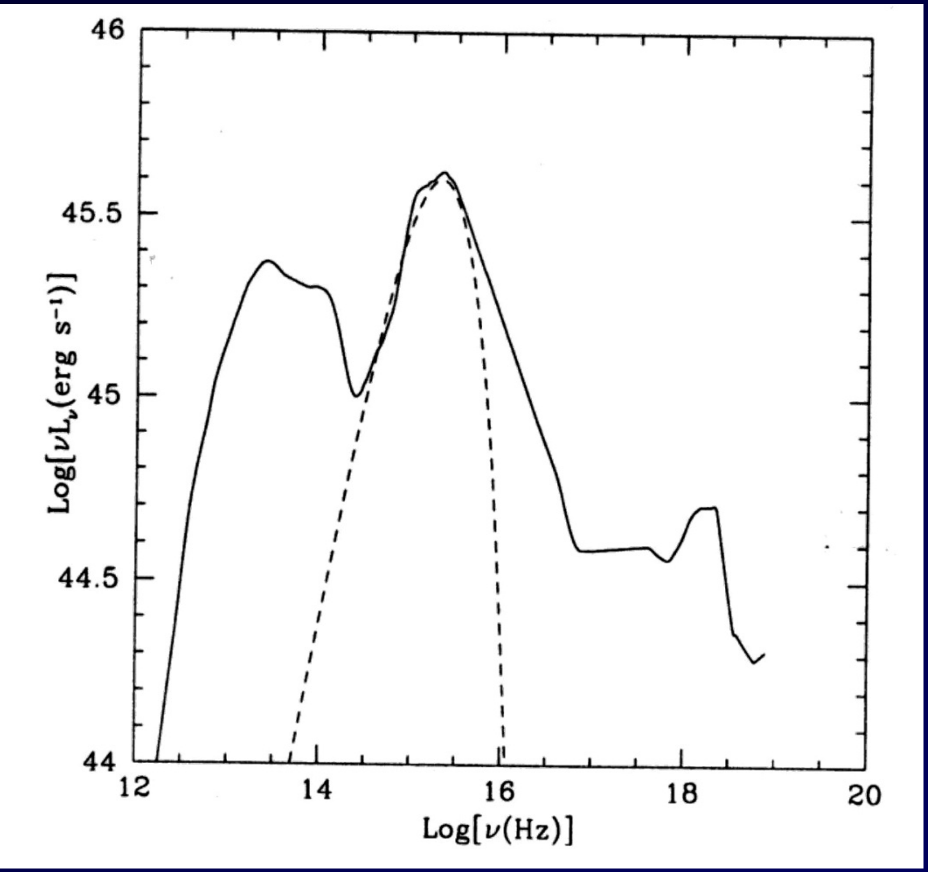
# ADVECTION-DOMINATED ACCRETION, WINDS AND JETS

Ramesh Narayan

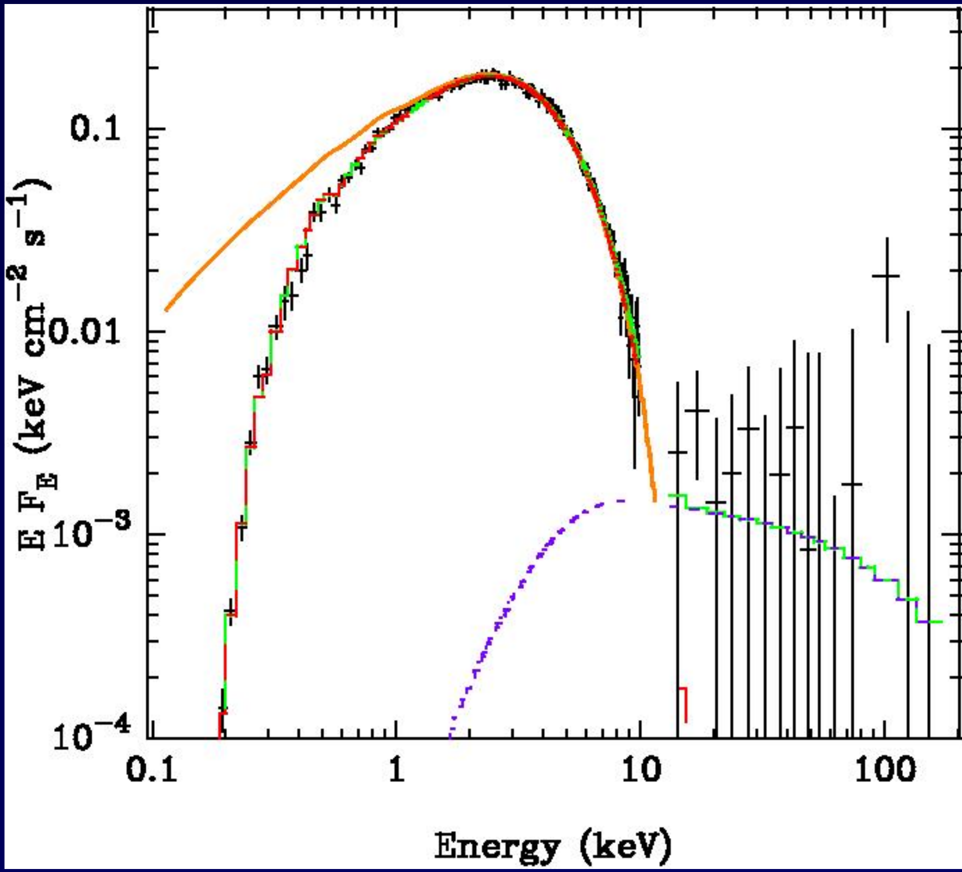
# Why Do We Need ADAFs?

- Black Hole (BH) accretion is not as simple as people had originally hoped
- Standard thin accretion disk model (Shakura & Sunyaev 1973; Novikov & Thorne 1973) is a great model for some sources
- But other sources – and even the same source at different times – are not consistent with the thin disk model
- If we want to go beyond empirical data-fitting, we need additional physical models

# Thin Disk Systems

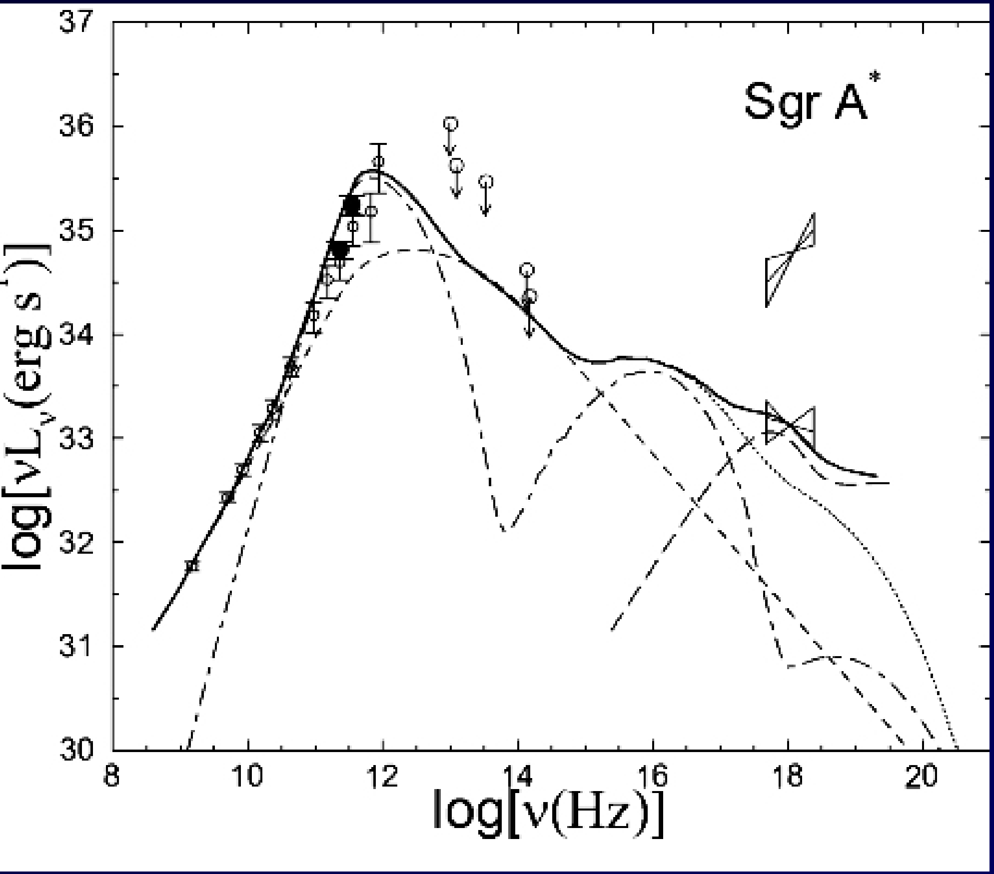


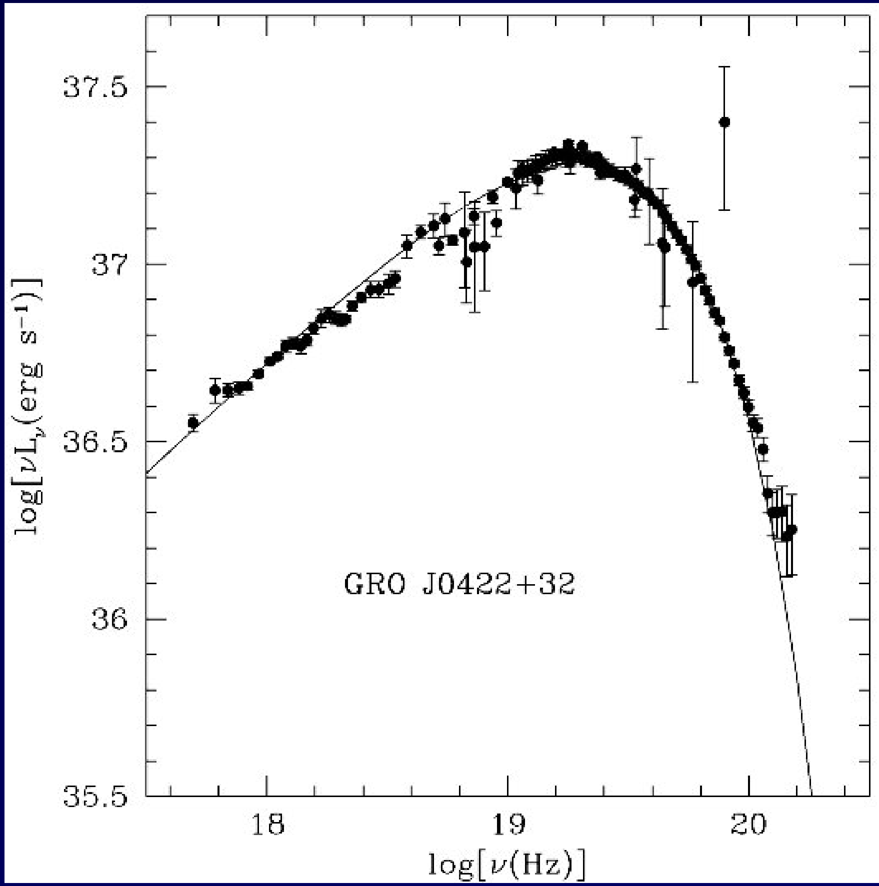

Composite quasar spectrum
(Elvis 1994)




LMC X-3 in the thermal state
(Davis, Done & Blaes 2006)

# No Thin Disks Here




Sagittarius A*
(Yuan et al. 2003)

GRO J0422+32 in outburst
(Esin et al. 1998)

# Energy Equation

$$q^{+} = q^{-} + q^{adv}$$

## Thin Accretion Disk

(Shakura & Sunyaev 1973; Novikov & Thorne 1973;...)

Most of the viscous heat energy is radiated

$$q^{+} \approx q^{-} >> q^{adv}$$

$$L_{rad} \approx 0.1 \dot{M} c^{2}$$

## Advection-Dominated Accretion Flow (ADAF)

(Narayan & Yi 1994, 1995ab; Abramowicz et al. 1995; Chen et al. 1995;...; Ichimaru 1977)

Most of the heat energy is advected with the gas

$$q^{+} \approx q^{adv} >> q^{-}$$

$$L_{rad} << 0.1 \dot{M} c^{2}$$

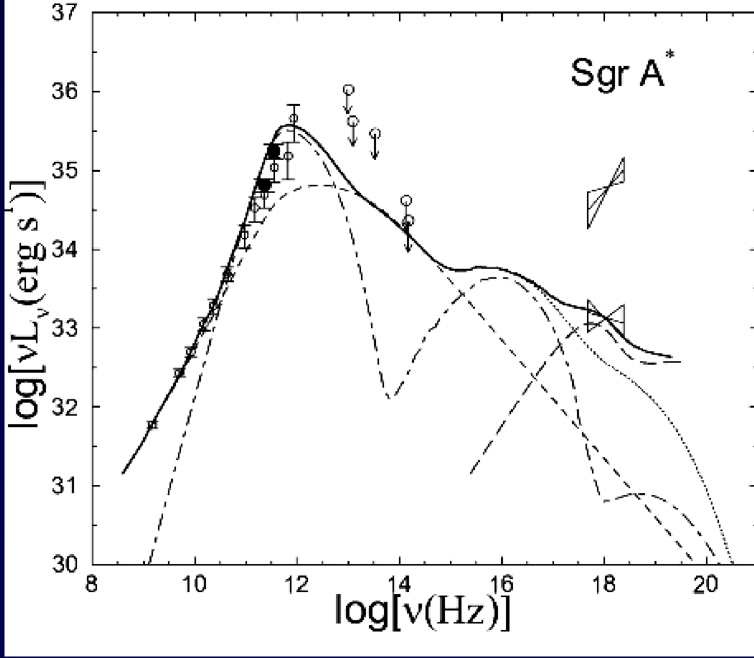
$$L_{adv} \approx 0.1 \dot{M} c^{2}$$

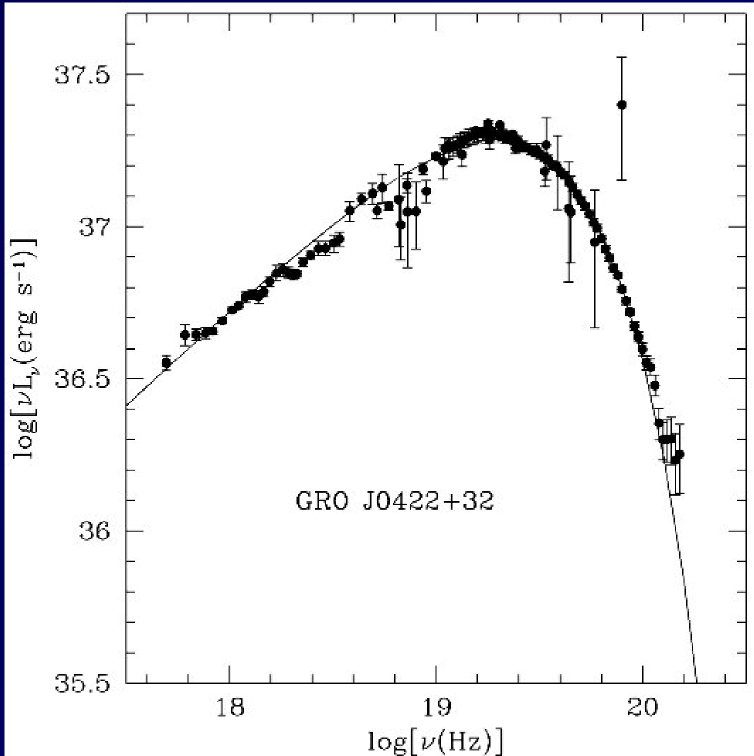
# *ADAFS Occur at Low Mdot*

- **Advection dominates** at low Mdot
  - Gas is very dilute and cannot radiate its thermal energy before it falls into the BH (NY 1994,1995; Abramowicz et al. 1995; Ichimaru 1977;...)
  - Radiatively Inefficient Accretion Flow: “RIAF”
  - Typical luminosities: $\mathbf{L \lesssim (0.01\text{-}0.1) L_{Edd}}$

# Properties of ADAFs: 1

- Very hot: $T_i \sim 10^{12}$K/r, $T_e \sim 10^{9\text{-}11}$K (virial, since ADAF loses very little heat)
  - Large pressure: $c_s \sim v_K$
  - Geometrically thick: **H / R ~ 1**
- Optically thin (because of low density)
- Expect thermal synchrotron (Sgr A* $T_B > 10^{10}$ K) and/or Comptonized emission (J0422 kT $\gtrsim$100 keV)
- **The ADAF is a Stable Solution**



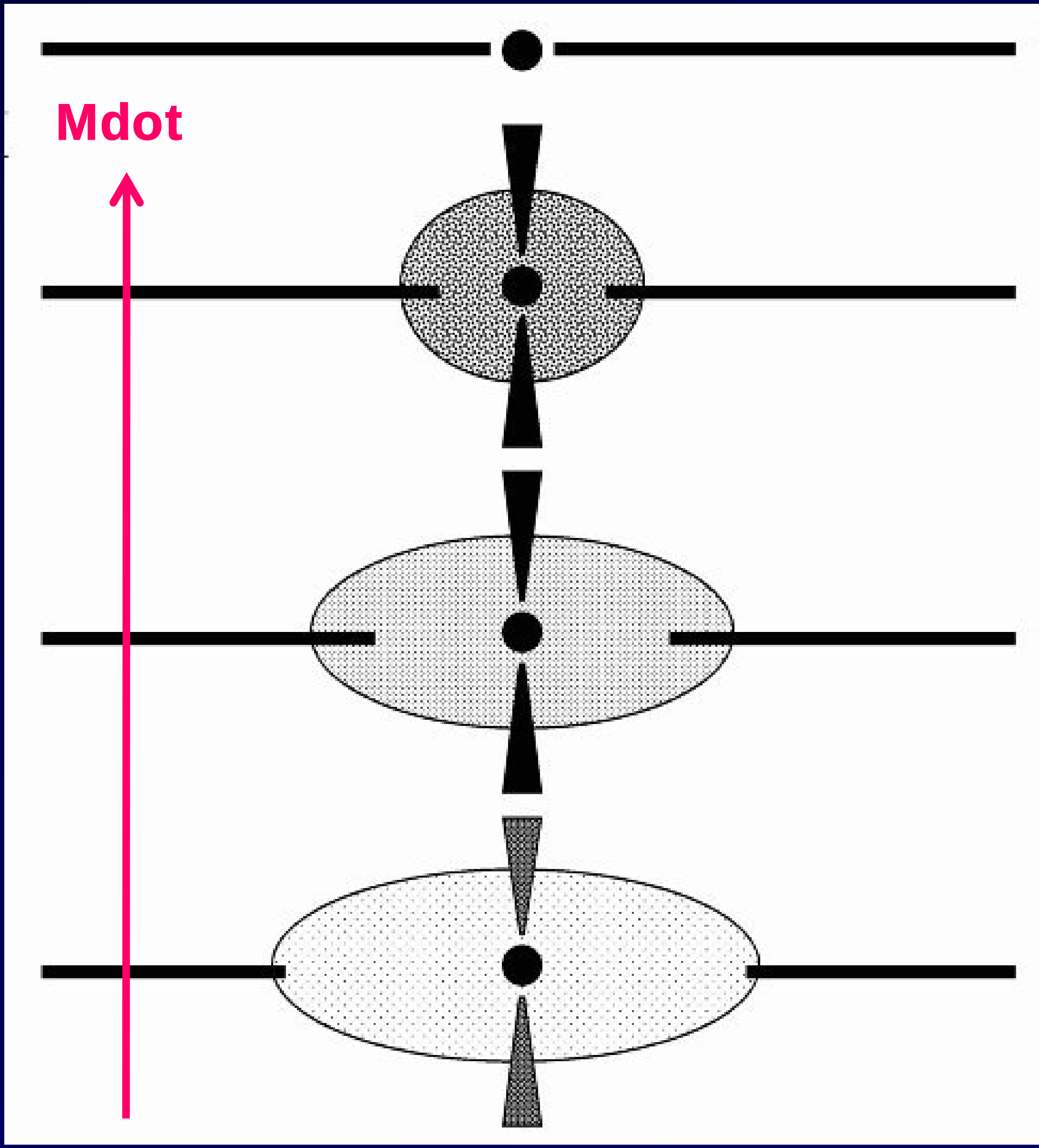



# Accretion Geometry vs Mdot

Mdot is the primary parameter that determines Thin Disk to ADAF boundary

Hysteresis effects...

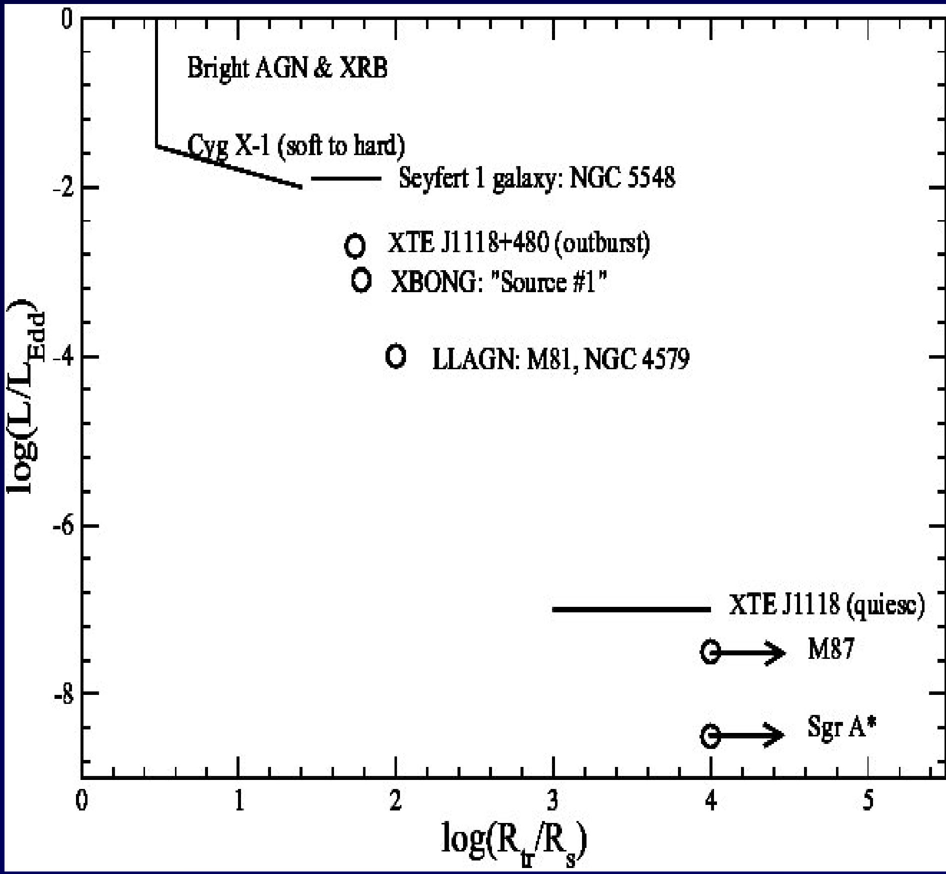
BH spin probably has some effect – perhaps minor?




Esin et al. 1997, Narayan &McClintock 2008

# Properties of ADAFs: 2

- Thin disk to ADAF/RIAF boundary occurs at $\dot{M}_{crit} \sim 0.01$—$0.1\ \dot{M}_{Edd}$ (for reasonable $\alpha \sim 0.1$)
- Location of the boundary is nicely consistent with $L_{acc}$ at which:
  - AGN switch from quasar mode to LINER mode (Lasota et al. 1996; Quataert et al. 1999; Yuan & Narayan 2004)
  - BH XRBs switch from the high soft state to the low hard state (Esin et al. 1997)



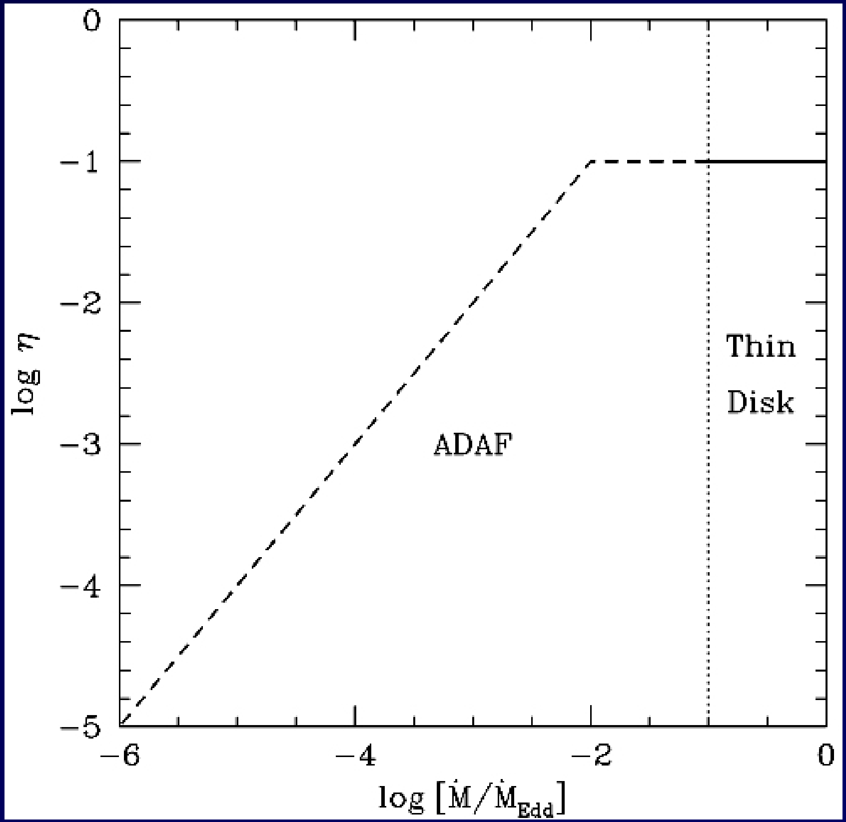

Yuan & Narayan (2004)

# Properties of ADAFs: 3

- By definition, an ADAF has low radiative efficiency
- Roughly, we expect a scaling (Narayan & Yi 1995)

$$\eta_{ADAF} \approx 0.1\left(\frac{\dot{M}}{\dot{M}_{crit}}\right); \quad L_{ADAF} \propto \left(\frac{\dot{M}}{\dot{M}_{crit}}\right)^2$$

- Extreme inefficiency of Sgr A* and other quiescent SMBHs is explained (N, Yi & Mahadevan 1995; Fabian & Rees 1995; Di Matteo et al. 1997, 2000, ...)




Narayan & Yi (1995)

Esin et al. (1997)

# ADAFs Are Everywhere

- Thin disk systems are bright (high Mdot, high efficiency) and tend to dominate observational programs
- ADAFs are much fainter, and harder to observe, but they occupy a very large range of parameter space
- Probably >90% of SMBHs in the universe are in the ADAF phase!

(Narayan & McClintock: New Astronomy Reviews, 51, 733, 2008; astro-ph/0803.0322)

# Where should we Look for ADAFs around SMBHs?

- Sgr A* (Narayan et al. 1995)
- LINERs (Lasota et al. 1996)
- FRI sources (Reynolds et al. 1996)
- LLAGN (Quataert et al. 1999)
- BL Lacs (Maraschi & Tavecchio 2003)
- Some Seyferts (Chiang & Blaes 2003)
- XBONGs (Yuan & Narayan 2004)

# Properties of ADAFs: 4
# Winds and Jets

**Narayan & Yi (1994, Abstract):**

> ... the Bernoulli parameter is positive, implying that advection-dominated flows are susceptible to producing outflows ... We suggest that advection-dominated accretion may provide an explanation for ... the widespread occurrence of outflows and jets in accreting systems

**Narayan & Yi (1995, Title):** "Advection-Dominated Accretion: Self-Similarity and Bipolar Outflows"

Strong outflows confirmed in numerical simulations

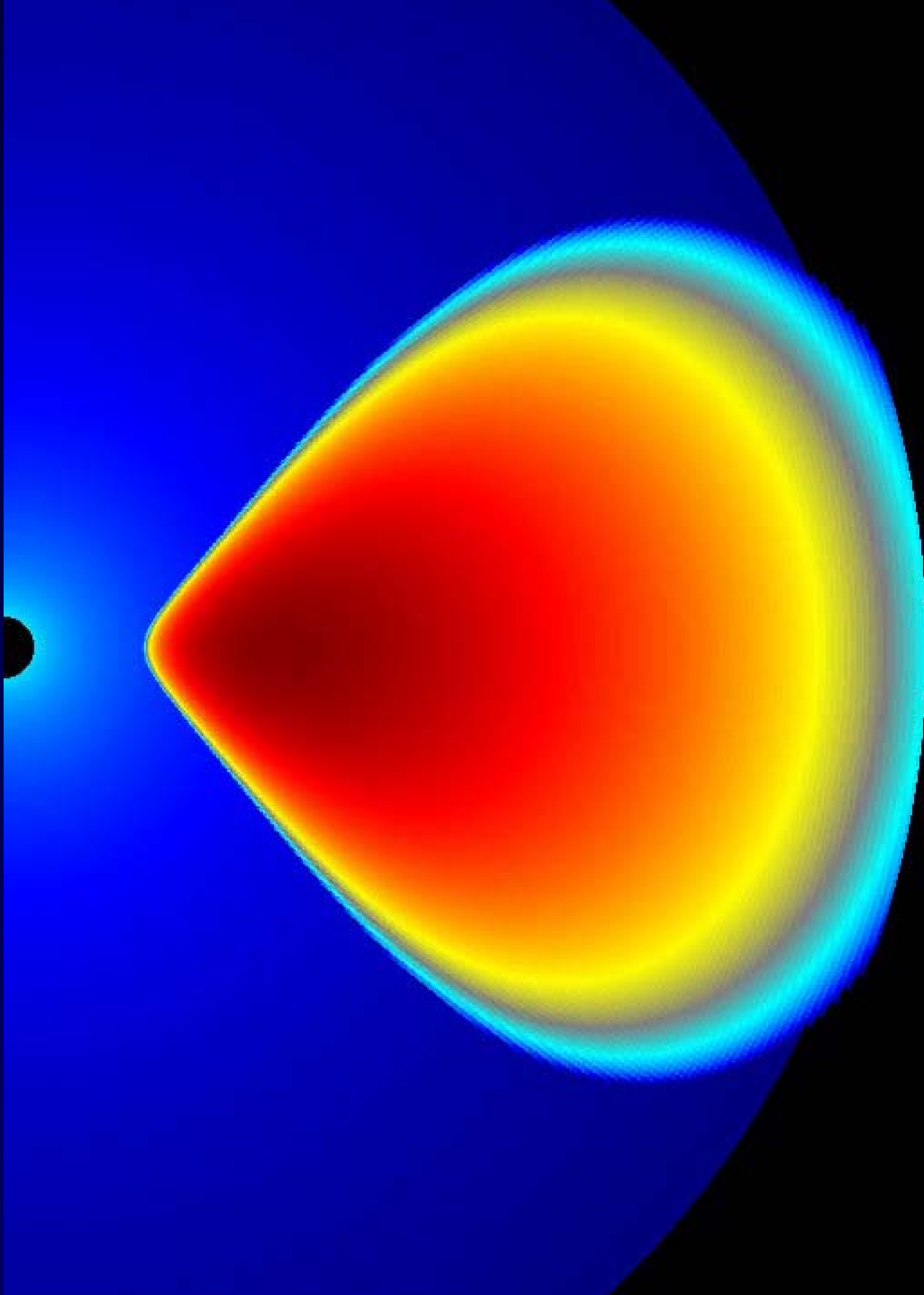
ADAFs ➔ WINDS, JETS

# GRMHD Simulation of a Magnetized ADAF

The simulation spontaneously sets up

1. a geometrically thick flow
2. with a strong wind and a
3. magnetized relativistic jet

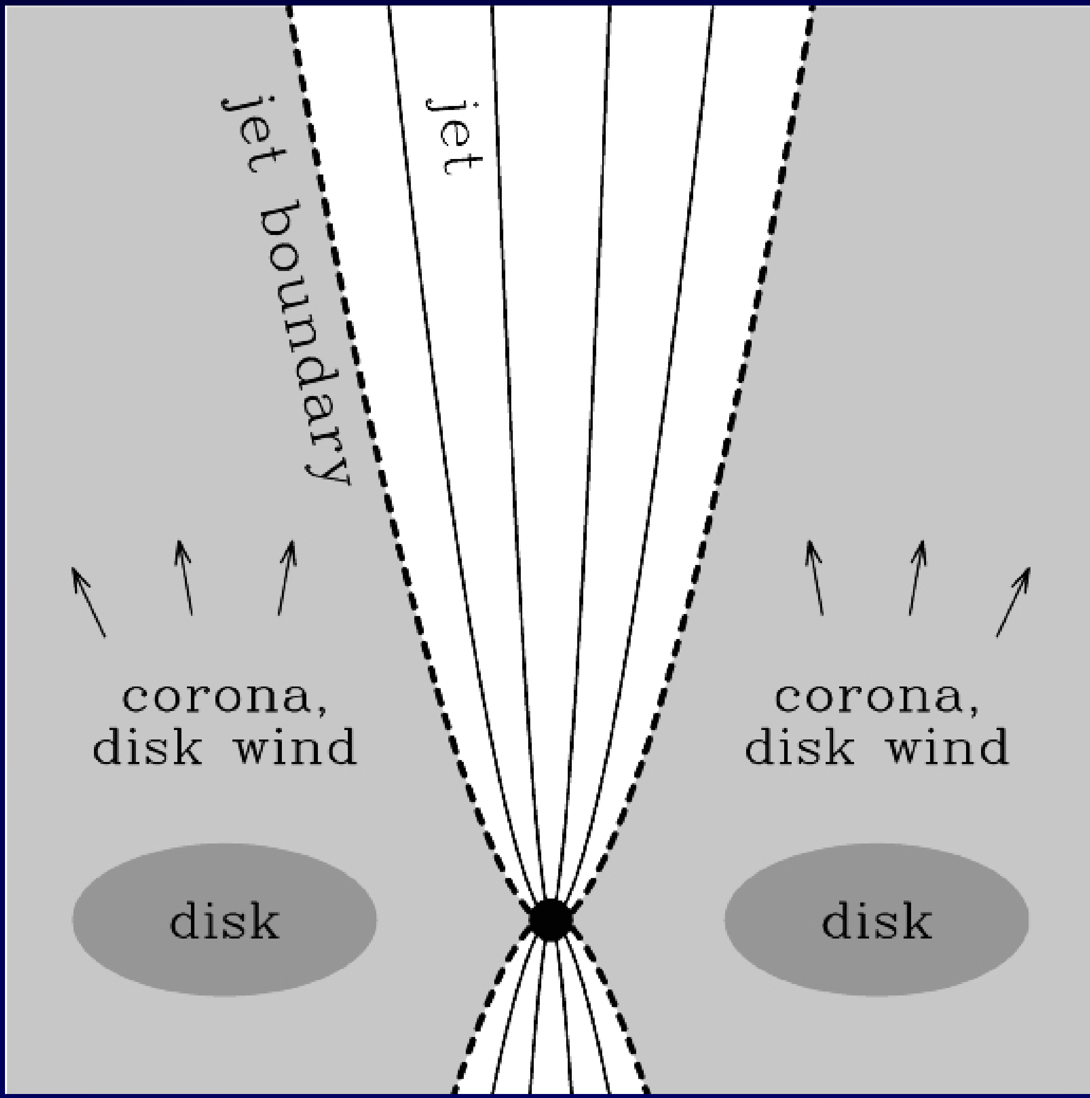
McKinney & Gammie (2004)



# Jet Physics

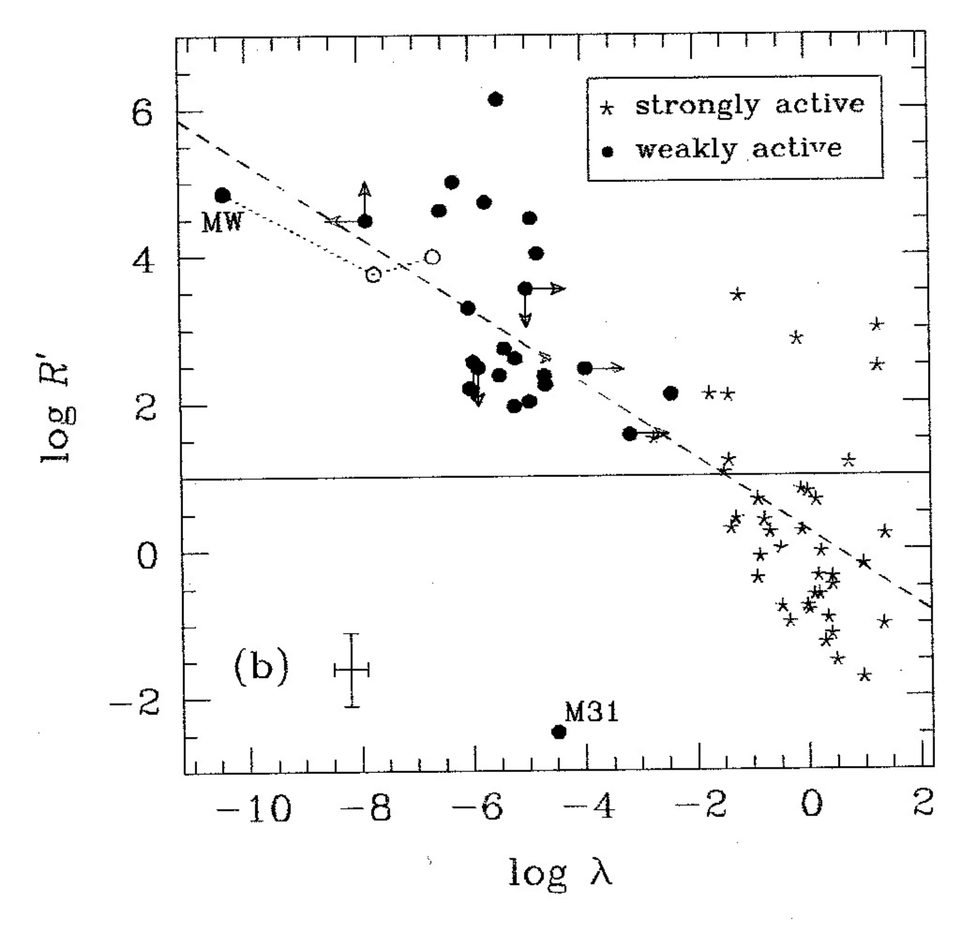
- Powerful jets require
  - Spinning BH
  - Magnetic field
  - Confining medium, e.g., disk wind
- ➔ ADAF

Poster 57 (Tchekhovskoy)



# ADAFs/Jets in LLAGN

- Enhanced Radio emission/Jet activity seen in low-luminosity AGN (LLAGN) →
  - $\lambda = L/L_{Edd}$
  - R' = 6 cm /B band
- Radio-quiet AGN probably have no ADAFs, only thin disks




Ho (2002)

# ADAFs and Feedback

- Radiative feedback from AGN during bright quasar phase is doubtless important
- Mechanical feedback through winds (and jets) is important during ADAF phase
- Causes reduced accretion – important for understanding AGN evolution
- Strongly affects galaxy formation
- "Radio mode" is related to ADAF physics

# Summary

- ADAFs are found all over the place
- Every LLAGN has an ADAF
- >90% of BHs in the universe have ADAFs !
- Strong connection between ADAFs, Winds and Jets
- Critical for AGN feedback, galaxy formation