BLANDFORD-ZNAJECK MECHANISM IN BINARY BLACK HOLEs

Denver (Colorado), 02 May 2009

C.Palenzuela, L.Lehner, M. Anderson, S. Liebling, D. Neilsen

Max-Planck Institute, AEI, Golm (Berlin)

LOOKING FOR BLANDFORD-ZNAJECK MECHANISM IN BINARY BLACK HOLEs:

Stirred, not shaken

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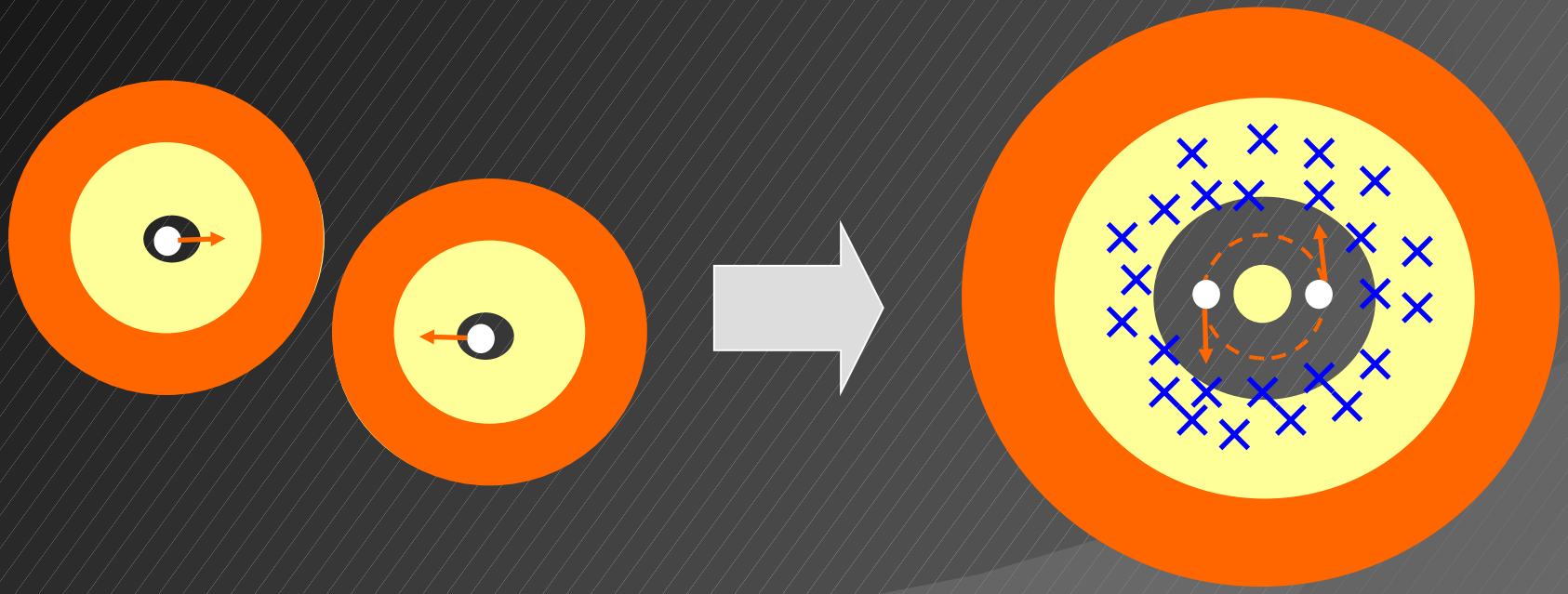
Overview

- Motivation
  - study the effects of the BBH mergers on the EM fields
- The evolution system
  - the Einstein-Maxwell equations
  - code implementation
- The asymptotic state; Wald's solution
  - Wald's solution
  - recovering the Wald's solution by (evolution) relaxation
- The transitory state; binary black hole merger
  - features of the evolution

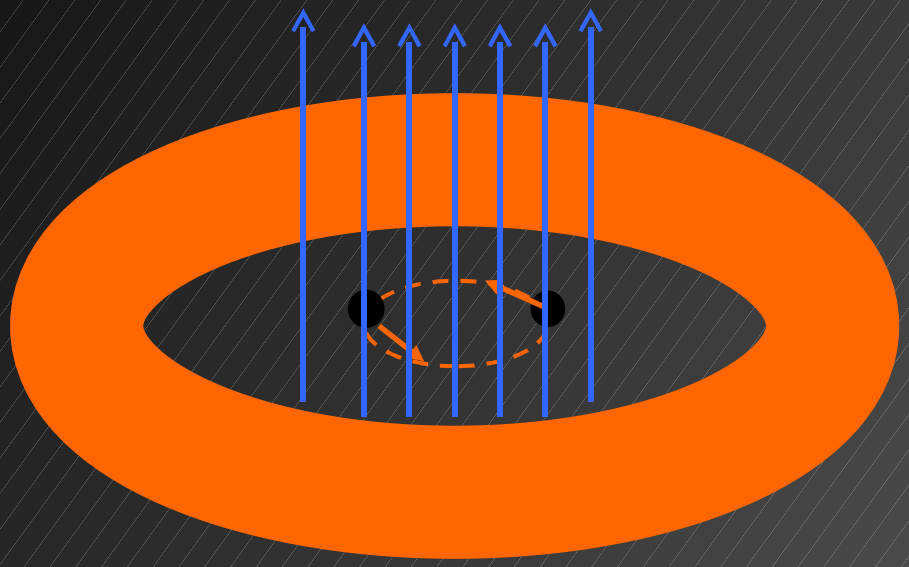
I. Motivation

-observations indicate that there are supermassive BHs in the center of galaxies, surrounded by gas and a disk
- during the merger of galaxies a circumbinary disk is formed, which produces a magnetic field near the black holes



I. Motivation

- study the effects of the binary BHs dynamics in the EM fields
- study the correlations between GW radiation & EM effects
- study systems with both bands → indirect observables
- help in the detection of one or the other



- General Relativity for the evolution of the spacetime
- Maxwell equations for the evolution of the EM fields
- Hydrodynamics for the evolution of the disc and gas
- Radiation processes due to the accretion,…

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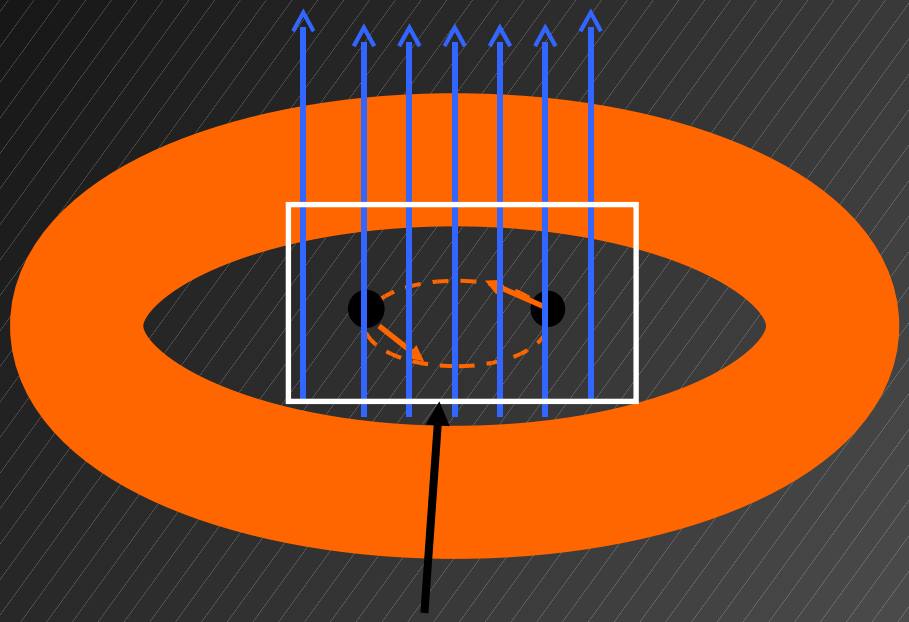


- sub-domain with the BHs, excluding the disk

- General Relativity for the evolution of the spacetime
- Maxwell equations for the evolution of the EM fields
- ~~Hydrodynamics for the evolution of the disc and gas~~
- ~~Radiation processes due to the accretion,…~~

II. The Einstein-Maxwell system

- Generalized Harmonic formulation of Einstein eq. with constraint dampings

$$R_{ab} + 2\,\nabla_{(a}Z_{b)} = 8\pi\,(T_{ab} - T\,g_{ab}/2) + \sigma(2\,n_{(a}Z_{b)} - g_{ab}\,Z^{c}n_{c})$$

$$T_{ab} = F_{ac}\,F^{c}{}_{b} - (F^{cd}F_{cd})g_{ab}/4$$

- Extended Maxwell equations with constraint dampings, written for the fields (E,B,Φ,Ψ)

$$\nabla_{a}\,(F^{ab} + g^{ab}\,\Psi) = \sigma\,n^{a}\,\Psi$$

$$\nabla_{a}\,({}^{*}F^{ab} + g^{ab}\,\Phi) = \sigma\,n^{a}\,\Phi$$

II. The numerical code

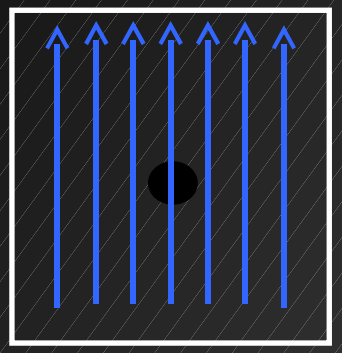
- First order reduction of the Einstein-Maxwell system

- Method of Lines for the evolution
  - 3^{rd} order RK for the time integration
  - 4^{th} order space discrete operators satisfying Summation By Parts rule

- The equations are implemented in the infrastructure “had”, which provides parallelization, Adaptative Mesh Refinement, excision for the black holes,…

III. Asymptotic state: Wald's solution

- study first the asymptotic stationary state, after the merger



- Exact solution (Wald 1974) for a BH immersed in a external magnetic field aligned with the spin (test field, valid in this case $M = 10^8\ M_\Theta$, $B = 10^4$ G)

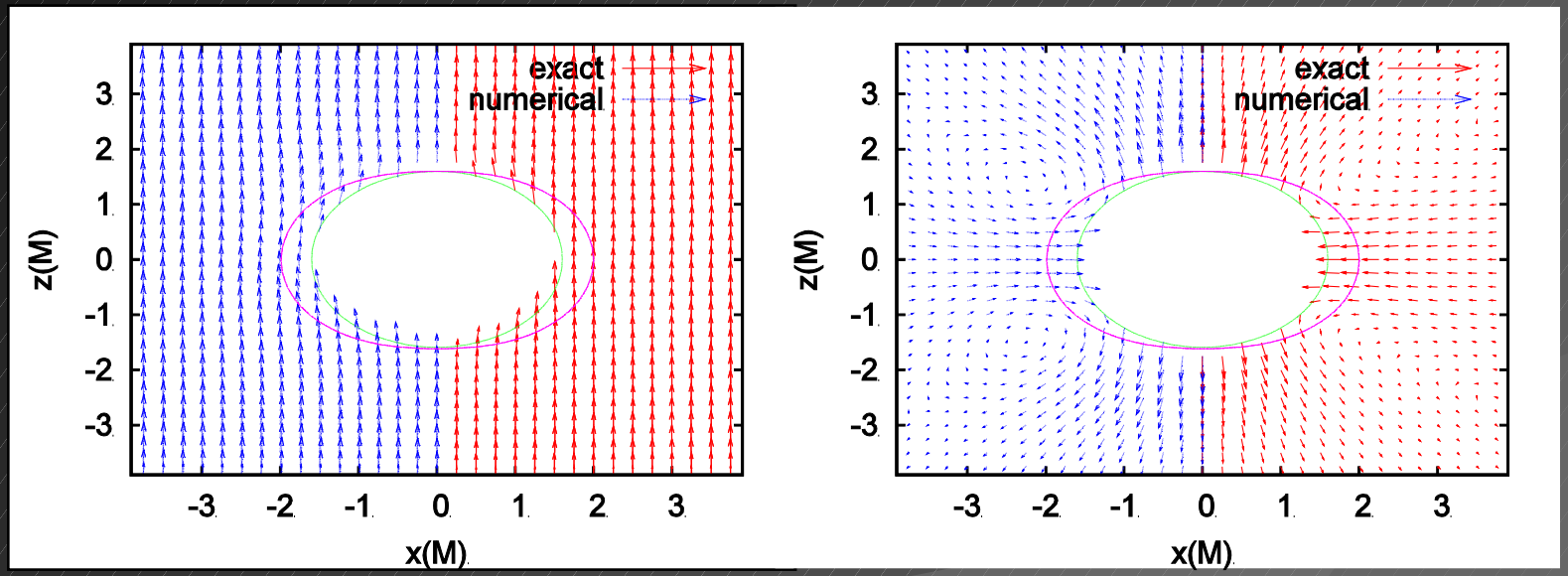
$$F = \tfrac{1}{2}\, B_0\, (d\Psi + 2J/M\, d\eta)$$

Ψ axial KV, η timelike KV

- Near the black holes, the magnetic fields from the disk (in the stationary state) tend to the Wald's solution (King, Lasota & Kundt 1975)

III. Asymptotic state: evolution

- consider a domain close to the BH without the disk
- set the magnetic field from the 'far away' disk by:
  - * an initial EM field $\mathbf{B} \approx B_0 \check{z}$, $\mathbf{E} = 0$
  - * boundary conditions (maximally dissipative on the rhs)
- evolve the Einstein-Maxwell system until the stationary state

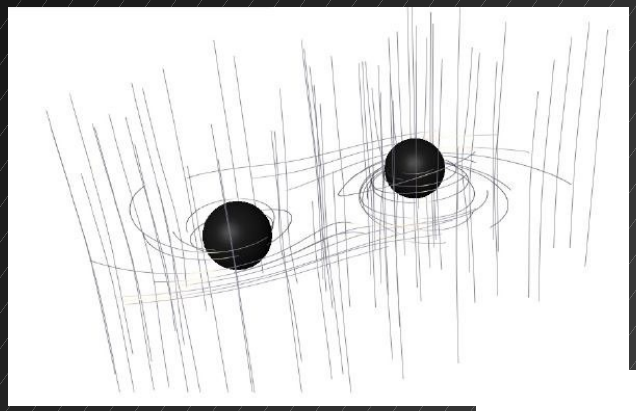


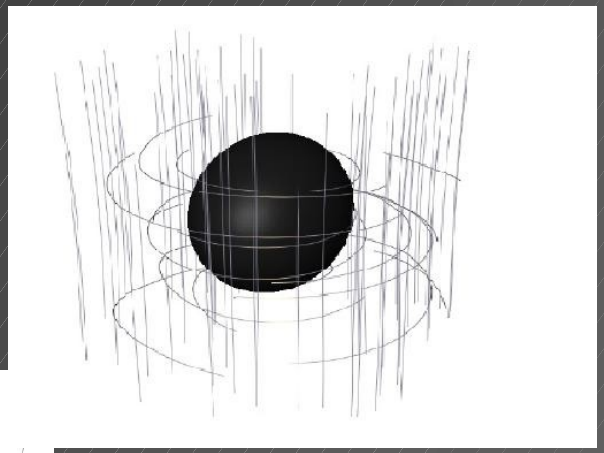
Magnetic field

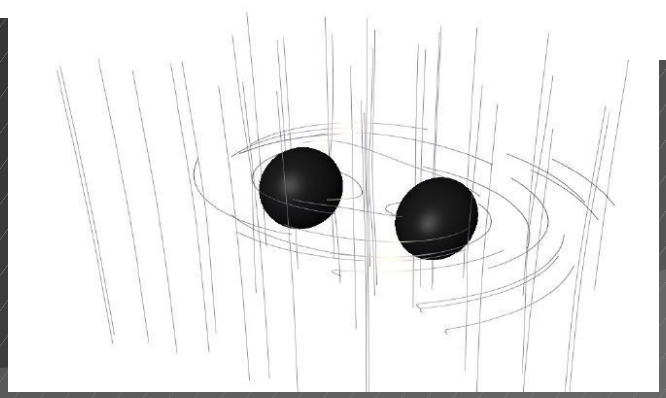
Electric field

III. Transitory state: binary BHs

- study the last orbit and merger of the binary black holes
- set the initial data with a binary BHs in quasi-circular orbits (provided by Lorene) and add the magnetic fields like before

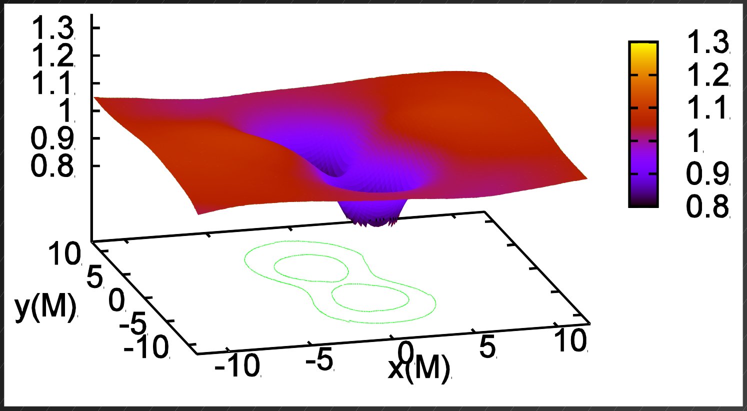


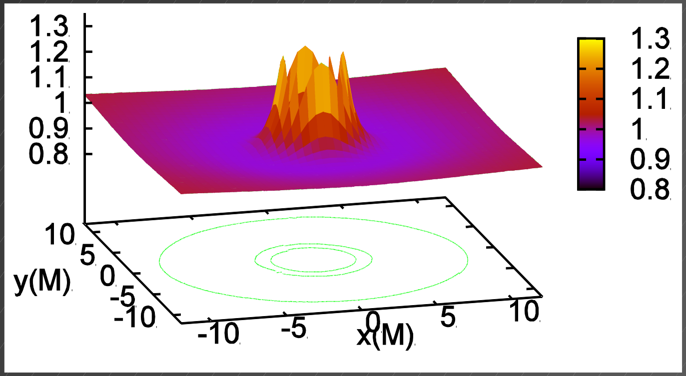


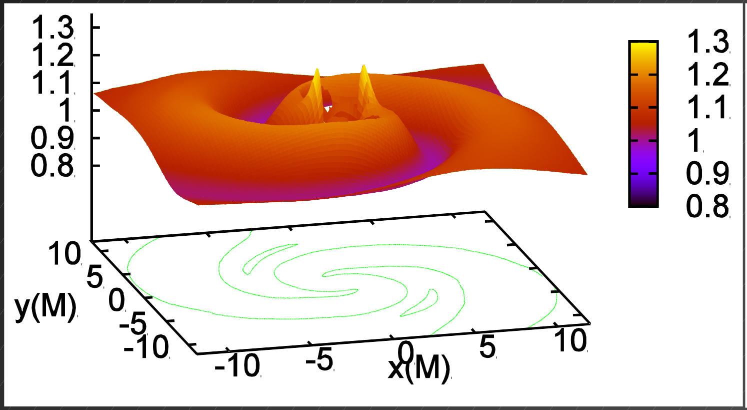


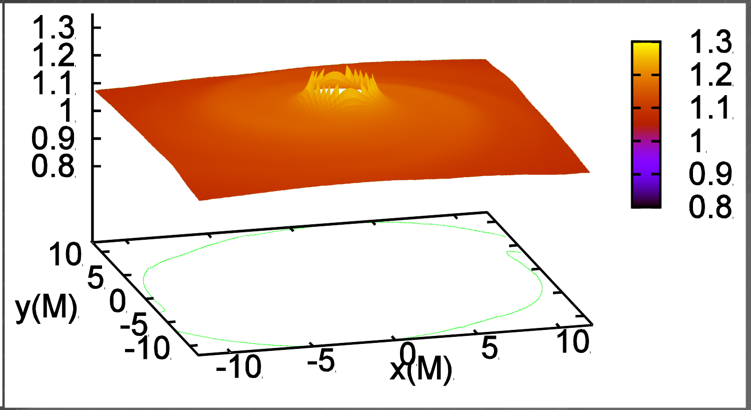
III. Transitory state: binary BHs

- compare the energy density from the binary BHs with the single BH case







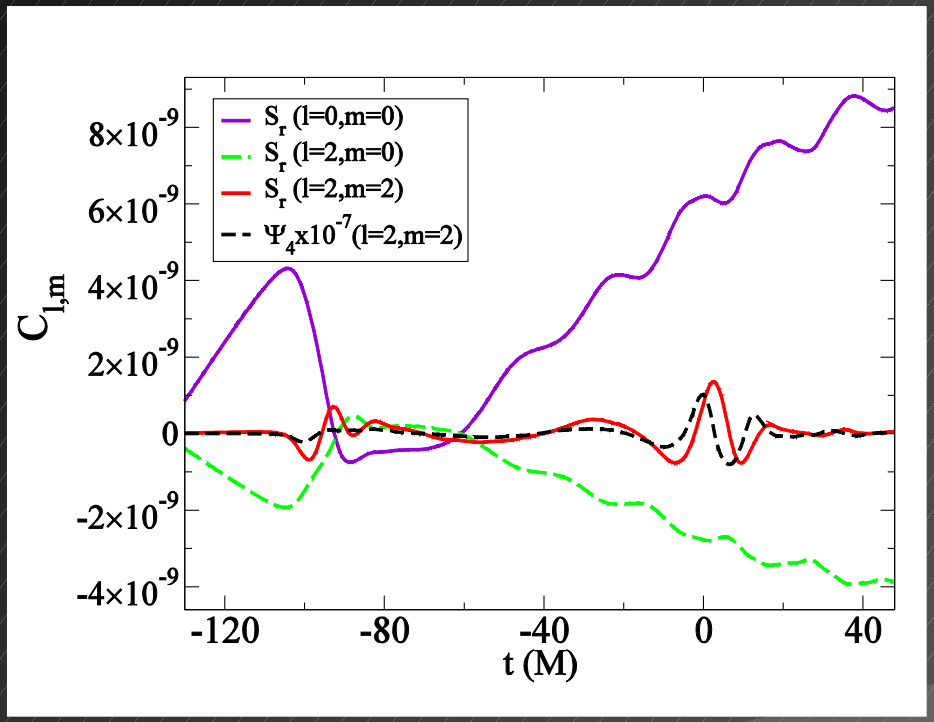


III. Transitory state: binary BHs

- compute the GW & EM radiations

$\Psi_4 = R_{abcd}\, k^a\, {}^*m^b\, k^c\, {}^*m^d$ $\Phi_2 = F_{ab}\, k^a\, {}^*m^b$

S_r Poynting flux



movie reminder

movie reminder

Summary

- we have evolved and analyzed the effects on the EM fields of the last orbit of a binary BH
- there is a enhancement on the EM energy at the merger
- there is a EM characteristics radiation profile quite tied to the BBH dynamics (spacetime tracer)

Ongoing/Future work

* firm up conjecture about lagging of EM "radiation"
* add spins to the binaries & unequal masses :
  extraction of energy due to Blandford-Znajeck mechanism?
* study the trajectories of charged particles in these evolutions