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Pseudo-Newtonian Simulations With Reissner–Nordström Naked Singularity

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Naked Singularities

- Solutions of Einstein equations with non-rotating black holes (BH, Schwarzschild 1916) and naked singularities (RN NkS, Reissner 1916, Nordström 1918) are not new, they were found more than 100 years ago, at the very beginning of the general relativity theory (1916).
- The first naked singularity solution included the electric charge, but it could be some other kind of “charge”. Also, some solutions for fast rotating objects are similar to NkS solutions.
- They became interesting again because of Event Horizon Telescope (EHT) observations: NkS are the last known possible alternative to BHs for an object in the centers of galaxies.

New pseudo-Newtonian potential for NkS

$$V(r) = -\frac{M}{r} + \frac{Q^2}{2r^2}$$

GR simulations are complicated. Our potential reproduces in Newtonian mechanics the location of the zero gravity sphere of RN NkS as a minimum of the potential V(r), and also the position of the angular velocity maximum. M is the mass and Q the electric charge of the gravitating body in gravitational units.

- For the dimensionless charge parameter q=Q/M > 1, spacetime is that of a spherically symmetric (point-like) NkS, in which all space at r > 0 is accessible to observations.

- There are many such approximations, each good for its purpose-some characteristic distances or surfaces are usually represented correctly in such pseudo-potentials. One notable example is Paczyński-Wiita potential (see poster **#1641** by our student Maria Koper).

NkS in pseudo-Newtonian potential with PLUTO code

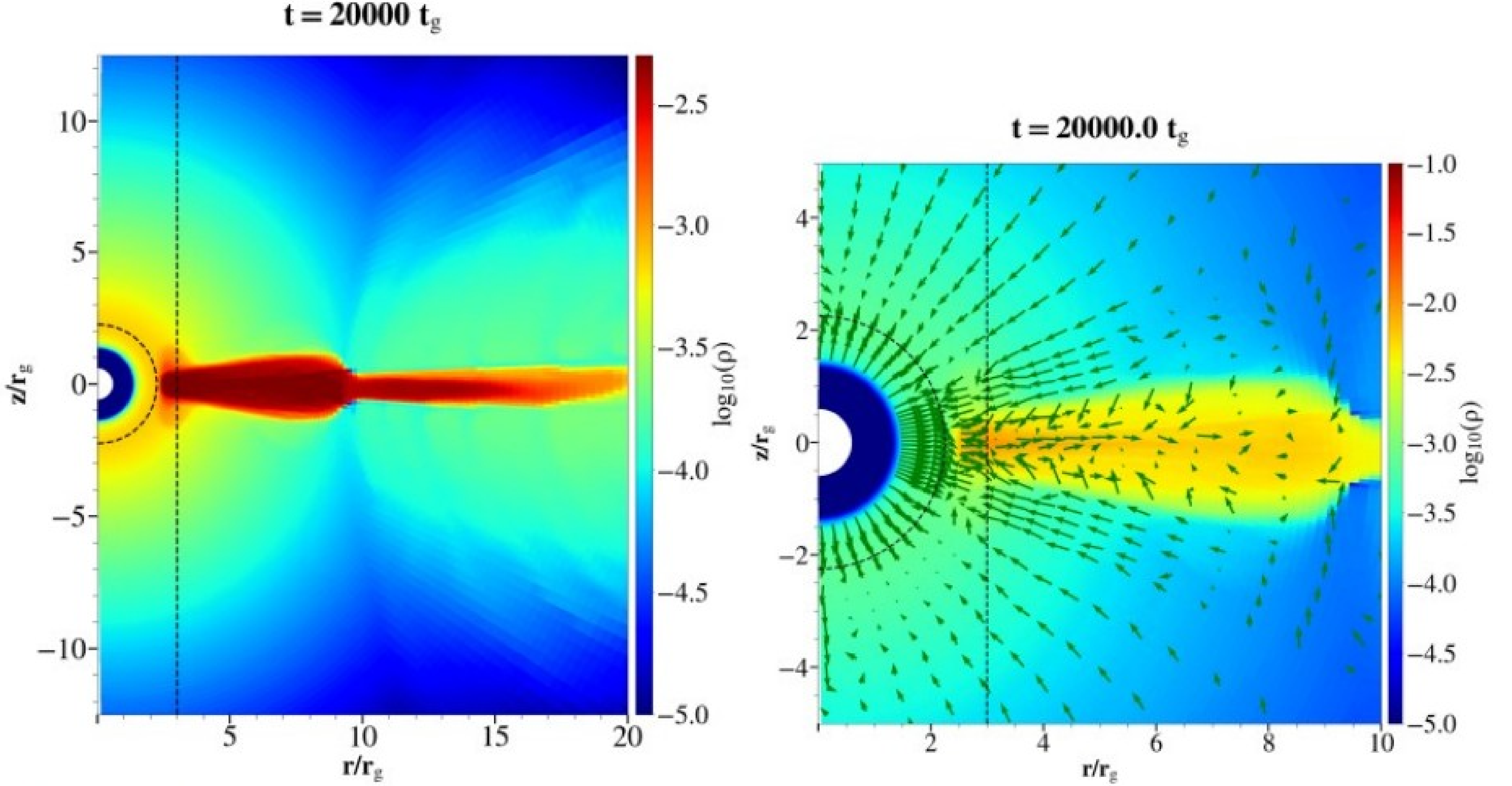

Fig. 2. Gas density in the simulation with $q = 1.5$. *Left panel*: a snapshot result at t=20000 t_g, where $t_g = r_g/c$. The zero-gravity radius r_0 is marked with the dashed half-circle and the radius, $4r_0/3$, at which test-particle Ω attains a maximum is marked with the straight black dashed line. *Right panel*: a zoom into the inner region of the accretion flow, obtained as an average over the time interval of $t \in [19000, 21000]$ t_g. Poloidal gas velocity vectors are indicated with green arrows.

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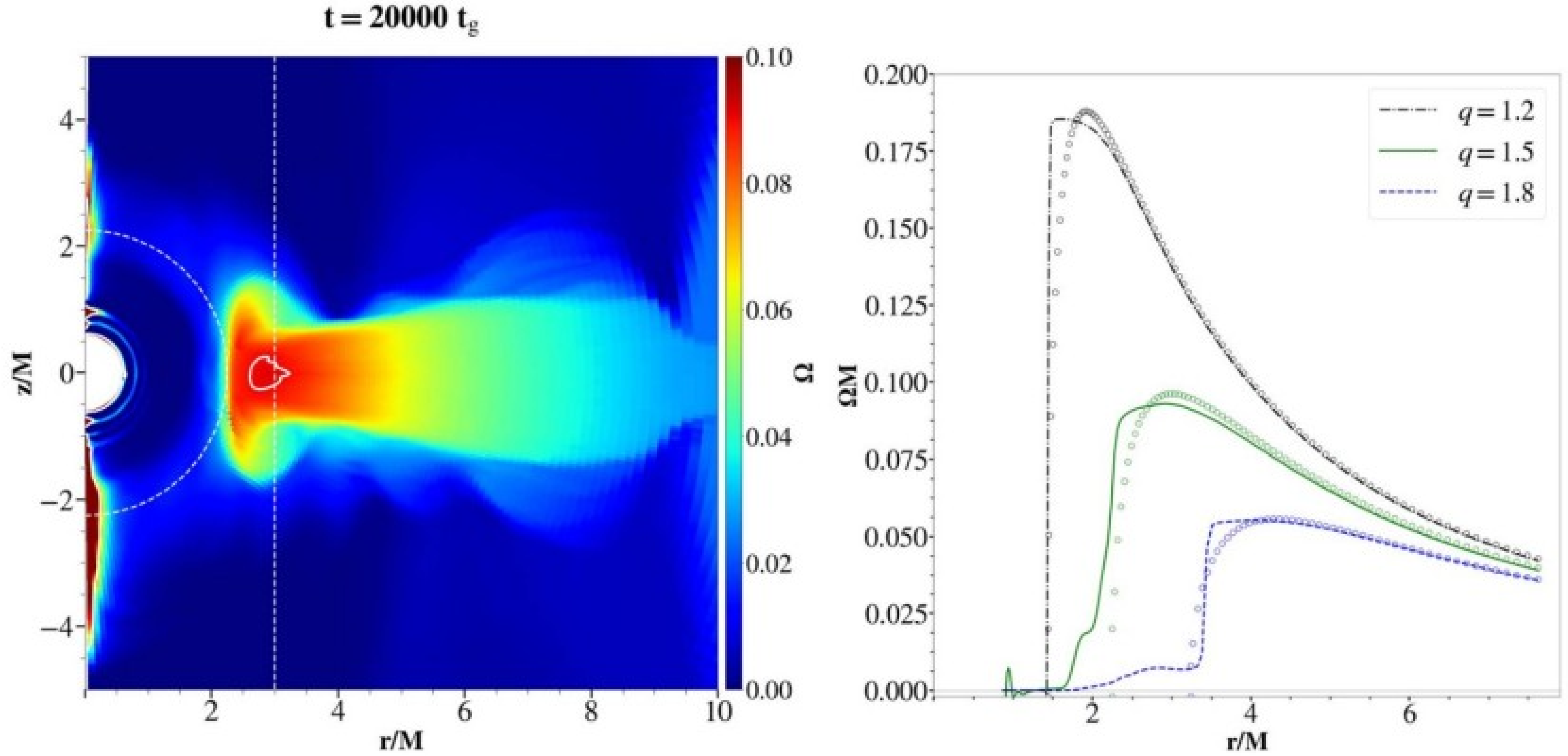

Figure 3. Left panel: angular velocity $\Omega = v_\phi/(r \sin\theta)$ in a linear color grading in a snapshot at $t = 20{,}000\, t_g$ in our simulation with $q = 1.5$. The contour of $\Omega = 0.09/M$, within which is located the test-particle orbital frequency value of $\Omega_{\max}$ at $r/M = 4q^2/3 = 3$, is shown with the white solid curve. The white dashed circular line indicates the zero-gravity sphere. Right panel: angular velocities in the equatorial plane in our numerical simulations, for NkS with $q = 1.2$, 1.5, and 1.8, are shown in dotted–dashed (black), solid (green), and dashed (blue) lines, respectively. Corresponding angular velocity profiles for test particles in RN metric Keplerian orbits are represented with small circles in the same color coding.

Summary

- Magnetized solutions with NkS are much easier to investigate with pseudo-Newtonian potential. We devised such potential for RN NkS and made simulations with PLUTO code.

- Our pseudo-Newtonian potential reproduces well the positions of the zero gravity sphere and the angular velocity maximum.

- Series of simulations of naked singularities can be used as a model for creating the observational pictures of M87 and Sgr A*.

- See our poster **#1058**, also the related posters by Ruchi Mishra **#1356** and Maria Koper **#1641**