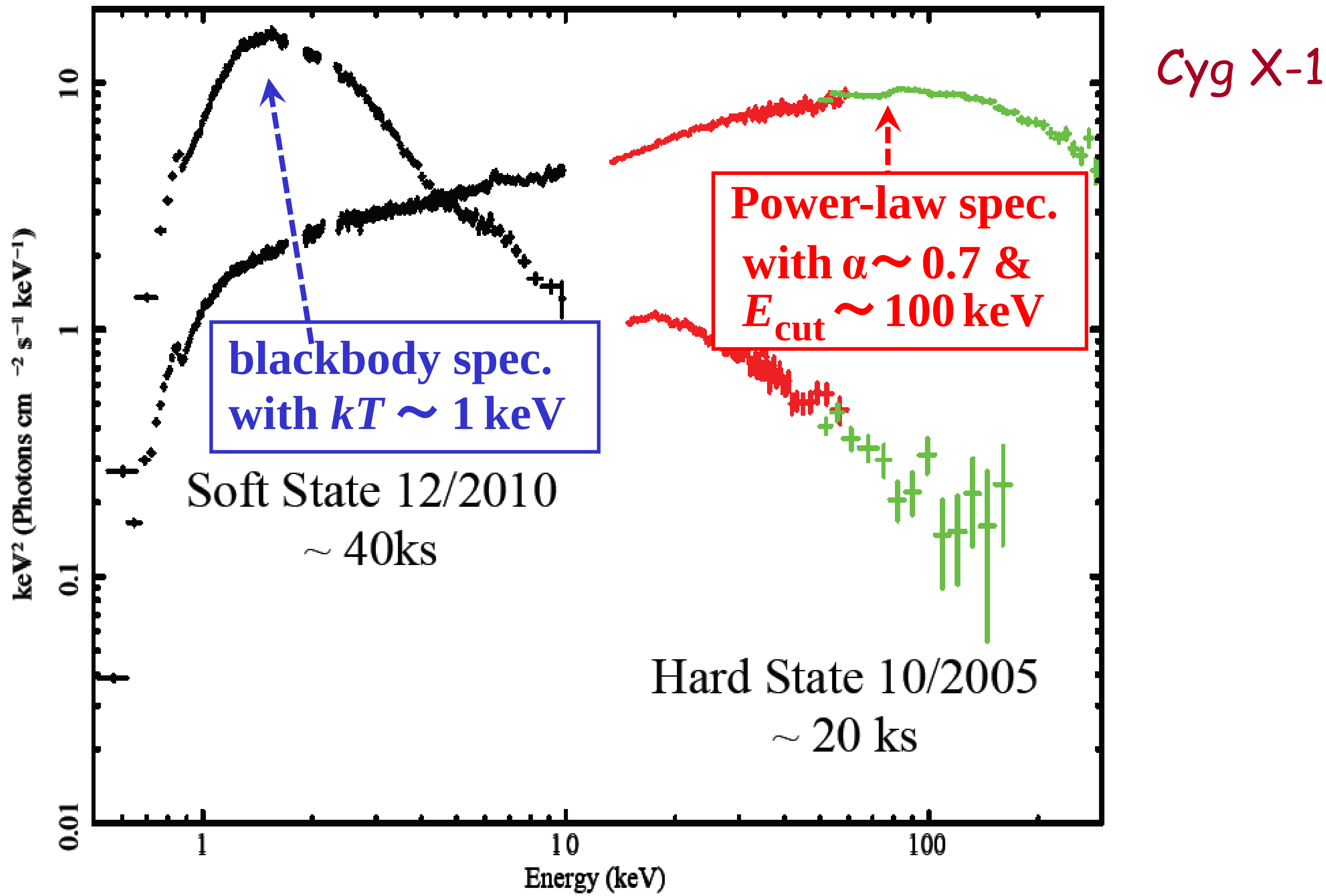
Comments on

MeV Gamma-Ray Emission from Accreting Black Holes

Shin Mineshige (Kyoto)

BH binaries: two (basic) spec. states

(Courtesy of S. Yamada)



Spectral cutoff at ~100 keV in the low-hard state, but no cutoff in the high-soft state (hard tail).

COMPTEL survey: ~1 MeV source

McConnell+1996

Source	F (cm^{-2} s^{-1} MeV^{-1}) 0.75–1 MeV	1–3 MeV	3–10 MeV	10–30 MeV
GRO J0422+32	$< 1.2\ 10^{-4}$	$< 2.3\ 10^{-5}$	$< 6.0\ 10^{-6}$	$< 2.9\ 10^{-7}$
LMC X-3	$< 2.8\ 10^{-4}$	$4.7(\pm1.1)\ 10^{-5}$	$4.7(\pm1.5)\ 10^{-6}$	$< 3.0\ 10^{-7}$
LMC X-1	$< 2.1\ 10^{-4}$	$< 5.1\ 10^{-5}$	$6.8(\pm1.5)\ 10^{-6}$	$< 3.0\ 10^{-7}$
CAL 87	$< 1.5\ 10^{-4}$	$< 4.2\ 10^{-5}$	$6.5(\pm1.5)\ 10^{-6}$	$< 3.1\ 10^{-7}$
A0620-00	$< 1.4\ 10^{-4}$	$< 1.9\ 10^{-5}$	$< 3.4\ 10^{-6}$	$< 4.9\ 10^{-7}$
GRS 1009-45	$< 2.7\ 10^{-4}$	$< 2.8\ 10^{-5}$	$< 5.2\ 10^{-6}$	$< 5.3\ 10^{-7}$
GRS 1124-684	$< 1.2\ 10^{-4}$	$< 1.7\ 10^{-5}$	$< 6.7\ 10^{-6}$	$< 6.4\ 10^{-7}$
GS 1354-645	$< 3.9\ 10^{-4}$	$< 3.4\ 10^{-5}$	$< 3.8\ 10^{-6}$	$< 1.0\ 10^{-6}$
A1524-617	$< 2.9\ 10^{-4}$	$< 4.1\ 10^{-5}$	$< 4.0\ 10^{-6}$	$< 1.4\ 10^{-6}$
4U 1543-475	$< 2.4\ 10^{-4}$	$< 2.1\ 10^{-5}$	$< 2.4\ 10^{-6}$	$< 3.7\ 10^{-7}$
4U 1630-472	$< 1.3\ 10^{-4}$	$< 1.7\ 10^{-5}$	$< 2.5\ 10^{-6}$	$< 6.0\ 10^{-7}$
GX 339-4	$< 1.4\ 10^{-4}$	$< 1.8\ 10^{-5}$	$< 2.5\ 10^{-6}$	$< 3.7\ 10^{-7}$
GRO J1655-40	$< 1.5\ 10^{-4}$	$< 1.9\ 10^{-5}$	$< 2.4\ 10^{-6}$	$< 5.8\ 10^{-7}$
H 1705-250	$< 1.6\ 10^{-4}$	$< 2.1\ 10^{-5}$	$< 2.8\ 10^{-6}$	$< 4.3\ 10^{-7}$
GRO J1719-24	$< 1.4\ 10^{-4}$	$3.9(\pm1.3)\ 10^{-5}$	$< 3.1\ 10^{-6}$	$< 3.9\ 10^{-7}$
1E 1740.7-2942	$< 1.6\ 10^{-4}$	$< 2.1\ 10^{-5}$	$< 2.8\ 10^{-6}$	$< 8.3\ 10^{-7}$
H 1741-322	$< 1.6\ 10^{-4}$	$< 2.1\ 10^{-5}$	$< 2.8\ 10^{-6}$	$< 3.6\ 10^{-7}$
4U 1755-338	$< 1.6\ 10^{-4}$		$< 2.8\ 10^{-6}$	$< 3.6\ 10^{-7}$
GRS 1758-258	$< 1.4\ 10^{-4}$	$< 1.9\ 10^{-5}$	$< 2.4\ 10^{-6}$	$< 3.2\ 10^{-7}$
GS 1826-238	$< 2.7\ 10^{-4}$	$< 4.4\ 10^{-5}$	$< 4.8\ 10^{-6}$	$< 5.5\ 10^{-7}$
EXO 1846-031	$< 2.0\ 10^{-4}$	$< 1.6\ 10^{-5}$	$< 4.0\ 10^{-6}$	$< 4.4\ 10^{-7}$
SS433	$< 1.7\ 10^{-4}$	$< 1.5\ 10^{-5}$	$< 4.0\ 10^{-6}$	$< 3.9\ 10^{-7}$
GRS 1915+105	$< 2.1\ 10^{-4}$	$< 1.7\ 10^{-5}$	$< 4.5\ 10^{-6}$	$< 3.8\ 10^{-7}$
Cyg X-1	$6.9(\pm.9)\ 10^{-4}$	$7.6(\pm1.0)\ 10^{-5}$	$6.2(\pm1.3)\ 10^{-6}$	$< 5.7\ 10^{-7}$
4U 1957+115	$< 1.1\ 10^{-4}$	$< 4.9\ 10^{-5}$	$5.1(\pm1.4)\ 10^{-6}$	$< 4.3\ 10^{-7}$
GS 2000+251	$< 1.1\ 10^{-4}$	$< 1.7\ 10^{-5}$	$< 5.0\ 10^{-6}$	$< 3.3\ 10^{-7}$
GS 2023+338	$< 2.5\ 10^{-4}$	$< 3.4\ 10^{-5}$	$< 3.7\ 10^{-6}$	$< 2.7\ 10^{-7}$

COMPTEL obs. of Cen A

Steinle+1998

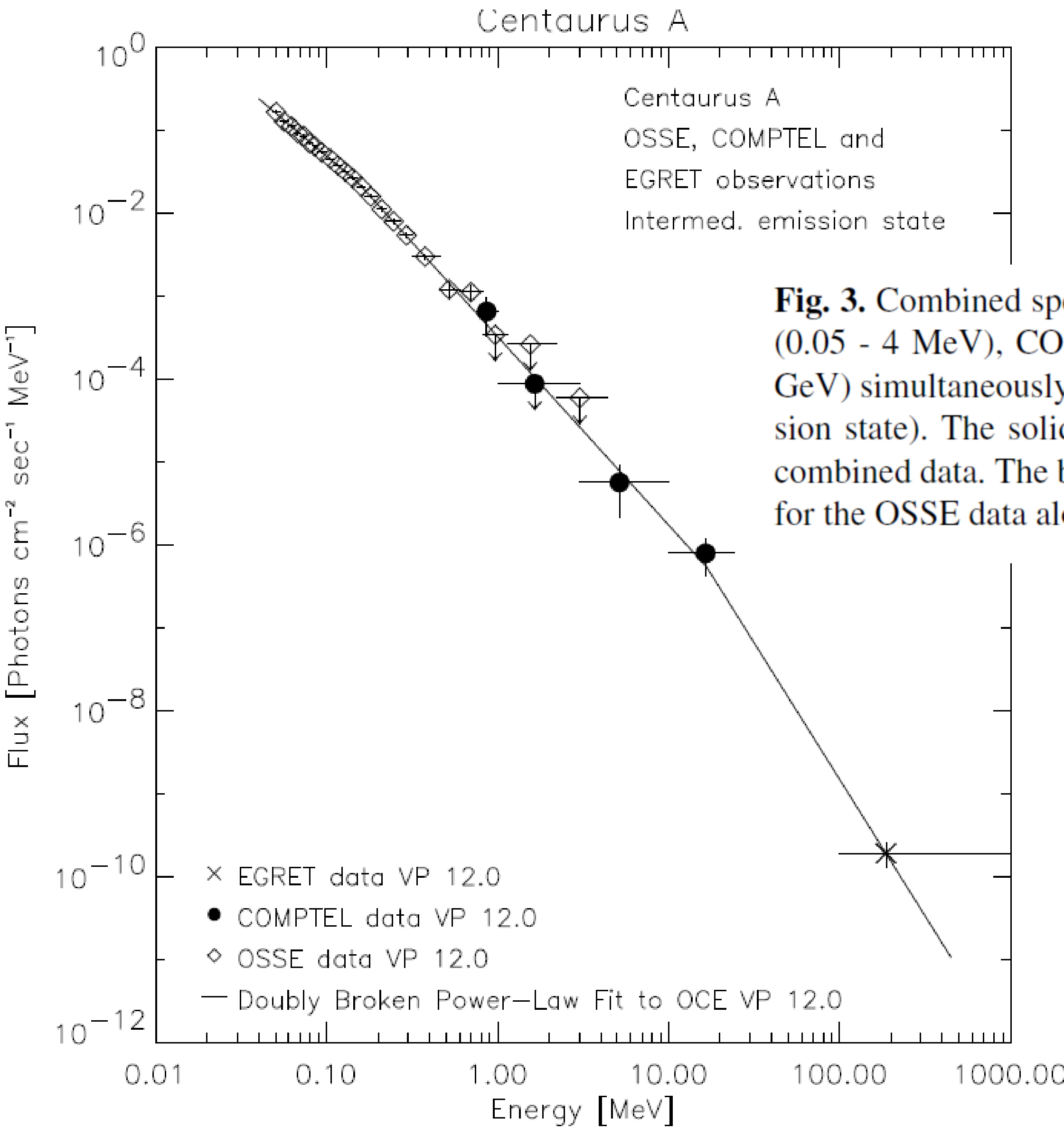


Fig. 3. Combined spectrum from Centaurus A as measured by OSSE (0.05 - 4 MeV), COMPTEL (0.75 - 30 MeV), and EGRET (0.1 - 1 GeV) simultaneously during Viewing Period 12.0 (intermediate emission state). The solid line is the doubly broken power-law fit to the combined data. The broken power-law fit given in Kinzer et al. (1995) for the OSSE data alone, is indistinguishable from the fit shown here.

Advection-dominated flow (ADAF)

Ichimaru (1977); Narayan & Yi (1994, 1995)

- Basics

  accretion energy → internal : hot faint flow

  - Appears below ~ $0.3\alpha^2 \times L_E$ (Eddington luminosity)
  - Steady, axisymmetric, sub-Keplerian, α-viscosity

  hard X-γ emission ⟶

$$T_{\rm ion} \approx 10^{12} \left(\frac{r}{r_{\rm S}} \right)^{-1} {\rm K}; \quad T_{\rm elec} \approx 10^{9-10} {\rm K}$$

- Spectrum

  Synchrotron (radio), brems. + inverse Compton (X-γ)

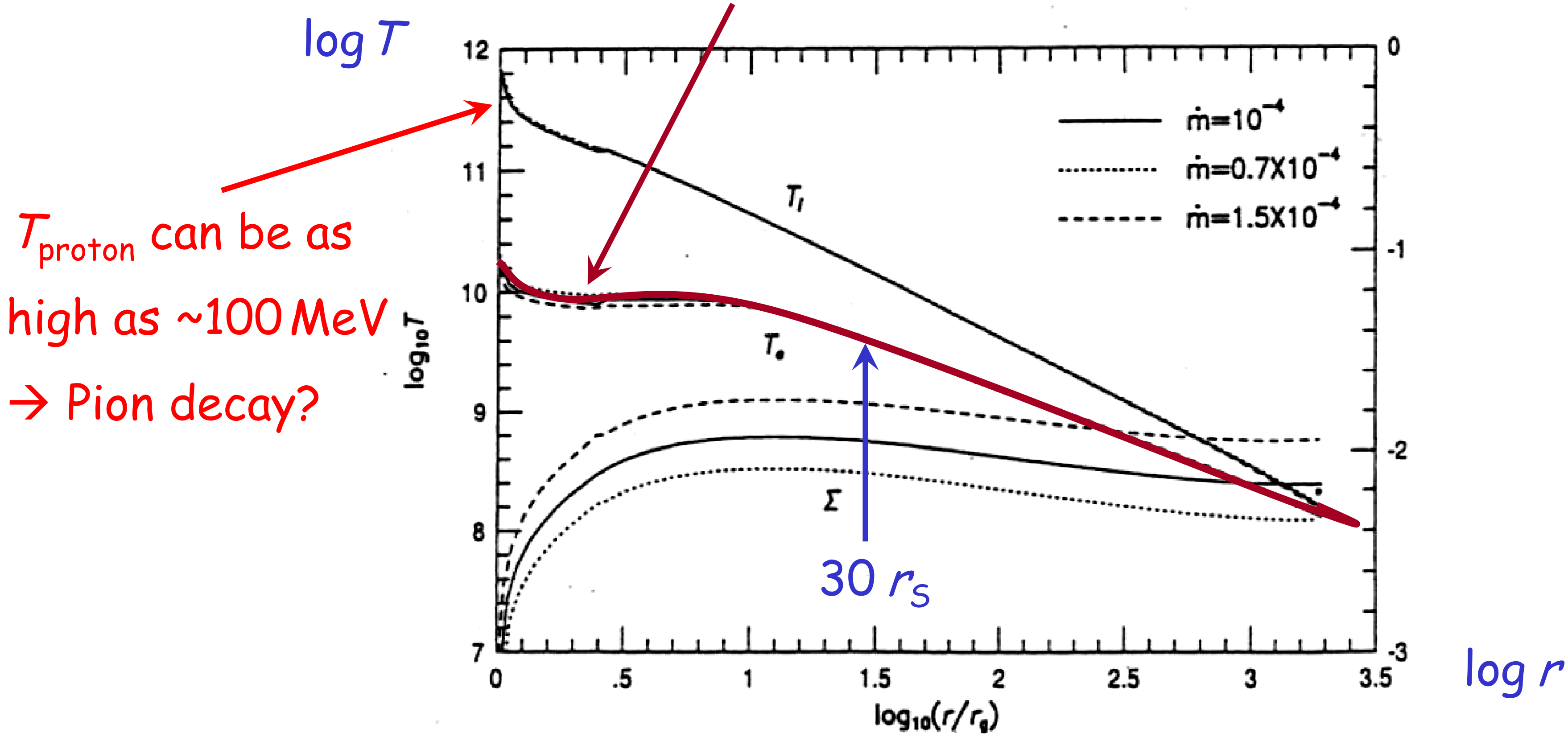
- Uncertainties
  - How much fraction of dissipated energy to ions?
  - Energy exchange rate between ions and electrons?

Calculated temp. profiles

Manmoto et al. (1996)

- ADAF (RIAF) model

Roughly, $T \propto r^{-1}$, but T_{elec} saturates at ~ 10^{10}K (~$2m_ec^2/k$)



For temp. $T > m_ec^2/k$ electrons become relativistic

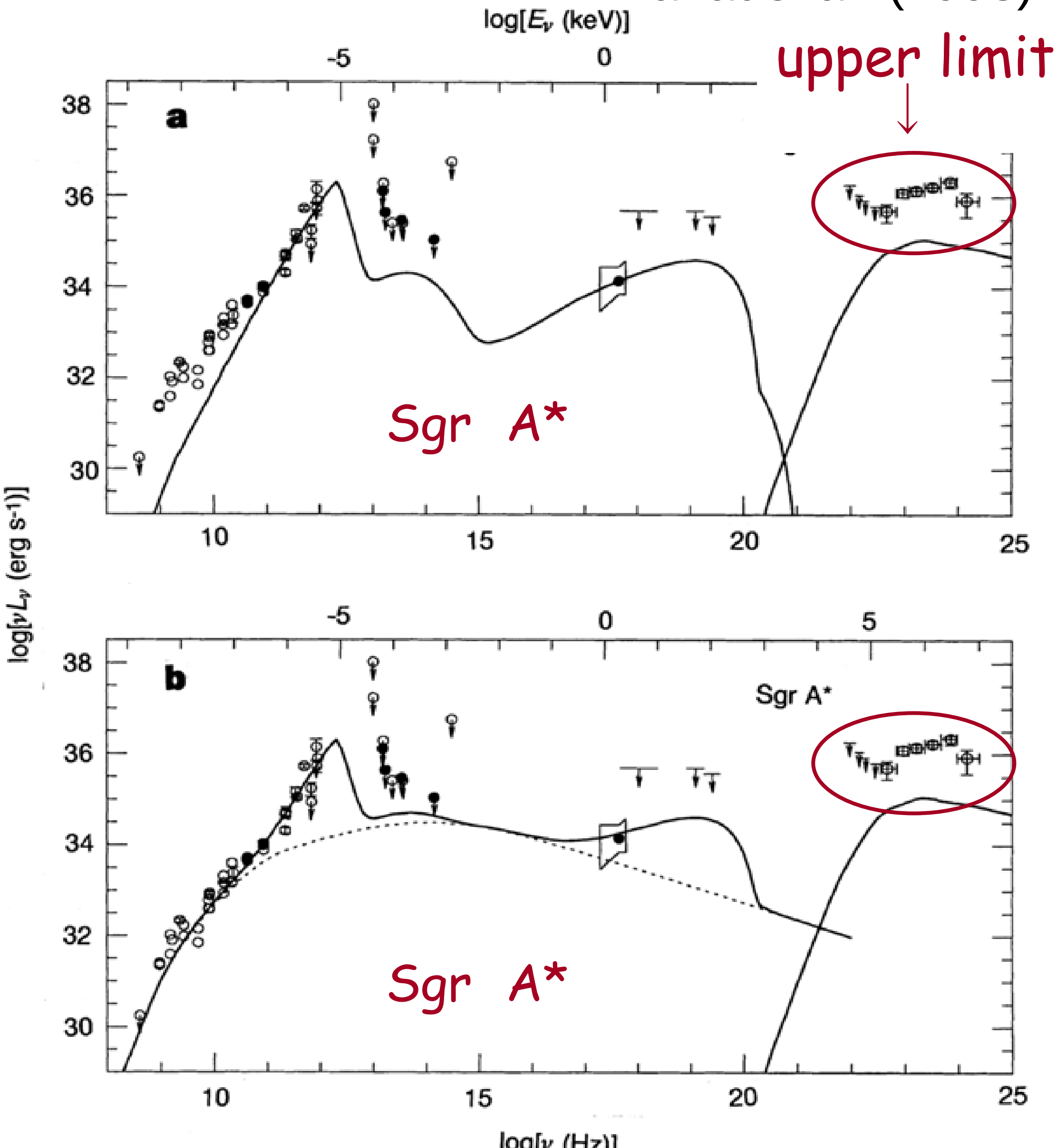
➔ Cooling rate enhanced ➔ electrons cool rapidly!!

Pion decay & MeV gamma-ray

Mahadevan (1998)

- Neutral pion decay
→ >1MeV emission

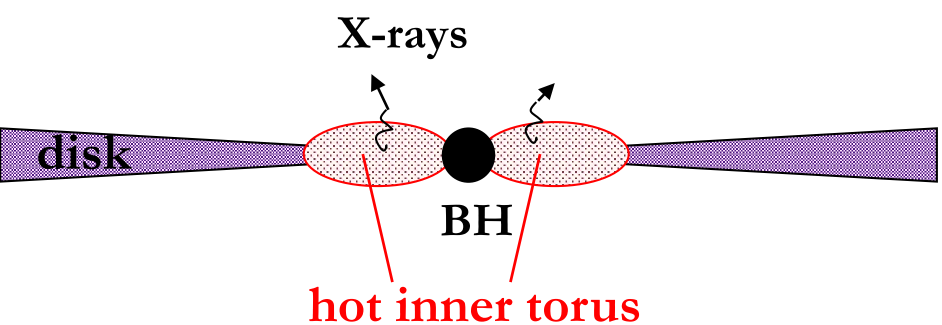
- Charged pion decay
→ e+e- pairs
→ synchrotron



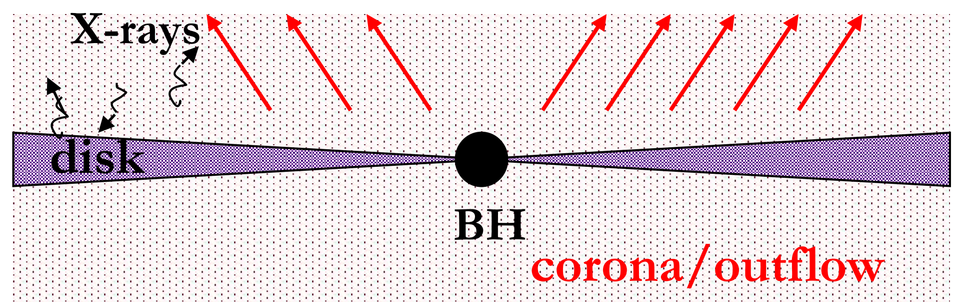
Situations may not be so simple…

Cool disks and hot corona/outflow

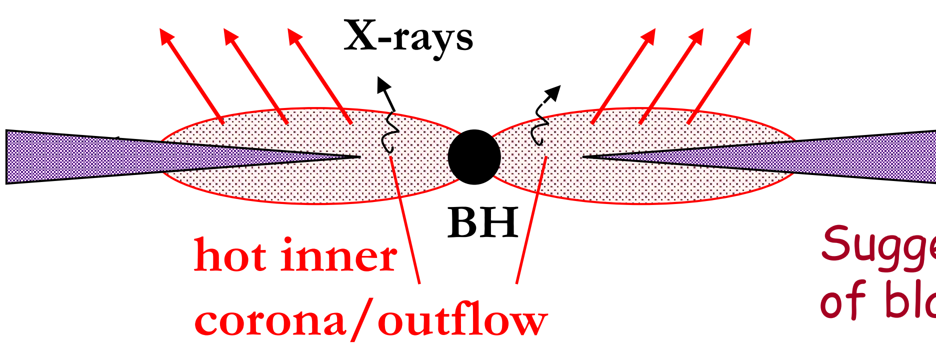
(a) horizontal separation



(b) vertical separation



(c) mixture type



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

Outflow provides another complication.

Physics of disk corona

Liu, Mineshige, & Shibata (2002)

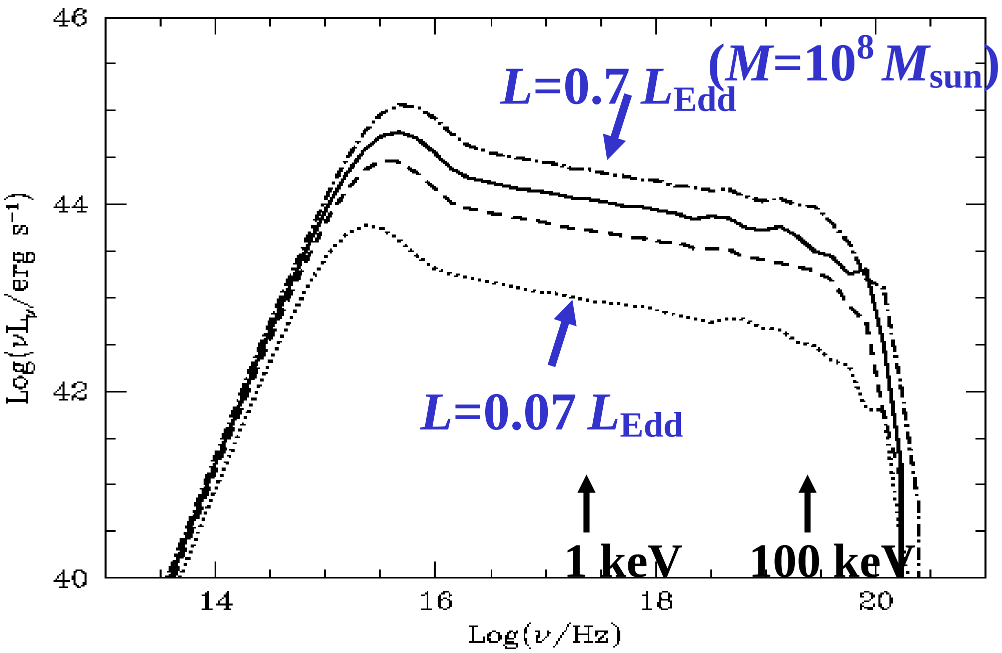
① reconnection heating = Compton cooling in corona

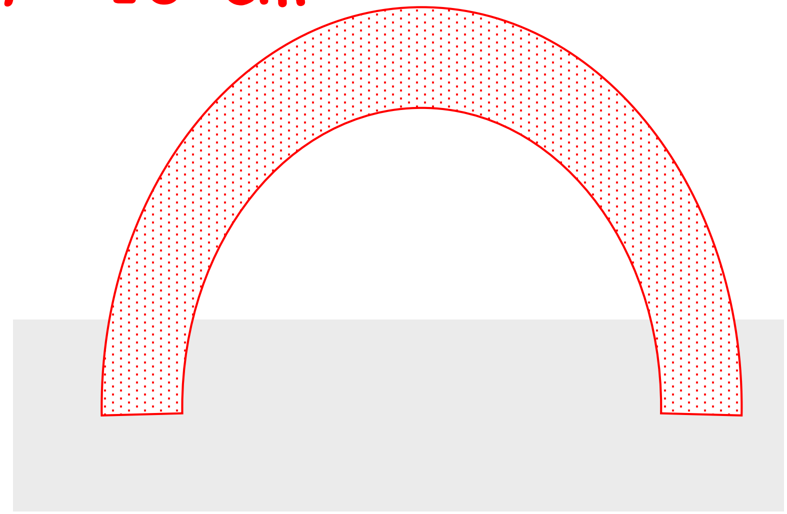
$$\frac{B^2}{4\pi} V_A \approx \frac{4kT}{m_e c^2} n \sigma_T c U_{seed} \ell \quad (\sim y c U_{seed})$$

② conduction heating = evaporation cooling in chromosphere

$$\frac{KT^{7/2}}{\ell} \approx \frac{\gamma}{\gamma - 1} nkT \left(\frac{kT}{m_H} \right)^{1/2}$$

① + ② ⇒ $T \sim 10^9$ K, $n \sim 10^9$ cm^{-3}





Nonthermal emission

Zdziarski+94, Svensson 1994

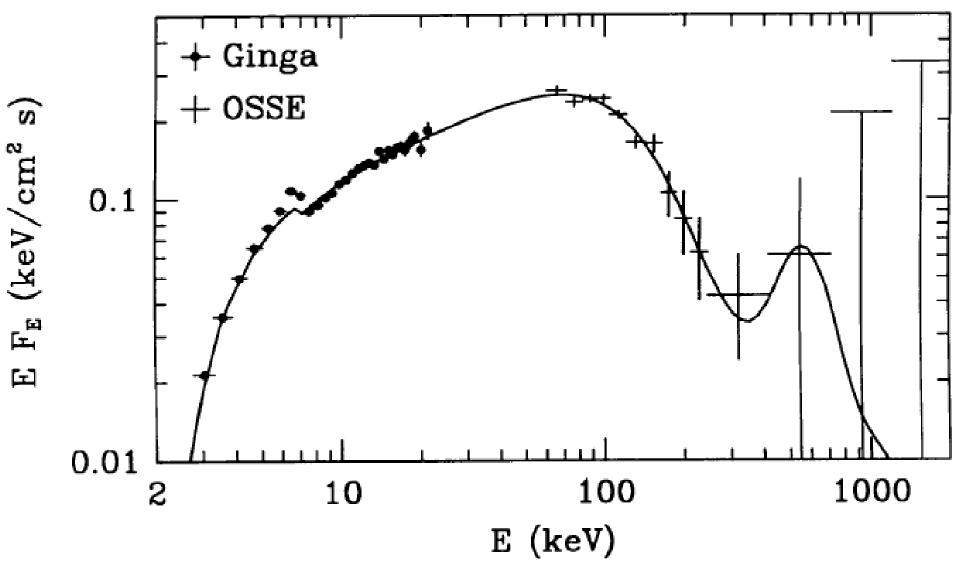
- Pair reflection models ~1990's

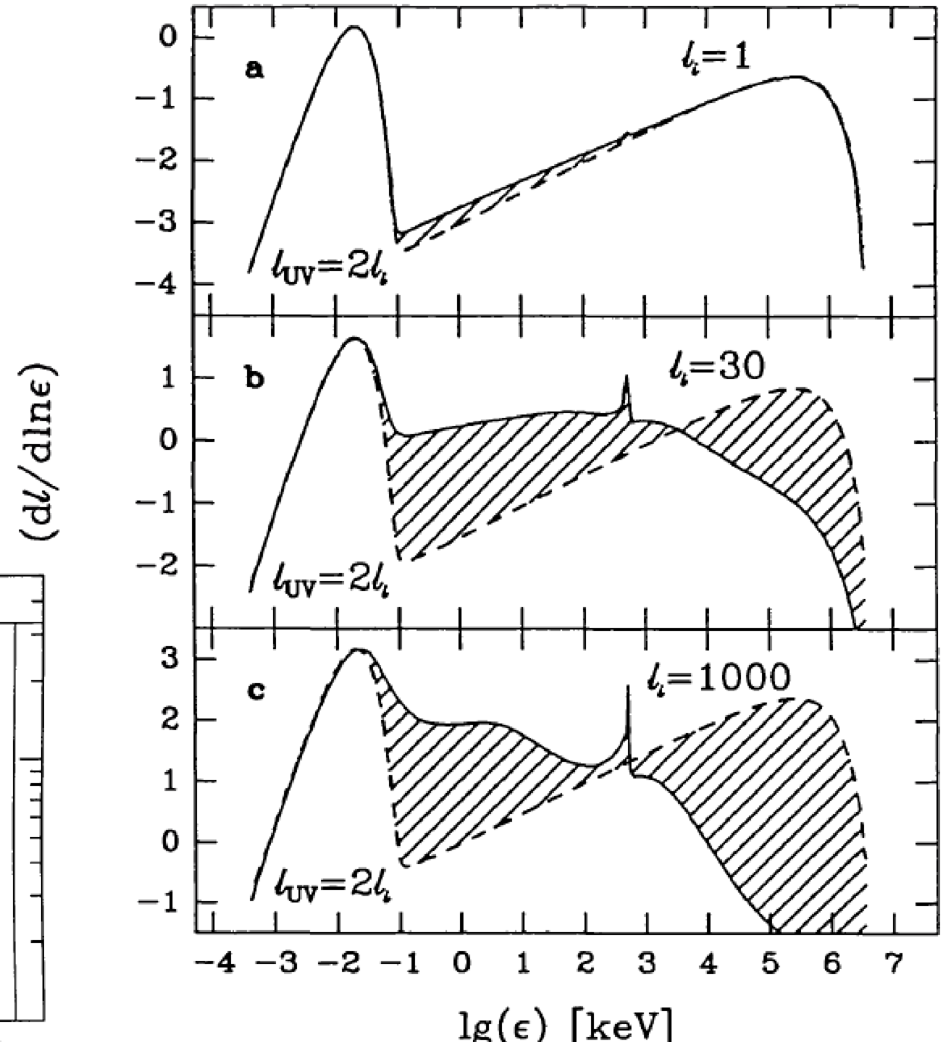
➔ Prominent 511 keV line

- Compactness parameter

$$l \equiv \frac{L}{R}\frac{\sigma_T}{m_e c^3} = \frac{2\pi}{3}\frac{m_p}{m_e}\left(\frac{L}{L_{Edd}}\right)\left(\frac{3R_S}{R}\right) \lesssim 3600\ .$$

- Case of NGC4151 ↓





compactness ↑ → pair cascade

Summary

- Hot accretion flow (ADAF, RIAF) nor disk corona are hard to produce ~1 MeV emission (since $T_e \lesssim m_e c^2/k$)
- Option #1 very hot protons → pion decay→ MeV gamma
  - Challenging to probe very hot protons of $T_p \sim m_p c^2/k$
- Option #2 nonthermal particles in corona (?)
  - Soft-state spectra are with hard X-rays extending to ~1 MeV
- Option #3 jet origin (?)
- 511 keV line emission (?)
- Polarimetry could be a key