The transition zone from the thin accretion disk to the advection-dominated accretion flow: constraints from the thermal X-ray line emission

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outline

- Introduction

  (background and motivation)

- Observations

  (NGC 4579 and M81)

- Model calculations

  (on continuum and thermal X-ray line emissions)

- Results and discussion

•Introduction

Different accretion modes:

Slim disk: geometrically thick, optically thick

$$H/R \sim 1, \quad \dot{m} > 0.2$$

Standard thin disk (SD): geometrically thin , optically thick

$$H/R << 1 \quad \dot{m}_{\rm crit} < \dot{m} < 0.2, \quad \dot{m}_{\rm crit} \sim 0.01.$$

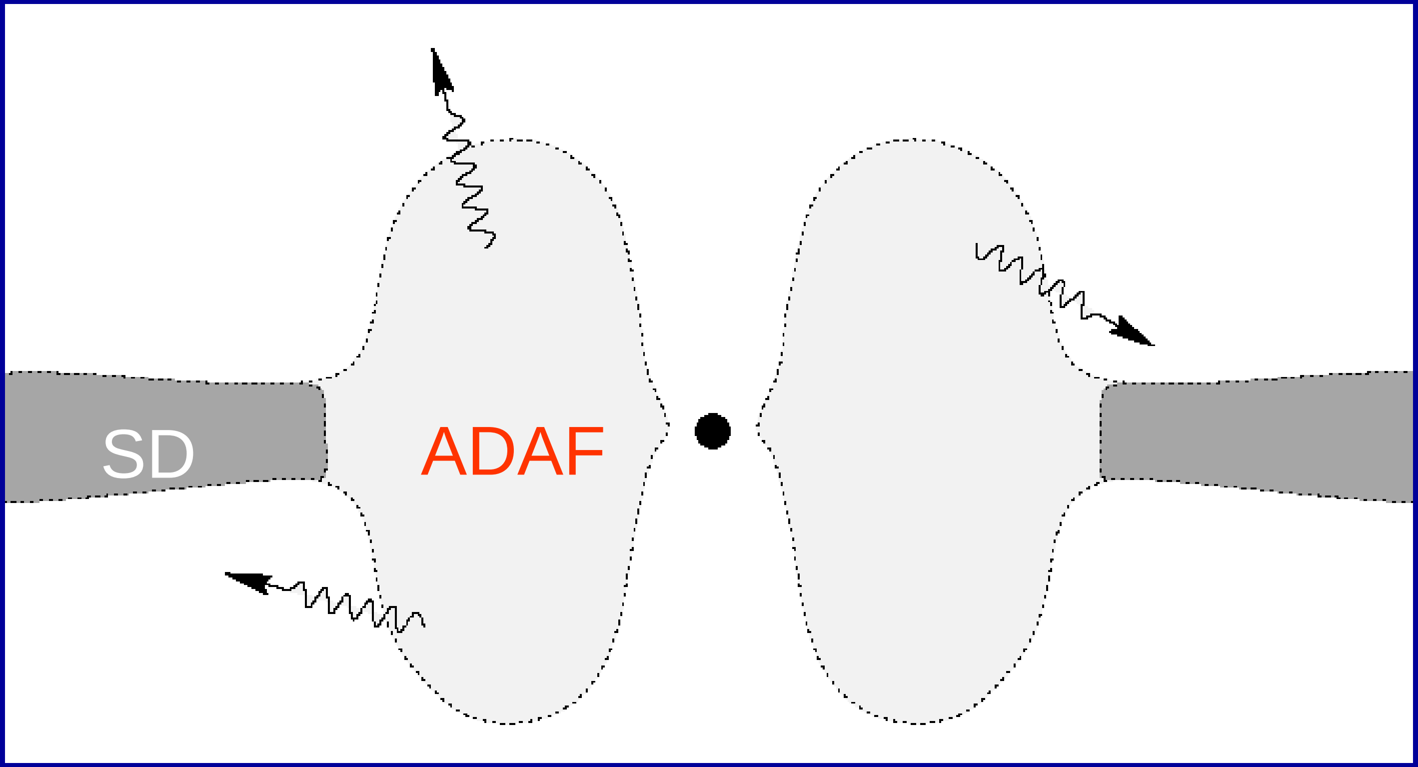
Advection dominated accretion flow (ADAF):
hot, geometrically thick , optically thin

$$H/R \sim 1 \quad \dot{m} < \dot{m}_{\rm crit}, \quad \dot{m}_{\rm crit} \sim 0.01$$

Accretion mode transition occurs while

$$\dot{m} \sim \dot{m}_{\rm crit}, \quad \dot{m}_{\rm crit} \sim 0.01$$

ADAF+SD geometry

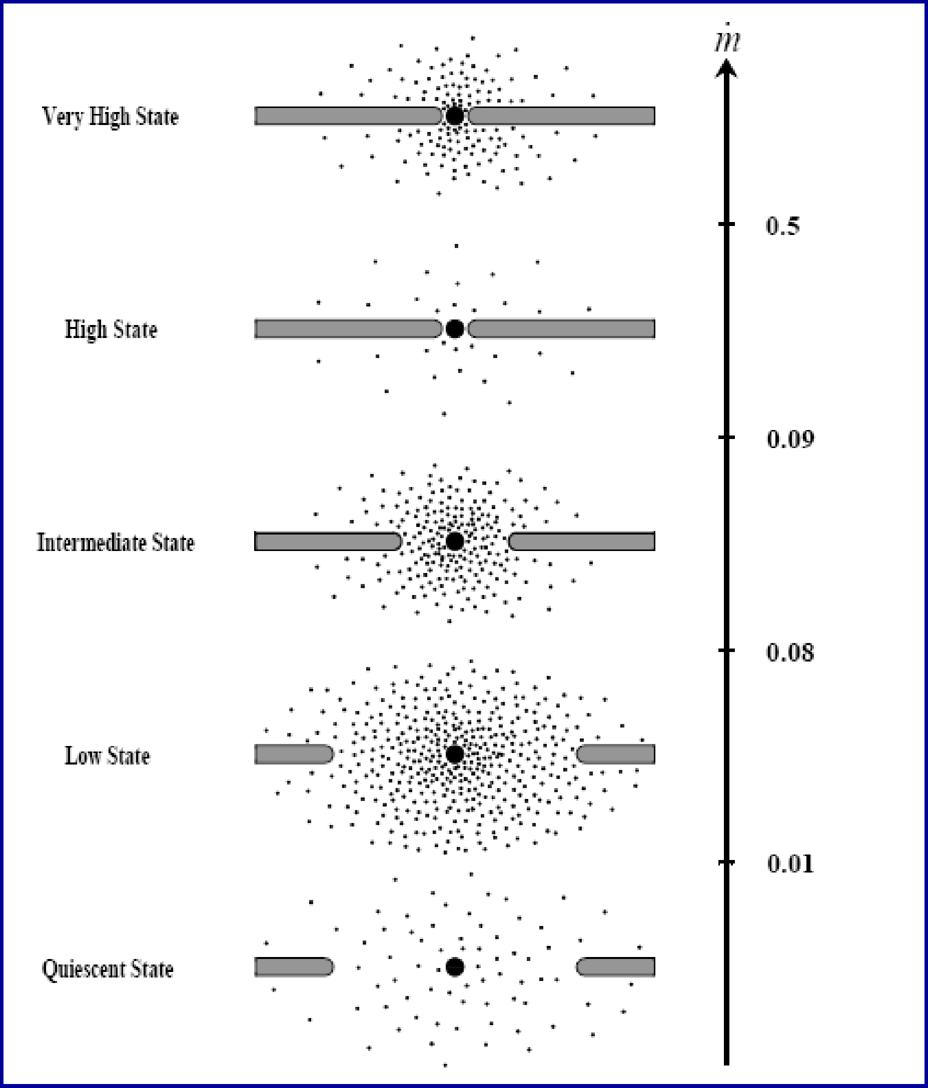


the inner hot ADAF near the black hole connects to a standard thin disk at a transition radius

Applications of ADAF+SD model

- Many different spectral states observed in black hole X-ray binaries can be understood as a sequence of ADAF+SD models with varying mdot and r_{tr}.

- The ADAF+SD models are also required for modeling on a variety of observations of AGNs accreting at the moderate rates.



Esin et al. 1997 , ApJ, 489, 865

Models of transition from SD to ADAF

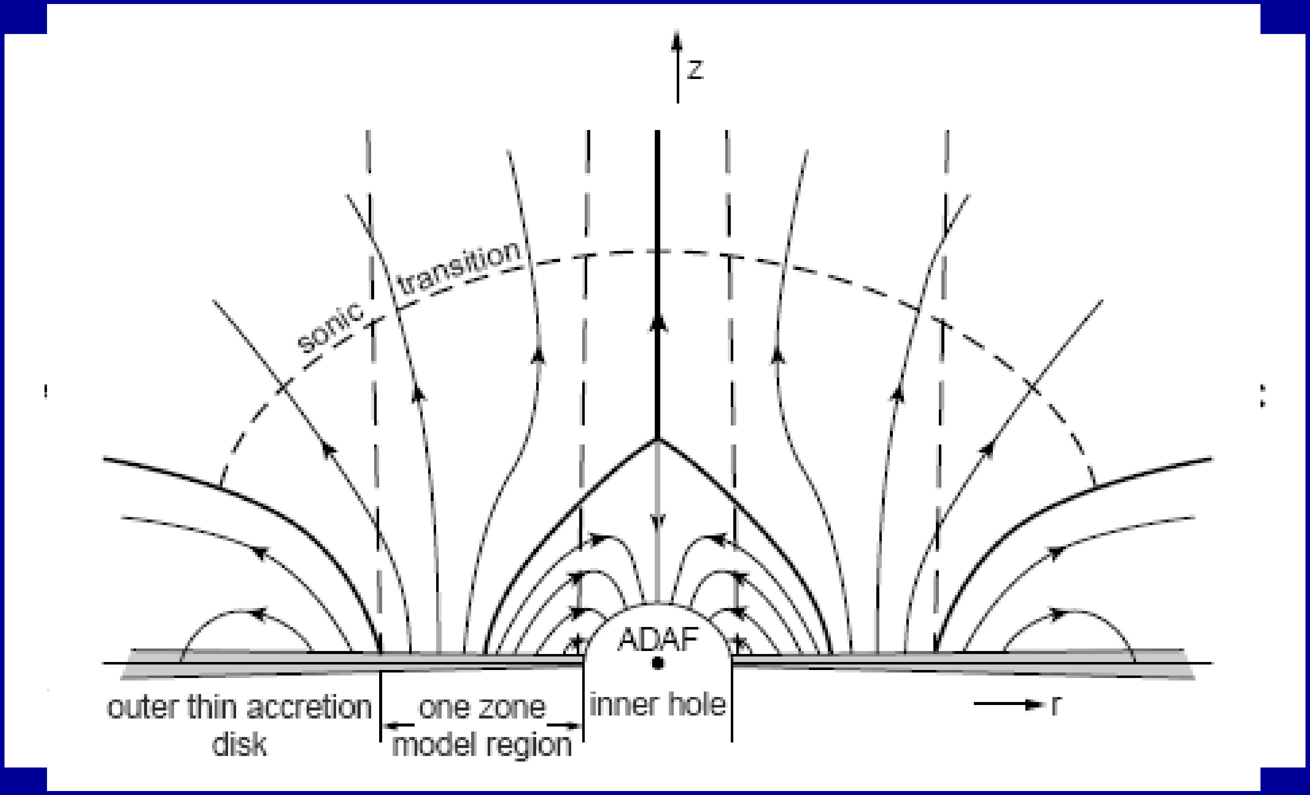
The physical mechanisms of the transition and its structure are still quite uncertain, though a few different scenarios were suggested.

- ✓ evaporation model
  (Meyer & Meyer-Hofmeister 1994, A&A, 288, 175;
  Liu, B. F. et al. 1999, ApJ, 527, L17; 2000, A&A, 361, 175)

- ✓ turbulence viscosity model
  (Honma 1996, PASJ, 48, 77;
  Manmoto, et al. 2000, ApJ 529, 127;
  2000, ApJ 538, 295)

Evaporation model

The disk is evaporated as heated by electron conduction from a hot corona, and then a quasi-spherical hot accretion flow/ADAF is formed.

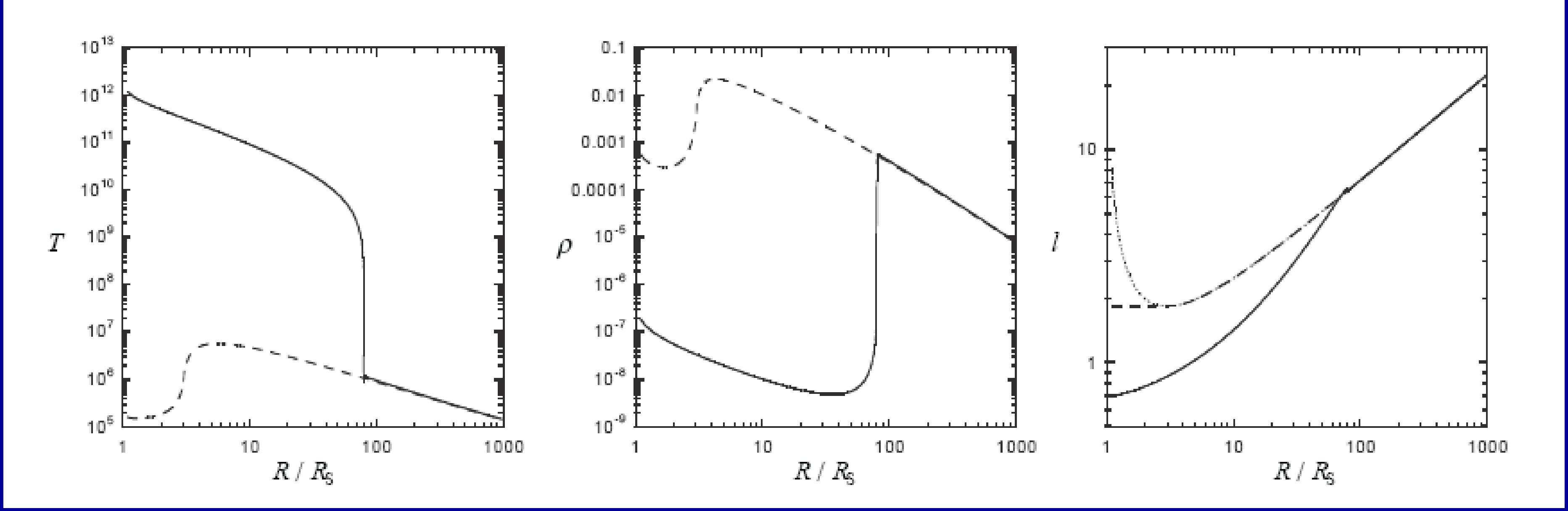


Meyer, Liu, & Meyer-Hofmeister 2000, A&A, 361, 175
Meyer & Meyer-Hofmeister 1994, A&A, 288, 175

Turbulence viscosity model

Honma assumed that when there is an entropy gradient in the radial direction in the ADAF, the turbulence of the flow can be a source of viscosity and transport energy.

$$Q_{\mathrm{adv}}^{-} = Q_{\mathrm{vis}}^{+} + Q_{\mathrm{turb}}^{+} - Q_{\mathrm{rad}}^{-} \,.$$



Manmoto, et al. ApJ 529, 127, (2000)
ApJ 538, 295, (2000)

Temperature distribution of the transition zone

A rapid decrease of temperature occurs within a narrow zone between the inner ADAF and the outer standard thin disk.

outer SD: $10^4 \sim 10^5$ K

inner ADAF: $10^9 \sim 10^{10}$ K

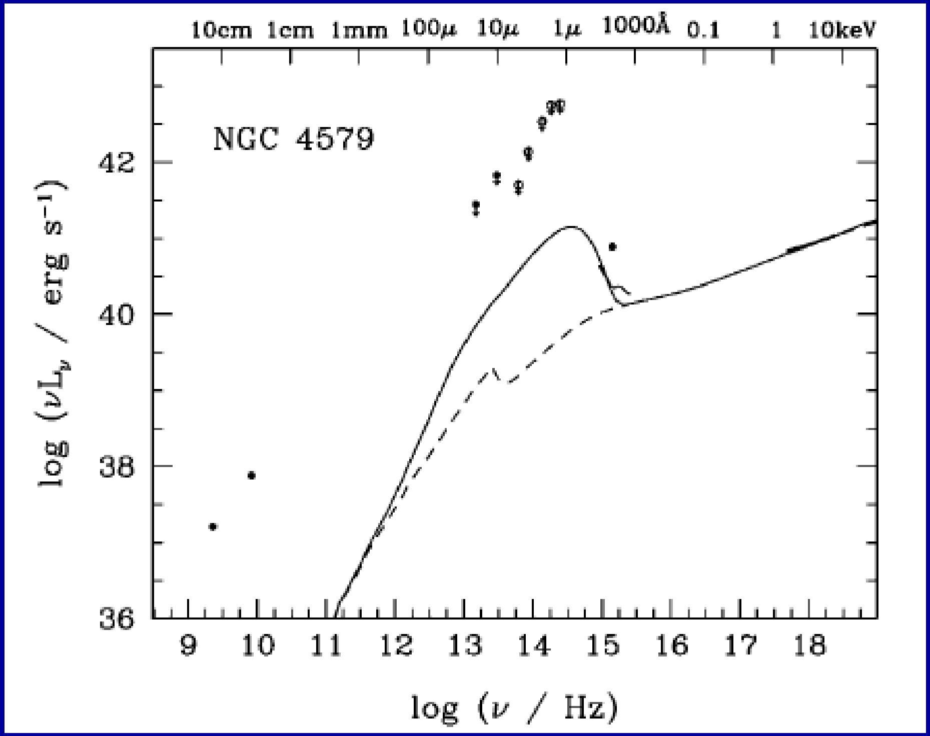
transition zone: $10^5 \sim 10^9$ K

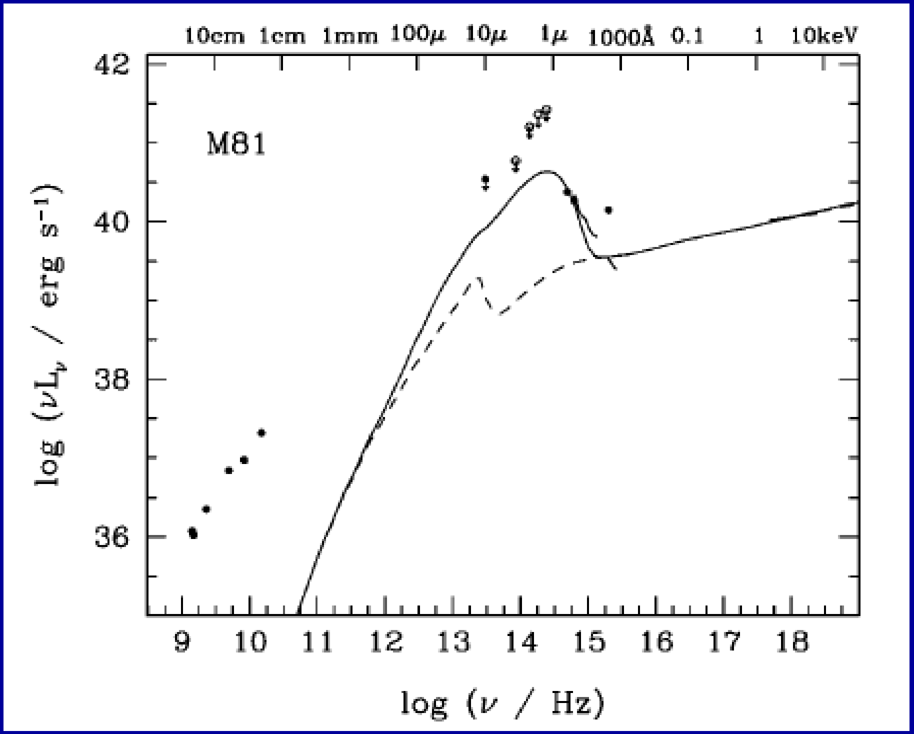
Thermal iron Kα line emission: E=6.7KeV & 6.97 KeV

He-like and H-like iron Kα line emission

• Observations

LLAGN: NGC4579 **M81**





ADAF+SD:

r_{tr} = 100, mdot = 0.03

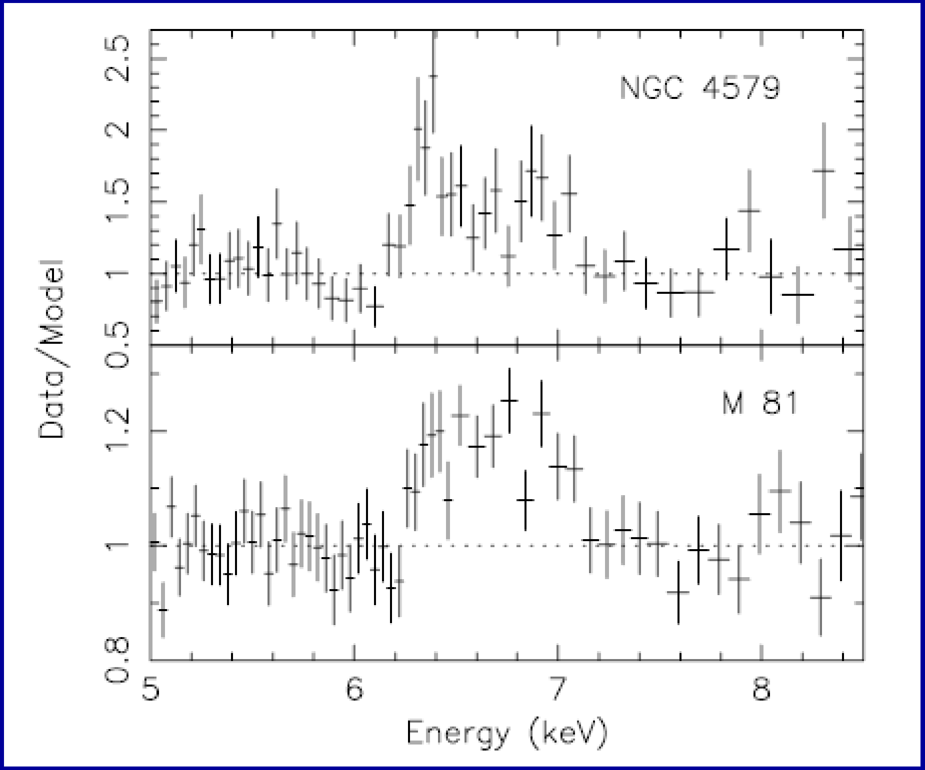
$$m = 4\times10^6$$

ADAF+SD:

r_{tr} = 100, mdot = 0.01

Quataert et al., ApJ 525, L89 (1999)

In addition to narrow iron Kα lines at 6.4 KeV, the broad line components centered at 6.79 KeV were also observed in these two sources.



	NGC4579	**M81**
$E_{K\alpha,b}$(keV)	$6.79^{+0.11}_{-0.13}$	$6.79^{+0.06}_{-0.07}$
σ (eV)	231^{+102}_{-97}	188^{+76}_{-57}
f^{d}	$9.9^{+4.4}_{-3.8}$	$10.4^{+3.2}_{-2.6}$
EW (eV)	287	101

Dewangan, et al., ApJ 607, 788 (2004)

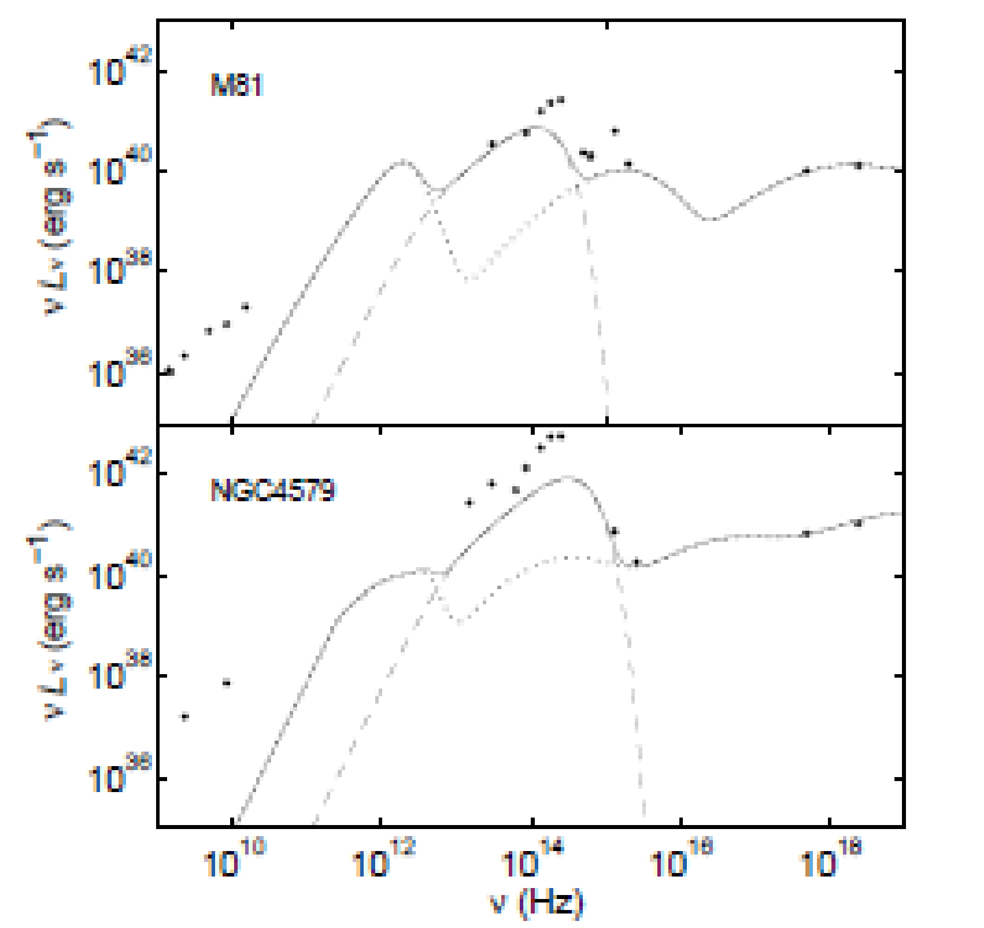
• Model calculations

I. Refitting on the observed SEDs with the ADAF+SD system

New masses: (Barth et al. 2001, ApJ, 546, 205;
Devereux et al. 2003, AJ, 125, 1226)

NGC4579 $m = 5\times 10^{7}$

M81 $m = 7\times 10^{7}$



New parameters:

NGC 4579:

$r_{\rm tr} = 80, \quad \dot{m} = 3.3\times 10^{-3}$

M81:

$r_{\rm tr} = 120, \quad \dot{m} = 3\times 10^{-4}$

II. The structure of the transition zone —Honma & Manmoto et al's turbulence viscosity model

$$v = -\alpha \frac{(3-a)}{5}[1-(R/R_{\mathrm{tr}})^{a}]v_{\mathrm{K}}(R),$$

$$\Omega = \sqrt{\frac{a+5}{5}}(R/R_{\mathrm{tr}})^{a/2}\Omega_{\mathrm{K}}(R),$$

$$c_{\mathrm{s}} = \sqrt{\frac{2}{5}}[1-(R/R_{\mathrm{tr}})^{a}]^{1/2}v_{\mathrm{K}}(R),$$

$$f = \frac{12a(3-a)-24(\alpha_{\mathrm{T}}/\alpha)(1-a)a}{(a+5)(3-a)^{2}},$$

$$L_{\mathrm{ADAF}} = \eta\dot{m}(1-f)\dot{M}_{\mathrm{Edd}}c^{2}.$$

III. Thermal X-ray line emission from the transition zone

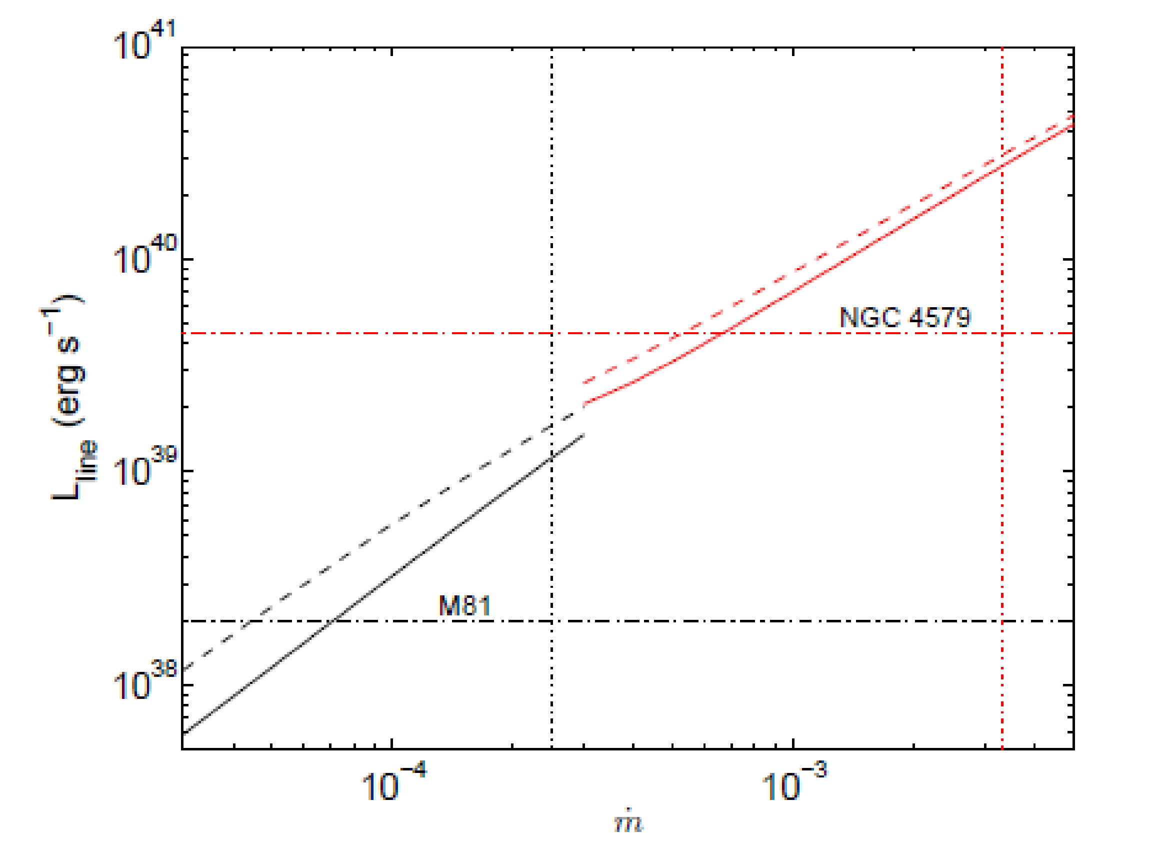
The line luminosity L_{line} can be calculated by integrating over the transition zone,

$$L_{\text{line}} = \int n_e^2(r)\varepsilon_{\text{line}} \frac{1 - e^{\tau_{\text{line}}(r)}}{\tau_{\text{line}(r)}} 4\pi r H(r) R_{\text{S}}{}^2 \mathrm{d}r$$

The line emissivity $\varepsilon_{\text{line}}$ as a function of temperature is calculated with the standard software package Astrophysical Plasma Emission Code (APEC).

τ_{line} is the optical depth of the emission line in the vertical direction.

The total line luminosities of H-like and He-like iron Kα lines as functions of accretion rate based on Honma et al's model.



The solid lines and the dashed lines correspond to the cases with the solar metallicity and five times solar metallicity. The observed values are marked in the figure (dash-dotted lines). The dotted lines represent the accretion rates derived from the ADAF+SD model fitting on the observed SEDs.

• Results and discussion

✓ Our best fits to the observed continuum spectra require the following parameters for the two sources

M81: $r_{\rm tr} = 120, \quad \dot{m} = 3 \times 10^{-4}$

NGC 4579: $r_{\rm tr} = 80, \quad \dot{m} = 3.3 \times 10^{-3}$

$$\frac{v_{\rm K\ M81}}{v_{\rm K\ NGC4579}} = [\frac{(r_{\rm tr})_{\rm M81}}{(r_{\rm tr})_{\rm NGC4579}} = 1.5]^{-1/2} \sim \frac{\sigma_{\rm M81}}{\sigma_{\rm NGC4579}} \approx 0.814$$

✓ Comparison of calculated thermal iron line emissions with the observations shows

M81: $\dot{m} = 7.1 \times 10^{-5}$

NGC 4579: $\dot{m} = 6.5 \times 10^{-4}$

✓ Though we cannot rule out this “turbulence viscosity” transition model only from their thermal X-ray line emissions, it seems that our calculation results are unable to support this model at least.

✓ An alternative ``evaporation'' model for the transition zone has a very thin layer between the cold thin disk and the hot corona. In principle, the evaporation model can also be tested by the observed thermal X-ray line emissions.

Thanks