BRAND NEW BOUNDS!

Remodeling Supernova Constraints on Neutrino Magnetic Dipole Moments

Damiano F.G. Fiorillo, **Martina La Rosa** [1 2], Federico Testagrossa, Edoardo Vitagliano

[1] Università di Padova [2] INFN - sezione Padova

Motivation

The possibility that neutrinos may possess a magnetic dipole moment is one of the most intriguing indications of physics beyond the Standard Model.
Since neutrinos dominate the energetics of core-collapse supernovae, the explosion of the Type II supernova **SN1987A** provides a unique laboratory to constrain novel energy-loss mechanisms and possible extensions of the standard properties of neutrinos.

Here we present a detailed investigation of the production and emission of right-handed neutrinos and antineutrinos via helicity-flip transitions mediated by a non-zero neutrino magnetic dipole moment within the extreme conditions of the proto-neutron star core.

Dipole moment scattering in SN core

The core of our investigation is the magnetic dipole moment interaction of a Dirac neutrino with the electromagnetic field $F^{\alpha\beta}$:

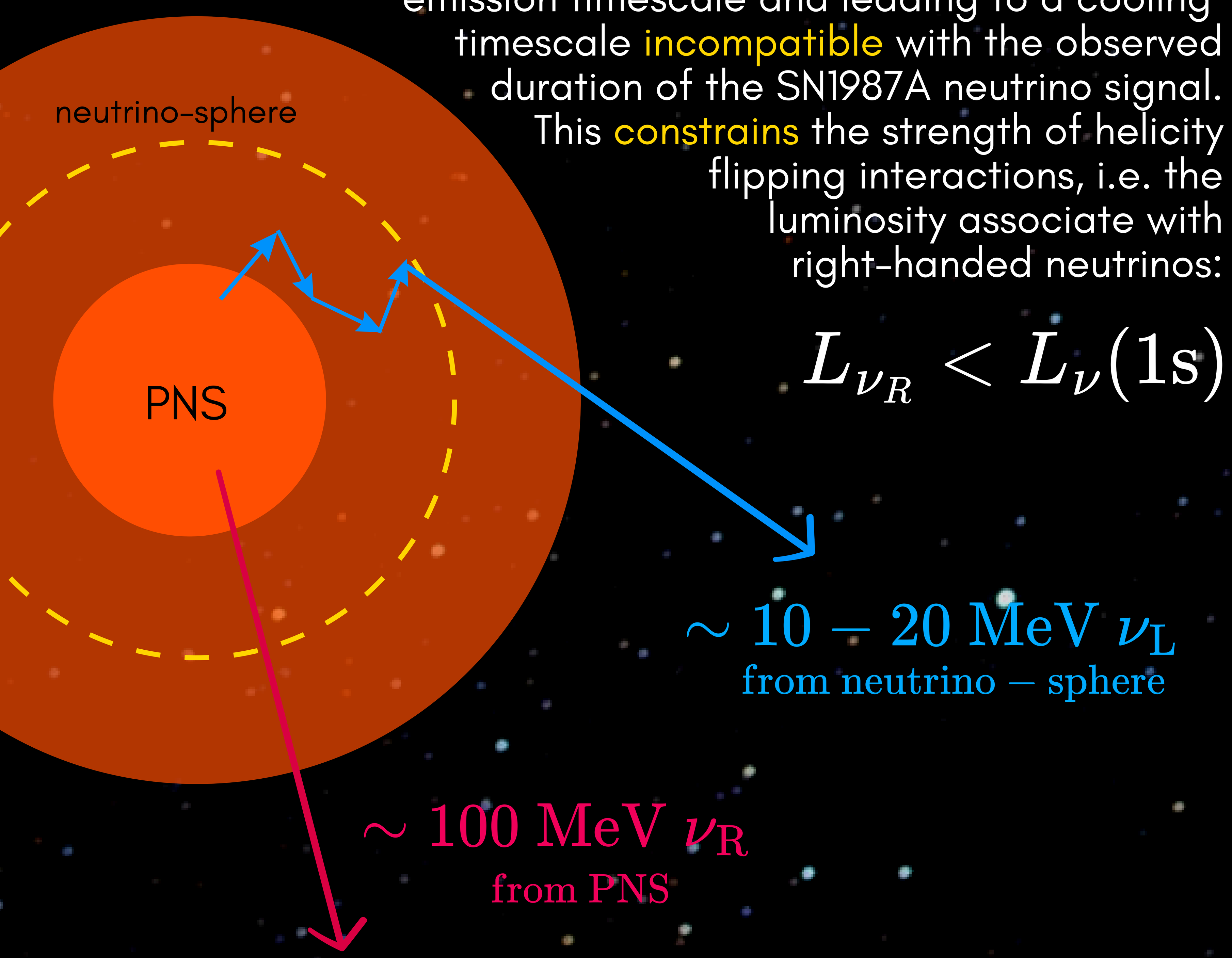
$$\mathcal{L} = \frac{1}{2}\mu_\nu \bar{\nu}\sigma_{\alpha\beta}\nu F^{\alpha\beta}$$

This results in the convertion $(\nu_L \to \nu_R)$ of trapped ν_L into free-streaming ν_R effectively opening a new channel for energy-loss.

Energy-loss

If too many right-handed neutrinos escape, the proto-neutron star loses energy too quickly, shortening the neutrino emission timescale and leading to a cooling timescale incompatible with the observed duration of the SN1987A neutrino signal. This constrains the strength of helicity flipping interactions, i.e. the luminosity associate with right-handed neutrinos:

$$L_{\nu_R} < L_\nu(1\mathrm{s})$$



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Credit: Anglo-Australian Observator

Where: *Large Magellanic Cloud*
When: *23 February 1987*
What: *Type II supernova, previously blue supergiant known as Sanduleak -69° 202*
How: *Gravitational collapse, core-collapse supernova explosion, intense neutrino burst*

Conversion in the galactic magnetic field

The right-handed (anti)neutrinos that leave the supernova can be reconverted into ν_L while propagating through the Galactic magnetic field $B_\perp$ and ultimately can be detected at Earth. The probability for a neutrino mass eigenstate μ_i to flip its helicity is:

$$P_i = |\mu_i|^2 \left| \int_D ds\, B_\perp(s) \right|^2 . \qquad \text{with } B_\perp \sim 0.2\,\mu\mathrm{G} \quad D = 49.6\,\mathrm{kpc}$$

Detection at IMB

Given this probability, we compute the fluence at Earth after reconversion for each neutrino flavour. For a given value of μ_x, we compute the fluence $\mathrm{F}(\mu_x)$ over a 10 s time window. From this, we determine the total number of expected events in the IMB detector, the largest detector that observed SN 1987A.

Results

IMB did not detect any events above 40 MeV at the time of the neutrino arrival. This allows us to set an upper limit on the values of the magnetic dipole moment parameter μ_x.
These represent the preliminary **most stringent bounds** on the neutrino magnetic dipole moments:

$$\mu_{ee} = 3.5 \times 10^{-13}\mu_B \qquad \mu_{\bar{e}\bar{e}} = 0.80 \times 10^{-12}\mu_B$$

$$\mu_{\mu\mu} = 1.04 \times 10^{-12}\mu_B \qquad \mu_{\bar{\mu}\bar{\mu}} = 0.84 \times 10^{-12}\mu_B$$

$$\mu_{\tau\tau} = 0.94 \times 10^{-12}\mu_B \qquad \mu_{\bar{\tau}\bar{\tau}} = 1.08 \times 10^{-12}\mu_B$$

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