Neutrinos from core-collapse supernovae at KM3NeT

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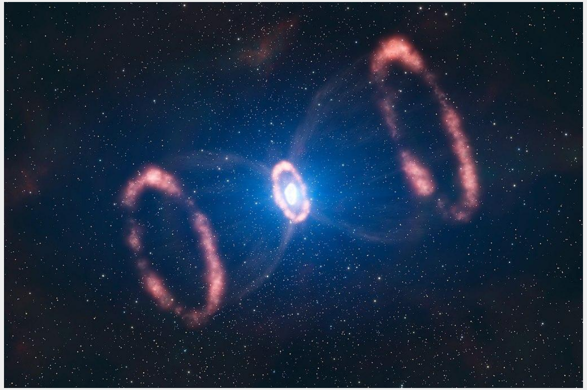
on behalf of the KM3NeT Collaboration
ICHEP 2022 - July 9, 2022



KM3NeT

Labex UnivEarthS

Investir l'avenir

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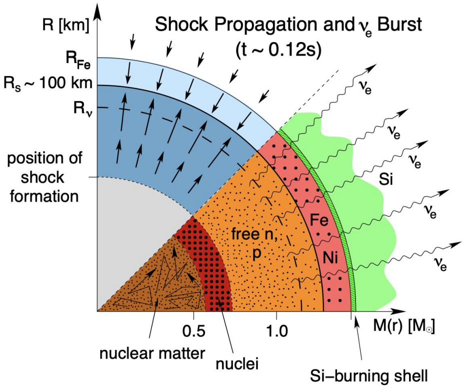
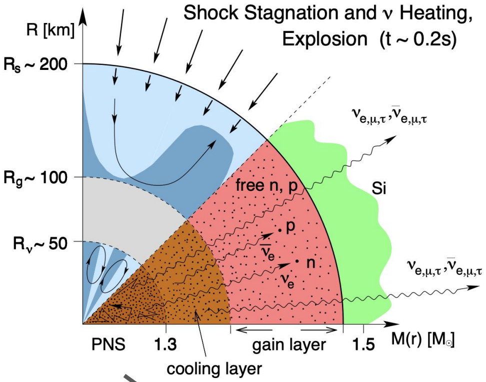
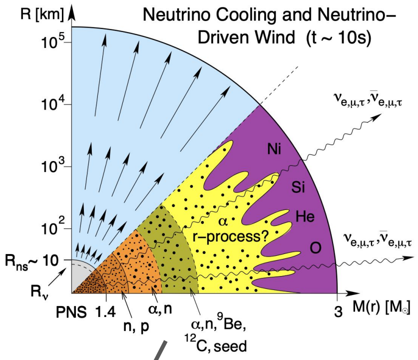
Introduction: Core-collapse supernovae (CCSNe)

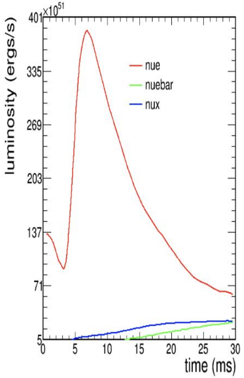




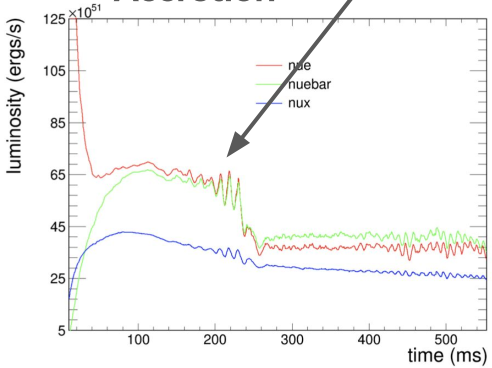


Standing accretion shock instability (SASI)

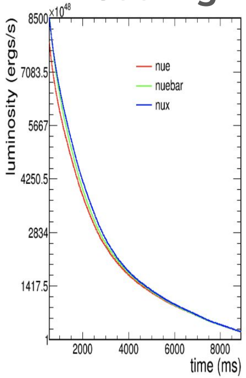
Electron neutrino burst



Accretion



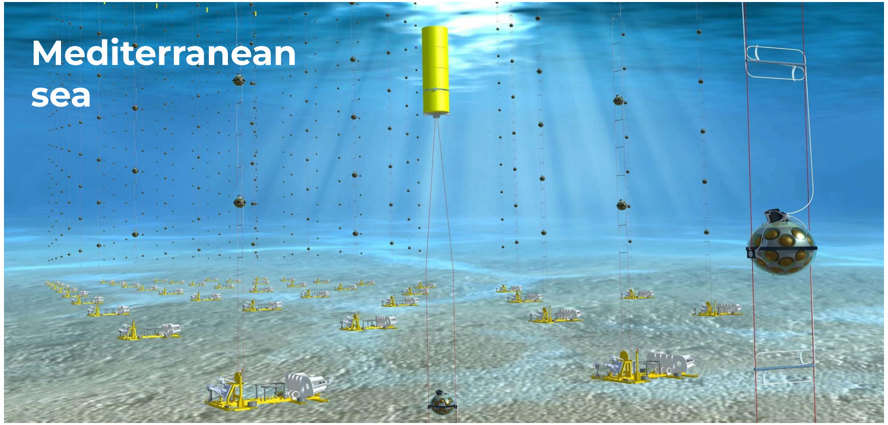
Cooling



- CCSN explosion mechanism
- Neutrino behaviour in dense environment

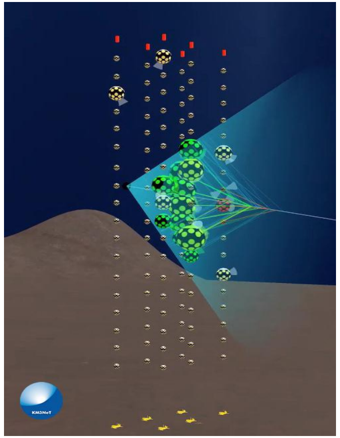
arXiv:astro-ph/0612072

KM3NeT - the next generation υ telescopes

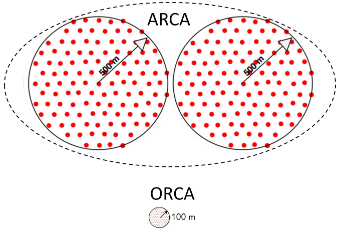


DOM = digital optical module, with 31 PMTs

DU = detection unit



Detection based on the measurement of cherenkov light emitted by the product particles



ARCA

- 36 m between DOMs
- 90 m between DUs
- 230 DUs
- Depth of about 3500 m
- Search for very **high-energy cosmic neutrinos** - origin, energy spectrum, flavour composition
- **TeV-PeV** energy range

ORCA

- 9 m between DOMs
- 20 m between DUs
- 115 DUs
- Depth of about 2500 m
- Study of the **neutrino mass ordering** with atmospheric neutrinos
- **1-100 GeV** energy range

Detection of CCSN neutrinos (I)

CCSN neutrinos:

- **10-20 MeV** energy range
- carry ~99% of the progenitor's gravitational energy

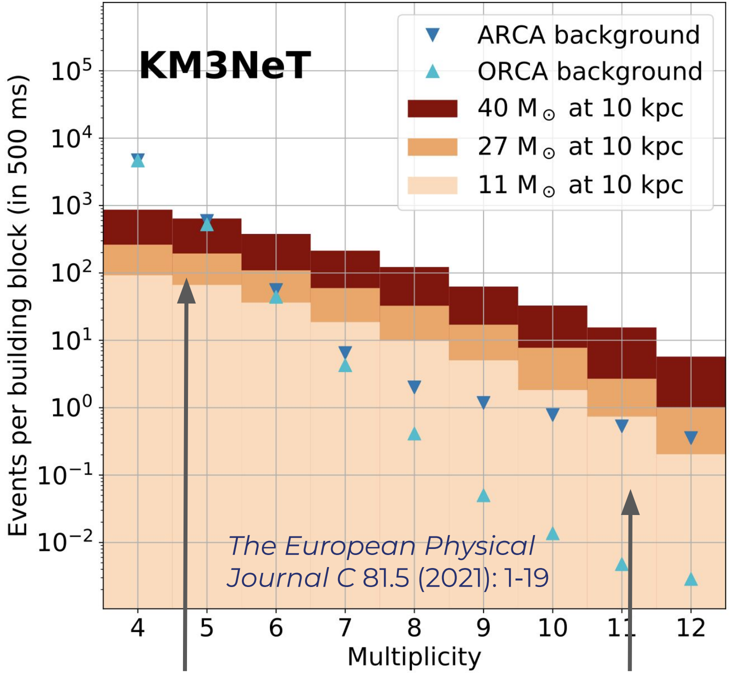
The complex DOM structure makes the following possible:

- **Background filtering**: atmospheric muons generate correlated coincidences during their passage through the water, bioluminescence is negligible in the present context
- CCSN neutrinos contribute to a signal if they interact in a **20 m radius sphere around the DOM** (main contribution: inverse beta decay)
- **Radioactive decay** in the sea water (mainly by K40) can be taken into account ⇒ *next slide*

Detection of CCSN neutrinos (II)

Detection mechanism
↳single-DOM signal:

- through observation of **coincidences in excess** over the background taking into account all the DOMs in the detector
- the **multiplicity distribution** of these coincidences can be exploited to discriminate the origin of the signal on a statistical basis



Dominated by Radioactive decays (K40)

Dominated by Atmospheric muons

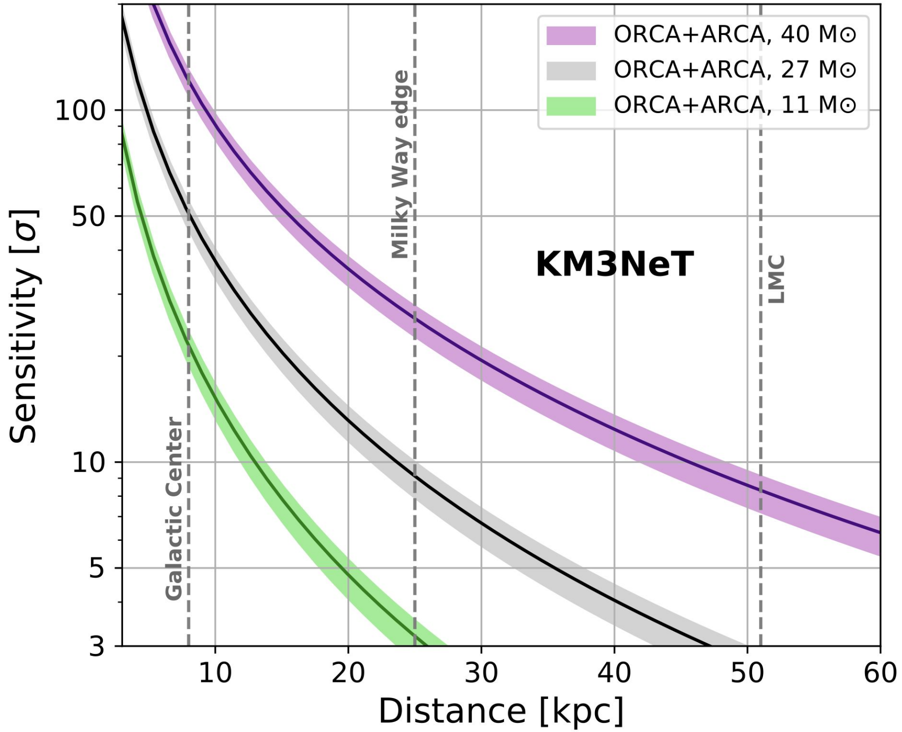
Multiplicity = number of PMTs hit in a coincidence (10 ns)

KM3NeT detection sensitivity

Best solution:
7-11 multiplicity range for both detectors

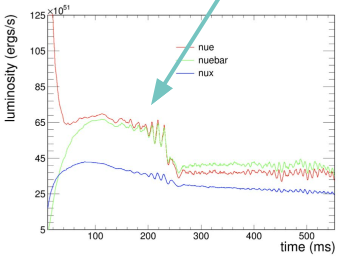
- the expected distribution of CCSNe as a function of the distance to the Earth is considered
- for the 11 solar mass scenario, more than **95% of the Galactic CCSNe** are covered by KM3NeT with a **5σ discovery** potential

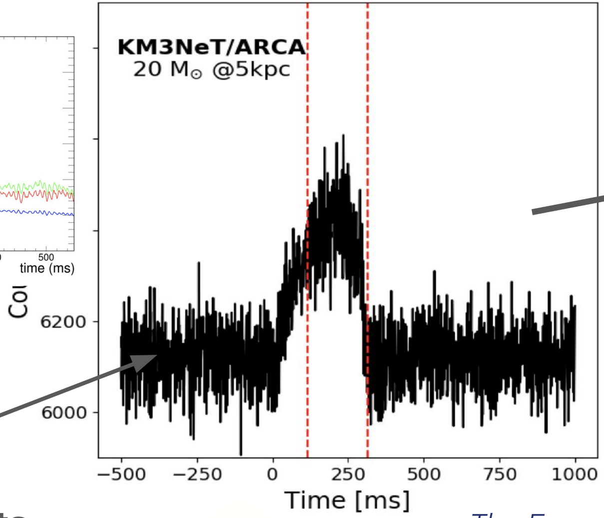
The European Physical Journal C 81.5 (2021): 1-19



Detection of the standing accretion shock instability (SASI)

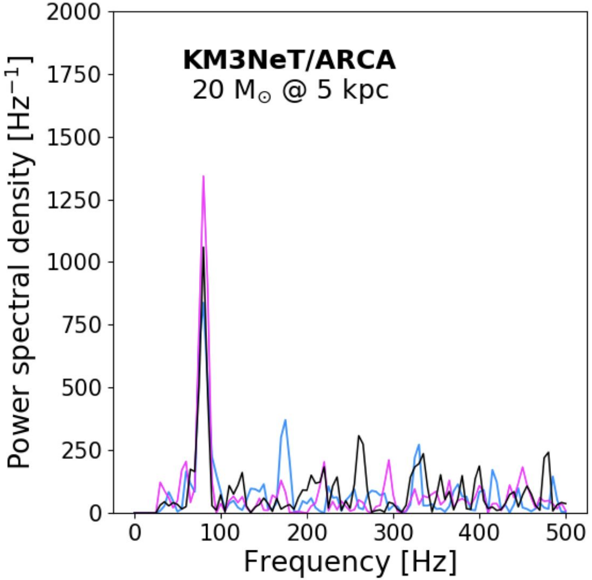
- 3D-simulations of CCSN predict fast and asymmetric hydrodynamic motions in the core during the accretion
- the SASI may produce oscillations of the core





Including Detector effects + background

Spectral analysis for L1-cut using a fast Fourier transform algorithm



3σ sensitivity to the SASI signature is reached for Galactic progenitors at distances between **3** (27M$_\odot$) and **5 kpc** (20 M$_\odot$)

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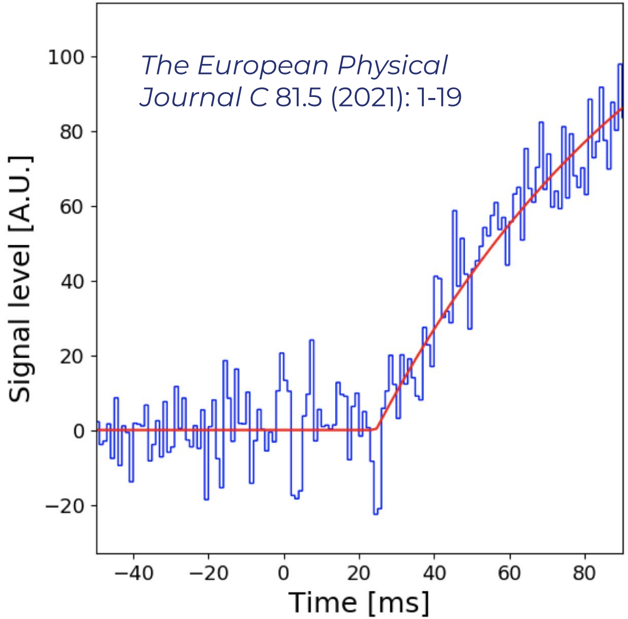
L1 = collection of all hits on a DOM with a time difference smaller than 10 ns

Arrival time of the CCSN neutrino signal

The arrival time can be estimated with an uncertainty of **3 ms** for a supernova at 5 kpc (also using L1-cut)



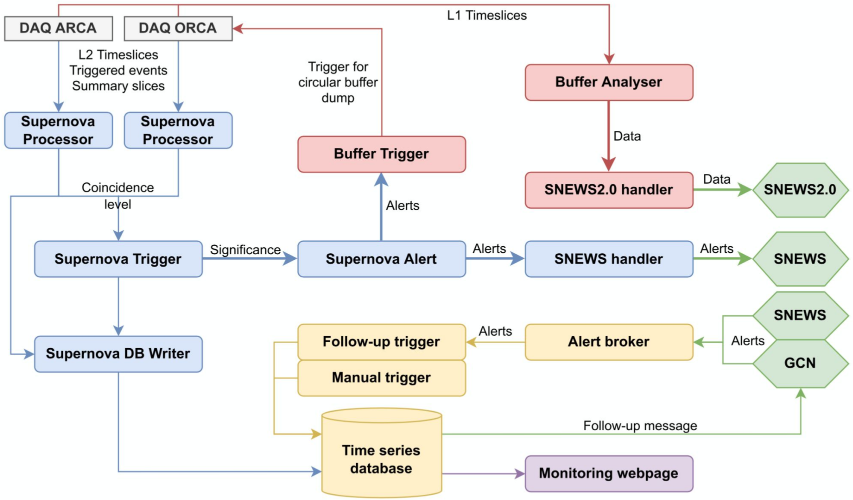
Main goals:

- arrival times at different detectors ⇒ localisation of the source by **triangulation**
- the relative start time of the electron antineutrino signal with respect to the electron neutrino burst is tied to **flavour conversion** processes in the **dense environment** of the star, which in turn depend on the neutrino mass ordering
  ↳ arXiv:2204.13135
- neutrinos can act as an **early warning for optical follow-ups**

Real-time Multi-Messenger Analysis Framework

Main goals:

- CCSN monitoring
- receive external electromagnetic, gravitational waves or neutrino alerts
- send all-flavour all-sky neutrino alerts to external observatories for follow-up



Monitoring the neutrino sky for the next Galactic CCSN with KM3NeT, Neutrino 2022, Godefroy Vannoye

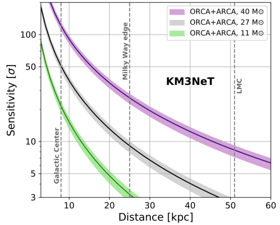
Status:

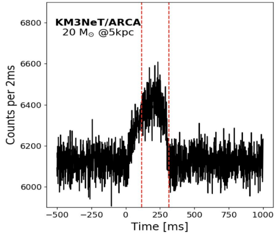
- **CCSN monitoring** fully functional and connected to SNEWS (SuperNova Early Warning System) ⇒ false alarm rate less than 1/week with latency less than 20 s
- **alert sender and receiver** mostly ready

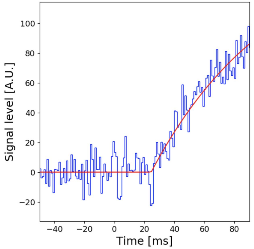
arXiv:2107.13908

Conclusions

- It will be possible to **detect neutrinos from CCSNe** using both detectors from KM3NeT, ARCA and ORCA
  ↳ Galactic supernovae
  ↳ real-time multi-messenger analysis framework
- What can we learn about the CCSN?
  ↳ **SASI** phenomenon
  ↳ **neutrino mass ordering** through flavour conversion in the dense environment
  ↳ **neutrino spectrum parameters** (mean neutrino energy, spectral index, signal scale, arXiv:2102.05977)







THANK YOU FOR YOUR ATTENTION!

Do you have any questions?

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