Modeling Strong Field Gravity:

Vacuum Collapse and Boson Stars

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Plan:

- Implementation
- Applications
  - Brill Wave Collapse
  - Global String Loop
  - Orbiting Boson Stars
- Summary

HAD

- Distributed AMR via MPI
  - Vertex and cell centered
  - Couple various projects together
  - Black hole excision
  - Surface Extraction
  - *Tapered* AMR boundaries [Lehner,SLL,Reula:gr-qc/0510111]
  - Elliptic solves
  - Public Release: http://had.liu.edu
- Projects:
  - MHD
  - GR…harmonic
  - GR…ADM
  - Various scalar Field models

Example: MHD + GR

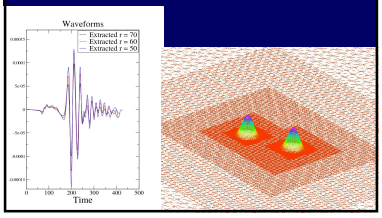
[Anderson,Hirschmann,Lehner,SLL,Motl,Neilsen,Palenzuela,Tohline:gr-qc/soon!]

- MHD
  - Vertex Centered HRSC
  - HLLE Flux w/ CENO PPM
  - Hyperbolic Div. Cleaning
- GR…Harmonic
- Same time integrator
  - MOL
  - RK3

Click for movie

MHD+GR

[Anderson,Hirschmann,Lehner,SLL,Motl,Neilsen,Palenzuela,Tohline:gr-qc/soon!]



Brill Critical Collapse

- Vacuum gravitational waves
- 1+Log time slicing
- Vary initial "amplitude":
  - Weak → dispersal
  - Strong → BH formation
- Search for threshold:
  - Black Hole Critical Behavior
  - First found (1D) by Choptuik '93
  - Next found (2D) by Abrahams & Evans '93

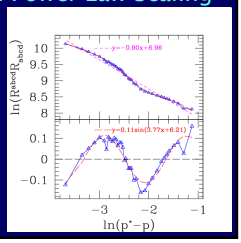
Brill Critical Collapse

- Use GR (ADM) formulation
- Difficulty tuning beyond: $\frac{|p^* - p|}{p^*} \approx 1\%$
- Try studying sub-critical power law scaling of

$$R_{abcd} R^{abcd} \propto |p^* - p|^{-4\gamma}$$

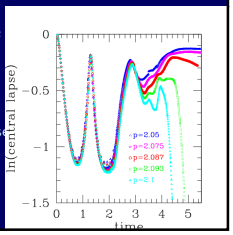
Subcritical Power Law Scaling

- From Fit:
  $\gamma \approx 0.23 \pm ?$
  $\Delta \approx 0.75 \pm ?$
- From A&E'93:
  $\gamma = 0.36$
  $\Delta = 0.60$



Maximal Slicing of Brill

- Time slicing may not be compatible with DSS [Garfinkle & Meyer gr-qc/9806052]
- Try maximal slicing
  - Enforce trK=0
  - Elliptic eq. for lapse
- Elliptic solve w/ AMR
  - Explicit & Tapered approach to AMR



Cosmic String

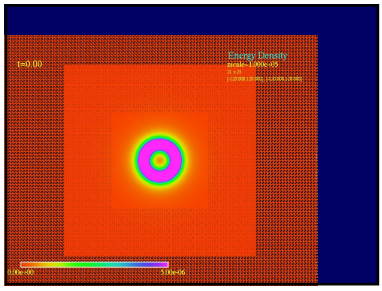
- Topological defect
- Two kinds:
  - Local—gauged
  - Global—long range
- Interesting because:
  - Phase transitions in early universe
  - String Theory
  - High energy astro (e.g. cosmic rays, GRB)
  - Detectable via gravitational waves

Modeling Strings

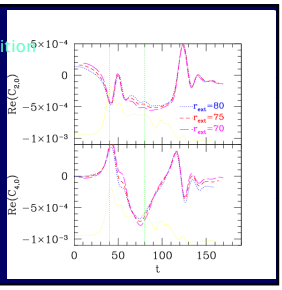
- Usual Approach:
  - Local strings
  - Assume infinitely thin—Nambu-Goto action
  - Simple gravity (e.g. linearize)

Modeling Strings

- ~~Usual~~ unusual Approach:
  - ~~Local~~ global strings
  - ~~Assume~~ Field theory infinitely thin—Nambu-Goto action
  - ~~Simple~~ Full GR gravity (e.g. linearize)



GR Decomposition



Orbiting Boson Stars

[Palenzuela,Lehner,SLL:gr-qc/0706.2435]

- Localized, nonsingular, stationary, asymp. flat
- GR + Complex Scalar Field
- Interest:
  - *Mathematical*: solitonic behavior similar to Q-balls
  - *Cosmological*: supermassive objects at centers of galaxies? Dark matter candidate?
  - *Astrophysical*: similar to neutron stars, has stable/unstable branches, compact objects

Orbiting Boson Stars

[Palenzuela,Lehner,SLL:gr-qc/0706.2435]

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Summary

- Brill Critical Collapse
  - Indications of subcritical power law scaling with periodic wiggle (DSS)
  - AMR evolutions w/ Maximal Slicing soon might reveal echoes
- Global String Evolutions
  - Indications of gravitational radiation from collapse of loops
  - More complicated initial data and possibly gauged strings to follow
- Orbiting Boson Stars
  - Useful probe of GR signal from compact objects
  - Interesting phenomenology…questions about stability, transitions, rotating solutions