

Monitoring the neutrino sky for the next Galactic supernova

Transient, MM and MW circle

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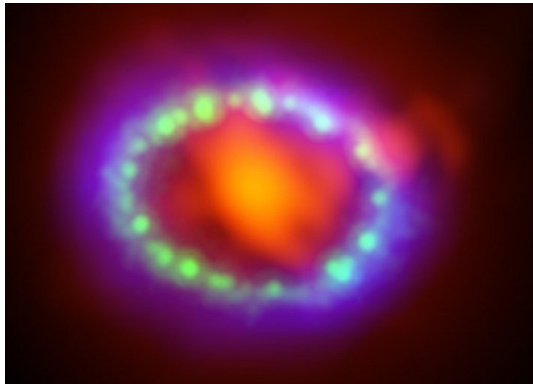
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Core-collapse supernovae

Motivations for the detection of supernova neutrinos



Supernova remnant of SN 1987A

Previous observations

To this day, only 25 supernova neutrinos have been detected, from SN 1987A

Supernova formation

A better understanding of supernova formation should bring new astro-, subnuclear and nuclear physics knowledge, and neutrinos play a key role in the formation mechanism

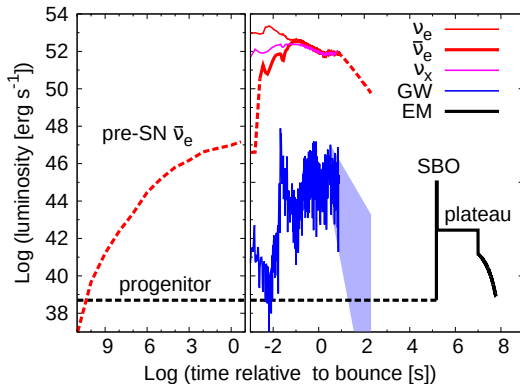
Signals emitted by a core-collapse supernova

Multi-messenger observation

Core-collapse supernovae emit signals in three cosmic messengers: neutrinos, gravitational waves and electromagnetic emission

Neutrino alert

Neutrinos can be used as an alert for gravitational waves and electromagnetic followup



Time sequence for multi-messenger signals

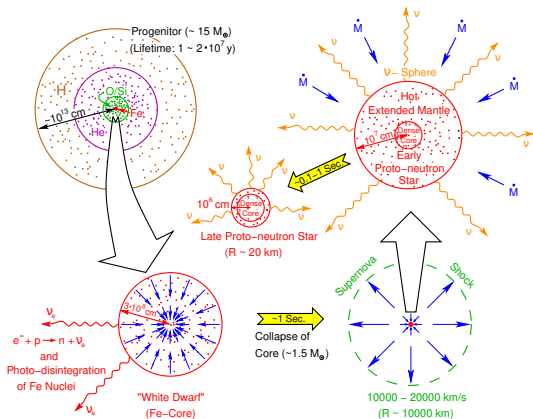
Physics of core-collapse supernovae

Core-collapse supernovae

Explosive phenomena ending the life of massive stars with an enormous energy release ($\sim 3 \times 10^{53}$ erg)

Physics of the core-collapse

Iron photo-dissociation and electron capture inside the iron-core \rightarrow diminution of the electron degeneracy pressure \rightarrow collapse of the core and shockwave propagation



Evolution of a massive star from the onset of iron-core collapse to a neutron star

Neutrino emission during a CCSN

Neutrino emission

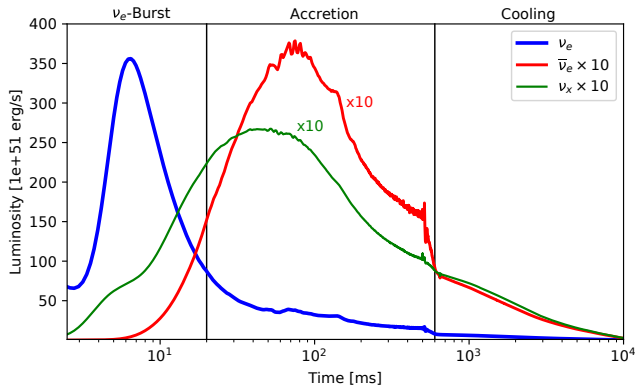
99% of the energy is released as low energy neutrinos (~ 10 MeV)

3 phases of emission: ν_e -burst, accretion phase and cooling phase

Neutrino detection

KM3NeT sensitive to $\bar{\nu}_e$ via inverse beta decay

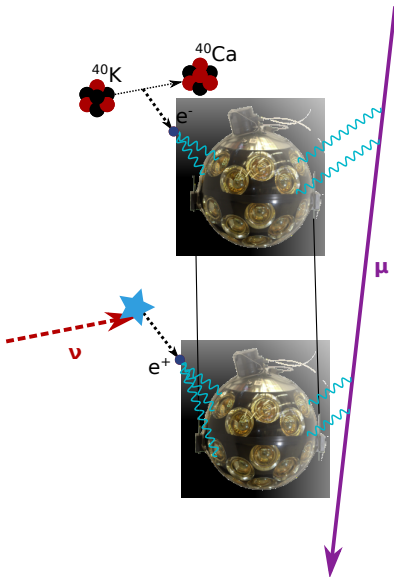
Detection time-window of ~ 500 ms



Expected neutrino time-profile during a CCSN

Detection with KMNeT

Detection of MeV CCSNe neutrinos with KM3NeT



Detection of low-energy neutrinos

Positrons generated *via* inverse beta decay cannot be reconstructed individually

Analysis principle: search for an excess of hit coincidences above the optical background

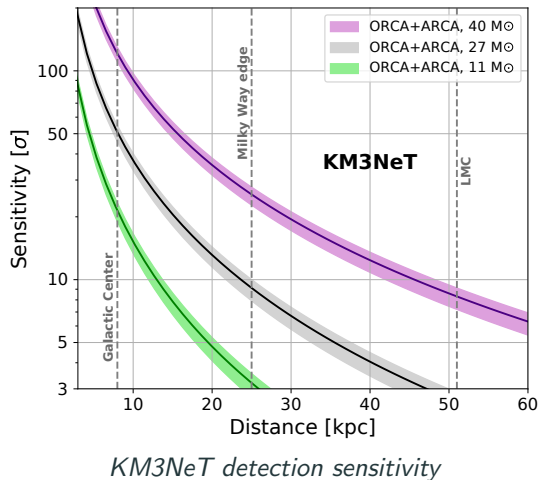
Sources of background

Radioactive decay: mostly ^{40}K in seawater

Bioluminescence: veto of PMTs with high rates

Atmospheric muons

CCSN detection sensitivity



Detection opportunities

Low energy, small cross-section \rightarrow only Galactic or near-Galactic events are detectable, expected rate of ~ 1.5 per century

The SNEWS network for CCSN detection

SNEWS (SuperNova Early Warning System)

Network connecting different neutrino detectors: if at least 2 detectors send a CCSN alert in less than 10 s, SNEWS sends a combined alert publicly to the community (FAR above 1 per century)



Detectors taking part in SNEWS

SuperK, LVD, IceCube, Borexino, KamLAND, HALO, Daya Bay, NOvA, KM3NeT and Baksan

Other capabilities of KM3NeT

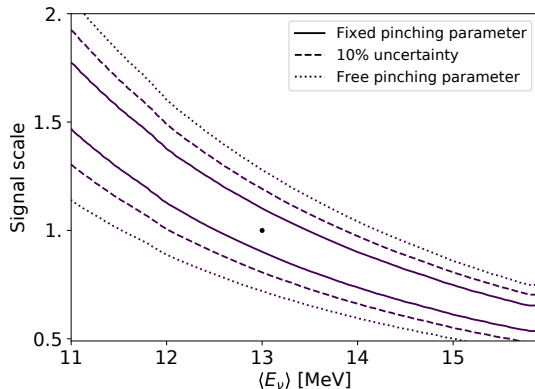
Energy estimation

Neutrino energy spectrum

The spectrum should follow a law depending on three parameters: the mean energy, the pinching parameter (width of the spectrum) and the signal scale (intensity and distance of the supernova)

Energy sensitivity of KM3NeT

Degeneracy in energy, estimation within 0.5 MeV with knowledge on the two other parameters (which can be measured by other detectors)



90% confidence area for parameters estimation

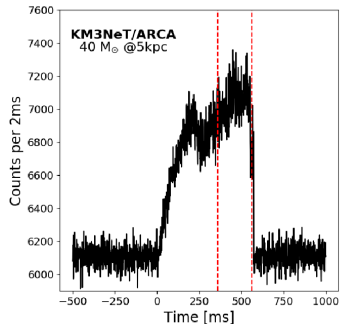
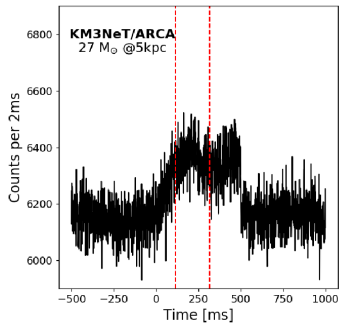
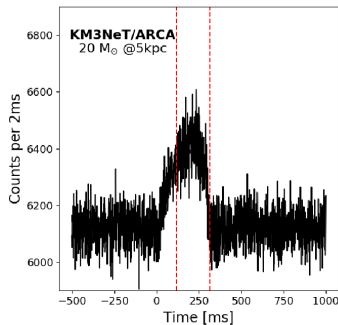
Light-curve analysis

Neutrino lightcurve

Higher statistics of coincidences to perform time analysis, stored when emitting a snews-level alert

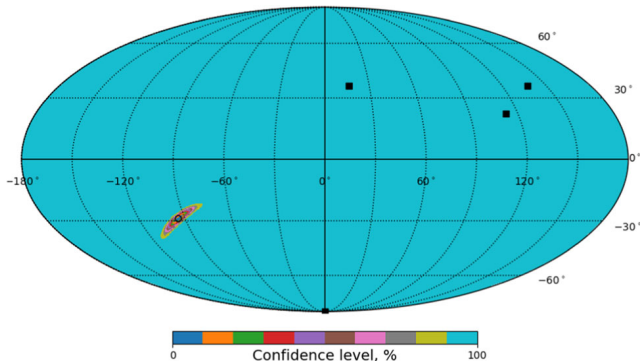
Possible analysis

Parameters estimation (distance, progenitor mass...), models constraints (oscillations in the lightcurve can be due to asymmetric hydrodynamic motions in the core...)



Simulated neutrino lightcurves

Source triangulation



*Triangulation between four detectors (black squares):
IceCube, KM3NeT/ARCA, Hyper-Kamiokande and
JUNO*

Arrival time estimation

Precise fit of the neutrino arrival time with the light curves can help to perform triangulation

Triangulation between detectors

By combining arrival times for multiple neutrino detectors, it is possible to triangulate the source of emission

Upgrade to SNEWS currently in development

Modern alert system

Modernize the alert software to be compatible with modern multi-messenger networks (HOPSKOTCH framework developed by the SCiMMA project)

Thresholds

Multiple thresholds, to constantly exercise the alert emission and to provide subscribers with a “choose your own threshold” alert

Light-curve combination

Ability for experiments to compare neutrino light-curves in real-time and to extract physics quickly: necessary for triangulation

Conclusion

Combining ARCA and ORCA, KM3NeT will be able to detect the next Galactic explosion with a 5σ discovery potential, and is currently connected to the SNEWS network.

KM3NeT will be able to estimate the mean energy of the CCSN neutrinos with sub-MeV accuracy, with previous knowledge of the other spectral parameters.

Light-curves are currently being computed when the significance is high enough, and they will be automatically transmitted to SNEWS2.0 soon. They will allow to measure parameters, constrain models of supernova formation and precisely measure the arrival time in order to triangulate the source signal.