IMPACT OF FERMI ON THE SEARCH FOR PARTICLE DARK MATTER

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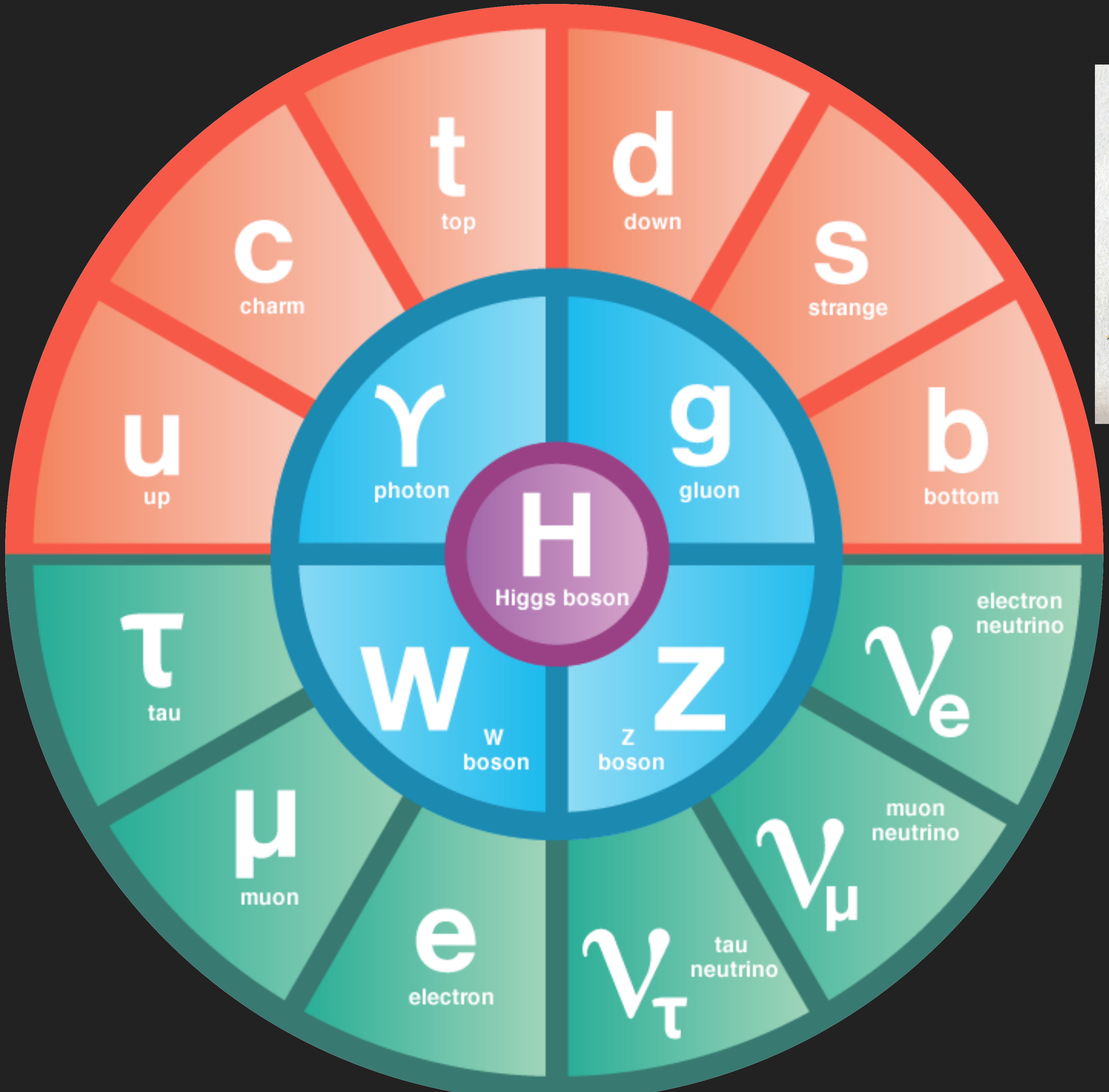
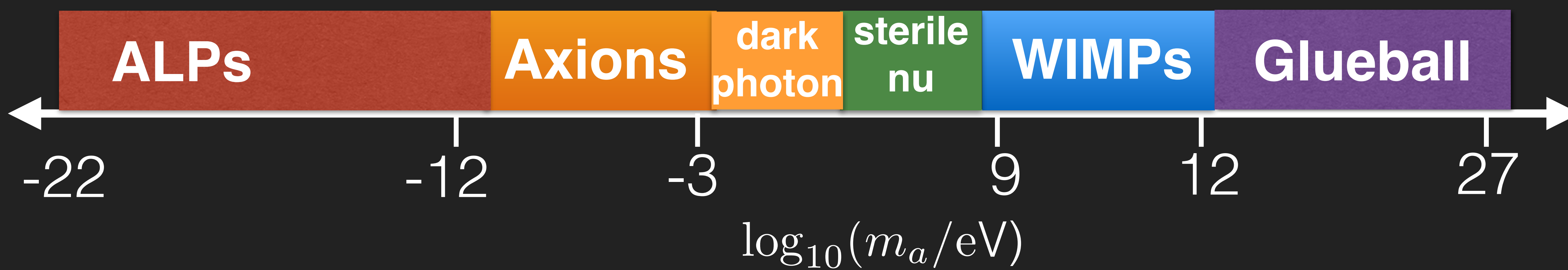
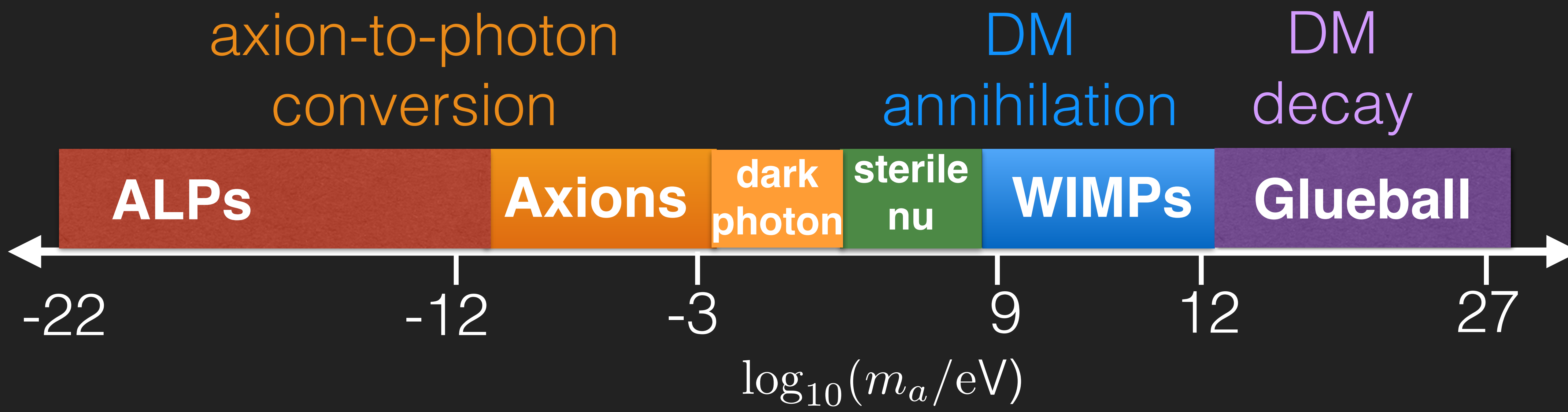
CONGRATULATIONS TO THE FERMI TEAM!

What is the miscroscopic nature of dark matter??



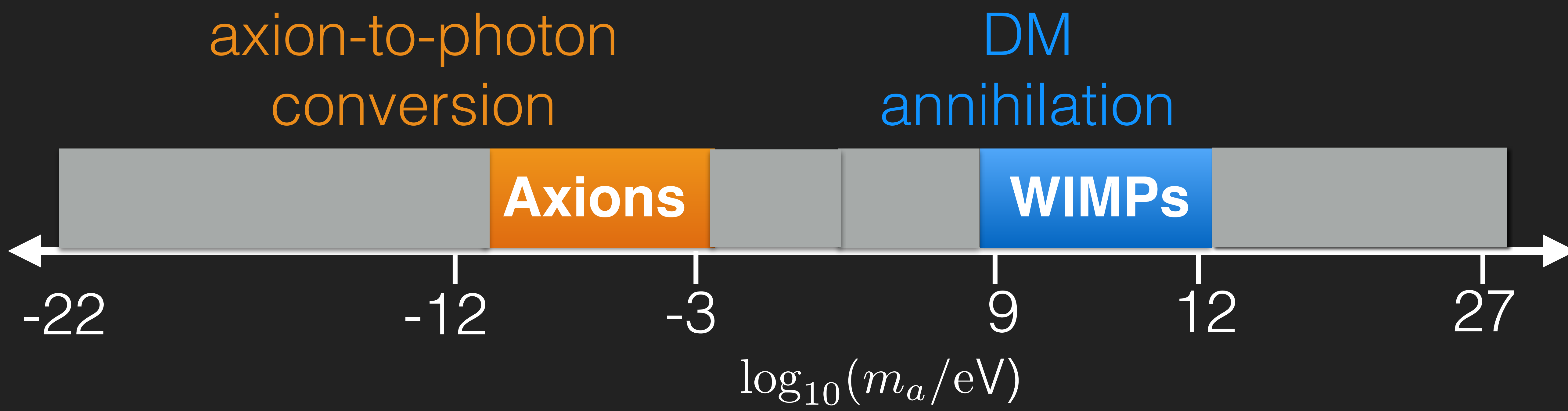
DM??


ALPs
Axions
dark photon
sterile nu
WIMPs
Glueball
-22
-12
-3
9
12
27
$\log_{10}(m_a/\text{eV})$

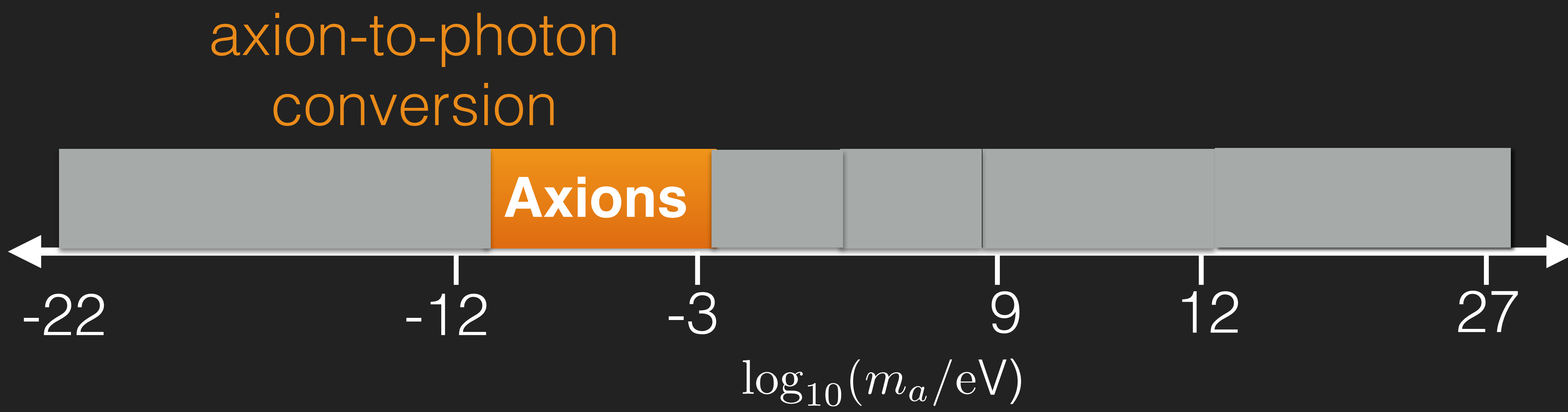


Many of these models could be first discovered in gamma-rays!

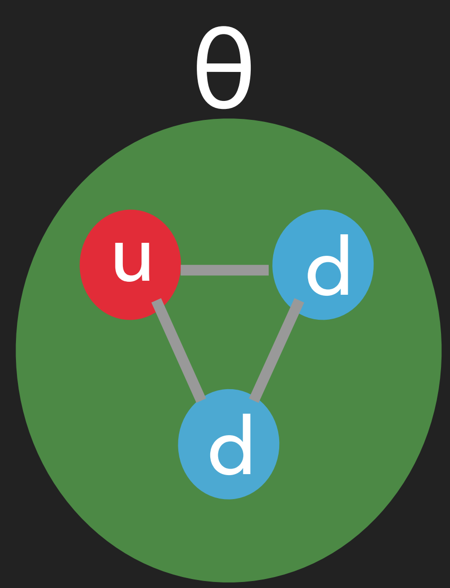
Best-motivated particle dark matter scenarios in my opinion



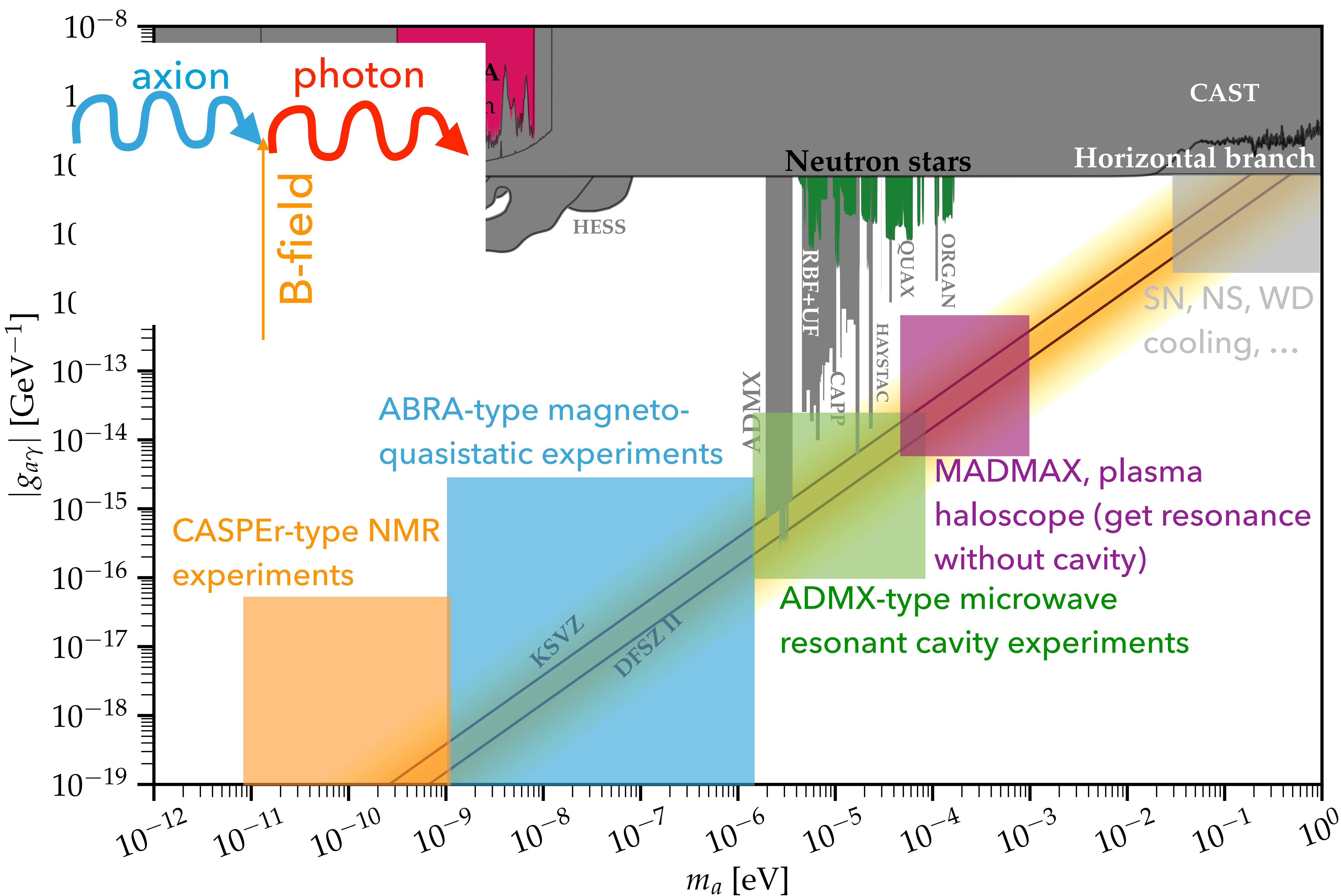
This talk: WIMPs, but start with few words axions



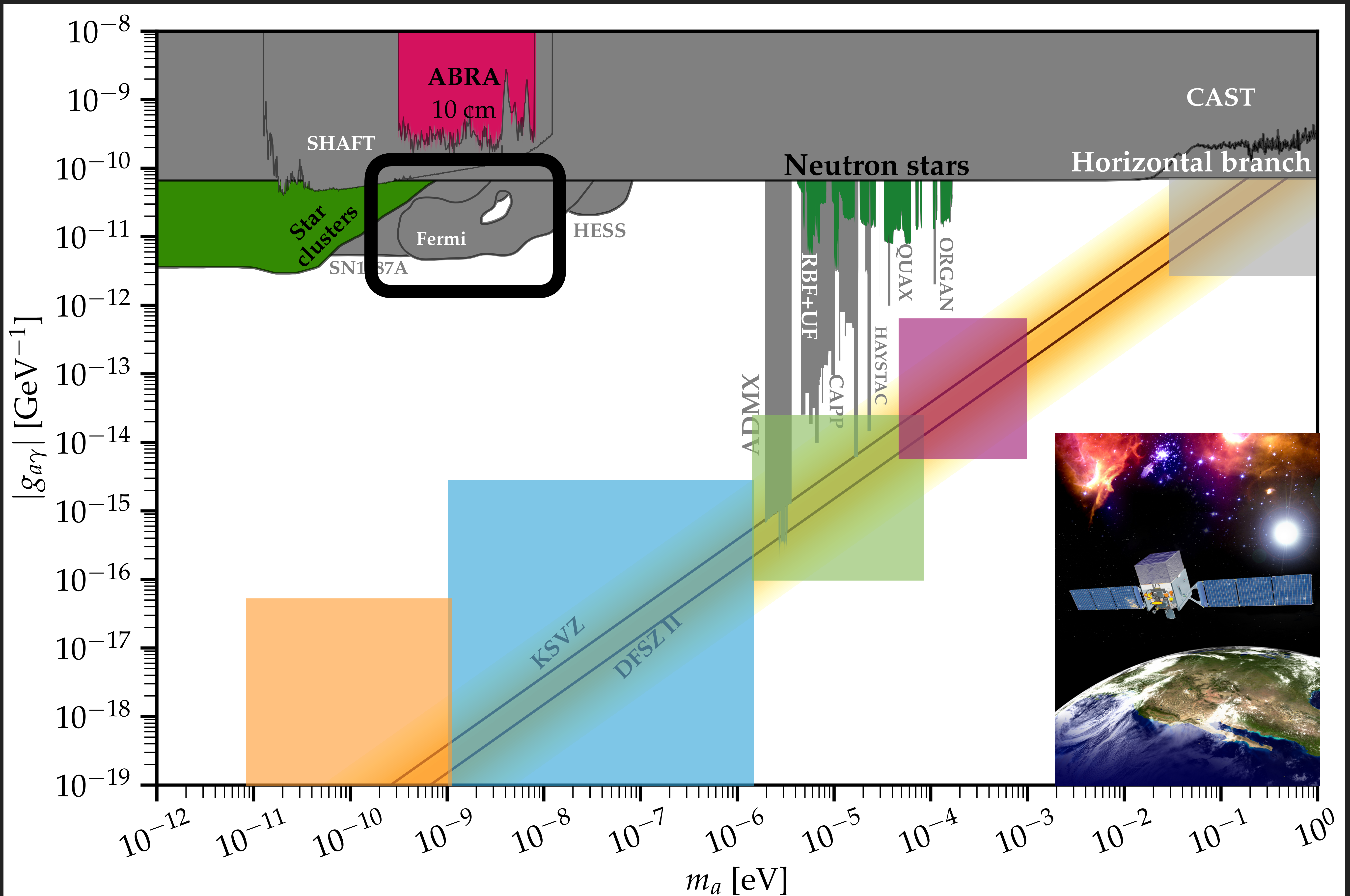
Axions introduced to solve strong-CP, also can be dark matter



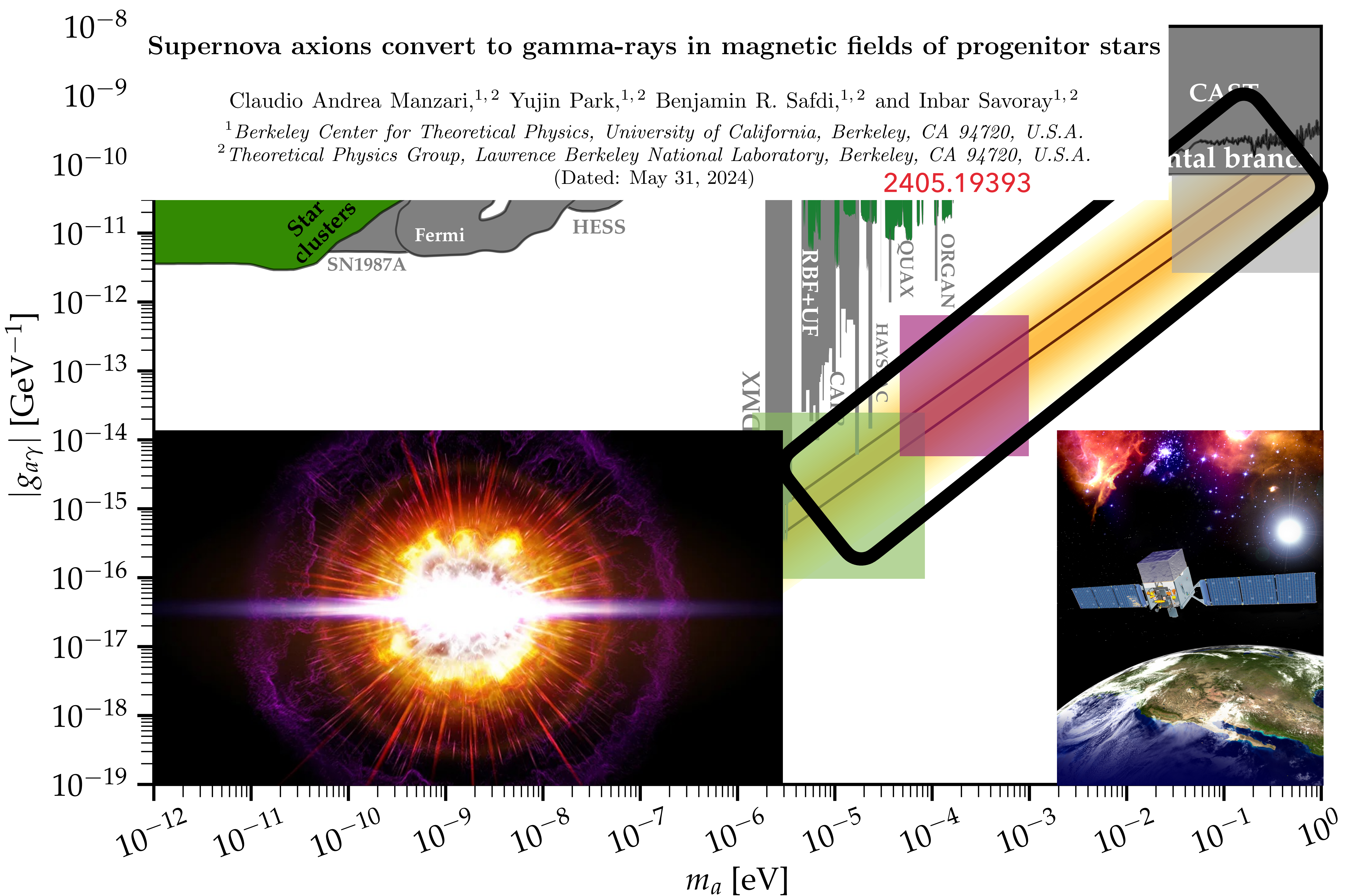
Axion Parameter Space to be Covered in Coming Years



Fermi has played a role in generalized ALP space

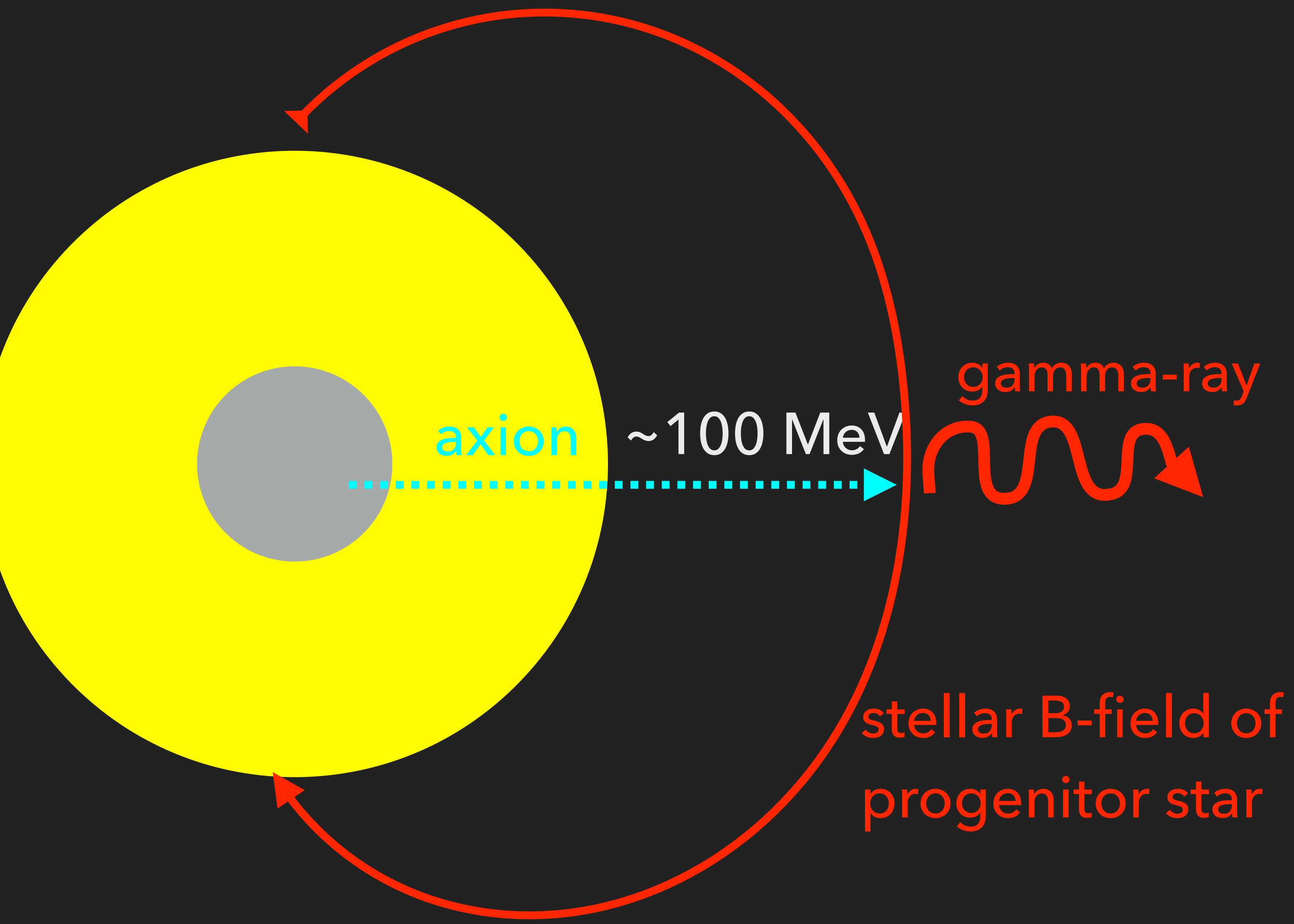


Fermi could detect QCD axions with Galactic supernova



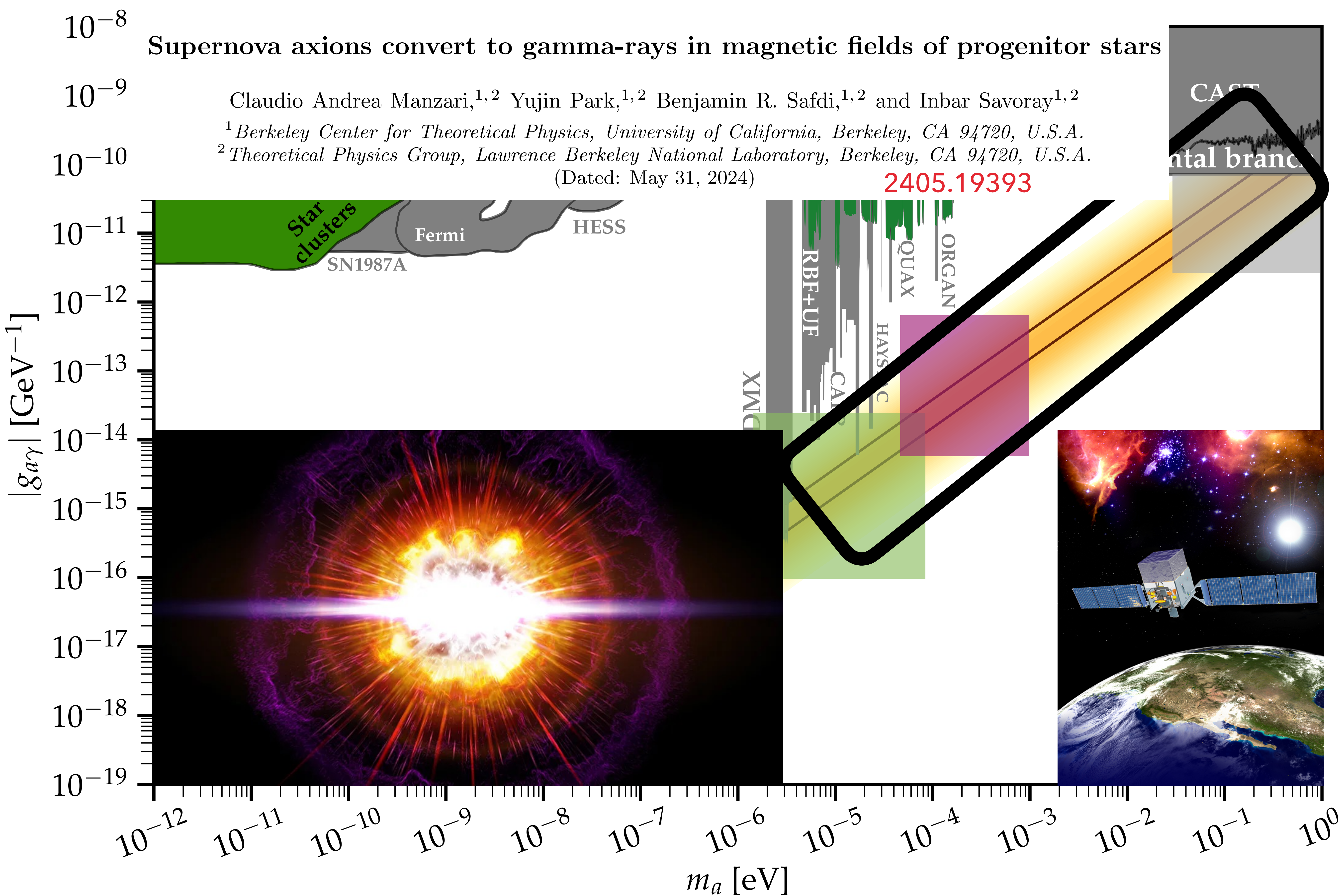
Convert proto-NS axions to gamma-rays on stellar field

~10 s gamma-ray burst in ~100 - 500 MeV coincident neutrinos



gamma-ray
telescope

Fermi could detect QCD axions with Galactic supernova



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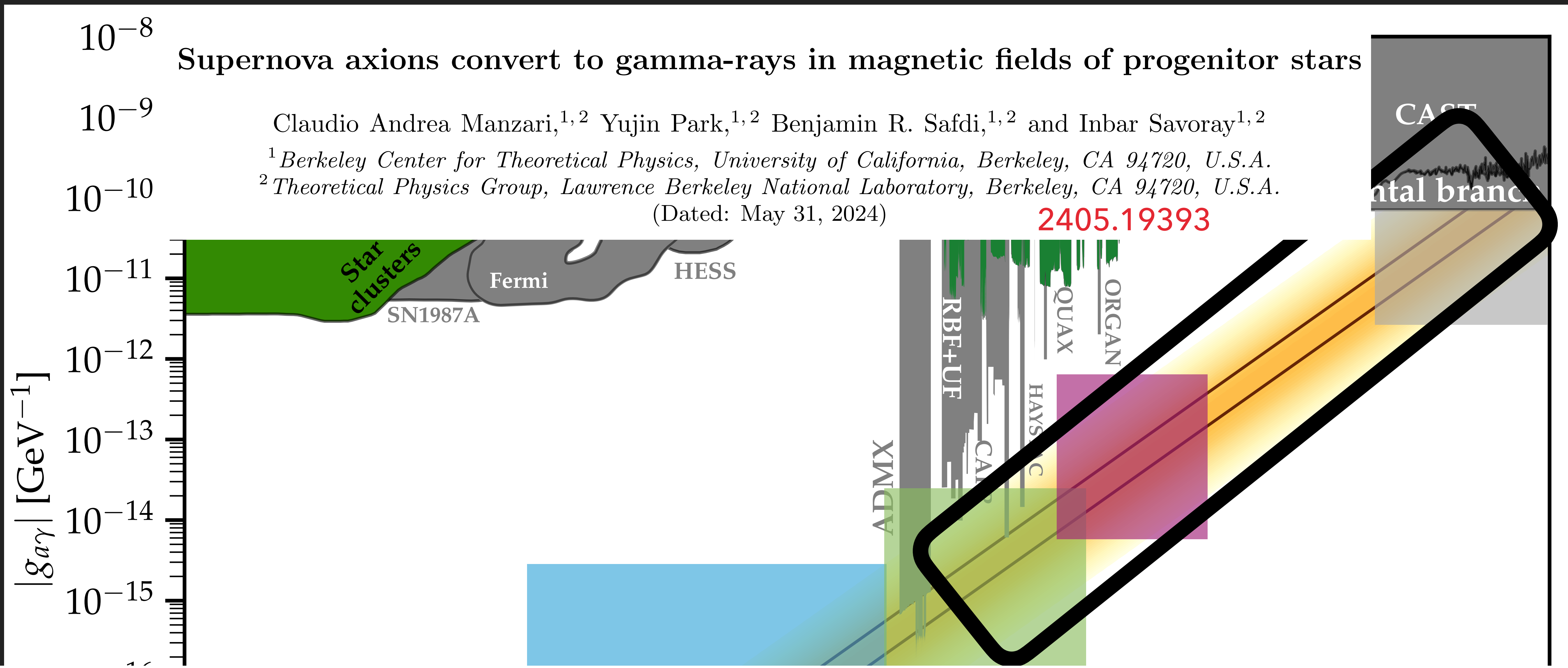
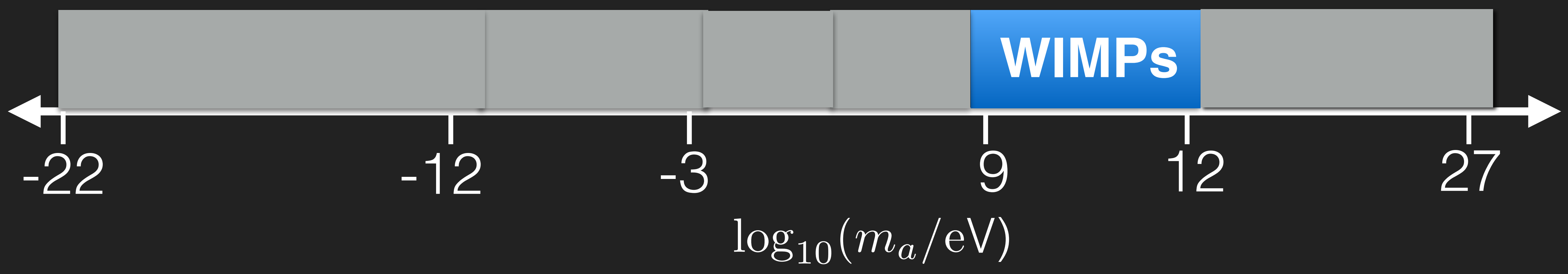
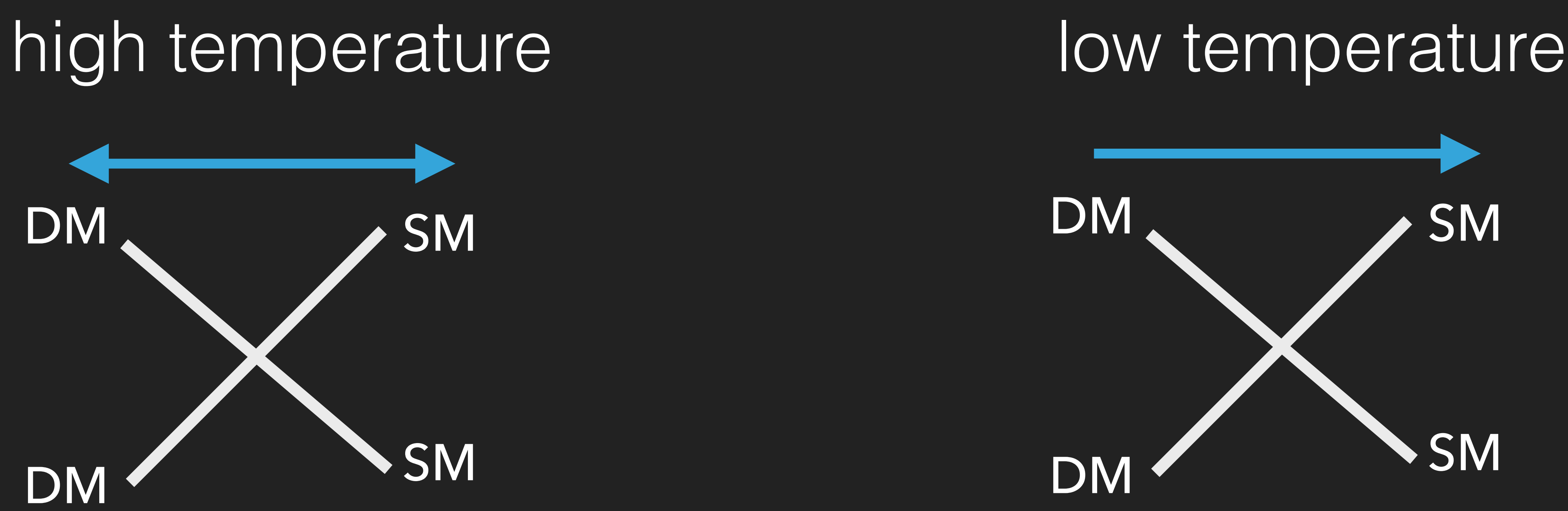
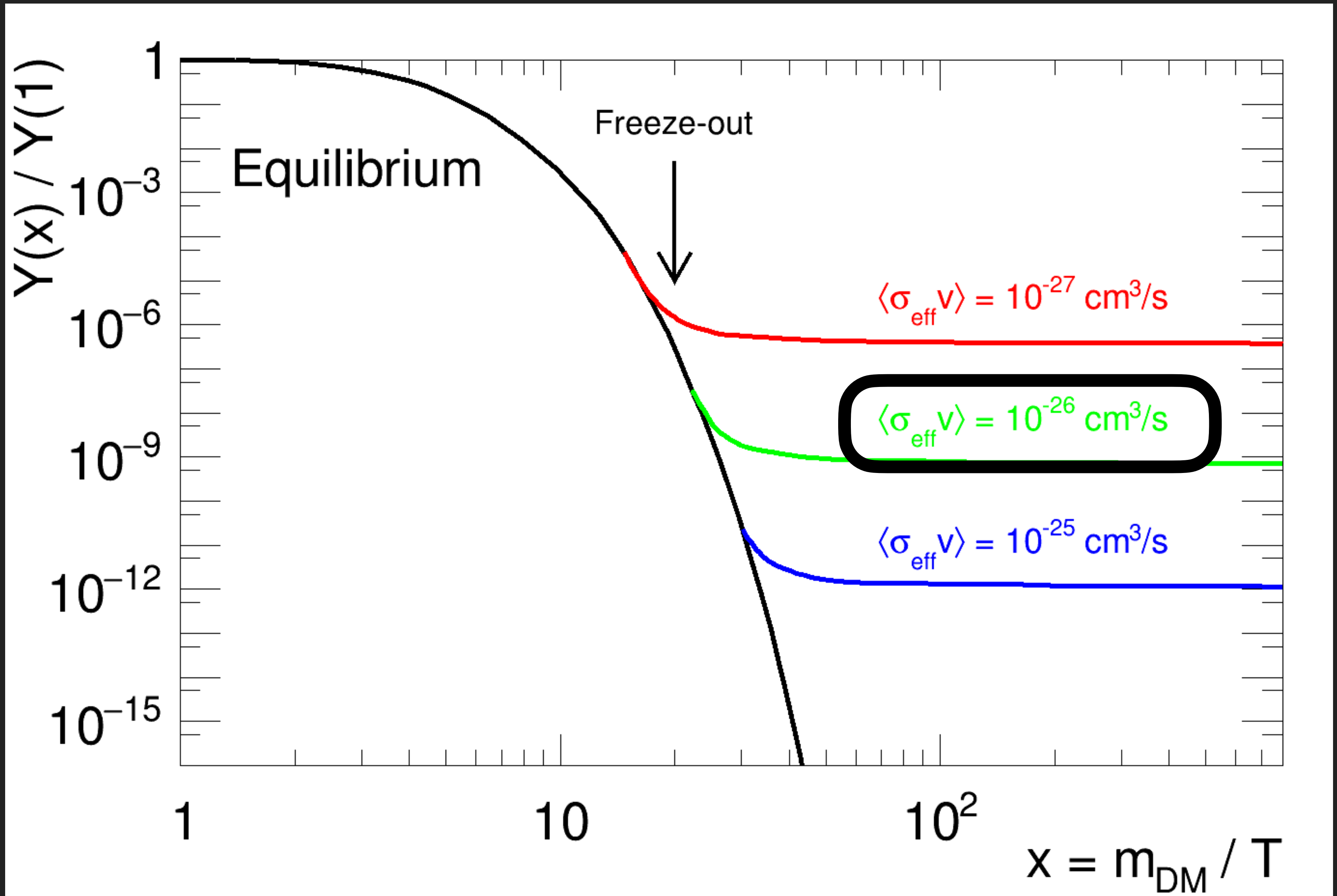


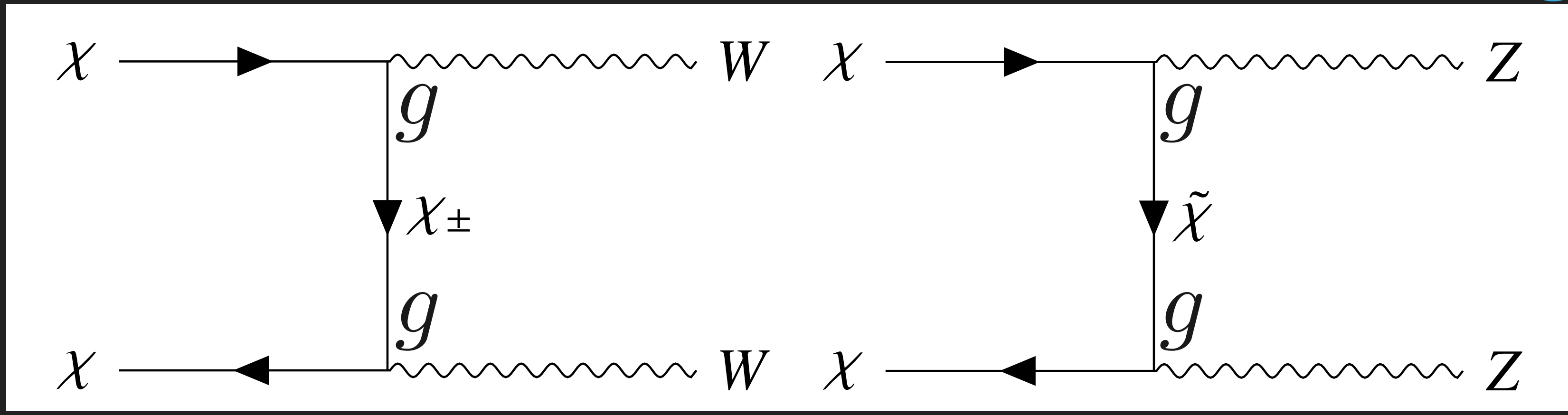

WIMPs
-22
-12
-3
9
12
27
$\log_{10}(m_a/\mathrm{eV})$

Recall the thermal (WIMP) DM Paradigm

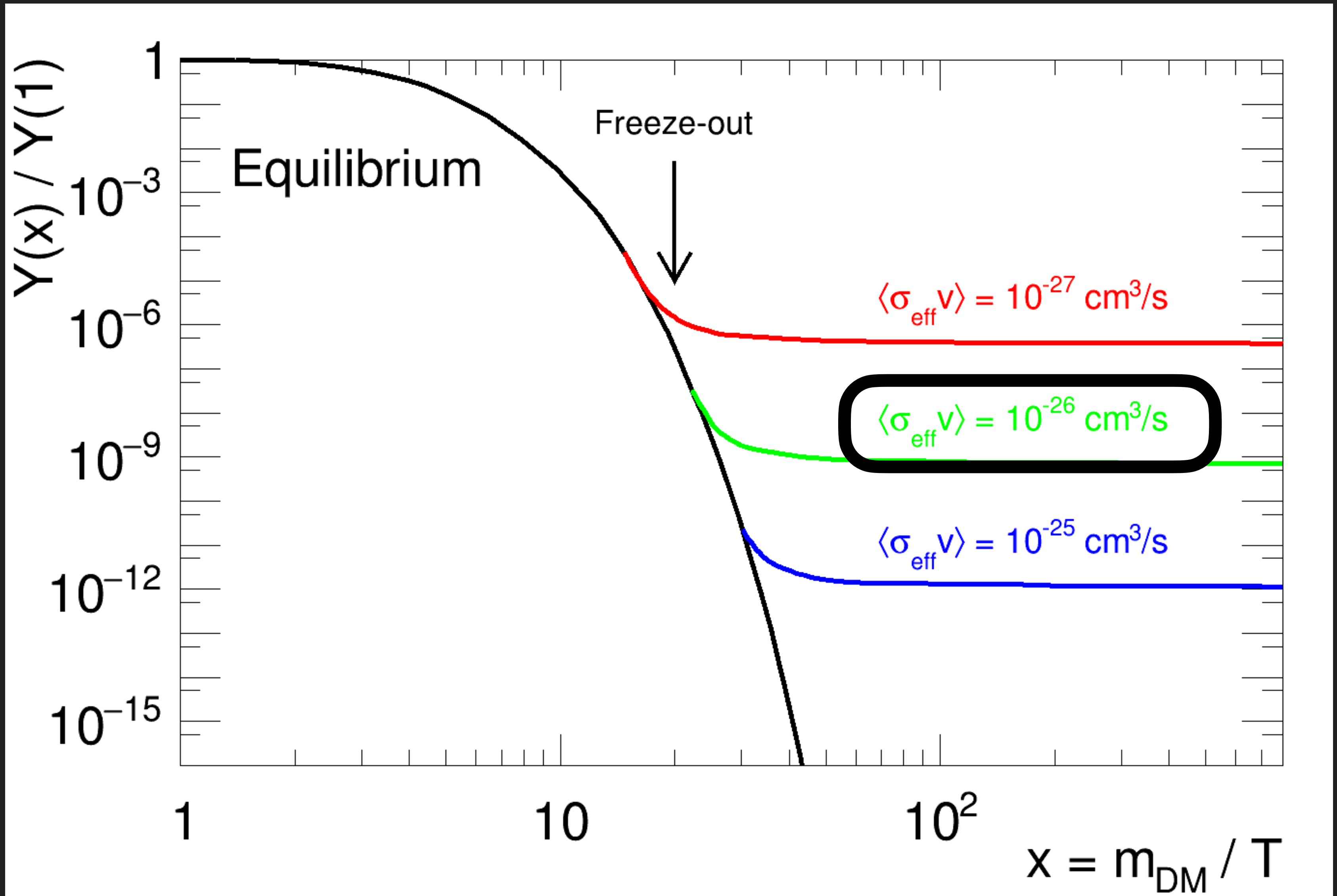




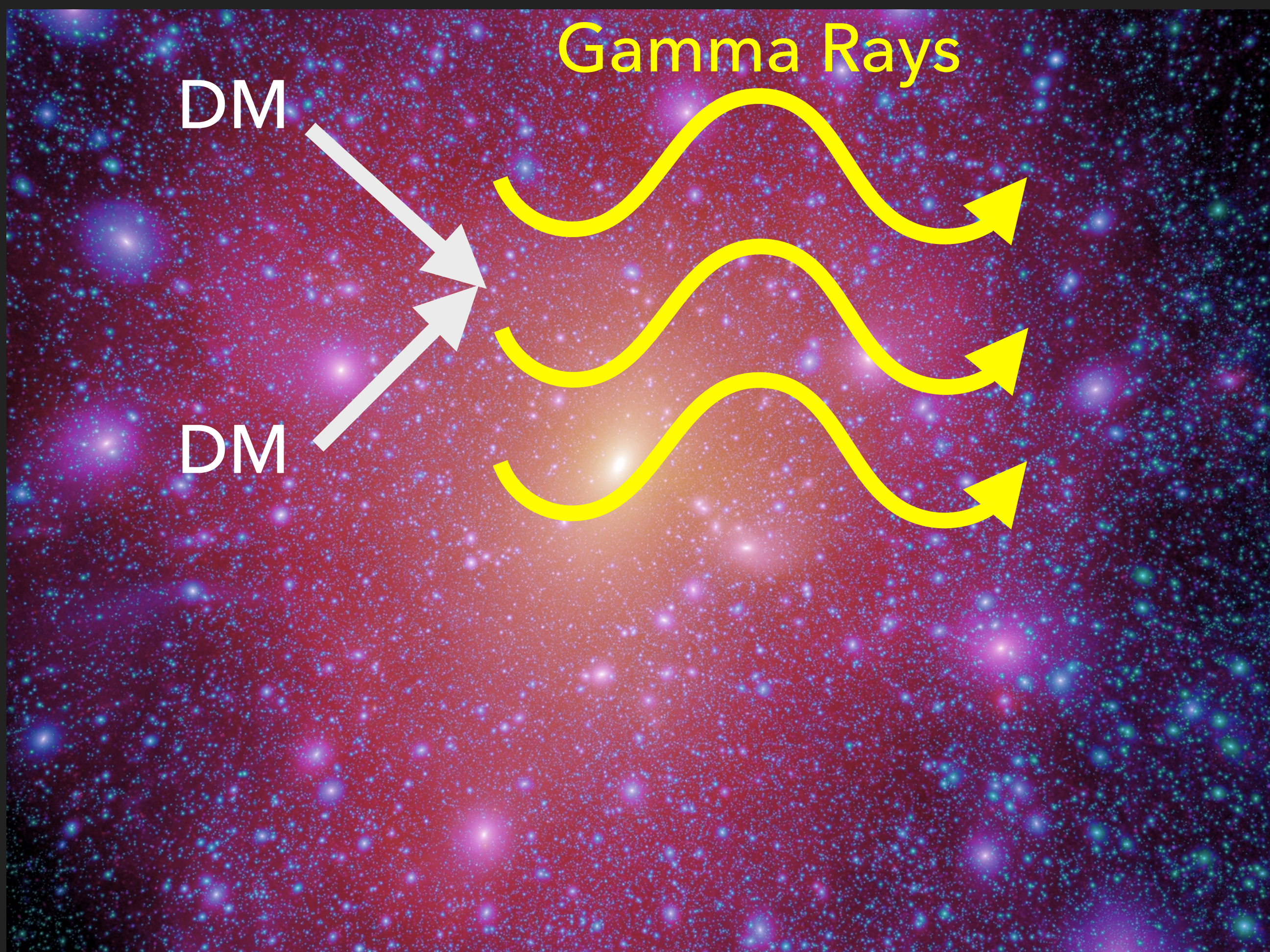
Recall the thermal (WIMP) DM Paradigm



$$\sigma v \sim \frac{g^4}{4\pi\, m_\chi^2} \sim \text{few} \times 10^{-26}\ \frac{\text{cm}^3}{\text{s}} \left(\frac{g}{0.5}\right)^4 \left(\frac{1\ \text{TeV}}{m_\chi}\right)^2$$

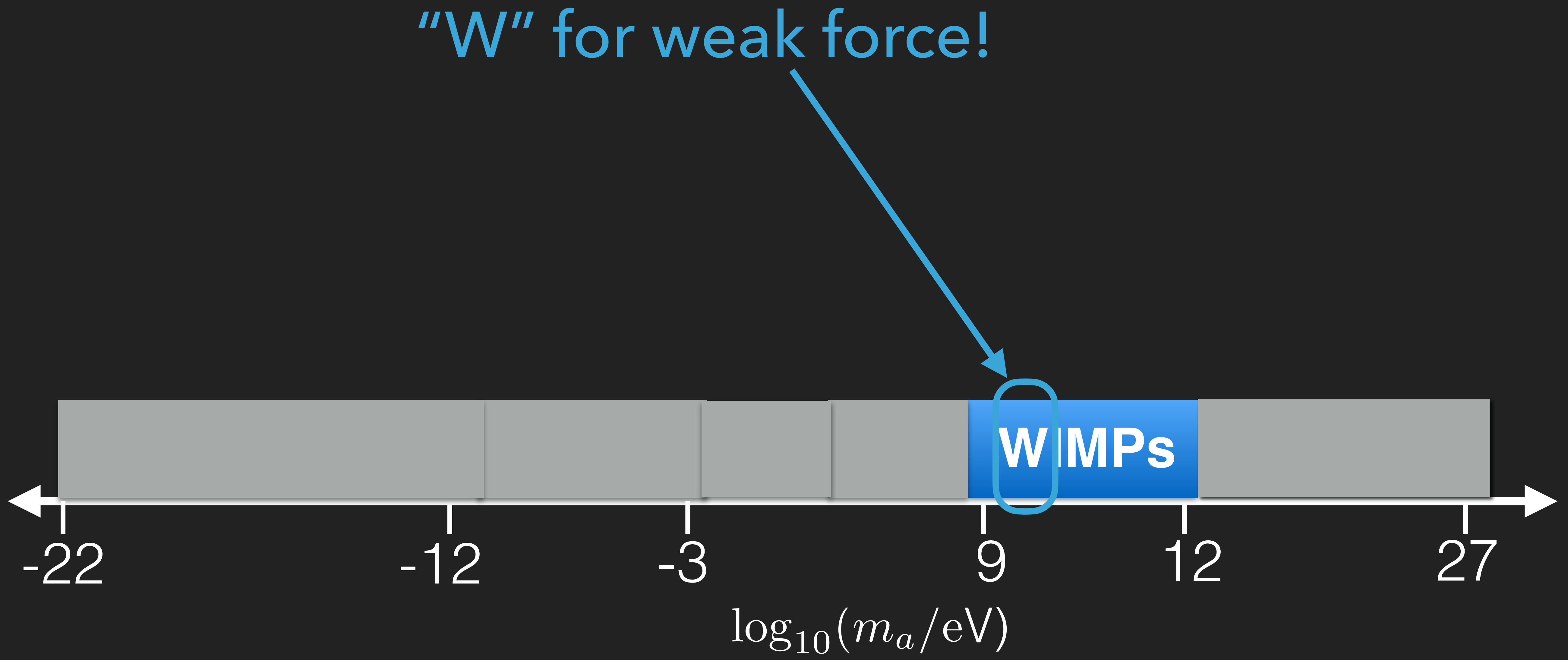


WIMP Indirect Detection: DM annihilation still happens today



WIMP DM annihilates to unstable particles, decaying to gamma-rays

Search for gamma-rays towards DM-dense regions (GC and dwarfs)


"W" for weak force!
WIMPs
-22
-12
-3
9
12
27
$\log_{10}(m_a/\mathrm{eV})$

WIMP DM in Purest Form: Minimal Dark Matter

1. Put DM in electroweak multiplet with neutral component

2. After EW symmetry breaking, charged components become heavier –> lightest compenent is DM

Quantum numbers			DM can	DM mass	$m_{DM^\pm} - m_{DM}$	Events at LHC	σ_{SI} in
$SU(2)_L$	$U(1)_Y$	Spin	decay into	in TeV	in MeV	$\int \mathcal{L}\, dt = 100/\text{fb}$	$10^{-45}\,\text{cm}^2$
2	1/2	0	EL	0.54 ± 0.01	350	$320 \div 510$	0.2
2	1/2	1/2	EH	1.1 ± 0.03	341	$160 \div 330$	0.2
3	0	0	HH^*	2.0 ± 0.05	166	$0.2 \div 1.0$	1.3
3	0	1/2	LH	2.4 ± 0.06	166	$0.8 \div 4.0$	1.3

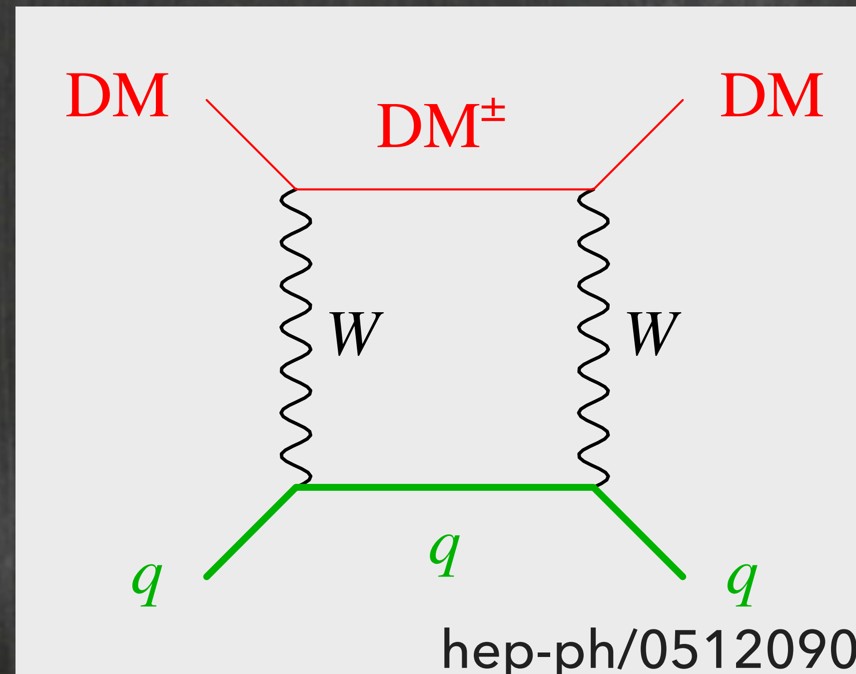
hep-ph/0512090

Higgsino

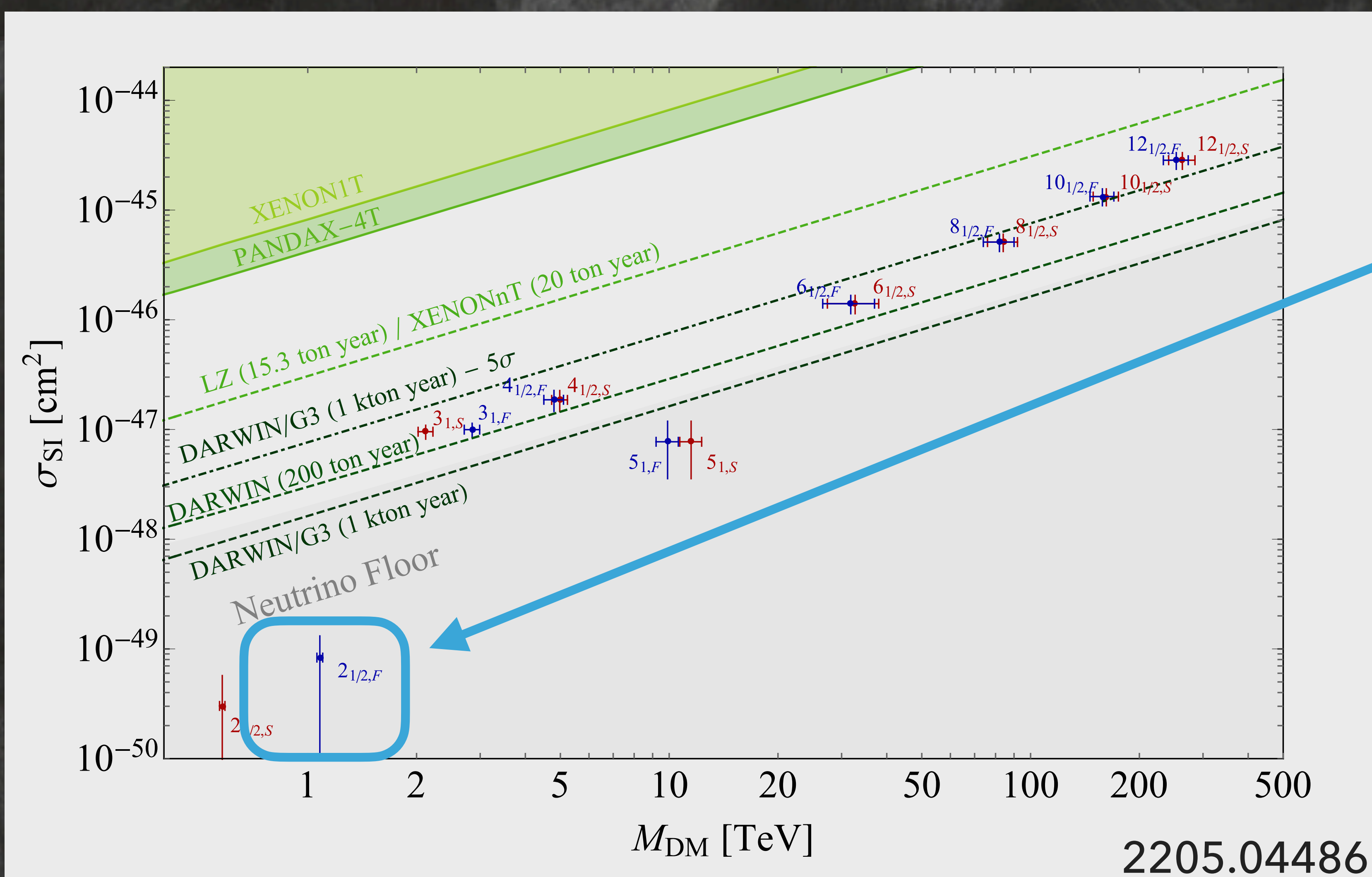
Wino

Mininal DM direct detection: hard but not impossible

No Z-exchange, scatter through loops and higher-dim operators

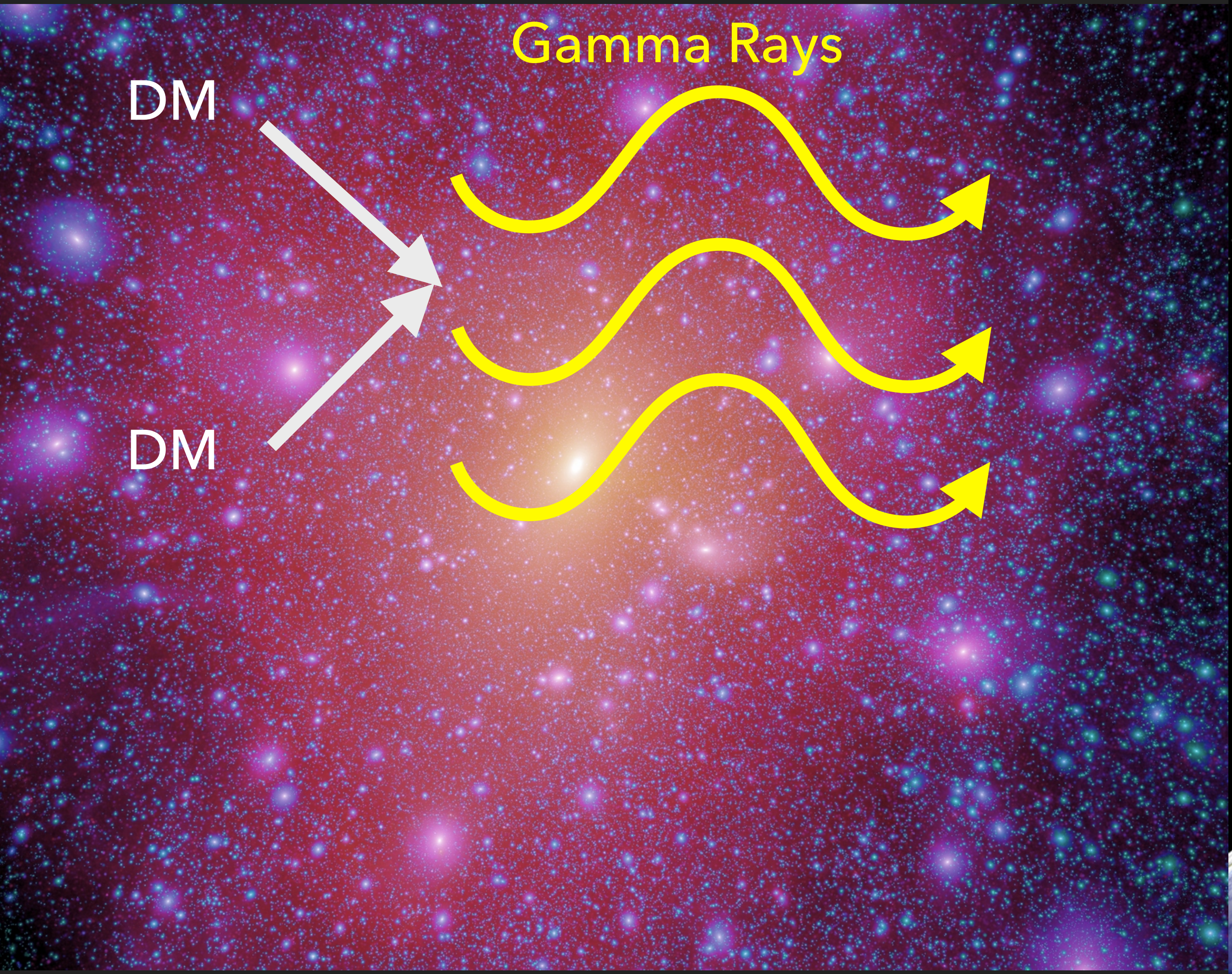


True WIMP DM (higgsino, wino, etc.) is very hard to detect with direct detection!



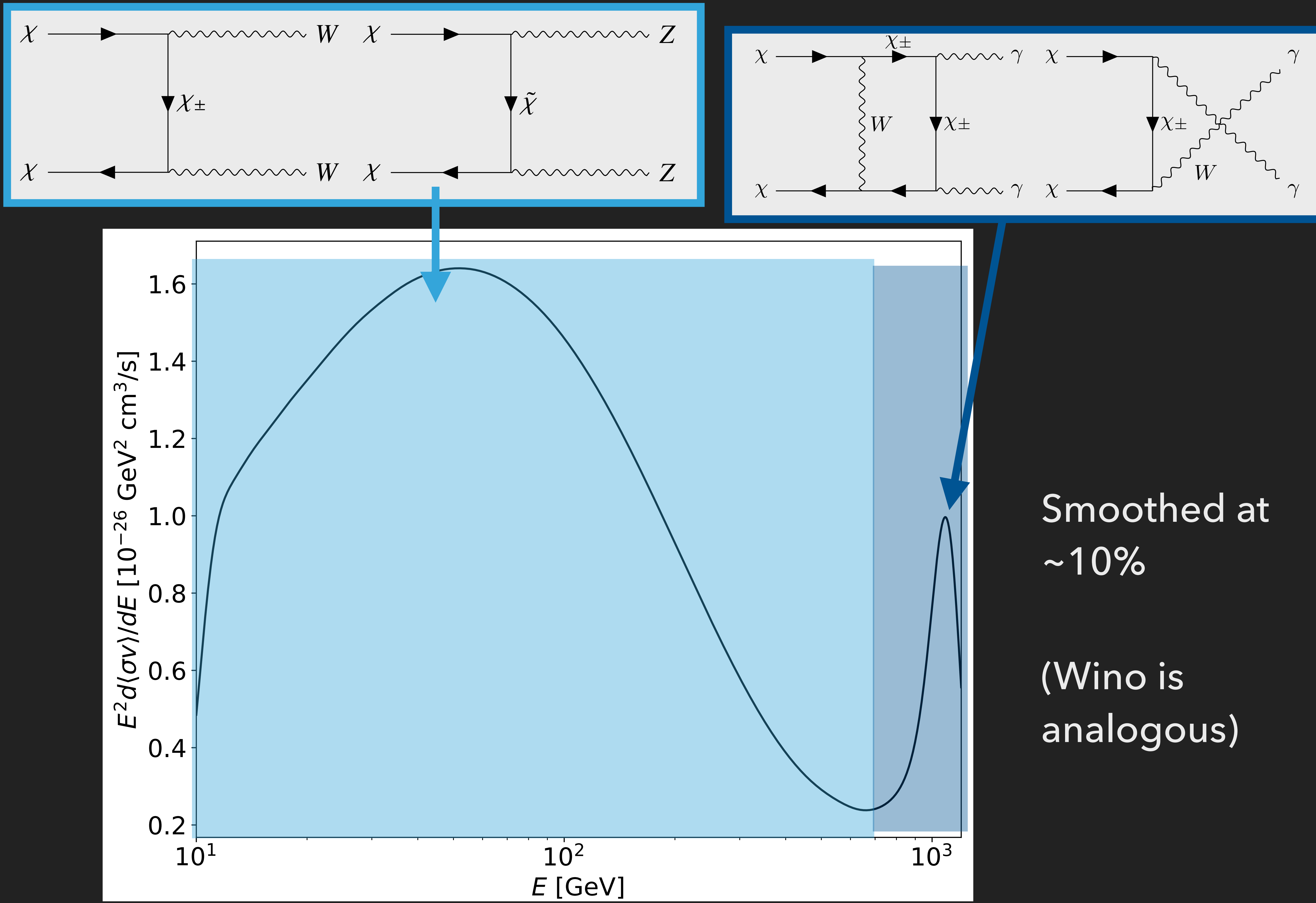
1. Below neutrino floor for minimal splittings

Indirect detection of WIMP dark matter



Fermi Gamma Ray Space Telescope

Higgsino gamma-ray annihilation spectrum today



Smoothed at ~10%

(Wino is analogous)

Fermi (and HESS) Excluded wino DM

Wino Dark Matter Under Siege

2013

Timothy Cohen,[1] Mariangela Lisanti,[2] Aaron Pierce,[3] and Tracy R. Slatyer[4,5]

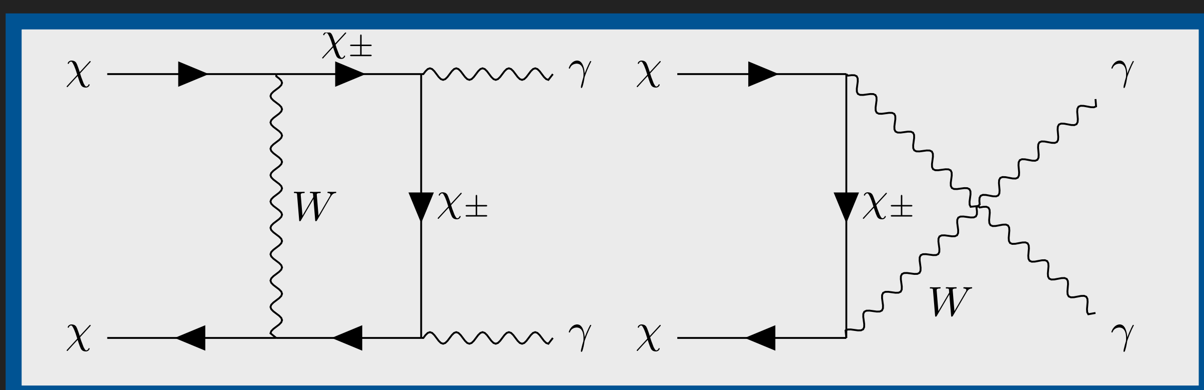
In Wino Veritas?

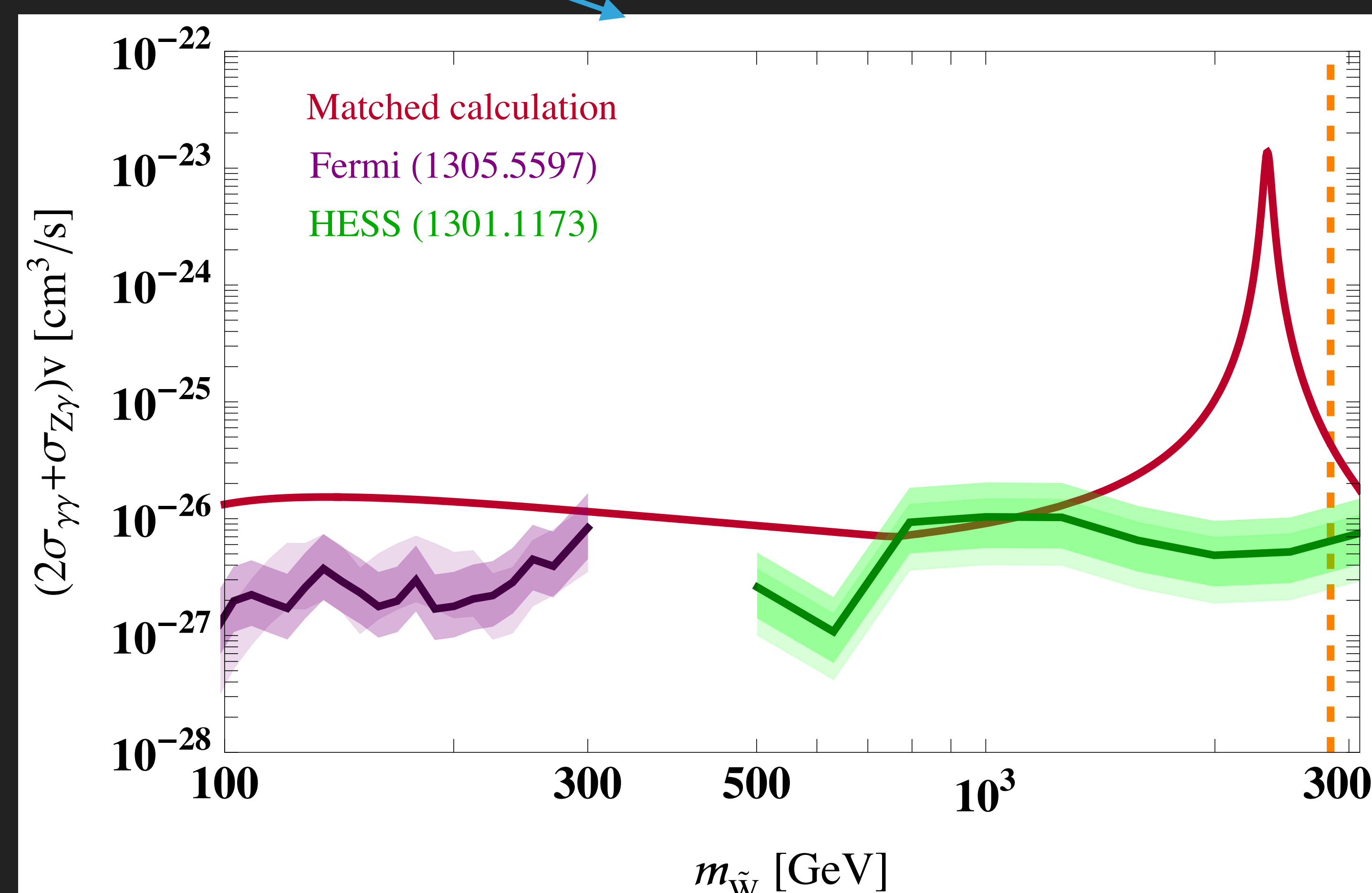
Indirect Searches Shed Light on Neutralino Dark Matter

2013

JiJi Fan and Matthew Reece

Department of Physics, Harvard University, Cambridge, MA 02138, USA





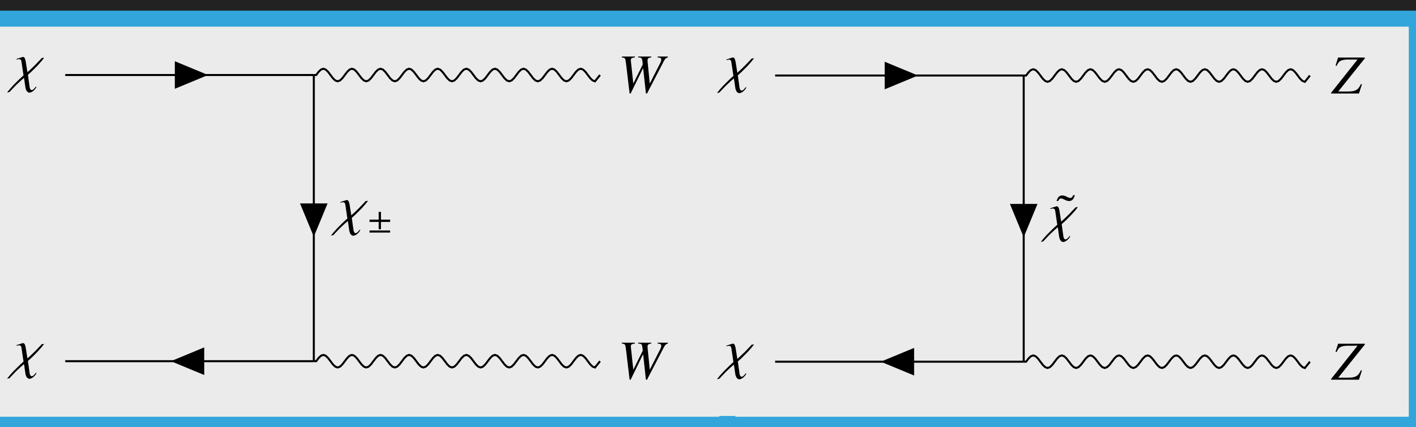
1. Used Ferni gamma-ray line search in the Inner Galaxy of Milky Way
2. Now well established for any reasonable DM profile, wino should have been discovered
3. Can exclude wino with Fermi alone using continuue (in progress!)

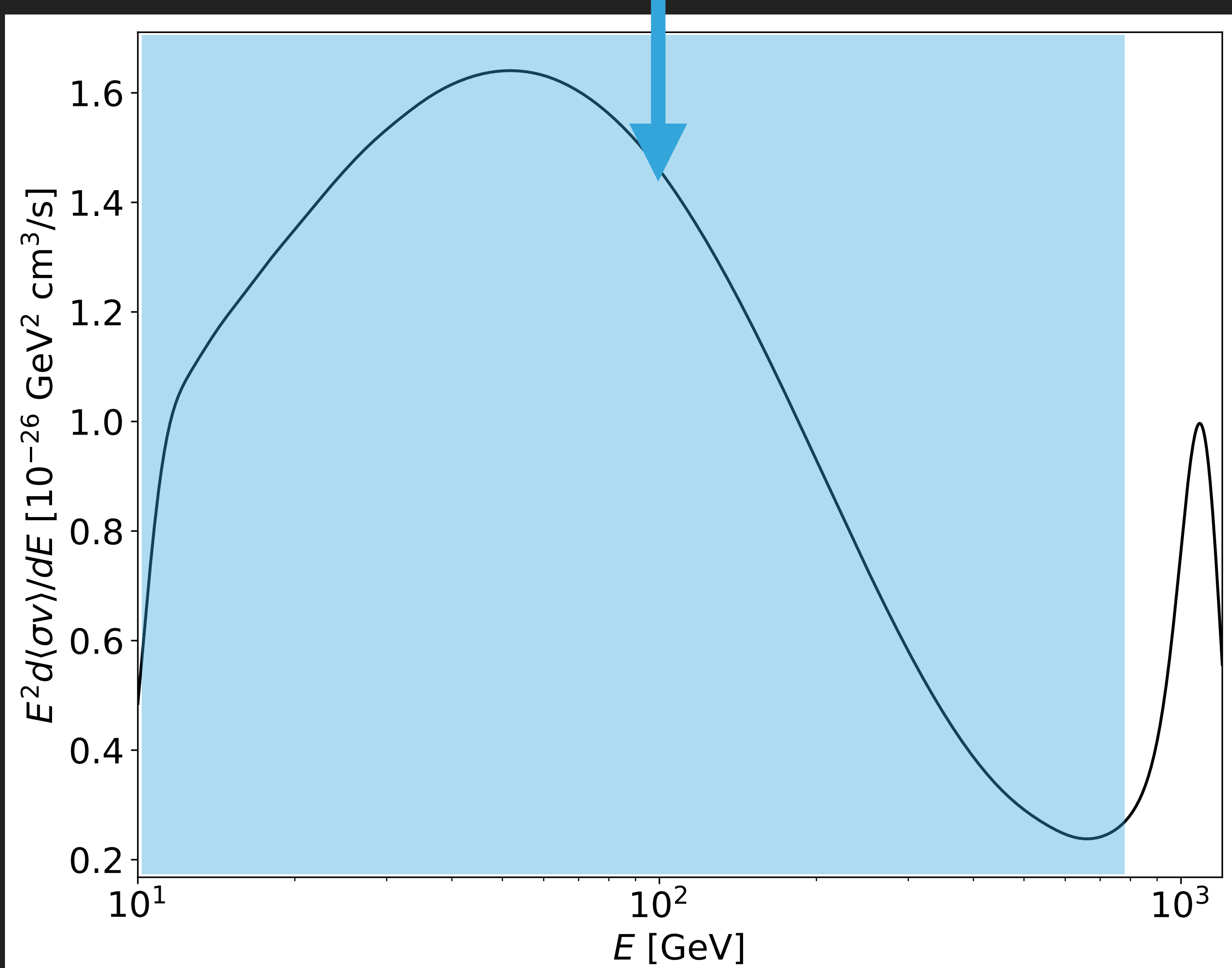
In Progress: Fermi continuum search GC Excludes all minimal WIMPs but higgsino

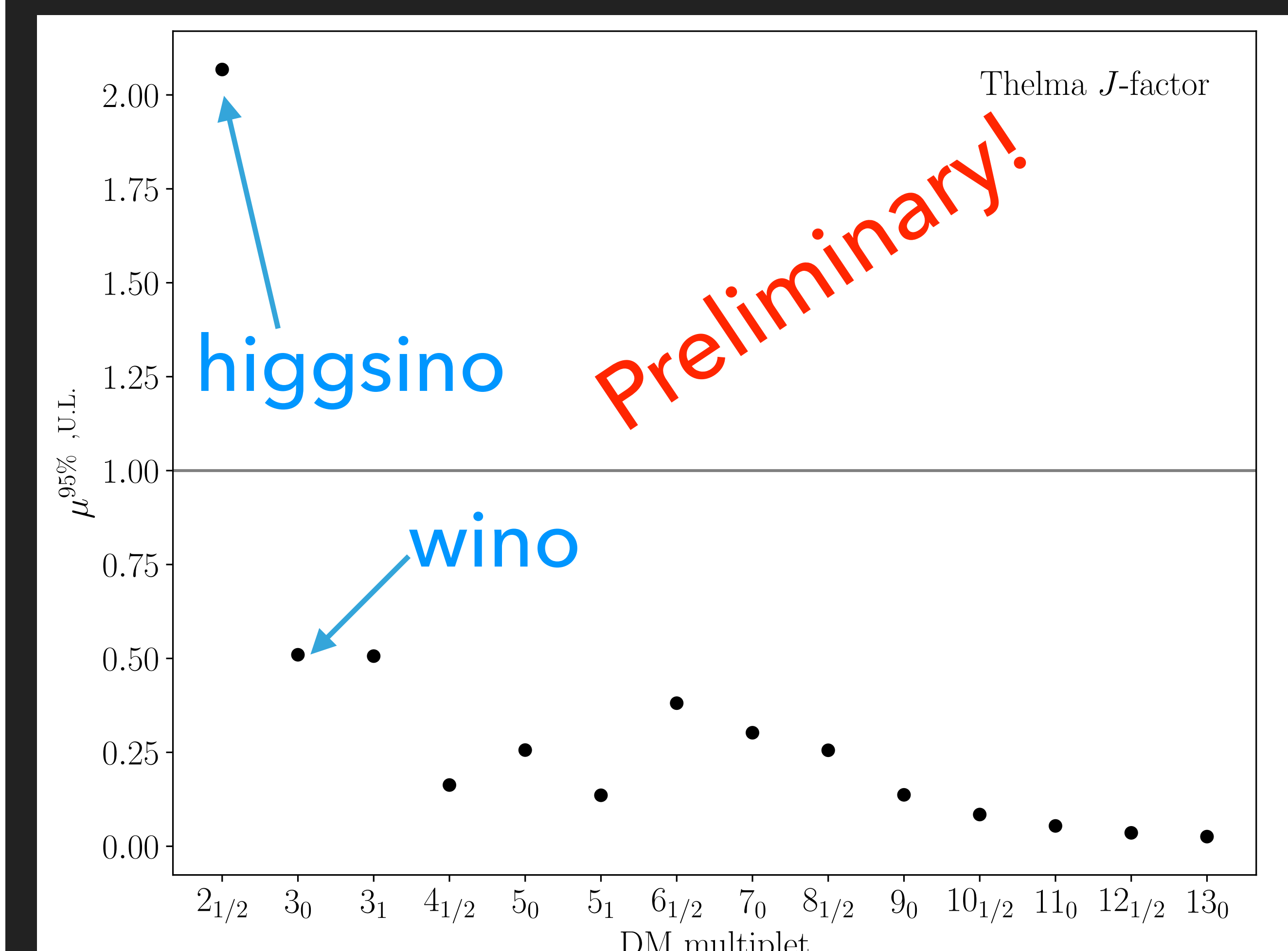
B.S., Linda Xu (Berkeley + SLAC), Nick Rodd (LBNL)

1. Look for continuum annihilation signal in inner 20 degrees above 100 GeV

2. Use most conservative DM profile from FIRE-2 sims







My opinion

Higgsino DM only true WIMP model left

1. mass of 1.01 TeV
2. too heavy for LHC –> maybe future collider
3. invisible to direct detection
4. not within reach of HESS
    1. within reach CTA (line)
5. **Marginally within reach of Fermi (continuum)**

Higgsino is the canoncial DM model in modern supersymmetry models, like split-SUSY

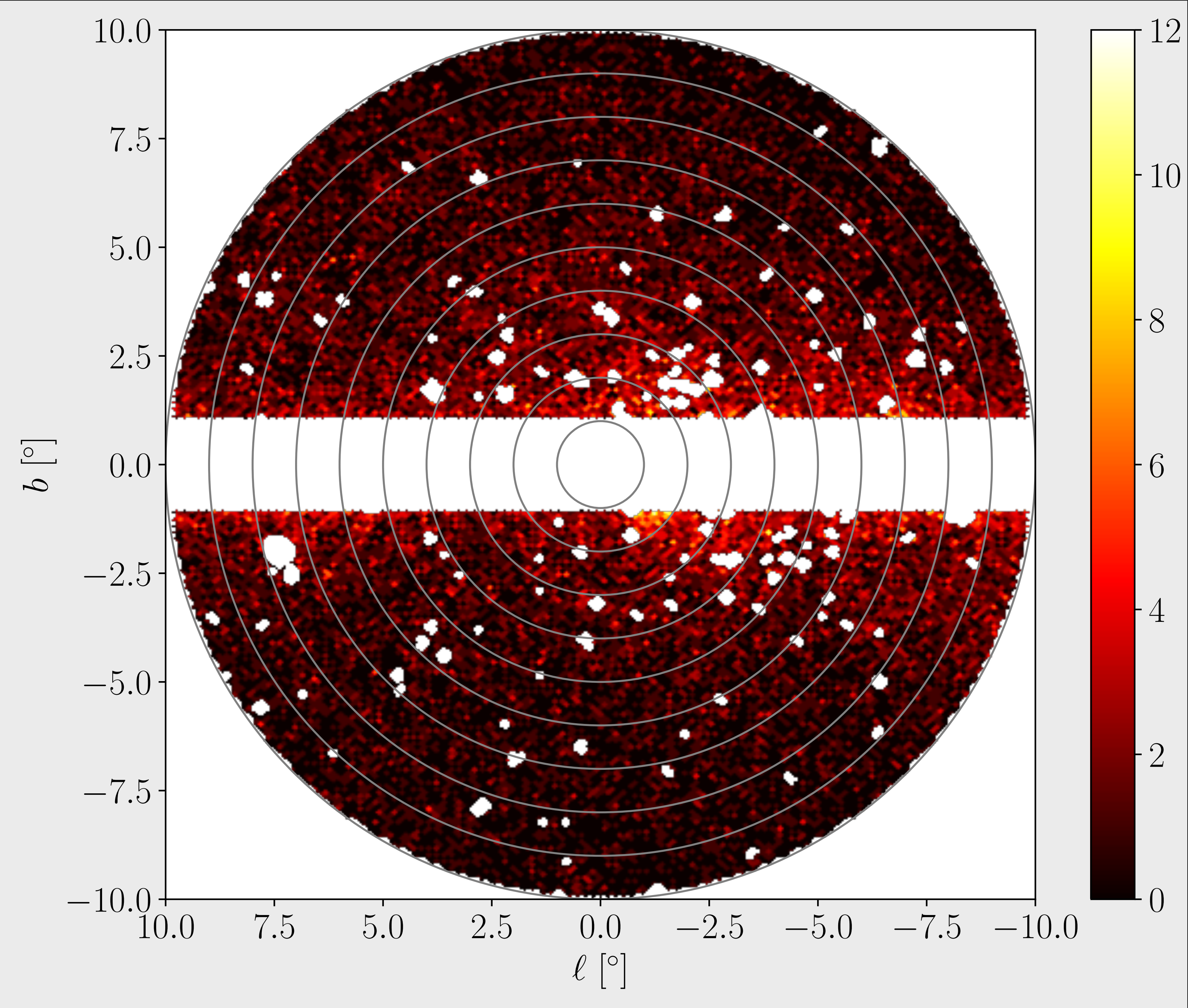
PHYSICAL REVIEW LETTERS 130, 201001 (2023)

Higgsino Dark Matter Confronts 14 Years of Fermi γ-Ray Data

Christopher Dessert,[1,2,3] Joshua W. Foster,[4] Yujin Park,[1,2] Benjamin R. Safdi,[1,2] and Weishuang Linda Xu[1,2]

Fermi Data Selection

1. 10 GeV - 1 TeV
2. SOURCE data from Aug. 2008 to June 2022
3. 9 concentric annuli out to 10 degrees around GC
    1. independent analysis /annulus
4. Mask plane and PSs



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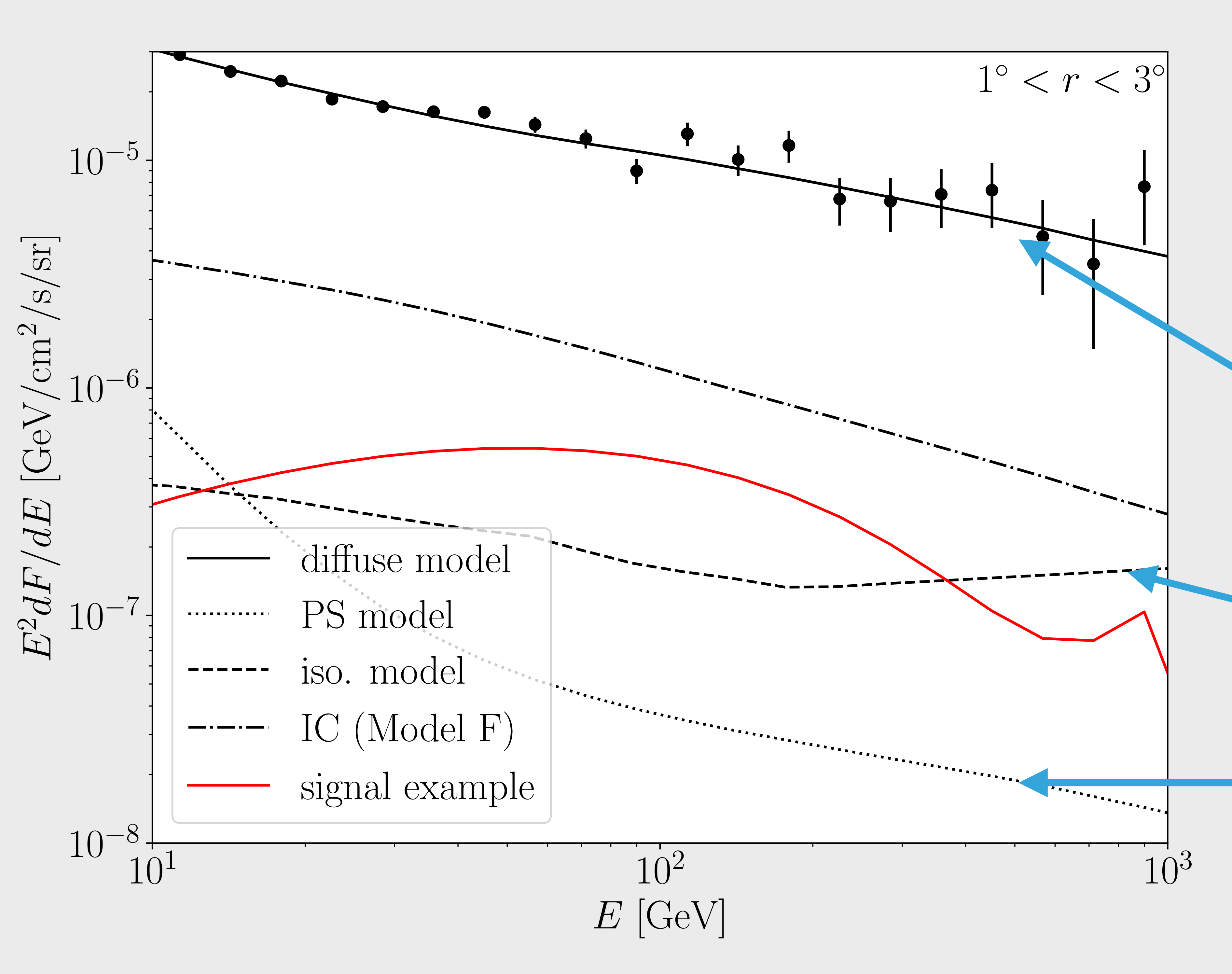

Galactic diffuse model (p8)

isotropic

residual PS model

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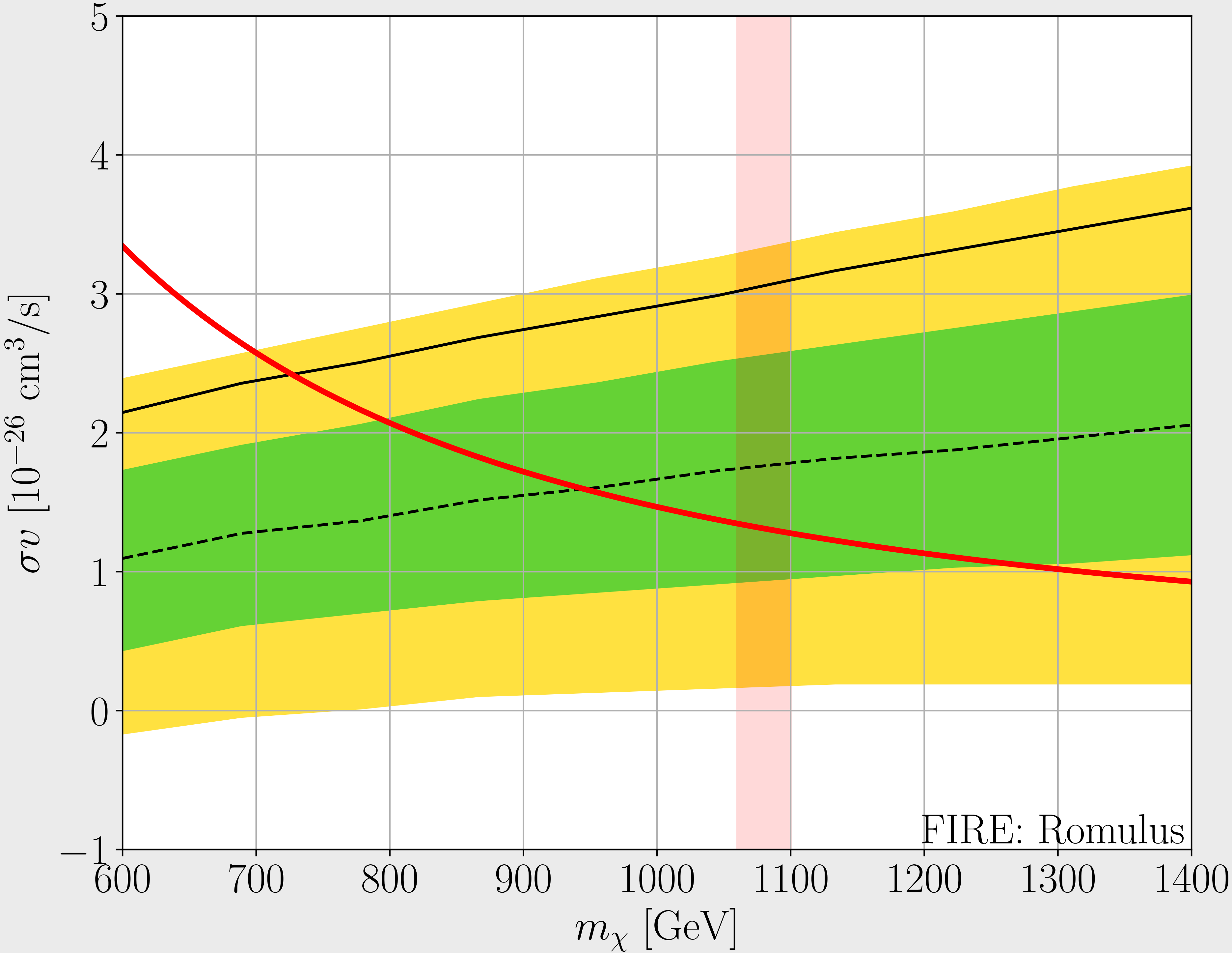

1. Roughly 2σ in favor of higgsino model
2. Similar across halo profiles

Need more data / analyses!

CTA can provide smoking gun with line

Beyond motivated targets, Fermi has significant impact on excluding / detecting!? WIMP DM parameter space

Searching for Dark Matter Annihilation from Milky Way Dwarf Spheroidal Galaxies with Six Years of Fermi-LAT Data

(The Fermi-LAT Collaboration)

1503.02641

1. Most robust constraints from Milky Way ultrafaint dwarf galaxies

2. Low number of stars -> Baryon dominated -> NFW good approx

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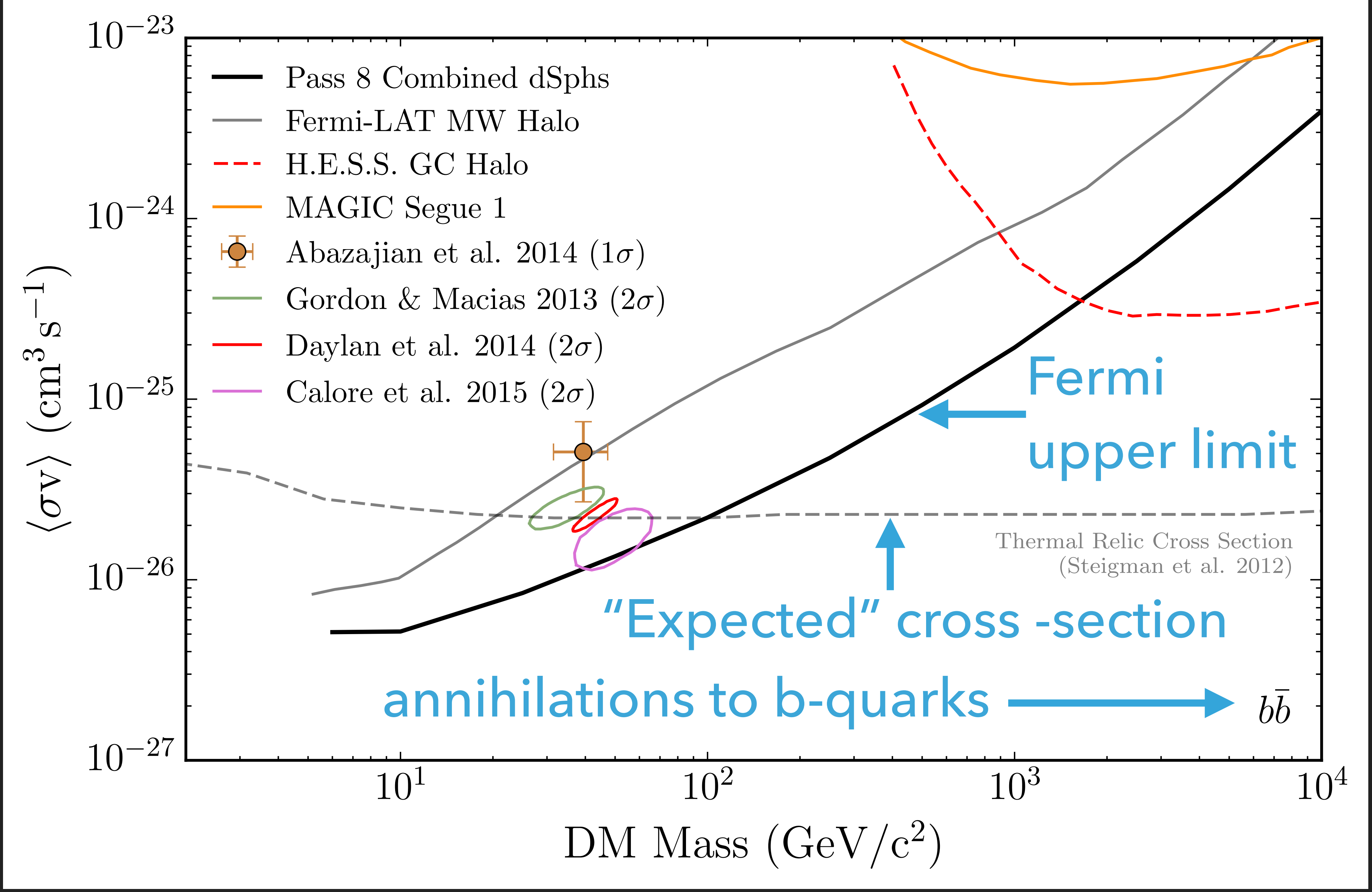

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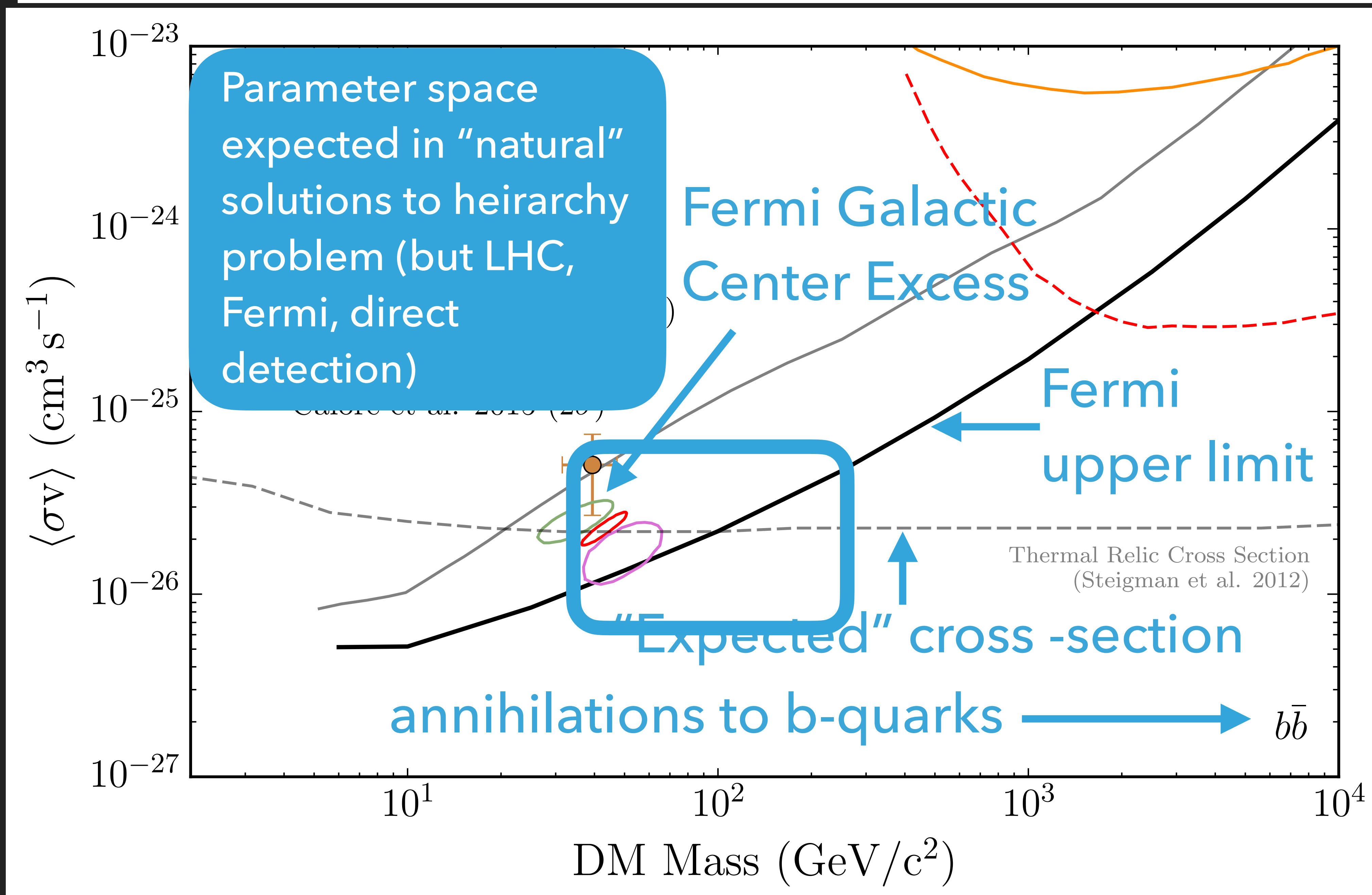
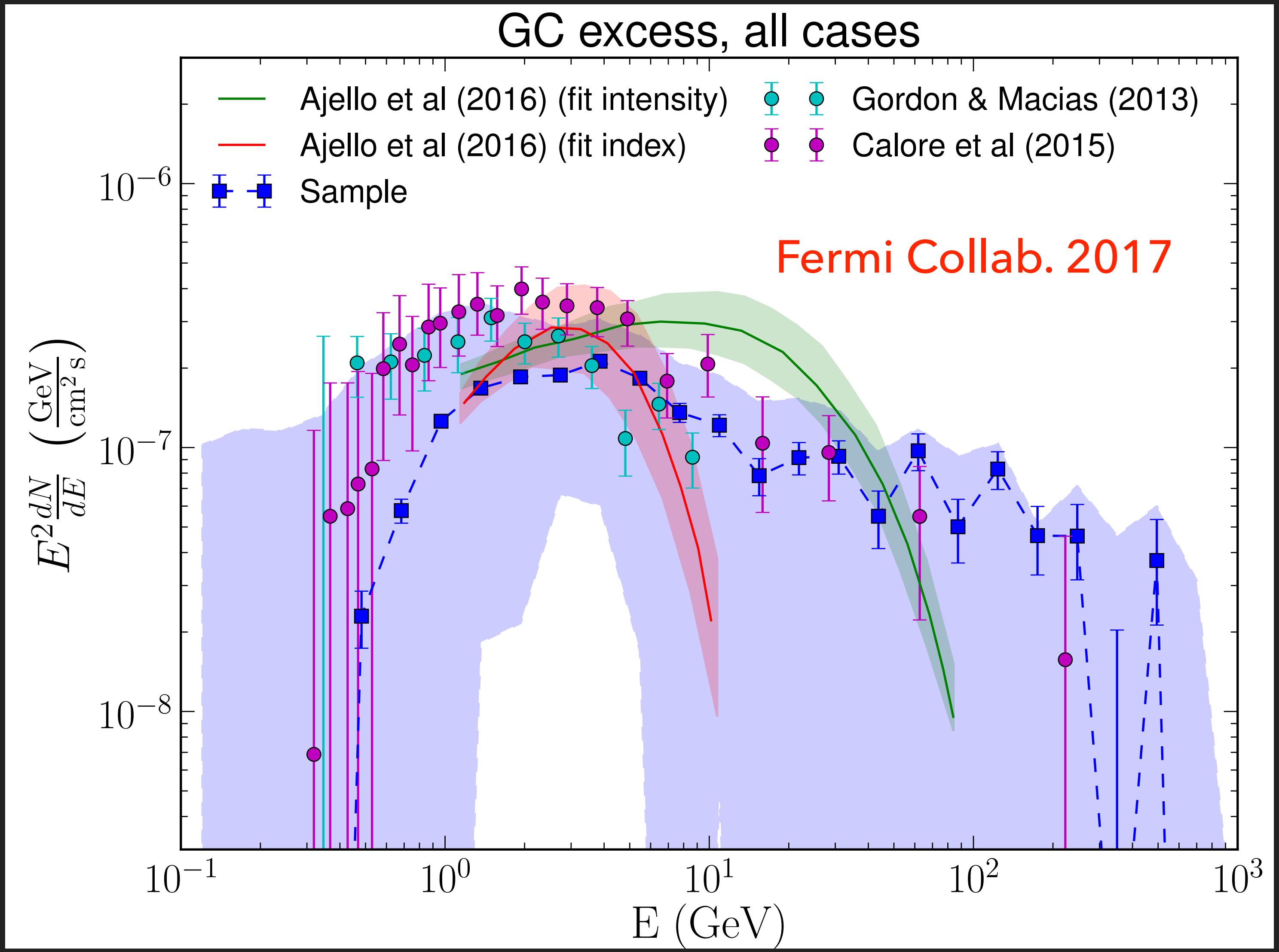


What is the Fermi Galactic Center Excess?



1. Roughly spherically symmetric gamma-ray excess around GC
2. First discovered: Goodenough & Hooper 2009
3. Radial dependence from GC consistent with DM annihilation
4. Near thermal annihilation cross-section for e.g. b-quark final states

What is responsible for Fermi GC Excess?

Outstanding question to be answered from Fermi data

Option 1: WIMP DM!

1. Morphology and cross-section consistent with WIMP expectation! (1402.6703)
2. WIMP (e.g., neutralino) models difficult because collider + direct detection constraints (1507.07008)
   1. Hidden sectors can work (1912.08821)
   2. But also strong constraints from 1-loop line (e.g., Higgs portal) (B.S. et al. 2212.07435)

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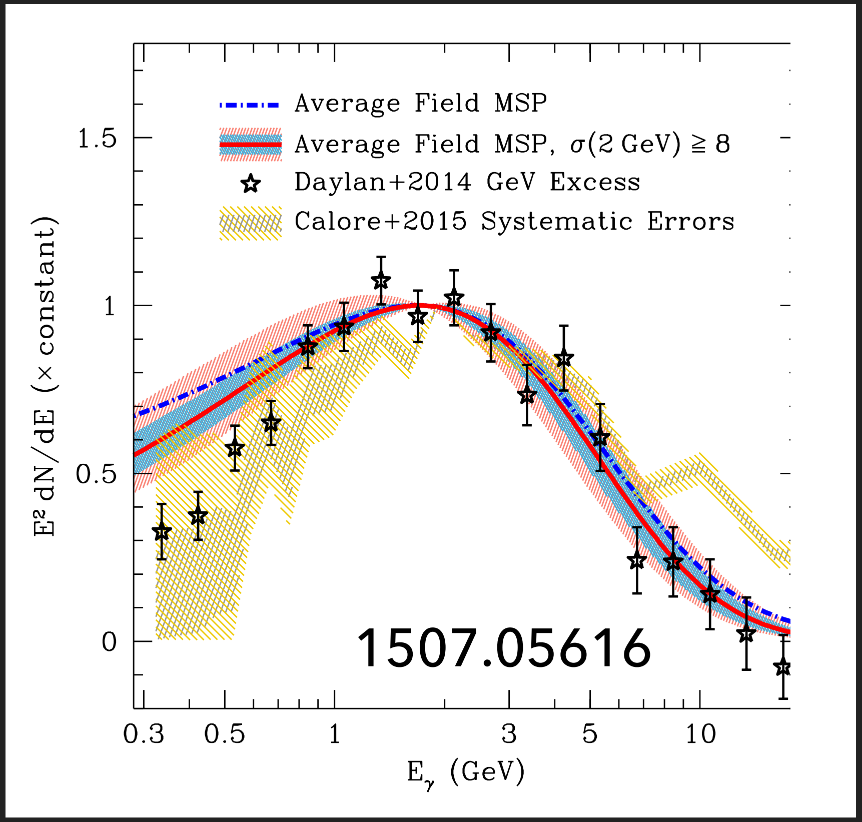
Option 2: Astrophysics

1. MSP energy spectrum suspiciously close to GC



2. Diffuse mismodeling could also contribute to morphology (2203.11626)

What is responsible for Fermi GC Excess?

Outstanding question to be answered from Fermi data

Optior

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Evidence for Unresolved Gamma-Ray Point Sources in the Inner Galaxy

Ben Safdi

Massachusetts Institute of Technology

2015

My First Fermi Symposium in 2015!

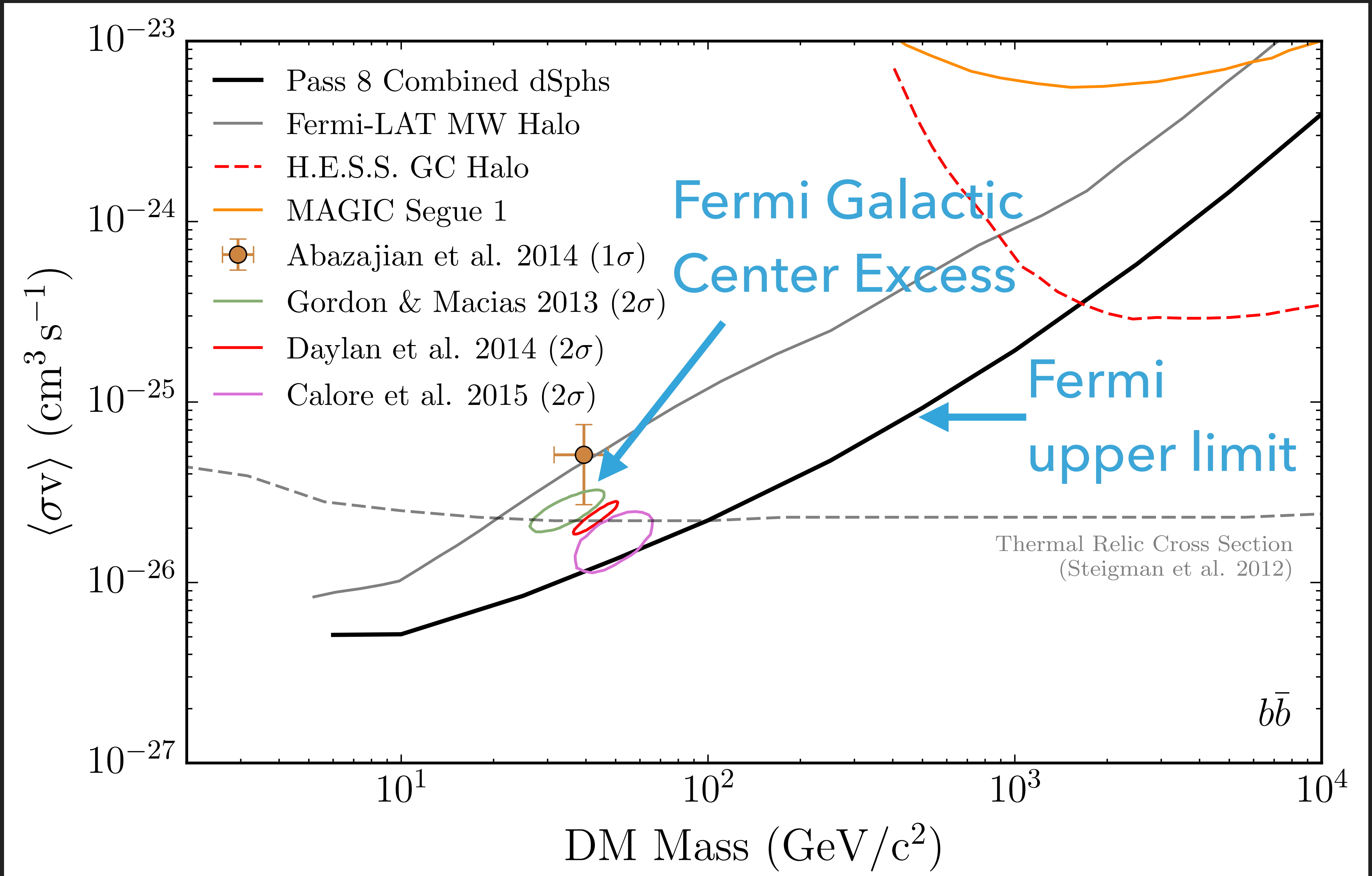
1. Stat. methods give some preference for PSs (e.g., pulsars)
2. Direct MSP searches wtih e.g. SKA will be useful

B.S., S. Lee, M. Lisanti, and B.S., S. Lee, M. Lisanti, T. Slatyer, W. Xue [1412.6099 and 1506.05124]

My opinion: DM question for GCE best resolved with improving dwarf constraints

1. Need more Fermi data + more dwarf targets + better J-factors

2. In progress: Folsom, Kaplinghat, Lisanti, Park, Raman, B.S. — more careful accounting of DM in dwarfs reduces limit factor ~2



Summary: past accomplishments and future outlooks for Fermi and WIMP DM

1. Indirect detection strong, nearly-model independent probe
2. Fermi legacy: exclude generic WIMP below ~many 10's of GeV
    1. Help (along with HESS) exclude wino benchmark model <– changed BSM
3. Fermi GCE –> might be sign of ~10's of GeV WIMP (or not)
    1. Future: more data / dwarfs / dwarf kinematic data & studies to test DM
4. Future: ~1 TeV higgsino last minimal WIMP. Marginal for Fermi. Need more data and analyses!
    1. For definitive detection need future instrumentation (CTA or space-based telescope more effective area at 1 TeV)

Axions: Fermi excluded some ALP space. Future gamma-ray transients from supernovae / NS-mergers very promising discovery tool. Future: full-sky instrumentation needed.

THANK YOU FERMI!