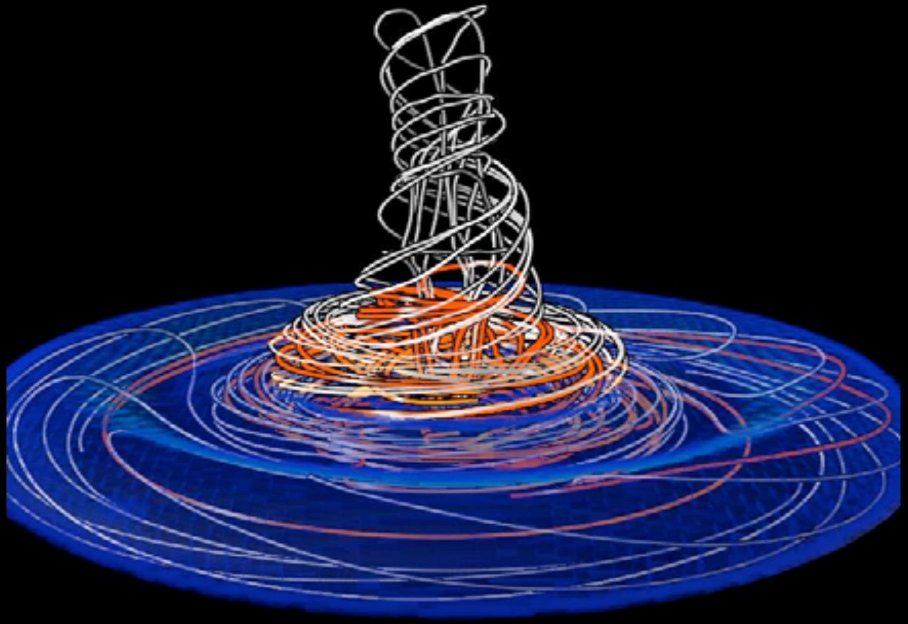
Key issues in black hole accretion

- Science by ASTRO-H -



Shin Mineshige (*Kyoto Univ.*)

Beyond the standard disk model

- Standard-type disk (standard disk or SS disk)

  Efficient machine to convert gravitational energy to radiation energy

- Standard disk model breaks down at low luminosities
  - Standard disks cannot produce high-energy (hard-X, γ) emission

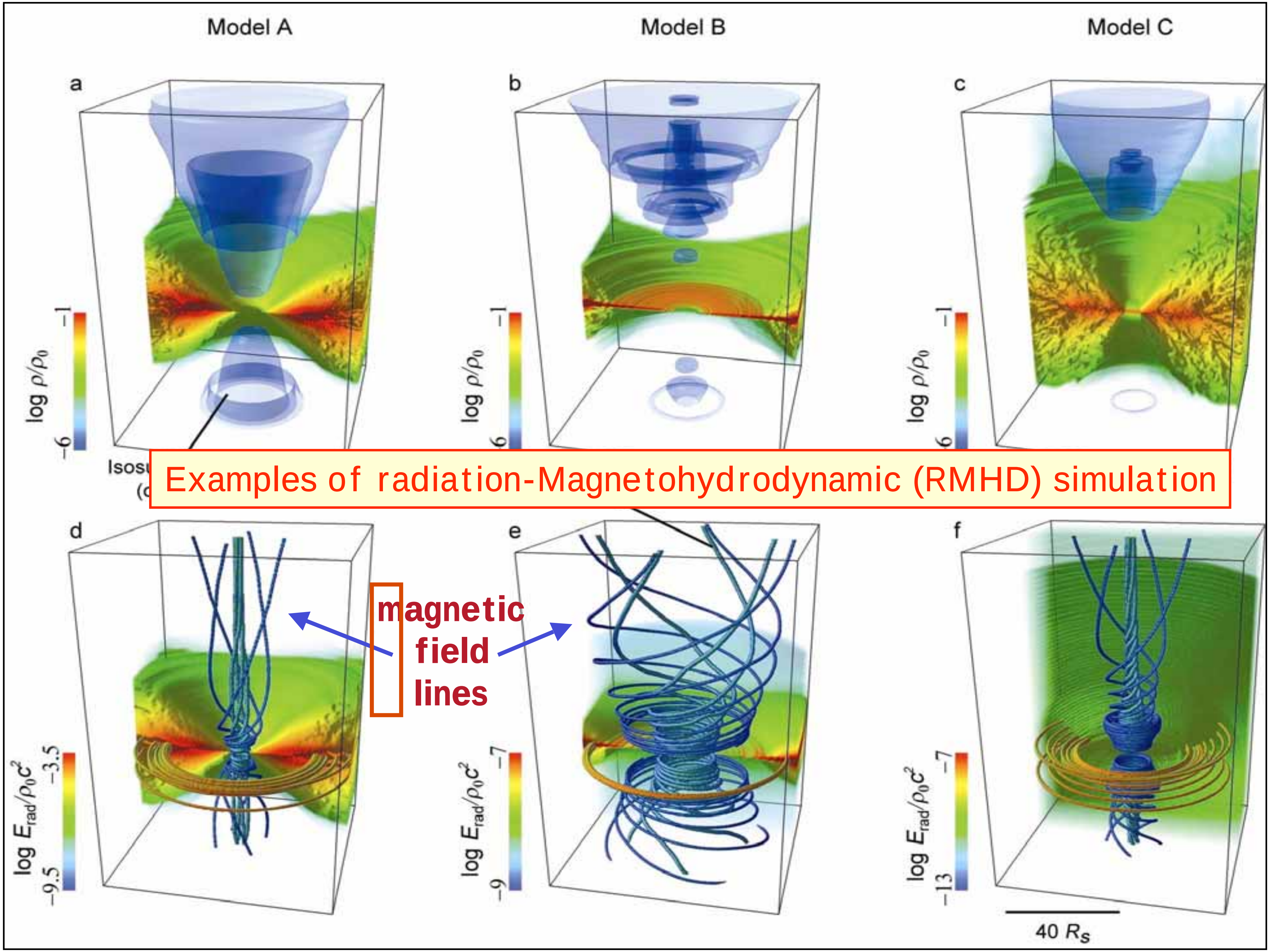
    → ADAF or RIAF models proposed
  - Cannot produce outflow nor time variation

Magnetic fields-matter interaction

- Standard disk model breaks down at high luminosities
  - Standard disk cannot explain super-Eddington sources

    → Slim disk model proposed
  - Cannot produce outflow and/or jet

Radiation-matter interaction



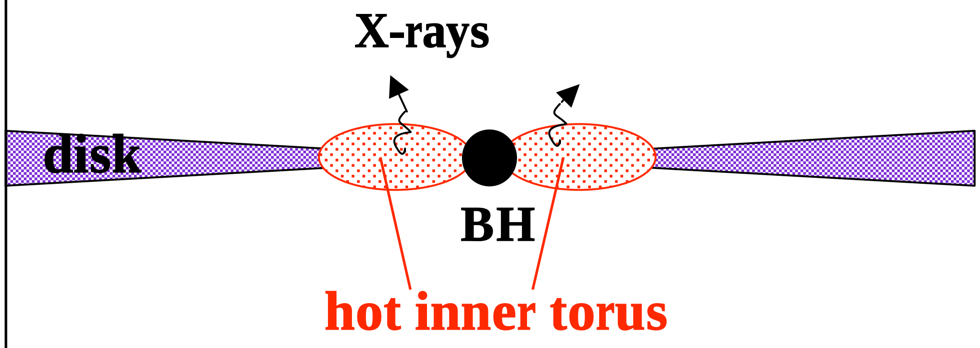
Examples of radiation-Magnetohydrodynamic (RMHD) simulation

magnetic field lines

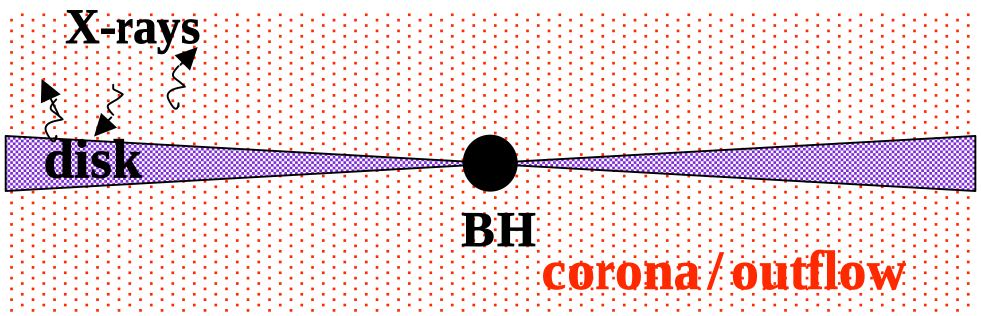
Situations may not be so simple...

Cool disks and hot corona/outflow

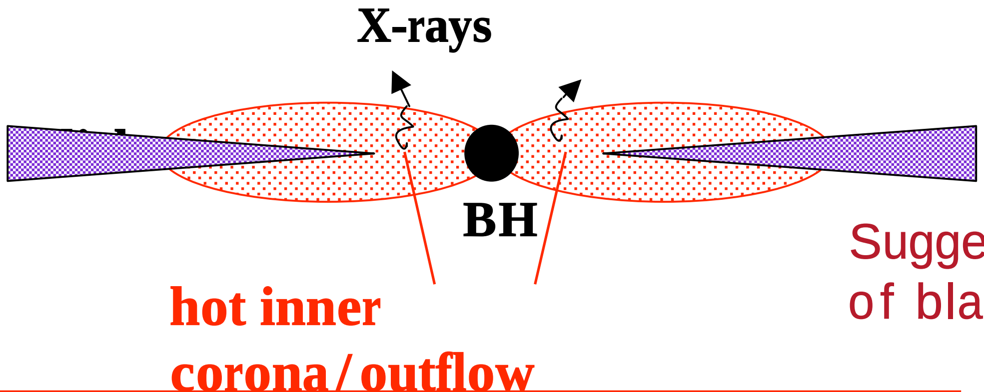
(a) horizontal separation



(b) vertical separation



(c) mixture type



Suggested by X-ray obs. of black hole binaries.

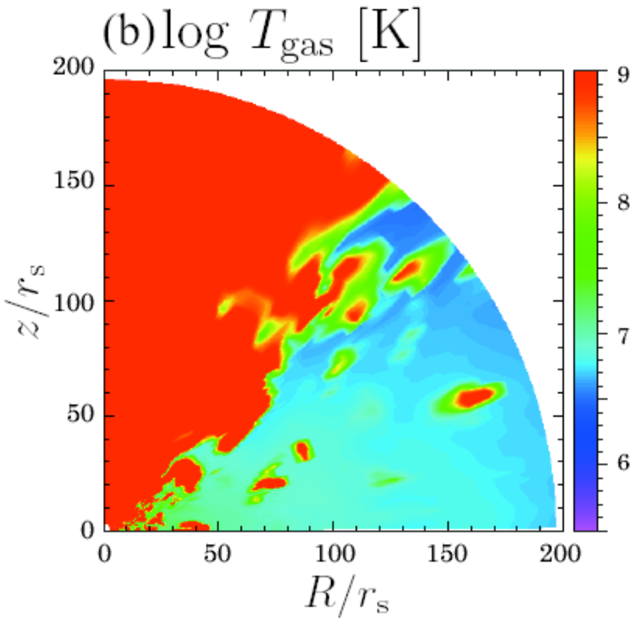
Two-phased media -> conduction
Hot and tenuous gas -> plasma effects

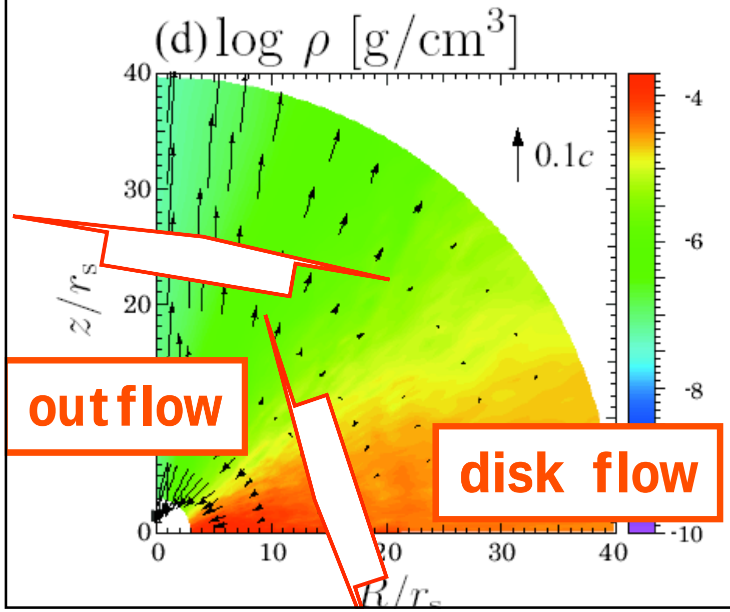
My subject:supercritical accretion

- What is supercritical accretion?
  - Accretion at a rate exceeding the critical rate yielding Eddington luminosity
- Why so interesting?
  - Strong radiation-matter interactions (e.g. photon trapping) - still not well understood
  - Significant outflow - produces absorption (emission) lines and gives large impact on the environments → triggering co-evolution of BHs and host galaxies(?)
  - Could be common in early universe (because of smaller BH masses)
- What is an ultimate goal?
  - Complete understanding of matter-radiation-magnetic field interaction, nature of hot plasmas under the extreme conditions

Overview of 2D super-critical flow

Kawashima et al. (2009)

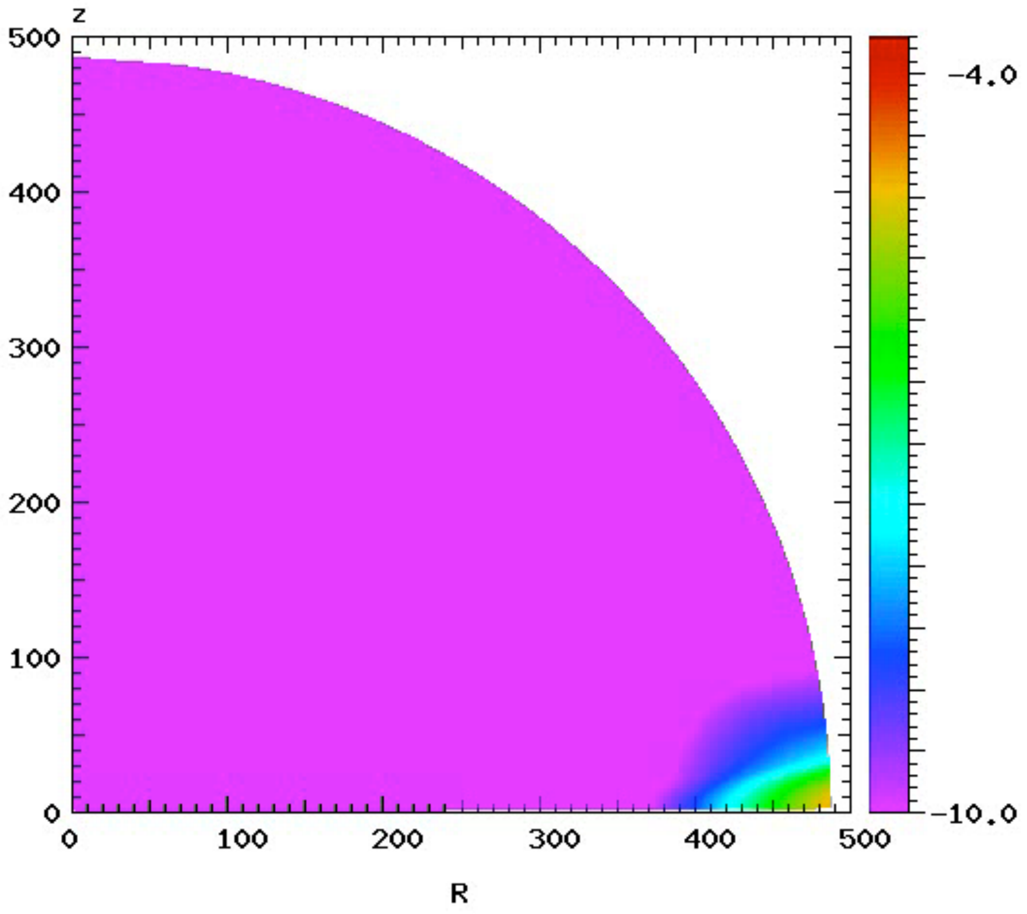




outflow

disk flow

$M = 10\ M_{\rm sun}$ and $\dot{M} = 1000\ L_E / c^2$



gas density

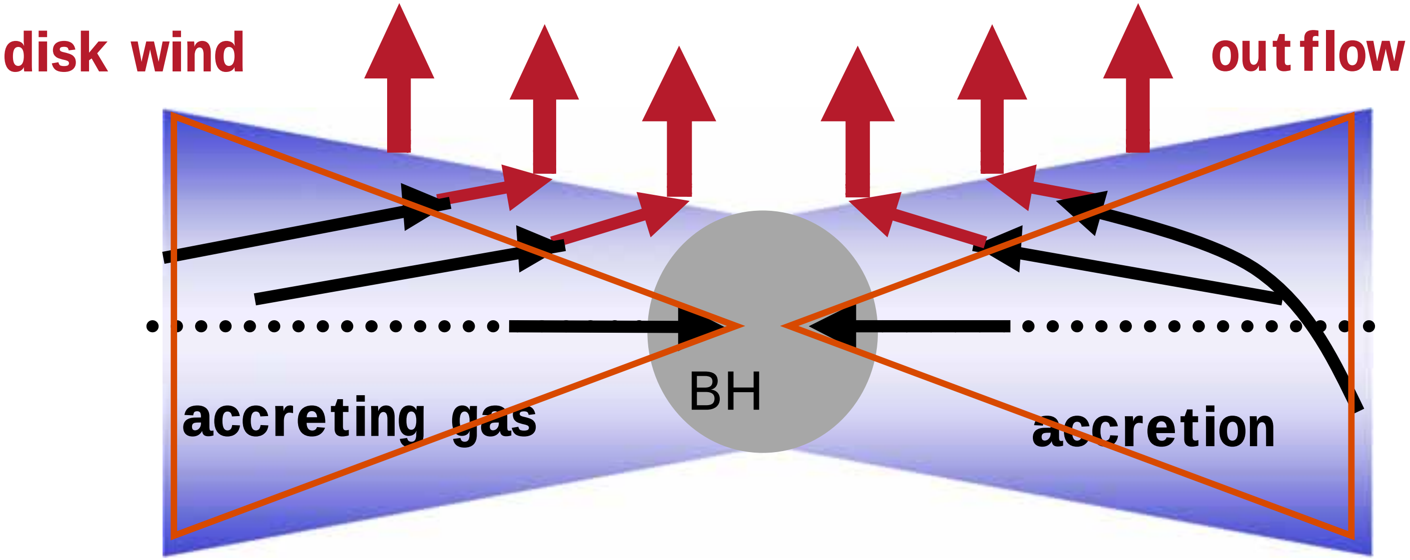
(c) Kawashima

Key process 1. Outflow

(Shakura & Sunyaev 1973; Poutanen et al. 2007)

Significant outflow from disk surface

Radiation pressure-driven outflow inevitably occurs.



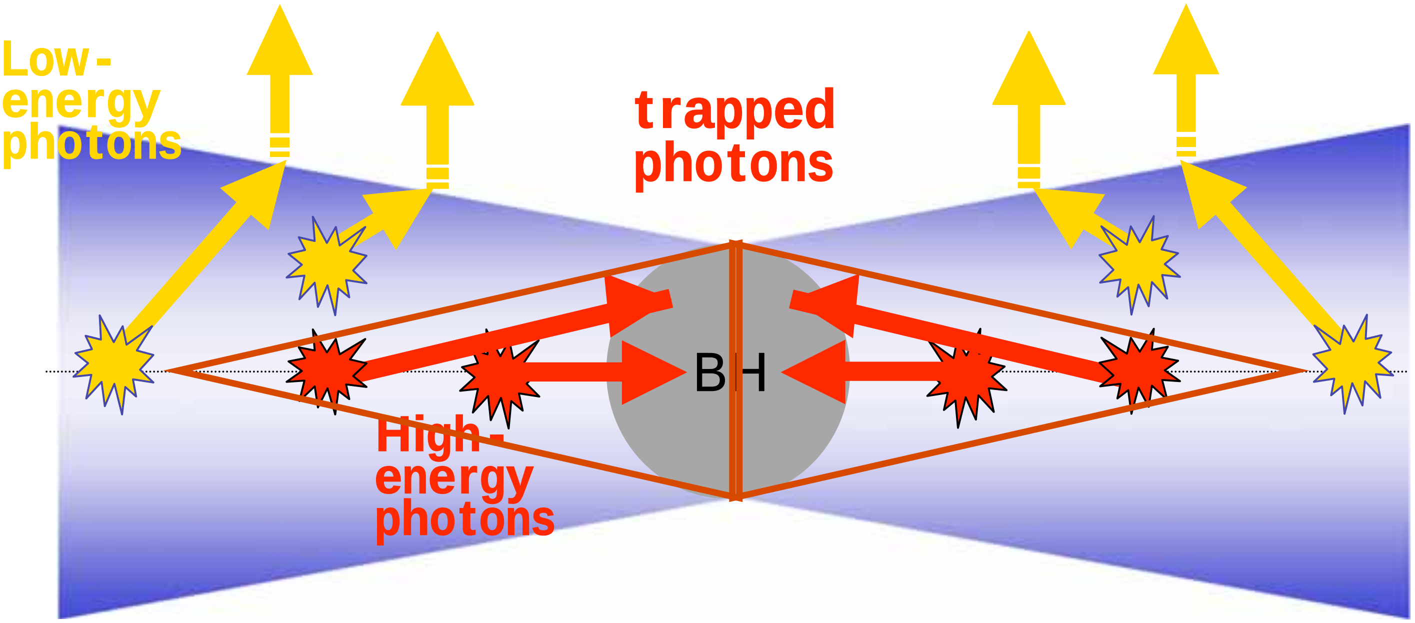
- **Critical radius = spherization radius:** $R_{sp} \sim (\dot{M}c^2 / L_E)\, r_s$
- **Inside this radius: flatter *T* profile:** $T \propto r^{-1/2}$

Key process 2. Photon trapping

Begelman (1978), Ohsuga et al. (2002)

Photon trapping within disk

Photons are trapped within high-mdot flow.



- **Critical radius = trapping radius:** $R_{trap} \sim (\dot{M}c^2/L_E)(H/r)\, r_s$
- **Inside this radius: flatter T profile:** $T \propto r^{-1/2}$

(c) K. Ohsuga

Spectral properties

(e.g. Kato et al. 2008)

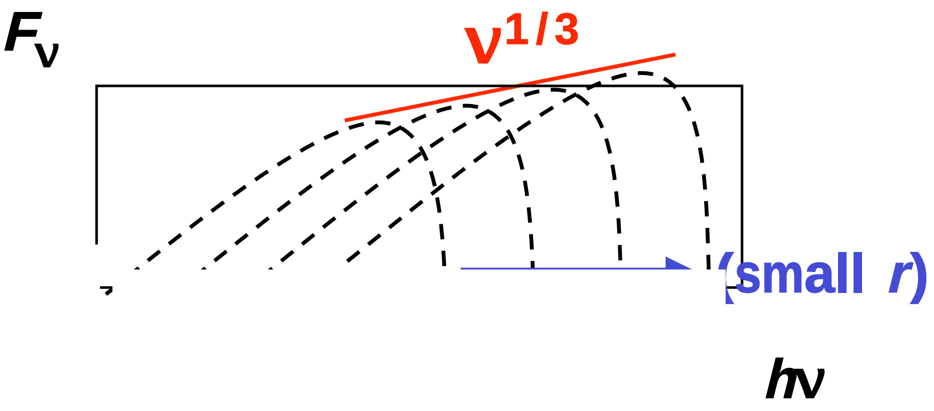
Disk spectra = multi-color blackbody radiation

Temp. profiles affect spectra: $F_\nu \propto \int B_\nu(T(r))\, 2\pi r dr$

$T \propto r^{-p} \Rightarrow F_\nu \propto \nu^{3-(2/p)}$

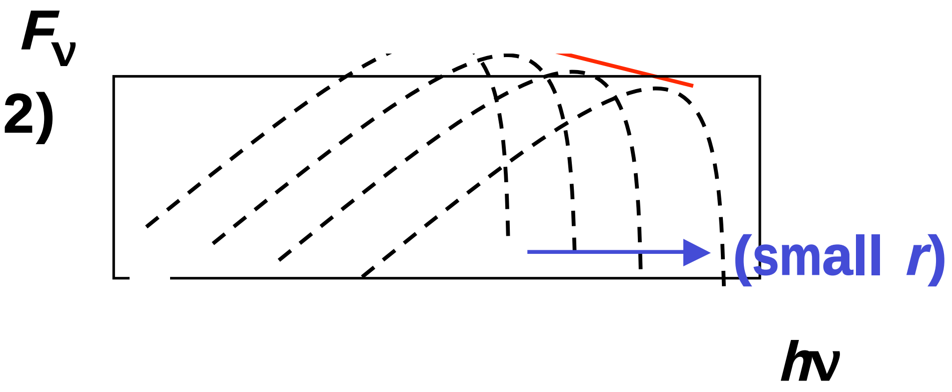
- **standard disk** (p=3/4)

  $\Rightarrow F_\nu \propto \nu^{1/3}$



- **supercritical disk** (p=1/2)

  $\Rightarrow F_\nu \propto \nu^{-1}$



Spectral fitting to ULXs

(Vierdayanti, SM, Ebisawa, Kawaguchi 2006)

We fit XMM-Newton data of several ULXs.

1. Fitting with disk blackbody (p=0.75) + power-law

⇒ low $T_{in}\sim 0.2$ keV and photon index of $\Gamma=1.9$

If we set $r_{in}\sim 3\,r_S$, BH mass is $M_{BH}\sim 300\,M_{sun}$.

2. Model fitting, assuming $T \propto r^{-p}$

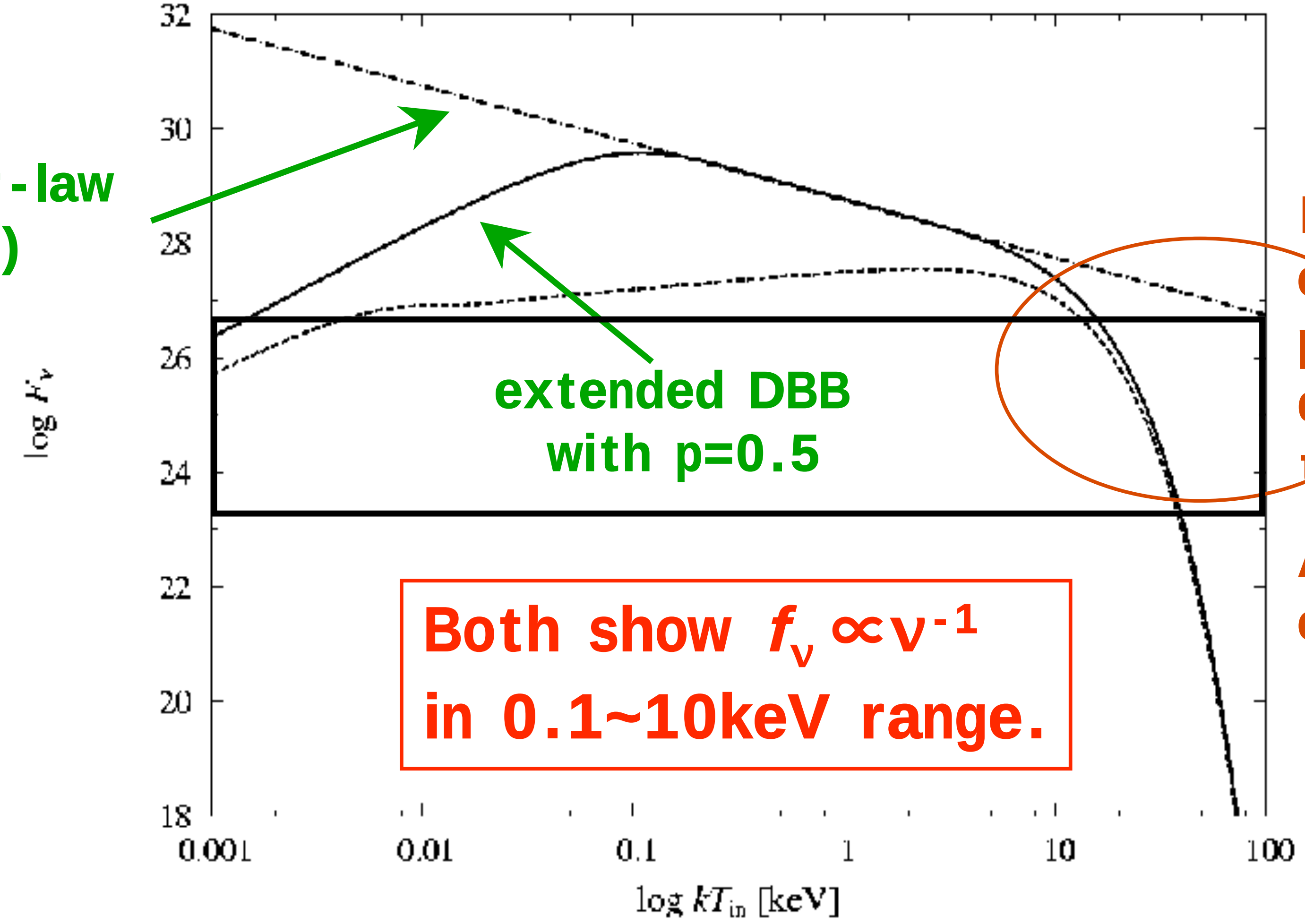
⇒ high $T_{in}\sim 2.5$ keV and $p=0.50\pm0.03$ (no PL comp.)

$M_{BH}\sim 12\,M_{sun}$ & $L/L_E\sim 1$, supporting slim disk model.

Both models give good fits. Why?

Why can both models give good fits?

Because the spectral shapes are similar below ~10 keV.



power-law
(Γ=2)

extended DBB
with p=0.5

Both show $f_\nu \propto \nu^{-1}$
in 0.1~10keV range.

Need to observe this part to discriminate them.

Avoid source contamination

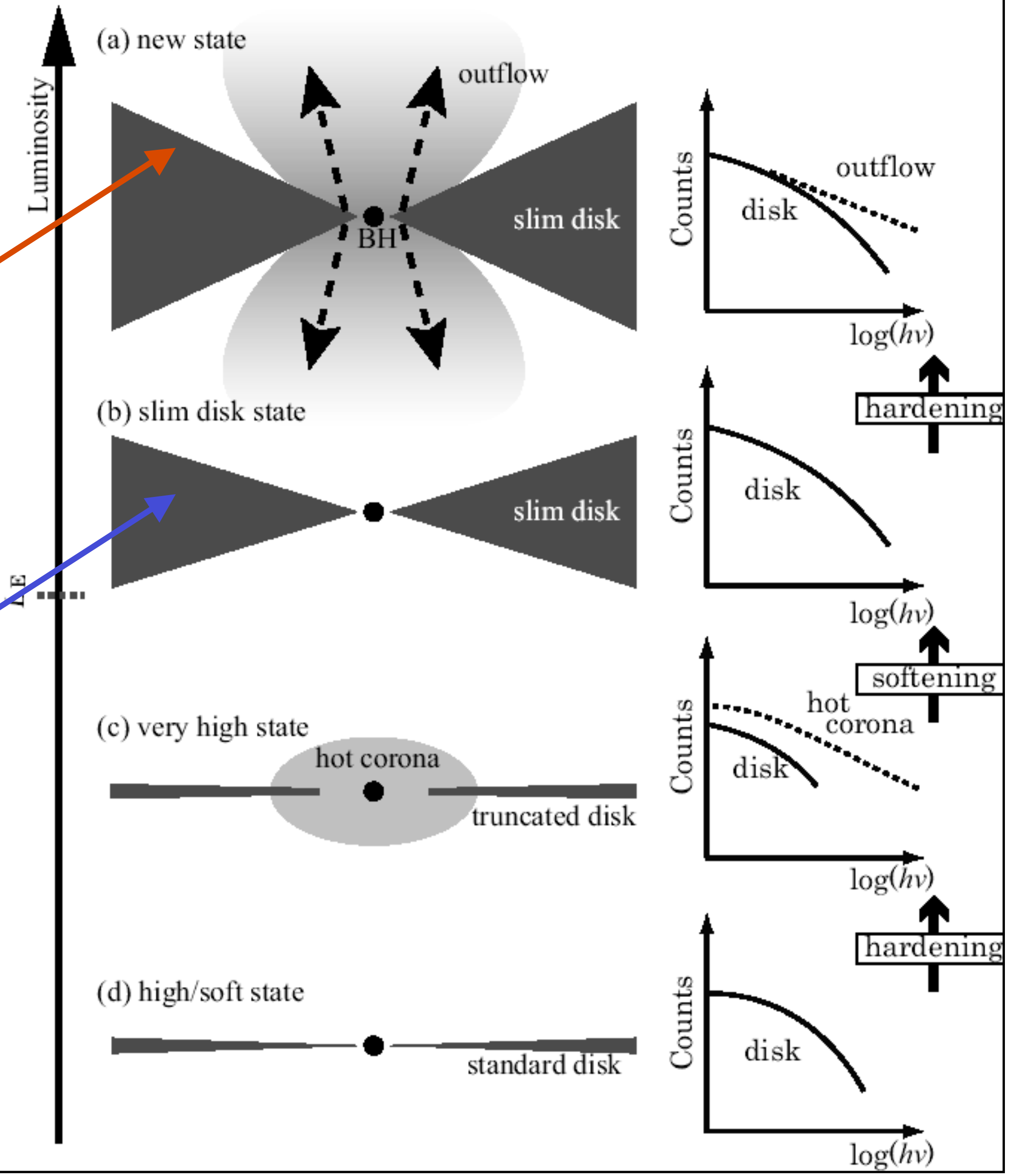
New state (?)

Kawashima et al. (2009)

A super-critical state with hard power-law emission; PL emission ↑ as L ↑ (e.g., NGC1313-X2 ?).

Ordinary (?) super-critical state with no power-law; PL emission ↓ as L ↑ (e.g., NGC1313-X1 ?).

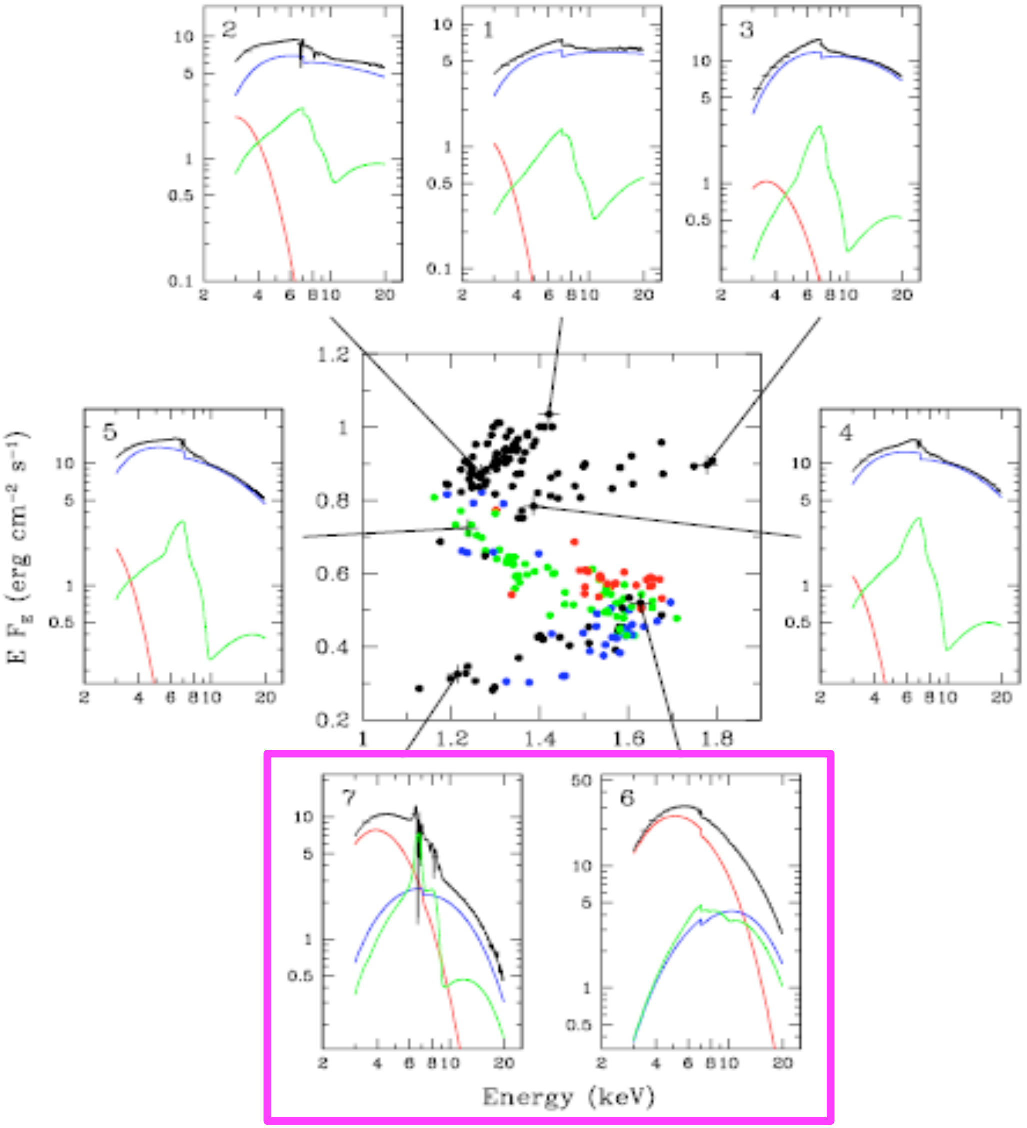
Wide band X-ray observation can test this scenario.



Case of microquasar, GRS1915+105

(Done et al. 2004)

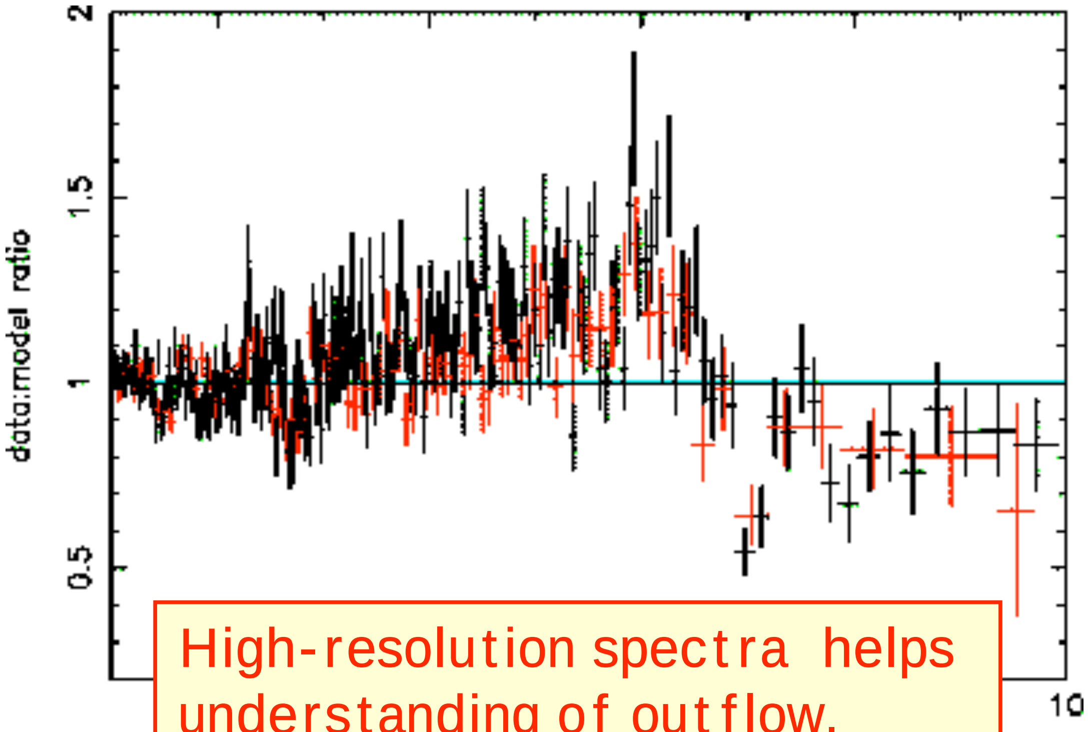
- **Let us check data of microquasar whose BH mass is known; i.e., GRS1915+105 with BH of 14±4 Msun).**
- **But it exhibits exceptionally complex behavior (both of spectra and timing) difficult to understand in a simple way.**



Related issue 1: Line absorption

X-ray absorption in quasars (Pounds et al. 2003)

- Outflow of 0.05-0.2c in X-ray spec.
- Mass outflow rate ~ the Eddington rate
- Can be explained by P_{rad} driven wind. Same for BAL quasars?

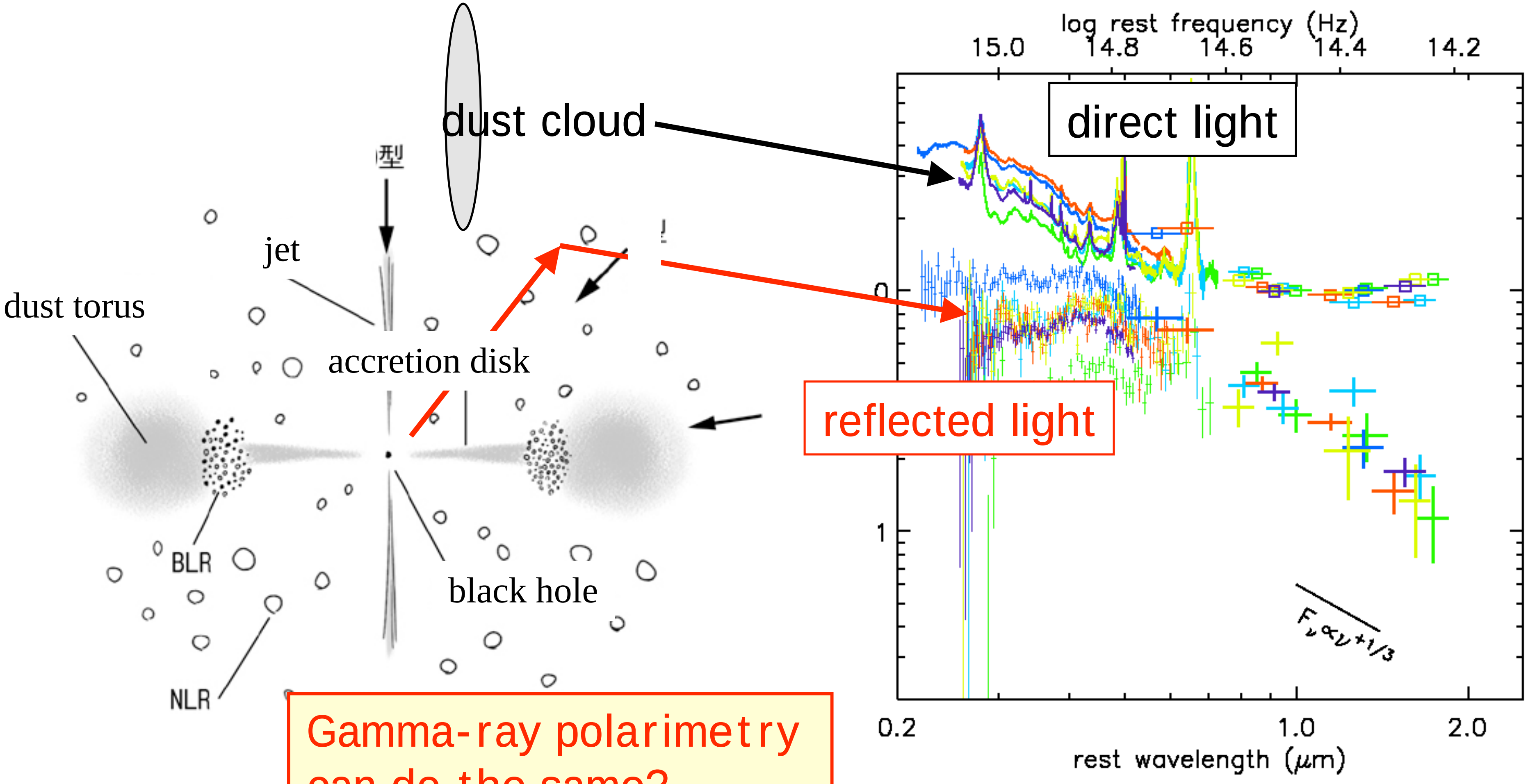


High-resolution spectra helps understanding of outflow.

Related issue 2.: polarization

Kishmoto et al. (2008)

- Opt.-IR polarimetry can resolve emission from inner disk

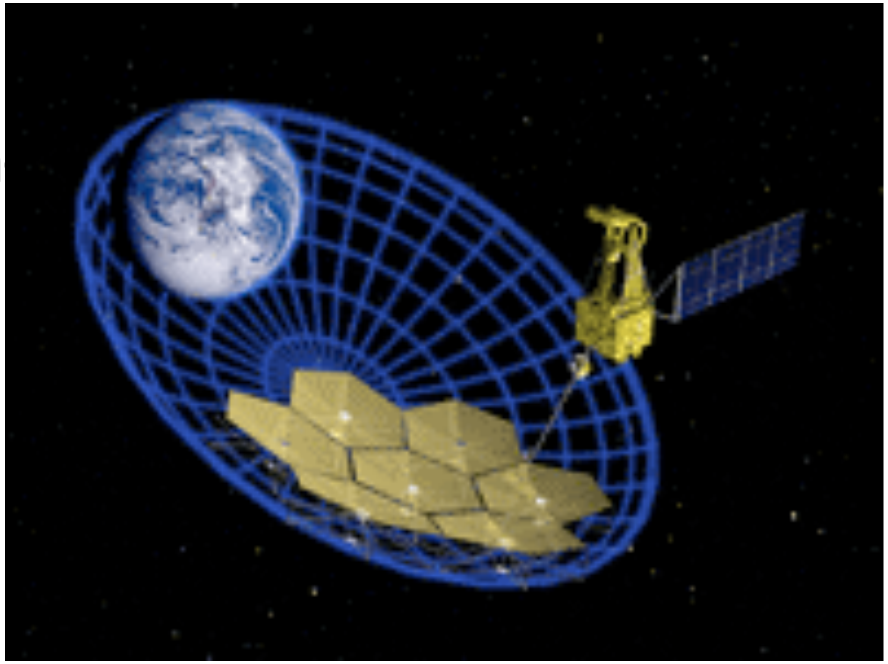


Gamma-ray polarimetry can do the same?

Related issue 3: collaboration with VSOP-2

What is VSOP-2?

http://vsop.mtk.nao.ac.jp/2007/VSOP-2project.html



VLBI Space Observatory Program
(radio space interferometer by usin
the ASTRO-G satellite)

- ➢ wave bands : 8, 22, 43 GHz
- ➢ highest resolution :
  37 micro-arcsec (43 GHz)
- ➢ polarization : LCP / RCP
- ➢ sensitivity : 22 – 107 mJy
  → temperature of 10^7 ~ 10^8 K
- ➢ launch year : 2012

corresponds to ~12 r_s for M87

($M=3\times10^9\ M_{sun}$, d= 17 Mpc)

Simultaneous observations of flaring events of M87 may be interesting!

Summary

- Standard disk model is powerful but observed accretion features seem to be more complex; matter-radiation-B-field interactions, two-phased (hot & cool) flow, …
- Supercritical accretion flow: wide-energy band & high-resolution observations can discriminate two scenarios of ULXs and understand physics of outflow.
- Collaborations with theory (MHD/RHD simulations) and ASTRO-G satellite could be useful.