General relativistic simulations of thick self-gravitating accretion disks around black holes

Vassilios Mewes

Collaborators: Toni Font
Pedro Montero
Nikolaos Stergioulas
Filippo Galeazzi

Universitat de València

vassilios.mewes@uv.es

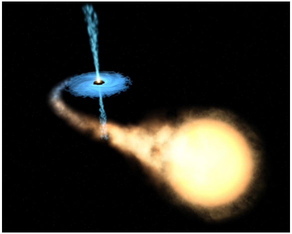
September 10, 2013

VNIVERSITAT DE VALÈNCIA

Outline

Thick accretion disks in the universe

- Thick accretion disks: believed to be formed in NS-NS and NS-BH mergers (a mechanism for *sGRB*), as well as in the CC of massive stars (a mechanism for *lGRB*).
- *Rezzolla et al (2010)* have shown that massive, thick disks form in simulations of unequal mass NS-NS mergers.
- to explain *sGRB* as energy released from accreted material coming from a thick disk, it must survive long enough > stability.



Instabilities of disks

- Papalouizou-Pringle Instability (PPI) (Papaloizou and Pringle (1984)): axisymmetry in the disk is broken and m planetary structures evolve, where m is the dominant mode.
- Runaway Instability (RI) (Abramowicz et al (1983)): initially stable disk is being accreted almost completely in a few dynamical timescales onto the central object.
- Aim to understand under which conditions (and if) these instabilities develop, and to understand the gravitational wave (GW) signal corresponding to the instabilities.

Model and initial data

- Initial data are self-gravitating, massive tori having constant angular momentum profiles around non-rotating stellar mass black holes, described in *Stergioulas (2011)*.
- Quasi-isotropic (QI) coordinates are used to describe the rotating spacetime around the BH, the metric takes the following form:

$$ds^2 = -\lambda^2 dt^2 + e^{2\alpha}(d\bar{r}^2 + \bar{r}^2 d\phi^2) + \frac{B^2}{\lambda^2}\bar{r}^2 sin^2\theta(d\phi - \omega dt)^2$$

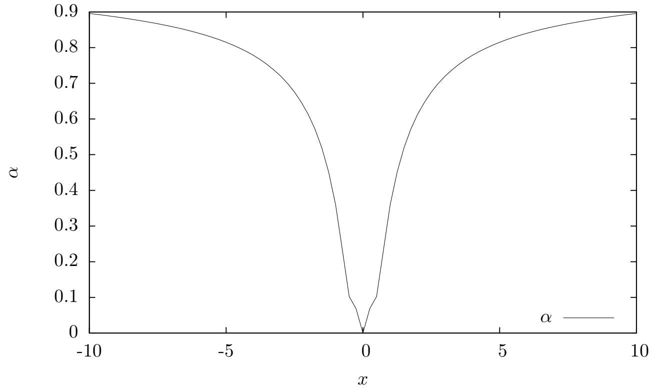
- Starting from an AJS disk (Polish doughnut), the field equations of the QI spacetime and the hydrostatic equilibrium equations are solved iteratively until an equilibrium solution is found.

Simulation software

- Simulations were performed using the publicly available *Einstein Toolkit* (`www.einsteintoolkit.org`).
- Spacetime evolution: *McLachlan* thorn, which solves the Einstein Equations in the BSSN formulation.
- Hydro evolution: *GRHydro* thorn, which solves the relativistic Euler equations in conservative form (*Valencia formulation*), using High Resolution Shock Capturing schemes.
- Mesh: *Carpet Code*, providing AMR.

Initial data, filling the BH

- Initial 2D axisymmetric does not fill event horizon (EH).
- Manual initialisation of spacetime variables inside EH introduces small perturbation as system relaxes to puncture solution.

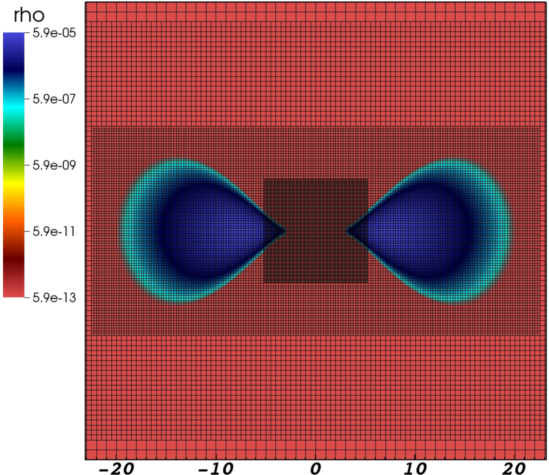


Other codes and their results

- Until very recently, full 3D GR simulations of self-gravitating tori around BH were not possible.
- *Kiuchi et al (2011)*, *Montero et al (2010)* (in 2D) and *Korobkin et al (2011,2012)* performed simulations of self-gravitating thick tori with different codes.
- We use a fourth code and different setup in our current work to redo some of the simulations of *Korobkin et al (2011/2012)* with similar initial data.

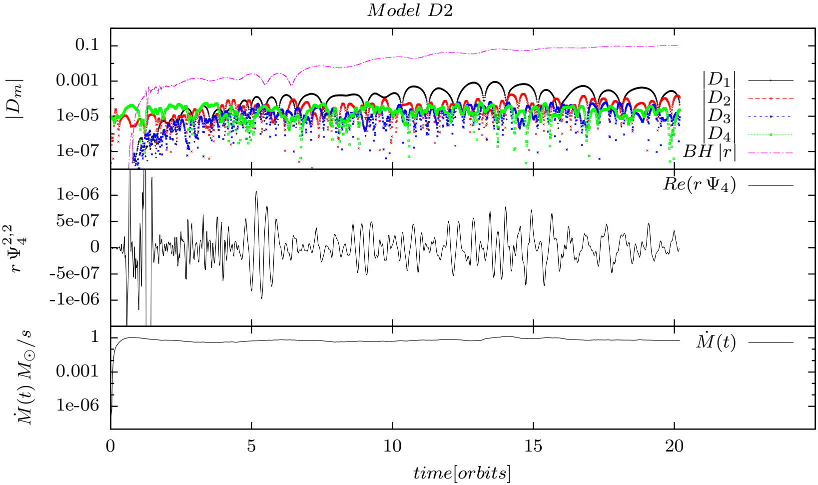
Models

Model	ρ_{max} $[G{=}c{=}M_\odot{=}1]$	l	M_{torus}/M_{BH}	f_{orb} $[Hz]$
D2	1.05e-05	3.75, constant	4.11e-02	1360
C1B	5.91e-05	3.67, constant	1.51e-01	1300



evolution of ρ model D2

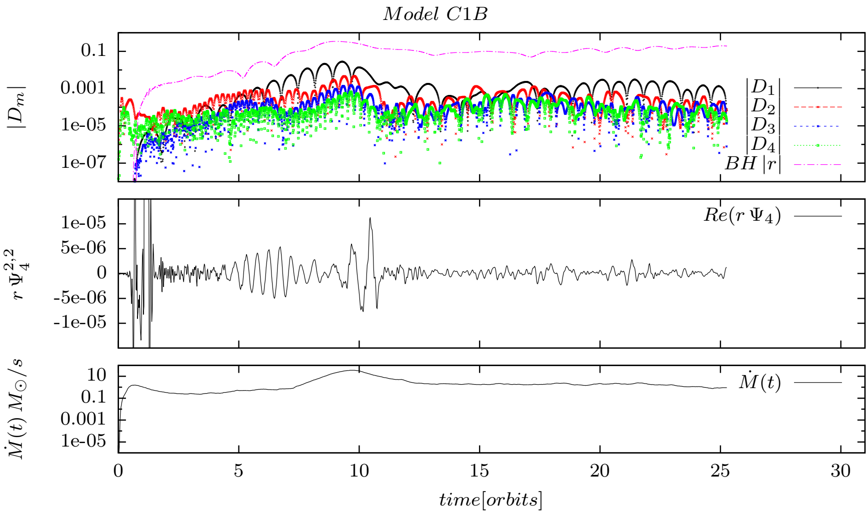
Results for model D2



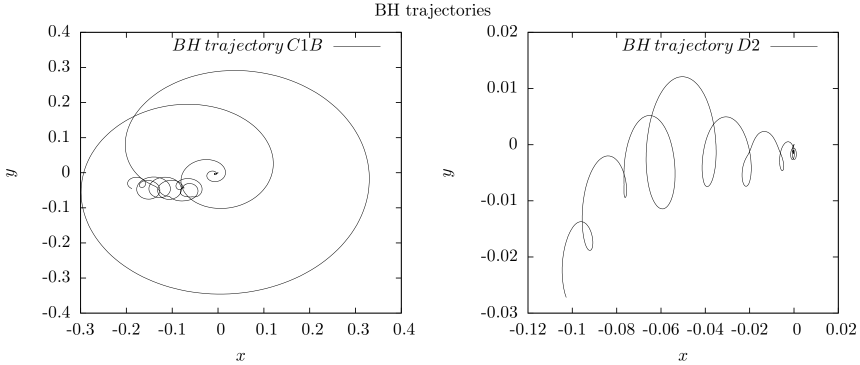
$D_m = \int \rho\, e^{-im\phi}\, d^3x$

evolution of ρ model C1B

Results for model C1B



BH movement in the evolutions

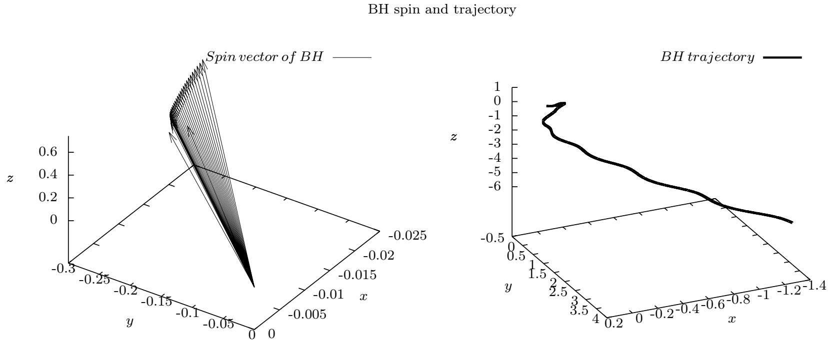


Tilted Disks: Motivation and previous work

- Computationally cheaper (due to symmetries) to consider $\mathbf{L_{BH}}$ and $\mathbf{L_{disk}}$ aligned.
- Situation idealized, expected that $\mathbf{S_{NS}}$ of merging NS aren't aligned during inspiral.
- Pioneering work in this field by *Fragile et al (2005,2006)* who have analysed tilted disks in the Cowling (fixed background spacetime) approximation.
- Perform simulations with spacetime evolution to investigate effects of BH response to disk precession.
- Rotate coordinate system about x-axis by angle θ prior to setting up a rotating Kerr BH, Hydro is unchanged

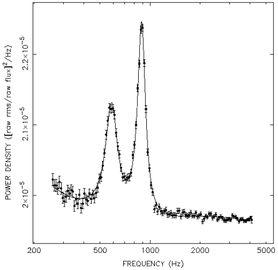
Tilted disk D2 isovolume animation

Tilted disk BH behaviour



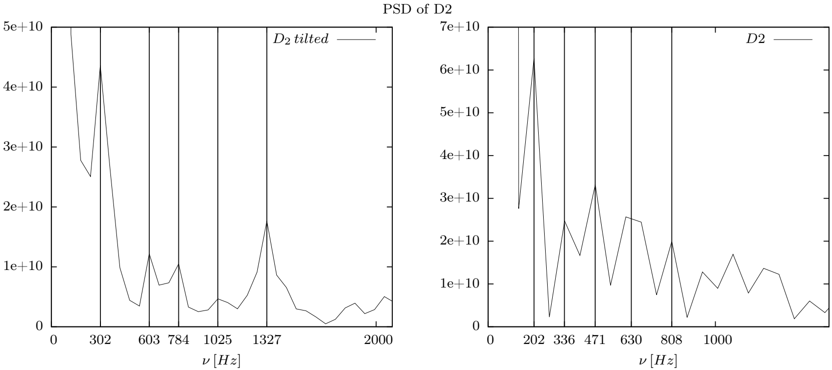
Density oscillations in the torus: explanation for QPOS?

- there are KHz QPOs in LMXRB, detected by the RXTE satellite.
- Those QPOs could be global oscillation modes in disk, excited by perturbations
- *Zanotti et al (2004)*, *Montero et al (2004)* performed studies in Cowling and linear perturbation theory



x-ray spectrum from Sco X1, image from NASA

QPOs II: PSD D2



QPOs III: o1 vs f

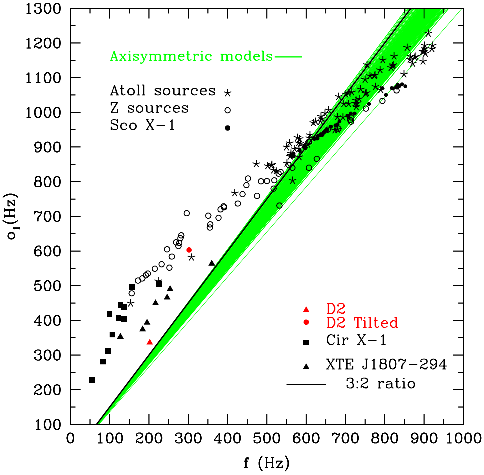


Figure by P. Montero

Summary

- Performed full 3D general relativistic simulations of thick tori around BH, as well as tilted disks.
- Some of the investigated models are stable, while others develop the PPI.
- No observation of the RI yet.
- Analysed density oscillations in the disks in the context of QPOs.

The End

Thank you for your attention!

This work is supported by the Spanish Ministerio de Educación y Ciencia in the project Computational Relativistic Astrophysics (AYA2010-21097-c03-01).