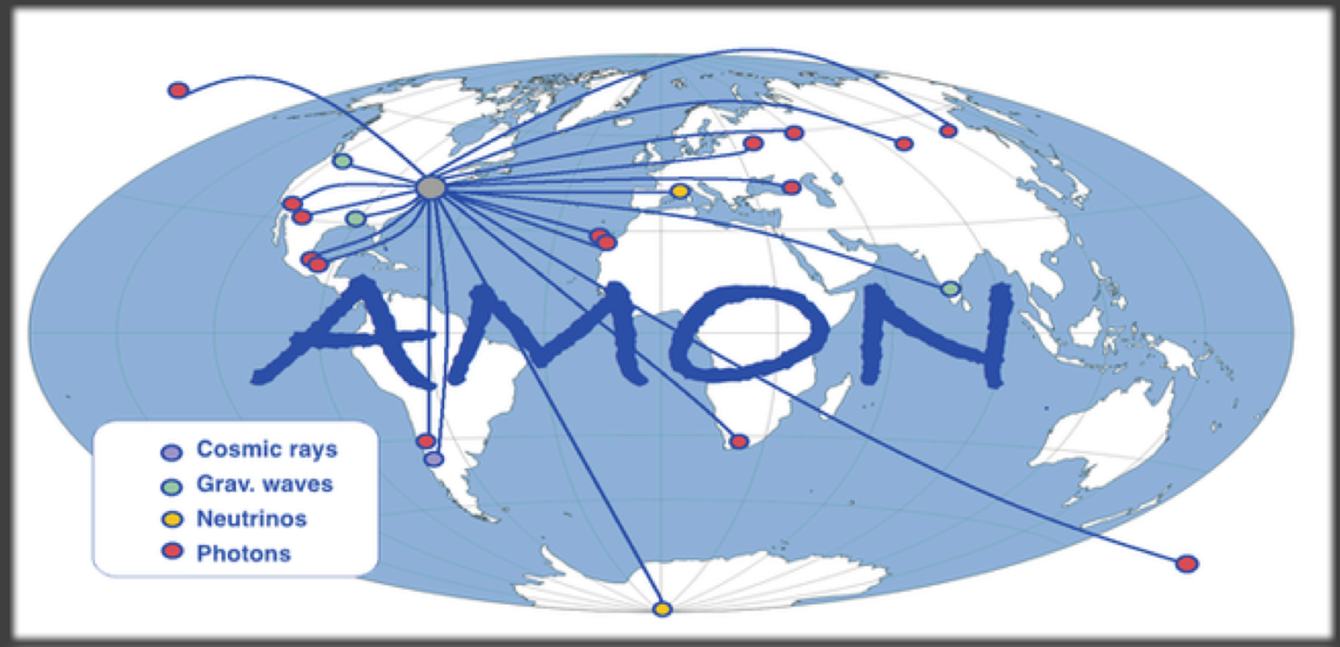
The Present and Future of Realtime Alerts from AMON



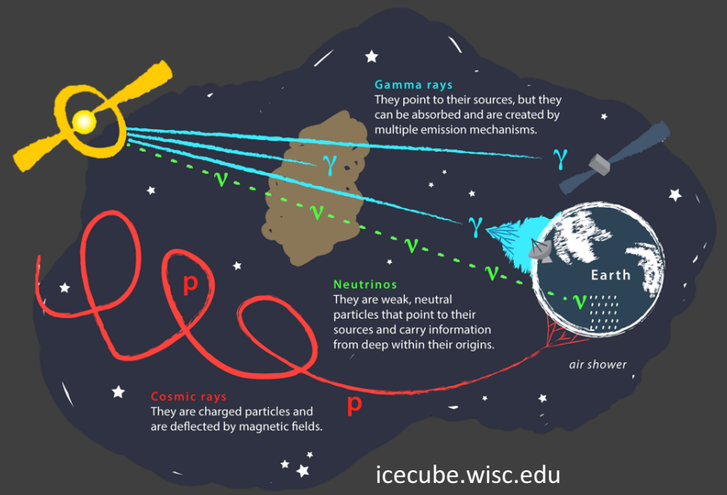
Azadeh Keivani
Penn State

Radio - γ-Ray:
Transient Alert Mechanism

Sept. 28, 2017

Multimessenger Astrophysics

- Use the messenger particles of all four of nature's fundamental forces
- Explore the most violent phenomena in the universe

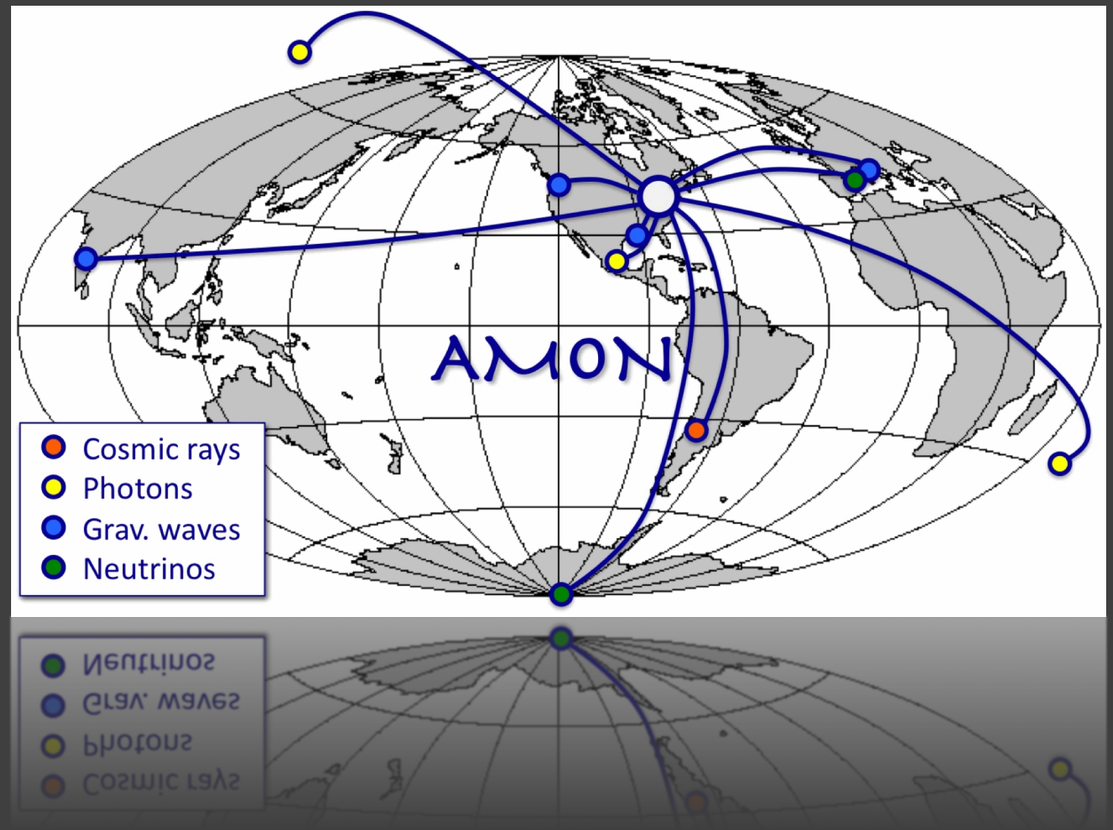


icecube.wisc.edu

Force	Messenger	Messenger Detected?	Source Identified	Multimessenger
EM	γ	✓	Loads	Sun, SN1987A
Weak	ν	✓	Twice	
Strong	p, nuclei	✓	No	No
Gravity	GW	✓	No	Probably

Astrophysical Multi-messenger Observatory Network

- AMON links high-energy astrophysical observatories into a single virtual system.
- AMON framework enables:
  - Real-time sharing of sub-threshold data between multi-messenger observatories
  - Real-time and archival searches for coincident signals
  - Prompt distribution of electronic alerts for follow-up observations



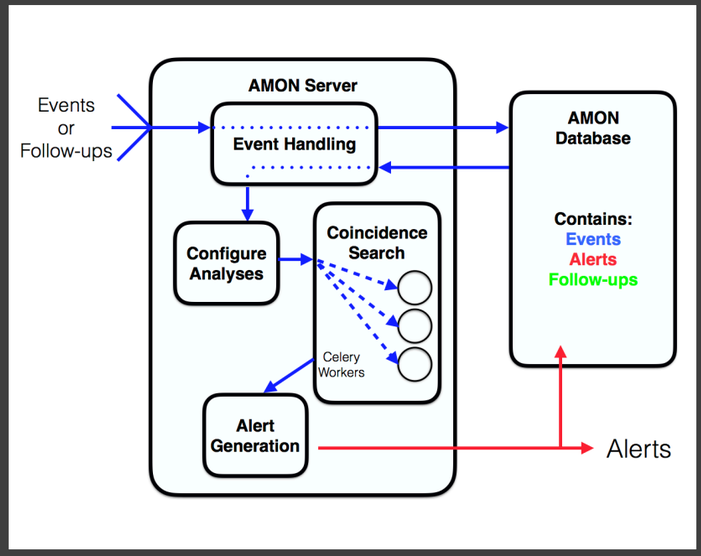
AMON Infrastructure

Application server

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

Hardware

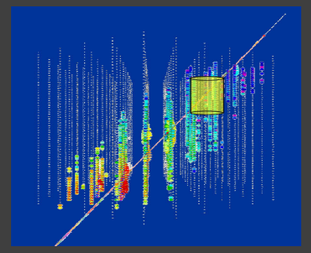
- Two high-uptime servers
  - Deployed at Penn State
  - Physically and cyber secure
  - Fully redundant systems

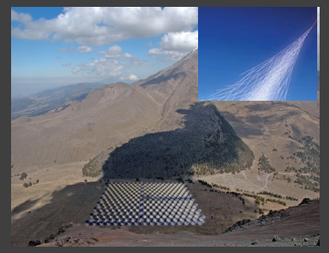


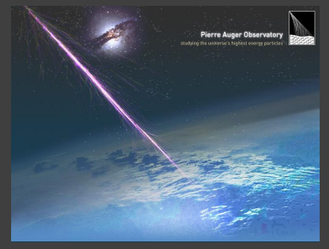
Network: Triggering and Follow-up

Triggering Observatories:

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

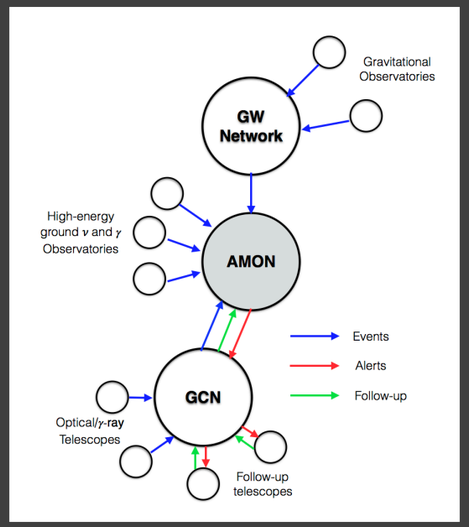


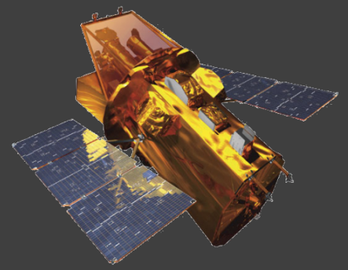




Follow-up Observatories:

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





Partner Observatories

Partner Observatories	Stream content/ 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	✓	✓	✓	✓	✓
Pierre Auger	✓	✓	✓	✓	In progress
FACT	✓	✓	✓	✓	In progress
HAWC	✓	✓	In progress		
VERITAS	In progress				
Swift BAT	✓	Not needed	Not needed	Not needed	✓
Fermi LAT	✓	Not needed	Not needed	Not needed	✓

Current Real-Time Alerts

Started issuing "pass-through" alerts of significant IceCube track-like events in April 2016

- Sent via connection to GCN (thanks to Scott Barthelmy)
- Public Alerts (receivable by all)
  - High Energy Starting Events (HESE)
  - Extremely High Energy (EHE)
- AMON GCN page https://gcn.gsfc.nasa.gov/gcn/amon.html

Stream	HESE	EHE	Multiplets
Description	Starting tracks	Very high energy through going tracks	~1TeV multiple tracks
Angular Error	> 0.4°	> 0.2°	~0.5°
Rate	~ 4/year	~ 4 - 6 / year	~ 2-6 / year

"The IceCube Realtime Alert System", Astroparticle Physics, 92, 30-41 (2017)

See Anna's talk

Follow-up Campaigns

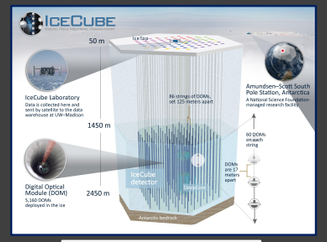
Follow-up campaigns of some of the IceCube high-energy ν's performed in 2016:

Alert name/type	161103/HESE	160814A/HESE	160806A/EHE	160731A/HESE	160731A/EHE	160427A/HESE
RA/DEC (rev1) RA/DEC (rev2)	[40.87°, 12.62°] [40.83°, 12.56°]	[199.31°, -32.02°] [200.25°, -32.35°]	[122.80°, -0.73°] [122.81°, -0.81°]	[215.11°, -0.46°] [214.54°, -0.33°]	[215.09°, -0.42°] [214.54°, -0.33°]	[239.66°, +6.85°] [240.57°, +9.34°]
Resolution	0.42° (50%),1.23°(90%) 0.65° (50%),1.10°(90%)	0.48° (50%), 1.49(90%)	0.11° (50%)	0.42° (50%),1.23°(90%) 0.35° (50%),0.75°(90%)	0.17° (50%),0.8°(90%) 0.35°(50%),0.75°(90%)	1.6° (50%), 8.9° (90%) 0.6° (90%)
ST or Signalness	0.30	0.12	0.28	0.91	0.85	0.92
Latency: Event t0 to GCN alert sending	40 s	42 s	37 s	41 s	54 s	81 s
Followups						

AGILE, ANTARES, FACT, Fermi GBM, Fermi LAT, HAWC, H.E.S.S, INTEGRAL, IPN, Konus-Wind, LCOGT, MAGIC, MASTER, Maxi/GSC, Pan-STARRS, PTF, Swift, VERITAS, CALET

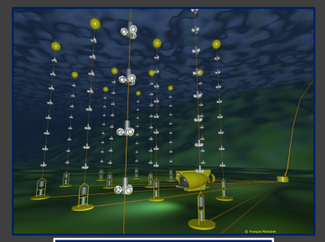
New Real-Time Alerts: Coming Soon

Real-Time γ-ν coincident alerts

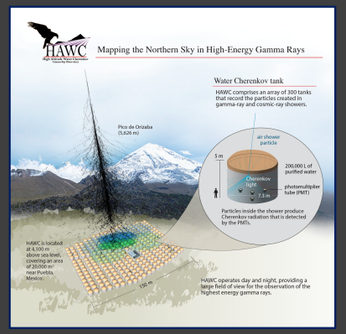


IceCube

Neutrinos
GeV - PeV



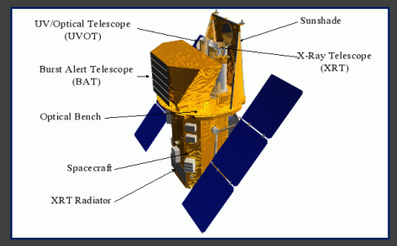
ANTARES



HAWC
TeV

FACT
100 Gev – 10 TeV

Fermi
MeV – GeV



Swift BAT
15 - 150 KeV

- AMON infrastructure ready to go
  - "Pass-through" alerts successfully brokered
  - Preliminary analyses running in real-time on scrambled/fake data
- What needs to happen
  - Cross-collaboration tuning and approval of analyses
  - Pull the "un-scramble" lever

IceCube Sub-Threshold Data

Data proposed for AMON	Through-Going Tracks
FOV	All Sky
Position Error	~ 1°
Rate	100's/day
Latency	~ 1 min

Through-going Track

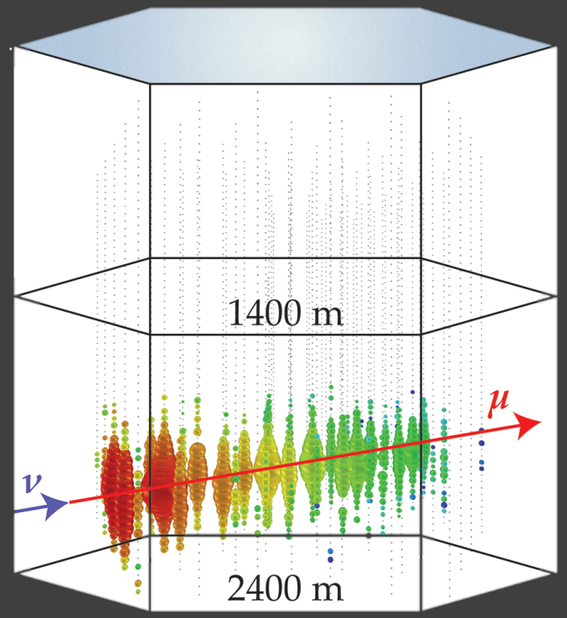
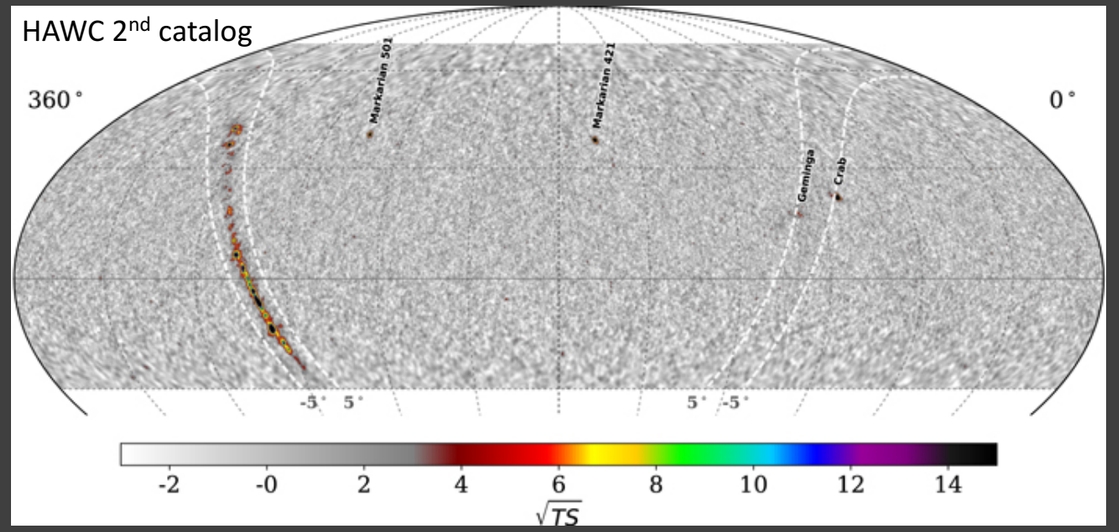


Illustration: APS/Joan Tycko; Neutrino event: IceCube

HAWC Hotspots

Data proposed for AMON	Sub-threshold signals in daily maps of TeV γ's
FOV	~15% sky
Position Error	~ 0.1°
Rate	100's/day
Latency	hours



AstrophysJ. 843 (2017) 1, 40

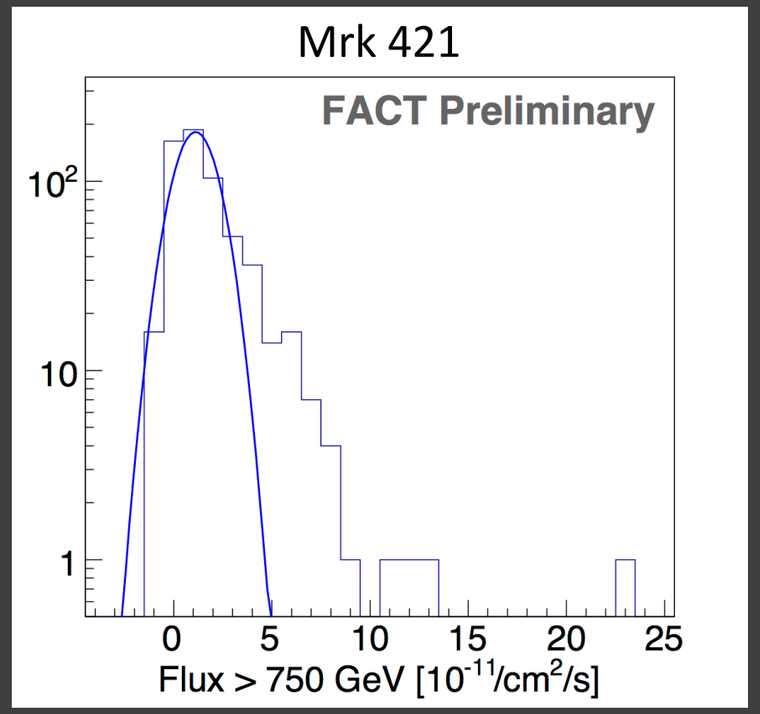
HAWC daily maps
Duration 6-7 hours

FACT Flares

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

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

Defining a flare
Right of the Gaussian curve is considered a Flare

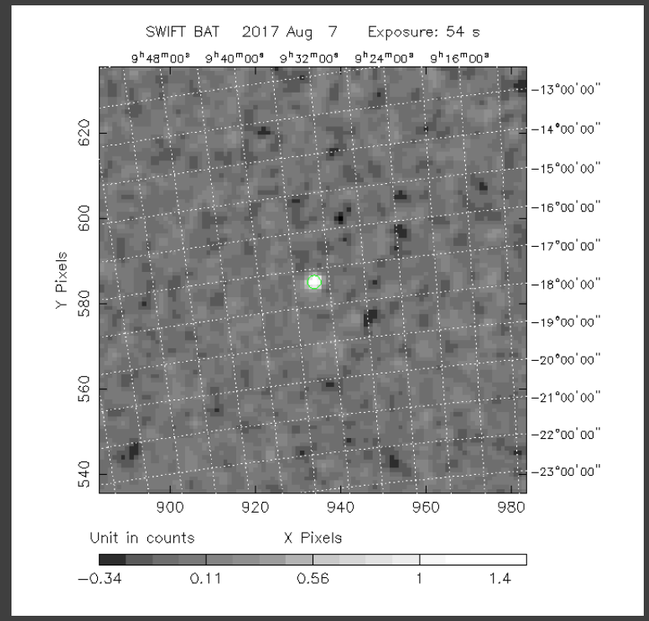


Credit: Daniela Dorner

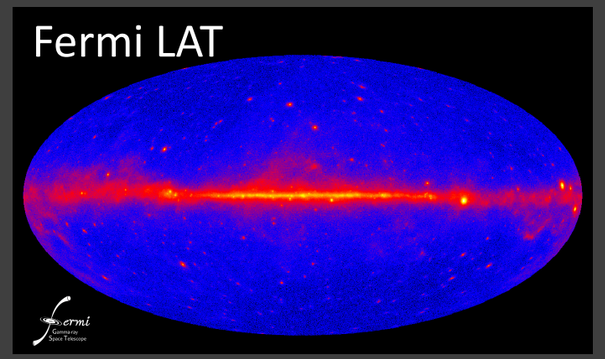
Swift BAT – Fermi LAT

	Swift BAT	Fermi
Data proposed for AMON	Low significance peaks found in onboard created images	>100 MeV single γ's
FOV	~15% sky	~15% sky
Position Error	~ 4 arcminutes	~ 0.1° - few°
Rate	100's/day	~ 10^4 / day
Latency	hours	hours

GRB 170807A

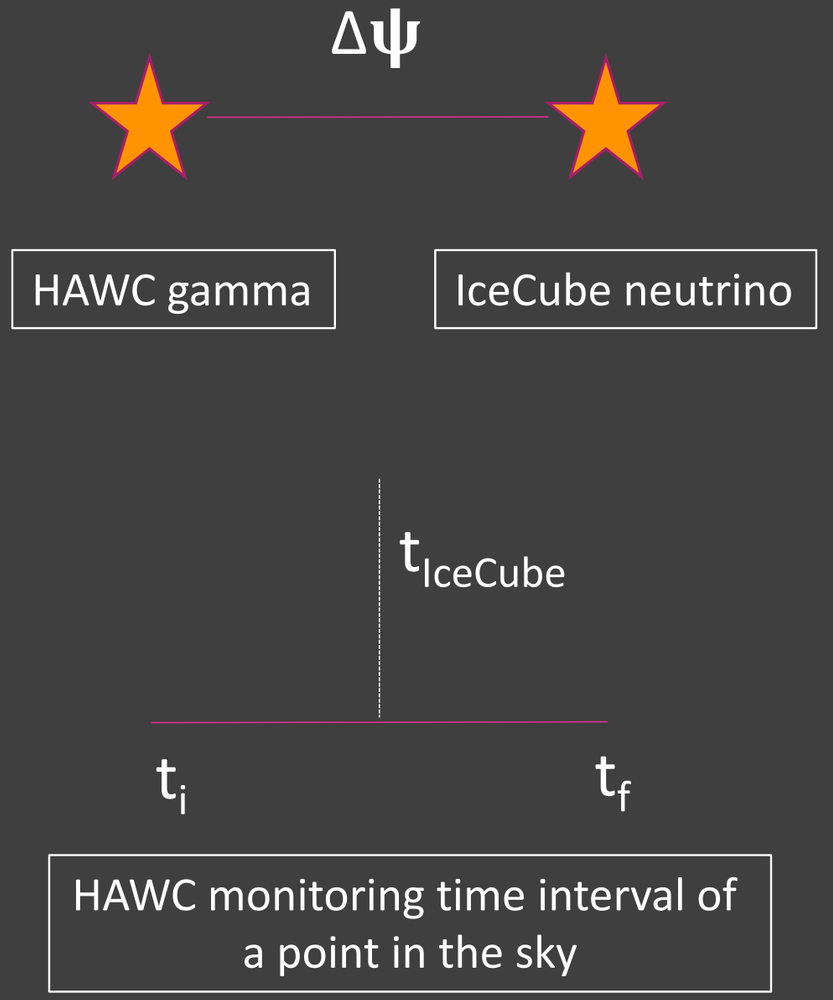


https://gcn.gsfc.nasa.gov/notices_s/766821/BA/



Example Correlation Analysis: IceCube-HAWC

- Spatial correlation: e. g. $\Delta\psi < 3.5^{\circ}$
- Temporal correlation: $t_i < t_{IceCube} < t_f$
- Define test statistic
- Study background and false positive rates
- Define threshold



AMON Prospects for Future Experiments

Neutrino:

- AMON currently receive real-time data from ANTARES and IceCube
- Future experiments
  - KM3Net
  - IceCube-Gen2
  - Better angular resolution
  - Broader energy range

Gamma-Ray:

- AMON currently receive data from and will soon send alerts to IACT community
- Interested in more connections (e.g. MAGIC)
- Future experiments
  - CTA
  - Join as both triggering and follow-up facility
  - Faster follow-up of AMON alerts (ν- γ)
  - Larger FOV → suitable also for neutrino cascades

AMON Prospects for Future Experiments

Radio:

- Interested in receiving LOFAR transients alerts (via “TraP”)
- Use in subthreshold multimessenger coincidence searches
- Send alerts to LOFAR for follow-up

Gravitational Waves:

- LIGO soon to be a triggering facility for AMON
- Final approval from LSC committee
- AMON will be a follow-up partner by O3
- Pipeline + archival analysis undergoing

Join AMON

- We’re always interested in new partners to join AMON
- Feel free to contact us about joining, receiving alerts, analyses, etc.
- For info about AMON see: https://sites.psu.edu/amon