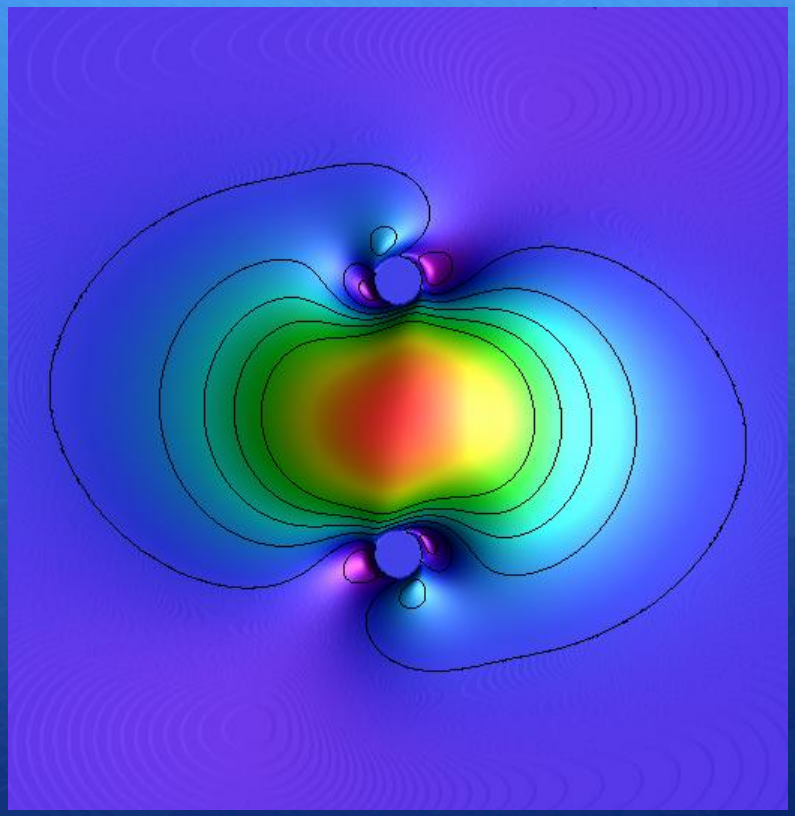
Spin-Spin Effects in Constraint-Satisfying Superposed Kerr-Schild Initial Data



and…

Involving Undergraduates in Numerical Relativity

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XSEDE Extreme Science and Engineering Discovery Environment
NICS National Institute for Computational Sciences
TG-PHY110046, TG-PHY090030

BELMONT UNIVERSITY

Matzner, Huq, Shoemaker, 1998

Background: "Binary Kerr-Schild"

- Kerr-Schild metric is

$$\mathrm{d}s^2 = \eta_{\mu\nu}\,\mathrm{d}x^\mu\,\mathrm{d}x^\nu + 2H(x^\alpha) l_\mu l_\nu\,\mathrm{d}x^\mu\,\mathrm{d}x^\nu,$$

$$H = \frac{mr}{r^2 + a^2\cos^2\theta} \qquad l_\mu = \left(1, \frac{rx + ay}{r^2 + a^2}, \frac{ry - ax}{r^2 + a^2}, \frac{z}{r}\right)$$

- This suggests a superposition:

$$\tilde{g}_{ij} = \eta_{ij} + \sum_A^N 2\ {}_A H\, {}_A l_i\ {}_A l_j,$$

$$\tilde{K} = \sum_A^N {}_A K_i^{\ i},$$

$$\tilde{A}_{ij} = \tilde{g}_{n(i} \sum_A^N {}_A K_{j)}^{\ n} - \frac{1}{3}\delta_{j)}^{\ n}\ {}_A K_i^{\ i}$$

- P. Marronetti and R. A. Matzner, *Phys. Rev. Lett.* 85 (2000)
- E. Bonning, P. Marronetti, D. Neilsen and R.A. Matzner, *Phys. Rev.* D68 (2003)
- S.H. Hawley, M.J. Vitalo, R.A. Matzner, qr-qc/0604100 (2006)
- G. Lovelace, R. Owen, H. P. Pfeiffer, T. Chu, *Phys. Rev*. D78 (2008)
- G. Lovelace, M. Boyle, M.A. Scheel, B. Szilagyi, *Class. Quant. Grav* 29 (2012)

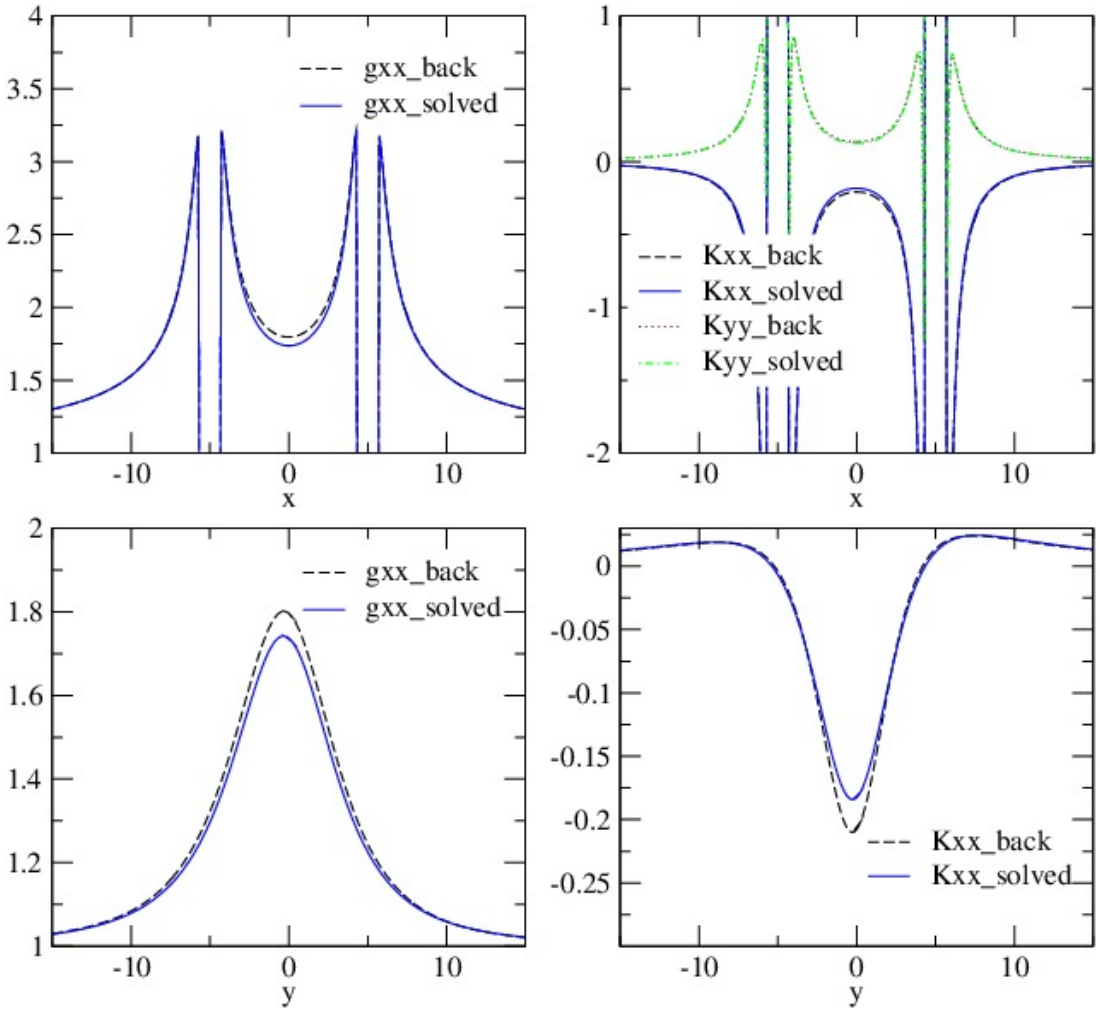
Constraint Equations

- Define background $\tilde{g}_{ij}$ and $\tilde{K}_{ij}$
- Then solve the constraint equations....

$$
\begin{aligned}
(\tilde{lw})^{ij} &\equiv \tilde{\nabla}^i w^j + \tilde{\nabla}^j w^i - \frac{2}{3}\tilde{g}^{ij}\tilde{\nabla}_k w^k \\
\tilde{\nabla}^2\phi &= (1/8)\Big(\tilde{R}\phi + \frac{2}{3}\tilde{K}^2\phi^5 - \\
&\qquad \phi^{-7}(\tilde{A}^{ij} + (\tilde{lw})^{ij})(\tilde{A}_{ij} + (\tilde{lw})_{ij})\Big) \\
\tilde{\nabla}_j(\tilde{lw})^{ij} &= \frac{2}{3}\tilde{g}^{ij}\phi^6\tilde{\nabla}_j K - \tilde{\nabla}_j\tilde{A}^{ij}
\end{aligned}
$$

...Solve for ϕ, w^i *numerically* via *multigrid method*

Background and Constraint Solution



Binding Energy

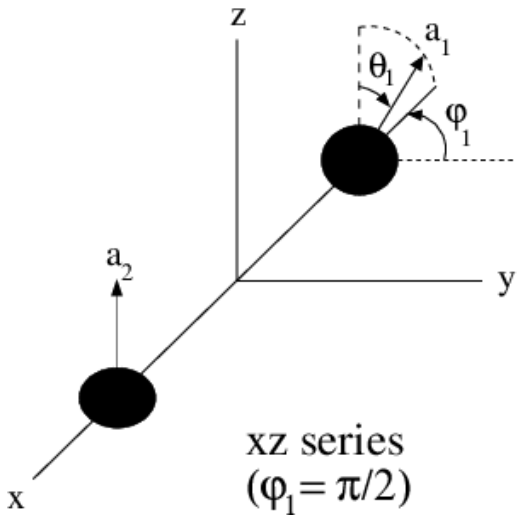
$$E_b = M_{\mathrm{ADM}} - (M_{\mathrm{AH1}} + M_{\mathrm{AH2}})$$

- Contribution due to spin is… (Wald 1972)

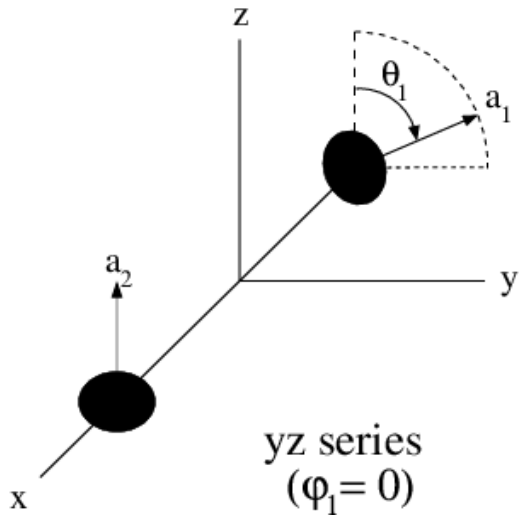
$$E_b = -\left(\frac{\vec{S}\cdot\vec{S}' - 3(\vec{S}\cdot\hat{n})(\vec{S}'\cdot\hat{n})}{d^3}\right)$$

S.H. Hawley, M.J. Vitalo, R.A. Matzner, qr-qc/0604100 (2006)

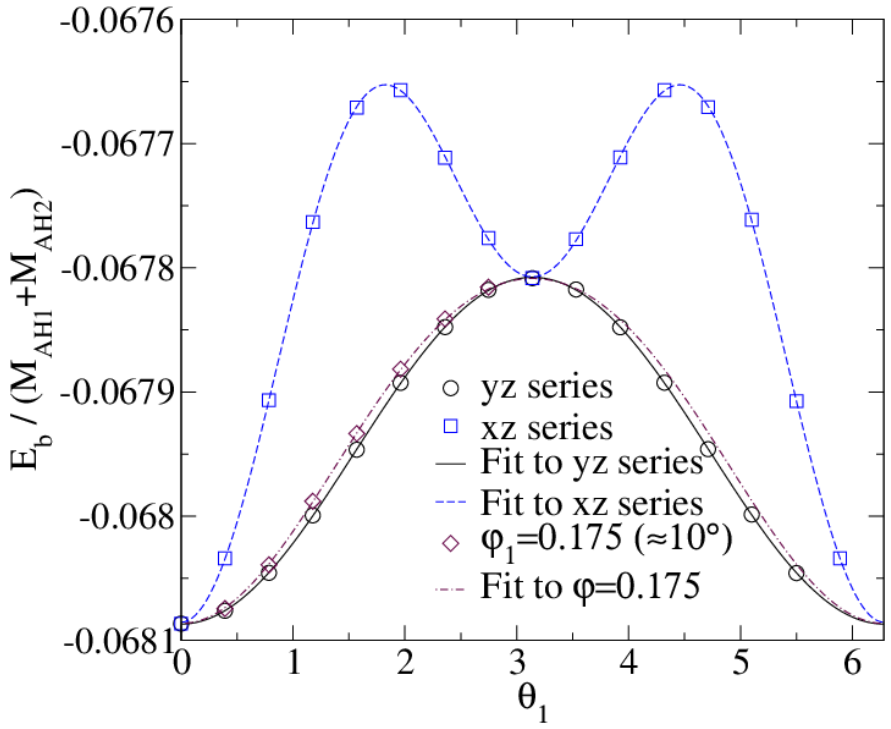
Undergrad!



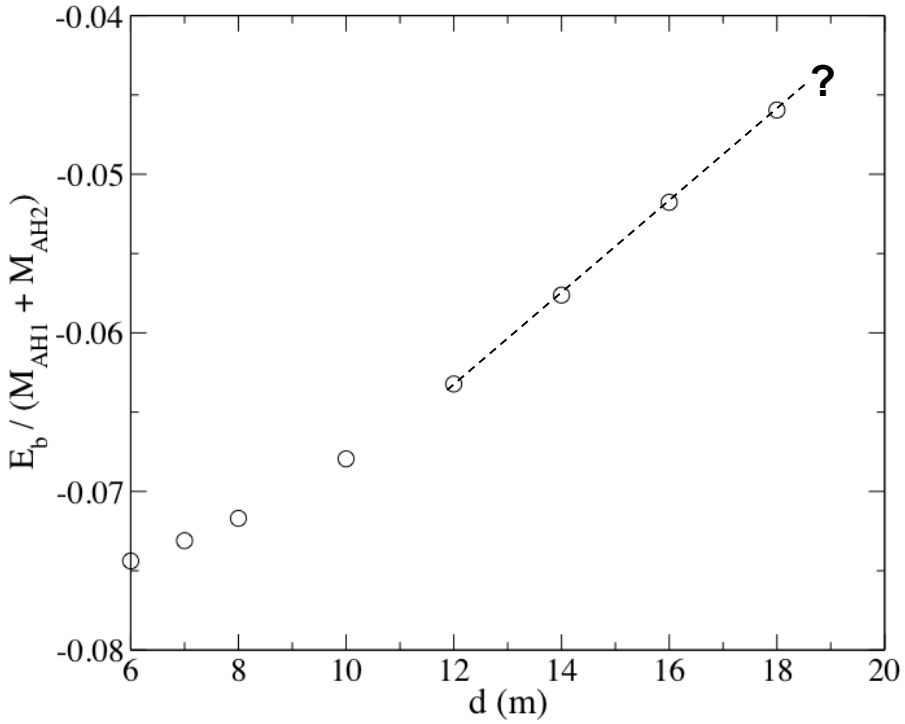
xz series
($\varphi_1 = \pi/2$)



yz series
($\varphi_1 = 0$)



Problem: Dependence on separation *d*:



- BE vs. separation graph (above) was not showing *1/d* dependence as *d* increased
- Possible problems:
  - Domain / separation too small.
  - Insufficient resolution
- Code was unigrid. Worked on adding FMR, MPI & OpenMP from 2006 on...

- Even with AMR, BE values were erratic for large separations.
- Realized that truncation error on coarse grid near ADM Mass integration surface was swamping BE values.

Toward Higher Accuracy

1. Put a "shell" of finer grids near outer boundary.
   - Code not designed to load-balance well for such a configuration*
2. Higher resolution everywhere
   - Existing code, bigger grids, more memory. NICS Nautilus for shared RAM -- Physics Undergrad: Lindsey Thompson
   - Thanks to Pragnesh Patel, NICS.
3. Greater parallelism: Merge with Cactus/Carpet --CS Undergrad: Grayson Carroll
   - *will also allow for "shell" FMR grids, make constraint solver usable by any Cactus user
   - Code: "BRUISER". Background solver already available
4. Higher order difference stencils
   - Implementing 4th order accurate excision scheme of Natchu & Matzner -- Physics undergrad: Chris Olfers

Involving Undergrads

- Typical "teaching" college, e.g. Belmont
  - Teaching load: 24+ hrs per year
  - 2 or 3 physics majors per graduating class
  - No grad students / postdocs
  - Students typically start calc-based physics in sophomore year. E&M, Analytical Mech., Diff. Eq. in junior or *senior* year.

Areas for UGR Contributions

- Assume you have a working code… ;-)
  - Parameter space surveys
  - "What if" scenarios. Tap in to students' creativity. Let *them* design & *discover*
  - Creating tutorials for the *next* student(s)
- Simple "upgrades"

Guidelines for UGR

- Projects: Only one semester long
  - Very well-defined,
  - Frequent meetings
- Easy, simple user interfaces
  - Scripts to automate
  - e.g., simfactory
- Let them *see* the results
- Lessons from Apple's MacIntosh, Cactus HTTPd Thorn…

Netscape: Cactus Downloadable Files

File Edit View Go Communicator Help

Bookmarks Location: http://localhost:5555/Output/viewport.html What's Related

Back Forward Reload Home Search Netscape Print Security Stop

Master Run Page

Environment:
Time: 23:02:23
Date: Sat 10 Feb 2001

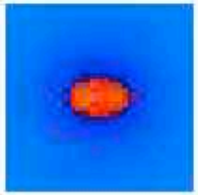
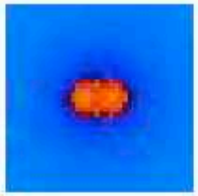
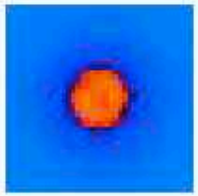
Simulation:
Cactus Simulation
`WaveDemo.par`
Iteration: 13152
Physical time: 168.62

Options:
Cactus Control
Thorns
Parameters
Groups and Variables
Message Board
Files
Viewport
Processor Information

Viewport

This page displays certain types of the output files from the download page as images (currently only jpegs [mime type image/jpeg]).

Many IO methods have *steerable* parameters which allow you to e.g. add fields and customise behaviour.Depending on your authorisation, you can access the parameter steering page

Variable File Name	Description	Image
WAVETOY::phi WaveIsoSurfacer/phi_2_3.jpeg	Jpegs of slices	
WAVETOY::phi WaveIsoSurfacer/phi_1_3.jpeg	Jpegs of slices	
WAVETOY::phi WaveIsoSurfacer/phi_0_3.jpeg	Jpegs of slices	

Involving Undergrads

- "BRUISER": Belmont Research for Undergraduates Studying Einstein's Relativity.

"Bruiser the Bruin"

Future work: Collaborations:

- Developing user interfaces
- Doing runs: parameter surveys, tests
- "Playing" with code: education / inspiration