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SUPERNOVA NEUTRINOS: UNVEILING THE HIDDEN INTERIOR OF THE STELLAR CORE-COLLAPSE

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RESUMEN

En este trabajo enumeramos y explicamos brevemente algunas de las piezas de información que sobre la física del colapso estelar y las propiedades de los neutrinos pueden ser obtenidas del estudio de señales de neutrinos desde supernovas con una alta estadística en detectores del presente y el futuro. Conjuntamente con la detección de ondas gravitacionales desde fuentes astrofísicas, los neutrinos desde las supernovas abrirán seguramente una nueva era en la Astronomía, la era de una verdadera Astronomía invisible.

ABSTRACT

We enumerate and briefly explain some of the potential information about core-collapse physics and neutrino properties that could be obtained from high statistics neutrino supernova signals in present and future detectors. Together with the still expected successful detection of gravitational waves from astrophysical sources, supernova neutrinos will open a new age in astronomy, the age of a real invisible astronomy.

Key Words: neutrinos — supernovae: general

Since the detection and successful analysis of neutrinos from SN1987A the potential that the study of the emission of neutrinos from stellar core-collapse has to yield information about neutrino properties on one hand and supernova physics on the other hand is fully recognized and has been tested in different ways.

The last Galactic Supernova was recorded by Tycho and Kepler in 1604. With an estimated frequency of 1-2 SNe/century in the Milky Way (Reed 2005) it could be likely that the next Galactic Supernova appears in any moment. But only in the last 30 years large neutrino detectors capable to catch signals from an invisible Supernova in the other side of the Galaxy has been operative. Therefore a SN closer than 10–20 kpc did not explode in the last three decades and the probability for such an event in the next 10–20 years is high.

Explosion models. The detailed statistical analysis by Loredo and Lamb of the signal from SN1987A (Loredo & Lamb 2002) has made evident the huge potential that a neutrino signal have to give us information about the events during and after the stellar core collapse. In their work Loredo and Lamb using a signal with just 20 events found evidence of a two component flux model as expected from a delayed explosion mechanism. More recently we have applied similar statistical analysis on synthetic signals from a future Galactic supernova (Nardi & Zuluaga 2005; Zuluaga 2005). The results confirm the very high sensitivity to the flux evolution obtained from the study of these signals

Supernova shock wave propagation. The detailed study of the effects that the shock wave has in the neutrino spectra could bring us information about the structure of the shocked regions and reveal for example the existence of a reverse shock created by the neutrino heated material behind the outgoing supernova shock (Tomàs et al. 2004).

When neutrino propagates through the collapsing matter of the supernova they find two resonance conversion regions where depending on several physical properties (neutrino mixing angles and mass hierarchy) the spectra of different neutrino flavors mix. The neutrino oscillation dynamics and its dependence upon the properties of the stellar matter where it happens gives the chance to study the shock wave effect at different positions through the mantle and then the space properties of the shock wave (see Figure 1).

Using a more detailed study of the neutrino signal, the density profile behind the shock wave could be reconstructed (Dasgupta & Dighe 2007). Methods like this could provide the first approximation to a real neutrino tomography of the supernova interior.

Neutrino properties. Neutrinos coming from a supernova (in almost any number) could be able to reveal the real mass hierarchy and/or constraint

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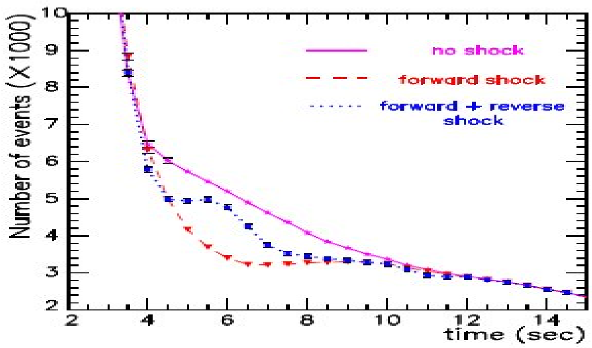

Fig. 1. Effects in the number of neutrino detected as a function of time produced by the propagation of the shock wave through the resonance region. Figure taken from Tomàs et al. (2004).

the unknown value of the mixing angle θ_{13} and the absolute scale of neutrino masses.

For example, the channel on which some of the effects expected by the resonant conversion in the supernova mantle will appear is a clear indication of the mass hierarchy (for a review material see Zuluaga 2005, and references therein). If the mass hierarchy is normal (electron neutrinos have a major content of the lighter mass eigenstates) the effects of the shock wave propagation will affect the flux of the electron neutrino flavor. In the other hand it the hierarchy is inverted the electron anti neutrinos will be the affected. So, observing the evolving spectra of neutrinos and anti neutrinos in the supernova signal will definitively solve the mass hierarchy.

Another example is the constrain of the elusive value of the mixing angle θ_{13} that determines the relative "intensity" of the conversion effect in the outer resonance region. The detailed analysis of the electron (anti)neutrino spectra and fluxes could impose constraints on this quantity.

High statistics supernova neutrino signals could be also used to constraint the absolute scale of neutrino mass. Measuring small delays among the arrival times of neutrinos with different energies a nonzero neutrino mass could be detected and its absolute scale measured (Raffelt 2002). We have recently performed a model independent statistical analysis on synthetic high statistics supernova neutrino signals and shown that the sensitivity of supernova based methods will not be below the 0.5 eV level, even using the largest future detectors (Nardi & Zuluaga 2004, 2005) (see Figure 2).

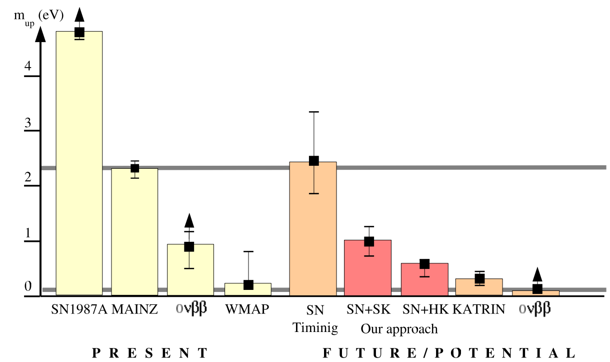

Fig. 2. Sensitivity and limits to the absolute scale of neutrino mass. Figure taken from Zuluaga (2005).

Supernova News. One interesting initiative known as SNEWS (Supernova Early Neutrino Warning System) was established at the end of the last decade (Habig & SNEWS Collaboration 2005) to join the operative neutrino detectors in a world wide network capable of generating a prompt alert to the astronomical community of a Galactic supernova. With an early announcement generated by this network Astronomers could be able to observe and study the first minutes to hours of the elusive initial phases of core collapse supernovae.

Given the lack of a real high statistics supernova signal we have developed a computer tool to synthesize them using the most robust supernova explosion models. We are producing with the tool, named SUNG2 (SUpernova Neutrino Generation), a library of signals that can be downloaded and analyzed on-line in the website `http://urania.udea.edu.co/facom`[2].

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[2]The complete presentation of this work can be downloaded from `http://urania.udea.edu.co/facom/facom-products/proceedings.php`.