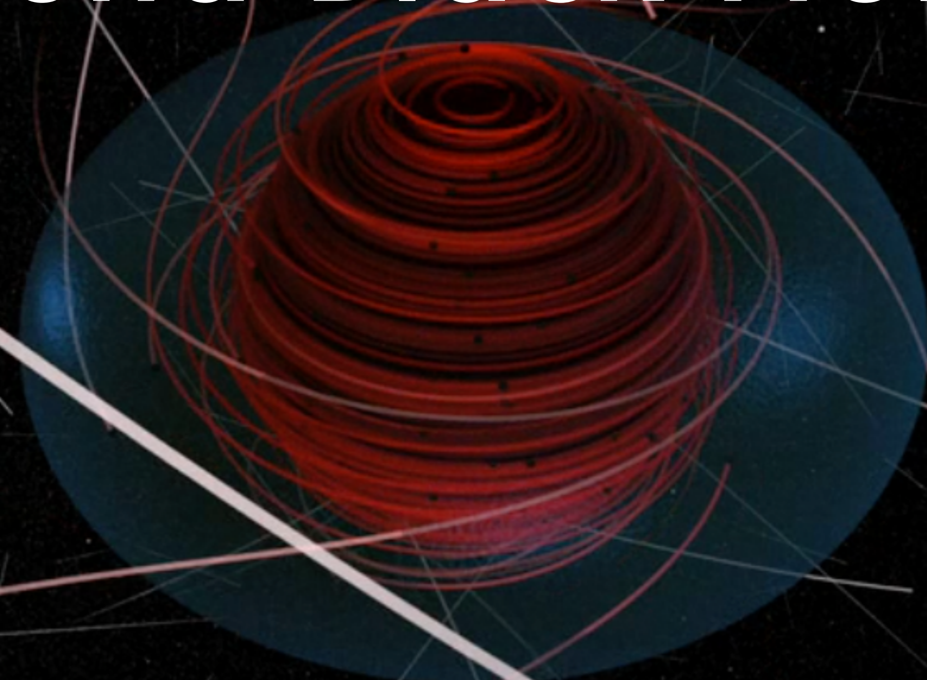
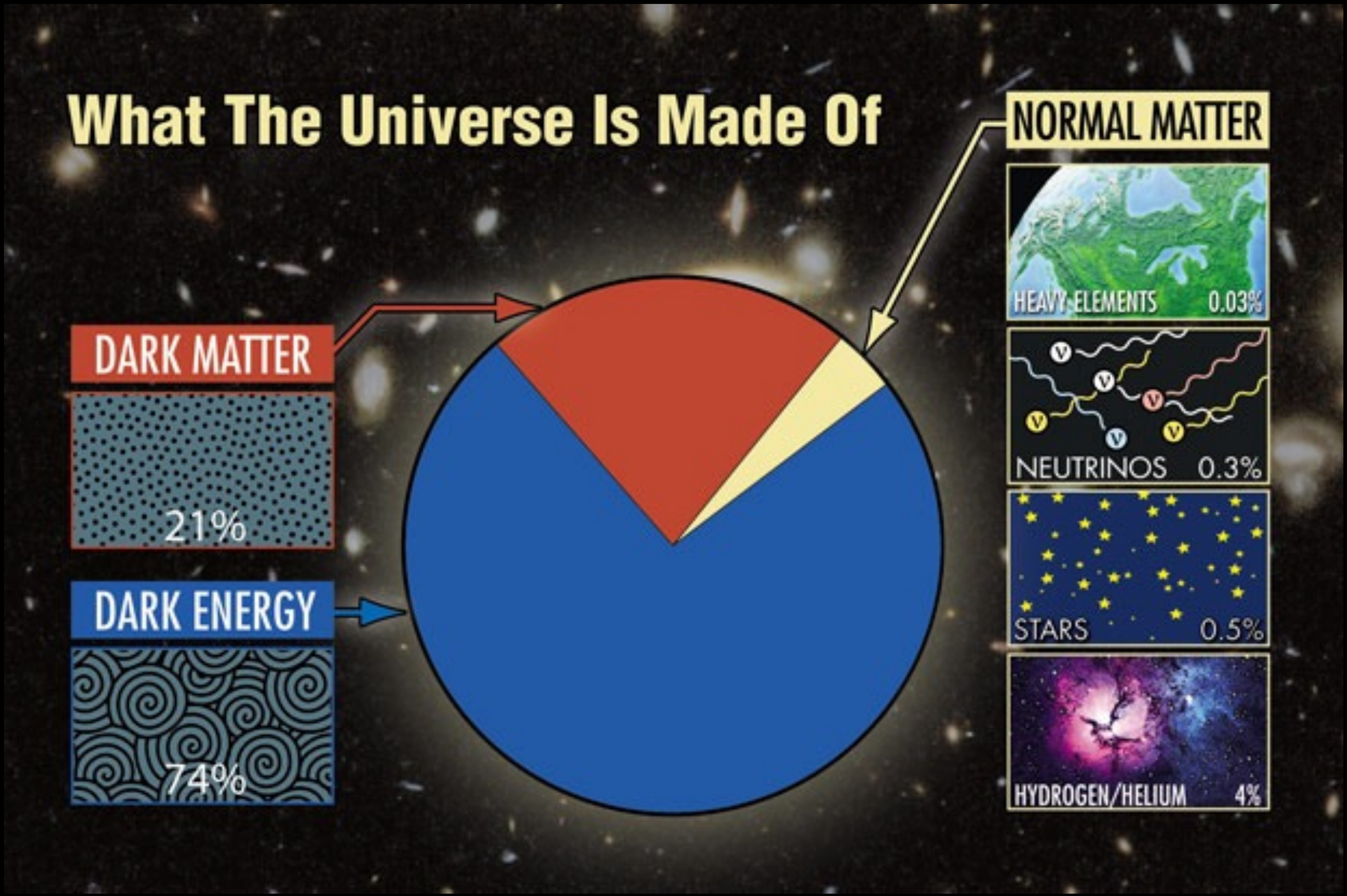
# Dark Matter Annihilation Around Black Holes



Jeremy Schnittman (NASA Goddard)
KMI2017, Nagoya University
Jan 6, 2017

# background/motivation



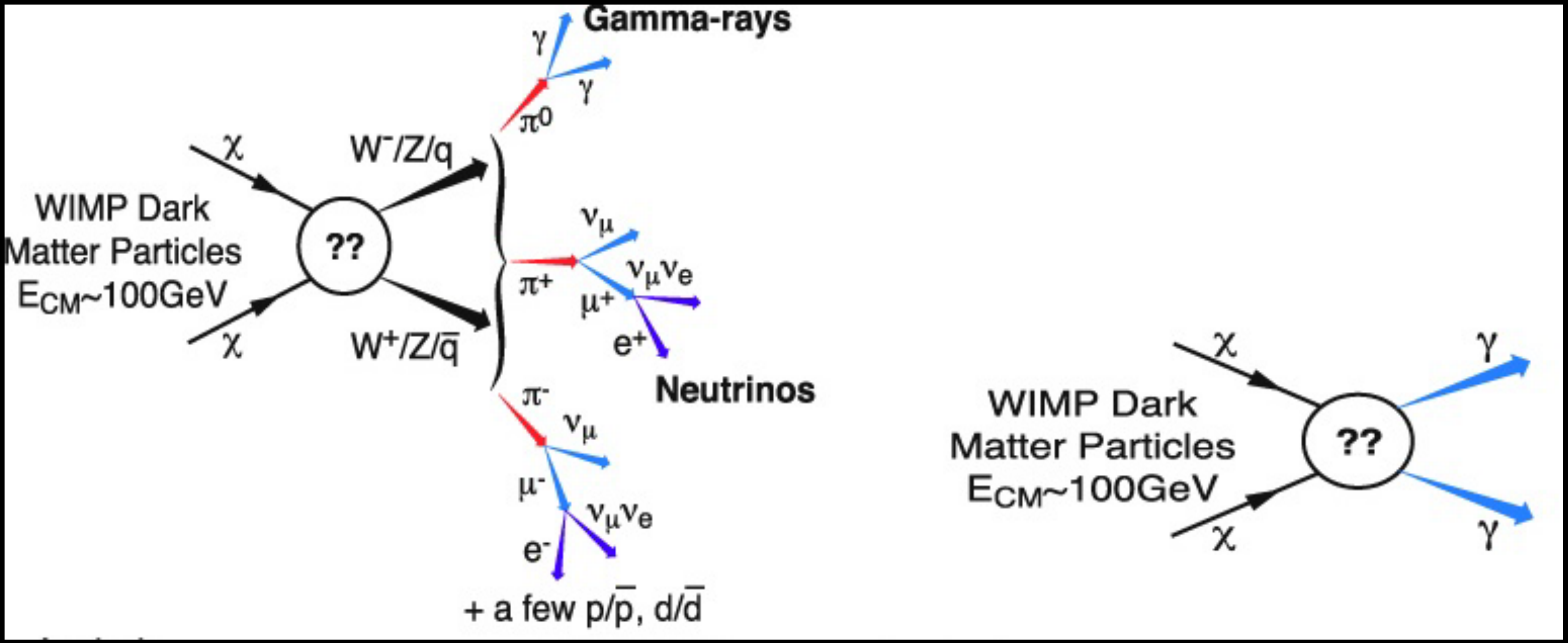
# background/motivation

partial selection of DM particle candidates
Bertone, Hooper & Silk (2004)

- SM neutrinos
- sterile neutrinos
- axions
- SUSY particles: neutralinos, sneutrinos, gravitinos, axinos
- light scalar DM
- "little Higgs" mechanism
- Kaluza-Klein excited states
- Wimpzillas
- Q-balls, mirror particles, CHAMPs, D-matter, cryptons, super-weakly interacting DM, brane world DM, fourth generation neutrinos, etc., etc…

# background/motivation

DM annihilation models



# background/motivation

## Black Holes as particle accelerators

**Dark matter distributions around massive black holes: A general relativistic analysis**

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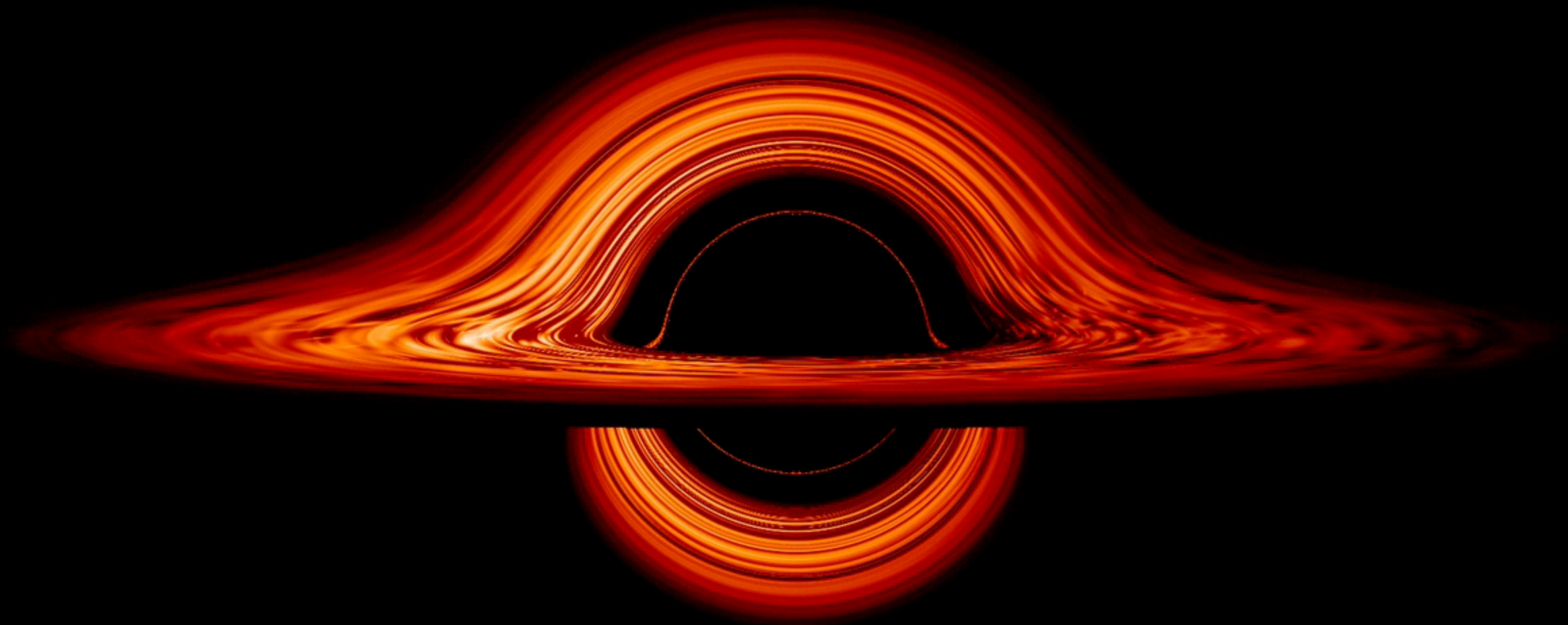
(Dated: May 14, 2013)

decay [11] or annihilation [12] processes for various kinds of dark matter. There are uncertainties in all aspects of these models. However one thing is certain: if the central black hole Sgr A* is a rotating Kerr black hole and if general relativity is correct, its external geometry is precisely known. It therefore makes sense to make use of this certainty as much as possible.

# `Pandurata`: black hole particle playground

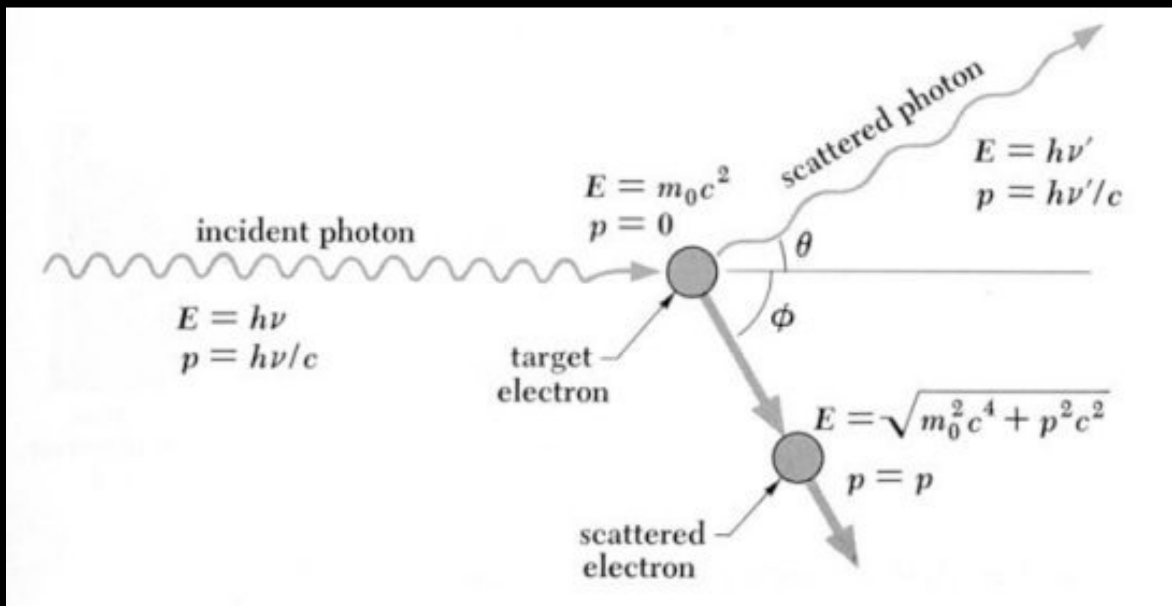


# background/motivation

Black Holes as particle accelerators

- Penrose (1969)
- Piran & Shaham (1977)
- Blandford & Znajek (1977)
- Baushev (2009)
- Banados, Silk, & West (2009) and references to [200+]
- Bejger+(2012), Harada+(2012), Zaslavskii(2012-16)
- JS (2014,2015)
- Ogasawara+(2016), Harada+(2016), Hedja & Bicak (2016)

# black hole basics




$$\mathbf{p}_1 + \mathbf{p}_2 = \mathbf{p}_3 + \mathbf{p}_4$$

$$\mathbf{p}_1 \cdot \mathbf{p}_2 = g_{\mu\nu} p_1^\mu p_2^\nu$$

$$g_{\mu\nu} = \begin{pmatrix} -\alpha^2 + \omega^2\varpi^2 & 0 & 0 & -\omega\varpi^2 \\ 0 & \rho^2/\Delta & 0 & 0 \\ 0 & 0 & \rho^2 & 0 \\ -\omega\varpi^2 & 0 & 0 & \varpi^2 \end{pmatrix}$$

$r_g = GM/c^2$

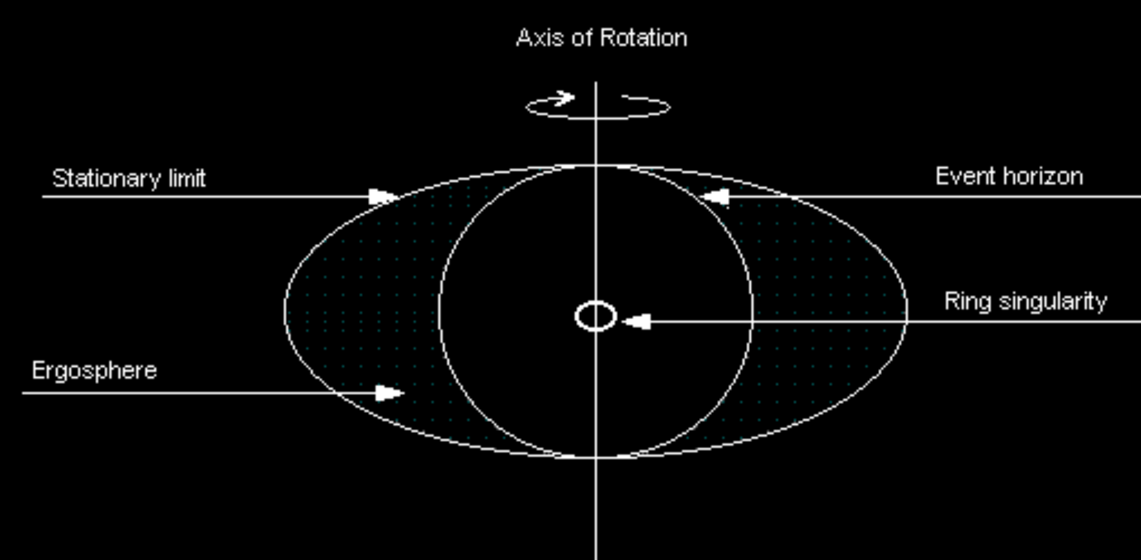
$$\mathbf{p}^2 = -m^2$$

$$\Omega \equiv \frac{d\phi}{dt} = \frac{p^\phi}{p^t}$$

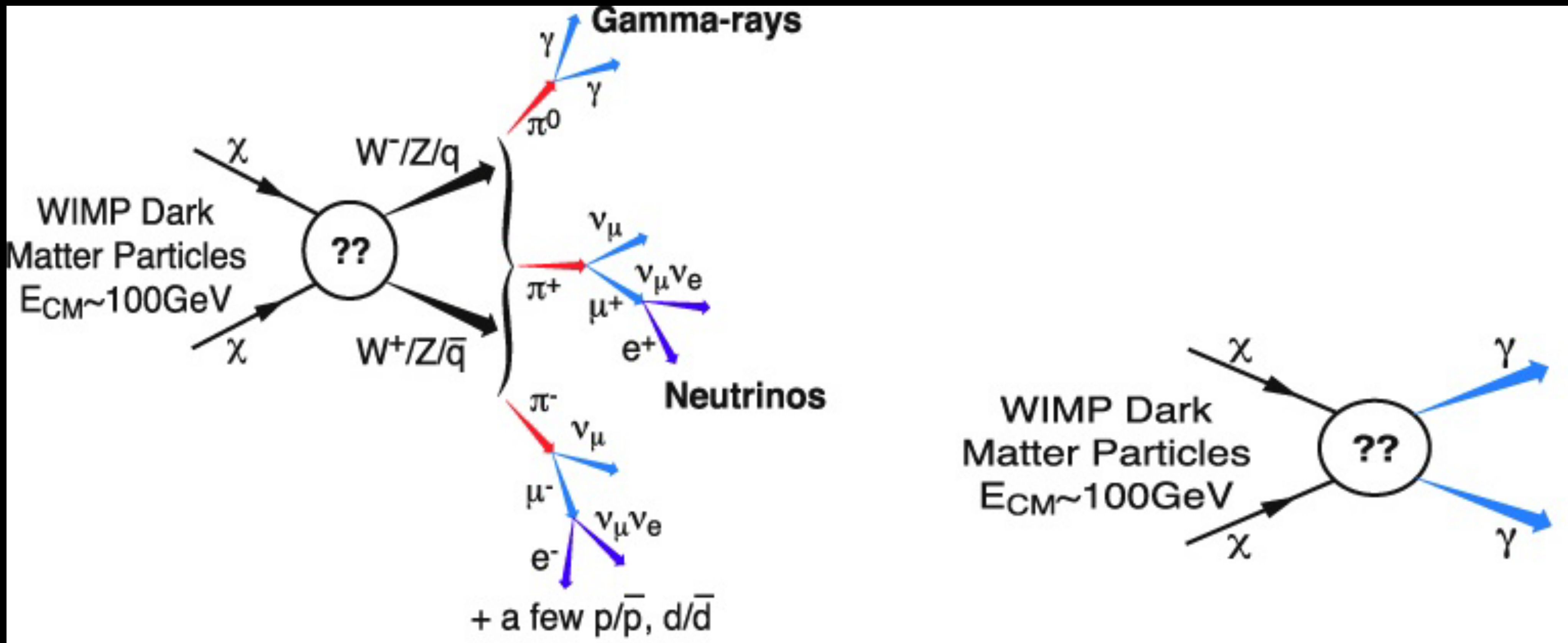
$$-m^2 = (p^t)^2(g_{tt} + 2\Omega g_{t\phi} + \Omega^2 g_{\phi\phi})$$

$$\Omega_\pm = \frac{-g_{t\phi} \pm \sqrt{g_{t\phi}^2 - g_{tt}g_{\phi\phi}}}{g_{\phi\phi}}$$

ergosphere surface: $g_{tt} = 0$



# DM annihilation models




self-annihilation (own anti-particle):

$$\chi + \chi \rightarrow 2\gamma$$

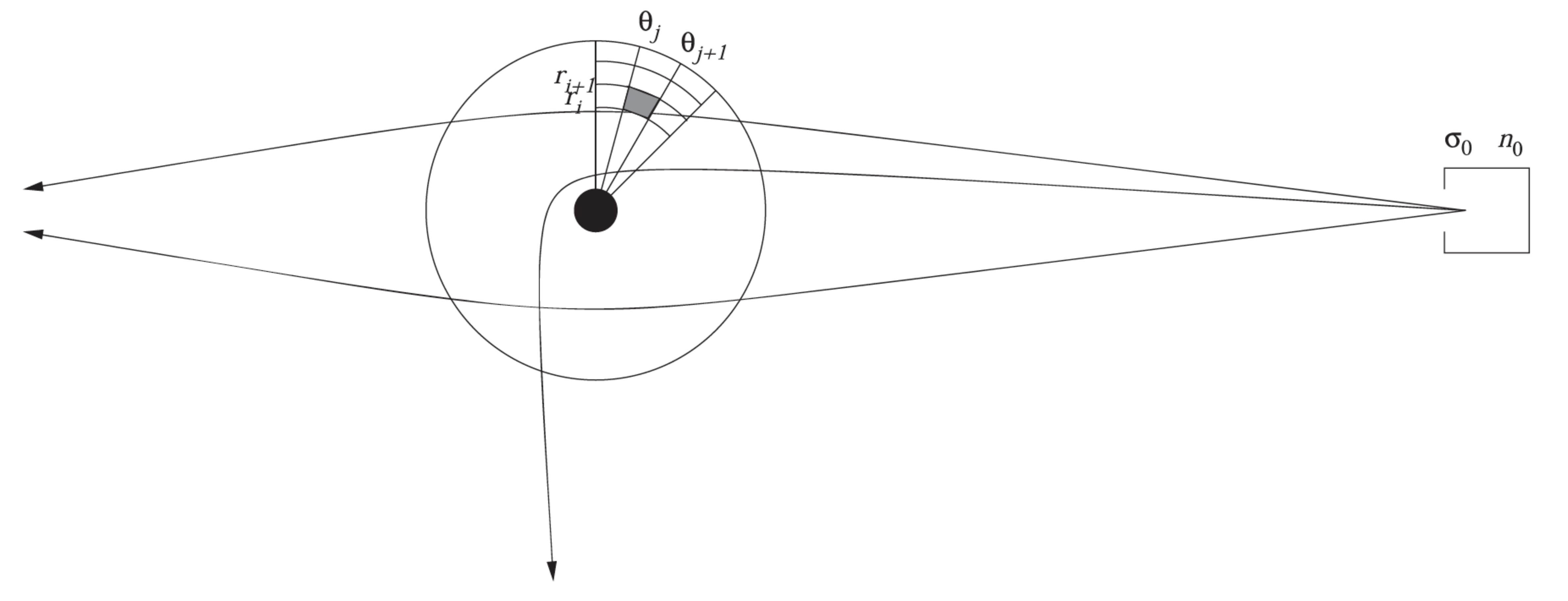
$\sigma \lesssim 10^{-33}\mathrm{cm}^2$ from *Fermi-LAT*, Sgr A*

intermediate product (minimum threshold energy):

$$\chi + \chi \rightarrow \chi^* + \bar{\chi}^* \rightarrow 2\gamma^*$$

$E_{\mathrm{thresh}} = 2m_{\chi^*}$, $\sigma(E_{\mathrm{com}} > E_{\mathrm{thresh}})$ free parameters

# step 1: populate the distribution function



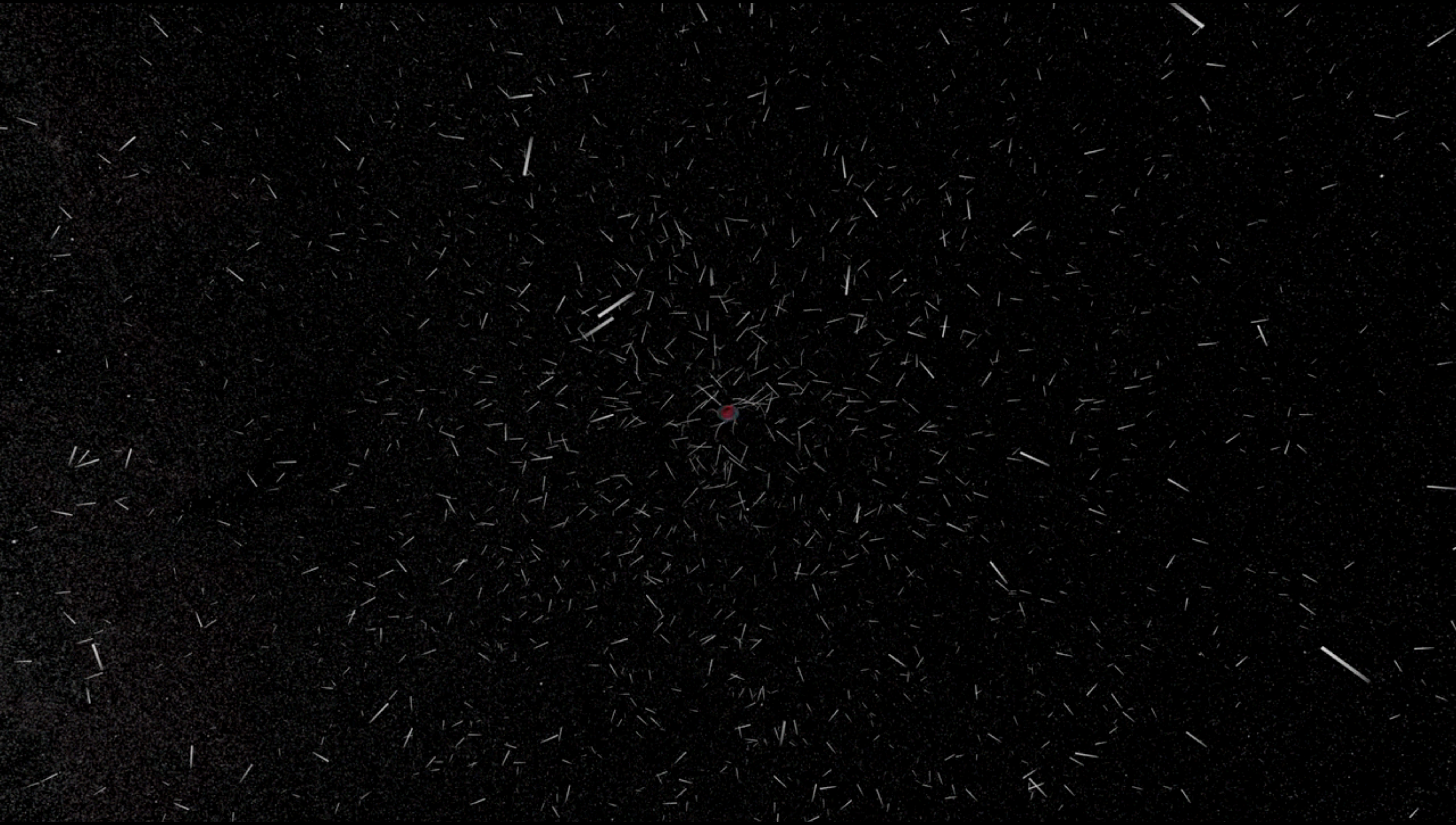

N-body simulations generically lead to NFW profile (Navarro, Frenk, & White 1996):

$$\rho_{\mathrm{NFW}}(r) = \frac{\rho_s R_s^3}{r(r+R_s)^2} \sim r^{-1}$$

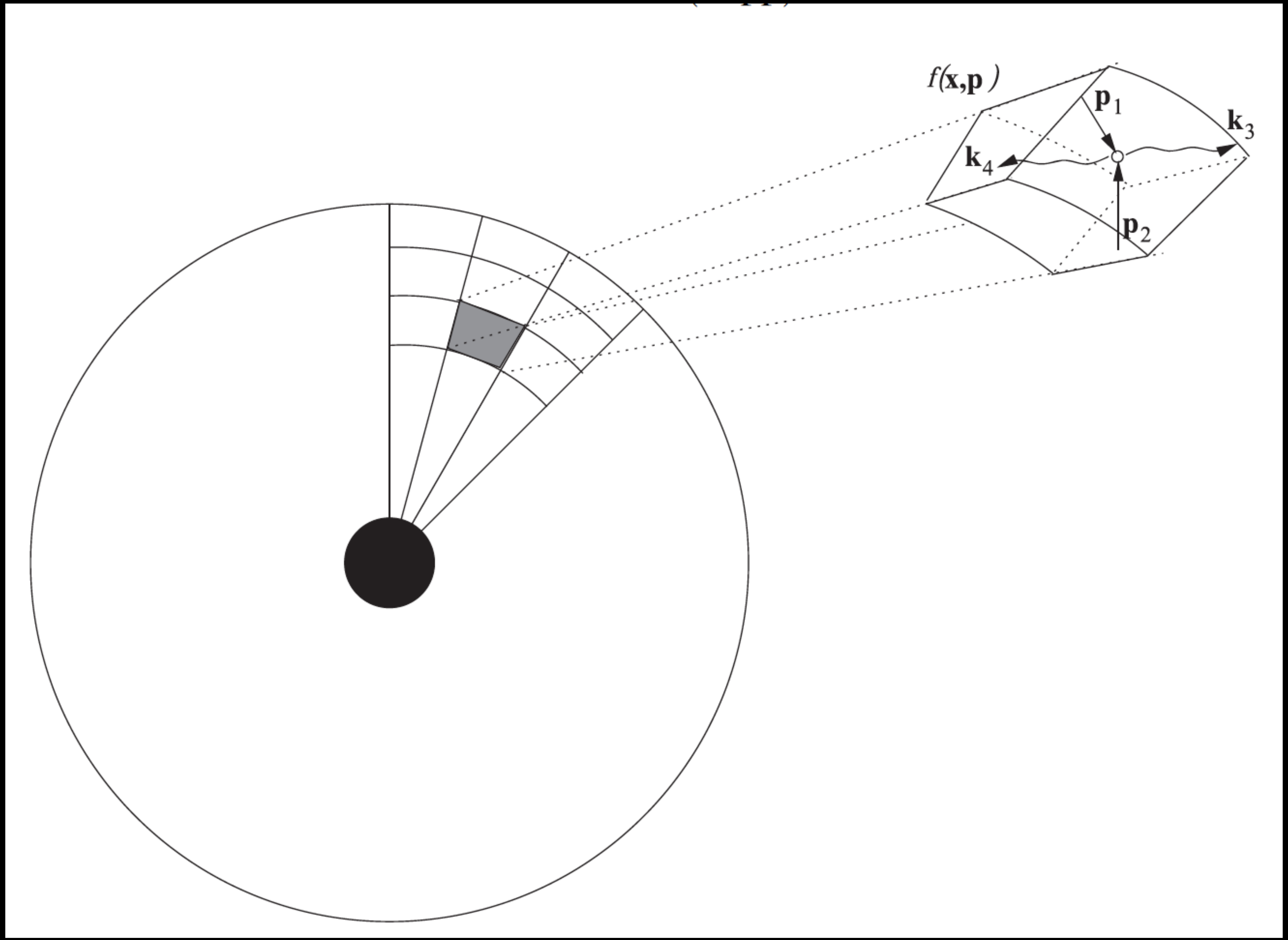
The *influence radius* is where the black hole begins to dominate gravitational potential:

$$r_{\mathrm{infl}} = \frac{GM}{\sigma^2} = 1\ \mathrm{pc} \left(\frac{M}{10^7 M_\odot}\right) \left(\frac{\sigma}{200\ \mathrm{km/s}}\right)^{-2} \approx 2 \times 10^6 M$$

# step 1: populate the distribution function



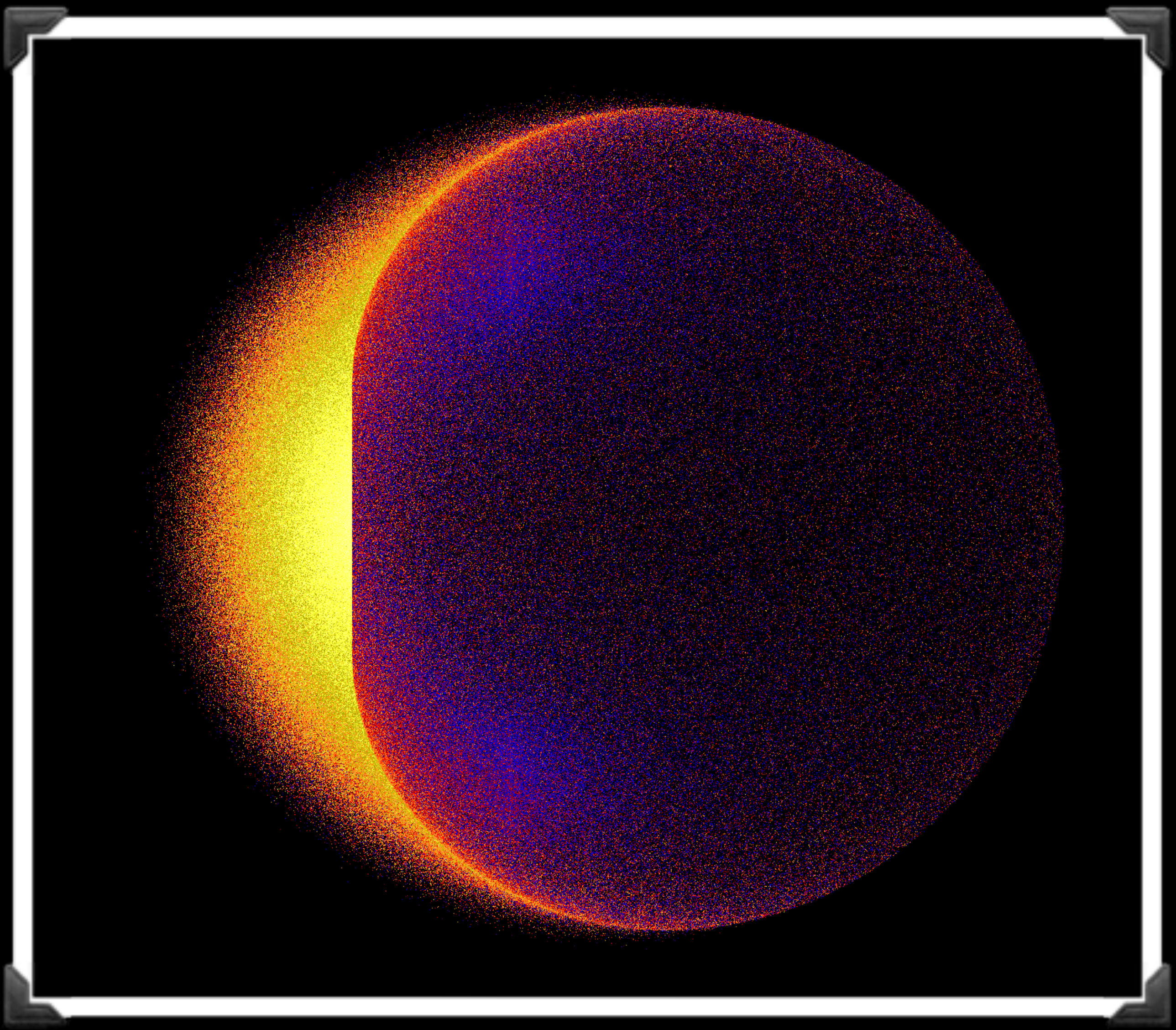
# step 2: calculate annihilation rates

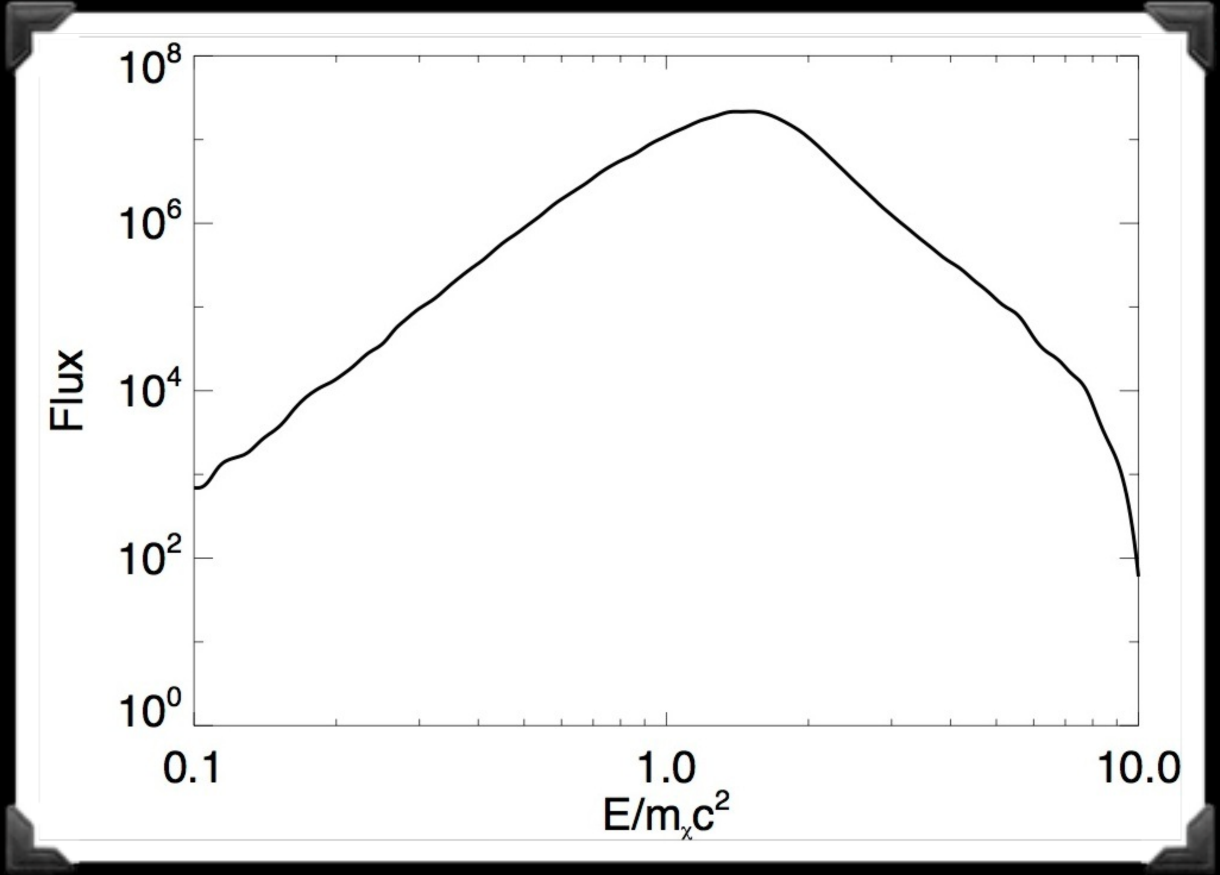



$$R(\mathbf{x}) = \int d^3\mathbf{p}_1 \int d^3\mathbf{p}_2 \, f(\mathbf{x},\, \mathbf{p}_1) f(\mathbf{x},\, \mathbf{p}_2) \frac{\gamma_{\rm rel}}{\gamma_1 \gamma_2} \, \sigma_\chi(\gamma_{\rm rel}) v_{\rm rel}$$

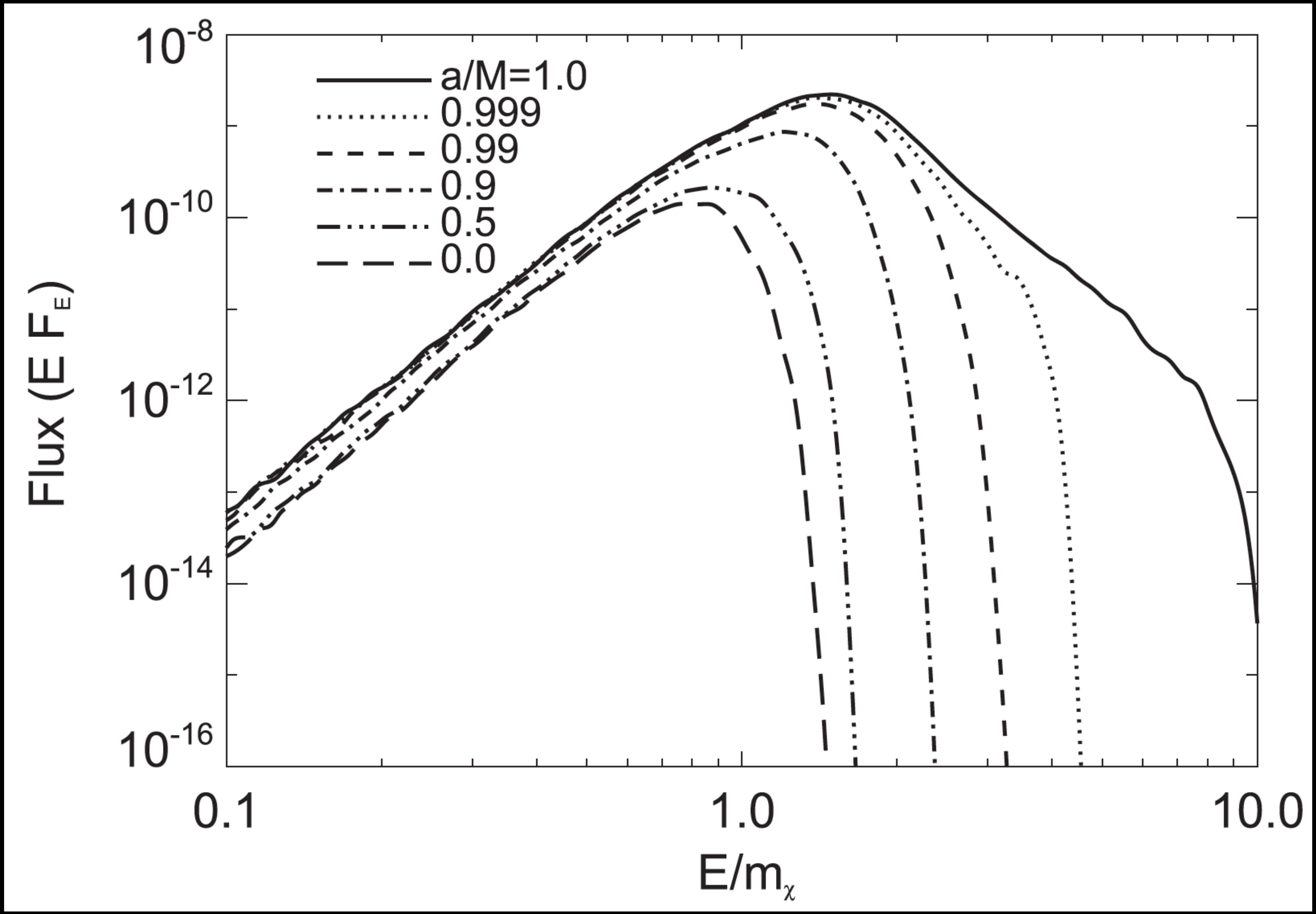
# step 3: track photons to infinity

$E_{com} > 3m_x$

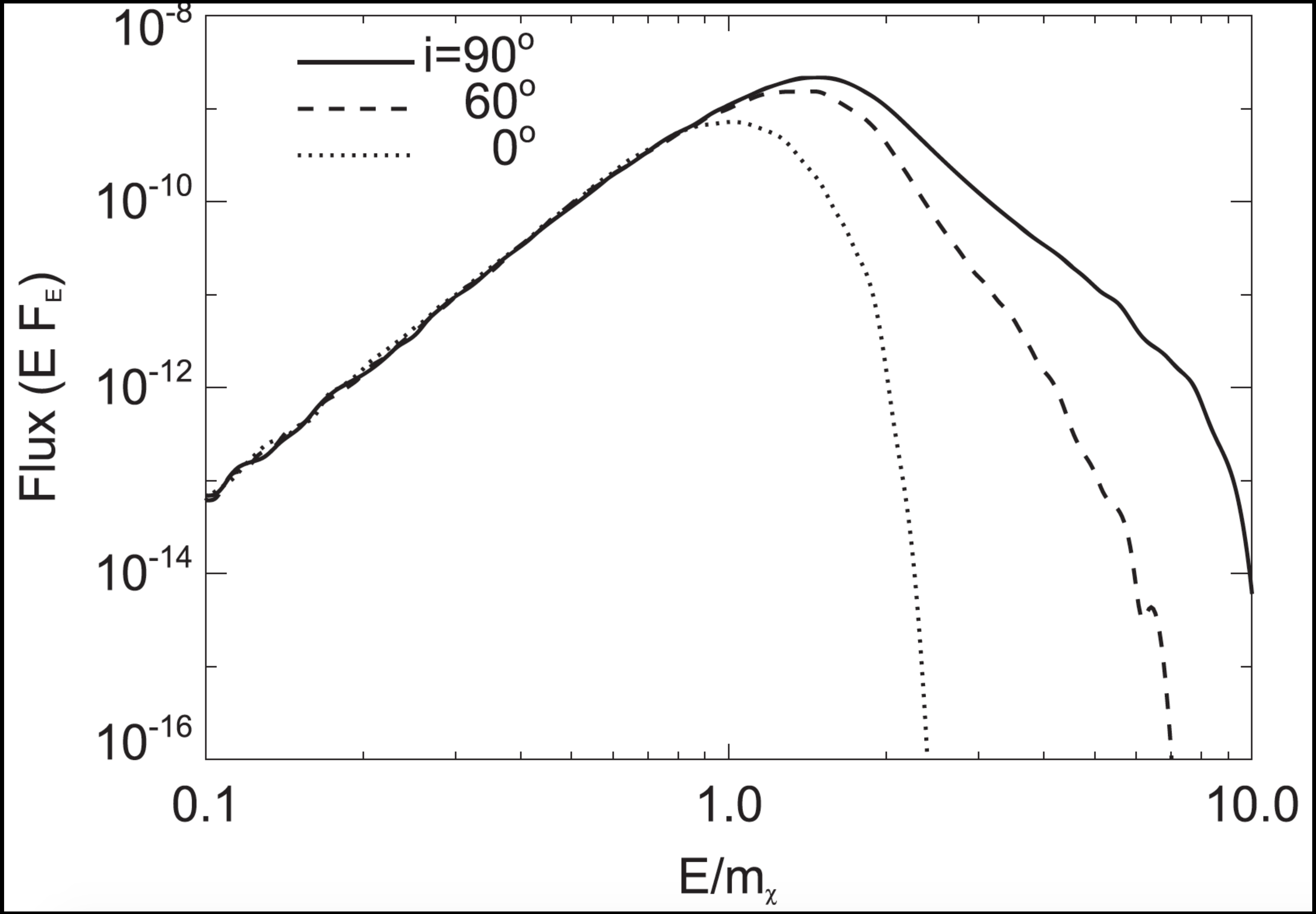




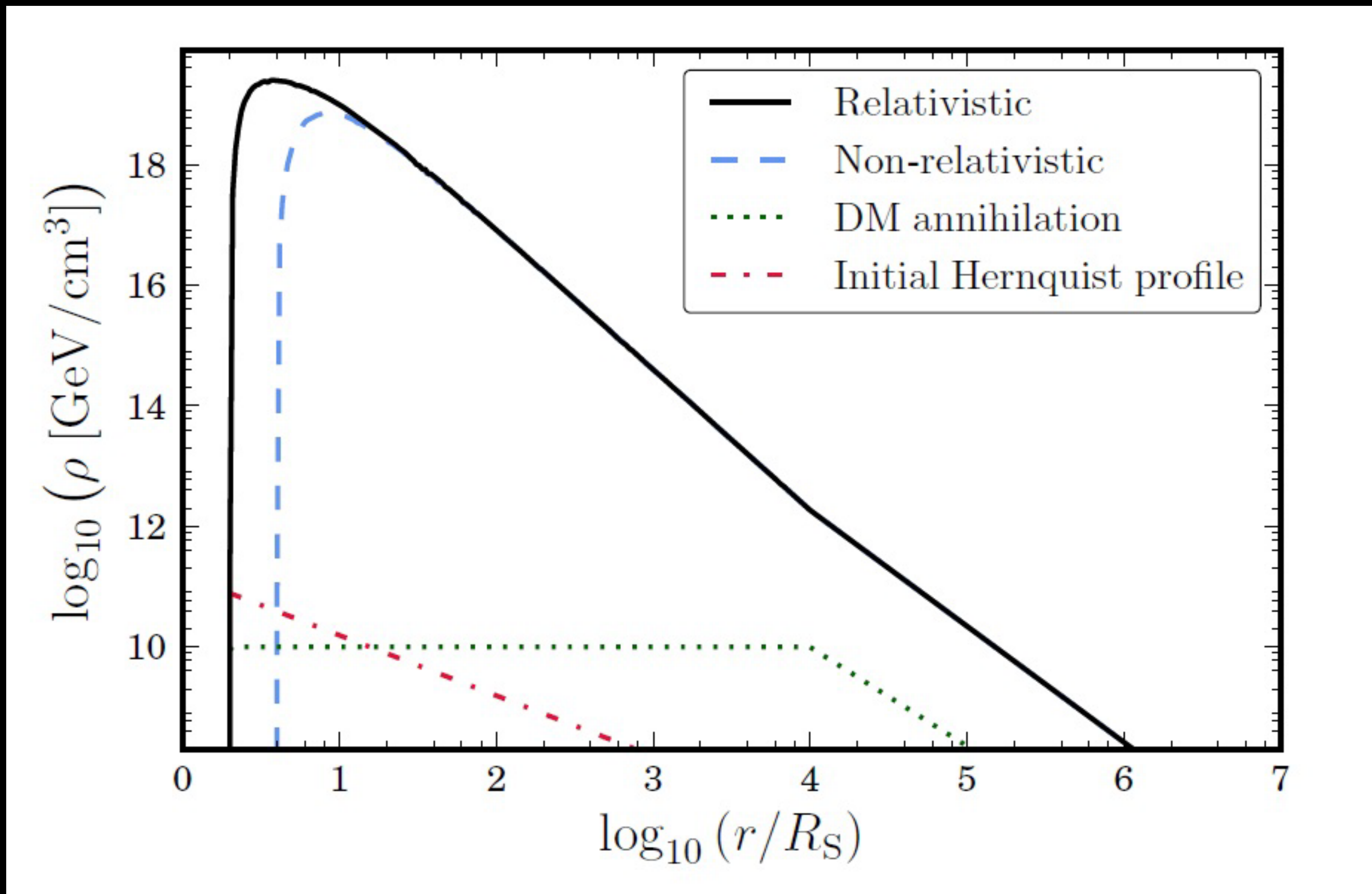
# dependence on black hole spin



# dependence on observer inclination



# bound dark matter




Gondolo & Silk (1999); Sadeghian, Ferrer, & Will (2013)

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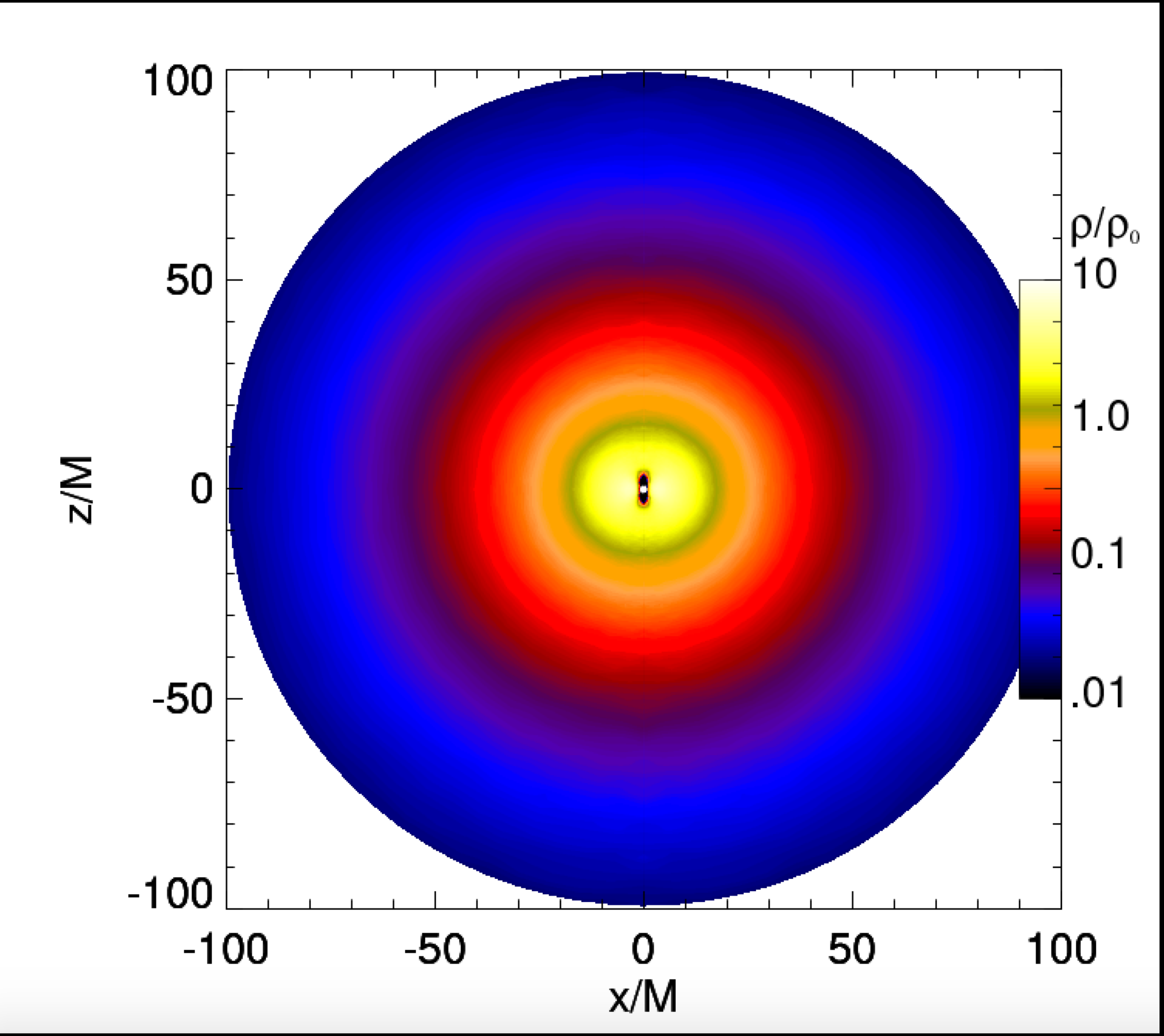

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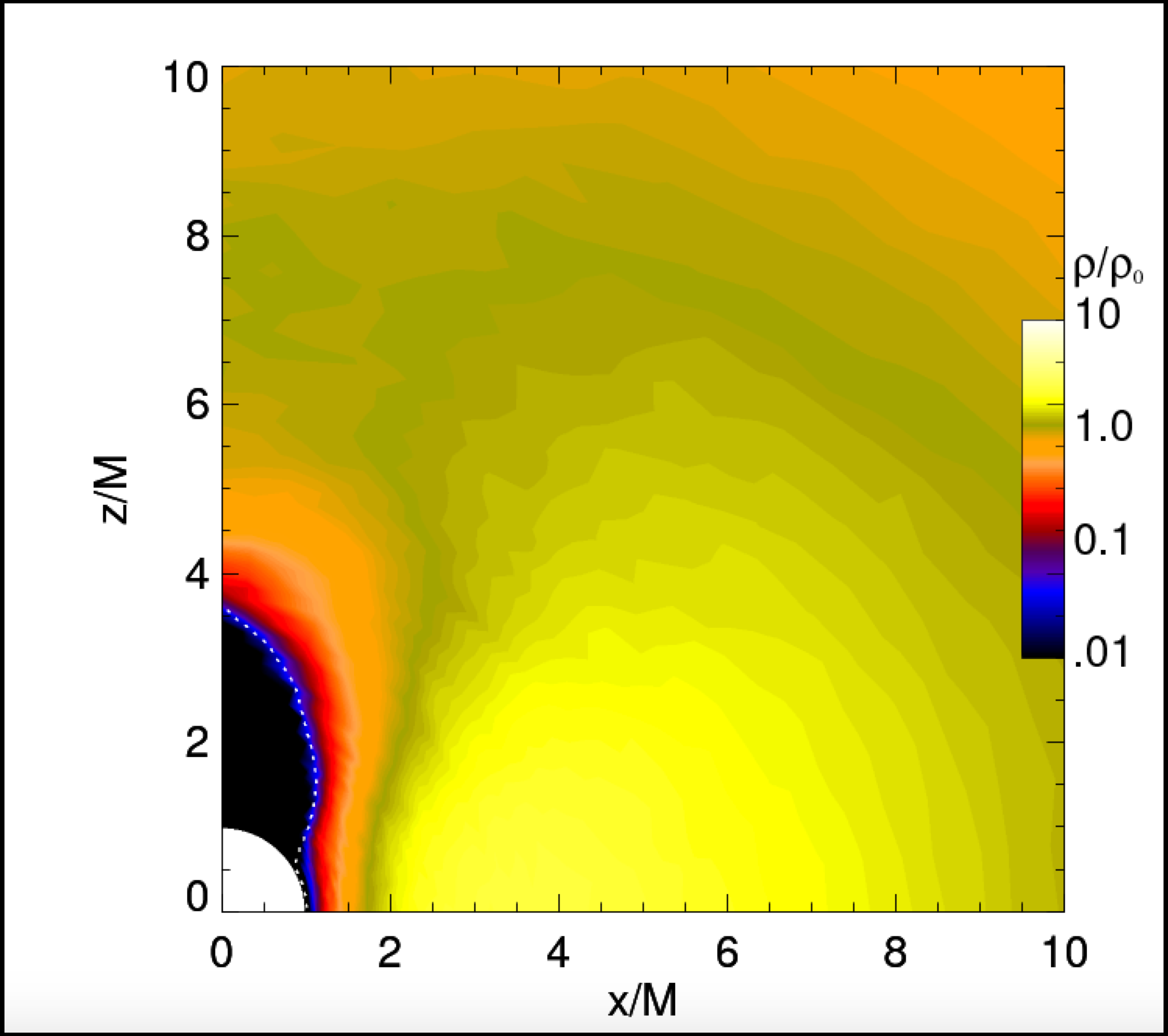
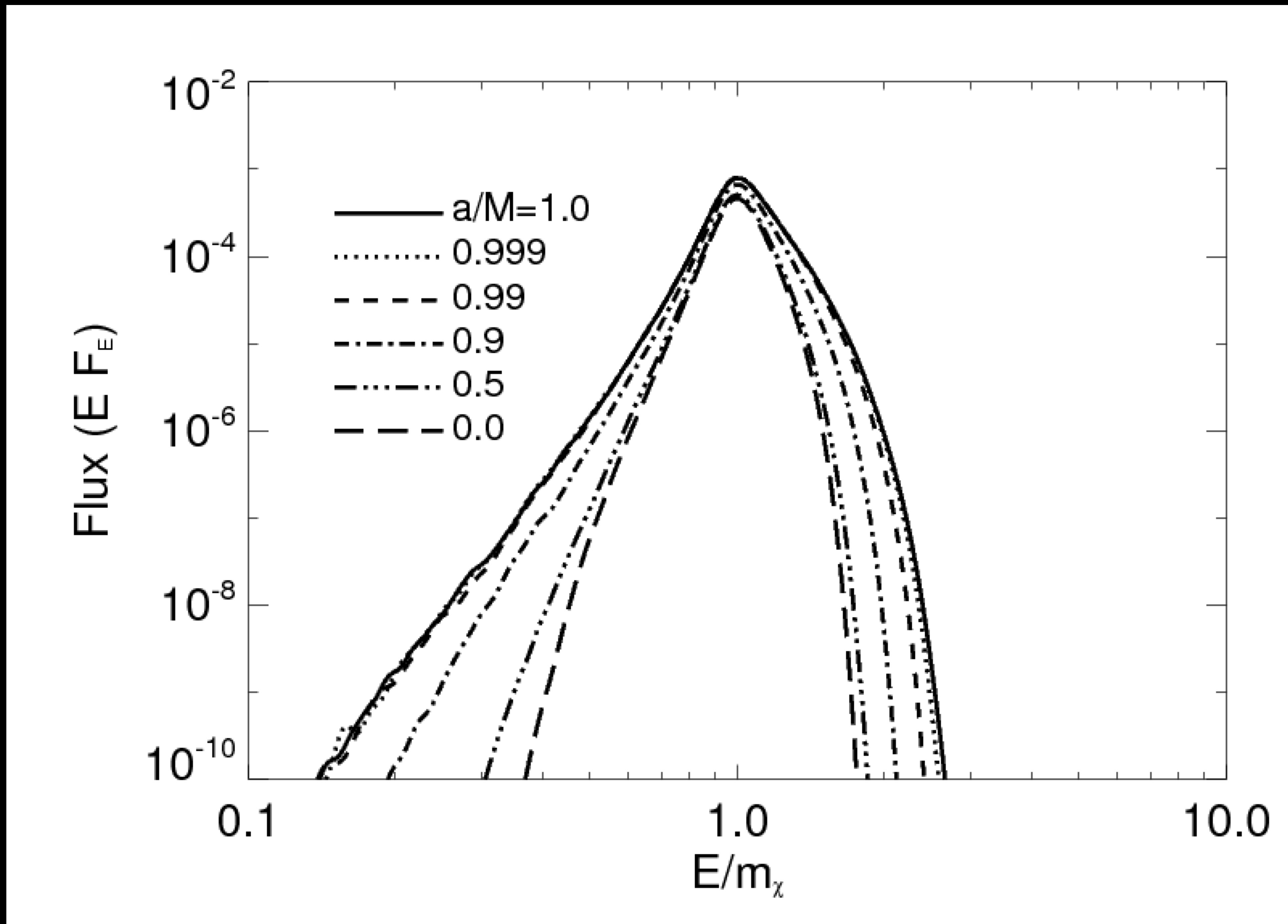
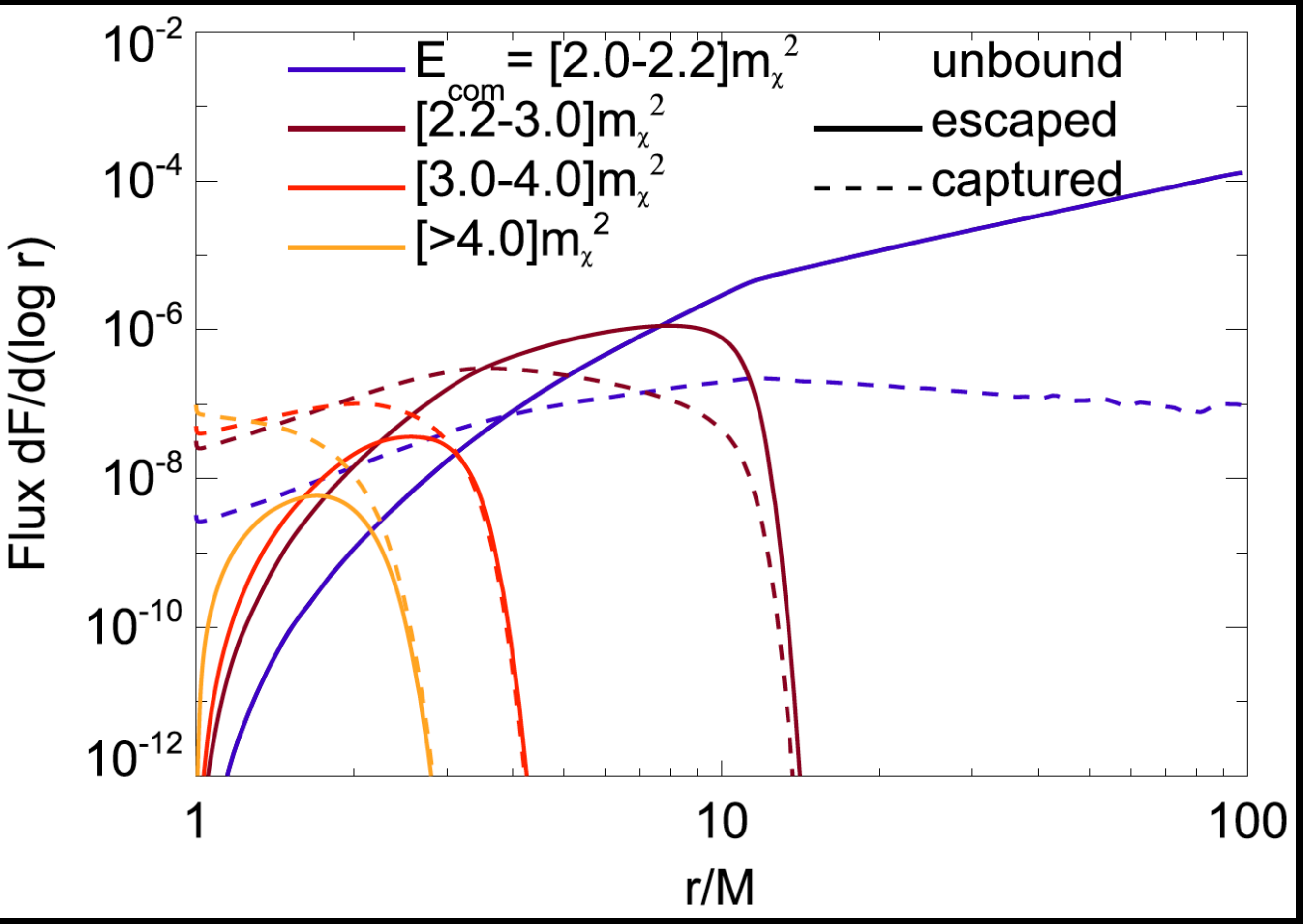
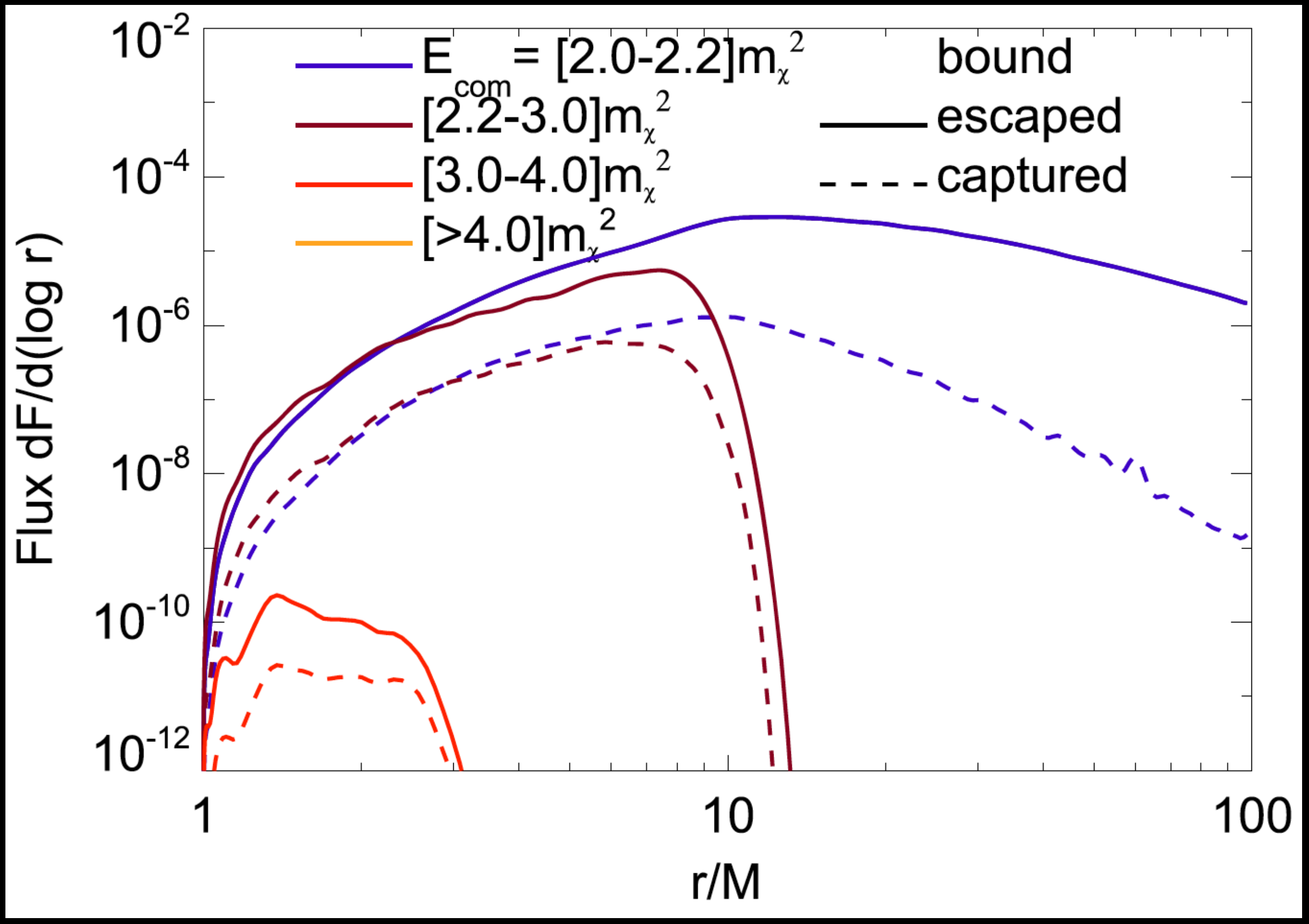


# bound dark matter: depedence on spin



# escape fractions: bound vs unbound



# astrophysical observability

$F \sim M^3 \rho^2 / D^2 \quad r_{infl}/r_g \sim M^{-1/2}$

$F \sim M^{-3/2}/D^2$ (unbound; no threshold)

$F \sim M^{3/2}/D^2$ (unbound; threshold E)

$F \sim M^0/D^2$ (bound)

| source | mass ($M_\odot$) | D (Mpc) | σ (km/s) | flux factor (no thresh) | flux factor (thresh) | flux factor (bound) |
|---|---|---|---|---|---|---|
| Sgr A* | $4 \times 10^6$ | 0.008 | 105 | 1 | 1 | 1 |
| M87 | $6 \times 10^9$ | 16.7 | 320 | 4E-12 | 0.015 | 2E-07 |
| omg Cen | $4 \times 10^4$ | 0.004 | 10 | 4000 | 4E-03 | 4 |
| NGC 1277 | $17 \times 10^9$ | 72 | 400 | 4E-14 | 4E-03 | 1E-08 |

# conclusions, future work

- black holes are very clean accelerators for dark matter
- most uncertainties lie in particle physics models
- enhanced annihilation for either bound population and/or energy threshold
- systematic survey of nearby quiescent black holes with Fermi
- HESS, VERITAS telescopes could probe TeV regime
- start with upper limits, but might lead to actual detection!
- spin measurements, Penrose process, explore dark sector

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どうもありがとう!