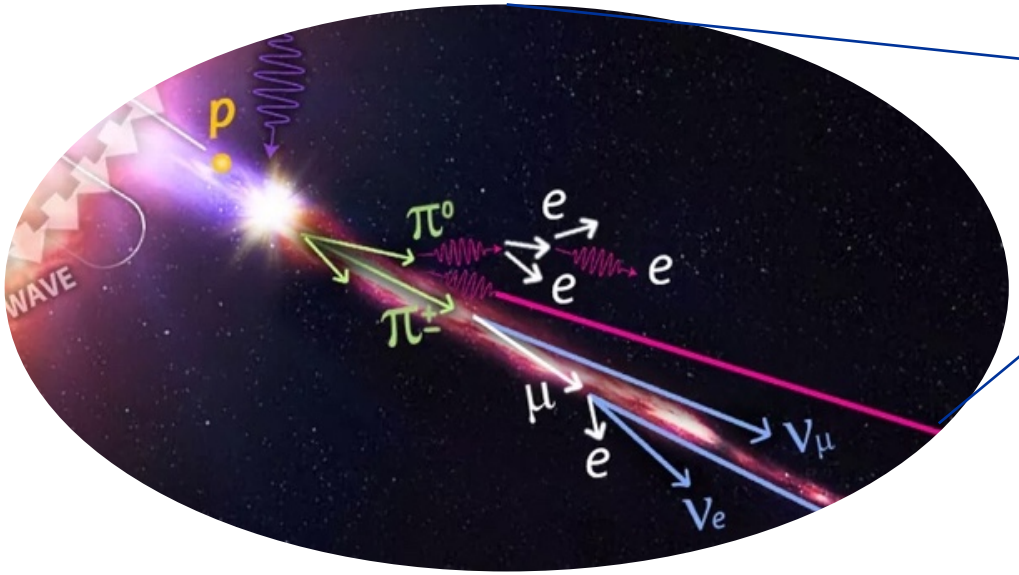
IceCube Overview and a Search for Neutrinos from Ultra-Luminous Infrared Galaxies

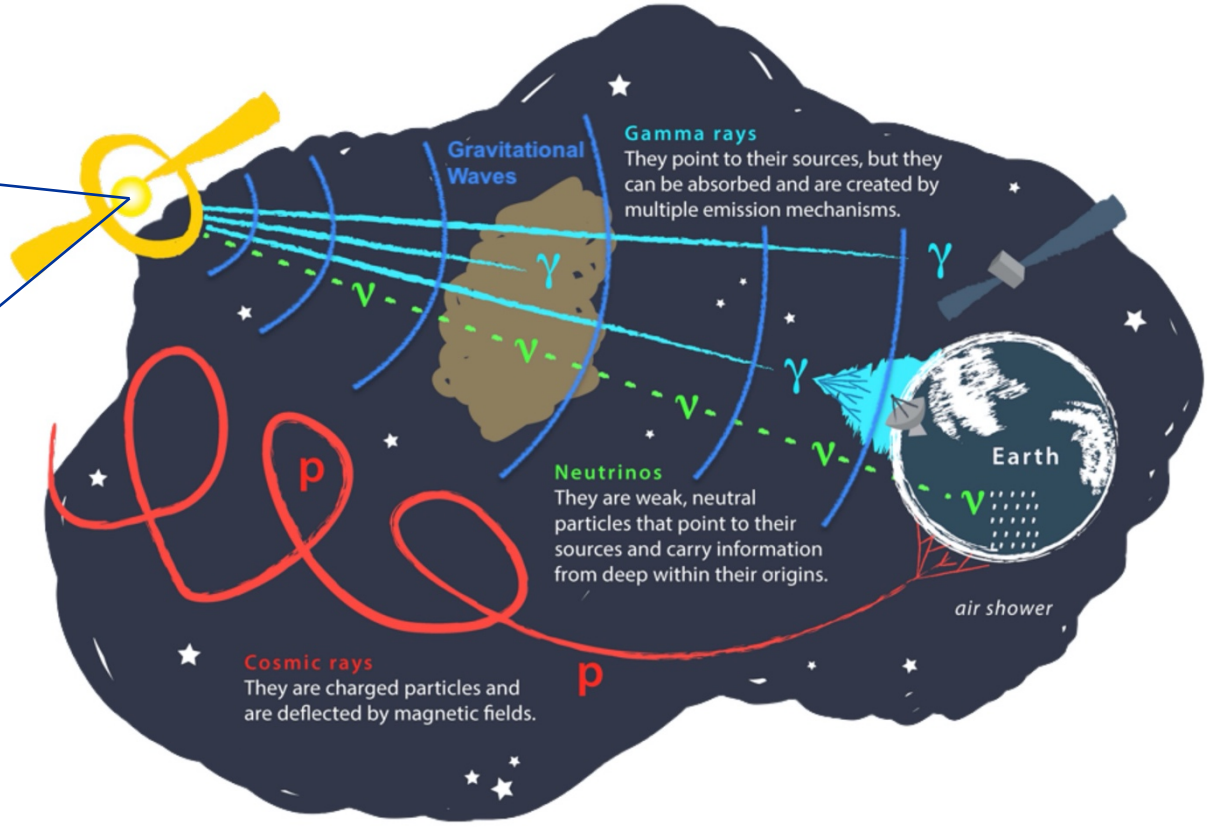
IIHE Annual Meeting
18 December 2020

Pablo Correa
for the IIHE-IceCube Group

Neutrinos in the Multimessenger Era

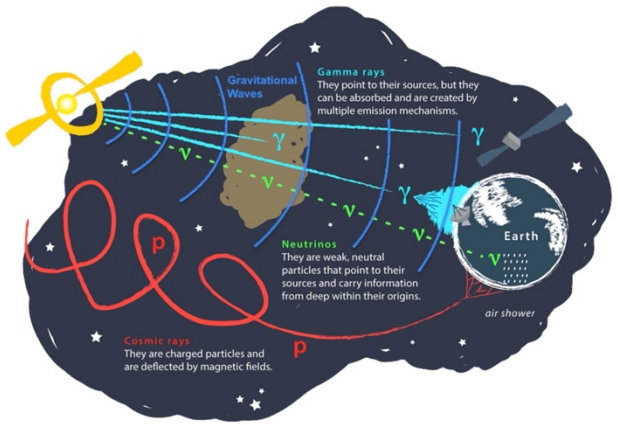
- Unknown origin of (ultra-high-energy) cosmic rays
- Neutrinos are ideal smoking-gun messengers of cosmic-ray sources

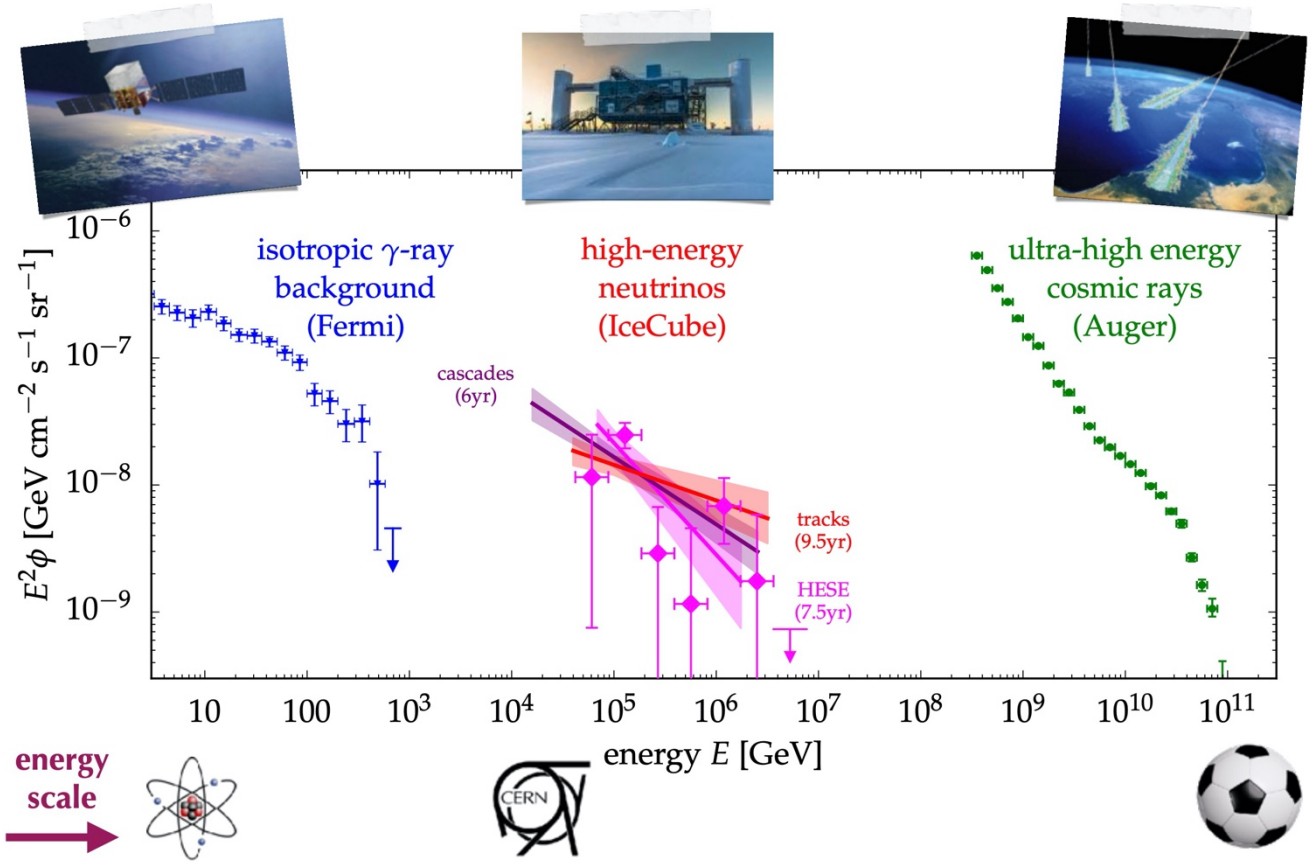




Multimessenger Observations

- Diffuse observations of GeV gamma rays, TeV-PeV neutrinos, and EeV cosmic rays
- Similar energy budgets
- Sources are likely linked!

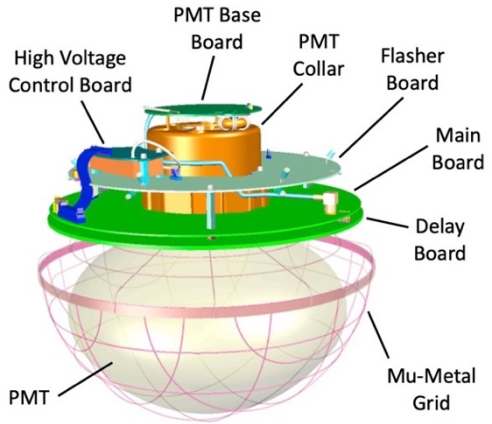


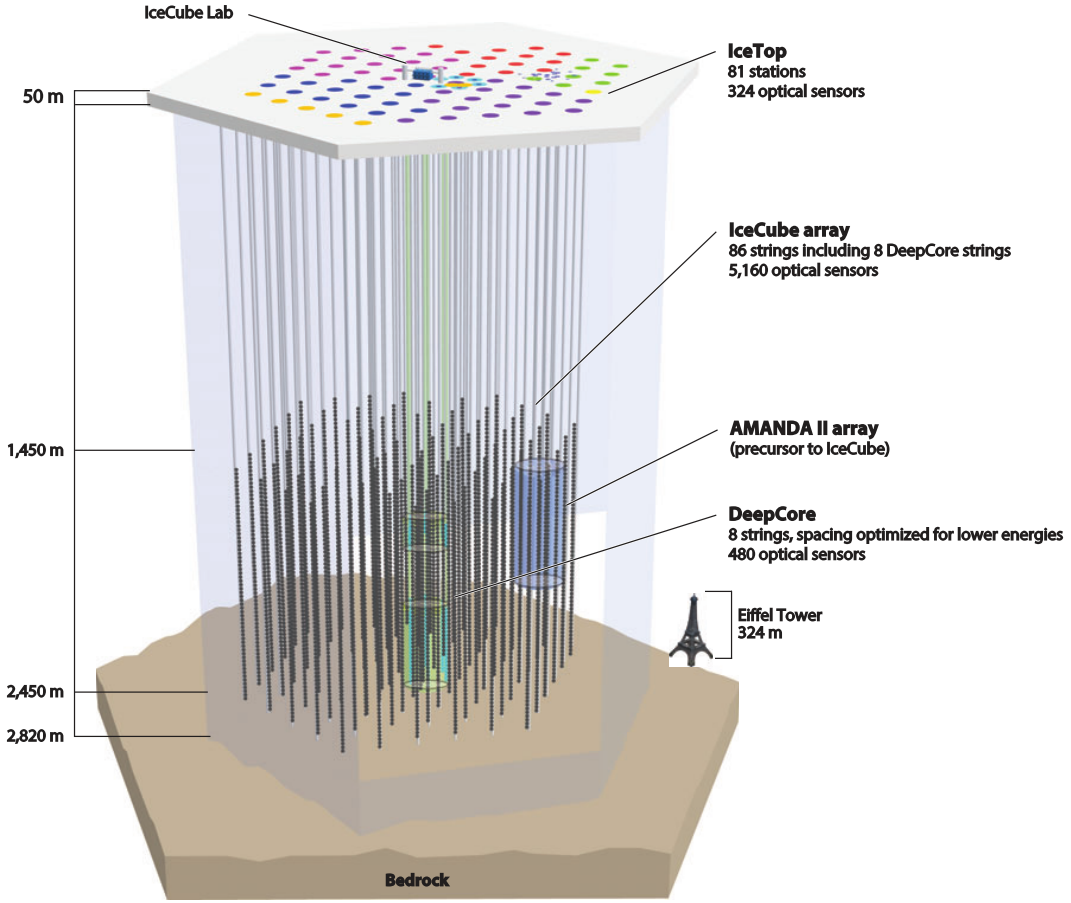


[M. Ahlers, invited seminar, 16 October 2020]

The IceCube Neutrino Observatory

- 1 km^3 in-ice detector at the South Pole
- 5160 digital optical modules (DOMs)
- 86 strings with 60 DOMs each
- 6 denser DeepCore strings
- 1 km^2 IceTop surface array (324 DOMs)





[JINST 12 (2017) P03012]

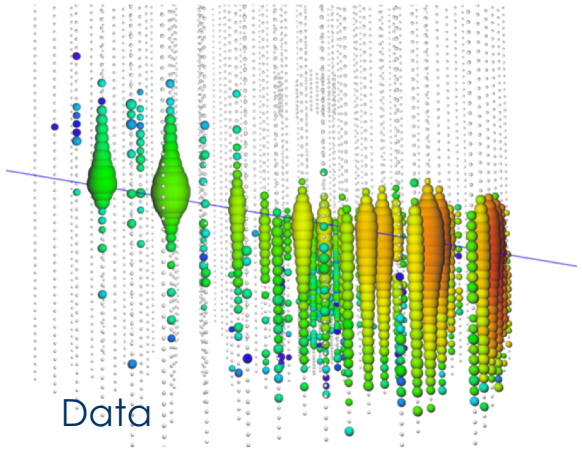
Detecting Neutrinos with IceCube

- Neutrinos can interact with the ice surrounding IceCube
- Secondary charged particles produce Cherenkov radiation

Track

ν_μ charged-current

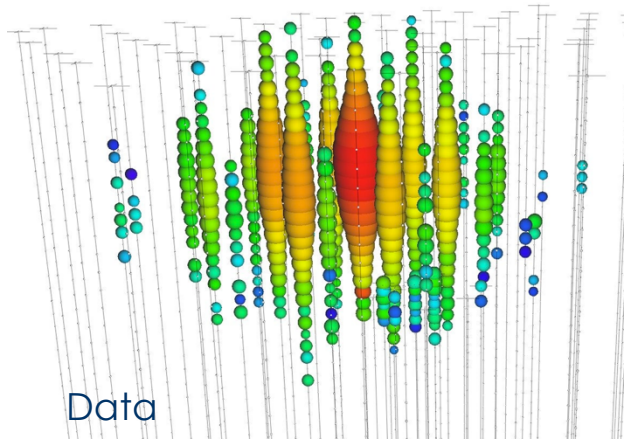
Good angular resolution, $\lesssim 1^\circ$



Cascade

ν_e (ν_τ) charged-current & all neutral-current

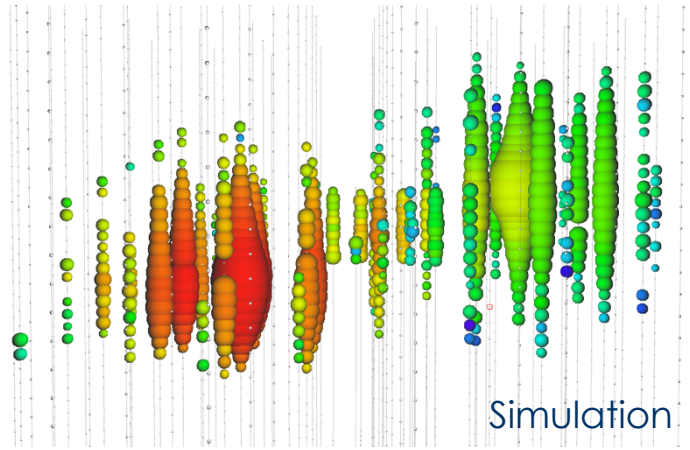
Good energy resolution, $\sim 15\%$

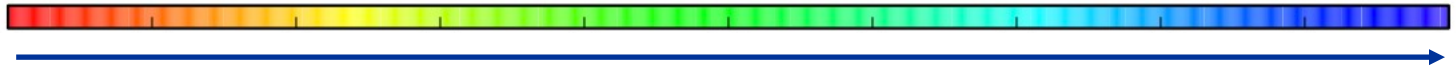


Double Bang

ν_τ charged-current at highest energies

First ν_τ now observed! [arXiv:2011.03561]

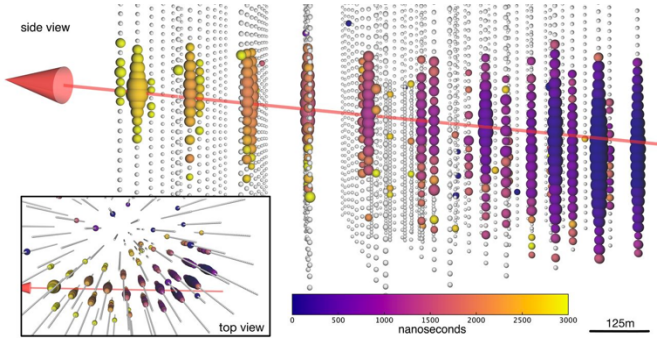




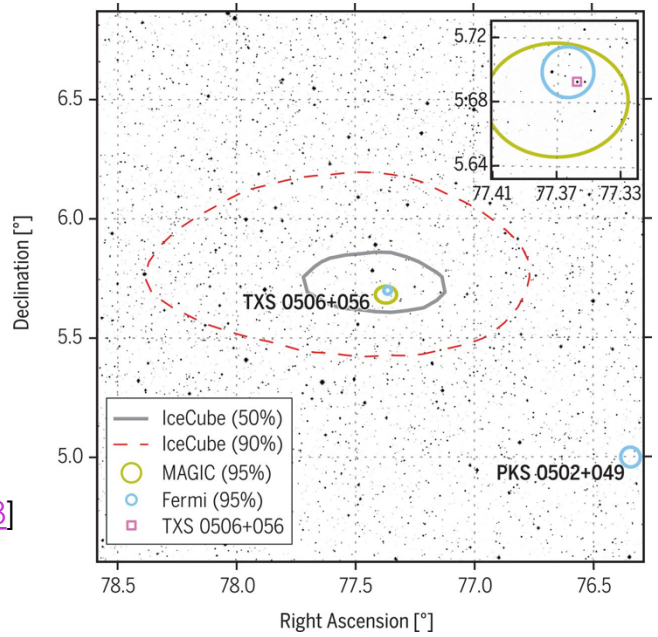
Neutrino Astronomy with IceCube

- Observed diffuse astrophysical neutrino flux
- Origin remains largely unknown
  - TXS 0506+056 is only neutrino source identified so far
  - We actively search for neutrino sources

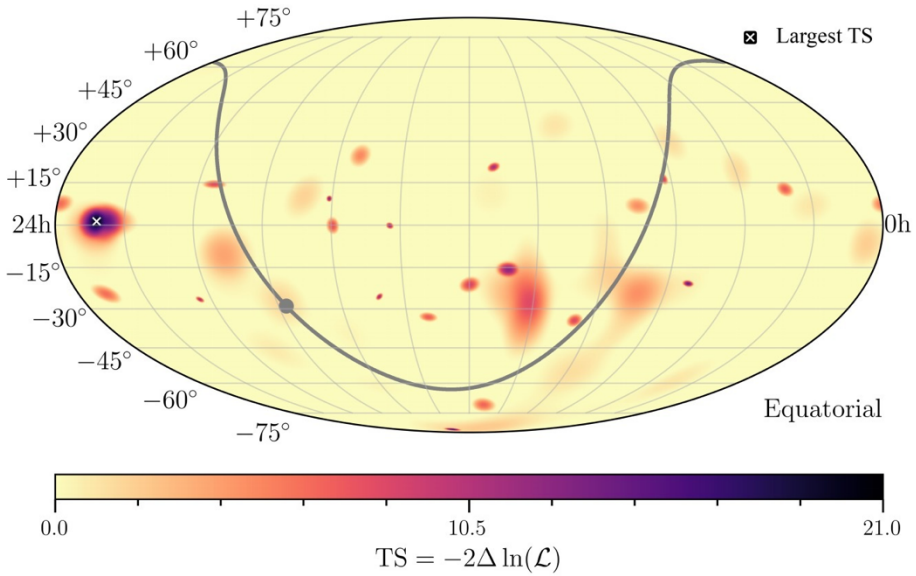
IC170922A



[Science 361 (2018) eeat1378]



The sky in 7.5 years of astrophysical neutrinos



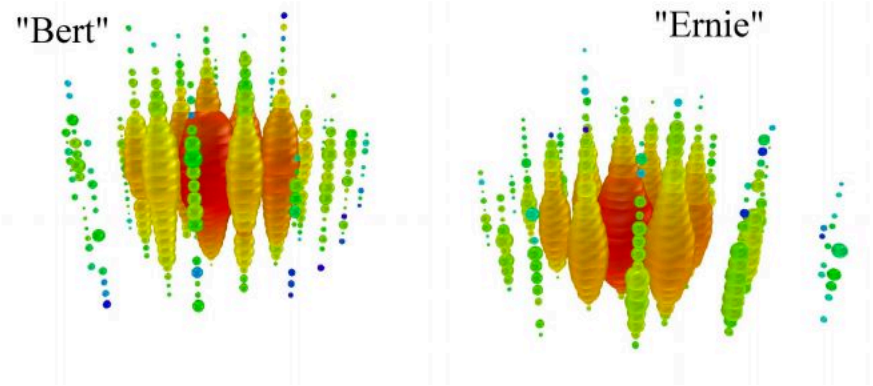
[arXiv:2011.03545]

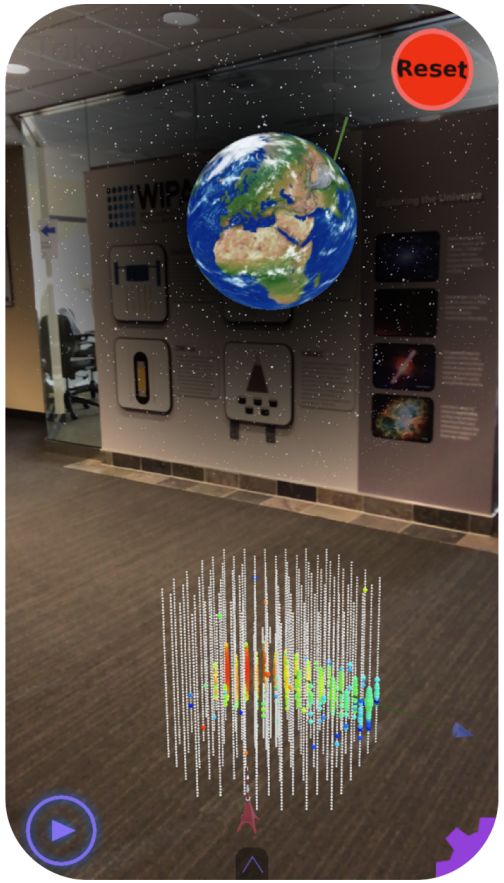
IceCubeAR Application

Available on the App Store link

GET IT ON Google Play link

- Watch event displays on your phone!
- Includes the classic muppets (Bert, Ernie,…)
- Live notifications from our realtime alert stream



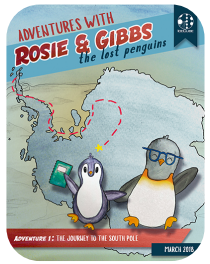


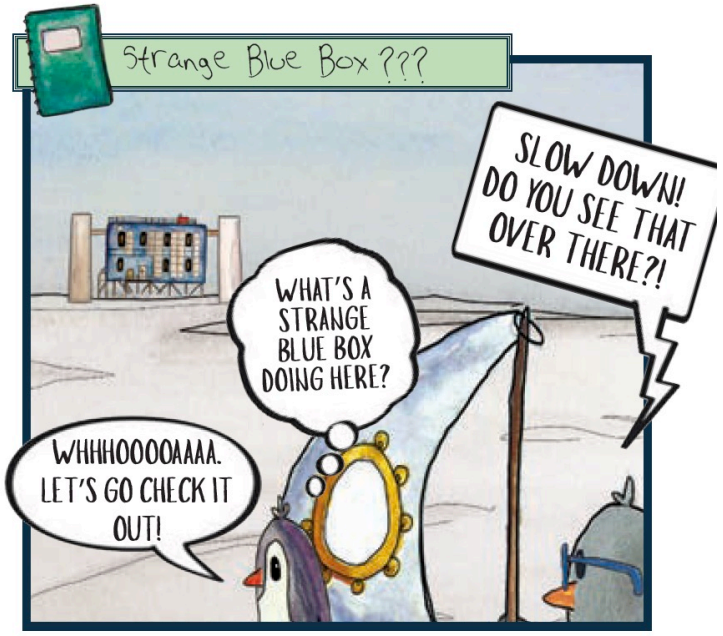
Scientific Scope

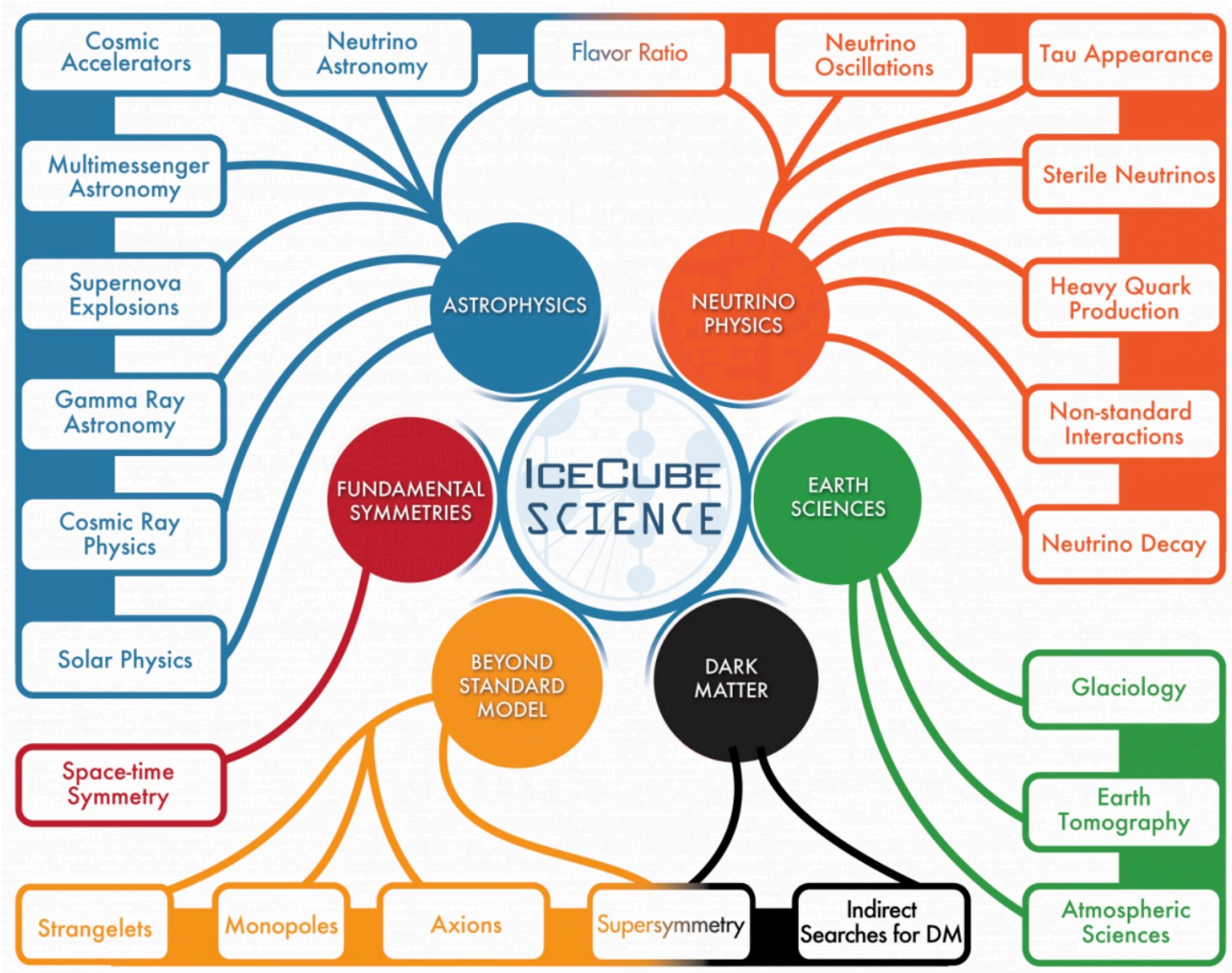
- We can do a lot with this "strange blue box"!

Rosie & Gibbs

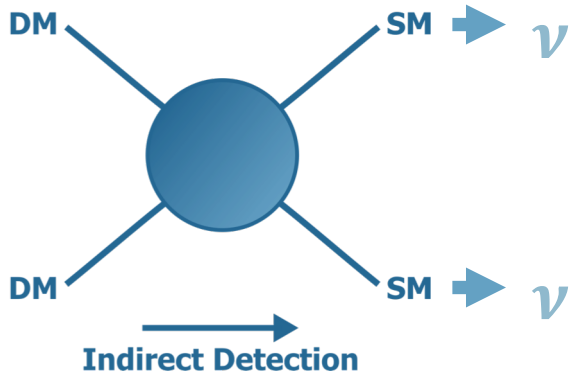
- 6 comics
- Available in EN, FR, NL,…
- Link





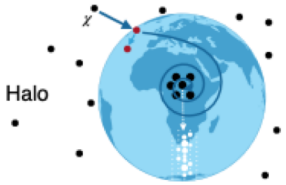


IIHE: Dark Matter

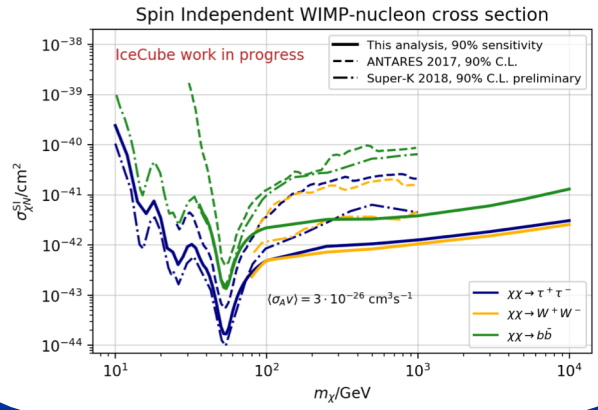


Earth WIMPs

Giovanni Renzi



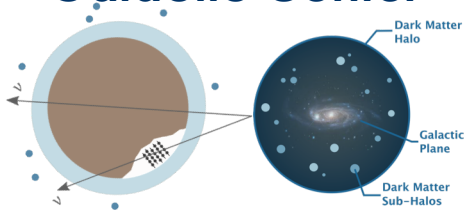
- 7 yr of data
- All ν flavors



Galactic Center

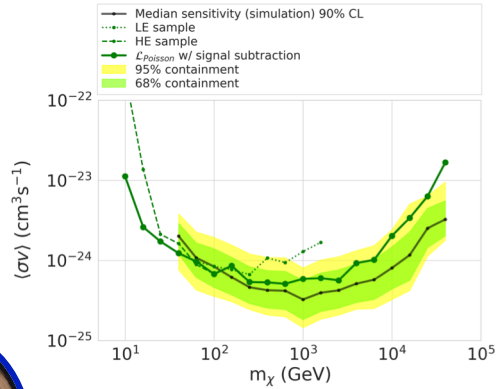
[PRD 102 (2020) 082002]

Juanan Aguilar et al.

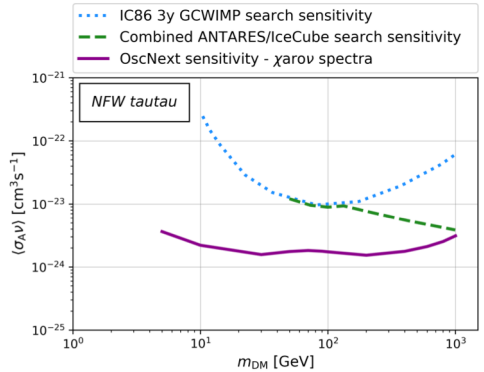


Nadège Iovine

- First GC DM search using energy along angular info



- Combined ANTARES search **published**!
- New search focused on low DM masses

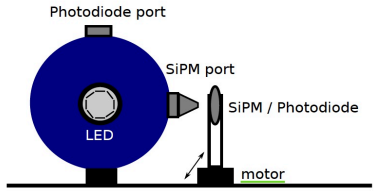


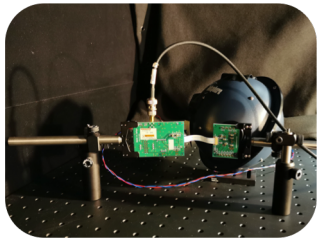
Sebastian Baur left us :(

IIHE: Hardware Upgrades & Neutrino Sources

Silicon Photomultipliers

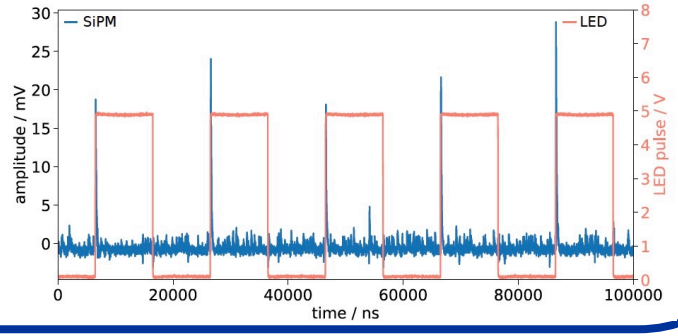
Daniela Mockler





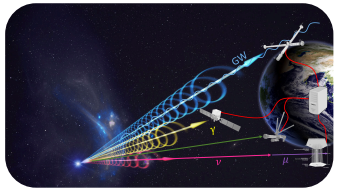
- Characterization of SiPM noise
- Identification of primary & correlated noise
- Determination of photon detection efficiency

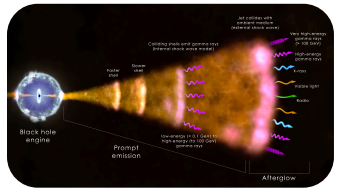
SiPM trace with pulsed LED light



Gamma-Ray Bursts

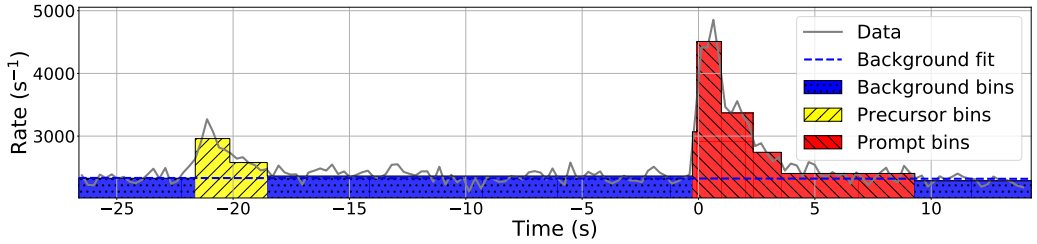
GRBweb 2.0





Paul Coppin

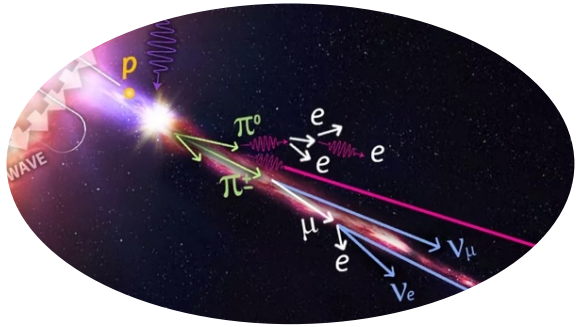
- Fermi-GBM data analysis **published**!
- 244 GRBs identified with a precursor
- Now searching for ν from GRB precursors

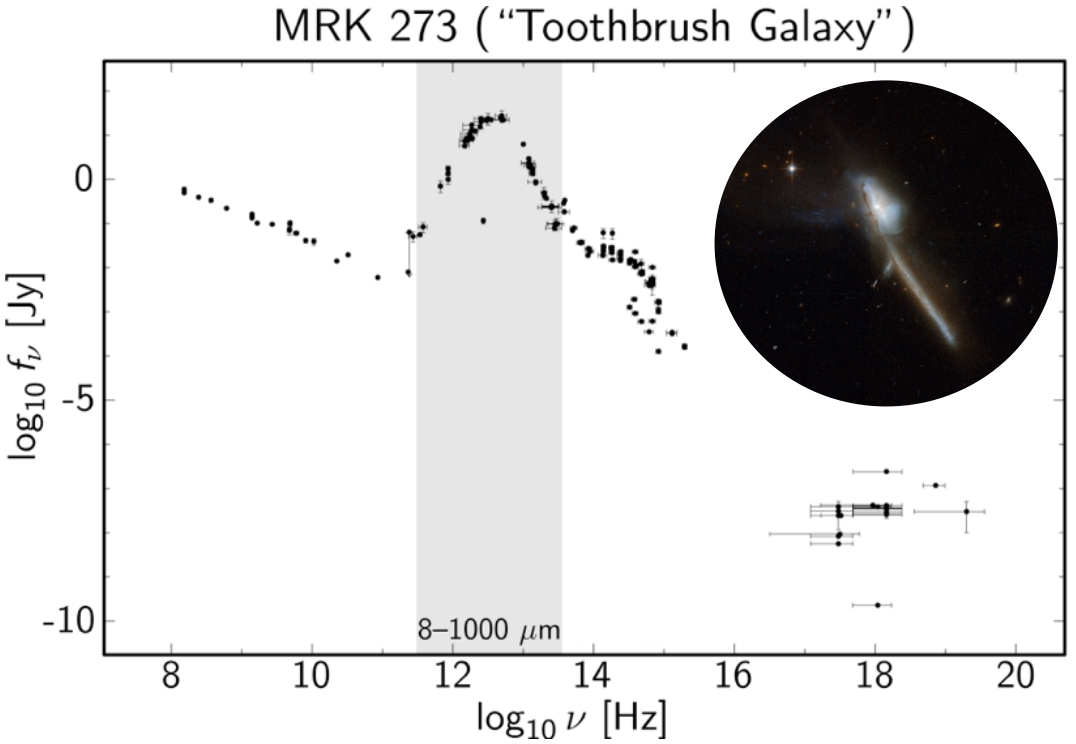


[PRD 102 (2020) 103014]

Ultra-Luminous Infrared Galaxies

- The most luminous objects in the IR sky
  - $L_{IR} \geq 10^{12}\ L_{\odot}$ between 8–1000 micron
  - Typically interacting galaxies
- Plausible hadronic accelerators
  - ULIRGs are mainly powered by starbursts
  - Possible contribution from active galactic nuclei
- Plausible neutrino sources



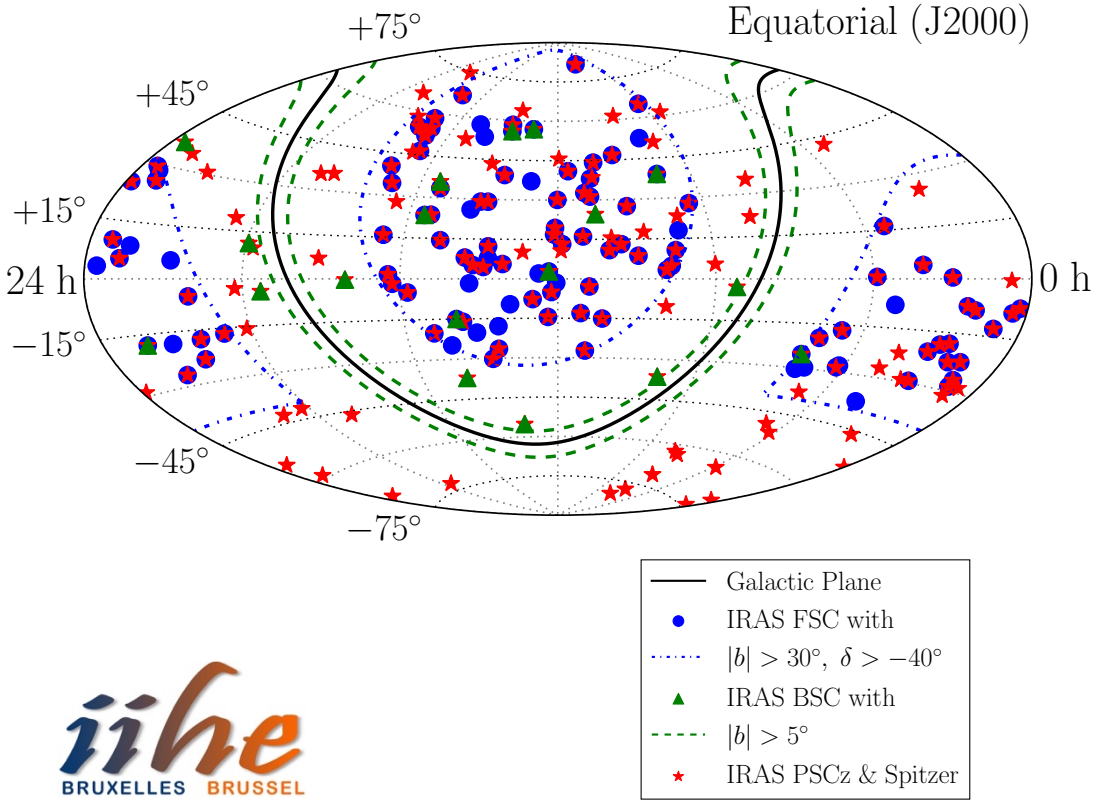


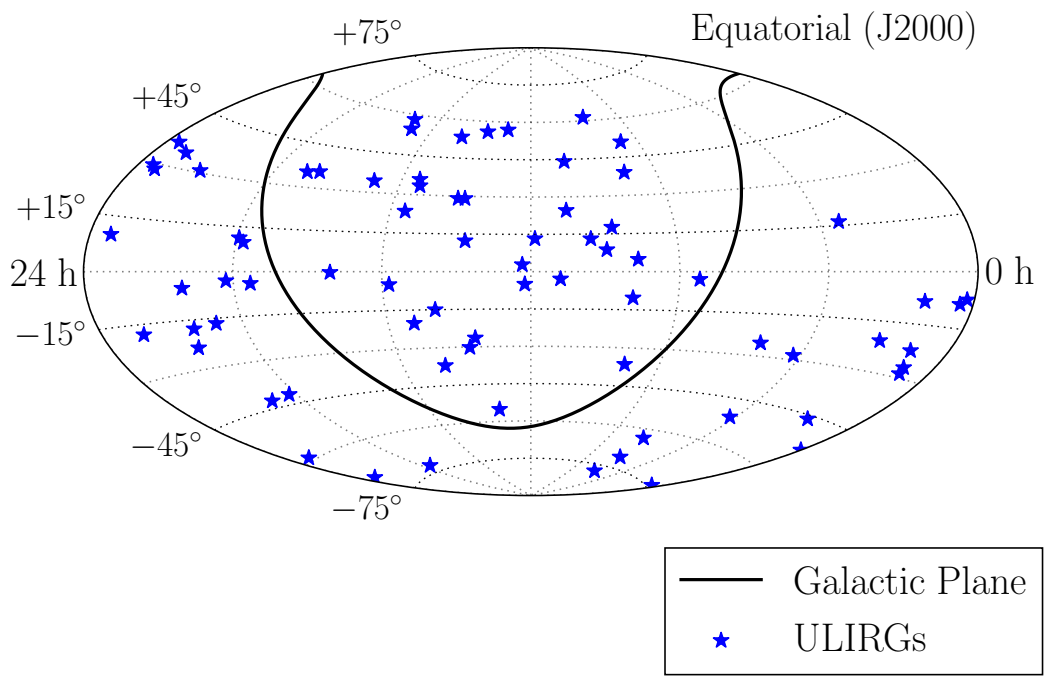
[ESA/Hubble, NASA/IPAC Extragalactic Database]

Selection of ULIRGs

IRAS-based catalogs
Sanders+ (2003) AJ 126 1607
Kim+ (1998) ApJ 508) 627
Nardini+ (2010) MNRAS 405 2505

- Start from three catalogs based on IRAS satellite data (189 ULIRGs)
- Select complete sample of 75 ULIRGs with redshift $z \leq 0.13$



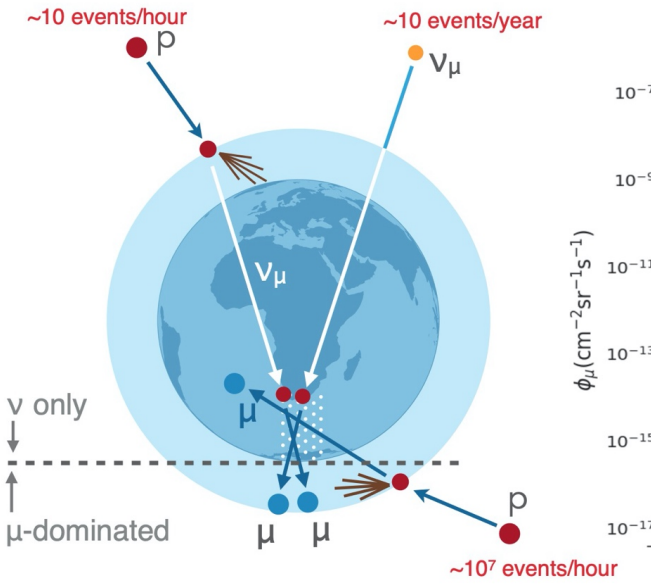


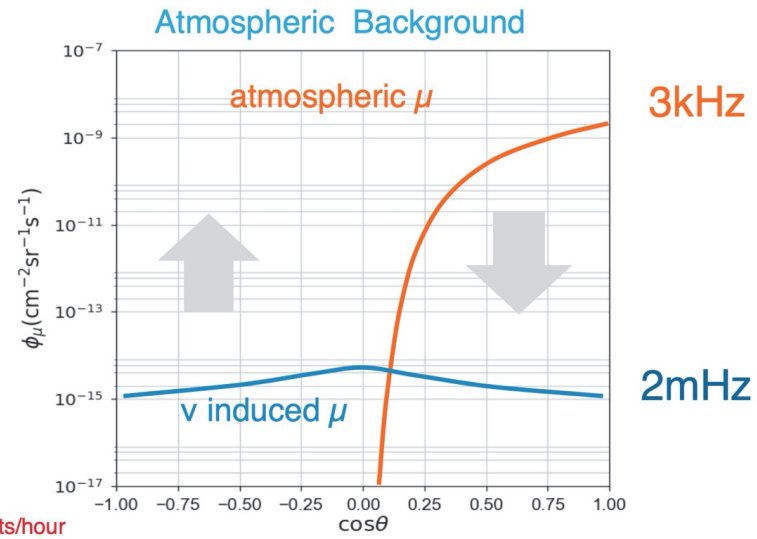
Data Set

[Astropart. Phys. 92 (2017) 30]

Sample	Livetime	Events
GFU 2011–2018	7.5 years	1.5 million

- GFU sample: 7.5 years of all-sky track data
- Atmospheric muons and neutrinos are main backgrounds
- Data is reduced to atmospheric neutrino level
- Mostly sensitive to Northern sources

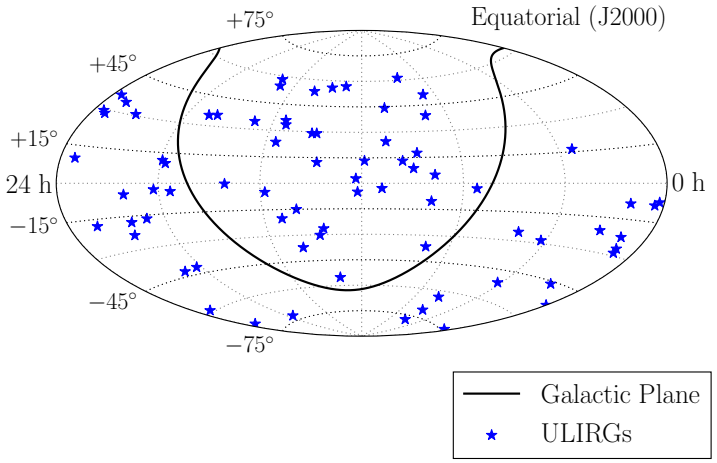




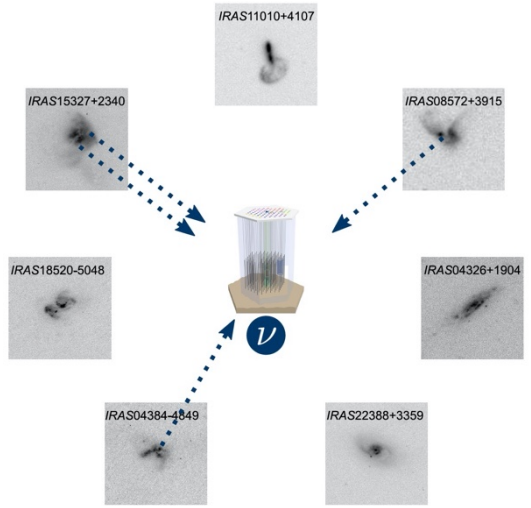
[S. Toscano, annual meeting 2019]

ULIRG Stacking Analysis

- Search for astrophysical ν from ULIRG locations
  - Perform maximum likelihood analysis
  - Look for excess in data above atmospheric background
- Stack ULIRGs to enhance sensitivity

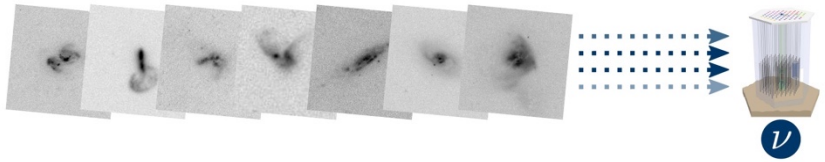


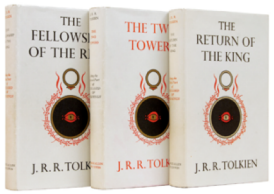
[Hung+ (2014) ApJ 791 63]



Stack

Increasing IR flux

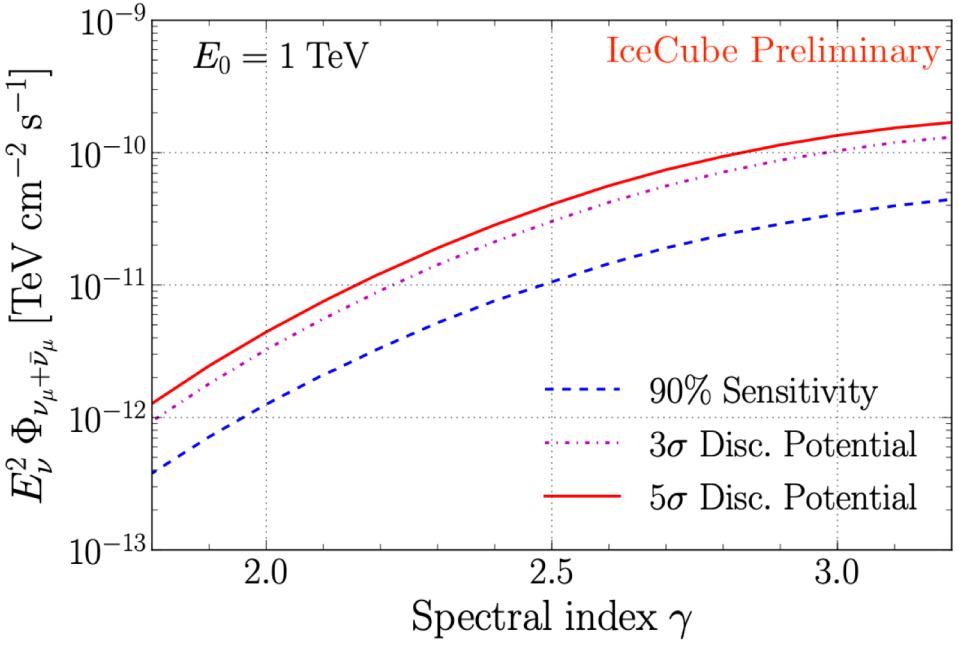


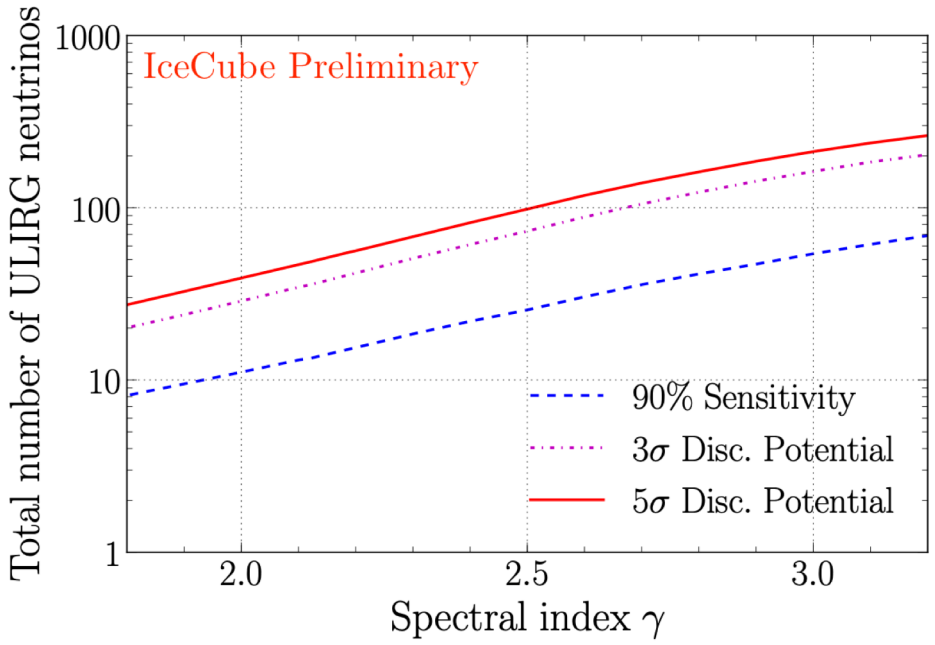


Stack

Sensitivities & Discovery Potentials

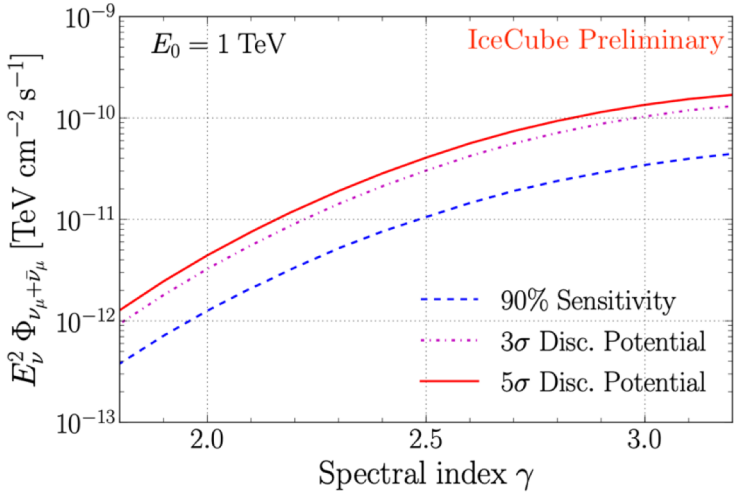
- Test analysis performance for $E^{-\gamma}$ spectrum
  - Steeper spectra are more difficult to separate from background





Results & Upper Limits

- Analysis consistent with background hypothesis
  - Obtained p-value = 1.0
- Set upper limits on flux from our 75 ULIRGs
  - Limits equal to sensitivity (90% CL)
  - Extrapolate to limits on full ULIRG source population



$$\Phi^{\text{all ULIRGs up to } z=z_{\max}}_{\nu_\mu+\bar{\nu}_\mu} = \frac{\xi_{z=z_{\max}}}{\xi_{z=0.13}} \Phi^{\text{all ULIRGs up to } z=0.13}_{\nu_\mu+\bar{\nu}_\mu}$$

$$\xi_{z=z_{\max}} = \int dz \, \mathcal{H}(z)$$

$$\mathcal{H}(z) = \begin{cases} (1+z)^4 & z \leq 1 \\ \text{flat} & z > 1 \end{cases}$$

ULIRG redshift evolution

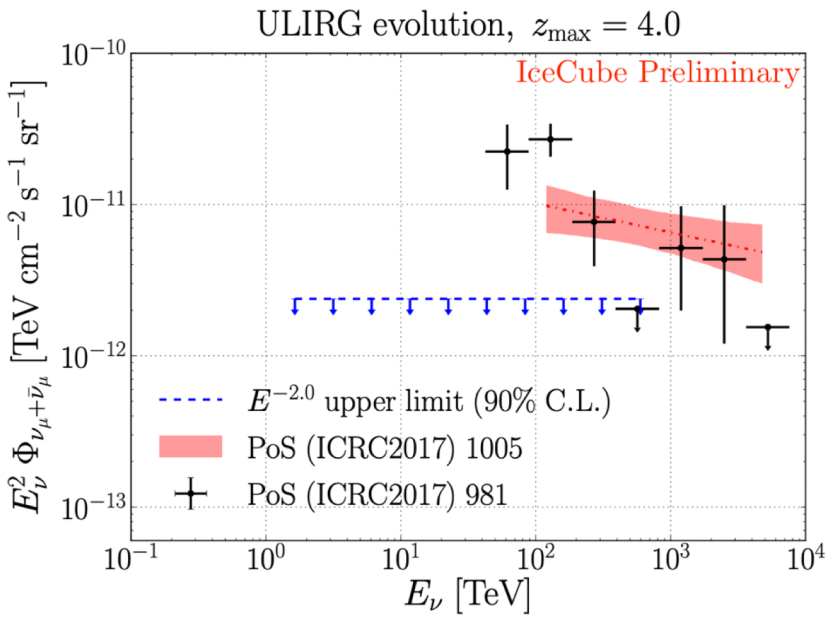
[Vereecken+, arXiv:2004.03435]

Spectral index γ	$\xi_{z=0.13}$	$\xi_{z=4.0}$	$\xi_{z=4.0}/\xi_{z=0.13}$
2.0	0.14	3.4	24
2.5	0.14	2.5	18
3.0	0.13	1.8	14

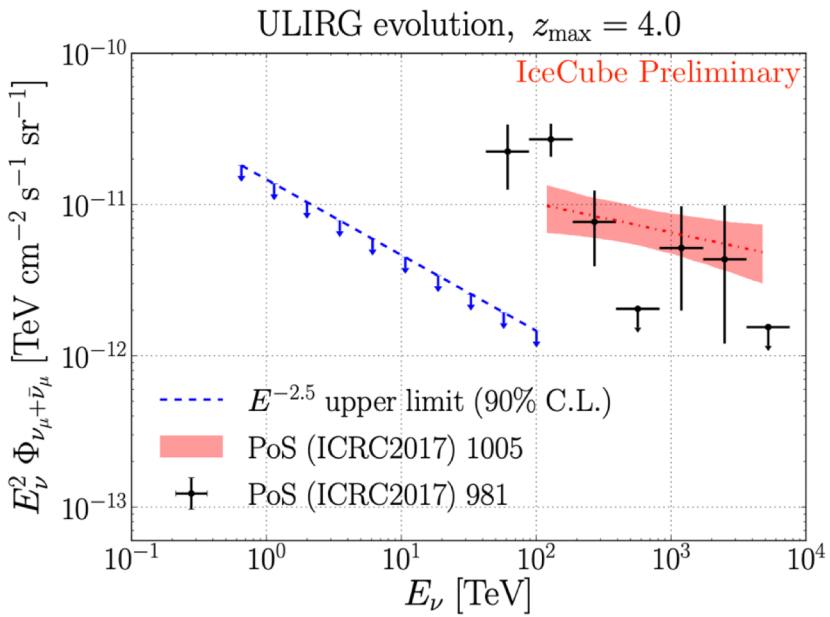
Upper Limits on Source Population I

- ULIRGs cannot be sole sources of the IceCube diffuse neutrino flux

$E^{-2.0}$ limit



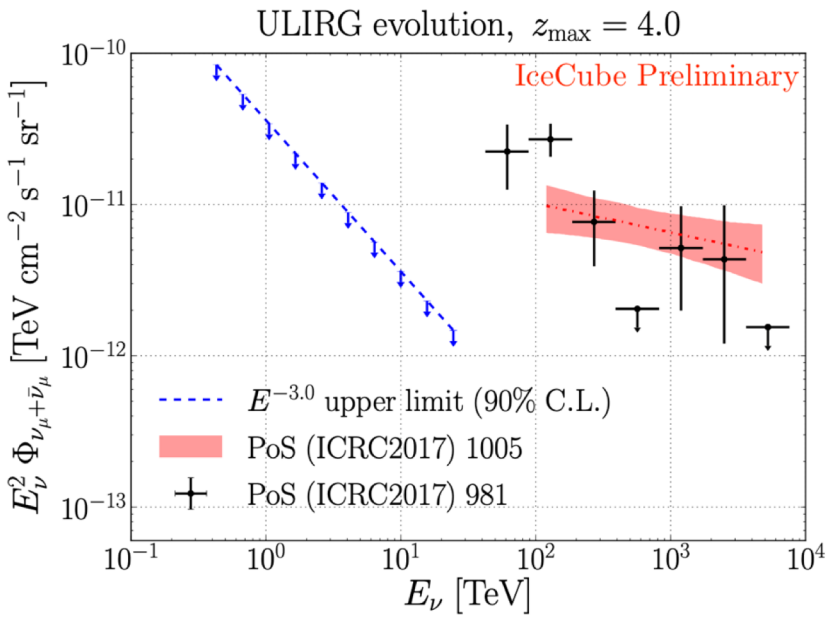
$E^{-2.5}$ limit



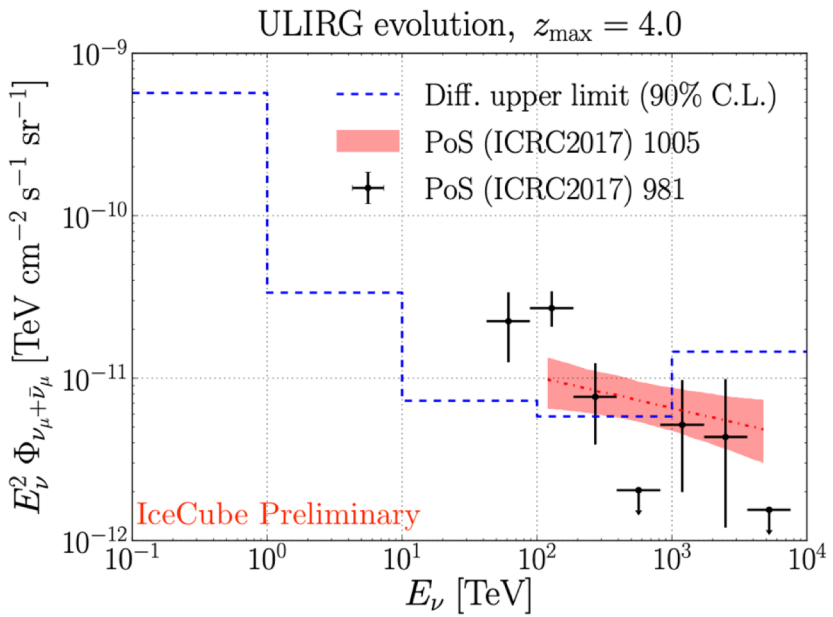
Upper Limits on Source Population II

- ULIRGs cannot be sole sources of the IceCube diffuse neutrino flux

$E^{-3.0}$ limit



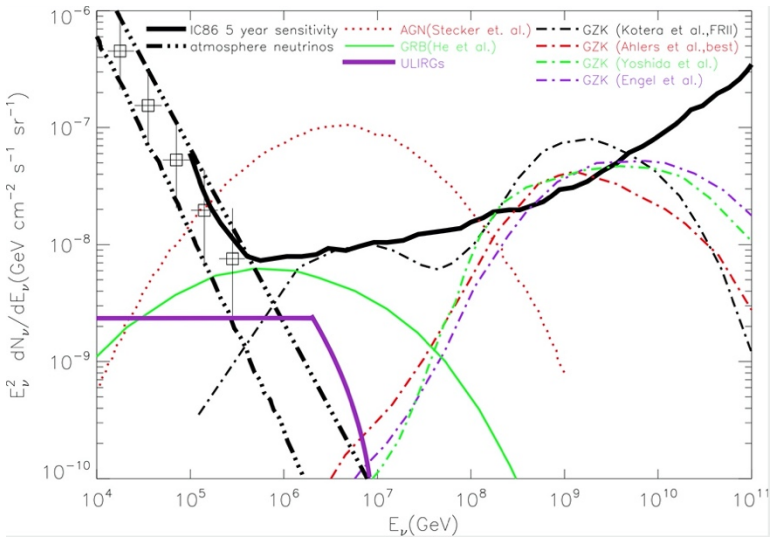
Differential limits



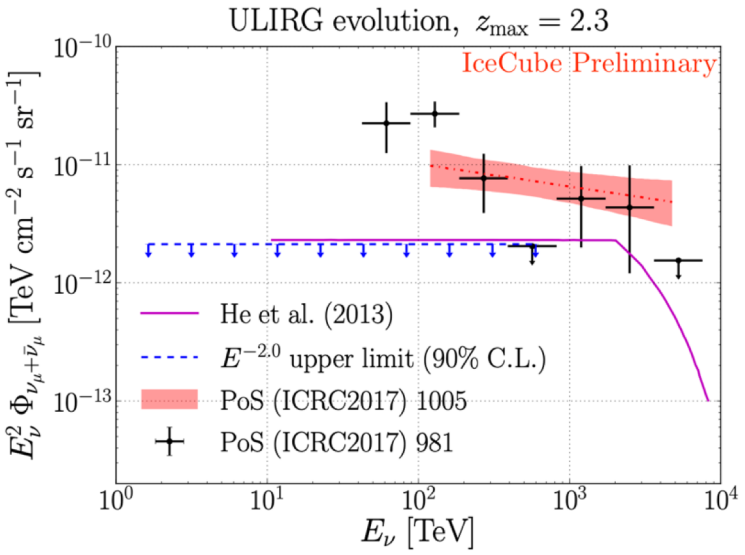
Comparison with Model Predictions I

- He+ (2013) PRD 87 063011
  - Hadronic acceleration due to enhanced hypernova rate
  - Predict PeV diffuse ULIRG neutrino flux
- In tension with limits

Prediction



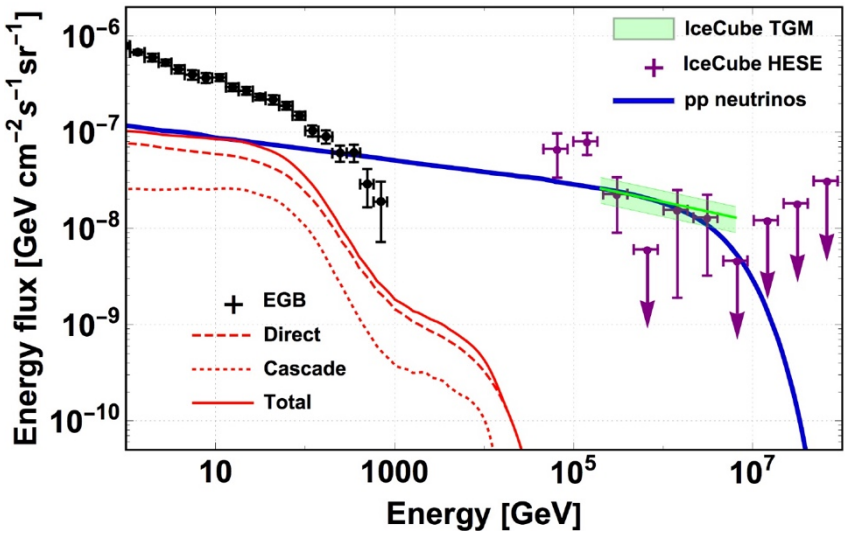
Limit



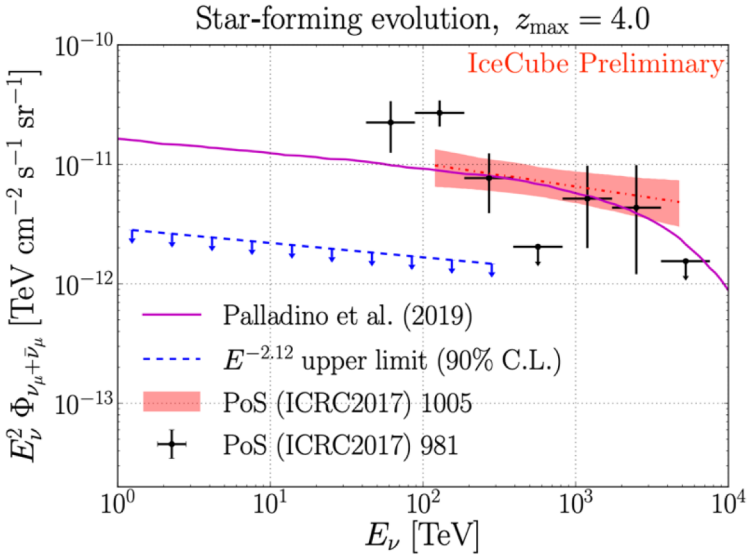
Comparison with Model Predictions II

- Palladino+ (2019) JCAP 09 004
  - Generic model of hadronically-powered gamma-ray galaxies (HAGS)
  - Model fit to diffuse neutrino observations
- ULIRGs excluded as sole HAGS

Prediction

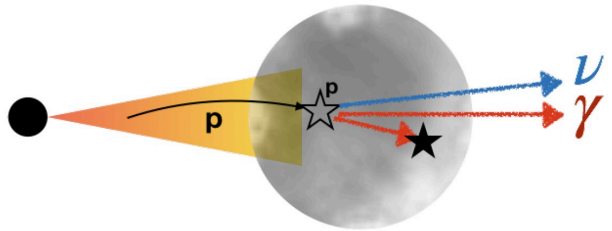


Limit



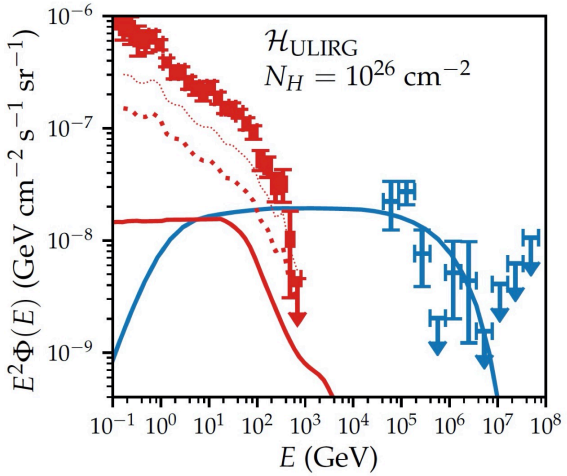
Comparison with Model Predictions III

- Vereecken+, arXiv:2004.03435
  - Neutrinos produced through AGN beam dump in dust clouds
  - Model fit to diffuse neutrino observations



- Set lower limit on most uncertain parameter $f_e = L_e/L_p$
  - Fit model to our $E^{-2.0}$ ULIRG limit
  - Consistent with previous limits on obscured AGN

Prediction



Limit

$$f_e \gtrsim 10^{-3}$$

All based on previous work done at the IIHE!

Conclusions & Future Prospects

Summary

- Performed IceCube stacking search for neutrinos from ULIRGs
- No astrophysical signal identified
- Set upper limits on ULIRG source population
- Constrained model predictions

Outlook

- IceCube paper on ULIRG analysis is in the pipeline
- Future studies will likely focus on gamma-ray dim neutrino sources
  - Subclass of (U)LIRGs?
  - Compton-thick active galactic nuclei?
  - Follow Yarno Merckx' MSc thesis work!

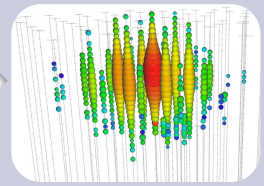
Astroparticle Physics at the IIHE

- IIHE is actively involved in cosmic-ray and (future) neutrino experiments!

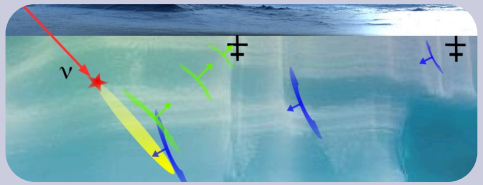
Optical | **Radar** | **Askaryan** | **Air showers**

Particle energy

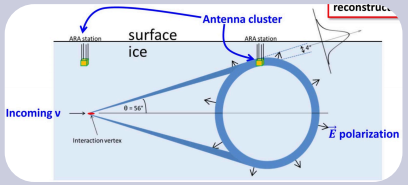
≲ 1–10 PeV



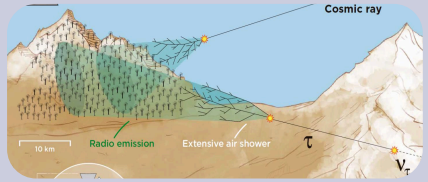
≳ 1 PeV



≳ 50 PeV



≳ 1 EeV



even higher

IceCube South Pole Neutrino Observatory

IceCube Gen2

Radar Echo Telescope

Askaryan Radio Array

Radio Neutrino Observatory - Greenland

LOFAR

GRAND

Pierre Auger Observatory

iihe Bruxelles Brussel

The IIHE Astroparticle Group

WE'LL MISS YOU MARLEEN!

THANK YOU!