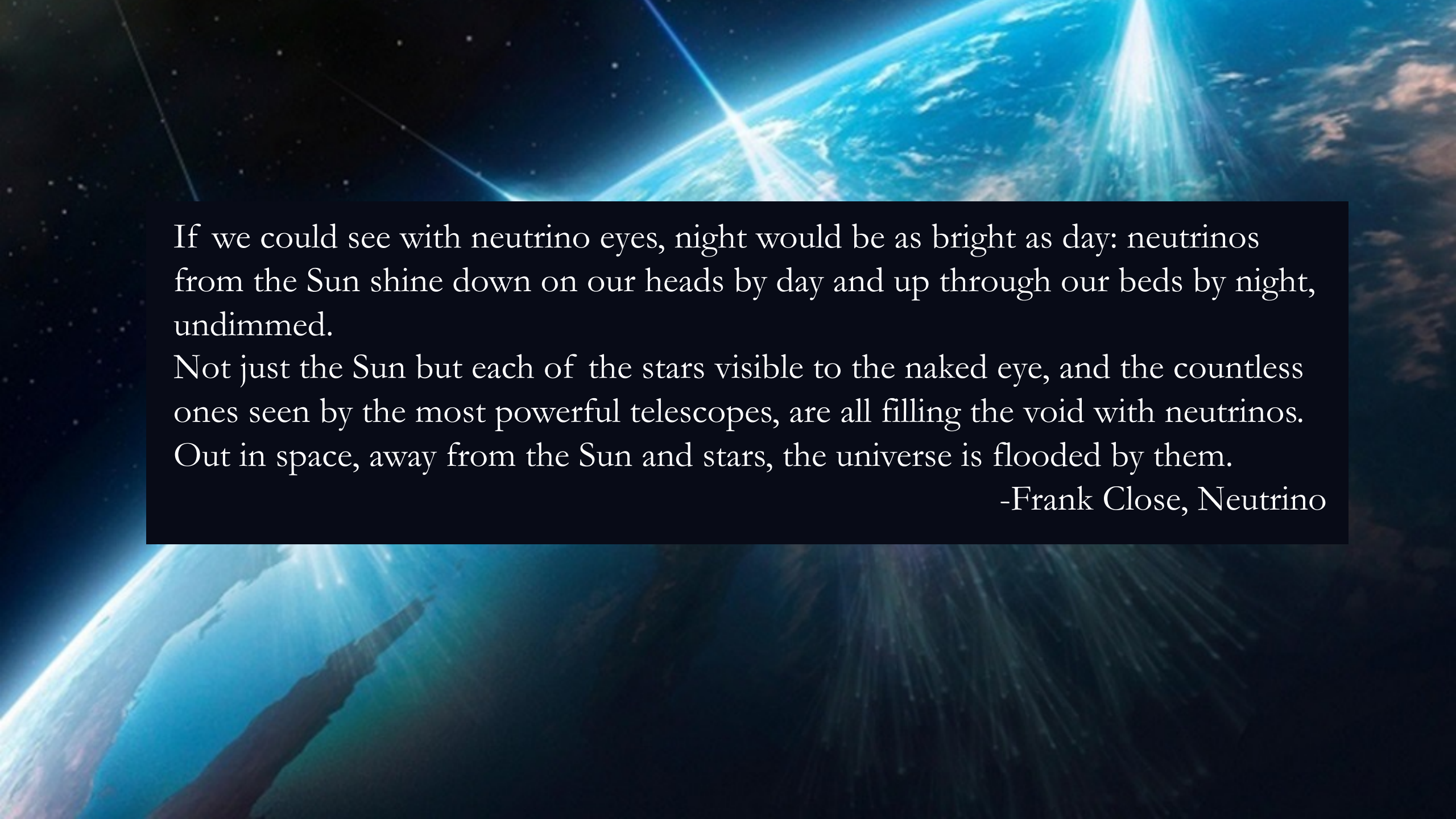


Highlights from the IceCube Neutrino Observatory

Erin O'Sullivan, for the IceCube Collaboration

Uppsala University

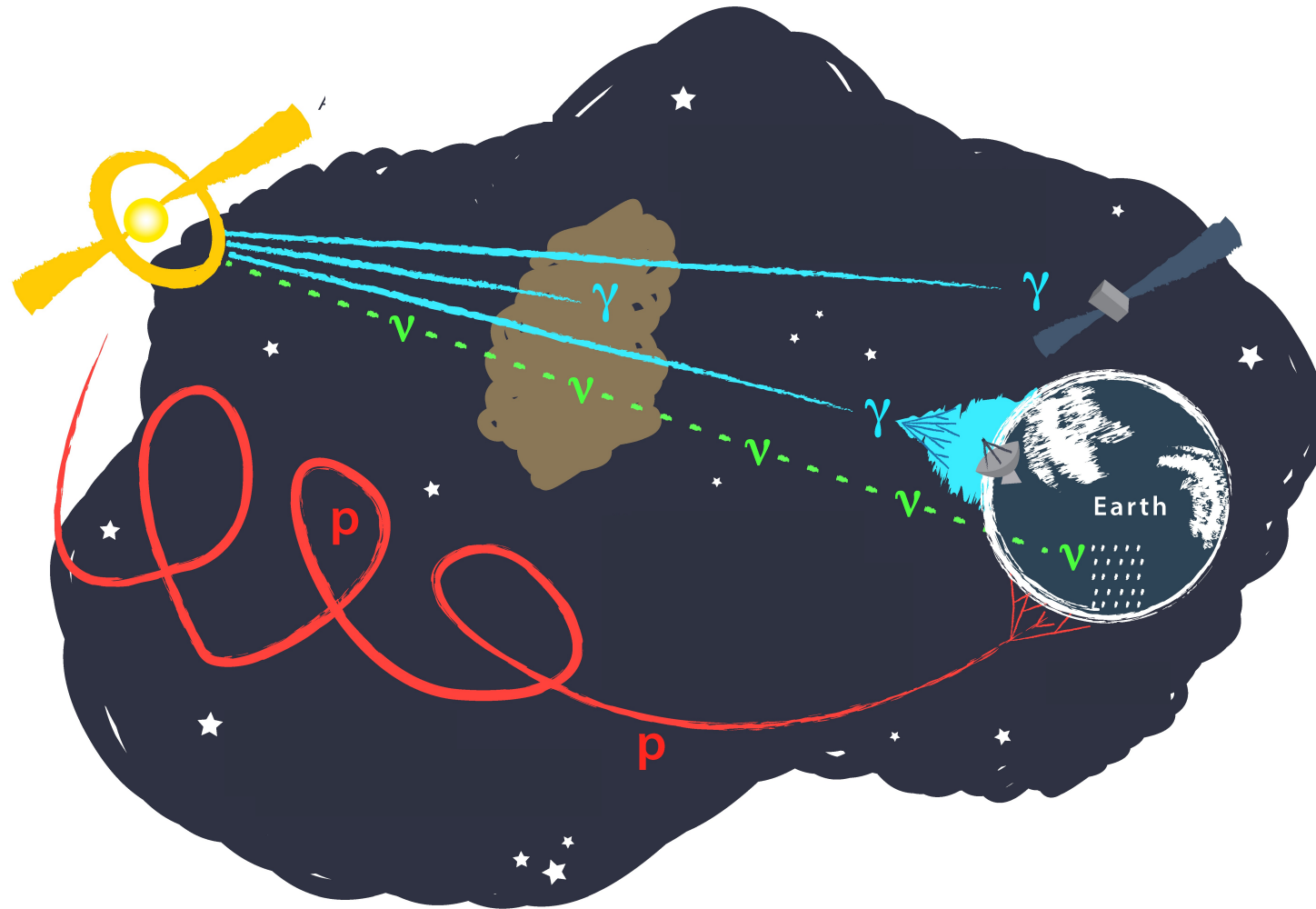
Nordic Baltic Astronomy Days, Turku 2026



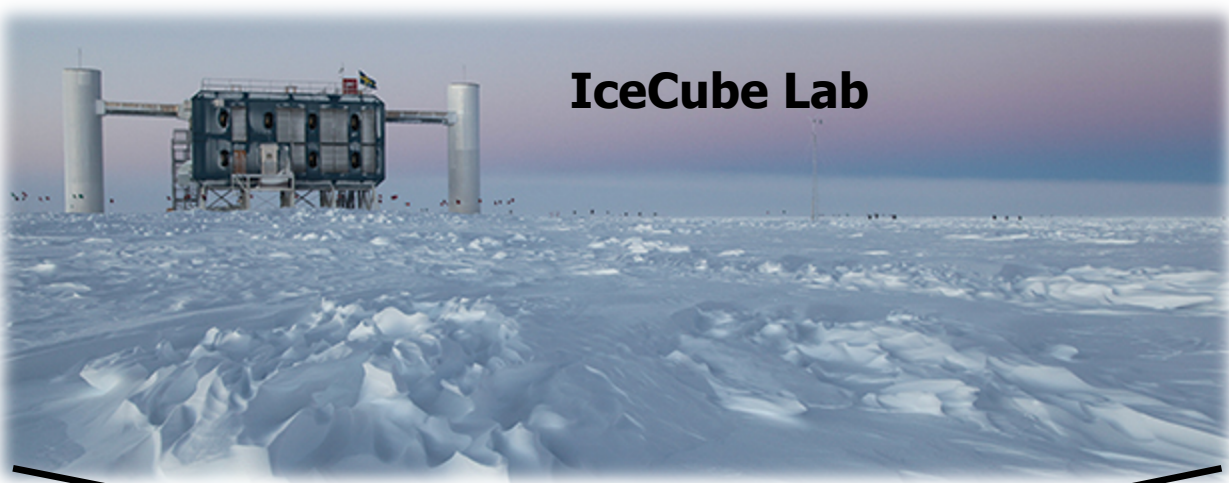
If we could see with neutrino eyes, night would be as bright as day: neutrinos from the Sun shine down on our heads by day and up through our beds by night, undimmed.

Not just the Sun but each of the stars visible to the naked eye, and the countless ones seen by the most powerful telescopes, are all filling the void with neutrinos. Out in space, away from the Sun and stars, the universe is flooded by them.

-Frank Close, Neutrino



Neutrinos are a direct, unobscured tracers of hadronic acceleration



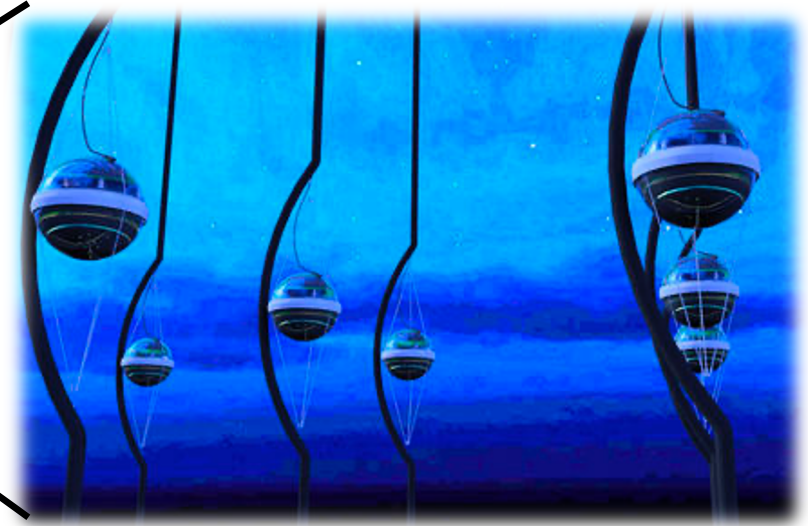
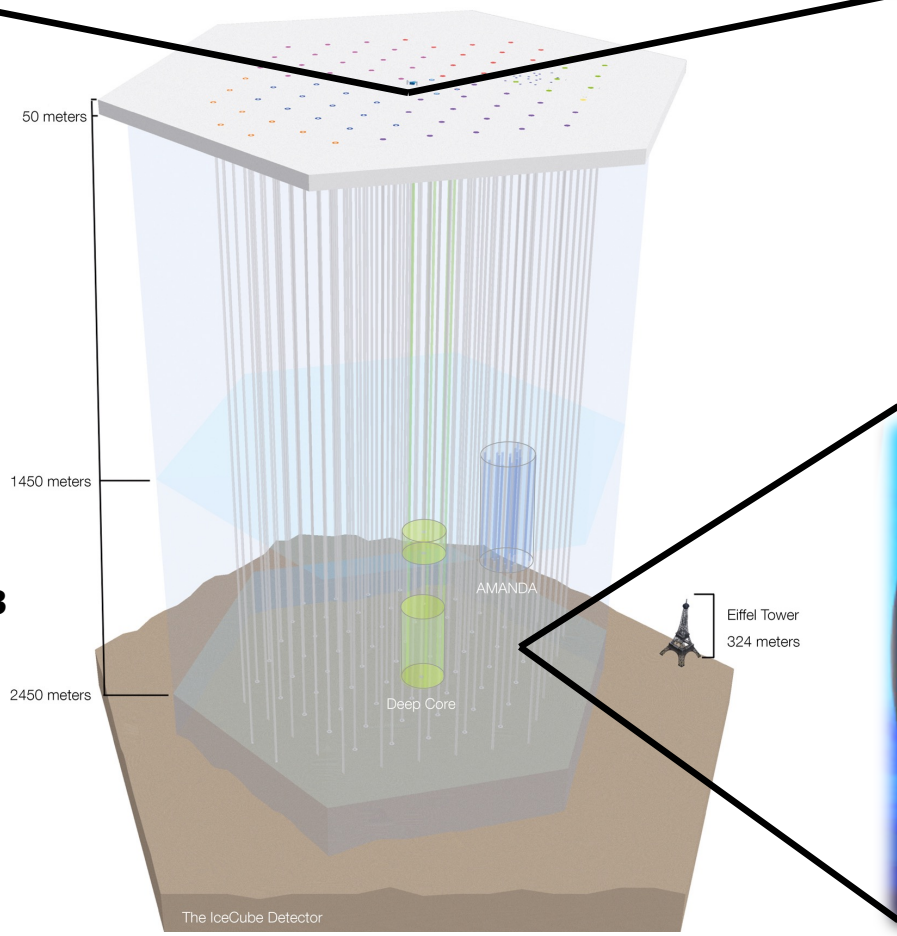
IceCube Lab



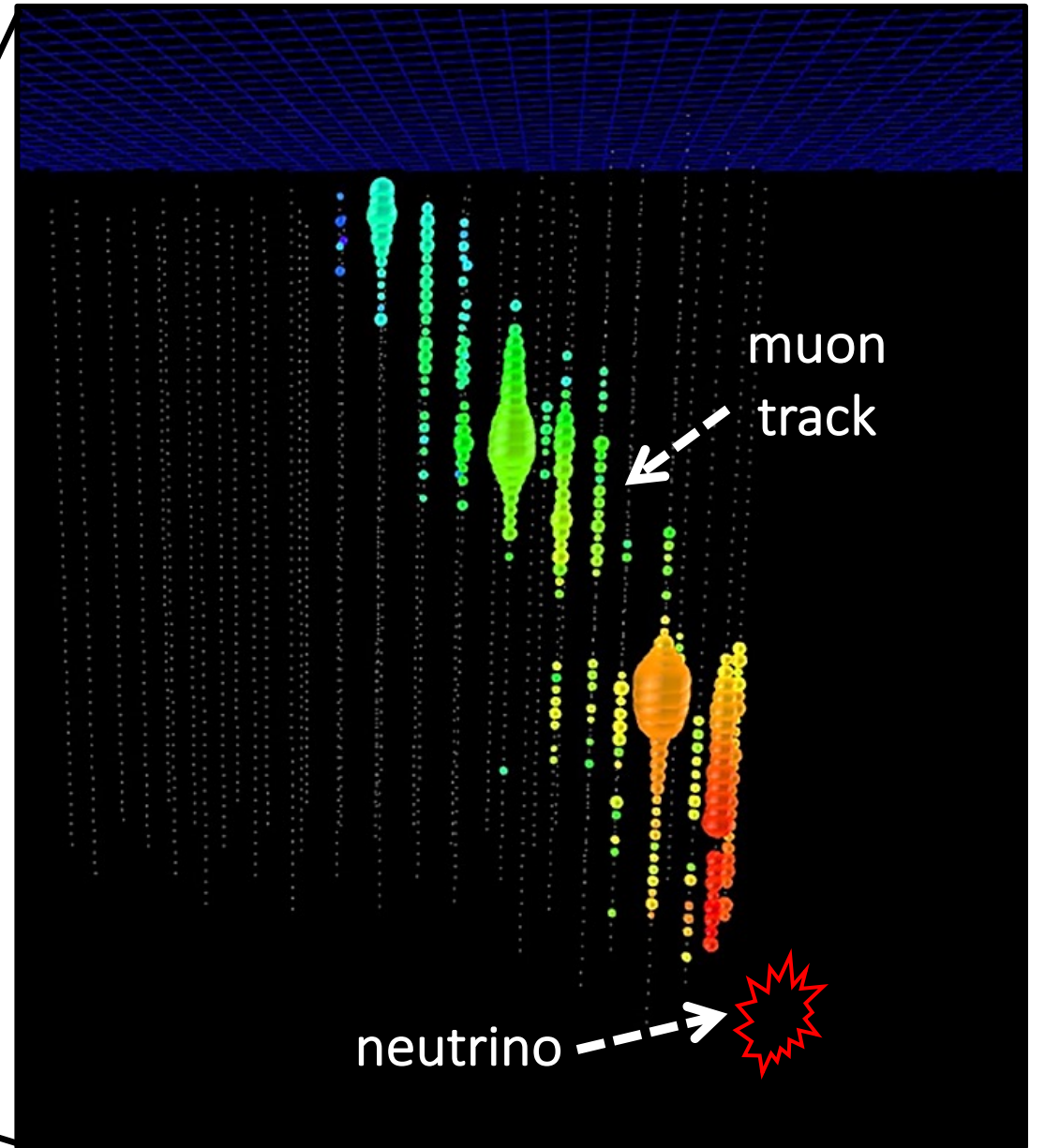
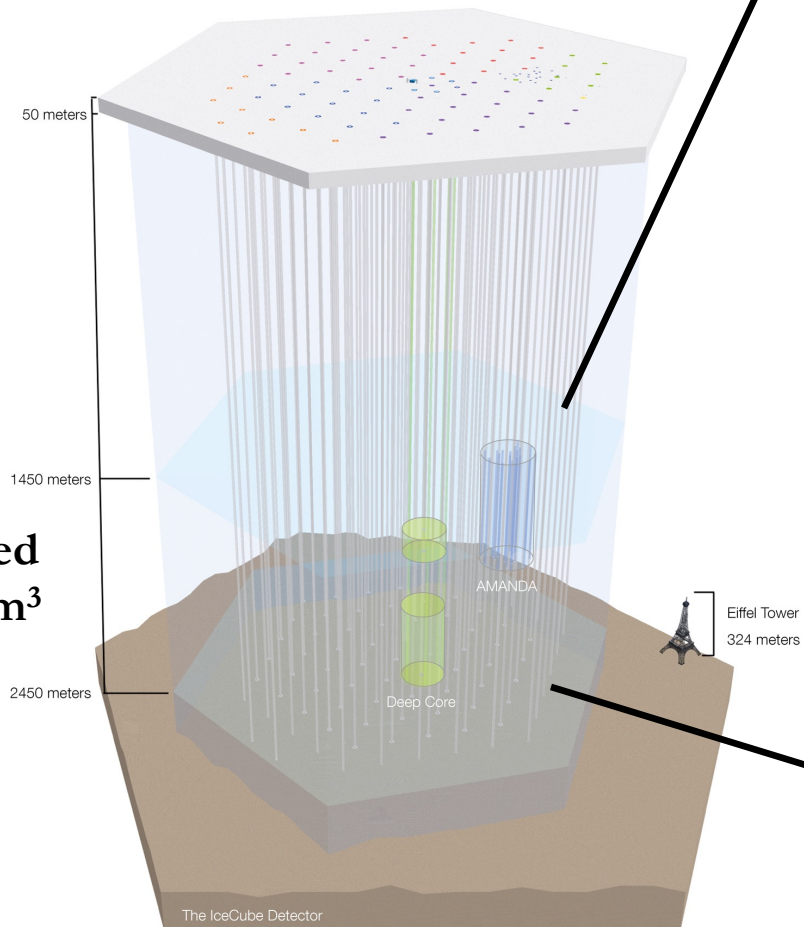
ICECUBE

86 strings completed 2011
+ 5 strings added in 2026

**Instrumented
volume: 1 km³**

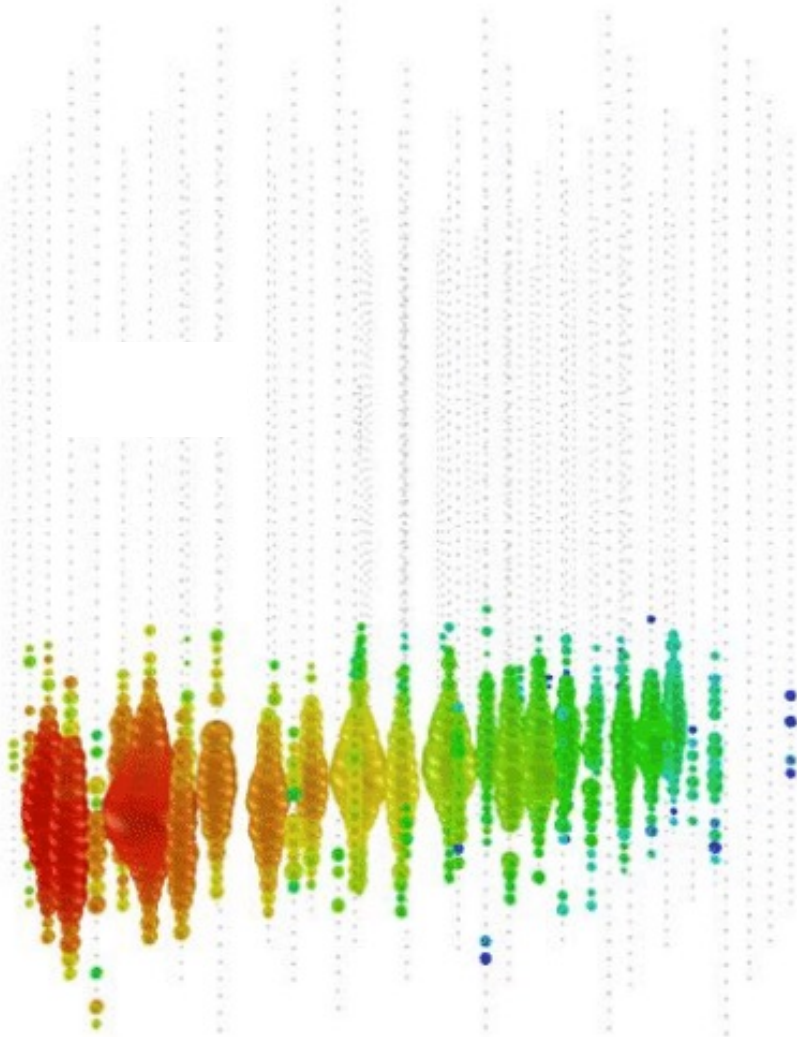


**Instrumented
volume: 1 km³**



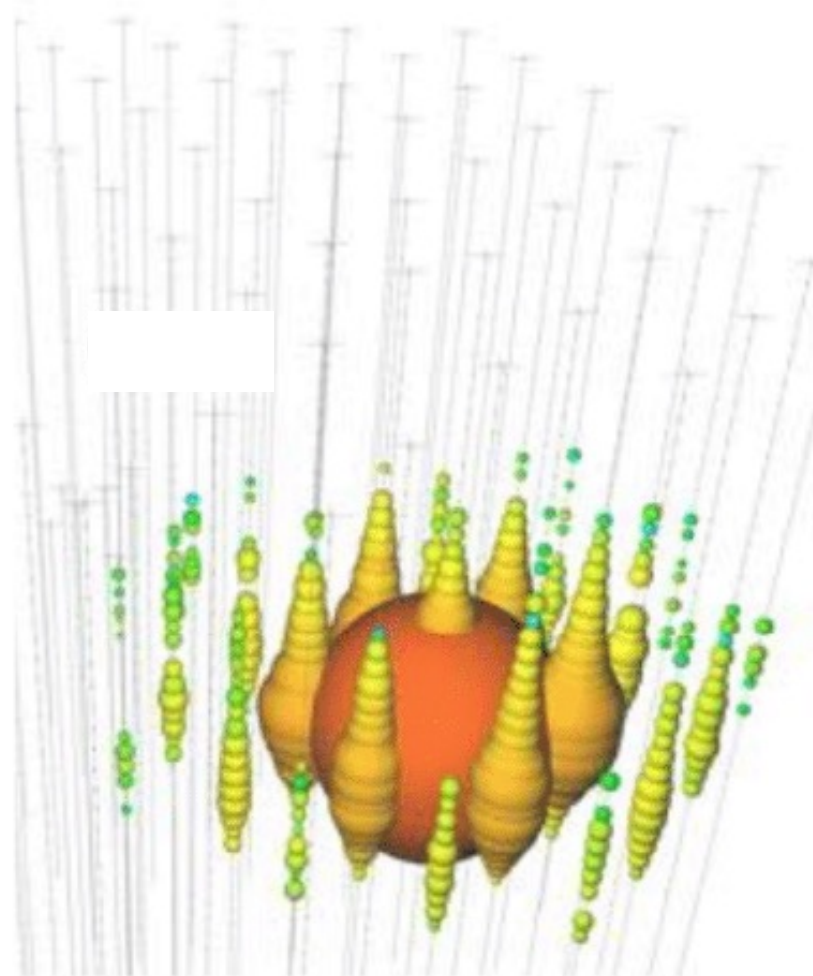
Tracks

Charged-current ν_μ
Good pointing: $0.2^\circ - 1^\circ$
(mostly) Northern Sky



Cascades

Charged-current ν_e or ν_τ and neutral current
Good for energy reconstruction
Some pointing: $5^\circ - 10^\circ$
All sky



THE ICECUBE COLLABORATION

AUSTRALIA

University of Adelaide

BELGIUM

UCLouvain
Université libre de Bruxelles
Universiteit Gent
Vrije Universiteit Brussel

CANADA

Queen's University
Simon Fraser University
University of Alberta-Edmonton

DENMARK

University of Copenhagen

GERMANY

Deutsches Elektronen-Synchrotron
ECAP, Universität Erlangen-Nürnberg
Humboldt-Universität zu Berlin
Karlsruhe Institute of Technology
Ruhr-Universität Bochum
RWTH Aachen University
Technische Universität Dortmund
Technische Universität München
Universität Mainz
Universität Münster
Universität Wuppertal

ITALY

University of Padova

JAPAN

Chiba University

NEW ZEALAND

University of Canterbury

REPUBLIC OF KOREA

Chung-Ang University
Sungkyunkwan University

SWEDEN

Stockholms universitet
Uppsala universitet

SWITZERLAND

Université de Genève

TAIWAN

Academia Sinica

UNITED KINGDOM

University of Oxford

UNITED STATES

Columbia University
Drexel University
Georgia Institute of Technology
Harvard University
Lawrence Berkeley National Lab
Loyola University Chicago
Marquette University

Massachusetts Institute
of Technology
Mercer University
Michigan State University
Ohio State University
Pennsylvania State University
South Dakota School of Mines
and Technology
Southern University
and A&M College
Stony Brook University
University of Alabama
University of Alaska Anchorage
University of California, Berkeley
University of California, Irvine
University of Delaware

University of Kansas
University of Maryland
University of Nevada, Las Vegas
University of Rochester
University of Utah
University of Wisconsin-Madison
University of Wisconsin-River Falls
Yale University

FUNDING AGENCIES

Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen
(FWO-Vlaanderen)

Federal Ministry of Education and Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)

Japan Society for the Promotion of Science (JSPS)
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat

The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)




ICECUBE
NEUTRINO OBSERVATORY


icecube.wisc.edu

Contributions to IceCube:

- 30% of sensors
- Cables
- Sweden Cameras

 **AUSTRALIA**
University of Adelaide

 **BELGIUM**
UCLouvain
Université libre de Bruxelles
Universiteit Gent
Vrije Universiteit

 **CANADA**
Queen's University
Simon Fraser University
University of Alberta-Edmonton

 **DENMARK**
University of Copenhagen

 **GERMANY**
Deutsches Elektronen-Synchrotron
ECAP, Universität Erlangen-Nürnberg
Humboldt-Universität zu Berlin
Karlsruhe Institute of Technology
Ruhr-Universität Bochum
RWTH Aachen University
Technische Universität Dortmund
Technische Universität München
Universität Mainz
Universität Münster
Universität Wuppertal


THE ICECUBE COLLABORATION

 **ITALY**
University of Padova

 **JAPAN**
Chiba University


 **NEW ZEALAND**
University of Canterbury

 **REPUBLIC OF KOREA**
Chung-Ang University
Sungkyunkwan University

 **SWEDEN**
Stockholms universitet
Uppsala universitet

 **DENMARK**
University of Copenhagen

 **UNITED KINGDOM**
University of Oxford

 **UNITED STATES**
Columbia University
Drexel University
Georgia Institute of Technology
Harvard University
Lawrence Berkeley National Lab
Loyola University Chicago
Marquette University

Southern University
and A&M College
Stony Brook University
University of Alabama
University of Alaska Anchorage
University of California, Berkeley
University of California, Irvine
University of Delaware

University of Kansas
University of Maryland
University of Nevada, Las Vegas
University of Rochester
University of Utah
University of Wisconsin-Madison
University of Wisconsin-River Falls
Yale University

 **SWEDEN**
Stockholms universitet
Uppsala universitet

Sweden: member since start of the experiment, 7 faculty members

Copenhagen: 3 faculty members

FUNDING AGENCIES

Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen
(FWO-Vlaanderen)

Federal Ministry of Education and Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)

Japan Society for the Promotion of Science (JSPS)
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat

The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)



ICECUBE
NEUTRINO OBSERVATORY

icecube.wisc.edu

A selection of IceCube highlights



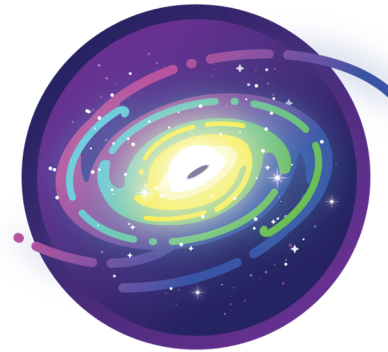
ASTROPHYSICAL NEUTRINOS
DISCOVERED

.....●.....
2013



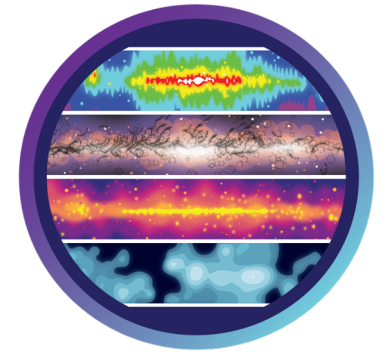
BLAZAR TXS 0506+056
NEUTRINO EMISSION IDENTIFIED

.....●.....
2018



ACTIVE GALAXY NGC 1068
NEUTRINO EMISSION IDENTIFIED

.....●.....
2022



MILKY WAY
NEUTRINO EMISSION IDENTIFIED

.....●.....
2023

And where we are now



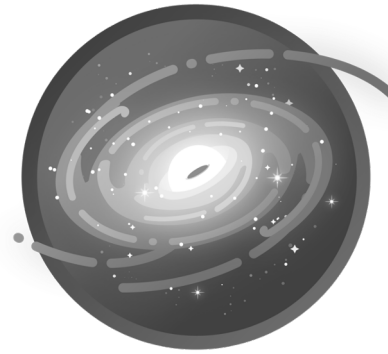
ASTROPHYSICAL NEUTRINOS
DISCOVERED

.....●.....
2013



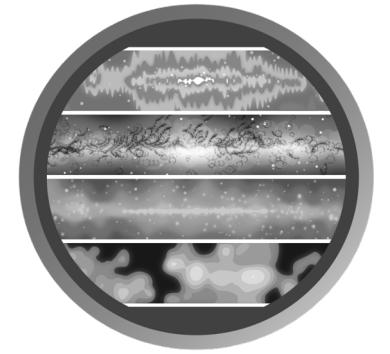
BLAZAR TXS 0506+056
NEUTRINO EMISSION IDENTIFIED

.....●.....
2018



ACTIVE GALAXY NGC 1068
NEUTRINO EMISSION IDENTIFIED

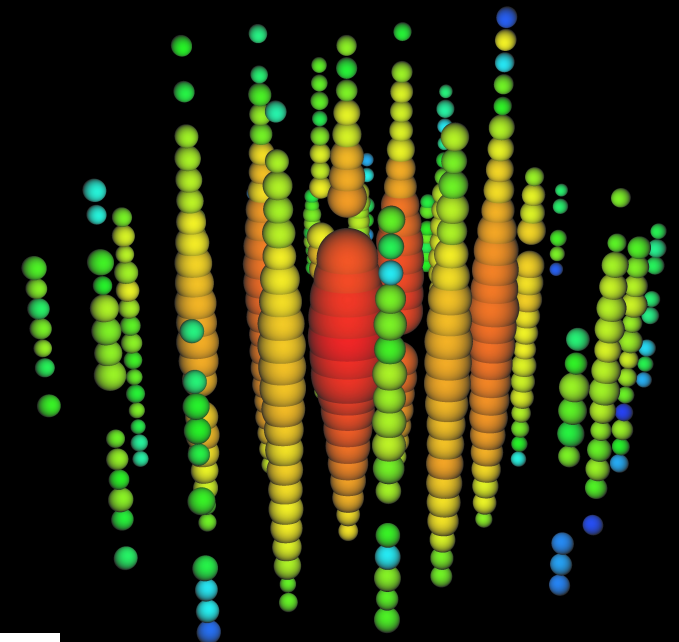
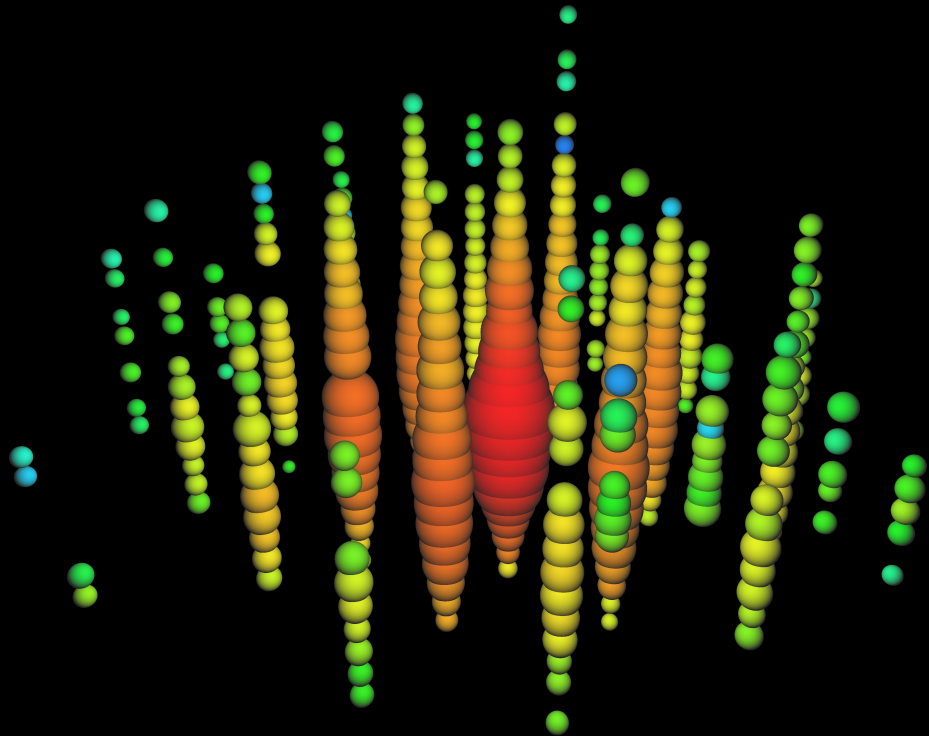
.....●.....
2022



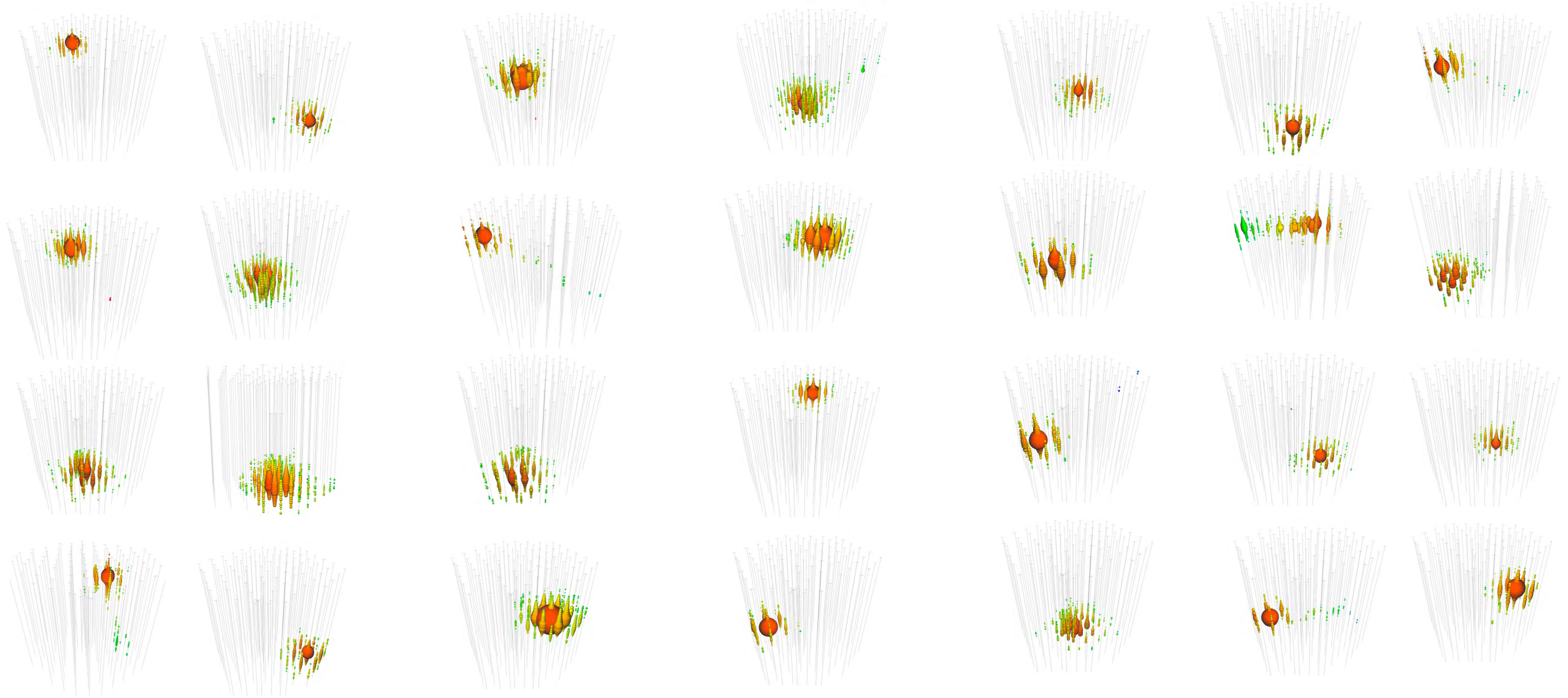
MILKY WAY
NEUTRINO EMISSION IDENTIFIED

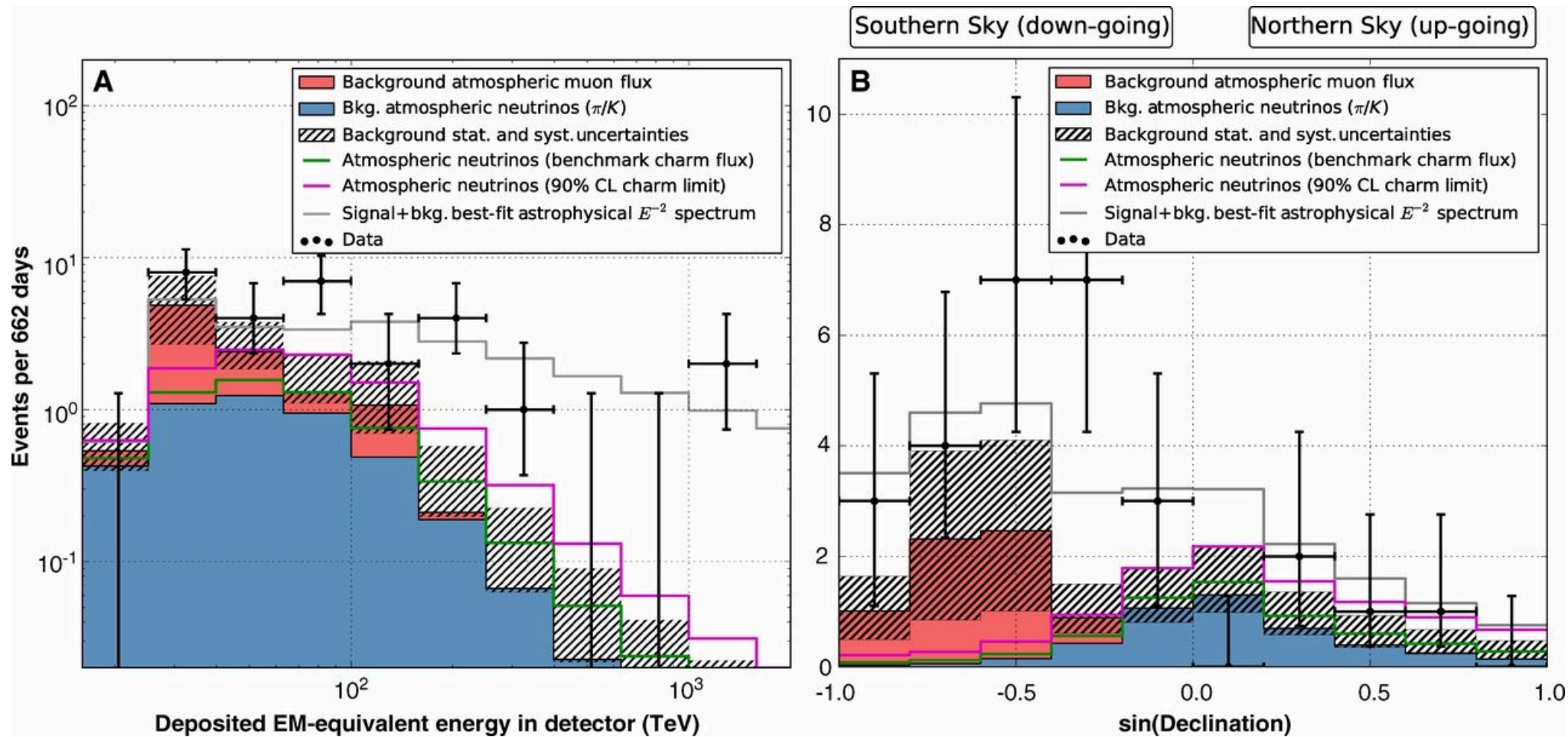
.....●.....
2023

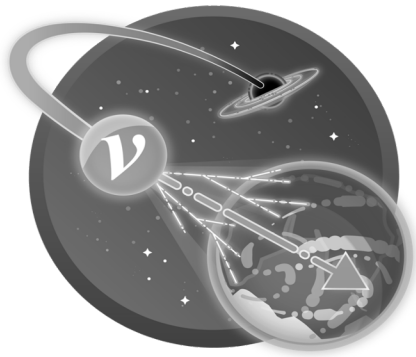
The first high energy (PeV) events



Discovering high energy astro neutrinos— the first 28 events







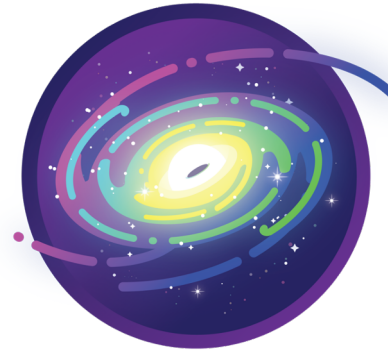
ASTROPHYSICAL NEUTRINOS
DISCOVERED

.....●.....
2013



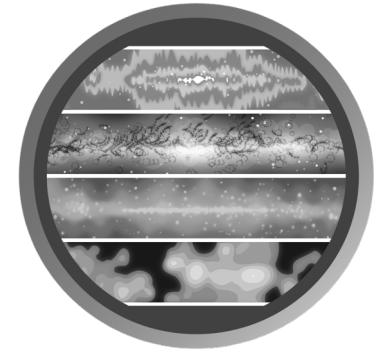
BLAZAR TXS 0506+056
NEUTRINO EMISSION IDENTIFIED

.....●.....
2018



ACTIVE GALAXY NGC 1068
NEUTRINO EMISSION IDENTIFIED

.....●.....
2022

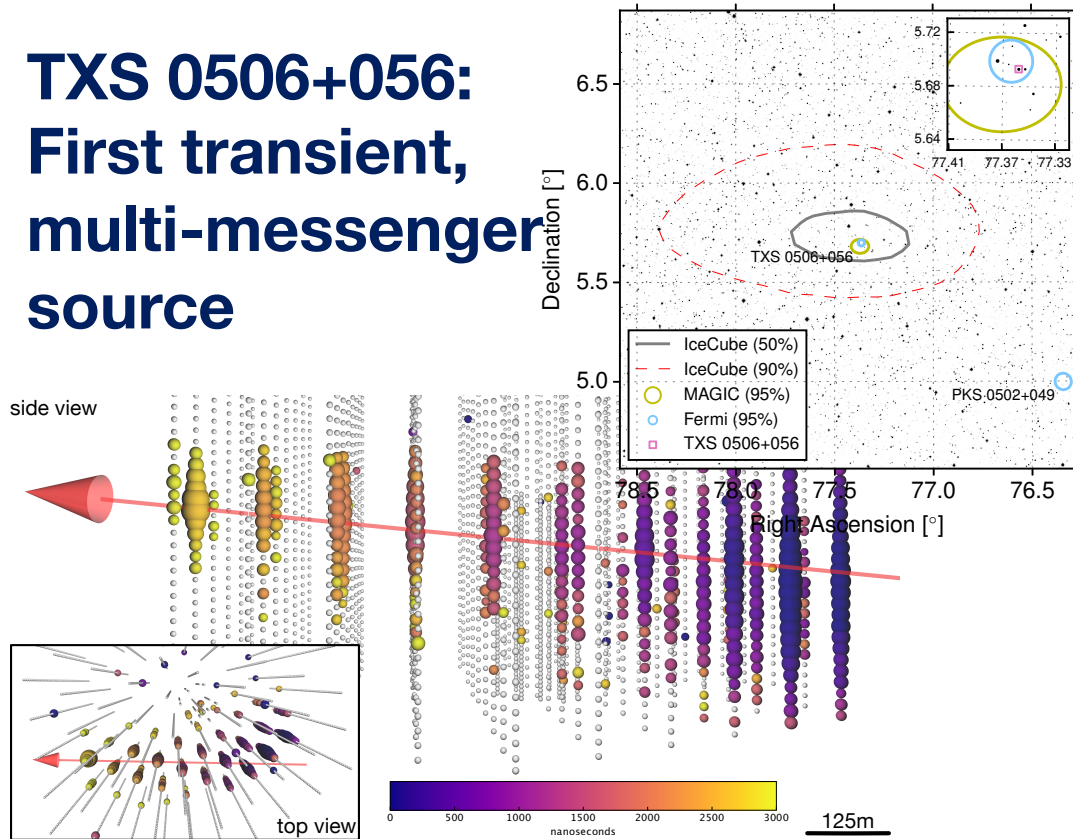


MILKY WAY
NEUTRINO EMISSION IDENTIFIED

.....●.....
2023

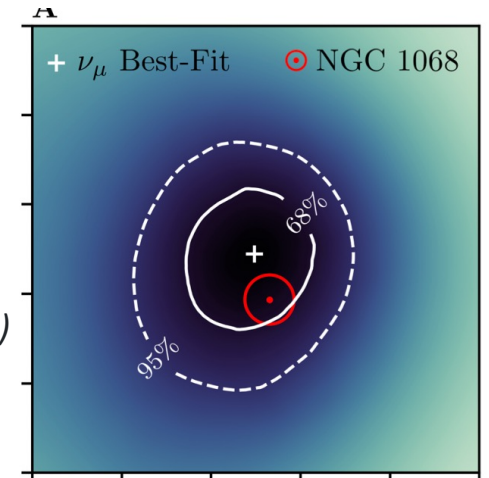
Identifying the sources of high energy neutrinos

TXS 0506+056: First transient, multi-messenger source



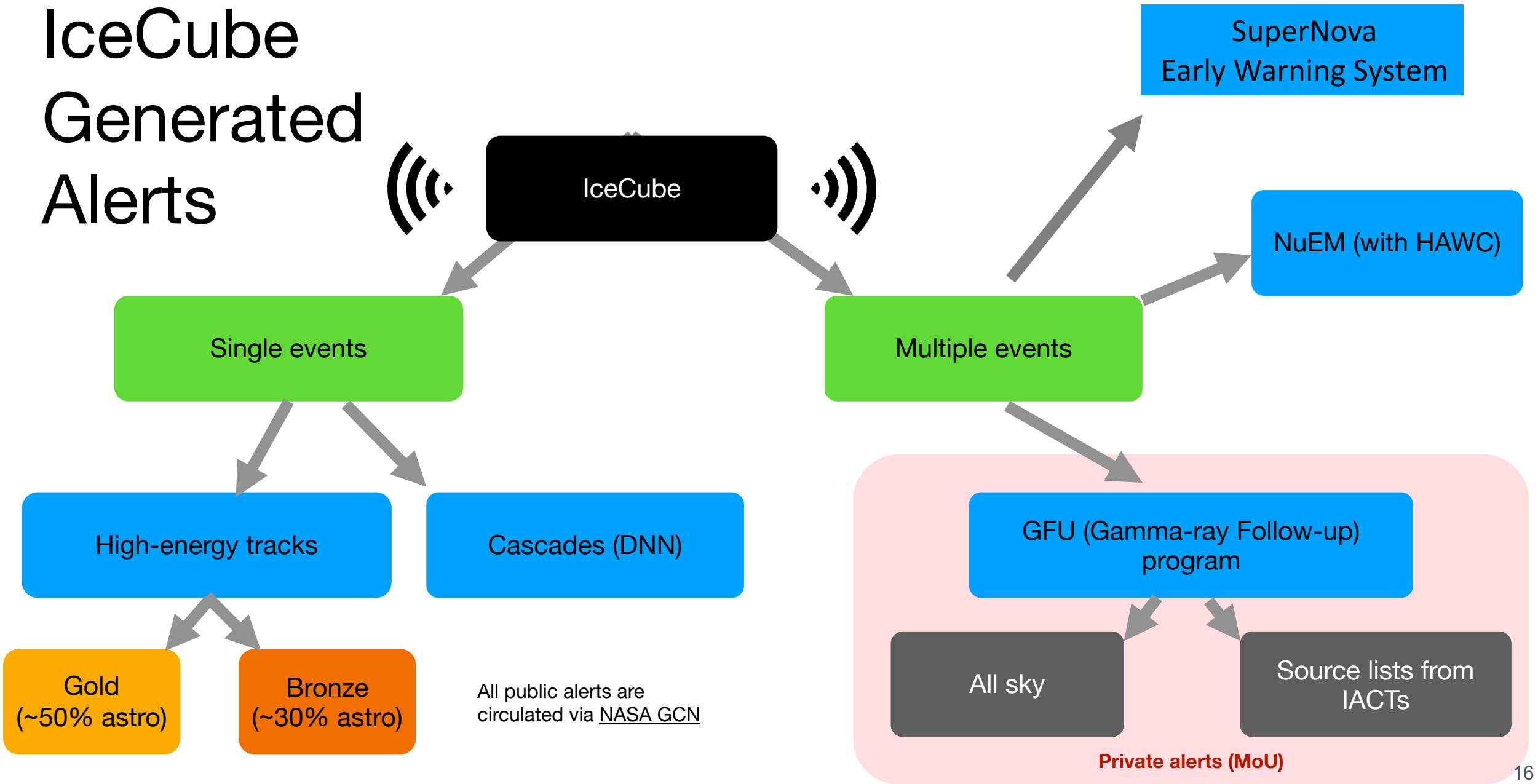
NGC1068: First steady- state neutrino source

IceCube Collaboration Science 378 (2022)



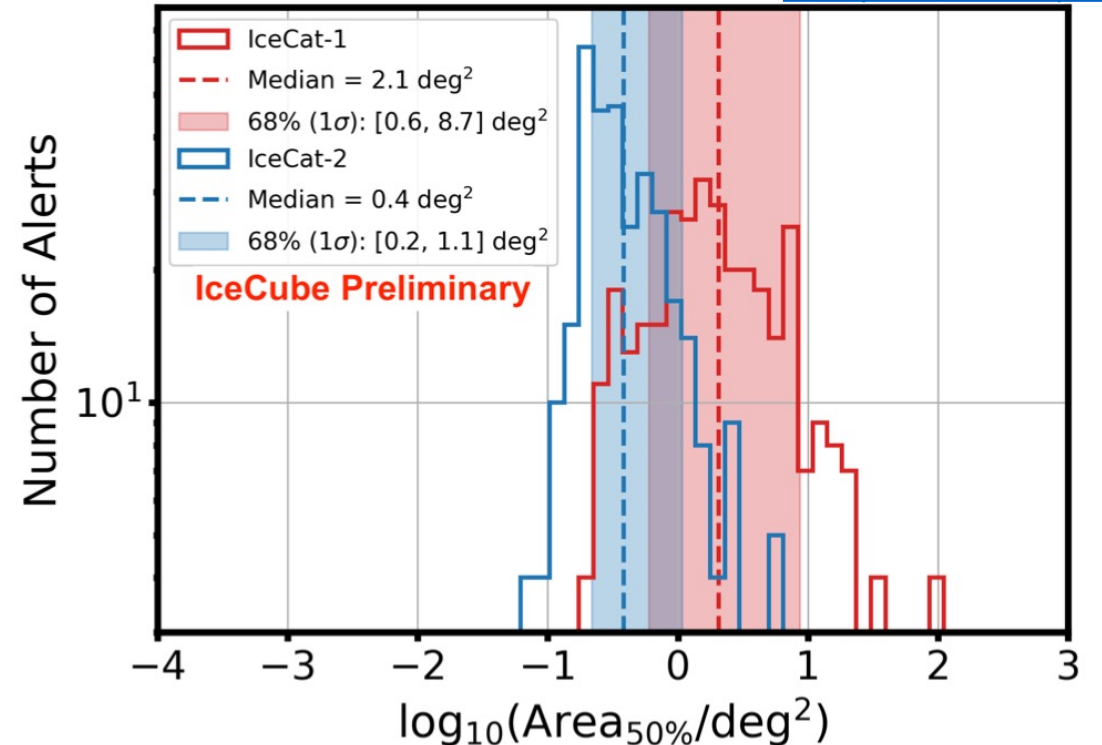
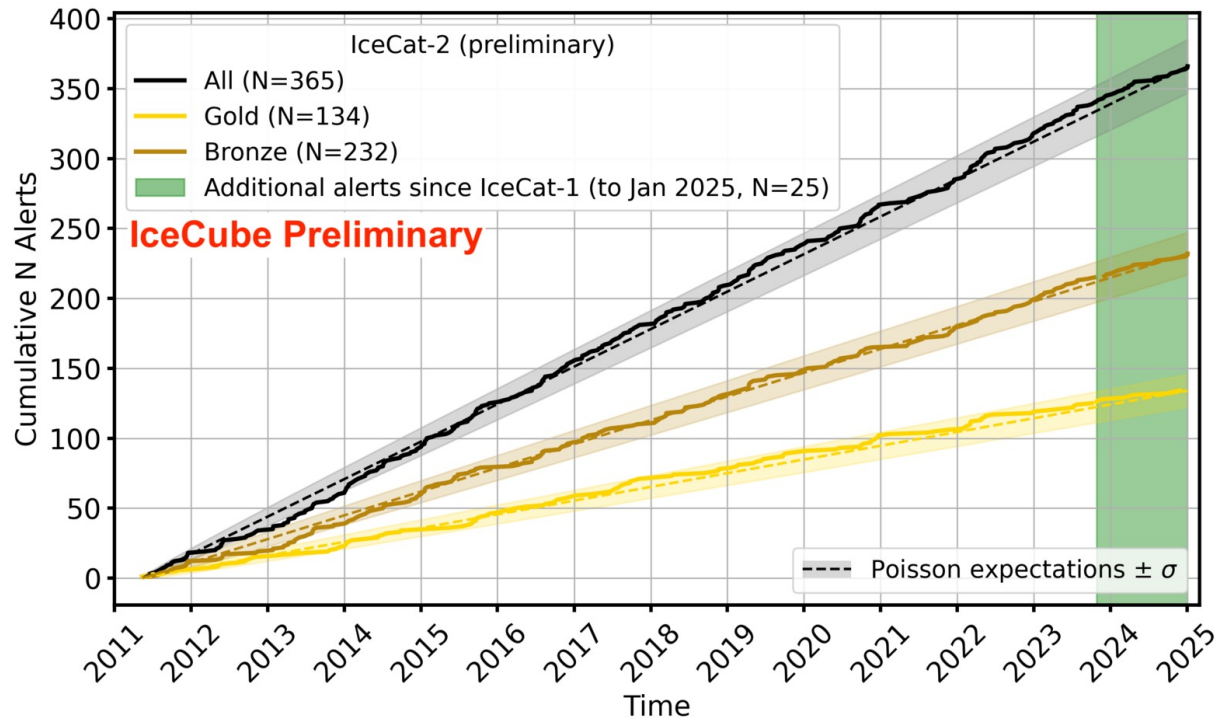
*IceCube Collaboration, FERMI-LAT, MAGIC, ASAS-SN,
H.E.S.S, INTEGRAL, KANATA, KISO, KAPTEYN, LIVERPOOL
TELESCOPE, SUBARU, SWIFT/NUSTAR, VERITAS, VLA/17B-
403 Science 361 issue 6398 (2018)*

IceCube Generated Alerts



IceCat-2: Improved alert catalog coming soon

PoS(ICRC2025)1224



[IceCat-1 catalog](#)

Preliminary release of selected events in IceCat-2

<https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/RX28YT>

IceCube Second Track Data Release IceTracks-DR2: Data from 2008-2022 for Neutrino Source Searches

Version 1.0



IceCube Collaboration, 2026, "IceCube Second Track Data Release IceTracks-DR2: Data from 2008-2022 for Neutrino Source Searches", <https://doi.org/10.7910/DVN/MMIIZA>, Harvard Dataverse, V1, UNF:6:6le7+6aiKRbA8tadvT/D0A== [fileUNF]

Cite Dataset ▾

Learn about [Data Citation Standards](#).

Access Dataset ▾

Edit Dataset ▾

Link Dataset

Contact Owner

Share

Dataset Metrics ?

536 Downloads ?

Description ?

The events contained in this release make up the event sample commonly used for IceCube's time-integrated neutrino point source searches. Events in this sample are track-like neutrino candidates detected by IceCube between April 2008 and May 2022.

This data release (referred to as "IceTracks-DR2") is an evolution of the previous 10-year version of this data sample that has been made publicly available here: <https://doi.org/10.7910/DVN/VKL316> (referred to as "IceTracks-DR1"). In comparison with IceTracks-DR1, IceTracks-DR2 includes four additional years of data collected with the full IceCube detector configuration and incorporates improved calibrations. See [1] for more details. IceTracks-DR2 is intended to supersede IceTracks-DR1, and events from IceTracks-DR2 are not intended to be combined with other IceCube public data releases.

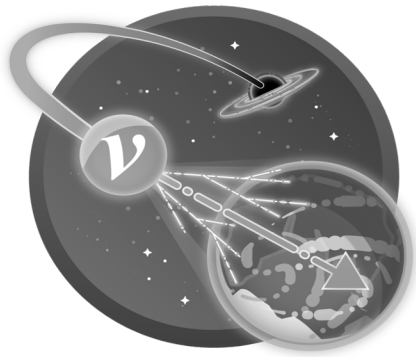
Standardized checks of generic point source results using this sample (including results associated with notable astrophysical neutrino source candidates such as NGC 1068 and TXS 0506+056) have been compiled in [1].

Data files:

* Read Me: A file describing each field of the data, uptime, and tabulated response files.

* The "events" subfolder contains the events observed in the 14-year sample of IceCube's point

Feedback



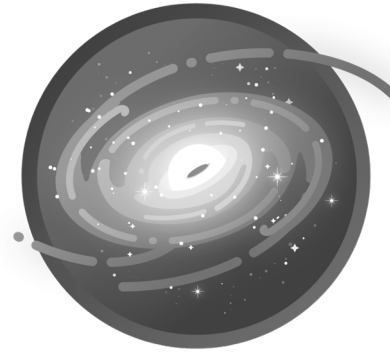
ASTROPHYSICAL NEUTRINOS
DISCOVERED

.....●.....
2013



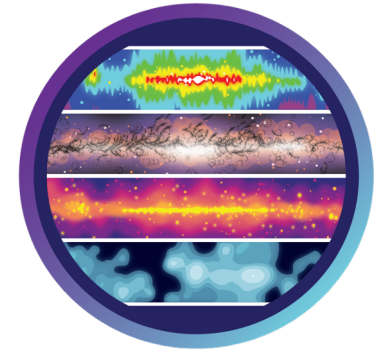
BLAZAR TXS 0506+056
NEUTRINO EMISSION IDENTIFIED

.....●.....
2018



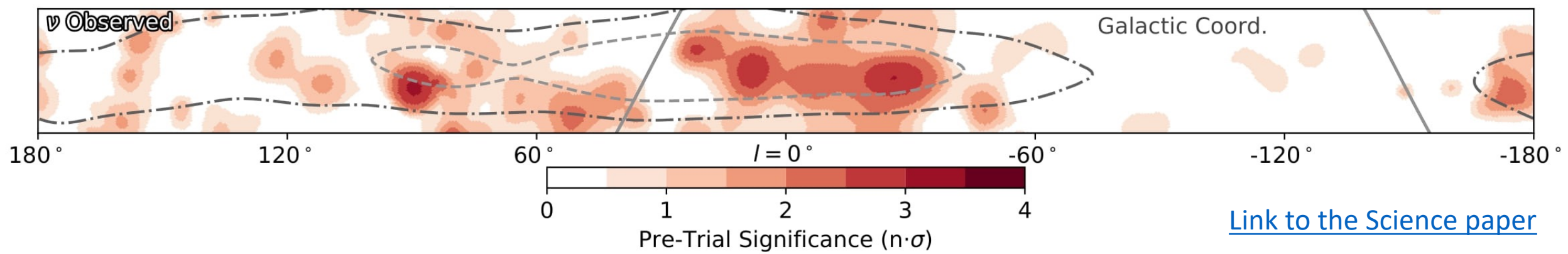
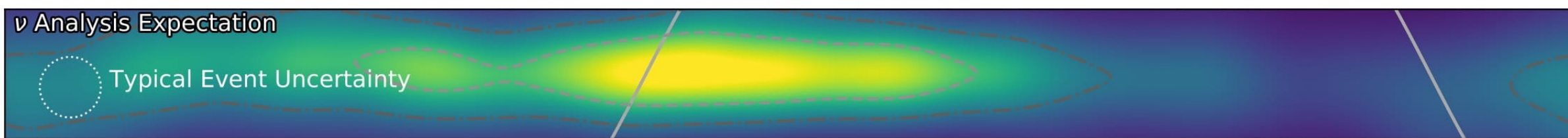
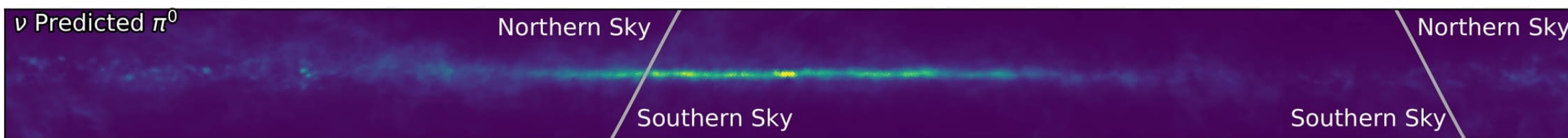
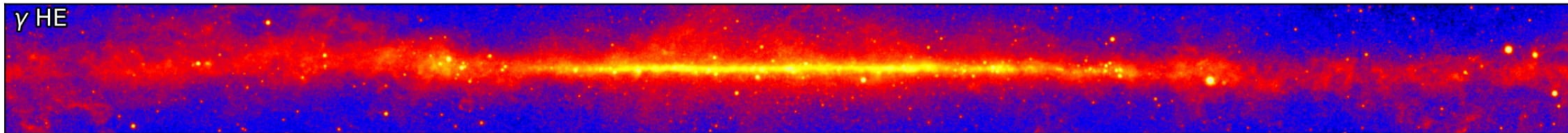
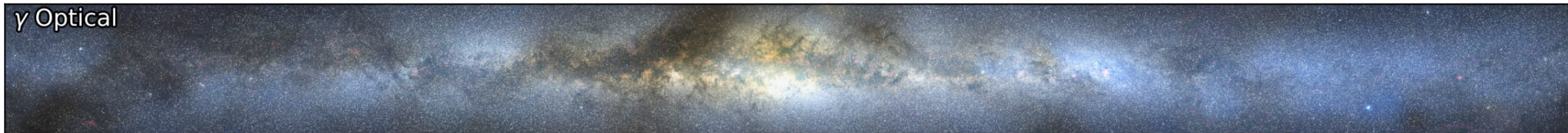
ACTIVE GALAXY NGC 1068
NEUTRINO EMISSION IDENTIFIED

.....●.....
2022



MILKY WAY
NEUTRINO EMISSION IDENTIFIED

.....●.....
2023



[Link to the Science paper](#)

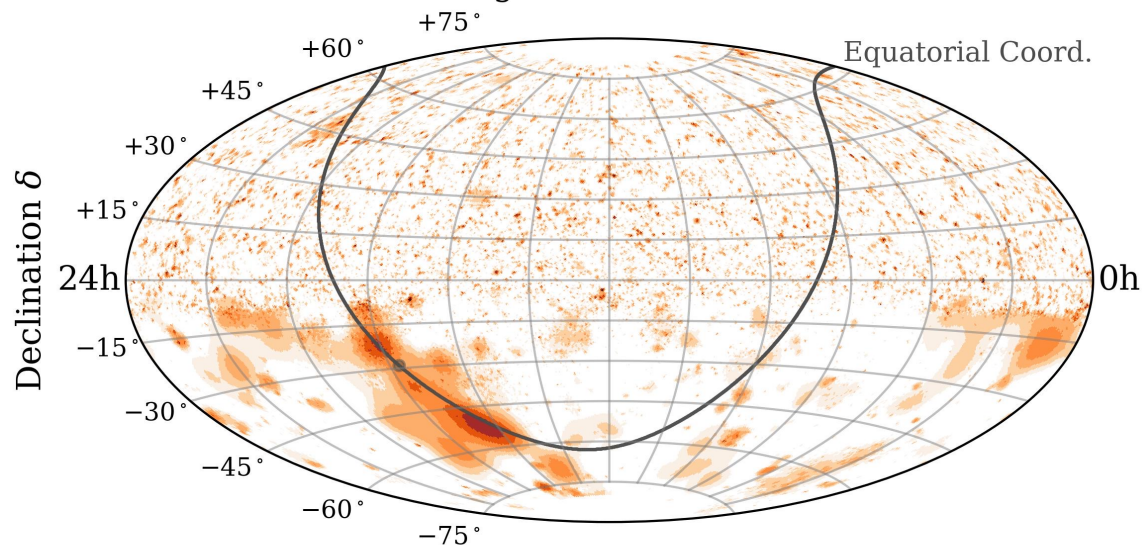
Science 2023: Galactic Plane in neutrinos at 4.5σ in cascades



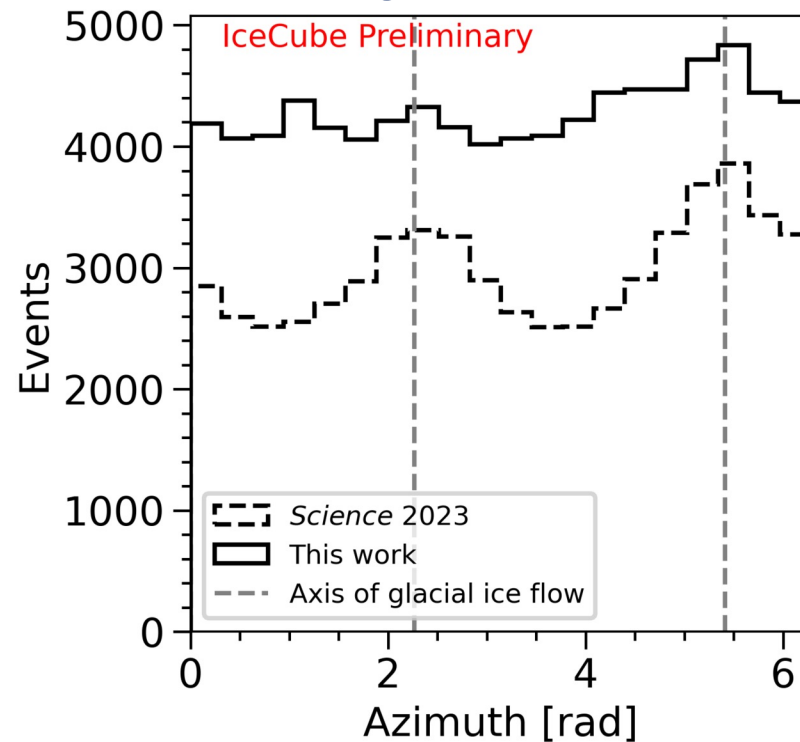
Now: More lifetime + tracks + improved modelling = improved significance 5.7σ



Right Ascension α



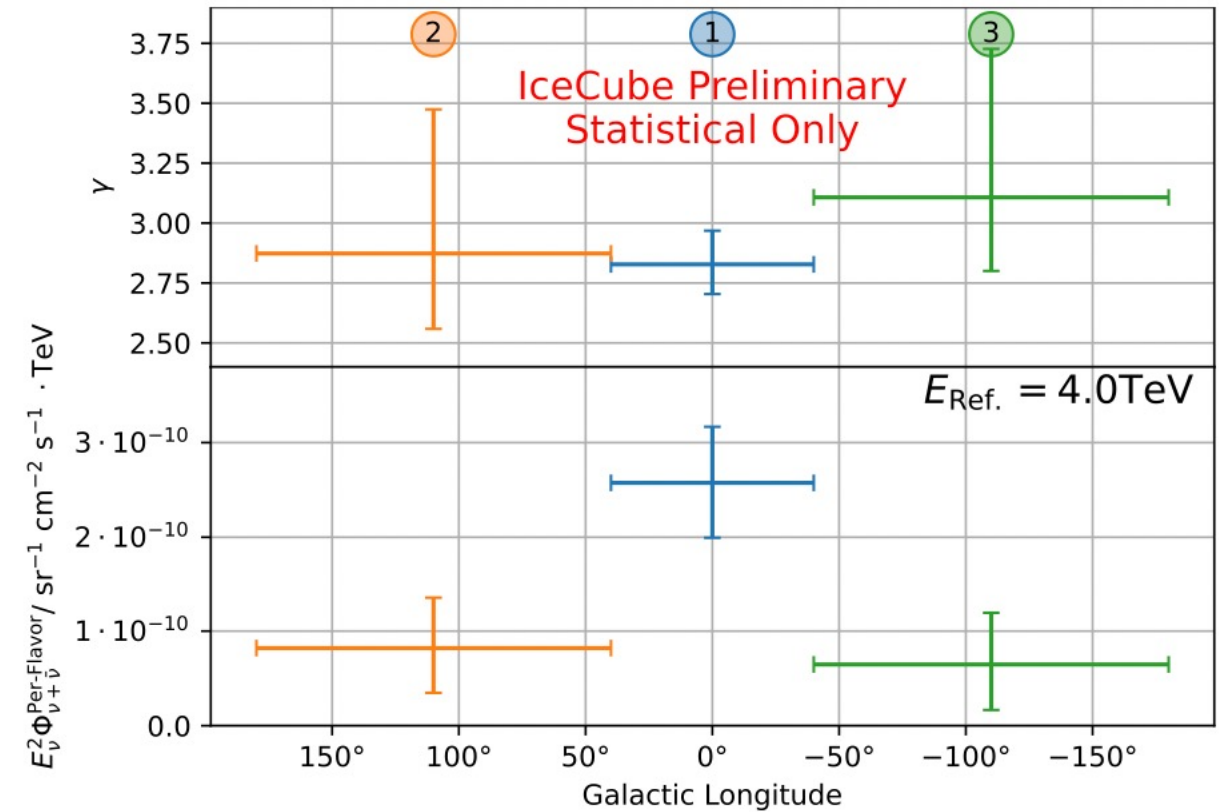
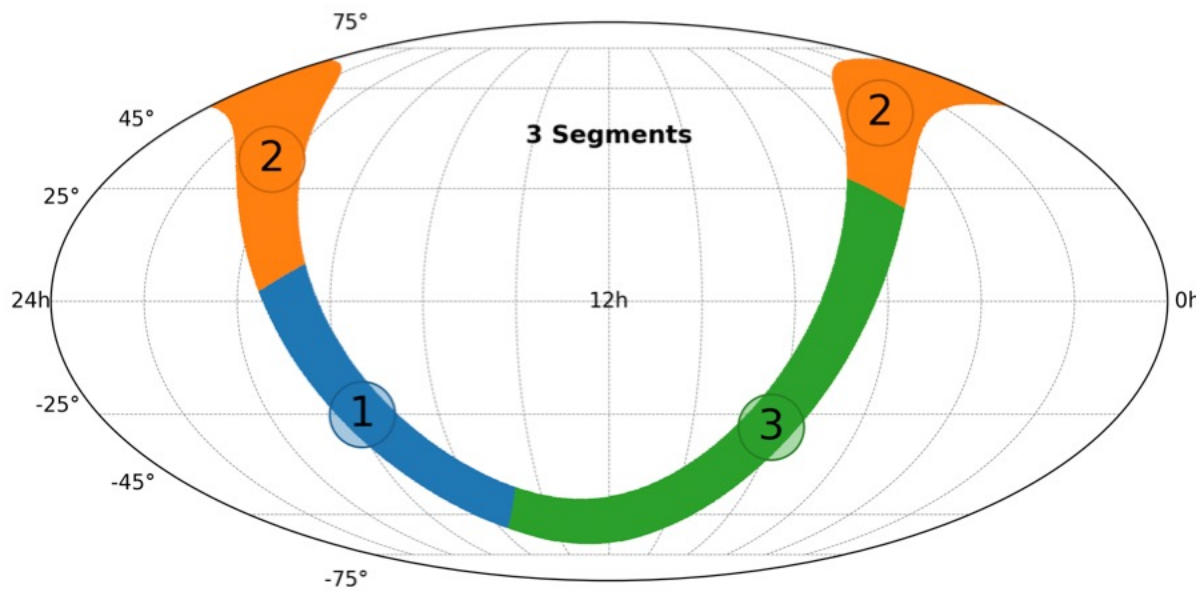
See slides at [TeVPA 2025](#),
previous version of data sample at [IceCube 2025](#)



See [PoS-ICRC2025-1193](#), slides at [TeVPA](#)

Towards more detailed studies: galactic plane characterization in regions

[PoS-ICRC2025-1130](#)



A selection of IceCube highlights



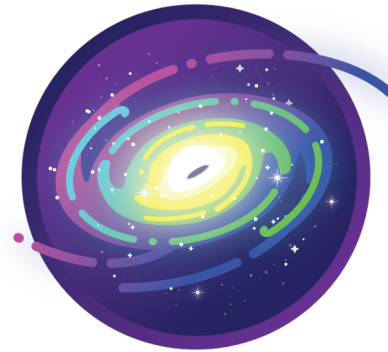
**ASTROPHYSICAL NEUTRINOS
DISCOVERED**

.....●.....
2013



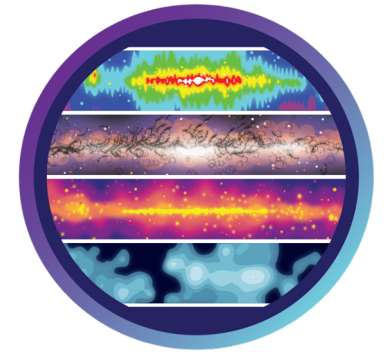
**BLAZAR TXS 0506+056
NEUTRINO EMISSION IDENTIFIED**

.....●.....
2018



**ACTIVE GALAXY NGC 1068
NEUTRINO EMISSION IDENTIFIED**

.....●.....
2022

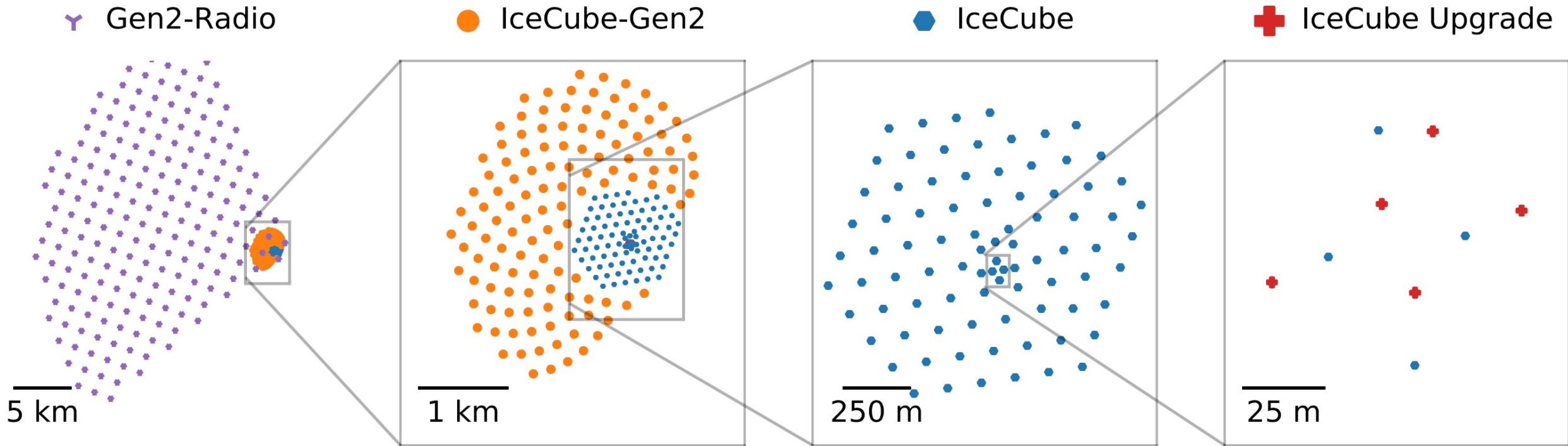


**MILKY WAY
NEUTRINO EMISSION IDENTIFIED**

.....●.....
2023

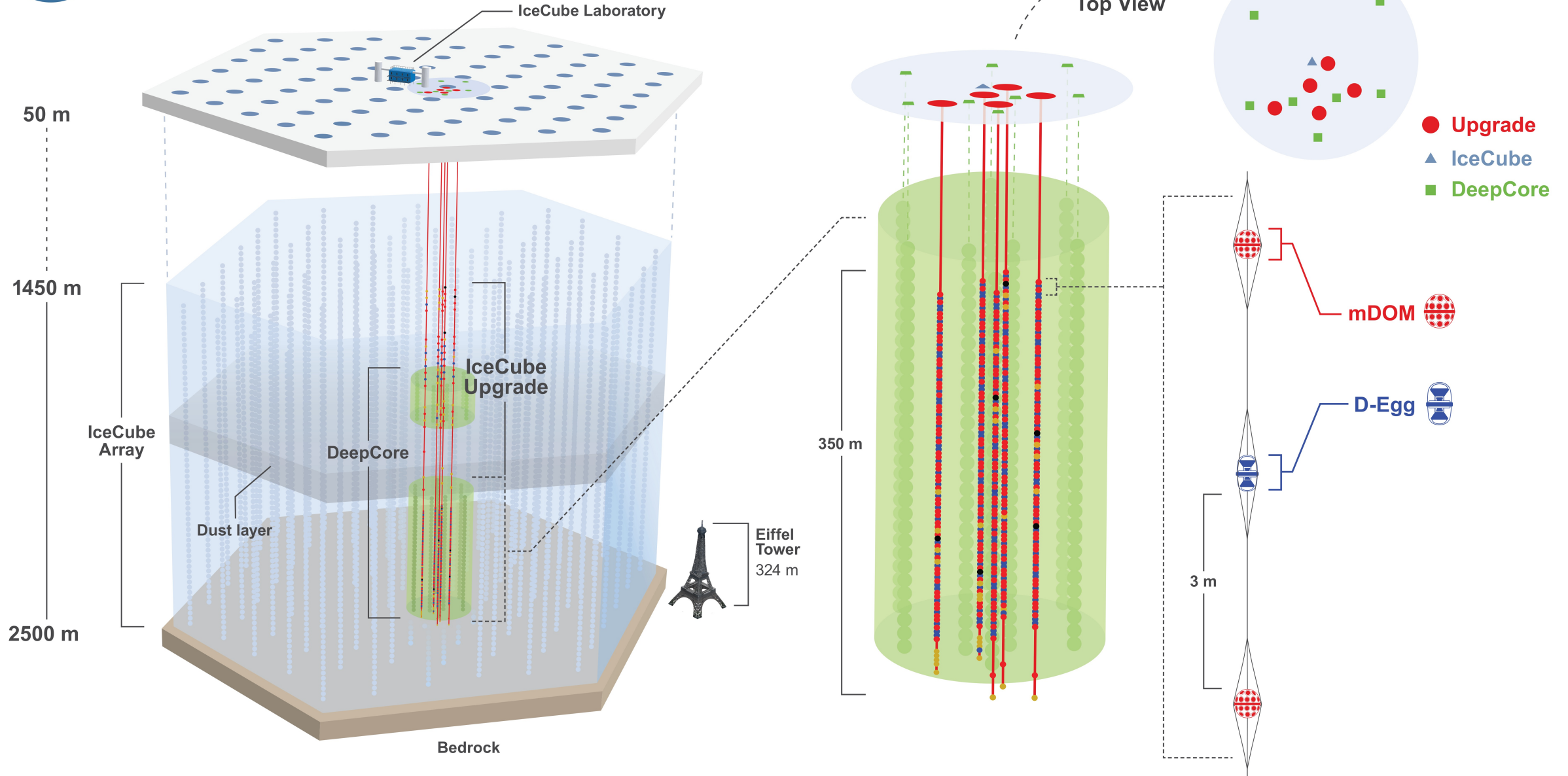
What's next?

IceCube, Upgrade, and IceCube-Gen2



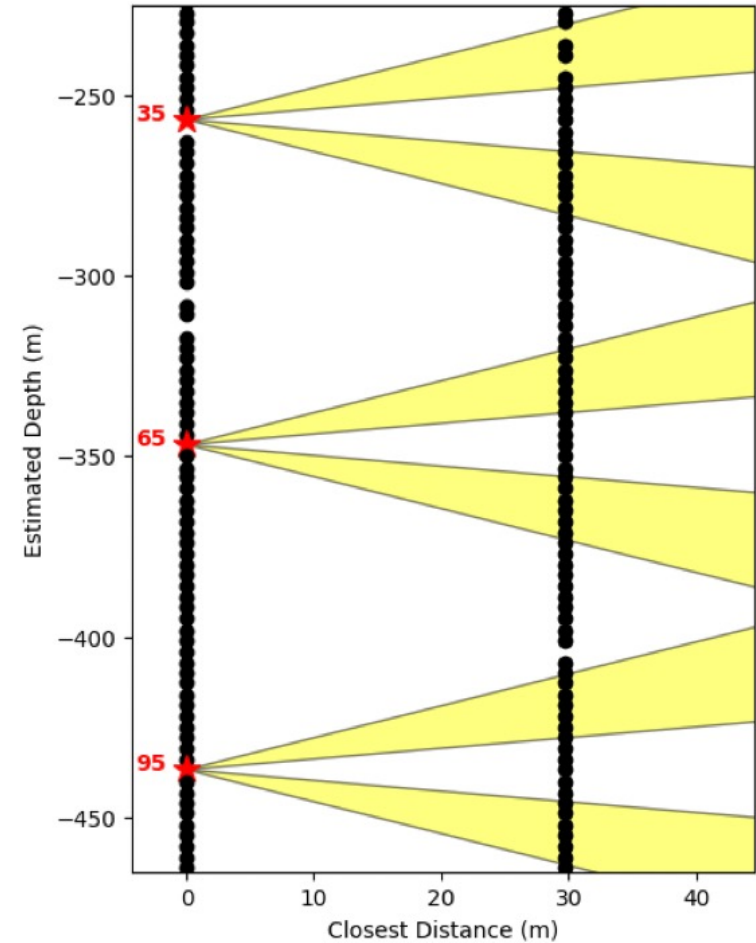
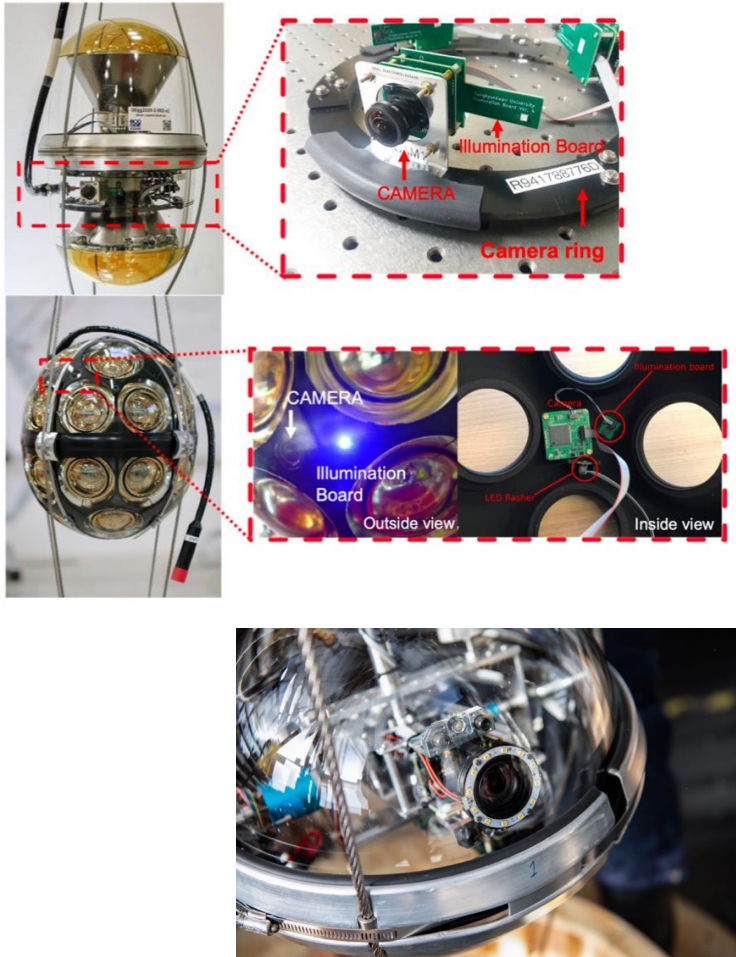
**Operating for
15 years**

New this year!

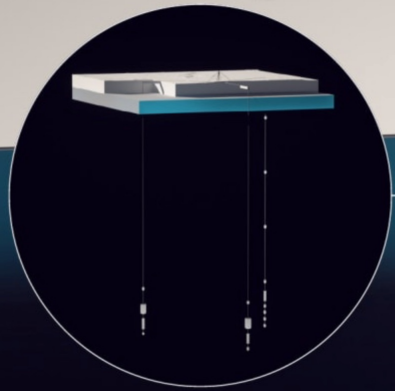




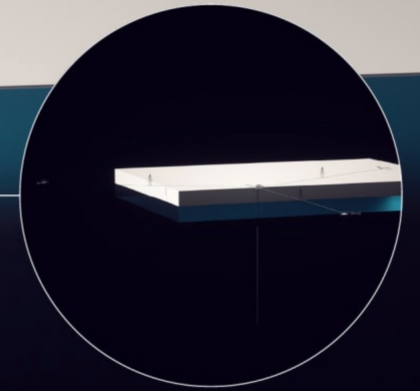
Ice Properties and photon propagation: dominant uncertainty in neutrino directional reconstruction



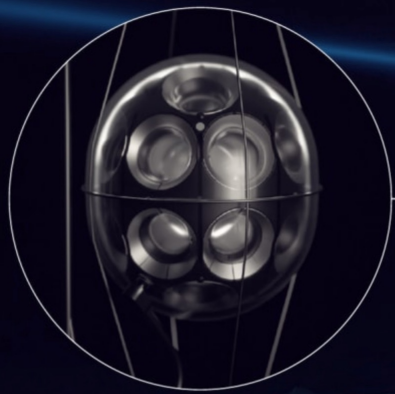
The next step: IceCube-Gen2



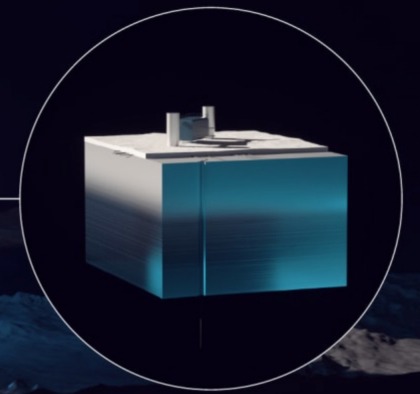
Radio Array | Station



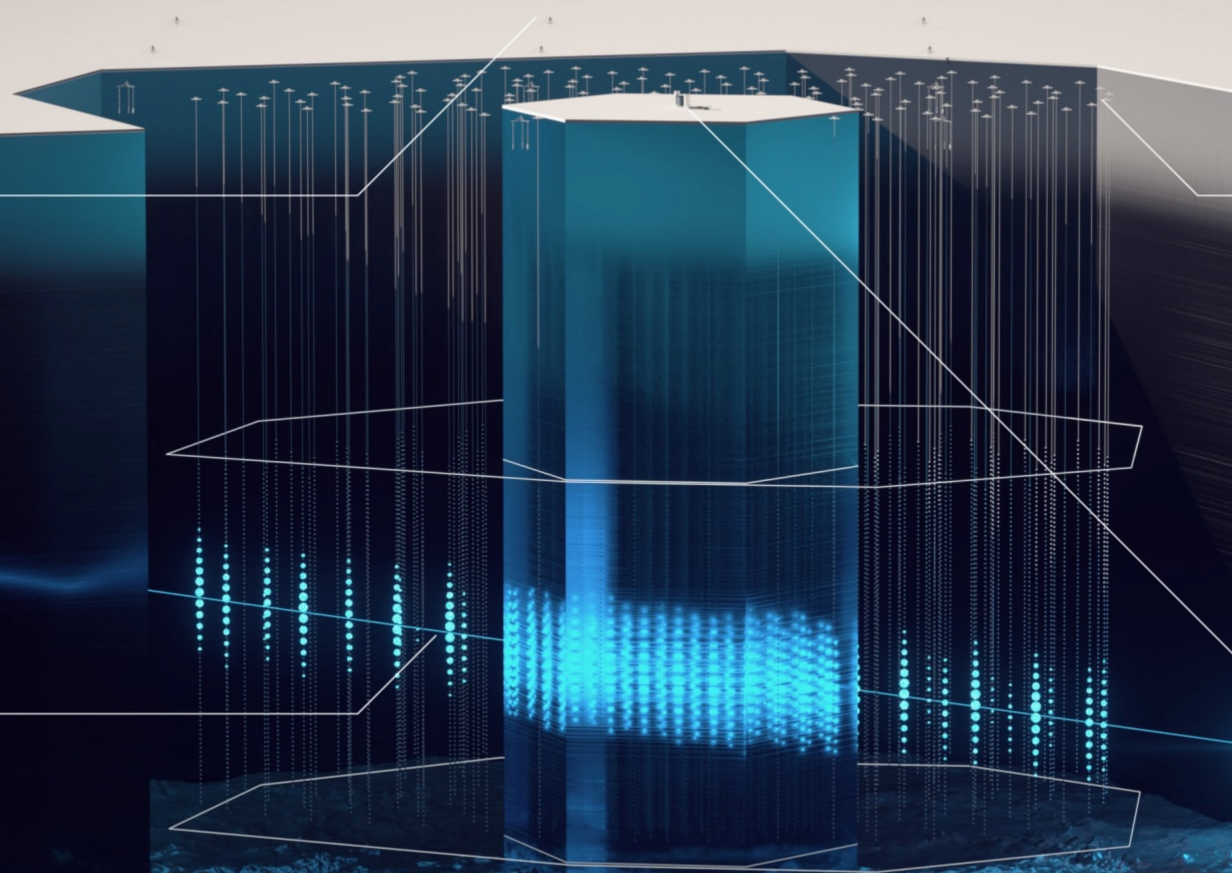
Surface Array | Station



Optical Array | Sensor



IceCube | Laboratory



Hightlights from the IceCube Neutrino Observatory

- We are building on our highlight results and getting an ever clearer picture of the neutrino universe
- Galactic plane: from original observation → greater than 5σ observation → beginings of detailed studies
- The upgrade has been successfully installed and gives new opportunities for recalibrating the detector
- Data products for the community: real time alerts, IceCat, IceTracks-DR2 14 years

Each year, IceCube records approximately:

100 000 000 000 events (about 3000 events per second)

Almost all of these are muons from cosmic rays hitting the atmosphere above the detector

-> Atmospheric muons

100 000 neutrino events (about 300 per day)

Almost all of these are ν 's from cosmic rays hitting the atmosphere

-> Atmospheric neutrinos

100s of astrophysical neutrinos (1 per day)

How to find astro. neutrinos (signal) in a background event rate 10^9 times higher?

		R.A.	Dec.	\hat{n}_s	$\hat{\gamma}$	$-\log_{10} p_{\text{local}}$	$-\log_{10} p_{\text{global}}$
Northern Sky Survey	Hottest Spot	40.69	0.02	102.6	3.4	6.6 (5.0 σ)	1.1 (1.4 σ)
110 gamma-ray sources							
Most significant source	NGC 1068	40.67	-0.01	102.2	3.4	6.6 (5.0 σ)	4.5 (4.0 σ)
Binomial test	3 Sources					4.8 (4.2 σ)	2.9 (3.0 σ)
Other sources in binomial excess	PKS 1424+240	216.76	23.80	96.3	3.6	4.1 (3.8 σ)	—
	TXS 0506+056	77.36	5.69	4.9	1.9	3.4 (3.3 σ)	—
47 X-ray bright AGN							
Most significant source	NGC 7469	345.82	8.87	5.5	1.9	4.1 (3.8 σ)	2.1 (2.4 σ)
Binomial test	11 Sources					4.8 (4.2 σ)	3.3 (3.3 σ)
Other sources in binomial excess	NGC 4151	182.64	39.41	27.6	2.7	2.9 (3.1 σ)	—
	CGCG 420-015	73.36	4.06	35.3	2.7	2.4 (2.7 σ)	—
	Cygnus A	299.87	40.73	3.4	1.6	2.2 (2.5 σ)	—
	LEDA 166445	42.68	54.70	57.1	4.4	1.8 (2.1 σ)	—
	NGC 4992	197.27	11.63	27.3	2.9	1.6 (2.0 σ)	—
	NGC 1194	45.95	-1.10	43.2	4.4	1.5 (1.8 σ)	—
	Mrk 1498	247.02	51.78	39.9	3.6	1.4 (1.7 σ)	—
	MCG +4-48-2	307.15	25.73	36.7	3.2	1.4 (1.7 σ)	—
	NGC 3079	150.49	55.68	33.8	3.6	1.3 (1.7 σ)	—
Mrk 417	162.38	22.96	4.4	2.0	1.3 (1.6 σ)	—	

Real time alerts of high energy events started in 2016

Tracks: ~10 alerts/year in the
gold channel (half from
background)

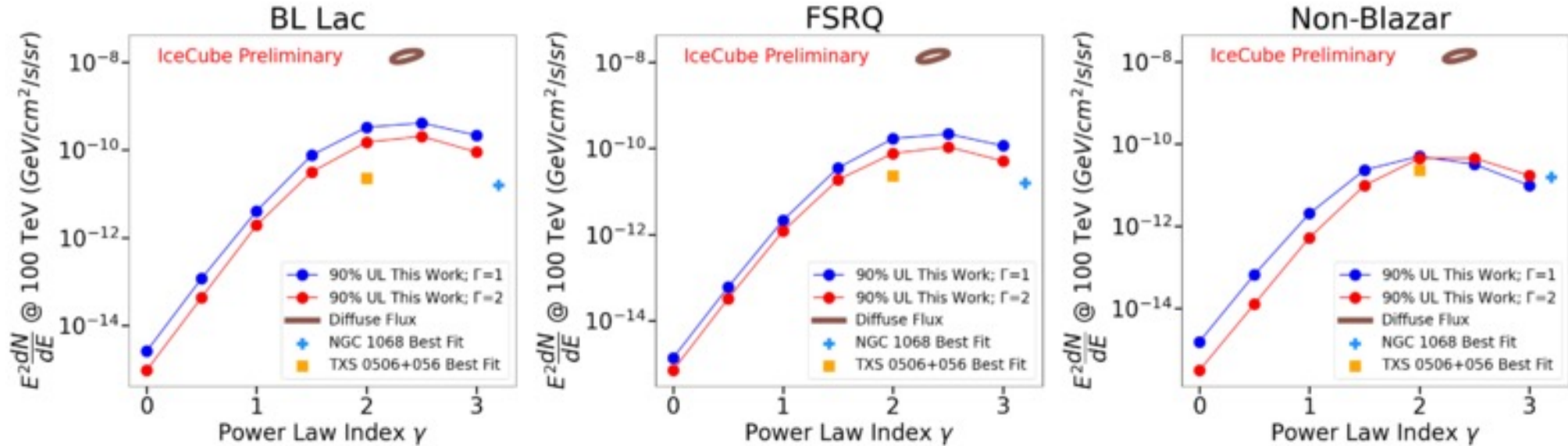
Cascades: ~8 alerts/year in the
gold channel (half from
background)

Typical latency of < 1 minute

[IceCat-1 catalog](#)

```
"$schema":  
"https://gcn.nasa.gov/schema/main/gcn/notices/icecube/single_neutrino_alerts.  
schema.json",  
"mission": "IceCube",  
"instrument": "IC86",  
"messenger": "Neutrino",  
"pipeline": "Bronze Track Alert",  
"record_number": 1,  
"event_name": ["IceCube-230416A"],  
"id": ["137840_57034692"],  
"alert_datetime": "2023-04-16T05:42:00.0Z",  
"alert_type": "initial",  
"alert_tense": "current",  
"alert_topology": "Track",  
"number_of_events": 1,  
"ra": 345.82,  
"dec": 9.01,  
"ra_dec_error": 0.5,  
"containment_probability": 0.9,  
"systematic_included": false,  
"healpix_url":  
"https://roc.icecube.wisc.edu/public/alerts/example/run00140078.evt000030891  
383.example.skymap_nside_1024_probability.fits.gz",  
"trigger_time": "2023-04-16T05:22:26.150574Z",  
"nu_energy": 127.29,  
"p_astro": 0.34064,  
"far": 8.029e-8
```

Further studies on gamma-bright AGN

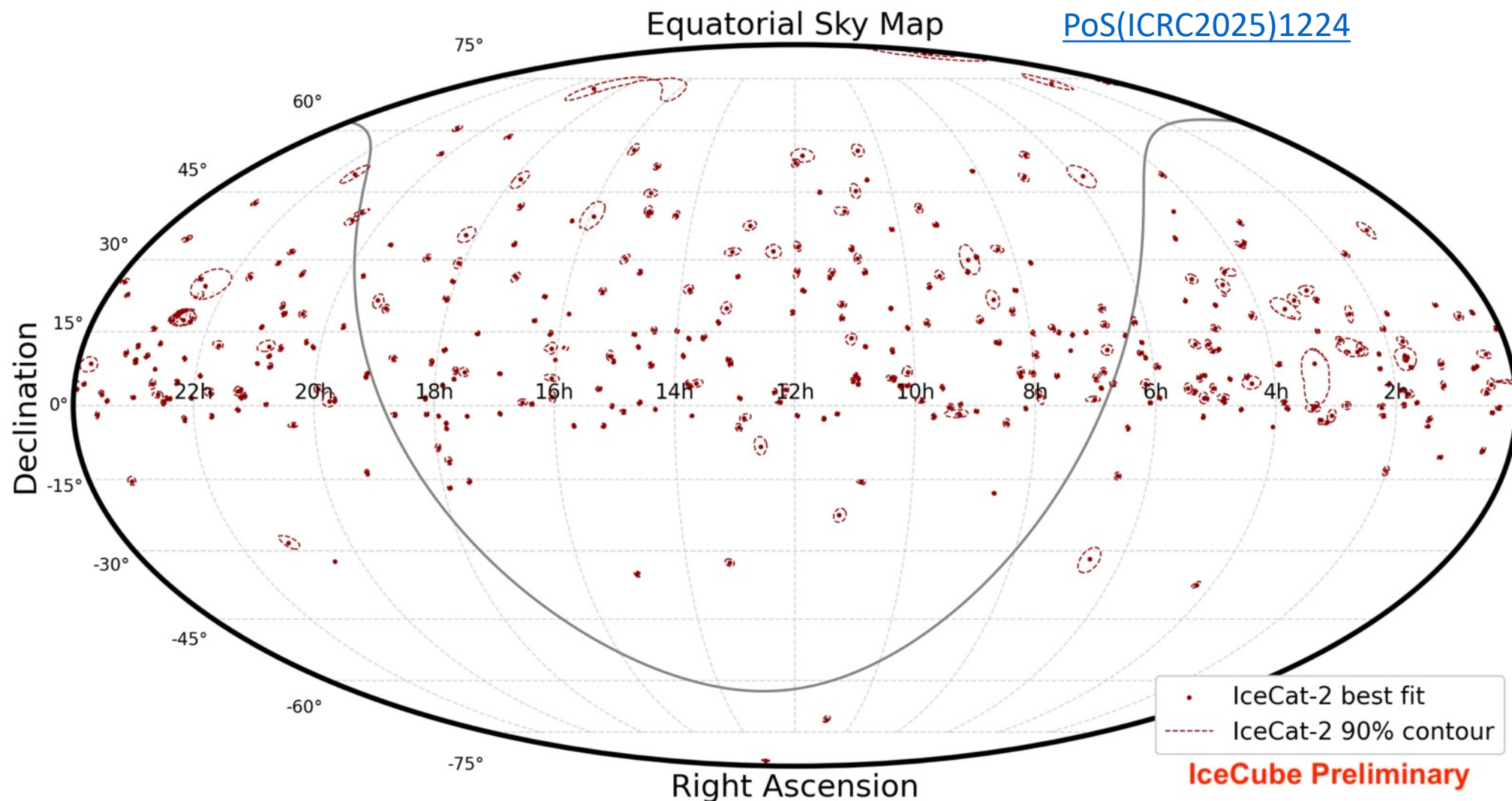


[PoS\(ICRC2025\)933](#)

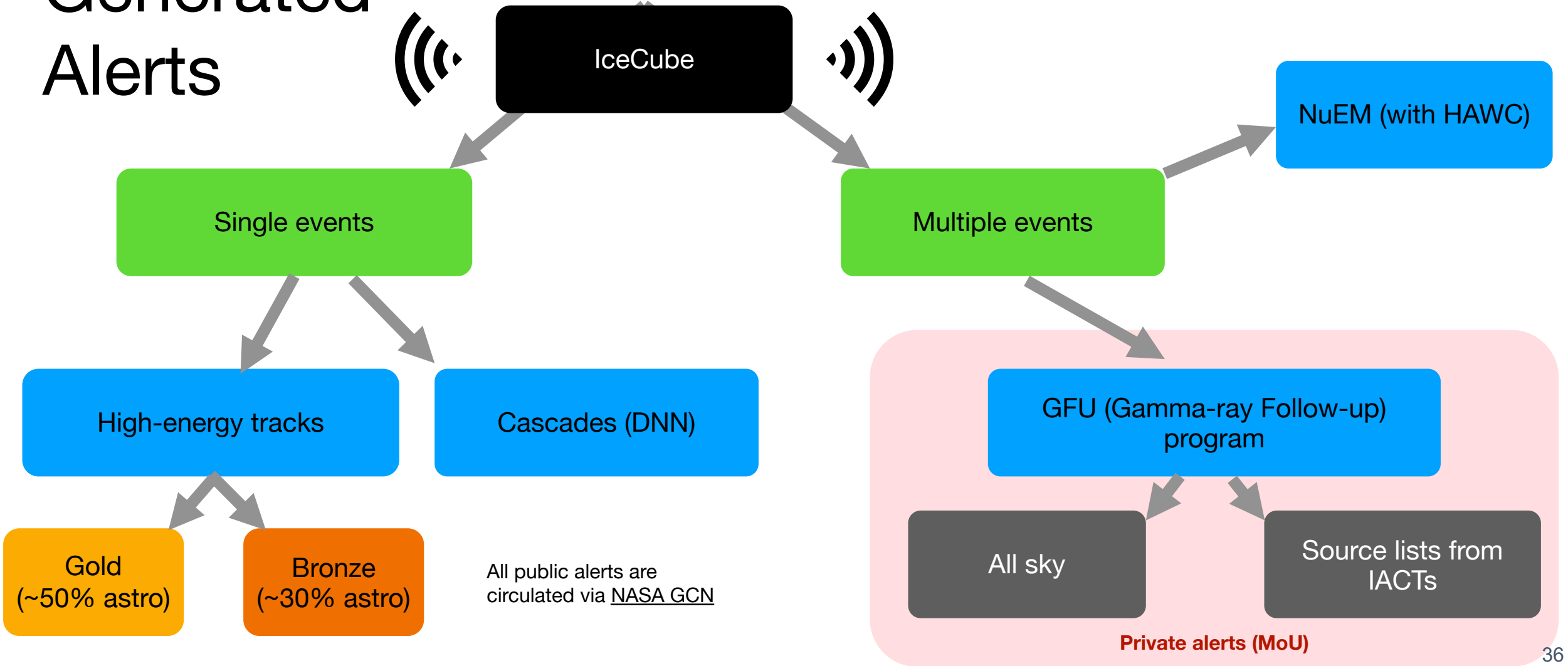
Stacked limits on gamma-ray bright AGN constrain to less than 1% of the diffuse flux

Binomial test, model-independent test for a sub-population: significance $< 3 \sigma$

Real-time alerts to improve chances of multi-messenger observations



IceCube Generated Alerts



IceCube responses to external triggers

