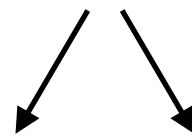


Stellar Basins of Gravitationally Bound Particles

Ken Van Tilburg

KITP @ UCSB



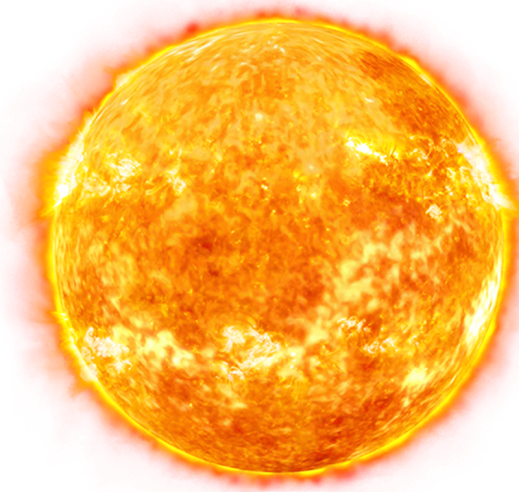
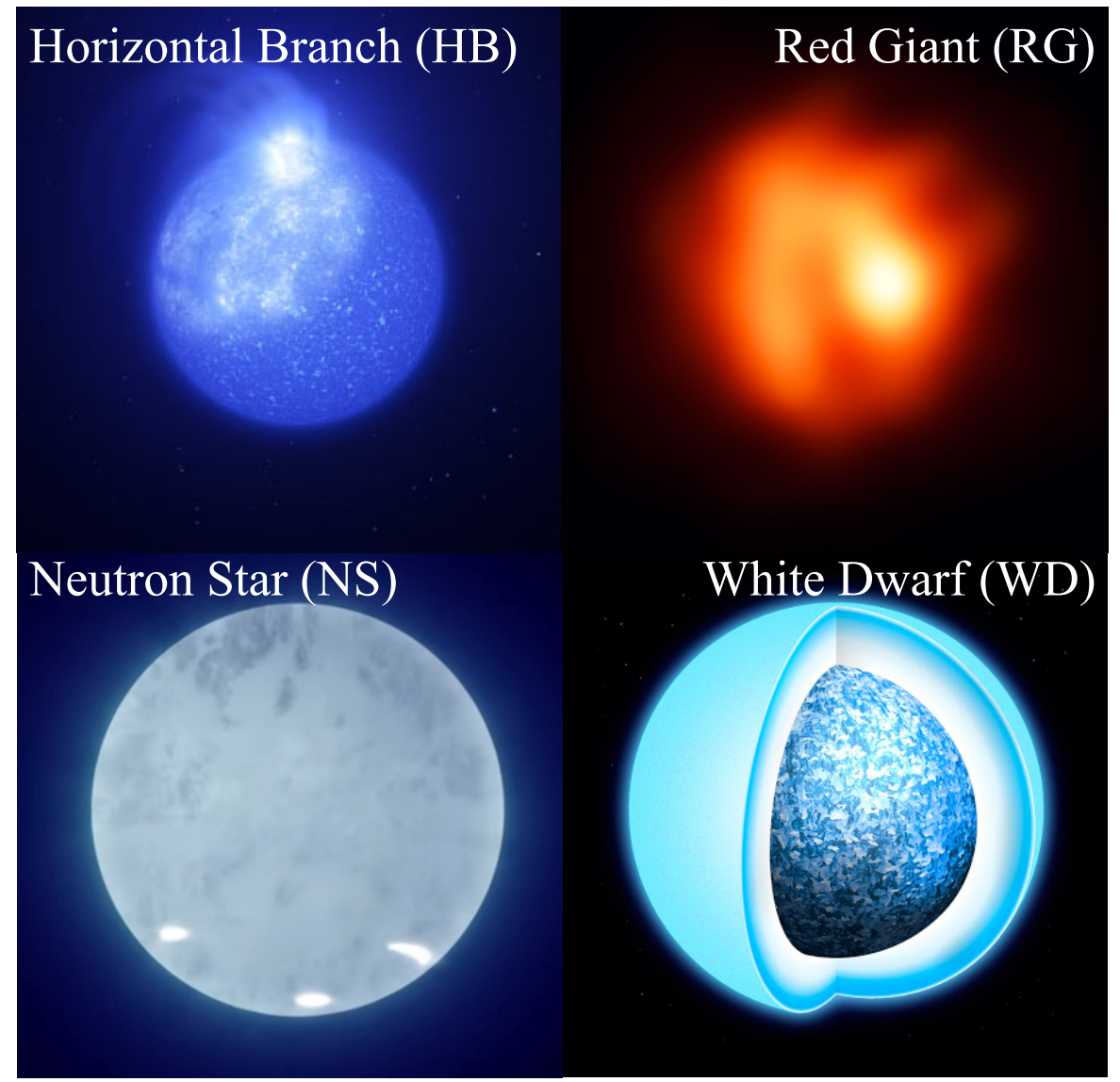
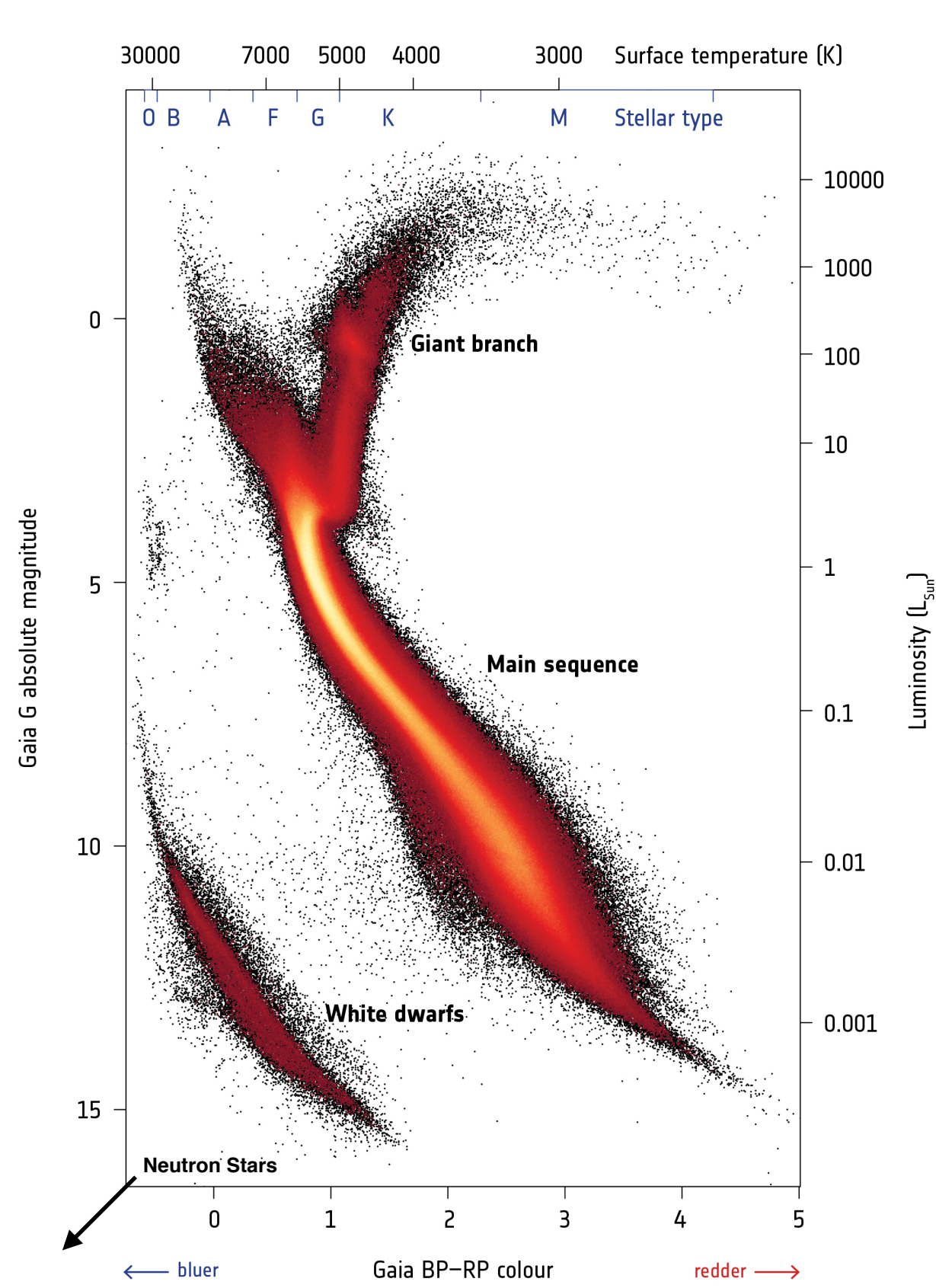
NYU + CCA @ Flatiron

Based on: KVT, “Stellar Basins of Gravitationally Bound Particles”, arXiv:2006.12431

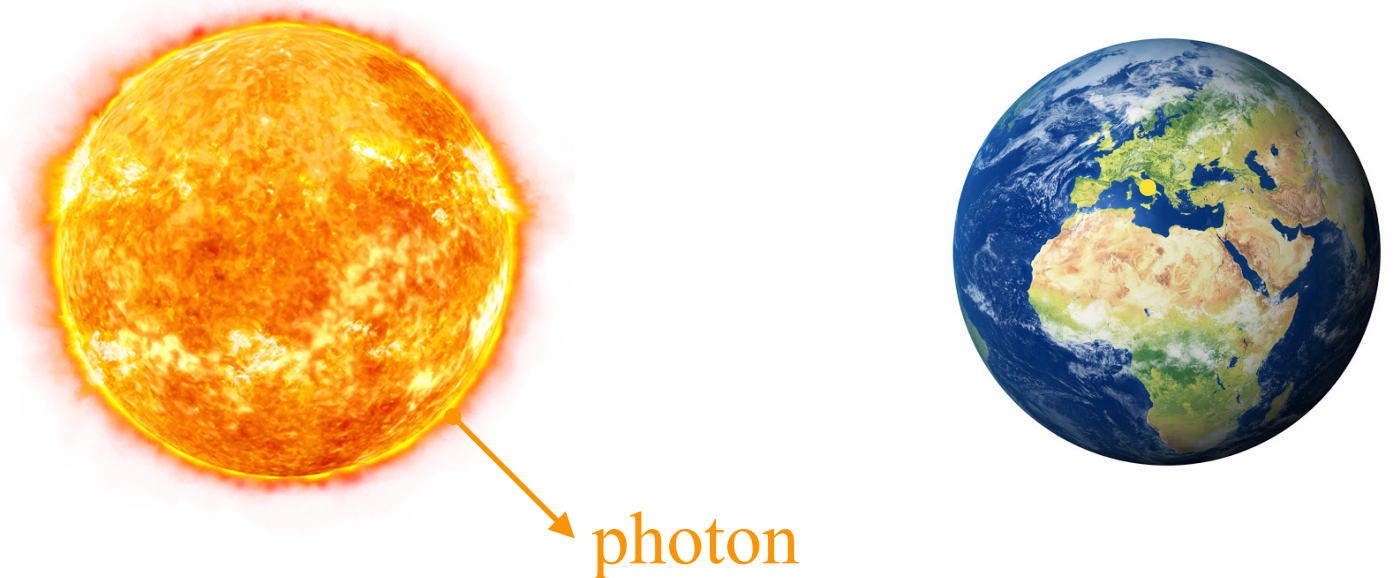
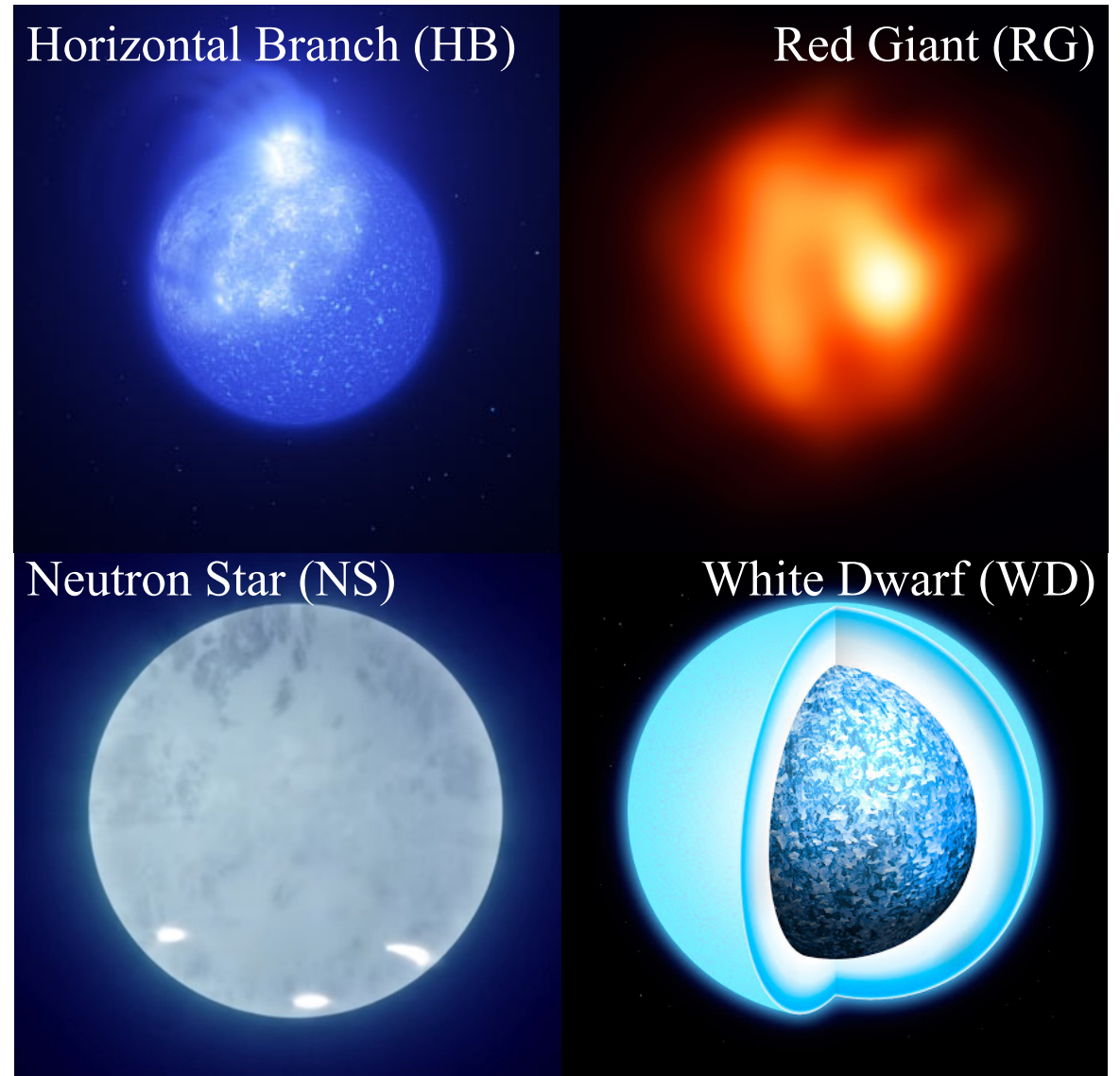
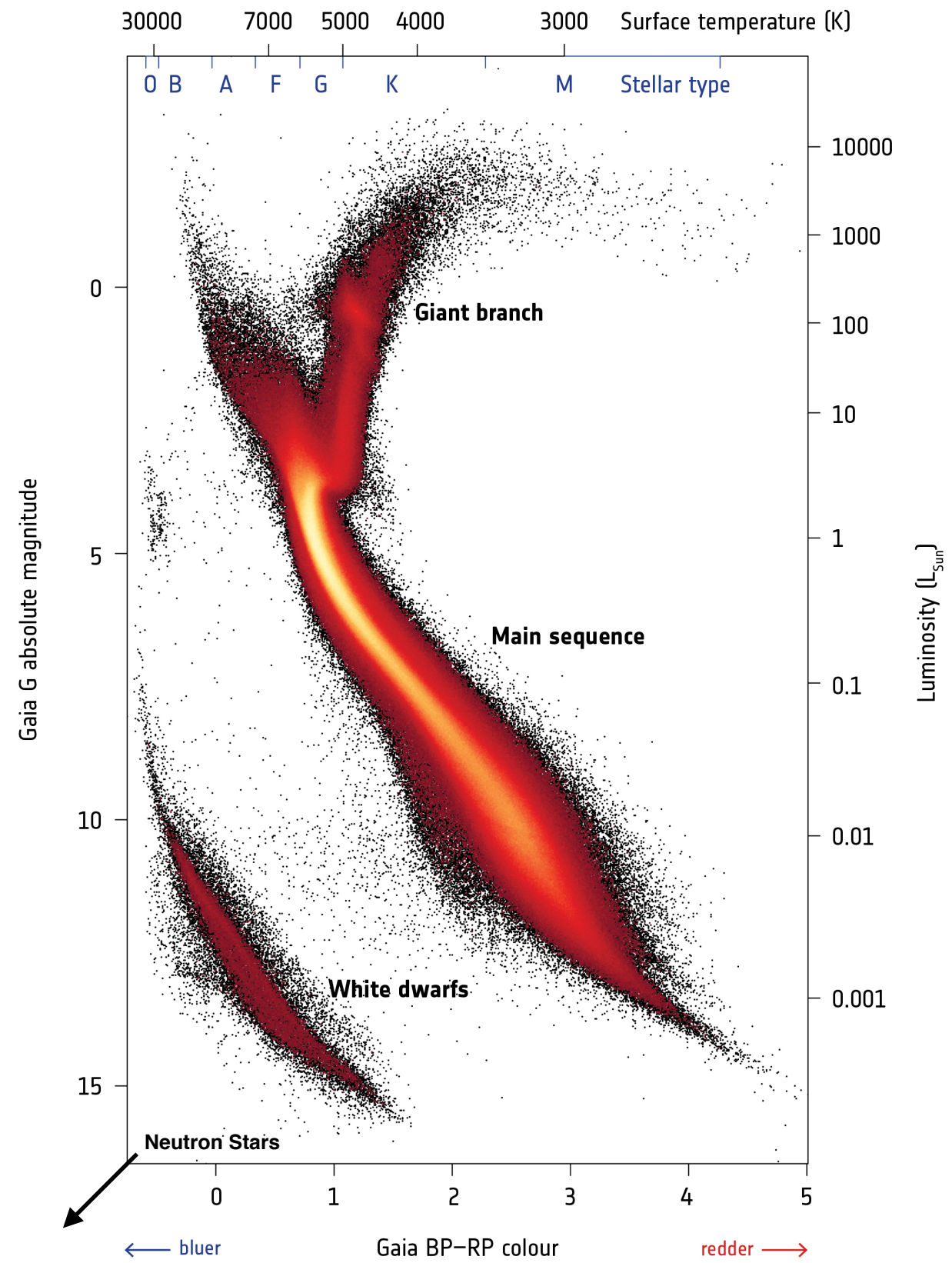
R. Lasenby, KVT, “Dark Photons in the Solar Basin”, arXiv:2008.08594

UC Davis, September 21, 2020

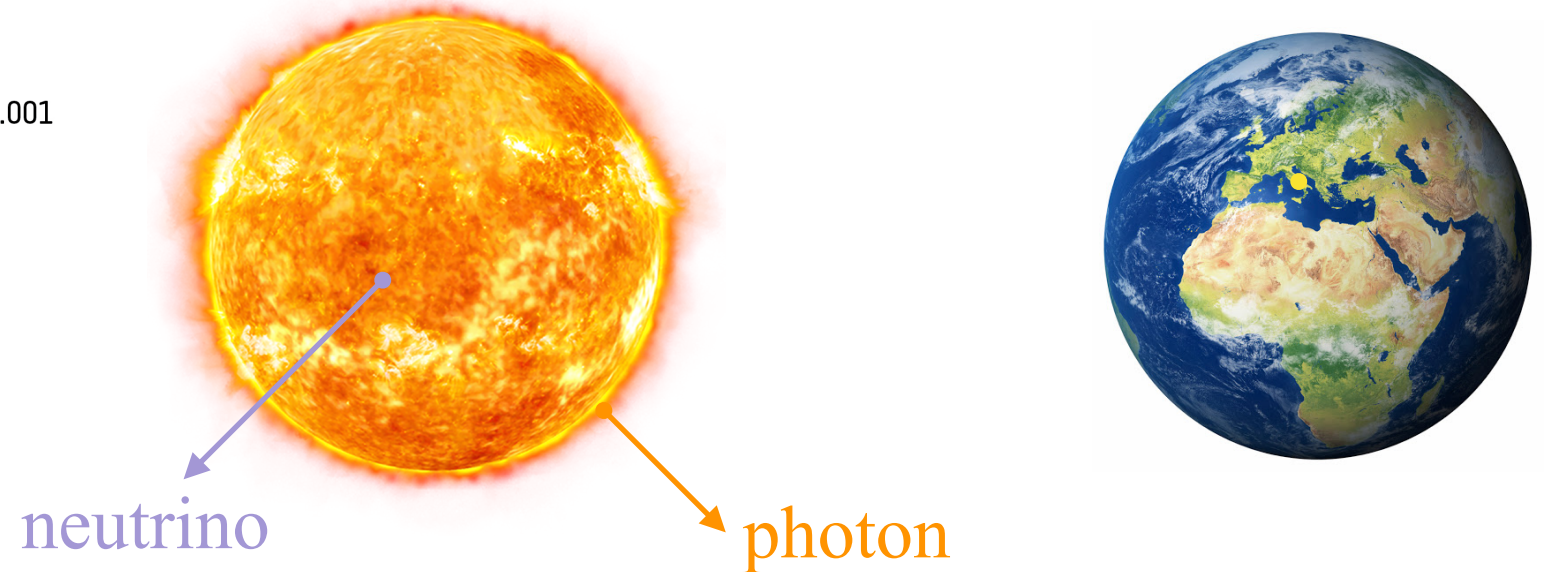
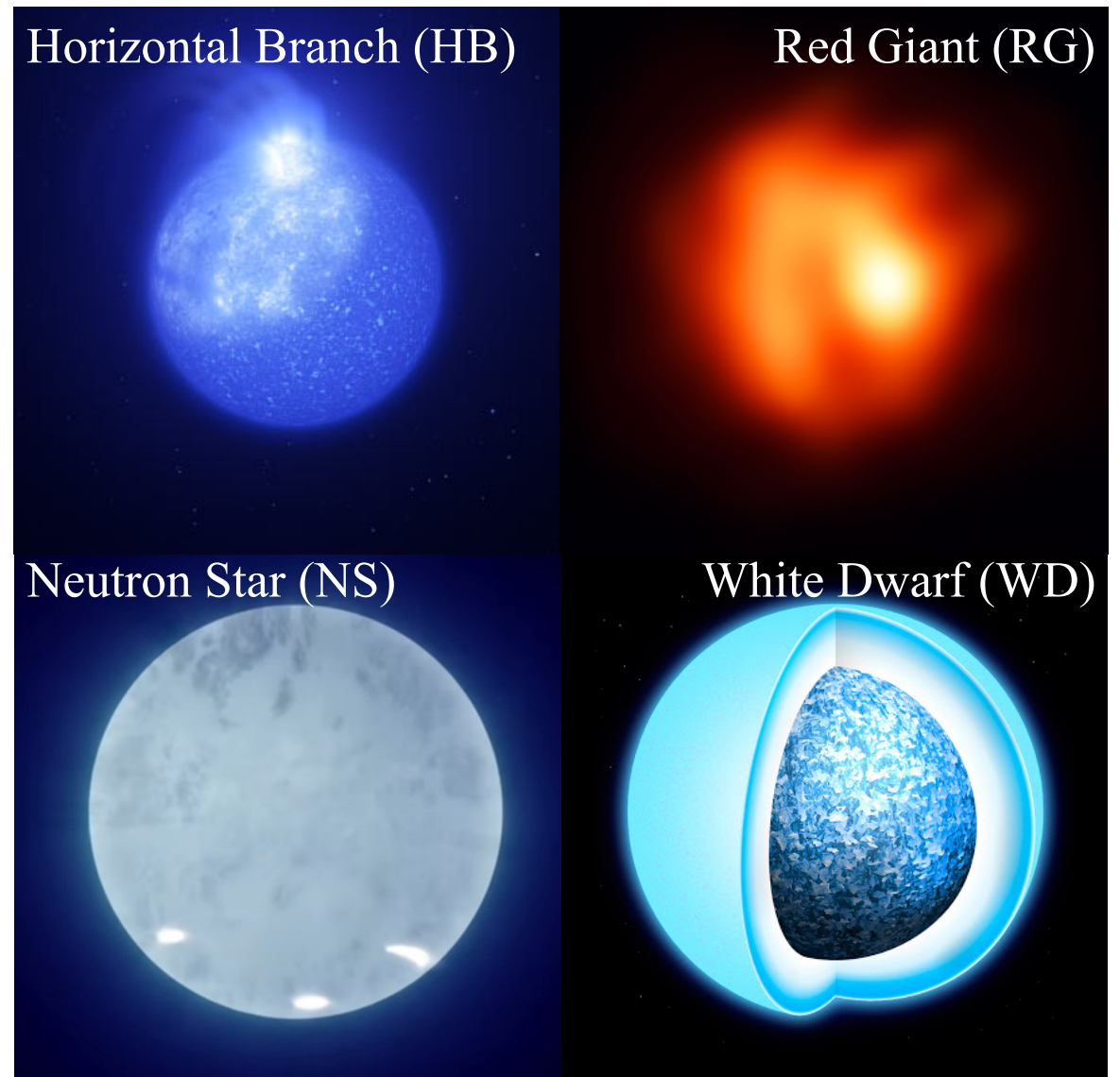
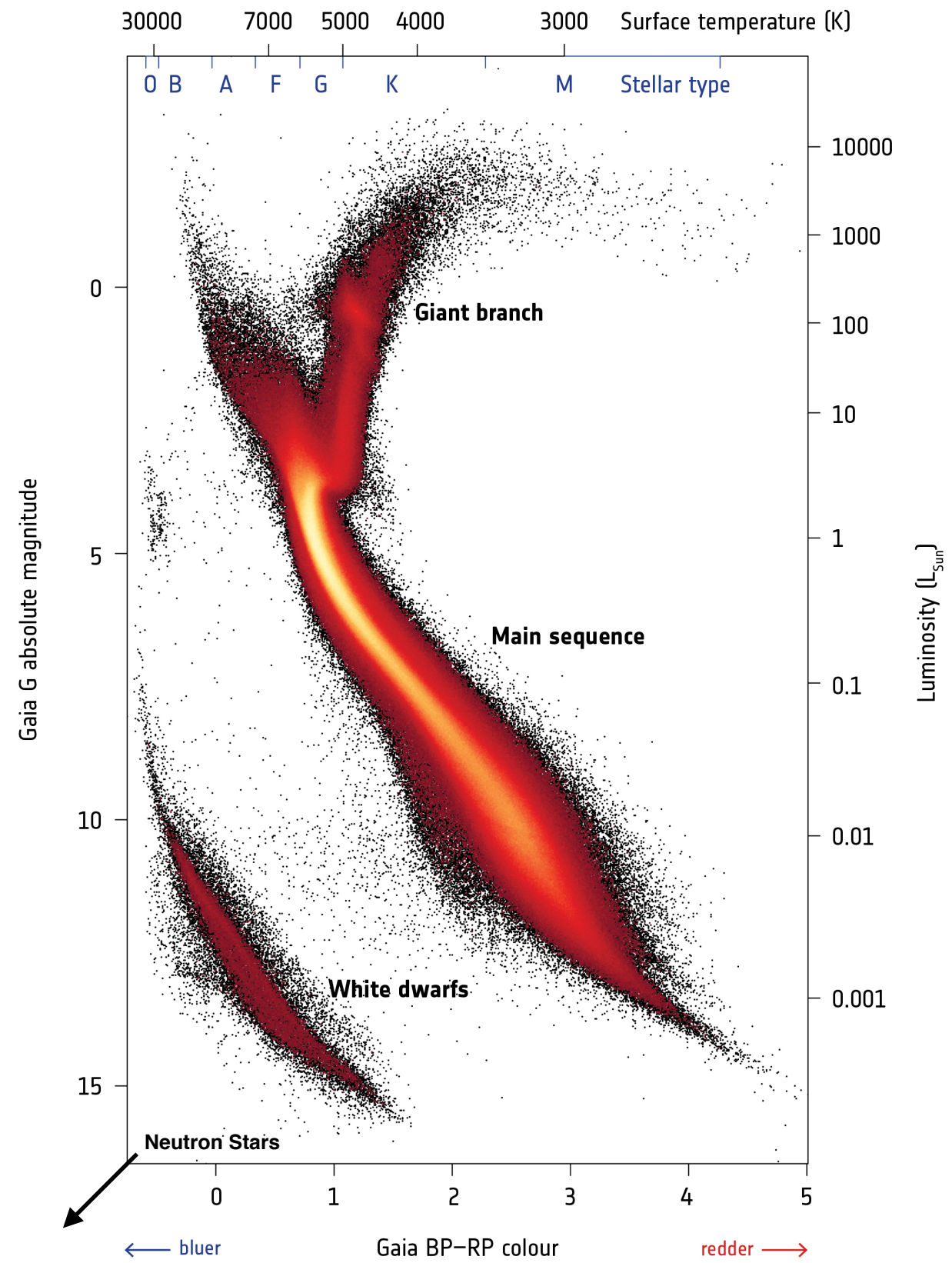
Stellar Emission



Stellar Emission

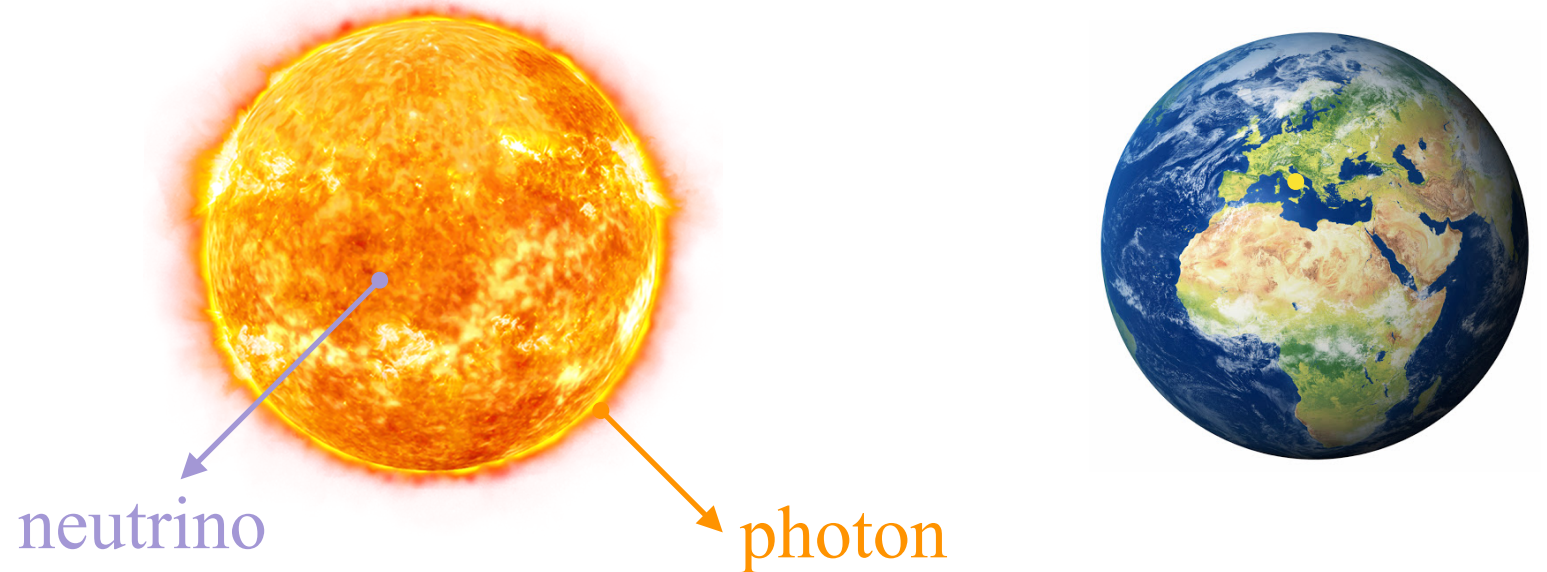
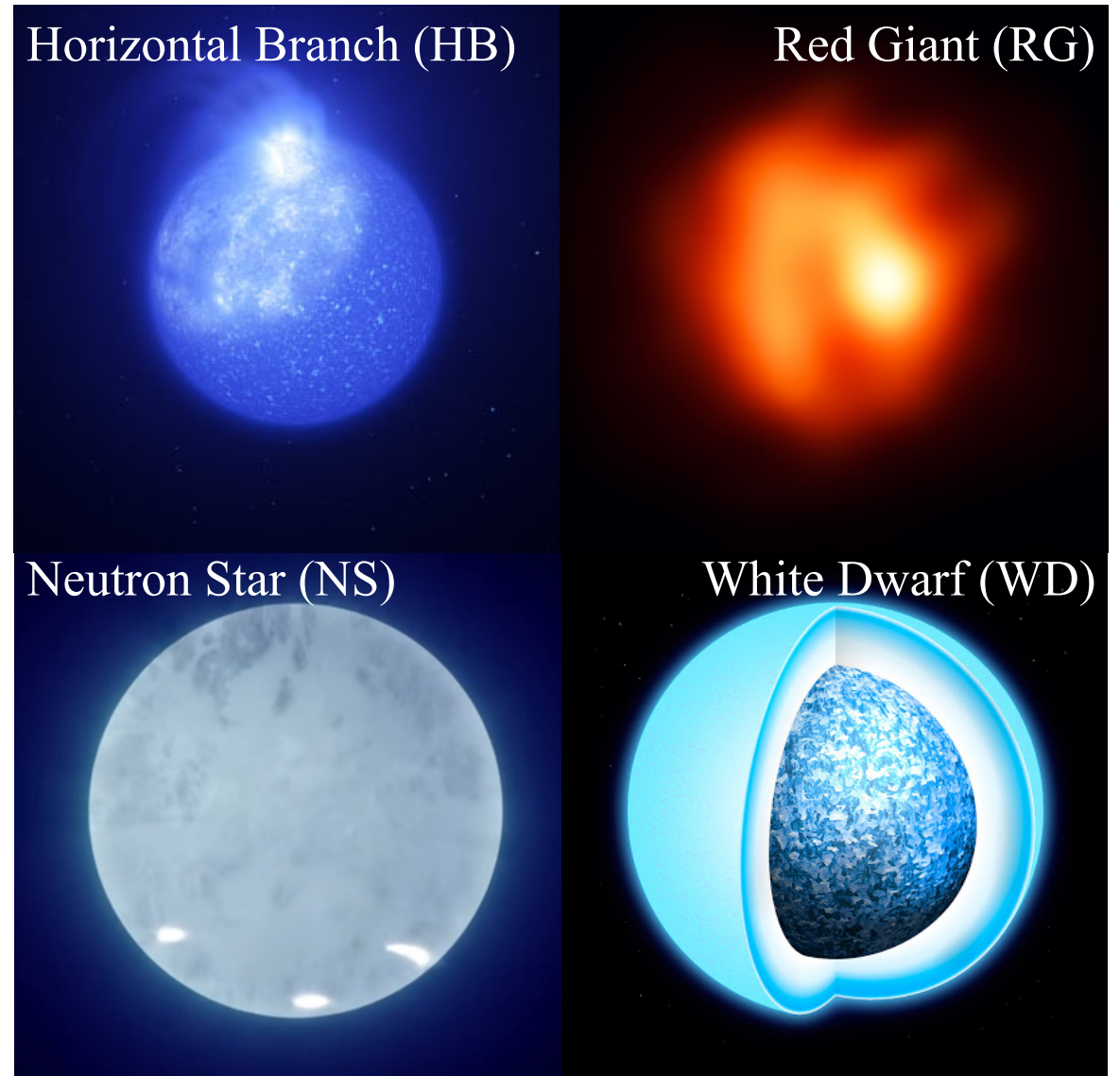
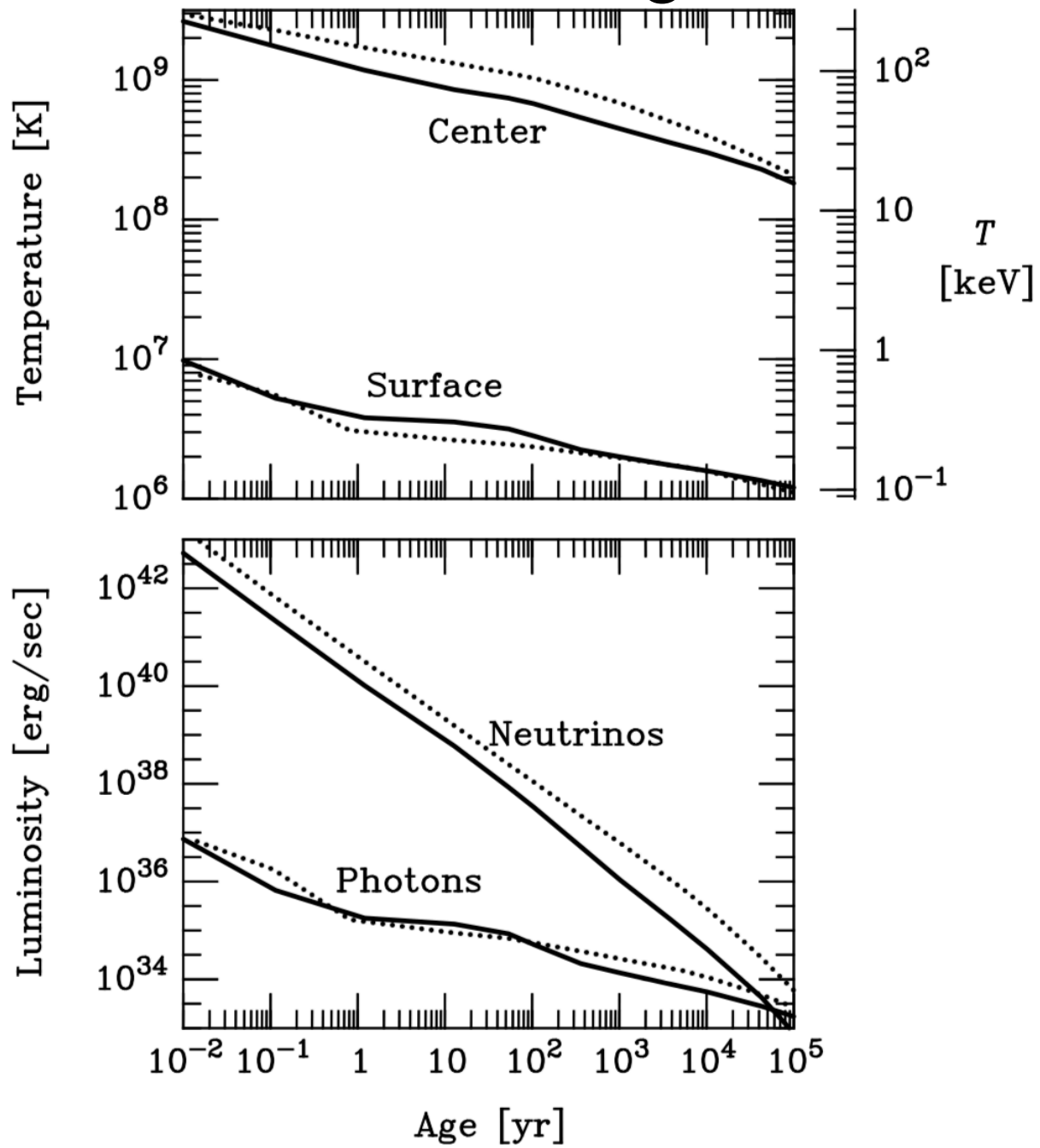


Stellar Emission

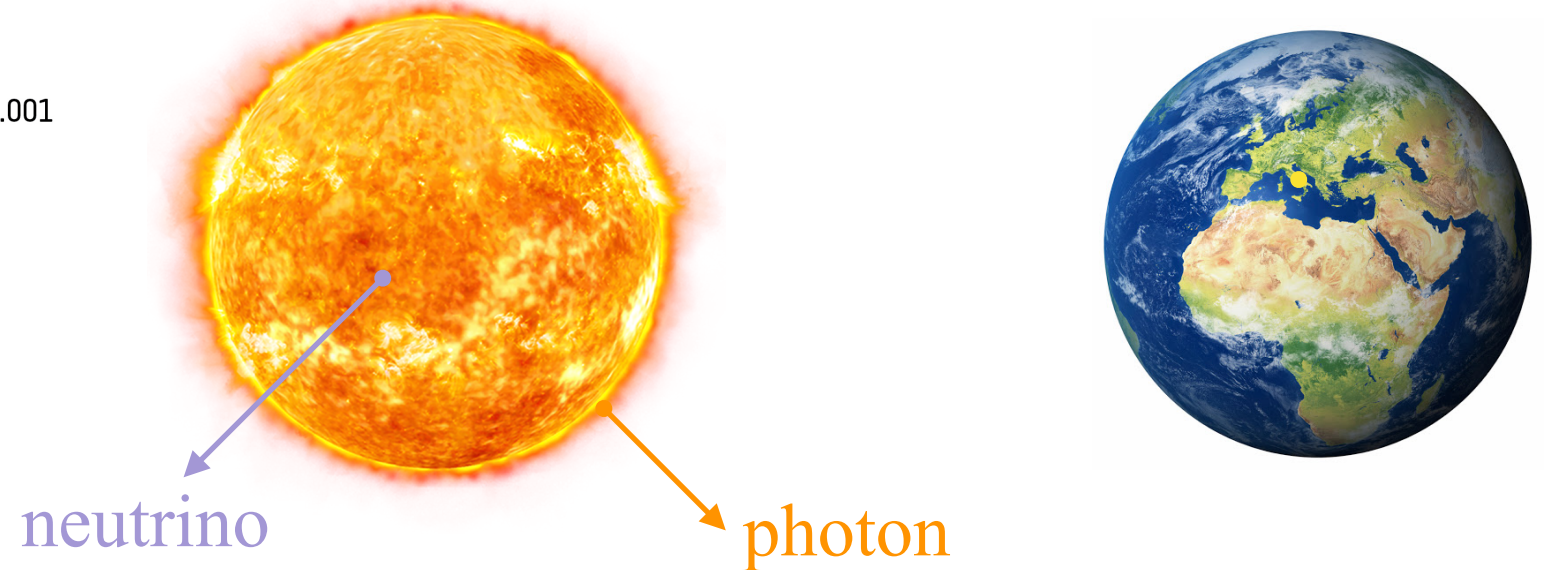
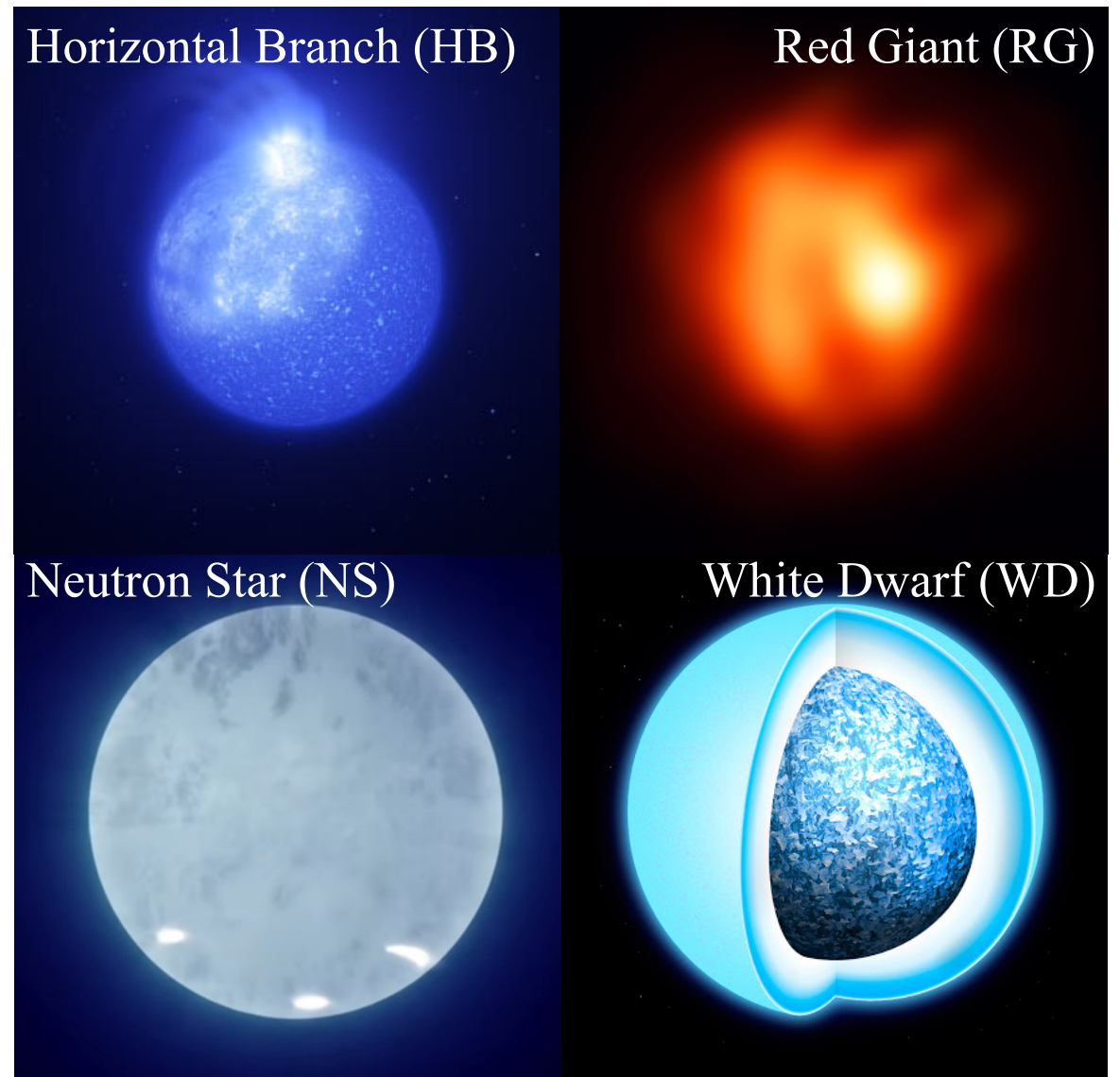
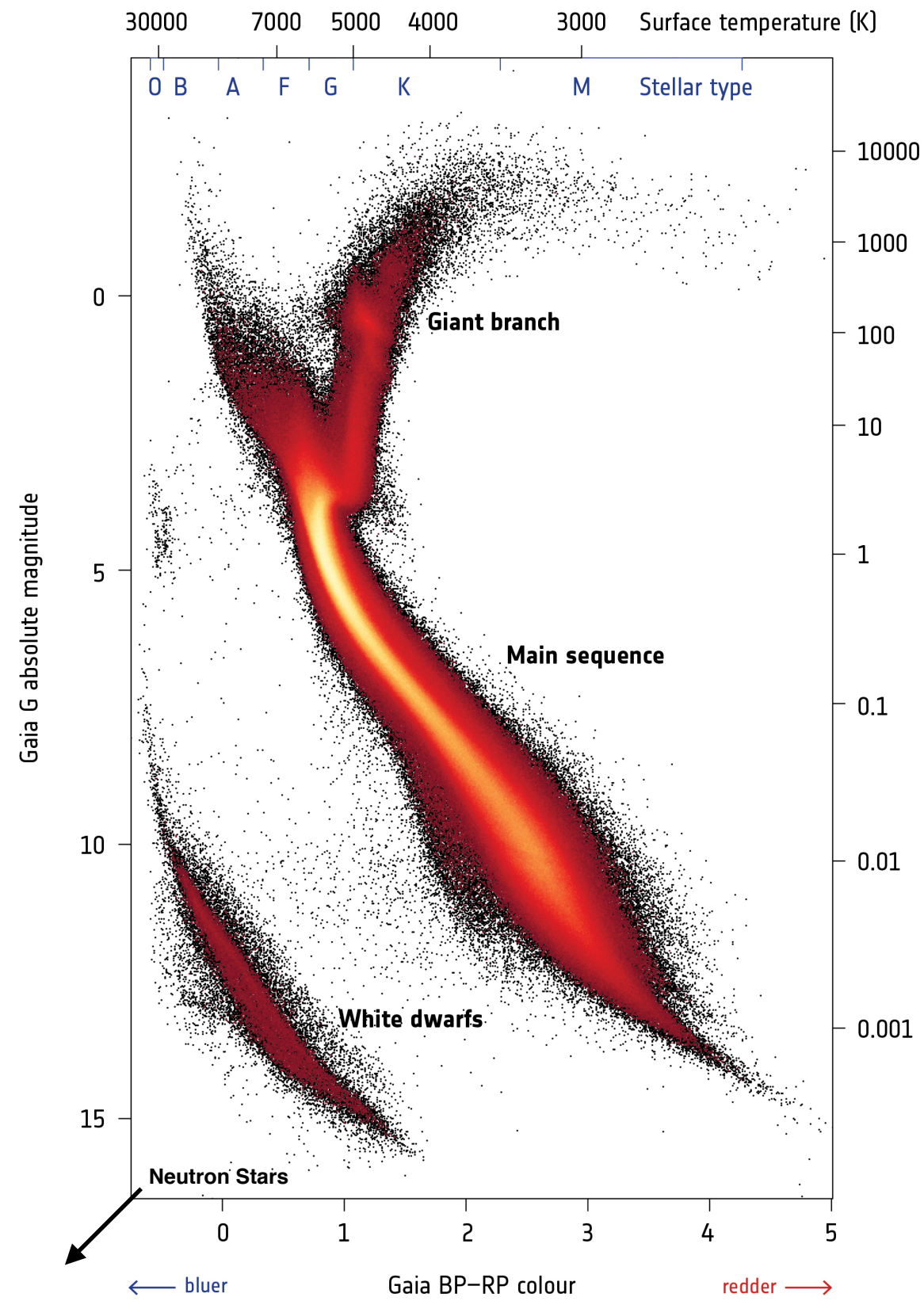


Stellar Emission

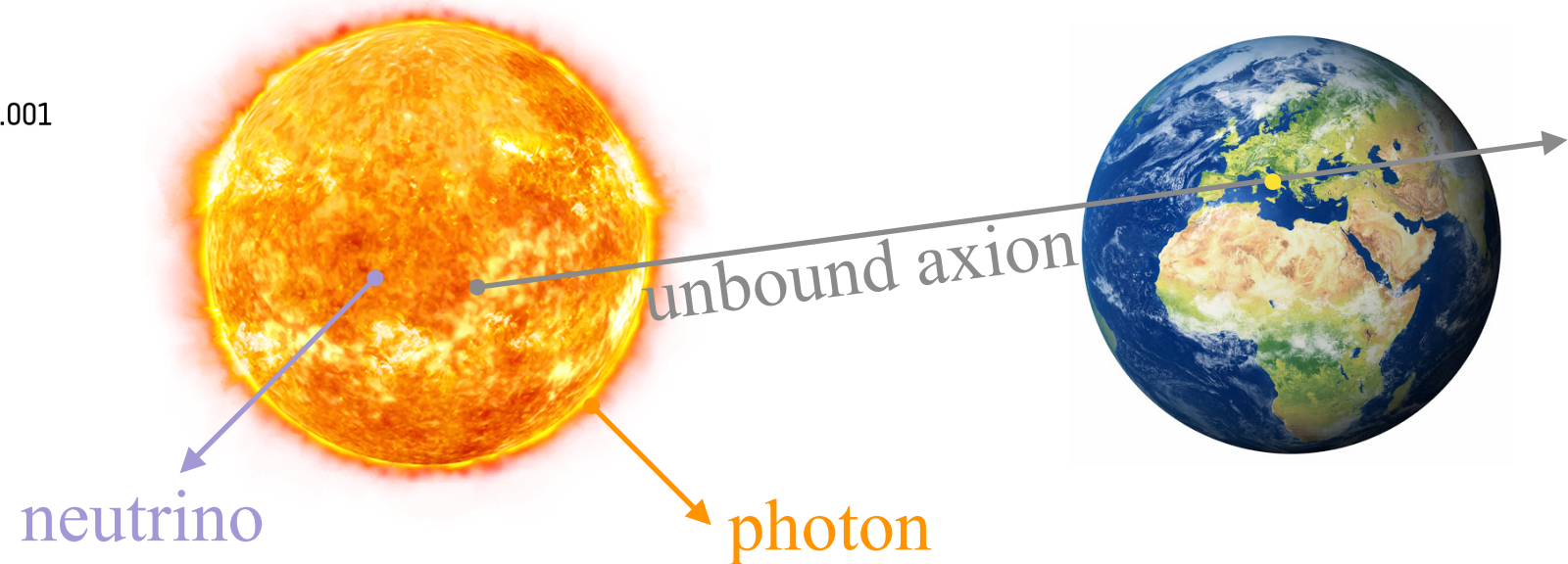
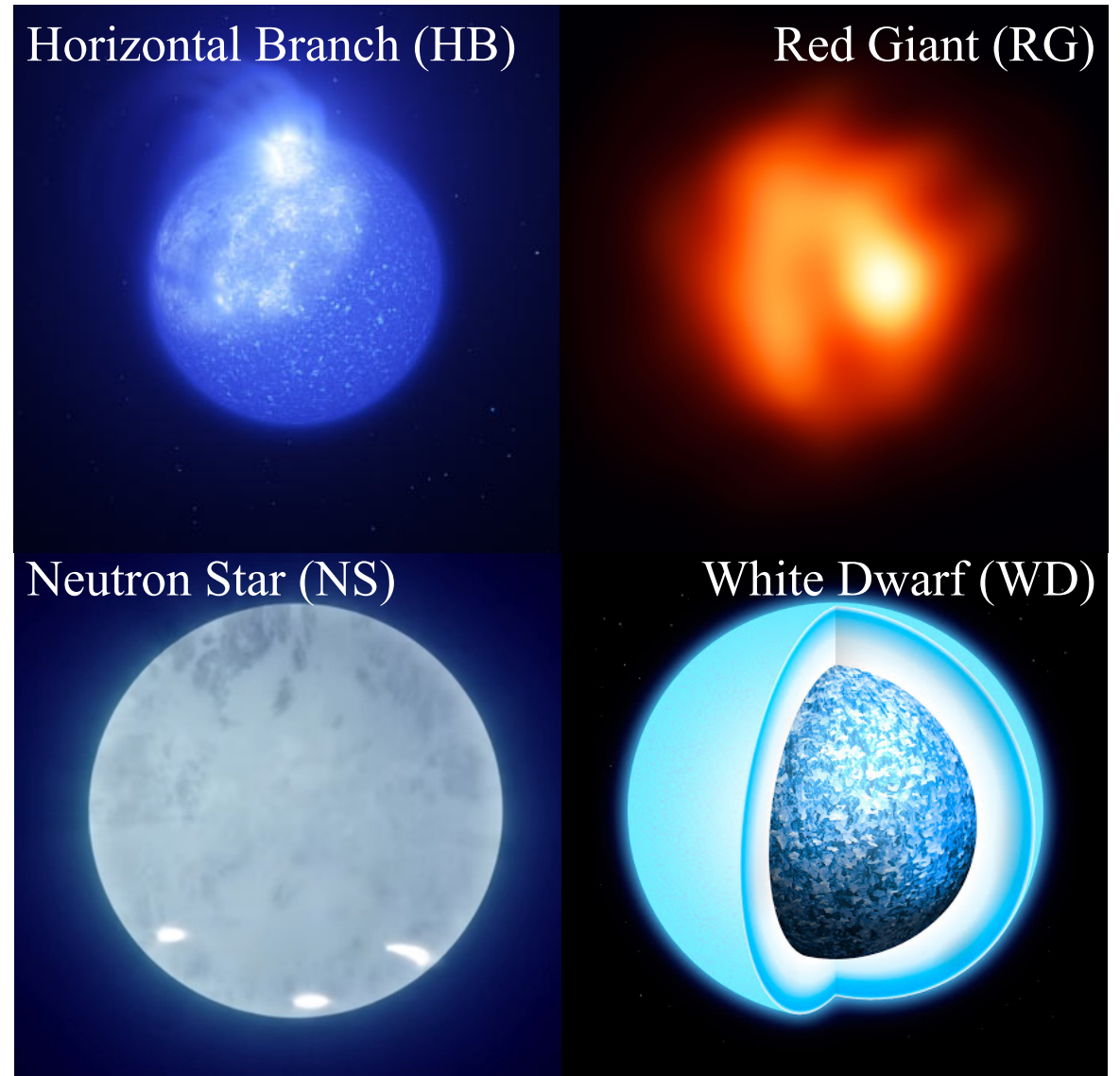
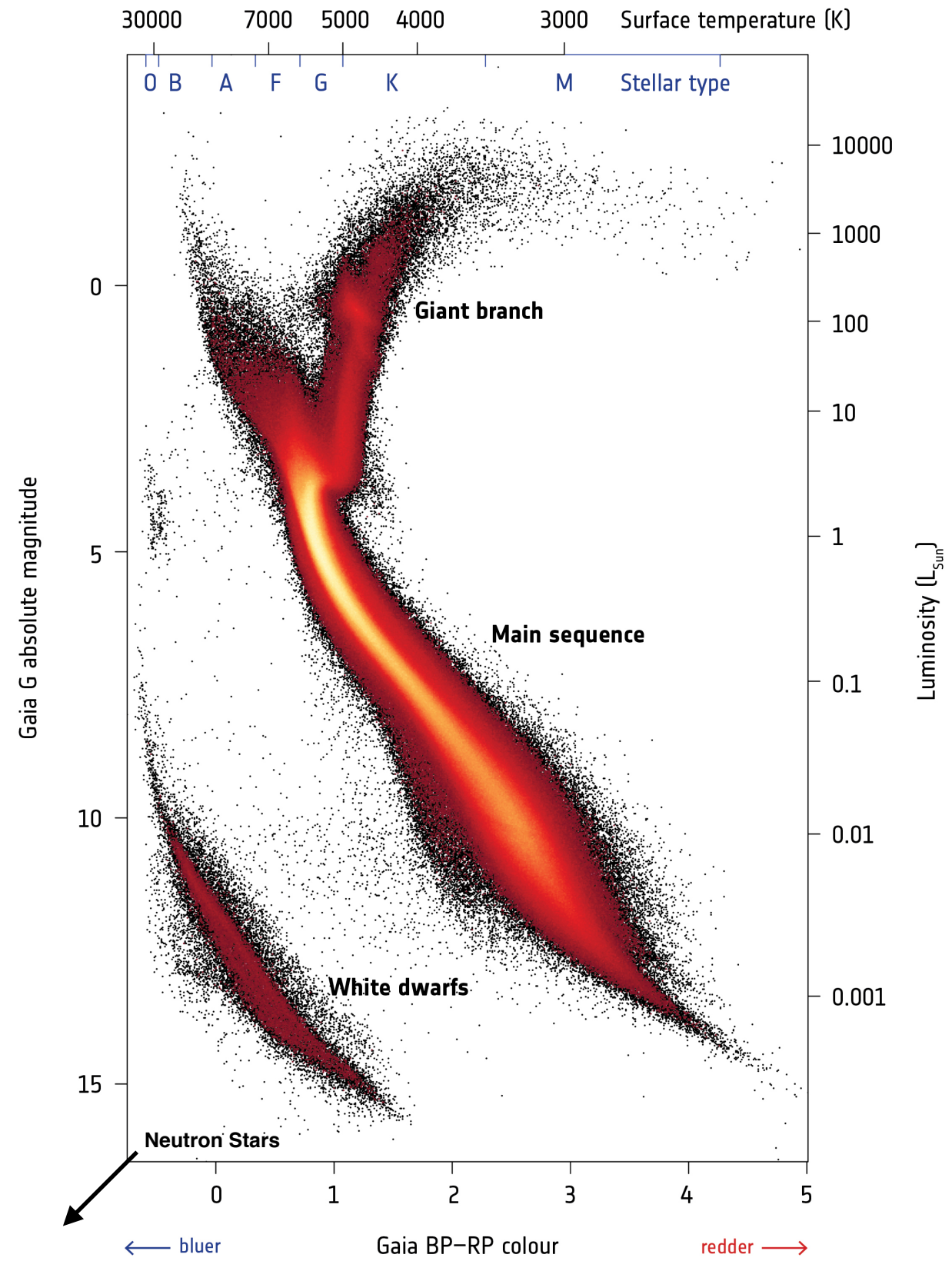
NS Cooling



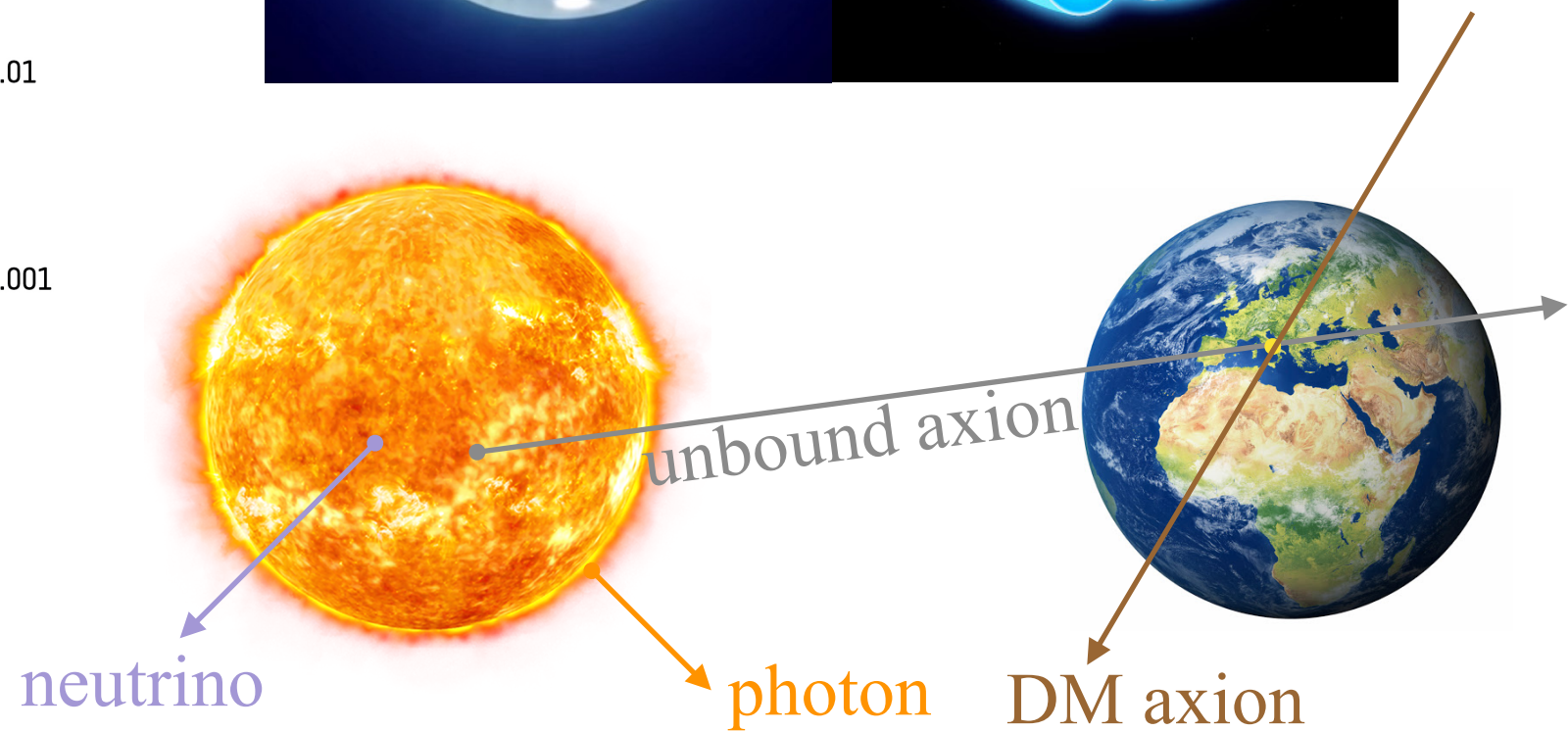
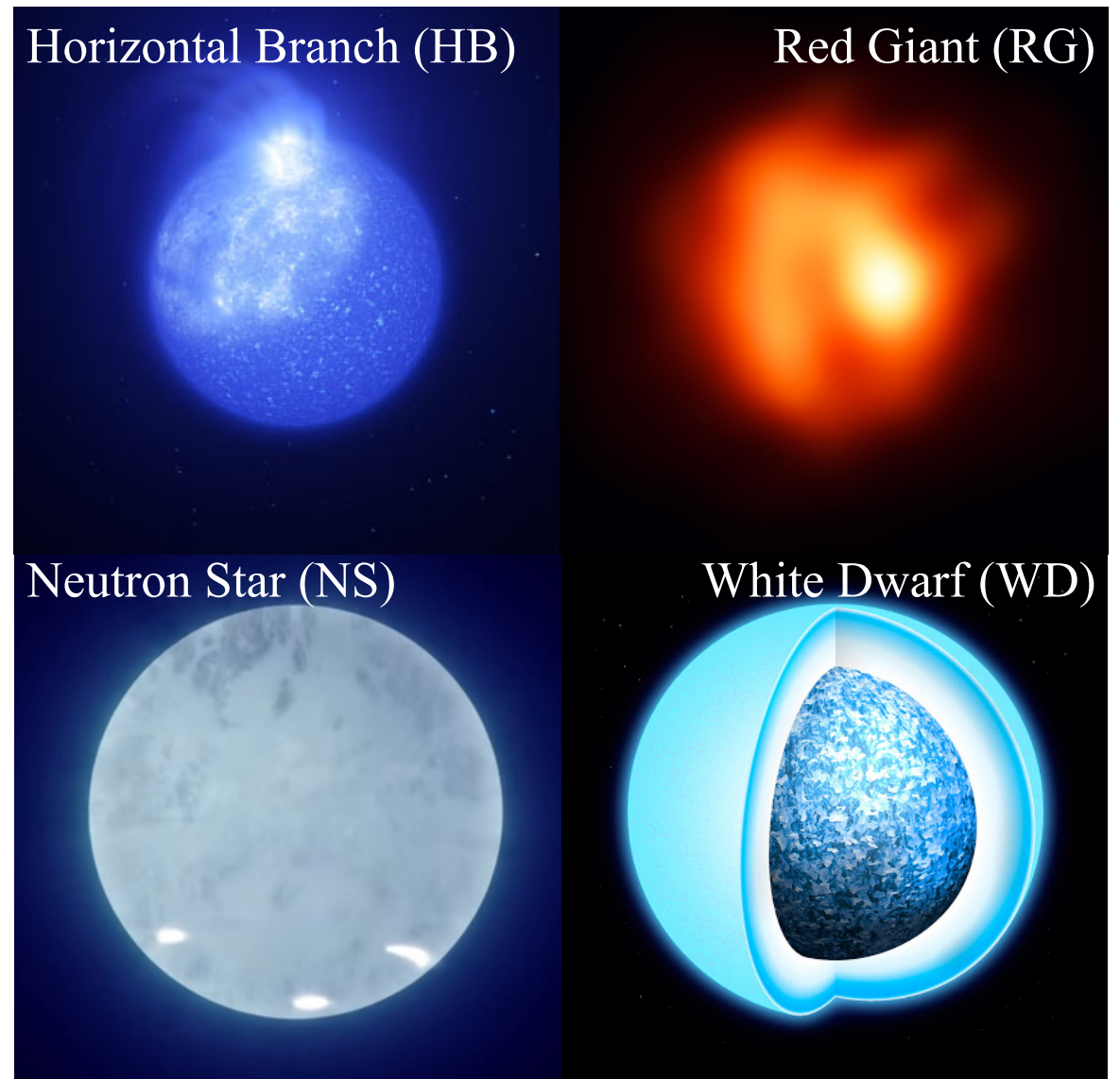
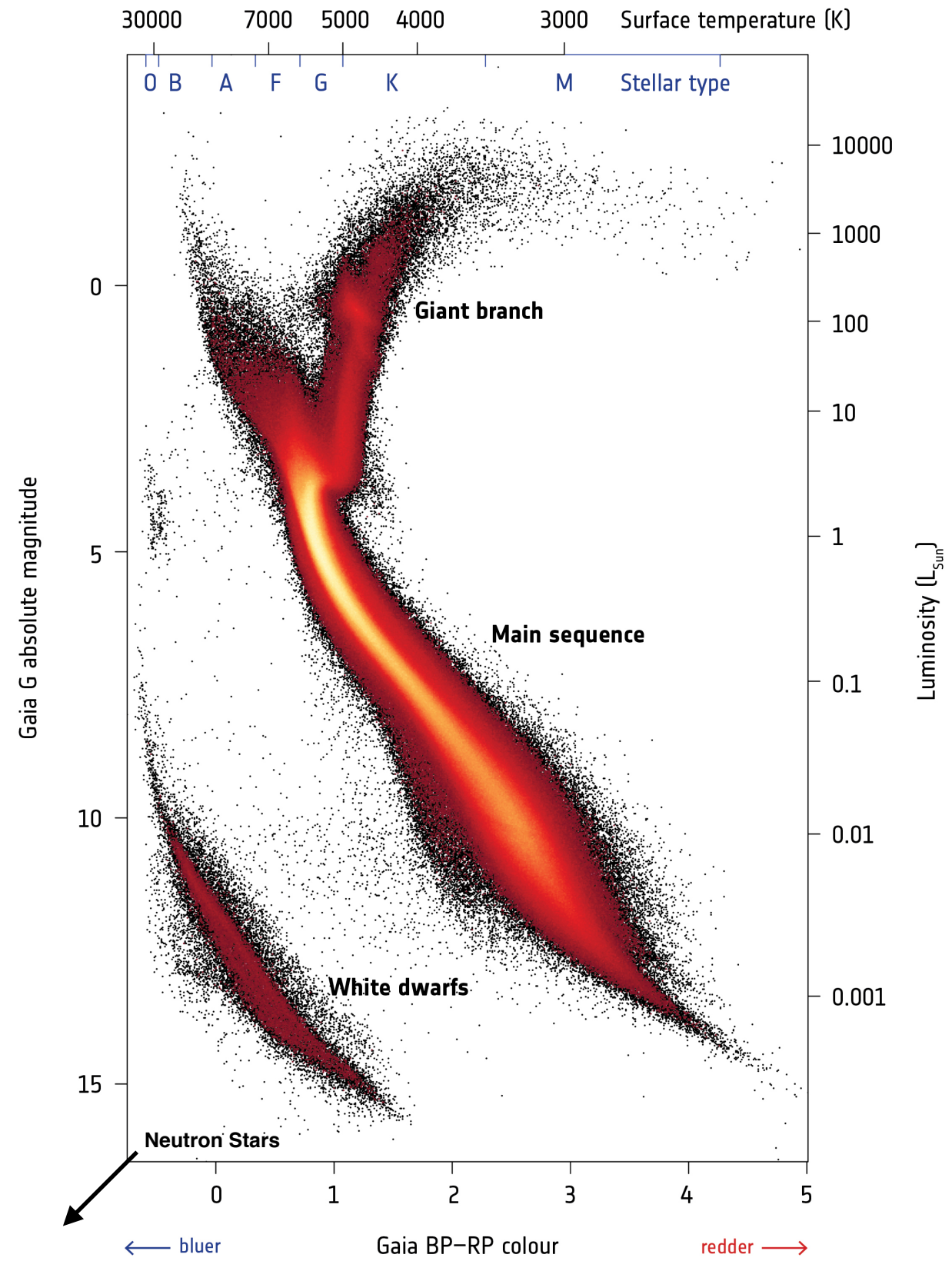
Stellar Emission



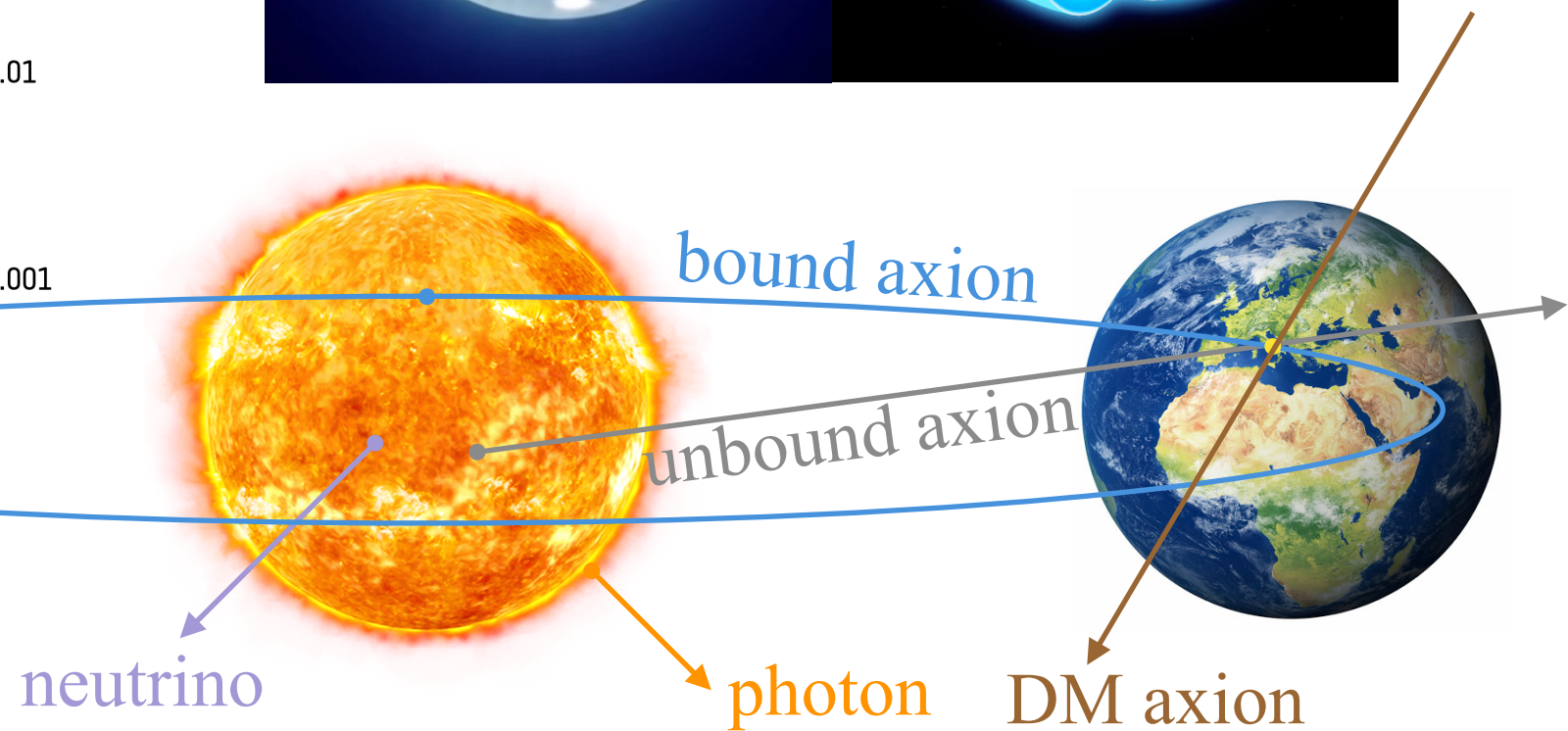
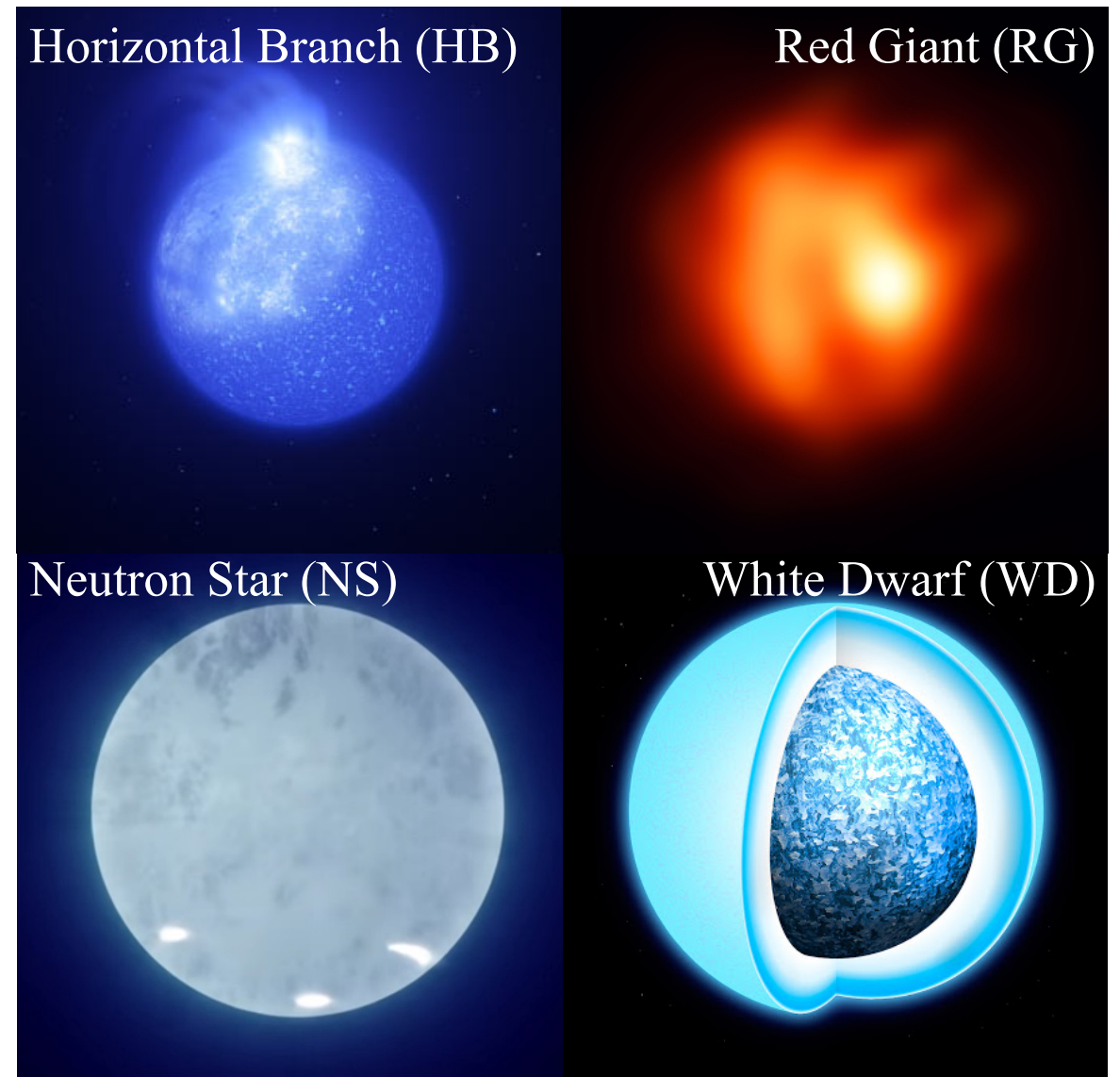
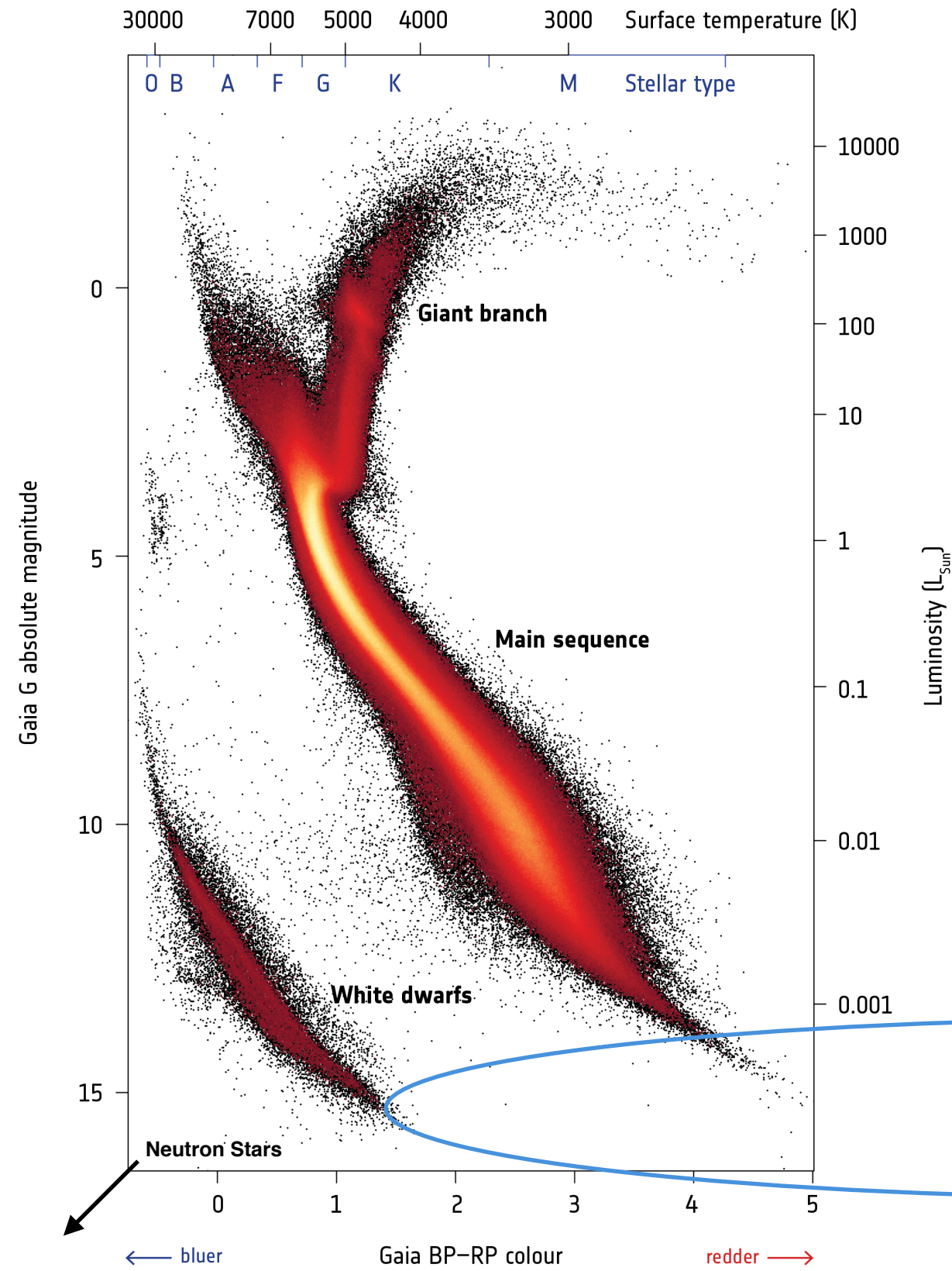
Stellar Emission



Stellar Emission



Stellar Emission



Bosonic Particles Produced in Stars

Scalar

Pseudoscalar

Vector

$$\phi \bar{e}e$$

$$\phi \bar{q}q$$

$$a \bar{e}i\gamma_5 e$$

$$a \bar{q}i\gamma_5 q$$

$$\epsilon A'_\mu J_{\text{EM}}^\mu$$

$$\phi F^2$$

$$\phi G^2$$

$$a F \tilde{F}$$

$$a G \tilde{G}$$

$$g A'_\mu J_{B-L}^\mu$$

Bosonic Particles Produced in Stars

Scalar

$$\phi \bar{e}e$$

$$\phi \bar{q}q$$

$$\phi F^2$$

$$\phi G^2$$

Pseudoscalar

$$a \bar{e}i\gamma_5 e$$

$$a \bar{q}i\gamma_5 q$$

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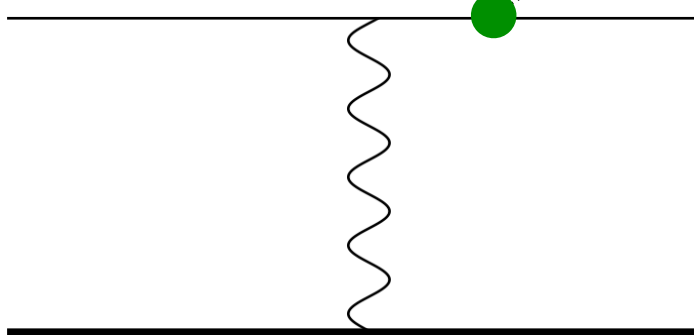
Vector

$$\epsilon A'_\mu J^\mu_{EM}$$

$$g A'_\mu J^\mu_{B-L}$$

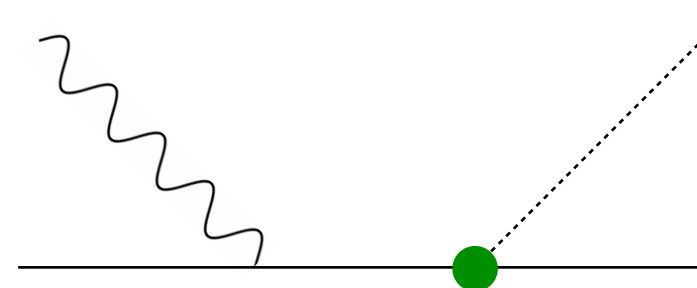
Bremsstrahlung

a

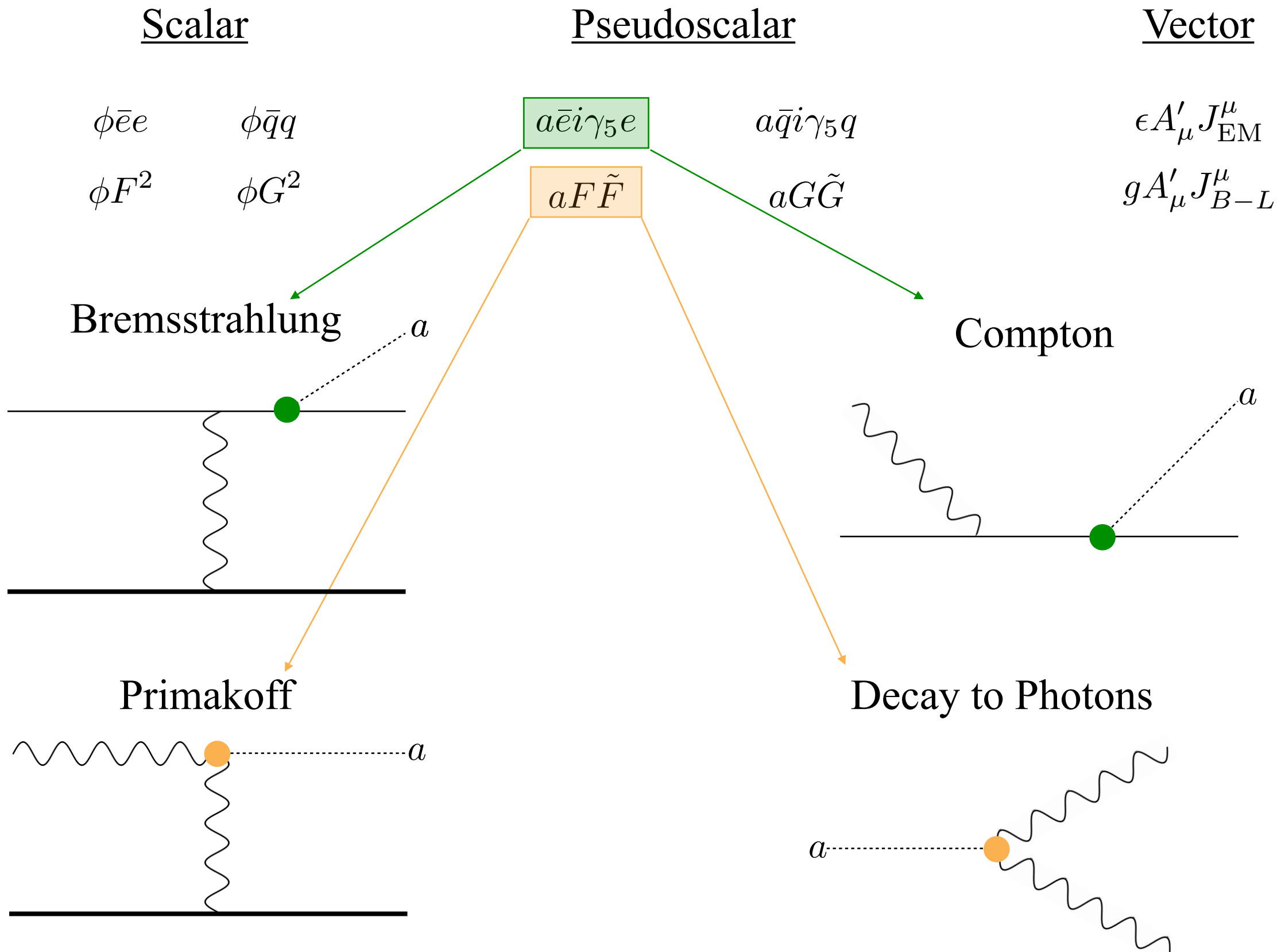


Compton

a



Bosonic Particles Produced in Stars



Bosonic Particles Produced in Stars

Scalar

$$\phi \bar{e}e$$

$$\phi \bar{q}q$$

$$\phi F^2$$

$$\phi G^2$$

Pseudoscalar

$$a \bar{e}i\gamma_5 e$$

$$a \bar{q}i\gamma_5 q$$

$$a F \tilde{F}$$

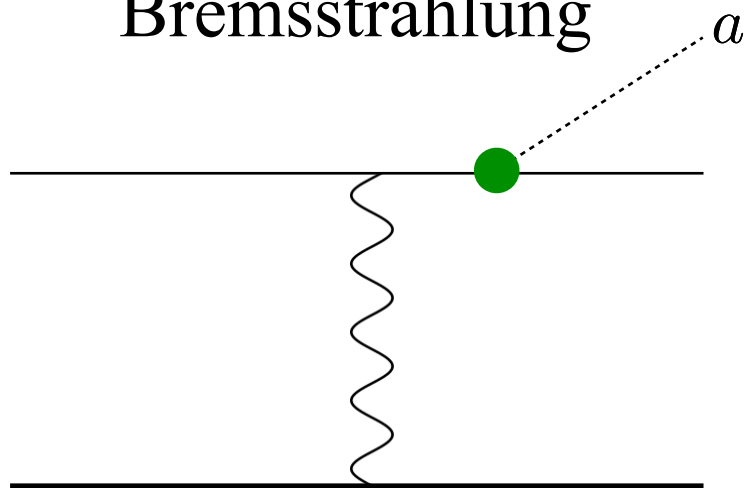
$$a G \tilde{G}$$

Vector

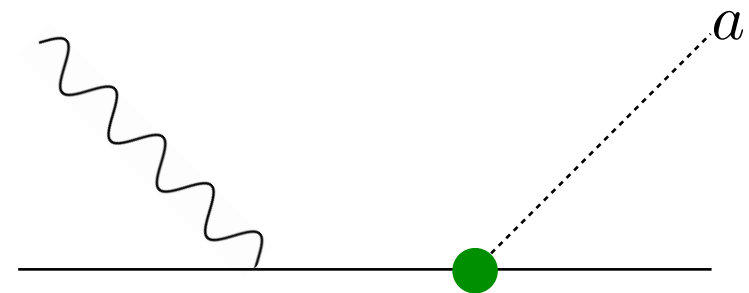
$$\epsilon A'_\mu J^\mu_{EM}$$

$$g A'_\mu J^\mu_{B-L}$$

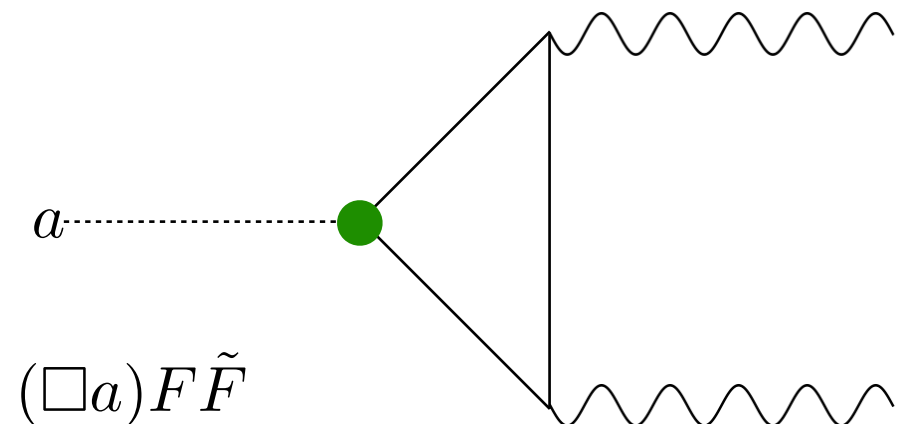
Bremsstrahlung



Compton



Decay to Photons



Bosonic Particles Produced in Stars

Scalar

$$\phi \bar{e}e \quad \phi \bar{q}q$$

$$\phi F^2 \quad \phi G^2$$

Pseudoscalar

$$a \bar{e}i\gamma_5 e$$

$$a F \tilde{F}$$

$$a \bar{q}i\gamma_5 q$$

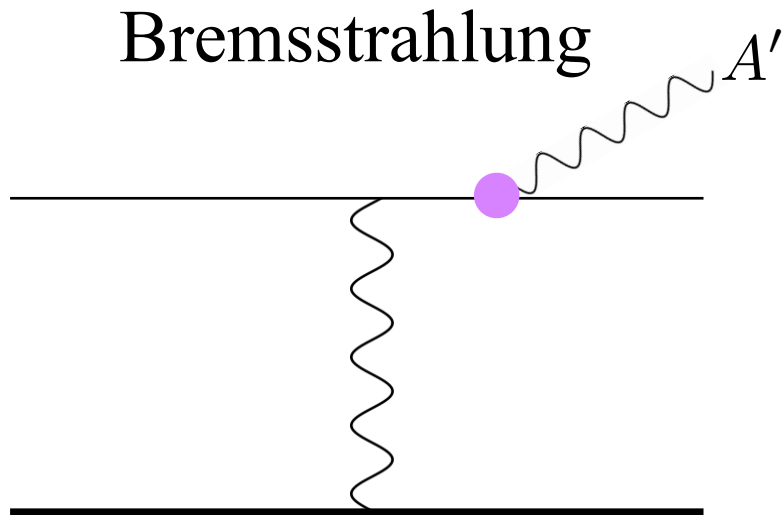
$$a G \tilde{G}$$

Vector

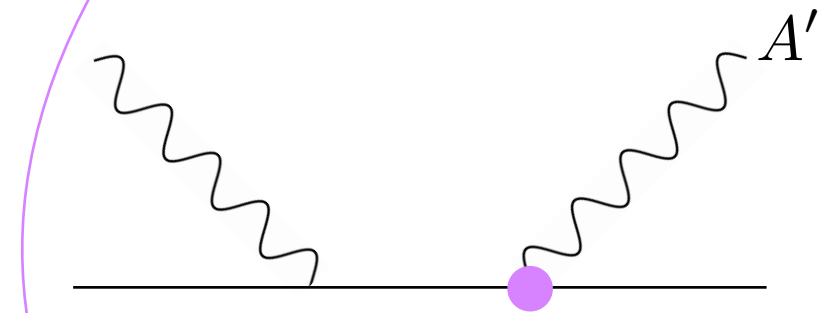
$$\epsilon A'_\mu J_{EM}^\mu$$

$$g A'_\mu J_{B-L}^\mu$$

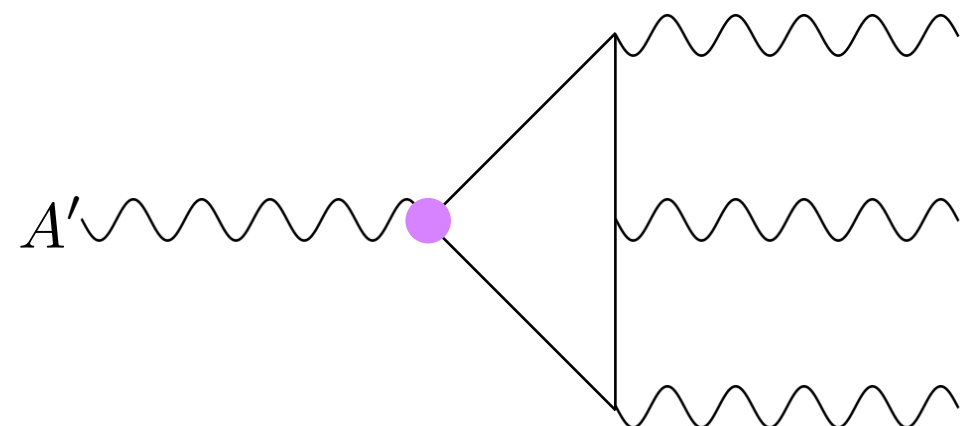
Bremsstrahlung



Compton

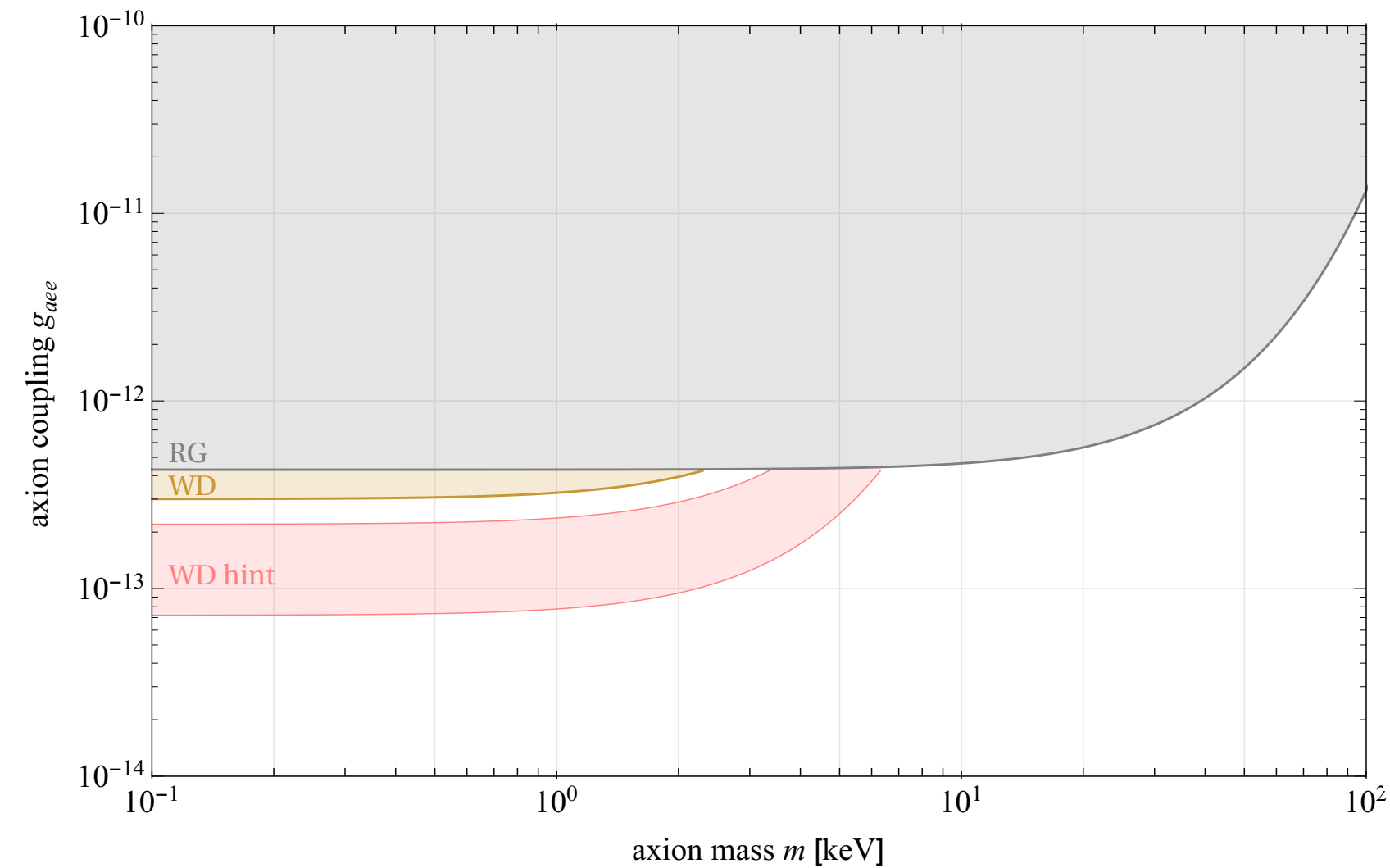


Decay to Photons

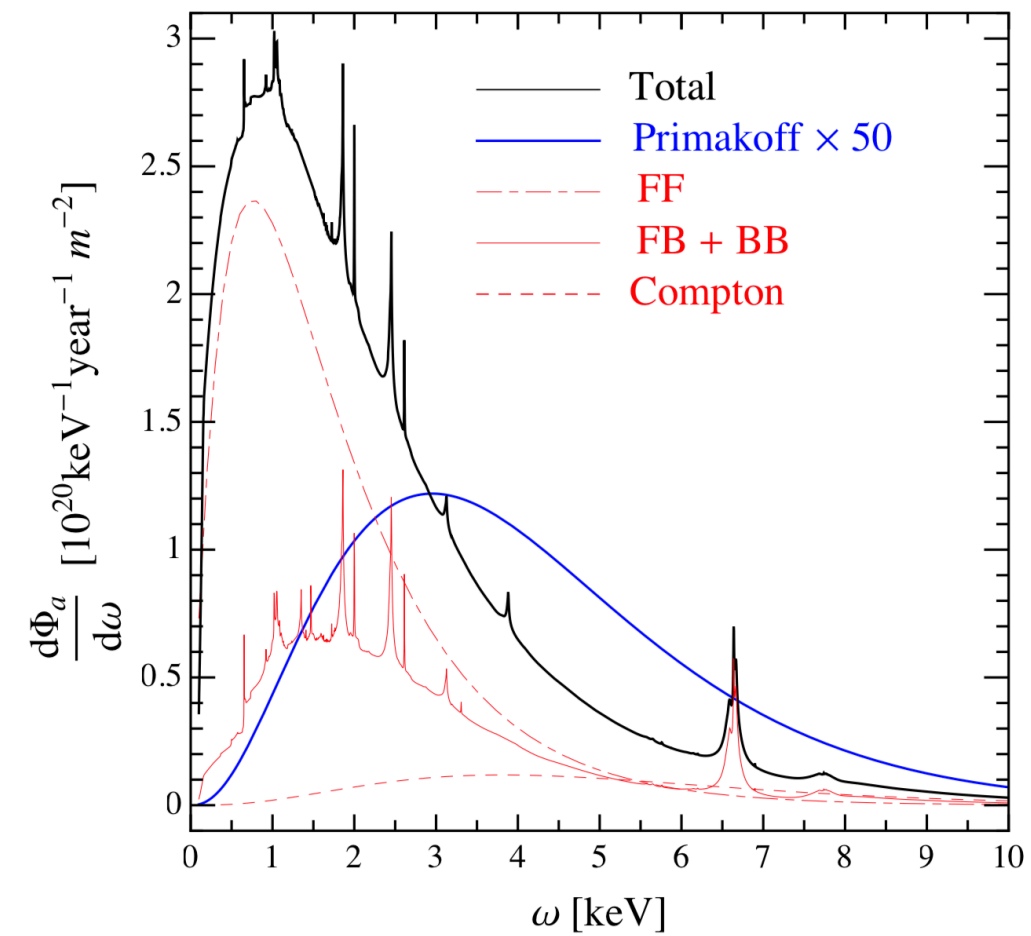


Anomalous Stellar Emission

$$\mathcal{L} = \frac{(\partial a)^2}{2} - \frac{m^2 a^2}{2} + \frac{g_{aee}}{2m_e} (\partial_\mu a) \bar{\psi}_e \gamma^\mu \gamma^5 \psi_e$$



Solar Axion Spectrum



[1310.0823]

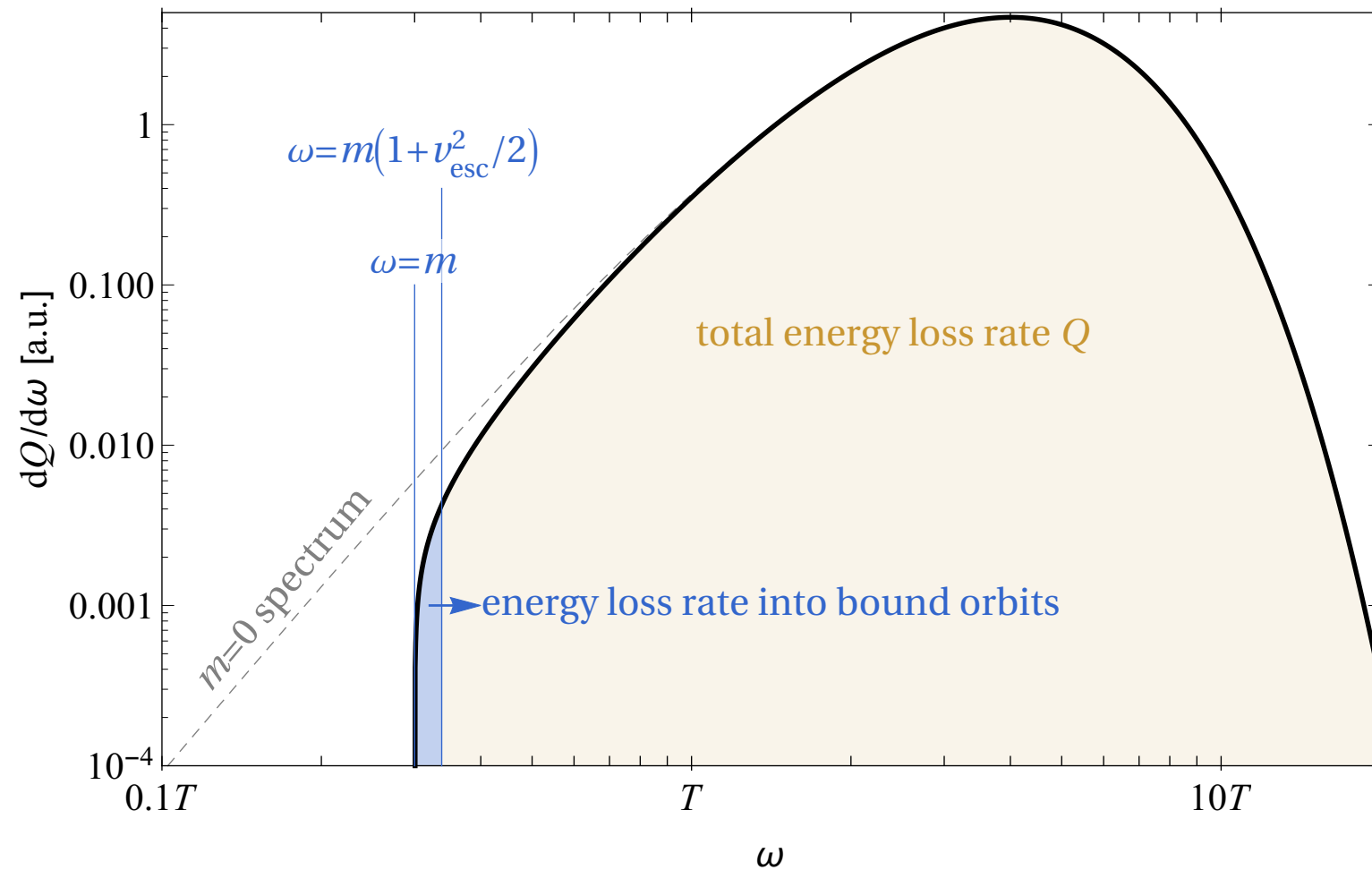
Bound Stellar Emission

Hannestad, Raffelt, *arXiv:hep-ph/0110067*

DiLella, Zioutas, *arXiv:astro-ph/0207073*

KVT, *arXiv:2006.12431*

Differential specific energy loss rate per energy



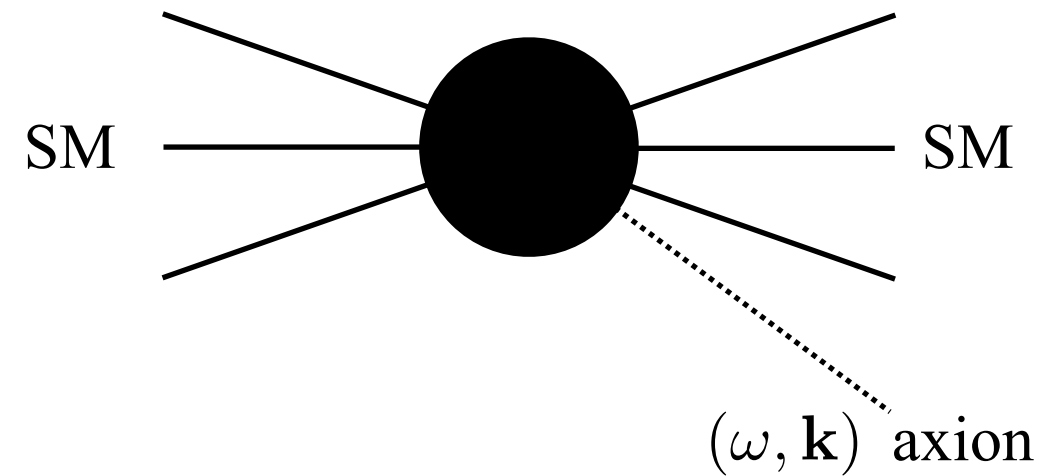
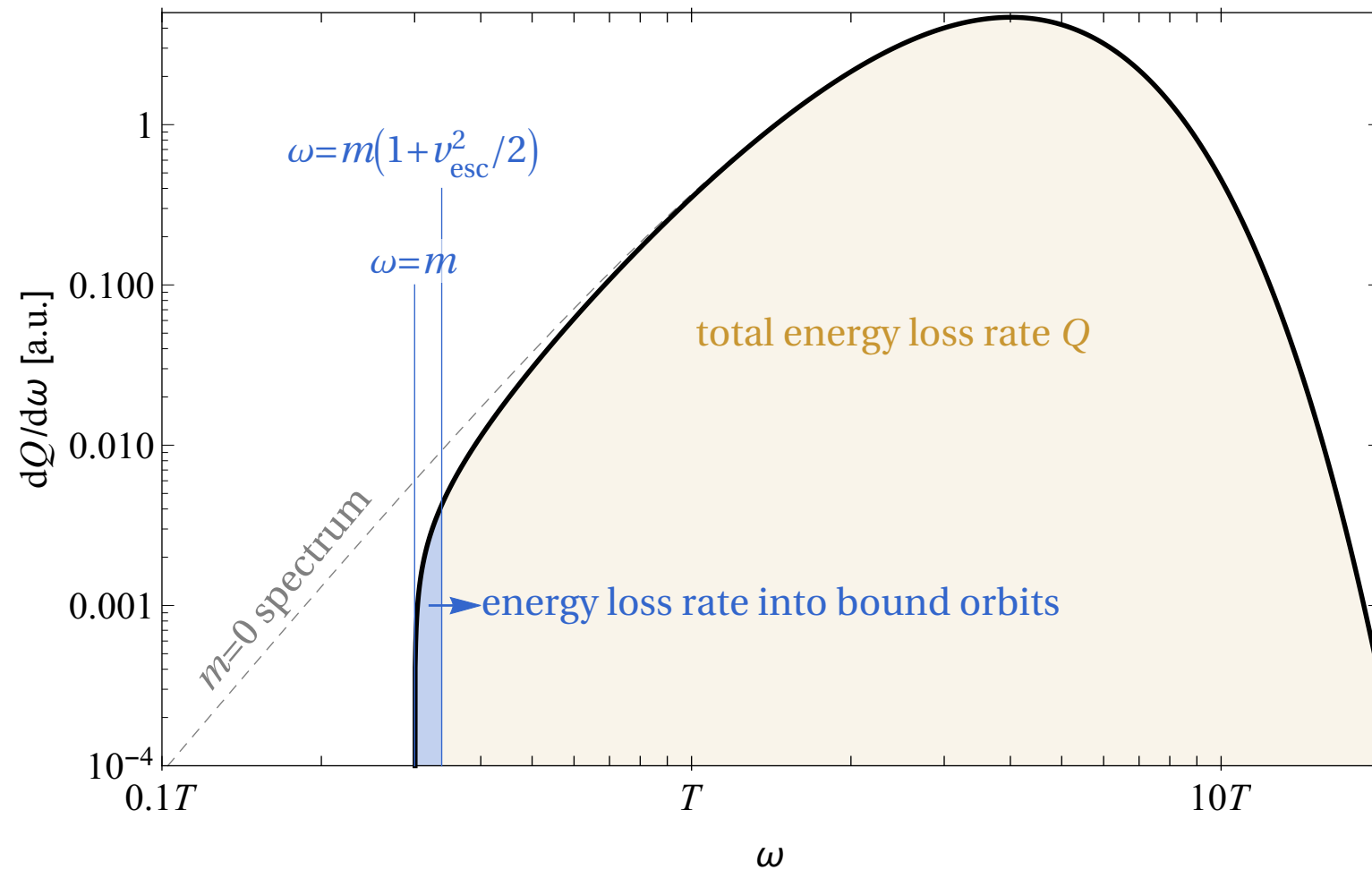
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Differential specific energy loss rate per energy



$$Q \sim \int d^3\mathbf{k} \frac{\tilde{Q}}{m^3}$$

bound: $(mv_{\text{esc}})^3$ unbound: T^3

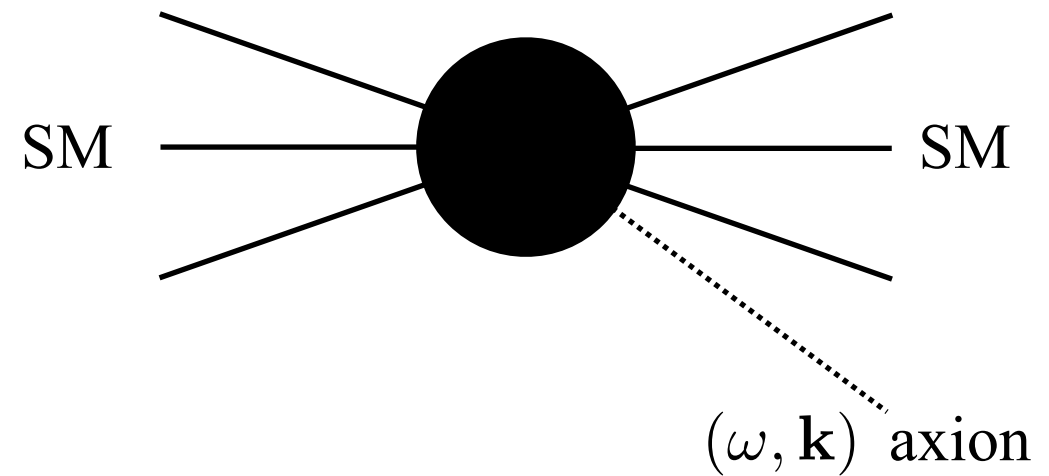
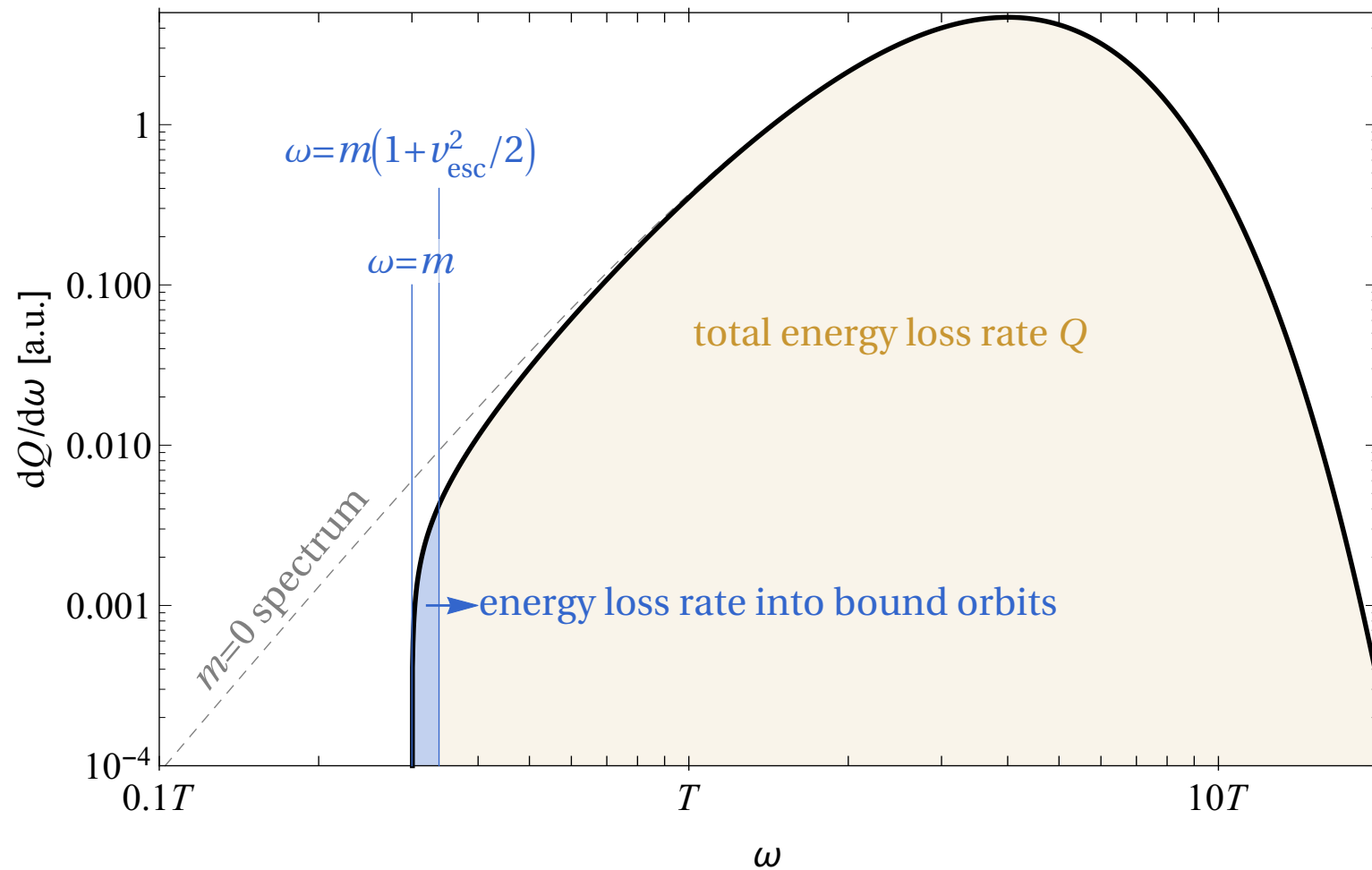
Bound Stellar Emission

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$$Q \sim \int d^3\mathbf{k} \frac{\tilde{Q}}{m^3}$$

bound: $(mv_{\text{esc}})^3$ unbound: T^3

$$\dot{\rho}_b(R) = \frac{3}{16\pi} \frac{G_N M_*}{R^4} \int d^3 R' \tilde{Q}(R') \sqrt{-\Phi(R')}$$

$$\rho_\infty(R) = \frac{1}{4\pi R^2} \int d^3 R' Q(R')$$

$$\frac{\rho_b}{\rho_\infty} \sim \frac{\tau}{R} v_{\text{esc}}^2(R) v_{\text{esc}}(0) \min \left\{ \frac{m^4}{T^4}, 1 \right\} \sim \frac{\tau}{10^6 \text{ yr}} @ R = 1 \text{ AU}$$

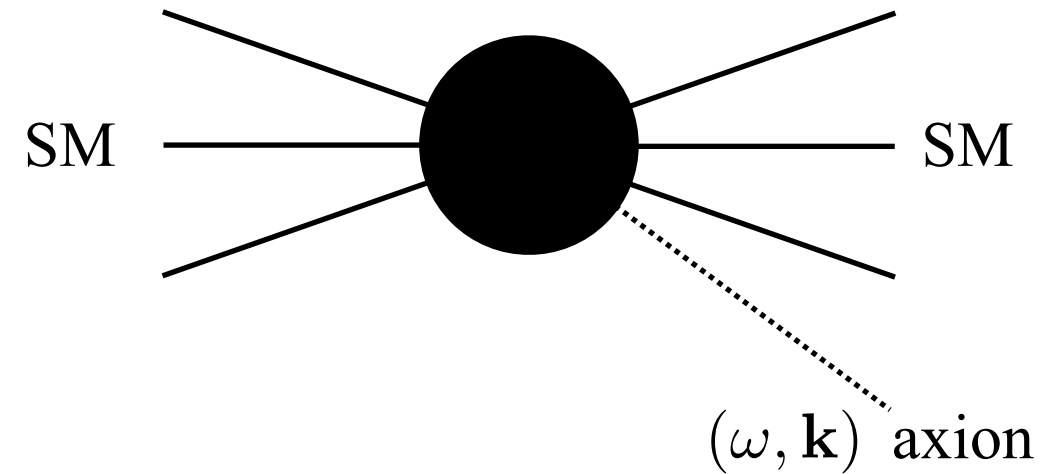
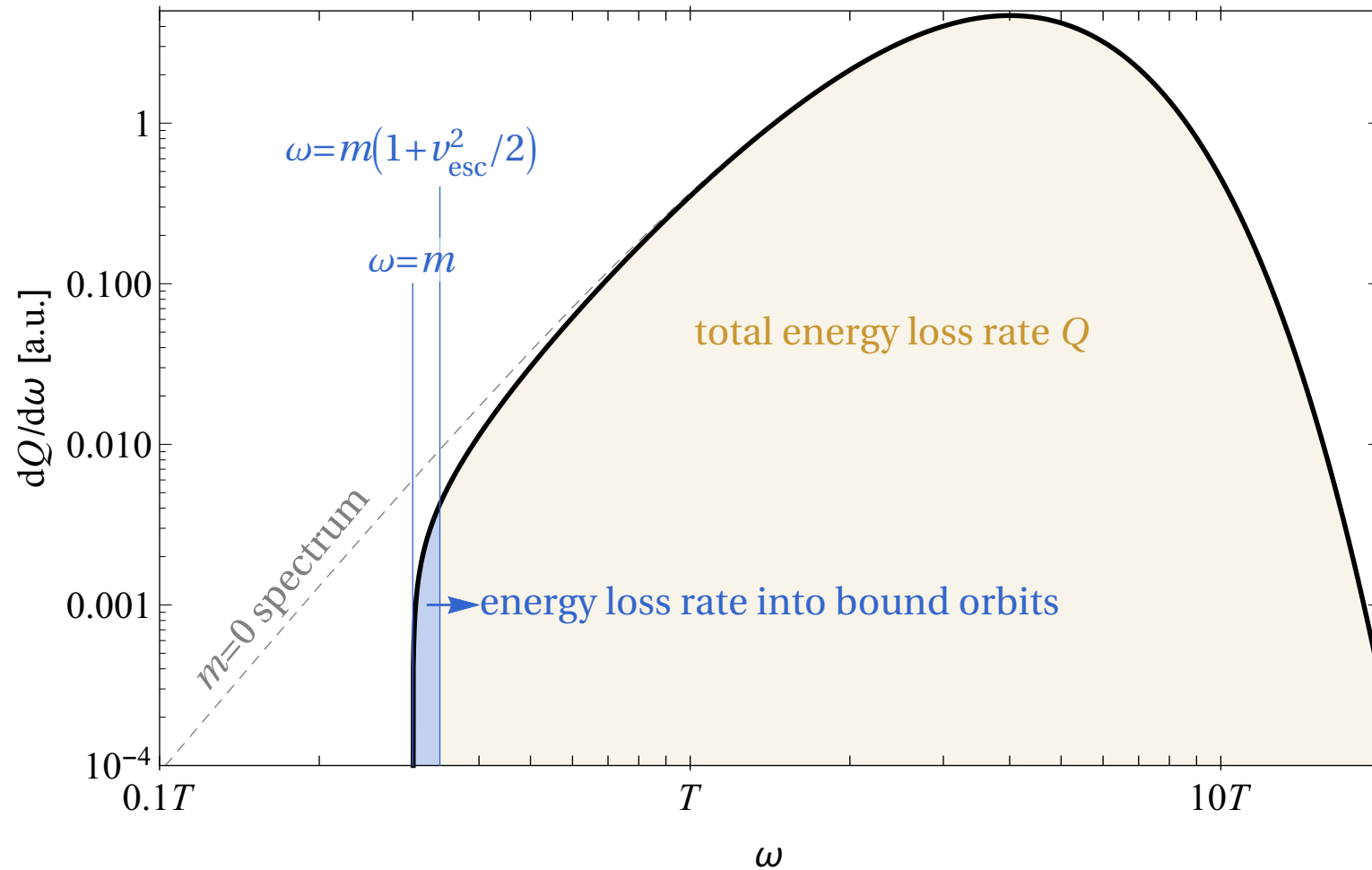
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$$\frac{\rho_b}{\rho_\infty} \sim \left(\frac{\tau}{R} \right) v_{\text{esc}}^2(R) v_{\text{esc}}(0) \min \left\{ \frac{m^4}{T^4}, 1 \right\} \sim \frac{\tau}{10^6 \text{ yr}} @ R = 1 \text{ AU}$$

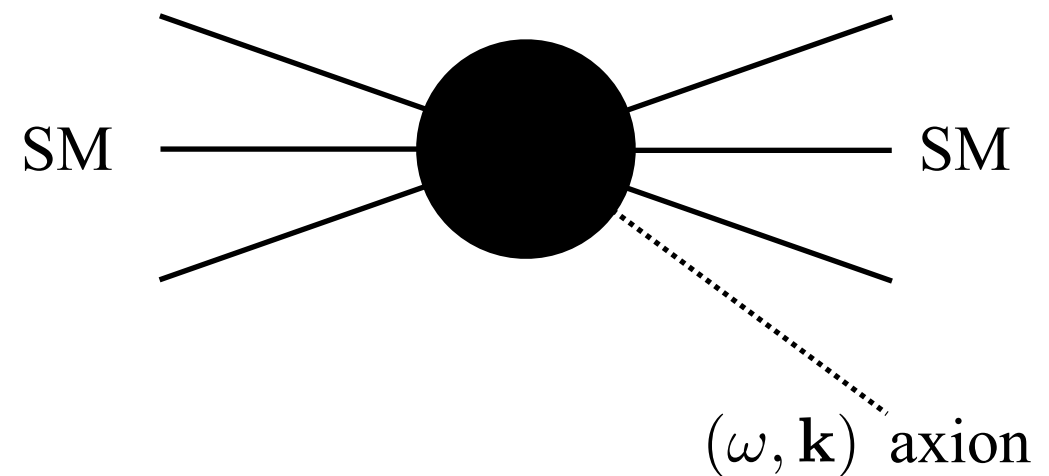
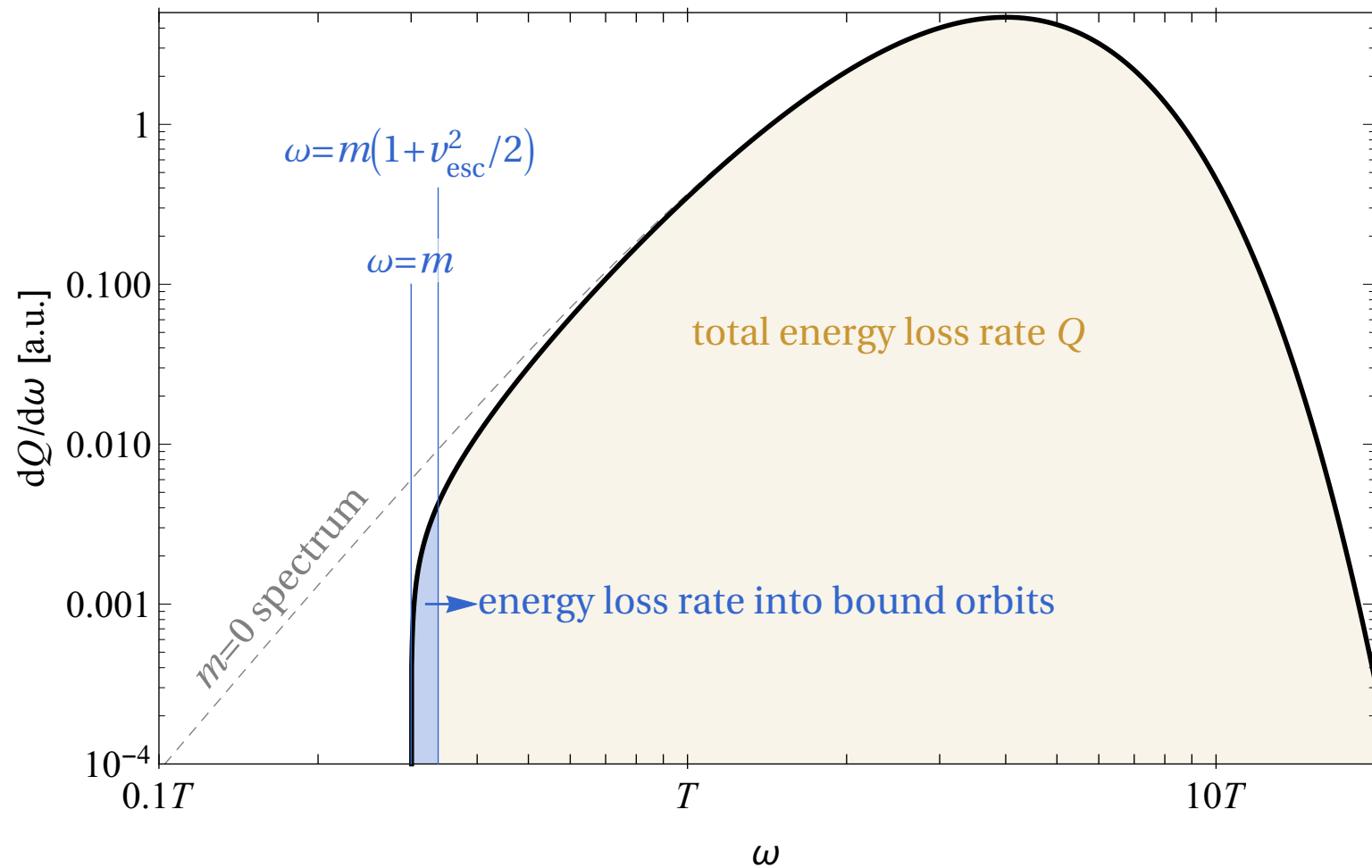
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bound: $(mv_{\text{esc}})^3$

unbound: T^3

$$\dot{\rho}_b(R) = \frac{3}{16\pi} \frac{G_N M_*}{R^4} \int d^3 R' \tilde{Q}(R') \sqrt{-\Phi(R')}$$

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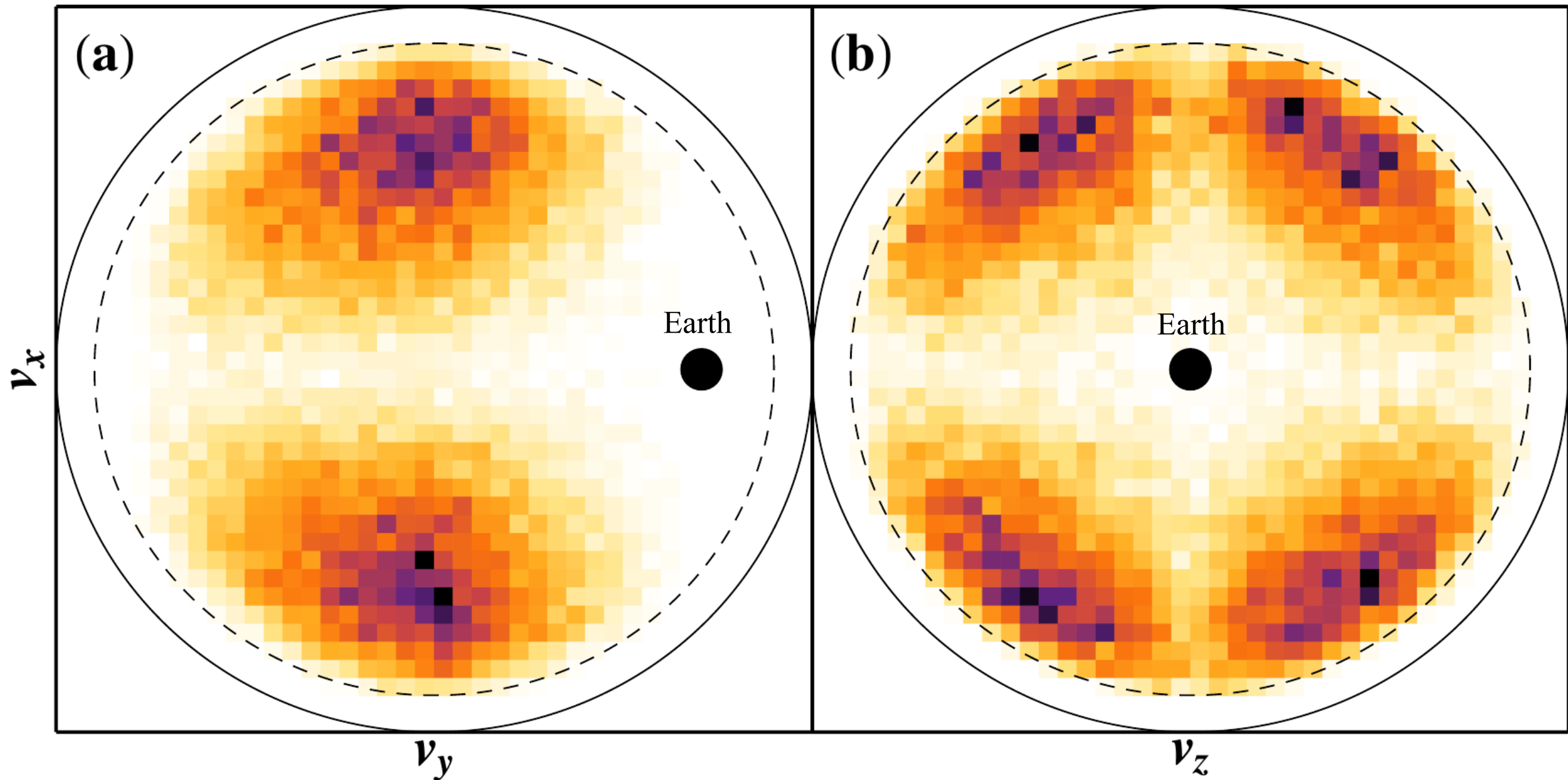
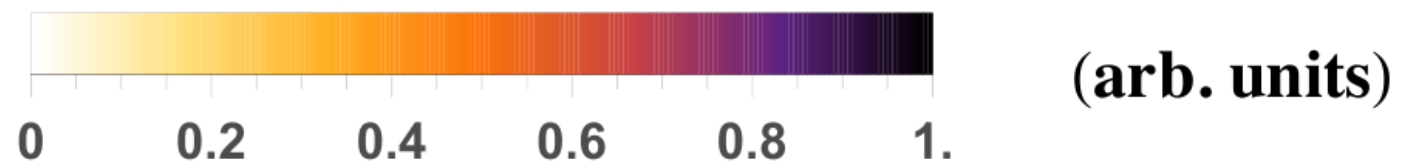
basin lifetime = orbital ejection time

- conservative: 2 Lyapunov times
→ $\tau \sim 10^7 \text{ yr}$
- fiducial: asteroid data + sims
→ $\tau \sim 10^8 \text{ yr}$
- optimistic: secular PT
→ $\tau \sim 4.5 \times 10^9 \text{ yr}$

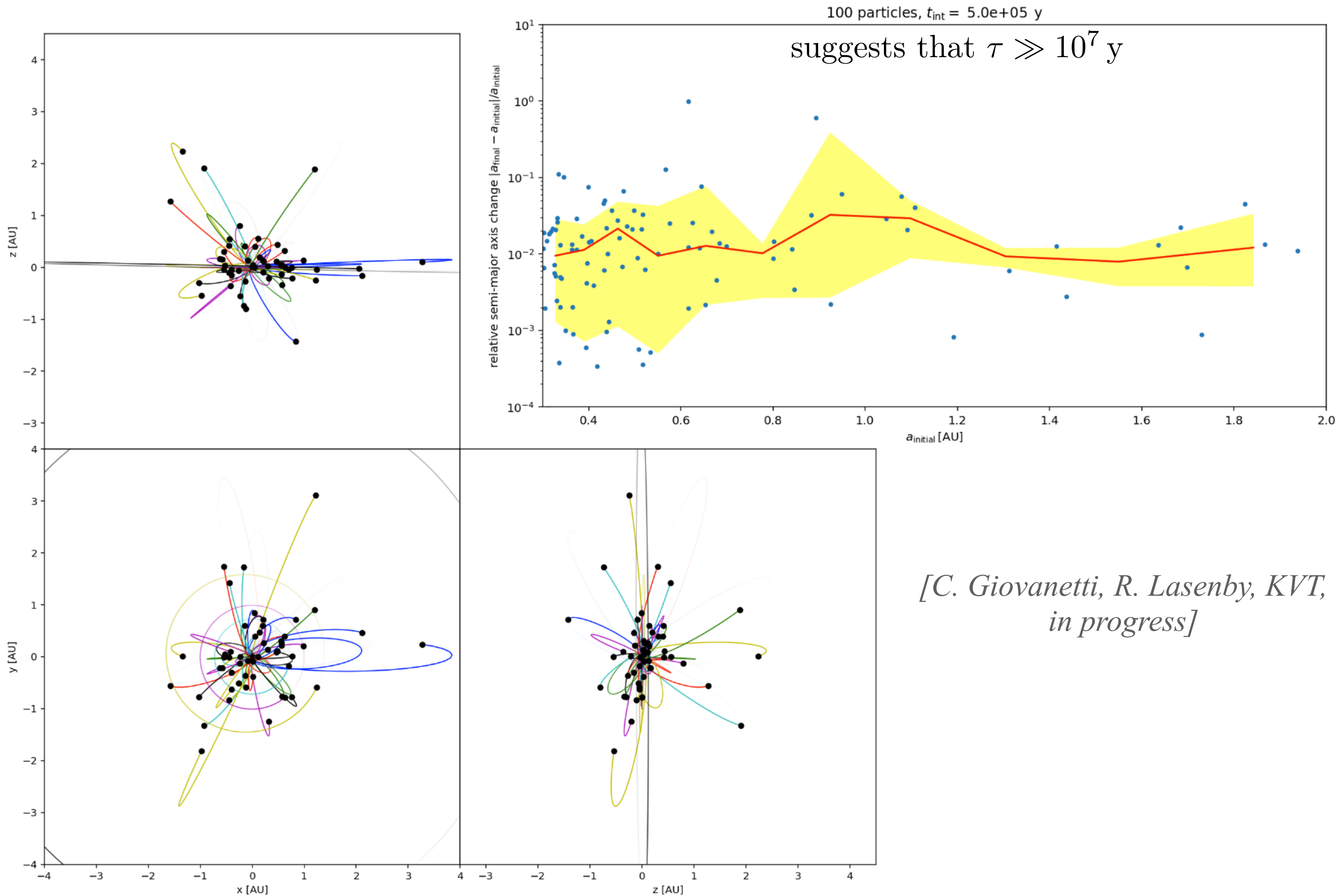
Gravitational Ejection

[Anderson et al, "Direct detection signatures of a primordial Solar dark matter halo", arXiv:2007:11016]

31% of non-Jupiter-crossing phase space survives 4.6 Gyr

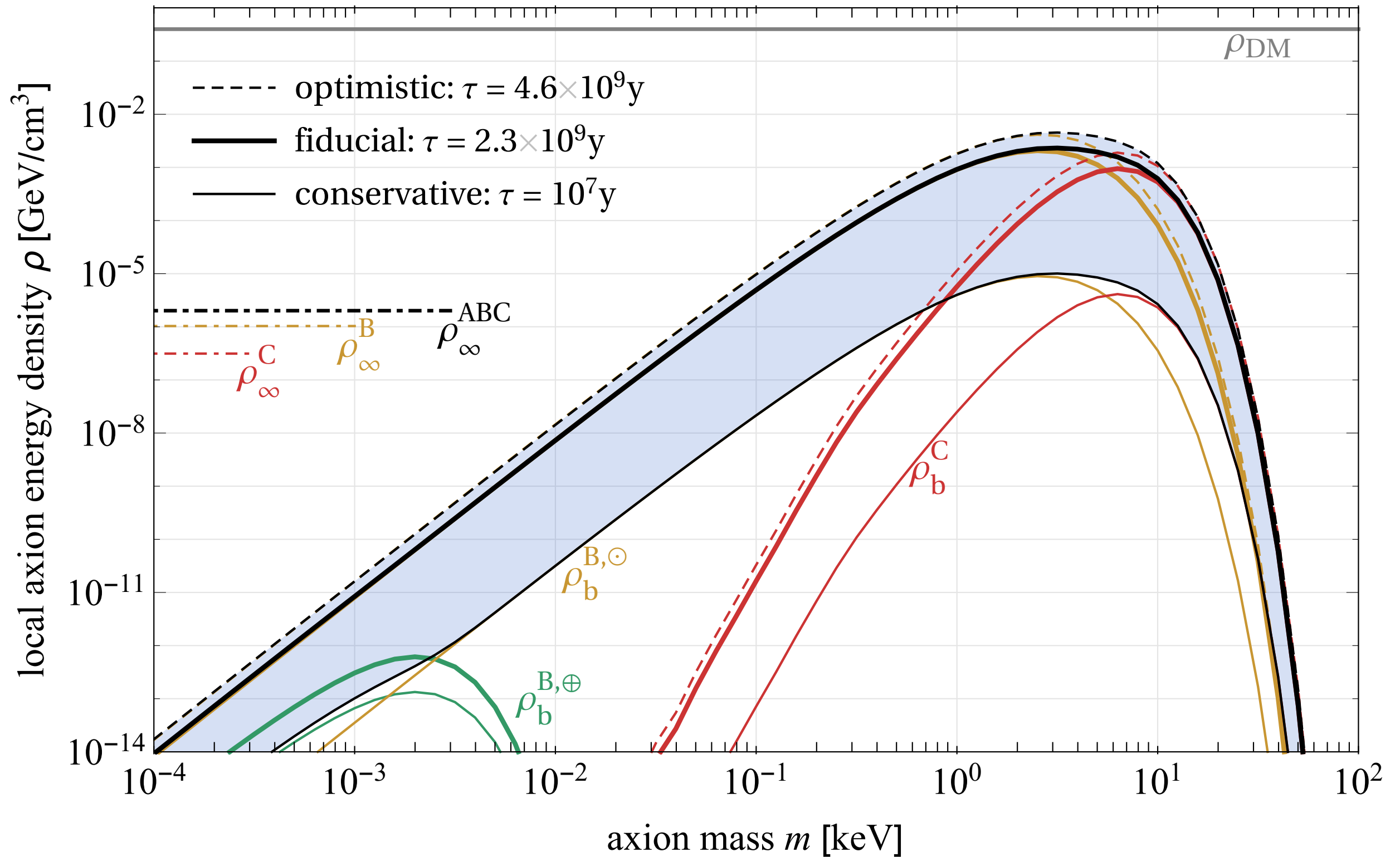


N-body simulations



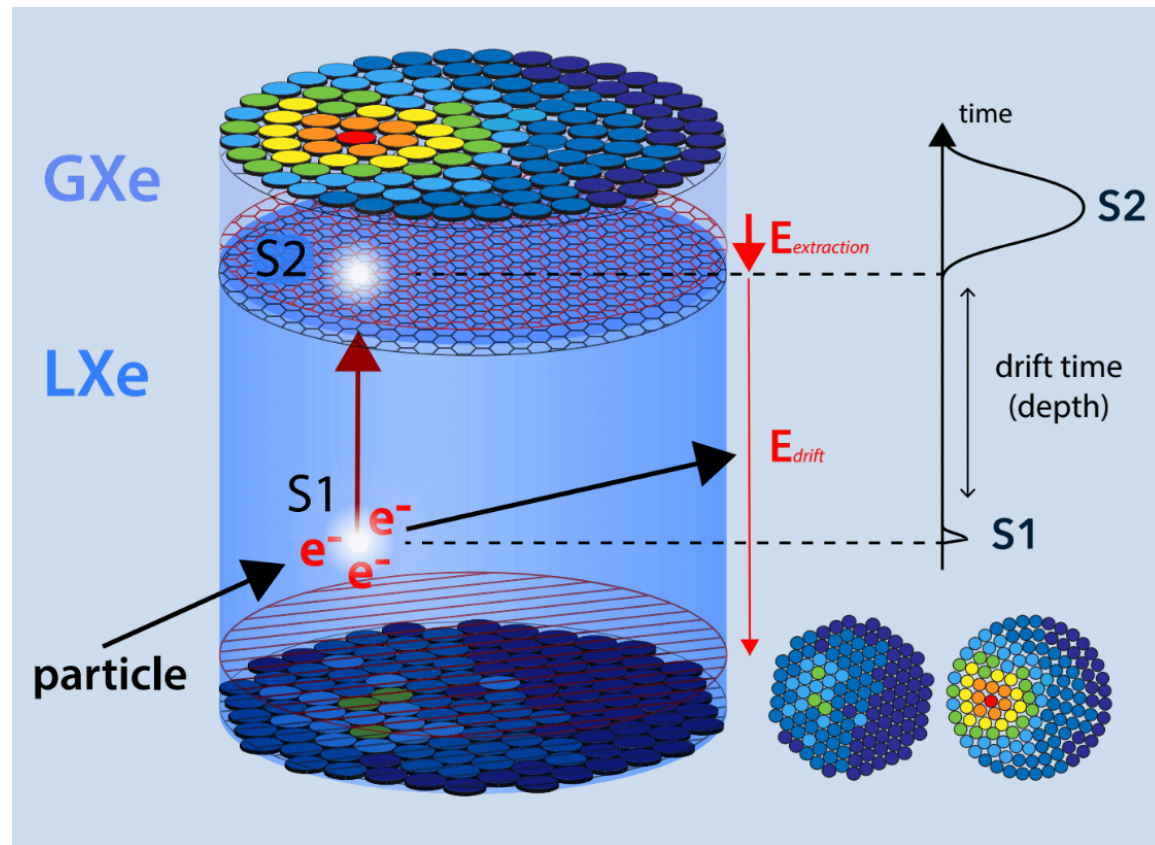
Solar Axion Basin

axion coupling $g_{aee} = 3 \times 10^{-13}$



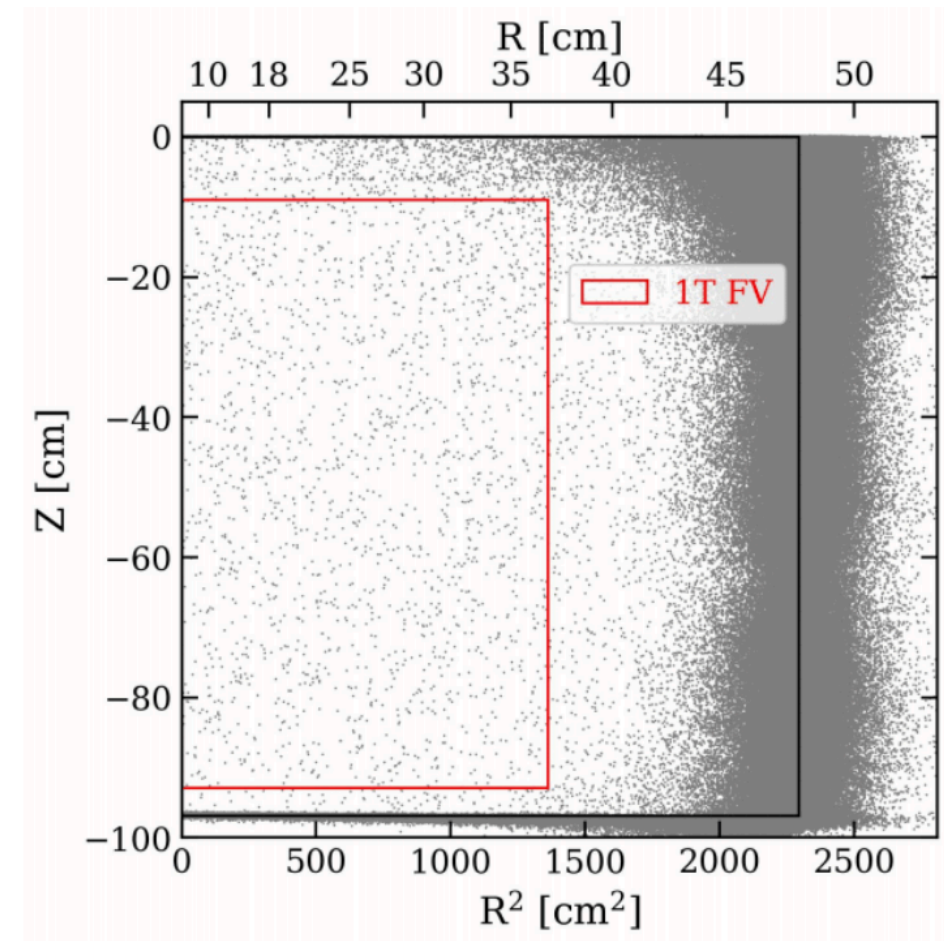
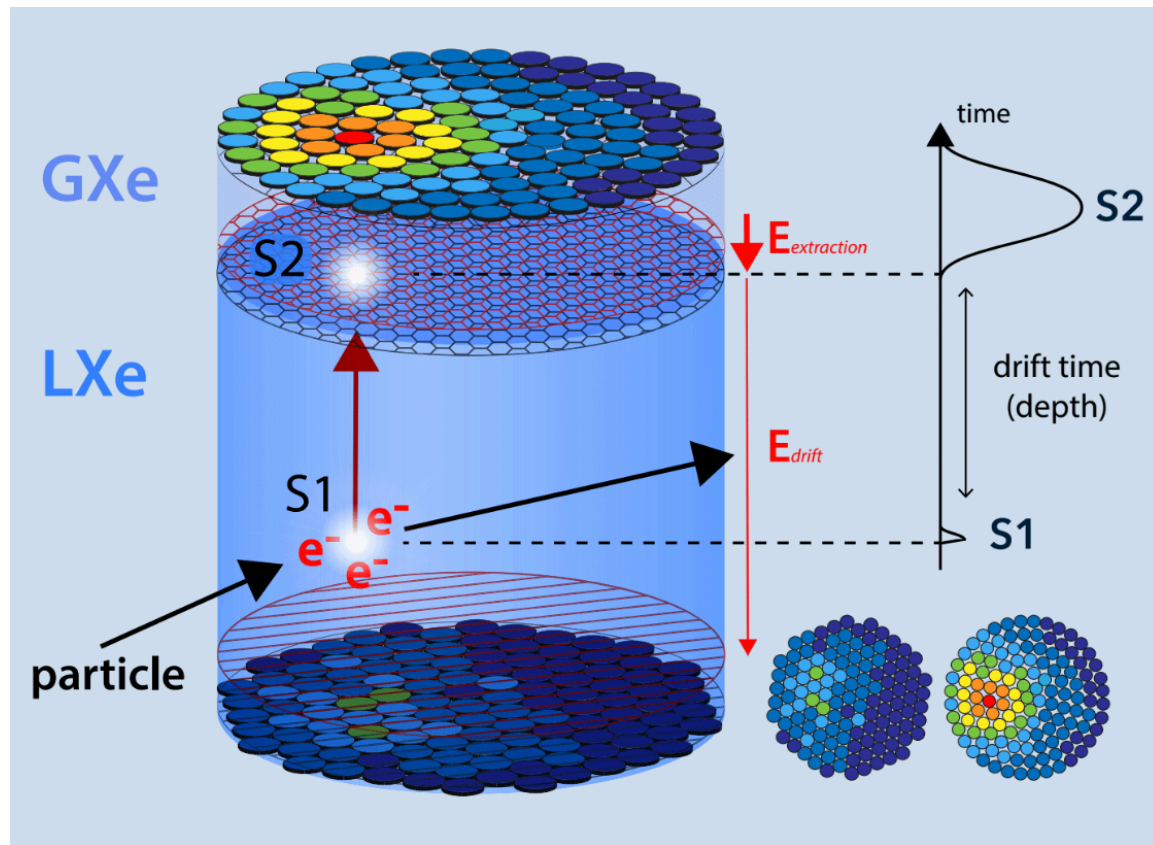
XENON1T: Results

[2006.09721]



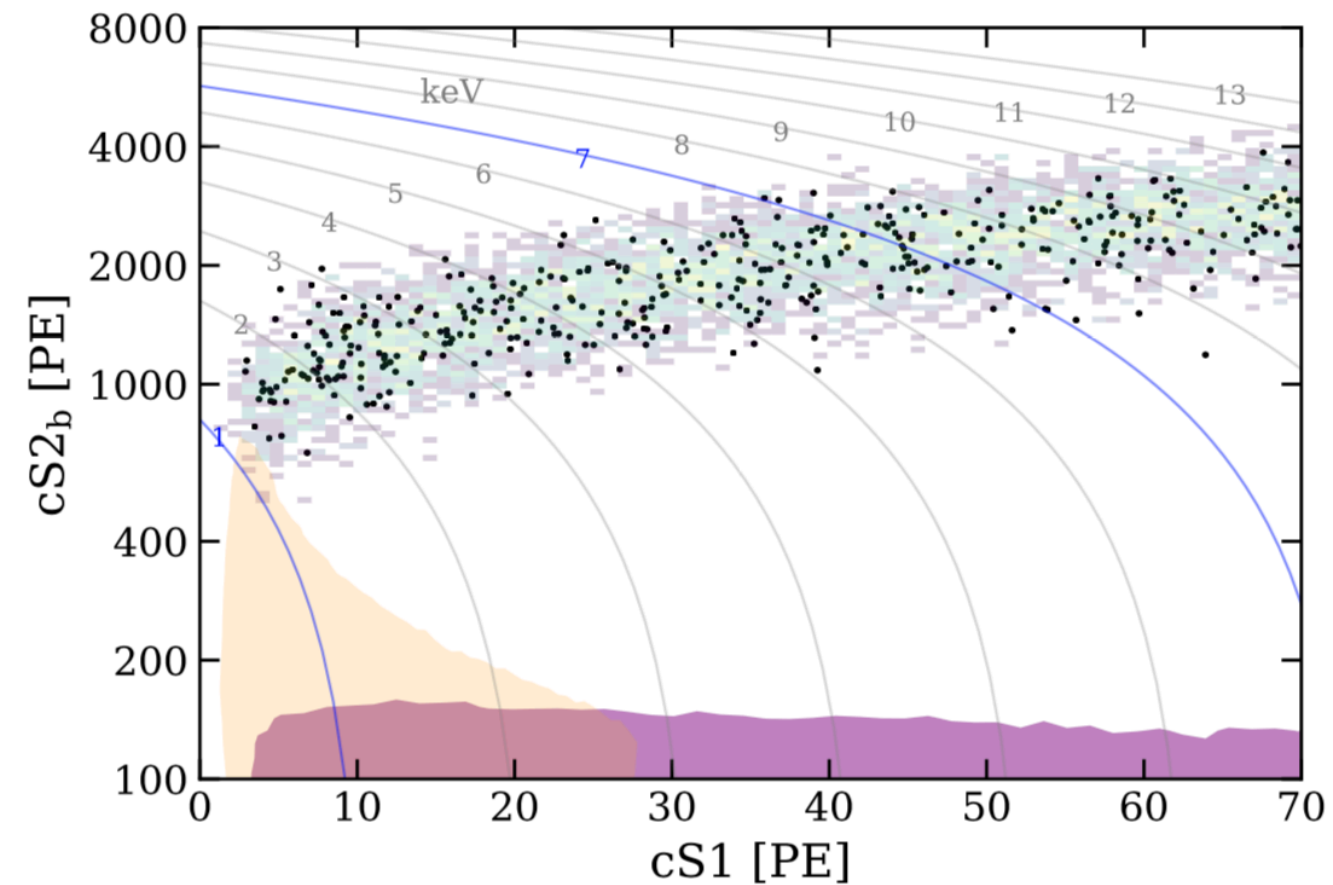
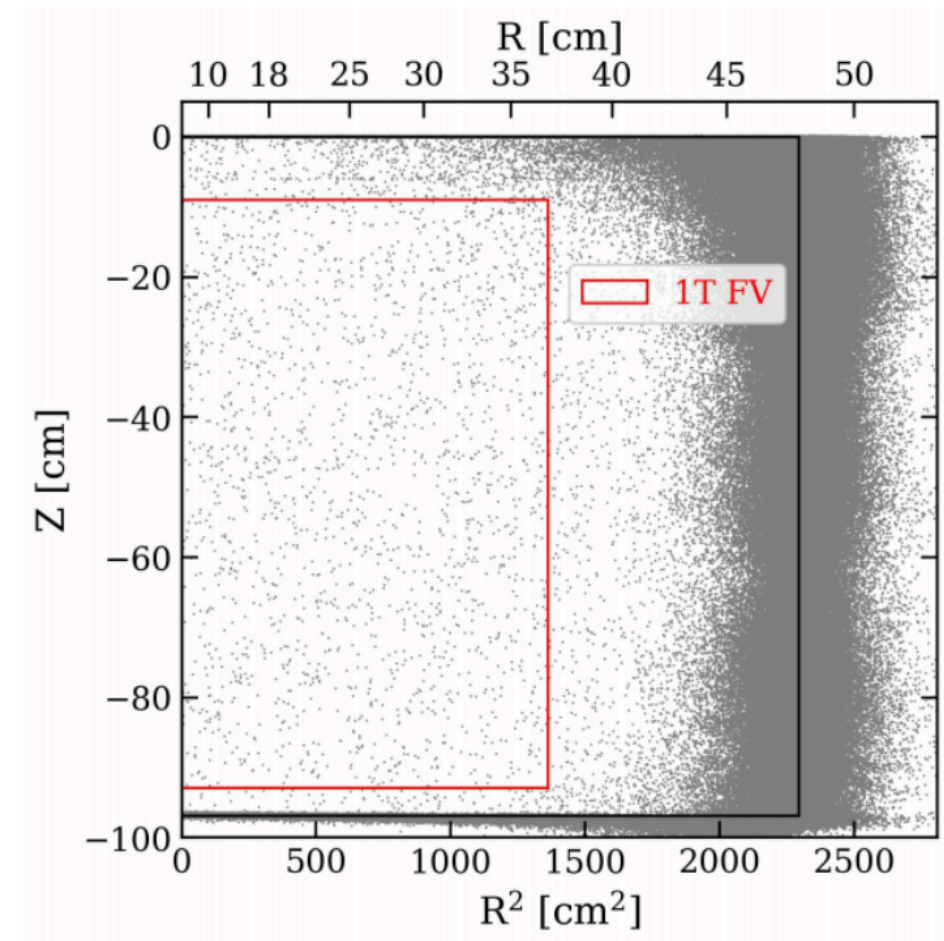
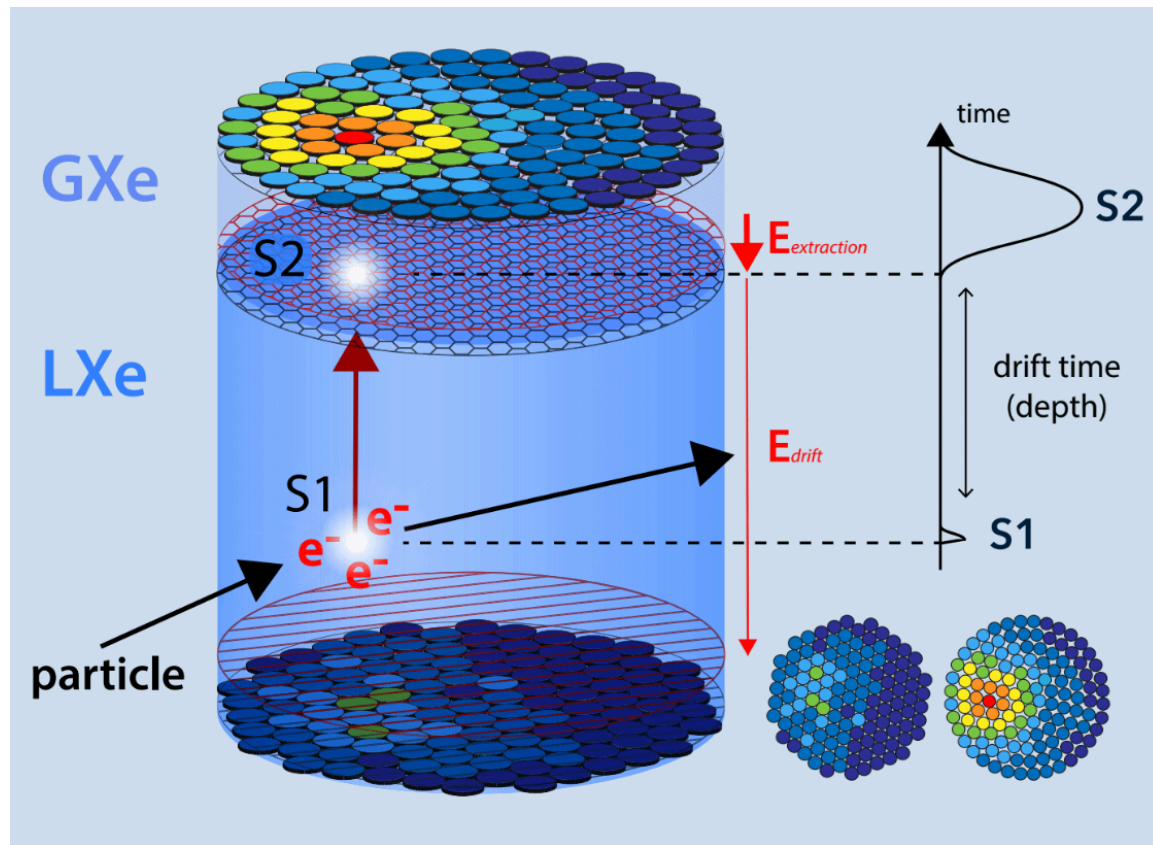
XENON1T: Results

[2006.09721]



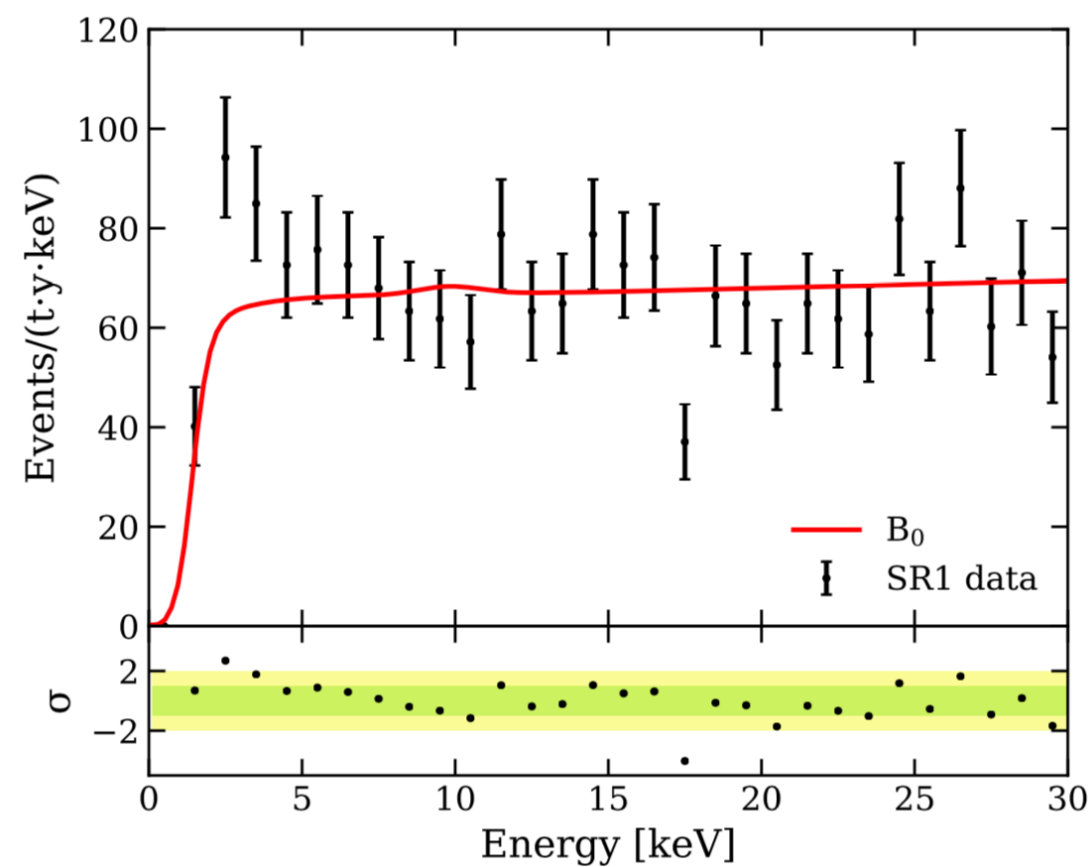
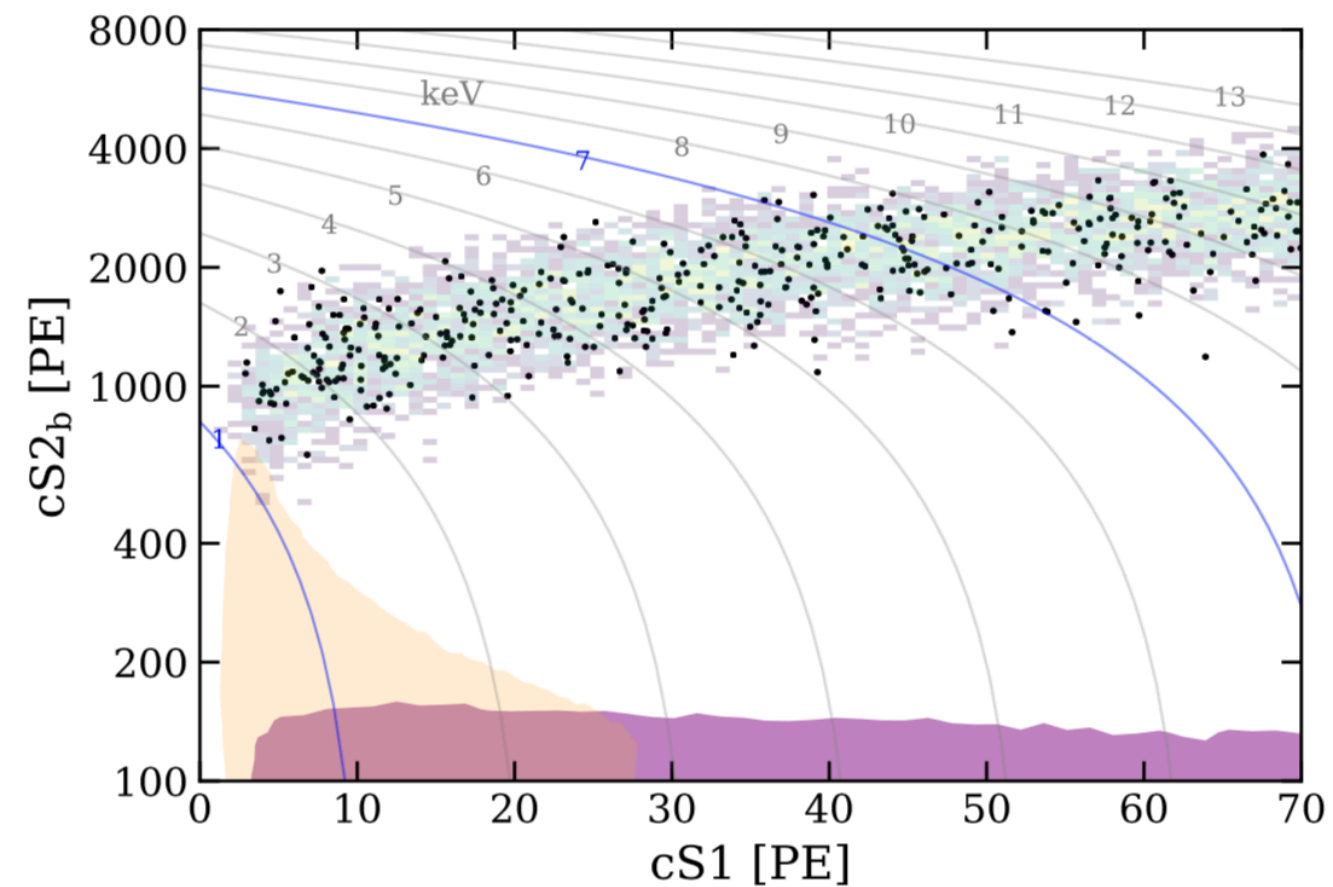
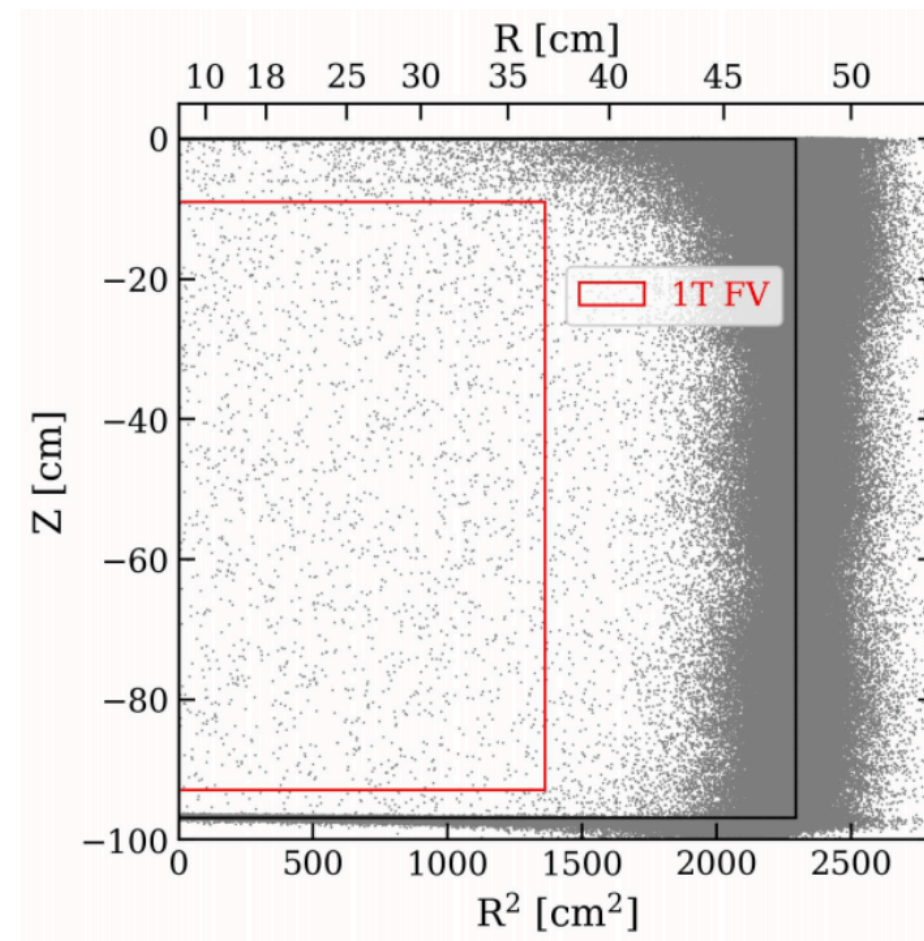
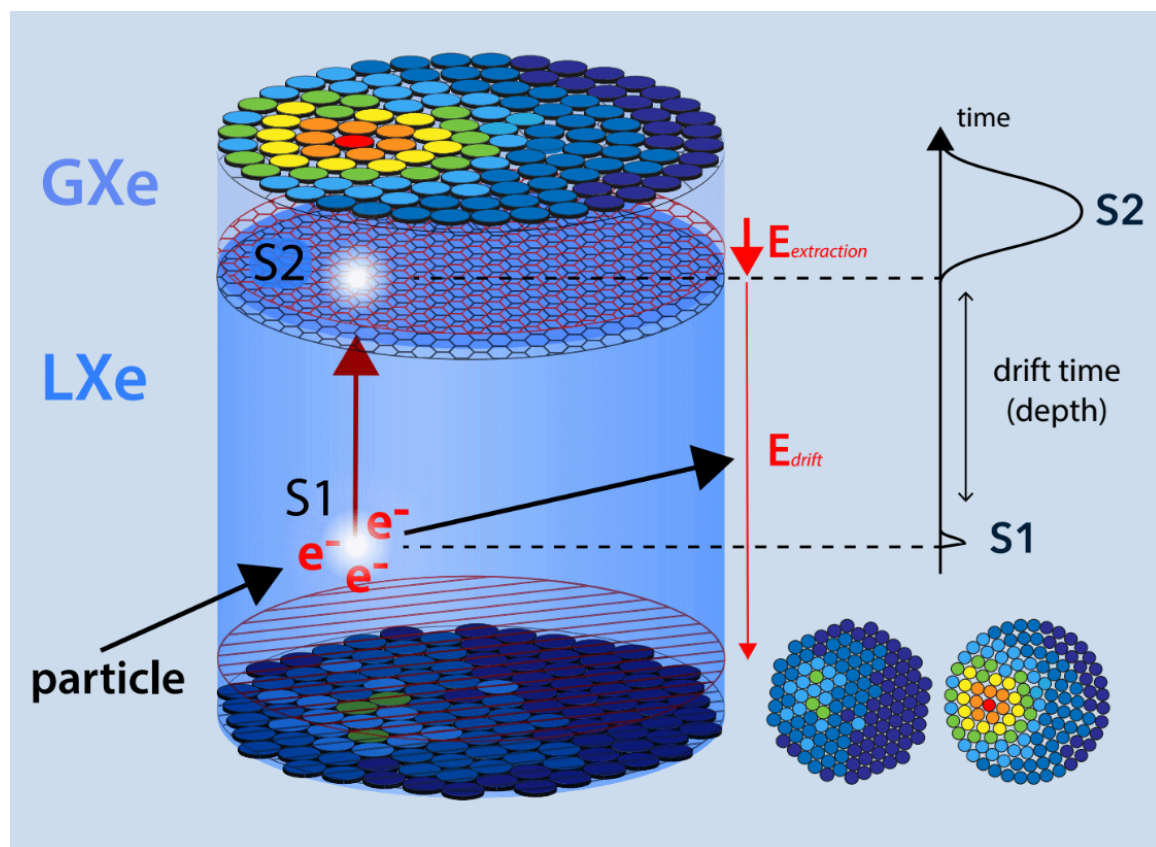
XENON1T: Results

[2006.09721]



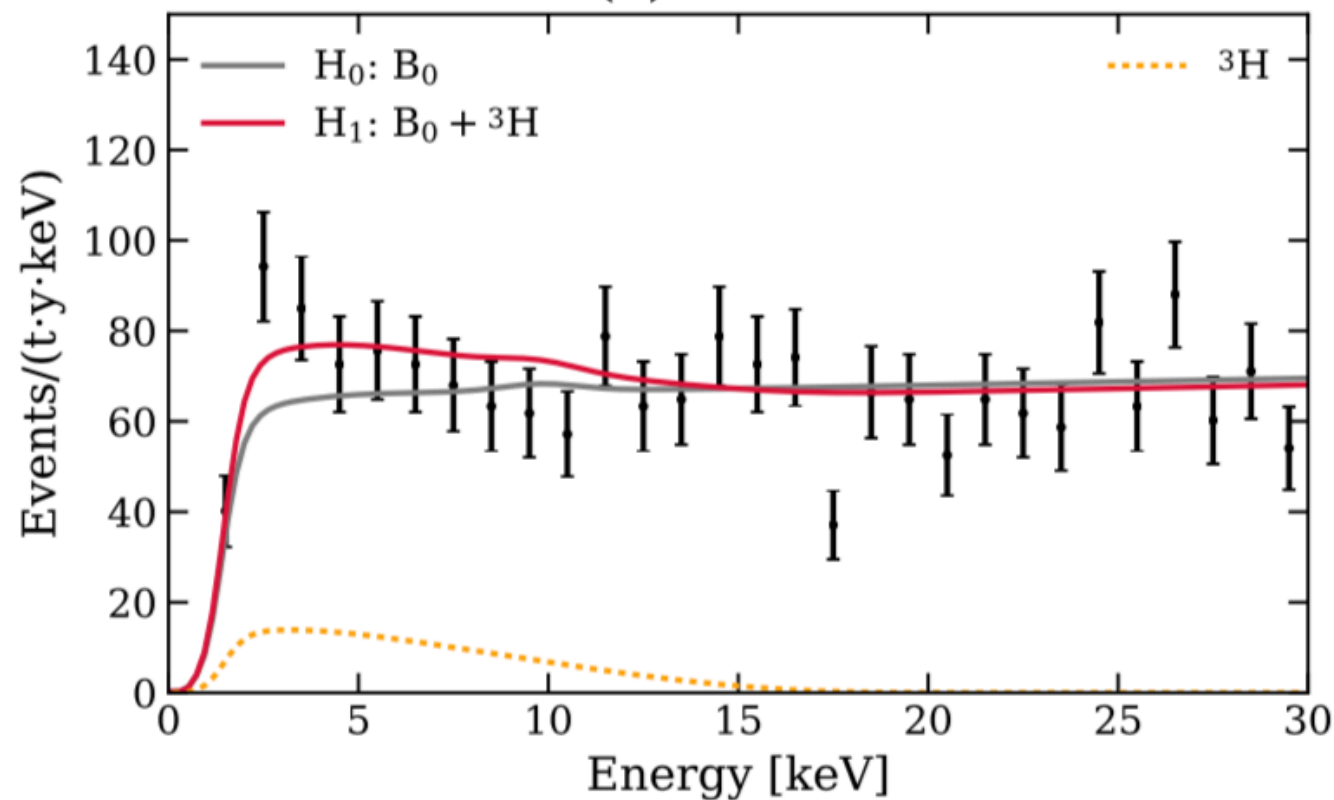
XENON1T: Results

[2006.09721]

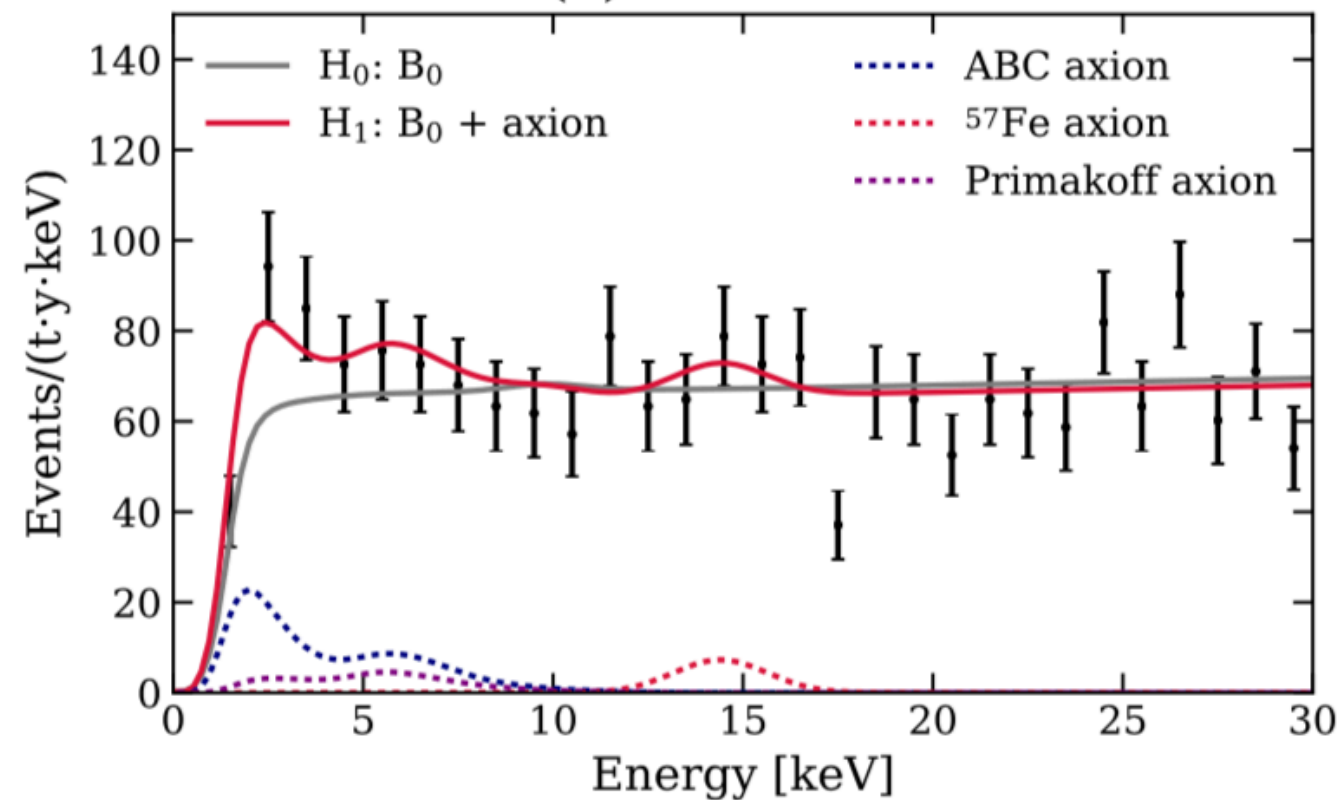


XENON1T: Interpretations

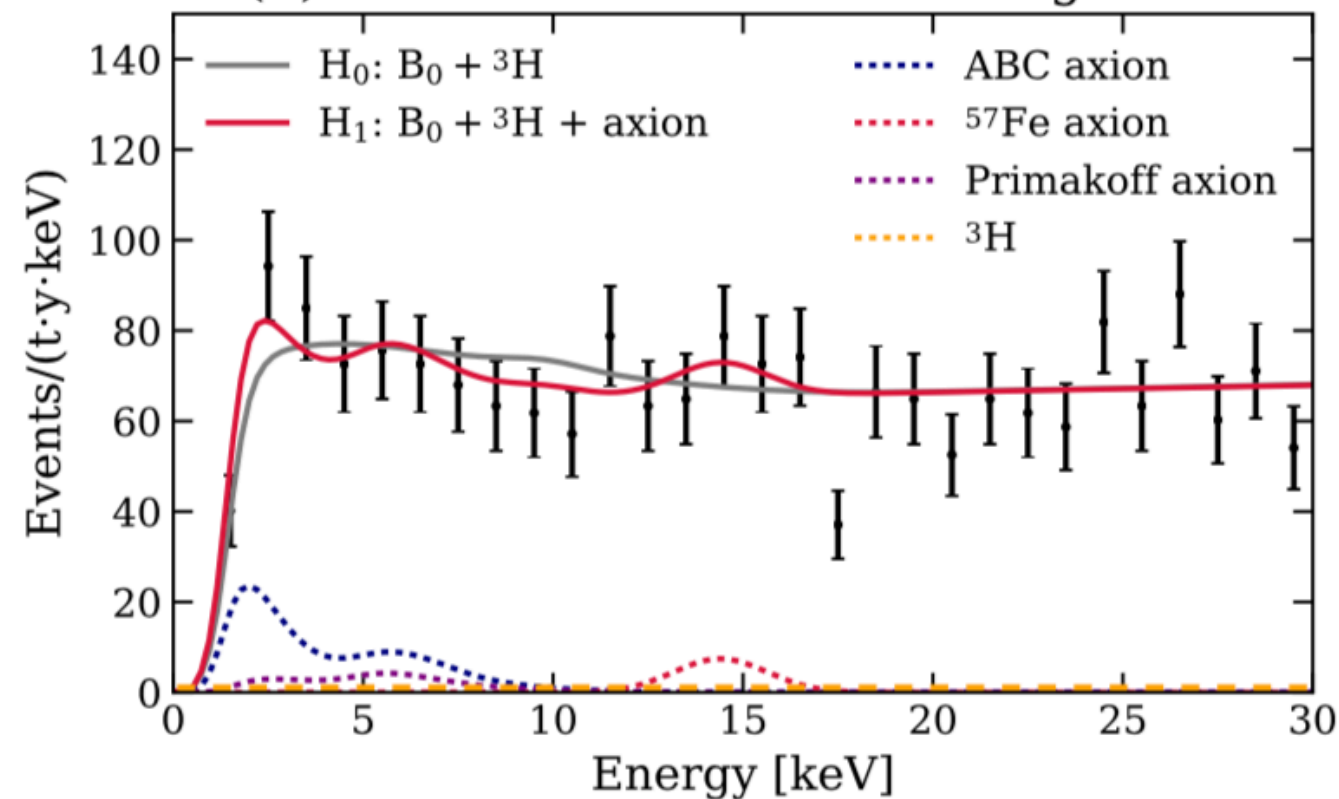
(a) Tritium



(b) Solar axion

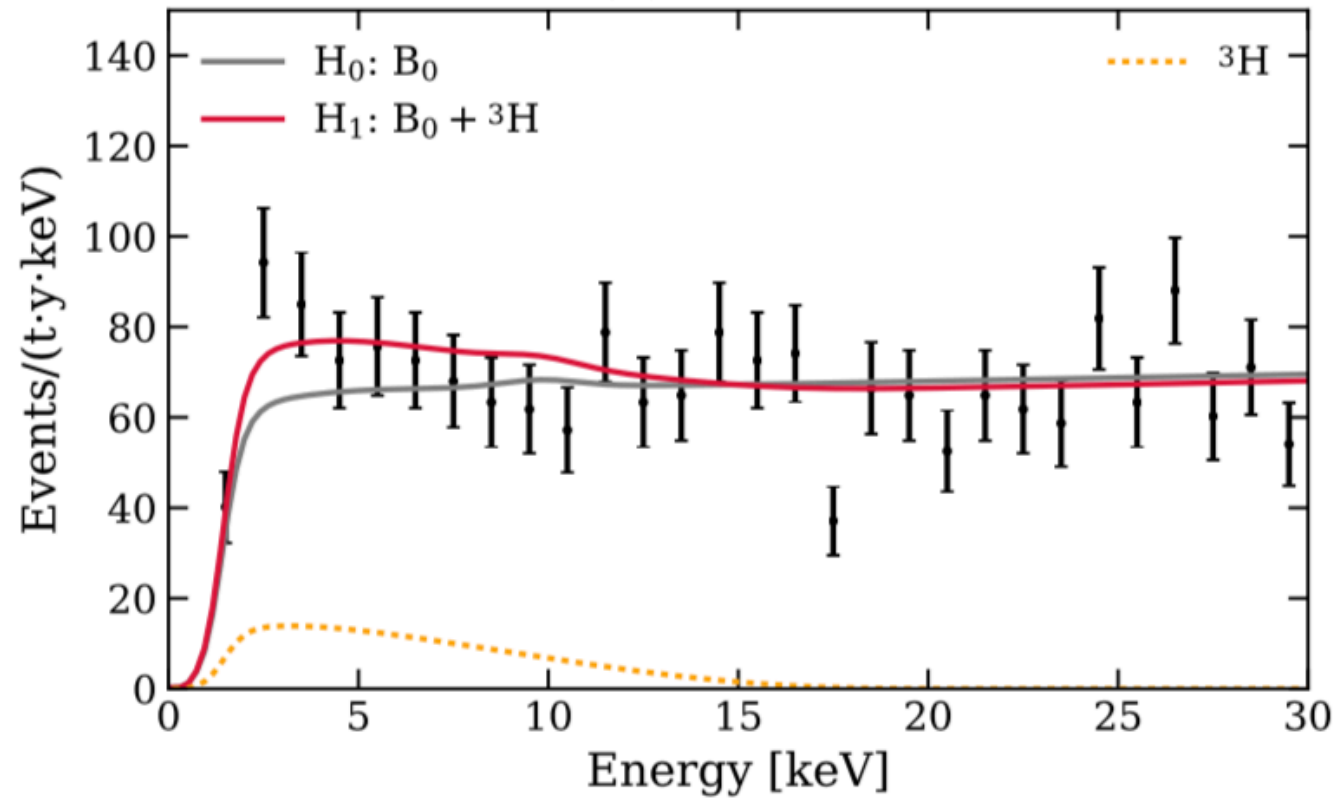


(d) Solar axion vs tritium background

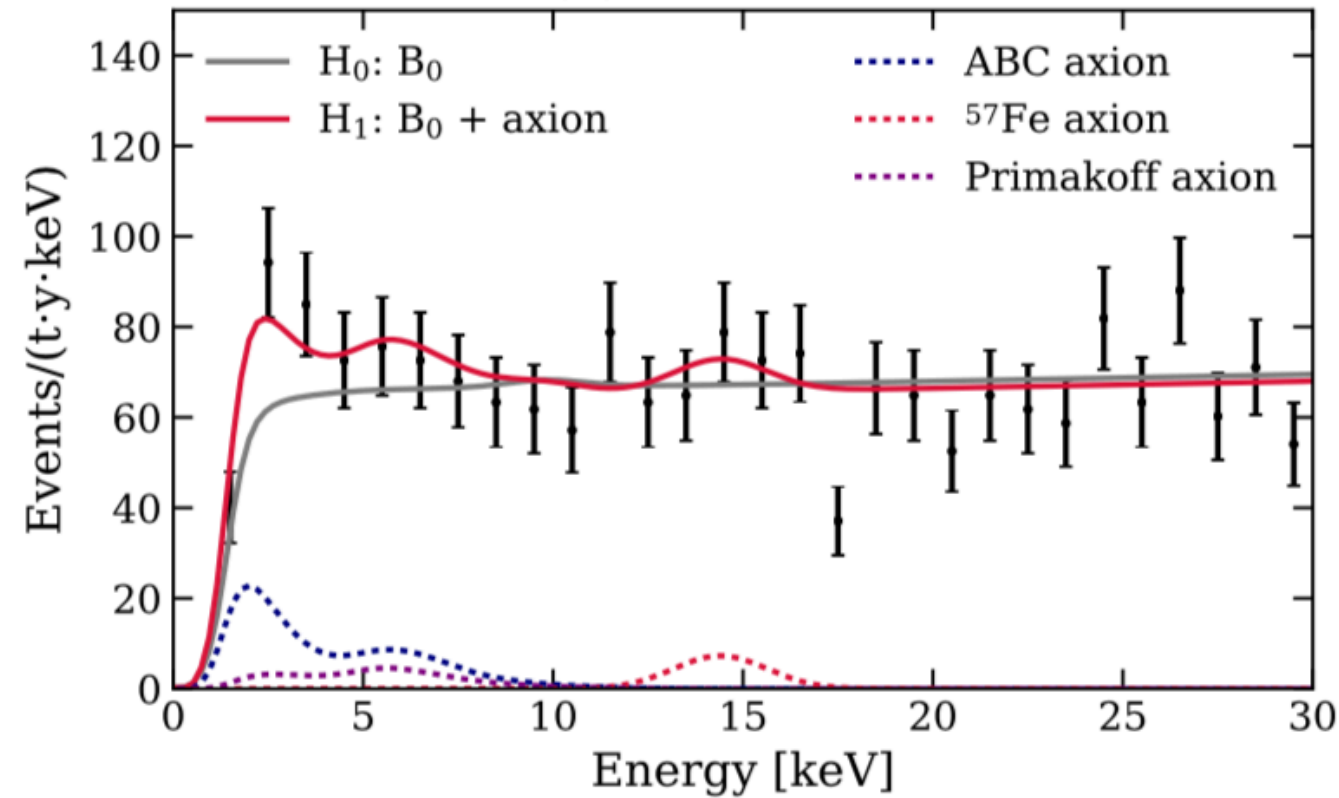


XENON1T: Interpretations

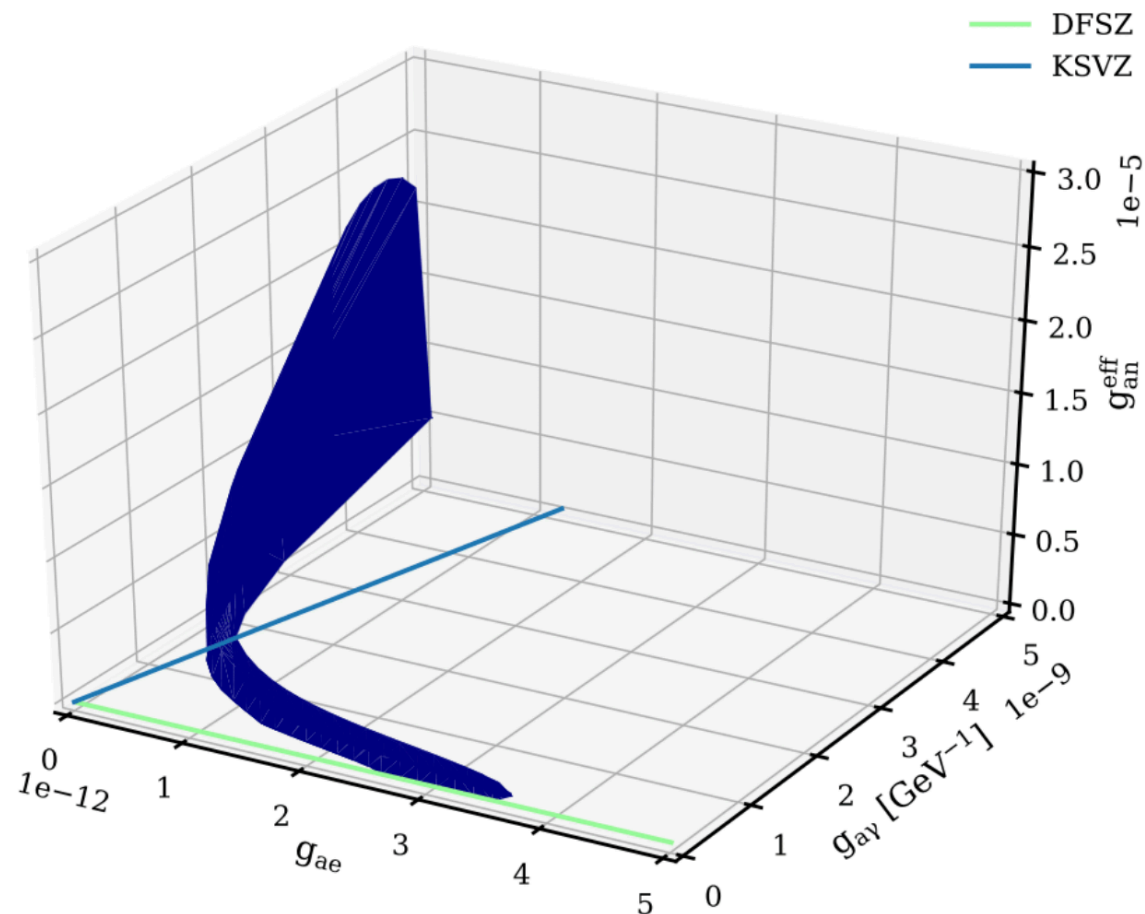
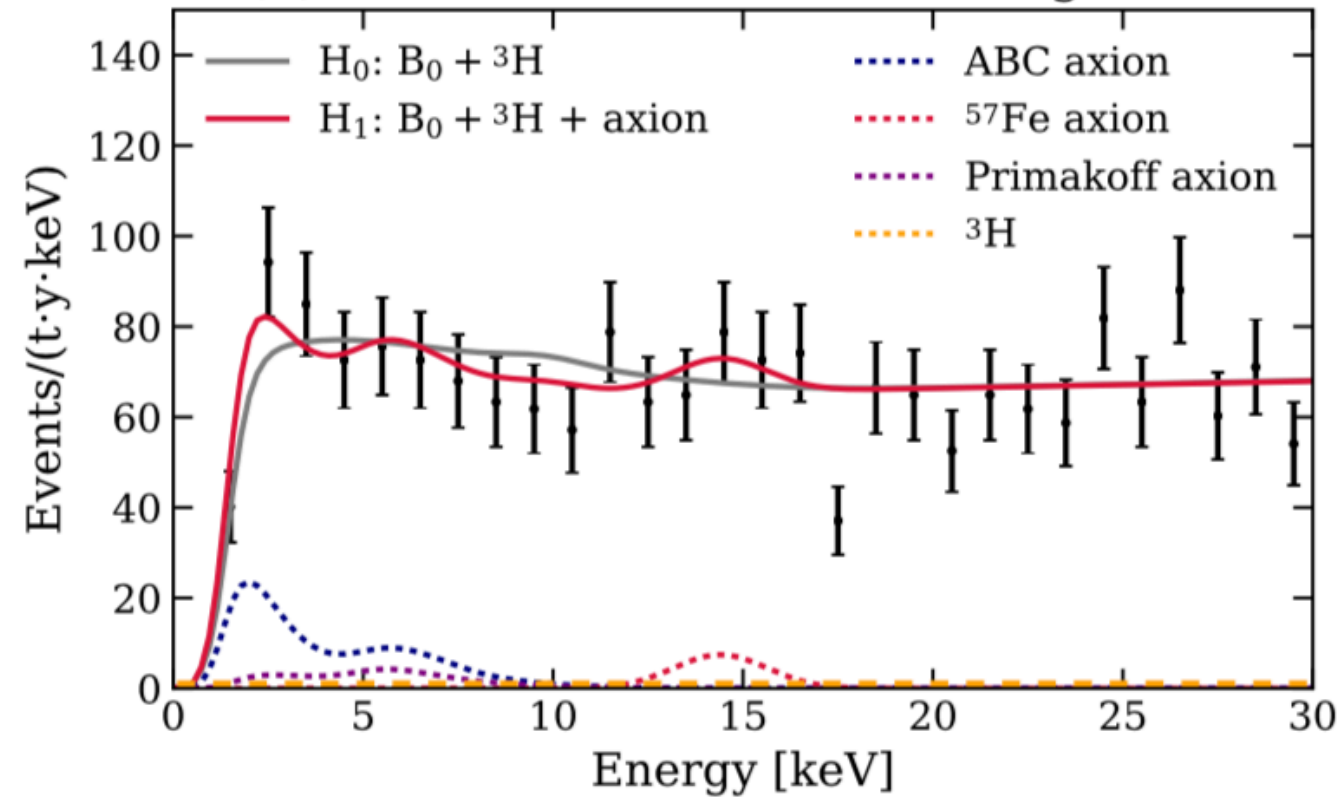
(a) Tritium



(b) Solar axion

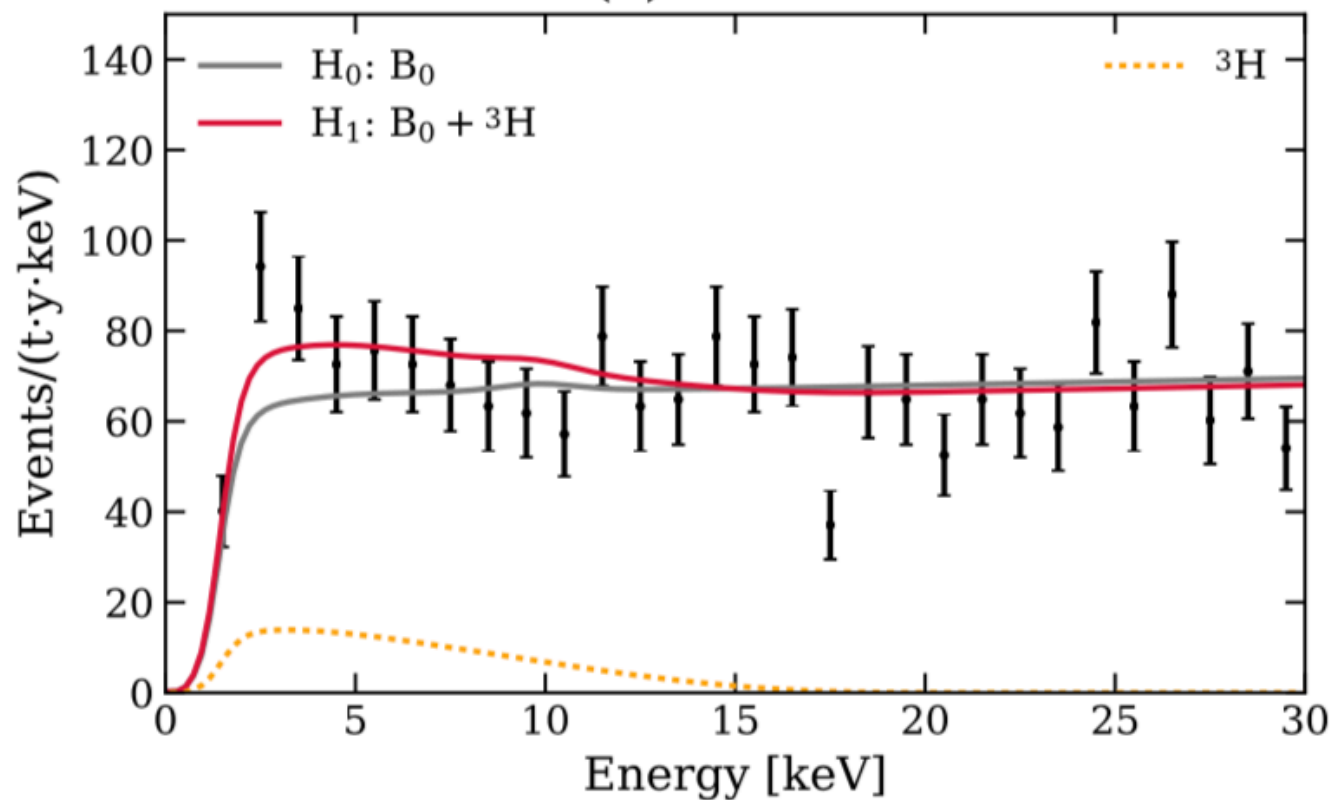


(d) Solar axion vs tritium background

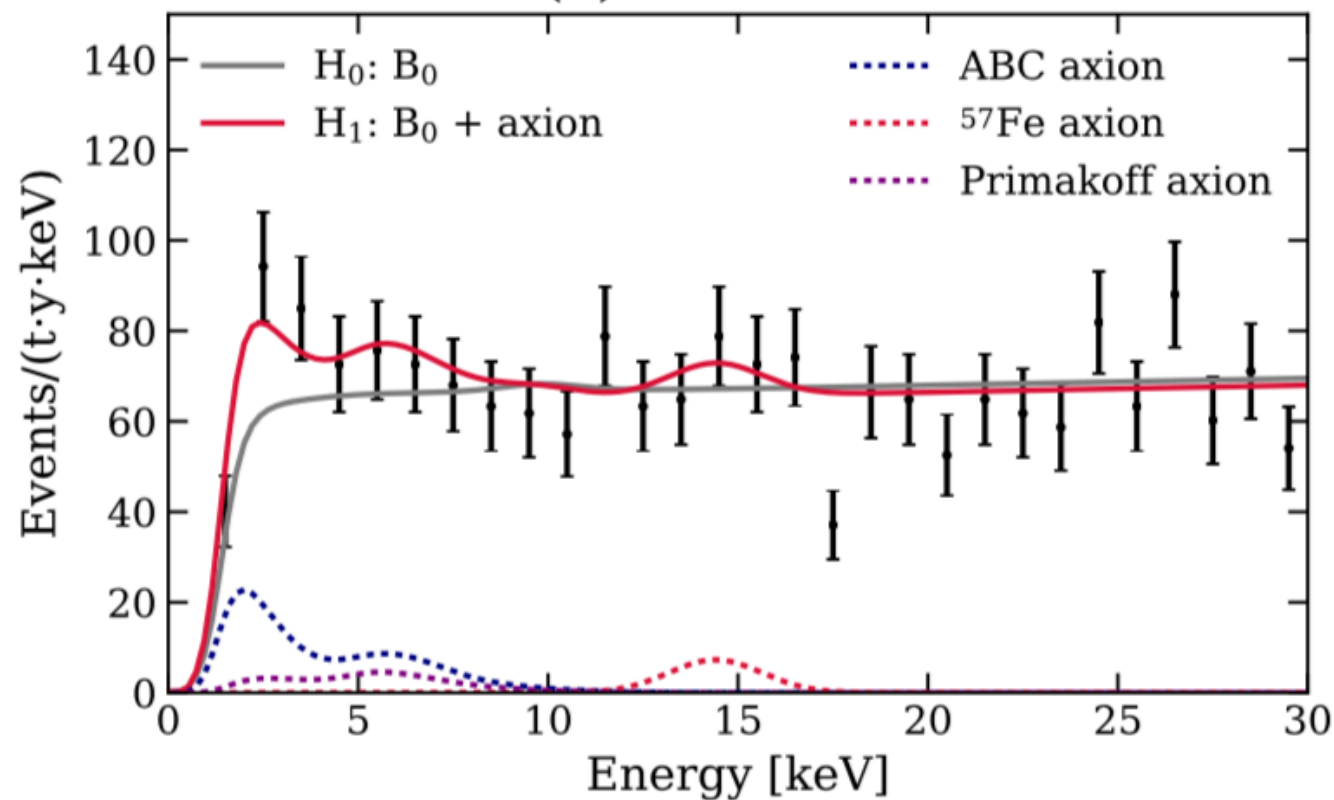


XENON1T: Interpretations

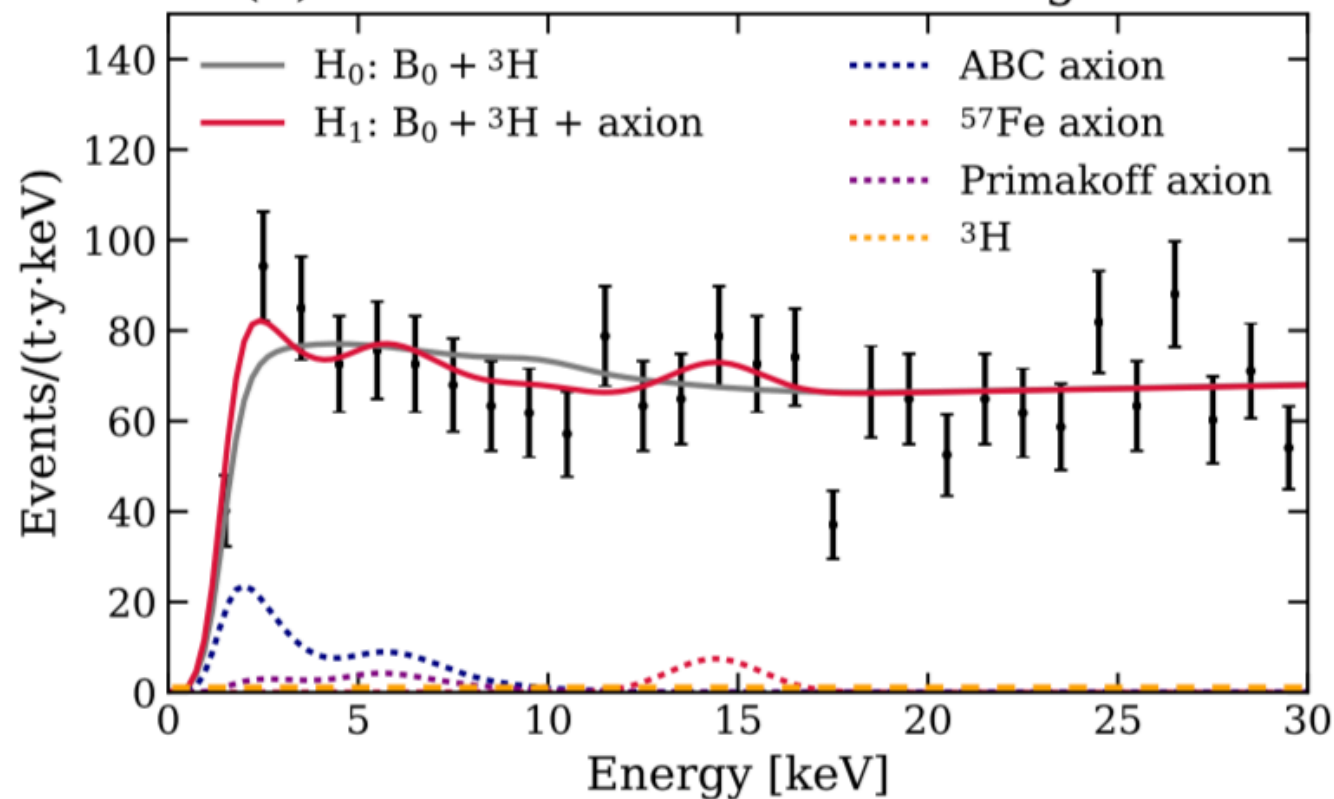
(a) Tritium



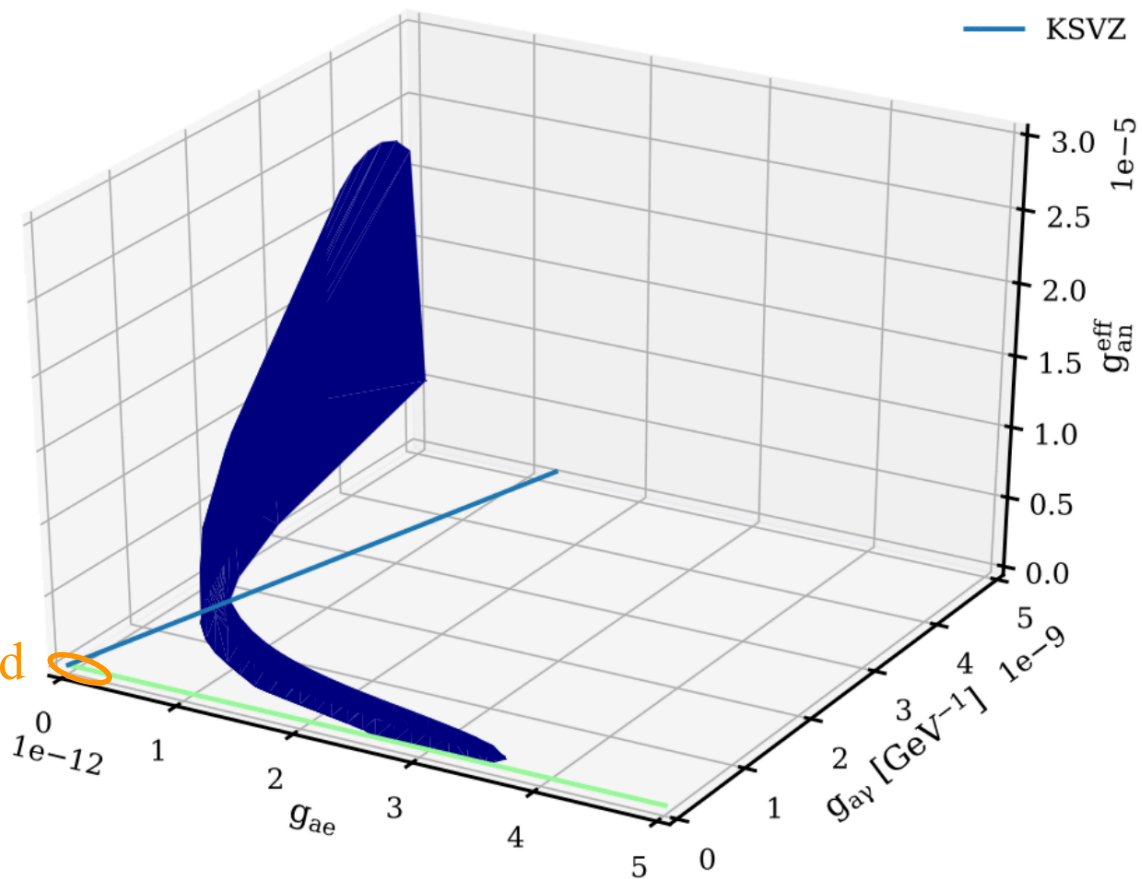
(b) Solar axion



(d) Solar axion vs tritium background

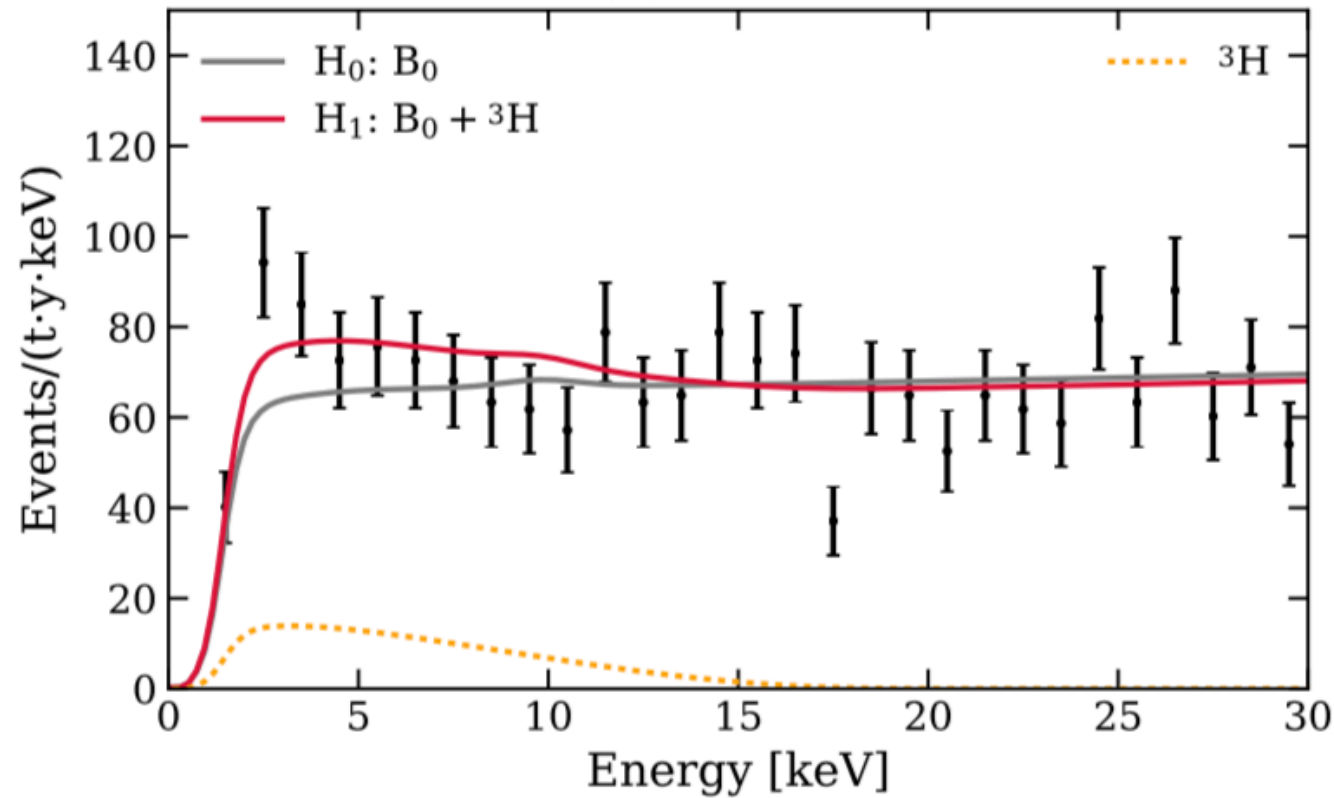


— DFSZ
— KSVZ

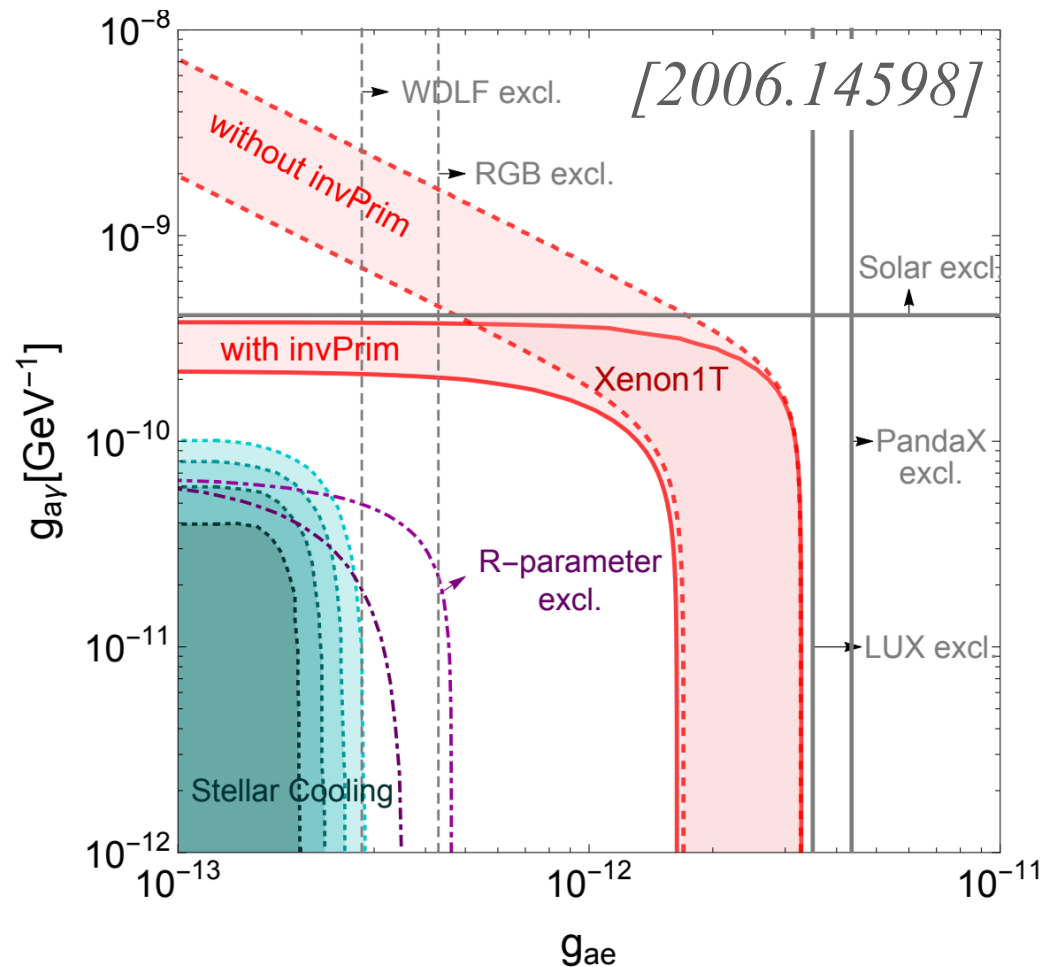
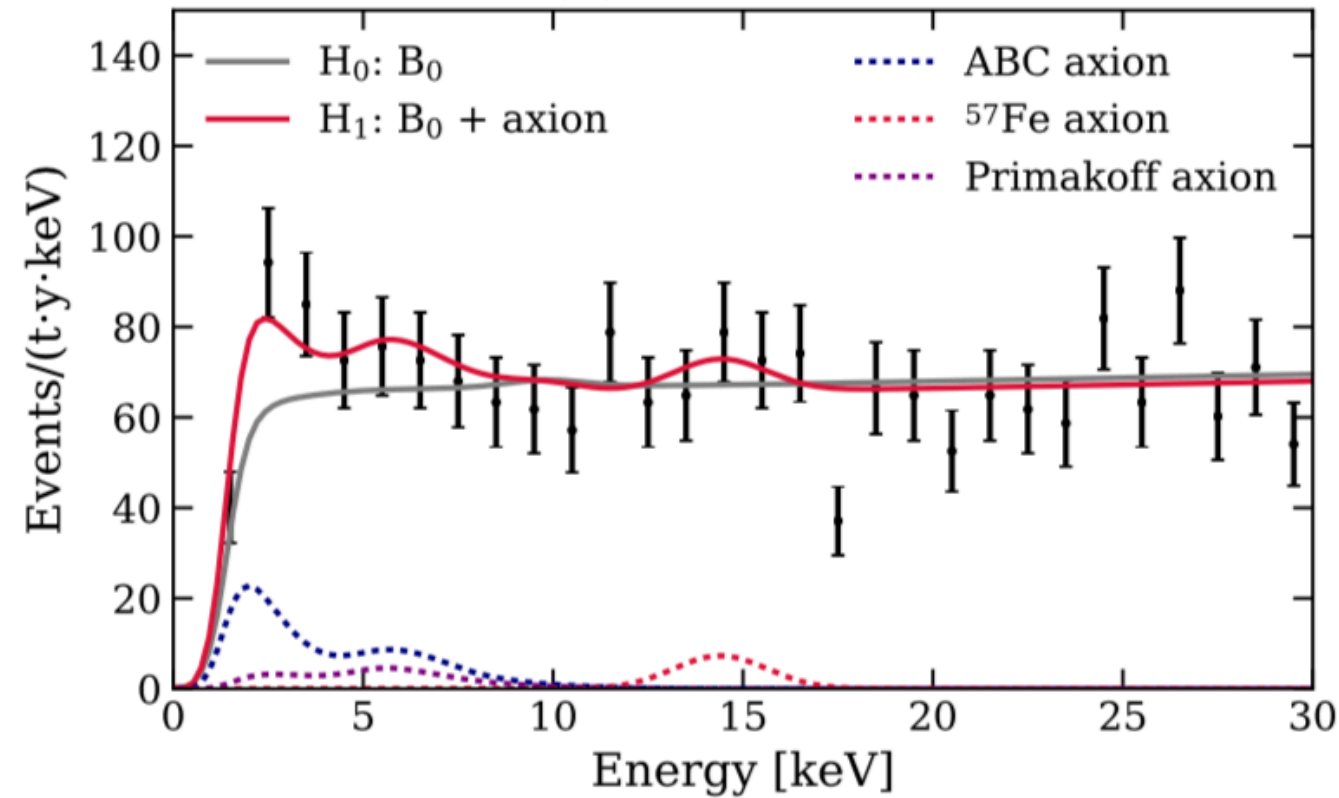


XENON1T: Interpretations

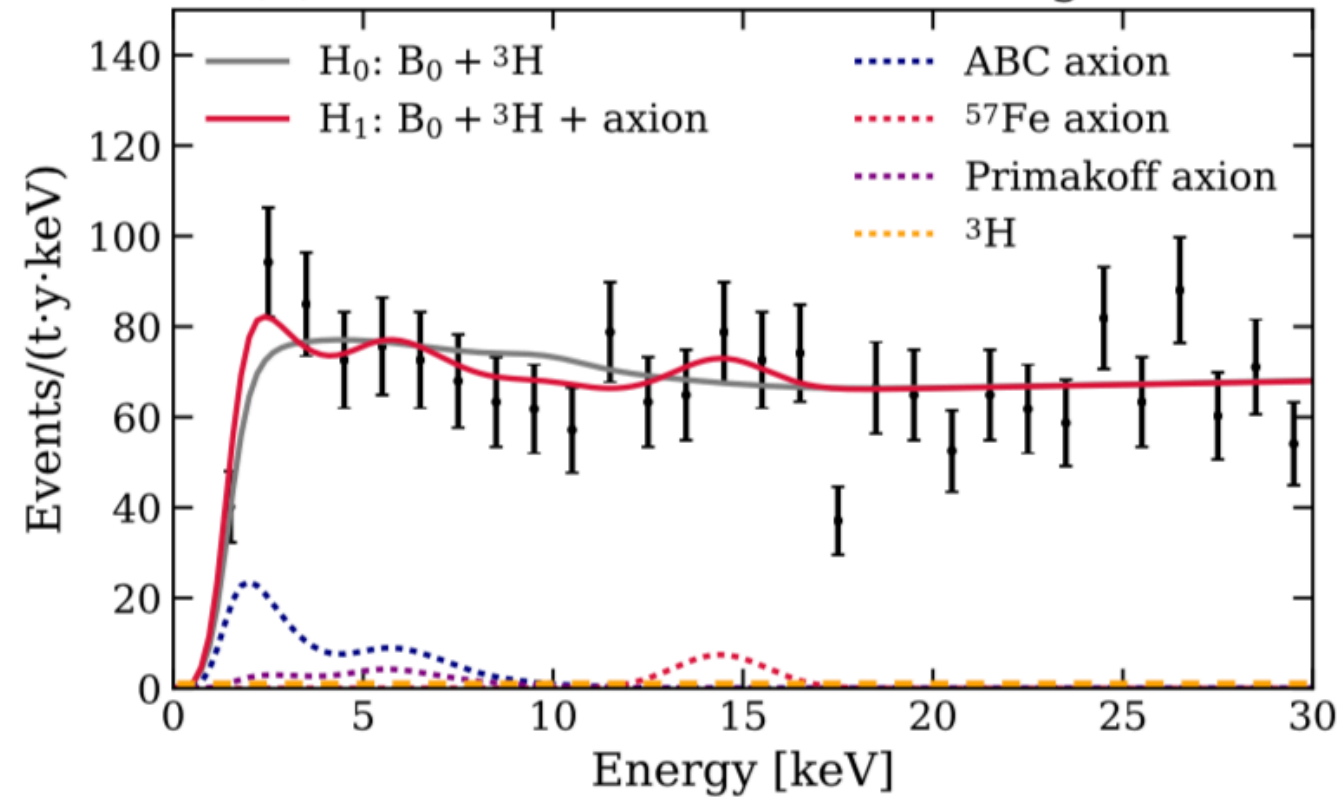
(a) Tritium



(b) Solar axion

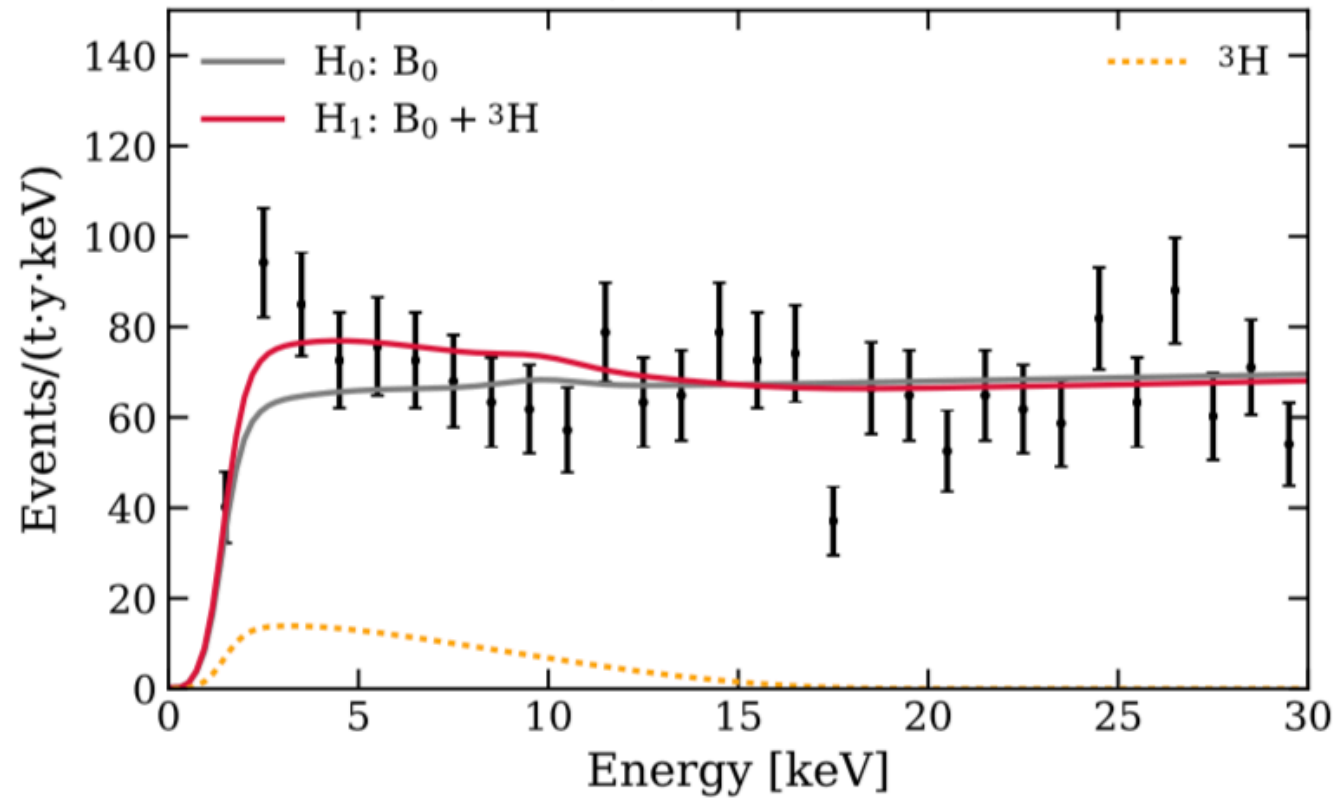


(d) Solar axion vs tritium background

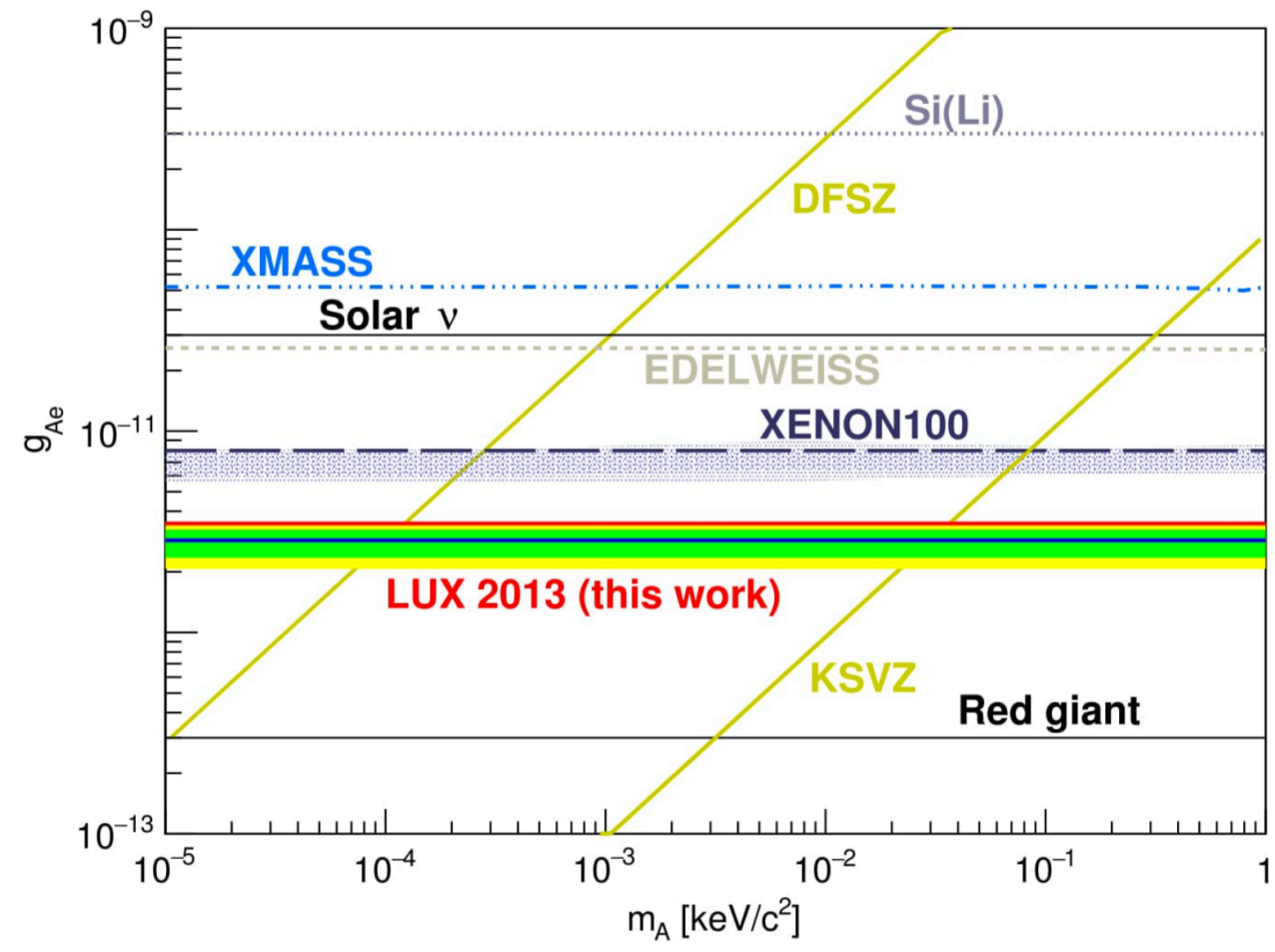
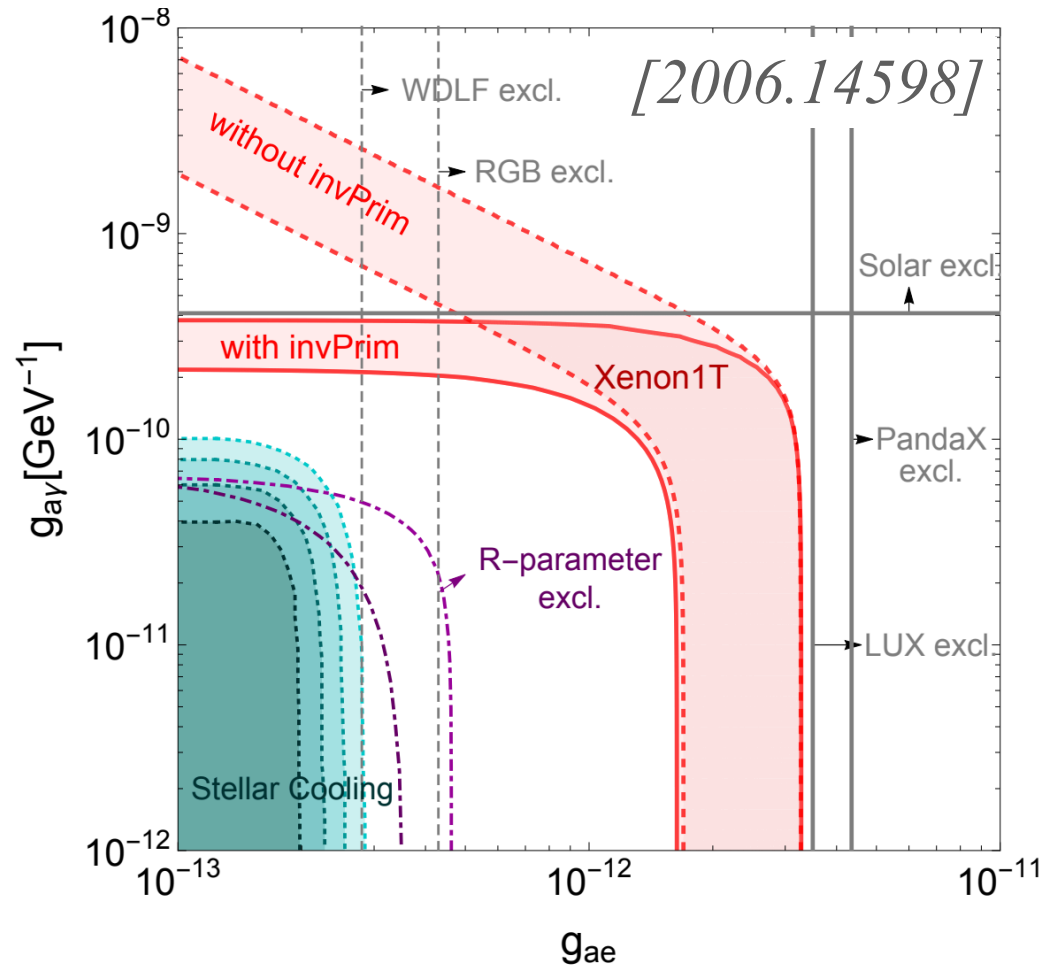
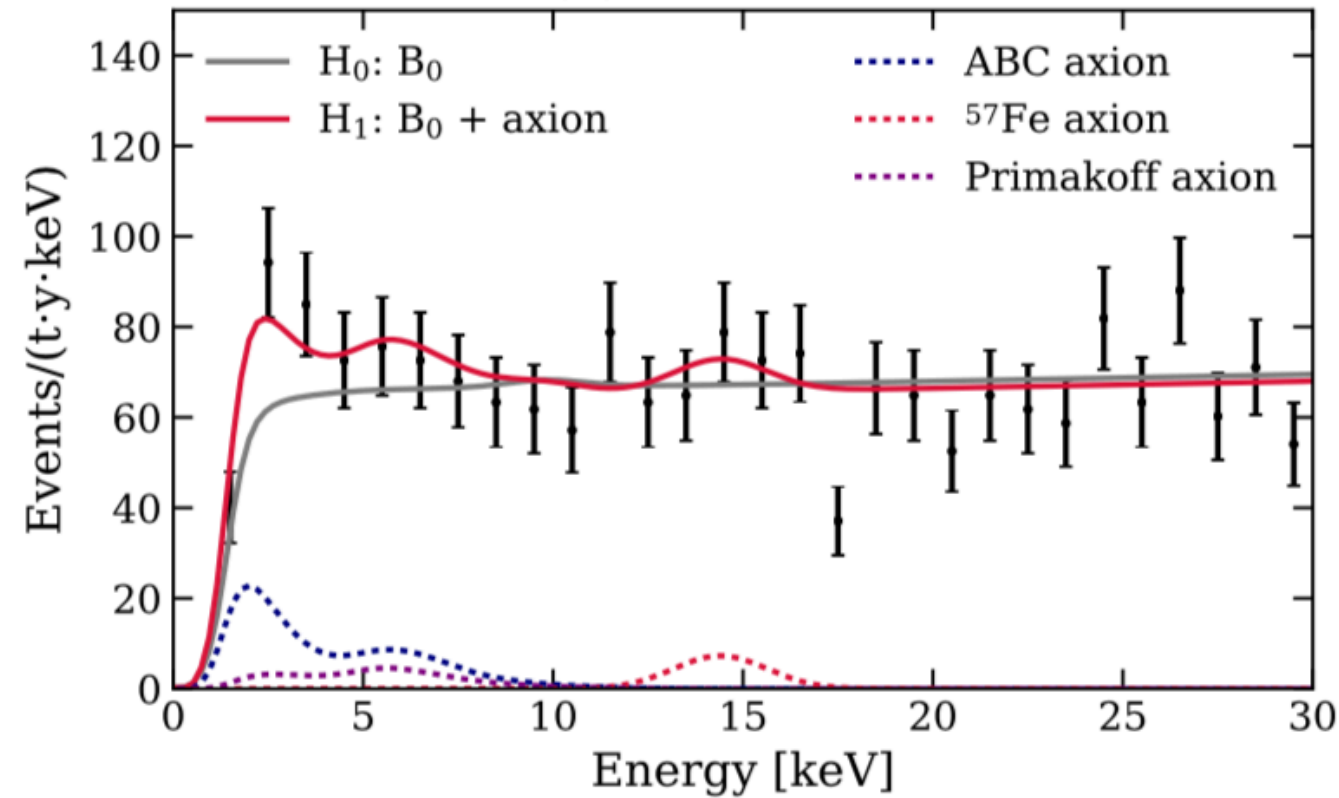


XENON1T: Interpretations

(a) Tritium

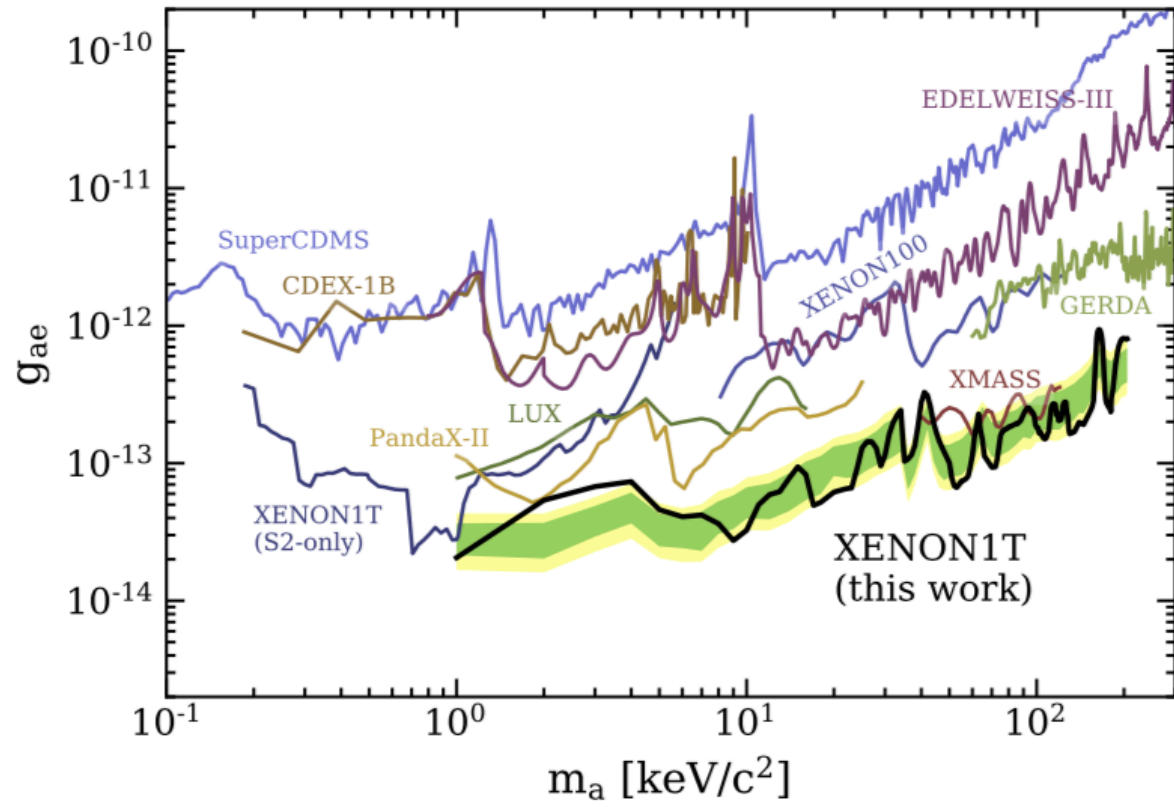


(b) Solar axion

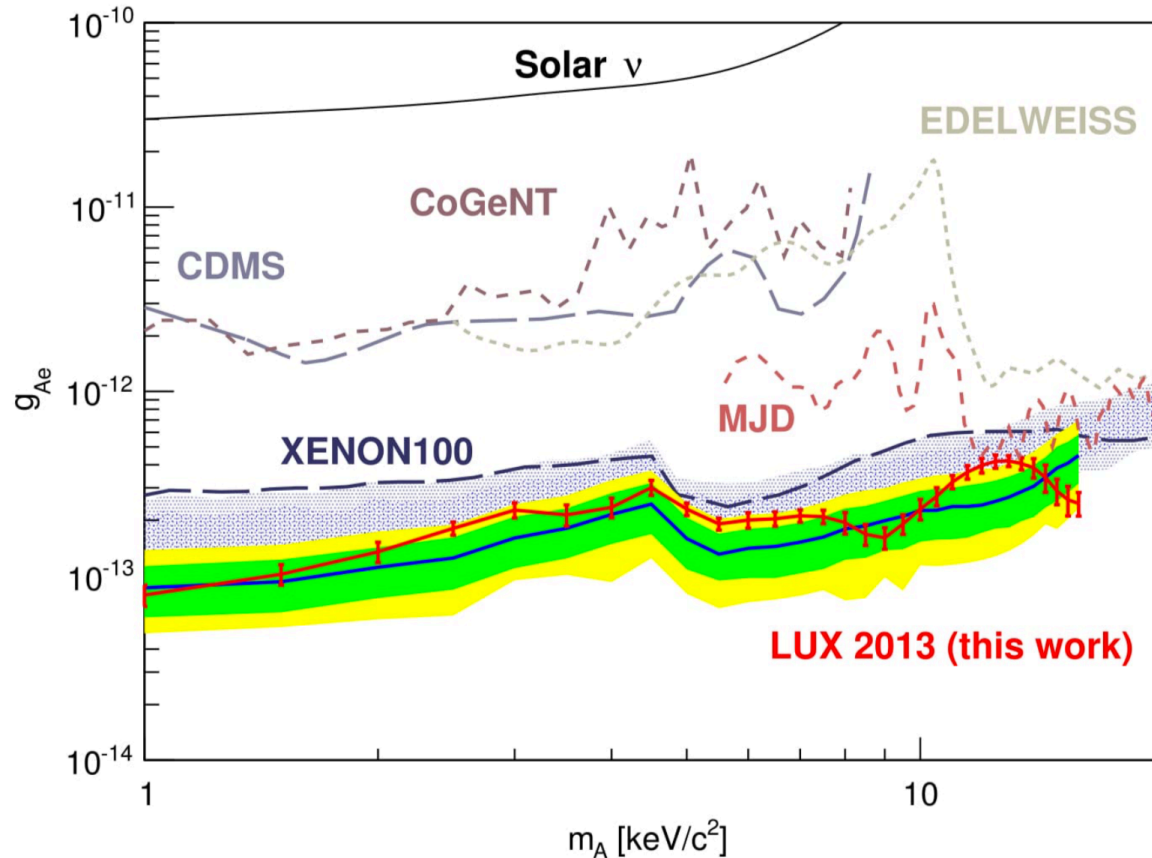
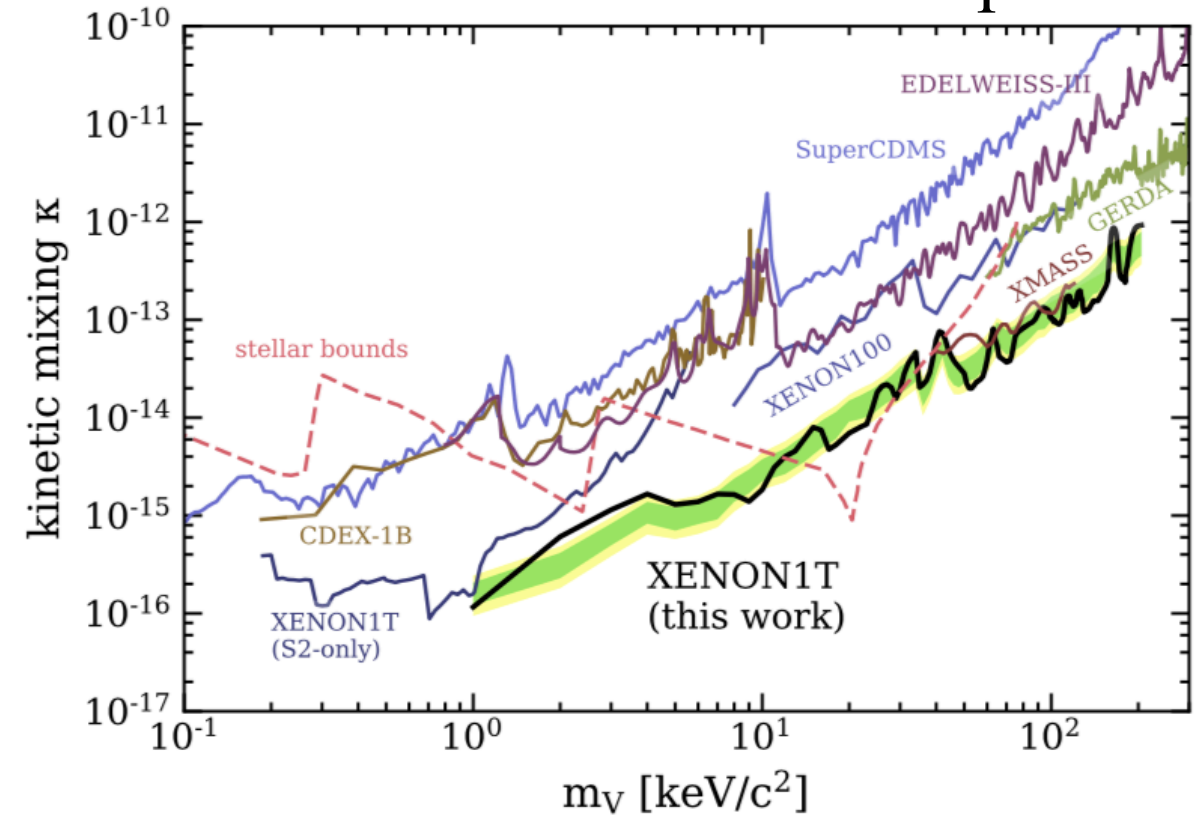


XENON1T: Dark Matter Interpretations

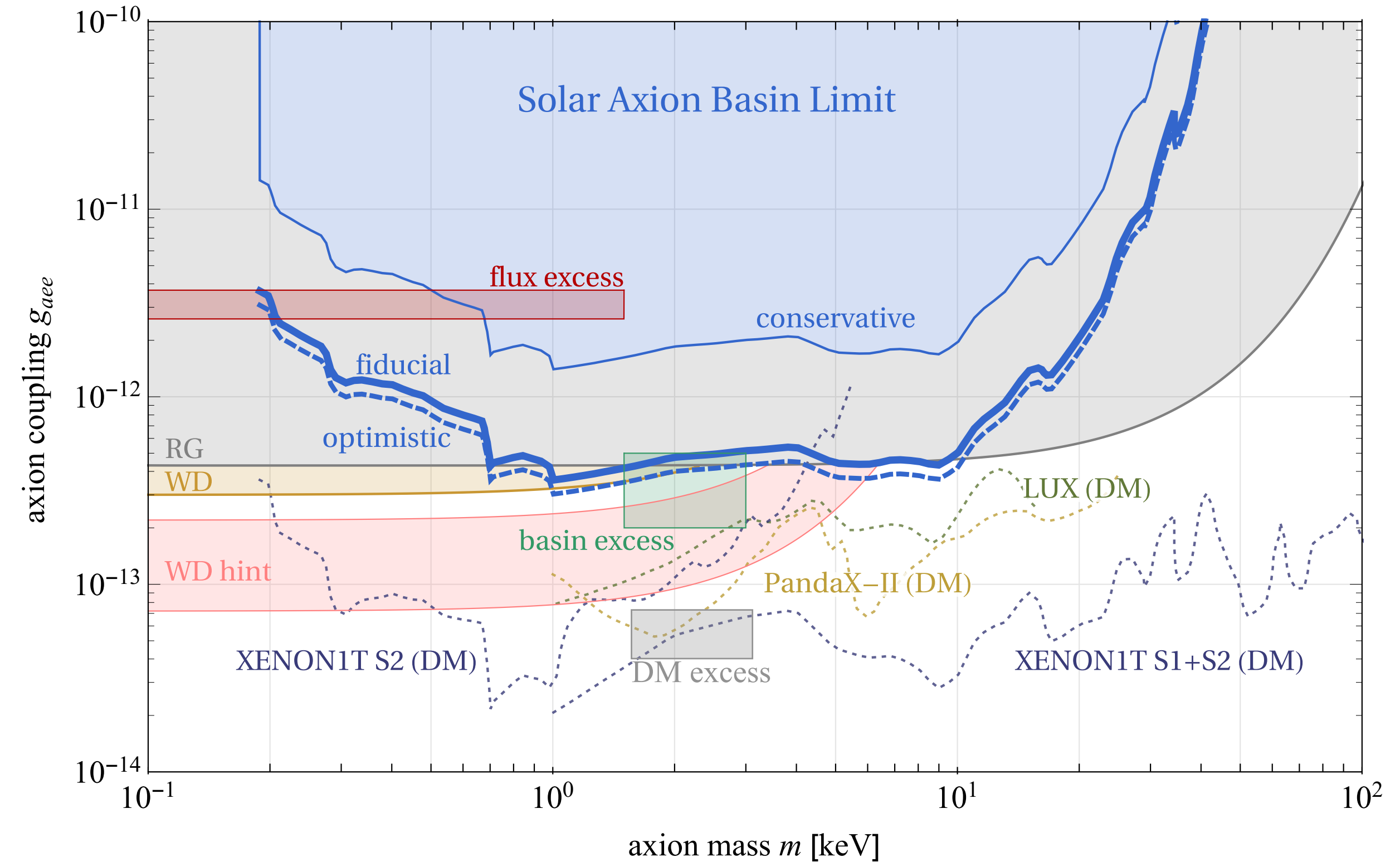
Axion DM absorption



Dark Photon DM absorption

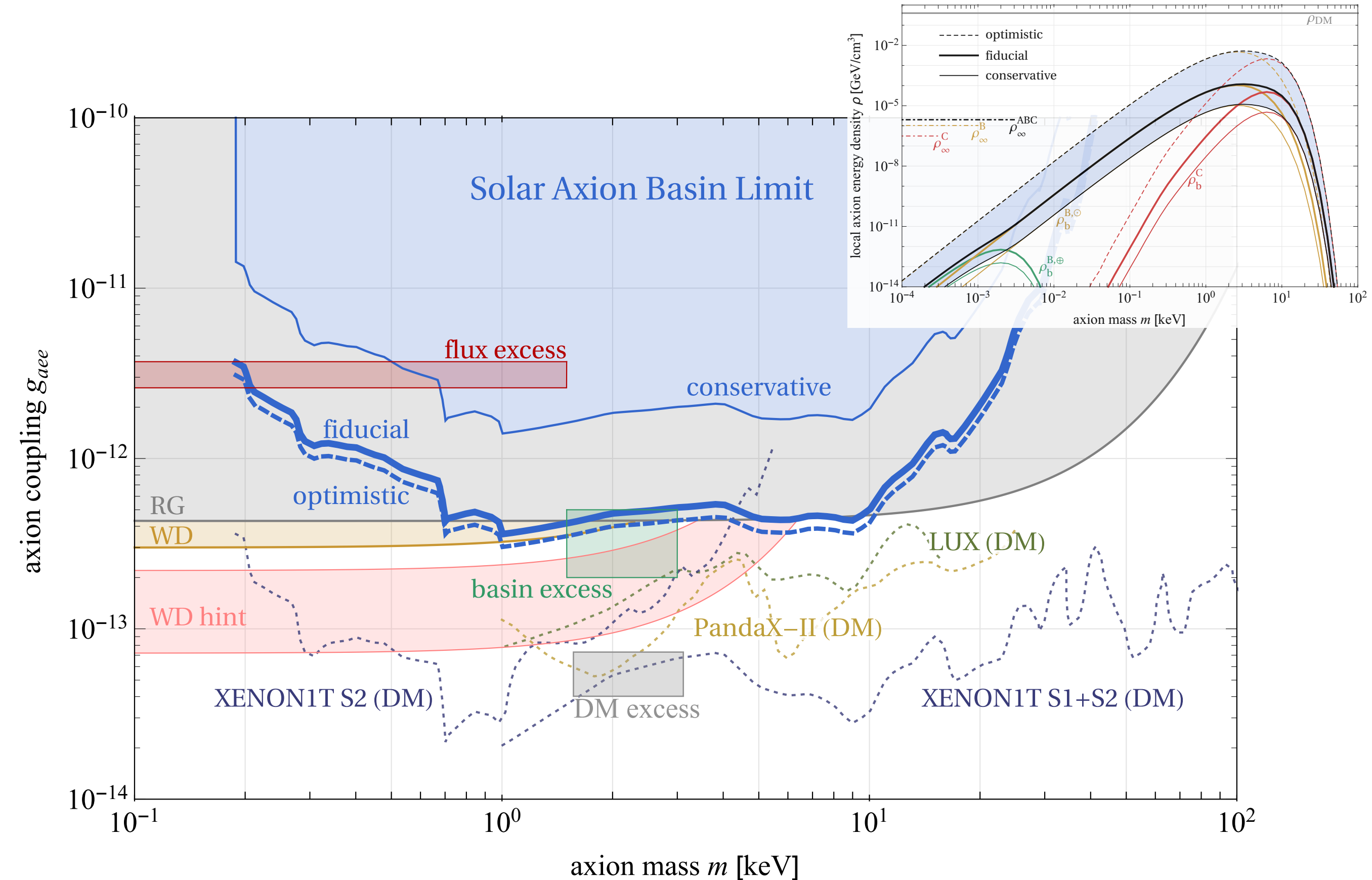


XENON1T: Axion Basin Interpretation



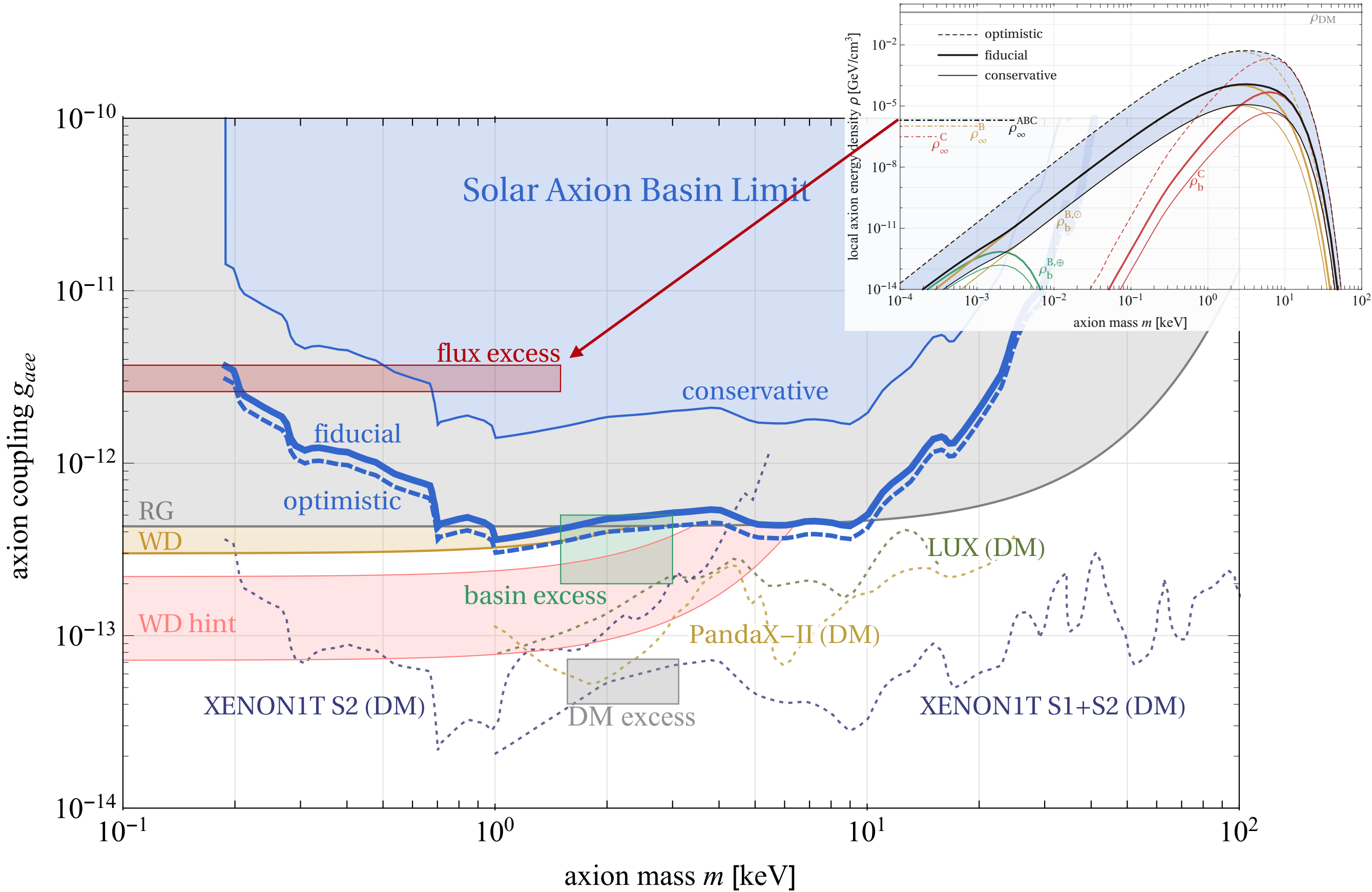
XENON1T: Axion Basin Interpretation

axion coupling $g_{aee} = 3 \times 10^{-13}$



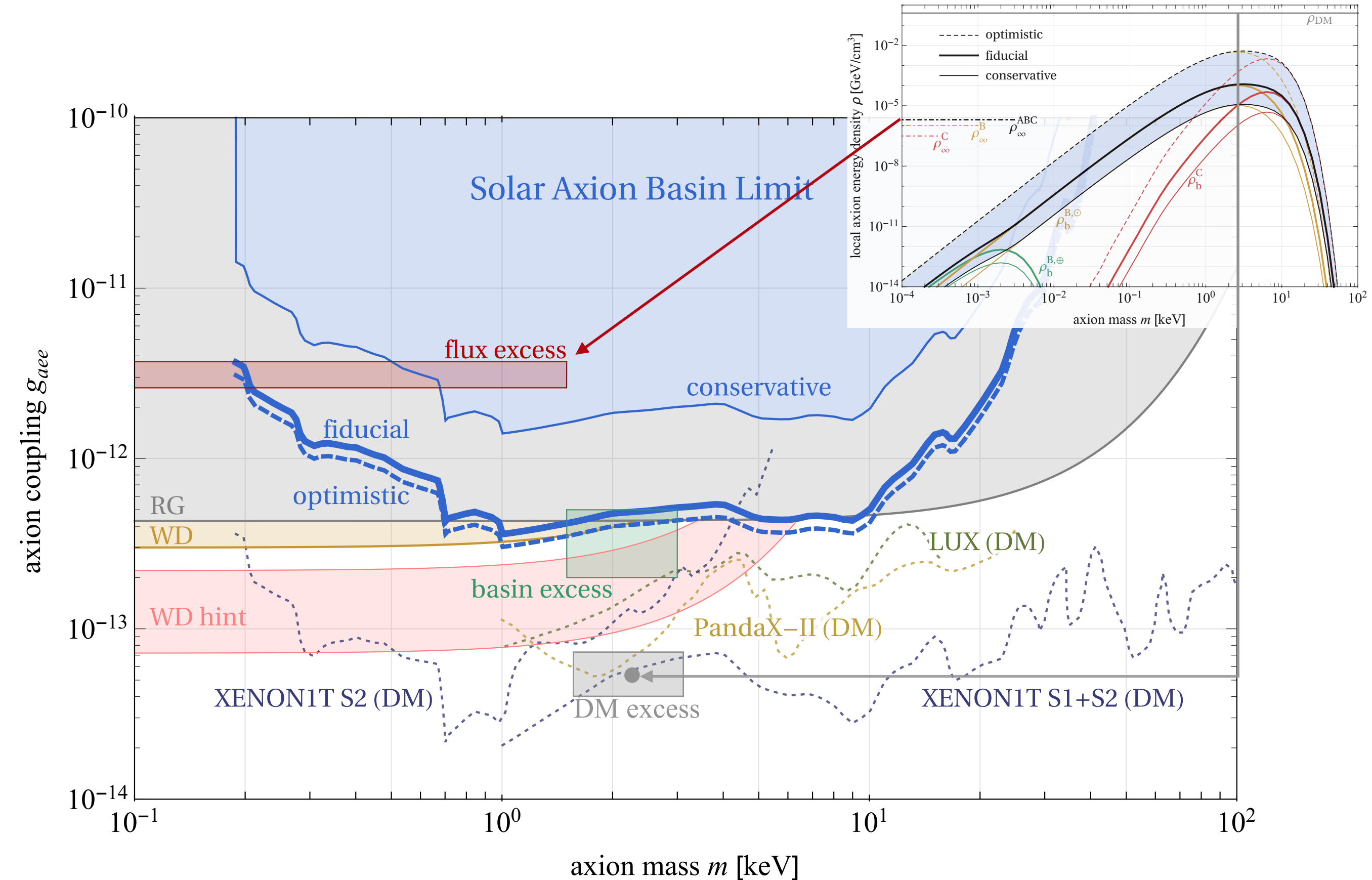
XENON1T: Axion Basin Interpretation

axion coupling $g_{aee} = 3 \times 10^{-13}$



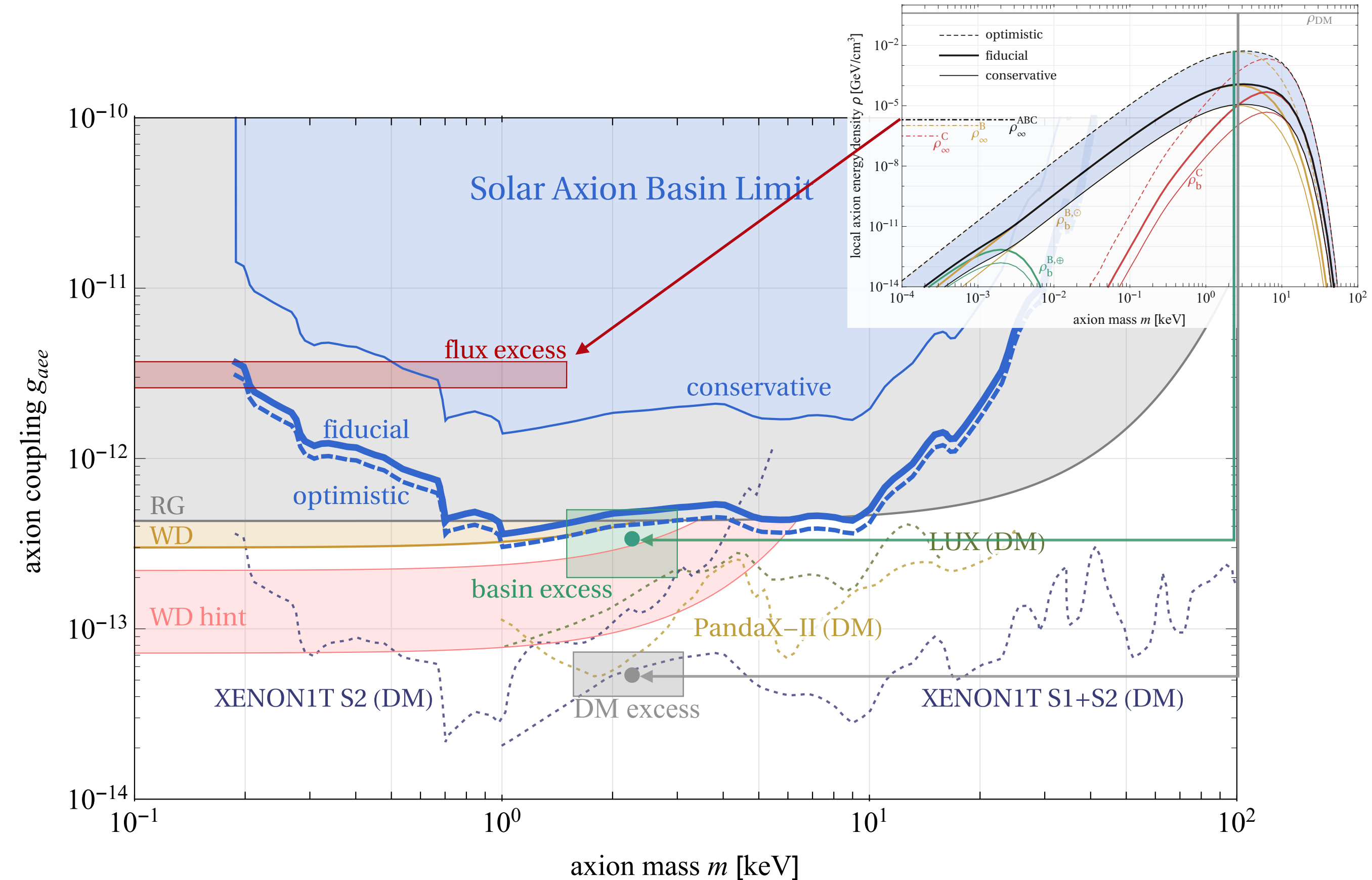
XENON1T: Axion Basin Interpretation

axion coupling $g_{aee} = 3 \times 10^{-13}$



XENON1T: Axion Basin Interpretation

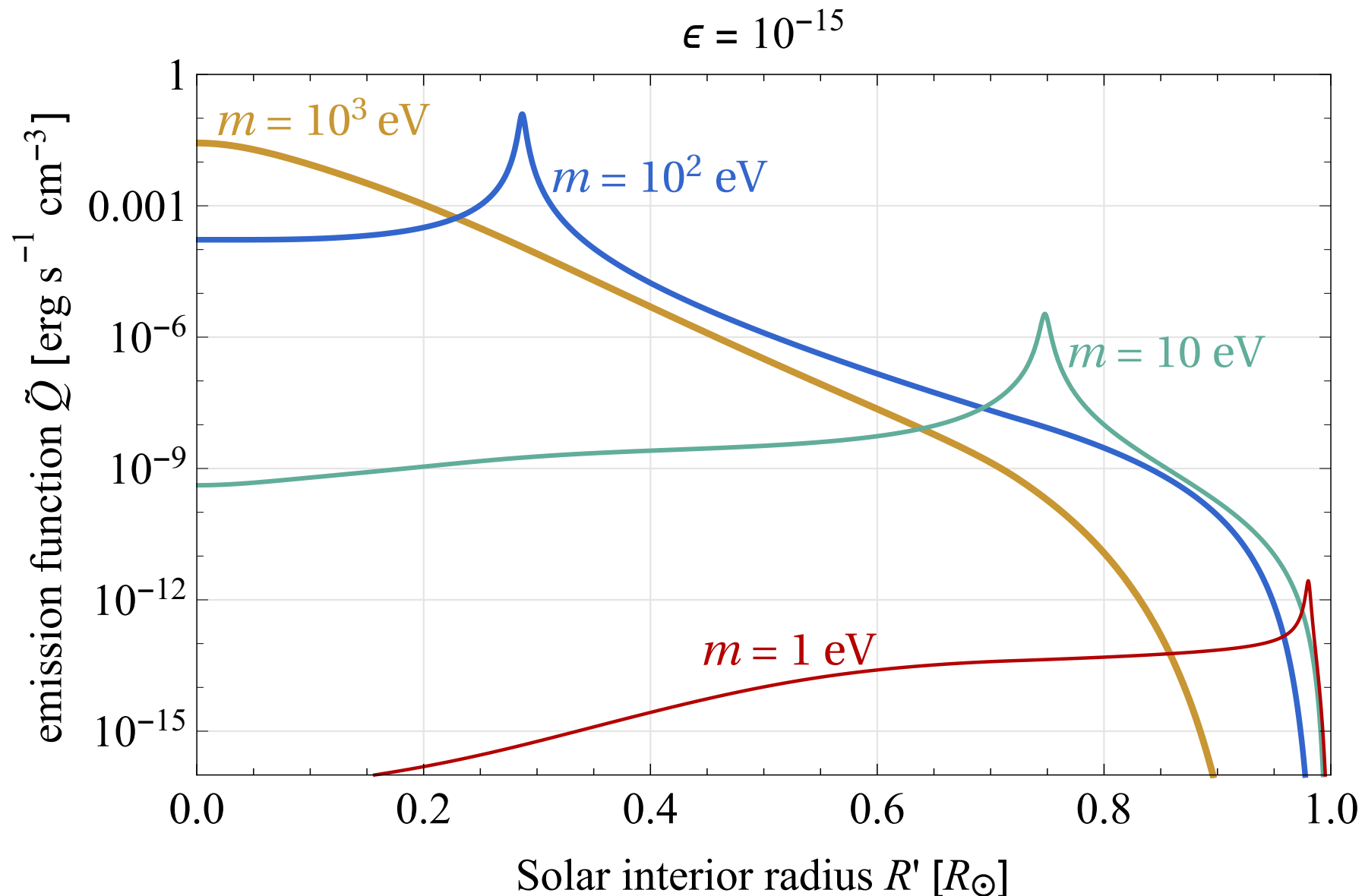
axion coupling $g_{aee} = 3 \times 10^{-13}$



Resonant Dark Photon Emission

R. Lasenby, KVT, "Dark Photons in the Solar Basin", arXiv:2008:XXXXX.

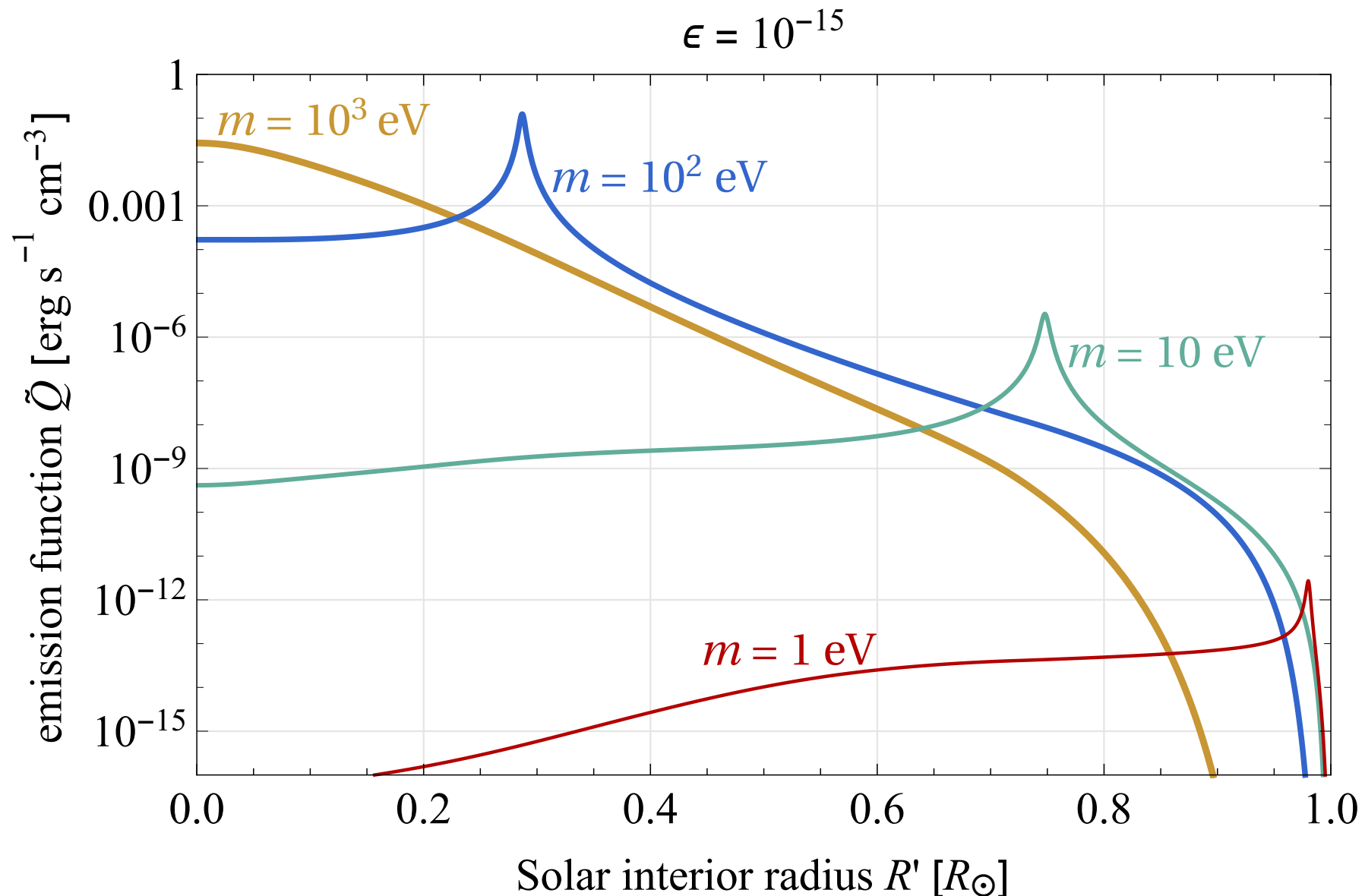
$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{\epsilon}{2}F_{\mu\nu}F'^{\mu\nu} + \frac{m^2}{2}A'_\mu A'^\mu + eA_\mu J_{\text{EM}}^\mu$$



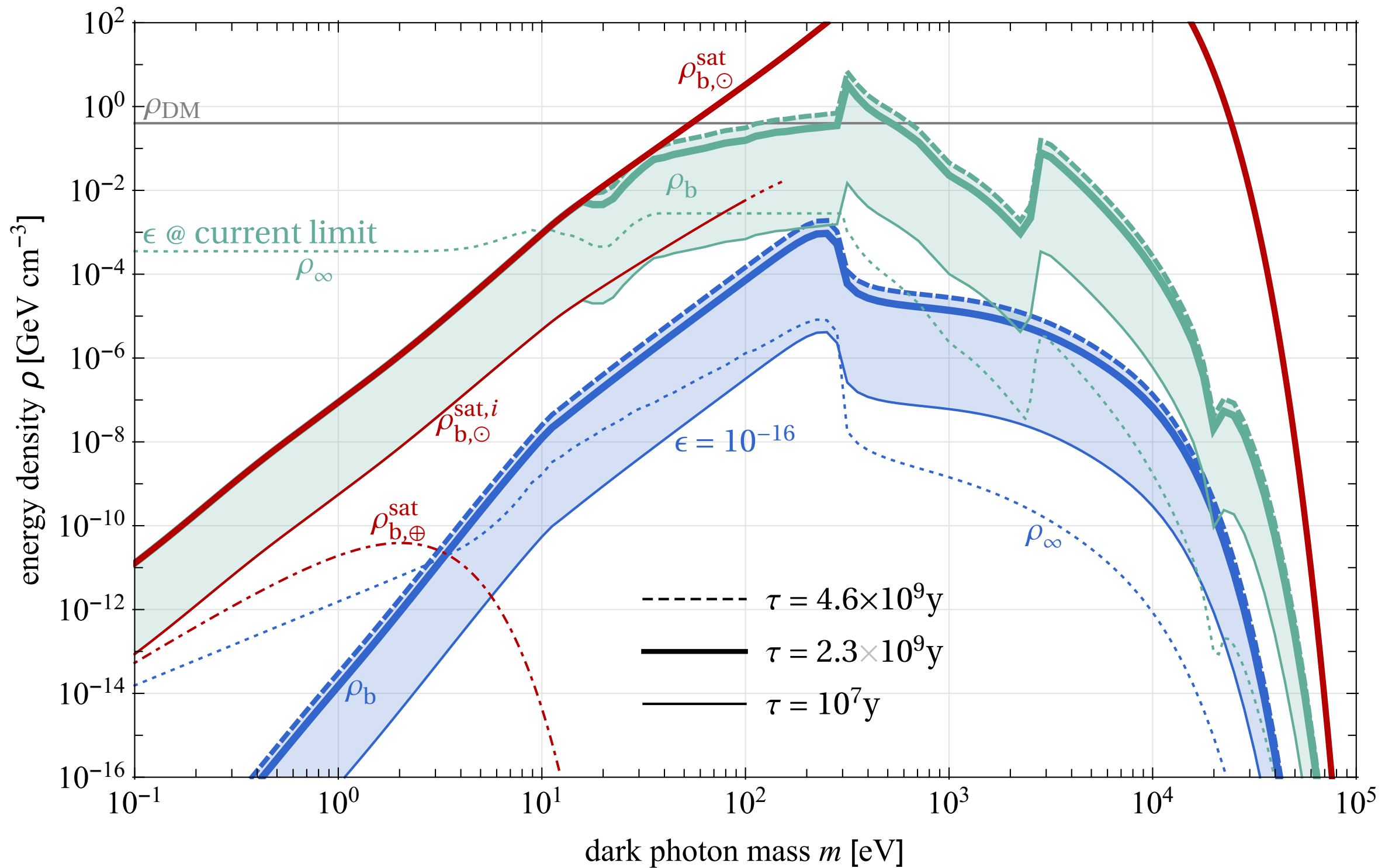
Resonant Dark Photon Emission

R. Lasenby, KVT, "Dark Photons in the Solar Basin", arXiv:2008:XXXXX.

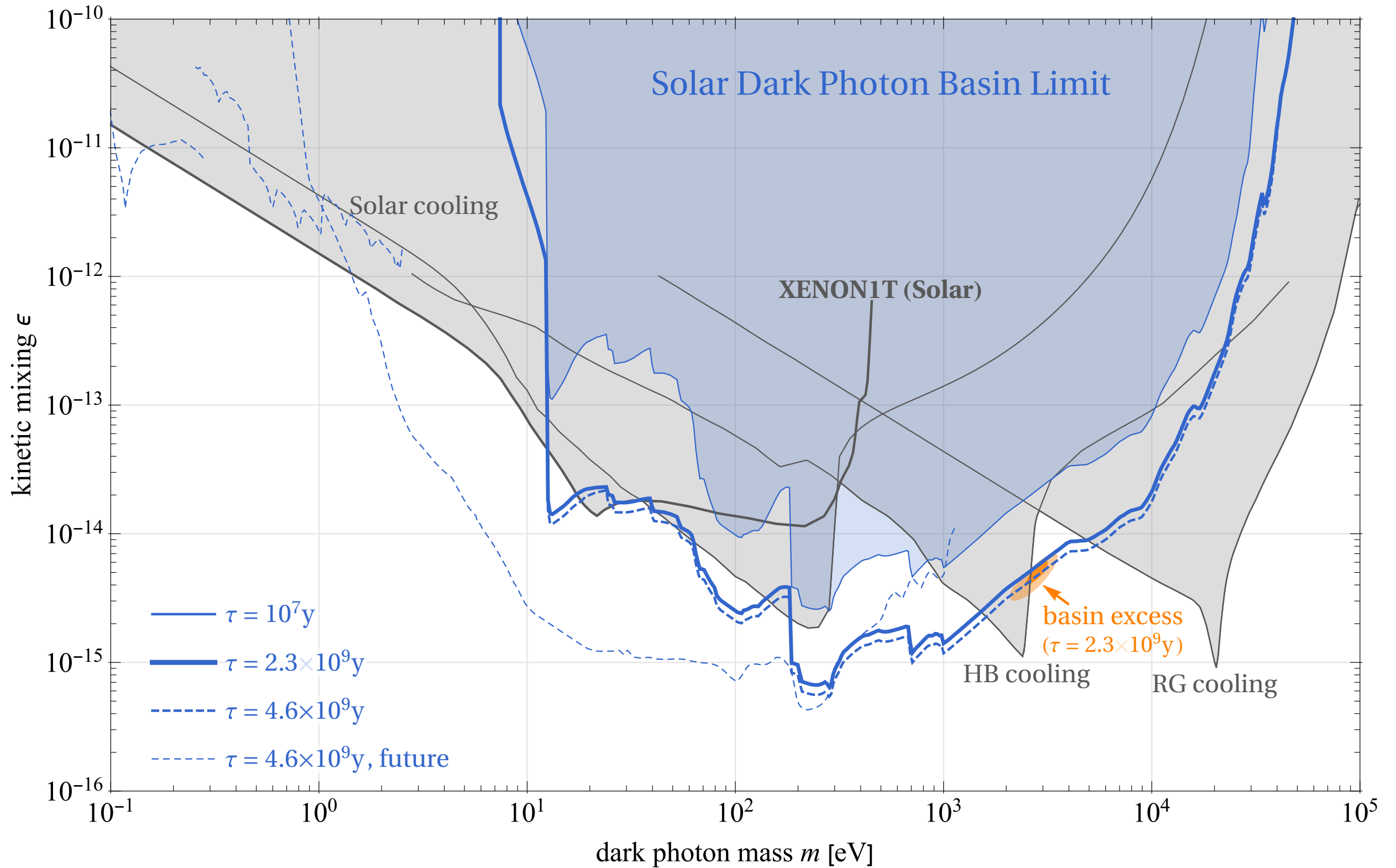
$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{\epsilon}{2}F_{\mu\nu}F'^{\mu\nu} + \frac{m^2}{2}A'_\mu A'^\mu + eA_\mu J_{\text{EM}}^\mu$$



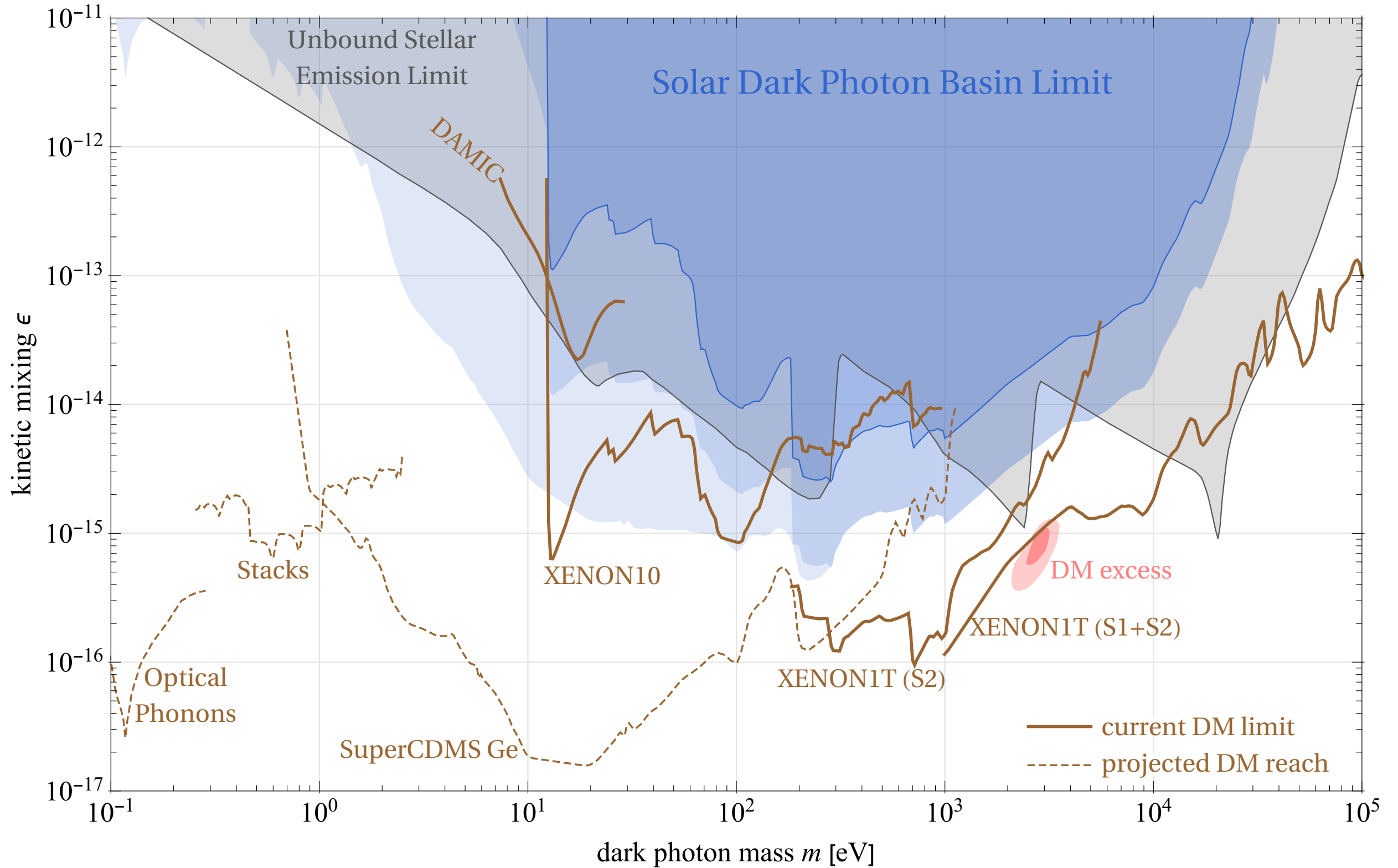
Dark Photon Basin Density



Dark Photon Basin



Dark Photon Dark Matter



Future Directions

Indirect Detection

X-ray lines from decay/conversion of axion basin around Sun and compact remnants

[J. Huang, S. Wegsman Gueron, KVT, in progress]

Other Couplings and Particles

hidden photon, CP-even scalar, general axion, fermion production

Orbital Dynamics of Stellar Basin

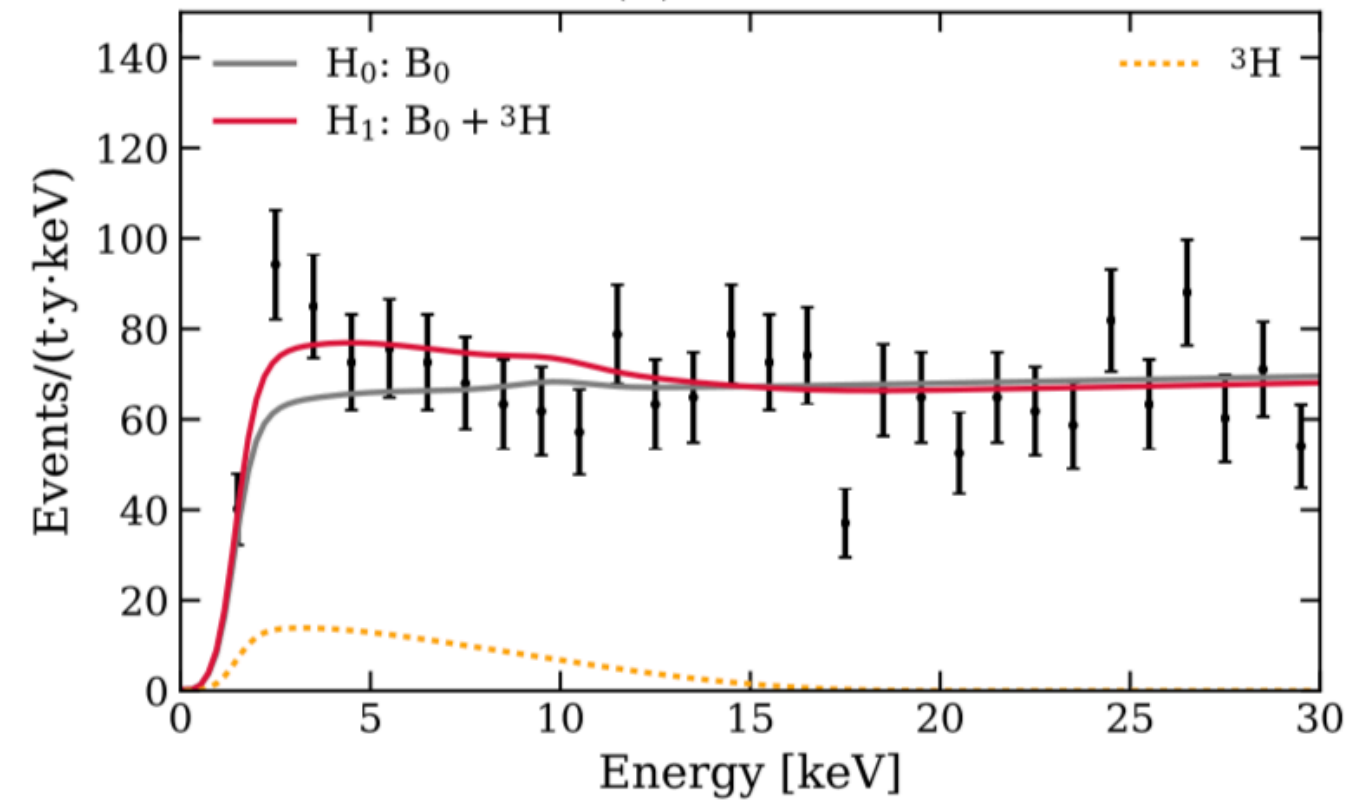
gravitational ejection time, re-absorption, statistical/temporal characteristics

Dedicated Direct Detection Analyses

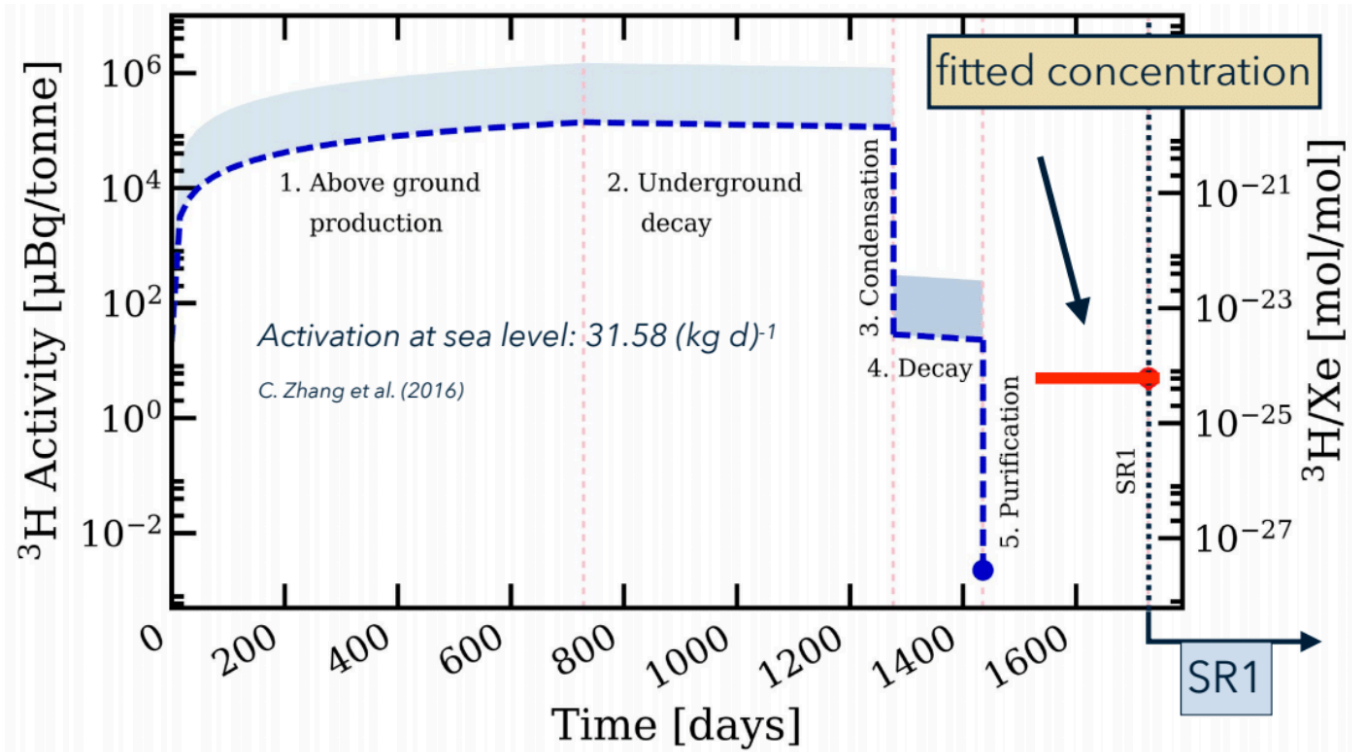
LZ, XENONnT, PandaX, XMASS, SuperCDMS, coherent absorption schemes

XENON1T: Interpretations

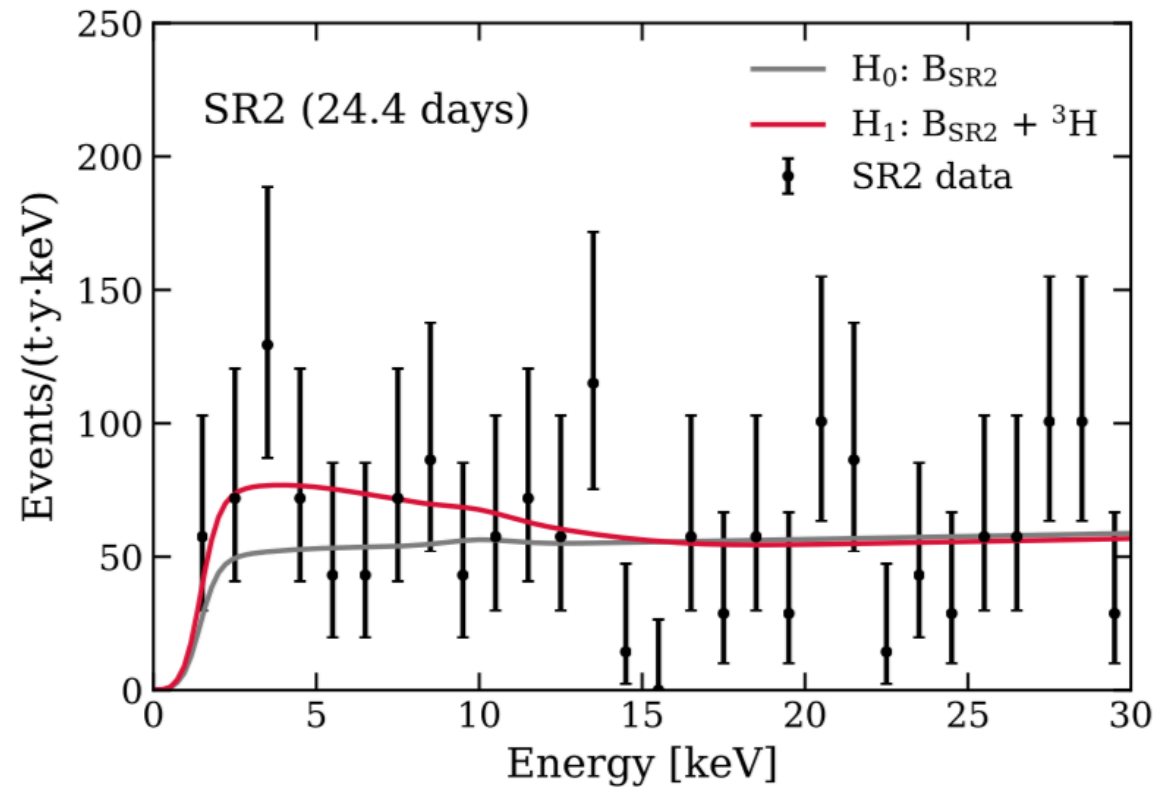
(a) Tritium



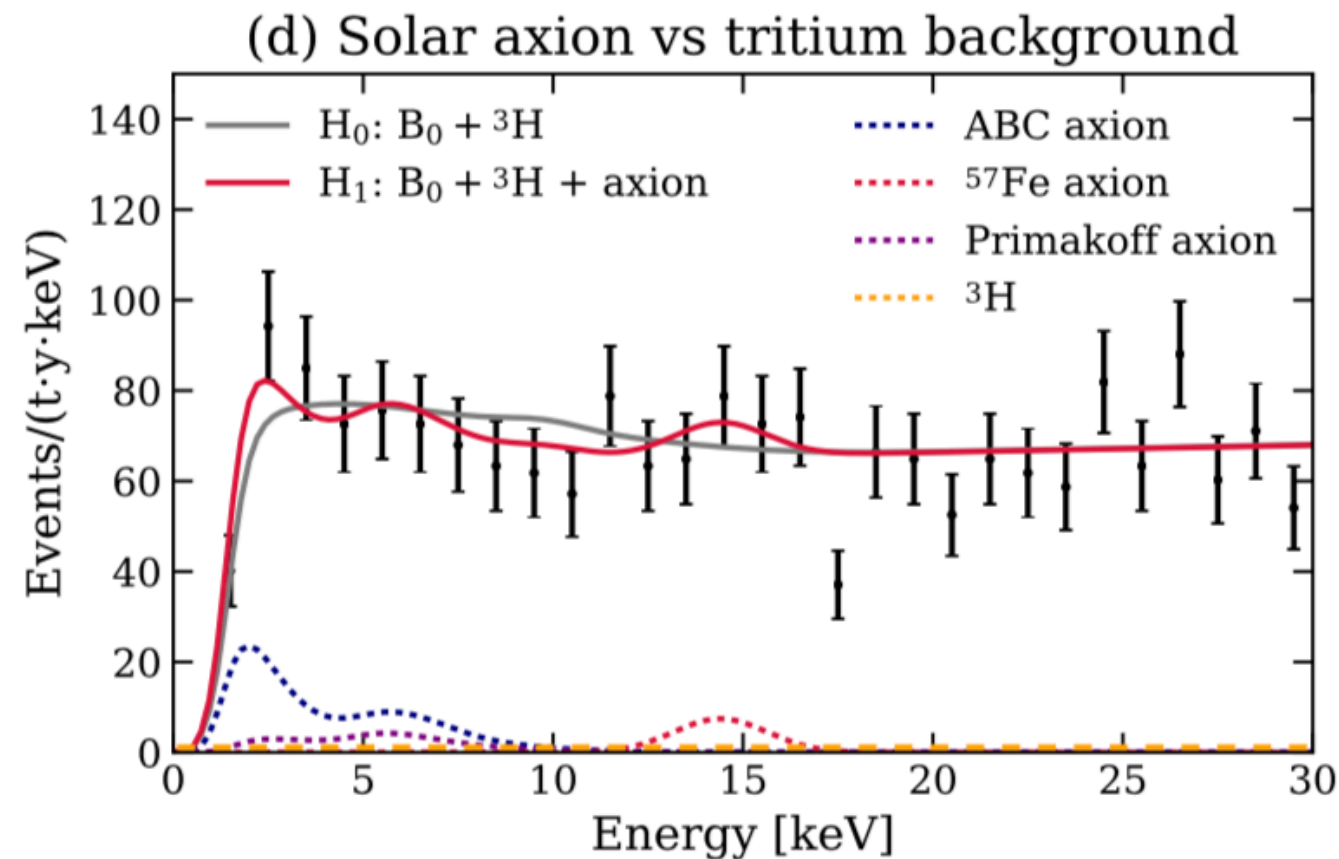
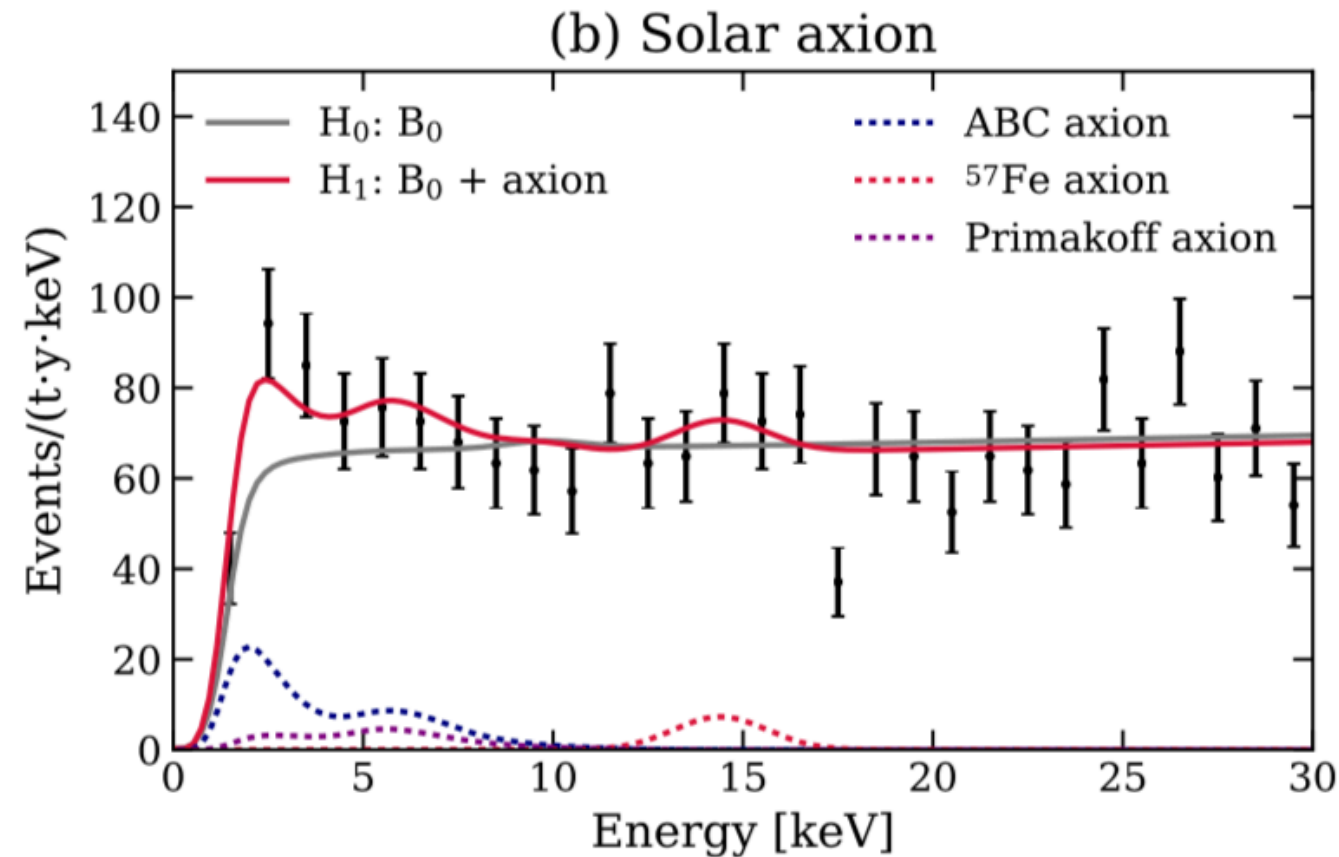
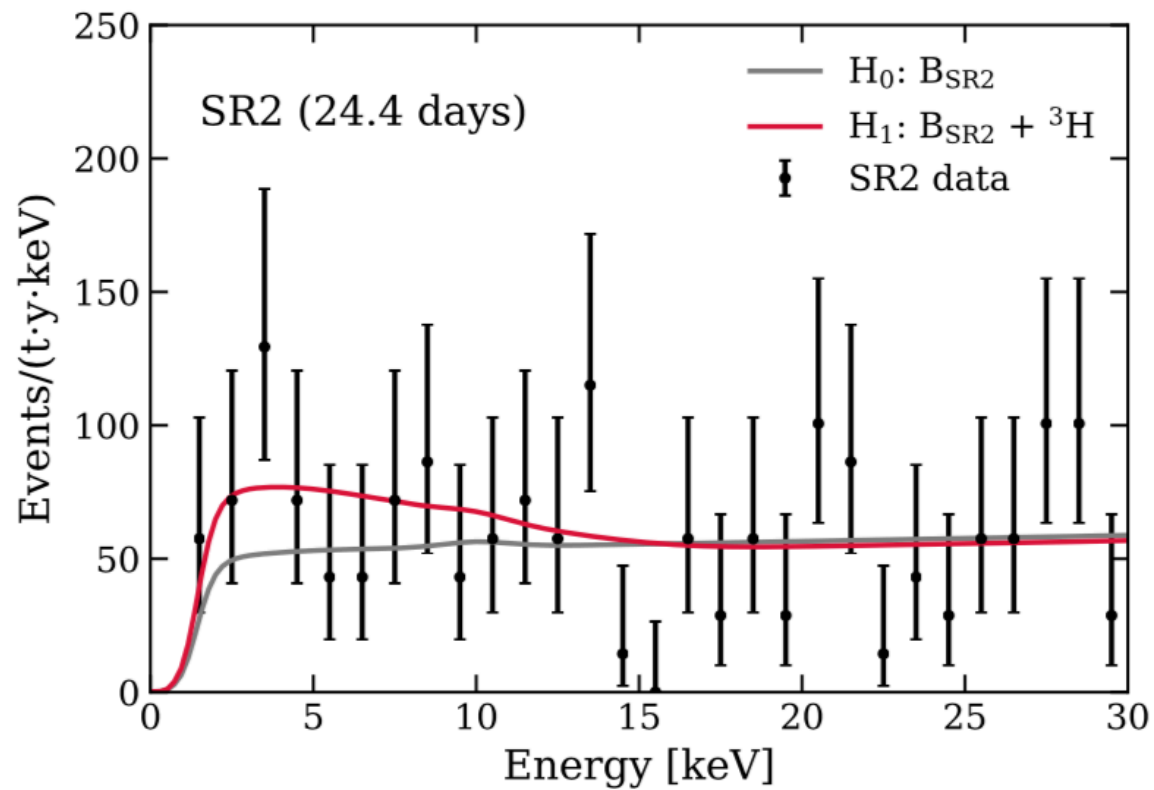
XENON1T: Interpretations



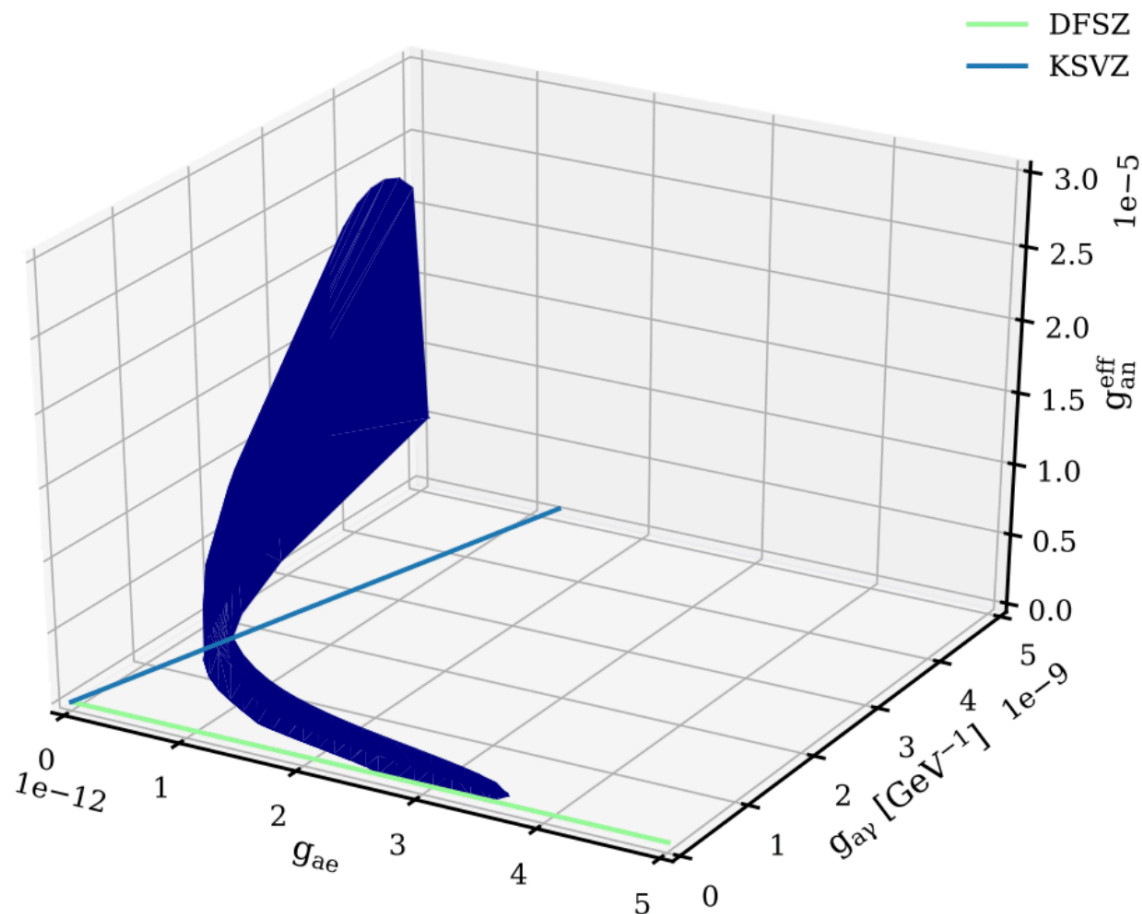
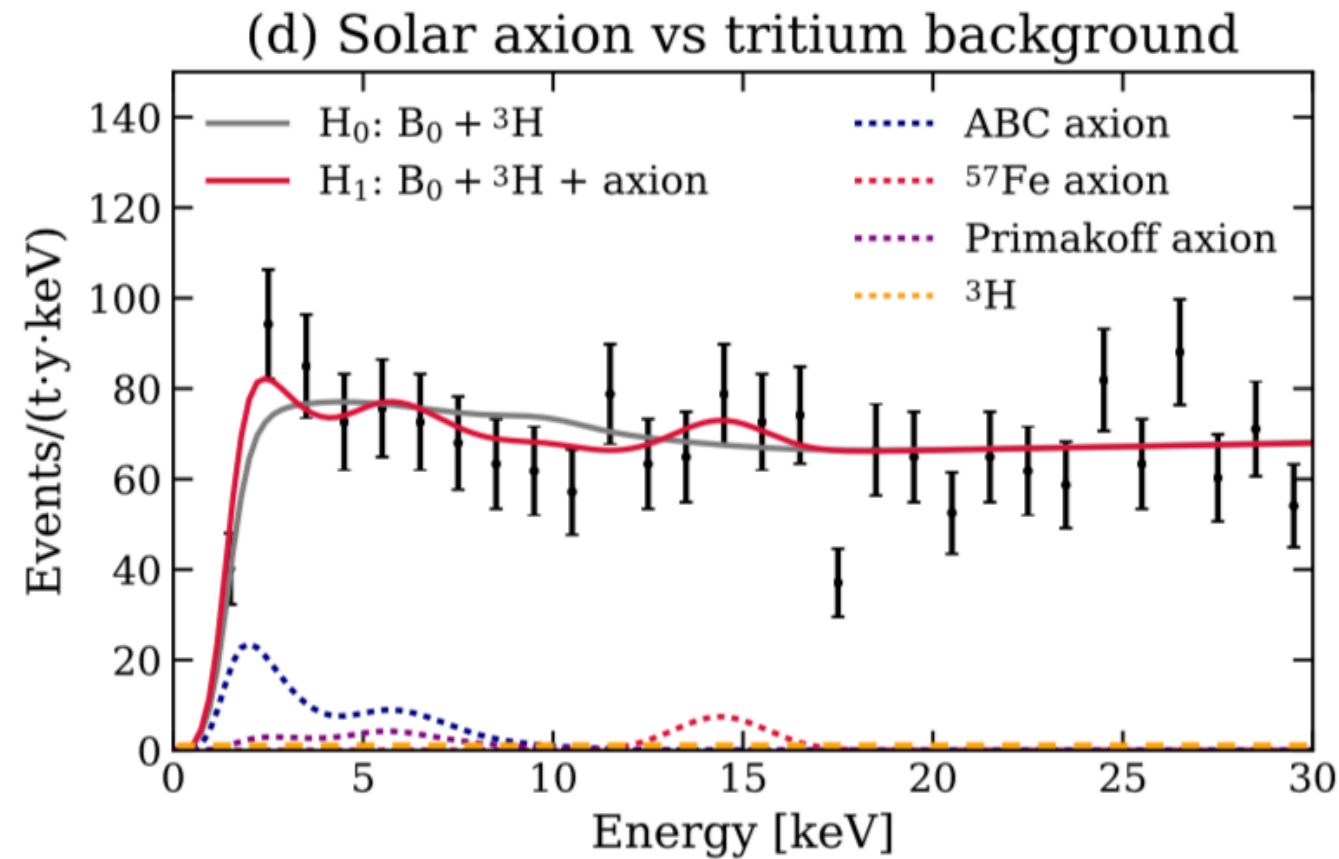
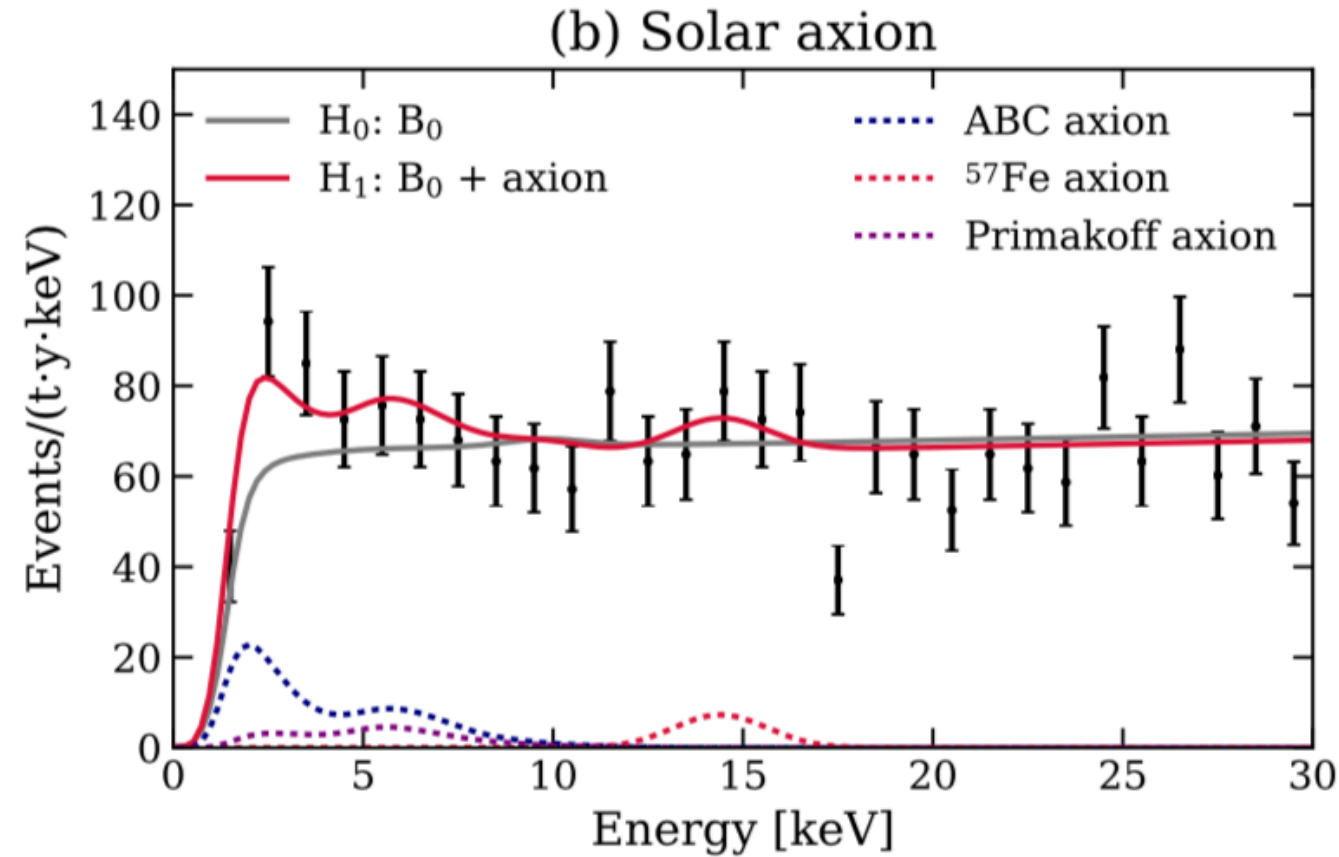
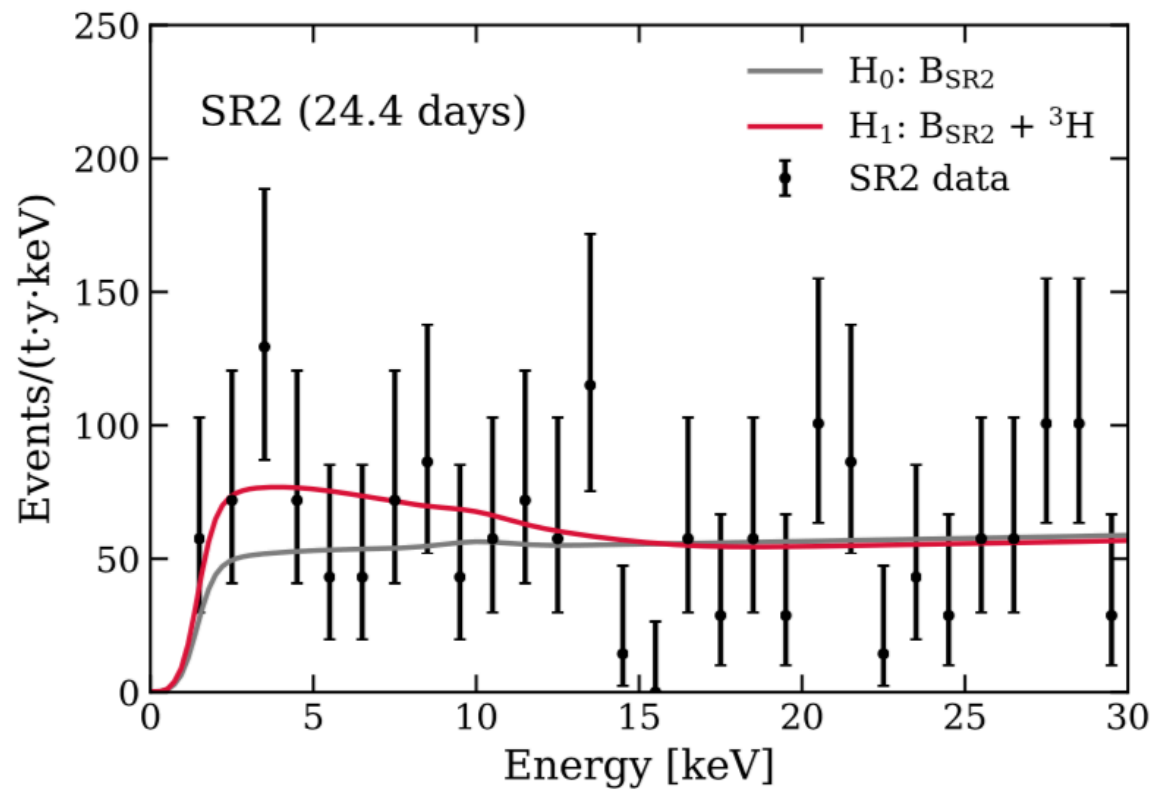
XENON1T: Interpretations



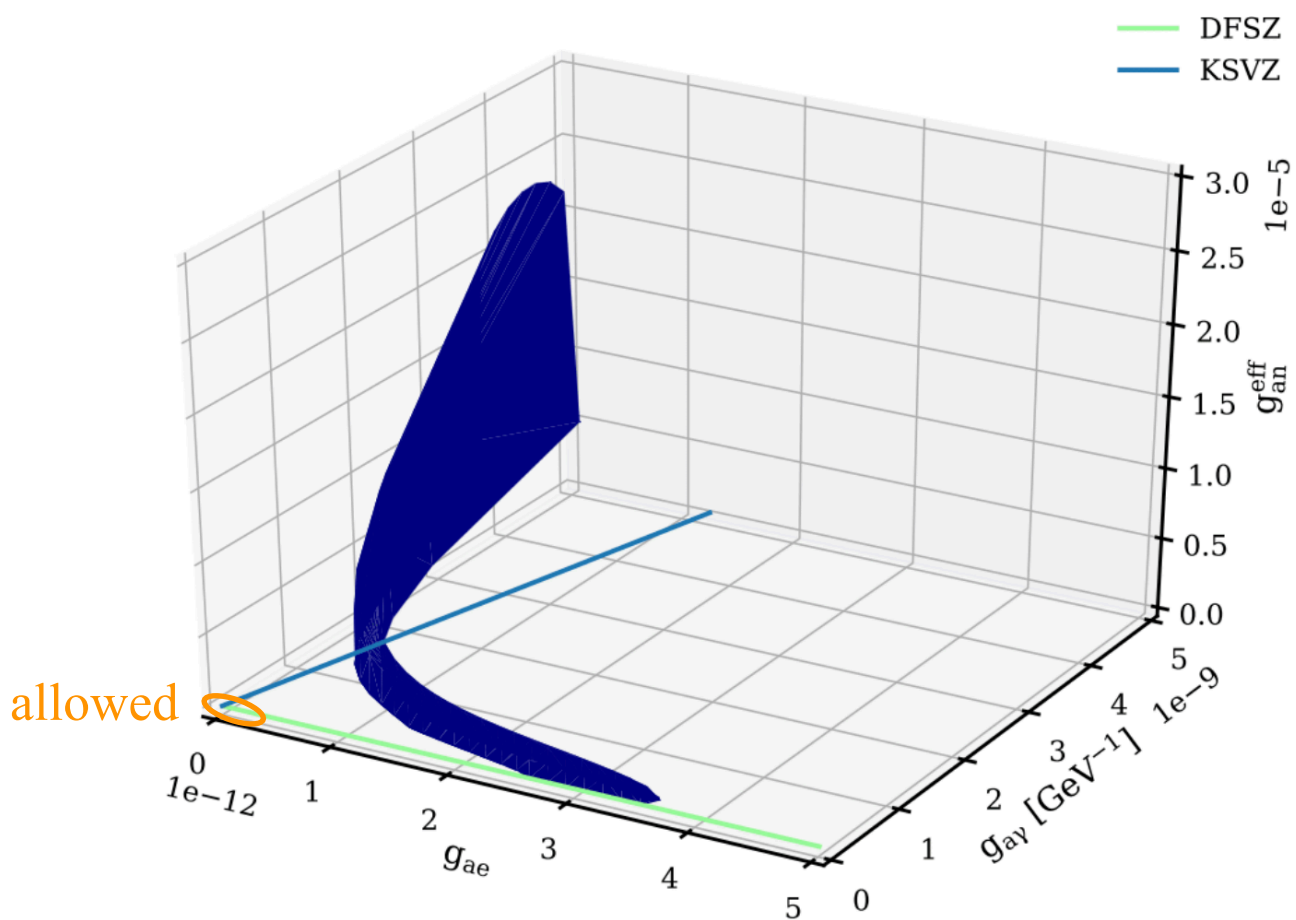
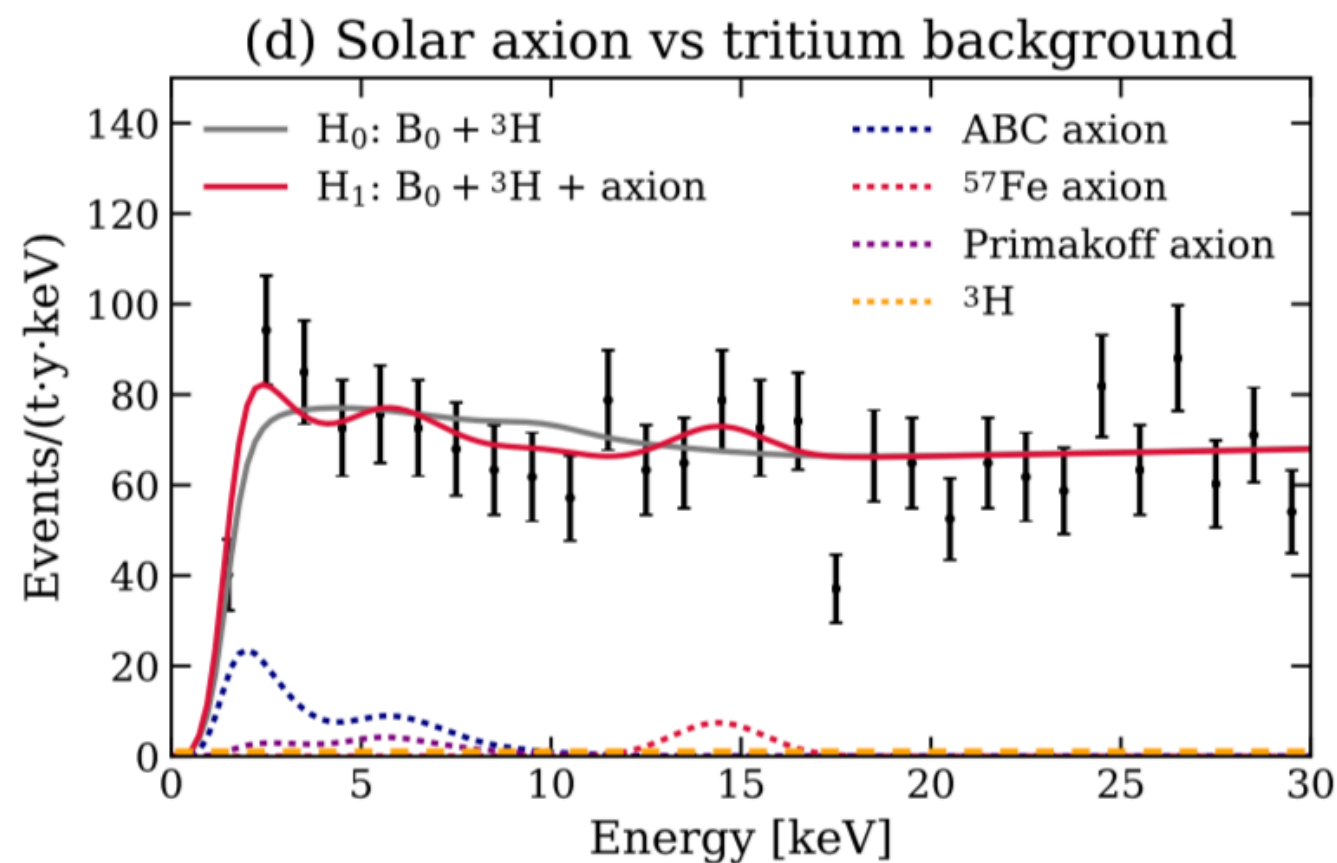
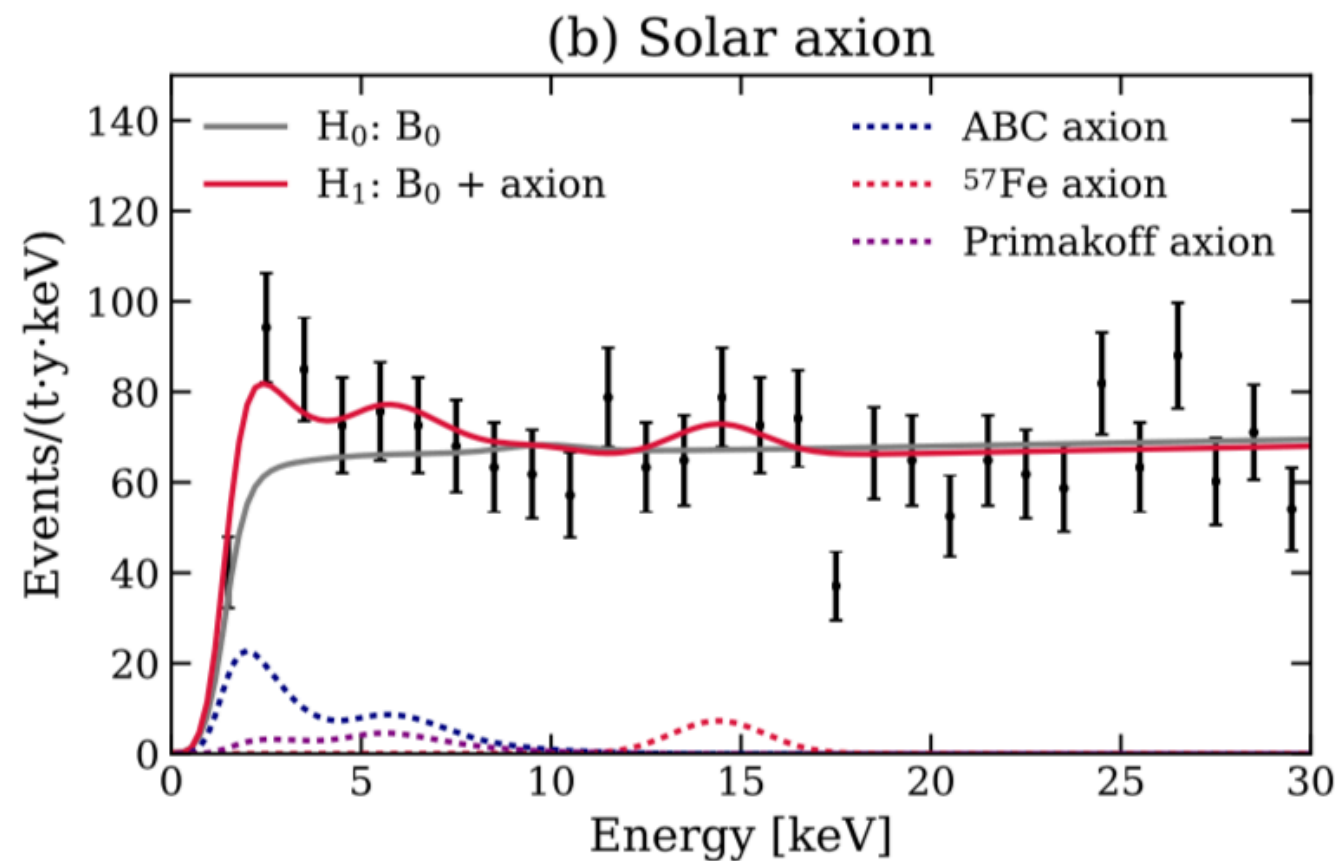
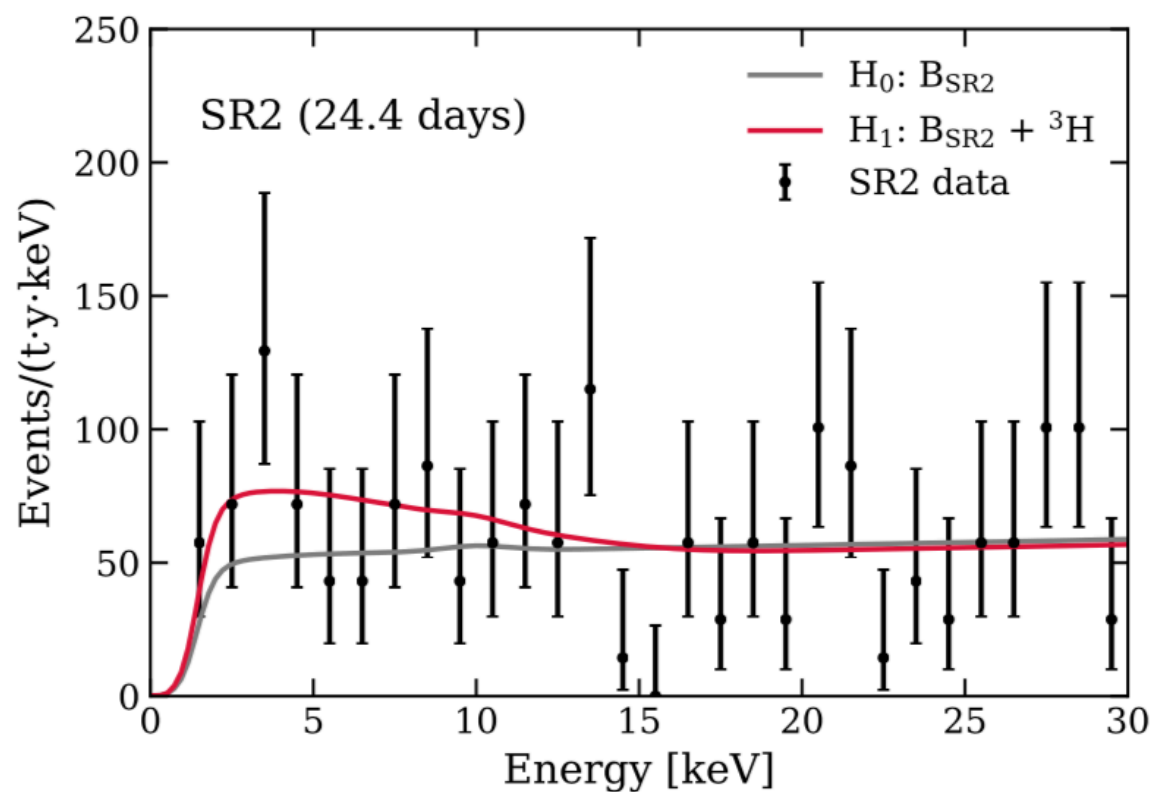
XENON1T: Interpretations



XENON1T: Interpretations



XENON1T: Interpretations



XENON1T: Interpretations

