

Multimessenger Astrophysics with AMON: Current and Future Alerts

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for the AMON Team



VLVnT 2018 Dubna

AMON
Astrophysical Multimessenger Observatory Network



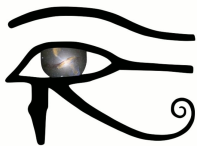
Outline

- What/Who is AMON
 - Astrophysical Multimessenger Observatory Network
- Current and Past Alert Campaigns
- Future Alerts

AMON searches for multimessenger transients using the messenger particles of all four fundamental forces

Triggering Observatories

- Provide sub-threshold candidate events to AMON in real time
- They have large FOV and high duty cycles

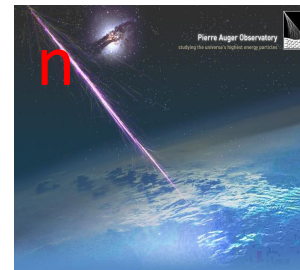
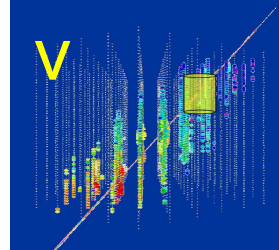
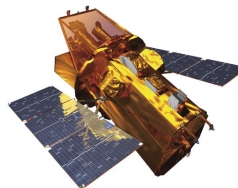


AMON

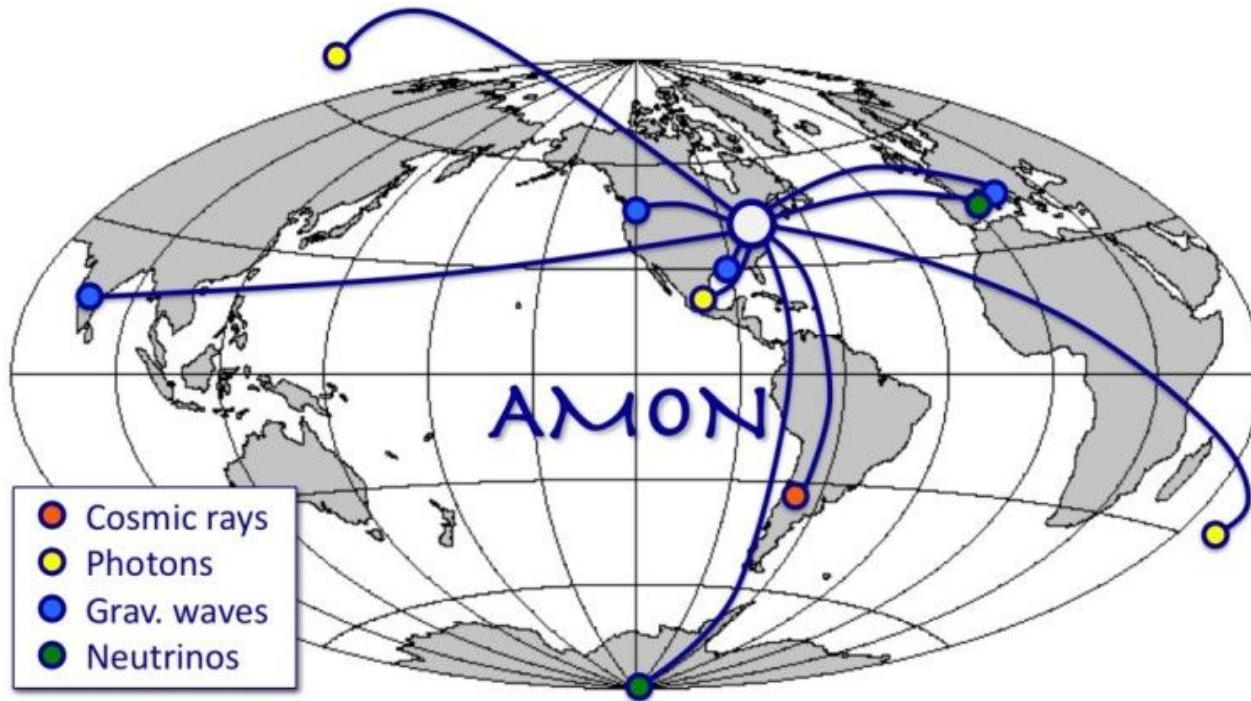
- Seeks coincidences in time and space
- Generates alerts, broadcasts, archives, and organizes
- Pass-through of above-threshold events (e.g. IceCube HESE)
- Dual High-Uptime Servers

Follow-up Observatories

- Receive and respond to AMON alerts
- Provide afterglow or delayed feedback on potential multimessenger transients



x-ray, UV, optical



MoU Highlights

- Each observatory retains full rights over use of its data
- No analyses are done without approval

MoU Template Found here:

<https://www.amon.psu.edu/join-amon/>

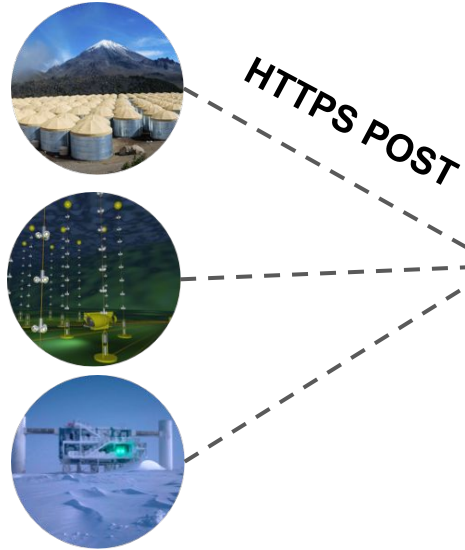
Triggering: IceCube, ANTARES, Pierre Auger, HAWC, VERITAS, FACT, Swift BAT, Fermi LAT & GBM, LIGO-Virgo*

Follow-up: Swift XRT & UVOT, VERITAS, FACT,, HESS, MAGIC, MASTER, LCOGT

* Ongoing MoU negotiations

Connecting To AMON

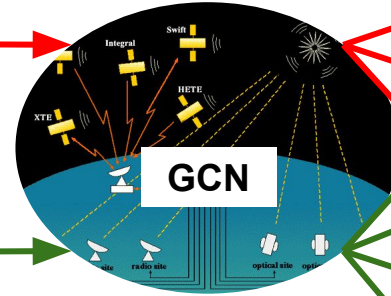
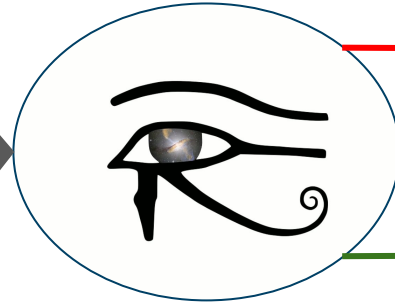
Triggering Observatories



Follow-Up Observatories

Private Alerts

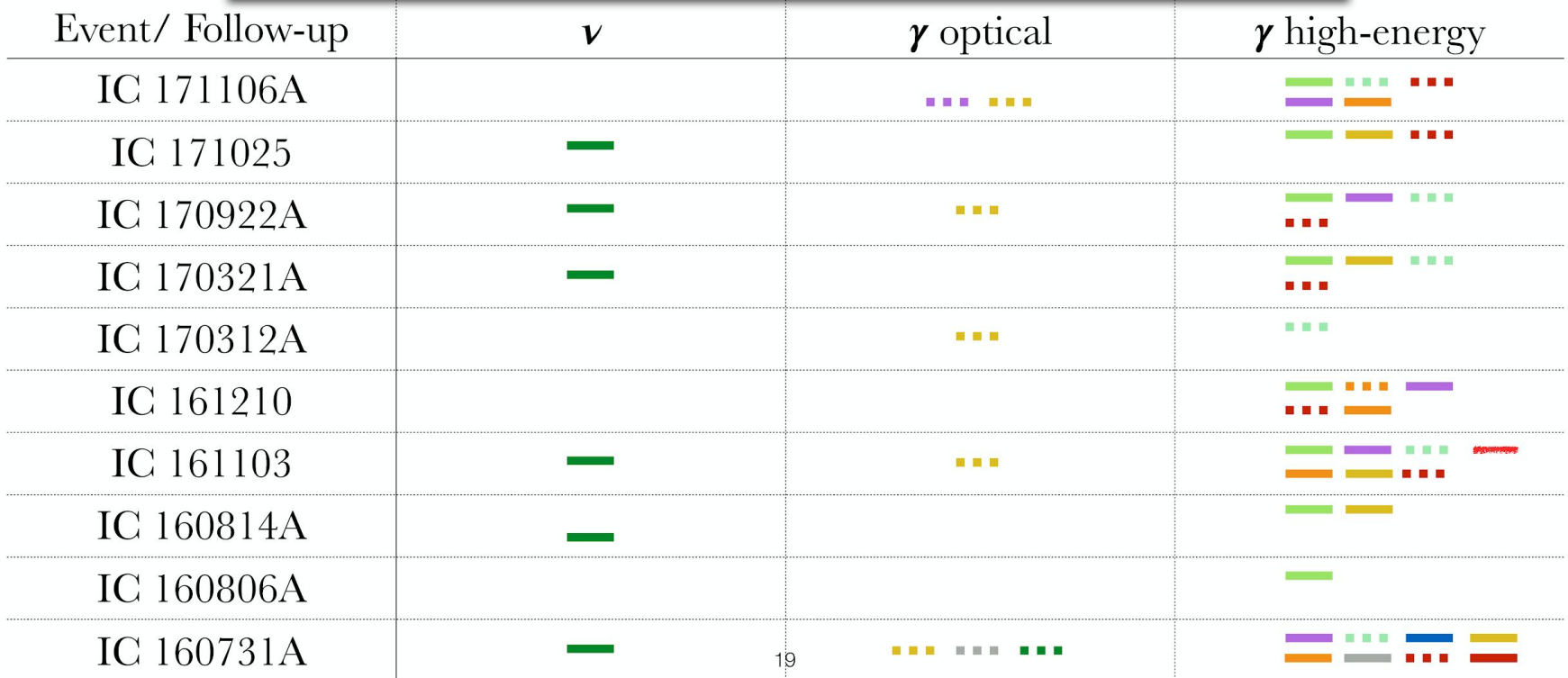
Public Alerts



- VOEvent sent via HTTPS Post
- AMON team provides:
 - TLS Certificate
 - Simple to run Post Client

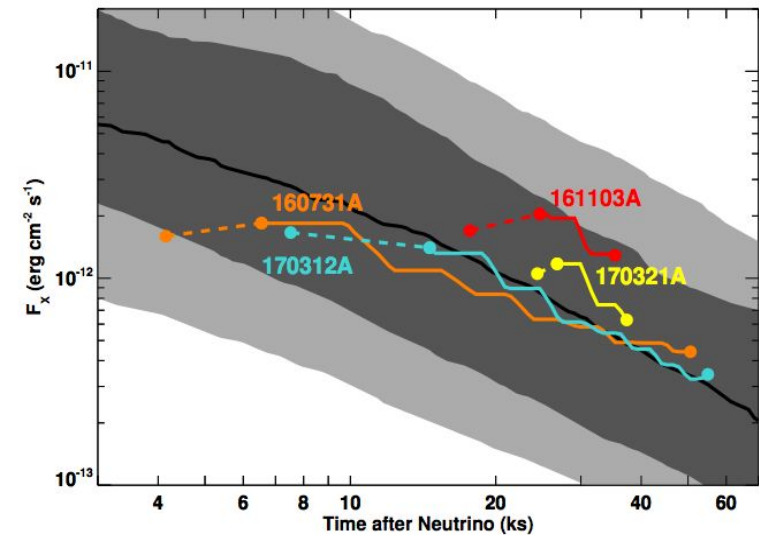
- GCN notices can be received as VOEvents or Emails
- To subscribe to GCN see here:
<https://gcn.gsfc.nasa.gov/gcn/invitation.html>

Current public alerts consist of High-Energy Tracks from IceCube, EHE and HESE

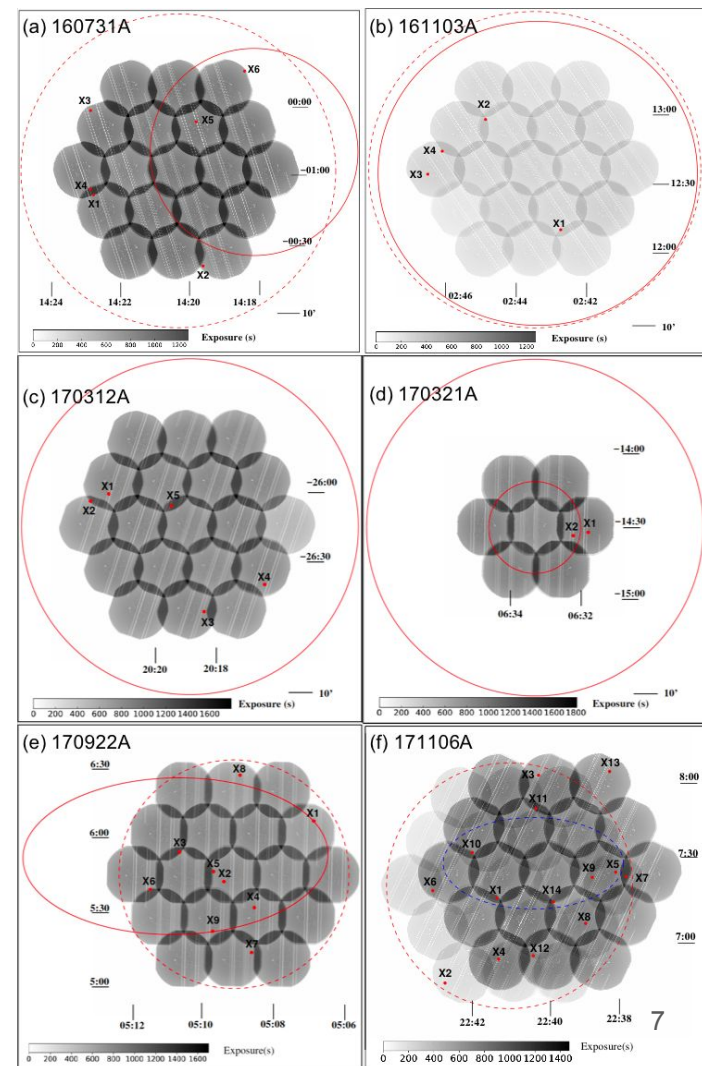


The Swift Campaigns: follow-up observations

- Observation tiles centered on first IceCube alert (dashed line) HESE/EHE alerts.
- 1st campaign: observations revealed multiple x-ray sources that were previously identified
- No compelling candidate X-ray or UV/optical counterpart for any of the events. Set up flux upper-limits

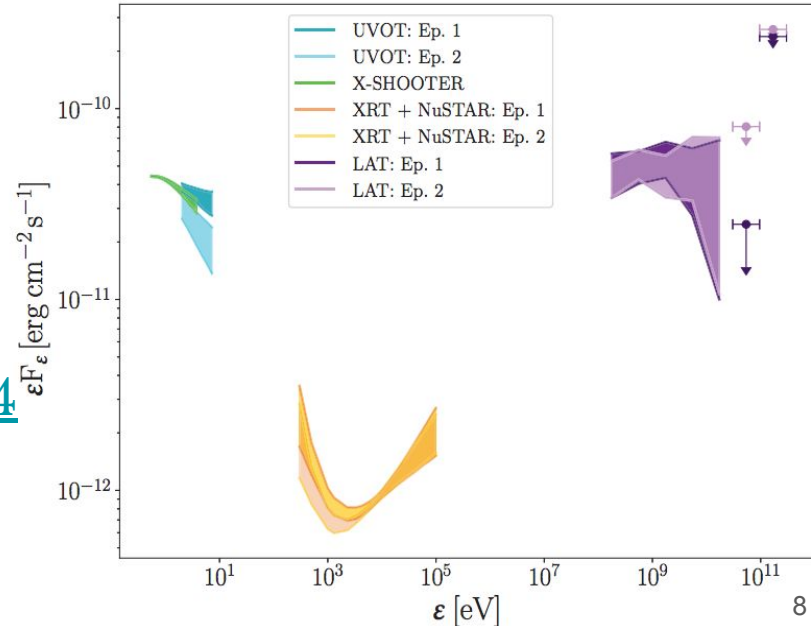
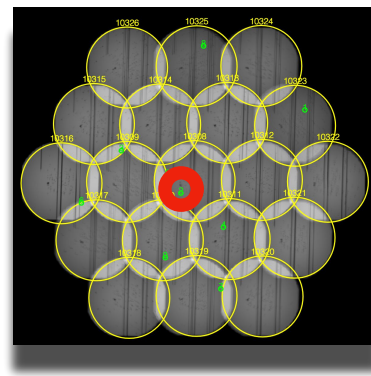


Keivani et al, ICRC 2017



The Swift Campaigns: IC170922A

- Tiles around IC170922A
 - Nine sources revealed in the field of view
- TXS 0506+056 or J0509+0541 is circled in Red
- Keivani et al. 2018: combined data from *Swift*, *NuSTAR*, and X-shooter data with *Fermi* observations. Lepton-hadronic model to explain emission.
<http://iopscience.iop.org/article/10.3847/1538-4357/aad59a/meta>
 - Expresses importance of full X-ray observations



Up-Coming Alerts

- Pass Through
 - Public IceCube Alerts
 - Simplified / Improved High-Energy Tracks
 - Private HAWC Alerts
 - GRB-like Transients
 - HAWC MoU members, possible Public Plans
- Gamma - Nu
- Gamma - GW

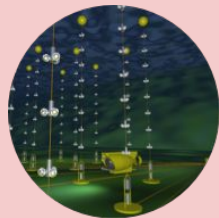


γ and ν Triggering Observatories

Neutrinos

ANTARES

Tev



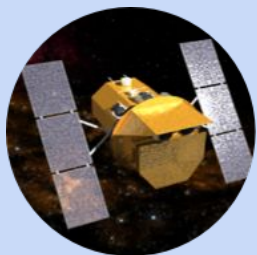
IceCube

Tev - PeV



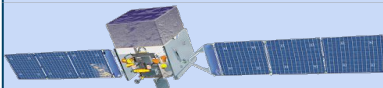
γ -Rays

Swift BAT



15 - 150 KeV

**Fermi
GBM/
LAT**



**10 - 1000 keV /
MeV - GeV**

FACT



100 GeV - 10 TeV

HAWC



TeV

ENERGY

γ - ν Coincident Analyses - Approval Pending



IceCube Tracks



HAWC Daily Map
Hot Spots

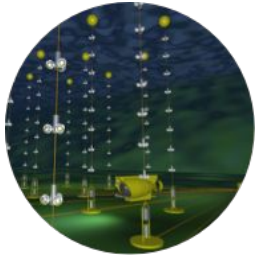
Coincident:

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

All ν 's from
rise to set time

Ranking:

$$\chi_{6+2n_\nu}^2 = -2 \ln [p_\lambda p_{HWC} p_{cluster} \prod_i^{n_\nu} p_{iIC}]$$



ANTARES
Tracks and
Cascades



Fermi LAT
Photons

Coincident:

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

$$\Delta t \pm 1000s$$

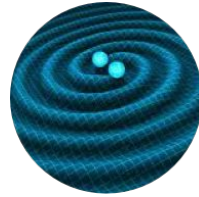
Ranking:

$$\lambda = 2 \ln \frac{P_{\nu\gamma}(\vec{x})(n_\nu! n_\gamma!)(\tau_{\nu\gamma})}{B_\gamma(\vec{x})}$$

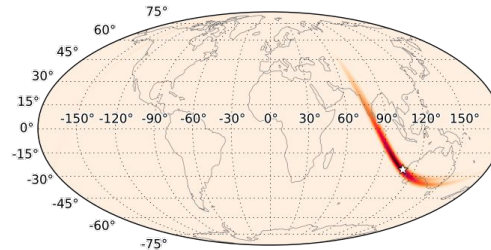
Preparing for O3: γ - GW

- GRB/GW 170817A has given huge motivation for dimmer, prompt γ -rays

- O3 Scheduled for early 2019
 - Public Alerts from LVC
 - FAR \lesssim 1 per month
 - Currently making proposals for an MoU to get sub-threshold alerts

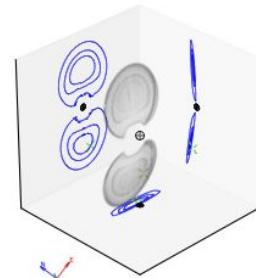
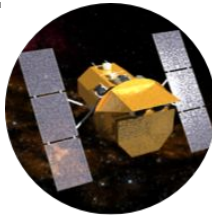


- Real-Time alerts include:
 - 2D or 3D Probability Sky Maps
 - FAR
 - EM Bright Probability



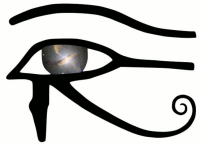
Proposing Coincident Searches with:

- Swift BAT
 - Sub-Threshold Image Blips
 - $\sim 4''$ 90% containment
 - Latency \sim 1-8 hours
- HAWC
 - Sub-Threshold GRBlike
 - TeV γ -rays should survive EBL for close by events ($d < 100$ Mpc)



Summary

- AMON has been up and running
 - Providing Pass-Through and helping to organize follow-ups
- New/Updated pass-through Alerts are coming
- γ - ν Coincident Analyses are in the works
- Preparing to make the most of O3

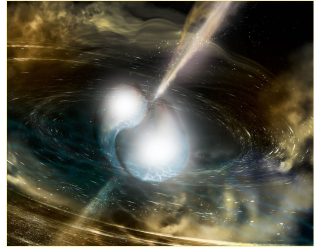


We're always looking for new AMON members, follow-up, triggering, analyses, or anything.

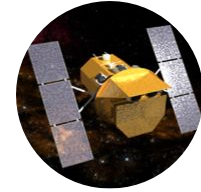
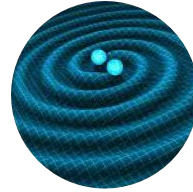
<https://www.amon.psu.edu/join/>

Backup Slides

LIGO-Virgo/Swift-BAT. We have proposed an analysis with sub threshold data.



**BNS
Mergers**



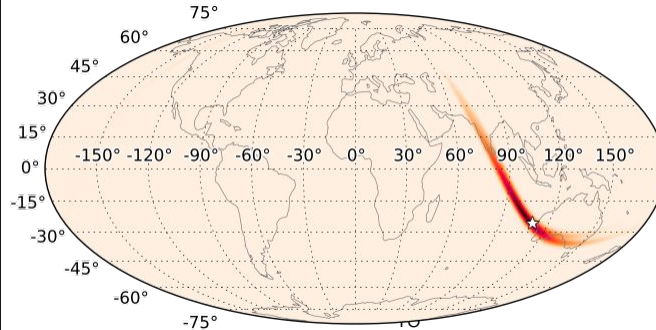
Data

- Low Latency CBC Detection Pipelines**
- Like GSTLAL
 - FAR, Mass Estimates or NS probability
- BAYESTAR Skymaps**
- 2D or 3D sky map localizations

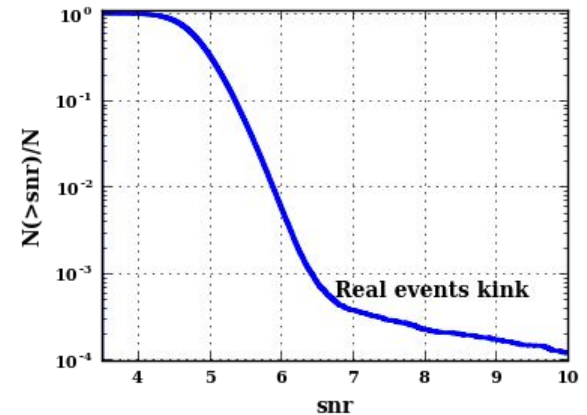
- Coded Mask Imager**
- Sub-threshold Image Peaks
 - Few arcmin localization
 - Exposure from milliseconds-minutes
 - 15-150 KeV

Background

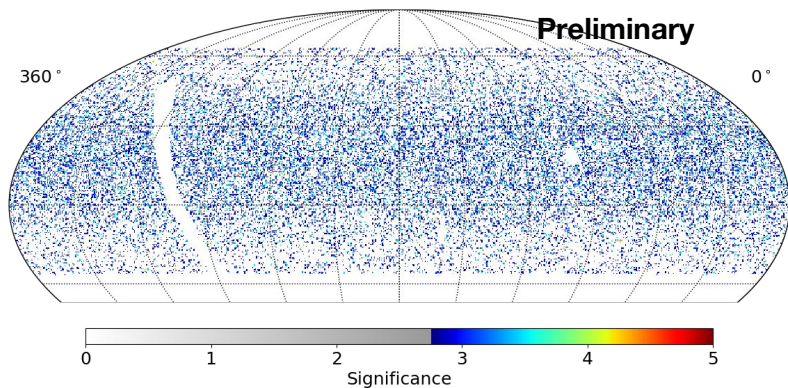
- Detector noise**
Non-astrophysical transients;
- Trucks driving by, etc.



Detector Noise Fluctuations

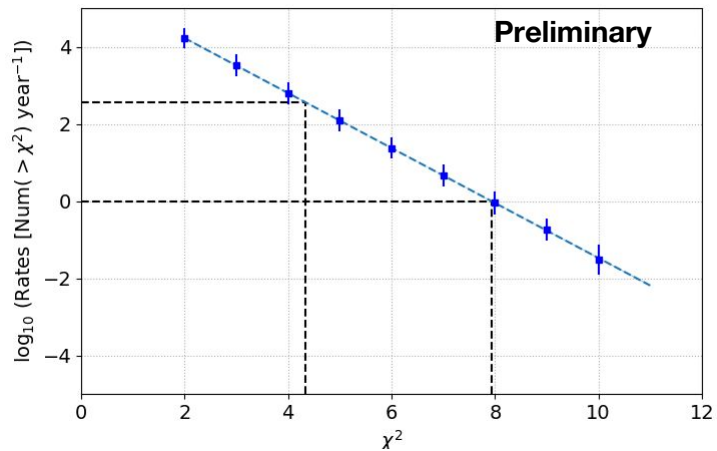
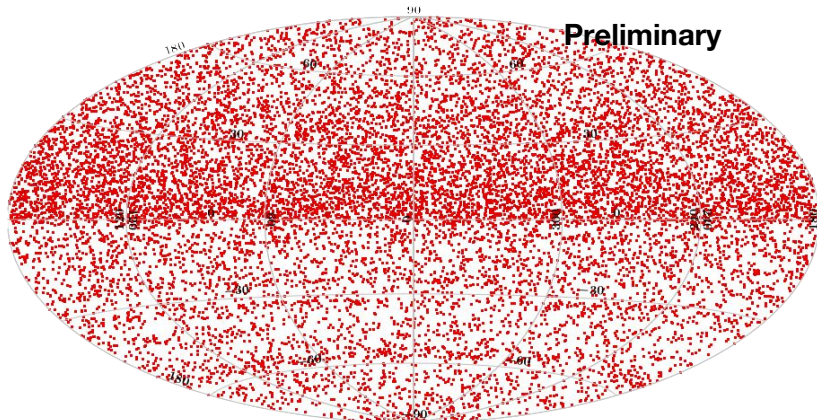


Current plan 1: IC-HAWC analysis has been defined and it is under review.
 Tested on 1 month of data from both observatories (scrambled).
 Alerts will be sent for specified thresholds that produce a specific FAR.



$$\chi_{6+2n_\nu}^2 = -2 \ln[p_\lambda p_{HWC} p_{cluster} \prod_i^{n_\nu} p_{iIC}]$$

$$\chi^{2'} = -\log p_{\chi_{6+2n_\nu}^2}$$



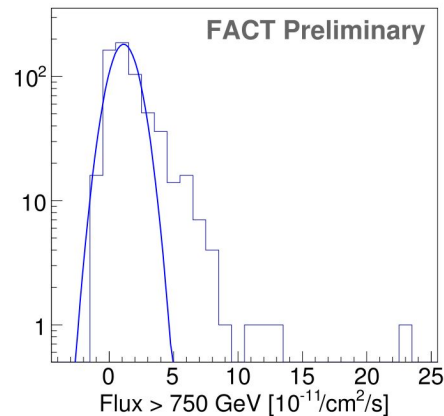


FACT

Data proposed for AMON	Tev γ -flares from a few bright sources in 20 minute bins
FOV	Small
Position Error	Known locations
Rate	?
Latency	~ hour

Work done by Daniela Dorner with the FACT collaboration

Mkr 421



- Excess Flux seen above “normal” flux in 20 minute bins

Defining a flare

- Right of the Gaussian curve is considered a Flare



- VOEvent format
 - Structured in XML format with simple schema
 - Easily interpreted by software, to be read by robotic telescopes
 - Already used by much of the astronomical community
- Sent out to AMON partners through AMON-GCN connection
 - Very fast delivery
 - Some day in the future, will be sent out publicly
- Content of AMON Alert
 - What
 - id number, stream number, revision number
 - False alarm rate, number of events, duration of events in alert
 - WhereWhen
 - Time, position of best fit, positional error