Influence of black hole magnetic torques on accretion disk

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Why this talk?

…we like to play around a black hole

…many AGN show relativistic jets

…what is the mechanism of powering them?

…are they enough?

…also for low accretion rate and very spinning BHs

…jets power – observational data

…at the end: a TOOL for estimating the BH spin parameter…

This talk:

1. Introduction
2. Jets driven by accretion and BH rotation:
   2.1. Basic assumptions
   2.2. Power of driving jets
   2.3. Efficiency of driving jets
3. Conclusions

How much energy can the JETS get from accretion and black hole rotation??

What is more important: accretion power or spin power?

What is the ratio of the jets power to the accretion and BH rot power?
- efficiency of driving jets -

What is the main ingredient for the mechanism of powering the jets?
- BH magnetic torques on the accretion disk -

Kerr Black Holes: M-mass; J-spin

$$ds^2 = g_{\mu\nu}\,dx^\mu dx^\nu$$

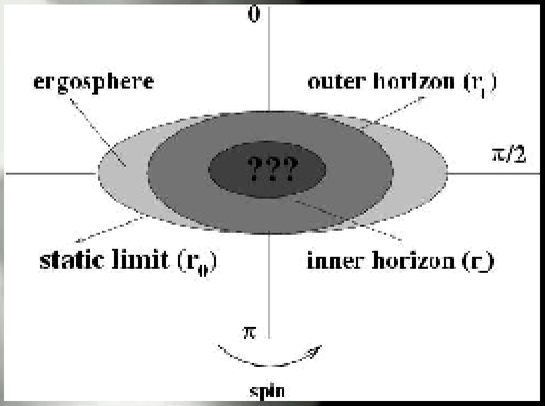
cylindrical coord: t, r, ϕ, z

$$r_g = \frac{GM}{c^2}, \quad a = \frac{J}{Mc}$$

spin parameter: $a_* = \dfrac{a}{r_g}$

$$r_H = r_g\left[1 + \left(1 - {a_*}^2\right)^{1/2}\right], \quad r_{sl} = 2r_g$$

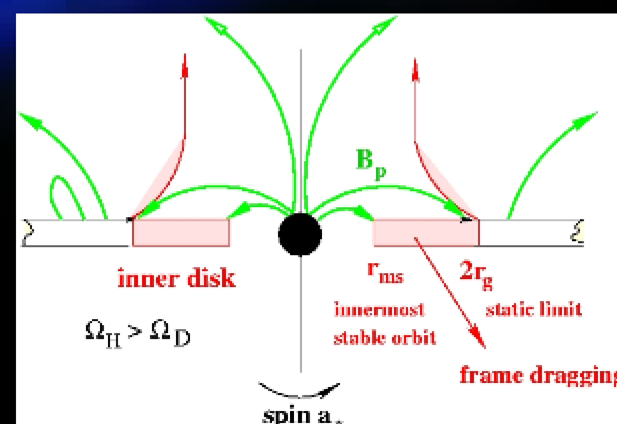
$$-1 \leqslant a_* \leqslant 1$$



2. Jets driven by accretion and BH rotation

2.1. Basic assumptions:

- **Kerr black hole $M \sim 10^9 M_{Sun}$ + thin accretion disk $r_{inner} = r_{ms}$**
- **innermost region of the disk: static limit $2r_g$ -» r_{ms} = the footring of the jet**
- **rotational energy and angular momentum are extracted from the black hole through magnetic field lines that connect the disk to the BH (magnetic coupling)**
- **instead of radiating the energy released from the innermost region of the disk, that energy is used to power the jets**



- $q_m = \dfrac{\dot M_{jets}}{\dot M_D} \cong 0.05$, Falcke and Biermann

$$\dot M_D = \dot m \dot M_{Edd}, \quad \dot M_{Edd} = 1.38 \times 10^{18} (M / M_{Sun})$$

2.2. Power of driving jets P_{jets}:

- **angular-momentum conservation law:**

$$\frac{d}{dr}\left[(1-q_m)\dot{M}_D c^2 L^+\right] = 4\pi r (J L^+ - H) \qquad T_{HD} = 2\int_{r_{ms}}^{r_{sl}} 2\pi r H \, dr$$

accretion ↑ jets ↑ BH ↑ rotation ↑ magnetic torque

- **energy conservation law:**

$$\frac{d}{dr}\left[(1-q_m)\dot{M}_D c^2 E^+\right] = 4\pi r (J E^+ - H\Omega_D), \qquad E^+ = \frac{E}{\mu} = \frac{r^{3/2} - 2r_g r^{1/2} + r_g^{1/2} a}{r^{3/4}(r^{3/4} - 3r_g r^{3/2} + 2r_g^{1/2} a)^{1/2}}$$

$$P_{jets} = 2\int_{r_{ms}}^{r_{sl}} 2\pi J E^+ r dr = (1-q_m)\dot{M}_D c^2 \left[E^+(r_{sl}) - E^+(r_{ms})\right] + 4\pi \int_{r_{ms}}^{r_{sl}} r H \Omega_D dr$$

accretion ↑ BH rotation ↑

- **flux of angular momentum transferred by poloidal magnetic field:**

$$H = \frac{1}{8\pi^{3} r}\left(\frac{d\Psi_D}{c\,dr}\right)^{2}\frac{\Omega_H - \Omega_D}{\left(-dR_H/dr\right)}$$

Li, L.-X., 2000

$$dR_H = R_H \frac{dl}{2\pi r_H}, \quad R_H = \frac{4\pi}{c} = 377\,\text{ohm}$$

Macdonald & Thorne, 1982

$$B_H\, 2\pi\, r_H\, dl = -B^{p}_{D} \sqrt{g_{(r\Phi)}}\, 2\pi\, r\, dr$$

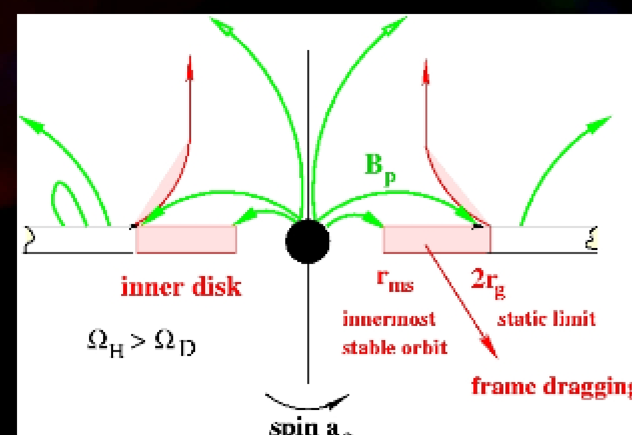
$$B_H = \zeta\, B^{p}_{H}(r_{ms}), \quad \text{where } \zeta \geq 1 \text{ !!}$$

$$B^{p}_{D} \propto r^{-n}, \quad n = 1.25 \text{ !!}$$

Blandford, 1976

$$B_H = a_*^{-1}\left(\frac{\eta_{rad}\dot{M}_{Edd}c^{2}}{4\pi G^{2} M^{2}}\right)^{1/2}$$

Znajek, 1978

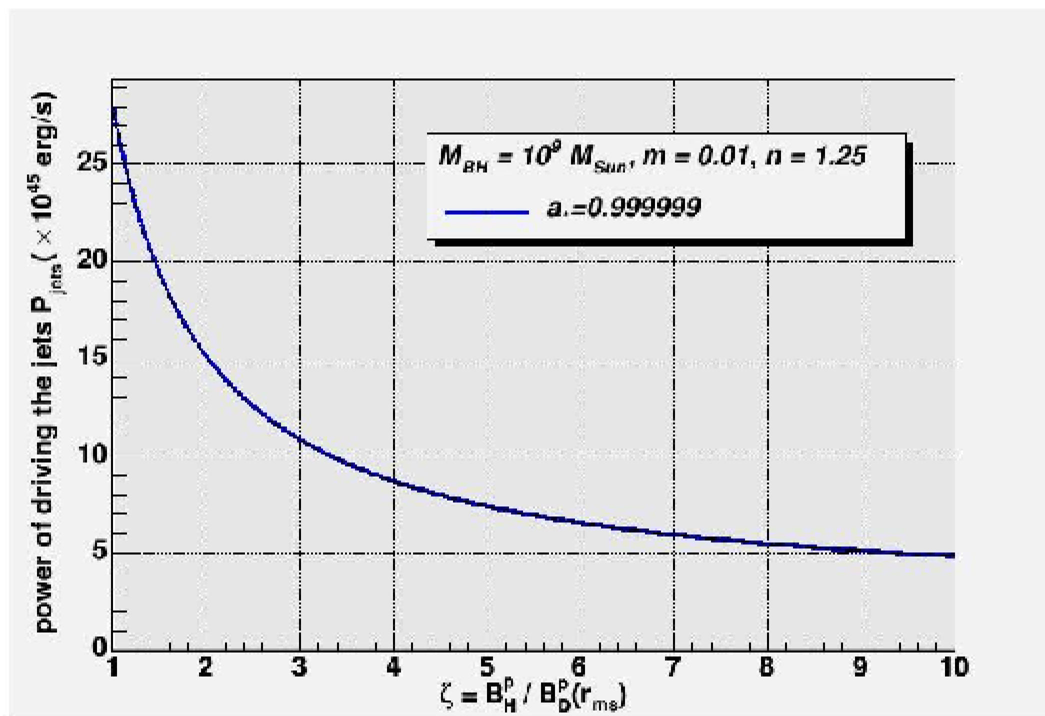


$$P_{jets} = (1-q_m)\dot{m}\dot{M}_{Edd}c^2\left(E^+(r_{sl_*}) - E^+(r_{ms_*})\right) + \frac{r_{ms_*}^n(1+\sqrt{1-a_*^2})}{4\pi\zeta}\int_{r_{ms*}}^{r_{sl*}} r_*^{3-n}\,\frac{1+r_*^{-2}a_*^{-2}+2r_*^{-3}a_*^2}{1-2r_*^{-1}+r_*^{-2}a_*^2}\cdot\left[\frac{a_*}{2(1+\sqrt{1-a_*^2})} - \frac{1}{r_*^{3/2}+a_*}\right]\cdot\frac{1}{r_*^{3/2}+a_*}\,dr_*$$

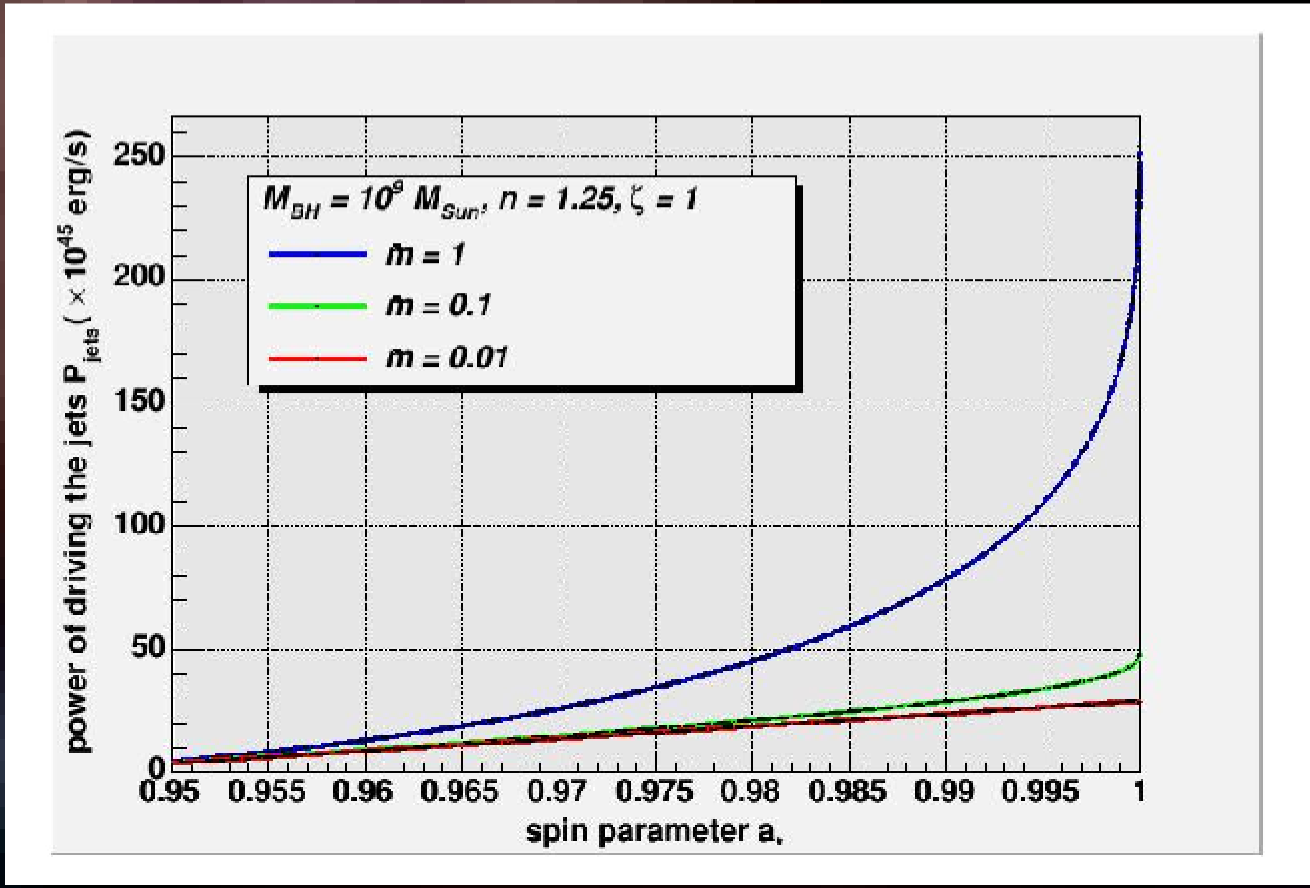
$$P_{jets} = P_{jets}^{acc} + P_{jets}^{rot}$$

Fixing the parameter ζ:

$$\zeta = 1$$



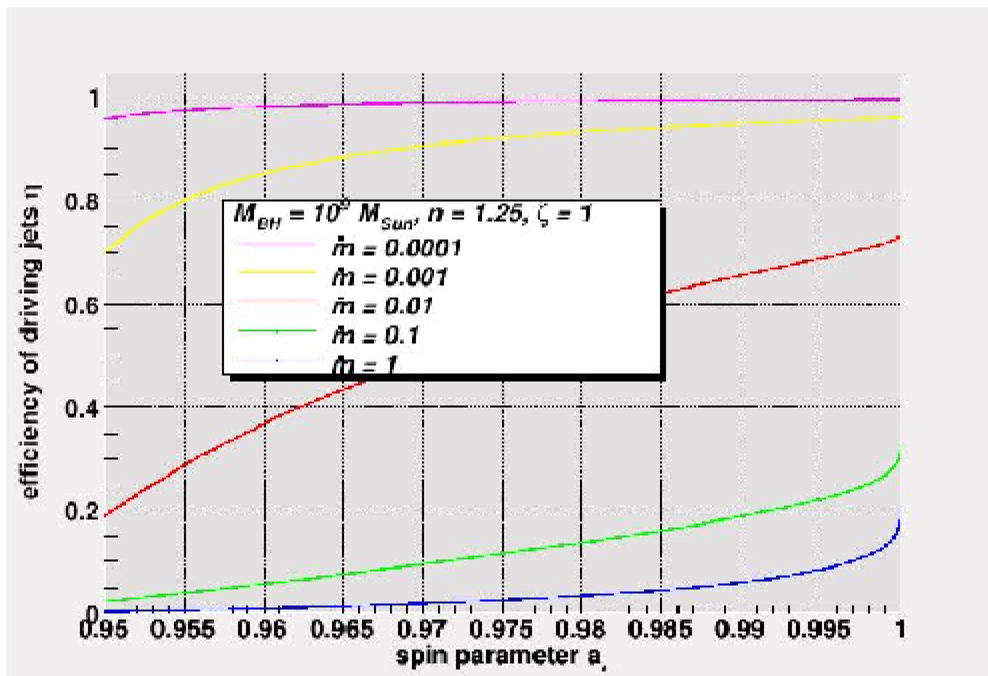
…power of driving jets vs. BH spin parameter



2.3. Efficiency of driving jets:

$$\eta = \frac{P_{jets}}{\dot{m}\dot{M}_D c^2 + P^{rot}_{jets}}$$

$\dot{m}\,[\dot{M}_{Edd}]$	$P_{jets}\,[\times 10^{46} erg/s]$	P^{rot}_{jets}/P_{jets}	$\beta = v_{jet}/c$
1	254.2010	0.1008	0.9692
0.1	48.4951	0.5286	0.9916
0.01	28.5521	0.9384	0.9997
0.001	27.0538	0.9941	0.9999
~~0.0001~~	26.9124	0.9994	~~1~~



3. Conclusions:

Strongest points:

- $\eta \sim 1$ ...the additional energy comes from the BH rotation energy by magnetic torques on the disk
- also for relativistic jets of some low-luminosity AGN…
- …the jets` power depends stronger on BH spin power than on accretion power
- possible low limit for accretion rate: $\dot{m} \sim 0.001$

Weakest points:

- time dependence of poloidal magnetic field…
- $q_m = \dfrac{\dot{M}_{jet}}{\dot{M}_D} \cong 0.05$ for all accretion rate values

...at the end: a TOOL for estimating the BH spin parameter...

- Thorne, K.
- Blandford, R. D.
- Znajek, R. L.
- Li, L.-X.
- Falcke, H.
- Biermann, P. L.