Chapter 8

Black Hole Gap Emission from Supermassive BHs

§1 VHE observations of Active Galactic Nuclei (AGNs)

§ 1 VHE observations of AGNs

So far, IACTs have detected 52 AGNs in VHE. Most of them are blazers, while five are non-blazers.

Fig.) Examples of Imaging **Atmospheric Cherenkov telescopes (IACTs).**

Upper: **MAGIC** (Major Atmospheric Gamma Imaging Cherenkov).

Lower: **CTA** (Cherenkov Telescope Array; *image*)

§ 1 VHE observations of AGNs

So far, IACTs have detected 52 AGNs in VHE. Most of them are blazers, while five are non-blazers.

Blazer jets are strongly beamed towards us, masking the faint central region near the BH.

Non-blazer jets are beamed away from our L.O.S. Thus, the central regions are more easily investigated.

Among them, IC310 and M87 exhibit horizon-scale rapid variability in VHE (Abramowski+ 2012, ApJ, 746, 151; Aleksić+ 2014, Sci 346, 1080, 2014).

In this talk, I thus focus on the horizon-scale VHE emission from such low luminosity AGNs.

§ 1 VHE observations of AGNs

For SMBHs, HE & VHE emissions are expected in the shock-in-jet model.

Marscher & Gear 1985, ApJ 298, 114

HE/VHE flux increases w/ increasing $\dot{M}$.

However, VHE emissions are also predicted to be emitted from the BH-gaps of SMBHs.

KH & Pu 2016, ApJ 818, 50; KH + 2016, ApJ 833, 142

VHE flux increases w/ decreasing $\dot{M}$.

We will focus on the BH-gap model and discuss its theoretical predictions.

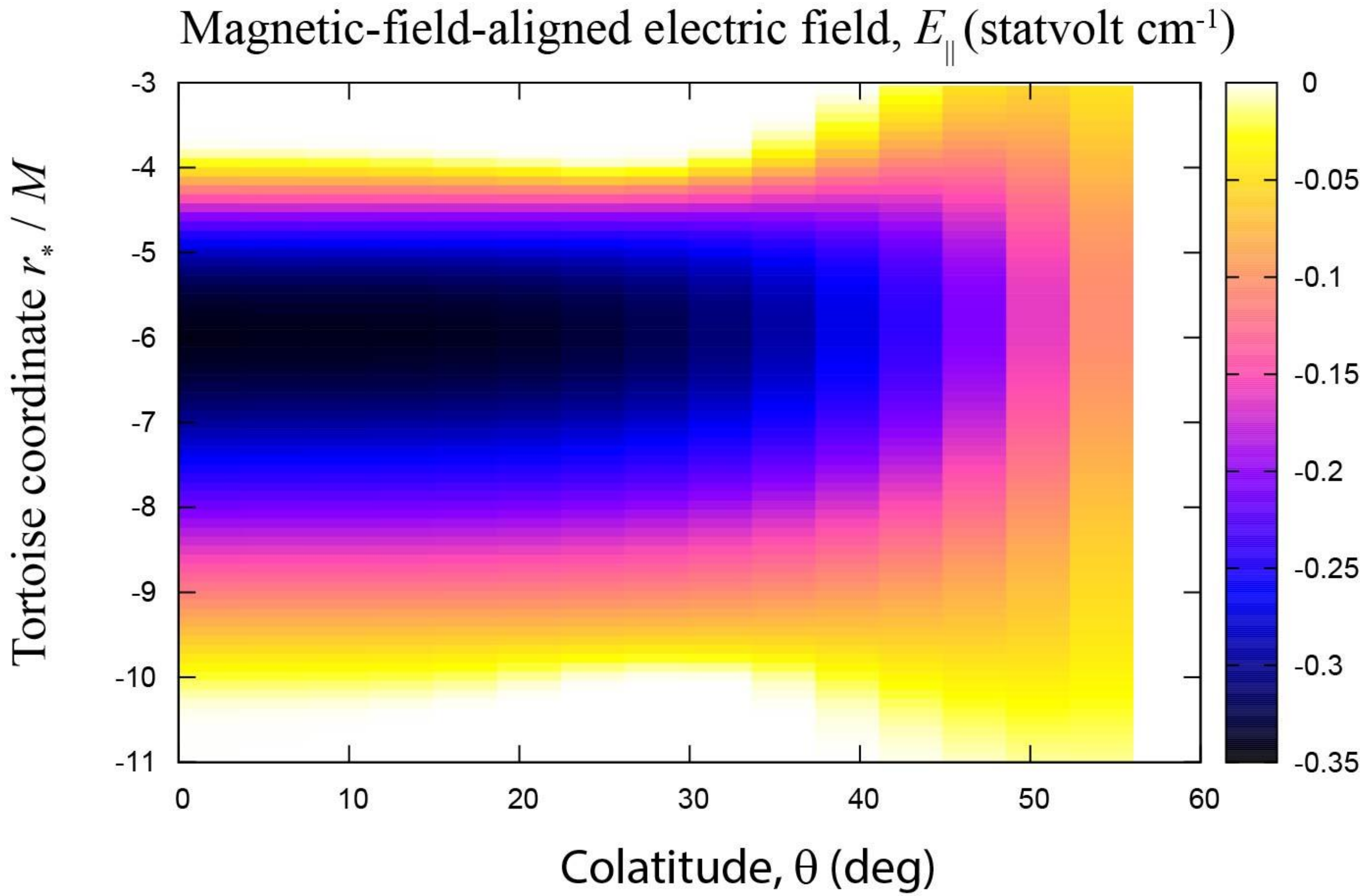
§ 2 BH gap: the case of billion solar mass

§2 BH gap: the case of billion solar masses

$E_{||}$ distribution on (r, θ) plane.

Polar funnel is bounded with ADAF at θ=60°.

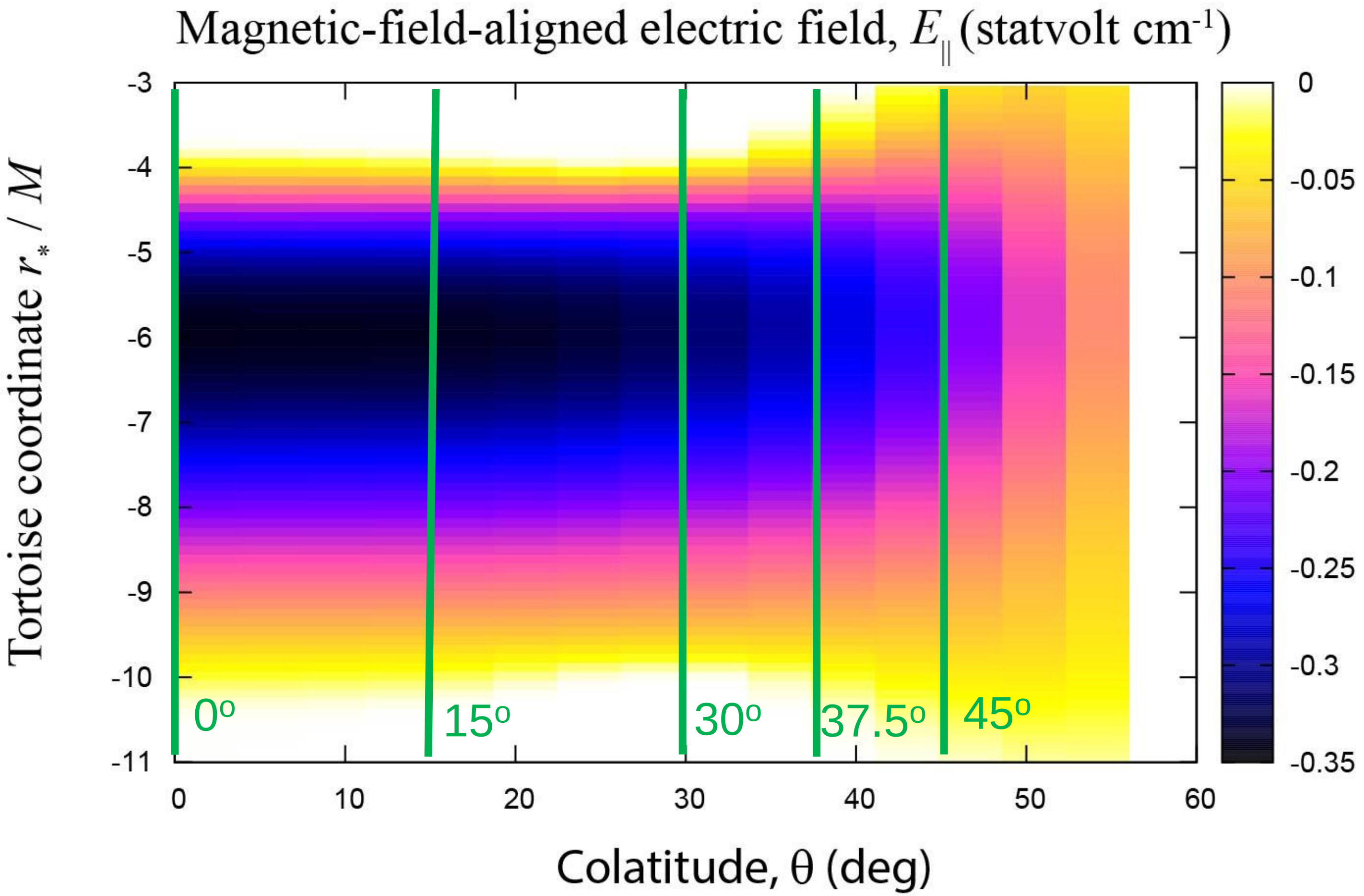
$M=10^9 M_\odot$ and $a=0.90M$. $\dot{m}=1.8\times10^{-5}$.



§ 2 BH gap: the case of billion solar masses

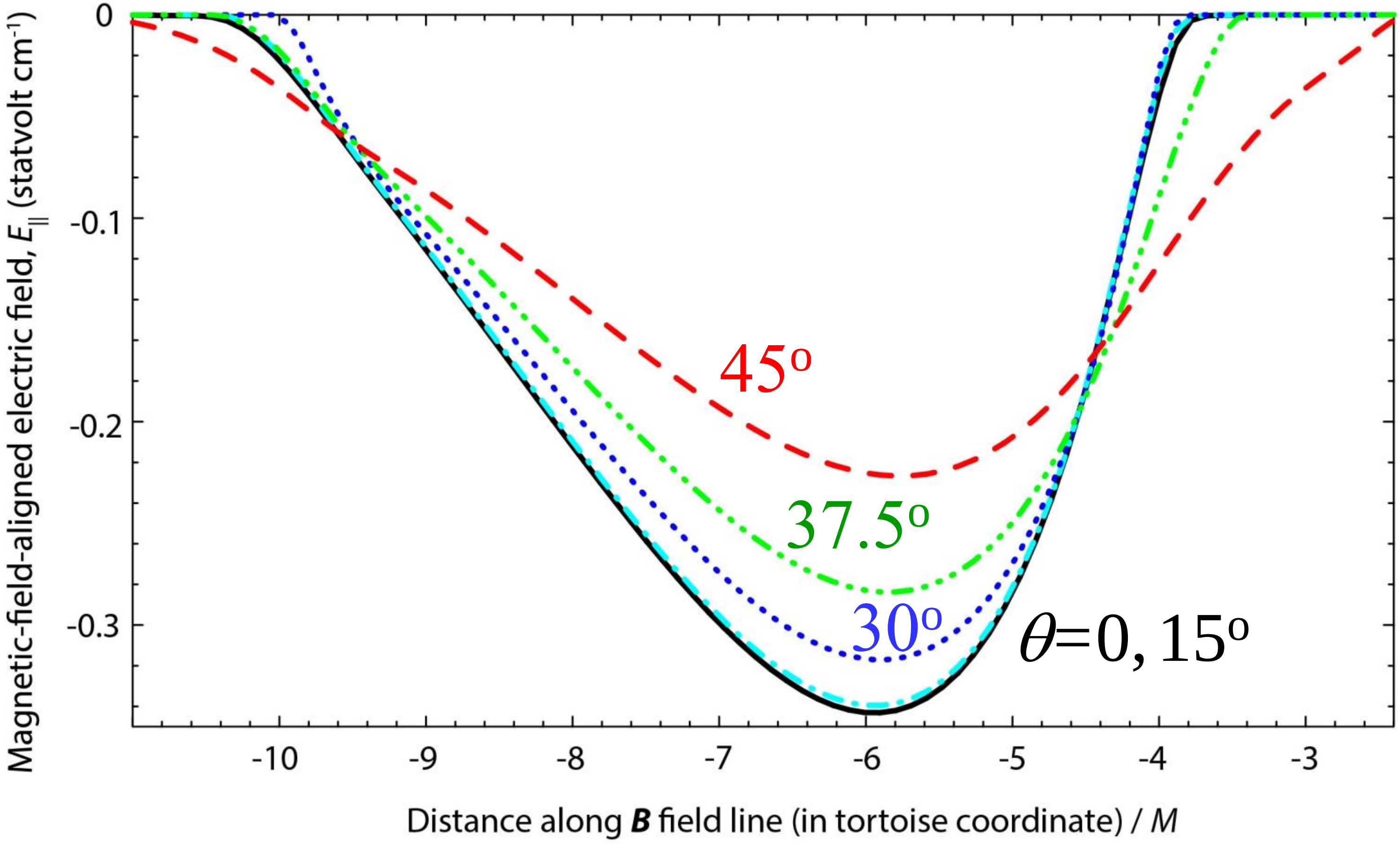
$E_{\|}$ distribution on (r, θ) plane.

Slice at five discrete colatitude, θ.



§ 2 BH gap: the case of billion solar masses

$E_{\|}$ at five discrete θ's.
Within $\theta < 15\text{-}30^{o}$, maximum potential drop is realized.
$M=10^9 M_{\odot}$ and $a=0.90M$. $\dot{m}=1.8\times10^{-5}$.

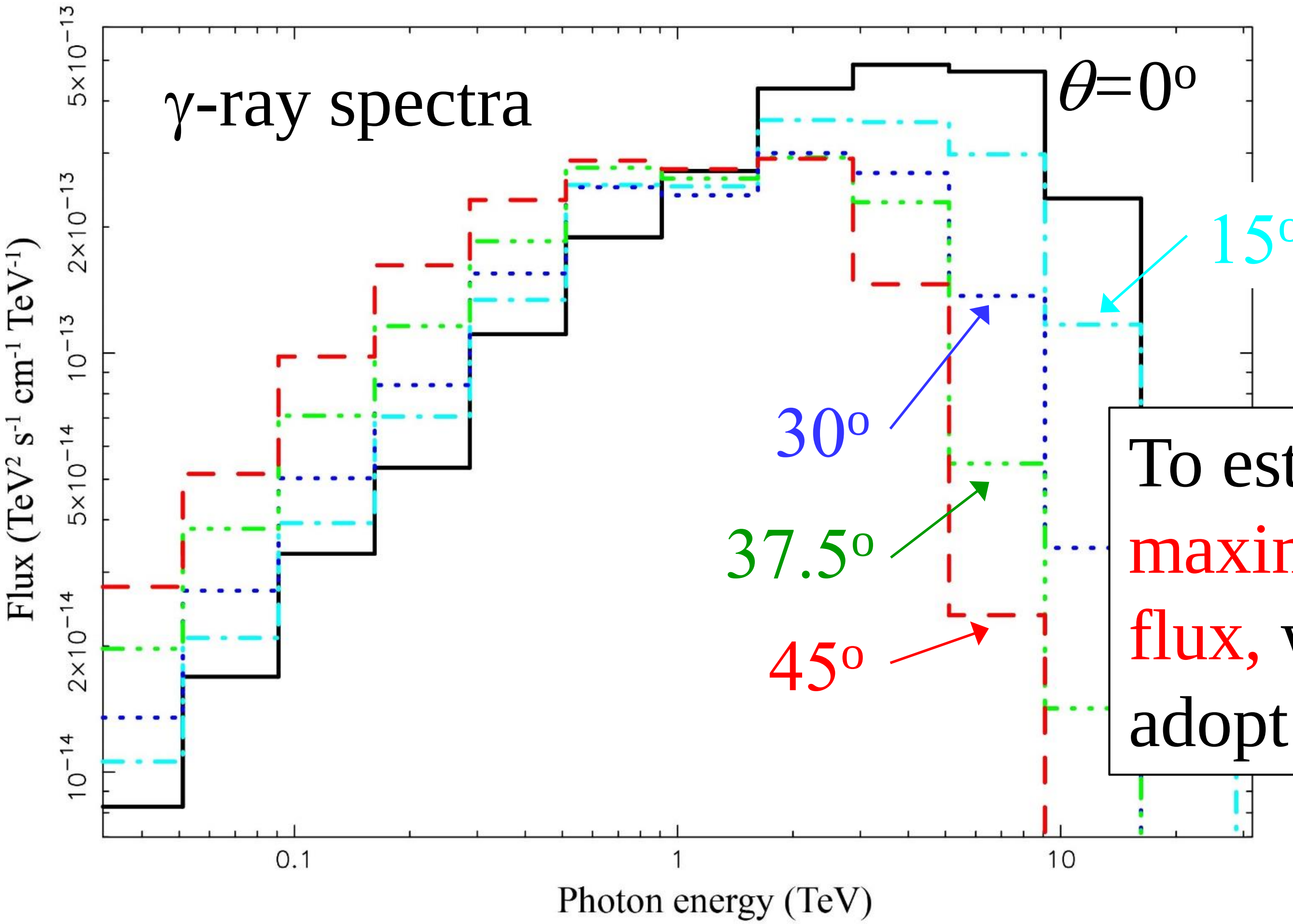


§ 2 BH gap: the case of billion solar masses

SED (30GeV-30TeV) vs. viewing angle, θ.

Gap emission is hardest along rotation axis, $\theta = 0^o$.

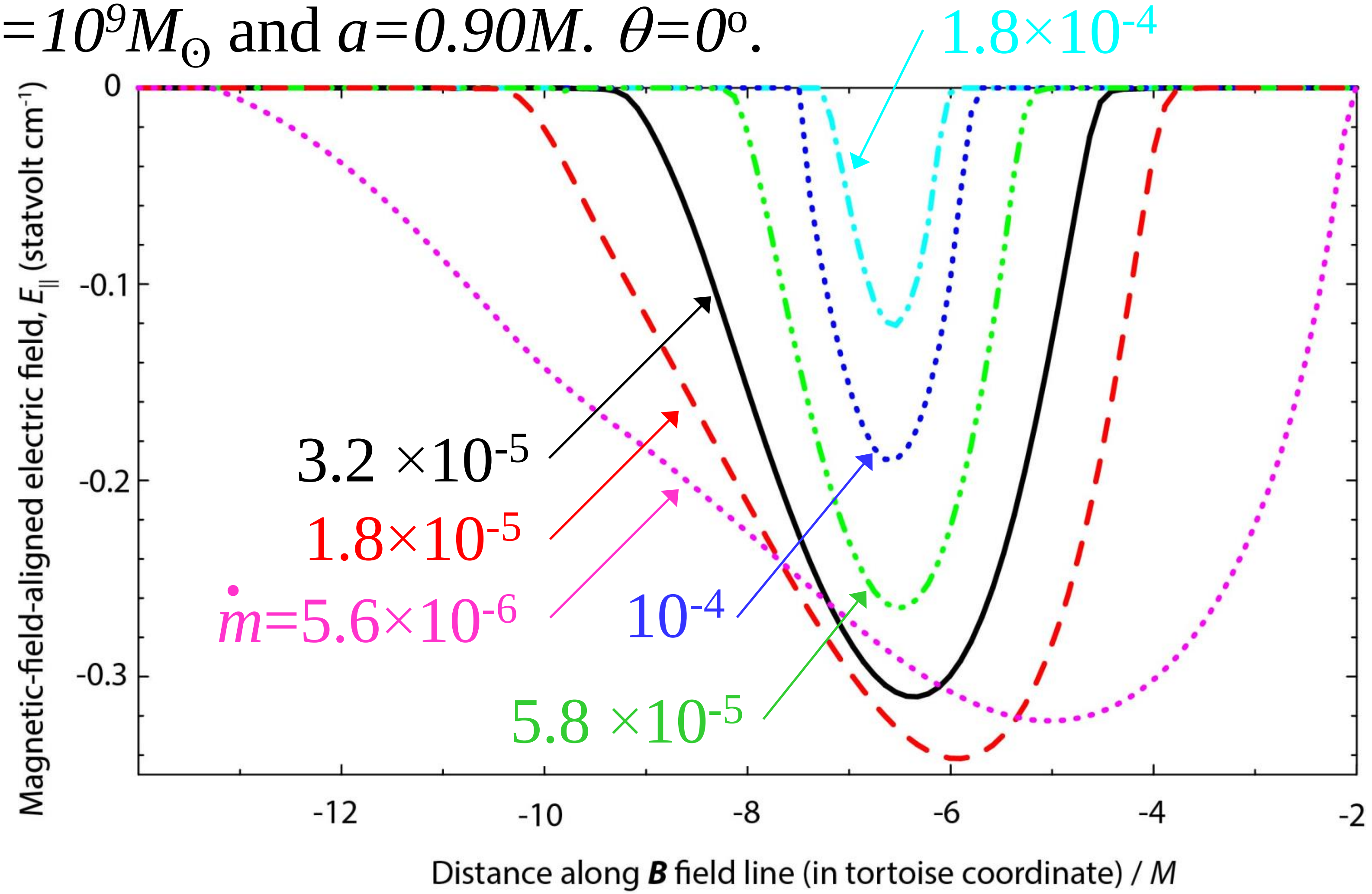
$M=10^9 M_\odot$ and $a=0.90M$. $\dot{m}=1.8\times10^{-5}$.



To estimate **maximum flux**, we adopt $\theta=0^o$.

§ 2 BH gap: the case of billion solar masses

$E_{||}$ at five six discrete accretion rates, $\dot{m}$'s.
Gap enlarges as $\dot{m}$ approaches the lower bound, ~3×10^{-5}.
$M=10^9 M_{\odot}$ and $a=0.90M$. $\theta=0^{\circ}$.

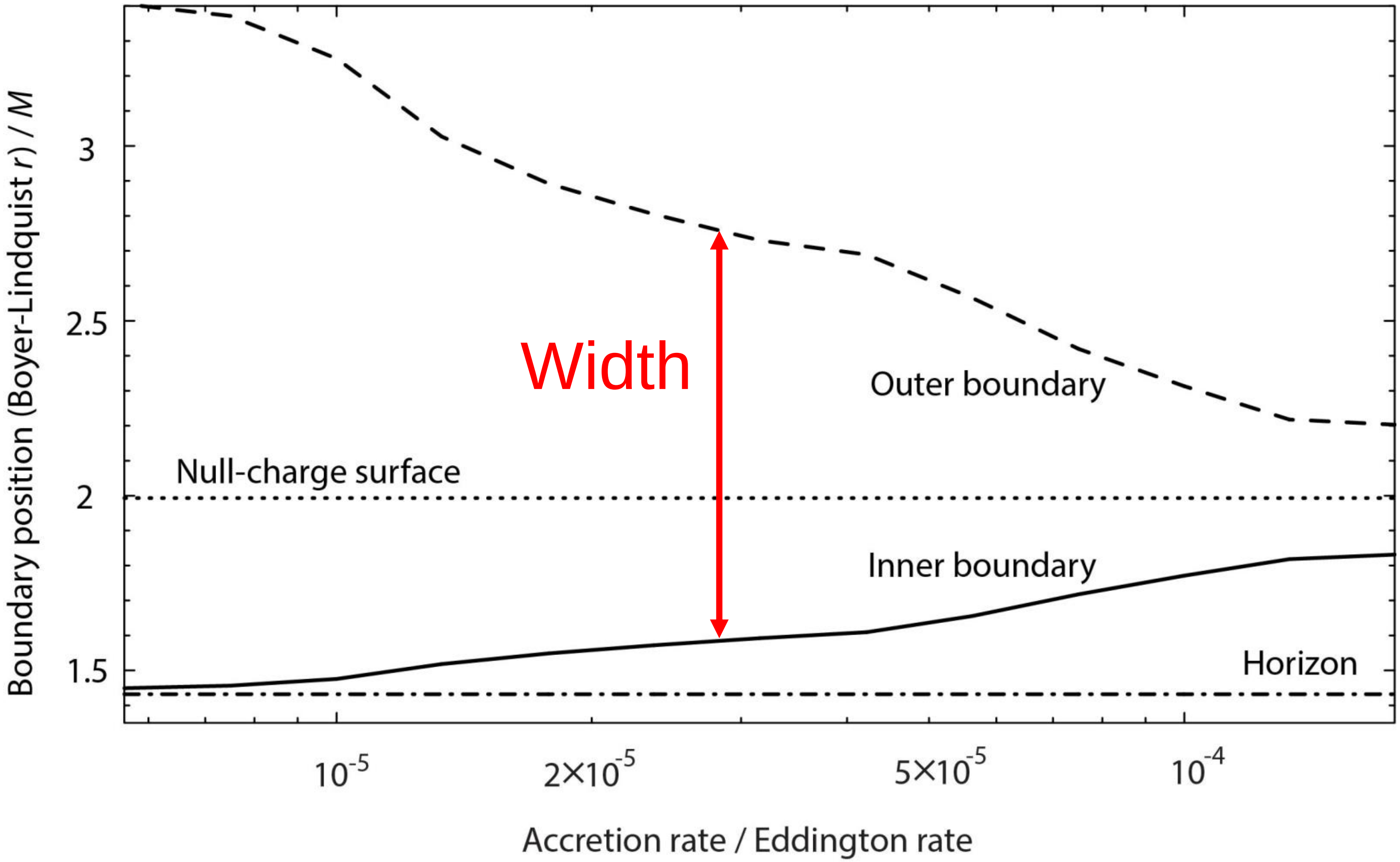


§ 2 BH gap: the case of billion solar masses

Gap extent vs. accretion rate, $\dot{m}$.

Gap enlarges as m approaches the lower bound, $\sim 3\times10^{-6}$.

$M=10^9 M_\odot$ and $a=0.90M$. $\theta=0^o$.

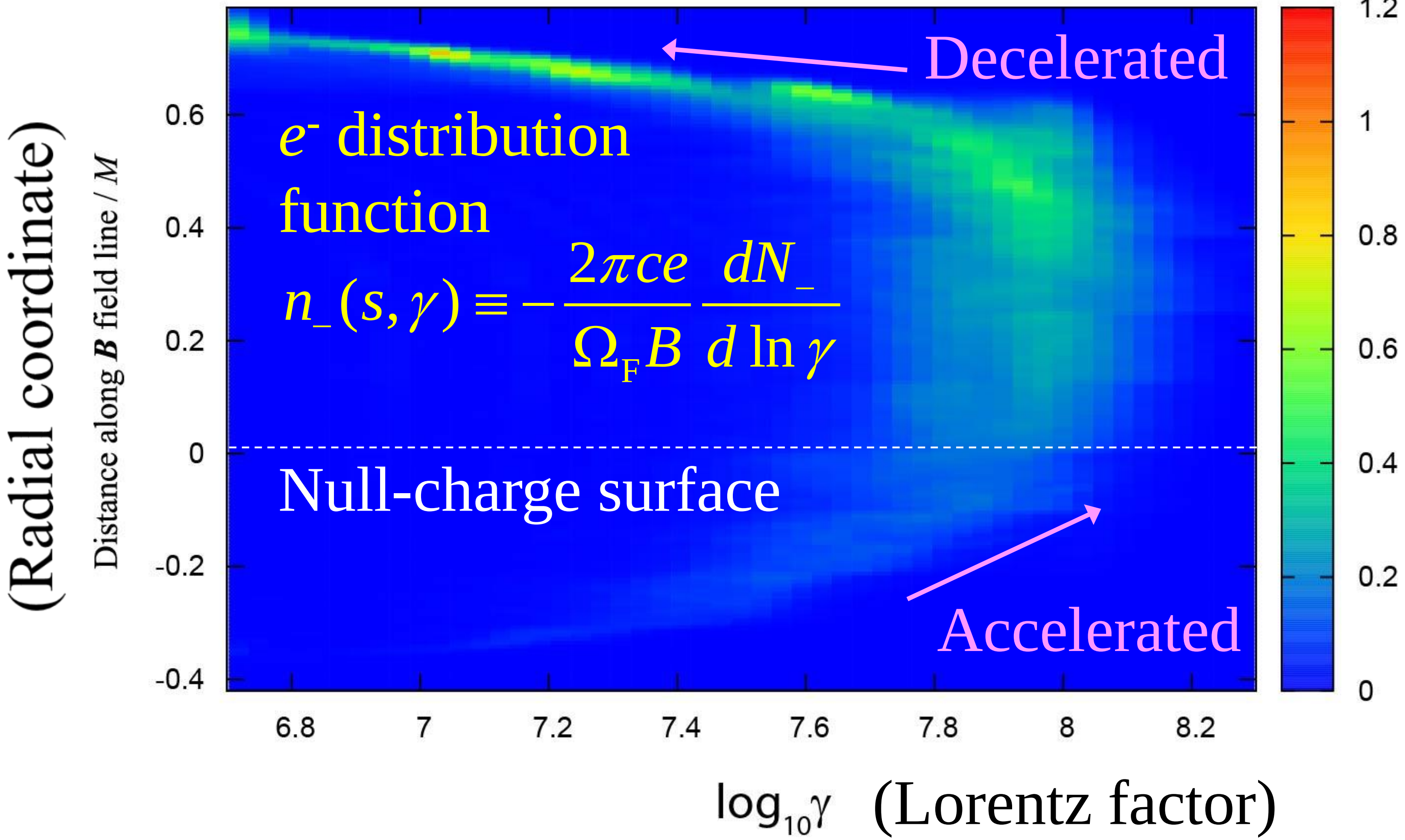


§ 2 BH gap: the case of billion solar masses

$E_{\parallel} < 0 \rightarrow e^-$'s ($e^+$'s) are accelerated outwards (inwards).

e^-'s saturate between $4\times10^7 < \gamma < 1.5\times10^8$ via ICS.

$M=10^9 M_\odot$ and $a=0.90M$. $\theta=0^\circ$.

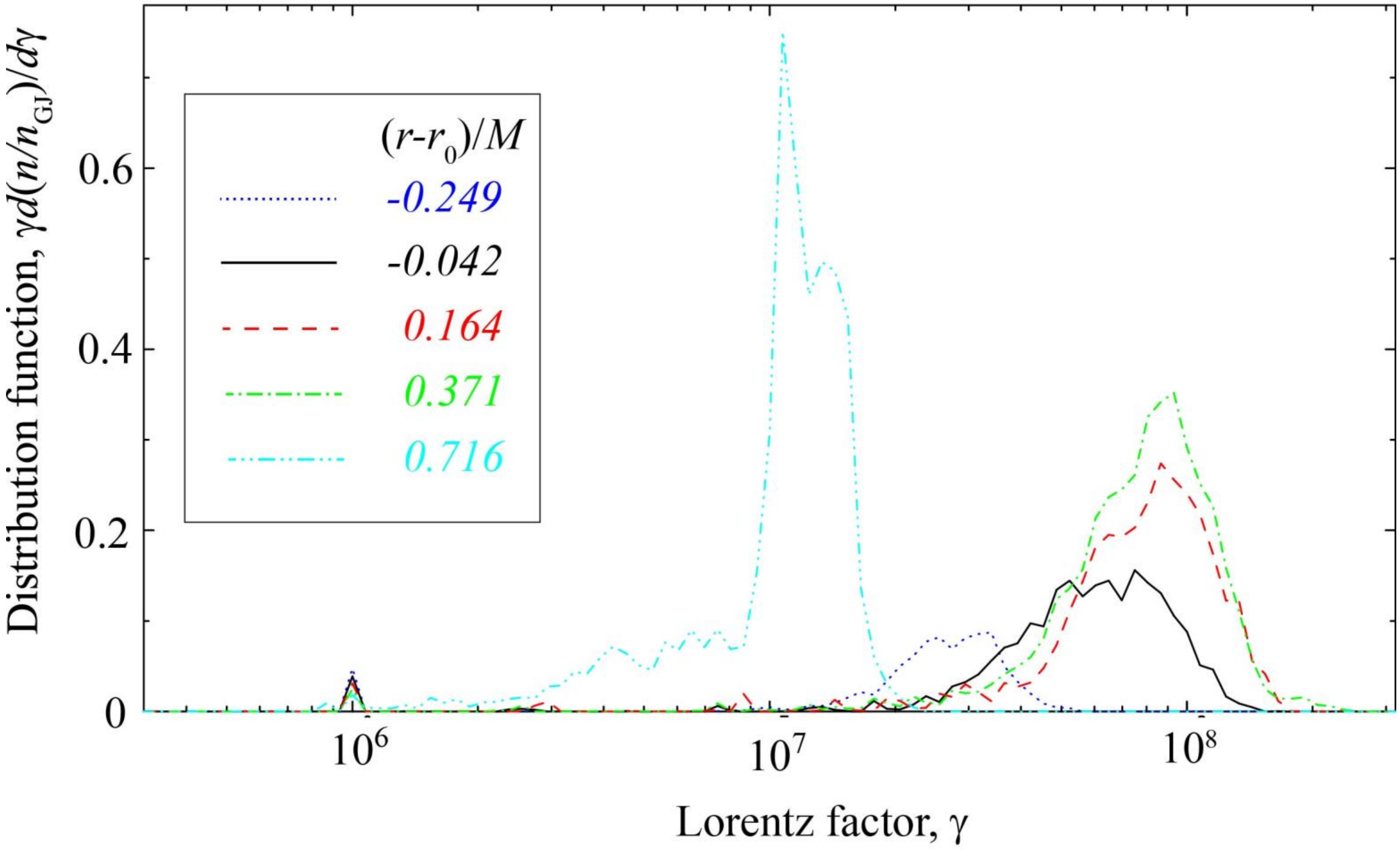


§ 2 BH gap: the case of billion solar masses

e^- distribution function @ five discrete radial coordinates.

e^-'s saturate between $4\times10^7 < \gamma < 1.5\times10^8$ via ICS.

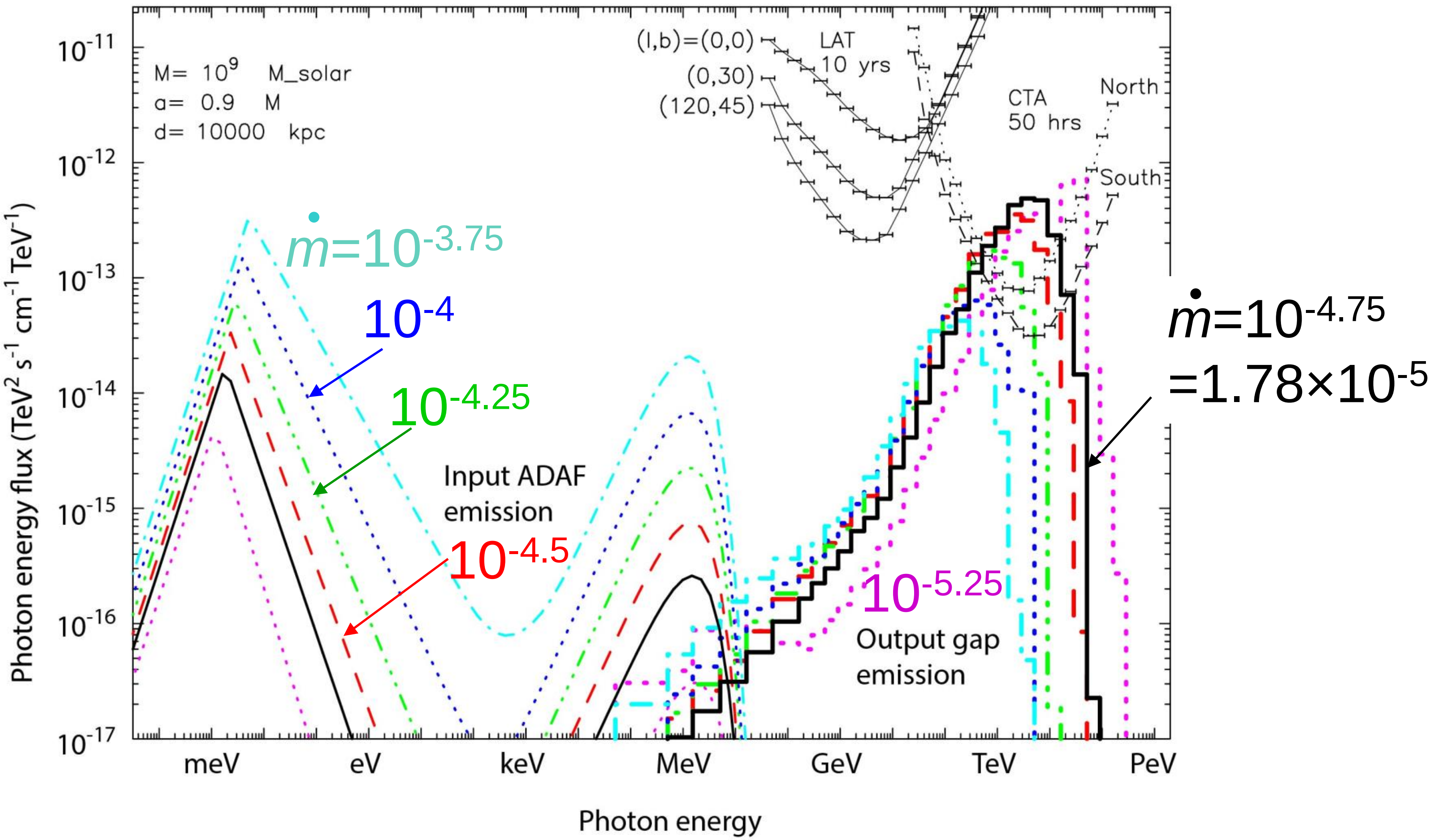
$M=10^9 M_\odot$ and $a=0.90M$. $\theta=0^o$.



§ 2 BH gap: the case of billion solar masses

SEDs @ six discrete accretion rates, $\dot{m}$.

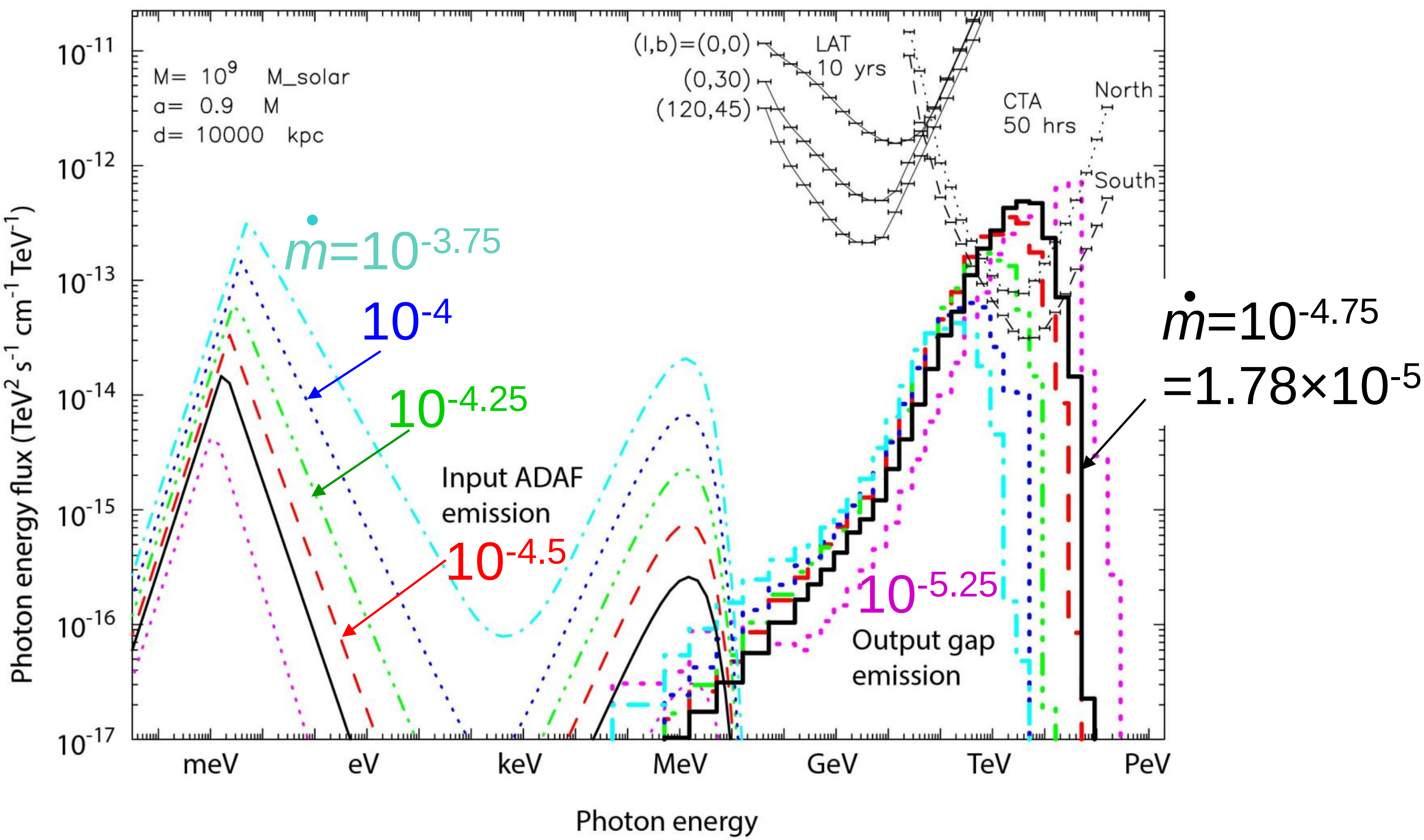
If $d<10$Mpc, a hyper-massive BH with $M=10^9 M_\odot$ can emit detectable gap emission in 1-30TeV.



§ 2 BH gap: the case of billion solar masses

Gap luminosity increases with decreasing $\dot{m}$.

→ Anti-correlation between mm & VHE fluxes.



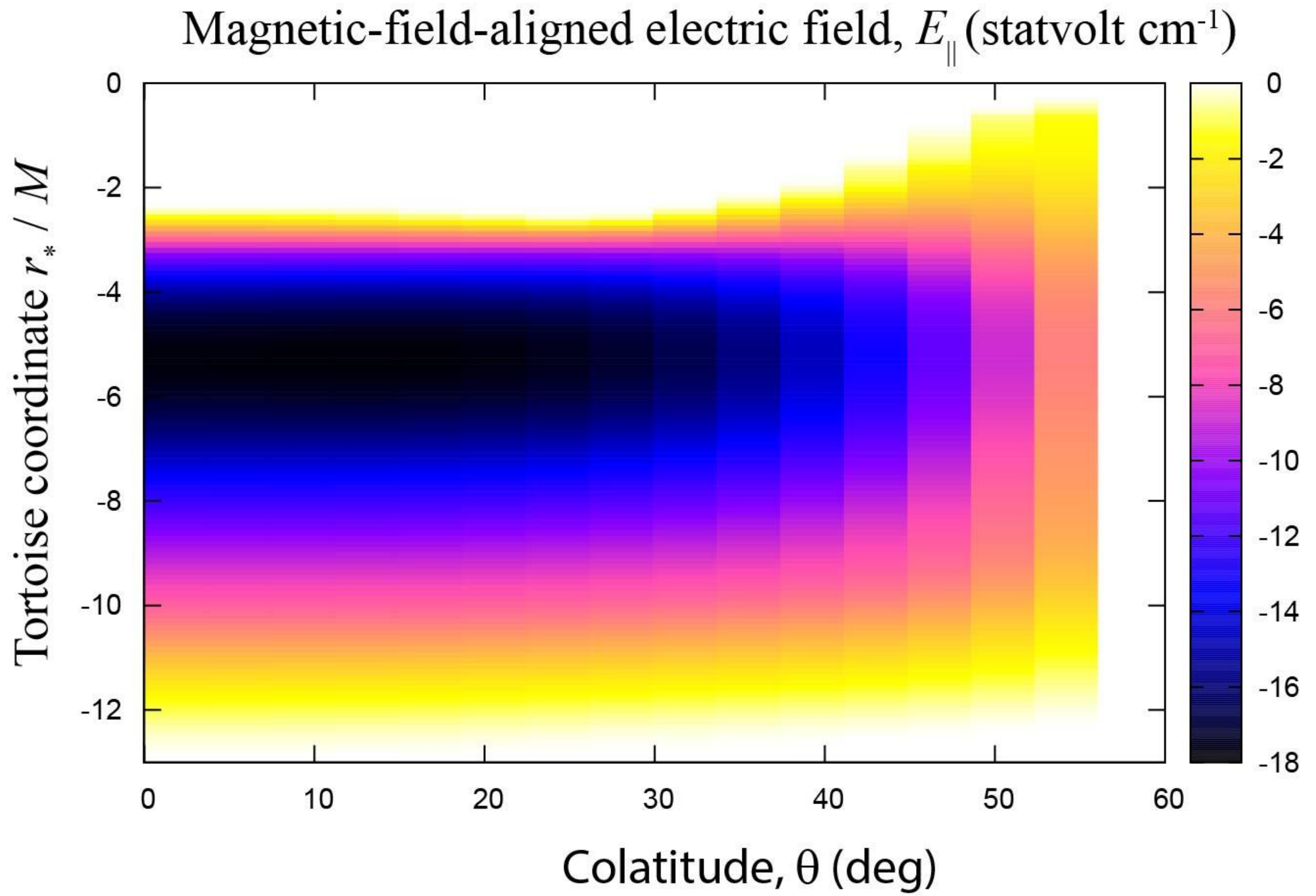
§ 3 BH gap: the case of million solar mass

§ 3 BH gap: the case of million solar masses

$E_{||}$ distribution on (r, θ) plane.

Polar funnel is bounded with ADAF at $\theta=60^{o}$.

$M=10^{6}M_{\odot}$ and $a=0.90M$. $\dot{m}=1.8\times 10^{-5}$.

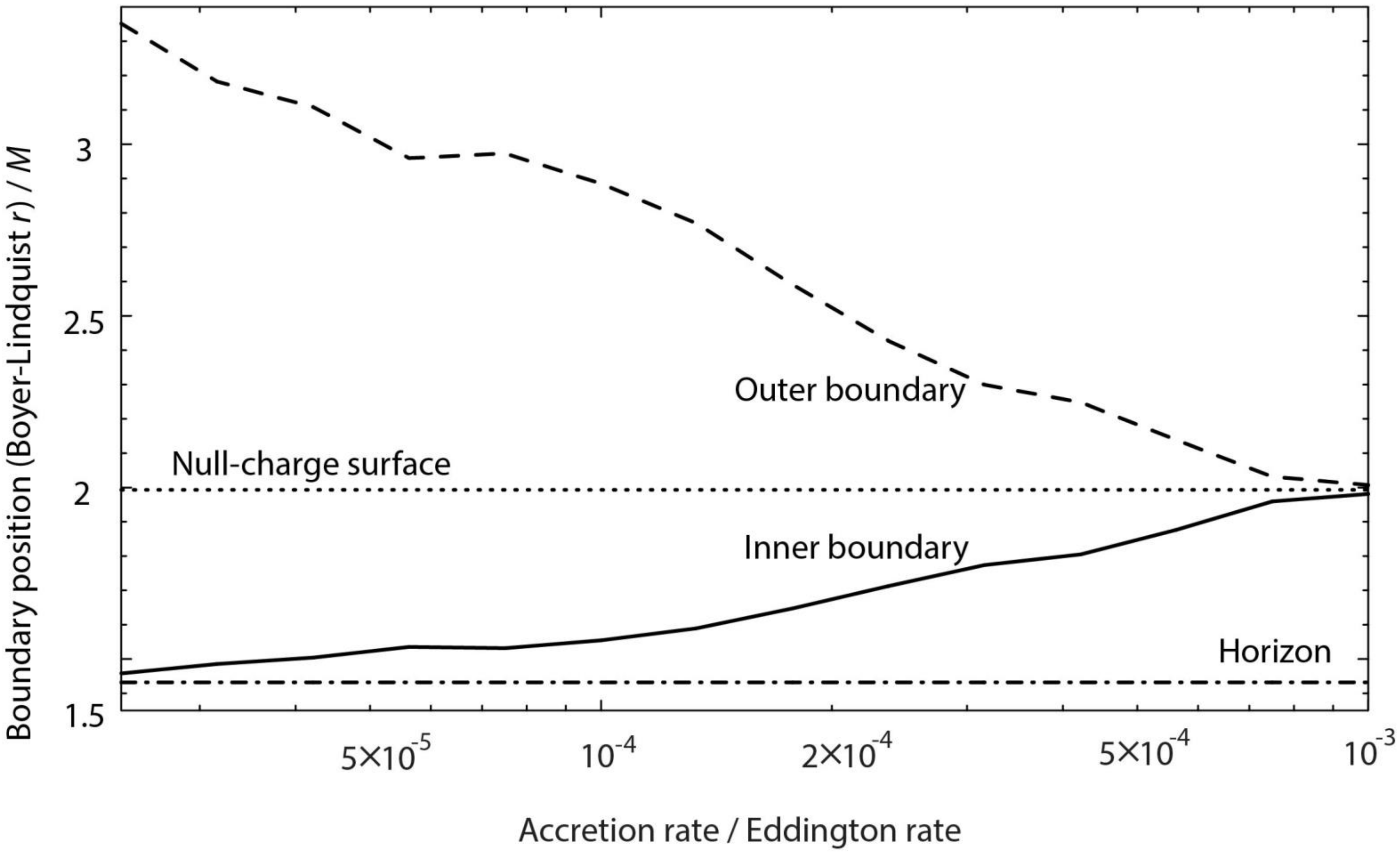


§ 3 BH gap: the case of million solar masses

Gap extent vs. accretion rate, $\dot{m}$.

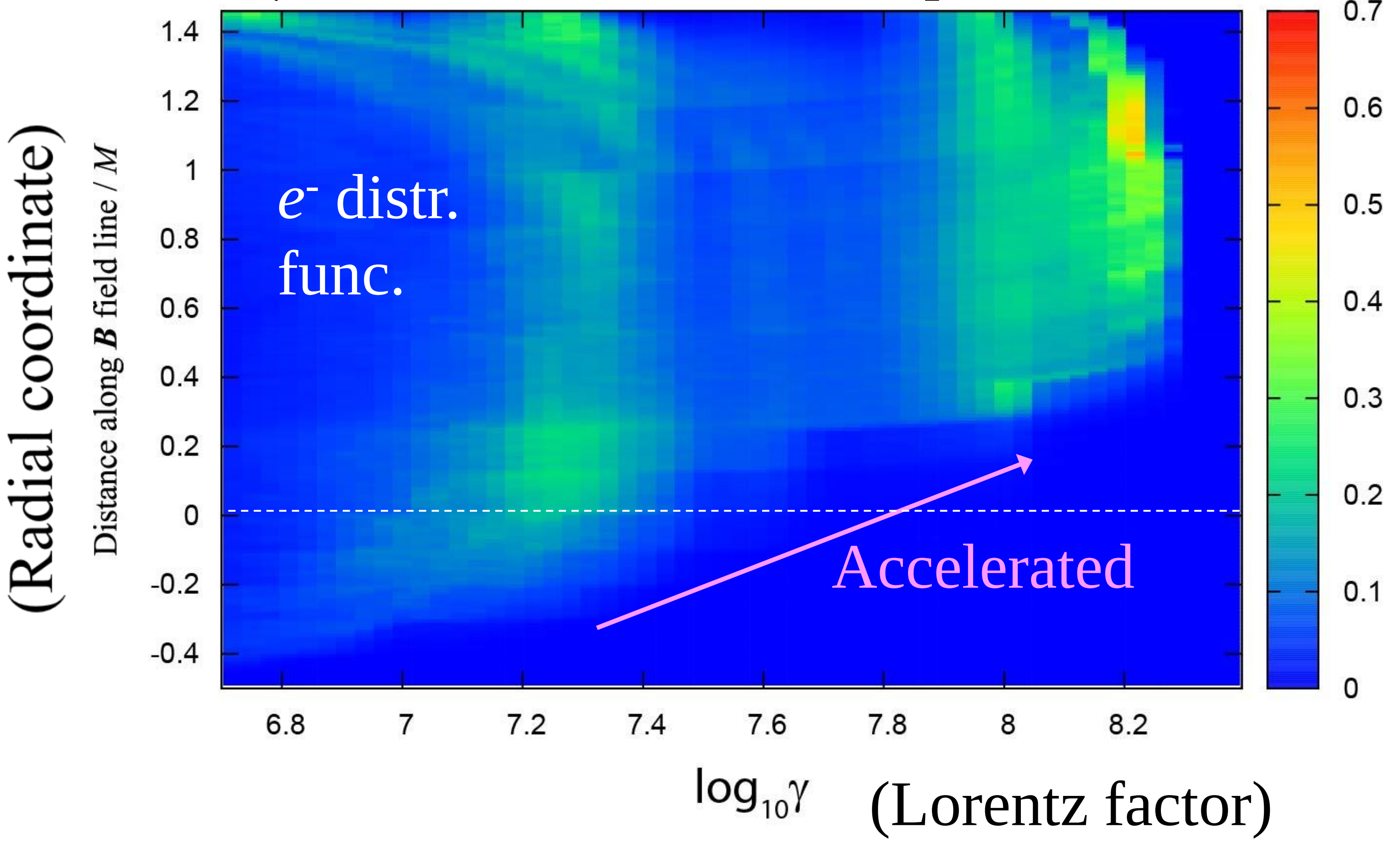
Gap enlarges as $\dot{m}$ approaches the lower bound, $\sim 1.8\times10^{-5}$.

$M=10^6 M_\odot$ and $a=0.90M$. $\theta=0^o$.



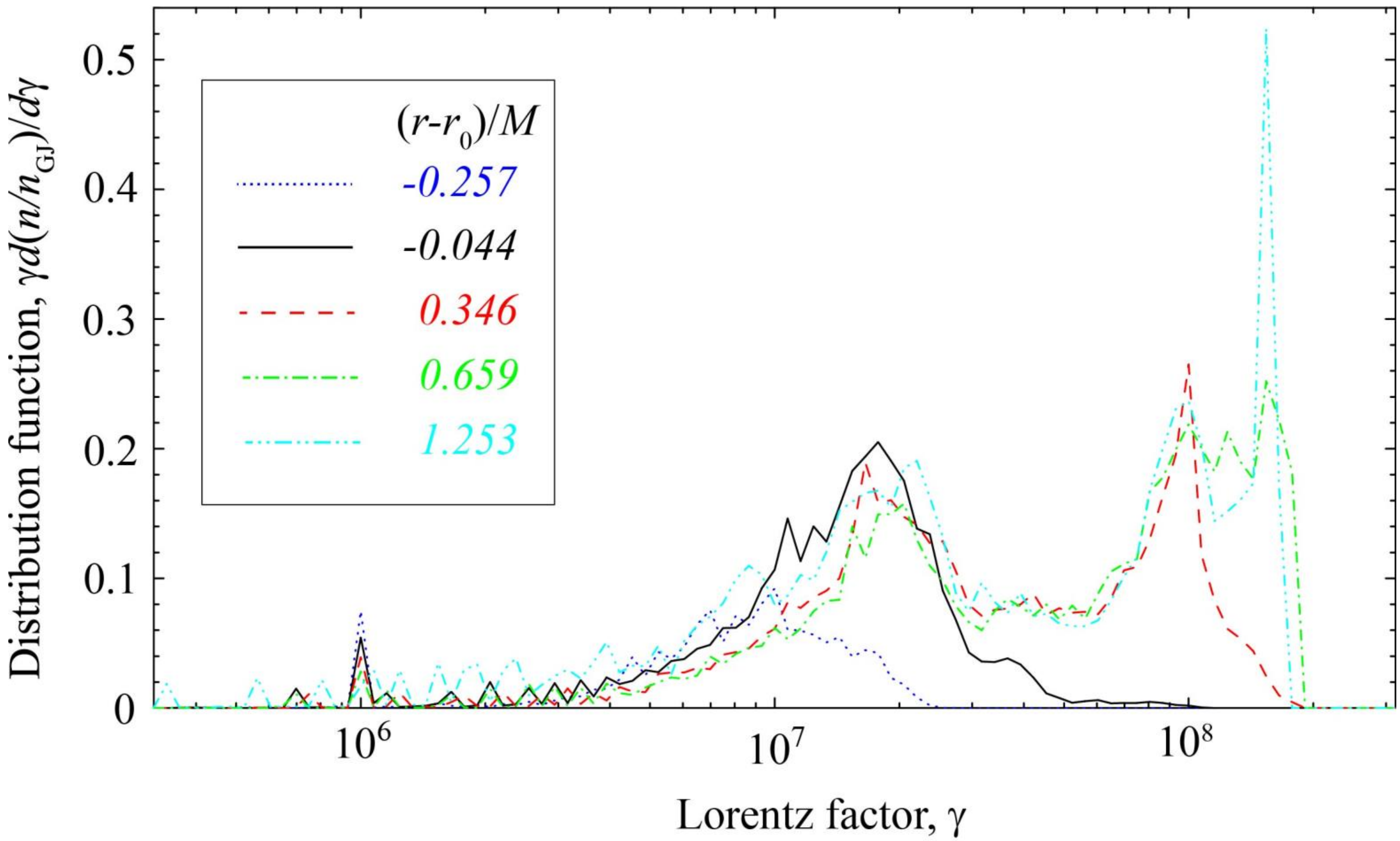
§ 3 BH gap: the case of million solar masses

$E_{\parallel}<0 \rightarrow e^-$'s ($e^+$'s) are accelerated outwards (inwards).
e^-'s saturate between $10^7 < \gamma < 2.5\times10^7$ via ICS, and
$9\times10^7 < \gamma < 1.8\times10^8$ via curvature process.



§ 3 BH gap: the case of million solar masses

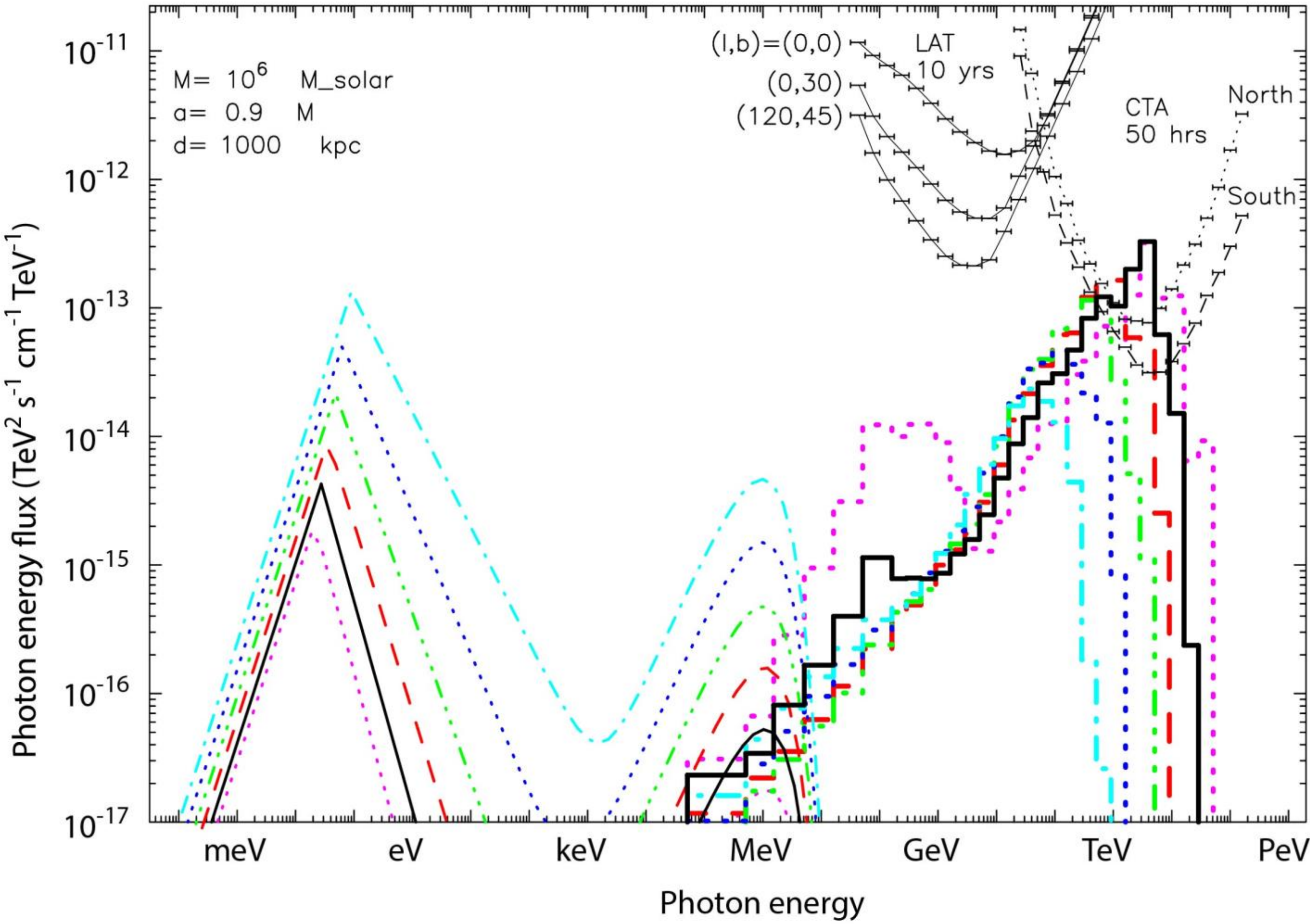
e^- distribution function @ five discrete radial coordinates. Energy distribution is broadened because both IC & curvature processes contribute for $M=10^6 M_\odot$ case.



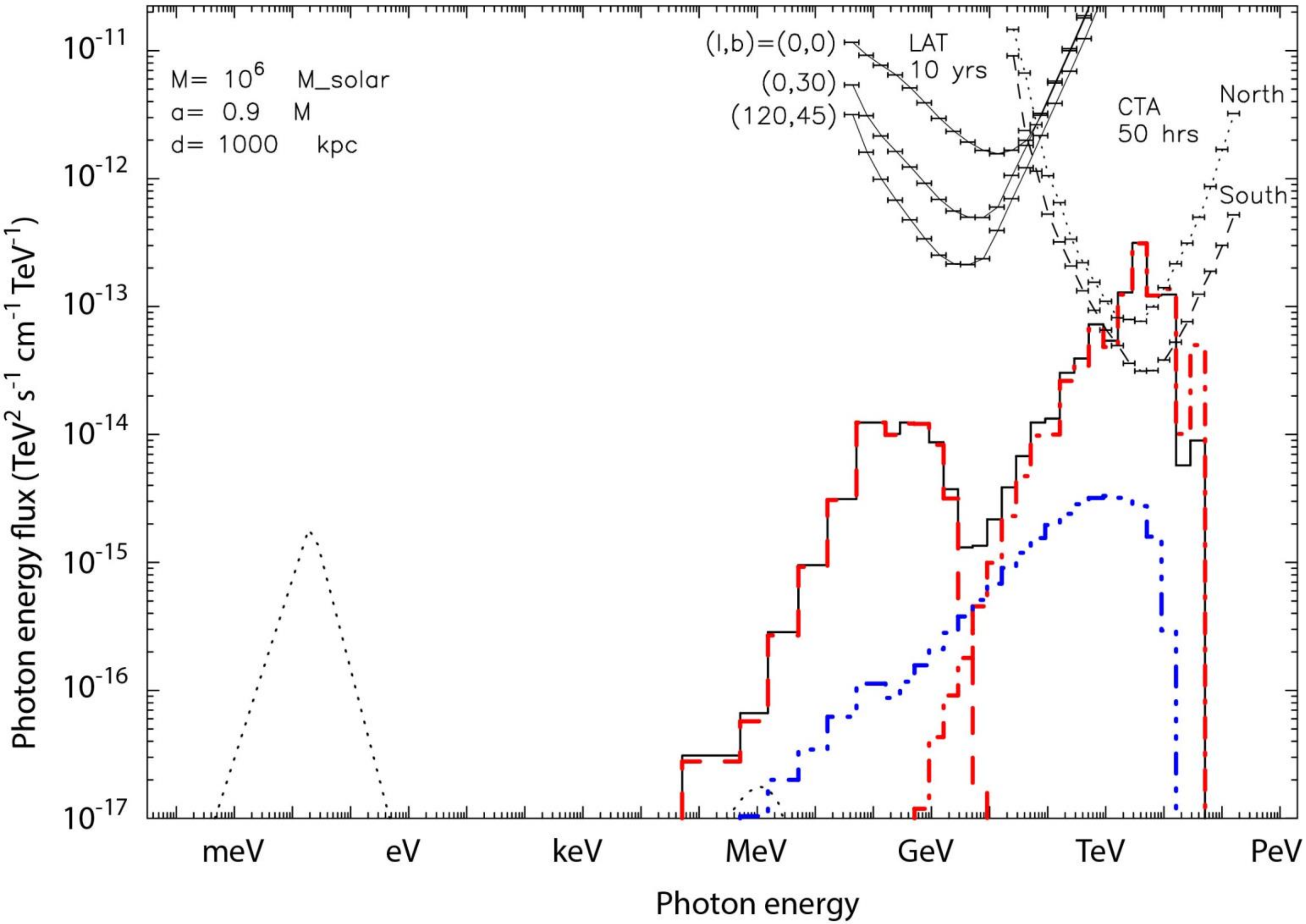
§ 3 BH gap: the case of million solar masses

SEDs @ six discrete accretion rates, $\dot{m}$.

If d<10Mpc, a hyper-massive BH with $M=10^9M_{\odot}$ can emit detectable gap emission in 1-30TeV.



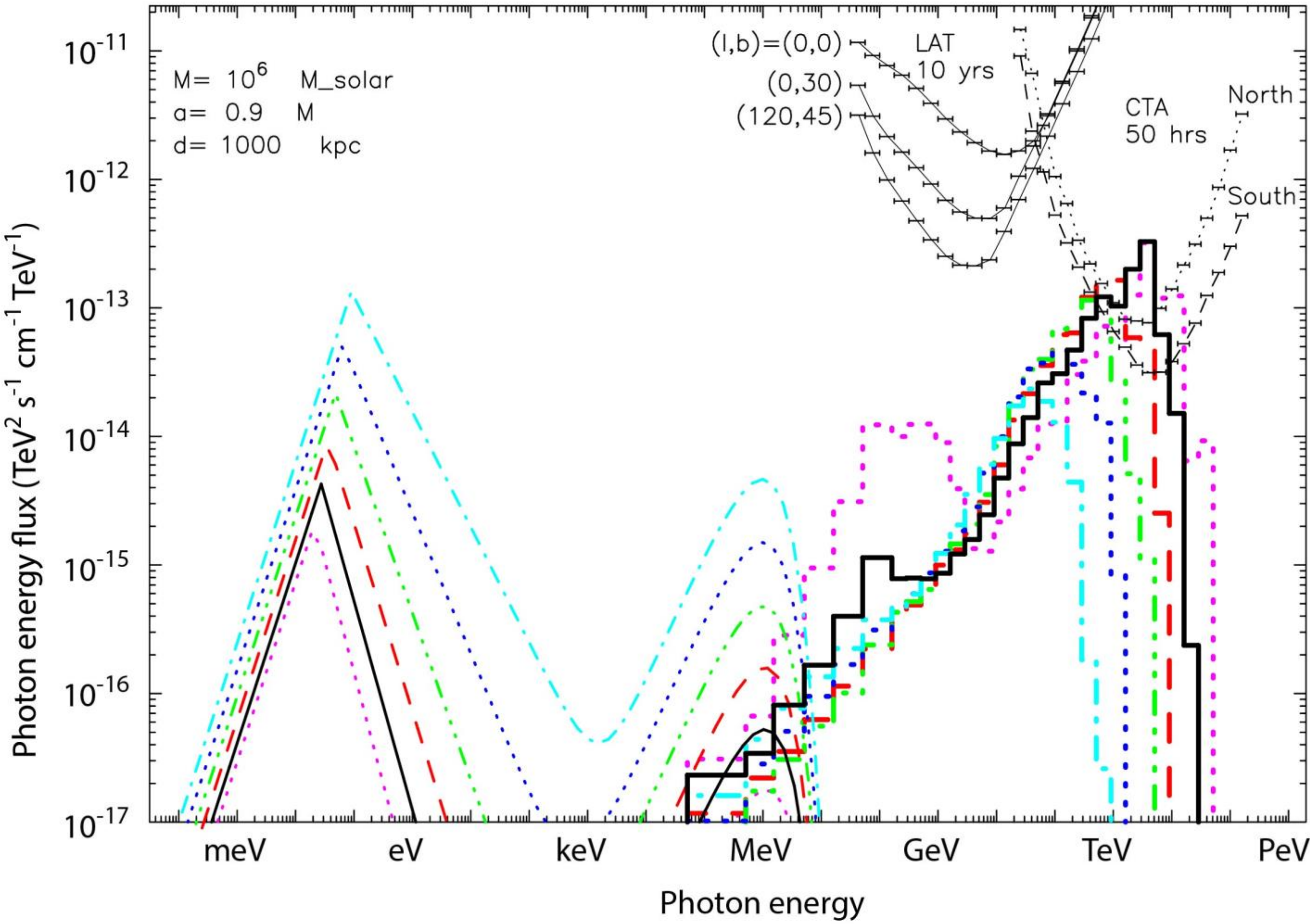
§ 3 BH gap: the case of million solar masses



§ 3 BH gap: the case of million solar masses

Gap luminosity increases with decreasing $\dot{m}$.

→ Anti-correlation betw. sub-mm & VHE fluxes.



Summary on SMBH gap

- When the mass accretion rate is highly sub-Eddington, the polar funnel becomes charge-starved, because the ADAF-emitted MeV photons materialize less efficiently.
- Owing to this charge starvation, particle accelerators (=gaps) appear within a few GM/c^2 above the event horizon.
- For low-luminosity AGNs (e.g., $M{\sim}10^9 M_\odot$), the BH gap emits IC photons in 0.5~30TeV along $\theta{\sim}0^o$. Such a flare is detectable with CTA if $d<30$ Mpc when the accretion rate resides in $6\times10^{-6} < \dot{M}/\dot{M}_{\rm Edd} < 2\times10^{-5}$.
- We can discriminate gap vs. jet emissions by anti-correlation vs. correlations at submillimeter (or near-IR) & VHE for a SMBH (or a stellar-mass BH).

END OF THE LECTURES