# Searching Accretion-Enhanced Dark Matter Annihilation Signals in the Galactic Centre

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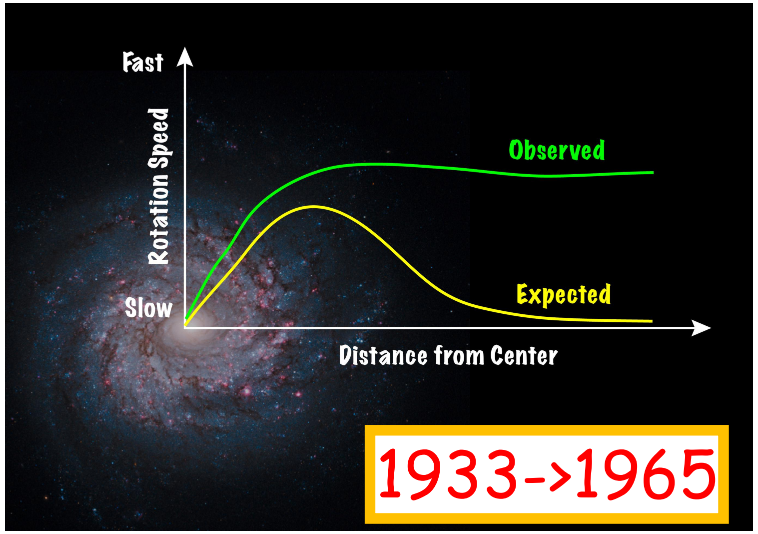
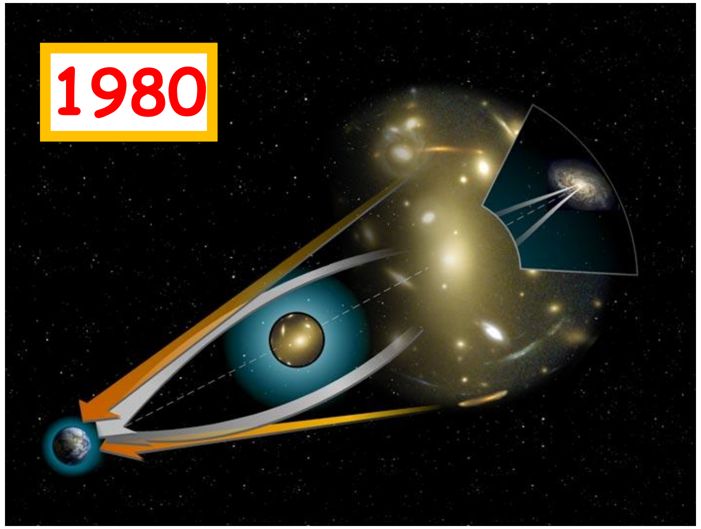
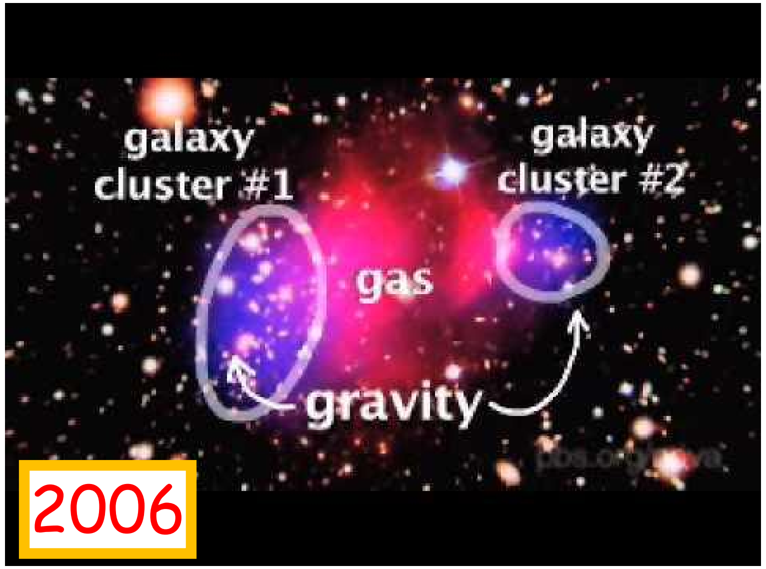
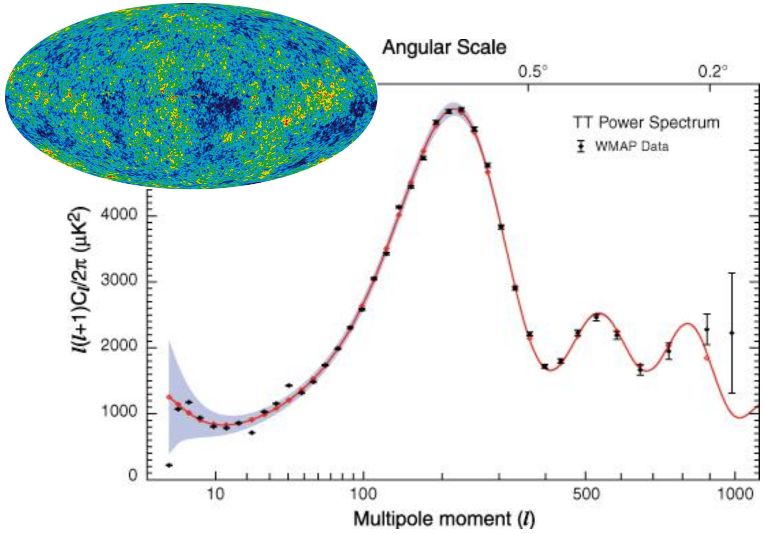
第十三届新物理会议@威海

# Dark Matter Problems

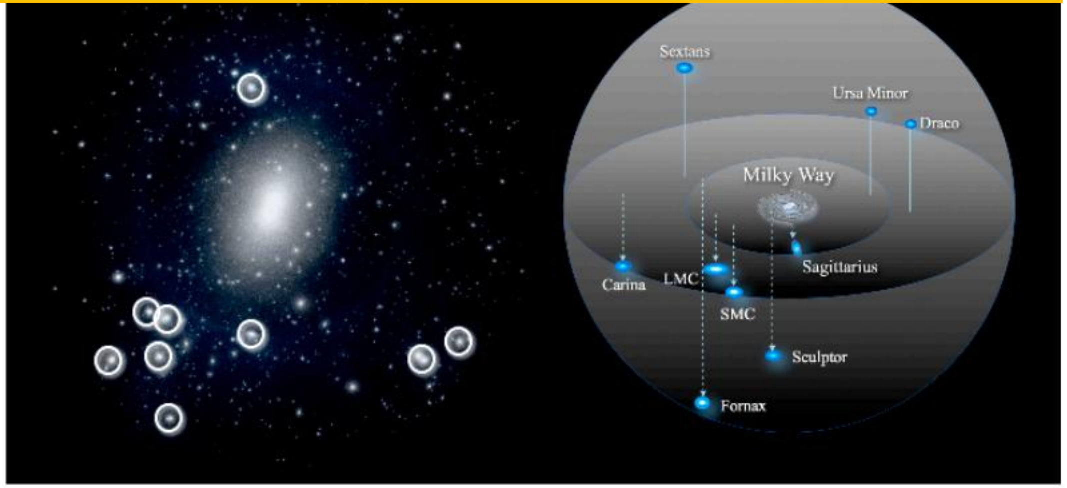



More and more dSphs were found!



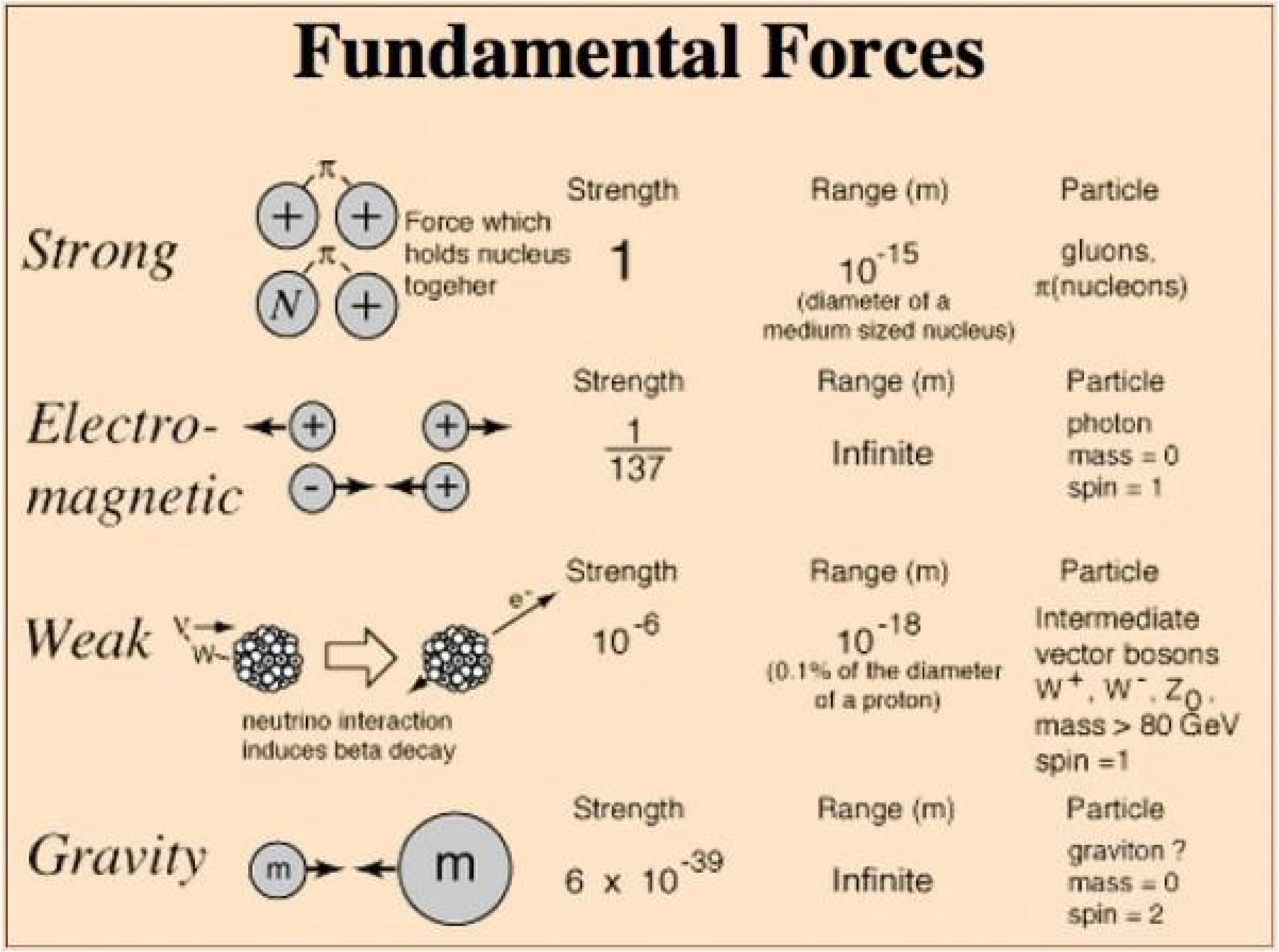

IF GR is correct, it will be difficult to explain the universe without DM assumption.

We learn from N-body simulation :

DM must be matter and everywhere!

We also learn from particle physics :

If DM is matter,
DM particles must be able to
be identified in the lab!



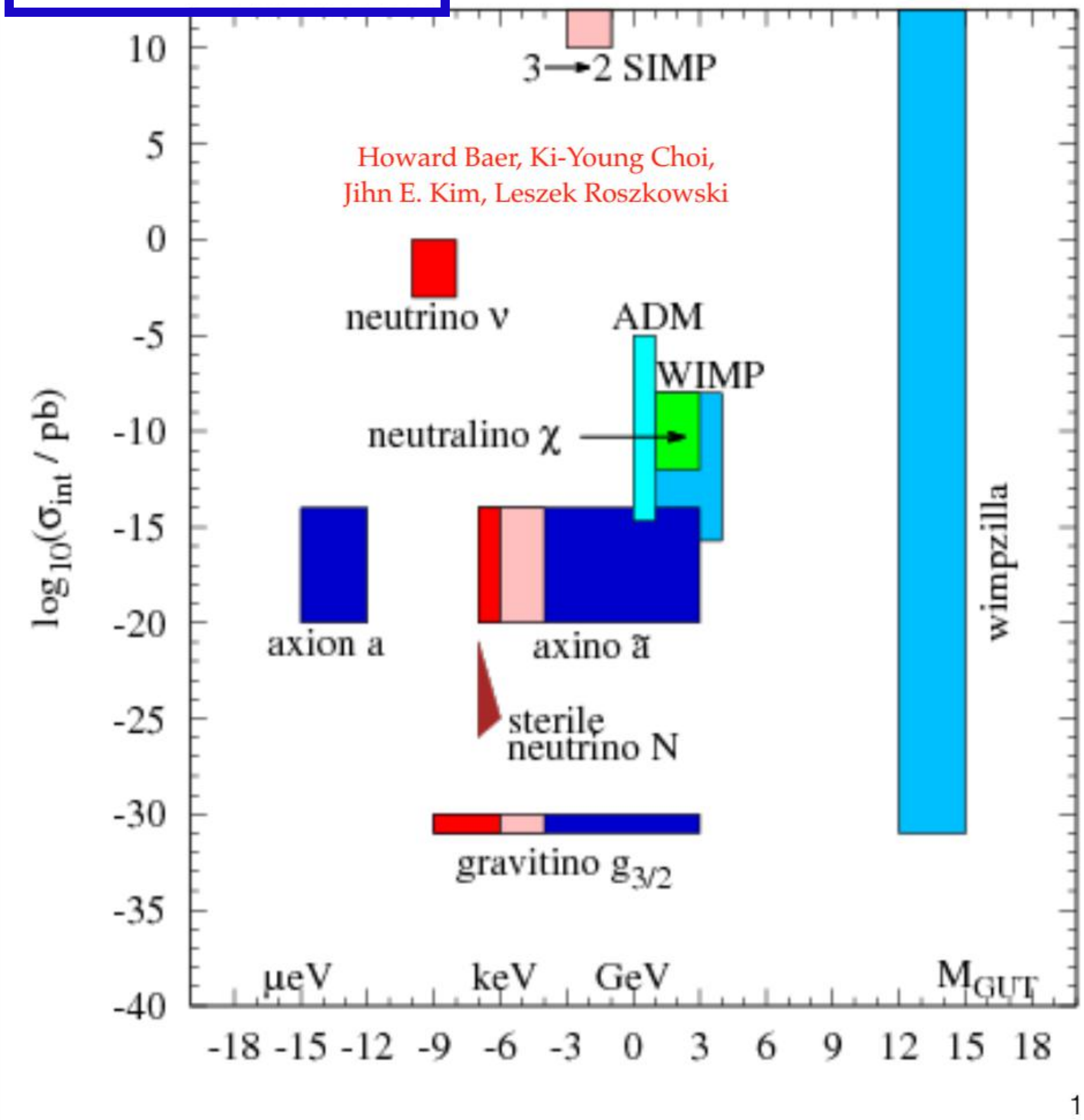

What is the DM-SM interaction strength?

How is possible that no interaction between 1e-6 and 1e-39?

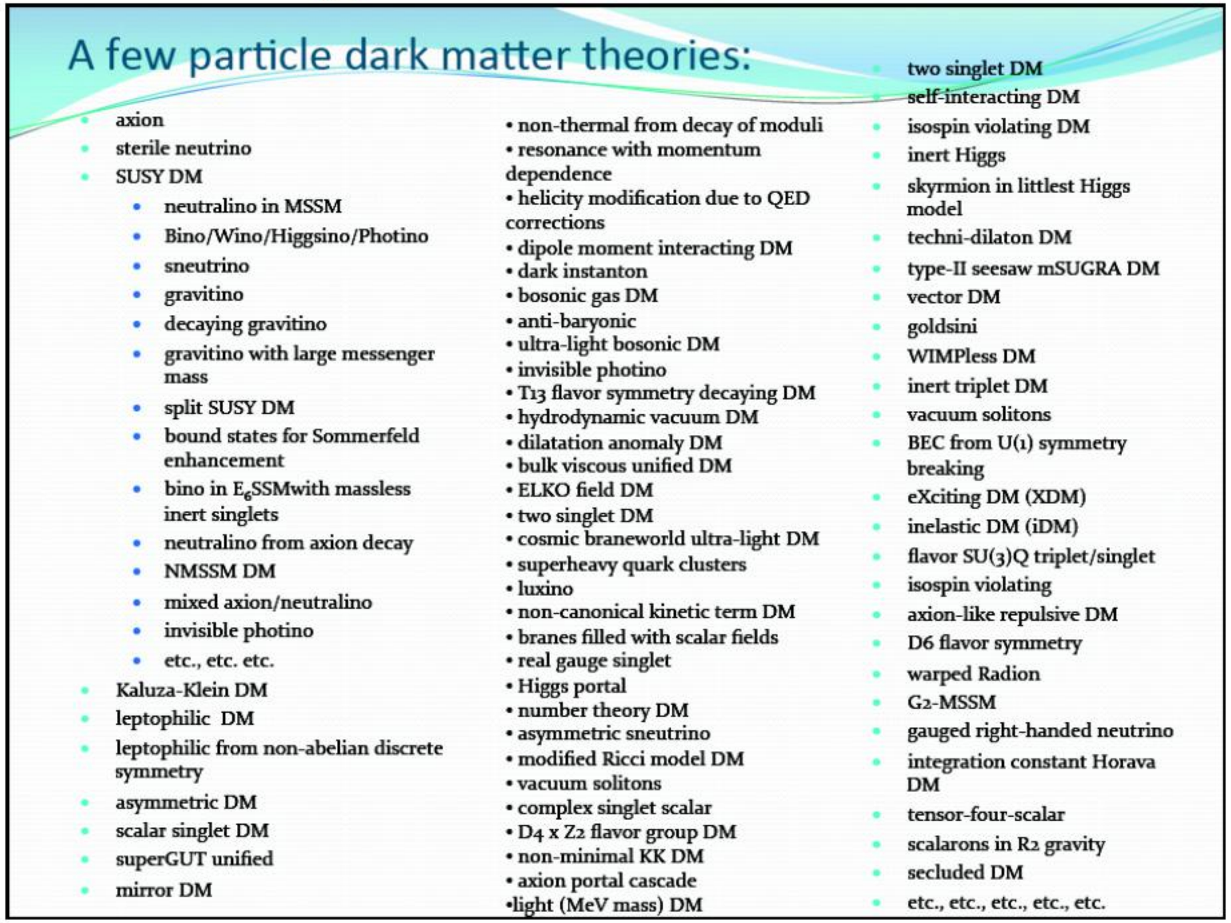
If new interaction greater than Gravity...

Collisional or Collisionless?

Blue for CDM!




# There are so many DM models located at different mass scales.



## A few particle dark matter theories:

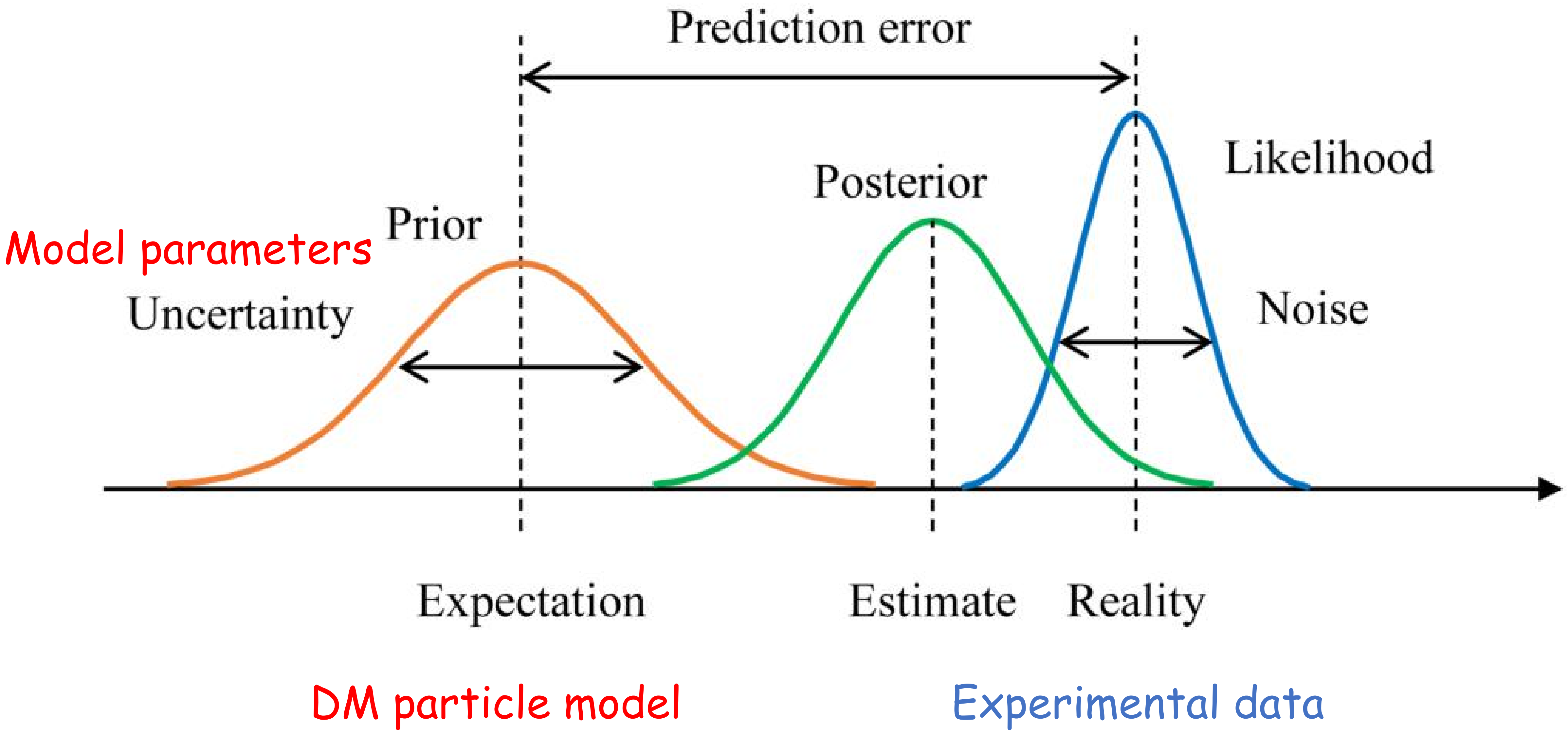
- axion
- sterile neutrino
- SUSY DM
  - neutralino in MSSM
  - Bino/Wino/Higgsino/Photino
  - sneutrino
  - gravitino
  - decaying gravitino
  - gravitino with large messenger mass
  - split SUSY DM
  - bound states for Sommerfeld enhancement
  - bino in $E_6$SSMwith massless inert singlets
  - neutralino from axion decay
  - NMSSM DM
  - mixed axion/neutralino
  - invisible photino
  - etc., etc. etc.
- Kaluza-Klein DM
- leptophilic DM
- leptophilic from non-abelian discrete symmetry
- asymmetric DM
- scalar singlet DM
- superGUT unified
- mirror DM

- non-thermal from decay of moduli
- resonance with momentum dependence
- helicity modification due to QED corrections
- dipole moment interacting DM
- dark instanton
- bosonic gas DM
- anti-baryonic
- ultra-light bosonic DM
- invisible photino
- T13 flavor symmetry decaying DM
- hydrodynamic vacuum DM
- dilatation anomaly DM
- bulk viscous unified DM
- ELKO field DM
- two singlet DM
- cosmic braneworld ultra-light DM
- superheavy quark clusters
- luxino
- non-canonical kinetic term DM
- branes filled with scalar fields
- real gauge singlet
- Higgs portal
- number theory DM
- asymmetric sneutrino
- modified Ricci model DM
- vacuum solitons
- complex singlet scalar
- D4 x Z2 flavor group DM
- non-minimal KK DM
- axion portal cascade
- light (MeV mass) DM

- two singlet DM
- self-interacting DM
- isospin violating DM
- inert Higgs
- skyrmion in littlest Higgs model
- techni-dilaton DM
- type-II seesaw mSUGRA DM
- vector DM
- goldsini
- WIMPless DM
- inert triplet DM
- vacuum solitons
- BEC from U(1) symmetry breaking
- eXciting DM (XDM)
- inelastic DM (iDM)
- flavor SU(3)Q triplet/singlet
- isospin violating
- axion-like repulsive DM
- D6 flavor symmetry
- warped Radion
- G2-MSSM
- gauged right-handed neutrino
- integration constant Horava DM
- tensor-four-scalar
- scalarons in R2 gravity
- secluded DM
- etc., etc., etc., etc., etc.

Taken from Griest (2014).

# Similarity to Bayesian theory



# The belief (prior) of the thermal DM "Miracle"

- Belief 1: DM cannot strongly couple to SM atoms, otherwise we have seen it already.
- Belief 2: The early universe (T>m) was at very high temperature and thermal equilibrium.
- BBN is successful theory.
- We can learn DM nature from its relic density.

Dinosaur ~ fossils + alligator
DM ~ relic density + BBN

# Thermal dark matter

VOLUME 39 — 25 JULY 1977 — NUMBER 4

## Cosmological Lower Bound on Heavy-Neutrino Masses

Benjamin W. Lee[(a)]
*Fermi National Accelerator Laboratory,*[(b)] *Batavia, Illinois 60510*

and

Steven Weinberg[(c)]
*Stanford University, Physics Department, Stanford, California 94305*
(Received 13 May 1977)

*s*- and *p*-wave
2GeV< mχ
s-wave unitarity
mχ<200 TeV

PHYSICAL REVIEW D — VOLUME 43, NUMBER 10 — 15 MAY 1991

## Three exceptions in the calculation of relic abundances

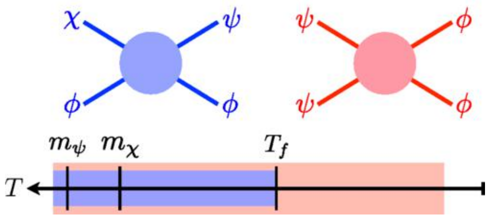
Kim Griest
*Center for Particle Astrophysics and Astronomy Department, University of California, Berkeley, California 94720*

David Seckel
*Bartol Research Institute, Universi*
(Received 1

Three exceptions

1. Resonance.
2. Forbidden DM.
3. Coannihilation.

Coscattering Mechanism




PRL 119, 061102 (2017) — PHYSICAL REVIEW LETTERS — week ending 11 AUGUST 2017

## Fourth Exception in the Calculation of Relic Abundances

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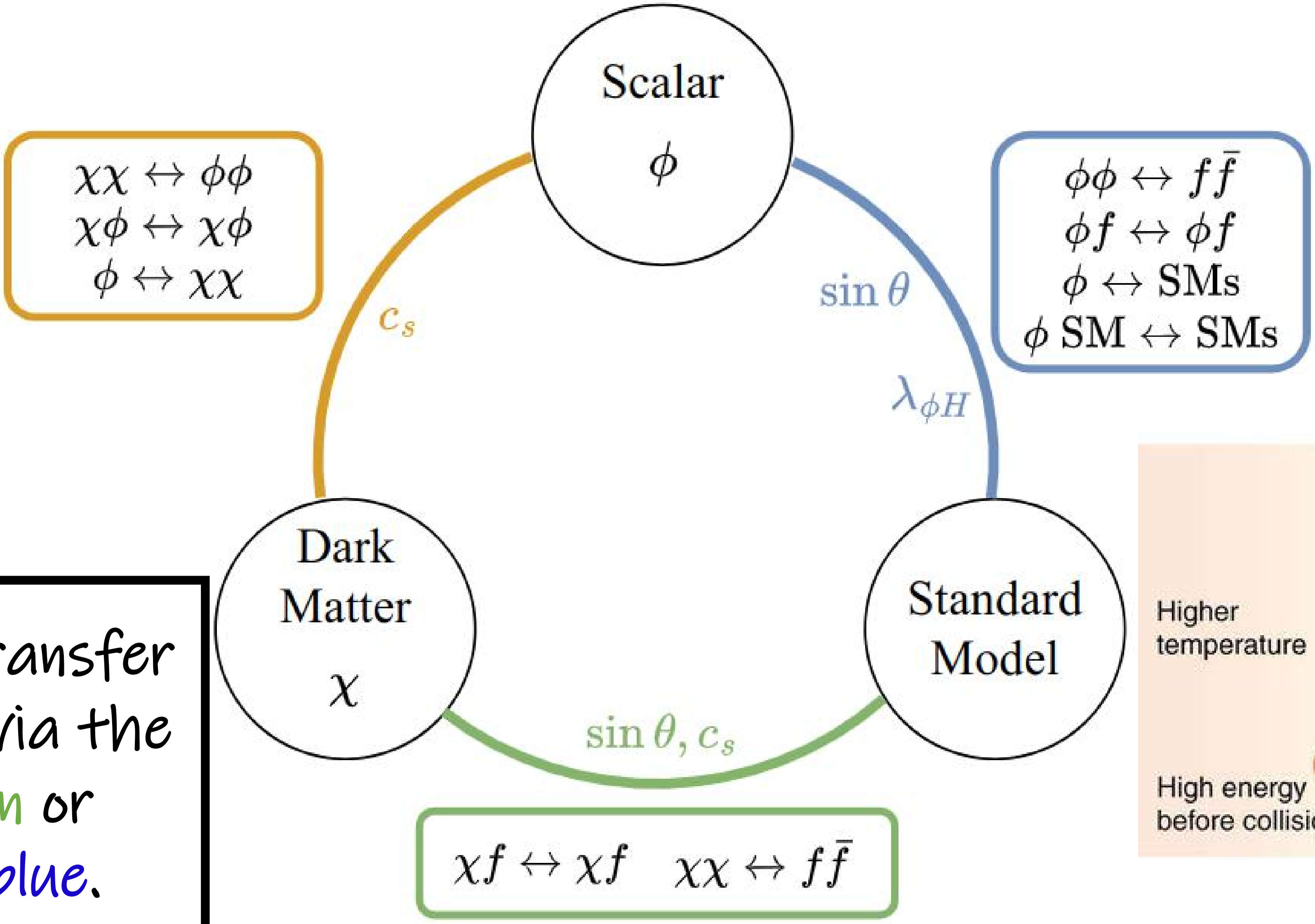
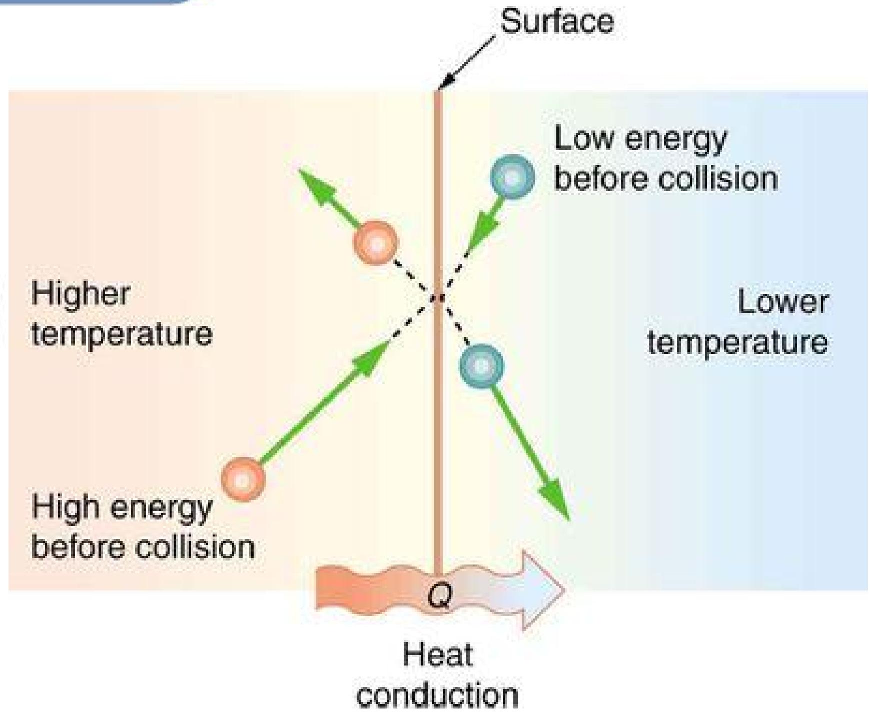
(Received 1 June 2017; revised manuscript received 10 July 2017; published 8 August 2017)

# Thermal dark matter



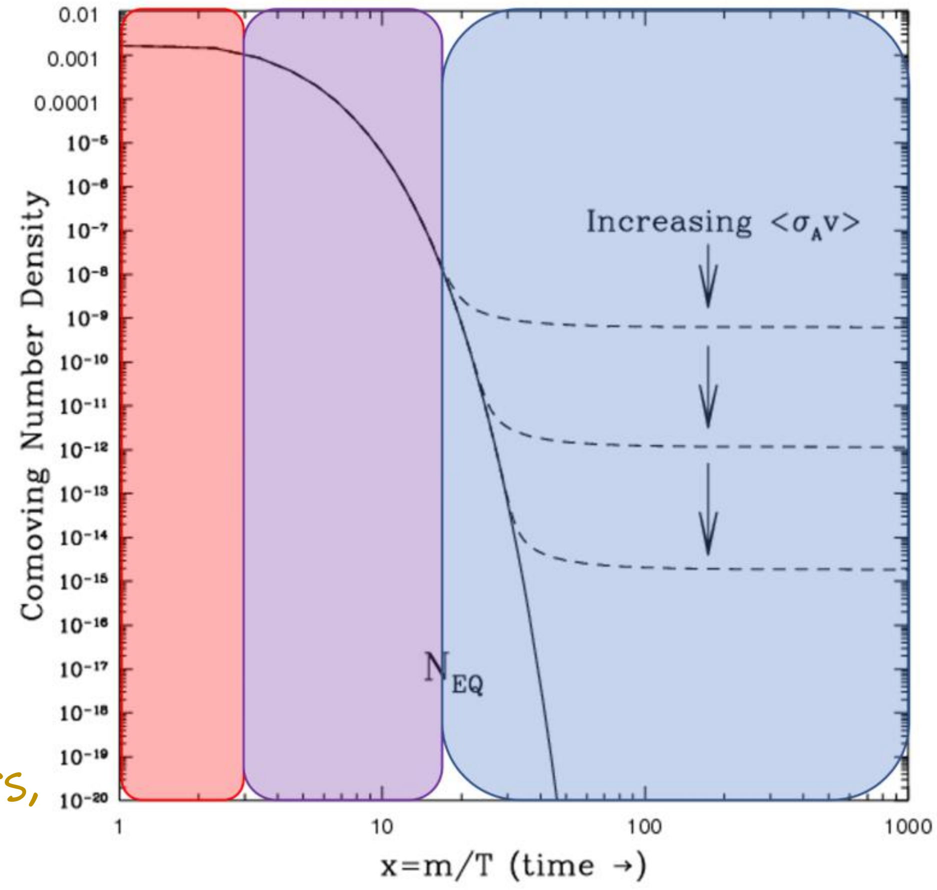



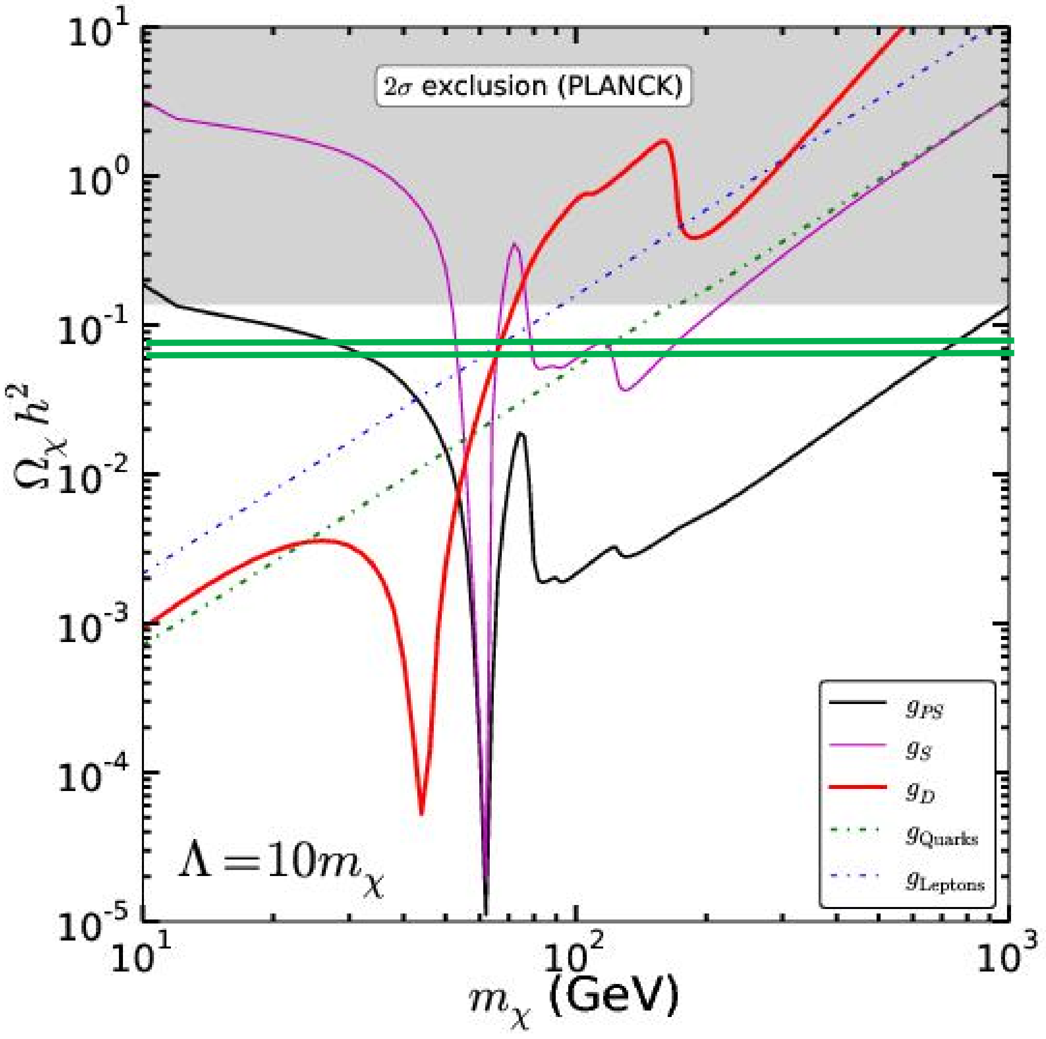

Heat transfer can be via the green or red+blue.

# Thermal dark matter

1. s-wave
2. p-wave
3. Resonance.
4. Forbidden DM.
5. Coannihilation.
6. Secluded DM

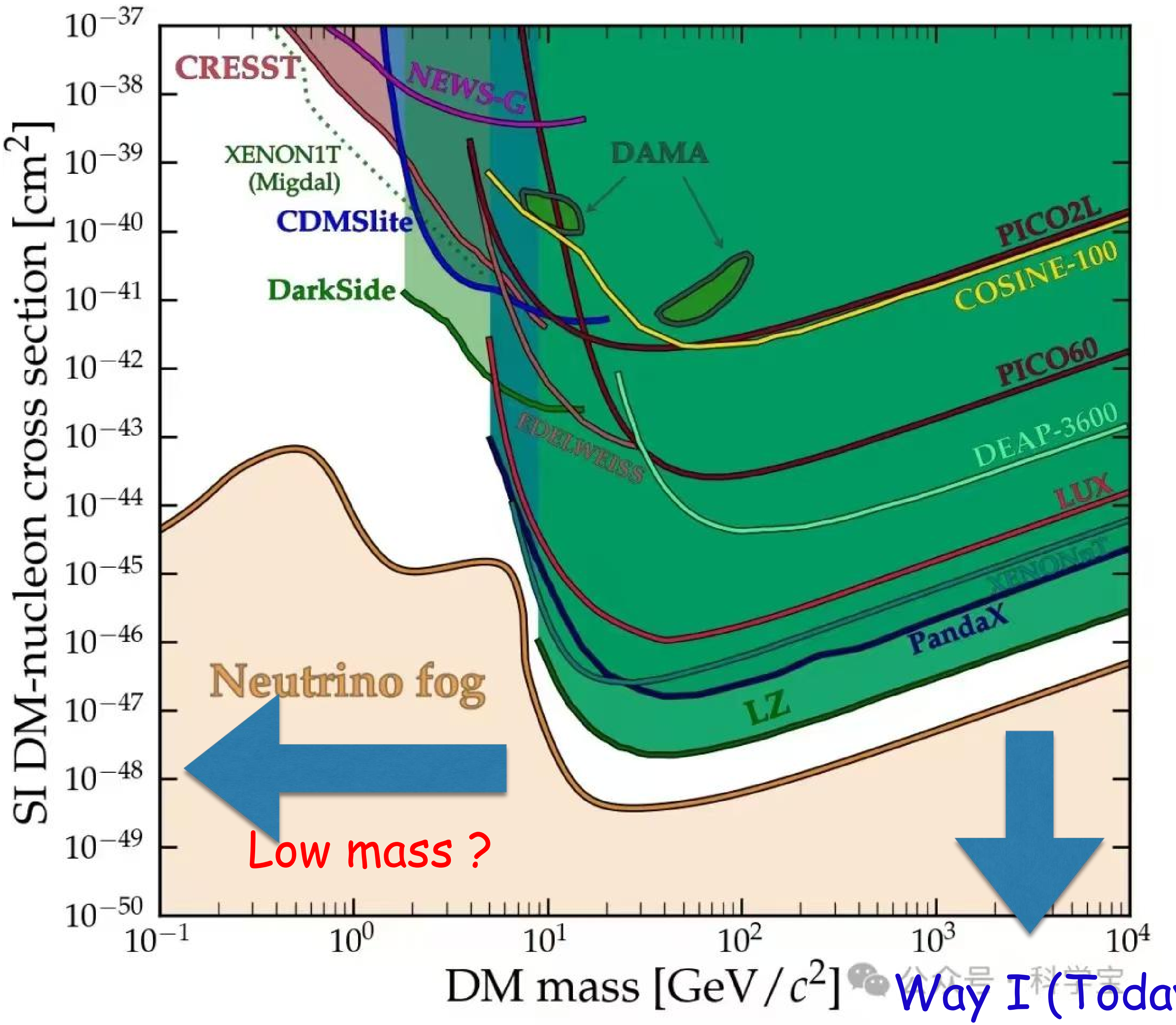
excluded by colliders, DD, and ID




To be detectable, the parameter space shall be confined!!!

Matsumoto, Mukhopadhyay, Tsai (JHEP), 1407.1859




Lower energy or higher exposure?

- p-wave
- Resonance
- Forbidden DM
- Coannihilation
- Secluded DM

Velocity dependent annihilations!

Way I (Today's talk)

# Velocity dependent annihilations

arXiv > hep-ph > arXiv:2407.06815

Similar works: Zhou, Ge...

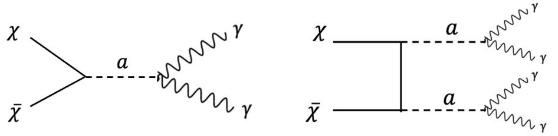
**High Energy Physics - Phenomenology**

*[Submitted on 9 Jul 2024]*

## Searching Accretion-Enhanced Dark Matter Annihilation Signals in the Galactic Centre

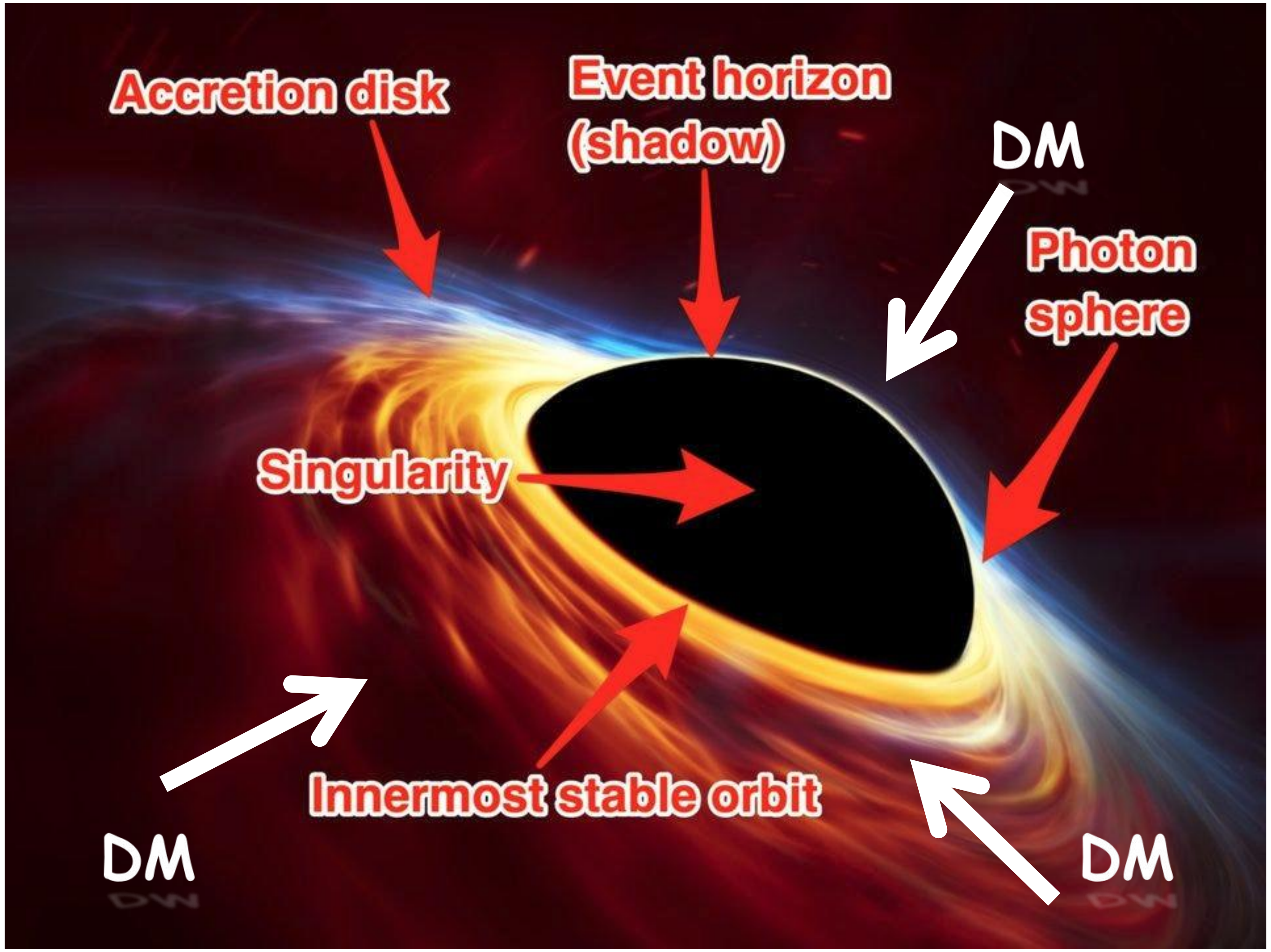
Mei-Wen Yang, Zhi-Qi Guo, Xiao-Yi Luo, Zhao-Qiang Shen, Zi-Qing Xia, Chih-Ting Lu, Yue-Lin Sming Tsai, Yi-Zhong Fan

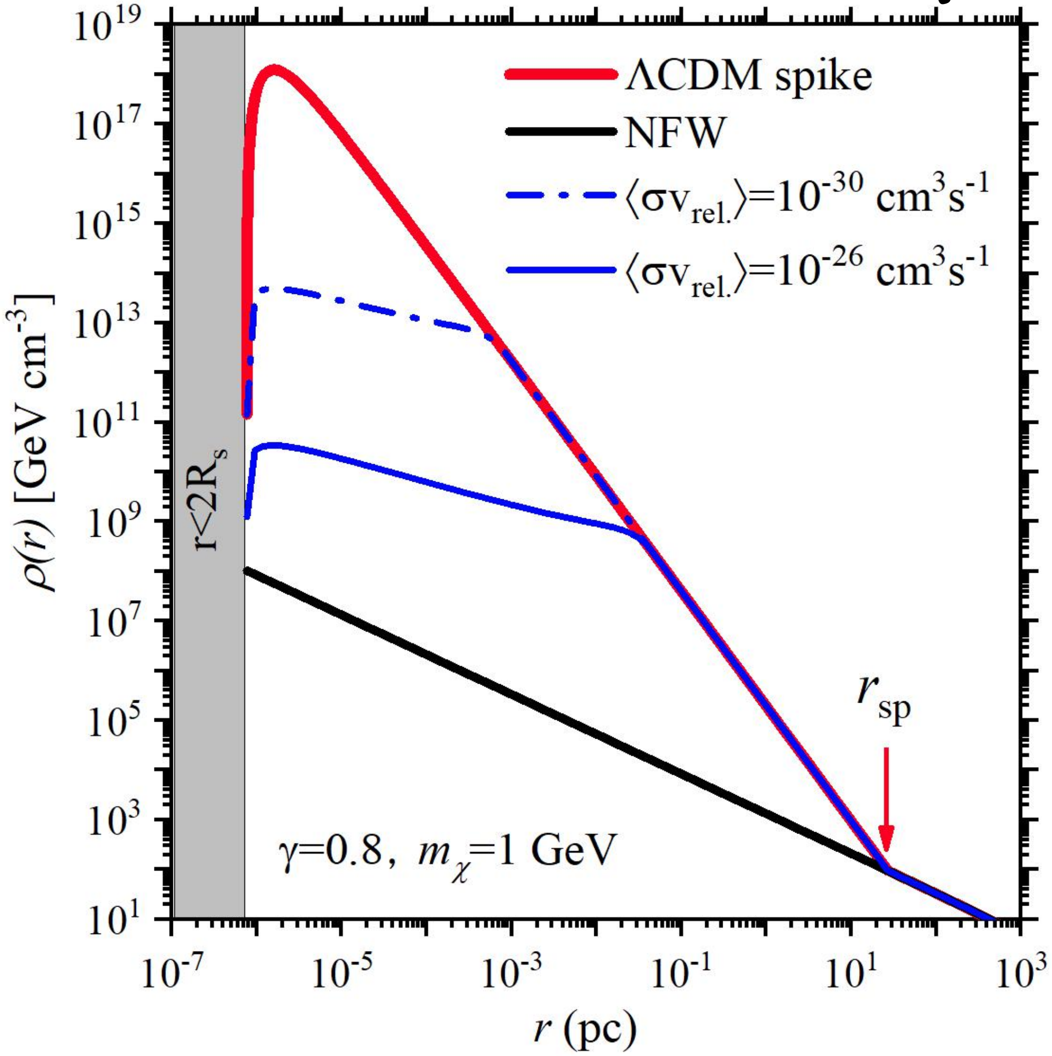
- $m_\chi > m_a$:
  The dominant DM annihilation channel is $\chi\overline{\chi} \to aa$ which is $p$-wave. The photon energy spectra are a box-shape due to Lorentz boost, especially for $m_\chi \gg m_a$.
- Resonance annihilation ($2m_\chi \approx m_a$):
  The annihilation cross-section of $\chi\overline{\chi} \to \gamma\gamma$ can undergo a large enhancement through an $a$-resonance. In the rest frame, its photon spectrum shapes as a monochromatic line, but this feature can become distorted under a high acceleration of DM particles. To characterize the resonance nature, we utilize $R_{a\chi} = \sqrt{1 - 4m_\chi^2/m_a^2}$ instead of $m_a$ itself.
- Forbidden annihilation ($m_\chi \lesssim m_a$):
  The annihilation process is also $\chi\overline{\chi} \to aa$, albeit with $m_\chi \lesssim m_a$. Essentially, forbidden annihilations cease when the kinetic energies of DM particles fall below threshold energies. The shape of the energy spectrum varies, either monochromatic or continuum, depending on the mass splitting $\Delta m \equiv m_a - m_\chi$. If $\Delta m$ exceeds a certain



These three velocity dependent scenarios might be interesting for post-WIMP epoch.

# Accretion-Enhanced Dark Matter Velocity

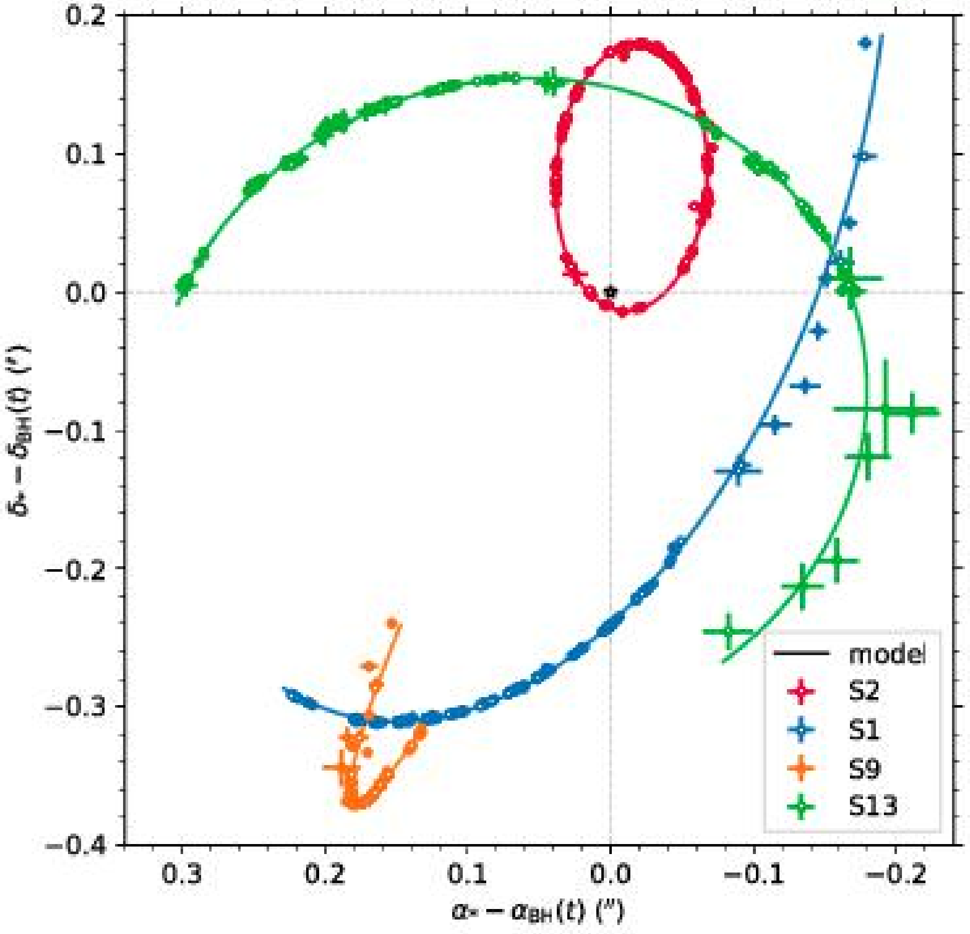


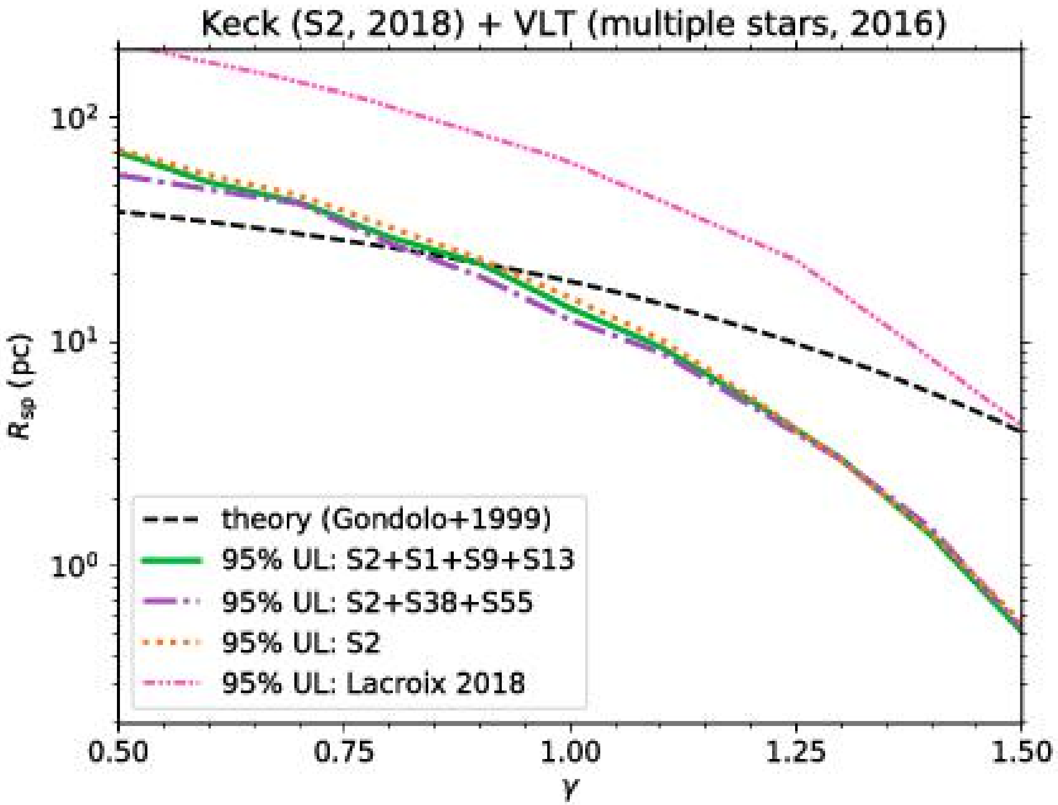




DM particles can be accreted near the SMBH with semi-relativistic velocity.

# S2 frequency shift to test DM

$$\frac{\mathrm{d}^2\boldsymbol{r}}{\mathrm{d}t^2} = -\frac{GM_{\rm tot}(r)}{r^3}\boldsymbol{r} - \frac{GM_{\rm tot}(r)}{c^2r^3}\left[(4\phi(r)+v^2)\boldsymbol{r} - 4\boldsymbol{v}(\boldsymbol{v}\cdot\boldsymbol{r})\right]$$

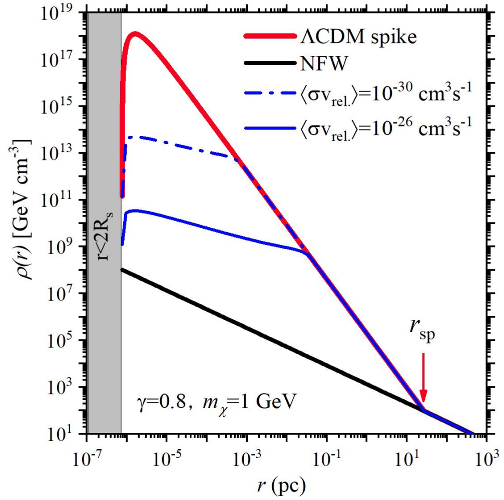


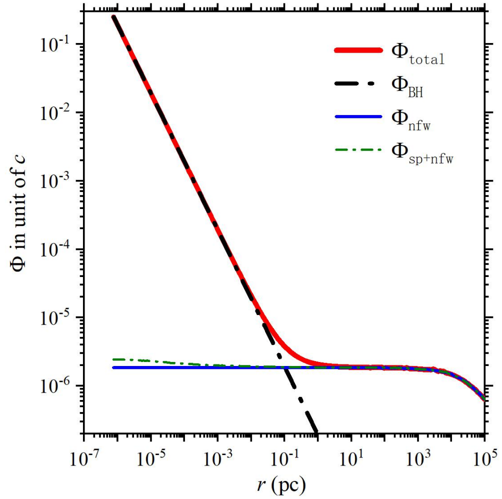



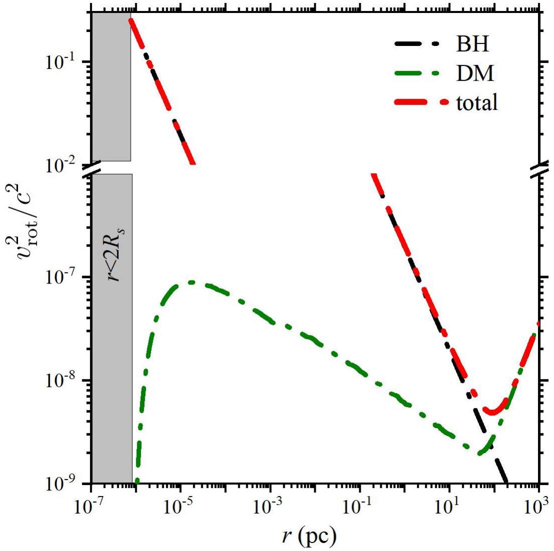

Shen, Yuan, Jiang, Tsai, Yuan, Fan [Mon.Not.Roy.Astron.Soc. 527 (2024) 3196]

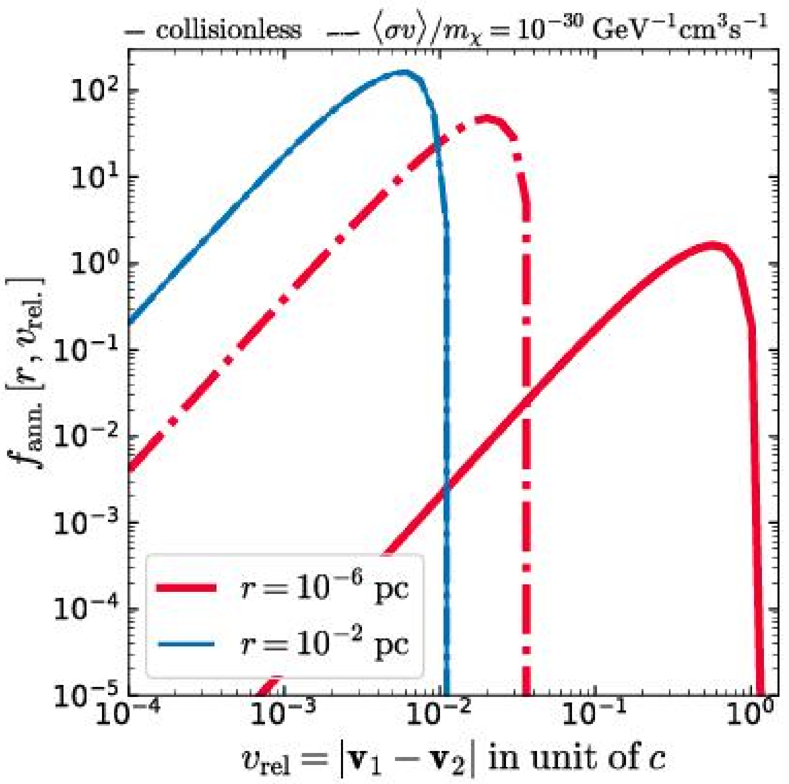
S-star motion is a good probe to DM interactions beyond collisionless.

# Accretion-Enhanced DM annihilation?




$$f_0(\epsilon) = \frac{1}{\sqrt{8}\pi^2}\int_0^{\varepsilon} \frac{\mathrm{d}\Phi}{\sqrt{\varepsilon - \Phi}} \frac{\mathrm{d}^2\rho_{\mathrm{NFW}}}{\mathrm{d}\Phi^2}$$

$$f_{\mathrm{ann.}}[r, \mathbf{v}_{\mathrm{rel.}}] \propto \int d^3\mathbf{v}_{\mathrm{CM}} f_1(\mathbf{v_1}, r) f_2(\mathbf{v_2}, r).$$

$$f_{\mathrm{ann.}}[r, v_{\mathrm{rel.}}] = \frac{v^2_{\mathrm{rel.}}}{N_0} \times \int_0^{v_{\mathrm{esc}}} dv_{\mathrm{CM}} v^2_{\mathrm{CM}} \int_{-1}^{1} d\cos\alpha \int_0^{2\pi} d\phi \times \int_{-\mu_0}^{\mu_0} d\cos\theta \times f_1(v_{\mathrm{rel.}}, v_{\mathrm{CM}}, L_1, r) \times f_2(v_{\mathrm{rel.}}, v_{\mathrm{CM}}, L_2, r),$$

$$\text{with} \quad \mu_0 \equiv \frac{4v^2_{\mathrm{esc}} - 4v^2_{\mathrm{CM}} - v^2_{\mathrm{rel.}}}{4v_{\mathrm{rel.}} v_{\mathrm{CM}}}, \quad \cos\alpha \equiv \frac{\mathbf{v}_{\mathrm{CM}} \cdot \mathbf{r}}{v_{\mathrm{CM}} \times r} \quad \text{and} \quad v_{\mathrm{esc}} = \sqrt{2\Phi_{\mathrm{tot}}(r)}.$$

The maximal particle velocity is around 0.6c.

# Model: an axion-portal dark matter

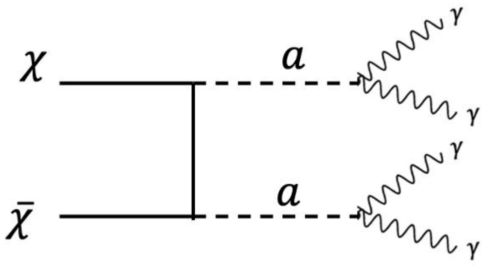
$$\mathcal{L}_{\rm DM-ALP} \;=\; C_{a\chi\chi} m_\chi a \bar{\chi} i\gamma_5 \chi,$$

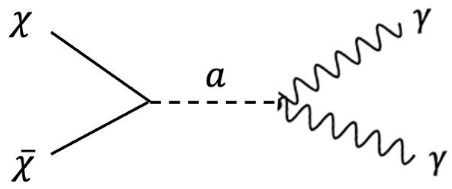
$$\mathcal{L}_{\rm gauge-ALP} = -\frac{C_{BB}}{4} a B_{\mu\nu}\widetilde{B}^{\mu\nu} - \frac{C_{WW}}{4} a W^i_{\mu\nu}\widetilde{W}^{i;\mu\nu}$$

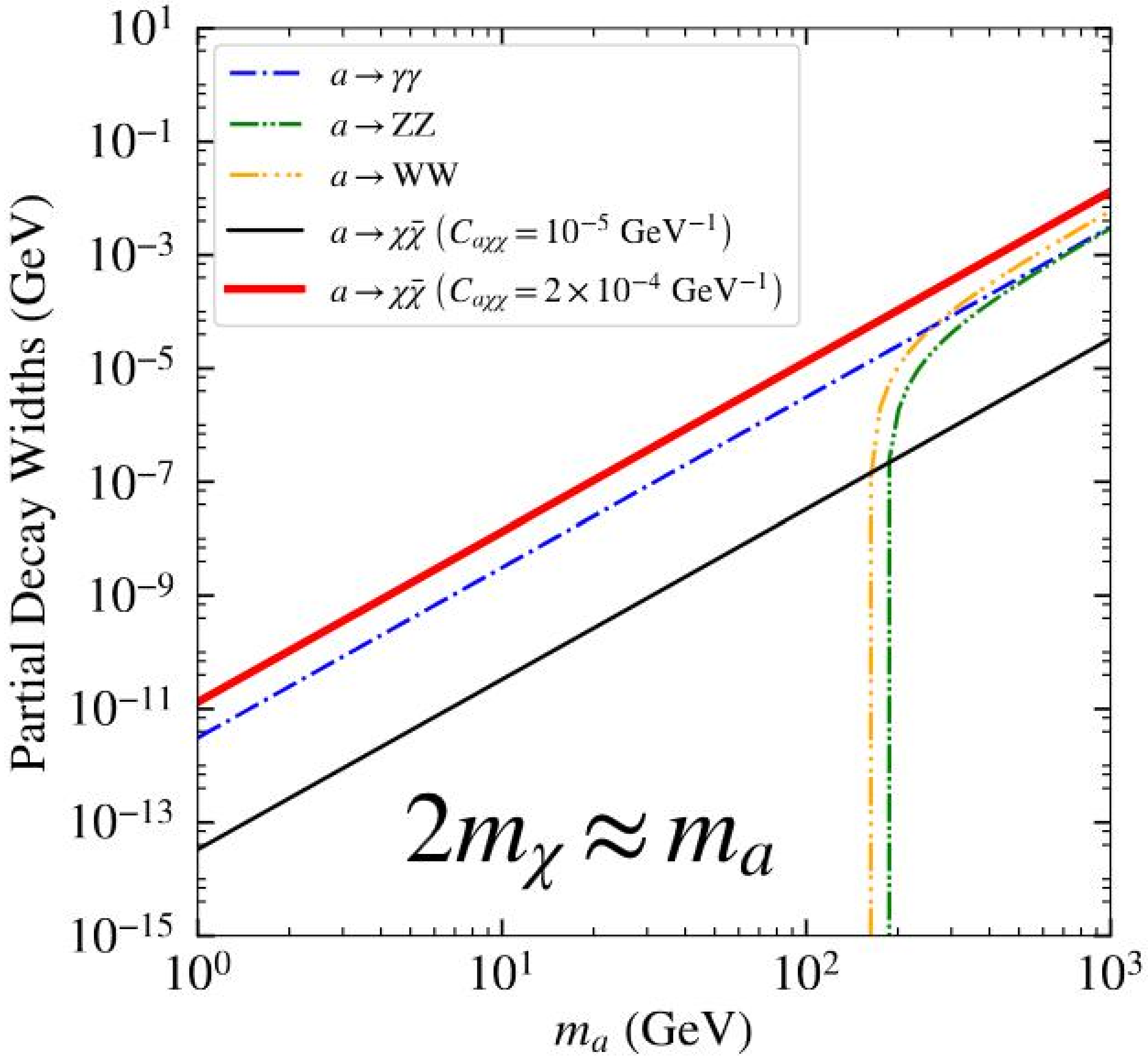
$$\mathcal{L} = \quad -\frac{1}{2}\partial_\mu a \partial^\mu a - \bar{\chi}(i\partial\!\!\!/ - m_\chi)\chi + \frac{1}{2}m_a^2 a^2 - C_{a\chi\chi} m_\chi a \bar{\chi} i\gamma_5 \chi$$
$$-\frac{C_{a\gamma\gamma}}{4} aF_{\mu\nu}\tilde{F}^{\mu\nu} - \frac{C_{aZZ}}{4} aZ_{\mu\nu}\tilde{Z}^{\mu\nu} - \frac{C_{a\gamma Z}}{2} aF_{\mu\nu}\tilde{Z}^{\mu\nu} - \frac{C_{aWW}}{2} aW^+_{\mu\nu}\tilde{W}^{-\mu\nu}.$$

$$C_{a\gamma\gamma} = C_{BB}\cos^2\theta_{\rm W} + C_{WW}\sin^2\theta_{\rm W},$$
$$C_{aZZ} = C_{BB}\sin^2\theta_{\rm W} + C_{WW}\cos^2\theta_{\rm W},$$
$$C_{a\gamma Z} = (C_{WW} - C_{BB})\sin\theta_{\rm W}\cos\theta_{\rm W},$$
$$C_{aWW} = C_{WW}.$$

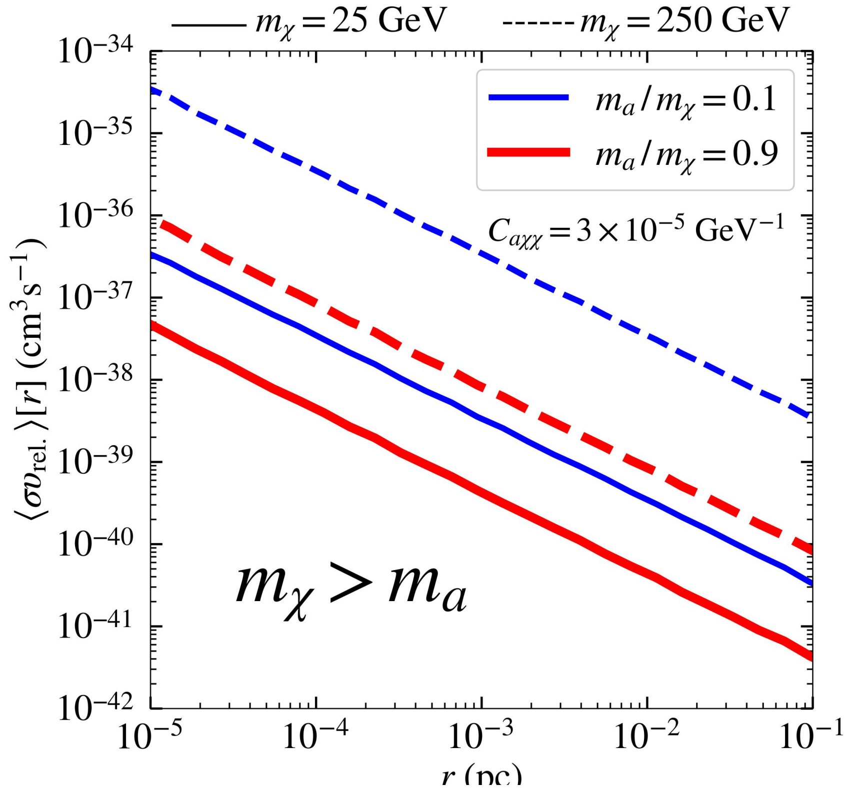
Toy model for simple parametrization.

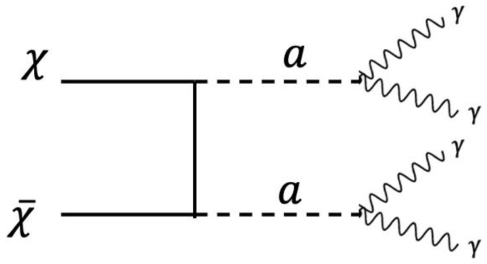


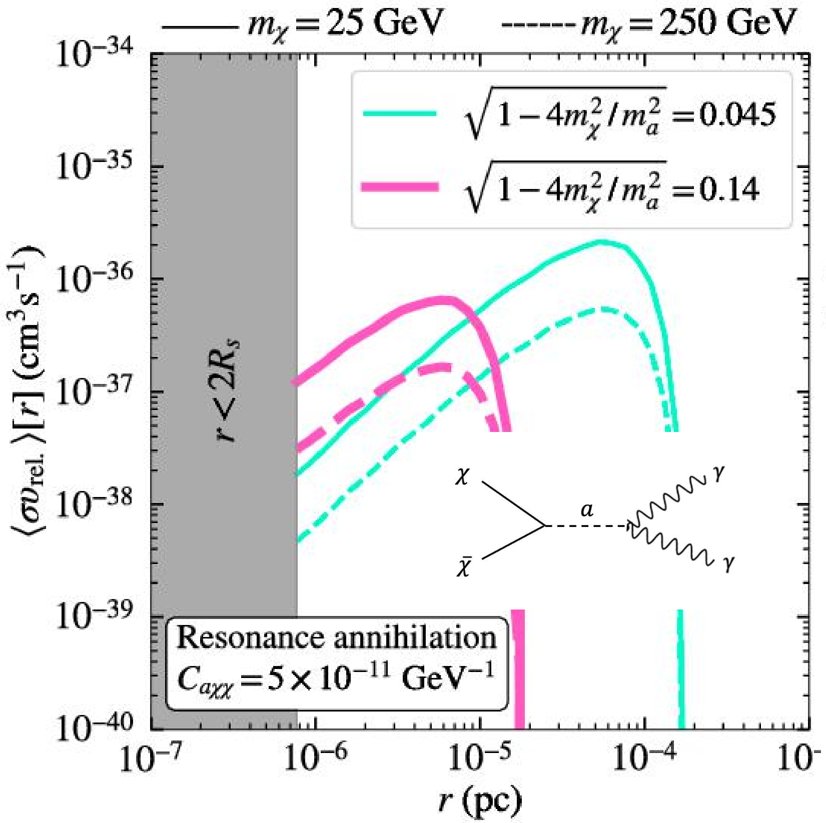



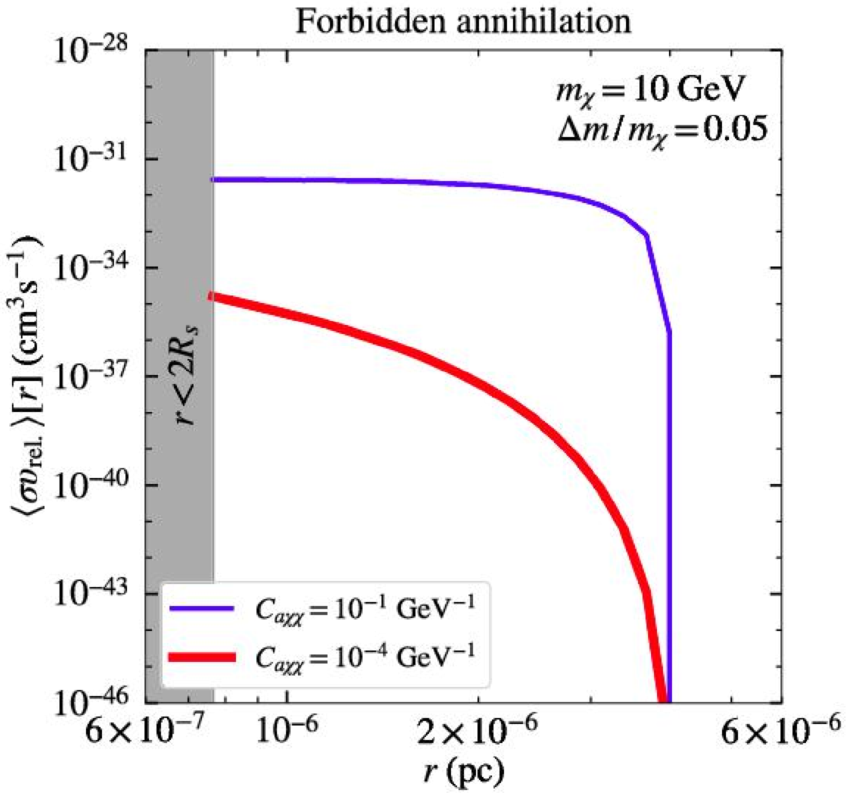



# What will happen if DM annihilation near Sgr A*? (1) Annihilation cross-sections



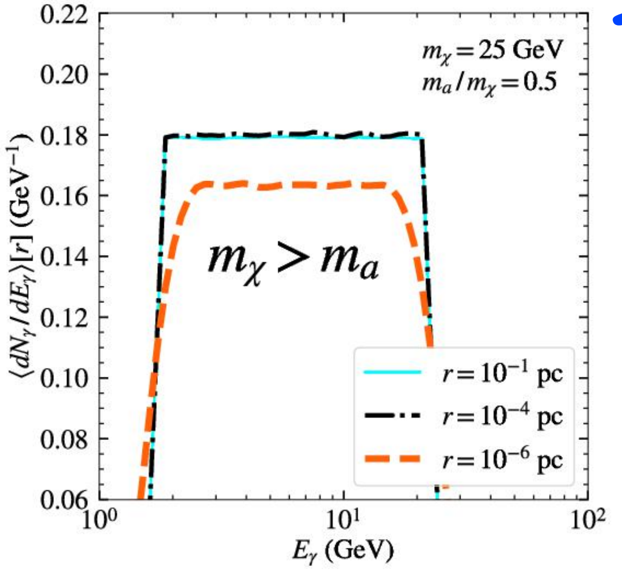



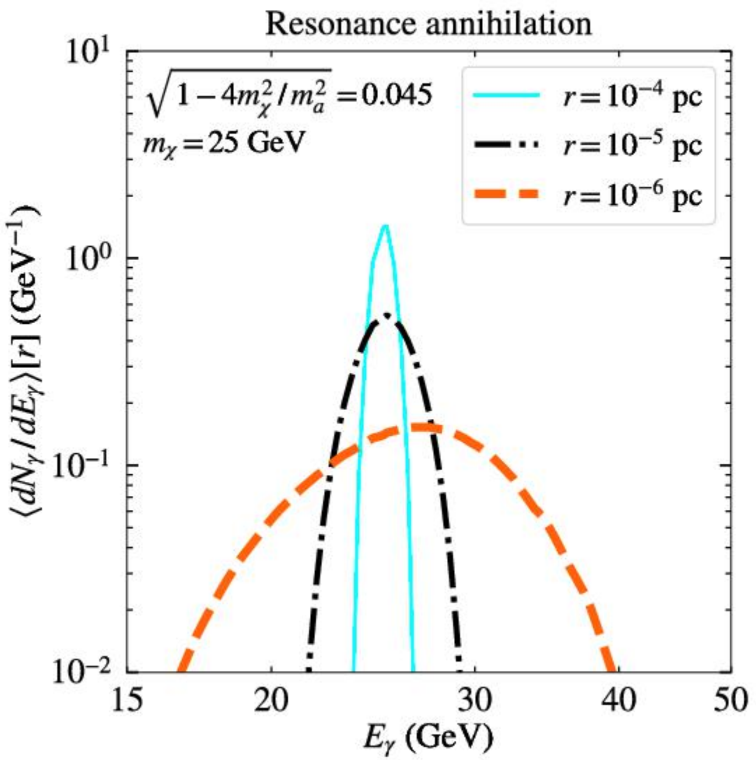



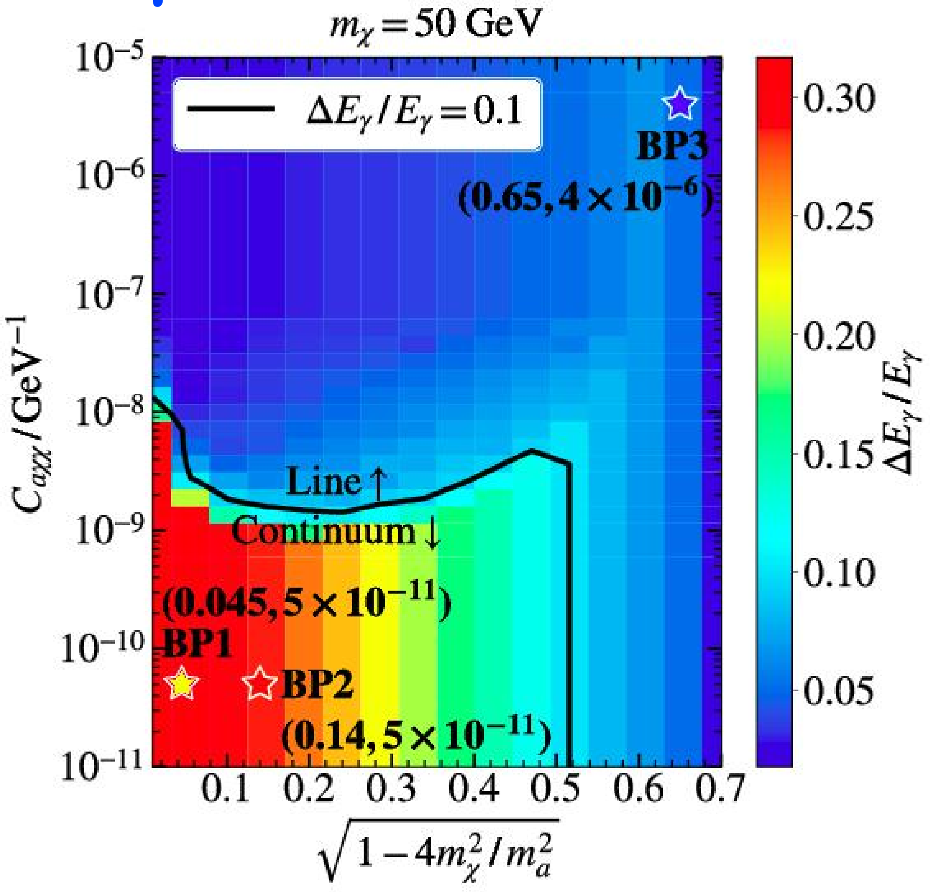



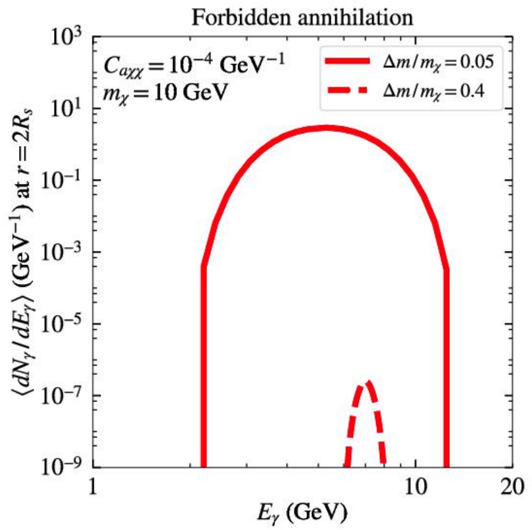

Detecable annihilation signals ONLY appear near Sgr A*.

# What will happen if DM annihilation near Sgr A*? (2) photon spectra



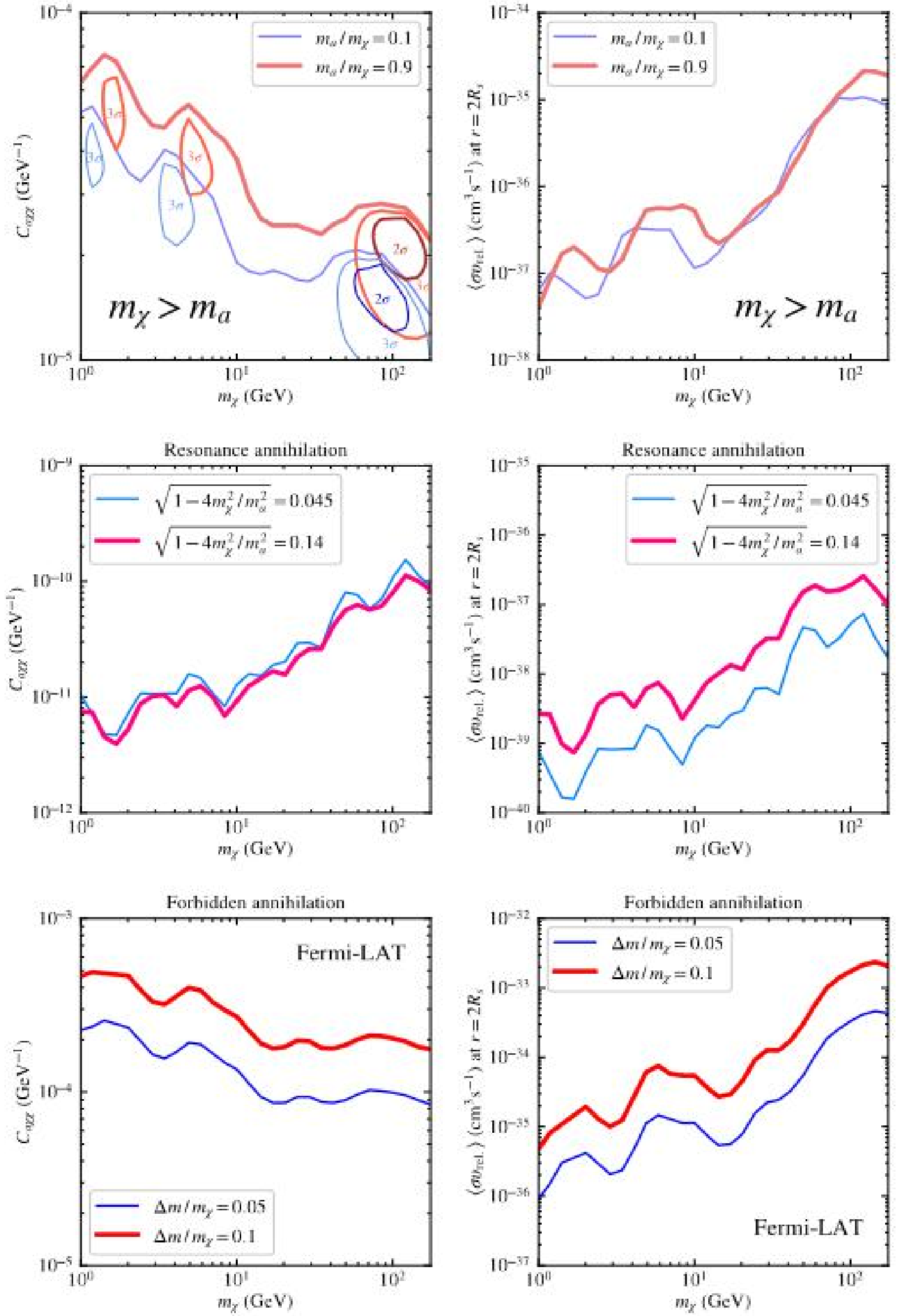



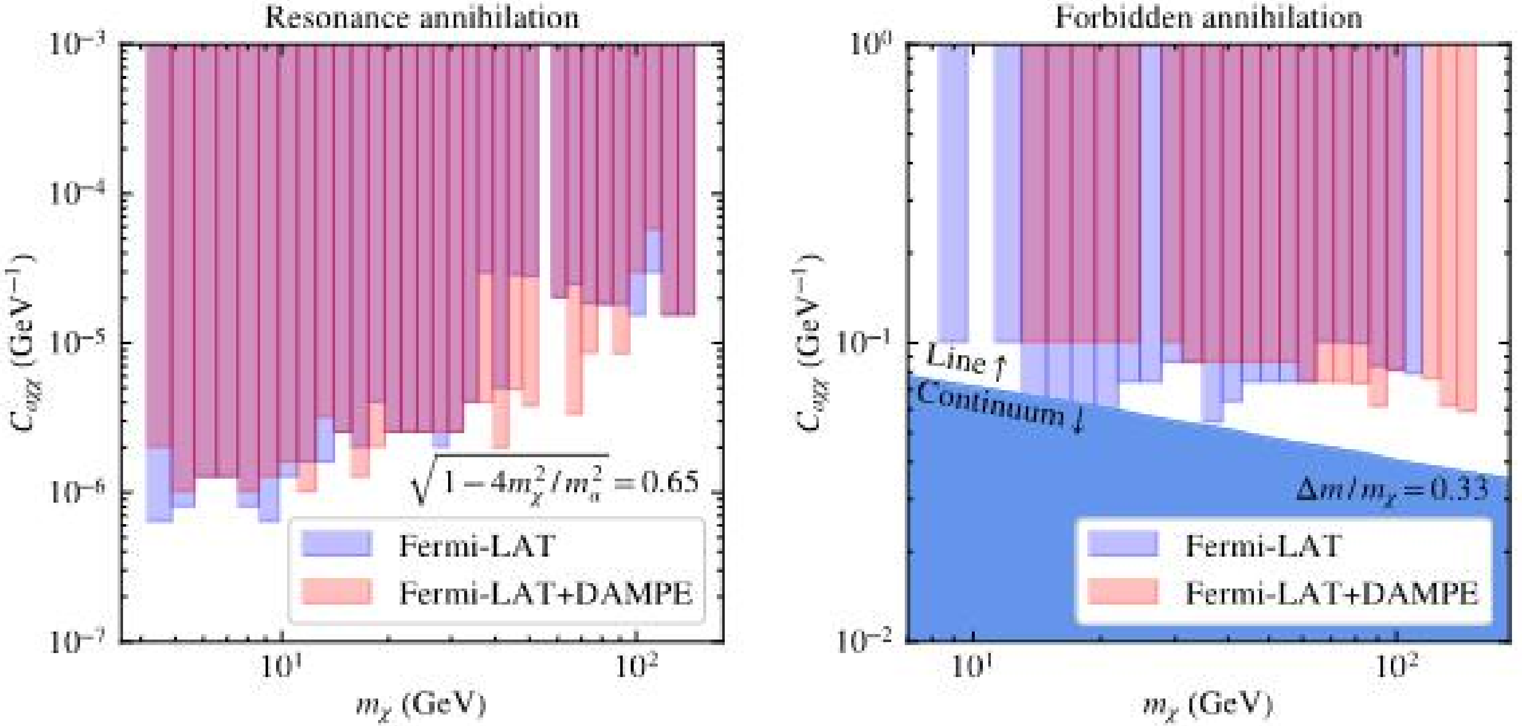




Searching spectral shape?

# Consstraints from Fermi and DAMPE




This is the only region for searching velocity-suppressed annihilation.

# Summary

- We know nothing but gravity about dark matter.
- It is nature to expolre dark matter interaction strength as long as it is matter.
- We need to find an anomally beyond what we expected (LCDM, the SM, and GR)
- We propose a spectrum shape analysis for searching three types of suppressed-annihilating DM.

这篇文章是关于暗物质的探索和理论的讨论，标题为《如果我们永远找不到暗物质怎么办？》，由Tracy R. Slatyer和Tim M. P. Tait撰写，发表在2024年9月的《科学美国人》杂志上。文章探讨了暗物质的性质、它在宇宙中的作用，以及科学家们如何尝试探测它。以下是文章的主要内容总结(By Kimi)：

1. 暗物质的探测挑战：尽管科学家们几十年来一直在尝试探测暗物质，但至今未能成功。这促使一些科学家思考是否我们寻找的方式或地点有误。

2. 暗物质的候选者：文章讨论了几种可能的暗物质候选者，包括弱相互作用大质量粒子（WIMPs）和量子色动力学（QCD）的轴子。这些理论塑造了科学家对暗物质的理解，并启发了许多实验。

3. 暗物质的理论范围：科学家们正在探索更广泛的可能解释，
包括暗物质可能与已知粒子不通过电磁力以外的任何机制相互作用，或者可能完全忽略常规物质。

4.  暗物质的探索策略：文章提到了科学家们采取的平衡策略，
即深入研究最受欢迎的暗物质理论，同时也广泛探索尽可能多的可能性。


5. 未来的探索：科学家们计划在未来几年内通过更精确的观测和实验技术来更深入地理解暗物质。这可能包括使用新的量子传感器技术。

6. 暗物质的未知性：文章最后指出，尽管科学家们对找到暗物质持乐观态度，但也有可能我们永远无法完全理解暗物质的真正本质。即使如此，未能找到暗物质也将是科学进步的一部分，因为它教会我们在哪里寻找是错误的。

Thank you for listening!