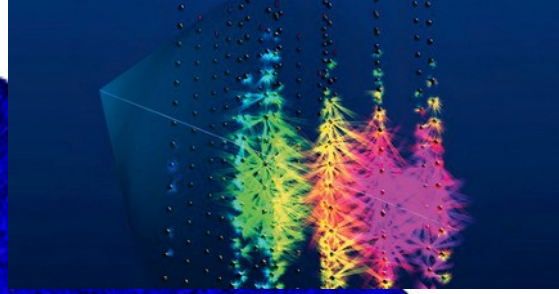


On the Potential Galactic Origin of the Ultra-High-Energy Event KM3-230213A

KM3-230213A

Mischa Breuhaus for the KM3NeT collaboration

8. July, EPS-HEP 2025

KM3NeT

Aix Marseille Université

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE

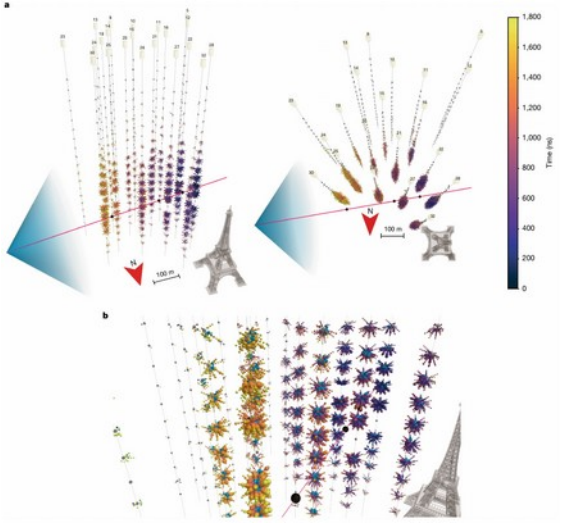
CPPM

Outline

- Based on an article accepted for publication in APJ, available on arXiv:2502.08387
- The neutrino event KM3-230213A
- Gas targets within the region
- Potential CR sources
  - Diffuse Galactic emission
  - Local CR accelerators
- Limits from γ-ray observations
- Conclusion

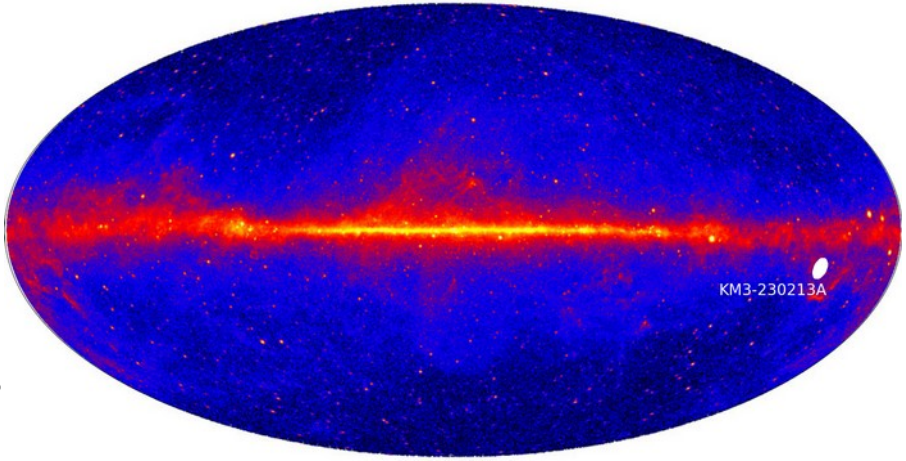
The event KM3-230213A

- Also: see plenary talk by Annarita Margiotta on Highlights from KM3NeT earlier today
- Detected on 13. February 23 at 01:16:47 UTC with the ARCA detector
- Published in nature on 12.2.25 together with 5 companion papers in arXiv
- With very high probability an astrophysical neutrino
- 3672 triggered PMTs (35% of all active PMTs)



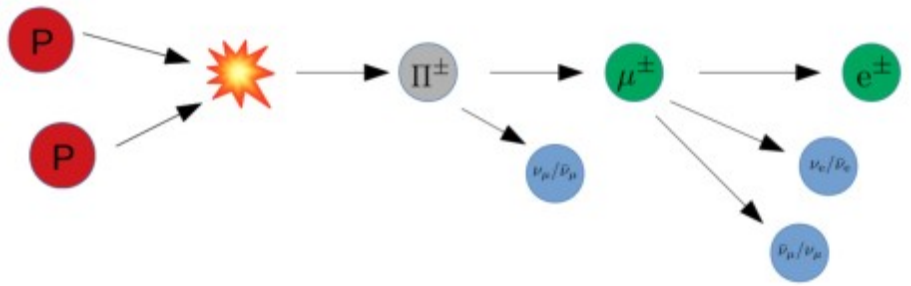
The event KM3-230213A

- Mean neutrino energy: 220 PeV
- 68% confidence 110-790 PeV, 90% confidence 72 PeV – 2.6 EeV
- RA = 94.3°, Dec = -7.8°
- R(68%) = 1.5°
- R(99%) = 3.0°
- Gal coord. l = 216.1°, b = -11.1°
- Galactic origin ?



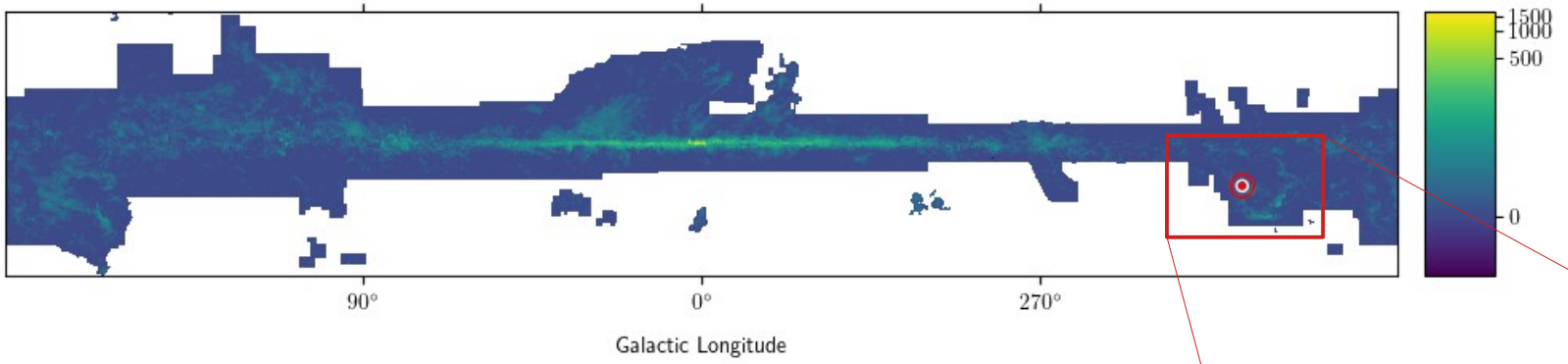
Potential gas target in the region

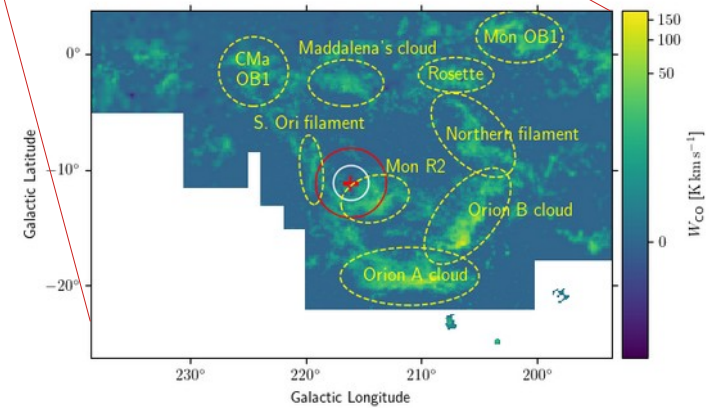
- Most important neutrino production mechanism: Collisions of CRs with ambient medium



Search for potential gas targets nearby

Potential gas target in the region

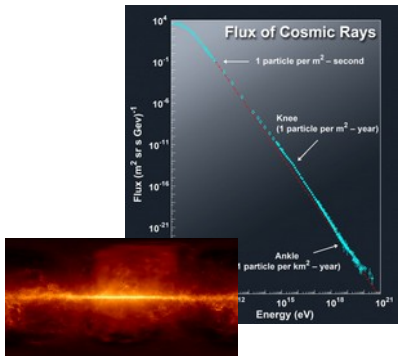




- CO map from Dame et al. 2001
- Nearby: Southern Orion filament
- Within error region: Monoceros R2 cloud, potential gas target for CRs
- Distance: ~830 pc, 9x10^4 solar masses

Potential CR Sources

Diffuse CRs



Stellar clusters

Figure credit: HST

Supernova remnants

Figure credit: X-ray: NASA/CXC/SAO.; Optical: DSS

Microquasars and X-ray binaries

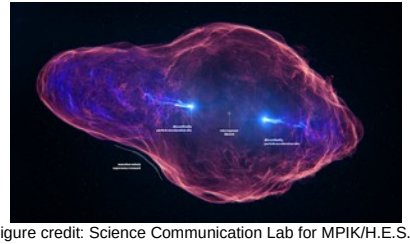


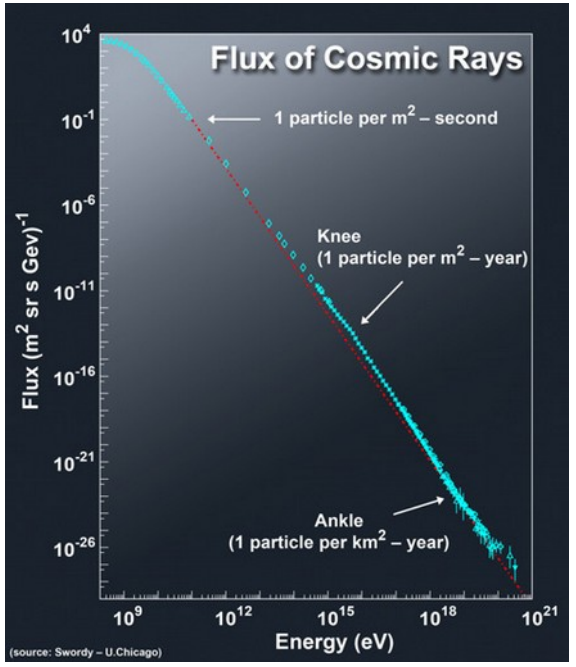
Figure credit: Science Communication Lab for MPIK/H.E.S.S.

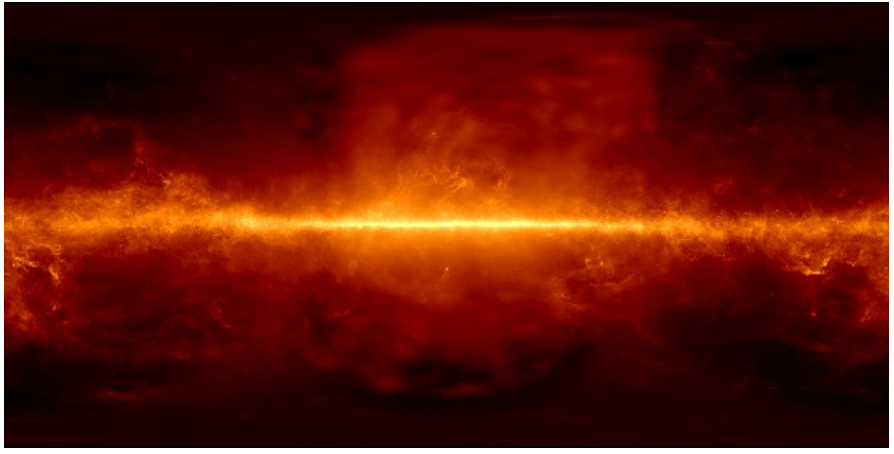
Pulsars/PWN

Figure credit: MARK GARLICK/SCIENCE PHOTO LIBRARY via Getty Images

Diffuse Galactic emission

- Diffuse CRs interacting with gas in the Milky Way
- Use Breuhaus et al. 2022 models and Gaggero et al. 2015, De La Torre Luque et al. 2022 for comparison

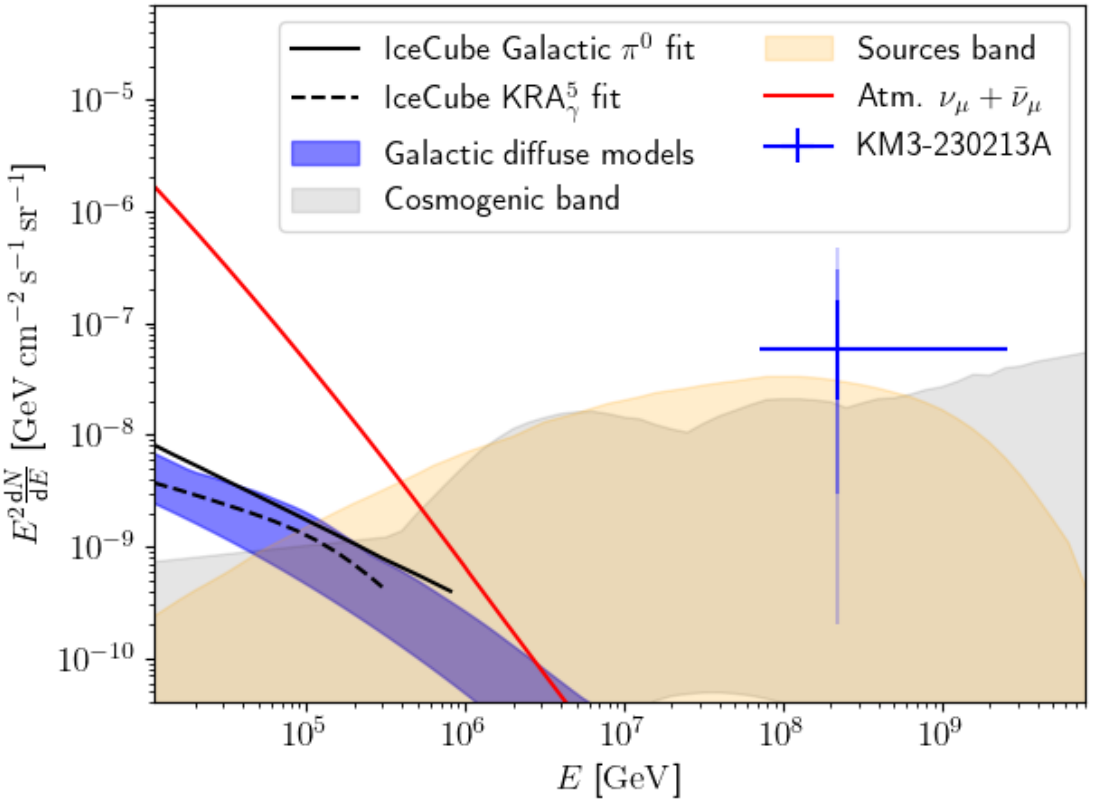




Diffuse Galactic emission from Fermi-LAT

Diffuse Galactic emission

- All models show similar behaviour
- Galactic diffuse emission negligible compared to extragalactic neutrino fluxes
- Enhanced densities in Mon R2 cloud do not change final result



Supernova Remnants

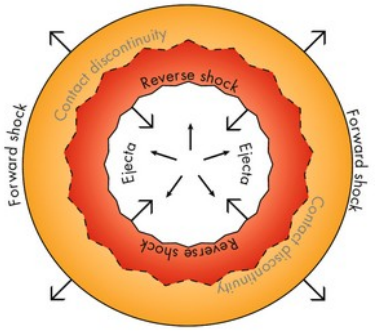
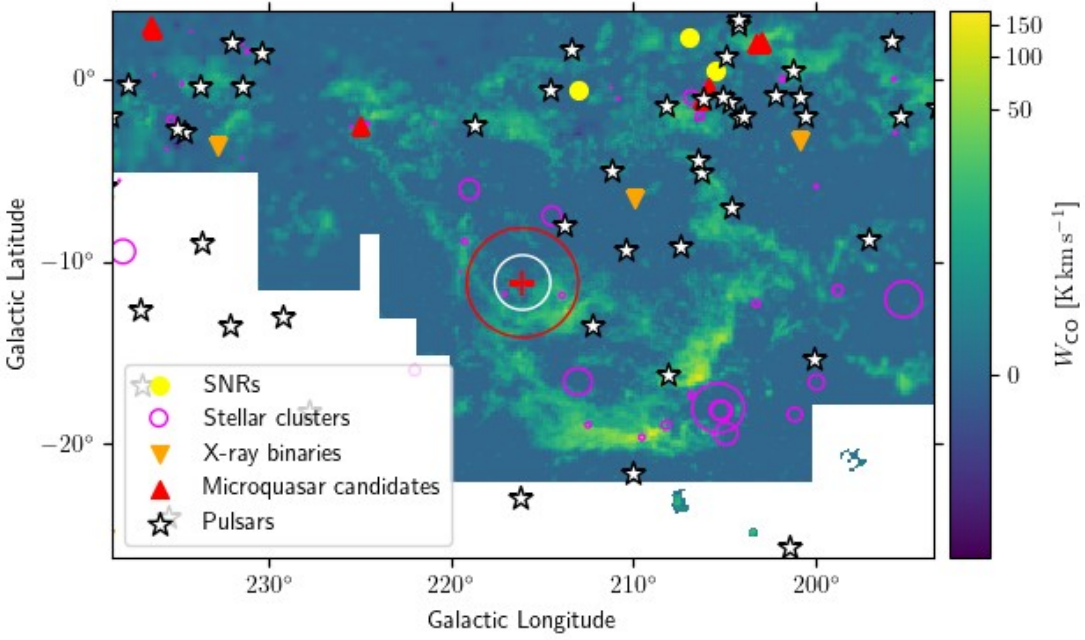


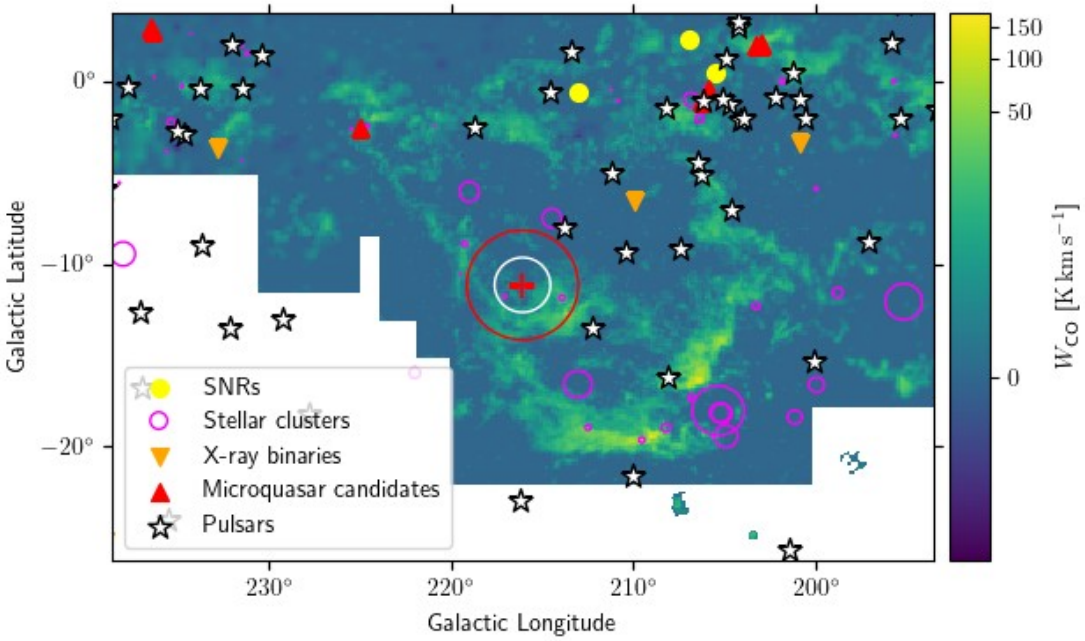
Figure: Vink 2020

- Maximum energies of few PeV
- In massive stellar clusters: few 100 PeV (Vieu & Reville 2023)
- No known SNR found nearby (Green's SNR catalogue)



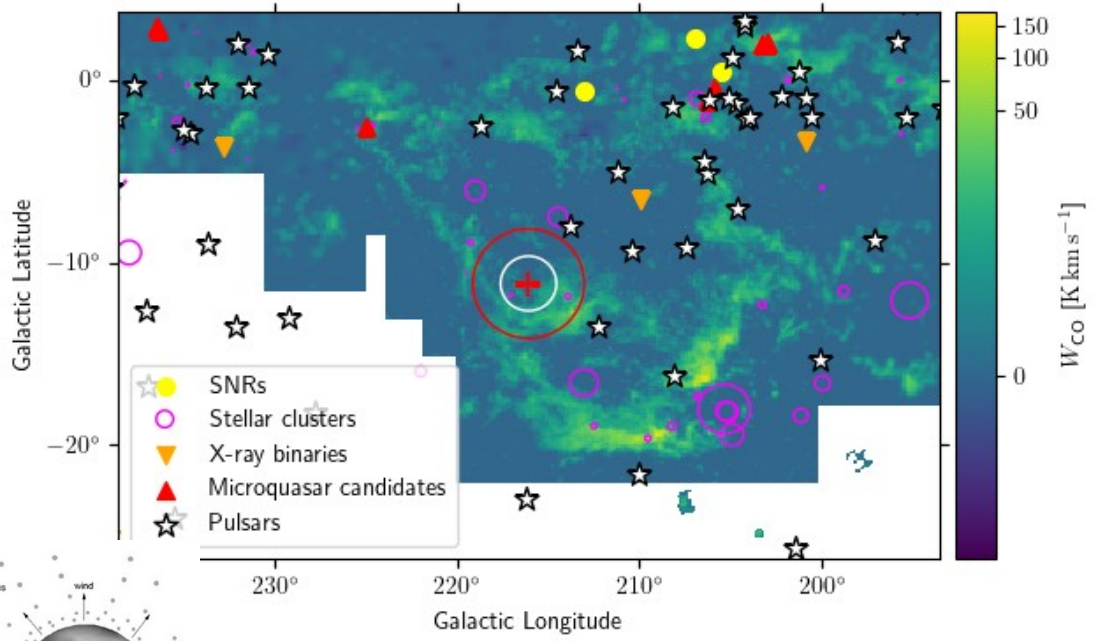
Stellar clusters

- Acceleration at collective wind termination shock
- 5 clusters within 5° from event (Celli et al 2024)
- Collective wind powers < 10^{34} erg/s
- Required energies can not be reached



X-ray binaries and microquasars

- Acceleration in jet or wind collision region
- Difficult to reach required energies
- No source nearby (Neumann et al. 2023, Avakyan et al. 2023, Combi et al. 2008)



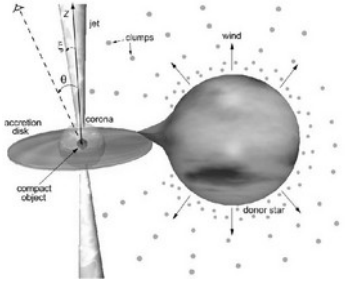
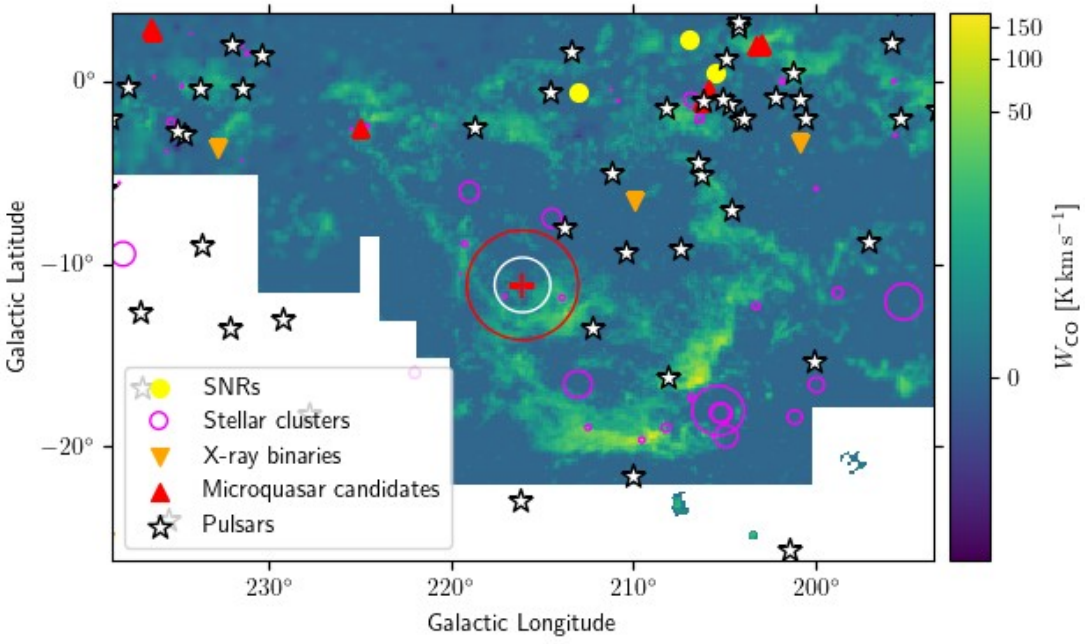


Figure: Reynoso & Romero 2009

Pulsars and Pulsar wind nebulae

- Acceleration at wind termination shock or pulsar magnetosphere, but largely leptonic
- 2 pulsars < 5° away (ATNF pulsar catalogue), spin-down powers < 10^{33} erg/s → too weak



Potential CR sources

- Galactic diffuse emission negligible
- No known powerful CR accelerator nearby
- Unknown accelerator?

Potential CR sources

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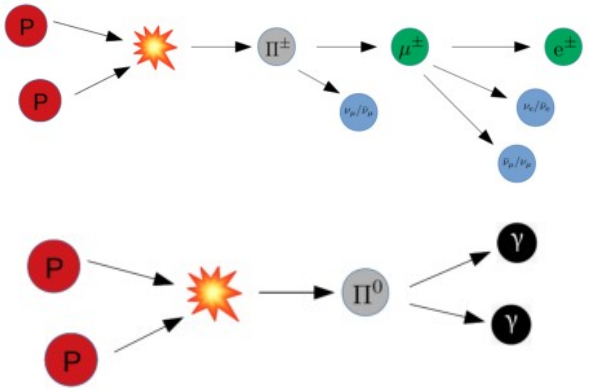
ν production by CRs → simultaneous γ-ray emission

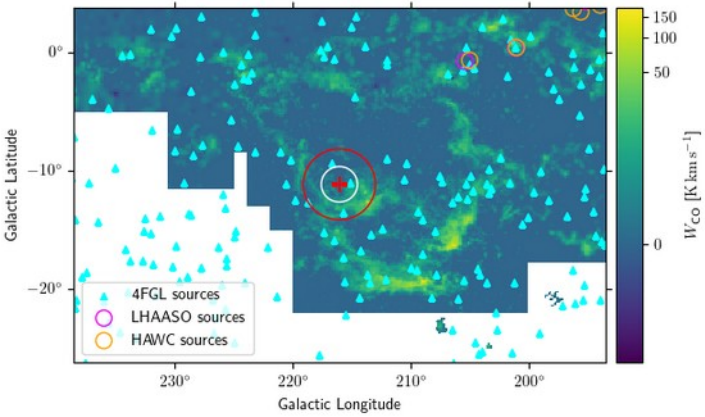


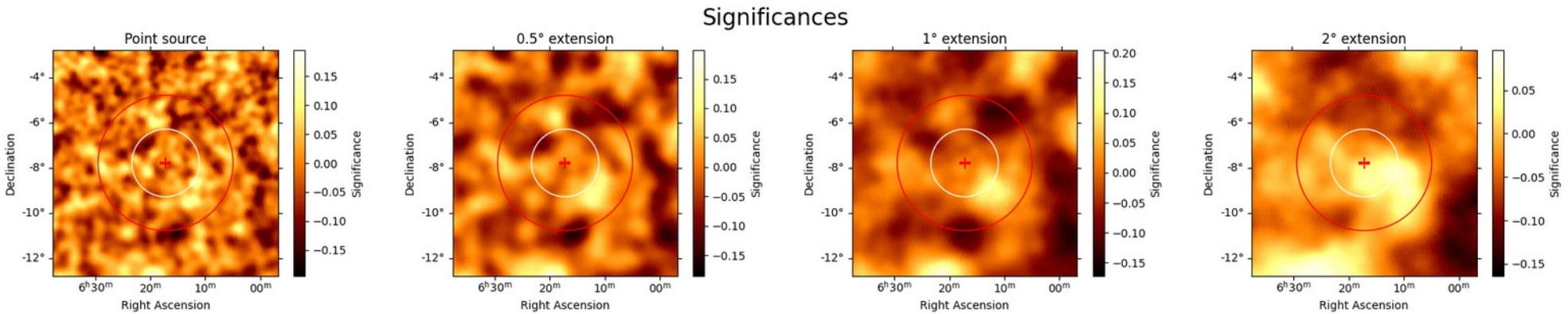
$$p + \gamma \rightarrow p + k \cdot \pi^0/\pi^{\pm}$$

Search for Galactic γ-ray sources

Gamma-ray sources in the region

- 2 unidentified Fermi-LAT sources within the region
- No reported HAWC or LHAASO source
- Public data from 3HWC survey

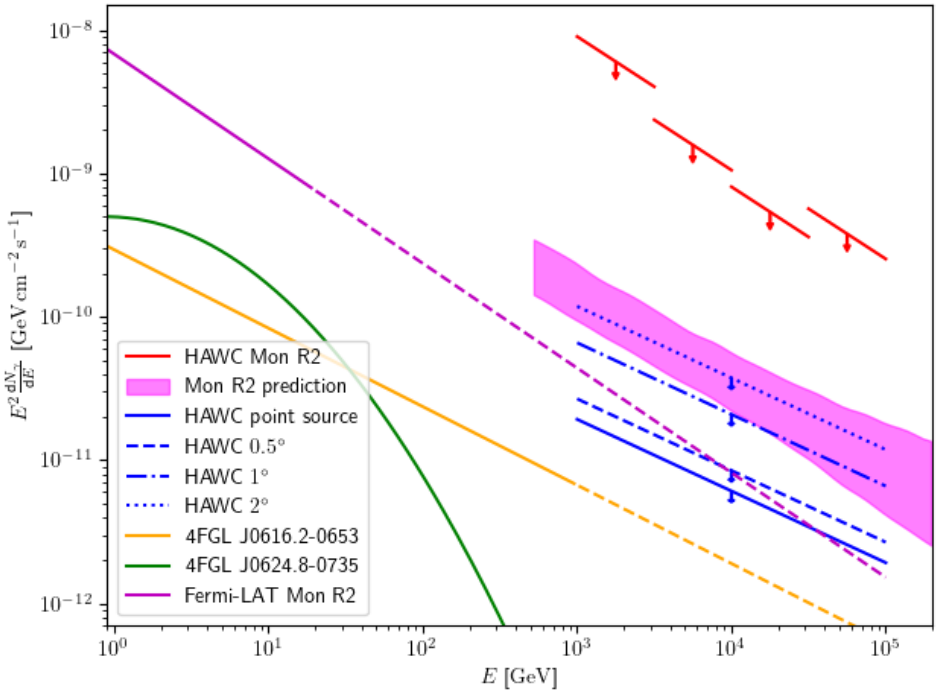




Significance maps from public HAWC data

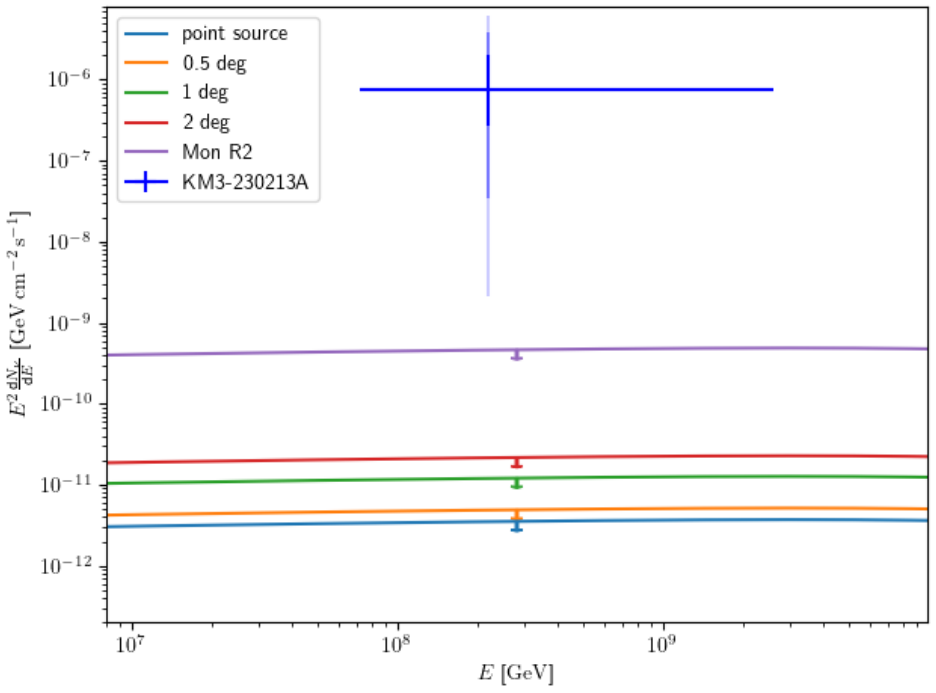
γ-ray spectra and limits

- Fermi:
  - 4FGL J0616.2-0653
  - 4FGL J0624.8-0735
  - Measurement of Mon R2 cloud by Marti et al. 2013
- HAWC limits:
  - Point source & different extensions
  - Limit for Mon R2 (Albert et al. 2021)
- Strictest constrains from HAWC limits



Neutrino limits from γ rays

- Assume E^{-2} distributed CRs fulfilling HAWC γ-ray limits
- Extrapolation to higher energies
- γ-ray absorption: would need 100 eV/cm^{-3} 60K radiation field over 400 pc region → highly unlikely
- Neutrino limits from HAWC non-detection well below PS flux of KM3-230213A



Conclusion

- Monoceros R2 cloud is a potential target
- Galactic diffuse emission is negligible
- No potential CR accelerator found
- Limits from γ-ray observations below PS flux

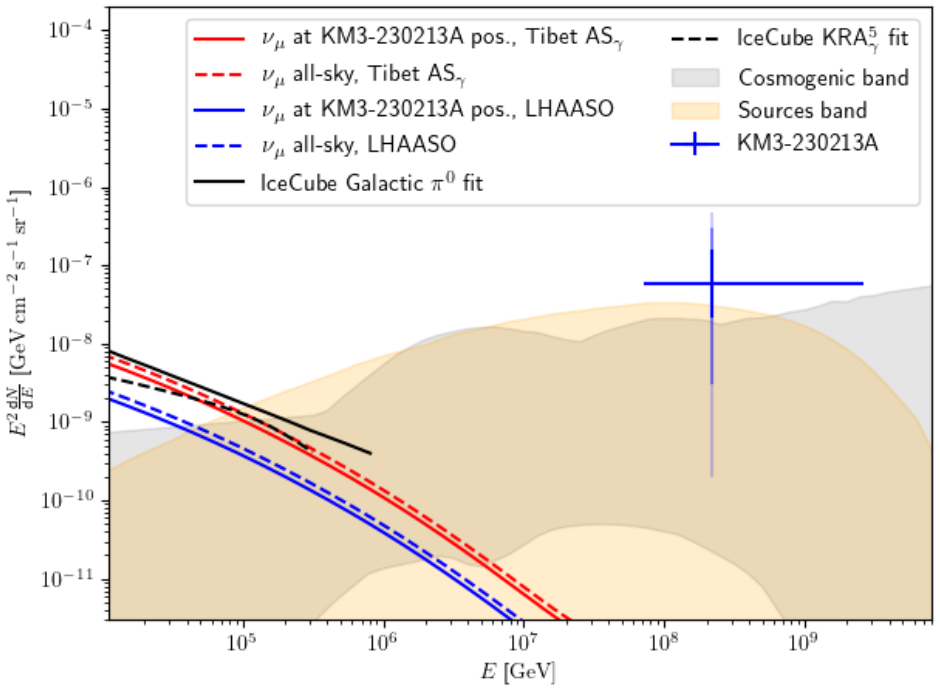
→ Galactic origin very unlikely

Thank you very much for your attention!

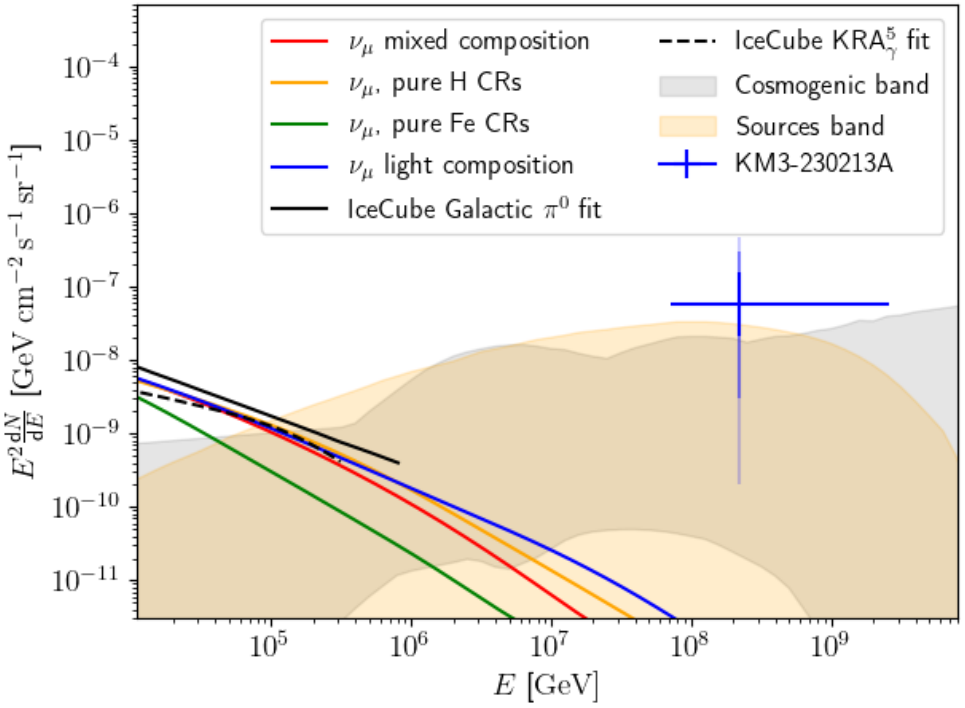
Backup slides

Diffuse Galactic emission

Matched to different γ-ray data

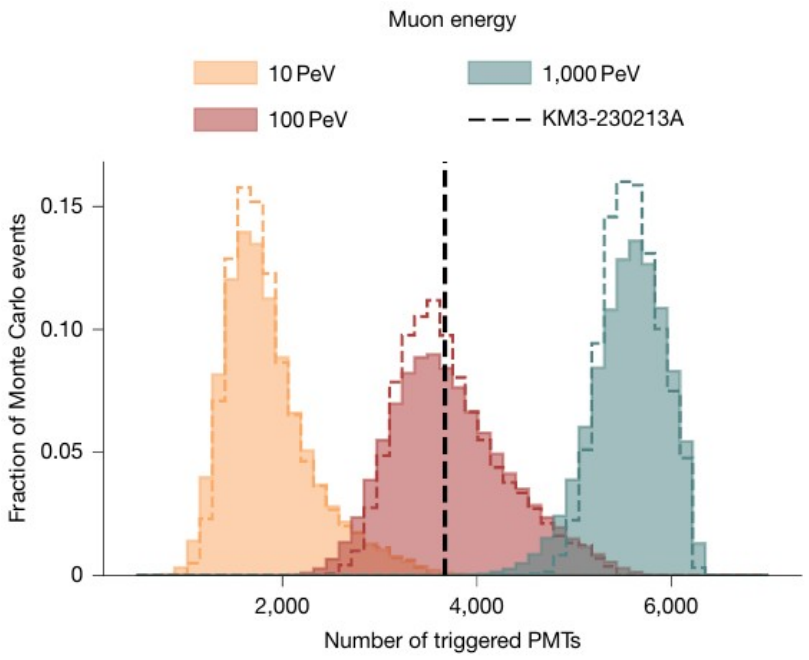


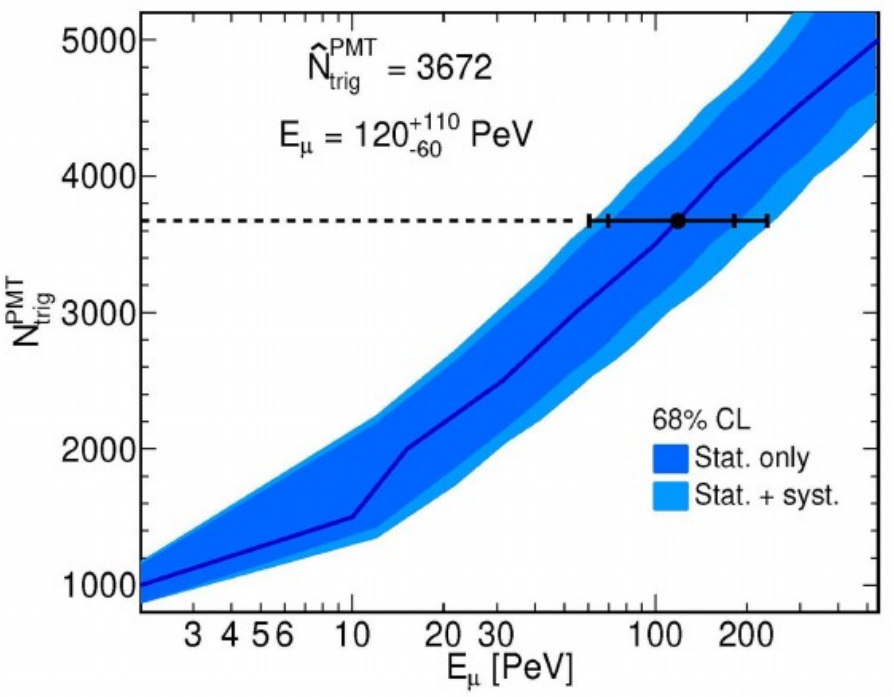
Different CR compositions



- In all cases: emission above tens of PeV below extragalactic expectations

Energy determination





- Directly related to number of triggered PMTs
- Estimated from dedicated MC simulations
- Uncertainties from absorption length, PMT efficiencies

90% confidence interval: 35-380 PeV
Inferred neutrino energy: 220 PeV, 68% confidence 110-790 PeV, 90% confidence 72 PeV – 2.6 EeV

Why are we very sure it is an astrophysical neutrino?

- Background: Muons, atm. Neutrinos
- Muons: 10^{-9} – 10^{-10} evt/yr, dependent on direction
- Atm. Neutrinos > 100 PeV: 1-5x10^{-5} evt/yr