IL NUOVO CIMENTO **47 C** (2024) 303
DOI 10.1393/ncc/i2024-24303-9

COMMUNICATIONS: SIF Congress 2023

Supernova neutrinos at the RES-NOVA experiment

A. L. DE SANTIS
Gran Sasso Science Institute - 67100 L'Aquila, Italy

received 31 January 2024

Summary. — Core-collapse Supernovae (SN) correspond to the death of massive stars, and are among the most energetic events in the universe. During their collapse, stars emit most of their energy in the form of neutrinos in a short burst. These particles allow us to directly access processes happening inside the stellar nucleus. A particularly interesting process to detect these astrophysical neutrinos is the coherent elastic neutrino-nucleus scattering (CEνVS). This process is characterized by a very high cross-section and detected signals in the keV range. The RES-NOVA experiment aims to measure these neutrinos using CEνVS through a revolutionary approach: an array of cryogenic detectors. To satisfy experimental requirements, RES-NOVA intends to use $PbWO_4$ crystals as absorbers operated at temperatures of the order of a few mK. Lead, on top of maximizing the CEνVS cross-section, will also be of archaeological origins to guarantee an extremely low background in the region of interest. These features will allow RES-NOVA to play an important complementary role in the detection of the next galactic supernova through an excellent energy resolution and high sensitivity to all neutrino flavors.

1. – Detection of SN-ν through CEνVS

Current neutrino observatories are sensitive mainly to ν_e and $\bar{\nu_e}$ through inverse beta decay (IBD) and electron elastic scattering (ES). However, during a SN explosion it is estimated that the star's binding energy is distributed evenly among all neutrino flavors [1]. In fig. 1(a) and (b) the time dependent luminosity and average energy of the neutrinos are shown. While there is a very short burst of $\bar{\nu_e}$ of a few ms over the ~ 10 s of the explosion the number of neutrinos equalizes giving the equipartition of energies among flavors. Therefore a detector that in equally sensitive to all neutrino flavors is crucial in understanding these complex events. RES-NOVA in particular aims to fill this gap through the use of the coherent elastic neutrino-nucleus scattering CEνVS [2]. This is a purely Neutral Current (NC) process making it sensitive to all neutrino and anti-neutrino flavors equally. This interaction is particularly efficient for heavy nuclei as the cross-section scales with the squared of the neutron number of the target. For Pb this results in a cross-section at least 10^2 larger than IBD (fig. 1(c)), opening the possibility of high-statistics SN-ν observation with a small-scale detector, equally sensitive to all flavors.

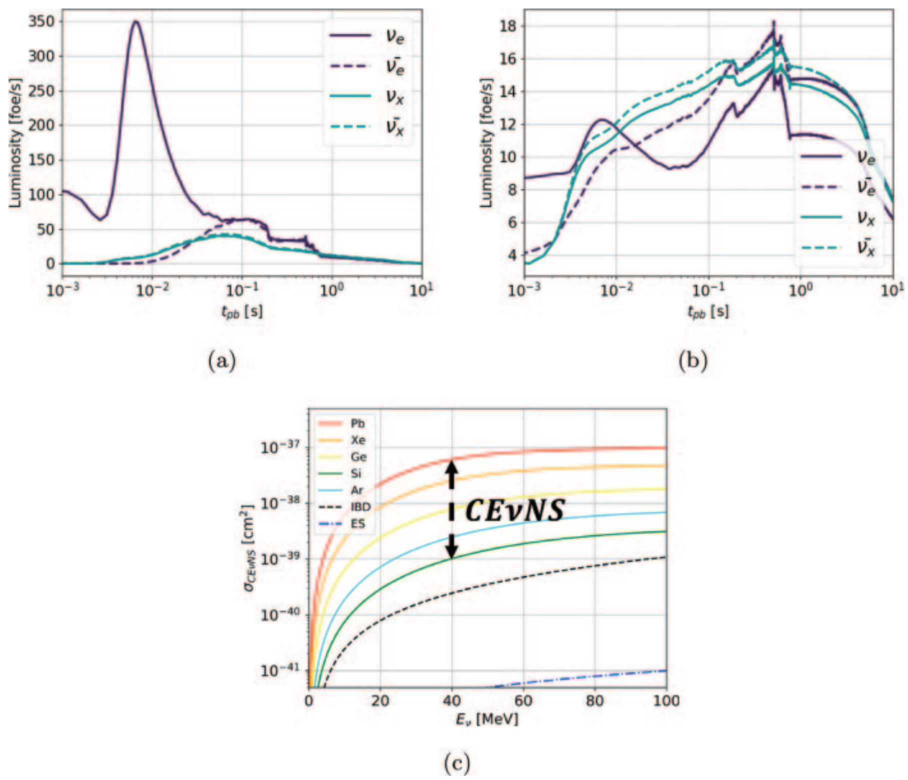
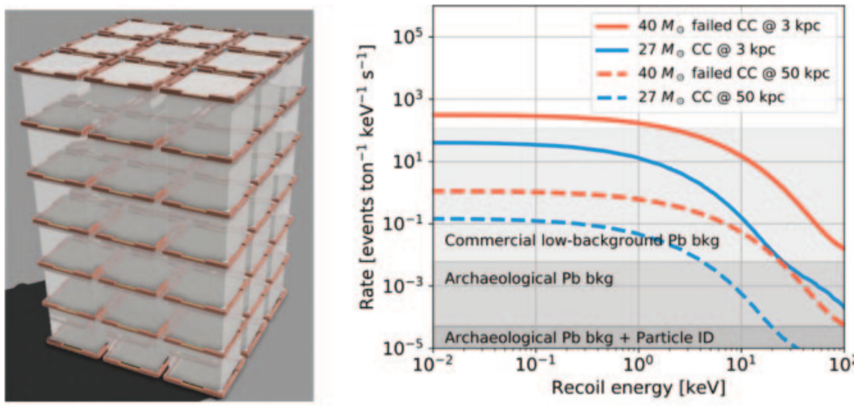


Fig. 1. – The expected ν luminosity (a) and average energy (b) for a 27 Solar Mass Core Collapse Supernova and the comparison between CEνNS cross-sections with IBD and ES (c).

Since the experimental signature of CEνNS is a nuclear recoil, detectors with a low-energy threshold of ≈1 keV are required. The requirement of Pb-based detectors with such a low-energy threshold can be addressed by low-temperature calorimeters operating at the mK scale [3].

2. – RES-NOVA demonstrator

The RES-NOVA demonstrator (fig. 2(a)) is a proposed ν observatory that will exploit archeological Lead based crystals used as cryogenic bolometers to detect supernova νs through CEνNS. The RES-NOVA demonstrator will consist in an array of 54 ^{arch}PbWO$_4$ crystals operated at around $T \sim O$(mK). For a total mass of 140 kg and a very compact detector with linear dimensions of about 30 cm. Transition Edge Sensors (TES) [3] will be used to read-out the detectors. Recent measurements have shown that ^{arch}PbWO$_4$ crystals paired with TES can reach an energy threshold of 300 eV, well below the 1 keV threshold that is required for the demonstrator. The detector is expected to have a fast time resolution of $\sim 100\ \mu$s, which significantly reduces pile-up in the case of a nearby SN detection, allows multiplicity analysis to reduce crystal background [4] and it provides a prompt alert to the community in case of a SN event [5]. RES-NOVA will be installed underground at the Gran Sasso National Laboratory (Italy) to suppress the cosmic ray-induced background. To further decrease the background in the region of interest of



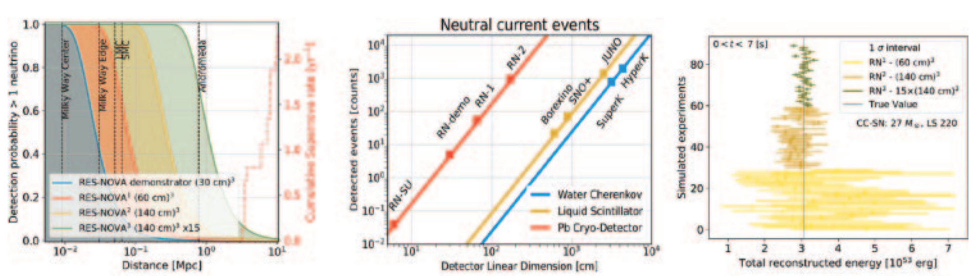
(a) (b)

Fig. 2. – The RES-NOVA Demonstrator (a) and the expected signal compared to various background hypothesis (b).

the detector ($\leq$ 30 keV), archeological Pb is used in the crystal growth. Commercial $PbWO_4$ have a significant background contribution from ^{210}Pb. However, ancient Roman lead that has already gone through purification and is more than 2000 years old shows extremely reduced background levels, reaching activities as low as 715 μBq/kg for ^{210}Pb [6]. Compared to other commercial low background Pb, only ^{arch}Pb can meet the stringent RES-NOVA target background index of $10^{-3}\frac{\text{counts}}{\text{keV}\cdot\text{ton}\cdot\text{s}}$ (see fig. 2(b)).

3. – Sensitivy

Despite the small size of the demonstrator, the low crystal background and high CEνNS cross-section give the detector a sensitivity to 90% of the galactic supernova candidates (fig. 3(a)) [7]. In order to increase the sensitivity to farther SN candidates, the future upgrades of RES-NOVA will focus on scaling up the active volume of the detector (fig. 3(b)). While there are currently other detectors sensitive to NC interactions, the vast majority of events within the RES-NOVA detector will be exclusively CEνNS, allowing



(a) (b) (c)

Fig. 3. – The RES-NOVA sensitivity for various stages (a) and the corresponding expected total neutral current events compared to other neutrino detectors (b). The reconstructed energy for a number of simulations is shown in (c) for the 3 RES-NOVA stages.

the detector an excellent precision on the reconstruction of the total energy emitted during a SN event (see fig. 3(c)).

4. – Conclusions

RES-NOVA is a newly proposed observatory for SN-ν, which will exploit CEνNS and ^{arch}PbWO$_4$ low-temperature calorimeters for intrinsic background suppression. CEνNS' high cross-section on Pb will allow highly-compact detectors equally sensitive to all neutrino flavors. This sensitivity will allow an unprecedented sensitivity to the total energy emitted by a SNe. RES-NOVA can therefore contribute in a complementary way to the existing SN-ν observatories to the first simultaneous detection of gravitational waves, electromagnetic counterpart and neutrino signals coming from a SNe, leading to major breakthroughs in multi-messenger astronomy. At the present time, RES-NOVA is the only European planned neutrino observatory solely dedicated for SNe neutrino studies.

REFERENCES

[1] Mirizzi A. *et al.*, *Riv. Nuovo Cimento*, **39** (2016) 1.
[2] Cadeddu M., Dordei F. and Giunti C., *EPL*, **143** (2023) 34001.
[3] Azzolini O. *et al.*, *Eur. Phys. J. C*, **78** (2018) 734.
[4] Pattavina L. *et al.*, *J. Cosmol. Astropart. Phys.*, **10** (2021) 064.
[5] Eller P. *et al.*, *J. Cosmol. Astropart. Phys.*, **10** (2022) 024.
[6] Pattavina L. *et al.*, *Eur. Phys. J. A*, **55** (2019) 127.
[7] Pattavina L., Nahuel Ferreiro I. and Tamborra I., *Phys. Rev. D*, **102** (2020) 063001.