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Simulating Magnetospheres with Numerical Relativity: The GiRaFFE code

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Simulating Magnetospheres with Numerical Relativity: the GiRaFFE code

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Background

- ✓ Numerical Relativity is successful in the simulation of black holes and gravitational waves. In recent years, teams have tackled the problem of the interaction of gravitational and electromagnetic waves.

Motivaton

- ✓ Where there are plasmas, the simulations often have trouble reproducing nature.
- ✓ Neutron stars, black hole accretion disks, astrophysical jets, are extreme environments both gravitationally and electromagnetically.

Objective

- ✓ We are creating the first open-source, dynamical spacetime general relativity force-free electrodynamics code: GiRaFFE
- ✓ The code and afferent tests will be released to the numerical relativity community.

Formalism

- ✓ The force-free regime is the limit of ideal MHD when the magnetic fields dominate
- ✓ Force-free constraints $\mathbf{E} \cdot \mathbf{B} = 0$ and $E^2 < B^2$
- ✓ Force-Free Electrodynamics (FFE) is a limit of ideal MHD with negligible plasma inertia.
- ✓ FFE applies to highly-conducting tenuous plasma, not to electrovacuum environment.
- ✓ Electrovacuum solutions satisfying the force-free conditions, are force-free as well.
- ✓ Force-free conditions $\mathbf{E} \cdot \mathbf{B} = 0$ and $E^2 < B^2$
- ✓ Replace $\mathbf{E}$ with Poynting vector $S_\mu = -n_\nu T^{EM}{}_{\mu\nu}$
- ✓ In $\boldsymbol{S}$-$\boldsymbol{B}$ formulation $S_i B^i = 0$ and $S^2 < B^4$

Numerical Recipe

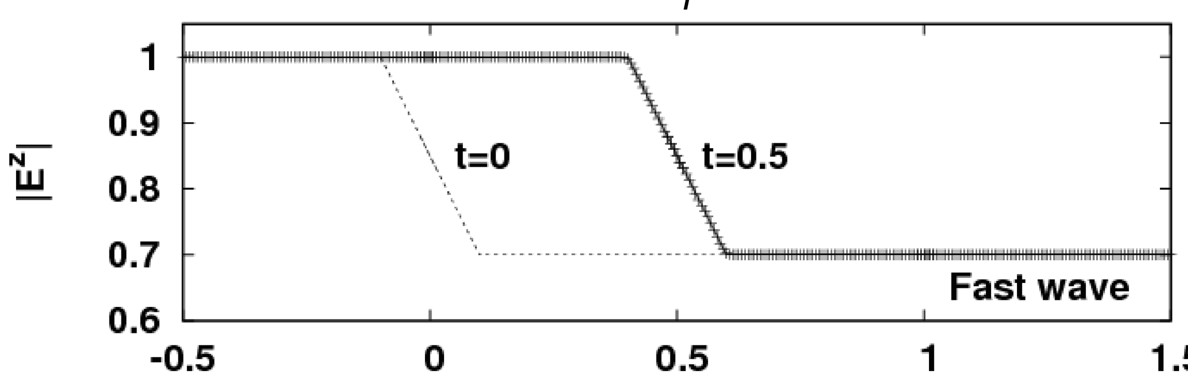
- ✓ The "conservative" evolved variables: (B^i, S_i)
- ✓ The "primitive" recovered variables: (B^i, v_i)

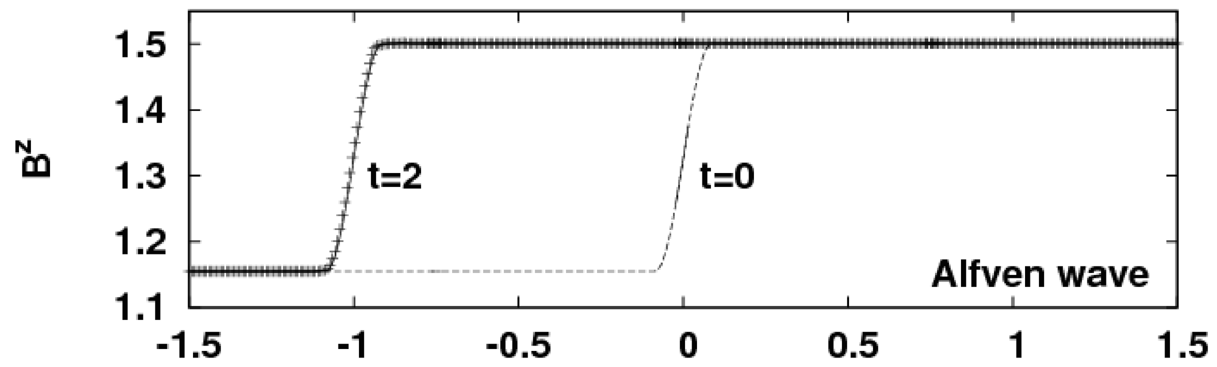
1. Ignore the matter by removing from the GRMHD code the perfect fluid stress tensor
2. Add algorithm for the primitives recovery.

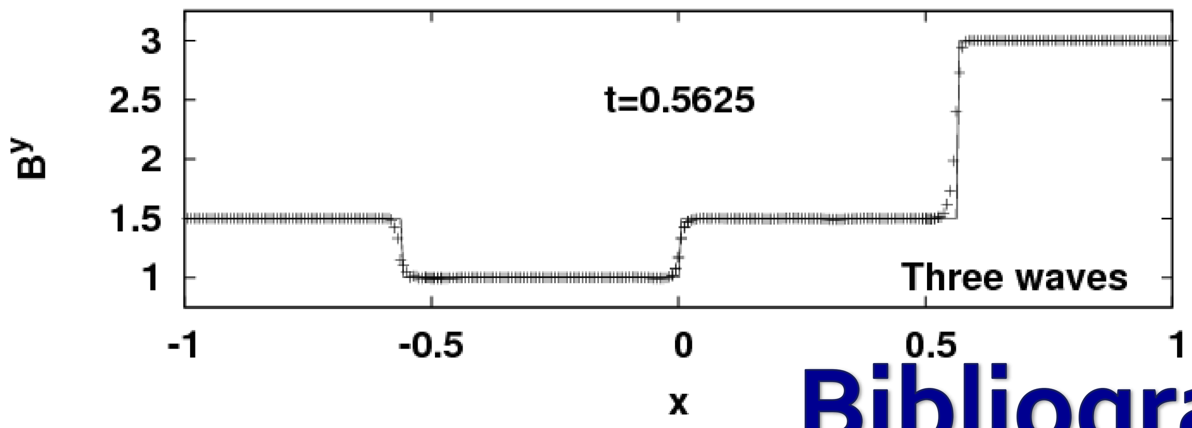
- ✓ $S_i B^i = 0$ is enforced algebraically after each evolution timestep: $S_i \rightarrow S_i - (S_j B^j) B^i / B^2$
- ✓ $S^2 < B^4$ is enforced in the same time by: $\tilde{S}_i \rightarrow \tilde{S}_i \min(1, f)$, $f = \mathrm{factor}(B^4, S^{-2})$
- ✓ Current sheets break down $S^2 < B^4$ $(E^2 < B^2)$
- ✓ The velocity normal to the current sheet is set to zero within 4 points around equator.

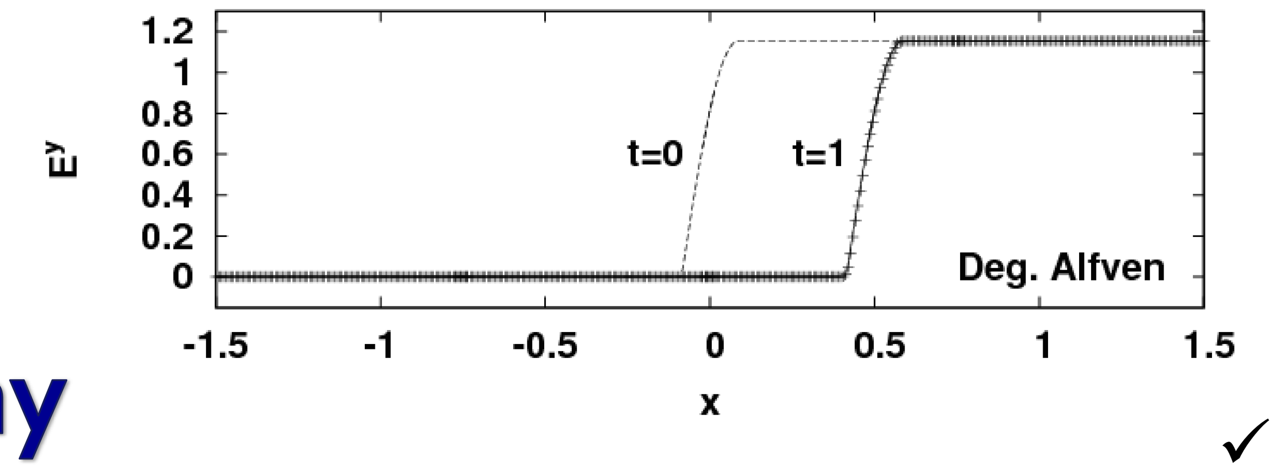
Initial Data

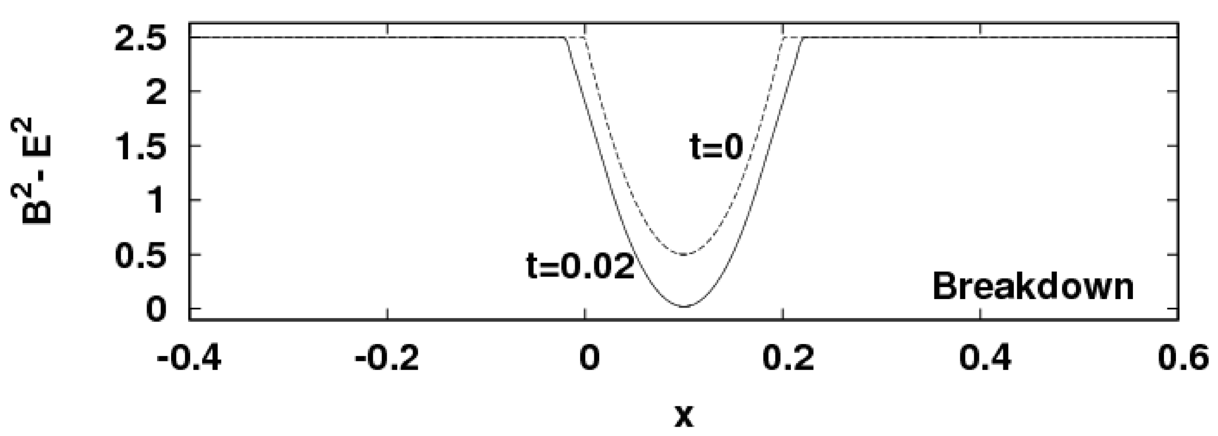
- ✓ Exact initial solutions for the pair (A_i, v^i)
- ✓ The 1D tests assume Minkowski spacetime
  1. Fast wave
  2. 2. Alfven wave
  3. Degenerate Alfven wave
  4. Three waves
  5. FFE breakdown
- ✓ The 3D tests assume Kerr-Schild spacetime
  1. Split monopole
  2. Exact Wald electrovacuum
  3. Magnetospheric Wald
  4. Force-free aligned rotator
  5. Exact null+ solutions











Conclusions

- ✓ We developed a new code for the numerical simulation of neutron and black hole magnetospheres, using the FFE formalism.
- ✓ We tested the performance of the new code named GiRaFFE, in 1D and 3D test suits.
- ✓ We will study magnetospheres, focusing on jets by the Blandford -Znajek mechanism.

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