Simulating Magnetized Neutron Stars with SpEC

Curran D. Muhlberger
curran@astro.cornell.edu

Department of Physics, Cornell University

15th East Coast Gravity Meeting
April 21, 2012

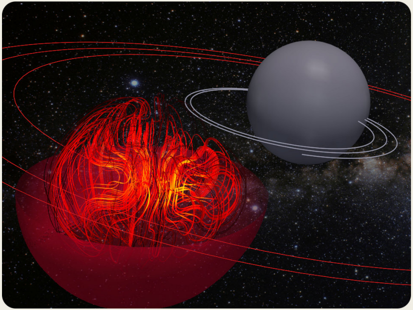
Compact Binaries

Why add B-fields to NS-NS and BH-NS simulations?

Magnetic Effects

- None during inspiral[a]
- Determine accretion rate
- Field amplification during merger
- Enable and power GRBs

[a]Giacomazzo et al. 2009



Isolated Stars

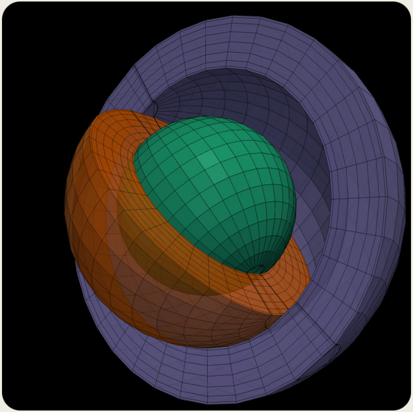
Why are single stars interesting?

Used to Study

- Core collapse SN remnants
- Low-mass NS-NS merger remnants

Magnetic Effects

- Collapse of spheroidal remnants
- Instabilities affect GWs



The Low-$T/|W|$ Instability

Core-Collapse Supernovae Remnants

- Dynamical $m = 2$ instabilities produce strong GWs
- Not susceptible to dynamical bar-mode instability
- Differential rotation enables shear instability, *but* ...
- Magnetic fields may suppress this instability[a]

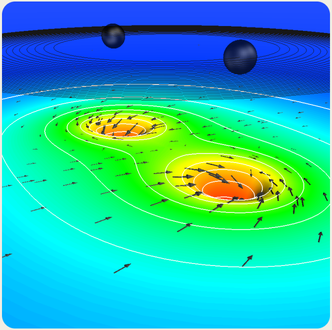
[a] Fu & Lai 2011

Goal: Investigate low-$T/|W|$ instability in full GRMHD

The Spectral Einstein Code

Numerical Methods

- Pseudospectral method with excision for smooth spacetime
- HRSC FV scheme for shock-prone matter
- Strengths: high efficiency in vacuum regions; high resolution fluid grid



SpEC is the product of a collaboration between Caltech, Cornell, CITA, and WSU

Generally Relativistic Magnetohydrodynamics

Shock Treatment

- WENO reconstruction
- HLL Riemann solver

Ideal MHD

- B-field confined to matter
- Perfect conductivity

Can evolve B-field with a generalization of

$$\partial_t \boldsymbol{B} = \nabla \times (\boldsymbol{v} \times \boldsymbol{B}) \, ,$$

but the equations are:

1. Not flux-conservative
2. Overconstrained

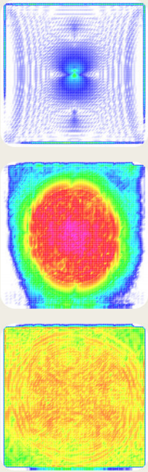
Maintaining the Solenoidal Constraint

Goal: $\nabla \cdot \boldsymbol{B} = 0$

Approaches

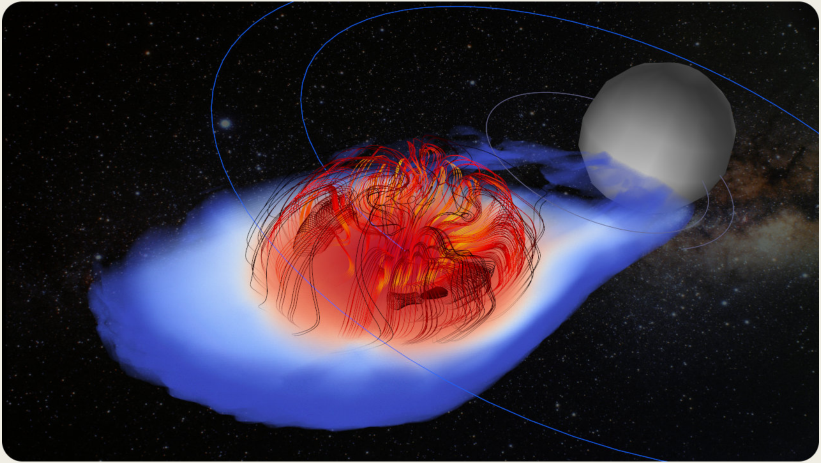
- Evolve $\boldsymbol{B}$ with Constrained Transport
  - Guarantees $\partial_t(\nabla \cdot \boldsymbol{B}) = 0$, *but* …
  - Monopoles created during interpolation
- Add Divergence Cleaning[a]
  - Reduces divergence over time, *but* …
  - Damping too slow during merger
- Evolve $\boldsymbol{A}$ with Constrained Transport
  - In progress

[a] Implemented by Francois Foucart



Current Capabilities

Magnetized BH-NS inspiral with a poloidal seed field



Future Work

Several researchers are investigating magnetized systems in SpEC, but I am personally focused on the following:

Projects in Progress

- Investigate effects of B-field on low-$T/|W|$ instability
- Follow B-fields through BH-NS merger
- Add B-fields to NS-NS simulations