

Hidden vectors from solar nuclear reactions

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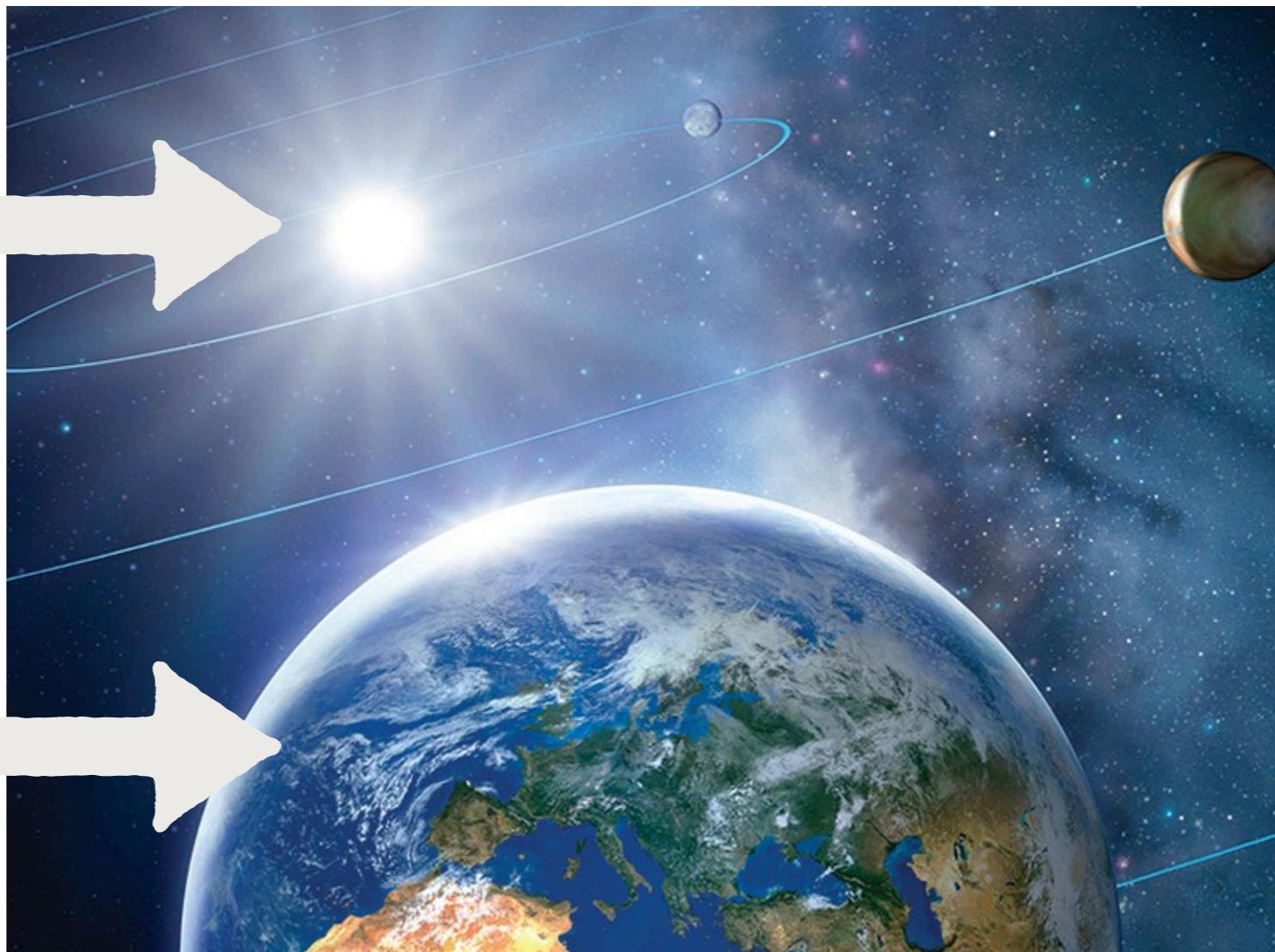


Particle Physics from Early Universe to Future Colliders

Portoroz — 13 April 2023

Solar Signals from Hidden Sectors

Weakly-coupled
particles produced in
the solar interior

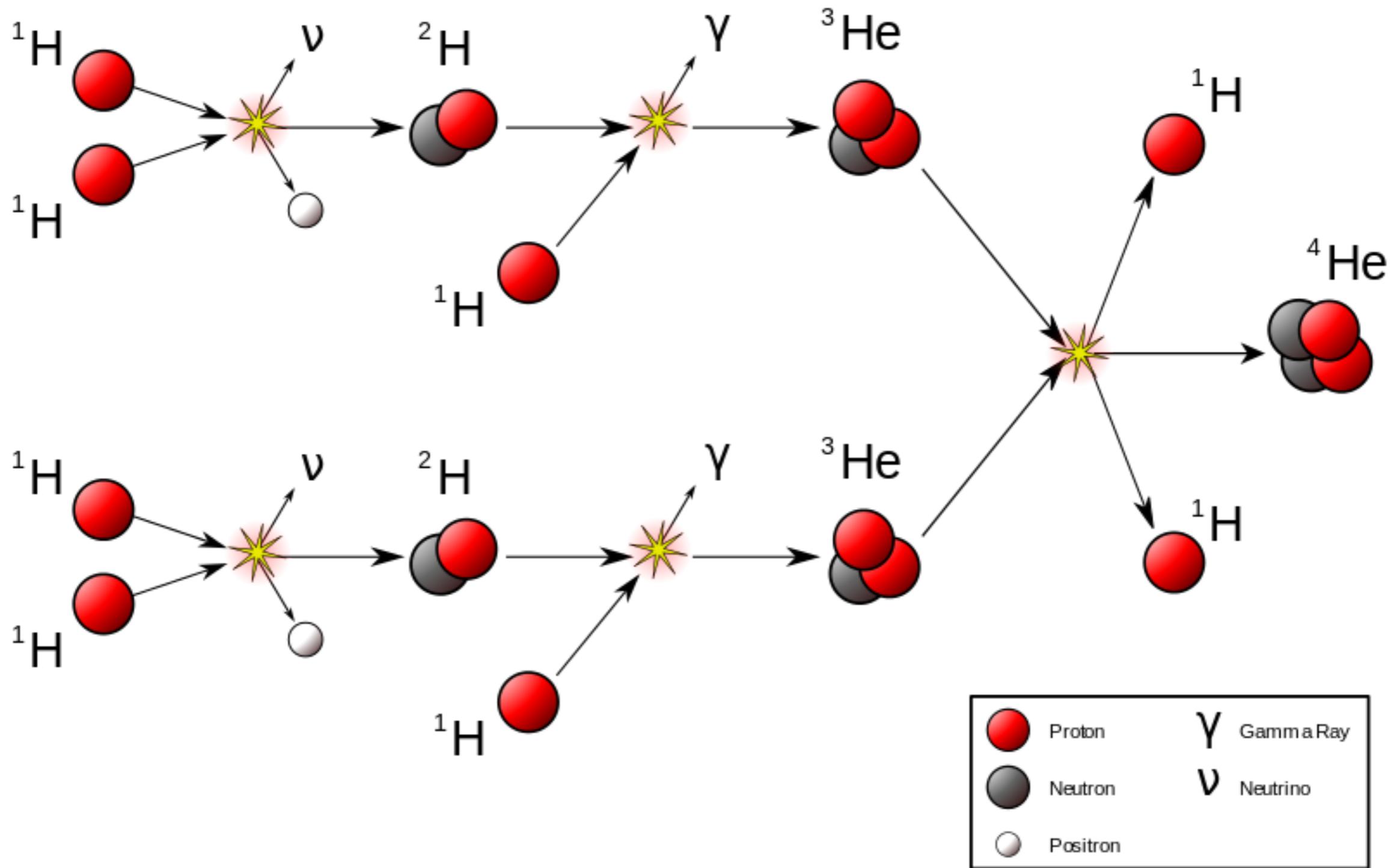


Terrestrial detection

In this talk:

Terrestrial detection of weakly-coupled particles
produced by solar nuclear reactions ($E \approx \text{MeV}$)

The p-p Chain



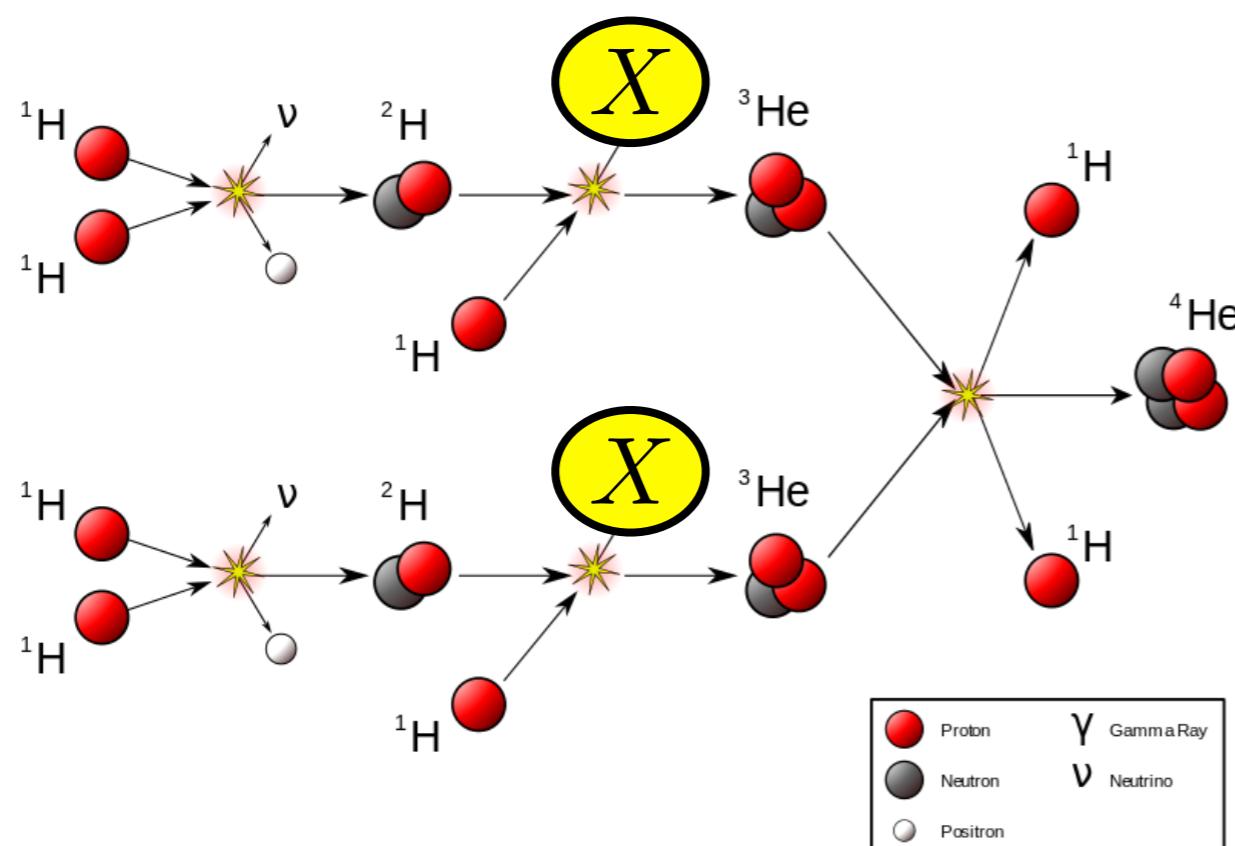
New States in the Solar Core

$$\mathcal{N}_1 \mathcal{N}_2 \rightarrow \mathcal{N}_3 X$$

Feebly coupled particle X
produced by nuclear reactions,
escape the solar interior
without further interactions

Donnelly et al., PRD18 (1978)

Raffelt and Stodolsky, PLB119 (1982)



$$p d \rightarrow ^3 \text{He } X$$

Second stage of the p-p chain:
monochromatic X (5.49 MeV)

$$\Phi_X = \frac{\Gamma_X}{\Gamma_\gamma} \Phi_{\nu,pp}$$

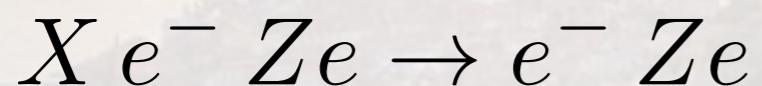
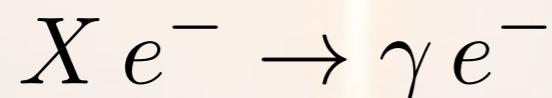
Terrestrial Detection

How to detect a flux of monochromatic X particles?

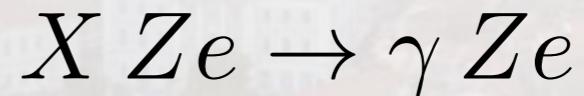
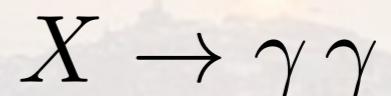
It depends on the target and on the X's properties
Couplings to electron and photon are crucial

Some examples:

Electron Coupling



Photon Coupling



A known example: the QCD Axion

QCD Axions (or ALPs in general) produced by solar nuclear reactions and detected on Earth

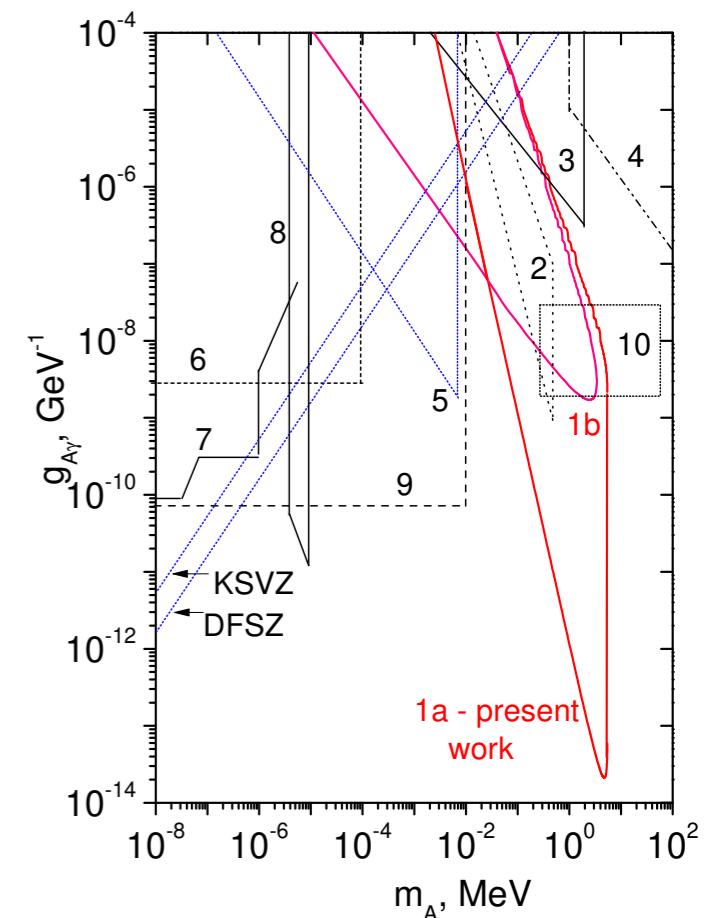
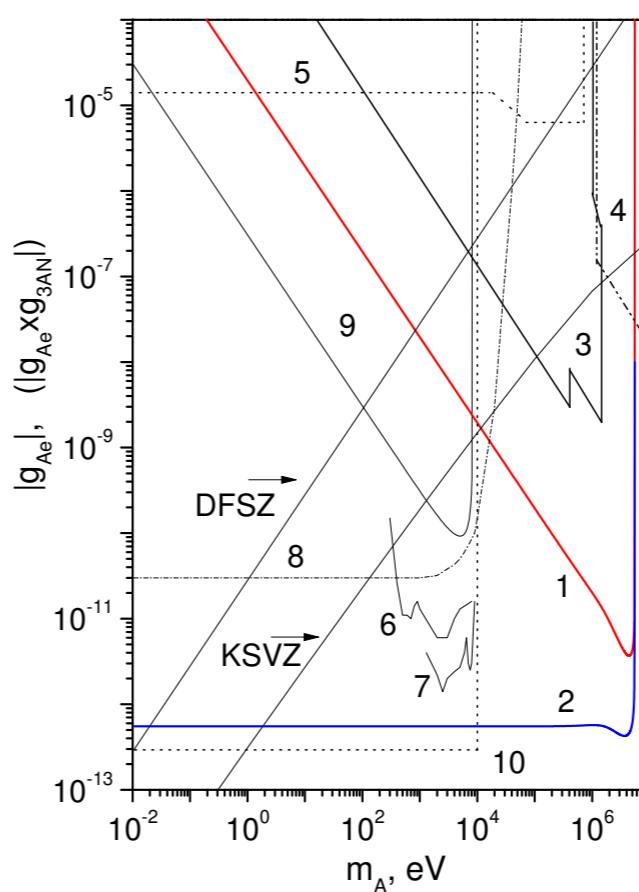
$$\mathcal{L}_a = -a \left[\bar{N}(g_{0N} + g_{3N}\tau^3)i\gamma^5 N + \frac{1}{4}g_{a\gamma}F_{\mu\nu}\tilde{F}^{\mu\nu} + g_{ae}\bar{e}i\gamma^5 e \right]$$

Axion production controlled by the iso-triplet coupling

$$\frac{\Gamma_a}{\Gamma_\gamma} \simeq 1.53 g_{3N}^2 \left(\frac{k_a}{k_\gamma} \right)^3$$

Avignone et al., PRD37 (1988)

Massarczyk et al., PRD105 (2022)

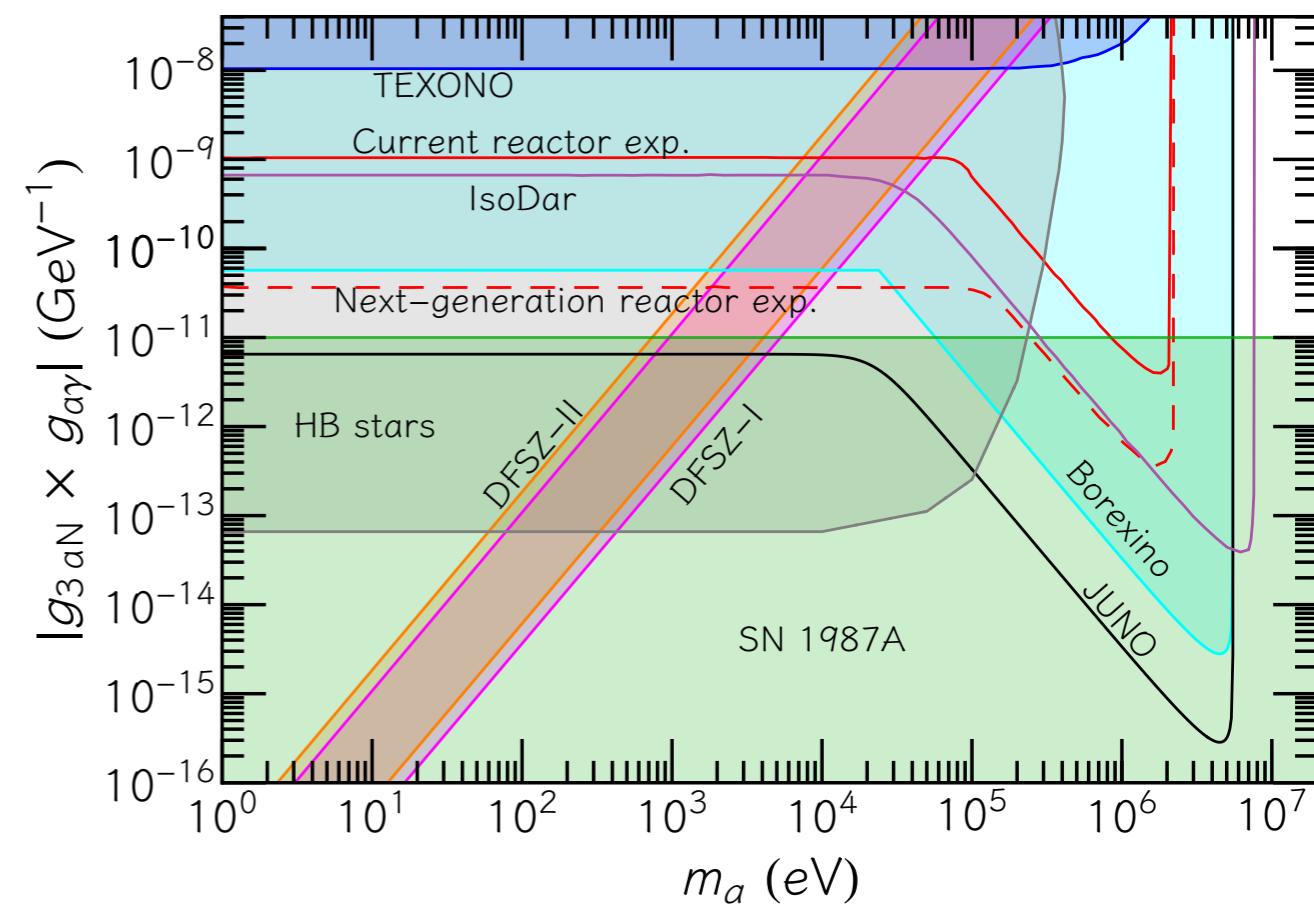
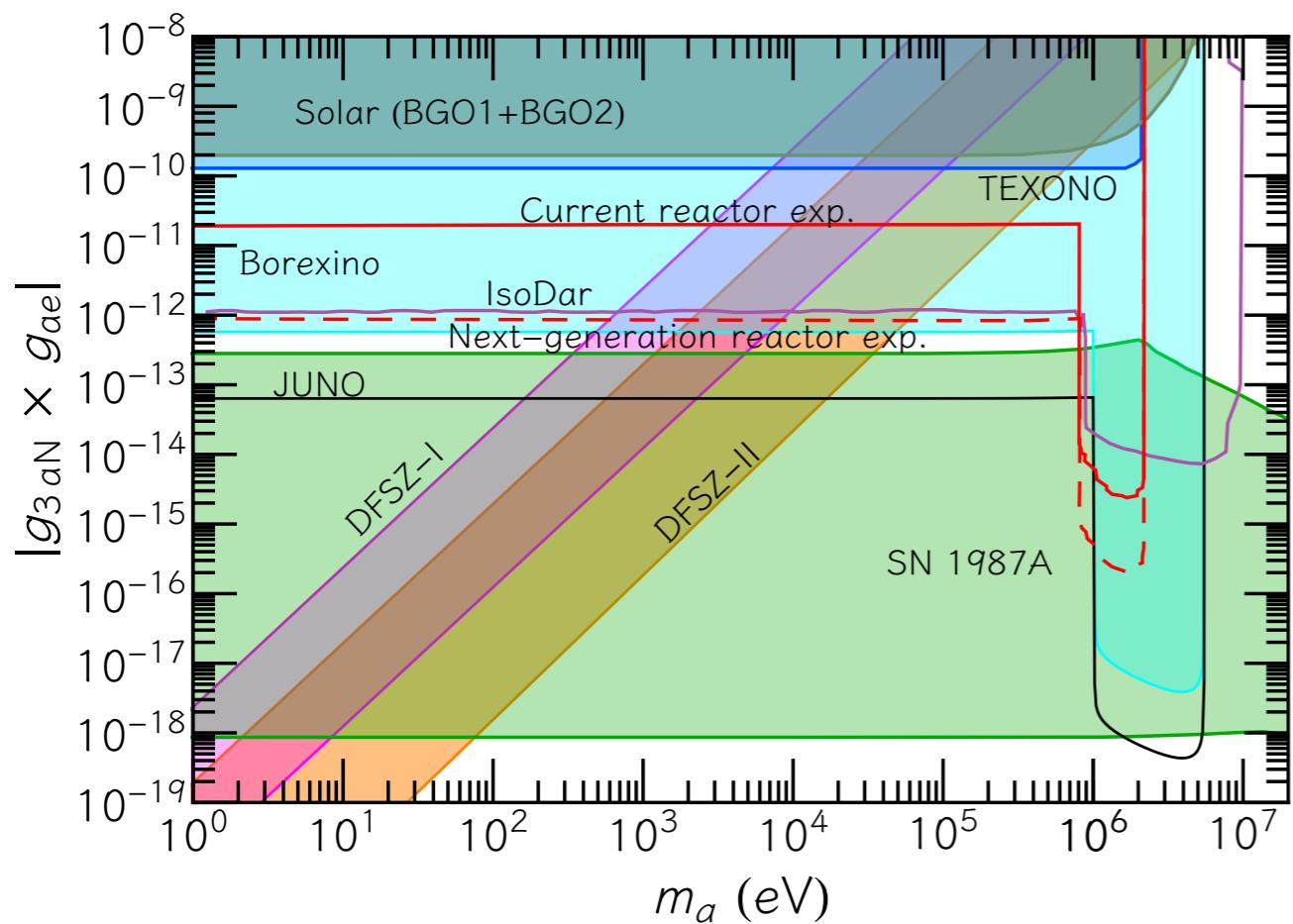


QCD Axion: Future Prospects

JUNO: Jiangmen Underground Neutrino Observatory

Large fiducial mass (~20 kton)
and
exquisite energy resolution ($3\% / (E(\text{MeV}))^{1/2}$)

JUNO Collaboration, Prog.Part.Nucl.Phys. 123 (2022)



Lucente et al., PRD 106 (2022)

Massive Vectors

Examples include: Abelian extensions of the SM gauge group, resonances from confining dark sectors, ...

Low-energy Lagrangian

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{m_{\gamma'}^2}{2}A'_\mu A'^\mu + \frac{\varepsilon}{2}F_{\mu\nu}F'^{\mu\nu} + eJ_{\text{EM}}^\mu A_\mu + e'J'^\mu A'_\mu$$

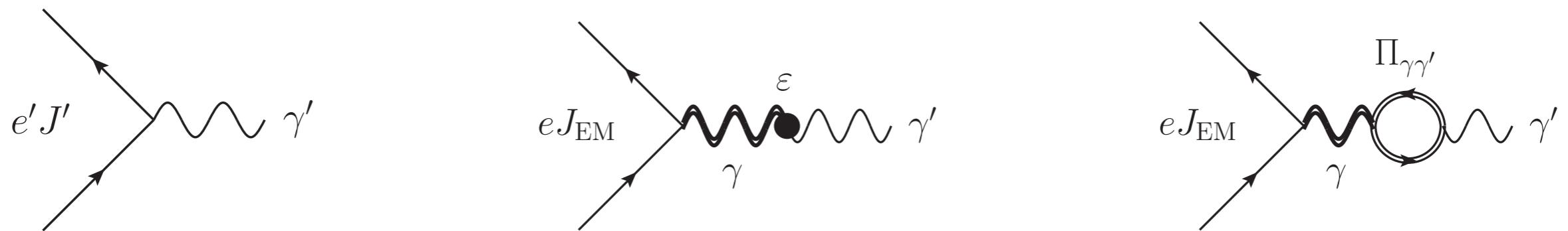
Portals to the visible universe:

- kinetic mixing ($\varepsilon \neq 0$)
- dark charges of SM states ($J' \neq 0$, vector-like charges)

Production I: Physical States

Procedure to identify physical states different than in the vacuum due to plasma effects

Hardi and Lasenby, JHEP02 (2017)
Hong et al., PRD103 (2021)



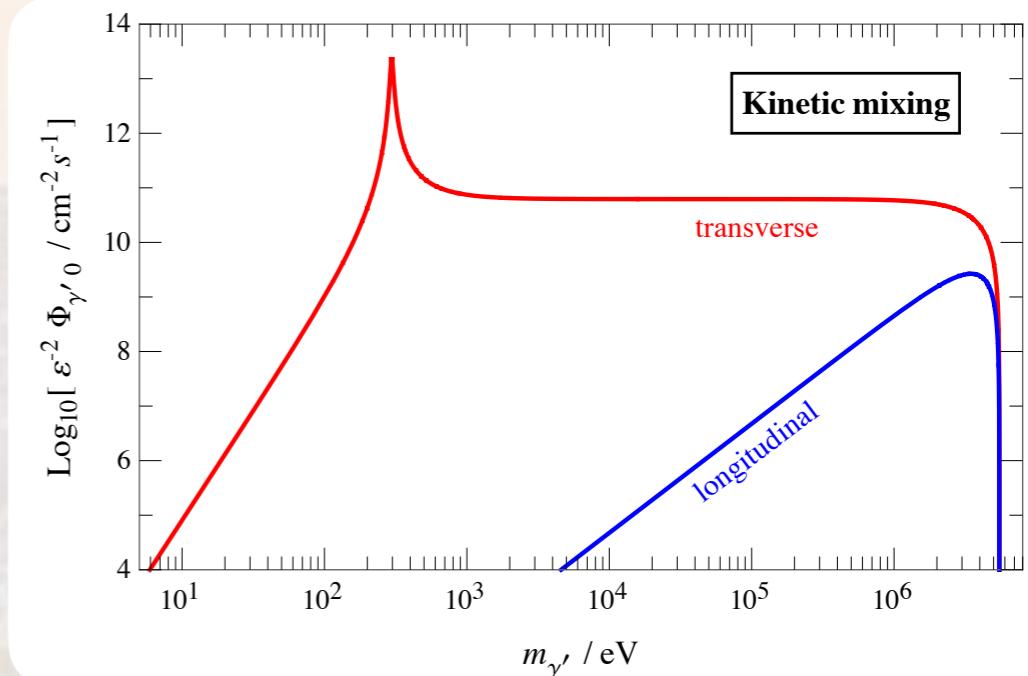
$$\mathcal{L}_{\text{plasma}} \supset e' J'^\mu A'_\mu + \left(\epsilon \frac{m_{\gamma'}^2}{m_{\gamma'}^2 - \pi_{T,L}} + \frac{e' q'_e}{eq_e} \frac{\pi_{T,L}}{m_{\gamma'}^2 - \pi_{T,L}} \right) e J_{\text{EM}}^\mu A'_\mu$$

Production dominated by the
iso-vector coupling to nucleons

Production II: Fluxes

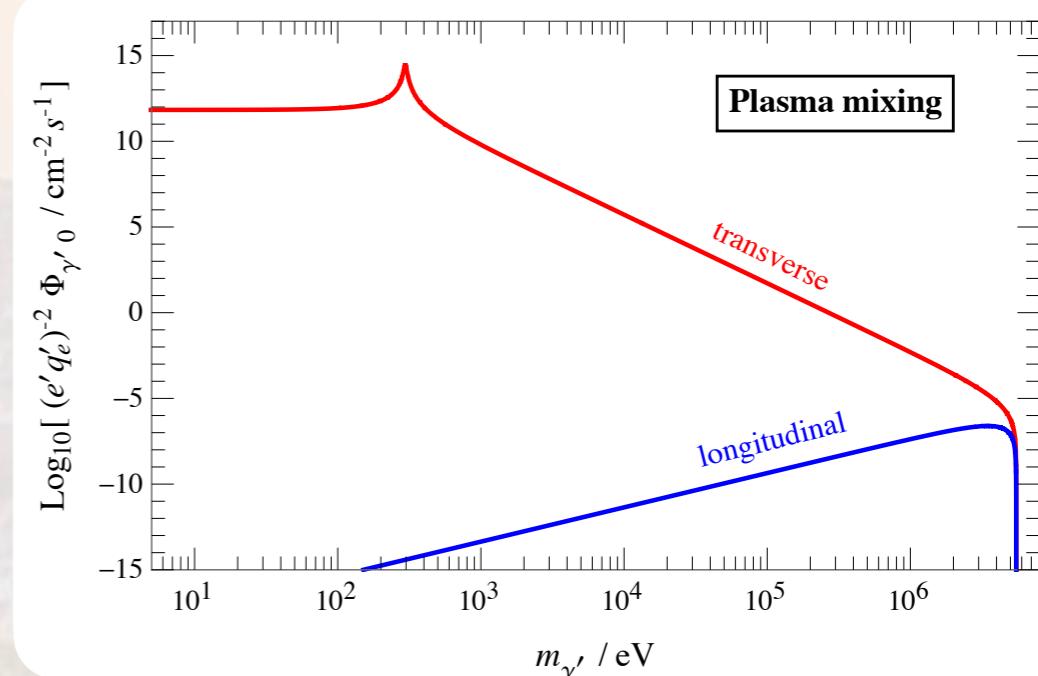
Kinetic Mixing

Only kinetic mixing switched on
Dark charges of SM states vanishing



Plasma Mixing

Production controlled by the
dark charge of the electron field
Kinetic mixing negligible

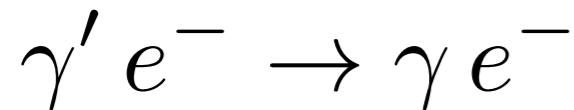


Detection Channels

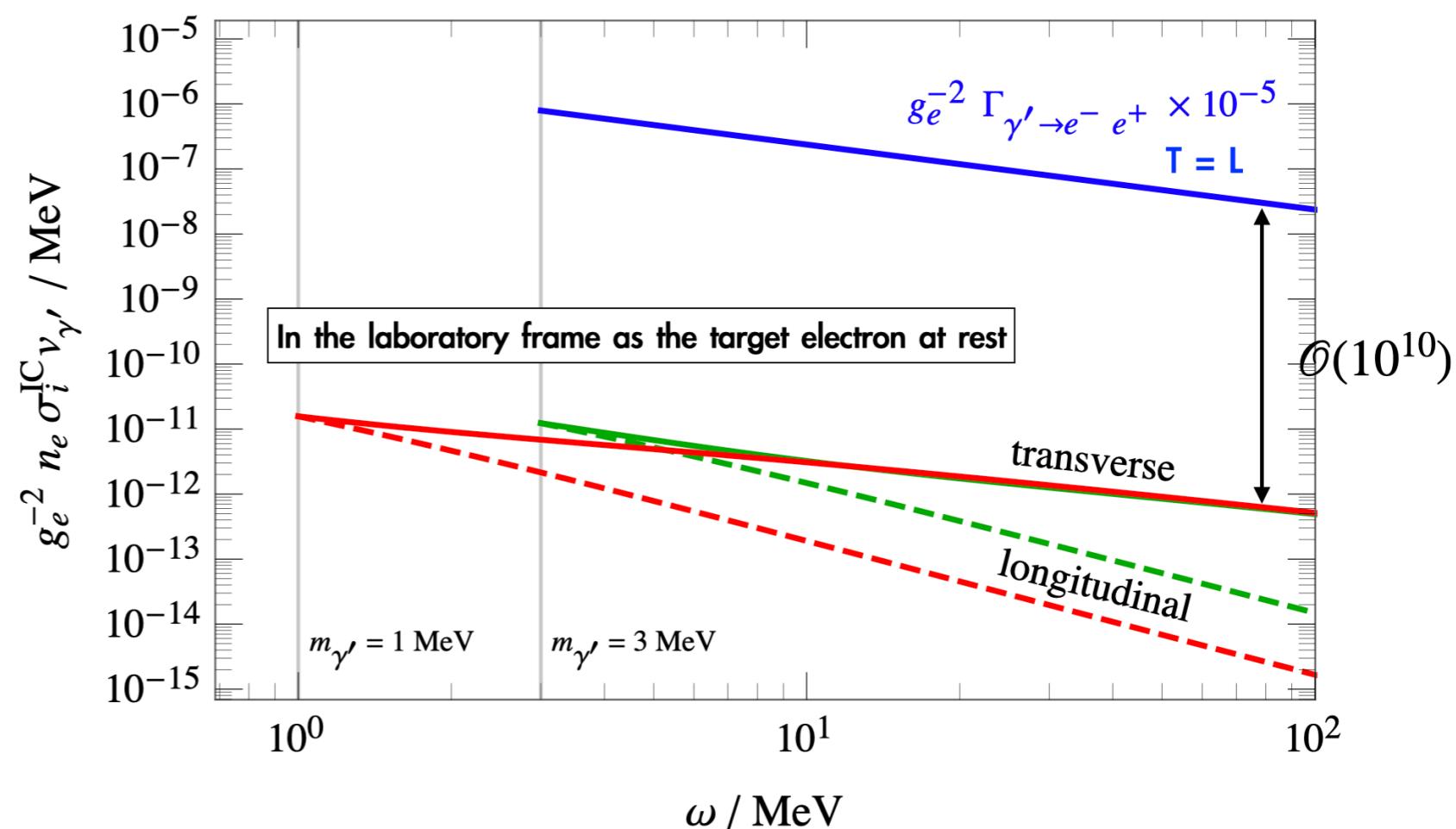
Detection controlled by the effective coupling to the electron

$$g_e = -\varepsilon e + e' q'_e$$

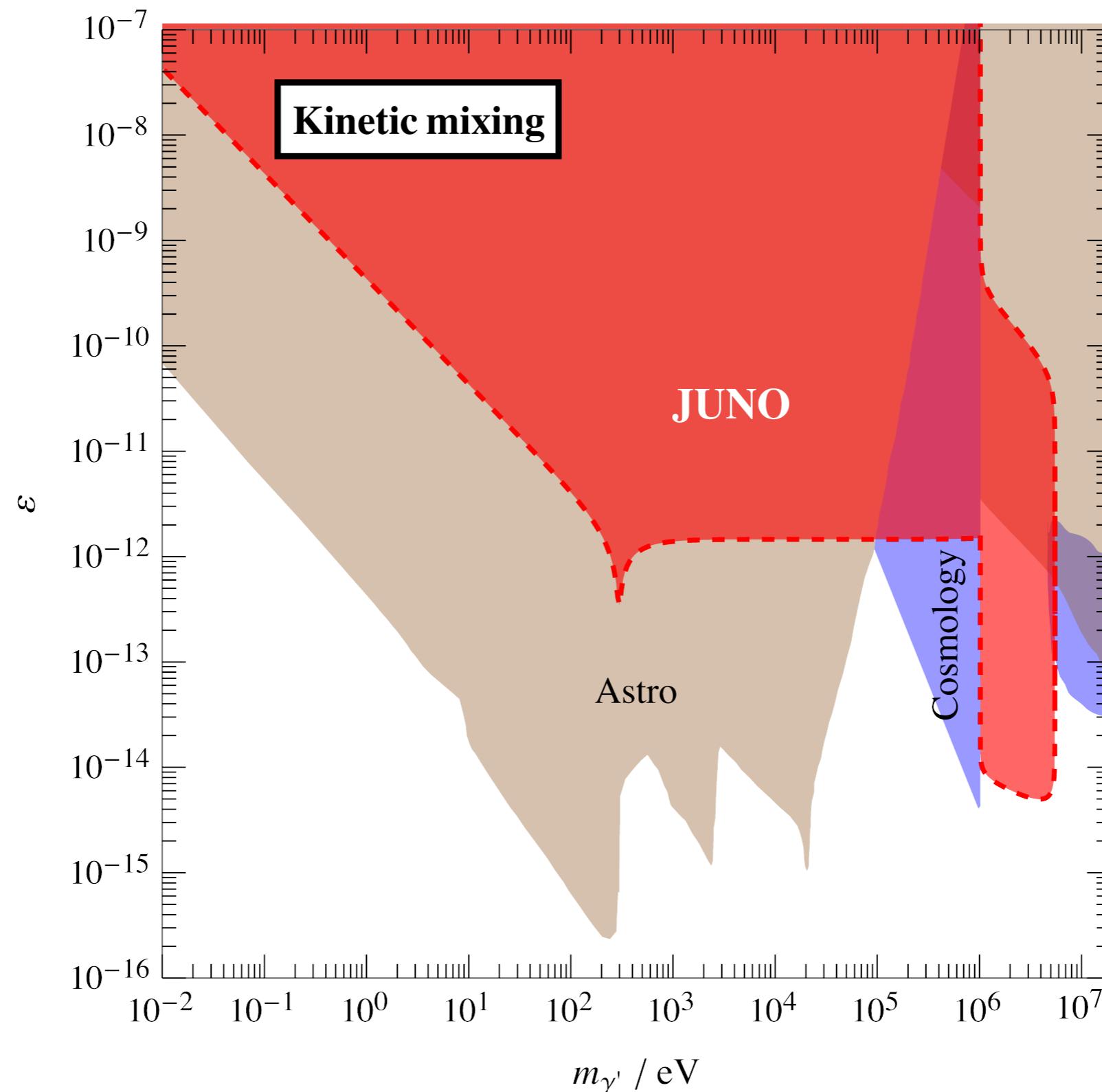
Inverse Compton-like



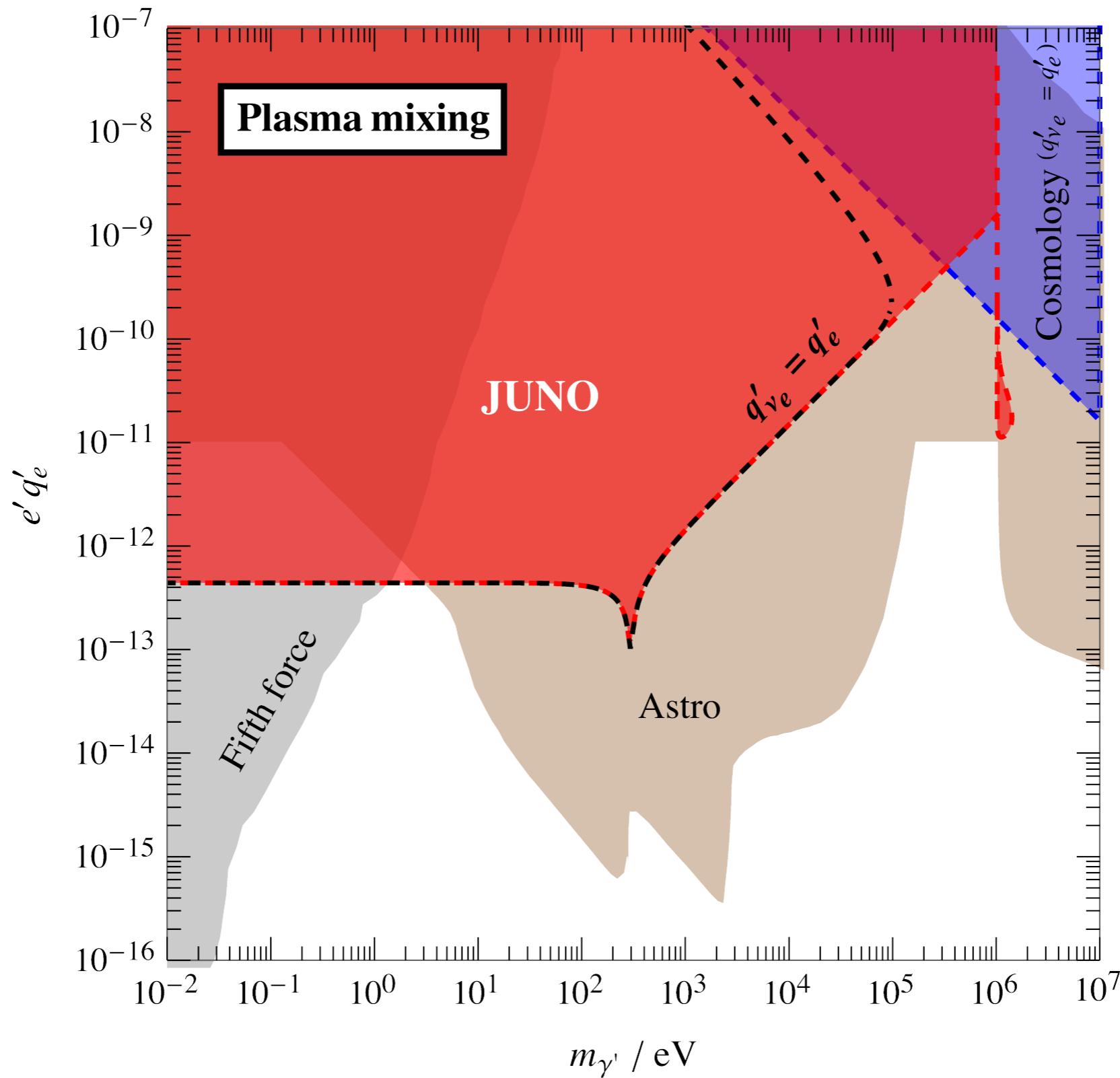
Dark vector decay



Results I: Kinetic Mixing



Results II: Plasma Mixing

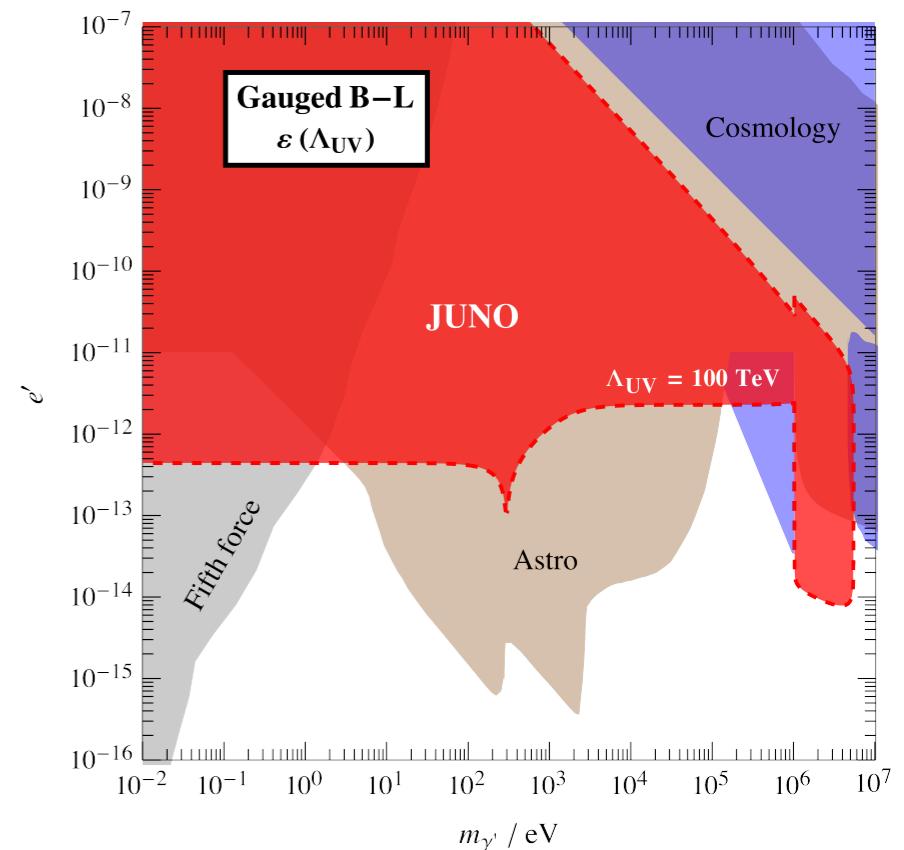
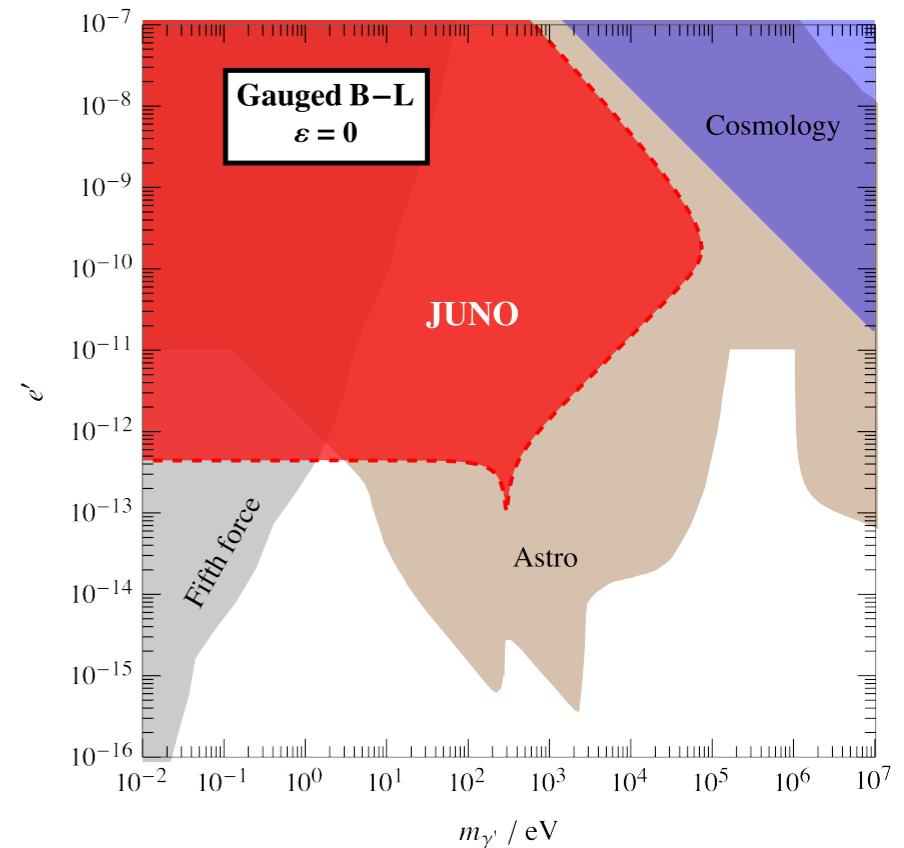


Outlook

- Solar core source of polarized massive vectors up to MeV mass
- Plasma effects crucial for computation of fluxes
- Single coupling phenomenology
- Two benchmark scenarios:
kinetic and plasma mixing
- Applications to UV completions?

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HVALA VAM!

