Dark Matter p-wave Annihilation Flux Enhancement Near the Supermassive Black Hole at the Center of M87*

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Outline

- Dark Matter Profile
- Particle Model
- Results

Dark Matter Profile

$$\rho_{\mathrm{DM}}(r) = \begin{cases} 0 & r < r_{\mathrm{m}} \\ \rho_{\mathrm{sp}}(r) & r_{\mathrm{m}} \le r < r_{\mathrm{sp}} \\ \rho_{\mathrm{h}}(r) & r_{\mathrm{sp}} \le r \le R_{200} \end{cases}$$

$$\rho_{\mathrm{h}}(r) = \begin{cases} \rho_{\mathrm{Burkert}}(r) & 0 \le r < 200 \\ \rho_{\mathrm{NFW}}(r) & 200 \le r \le R_{200} \end{cases}$$

$$\rho_{\mathrm{NFW}} = \frac{\rho_{\mathrm{s}}}{\frac{r}{r_{\mathrm{s}}}\left(1+\frac{r}{r_{\mathrm{s}}}\right)^2}$$

$$\rho_{\mathrm{Burkert}} = \frac{\rho_0}{\left(1+\frac{r}{r_0}\right)\left(1+\frac{r}{r_0}\right)^2}$$

SMBH →

$$\rho_{\mathrm{sp}} \propto r^{-\gamma_{\mathrm{sp}}}$$

$$\gamma_{\mathrm{sp}} = (3+a)/4$$

$$\sigma \propto v^{-a}$$

$$v_{\mathrm{h}}(r_{\mathrm{spike}})^2 = GM_{\bullet}/r_{\mathrm{spike}}$$

$r \to 0$ →

$$\rho(r) \propto r^0$$

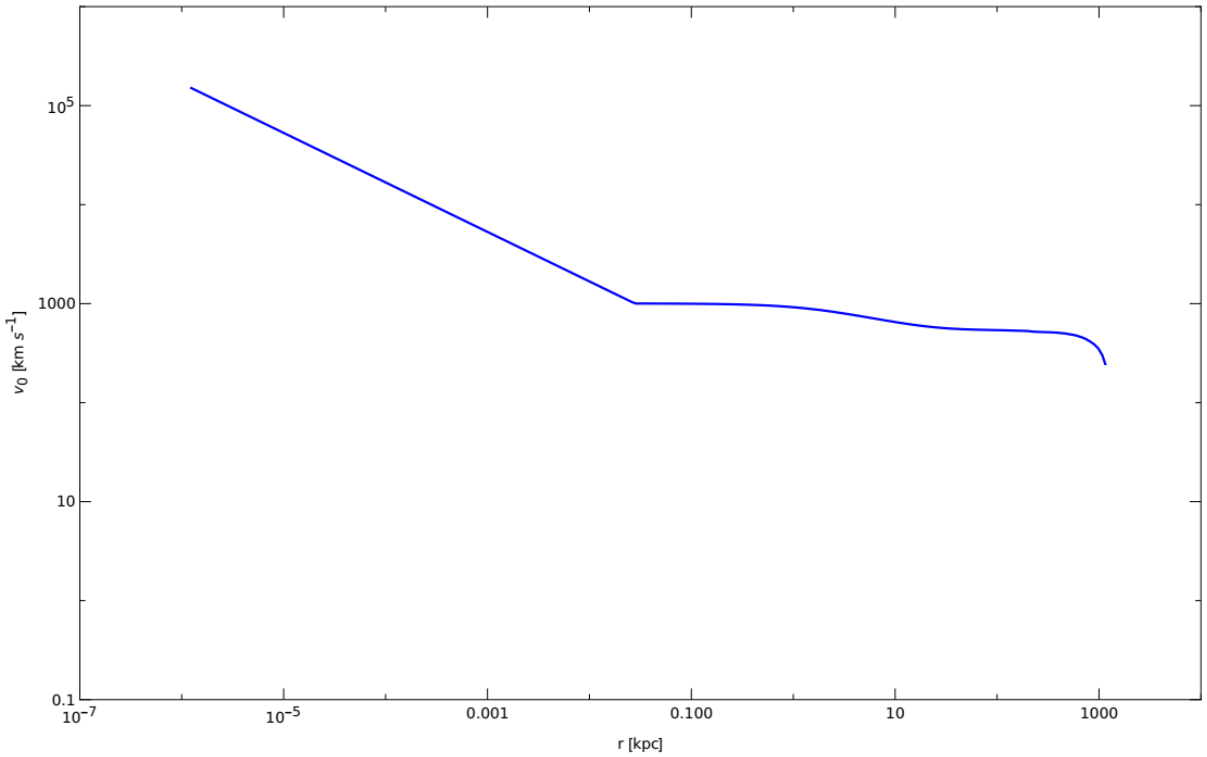
Velocity Dispersion

$$v_0(r) = \begin{cases} v_{\rm h}(r_{\rm sp})\left(\frac{r_{\rm sp}}{r}\right)^{\frac{1}{2}} & r_{\rm m} \leq r < r_{\rm sp} \\ v_{\rm h}(r) & r_{\rm sp} \leq r \leq R_{200} \end{cases}$$

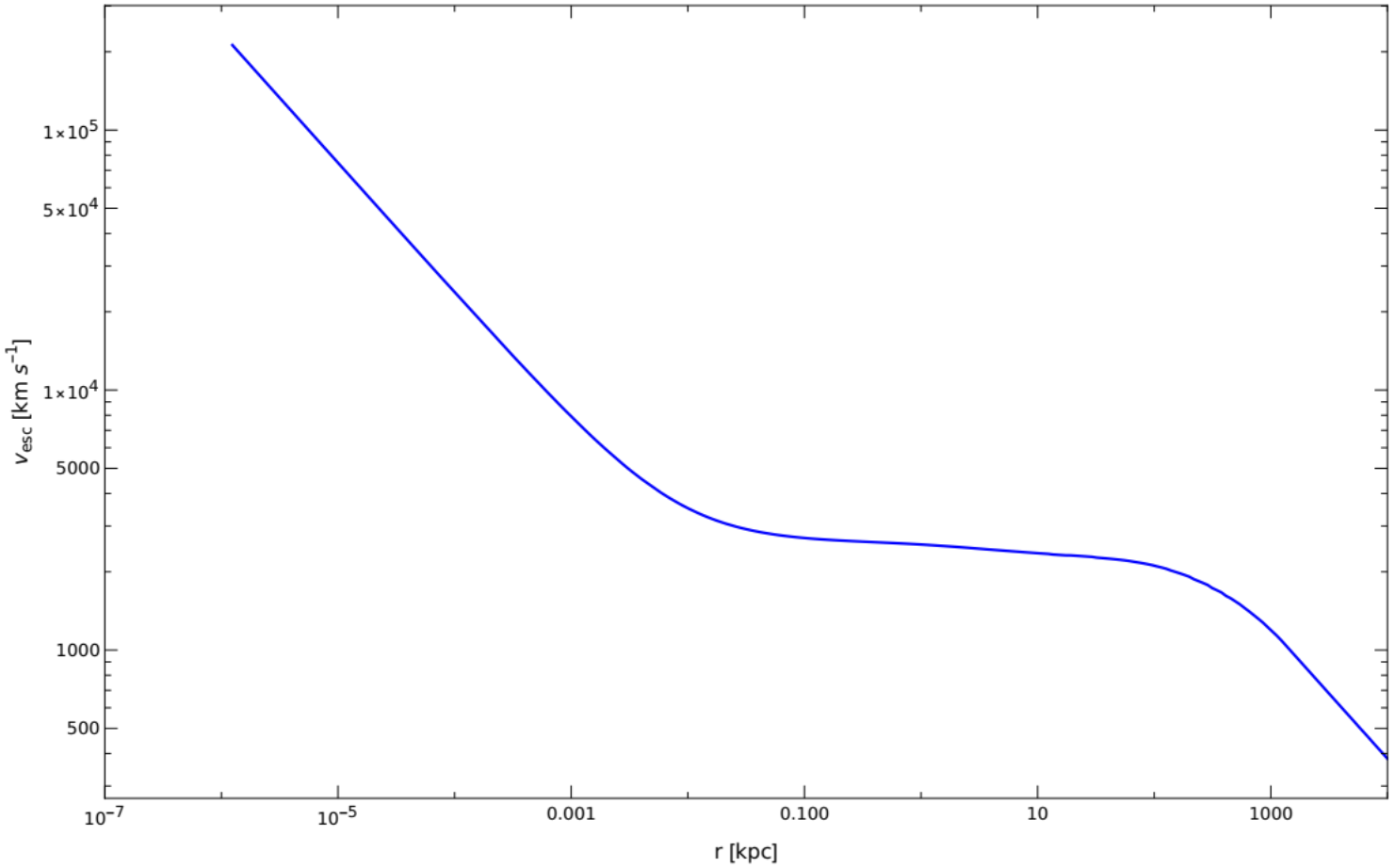
Jeans equation

$$v_{\rm h}^2(r) = \frac{1}{\rho_h(r)} \int_r^\infty dr' \rho_h(r') \frac{d\Phi}{dr'}$$

SMBH → $v_0 \propto r^{-1/2}$

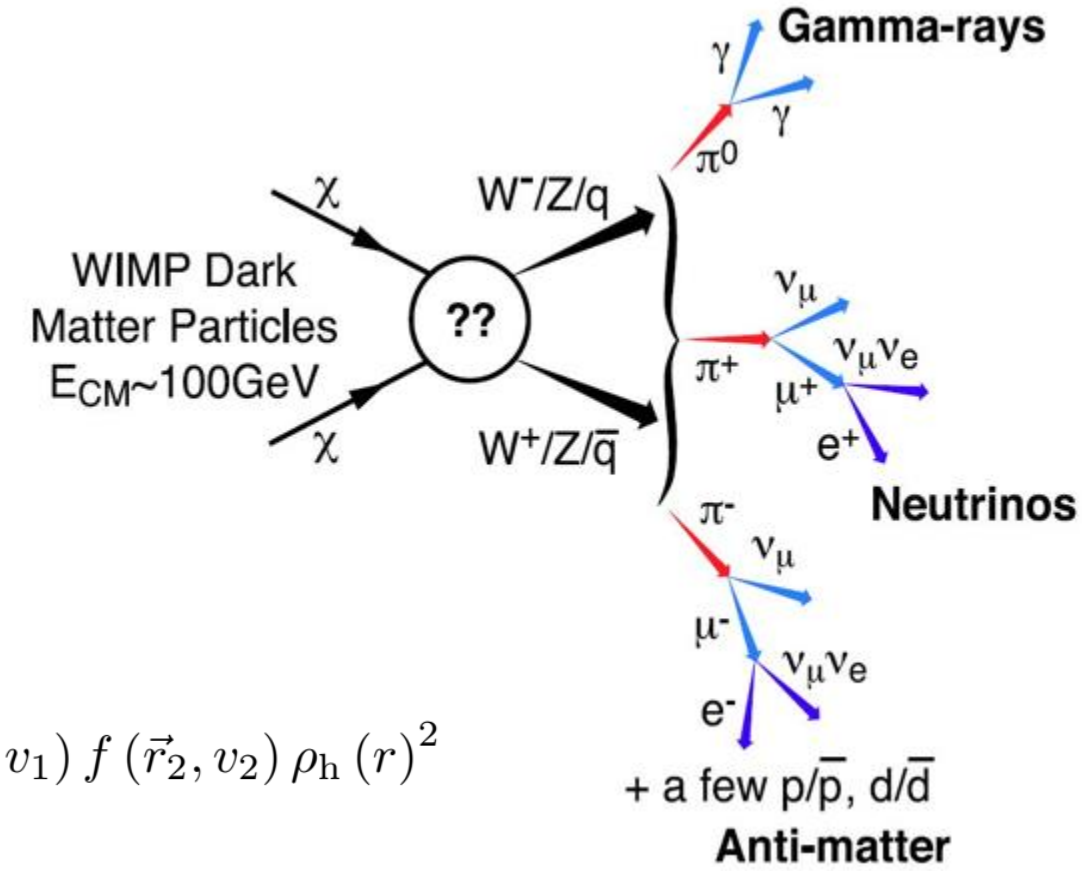


Escape Velocity



$$\Phi(r) = -4\pi G\left[\frac{1}{r}\int_0^r dr' r'^2\left(\rho_{\rm DM}(r') + \rho_\star(r')\right) + \int_r^R dr' r'\left(\rho_{\rm DM}(r') + \rho_\star(r')\right)\right] - \frac{GM_\bullet}{r}$$

Annihilation Signals



J-Factor and Q-Factor

$$J(\Omega) = \int d\ell \int d^3v_1 \int d^3v_2 \; (\sigma v) \, f(\vec{r}_1, v_1) \, f(\vec{r}_2, v_2) \, \rho_{\rm h}(r)^2$$

$$Q(\Omega) = \frac{1}{D^2} \int_{r_{\rm m}}^{r_{\rm spike}} dr \, r^2 \rho_{\rm spike}(r)^2 \int d^3v_1 \int d^3v_2 \; (\sigma v) \, f(\vec{r}_1, v_1) \, f(\vec{r}_2, v_2)$$

Particle Model

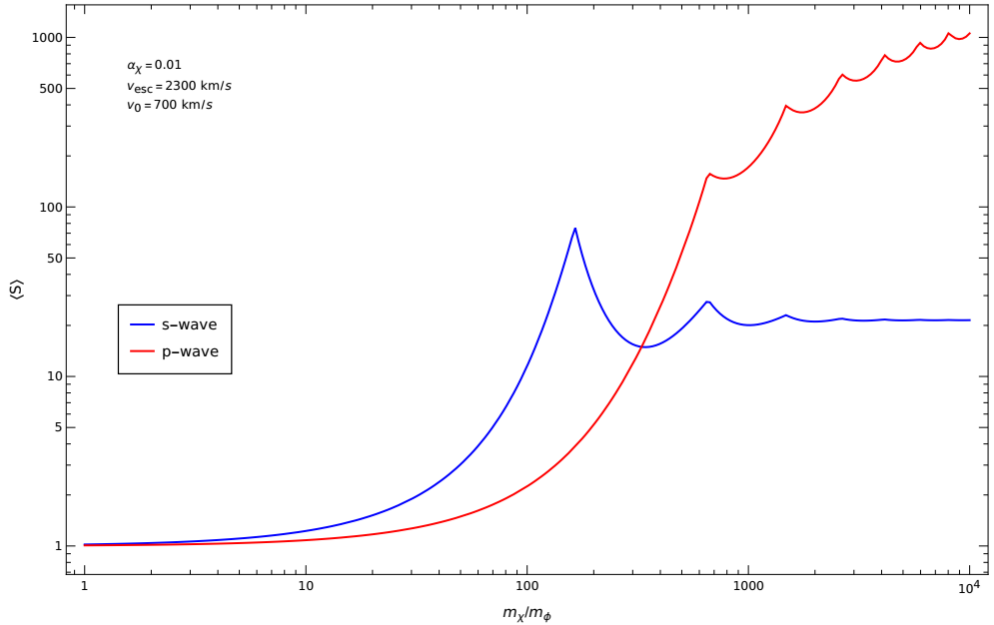
Particle Model (SIDM)

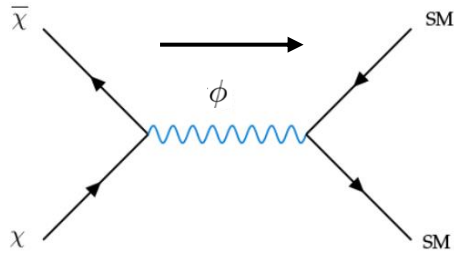
$$\mathcal{L}_{int} = \begin{cases} g_\chi\, \bar{\chi}\gamma^\mu \chi \phi_\mu & \text{vector mediator} \\ g_\chi\, \bar{\chi}\chi\phi & \text{scalar mediator} \end{cases}$$

$$(\sigma v)^{\text{tree}} = \begin{cases} \dfrac{\pi\alpha_\chi^2}{m_\chi^2}\sqrt{1-\dfrac{m_\phi^2}{m_\chi^2}} & \text{vector mediator } (\text{s}-\text{wave}) \\ \dfrac{3}{4}\dfrac{\pi\alpha_\chi^2}{m_\chi^2}\, v^2 \sqrt{1-\dfrac{m_\phi^2}{m_\chi^2}} & \text{scalar mediator } (\text{p}-\text{wave}) \end{cases}$$

$$S_{\text{n}}(v) = \begin{cases} \dfrac{\pi}{a}\dfrac{\sinh(2\pi ab)}{\cosh(2\pi ab)-\cos\left(2\pi\sqrt{b-(ab)^2}\right)} & \text{n}=0\ (\text{s}-\text{wave}) \\ \dfrac{\pi}{a}\dfrac{\sinh(2\pi ab)}{\cosh(2\pi ab)-\cos\left(2\pi\sqrt{b-(ab)^2}\right)}\dfrac{(b-1)^2+4(ab)^2}{1+4(ab)^2} & \text{n}=2\ (\text{p}-\text{wave}) \end{cases}$$

$$a = v/2\alpha_\chi \qquad b = 6\alpha_\chi m_\chi/\pi^2 m_\phi$$





time

Dark Matter Fine Structure

Boltzmann Equation

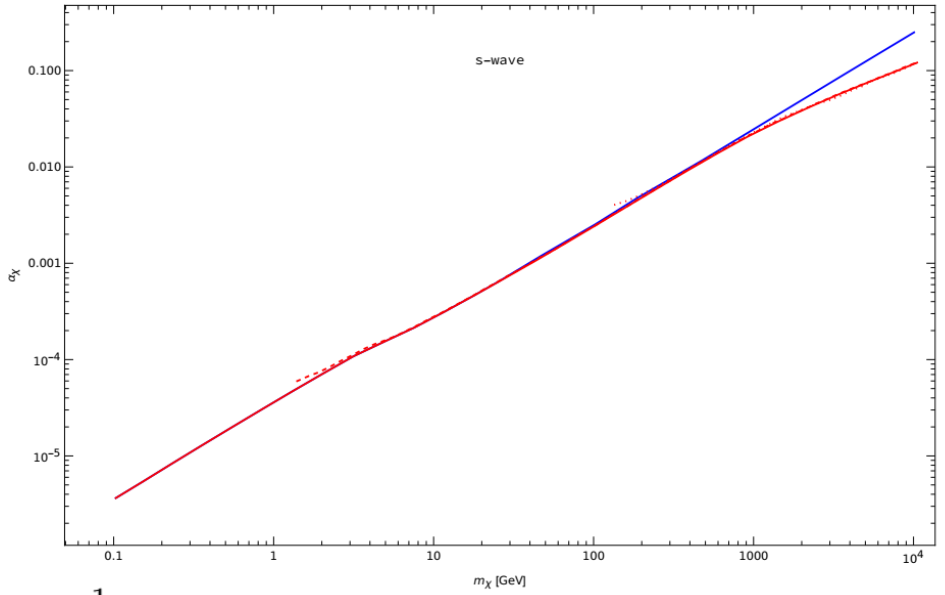
$$\frac{63\sqrt{5}\,x_{\mathrm{f}}^{-1/2}e^{-x_{\mathrm{f}}}\,g}{32\pi^3}\frac{g_*^{1/2}\left(x_{\mathrm{f}}\right)}{g_{*\mathrm{s}}\left(x_{\mathrm{f}}\right)}m_\chi m_{\mathrm{pl}}\langle\sigma v\rangle\;=\;1$$

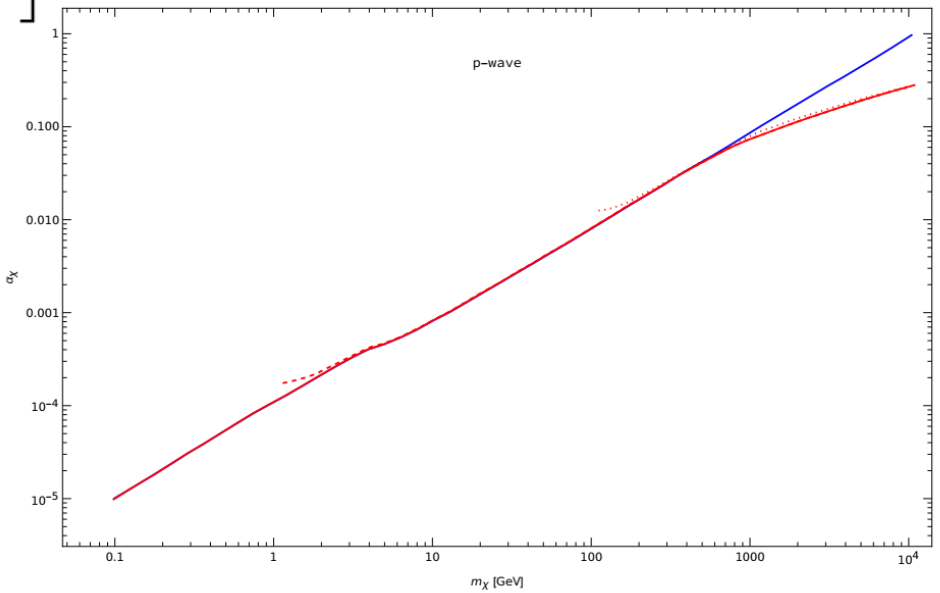
$$\Omega_\chi h^2\;=\;8.77\times10^{-11}\mathrm{Gev}^{-2}\left[\int_{x_{\mathrm{f}}}^{x_{\mathrm{kd}}}\frac{g_{*\mathrm{s}}\left(x\right)}{g_*^{1/2}\left(x\right)}\frac{\langle\sigma v\rangle}{x^2}dx+\int_{x_{\mathrm{kd}}}^{x_0}\frac{g_{*\mathrm{s}}\left(x\right)}{g_*^{1/2}\left(x\right)}\frac{\langle\sigma v\rangle}{x^2}dx\right]^{-1}$$

$$\langle\sigma v\rangle=\left(2\pi v_0^2\right)^{-\frac{3}{2}}\int d^3v\;e^{-\frac{v^2}{2v_0^2}}S_{\mathrm{n}}\left(v\right)\times\left(\sigma v\right)^{\mathrm{tree}}$$

$$v_0\;=\;\sqrt{2/x}$$

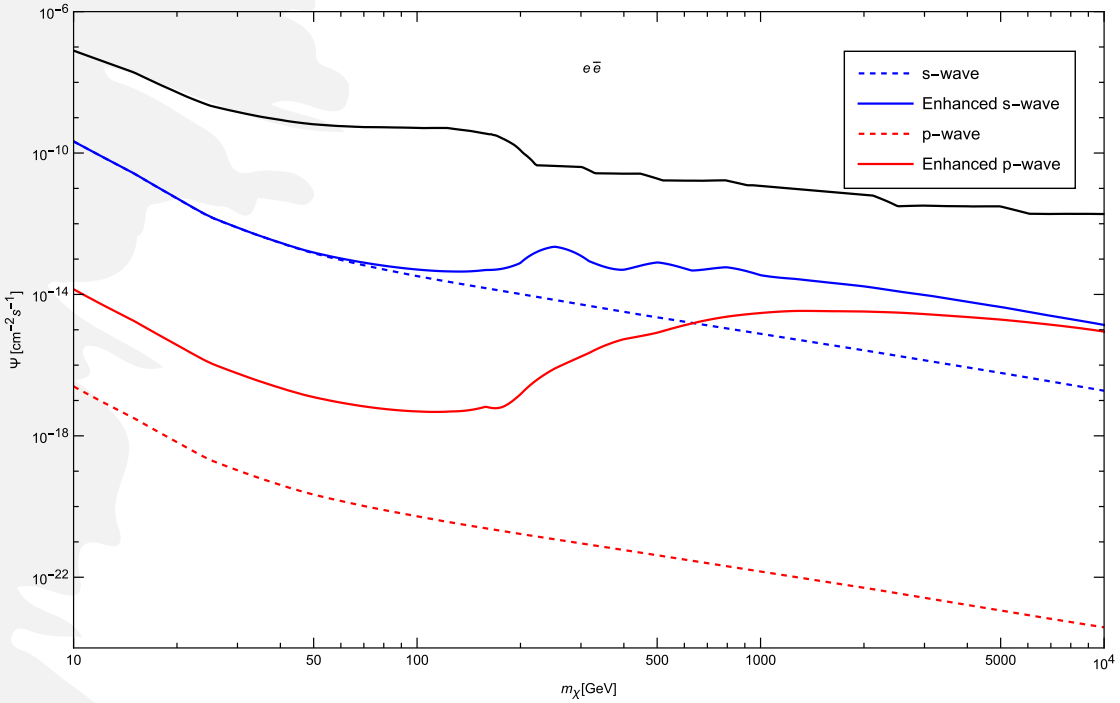
$$v_0\;=\;\sqrt{2m_\chi/T_{\mathrm{kd}}}/x$$



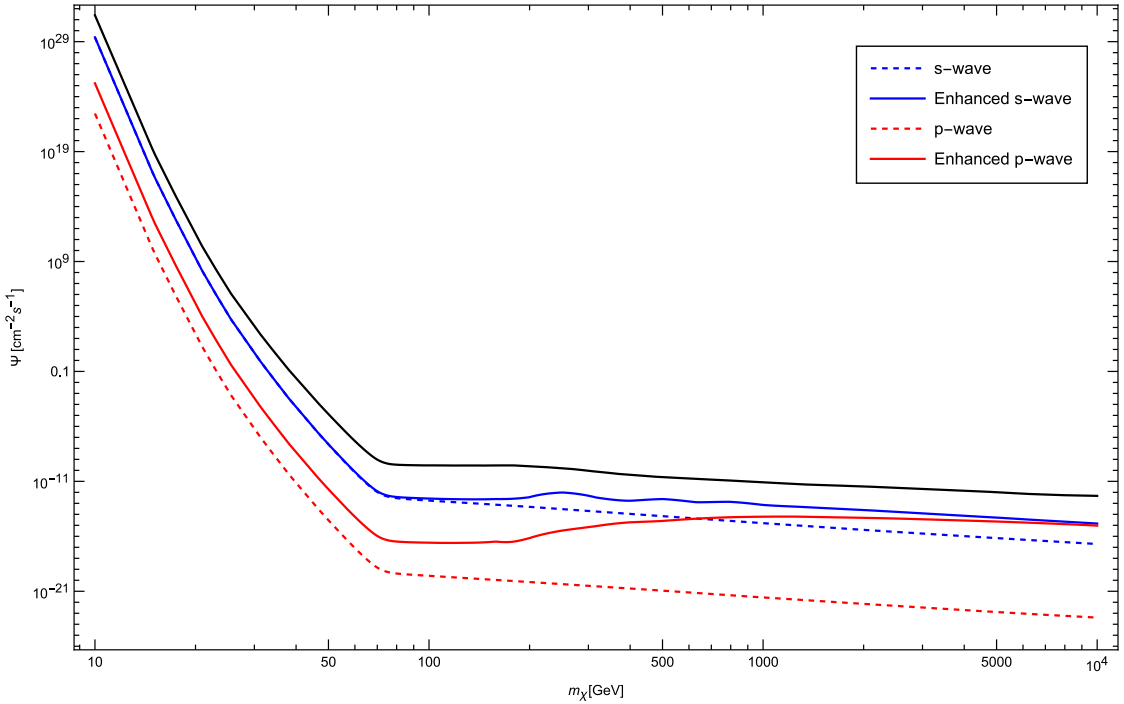


Flux Comparison

$$m_{\phi} = 5\ GeV$$



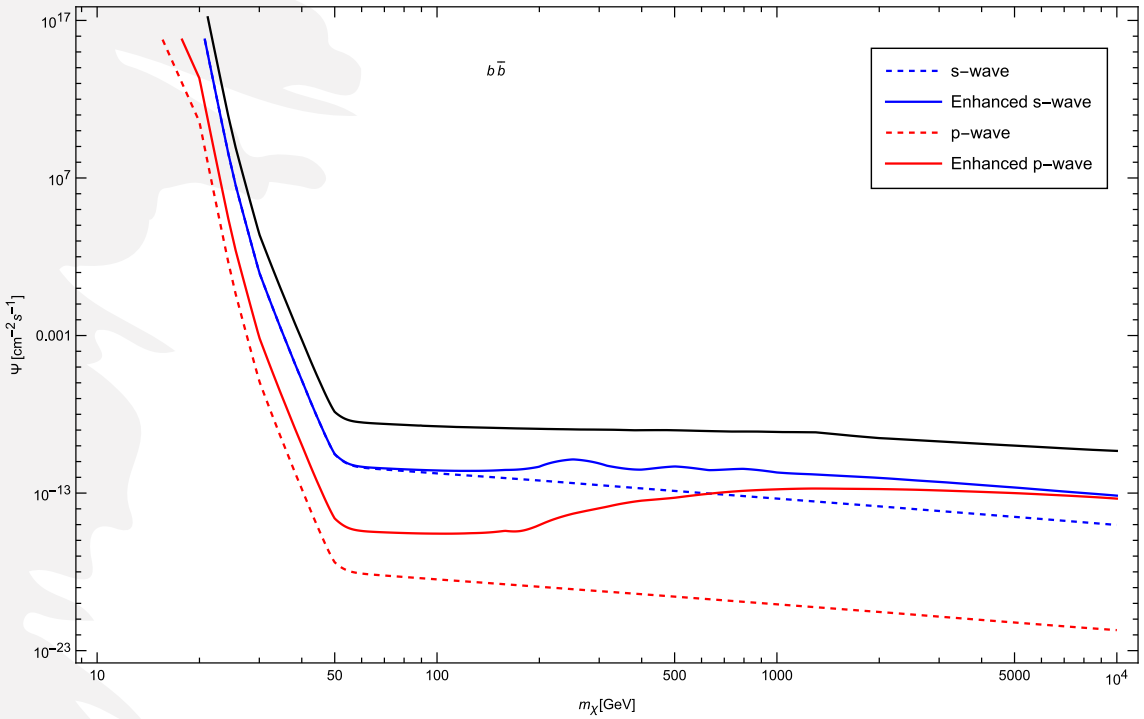
$e\bar{e}$



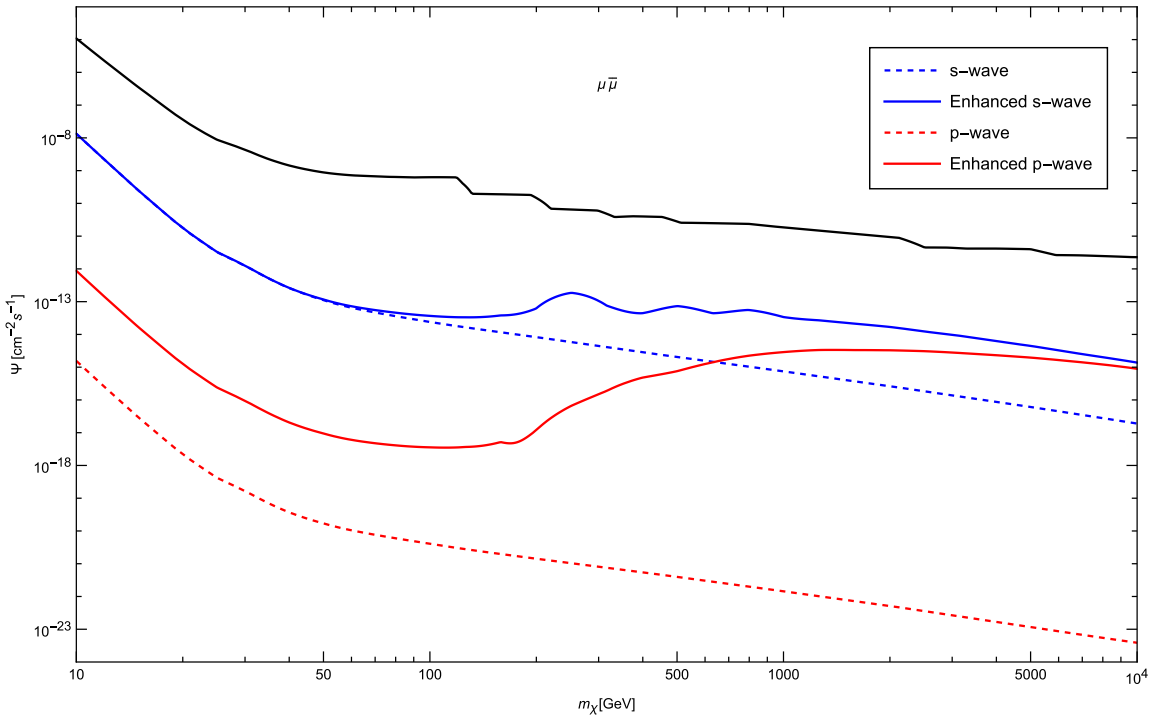
$\tau\bar{\tau}$

Flux Comparison

$$m_{\phi} = 5\ GeV$$



$b\bar{b}$



$\mu\bar{\mu}$

Summary

- Existence of Supermassive black hole redistributes Dark Matter halo on the region of influence, creating a spike.
- The spike boosts the annihilation cross section.
- In the light mediator model, Sommerfeld enhancement further enhances the annihilation cross section.
- Dark matter spike and Sommerfeld enhancement boost the p-wave annihilation flux, making it comparable to the s-wave annihilation flux.

Thank You

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