Real-time multimessenger work with the MAGIC telescopes

GRB190114C, TXS0506+056 and beyond

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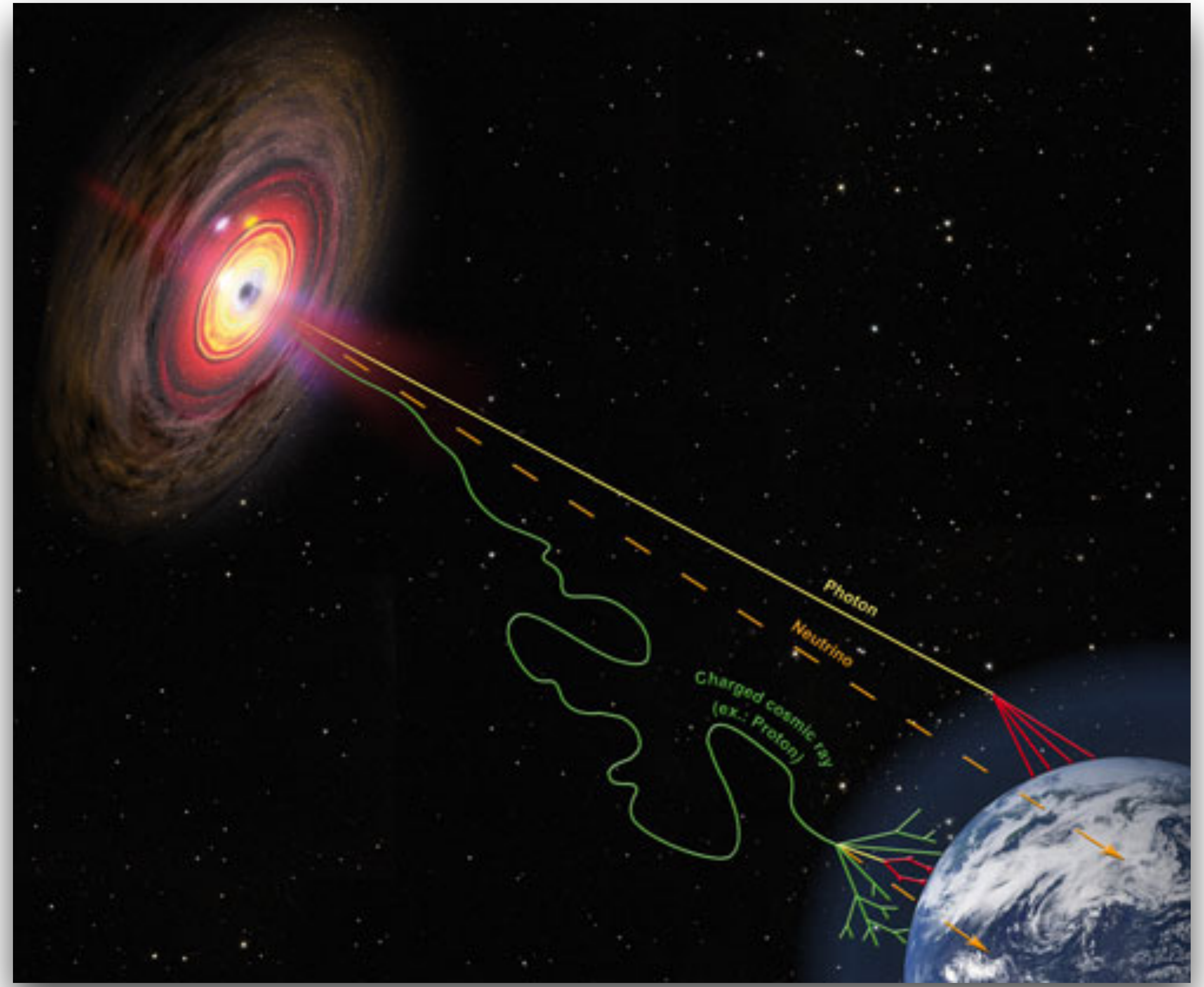
for the MAGIC collaboration and the CTA consortium

DESY

Town Hall KM3NeT meeting - Marseille, December 17 2019

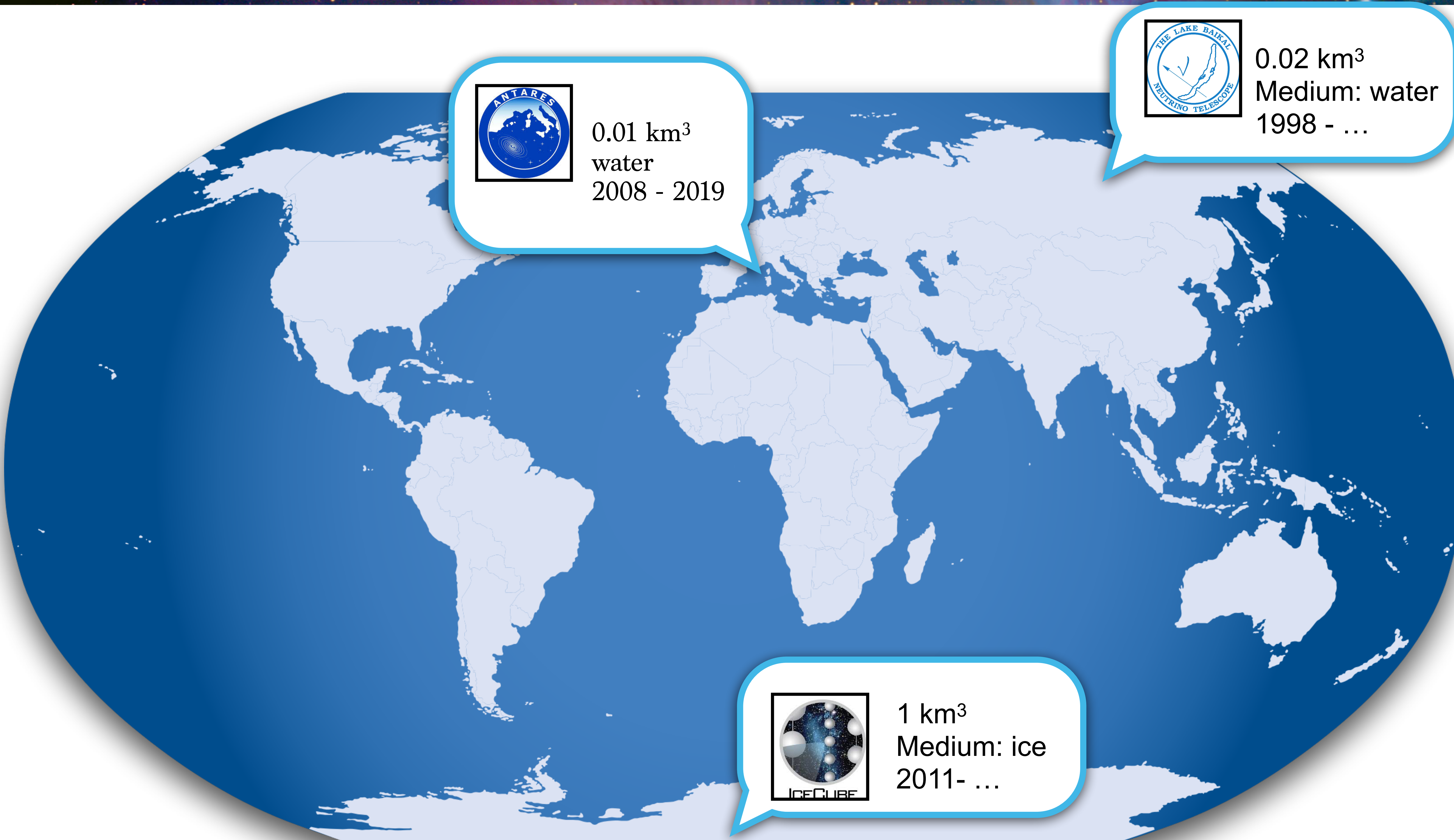
Connection among cosmic messengers

Open issue about the origin of Ultra-High Energy Cosmic Rays



Neutrinos are ideal cosmic messengers...
Also smoking gun for hadronic interactions

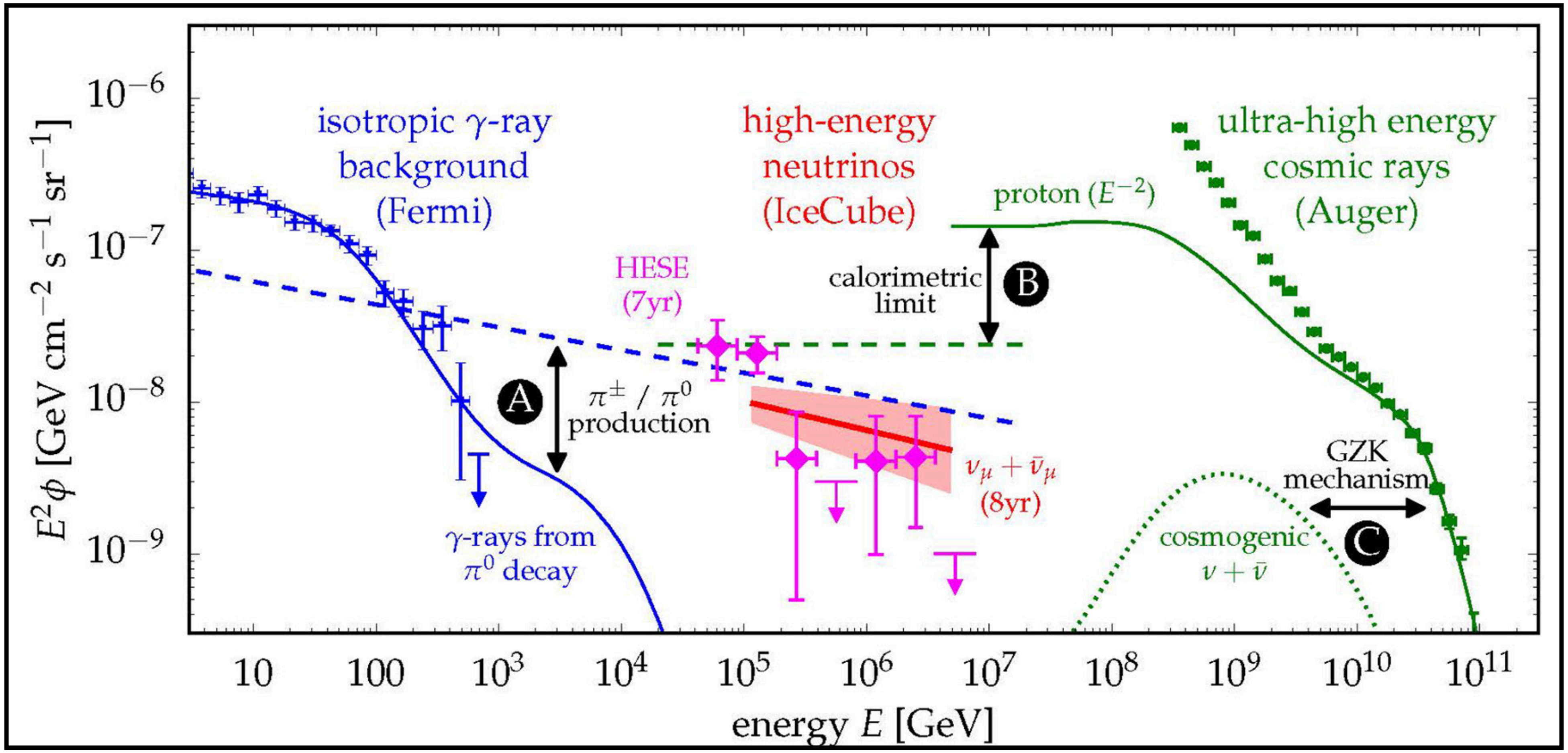
Neutrino astronomy today



Big detectors in ice/water to measure cosmic neutrinos.
Future of the field: KM3NeT, IceCube Upgrade, IceCube-Gen2, ..

Connection among cosmic messengers

Cosmic messengers have the same energy density



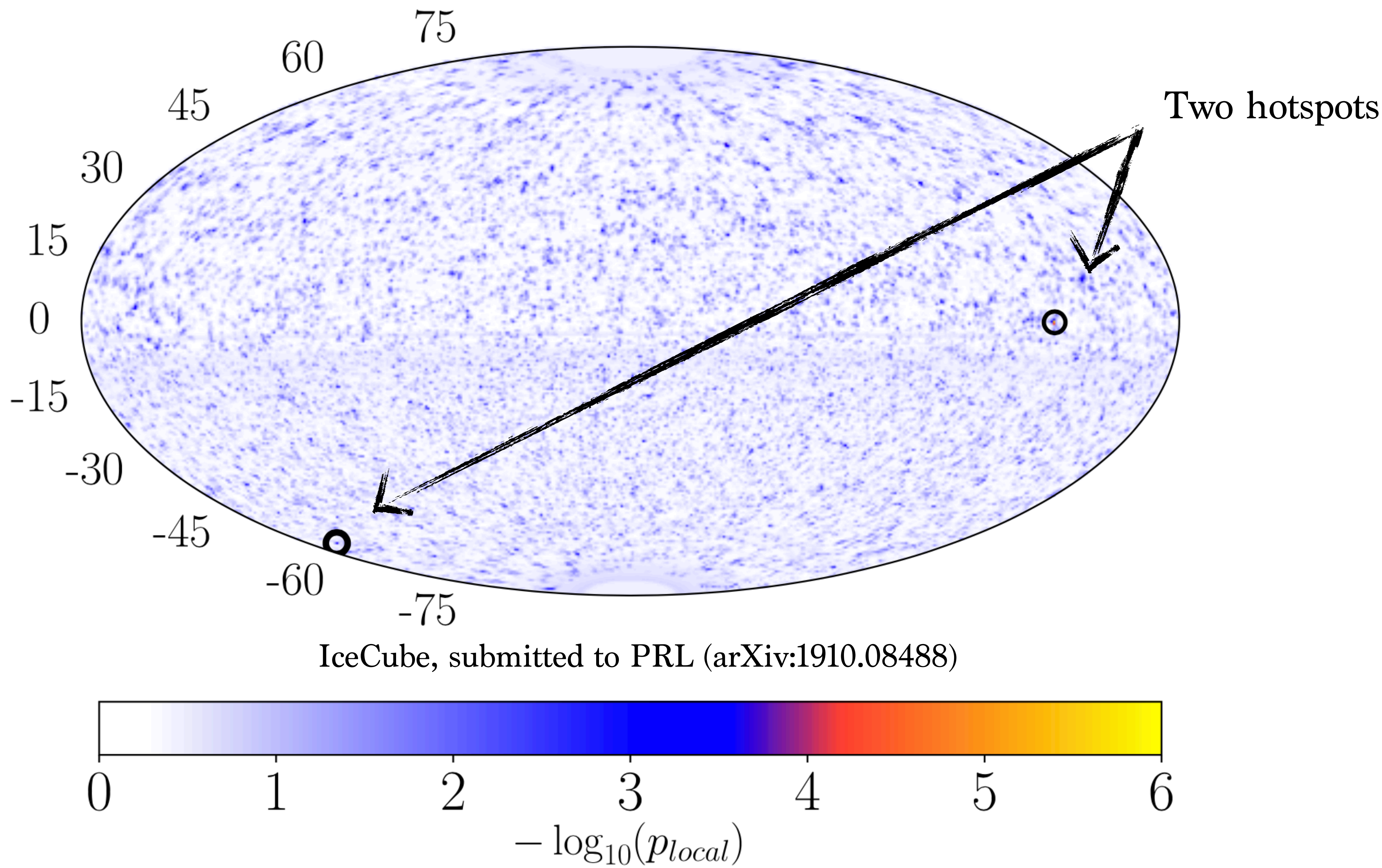
[M. Ahlers, F. Halzen, Prog. Part. Nucl. Phys. 102 (2018) 73-88]

This might indicate a common origin of the signal and provides excellent conditions for multi-messenger studies.

Astrophysical neutrinos: YES!

Cosmic neutrino sources?

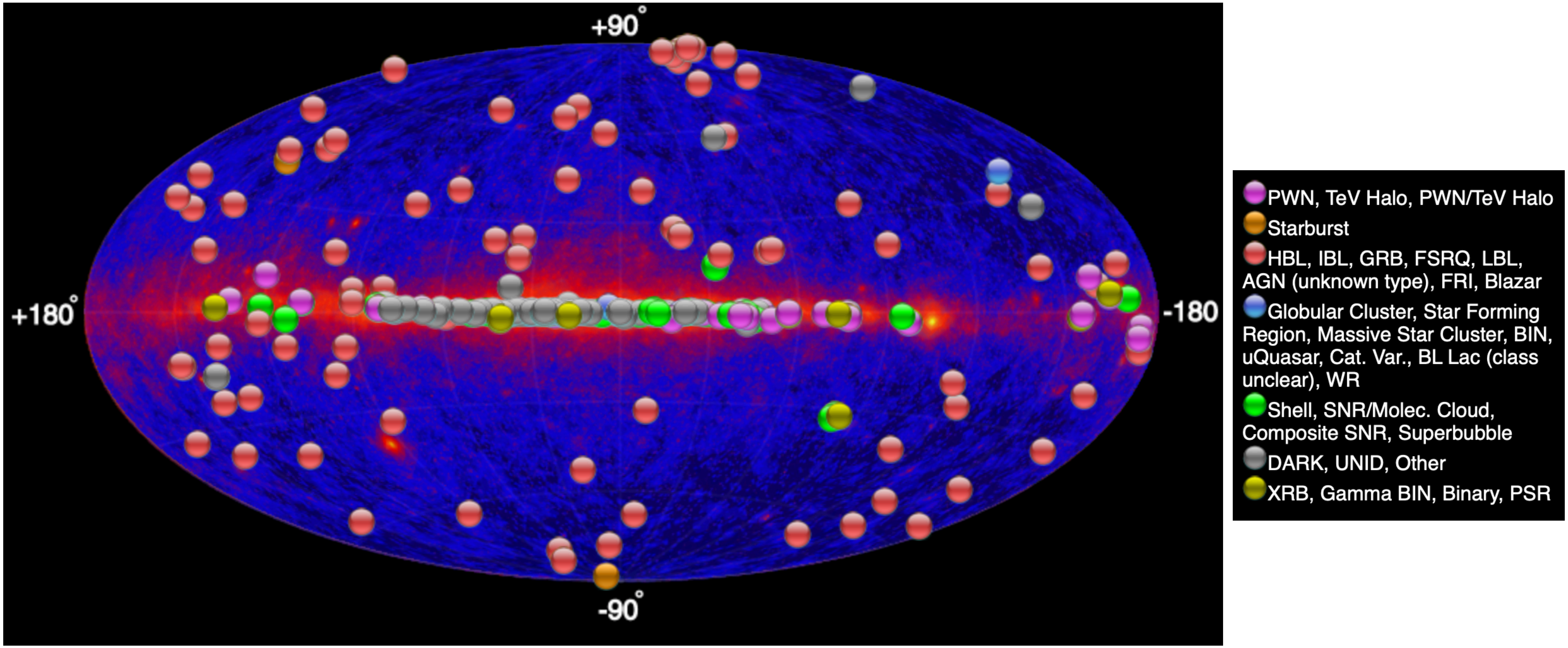
The "neutrino sky" by IceCube



IceCube, submitted to PRL (arXiv:1910.08488)

A sample of ~10^6 neutrinos recorded by IceCube in 10 years provides no evidence for neutrino sources in the full sky and in locations motivated by gamma-ray observations

Gamma-Ray sky

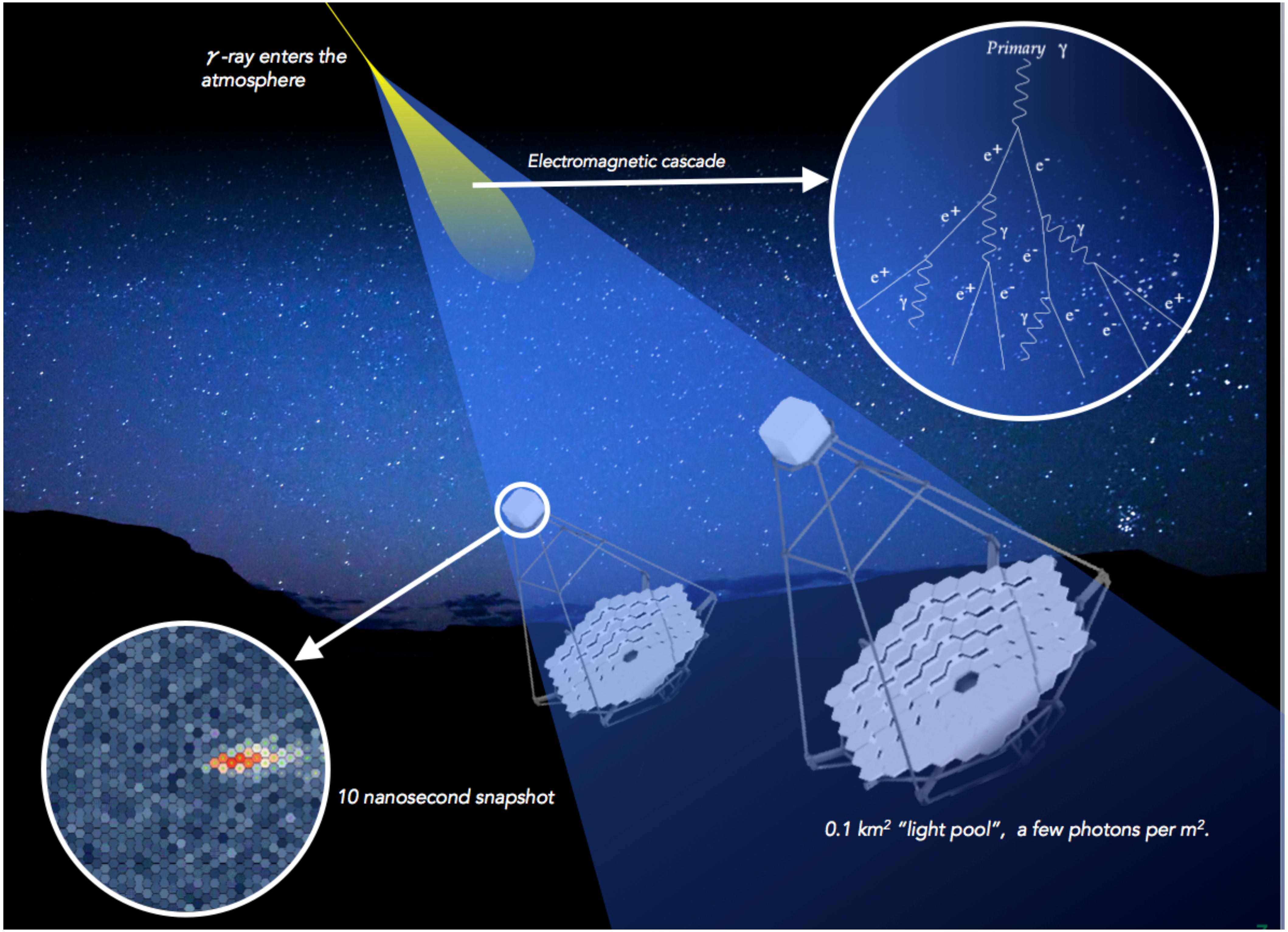


Credit: TeVCat

Steady sources, but also flaring sources!

Real-time multimessenger study to solve the puzzle

Gamma-ray astronomy from ground

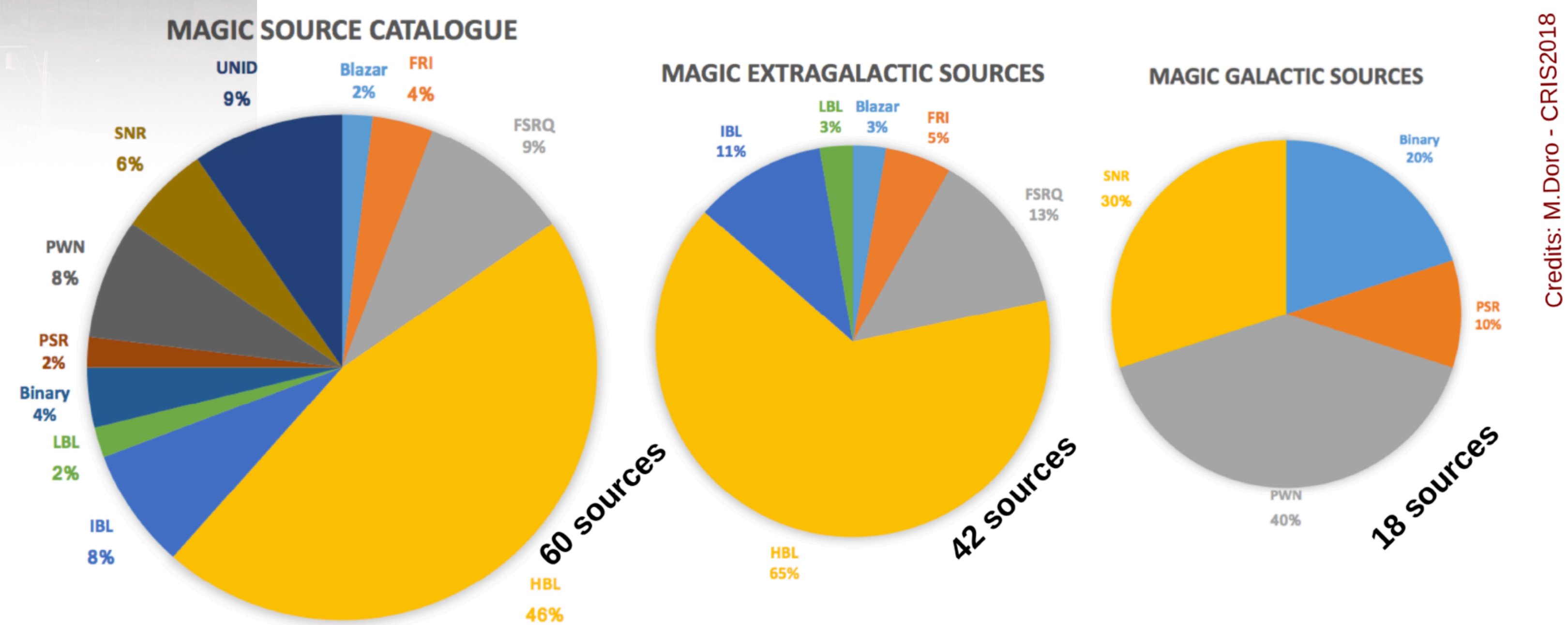


Credit: https://www.cta-observatory.org/about/how-cta-works/

The MAGIC telescopes

- Energy range ~50 GeV ~70 TeV
- Field of view 3.5°
- Sensitivity 0.66% Crab flux (5σ in 50 h)
- Energy resolution 15-24%
- Angular resolution 0.05°-0.1°
- Low energy threshold
- Operation during moonlight
- Mechanical structure suited for fast repositioning

MAGIC, Astropart. Phys. 72 (2016)



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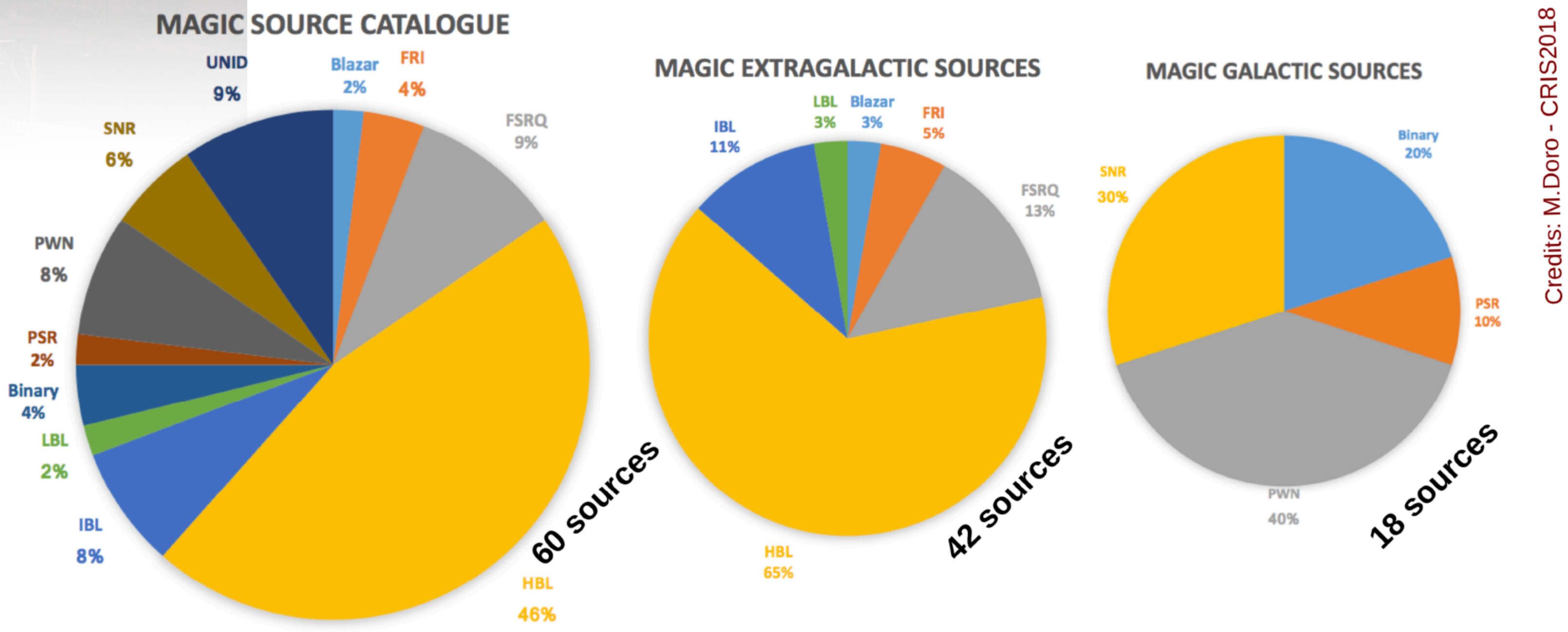
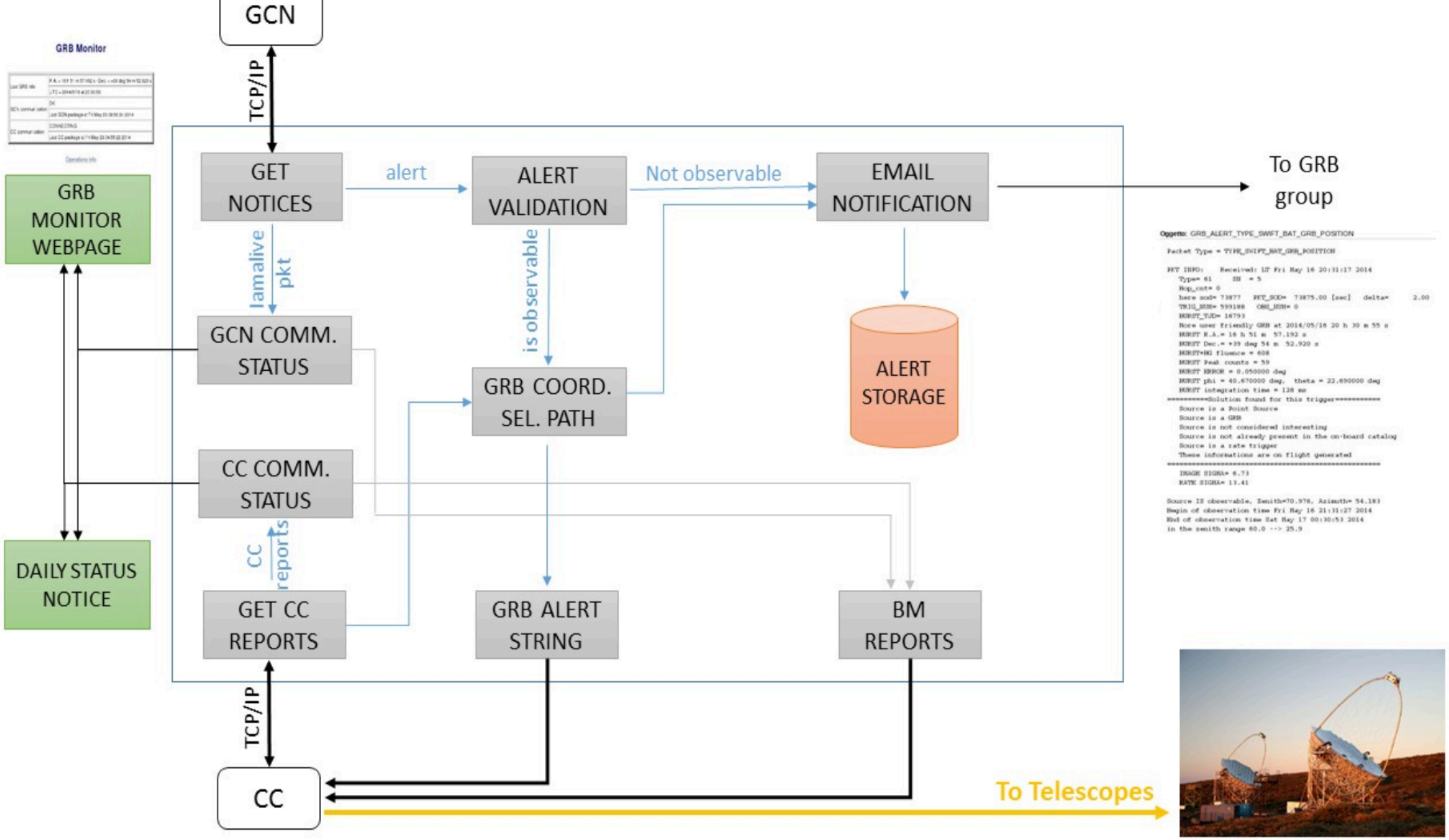
See the video

MAGIC can perform
fast follow-up of transient sources



The MAGIC Automatic Alert System

A. Berti, et al., for MAGIC, PoS(ICRC2019)633



Credit: A. Carosi

Originally thought for GRB searches, now it is **also adapted for gravitational waves** and **neutrino counterpart searches**

Searches of transients with MAGIC

There is a very dense research program, each year about 15% of time invested on it

Gamma-ray Bursts

Gravitational waves counterparts

neutrino counterparts (and tau neutrinos also!)

Fast Radio Bursts

Searches of transients with MAGIC

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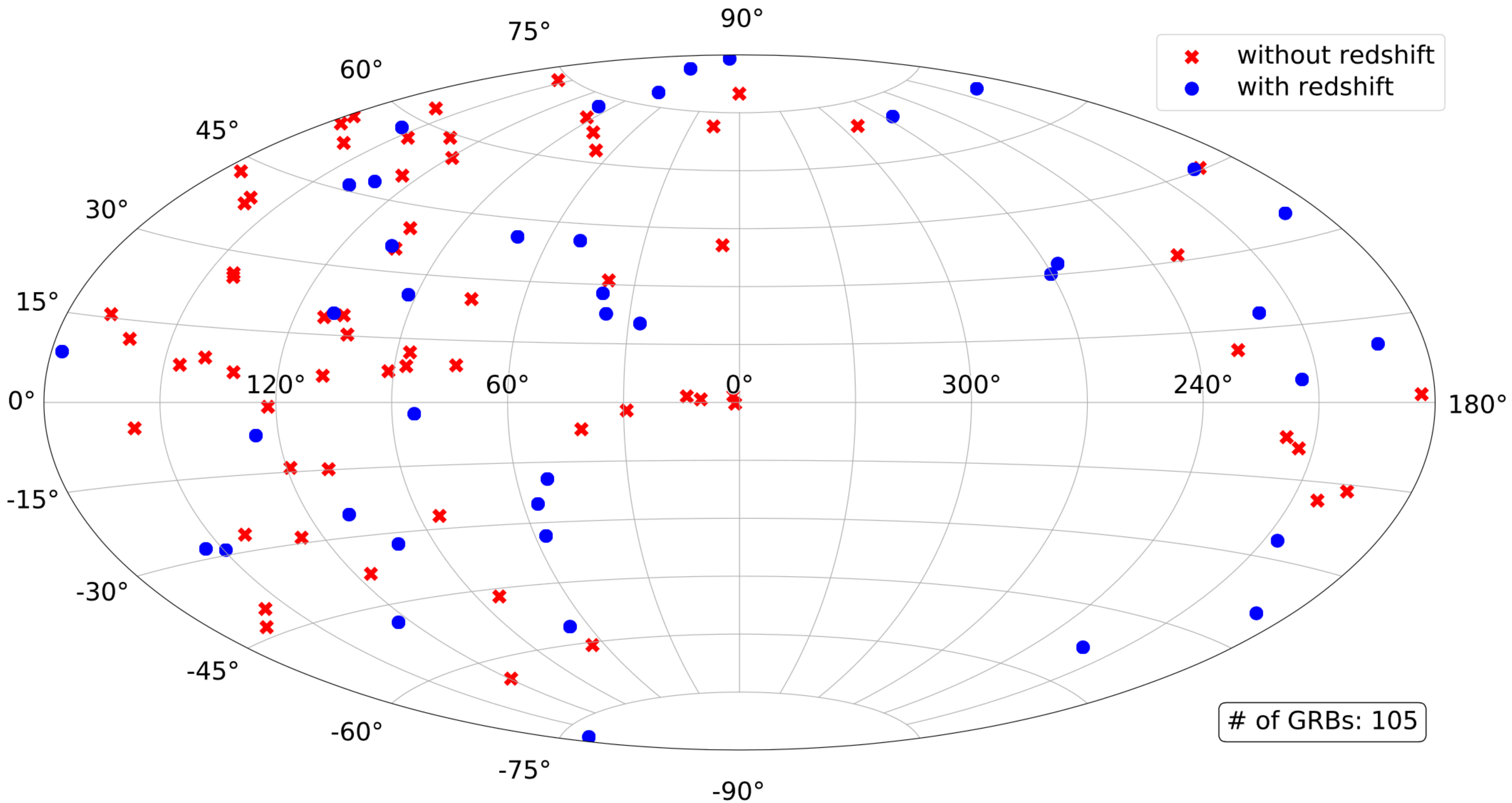
Gravitational waves counterparts

ν counterparts (and ν_τ also!)

Fast Radio Bursts

Gamma-Ray Bursts searches



More than 100 GRBs observed so far by MAGIC

Breakthrough discovery from MAGIC

nature

Article | Published: 20 November 2019

Teraelectronvolt emission from the γ-ray burst GRB 190114C

MAGIC Collaboration

Nature **575**, 455–458(2019) | Cite this article

4366 Accesses | **493** Altmetric | Metrics

Abstract

Long-duration γ-ray bursts (GRBs) are the most luminous sources of electromagnetic radiation known in the Universe. They arise from outflows of plasma with velocities near the speed of light that are ejected by newly formed neutron stars or black holes (of stellar mass) at cosmological distances[1,2]. Prompt flashes of megaelectronvolt-energy γ-rays are followed by a longer-lasting afterglow emission in a wide range of energies (from radio waves to gigaelectronvolt γ-rays), which originates from synchrotron radiation generated by energetic electrons in the accompanying shock waves[3,4]. Although emission of γ-rays at even higher (teraelectronvolt) energies by other radiation mechanisms has been theoretically predicted[5,6,7,8], it has not been previously detected[7,8]. Here

nature

Article | Published: 20 November 2019

Observation of inverse Compton emission from a long γ-ray burst

MAGIC Collaboration, P. Veres, [...] D. R. Young

Nature **575**, 459–463(2019) | Cite this article

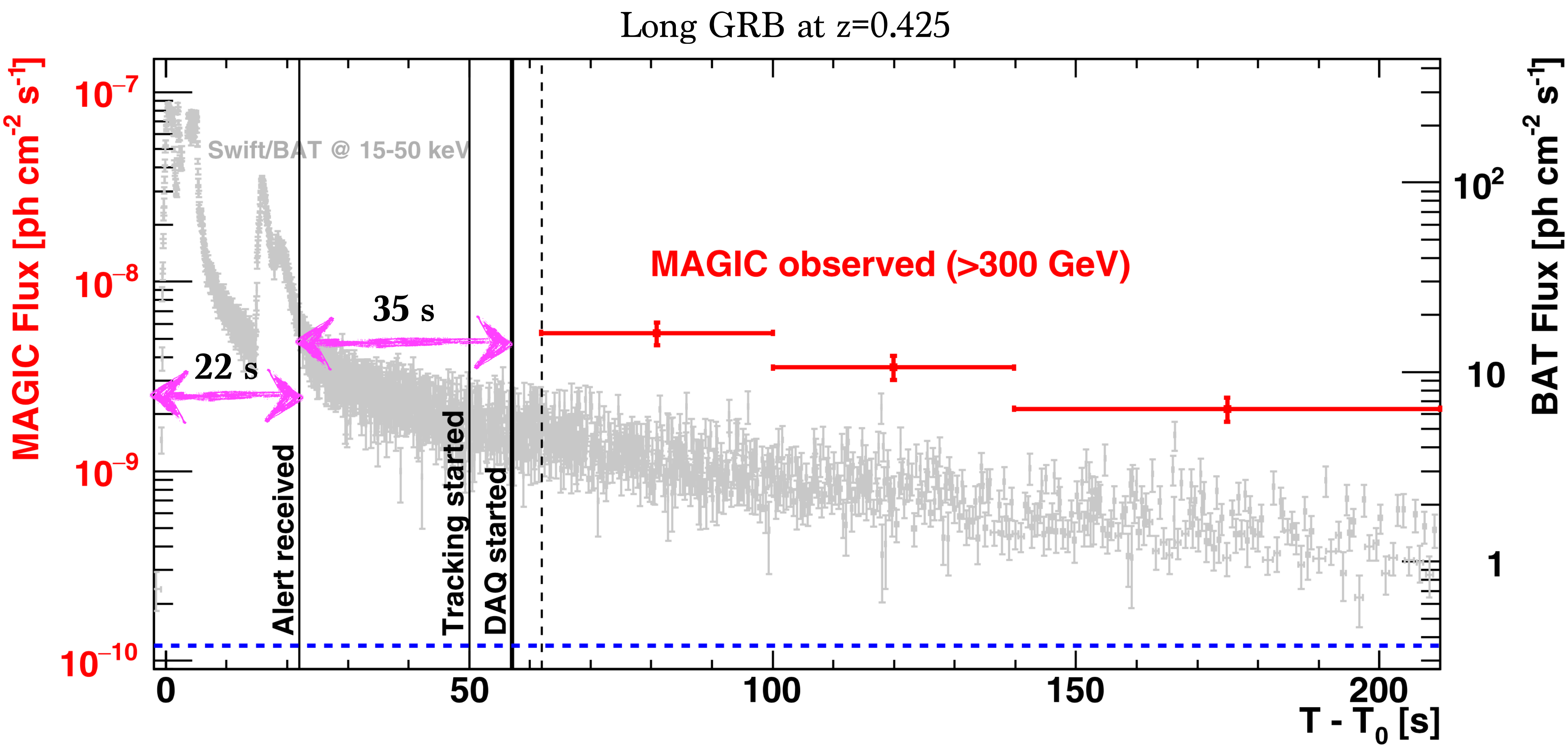
4707 Accesses | **758** Altmetric | Metrics

Abstract

Long-duration γ-ray bursts (GRBs) originate from ultra-relativistic jets launched from the collapsing cores of dying massive stars. They are characterized by an initial phase of bright and highly variable radiation in the kiloelectronvolt-to-megaelectronvolt band, which is probably produced within the jet and lasts from milliseconds to minutes, known as the prompt emission[1,2]. Subsequently, the interaction of the jet with the surrounding medium generates shock waves that are responsible for the afterglow emission, which lasts from days to months and occurs over a broad energy range from the radio to the gigaelectronvolt bands[1,2,3,4,5,6]. The afterglow emission is generally well explained as synchrotron radiation emitted by electrons accelerated by the external shock[7,8,9]. Recently, intense long-lasting emission between 0.2 and 1 teraelectronvolts was observed from GRB 190114C[10,11]. Here we report

MAGIC discovery paper: received 10 May 2019, accepted 2 September 2019

GRB 190114C

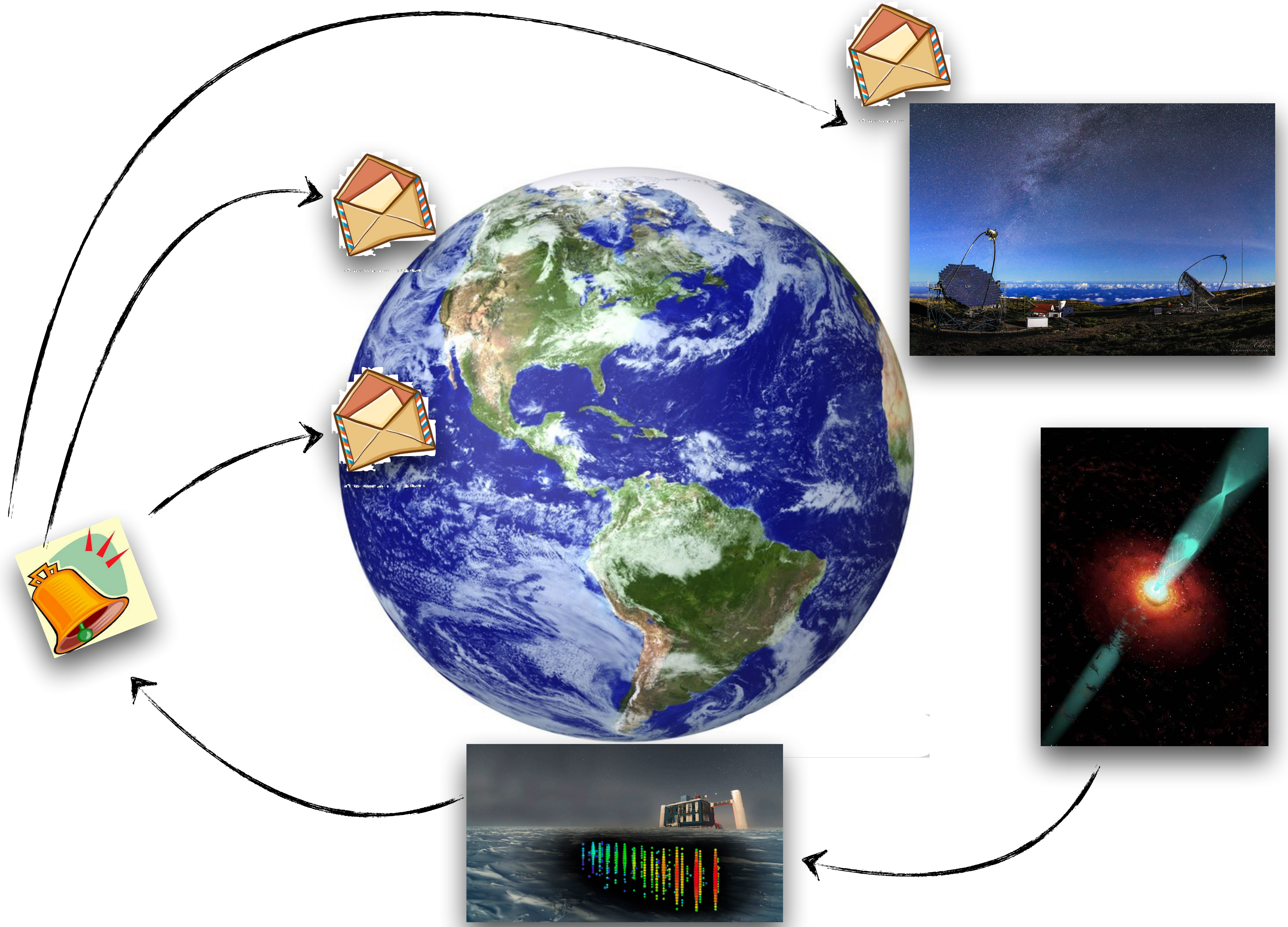


In the first 30 seconds of observation, GRB190114C was the brightest source to date at 0.3 TeV, with flux about 100 times higher than the one from the Crab Nebula.

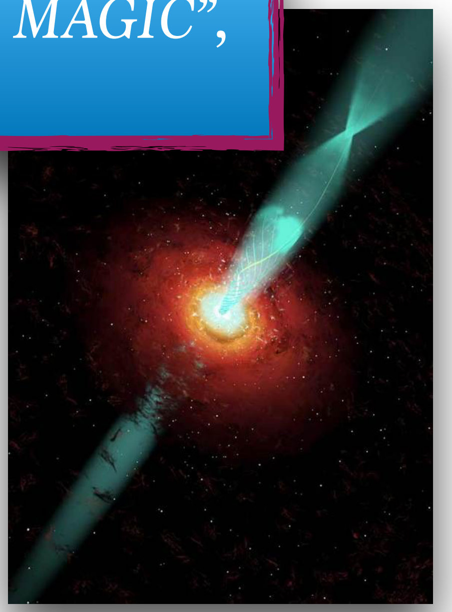
Results possible thanks to real-time multiwavelength work!

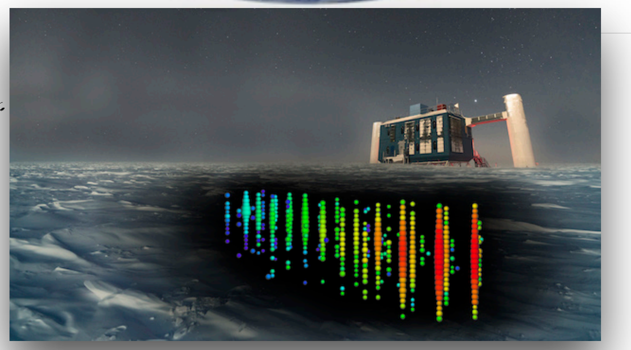
Same concept extends to multimessenger field.

Neutrino counterpart searches



Very first seed of synergic work started more than 10 years ago:
“Neutrino Triggered Target of Opportunity (NToO) test run with AMANDA-II and MAGIC”,
E. Bernardini, et al. ICRC2007 (arXiv:0711.0353)





Neutrino counterpart searches

public

- Follow-up of high-energy neutrinos from IceCube, now classified as gold/ bronze alerts

private

- Follow-up of neutrino clusters from IceCube (catalogue-based + all-sky). Specific programs aimed at gamma-ray and optical telescopes.

MoU with Imaging Air Cherenkov Telescopes

Most of this real-time infrastructure has been developed for **Gamma-ray Follow-up** (GFU) pioneered by the collaboration with MAGIC.

2019 news from MAGIC

- Follow-up of 6 alerts for a total about 15 hours of observations
- The MAGIC Automatic Alert System is optimised and works for automatically repointing to gold alerts.

See T. Kintscher's talk (tomorrow) for more info from IceCube side

Neutrino counterpart searches

public

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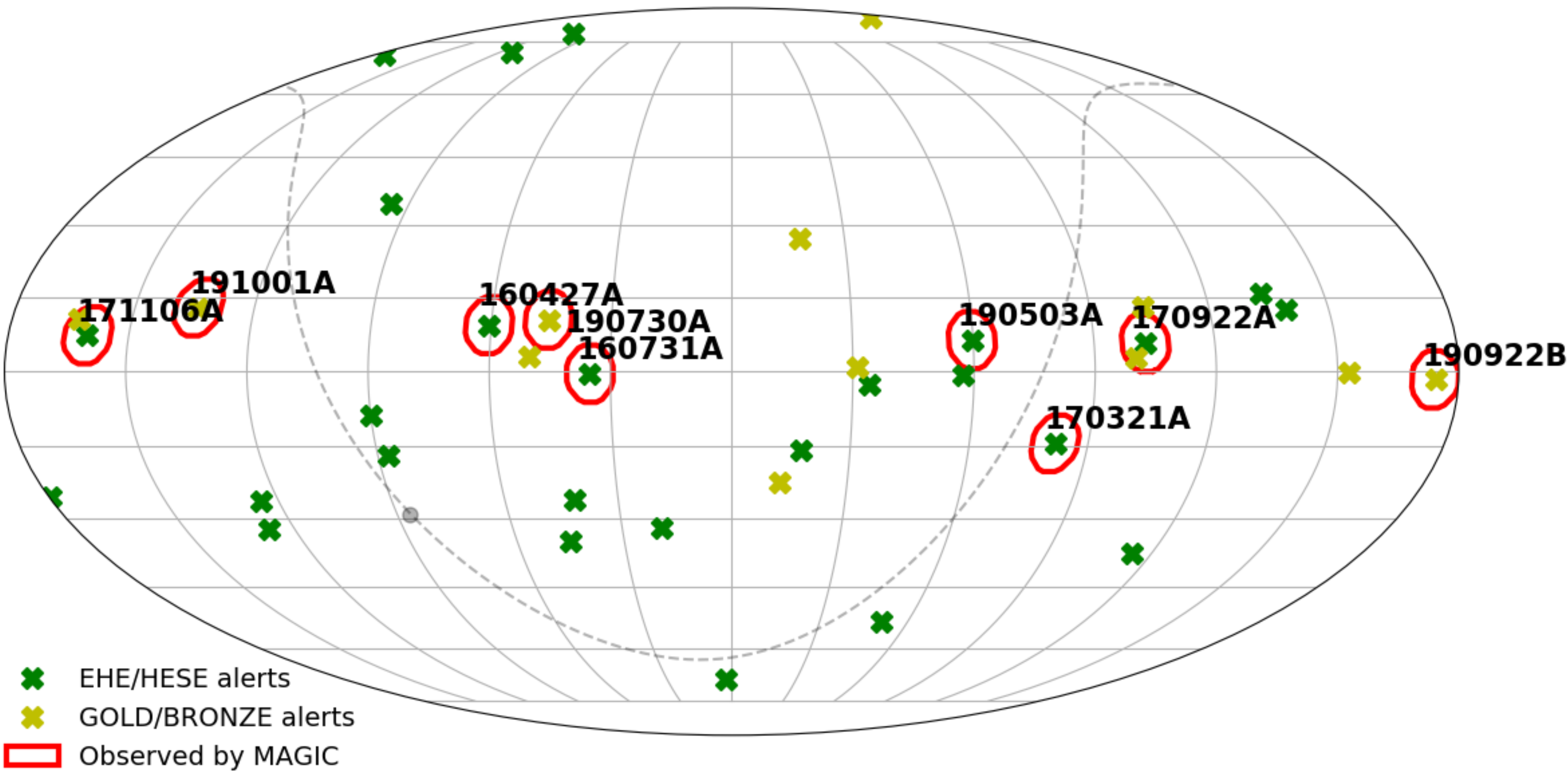
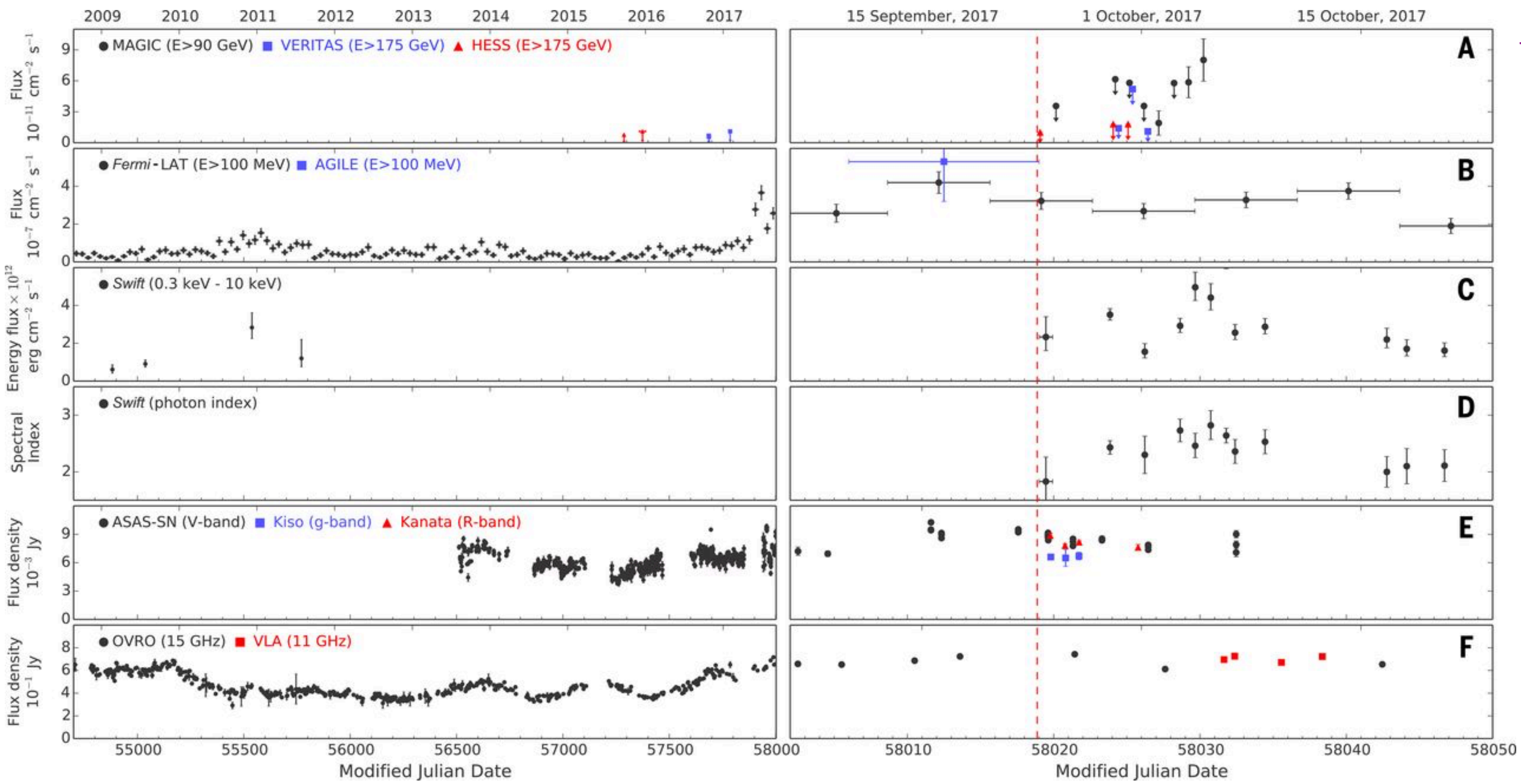


Credit: A. Fattorini

IC170922A - TXS0506+056

Thanks to real-time work and synergic work: first association!

IC-170922A



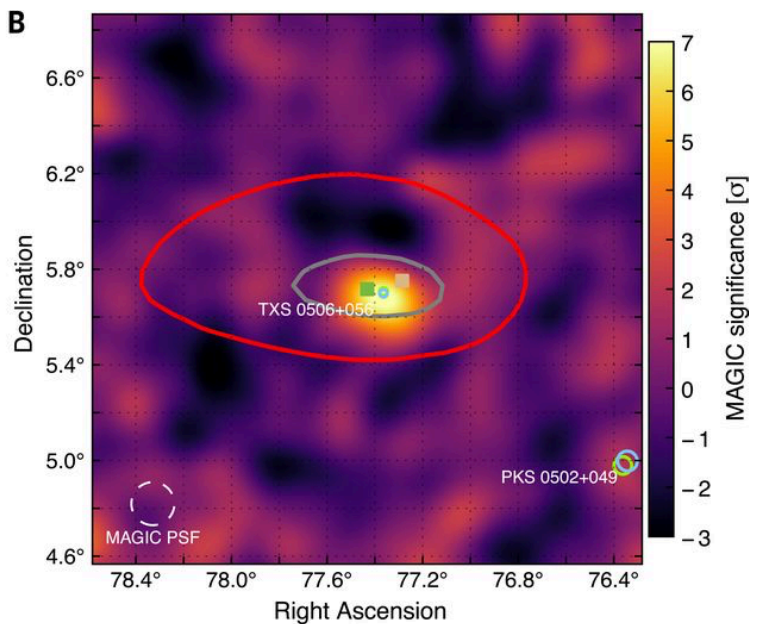
VHE γ rays: MAGIC discovery
Day-scale variability

HE γ rays: flare

X-ray: day-scale variability

Optical: enhanced emission

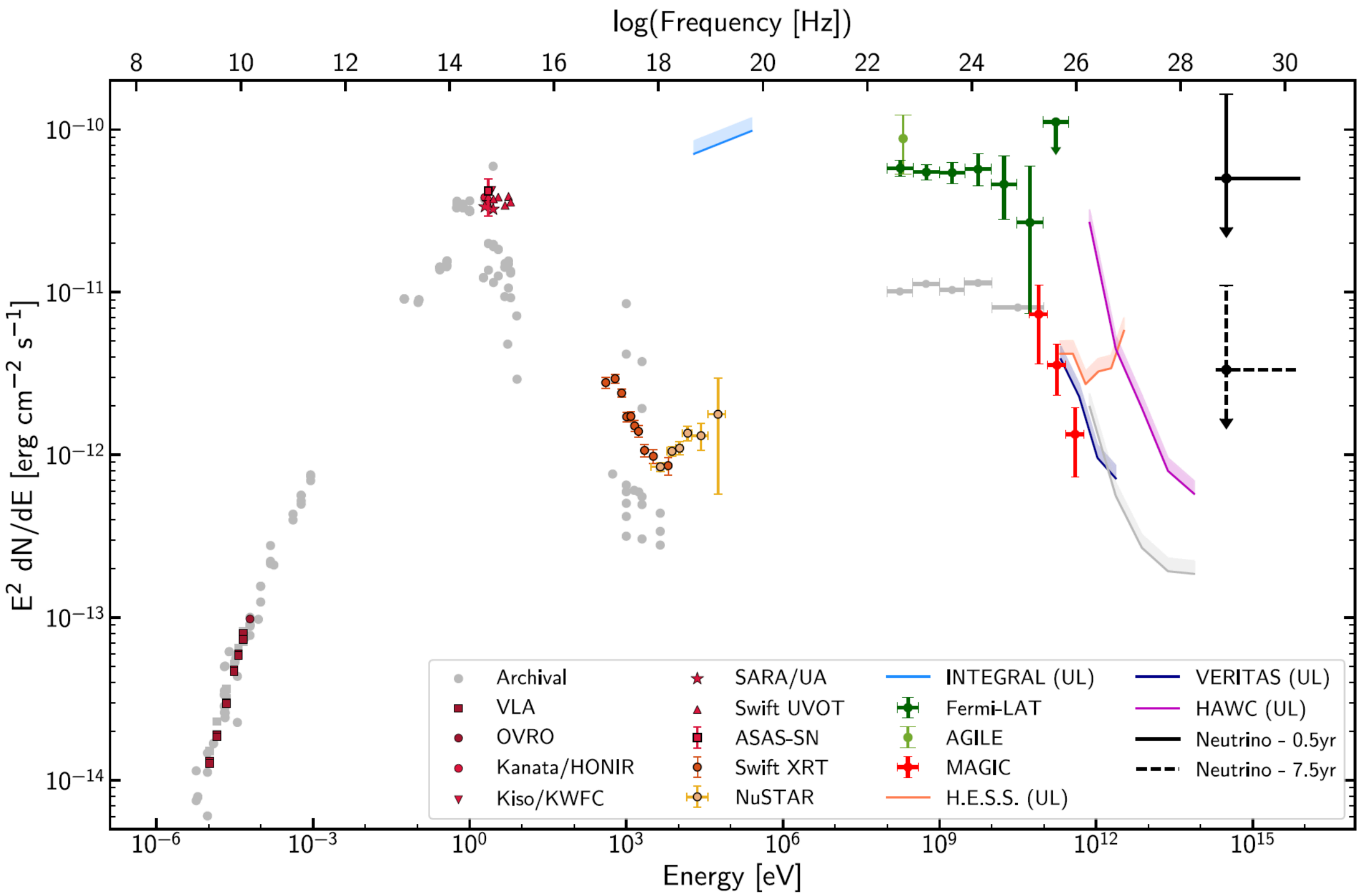
Radio: enhanced emission



IC+Fermi+MAGIC+++, Science 361, 146 (2018)

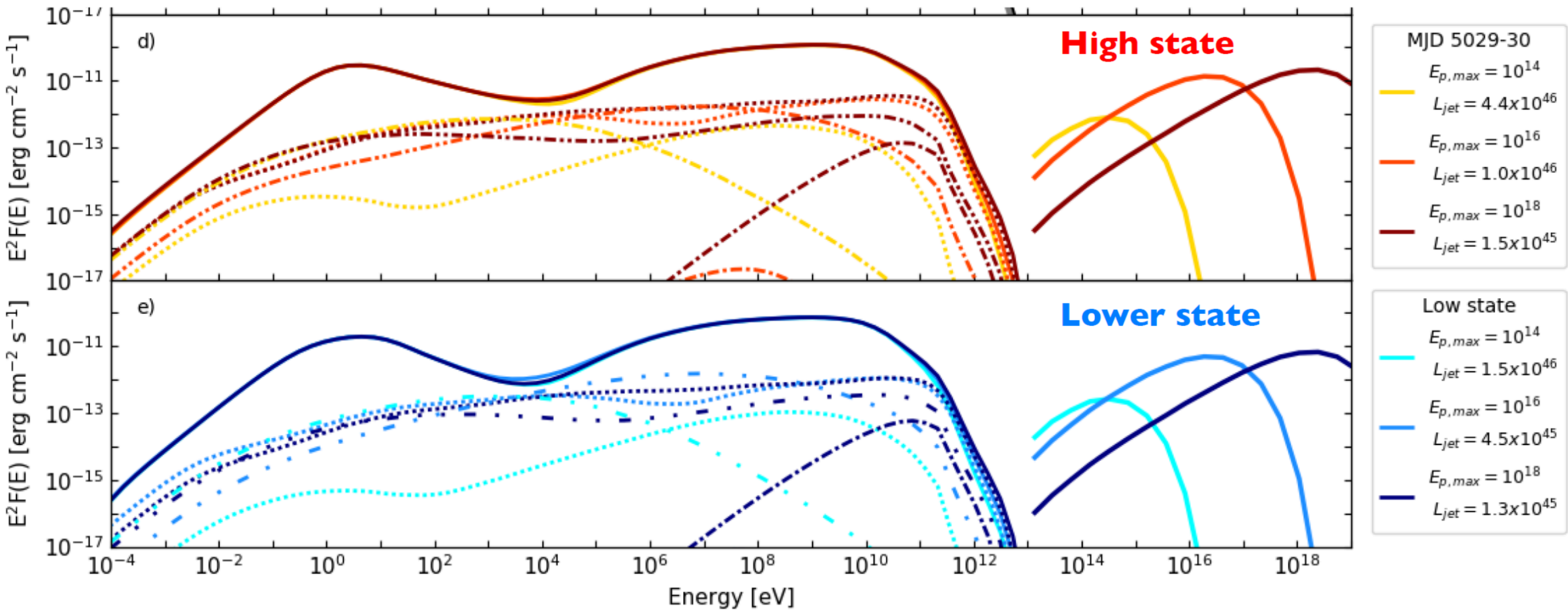
Association by chance coincidence
excluded at 3 sigma C.L.

IC170922A - TXS0506+056



First multimessenger spectral energy distribution

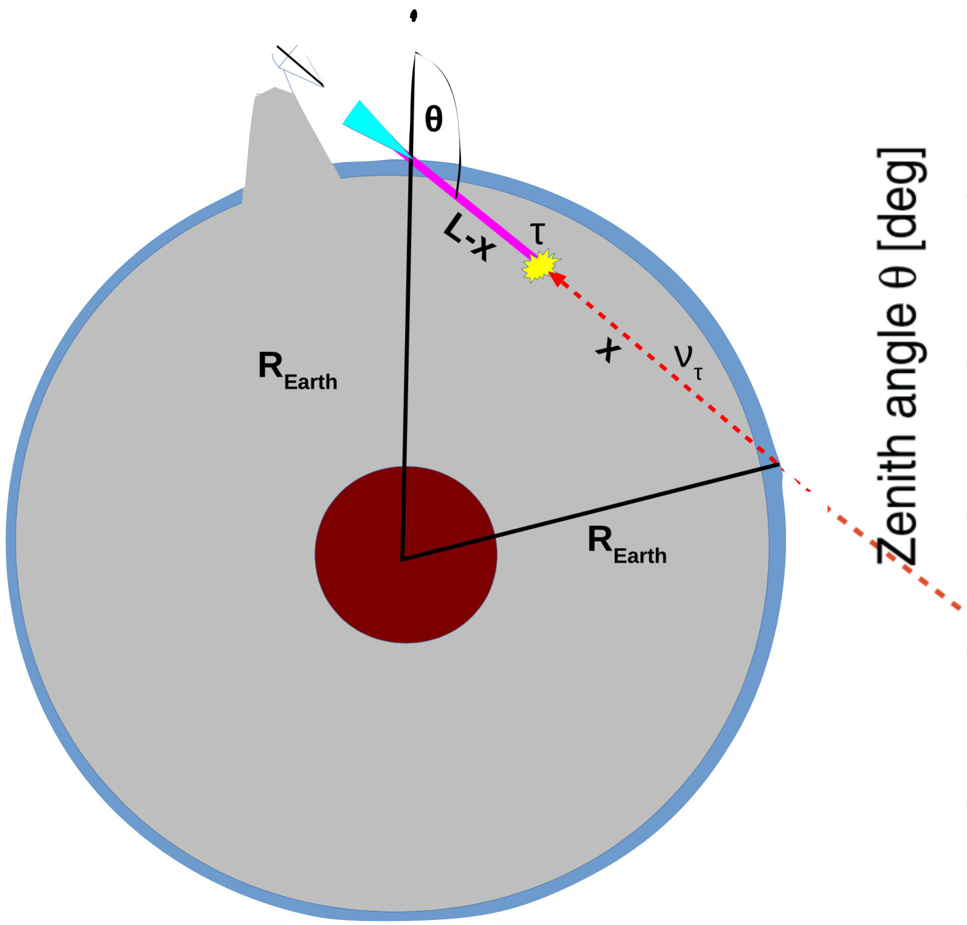
Probing the production of UHECRs

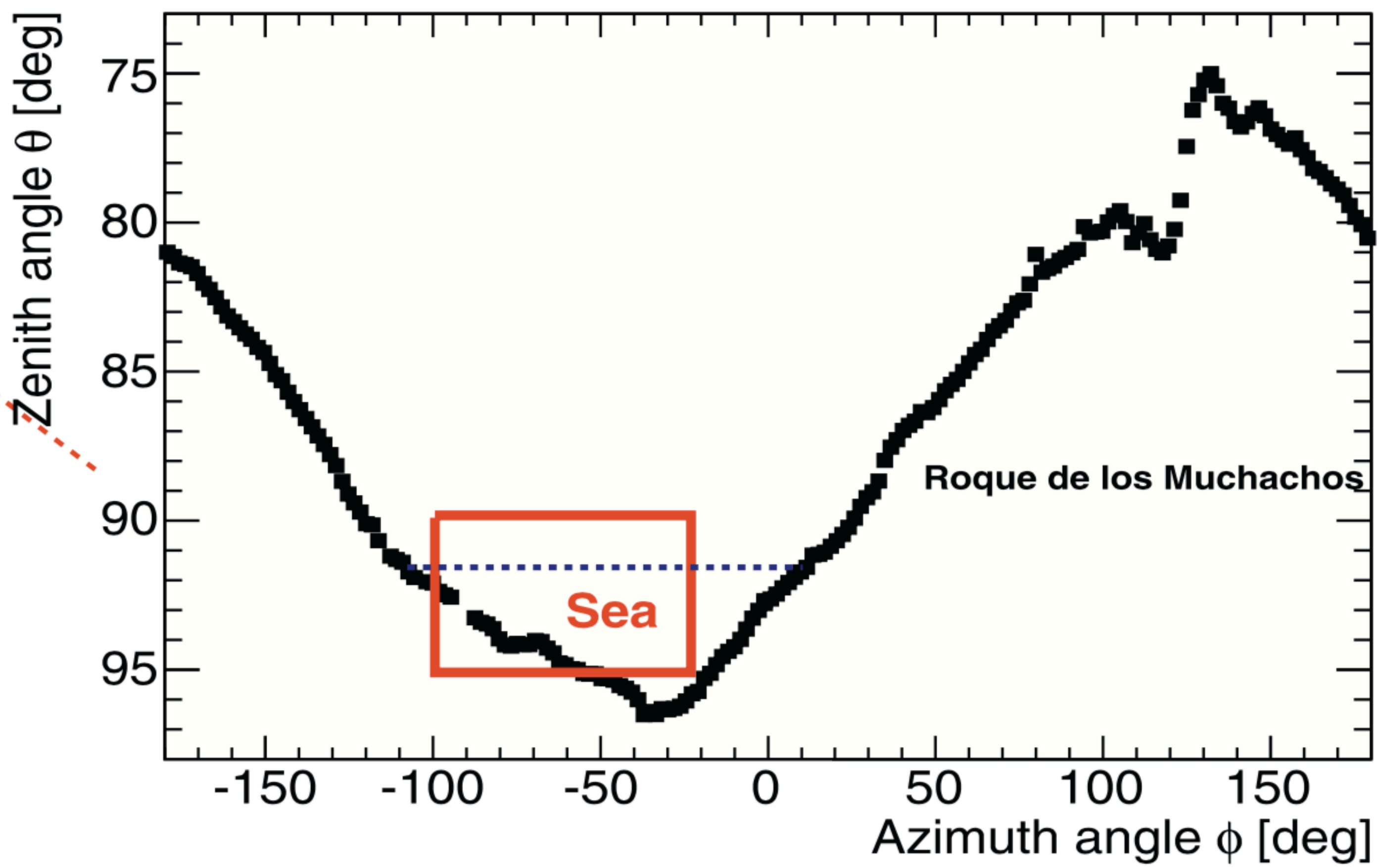


MAGIC, ApJL 863 (2018) L10

Neutrino searches: MAGIC as a neutrino detector

Earth-skimming technique for the detection of high-energy τ-neutrinos





MAGIC can observe τ-lepton showers deriving from PeV-EeV τ-neutrinos

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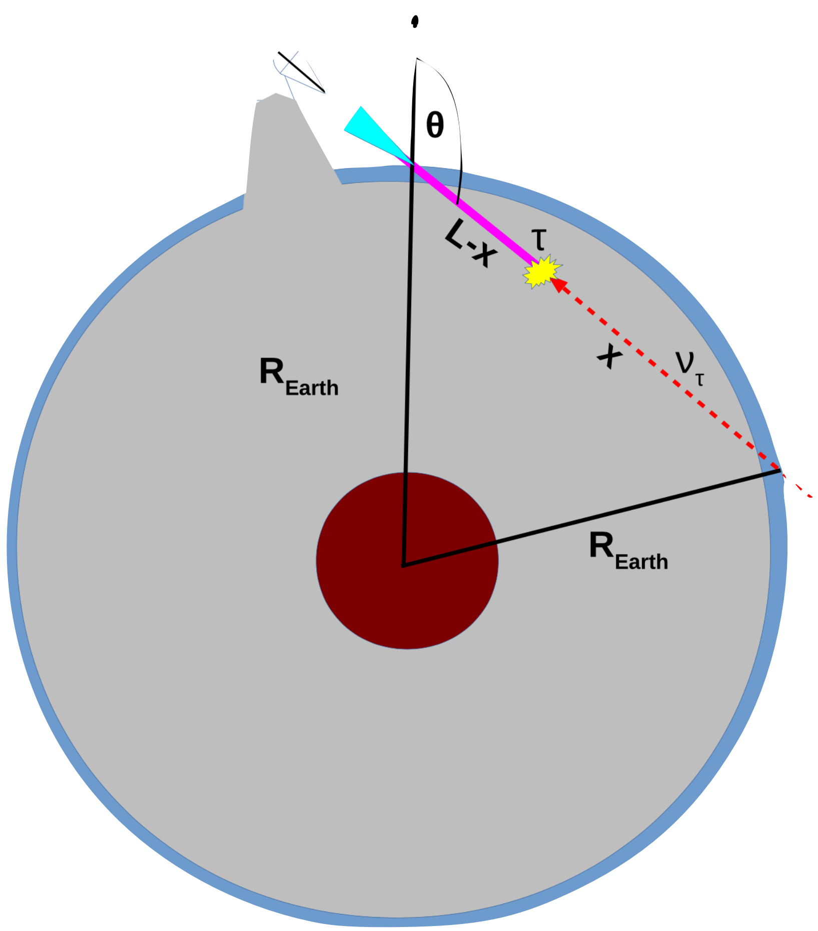

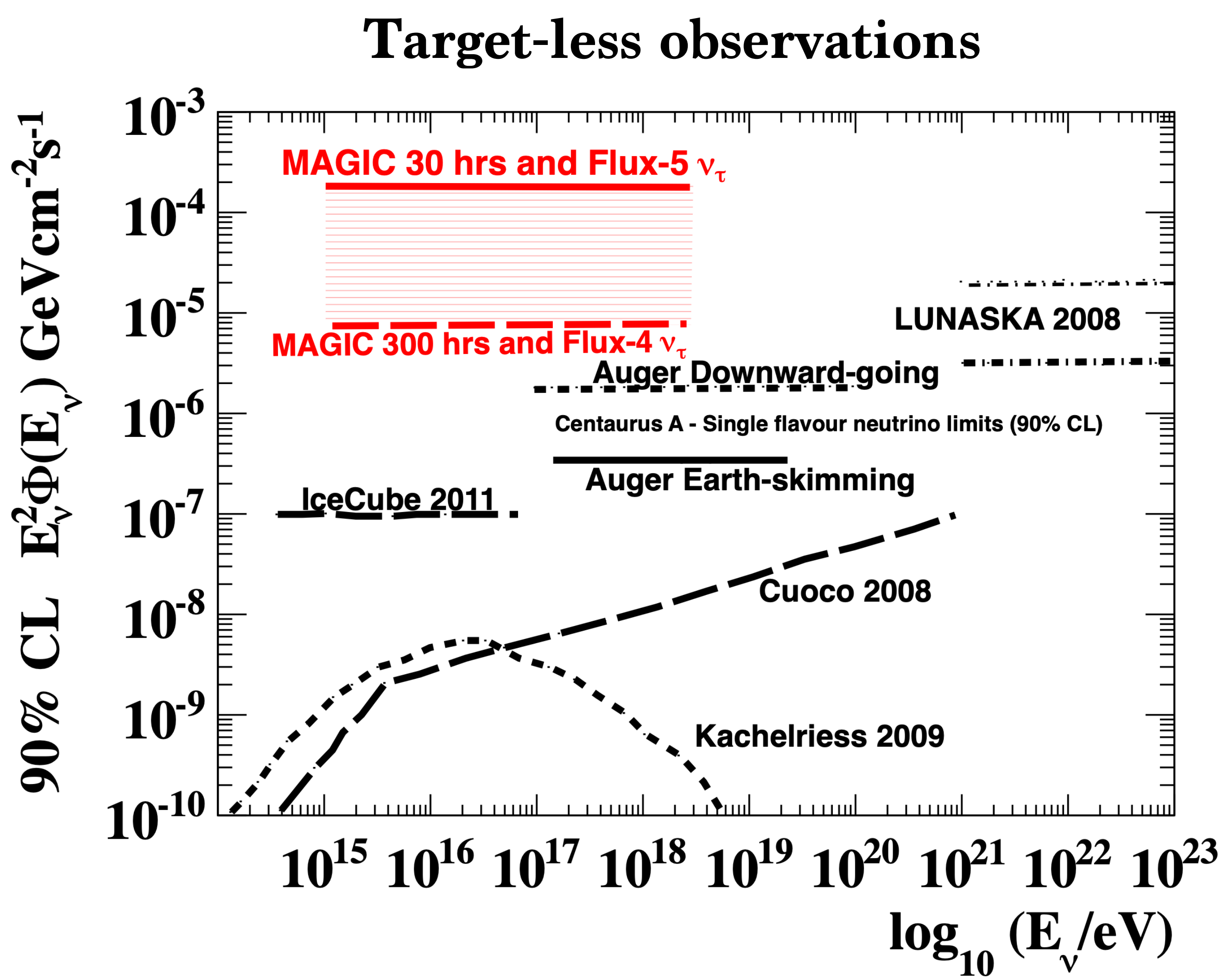

MAGIC, Astropart. Phys. 102 (2018) 77

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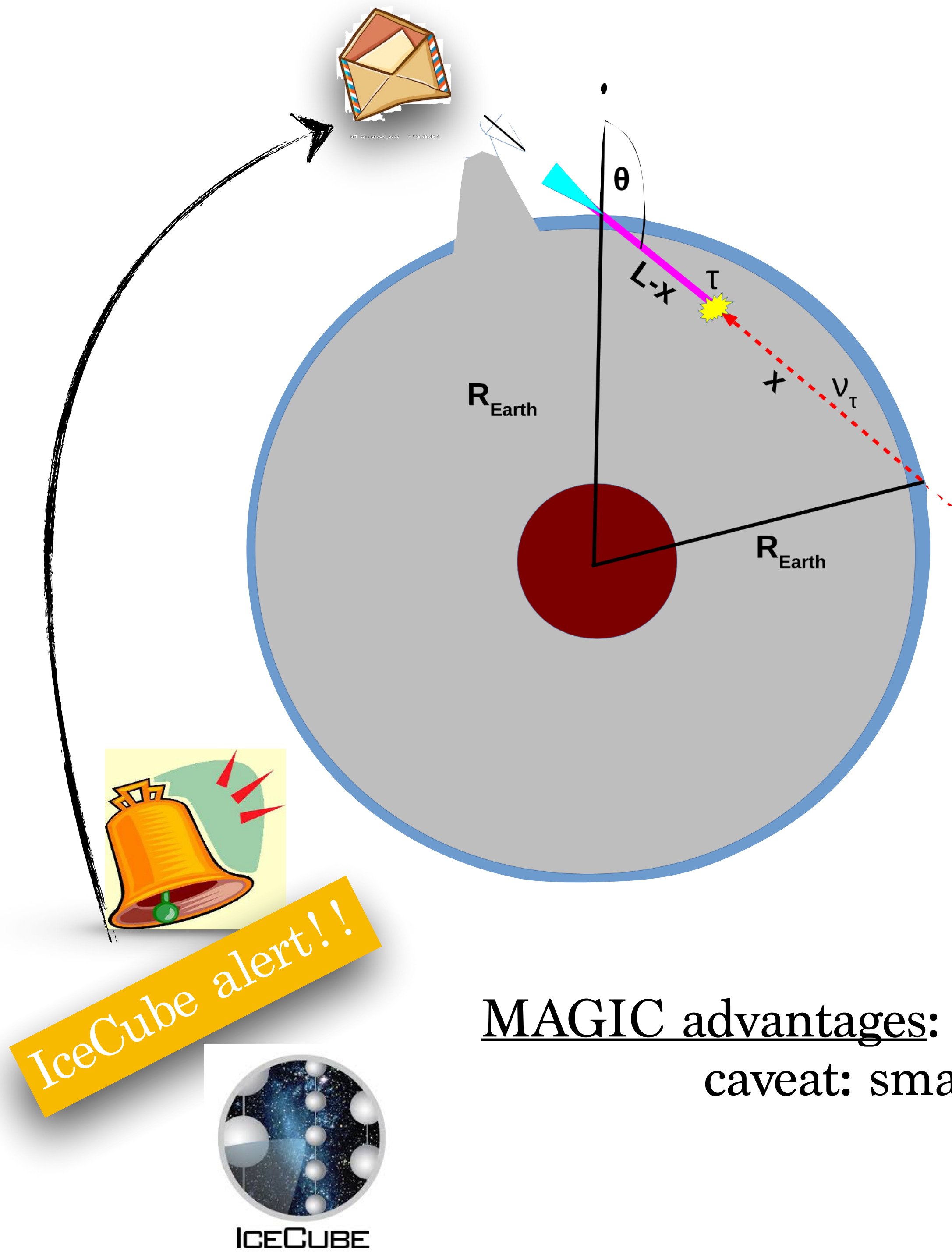
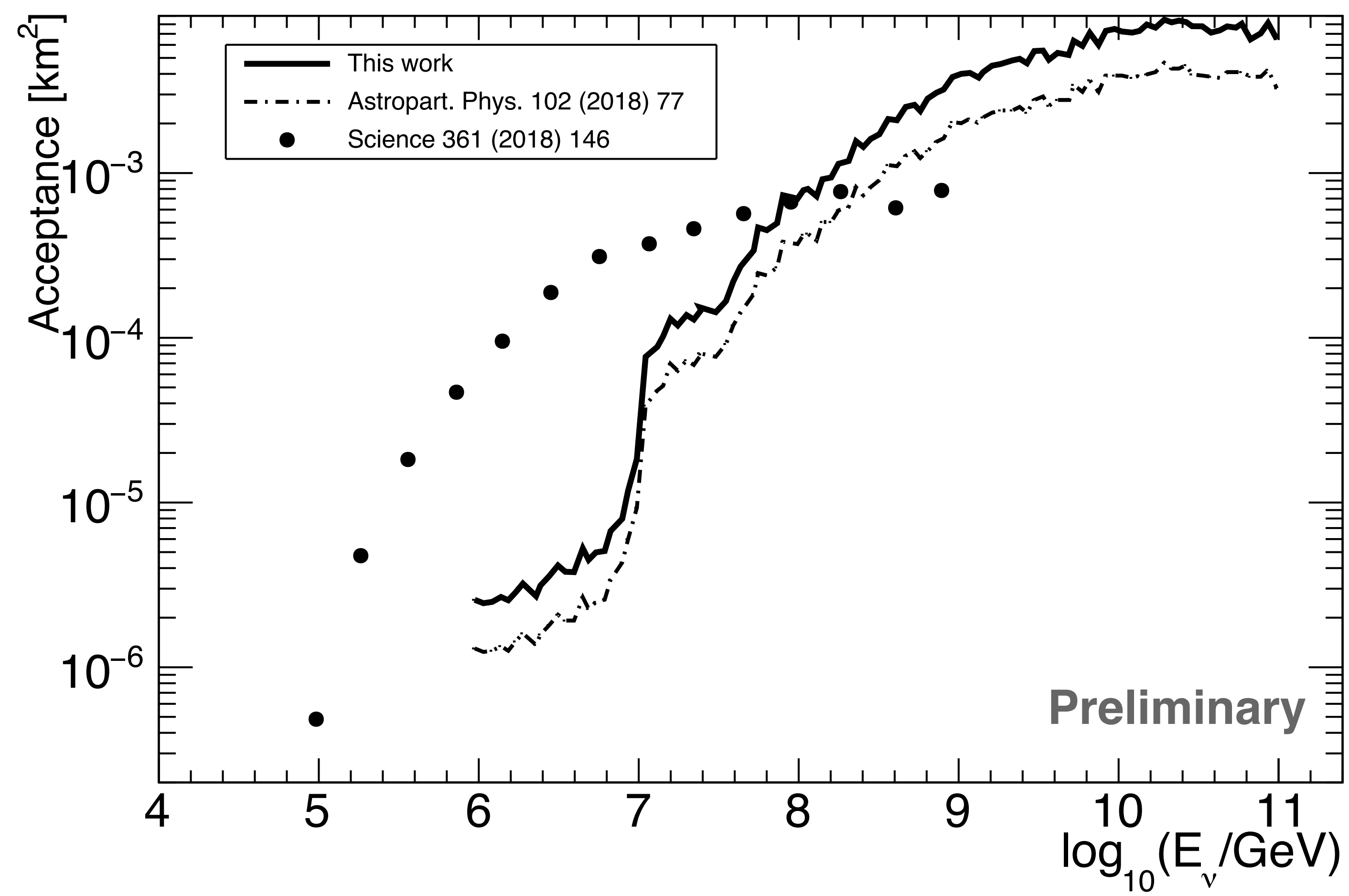


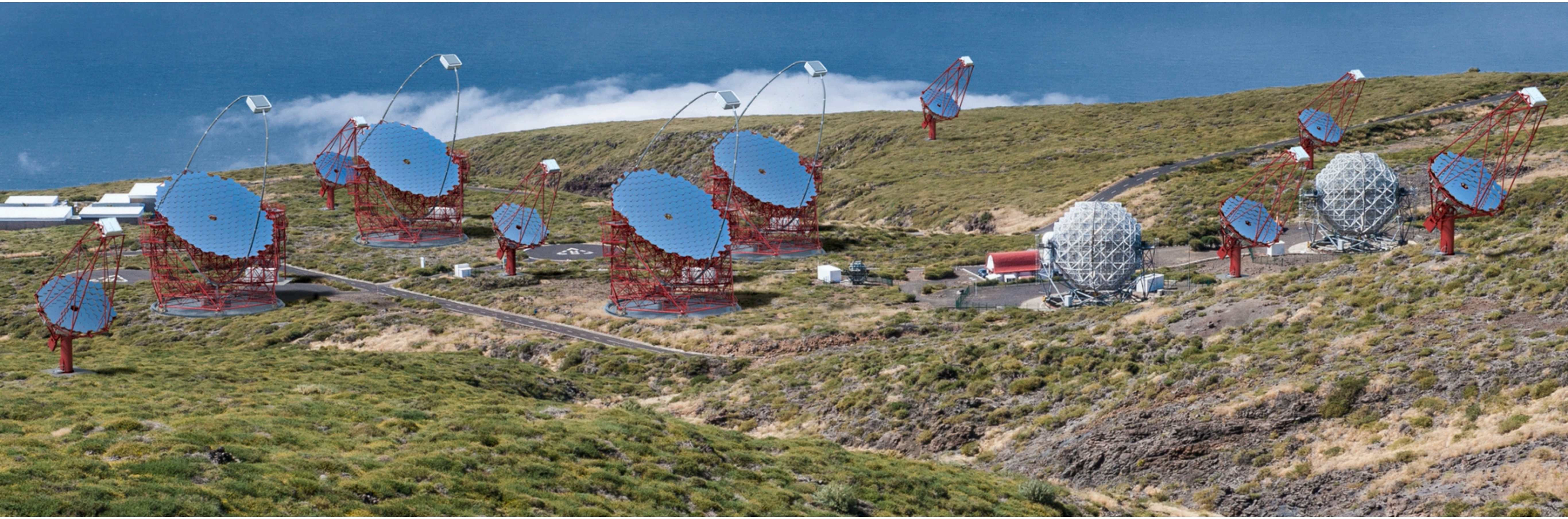
M. M. et al. for MAGIC,PoS(ICRC2019)953



MAGIC advantages: the best sensitivity starting from 100 PeV;
caveat: small FoV, limited observation time

Searches triggered by dedicated observatories have a high discovery potential

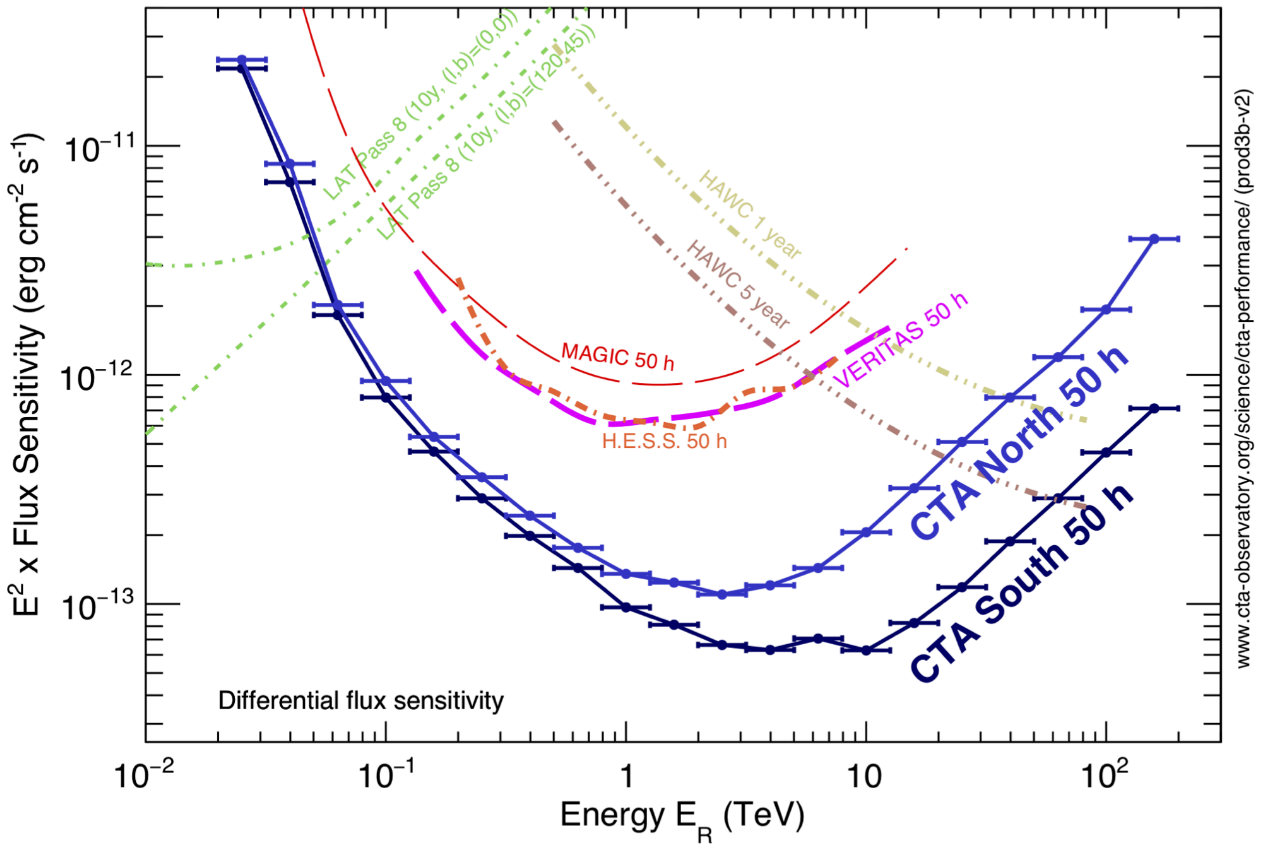
What next? The Cherenkov Telescope Array



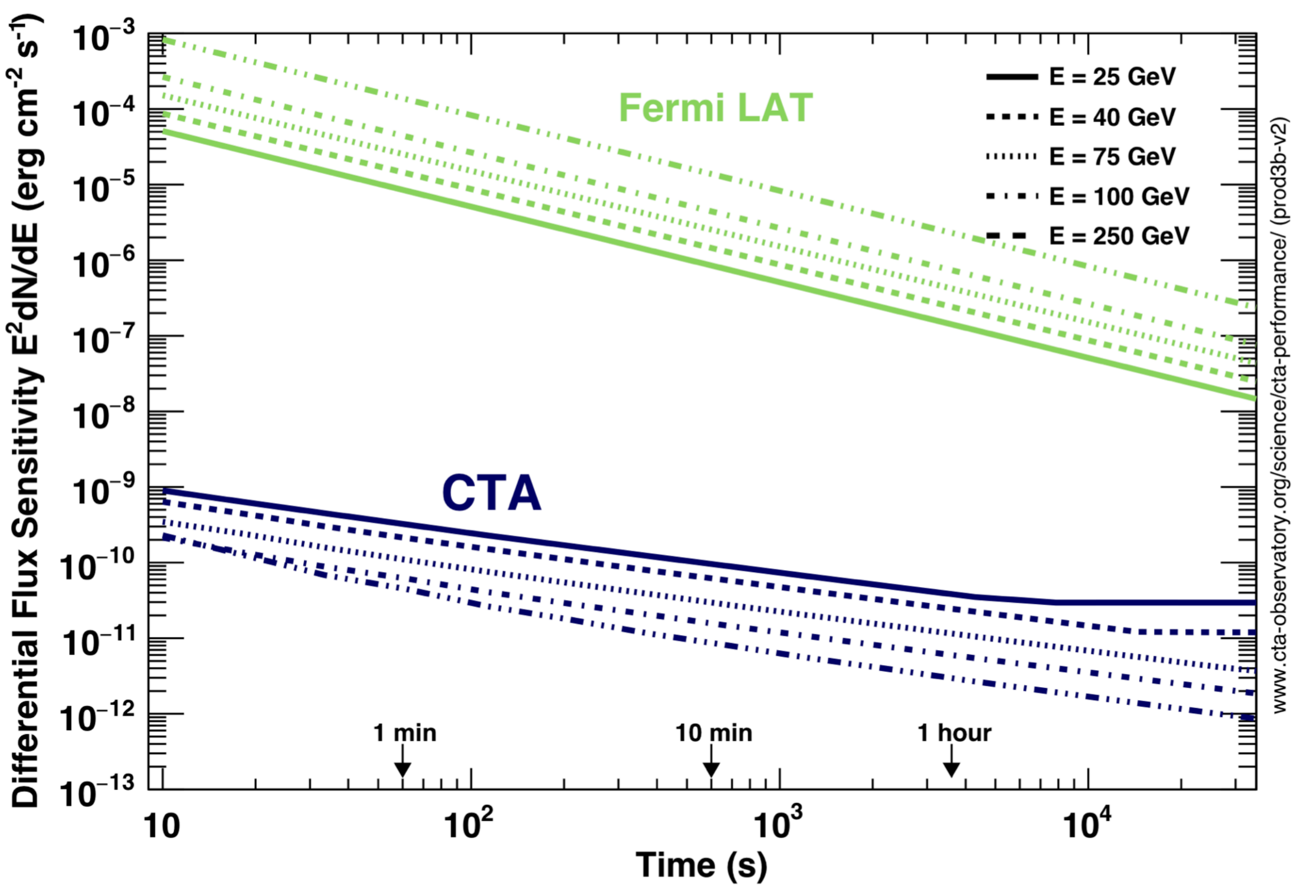
Array of telescopes of 3 different sizes:

- Large-Sized (24 m)
- Medium-Sized (12 m)
- Small-Sized (4 m)

What next? The Cherenkov Telescope Array



- Improvement in sensitivity of a factor of 10
- Ideal also for observations of transient phenomena



Transient Key Science Program with CTA

		Observation times (h yr^{-1} $site^{-1}$)		
Priority	Target class	Early phase	Years 1–2	Years 3–10
1	GW transients	20	5	5
2	HE neutrino transients	20	5	5
3	Serendipitous detections	100	25	25
4	GRBs	50	50	50
5	MWL transients	50	10	10
6	Galactic	150	30	0
Prel. total observation time		390	125	95

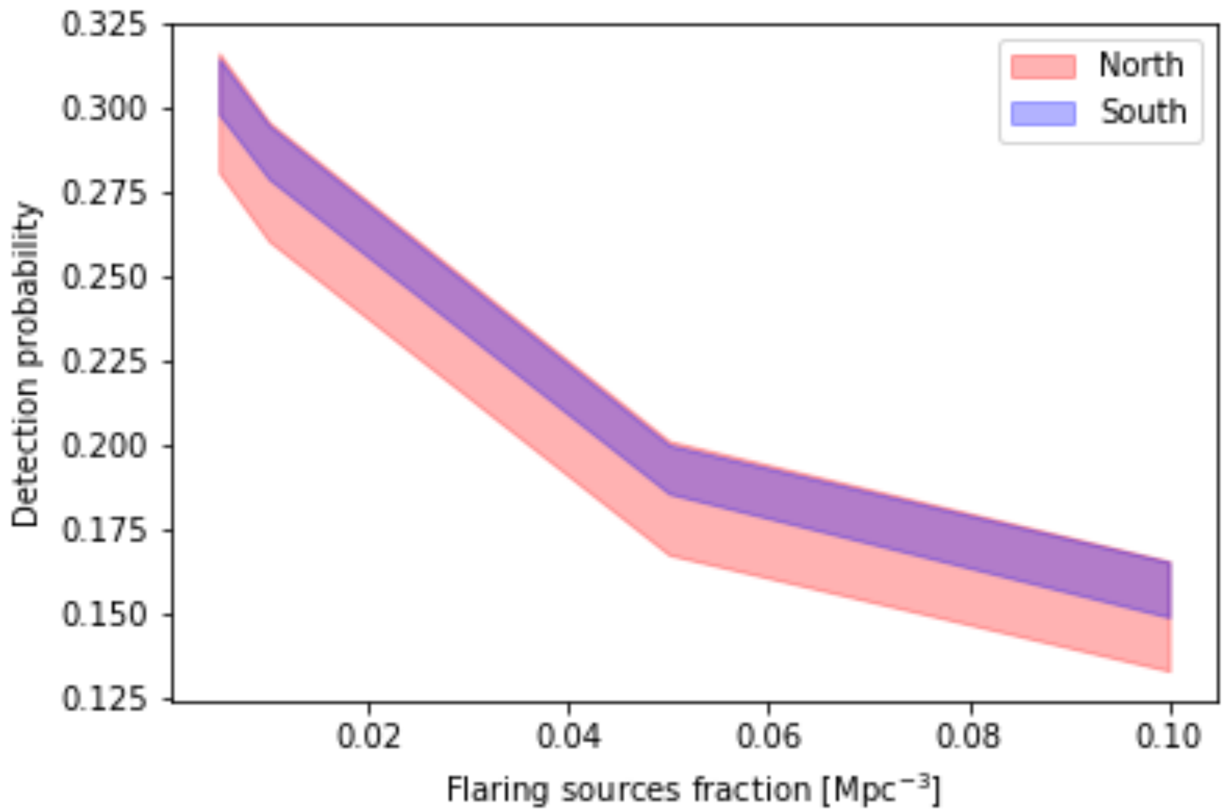
F. Schüssler for the CTA consortium, PoS(ICRC2019)788

Work ongoing to derive optimal follow-up strategies and the potential science reach of the NToO program for CTA.

Neutrino Target of Opportunity with CTA

FIRESONG: software used to simulate neutrino source populations which could be responsible for the diffuse neutrino flux measured by IceCube

- Population of TXS-like flaring sources (model from Halzen et al., ApJL 874 (2019) 1)
- **Absorption from extragalactic background light + Instrument Response Functions** from CTA to calculate, if the source is detectable in gamma-rays.
- Criteria for detection: excess significance > 5σ



K. Satalecka et al., for the CTA consortium
PoS(ICRC2019)784

CTA has a 30% chance of detection, assuming that 50% of IceCube alert corresponds to real sources and that all of them are observable by CTA

Final remarks

MAGIC is currently very **well prepared for transients follow-up**, thanks to the hardware, software and technological solutions adopted for this purpose.

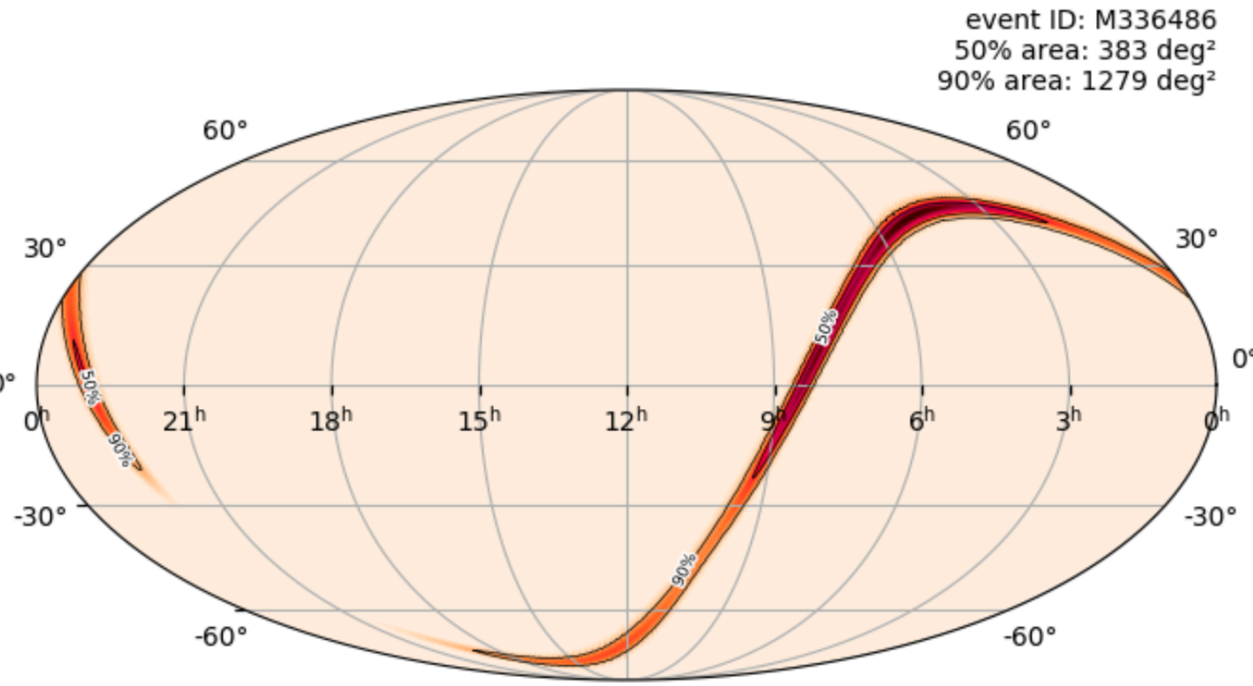
We build and we are going to build **bigger detectors on both Earth hemispheres** for more statistics, for a larger energy coverage, for a full sky coverage.

More and more **real-time work needed:** collaboration among interested partners. Multimessenger work starts from here!

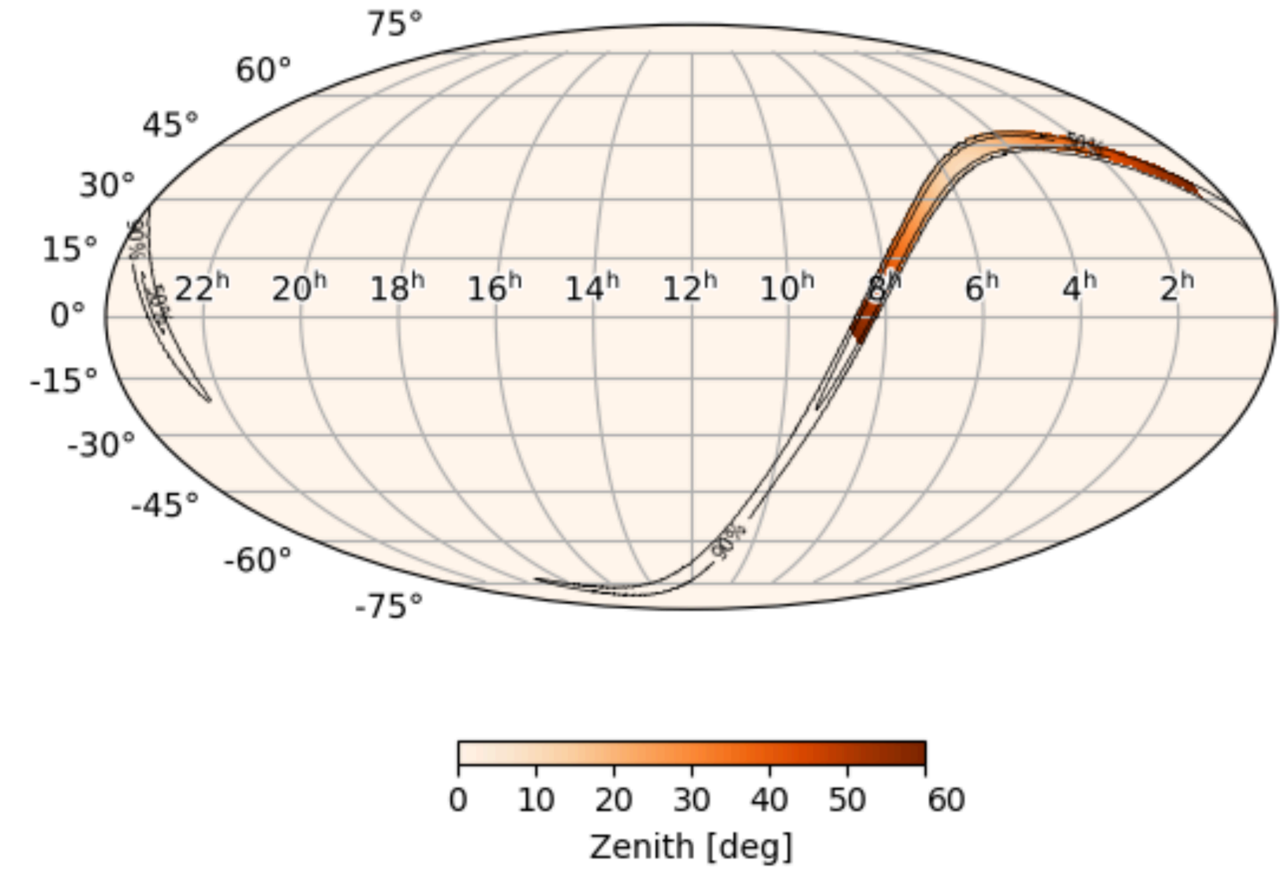
Puzzle on UHECRs still there: multimessenger data interpretation offers a unique opportunity for solving fundamental questions about non-thermal Universe.

GW counterpart searches

MAGIC joined the LIGO/Virgo call for identification and follow-up of electromagnetic counterparts of gravitational wave candidate events in 2014.



D. Miceli et al., for MAGIC coll., ICRC2019



MAGIC advantages: fast slewing, the best sensitivity at E<100 GeV; caveat: small field of view.
Two possibilities:

- Automatic follow-up
- Follow-up of identified electromagnetic counterparts