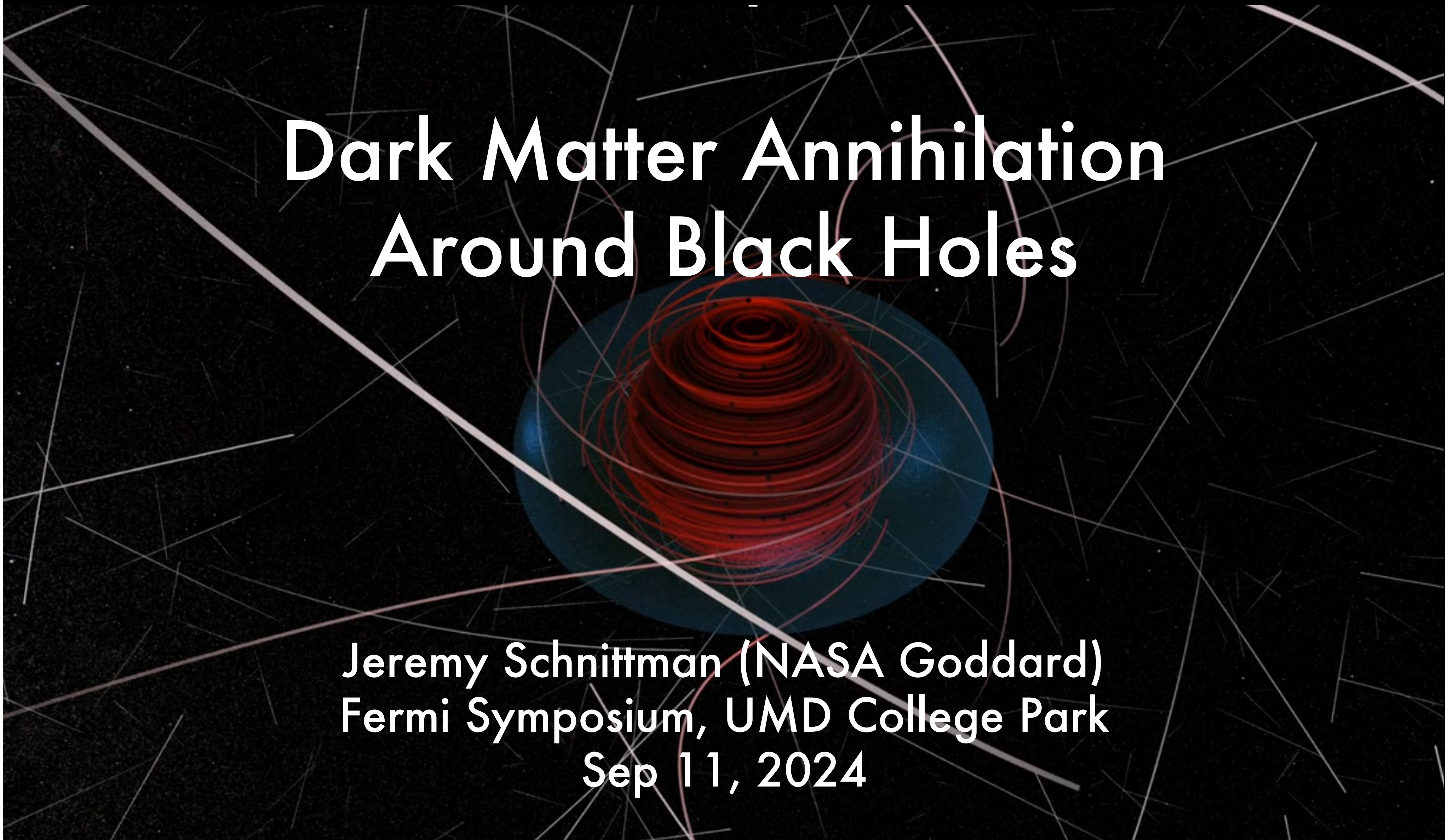
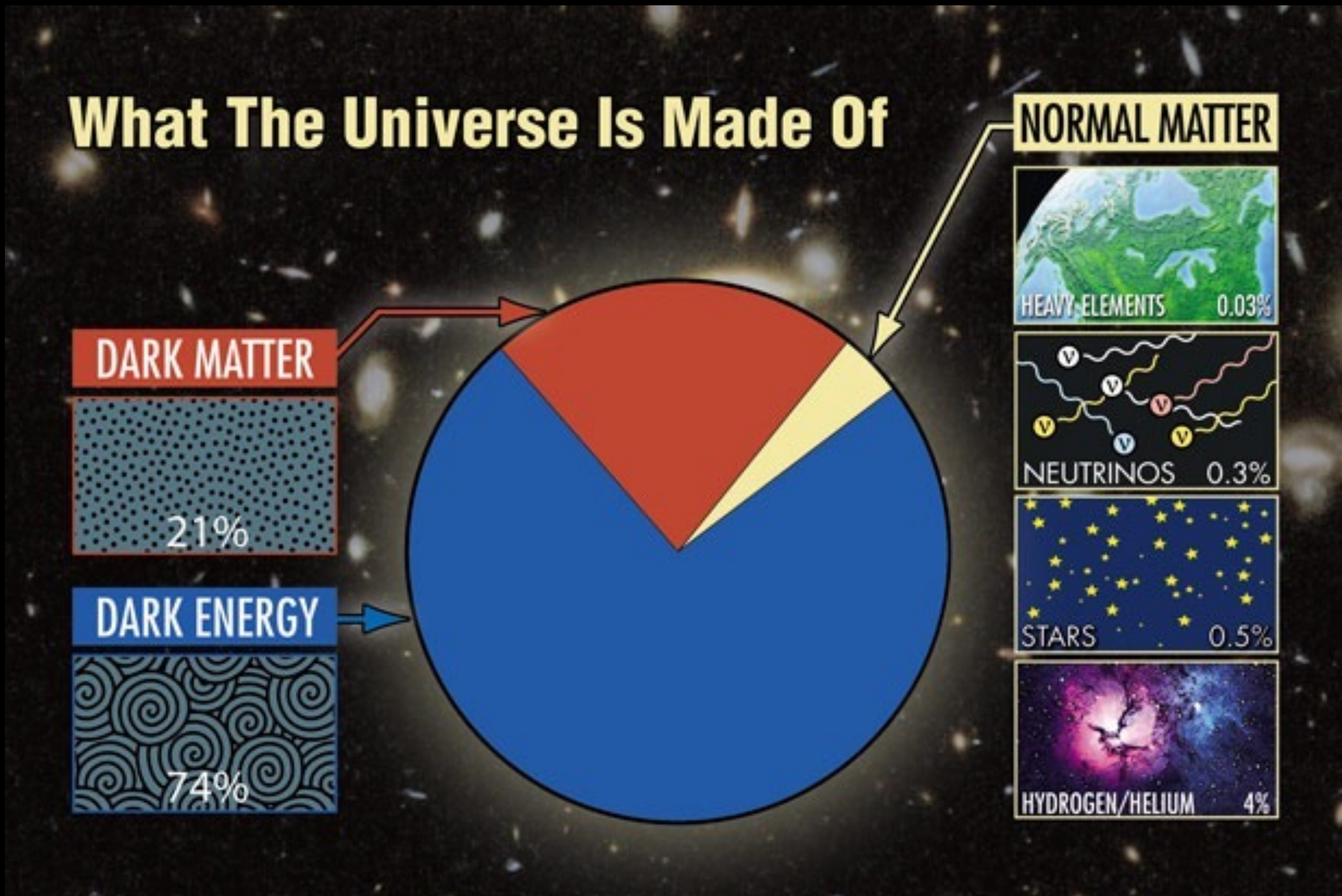
Dark Matter Annihilation Around Black Holes



Jeremy Schnittman (NASA Goddard)
Fermi Symposium, UMD College Park
Sep 11, 2024

background/motivation



background/motivation

Black Holes as particle accelerators

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

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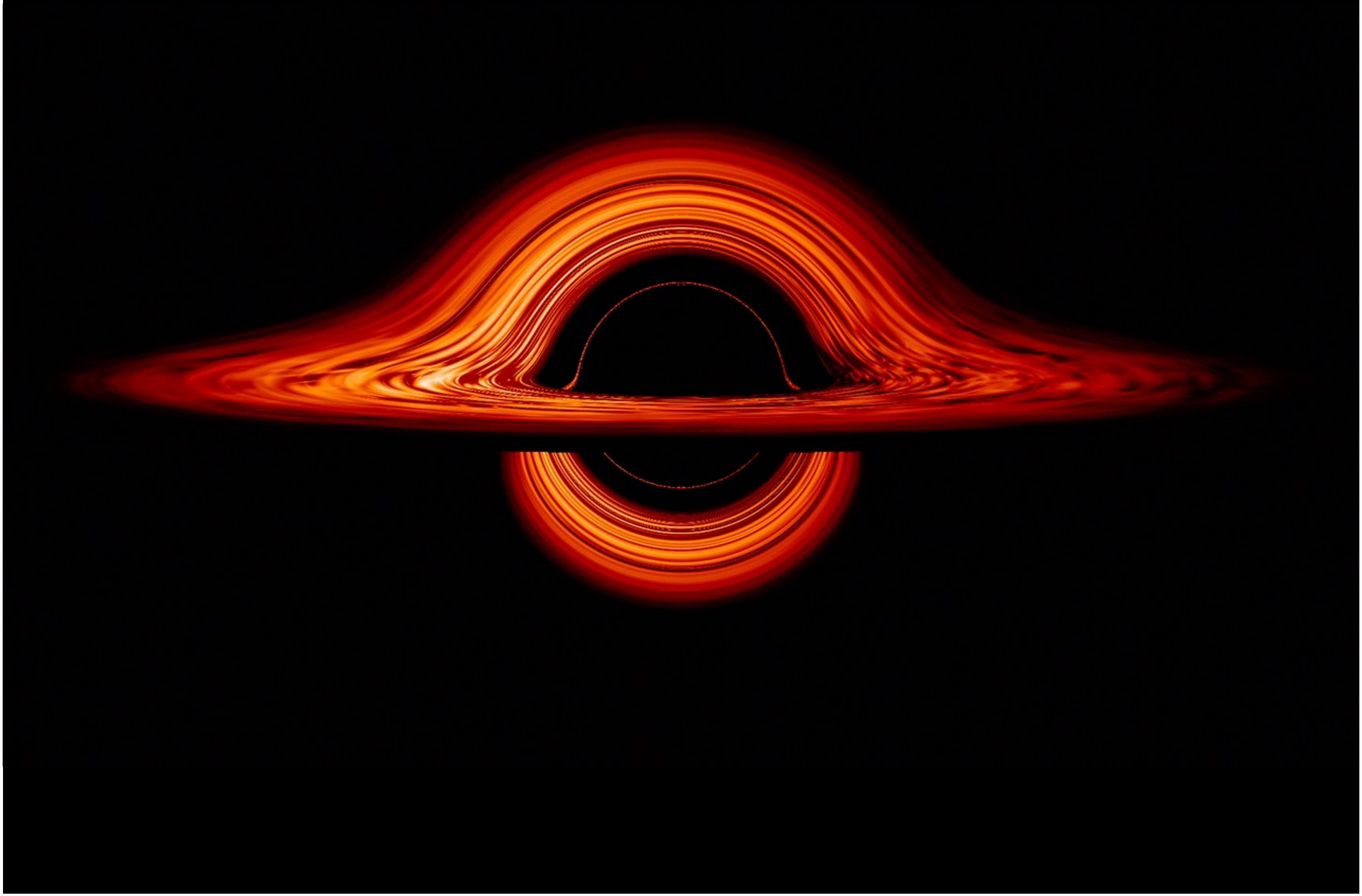
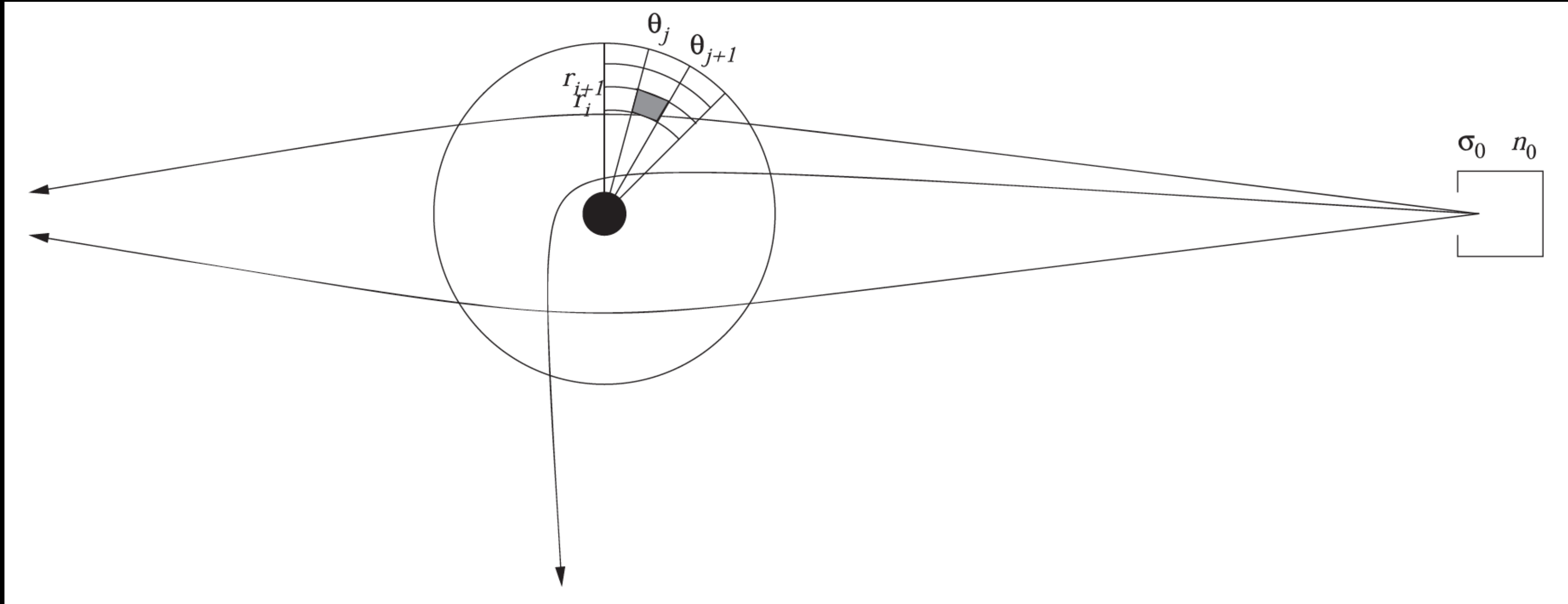
decay [11] or annihilation [12] processes for various kinds of dark matter. There are uncertainties in all aspects of these models. However one thing is certain: if the central black hole Sgr A* is a rotating Kerr black hole and if general relativity is correct, its external geometry is precisely known.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

Pandurata: **black hole particle playground**



step 1: populate the distribution function



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

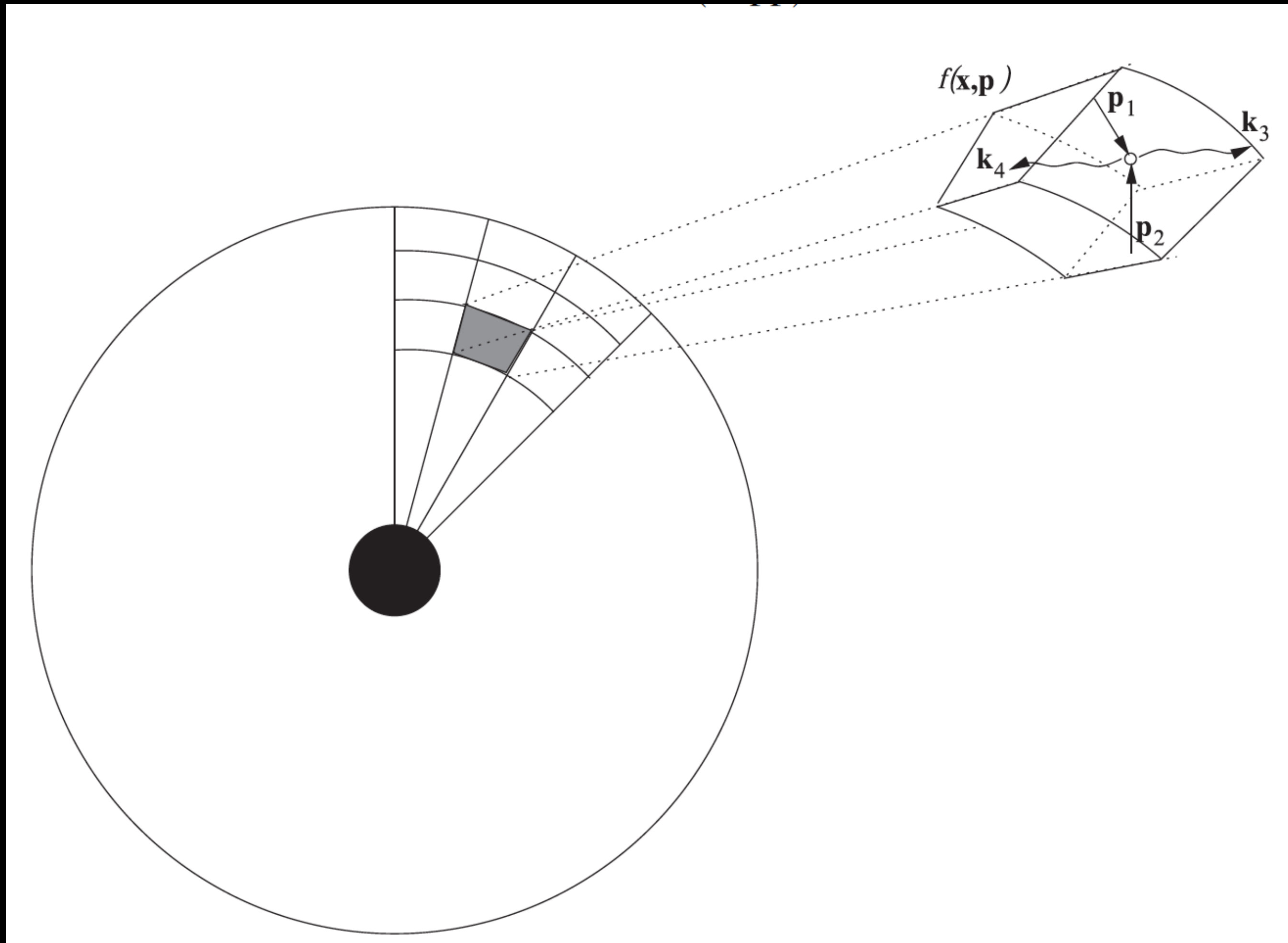
$$\rho_{\rm NFW}(r) = \frac{\rho_s R_s^3}{r(r+R_s)^2} \sim r^{-1}$$

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

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

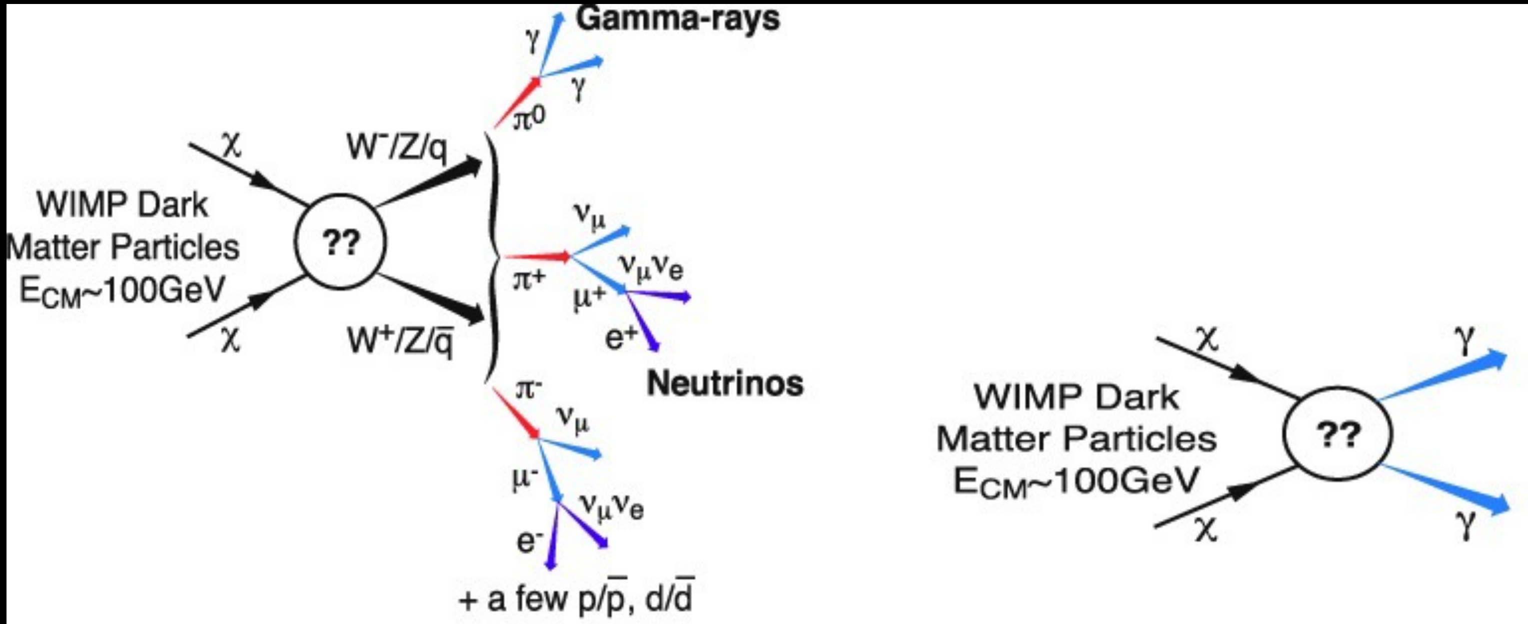
step 1: populate the distribution function

step 2: calculate annihilation rates



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

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*

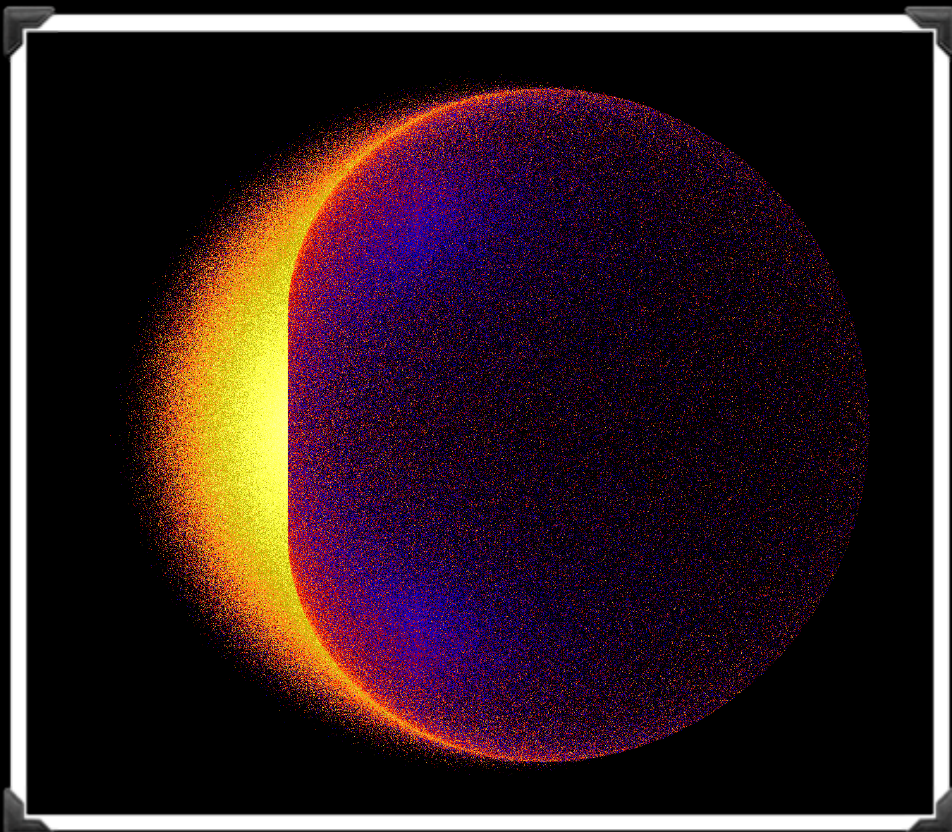
intermediate product (minimum threshold energy):

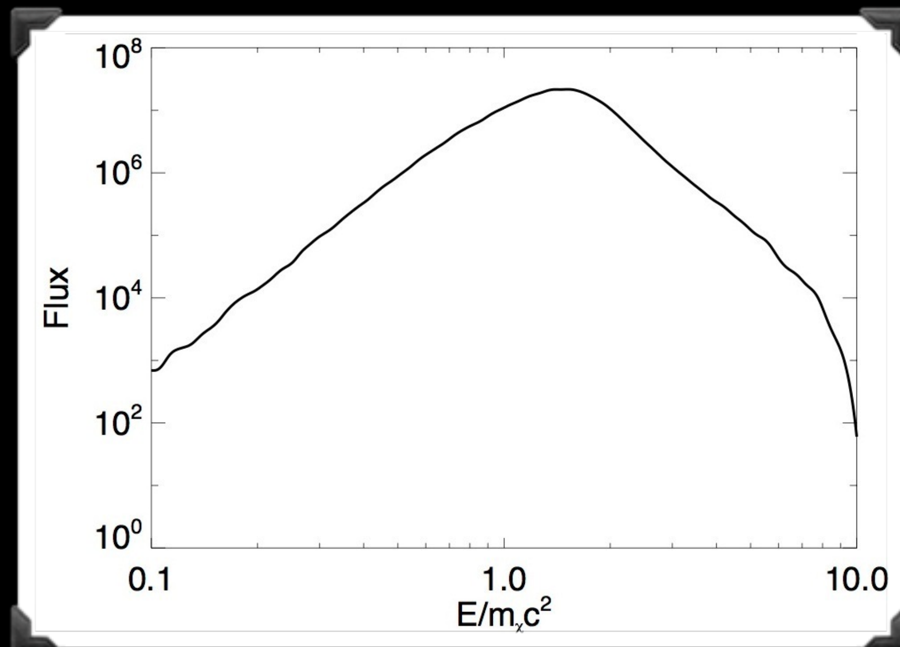
$$\chi + \chi \rightarrow \chi^* + \bar{\chi}^* \rightarrow 2\gamma^*$$

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

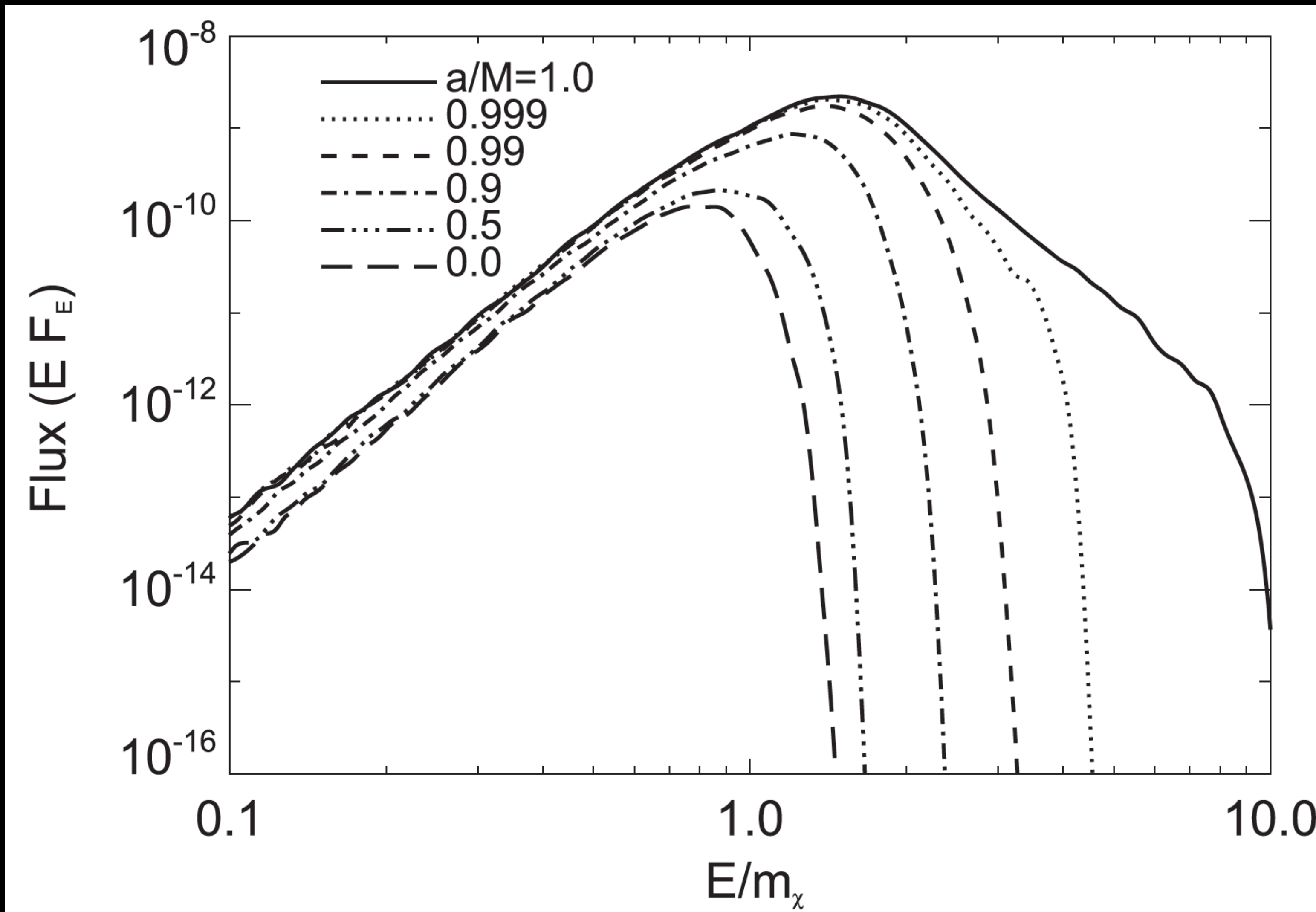
step 3: track photons to infinity

$E_{com} > 3m_x$

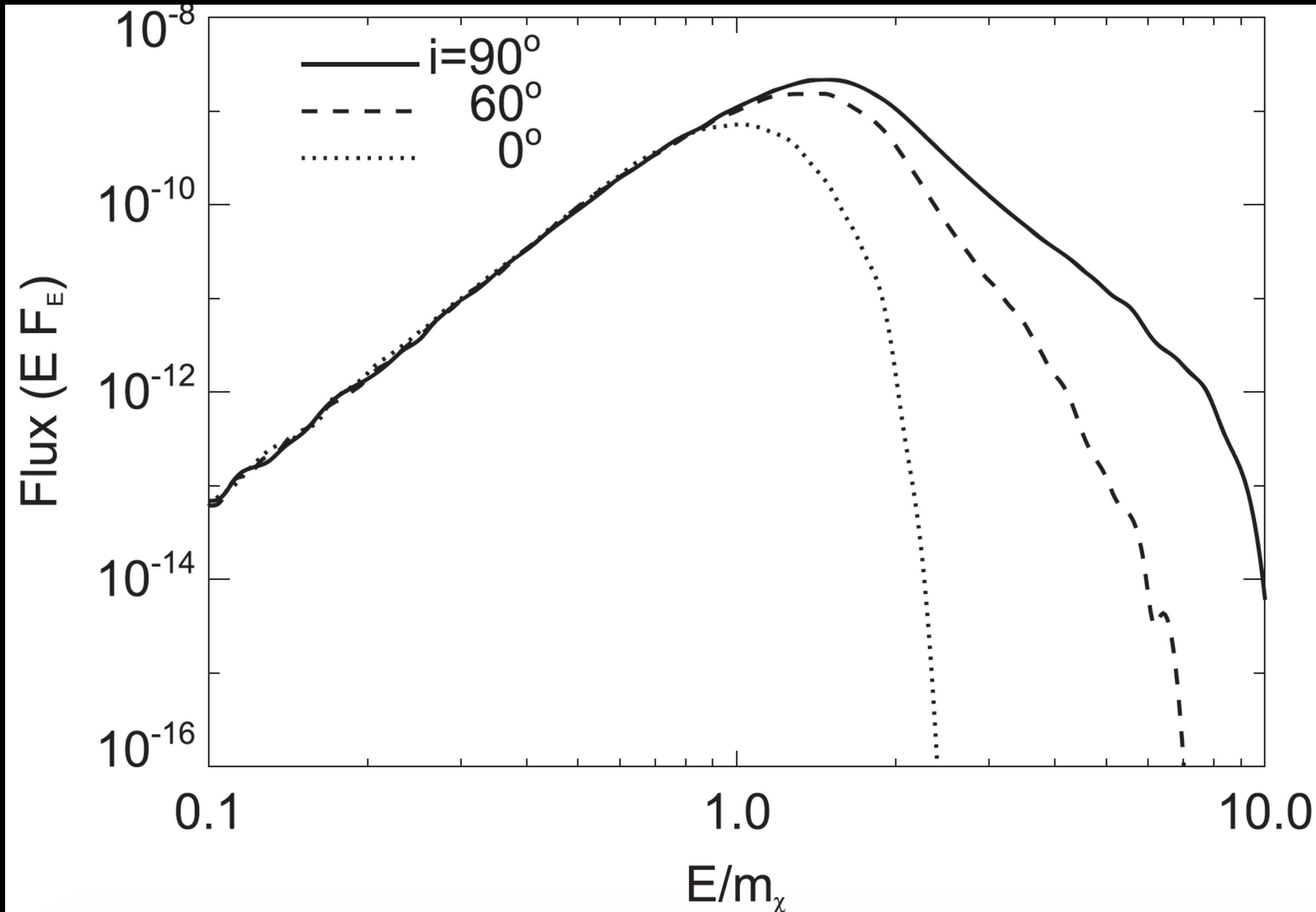




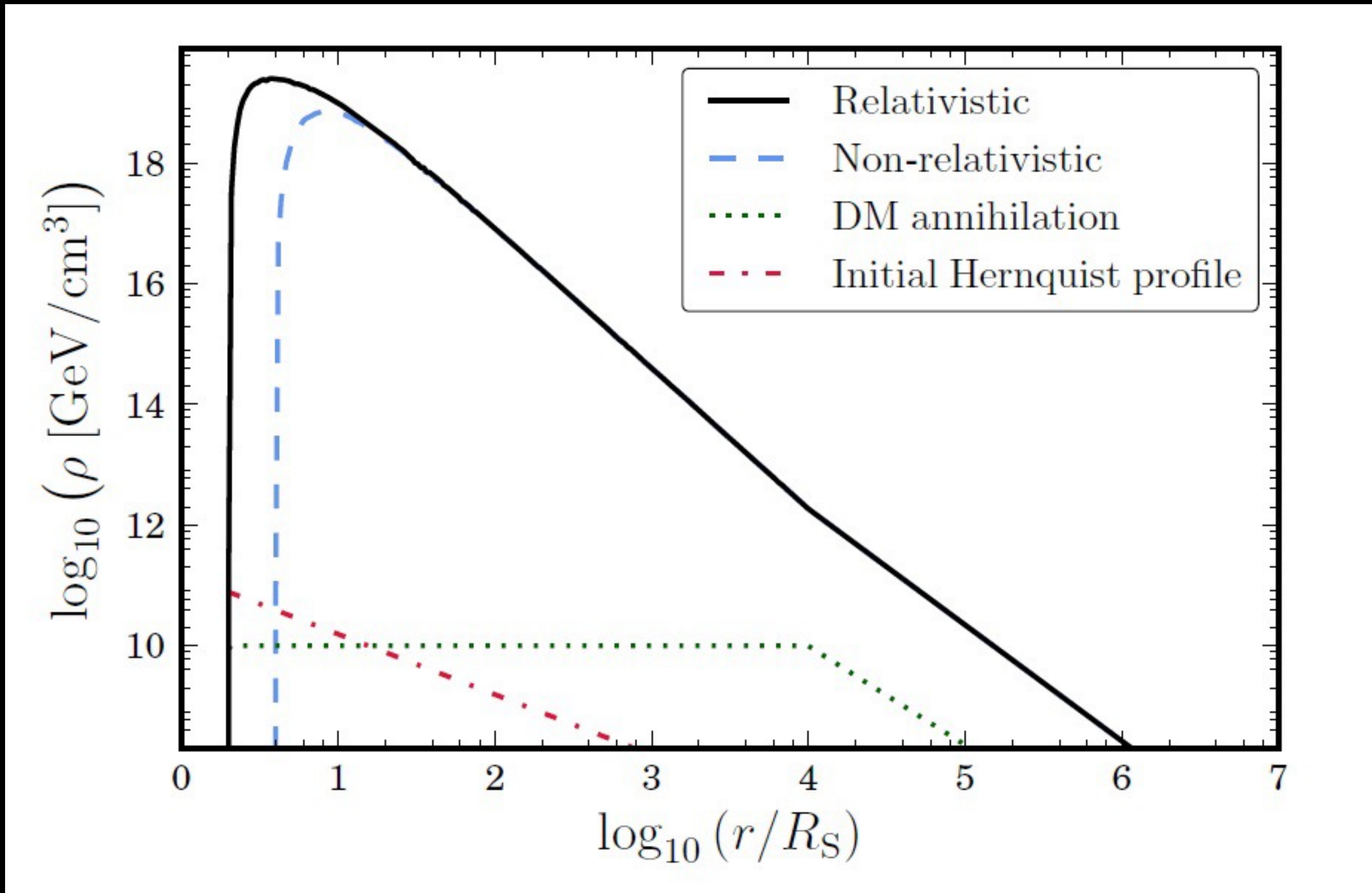
dependence on black hole spin



dependence on observer inclination

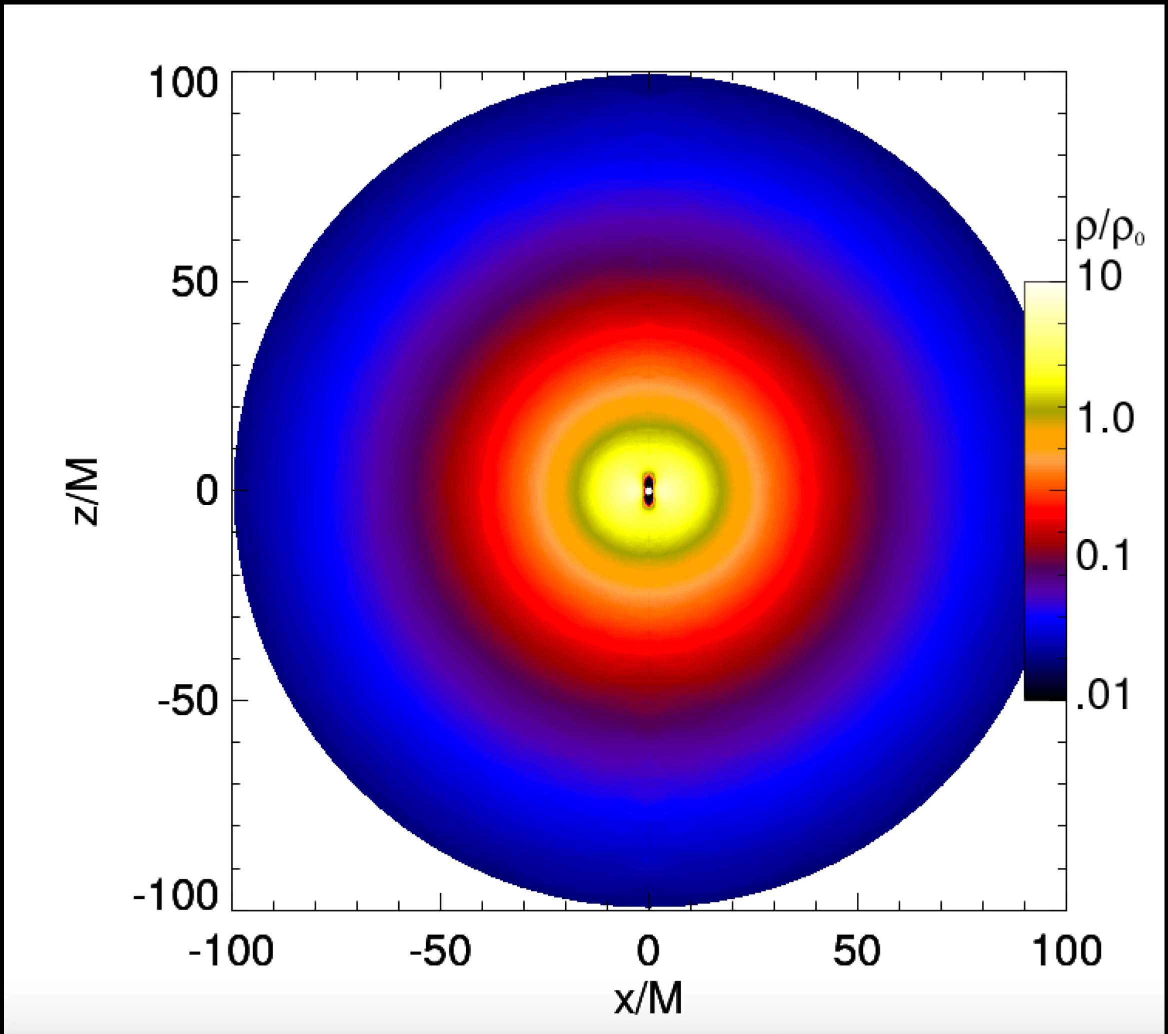


bound dark matter

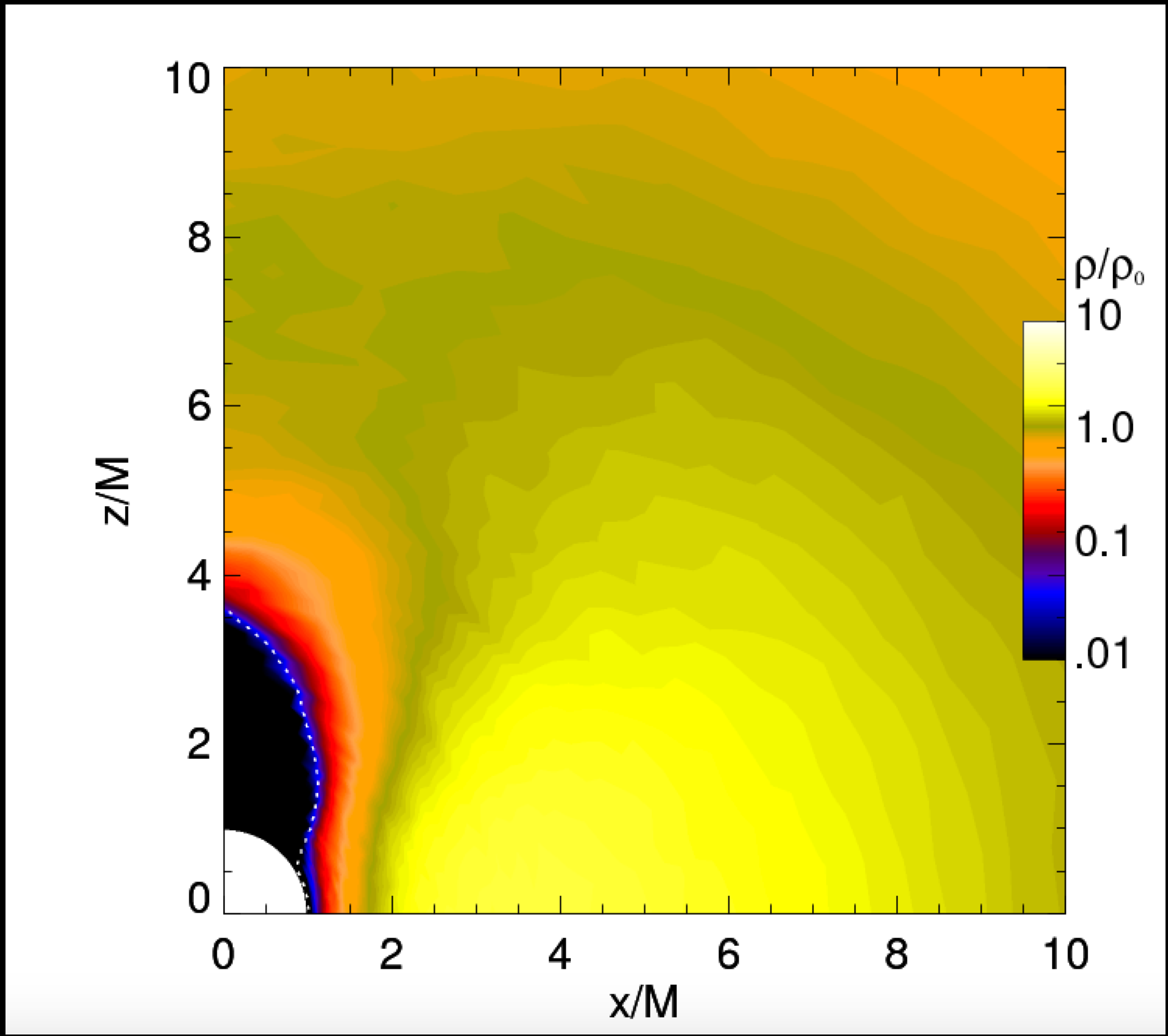


Gondolo & Silk (1999); Sadeghian, Ferrer, & Will (2013)

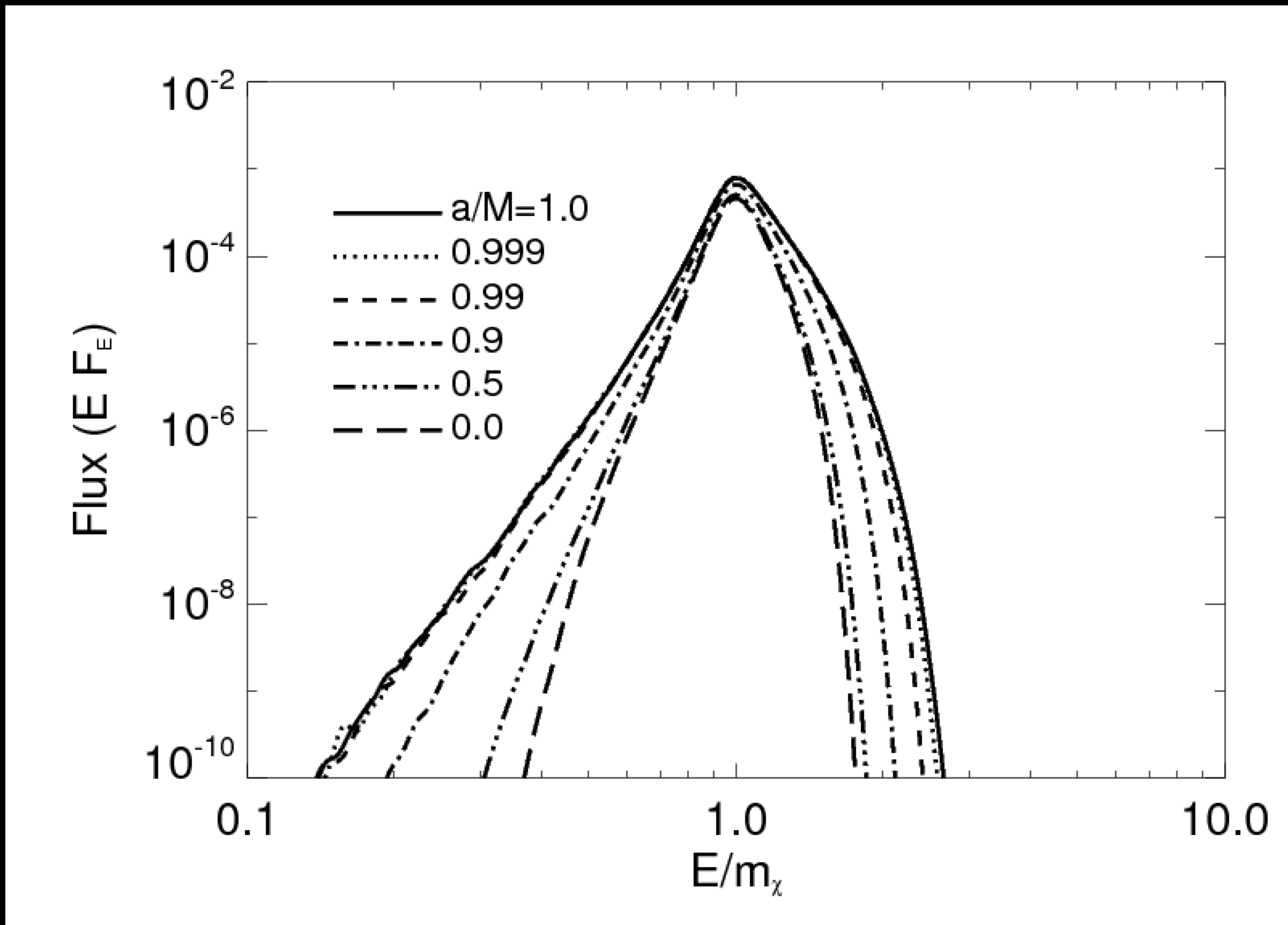
bound dark matter



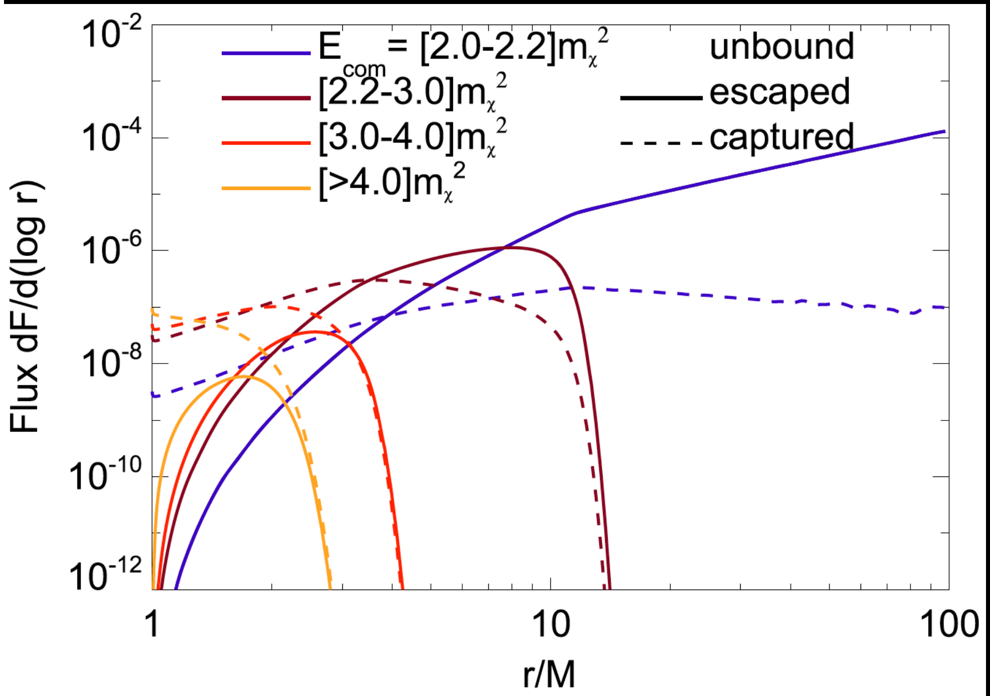
bound dark matter

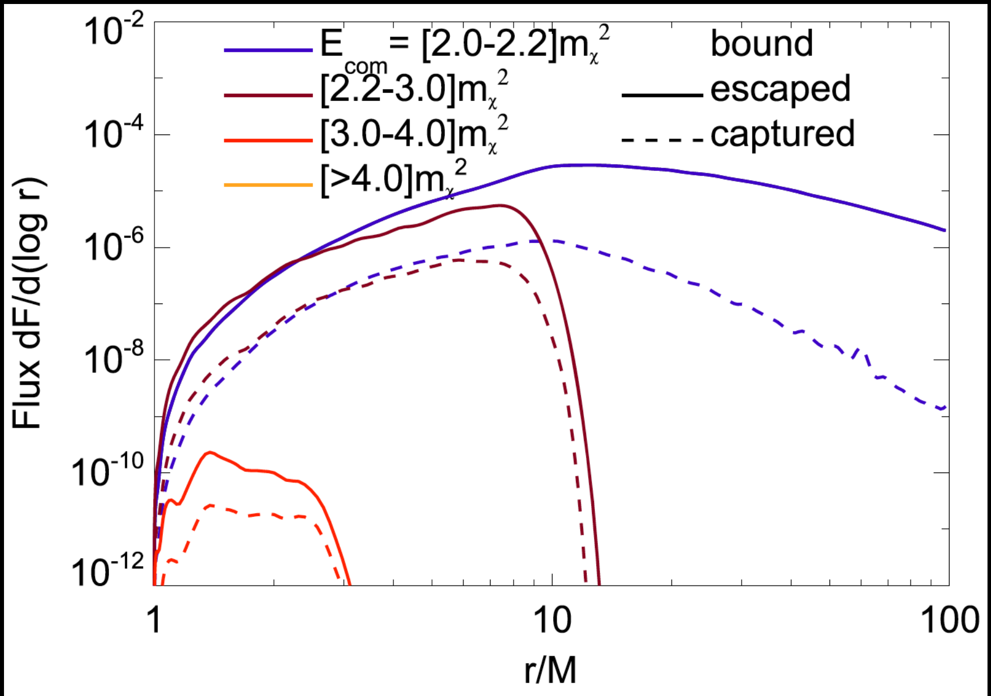


bound dark matter: depedence on spin



escape fractions: bound vs unbound





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
- start with upper limits, but might lead to actual detection!
- spin measurements, Penrose process, explore dark sector