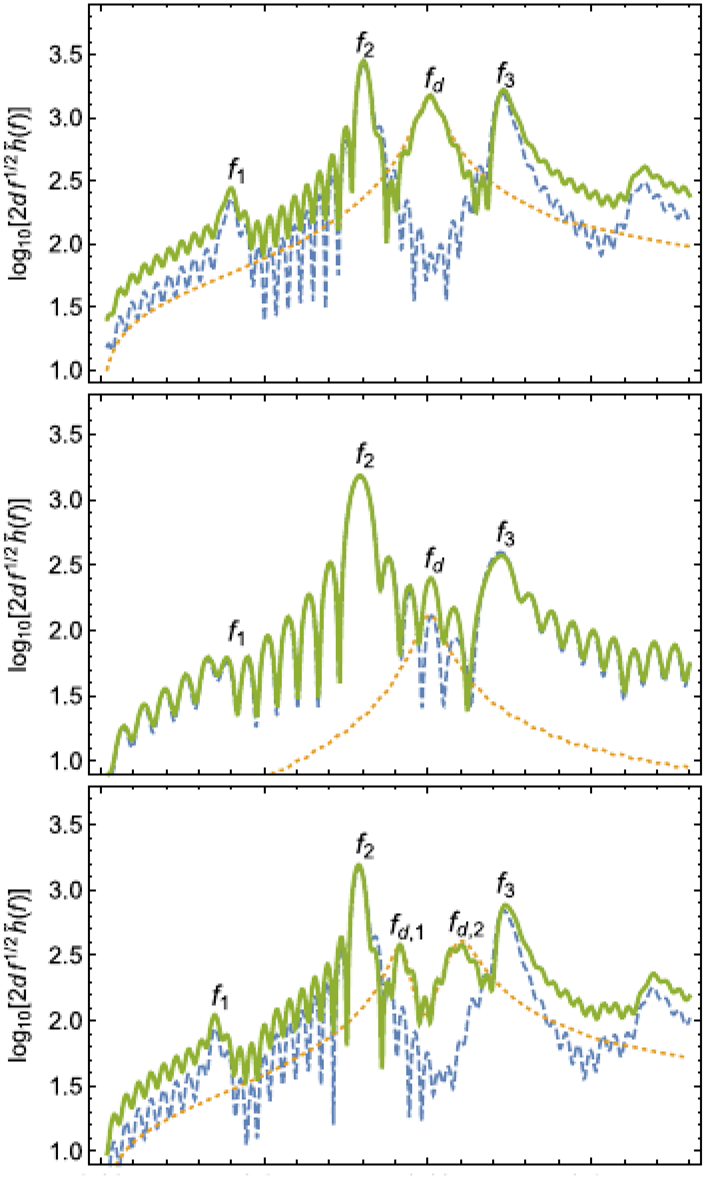
Configuration

- Two neutron stars
  - equal-mass
  - irrotational stars (no spin)
  - quasi-circular orbit



Motivation for Second Fluid

- 16 % dark matter fraction can create visible peak (f_d) in gravitational wave spectrum
  [Ellis *et al.*
  – Phys Lett. B 781 (2018) 607]



Motivation for Second Fluid

- Dark matter core causes one-arm instability in post-merger phase
  [Bezares *et al.* – PRD 100 (2019) 044049]
- 0.1 $M_\odot$ core detectable by aLIGO
  0.01 $M_\odot$ core detectable by ET
  [Bauswein *et al.* – arXiv:2012.11908 (2020)]
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talk by Edoardo Giangrandi (Tuesday)

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- Dark Matter
  - capture of dark matter particles
    ⇒ $\sim 10^{-10}\,M_\odot$ dark matter core
  - “Big Bang overdensities“
  - Dynamical formation

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  [Gleason *et al.* – PRD 105 (2022) 023010]

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talk by Fabrizio Di Giovanni (Tuesday)

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  [Gleason *et al.* – PRD 105 (2022) 023010]

- Superfluid component
  [Prix *et al.* – PRD 71 (2005) 043005]
  [Chamel – Mon. Not. Roy. Astron. Soc. 388 (2008) 737]

SGRID

- SGRID code [Tichy *et al.* - PRD 100 (2019) 124046]
- Spectral grid
  → fields are expanded in polynomials
- Decomposition of the spacetime metric

$$ds^2 = -\alpha^2 dt^2 + \psi^4 \delta_{ij}(dx^i + \beta^i dt)(dx^j + \beta^j)$$

- Extended Conformal-Thin-Sandwich equations

$$\bar{D}^j \bar{D}_j \psi = ...$$

$$\bar{D}^j \bar{D}_j \beta^i = -\frac{1}{3}\bar{D}^i \bar{D}_j \beta^j + ...$$

$$\bar{D}^j \bar{D}_j (\alpha\psi) = ...$$

Quasi-Equlibrium Assumption

- Assume existence of helical Killing vector

$$\mathcal{L}_k g_{\mu\nu} = 0$$

$$\mathrm{k}^{\mu} = (1, \ -\Omega y, \ \Omega(x - x_c), \ 0)$$

Two Fluid System

- Stress-energy-tensor of the system:

$$T_{\mu\nu} = T_{\mu\nu}^{(\mathrm{fluid1})} + T_{\mu\nu}^{(\mathrm{fluid2})}$$

- Ideal fluid:

$$T_{\mu\nu}^{(\mathrm{fluid})} = (\rho + P) u_\mu u_\nu + P g_{\mu\nu}$$

$$\begin{aligned} \rho &- \text{proper energy density} \\ P &- \text{fluid pressure} \\ u^\mu &- \text{fluid four-velocity} \\ g_{\mu\nu} &- \text{spacetime metric} \end{aligned}$$

Two Fluid System

- Each fluid satisfies the continuity equation

$$\nabla_\mu (n u^\mu) = 0$$

n - particle number density

- Quasi-equlibrium assumption

$$\mathcal{L}_k n = 0 \qquad \mathcal{L}_k u^\mu = 0$$

- Define: $\nabla^\mu \phi = h u^\mu$

ϕ - velocity potential

h - specific enthalpy

$\Rightarrow$ Extra elliptic equation for each fluid

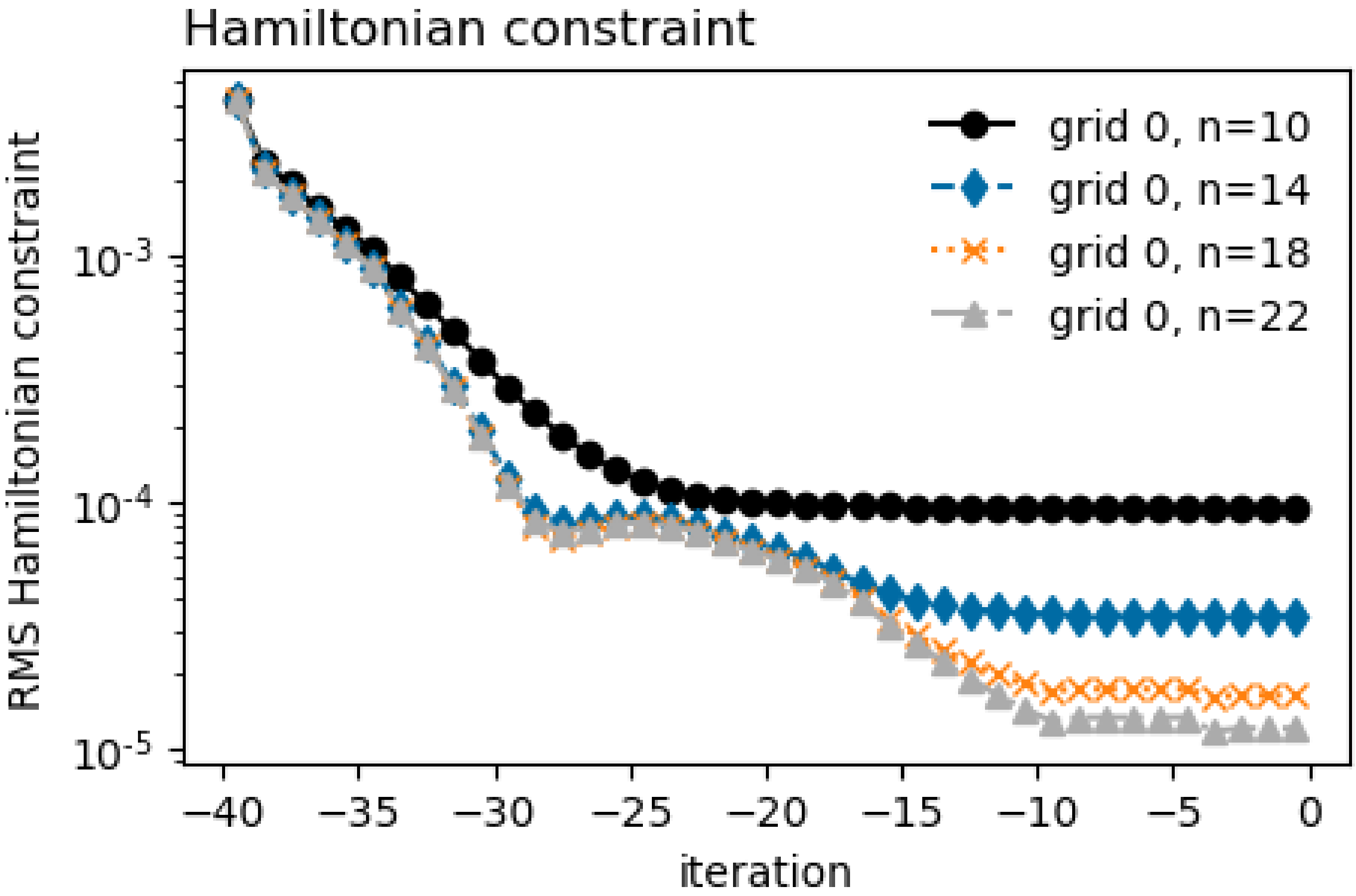
$$D_i\left(\frac{n\alpha}{h} D^i \phi\right) = \dots$$

Constraints

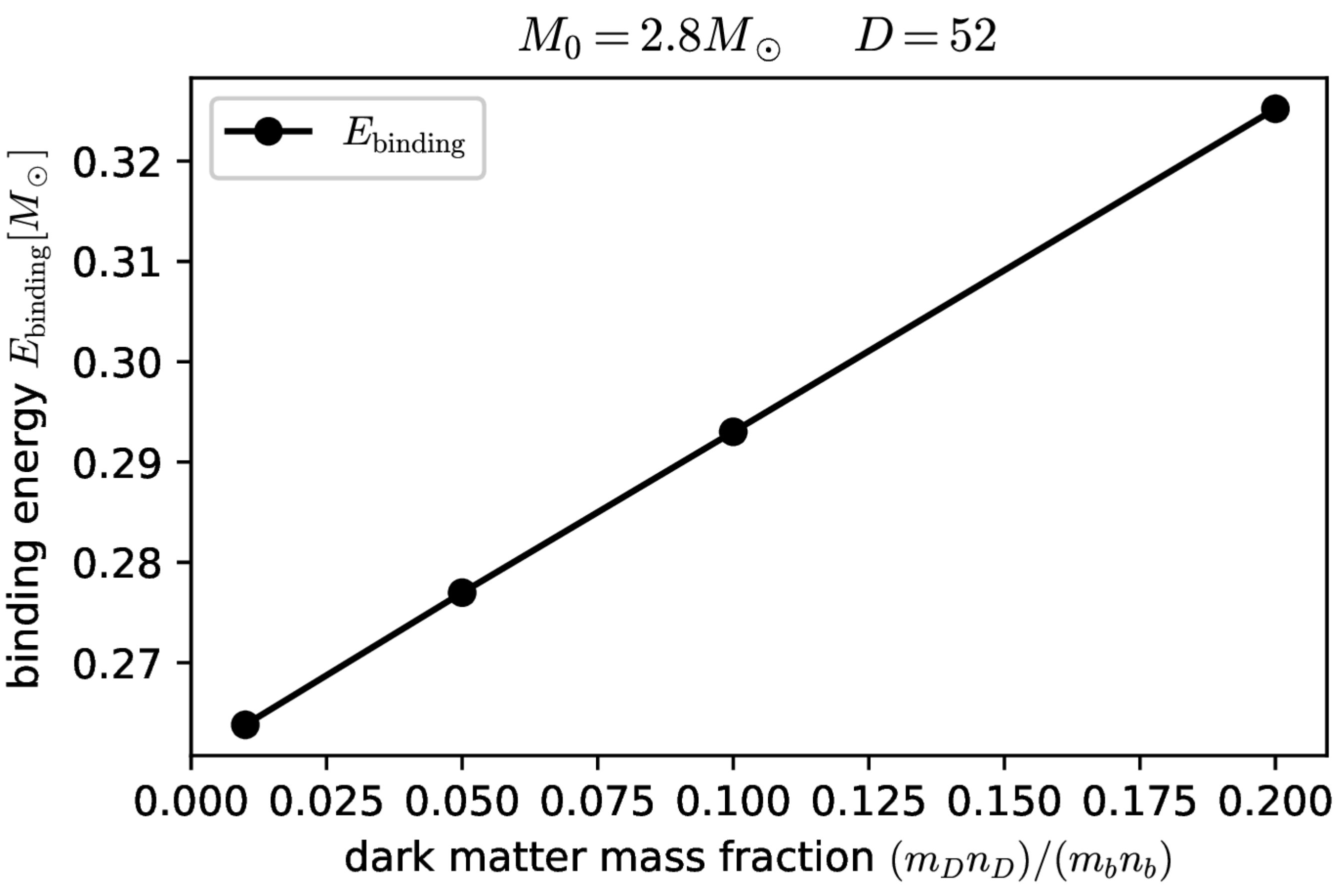
1.4 $M_\odot$ + 1.4$_\odot$ M, 1% dark matter

Constraints

- Analyse Convergence



Effect of Dark Matter



$$E_{\text{binding}} = M_0 - M_{ADM}$$

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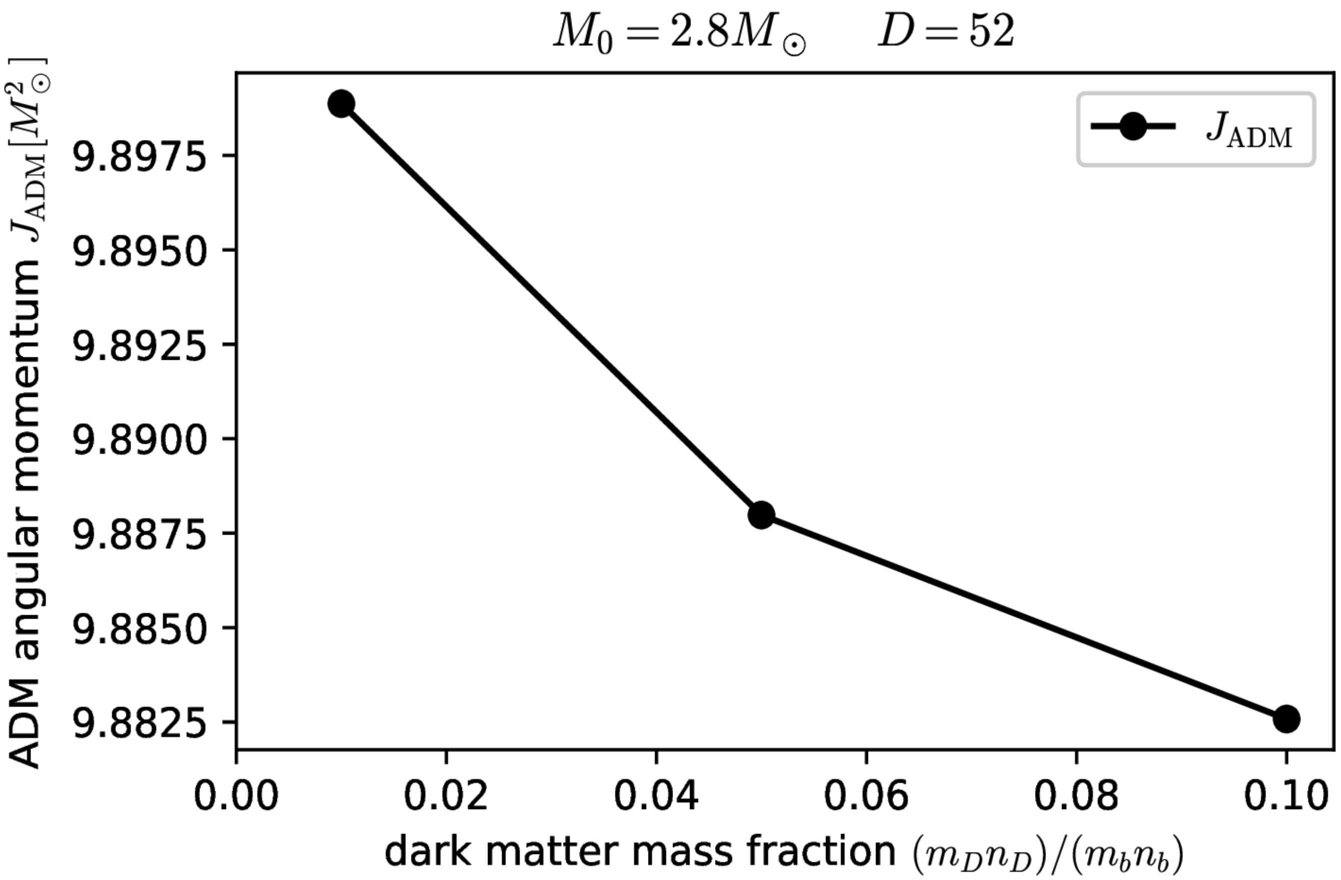

Outlook

- Evolutions with physically accurate initial data
- Test different dark matter equation of state
  → improve on non-quasi-equilibrium
  configurations of mirror dark matter

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Earlier talk by Mattia Emma (Monday)

Outlook

- Evolutions with physically accurate initial data
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  → improve on non-quasi-equilibrium
    configurations of mirror dark matter
- Understand dark matter imprint on GW signal and binary dynamics, ejecta …

Equation of State

- Baryonic matter:
  SLy4 piecewise polytropic equation fo state
- Dark matter:
  Ideal Fermi gas
  particle mass 1 Gev

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