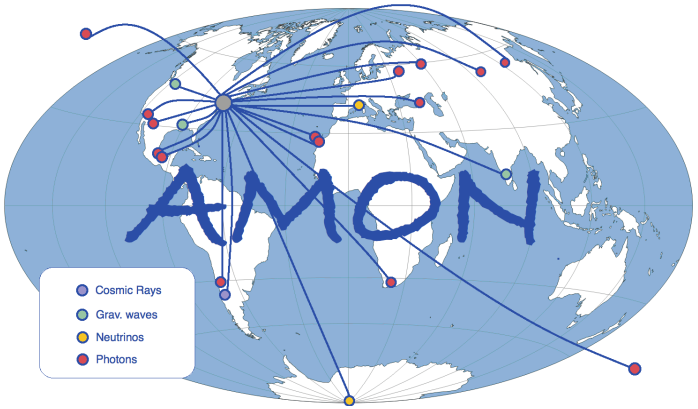


GRAND within a Multi-Messenger Universe

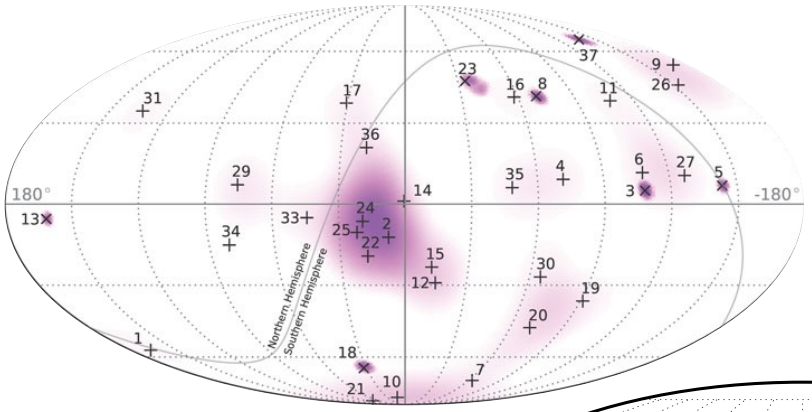
Experimental point of view

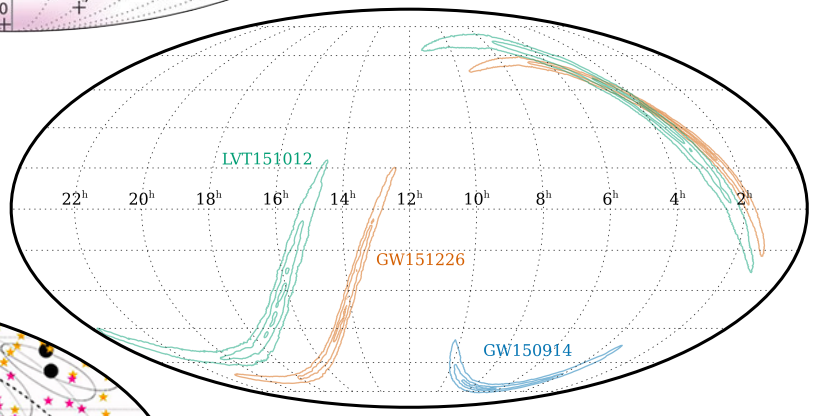
Miguel Mostafá
PennState
Eberly College of Science

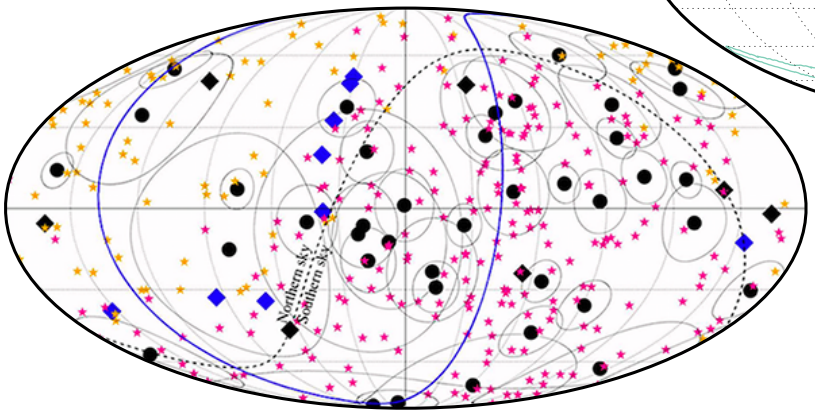
GRAND workshop at Huize Heyendael Nijmegen- February 20-22, 2018

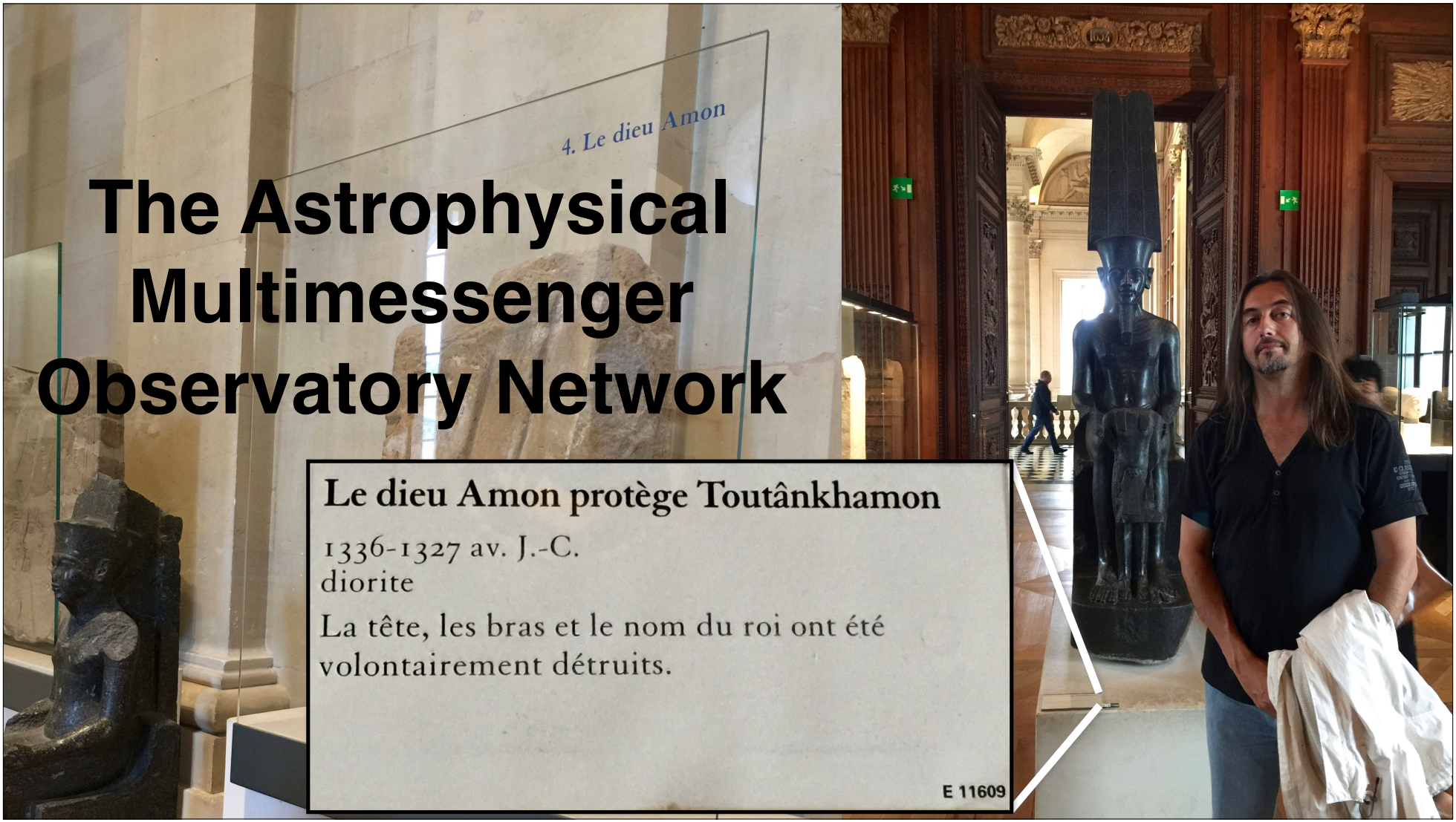
Outline

- Current status of AMON
- Where and how does GRAND fit in?
- Outlook







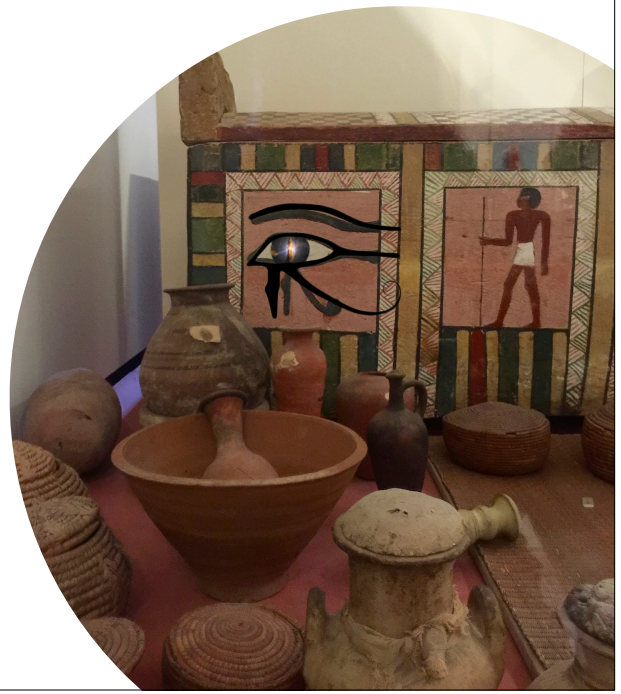


The Astrophysical Multimessenger Observatory Network

The AMON concept

AMON provides the **framework** for:

- **Realtime** and near realtime sharing of *subthreshold* data among *multimessenger* observatories
- Realtime and archival searches for any **coincident** (in time and space) signals.
- Prompt distribution of **alerts** for follow-up observations

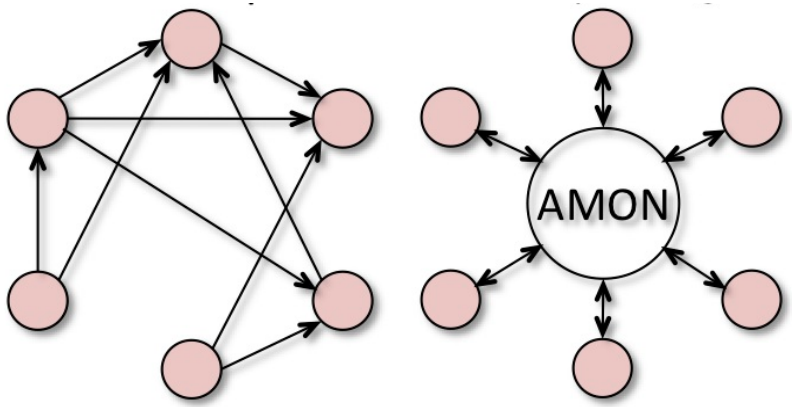


The AMON concept

AMON provides the **framework** for:

- **Realtime** and near realtime sharing of *subthreshold* data among *multimessenger* observatories
- Realtime and archival searches for any **coincident** (in time and space) signals.
- Prompt distribution of **alerts** for follow-up observations

AMON unifies and simplifies existing *multimessenger* efforts:

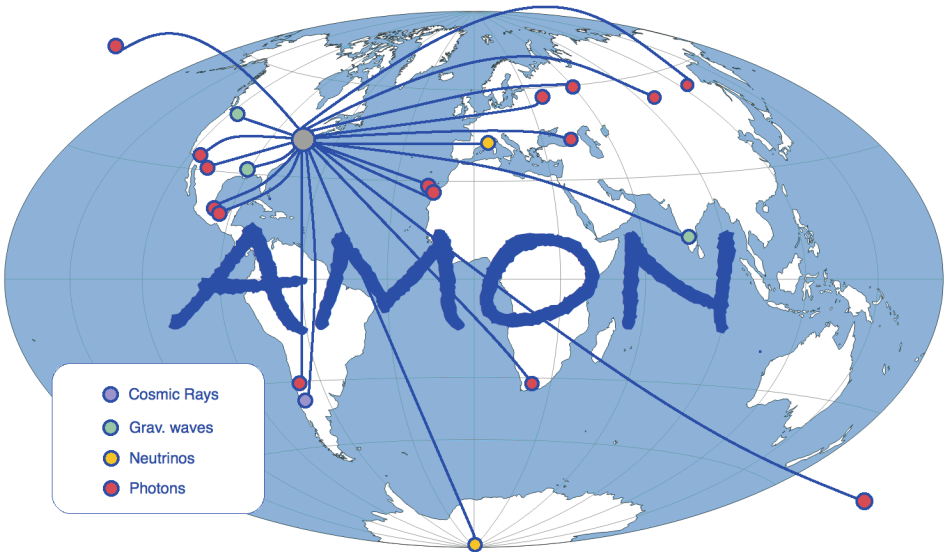


Astrop.Phys. Vol. 45, 56–70, 2013

http://amon.gravity.psu.edu/

The Network

- **Triggering:** IceCube, ANTARES, Auger, HAWC, VERITAS, FACT, Swift-BAT
- **Follow-up:** Swift-XRT & UVOT, VERITAS, FACT, MASTER, LCOGT
- **Pending:** LIGO, MAGIC, HESS, PTF, TA, …



http://amon.gravity.psu.edu/mou_may2015.shtml

Real-time streams

- Realtime streams
  - **IC**
    - *Singlets*: position, time, FPRD, parameters to determine PSF, (so far the RA is randomized)
    - *Multiplets*: position, angular window, time, time window
    - *HESE*: position, time, signal “trackness”, charge,
    - *EHE*: position, time, “signalness”
  - **HAWC**
    - Hotspots integrated over time. Position and its uncertainty, transit time, *p*-value (significance)
  - **Antares**
    - Position, time, error and FPR (1^{o} y 0.0001463 resp. for all the events…)
  - **Auger**
    - Position, time, error, FPR, and energy
  - **Swift** (*sub-sub-threshold*), and **Fermi** are public. We read them from GCN and their website, resp.
  - WE used to receive real-time data from **FACT** but (preparing this presentation) I found the last events are from July…

IC streams details

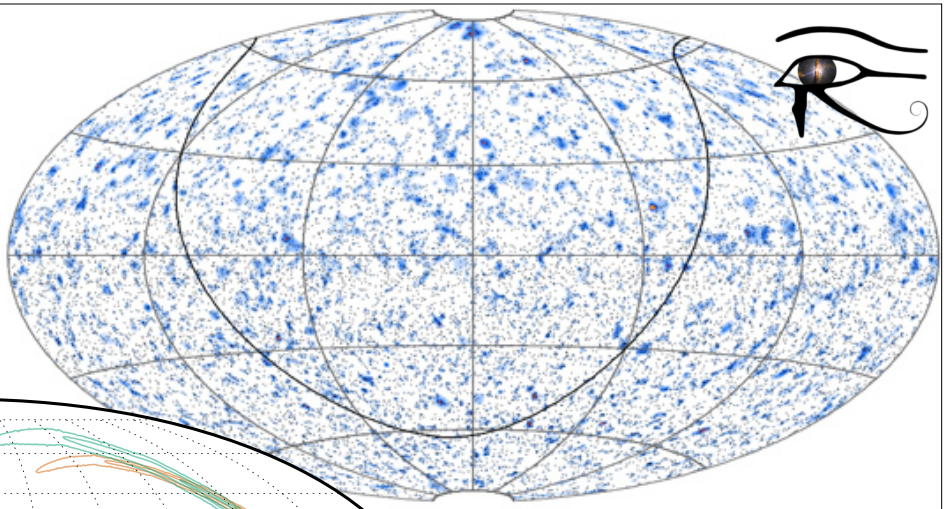
- IC realtime streams
  - *Singlets*: these are “track events” produced by muons, from muon neutrinos. They are selected mainly based on energy, but they use several parameters.
  - *Multiplets*: these are singlets within a 3.5° angular window and a 100 s time period.
  - *HESE*: based mainly on total charge and how much of a “track” they look like. (Online documentation: https://gcn.gsfc.nasa.gov/doc/Public_Doc_AMON_IceCube_GCN_Alerts_Oct2016_v7.pdf where the selection is charge > 6000 PEs and signal trackness ≥ 0.1)
  - *EHE*: mostly based on the number of photoelectrons. (Online documentation: https://gcn.gsfc.nasa.gov/doc/AMON_IceCube_EHE_alerts_Oct31_2016.pdf The main cuts are in page 2.)

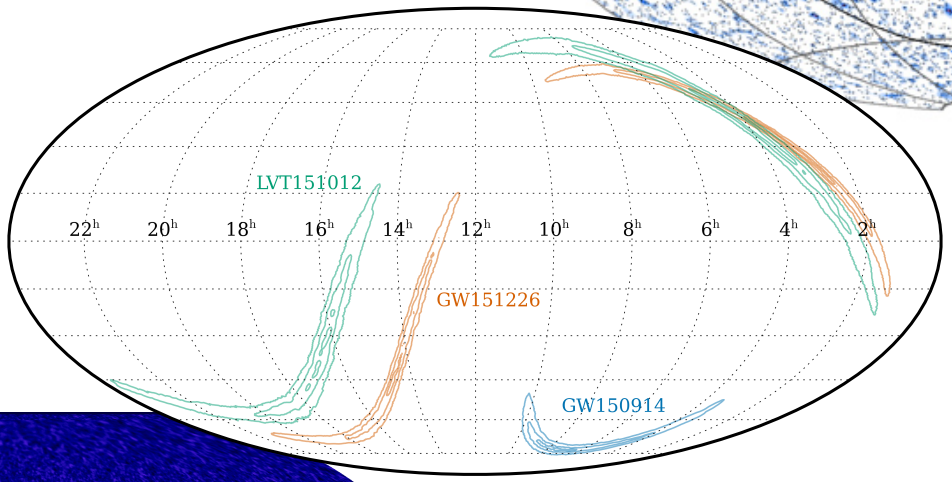
Online analyses & proposals

- Realtime ν alerts
  - **HESE** GCN notices went live in **April 2016**
  - **EHE** notices followed in **July 2016**
  - The **Multiplet** stream is also sent to GCN, but it's a **private** stream
  - HE ν from flaring blazar?
- Swift proposals
  - X-ray and UV/optical counterparts to HE ν's
  - X-ray and UV/optical counterparts to ν's + X- and γ-ray coincidences

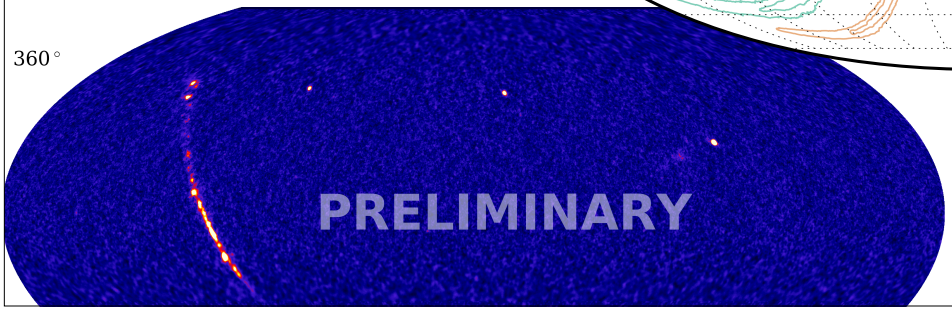
AMON Prospects

ν's





GW



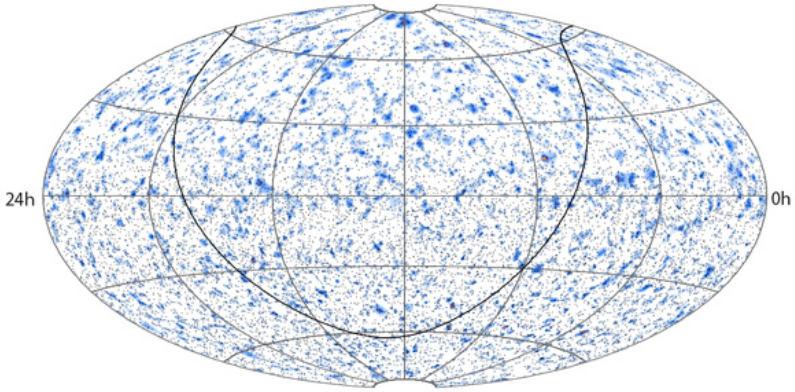
γ rays

AMON progress

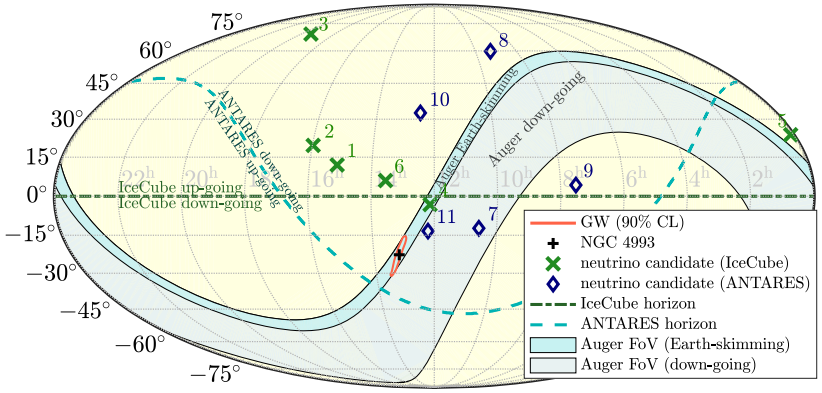
- AMON has made a significant progress toward **real-time** and archival analyses
- AMON server is online
- New high-uptime dual hardware is **fully operational**
- Ongoing realtime streams from IceCube
- IceCube's HESE and EHE **alerts** distributed via GCN (public!)
- More real-time electronic alerts via AMON/GCN (e.g., IceCube's EHE, OFU) and incoming event streams (e.g., Auger and HAWC)

GRAND outlook

- Realtime streams should be similar to IC
  - Need to define sub-threshold stream
  - May include a "*neutrinoness*" value…



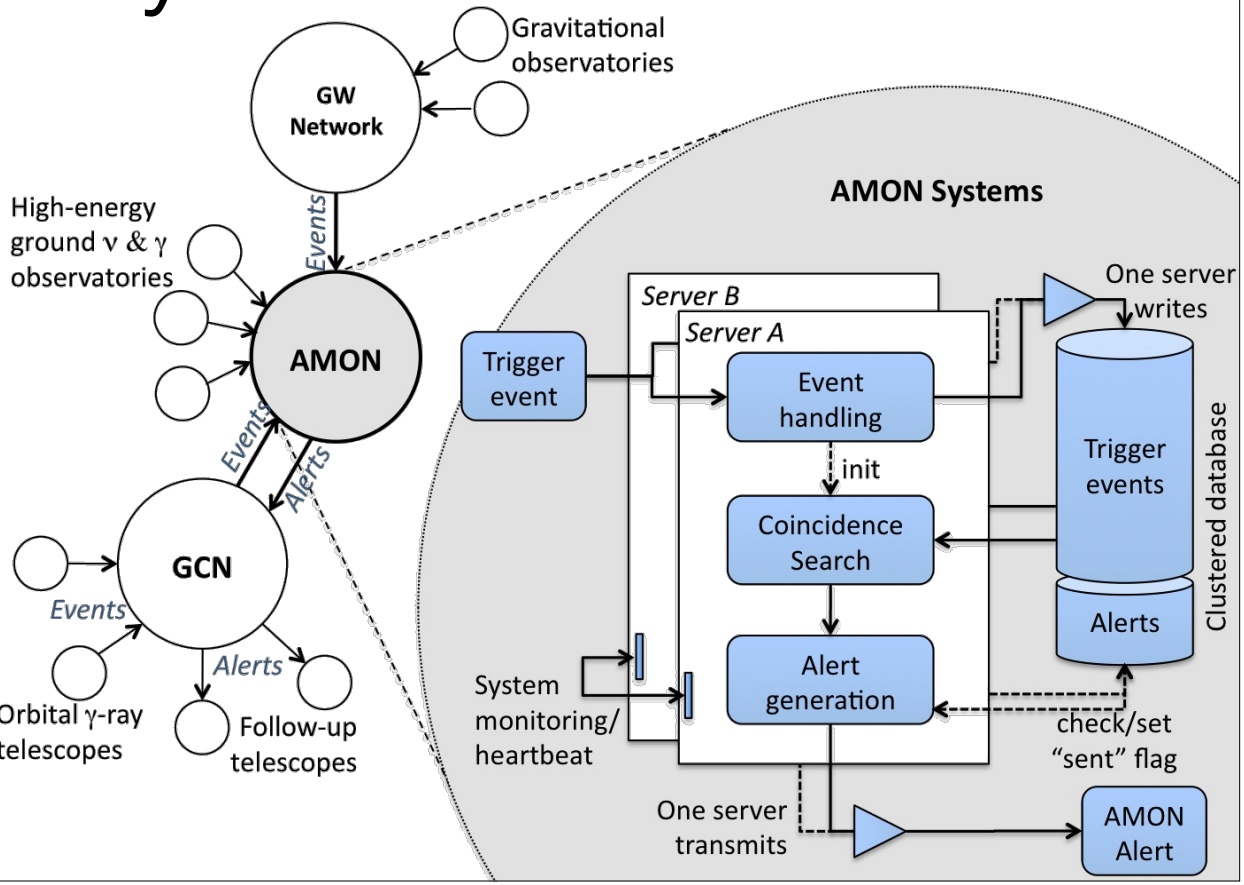
- Correlation with (multiple) other sub-threshold streams



Back ups

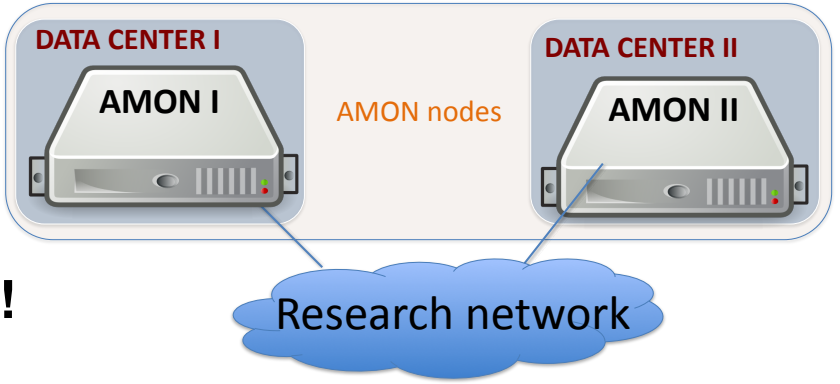
The AMON system + data flow

- *Subthreshold* data from **triggering** observatories are sent in a **VOEvent** format and stored in a secure database.
- VOEvents from **satellite** experiments are received via the Gamma-ray Coordinates Network (**GCN**)
- AMON **alerts** are distributed as VOEvents to follow-up observatories via GCN



The network status - new hardware

- Deployed two new **high-uptime servers**
  - systems are physically and cyber **secure**
  - hardware and power **redundant**
  - memory mirroring
- Fully operational since **February 2016!**



The network status - database

First full version of the **AMON database** designed, implemented, and tested! Now being used.

- Data from **triggering** observatories implemented:
  - public completed: IC-40, IC59, Swift, Fermi
  - private completed: ANTARES 2008, Auger
  - in progress: IceCube, HAWC, VERITAS, ANTARES, LIGO S5 & S6
- **Realtime tests** with simulated and real (IC) data constantly being performed

The network status - application server

The AMON application server has been up and running since **August 2014!**

- Built using Python/Twisted, asynchronous, **tested** with several simulated and real clients
- Accepts HTTPS POST requests
- Open for authorized connections (TLS certificates)
- Started issuing ***alerts*** from scrambled realtime data (VOEvents) via GCN in **May 2015**

Archival analysis example

IceCube + Fermi LAT (public data)

- IC-40 run period **(done)**
  - ~14 k ν's
  - ~ 4 M γ's
- IC-59 run period **(on going)**
  - ~43 k ν's
  - ~ 6 M γ's

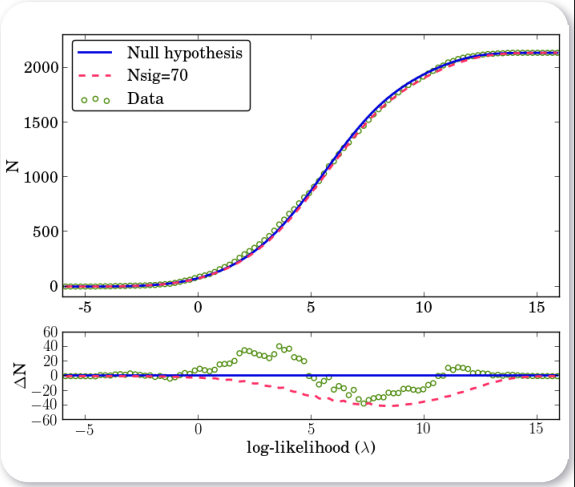
Coincidence parameters

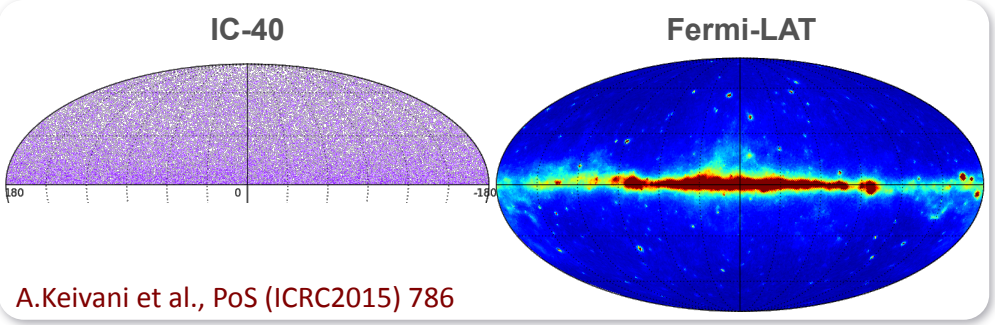
$$\Delta t = \pm 50 \text{ s}$$

$$\Delta\theta < 10^{\circ}$$

IceCube + Fermi LAT

- IC-40 run period
  - data = 2138 ν+γ pairs
  - bkg = 2207±40 pairs
  - p-value = 15%
- IC-59 run period
  - data = 9025 ν+γ pairs
  - bkg = 9077±153 pairs
  - p-value = 9%

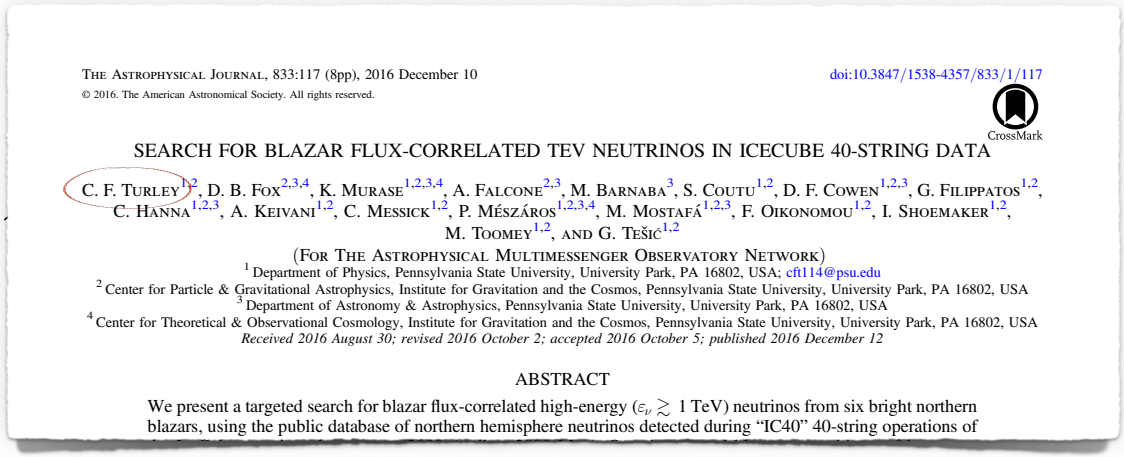




A.Keivani et al., PoS (ICRC2015) 786

- In addition, clustering of detected pairs, time distribution and multiplicity are consistent with background expectation

analyses



The Astrophysical Journal, 833:117 (8pp), 2016 December 10 doi:10.3847/1538-4357/833/1/117

SEARCH FOR BLAZAR FLUX-CORRELATED TEV NEUTRINOS IN ICECUBE 40-STRING DATA

C. F. Turley[1,2], D. B. Fox[2,3,4], K. Murase[1,2,3,4], A. Falcone[2,3], M. Barnaba[3], S. Coutu[1,2], D. F. Cowen[1,2,3], G. Filippatos[1,2], C. Hanna[1,2,3], A. Keivani[1,2], C. Messick[1,2], P. Mészáros[1,2,3,4], M. Mostafá[1,2,3], F. Oikonomou[1,2], I. Shoemaker[1,2], M. Toomey[1,2], and G. Tešić[1,2]
(For The Astrophysical Multimessenger Observatory Network)
[1] Department of Physics, Pennsylvania State University, University Park, PA 16802, USA; cft114@psu.edu
[2] Center for Particle & Gravitational Astrophysics, Institute for Gravitation and the Cosmos, Pennsylvania State University, University Park, PA 16802, USA
[3] Department of Astronomy & Astrophysics, Pennsylvania State University, University Park, PA 16802, USA
[4] Center for Theoretical & Observational Cosmology, Institute for Gravitation and the Cosmos, Pennsylvania State University, University Park, PA 16802, USA
Received 2016 August 30; revised 2016 October 2; accepted 2016 October 5; published 2016 December 12

ABSTRACT

We present a targeted search for blazar flux-correlated high-energy ($\varepsilon_\nu \gtrsim 1$ TeV) neutrinos from six bright northern blazars, using the public database of northern hemisphere neutrinos detected during "IC40" 40-string operations of

-
  - IC40/59 and Swift-BAT sub-threshold (in progress)
  - IC40 and VERITAS blazar TeV flares: Astrophys. J. **833** (2016) 117
- γ rays + gravitational waves
  - Swift and LIGO S5 (in progress)
- ν's + γ rays + cosmic rays
  - PBH evaporation searches, G. Tešić, PoS (ICRC'15) 328 (2015)
- others… FRB + Swift: ApJL **832** (2016) L1

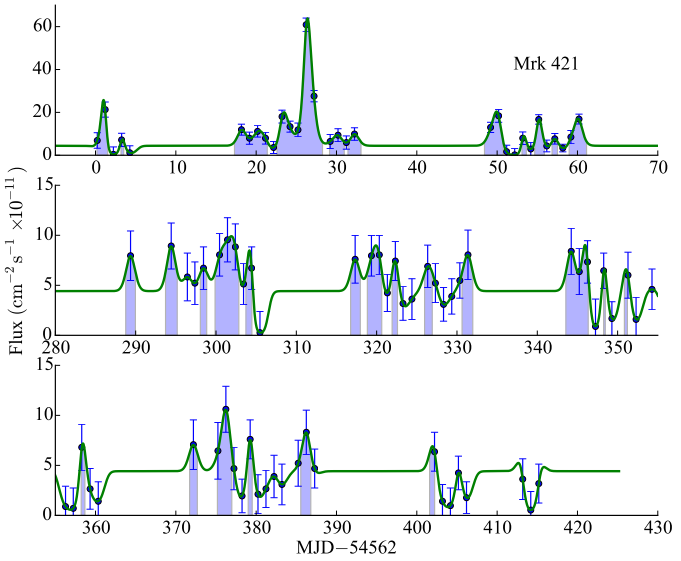


Fig. 2.— Times of interest for Markarian 421. These times were selected in our initial optimization as the most sensitive search for associated neutrinos (Sec 2.3). The selection includes 45.6 days with a total γ-ray fluence of $4.1 \times 10^{-4}\,\mathrm{cm}^{-2}$ and yields an expected background of 1.03 neutrinos.

Ongoing archival analyses

- ν's + γ rays
  - IC40 and Fermi-LAT, A. Keivani et al., PoS (ICRC'15) 786 (2015)
  - IC40/59 and Fermi-LAT (final stage)
  - IC40/59 and Swift-BAT sub-threshold (in progress)
-
-
- others… FRB + Swift: ApJL **832** (2016) L1

The Astrophysical Journal Letters, 832:L1 (9pp), 2016 November 20 doi:10.3847/2041-8205/832/1/L1

DISCOVERY OF A TRANSIENT GAMMA-RAY COUNTERPART TO FRB 131104

J. J. DeLaunay[1,3], D. B. Fox[2,3,4], K. Murase[1,2,3,4], P. Mészáros[1,2,3,4], A. Keivani[1,3], C. Messick[1,3], M. A. Mostafá[1,3], F. Oikonomou[1,3], G. Tešić[1,3], and C. F. Turley[1,3]
[1] Department of Physics, Pennsylvania State University, University Park, PA 16802, USA; jjd330@psu.edu
[2] Department of Astronomy & Astrophysics, Pennsylvania State University, University Park, PA 16802, USA
[3] Center for Particle & Gravitational Astrophysics, Institute for Gravitation and the Cosmos, Pennsylvania State University, University Park, PA 16802, USA
[4] Center for Theoretical & Observational Cosmology, Institute for Gravitation and the Cosmos, Pennsylvania State University, University Park, PA 16802, USA
Received 2016 September 26; accepted 2016 September 29; published 2016 November 11

ABSTRACT

We report our discovery in *Swift* satellite data of a transient gamma-ray counterpart (3.2σ confidence) to the fast radio burst (FRB) FRB 131104, the first such counterpart to any FRB. The transient has a duration $T_{90} \gtrsim 100$ s and a fluence $S_\gamma \approx 4 \times 10^{-6}$ erg cm^{-2}, increasing the energy budget for this event by more than a billion times; at the nominal $z \approx 0.55$ redshift implied by its dispersion measure, the burst's gamma-ray energy output is $E_\gamma \approx 5 \times 10^{51}$ erg. The observed radio to gamma-ray fluence ratio for FRB 131104 is consistent with a lower

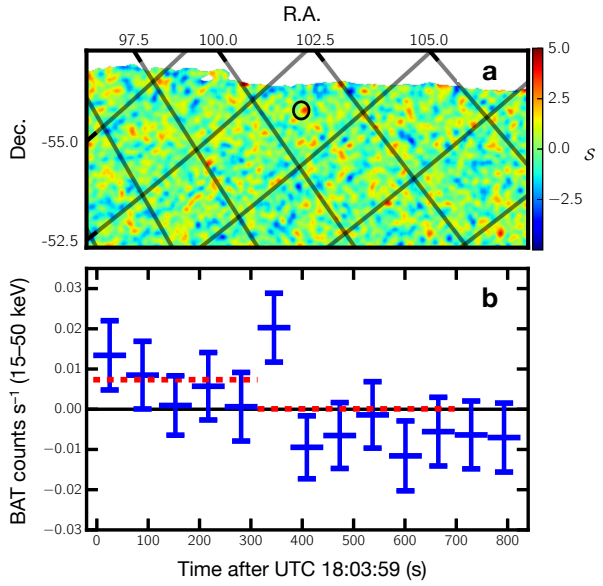
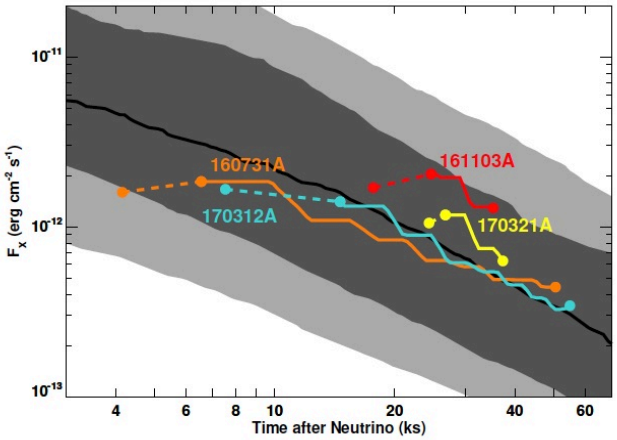
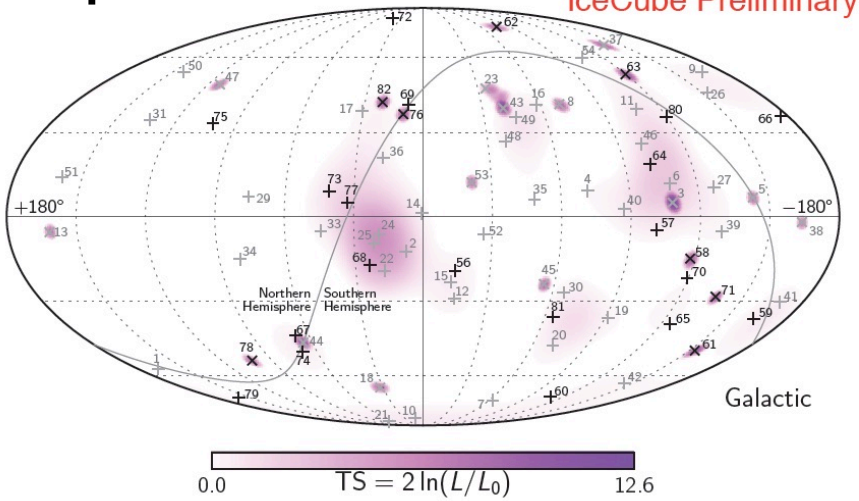


Figure 1. Swift BAT discovery image and light curve for the transient gamma-ray counterpart to FRB 131104, Swift J0644.5−5111. (a) Swift J0644.5−5111 discovery image (15–150 keV; UTC 18:03:52 start; 300 s exposure), showing a small portion of the BAT field of view in tangent plane projection. The search region for FRB 131104 (black circle) is shown; regions with <1% coding are masked. The point-like excess associated with the gamma-ray transient peaks at signal-to-noise $\mathcal{S} = 4.2\sigma$. (b) Soft-band (15–50 keV) light curve for Swift J0644.5−5111. Time is measured from the FRB detection, UTC 18:03:59. Both 64 s (blue) and 320 s (red dashed) flux measurements are shown; error bars are $\pm 1\sigma$.

Swift proposals





ν	γ	r_{90}	Average Latency	Potential Sources
ANTARES	*Fermi*-LAT	~0.3°	~5 hrs	AGNs, GRBs
IceCube	HAWC	~0.1°	~7 hrs	
IceCube	*Fermi*-LAT	~0.3°	~5 hrs	
IceCube	*Swift* BAT	~4'	~8 hrs	

Following HE ν's

```
////////////////////////////////////////////////////////////////////////
TITLE:            GCN/AMON NOTICE
NOTICE_DATE:      Fri 22 Sep 17 20:55:13 UT
NOTICE_TYPE:      AMON ICECUBE EHE
RUN_NUM:          130033
EVENT_NUM:        50579430
SRC_RA:            77.2853d {+05h 09m 08s} (J2000),
                   77.5221d {+05h 10m 05s} (current),
                   76.6176d {+05h 06m 28s} (1950)
SRC_DEC:           +5.7517d {+05d 45' 06"} (J2000),
                   +5.7732d {+05d 46' 24"} (current),
                   +5.6888d {+05d 41' 20"} (1950)
SRC_ERROR:        14.99 [arcmin radius, stat+sys, 50% containment]
DISCOVERY_DATE:   18018 TJD;   265 DOY;   17/09/22 (yy/mm/dd)
DISCOVERY_TIME:   75270 SOD {20:54:30.43} UT
REVISION:         0
N_EVENTS:         1 [number of neutrinos]
STREAM:           2
DELTA_T:          0.0000 [sec]
SIGMA_T:          0.0000e+00 [dn]
ENERGY :          1.1998e+02 [TeV]
SIGNALNESS:       5.6507e-01 [dn]
CHARGE:           5784.9552 [pe]
SUN_POSTN:        180.03d {+12h 00m 08s}   -0.01d {-00d 00' 53"}
SUN_DIST:         102.45 [deg]   Sun_angle= 6.8 [hr] (West of Sun)
MOON_POSTN:       211.24d {+14h 04m 58s}   -7.56d {-07d 33' 33"}
MOON_DIST:        134.02 [deg]
GAL_COORDS:       195.31,-19.67 [deg] galactic lon,lat of the event
ECL_COORDS:        76.75,-17.10 [deg] ecliptic lon,lat of the event
COMMENTS:         AMON_ICECUBE_EHE.
```