Axions and neutrinos in astrophysics and cosmology

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Outline

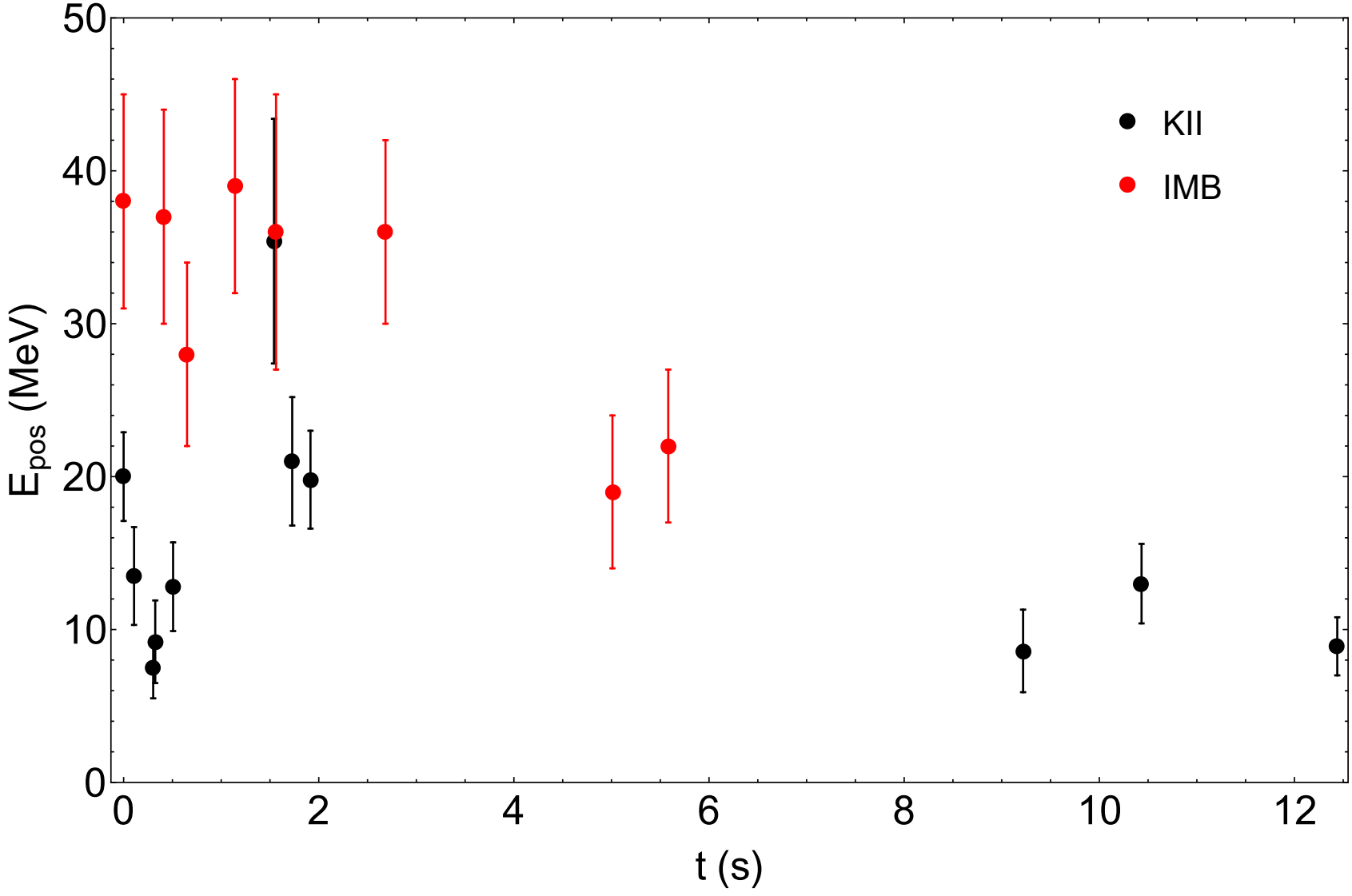
- Accomplished and ongoing projects
- Exams
- Schools, conferences, collaborations and talks

Medium modification of axion emission: Impact on the SN 1987A bound

P. Carenza, T. Fischer, M. Giannotti, G. Guo, G. Martinez-Pinedo and A. Mirizzi, "Improved axion emissivity from a supernova via nucleon-nucleon bremsstrahlung," JCAP **1910** (2019) no.10, 016 [arXiv:1906.11844 [hep-ph]].

SN1987A: neutrino signal

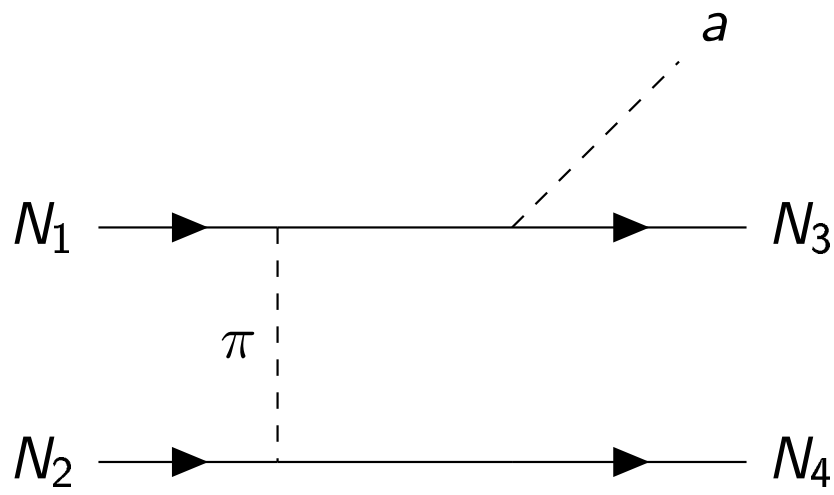
$\sim 10^{53}$ erg emitted as neutrinos with energy $\sim O(15\,\mathrm{MeV})$ in $\sim 10\,\mathrm{s}$



Axion production in SNe

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

SN axions are produced by nucleon-axion bremsstrahlung



in the One Pion Exchange (OPE) approximation and neglecting the pion mass, the matrix element is

$$S \times \sum |\mathcal{M}|^2 = \frac{64}{3} g_a^2 m_N^2 \left(\frac{g_A}{2 f_\pi} \right)^4$$

Beyond the OPE approximation

- Non-zero pion mass in the propagator$\rightarrow \sqrt{3 m_N T} \sim m_\pi$
- Two-pions exchange$\rightarrow$ Important around $2\mathrm{fm} \simeq 1.5 {m_\pi}^{-1}$
- Effective nucleon mass$\rightarrow m_N^*(\rho)$
- Multiple nucleon scatterings$\rightarrow$ Nucleon spin fluctuations

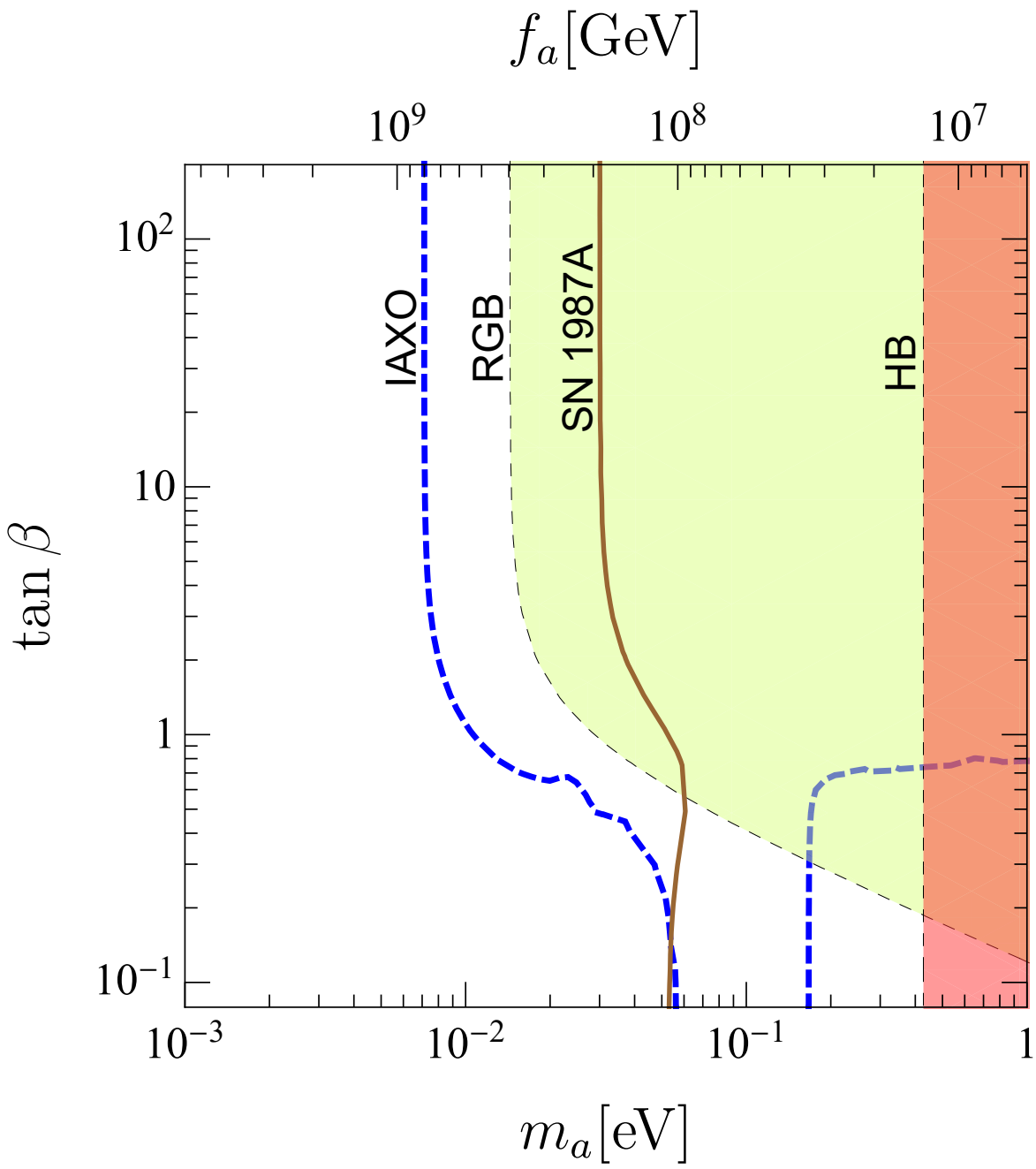
KSVZ axion bound

Bounds on axion couplings and mass for KVSZ model in our SN model at $t_{\rm pb} = 1$ s.

$C_{ap} = -0.47$; $C_{an} = 0$	g_{ap} $(\times 10^{-10})$	m_a (meV)	$f_a (\times 10^8$ GeV)
OPE	8	10	5.5
OPE+MS	9	11	4.9
OPE+corr. (no MS)	32	42	1.4
OPE+corr.+MS	33	43	1.3

A more accurate bound can be obtained by SN simulations

DFSZ axion bound



Dynamical evolution of axion condensates under stimulated decays into photons

work in progress with A. Mirizzi and G. Sigl

Axion-photon interaction

The axion-photon vertex is described by

$$\mathcal{L}_{\rm int} = -\frac{g_{a\gamma}}{4}\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$$

The $a \to \gamma\gamma$ decay rate is

$$\Gamma_{\rm dec} = \frac{g_{a\gamma}^2}{64\pi} m_a^3 = 10^{-24}\,{\rm s}^{-1}\left(\frac{m_a}{\rm eV}\right)^5$$

And the axion can be considered stable with respect to the lifetime of the Universe $\sim 10^{17}\,{\rm s}$

Enhancing the axion-photon interaction

The axion decay can be stimulated by photons

$$\Gamma_{\rm eff} = \Gamma_{\rm dec}(1+f_\gamma)^2 \simeq \Gamma_{\rm dec}\,(1+2f_\gamma) = \\ = \Gamma_{\rm dec}\left(1+\frac{8\pi^2\phi_0 n_\gamma}{m_a^2 g_{a\gamma} n_a}\right)$$

and for $n_\gamma \gg 1$ the effective rate is proportional to $g_{a\gamma}$ and not to $g_{a\gamma}^2$ as for the spontaneous decay

Kinetic equations

For this system we obtain

$$\dot{N}_{\mathbf{k}} = 2\left[b^{\dagger} C_{\mathbf{k}} + b C_{\mathbf{k}}^{\dagger}\right]$$

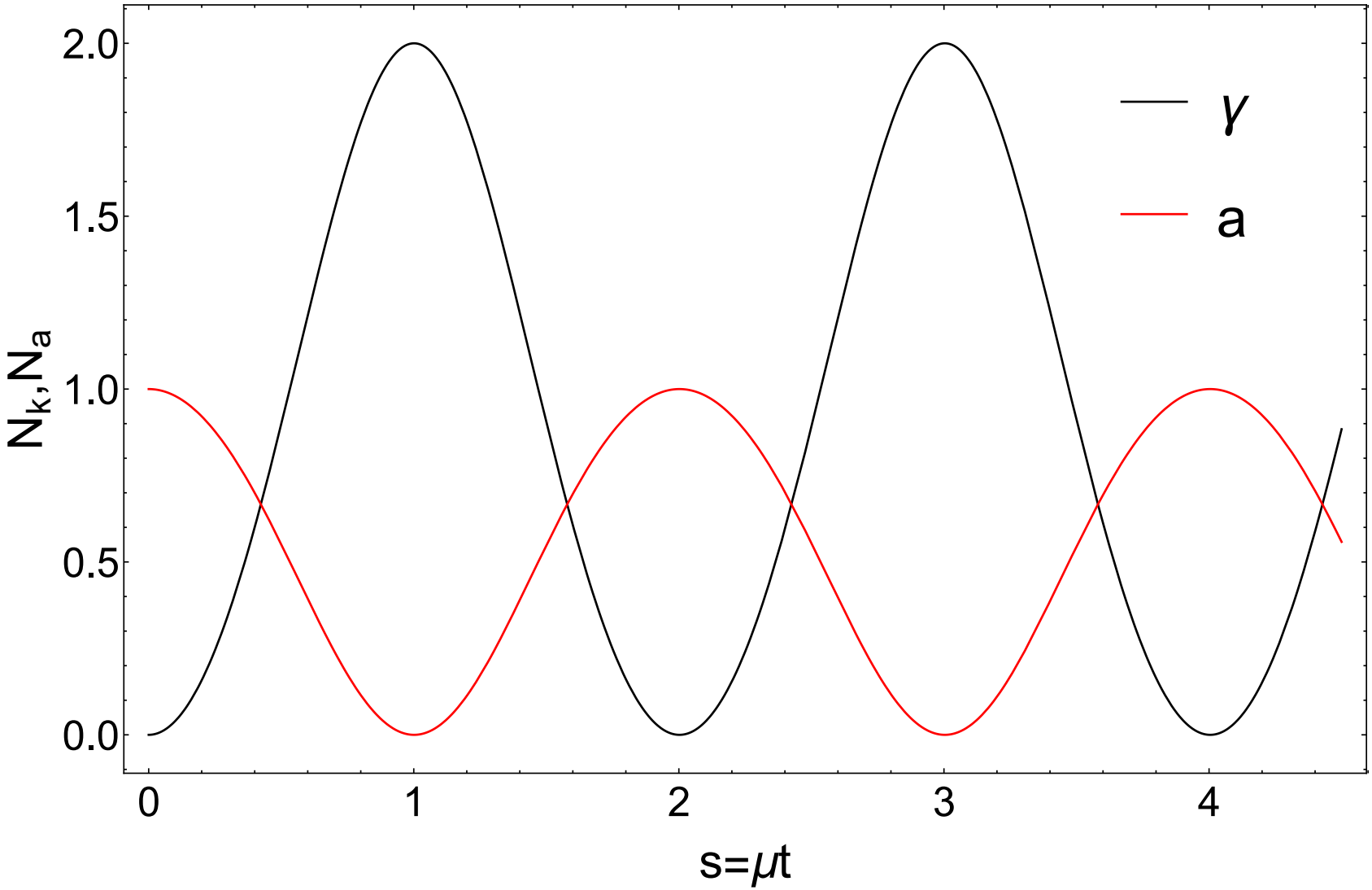
$$\dot{C}_{\mathbf{k}} = \left(\frac{2}{N_a} + N_{\mathbf{k}}\right) b$$

$$\dot{b} = -\int d^3\mathbf{k}\, C_{\mathbf{k}}$$

where N_a is the initial number of axions, $N_{\mathbf{k}}$ is the photon number, $C_{\mathbf{k}}$ photon pair correlator and b is the axion annilihation operator.

Period of axion-photon conversion

The axion conversion time is $T \sim 2/\mu$, $\mu = g_{a\gamma}\phi_0 m_a/4$



Possible relevance in early Universe and axion clumps

Exams and conferences

Exams:

- Promozione della ricerca
- How to prepare a technical speech in English
- Programming with Python
- Standard model and beyond
- Machine Learning Techniques in High Energy Physics
- C++
- Advanced Cosmology
- Hadron Physics
- **Gamma-ray astrophysics**

Schools attended:

- 55th Karpacz winter school of nuclear astrophysics, Karpacz (PL), 24-02-2019 / 02-03-2019

Conferences:

- 15th Patras workshop on ALPs, axions and WIMPs, Freiburg (DE), 03-06-2019/07-06-2019
- Workshop Axions in the lab and in the cosmos, Geneve (CH), 15-07-2019/ 19-07-2019

Scientific collaborations:

- Universita' degli Studi di Ferrara, Ferrara (IT) - M. Lattanzi and F. Forastieri, 31-03-2019/ 03-04-2019
- GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt (DE) - G. Martinez-Pinedo and G. Guo, 08-07-2019/12-07-2019

Talks:

- 55th Karpacz winter school of nuclear astrophysics, Karpacz (PL) - "Reexamining the SN1987A bound on axions"
- 15th Patras workshop on ALPs, axions and WIMPs, Freiburg (DE) - "Improved axion emissivity from a supernova and the SN1987A bound"
- GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt (DE) - "Improved axion emissivity from a supernova and the SN1987A bound"

Thanks for your attention