



北京大学
PEKING UNIVERSITY

Illuminating Black Hole Shadows with Dark Matter Annihilation

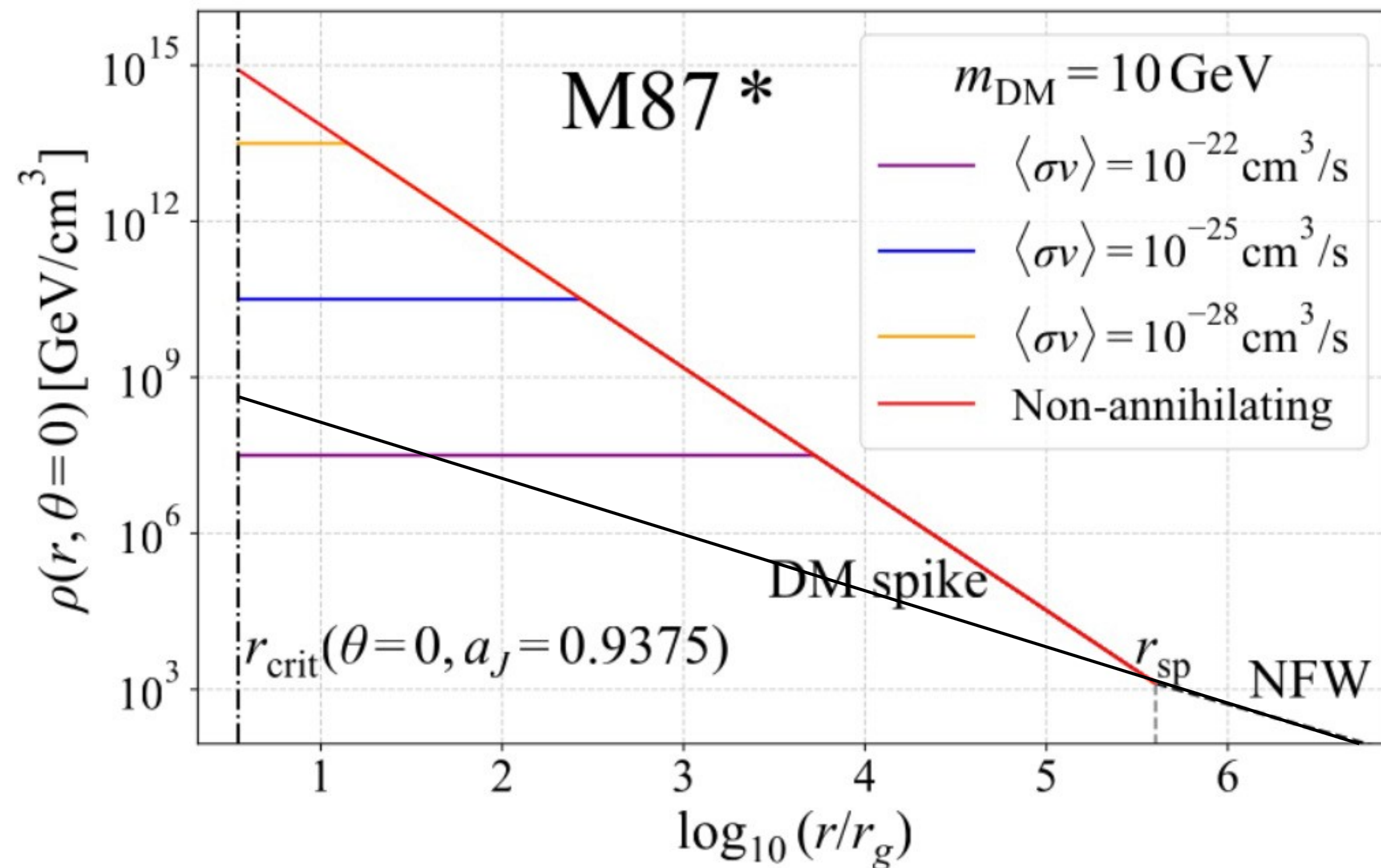
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Collaborated with Y.C., R.D., Y.L., Y.M., J.S. and H.Y.

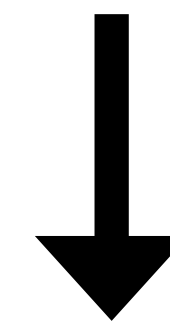


Black hole as dark matter detector



- SMBH** in the galactic center → DM halo grow → **DM spike**

$$\Gamma_{\text{ann}} \propto \rho_{\text{DM}}^2$$



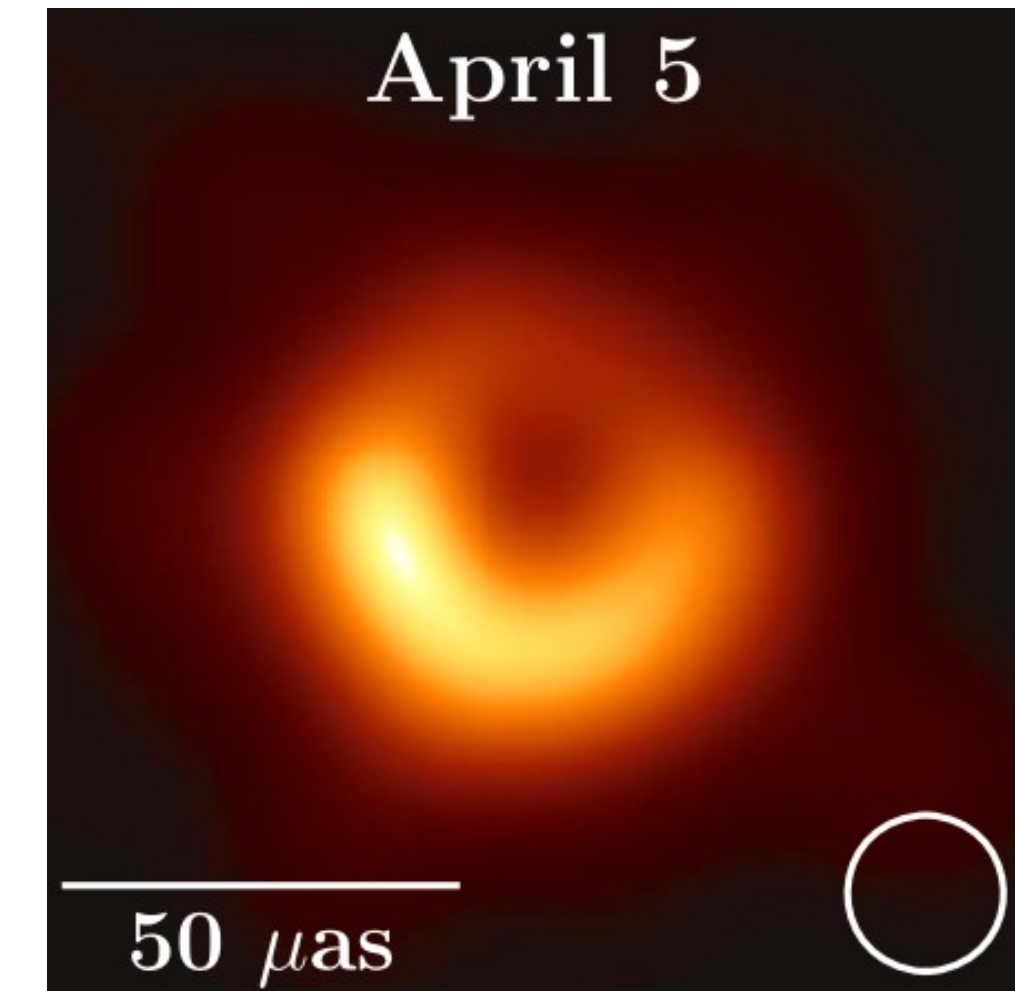
Enhanced radio signal

Why Event Horizon Telescope (EHT)

Conventional observation:

$$F_\nu = \int I_\nu(\alpha, \beta) d\Omega$$

Integrated flux only



EHT M87* Paper.IV

Excellent angular resolution $\Delta\theta \approx 50 \mu\text{as}$



Horizon scale **spatial information**

Black hole shadow

- Where do the photons come from:

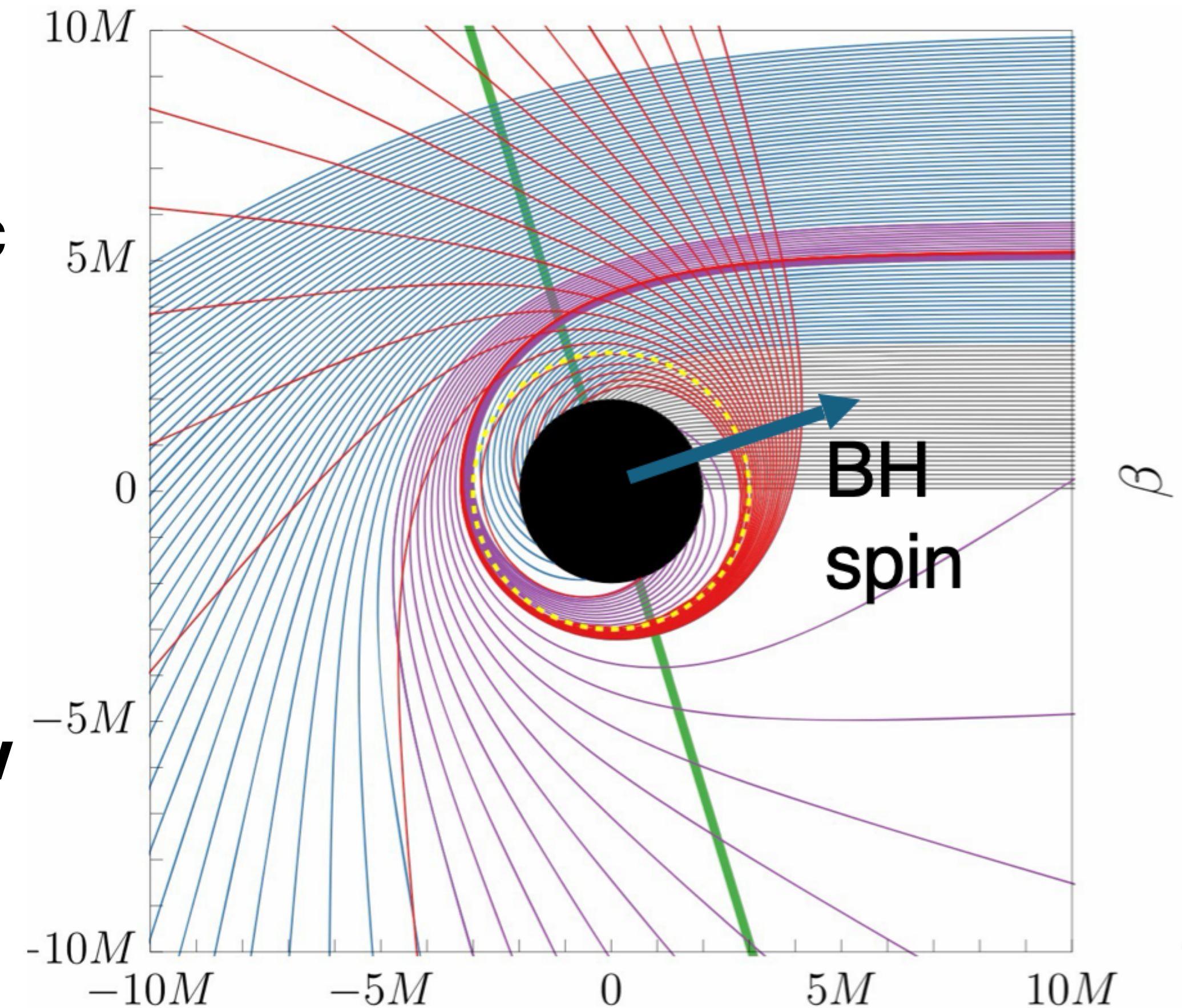
Accretion flow: relativistic electrons + magnetic field → **synchrotron**

Jet: merely electrons → much lower emissivity

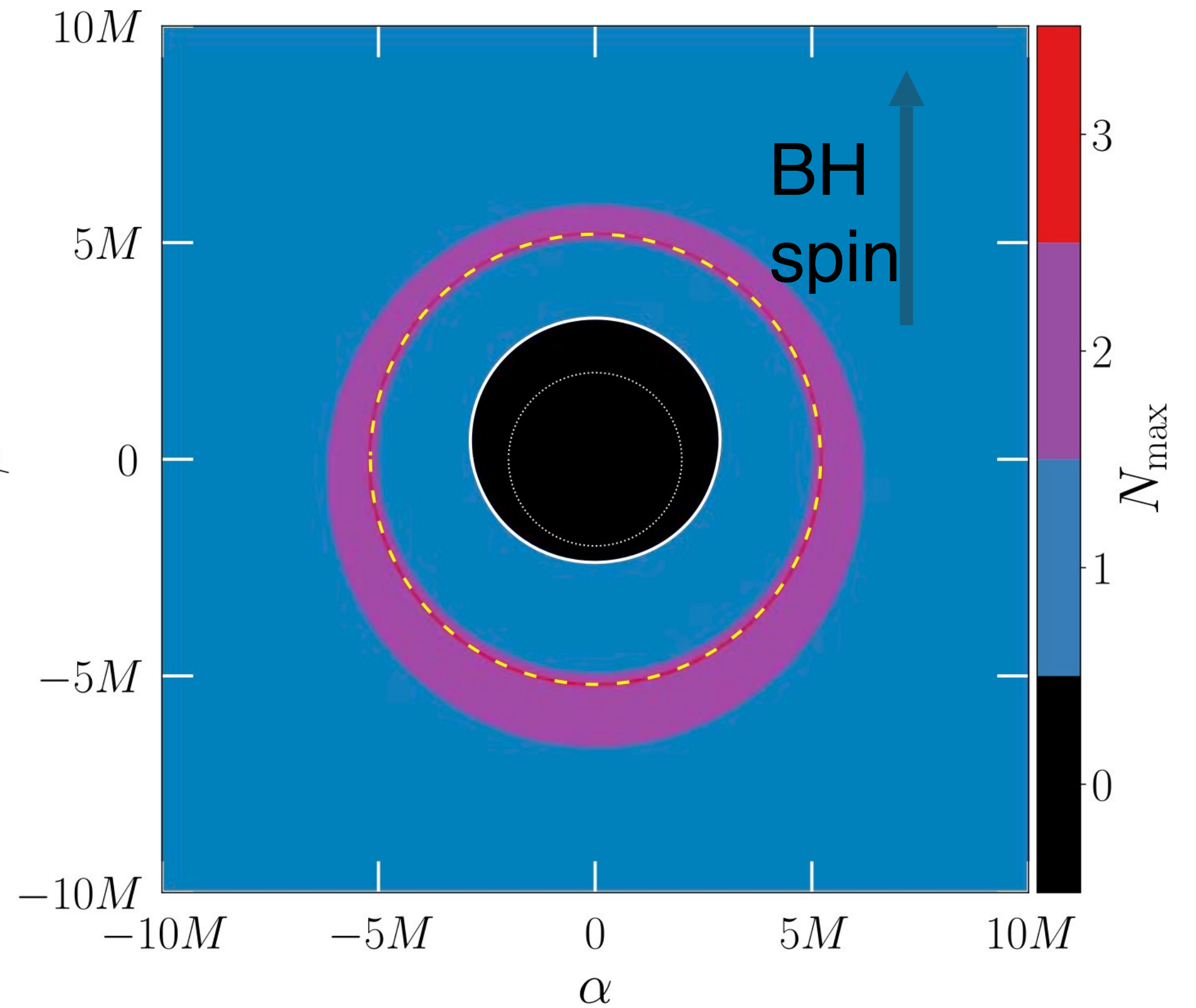
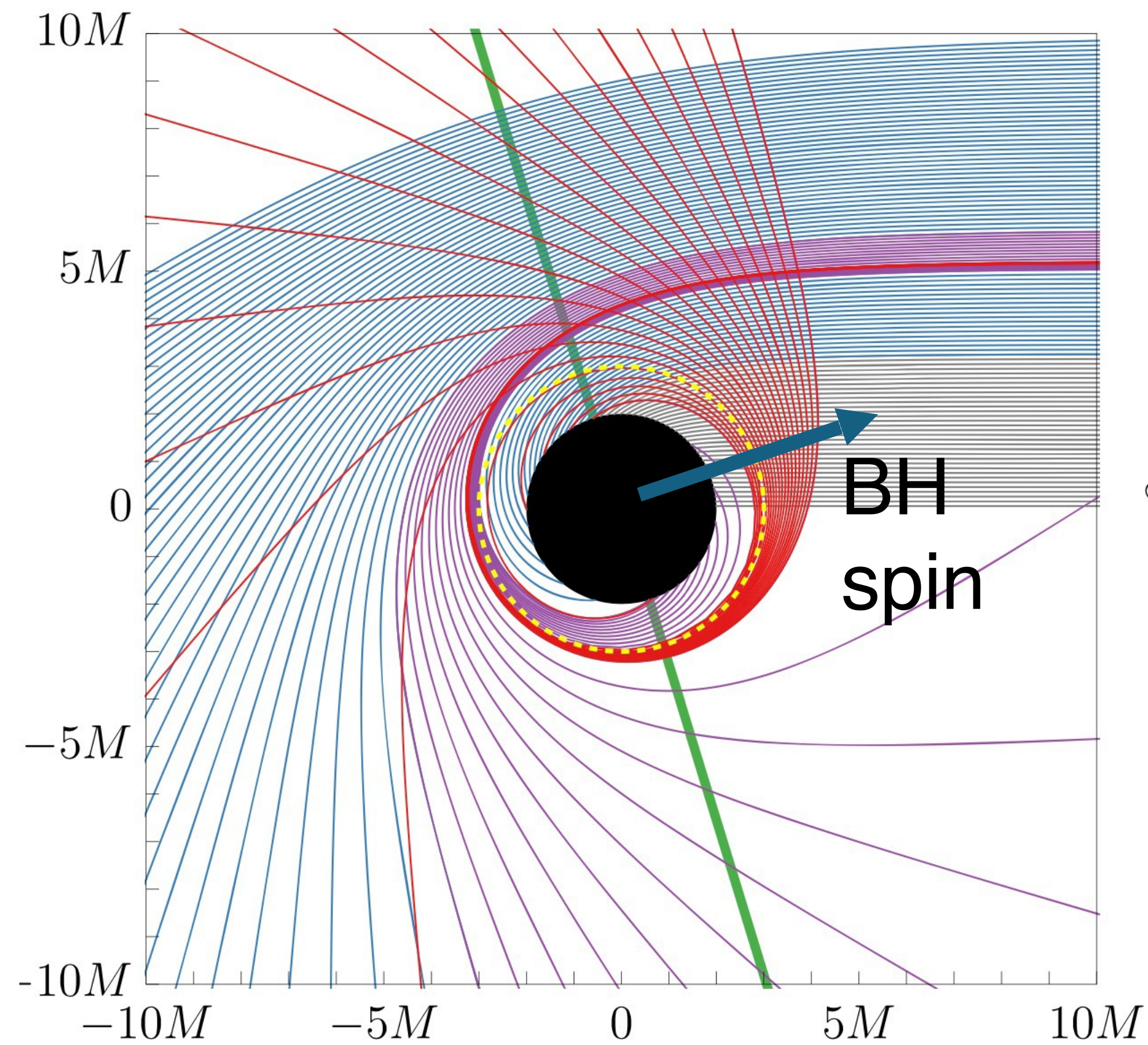
- Null geodesics seen by a far observer

Do NOT cross **equatorial plane (disk)** → **shadow**

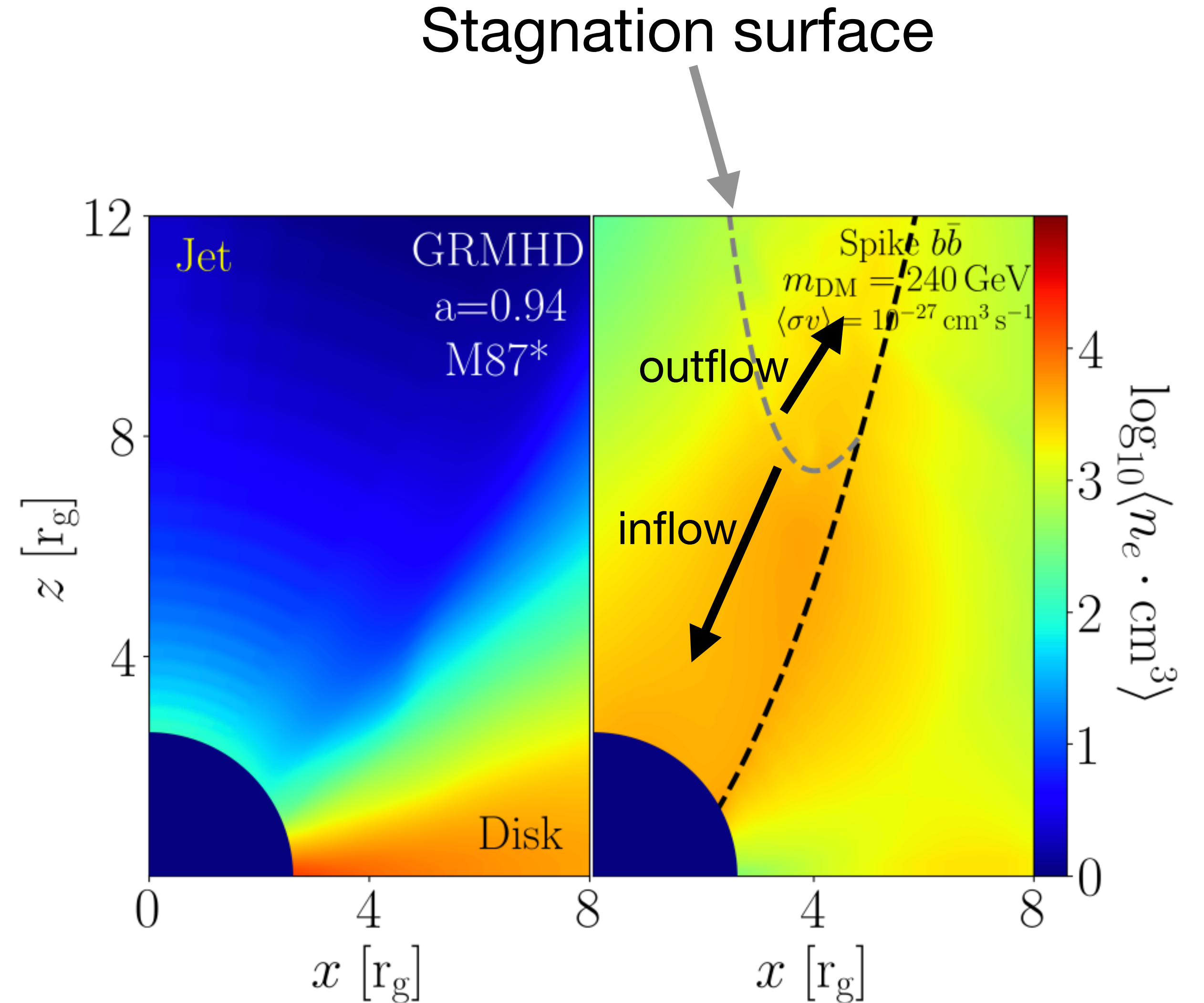
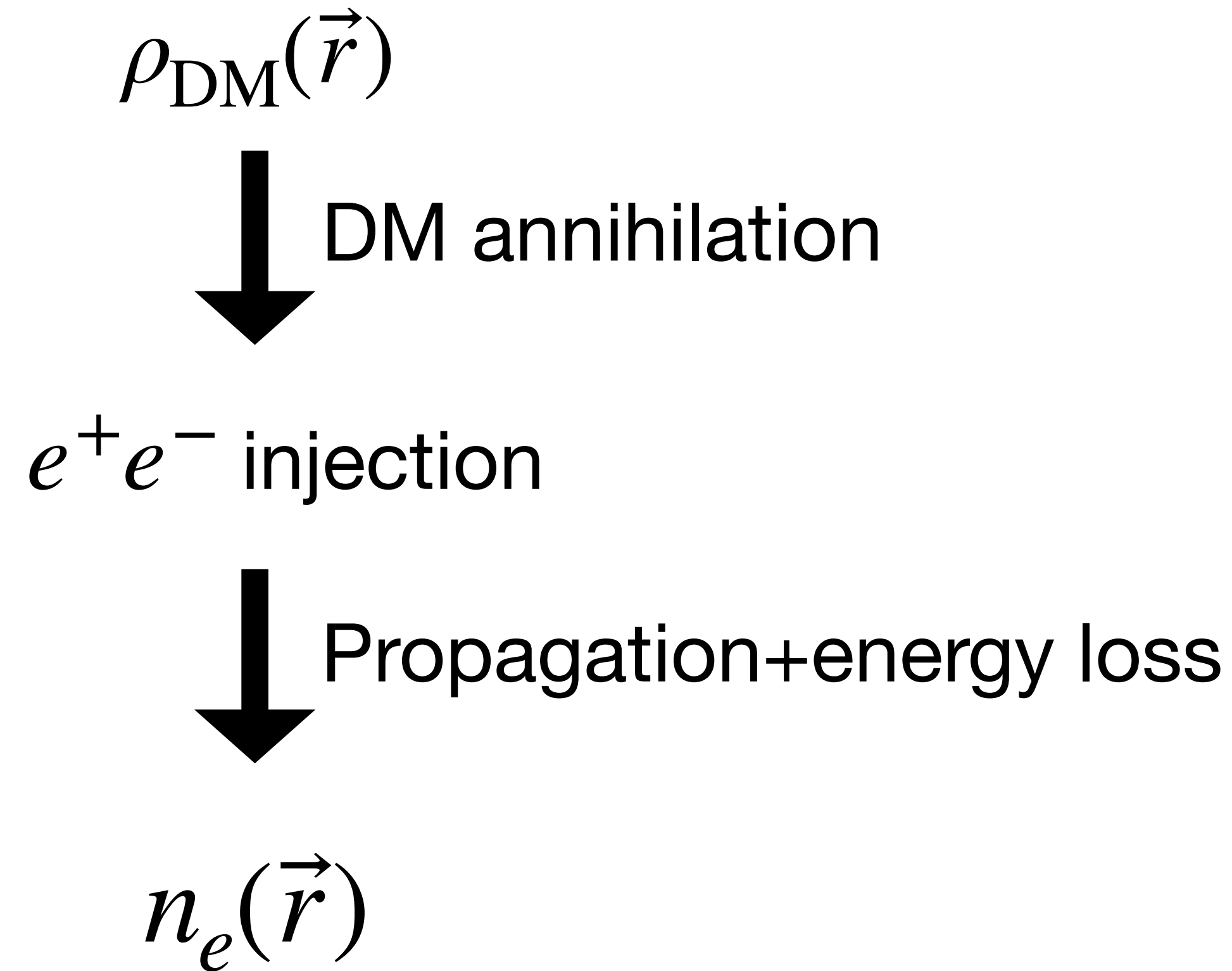
Asymptotic bound orbits → **photon ring**



Black hole shadow



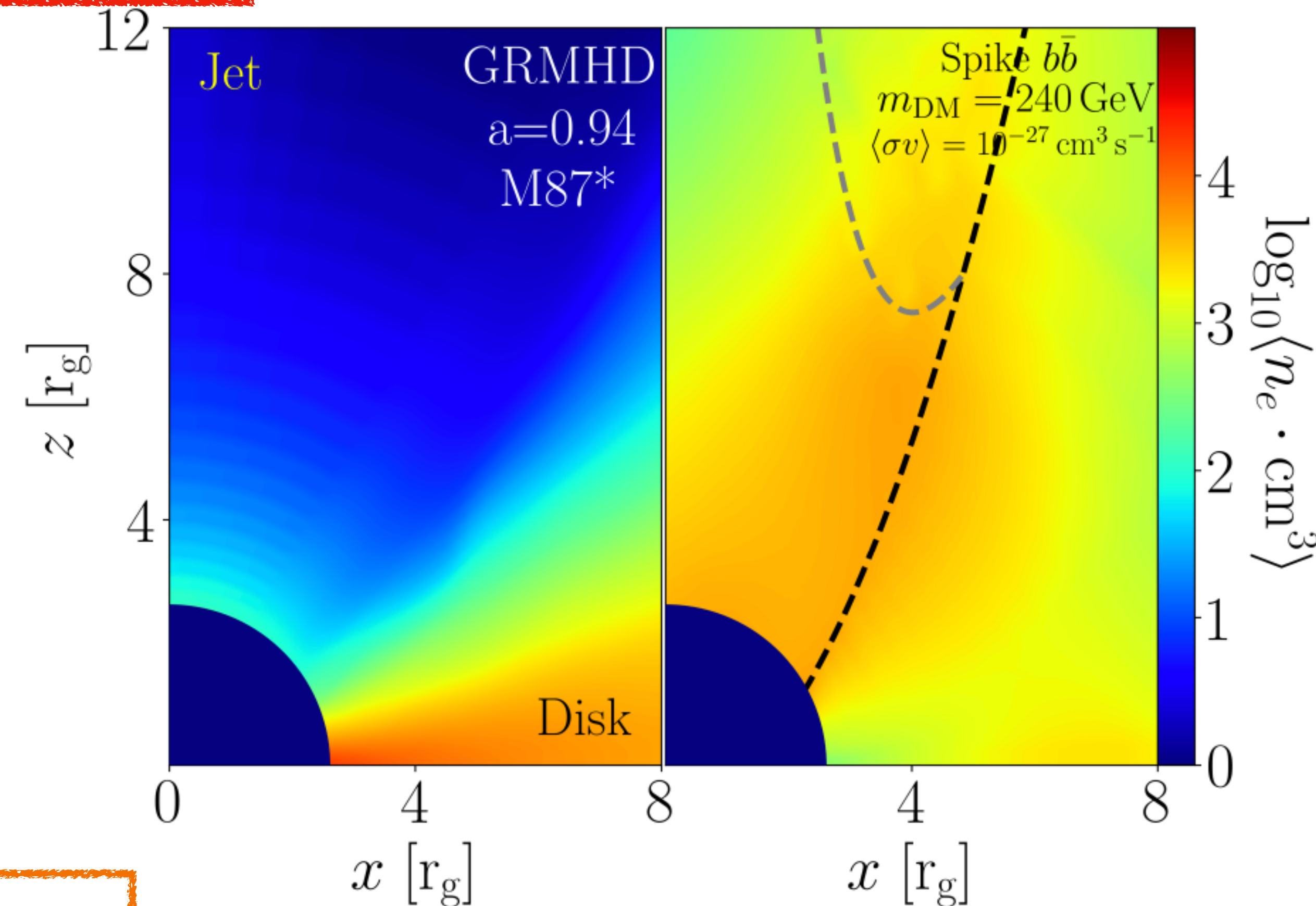
Electrons from DM annihilation



Electrons from DM annihilation

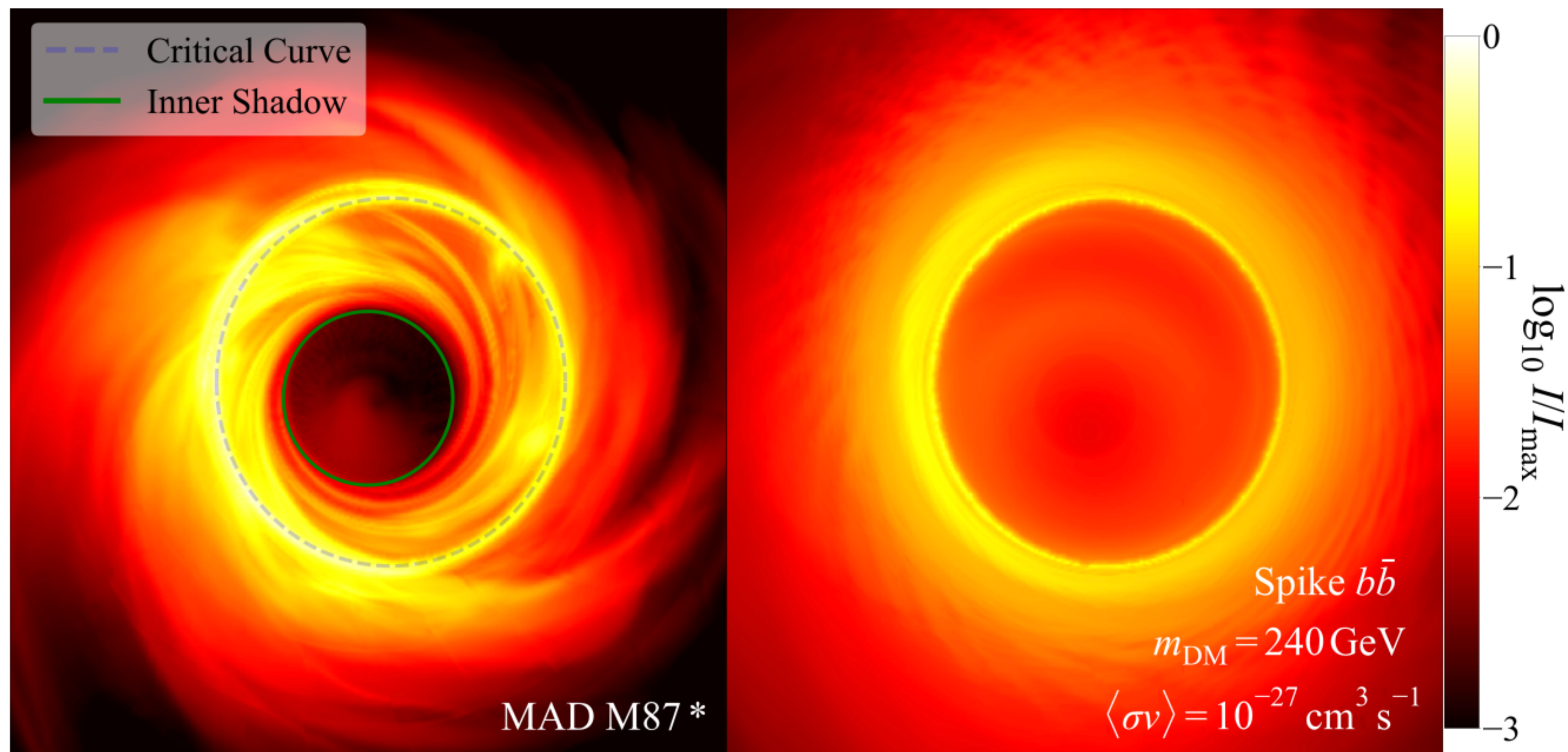
MAD model
suggested by EHT

- Analytic fit of background $\vec{B}$
- $\hat{v}_b$ follows $\vec{B}$, magnitude influenced by **gravity** and **centrifugal force**.
- Momentum transfer:
synchrotron + adiabatic convection



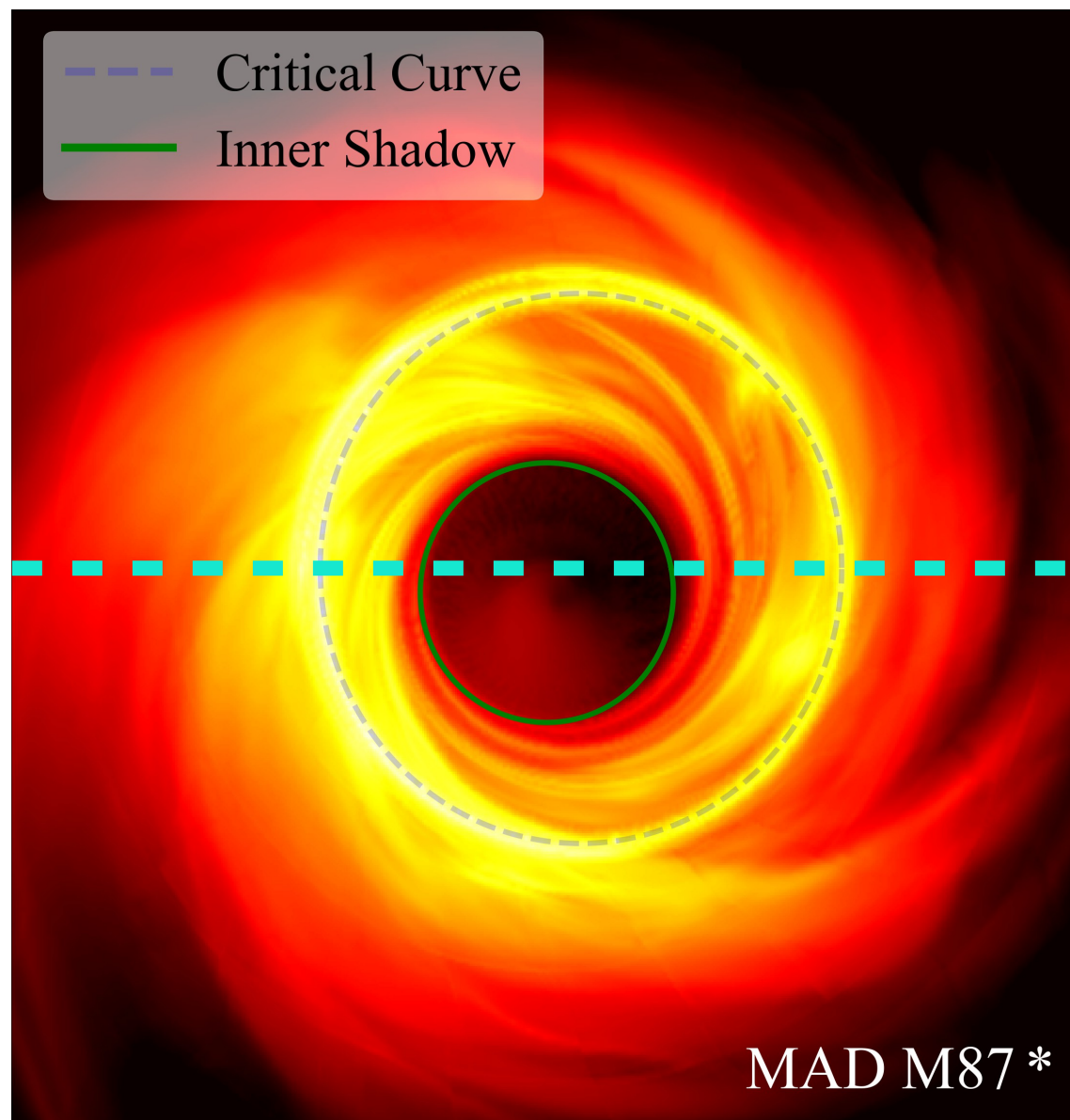
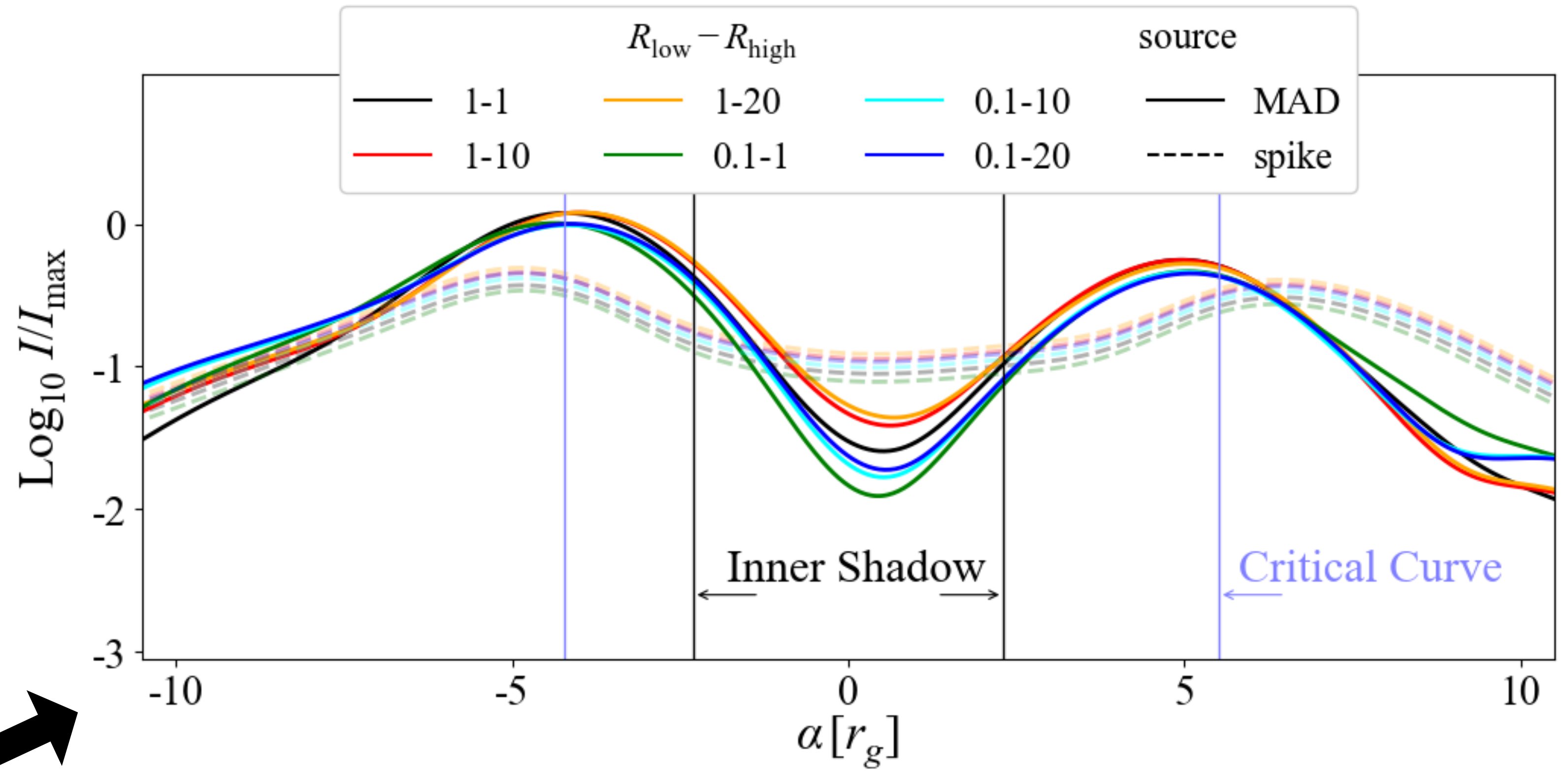
$$f_e(\vec{r}, p) = \int_{s_b}^{s_{\vec{r}}} ds_i \frac{q(s_i, p_i(s_i))}{v_b(s_i)} \exp \left[\int_{s_{\vec{r}}}^{s_i} ds \frac{4 \dot{p}_{\text{syn}}(s, p_i(s))}{p_i(s) v_b(s)} \right]$$

Dark matter illuminates the shadow



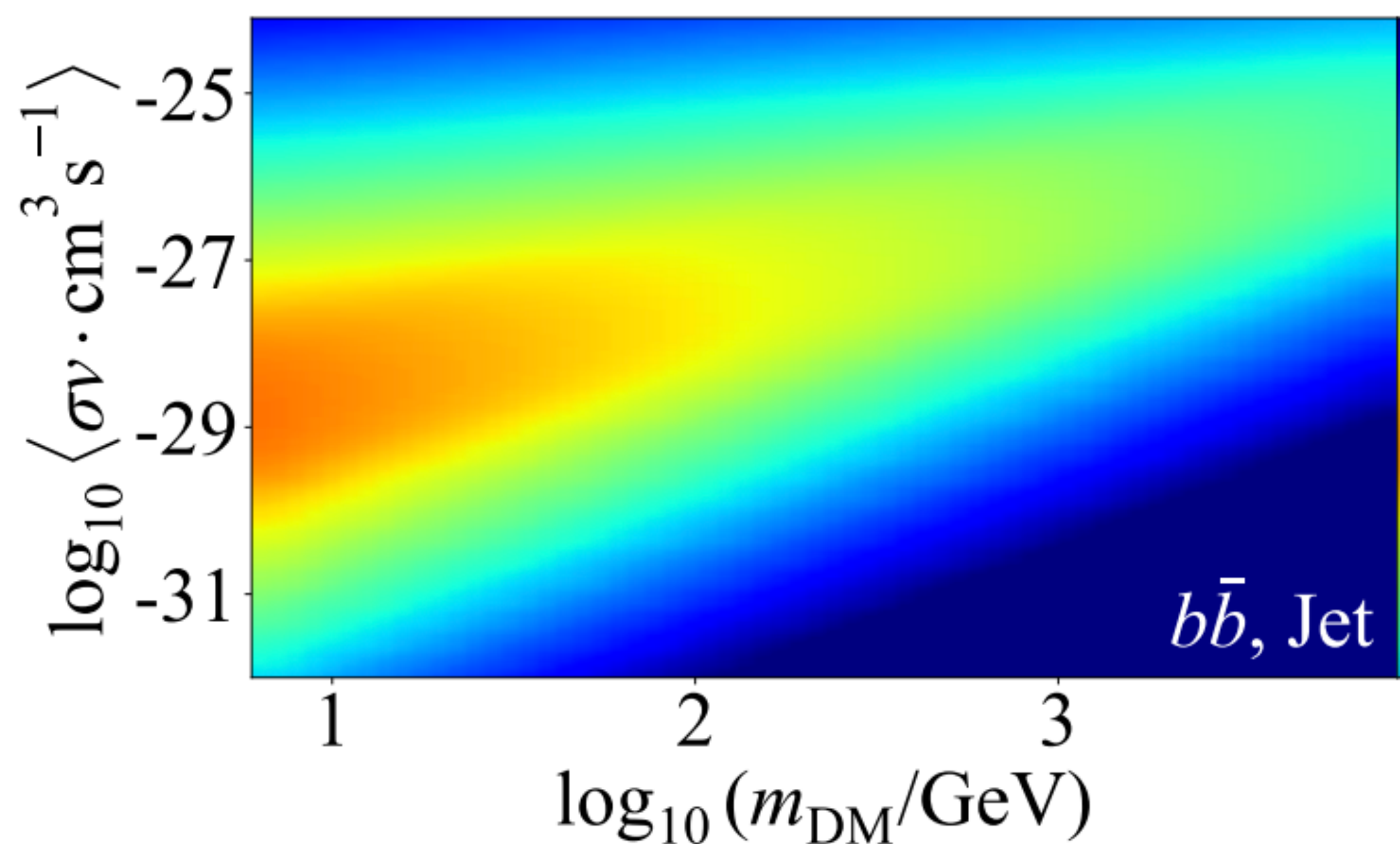
Morphology robustness

- Uncertainties of GRMHD parameters: R_{high} , R_{low}

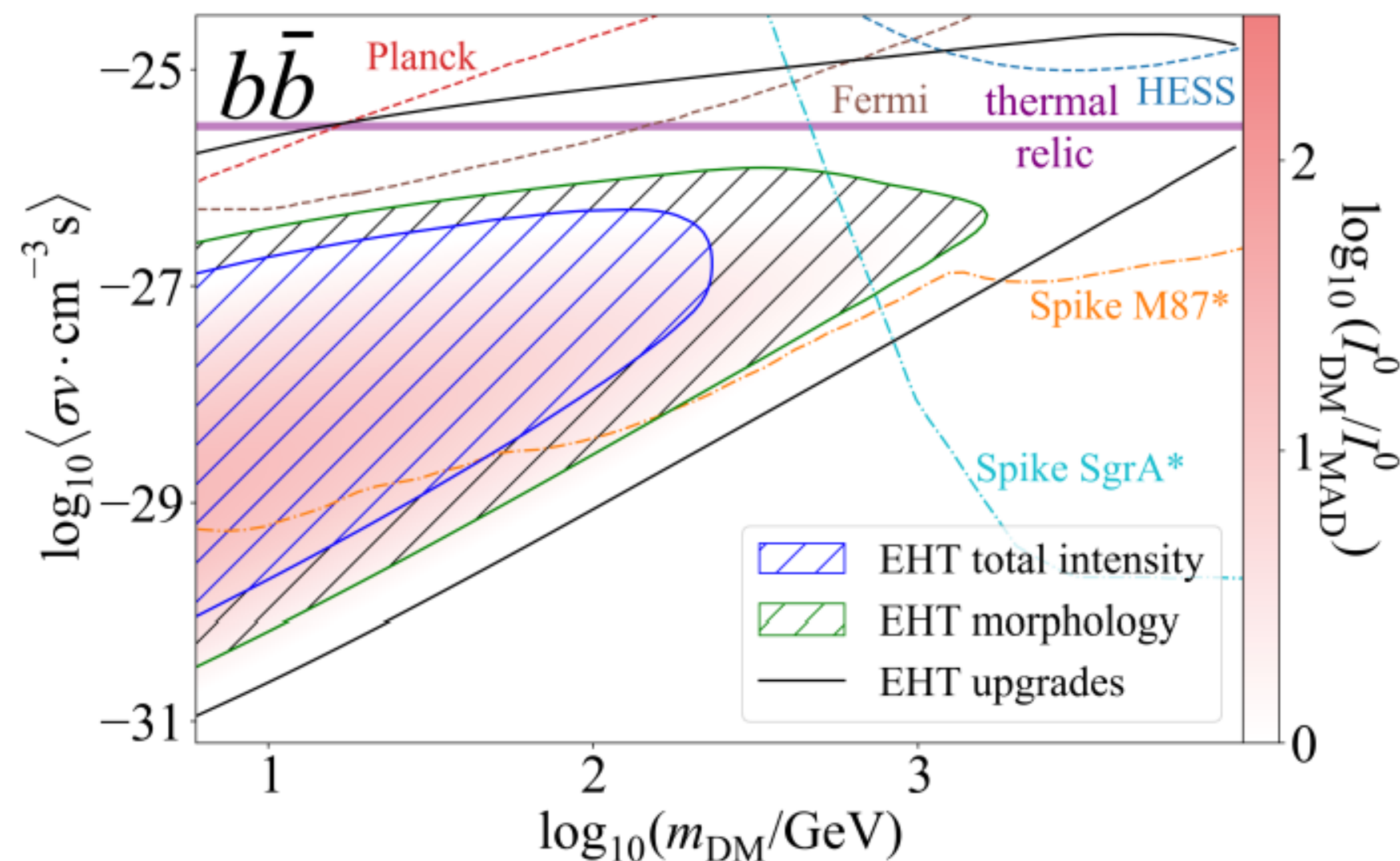


1-d luminosity plot

Exclusion



Electron number density at $4r_g$



Exclusion limits almost follow the number density

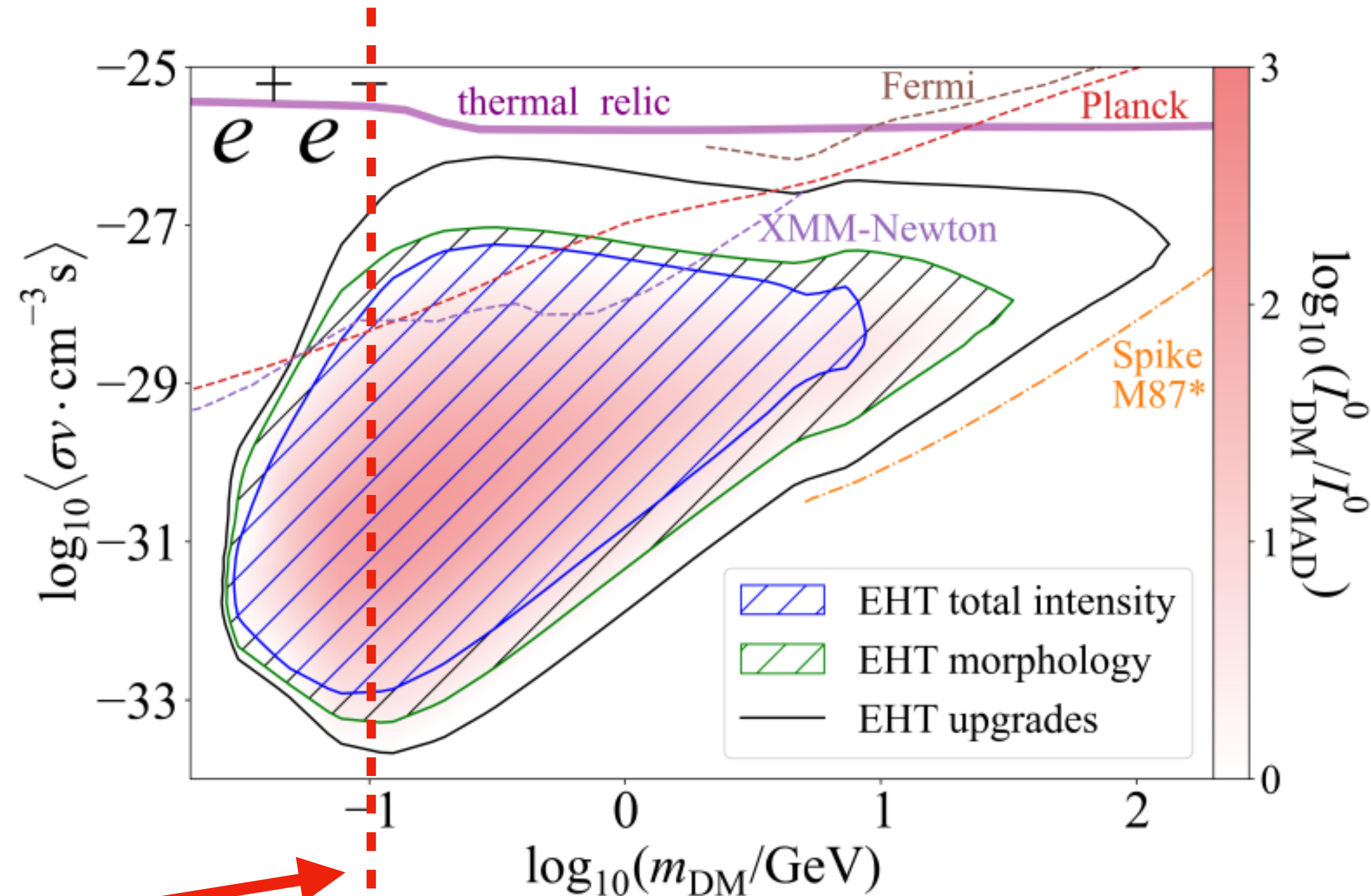
Exclusion-different annihilation channel

Lighter dark matter:

Reduced synchrotron efficiency
at 230 GHz $\rightarrow$ worse sensitivity

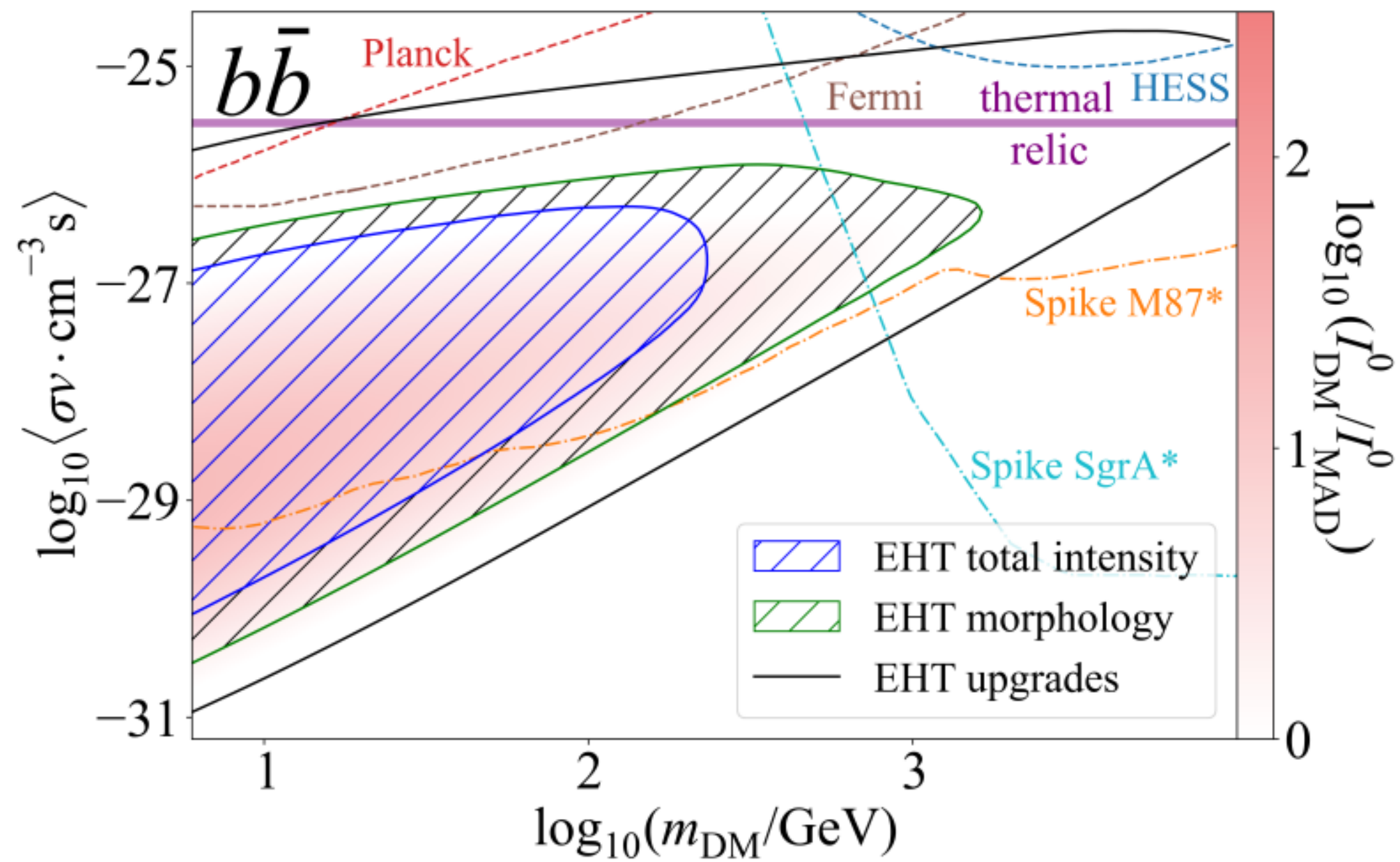
Critical frequency of synchrotron

$$\nu_c \approx 180 \text{ GHz} \times \left(\frac{B}{7 \text{ G}} \right) \times \left(\frac{p}{0.1 \text{ GeV}} \right)^2$$

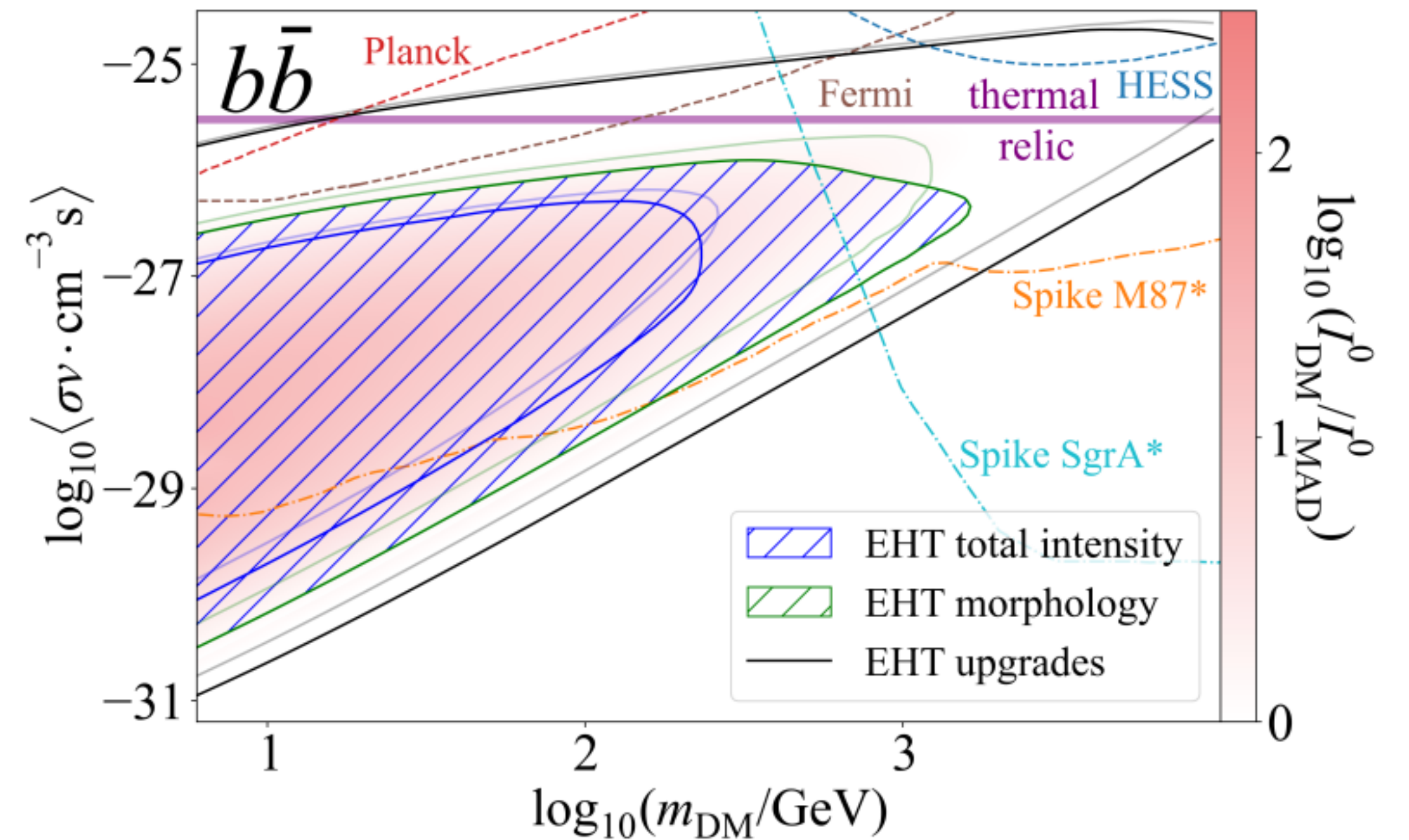


Morphology robustness

Uncertainties of Spin



$$a_J = 0.9375$$



$$a_J = 0.5$$

Summary

- Black hole images from EHT has spatial information (**shadow** and **photon ring**), providing a new opportunity for DM detection
- DM annihilation will inject **extra electrons**, especially in the **jet** region
- Synchrotron of injected electrons will **illuminate black hole shadow**, thus the black hole image can be used to constrain DM annihilation cross section
- The method is robust for potential parameter uncertainties