Mass Accretion Rate of Rotating Accretion Flow onto Black Holes (Generalized Bondi Flow)

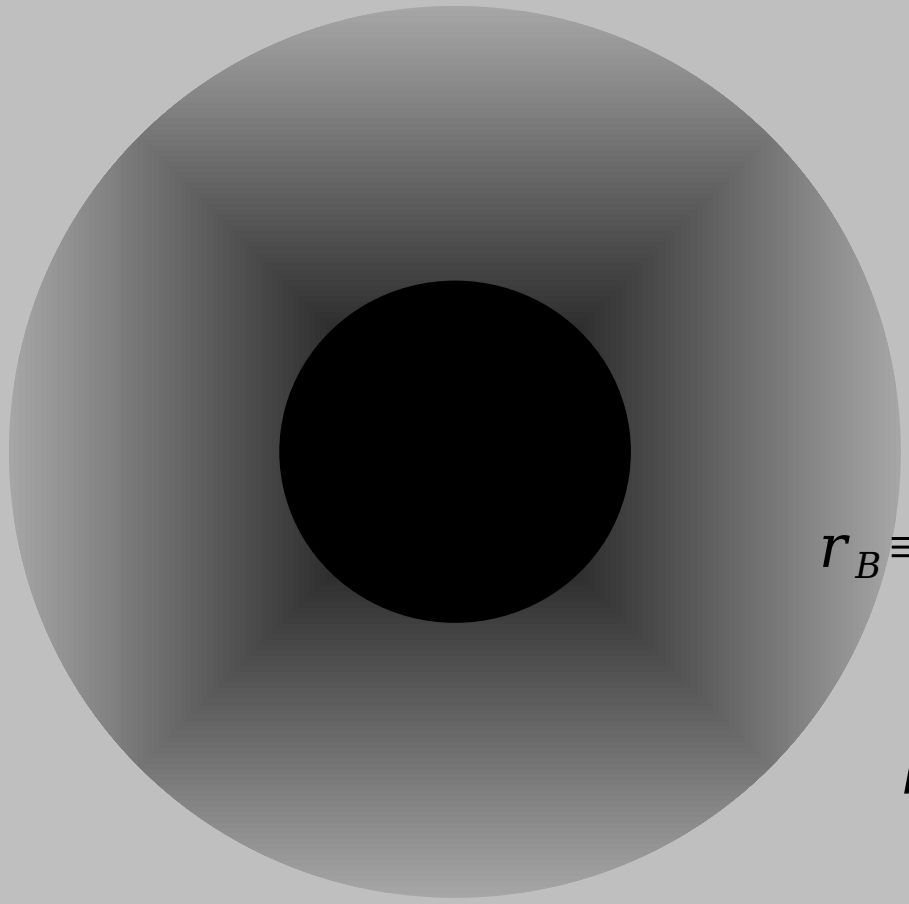
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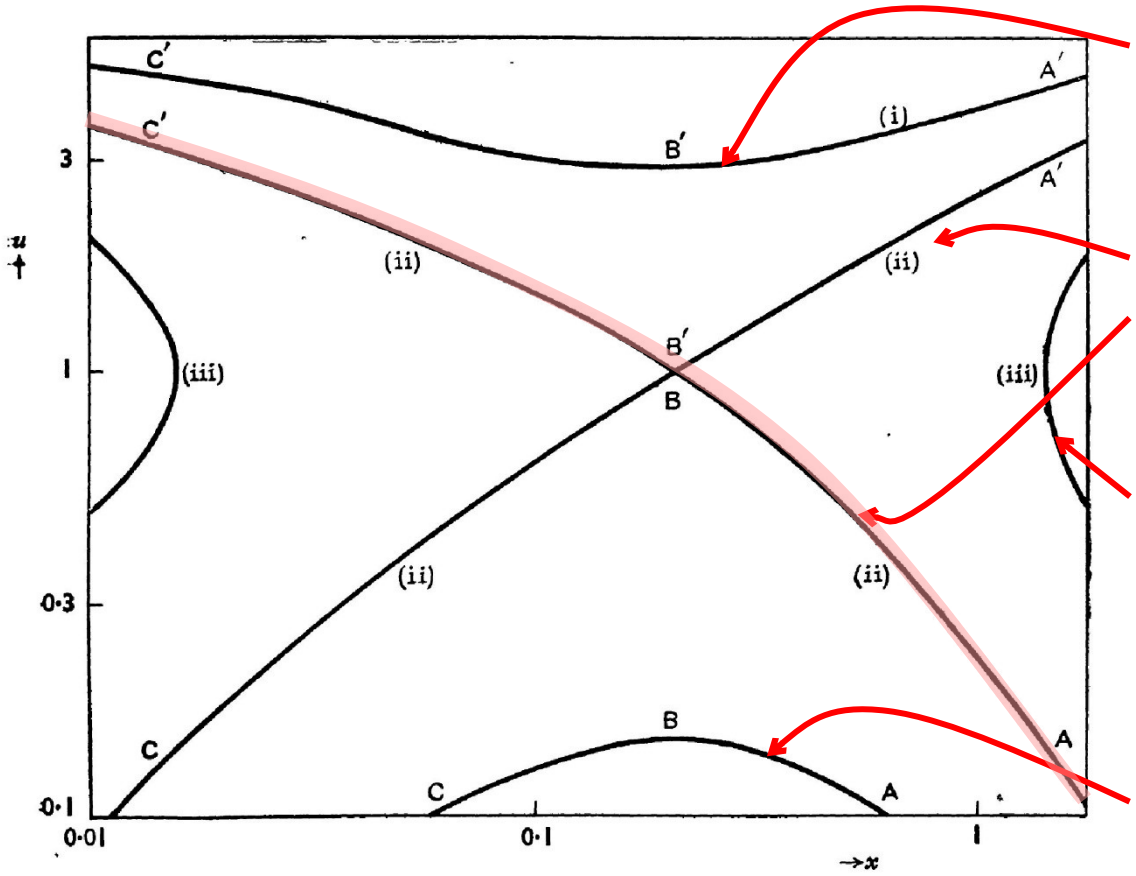
How much can a black hole accrete?



$$r_B \equiv \frac{GM}{c_{s,\infty}^2}$$

$$\rho_\infty, T_\infty (c_{s,\infty})$$

Bondi solutions (1952)



1. Supersonic
2. Transonic
3. Non-physical
4. Subsonic

$$\frac{dv_r}{dr} = -C\frac{\frac{GM}{2r} - c_{s,ad}^2}{v_r^2 - c_{s,ad}^2}$$

$$\dot{M}_{Bondi} = \lambda\, 4\pi r_B^2 \rho_\infty c_{s,\infty}$$

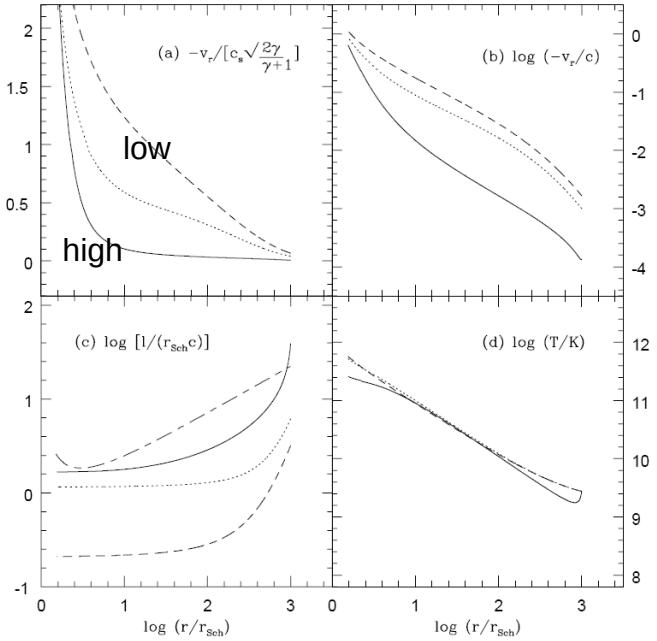
Rotating viscous accretion flow

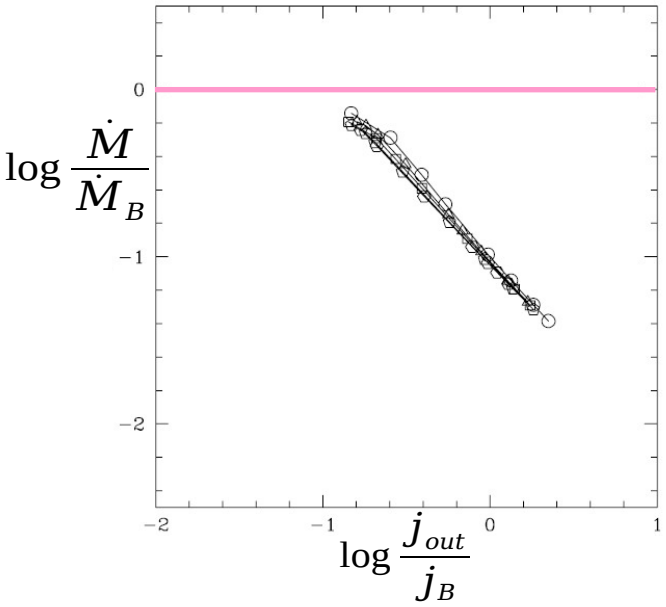
- What is the nature of the accretion flow with an-gular momentum?

- What would be the mass accretion rate of these accretion flow?

Park (2009)

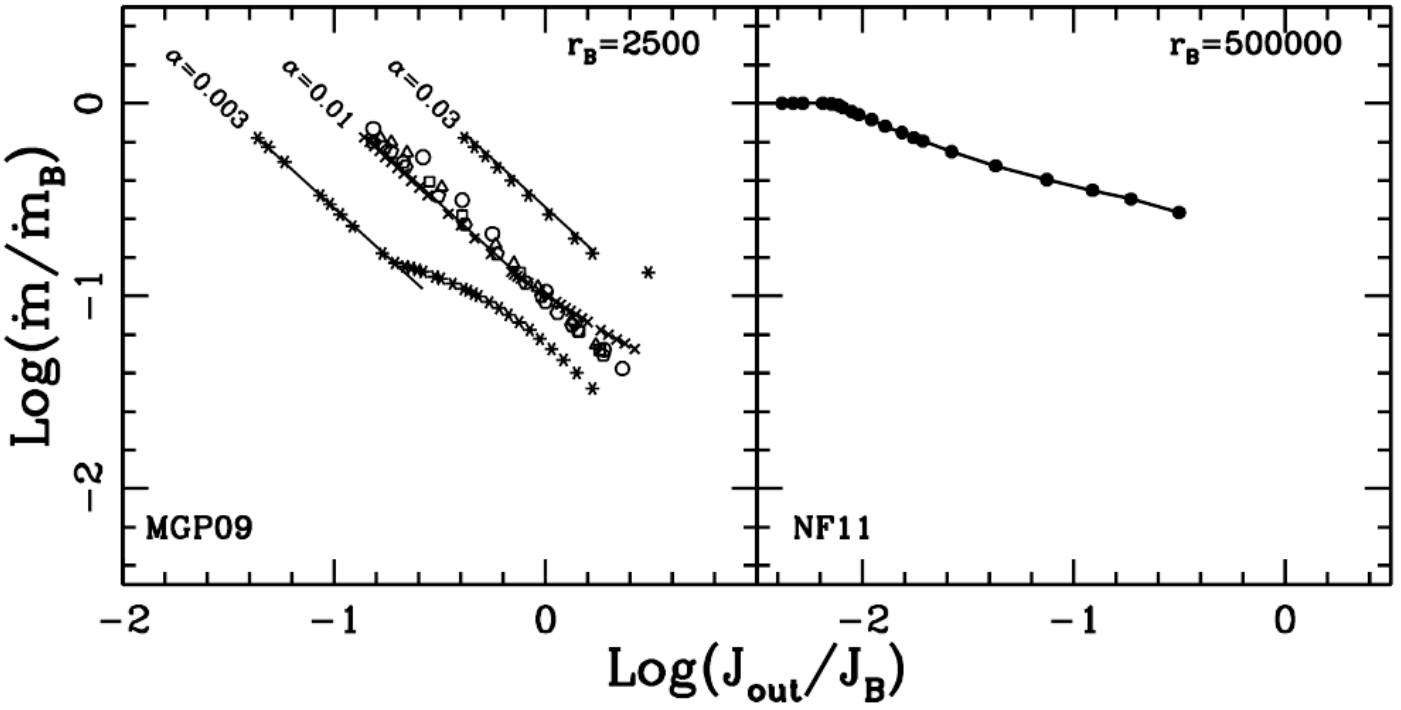
- Angular momentum equation: $\rho v_r(\Omega r^2 - l_0) = \eta \alpha r P$
- Flow properties
  - Low angular momentum flow resembles Bondi flow.
  - High angular momentum flow resembles disk flow.
- Mass accretion rate decreases as angular momentum increases.





Narayan & Fabian (2011)

- Bondi flow from a slowly rotating hot atmosphere, in the context of cooling flow
- Solutions have similar properties, but show different .



Generalized Bondi Flow



Du-Hwan Han

- Rotating viscous polytropic accretion flow
  - Better comparison with Bondi flow

- Slim disk approximation
  - Angular momentum equation:

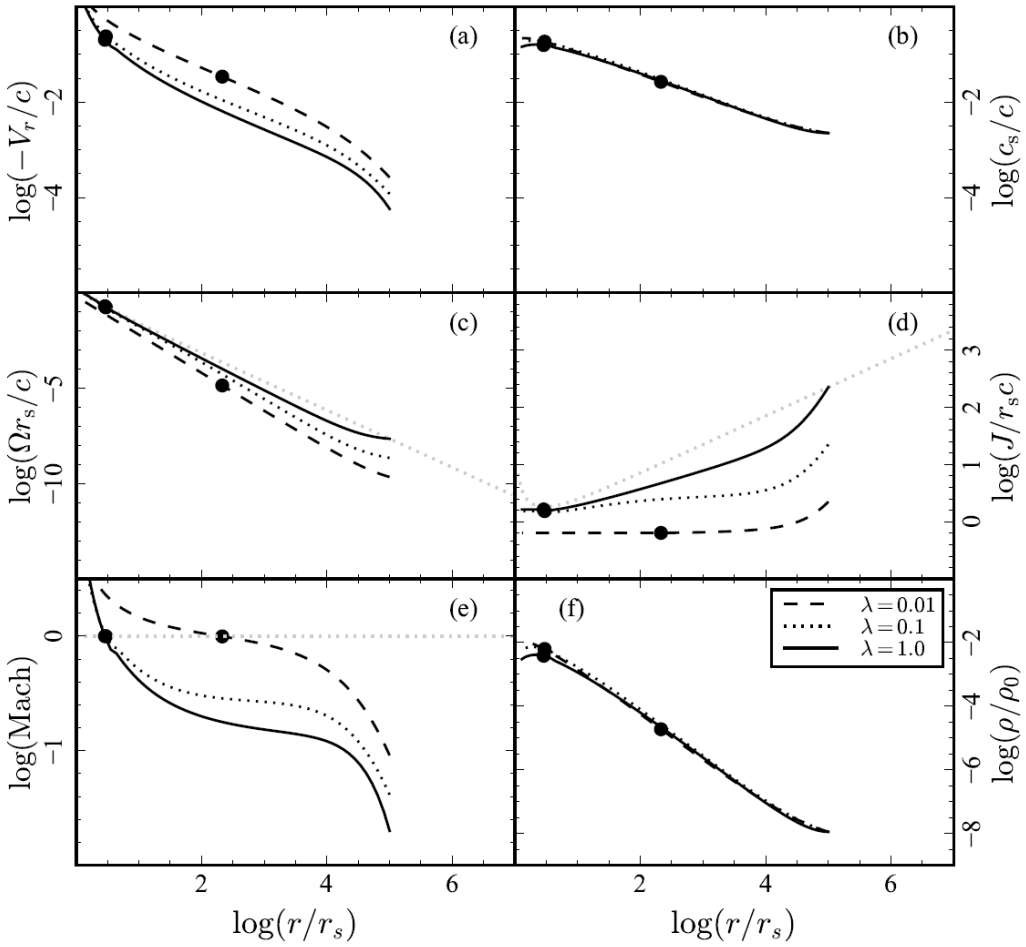
$$\rho v_r \left(\Omega r^2 - j_0 \right) = \eta \alpha r P \qquad \eta \equiv \left(\frac{r}{H} \right) \left(\frac{r}{\Omega_K} \right) \left(\frac{d\Omega}{dr} \right)$$

- Flow properties and mass accretion rate dependence on

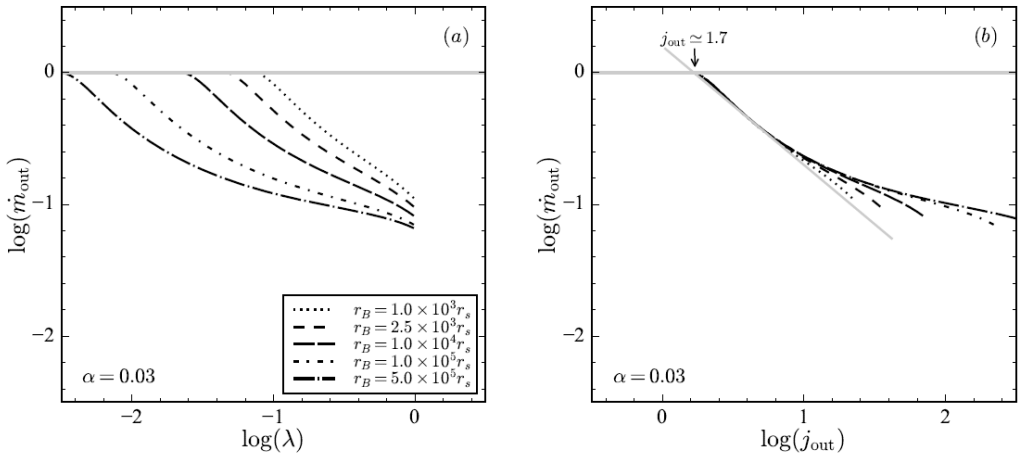
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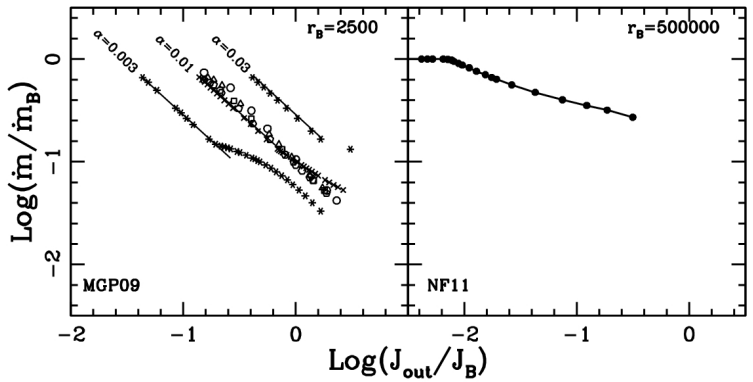
- Relaxation code
  - Narayan, Kato, Honma (1997), Narayan, Fabian (2011)
  - Critical point (sonic point)

Flow profile



Mass Accretion Rate



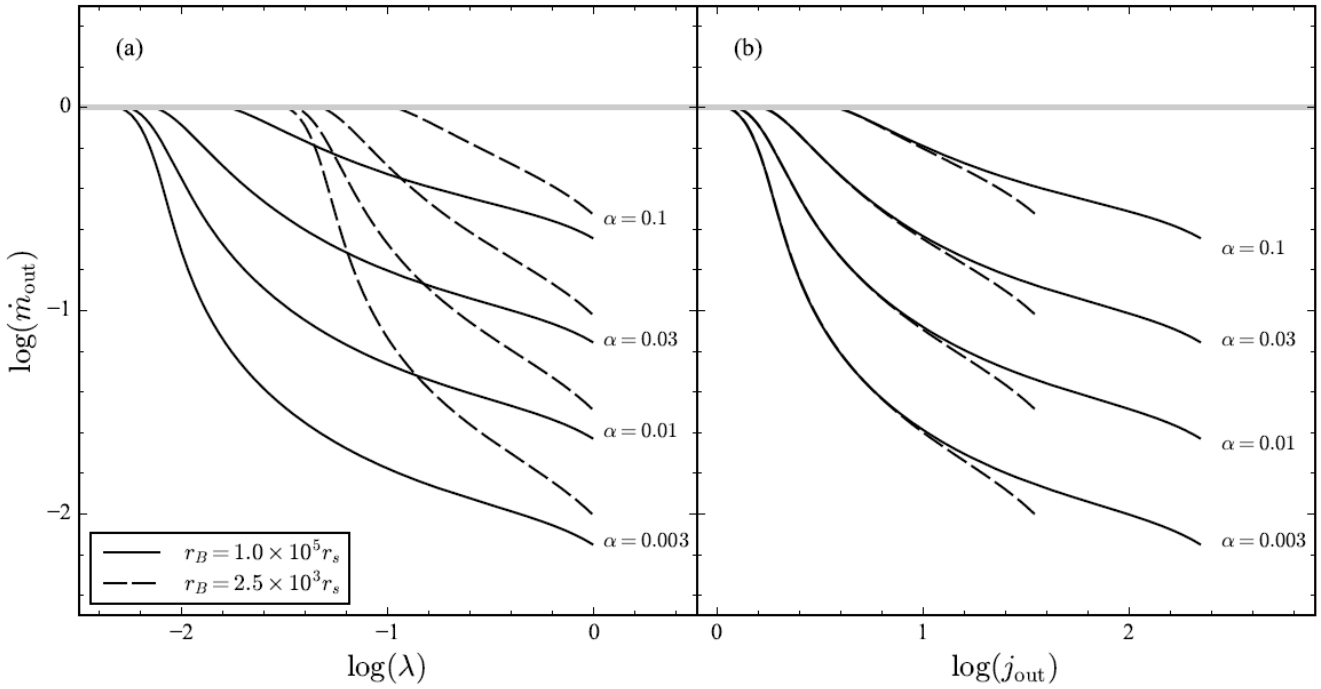


- Mass accretion rate vs angular momentum

  or

- Relation becomes shallower as increases
- Discrepancy between Park (2009) vs Narayan & Fabian (2011) is due to the difference in mostly along with .
- Mass accretion rate reaches the Bondi rate at a given for given .

- Dependence on α



Accretion with Outflow

- Blanford & Begelman (1999)
  - simple scaling model for Advection-Dominated Inflow-Outflow Solutions (ADIOS)

- Mass conservation

$$\dot{M}(r) = -4\pi H \rho v_r = \dot{M}_{out}\left(\frac{r}{r_{out}}\right)^s$$

- Radial momentum

$$v_r \frac{dv_r}{dr} + \left(\Omega_K^2 - \Omega^2\right) r + \frac{1}{\rho}\frac{dP}{dr} = 0$$

- Angular momentum

$$\rho v_r \left[\left(1 - \lambda_{BB}\right)\Omega r^2 - \frac{j_0}{r^p}\right] = \frac{r^2}{c_s}\frac{d\Omega}{dr}\alpha r P$$

- Equation of State

$$P = P_{out}\left(\frac{\rho}{\rho_{out}}\right)^\gamma$$

Mass accretion rate of ADIOS

- Mass infall rate (at outer boundary) increases because outflow removes angular momentum.
- However, the actual mass accreted into the horizon can be much smaller than the mass infall rate at the outer boundary.
- Black hole growth rate is determined by .
- Energy production is determined by , , and the detailed processes within the accretion flow.

