Black hole spin evolution and magnetic field decay

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Outline

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- Accretion on a black hole
- Electromagnetic processes
- Standard disk
- ADAF
- Magnetic field decay
- Conclusions
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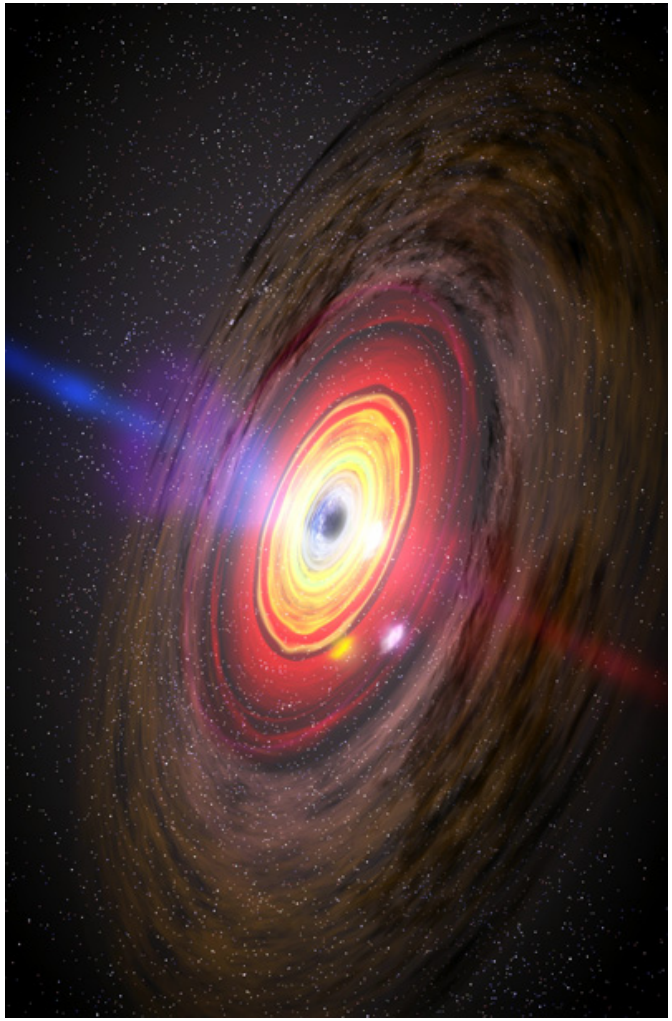
- Plans for the future



No-hair theorem: (John Archibald Weeller)

$a = \frac{c}{G}\frac{J}{M^2}$ (J - the total angular momentum of the BH).

According to black hole membrane paradigm the surface of black hole has angular frequency

$$\Omega_H = \frac{a}{2}\frac{c}{R_H}$$

(R_H - the horizon radius of the BH).

Accretion disk around black hole

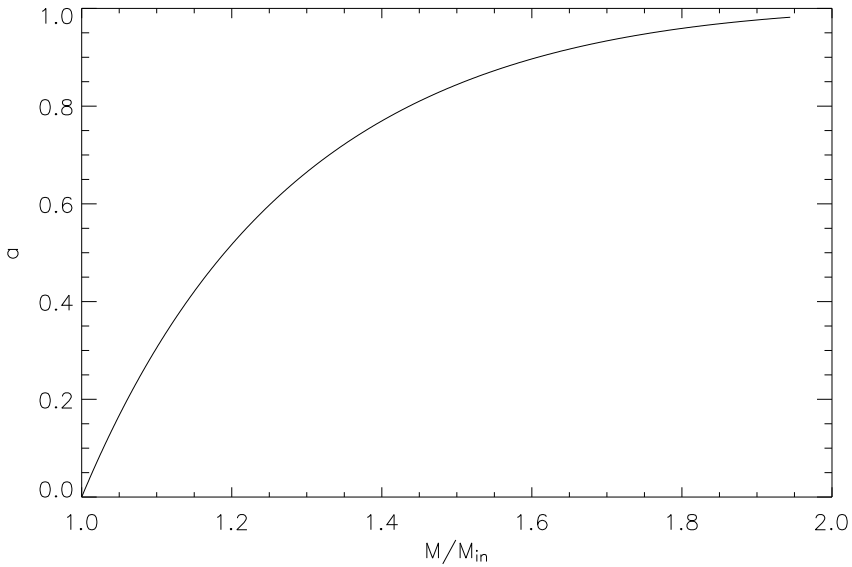
Spin evolution of black hole:

$$\frac{da}{d\ln M} = \frac{1}{M}\frac{L^+(a,M)}{E^+(a)} - 2a$$

here E^+ is specific energy at infinity,
L^+ is specific angular momentum.

$$a = \left(\frac{2}{3}\right)^{1/2}\frac{M_i}{M}\left[4 - \left(\frac{18M_i^2}{M^2} - 2\right)^{1/2}\right]$$

(Bardeen, 1970 and Thorne, 1974)

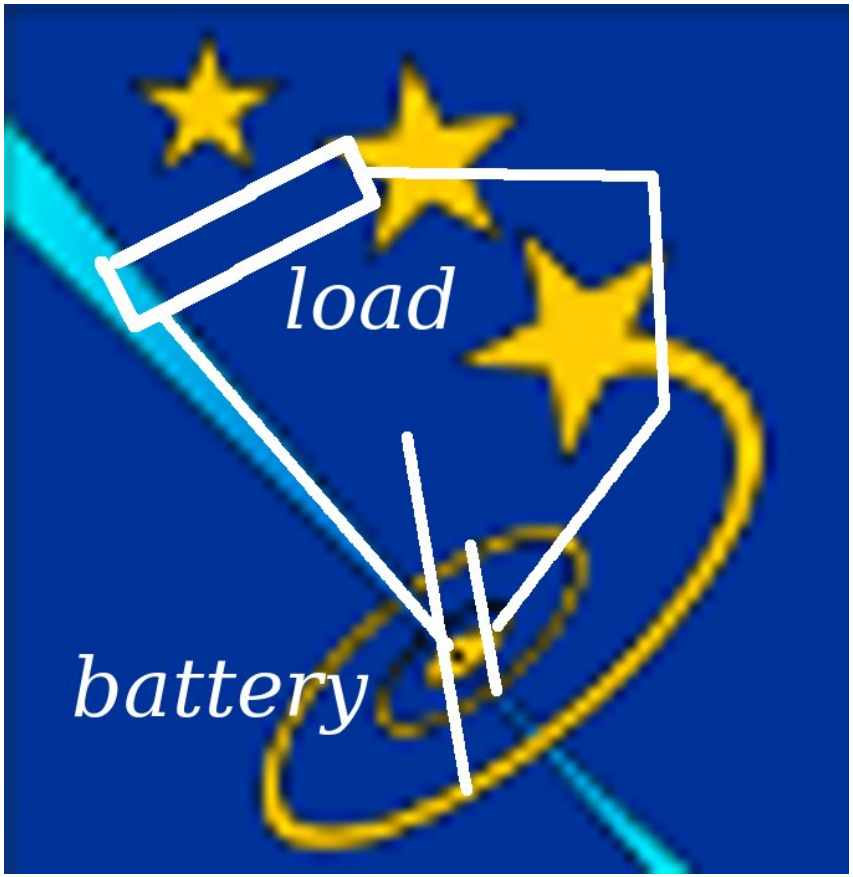


Black-hole as electric chain

$$\frac{dE}{dt} = \frac{1}{8c}\Omega_F(\Omega_H - \Omega_F)R_H^4 B_p^2$$

$$\frac{dJ}{dt} = \frac{1}{8c}(\Omega_H - \Omega_F)R_H^4 B_p^2$$

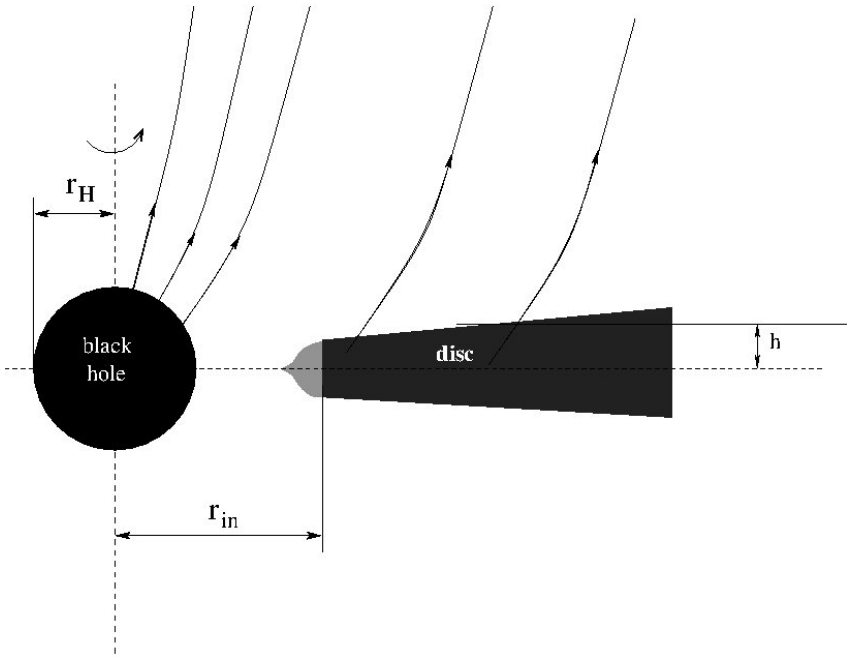
$$\frac{da}{dt} = \frac{c}{G}\left(\frac{1}{M^2}\frac{dJ}{dt} - \frac{2aG}{Mc}\frac{dM}{dt}\right)$$



We assume that magnetic field is equipartition with gas+radiation pressure as $\frac{B_p^2}{8\pi} = \frac{1}{\beta}$

Electro-magnetic processes

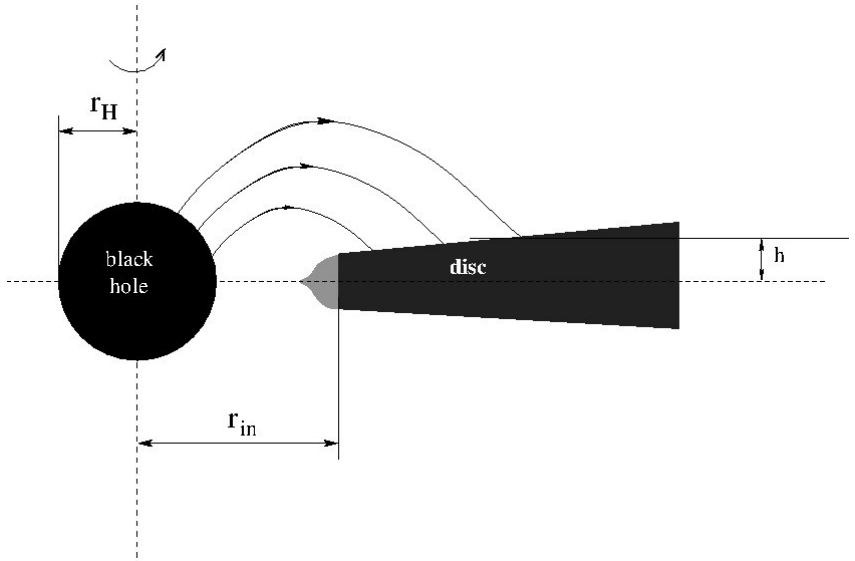
Blandford-Znajek



$\Omega_F = \Omega_H/2$

(Blandford, Znajek, 1977)

Direct magnetic link (DML)



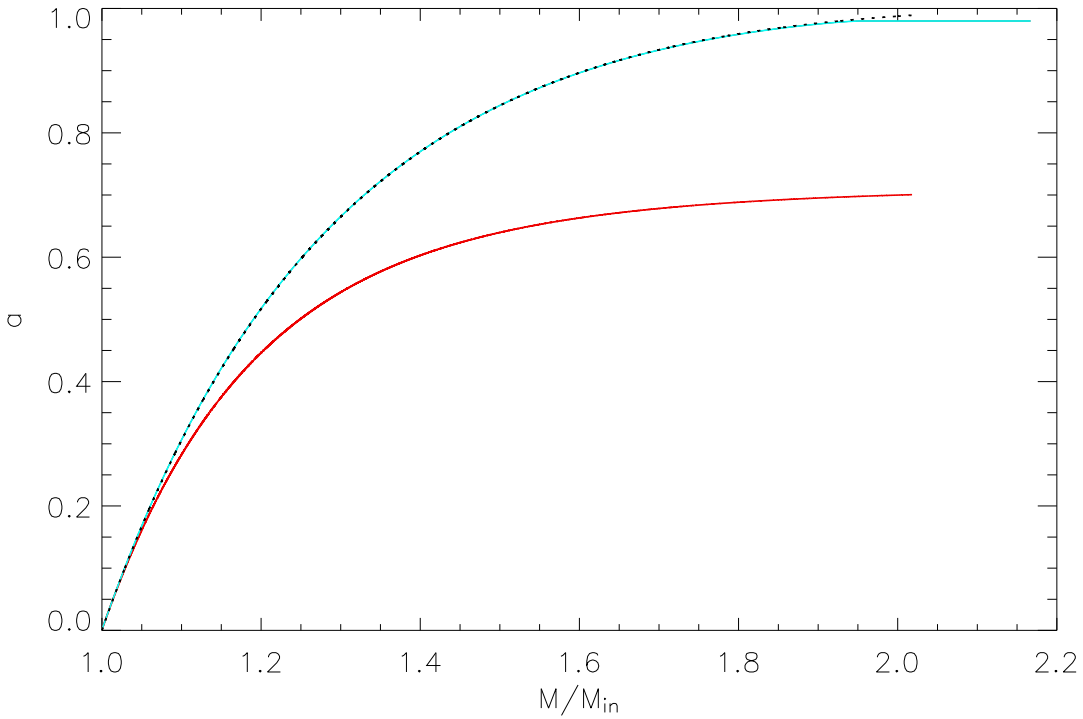
$\Omega_F = \Omega_K$

(Zeldovich, Shvartsman, 1970)

Standard disk

$$\frac{da}{dt} = \frac{\mu \dot{M}}{M^2}(j^+ - 2aM) - \frac{c}{G}\left(\frac{1}{M^2}\frac{dJ}{dt} - \frac{2aG}{Mc}\frac{dM}{dt}\right)$$

$10^{-2} < \dot{M}/\dot{M}_{edd} < 1$
Standard
Shakura-Sunyaev disk
(1973)



Rotational evolution of standard black hole ($M_{in} = 10^6 \odot M$, $\dot{M} = 0.4\dot{M}_{edd}$). Dotted line is matter accretion contribution, red line is Blandford-Znajek and cyan line is DML.

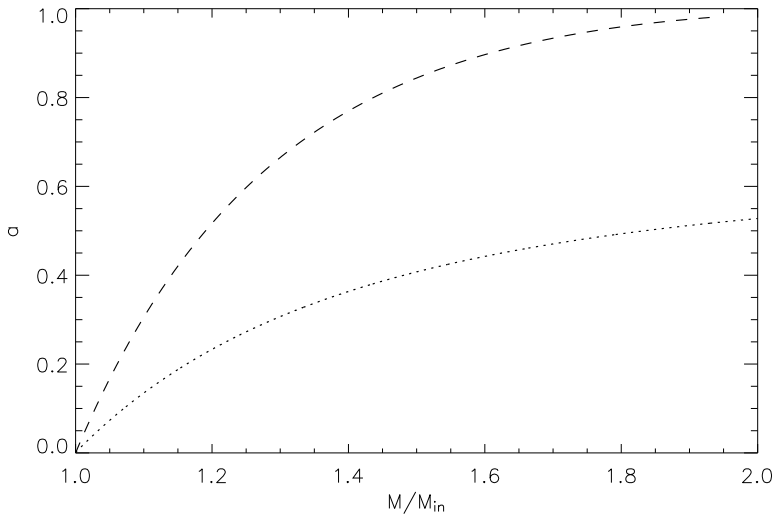
ADAF regime

$$\dot{M}/\dot{M}_{edd} < 10^{-2}$$

The main differences from the Shakura-Sunyaev disk:

- Non Keplerian velosity;
- Geometry thick, opticaly thin.

(Narayan,Yi, 1994)



Rotational evolution of standard black hole ($M_{in} = 10^6 M\odot$, $\dot{M} = 10^{-2}\dot{M}_{edd}$). Dashed line is matter accretion contribution in the standard disk and dotted line is matter accretion contribution in ADAF case.

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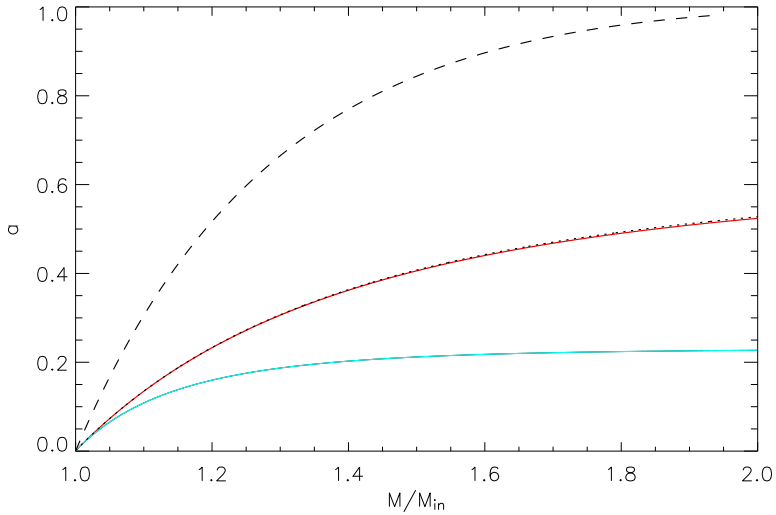


Rotational evolution of standard black hole($M_{in} = 10^6 M\odot$, $\dot{M} = 10^{-2}\dot{M}_{edd}$). Dashed line is matter accretion contribution in the standard disk, dotted line is matter accretion contribution in ADAF case, cyan line is ADAF DML red line is ADAF Blandford-Znajek.

Magnetic field decay

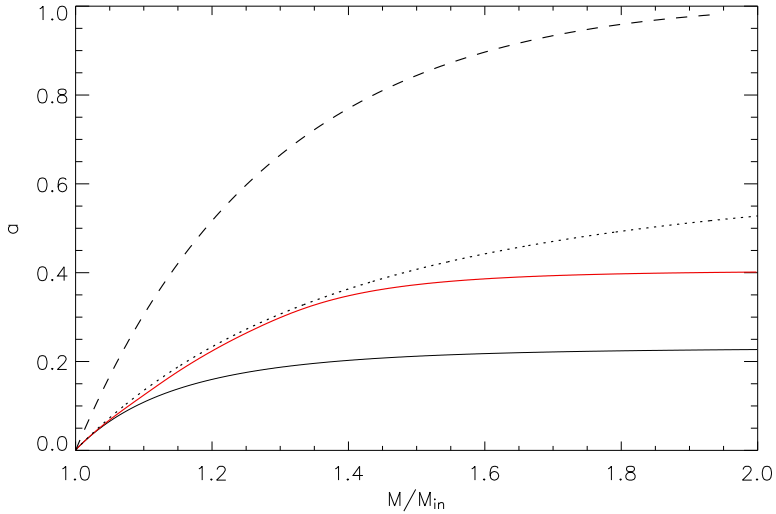
Abnout Ohm decay.

$$L_J = \left(\frac{\Omega_H}{\Omega_F} - 1\right)\frac{dE}{dt}$$

$$\frac{B^2}{8\pi} \cdot v_r \cdot 2\pi R_{in} \cdot 2h \geq L_J$$

$$v_{min} = \frac{8\pi L_J}{B^2 2\pi R_{in} 2h}$$

Changes in the a(t), M(t) in ADAF DML case:



$$\frac{da}{dt} = \frac{\mu\dot{M}}{M^2}(j^+ - 2aM) - \frac{c}{G}\left(\frac{1}{M^2}\frac{dJ}{dt} - \frac{2aG}{Mc}\frac{dM}{dt}\right)\exp(-v_{min}/v_r)$$

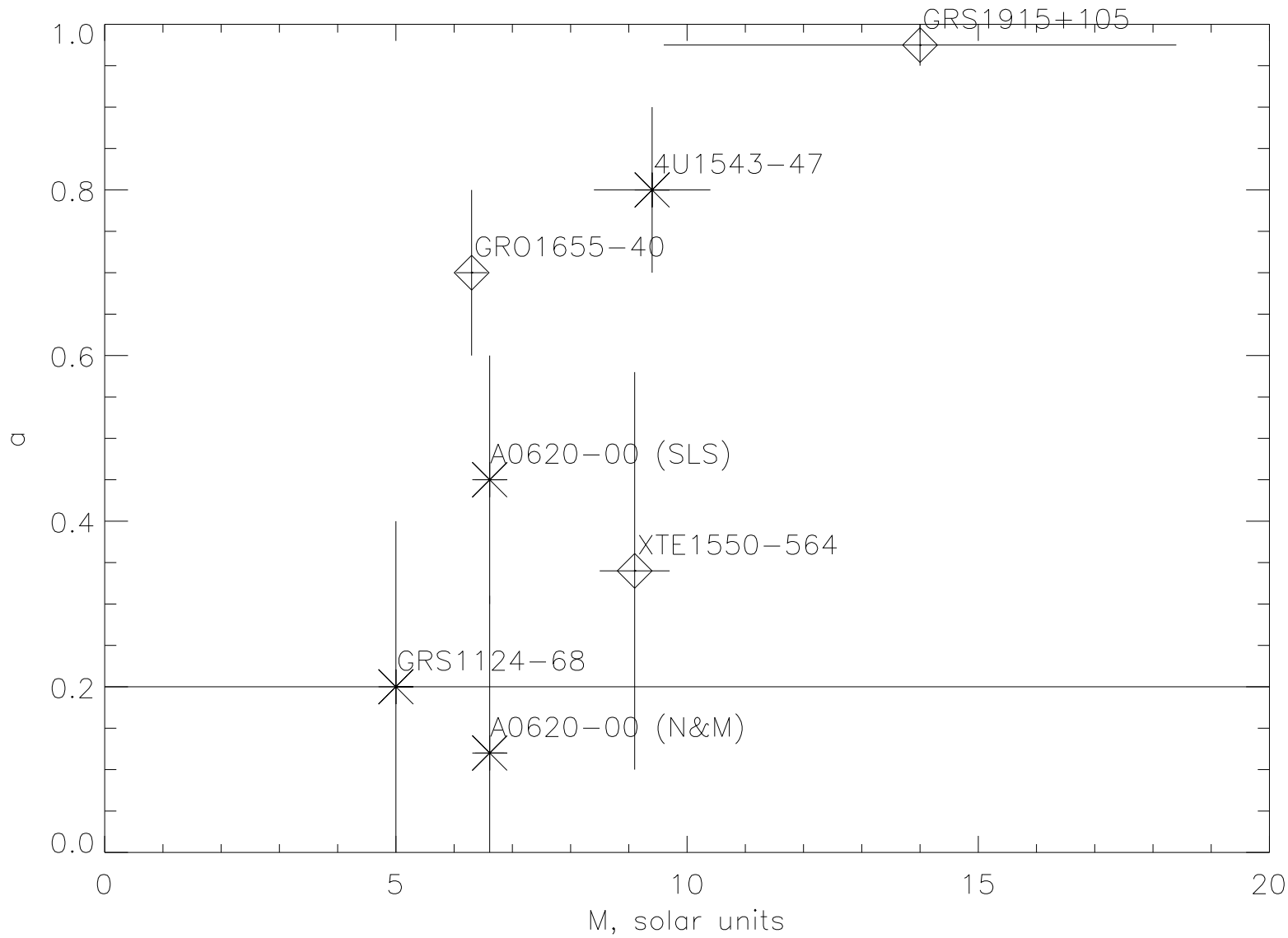
Conclusions

- Depending on the prevailing accretion regime and mass accretion rate black hole may be spun up to different values of Kerr parameter between $\sim$0.2 and $\sim$0.998
- Thick disc causes efficient spin-down
- Magnetic field decay is important influence on the efficiency of direct magnetic link

Observational tests

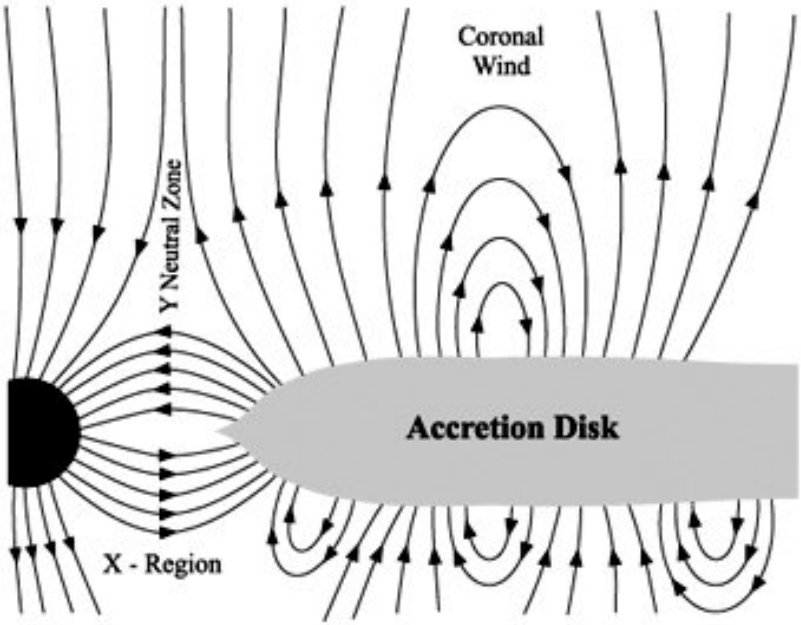
1. X-ray continuum fitting method. (Narayan, McClintock, 2012)
   - X-ray Nova A0620: $a = 0.12 \pm 0.19$, $M/M\odot = 6.61 \pm 0.25$
   - X-ray Nova 4U 1543-47: $a = 0.8 \pm 0.1$, $M/M\odot = 9.4 \pm 1.0$
   - Microquasars XTE J1550-564: $a = 0.34 \pm 0.24$, $M/M\odot = 9.10 \pm 0.61$
   - Microquasars GRO J1655-40: $a = 0.7 \pm 0.1$, $M/M\odot = 6.30 \pm 0.27$
   - Microquasars GRS 1915+105: $a = 0.975 \pm 0.025$, $M/M\odot = 14.0 \pm 4.4$
2. Light curve fitting. (Suleimanov, Lipunova, Shakura, 2008)
   - X-ray Nova A0620: $a = 0.12 \pm 0.19$, $M/M\odot = 6.61 \pm 0.25$
   - X-ray Nova GRS 1124-68: $a \leq 0.4$

Observational tests



Plans for the future

BZ+DML?



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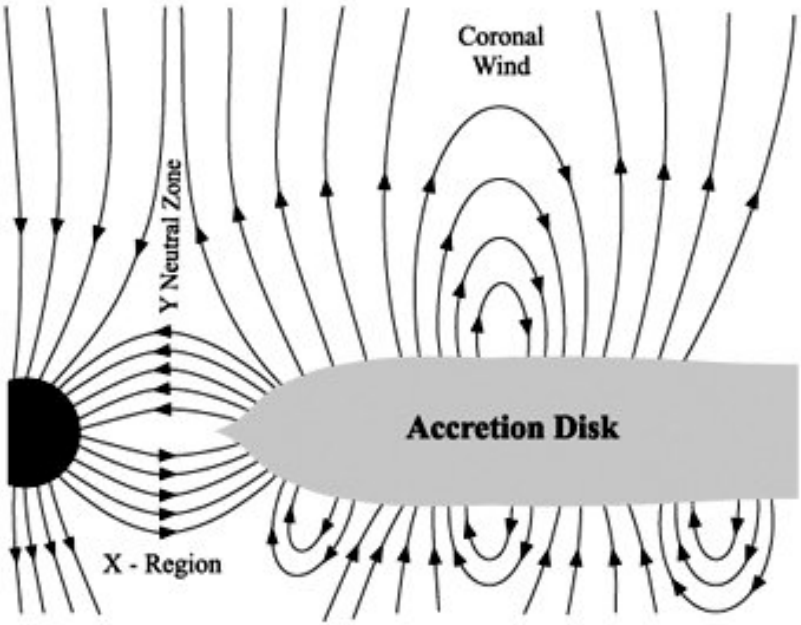
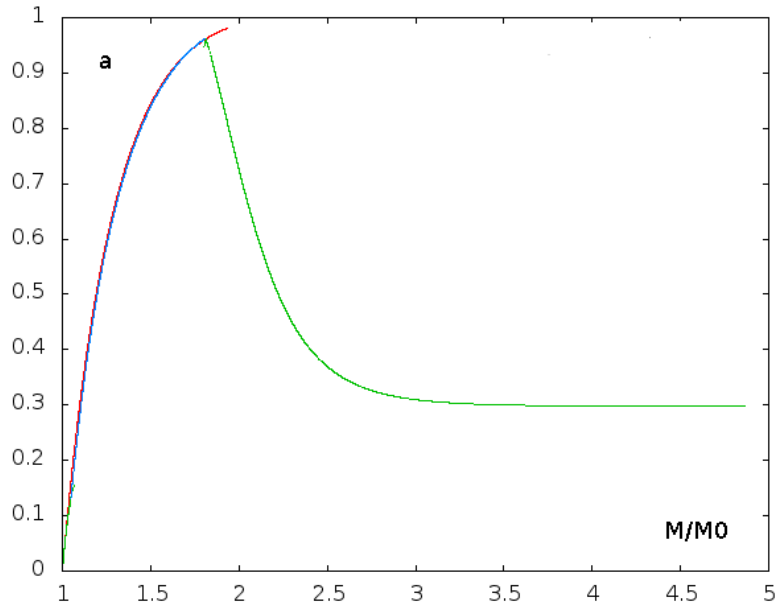


Nonstationary accretion



$\dot{M} \propto t^{1.3}$ (Binney,Tabor,1995)