Gamma-ray observation of SN axion conversion in stellar magnetic field

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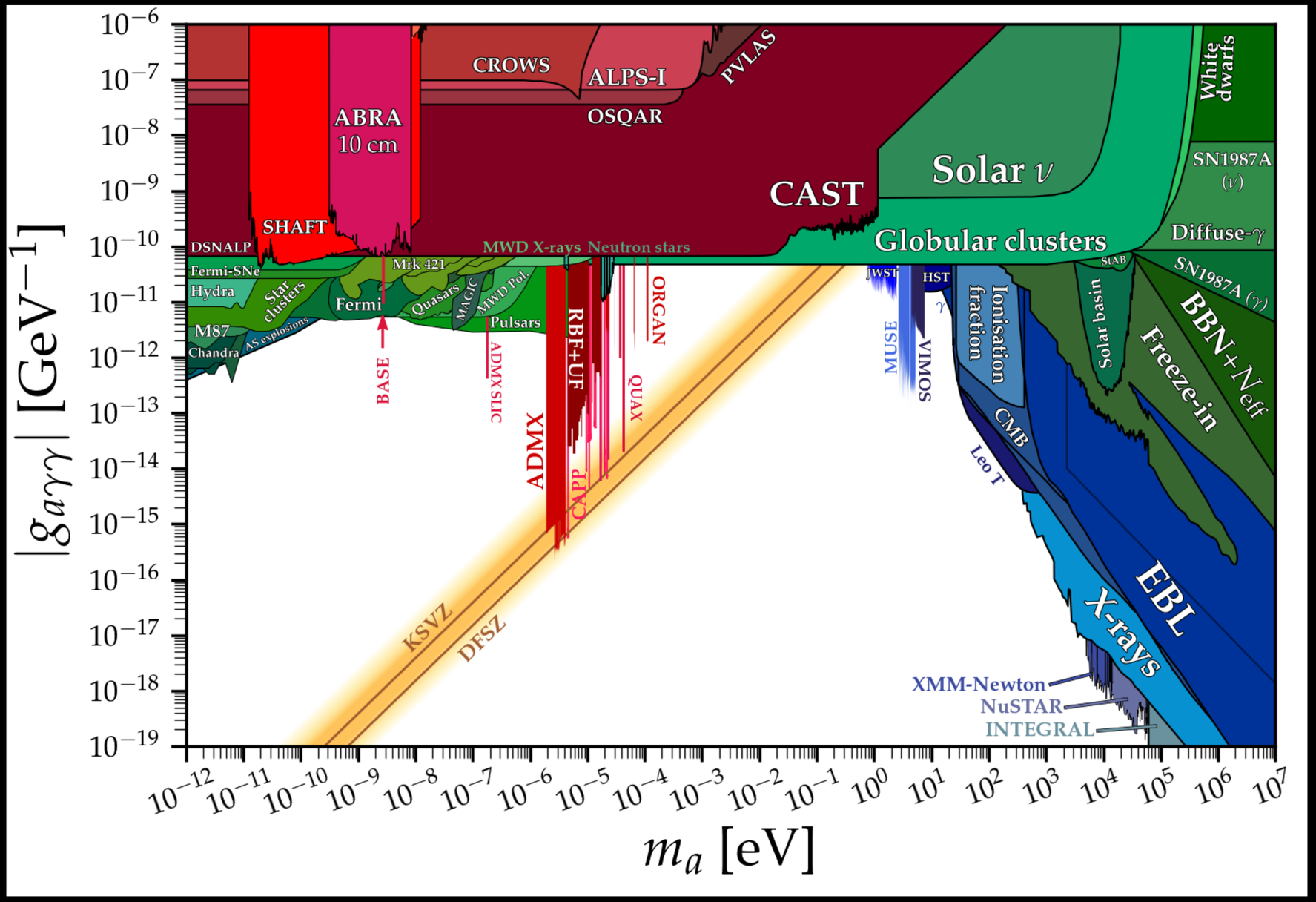
Berkeley Week, 2024

Axions

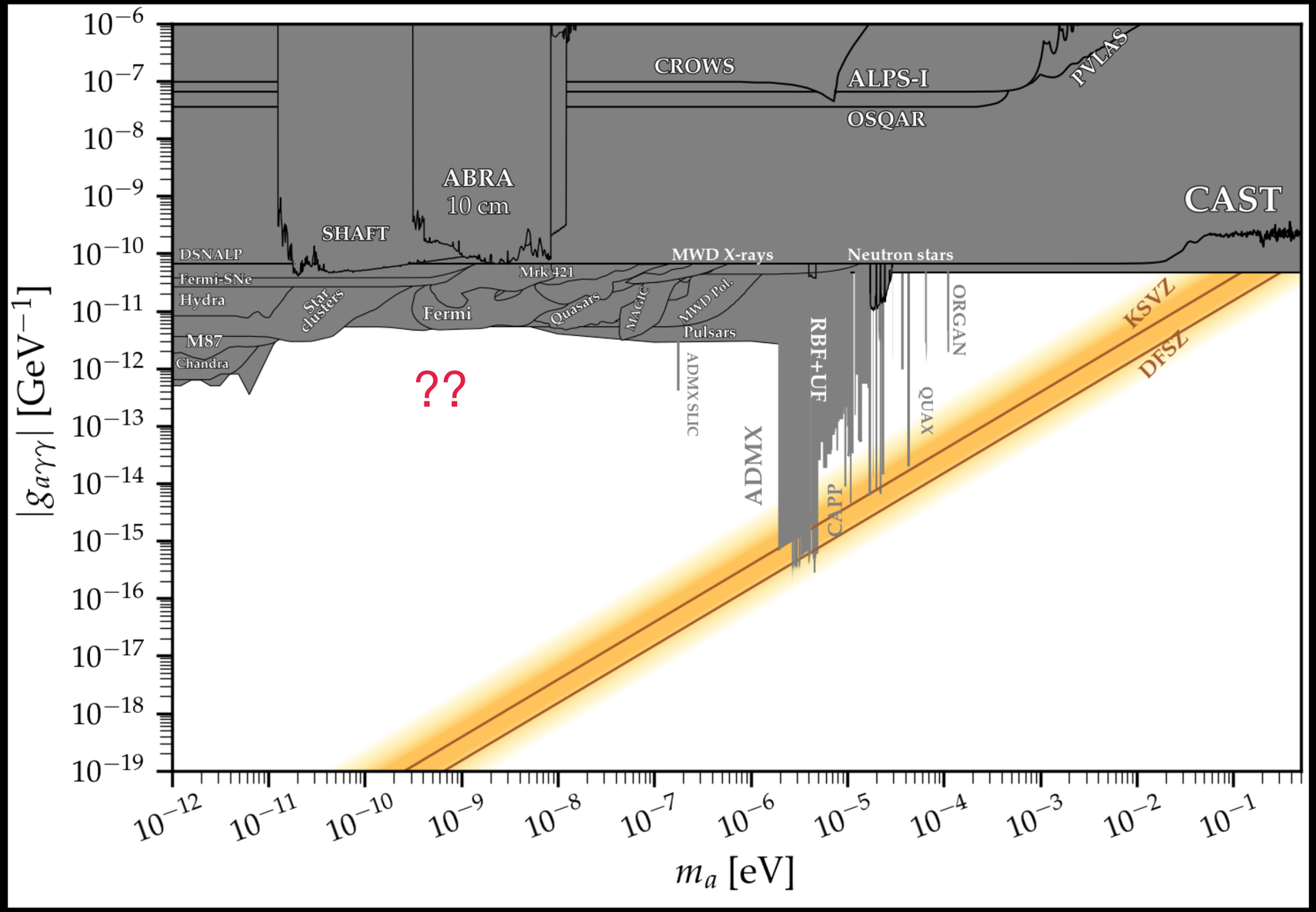
- Light pseudoscalar boson with a two-photon coupling
- Addresses the strong CP problem
- Dark matter candidate
- Additional theoretical motivation in quantum gravity and string theory

$$\mathcal{L} \supset \frac{1}{4} g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu} = g_{a\gamma\gamma} a \, \mathbf{E} \cdot \mathbf{B}$$

Axions


CROWS
ALPS-I
PVLAS
OSQAR
ABRA
10 cm
SHAFT
CAST
Solar ν
White dwarfs
SN1987A (ν)
Diffuse-γ
Globular clusters
DSNALP
MWD X-rays
Neutron stars
Fermi-SNe
Hydra
Star clusters
Mrk 421
Fermi
Quasars
MAGIC
MWD Pol.
Pulsars
M87
Chandra
AS explosions
BASE
ADMX SLIC
ADMX
RBF+UF
CAPP
ORGAN
QUAX
JWST
HST
MUSE
VIMOS
Ionisation fraction
Solar basin
StAB
SN1987A (γ)
BBN+$N_{\rm eff}$
Freeze-in
CMB
Leo T
EBL
X-rays
XMM-Newton
NuSTAR
INTEGRAL
KSVZ
DFSZ
$|g_{a\gamma\gamma}|$ [GeV^{-1}]
m_a [eV]

Axions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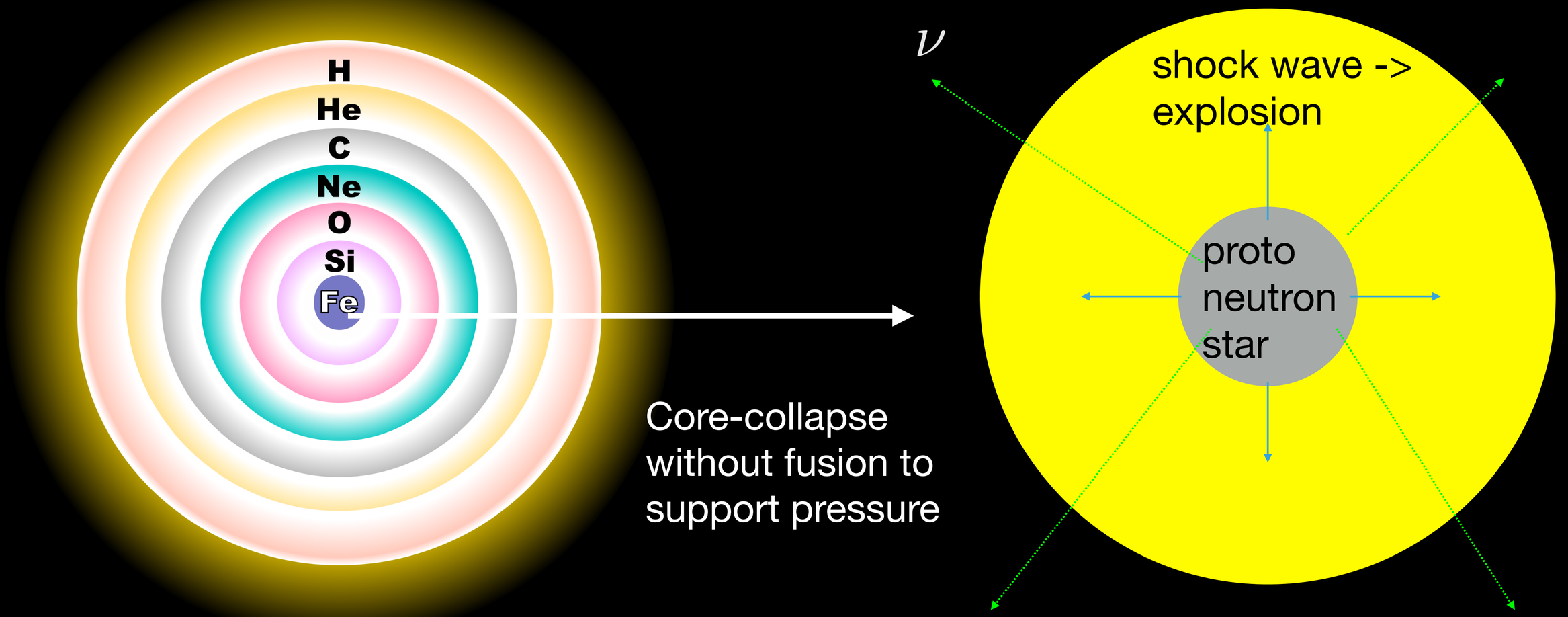
ORGAN
KSVZ
DFSZ
??
$|g_{a\gamma\gamma}|$ [GeV^{-1}]
m_a [eV]

Axion-induced Gamma-Ray

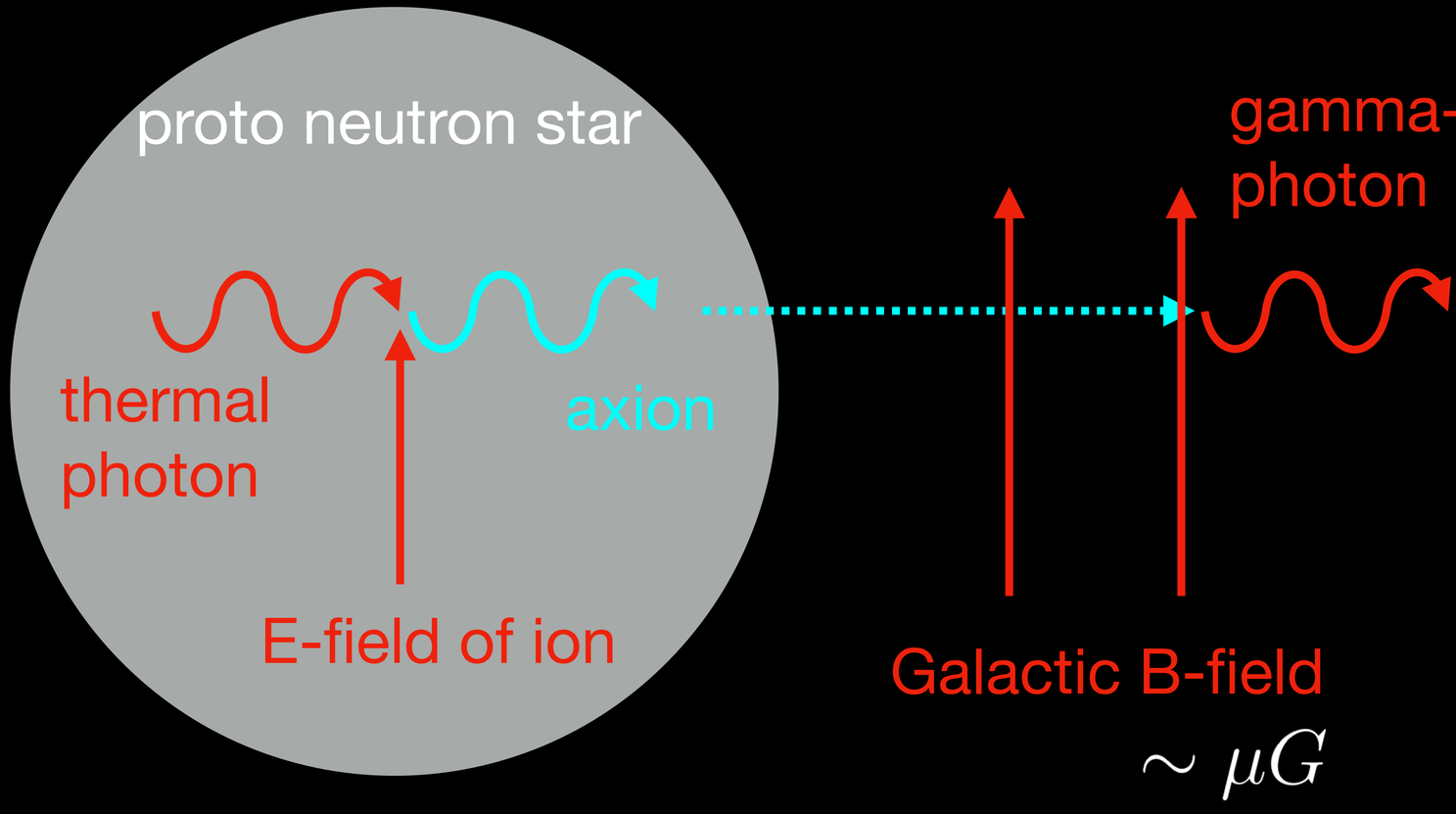
Type II supernova



Axion-induced Gamma-Ray

With SN1987A

- distance : 50kpc



Solar Maximum Mission (Wikipedia)

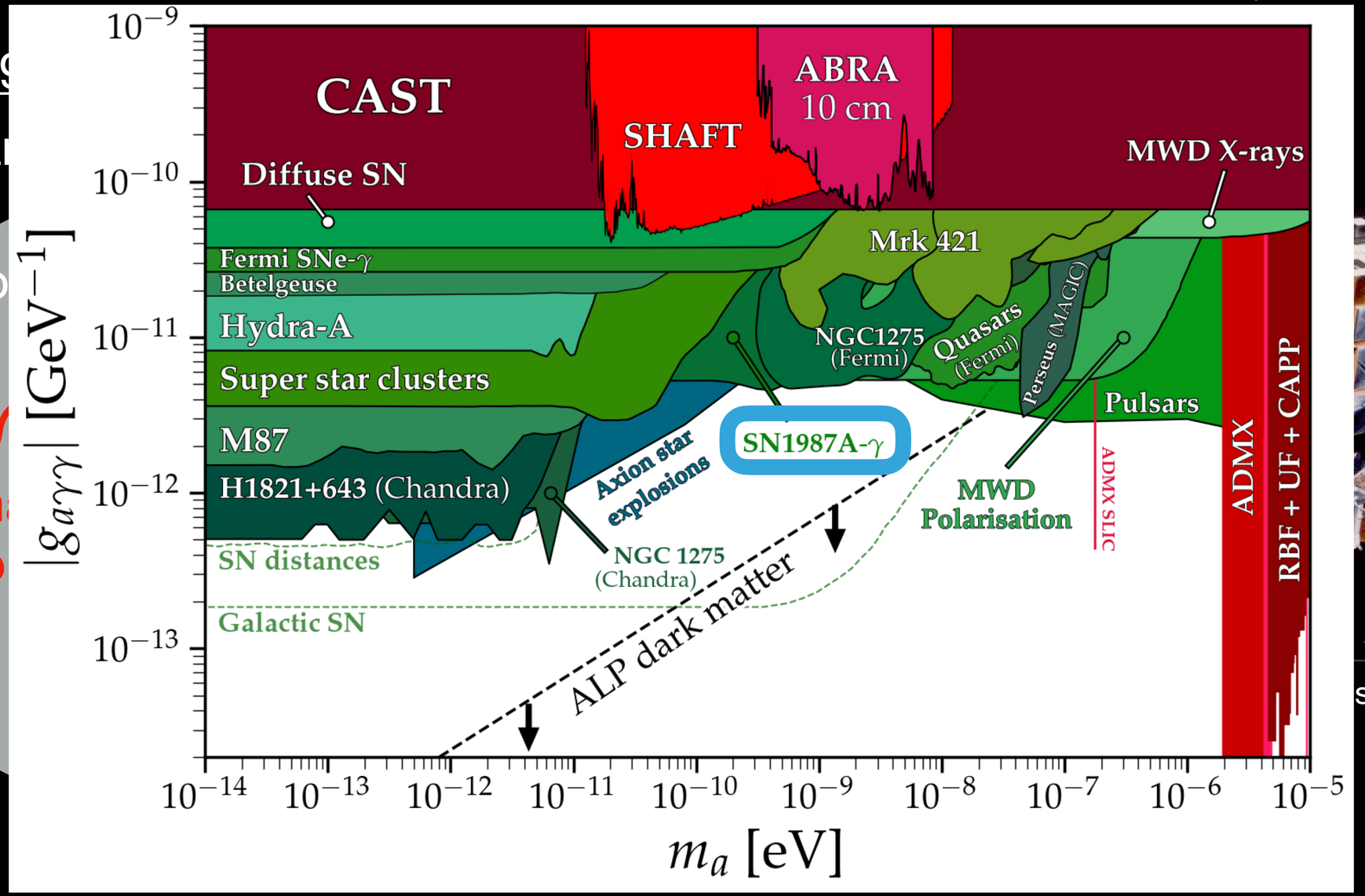
Axion-induced Gamma-Ray

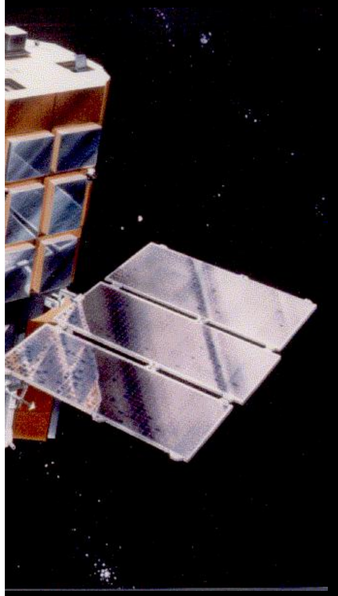
With SN19

- distar

pro

therma
photo



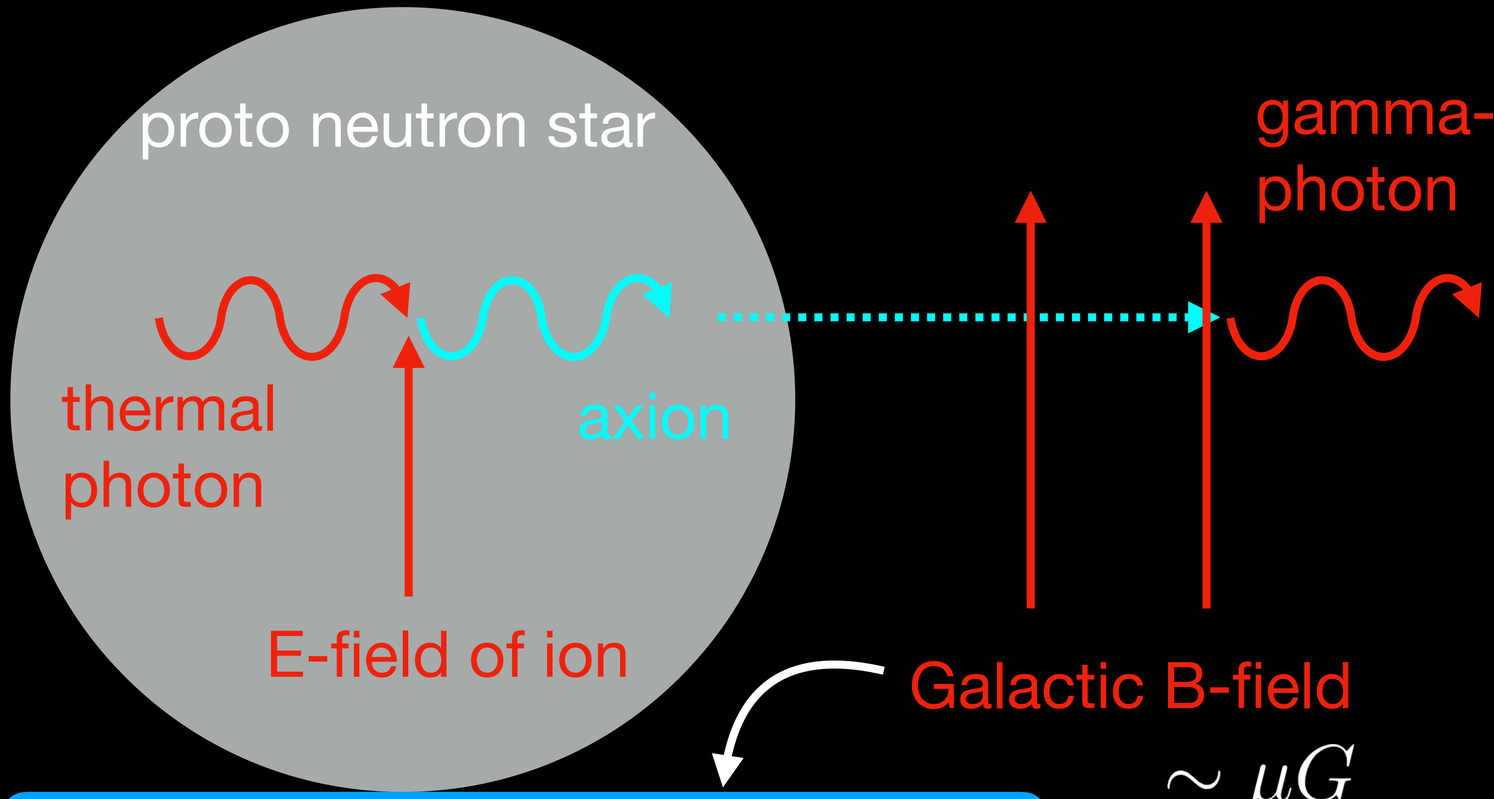


sion (Wikipedia)

Axion-induced Gamma-Ray

With SN1987A

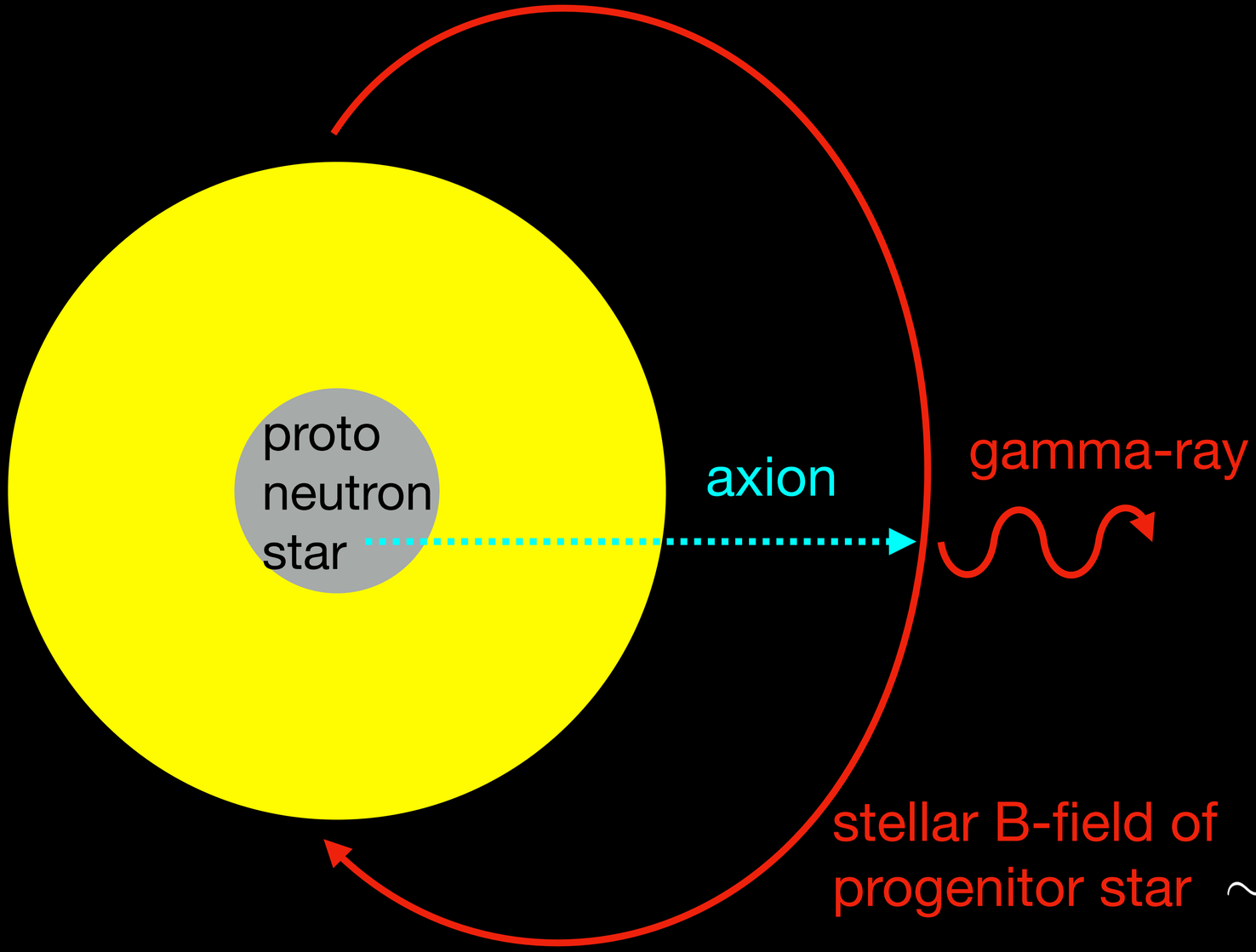
- distance : 50kpc



use stellar magnetic field instead?

Solar Maximum Mission (Wikipedia)

Axion-induced Gamma-Ray



Solar Maximum Mission (Wikipedia)

Axion-induced Gamma-Ray

conversion probability for SN1987A

$$P_{a\gamma} \sim g_{a\gamma\gamma}^2 B^2 L^2 \sim g_{a\gamma\gamma}^2 (1\mathrm{kG})^2 (45 R_\odot)^2$$

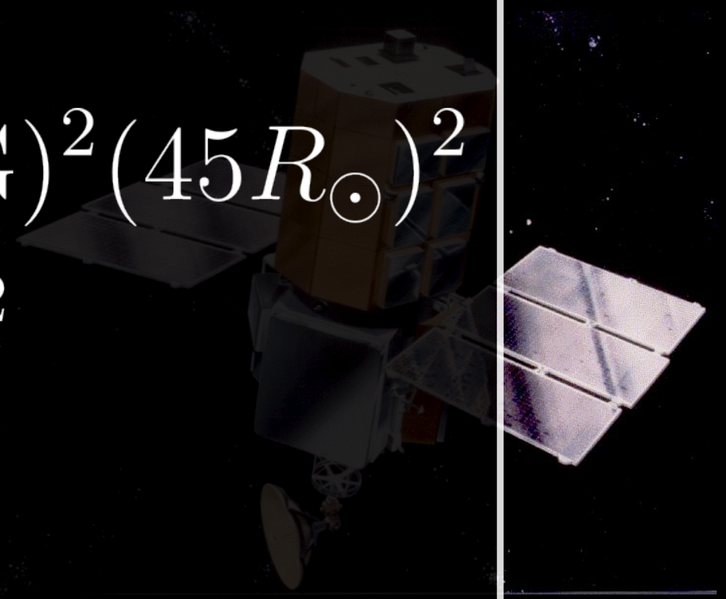
$$\sim 10^{-5} \left(\frac{g_{a\gamma\gamma}}{10^{-12}\mathrm{GeV}^{-1}} \right)^2$$

proto neutron star

axion

gamma-ray

stellar B-field of progenitor star $\sim kG$

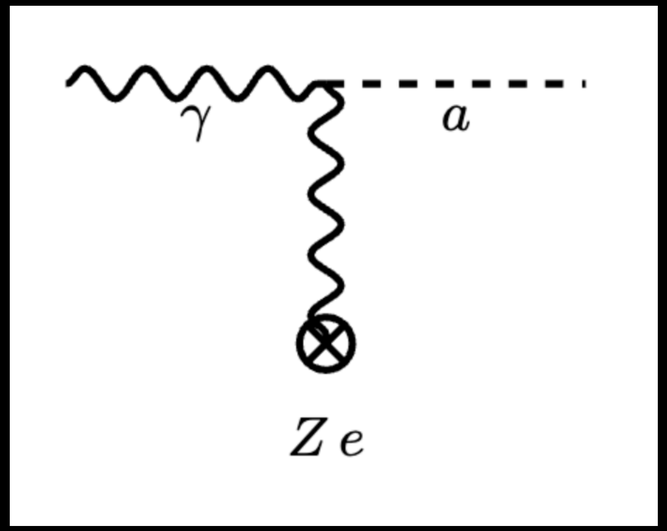


Fermi Gamma-ray Space Telescope Mission (Wikipedia)

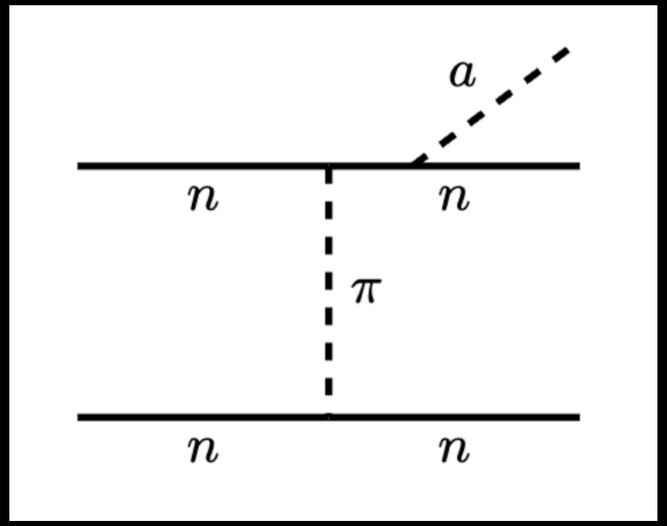
→ comparable to galactic conversion probability

Axion Production

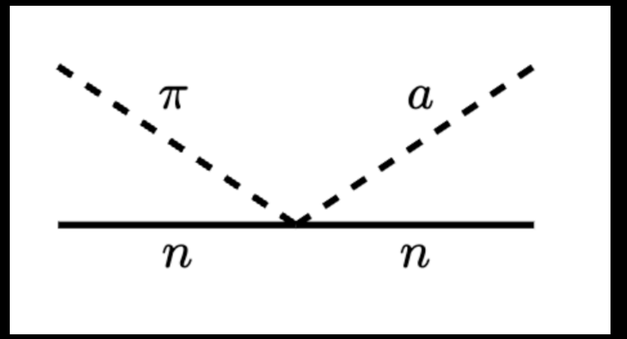
Primakoff

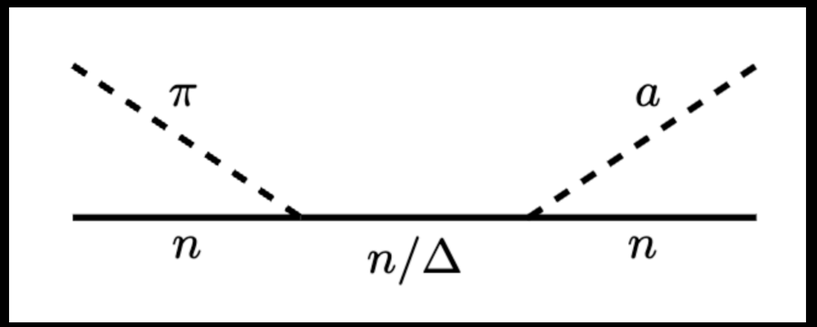


Nucleon Bremsstrahlung

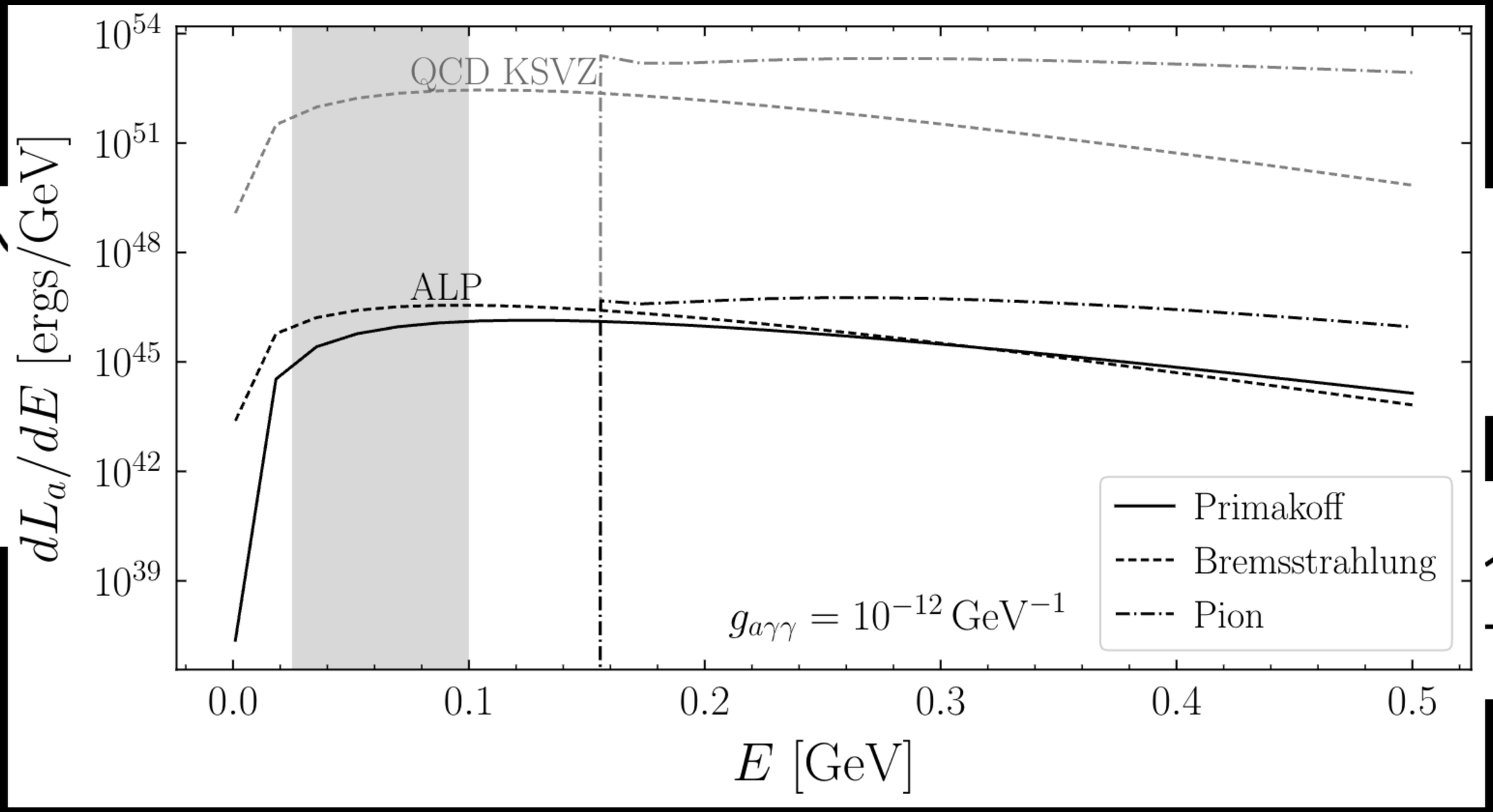


Pion conversion





Axion Production



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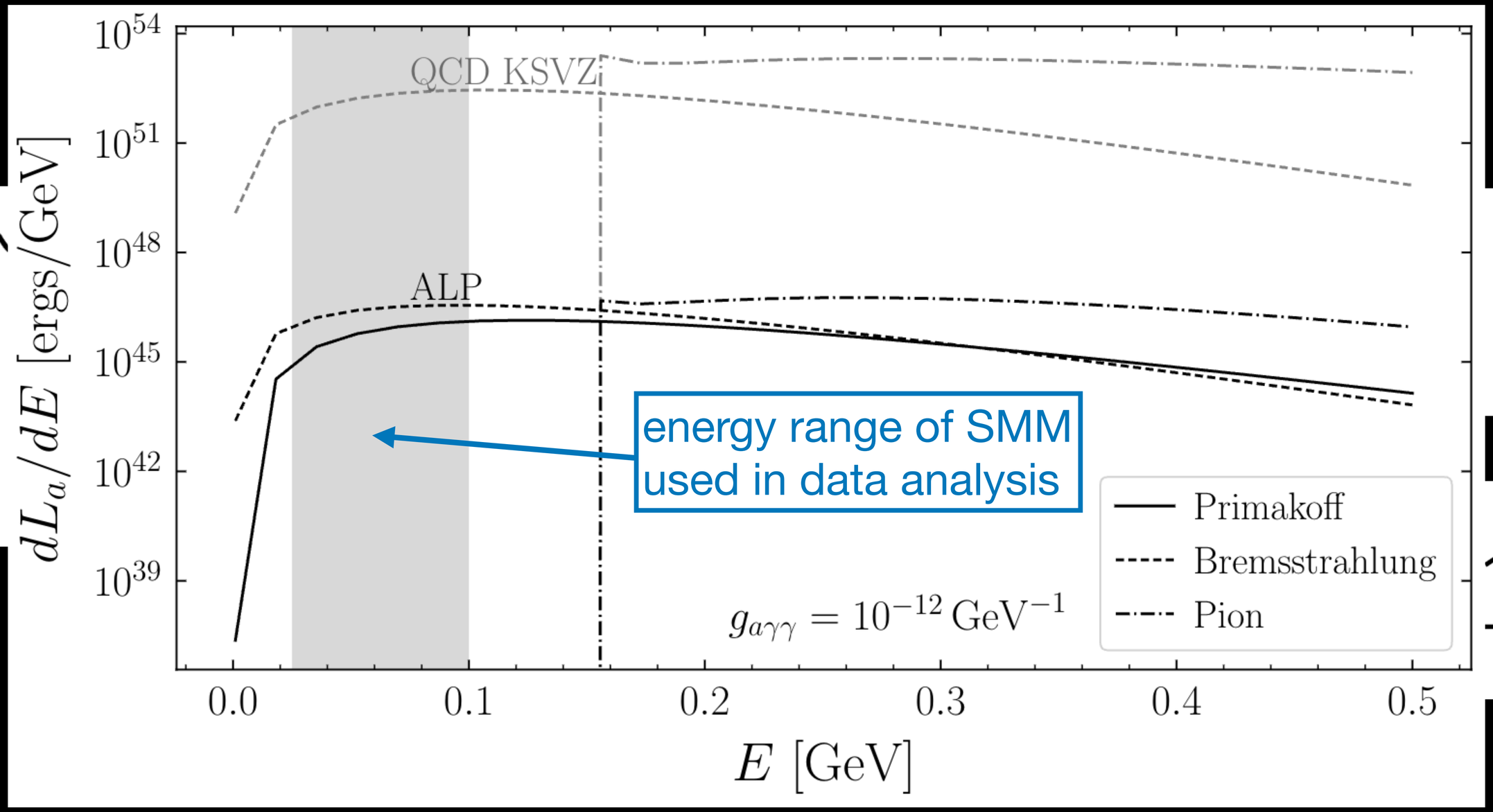
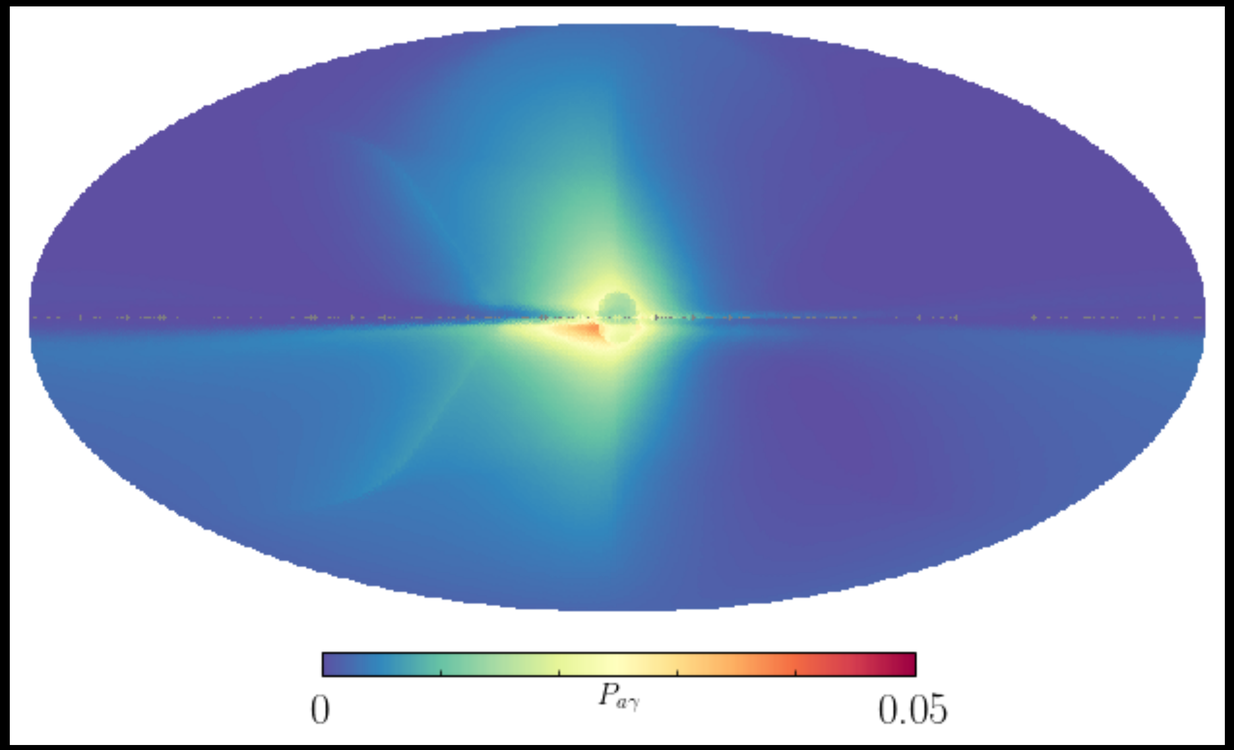
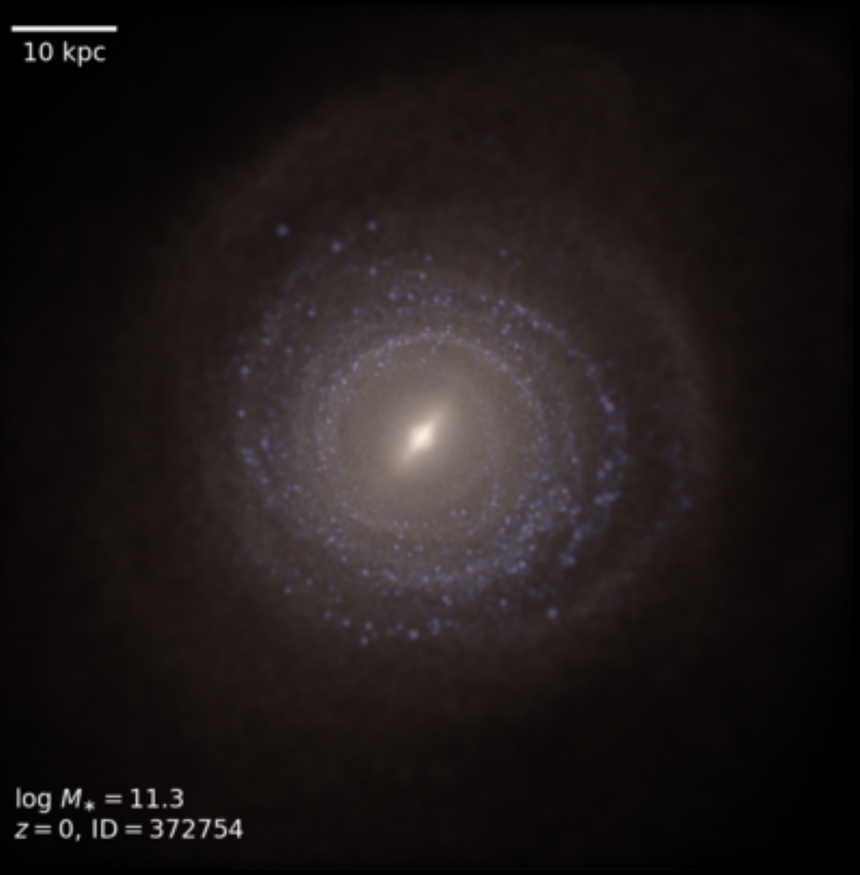


Galactic Magnetic Field

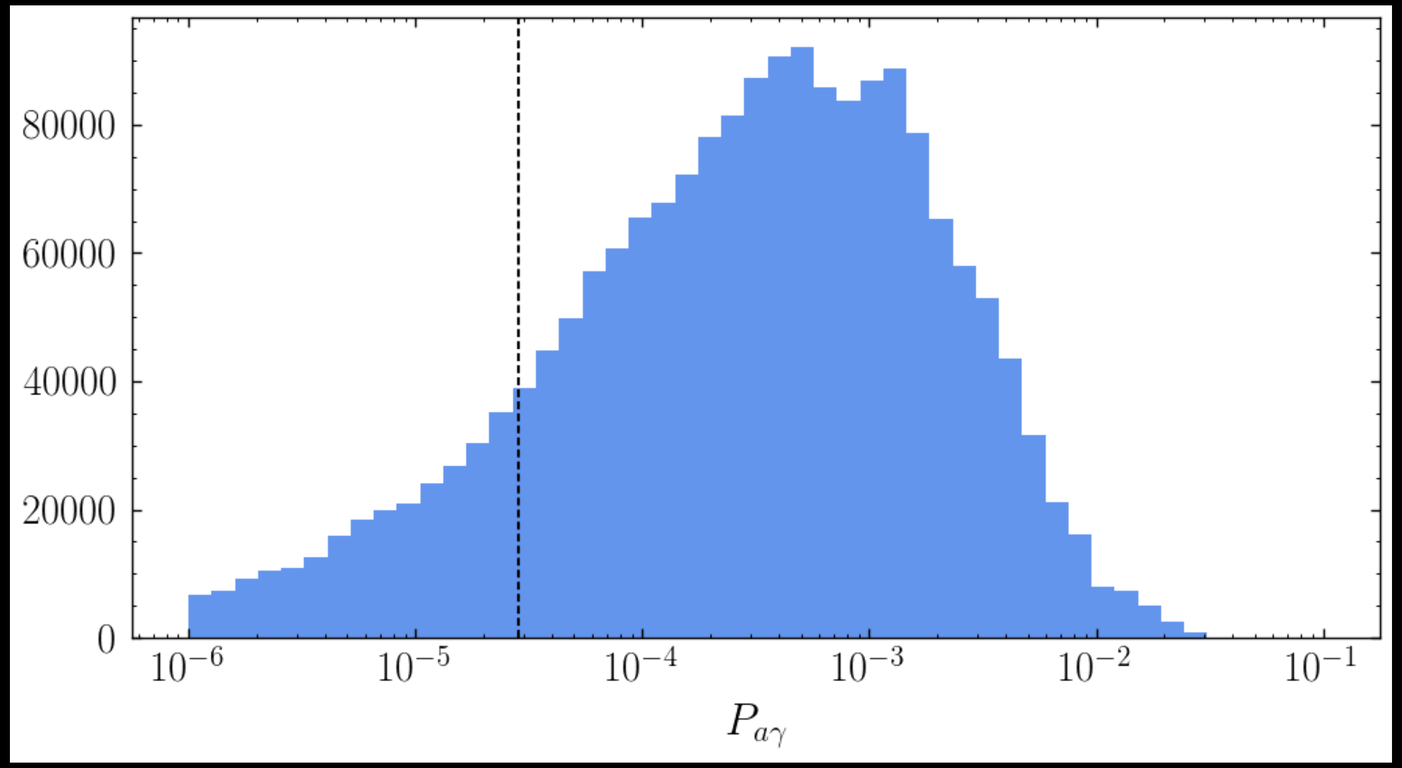
Jansson-Farrar model



IllustrisTNG



Galactic Magnetic Field



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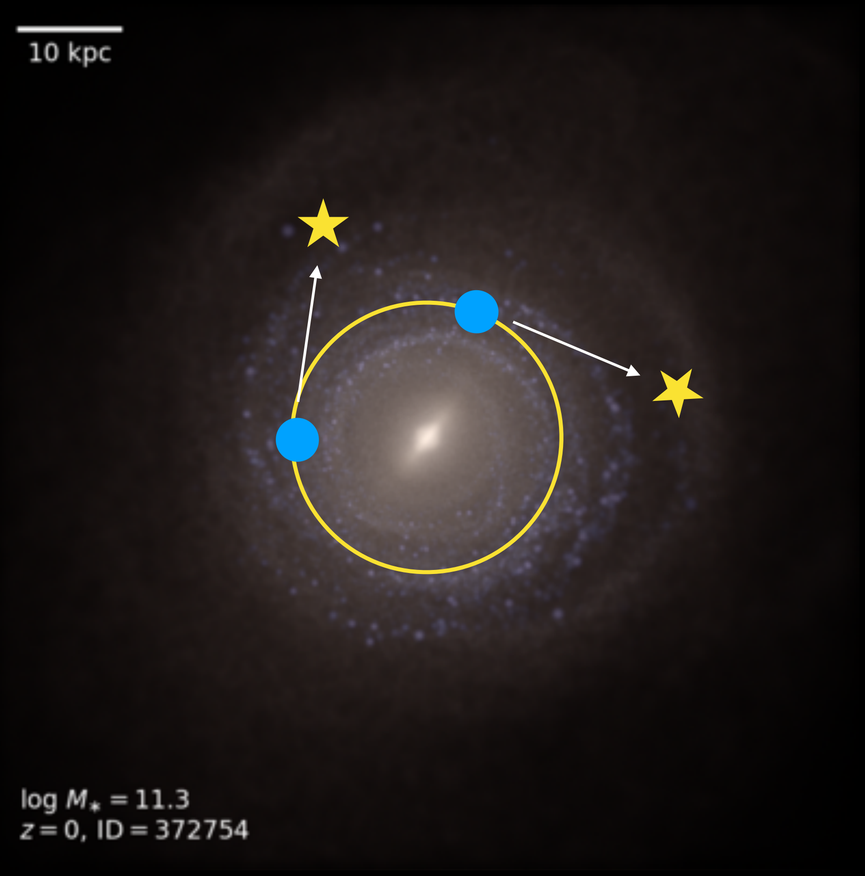
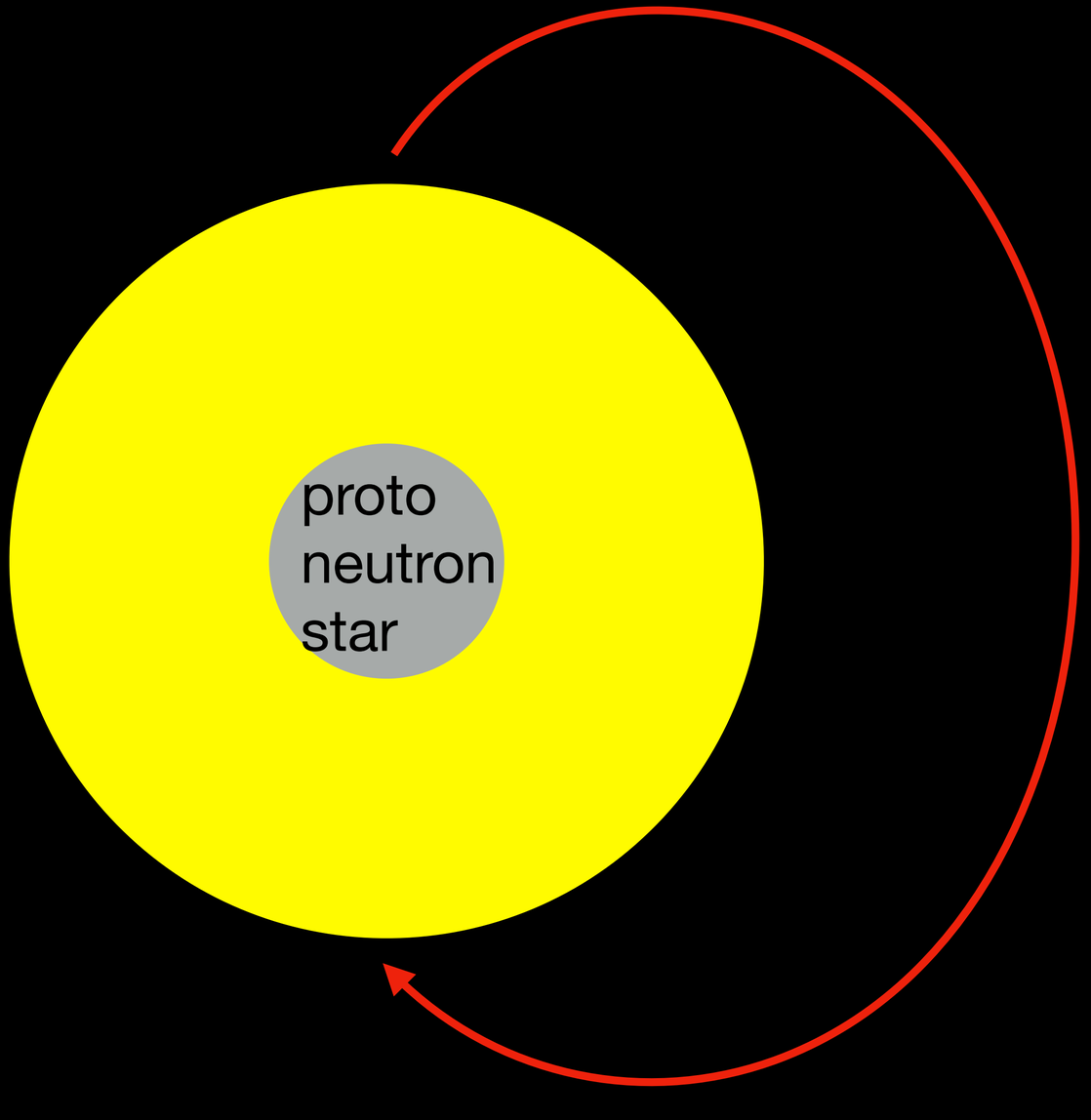
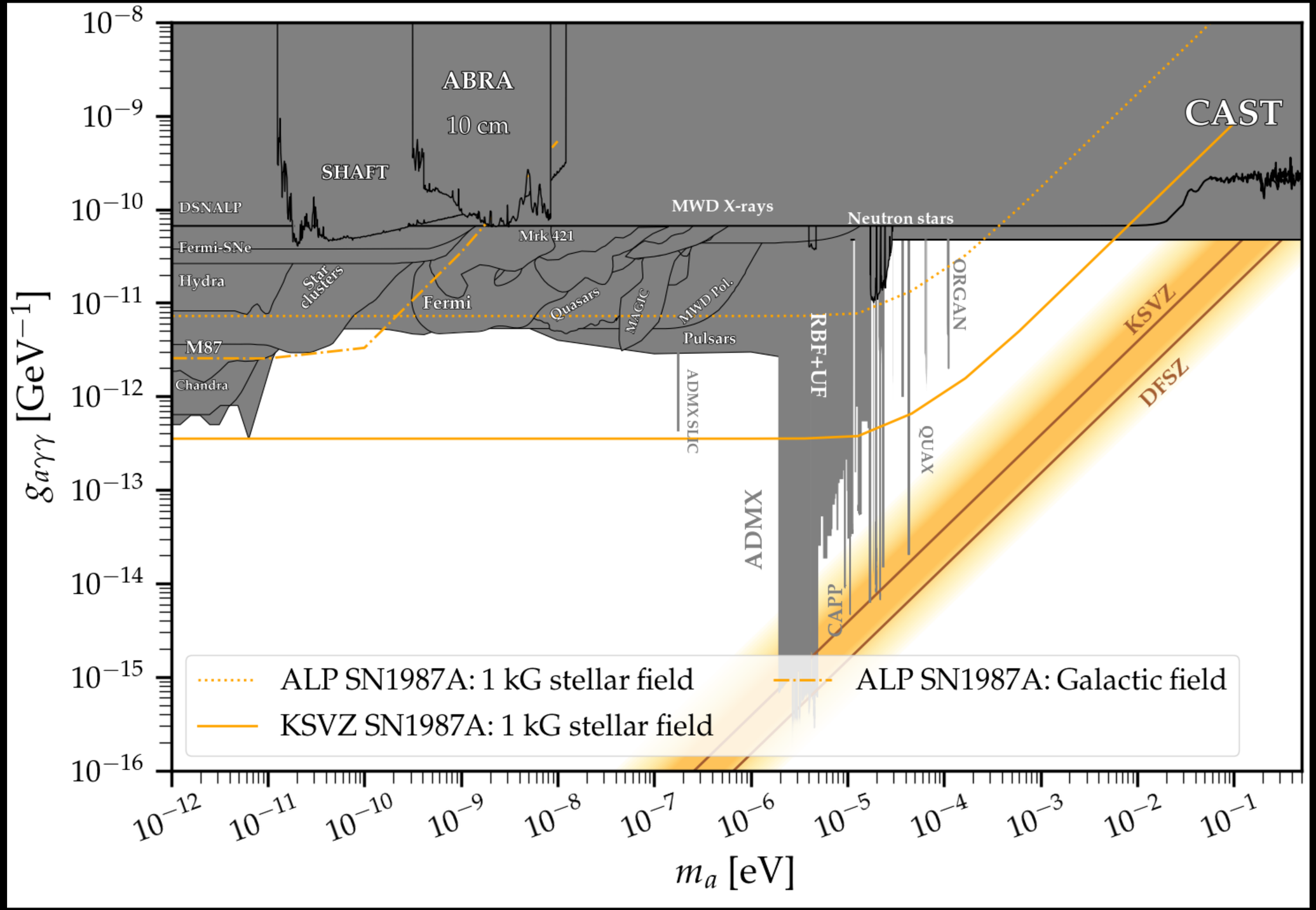


Stellar Magnetic Field



- Model as dipole magnetic field
- Field strength at stellar mid-plane fixed to 1kG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KSVZ SN1987A: 1 kG stellar field
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m_a [eV]
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
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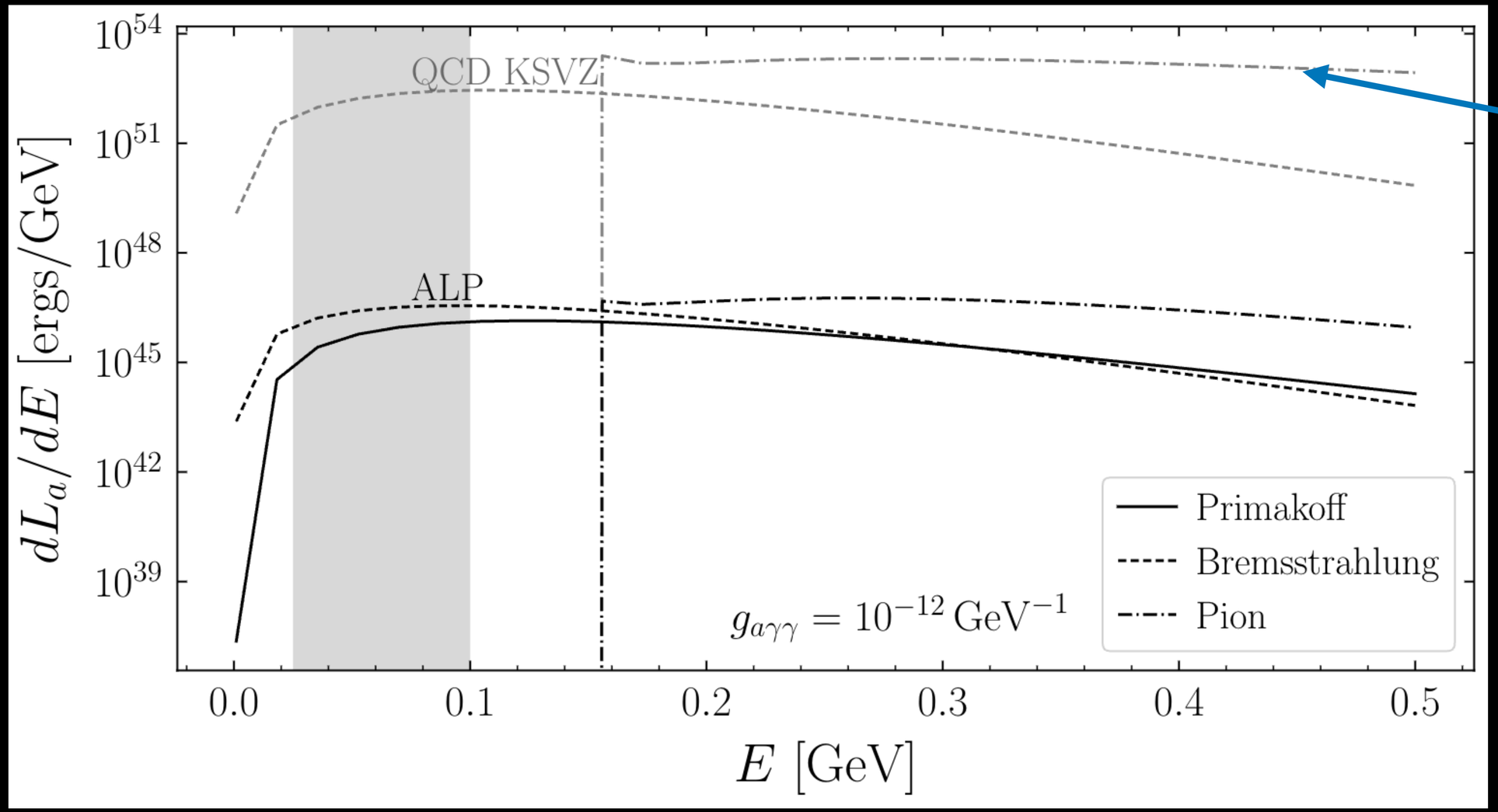
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}

Future Supernova

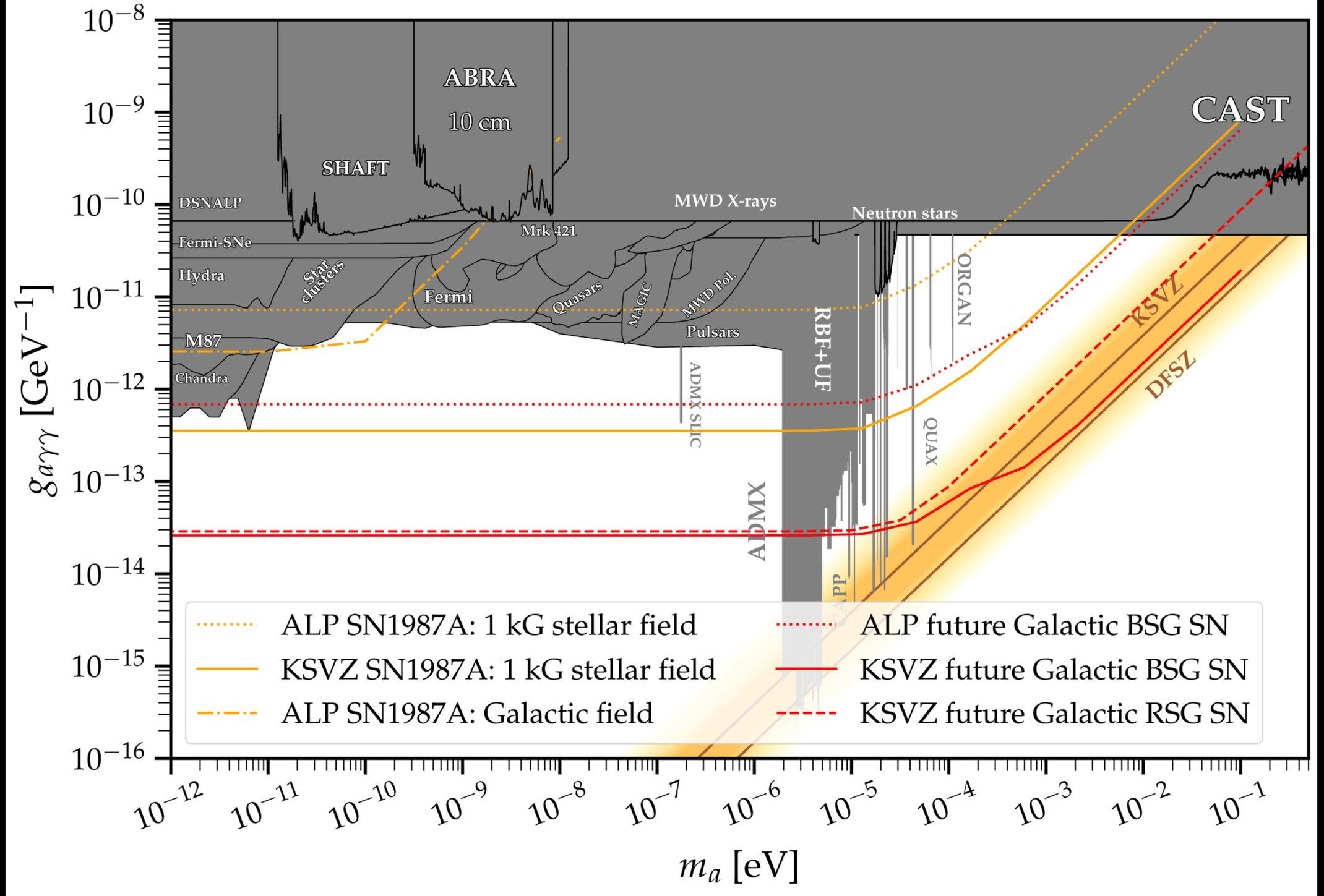
- Galactic supernova rate : 1 in every ~100 yrs
  → could occur very soon!

- Would we observe this?
  → unlikely due to Fermi-LAT observing portion of the sky at a time

Future Supernova



Pion conversion is above ~100MeV which increases the observable signal for future observation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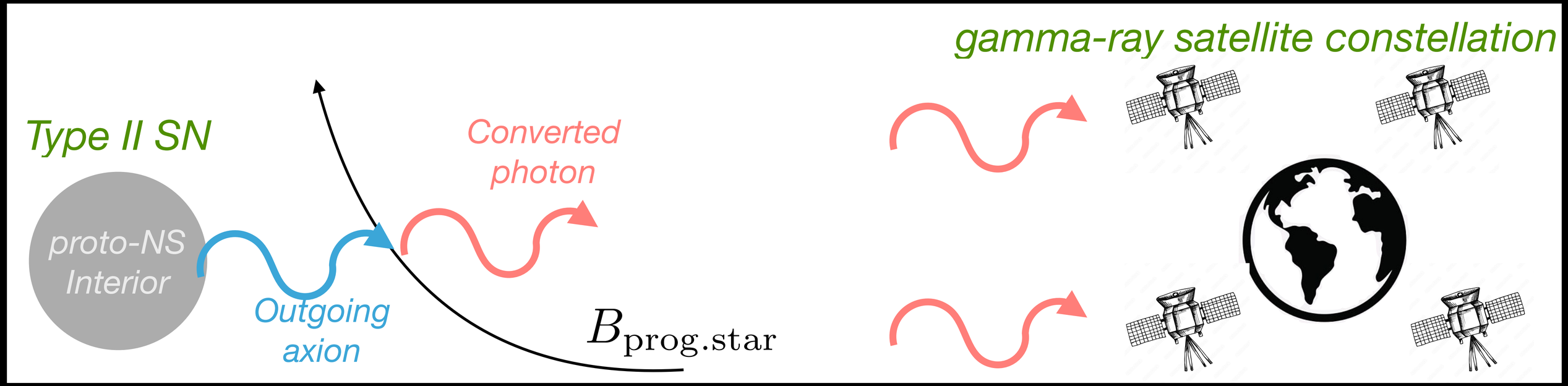
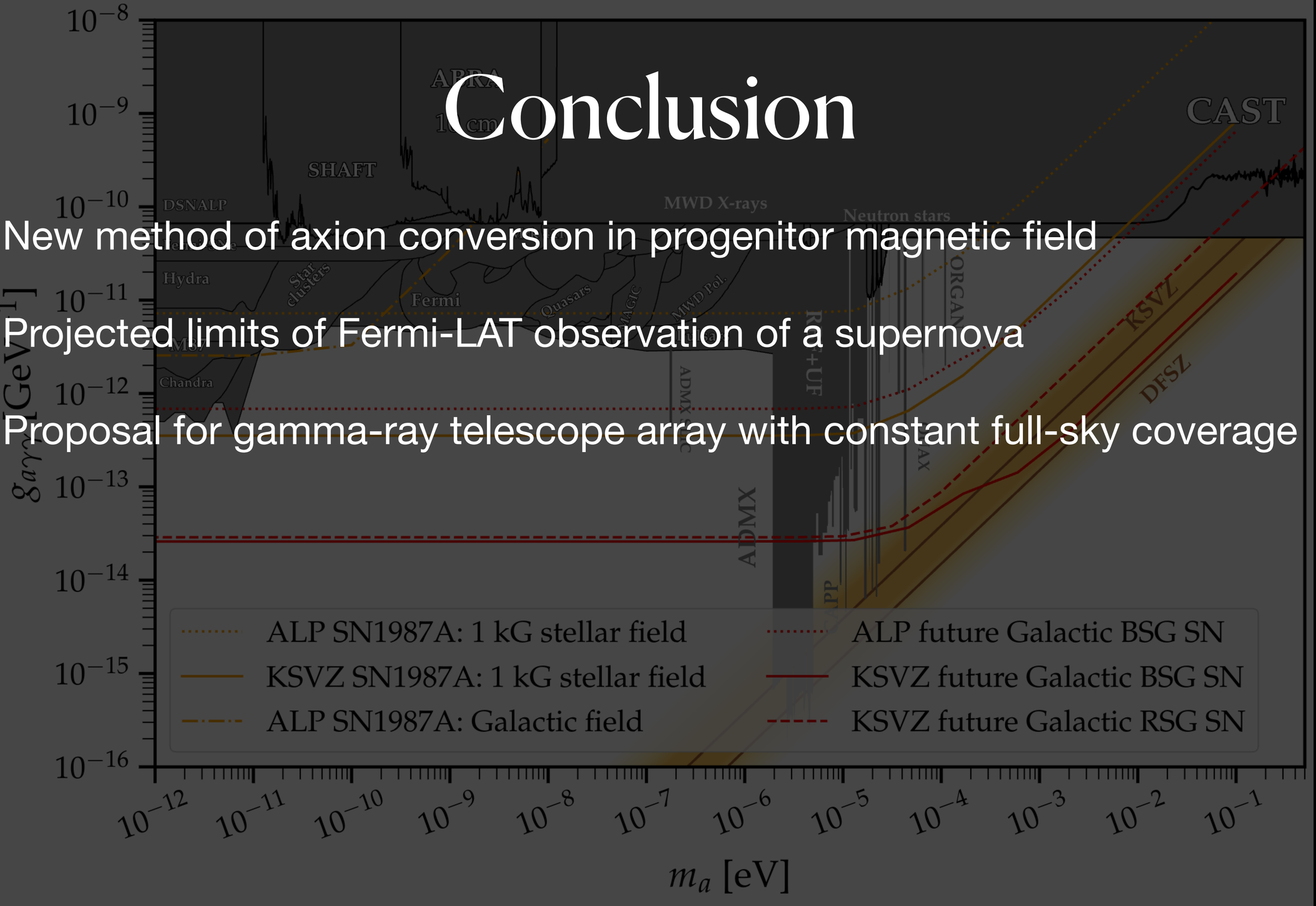
APP
ALP SN1987A: 1 kG stellar field
KSVZ SN1987A: 1 kG stellar field
ALP SN1987A: Galactic field
ALP future Galactic BSG SN
KSVZ future Galactic BSG SN
KSVZ future Galactic RSG SN
$g_{a\gamma\gamma}$ [GeV^{-1}]
m_a [eV]

Proposal

Full-Sky constellation of SmallSats for continuous,
full-sky ~100-500 MeV gamma-ray detection



Conclusion

- New method of axion conversion in progenitor magnetic field
- Projected limits of Fermi-LAT observation of a supernova
- Proposal for gamma-ray telescope array with constant full-sky coverage