Selection Rule in Enhanced Dark Matter Annihilation

Anirban Das

SUSY 2017, TIFR

Based on PRL 118, 251101 with Basudeb Dasgupta

tifr

LCDM works very well at large scales in our universe

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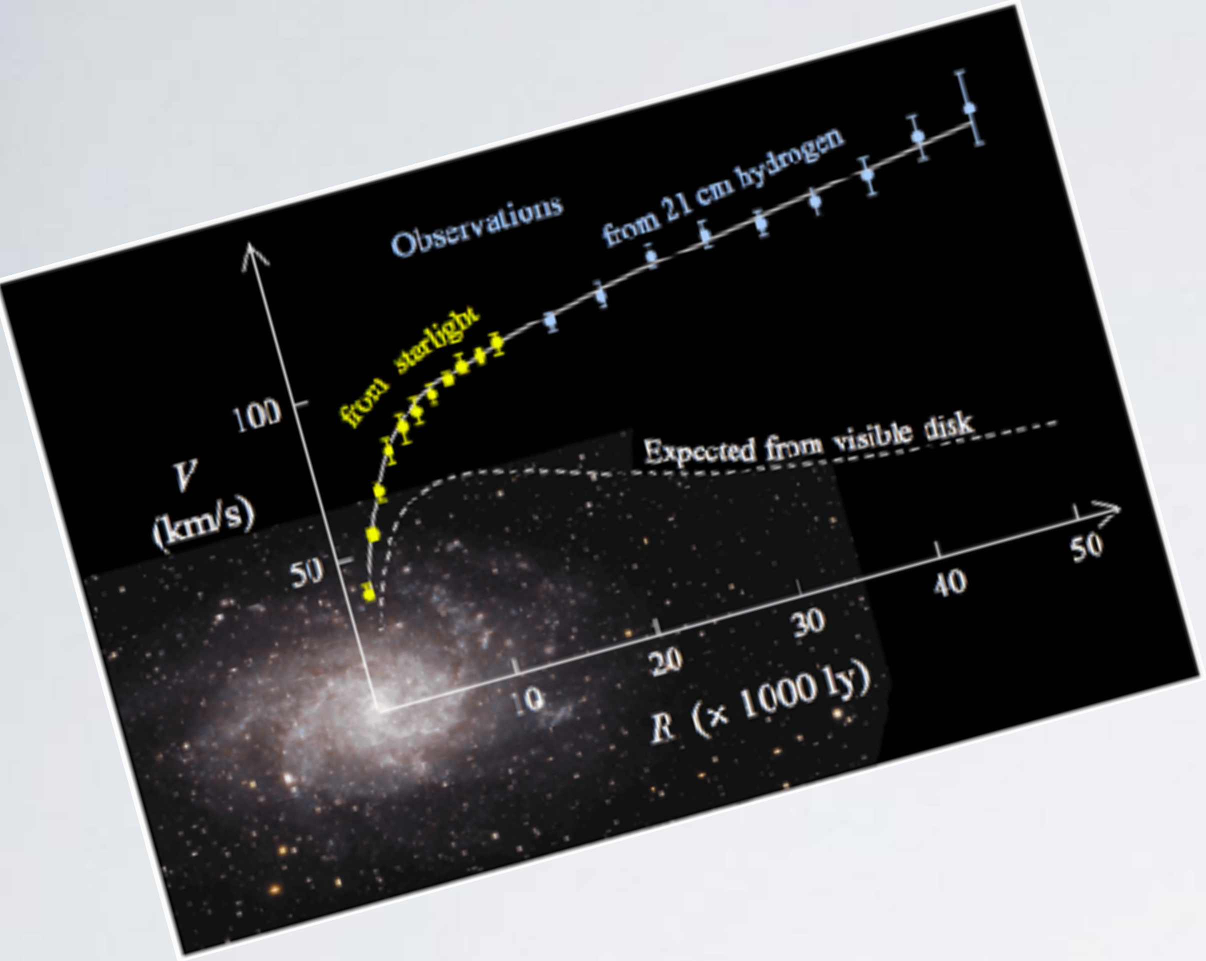

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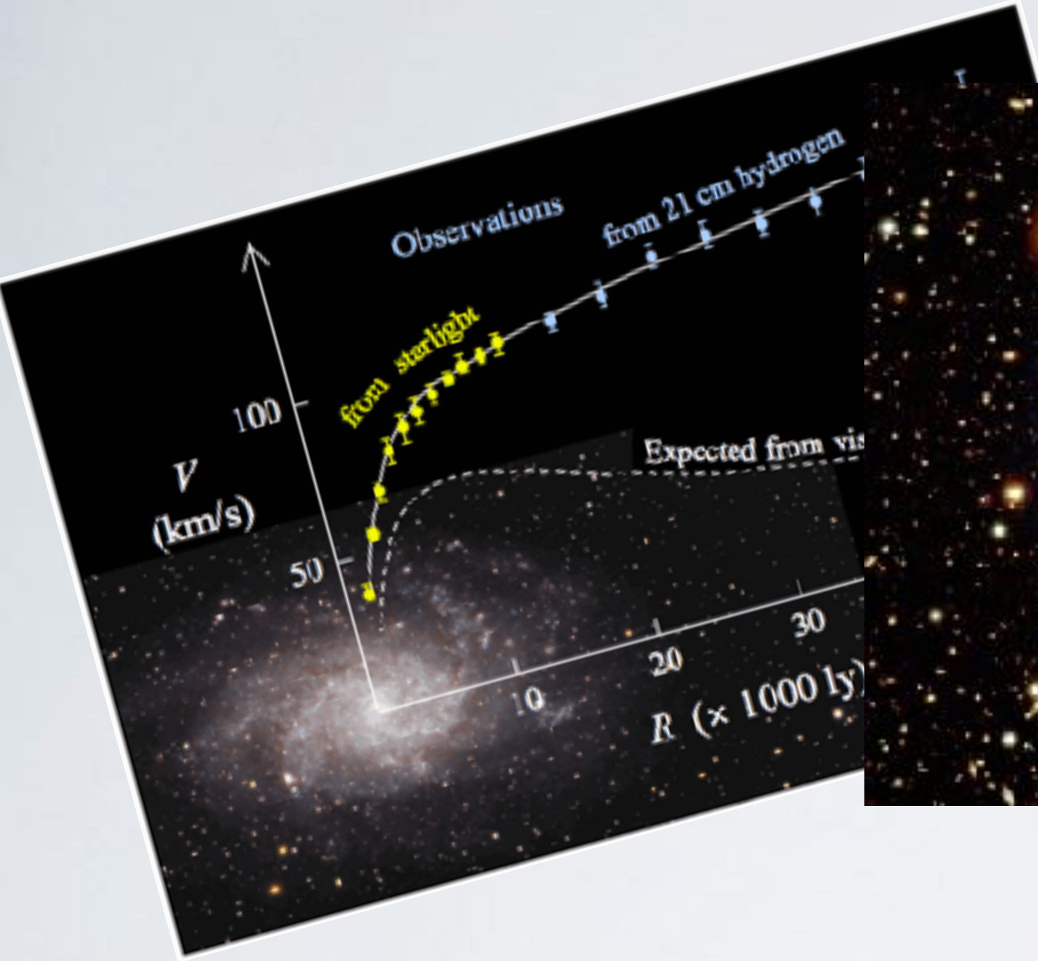

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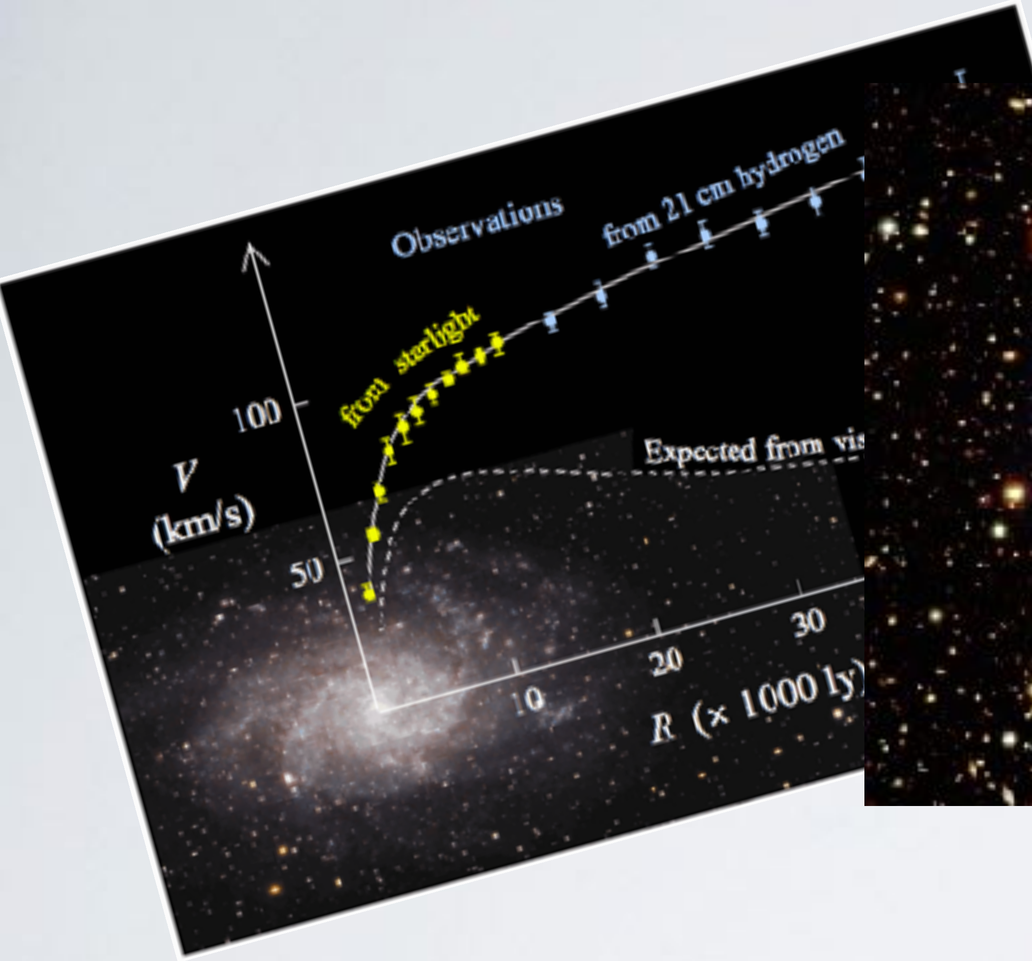

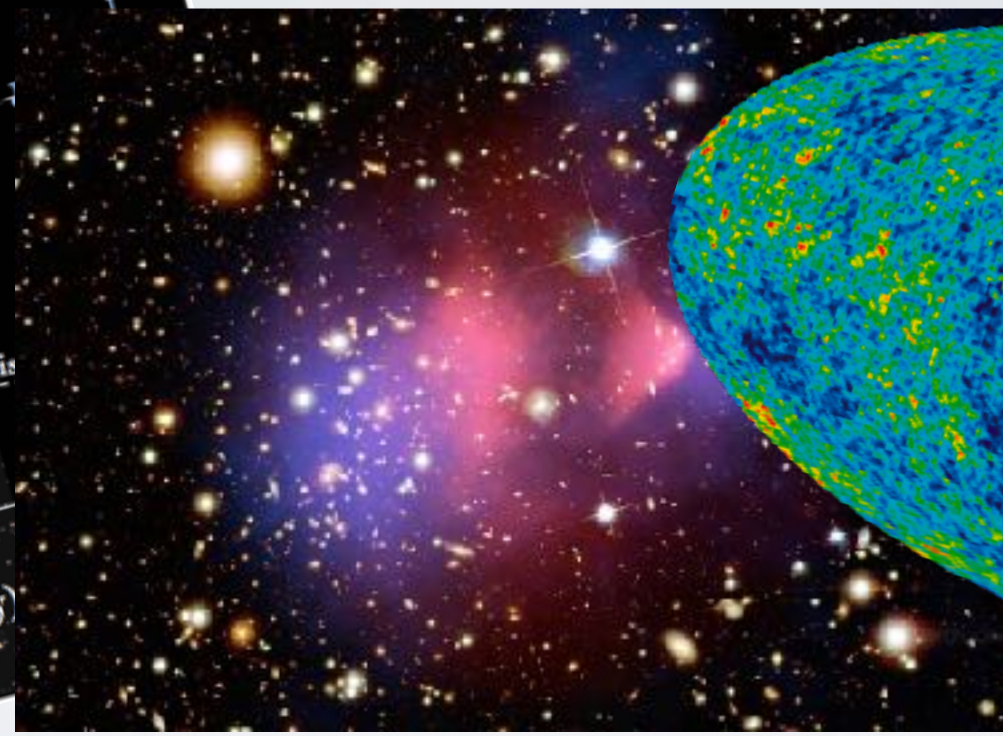

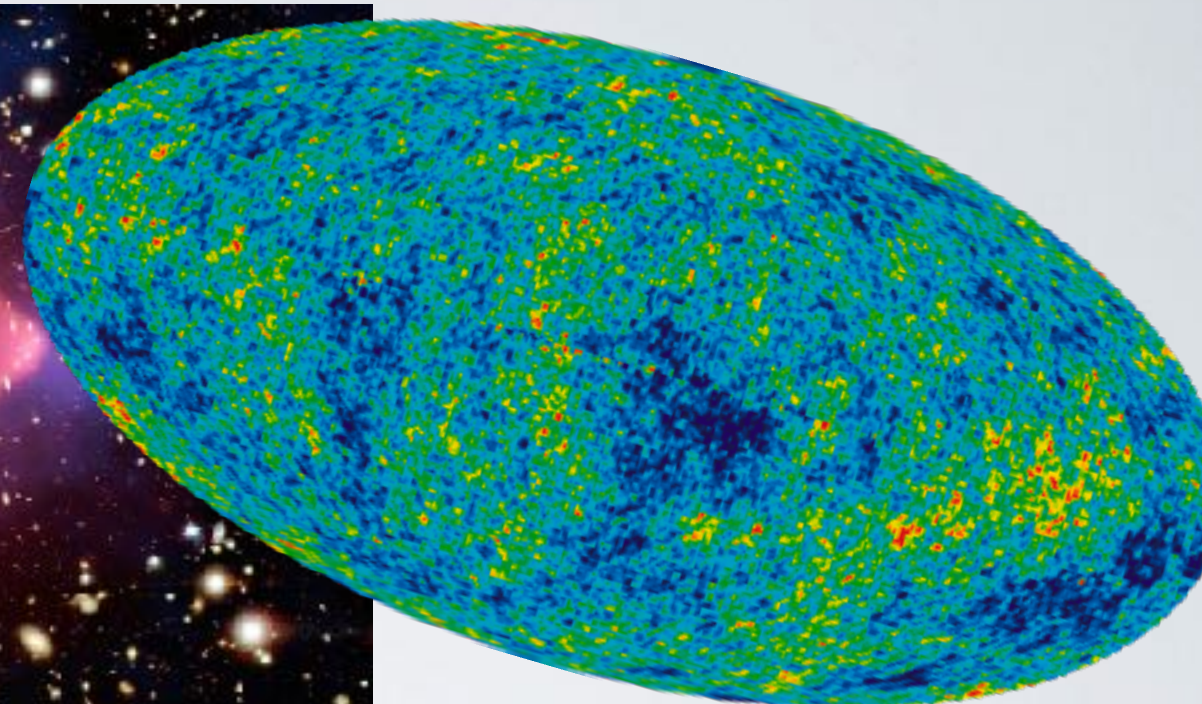

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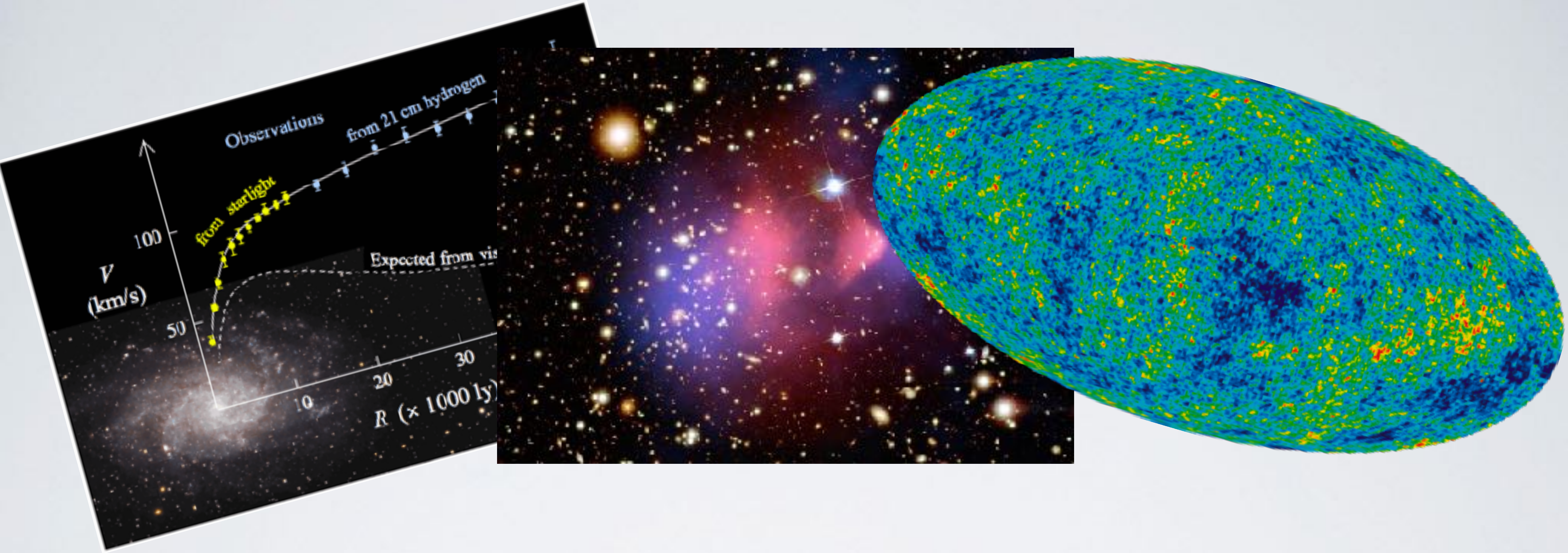

Issues at sub-galactic scales

Too big to fail

We should see more massive dwarf galaxies around us

Core vs. cusp

DM halos have central cores instead of cusps

Missing satellites

MW is missing its satellite galaxies

One of the solutions → Self-interacting DM

DM interact with other light particle in the dark sector

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↓

Sommerfeld Effect

A nonperturbative corr. to the tree level annihilation cross-section

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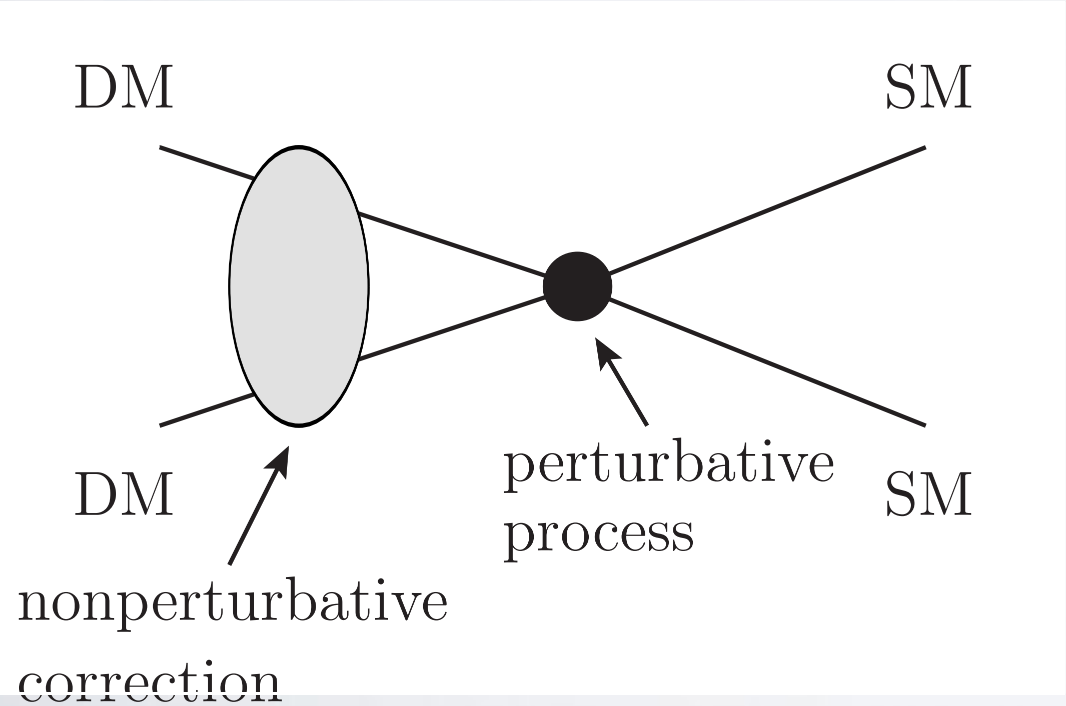

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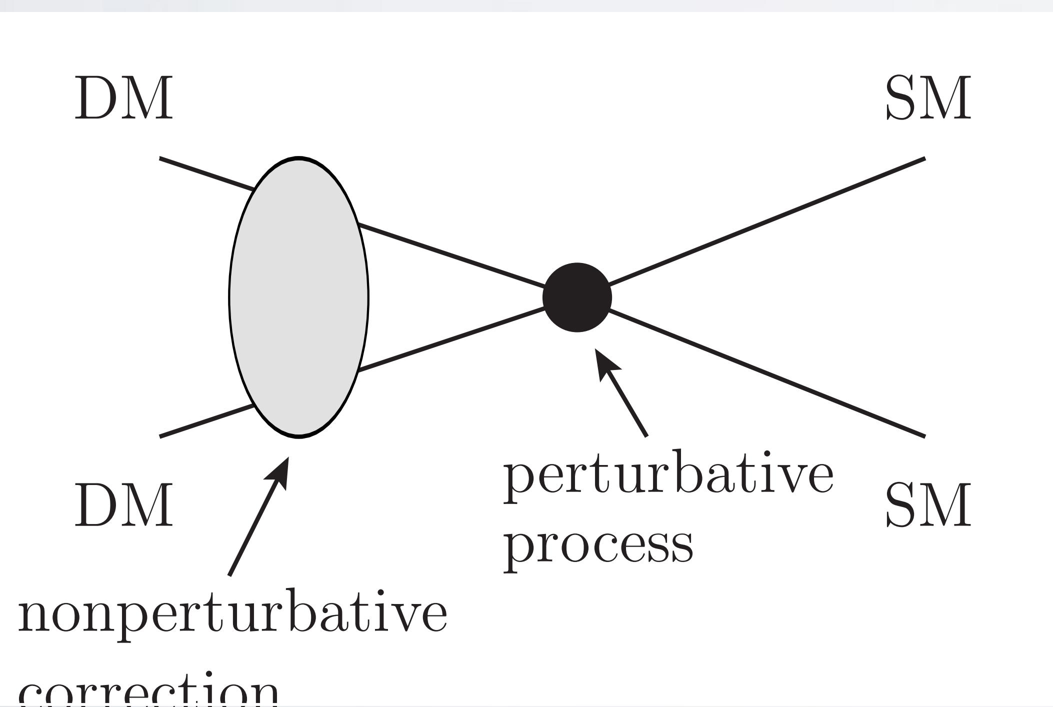
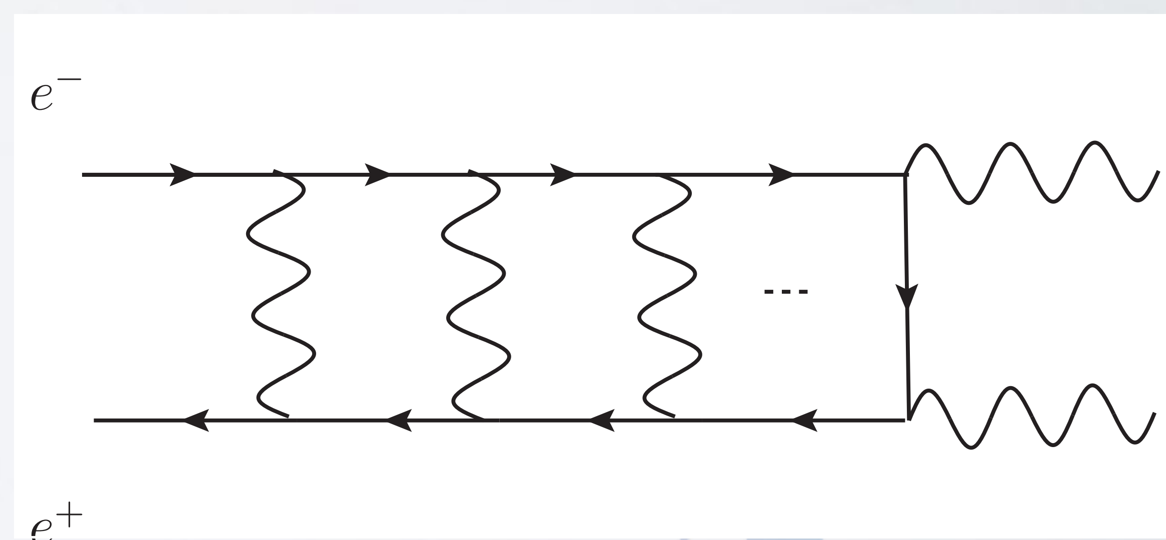
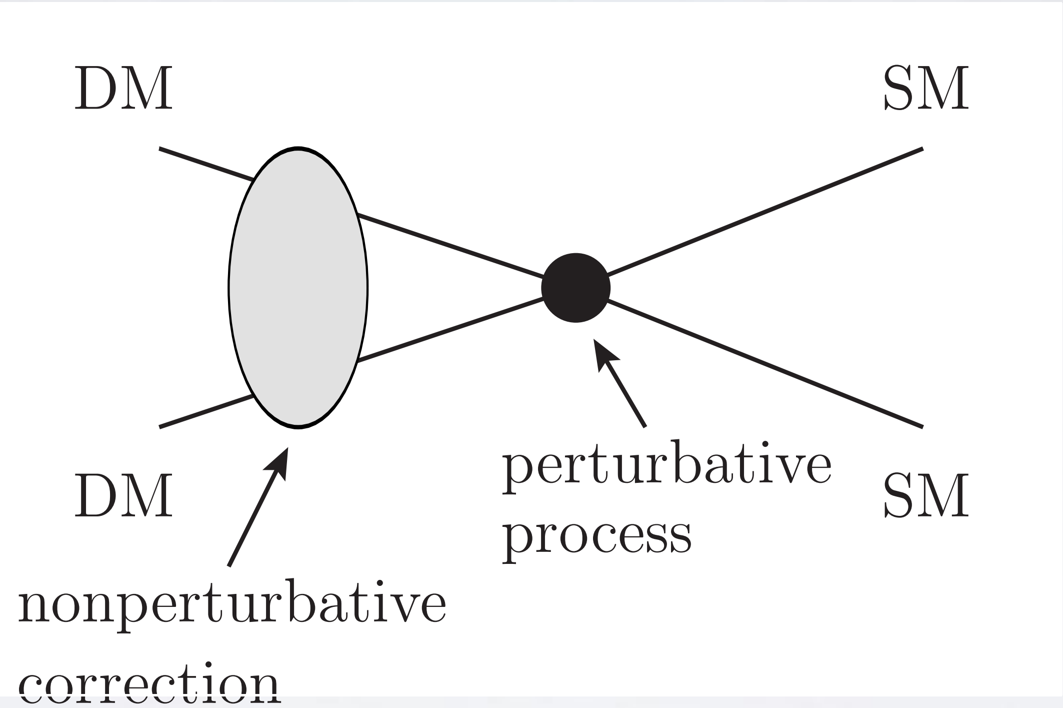




Coulomb potential in QED

A. Sommerfeld 1931

The Sommerfeld Factor S



$$\sigma_\ell \equiv S_\ell \sigma_{0\ell}\,, \quad \ell = 0, 1, \ldots$$

The dark sector

$$\mathcal{L} \supset \partial^\mu \phi^\dagger \partial_\mu \phi + \mu^2 |\phi|^2 - \lambda |\phi|^4 + \mathcal{L}_{U(1)-\mathrm{breaking}}$$

$$+ i\overline{\chi}\gamma_\mu \partial^\mu \chi - M\overline{\chi}\chi - \left(\frac{f}{\sqrt{2}} \phi \overline{\chi} \chi^c + h.c. \right) .$$

S. Weinberg 2013, C. Garcia-Cely et al. 2013, X. Chu et al. 2014

The approx. U(1) symmetry is broken by the VEV of ϕ

$$\phi \to v_\phi + \rho + i\eta$$

the GB gets mass from U(1) breaking term

After symmetry breaking interactions-

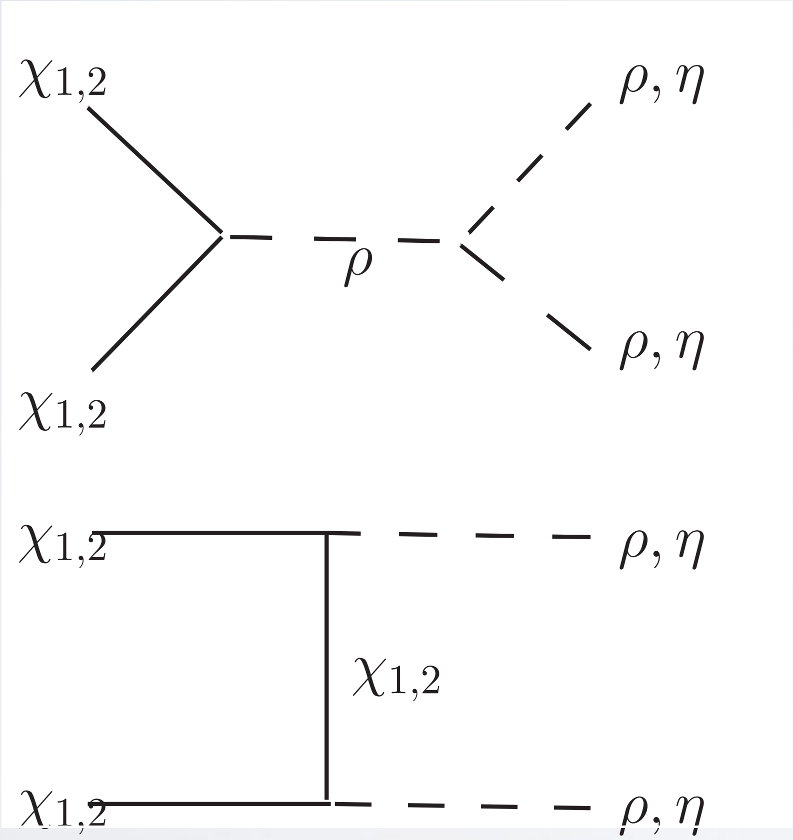
$$-\frac{f}{2}\rho(\bar{\chi}_1\chi_1 - \bar{\chi}_2\chi_2) - \frac{f}{2}\eta(\bar{\chi}_1\chi_2 + \bar{\chi}_2\chi_1)$$

Two Majorana particles $m_\chi, m_\chi + \Delta$

DM annihilates into the lighter particles-

Annihilation

$$|\chi_1\chi_1\rangle, |\chi_2\chi_2\rangle \to \rho\rho, \eta\eta$$

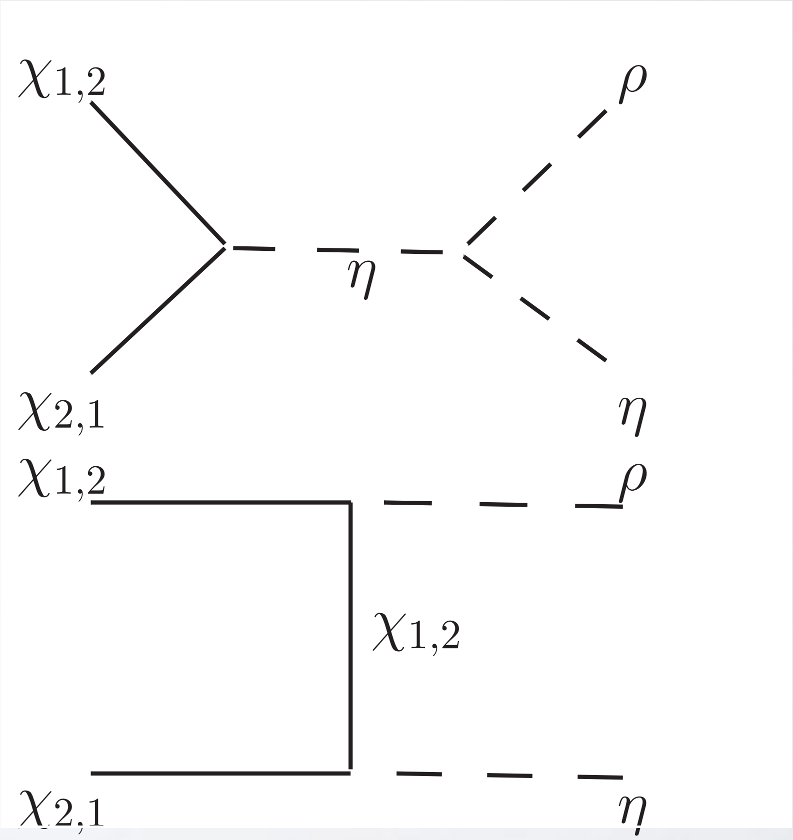


+ u channel

s-wave not allowed

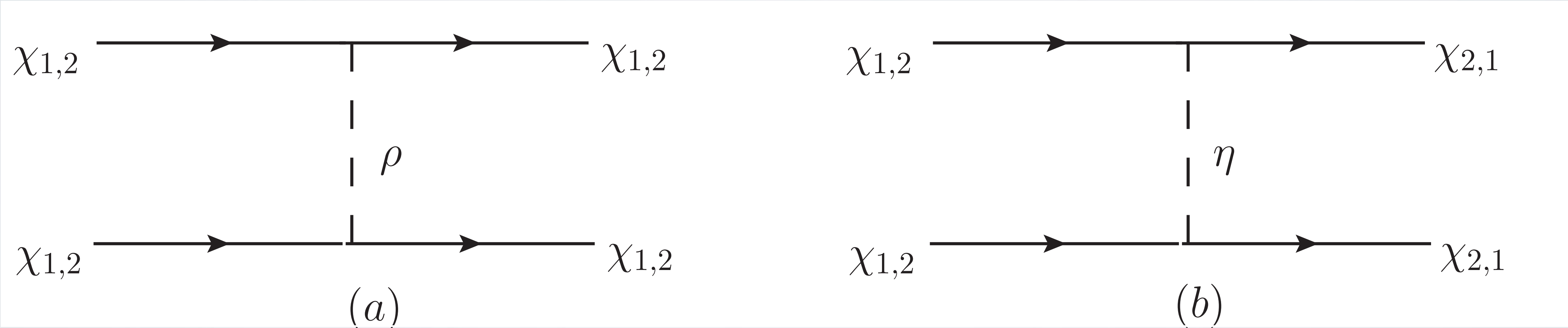
Coannihilation

$$|\chi_1\chi_2\rangle \to \rho\eta$$



s-wave allowed

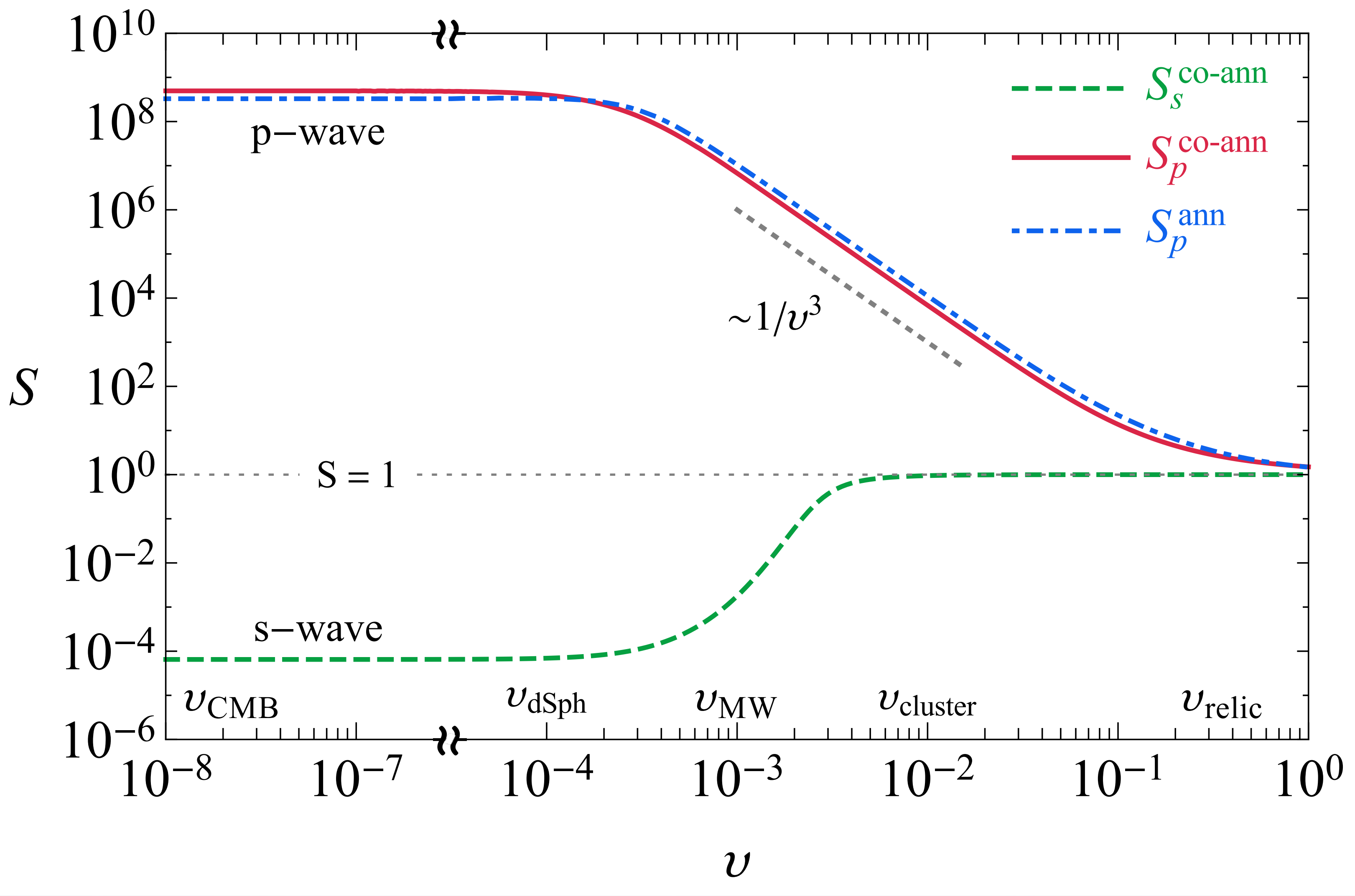
The potentials



$$V_{11} = V_{22} = -\frac{\alpha e^{-m_\rho r}}{r}$$

$$V_{12} = V_{21} = -\frac{\alpha e^{-m_\eta r}}{r}$$

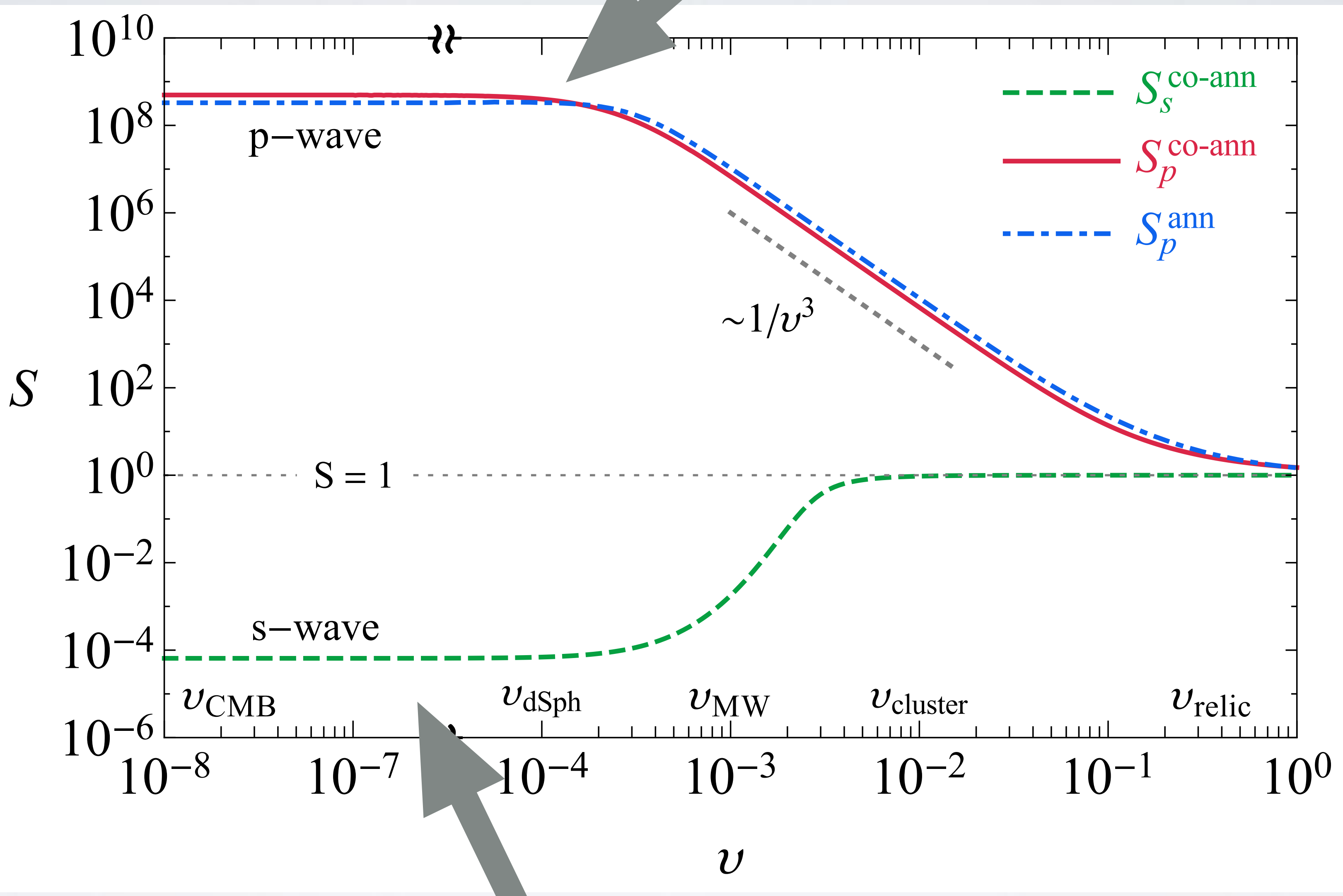
Results



10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
S
p−wave
s−wave
S = 1
$\sim 1/v^3$
$S_s^{\text{co-ann}}$
$S_p^{\text{co-ann}}$
S_p^{ann}
v_{CMB}
v_{dSph}
v_{MW}
v_{cluster}
v_{relic}
10^{-8}
10^{-7}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
v

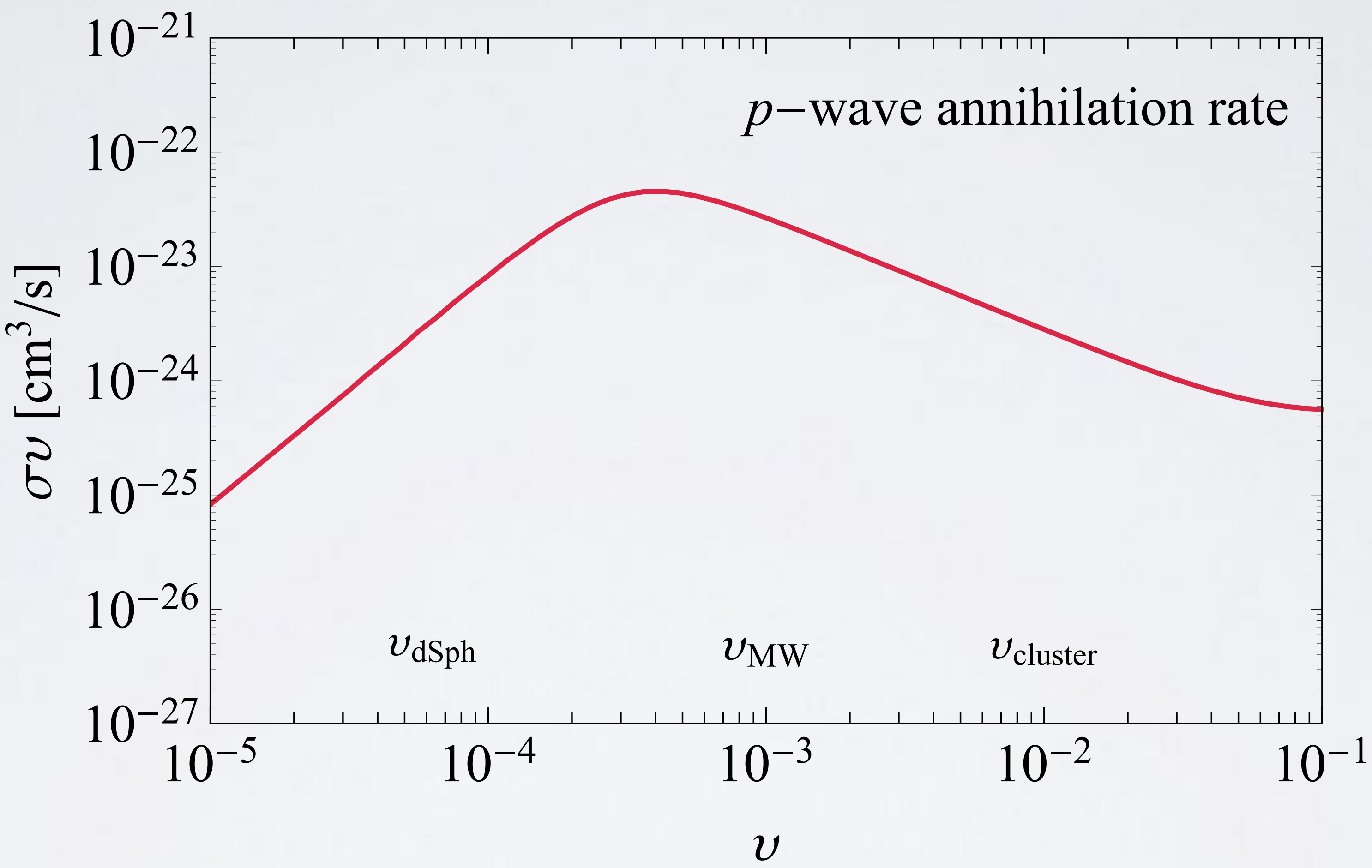
Results

$S_p \gg 1$



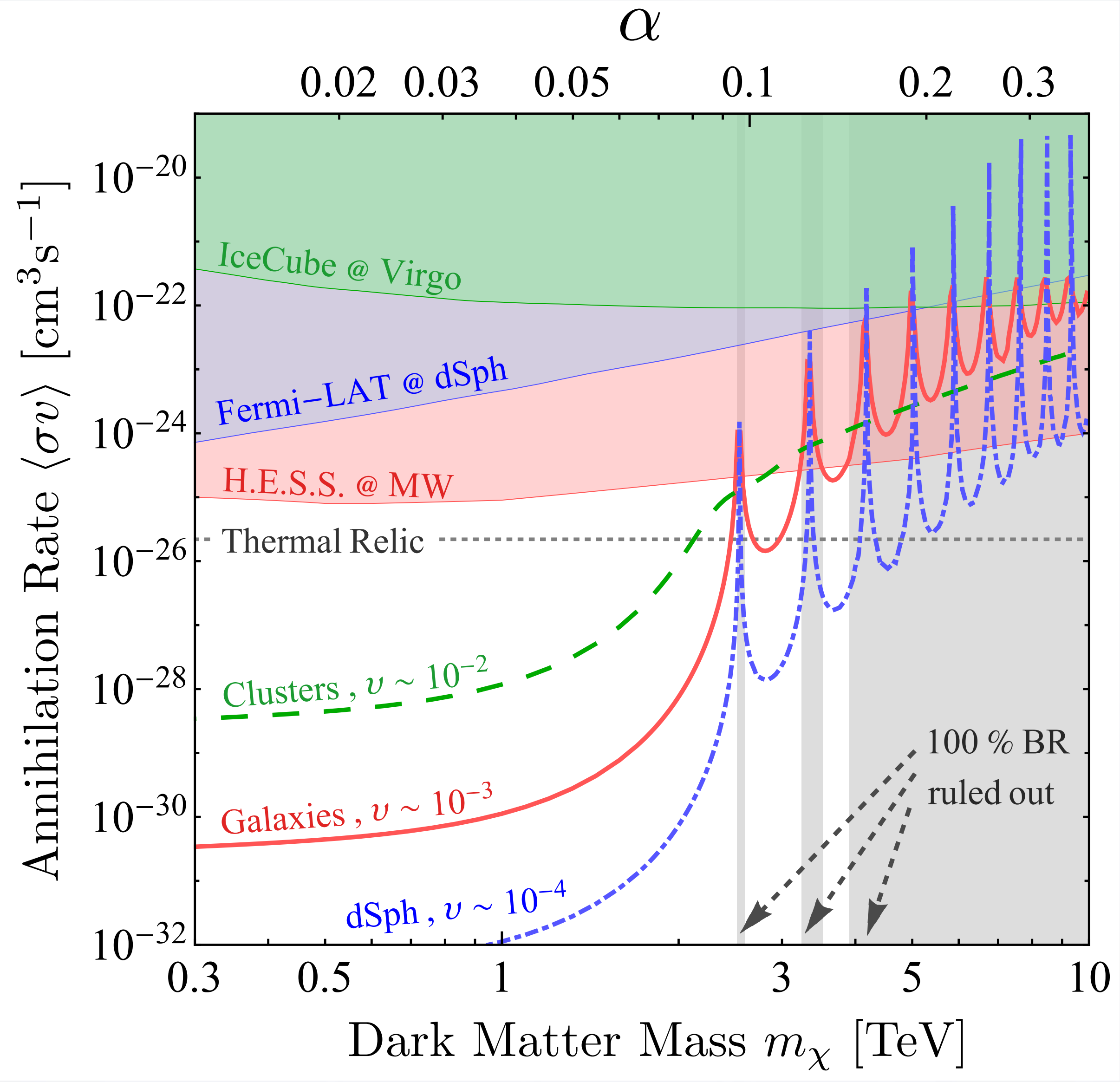
$S_s \ll 1$

Results



p−wave annihilation rate
σv [cm³/s]
10−21
10−22
10−23
10−24
10−25
10−26
10−27
10−5
10−4
10−3
10−2
10−1
v
vdSph
vMW
vcluster

Results



DM annihilation today is given by *p*-wave process !

Explanation using Particle Exchange Symmetry

- Suppose *A* & *B* are two fermions-

$$|BA\rangle = (-1)^{\ell+s}|AB\rangle$$

- $(-1)^{\ell}$ from angular momentum
- $(-1)^{s+1}$ from spin
- (-1) from Wick exchange of spinors

Explanation using Particle Exchange Symmetry

- The exchange symmetry $|\chi_1\chi_1\rangle \leftrightarrow |\chi_2\chi_2\rangle$ is not exact

$$|\chi_2\chi_2\rangle \simeq (-1)^{\ell+s}|\chi_1\chi_1\rangle + \mathcal{O}(\Delta/m_\chi)$$

- The equations can be combined into a single equation with an effective potential

$$V_{\rm eff} = V_{11} + (-1)^{\ell+s} V_{12}$$

$$\ell = 0, s = 1$$

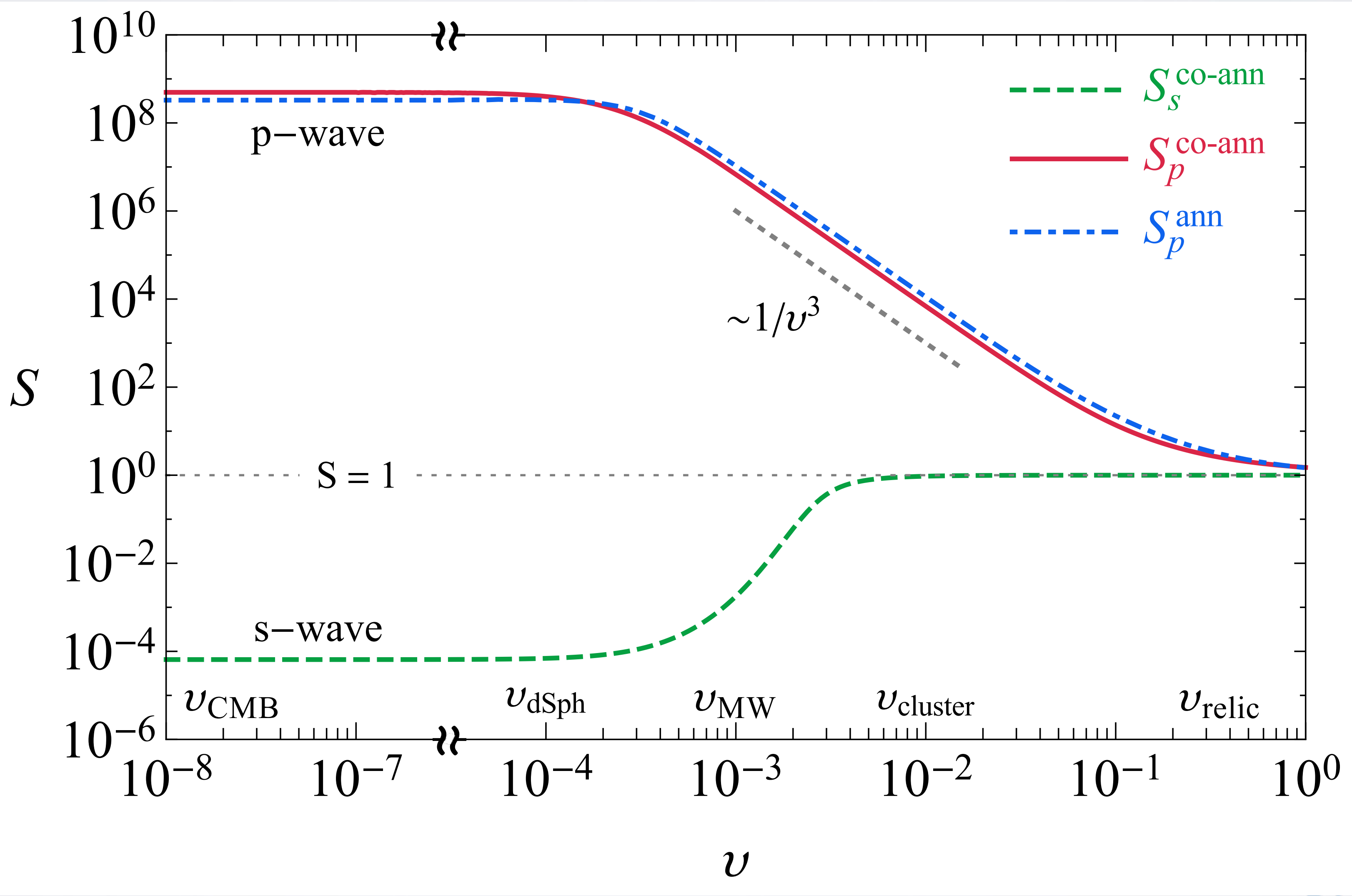
$$V_{\rm eff} = V_{11} - V_{12}$$

$$\ell = 1, s = 1$$

$$V_{\rm eff} = V_{11} + V_{12}$$

Explanation using Particle Exchange Symmetry

$$V_{\rm eff}^{\ell=0} = -\frac{\alpha e^{-m_\rho r}}{r} + \frac{\alpha e^{-m_\eta r}}{r}, \quad V_{\rm eff}^{\ell=1} = -\frac{\alpha e^{-m_\rho r}}{r} - \frac{\alpha e^{-m_\eta r}}{r}$$



Conclusions

- Contrary to our expectation, $S_p \gg 1$ but $S_s \ll 1$.
- Particle exchange symmetry $\longrightarrow$ selection mechanism.
- The unique velocity behaviour of the *p*-wave cross-section becomes crucial.
- DM annihilation rate is preferably enhanced in the galaxies.
- Future direction: more than two DM states, repulsive potential from gauge particles, multiple mediators etc.

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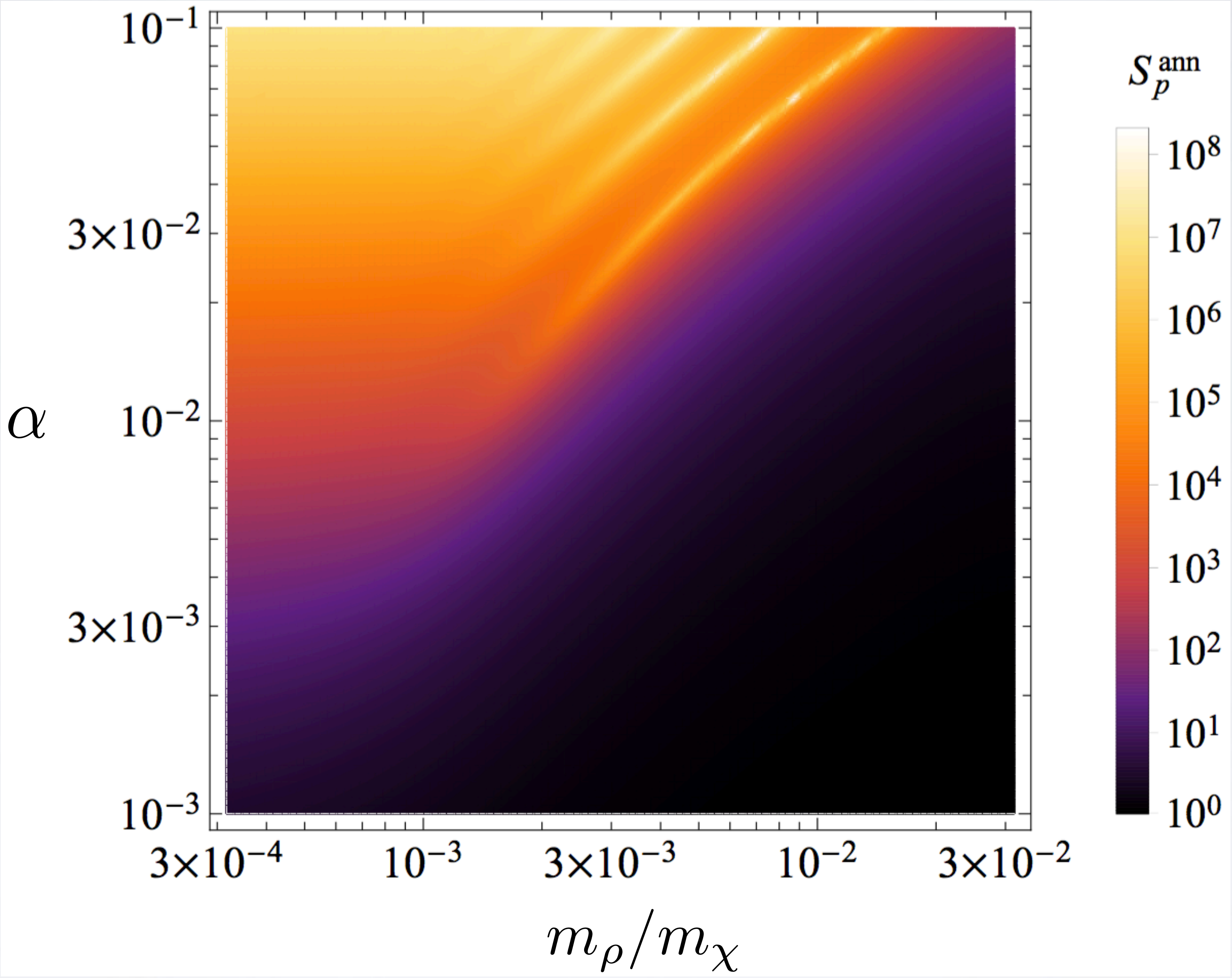
Thank you!

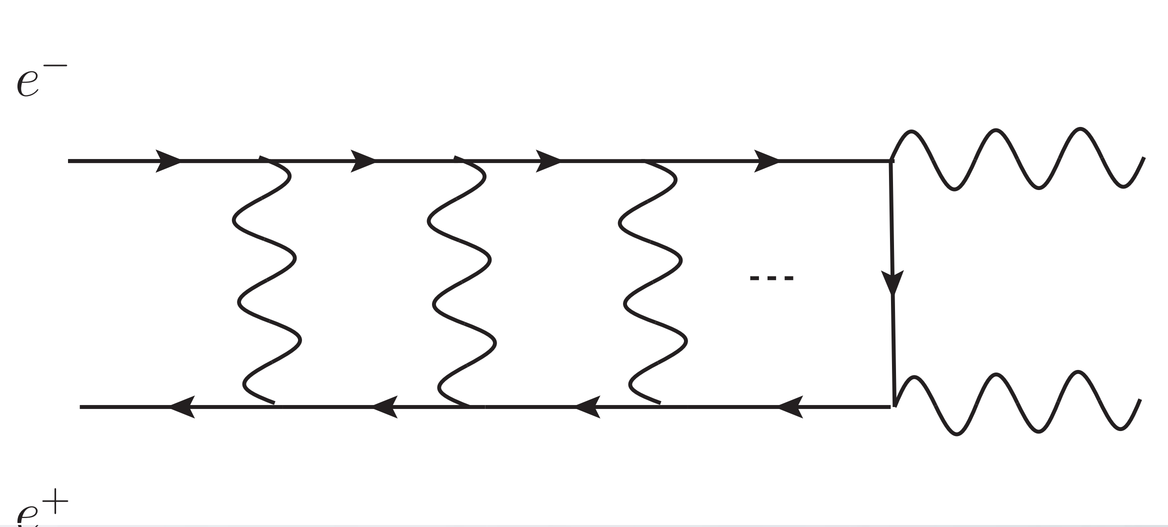
Back ups



Resonances at $\dfrac{6\alpha m_\chi}{\pi^2 m_\rho} = (n+2)^2$

Back ups

α-scaling in a ladder graph



Typical momentum exchange ~ αm_χ

$$|\mathbf{p}| \sim \alpha m_\chi \implies p^0 \sim \frac{|\mathbf{p}|^2}{2m_\chi} \sim \alpha^2 m_\chi$$

One photon exchange graph ~ $\dfrac{\alpha}{|\mathbf{q}|^2} \sim \dfrac{1}{\alpha}$

Two photon exchange graph ~ $\alpha^2 \left(\dfrac{1}{\alpha^2}\right)^2 \left(\dfrac{1}{\alpha^2}\right)^2 \alpha^5 \sim \dfrac{1}{\alpha}$

Back ups

Gamma matrices to the leading order in *v*

$$\Gamma_p^{\text{ann}} = \frac{6\pi\alpha^2 v^2}{m_\chi^2}\begin{pmatrix} +1 & +1 \\ +1 & +1 \end{pmatrix}$$

$$\Gamma_s^{\text{coann}} = \frac{\pi\alpha^2}{3m_\chi^2}\begin{pmatrix} +1 & -1 \\ -1 & +1 \end{pmatrix} \qquad \Gamma_p^{\text{coann}} = \frac{\pi\alpha^2 m_\rho^4 v^2}{4m_\chi^4\Delta^2}\begin{pmatrix} +1 & +1 \\ +1 & +1 \end{pmatrix}$$

Back ups