AMON

Astrophysical Multimessenger Observatory Network

AMON Status Report:
Realtime Alerts and Archival Studies

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The Pennsylvania State University

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NSF

PennState

Multimessenger Astrophysics

- Cosmic Messengers:
  - Cosmic rays
  - Gamma rays
  - Neutrinos
  - Gravitational waves

- Use the messenger particles of all four of nature's fundamental forces

- Explore the most violent phenomena in the universe

- Various source candidates

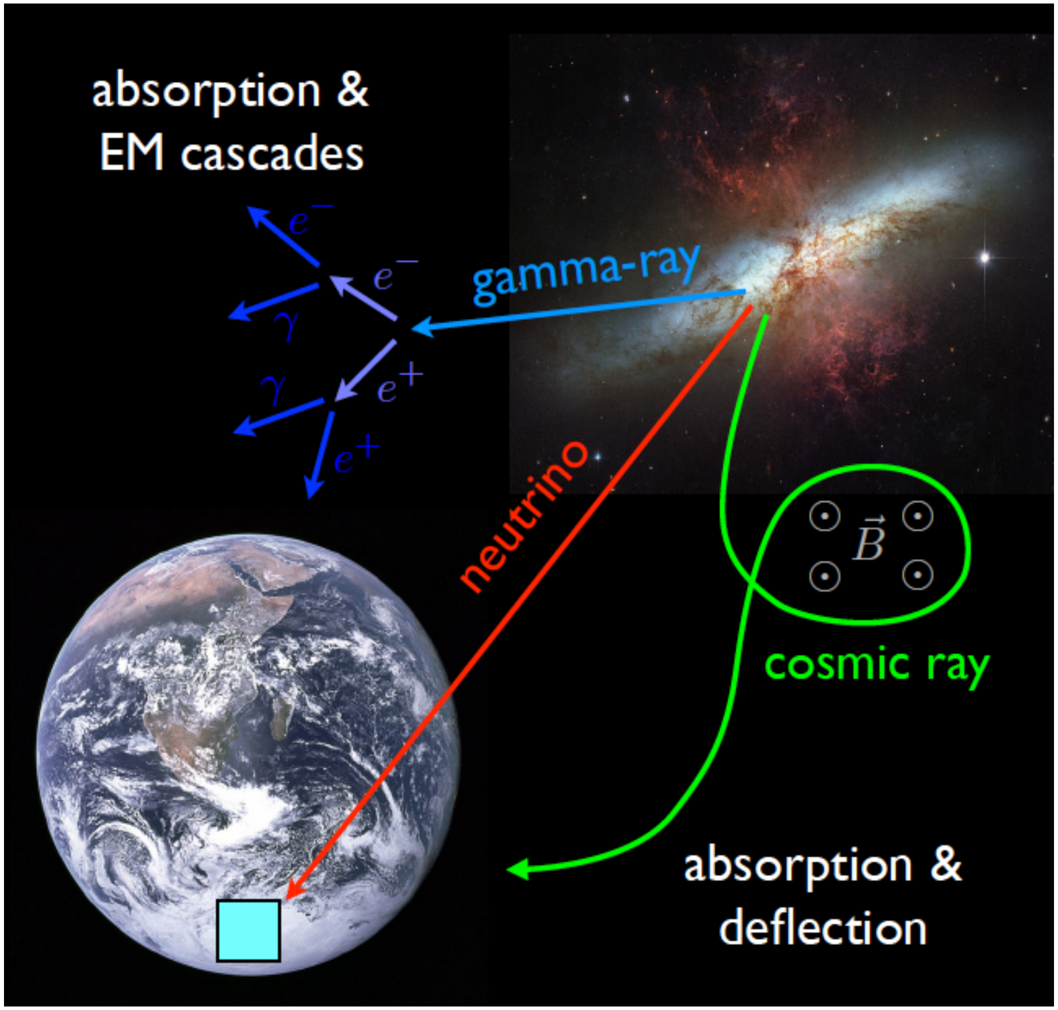
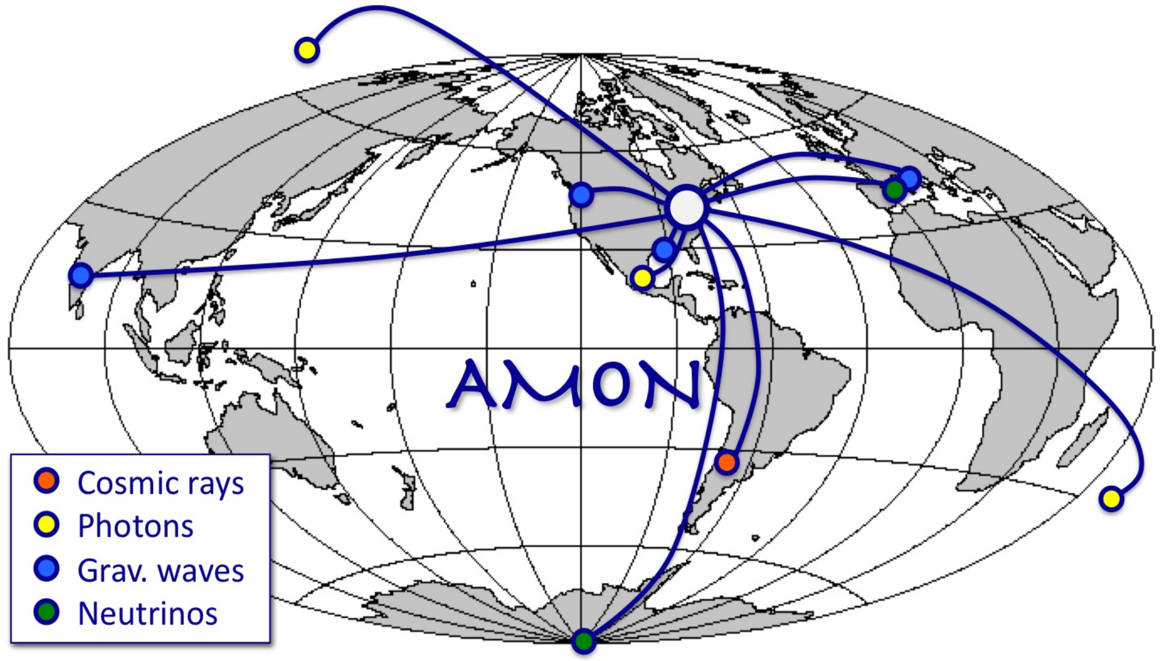


Image credit: M. Ahlers

See talk by Anna Franckowiak

Astrophysical Multimessenger Observatory Network

AMON links high-energy astrophysical observatories into a single virtual system.



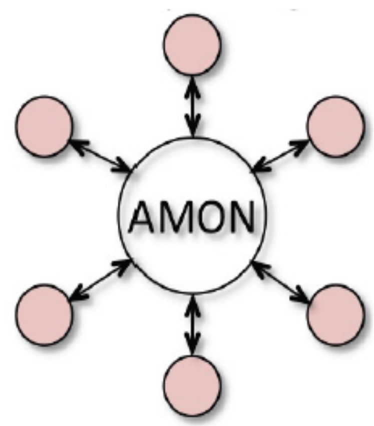
AMON framework enables:

- Real-time and near real-time sharing of sub-threshold data between multimessenger observatories

http://sites.psu.edu/amon

- Real-time and archival searches for coincident signals

- Prompt distribution of electronic alerts for follow-up observations

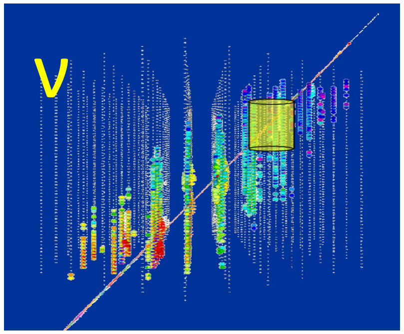


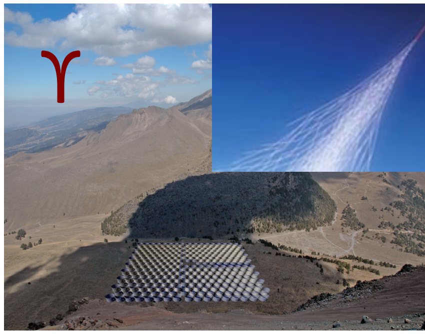
Astroparticle Physics Vol. 45, 56–70, 2013

AMON Network

✧Triggering observatories:

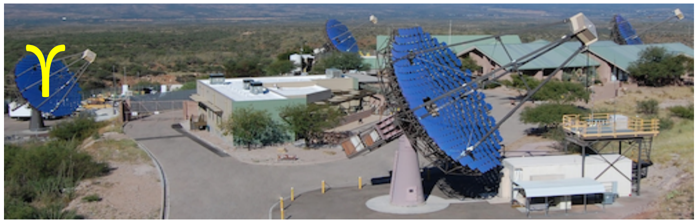
- Provide "sub-threshold" candidate events to AMON in real-time
- IceCube, ANTARES, Auger, HAWC, VERITAS, FACT, Swift BAT, Fermi, LIGO/VIRGO



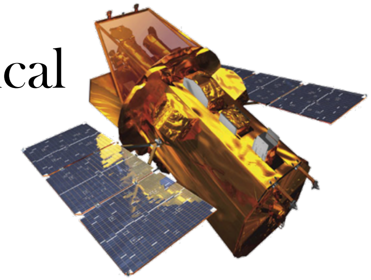


✧Follow-up Observatories:

- Respond to AMON alerts
- Provide optical feedback on potential multimessenger transients
- Swift XRT & UVOT, VERITAS, FACT, MASTER, LCOGT

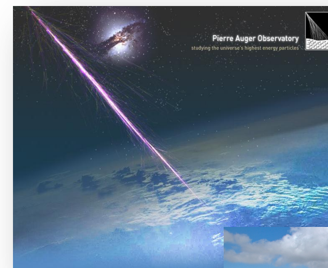


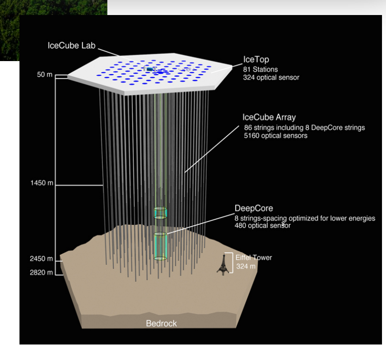
X, UV, Optical



AMON Functionality

- **Archival Searches**
  - ❑ AMON Stores events from participating observatories in the database
  - ❑ AMON searches through this database for temporal and spatial coincidences
- **Pass-Through**
  - ❑ AMON receives events and broadcasts them immediately via Gamma-ray Coordinate Network (GCN) to astronomical community for follow-up
    - ❑ E.g. IceCube high-energy neutrinos
- **Real-time Coincidences**
  - ❑ AMON receives “sub-threshold” events from multiple triggering observatories and searches in real-time for coincidences in direction and time
    - ❑ E.g. a single muon neutrino in coincidence with ≈15 photons from HAWC
  - ❑ AMON issues GCN alerts for follow-up





AMON Status: Infrastructure

AMON event database

- Designed and implemented
- Contents:
  - Inserted: IceCube40/59 and year 1 of 86, Swift, Fermi (public)
  - Inserted: ANTARES 2008, Auger, IceCube (private)
  - In progress: LIGO S5 and S6 (public)
  - Awaiting approval: HAWC, VERITAS, ANTARES (private)

AMON application server

- Running stably since August 2014
  - Python/Twisted, asynchronous, tested with simulated and real clients
  - Accepts HTTP POST requests
  - Open for authorized connections using TLS certificates
- Started issuing public AMON alerts using VOEvent format/protocol in April 2016

AMON hardware

- Two new high-uptime servers
  - Now deployed at Penn State
  - Physically and cyber secure; fully redundant systems

AMON Status: Participation

Observatories with AMON MoU	Stream content and format	TLS certificate	Test stream (fake data)	Test stream (real data scrambled)	Real data stream
IceCube singlet	✓	✓	✓	✓	In progress
IceCube HESE	✓	✓	✓	✓	✓
IceCube EHE	✓	✓	✓	✓	✓
IceCube OFU	✓	✓	✓	✓	✓
ANTARES	✓	✓	In progress		
Pierre Auger	✓	✓	✓	✓	In progress
HAWC	✓	In progress			
VERITAS	In progress				
FACT	✓	✓	✓	✓	In progress
Swift BAT	✓	Not needed	Not needed	Not needed	✓
Fermi LAT	✓	Not needed	Not needed	Not needed	✓

Archival vs. Realtime Analysis

	Pros	Cons
Archival studies	• Precise event properties: position, localization, false positive rate • Construct statistical tools/methods (needed for realtime analyses)	• Too late to do additional observations in case of a significant signal
Realtime studies	• Rapid followup of events and alerts • Discovery potential of transient sources and extended followup observation	• Use only fast online tools • Larger uncertainties • Harder to reject background events

AMON Analyses

- Archival analyses:
  - Fermi LAT – IC40 (AK et al, PoS(ICRC2015)786 (2015))
  - Fermi LAT – IC40/59 (C. F. Turley et al., in preparation)
  - Primordial black holes (G. Tešić, PoS(ICRC2015)328 (2015))
  - VERITAS blazars – IC40 (C. F. Turley et al., APJ 833, 117 (2016))

- Realtime analyses:
  - Swift XRT/UVOT – IceCube HESE (AK et al, in preparation)
  - Swift BAT – IceCube subthreshold ν's (Jimmy DeLaunay for AMON, IceCube, and Swift BAT)

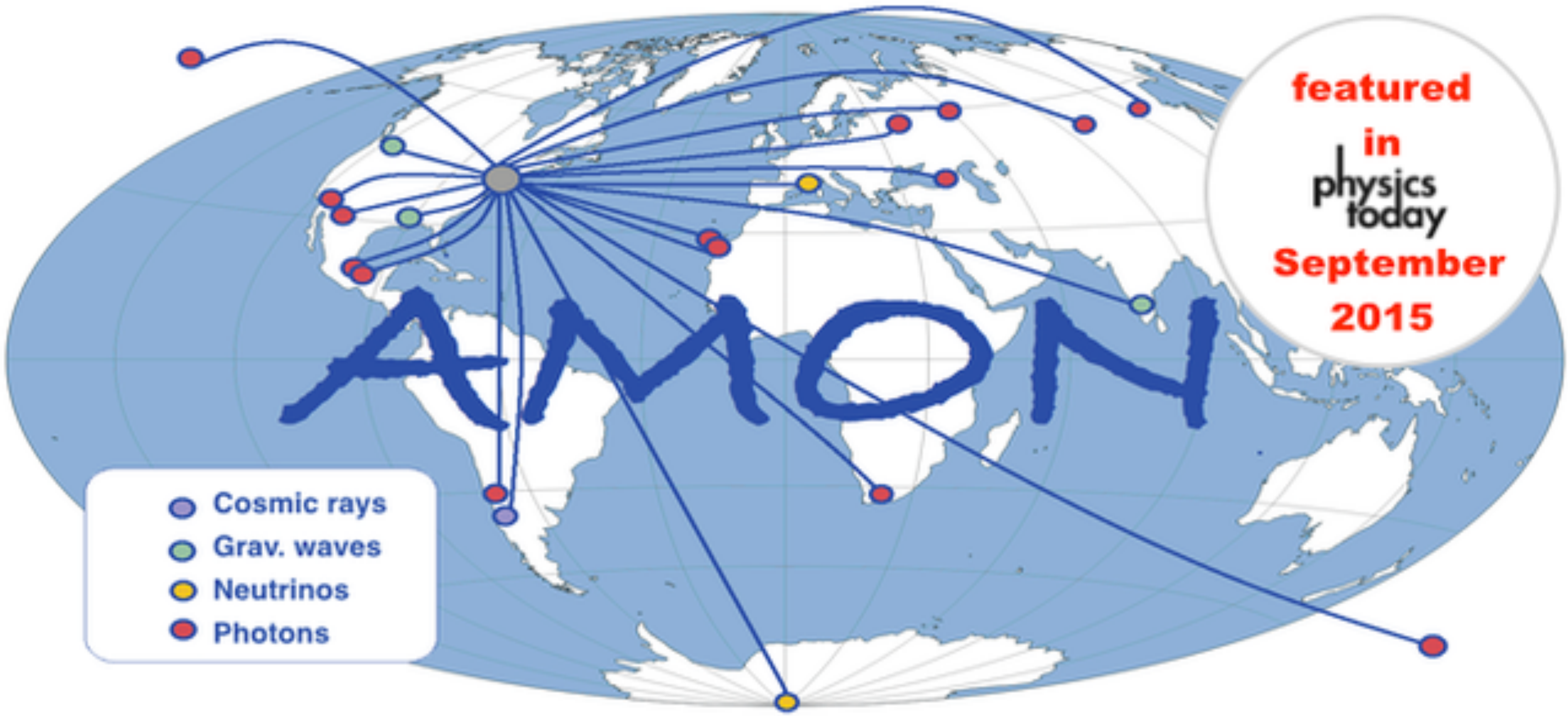
See talk by Jimmy DeLaunay

  - HAWC – IceCube subthreshold ν's (AK for AMON, IceCube, and HAWC)
  - Auger – IceCube subthreshold ν's (George Filippatos for AMON, IceCube and Pierre Auger)
  - IceCube Triplet follow-up (submitted to A&A)

Summary

- AMON expands discovery space in new ways
  - Unleashes sub-threshold data for multimessenger searches in real-time
  - Creates bidirectional, multilateral connections between triggering and follow-up observatory partners
  - Enables complex real-time and archival searches
- AMON greatly simplifies multimessenger searches
  - Common transfer protocol, data format, event database, MoUs
- AMON has made a significant progress towards real-time and archival analysis
- AMON server is up and running: open for authorized connections!
- AMON started issuing alerts in April 2016!
- New participants are always welcome!

Thanks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Grav. waves
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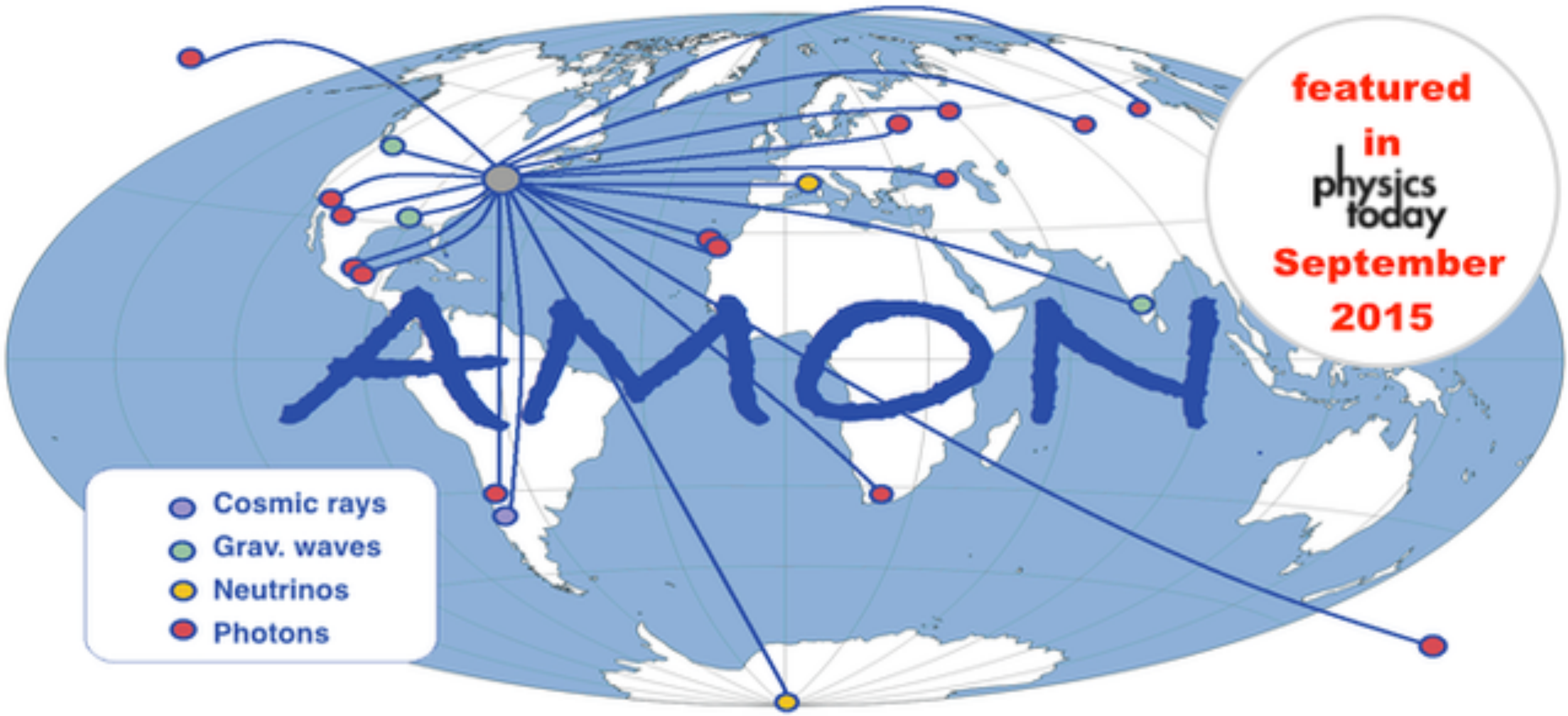
Photons

Back-Ups



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Multimessenger Transient Source Candidates

- High-Luminosity Gamma-Ray Bursts:
  - long duration
  - high luminosity
  - seconds to minutes γ-radiation
  - $z > 1$
  - relativistic jet

- Low-luminosity Gamma-Ray Bursts:
  - long duration
  - under-luminous
  - $z < 0.5$

- Short-Hard Gamma-Ray Bursts
  - similar to HL-GRBs
  - shorter duration
  - harder spectra

- Chocked jet supernova
- Core collapse supernova
- Blazars
- Ultra-luminous star-forming galaxies
- Starburst galaxies
- Primordial black holes
- Other exotica

Potential 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	✔	✔	✔	✔			

AMON Core Team

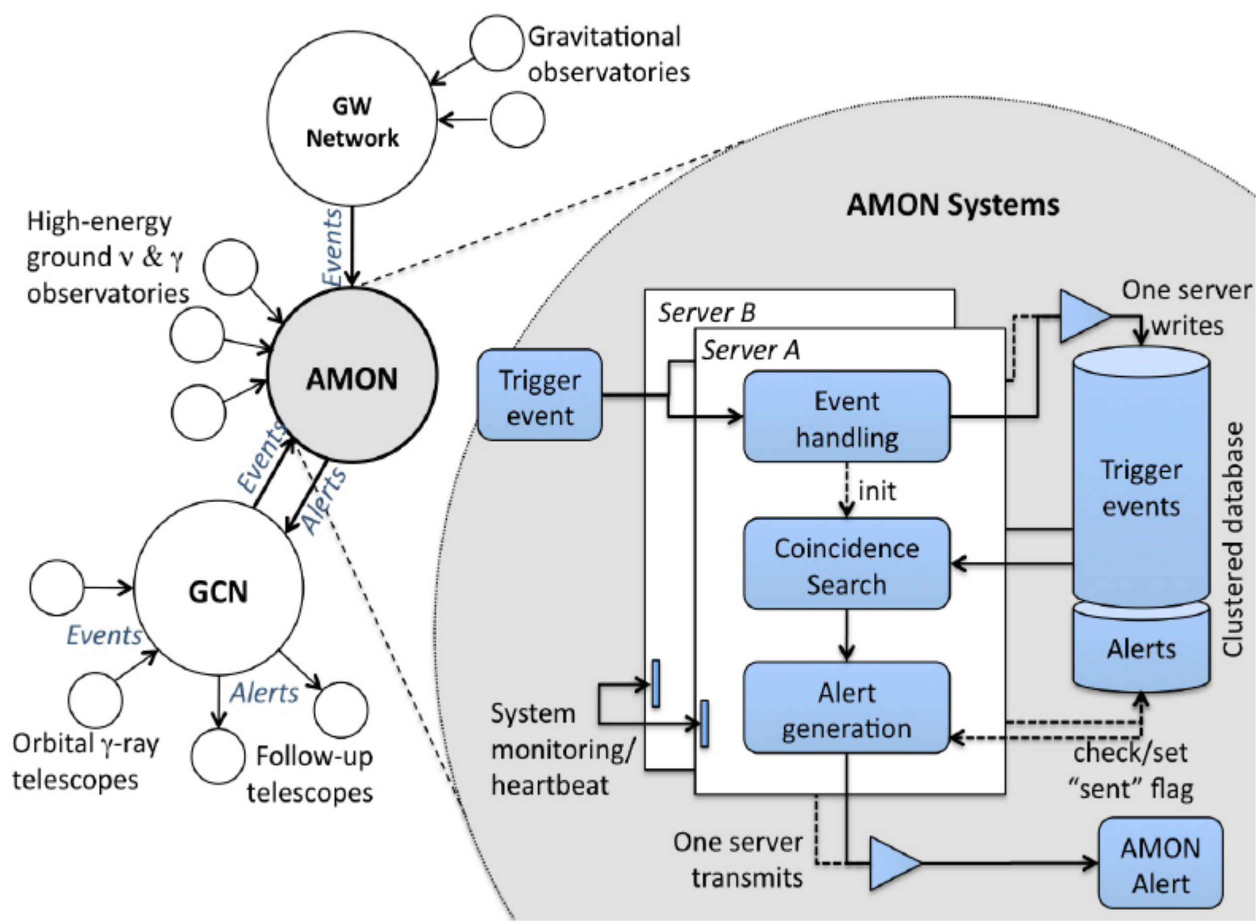
- Founded and Hosted at Penn State
- Current AMON Development and Advisory Team at Penn State:
  - Doug Cowen, Miguel Mostafa, Derek Fox,
    Stephane Coutu, Kohta Murase, Chad Hanna,
    B. S. Sathyaprakash, Peter Meszaros,
    Abhay Ashtekar, Abe Falcone
  - Azadeh Keivani, Jimmy DeLaunay,
    Colin Turley, George Filippatos,
    Cody Messick, Sydney Chamberlin

Data Flow

✧ Sub-threshold data from triggering observatories:
- sent in a standard VOEvent format
- store in a secure database

✧ VOEvents from satellite experiments via GCN

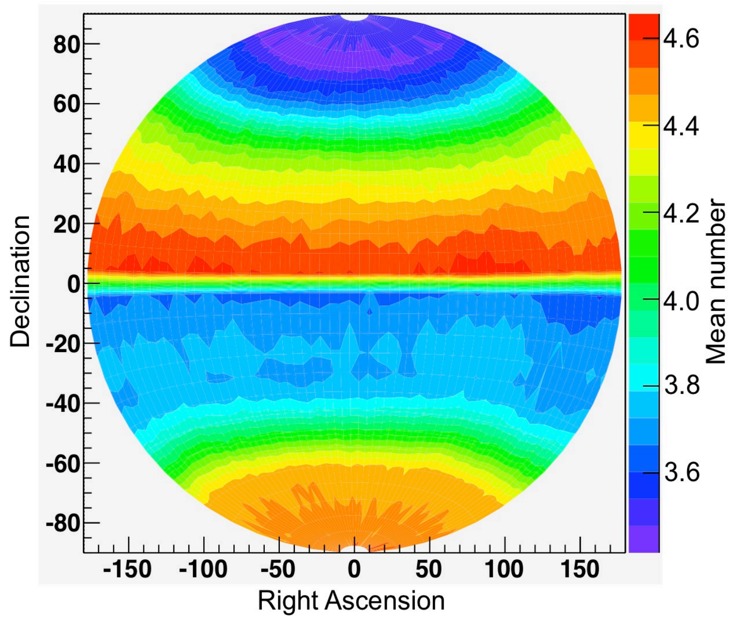
✧ Use GCN to distribute AMON alerts to the follow-up observatories as VOEvents



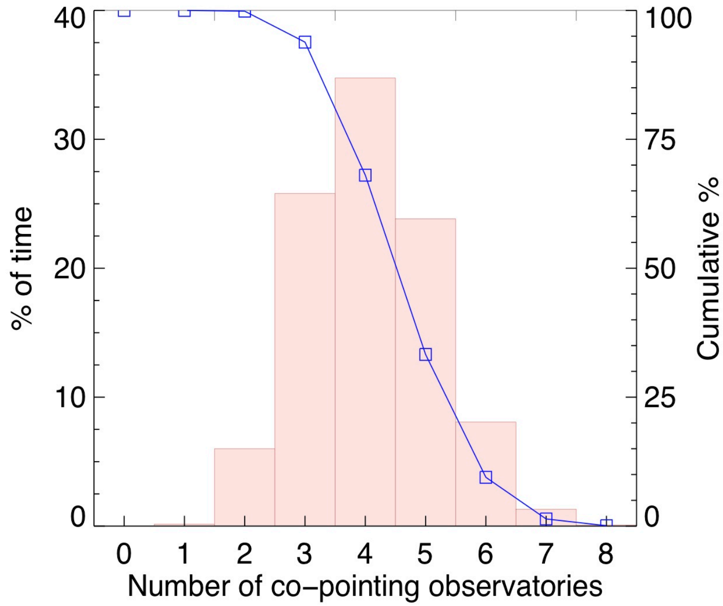
Field of View

1-year simulation for IceCube, ANTARES, HAWC, Swift BAT, Pierre 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-yr is within the FoV of 3 or more observatories
> 2+ observatories are viewing any given part of the sky simultaneously