PRIN 2022 «PANTHEON»

Perspectives in Astroparticle and Neutrino Theory with Old and New Messengers

REPORT FROM THE BARI UNIT

Alessandro Mirizzi (Uniba)

Rome, 4 October 2024

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Ministero dell'Università e della Ricerca
Italiadomani
INFN

BARI UNIT

- Antonio Marrone
- Alessandro Mirizzi
- Daniele Montanino
- Antonio Palazzo
- Luigi Tedesco

+ PhD students

- Alessandro Lella
- Eliseo Pavone

Project of Pantheon in Via Sparano, beginning of XX century

NEWS

10 SETTEMBRE 2024

Premio Nazionale "Giuliano Preparata" della SIF al dott. Giuseppe Lucente

PhD Thesis on "**Astrophysical probes of feebly-interacting particles**",

BUDGET

- Initial amount: 44.900 euros
- Overheads: 8367 euros
- Expenses: 7417 euros
- Residuals: 29.116 euros

PUBLICATIONS

1. A. Lella, P. Carenza, G. Co', G. Lucente, M. Giannotti, A. Mirizzi and T. Rauscher, ``Getting the most on supernova axions,'' Phys. Rev. D 109 (2024) no.2, 023001 doi:10.1103/PhysRevD.109.023001 [arXiv:2306.01048 [hep-ph]].
2. P. Carenza, G. Lucente, L. Mastrototaro, A. Mirizzi and P. D. Serpico, ``Comprehensive constraints on heavy sterile neutrinos from core-collapse supernovae,'' Phys. Rev. D 109 (2024) no.6, 063010 doi:10.1103/PhysRevD.109.063010 [arXiv:2311.00033 [hep-ph]].
3. G. Lucente, M. Heinlein, H. T. Janka and A. Mirizzi, ``Simple fits for the neutrino luminosities from protoneutron star cooling,'' Phys. Rev. D 110 (2024) no.6, 6 doi:10.1103/PhysRevD.110.063023 [arXiv:2405.00769 [astro-ph.HE]].
4. A. Lella, F. Calore, P. Carenza, C. Eckner, M. Giannotti, G. Lucente and A. Mirizzi, ``Probing protoneutron stars with gamma-ray axionscopes,'' [arXiv:2405.02395 [hep-ph]].
5. A. Lella, F. Calore, P. Carenza and A. Mirizzi, ``Constraining gravitational-wave backgrounds from conversions into photons in the Galactic magnetic field,'' [arXiv:2406.17853 [hep-ph]].
6. A. Lella, E. Ravensburg, P. Carenza and M.C.D. Marsh, ``Supernova limits on QCD axionlike particles,'' Phys. Rev. D 110 (2024) no.4, 043019 doi:10.1103/PhysRevD.110.043019 [arXiv:2405.00153 [hep-ph]].
7. J. Kostensalo, E. Lisi, A. Marrone and J. Suhonen, ``Analysis of ^{115}In β decay through the spectral moment method,'' [arXiv:2405.11920 [nucl-th]].
8. E. Lisi, F. Capozzi, E. Di Valentino, A. Marrone, A. Melchiorri, N. Nath and A. Palazzo, ``Recent topics in the analysis of neutrino mass-mixing parameters,'' PoS {CORFU2023} (2024), 118.
9. G. J. Ding, E. Lisi, A. Marrone and S. T. Petcov, ``Interplay and Correlations Between Quark and Lepton Observables in Modular Symmetry Models,'' [arXiv:2409.15823 [hep-ph]].
10. S. S. Chatterjee and A. Palazzo, ``Status of tension between NOvA and T2K after Neutrino 2024 and possible role of non-standard neutrino interactions,'' [arXiv:2409.10599 [hep-ph]].
11. A. Palazzo «Confronting sterile neutrinos with NSI in the interpretation of T2K and NOvA», https://zenodo.org/records/10571948
12. L.Tedesco, ``Ellipsoidal Universe and Cosmic Shear,'' Universe 10 (2024), 363 [arXiv:2409.07509 [gr-qc]].

TALKS

1. A. Lella ``Axion-like particles from Supernovae'', invited Seminar for Astroparticle Physics Seminars at DESY, Hamburg (Germany), 25th January 2024.
2. A. Lella ``Getting the most on Supernova axions'', invited talk at the 2nd Working Group Meeting of COST Action COSMIC WISPers (CA21106), DESY, Hamburg (Germany), 1st February 2024.
3. A. Lella ``Core-Collapse Supernovae shining in Axion-like particles'', invited Seminar for IAXO Physics group at University of Zaragoza, Zaragoza(Spain), 9th May 2024.
4. A. Lella ``SN ALPs coupled to nucleons shining into photons'', talk at 2nd Training School COST Action COSMIC WISPers, Ljubljana (Slovenia), 12th June 2023. T12).
5. A. Lella ``Axion-like particles as probes of the SN core'', parallel talk at the 15th International Conference on ``Identification of Dark Matter'' (IDM2024), L'Aquila (Italy), 9th July 2024.
6. A. Lella ``Gravitational Waves from Supernovae'', parallel talk at 12th ``Neutrino Oscillation Workshop'' (NOW 2024), Otranto (Italy), 7th September 2024.
7. A. Lella ``High frequency gravitational waves shining in photons in Galactic magnetic fields}'', talk at DESY Theory Workshop 2024: ``Whispers from the Dark Universe - Particles & Fields in the Gravitational Wave Era'', DESY, Hamburg (Germany), 26th September 2024.
8. A. Mirizzi, Lectures on Axions at GGI Astroparticle Phd School, Arcetri, 11- 22 March 2024.
9. A. Mirizzi Lectures on Supernova neutrinos at INSS 2024, Bologna, 3-14 June 2024
10. A. Mirizzi «Talk for Andreas Ringwald fest», talk at DESY Theory Workshop 2024: ``Whispers from the Dark Universe - Particles & Fields in the Gravitational Wave Era'', DESY, Hamburg (Germany), 27th September 2024.
11. A. Palazzo «Confronting Sterile Neutrinos with NSI in the interpretation of T2K and NOVA», talk at XX Neutrino Telescope, Venice 23-27 October 2023
12. A. Palazzo «T2K-NOvA tension and physics BSM» talk at NOW 2024, 2-8 Sept. 2024.

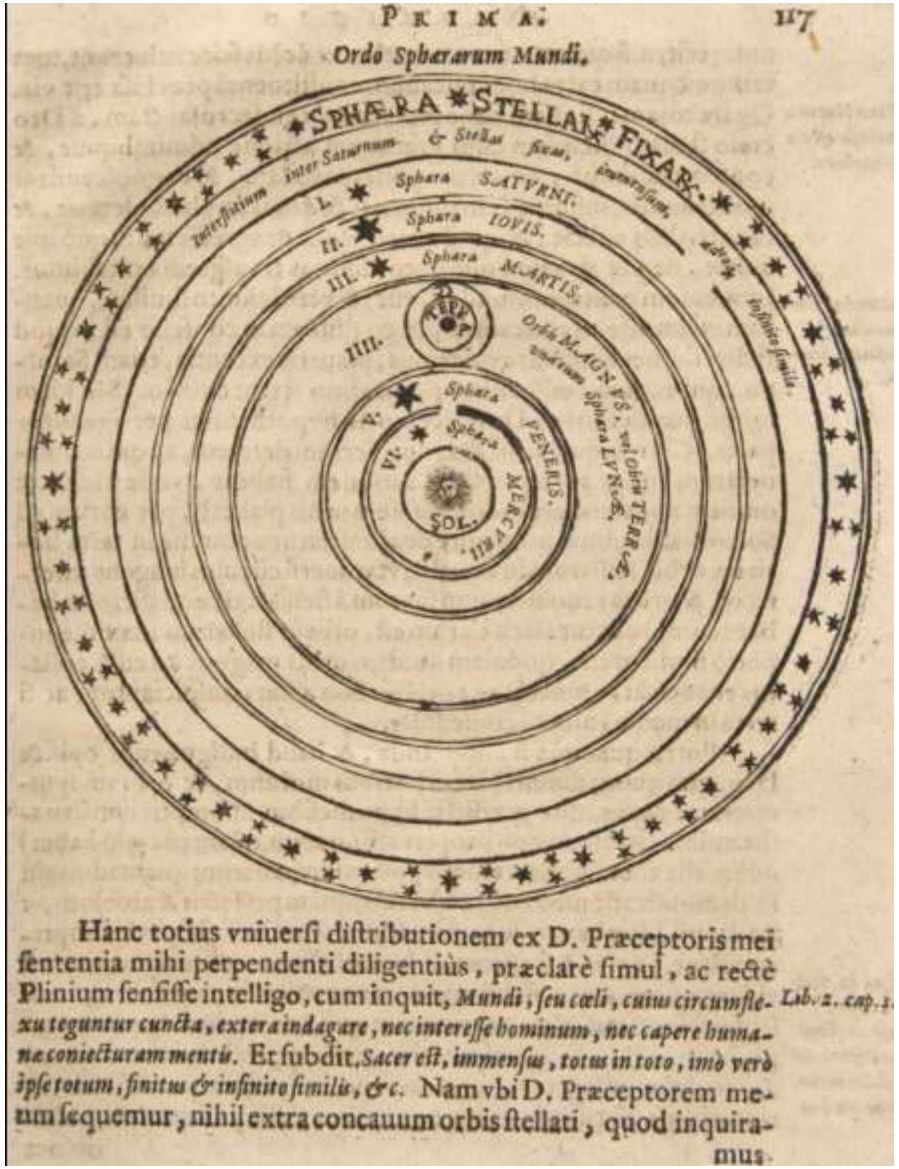
ORGANIZATION ACTIVITIES

- Antonio Marrone has been member of the SAC of «Neutrino 2024» in Milano

- Antonio Marrone, Alessandro Mirizzi, Daniele Montanino, Antonio Palazzo have been members of the LOC of «NOW 2024»

- Alessandro Mirizzi chaired the Training School and the General Meeting of the COST Action «COSMIC WISPers»

WP1: STANDARD NEUTRINO FRAMEWORK



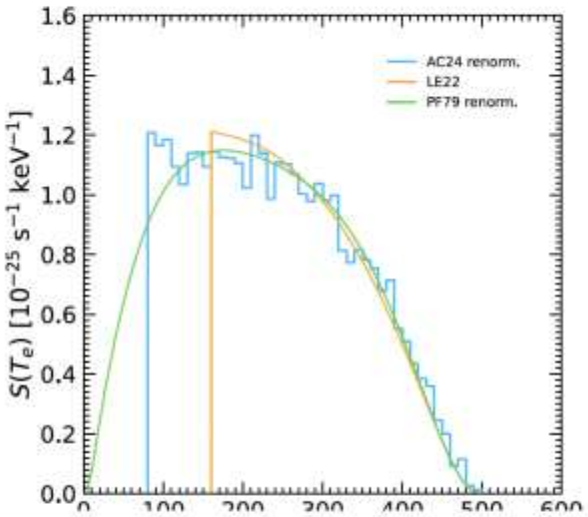
Ordo Sphærarum Mundi.

Hanc totius vniuerſi diſtributionem ex D. Præceptoris mei ſententia mihi perpendenti diligentiùs, præclarè ſimul, ac rectè Plinium ſenſiſſe intelligo, cum inquit, *Mundi, ſeu cœli, cuius circumflexu teguntur cuncta, extera indagare, nec intereſſe hominum, nec capere humanæ coniecturam mentis.* Et ſubdit. *Sacer eſt, immenſus, totus in toto, imò verò ipſe totum, finitus & infinito ſimilis, &c.* Nam vbi D. Præceptorem meum ſequemur, nihil extra concauum orbis ſtellati, quod inquiramus. *Lib. 2. cap. 1.*

Analysis ^{115}In beta decay through the spectral moment method

Joel Kostensalo (Unlisted, FI), Eligio Lisi (INFN, Bari), Antonio Marrone (INFN, Bari and Bari U.), Jouni Suhonen (Jyvaskyla U. and CIFRA)

e-Print: 2405.11920 [nucl-th]

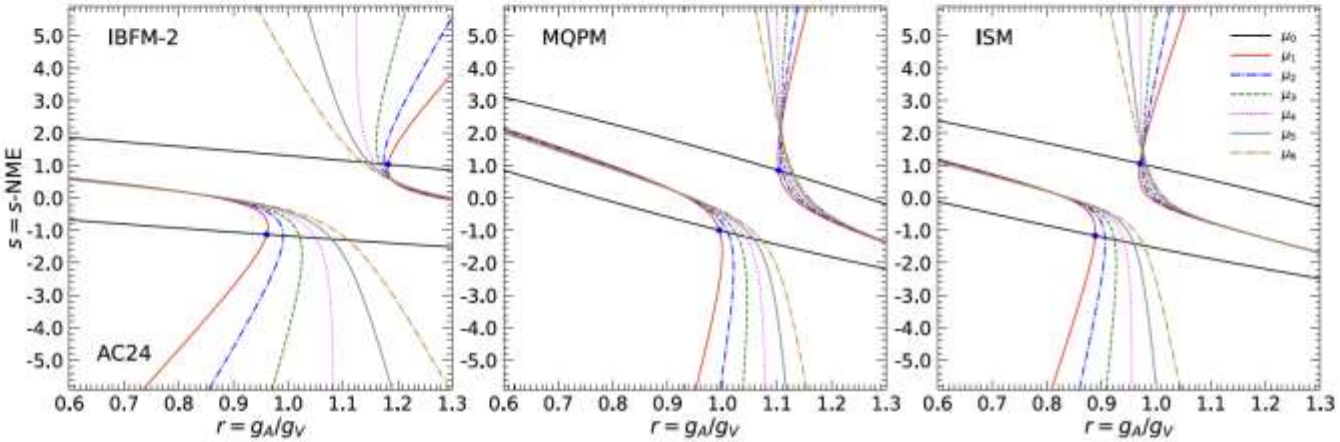


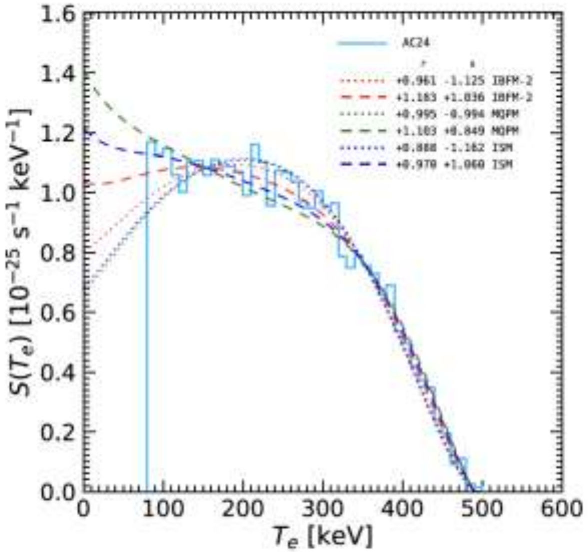
The spectral moment method for ^{115}In

Nuclear model calculations depend on two free parameters: the ratio of axial-vector to vector couplings, $r=g_A/g_V$ and the small vector-like relativistic nuclear matrix element s

The first few spectral moments can determine (r , s) values in good agreement with those obtained by a complete analysis.

We find that, although g_A quenching is generally favored, the preferred quenching factors may differ considerably depending on the chosen experimental data and nuclear models.



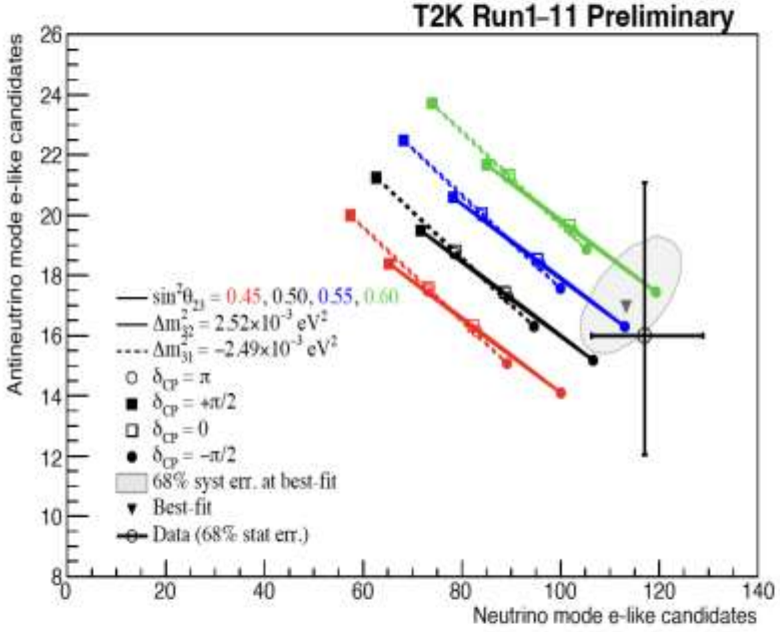


Global analysis of oscillation parameters after Neutrino 2024
Eligio Lisi, Antonio Marrone, et al.

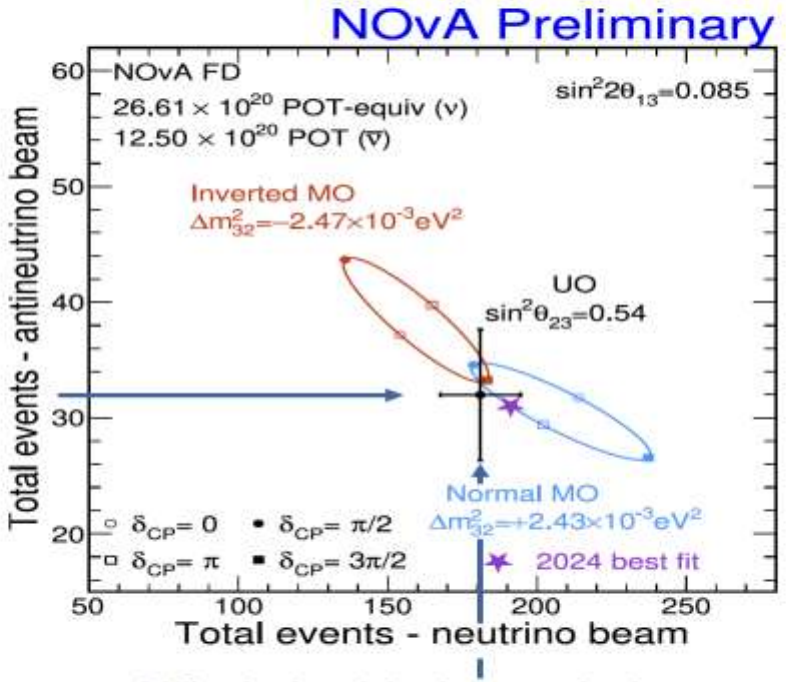
In preparation

WP2: BEYOND THE STANDARD NEUTRINO FRAMEWORK

Bievents plots from Neutrino 2024



T2K almost unaltered statistics



NOvA doubled ν statistics

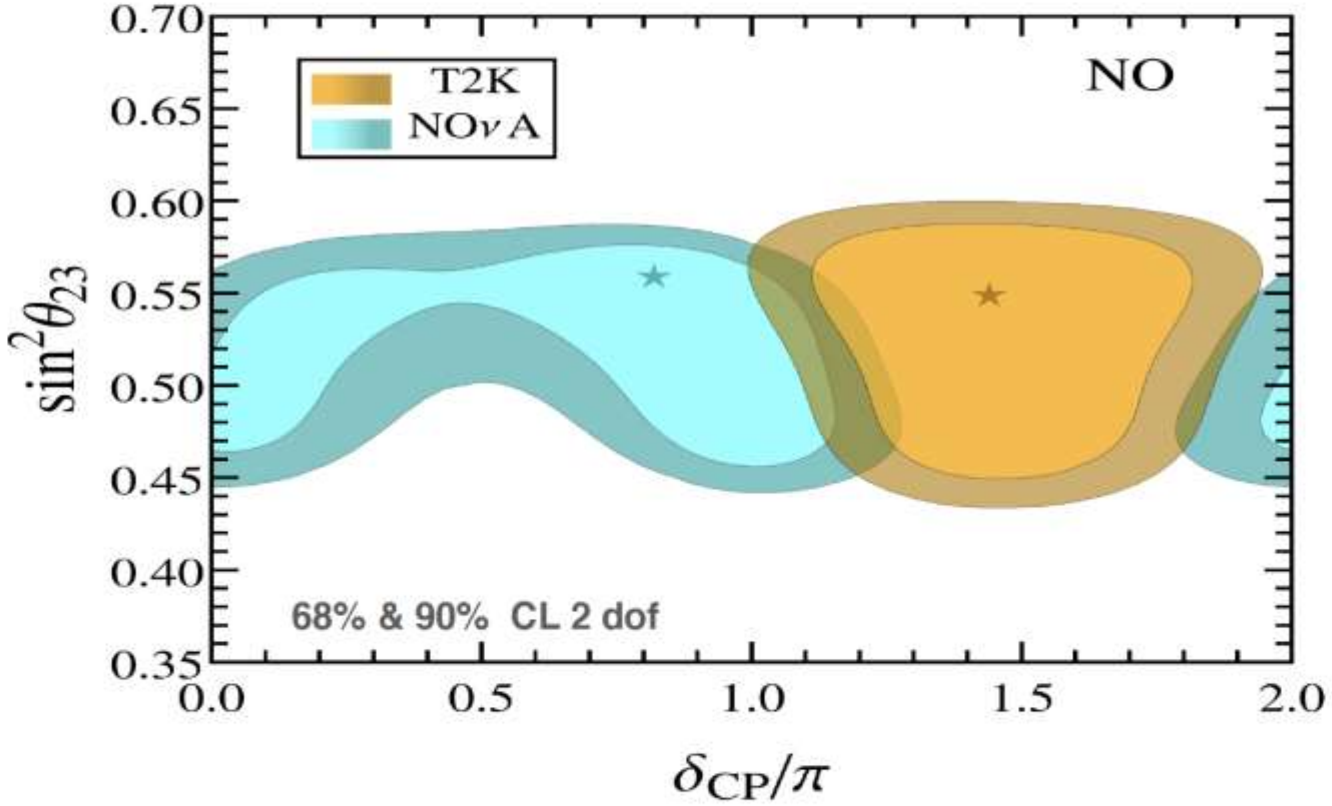
PERSISTING TENSION for Nomal Ordering:

- **T2K prefers $\delta_{CP} \sim 1.5\pi$**
- **NOνA prefers $\delta_{CP} \sim 0.9\pi$**

Tension at ~2 sigma

Chatterjee & Palazzo arXiv:2409.10599

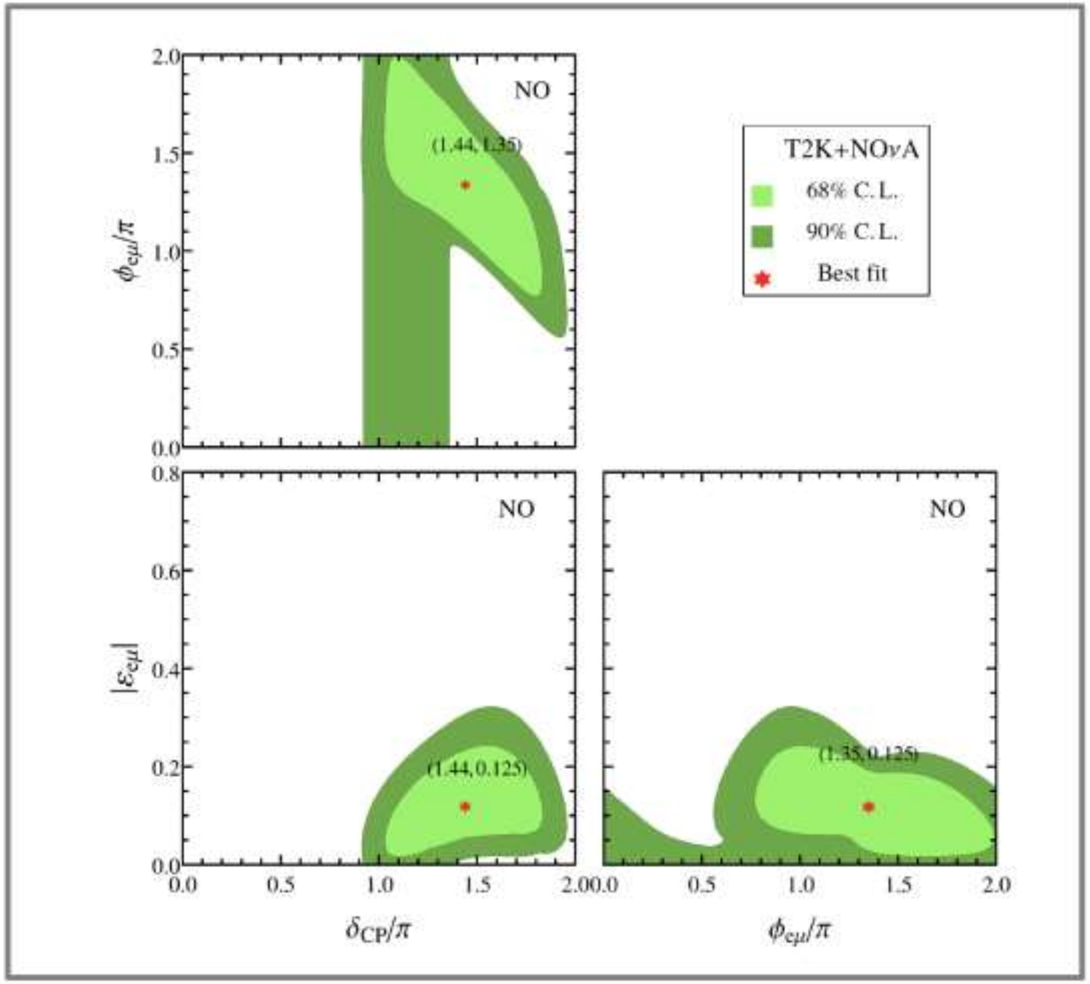
View in two-paramer space



Maybe a statistical fluctuation or a systematic error

But interesting to consider alternative explanations…

Indication of non-zero $\varepsilon_{e\mu}$ from T2K + NOνA

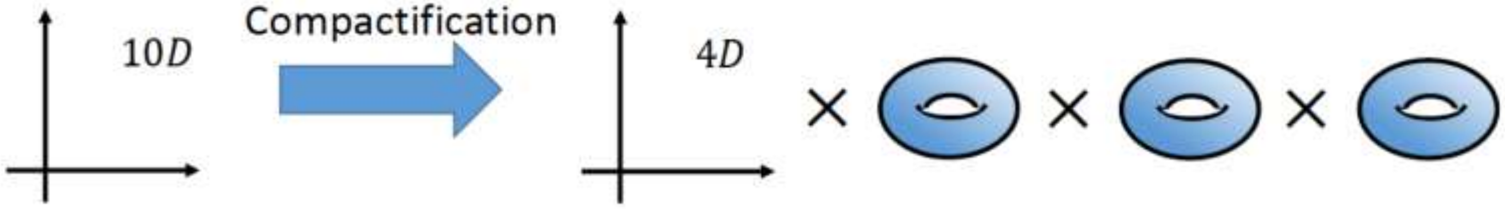


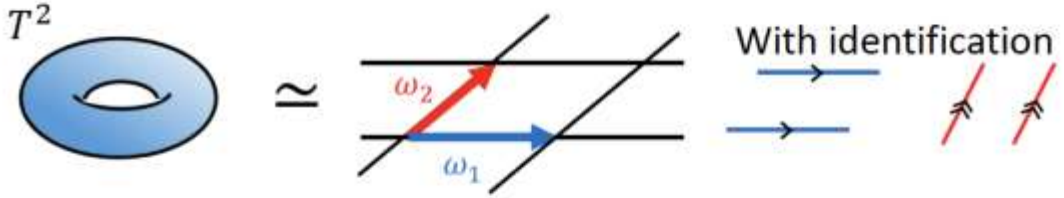
~1.8 sigma preference for NSI

Modular invariance

String theory requires extra dimensions

Images: Takuya H. Tatsuishi





$$\tau = \frac{\omega_2}{\omega_1}, \quad \mathrm{Im}(\tau) > 0$$

modulus

Lattice left invariant by modular transformations

$$\tau \to \gamma\tau \equiv \frac{a\tau + b}{c\tau + d} \qquad a, b, c, d \in \mathbb{Z} \qquad ad - bc = 1$$

These transformations form an infinite discrete group

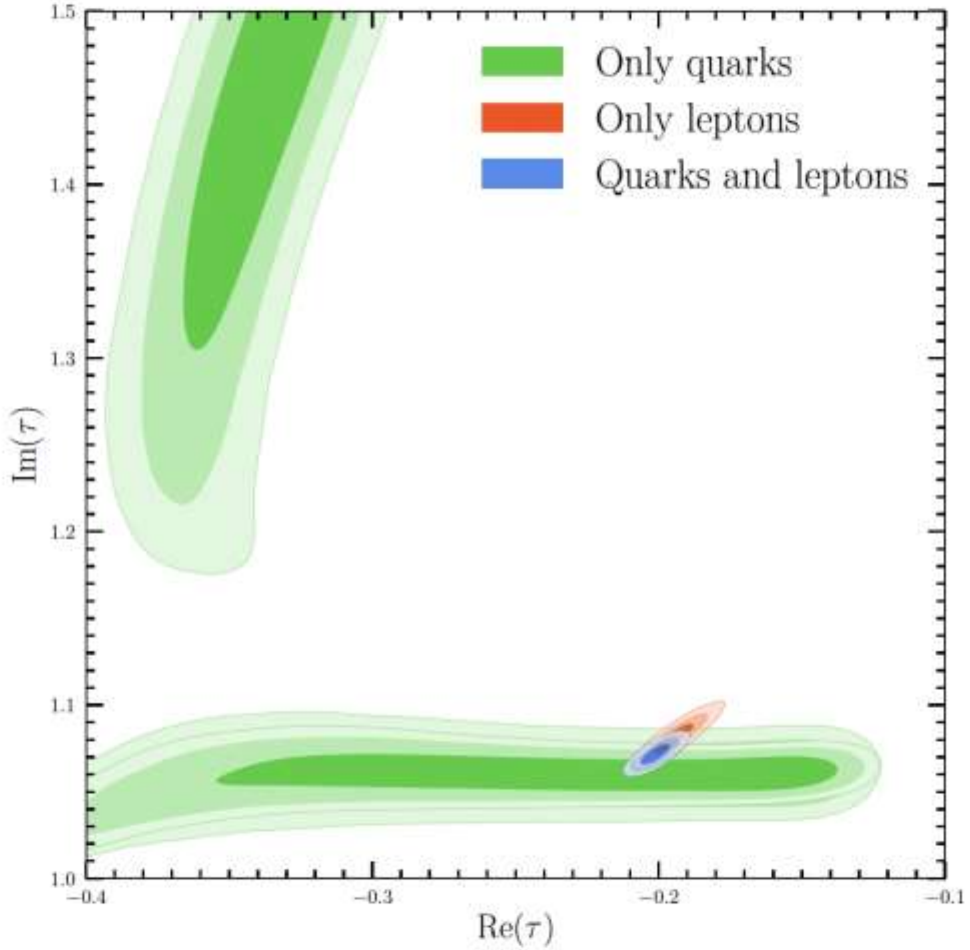
Modular symmetry allows to construct quite predictive lepton models.

Interplay and Correlations Between Quark and Lepton Observables in Modular Symmetry Models

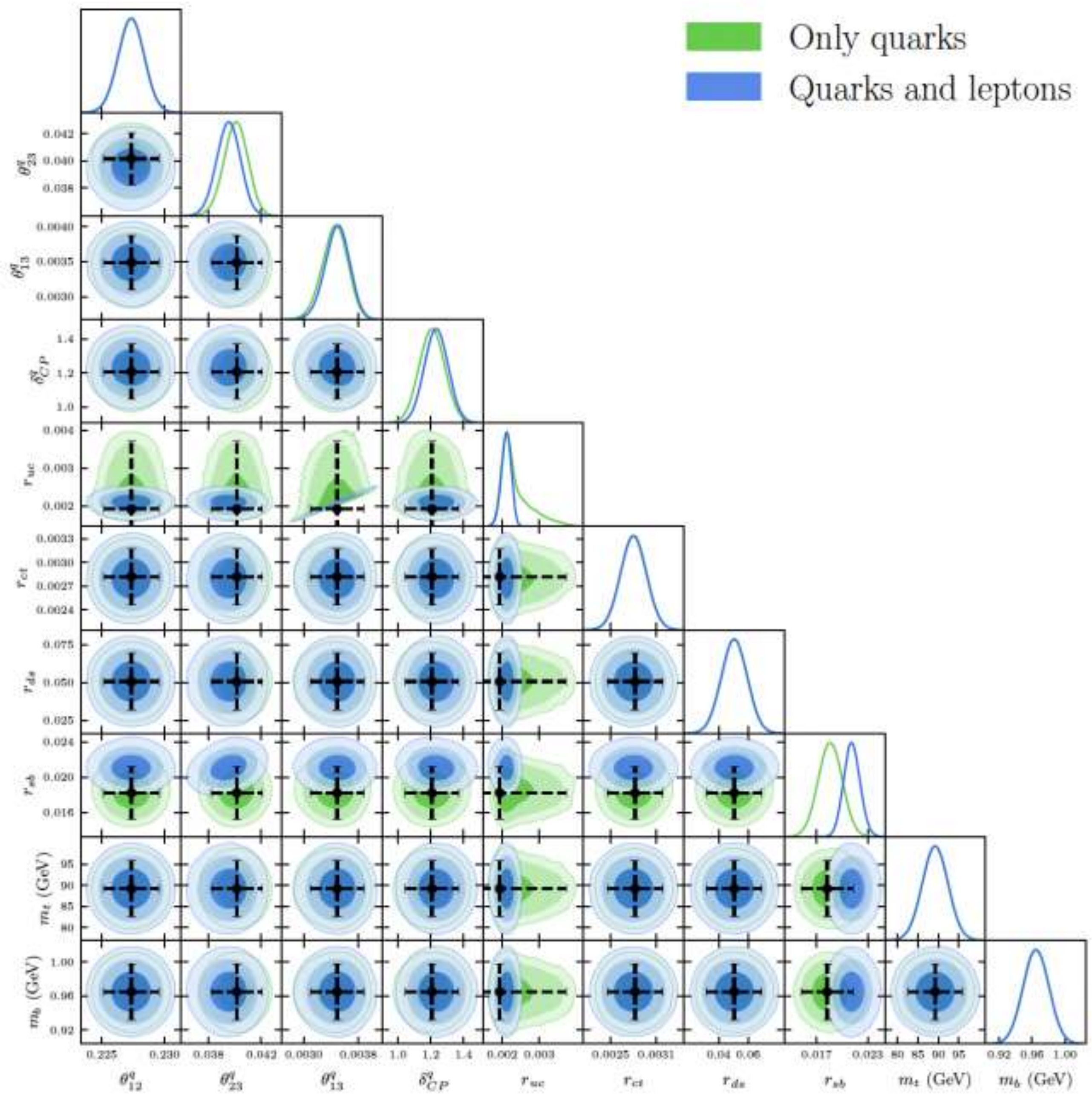
First combined analysis of quark and lepton observables in flavour models based on modular invariance (2O group)

Unified treatment under a single framework governed by a common complex modulus tau and 12 real parameters. The model is in good agreement with experimental data,

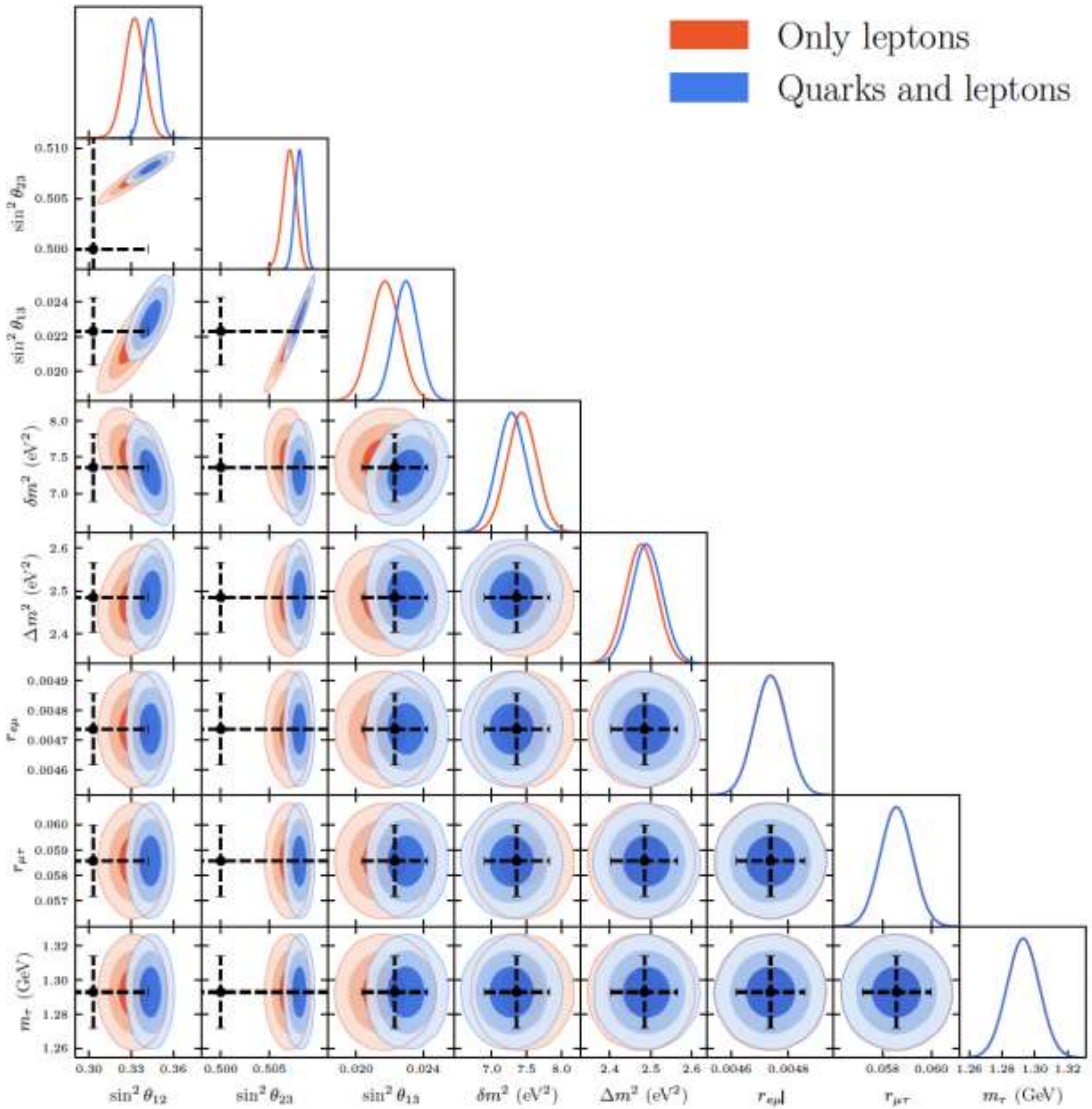
Predictions for unmeasured lepton observables such as the Dirac CP-violation phase, the two Majorana phases, the lightest neutrino mass, m_β and $m_{\beta\beta}$



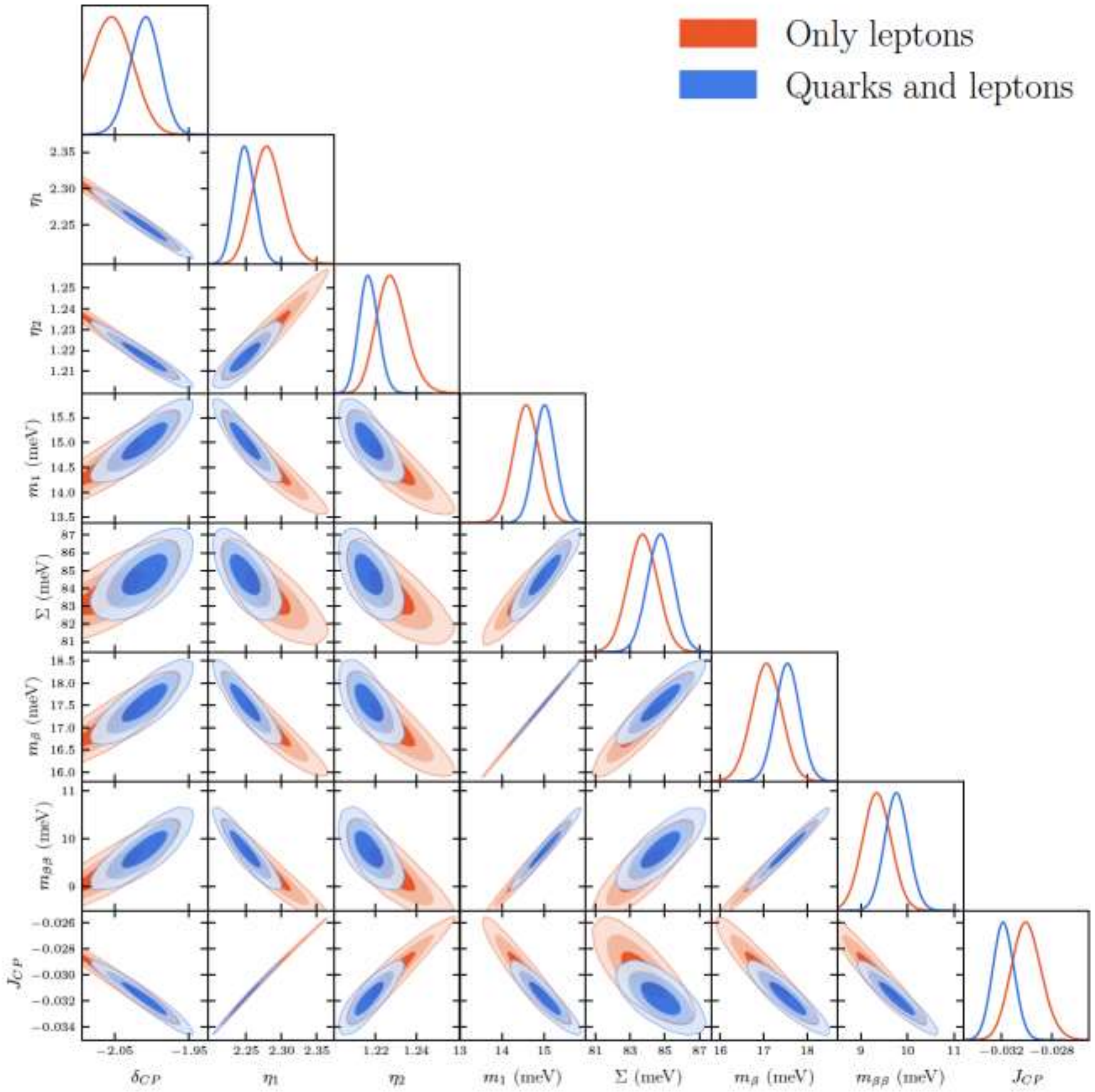
G. J. Ding, E. Lisi, A. Marrone and S. T. Petcov, ``Interplay and Correlations Between Quark and Lepton Observables in Modular Symmetry Models,'' [arXiv:2409.15823 [hep-ph]].



Only quarks
Quarks and leptons
θ^q_{12}
θ^q_{23}
θ^q_{13}
δ^q_{CP}
r_{uc}
r_{ct}
r_{ds}
r_{sb}
m_t (GeV)
m_b (GeV)



Only leptons
Quarks and leptons
$\sin^2\theta_{12}$
$\sin^2\theta_{23}$
$\sin^2\theta_{13}$
δm^2 (eV^2)
Δm^2 (eV^2)
$r_{e\mu}$
$r_{\mu\tau}$
m_τ (GeV)



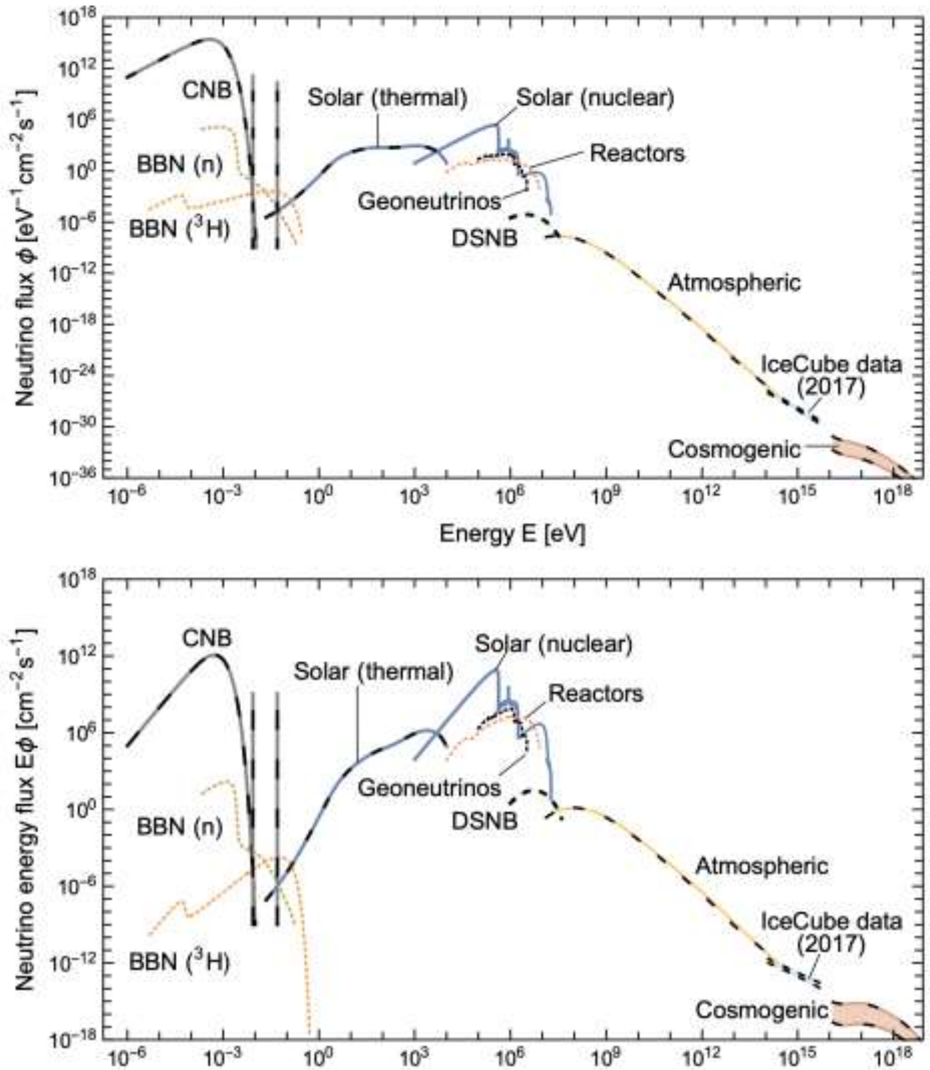
The combined analysis accommodates all quark and lepton observables very well, with theoretical values that closely match the experimental measurements.

The great advantage of the combined analysis is that it allows for a deeper understanding of the fit by examining the correlations between the model parameters and observables

WP3: SOURCES AND FLUXES OF OLD AND NEW MESSENGERS

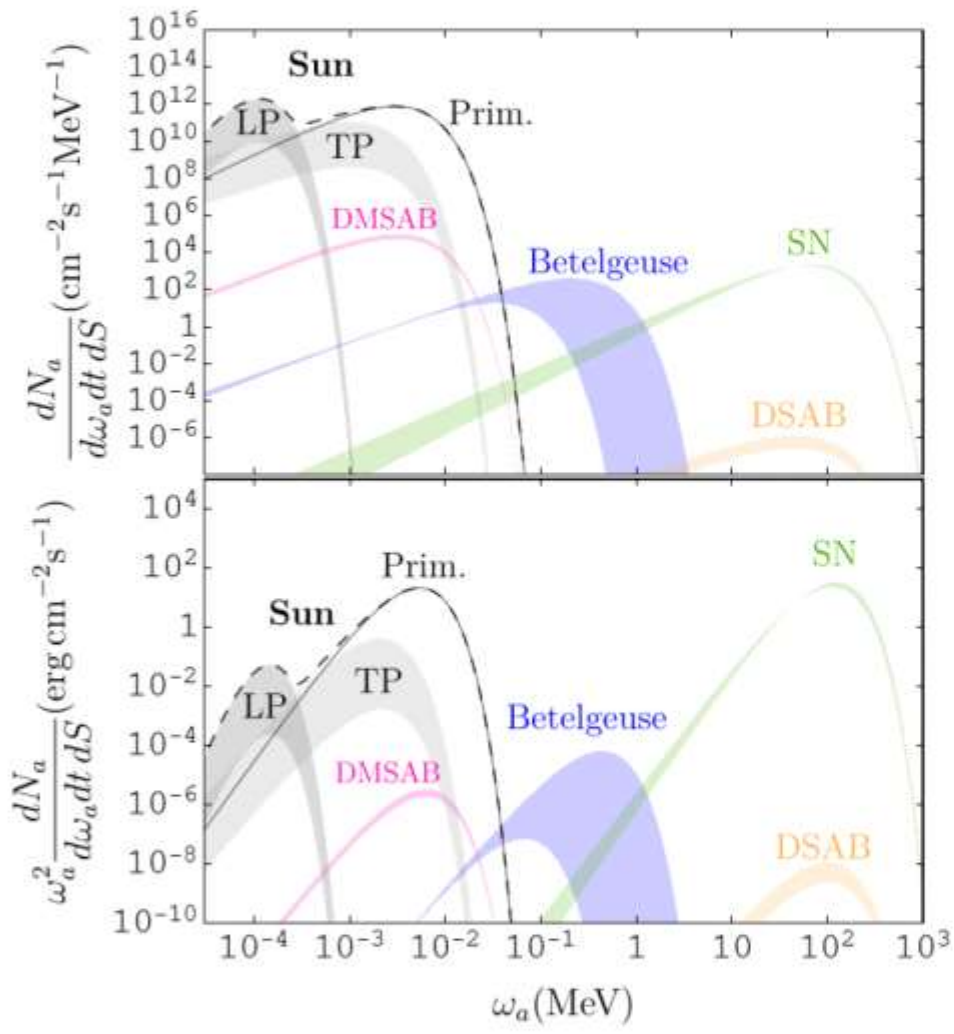
GRAND UNIFIED NEUTRINO SPECTRUM AT EARTH

[Vitagliano, Tamborra Raffelt, 1910.11878]



GRAND UNIFIED AXION SPECTRUM AT EARTH

[P. Carenza, M. Giannotti, J. Isern, A. Mirizzi, O. Straniero, review project on «Axion Astrophysics» for Physics Report]



AXION EMISSION FROM SNE

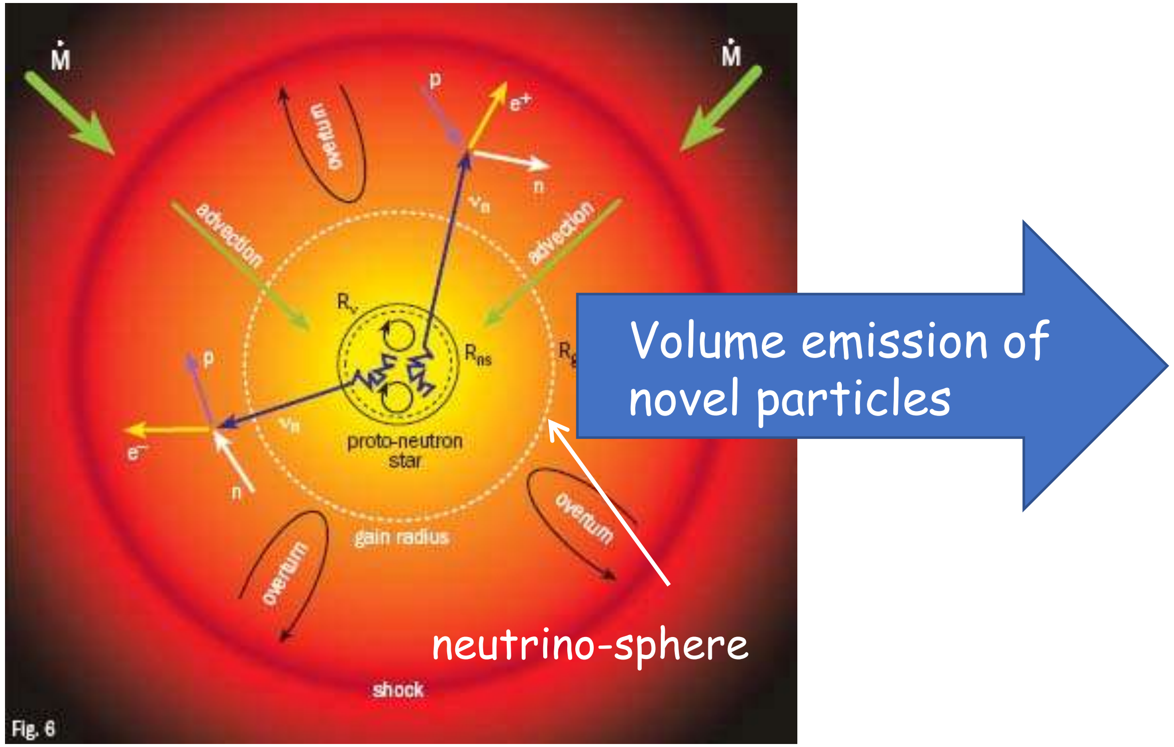


Fig. 6

Emission of axions would "steal" energy from the neutrino burst and shorten it.

Assuming that the SN 1987A neutrino burst was not shortened by more than ~½ leads to an approximate requirement on a novel energy-loss rate of

$$\varepsilon_X < 10^{19}\ \mathrm{erg\ g^{-1}\ s^{-1}}$$

" Raffelt criterium "

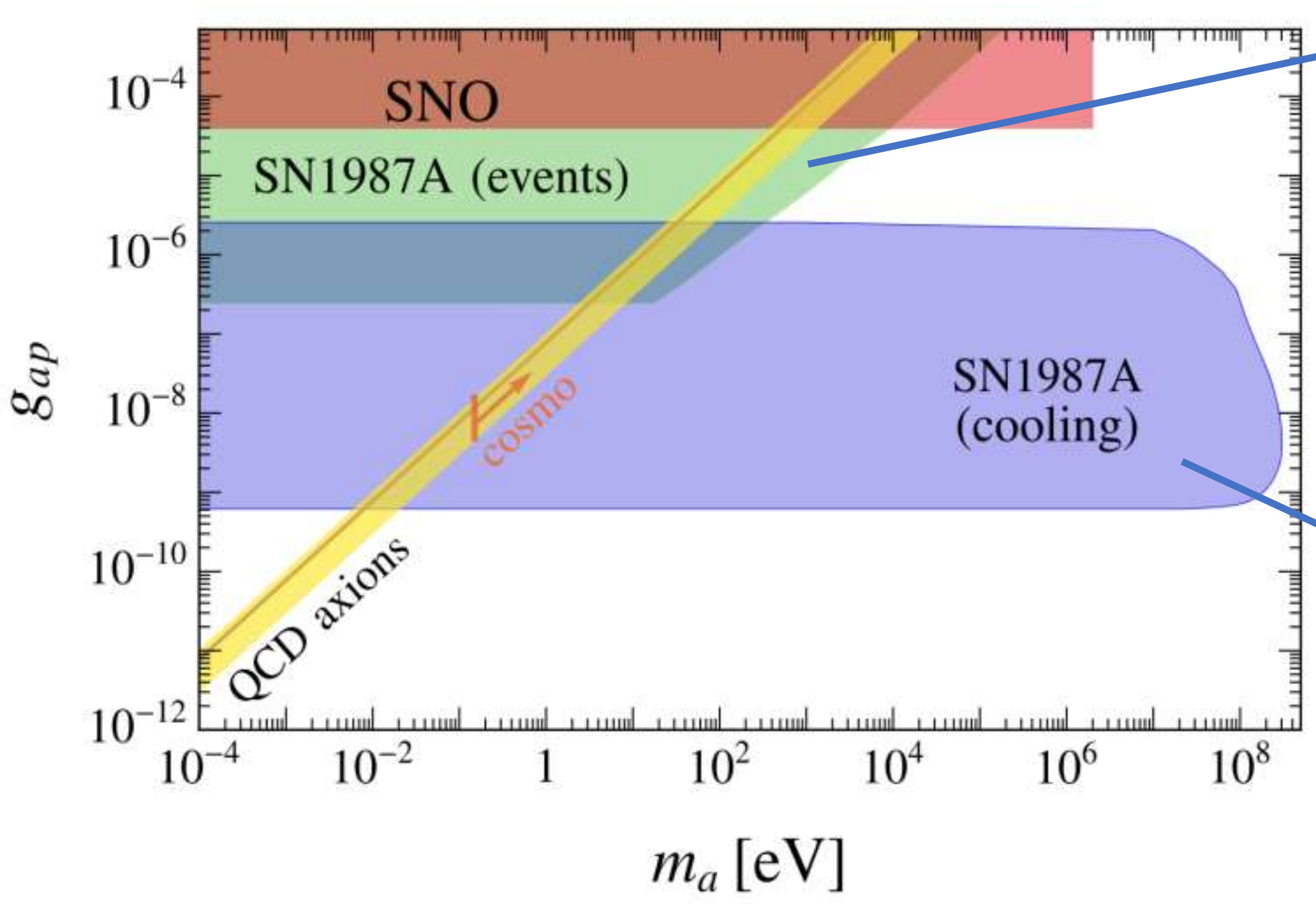
[Phys. Rept. 198, 113 (1990)]

for $\rho \approx 3 \times 10^{14}\ \mathrm{g\ cm^{-3}}$ and $T \approx 30$ MeV

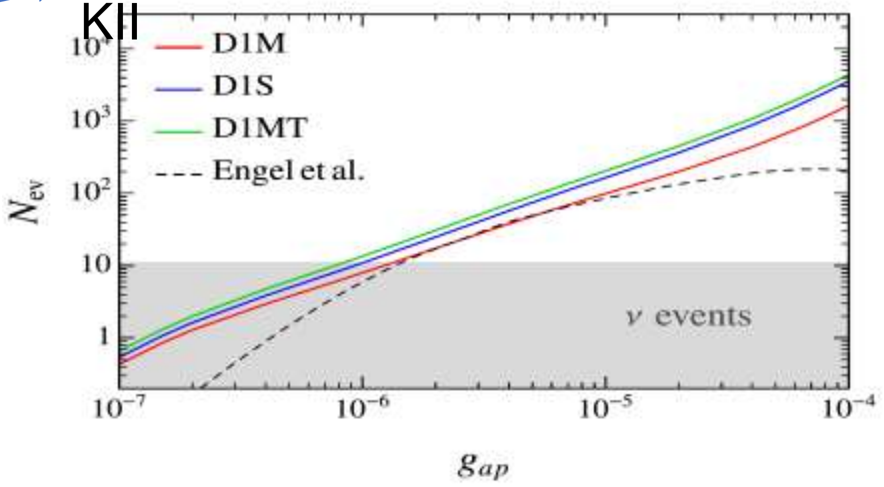
Getting the most on SN axions

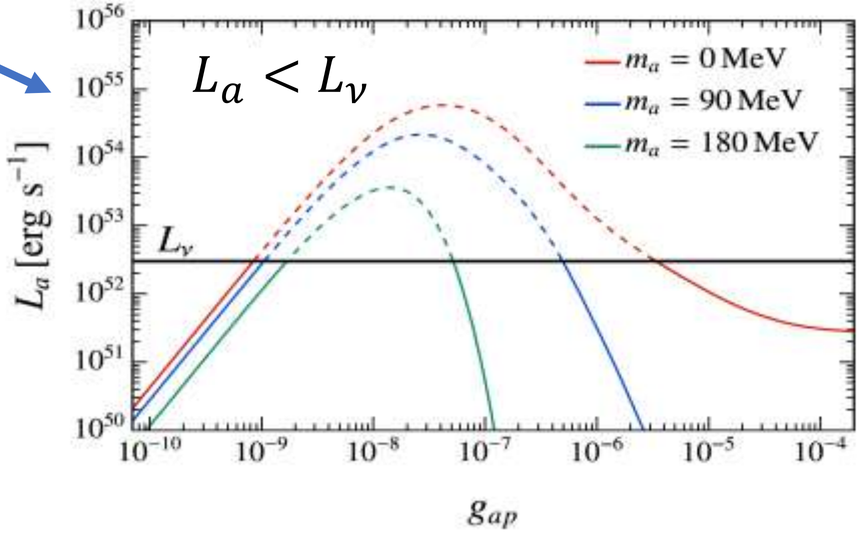
[A. Lella, G. Co', P. Carenza, G. Lucente, M. Giannotti, A. Mirizzi, T. Rauscher, Phys. Rev. D 109 (2024) 2]

Observations of the SN 1987A neutrino burst severly constrain the axion parameter space



No axion-induced event detected in KII

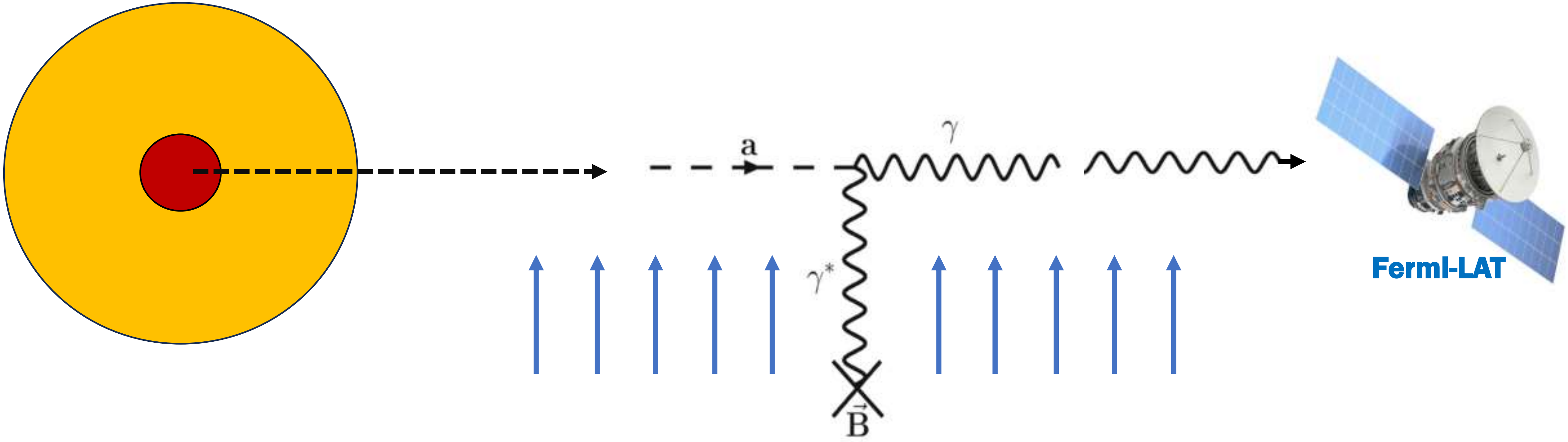




Probing protoneutron stars with γ-ray axionscopes

[A. Lella, F. Calore, P. Carenza, C. Eckner, M. Giannotti, G. Lucente, A. Mirizzi, arXiv:2405.02395 [hep-ph]]

Once emitted from SNe, ultra-light ALPs $(m_a \leq \mathcal{O}(1)\; neV)$ can convert into photons in Galactic Magnetic fields

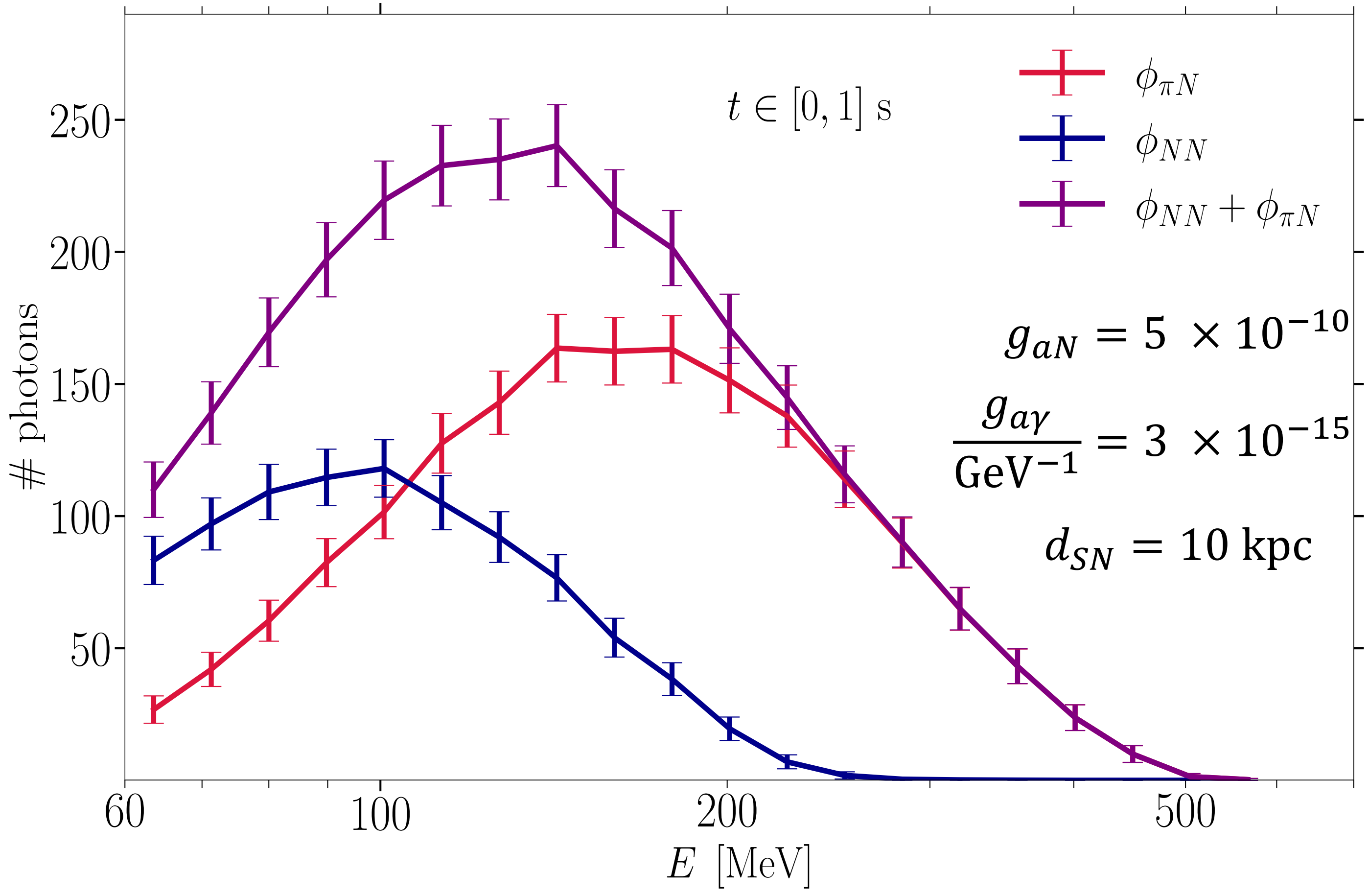


The observation of the ALP-induced γ-ray burst could probe the SN core!

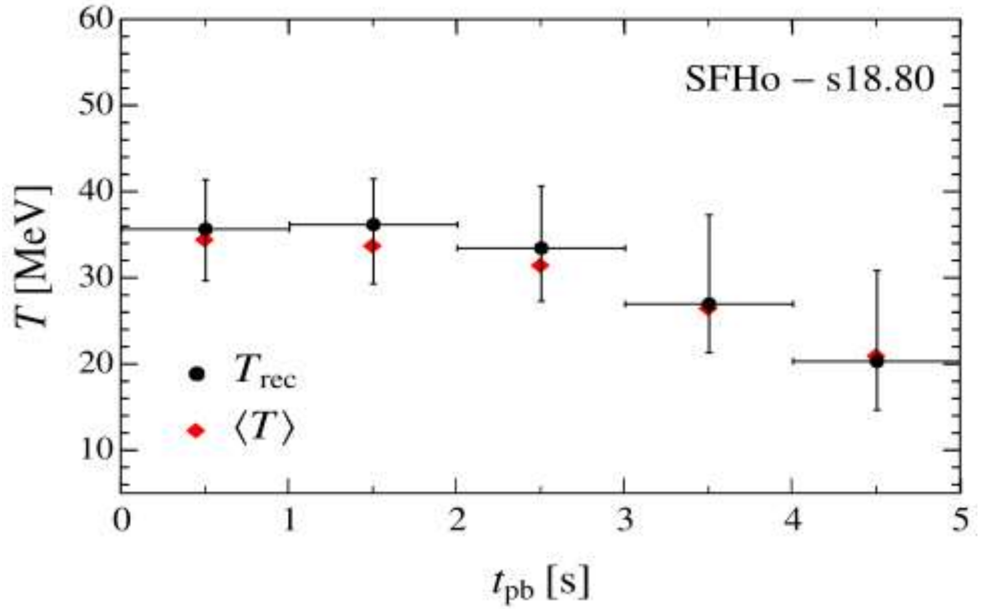
Probing protoneutron stars with γ-ray axionscopes

[A. Lella, F. Calore, P. Carenza, C. Eckner, M. Giannotti, G. Lucente, A. Mirizzi, arXiv:2405.02395 [hep-ph]]

The expected SN ALP-induced gamma-ray signal simulated with the Fermi Science Tools.

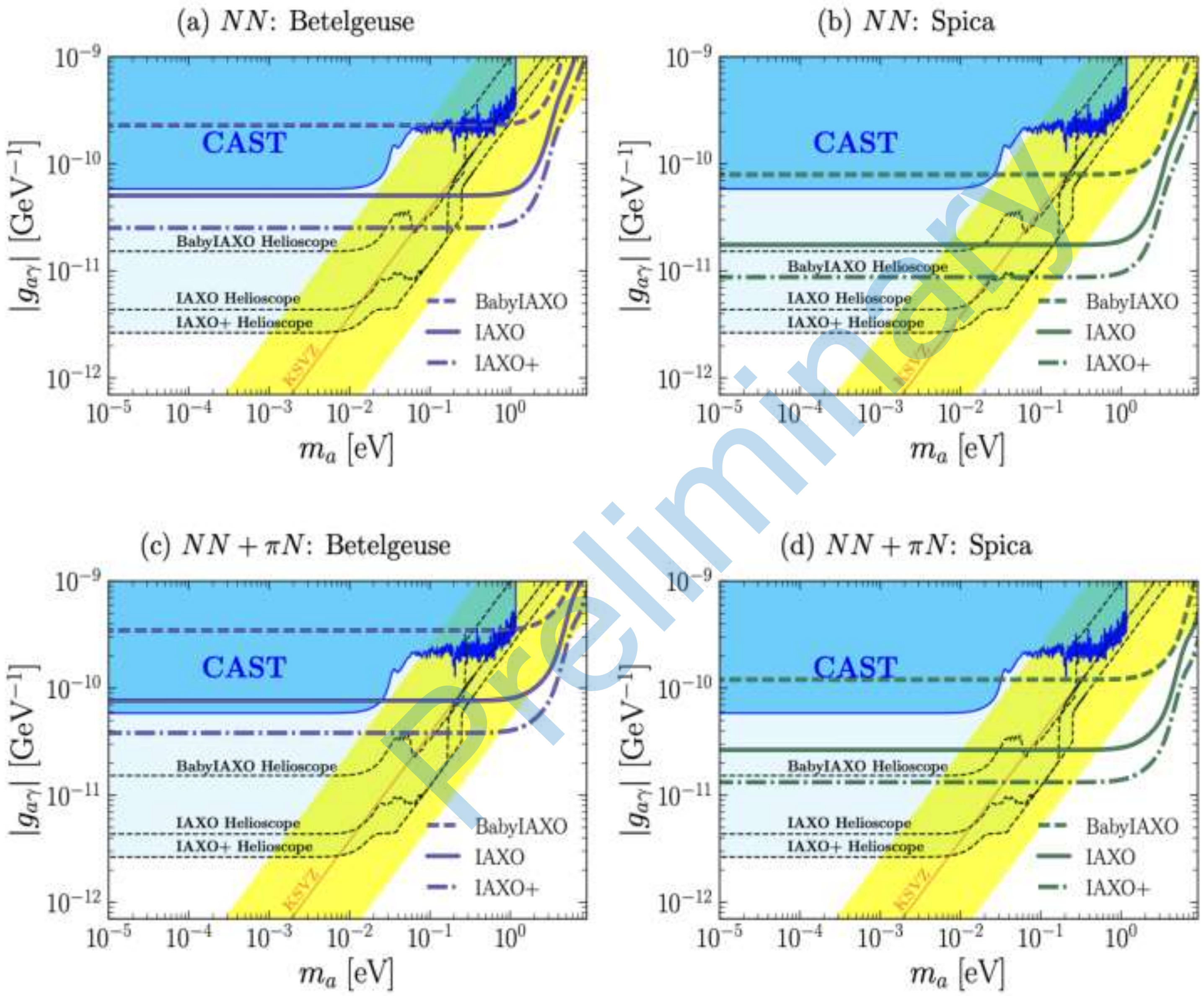


- Bayesian evidence for the presence of pions in the core
- Reconstruction of the temperature in the SN core



Detecting SN axions with IAXO

[M. Giannotti, A. Lella , A. Mirizzi, M. J. Puyuelo , J. A. Garcia Pascual, P. Carenza , M. Kaltschmidt , G. Lucente, I. G. Irastorza, A. Lindner, in



Study of the discovery potential for SN axions employing the IAXO experiment

- Based on the installation of a MeV gamma-ray detector based LiquidO technology
- Tracking system employs the early SN alert protocol (SNEWS)
- Many nearby SN candidates considered in the analysis

HEAVY STERILE NEUTRINO PRODUCTION IN THE SN CORE

[Carenza, Lucente, Mastrototaro, Mirizzi, Serpico, PRD 109 (2024) 6, 063010]

The production of $\sim O(100)$ MeV heavy sterile neutrinos in the SN core revisited including:

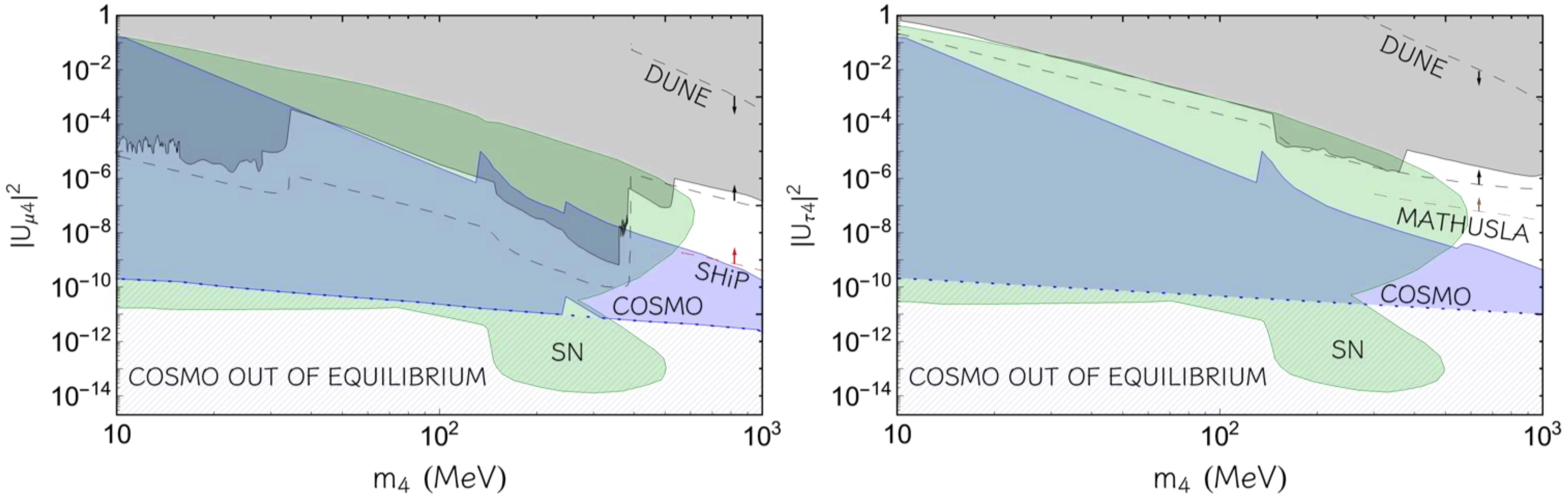
- NC interactions with nucleons (dominant process, previously neglected)
- CC interactions with muons (included only in state-of-the-art SN simulations)

Process	$\lvert U_{\alpha 4}\rvert^{-2}\lvert\mathcal{M}\rvert^2$
$\nu_\alpha + \bar{\nu}_\alpha \leftrightarrow \bar{\nu}_\alpha + \nu_4$	$64G_F^2(p_1\cdot p_3)(p_2\cdot p_4)$
$\nu_\alpha + \nu_\alpha \leftrightarrow \nu_\alpha + \nu_4$	$32G_F^2(p_1\cdot p_2)(p_3\cdot p_4)$
$\nu_\beta + \bar{\nu}_\beta \leftrightarrow \bar{\nu}_\alpha + \nu_4$	$16G_F^2(p_1\cdot p_3)(p_2\cdot p_4)$
$\nu_\alpha + \bar{\nu}_\beta \leftrightarrow \bar{\nu}_\beta + \nu_4$	$16G_F^2(p_1\cdot p_3)(p_2\cdot p_4)$
$\nu_\alpha + \nu_\beta \leftrightarrow \nu_\beta + \nu_4$	$16G_F^2(p_1\cdot p_2)(p_3\cdot p_4)$
$e^+ + e^- \leftrightarrow \bar{\nu}_\alpha + \nu_4$	$64G_F^2[\tilde{g}_L^2(p_1\cdot p_4)(p_2\cdot p_3) + g_R^2(p_1\cdot p_3)(p_2\cdot p_4) - \tilde{g}_L g_R m_e^2(p_3\cdot p_4)]$
$\nu_\alpha + e^- \leftrightarrow e^- + \nu_4$	$64G_F^2[\tilde{g}_L^2(p_1\cdot p_2)(p_3\cdot p_4) + g_R^2(p_1\cdot p_3)(p_2\cdot p_4) - \tilde{g}_L g_R m_e^2(p_1\cdot p_4)]$
$\nu_\alpha + e^+ \leftrightarrow e^+ + \nu_4$	$64G_F^2[g_L^2(p_1\cdot p_3)(p_2\cdot p_4) + \tilde{g}_R^2(p_1\cdot p_2)(p_3\cdot p_4) - \tilde{g}_L g_R m_e^2(p_1\cdot p_4)]$
$\nu_\alpha + N \leftrightarrow N + \nu_4$	$\lvert\mathcal{M}\rvert^2_{AA} + \lvert\mathcal{M}\rvert^2_{VA} + \lvert\mathcal{M}\rvert^2_{VV}$
$\mu^- + N \leftrightarrow N' + \nu_4$	$\lvert\mathcal{M}\rvert^2_{AA} + \lvert\mathcal{M}\rvert^2_{VA} + \lvert\mathcal{M}\rvert^2_{VV}$
$\mu^- + \nu_e \leftrightarrow e^- + \nu_4$	$64G_F^2(p_1\cdot p_2)(p_3\cdot p_4)$

UPDATED SN CONSTRAINTS

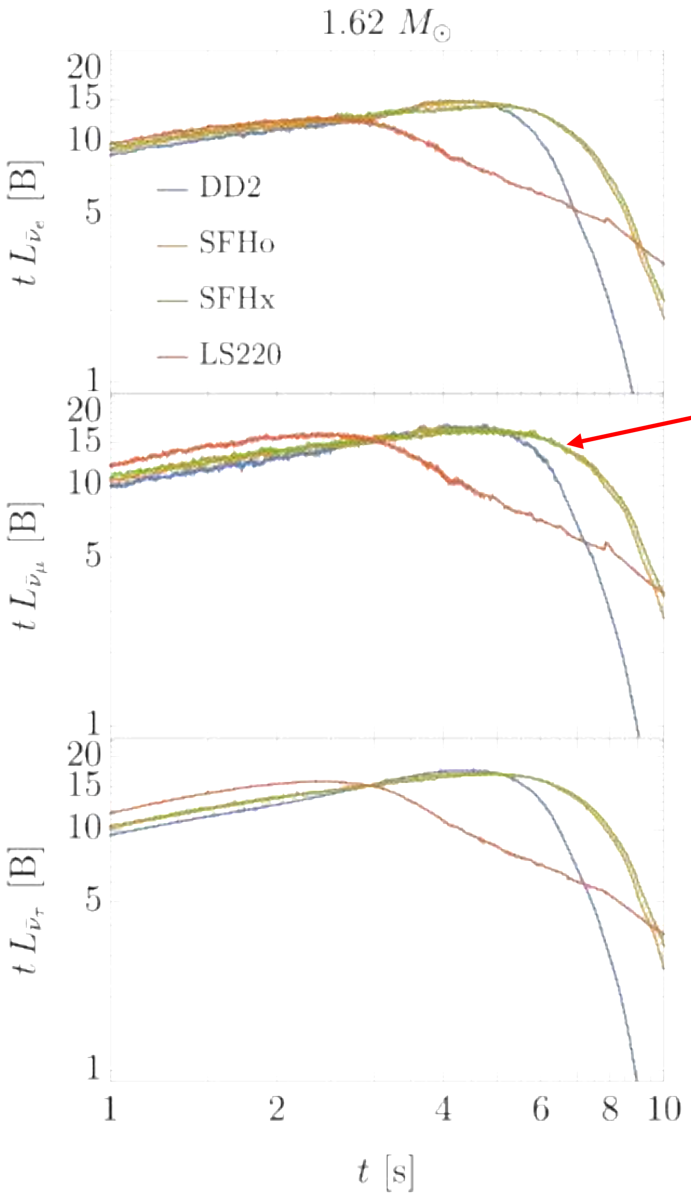
[Carenza, Lucente, Mastrototaro, Mirizzi, Serpico, PRD 109 (2024) 6, 063010]

Bounds from SN 1987A cooling and heavy ν_4 decays.



SIMPLE FITS FOR SN NEUTRINO LUMINOSITIES

[Lucente, Heinlein, Janka, Mirizzi, PRD 110 (2024) 6, 063023]

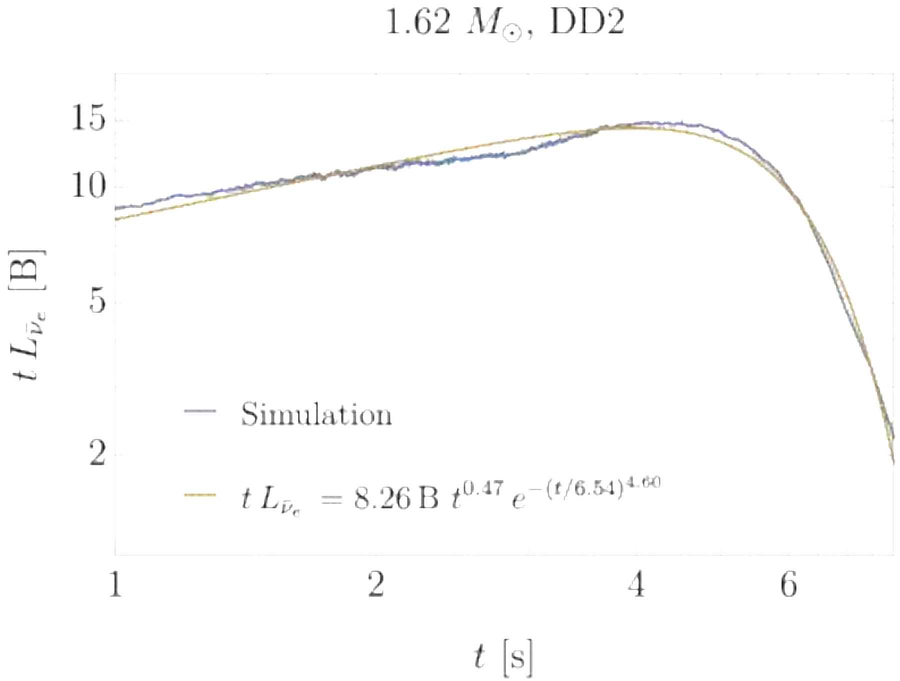


Large sample of current state-of-the-art SN simulations for different EoS and NS masses. [https://wwwmpa.mpa-garching.mpg.de/ccsnarchive//]

End of convection in the PNS mantle

$$L_\nu(t) = C\, t^{-\alpha}\, e^{-(t/\tau)^n}$$

Fit works well for all (anti)neutrino species, NS masses and EoS.



LINEAR DEPENDENCE ON THE PNS MASS

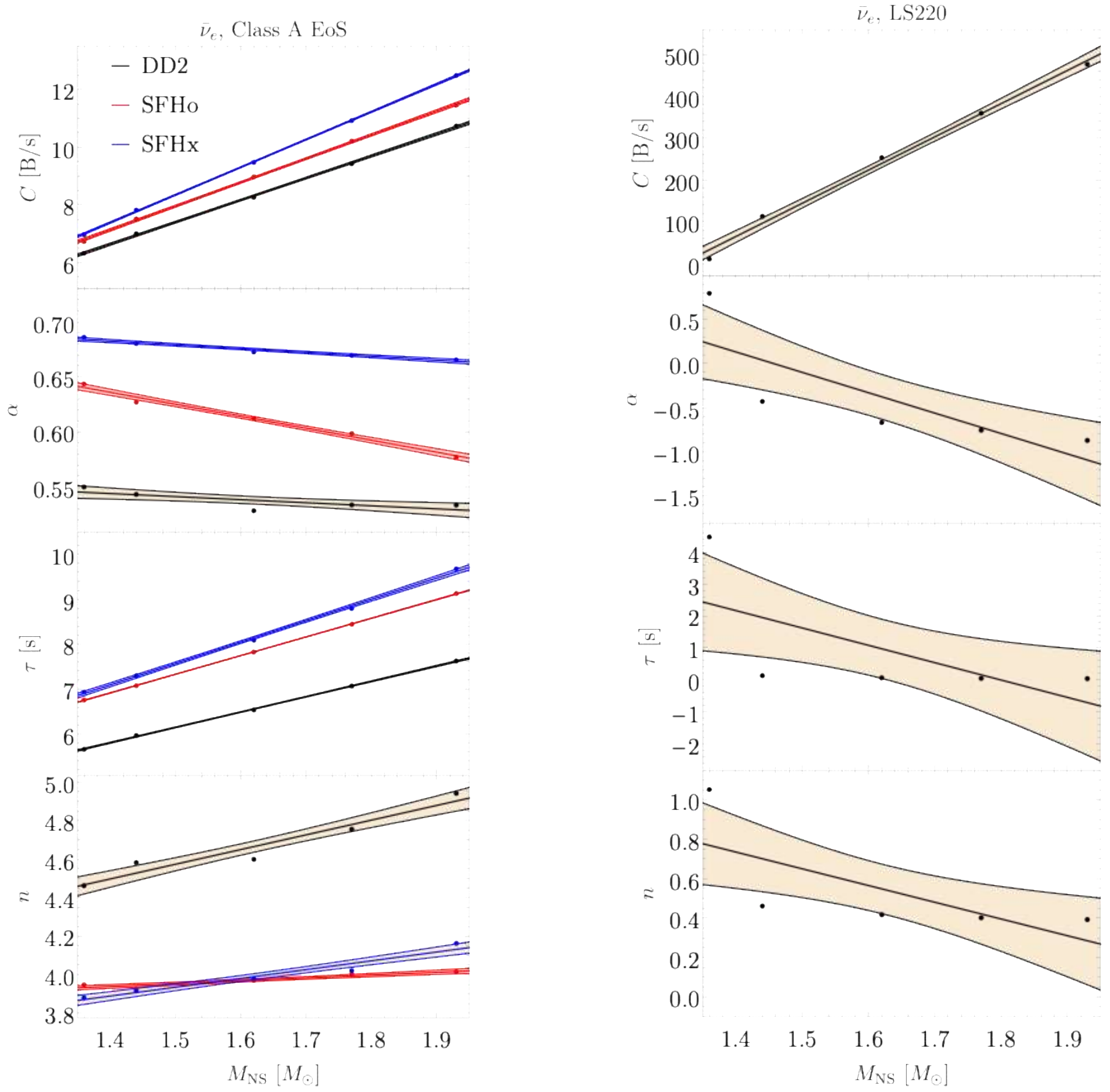
Best-fit parameters for all (anti)neutrino species linearly depend on the PNS mass.

DD2, SFHo, SFHx similar behavior.

Counting rate in neutrino detectors proportional to the neutrino luminosity.

⬇

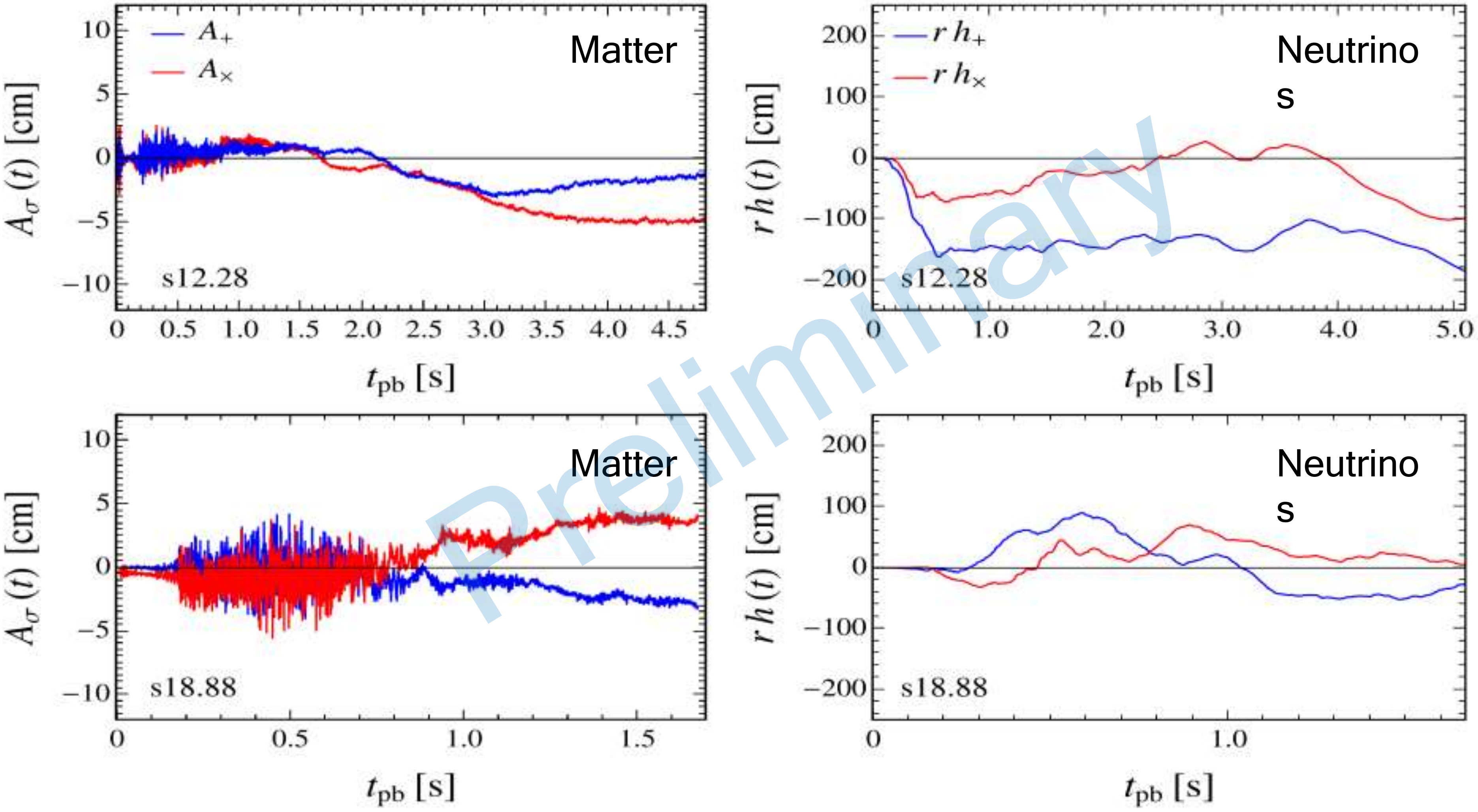
Possibility to characterize PNS mass and EoS with future observation of the neutrino signal.



Gravitational Waves from SNe

[A. Lella, H.T. Janka, D. Kresse, G. Lucente, A. Mirizzi, in preparation.]

Non radial mass flows and the anisotropic emission of neutrinos could lead to a powerful emission of GWs from a core-collapse SN.

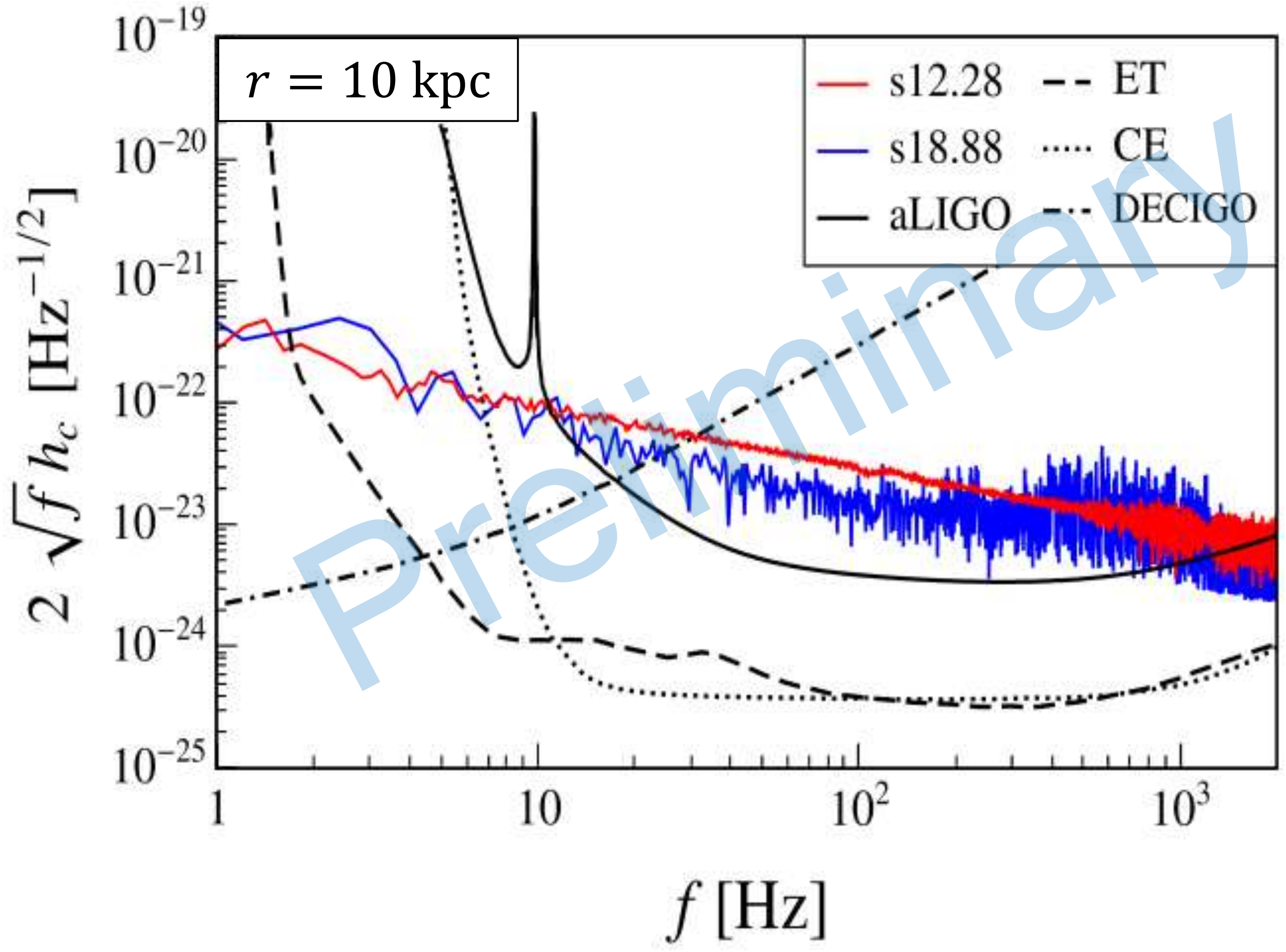


Results based on 3D
SN simulations by Garching group [Münich]

Gravitational Waves from SNe

[A. Lella, H.T. Janka, D. Kresse, G. Lucente, A. Mirizzi, in preparation]

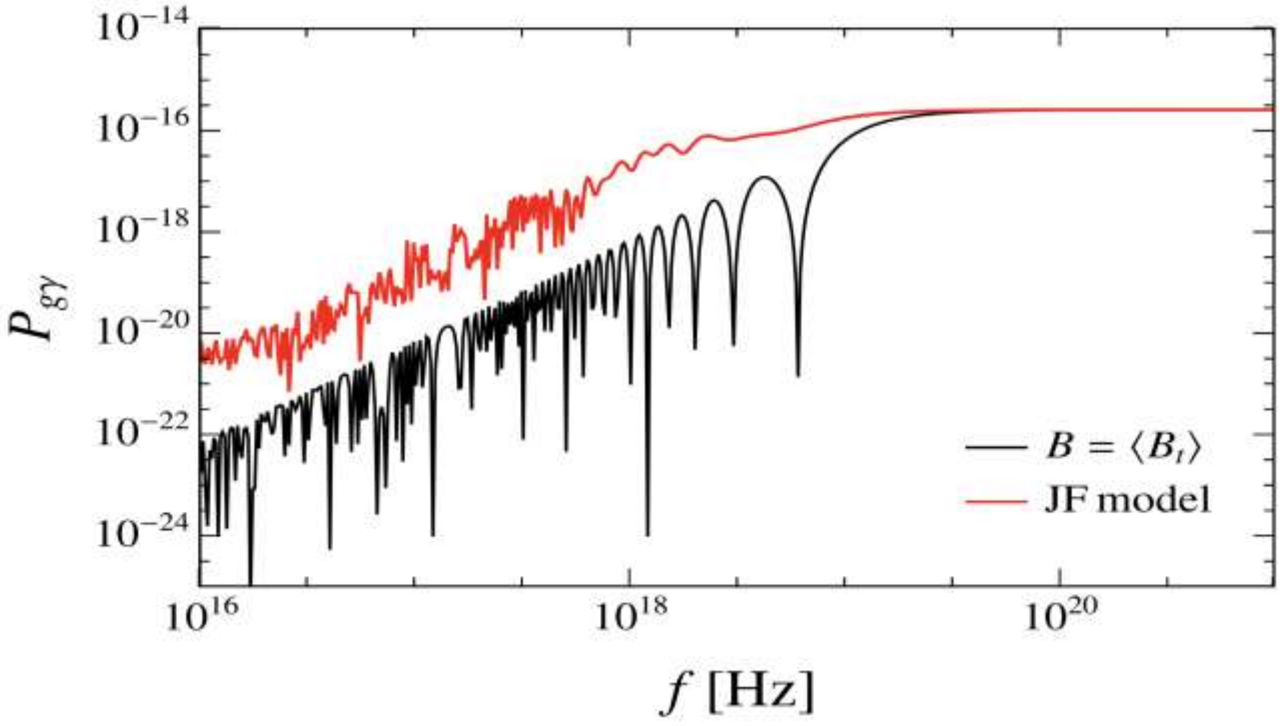
- GWs from hydro instabilities encode phases of SN explosion mechanism
- Neutrino memory GWs are related to highly time-dependent anisotropic emission
- Both matter and neutrino GWs from the next Galactic SN are in the reach of current and future GW detectors

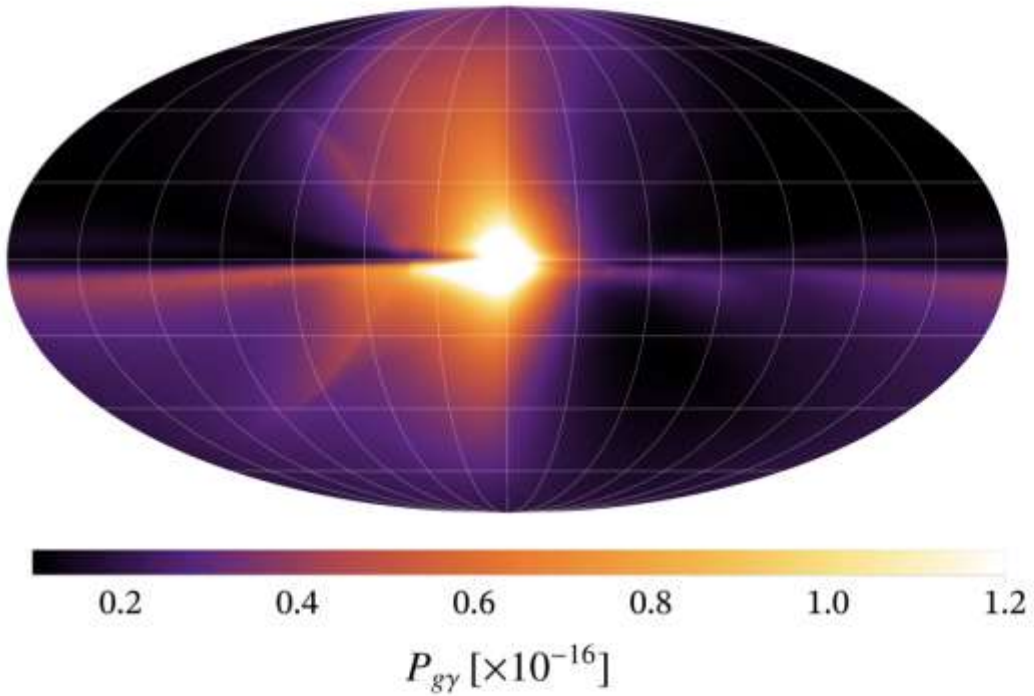


Constraining gravitational-wave backgrounds from conversions into photons in the Galactic magnetic field

[A. Lella, F. Calore, P. Carenza, A. Mirizzi, arXiv:2406.17853 [hep-ph]]

High-frequency GWs can mix with the photon field in presence of an external magnetic field

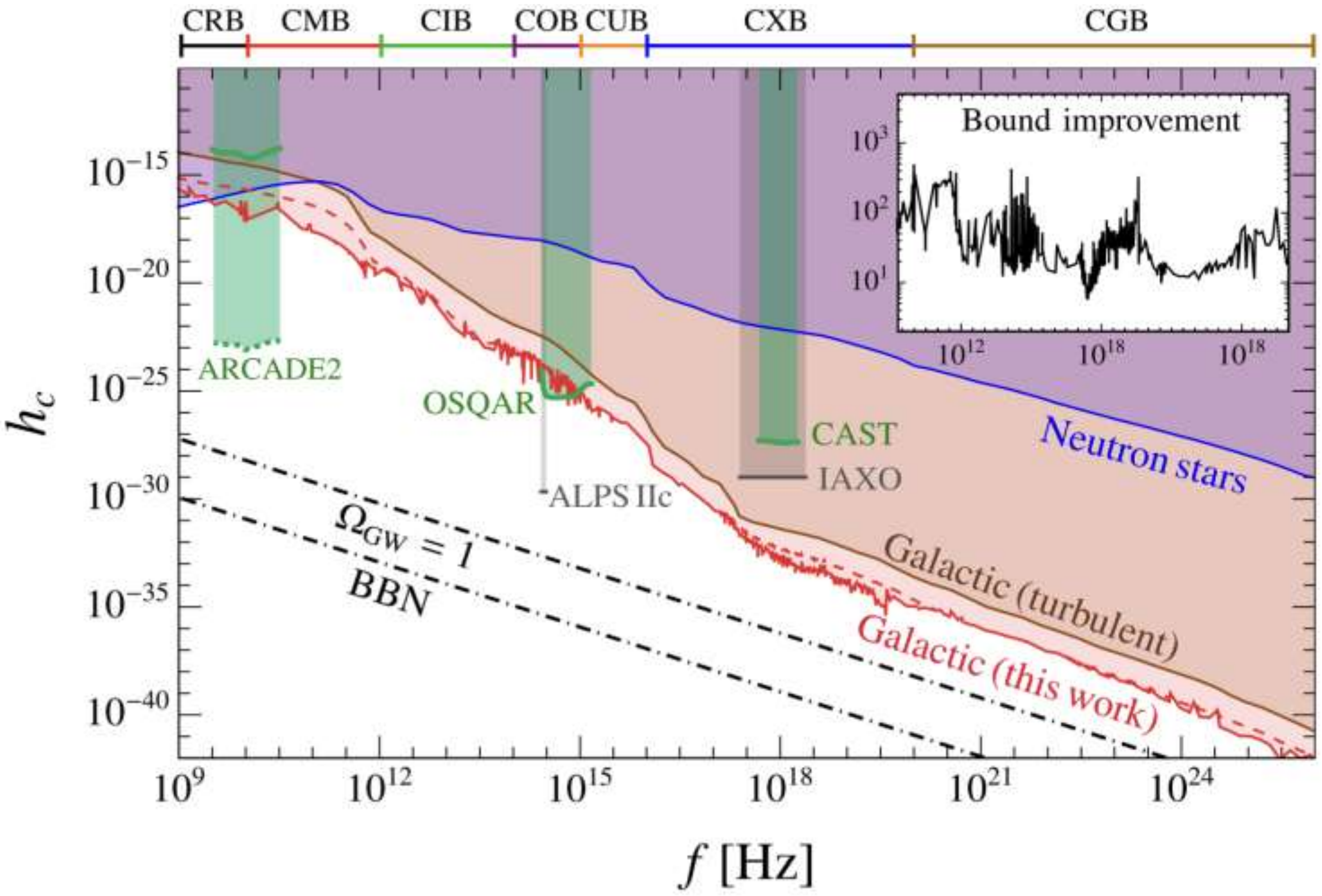




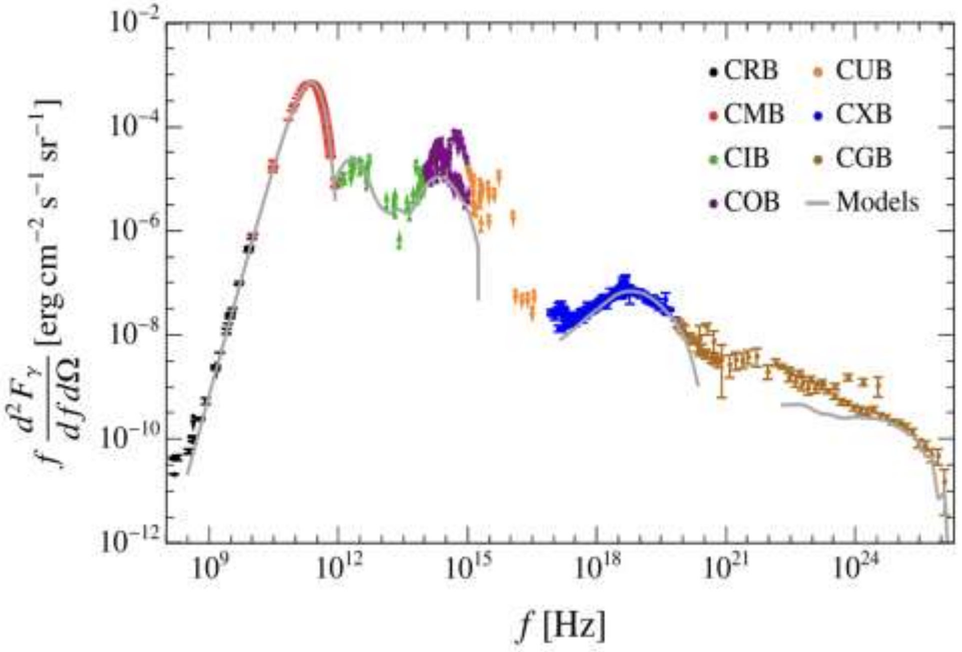
Conversions of a stochastic GW background in the Galactic magnetic field ($B_G \sim 1\ \mu$G) could produce a diffuse photon background

Constraining gravitational-wave backgrounds from conversions into photons in the Galactic magnetic field

[A. Lella, F. Calore, P. Carenza, A. Mirizzi, arXiv:2406.17853 [hep-ph]]



Observations of the CPB induce constrain on the amplitude of the GW background

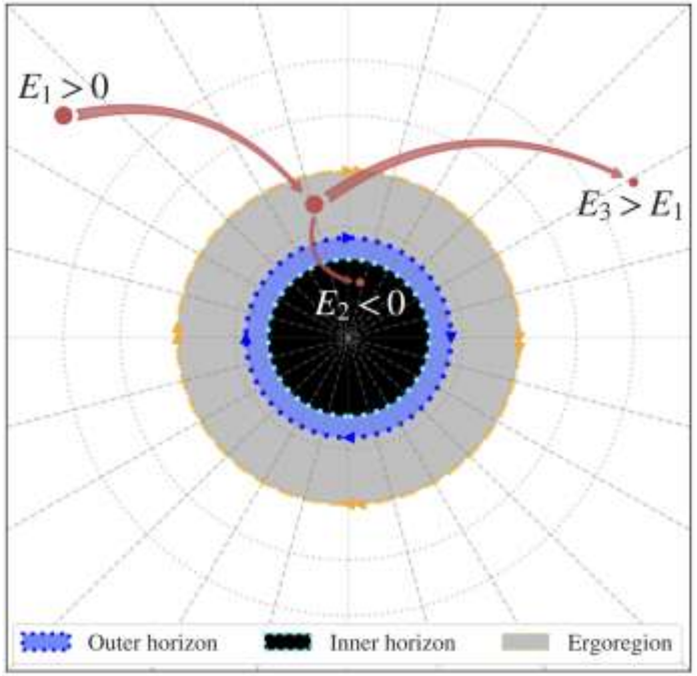


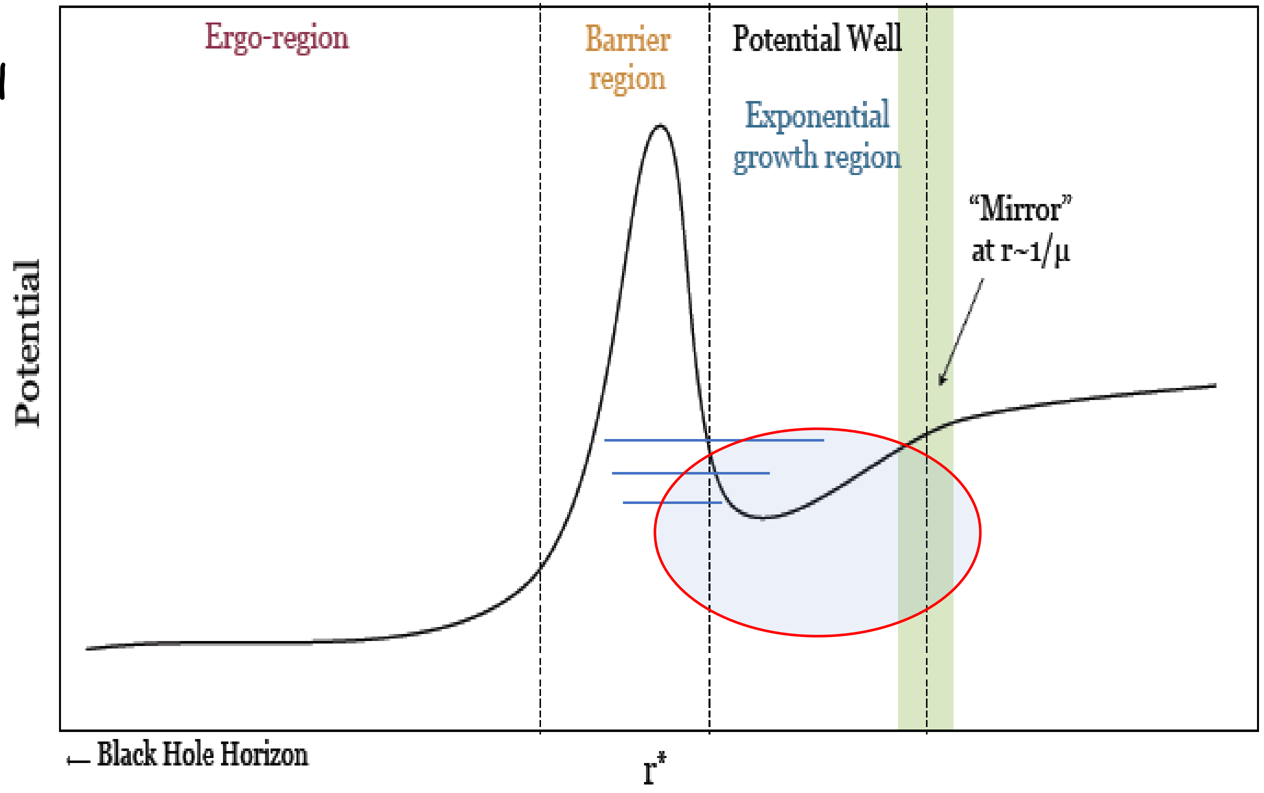
ALPs from primordial BH evaporation and superradiance

Marco Manno & Daniele Montanino (in preparation)
Università del Salento & INFN, Lecce

- Light ($M<10^8$g) primordial Black Holes (LBHs) can be produced during post-inflationary era due to fluctuations of the background and evaporate before BBN
- Hawking evaporation of LBHs can be a source of non-standard heavy particles (e.g., WIMPS) or light particles (Axions or Axion-like particles).
- In addition to Hawking evaporation (Kerr) BH can feature *superradiant instability*, allowing efficient transfer of energy and angular momentum to the surrounding environment

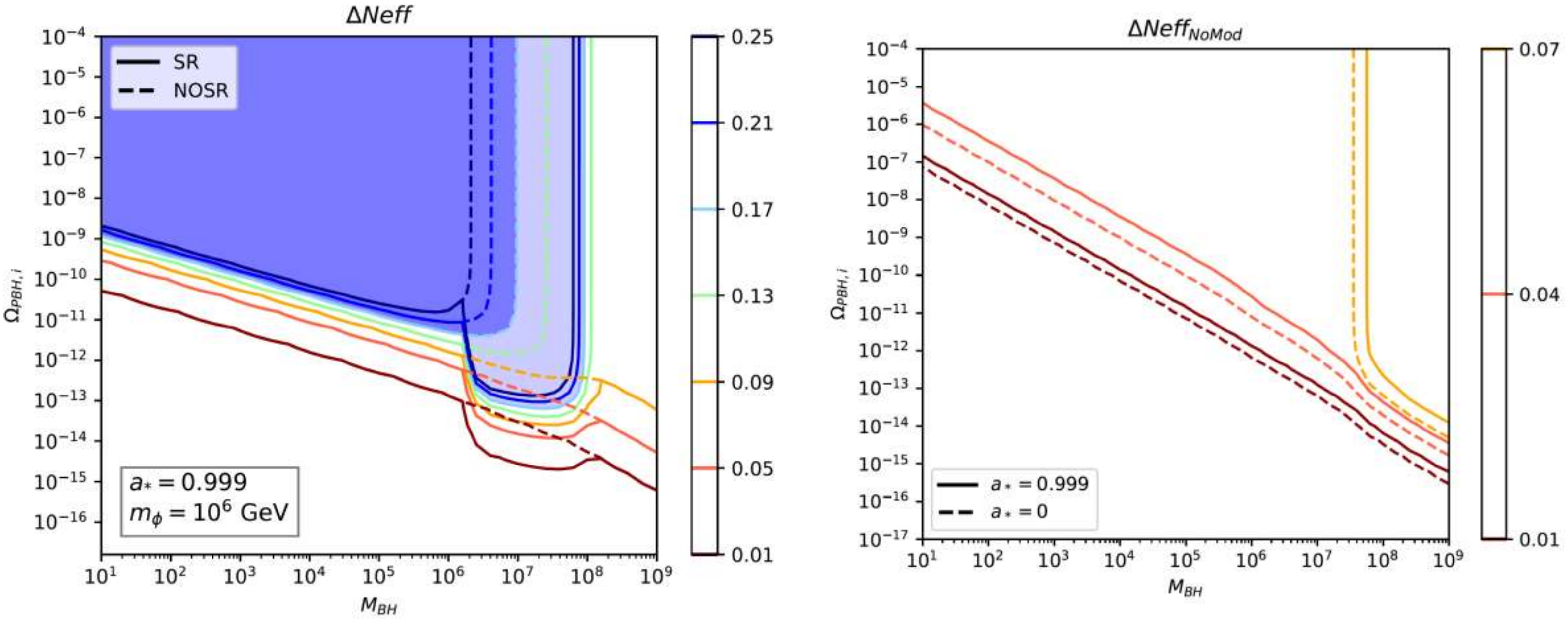
- Bosons can trap in the potential well created by the gravitational field of the spinning BH giving rise to a toroidal cloud of "gravitational atoms"
- Bosonic occupation number grows exponentially, efficiently removing angular momentum from the BH





- Massive bosons can be stable and behave as cold dark matter
- Conversely, unstable bosons can decay into standard model particle and light (m_a<1MeV) axion or axion-like particles (ALPs). This scenario was studied earlier in terms of "moduli" Φ
  - M. Cicoli, J.P. Conlon and F. Quevedo, Phys. Rev. **D87** (2013), 043520
  - C. Evoli, M. Leo, A. Mirizzi and D. Montanino, JCAP **05** (2016), 006
- Cosmological and BHs evolution by including SR in the *FRIedmann Solver for Black Hole Evaporation in the Early-universe* (FRISBHEE) available @ https://github.com/yfperezg/frisbhee

- The number of ALPs can thus be enhanced respect to the case of pure evaporation
- ALPs act as dark radiation and thus give contribution to $\Delta N_{\nu,eff}$
- Impact on cosmic reionization or other astrophysical observables from axion decay or oscillations will be studied.



ΔNeff
SR
NOSR
$a_* = 0.999$
$m_\phi = 10^6$ GeV
$\Omega_{PBH,i}$
M_{BH}
0.25
0.21
0.17
0.13
0.09
0.05
0.01
$\Delta Neff_{NoMod}$
$a_* = 0.999$
$a_* = 0$
0.07
0.04
0.01

WP4: THE STANDARD COSMOLOGICAL MODEL AND BEYOND

pre Big Bang String Cosmology:
Bouncing solutions in non-perturbative String Theory

[L. Tedesco, E. Pavone]

General criteria to have bouncing solutions using Hohm Zwiebach (HZ) action (all order α' action) starting from perturbative vacuum of String Theory

- Dilaton stabilisation, FLRW and de-Sitter attractor from non-perturbative dilaton potential

- Isotropisation mechanism via α' corrections and Dilaton potential

Ellipsoidal Universe and Cosmic Shear

In an Bianchi I Universe has been studied the most general correlation among Cosmic shear, Eccentricity and the lower quadrupole of the large-scale CMB anisotropy (*).

Next we will study the different evolution of jerk parameters in ellipsoidal universe and the connection with the Hubble tension.

(*) L. Tedesco*, Universe* **2024**, 10, 363.

CONCLUSIONS

Like dwarfs on the shoulders of giants….


LOOKING UNDER THE LAMPPOST
LOST YOUR KEYS?
YEAH, I LOST THEM OVER THERE BUT THE LIGHT'S BETTER HERE
sketchplanations