Hydrodynamical simulations of the AGN central engine in 3D

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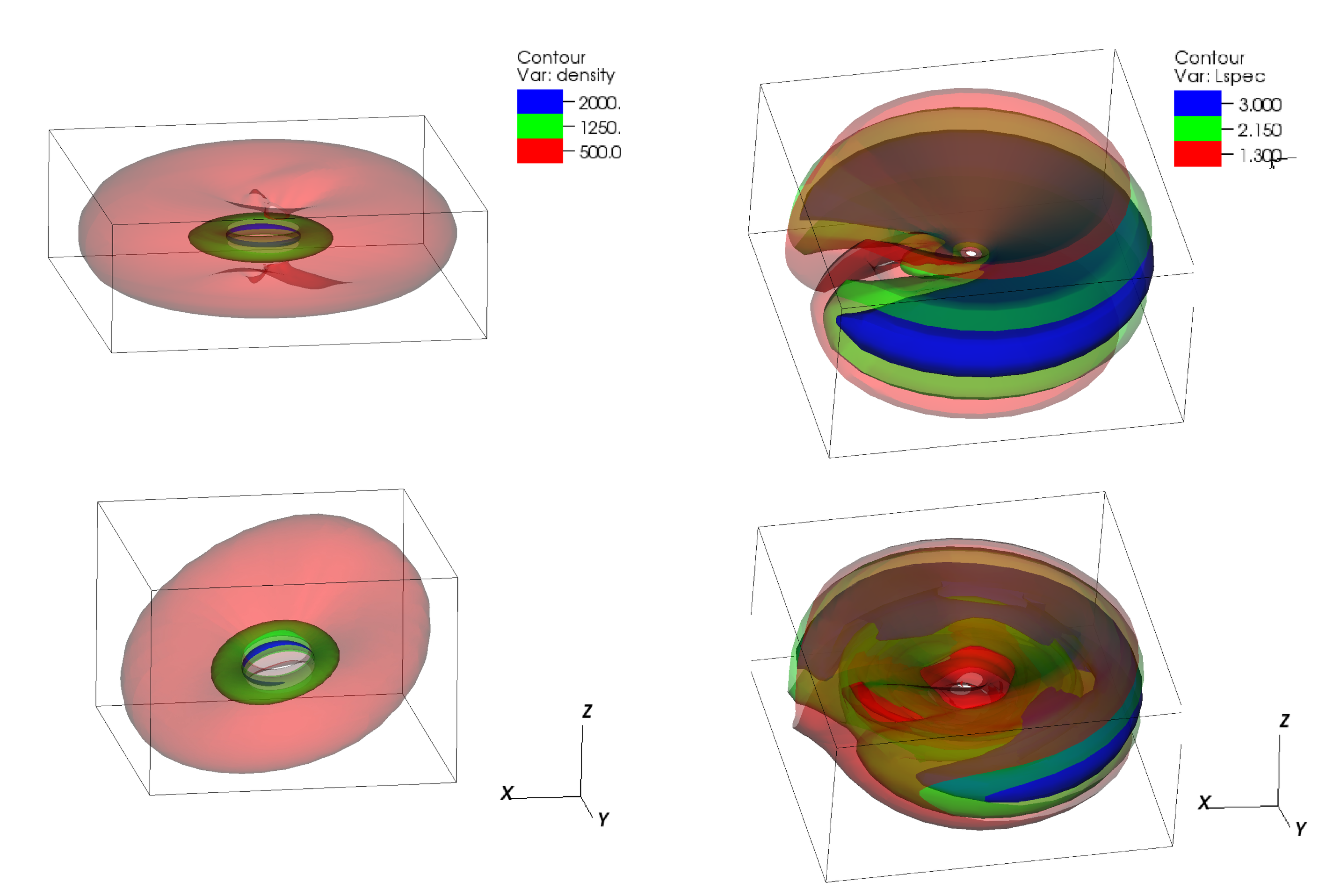
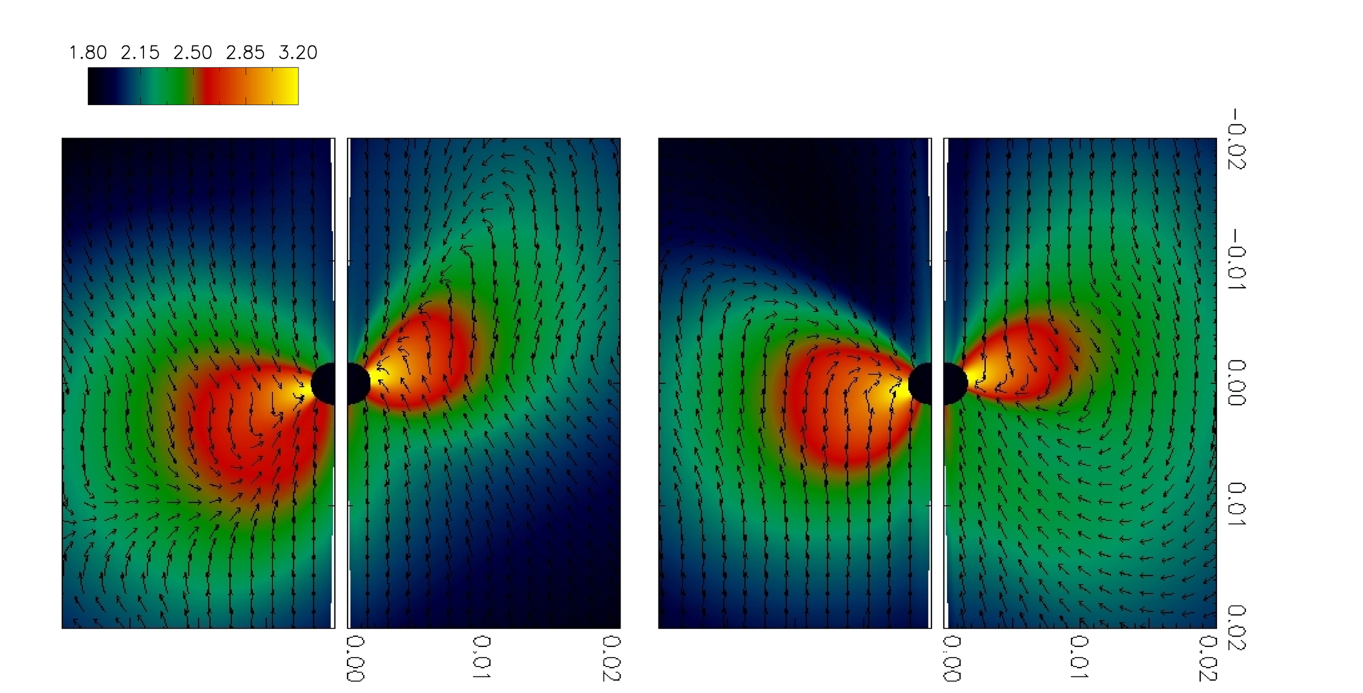
We consider hydrodynamics of inviscid accretion flows, assuming the spherically symmetric density distribution at the outer boundary, but brake the flow symmetry by introducing a small, either latitude dependent, or both latitude- and azimuth dependent angular momentum. The material that has too much angular momentum to be accreted radially, forms a thick torus near the equator.

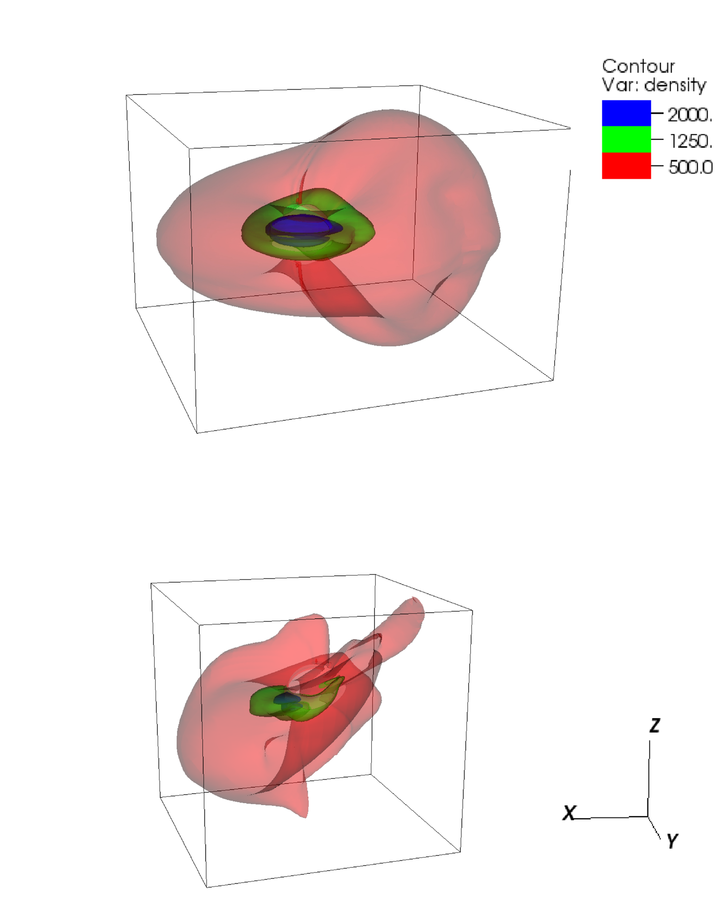
Consequently, accretion proceeds only through the polar funnel, and the mass accretion rate through the funnel is constrained by the size and shape of the torus, not by the outer conditions. In 3-D simulations, we found that the torus precesses, even for axisymmetric conditions at large radii. For the latitude and azimuth-dependent angular momentum, the non-rotating gas near the equator can also significantly affect the evolution of the rotating gas. In particular, it may prevent the formation of a proper torus (i.e. its closing, in the azimuthal direction). In such models, the mass accretion rate is only slightly less than the corresponding Bondi rate.



Results of the 3-D simulation with non-axisymmetric initial condition, model A: rotating gas is at $\Delta\varphi_0=330°$.
Figures show the isosurfaces of density (left) and specific angular momentum (right), for the two time snapshots: t'=0.018 (top) and t'=0.29 (bottom). The spacial extensions of the boxes are about: r=0.004 R_B (left) and r=0.6 R_B (right).



Results for model A. Figures show the density maps and velocity fields at time t'=0.29, in the r-θ plane, for 4 azimuth values: φ=180°, 0°, 270° and 90° (from left to right).



Results of the 3-D simulation with non-axisymmetric initial condition, model B: rotating gas is at $\Delta\varphi_0=240°$.
Figures show the isosurfaces of density, for the two time snapshots: t'=0.018 (top) and t'=0.29 (bottom). The spacial extensions of the boxes is about: r=0.004 R_B.

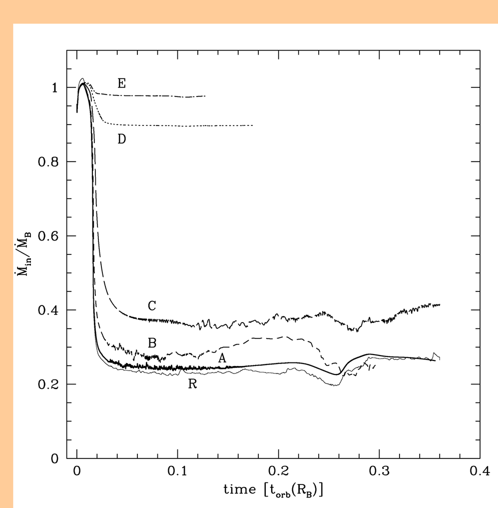
Table 1: Summary of the models

Model	$\Delta\phi_0$ [°]	Resolution [$N_r \times N_\theta \times N_\phi$]	T_{end} [$t_{orb}(R_B)$]	$\dot{M}$ [$\dot{M}_B$]	Presence of torus	Precession
A_{32}	330	140x96x32	0.36	0.25	yes	yes
A_{60}	330	140x96x60	0.20	0.25	yes	yes
B_{60}	240	140x96x60	0.30	0.28	not closed	–
C_{32}	120	140x96x32	0.36	0.37	not closed	–
C_{60}	120	140x96x60	0.16	0.35	not closed	–
D_{32}	60	140x96x32	0.18	0.90	no	–
E_{32}	30	140x96x32	0.14	0.98	no	–
R_{10}	360	140x100x10	0.32	0.24	yes	no
R_{32}	360	140x96x32	0.36	0.24	yes	yes
R_{60}	360	140x96x60	0.36	0.24	yes	yes
M_{100}	360	140x96x32	11	–	yes	no
M_{300}	360	140x96x32	2.19	–	yes	no

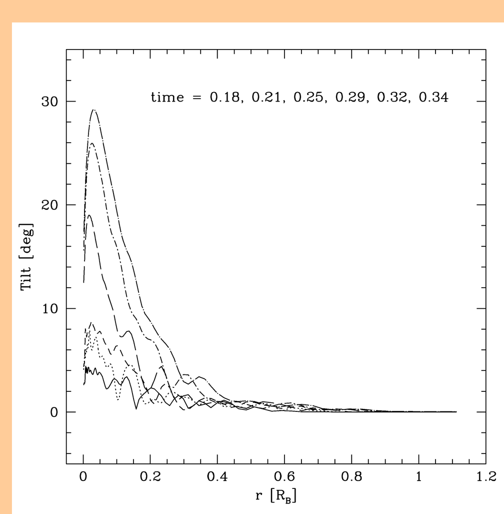
Parameter $\Delta\varphi_0$ measures the initial condition for the amount of the rotating gas at infinity. The density is given in the units of ρ_∞, and the specific angular momentum is given in the units of $l_{crit} = 2 R_{Schw} c$. The time is in the units of the orbital time at the Bondi radius. Models A-R have the Bondi radius of 1200 R_{Schw}, while models M_{100} and M_{300} have R_B=100 and 300 R_{Schw}, respectively, so that the sound speed at infinity in these models is much larger.

Conclusions

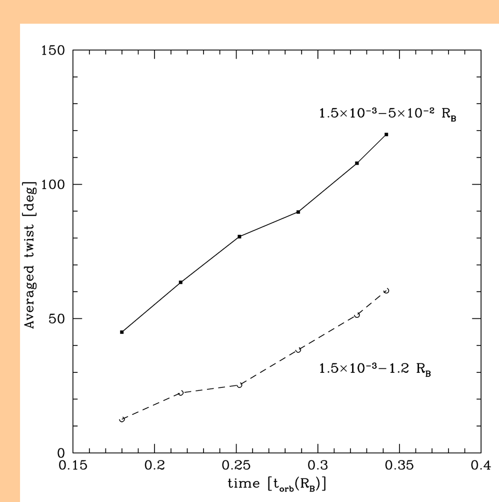
- The non-axisymmetry in the initial distribution of the angular momentum at large distances from the AGN central engine may prevent the formation of the rotationally supported torus.
- If the torus does not close, the accretion rate onto the BH may either be well below the Bondi rate, or comparable to it, depending on the amount of rotating gas at infinity.
- At late phases of the time evolution, the innermost parts of the torus tilt and the torus precesses.
- The precession is caused by the acoustic-advective instability and does not depend on whether the initial conditions were axisymmetric or not. The instability grows because of shocks when the Mach number at the inner radius is large (M>~4.5).



Time evolution of the mass accretion rate onto black hole, in units of the Bondi rate. The model marked with R has an axisymmetric initial conditions for the specific angular momentum distribution. Other models have non-axisymmetric conditions (see Table).



The tilt (angle between the z axis and angular momentum vector of the rotating gas) as a function of radius, for several time snapshots during the evolution. The initial model was axisymmetric (tilt was zero).



The cumulative twist angle, as a function of time, after the disk tilted. Initial model was axisymmetric. The solid line shows the twist averaged over the innermost radii, and dashed line is the twist averaged over the whole range of radii.

References

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