Exploring the Potential of Multi-Detector Analyses for Core-Collapse Supernova Neutrino Detection

Meriem Bendahman[a,b] , Matteo Bugli[c], Alexis Coleiro[b],Marta Colomer Molla[e], Gwenhaël de Wasseige[b], Thierry Foglizzo[c], Antoine Kouchner[b,d], Mathias Regnier[b], Yahya Tayalati[a], Alessandra Tonazzo[b] and Véronique Van Elewyck[b,d]

Faculty of Sciences, Mohammed V University in Rabat[a]

Université de Paris, CNRS, Astroparticule et Cosmologie, F-75013 Paris, France[b]

CEA Saclay, Department of Astrophysics[c]

Institut Universitaire de France, 1 rue Descartes, F-75005 Paris, France[d]

Inter-university Institute for High Energies, Université libre de Bruxelles (ULB)[e]

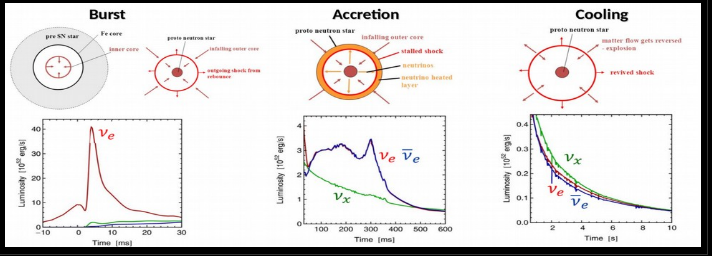
mbendahman@km3net.de

Motivation

Study different techniques to enhance the potential of neutrino telescopes to low-energy astrophysical neutrinos.
Two studies are presented:

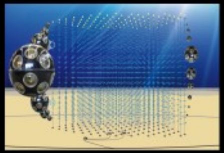
- the potential of using a Bayesian approach to triangulate the position of a close-by CCSN.
- the potential of multi-detector analyses in constraining the characteristics of the CCSN and neutrino oscillation parameters.

Three phases of neutrinos emission



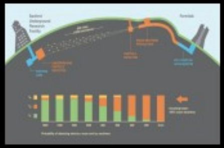
Experiments

KM3NeT



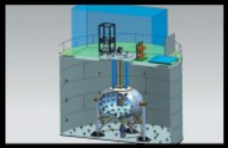
- Water Cherenkov detector
- Sensitive to anti-nue
- Effective mass: ~2.5 kt

DUNE



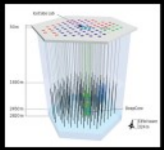
- Ar detector
- Sensitive to νe
- Effective mass: 40 kt

DarkSide-20k



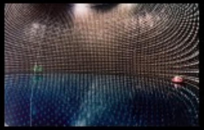
- Dark matter (Ar) detector
- Sensitive to all ν flavors
- Effective mass: 0.02 kt

IceCube



- Water Cherenkov detector
- Sensitive to anti-nue
- Effective mass: 51600 kt

Super-Kamiokande



- Water Cherenkov detector
- Sensitive to anti-nue
- Effective mass: 32 kt

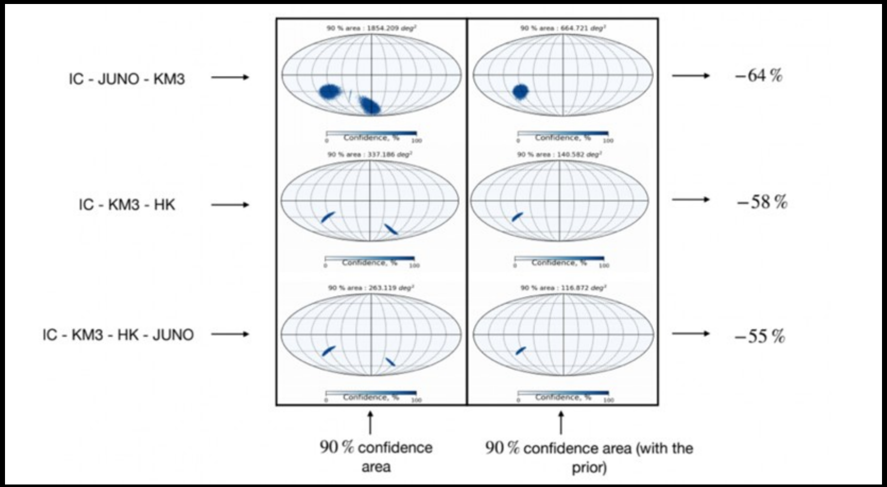
Multi-detector approach for CCSN triangulation

Goal : estimate the time delay between the light curves recorded by IceCube, KM3NeT, and Super-Kamiokande detectors during a CCSN to estimate its position in the sky.

The impact of using a prior on the position of the potential CCSN through a Bayesian approach was studied.

The tested prior was a map of GAIA showing the dust distribution in the Milky Way.

This approach allows us to reduce the 90% confidence area of the source localization by more than 55%, depending on the combination of neutrino telescopes.

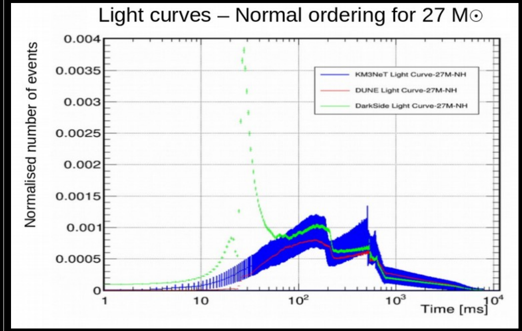


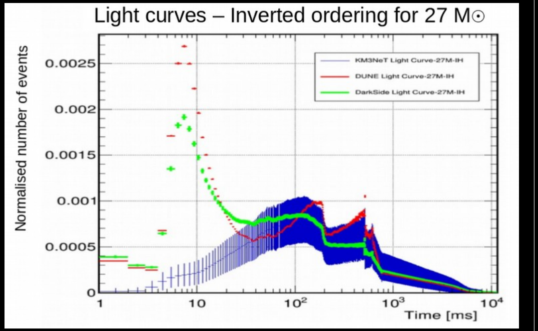
Comparison of the confidence areas obtained by the CCSN triangulation method with and without using a prior.

Multi-detector approach for enhancing the scientific output

Goal: set constraints on the models (mass ordering, progenitor mass).
- hierarchy dependence study for 11 M☉ and 27 M☉ progenitors.
- mass dependence study for normal and inverted ordering.

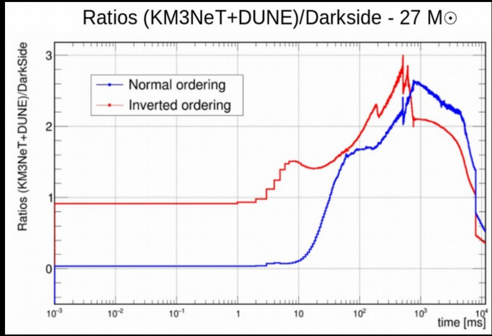
1. Estimation of the CCSN neutrino event rate in the detectors KM3NeT, DUNE and DarkSide

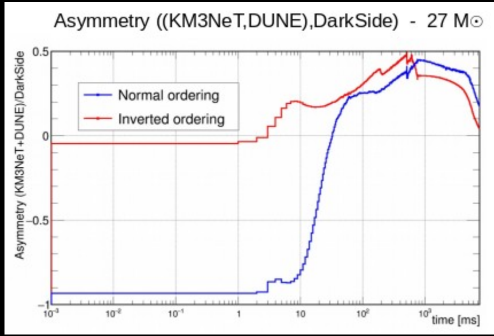




Light curves from KM3NeT, DUNE and Darkside respectively on blue, green and red for a 27 M☉ progenitor.

2. Light curve comparison using ratios or asymmetries variables

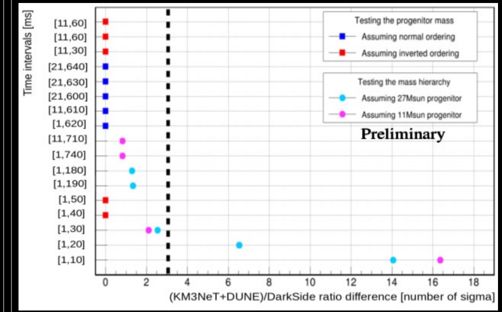


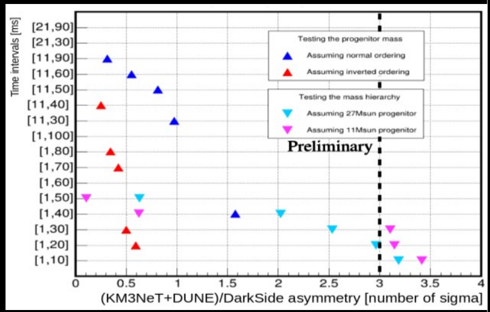


Ratio and asymmetry for KM3NeT, DUNE and DarkSide light curves

3. Statistical methods for model discrimination

1) Loop over time throughout the duration of the light curves with a step of 10 ms.
2) Calculate the difference between two hypotheses.
3) Select the time windows giving the highest differences between two hypotheses.





Mass ordering and progenitor mass estimate for ratio and asymmetry variables

Conclusion

- Significant difference estimated for mass ordering study:
  - More than 14 σ for [1,10] ms and more than 6 σ for [1,20] ms for ratio variable.
  - More than 3 σ is estimated for [1,10] ms for the asymmetry variable.
- No time window leading to a 3 σ difference could be identified for the two progenitor masses.

Good sensitivity to mass ordering estimate