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KM3NeT: Towards a km^3 Mediterranean neutrino telescope

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Abstract

The observation of high-energy extraterrestrial neutrinos is one of the most promising future options to increase our knowledge on non-thermal processes in the universe. Neutrinos are e.g. unavoidably produced in environments where high-energy hadrons collide; in particular, this almost certainly must be true in the astrophysical accelerators of cosmic rays, which thus could be identified unambiguously by sky observations in ‘‘neutrino light’’. To establish neutrino astronomy beyond the detection of single events, neutrino telescopes of km^3 scale are needed. In order to obtain full sky coverage, a corresponding detector in the Mediterranean Sea is required to complement the IceCube experiment currently under construction at the South Pole. The groups pursuing the current neutrino telescope projects in the Mediterranean Sea, ANTARES, NEMO and NESTOR, have joined to prepare this future installation in a 3-year, EU-funded design study named KM3NeT (in the following, this name will also denote the future detector). This report will highlight some of the physics issues to be addressed with KM3NeT and will outline the path towards its realisation, with a focus on the upcoming design study.

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Keywords: Neutrino astronomy; Neutrino telescopes; KM3NeT

1. Physics with KM3NeT

The energy range accessible to neutrino telescopes is intrinsically limited by the detection method to some 10 GeV at its lower end, while at energies beyond roughly 10^{17} eV the neutrino flux is expected to fade below detection thresholds even for future km^3-scale detectors. The lower-energy region is dominated by the flux of *atmospheric neutrinos* (cf. Fig. 3), produced in reactions of cosmic rays with the atmosphere. There are three approaches to identify cosmic muon signals on top of this background:

(i) Neutrinos from specific astrophysical objects (*point sources*) produce excess signals associated to particular celestial coordinates.
(ii) Neutrinos not associated to specific point sources (*diffuse flux*) are expected to have a much harder energy spectrum than the atmospheric neutrinos and to dominate the neutrino flux above 10^{14}–10^{15} eV.
(iii) Exploitation of coincidences in time and/or direction of neutrino events with observations by telescopes (e.g. in the radio, visible, X-ray or gamma regimes) and possibly also by cosmic ray detectors (*multi-messenger method*).

The various astro- and particle physics questions to be addressed with the resulting data have been summarised e.g. in Ref. [1] and references therein. Here, we will focus on a few central topics, including a recent development.

1.1. Neutrinos from galactic shell-type supernova remnants

The shock waves developing when supernova ejecta hit the interstellar medium are prime candidates for hadron acceleration through the Fermi mechanism. Recent observations of gamma rays up to energies of about 40 TeV from two shell-type supernova remnants in the Galactic plane (RX J1713.7-3946 and RX J0852.0-4622) [2,3] with the H.E.S.S. Cherenkov telescope support this hypothesis and disfavour explanations of the gamma flux by purely

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electromagnetic processes. The detection of neutrinos from these sources would, for the first time, identify unambiguously specific cosmic accelerators. Note that this is only possible with Northern-hemisphere neutrino telescopes which, in contrast to the South Pole detectors, cover the relevant part of the Galactic plane in their field of view (see Fig. 1).

The expected event rates can be estimated using the rough assumption that the gamma flux follows a power-law spectrum without high-energy cut-off and the muon neutrino and gamma fluxes are in relation $\phi_{\nu_\mu}/\phi_\gamma = \frac{1}{2}$, taking into account the relative production probabilities of charged and neutral pions, their decay chains and neutrino oscillations. Preliminary calculations indicate that the first-generation Mediterranean neutrino telescopes may have a chance to observe a few events, whereas a significantly larger signal is expected in a future cubic-kilometre set-up; a tentative estimate of the neutrino sky map of RX J0852.0-4622 after 5 years of data taking with KM3NeT is shown in Fig. 2.

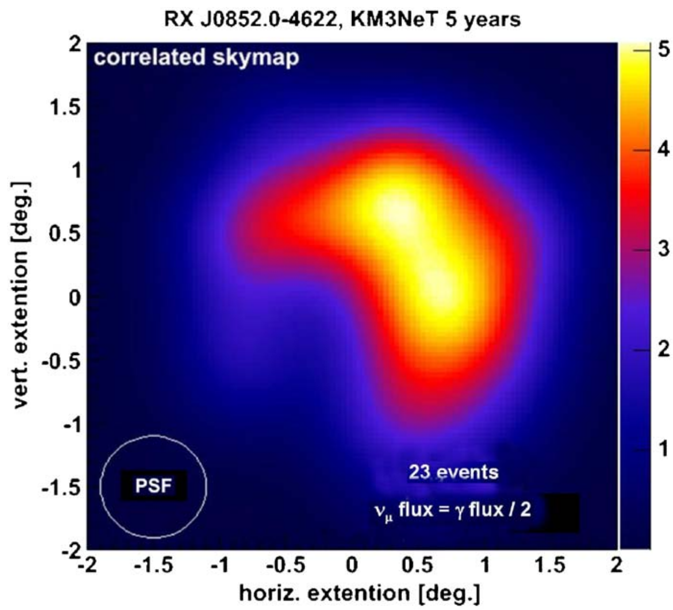

Fig. 2. A skymap of the simulated neutrino signal from RX J0852.0-4622 as seen by a km^3-scale neutrino telescope in the Mediterranean Sea after 5 years of data taking. In the simulation, a power-law gamma spectrum without energy cut-off and the relation $\phi_{\nu_\mu}/\phi_\gamma = \frac{1}{2}$ have been assumed. The background of atmospheric neutrinos, not included in the plot, can be efficiently reduced by adjusting the lower energy cut without affecting significantly the signal. The circle in the lower left corner indicates the average angular resolution (point spread function).

1.2. The diffuse neutrino flux

The sensitivity of current and future experiments is compared to various predictions of diffuse neutrino fluxes in Fig. 3 (following Refs. [4,5]). Whereas some of the models are already now severely constrained by the data, others require km^3-size neutrino telescopes for experimental assessment and potential discoveries. The measurement of the diffuse neutrino flux would allow for important clues on the properties of the sources, on their cosmic distribution, and on more exotic scenarios such as neutrinos from decays of topological defects or superheavy particles (*top-down scenarios*).

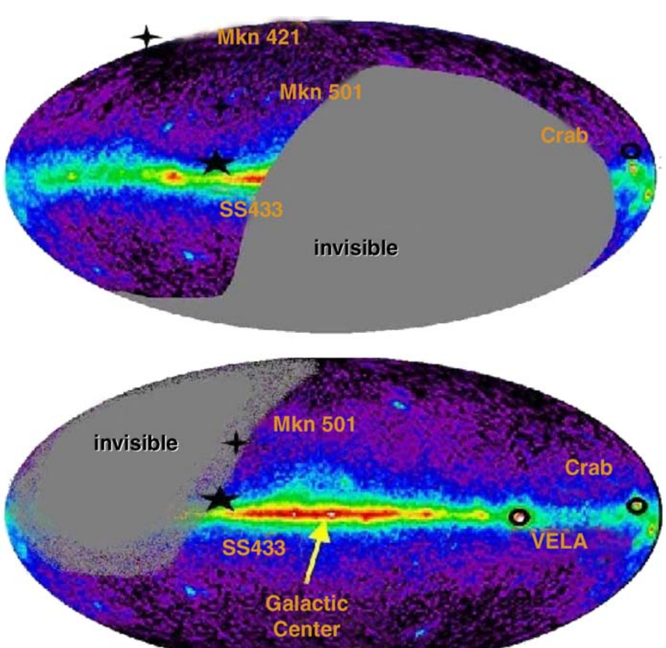

Fig. 1. Field of view of a neutrino telescope at the South Pole (top) and in the Mediterranean (bottom), given in galactic coordinates. A 2π-downward sensitivity is assumed; the grey regions are then invisible. Indicated are the positions of some candidate neutrino sources.

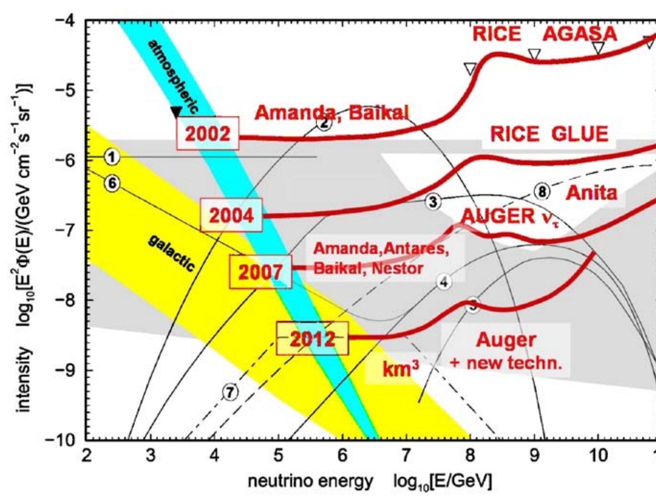

Fig. 3. Experimental sensitivity to the diffuse neutrino flux for various current and future experiments (red lines), compared to different models for contributions to the diffuse flux (numbered lines). See Ref. [5] for detailed explanations. The flux of atmospheric neutrinos is indicated as blue band. Plot provided by courtesy of C. Spiering.

1.3. Search for dark matter annihilation

The major part of the matter content of the universe is nowadays thought to be formed by *dark matter*, i.e. non-