GNN Monthly

The Global Neutrino Network

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ANTARES

ANTARES has a new website ("one step in the legacy strategy", as Antoine Kouchner wrote to me): antares.in2p3.fr

KM3NeT

The KM3NeT and ANTARES collaborations have held a common collaboration meeting from June 5 to 9 in Salerno, Italy. KM3NeT was joined by a new institution with observer status: The Institute of Experimental Physics, Slovak Academy of Science, Kosice, (group of Slavo Pastircak).

IceCube

Almost all readers of GNN Monthly will have got the message about the press release of the Galactic Plane results, and many of you will have followed the press conference. See the report about the results under "Publications".

Meanwhile, IceCube is continuing data taking, with its typical 99.5% uptime. Apart of keeping everything running, the winterovers are sending their wonderful aurora photographs. The first one below (a very bright aurora over the station) was made by Hrvoje Dujmovic, the second ("the devil comes as aurora") by Marc Jacquart.

The IceCube Summer School, formerly known as "Bootcamp," took place at the Wisconsin IceCube Particle Astrophysics Center in Madison and ran from June 5-9. The workshop exposed new collaboration members around the world to everything IceCube-related. The picture below shows the participants.

Baikal-GVD

The Baikal-GVD collaboration held its collaboration meeting from May 30 to June 2 in Dubna.

Multi-messenger astrophysics workshop

The 2nd Astro-COLIBRI multi-messenger astrophysics workshop that will take place from November 20 to November 24, 2023, at Institut Pascal at the Paris-Saclay University (France).

See details on the agenda on their website, where you can also register for the event: https://astrophysics-workshop-2nd.web.app . Application for participation is possible until August 31. The selected participants will be announced shortly after that.

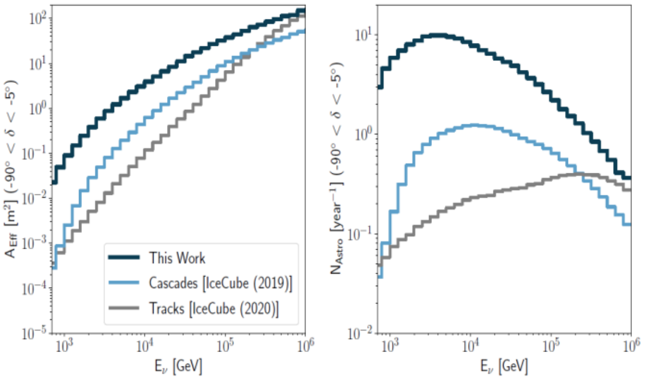
Publications

The IceCube Collaboration has published a paper *Observation of High-Energy Neutrinos from the Galactic Plane* in Science and finds a 4.5σ significance in rejecting a background-only hypothesis. Apart from the all-sky diffuse flux discovered a decade ago, this is the most significant result obtained in any of the IceCube searches for an extraterrestrial signal of neutrinos. The neutrino signal is consistent with diffuse emission from the Galactic plane, potentially in combination with emission by a population of sources. The key authors for this paper are Mirco Hünnefeld (Dortmund University, Germany) and Steve Sclafani (Drexel University, USA)

There are two factors which made this result possible:

The first is the choice of the event type (namely cascades). Seen from IceCube, the Galactic center is above the detector. If one would use muon tracks with their superior angular resolution (< 1°), any signal would be buried in the background of atmospheric muons punching down to the detector depth (about 10^8 muons for every astrophysical neutrino!). Therefore, one has to use events starting within the detector. Selection of such “starting events” greatly reduces the contamination of cosmic-ray muons entering the instrumented volume. Cascade events, apart from the mentioned advantage w.r.t. atmospheric muons, have another advantage: a smaller contamination of the sample by atmospheric neutrinos. The background from atmospheric neutrinos is dominated by muon neutrinos, which are largely detected as tracks in IceCube. At energies above 1 TeV, the contamination with atmospheric neutrinos in a cascade sample is therefore much smaller than for track events (about one order of magnitude!). The resulting improved purity, together with the better energy resolution and lower energy threshold for cascade events, by far compensates the inferior angular resolution of cascade events compared to track events (< 10°) – an effect which, however, is less important for extended sources like the Galactic Plane.

The second factor is the use of artificial intelligence. Different to previous event selections for astrophysical cascade events, this work uses newly developed tools based on convolutional neural networks (CNNs). They allow for more signal-efficient event selections which retain over an order of magnitude more signal events while maintaining relative background contamination at a comparable level, see the next figure.



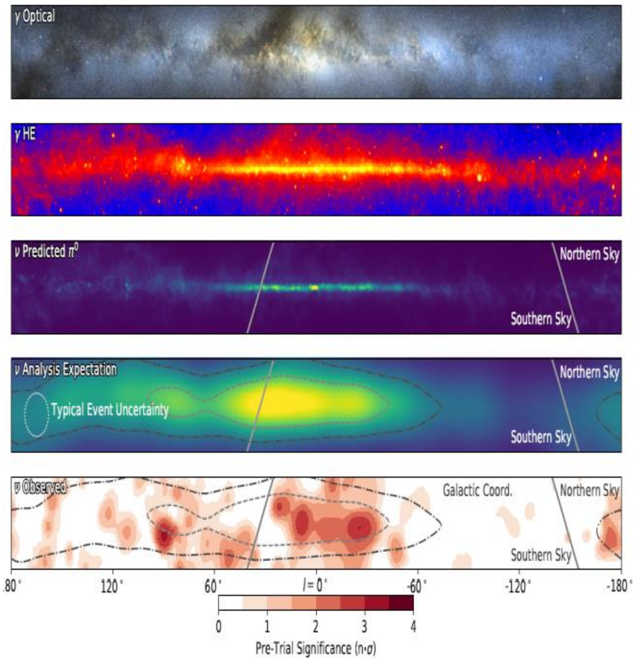
Left: The all-flavor Southern Sky effective area averaged over solid angle in the declination range between -90° and -5° (including the central part of the galactic plane) vs. neutrino energy for the event selection in this work, the cascade event selection in IceCube (2019), and the track event selection in IceCube (2020). Right: The number of signal events in the Southern Sky per energy bin for one year for each event selection, assuming an isotropic astrophysical flux according to IceCube's cascade measurement. Calculations are based on equal contributions of each flavor at Earth due to neutrino oscillations.

The high speed of the neural networks (milliseconds per event), enables a complex filtering strategy at earlier stages of the event selection pipeline. This allows for a lower energy threshold of the event selection (see the first figure above) and the inclusion of more challenging cascade events, which are harder to reconstruct and distinguish from background due to their location at the boundaries of the instrumented volume or in regions of the ice with degraded optical clarity due to higher concentrations of impurities.

Once the selection of events was performed, event properties such as the direction of the incoming neutrino and deposited energy were refined with a dedicated reconstruction method using the patterns of deposited light in the detector. The likelihood of the observed light pattern under a given event hypothesis is maximized in order to find the event properties that best describe the data. For this purpose, a hybrid reconstruction method is utilized that combines the benefits of maximum likelihood estimation with those of deep learning. In this approach, a neural network (NN) is used to parameterize the high-dimensional and complex relationship between the event hypothesis and expected light yield in the detector. The application of novel tools results in an event selection that is able to retain more than 20 times (!!) as many events as the selection used in the previous cascade-based Galactic plane analysis (see again the first figure above), while delivering improved angular resolution (almost twice as good at a few TeV).

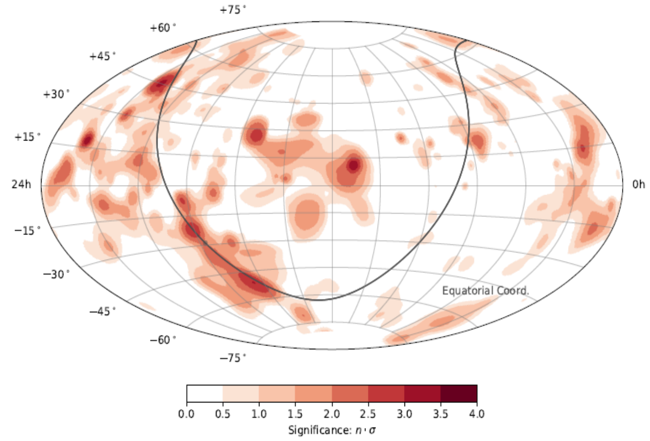
The analysis is based on ten years of IceCube data collected between May 2011 and May 2021. A total of 59,592 events (compared to 1,980 events from seven years in a previous selection) are selected over the entire sky in the 500 GeV to multiple-PeV energy range. An atmospheric muon contamination of about 6% is expected, while the astrophysical neutrino contribution is estimated to about 7%. The remainder of the events consists of atmospheric neutrinos.

The Milky Way is an emitter across the electromagnetic spectrum ranging from radio to gamma rays (see the next figure, panel 1 and 2, for optical and gamma rays). A majority of the observed gamma-ray flux is believed to consist of photons from the decays of π^0s produced by cosmic rays colliding with the interstellar medium. The diffuse neutrino flux from the corresponding $\pi^\pm$ decays along the Galactic plane (galactic latitudes < 5°) has been estimated but – apart from some weak hints seen by ANTARES (see GNN Monthly of December) and IceCube – remained elusive until now. The expected TeV-energy neutrino flux based on an extrapolation of the GeV-energy Fermi-LAT π^0 data is shown in the third panel.



The plane of the Milky Way galaxy in photons and neutrinos. Each panel is in Galactic coordinates, with the origin being at the Galactic Center, extending ±15° in latitude and ±180° in longitude.
(A) Optical color image, which is partly obscured by clouds of gas and dust that absorb optical photons.
(B) The integrated flux in gamma rays from the Fermi-LAT 12-year survey at energies greater than 1 GeV.
(C) The emission template calculated for the expected neutrino flux, derived from the π° template that matches the Fermi-LAT observations of the diffuse gamma-ray emission.
(D) The emission template from panel (C) including the detector sensitivity to cascade-like neutrino events and the angular uncertainty of a typical signal event (7°, indicated by the dotted white circle). Contours indicate the central regions that contain 20% and 50% of the predicted diffuse neutrino emission signal.
(E) The pre-trial significance of the IceCube neutrino observations, calculated from all-sky scan for point-like sources using the cascade neutrino event sample. Contours are the same as panel (D).
Grey lines in (C) - (E) indicate the Northern-Southern sky horizon line at the IceCube detector.

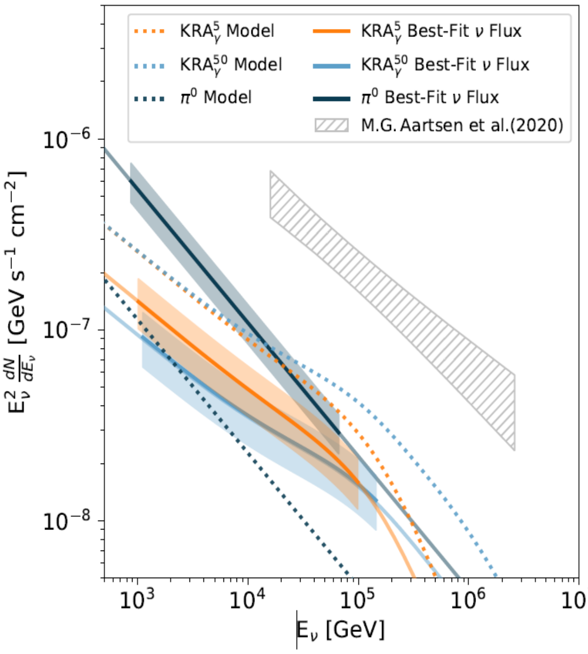
The fifth panel with the result of this analysis is shown in another projection in the next figure. Apart from the diffuse emission, the Galaxy is densely populated with numerous high-energy gamma-ray sources, several classes of which are considered potential cosmic-ray accelerators and therefore neutrino sources. However, all warm spots in the figure next page which might be interpreted as indication of point sources are consistent with background fluctuations.



Best-fit pre-trial significance as a function of direction, in equatorial coordinates (J2000), for the all-sky scan. The Galactic plane is indicated by a grey curve, and the Galactic center as a dot. Individual warm spots are consistent with background fluctuations.

The last figure (next page) shows the predicted energy spectra integrated over the entire sky for the tested Galactic plane models and their best-fit normalization.

The “π^0 model” derives the TeV-energy diffuse neutrino flux due to $\pi^{\pm}$ decays along the Galactic plane (galactic latitudes < 5°) from the extrapolation of the GeV-energy Fermi-LAT data. This simple model under-predicts the amount of gamma rays above a few GeV in the Galaxy, especially for higher-energy observations of the H.E.S.S and Milagro collaborations. The KRA-γ model allows for a diffusion coefficient that depends on Galactic radius and an advective wind, and matches the high-energy gamma-ray data better. A free cut-off parameter offers another degree of freedom.



Energy scaled per-flavor neutrino flux vs. energy for each of the Galactic plane models and corresponding best-fit normalizations in the region of the central 90% energy range that contribute to the observed significance for each model. These results are scaled to an all-sky (4π) diffuse flux and 1σ flux uncertainty bands are shown for each observation. Also shown is the measured all-sky flux from IceCube, with corresponding 1σ uncertainty.

The highlighted range for each observation corresponds to the central 90% neutrino energy range of observed events that maximally contribute to the resulting significance. While these ranges provide insight into the neutrino energies that support the measurement, the fit is performed on the entire sample of events, with neutrino energies up to a few PeV.

Model-to-model flux comparisons can vary depending on the regions of the sky considered. The KRA best-fit model normalizations are *lower* than the model expectations, and could be an indication of a spectral cutoff that is inconsistent with the 5 PeV and 50 PeV values assumed. The observed best-fit flux for the π^0 model is a factor 5 *above* the simple extrapolation of the π^0 flux from GeV energies to 100 TeV. However, this best-fit flux appears to be consistent with recent observations of 100 TeV gamma rays by the Tibet Air Shower Array. The π^0 model mismatch could arise from propagation and spectral differences for cosmic rays in the Galactic center region or from contributions from unresolved neutrino sources.

However – the results of this analysis confirm the presence of Galactic plane neutrino emission for every model tested. They do not clearly distinguish a preferred underlying model.

The initially quoted 4.5σ post-trial significance (three models correspond to three trials) results from the significances 4.71σ (π° model), 4.37σ (KRA-γ^5 model) and 3.96σ (KRA-γ^{50} model).

See the press conference on:
https://www.youtube.com/watch?v=35YUzuhadOs

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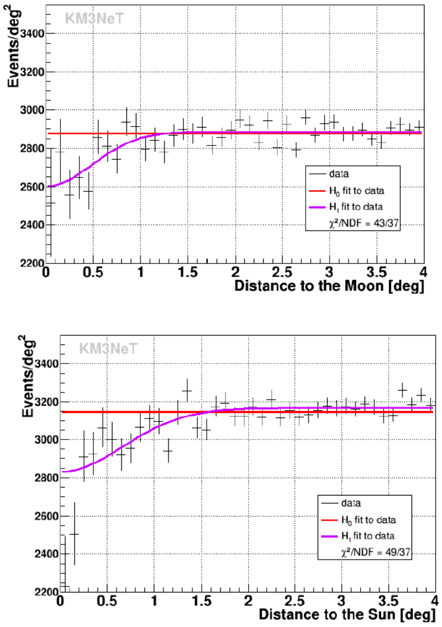
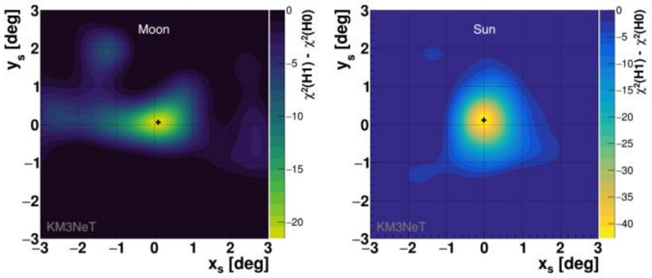
I have missed this paper last year: The KM3NeT collaboration has posted a paper *First observation of the cosmic ray shadow of the Moon and the Sun with KM3NeT/ORCA* at https://arxiv.org/pdf/2211.08977.pdf (V2 from May 2023). It has been meanwhile published in Eur. Phys. J. C 83, 344 (2023). The main authors are Jürgen Brunner and Luc Cerisy from CPPM in Marseille.

The analyzed data have been taken between February 2020 and November 2021, when the detector had only 6 of the meanwhile 18 Detection Units deployed. The shadows induced by the Moon and the Sun were detected at their nominal position with a statistical significance of 4.2σ and 6.2σ, and muon angular resolutions of σ_{res} = 0.49° and σ_{res} = 0.66°, respectively, consistent with the prediction of 0.53° from simulations.



Event density as a function of the distance to the Moon on (top) and the Sun (bottom). Data (black crosses) are compared to the H_0 fit (background hypothesis, red) and the H1 fit (Background + signal hypothesis, magenta).



Colour-coded $\Delta\chi^2_{H1/H0}$ as a function of angular coordinates for the Moon (left) and the Sun (right).

The demonstrated sensitivity to the shadow observation with only one and a half years of data taking and a yet rudimentary detector reflects the good understanding of the detector positioning, orientation, time calibration and reconstruction capabilities. The shadow observed in data is compatible with expectations from Monte Carlo simulations concerning the significance, angular width and amplitude, except for the Sun's amplitude, where it was found above expectations.

The KM3NeT Collaboration has posted another paper, this time not yet with experimental results but MC simulations: *Probing invisible neutrino decay with KM3NeT/ORCA* (https://arxiv.org/pdf/2302.02717.pdf). Corresponding author is Tarak Takore from IFIC Valencia (now University of Cincinnati).

The paper supposes a three-flavor neutrino oscillation scenario, where the third neutrino mass state ν_3 decays into an invisible state, e.g. a sterile neutrino (The decay of ν_1 and ν_2 is excluded by solar and SN results). For this, the mass term Δm^2_{31} in the Hamiltonian would be replaced by $\Delta m^2_{31} - i\cdot\alpha_3$. They find that KM3NeT/ORCA would be sensitive to invisible neutrino decays with $1/\alpha_3 = \tau_3/m_3 < 180$ ps/eV at 90% confidence level, assuming true normal ordering. This sensitivity is comparable with the lower limit obtained from K2K, MINOS and Super-K I+II and significantly better than what would be obtained from all other experiments considering realization chances and realistic time scales – see the table below.

Experiment	UL (90% CL) [10^{-6}eV^2]	LL (90% CL) [ps/eV]
KM3NeT/ORCA (3 yr)	5.7	120
KM3NeT/ORCA (10 yr)	3.7	180
T2K, NOvA	290	2.3
T2K, MINOS	240	2.8
K2K, MINOS, SK I+II	2.3	290
MOMENT (10 yr)	24	28
ESSnuSB ($5\nu+5\bar{\nu}$) yr	16 – 13	42 – 50
DUNE ($5\nu+5\bar{\nu}$) yr	13	51
JUNO (5 yr)	7	93
INO-ICAL (10 yr)	4.4	151

Upper limits (UL) and their corresponding conversion into lower limits (LL) at 90% CL for the decay constant and its inverse for current (blue) and future experiments.

Also, the impact of neutrino decay on the precision of KM3NeT/ORCA measurements for θ_{23}, Δm^2_{31} and mass ordering have been studied. No significant effect of neutrino decay on the sensitivity to these measurements has been found.

Impressum

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