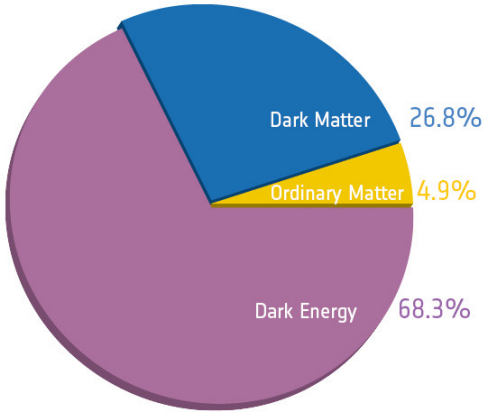
ASTROPHYSICAL PROBES OF DARK MATTER

Jae Hyeok Chang
Johns Hopkins University and University of Maryland

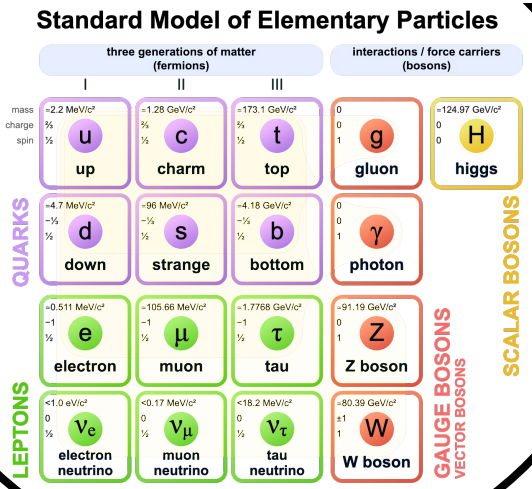
2023/06/29

Cosmology Workshop on the Crossroad of
Astrophysics and Particle physics: dark matter


DARK SECTOR
DARK MATTER



SM SECTOR



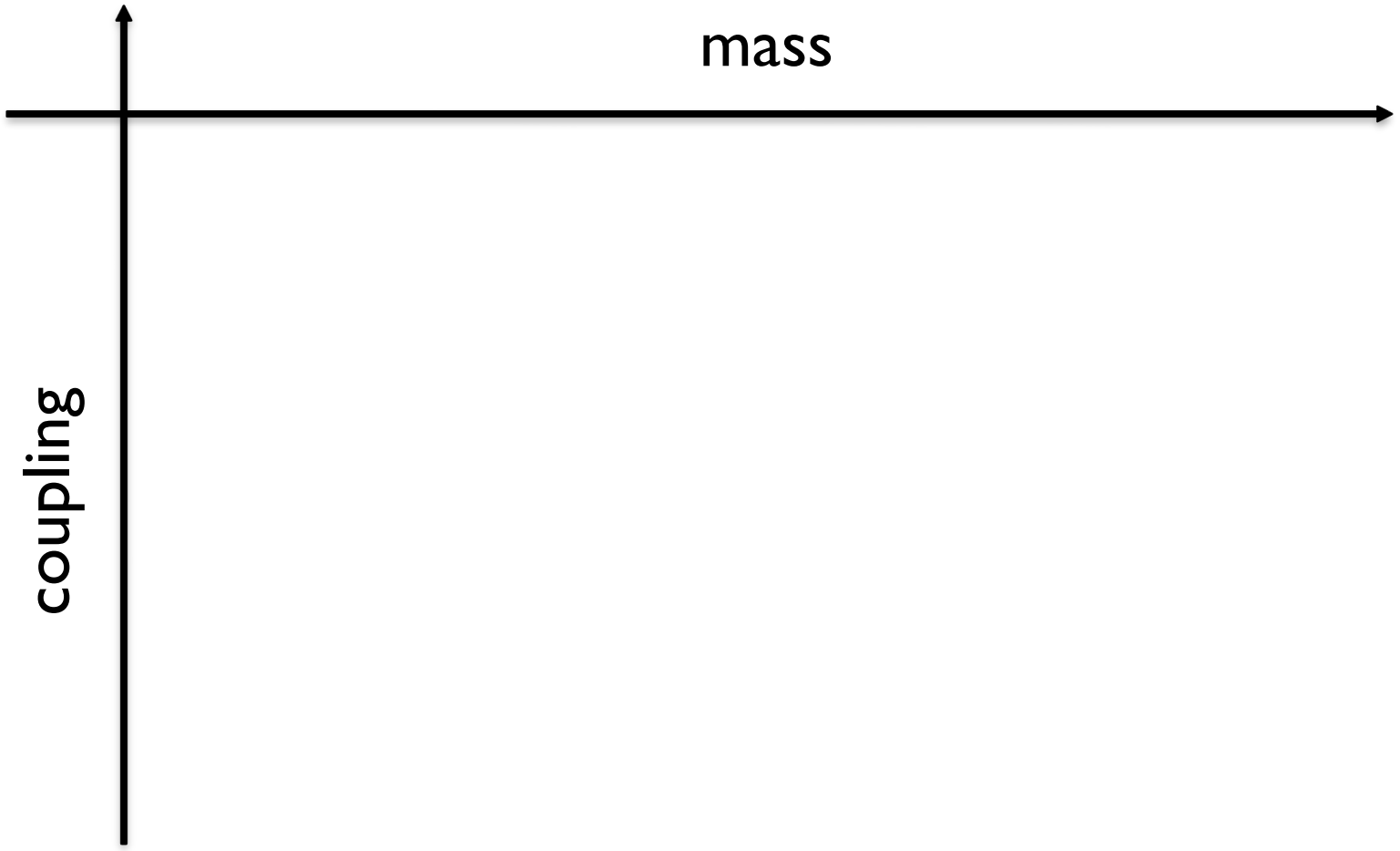
DARK SECTOR

Dark Photon

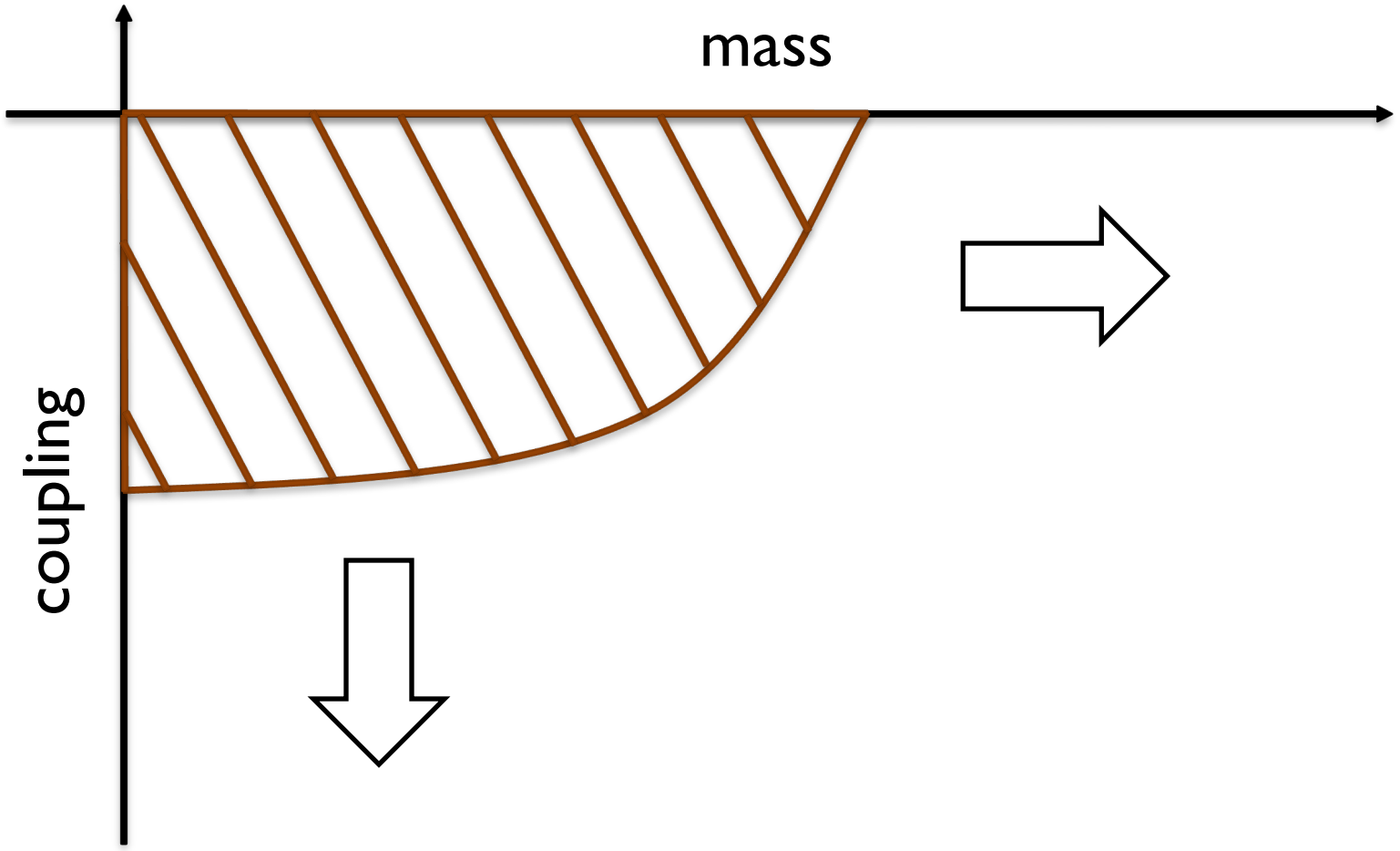
DARK MATTER

Axion-like Particle

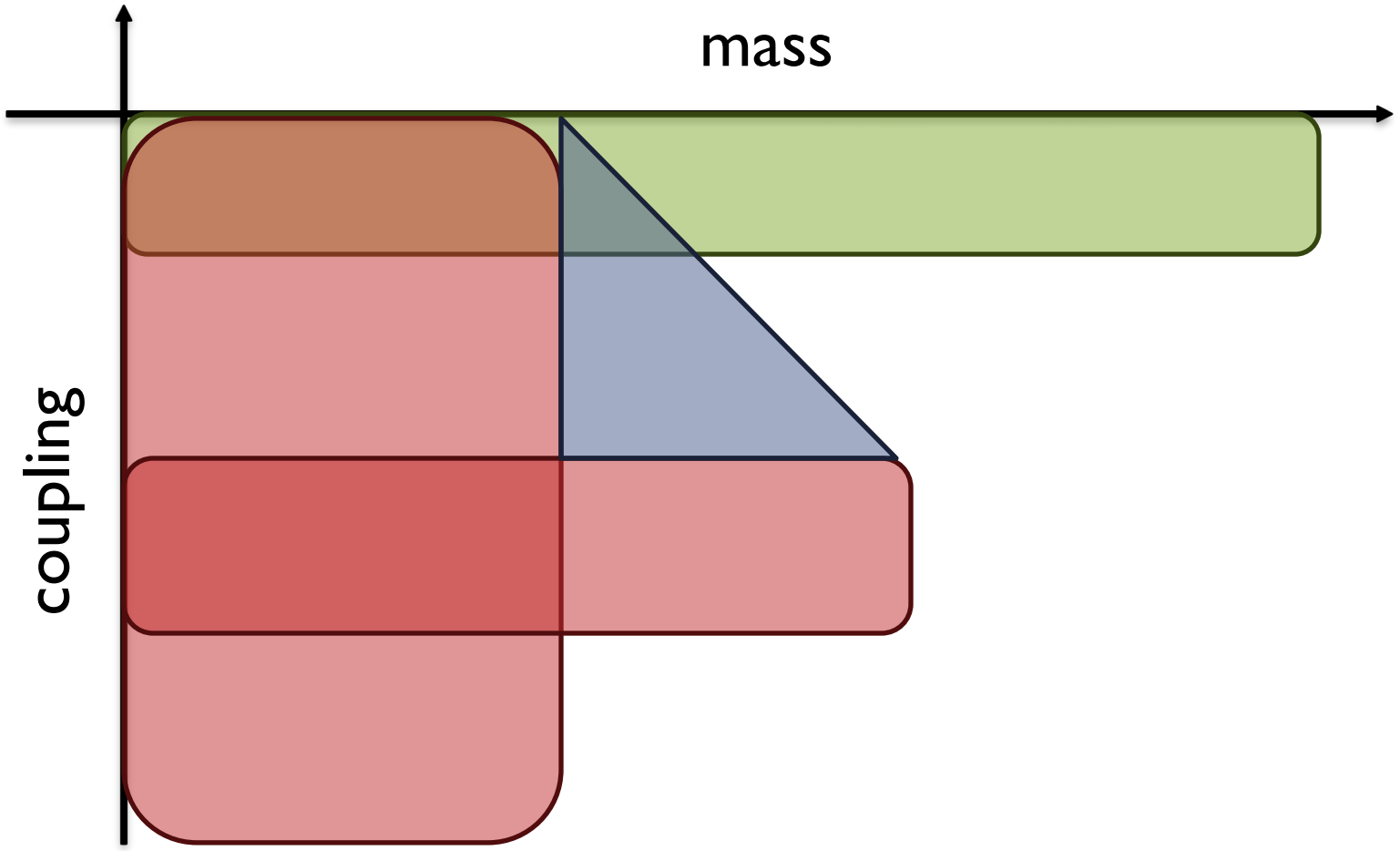
Dark Sector Particle Probes



Dark Sector Particle Probes



Dark Sector Particle Probes



Dark Photon Constraints

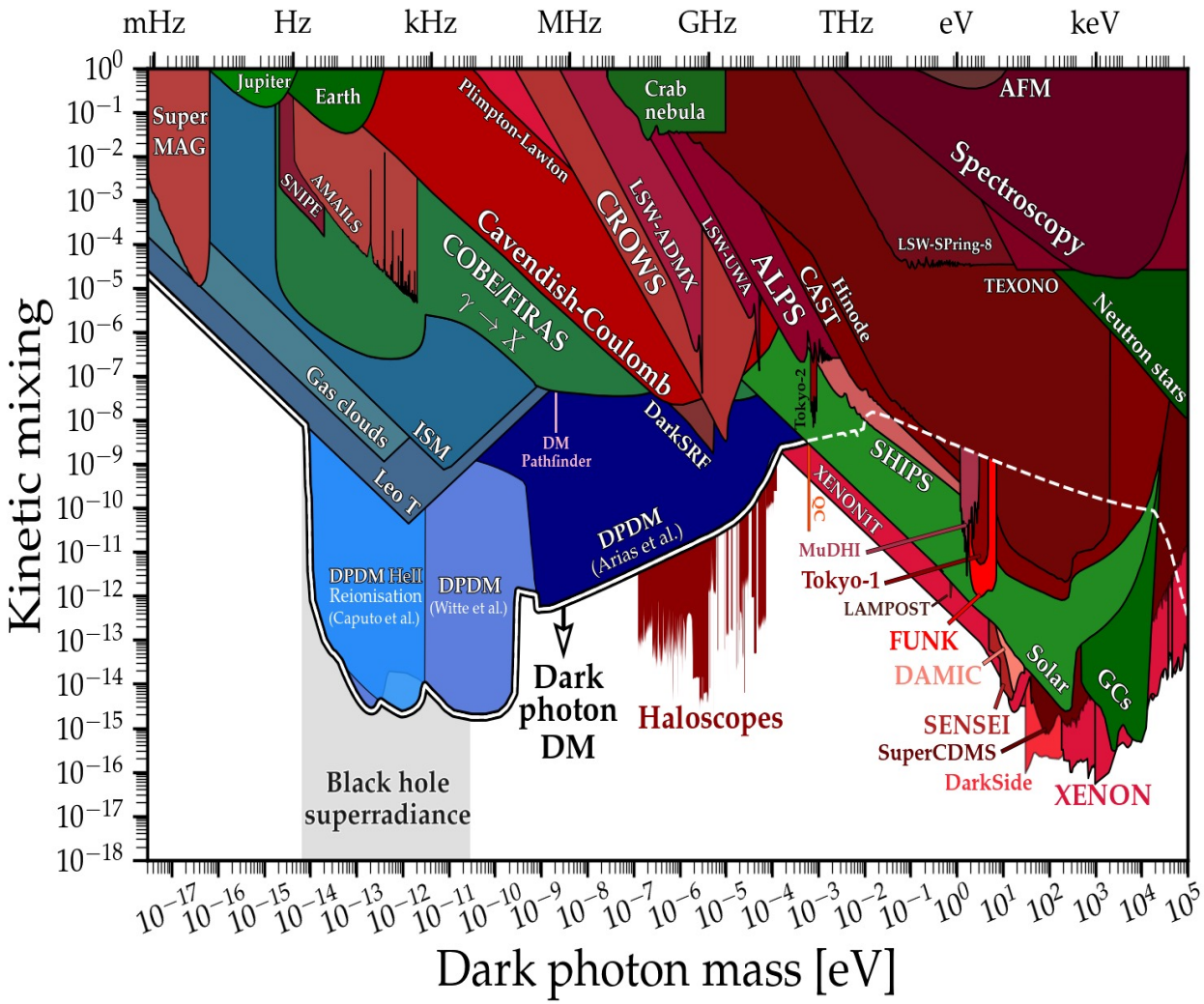


Image from arXiv:2105.04565

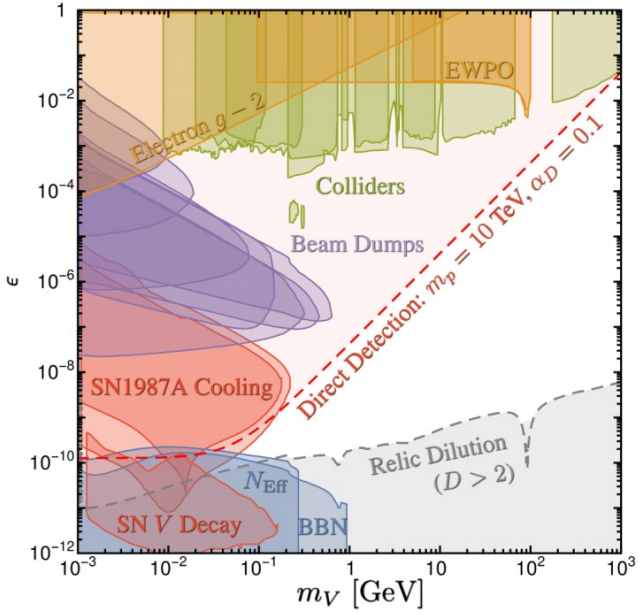


Image from arXiv:2007.13787

Axion-like Particle Constraints

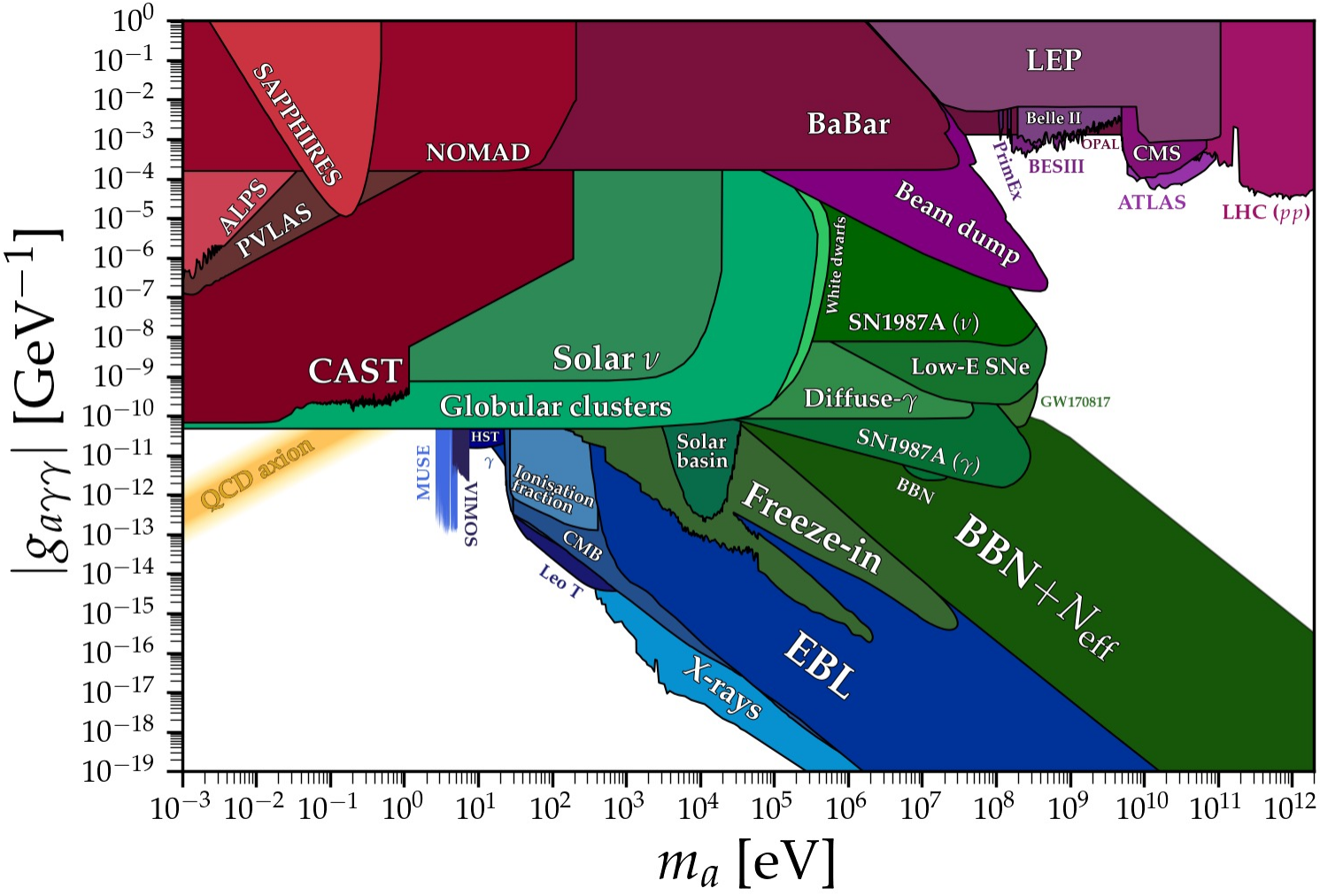
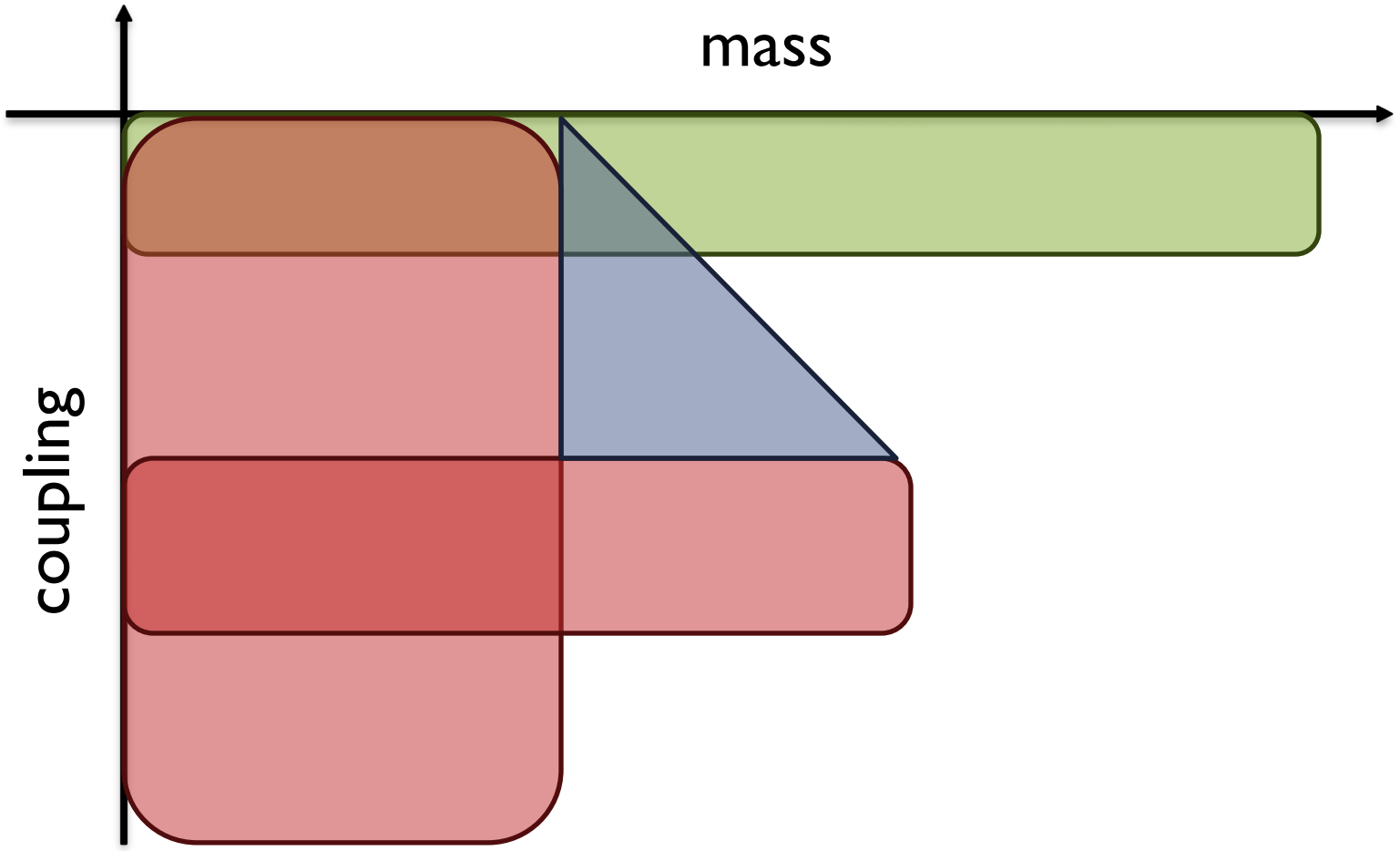
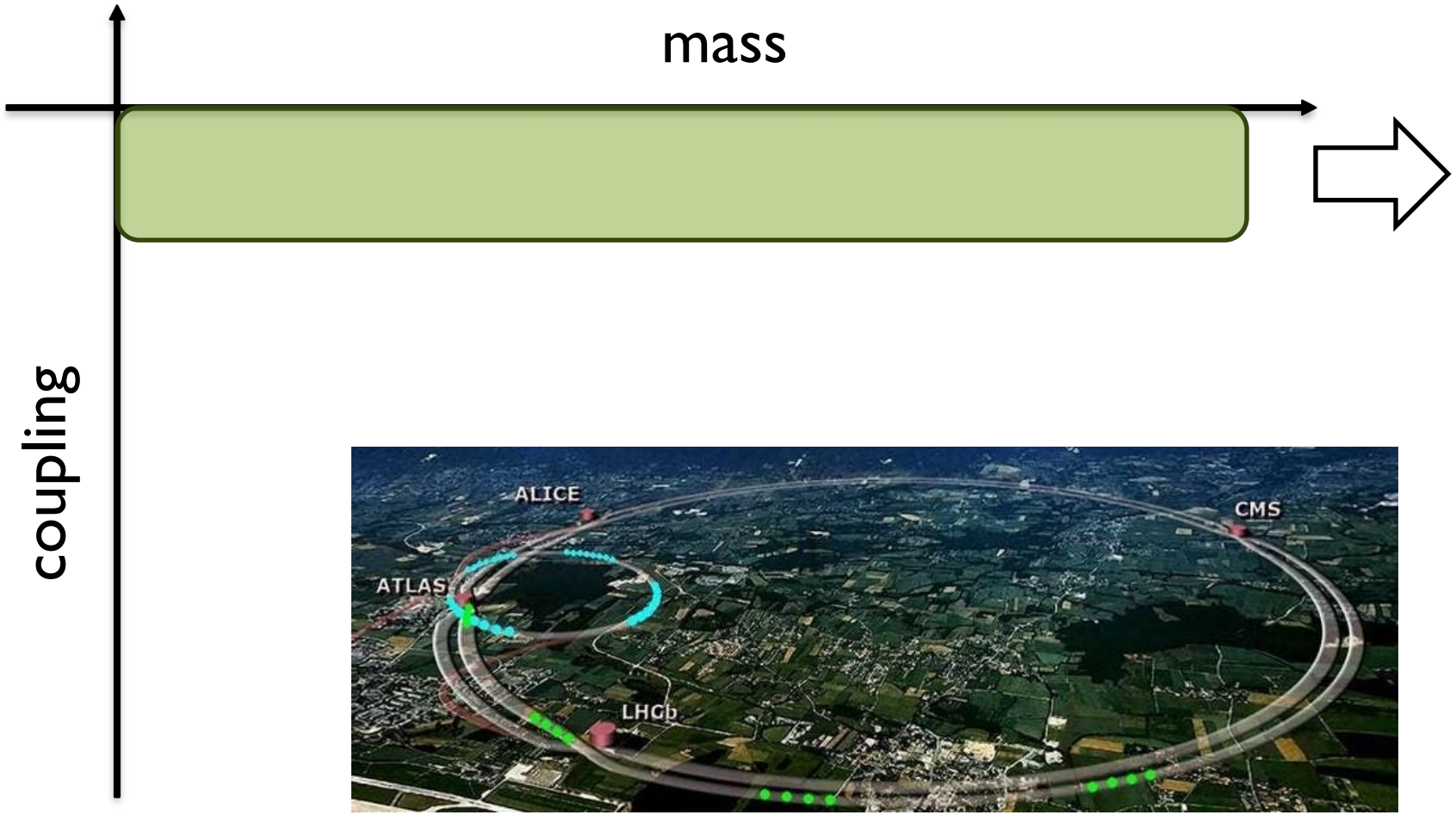


Image from https://cajohare.github.io/AxionLimits/docs/ap.html

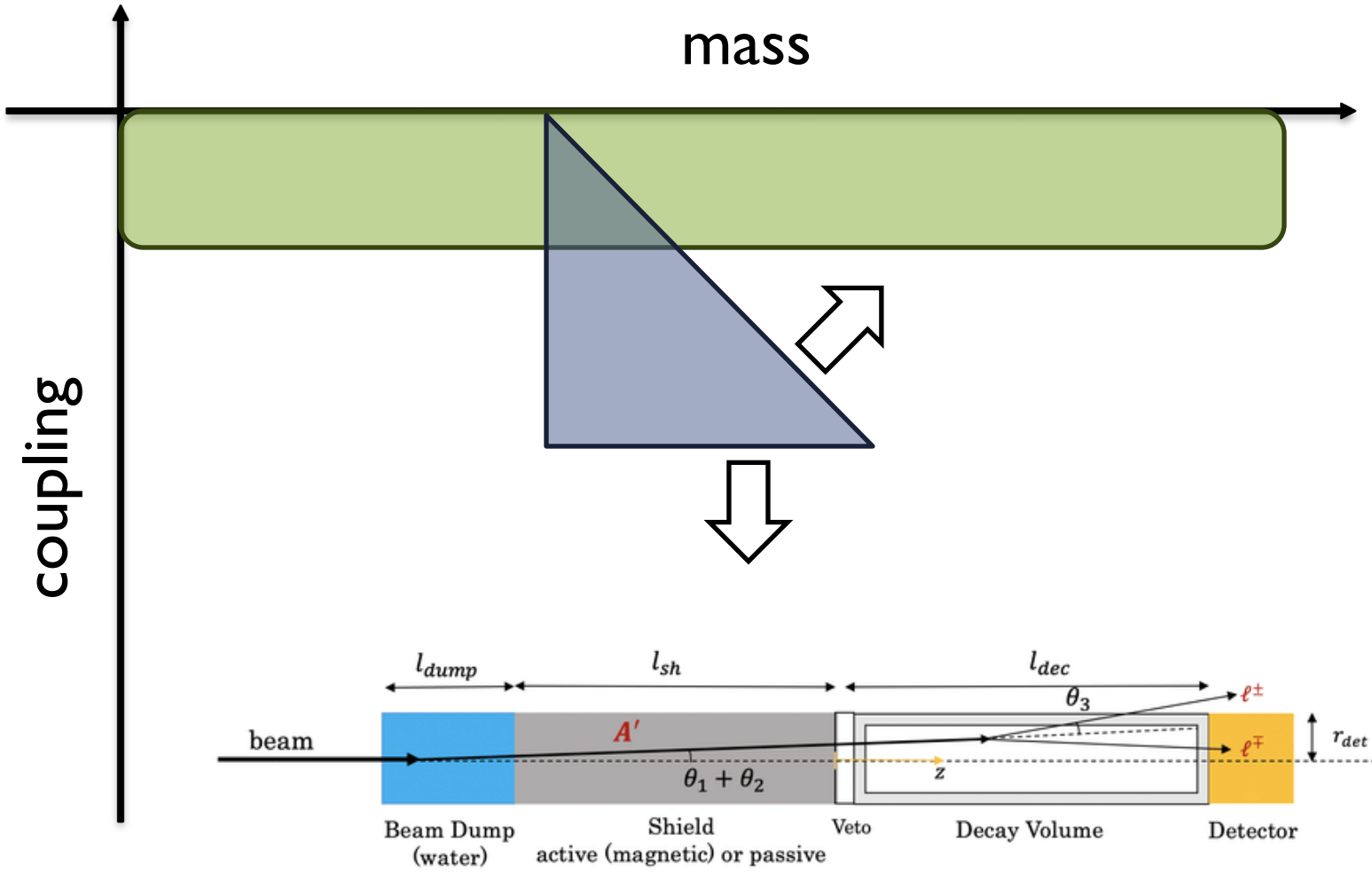
Dark Sector Particle Probes



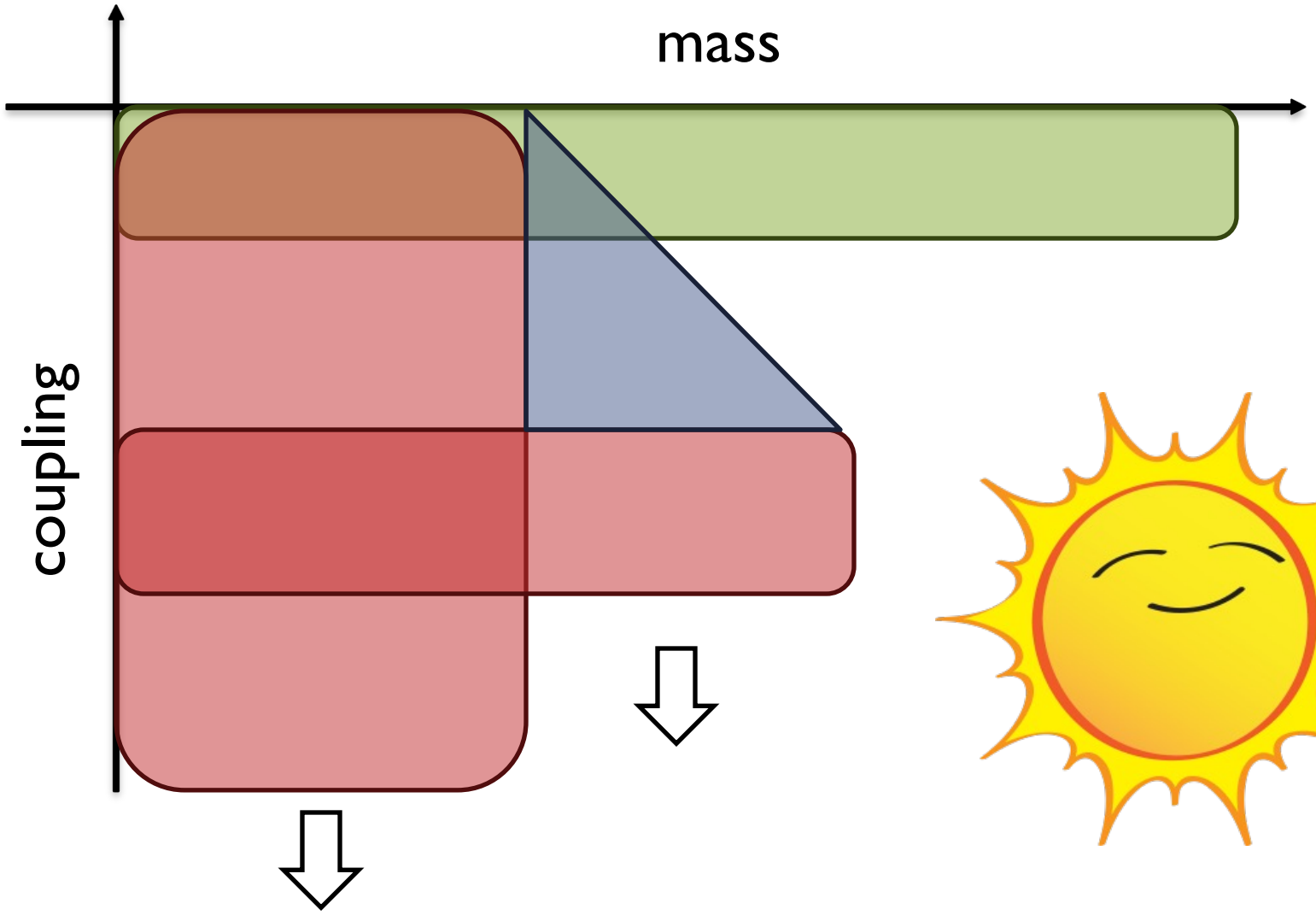
Collider Searches



Beam Dump Experiments



Astrophysical Searches



Dark Photon Constraints

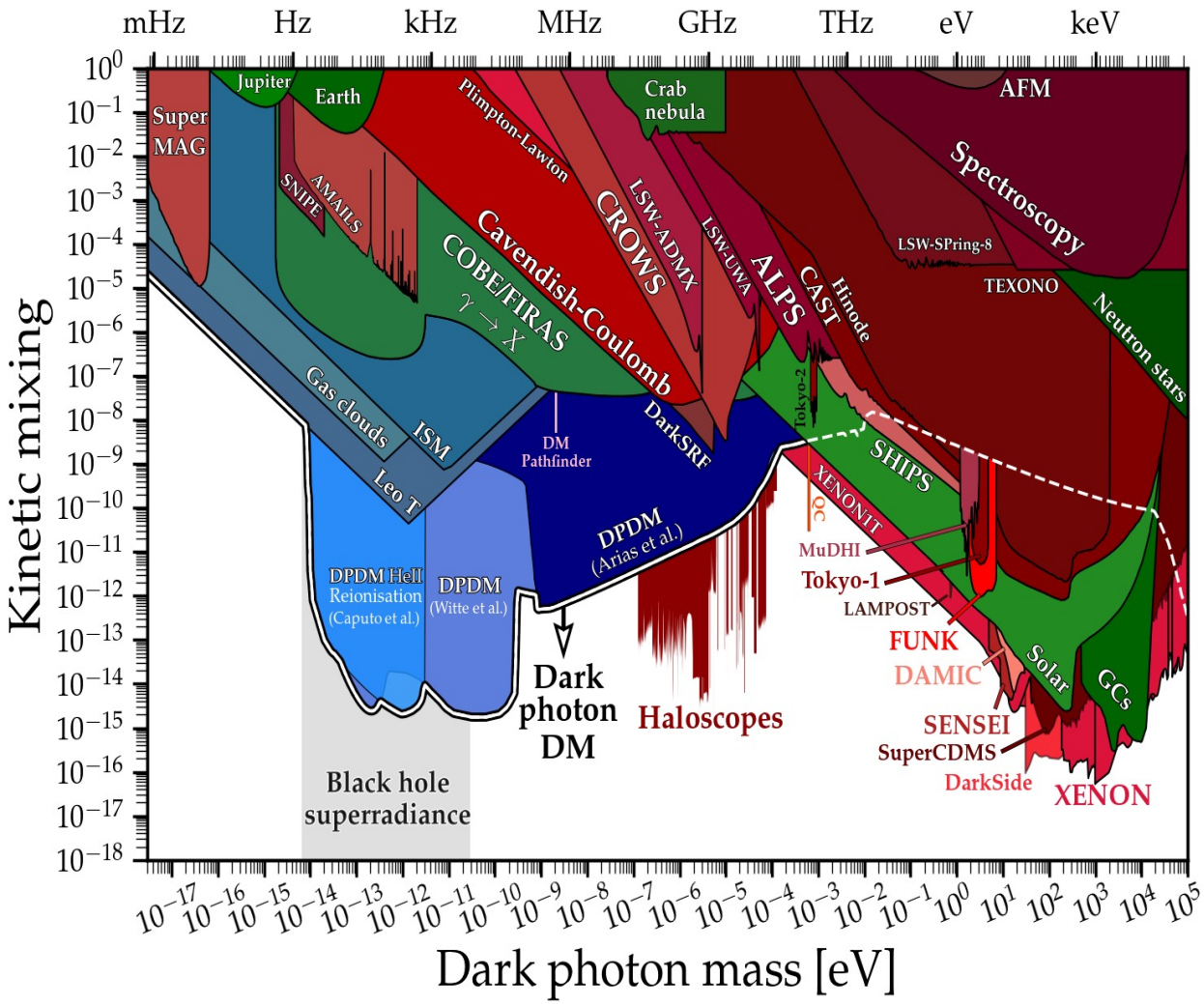


Image from arXiv:2105.04565

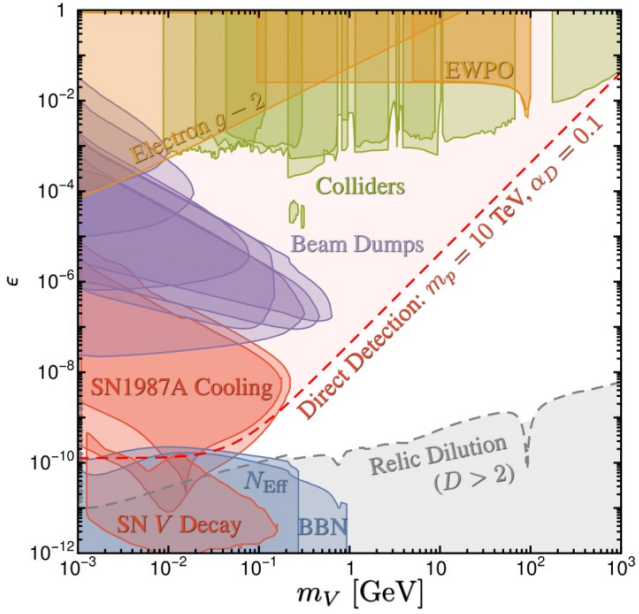


Image from arXiv:2007.13787

Dark Photon Constraints

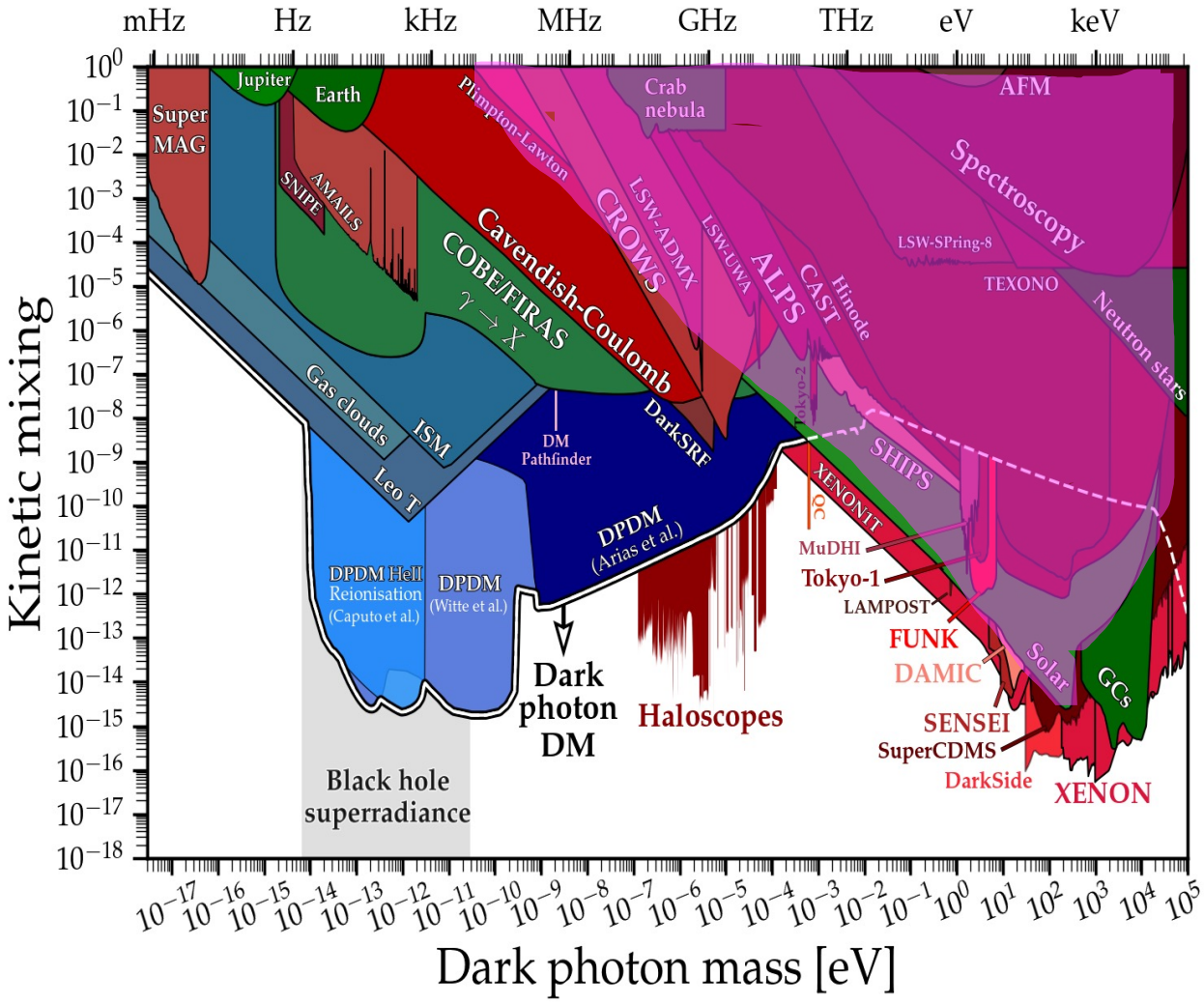


Image from arXiv:2105.04565

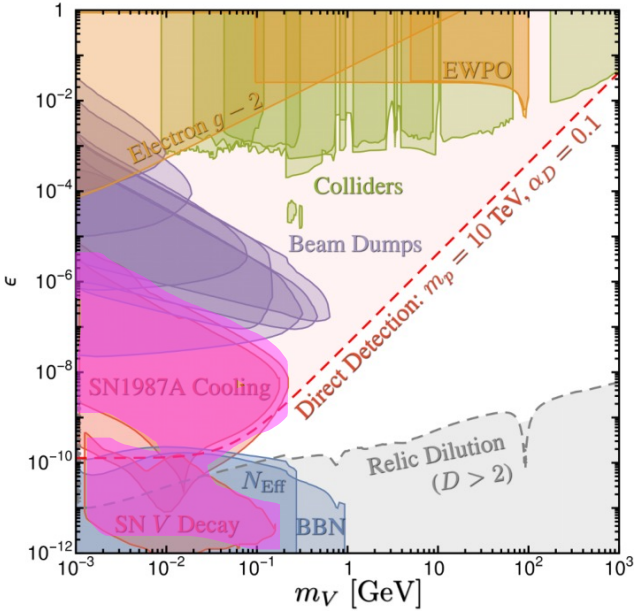


Image from arXiv:2007.13787

Axion-like Particle Constraints

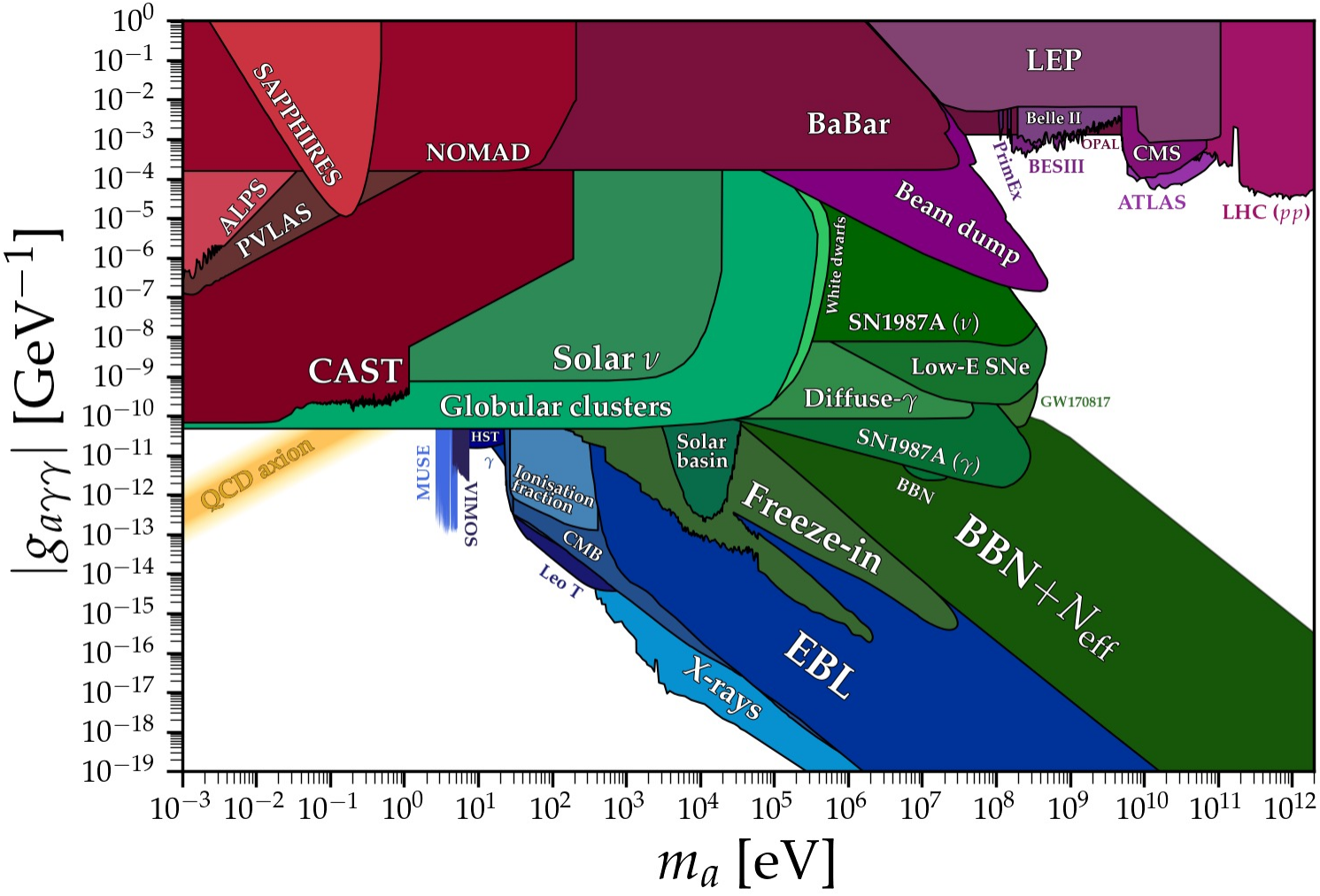


Image from https://cajohare.github.io/AxionLimits/docs/ap.html

Axion-like Particle Constraints

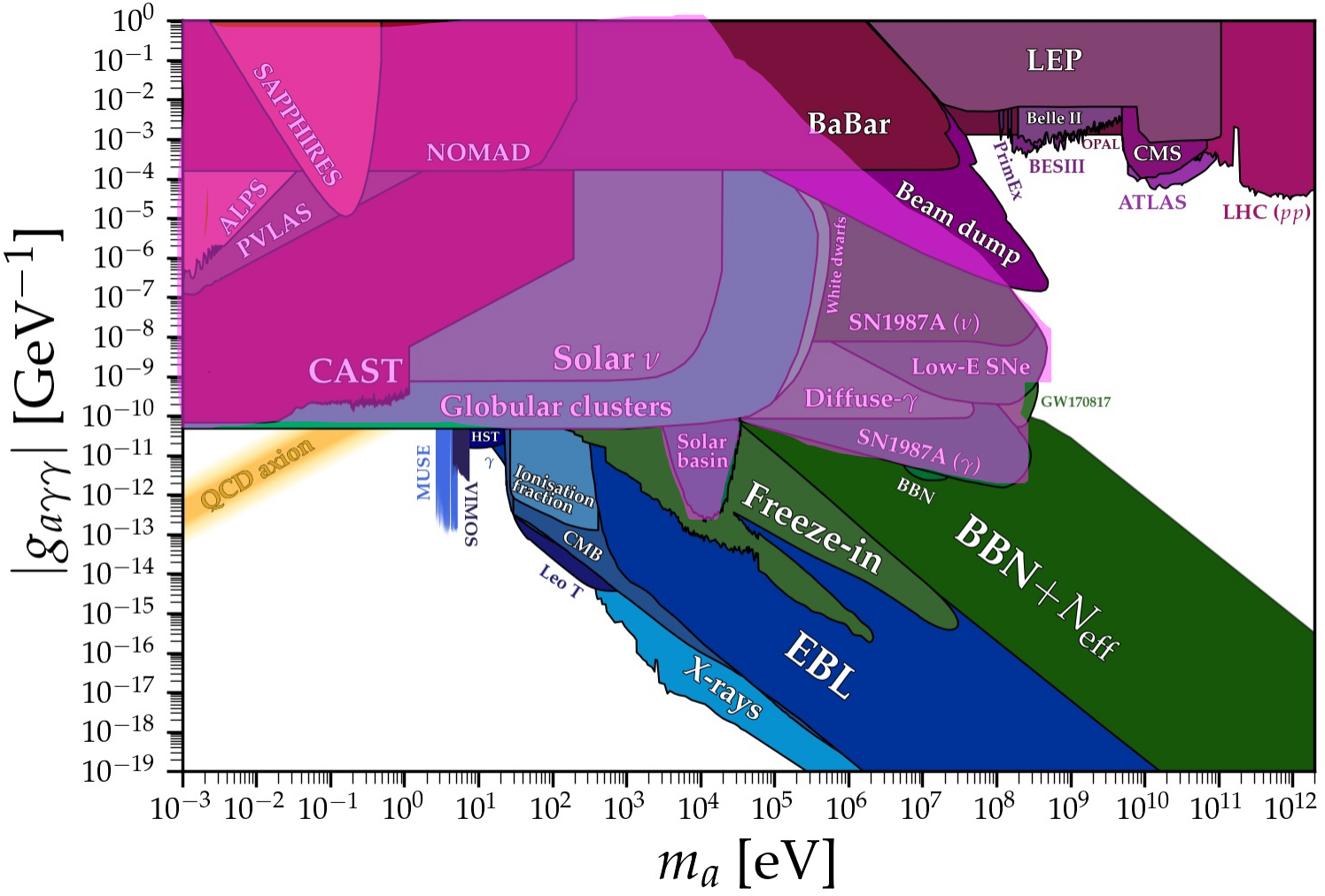


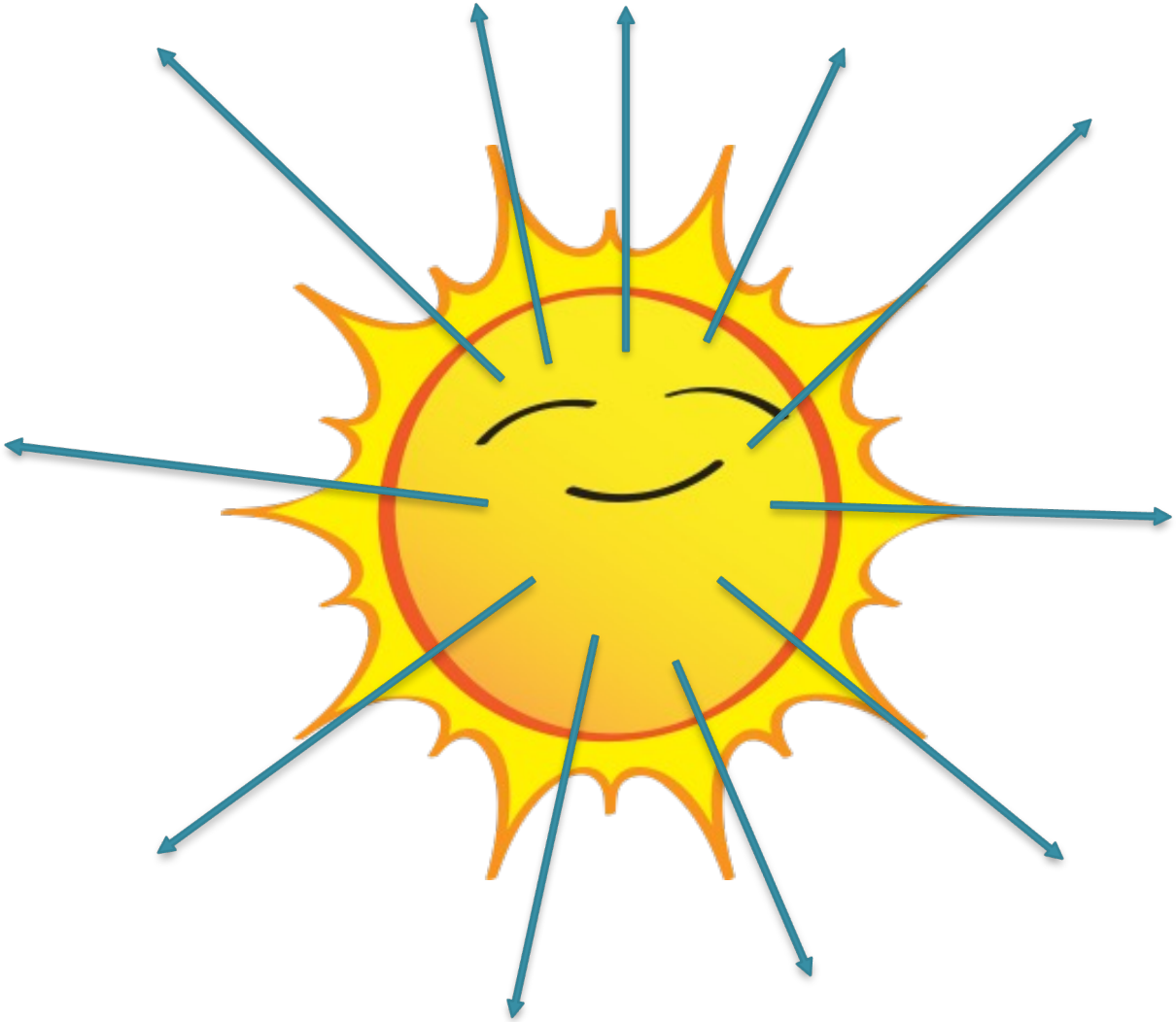
Image from https://cajohare.github.io/AxionLimits/docs/ap.html

Astrophysical Searches

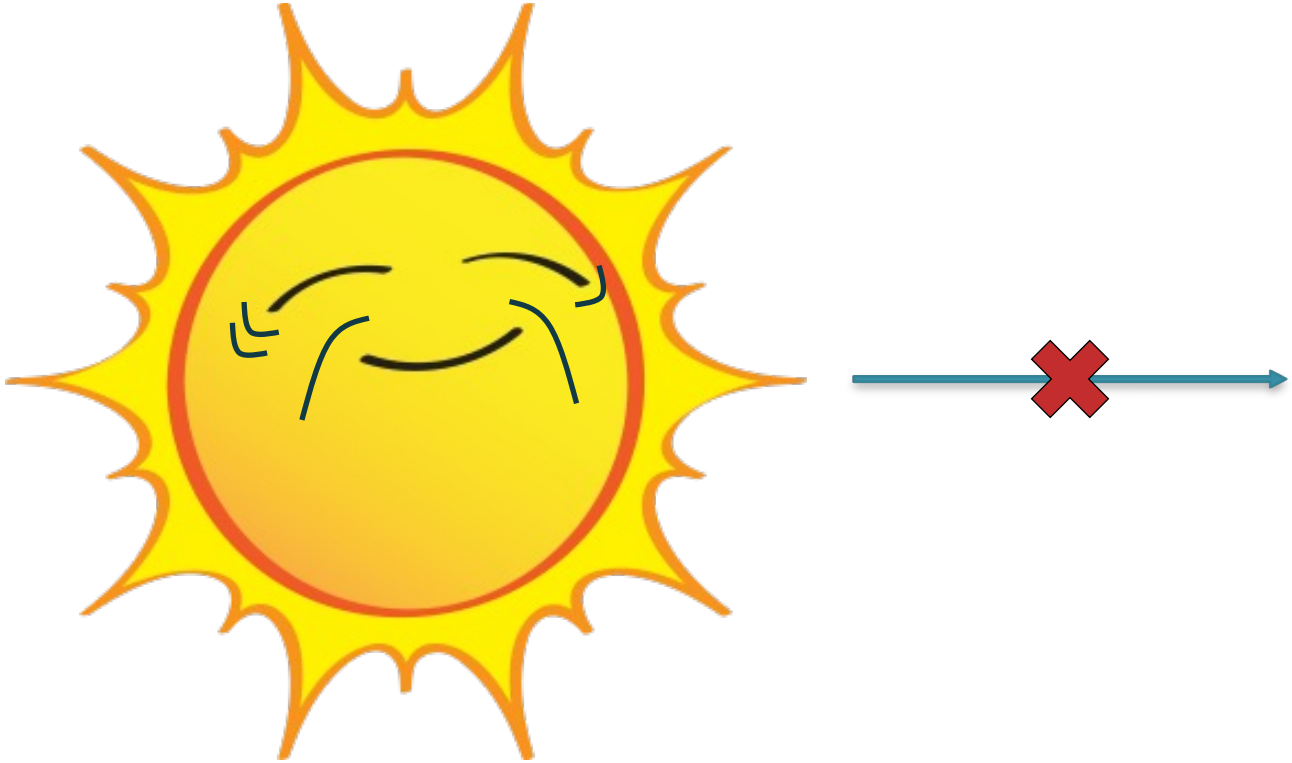
- Often serve to constrain a substantial amount of parameter space for dark sector particles
- Especially light mass and small coupling regions
- To go further, a comprehensive understanding of *both* astrophysics and particle physics is essential
- Let's explore a few examples

COOLING CONSTRAINTS

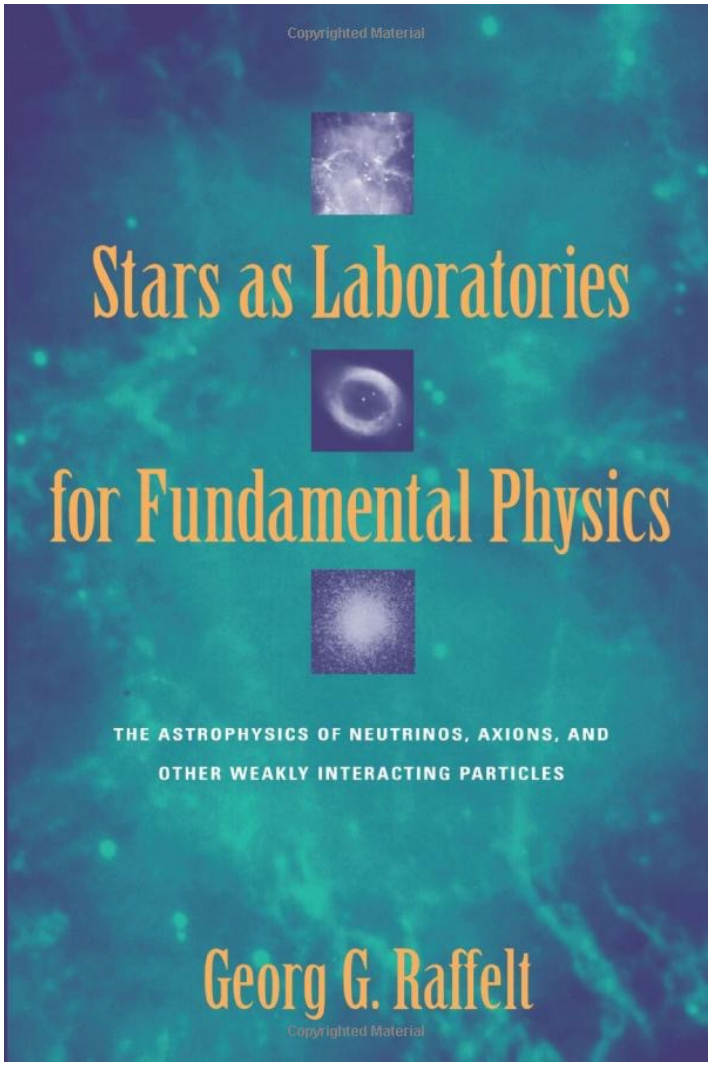
Cooling of Stars



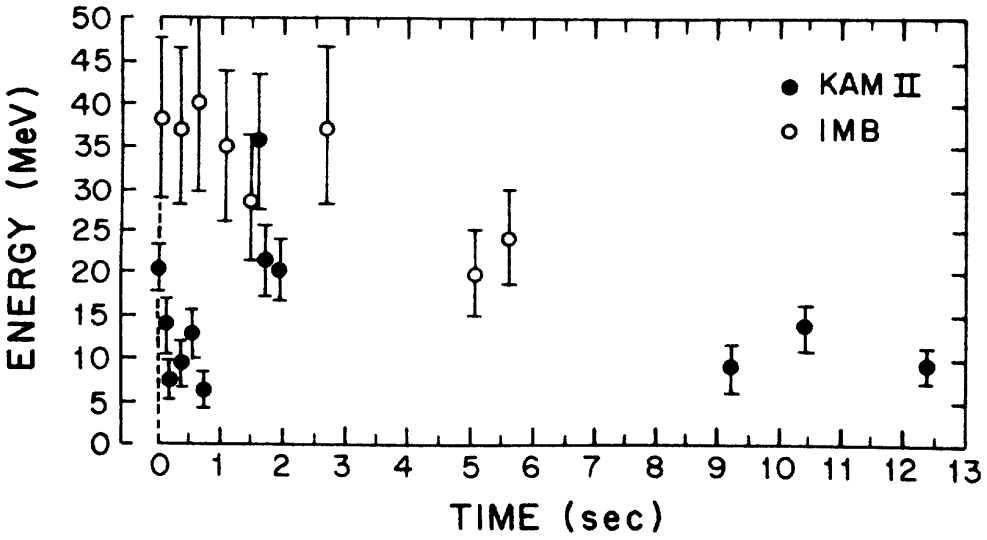
Cooling of Stars

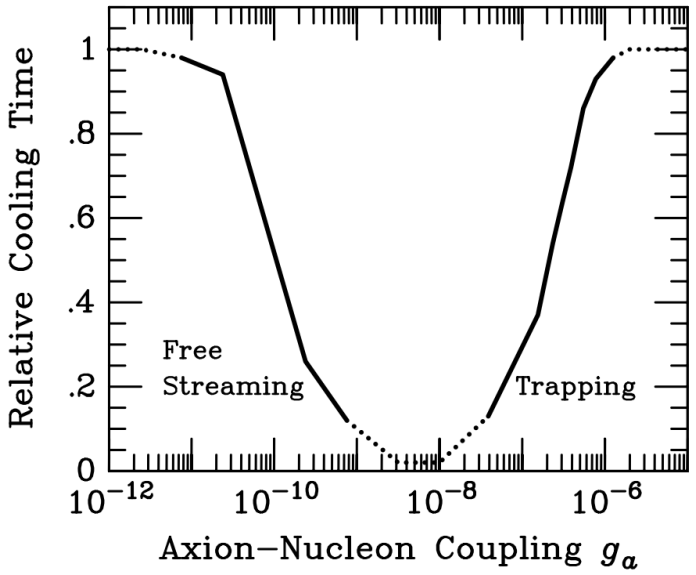


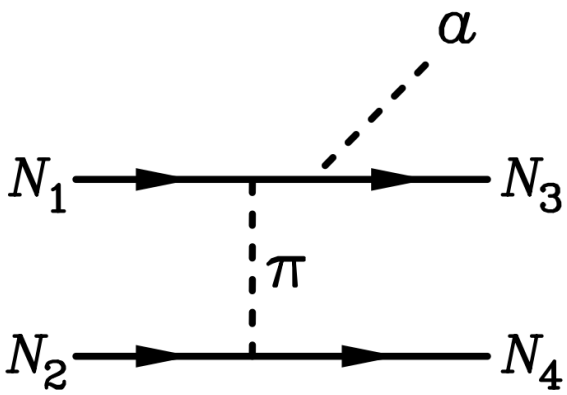
Raffelt Criterion



Raffelt Criterion for SN1987A







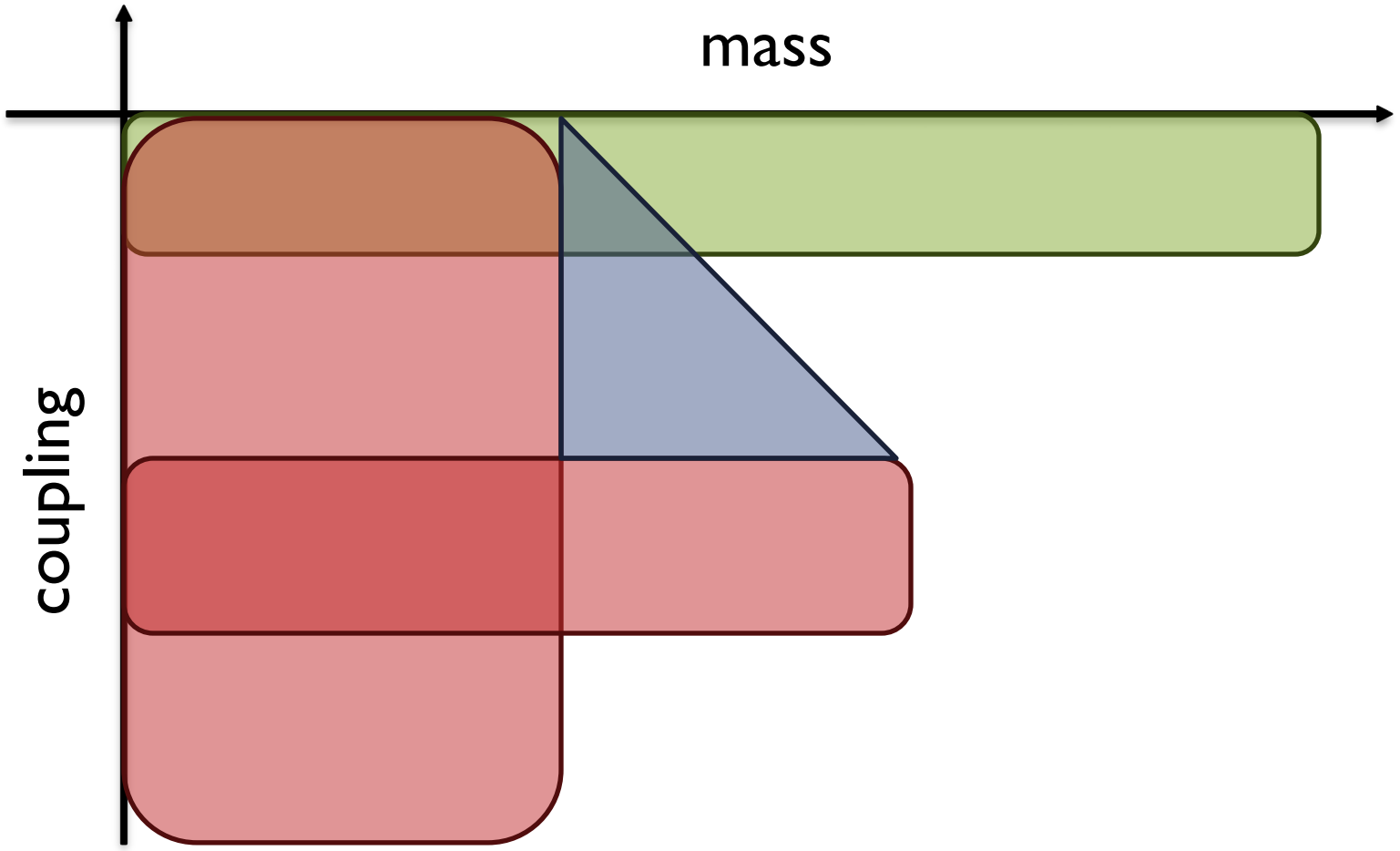
$$L_{\text{Dark}} < L_\nu$$

Cooling constraints from

- Supernova1987A → $T_{\mathrm{core}} \approx 30\ \mathrm{MeV}$
- Red giants
- Horizontal Branch
- White Dwarfs
- The Sun

} $T_{\mathrm{core}} \approx 1\ \mathrm{keV}$

Dark Sector Particle Probes



Axion-like Particle Constraints

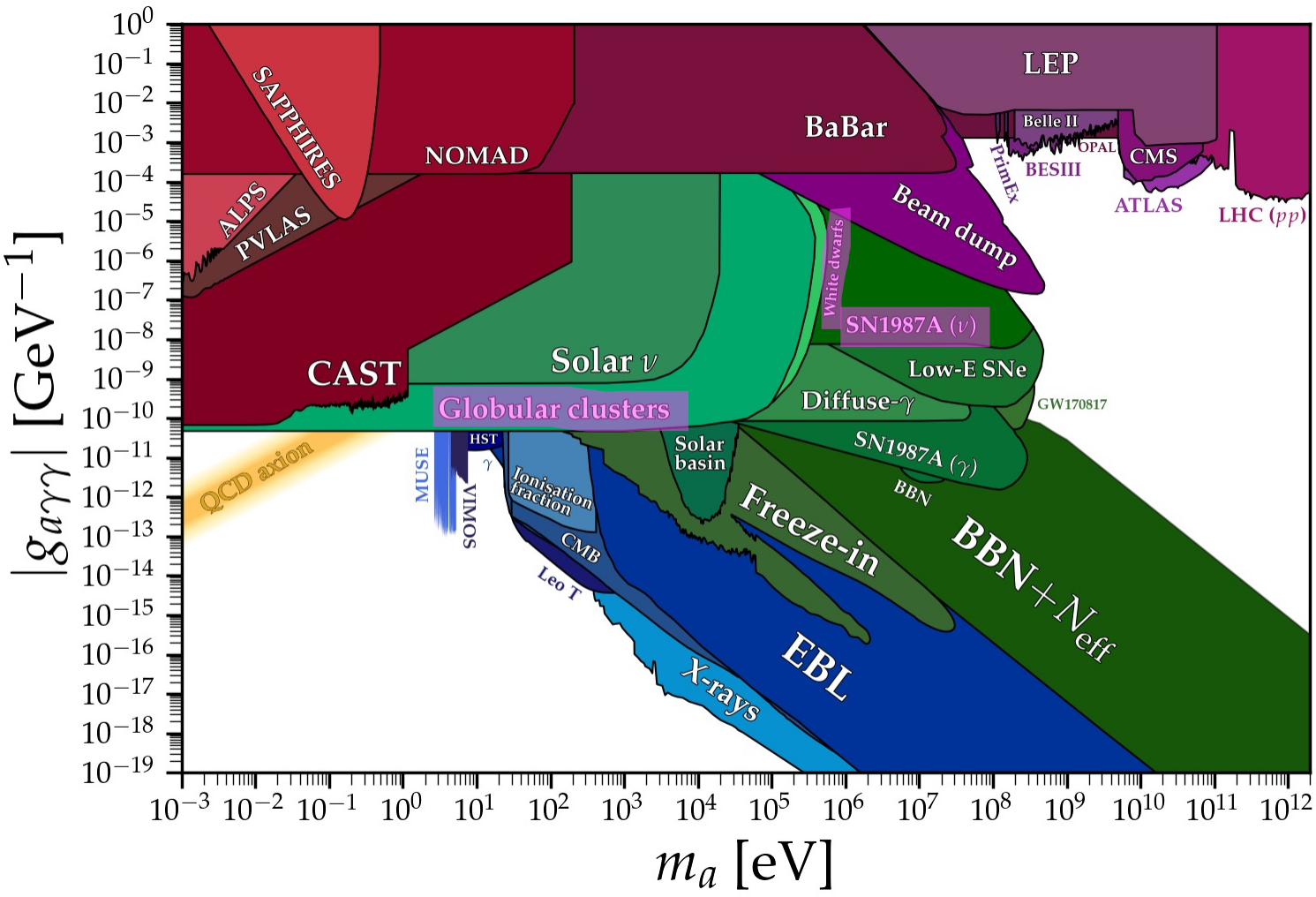


Image from https://cajohare.github.io/AxionLimits/docs/ap.html

Dark Photon Constraints

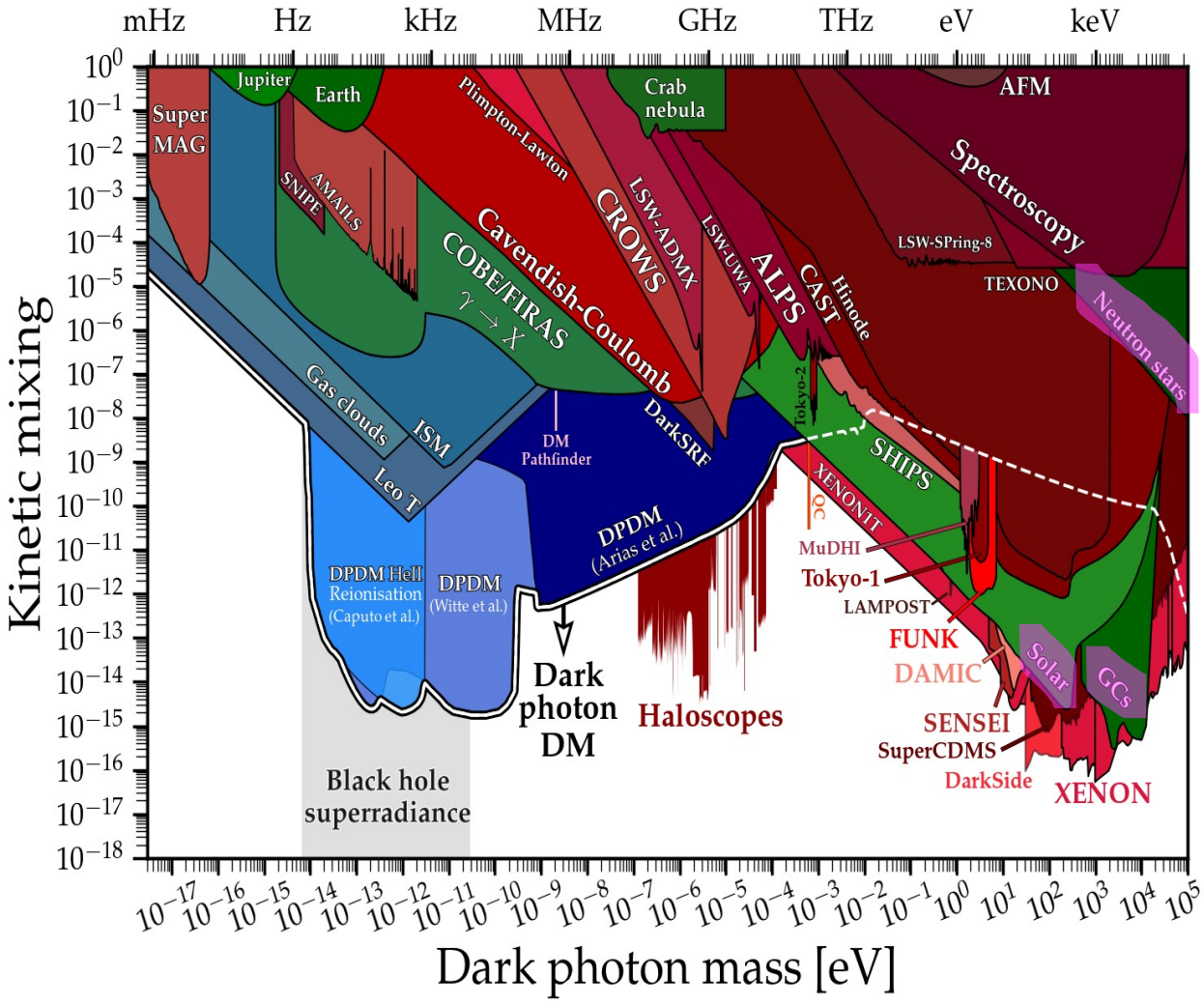


Image from arXiv:2105.04565

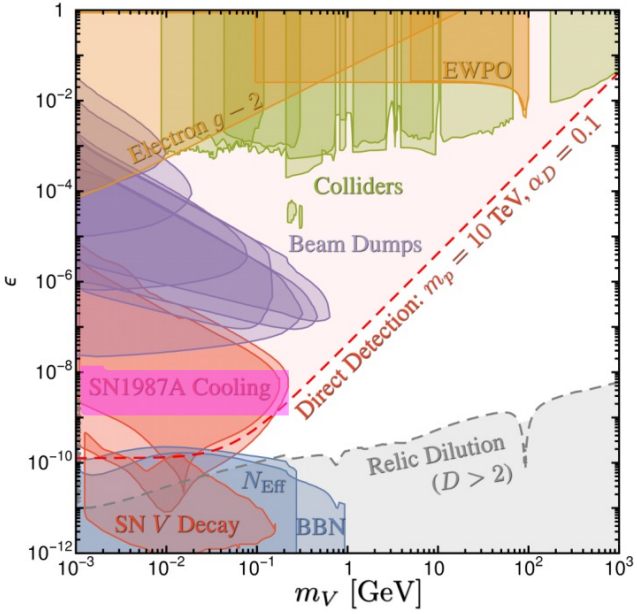


Image from arXiv:2007.13787

Need to understand particle physics in a hot plasma





$$\omega^2 - k^2 = \mathrm{Re}\Pi$$

Dark Photon Cooling Constraints with plasma effects

From the Sun : Redondo, arXiv:0801.1527
From HB : An, Pospelov, and Pradler, arXiv:1302.3884
From SN1987A : JHC, Essig, and McDermott, arXiv:1611.03864

Dark Photon Constraints

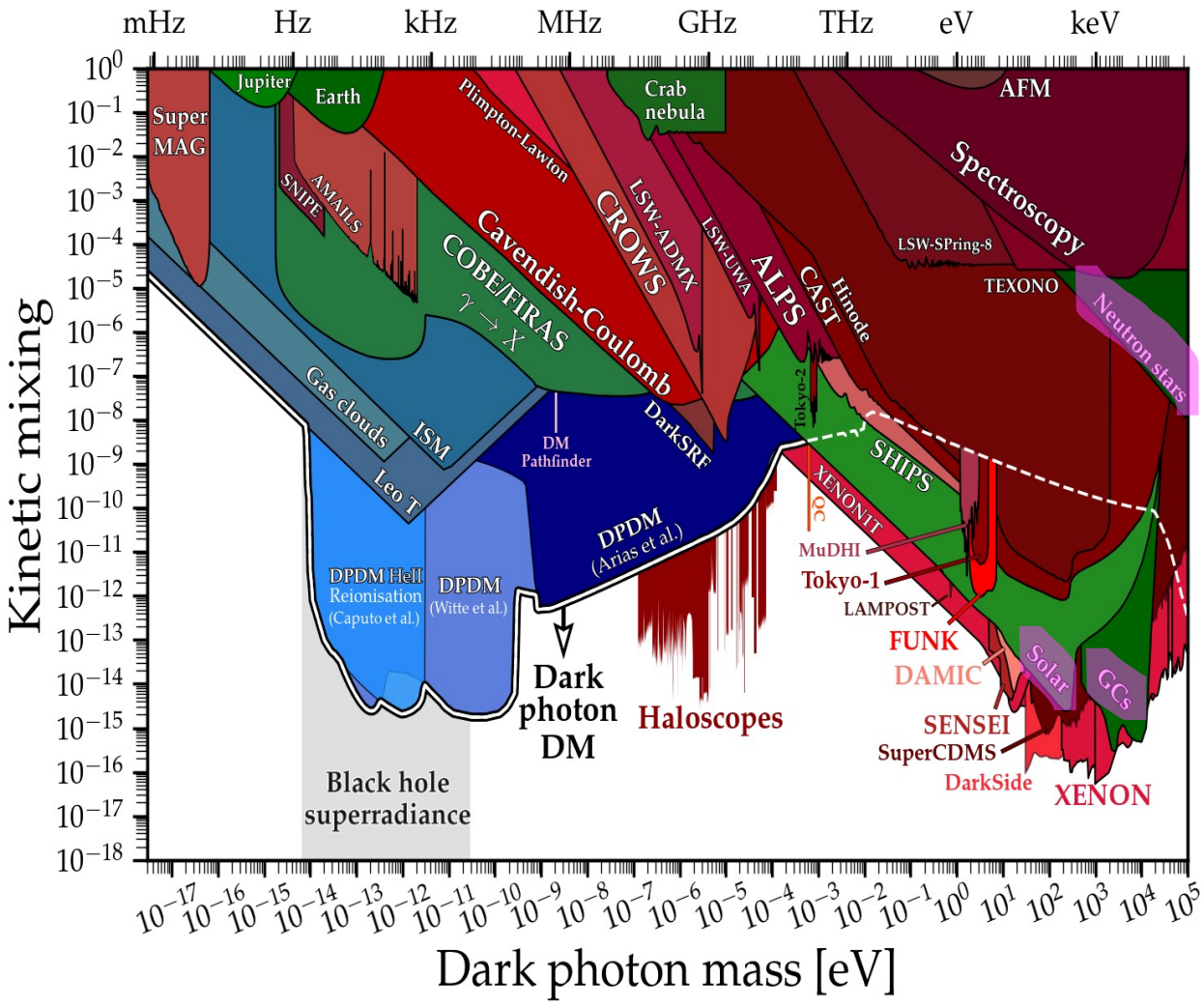


Image from arXiv:2105.04565

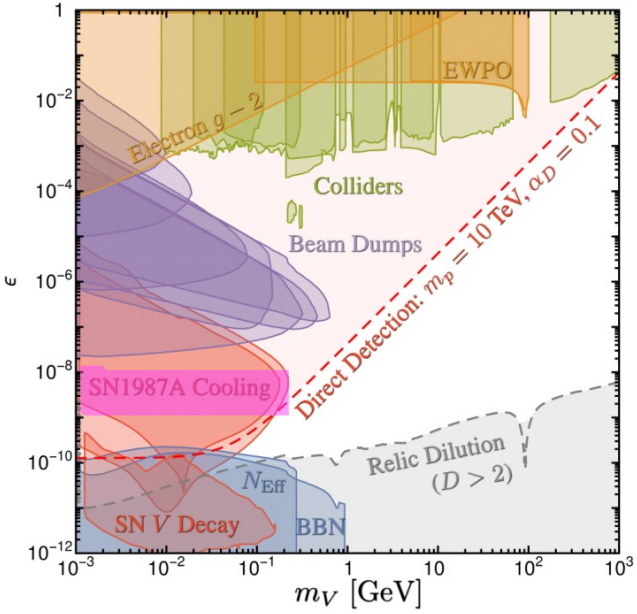


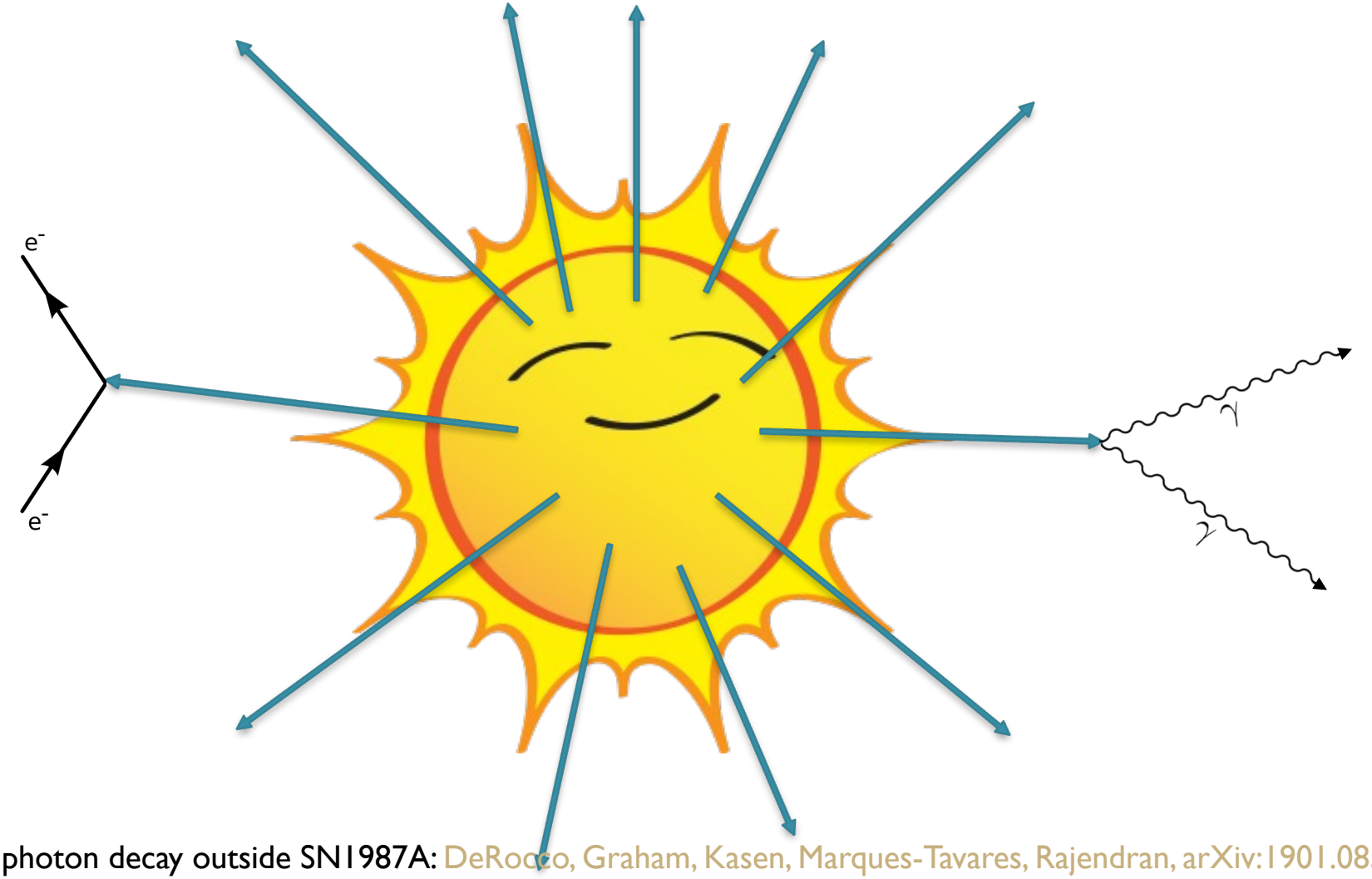
Image from arXiv:2007.13787

An example of improvements on cooling constraints: π^- contribution

- The number density of π^- is not negligible in SN : Fore and Reddy, arXiv:1911.02632
- π^- contribution to produce axions can enhance the axion cooling constraints : Fischer et al, arXiv:2108.13726
- π^- contribution is even more enhanced with a resonance : S-Y Ho, J Kim, P Ko, J-h Park, arXiv:2212.01155
- π^- contribution to dark gauge boson production : C S Shin and S Yun, arXiv:2211.15677

CONSTRAINTS FROM DECAY OR CONVERSION

Decay to EM energy



Dark photon decay outside SN1987A: DeRocco, Graham, Kasen, Marques-Tavares, Rajendran, arXiv:1901.08596
Low-Energy Supernovae : Caputo, Janka, Raffelt, Vitagliano, arXiv:2201.09890
ALP decay outside SN1987A: Hoof and Schulz, arXiv:2212.09764

Dark Photon Constraints

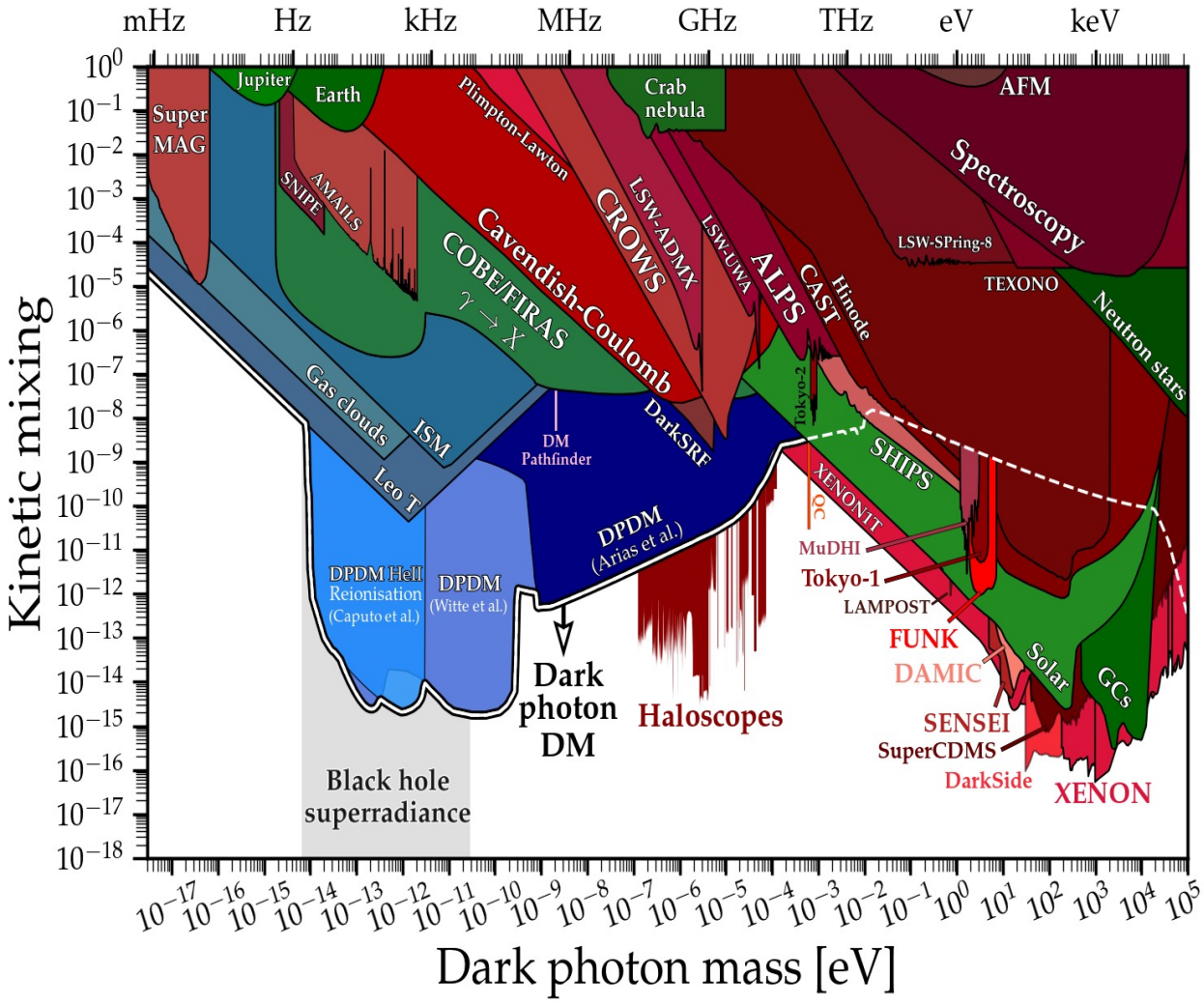


Image from arXiv:2105.04565

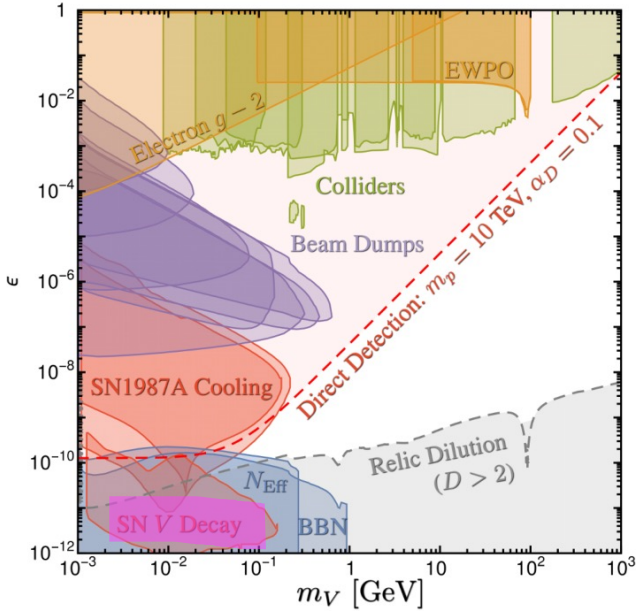


Image from arXiv:2007.13787

Axion-like Particle Constraints

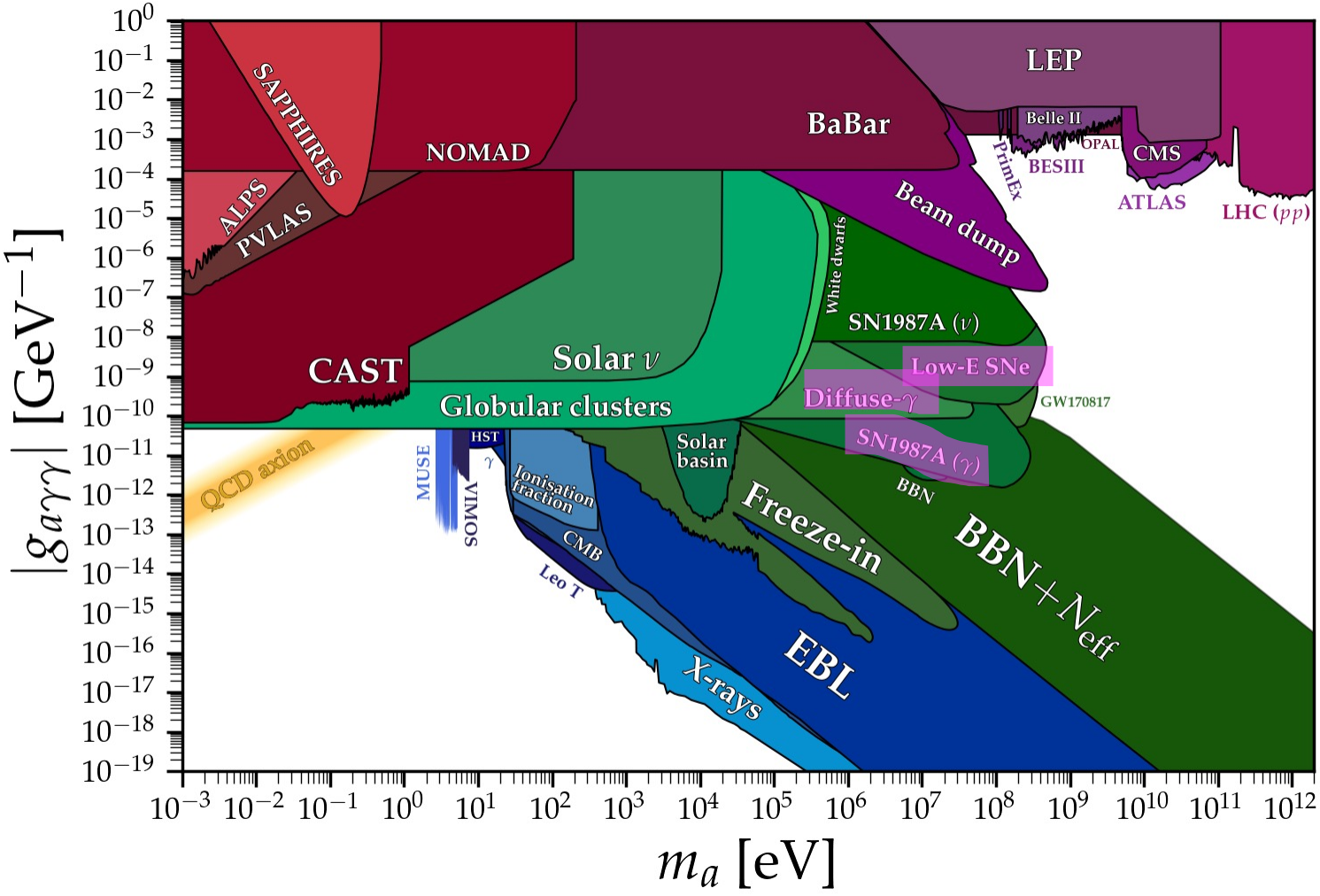
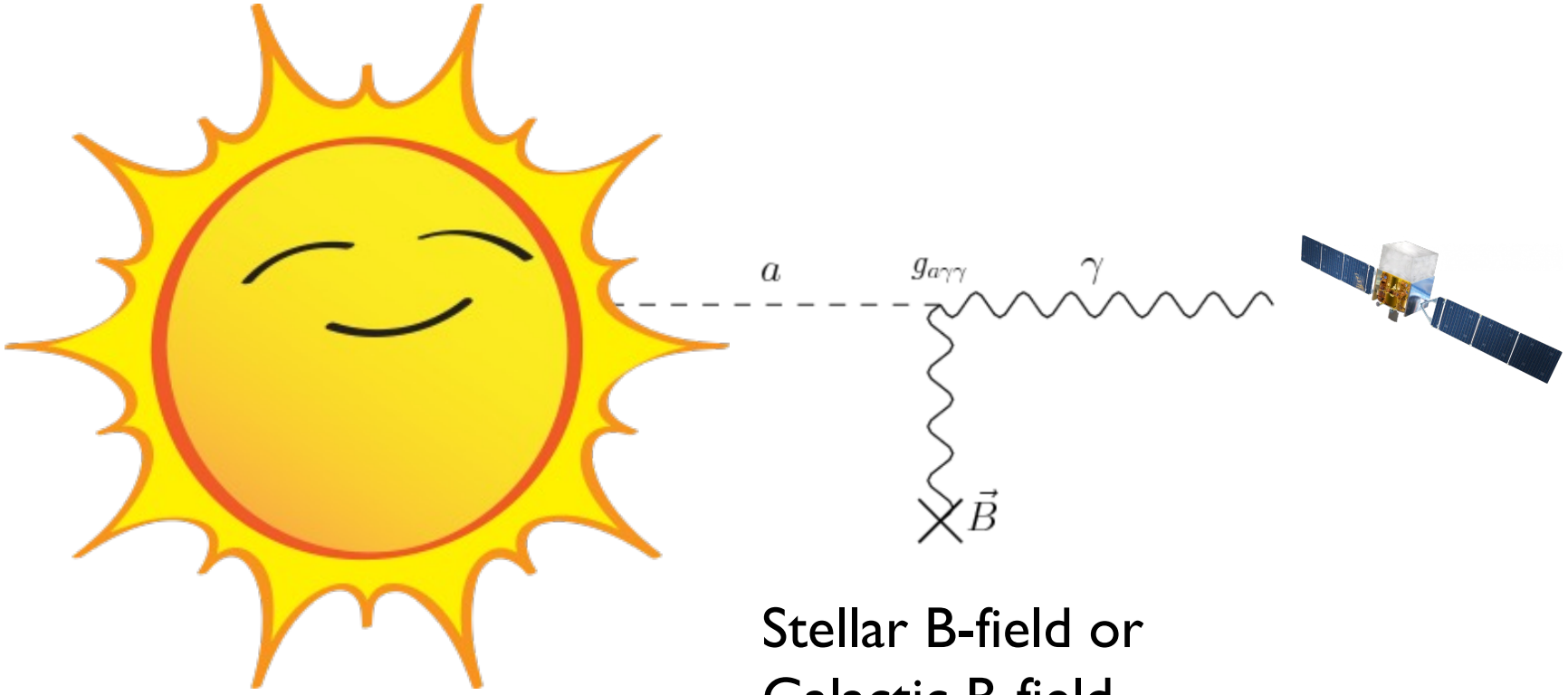


Image from https://cajohare.github.io/AxionLimits/docs/ap.html

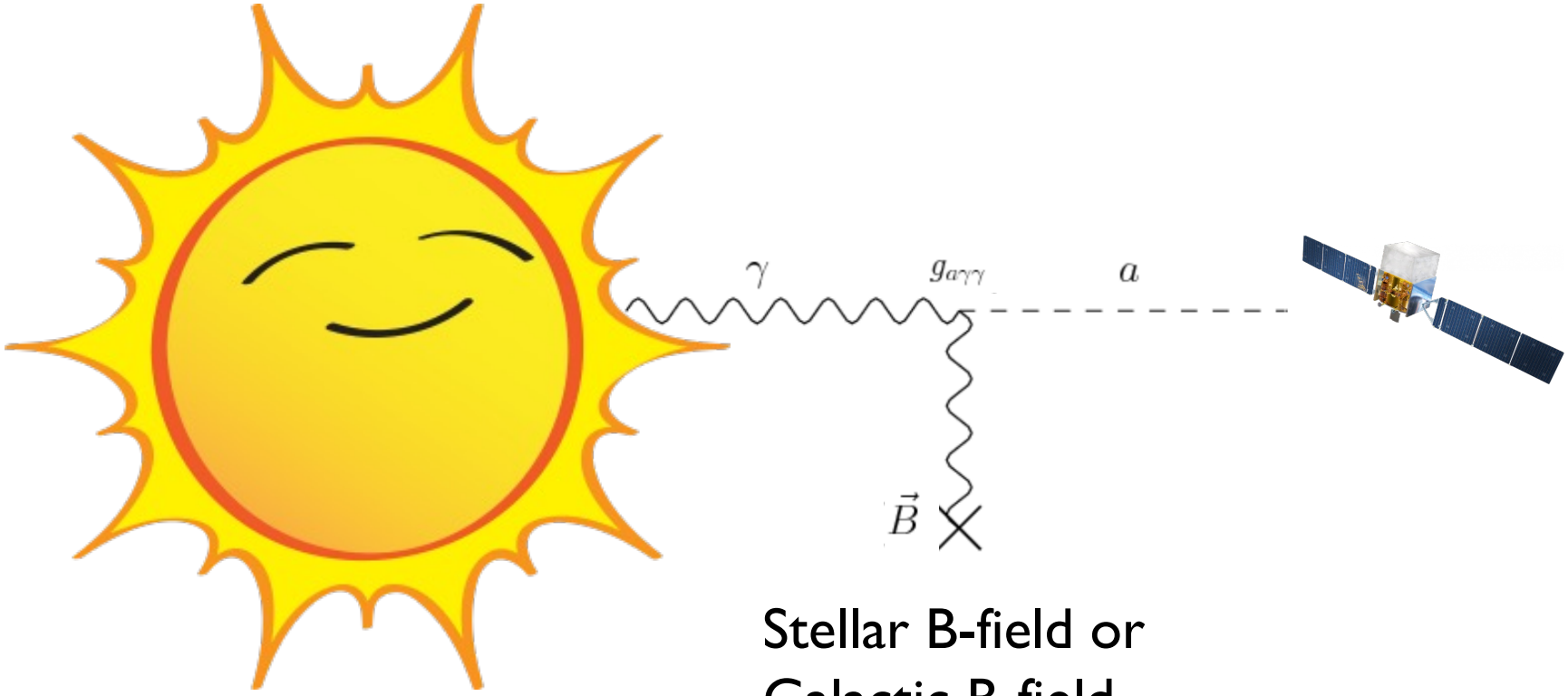
Conversion to Photons



Stellar B-field or
Galactic B-field

Diffuse γ from SNe: Calore et al, arXiv:2110.03679
From SN1987A: Hoof and Schulz, arXiv:2212.09764
From pulsars: Noordhuis et al, arXiv:2209.09917
And many…

Conversion from Photons



Stellar B-field or
Galactic B-field

From photon polarization: Dessert, Dunsky, and Safdi, arXiv:2203.04319
From blackbody stars: JHC, Ebadi, Luo, and Tanin, arXiv:2305.03749
And many…

Axion-like Particle Constraints

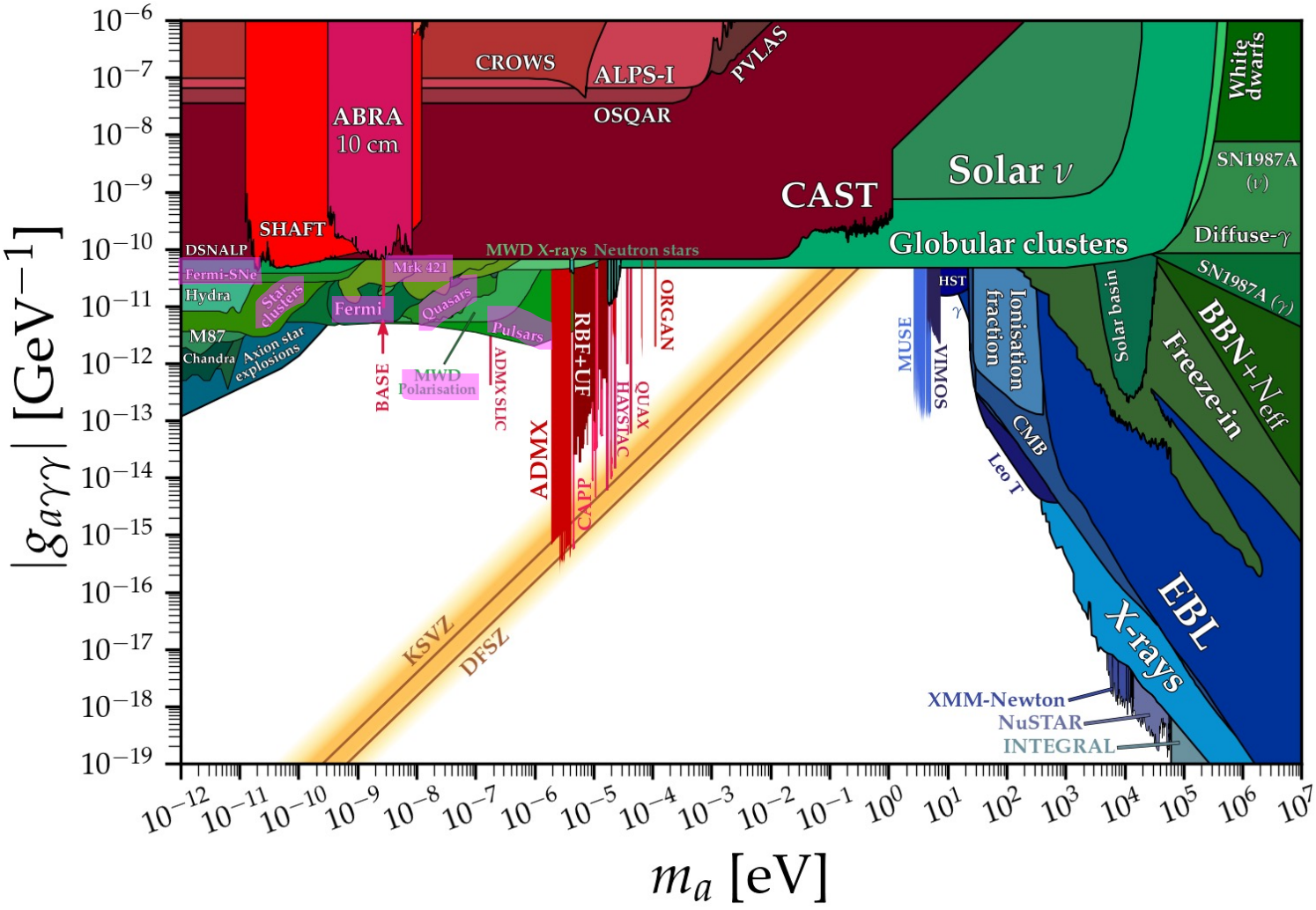
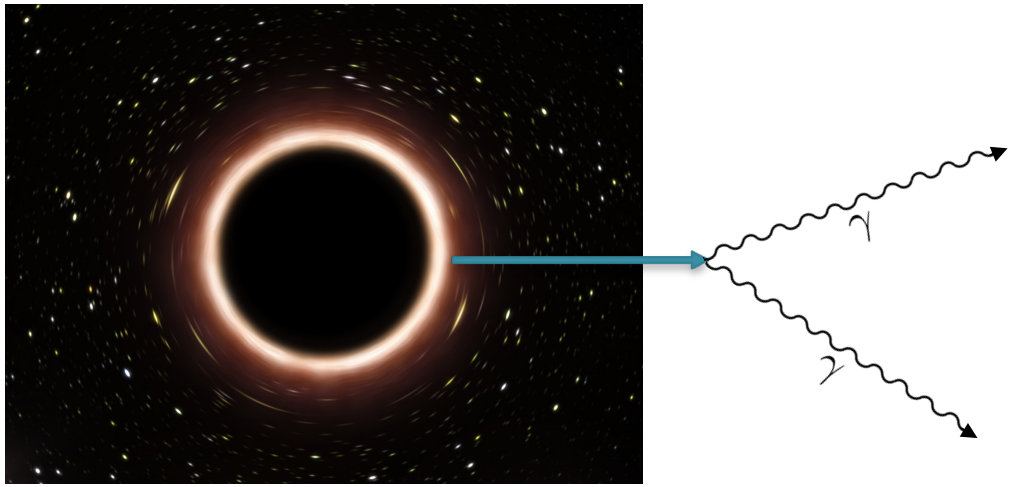


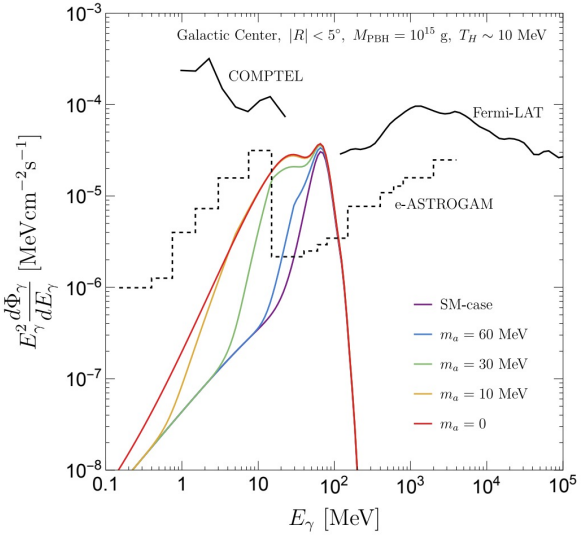
Image from https://cajohare.github.io/AxionLimits/docs/ap.html

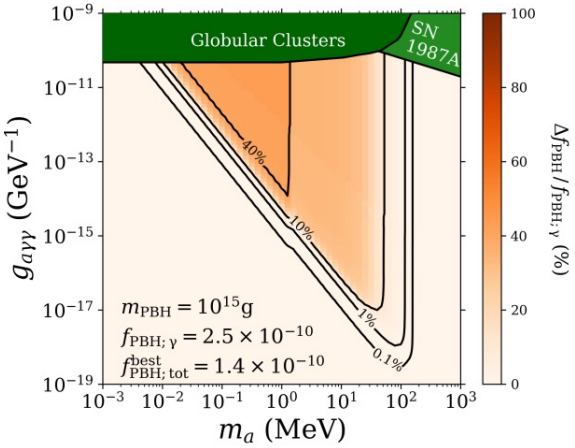
Another source: Blackholes

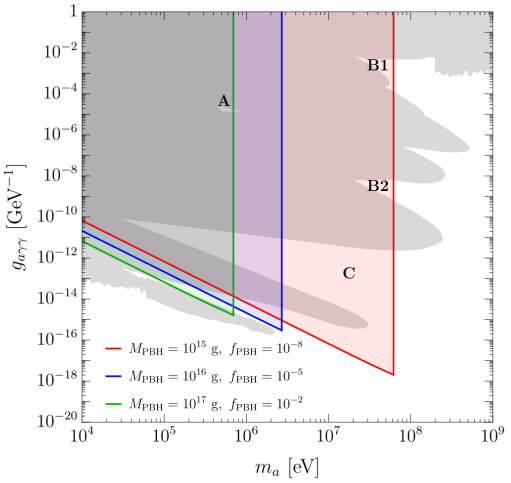


From extra galactic γ-ray : Y Jho, T-G Kim, J-C Park, S C Park, Y Park, arXiv: 2212.11977

From galactic center γ-ray: Agashe, JHC, Clark, Dutta, Tsai, and Xu, arXiv: 2212.11980

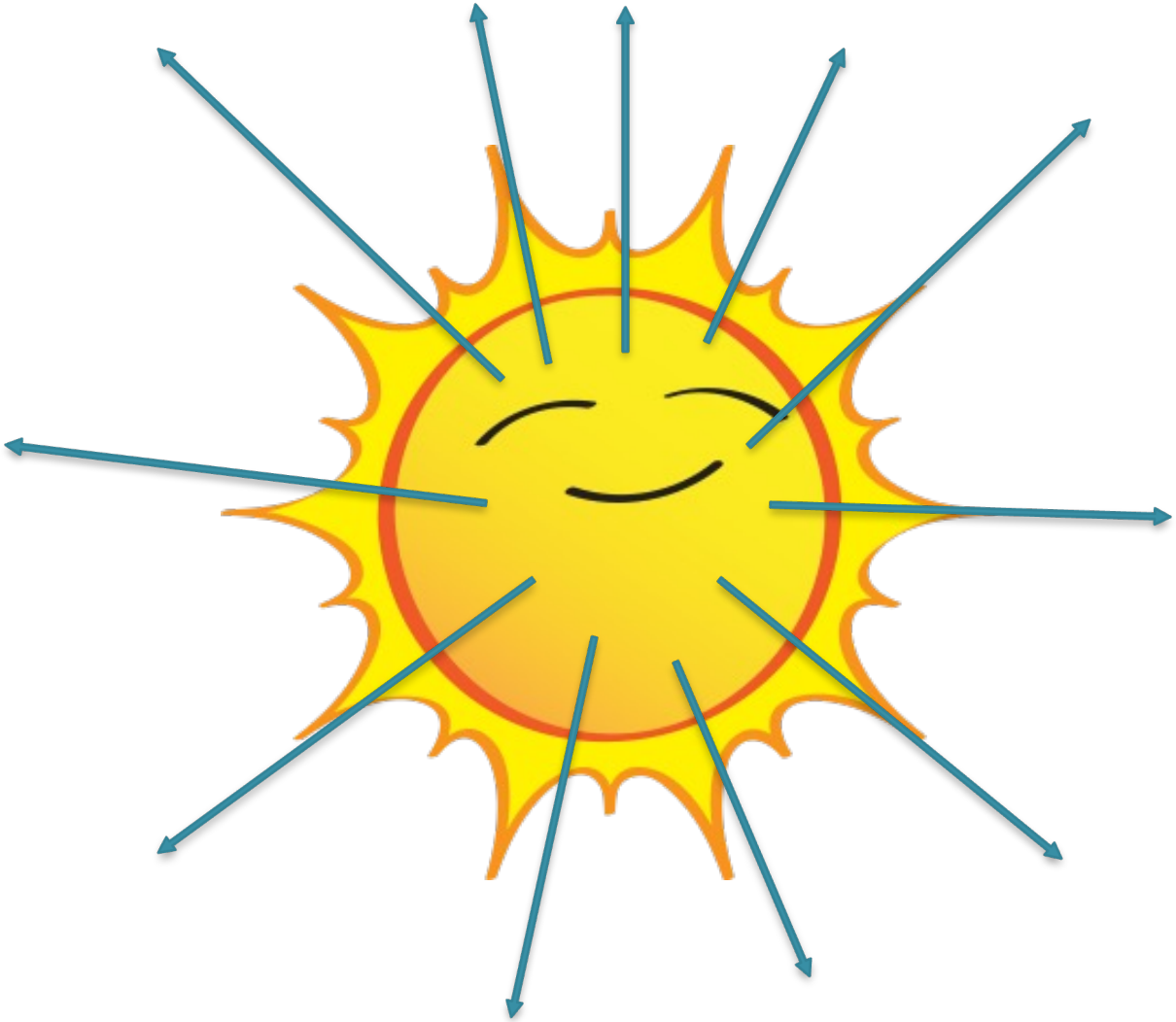


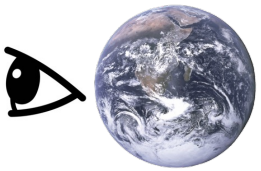




OBSERVATION OF PRODUCED PARTICLES

Observation at Earth





Axion-like Particle Constraints

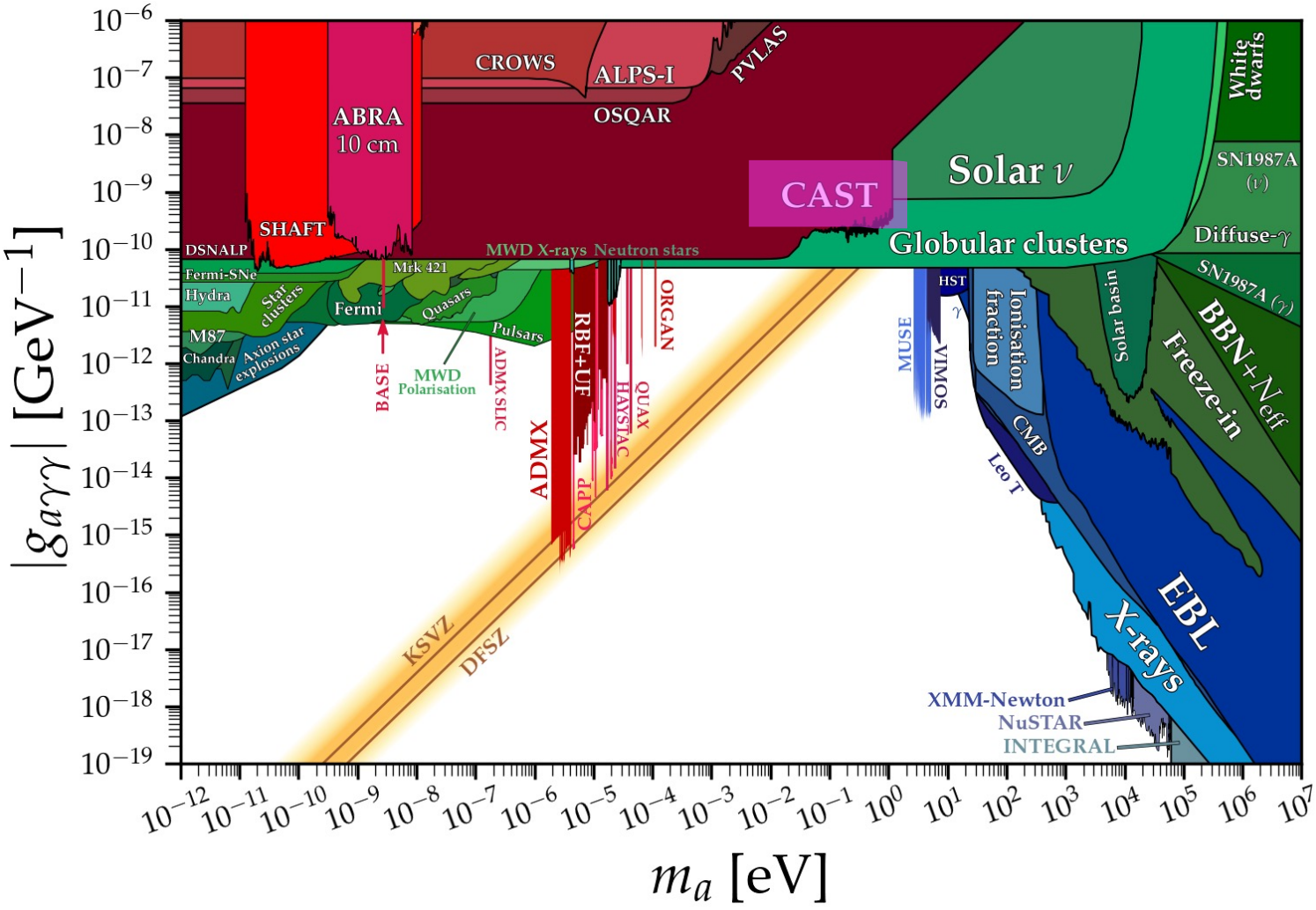
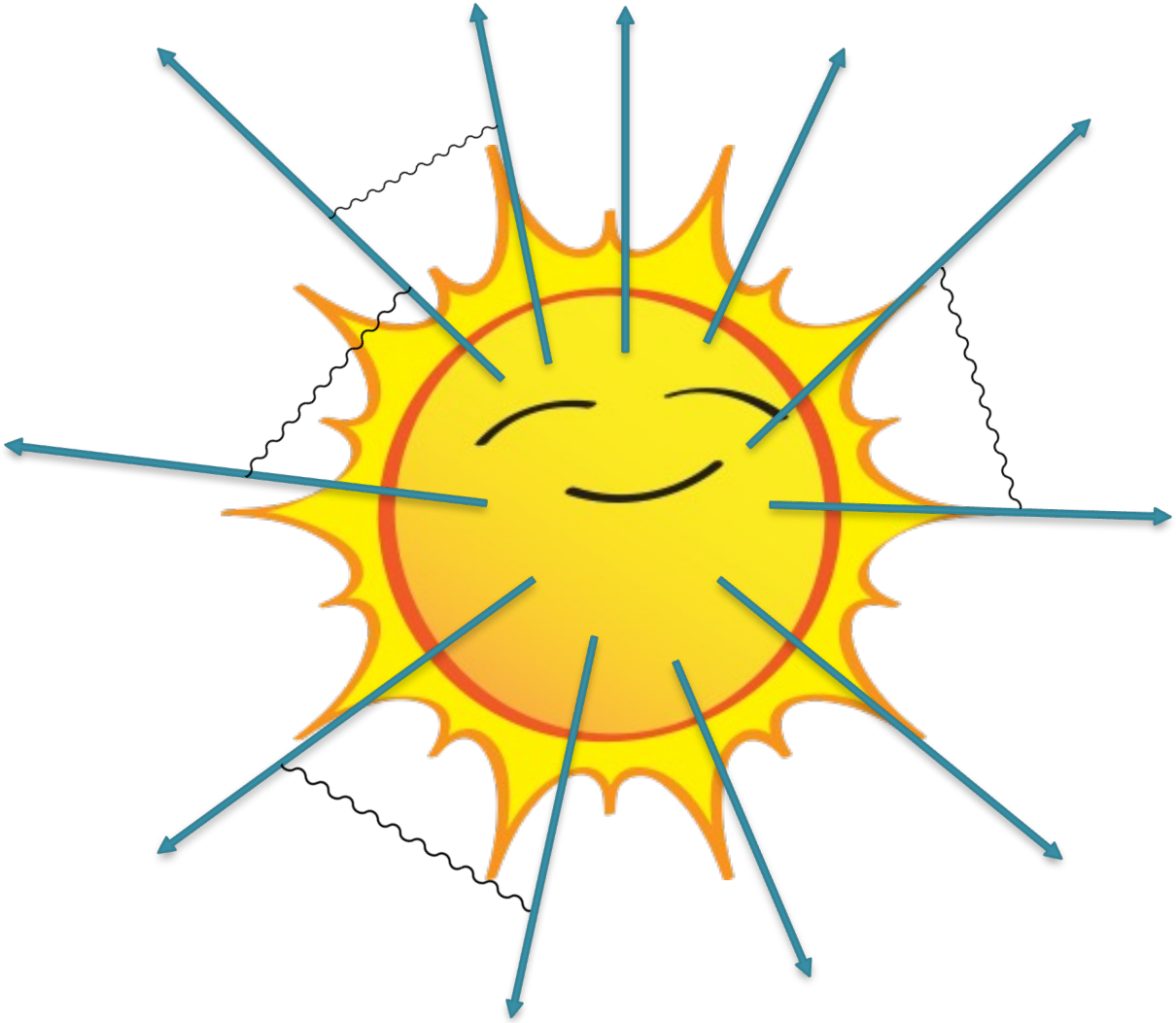
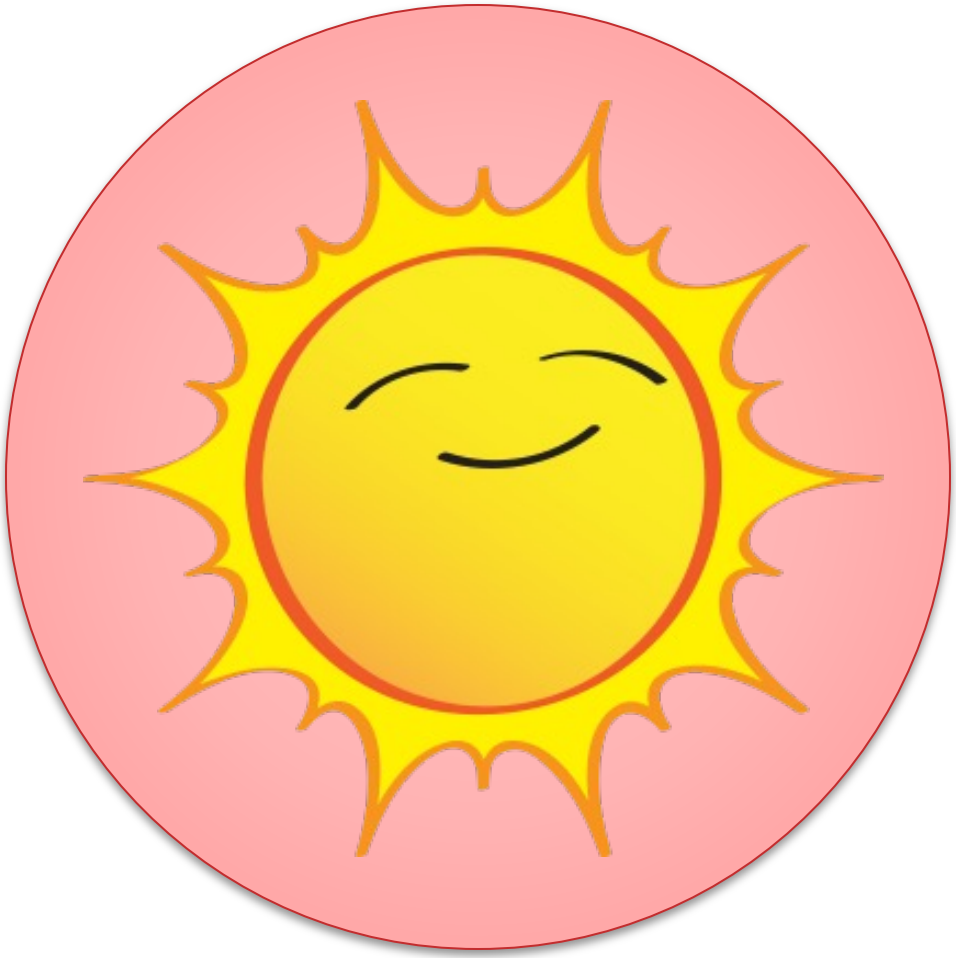


Image from https://cajohare.github.io/AxionLimits/docs/ap.html

If dark particles have self-interactions



If dark particles have self-interactions



Dark Solar Wind: JHC, Kaplan, Rajendran, Ramani, and Tanin

SUMMARY

- Astrophysical objects have great potentials to probe dark sectors

- For this, we need a comprehensive understanding of *both* astrophysics and particle physics

THANK YOU