THEORETICAL INTERPRETATIONS OF THE XENON1T RESULT

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OUTLINE

- My favourite explanation (a disclaimer)
- The Axion
- Cherry-picking

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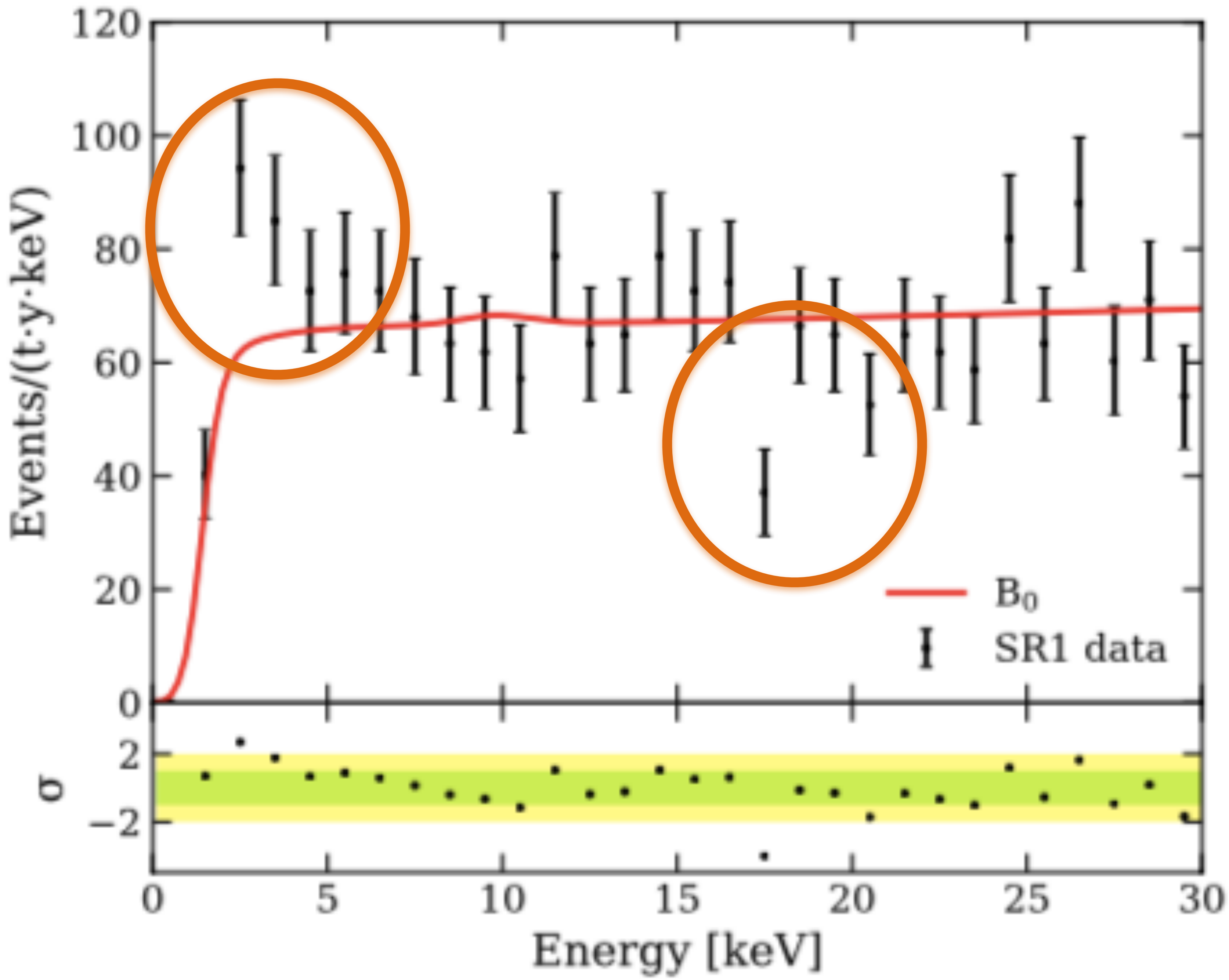
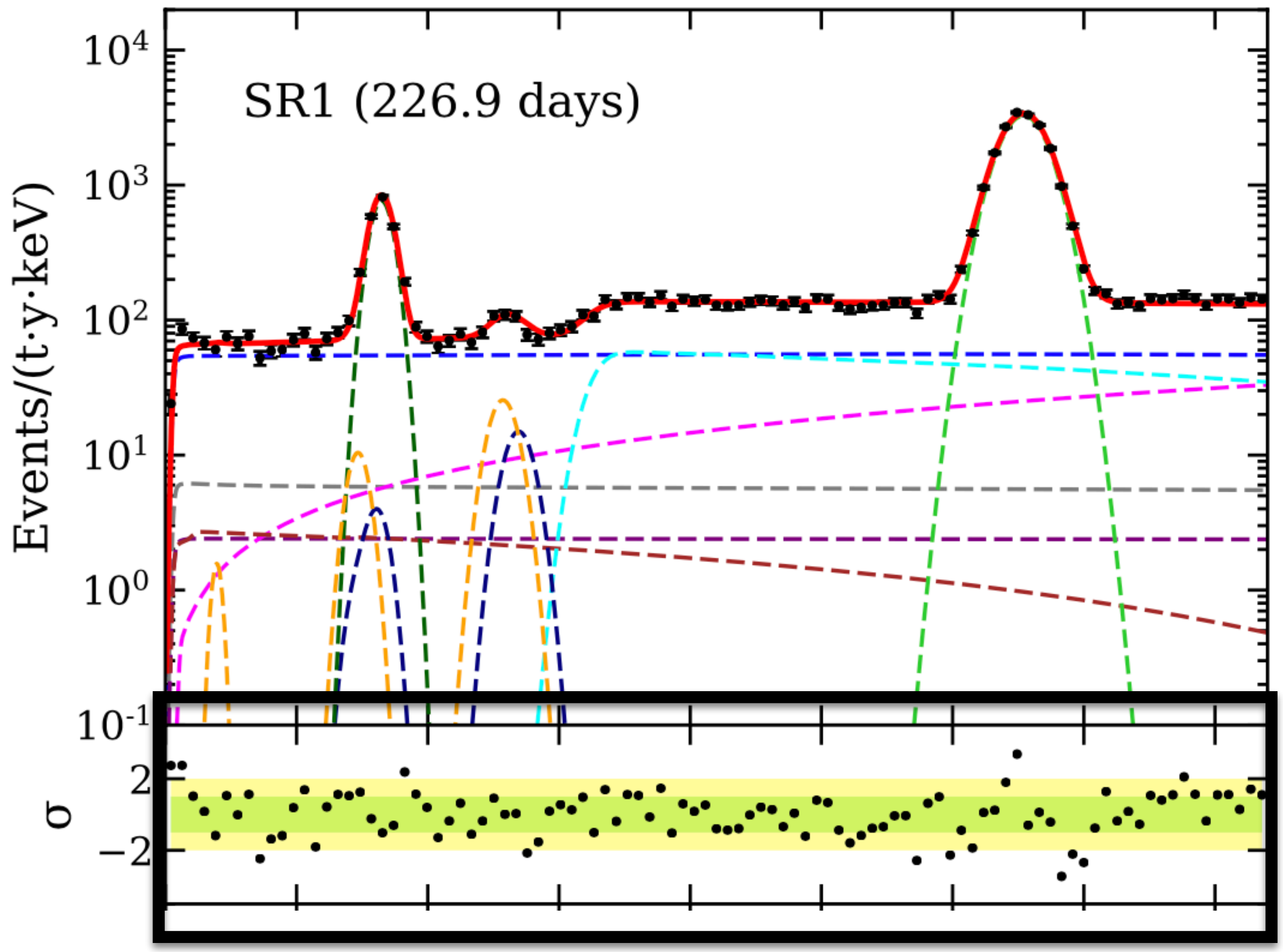
Consumer Notice:

Not at all comprehensive and rich in personal biases



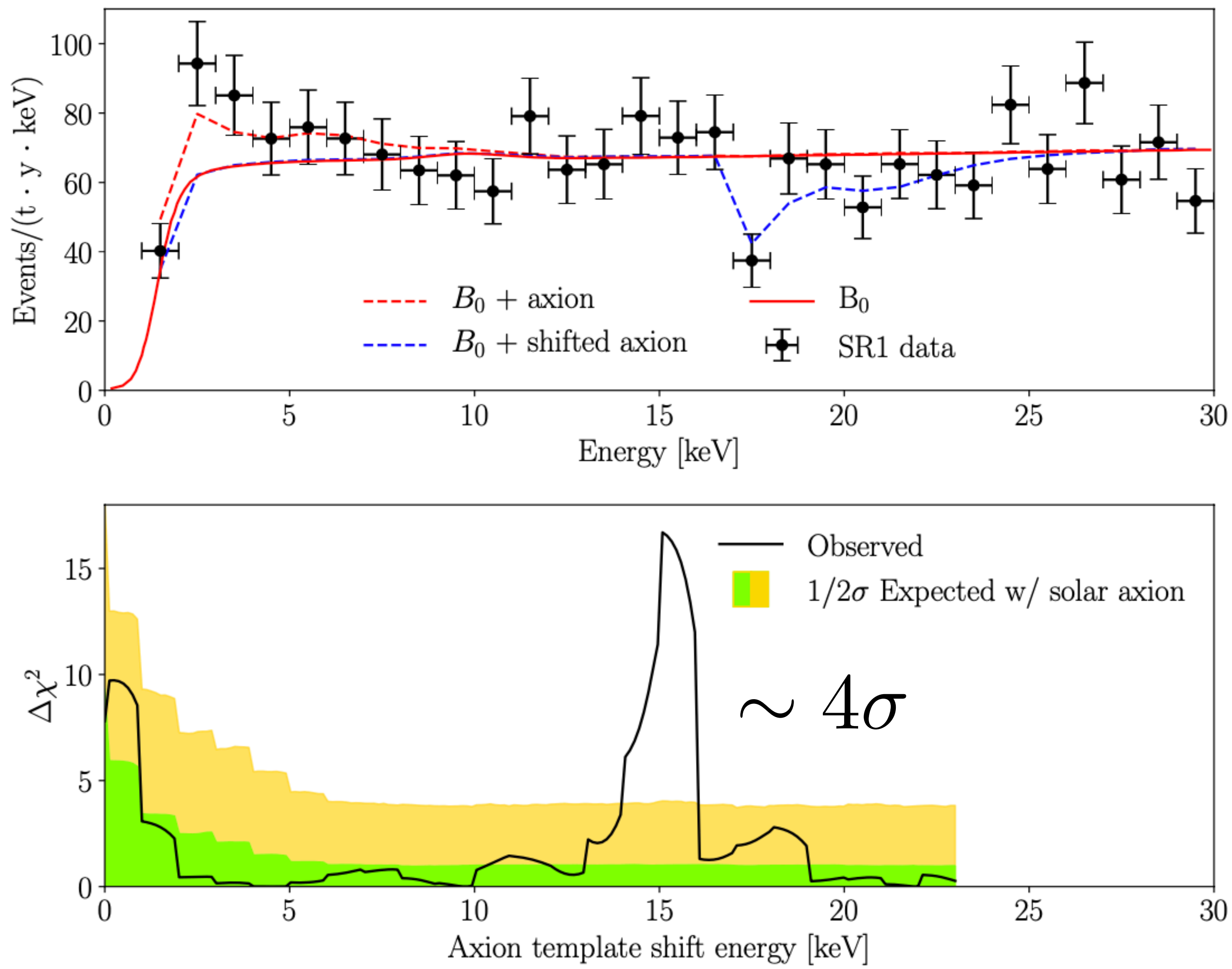
Toro Principle

If you rotate a plot by 180 degrees and you are still excited, you probably shouldn't write a paper about it


SR1 (226.9 days)
Events/(t·y·keV)
10^4
10^3
10^2
10^1
10^0
10^{-1}
σ
2
−2

Dessert, Foster, Kahn, Safdi

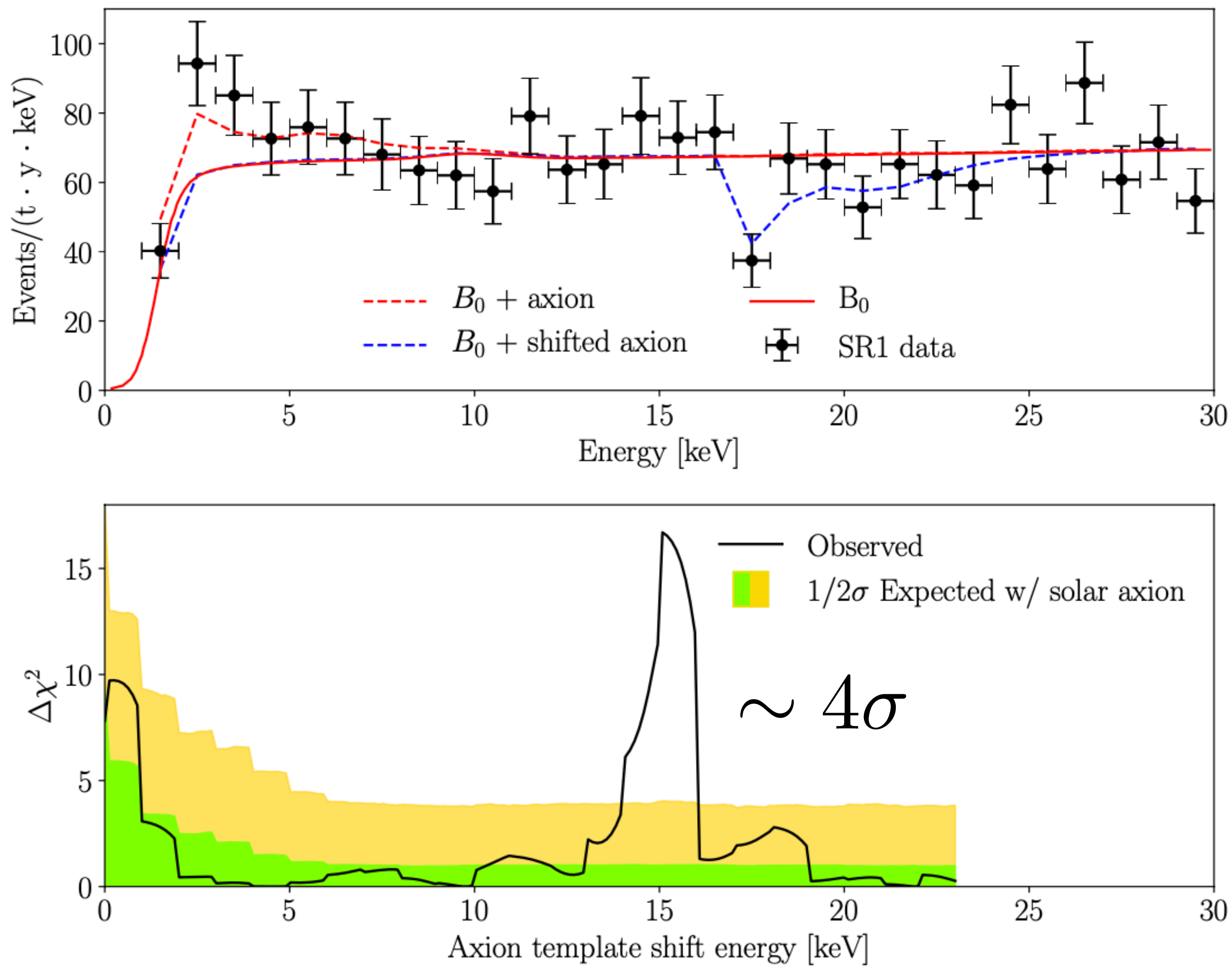
2006.16220



An unphysical axion flux from the sun gives a “better fit” to the data

Dessert, Foster, Kahn, Safdi

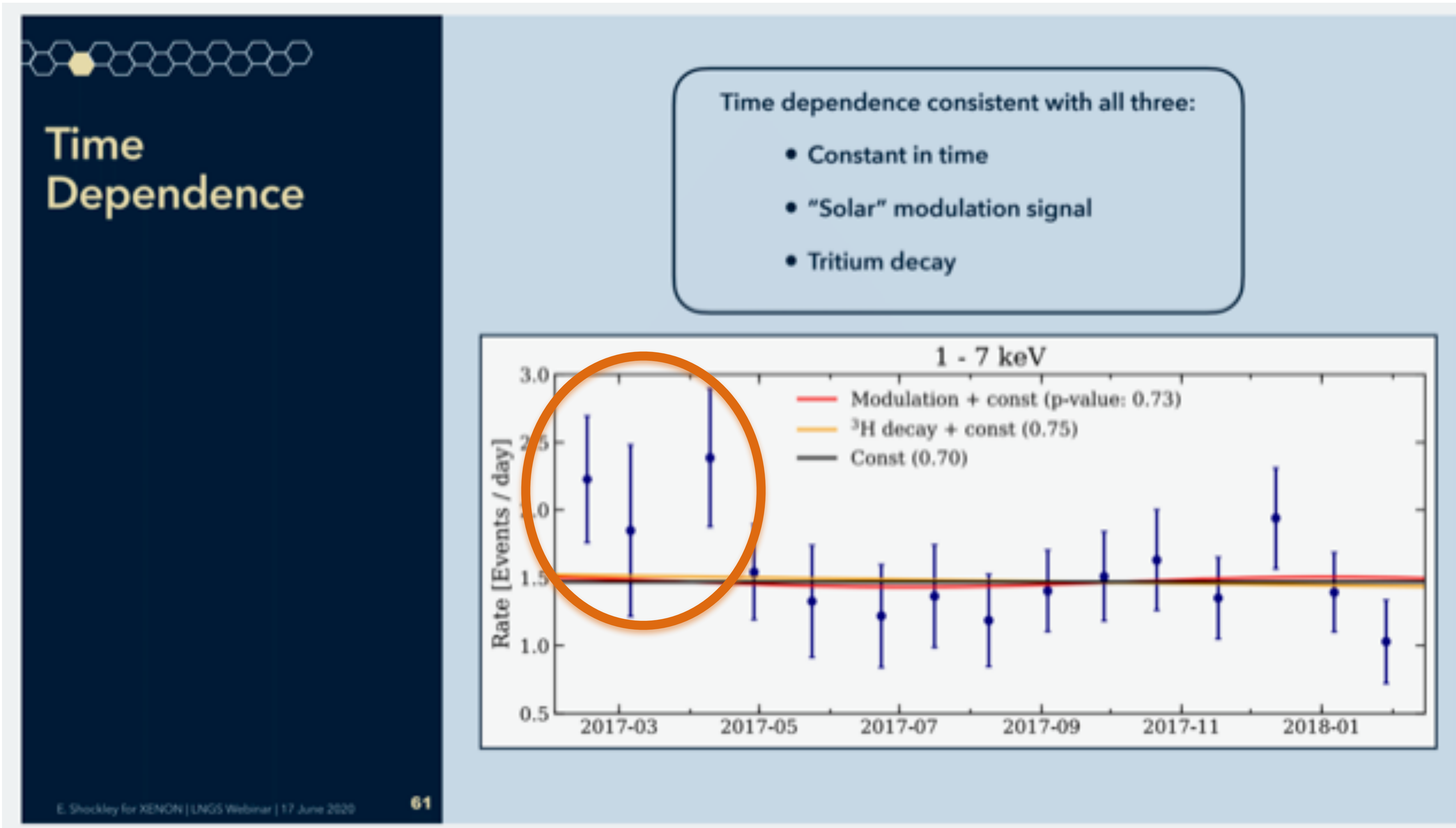
2006.16220



Claim: if this signals a bkg mismodeling that can happen with equal probability at lower energies, the axion p-value is ~ 0.1

Real Message: Toro Principle

From the original talk by the collaboration (backup slides)




Standard Model
AXION
HYPOTHETICAL ELEMENTARY PARTICLE
PROMISES TO "CLEAN UP" YOUR STRONG CP PROBLEM!

WHY THEORISTS LIKE AXIONS

- UV Motivation from String Theory
- Strong CP
- Generically predicted in a class of solutions to the Electroweak Hierarchy Problem
- Simple and predictive cosmology

AXION-LIKE PARTICLES

Loosely, Goldstone Bosons of a symmetry broken at high scales

$$f_a \gg v$$

Derivatively coupled to the SM

$$g(\partial a)\mathcal{O}_{\rm SM}$$

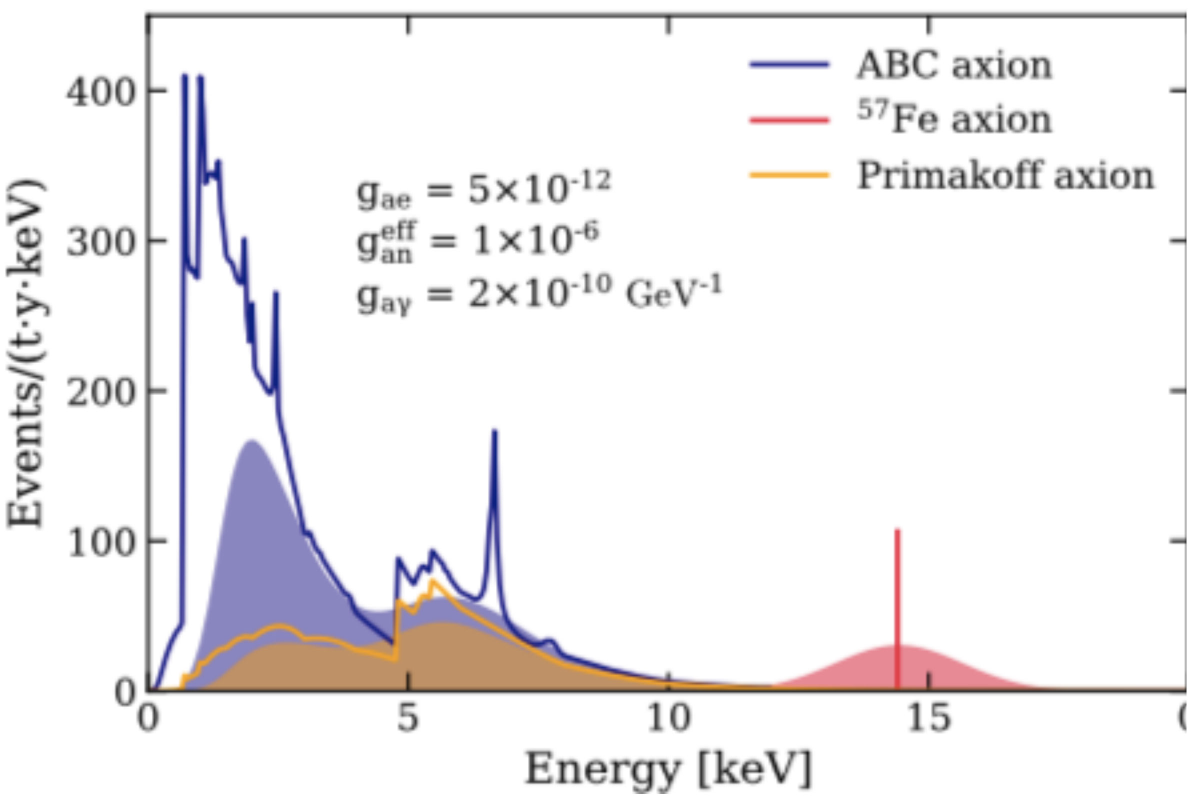
3 couplings are used in Xenon's analysis

$$\mathcal{L} \supset -i g_{ae} a \bar{e}\gamma_5 e - g_{a\gamma} a F_{\mu\nu}\widetilde{F}^{\mu\nu} - i a \bar{N}(g^0_{an} + g^3_{an}\frac{\sigma_3}{2})N$$

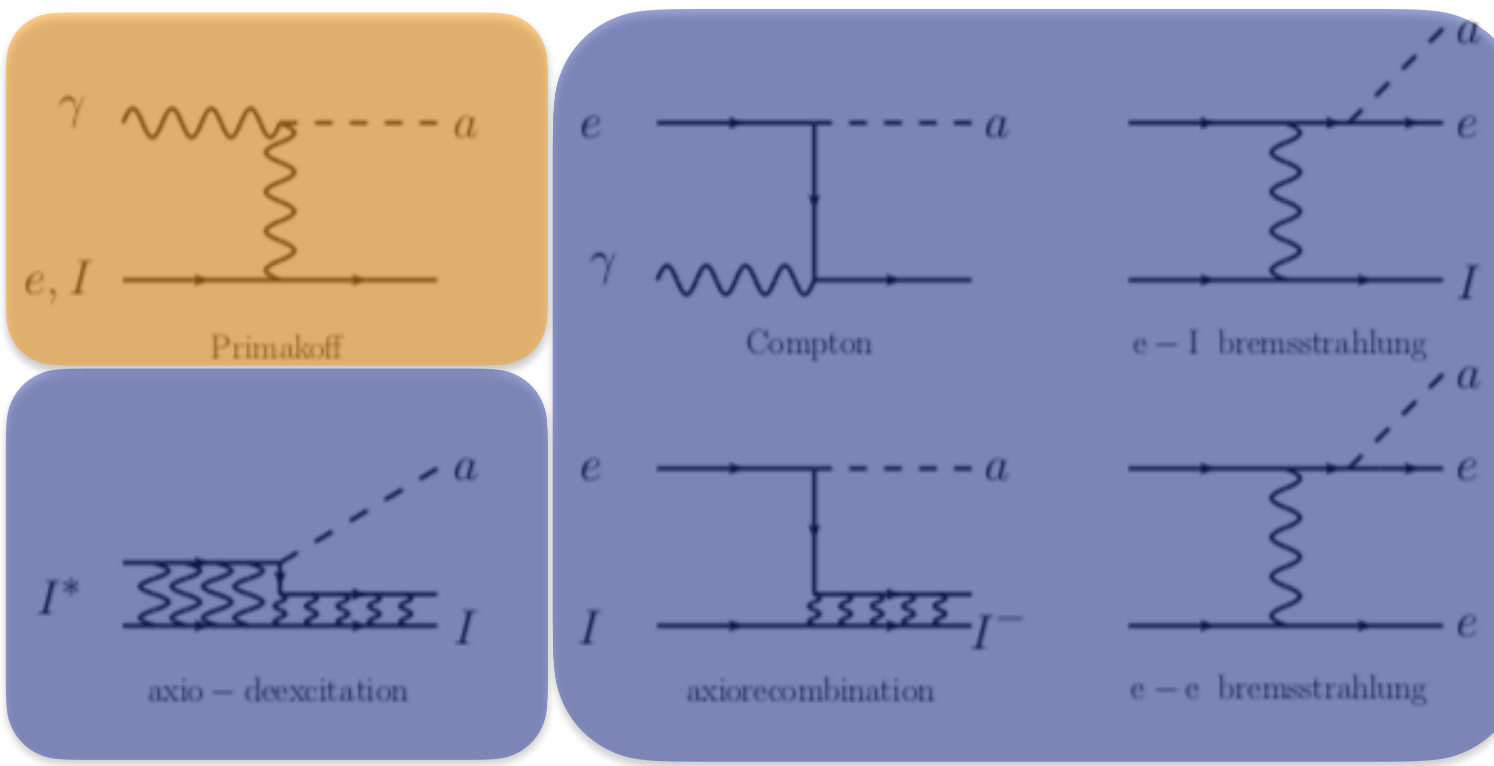
$$g^{\rm eff}_{an} = -1.19 g^0_{an} + g^3_{an}$$

AXIONS FROM THE SUN

$m_a \lesssim T_\odot$

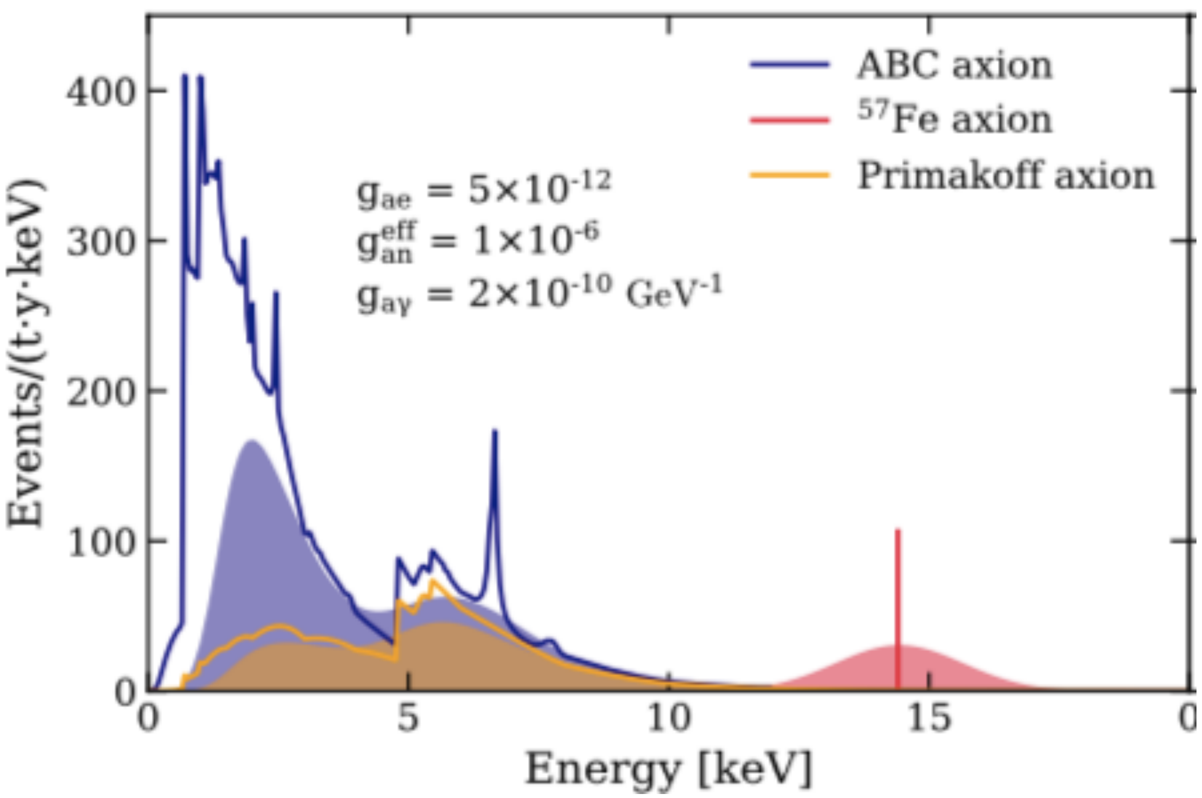


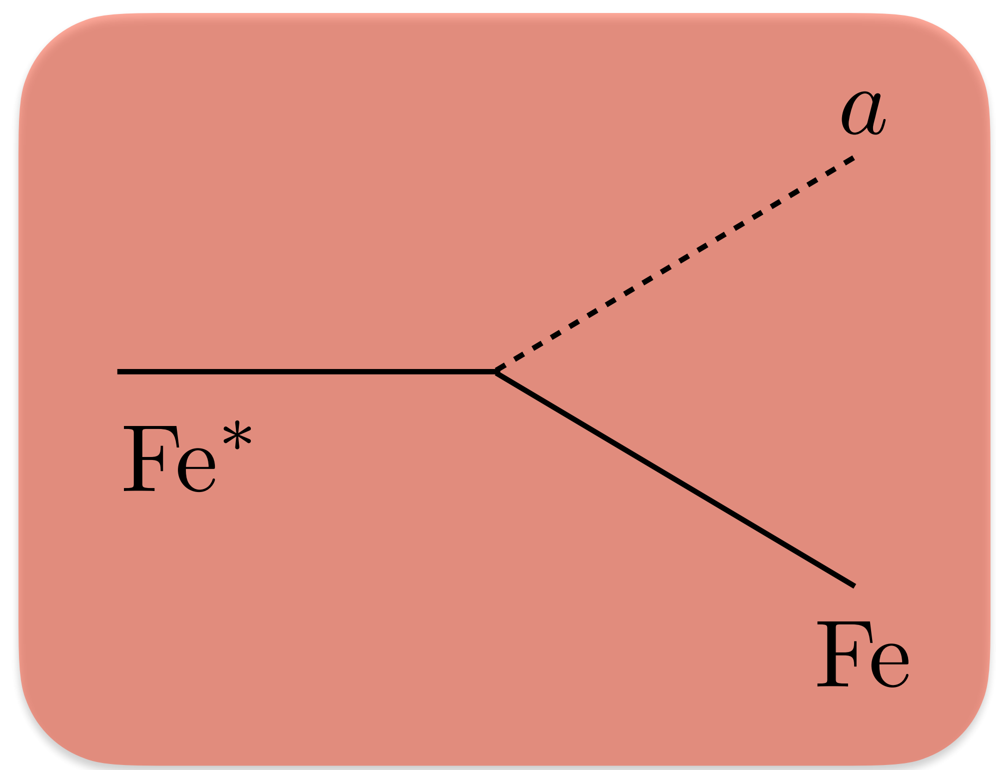
$g_{a\gamma}^2$



g_{ae}^2

AXIONS FROM THE SUN

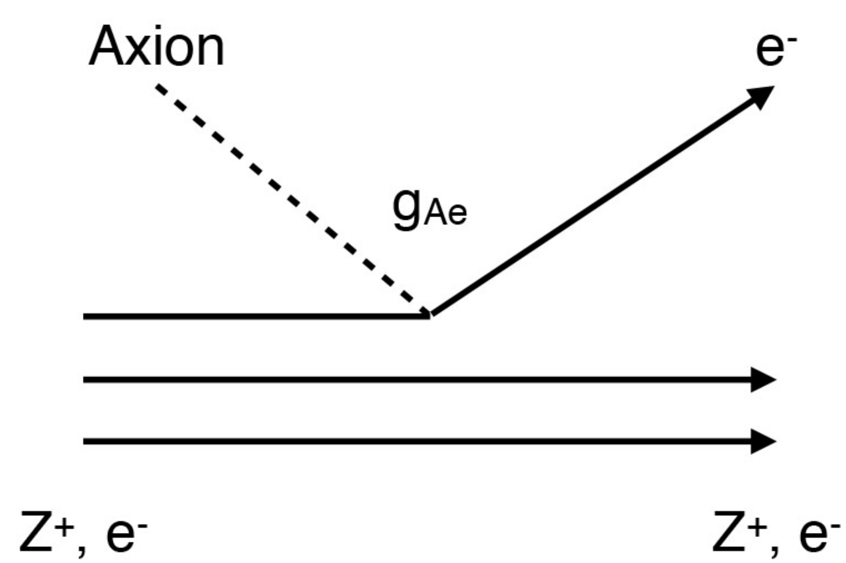




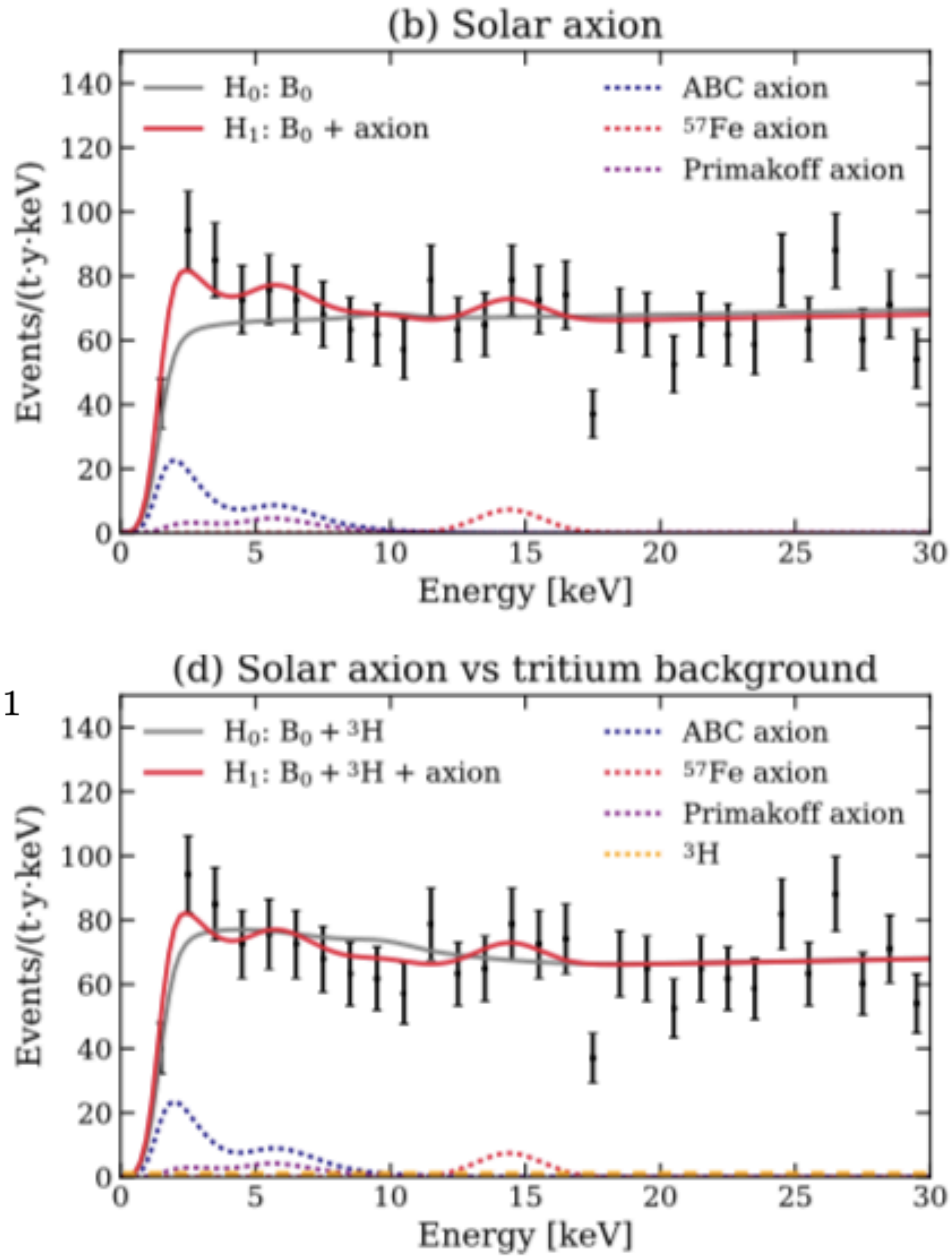
$(g_{an}^{\mathrm{eff}})^2$

DETECTION IN XENON

Axio-electric effect ~ Photoelectric effect



$$\sigma_{\mathrm{ae}} = \sigma_{\mathrm{pe}} \frac{g_{\mathrm{ae}}^2}{\beta} \frac{3E_{\mathrm{a}}^2}{16\pi\alpha m_{\mathrm{e}}^2} \left(1 - \frac{\beta^{2/3}}{3}\right)$$



Axion preferred at 3.5 sigma

$$g_{ae} < 3.7 \times 10^{-12}$$
$$g_{ae} g_{an}^{eff} < 4.6 \times 10^{-18}$$
$$g_{ae} g_{a\gamma} < 7.6 \times 10^{-22}\ \mathrm{GeV}^{-1}$$

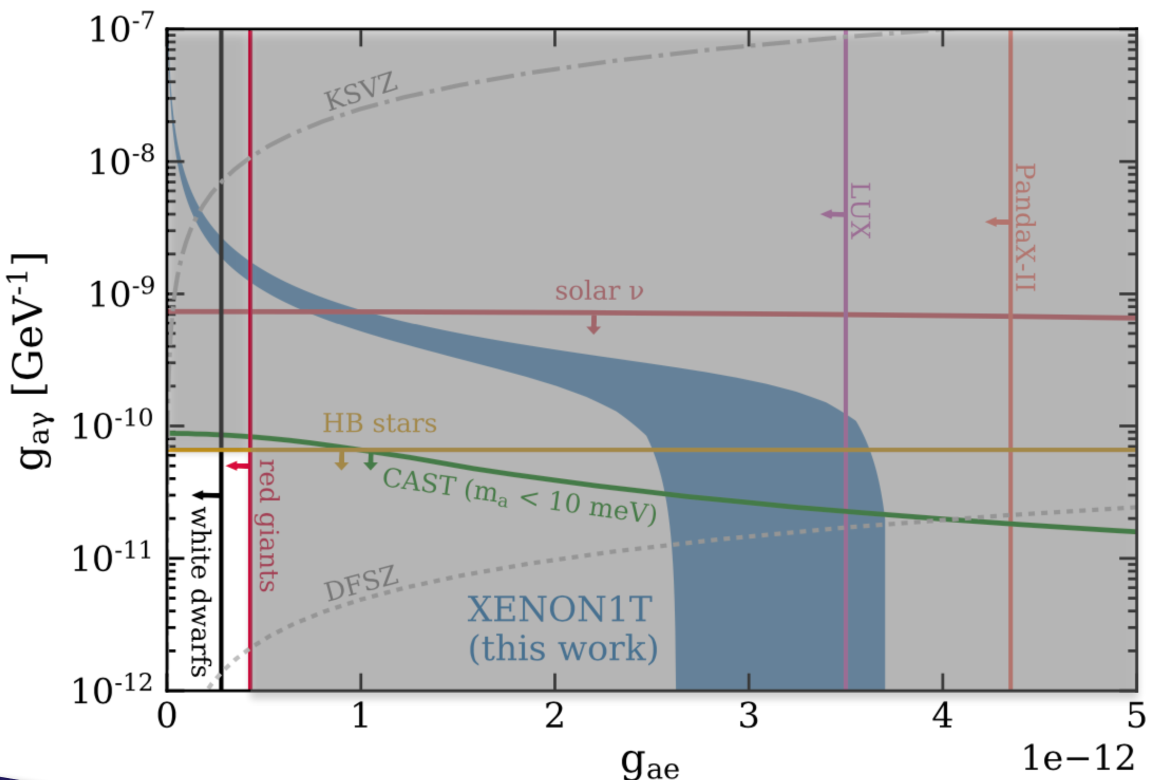
Axion preferred at 2.1 sigma

TIP OF RGB STARS

M5 $g_{ae} < 4.3 \times 10^{-13}$ 1311.1669

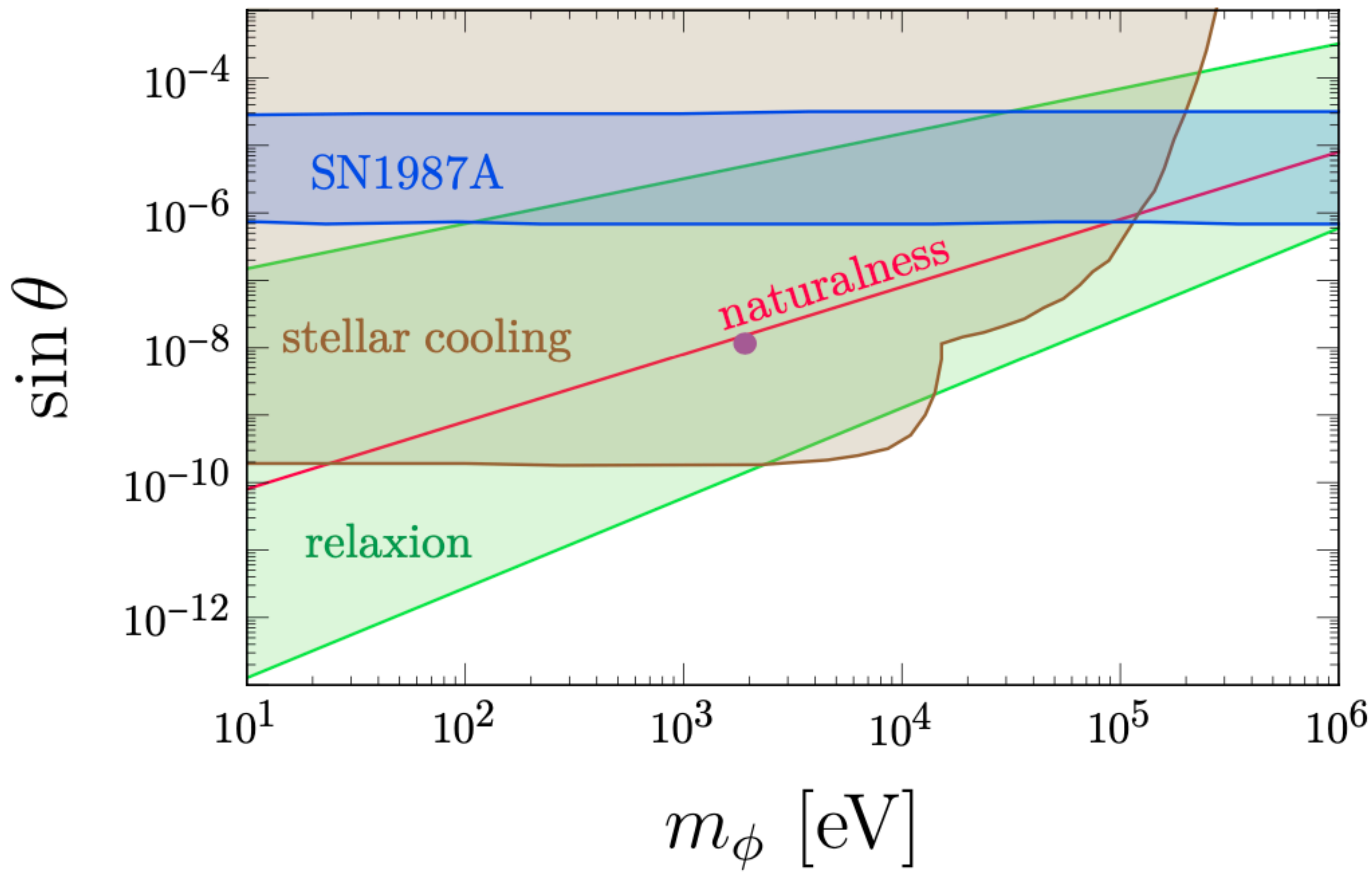
M3 $g_{ae} < 2.57 \times 10^{-13}$ 1802.10357

$$(g_{ae})_{\mathrm{Xenon}} \sim \text{few} \times 10^{-12}$$



White Dwarf Constraints:
1406.7712
(more model dependent)

RELAXION



Budnik, Kim, Matsedonski, Perez, Soreq

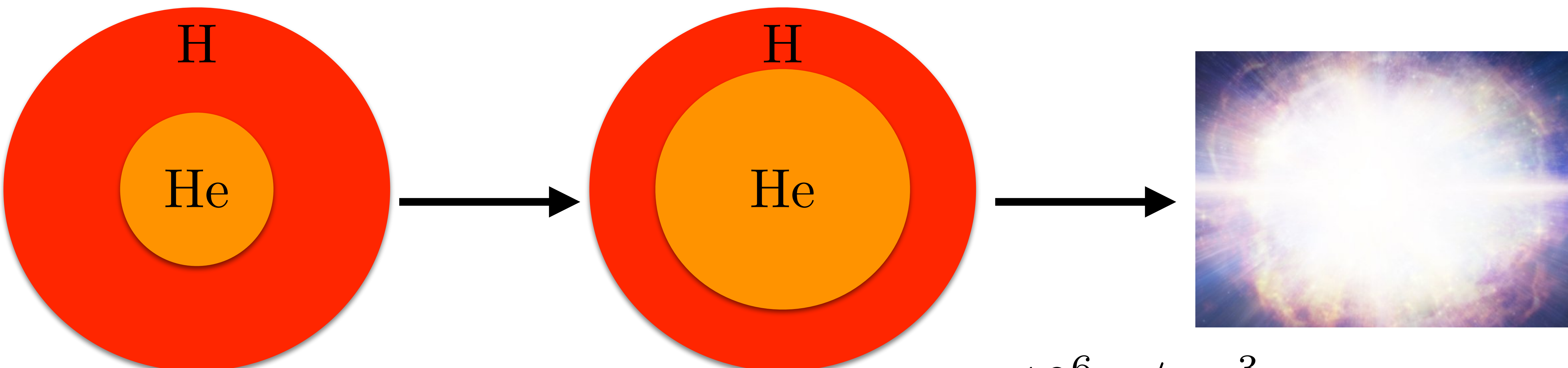
2006.14568

TIP OF RGB STARS

Extra cooling from the axion delays the explosion

(i.e. more He in the core) increasing the peak luminosity

$$T \simeq 10^8 \text{ K} \simeq 10 \text{ keV}$$



$$\rho \simeq 10^6 \text{ g/cm}^3$$

For a recent review relevant to Xenon1T:

Di Luzio, Fedele, Giannotti, Mescia, Nardi

2006.15112

WHAT DOES IT TAKE TO EVADE STELLAR COOLING?

$$m_{\text{medium}} \neq m_{\text{vacuum}}$$

SM example: Photon

DeRocco, Graham, Rajendran
2006.15112

WHAT DOES IT TAKE TO EVADE STELLAR COOLING?

$$m_{\text{medium}} \neq m_{\text{vacuum}}$$

In practice you need to work for it:

$$\mathcal{L} \supset \frac{a}{f_{SM}} F\tilde{F} - g_1 \phi \chi_1^c \chi_2 - g_2 \phi \chi_2^c \chi_1 - M \chi_1^c \chi_1 - g_N \phi \bar{N} N + \frac{a}{f_h} G_h \tilde{G}_h$$

1. New confining gauge group
2. New fermions
3. New long range force
4. New source of tuning

Parameter	Value
g_N	10^{-24}
$\sqrt{g_1 g_2}$	3×10^{-11}
m_ϕ	10^{-14} eV
λ	$< 10^{-78}$
Φ_0	10^{15} GeV
M	30 TeV
Λ_h	30 TeV
f_h	3000 TeV

DeRocco, Graham, Rajendran
2006.15112

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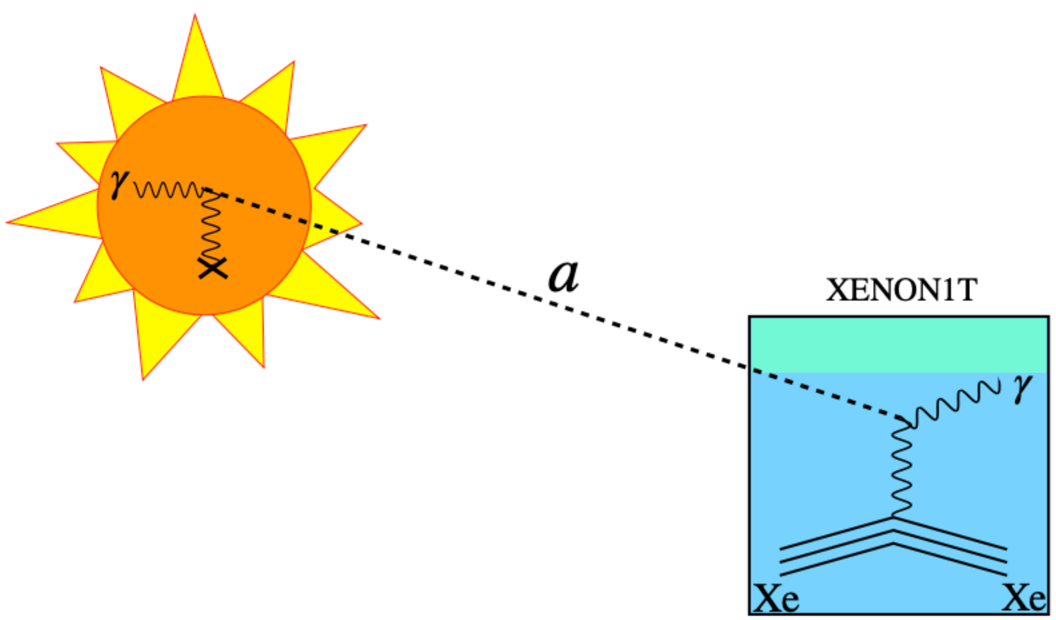
$$\langle \phi \rangle = \frac{g_N n_B}{m_\phi^2}$$

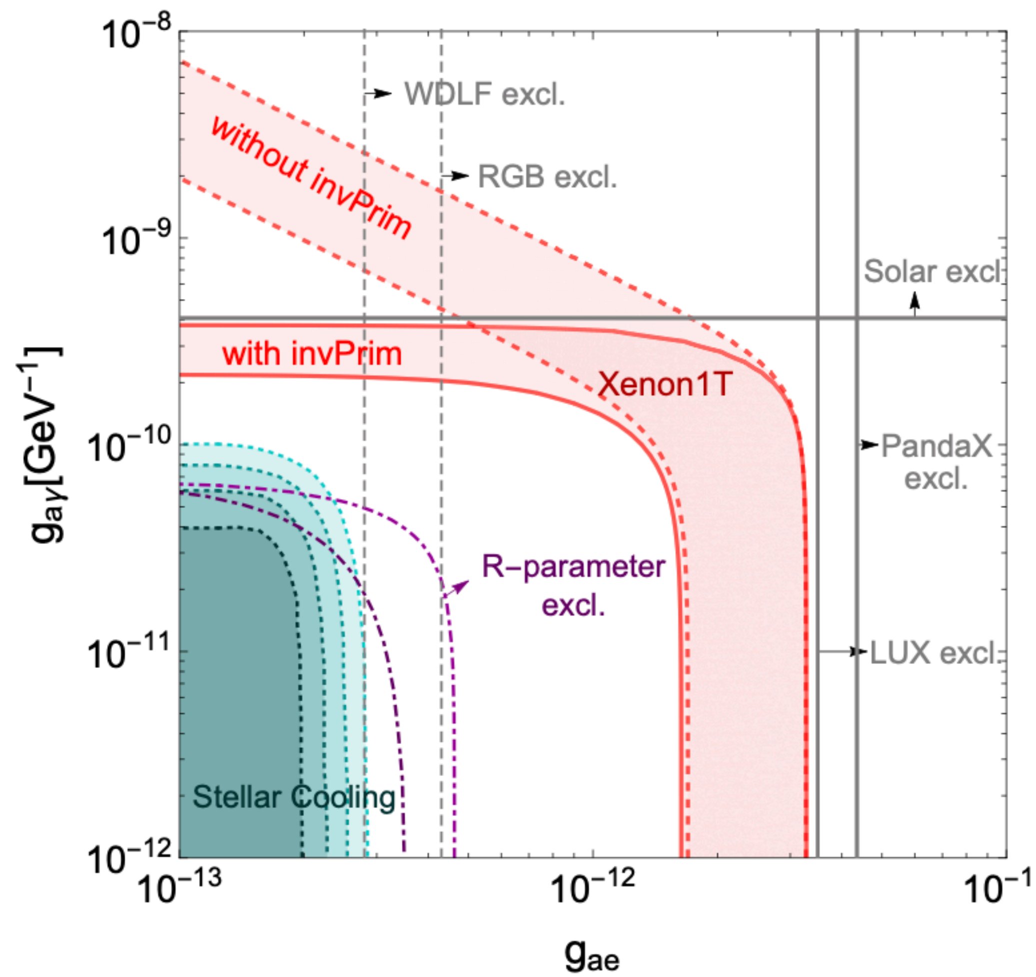
$$m_\chi \sim g_1 g_2 \frac{\langle \phi \rangle^2}{M}$$

DeRocco, Graham, Rajendran
2006.15112

STELLAR COOLING EVADED?

Inverse Primakoff





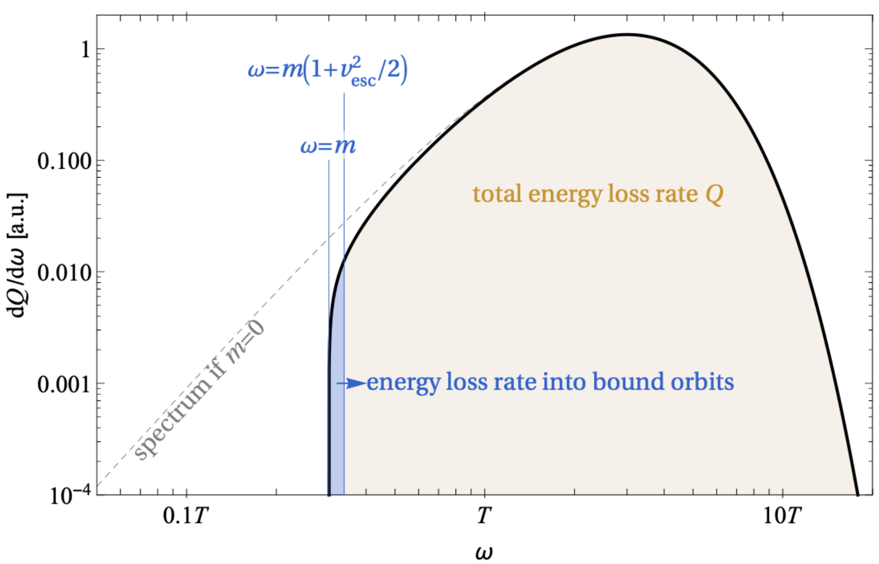
Gao, Liu, Wang, Wang, Xue, Zhong
2006.14598

STELLAR BASINS

Particles emitted near threshold can be captured on **long-lived orbits**

$$E \simeq m$$

$$\frac{E-m}{m} + \Phi(R) < 0$$

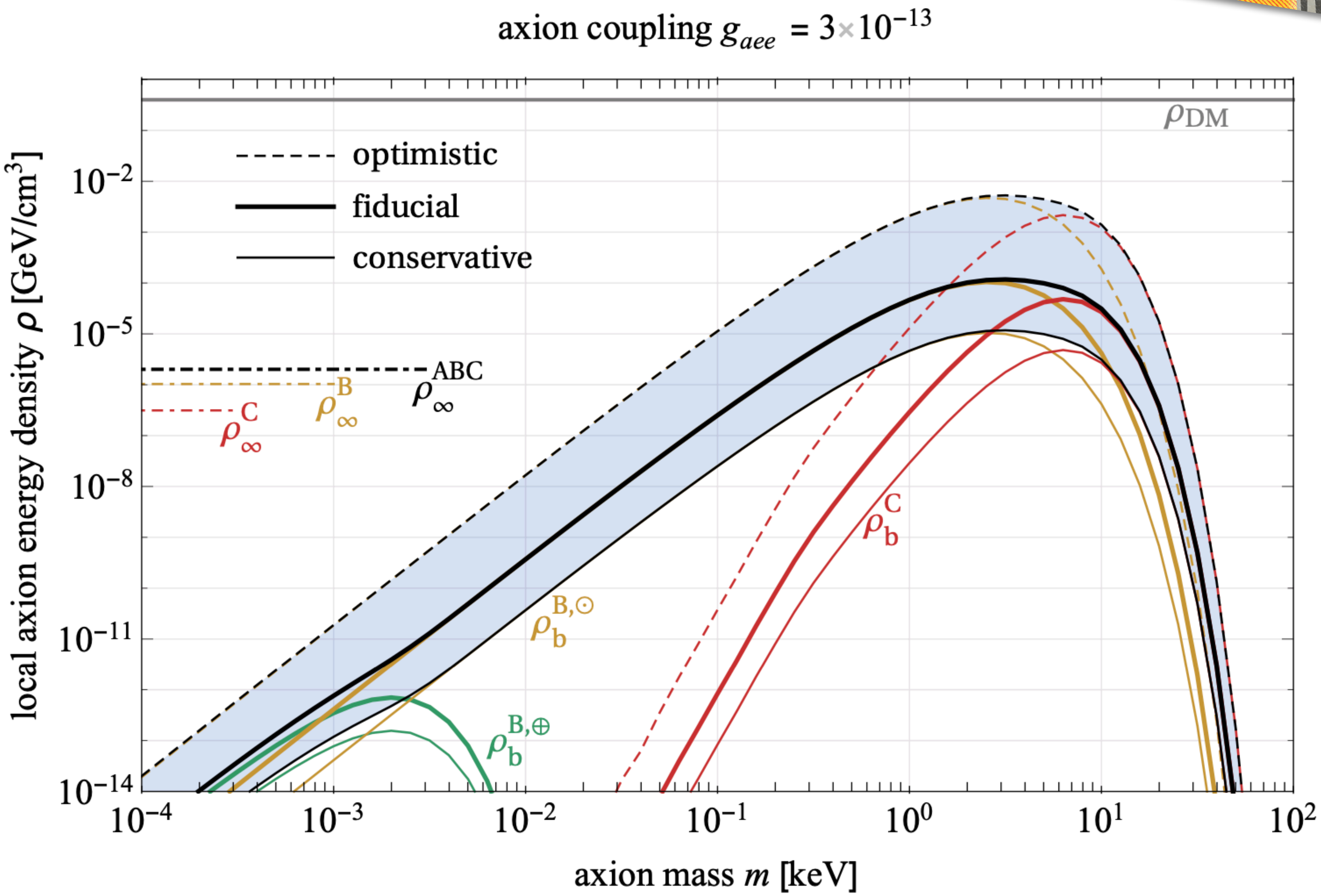


Small phase space (and hence production rate)
but **astrophysically long times**

$$\tau \sim 10^7 \text{ y}$$

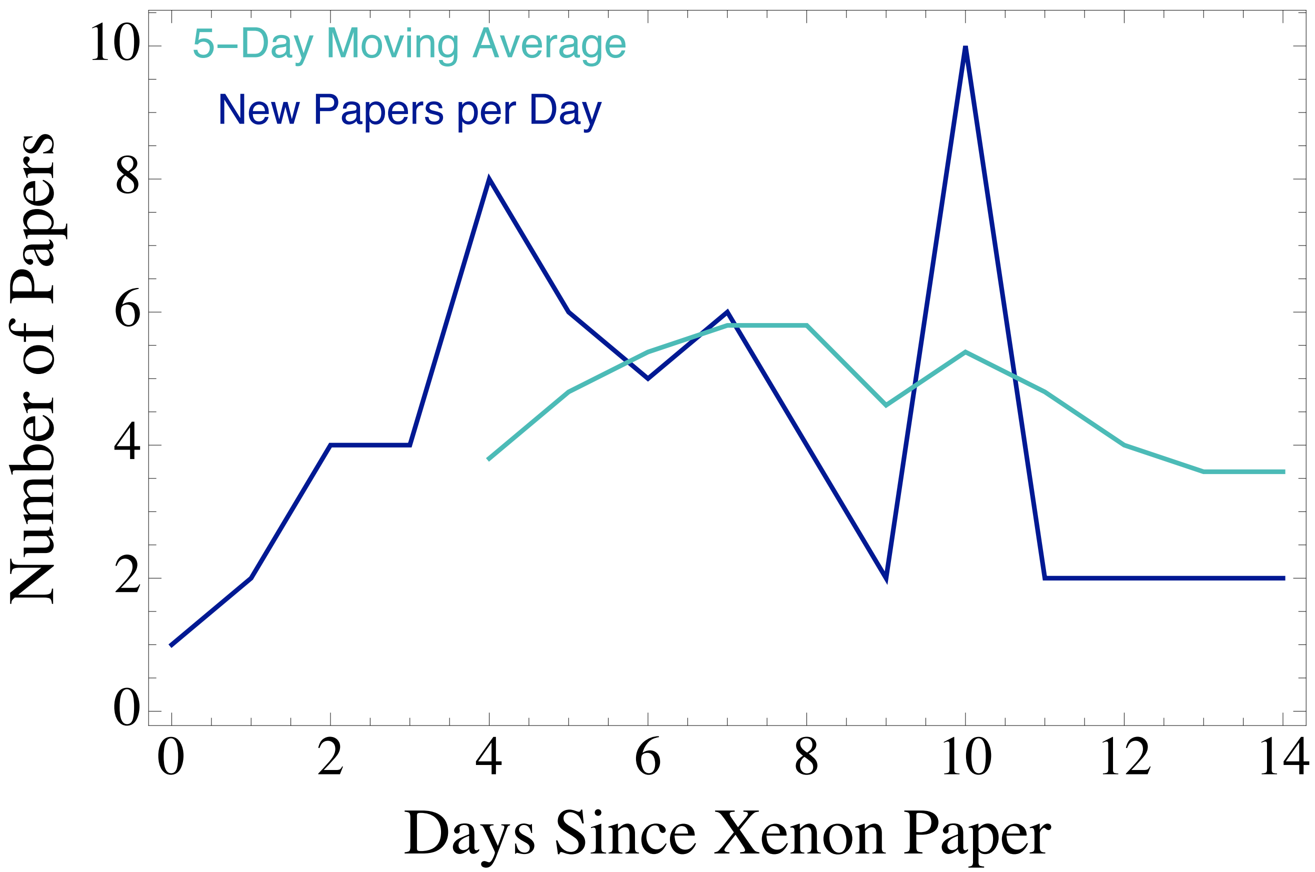
Van Tilburg
2006.12431

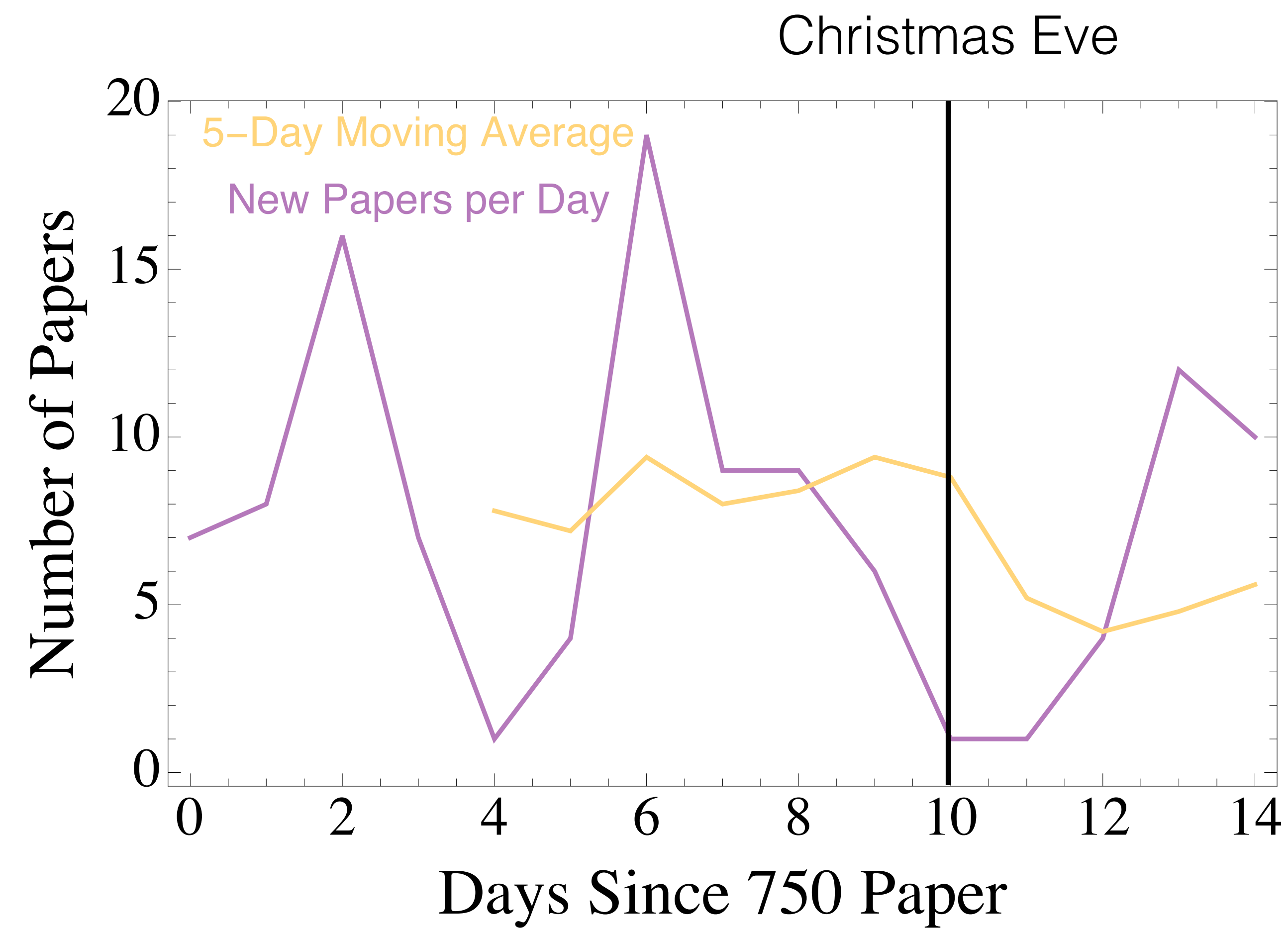
AXION BASIN



Van Tilburg
2006.12431


CHERRY PICKING


5–Day Moving Average
New Papers per Day
Number of Papers
0
2
4
6
8
10
0
2
4
6
8
10
12
14
Days Since Xenon Paper


Christmas Eve
5–Day Moving Average
New Papers per Day
Number of Papers
0
5
10
15
20
0
2
4
6
8
10
12
14
Days Since 750 Paper

INELASTIC DARK MATTER

$$\chi, \chi^*$$

Dirac mass + small Majorana mass

$$\delta = m_{\chi^*} - m_\chi$$

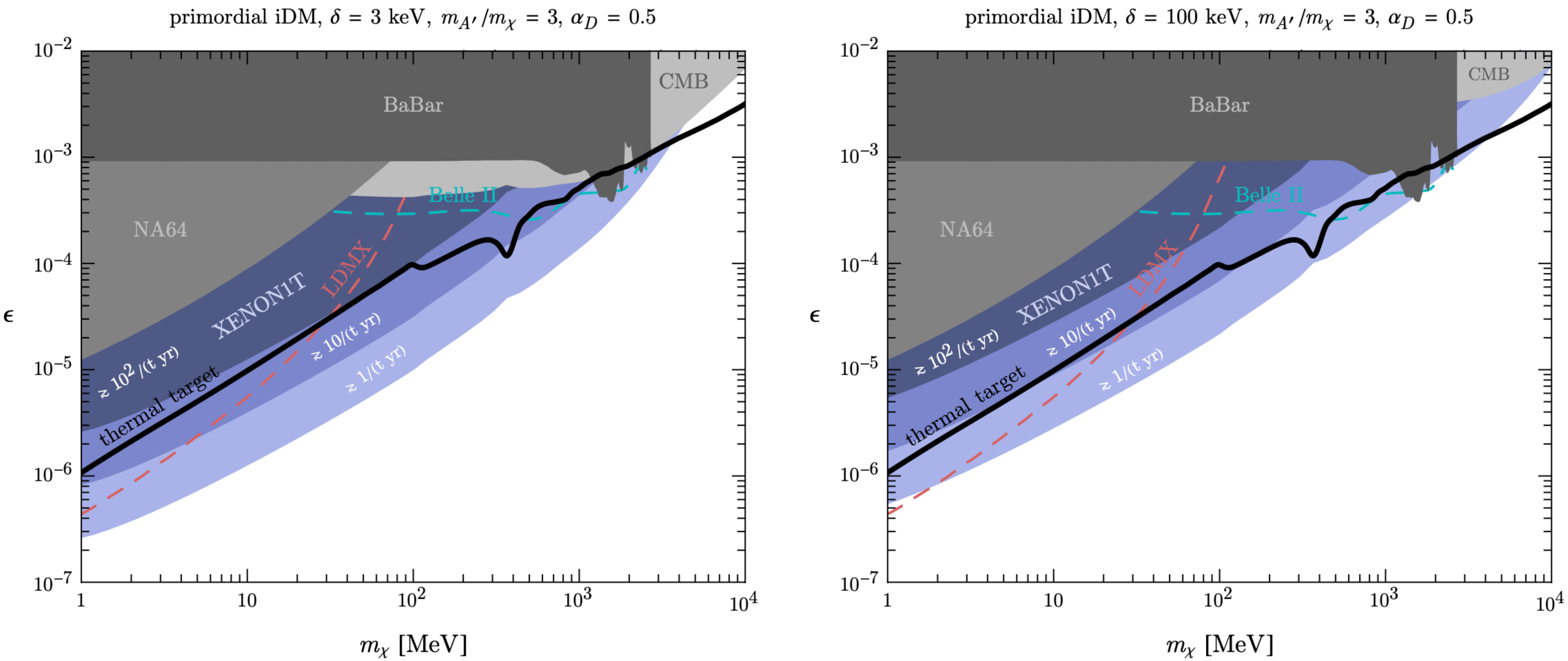
$$\mathcal{L} \supset \frac{\epsilon}{2} F_{\mu\nu} F'^{\mu\nu} + i e_D \, A'_\mu \, \bar{\chi}^* \gamma^\mu \chi + \frac{1}{\Lambda_d} \, \bar{\chi}^* \sigma^{\mu\nu} \chi \, F_{\mu\nu}$$

$$f_* \equiv \frac{n_{\chi^*}}{n_\chi + n_{\chi^*}} \simeq e^{-\delta/T_{\chi,\mathrm{chem}}}$$

Baryakhtar, Berlin, Liu, Weiner

2006.13918

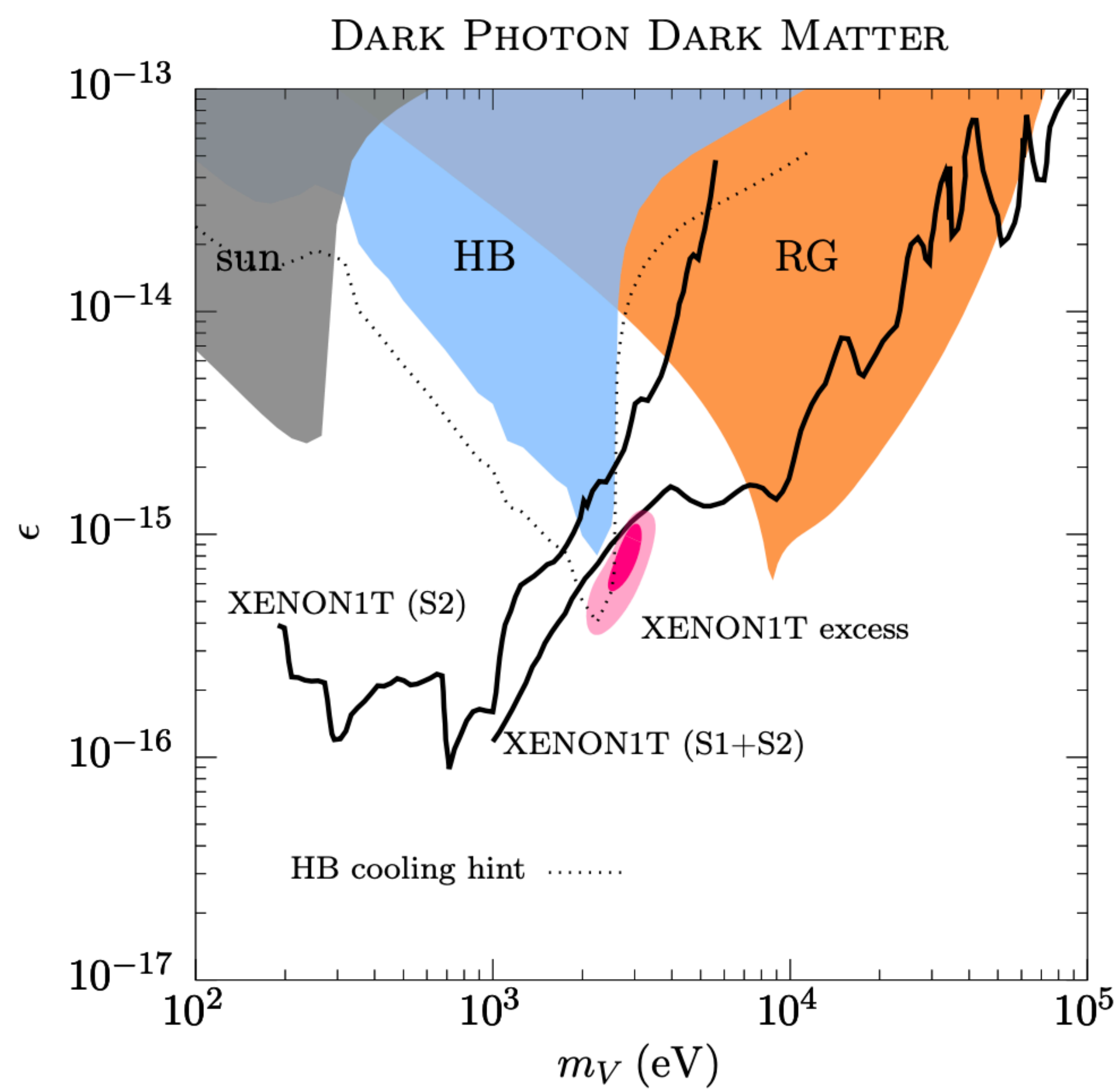
INELASTIC DARK MATTER



Baryakhtar, Berlin, Liu, Weiner

2006.13918

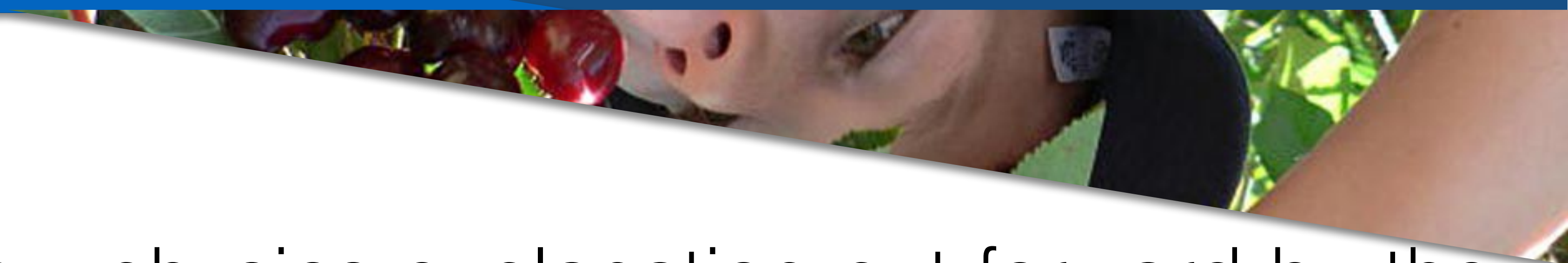
DARK PHOTON ABSORPTION



An, Pospelov, Pradler, Ritz

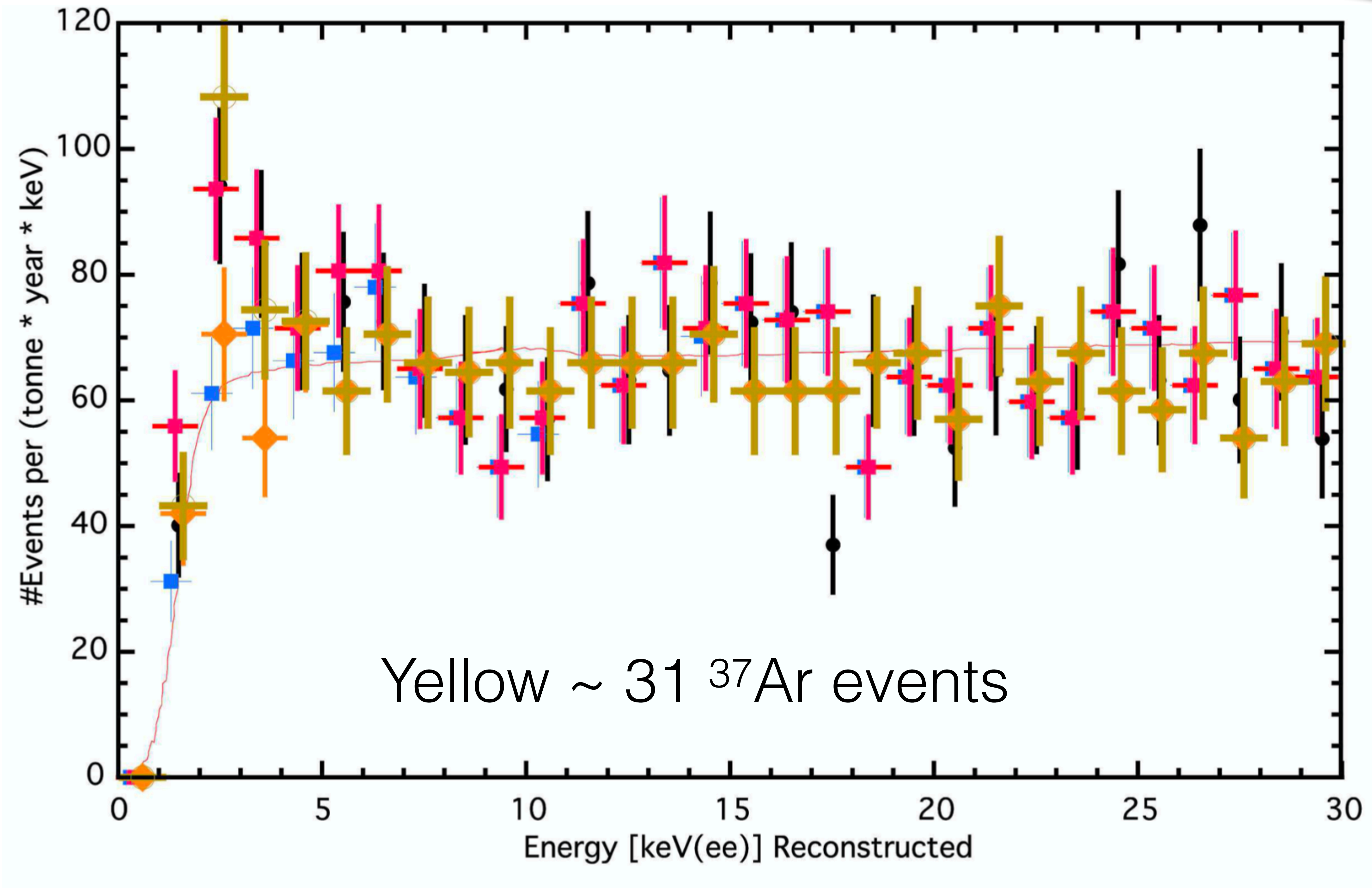
2006.13929

CONCLUSION



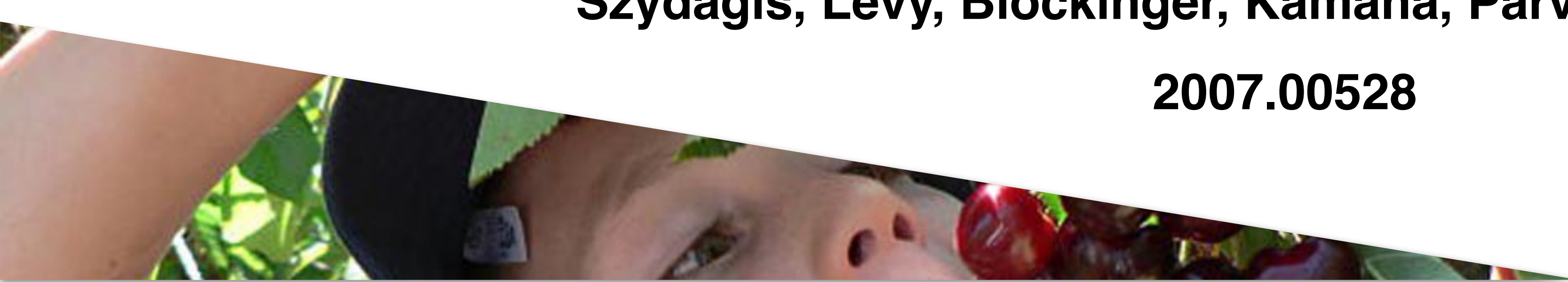
- The most appealing new physics explanation put forward by the collaboration requires some model building work (or Primakoff events in the detector).
- There are simple alternative new physics explanations that can (superficially) fit the excess (e.g. inelastic pseudo-Dirac dark matter)
- Once the initial excitement will be over (maybe it already is) we will be left with a few interesting theoretical results (for instance stellar basins)

BACKUP

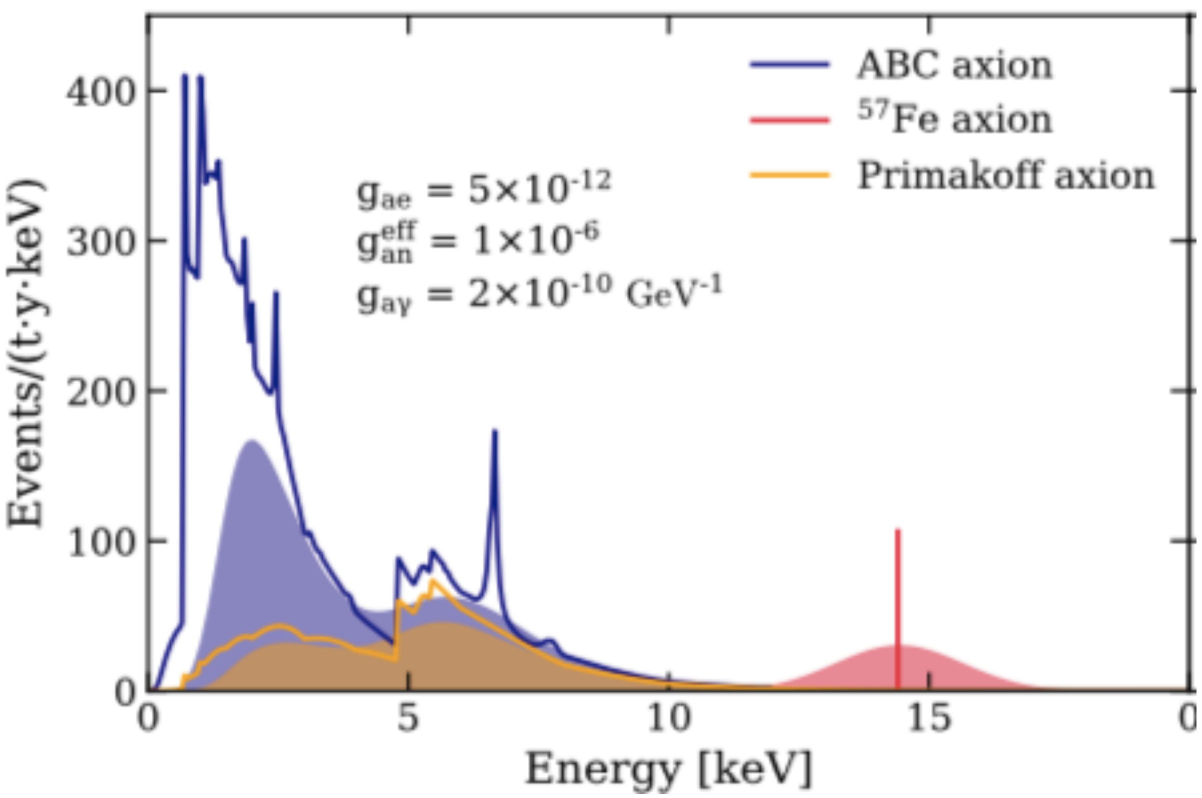


Szydagis, Levy, Blockinger, Kamaha, Parveen, Rischbieter

2007.00528



SIGNAL

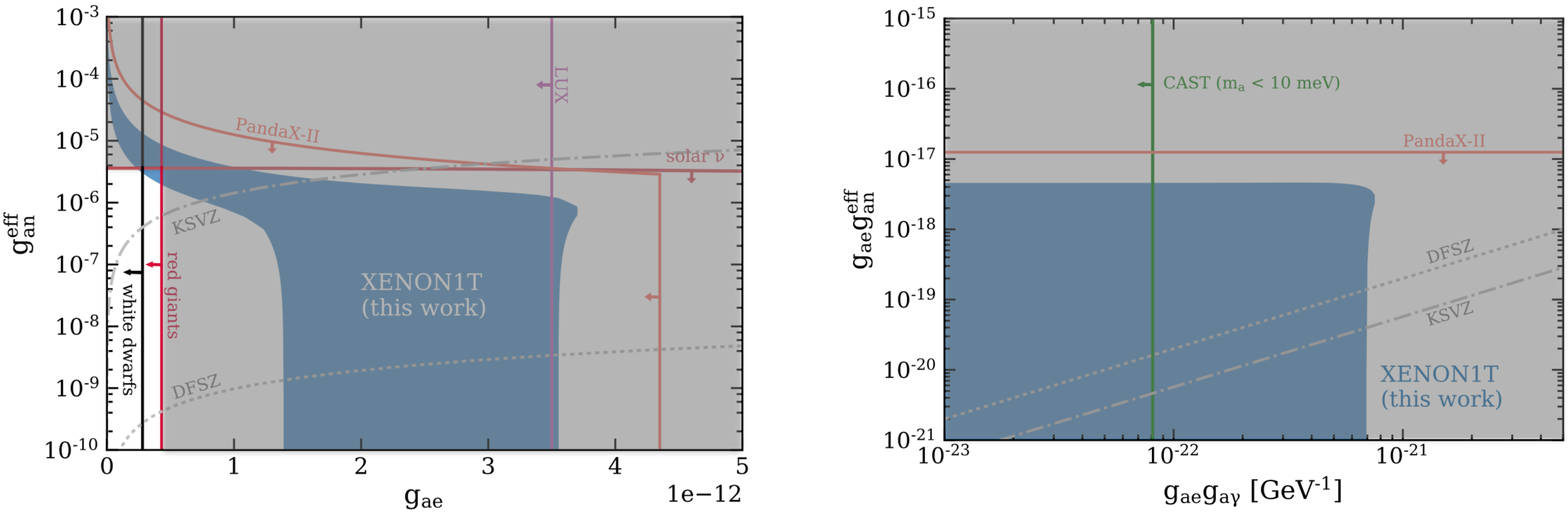


$$\text{ABC} \sim g_{ae}^4$$

$$\text{Primakoff} \sim g_{ae}^2 g_{a\gamma}^2$$

$$\text{Fe} \sim g_{ae}^2 (g_{an}^{\text{eff}})^2$$

RESULTS



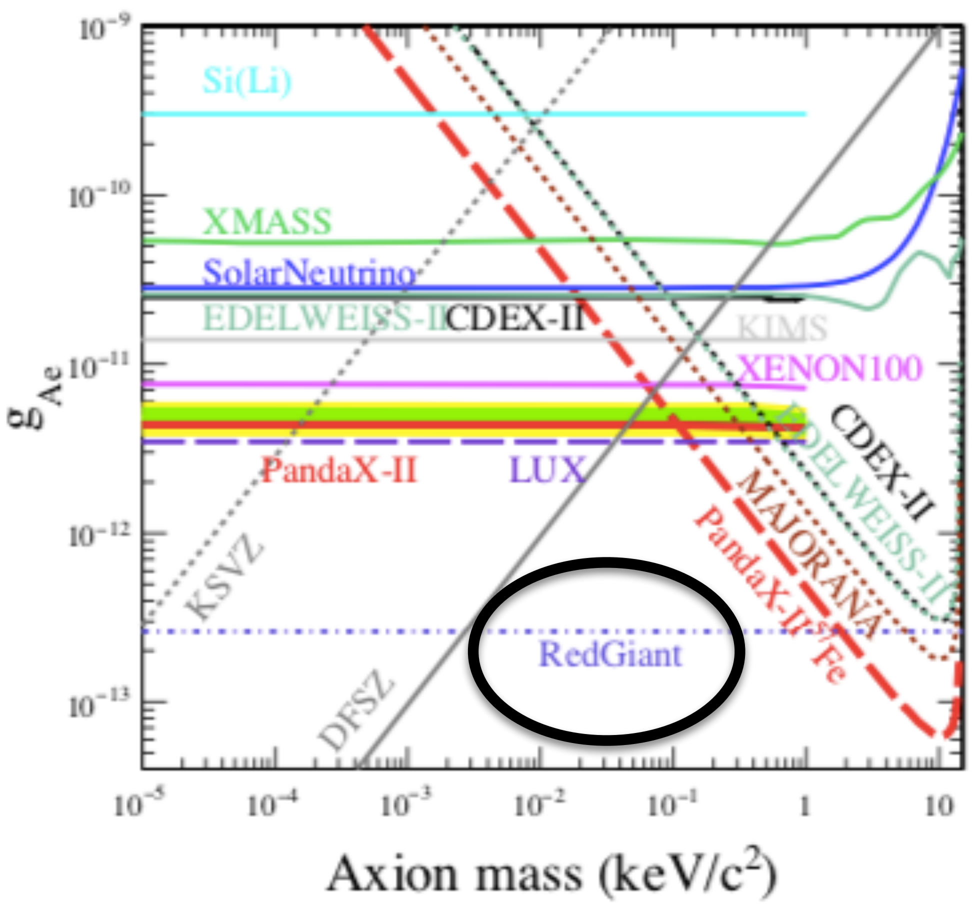
"natural" stellar cooling $g_{ae} \lesssim \frac{m_e}{f_a}$ $g_{an}^{\rm eff} \lesssim \frac{m_N}{f_a}$ $g_{a\gamma} \lesssim \frac{\alpha}{8\pi f_a}$

PANDAX-II

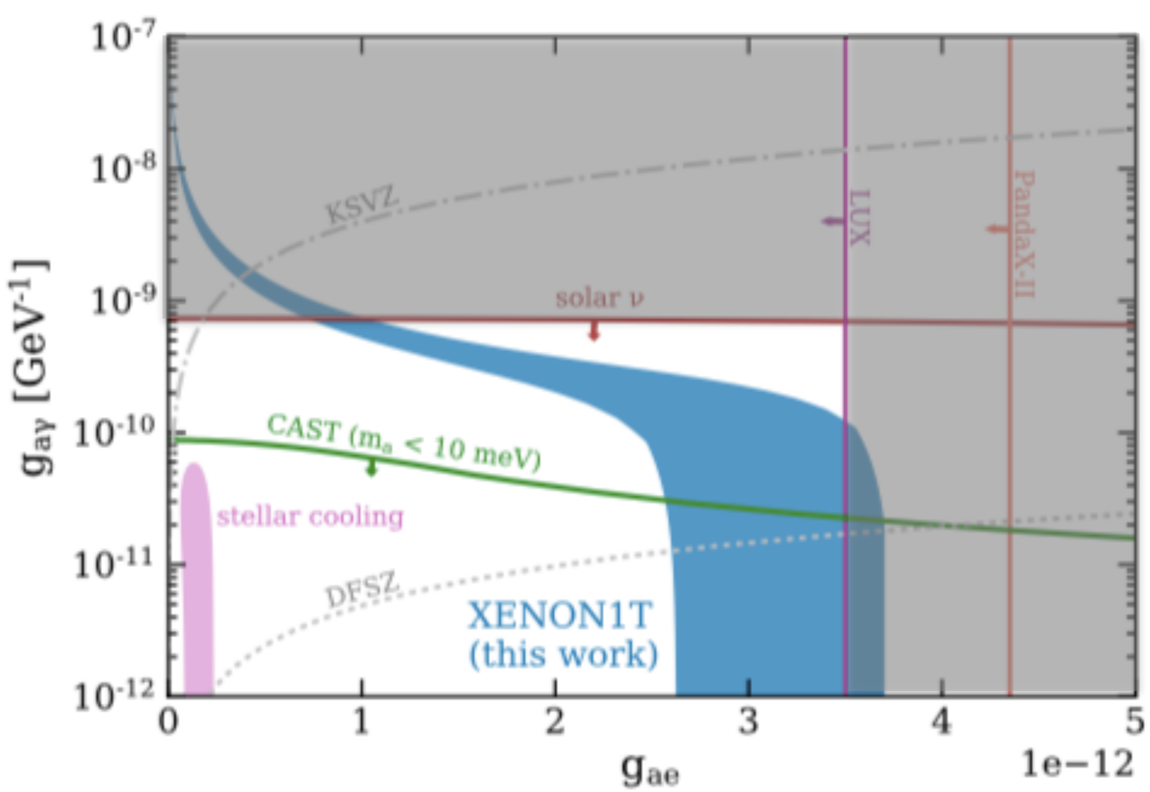
arXiv:1707.0792

Same axion production and detection mechanisms

PandaX-II



Xenon1T



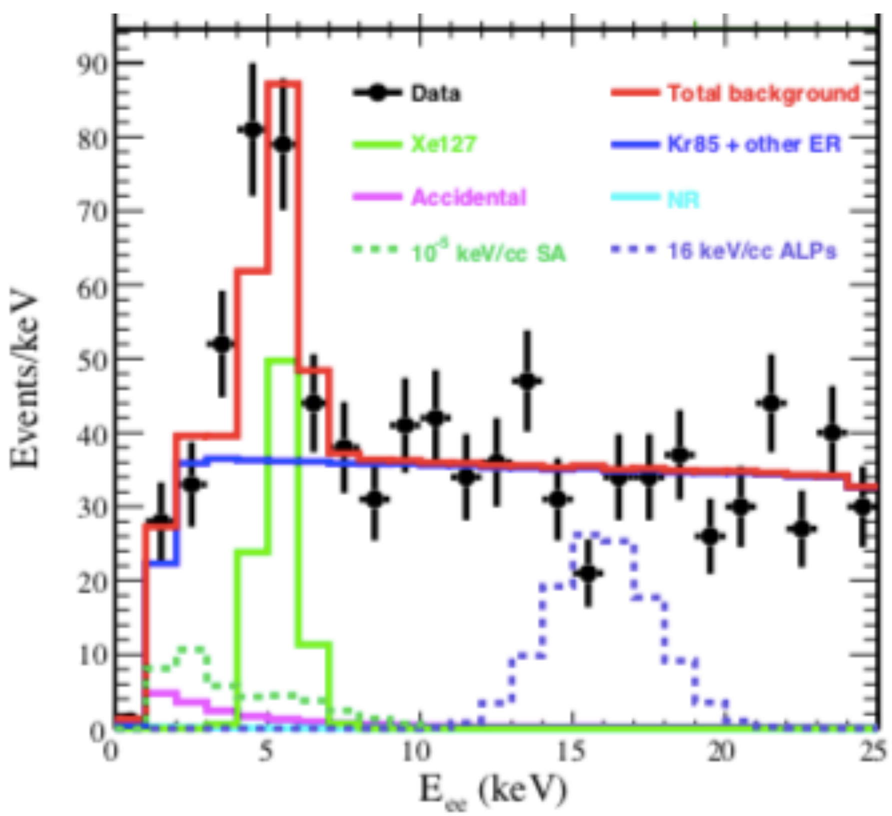
PANDAX-II

Excludes Xenon Excess

arXiv:1707.0792

Same axion production and detection mechanisms

PandaX-II



$$2.7 \times 10^4 \text{kg} \times \text{day}$$

Xenon1T