Chandra Fellows Symposium

Disk Powered by a Black Hole through Magnetic Connection

Li-Xin Li

Harvard University

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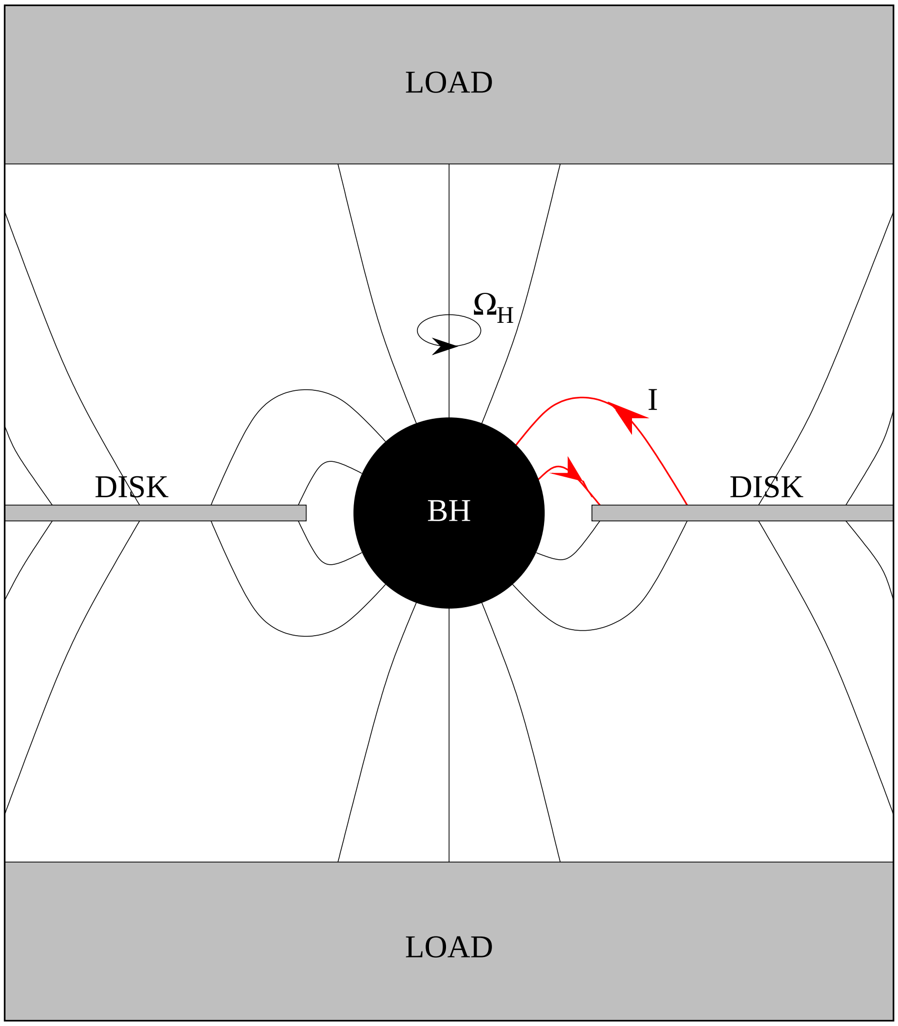
I. Introduction

- Magnetic connection



(Comments: Zel'dovich & Schwartzman 1974, Blandford 1999, ...)

- A black hole (BH) is a conductor with a surface resistivity $R_H = 4\pi \approx 377$ Ohm. Thus, if a magnetic field connects a Kerr BH to a disk, electromotive forces are produced on the BH and the disk, which transfers energy and angular momentum between them.

- A disk powered by a BH is expected to show specific features different from a standard accretion disk, it would be interesting and important to study these new features.

- With the rapid development of X-ray astronomy, observing the region close to the central BH is becoming possible. It can be expected that in in the near future it will be possible to test the model of magnetic connection.

II. Extracting Energy from a BH through Magnetic Connection

The BH exerts a torque on the disk through magnetic connection

$$T_{HD} = \left(\frac{\Delta\Psi}{2\pi}\right)^2 \frac{\Omega_H - \Omega_D}{Z_H}$$

which produces a power

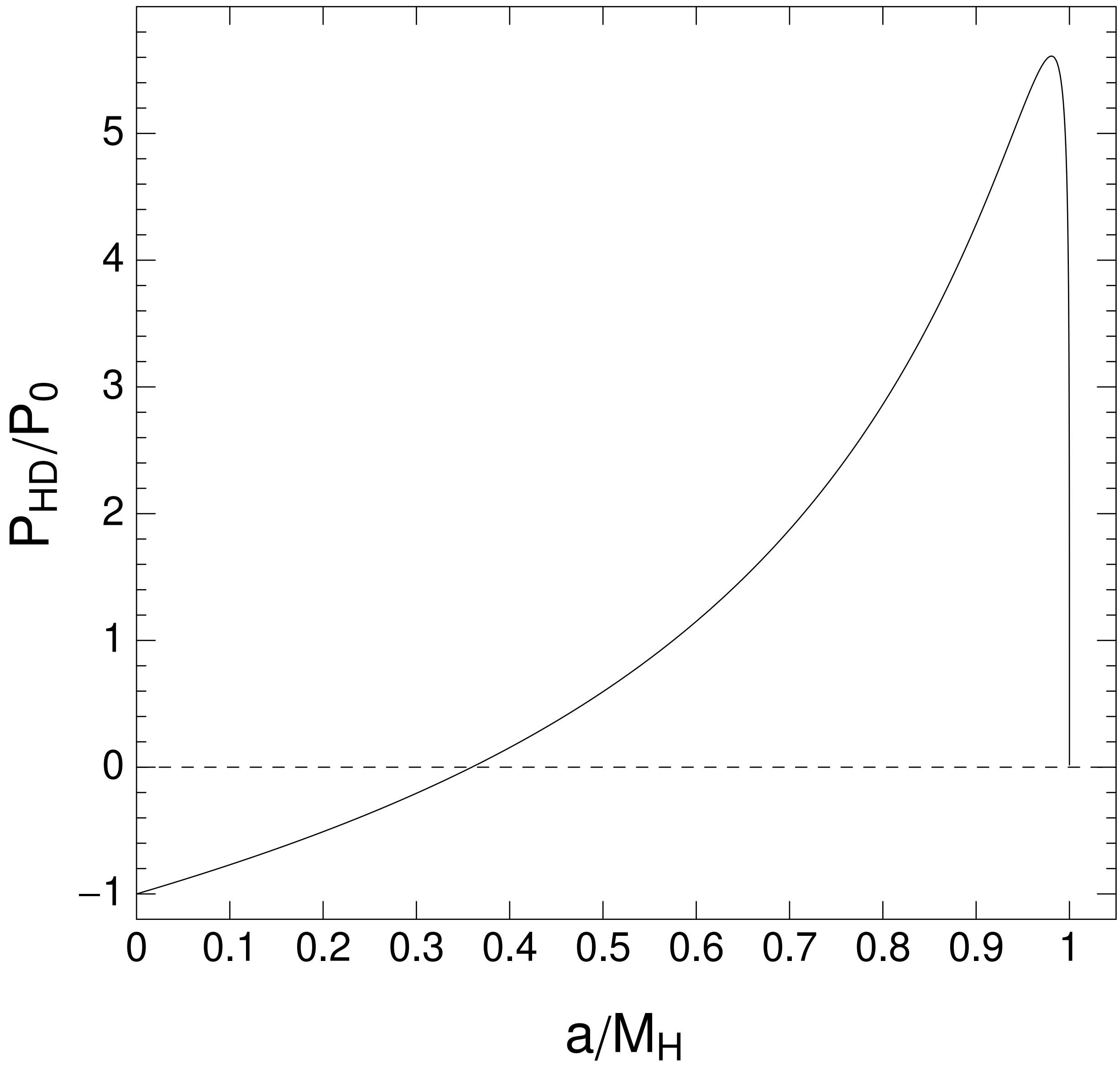
$$\begin{aligned} P_{HD} = T_{HD}\Omega_D &\approx 10^{45}\,\mathrm{erg/sec} \\ &\times \left(\frac{a}{M_H}\right)^2 \left(\frac{M_H}{10^9 M_\odot}\right)^2 \left(\frac{B}{10^4\mathrm{G}}\right)^2 \end{aligned}$$

– The direction of the transfer of energy is determined by the sign of $\Omega_H - \Omega_D$.

– Assume the field lines touch the disk at the inner boundary, then $\Omega_D = \Omega_{ms}$:

$$\begin{aligned} P_{HD} &> 0 \quad \text{if} \quad a > 0.36 M_H; \\ P_{HD} &< 0 \quad \text{if} \quad a < 0.36 M_H. \end{aligned}$$

– Total energy extracted from the BH: up to $0.15 M_H c^2$.



$P_{HD} = 0$ at $a = 0.36M_H$

P_{HD} peaks at $a = 0.981M_H$

III. Radiation without Accretion: A Disk Powered by a BH

In the weak magnetic field approximation, the energy extracted from the BH is dissipated and radiated away by the disk. The total luminosity of the disk is

$$L_D = \epsilon_0 \dot{M} c^2 + 2P_{HD} \equiv \epsilon \dot{M} c^2$$

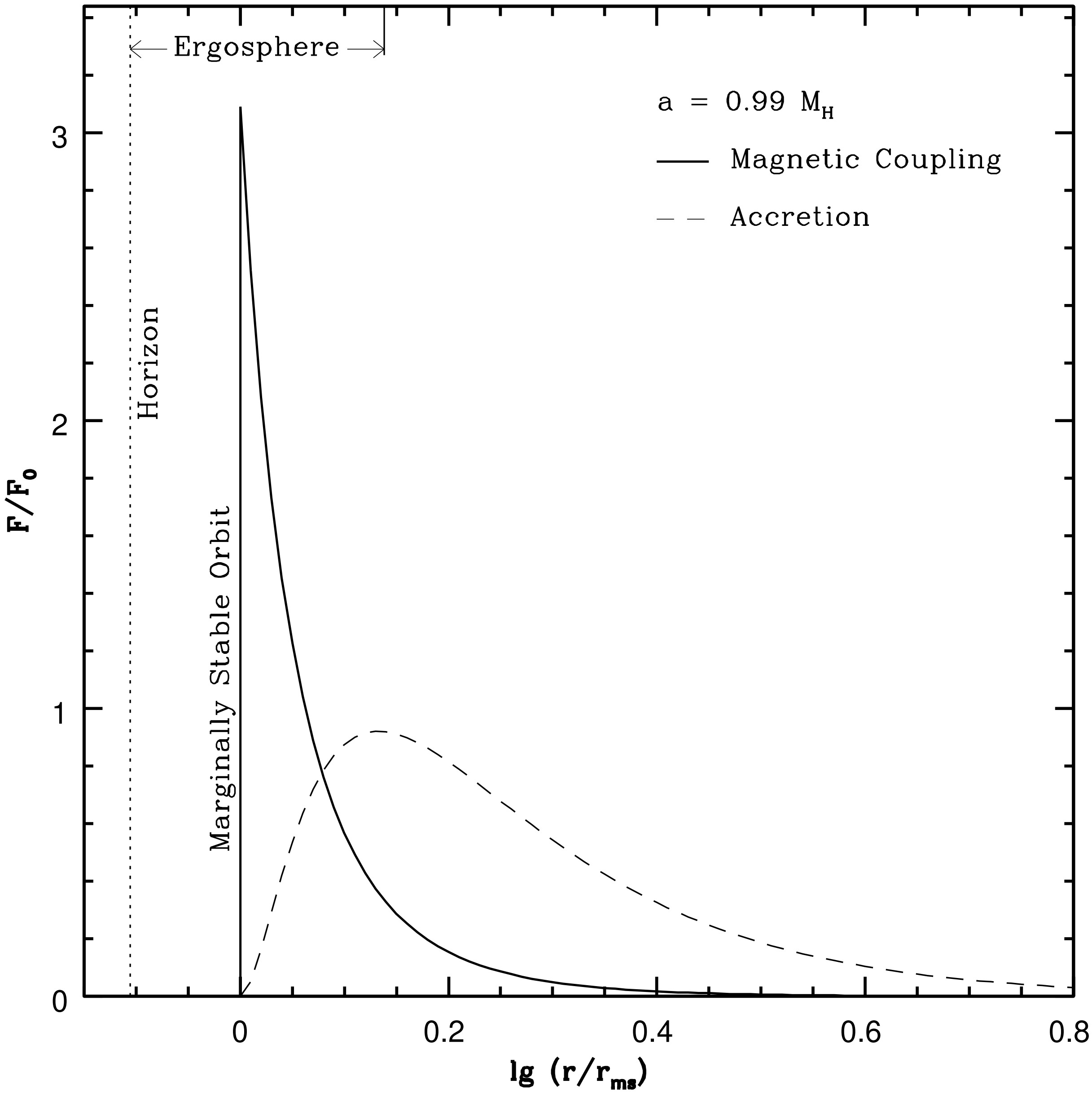
Though $\epsilon_0 \leq 0.42$ always, the total efficiency ϵ can be $\gg 1$ for small $\dot{M}$ and large P_{HD}.

When $\dot{M} = 0$ and $P_{HD} > 0$, the disk radiates without accretion, the radiation flux is

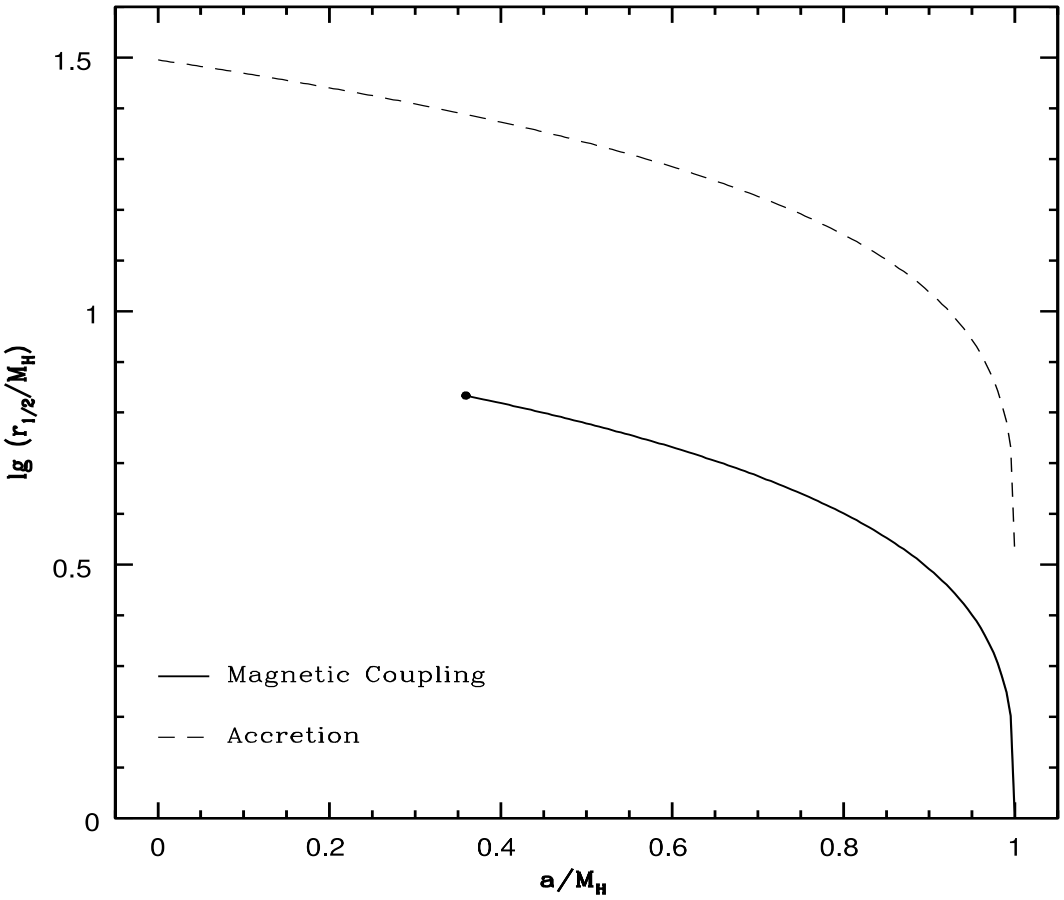
$$\begin{aligned} F &= \frac{1}{r}\left(-\frac{d\Omega_D}{dr}\right)\left(E^+ - \Omega_D L^+\right)^{-2} \\ &\quad \times \int_{r_{ms}}^{r} \left(E^+ - \Omega_D L^+\right) H r dr \end{aligned}$$

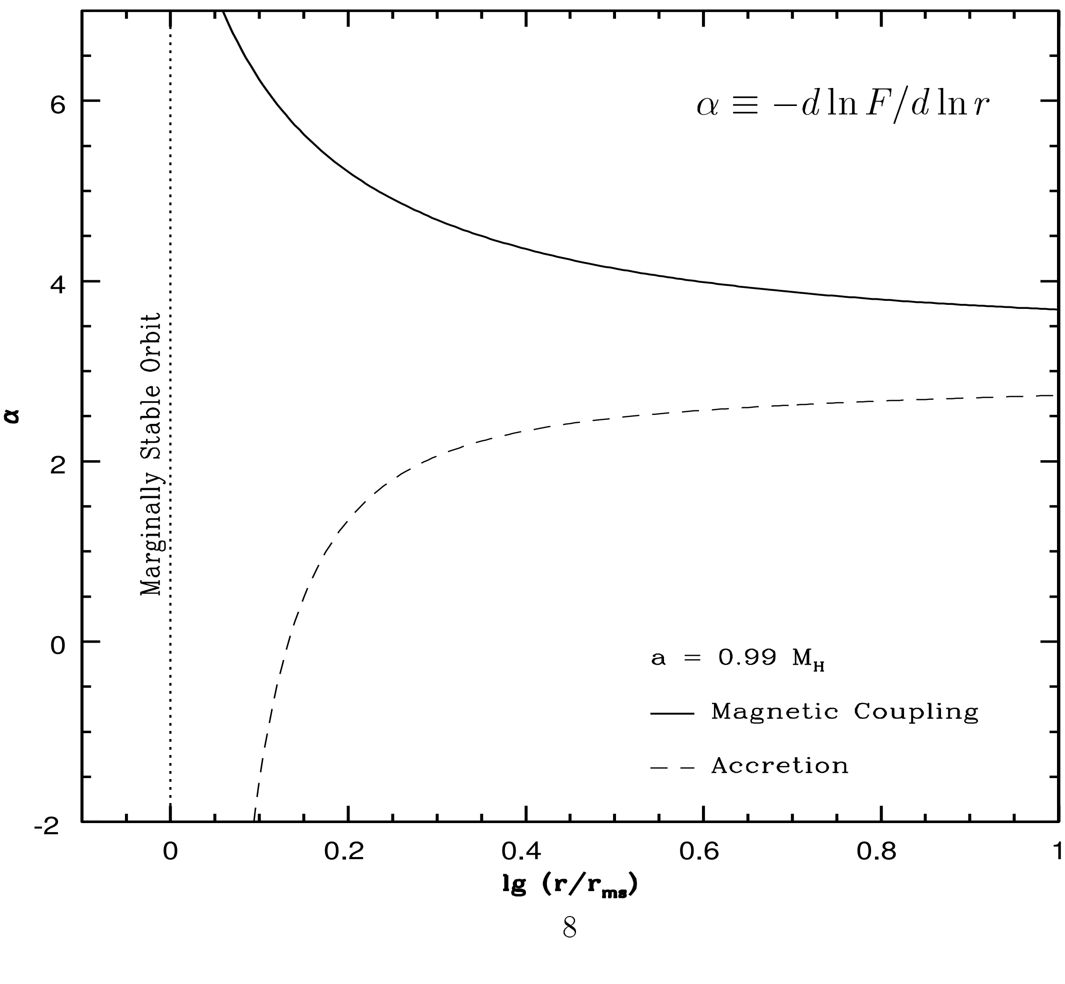
where

$$H = \frac{1}{8\pi^3}\left(\frac{d\Psi_{HD}}{dr}\right)^2 \frac{\Omega_H - \Omega_D}{-r dZ_H/dr}$$



$$F_0 \equiv \frac{1}{2\pi r_{ms}^3}\left(\frac{\Delta\Psi}{2\pi}\right)^2 \frac{\Omega_H - \Omega_D}{Z_H}$$

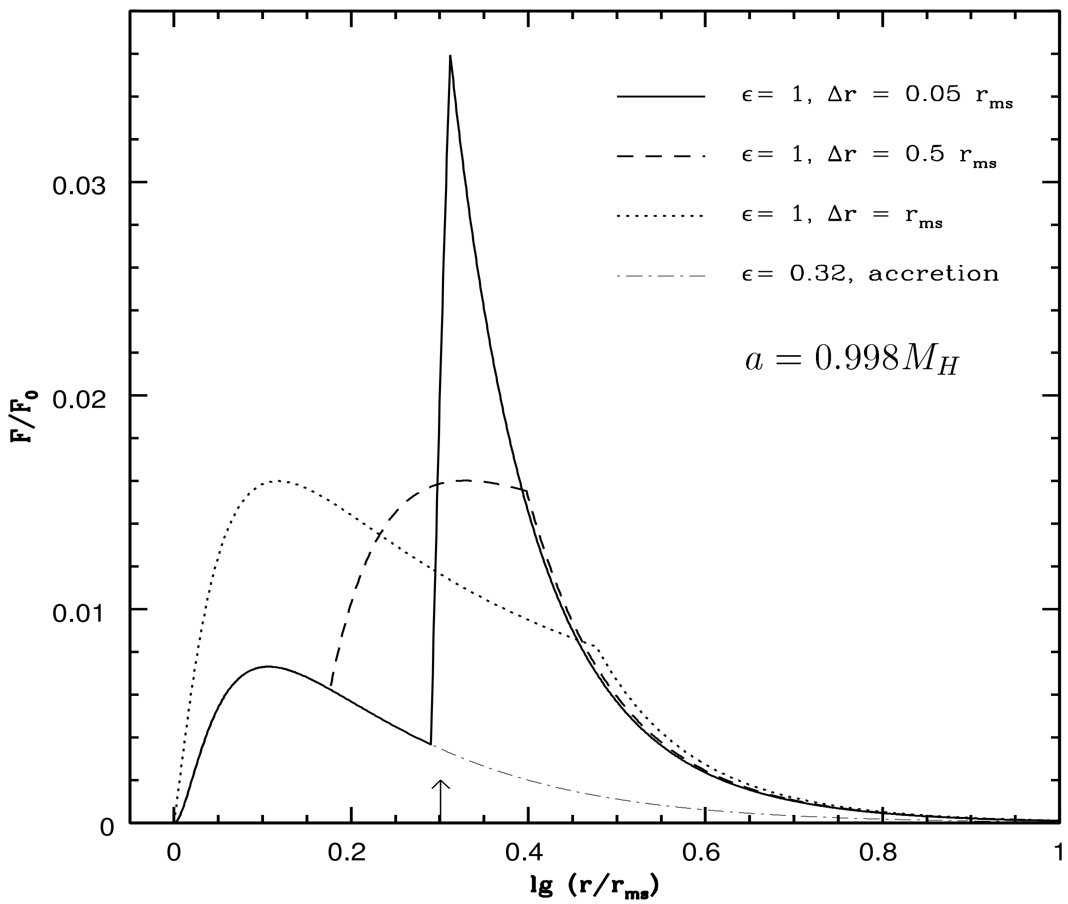

1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
lg (r1/2/MH)
a/MH
Magnetic Coupling
Accretion


$\alpha \equiv -d\ln F/d\ln r$
Marginally Stable Orbit
6
4
2
0
-2
0
0.2
0.4
0.6
0.8
1
α
lg (r/rms)
a = 0.99 MH
Magnetic Coupling
Accretion

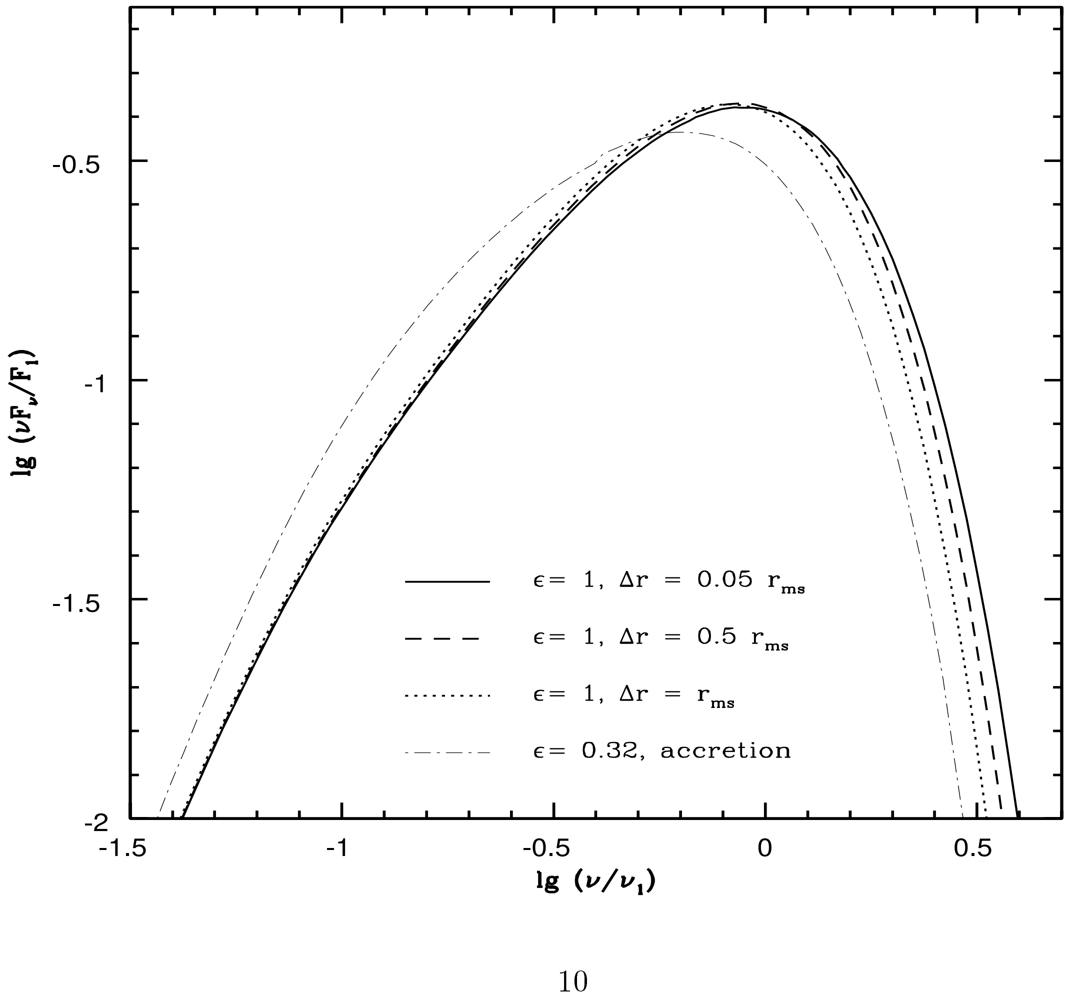
IV. Spectral Signature of the Magnetic Connection

When accretion and the magnetic connection co-exist, the radiation flux of the disk is the superposition of the radiation flux produced by accretion and that produced by the magnetic connection.

The shape of the radiation flux curve sensitively depends on the distribution of the magnetic field in the disk, but the spectral signature of the magnetic connection can be robust.



ϵ= 1, Δr = 0.05 r_ms
ϵ= 1, Δr = 0.5 r_ms
ϵ= 1, Δr = r_ms
ϵ= 0.32, accretion
$a = 0.998M_H$
F/F_0
lg (r/r_ms)



ϵ= 1, Δr = 0.05 r_ms
ϵ= 1, Δr = 0.5 r_ms
ϵ= 1, Δr = r_ms
ϵ= 0.32, accretion
lg (νF_ν/F_1)
lg (ν/ν_1)

V. Summary and Future Prospects

- With magnetic connection to a BH the radiation properties of a disk is significantly modified. Not only the radiation efficiency is changed, but also the radiation profile is very different from that of a standard accretion disk.

- It would be interesting to calculate a more realistic model with magnetic connection, and compare the results with current and future observations.

- Probably some features of the magnetic connection has already been seen in the current observations, e.g. the recent *XMM-Newton* observation of Narrow Line Seyfert 1 galaxies and the *RXTE* observations of QPOs.

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