The Astrophysical Multimessenger Observatory Network

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Penn State University
HotWiredVI
21 Aug 2019
The AMON Idea
amon.psu.edu

Ayala Solares+19
Astrophysical Multimessenger Observatory Network: Multimessenger subthreshold coincidence searches
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Evoke: Discovery of transient multimessenger sources
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- **Astrophysical Multimessenger Observatory Network:** Multimessenger subthreshold coincidence searches
- **Evoke:** Discovery of transient multimessenger sources
- **Exploit:** Trigger follow-up observations to identify & study counterparts

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- **Astrophysical Multimessenger Observatory Network:** Multimessenger subthreshold coincidence searches
- **Evoke:** Discovery of transient multimessenger sources
- **Exploit:** Trigger follow-up observations to identify & study counterparts
- **Explore:** Archival analyses in search of multimessenger activity

Ayala Solares+19
AMON Members
AMON Members

CR
Pierre Auger
AMON Members

CR Pierre Auger

ν ANTARES IceCube
AMON Members

CR  Pierre Auger

\( \gamma \)

SWIFT
VERITAS
HESS
MAGIC
FACT
Fermi
HAWC

\( \nu \)

ANTARES
IceCube
AMON Members

CR
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γ
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ν
ANTARES
IceCube

GCN/TAN

AMON
AMON Members

- CR Pierre Auger
- ANTARES IceCube
- GW LIGO-Virgo*
- SWIFT VERITAS HESS MAGIC
- FACT Fermi HAWC
- LMT GROWTH/ZTF MASTER
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- ANTARES IceCube
- LIGOVirgo*
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*LVC Council approval of first data-sharing agreement pending†

† Indicates an uncertain or pending status.
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† Or complete, maybe
# A Multimessenger Menagerie

<table>
<thead>
<tr>
<th>Possible</th>
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<td><strong>Bright</strong></td>
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<td>G.CR\text{EeV}</td>
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**G:** Galactic  
**SN:** Supernova  
**GRB:** Gamma-Ray Burst  
**PBH:** Primordial Black Hole

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**—Transient—**

- Gravitational Wave
- Neutrino
- Cosmic Ray

**Persistent**

July 2017
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Transient

Gravitational Wave  
Neutrino  
Cosmic Ray
Asynchronous real-time ingest, calculation, distribution of coincidence search results
AMON INFRASTRUCTURE

- Asynchronous real-time ingest, calculation, distribution of coincidence search results
- VOEvent protocol
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- Python implementation with Celery, Twisted, Comet
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- Exploring integration with ZTF/LSST broker/TOM systems

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**AMON Infrastructure**

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- VOEvent protocol
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- AmonPy on GitHub: [github.com/AMONCode/Analysis](https://github.com/AMONCode/Analysis)

Ayala Solares+19
Memorandum of Understanding between observatories participating in the Astrophysical Multimessenger Observatory Network

AMON Executive Board
May 24, 2019

The Astrophysical Multimessenger Observatory Network (AMON) provides a framework for correlating high energy astrophysical signals across all possible astronomical messengers: photons, neutrinos, cosmic rays, and gravitational waves. The primary goals of the program are: (1) To allow participating observatories to share their data with one another with strict anonymity, confidentiality and in accordance with their blind analysis procedures, (2) To enhance the combined sensitivity of participating observatories to astrophysical transients by enabling them to search for coincidences in their sub-threshold archival data and then in their sub-threshold real-time data and (3) To enable follow-up imaging of possible astrophysical sources with minimal latency.

Membership

Participants in AMON can be characterized as either “triggering,” “follow-up” or both. Triggering participants are generally wide field-of-view observatories that feed a stream of sub-threshold
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* “As simple as possible, but no simpler”
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- Ultimately: Joint or separate (but coordinated) publication
AMON: A Brief History

Prehistory: Archival multimessenger analyses + partner negotiations

\[
\lambda = 2 \ln \frac{(P_{\gamma_1}(\vec{x})P_{\gamma_2}(\vec{x})...P_{\gamma_n}(\vec{x}))n!(P_\nu(\vec{x}))}{B_1(\vec{x}, E_1, \theta_1)B_2(\vec{x}, E_2, \theta_2)...B_n(\vec{x}, E_n, \theta_n)}
\]

Keivani+15, Turley+18
AMON: A BRIEF HISTORY

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Serendipity: An FRB gamma-ray counterpart (DeLaunay+16), Nov 2016

DeLaunay+16
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- **First Alerts:** IceCube likely-cosmic neutrino pass-through alerts, April 2016

**Bacodine**

To: Derek Fox

Reply-To: Scott Barthelmey

AMON IceCube HESE Notice type added to GCN

TO: All GCN Notice recipients

RE: AMON IceCube HESE Notice type is available

DT: 08 April 2016

**INTRODUCTION:**

The GCN system has been modified to incorporate the distribution of candidate coincidence events produced within a single instrument and/or between multiple instruments within the AMON project. Currently, only HESE (High Energy Starting Event) notices within the IceCube instrument are being produced. This will expand to include the AMON,ICECUBE_COINC type and others in the future.

Like all the other sources of transient information within the GCN system, users can elect to receive this AMON,ICECUBE_COINC Notice type.

**OCURRENCE RATE:**

There will be about 4 AMON,ICECUBE_COINC Notices per year.

**TIME DELAY:**

The time delays for this notice type will range from 0.5 to 3 minutes after the neutrino interacts in the IceCube detector.

**LOCATION ERROR:**

The location uncertainties are in the 2-9 deg range (radius, stat+sys, 90% containment).

The uncertainty in the location will depend on:

(a) the energy of the neutrino, and

(b) the track or cascade nature of the energy deposited in IceCube.
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- **First MM Discovery:** IceCube 170922A neutrino & TXS 0506+056 (IceCube et al. 2018) + Swift/NuSTAR obs. (Keivani+18), Sep 2017+
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*First MM Alerts:* *Fermi* + ANTARES private alert stream (see *Turley+19*), July 2019

Turley+19
Hotwiring the Transient Universe with AMON
'Hotwiring the Transient Universe with AMON'

- Tremendous recent multimessenger success via both gravitational waves and high-energy neutrinos.
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Open questions
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GW: Genericity of 170817, NS+BH, r-process, $H_0$ …
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AMON is carrying out near real-time subthreshold MM coincidence searches today
Why Join AMON?
amon.psu.edu/join-amon/
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  * Current: ANTARES $\nu + \text{Fermi} \gamma$
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- Current: ANTARES \( \nu \) + *Fermi* \( \gamma \)
- Soon: LIGO+Virgo GW + *Swift* \( \gamma \)
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- AMON is also open to collaborating with new partners on novel MM coincidence analyses and alert streams

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