The Astrophysical Multimessenger Observatory Network (AMON)

STATUS OF AMON

Gordana Tešić
(for the AMON team)

The Third AMON Workshop
December 11-12, 2014, DESY in Zeuthen, Germany

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AMON project

- Founded and hosted at Penn State
  - Internal initial funding
- Official NSF funded project as of 2014

AMON development and advisory team

Penn State

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Others

Scott Barthelmy[1], Imre Bartos[2], Farhan Feroz[3], Miles Smith[4], Ignacio Taboada[5]

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Disclaimer

- AMON is a *consortium* of observatories and a system of cyber infrastructure for joint analysis of data and alert distribution.

- AMON is intended as a *service* to the participating collaborations, but is not in of itself a scientific collaboration.
  - The AMON development team will not publish data, other than performance reports.

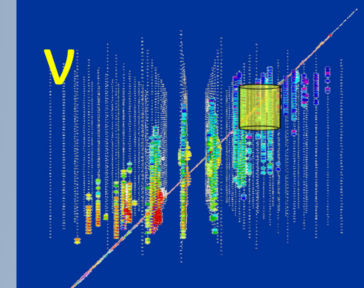
- Decisions about data sharing and analysis are made by the participating collaborations.
  - Collaborations are represented by working groups and the AMON Executive Board.

See AMON Memorandum of understanding (MOU): http://amon.gravity.psu.edu/mou_aug2012.shtml

The AMON Idea

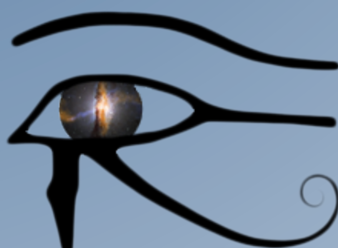
The AMON Idea

Use messenger particles of all four fundamental forces



Triggering observatories

- Provide **sub-threshold** candidate events to AMON in real time



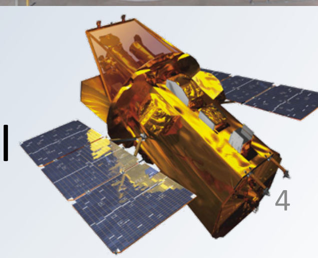
AMON

- Seeks **coincidences** in time and space
- Generates **alerts** - broadcast and archived
- Enables archival analyses

Follow-up observatories

- respond to AMON alerts

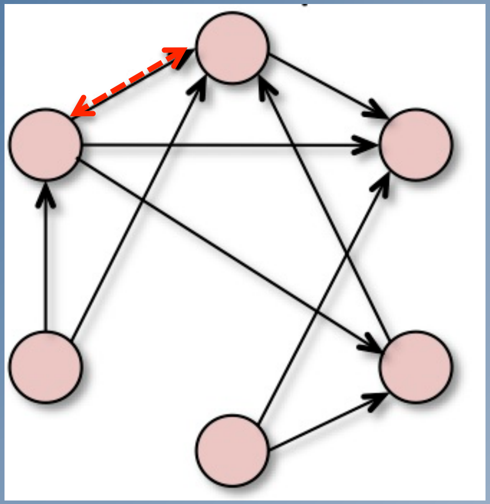
x, UV, optical



The AMON Idea

The AMON Idea

Status quo

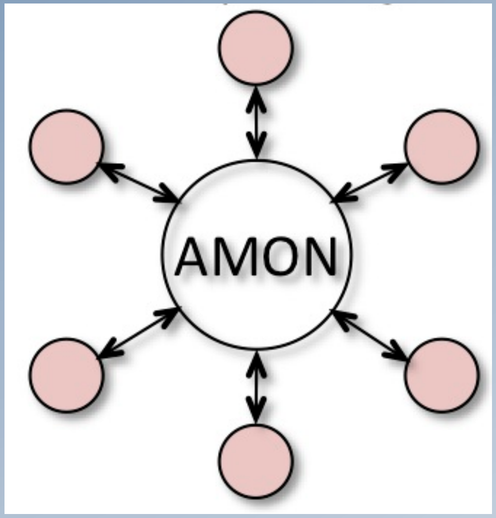


Many bilateral agreements among various observatories and cross-collaborative analyses

No unified multilateral agreement and unified analyses of multimessenger data

Mostly unidirectional

Future



AMON serves as a central hub for collecting data from various multimessenger facilities

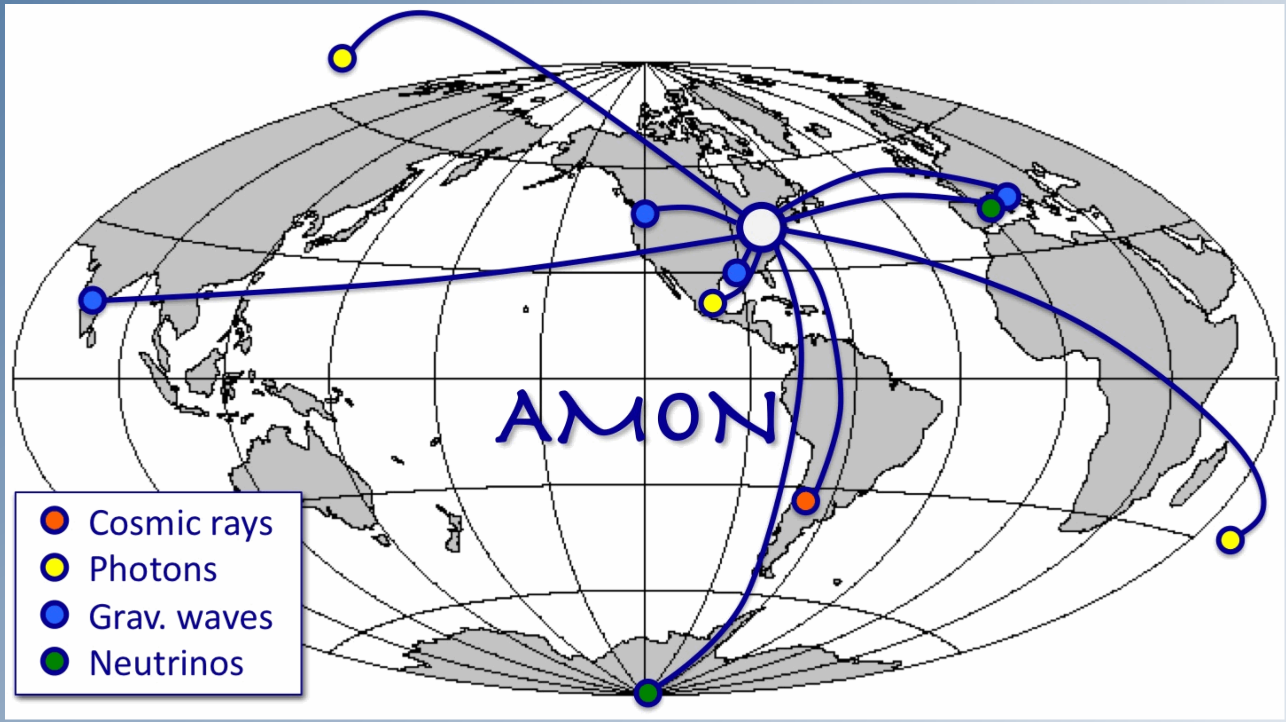
Performs unified analyses on multimessenger data

Gain in effective aggregate sensitivity

Simplified protocols of cross-collaborative analyses

AMON Network

6 Memoranda of Understandings (MoUs) signed
+ 1 MoU in review
+ 2 more letter of collaboration
+ many more in the future



Triggering:

Astrop.Phys. Vol. 45, 56–70, 2013

IceCube
ANTARES
Auger
HAWC
VERITAS
Swift BAT…

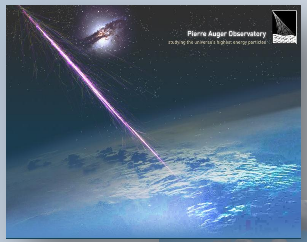
Follow-up:

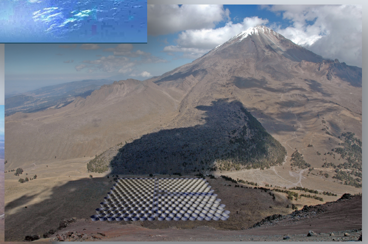
Swift XRT &UVOT
VERITAS…

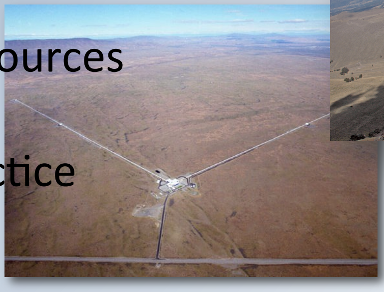
Evoke, Exploit, Explore

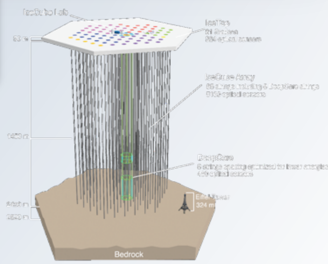
The goals of AMON:

- ***Evoke***
  - Multi-facility sub-threshold coincident search
  - Convert *noise* to *signal*
  - Increase sensitivity for sources emitting in >1 channel
- ***Exploit***
  - Many such sources expected to be transient (GRBs, SNe, AGN flares…)
  - Prompt identification *required* for follow-up and exploitation
- ***Explore***
  - Follow-up + exploitation of first sources will be difficult
  - Organize follow-up network, practice with subthreshold alerts
  - Carry out archival analyses
  - Ready for best-case scenario science







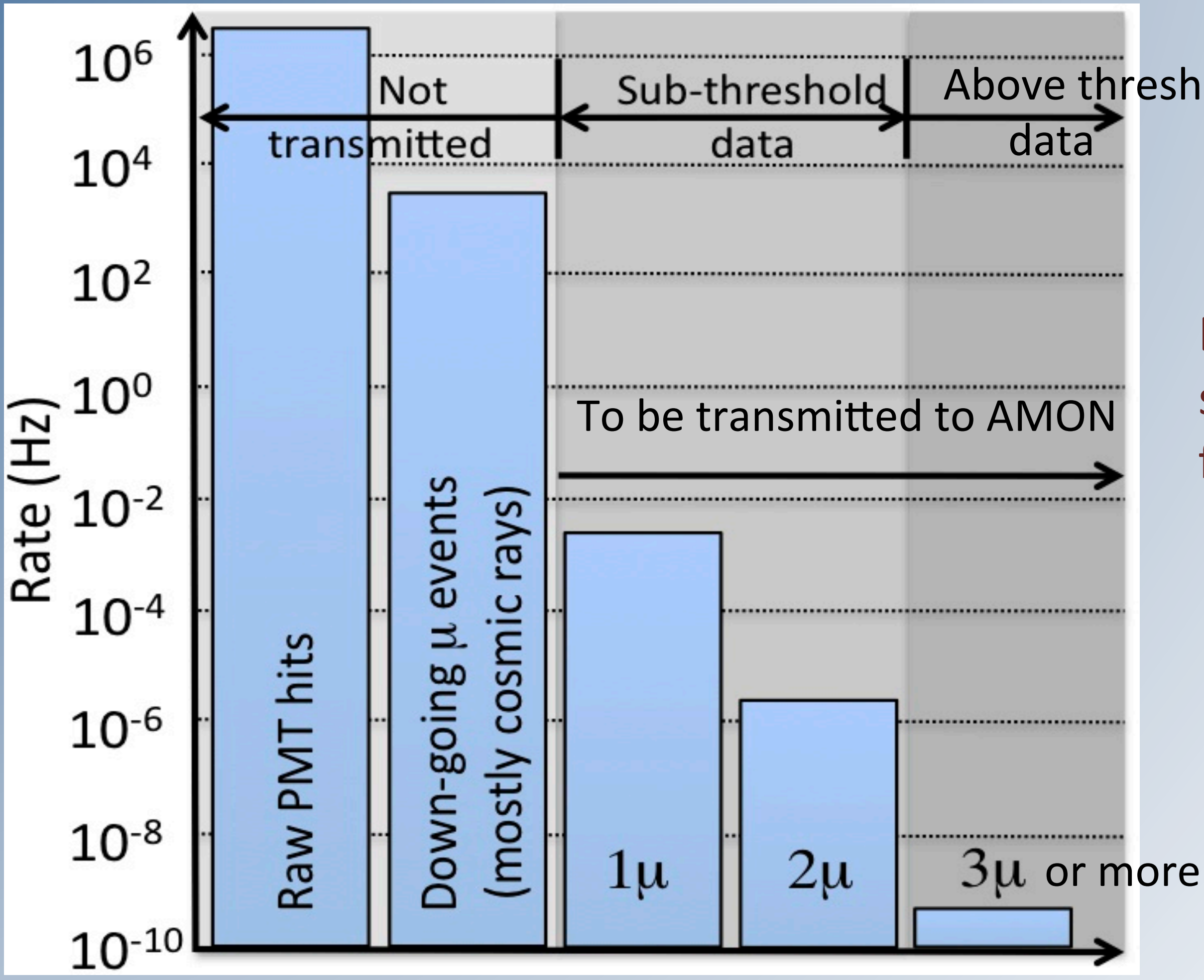


Scientific motivation- sources

	Prompt				Delayed		
Event class	γ	ν	n	gw	x	IR/O/UV	Radio
High-luminosity GRBs (HL-GRB)	✔	✔		✔	✔	✔	✔
Low-luminosity GRBs (LL-GRBs)	✔	✔		✔	✔	✔	✔
Short-hard GRBs (SHBs)	✔	✔		✔	✔	✔	✔
Choked jet SN		✔		✔	✔	✔	✔
Core-collapse SN		✔	✔		✔	✔	
Blazars	✔	✔			✔	✔	✔
Primordial black holes (PBHs)	✔	✔	✔				
Other exotica	✔	✔	✔	✔			

Scientific motivation- data

- False positive rate (FPR) dominates in the total event rate
- Subthreshold events from a single facility cannot be distinguished from backgrounds
- AMON will analyze subthreshold signal-like events from all triggering observatories

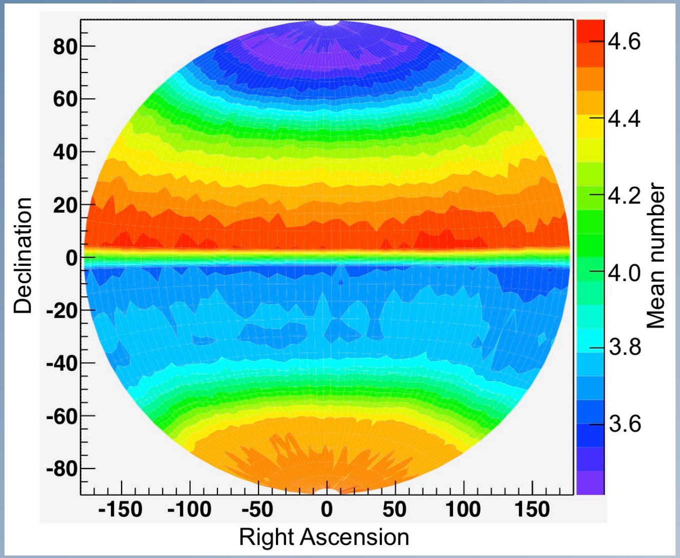


Example of the subthreshold data for IceCube

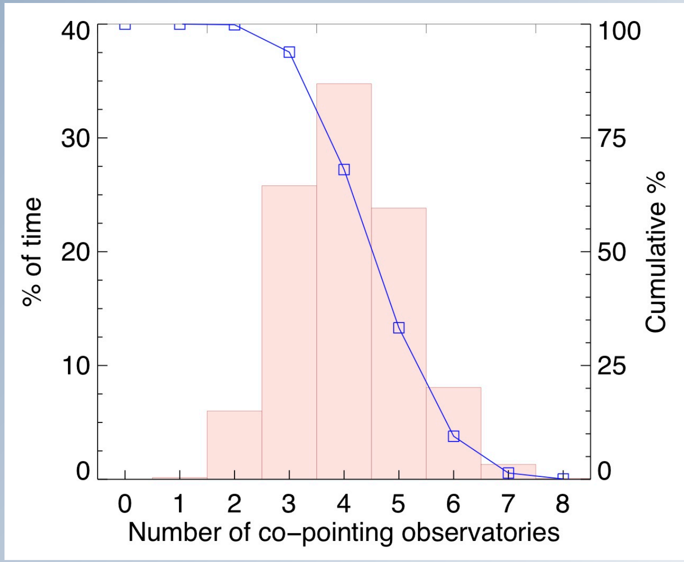
Scientific motivation- field of view (FoV)

1-year simulation for IceCube, ANTARES, HAWC, Swift BAT, Auger, Fermi LAT and LIGO-Virgo

Average number of observatories viewing a source simultaneously

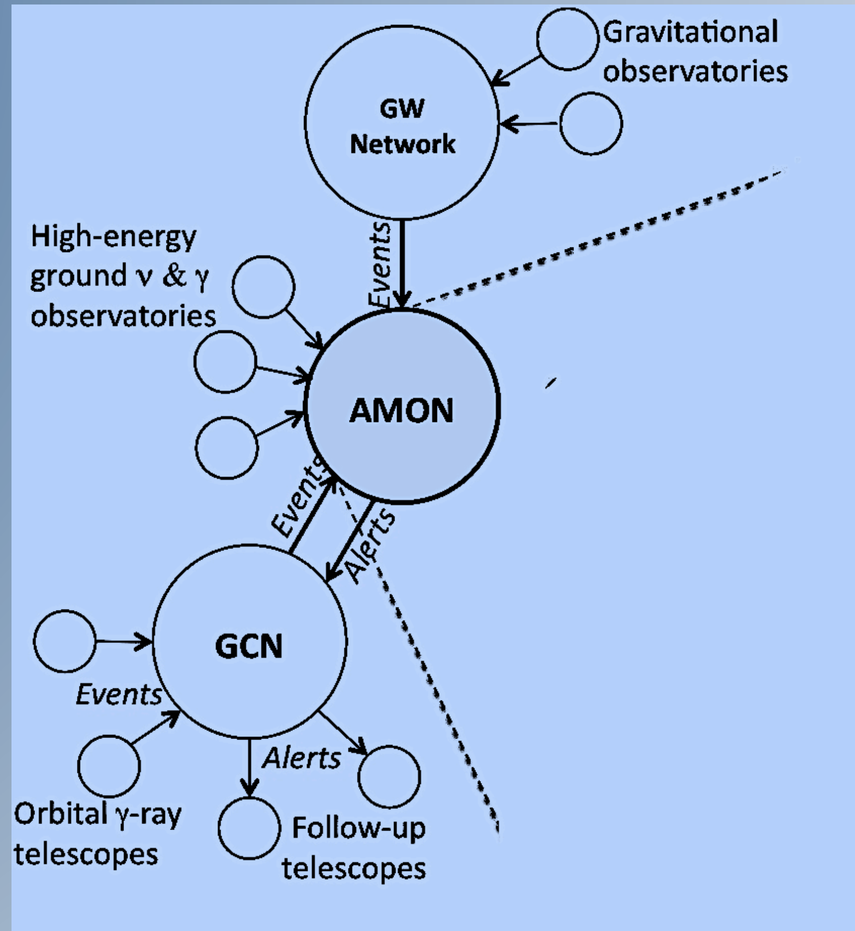


Number of triggering facilities observing a source (averaged over time and sky location)



- 94% of 4π sr-y is within the FoV of 3 or more observatories
- 2+ observatories are viewing any given part of the sky simultaneously

AMON system–data flow



AMON will utilize existing:

Gamma-ray Coordinates Network (GCN)
Gravitational Wave (GW) Network
Open to other networks (e.g. SNEWS)

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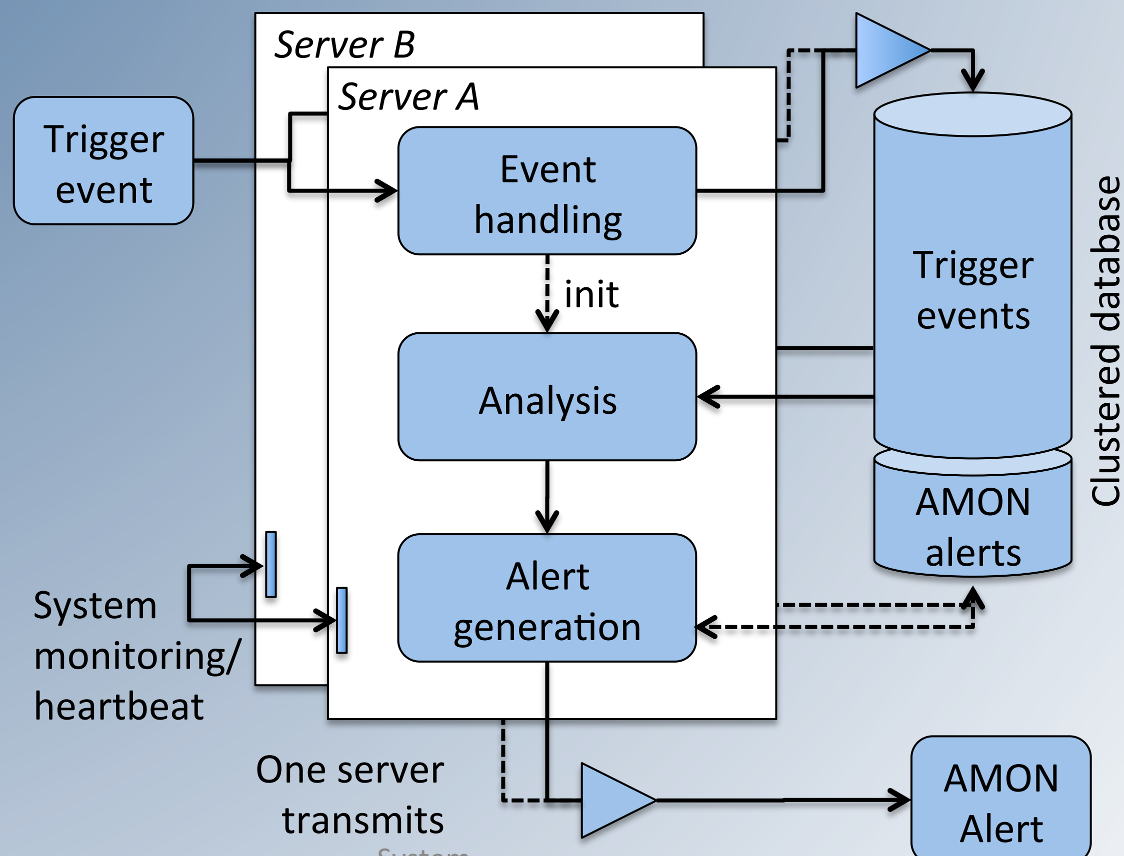
AMON system – infrastructure

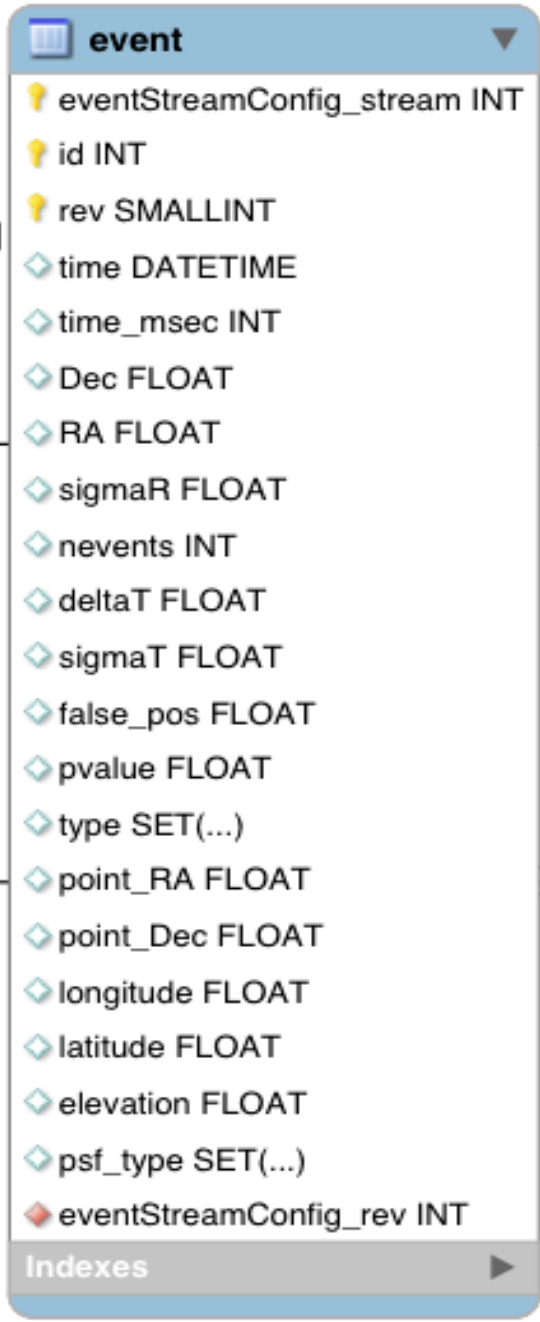
Main systems housed at Penn State:

- Dual servers and "clustered" database for redundancy
- Systems physically and cyber-secure
- Very high level of uptime
- Modest data needs: 10 kB/sec (av), 1 MB/sec (peak), storage: 2 TB (5 yr), processing: < 0.1 CPU



Event content common to each observatory

Event content



Event content:

(<u>stream number</u>, <u>id number</u>, <u>revision number</u>

trigger time: *time, time_msec*

position: *RA/Dec*

positional error: *sigmaR*

number of events: *nevents*

time window: *deltaT*

error on time: *sigmaT*

false positive rate density: *false_pos*

p-value*: pvalue*

type of the event: *type* ("*observation*", *"prediction", "utility", "test", "sim"*)

pointing: *point_RA, point_Dec*

observatory location: *longitude, latitude, elevation*

type of the PSF: *psf_type* (*"skymap", "fisher", "king", "kent"*)

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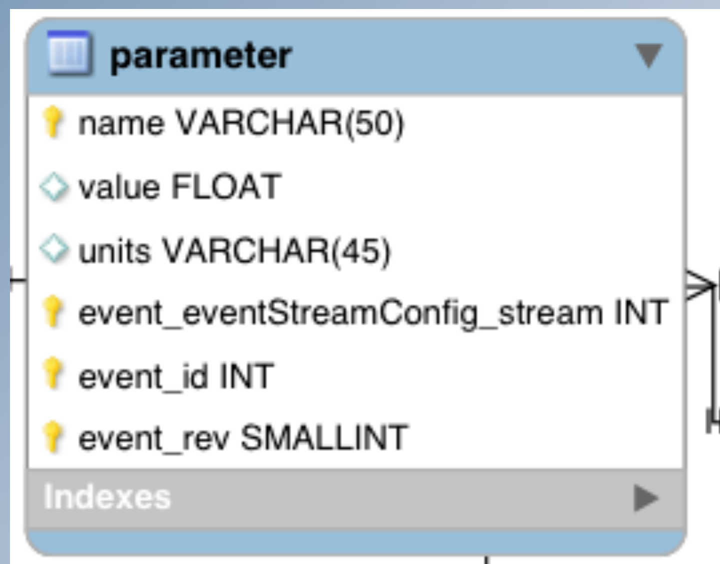
Event content

Event content specific to each observatory

parameter name: *name (energy, SNR, etc)*.
value of the parameter: *value*
units: *units* (*TeV etc*.)



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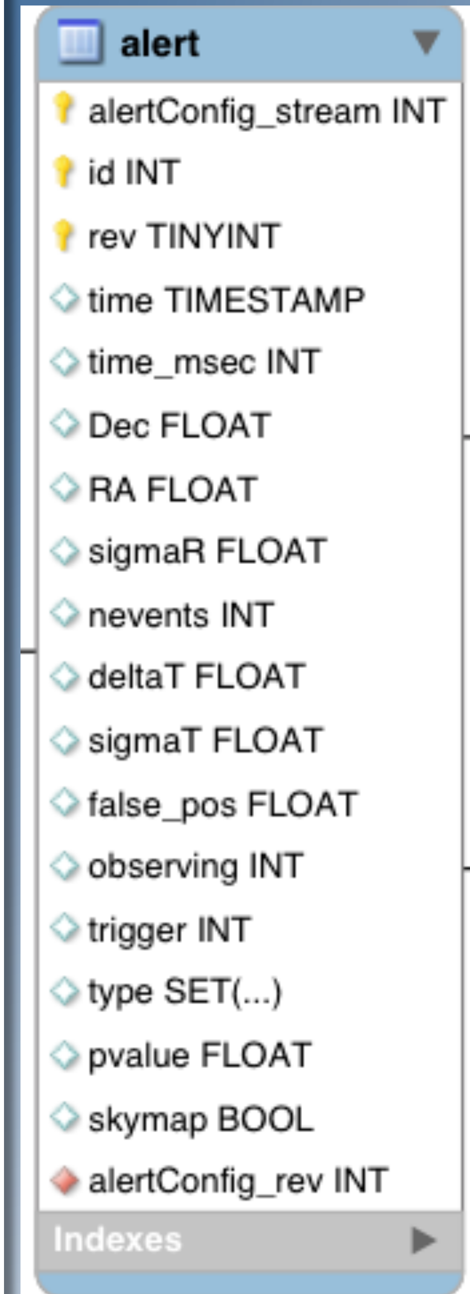
Define AMON alert content

Alert content



Alert content:

(<u>stream number</u>, <u>id number</u>, <u>revision number)</u>

time – *time, time_msec*

position of the best fit: *Dec/RA*

positional error - *sigmaR*

number of events: *nevents*

time window: *deltaT*

error on time: *sigmaT*

false positive rate density: *false_pos*

experiments observing [sum 2^k]: *observing*

experiments triggered [0- not reporting, sum 2^k]: *trigger*

type of the event: *type* ("*observation*", *"prediction", "utility","test", "sim"*)

p-value: pvalue

skymap

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Event/Alert Format

AMON will receive events and send alerts in VOEvent format

- Standardized data packet format simplifies protocols for data handling (e.g. adding new observatory will not require new methods for injection of data into database and analysis stream)
- VOEvent is used by larger astronomical community i.e. became a standard for real-time event distribution (e.g. GCN notices, Swift, Fermi, LIGO, AMON etc.)
- Well structured in XML format with simple schema
- Easily interpreted by software, can be read by robotic telescopes (important for real-time analysis and near real-time follow-up)

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Phases of operation

Phase I- archival operations (ongoing)

- using archival data to tune analysis algorithms:
- public data (Swift BAT, Fermi LAT, IceCube-40, LIGO-S5)
- private data (more recent IceCube, ANTARES, HAWC, Auger – pending permissions)
- may lead to discovery of new astrophysical sources

Phase II – real time operations (starting)

- real-time reception of data streams from triggering observatories
- identification of statistically significant candidate sources in real-time
- alert distribution to triggering facilities
- False alarm rate (FAR) < 0.1 per year may lead to publication

Phase III- triggered follow-up operations

- final phase
- alert distribution to follow-up facilities enabling the near real-time search for electromagnetic counterparts
- FAR < 100 per year => follow-up
- FAR < 0.01 per year = > publication

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Discovery Power

Performed simulations to demonstrate discovery power

1. Neutrino + Gamma-ray Transients
   - Easy increase in efficiency of follow-up searches
   - Projected gains of >100x
2. Neutrino + gravitational wave transients
   - Extend searches into subthreshold regime
   - Projected gains of >8x
3. Primordial black hole evaporation
   - Results complementary to HAWC-only analyses
   - 1-year of observation could probe PBH multimessenger signature (HAWC+IceCube)

Details: Smith et al. 2013, Particle Astrophysics 45, 56–70 (ArXiv.org: 1211.5602)

Current Status

Database

First full version of AMON database designed and implemented, now being used and tested:

- Data from triggering observatories inserted
  - -done: IceCube, Swift, Fermi [public]
  - -in progress: IceCube, HAWC, Auger, VERITAS [private – pending permissions]
    LIGO [public]
- Real-time test with fake data performed

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AMON code

AMON code for data handling and analysis

- AmonPy provides analysis framework
- AMON Server built using Python/Twisted, asynchronous, tested with several simulated clients

  - Accepts HTTP POST requests (Twisted client available, but accepts other clients)

- Tested on RHEL 5 & 6, Mac 10.6.8 & 10.9.1
- Code repository on GitHub (email G. Tešić <gordana@tesic.net> for access)

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AMON server

AMON server is up and running!

- built using Python/Twisted, asynchronous, tested with several simulated clients
- Accepts HTTP POST requests (Twisted client available, but accepts other clients)
- Open for authorized connections (TLS certificates)
- Start issuing alerts (VOEvents) in spring 2015

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Current status

Archival analysis using public data:

- IC40 and Fermi LAT (first pass analysis done – see talk by A. Keivani tomorrow)
- IC40/59 and Swift BAT sub threshold (underway)
- IC40/59 and Fermi LAT
- Swift and LIGO S5 (starting)

First efforts and tests toward real-time analysis:

- Neutrino singlet stream (IceCube) - test stream is running
- IceCube HESE events (talk by A. Keivani)
- Ongoing efforts with other member collaborations on getting their real-time subthreshold streams

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Members' steps to connect to AMON

Step 1: Define the data content and event rate

Step 2: Create **VOEvent**

- AMON can provide a template and/or Python module

Step 3: Certificate to be authorized to connect

- Observatory creates a certificate request (OpenSSL)
- AMON creates a certificate

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Members' steps to connect to AMON

Step 4: Create a client to transmit events

- Observatory makes a client that uses HTTP Post method over TLS **or**
- AMON provides a Twisted/Python based client (already available)

Step 5: Create a test link (fake events)

Step 6: Send time scrambled data

Step 7: Send real data

Observatory links to AMON

Steps needed to set up a real-time stream with AMON

Observatory	Stream content & format	TLS certificate	Test stream (fake data)	Test steam (real data scrambled)	Real data stream
IceCube	✔	✔	✔	In progress	
Auger	✔	✔	In progress		
HAWC	In progress				
VERITAS	In progress				
Swift	✔	Not needed	Not needed	Not needed	In progress
Fermi	✔	Not needed	Not needed	Not needed	In progress

Joining AMON

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

Join AMON

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

AMON MoU

http://amon.gravity.psu.edu/mou_aug2012.shtml

Conclusions (I)

- Motivations:

1. **Evoke** discovery of multimessenger transients from within observatory subthreshold data streams
2. **Exploit** these transients for purposes of astronomy and fundamental physics
3. **Explore** archival multimessenger datasets in search of rare or exotic astrophysical phenomena

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Conclusions (II)

- AMON has made a significant progress toward real-time and archival analysis
- AMON server is online - open for authorized connections!
- AMON is ready to start issuing alerts in spring 2015
- Our current and future collaborators are encouraged to take advantage of what AMON has to offer

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EXTRA SLIDES

AMON system – analysis algorithms

- **Event:** trigger time, event coordinates, number of events, positional error/probability density function (PDF), observatory pointing and FPR

Clustering analysis

Subthreshold rates from observatories a and b

Search area

False alarm rate (FAR) for pairwise coincidences

$$R_{ab}^{FA} \approx \frac{R_a}{\Omega_a} \frac{R_b}{\Omega_b} \Delta T \Delta\Omega \langle \Omega_{ab} \rangle$$

FoV overlap

FoV for observatories a and b

Time window

Distribute candidate source position in real-time to follow-up facilities together with statistically valid FAR.

AMON system – analysis algorithms

FAR per year from clustering analysis: ΔT=100 s (1 s for PBH) and 3σ spatial window

Astrop.Phys.
Vol. 45, 56–70, 2013

		IceCube	Antares	LIGO-Virgo	Auger	BAT	GBM	LAT	HAWC
Single streams	Above thresh.	~0	~0	~0	~0	~100	~250	~10	~10
	Subthreshold	8.8×10^4	2.9×10^4	3.2×10^3	2.4×10^5	1.4×10^5	3.1×10^2	3.9×10^4	2.6×10^4
	IceCube	30	1.5	35	1.8	11	10	24	6.5
	ANTARES	1.5	0.5	12	1.1	0.7	3.5	7.1	0.6
	LIGO-Virgo	35	12	N/A	8.4	53	0.6	16	10
(b) Pair-wise FPR	Auger[a]	1.8	1.1	8.4	20	2.9	2.5	5.9	1.5
	BAT	11	0.7	53	2.9	N/A	16	32	3.3
	GBM	10	3.5	0.6	2.5	16	N/A	5.0	3.2
	LAT	24	7.1	16	5.9	32	5.0	N/A	6.8
	HAWC	6.5	0.6	10	1.5	3.3	3.2	6.8	N/A
	GRB lt. curve[b]	0.071	0.003	0.16	–	0.0004	0.08	0.13	0.019
	SNe lt. curve[b]	1.5	0.07	3.4	–	0.009	1.6	2.7	0.4
(c) High significance	3-fold coinc.	0.15	0.03	0.31	0.64	0.12	0.09	0.40	0.08
	3-fold coinc[a]	0.10	0.02	0.15	0.06	0.08	0.04	0.23	0.04
	High-sig. EM[c]	0.015	0.002	0.045	0.044	0.010	0.014	0.039	0.005
	PBH search[d]	0.13	0.01	–	0.21	–	–	–	0.35

AMON system – analysis algorithms

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	GBM	10	3.5	0.6	2.5	16	N/A	5.0	3.2
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	PBH search[d]	0.13	0.01	–	0.21	–	–	–	0.35

Orders of magnitude lower FAR for pairwise coincidence

AMON system – analysis algorithms

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	PBH search[d]	0.13	0.01	-	0.21	-	-	-	0.35

FAR further decreased by serendipitous follow-up detection of GRB/SN

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	ANTARES	1.5	0.5	12	1.1	0.7	3.5	7.1	0.6
	LIGO-Virgo	35	12	N/A	8.4	53	0.6	16	10
(b) Pair-wise FPR	Auger[a]	1.8	1.1	8.4	20	2.9	2.5	5.9	1.5
	BAT	11	0.7	53	2.9	N/A	16	32	3.3
	GBM	10	3.5	0.6	2.5	16	N/A	5.0	3.2
	LAT	24	7.1	16	5.9	32	5.0	N/A	6.8
	HAWC	6.5	0.6	10	1.5	3.3	3.2	6.8	N/A
	GRB lt. curve[b]	0.071	0.003	0.16	–	0.0004	0.08	0.13	0.019
	SNe lt. curve[b]	1.5	0.07	3.4	–	0.009	1.6	2.7	0.4
High signific.	3-fold coinc.	0.15	0.03	0.31	0.64	0.12	0.09	0.40	0.08
	3-fold coinc.*	0.10	0.02	0.15	0.06	0.08	0.04	0.23	0.04
	High sig. EM	0.015	0.002	0.045	0.044	0.010	0.014	0.039	0.005
	PBH search	0.13	0.01	–	0.21	–	–	–	0.35

FAR lowered by strengthening the cuts or requiring one event to be of higher significance or 3-fold coincidences