Simulating neutron stars with discontinuous Galerkin methods and Charm++

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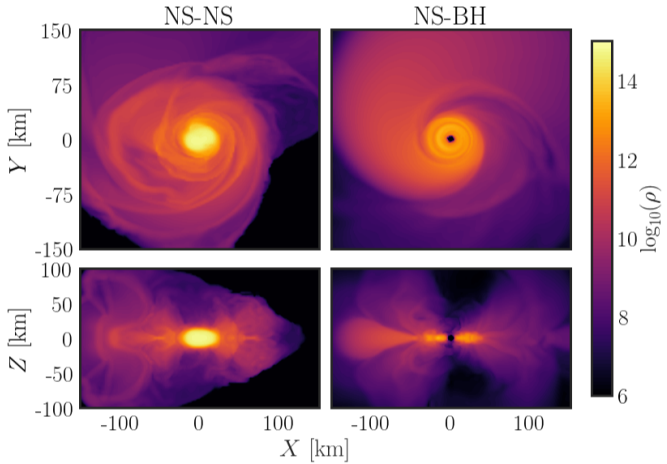
Caltech

- Binary neutron star mergers
- Accretion disks
- Core-collapse supernova explosions



Hinderer et al. 2018

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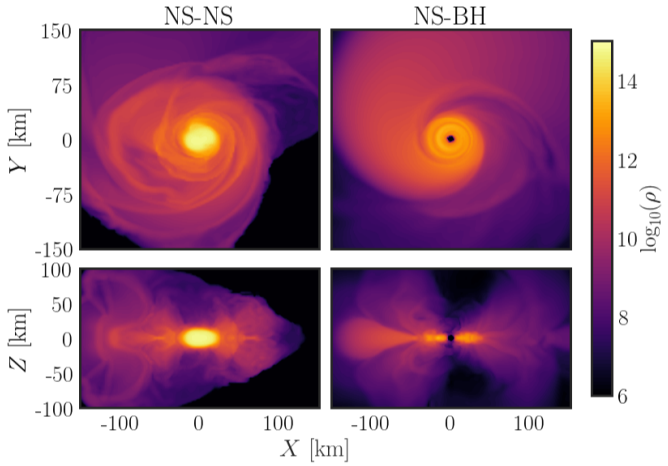
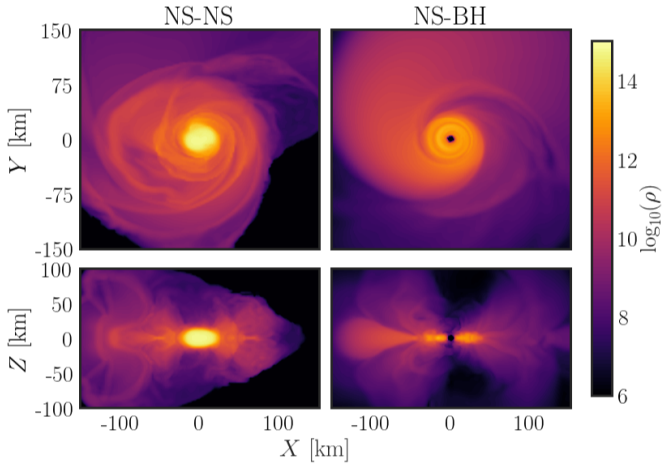


Hinderer et al. 2018

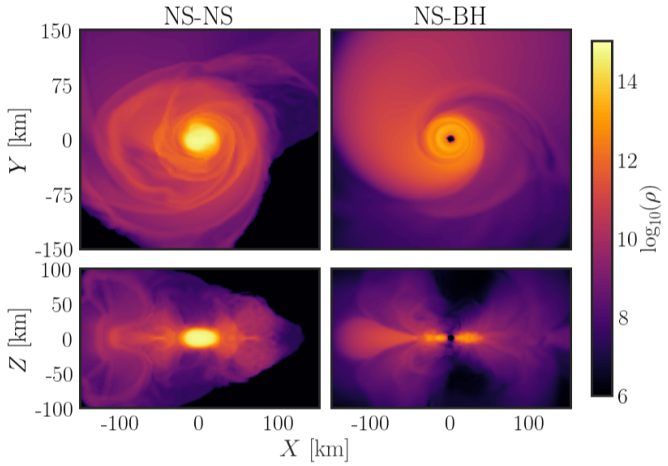
Binary Neutron Star Simulation Goals

- Resolve $\Longrightarrow$ high resolution
- Resolve surface of stars
- Resolve tidal deformability



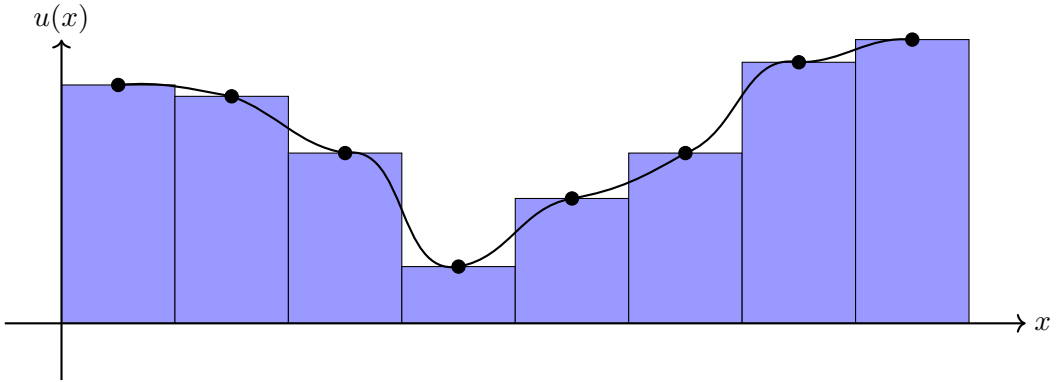
Hinderer et al. 2018

- Resolve $\Longrightarrow$ high resolution
- Resolve surface of stars
- Resolve tidal deformability
- Can't wait for bigger computers

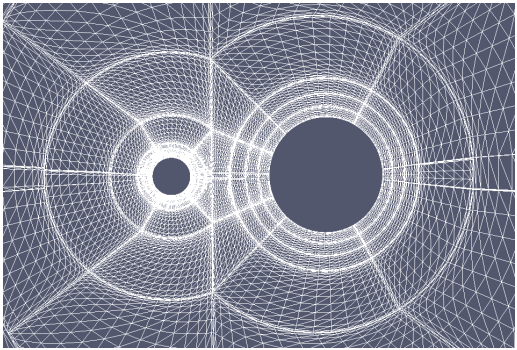


Hinderer et al. 2018

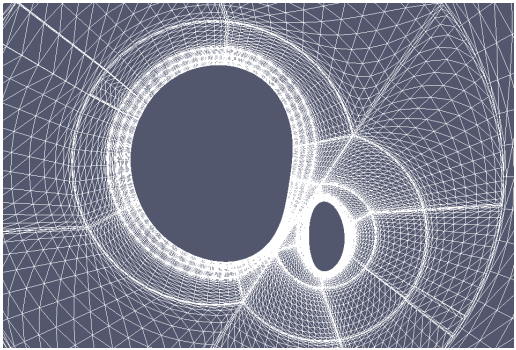
- Solution error $\sim 1/N^2$
- Cartesian grids



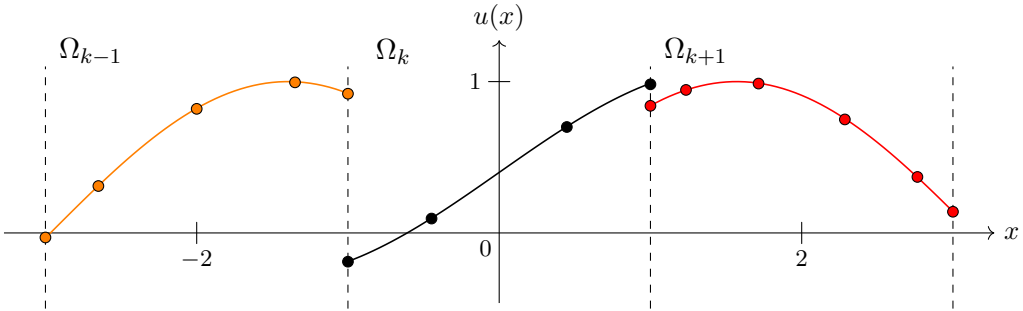
- Solution error $\sim \exp(-N)$

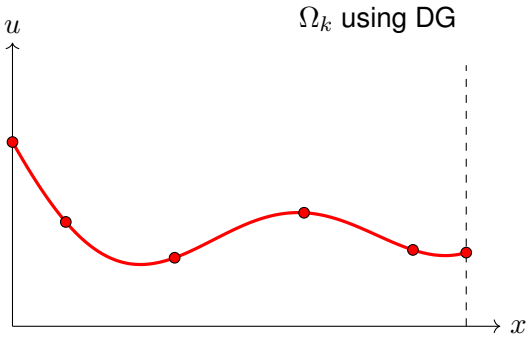


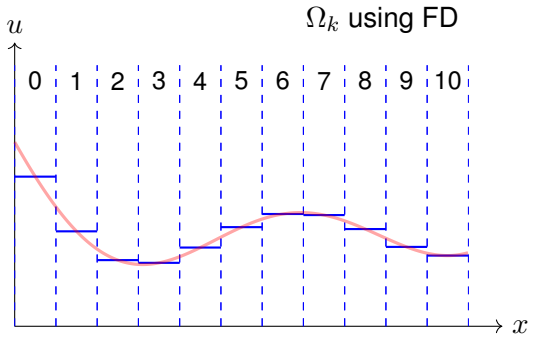
- Curved grids

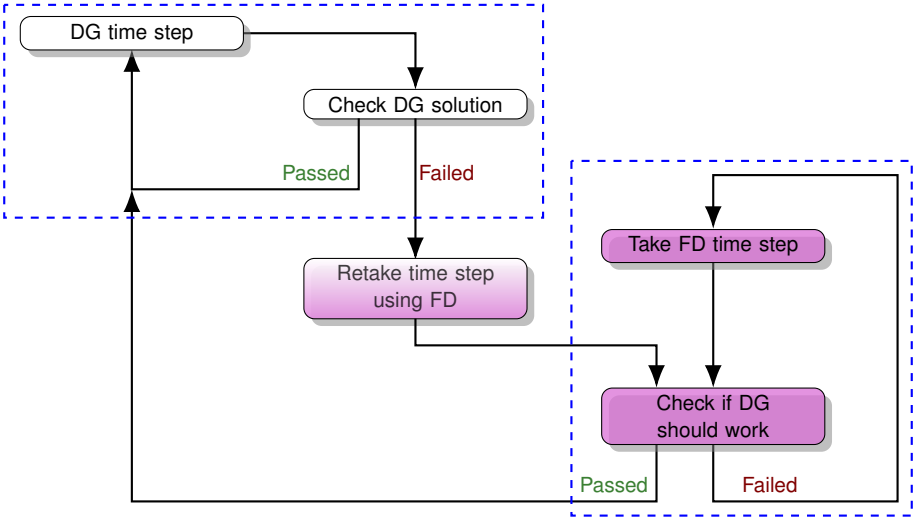


- Solution error $\sim \exp(-N)$
- Shock capturing

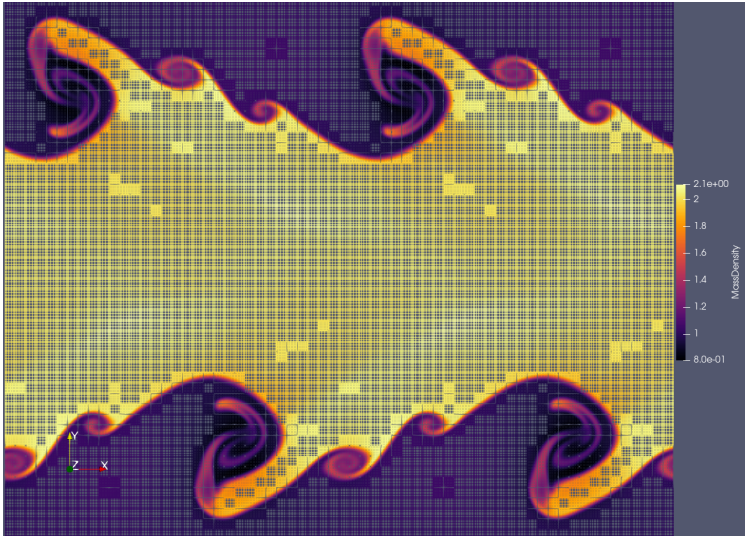



u
Ω_k using DG
x


u
Ω_k using FD
0
1
2
3
4
5
6
7
8
9
10
x

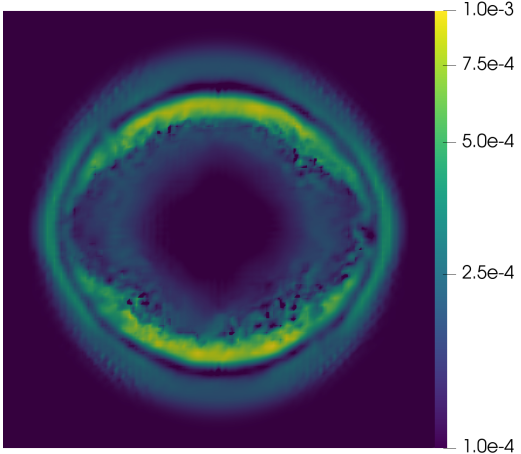

DG time step
Check DG solution
Passed
Failed
Retake time step
using FD
Take FD time step
Check if DG
should work
Passed
Failed

Newtonian Kelvin-Helmholtz Instability

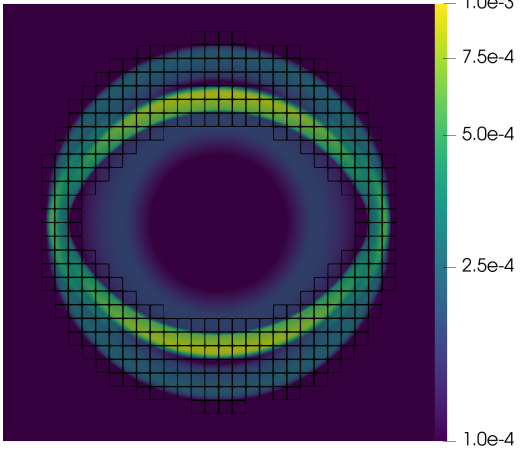


GRMHD Cylindrical Blast Wave

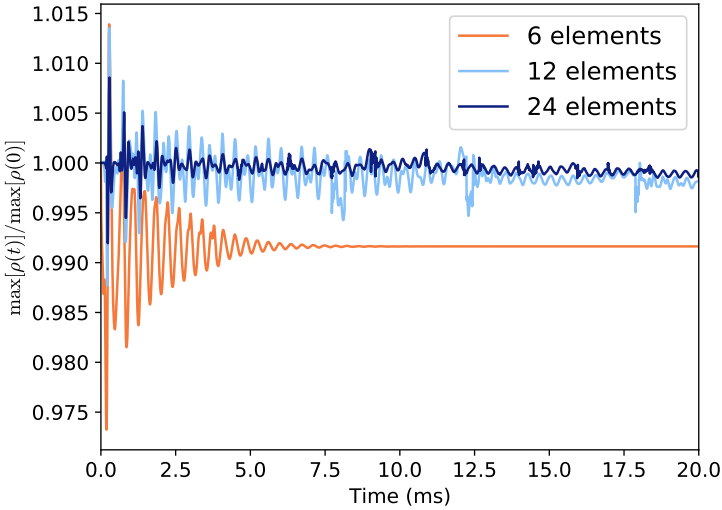
3rd order DG+Simple WENO



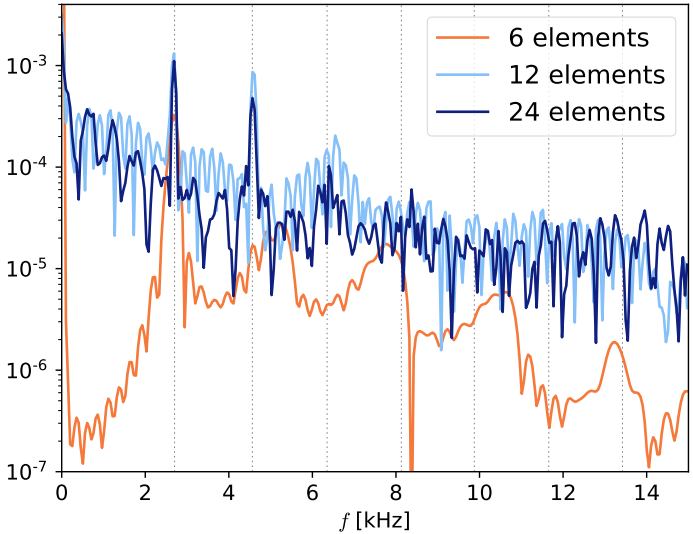
6th order DG-FD



Magnetized Neutron Star: Maximum Density



Magnetized Neutron Star: Oscillation Frequencies



Neutron Star Evolution Summary

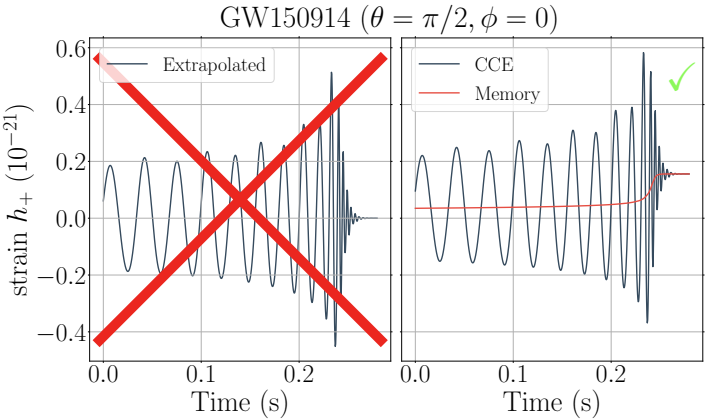
Current:

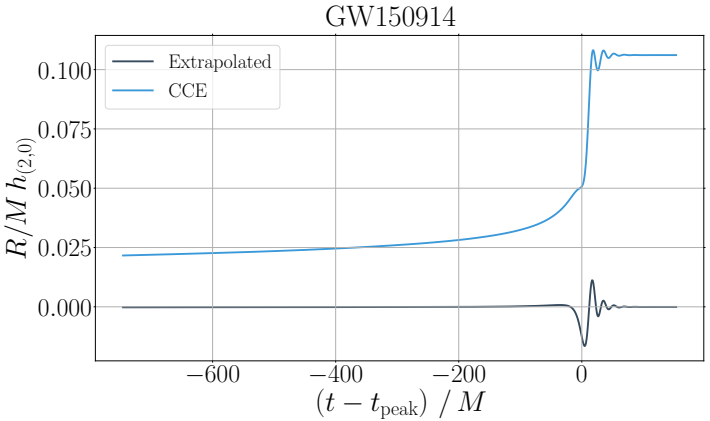
- Evolve magnetized neutron star
- DG-FD hybrid approach

Ongoing and future:

- Einstein's equations
- High-order FD
- Curved meshes + AMR
- Binary neutron star merger
- Neutrinos

Led by Jordan Moxon & Keefe Mitman (Caltech)




GW150914
Extrapolated
CCE
0.100
0.075
0.050
0.025
0.000
$R/M\, h_{(2,0)}$
−600
−400
−200
0
$(t - t_{\mathrm{peak}})\ /\ M$

Summary

- Magnetized neutron star with DG-FD (arXiv: 2109.11645, 2109.12033)
- Accurate gravitational wave extraction (arXiv: 2007.01339, 2007.11562, 2105.02300)