

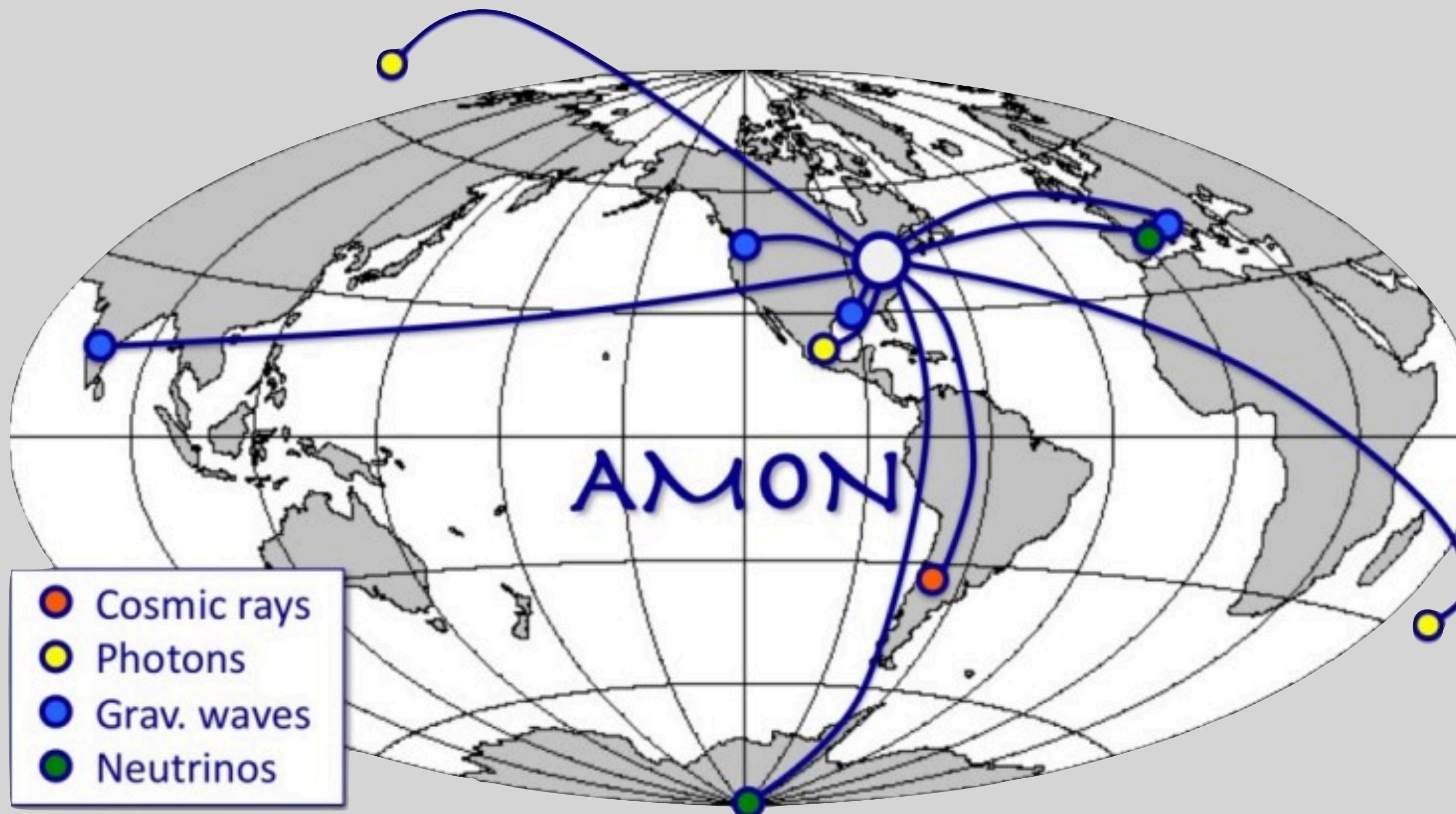
Multimessenger searches with AMON

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Astrophysical Multimessenger Observatory Network: a Multimessenger approach

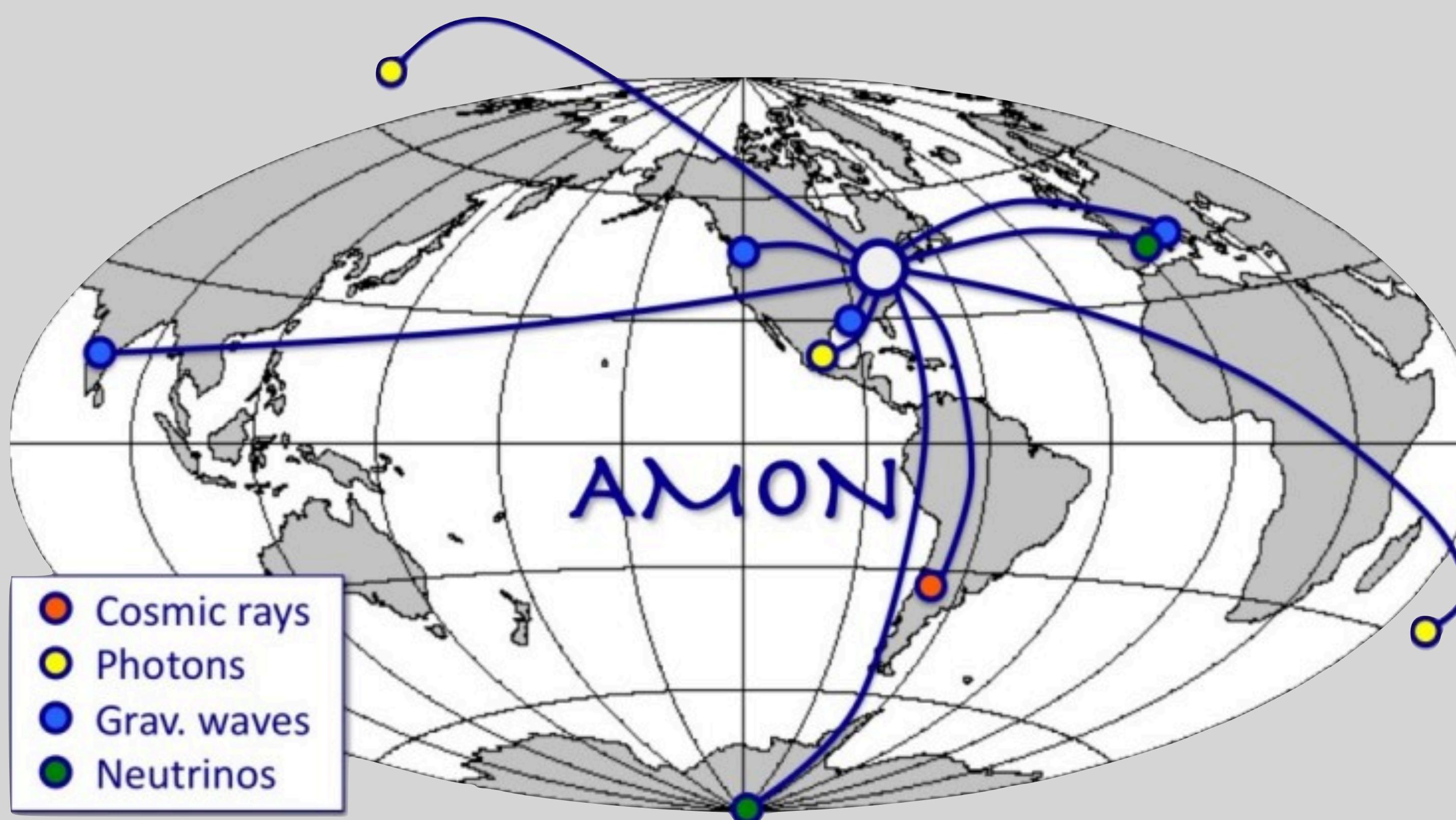


- *Discover transient multi-messenger sources*
- *Trigger follow-up observations to identify and study counterparts*
- *Analyze archival data in search of multi-messenger activity*

AMON

H. A. Ayala Solares et al
2019 Astro. Phys. 114 68-76

AMON: a framework to perform multi-messenger searches

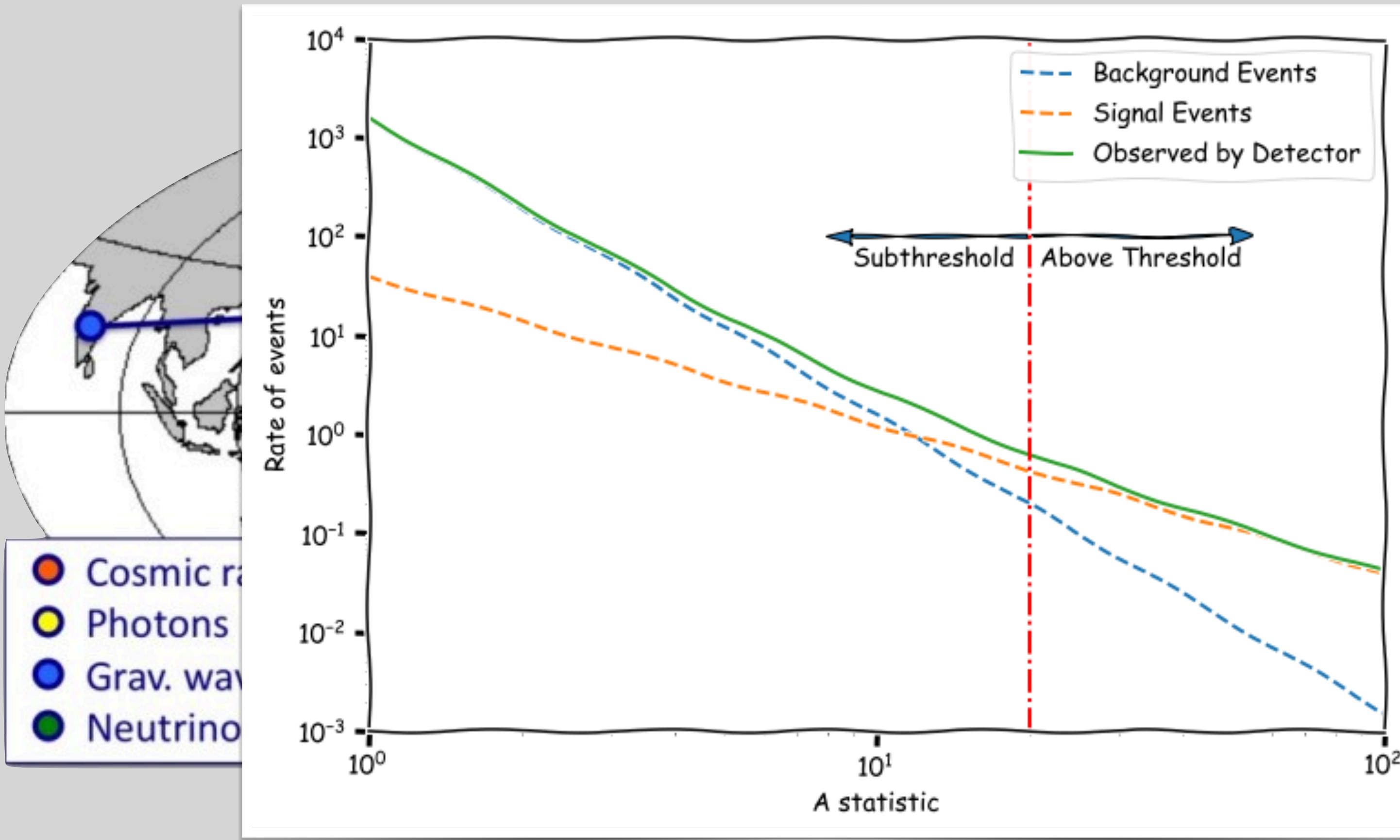


- Real-time coincidences
 - Use of **sub-threshold data**
- Archival Studies
 - Store events
 - Coincidence analyses
- Partners:
 - Triggering Observatories
 - Follow-up Observatories
- Pass-Through
- Broadcast directly to GCN/TAN and SCIMMA

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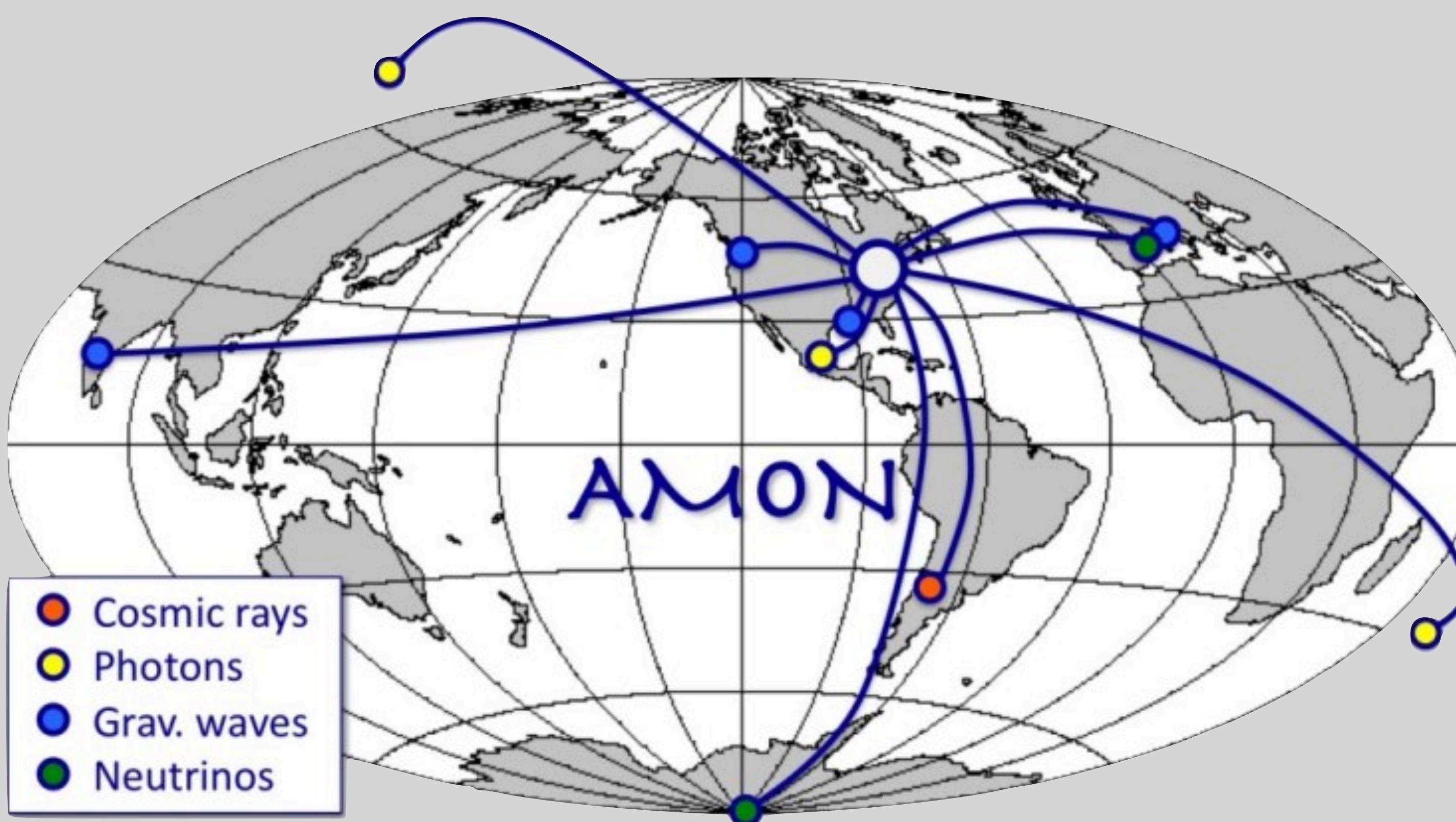


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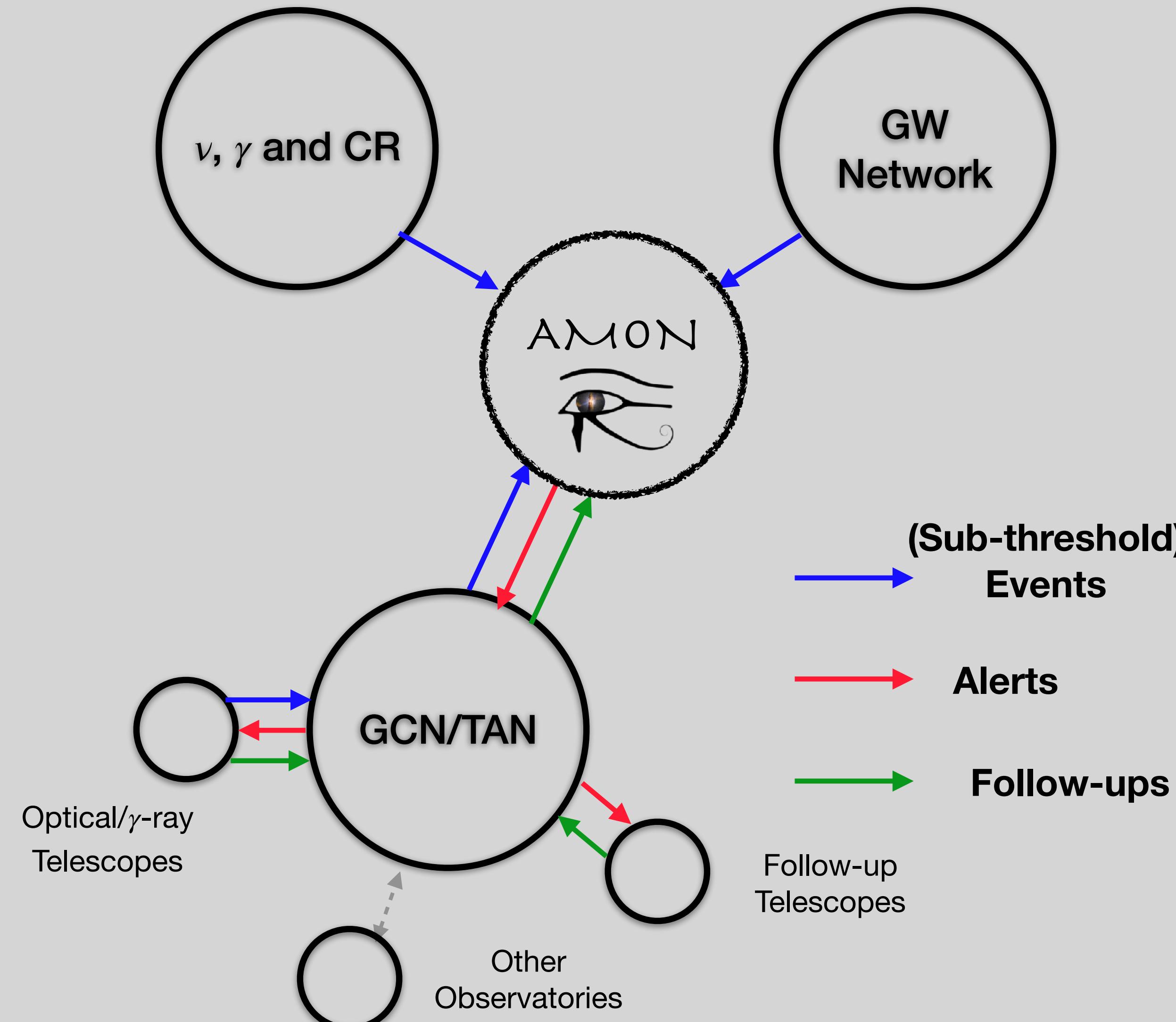


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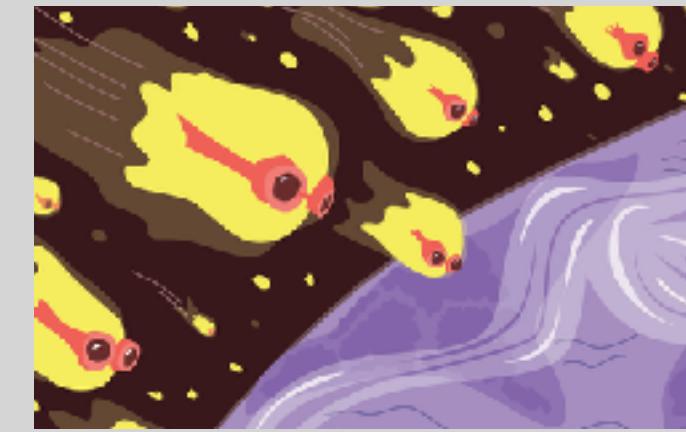
AMON

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AMON Network



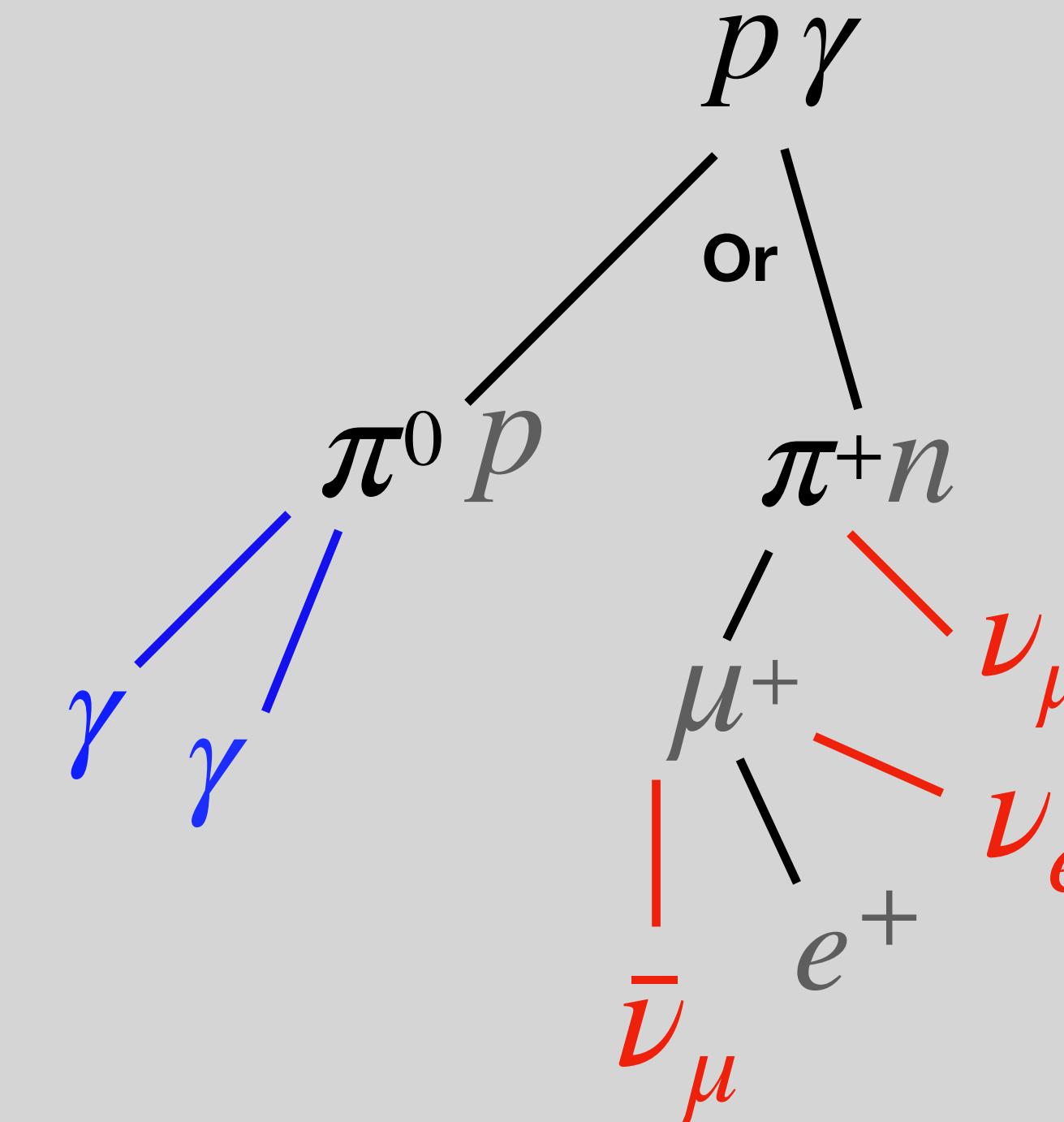
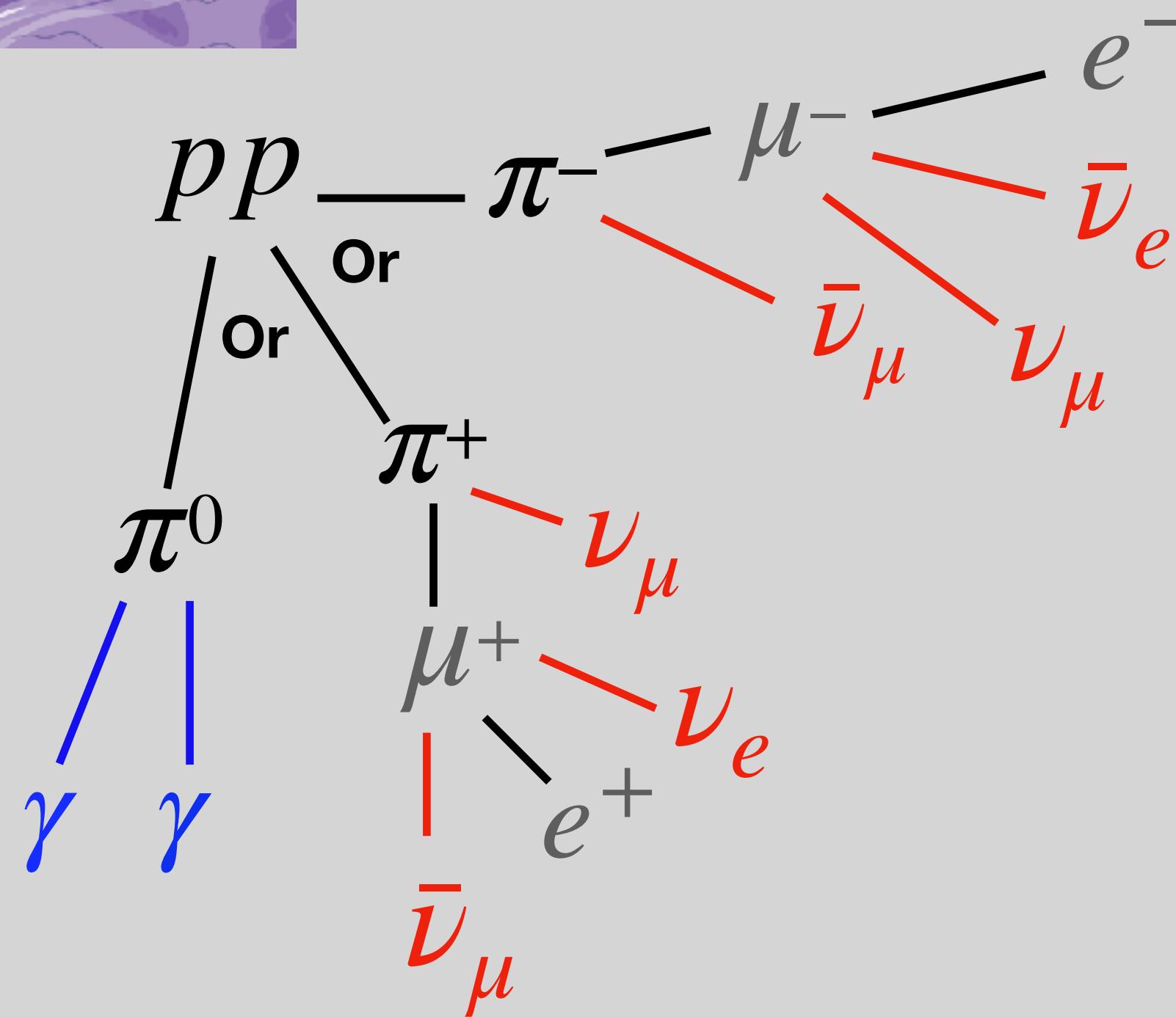
The Neutrino-Electromagnetic Channel



The Neutrino-Electromagnetic channel

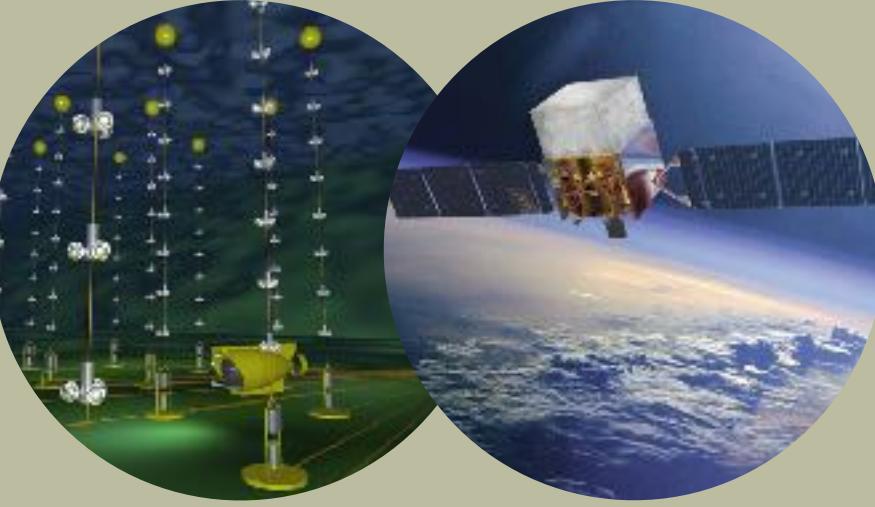


- Coincidence analyses between very-high-energy gamma-ray data and high-energy neutrino data
- Objective: Search for sources of high-energy neutrinos (i.e. hadronic accelerators)



The NuEM channel: analyses

Archival Analysis



ANTARES +Fermi LAT

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2019 ApJ 886 98

Real-time analysis



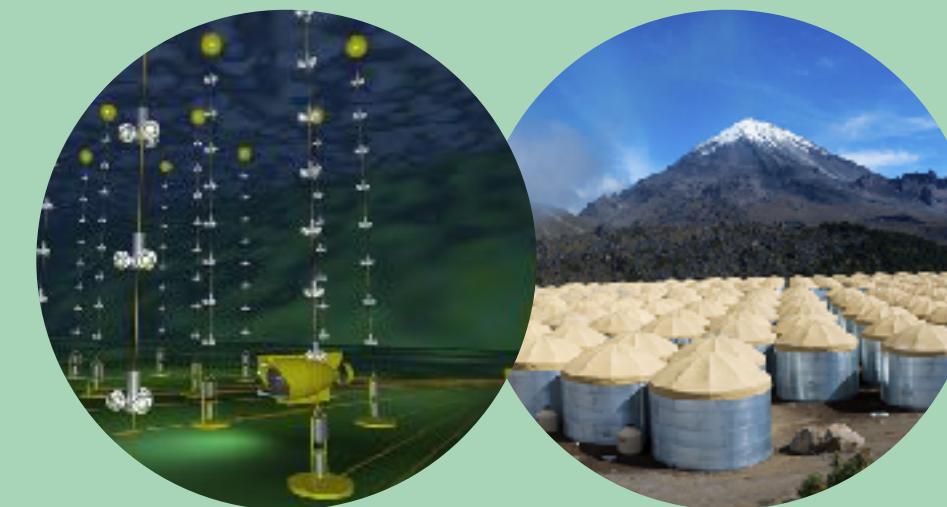
IceCube + HAWC

H. A. Ayala Solares et al
2021 ApJ 906 63



IceCube +Fermi LAT

C. F. Turley et al 2018
ApJ 863 64



ANTARES + HAWC

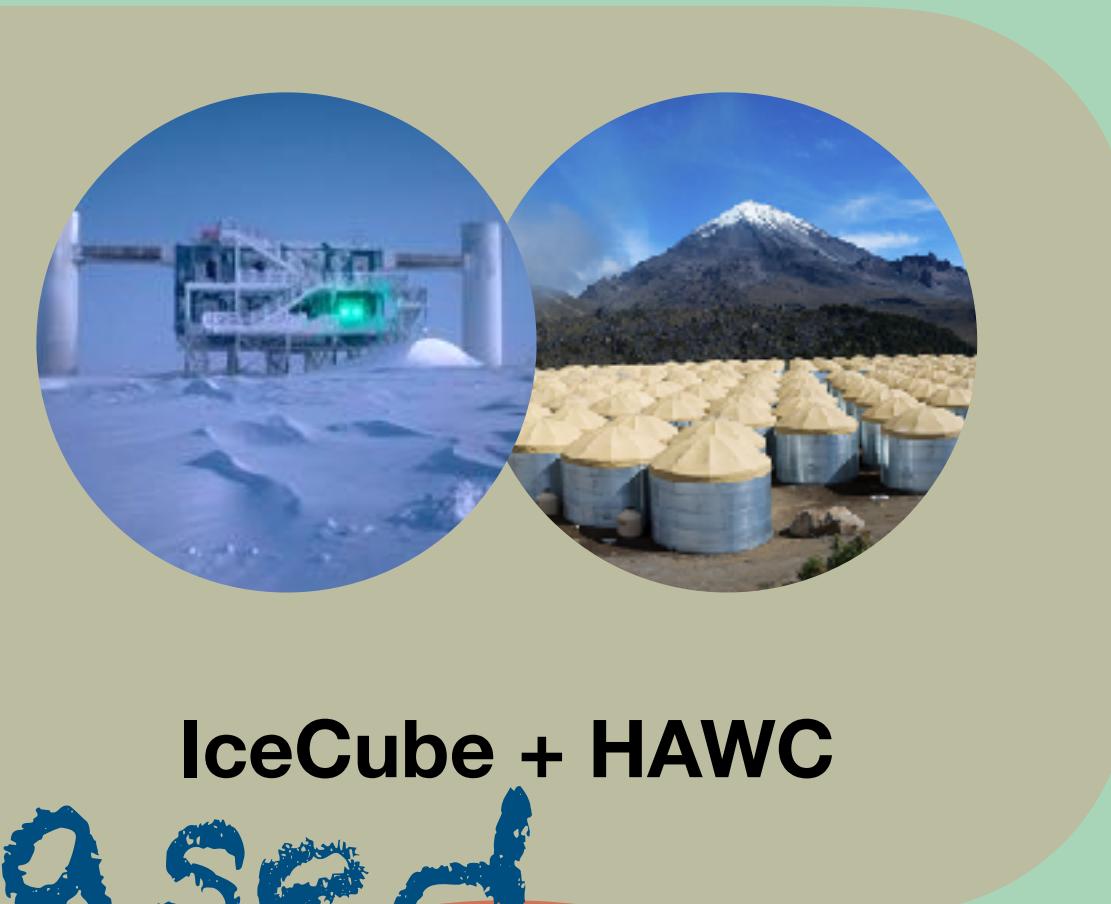
H. A. Ayala Solares et al
2023 ApJ 944 166

The NuEM channel: analyses

Archival Analysis

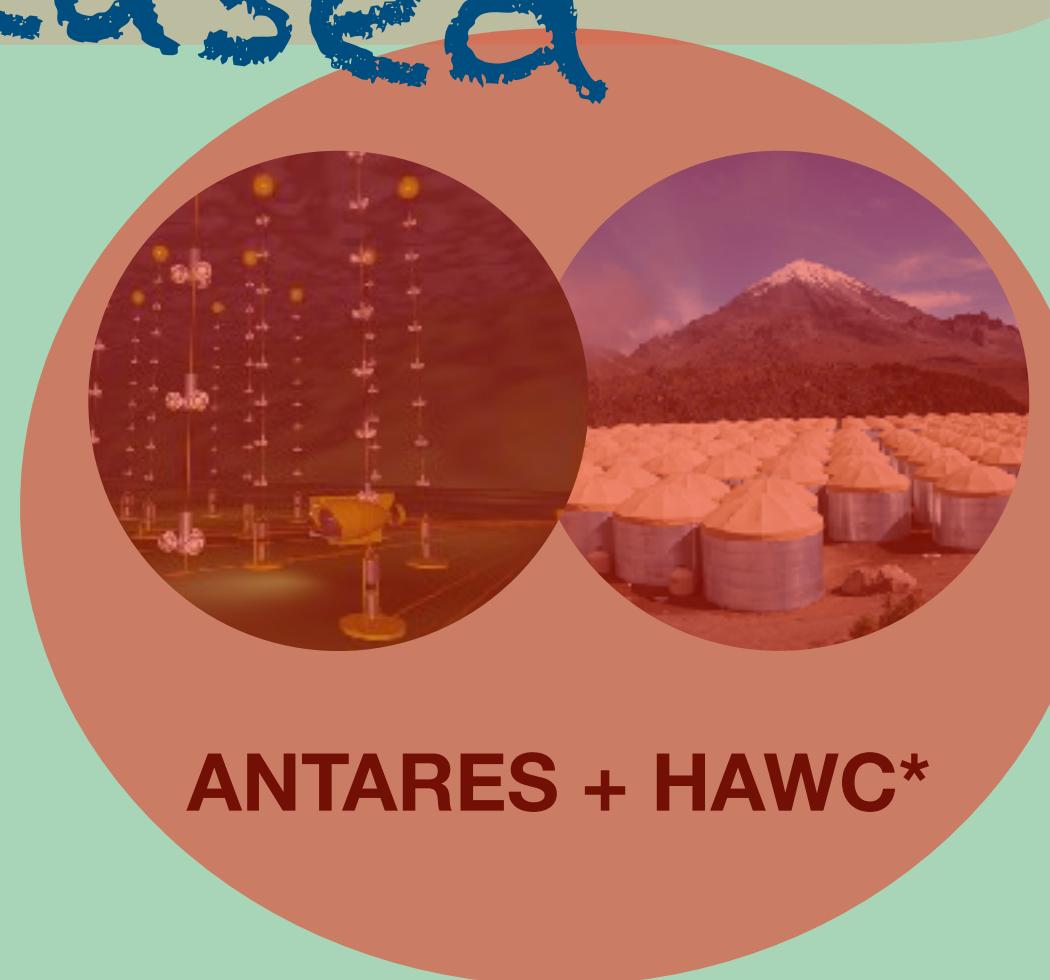


Real-time analysis

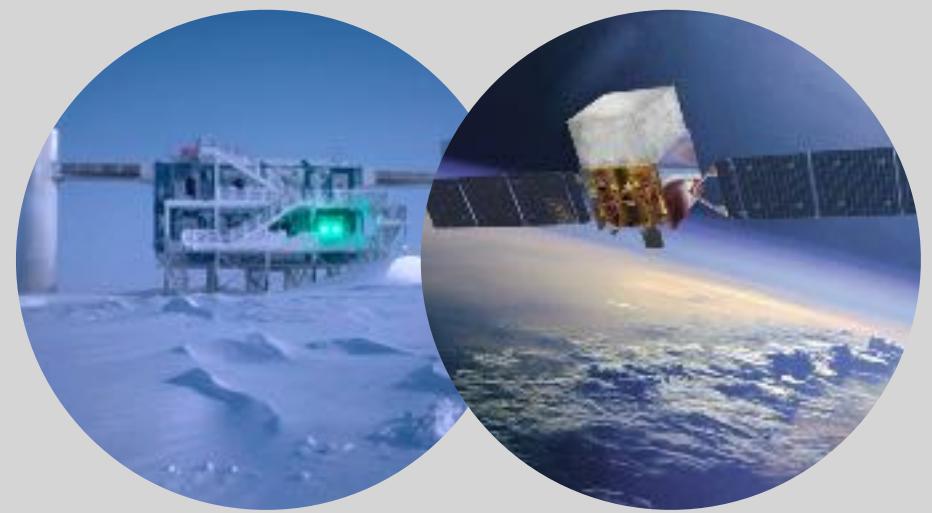


IceCube + Fermi LAT

ANTARES has ceased
operations



The NuEM Channel: selection criteria

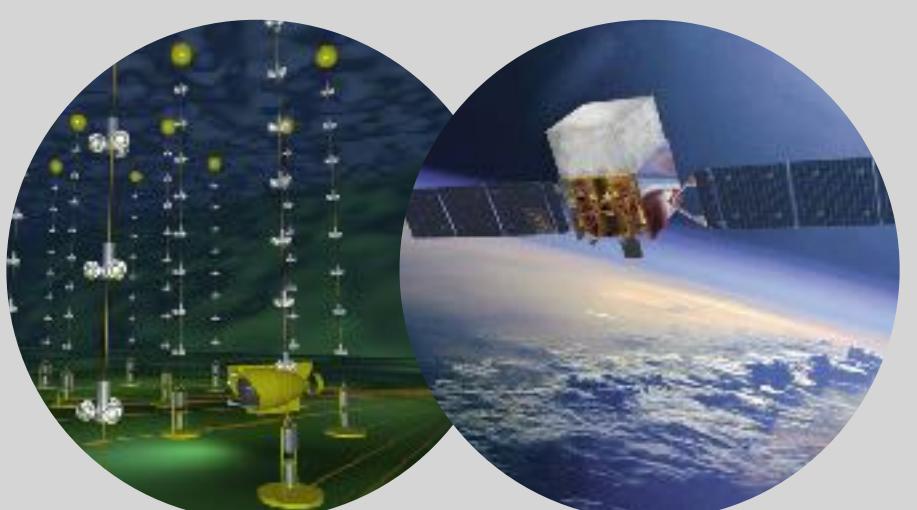


ANTARES +Fermi LAT
H. A. Ayala Solares et al
2019 ApJ 886 98

A neutrino event
and all photons

$$\Delta\theta < 5^\circ$$

$$\Delta t \pm 100s$$



IceCube +Fermi LAT
C. F. Turley et al 2018
ApJ 863 64

Neutrino event
tracks (cascades)
And photons

$$\Delta\theta < 5^\circ(10^\circ)$$

$$\Delta t \pm 1000s$$

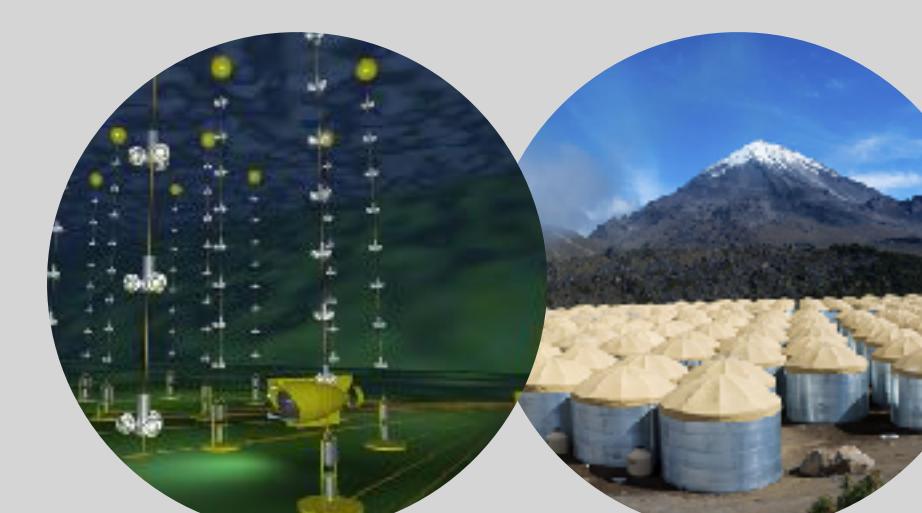


IceCube + HAWC
H. A. Ayala Solares et al
2021 ApJ 906 63

A HAWC event and
Neutrino events

$$\Delta\theta < 3.5^\circ$$

$$\Delta t \sim HAWC_{\text{transit}}$$



ANTARES + HAWC
H. A. Ayala Solares et al
2023 ApJ 944 166

Archival coincidences: HAWC-IceCube



A HAWC event and
Neutrino events

$$\Delta\theta < 3.5^\circ$$

$$\Delta t \sim HAWC_{\text{transit}}$$

- No counterpart found in the SIMBAD catalog and the Fermi All-sky Variability Analysis (FAVA) monitoring, but several sources in the region.

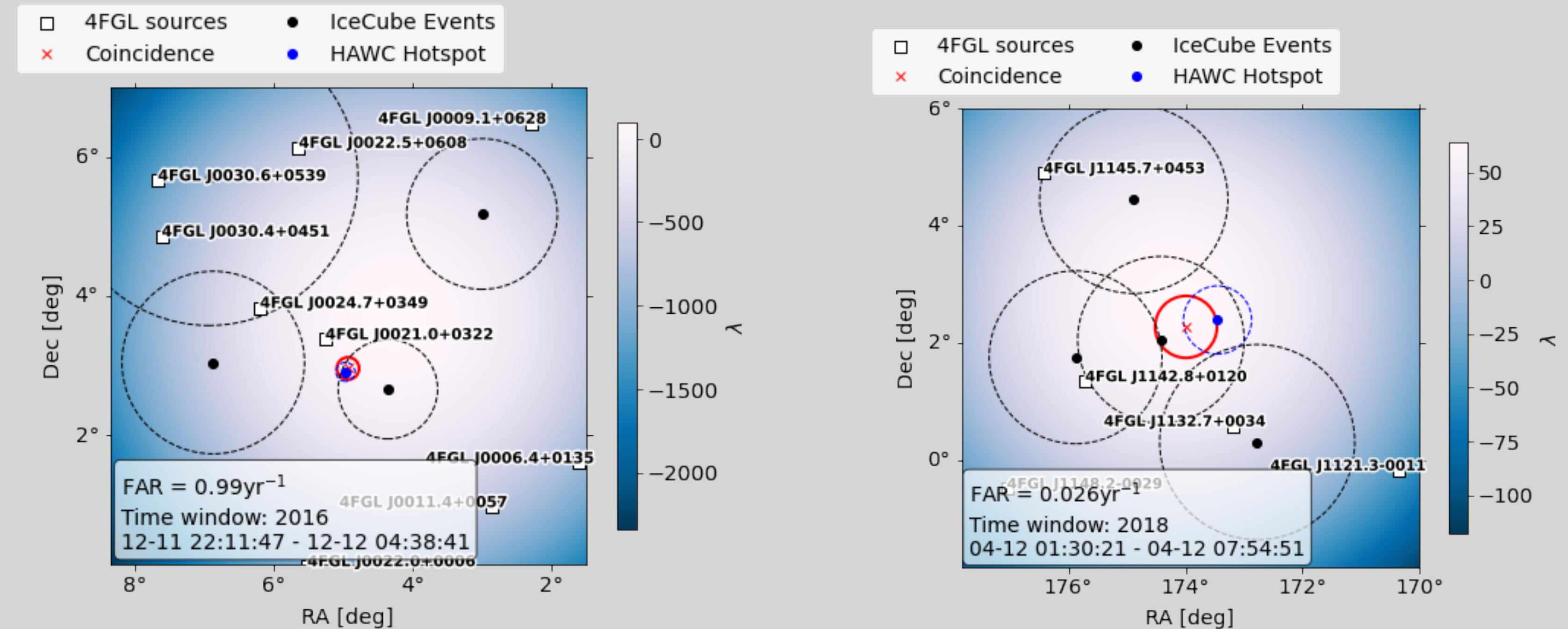
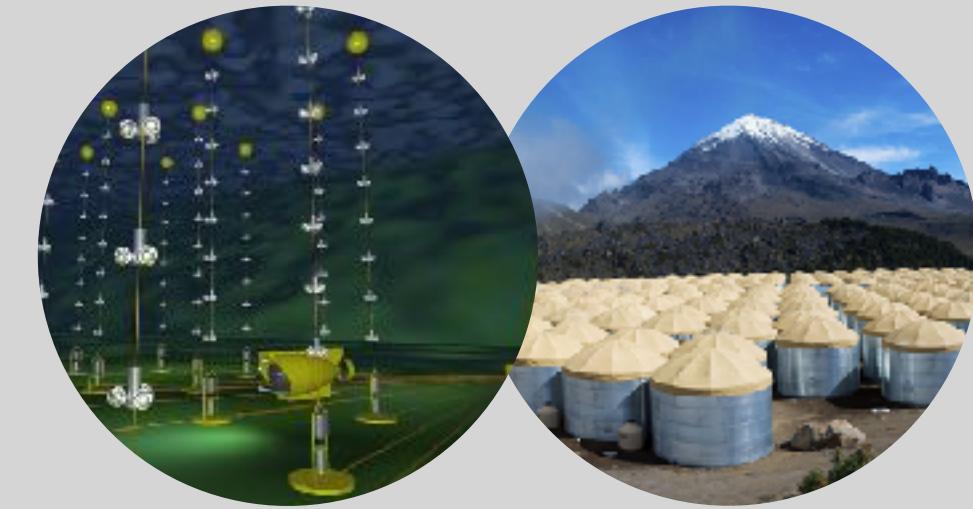
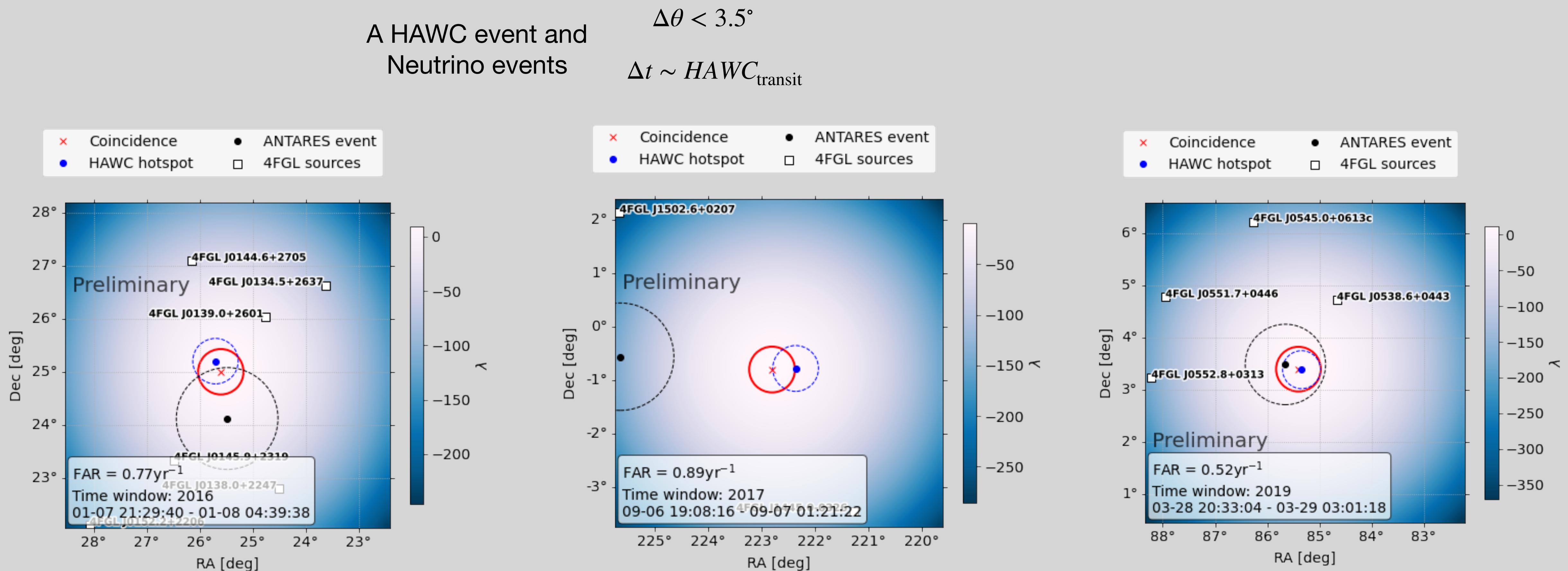


Figure 5. Skymaps of the coincidences with the lowest FAR found in the 3 years of archival data. Position of the individual events are marked with the dots. The best-fit combined positions x_{coinc} , found after optimizing Eq. 3, are marked with a cross. Circles are the 50% containment region.

Archival coincidences: HAWC-ANTARES



- No counterpart found in the SIMBAD catalog and the Fermi All-sky Variability Analysis (FAVA) monitoring



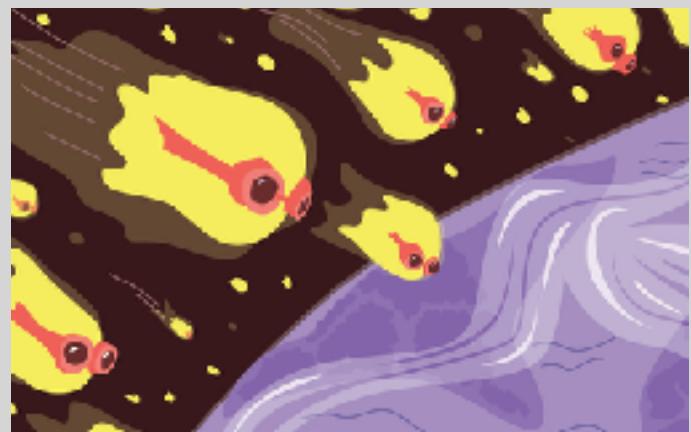
Coincidences in the NuEM Channel

Name	R.A. [°]	Decl. [°]	$\delta\theta$ [°]	FAR [yr^{-1}]	Time UTC
Real-time alerts					
NuEM-230523A	143.40	4.83	0.14	0.87	2023-5-23 02:57:20
NuEM-230414A	47.22	27.42	0.26	0.29	2023-04-14 23:21:11
NuEM-230313A	206.01	16.16	0.13	3.32	2023-03-13 11:59:46
NuEM-230125A	198.23	59.51	0.23	3.50	2023-01-25 13:13:35
NuEM-220728A	108.9	40.9	0.27	1.14	2022-07-28 20:25:53
NuEM-220220A	221.35	13.23	0.17	1.25	2022-02-20 14:19:37
NuEM-220212A	307.57	1.60	0.31	2.87	2022-02-12 20:19:02
NuEM-220116A	322.13	27.26	0.14	0.57	2022-01-16 23:26:40
NuEM-211209A	12.03	-5.75	0.18	2.06	2021-12-09 04:38:48
NuEM-211020A	99.76	9.07	0.17	0.86	2021-10-20 14:13:38
NuEM-210515A	93.64	14.66	0.15	3.93	2021-05-15 00:20:43
NuEM-210515B	93.93	12.51	0.20	1.90	2021-05-15 00:19:27
NuEM-210111A	162.34	19.46	0.37	3.85	2021-01-11 13:06:41
NuEM-201124A	134.99	7.74	0.23	2.96	2020-11-24 14:13:37
NuEM-201107A	140.20	29.76	0.15	3.49	2020-11-07 15:55:31
ANTARES-Fermi 200704A	255.42	-34.48	0.43	0.98	2020-07-04 15:53:48
NuEM-200202A	200.30	12.71	0.17	1.39	2020-02-02 14:07:52
ANTARES-Fermi 191011A	49.96	18.80	0.40	1.21	2019-10-11 15:54:32

- FAR threshold is < 4 per year for real-time alerts.
- 18 alerts sent to GCN

More Comments on NuEM Channel

- AMON NuEM channel is active
 - Using sub-threshold data
- We encourage follow-up observations of these coincidences



Name	Followed by
NuEM-230523A	MAGIC
NuEM-230313A	Swift-XRT
NuEM-230125A	Swift-XRT
NuEM-220220A	MASTER
NuEM-211020A	ANTARES,Swift-XRT
NuEM-210515A/B	ANTARES
NuEM-210111A	ANTARES, INTEGRAL,MAXI
NuEM-201124A	ANTARES
NuEM-201107A	<i>Fermi</i> -LAT
NuEM-200202A	MASTER, ANTARES
FERMI-ANTARES-191011A	MASTER

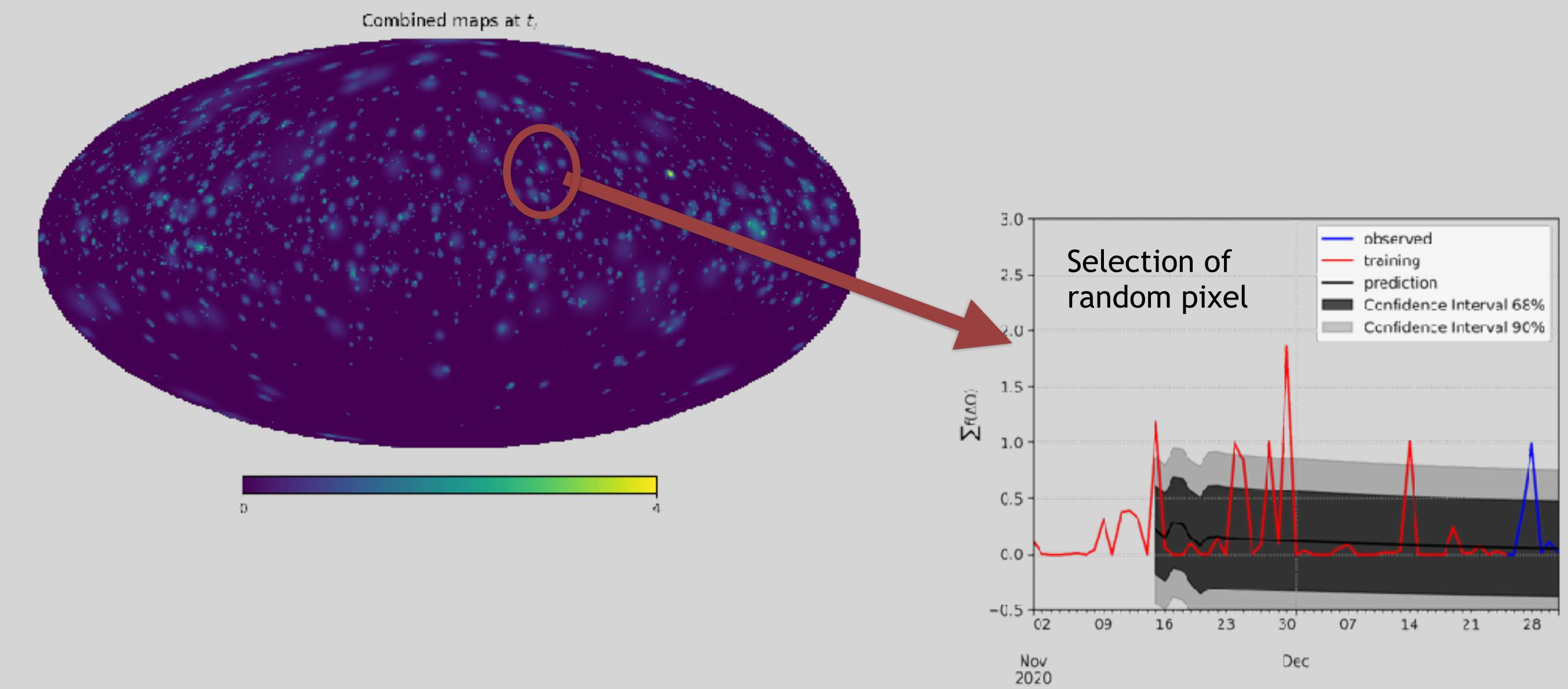
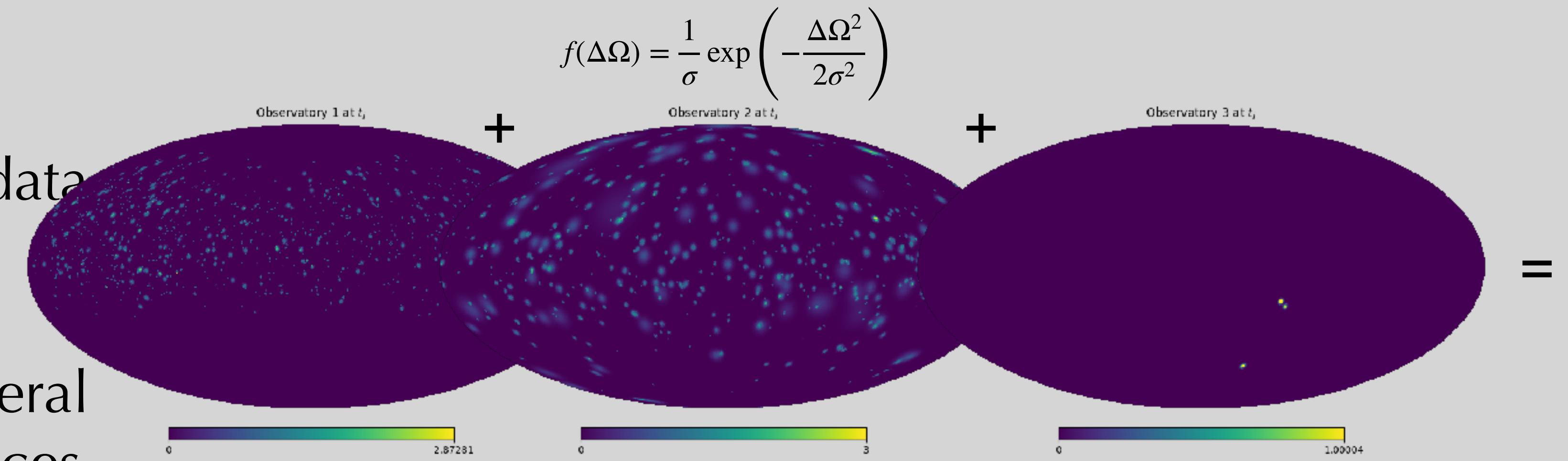
- Visit the <https://amontom.science.psu.edu/> to query alerts

Future Projects



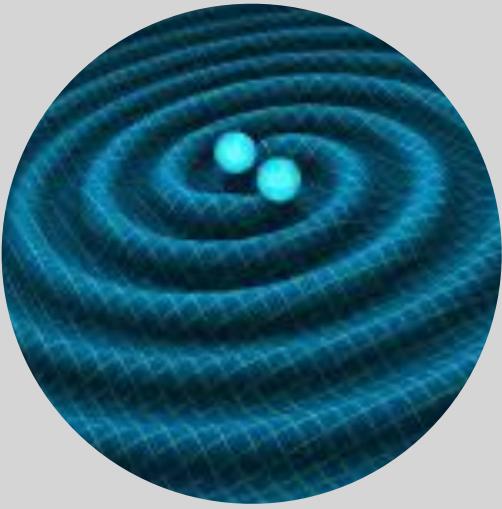
Future of the NuEM Channel: Outlier detection

- So far we have combined data from 2 detectors.
- Looking to incorporate several detectors to find coincidences
- Using Outlier Detection methods:
 - Currently focusing on forecasting methods
- Example with mock data —>



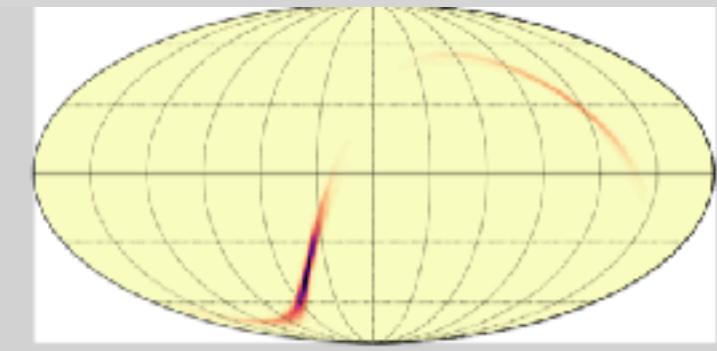
Future of AMON:

- Ligo Virgo Kagra O4 is coming up.
- Working towards a **GW-Nu-EM**
 - Follow-up the **sub threshold** events from LVK using SCiMMA
 - Use IceCube data from the NuEM Channel
 - Use **new stream** from HAWC data that follow-ups GW events.
 - Using a Bayesian Approach

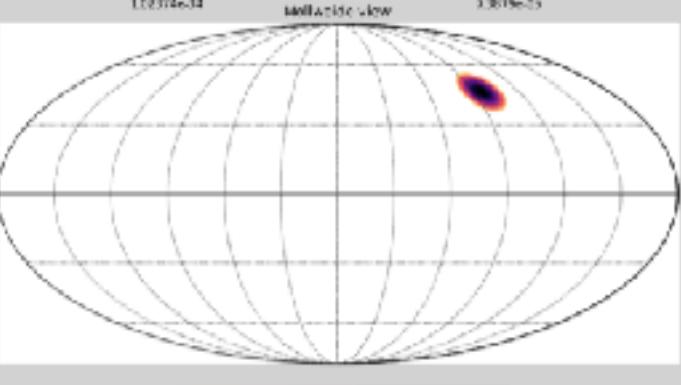
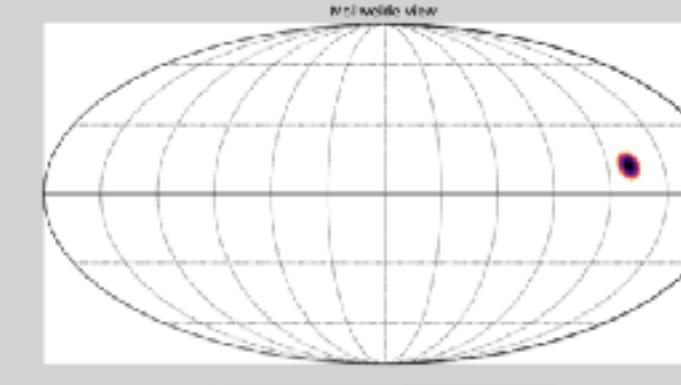
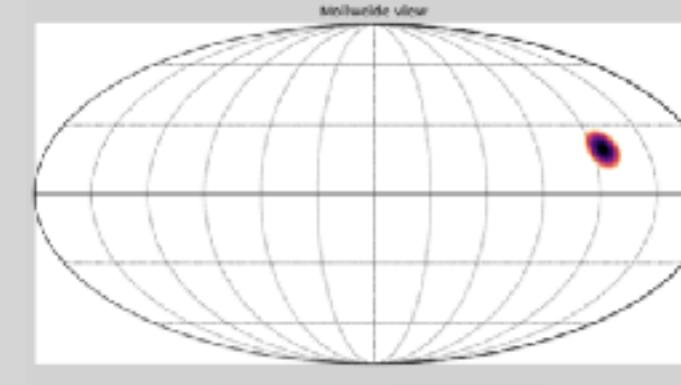


Quick Test

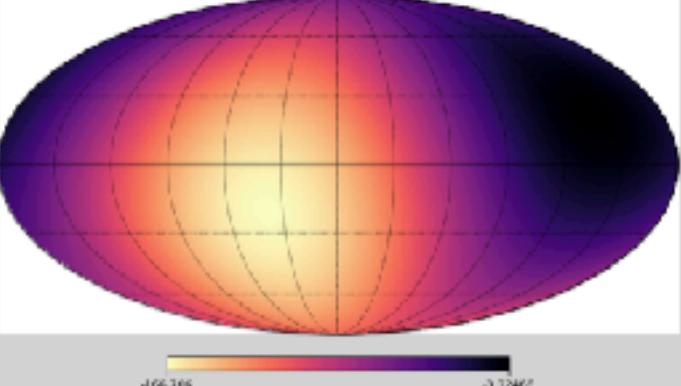
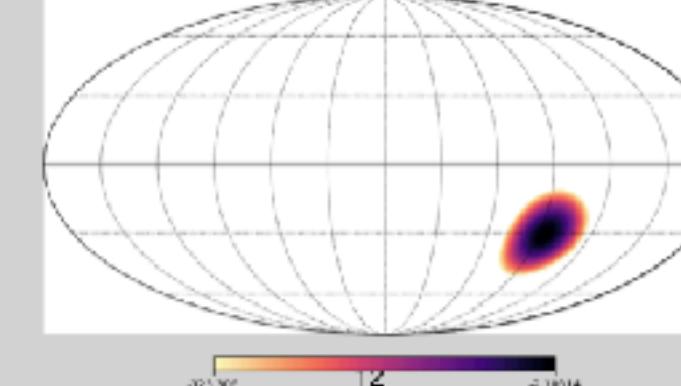
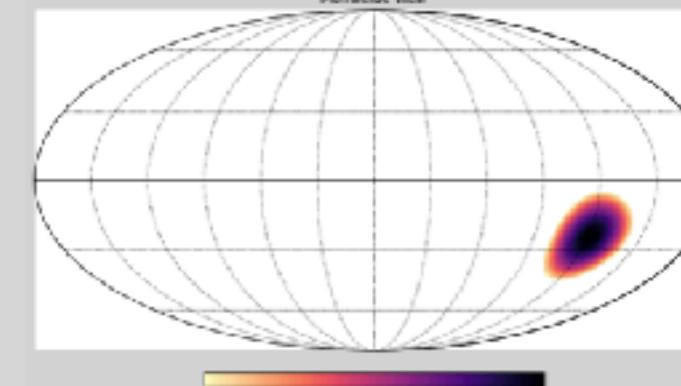
- 3 neutrino events, 3 hotspots and 1 GW



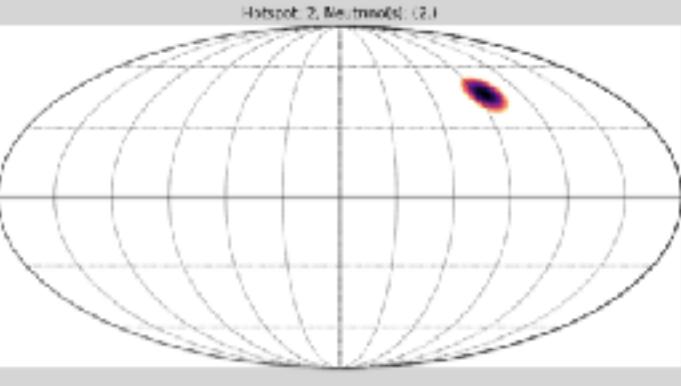
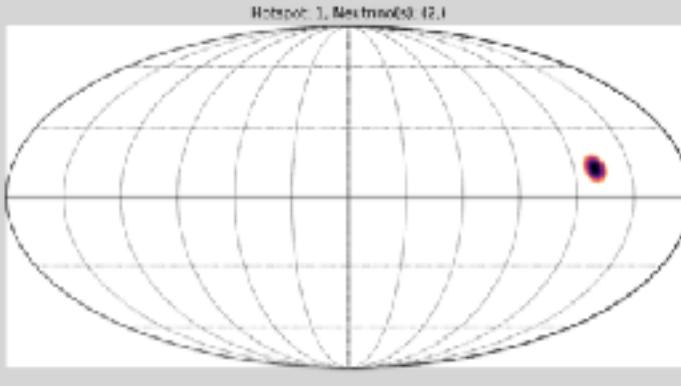
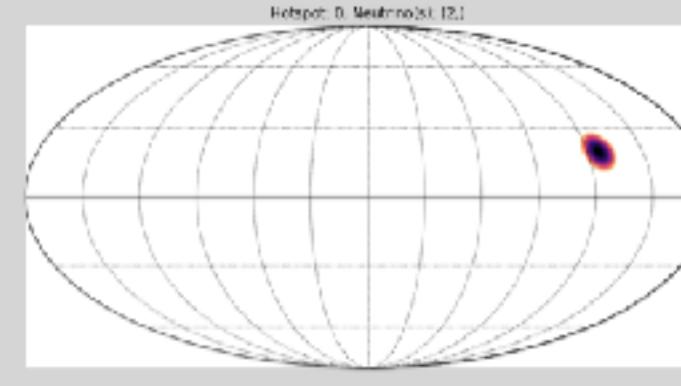
**Gamma-ray
Sim. Data**



**Neutrino
Sim. Data**



**Probability
Maps
Different
Scenarios**

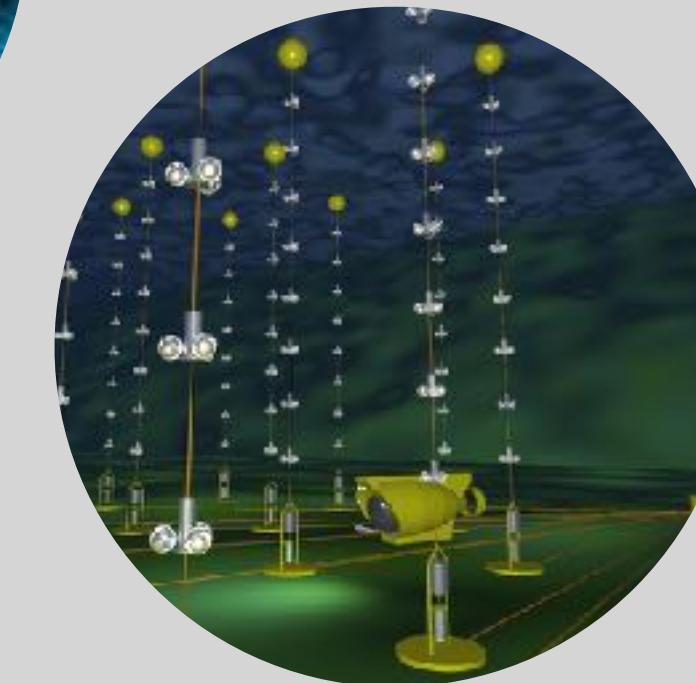
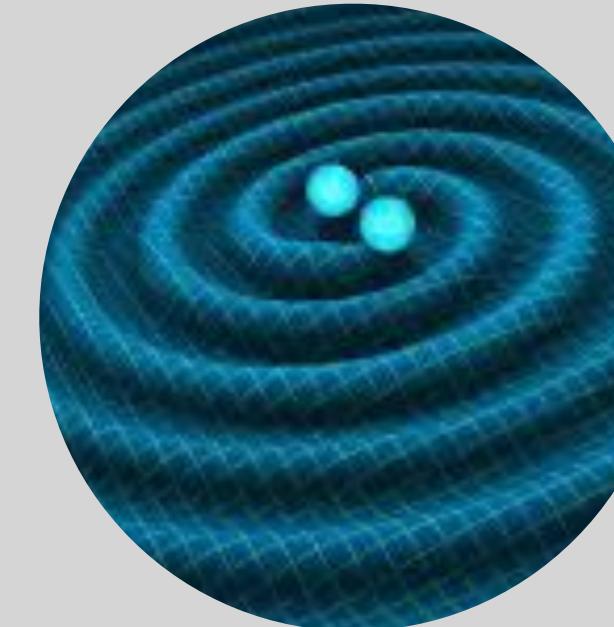
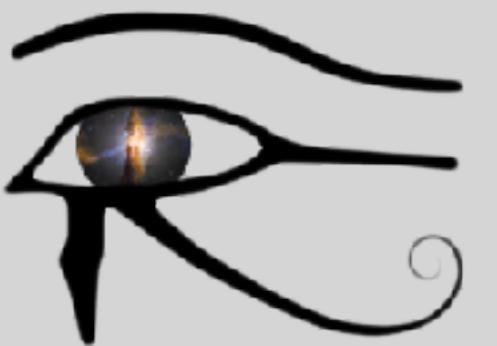


Thank you



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