Overview of the results of the ANTARES neutrino telescope

CRIS2022 - Napoli
12th - 16th September 2022

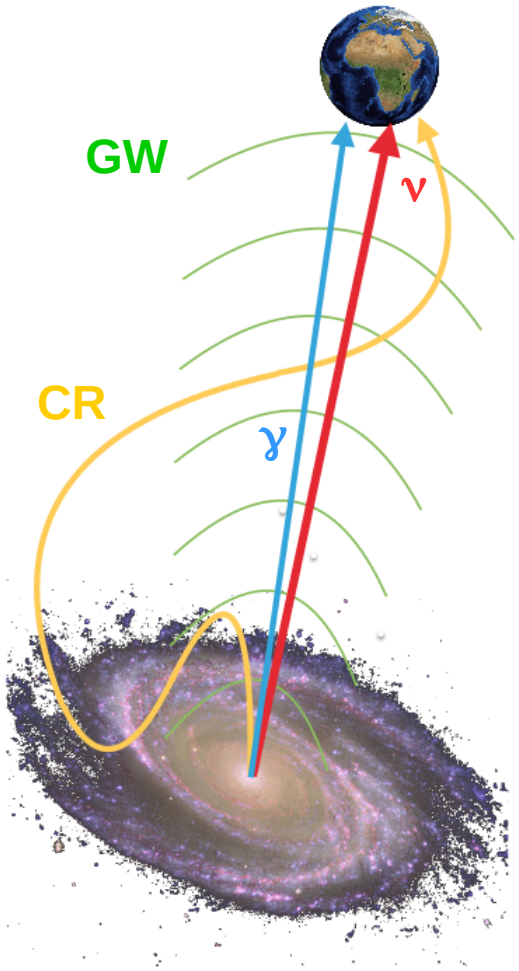
Luigi Antonio Fusco
lfusco@unisa.it
Università di Salerno and INFN

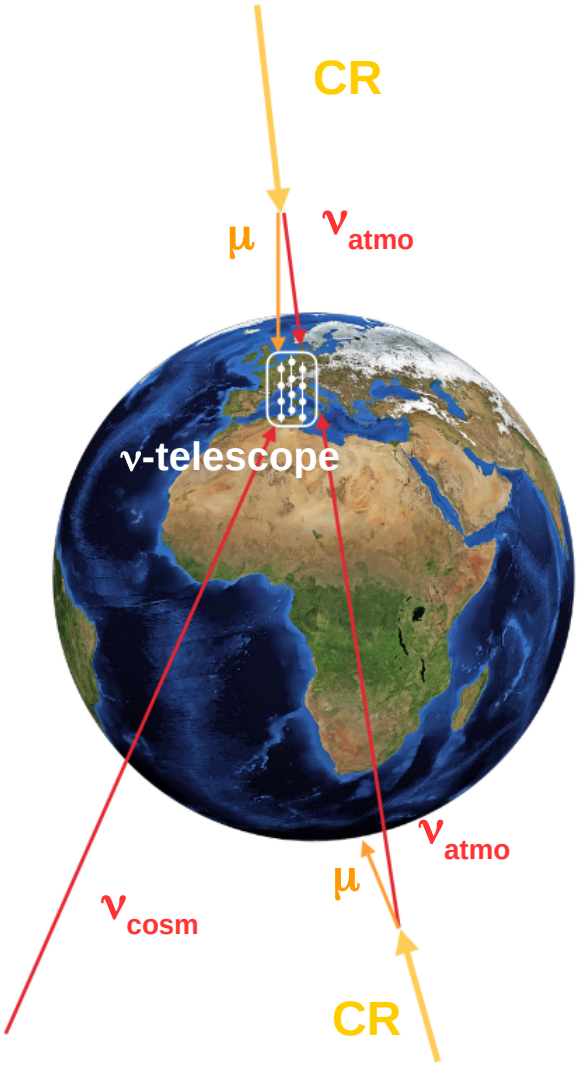
On behalf of the ANTARES Collaboration

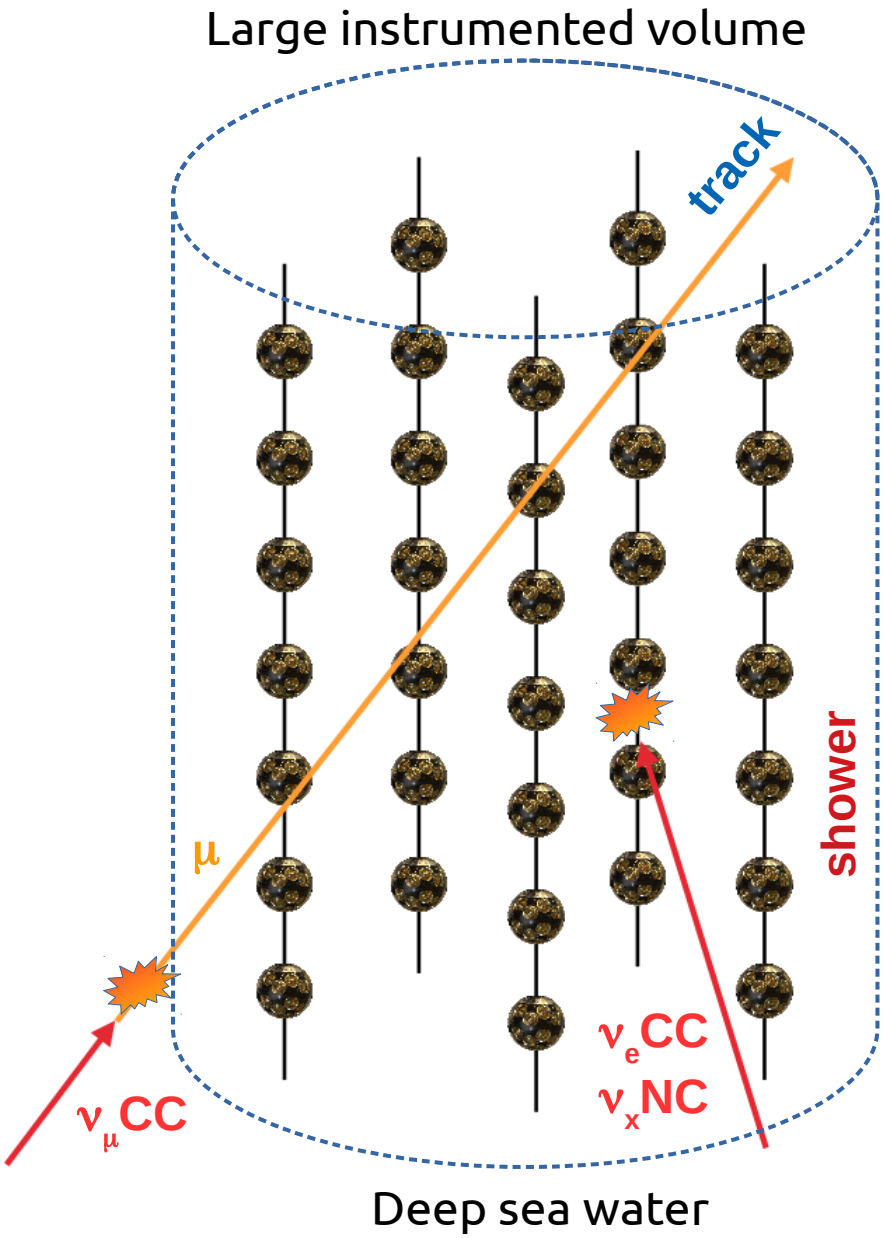
Outline

- Why neutrino astronomy/astrophysics?
- The ANTARES detector
- Recent results and outlook

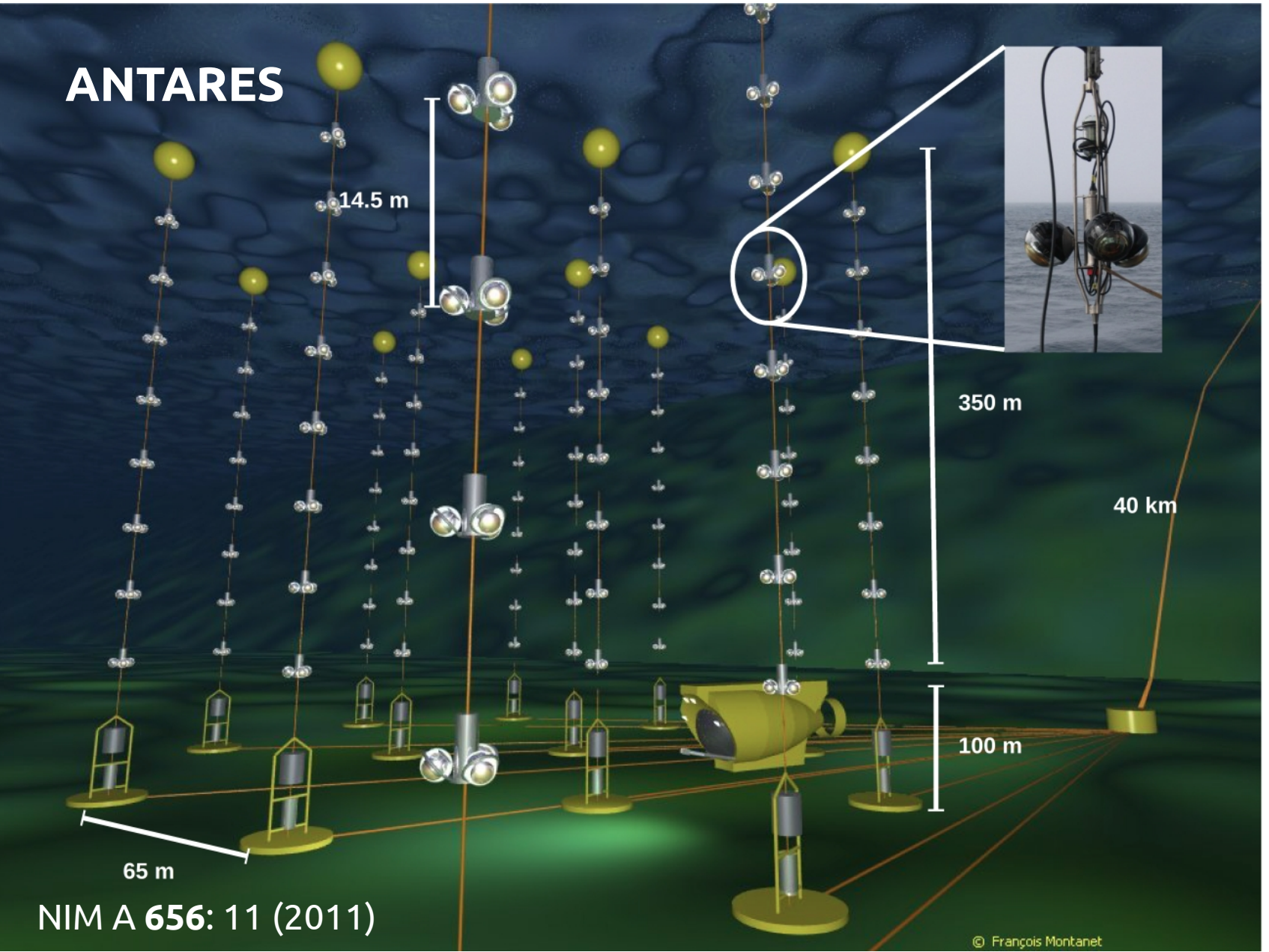
Neutrino astrophysics in a nutshell







The ANTARES detector



NIM A **656**: 11 (2011)

0.01 km³ neutrino Telescope

12 lines, 885 PMTs

15 years of data taking in the Mediterranean Sea (France)

Switched off Feb 2022
Decommissioned May 2022

The ANTARES detector

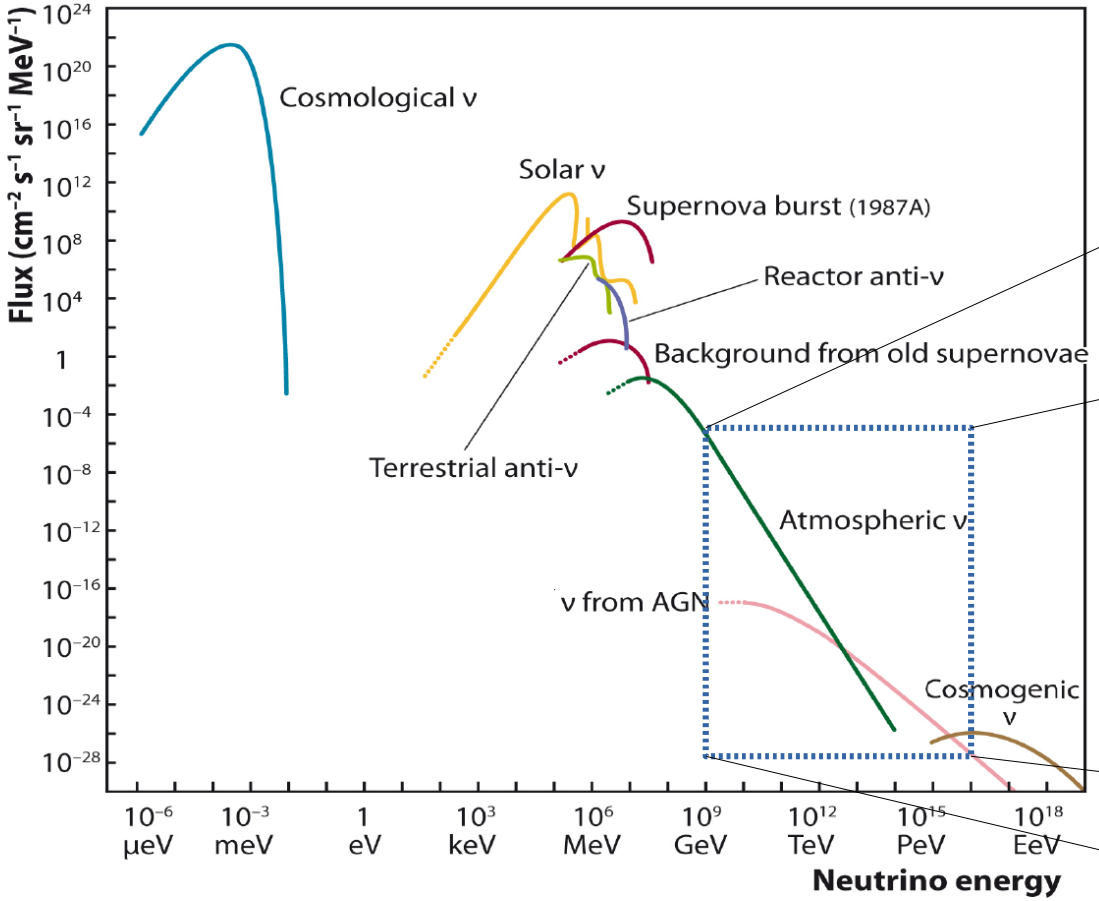
0.01 km³ neutrino Telescope

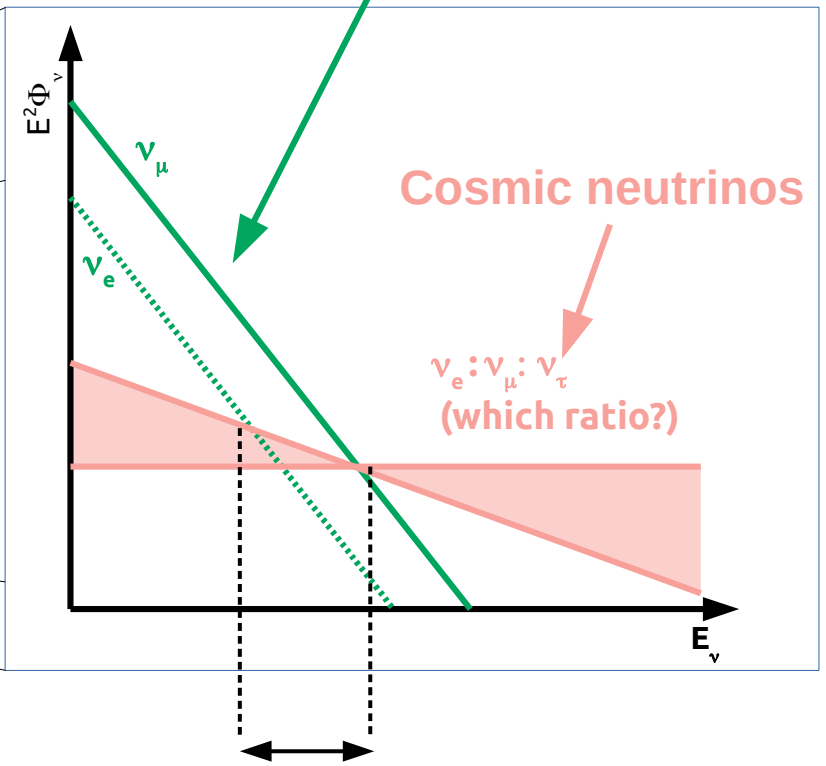
12 lines, 885 PMTs

15 years of data taking in the Mediterranean Sea (France)

Switched off Feb 2022
Decommissioned May 2022

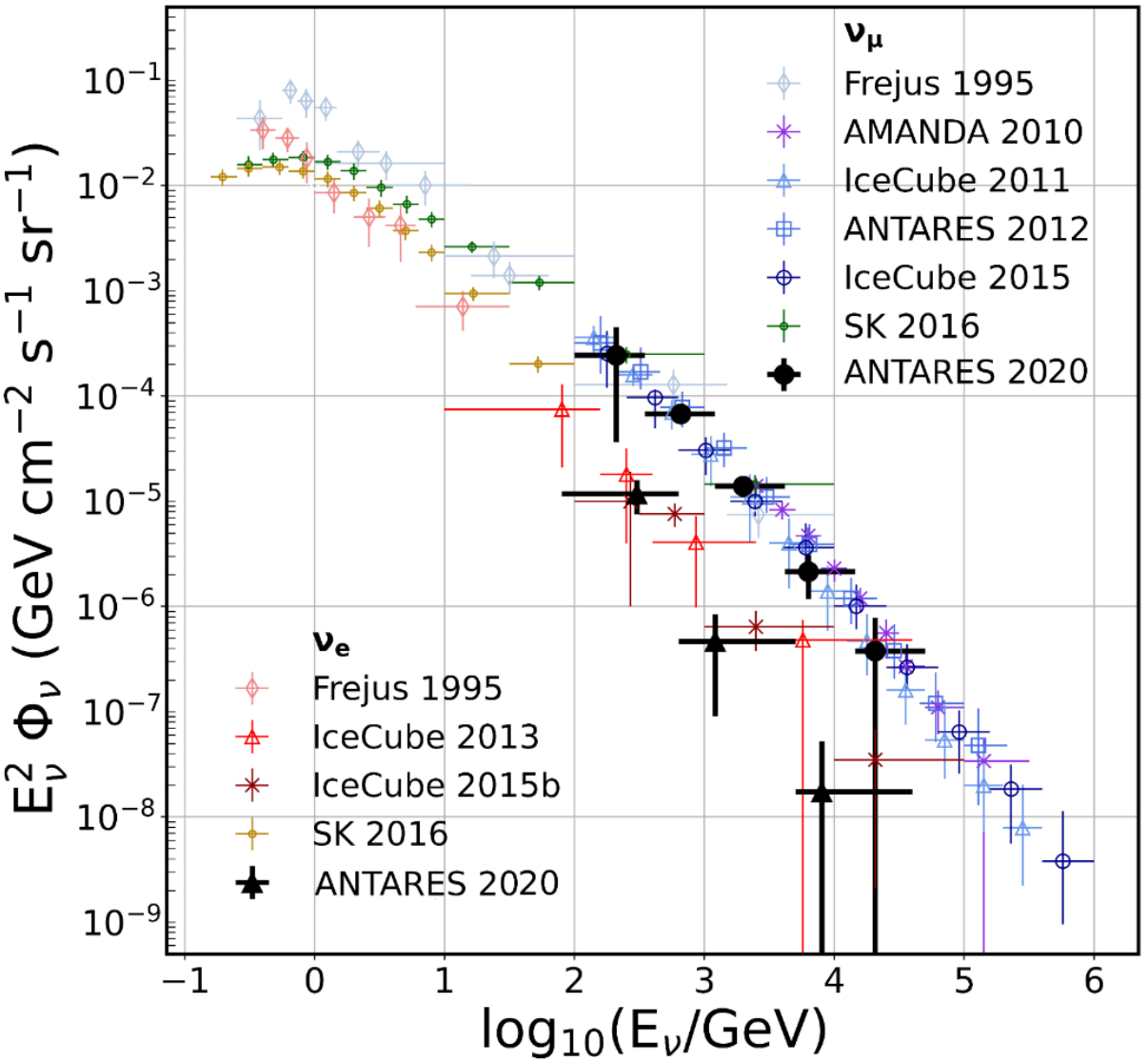
Diffuse flux searches





Atmospheric/Cosmic transition 30-200 TeV

The atmospheric neutrino background



Muon and electron neutrino energy spectra in the atmosphere can be measured

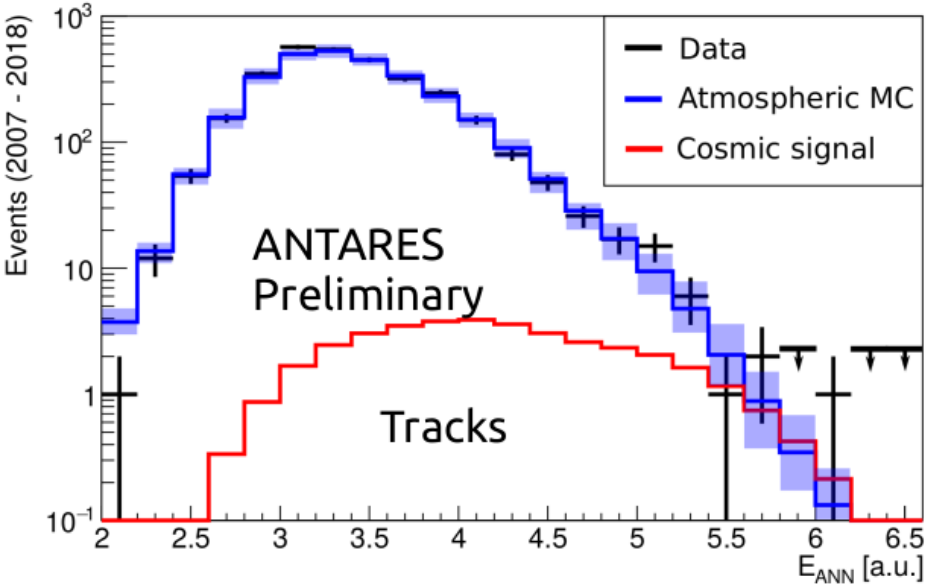
– energy estimation
– detector systematics

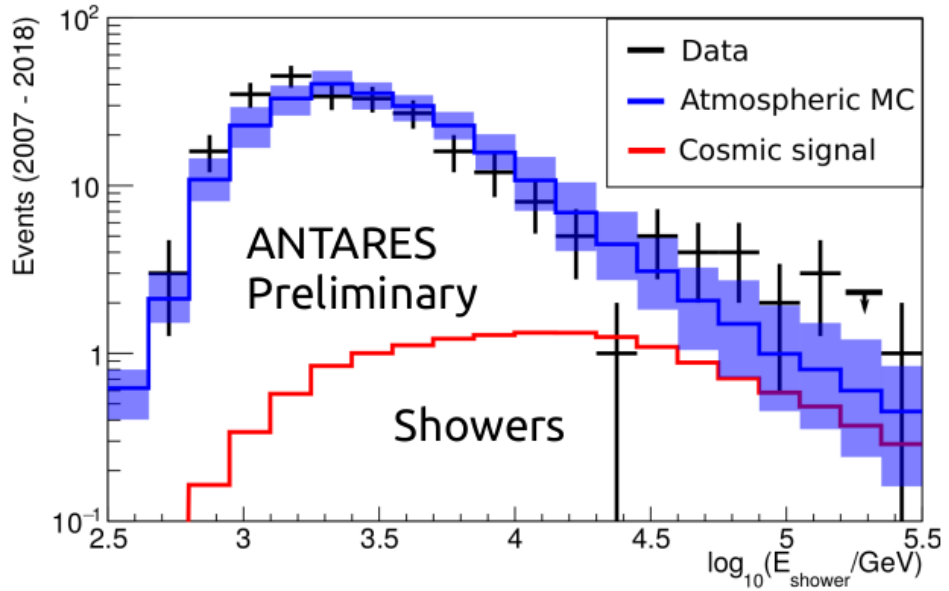
2 dedicated analyses in ANTARES

Track events: EPJ **73:** 2606 (2013)

Shower events: Phys. Lett.B **816:** 136228 (2021)

The cosmic diffuse flux





3380 days of livetime

Considering the HE tail (~1% highest E)

→ **data: 50** events
(**27** tracks + **23** showers)

→ **bkg MC: 36.1 ± 8.7** (stat.+syst.)
(**19.9** tracks and **16.2** showers

→ **signal MC: ~10 events expected**
(**4.5** tracks and **5.5** showers)

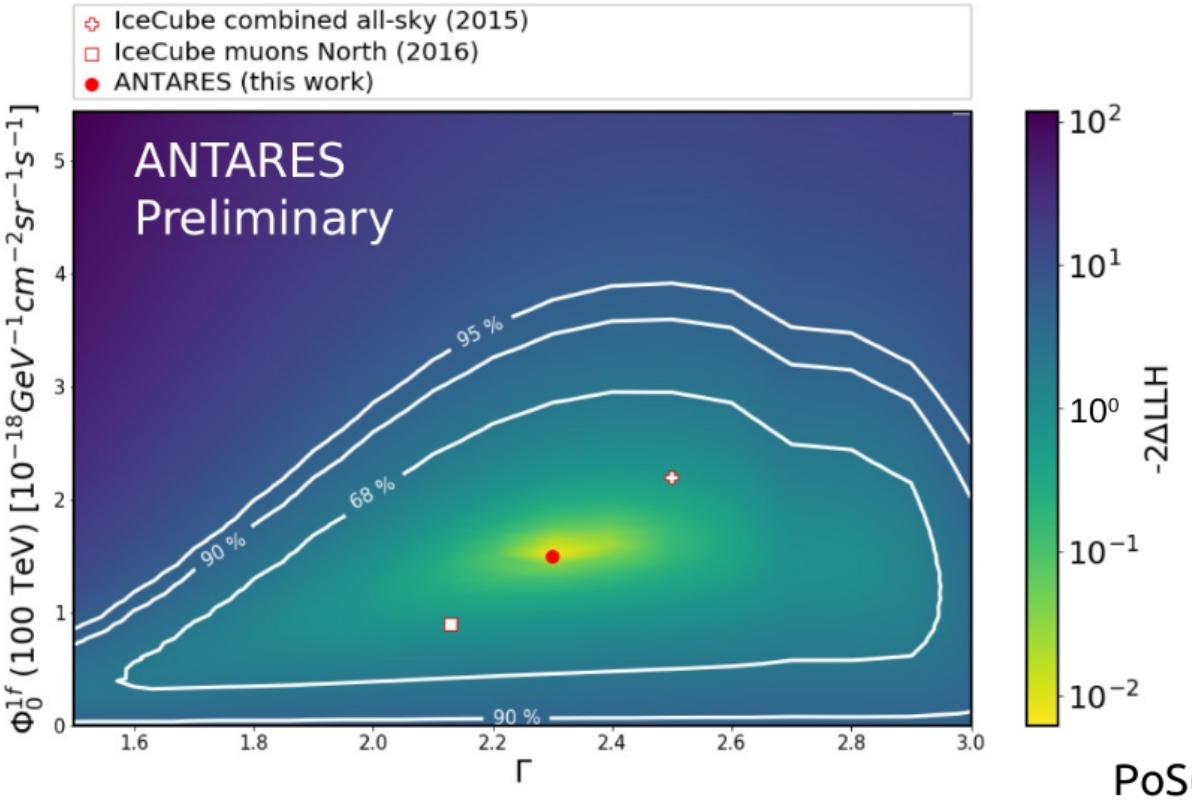
Null-cosmic excluded at 90% C.L.
1.8σ excess

PoS(ICRC2019)891

The cosmic diffuse flux

Upward-going events, simultaneous fit for the shower and track sample

$\Phi^{1f}(100\ \text{TeV}) = (1.5 \pm 1.0)\ 10^{-18}\ (\text{GeV cm}^2\ \text{s sr})^{-1}$
$\Gamma = 2.3 \pm 0.4$



When fitting individually the samples

Tracks

$\Phi^{1f}(100\ \text{TeV}) = (0.8^{+0.5}_{-0.4})\ 10^{-18}$
$\Gamma = 2.0^{+0.8}_{-0.4}$

Showers

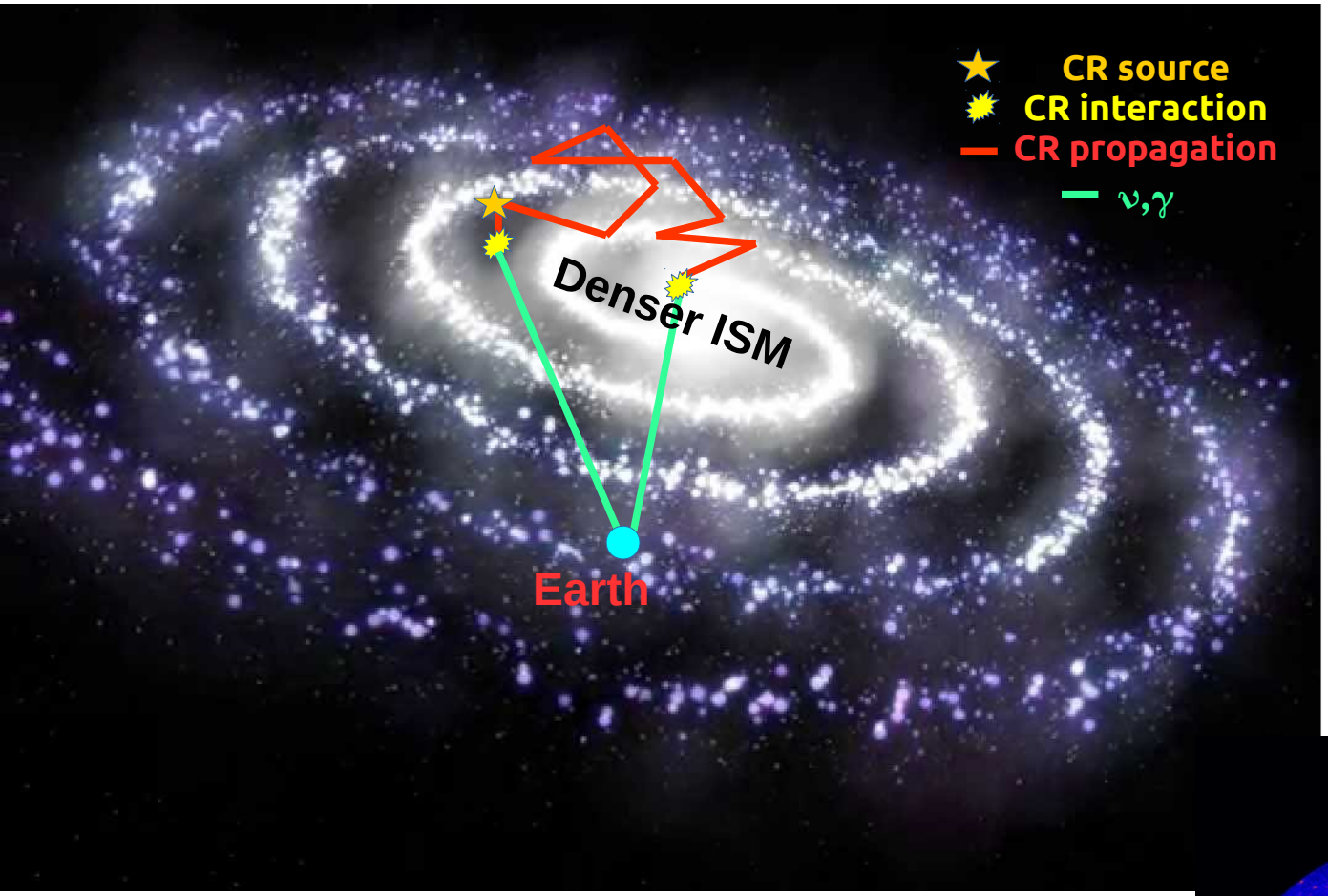
$\Phi^{1f}(100\ \text{TeV}) = (2.1 \pm 0.8)\ 10^{-18}$
$\Gamma = 2.4 \pm 0.4$

NB: Atmospheric flux is fitted as more intense than in the model; prompt is forced to exist in the fit

PoS(ICRC2019)891

More data being analysed

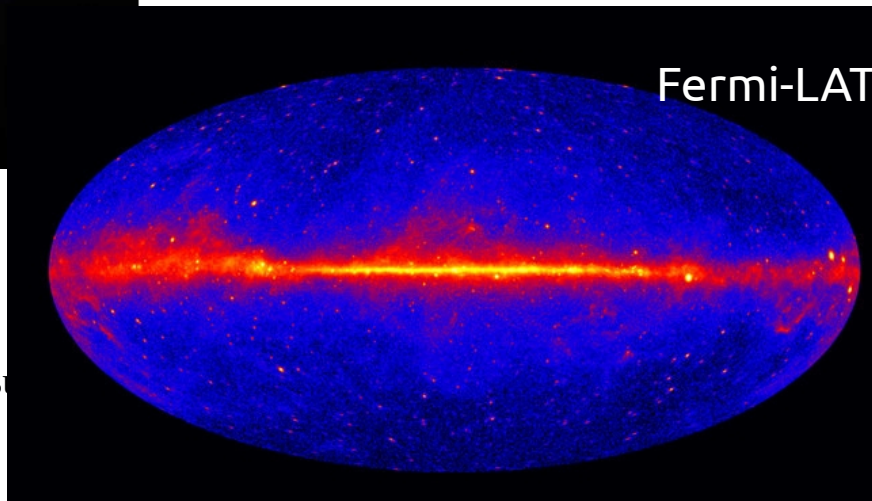
Galactic plane searches



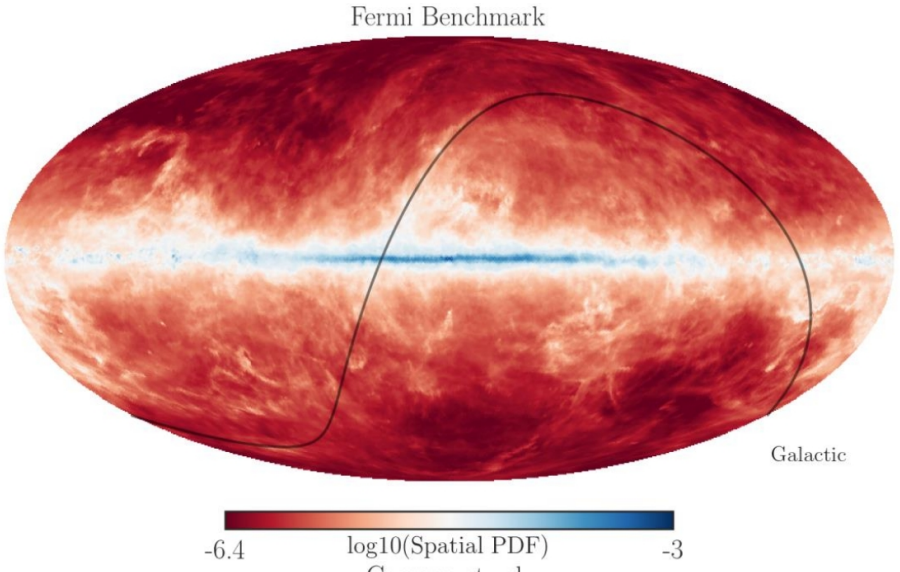
Neutrinos carry direct information on CR propagation. e.g.:

- Non-homogeneous diffusion can enhance γ and ν emission

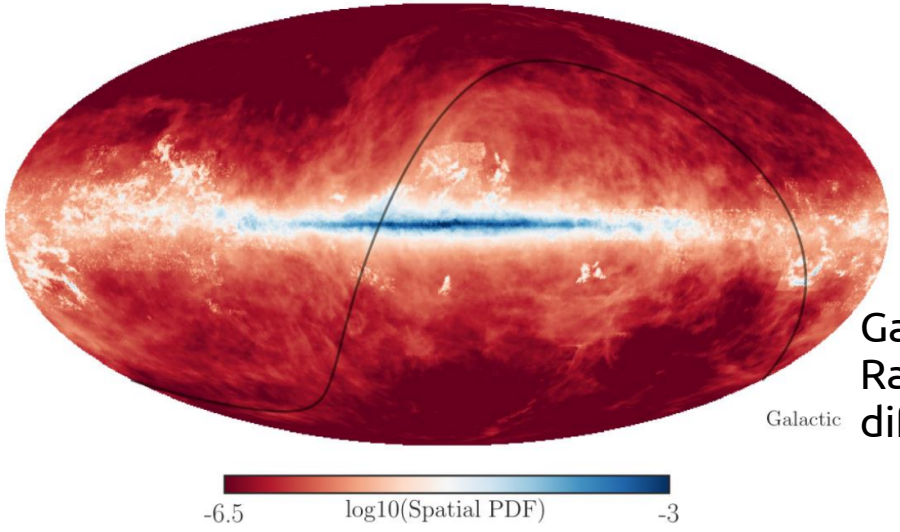
- Molecular clouds/dense environments boost γ and ν fluxes



Galactic plane searches

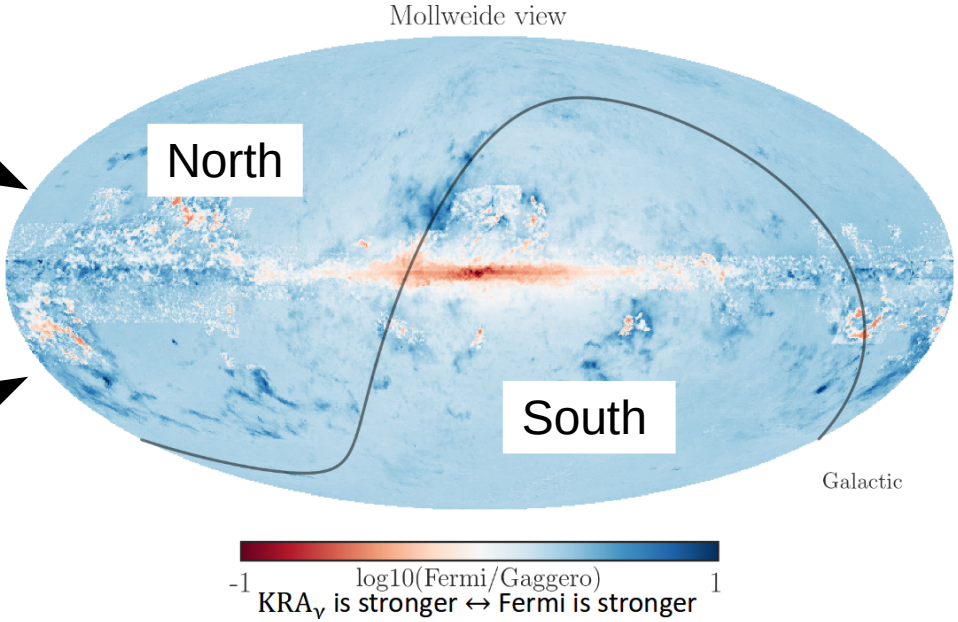


Standard model (Fermi)



Gaggero et al.
Radially dependent diffusion – data tuned

Ratio of the two



Harder/stronger in the centre
Softer/lower in the periphery
→ different fields of view can test the model differently

Plots by C.Haack, for the IceCube Collaboration

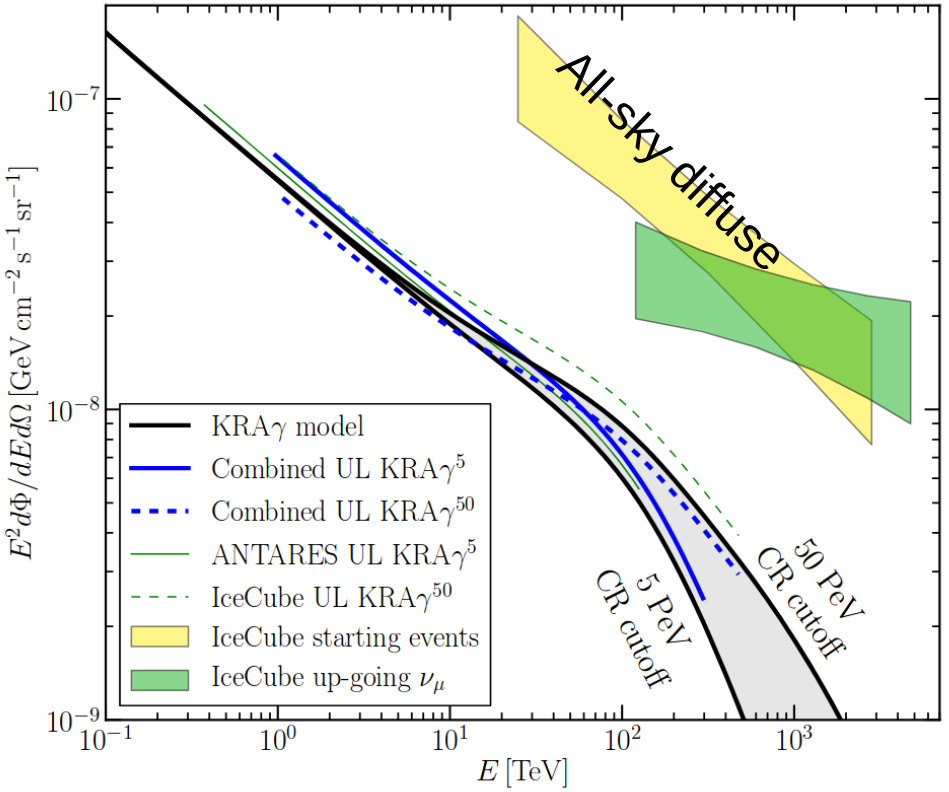
Galactic plane searches

ANTARES + IceCube constraints

Low latitude Galactic contribution constrained to 8% of the all-sky flux

More data being analysed

No significant excess observed



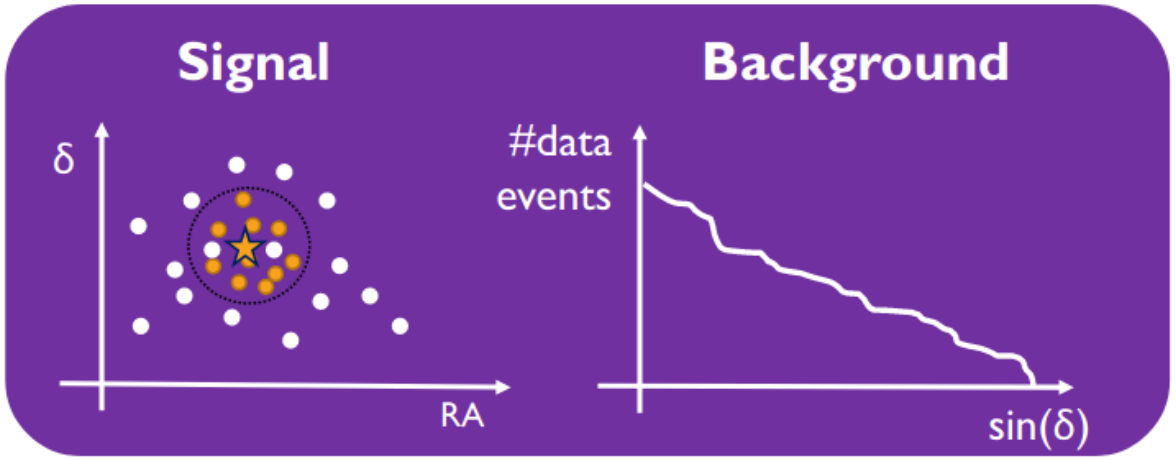
Astrophys.J. 868 (2018) no.2, L20

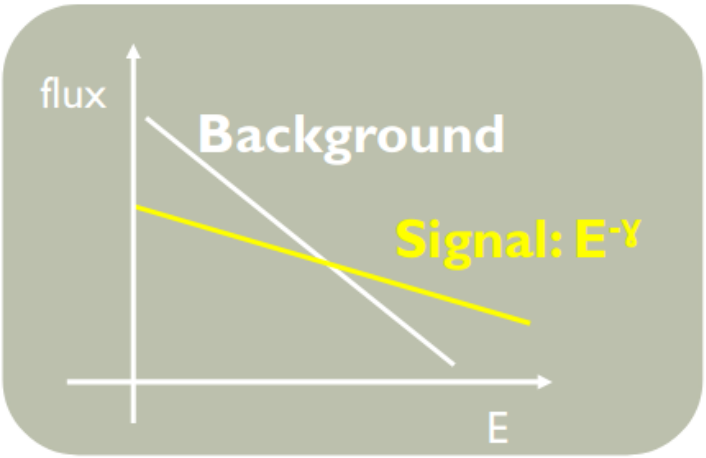
Individual sources

Search in data for spatial clustering of events with respect to isotropic background

1) Scan from the whole sky to search for clusters

2) Search in the direction of known candidates (e.g. TeV gamma ray emitters)

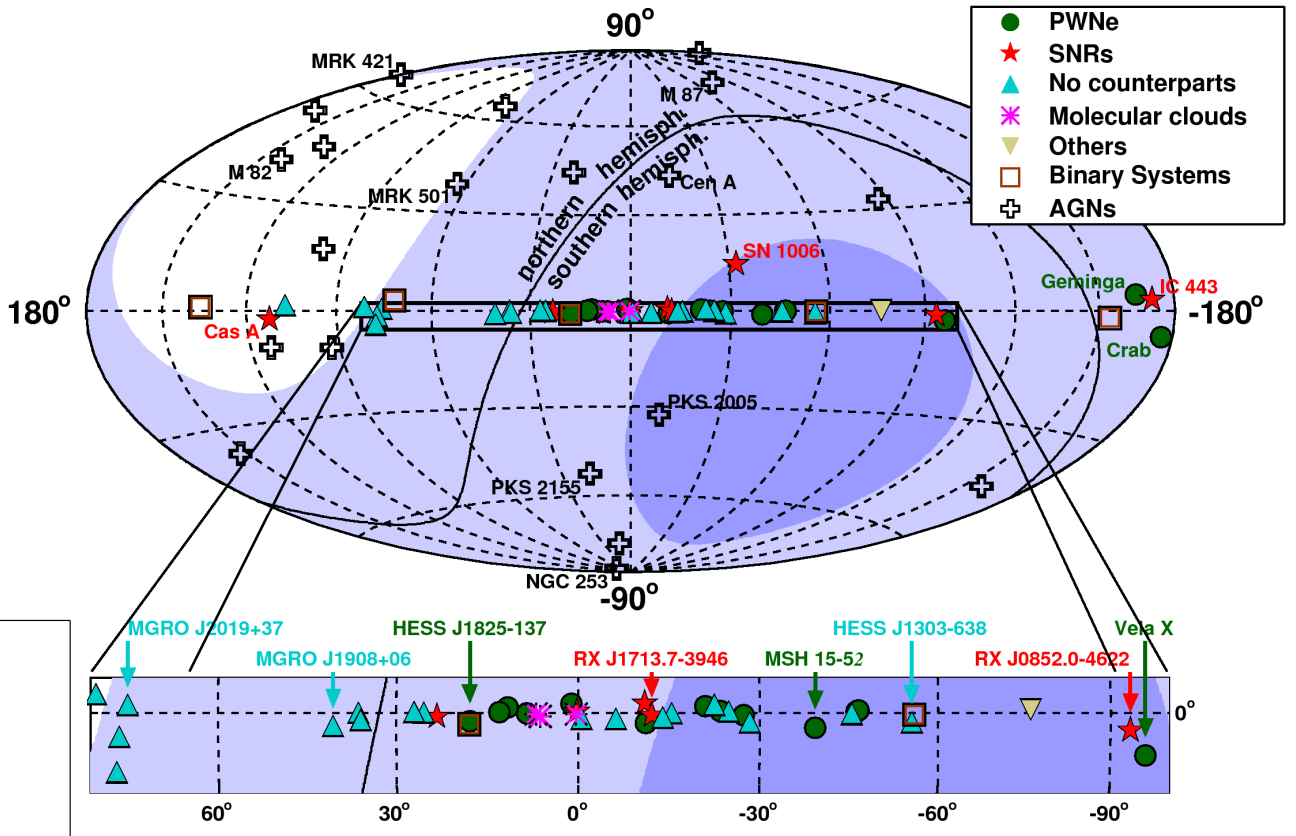


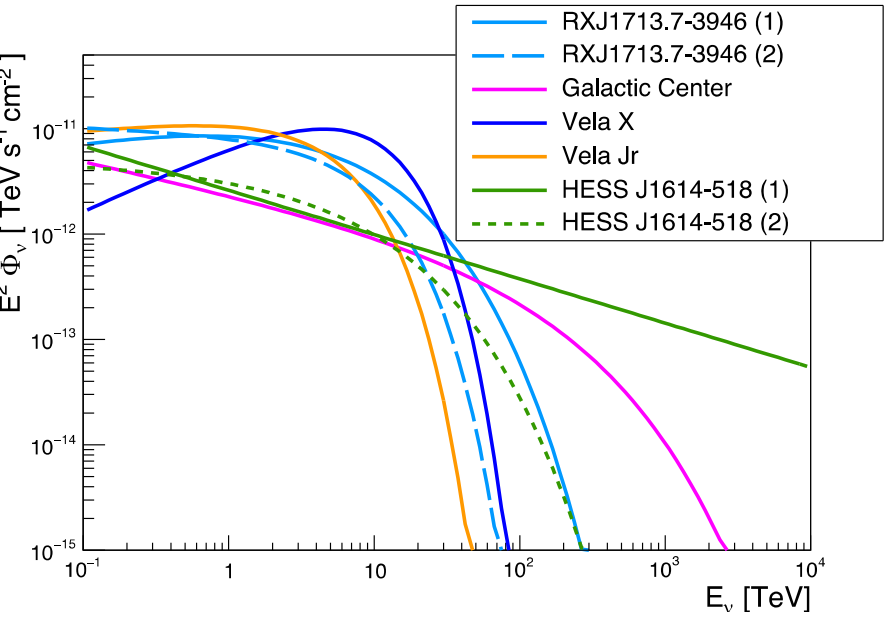


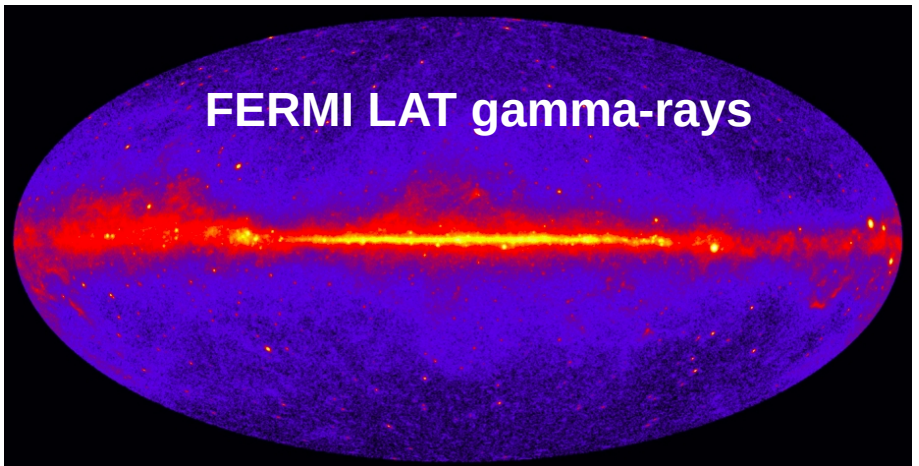
Where to look for individual sources?

Galactic gamma ray sources mostly in the Southern Sky
→ best pointing from a N-hemisphere telescope

Rather soft spectra
→ low detection threshold



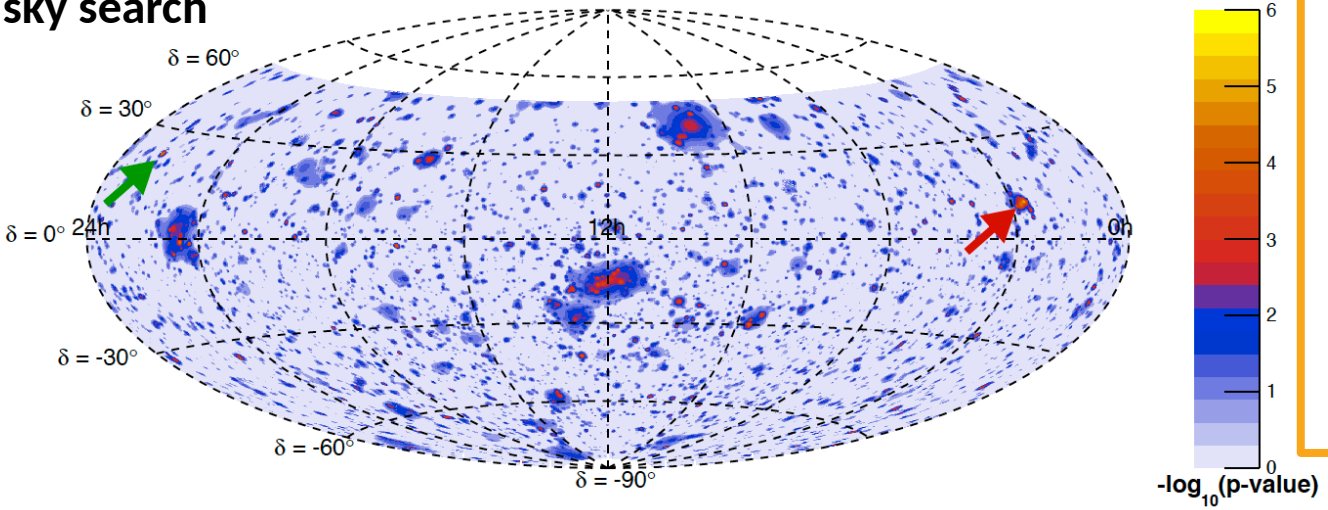




ANTARES searches for point-like sources

ANTARES 13 years (3845 days of livetime): 10162 tracks and 225 showers

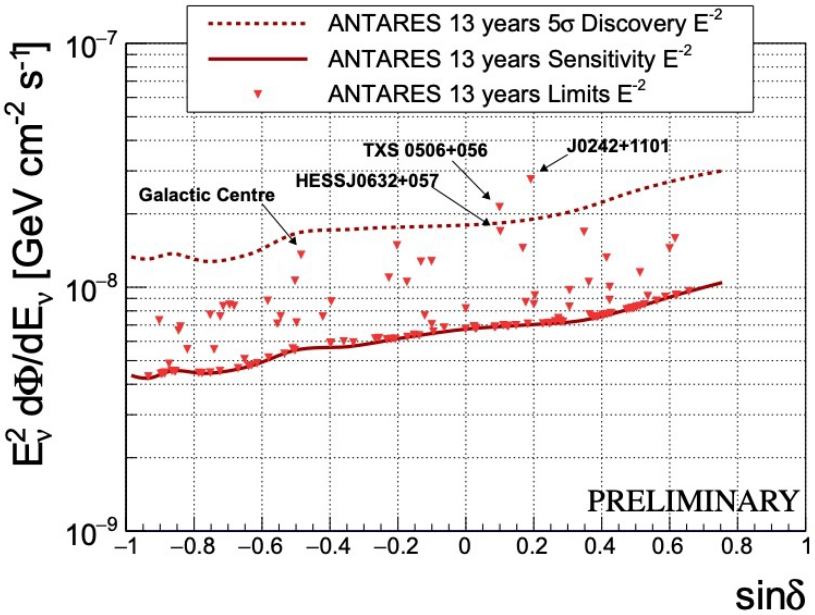
Full sky search



Most significant cluster:
RA=39.6° δ=+11.1°
pre-trial: 4.3 σ (48% post-trial)
Within 1 degree of **J0242+1101**

2nd most significant cluster:
RA=343.8° δ=+23.5°
pre trial: 4.2 σ
Close to blazar MG3 J225517+2409

Catalog search : 121 candidates

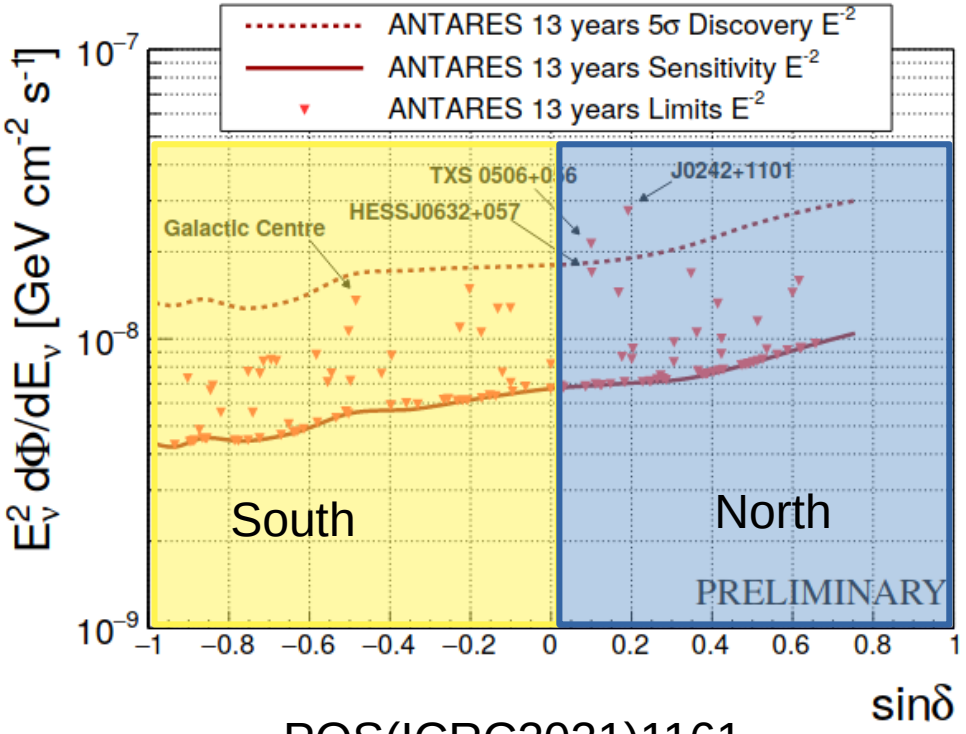


Most significant candidate
Radio-bright blazar J0242+1101
Pre-trial: 3.8σ
Post-trial: 2.4σ

POS(ICRC2021)1161

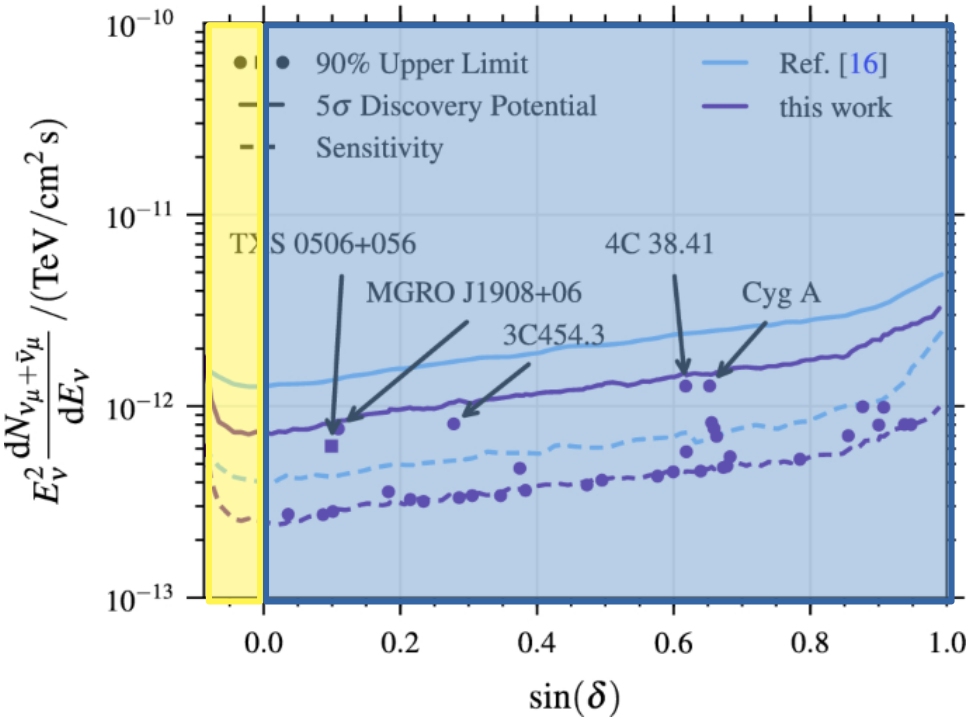
ANTARES searches for point-like sources

ANTARES



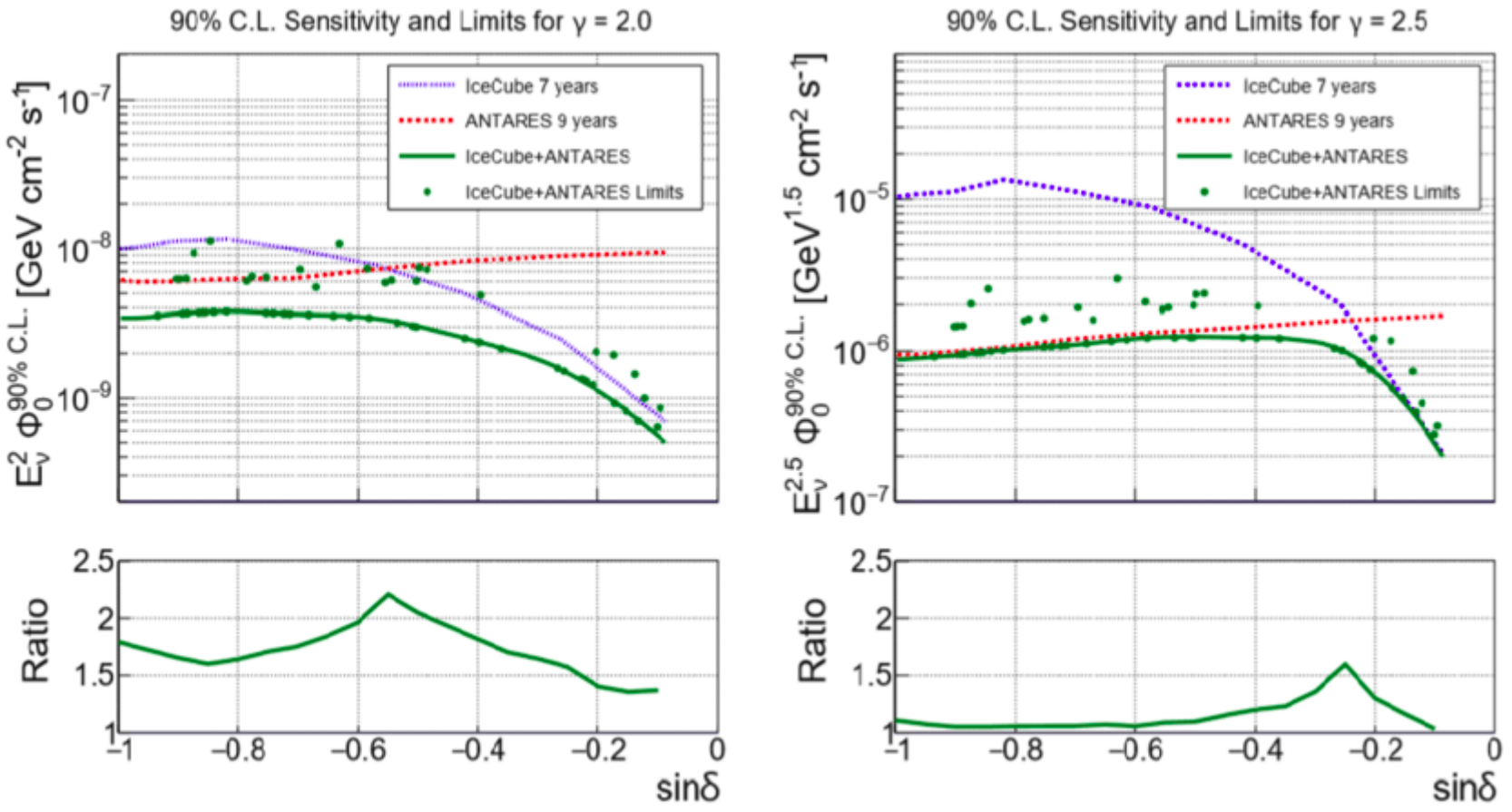
POS(ICRC2021)1161

IceCube



ANTARES searches for point-like sources

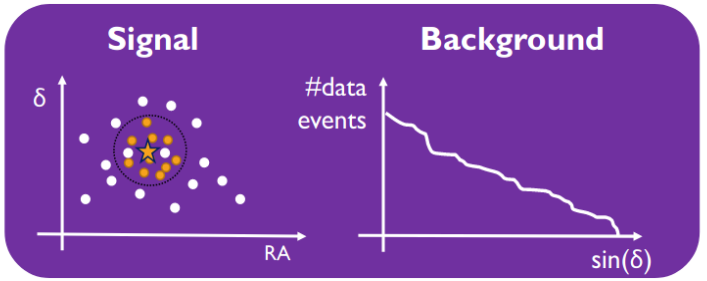
ANTARES + IceCube point sources from the Southern Sky

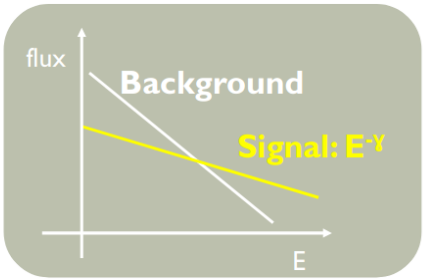


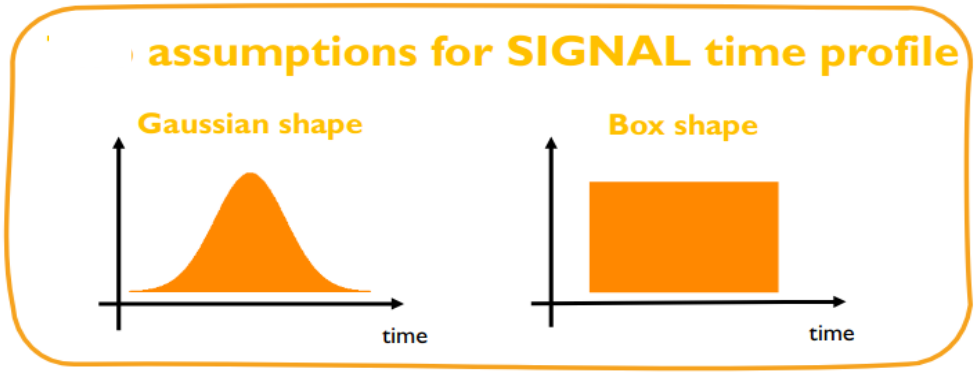
Astrophys. J. **892** (2020) 92

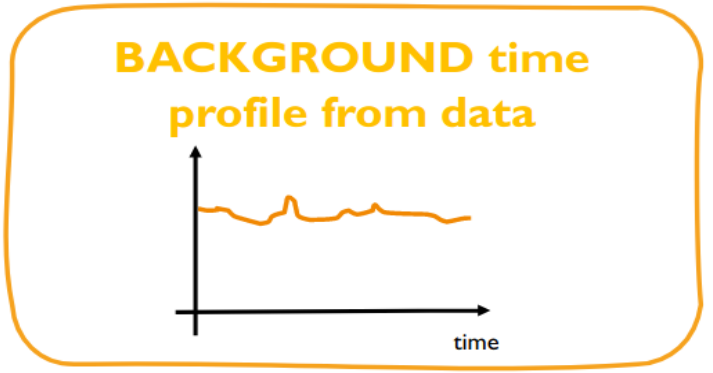
The multimessenger approach

- How to reduce the overwhelming backgrounds?
  - Look in a specific direction
    - In coincidence with other observatories
  - Look at specific times
    - In coincidence with other observatories
    - In self-coincidence
  - Do all the above together









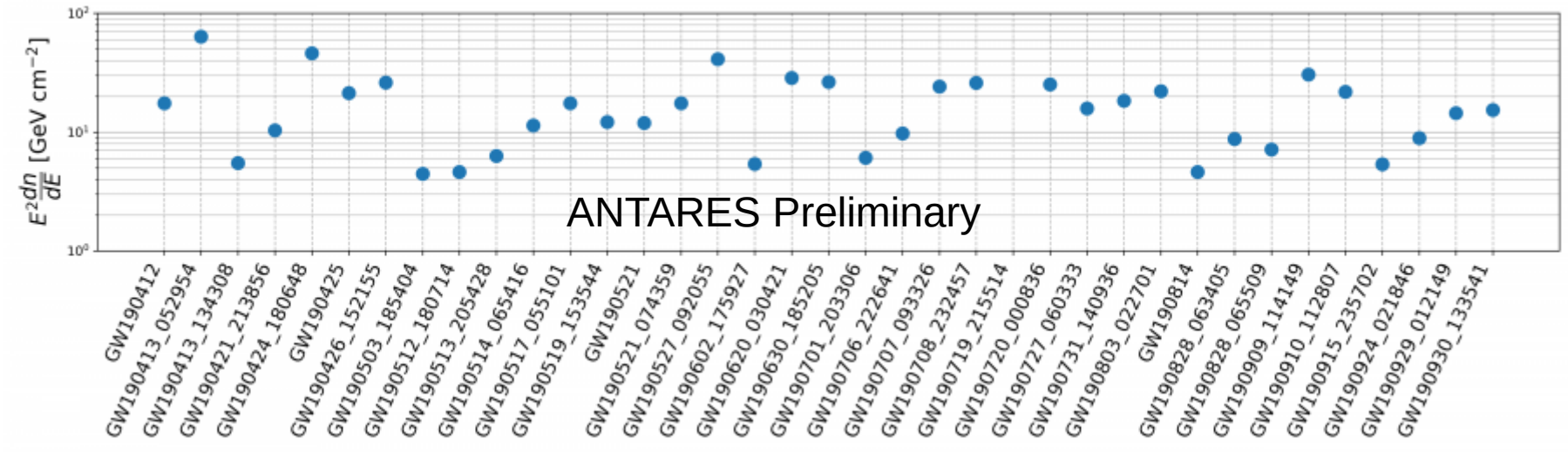
The multimessenger approach

- **Gravitational Waves**
- **Flaring blazars**
- Tidal Disruption Events
- Radio galaxies
- …

Gravitational Waves

39 gravitational wave sources in GWTC-2 catalog
- ✔ 37 sources followed with ANTARES data (2 during downtime)
- ✔ Total expected background: **~0.38** events over the 37 GWs
- ✔ Observed number of events: **0** for all sources

Upper limits on the all-flavour neutrino flux, assuming E^{-2} spectrum

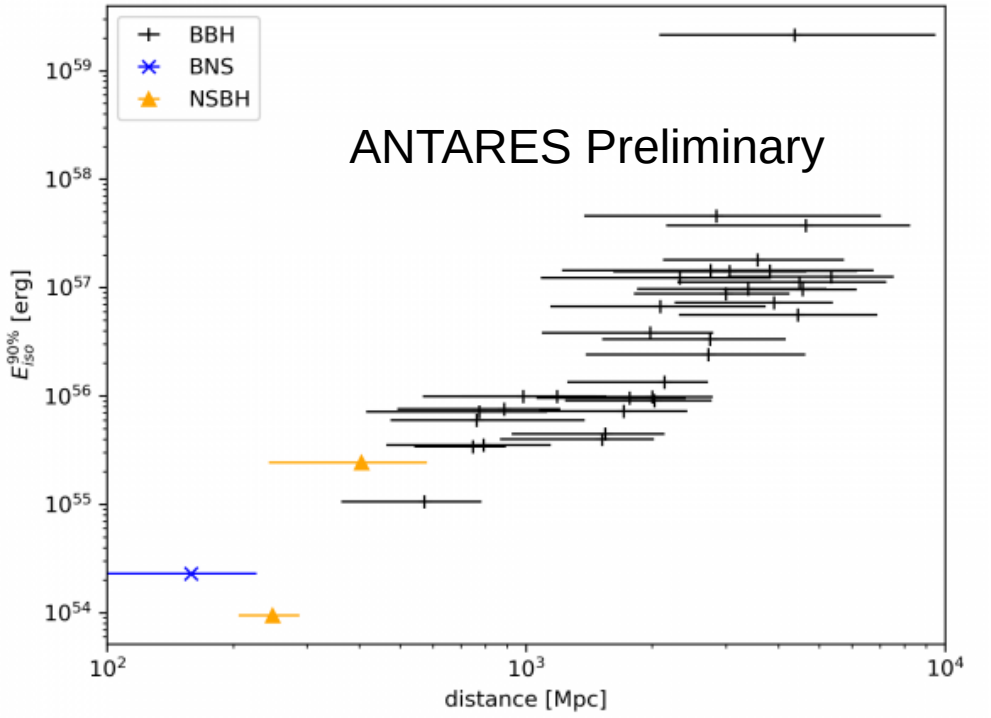


M. Lamoureux
@Neutrino2022

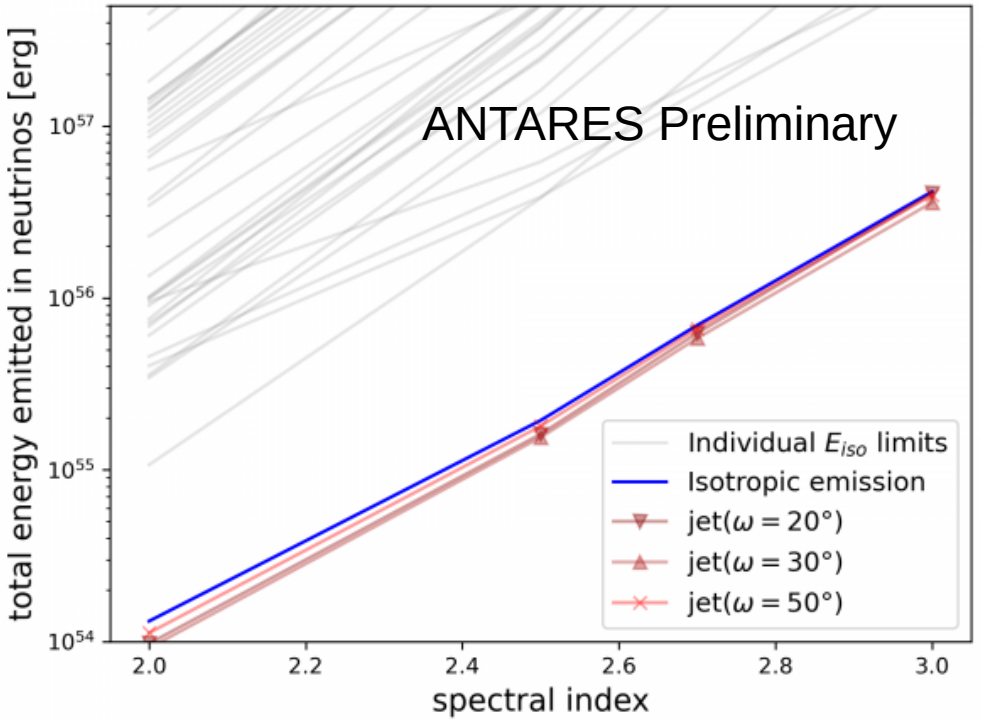
Gravitational Waves

39 gravitational wave sources in GWTC-2 catalog
✔ 37 sources followed with ANTARES data (2 during downtime)
✔ Total expected background: **~0.38** events over the 37 GWs
✔ Observed number of events: **0** for all sources

Upper limits on total energy



Stacked limits for different spectrum and jet models



M. Lamoureux @Neutrino2022

Radio-bright Blazars

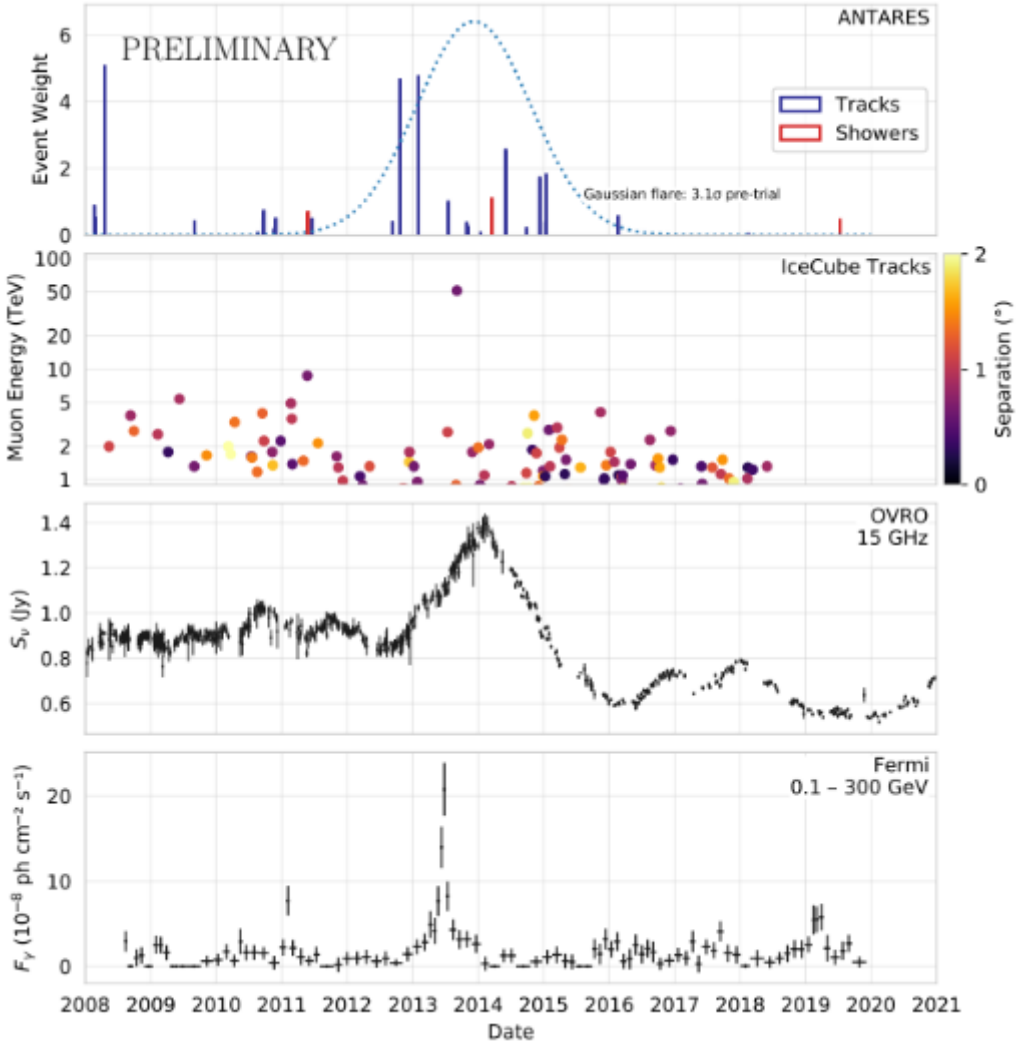
Search for spatial and temporal coincidence of neutrinos with radio blazars

2774 radio-bright blazars investigated.

No significant evidence of neutrino flare found.

Notable case of J0242+1101 (PKS 0239+108)

Post-trial p-value of 56% (40%) for the Gaussian (Box) shape.



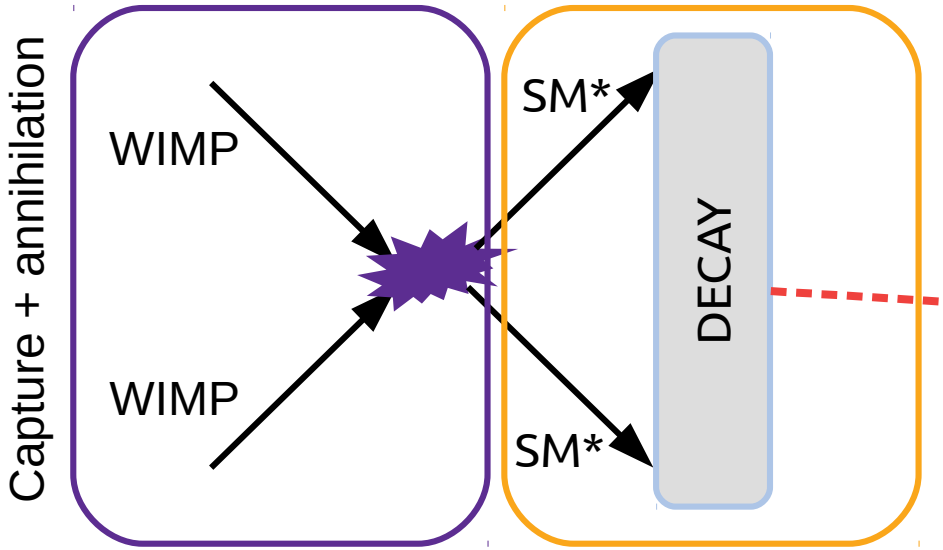
G. Illuminati @Neutrino2022

Beyond Standard Model

- Neutrinos can also be probes of BSM physics
- Dark matter searches from astrophysical objects
- BSM effects in neutrino oscillation

- *For lack of time, just one example*

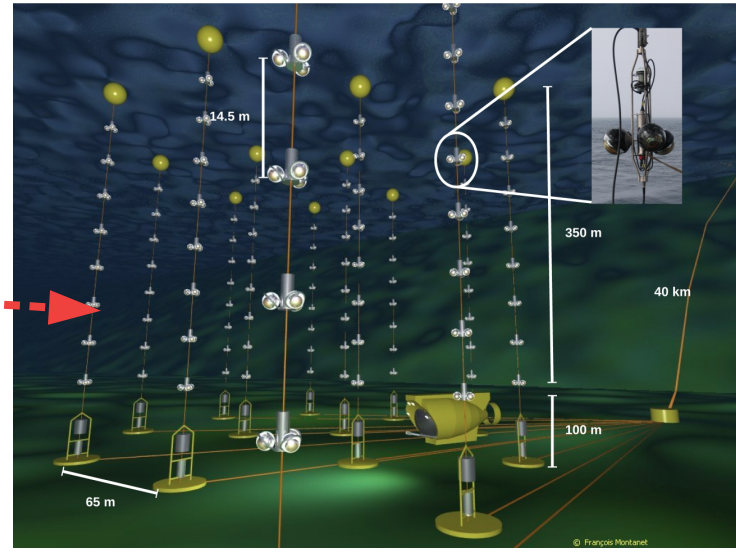
Indirect searches from Dark Matter



Astrophysics
+ BSM

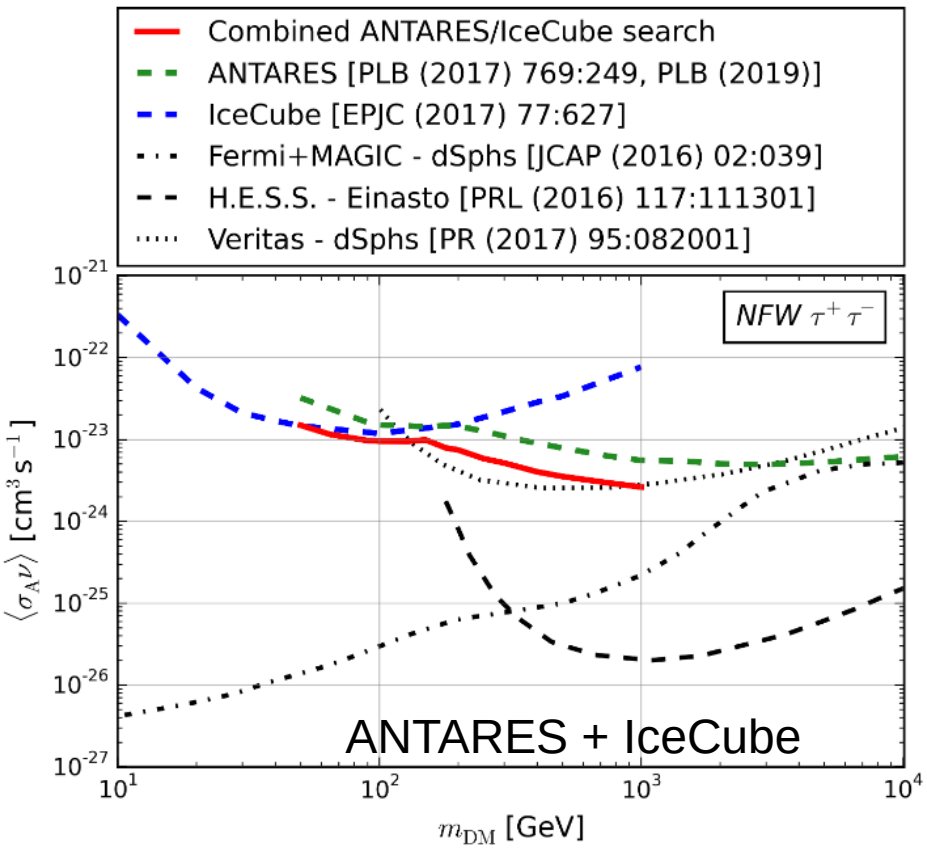
Astrophysics
+ Standar Model
Physics

Neutrinos



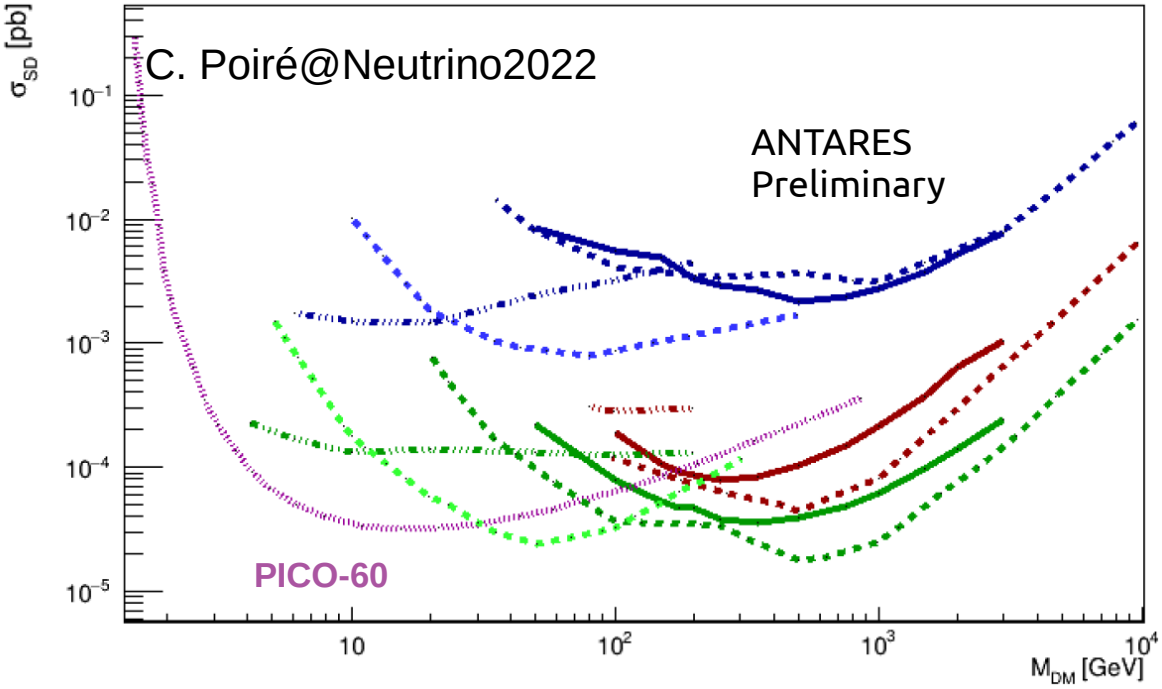
Indirect searches from Dark Matter

Galactic Centre
→ annihilation cross-section



Phys. Rev. D 102, 082002 (2020)

Sun
→ scattering cross-section



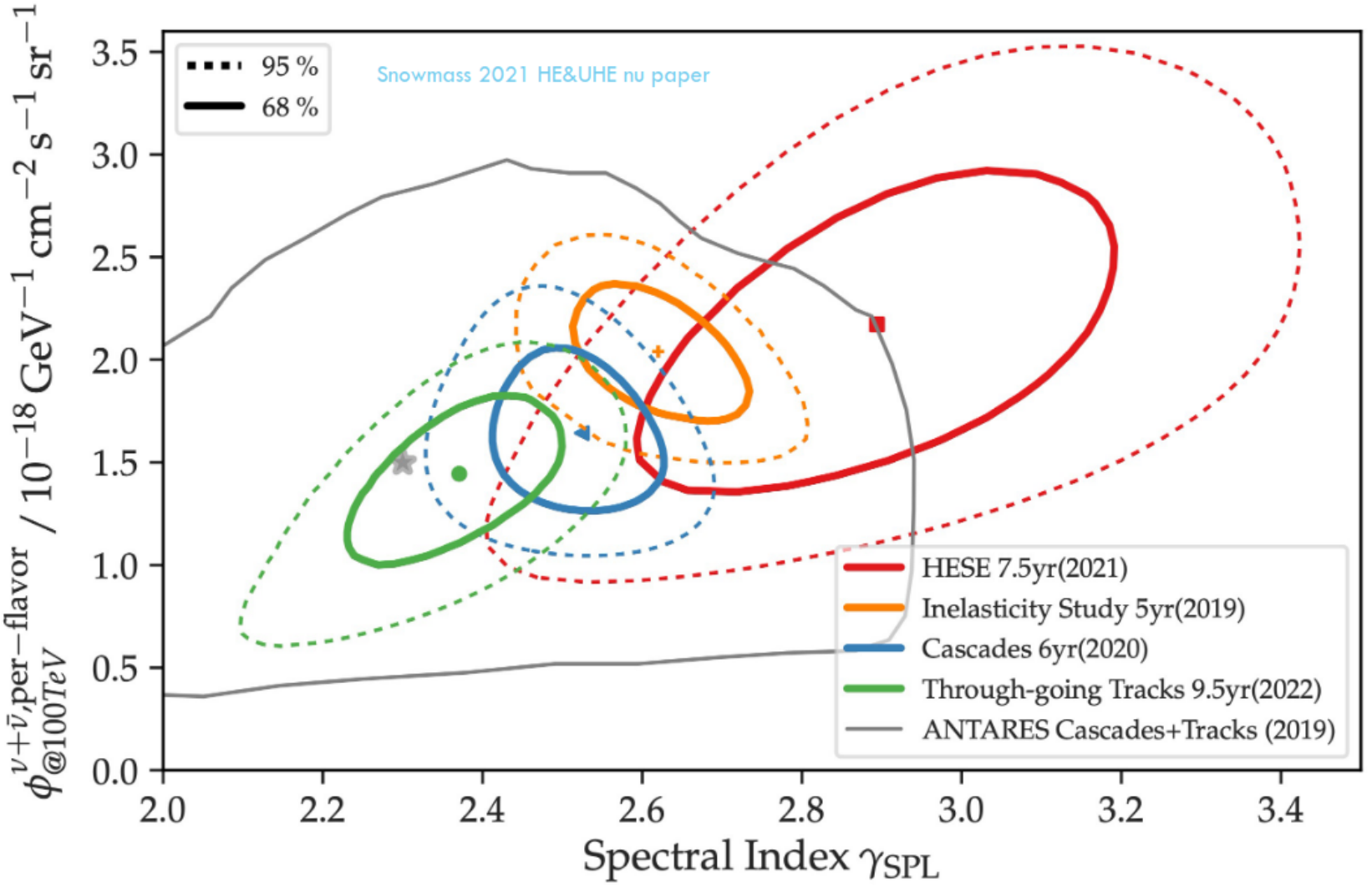
ττ WW bb
Solid lines: ANTARES
Dashed: IceCube
Dot-Dashed: SuperK

Outlook

- 15 years of stable ANTARES data taking have proven that neutrino astronomy can be done undersea
- Excellent results already obtained and final data being analysed
- ANTARES has played a significant role in the field and the next generation neutrino observatory, KM3NeT ARCA and ORCA are now ready to take its place

Backup

The cosmic diffuse flux



Galactic plane templates recipe

Gaggero et al. 2015

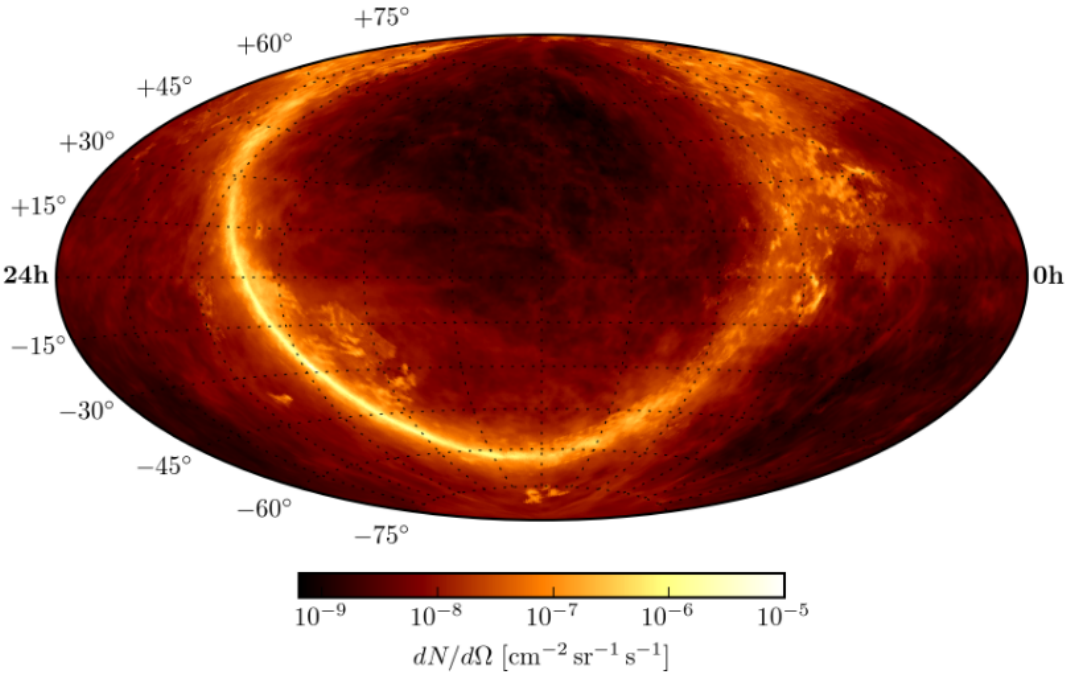
From e-m observations
- matter distribution
- gamma-ray flux

Add model for CR propagation

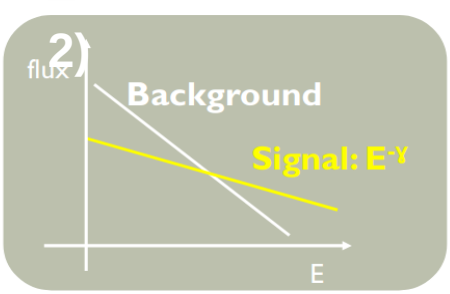
→ obtain neutrino flux

Convolute with detector simulation

→ obtain neutrino expected PDF
(in space and energy)



Then search for clustering of neutrinos according to PDF

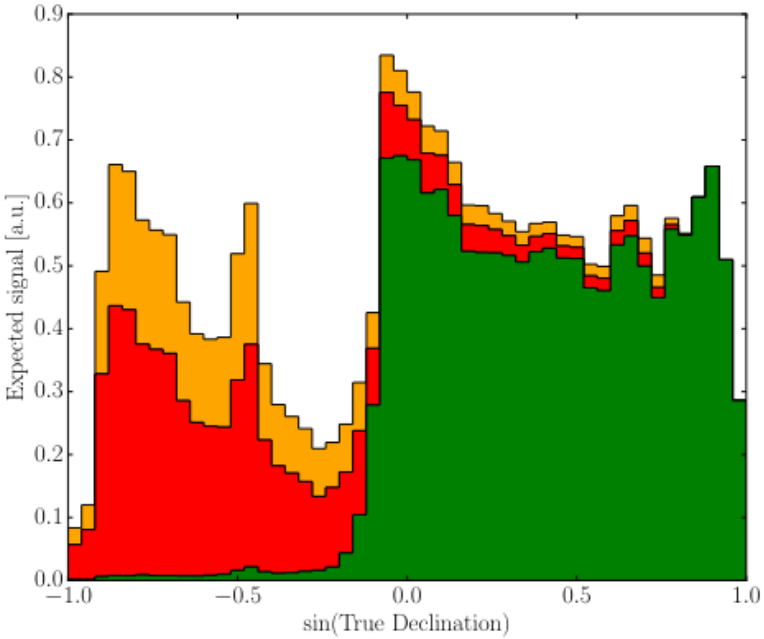


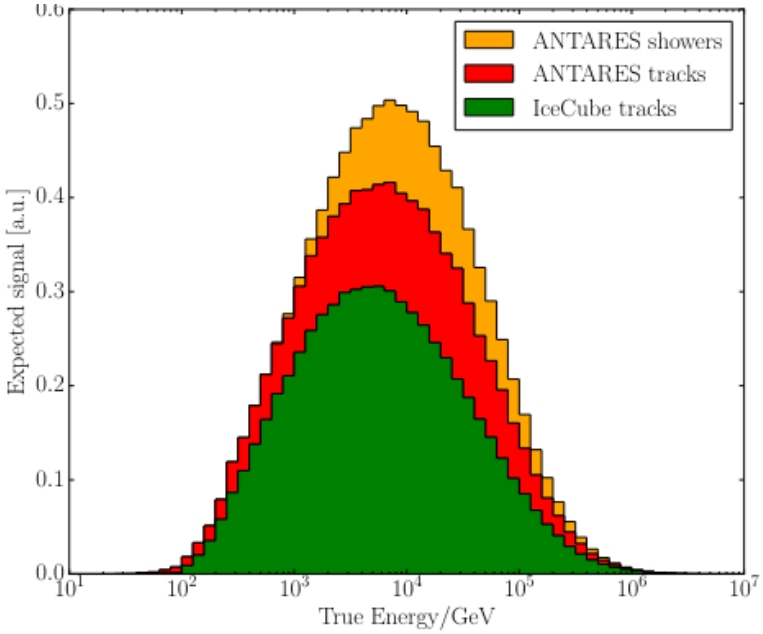
Astrophys.J. 868 (2018) no.2, L20

Galactic plane searches

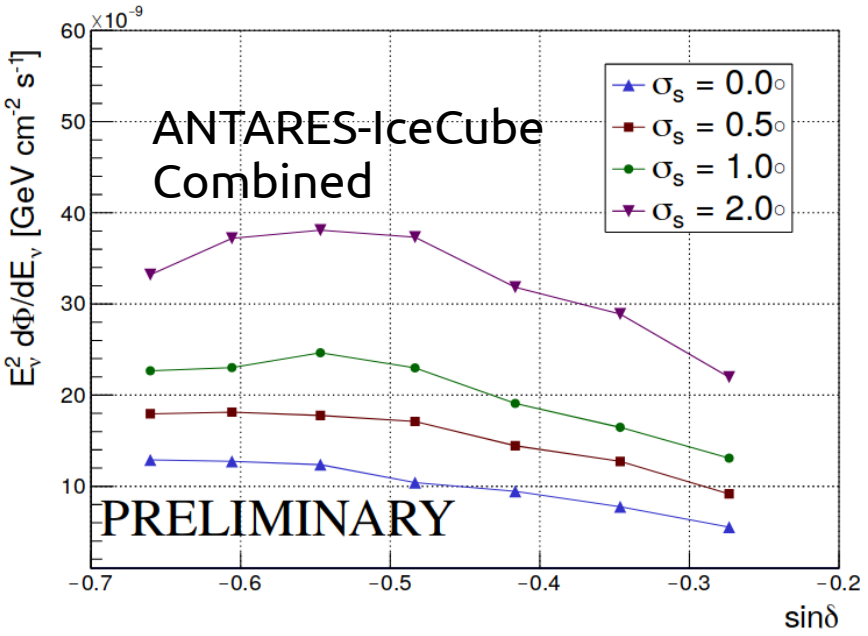
ANTARES (tracks + showers)
+ IceCube (tracks)
joint dataset

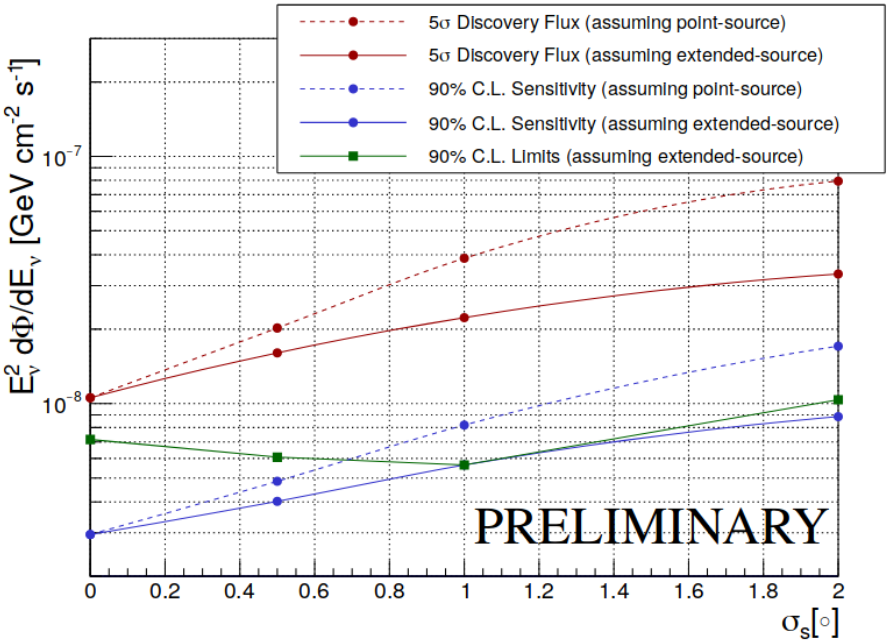
Different exposure, different spectral sensitivities
→ cover the full galactic plane emission

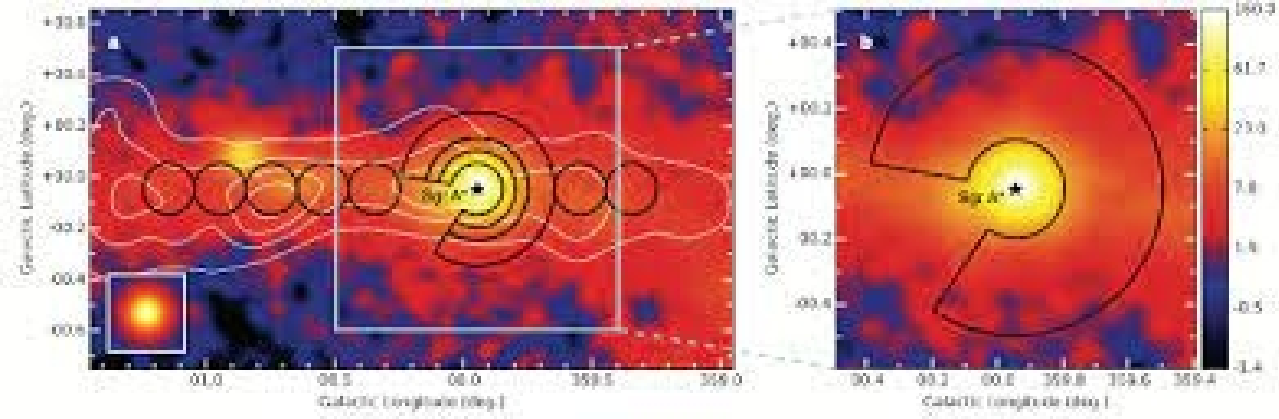




The Galactic centre



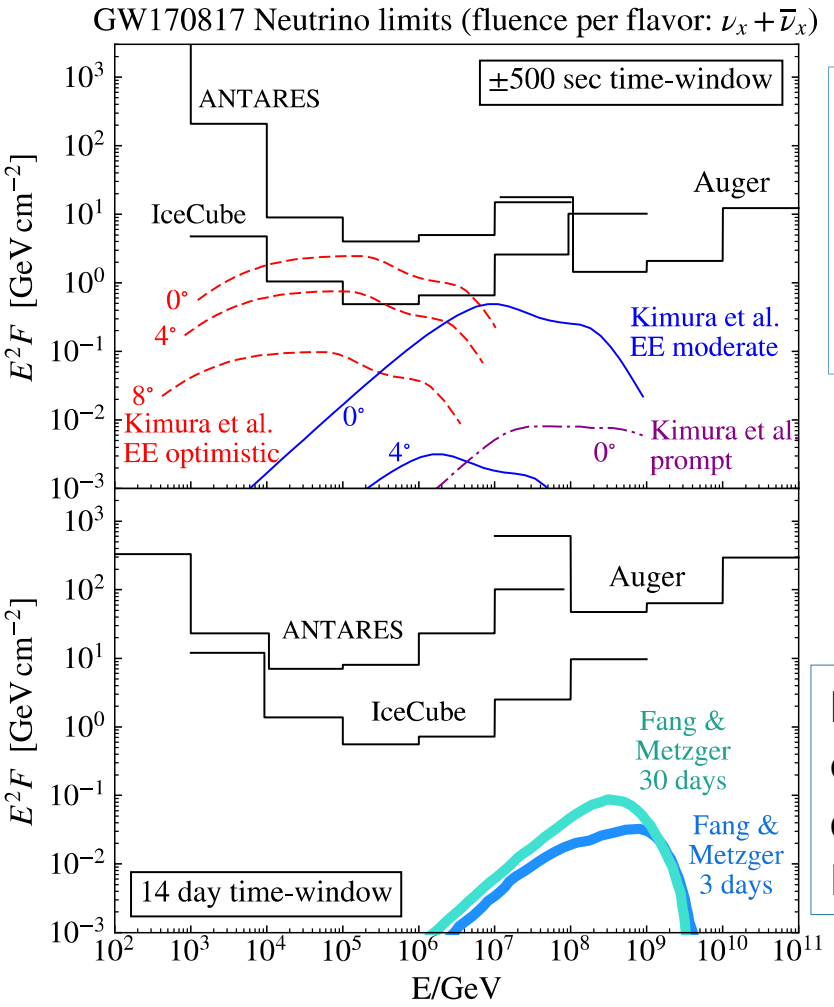




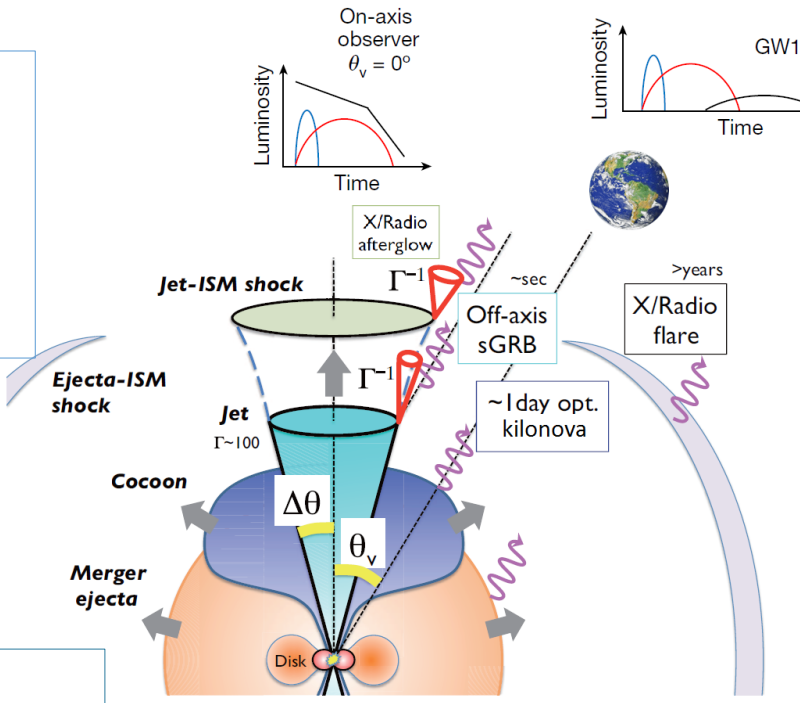
H.E.S.S. GC

ANTARES, IceCube, Pierre Auger, LIGO/ Virgo. ApJL 850 L35 (2017)

GW170817



Non-detection: consistent with a short GRB observed at large off-axis angle (Kimura et al. ApJL 848, L4)



No detection during extended time period of 14 days after the GRB (Fang& Metzger, arXiv:1707.04263)