20^{th} May 2021

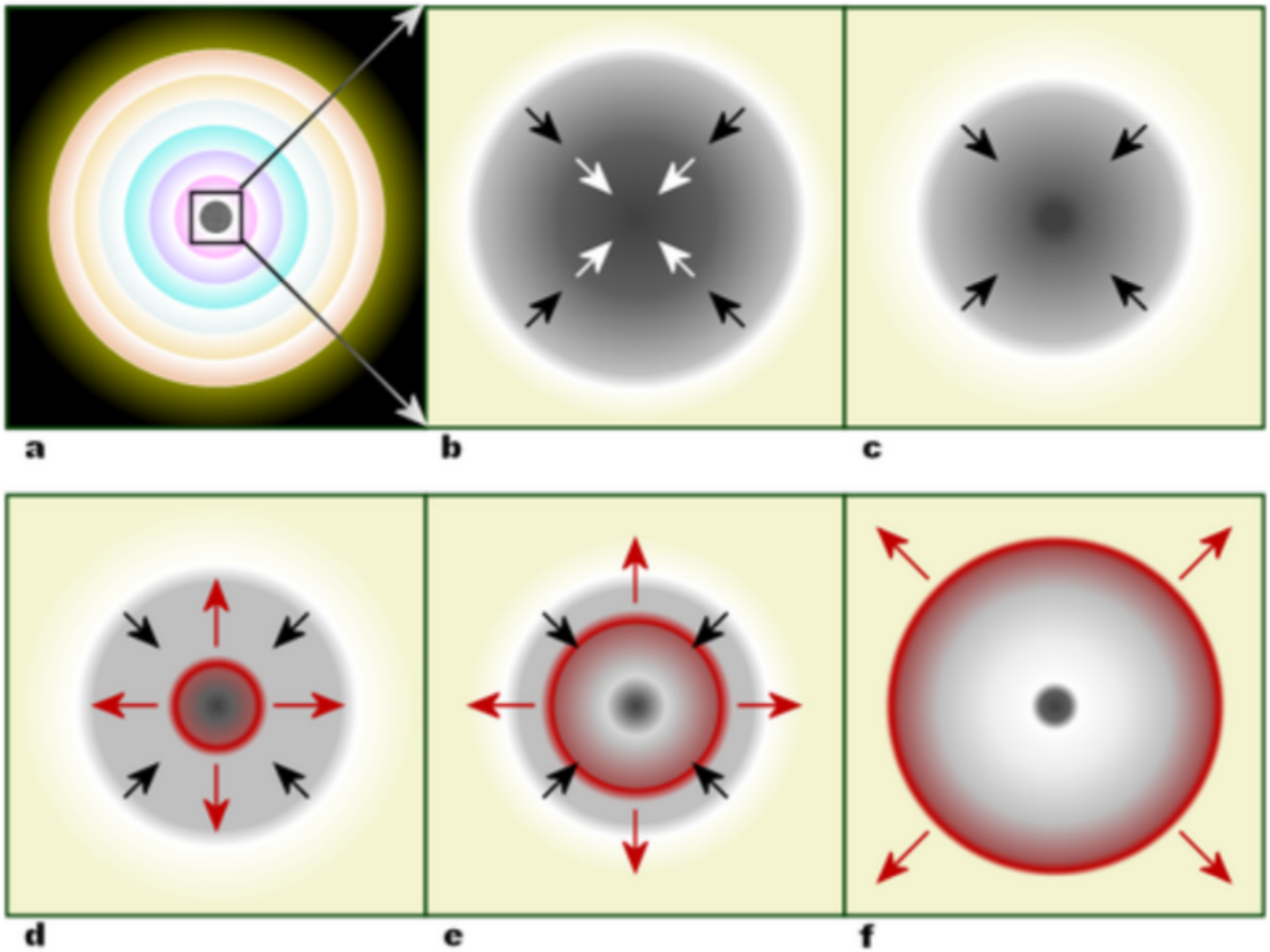
Supernova bounds on axion-like particles coupled with nucleons and electrons

Based on
F. Calore, PC, M. Giannotti, J. Jaeckel, G. Lucente and A. Mirizzi,
in preparation

Pierluca Carenza
Bari Univ. & INFN
pierluca.carenza@ba.infn.it

Core-Collapse Supernovae

For massive stars ($M > 8M_{\odot}$) the nuclear fusion produces heavy elements in an onion structure and a degenerate iron core

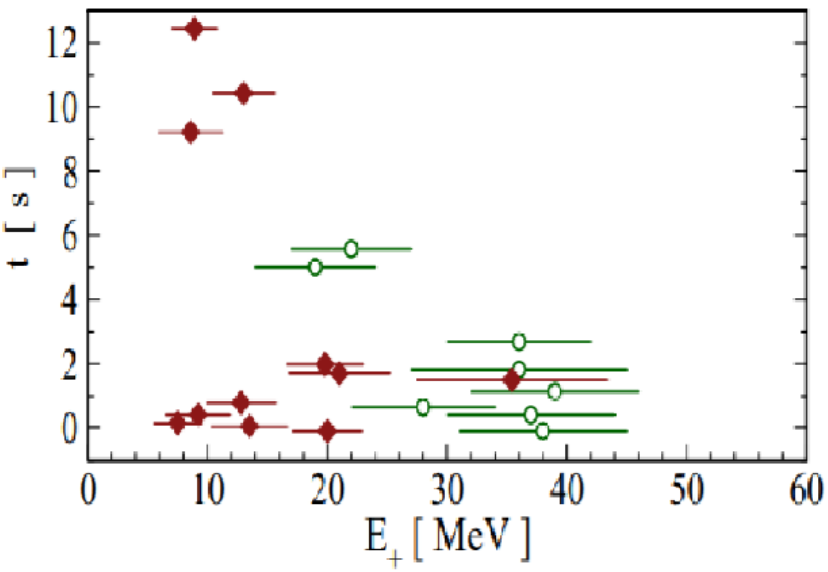


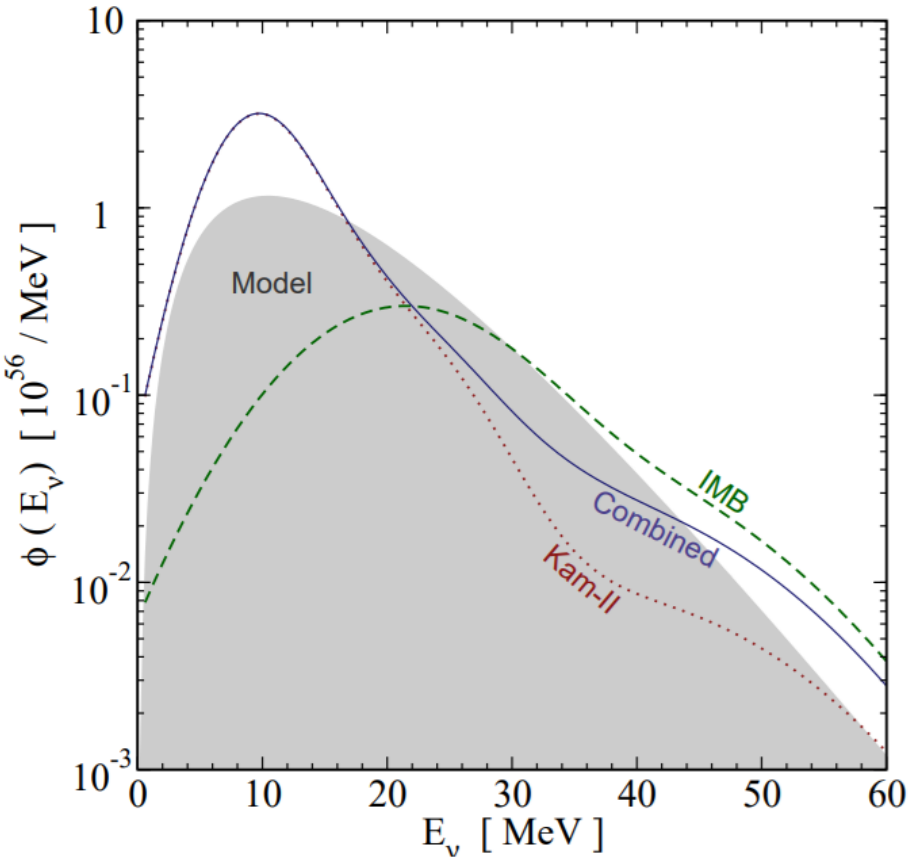
Iron in the core cannot be burnt and the star starts to collapse

SN1987A: neutrino signal

H. Yuksel and J. F. Beacom, Phys. Rev. D **76** (2007), 083007

$\sim 10^{53}$ erg emitted as neutrinos with energy $\sim O(15\,\mathrm{MeV})$ in $\sim 10\,\mathrm{s}$





Axions and ALPs

R. D. Peccei *et al.*, Phys. Rev. Lett. **38** (1977)
S. Weinberg - F. Wilczek, Phys. Rev. Lett. **40** (1978) 223 - 279

The ALP-fermion interaction is a general feature of many ALP models

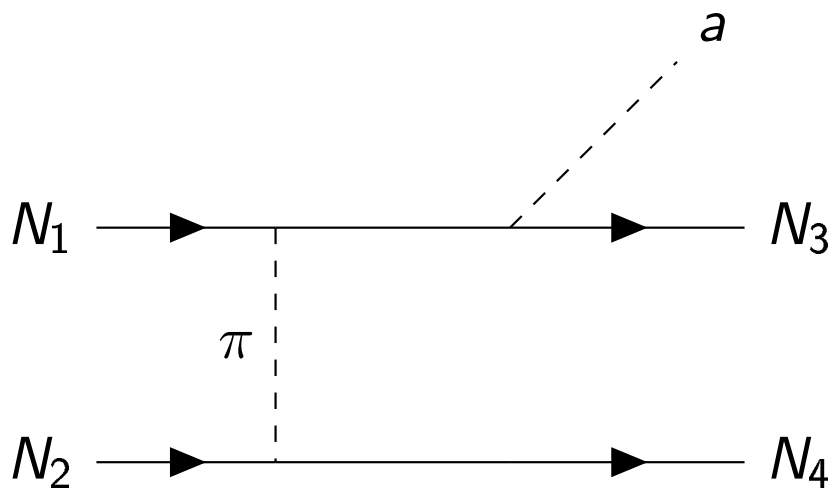
$$\mathcal{L}_{\rm ax} = \frac{1}{2}\partial_\mu a \partial^\mu a - \xi \frac{a}{f_a}\frac{g^2}{32\pi^2}\tilde{G}^a_{\mu\nu}G^{\mu\nu a} + \\ + \boxed{\frac{g_a}{2m}\bar{\Psi}\gamma^\mu\gamma^5\Psi\partial_\mu a} - \frac{g_{a\gamma}}{4}a\tilde{F}^{\mu\nu}F_{\mu\nu}$$

We are interested in couplings with electrons and nucleons

Axion-nucleon bremsstrahlung in SNe

M. S. Turner, Phys. Rev. Lett. **60** (1988)

SN axions are produced by nucleon-axion bremsstrahlung

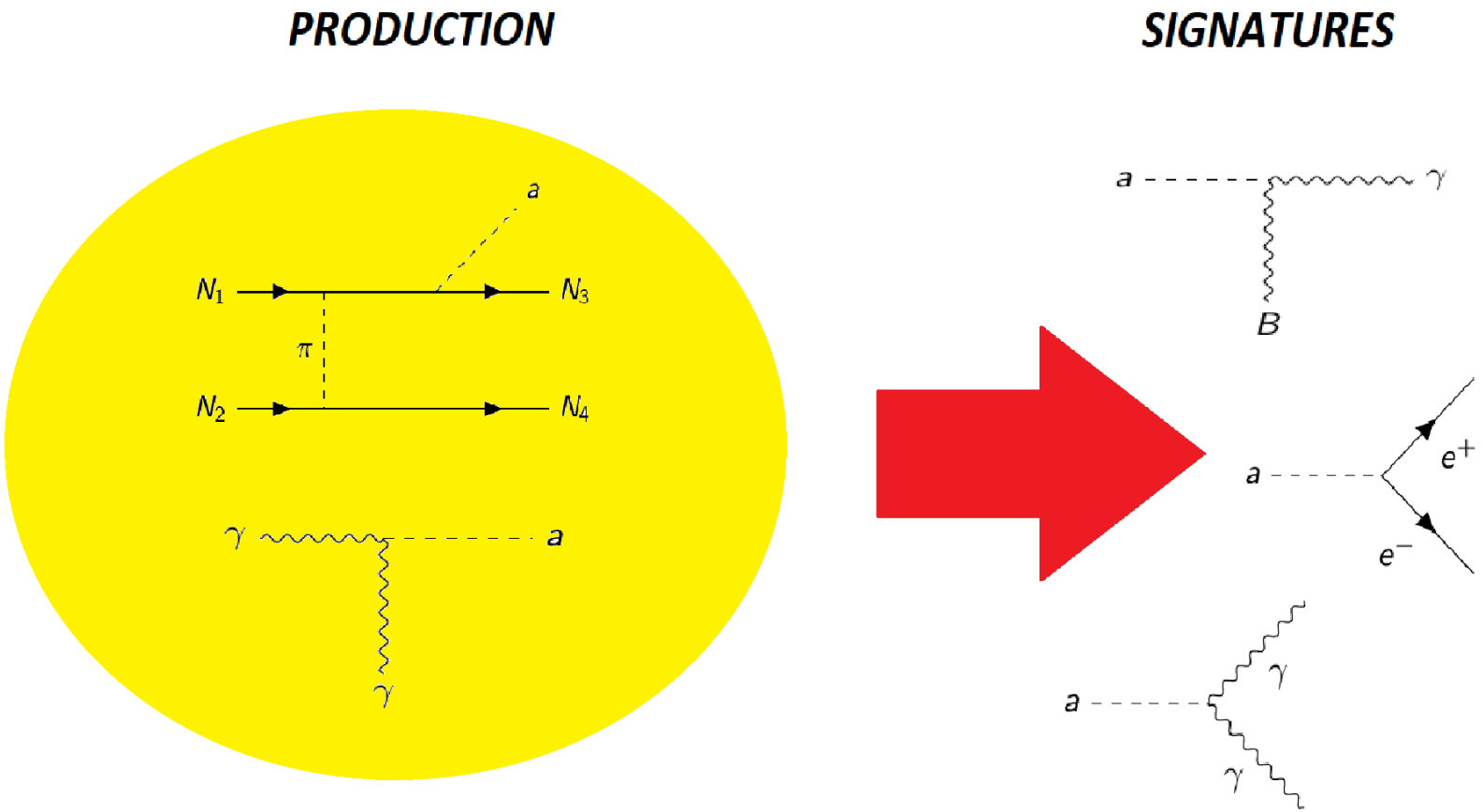


See PC *et al.* [arXiv:1906.11844 [hep-ph]] for an updated calculation

Higher energy processes are negligible, as $\pi^- p \to a n$
PC, B. Fore *et al.* Phys. Rev. Lett. **126** (2021) no.7, 071102

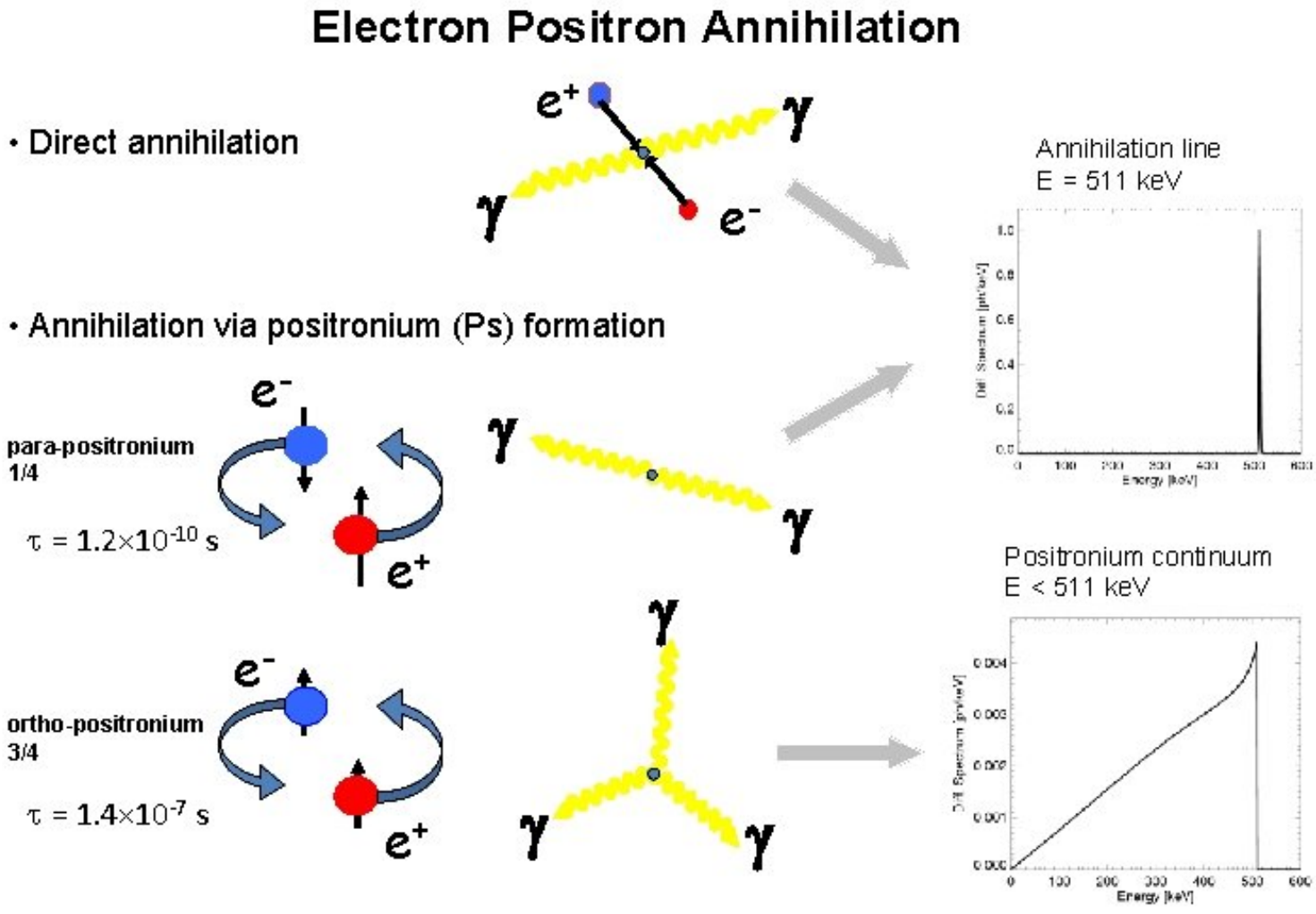
ALPs for diffuse fluxes

Many different possibilities with ALPs



ALPs & 511 keV line

Positrons lose energy in $10^3 - 10^6$ yrs

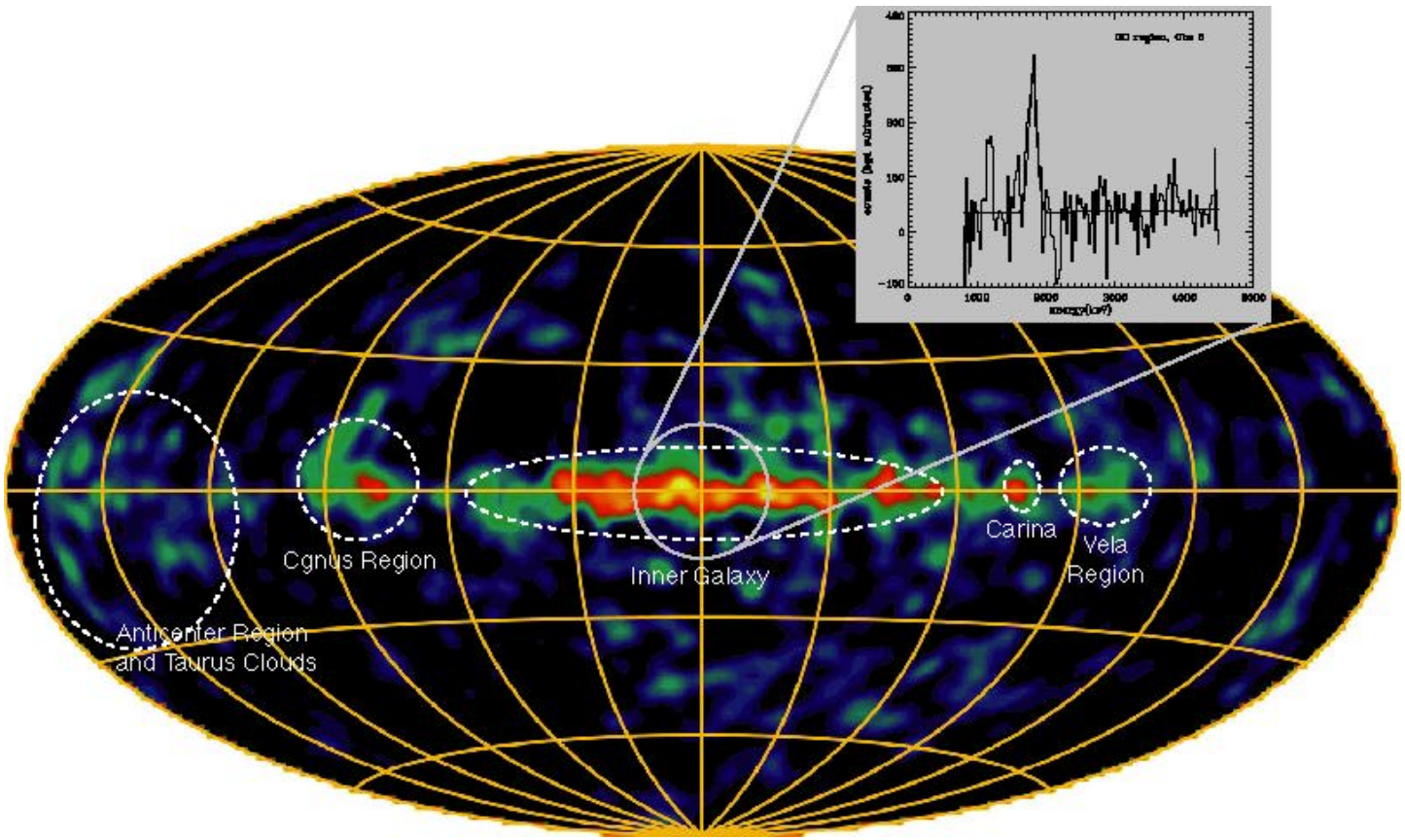


Is it possible to explain the 511 keV line with ALPs?

The 511 keV line

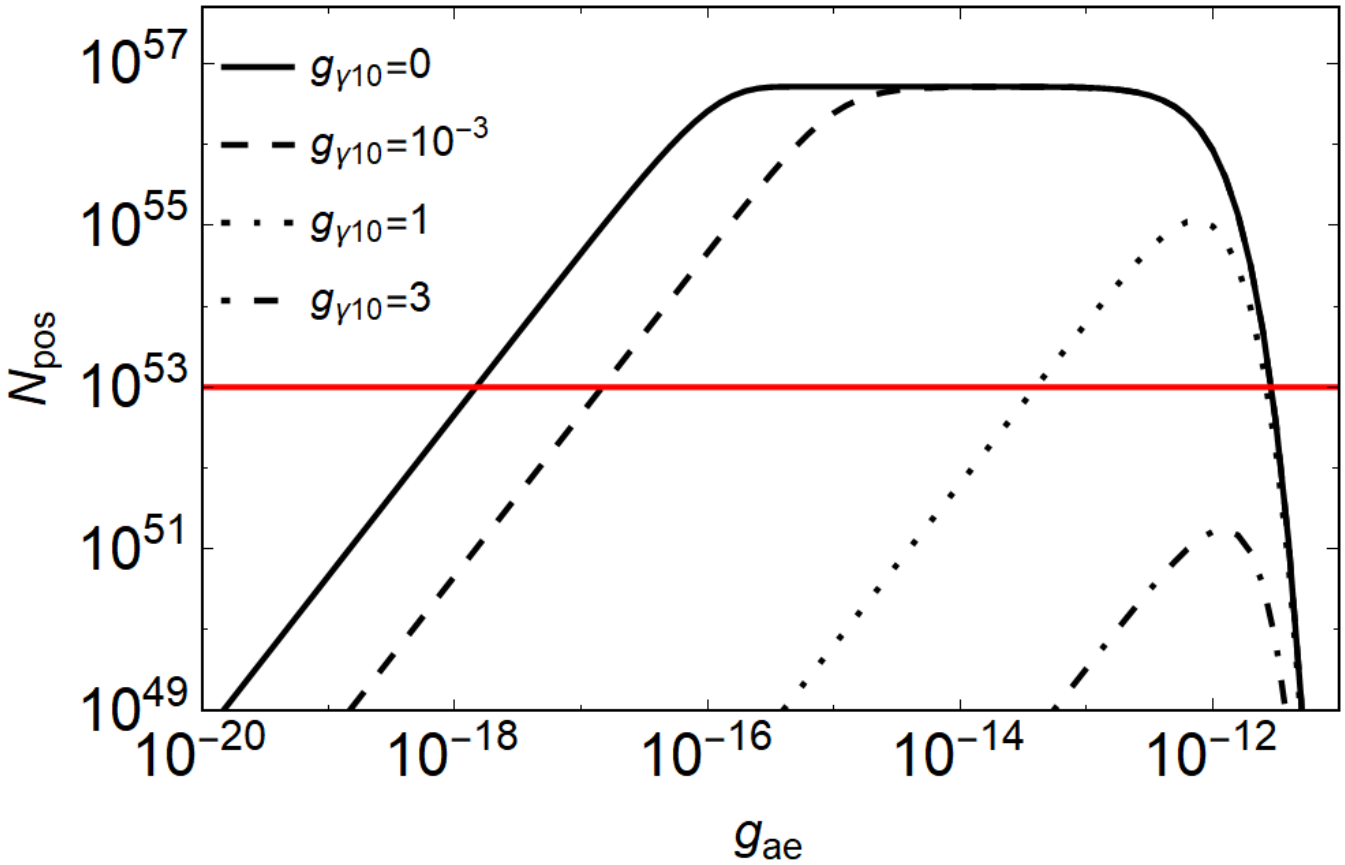
N. Prantzos *et al.* Rev. Mod. Phys. **83** (2011), 1001-1056

The Galactic flux at 511 keV is partially unexplained



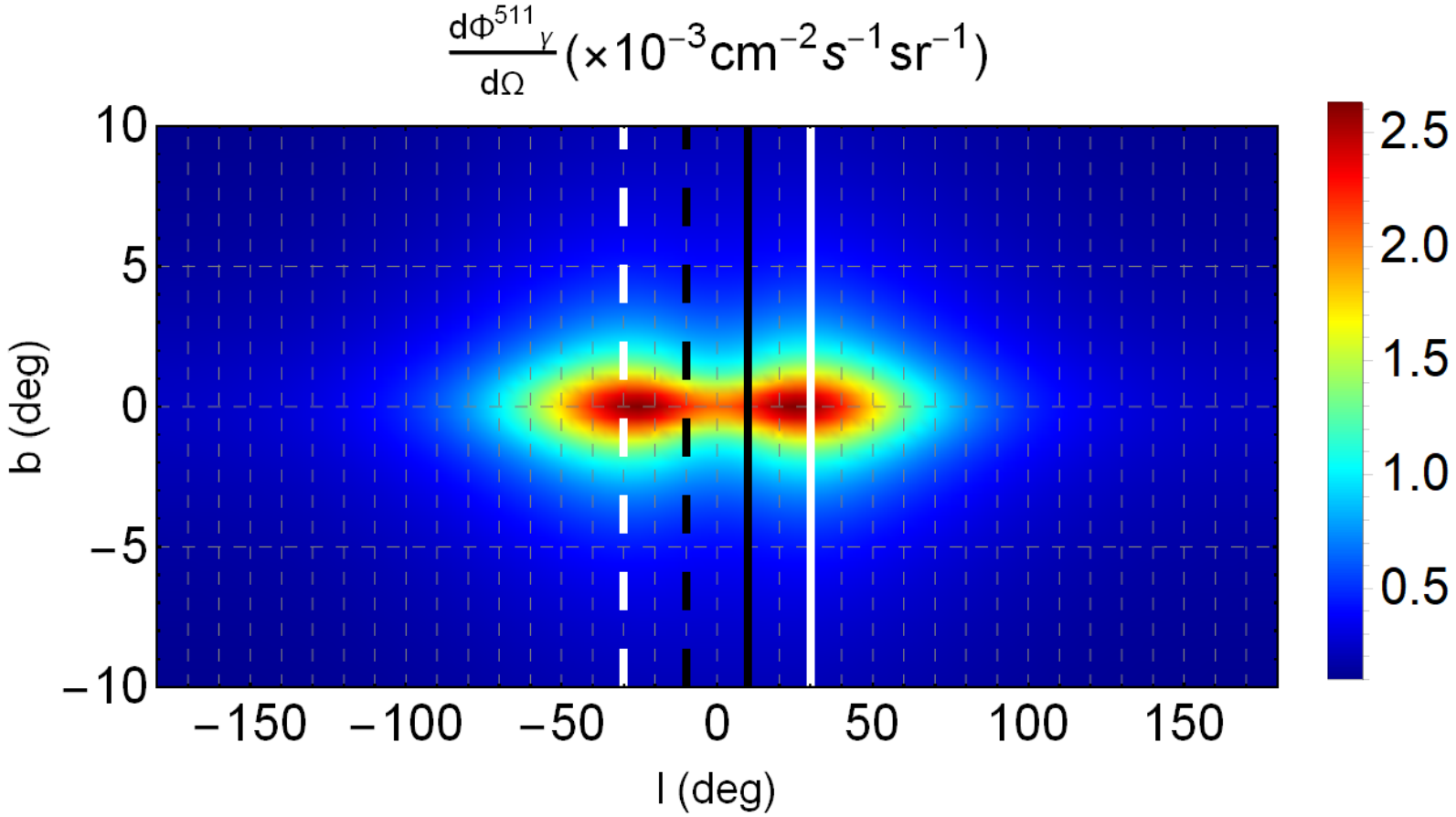
SN positron production

Positrons must escape the SN photosphere and remain in the Galaxy



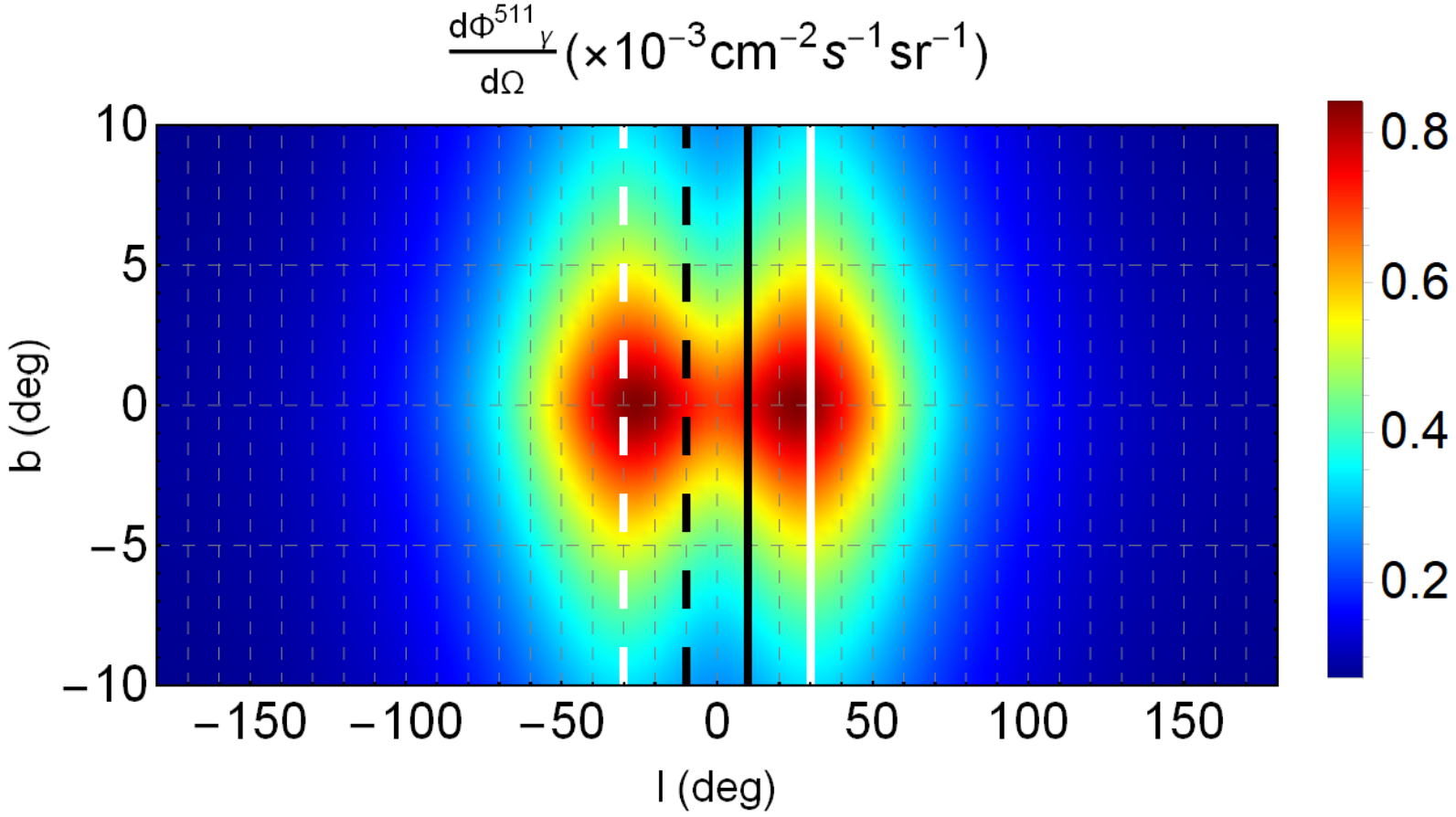
Number of positrons for $g_{ap} = 10^{-9}$ and $m_a = 30$ MeV

511 keV photon skymap for $g_{ae} = 4 \times 10^{-12}$



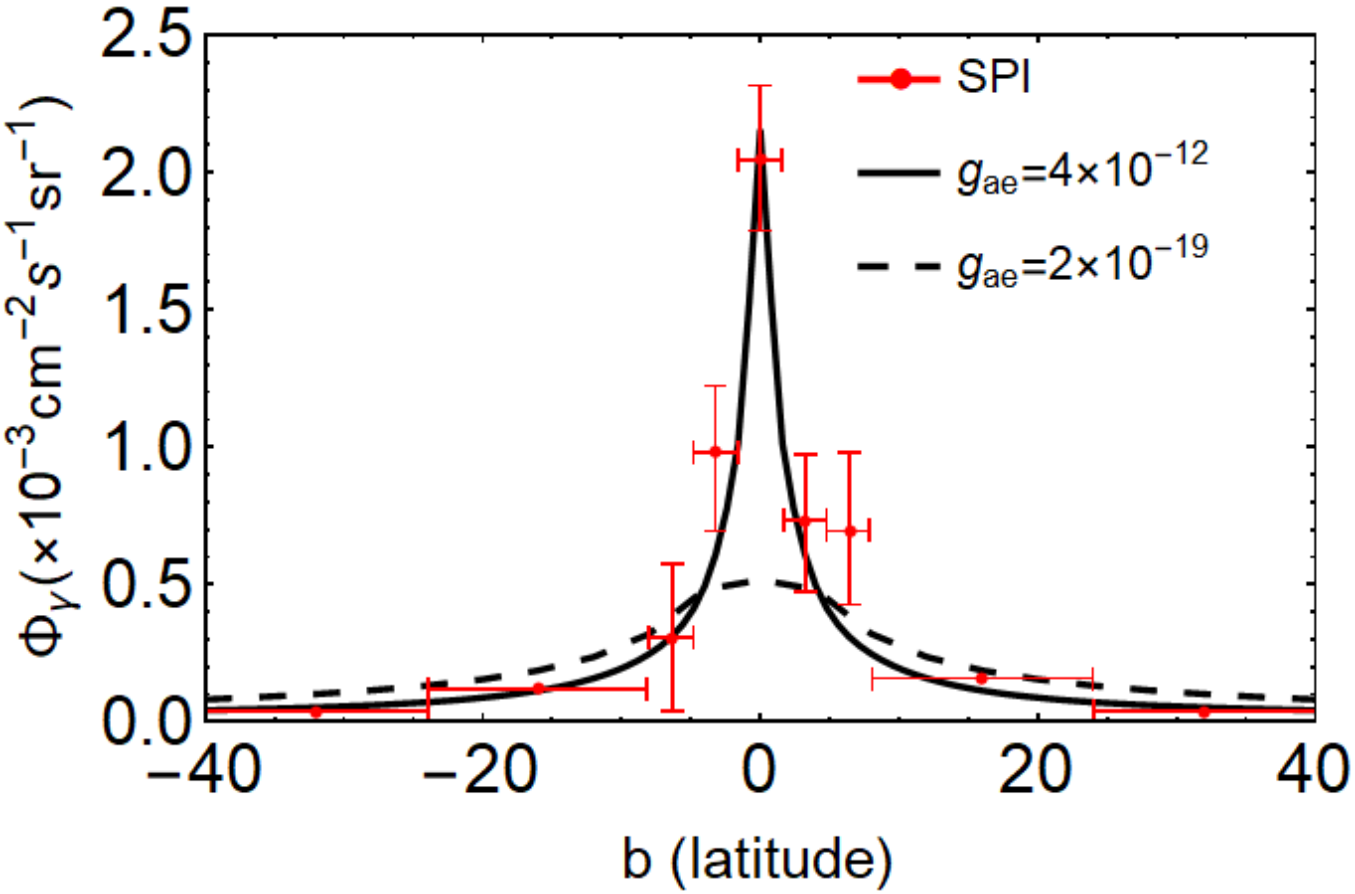
ALPs decay very close to the SN and positrons are trapped by $B \sim O(\mu G)$

511 keV photon skymap for $g_{ae} = 2 \times 10^{-19}$



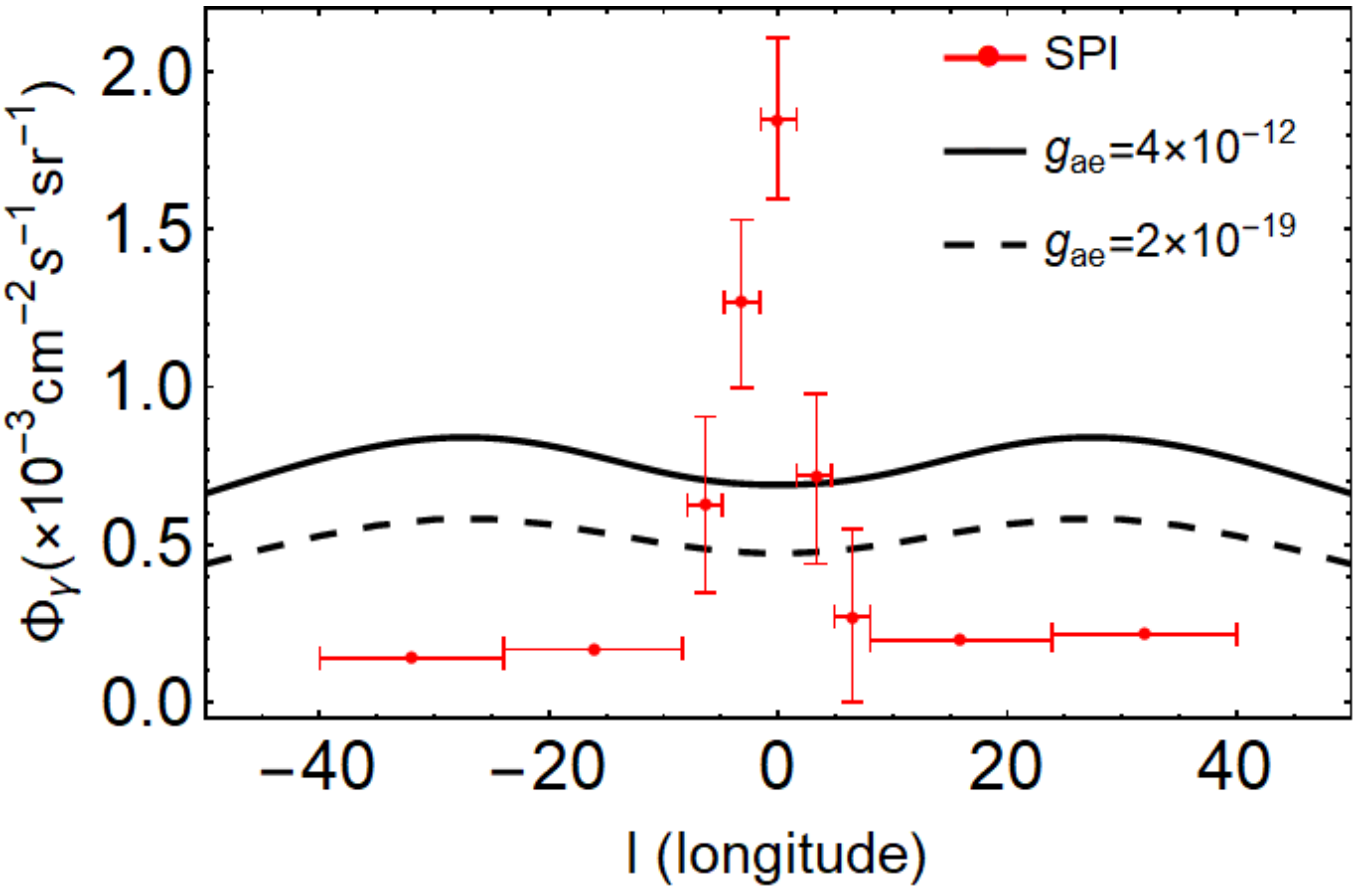
ALPs decay far from to the SN, smeared distribution

Let's compare with SPI data...



Very good agreement for the vertical distribution...

... much less agreement with the horizontal one



No ccSN-based mechanism explains the 511 keV line!!

Diffuse SN Axion Background

G. G. Raffelt *et al.*, Phys. Rev. D **84** (2011), 103008

In analogy to neutrinos, the DSAB is created by all past SNe

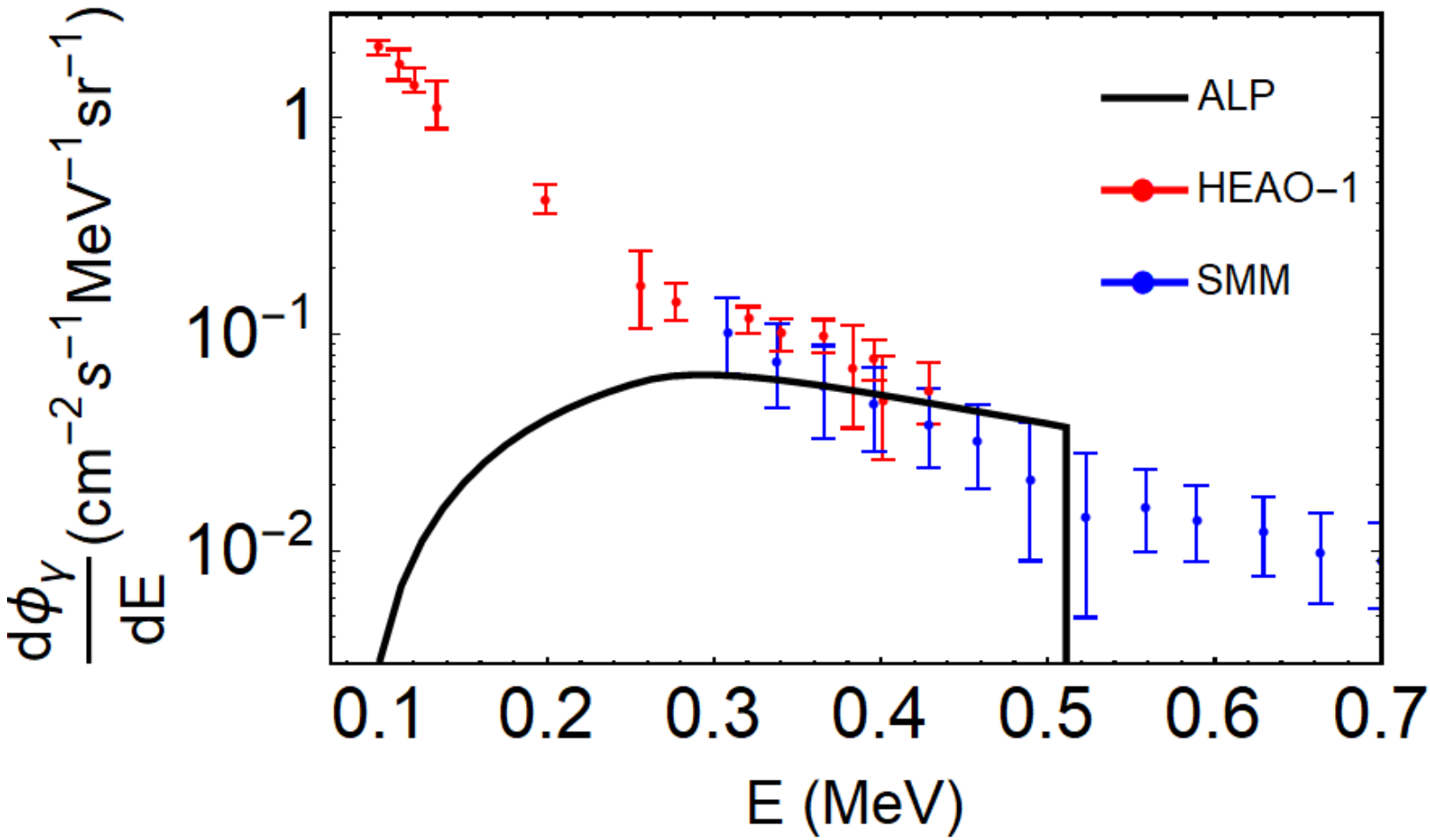
$$\frac{d\phi_a(E_a)}{dE_a} = \int_0^\infty (1+z) \frac{dN_a(E_a(1+z))}{dE_a} [R_{SN}(z)] \left[\left| c \frac{dt}{dz} \right| dz \right]$$

Where:

- dN_a/dE is the SN axion flux
- R_{SN} is the cosmological SN rate
- dt/dz depends on the cosmological parameters

Extragalactic X-ray diffuse flux

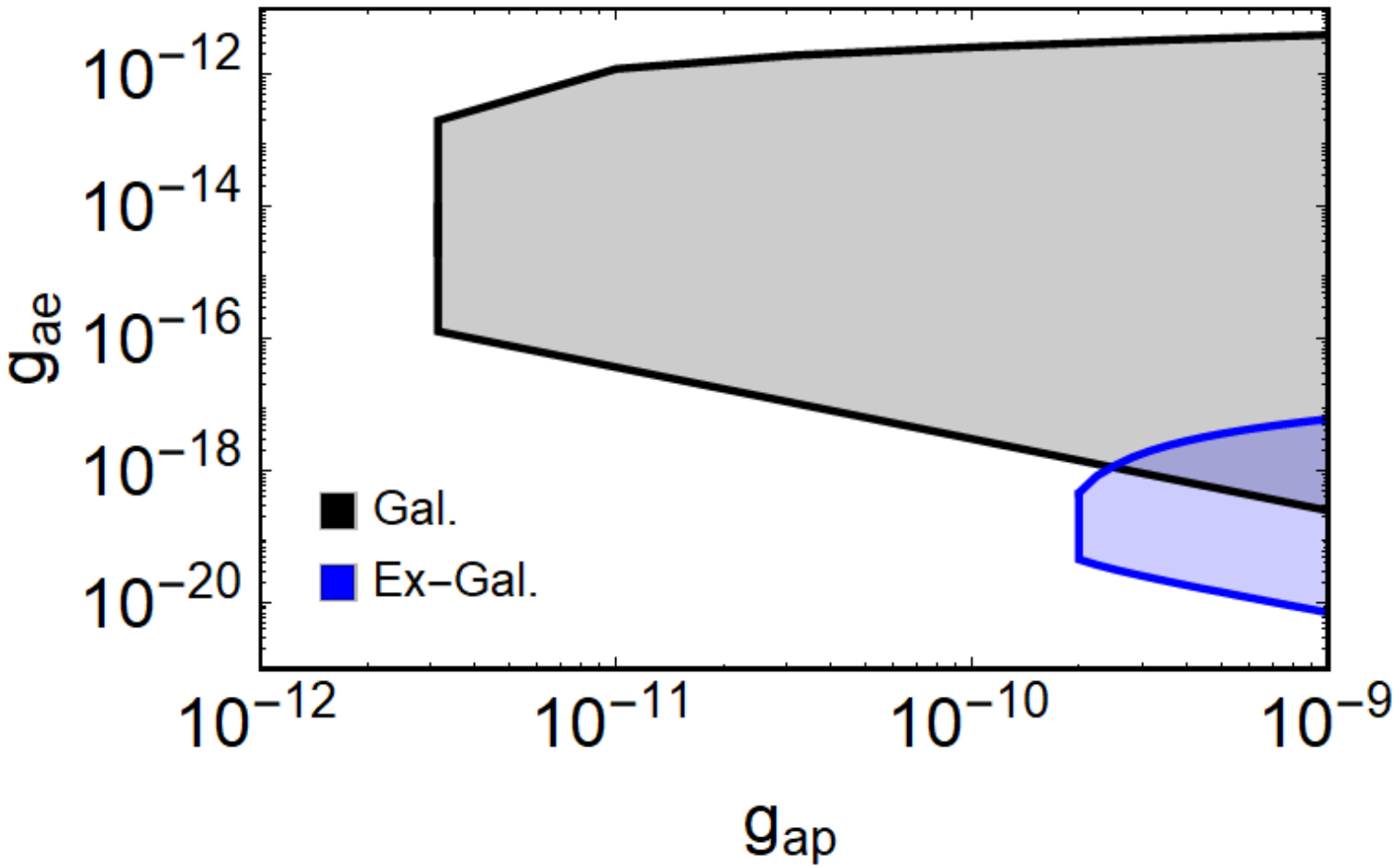
The extragalactic flux is redshifted, no more 511 keV line



Diffuse flux for $g_{ae} = 7 \times 10^{-21}$

Bounds for $m_a = 30\,\mathrm{MeV}$

This bound covers many orders of magnitude



Conclusions

- Is there an ALP-based mechanism to explain the 511 keV line? Not with SNe
- A new astrophysical ALP bound
- Even more informations from future data and more accurate analysis

Thanks for your attention