High-energy signatures of binary supermassive black holes

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The innermost region of relativistic jets and their magnetic fields

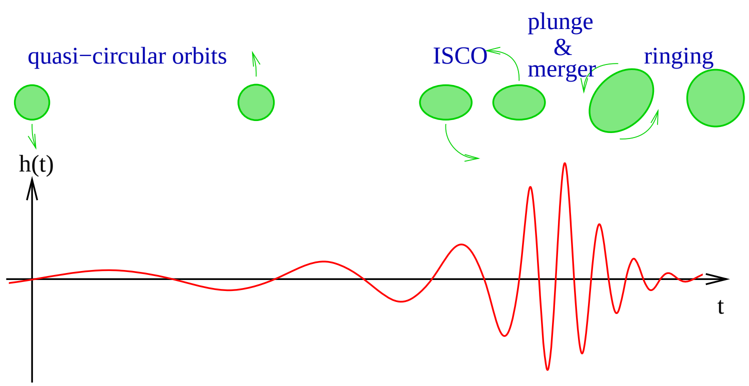
Granada, June 14th 2013

Binary supermassive BHs

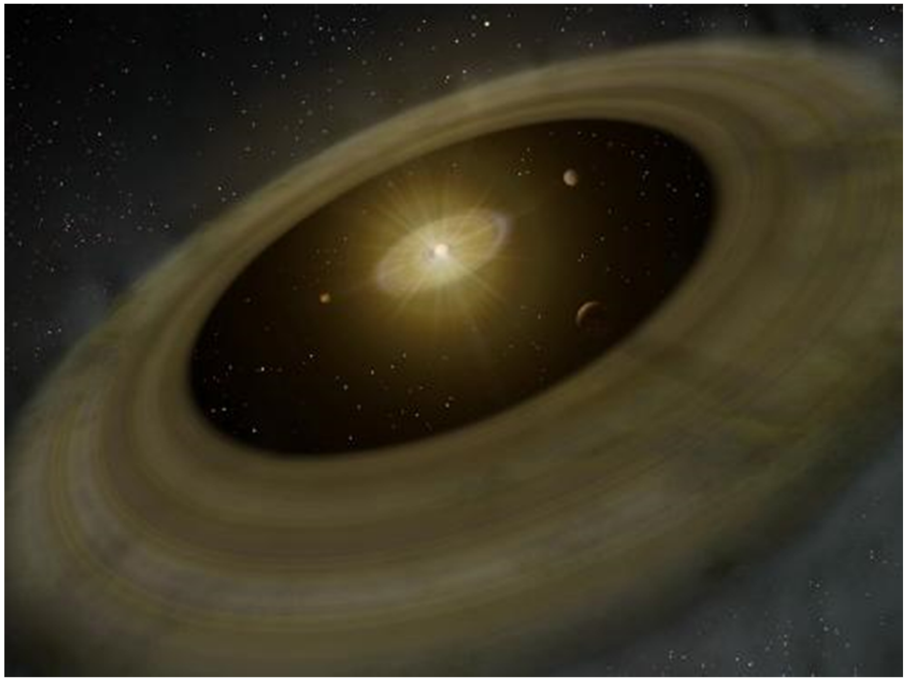
Komossa (2003, 2006)

M. Dotti (2012)

- Late stage (before merger of the BHs) of the merger of two galaxies.
- A few (< 20) have been already identified. Many more candidates.
- Closest known binary separation ~ 7 pc (Rodriguez et al. 2006); several sub-pc separation candidates (e.g. Tsalmantza et al. 2011, Eracleous et al. 2012).
- Interest: merger of two SMBHs is a source of **gravitational waves.**



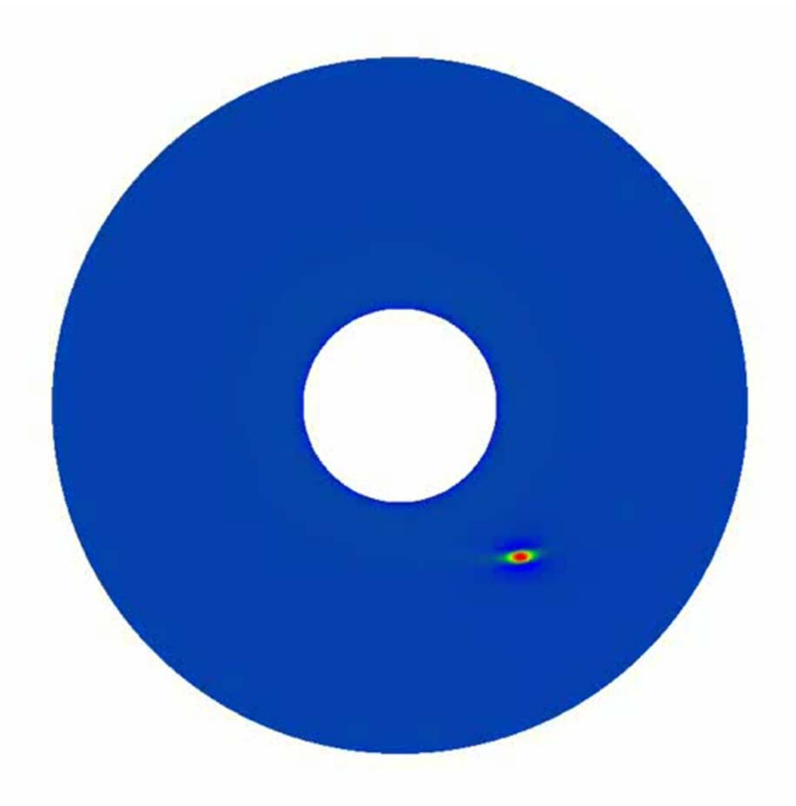
Binary supermassive BHs

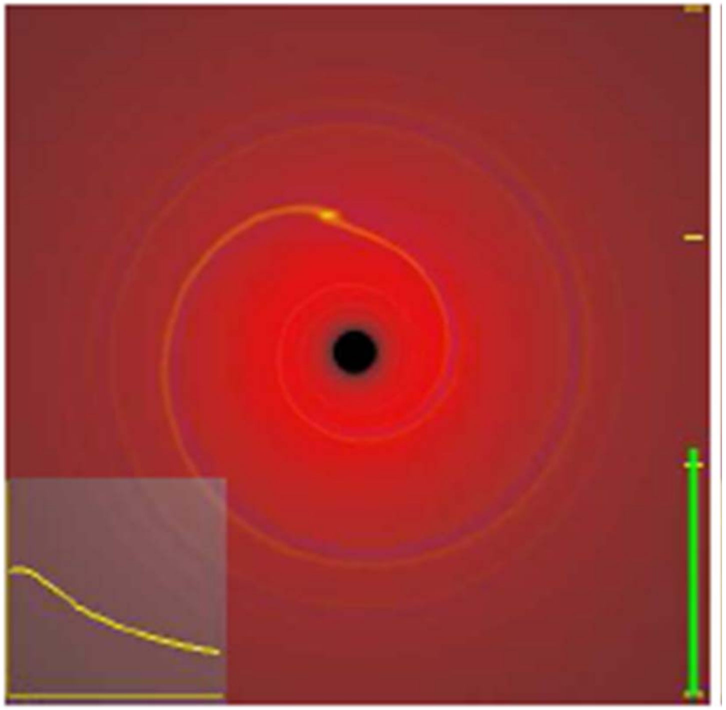


Circumbinary accretion disks

- Results from planetary migration

Type I migration



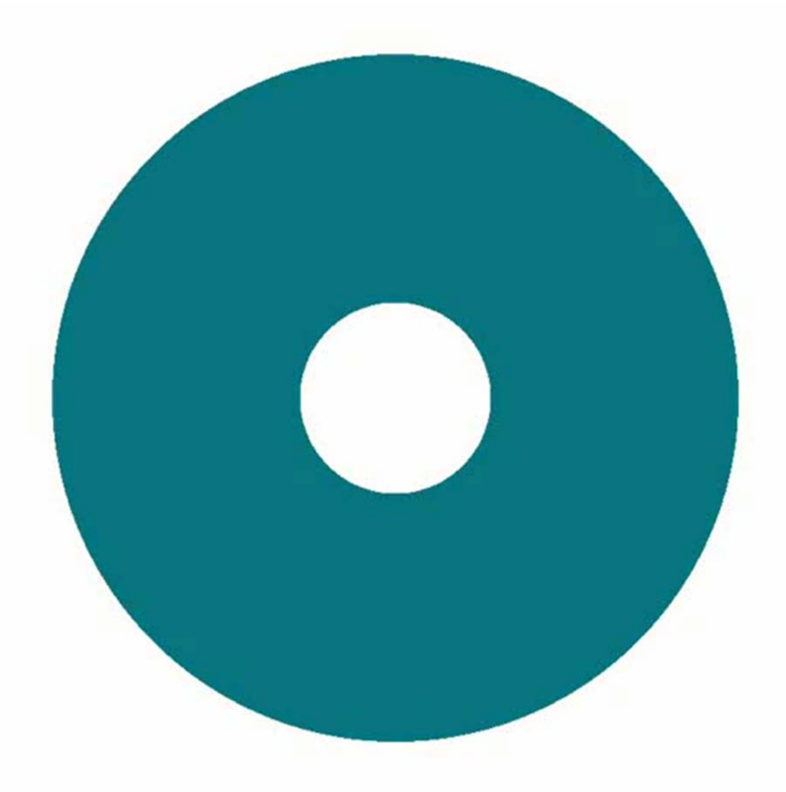


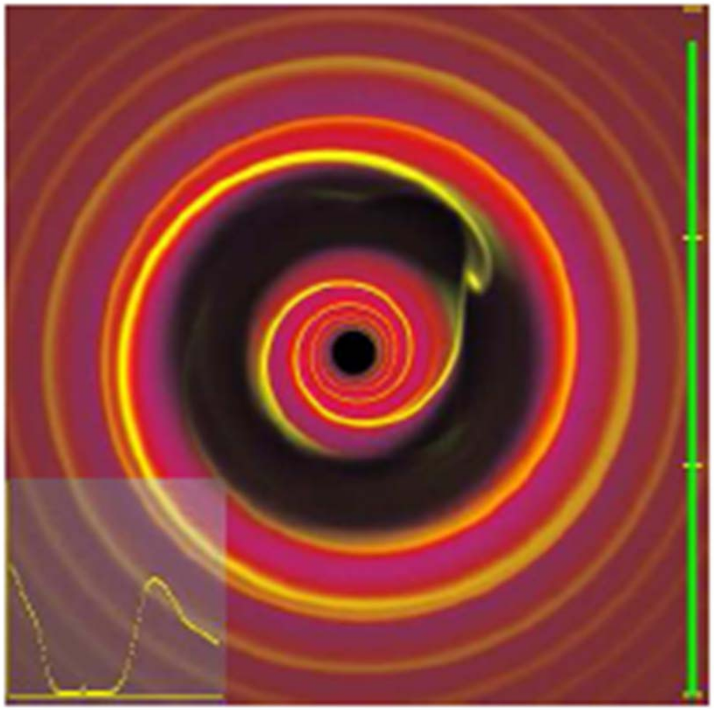
Movie by Hanno Rein, snapshot P. Armitage

Circumbinary accretion disks

- Results from planetary migration

Type II migration

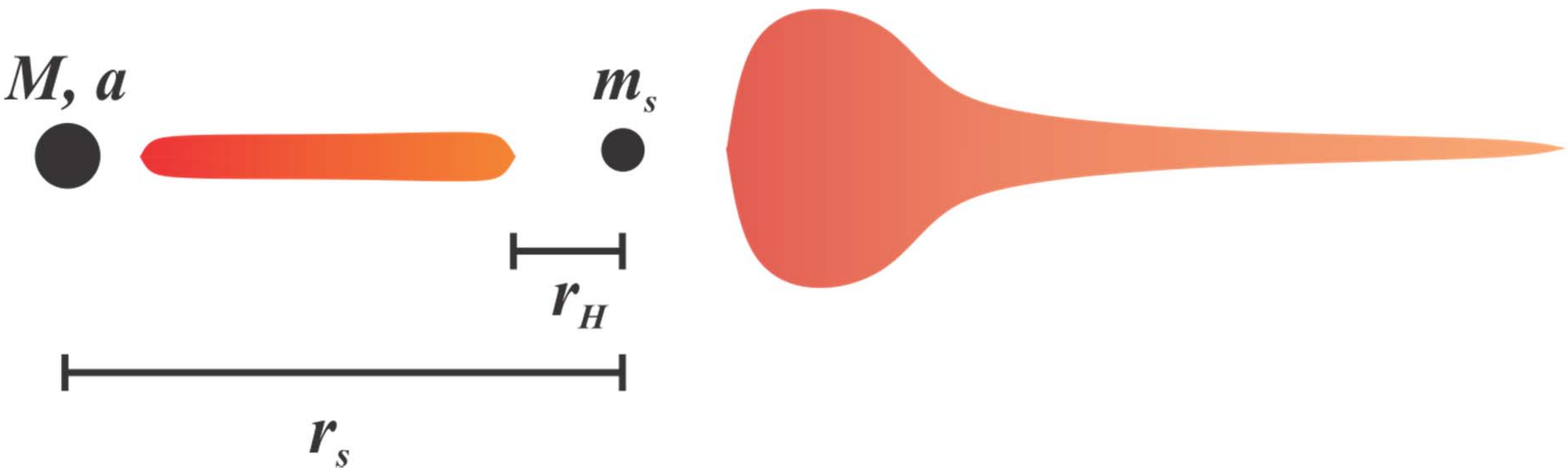




- Disk-dominated
- Secondary-dominated

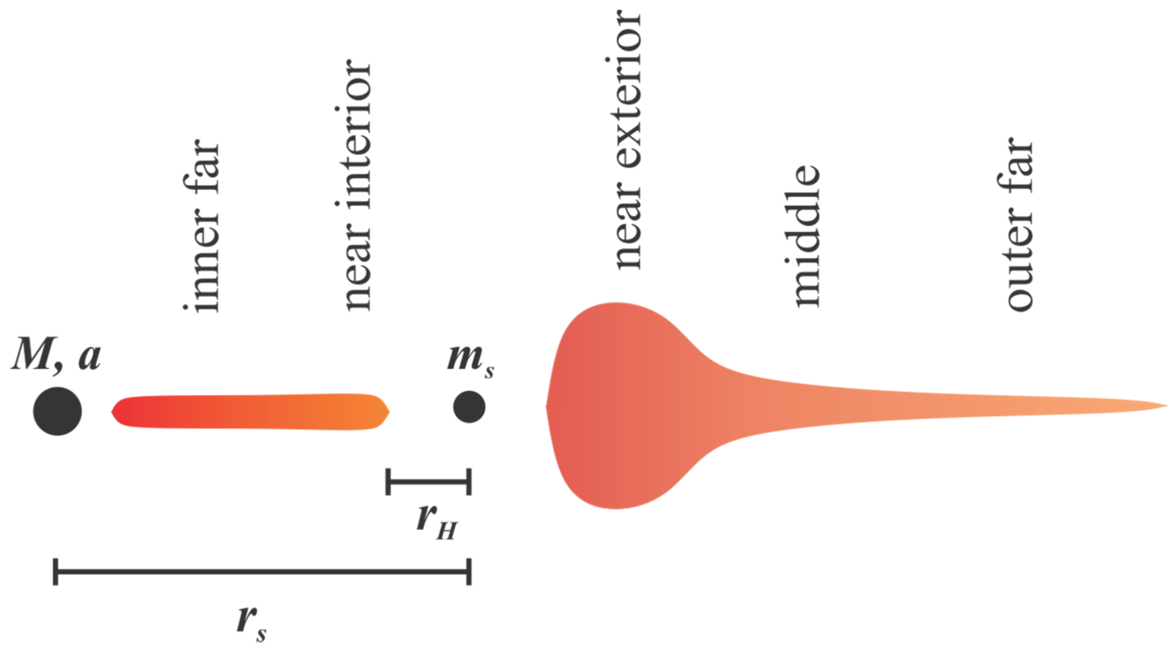
Movie by Hanno Rein, snapshot P. Armitage

Circumbinary accretion disks



$$\Delta r \sim r_H = r_s \left(\frac{q}{3}\right)^{1/3} \qquad q \equiv \frac{m_s}{M}$$

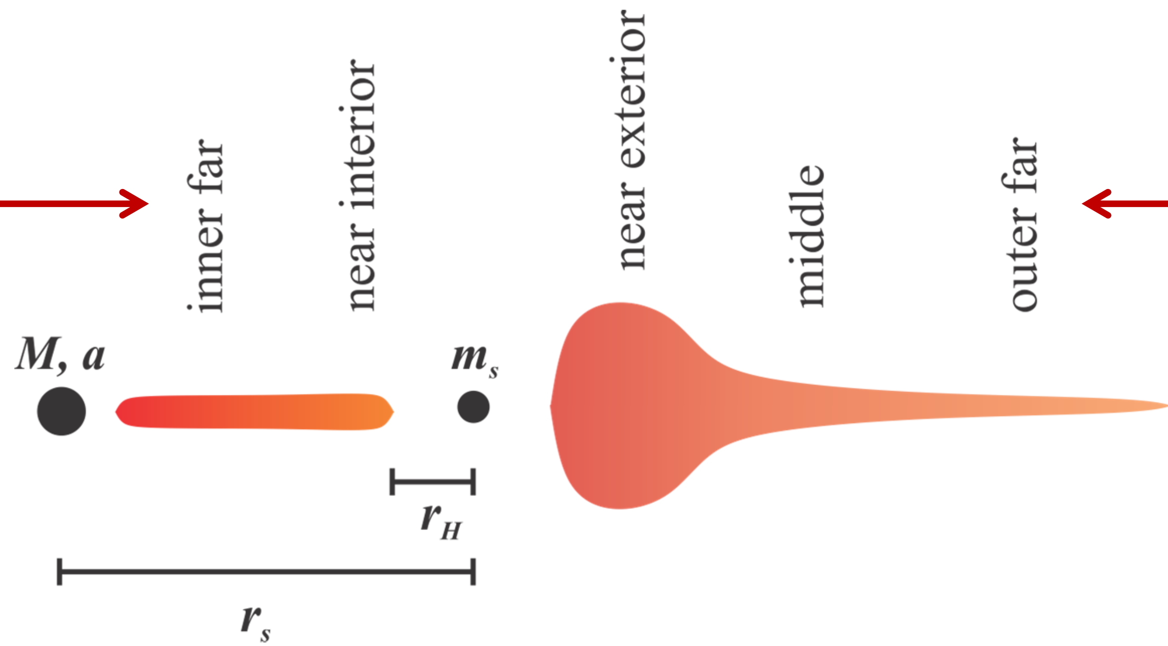
Circumbinary SMBH accretion disks



Kocsis, Haiman & Loeb (2012)

Circumbinary SMBH accretion disks

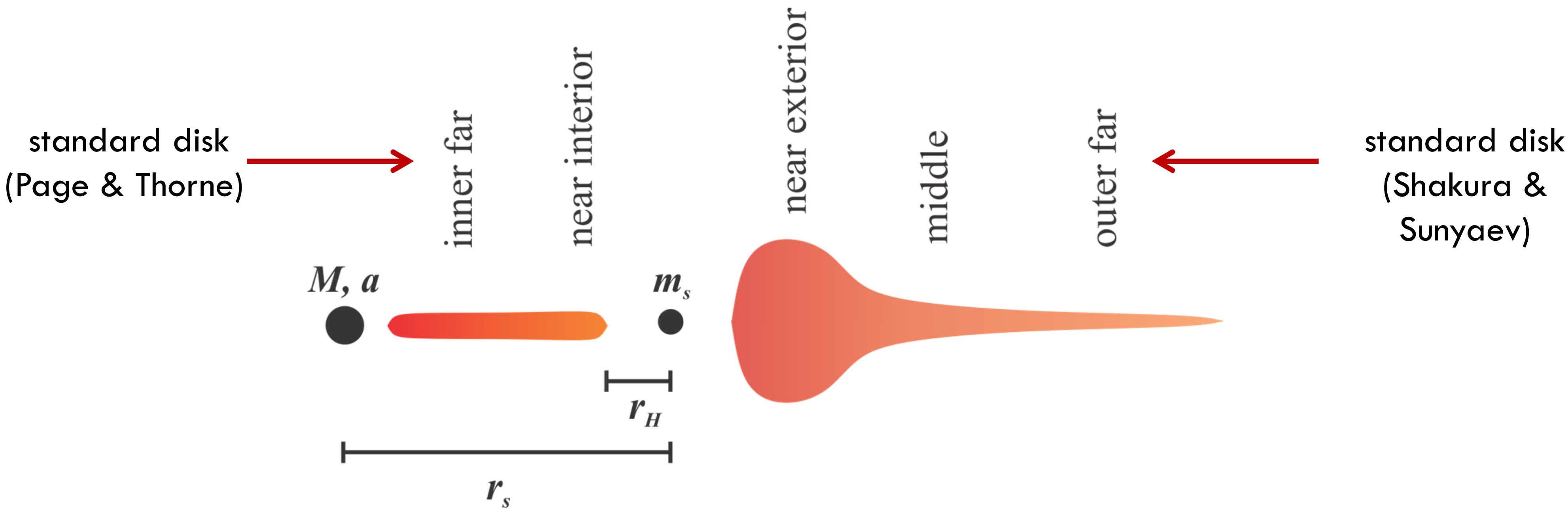
standard disk
(Page & Thorne)



standard disk
(Shakura &
Sunyaev)

Kocsis, Haiman & Loeb (2012)

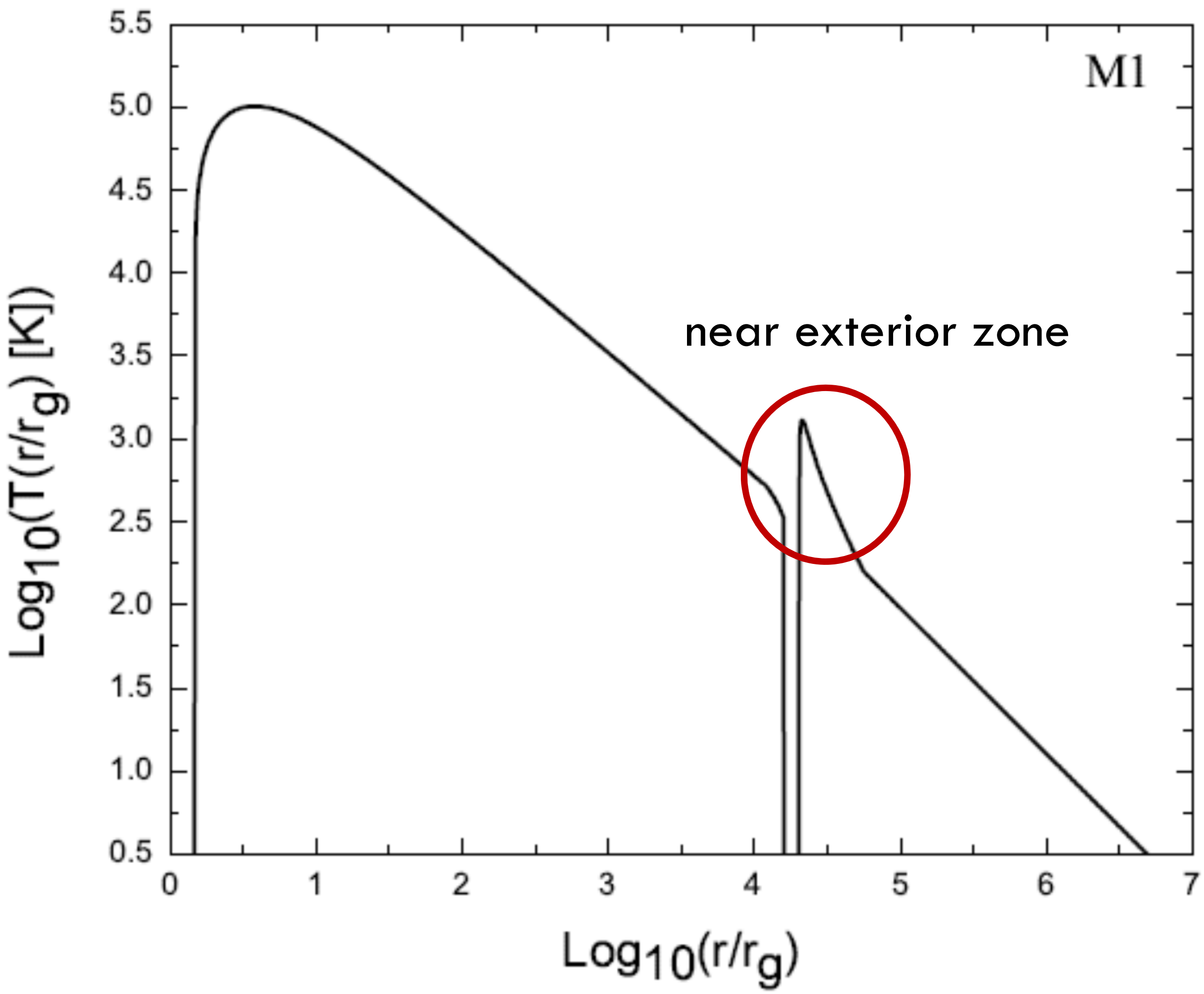
Circumbinary SMBH accretion disks



- $T_{\rm ni} \sim C_{\rm ni}\ r^{-7/16} \left|1 - \frac{r_s}{r}\right|^{1/4}$ $\quad T_{\rm ne} \sim C_{\rm ne}\ r^{-77/96} \left(\frac{r - r_s}{r_s}\right)^{1/4}$ $\quad T_{\rm m} \sim C_{\rm m}\ r^{-7/8}$
- $C_i = C_i(M, q, \dot{M}, \alpha, \ldots)$
- $r_i = r_i(M, q, \dot{M}, \alpha, \ldots)$

Kocsis, Haiman & Loeb (2012)

Disk temperature profiles



$M = 10^7\ M_{\text{sun}}$

$a = 0.99$

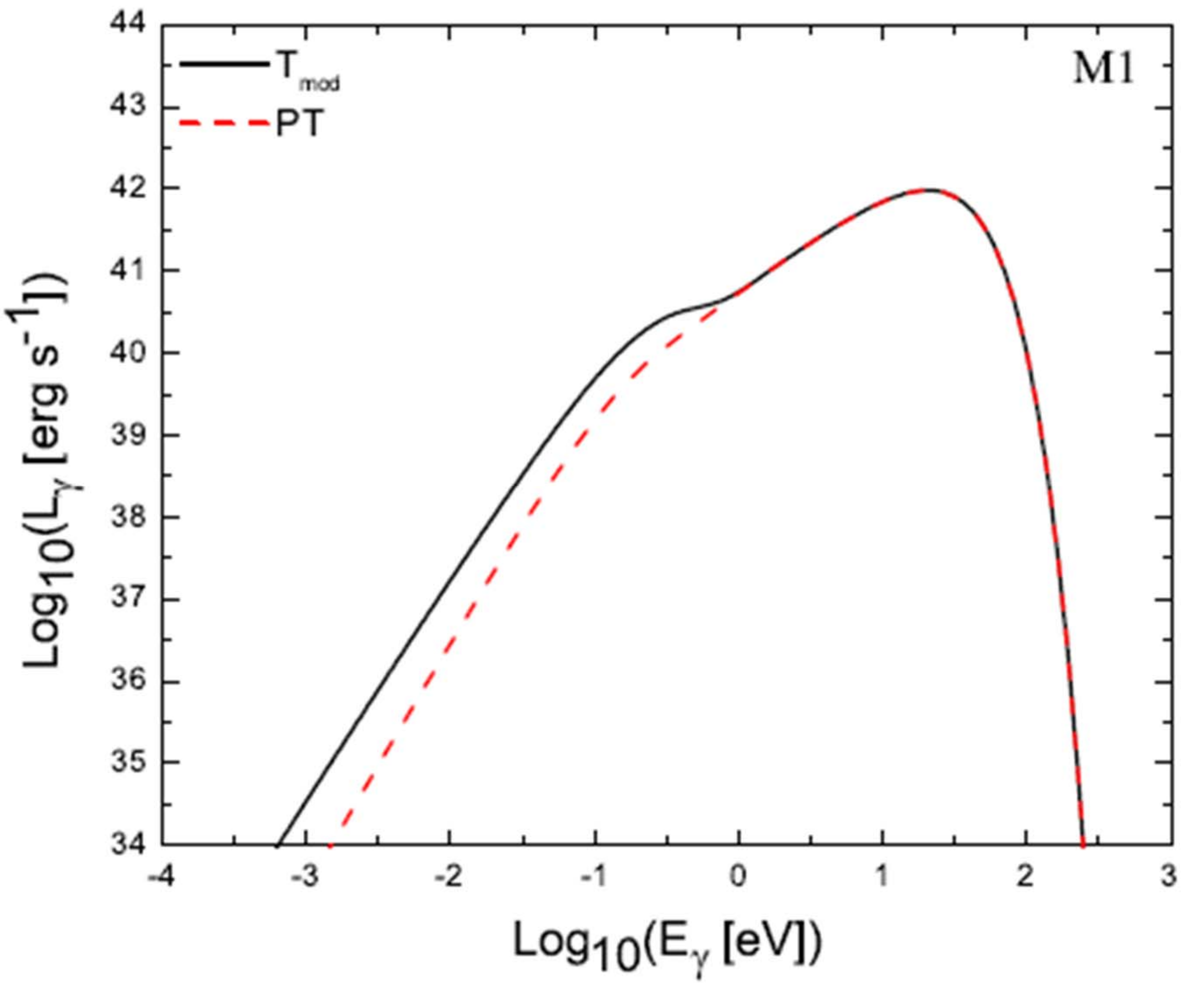
$q = m_s / M = 5.5\text{x}10^{-3}$

$r_s = 18000\ R_{\text{grav}}$

$r_H = 2200\ R_{\text{grav}}$

$dM/dt = 0.1\ (dM/dt)_{\text{Edd}}$

Disk emission spectrum



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$r_s = 18000\ R_{grav}$

$r_H = 2200\ R_{grav}$

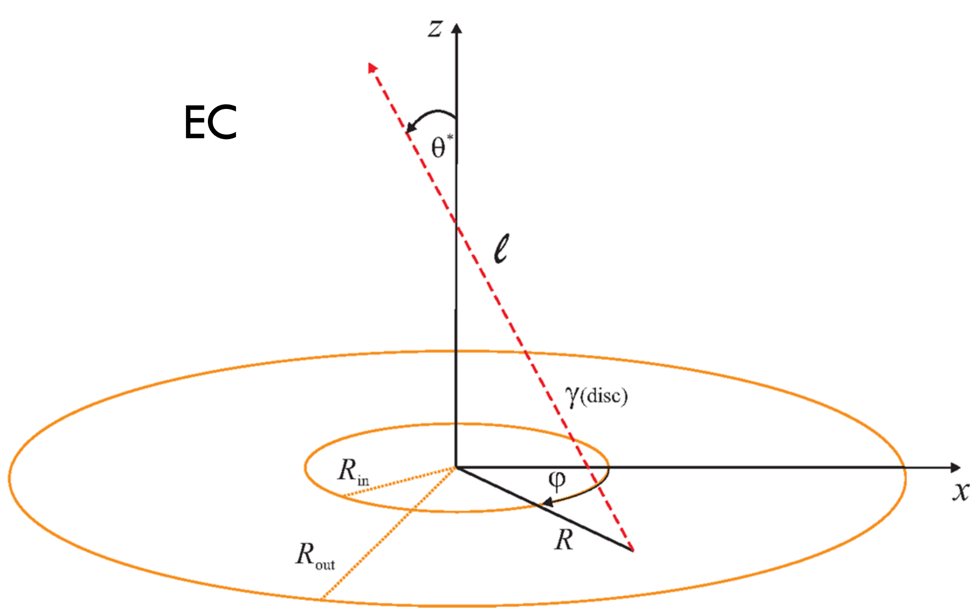
$\mathrm{d}M/\mathrm{d}t = 0.1\ (\mathrm{d}M/\mathrm{d}t)_{Edd}$

See also, e.g., Gültekin & Miller (2012)

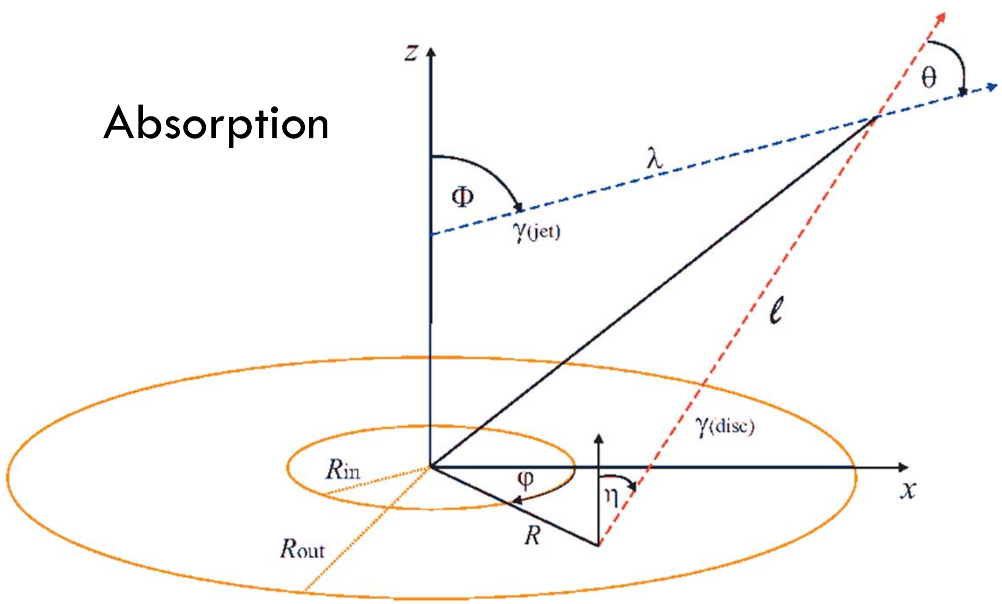
Any signature in the jet's SED?

We have studied the **inverse Compton** interaction of **photons from the disk** with a population of **non-thermal electrons in the jet** (external inverse Compton, EC).

- The disk photon field is **anisotropic** as seen from the jet frame.



$$\gamma_{\rm d} + e_{\rm jet} \longrightarrow \gamma + e$$



$$\gamma_{\rm d} + \gamma_{\rm jet} \longrightarrow e^{+} + e^{-}$$

Disk emission spectrum

- Conditions for «overflowing regime»

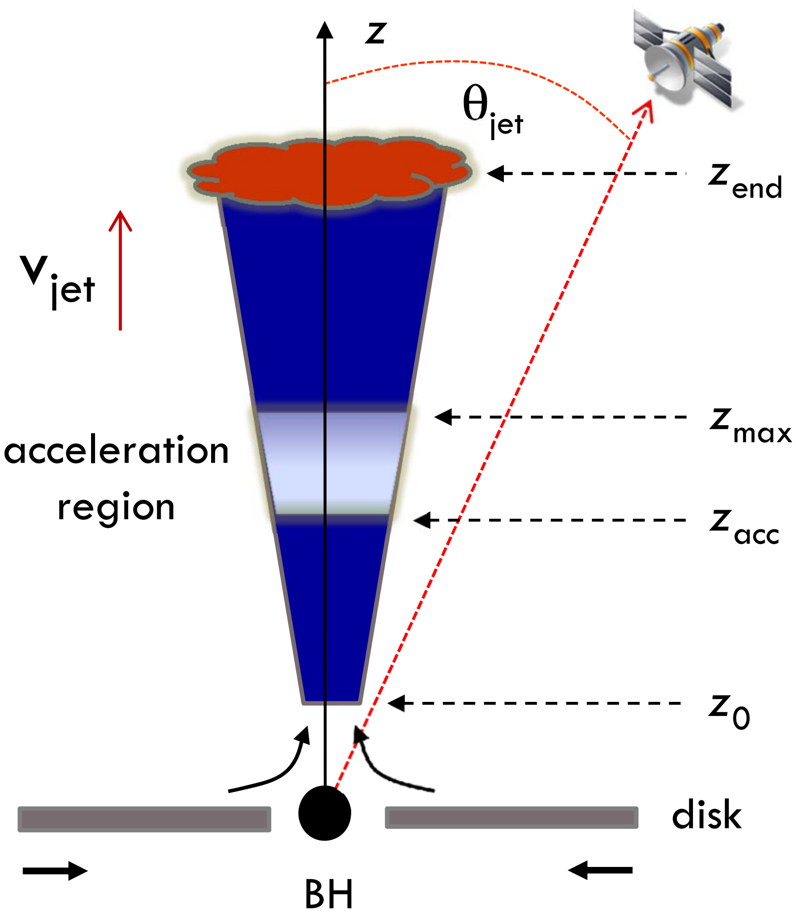
Model	$M_\bullet$	q	r_s	$\dot{M}$	$\dot{M}_{Edd}$	r_H	r_{in}	r_{out}	r_{ni}	r_{neu}
M1	10^7	$5.50\ 10^{-3}$	18000	$0.15\ 10^{24}$	$0.15\ 10^{25}$	2203.03	15796.97	20203.03	11735.10	56309.40
M2	$5\ 10^7$	$3.00\ 10^{-3}$	3400	$0.72\ 10^{24}$	$0.72\ 10^{25}$	340	3060	3740	2355.30	9266.04
M3	10^8	$2.38\ 10^{-3}$	1500	$0.15\ 10^{25}$	$0.15\ 10^{26}$	138.86	1361.14	1638.86	1056.43	3944.98
M4	$5\ 10^8$	$1.28\ 10^{-3}$	280	$0.72\ 10^{25}$	$0.72\ 10^{26}$	21.08	258.92	301.08	208.35	643.95

➡ the «gap» or «ring» becomes narrower as M increases

Jet model

Adapted from Romero & Vila (2008)

Vila et al. (2012)



- Jet power

$$L_{\rm accr} = \dot{M}c^2 = q_{\rm accr} L_{\rm Edd}$$

$$L_{\rm jet} = L_{\rm B} + L_{\rm m} + L_{\rm k} = q_{\rm jet}\, L_{\rm accr} \quad q_{\rm jet} < 1$$

- Non-thermal particles

$$L_{\rm rel} = q_{\rm rel} L_{\rm jet} \qquad q_{\rm rel} \ll 1$$

$$L_{\rm rel} = L_p + L_e$$

- Injection function [cm^{-3} erg^{-1} s^{-1}]

$$Q(E) \propto Q_0\, E^{-\alpha} \qquad 1.4 \lesssim \alpha \lesssim 2.4$$

$$E_{\rm min} \le E \le E_{\rm max}$$

Jet model

Adapted from Romero & Vila (2008)

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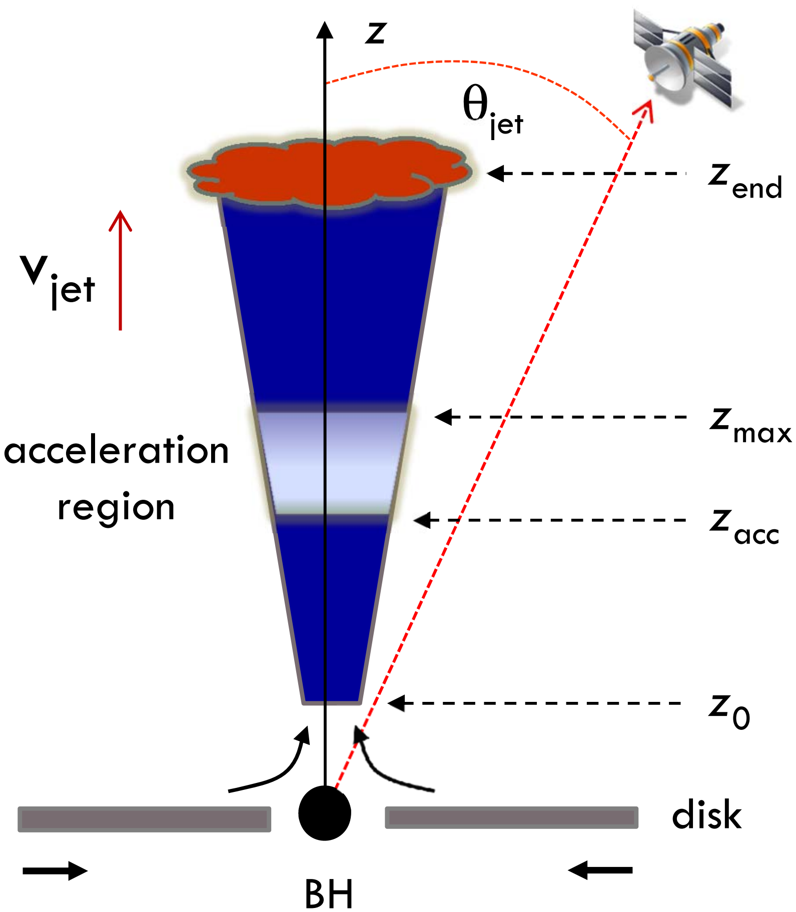

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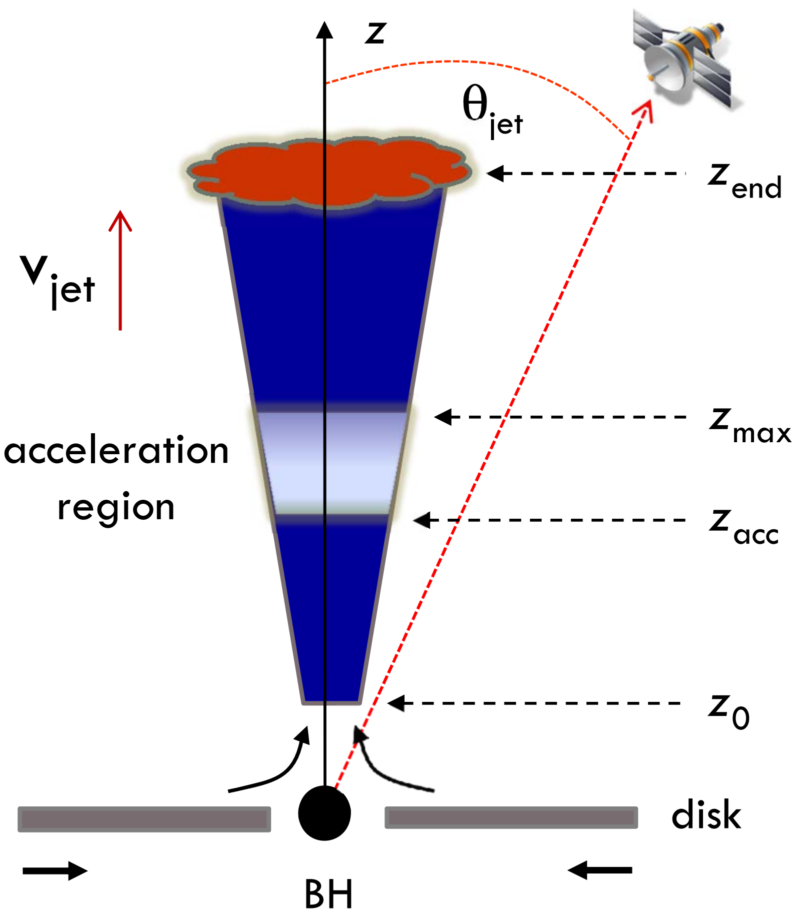

- Jet power

$$L_{accr} = \dot{M}c^2 = q_{accr} L_{Edd}$$

$$L_{jet} = L_B + L_m + L_k = q_{jet}\, L_{accr} \quad q_{jet} < 1$$

- Non-thermal particles

$$L_{rel} = q_{rel} L_{jet} \qquad q_{rel} \ll 1$$

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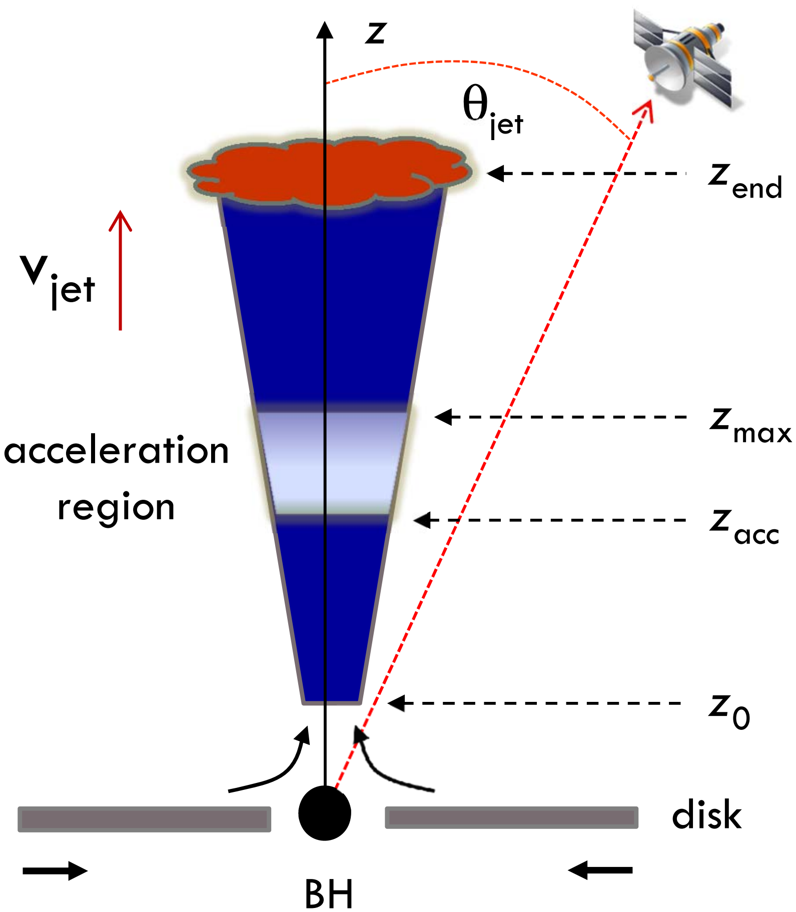
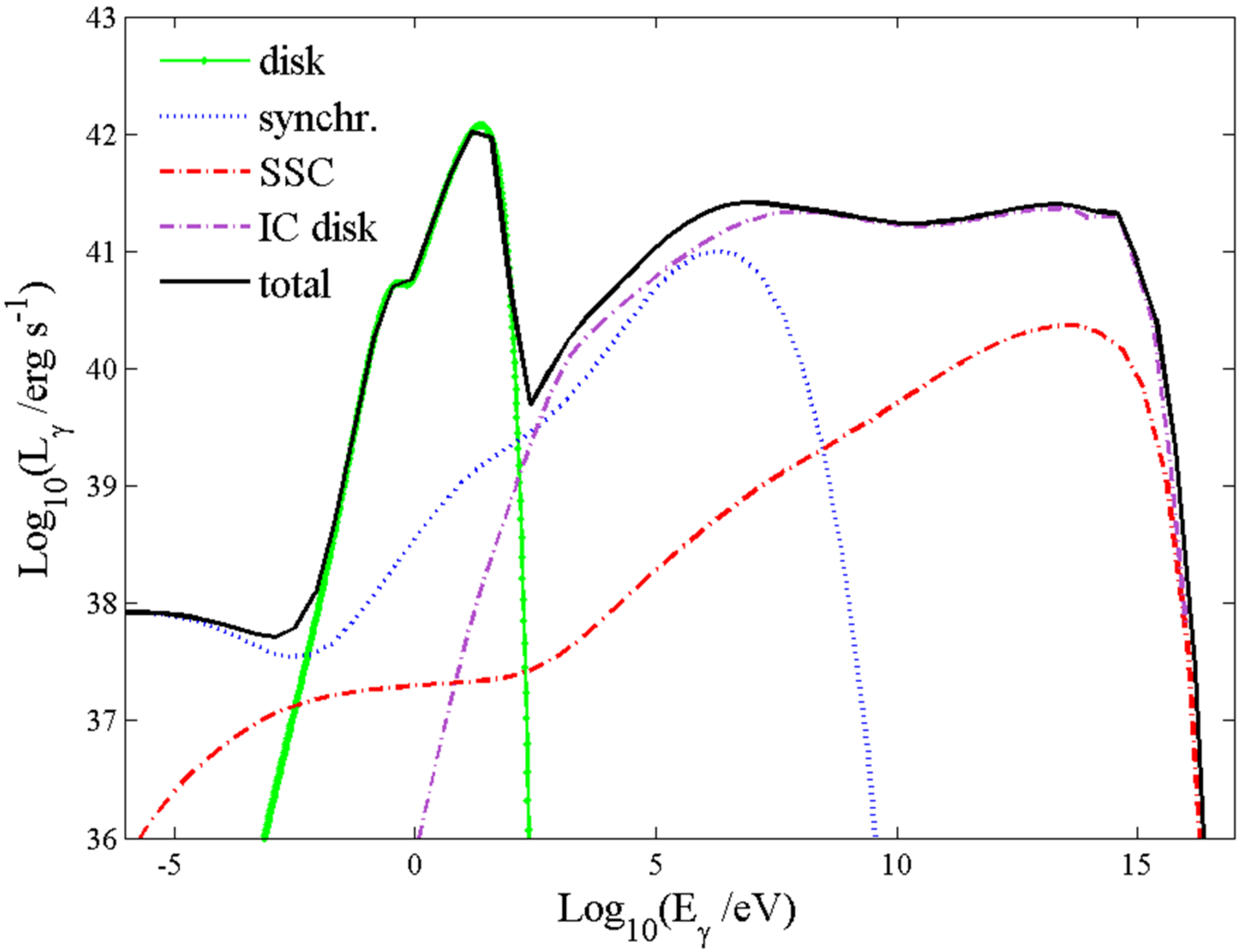


- Steady-state particle distribution [cm^{-3} erg^{-1}]

$$v_{\text{jet}} \frac{\partial N}{\partial z} + \frac{\partial}{\partial E}\left(\frac{dE}{dt} N\right) = Q$$

- Energy losses
  - Adiabatic losses
  - Relativistic Bremsstrahlung
  - Synchrotron radiation
  - Inverse Compton
    - Disk photons (EIC)
    - Synchrotron photons (SSC)

SEDs



$M = 10^7\ M_{\rm Sun}$

$q = m_s / M = 5.5\text{x}10^{-3}$

$r_s = 18000\ R_{\rm grav}$

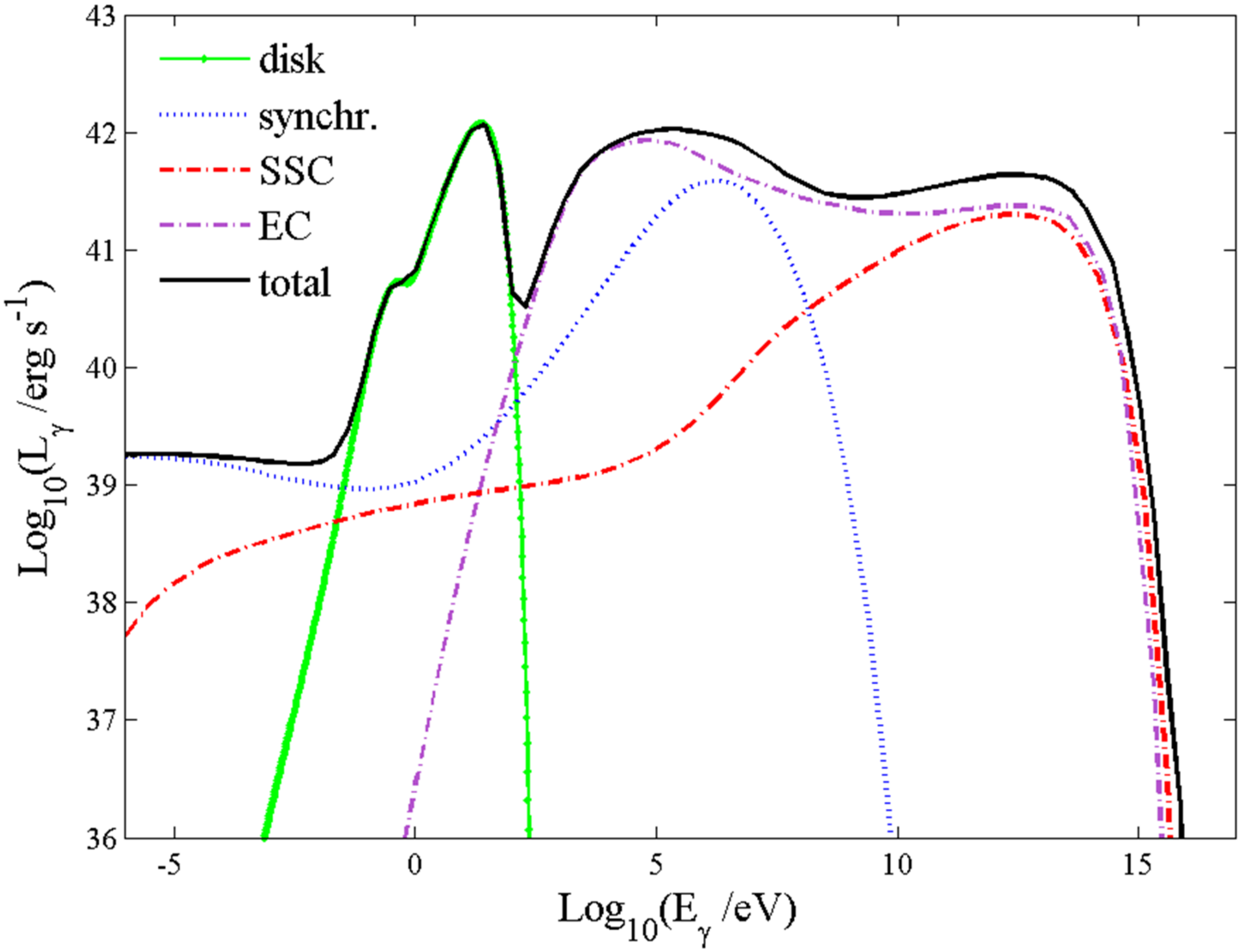
$\theta_{\rm jet} = 5°$

$\Gamma_{\rm jet} = 20$

$z_{\rm acc} \sim 670\ R_{\rm grav}$

$B(z_{\rm acc}) \sim 4\text{x}10^{-2}$ G

SEDs



$M = 10^7\ M_{Sun}$

$q = m_s/M = 5.5x10^{-3}$

$r_s = 18000\ R_{grav}$

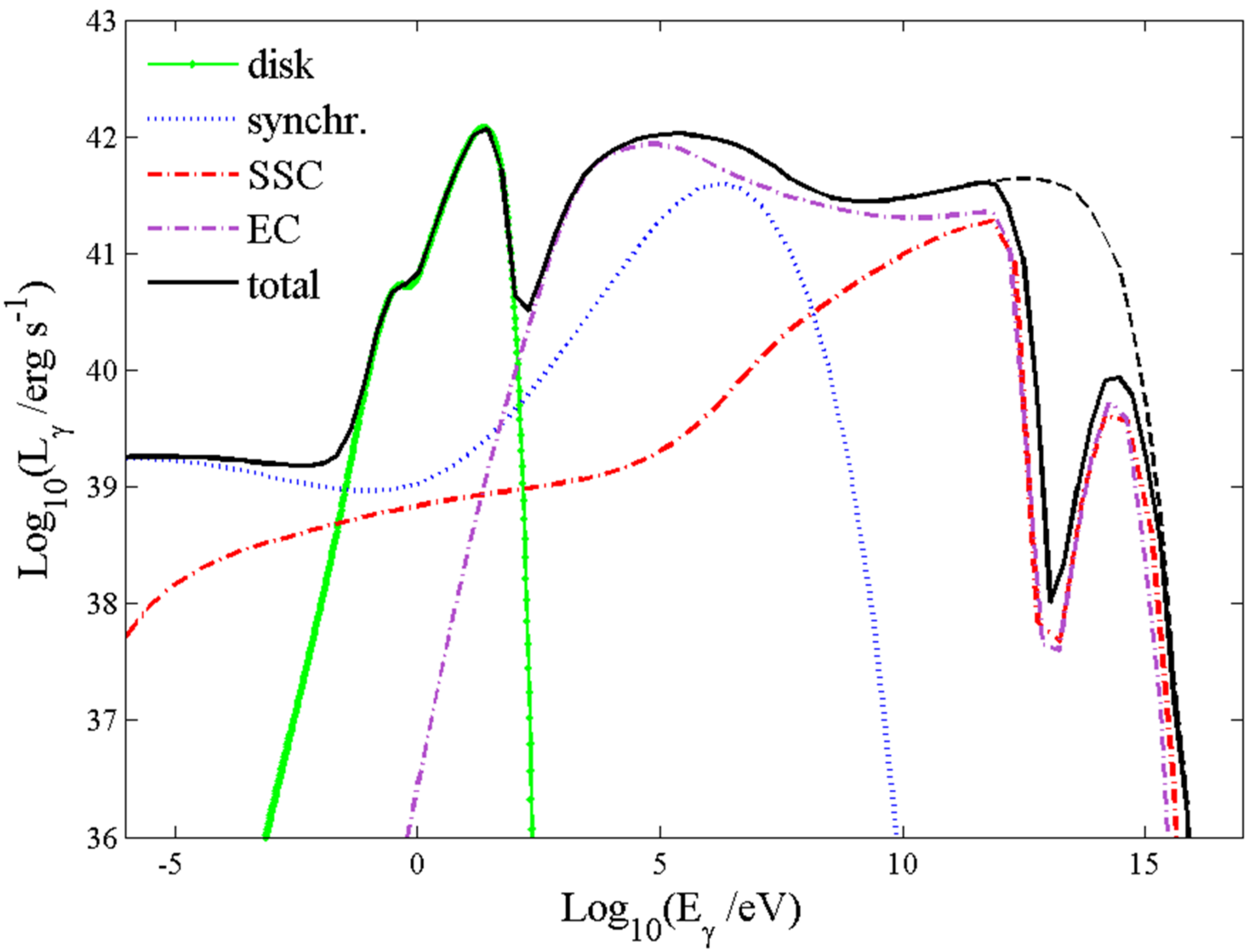
$\theta_{jet} = 5°$

$\Gamma_{jet} = 20$

$z_{acc} \sim 67\ R_{grav}$

$B(z_{acc}) \sim 2$ G

SEDs



$M = 10^7\ M_{\rm Sun}$

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$r_{\rm s} = 18000\ R_{\rm grav}$

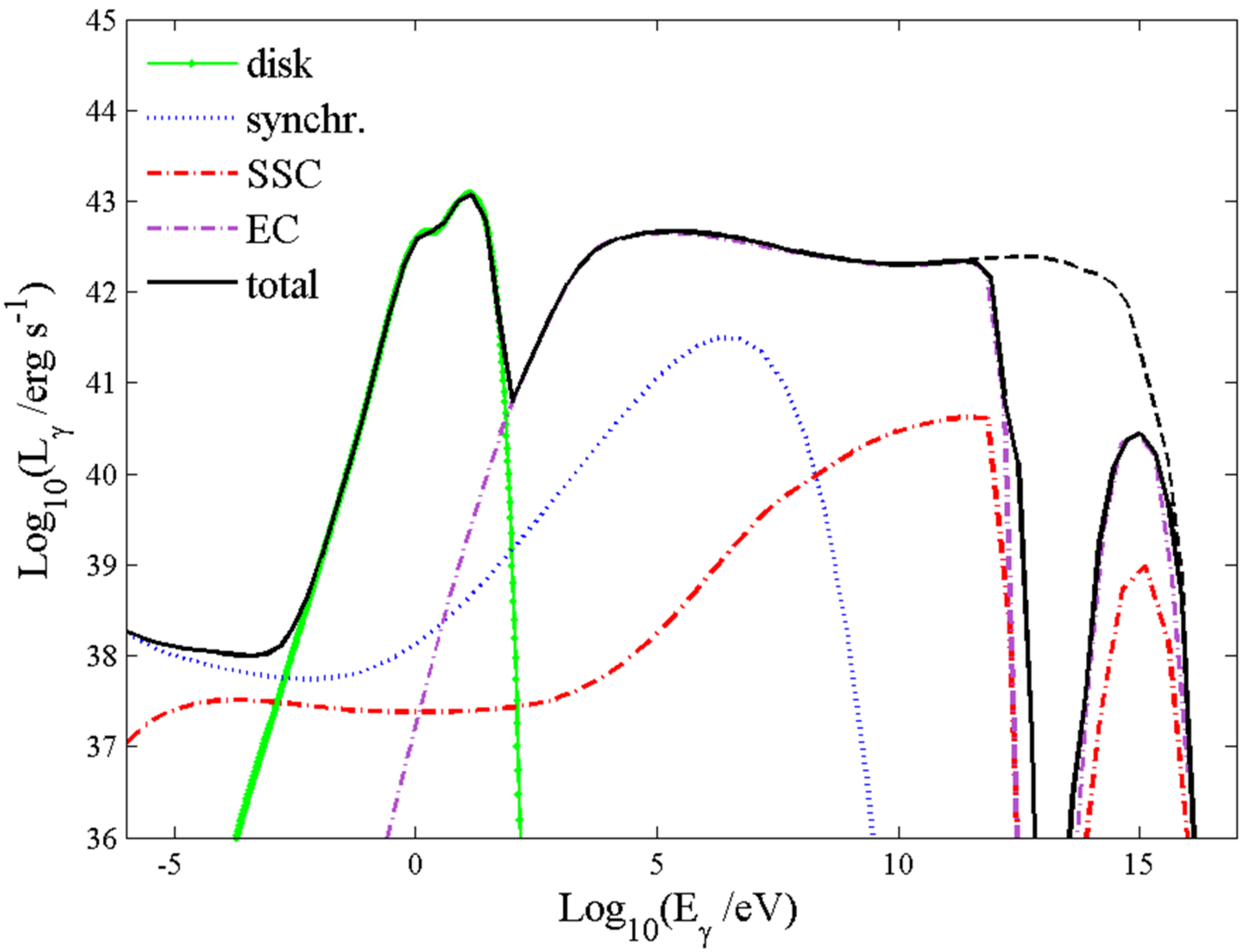
$\theta_{\rm jet} = 5°$

$\Gamma_{\rm jet} = 20$

$z_{\rm acc} \sim 67\ R_{\rm grav}$

$B(z_{\rm acc}) \sim 2$ G

SEDs



$M = 10^8\ M_{Sun}$

$q = m_s / M = 2.4\text{x}10^{-3}$

$r_s = 1500\ R_{grav}$

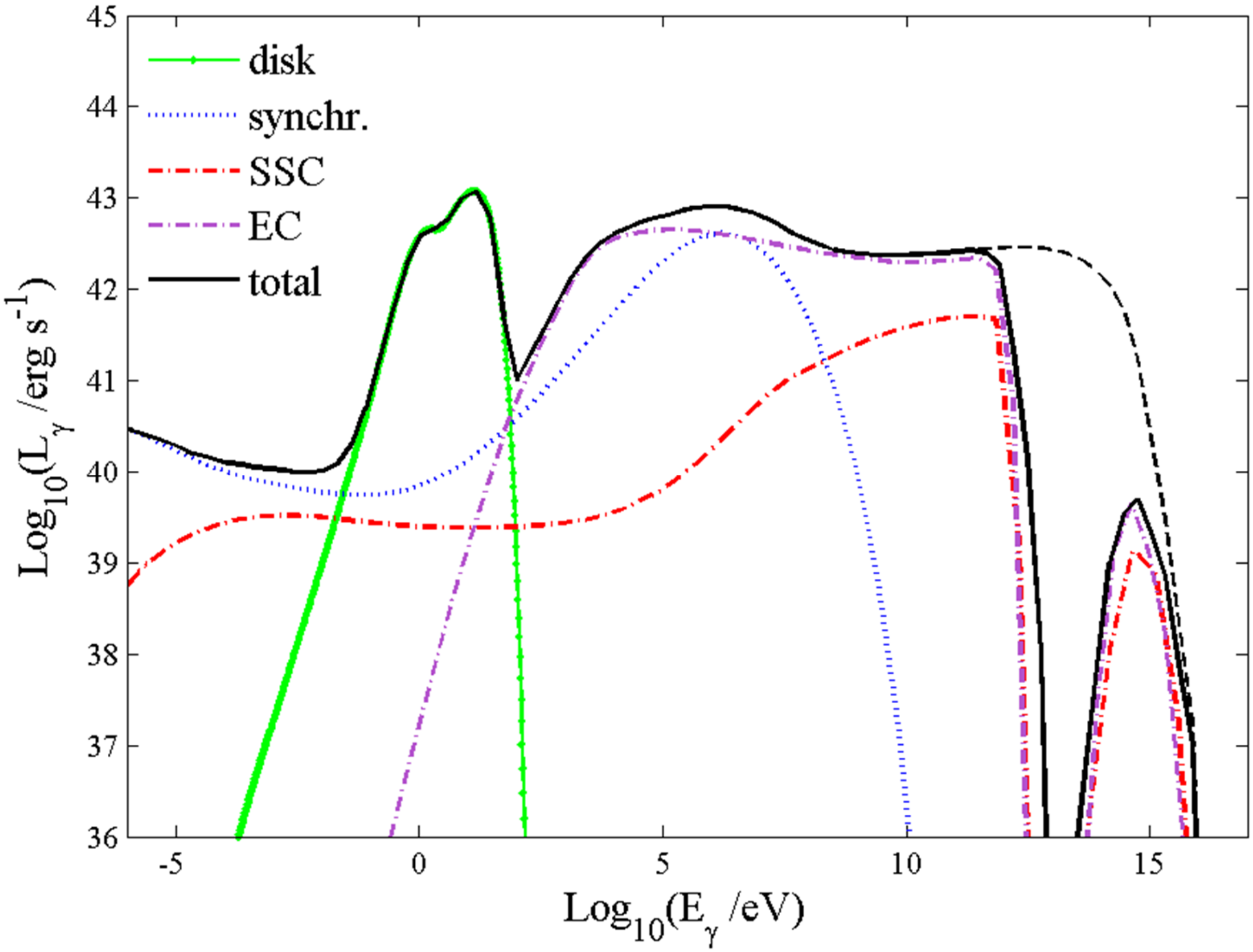
$\theta_{jet} = 5°$

$\Gamma_{jet} = 20$

$z_{acc} \sim 67\ R_{grav}$

$B(z_{acc}) \sim 0.1$ G

SEDs



$M = 10^8\ M_{Sun}$

$q = m_s/M = 2.4\text{x}10^{-3}$

$r_s = 1500\ R_{grav}$

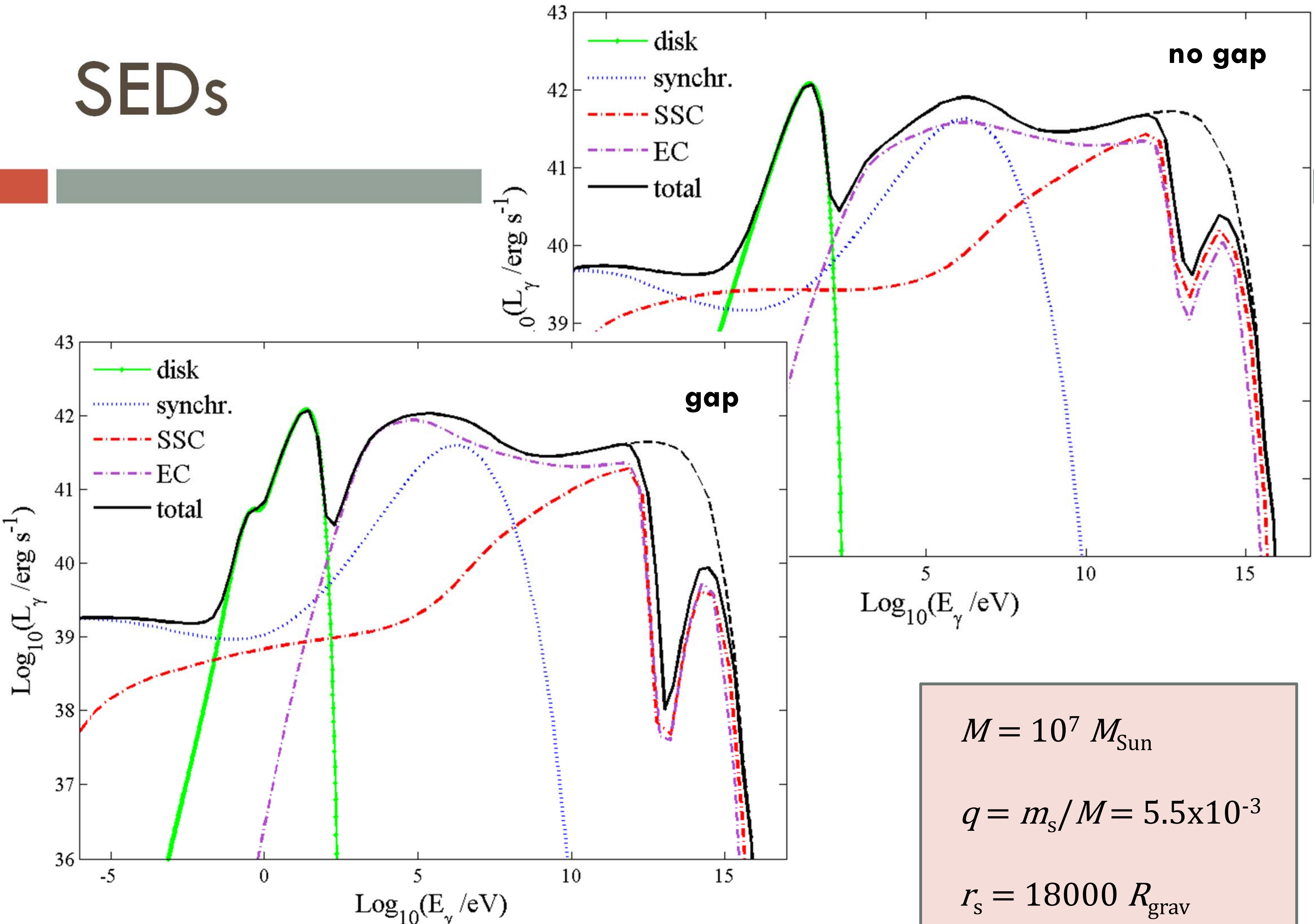
$\theta_{jet} = 5°$

$\Gamma_{jet} = 20$

$z_{acc} \sim 67\ R_{grav}$

$B(z_{acc}) \sim 1.3$ G

SEDs



$M = 10^7\ M_{Sun}$

$q = m_s / M = 5.5x10^{-3}$

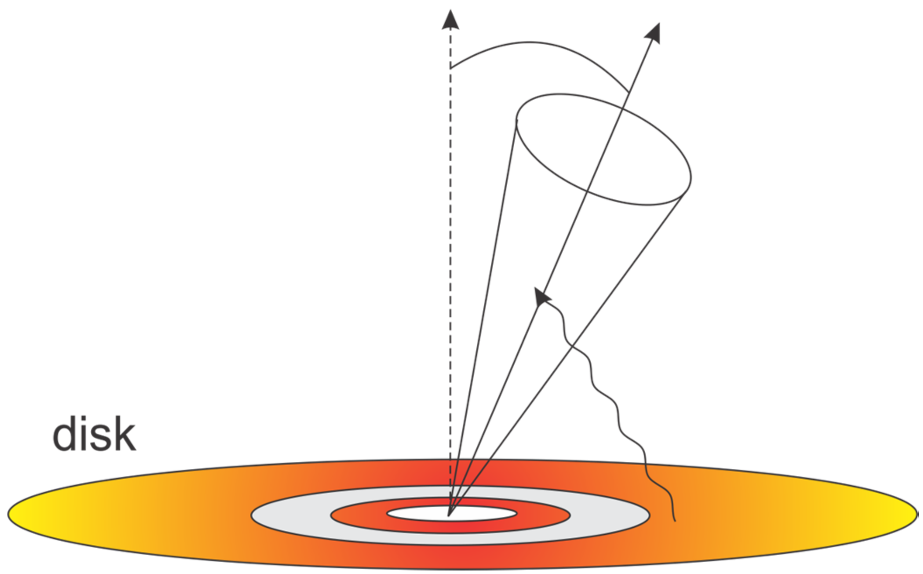
$r_s = 18000\ R_{grav}$

(instead of) Conclusions

- No clear signatures revealing the presence of the secondary in the EC spectrum of the jet of the primary SMBH.

- Two more things to try:

1. **Misaligned jet**



2. **Intermediate-mass primary** (10^3-10^4 M_{Sun}) $\Longrightarrow$ **wider «gap»** expected