RELATIVISTIC FLUIDS AROUND COMPACT OBJECTS 2025 CAMK, WARSAW

Beyond the Kerr Black Hole-Torus paradigm

Héctor Olivares Sánchez h.sanchez@ua.pt Universidade de Aveiro May 7th, 2025





Fundação para a Ciência e a Tecnologia





Simulation-based modeling in the Event Horizon Telescope



- Large constraining power of EHT+MW observations for GRMHD library models
- Most of the library: 'Black Hole-Torus' (BHT) simulations







Some limitations

- Lack of connection to larger scales
- No model passes all constraints. Could there be a better model outside the set?

• Simulations run out of mass: inconvenient for long term variability studies

• Lack of exploration of non-Kerr BH models

Beyond the torus paradigm

Input from the large scales (Sgr A*)



Transonic accretion flows

- Solutions connecting the BH with infinity (large scales)
- Rich phenomenology
- Less explored than tori as initial conditions
- However, Proga & Begelman 2003 a,b , Janiuk+2008, Janiuk 2009, Suková 2017, Kim+2018

ACCRETION OF LOW ANGULAR MOMENTUM MATERIAL ONTO BLACK HOLES: TWO-DIMENSIONAL MAGNETOHYDRODYNAMIC CASE

DANIEL PROGA AND MITCHELL C. BEGELMAN¹ JILA, University of Colorado, Boulder, CO 80309-0440; proga@colorado.edu, mitch@jila.colorado.edu Received 2003 February 20; accepted 2003 April 7

change if we switch on or off resistive heating. Overall our simulations are very similar to those presented by Stone, Pringle, Hawley, and Balbus despite different initial and outer boundary conditions. Thus, we confirm that MRI is very robust and controls the nature of radiatively inefficient accretion flows. Although the time-averaged properties of our models approach a steady state, we find that the instantaneous mass-accretion rate

A recent simulation setup

 Transonic solution + interstellar turbulence

- Models bridge Bondi-like quasispherical flows and tori.
- Non-MRI turbulence, shocks and filaments
- Constant matter supply

Magnetized case (coming soon)

Beyond the Kerr paradigm

Are alternatives to Kerr ruled out?

- EHT results: test of the Kerr hypothesis across orders of magnitude in mass
- Persistent size of the shadow
- Measured size is consistent with Kerr, but also with several other models.

Non-Kerr covariant MHD simulations

- Mizuno+ 2018: first GRMHD simulations onto non-Kerr BHs, Röder+ 2023
- Nampalliwar+2022: Parameterized metric
- Chatterjee+ 2023a,b: near extremal Kerr-Sen BHs. Other outflow mechanisms and universality of Blandford-Znajek

Non-BH objects: Naked singularities

- Bambi+ 2009: GRHD accretion onto Kerr superspinars
- Kluźniak & Krajewski 2024: GRHD on RN spacteimes
- Dihingia+ 2025: GRMHD accretion onto Kerr superspinars
- Olivares+ 2025 (*in prep.*): GRMHD accretion onto singularities in quadratic gravity.

Formation of a shadow due to capture of light rays by the singularity.

New fundamental fields: bosonic stars

- Made of coherent bosonic fields
- Ubiquitous in cosmology, extensions to Standard Model, string theory
- Among BH mimickers: known formation mechanism and stability properties
- Mass range depends on boson mass

See e.g. review by Liebling & Palenzuela (2012)

- No singularity
- No surface
- No event horizon

A hollow can look like a shadow

Olivares+ 2020

Suppressing the MRI

MRI takes place if $d\Omega/dR < 0$

For geodesic orbits,

$$\Omega^2(r) = \frac{Gm(r)}{r^3}$$

⇒ The instability can be suppressed if $m \propto r^3$ or faster.

- Suppression radius can be predicted by metric inspection.
- Is it robust? Can it mimic a BH?

Conclusion

- Importance of exploring alternative models
- Simulation setups controlled by few parameters and with a cost comparable to simulations in the EHT library can produce a rich phenomenology that includes tori as a special case and avoids some or their problems
- Many ways to produce ring-like images: a photon ring is not needed.
- Advertisement: Review "GRMHD simulations of accretion onto exotic compact objects", Olivares, Kocherlakota & Herdeiro (2025)