Chasing Serendipity: Tackling Transient Sources with Neutrino Telescopes

arxiv:2505.24666/arxiv:2505.24652

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FAPESP
FUNDAÇÃO DE AMPARO À PESQUISA DO ESTADO DE SÃO PAULO

IFUSP
Instituto de Física da USP

First question of the audience

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What is serendipity?

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What is serendipity?

“The occurrence and development of events by chance in a happy or beneficial way.”

“An aptitude for making desirable discoveries by accident.”

Motivation: Multi Messenger astronomy

Photons + Neutrinos

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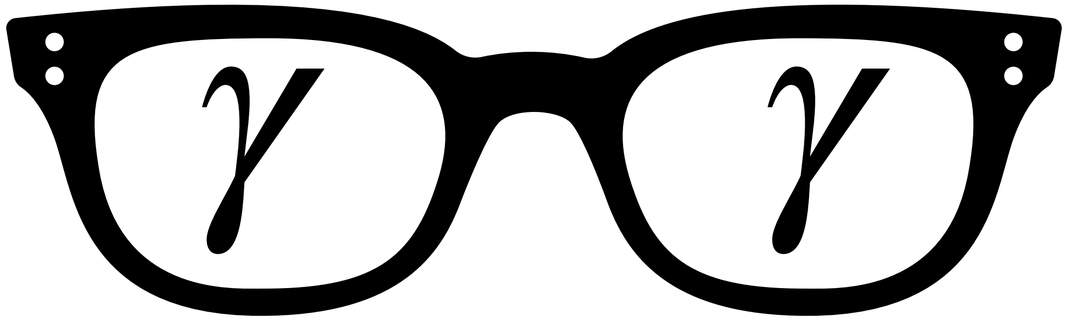
~~Photons +~~ Neutrinos

Can neutrinos be the only candidate for observing a source?

Probing the universe through photons



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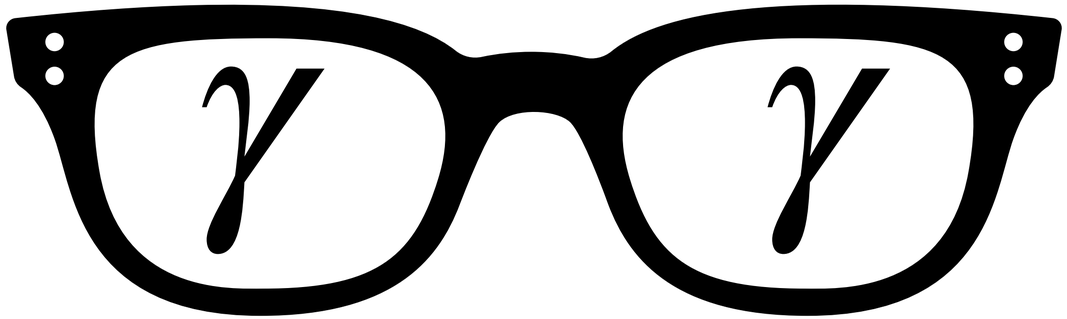
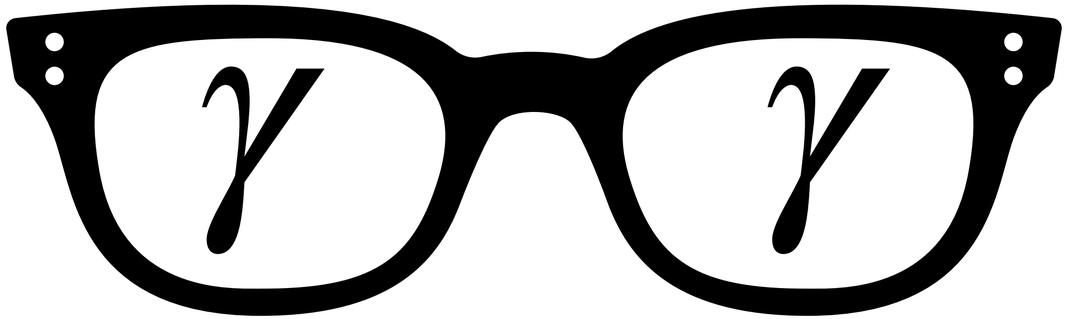


Key concepts:

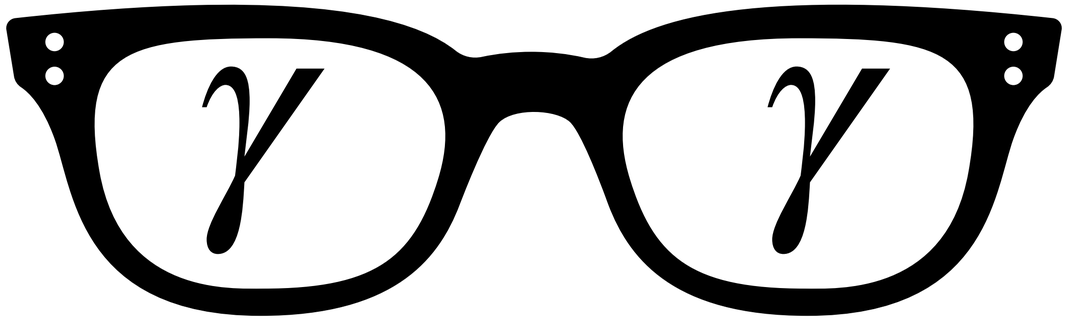
Probing the universe through photons



Key concepts:

- Field of view

Probing the universe through photons



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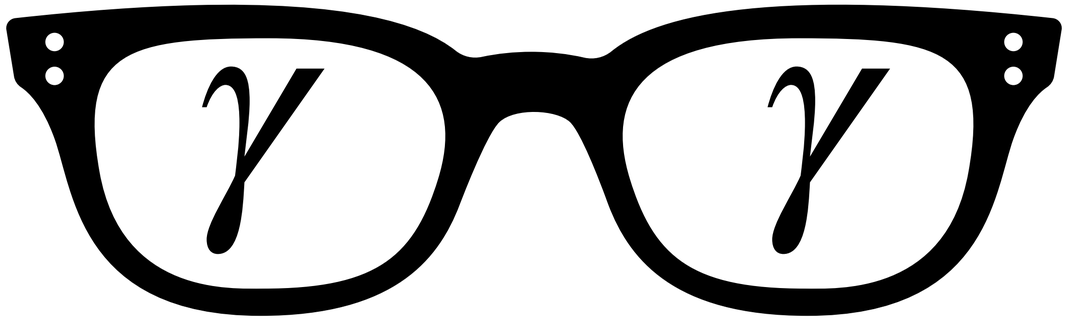


Key concepts:

- Field of view

- Coordinates

- Interactions

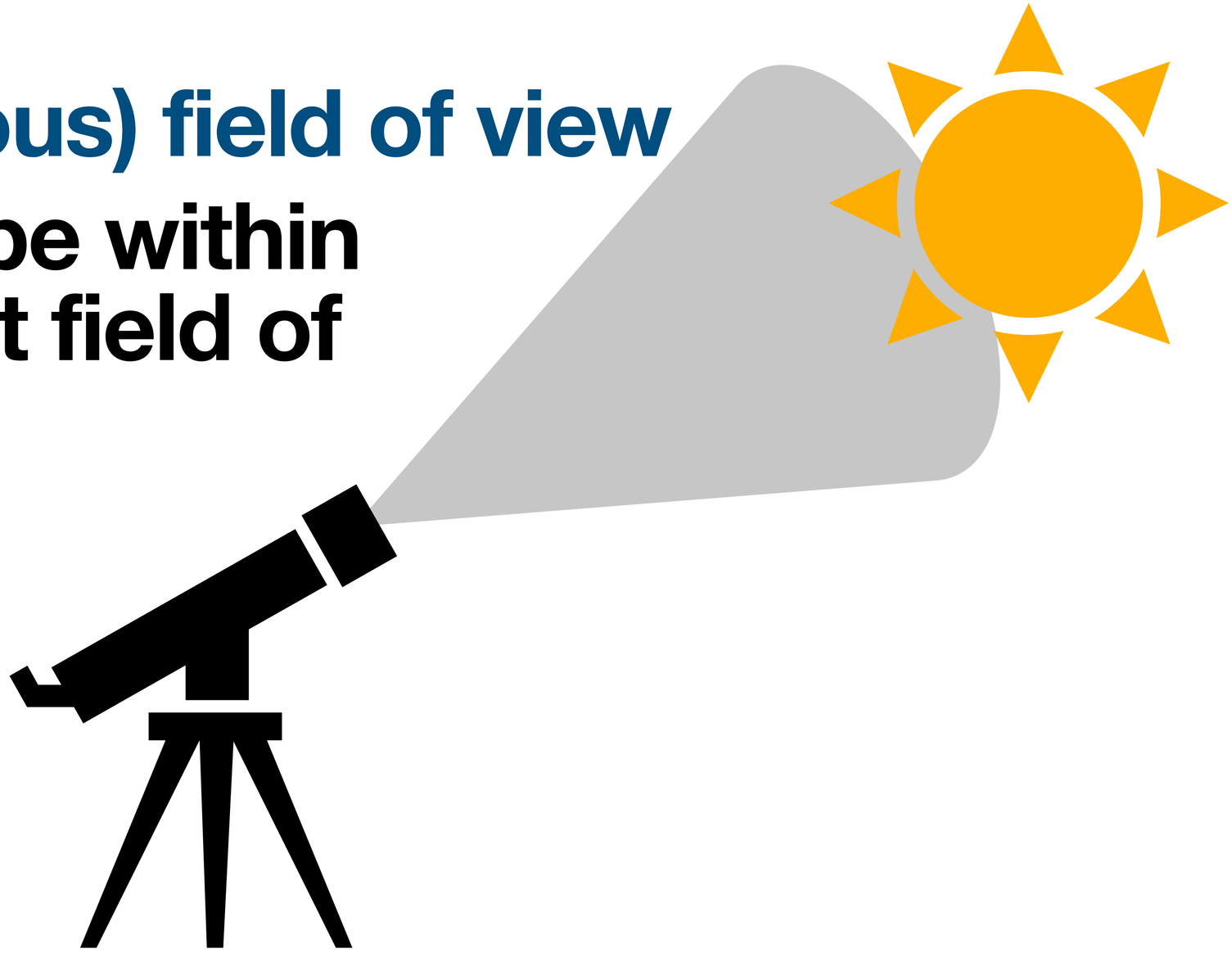
The field of view

The field of view

Portion of the sky the experiment monitors

The (instantaneous) field of view

A source may be within the experiment field of view



The (instantaneous) field of view

As Earth rotates this may change

Example: Gamma ray observatories

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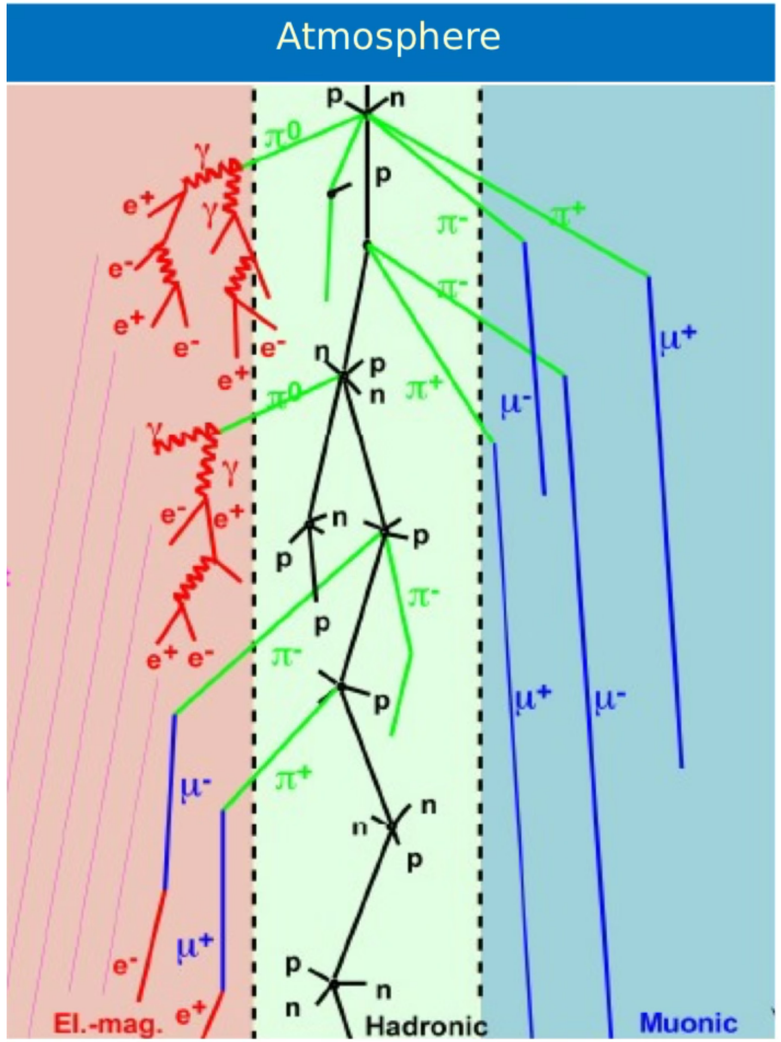
Working principle

Example: Gamma ray observatories

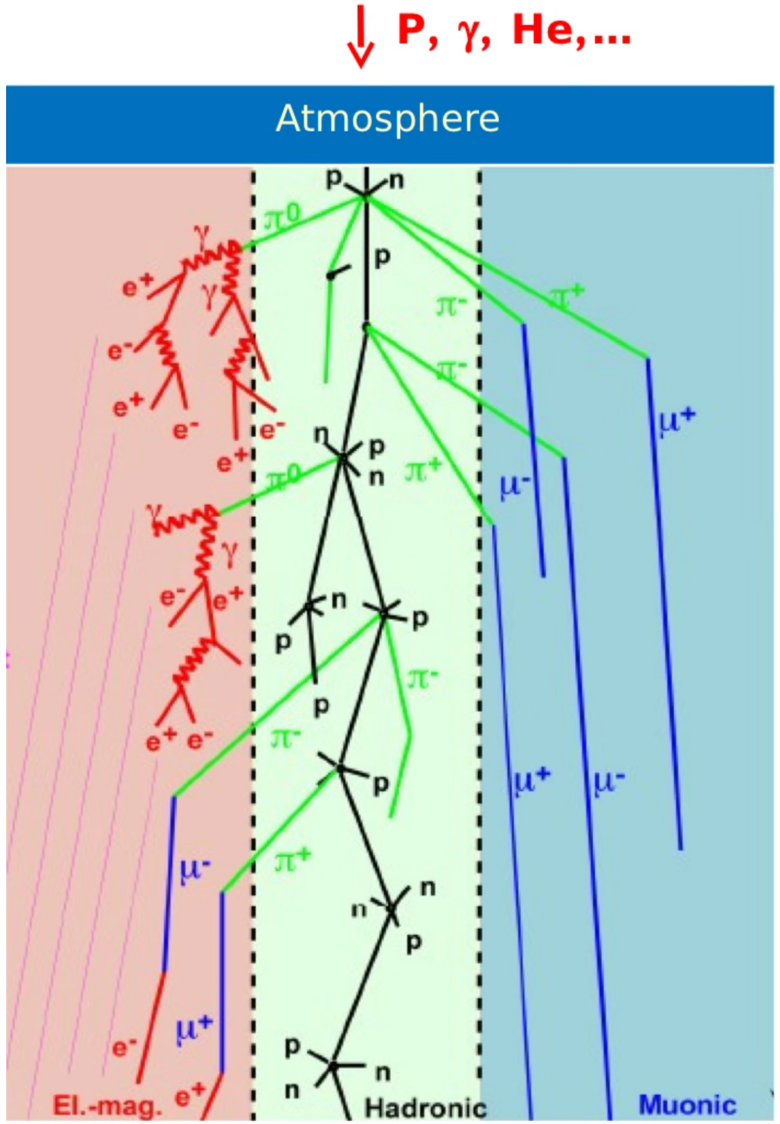
Working principle

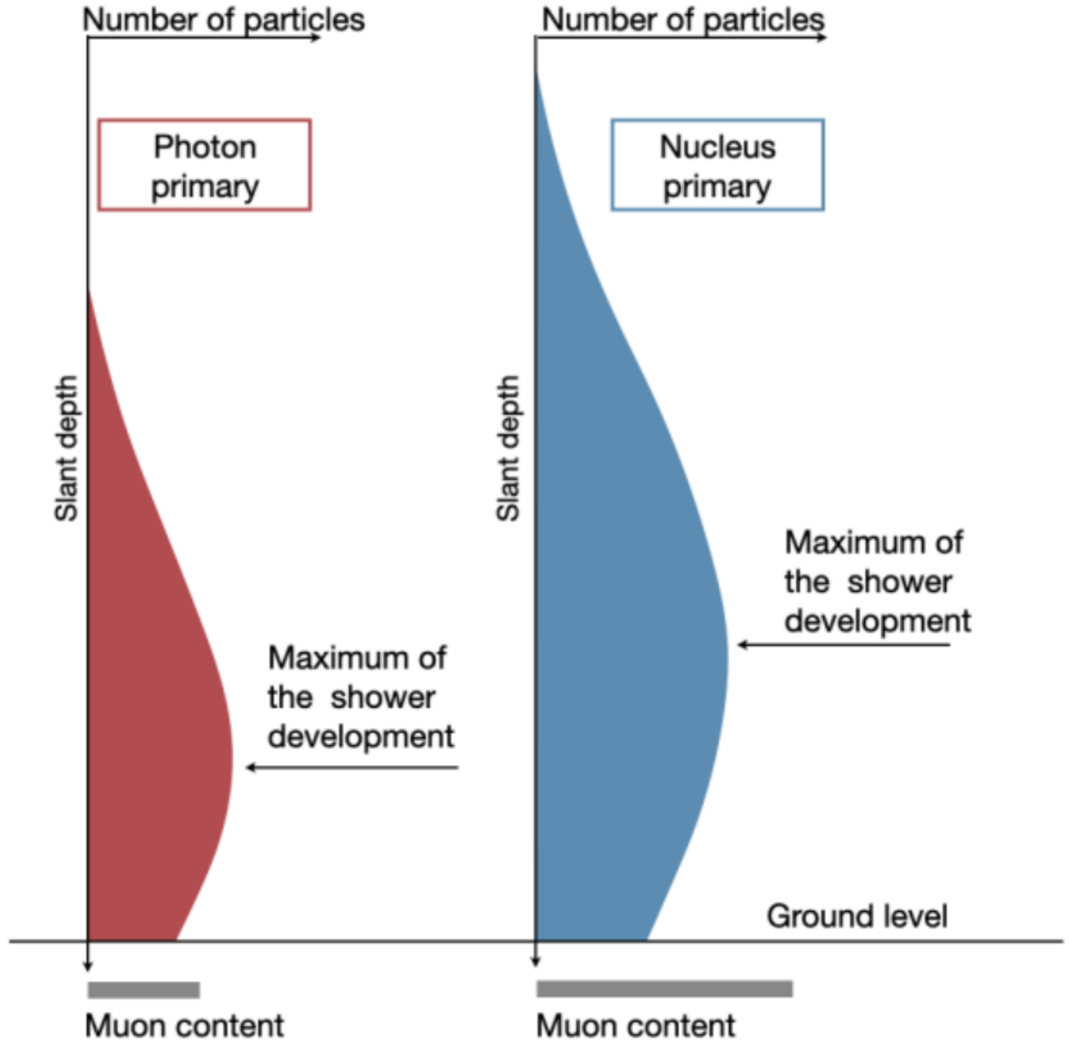
P, γ, He,...



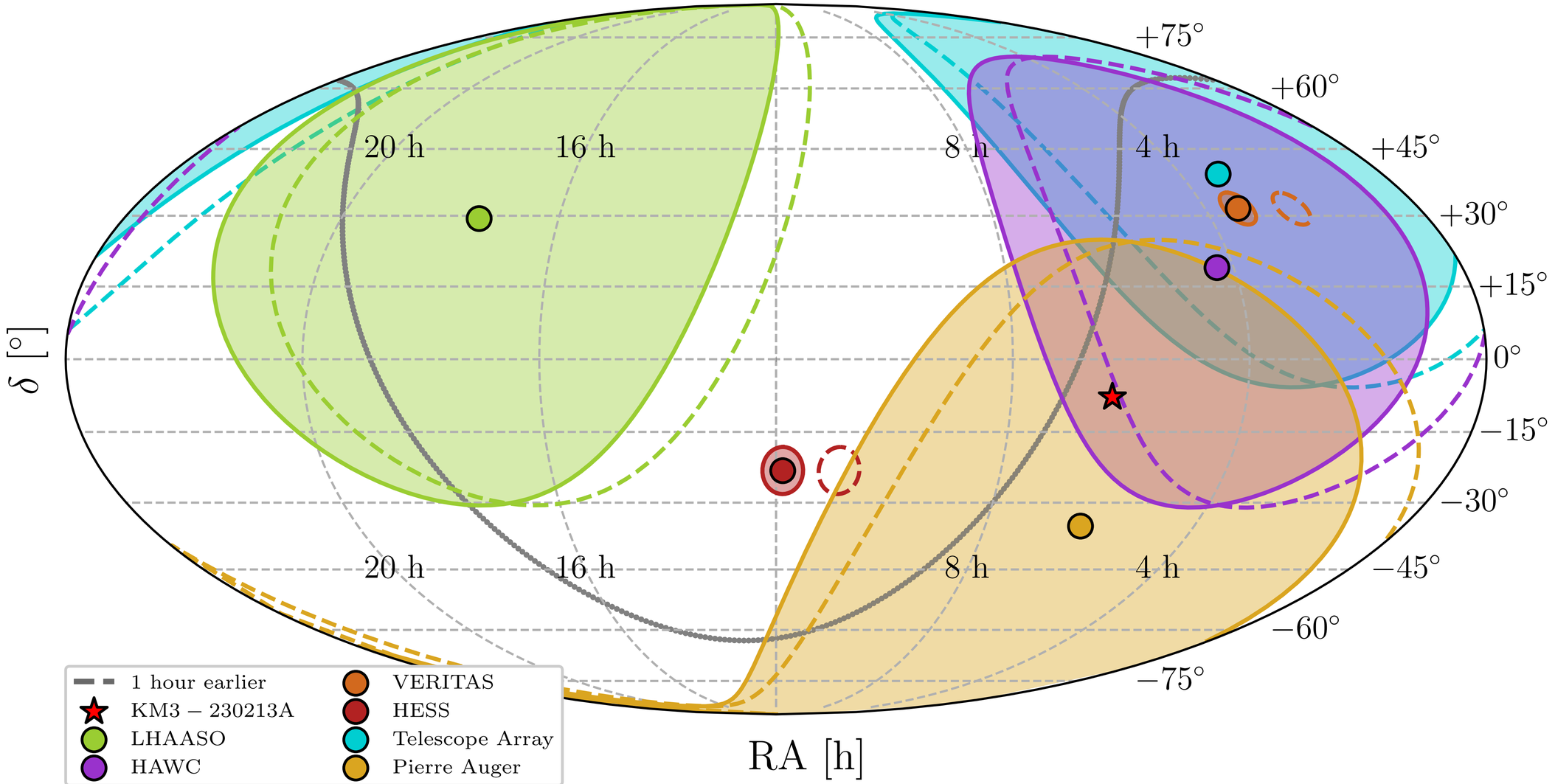
Example: Gamma ray observatories

Working principle





Their instantaneous field of view



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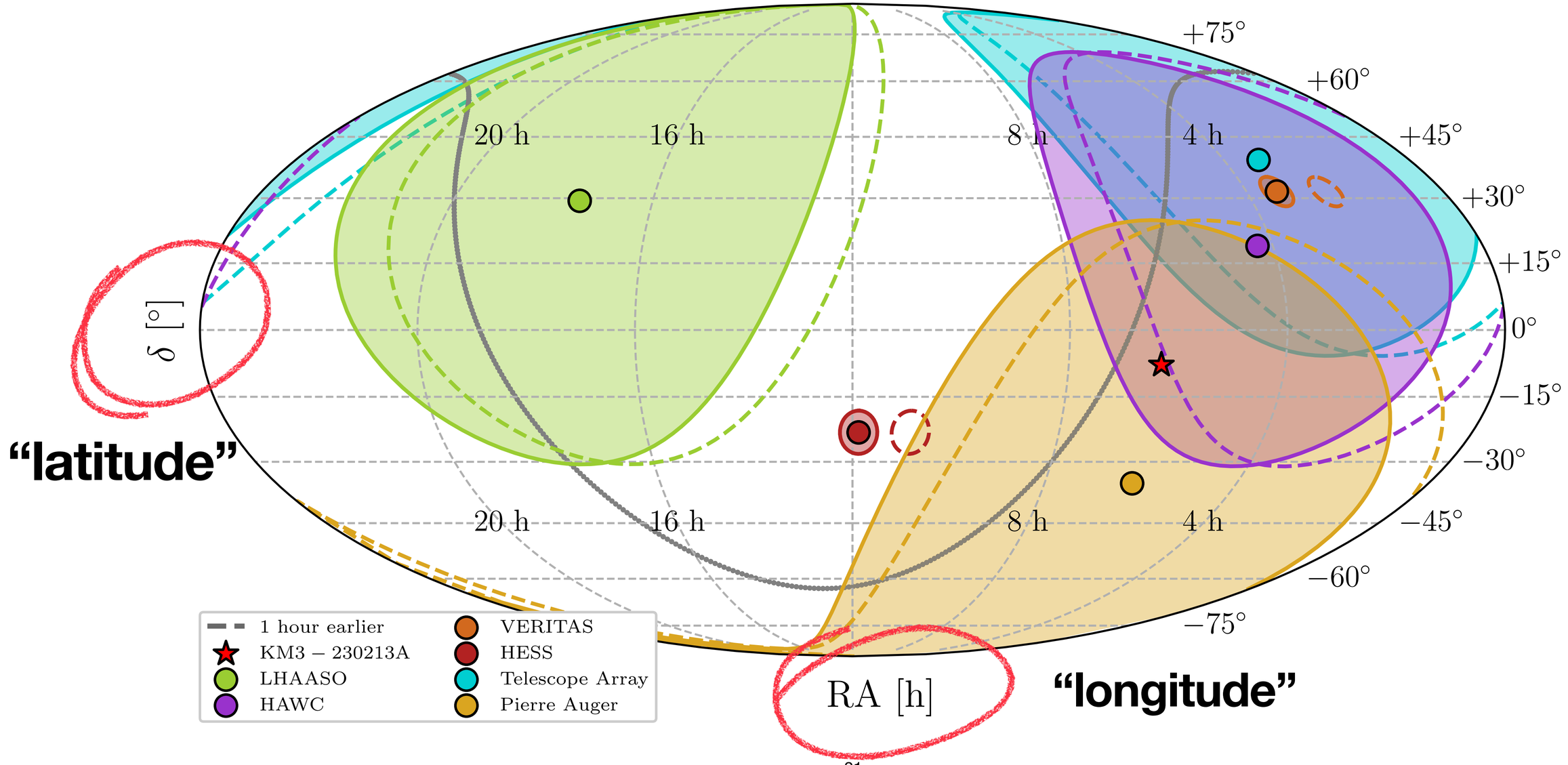
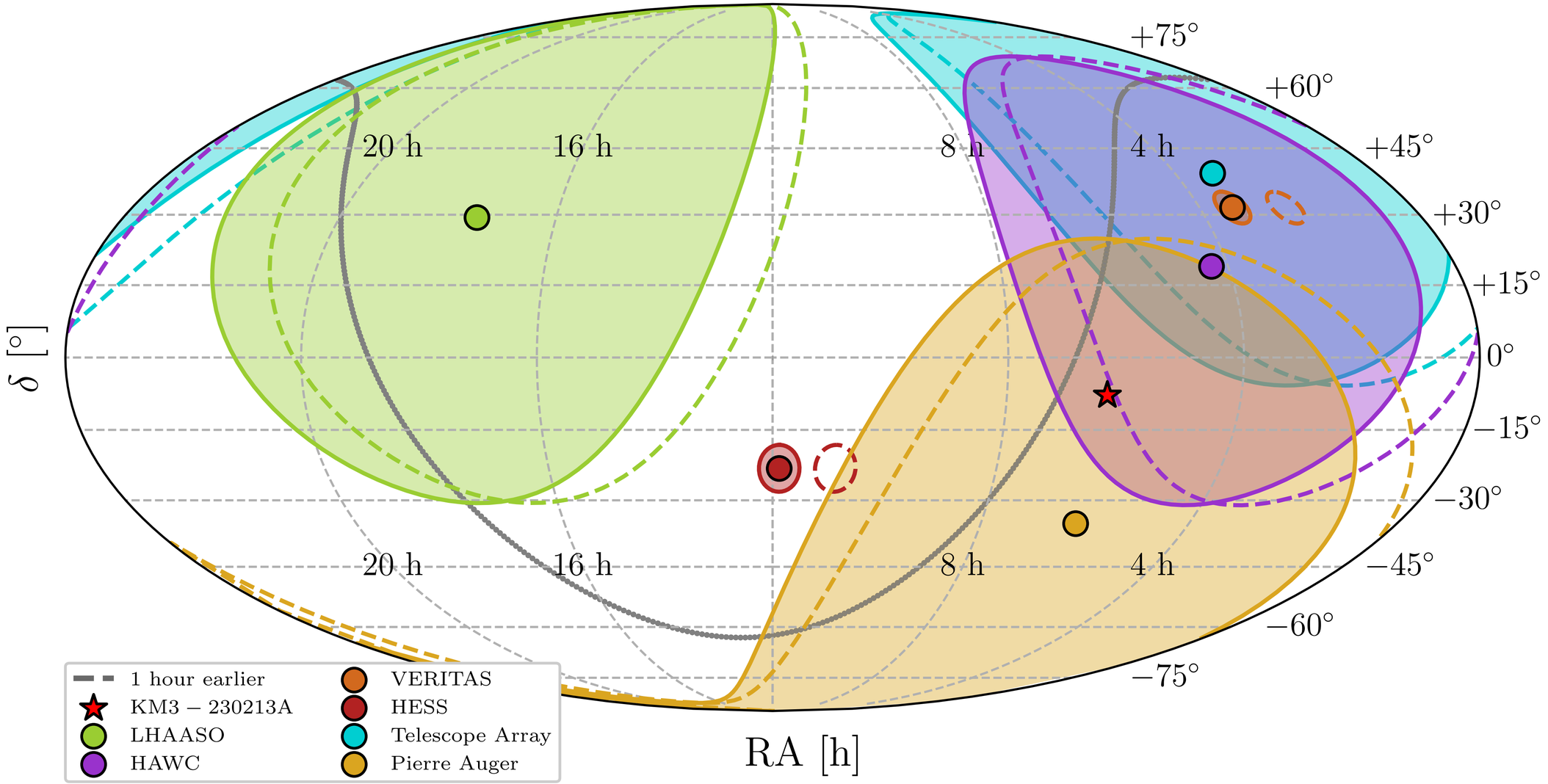


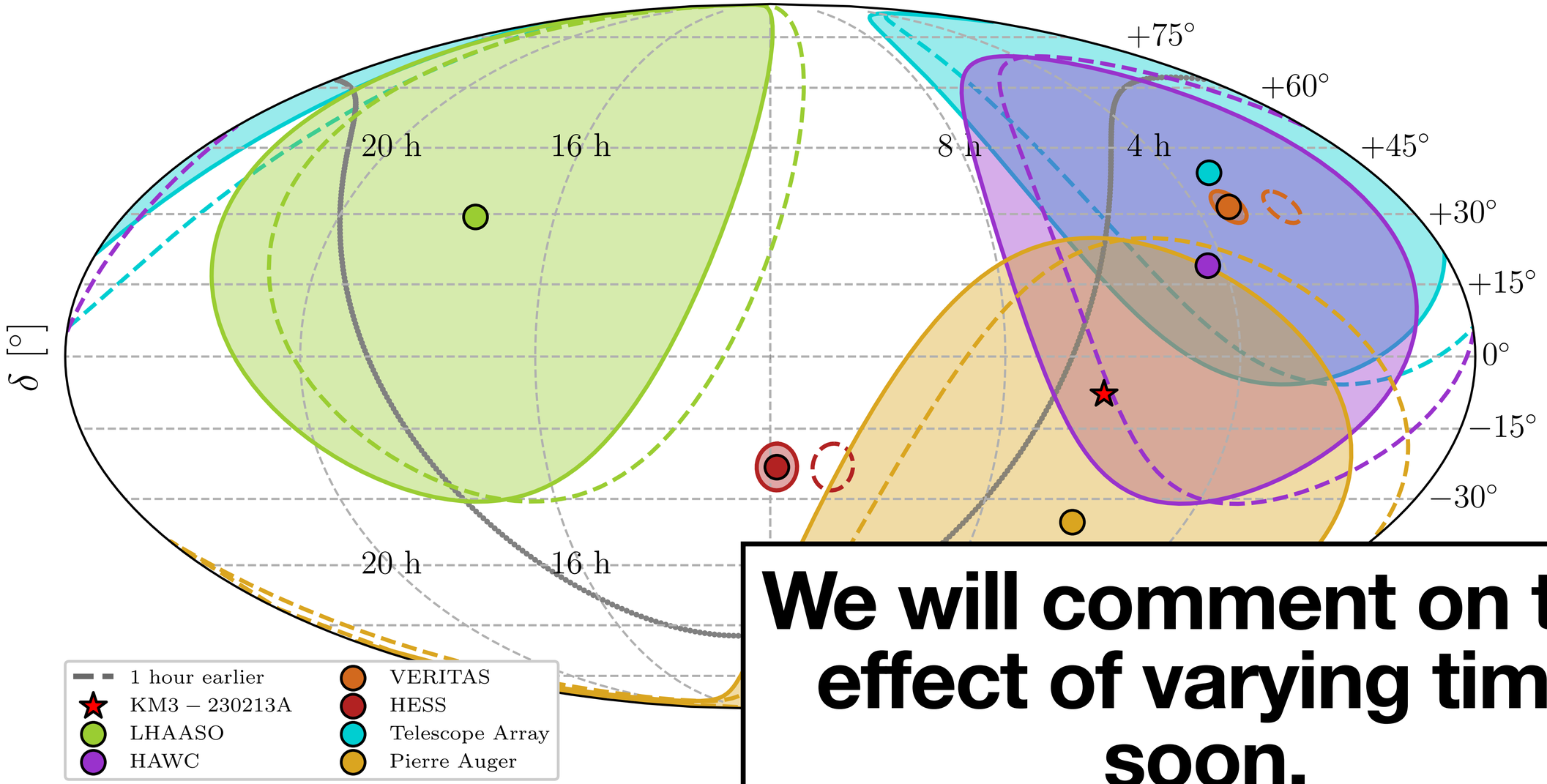
“latitude”

“longitude”

Their instantaneous blind spots

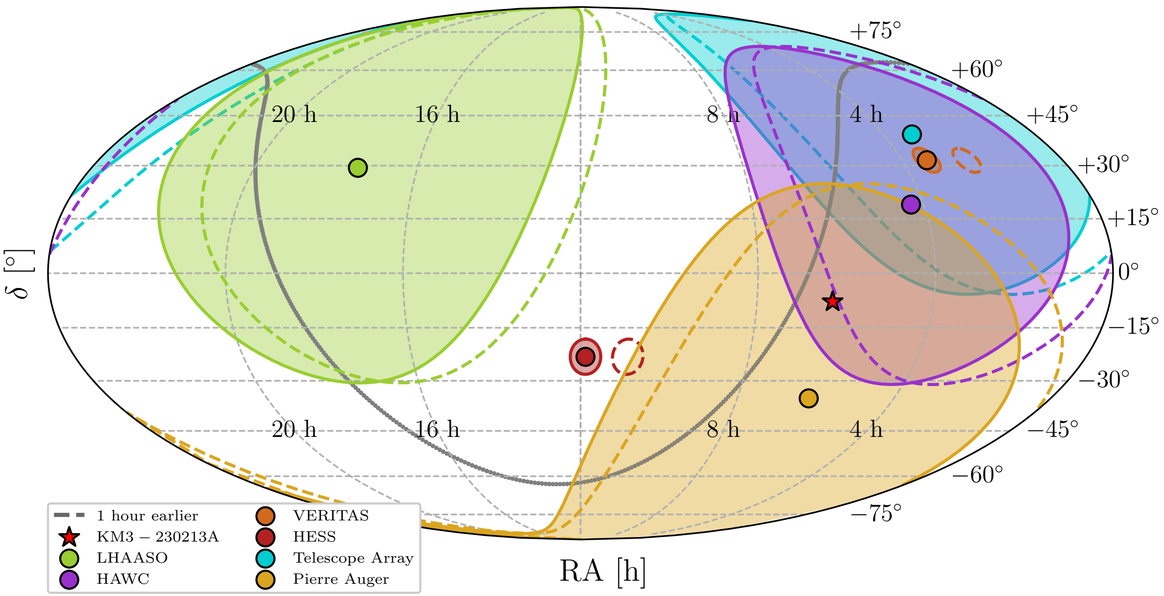


Their instantaneous blind spots



We will comment on the effect of varying time soon.

Gamma ray synergy



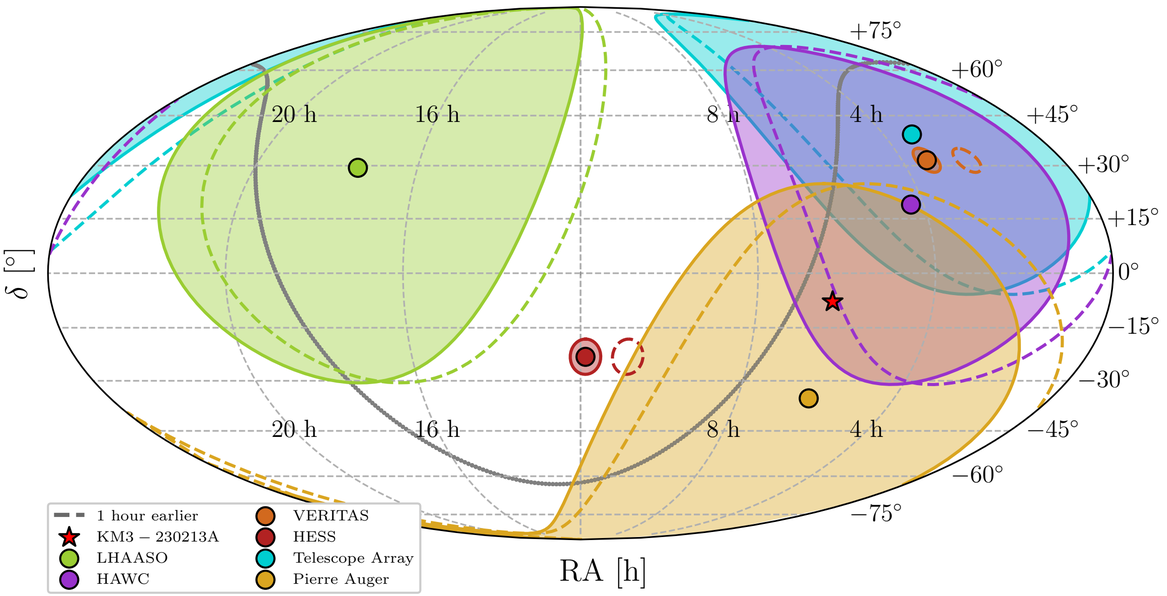
HAWC

10's GeV - 100's TeV

🇲🇽

HAWC, arxiv:2304.00730/1911.04356

Gamma ray synergy



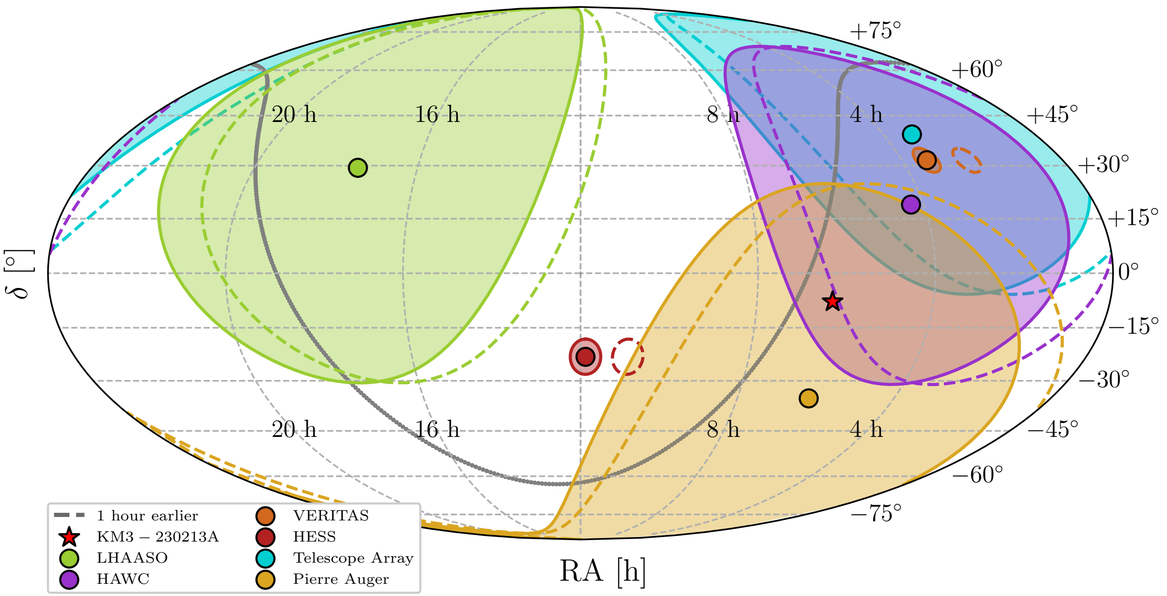
LHAASO

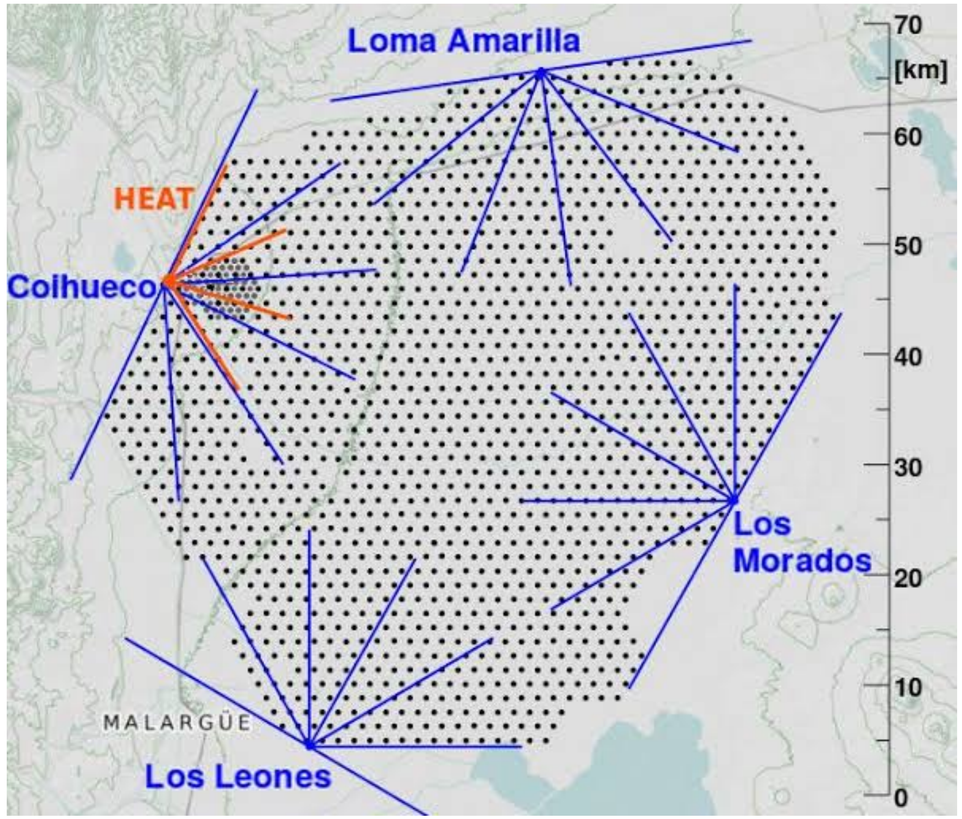
10's GeV - PeV's

🇨🇳

HAWC, arxiv:1602.07600/1905.02773

Gamma ray synergy



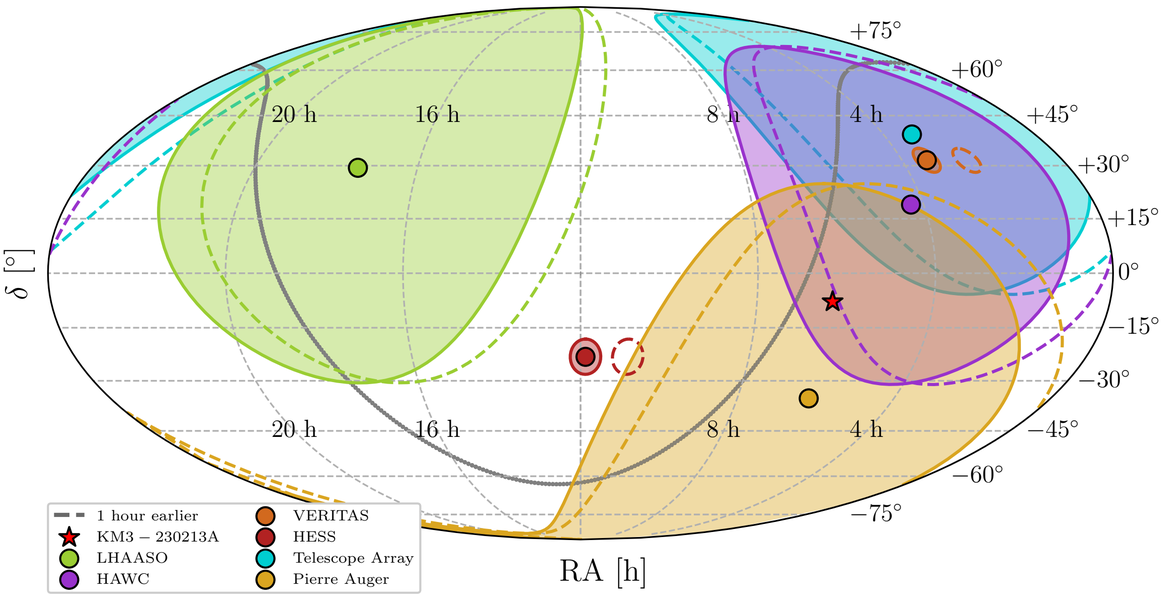


Pierre Auger

~EeV

PA, arxiv:1502.01323

Gamma ray synergy



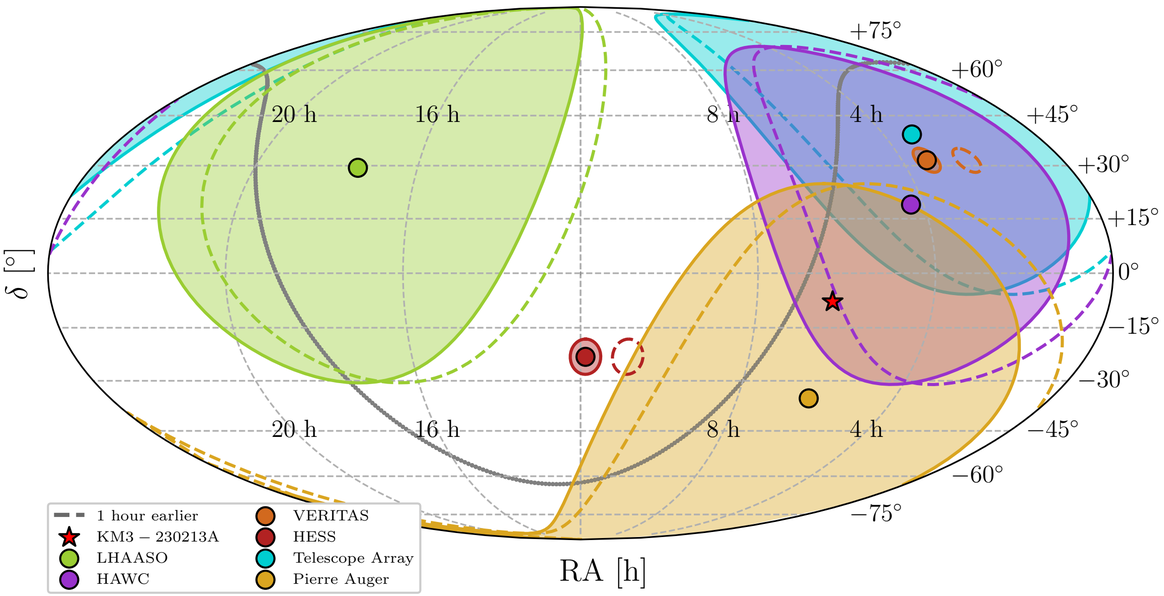
Telescope Array

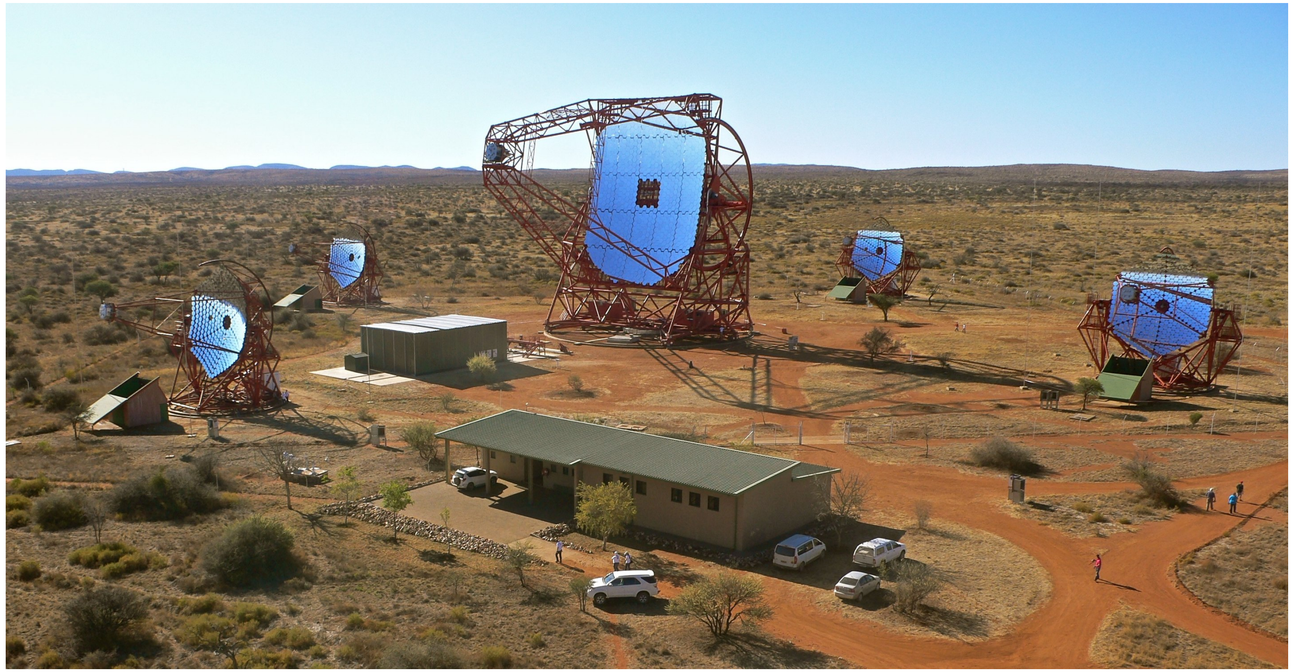
~EeV

🇺🇸

TA, arxiv:1205.5067/1201.4964

Gamma ray synergy





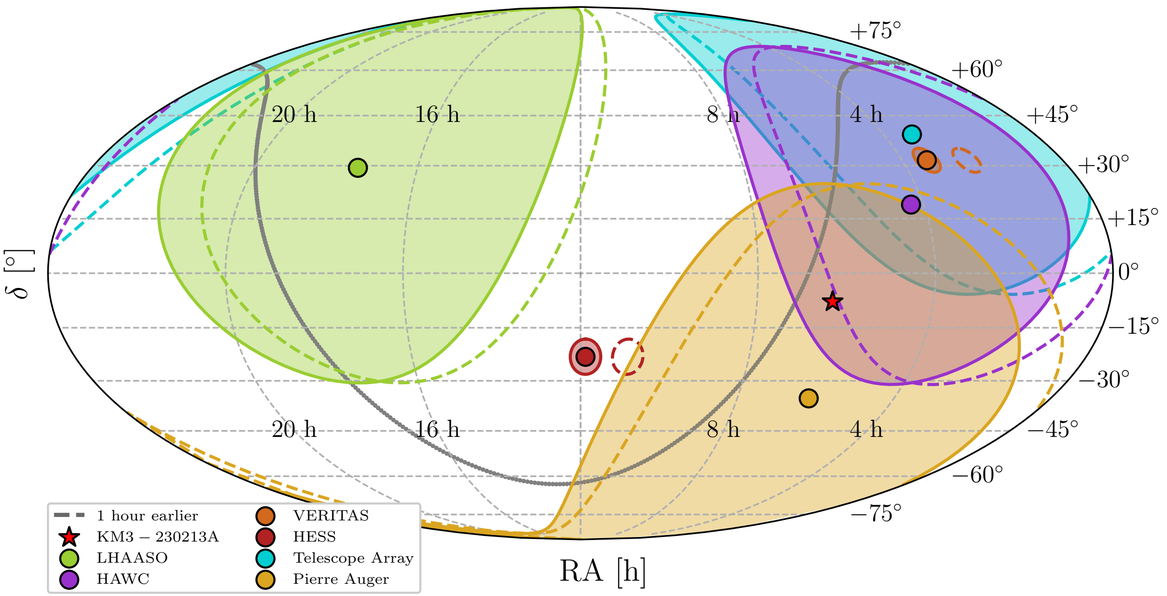
HESS

~TeV

🇳🇦

HESS, arxiv:1804.02432/2303.12855

Gamma ray synergy



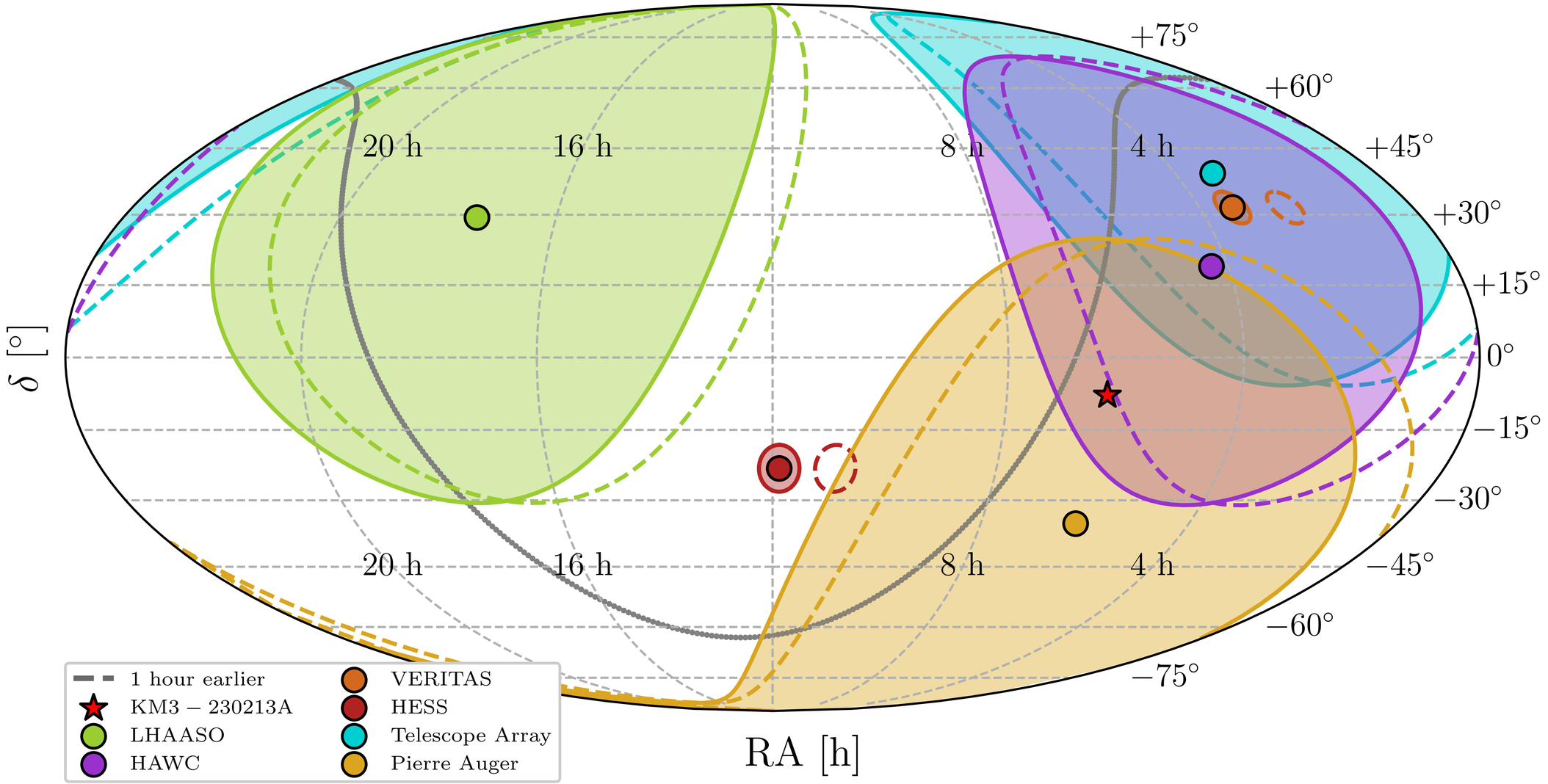
VERITAS

~TeV

🇺🇸

VERITAS, arxiv:0604119/1709.00307

Their instantaneous field of view



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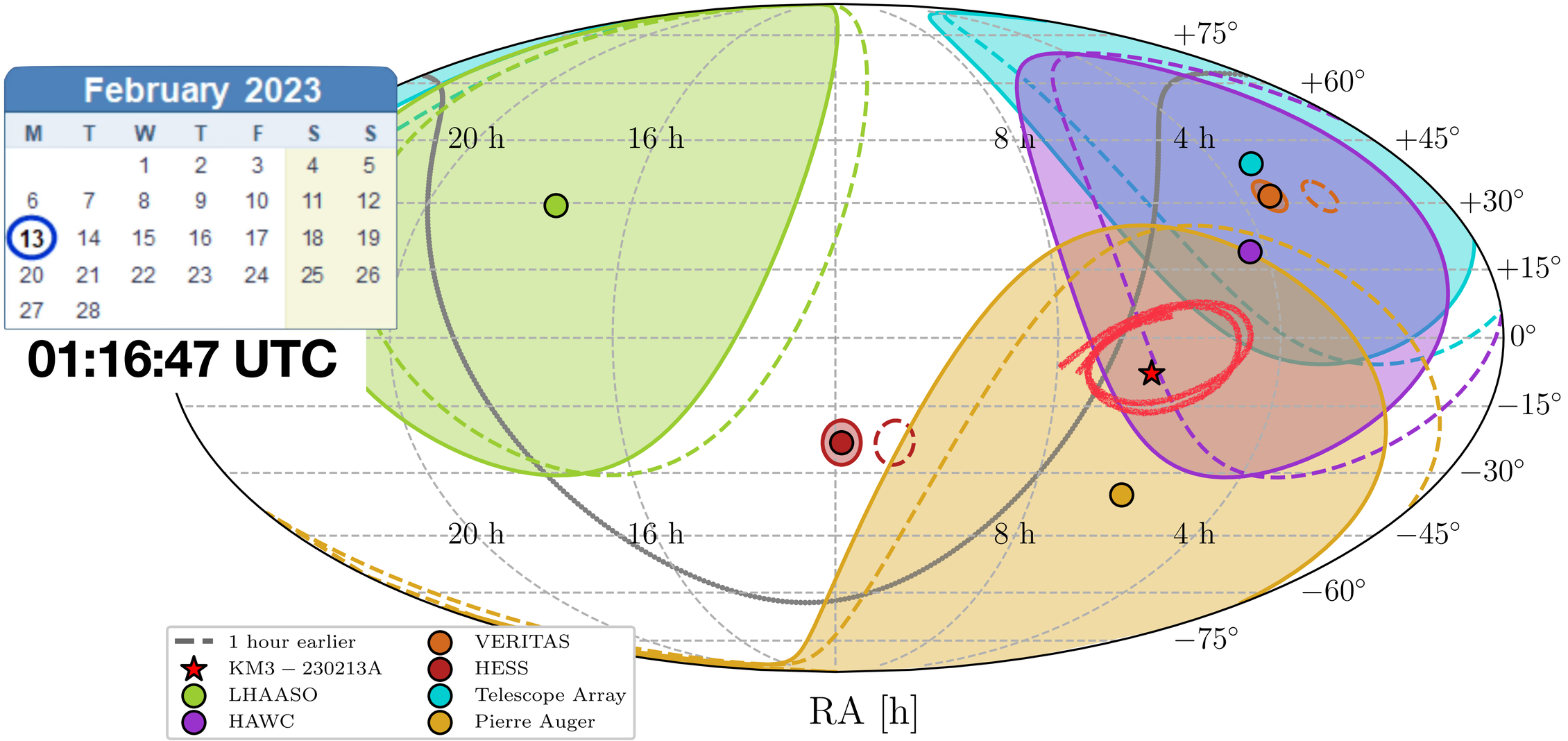


The KM3-230213A event

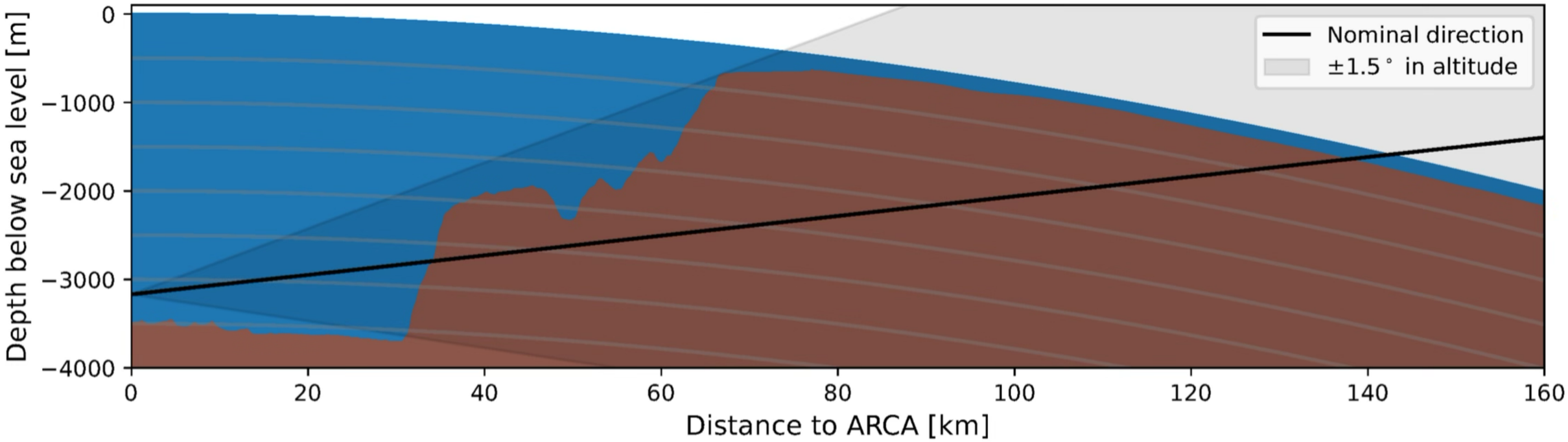
KM3NeT, Nature 638, 376-382

“The signal of the most energetic elementary particle ever observed.”

KM3NeT video archive

The KM3-230213A event

$$E_\mu = 120 \text{ PeV}$$
$$\theta = 0.6^\circ$$



Serendipity in practice

Our work started before the KM3NeT paper, but after their result we have a highly motivated example to study.

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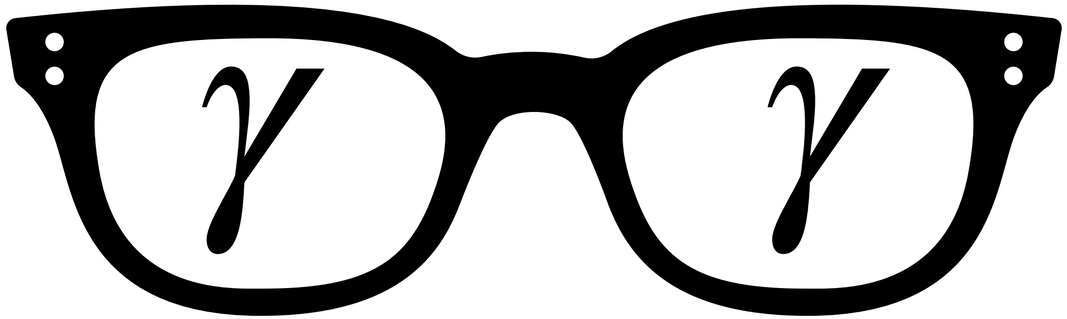
****However, everything we have discussed so far is always true**

Serendipity in practice

The announcement of the KM3NeT event firsthand in the neutrino 2024 conference

Summary, so far.



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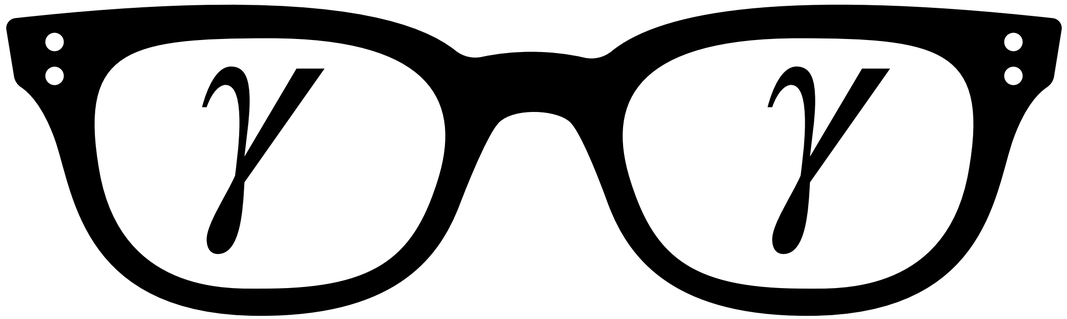

We showed that there are blind regions in the instantaneous field of view of gamma ray experiments

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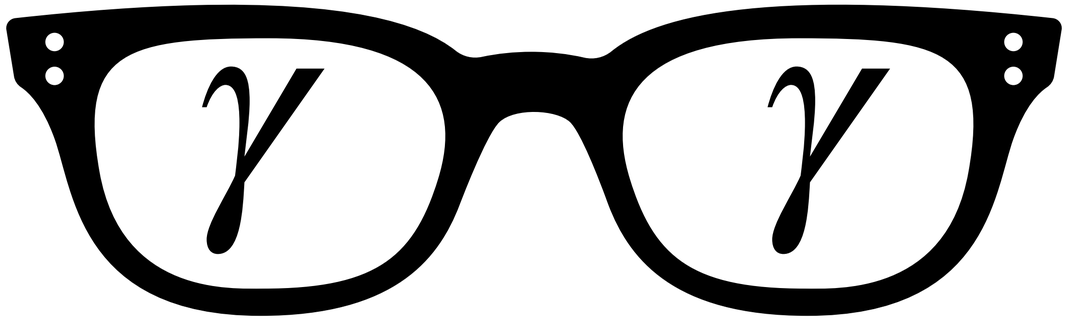

We showed that there are blind regions in the instantaneous field of view of gamma ray experiments

But why instantaneous?

Ultra high energy unknown in particle physics

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Clash of Titans

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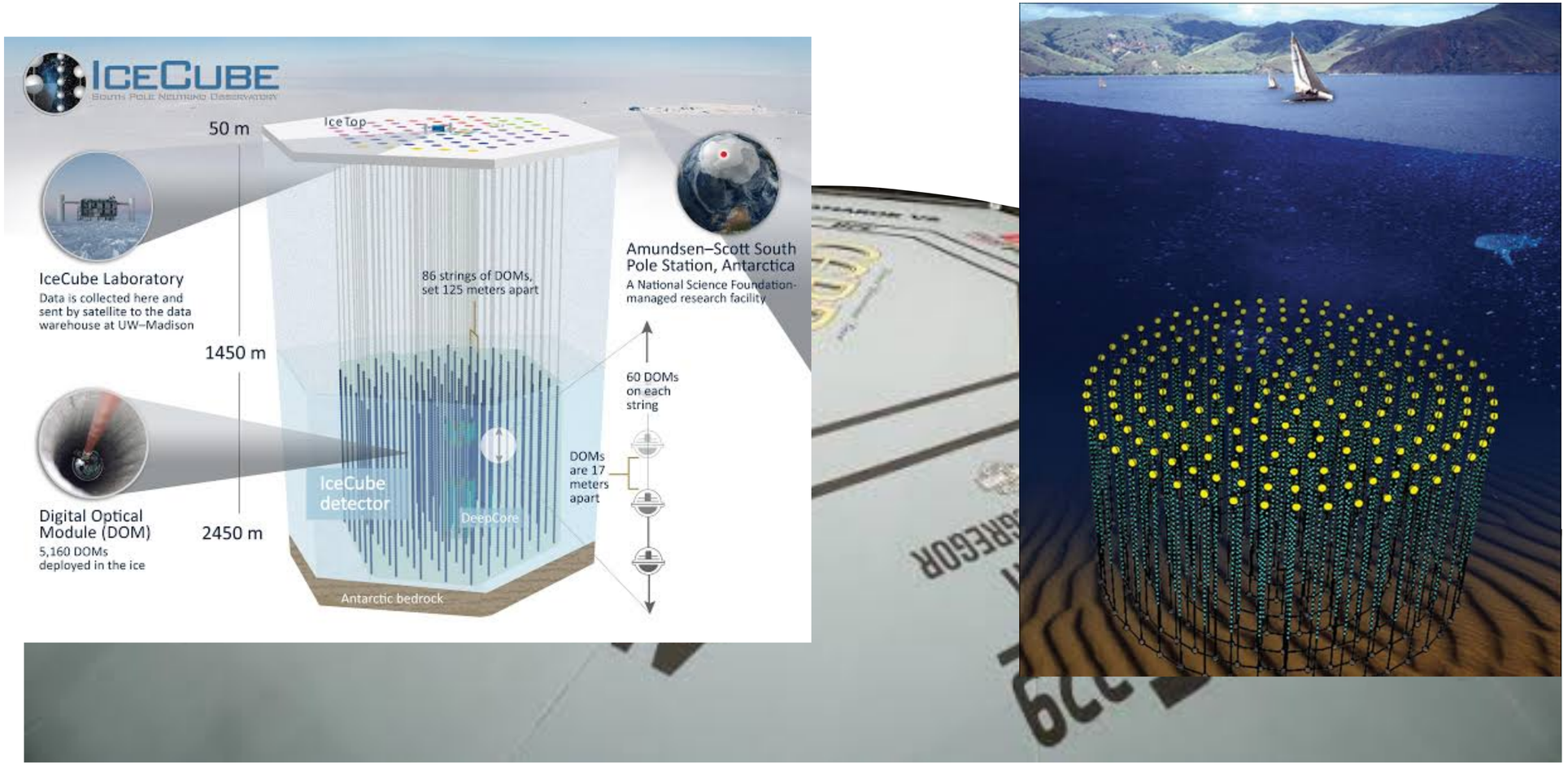
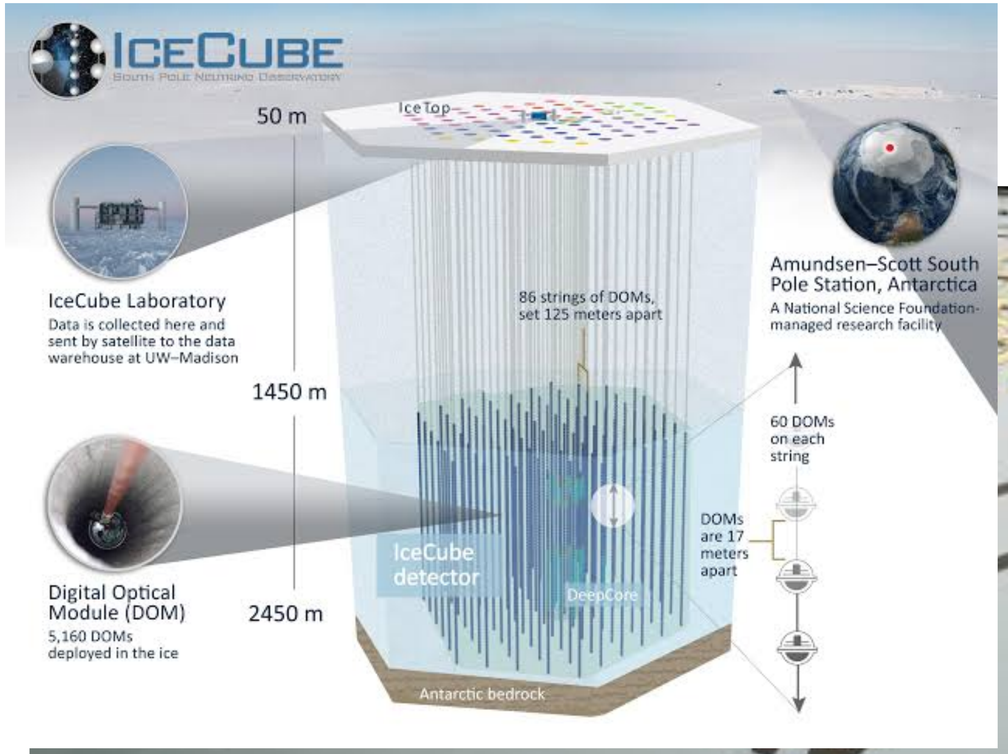
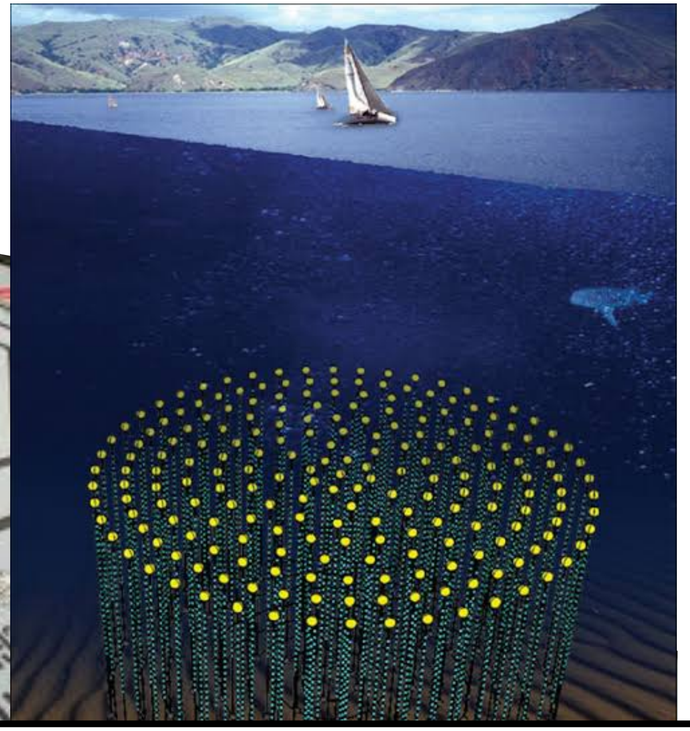


Ultra high energy unknown in particle physics

Clash of Titans





10% of strings!!

Ultra high energy unknown in particle physics

Origin?

Schwemberger, arxiv:2502.04508

Ultra high energy unknown in particle physics

Diffuse ~ $3.5\ \sigma$

Origin?

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Ultra high energy unknown in particle physics

Origin?

Diffuse ~ $3.5\ \sigma$

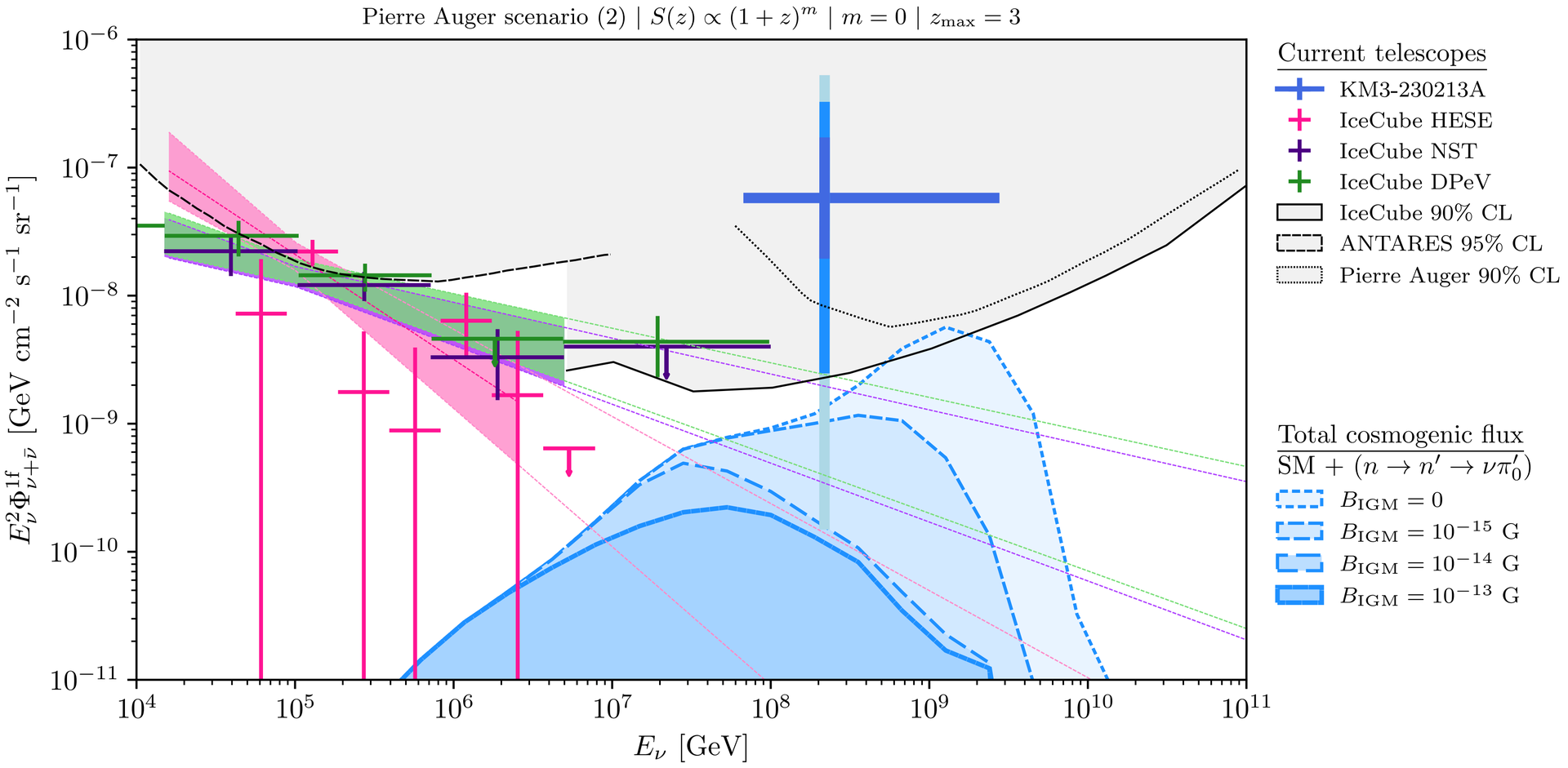
Cosmogenic ~ $3.1 - 3.6\ \sigma$

Schwemberger, arxiv:2502.04508

Pause for a shameless self-promotion

Neutron portal to ultra-high-energy neutrinos

Gustavo F. S. Alves,[1,*] Matheus Hostert,[2,†] and Maxim Pospelov[3,4,‡]



Ultra high energy unknown in particle physics

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Schwemberger, arxiv:2502.04508

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A transient burst helps in recoinciling the (non) observation.

Schwemberger, arxiv:2502.04508

Ultra high energy unknown in particle physics

Origin?

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Cosmogenic ~ $3.1 - 3.6\ \sigma$

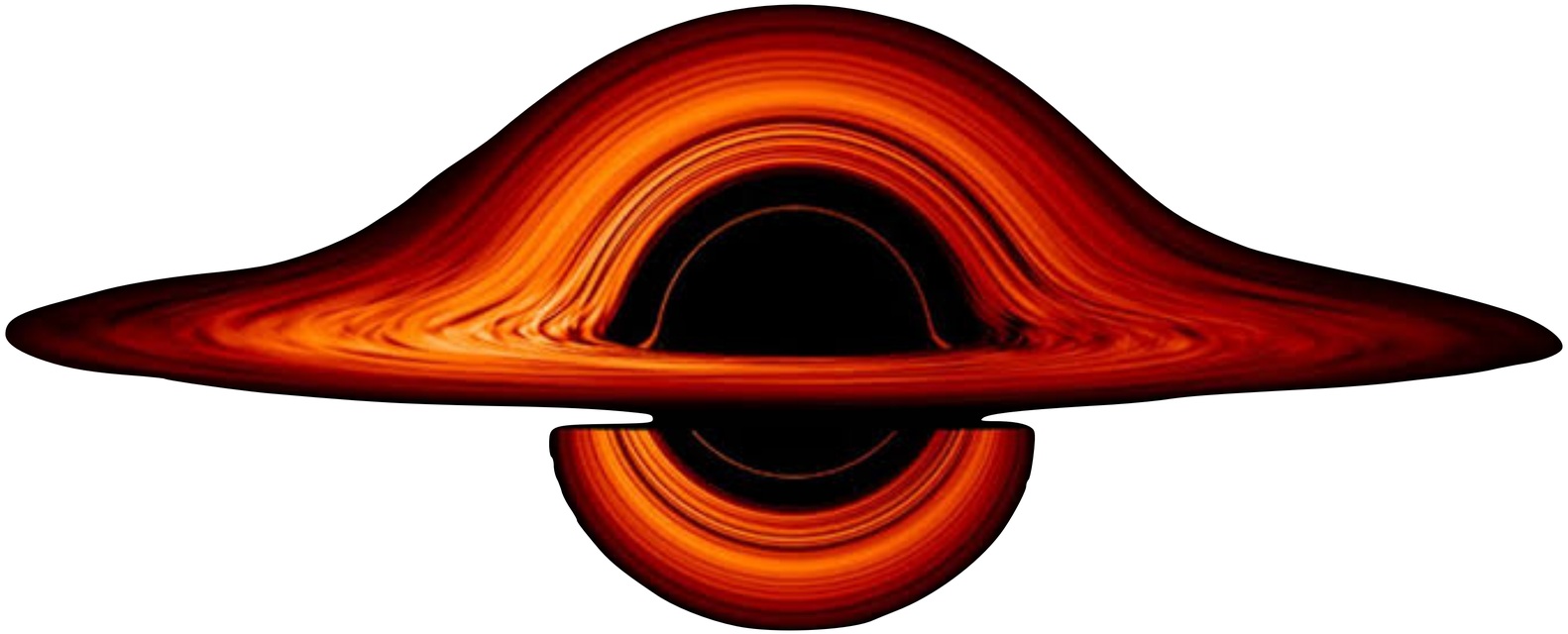
Transient ~ $2\ \sigma$

A transient burst helps in recoinciling the (non) observation.

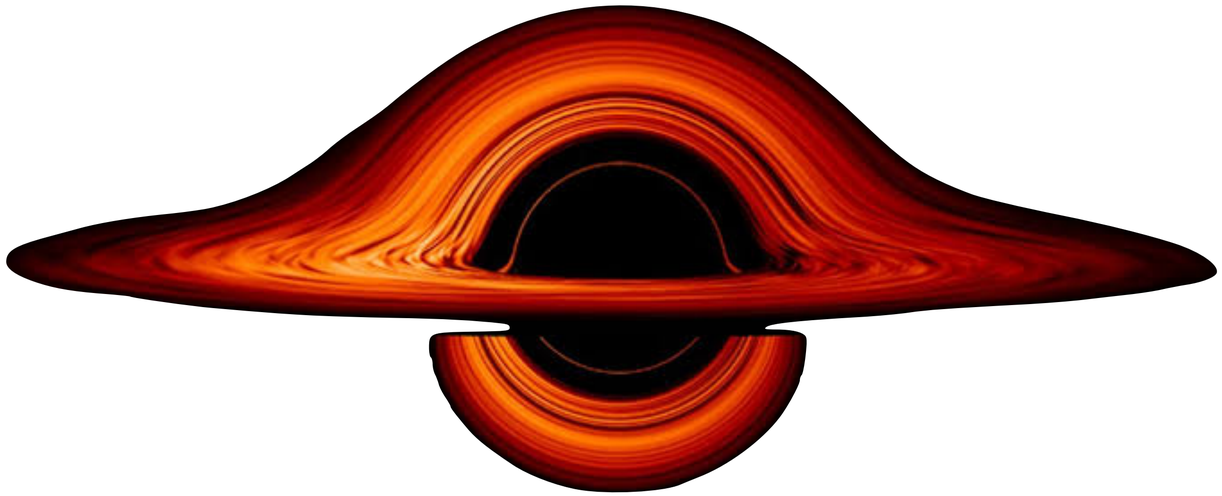
***For fast transient signals, instantaneous field of view is what matters!**

Schwemberger, arxiv:2502.04508

One example: Primordial Black Holes



The PBH evaporates



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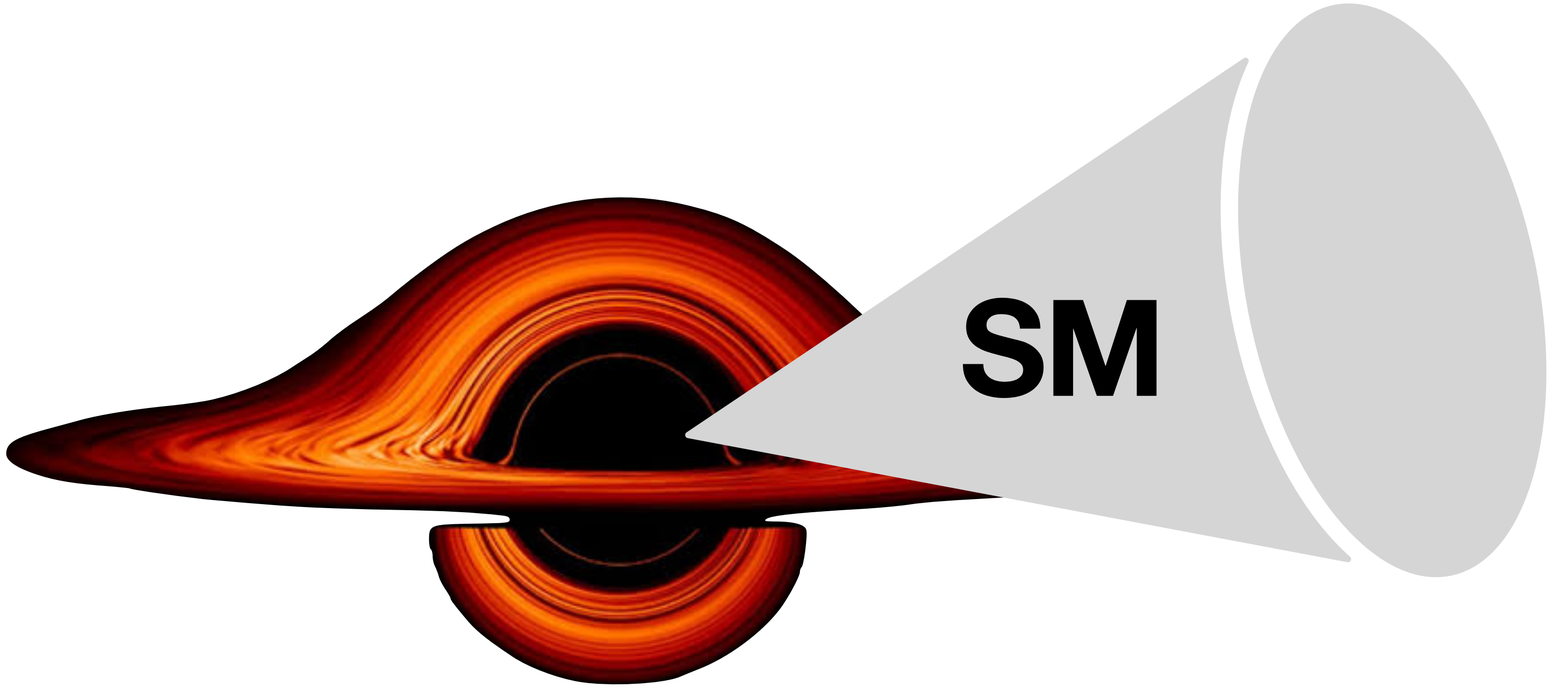

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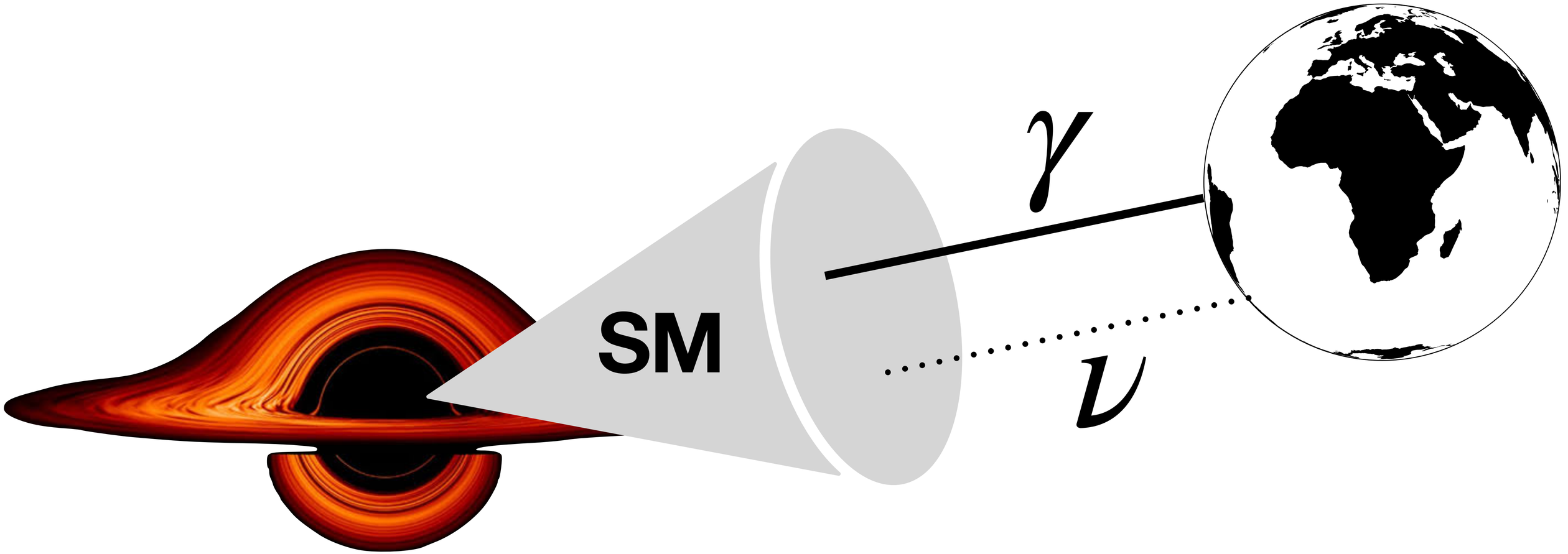

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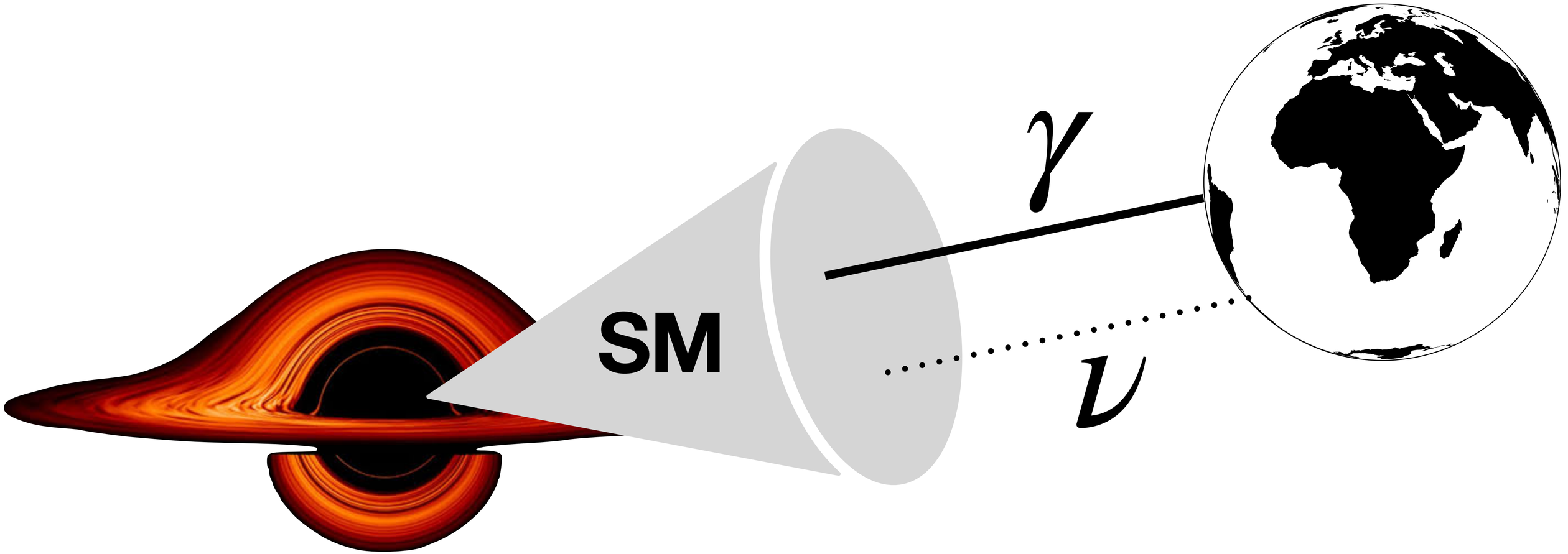
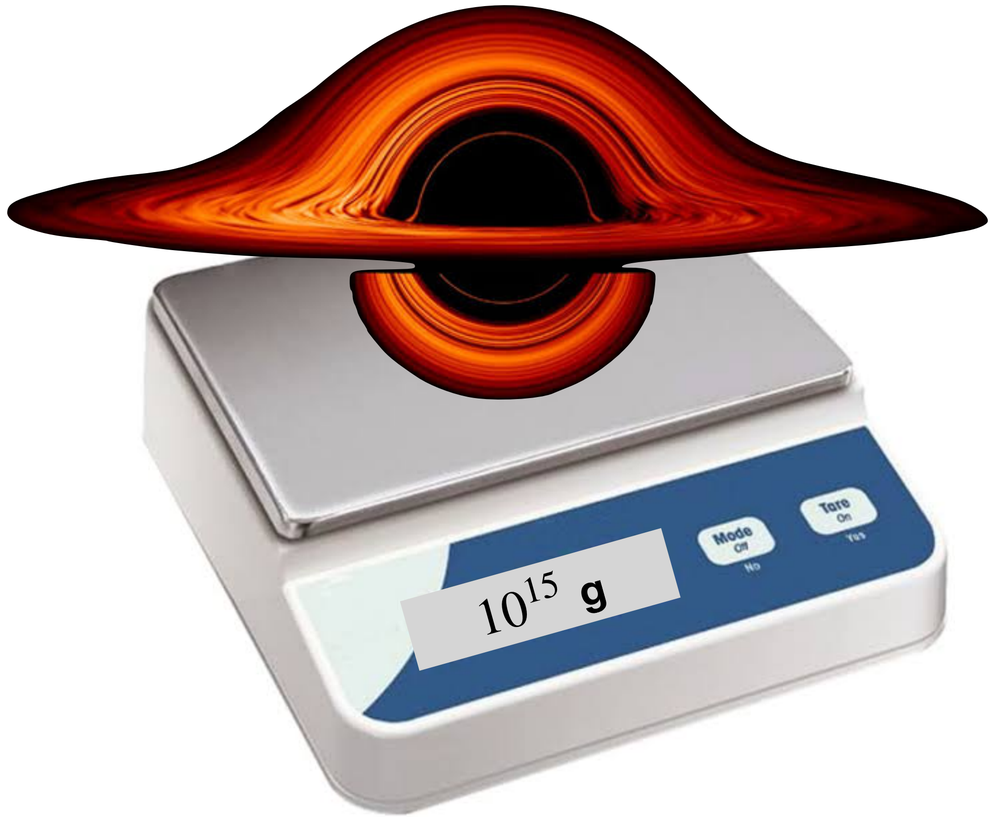
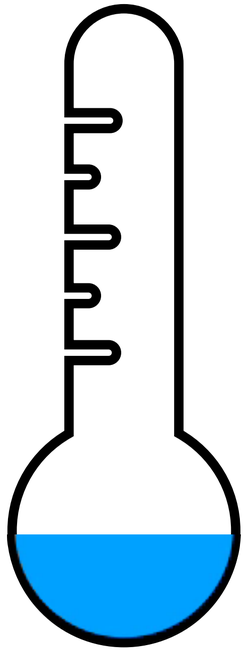


Secondary vs primary

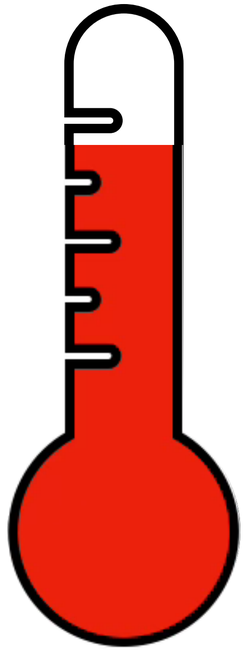
Temperature is low when it is heavy



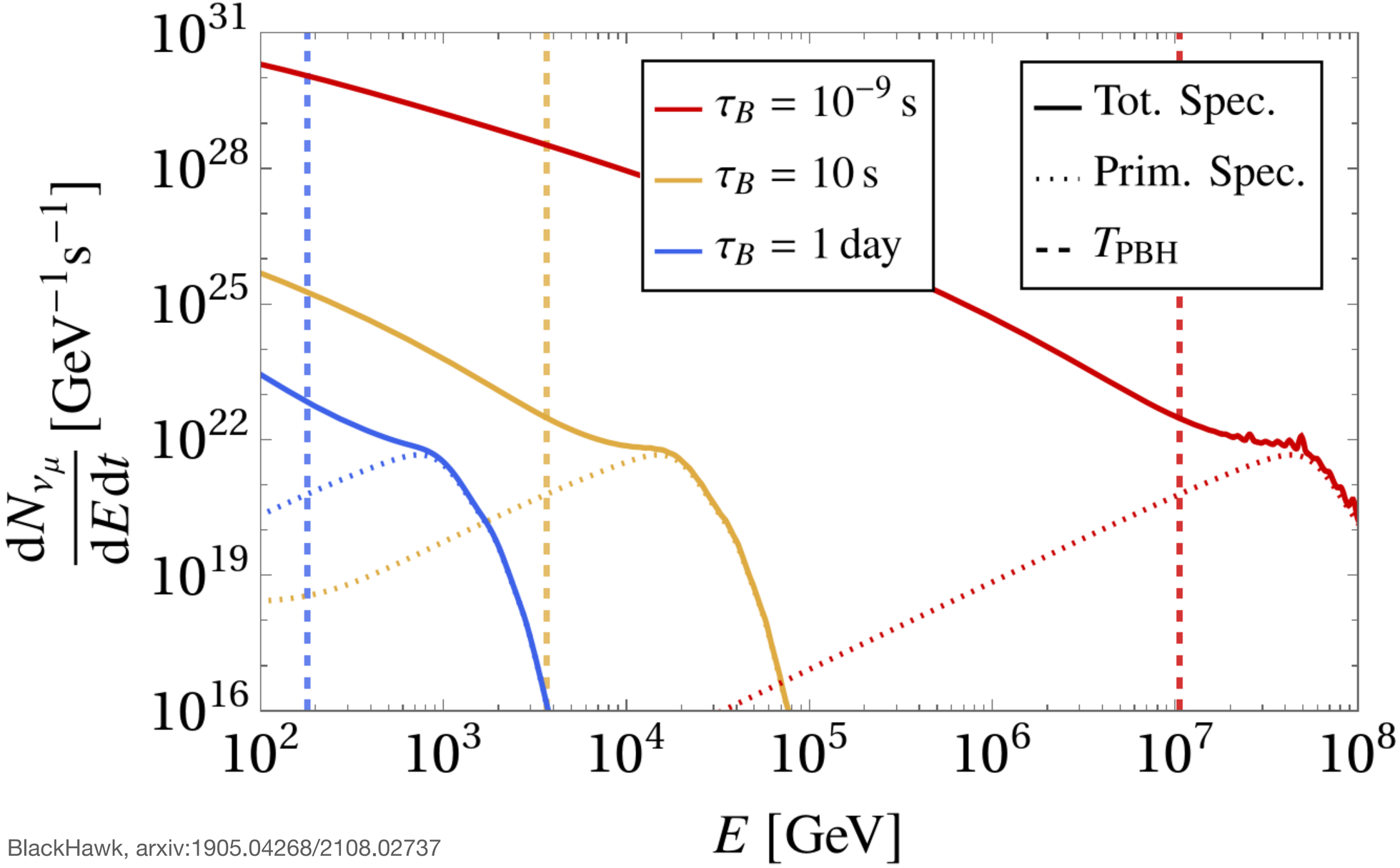


Temperature is high when it is light

$$T \sim 1 \text{ TeV} \left(\frac{10^{10} \text{ g}}{\text{M}} \right)$$

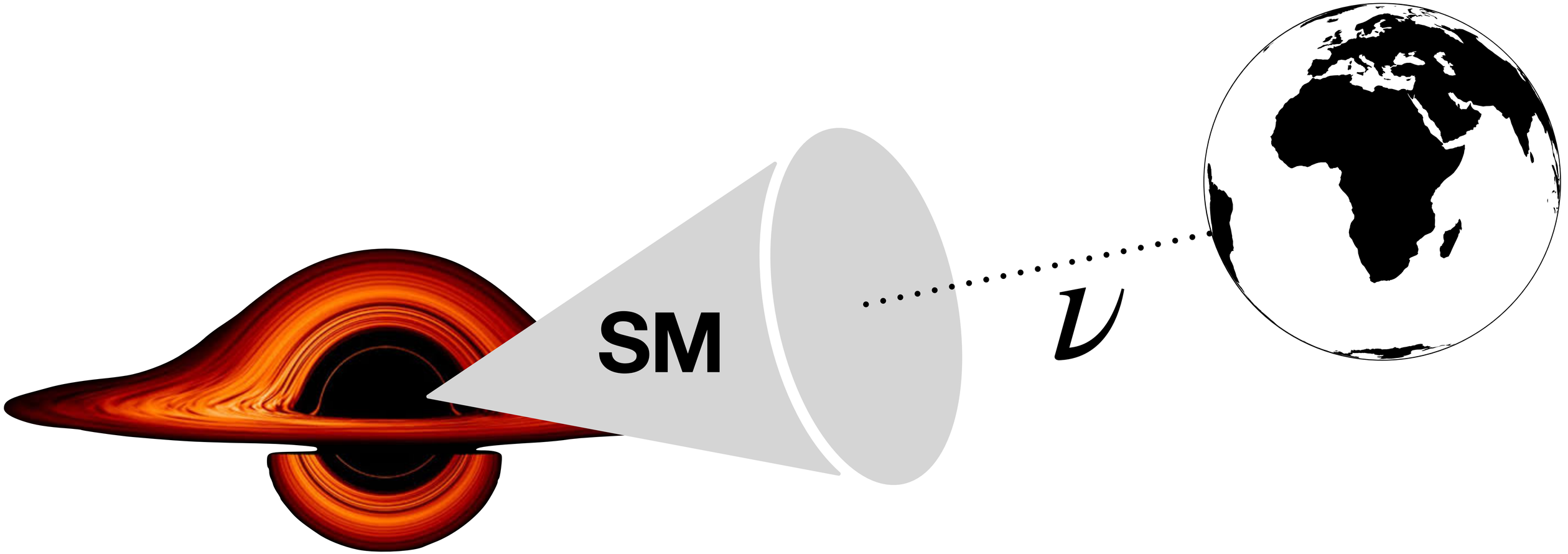


The (neutrino) burst



BlackHawk, arxiv:1905.04268/2108.02737

The “instantaneous field of view” of neutrino telescopes



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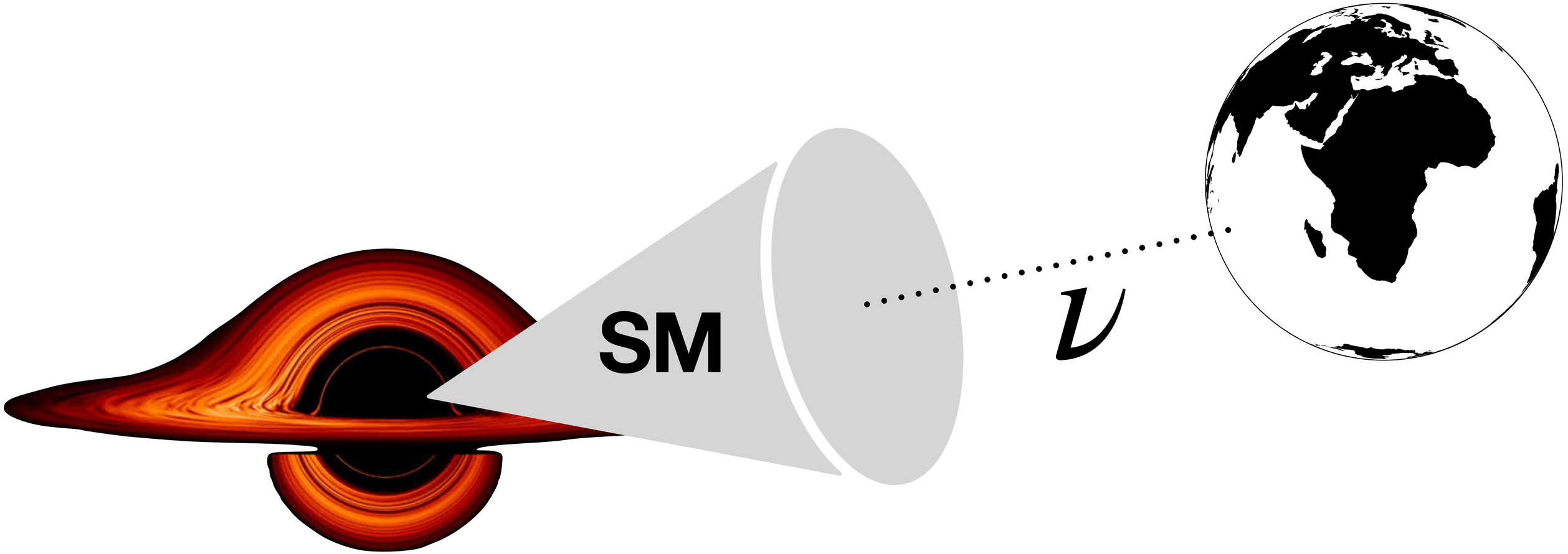
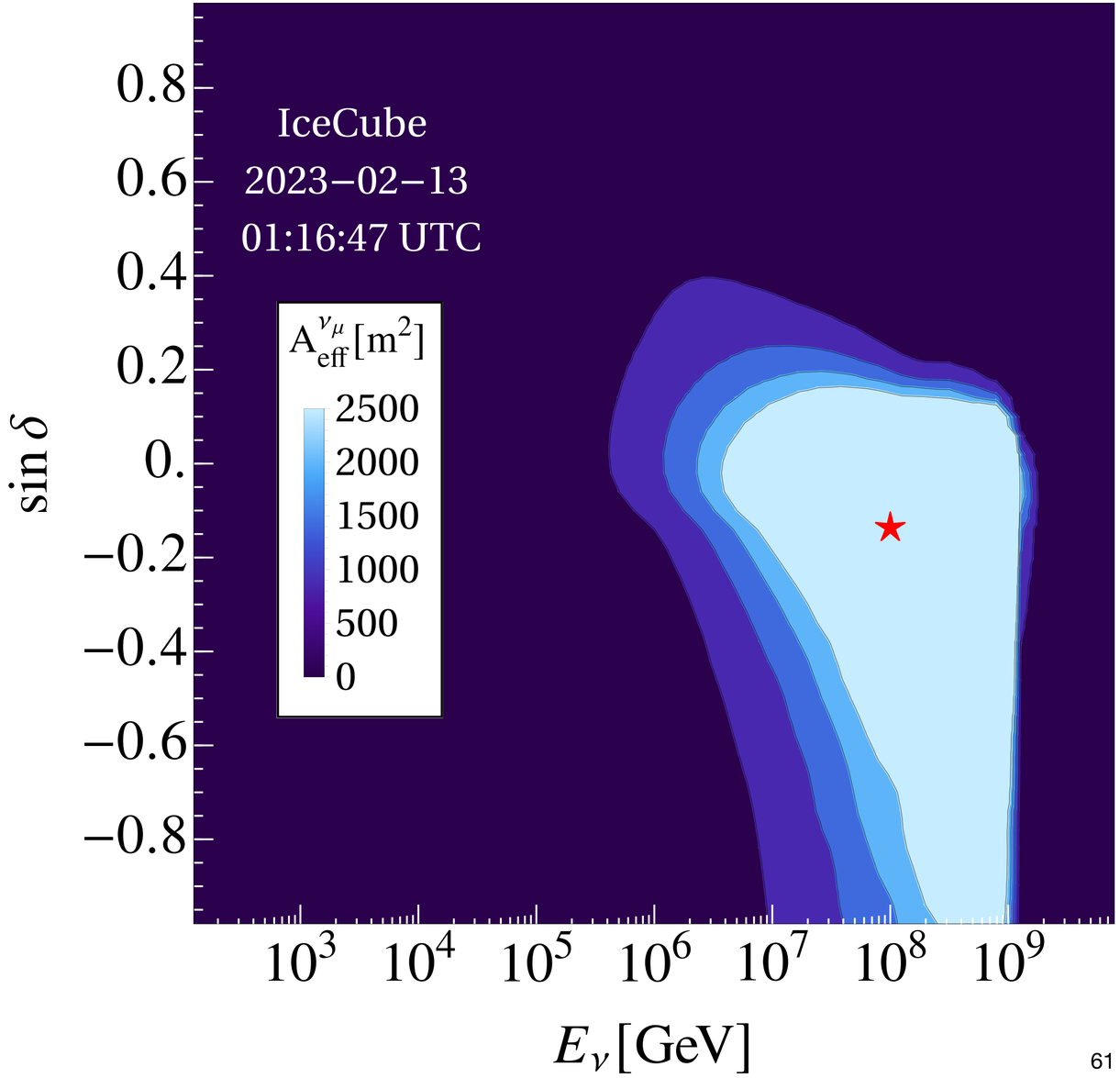
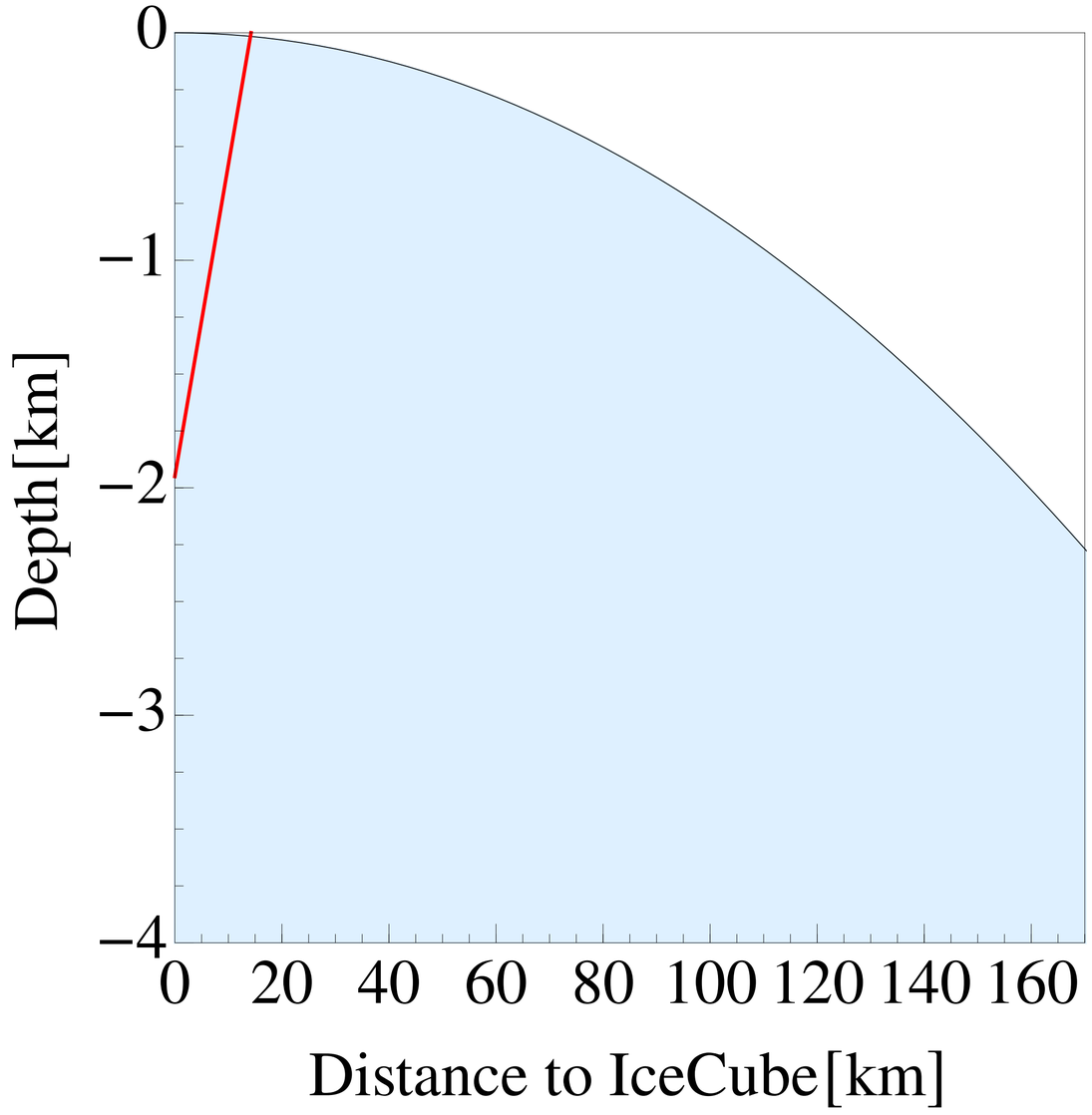


We start with IceCube

IceCube, arxiv:2101.09836





The effective area rotation

$$(\delta, \mathrm{RA})$$

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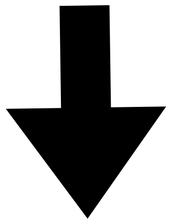

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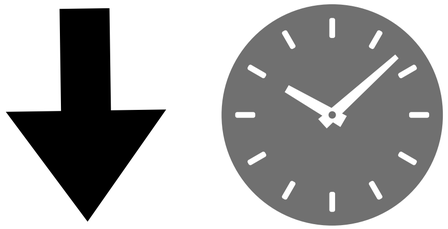

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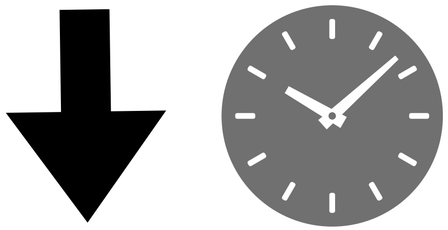
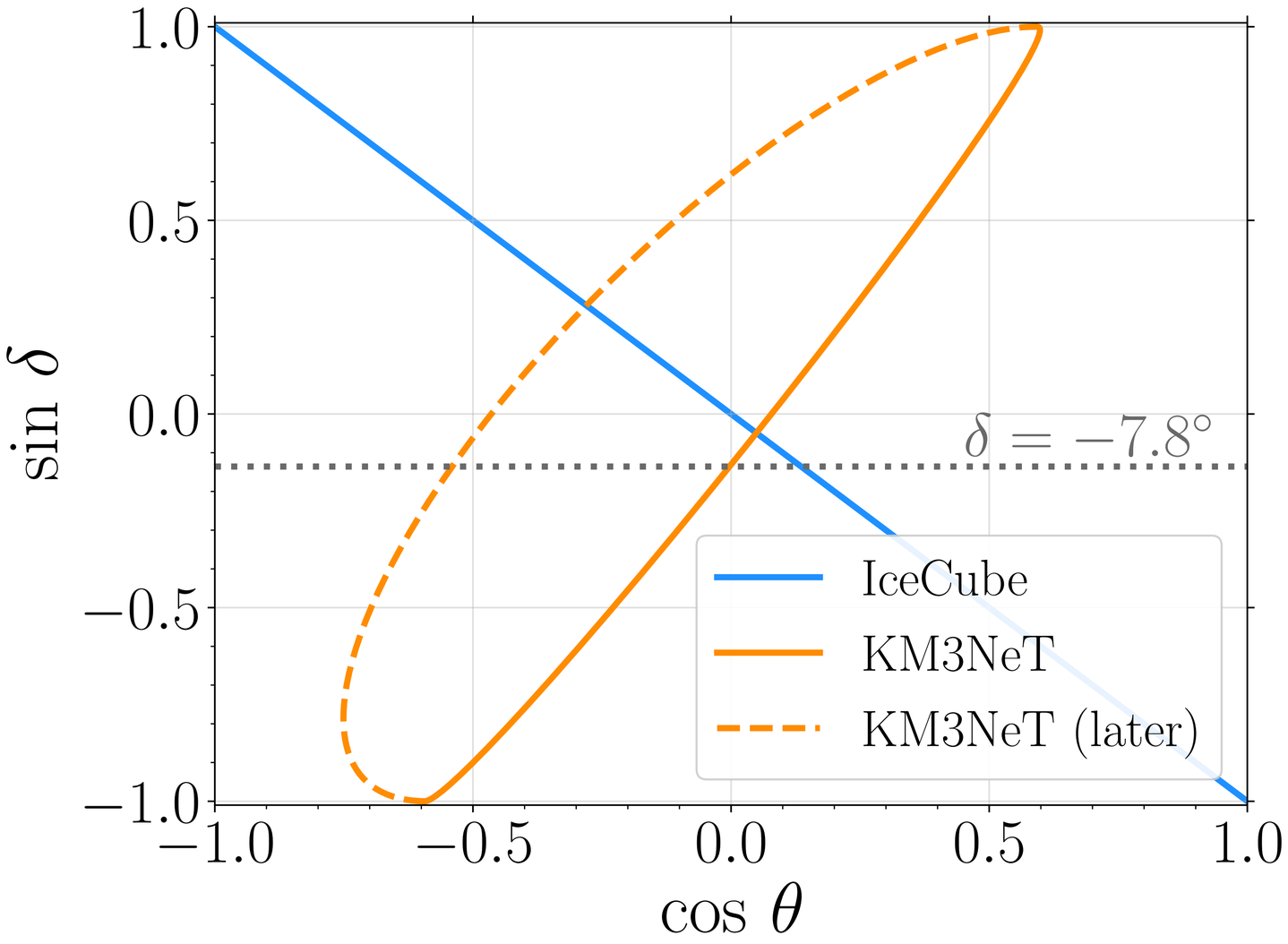
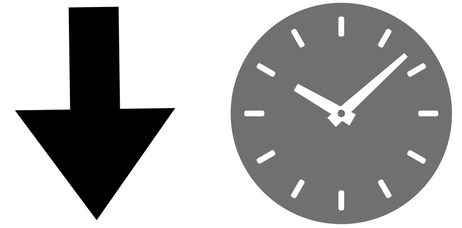


$$\theta_z$$

The effective area rotation



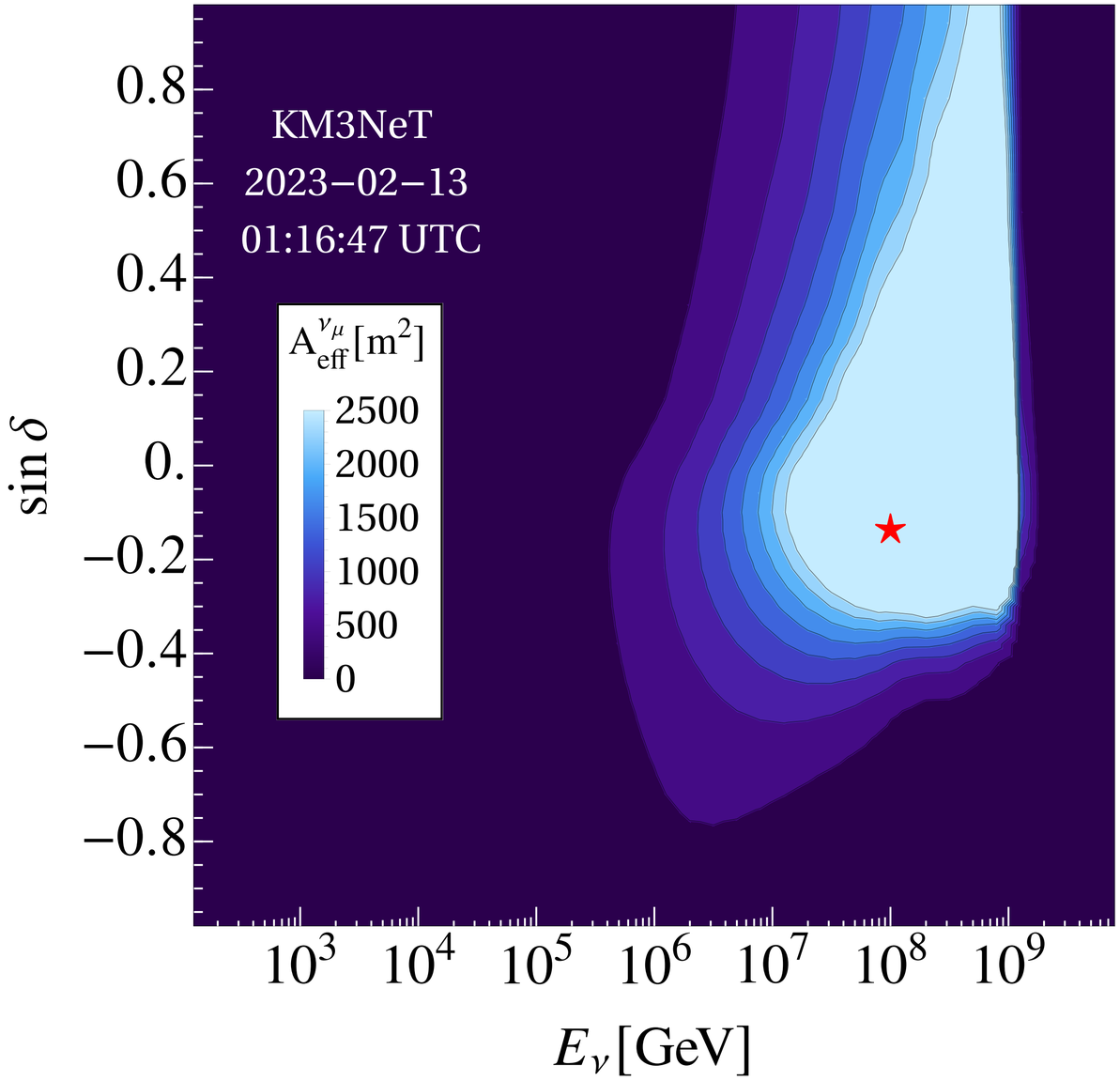
(δ, RA)

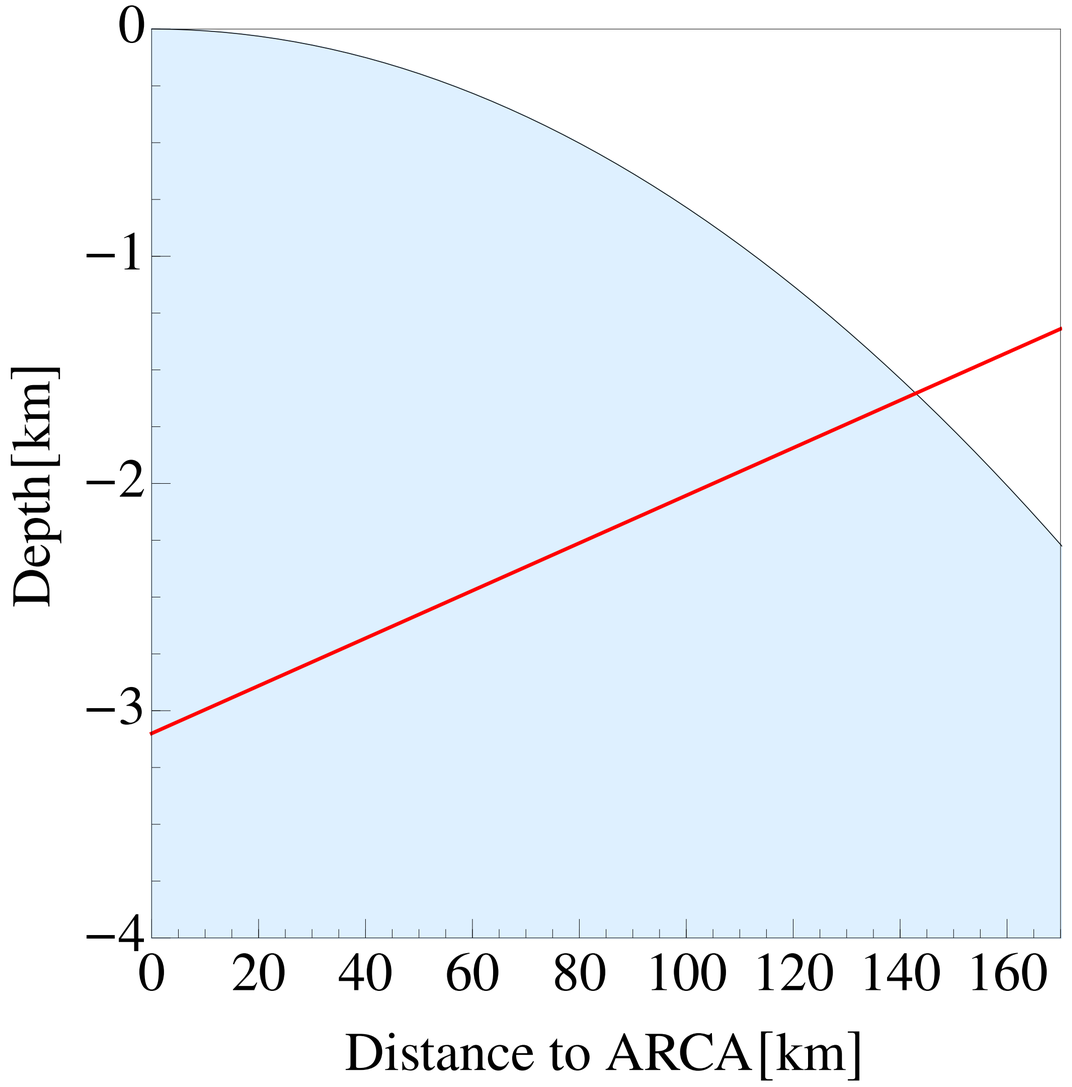


θ_z

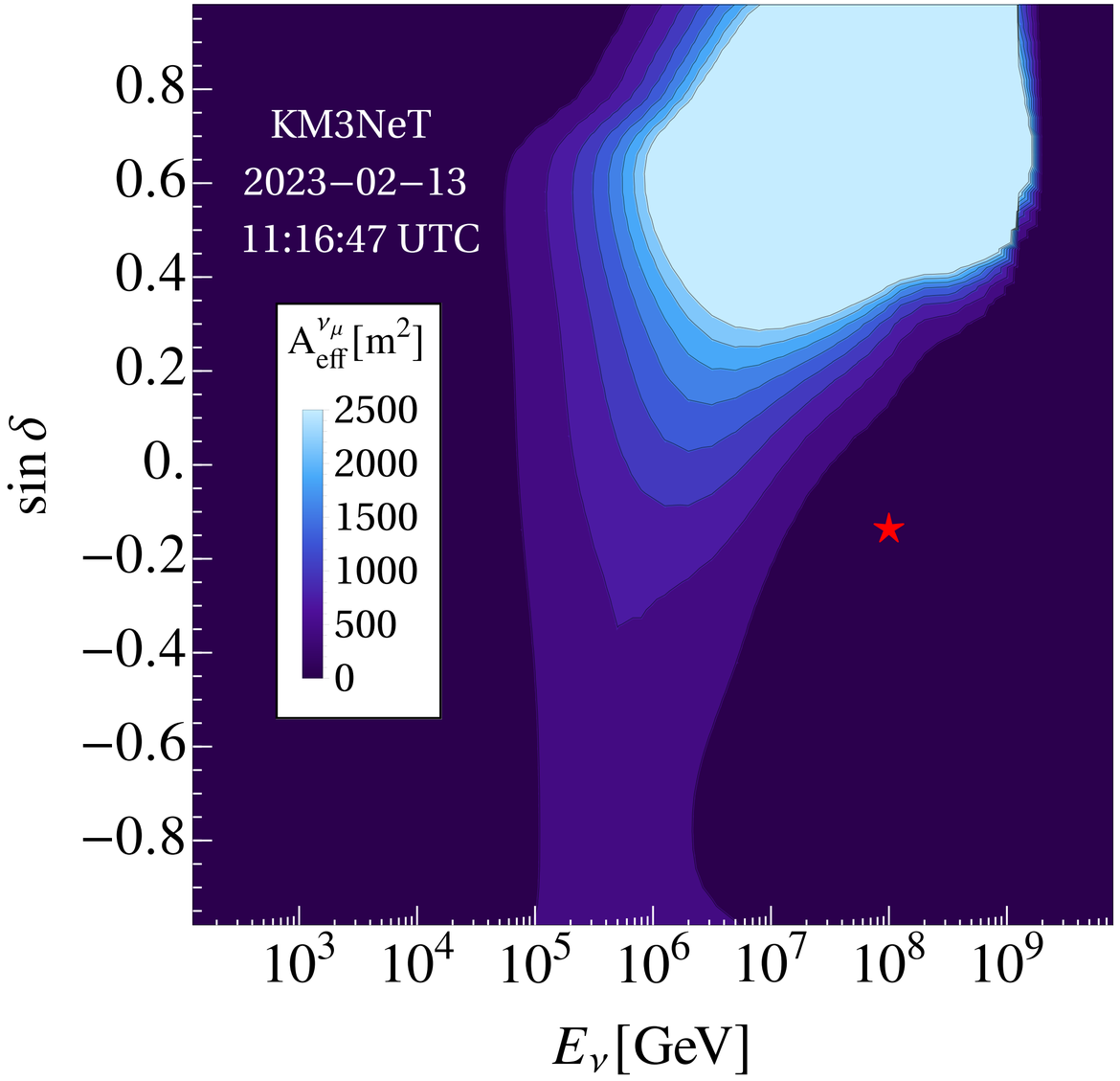
Plenum, arxiv:2503.07549/2107.13534

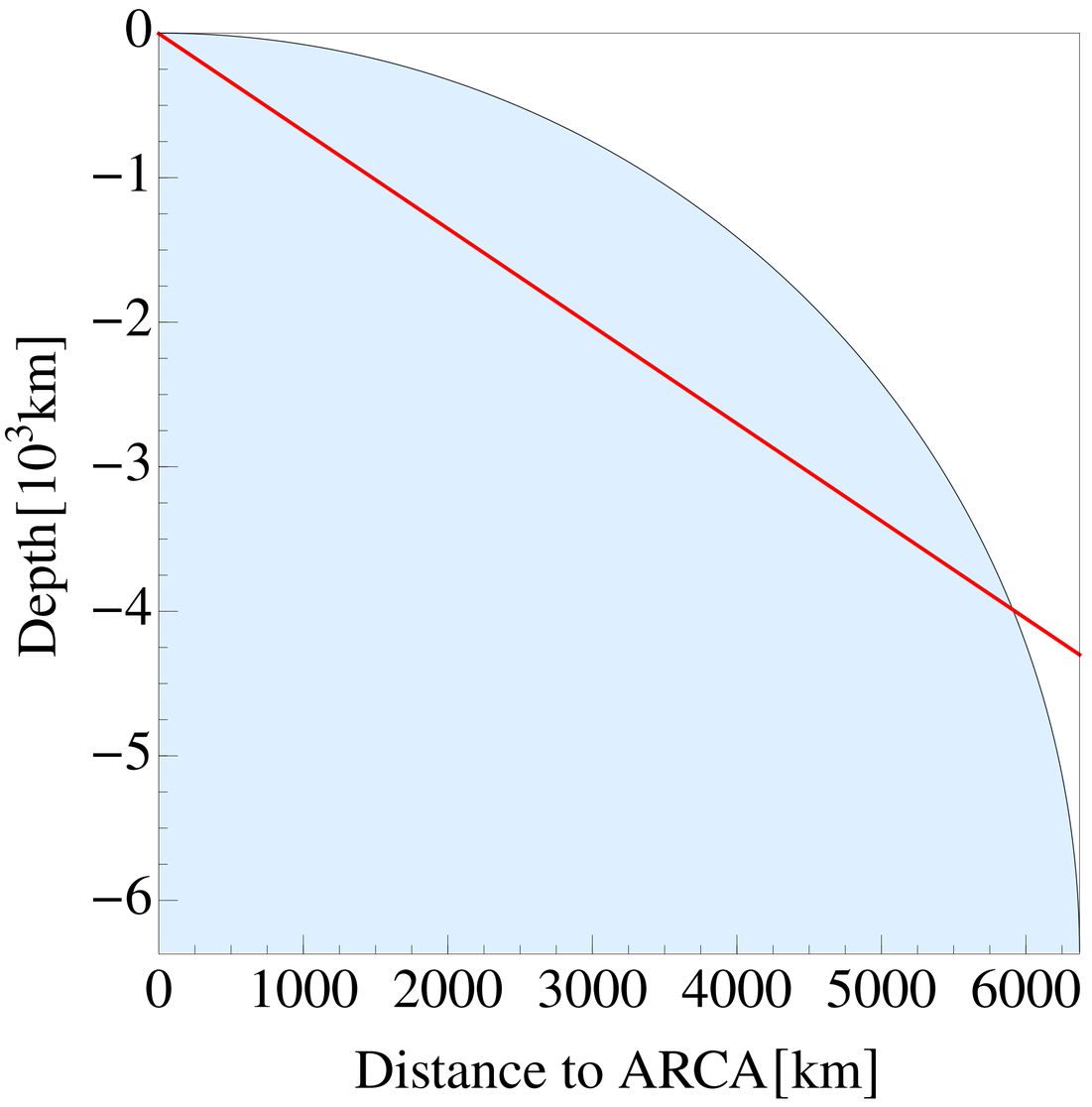
KM3NeT effective area at the time of the event





10 hours later…





Number of events

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$$N_{\text{evts}} = \frac{1}{4\pi d^2} \int dE\ A(E, \delta, \text{RA}) \int_0^{\tau_B} dt \frac{dN}{dt dE}\Big|_{\text{Earth}}$$

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What is the relevant τ_B ?

The high energy tail

$$T \simeq 7.8 \times 10^3 \times \left(\frac{1\ \mathrm{s}}{\tau_B} \right)^{1/3} \mathrm{GeV}$$

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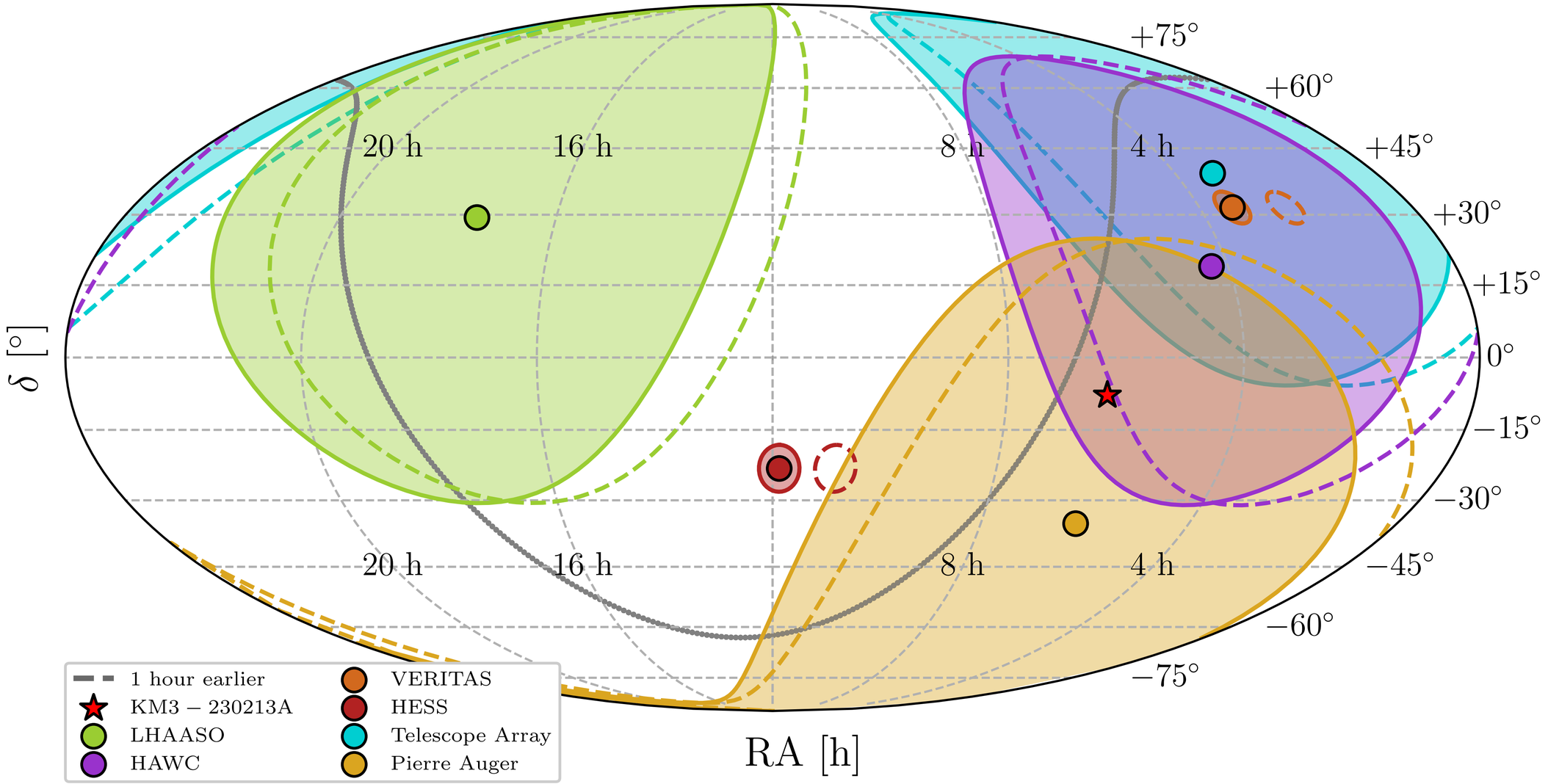
$$15\ y \rightarrow 10\ \mathrm{GeV}$$

Can the KM3NeT be a PBH burst?



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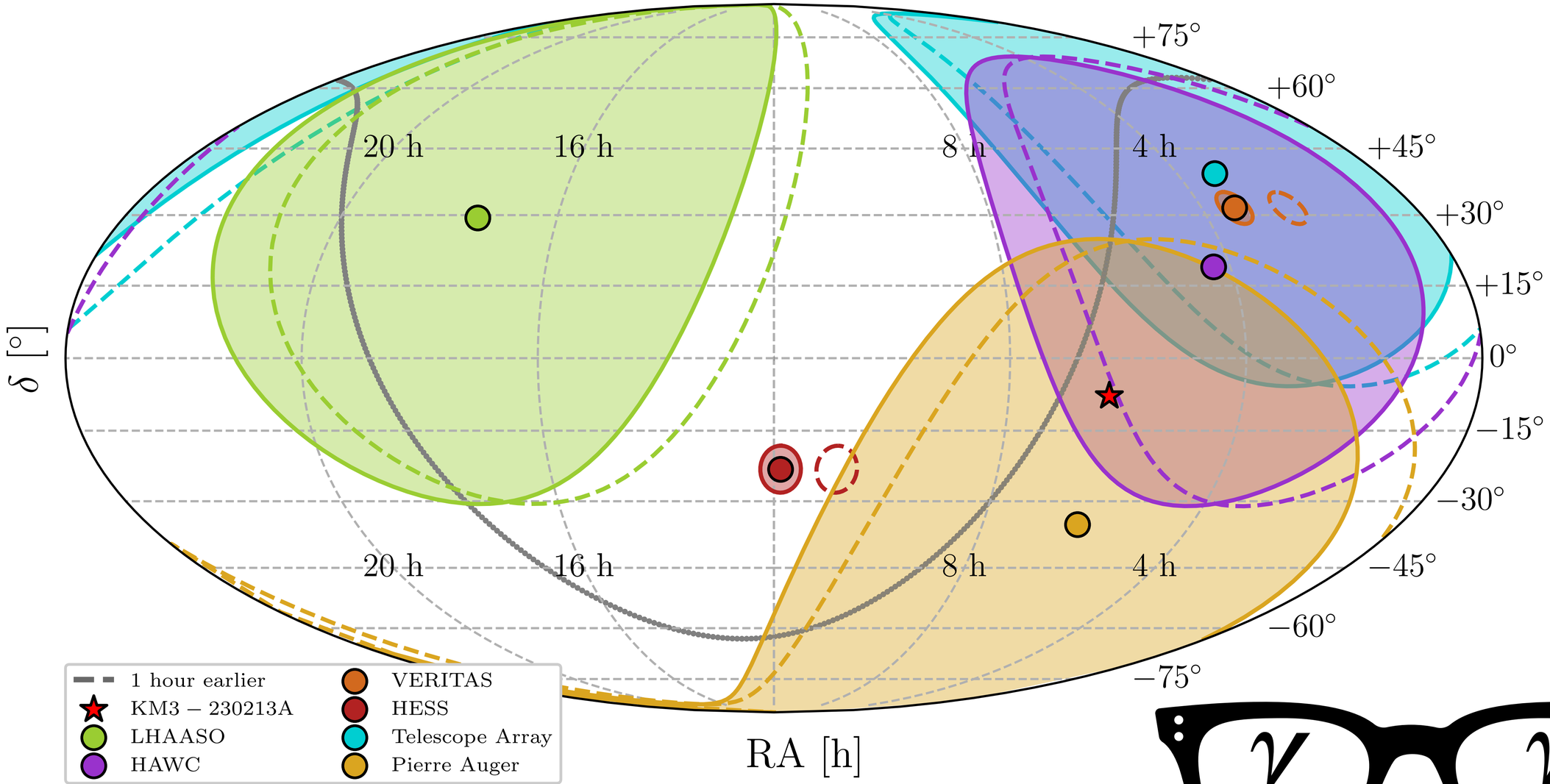
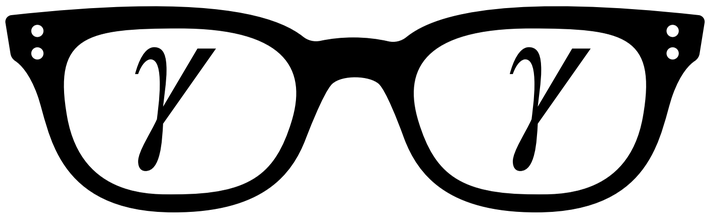




Can the KM3NeT be a PBH burst?

HAWC follow-up observations of the KM3NeT neutrino event KM3-230213A

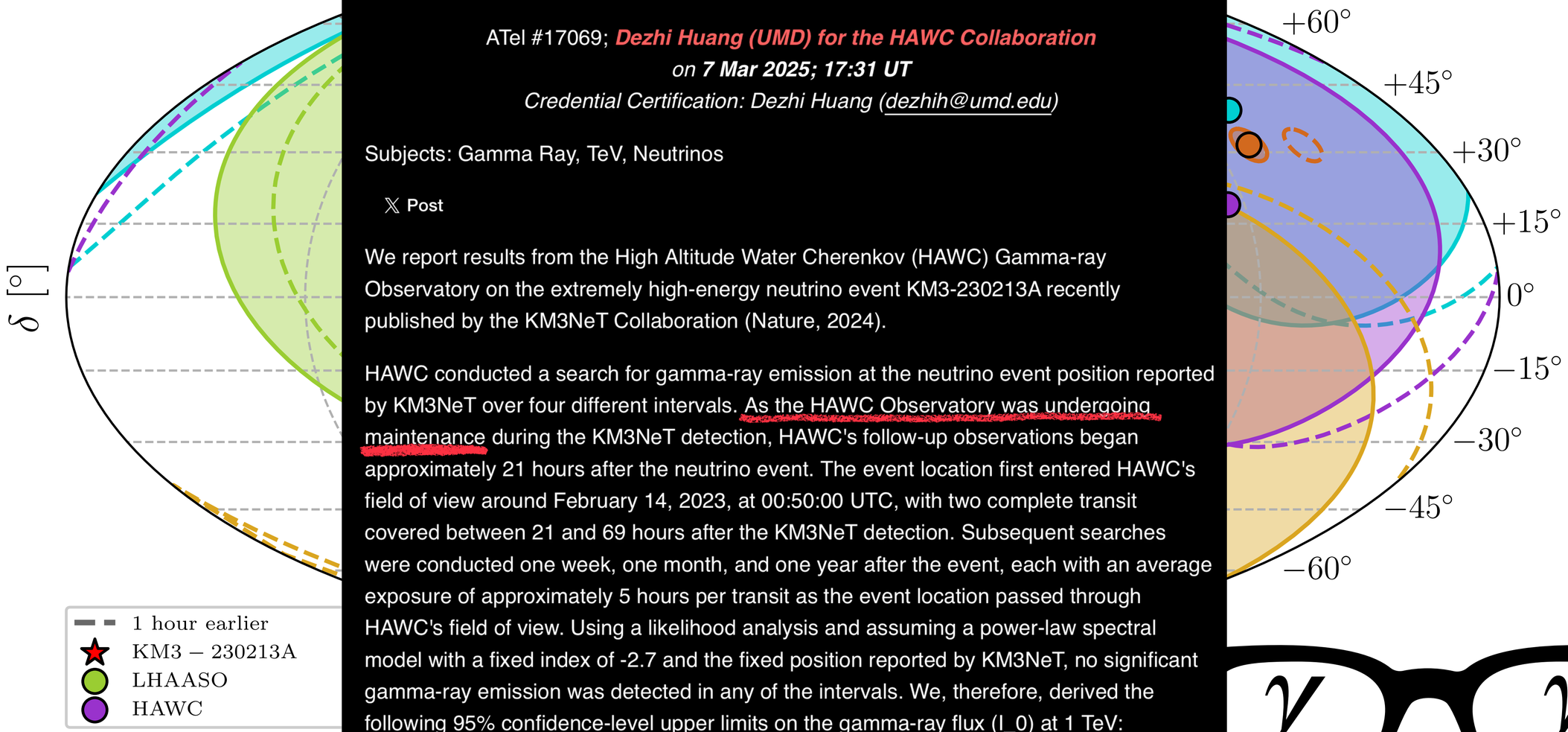
ATel #17069; ***Dezhi Huang (UMD) for the HAWC Collaboration***
*on **7 Mar 2025; 17:31 UT***
Credential Certification: Dezhi Huang (dezhih@umd.edu)

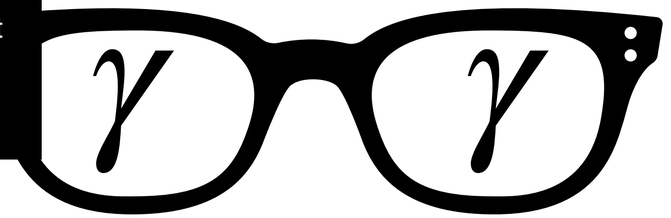
Subjects: Gamma Ray, TeV, Neutrinos

𝕏 Post

We report results from the High Altitude Water Cherenkov (HAWC) Gamma-ray Observatory on the extremely high-energy neutrino event KM3-230213A recently published by the KM3NeT Collaboration (Nature, 2024).

HAWC conducted a search for gamma-ray emission at the neutrino event position reported by KM3NeT over four different intervals. As the HAWC Observatory was undergoing maintenance during the KM3NeT detection, HAWC's follow-up observations began approximately 21 hours after the neutrino event. The event location first entered HAWC's field of view around February 14, 2023, at 00:50:00 UTC, with two complete transit covered between 21 and 69 hours after the KM3NeT detection. Subsequent searches were conducted one week, one month, and one year after the event, each with an average exposure of approximately 5 hours per transit as the event location passed through HAWC's field of view. Using a likelihood analysis and assuming a power-law spectral model with a fixed index of -2.7 and the fixed position reported by KM3NeT, no significant gamma-ray emission was detected in any of the intervals. We, therefore, derived the following 95% confidence-level upper limits on the gamma-ray flux (I_0) at 1 TeV:





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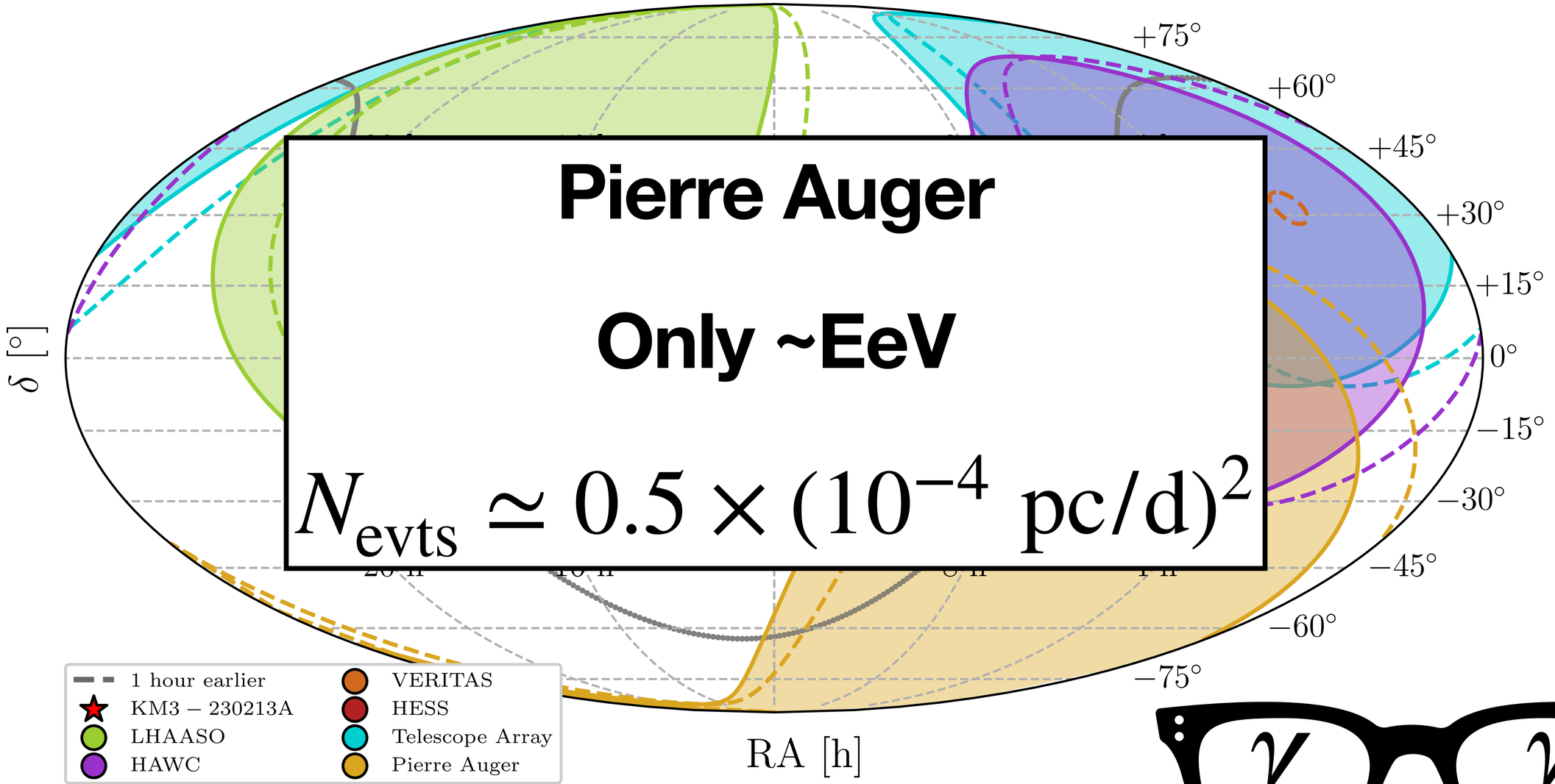
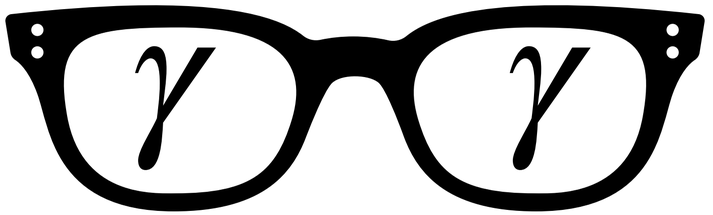
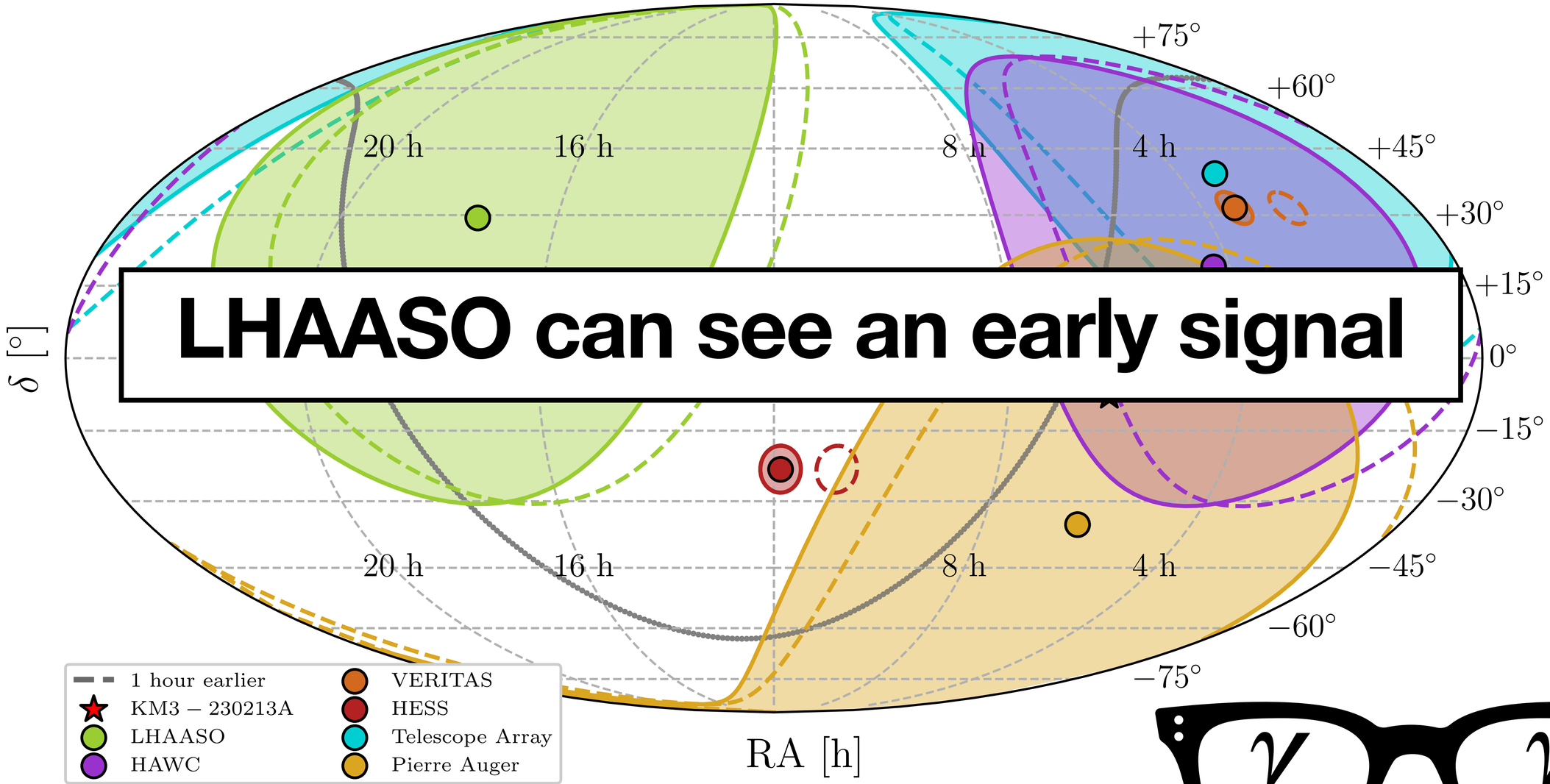
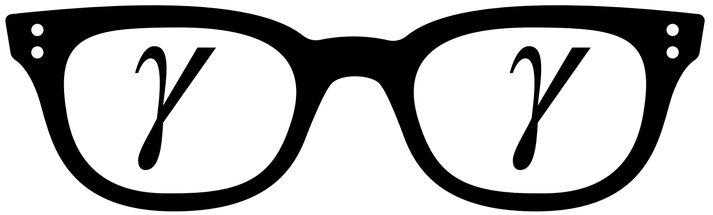




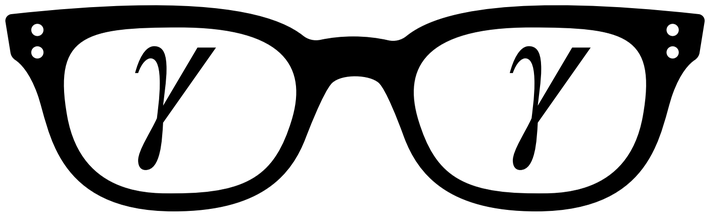
Caveat: Spoiler alert! Pre burst monitors





One PBH event in KM3NeT would not be serendipitous

ARCA is optimized for the TeV range



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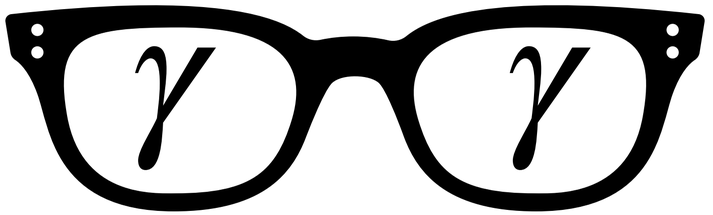

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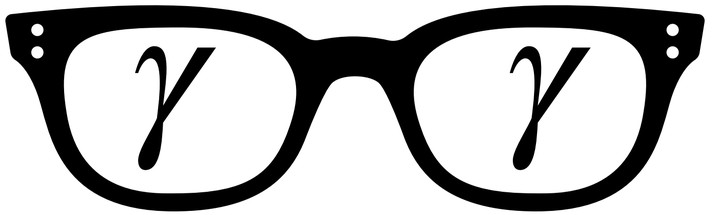

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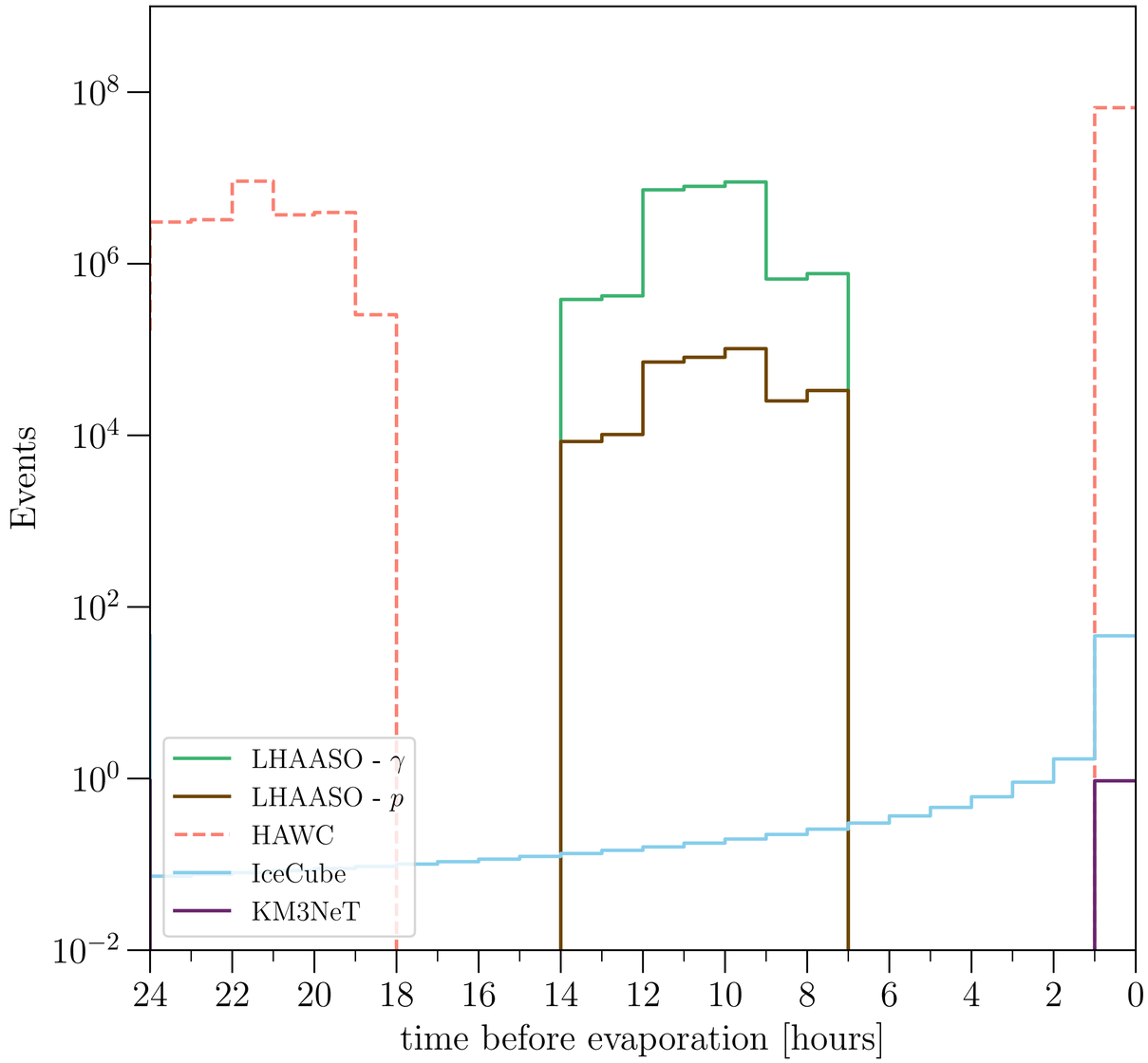

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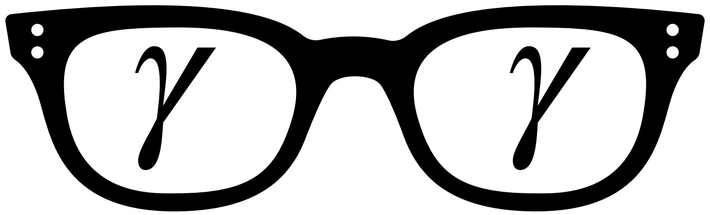

Back to square one

Can neutrinos be the only candidate for observing a source?

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Gamma rays can be:

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Gamma rays can be:

Trapped or attenuated

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Meszaros, arxiv:1904.04226
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Outside the field of view

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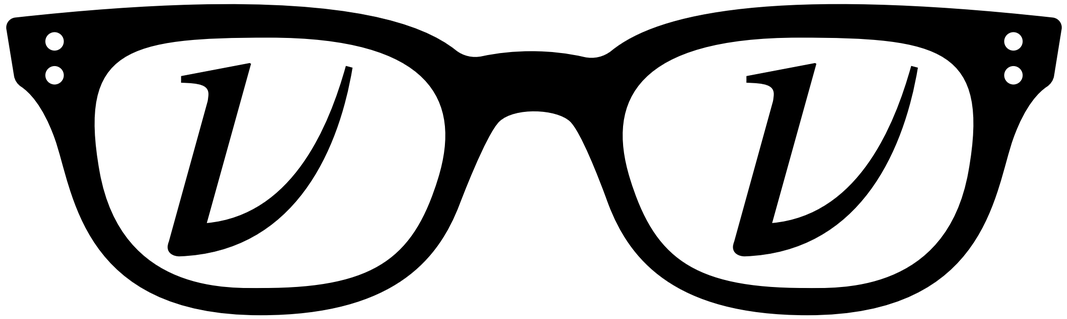
Outside the field of view

Observing the universe through the neutrino lens



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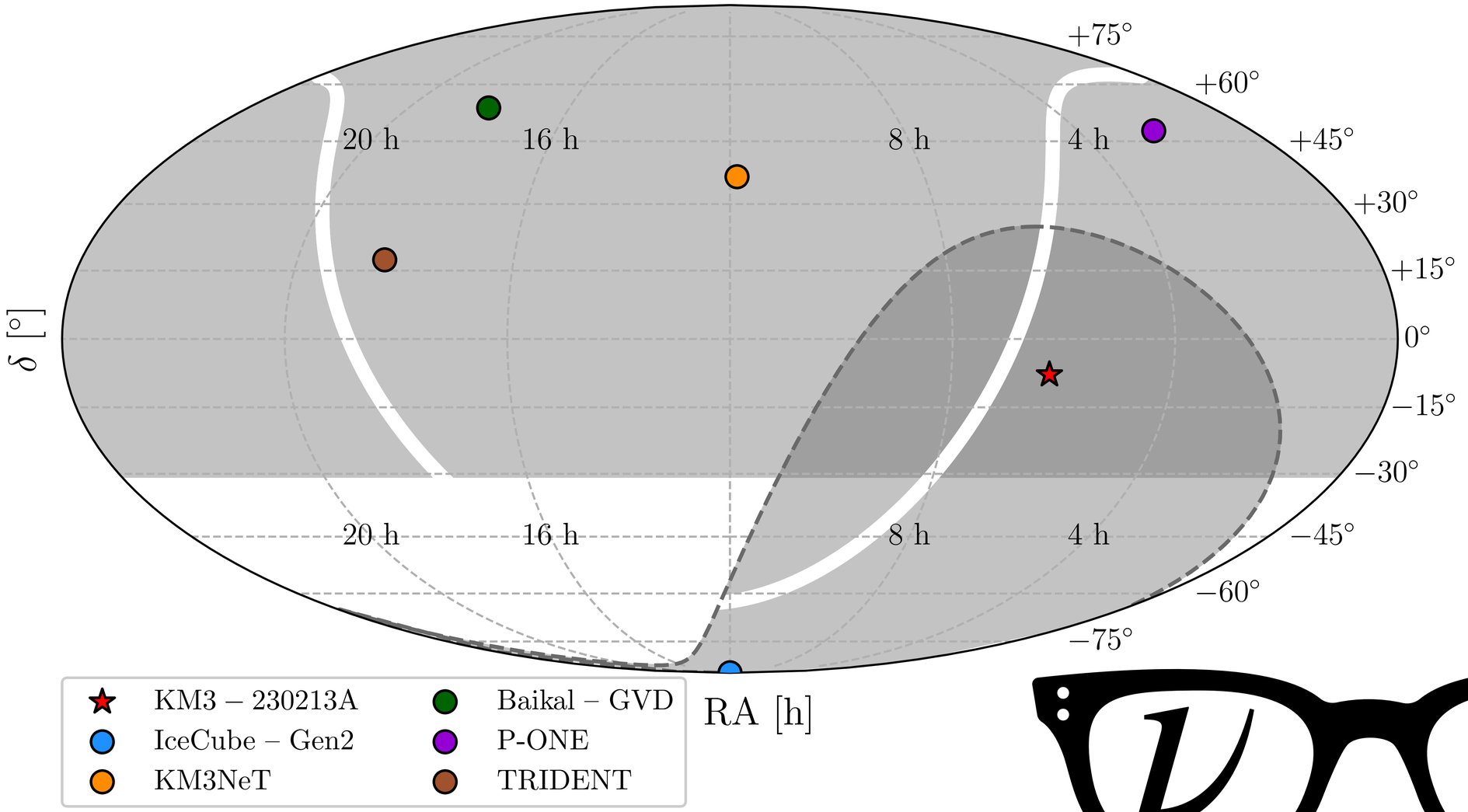
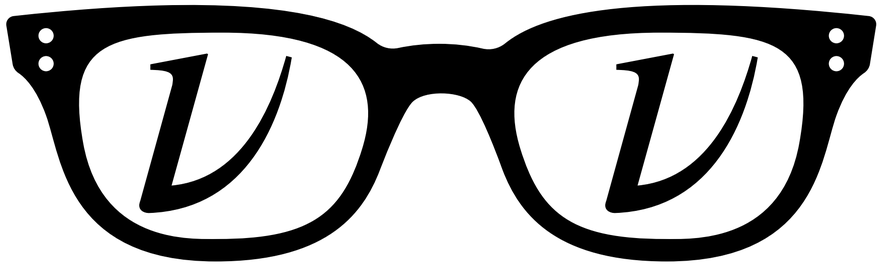
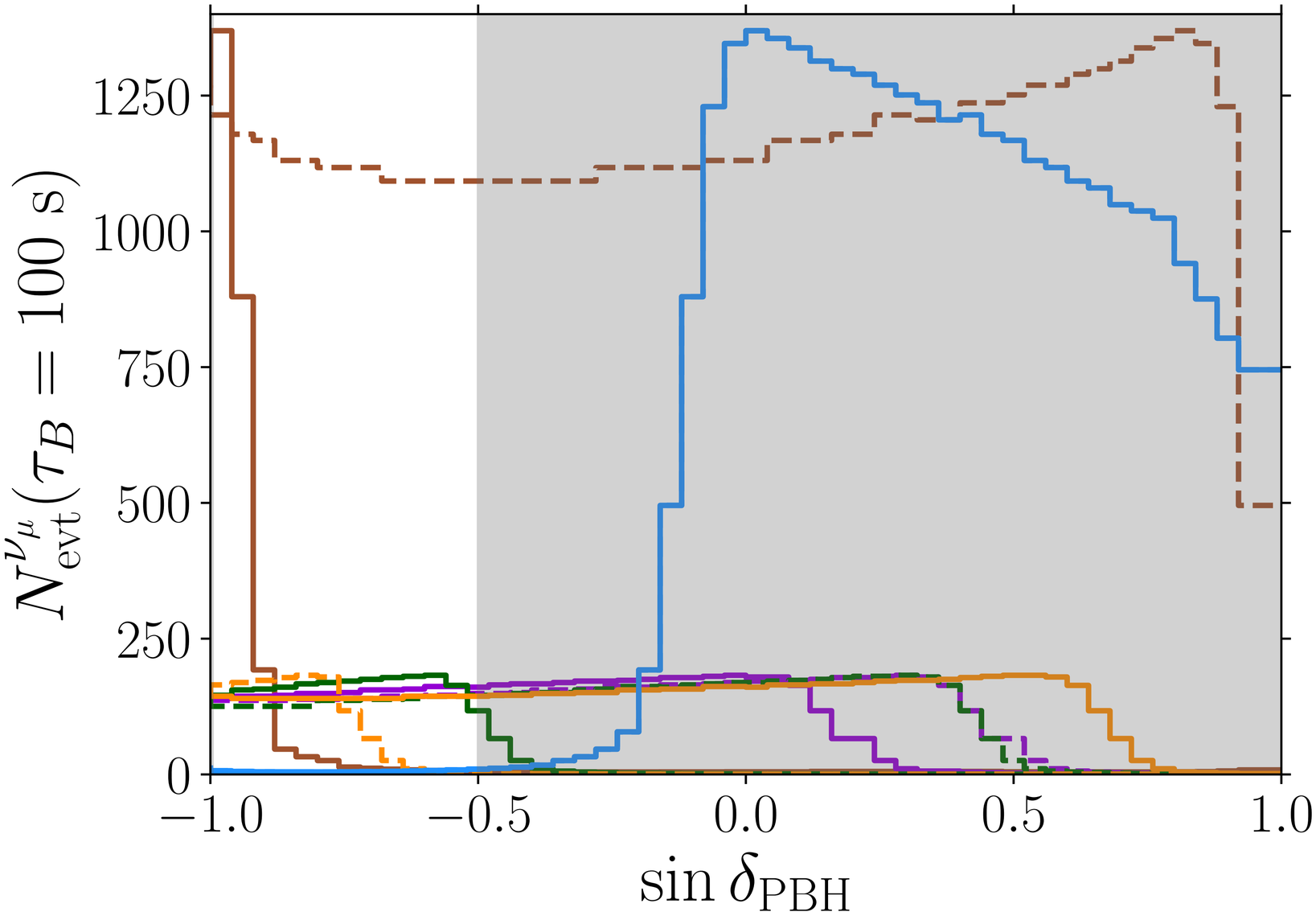




Neutrino telescope synergy

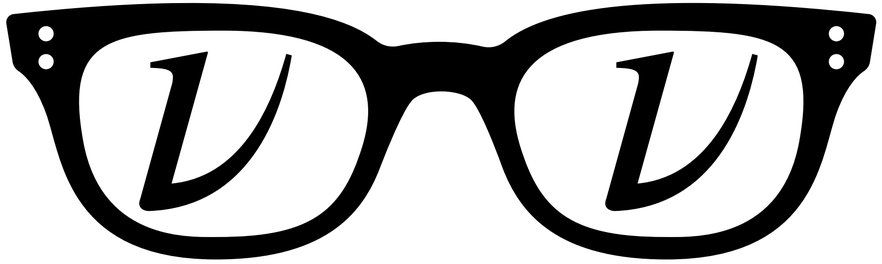


$\mathrm{RA_{PBH}} = 300°$ (20h)

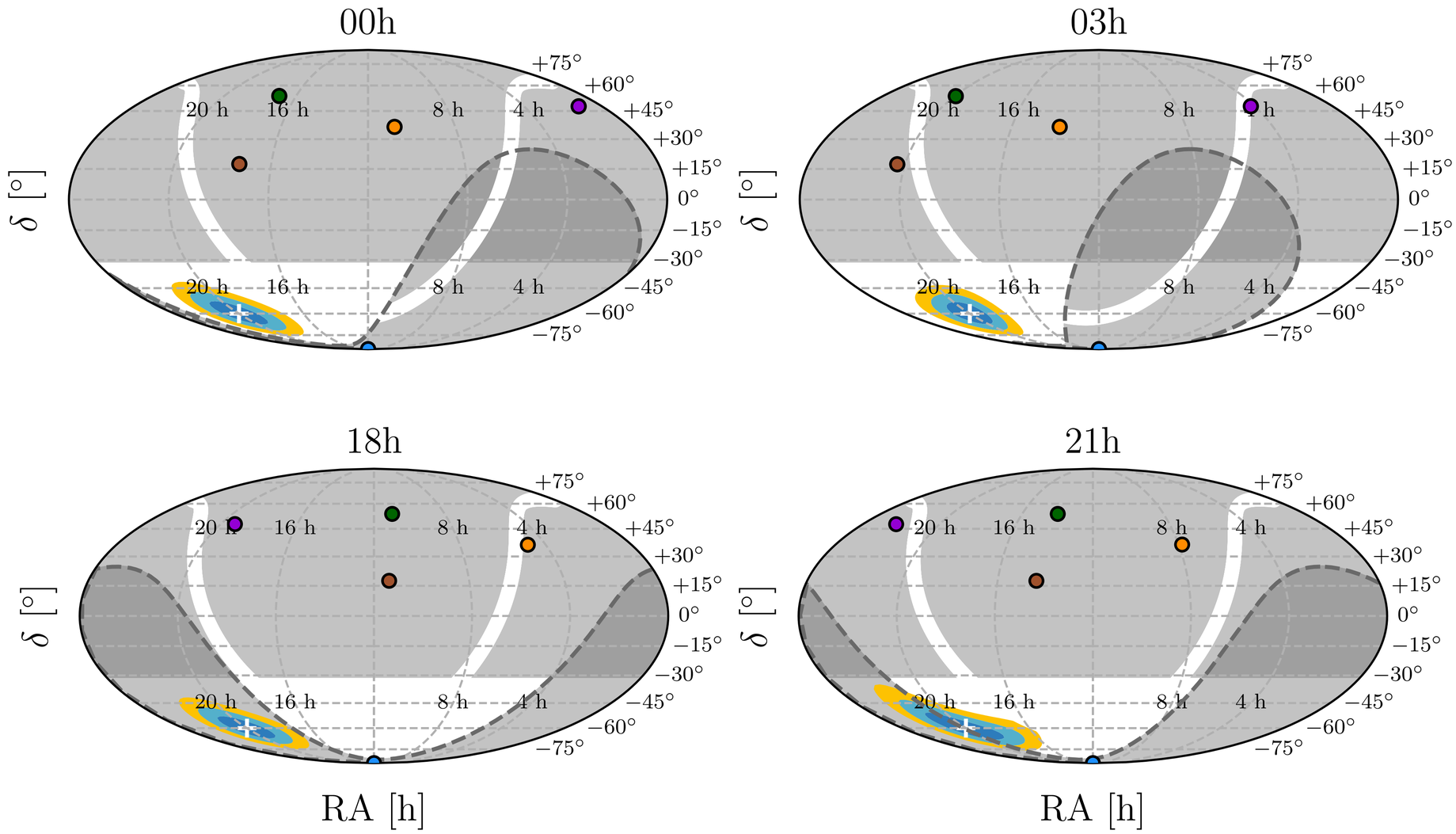
- IceCube – Gen2
- KM3NeT
- Baikal – GVD
- P – ONE
- TRIDENT

13th of February 2023

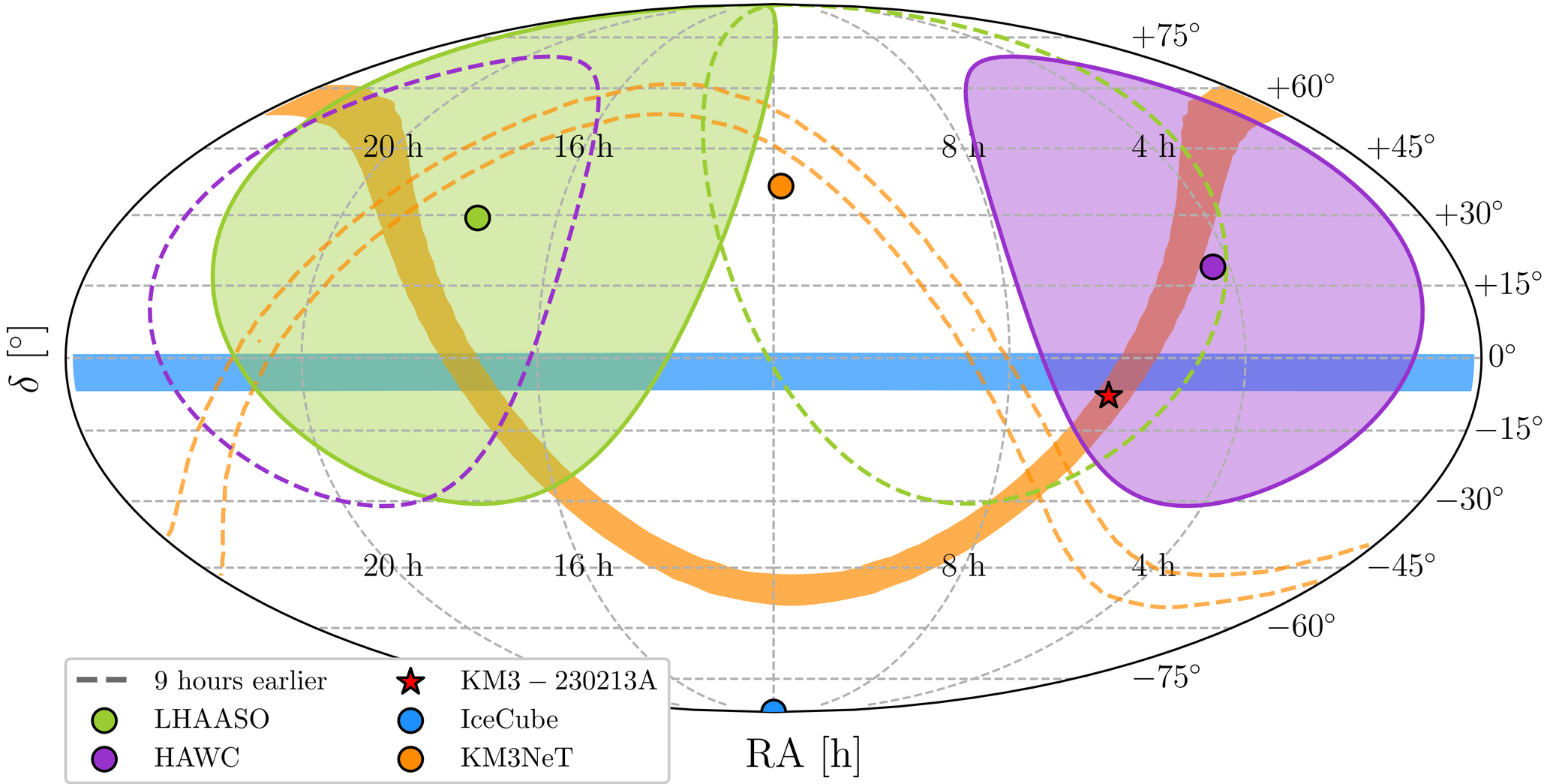
- 01 : 16 : 47 UTC
- 11 : 16 : 47 UTC



Pointing in the sky with neutrino telescopes



What did we learn today?



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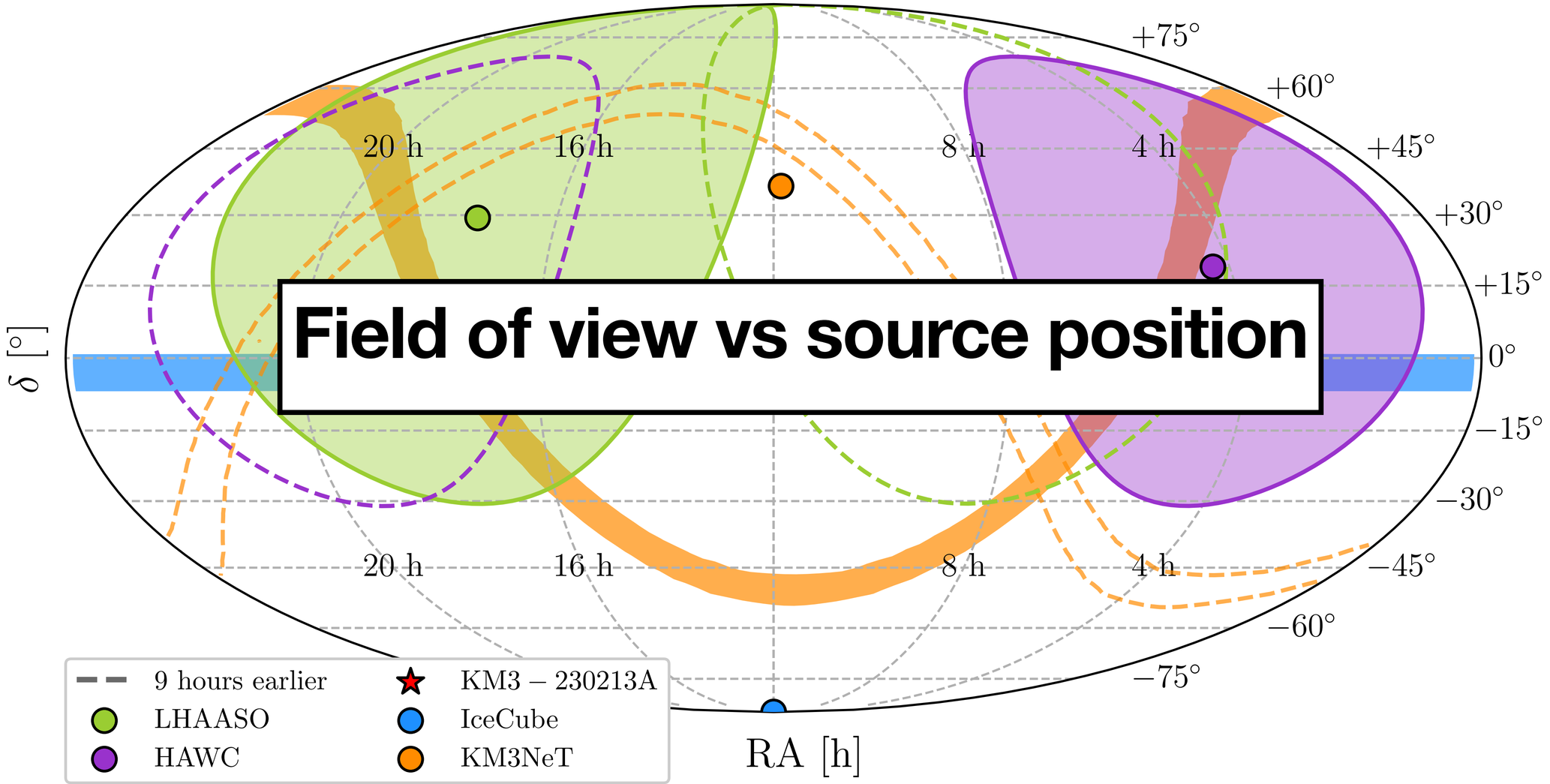

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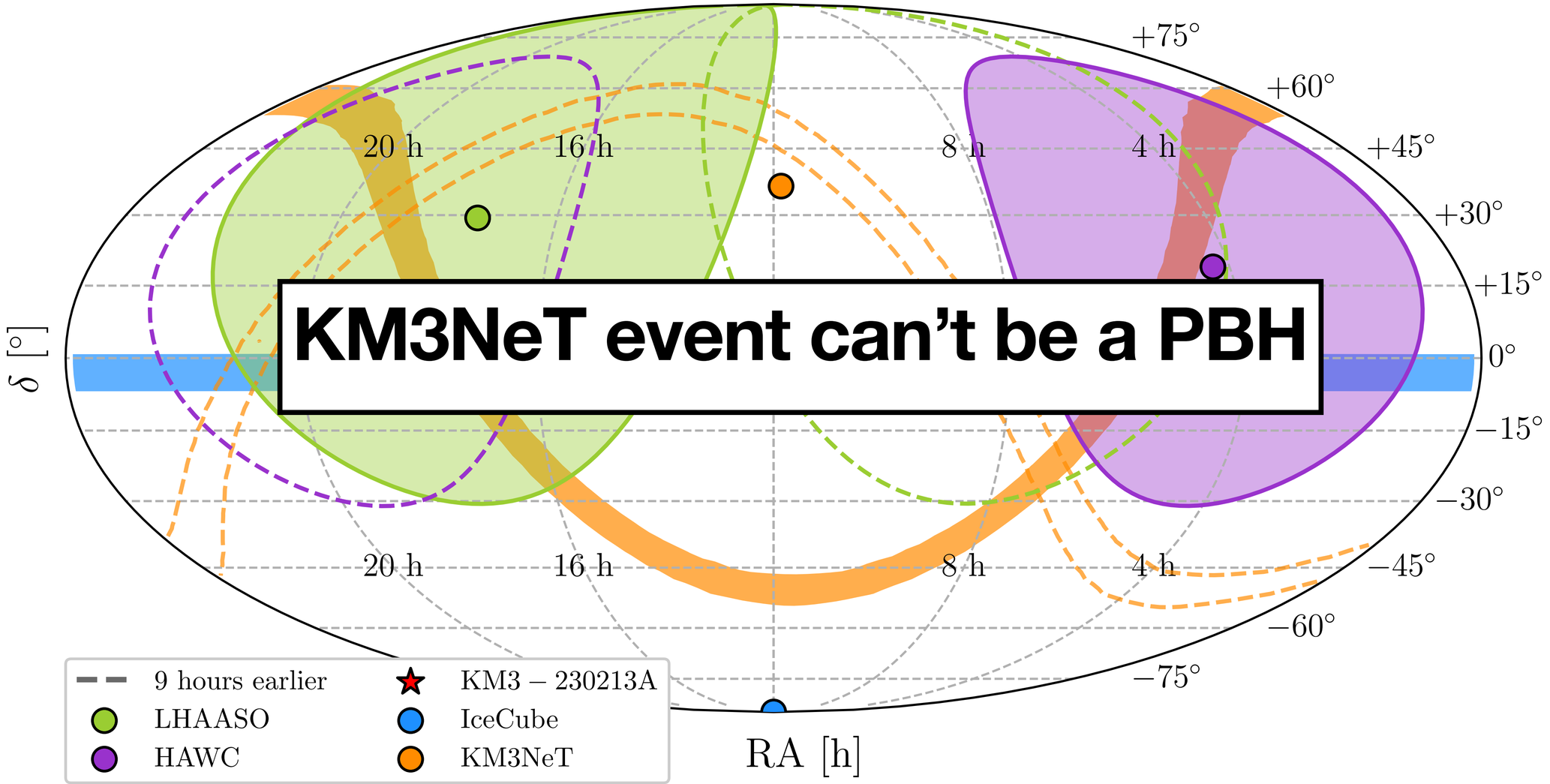

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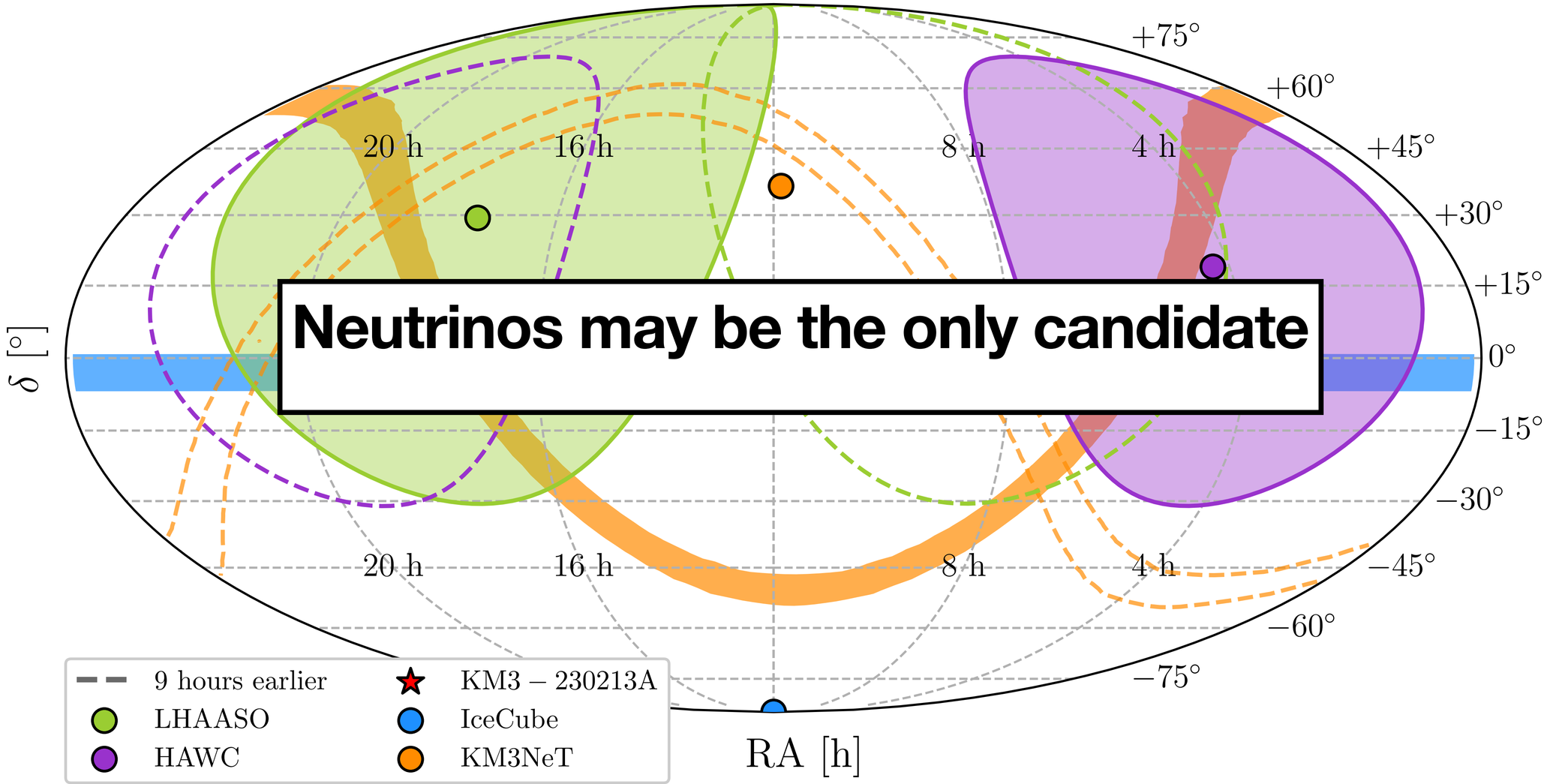

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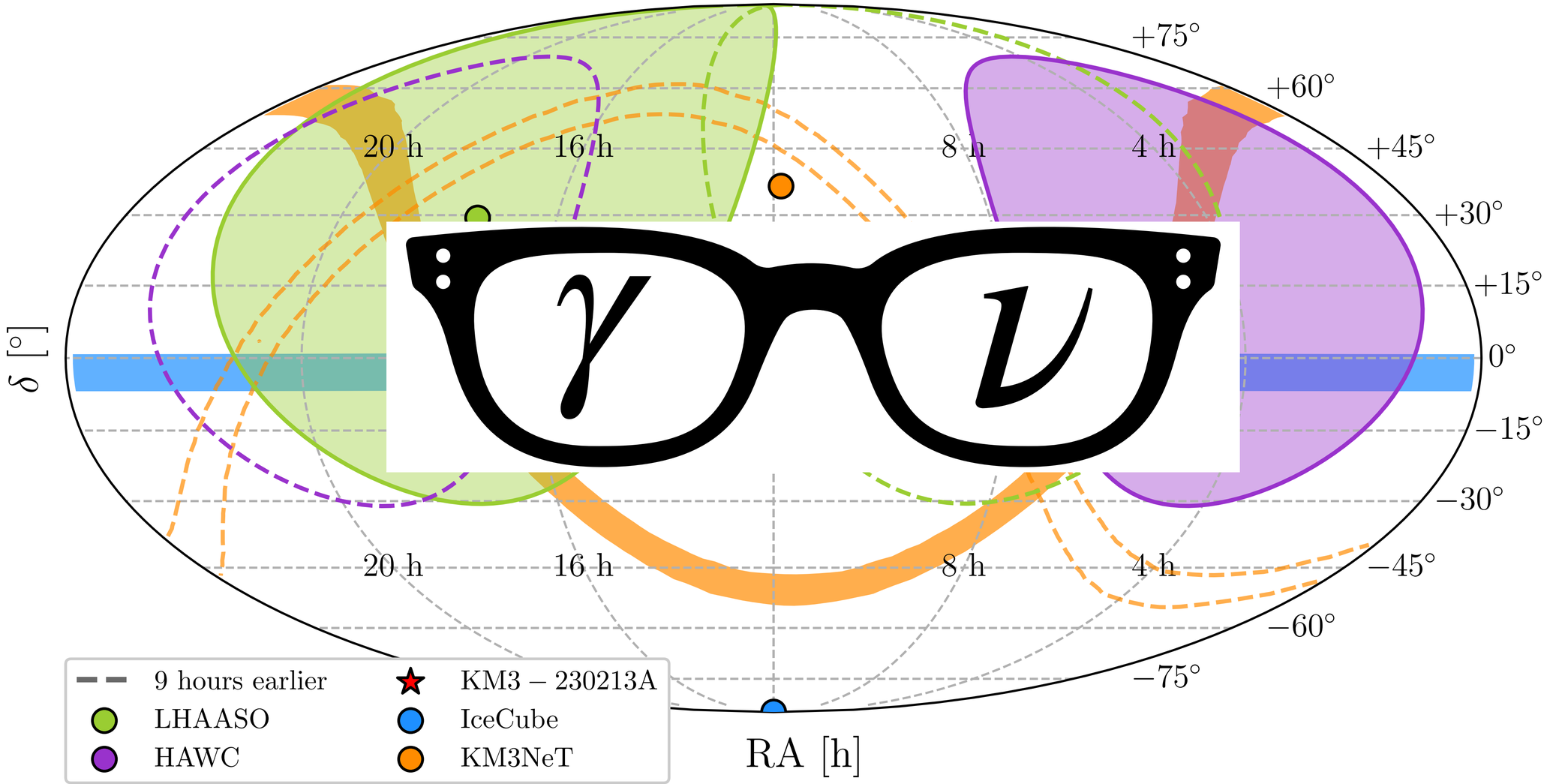

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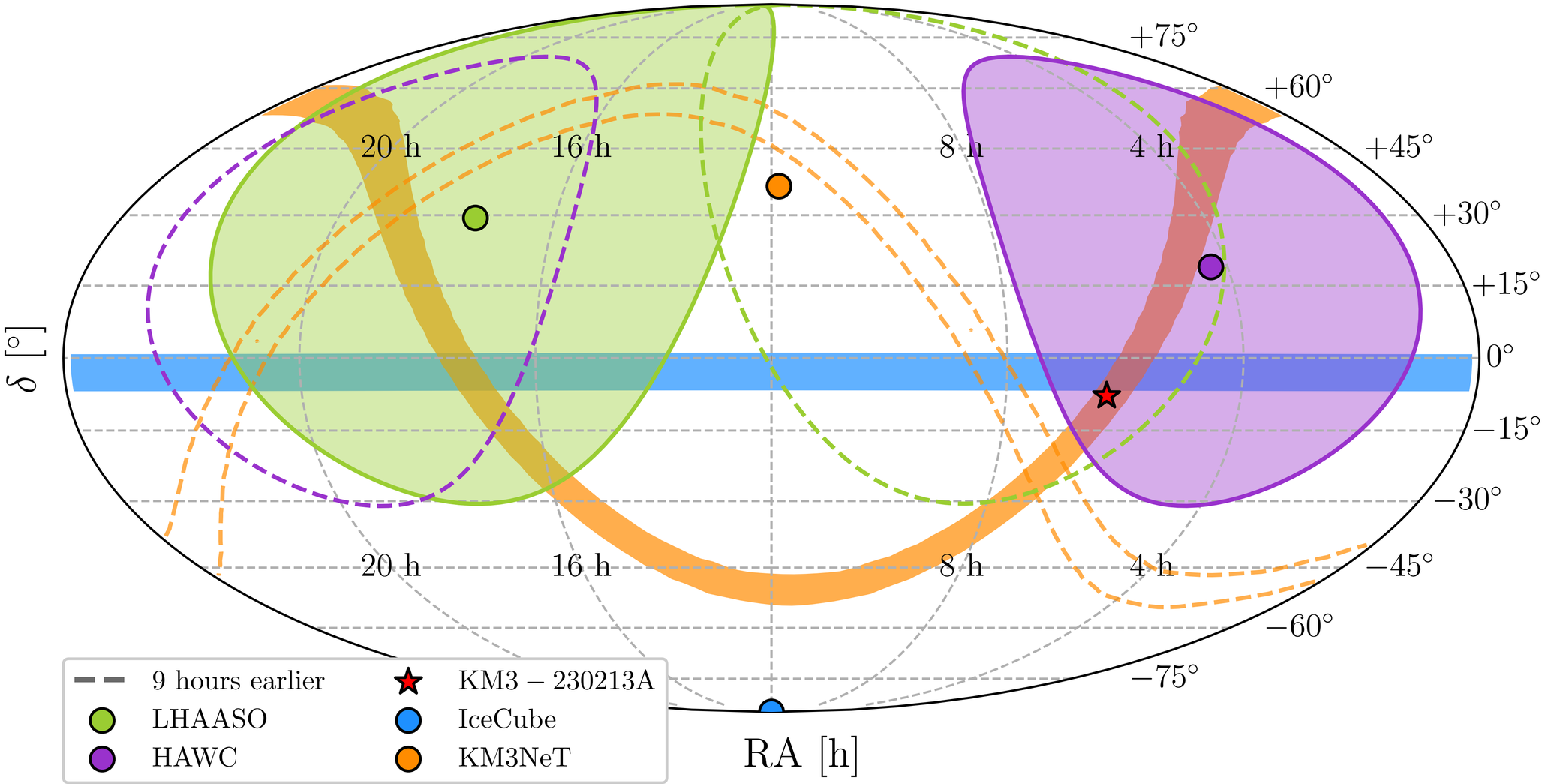

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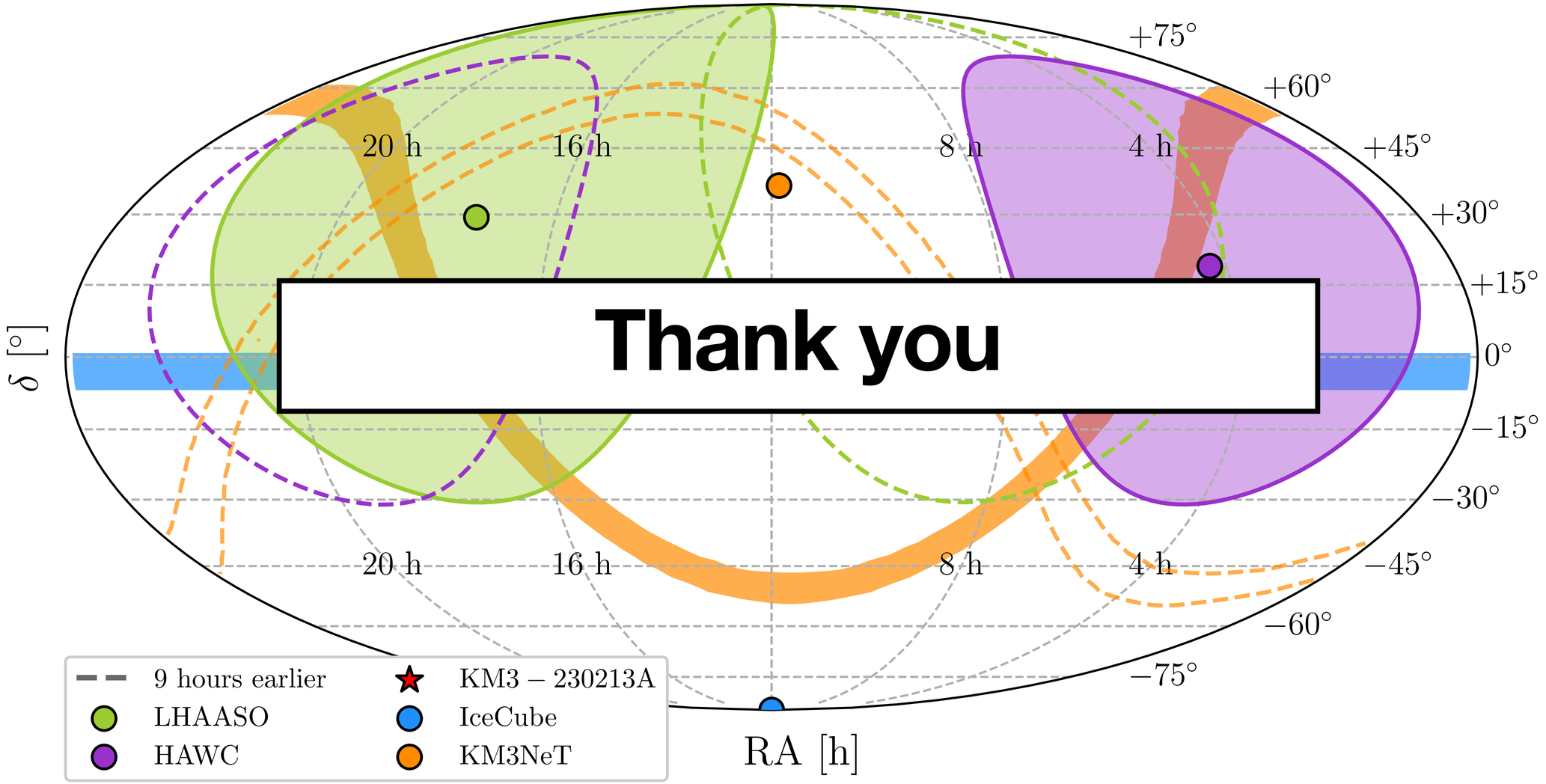

Thank you