Can black holes spin faster than a_*=0.998?

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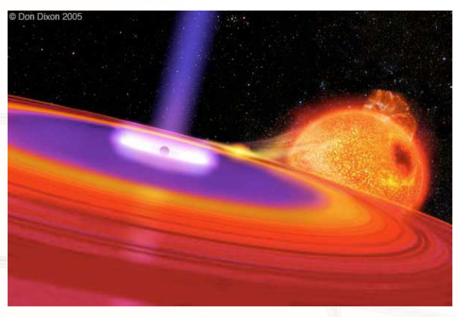
Statement of the problem

In principle - **yes**, a black hole can spin arbitrarily close to a/M=1. It cannot exceed this value according to the 3rd law of black hole (BH) thermodynamics.

Note: But it does not mean that spins a/M>1 are forbidden. BHs cannot spin so fast. Kerr naked singularities, on the contrary, have a/M>1. But we know no astrophysical process that can lead to naked singularities.

Accretion of matter spins BHs up



The standard thin disk (Novikov & Thorne, 1973) spins the central BH up to the well known terminal spin value (Thorne, 1974):

a/M = 0.998

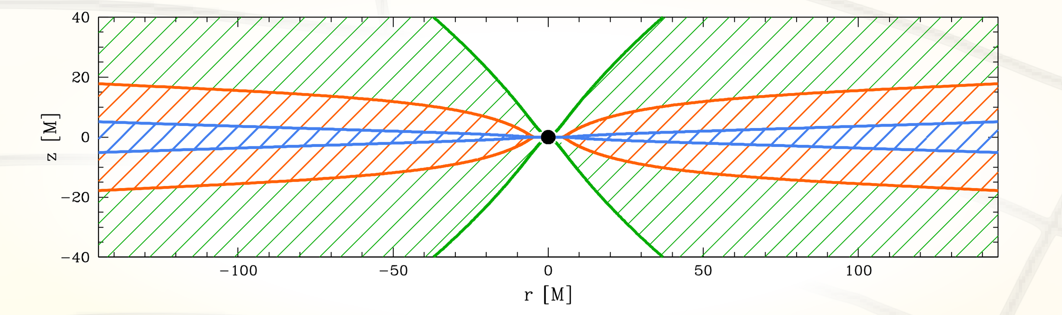
What if the accretion rate is large and the standard thin disk model is not applicable? Geometrically thick disks may spin BHs to higher values (Abramowicz & Lasota, 1980).

What is infact the maximal spin of a BH?

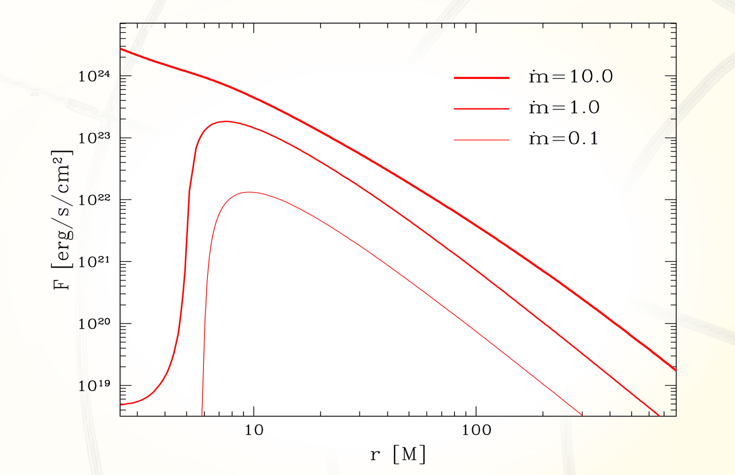
Can astrophysical BHs rotate with spins arbitrarily close to a/M=1?

Model of accretion disk

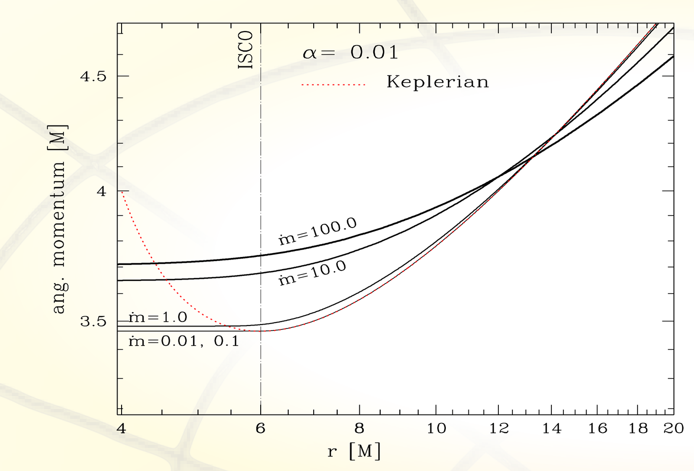
We model accretion at high rates using slim disks (Abramowicz et al. 1998, Sądowski 2009) - hydrodynamical, alpha-P, optically thick, advective disks generalizing the Novikov & Thorne model to high accretion rates.



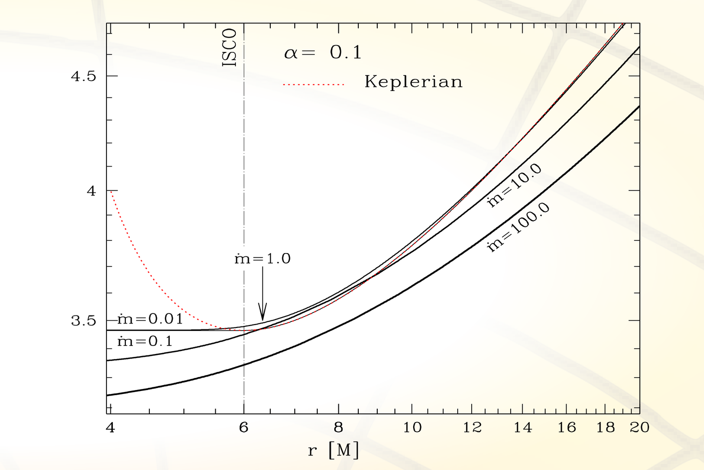
Disk thickness profiles for 0.1 (blue), 1.0 (red) and 10 (green) Eddington accretion rates.



Disk emission for 10 Msun BH



Angular momentum profiles for alpha = 0.01



Angular momentum profiles for alpha = 0.1

Method

We solve equations describing the spin evolution assuming that accretion of gas and radiation hitting the BH are the only processes affecting the BH spin:

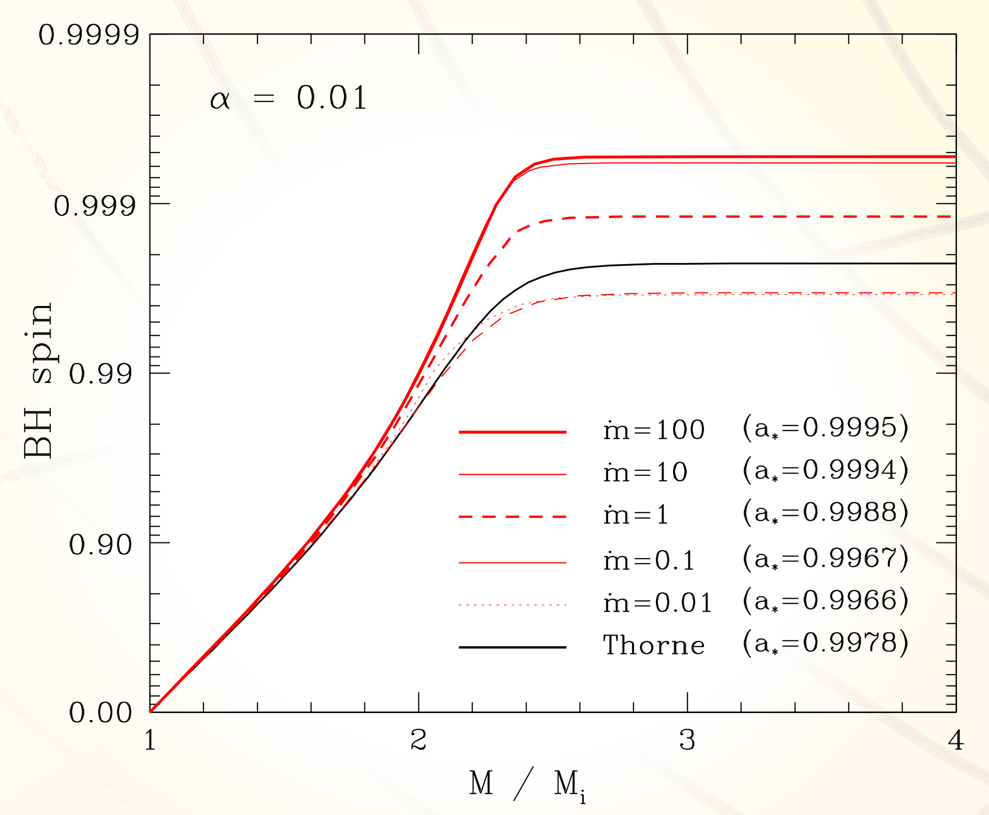
$$\frac{\mathrm{d}a_*}{\mathrm{d}\ln M} = \frac{\mathrm{d}J/M^2}{\mathrm{d}\ln M} = \frac{1}{M}\frac{\dot M_0 u_\phi + \left(\frac{\mathrm{d}J}{\mathrm{d}t}\right)_{\rm rad}}{\dot M_0 u_t + \left(\frac{\mathrm{d}M}{\mathrm{d}t}\right)_{\rm rad}} - 2a_*$$

$$\frac{\mathrm{d}M}{\mathrm{d}M_0} = u_t + \left(\frac{\mathrm{d}M}{\mathrm{d}t}\right)_{\rm rad} / \dot M_0$$

The emission, photosphere location, radial and rotational velocities are taken from the slim disk model.

Raytracing is performed using numerical methods developed by Bursa (2002).

Spin evolution for alpha = 0.01

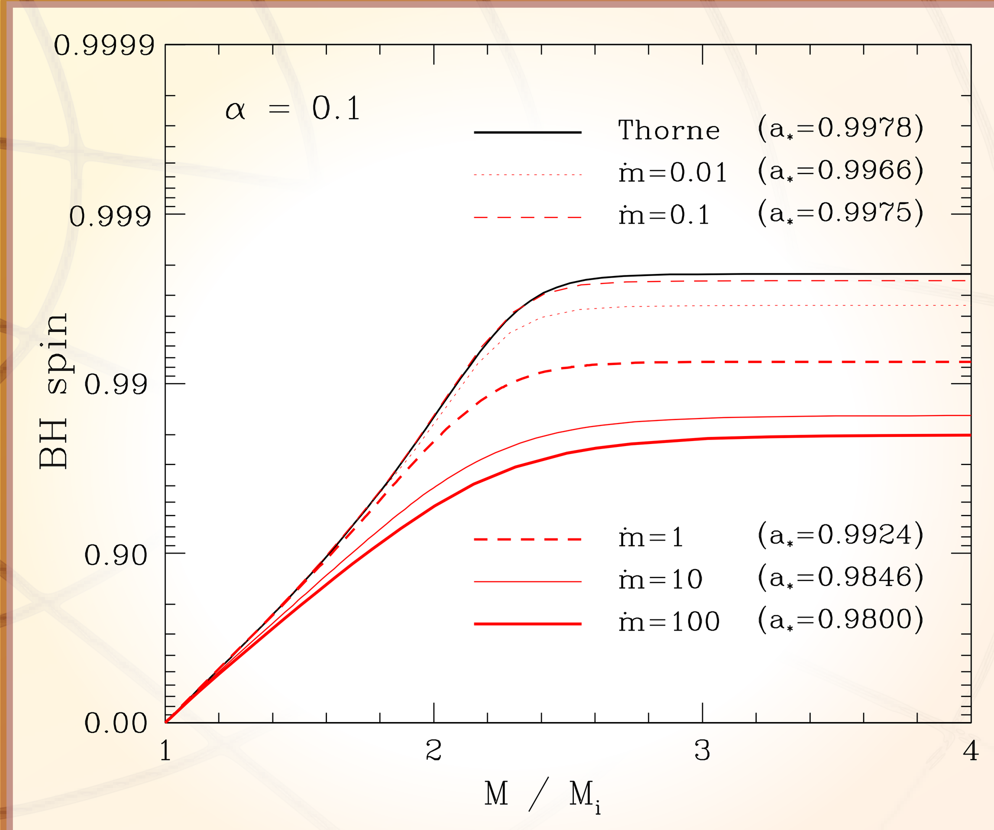


Spin evolution for various accretion rates and alpha = 0.01

Yes, it can!

BH can be spun up to a/M as high as 0.9995 for low alpha and super-critical accretion

Spin evolution for alpha = 0.1



Spin evolution for various accretion rates and alpha = 0.1

Terminal spin values

model:		A	NR
thin disk		**0.9978**	→ 1
$\alpha = 0.01$	$\dot m = 0.01$	**0.9966**	→ 1
	$\dot m = 0.1$	**0.9967**	→ 1
	$\dot m = 1$	**0.9988**	0.9998
	$\dot m = 10$	**0.9994**	0.9996
	$\dot m = 100$	**0.9995**	0.9995
$\alpha = 0.1$	$\dot m = 0.01$	**0.9966**	→ 1
	$\dot m = 0.1$	**0.9975**	→ 1
	$\dot m = 1$	**0.9924**	0.9948
	$\dot m = 10$	**0.9846**	0.9951
	$\dot m = 100$	**0.9800**	0.9801

Terminal spin values (A) for a set of models: the standard thin disk, slim disk with alpha=0.01 and alpha=0.1. Results for the spin evolution driven only by the accretion (radiation is neglected) are also presented (NR).

Terminal spins at high accretion rates are very sensitive to the value of the alpha viscosity parameter. The higher value of alpha, the lower the terminal spin. It reflects the alpha-dependence of the angular momentum of gas at BH horizon (see appropriate figures above).

Spins arbitrarily close to a/M=1 (e.g., 0.99999) cannot be obtained under reasonable assumptions.

What drives the spin-up?

The accretion of gas brings angular momentum and mass onto the BH.

The radiation captured by the BH decelerates this process.

The terminal spin value is reached when these factors balance each other.

Disks accreting at super-critical rates are known to be radiatively inefficient (heat is advected instead of being radiated away).

Thus, **the value of the terminal spin at high accretion rates is determined by the gas properties at BH horizon** (i.e., its angular momentum and specific energy) only - radiation does not affect the spin evolution (see results for high accretion rates in the adjacent table).

Assumptions

Performing this research we adopted the following assumptions (Thorne, 1974):

- accretion of gas and captured radiation are the only processes affecting the BH spin (any disk-jet coupling, like Blandford-Znajek, is neglected),

- disk is assumed to be described by the appropriate disk model (thin or slim - hydrodynamical, alpha-P, optically thick, neglecting large scale magnetic fields),

- radiation returning to disk is neglected,

- radiation is emitted isotropically,

- in case of slim disks the ang. momentum taken away by radiation is neglected.

References

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