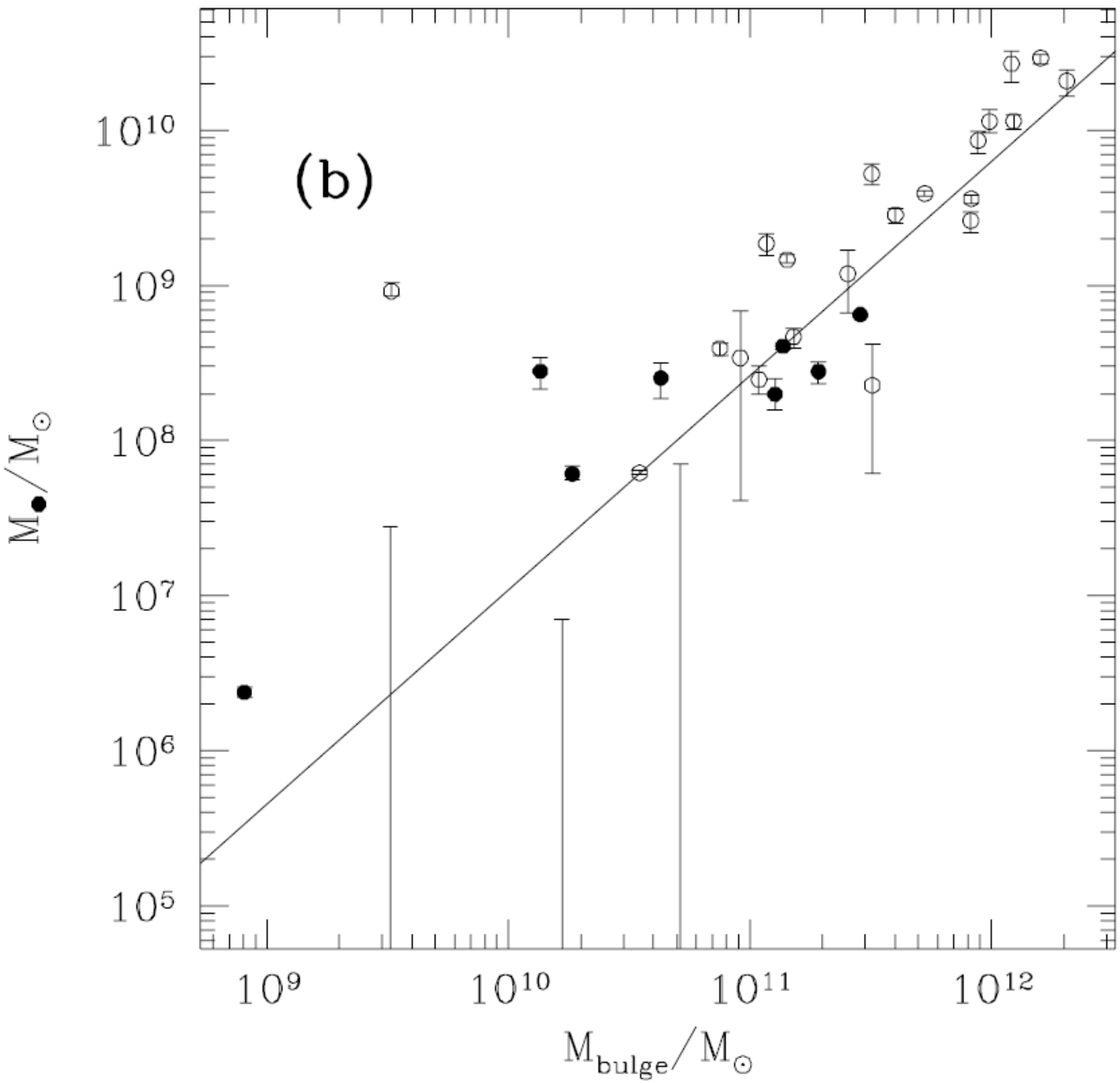
Mass Accretion Rate of Accretion Flow and Black Hole Mass

Myeong-Gu Park

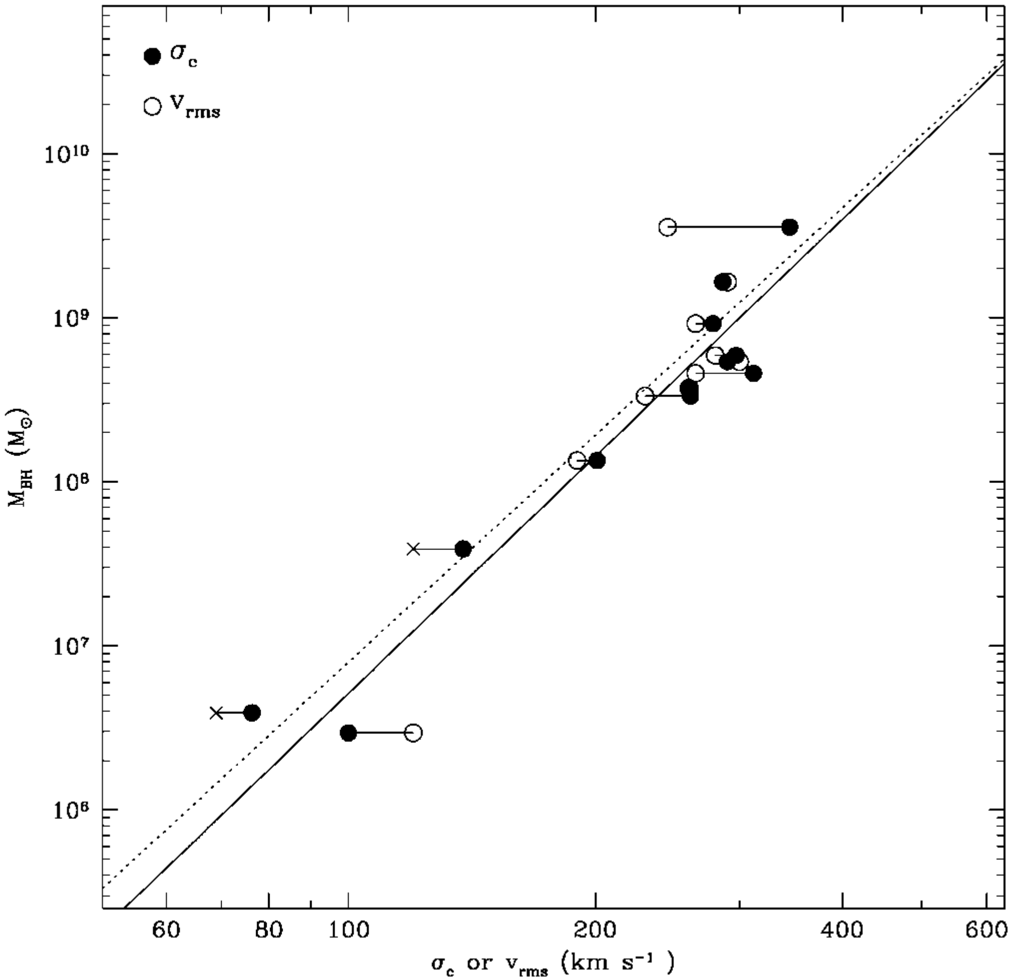
Kyungpook National University
Department of Astronomy & Atmospheric Sciences

Black Holes in Galaxies

- Black Holes in Galaxies
  - black holes are everywhere from dynamical evidence
- Black Hole Mass
  - radial velocity
    - velocity anisotropy unknown
  - 3D velocity
    - only for Milky Way
  - maser
    - only for NGC4258
- Black Hole Mass Function
  - SDSS quasars BHs



Magorrian et al. 1998



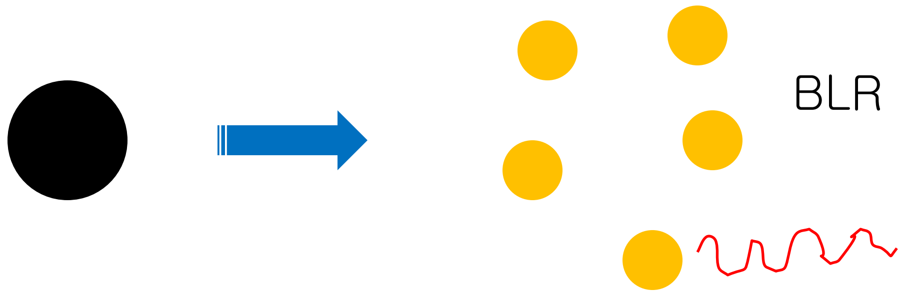
Ferrarese & Merritt 2000

black hole mass

– reverberation method (for AGN)

- no angular resolution required
- can be used for large number of galaxies
- physics of BLR uncertain
- mass:

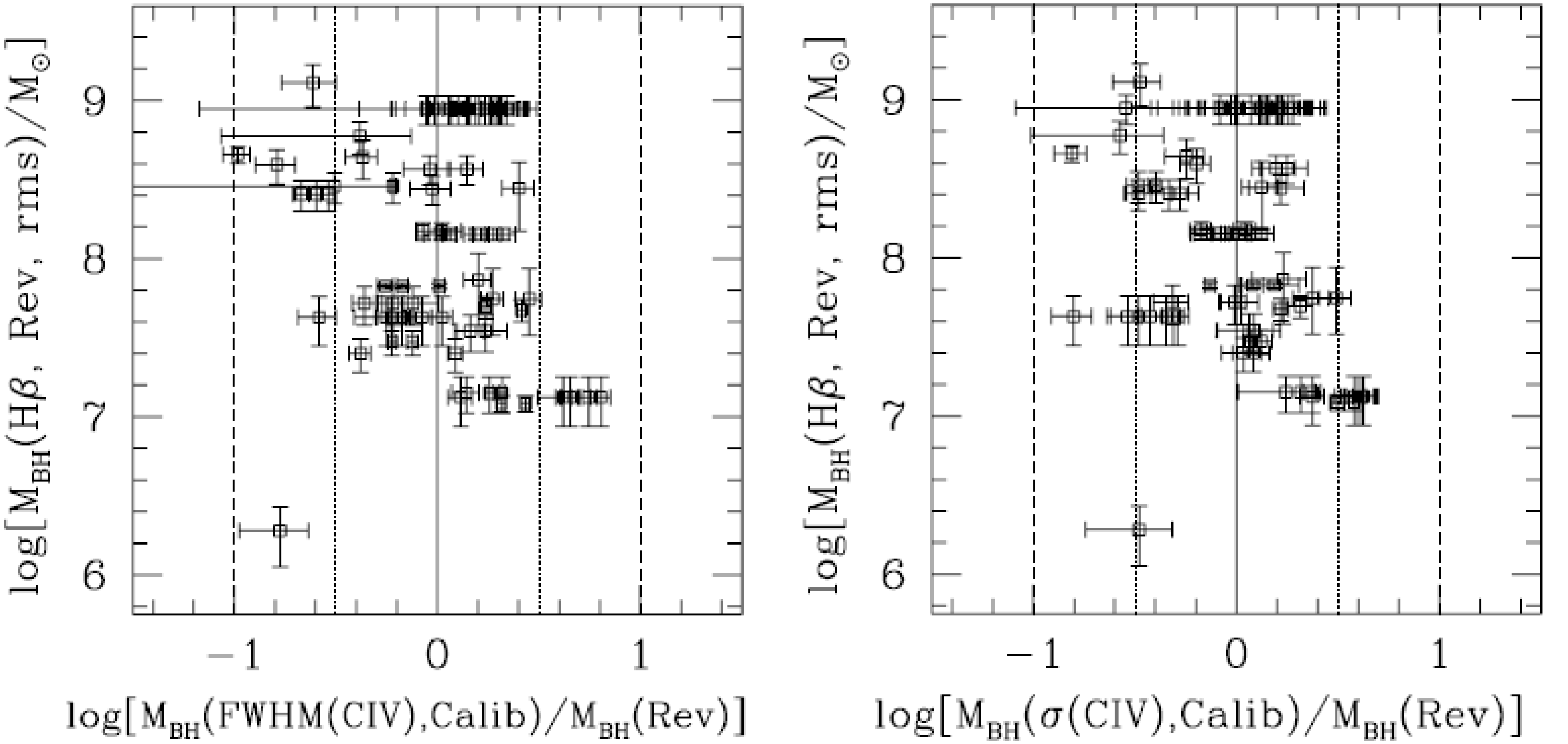
$$M_{BH} = \frac{fR\Delta V^2}{G} \qquad R = c\Delta\tau$$



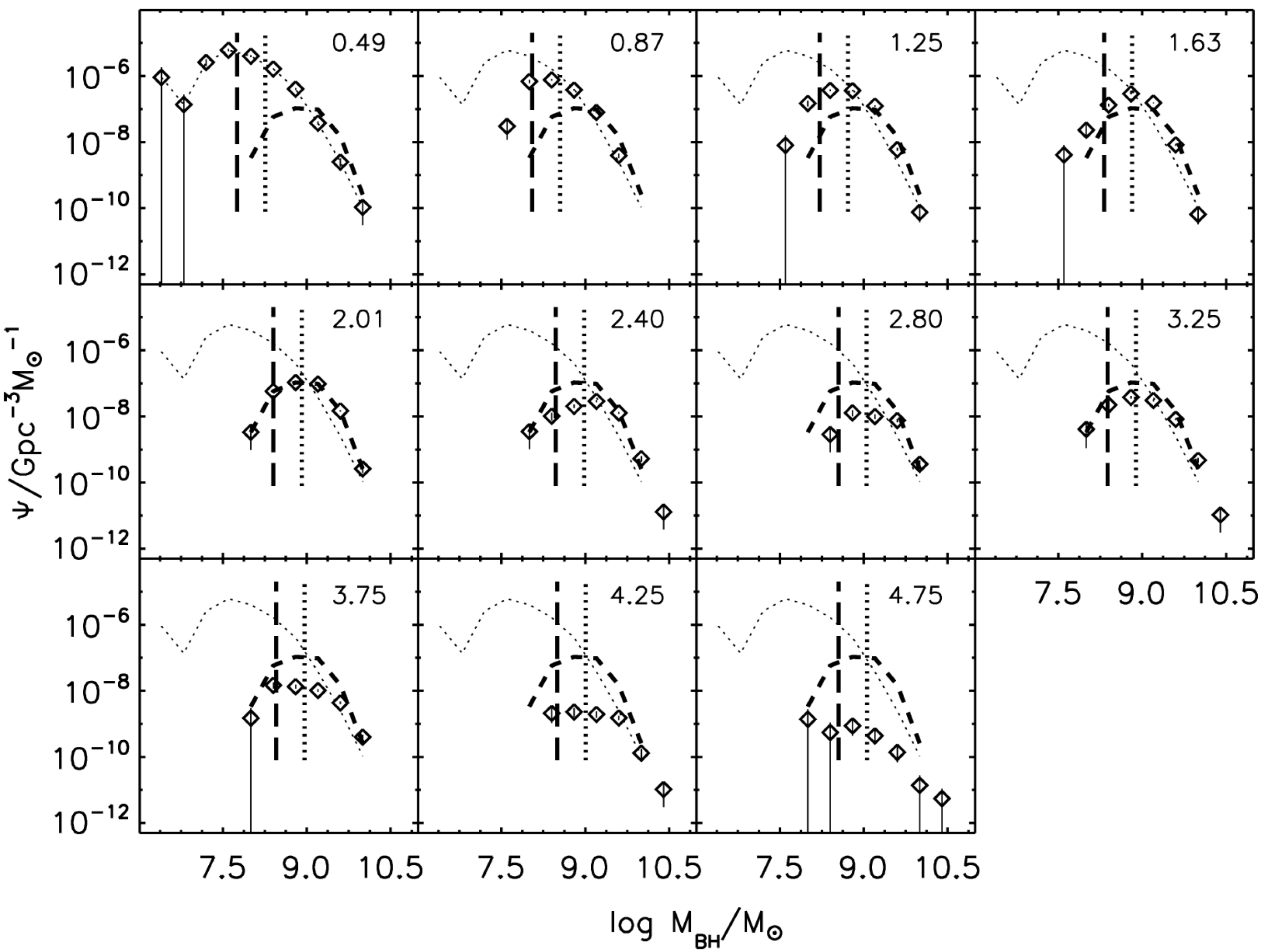
- BLR size R – continuum luminosity L relation

$$R \propto L^{\gamma}$$

→ single spectrum can determine the BH mass



Vertergaard & Peterson 2006



Vertergaard et al. 2008

How to Grow Black Holes

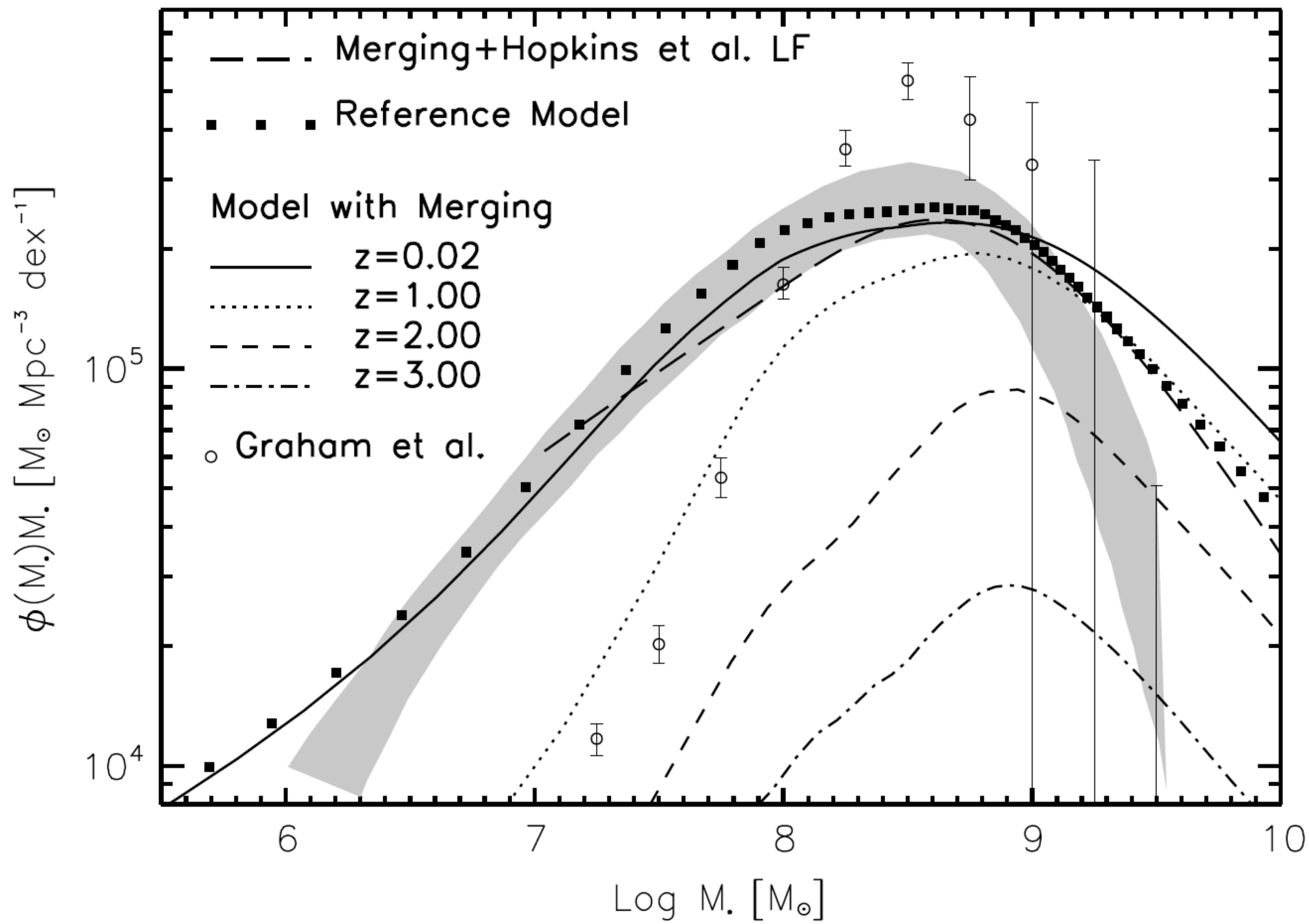
- Black Hole Growth
  - accretion
  - merger
- Accretion
  - luminosity

$$L = \varepsilon \dot{M} c^2$$

  - radiation efficiency

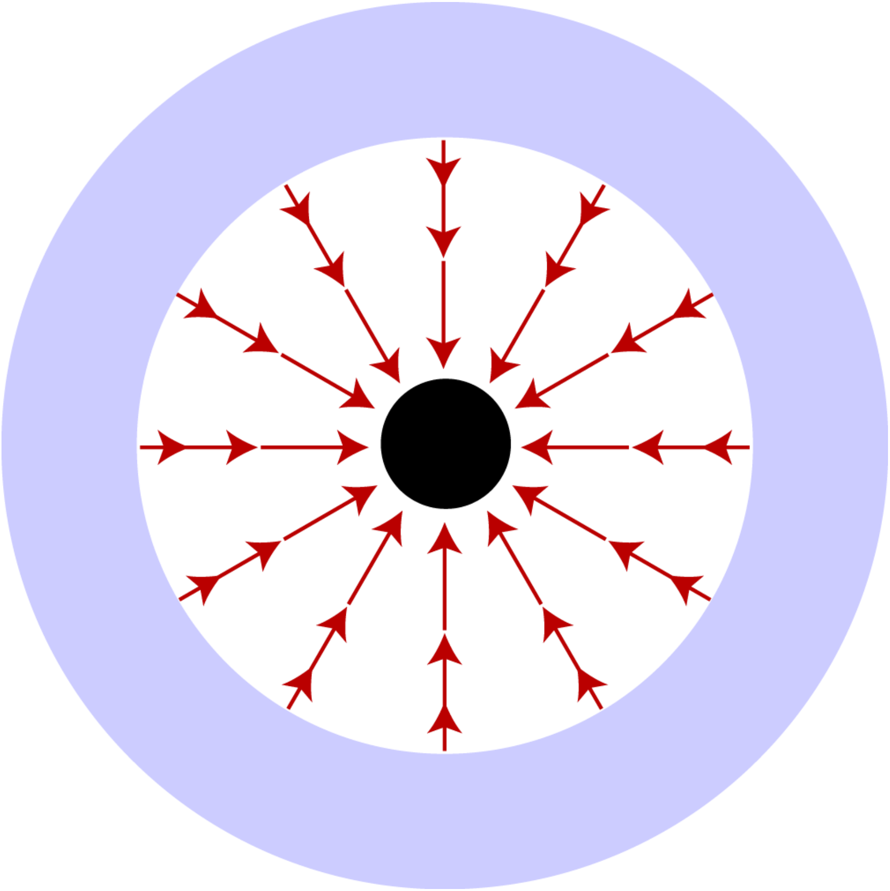
$$\varepsilon \equiv \frac{L}{\dot{M} c^2}$$

  - mass accretion rate



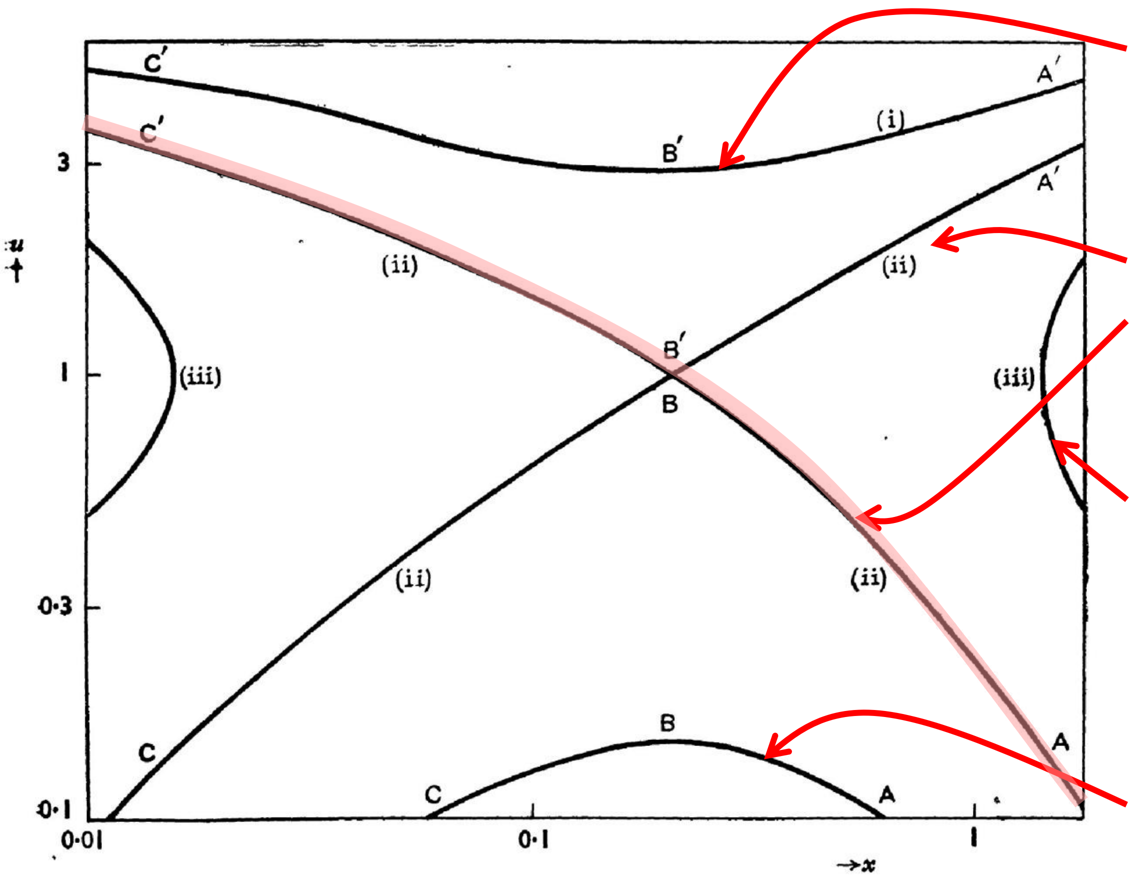
Shankar, Weinberg & Miralda-Escude 2009

Spherical accretion



- Bondi (1952)
- Newtonian
- Zero angular momentum
- Polytropic EOS
- Inviscid

Bondi solutions

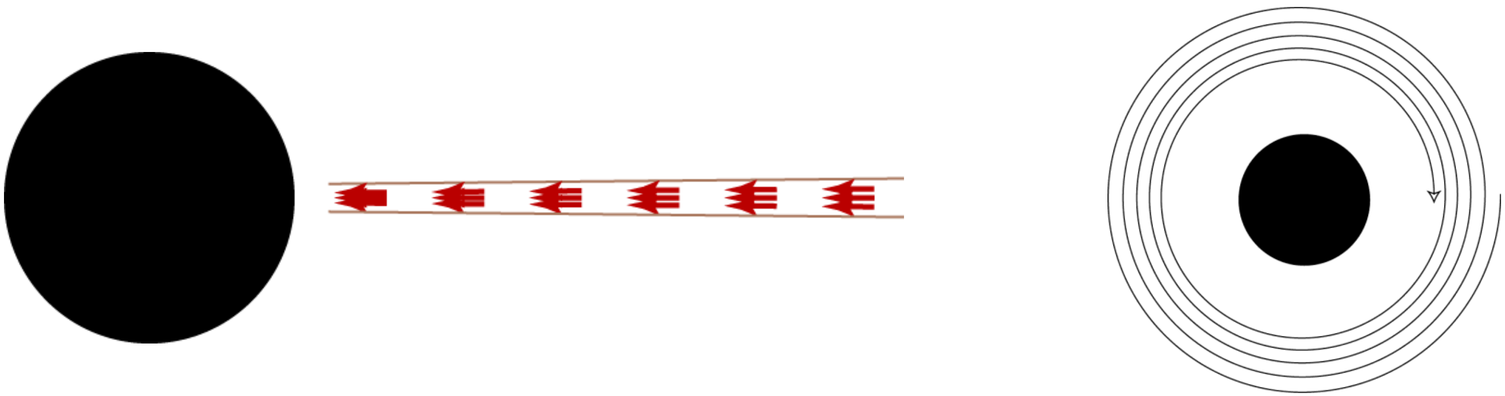


1. Supersonic
2. Transonic
3. Non-physical
4. Subsonic

Bondi flow

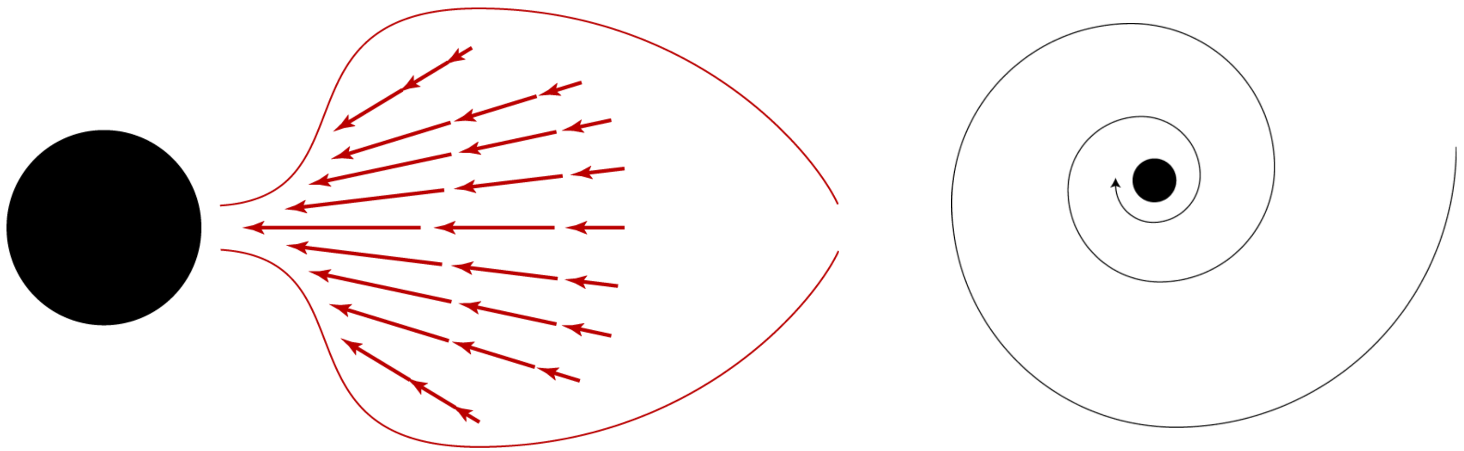
- Transonic flow
  - subsonic – sonic point – supersonic
  - nearly free-fall
  - Bondi radius: $r_{Bondi} \equiv \frac{GM}{c_{s,\infty}^2}$
- Mass accretion rate
  - depends only the density and temperature of gas at infinity
  - Bondi rate $$\dot{M}_{Bondi} = \lambda \gamma^{-3/2} 4\pi \ r_B^2 \rho_\infty c_{s,\infty} = \lambda 4\pi \frac{(GM)^2 \rho_\infty}{\gamma^{3/2} c_{s,\infty}^{3/2}}$$
    - 10 M_{sun} BH in 1 cm^{-3}, 10^2 K ISM accretes ~10^{-10} M_{sun}/yr
- Very low radiation efficiency
  - $\varepsilon \equiv L / \dot{M}c^2 < 10^{-6}$

Disk accretion: Thin disk



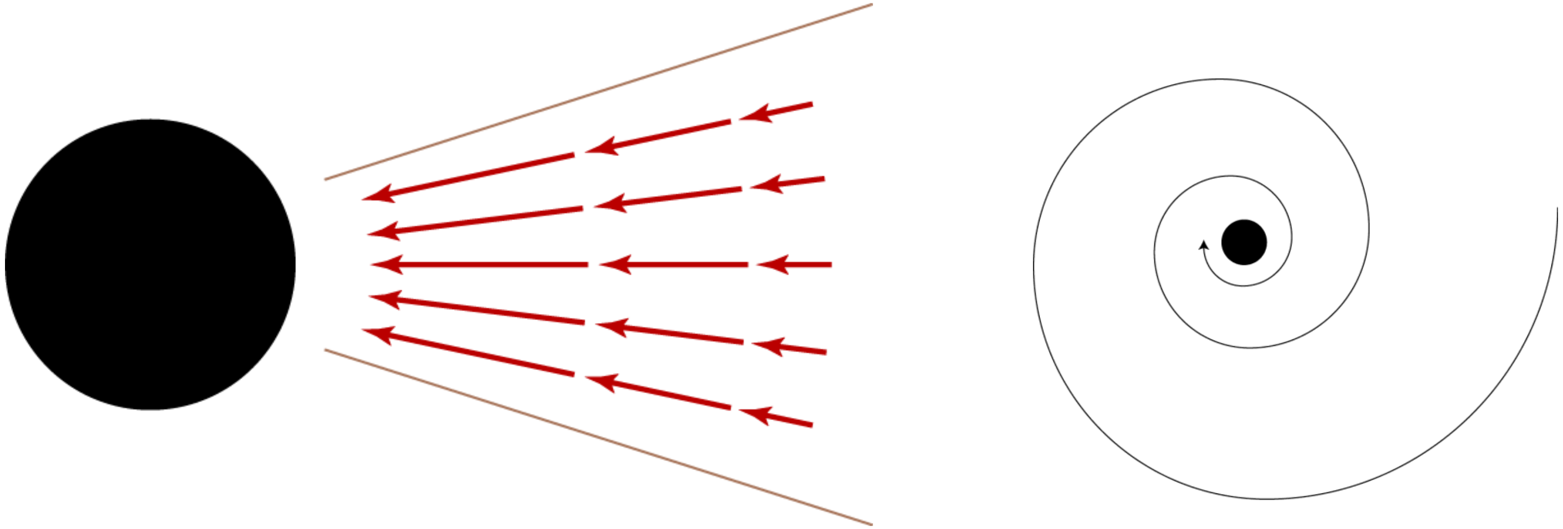
- Shakura & Sunyaev (1973)
  - nearly Keplerian rotation
  - very small radial motion, no sonic point
  - high radiation efficiency: $\varepsilon \sim 0.1$
  - low temperature
  - geometrically thin
  - viscous stress $\propto \alpha \cdot$pressure

Disk accretion: Thick disk



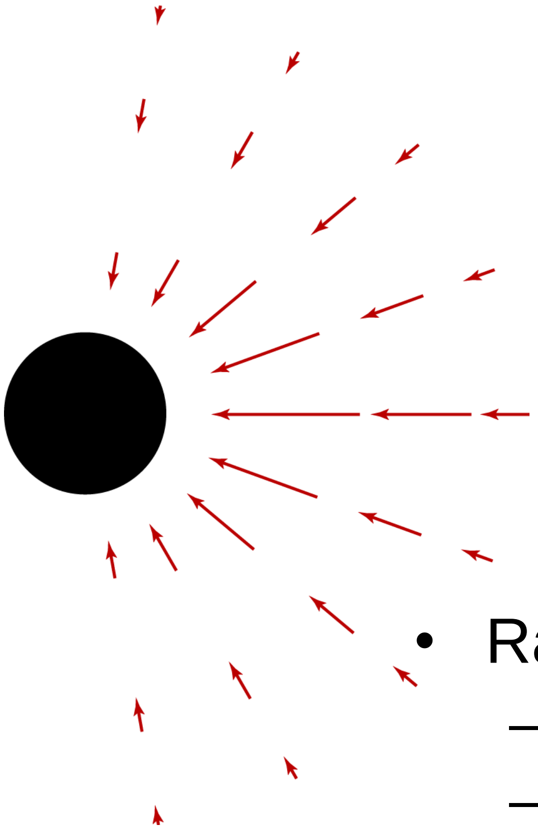
- Paczynski et al. (1980s)
  - sub-Keplerian rotation
  - significant radial motion
  - pressure is important
  - sonic point
  - vertical structure (2-dimensional)

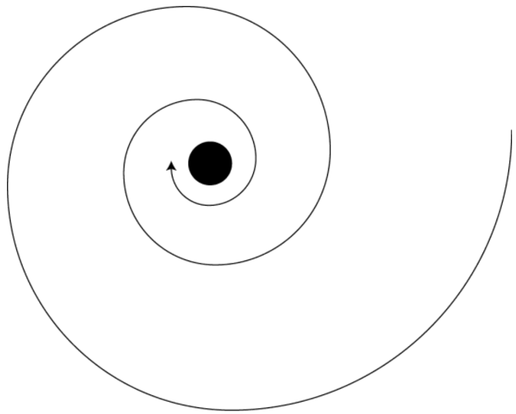
Disk accretion: Slim disk



- Abramowicz et al. (1988)
  - thick disk (2D) is vertically integrated/averaged and treated as thin disk (1D)
  - viscous stress $\propto \alpha \cdot$pressure
  - sonic point
  - angular momentum is an eigenvalue for given mass accretion rate

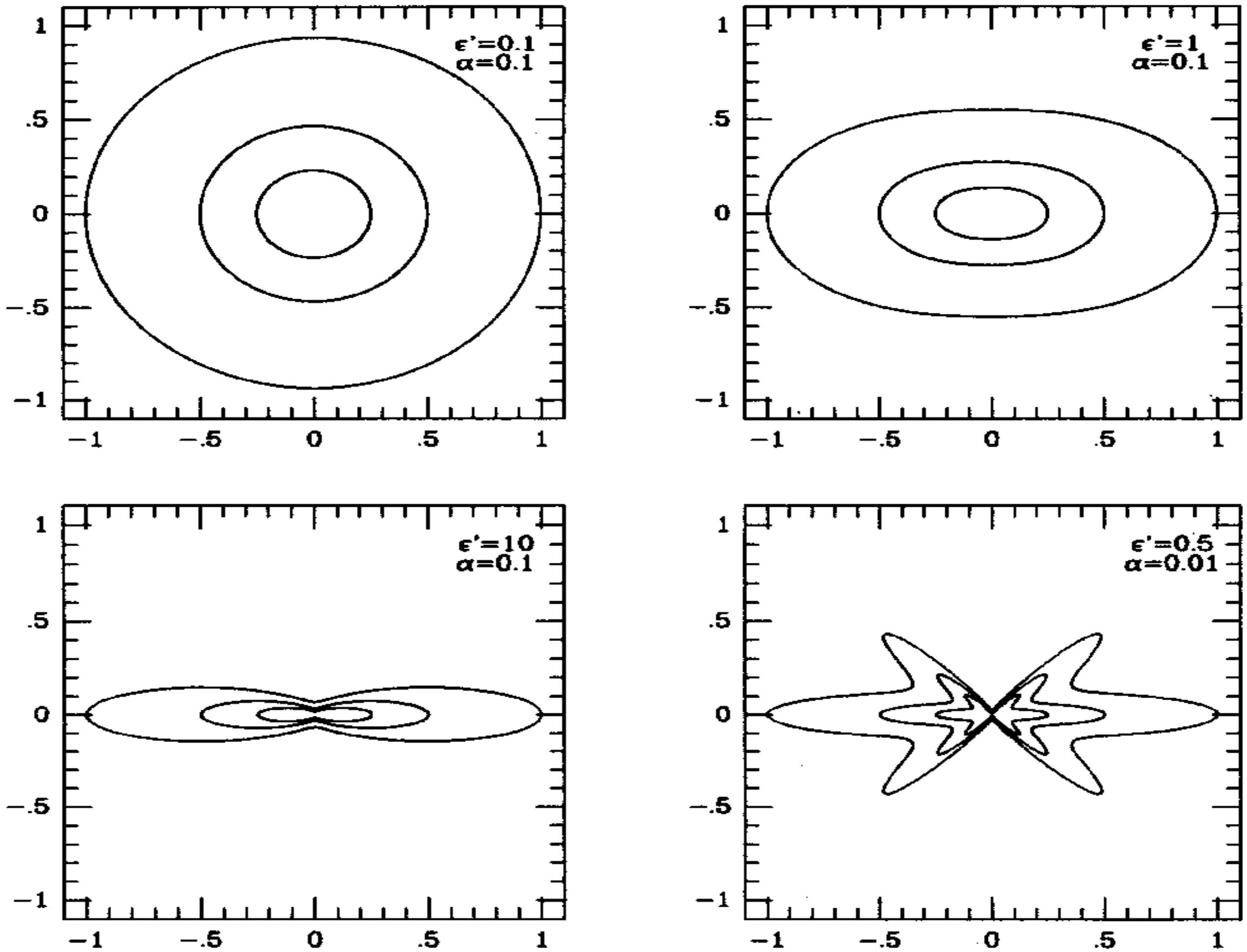
Disk accretion: RIAF

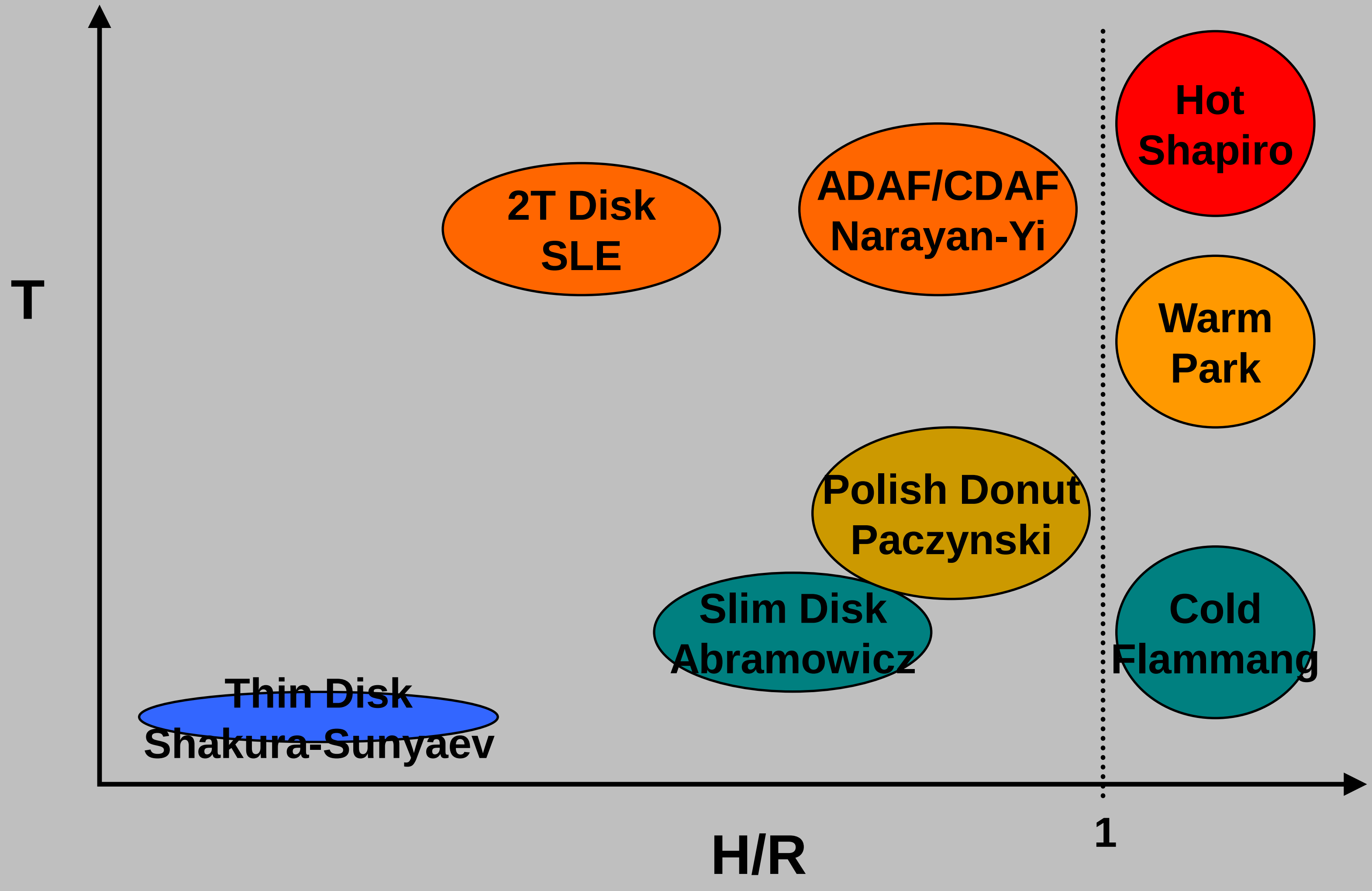




- Radiatively Inefficient Accretion Flow
  - ADAF (Narayan & Yi 1994), CDAF, ADIOS
  - low mass accretion rate
  - high temperature
  - low radiation efficiency
  - local or global

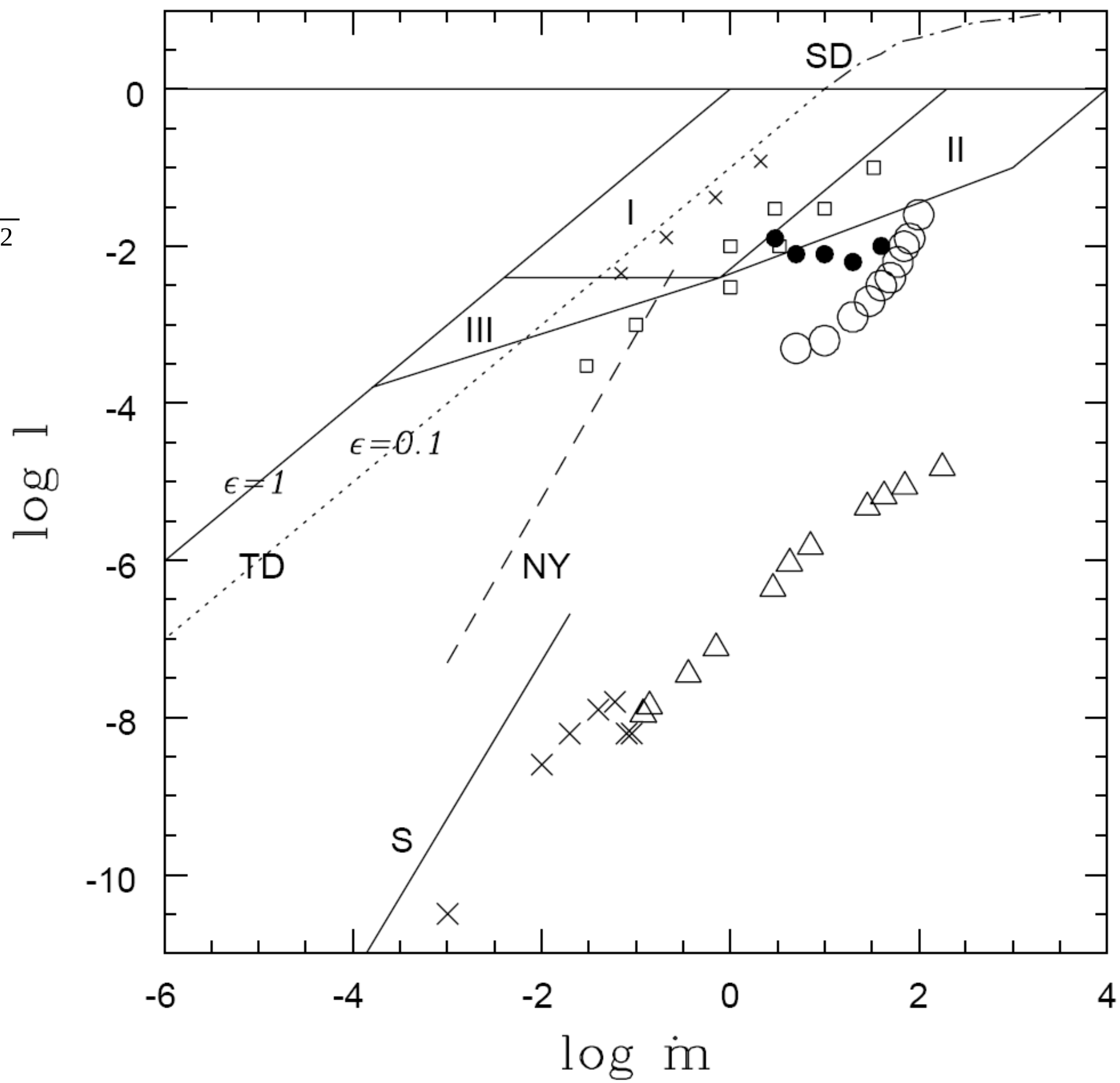
Isodensity Contour of ADAF




T
H/R
1
Hot
Shapiro
2T Disk
SLE
ADAF/CDAF
Narayan-Yi
Warm
Park
Polish Donut
Paczynski
Slim Disk
Abramowicz
Cold
Flammang
Thin Disk
Shakura-Sunyaev

$$l \equiv \frac{L}{L_{Edd}}$$

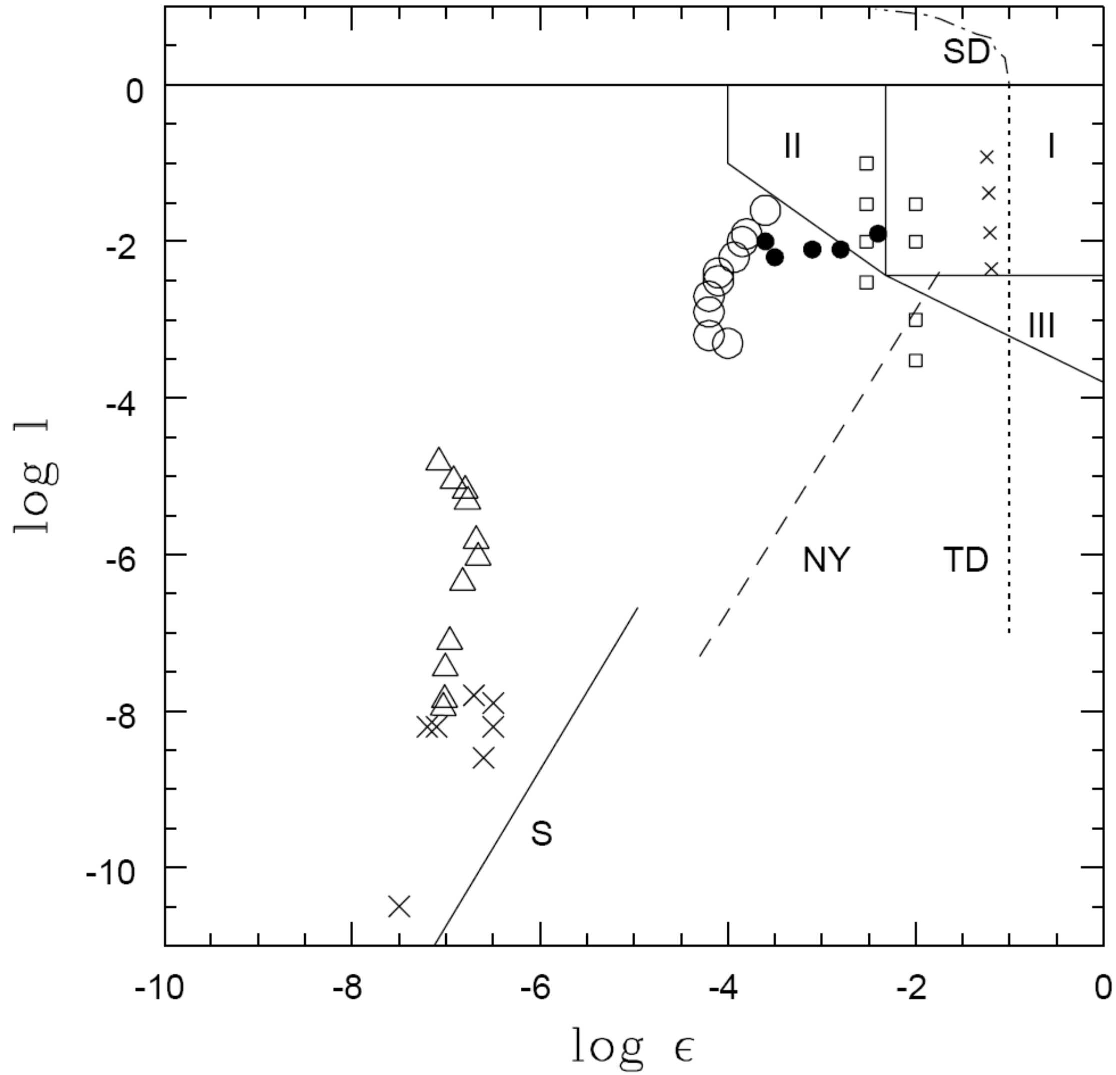
$$\dot{m} \equiv \frac{\dot{M}}{\dot{M}_{Edd}} \equiv \frac{\dot{M}}{L_{Edd}/c^2}$$



luminosity vs mass accretion rate

$$l \equiv \frac{L}{L_{Edd}}$$

$$\varepsilon \equiv \frac{L}{\dot{M}c^2}$$



luminosity vs radiation efficiency

Unquestioned Questions on Rotating Accretion Flow

- Boundary condition
  - $j_{out} = j_{Kepler}$?

- Mass accretion rate
  - $\dot{M}(M_{BH}, \rho_\infty, T_\infty, j_\infty)$?

Equations

- Basic assumptions
  - height-averaged: 2D $\rightarrow$ 1D
  - viscous stress $\propto \alpha \cdot$pressure
  - relativistic bremsstrahlung

Equations

- Mass conservation

$$\dot{M} = -4\pi r H \rho v_r$$

- Radial momentum

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

- Angular momentum

$$\rho v_r (\Omega r^2 - l_0) = \eta \alpha r P$$

- Energy equation

$$\rho v_r \left[\frac{d\epsilon}{dr} + P \frac{d}{dr}(\frac{1}{\rho}) \right] = q^+ - q^-$$

  - viscous dissipation

$$q^+_{vis} = -\zeta \alpha P r (d\Omega/dr).$$

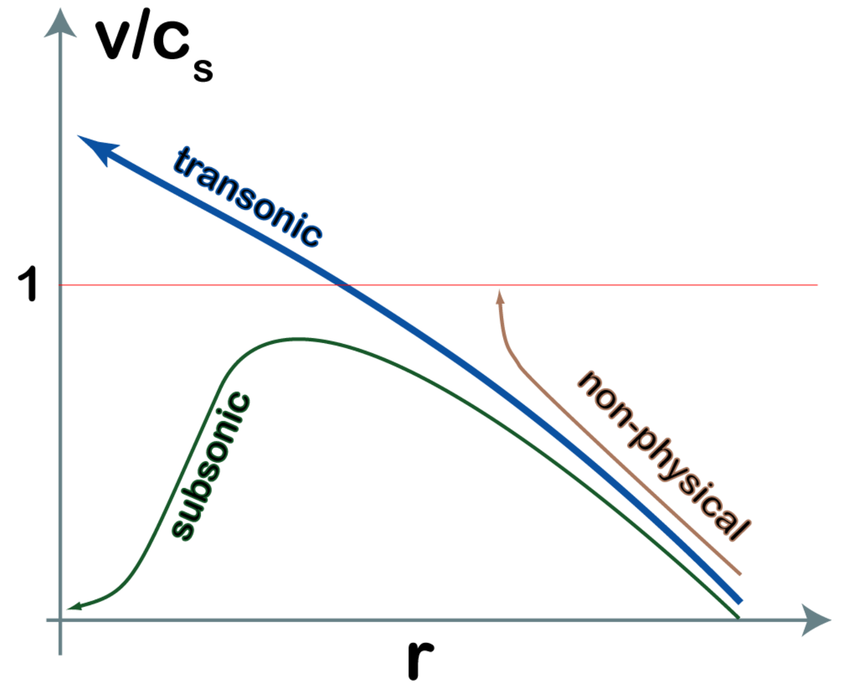
  - relativistic bremsstrahlung cooling

$$q^- = \alpha_f r_e^2 m_e c^3 n_p n_e (32/3)(2/\pi)^{1/2} \left[1 + 1.78 \left(\frac{kT}{m_e c^2} \right)^{1.34} \right]$$

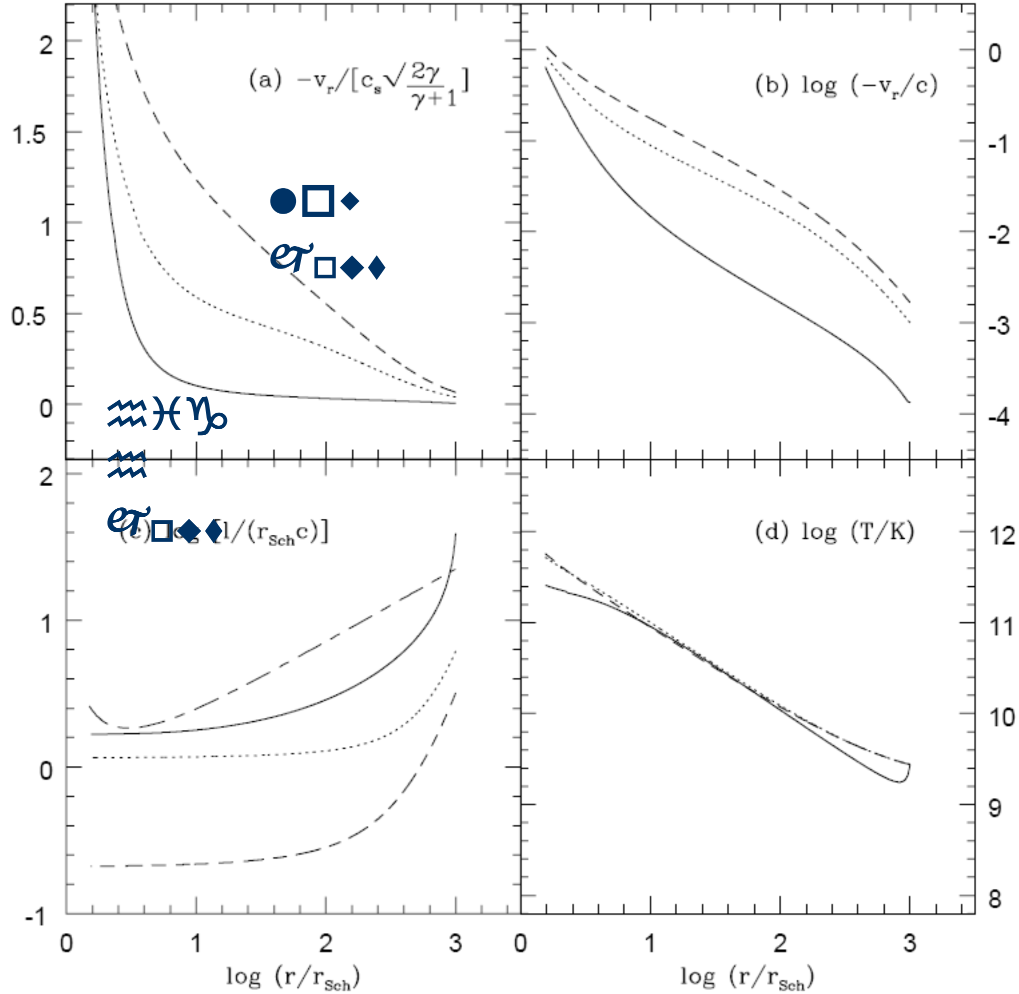
Method of Calculation

- Find transonic solutions for given $M, \alpha, \rho_{out}, T_{out}, j_{out}$
  - determine $\dot{M}$

- Shooting method

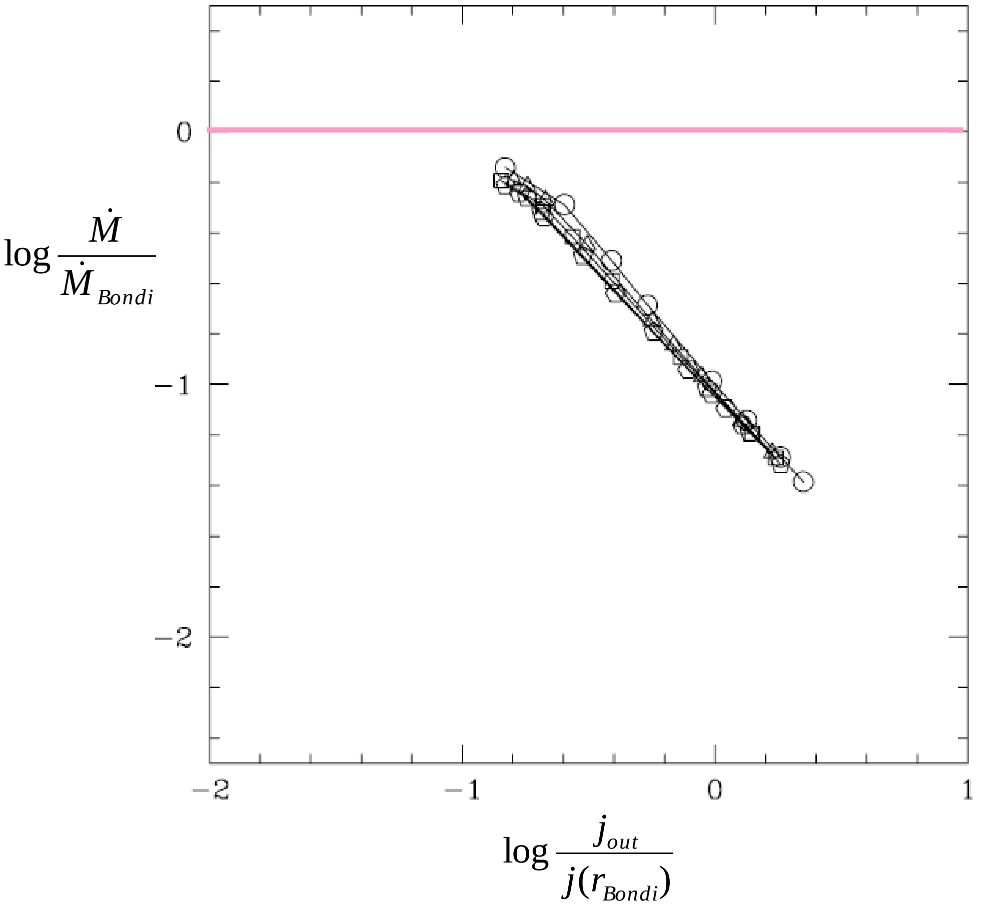


Flow Properties



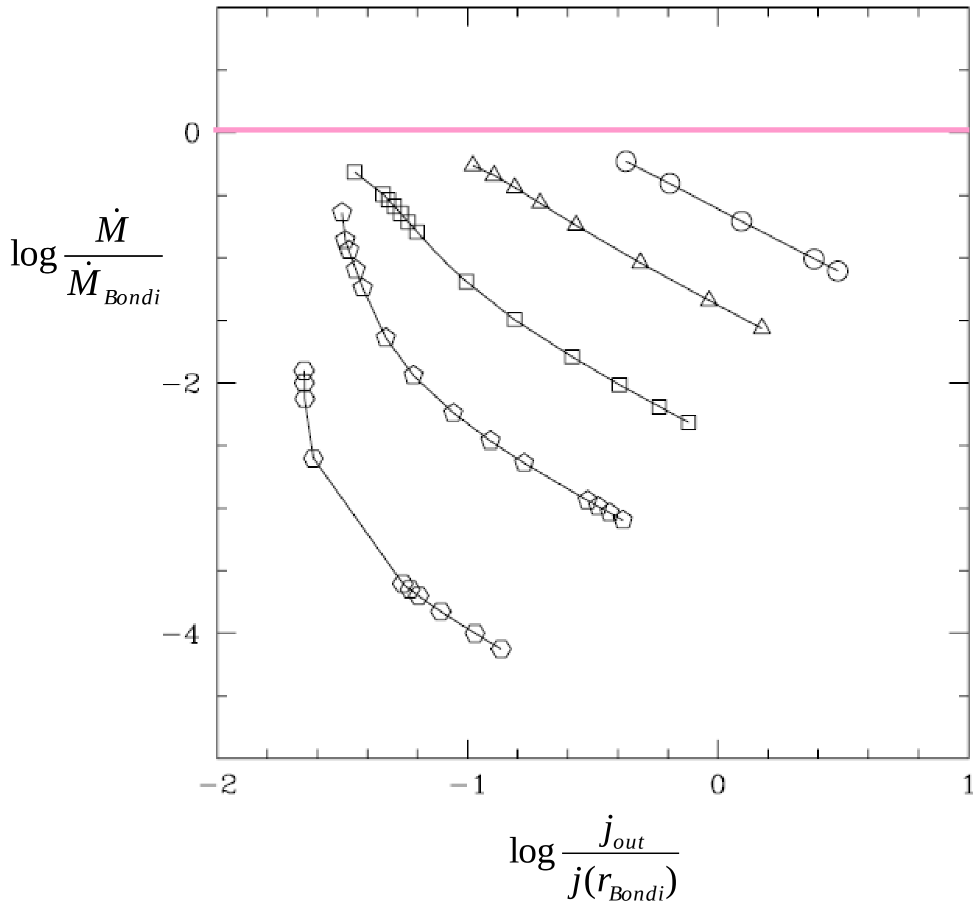
Mass Accretion Rate

- $T_{out} = T_{virial}$
  or $r_{out} = r_{Bondi}$



Mass Accretion Rate

- $T_{out} = T_{fixed}$
  or $r_{out} = r_{fixed}$



Conclusion & Discussion

- Spherical to Disk Accretion Flow
  - solutions within one framework only with different angular momentum
- Radiation Efficiency
  - efficiency can be anything in case of black hole accretion
- Mass accretion rate
  - mass accretion rate of rotating viscous accretion flow can be much smaller than the classic Bondi rate!