Neutron Stars, BlackHoles, and Photons

David Neilsen
(Luis Lehner, Matthew Anderson, Steven Liebling,
Carlos Palenzuela, Eric Hirschmann, Patrick Motl, Joel Tohline)

MICRA 2009
Niels Bohr Institute, Copenhagen

Provocative(?) Summary

- Simultaneous detection in electromagnetic, gravitational, and neutrino bands is really necessary....

Provocative(?) Summary

- Simultaneous detection in electromagnetic, gravitational, and neutrino bands is really necessary....
- ....but it is really hard to model.

Introduction

- NS-NS with magnetic fields
- BH-NS with magnetic field
- BH-BH in external electromagnetic field
- Radiation transfer and binaries (to come)

NS-NS with magnetic field

- Superposed, boosted TOV stars

$$M = 0.89 M_\odot \qquad R = 16.3 \text{ km}$$

- Ideal gas EOS, Gamma=2
- Poloidal magnetic field (extreme magnetar limit)

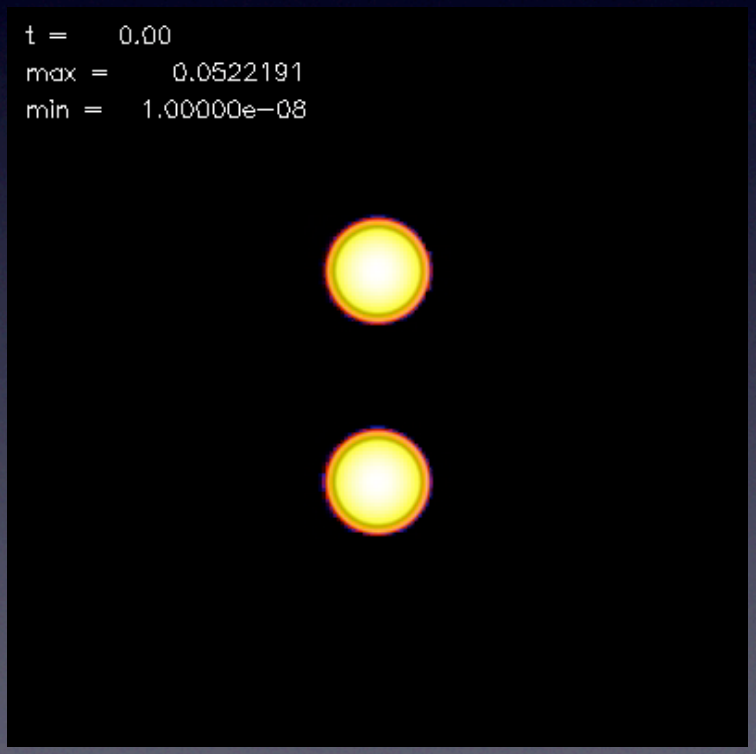
$$B \approx 10^{16} \text{ G} \qquad A_\phi = r^2 \max(P - P_{\rm vac}, 0)$$

- Test case to see what may be there...

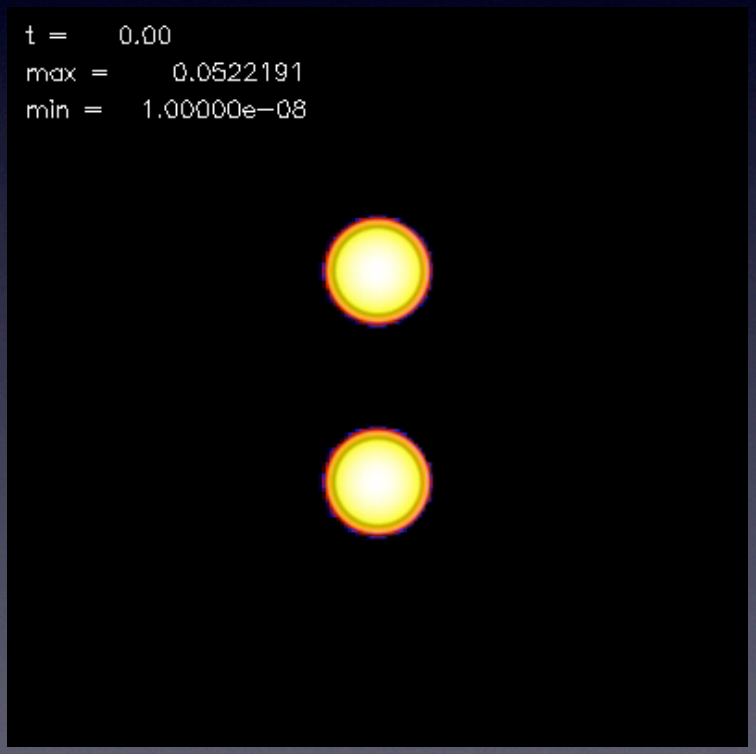
  Price & Rosswog, Science (2006)
  Anderson, et al. PRL (2008),
  Liu, Shapiro, Etienne, Taniguchi, PRD (2008),
  Giacomazzo, Rezzolla, Biaotti (2009)

Movie Comparison

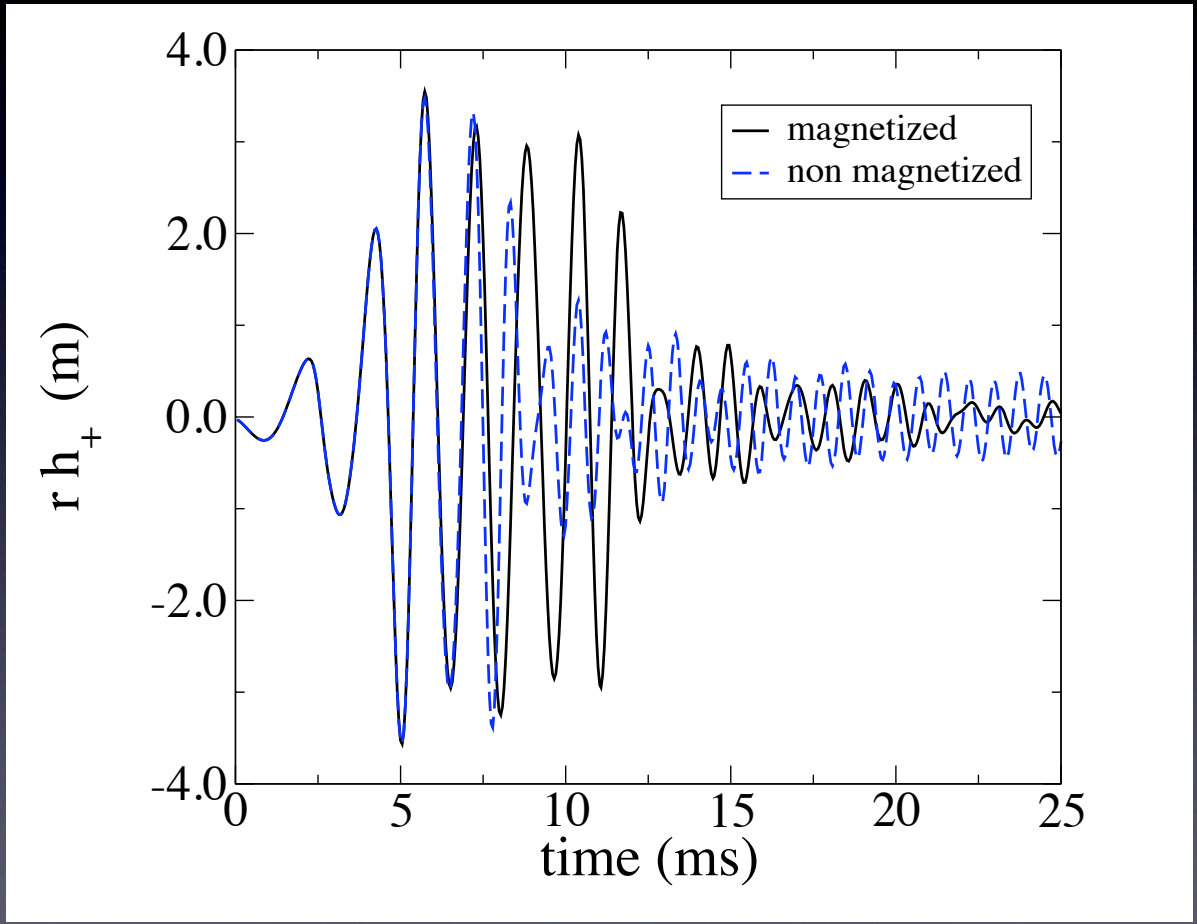
HD



MHD



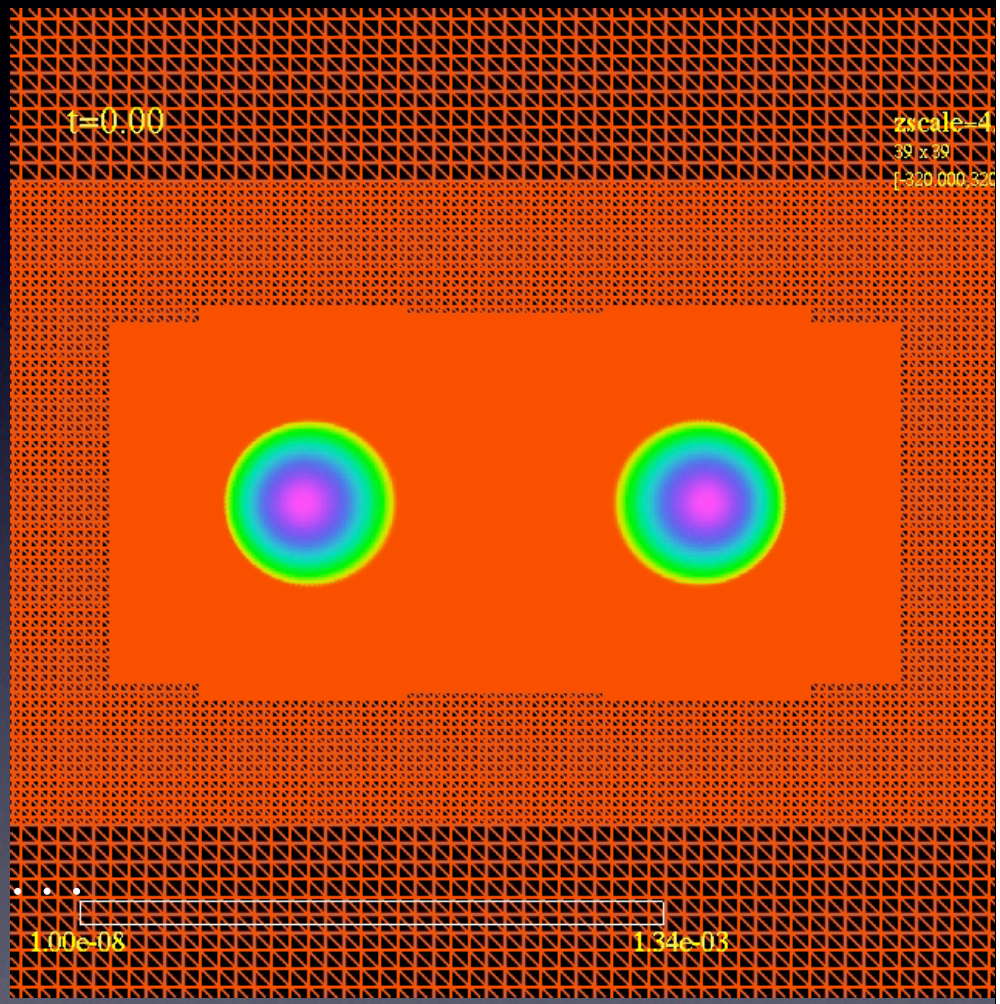
Gravitational wave signal



NS-NS with hybrid EOS

- Clues to NS EOS in gravitational waves
- Parameterized, hybrid EOS by Friedman & collaborators (Read et al 2009)
- Initial data provided by Taniguchi

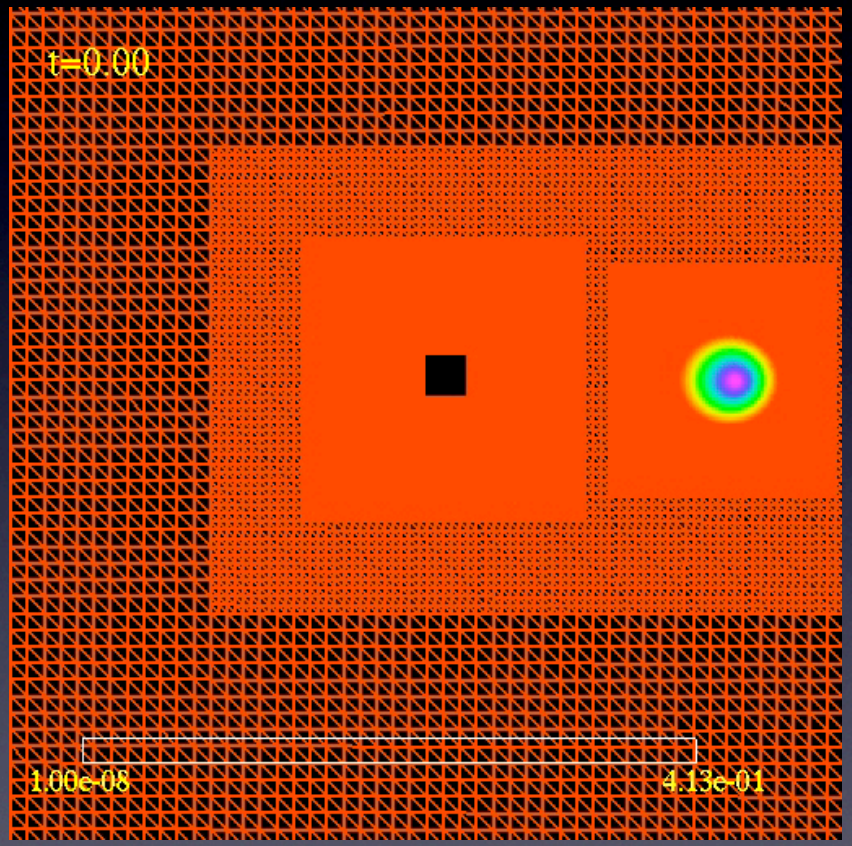
$$P = P_{\rm cold} + P_{\rm thermal}$$
$$P_{\rm cold} = \kappa_i {\rho_0}^{\Gamma_i}, \quad i = 1, 2, \ldots$$
$$P_{\rm thermal} = (\Gamma - 1)\rho_0 \epsilon$$

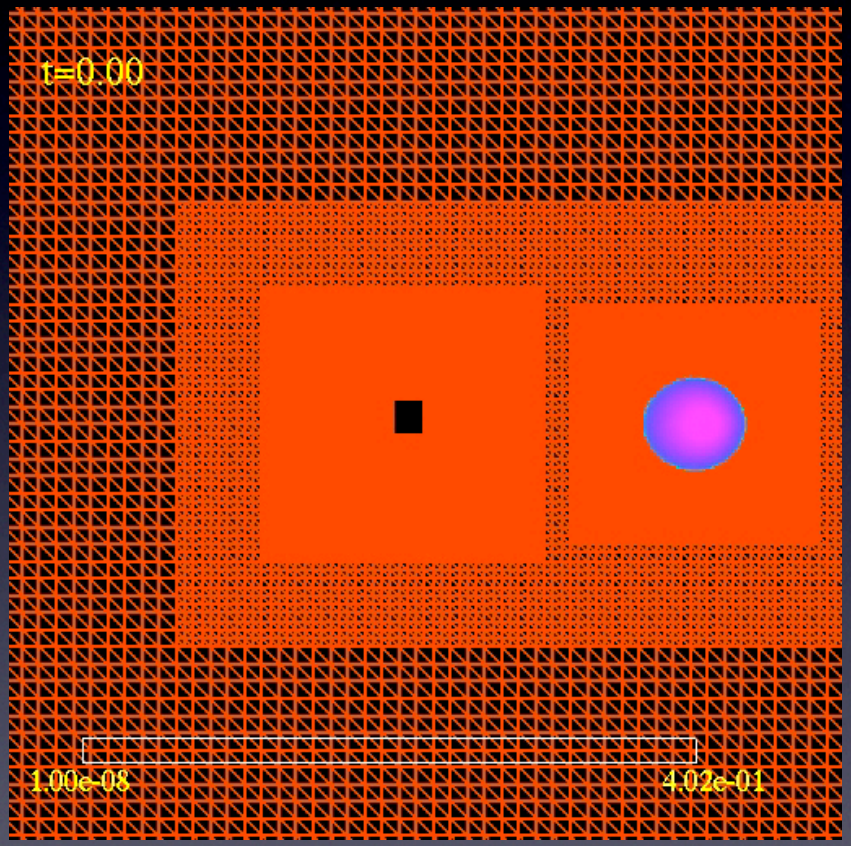


BH-NS & magnetic field

- BH-NS possible sources for SGRBs
- See work done by
  - Shibata, Taniguchi (2008)
  - Etienne, Faber, Liu, Shapiro, Taniguchi (2008)
  - Yamamoto, Shibata, Taniguchi (2008)
  - Duez, Foucart, Kidder, Pfeiffer, Scheel, Teukolsky (2008)
  - Shibata, Kyutoku, Yamamoto, Taniguchi (2009)
- Largest disk with q=1 and spinning BH
- What happens with a magnetic field?

BHNS binary (q=5)

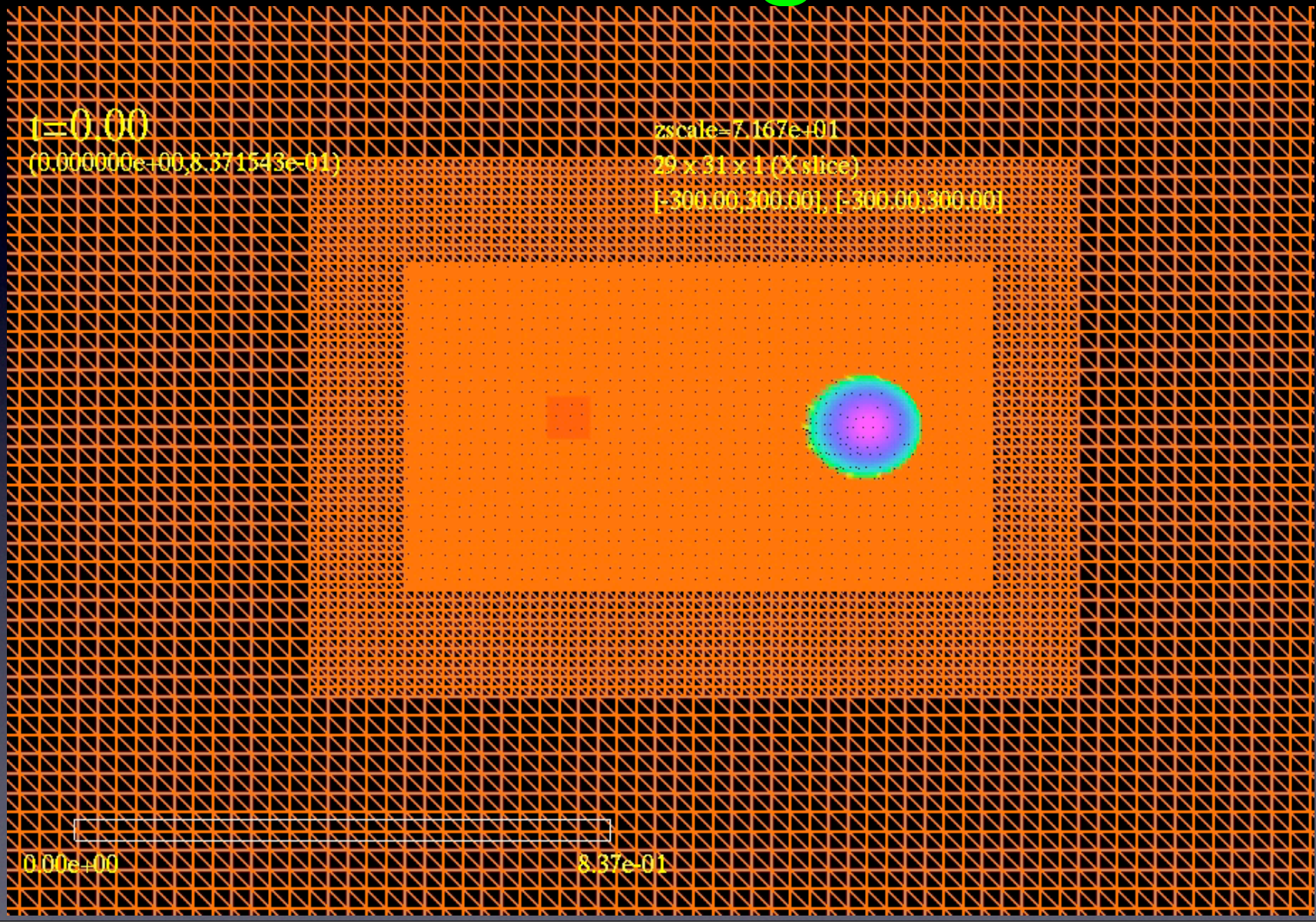




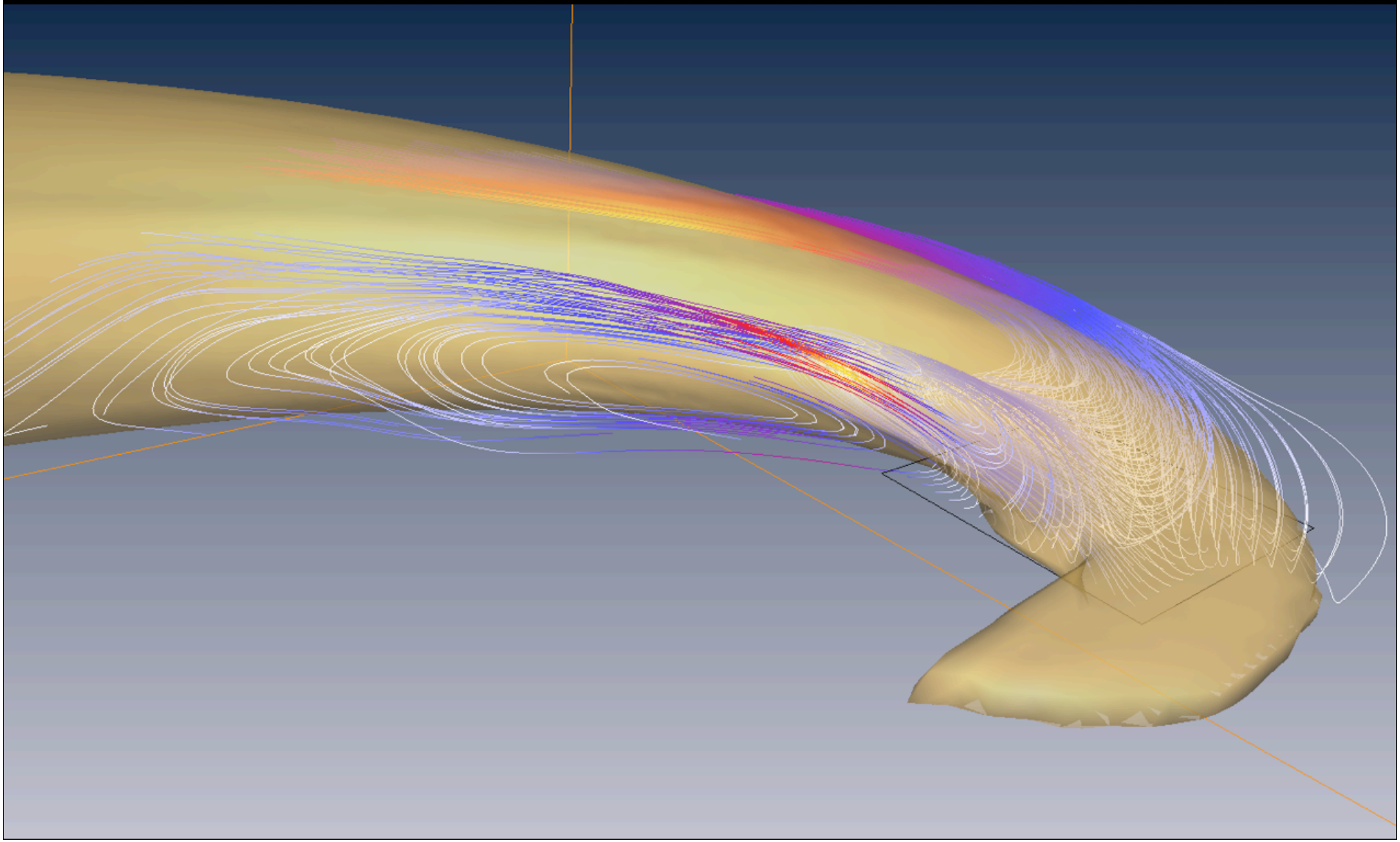
a = 0

a = 0.5

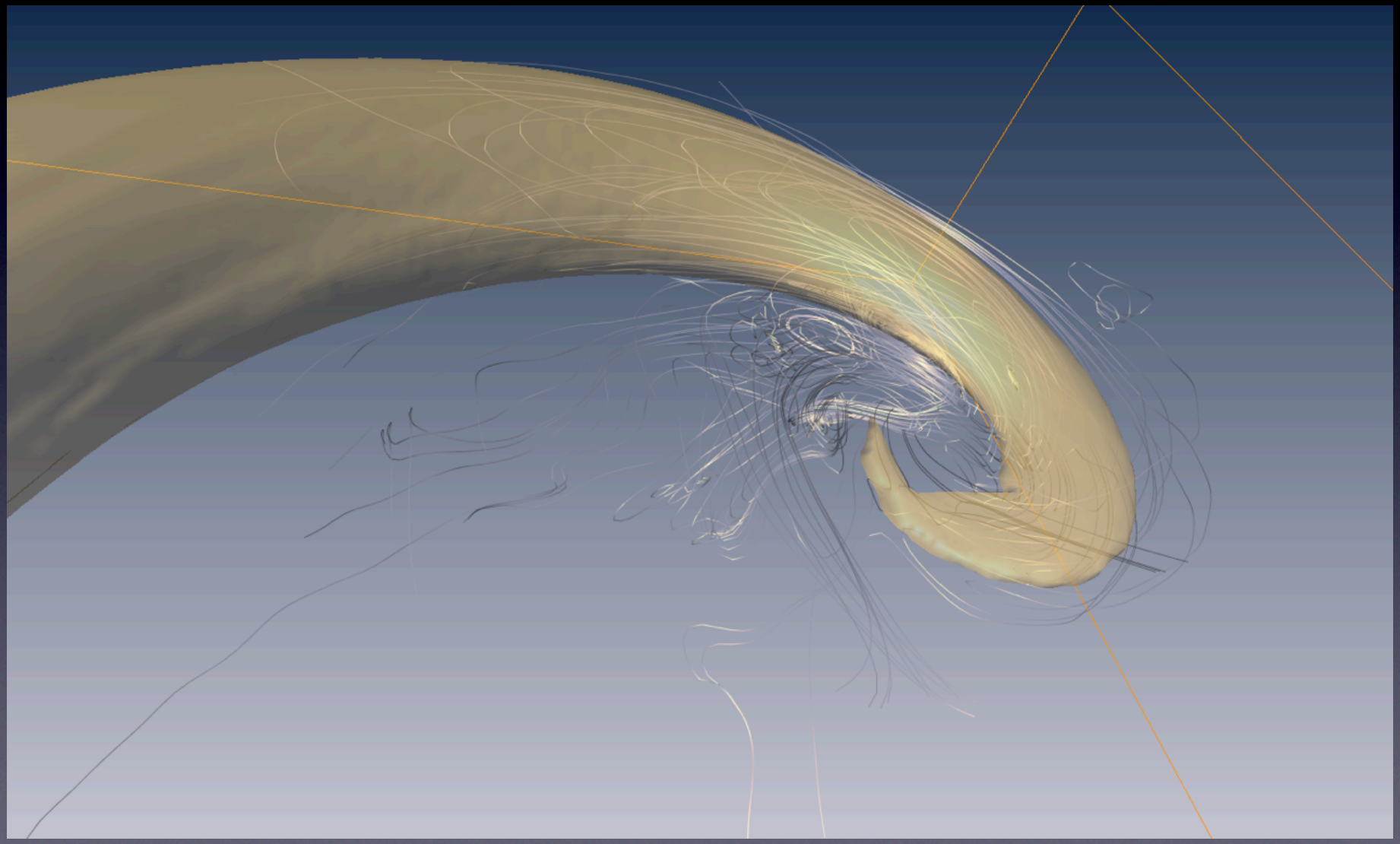
BHNS with magnetic field



Magnetic field I



Magnetic field II



BBH + EM

- Binary BH with disk
- Poloidal magnetic field approx. constant along z
- Evolve Einstein+Maxwell
- $M=10^8\ M_{sun}$, $a=0.7$, $B=10^4$ G

Stirring Not Shaking:

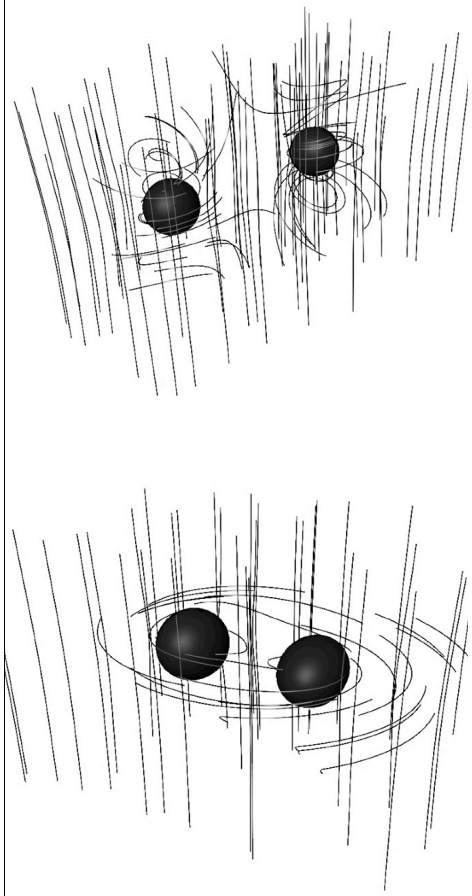
Binary Black Holes' Effects on Electromagnetic Fields

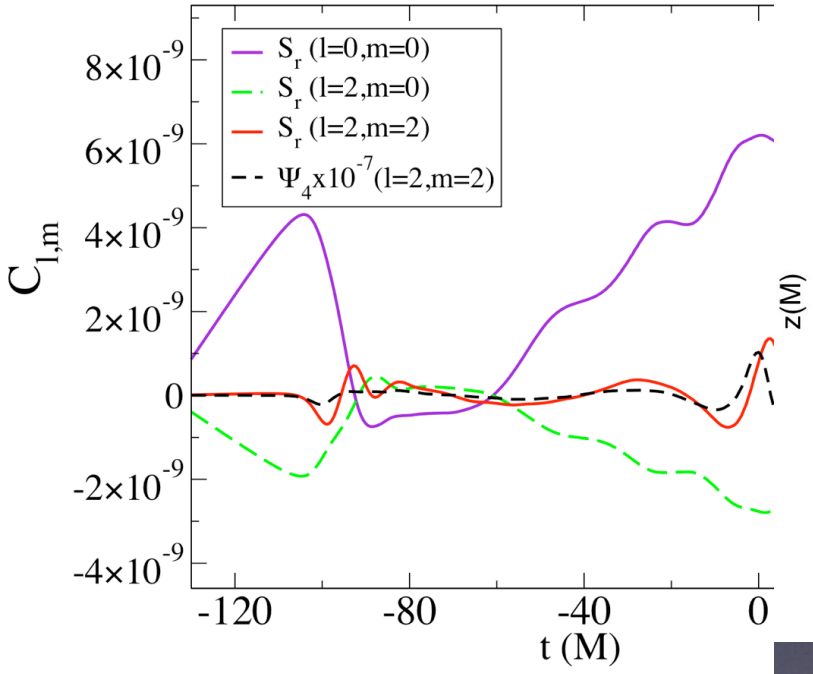
EM Energy Density

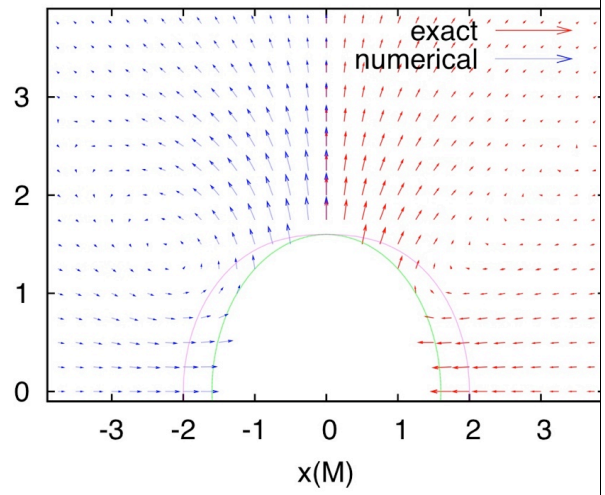
(arXiv:0905.1121)

Palenzuela, Anderson, Lehner, Liebling, Neilsen, PRL (2009)

Hints to EM radiation







Radiation Transfer

- Classical radiation eq. along geodesics
- Emission
  - Black body (optically thick)
  - Bremsstrahlung (optically thin)
- Absorption: Kramer's opacity law
- Ideal gas EOS & temperature

$$\frac{dI}{d\lambda} = -p^{\alpha} u_{\alpha} \left(-\chi_0 I + \eta_0\right)$$

Geodesic eqs.

$$\frac{dx^{\mu}}{d\lambda} = p^{\mu}$$

$$\frac{dp_{\mu}}{d\lambda} = g^{\gamma\beta}\Gamma^{\alpha}{}_{\mu\gamma} p_{\alpha} p_{\beta}$$

Test Case: Kicked BH+Disk

- Toroidal disk about BH
- Disk radius

$$R = 4.5 \times 10^{14} \mathrm{cm}$$

- BH

$$M_{\mathrm{BH}} = 10^8 M_\odot$$

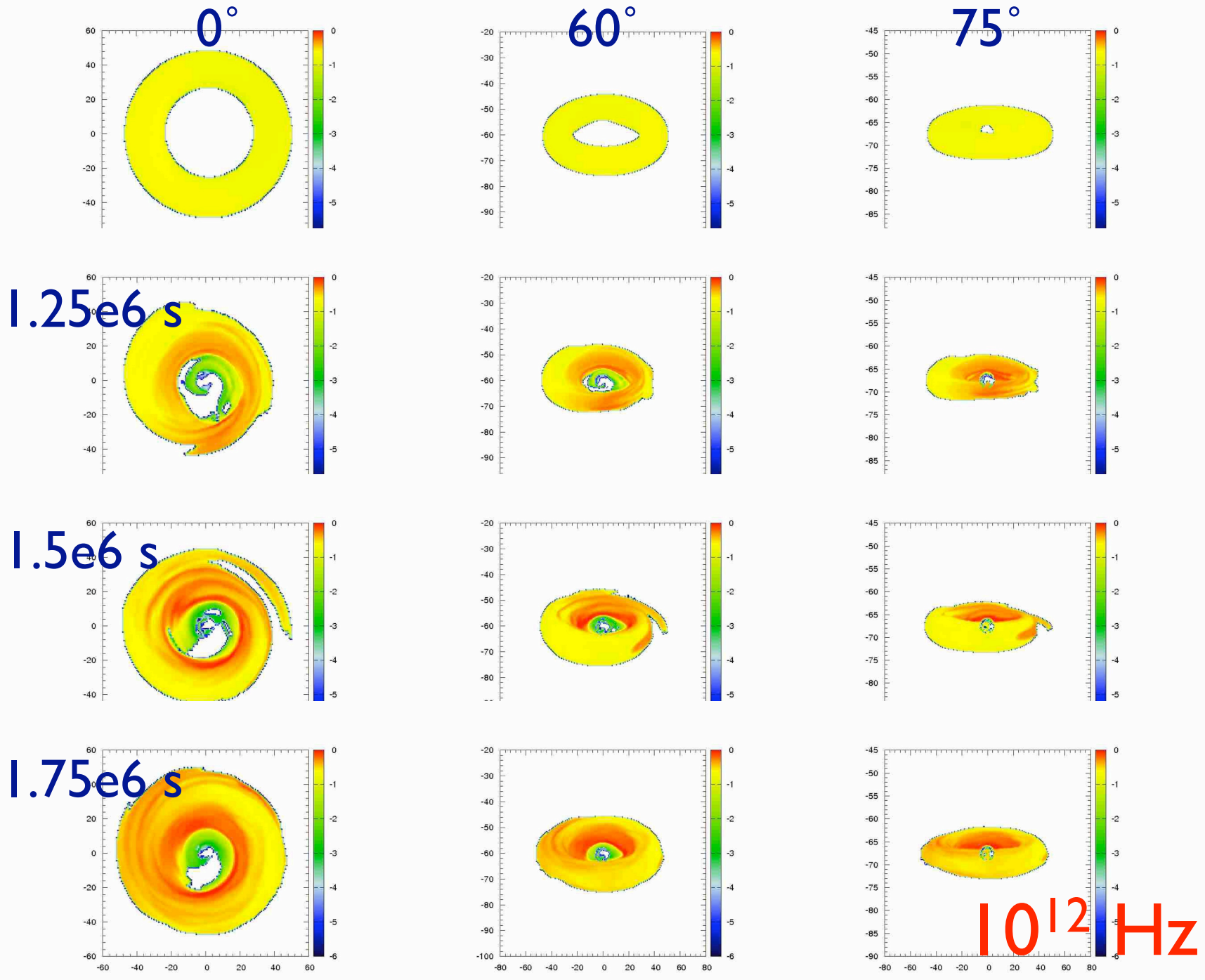
- Accretion rate

$$\dot{M} = M_\odot / \mathrm{yr}$$

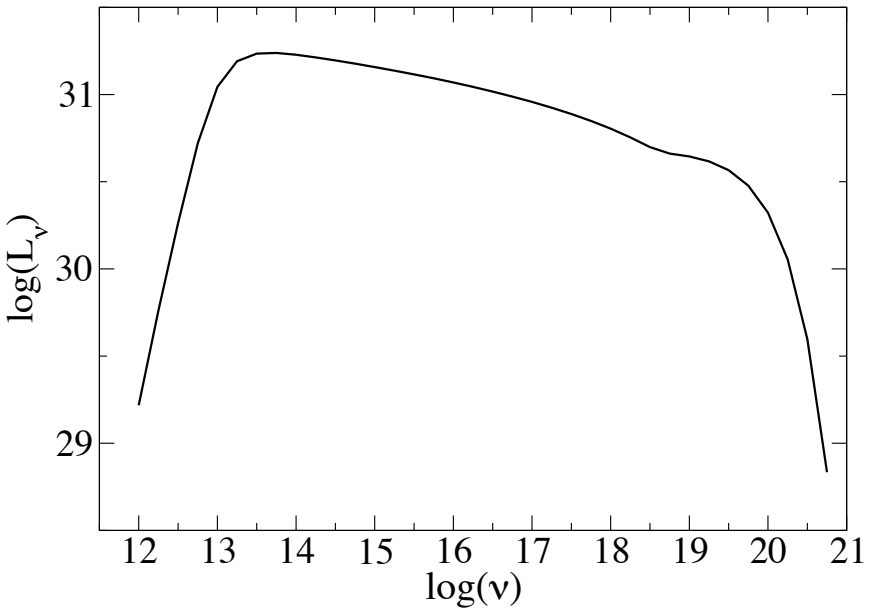
- BH kick

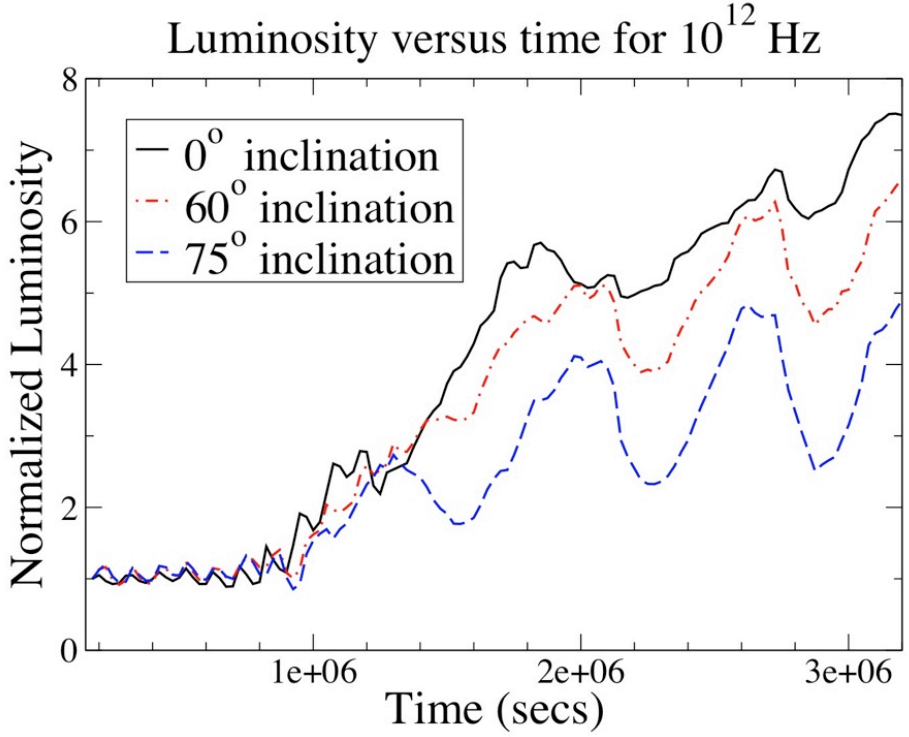
$$v = 3,000\,\mathrm{km/s}$$

Megevand, Anderson, Frank, Hirschmann, Lehner, Liebling, Motl, Neilsen (2009)


0°
60°
75°
1.25e6 s
1.5e6 s
1.75e6 s
10^12 Hz

Luminosity and spectrum





Summary

- Significant progress in evolving compact objects in general relativity with idealizations.
  (cf. Rezzolla, Shibata, Duez in this session)
- Gravitational waveforms have been computed.
  (for caveats cf. Rezzolla)
- Results depend sometimes on physics included
- Working on more realistic descriptions,
- Plans for including radiation hydro.
- Needed: petaflops computing for AMR and scaling on thousands of cores.