Neutrinos from galactic sources and the perspective for the coming years

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APC, Paris

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

MSCA
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Cosmic accelerators and neutrinos

There are different possible sources of cosmic rays, among which:

- Supernova remnant: considered the major source of galactic cosmic rays
  first suggested by Walter Baade and Fritz Zwicky in 1934
  in 2013 the Fermi satellite has revealed γs from π^0 decay for SNR IC443 and W44
  $\rightarrow$ evidence for SNR as sources of cosmic-rays *M. Ackermann et al., 1302.3307 [astro-ph.HE]*
- Gamma ray bursts
- Active Galactic Nuclei

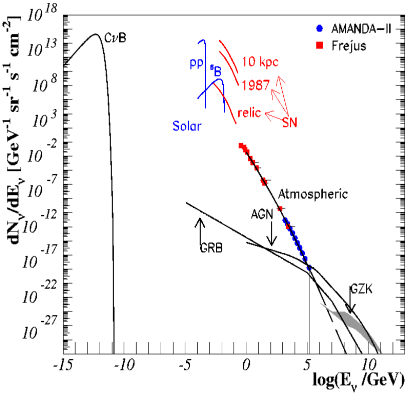
Calculation of neutrinos expected at KM3 detectors from specific *galactic* sources of high-energy neutrinos

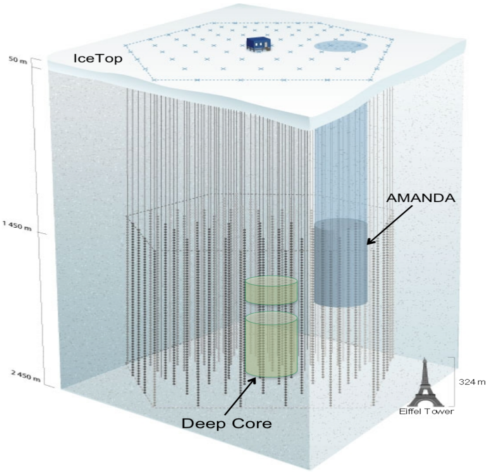
$\Rightarrow$ Milagro sources *M.C. Gonzalez-Garcia, F. Halzen, V. Niro, arXiv:1310.7194 [astro-ph.HE];*
F. Halzen, A. Kheirandish, VN, arXiv:1609.03072 [astro-ph.HE]

$\Rightarrow$ 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]

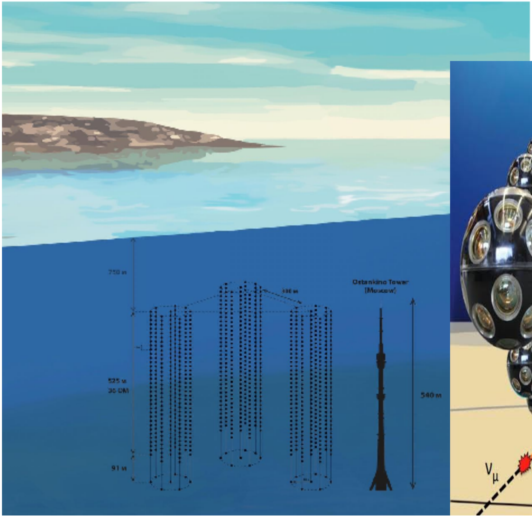
$\Rightarrow$ Neutrinos from eHWC J1825-134 source

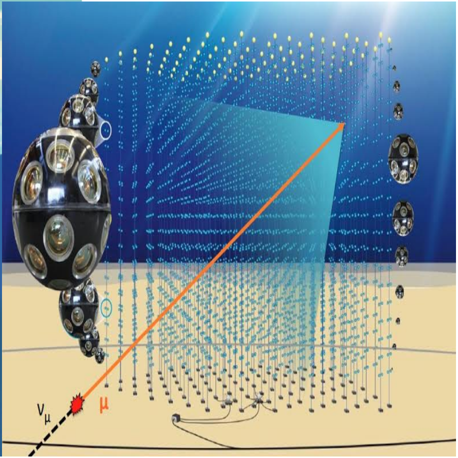
Flux of neutrinos and KM3 detectors





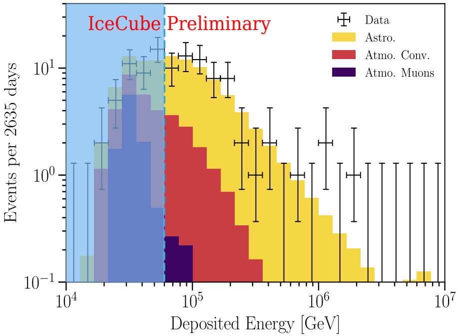
KM3 detectors





Diffuse flux at IceCube

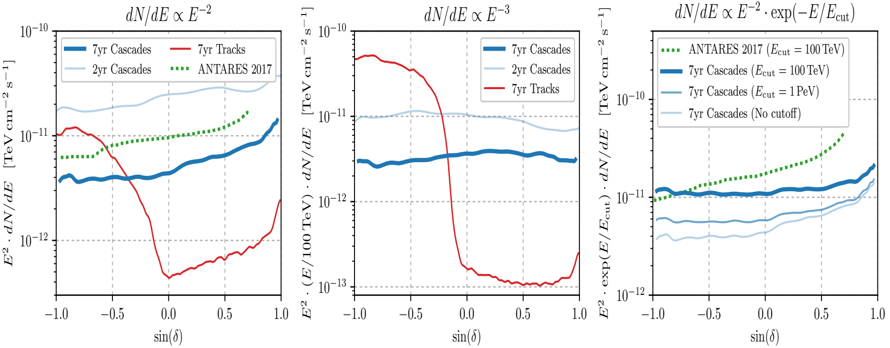
From the data collected in 7.5 years of running of the IceCube detector, 60 events were identified with deposited energy $E_{dep} > 60$ TeV.



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

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

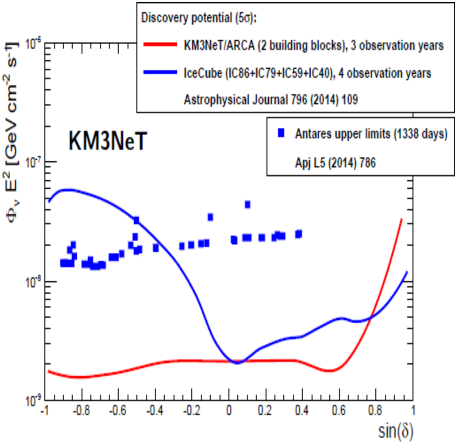
IceCube sensitivity to point-sources



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

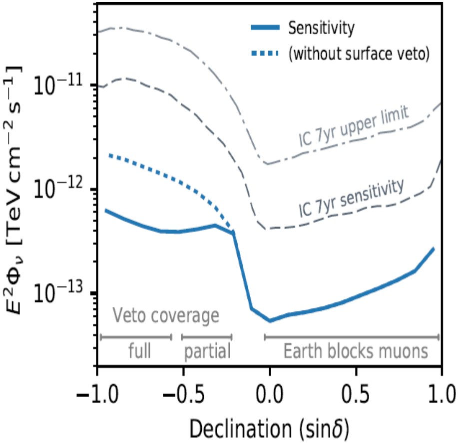
The IceCube detector has an optimal sensitivity for sources located in the northern hemisphere, and is less sensitive to sources located in the southern sky, using tracks events.

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



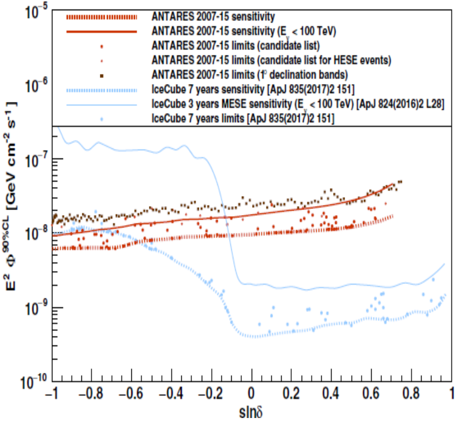
Letter of intent for KM3NeT 2.0, arXiv:1601.07459 [astro-ph.IM]

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



IceCube-Gen2: the next-generation neutrino observatory for the South Pole, PoS(ICRC2017)991

Sensitivity to point sources: spectrum with energy cut-off



A. Albert et al., arXiv:1706.01857 [astro-ph.HE]

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 estimation 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.

Cherenkov Telescope versus Air Shower Array

Two complementary methods for gamma-ray air showers

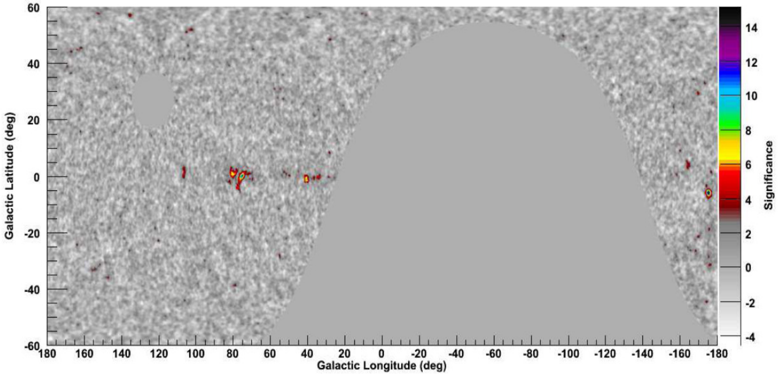
	Cherenkov Telescope	Air Shower Array
Energy Threshold	Low (< 200 GeV)	High (> 10 TeV)
Background Rejection	Excellent (> 99.7%)	Moderate (> 50%)
Field of View	Small (< 2°)	Large (> 45°)
Duty Cycle (uptime)	Low (5% – 10%)	High (> 90%)

http://www.hawc-observatory.org/science/detection.php

Imaging air Cherenkov telescopes: large upward-facing mirror to focus the Cherenkov light generated by the air shower.
Air Shower Array: array of particle counters on the ground (plastic scintillators or tanks full of water).

Milagro sources

The highest energy survey of the Galactic plane has been performed by Milagro
⇒ bright sources in the nearby Cygnus star-forming region and in the inner part of the Galaxy

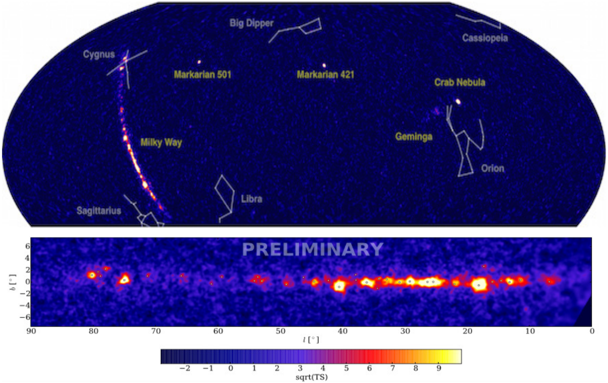


A. Abdo PhD thesis; A. Abdo et al., arXiv:0705.0707, A. Abdo et al., arXiv:0904.1018;
A. Abdo et al., arXiv:1202.0846, A.J. Smith, arXiv:1001.3695

HAWC results

In 2016, the HAWC experiment has confirmed four of the six sources:
MGRO J1908+06, MGRO J1852+01, MGRO J2031+41, and MGRO J2019+37

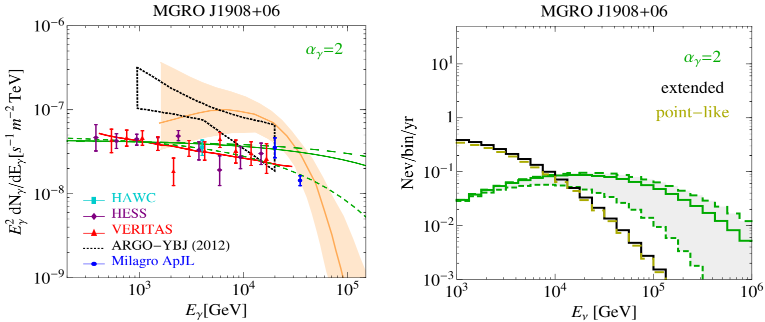
A.U. Abeysekara et al., arXiv:1509.05401 [astro-ph.HE]; A. Sandoval, talk at Gamma2016



HAWC press release, April 18, 2016

April Meeting of the American Physics Society in Salt Lake City, Utah

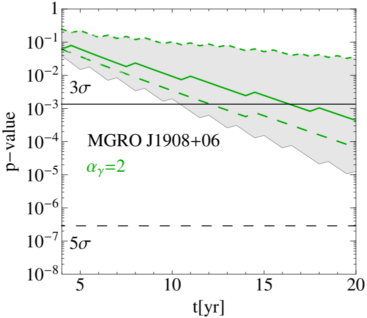
MGRO J1908+06

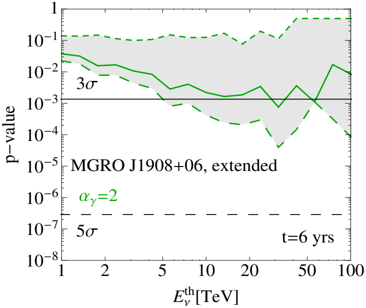


Observed by HAWC with similar energy spectrum than VERITAS.

cut-off energy: 30; 300; and 800 TeV.

MGRO J1908+06



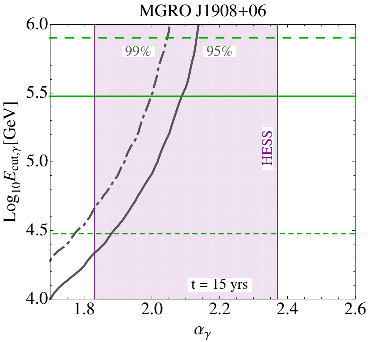


3σ discovery is possible in six years, if an energy threshold of about 5 TeV can be reached in the analysis, and that the spectrum extends to $E_{\mathrm{cut},\gamma}$ of 800 TeV

If $E_{\mathrm{cut},\gamma} \sim 300$ TeV, expected for galactic sources able to explain the cosmic-ray spectrum up to the knee $\rightarrow$ an energy threshold of about 10 TeV would be required

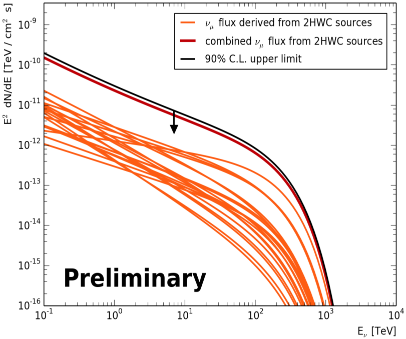
A 3σ discovery at a specific energy threshold will indicate a particular value of $E_{\mathrm{cut},\gamma}$

Confidence level limits



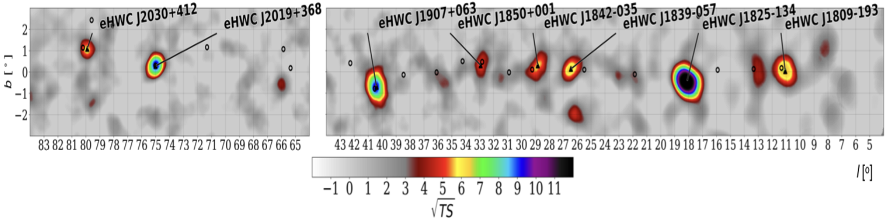
MGRO J1908+06: IceCube is able to constrain a major part of the values for α_γ reported by the HESS detector.

HAWC and IceCube results



Upper limit (90% C.L.) on the flux of high-energy muon neutrinos (black) for the stacking search of non-PWN sources in the 2HWC catalog. The projected muon neutrino fluxes (thin orange) represent the expected flux from each source. The combined flux (red) shows sum of the individual fluxes. *A. Kheirandish, J. Wood, 1908.08546 [astro-ph.HE]*

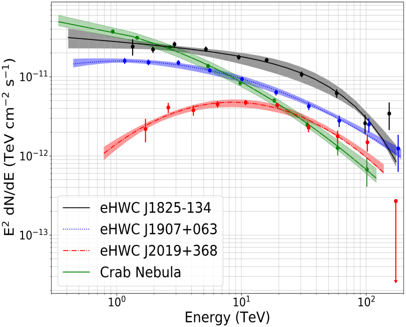
eHWC sources



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

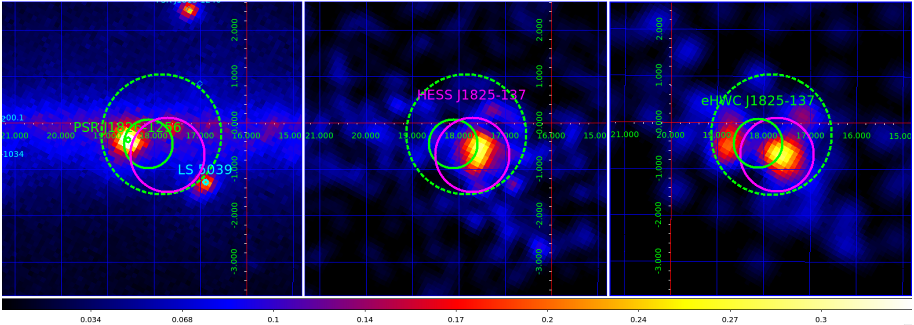
eHWC sources



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

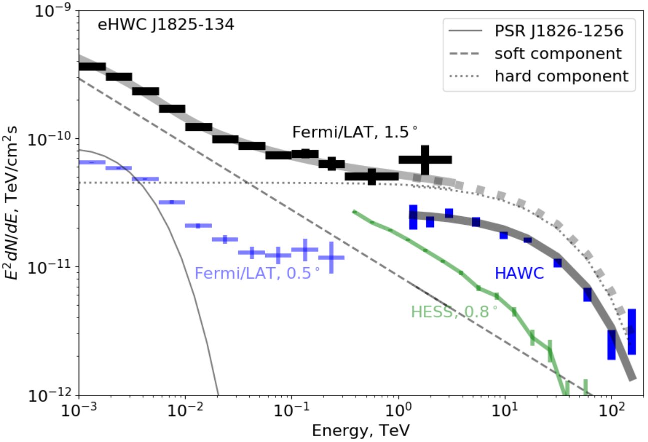
eHWC J1825-134 source ⇒ Amongst the HAWC sources, it is the most luminous in the multi-TeV domain and therefore is one of the first that should be searched for with a neutrino telescope in the northern hemisphere

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 flux

The neutrino fluxes at Earth can be described by:

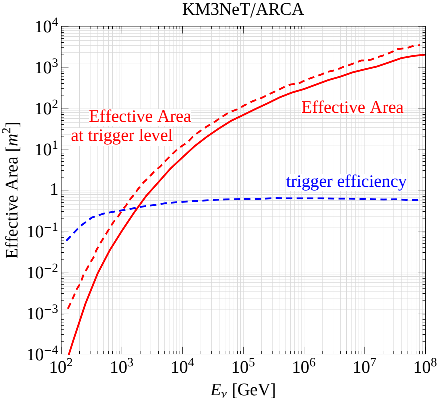
$$N_{\rm ev} = \epsilon_\theta \epsilon_v \, t \int_{E_\nu^{\rm th}} dE_\nu \, \frac{dN_\nu(E_\nu)}{dE_\nu} \times A_\nu^{\rm eff} \, ,$$

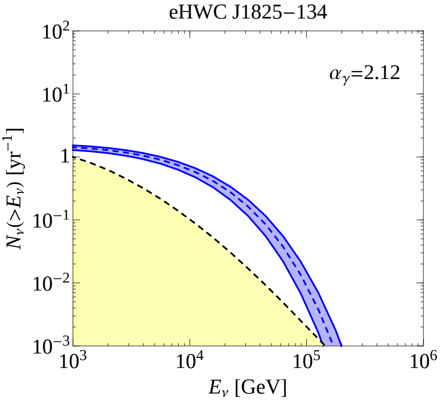
where a sum over neutrino and antineutrino contributions is implicit.

$\epsilon_v = 0.57$: 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.

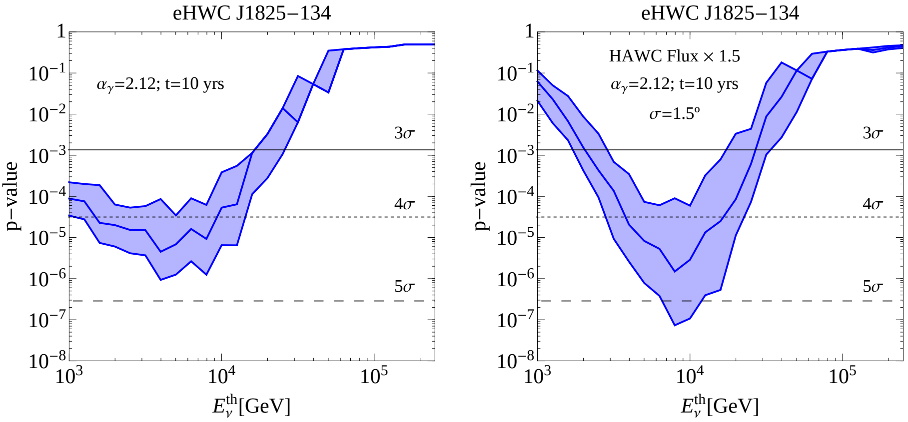
Effective area and source eHWC J1825-134





Right: Effective area used in the analysis (red solid line), effective area at trigger level (red dashed line), and trigger efficiency (blue dashed); Left: 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 $E_{cut,\gamma}$. *Niro et al., 2019*

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 detectorin Baikal Lake will have the discovery potential for this source similar to the KM3NeT 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
- The source MGRO J1908+06 was predicted to be one of the most promising source to be detected at the IceCube detector

  $\Rightarrow$ Will eHWC J1825-134 be the first PeVatron source detected by the KM3NeT detector?