Neutrinos from galactic sources

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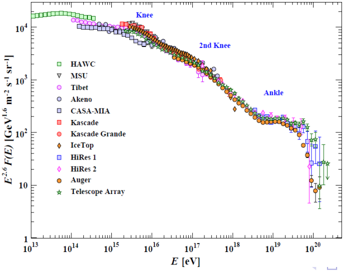
based on VN, A. Neronov, L. Fusco, S. Gabici, D. Semikoz, arXiv:1910.09065 [astro-ph.HE]
see also F. Halzen, A. Kheirandish, VN, arXiv:1609.03072 [astro-ph.HE]
M.C. Gonzalez-Garcia, F. Halzen, VN, arXiv:1310.7194 [astro-ph.HE]

Cosmic-rays

- Cosmic-rays discovered in 1912 by Victor Hess
- The observed energy spectrum of *cosmic-rays* is described by a power law with spectral index of about 2.7 up to energies of a few PeV, where the spectrum gets steeper and a feature called the "knee" originates.
- The knee is believed to mark the maximum energy for cosmic-rays accelerated by *Galactic sources*, or the energy above which the effectiveness of the confinement within the Galaxy is reduced. *A.M. Hillas, J.Phys.Conf.Ser. 47 (2006) 168-177*



Cosmic-rays and neutrinos

- *Neutrinos* are particles that rarely interact with matter and do not feel the magnetic field
  $\Rightarrow$ they can carry information on the physics of acceleration of particles and on the most energetic and distant phenomena in the Universe

- Neutrinos can permit to discriminate unambiguously between *leptonic* and *hadronic* scenarios
  $\Rightarrow$ They are "smoking gun" signature of cosmic-rays accelerators

Calculation of neutrinos expected at KM3 detectors from specific *galactic* sources:

$\Rightarrow$ Milagro sources at IceCube *M.C. Gonzalez-Garcia, F. Halzen, V. Niro, arXiv:1310.7194 [astro-ph.HE]; F. Halzen, A. Kheirandish, VN, arXiv:1609.03072 [astro-ph.HE]*

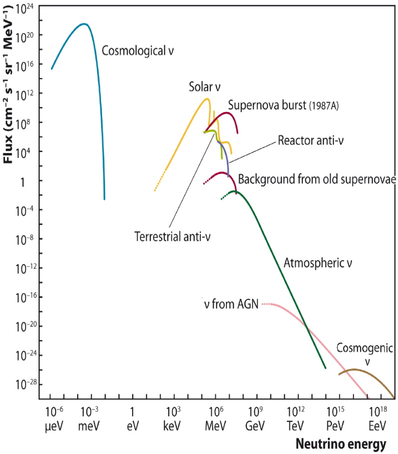
$\Rightarrow$ Neutrinos from RX J1713.7-3946, Vela Junior, Milagro sources, Fermi Bubble

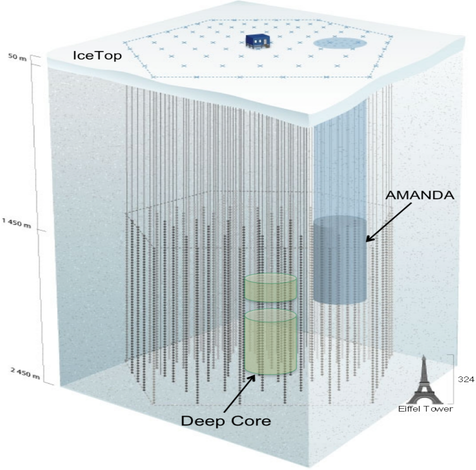
F. Vissani, F. Aharonian, arXiv: 1112.3911 [astro-ph.HE], F. Vissani, F. Aharonian, N. Sahakyan, arXiv: 1101.4842 [astro-ph.HE]

$\Rightarrow$ Neutrinos from eHWC J1825-134 source

VN, A. Neronov, L. Fusco, S. Gabici, D. Semikoz, arXiv:1910.09065 [astro-ph.HE]

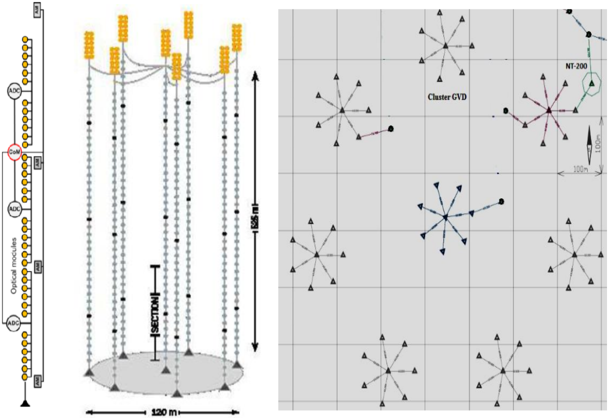
Flux of neutrinos and KM3 detectors: IceCube





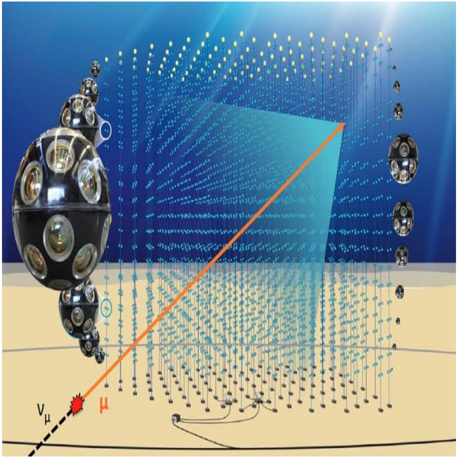
U. F. Katz, C. Spiering, arXiv:1111.0507 [astro-ph.HE]

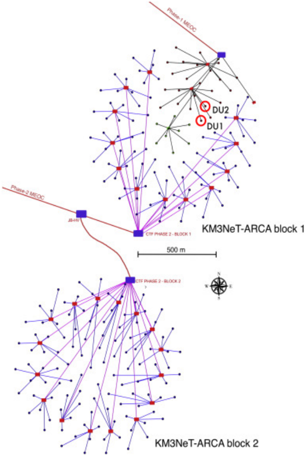
KM3 detectors: Baikal



2020: 7 clusters. The effective volume expanded up to 0.35 km^3.

KM3 detectors: KM3NeT

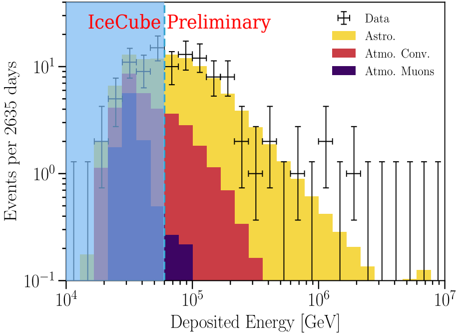




ARCA/ORCA: Astrophysics/Oscillation Research with Cosmics in the Abyss

Diffuse flux at IceCube

From the data collected in 7.5 years of running of the IceCube detector, 60 events were identified with deposited energy $E_{dep} > 60$ TeV.

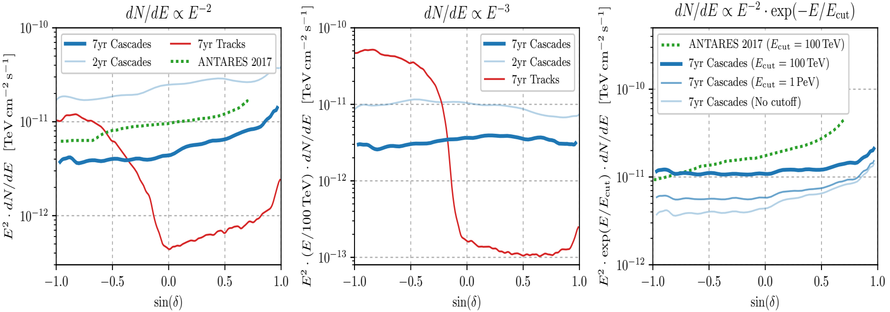


A. Schneider, arXiv:1907.11266 [astro-ph.HE], PoS-ICRC2019-1004

Moreover, a 3.5σ evidence is present for neutrino emission coming from the direction of the blazar TXS 0506+056

M. G. Aartsen et al., arXiv:1807.08794 [astro-ph.HE], Science 361 (2018) 6398

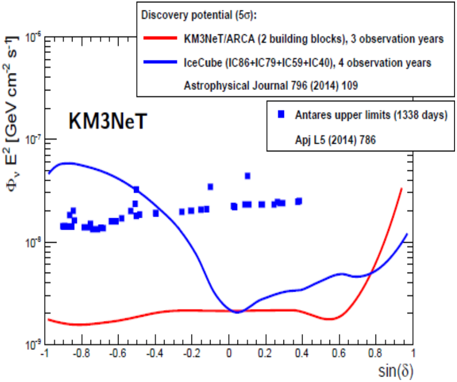
IceCube sensitivity to point-sources



M. G. Aartsen et al., arXiv:1907.06714 [astro-ph.HE]

The IceCube detector has an optimal sensitivity for sources located in the northern hemisphere, and is less sensitive to sources located in the southern sky, using tracks events.

Sensitivity to point sources: E^{-2} spectrum



Letter of intent for KM3NeT 2.0, arXiv:1601.07459 [astro-ph.IM]

A multi-messenger approach

- A multi-messenger search is mandatory for the identification of the origin of cosmic neutrinos.
- Gamma-ray data are necessary to make correct estimations of neutrino fluxes from point-sources.
- The characteristic gamma-ray feature of a PeVatron include an hadronic, hard spectrum that extends until at least several tens of TeV.

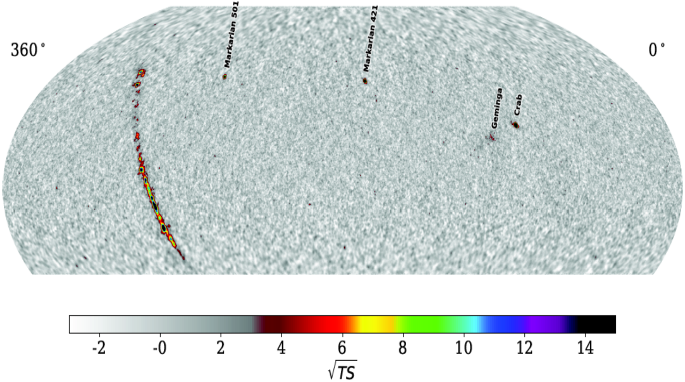
  $\Rightarrow$ a gamma-ray experiment with sensitivity to make detections up to about 100 TeV is of fundamental importance.

HAWC results

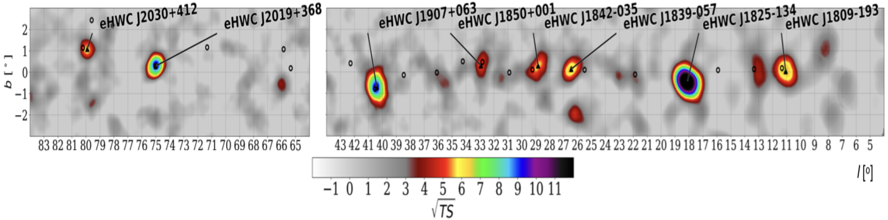
2HWC catalogue: first catalog of TeV gamma-ray sources realized with the High Altitude Water Cherenkov Observatory.

⇒ 39 very high energy gamma-ray sources identified.

A.U. Abeysekara et al., arXiv:1702.02992v1 [astro-ph.HE]



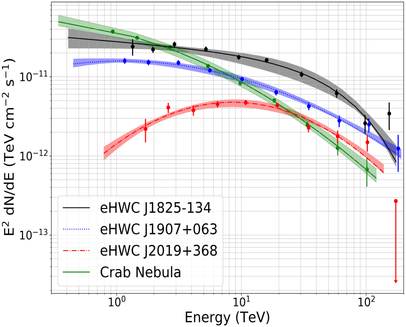
eHWC sources



A. U.Abeysekara et al., arXiv:1909.08609 [astro-ph.HE]

Nine sources are observed above 56 TeV, all of which are likely Galactic in origin

eHWC sources



A. U.Abeysekara et al., arXiv:1909.08609 [astro-ph.HE]

eHWC J1825-134 source ⇒ Amongst the HAWC sources, it is the most luminous in the multi-TeV domain and therefore is one of the first that should be searched for with a neutrino telescope in the northern hemisphere

eHWC J1825-134 source

We will use for the analysis the spectrum reported in the eHWC catalogue, where a power-law with exponential cut-off fit was considered:

$$\frac{dN_\gamma}{dE_\gamma} = \phi_0 \left(\frac{E_\gamma}{10\ \mathrm{TeV}}\right)^{-\alpha_\gamma} \exp\left(-\frac{E_\gamma}{E_{cut,\gamma}}\right),$$

with $E_{cut,\gamma}$ being the cut-off energy of the gamma-ray spectrum, α_γ the spectral index and ϕ_0 the flux normalization:

$$E_{cut,\gamma} = (61 \pm 12)\ \mathrm{TeV}\,, \qquad \phi_0 = (2.12 \pm 0.15)\ \times\ 10^{-13}\ \mathrm{TeV}^{-1}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\,,$$

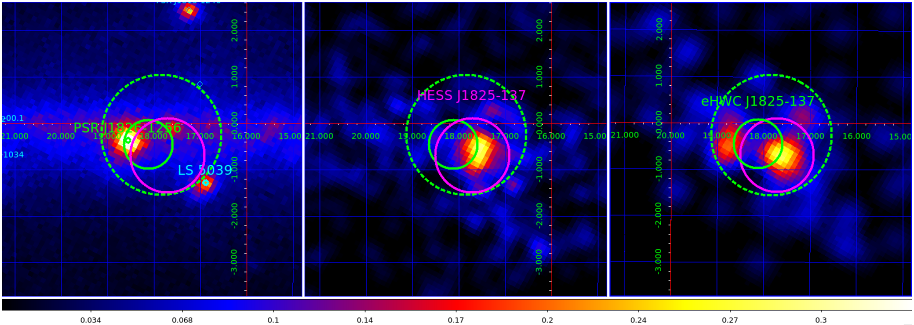
$$\alpha_\gamma = 2.12 \pm 0.06\,, \qquad \sigma_{\mathrm{ext}} = 0.53^\circ \pm 0.02^\circ\,,$$

where σ_{ext} is the extension of the source.

⇒ The sensitivity of HAWC to the high energy tail of the spectrum is of fundamental importance for the correct prediction of the neutrino flux.

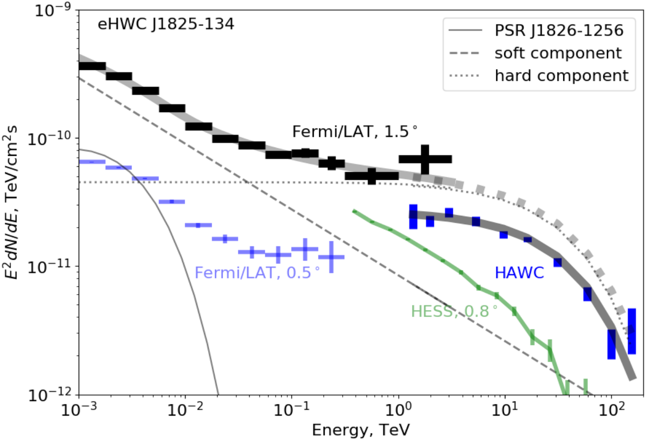
⇒ The eHWC J1825-134 overlaps with two HESS sources: the very bright HESS J1825-137 and the much weaker HESS J1826-130.

Fermi/LAT data



Fermi/LAT countmaps of the source region in 1-10, 100-300 and $>$ 300 GeV energy ranges (left to right). The 1-10 GeV and 100-300 GeV maps are smoothed with 0.3 degree Gaussian, the 300 GeV map is smoothed with 0.5 degree Gaussian.

eHWC J1825-134 region



Spectrum of eHWC J1825-134 region measured by Fermi/LAT compared to the HAWC and HESS spectral measurements.

Neutrino event rate

The event rate at KM3NeT detector can be described by:

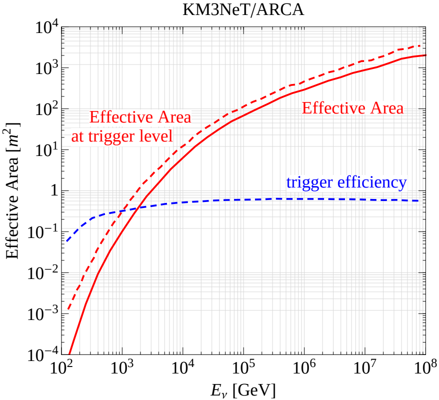
$$N_{\rm ev} = \epsilon_\theta \epsilon_v \, t \int_{E_\nu^{\rm th}} dE_\nu \, \frac{dN_\nu(E_\nu)}{dE_\nu} \times A_\nu^{\rm eff} \, ,$$

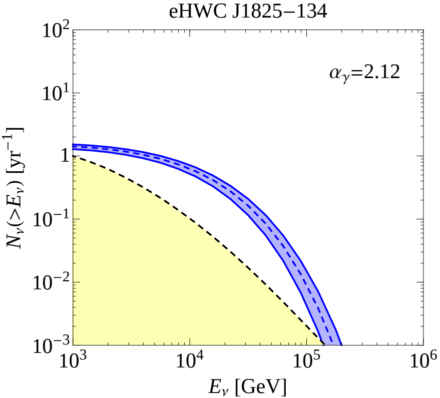
where a sum over neutrino and antineutrino contributions is implicit.

$\epsilon_v = 0.57$: visibility of the source,
$\epsilon_\theta = 0.72$: takes into account a reduction factor due to the fact that only a fraction of the signal will be detected if the source morphology is assumed to be a Gaussian of standard deviation σ_{ext} and the signal is extracted within a circular region of radius $\sigma_{\rm eff} = 1.6\sqrt{\sigma_{\rm ext}^2 + \sigma_{\rm res}^2}$.

$\sigma_{\rm res} \sim 0.1^\circ$: angular resolution of KM3NeT/ARCA.

Effective area and source eHWC J1825-134





Left: Effective area used in the analysis (red solid line), effective area at trigger level (red dashed line), and trigger efficiency (blue dashed); *Right:* number of events expected for the atmospheric background (yellow area) and for the source for the best-fit value of α_γ and different values of $E_{cut,\gamma}$.

Statistical significance

For the statistical significance of discovery, we use the total number of expected signal and bkg events and we compute the bkg-only p-value:
ATL-PHYS-PUB-2011-011, CMS-NOTE-2011-005

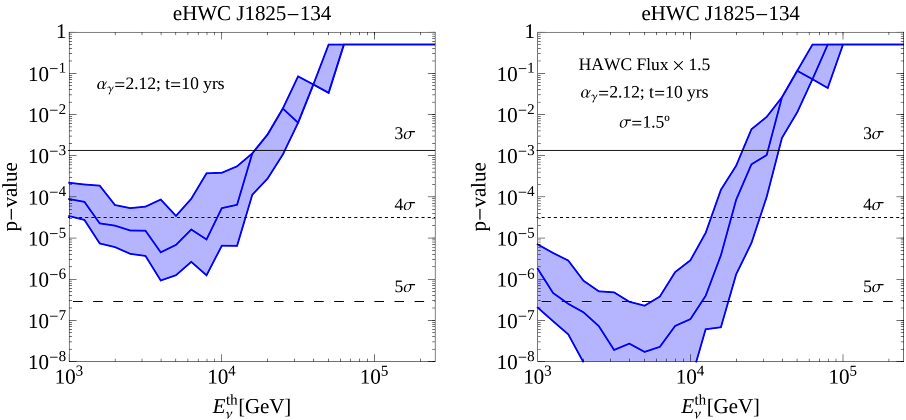
$$p_{\mathrm{value}} = \frac{1}{2}\left[1 - \mathrm{erf}\left(\sqrt{q_0^{obs}/2}\right)\right] ,$$

where q_0^{obs} is defined as

$$q_0^{obs} \equiv -2 \ln \mathcal{L}_{b,D} = 2\left(Y_b - N_D + N_D \ln\left(\frac{N_D}{Y_b}\right)\right) ,$$

with N_D the estimated experimental data –generated as the median of a large sample of event numbers that are Poisson distributed around the expectation of signal plus bkg– and Y_b the theoretical expectation for the bkg.

eHWC J1825-134 source and extended region



p-value for the best-fit value of α_γ and different values of $E_{cut,\gamma}$ for 10 years of running of the KM3NeT detector. The blue band represents the statistical errors in $E_{cut,\gamma}$.

Conclusions

- The BAIKAL-GVD detector in the Baikal Lake will have the discovery potential for this source similar to the KM3NeT detector
- The cascade channels represent the most promising way to discover this source at the IceCube detector
- KM3 detectors in water: better angular resolution of cascade events, which is about 2 degrees instead of about 10 degrees
- Combined analysis of different KM3 detectors could improve the sensitivity to this source
- Will eHWC J1825-134 be the first PeVatron source detected by the KM3NeT detector?