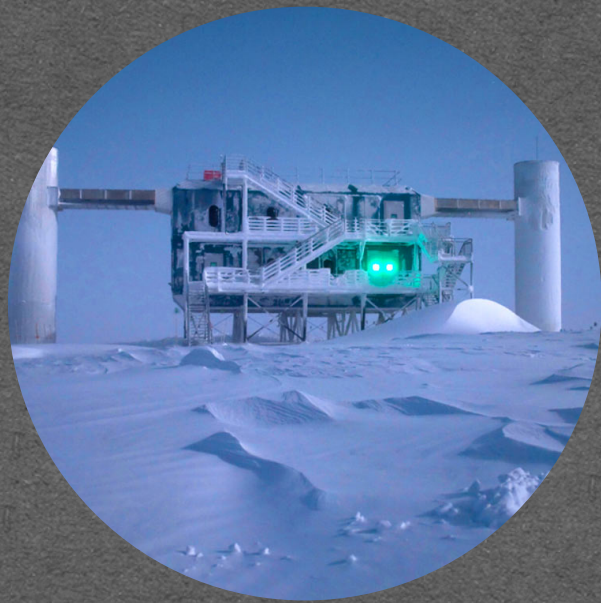
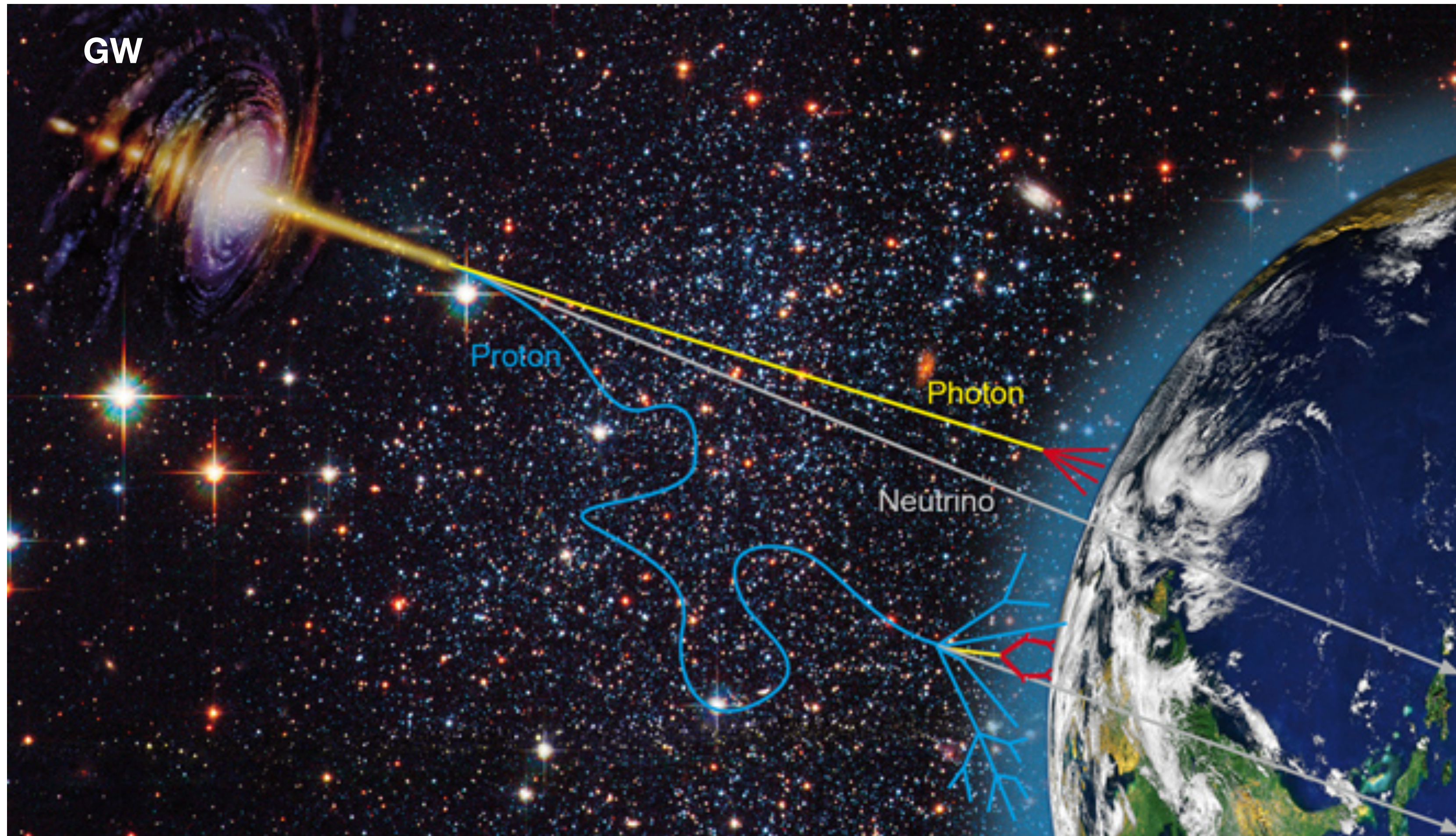


Multimessenger Alerts from High-Energy Gamma Ray and Neutrinos with AMON

Hugo Ayala



Entering a new era where we can detect the messengers of the four forces of nature.



Real-time searches for transients can continue to advance multimessenger astrophysics. AMON has been built with this idea and with the use of **sub-threshold data**



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

Another approach to multimessenger astrophysics is real-time searches. AMON has been built with this idea and with the use of **sub-threshold data**



- **Real-time coincidences**

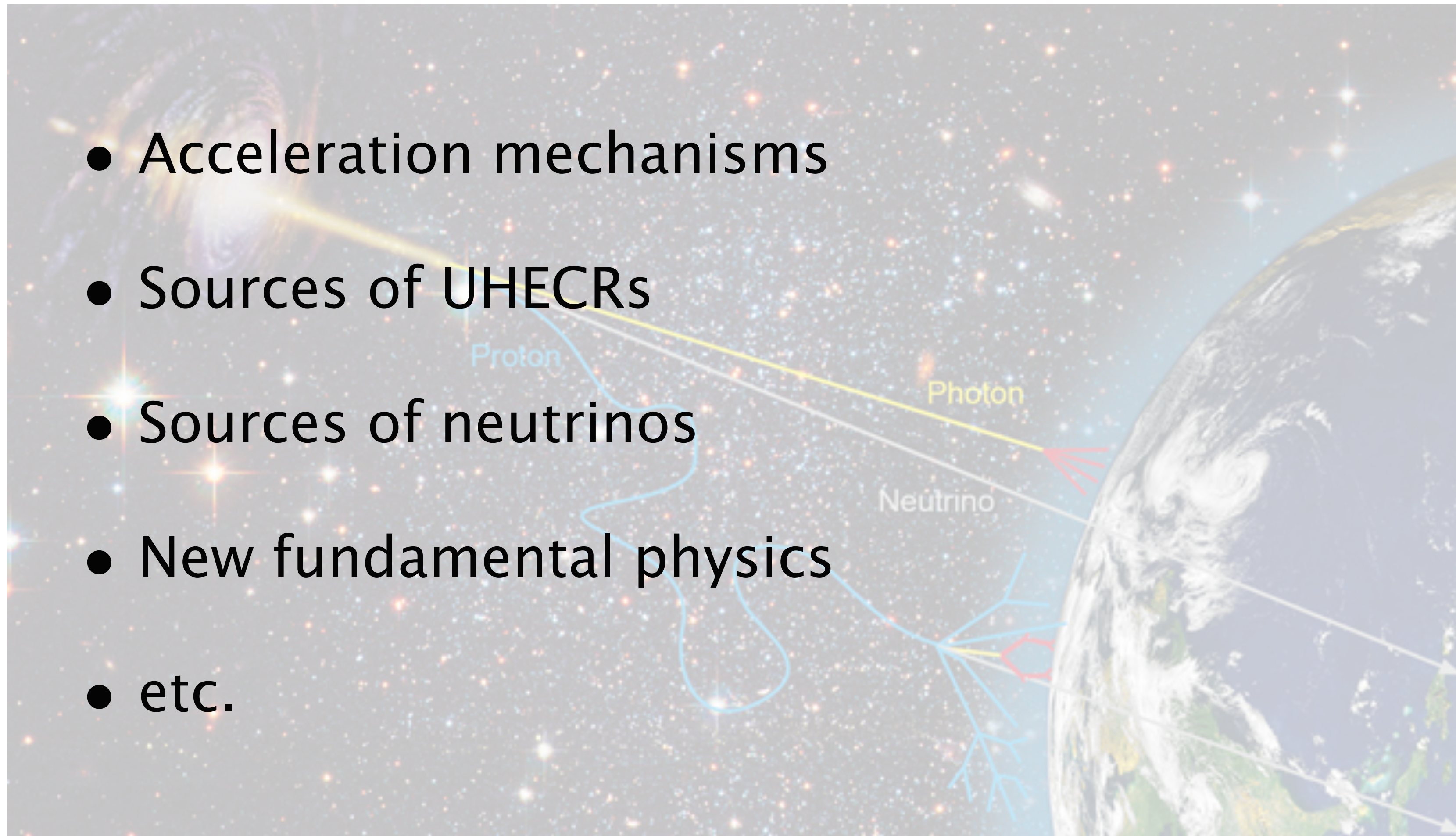
- Receive the event after it is built in each observatory and do the coincidence analysis right away in the AMON servers.

- **Sub-threshold data**

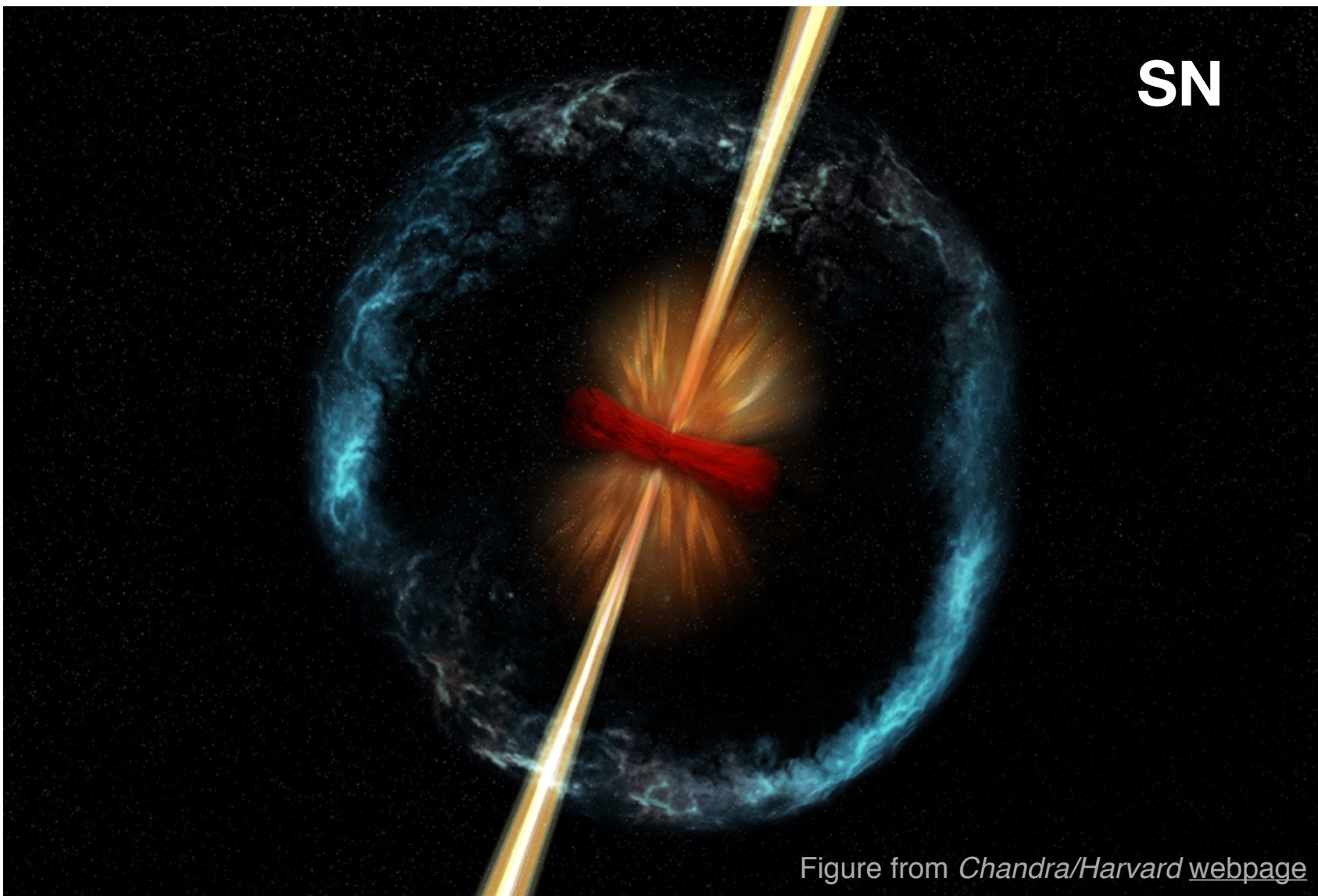
- Data that is below the detection threshold from each observatory. Examples:
 - HAWC significance hotspots below 5 sigma
 - IceCube singlets with low signal ness

Focusing on high-energy astrophysics. We want to help solve some of the current questions in the field

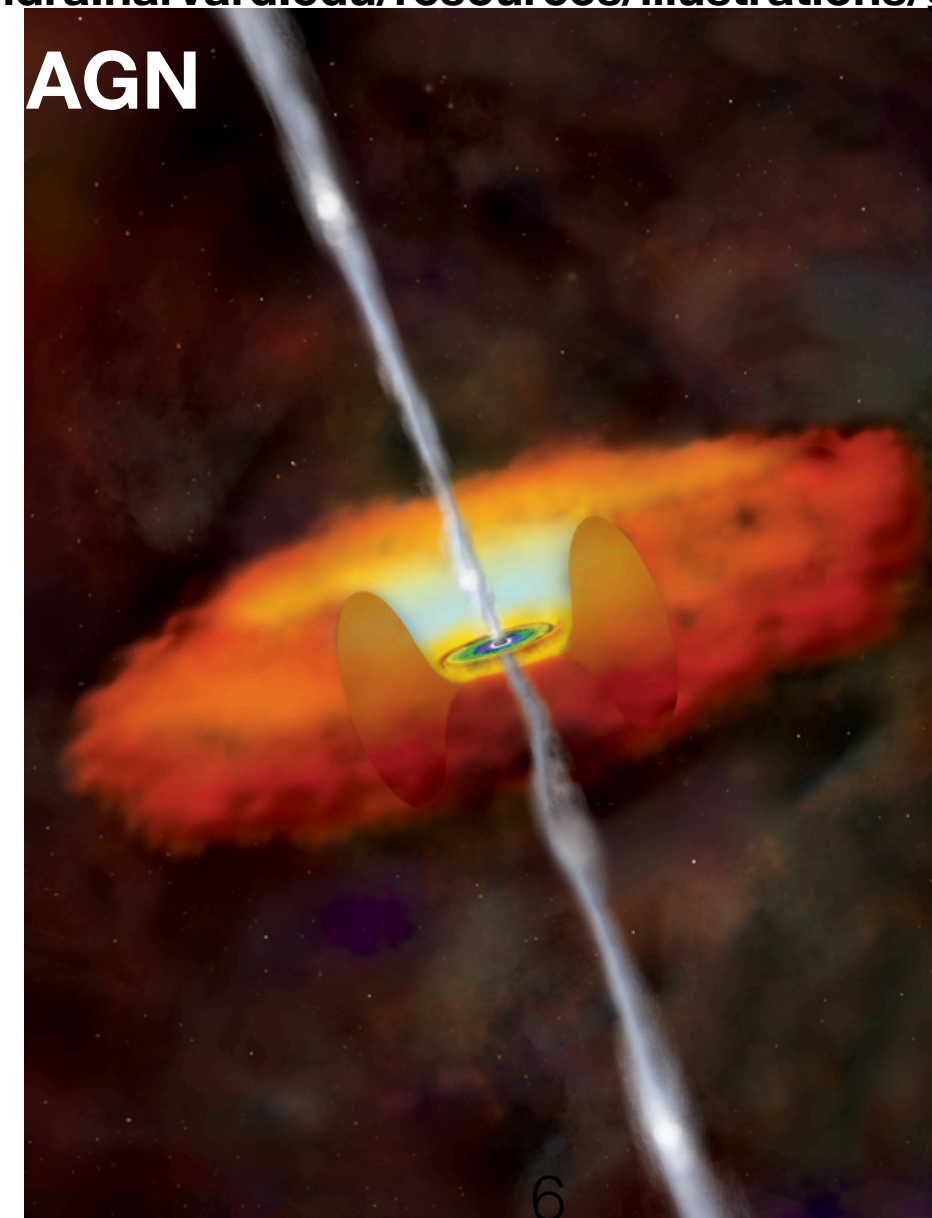
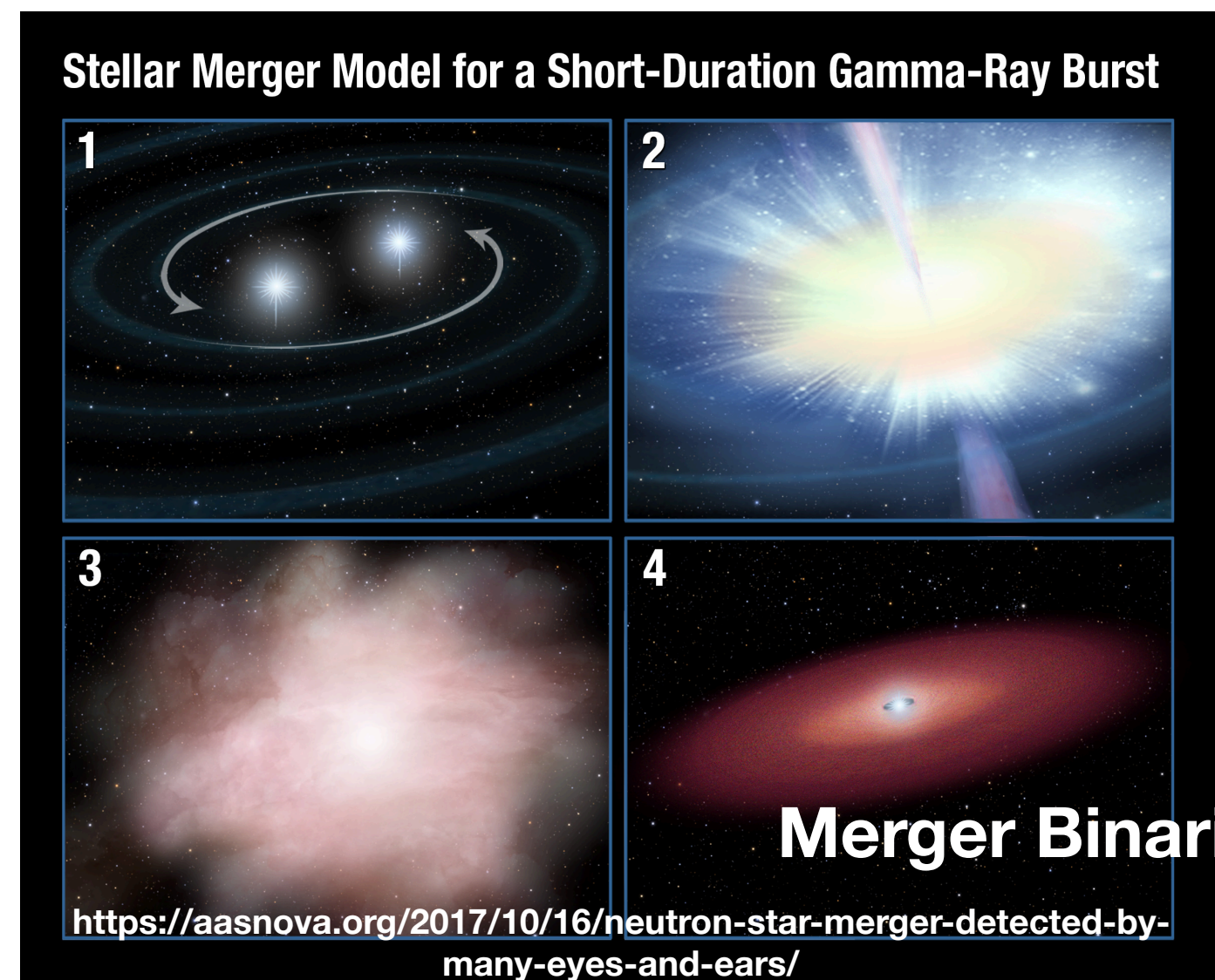
- Acceleration mechanisms
- Sources of UHECRs
- Sources of neutrinos
- New fundamental physics
- etc.



Large span of transient events that we can look for:



<http://chandra.harvard.edu/resources/illustrations/grb.html>



<http://chandra.harvard.edu/photo/2007/agns/>

- Long GRBs
- Short GRBs
- SN
- Choked jet supernova
- Blazars
- PBHs
- Binary Mergers
- ...

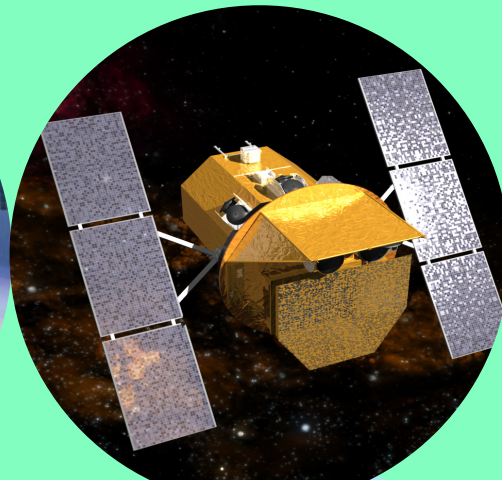
AMON members and prospective* members.

CR



**Pierre
Auger**

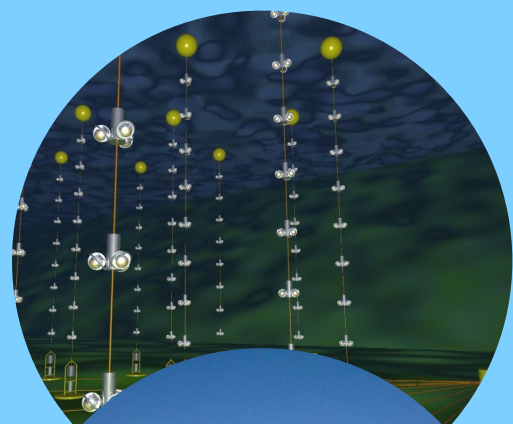
γ



**SWIFT
VERITAS
HESS
MAGIC**

**FACT
Fermi
HAWC**

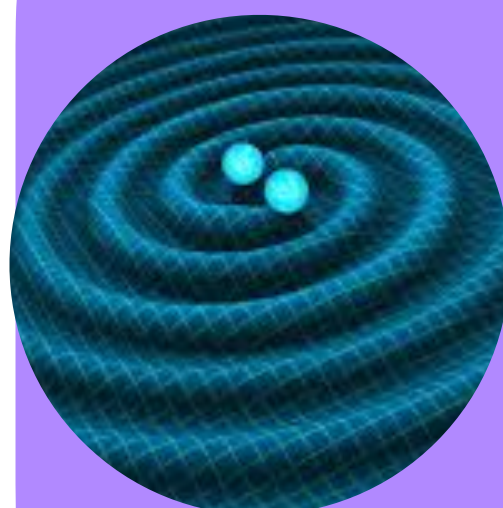
ν



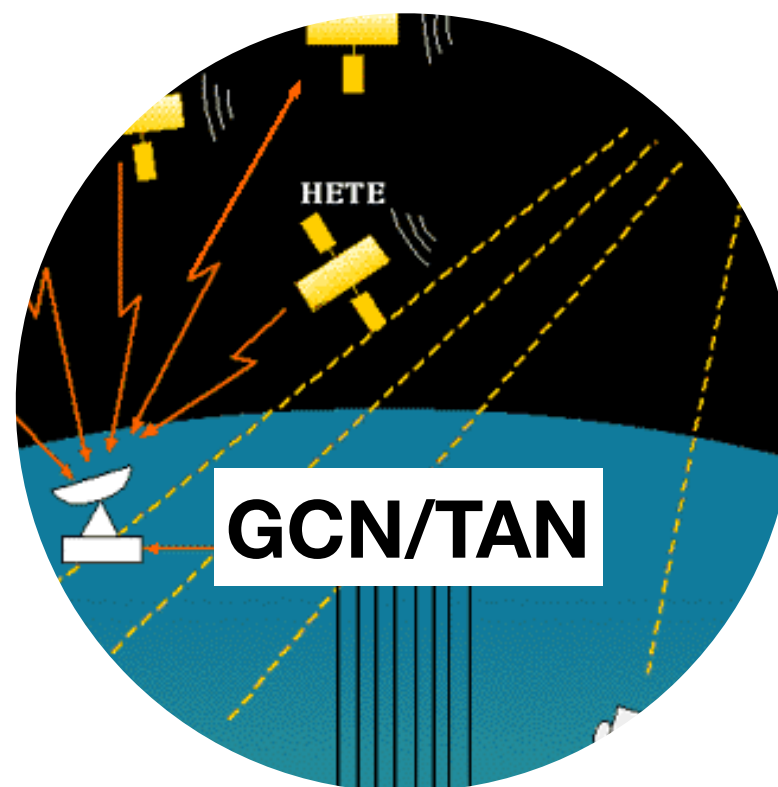
**IceCube
ANTARES**



GW



***LIGO-
Virgo**

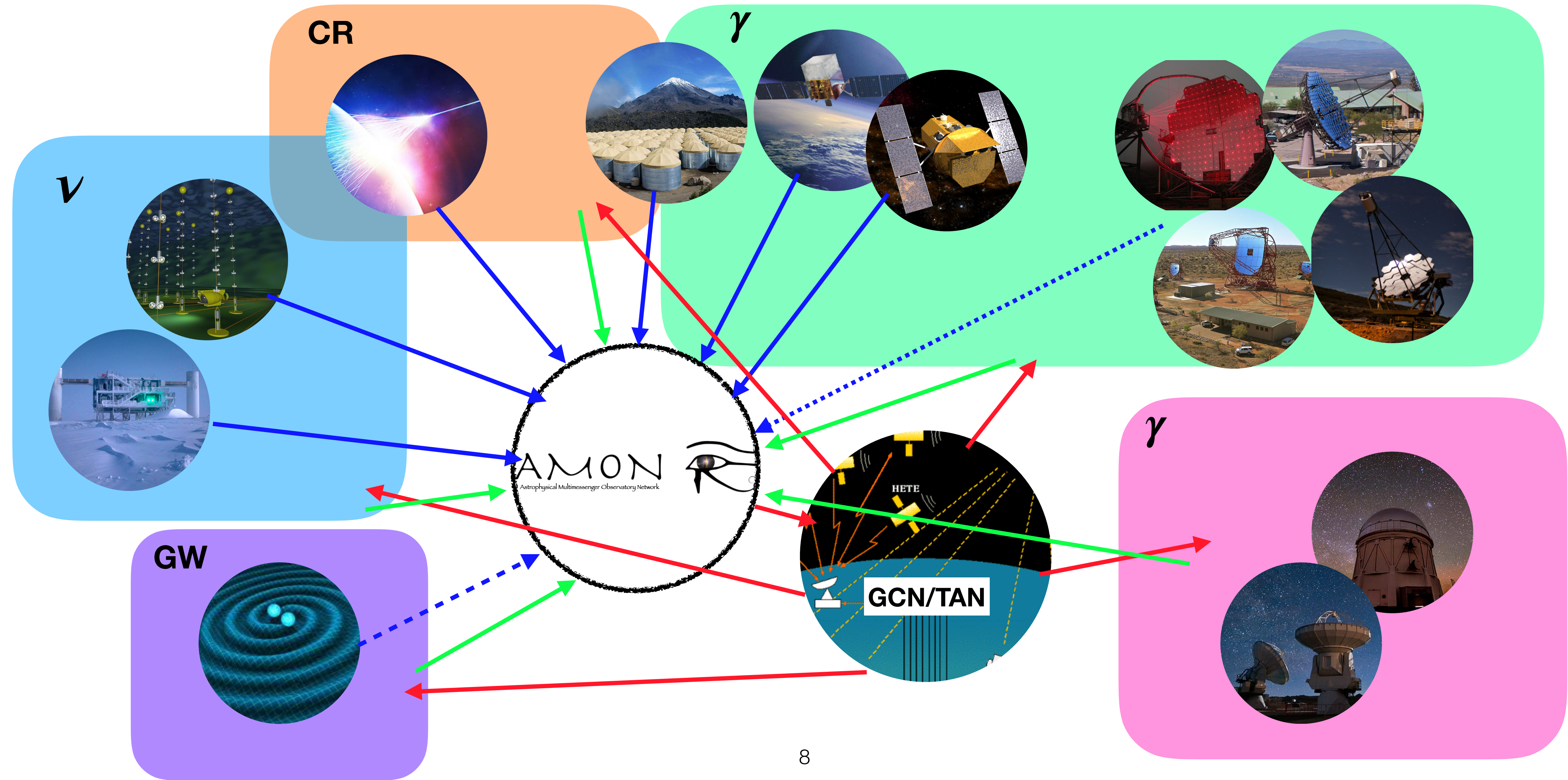


γ

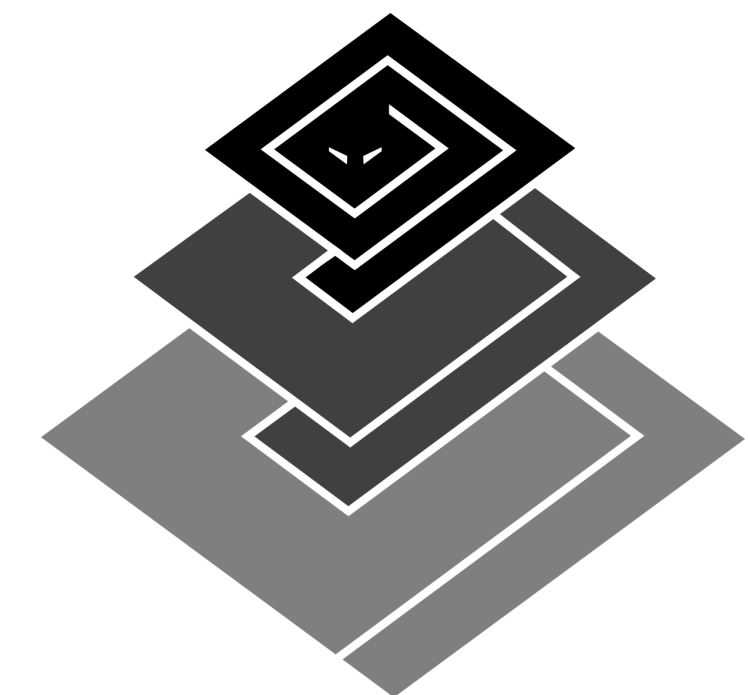
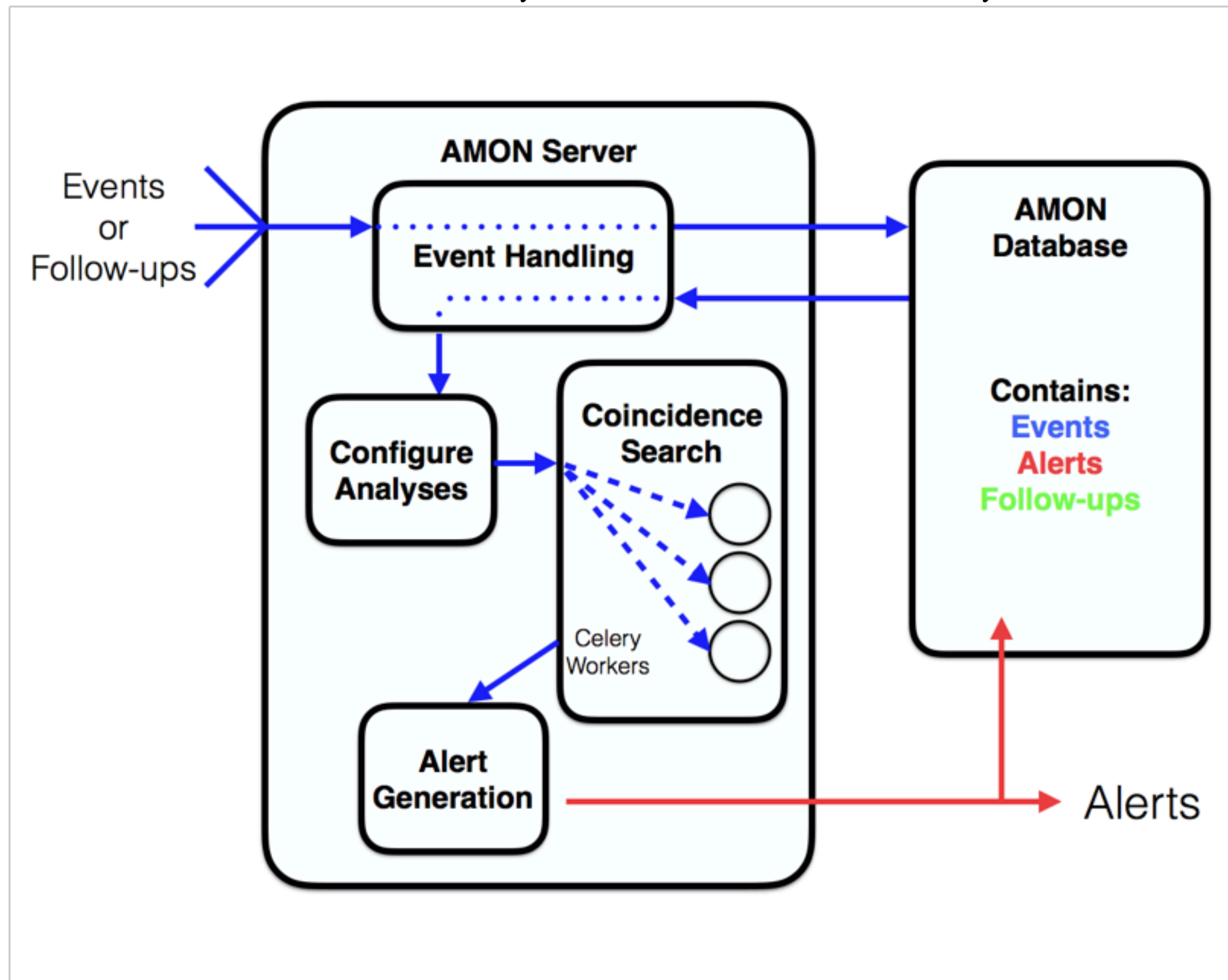


**LMT
Palomar Transient Factory
MASTER**

AMON *receives* sub-threshold data events and *sends* alerts to GCN/TAN which then are *distributed* to partner observatories/public. Interesting follow-ups are *sent back* to AMON and AMON then broadcasts alert revisions



Technical Implementation: AMON uses an **asynchronous distribution system** to calculate coincidence searches in real-time. Using the **VOEvent protocol**. Software is written in Python. Uses Celery, Twisted and Comet.



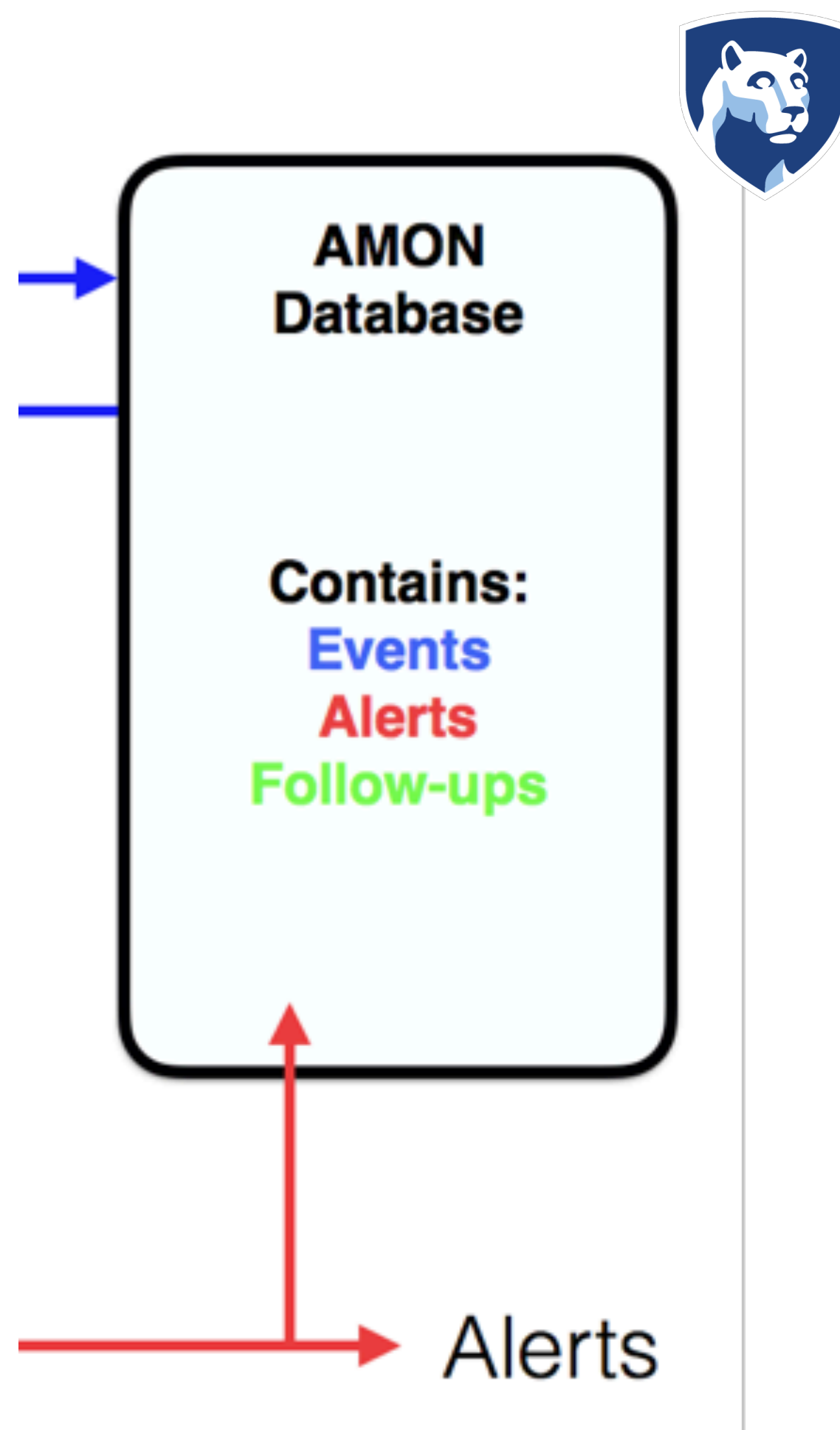
TWISTED



COMET

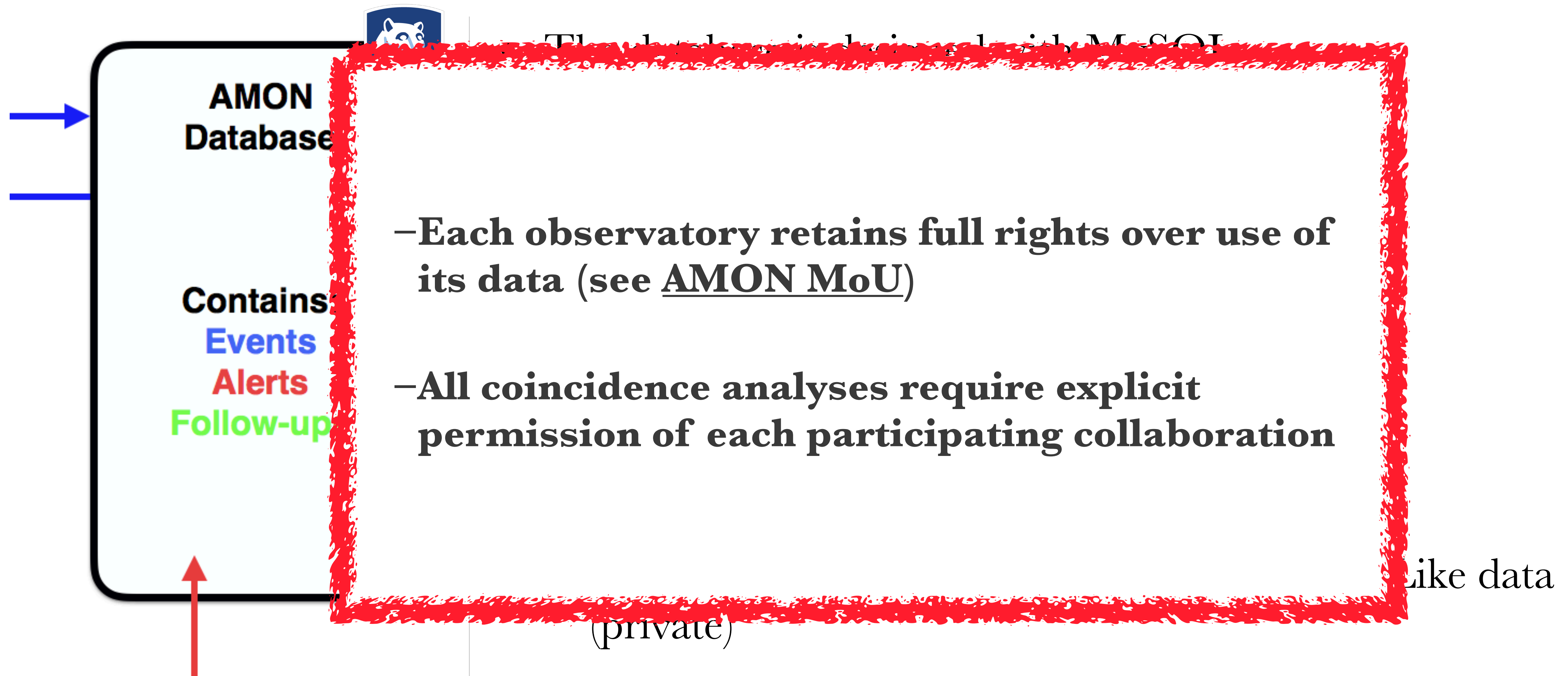
AmonPy software in GitHub:<https://github.com/AMONCode/Analysis>

AMON Database resides in two servers at Penn State. Anticipate 1TB/yr of data.



- Servers are mirrored and redundant for safety.
- Uptime of 99.99% (<1 hr of downtime per year)
- The database is designed with MySQL
- It currently contains:
 - Public:
 - IC 40/59 and 1 year of IC 86, SWIFT and Fermi data
 - Private:
 - ANTARES, Auger data, HAWC Daily Monitoring and HAWC GRB-Like data

AMON Database resides in two servers at Penn State.
Anticipate 1TB/yr of data.



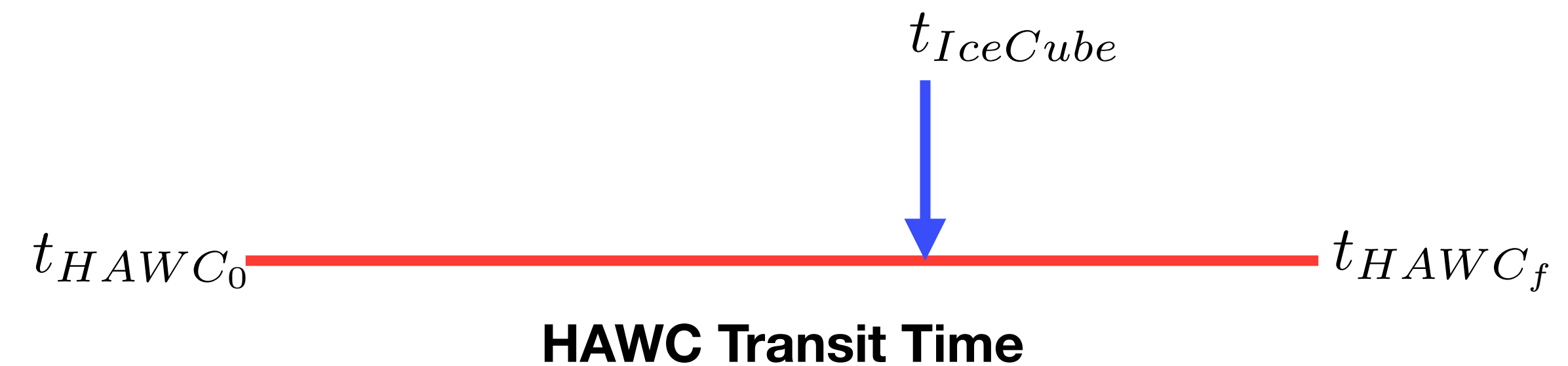
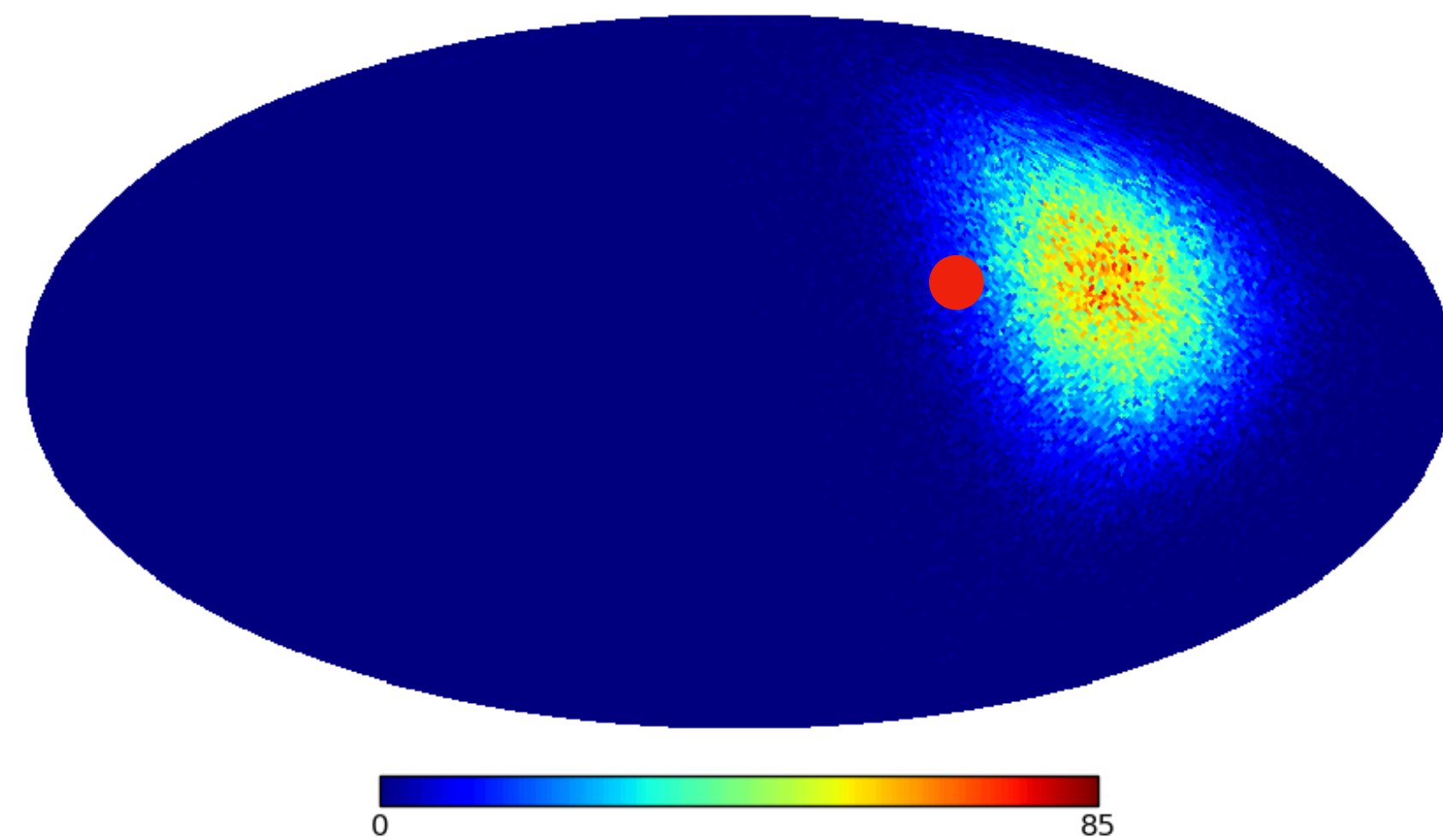


Example Analysis in the AMON Framework

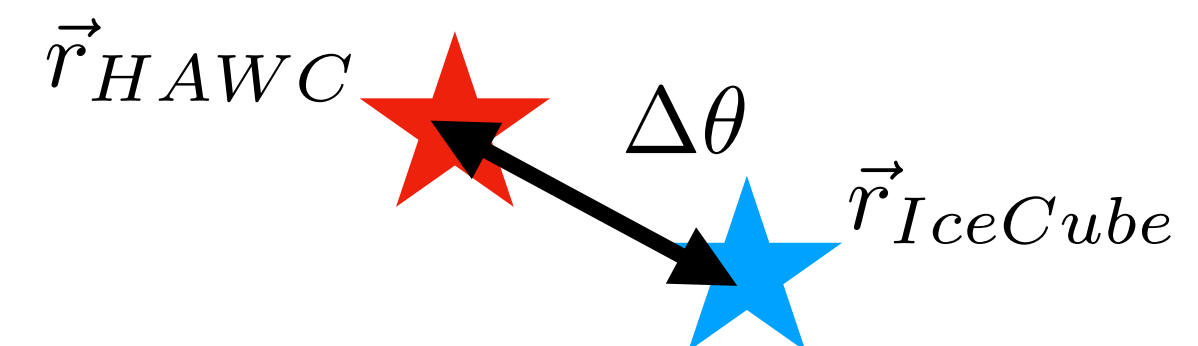
Summary of analysis.

Coincidence criteria for analysis is divided in two parts.

- Selection:
 - **Temporal selection:** Time of IceCube event inside of HAWC monitoring transit time



- **Spatial selection:** Distance from IceCube and HAWC hotspot is less than 3.5°



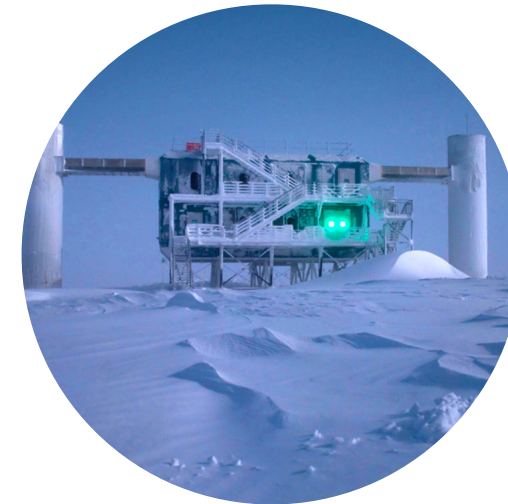
Data description:

HAWC events are “hotspots” of significant excesses above background averaged over 1 transit of the event above the detector.

IceCube events are single through-going track events.



- **Position**
- **Uncertainty in position**
- **Significance (>2.75)**
- **Start time of transit**
- **End time of transit**

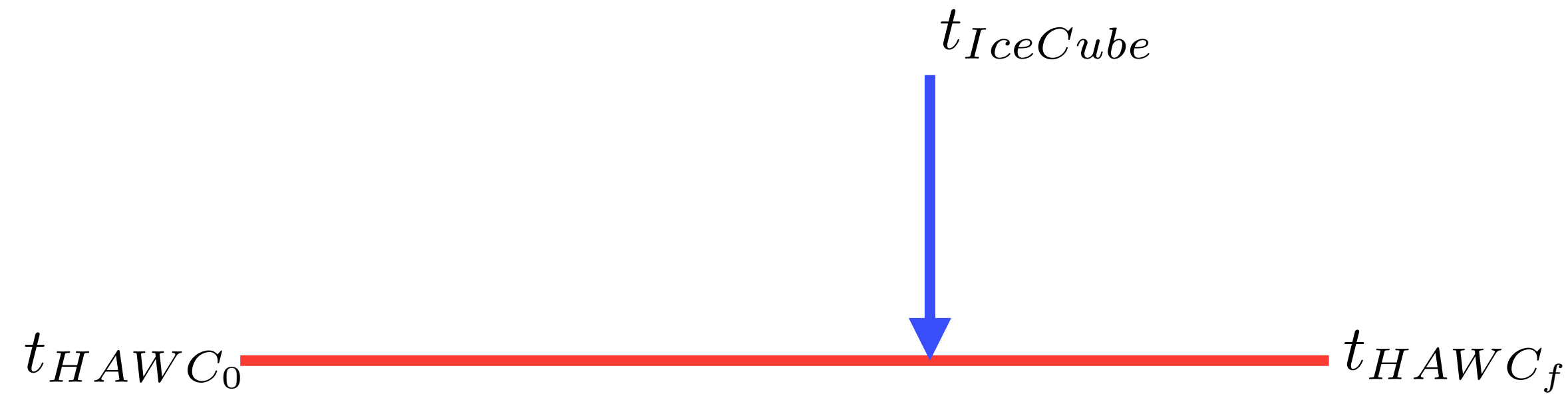


- **Position**
- **Uncertainty in position**
- **Time of event**
- **False positive rate density (FPRD)**
- **Signal acceptance**

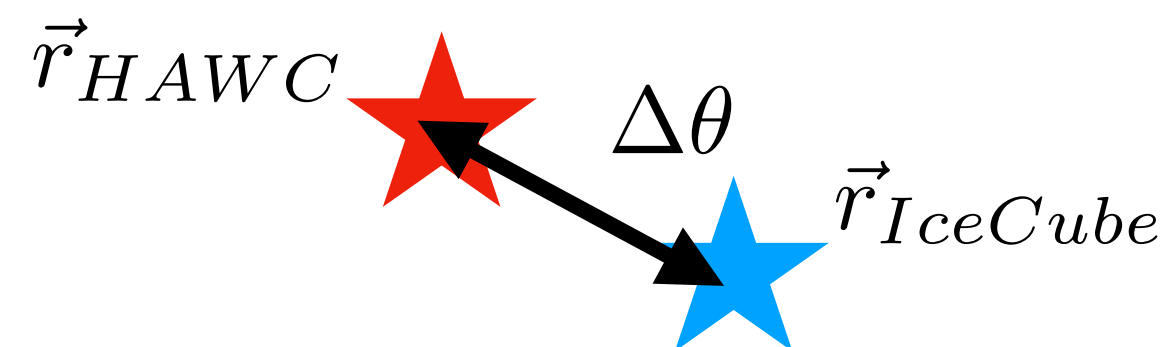
From both observatories we got 1-month of data that we scramble several times to get enough statistics. Future plots are based on that.

HAWC-IC Coincidence Analysis

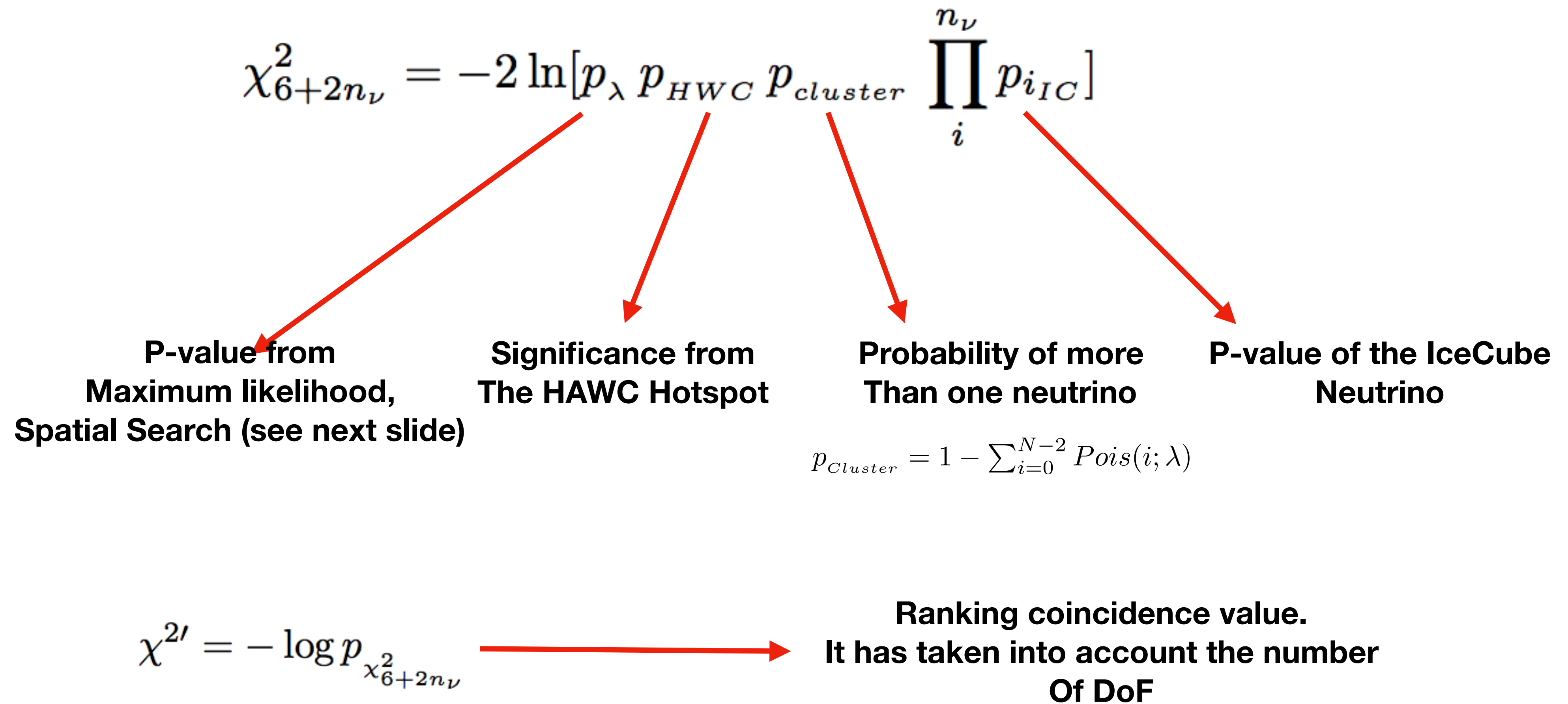
- Selection:
- **Temporal selection:** Time of IceCube event inside of HAWC monitoring transit time



- **Spatial selection:** Distance from IceCube and HAWC hotspot is less than 3.5°



Ranking the coincidences is based on Fisher's method. Due to the fact that the DoF are different depending on the number of neutrinos we add an extra step to get the ranking value

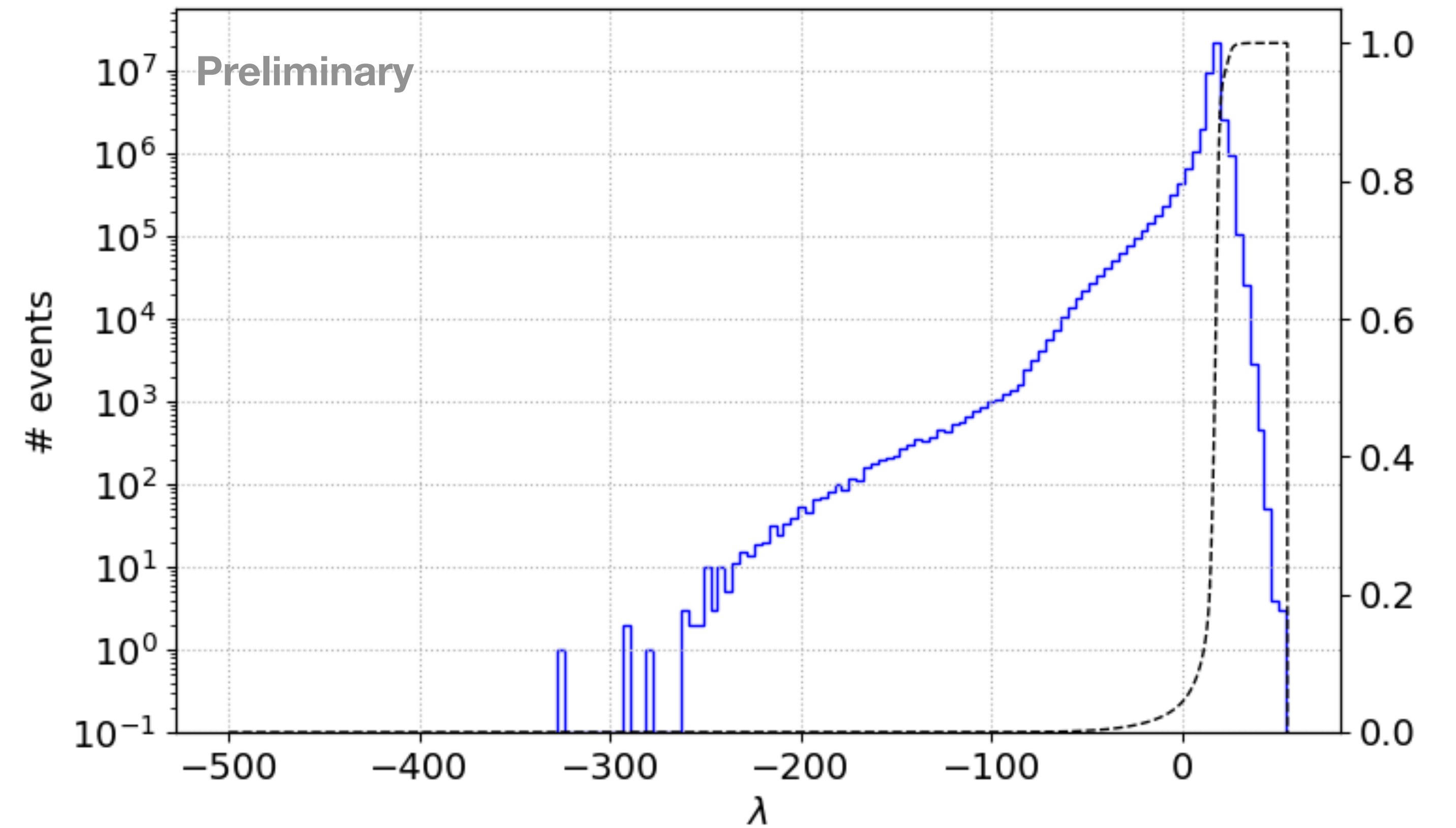


We maximize the spatial likelihood calculation.

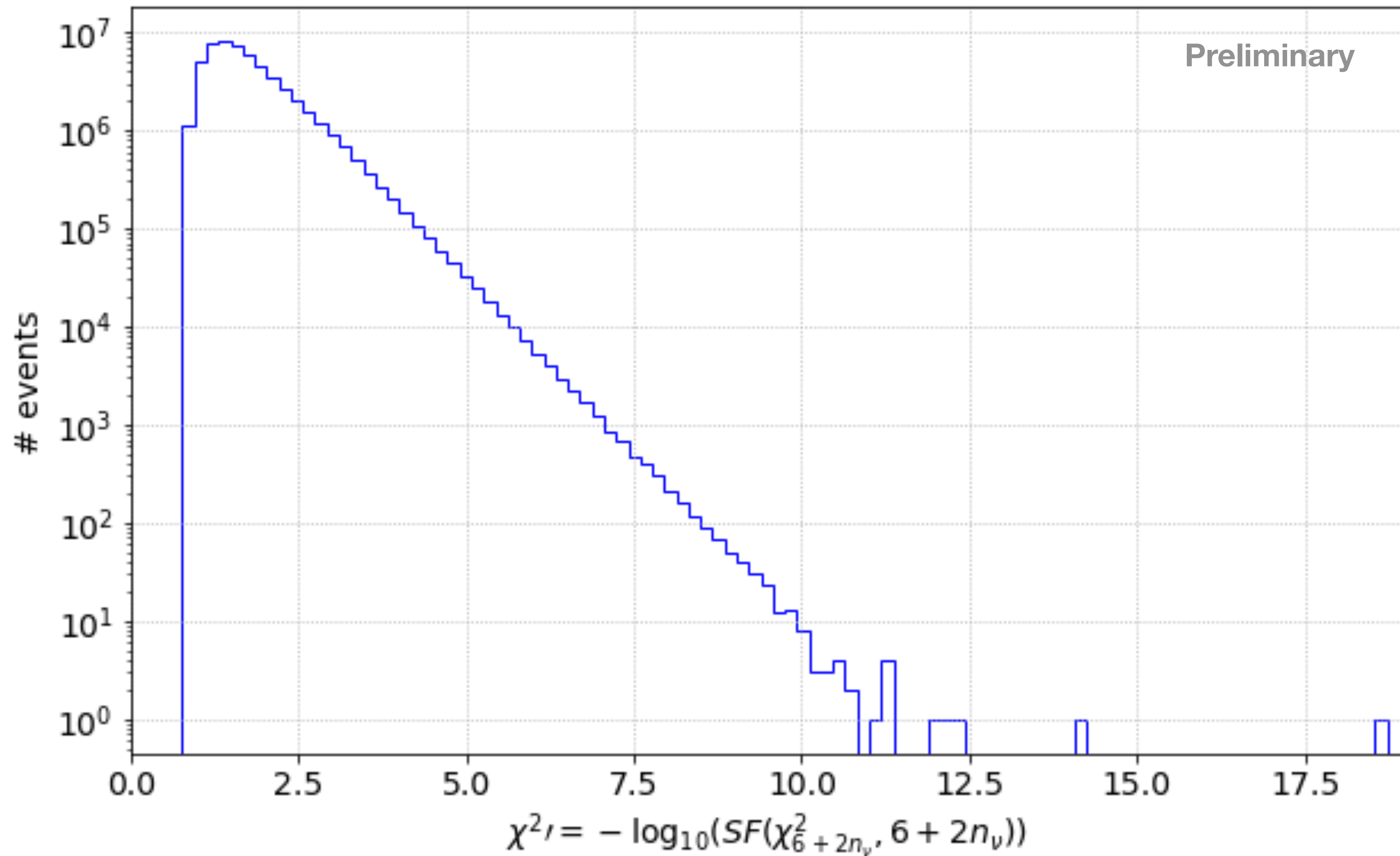
This is the histogram used to generate the λ **p-value**.

Data was scrambled several times such that the search period is ~ 900 years

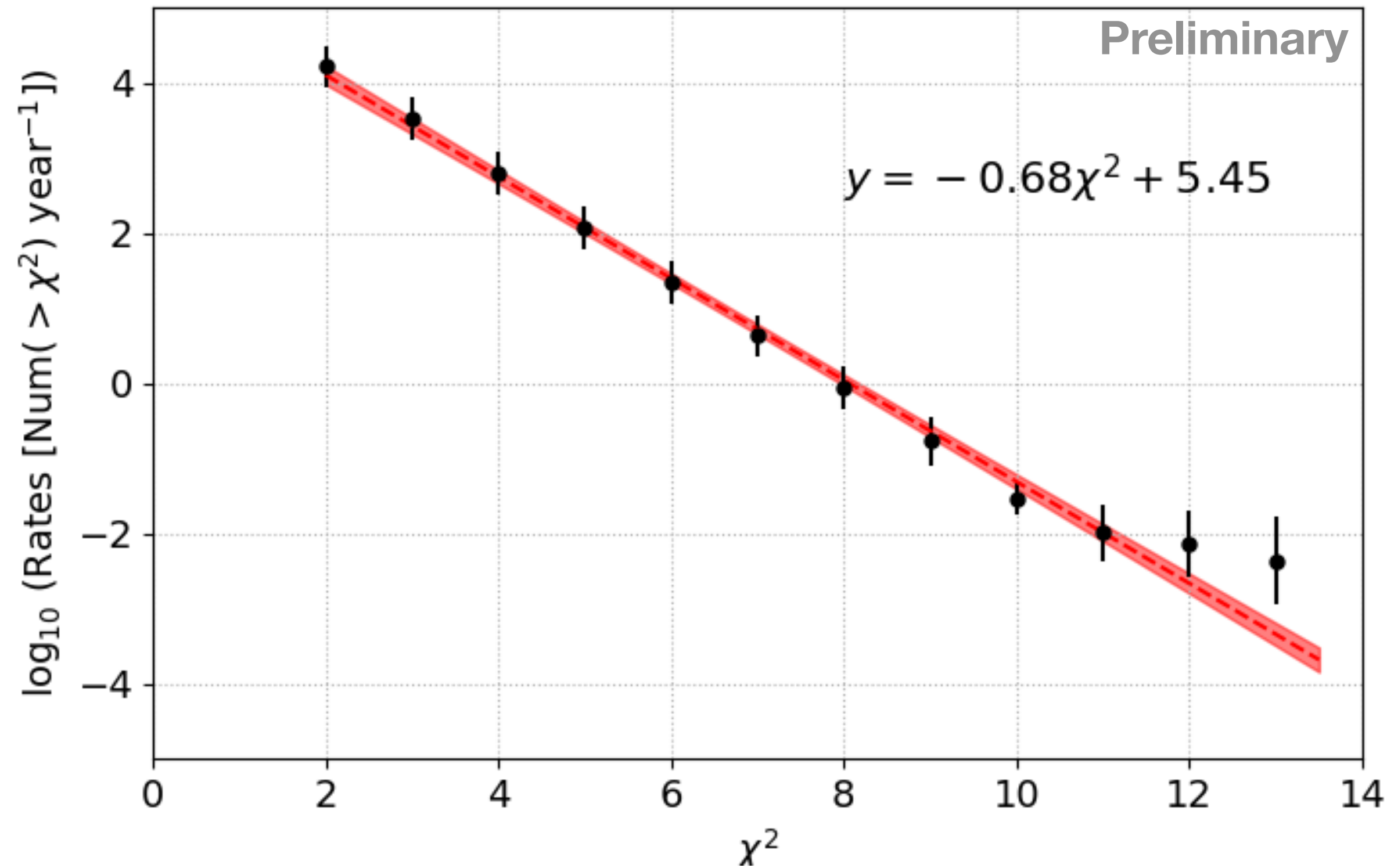
$$\lambda(\vec{x}) = \sum_{i=1}^N (\ln(S_i(\vec{x})) - \ln(B_i))$$



Final ranking statistic value after combining the information that we have. Built from scrambling both datasets several times (corresponds to a ~ 900 years).



False alarm rate vs ranking statistic:



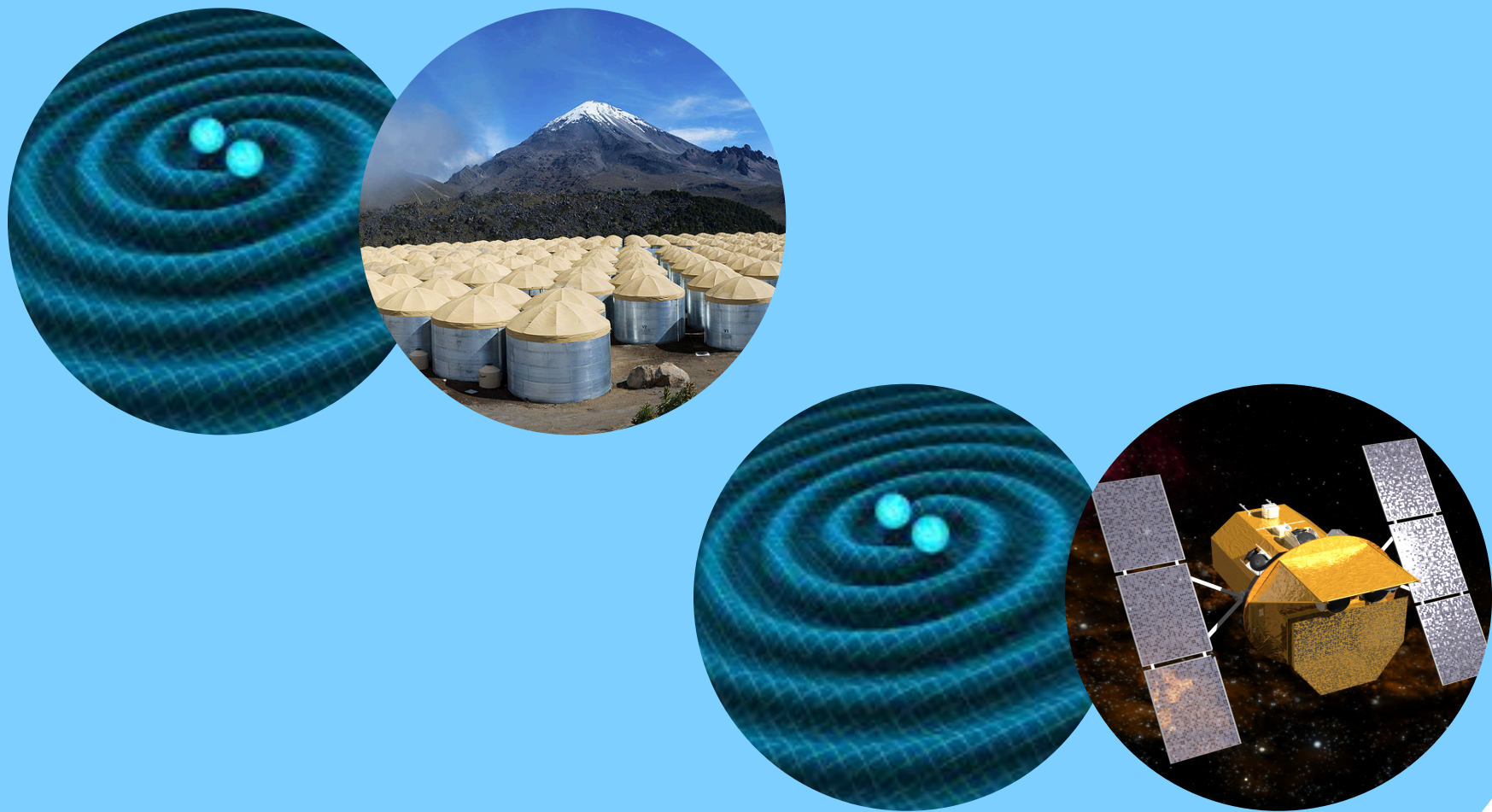
FAR (yr ⁻¹)	Chi2
10	6.4
1	7.9
0.5	8.4
0.1	9.4

NEXT STEPS

- Working on getting the analysis vetted by collaborations:
 - Running analysis on 2 years of unblinded archival data from HAWC and IceCube.
- Alerts will be sent after unblinding analysis is done.

Other On-going analysis

GW + γ



$\gamma + \nu$



Turley, et al 2018

Pass-Through



Synergies

Combine databases

Exchange analyses techniques

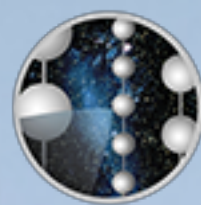


At least one server always up

AMON server is up and running

- AMON using **sub-threshold** data for multimessenger searches in **real-time**.
- AMON greatly **simplifies multimessengers searches**:
 - Common data format, transfer protocol, event database, MoUs.
- New participants are always welcome!
- Webpage: <http://www.amon.psu.edu/>
- MoU: <http://www.amon.psu.edu/join-amon/>





ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY



HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

Back-Up

Entering a new era where we can detect the messengers of the four forces of nature

Force	Messenger	Messenger Detected	Sources?
EM	Photons	👍	Several
Weak	Neutrinos	👍	Three (Sun, SN1987A, TXS 0506 (3.5σ *))
Strong	p, nuclei	👍	?
Gravity	Gravitational Waves	👍	Few and increasing

Each messenger has advantages and disadvantages.

Messenger	Sample Size	Straight Trajectory	Pointing Res.	Cutoff
γ			$\ll 1^\circ$	$E_\gamma < 50 \text{ TeV}$ $\gamma\gamma_{IR} \rightarrow e^-e^+$
ν	$\sigma_{\nu, matter} < 1$		$\sim 1^\circ$	
p, nuclei		\vec{B}	-	GZK cutoff $E_p < 30 \text{ EeV}$
GW			2obs: ~ 1000 sq.deg.	