IceCube: Exploring the Universe with neutrinos

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Partikeldagarna 2017

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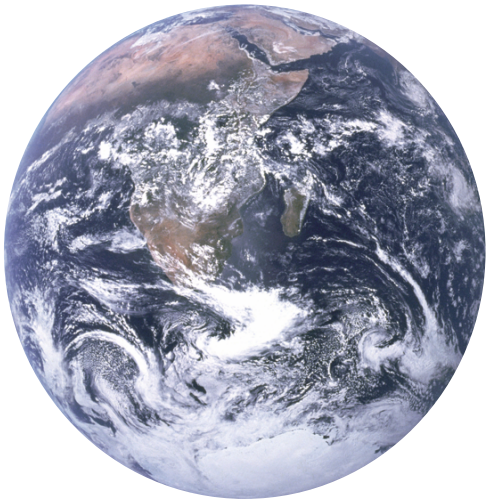
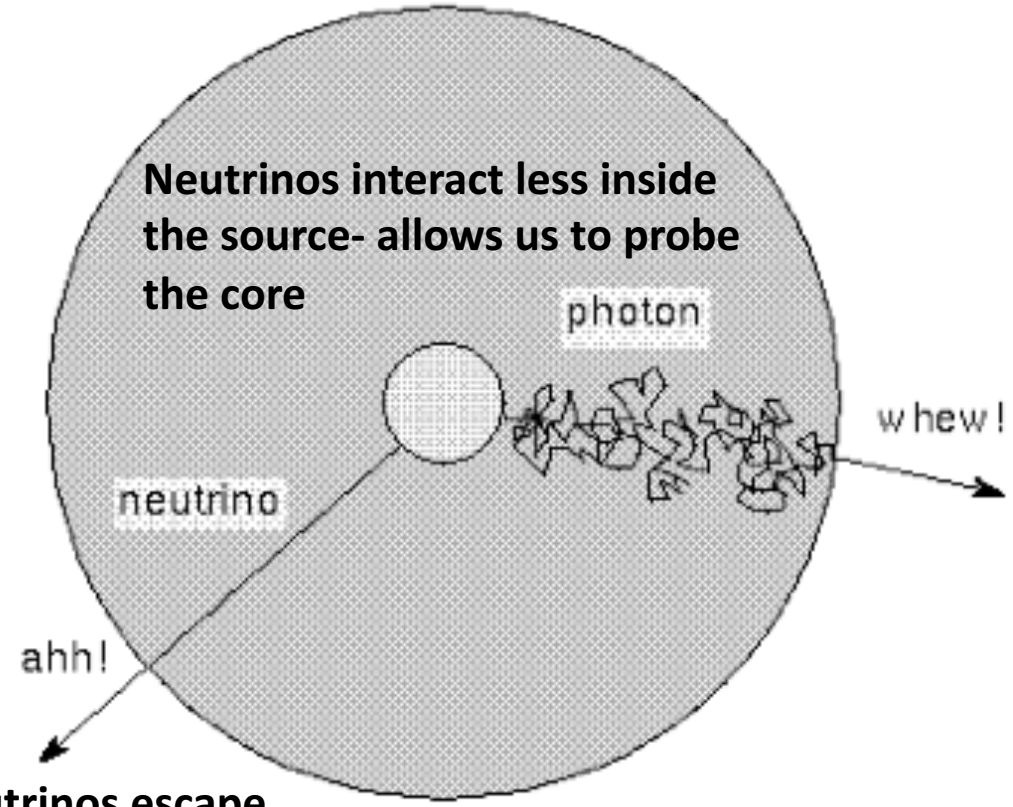
Why do astronomy with neutrinos?

Neutrinos do not interact between source and detector – clean signature



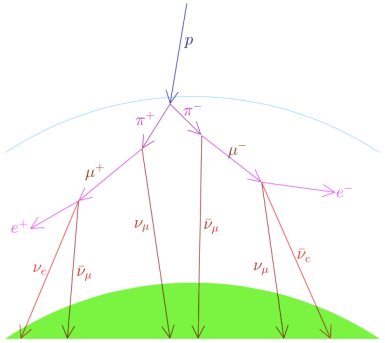


Neutrinos escape before photons – can provide early warning!

Astrophysical systems also give us extreme environments to test particle physics in a way we can't do on Earth

Supernova neutrinos (might) test:

- **mass hierarchy**
- **collective neutrino oscillations**
- **neutrino oscillations under turbulent conditions**



Atmospheric neutrinos: span orders of magnitude in energy and have many pathlengths – good for **measurement of oscillation parameters**

High energy neutrinos probe the **presence of hadronic interactions** in astrophysical phenomena

IceCube research in Sweden

Stockholm University

Klas Hultqvist
Chad Finley
Christian Walck
Christian Bohm
Erin O'Sullivan
Maryon Ahrens
Kunal Deoskar

Uppsala University

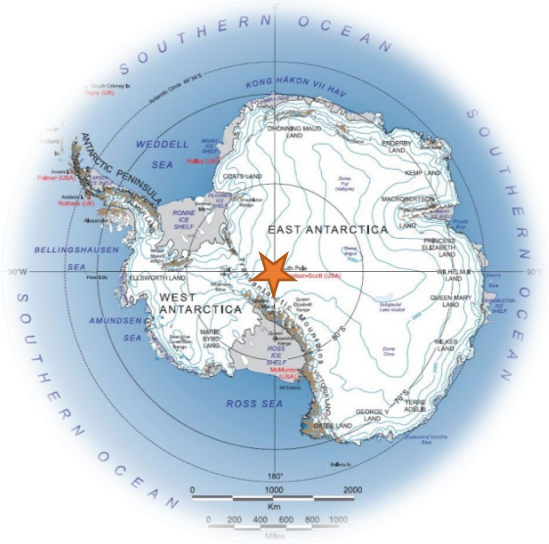
Olga Botner
Allan Hallgren
Carlos de los Heros
Lisa Unger
Alexander Burgman

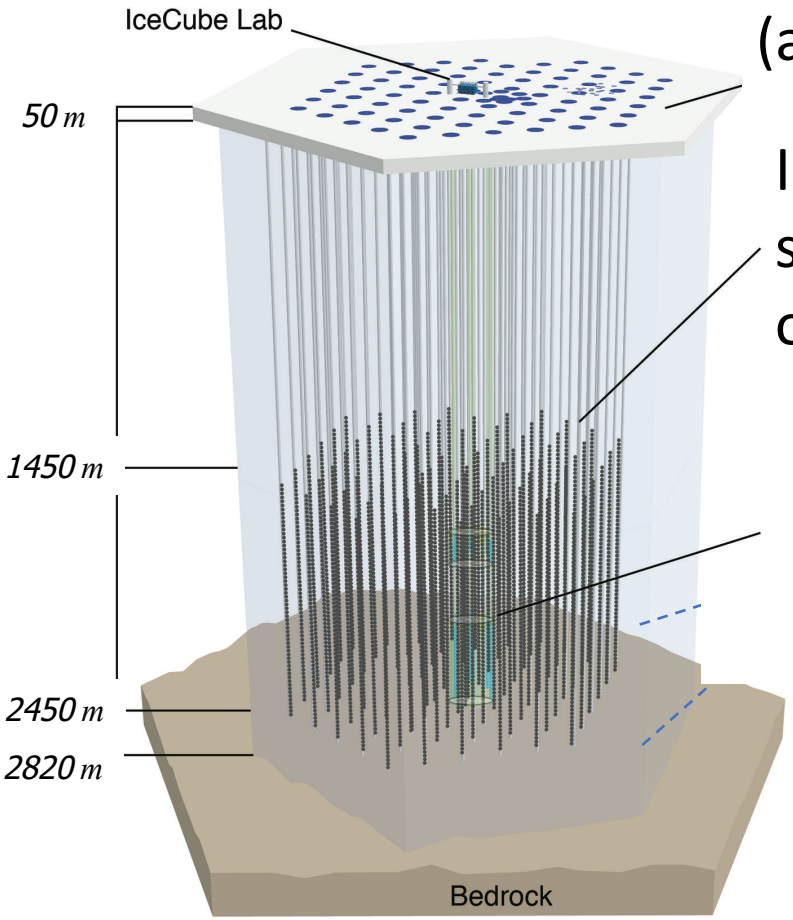
IceCube collaboration

300 physicists from 47 institutes
Sweden is 4th largest group

IceCube

completed 2011

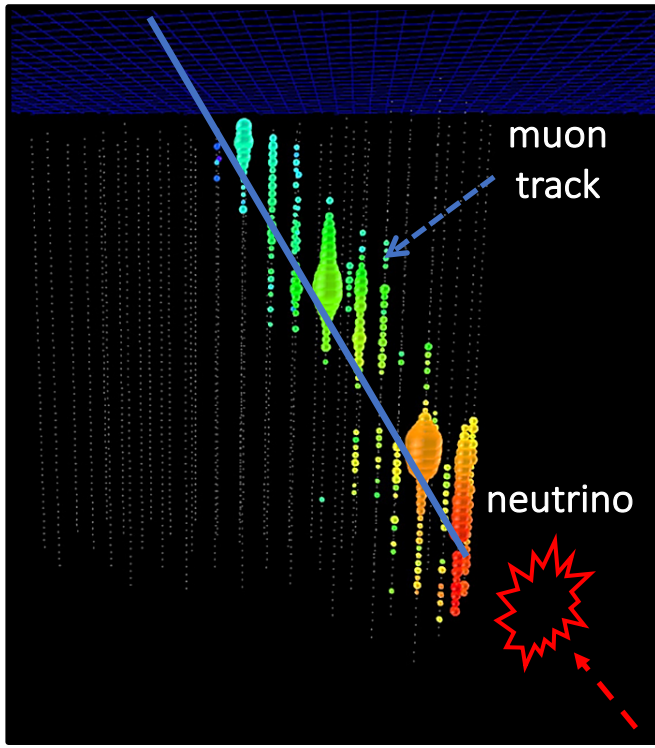


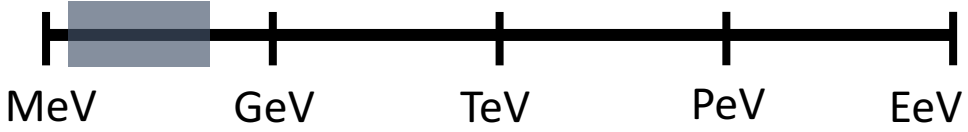


IceTop surface array (acts as veto - 1 km^2)

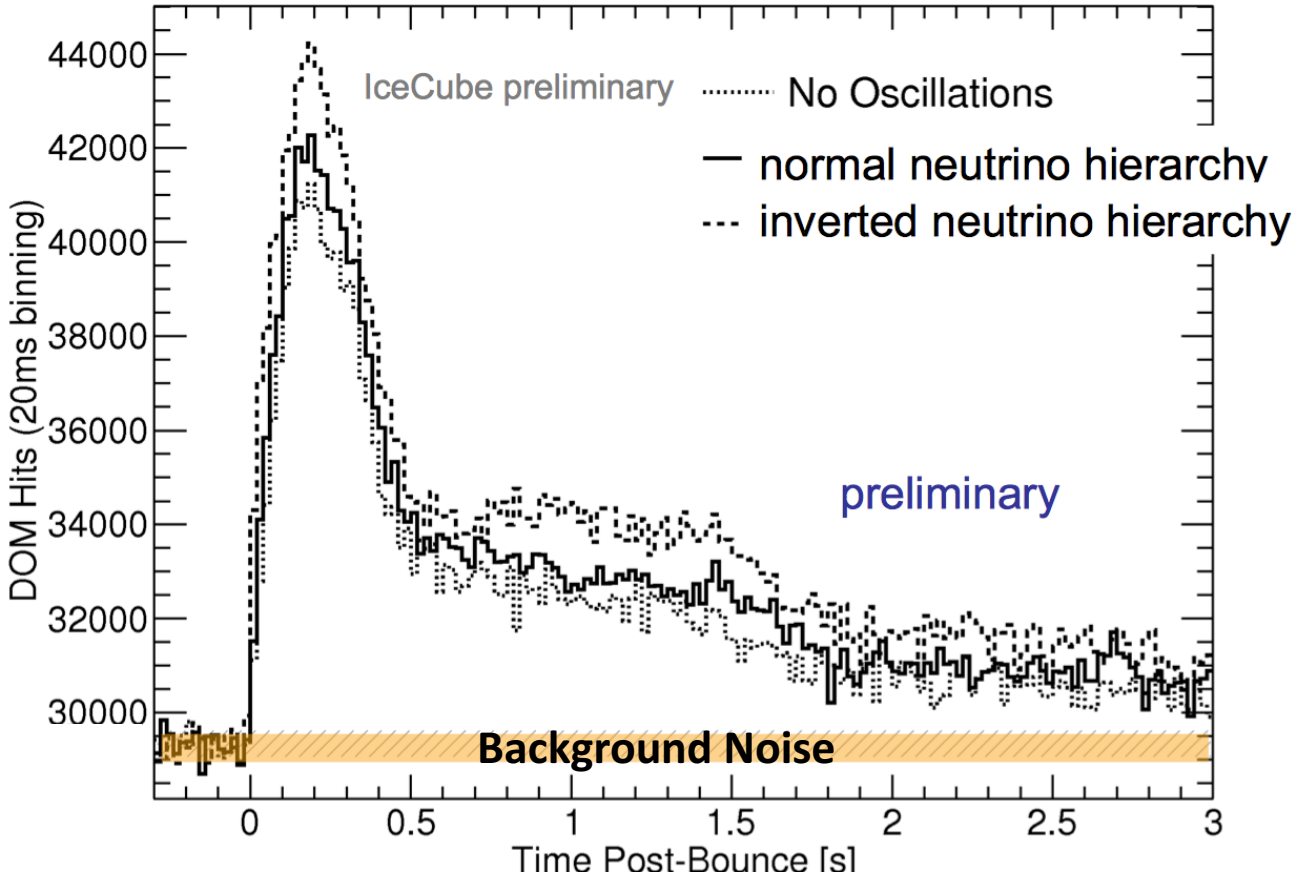
IceCube array – 86 strings with 5160 optical modules

DeepCore
- 8 infill strings for lower energy



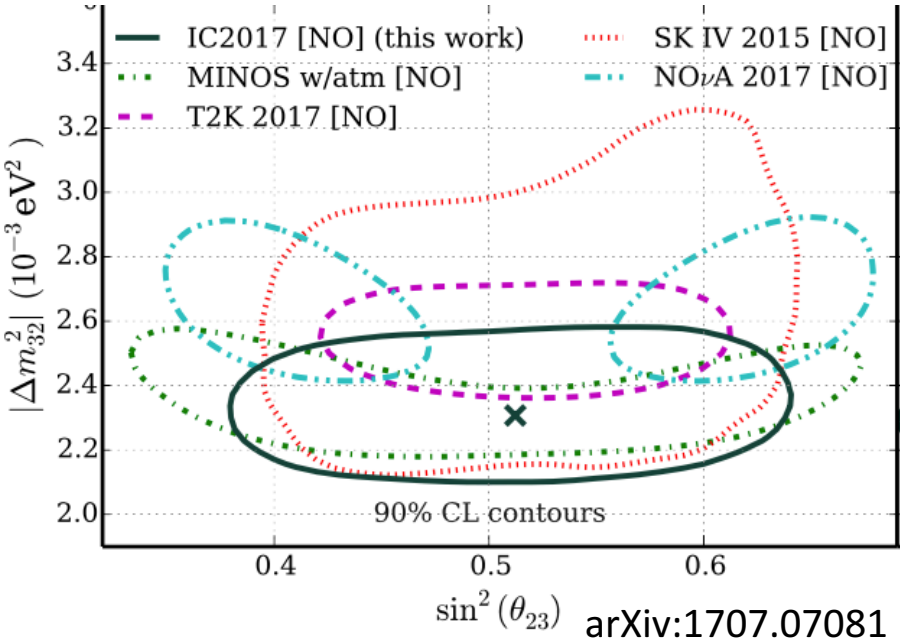


MeV scale: Supernova neutrinos



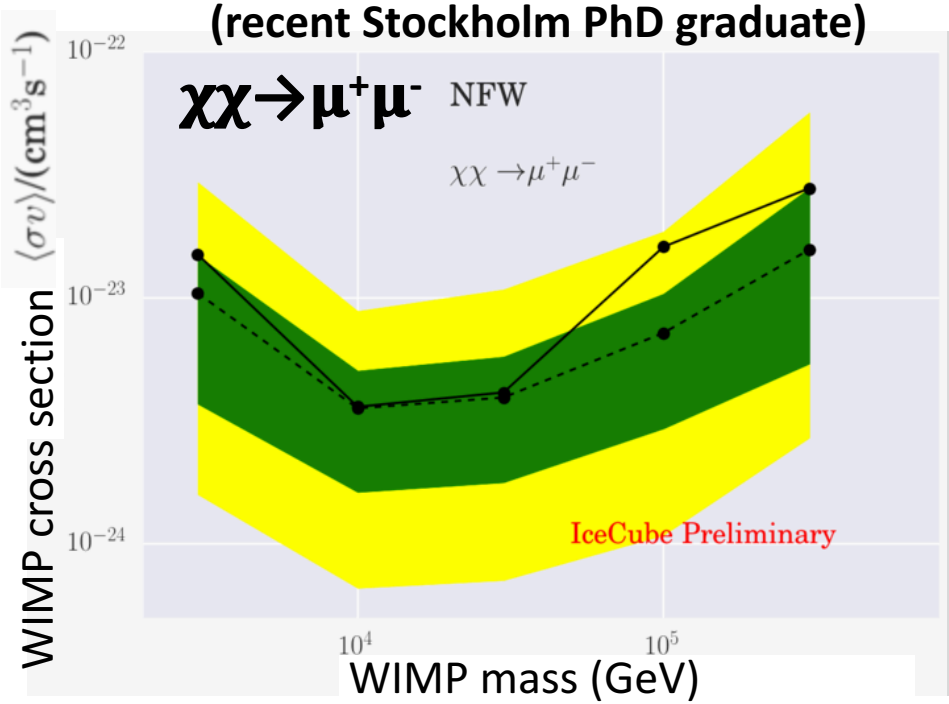
IceCube will be the best measurement of the early timing structure of a nearby supernova neutrino burst

GeV scale: Atmospheric neutrinos and dark matter



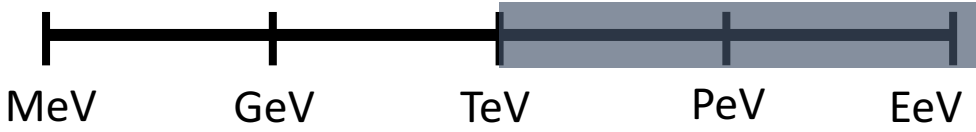
arXiv:1707.07081

Galactic halo search from Samual Flis (recent Stockholm PhD graduate)

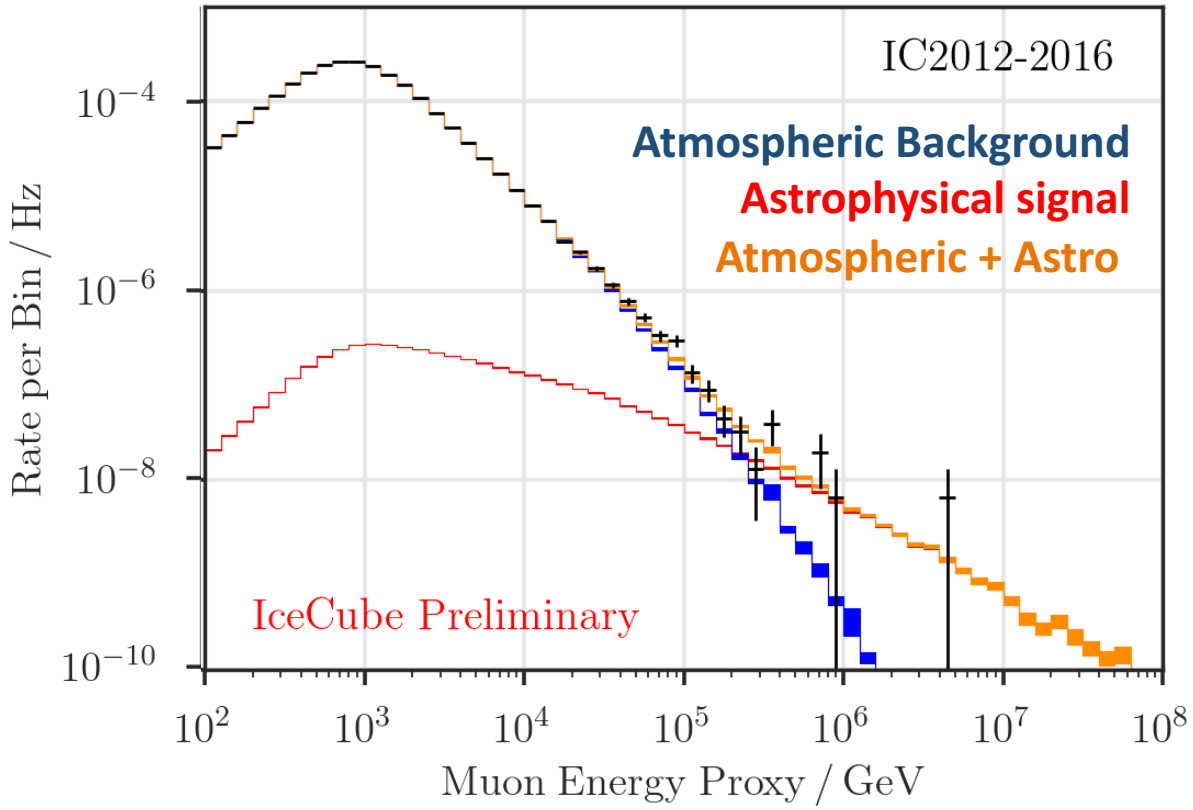


Atmospheric neutrinos: Many pathlengths and energies allow for precision measurements of oscillation parameters

Dark matter: Search for dark matter annihilating to products that create neutrinos. Look for signal from the **Sun, galactic center, Earth center**, etc



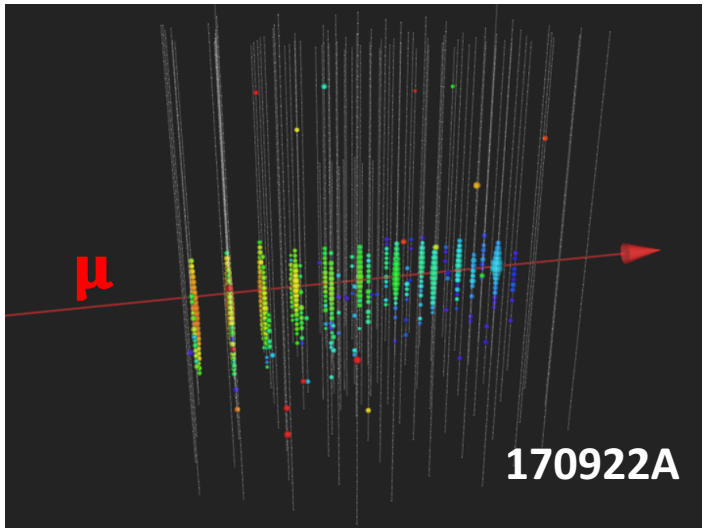
TeV and beyond: High energy astrophysics

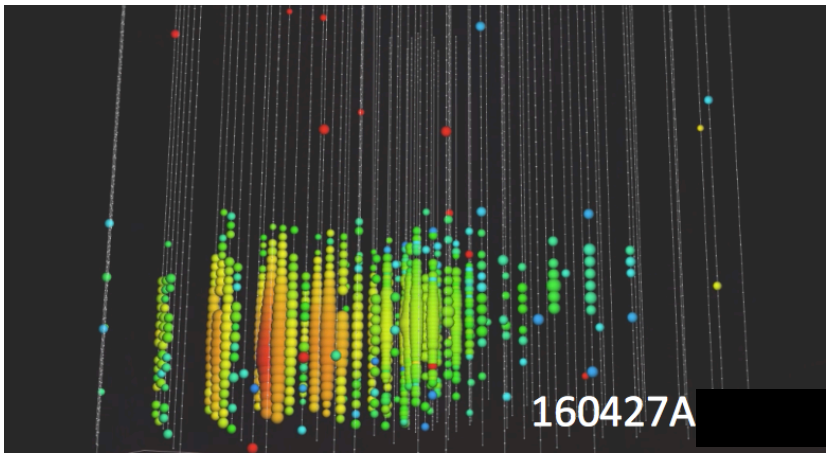


Excess of events over expectation from atmospheric background. Energy shape is also different than background!

Public real-time alerts sent via GCN

Highest energy events
Expect ~10 alerts/year (half from background)
Typical latency of < 1 minute



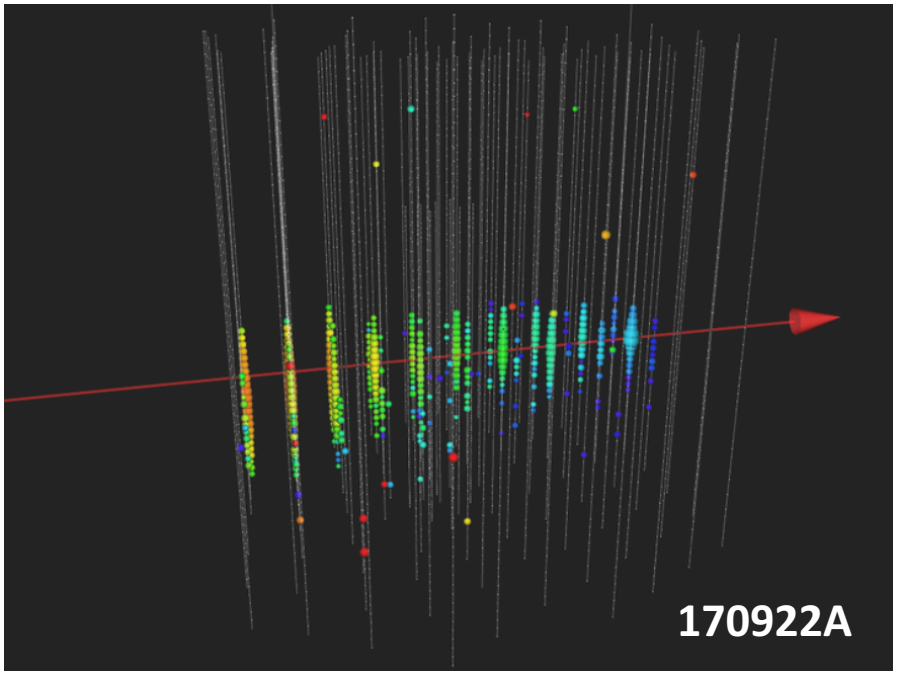


Alerts also sent, for example to supernova early warning system (SNEWS), and multiplet alerts sent privately to partners for optical and gamma follow-up

GCN webpage: https://gcn.gsfc.nasa.gov

IceCube highlights: IC170922

Event details



Time: September 22, 20:54:30.43 UTC

Direction:
RA=77.43^{o},Dec=5.72^{o}
Error: ~1^{o}

Neutrino energy: Greater than 100 TeV

IceCube alert sent out 43 seconds after event.

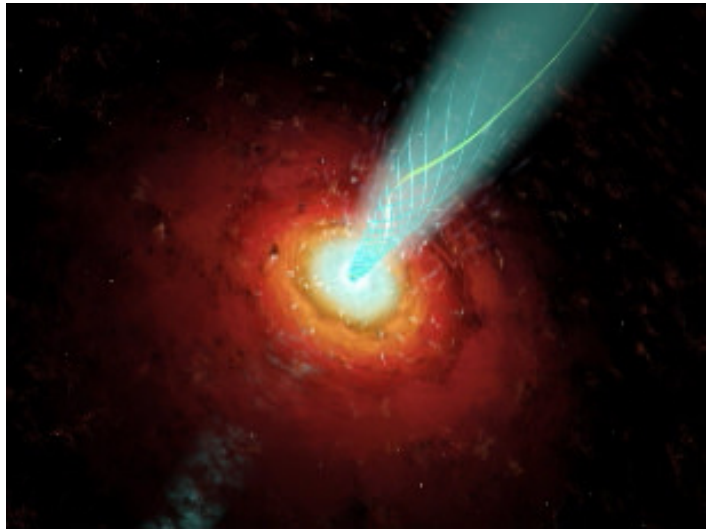
IceCube highlights: IC170922

Follow-up observations made by space and ground-based telescopes Swift, VERITAS, HAWC, Integral, ASAS-SN, HESS, others


Fermi telescope

Fermi finds blazar TXS 0506+056, 0.08^{o} from best fit neutrino direction (Atel 10791) that was in a recent, flaring state.

Blazar: supermassive black hole with an accretion disk that has a jet along our line-of-sight

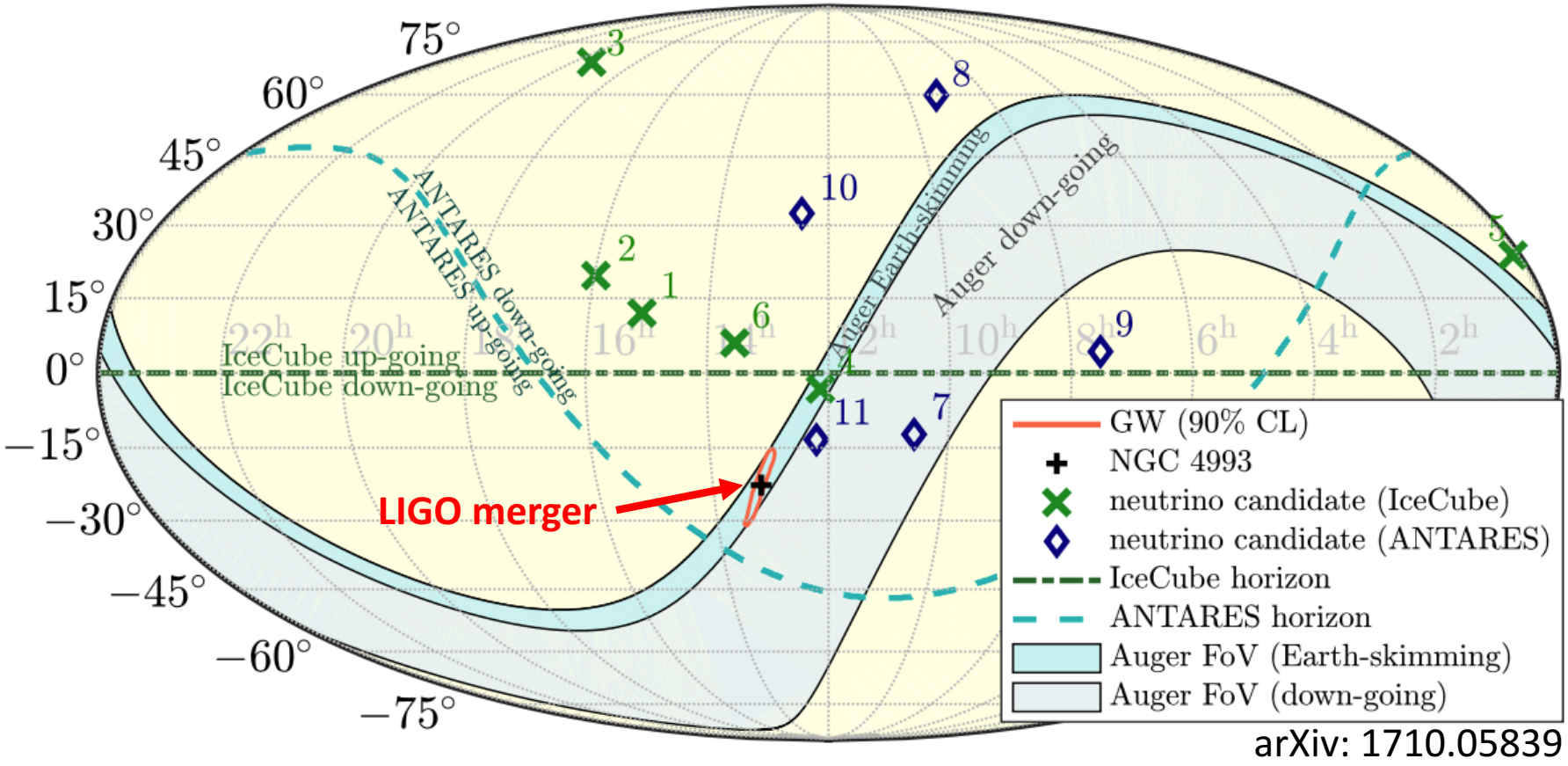


Magic detects gamma rays with energies above 100 GeV from TXS 0506+056.

Interpretation of this information is ongoing – stay tuned!

IceCube highlights: GW coincidence search

6 IceCube neutrinos detected ±500s from LIGO detection



arXiv: 1710.05839

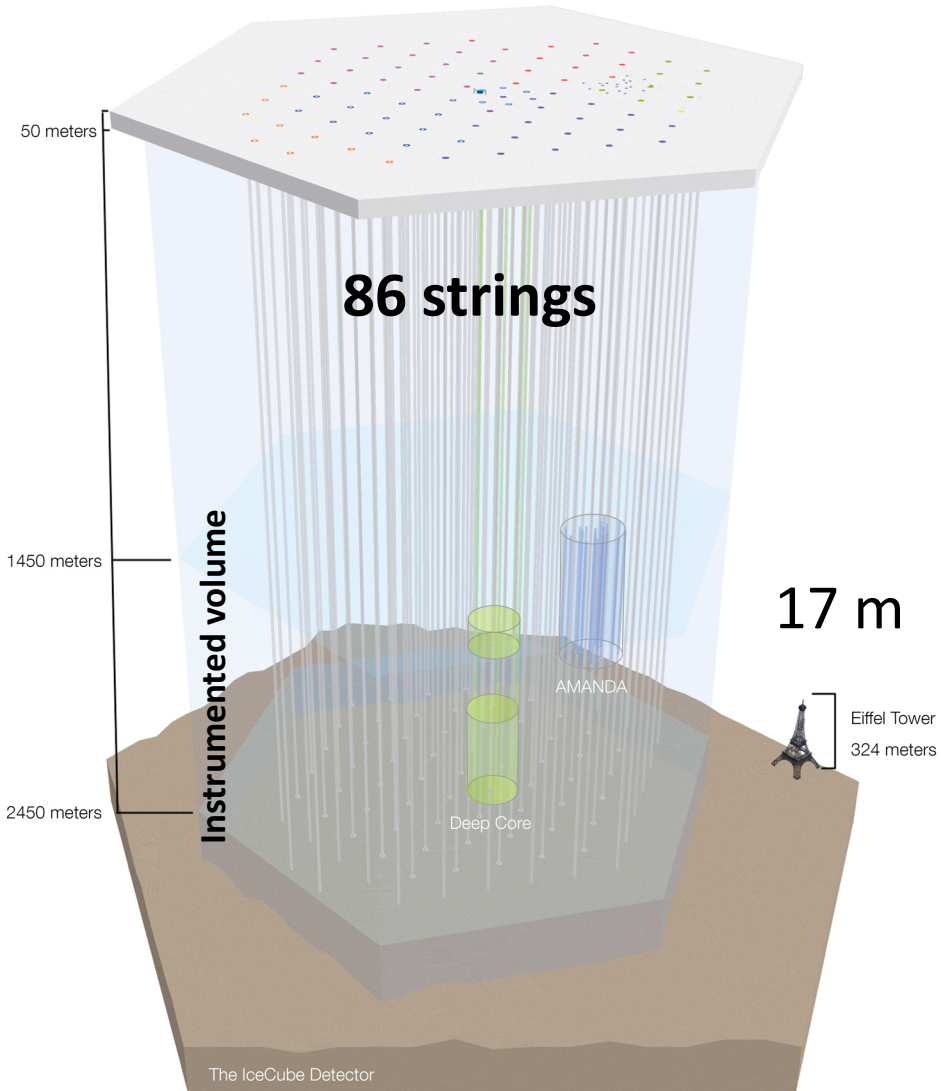
No neutrinos directionally coincident with the merger detected by LIGO…this time

What does the future hold for IceCube?

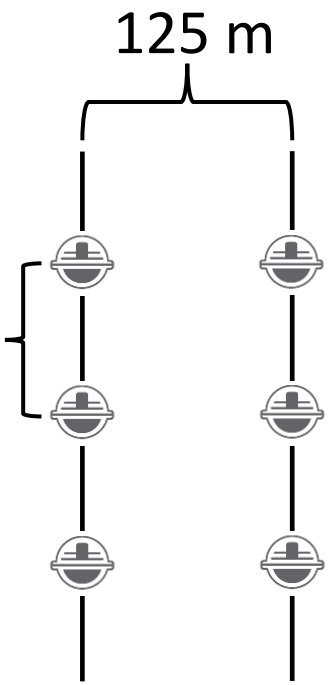
- **Characterizing the properties** of the astrophysical signal.
- **Searching for the source** of our astrophysical neutrinos.
  - Evidence for neutrino emission from blazars?
  - Looking for other sources – see Lisa's Fermi bubble talk this afternoon
- Making **more real-time alert** channels available.
- Testing **exotic physics** models– see Alexander's magnetic monopole talk this afternoon
- Working on **next generation** ideas – see Chad's talk on the IceCube upgrade and Allan's ARIANNA talk

The IceCube detector

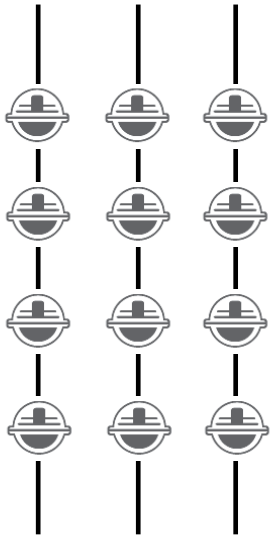
IceTop surface array (acts as veto - 1 km^2)



Most strings optimized for high energy neutrinos



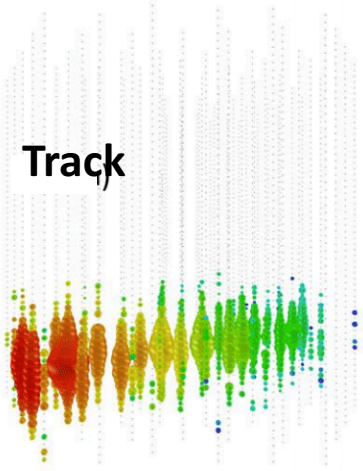
DeepCore: 8 infill strings that are more densely instrumented to lower the energy threshold to ~10 GeV



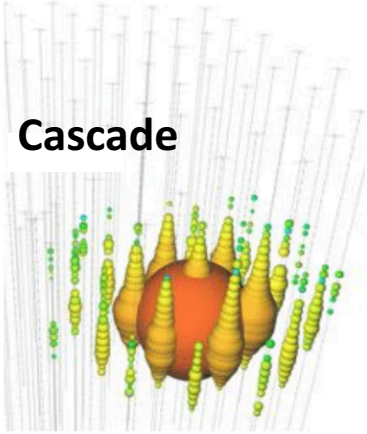
Neutrino interactions in IceCube

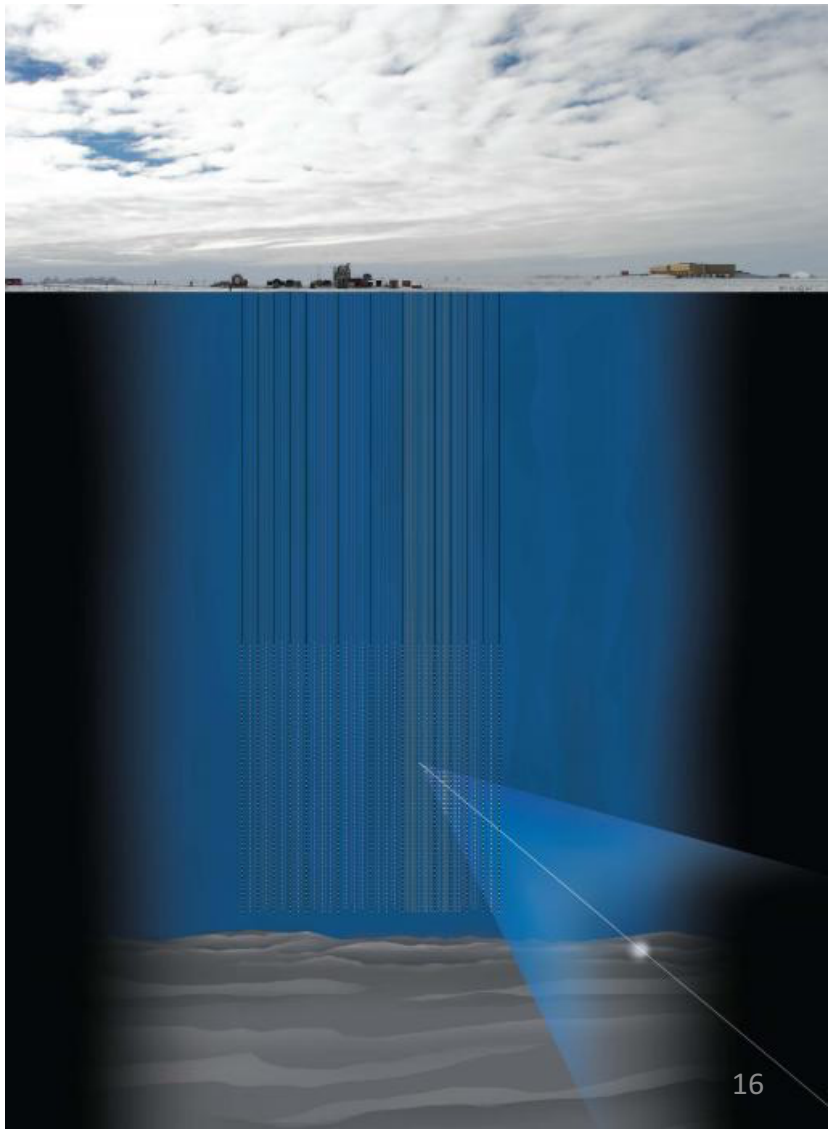
Two event topologies in IceCube

Charged-current ν_μ



Charged-current ν_e or neutral current





The IceCube collaboration

Founding institutes of Amanda (predecessor of IceCube)

- Stockholm
- Uppsala
- UW Madison
- UC Berkeley
- UC Irvine

Now, 300 scientists from 47 institutes

IceCube activities in Sweden

People by the numbers

2 institutions: Stockholm University and Uppsala University

7 faculty members
1 postdoc
4 PhD students

Main Activities

- Fermi Bubbles (Lisa Unger)
- Magnetic monopoles (Alexander Bergman)
- ARIANNA (Allan Hallgren)
- IceCube Upgrade (at Stockholm and Uppsala – talk by Chad Finley)
- Conveners for the point source and diffuse source working groups

See this afternoon's talks for details!

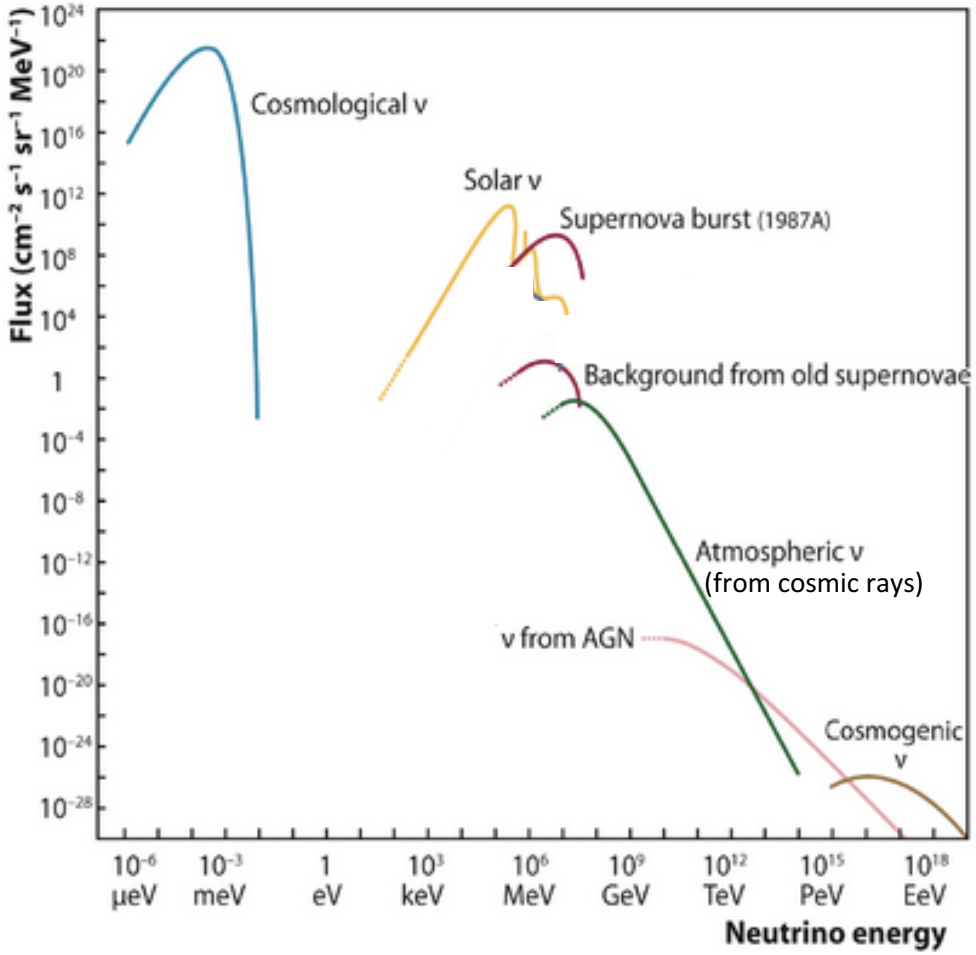
Historical real time alerts

Historical IceCube Public Alerts

Name	Date/Time (UTC)	RA (deg, J2000)	DEC (deg, J2000)	Angular Uncertainty (90%,deg)	Deposited Energy	Alert Stream	Signalness/Signal-Trackness	Latency	GCN Notice	GCN Circular
IceCube-160427A	16/04/27 05:52:32	250.6	+9.3	0.6	150 TeV	HESE	0.92	81 sec	67093193_127853	19363
IceCube-160731A	16/07/31 01:55:04	214.5	-0.33	0.75	130 TeV	HESE and EHE	0.91/0.85	41 sec	6888376_128290	NA
IceCube-160806A	16/08/06 12:21:33	122.8	-0.8	0.5	62 TeV	EHE	0.28	37 sec	26552458_128311	19787
IceCube-160814A	16/08/14 21:45:54	200.3	-32.4	1.5	97 TeV	HESE	0.12	42 sec	58537957_128340	NA
IceCube-161103A	16/11/03 09:07:31	40.8	+12.6	0.9	47 TeV	HESE	0.30	37 sec	38561326_128672	20119
IceCube-161210A	16/12/10 20:06:40	46.6	+15.0	0.7	56 TeV	EHE	0.49	27 sec	80127519_128906	20247
IceCube-170312A	17/03/12 13:49:39	305.2	-26.6	0.5	55 TeV	HESE	0.78 (*)	59 sec	65274589_129281	20857
IceCube-170321A	17/03/21 07:32:20	98.3	-15.0	1.2	16 TeV	EHE	0.28	13 sec	80305071_129307	20929
IceCube-170506A	17/05/06 12:36:56	221.8	-26.0	2.5	38 TeV	HESE	0.35 (*)	1465 sec	32674593_129474	21075
IceCube-170922	17/09/22 20:54:30.43	77.43	5.72	1.3 (non-symmetric)		EHE				21916
IceCube-171015	17/10/15 01:34:30.06	162.86	-15.44	2.6 (non-symmetric)		HESE				22016

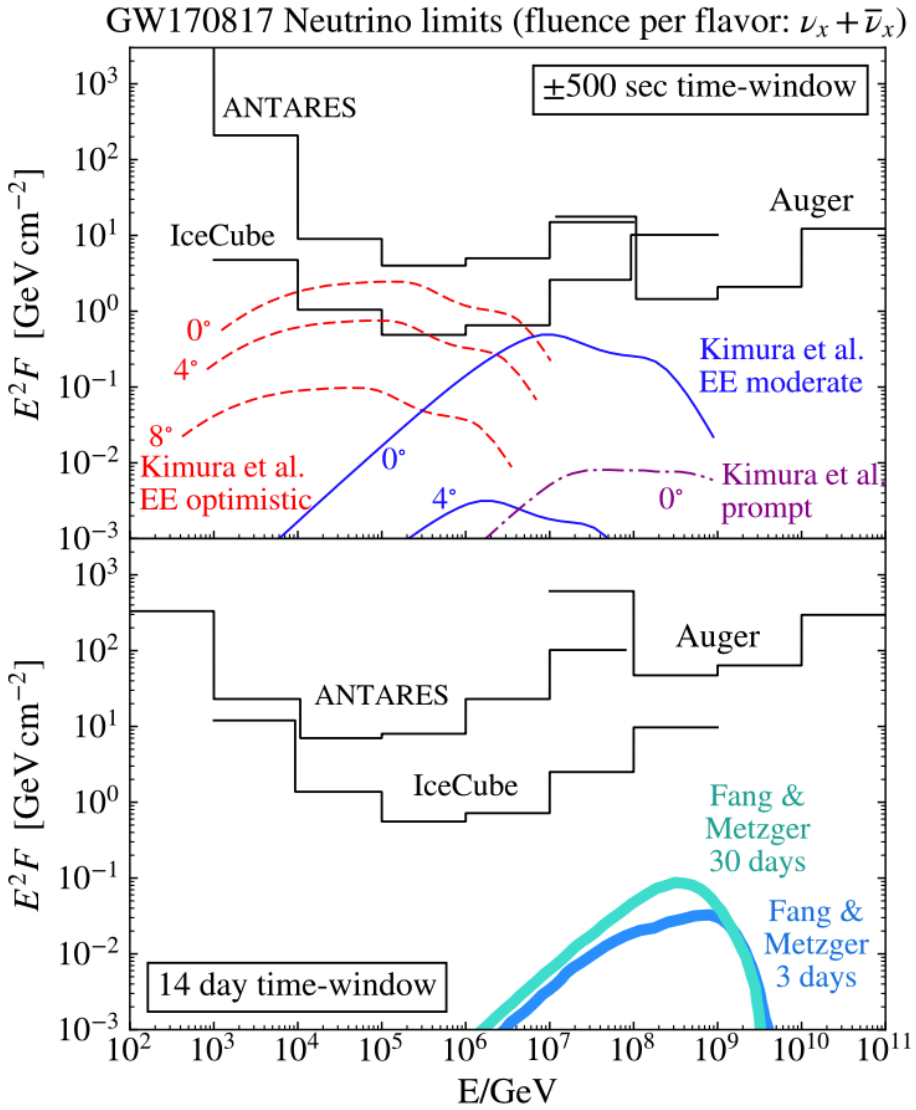
(*)- Event identified in offline checks as likely being from background

Astrophysical neutrinos span orders of magnitude in energy



But… neutrinos are really hard to detect! For high energy astrophysical neutrinos, we need a large detector

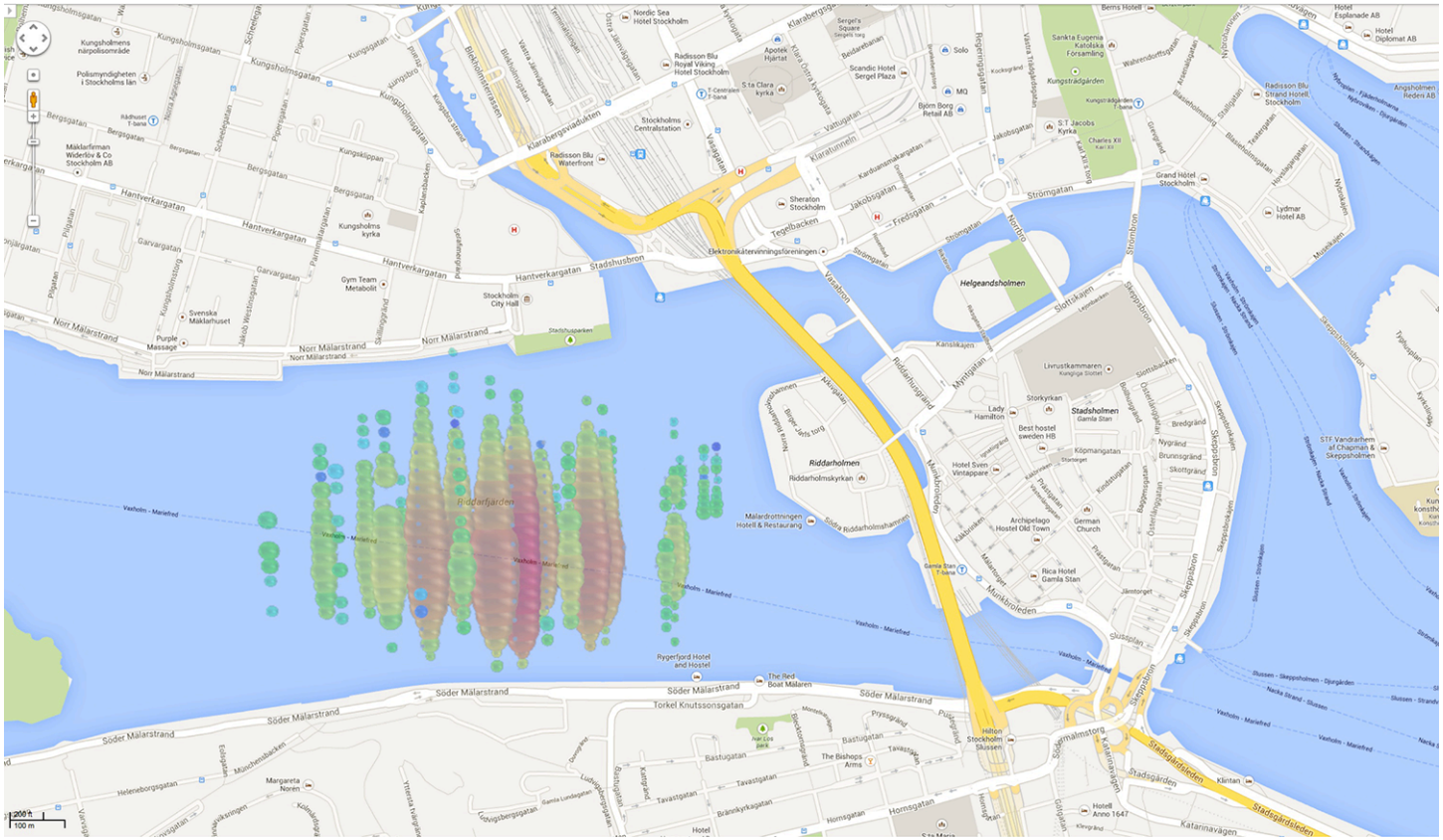
IceCube highlights: GW coincidence search



Set limits on neutrino fluence emitted by merger. Our measurement can constrain optimistic, on-axis emission models

Also can set limits on long-term neutrino fluence emitted by merger (14 days).

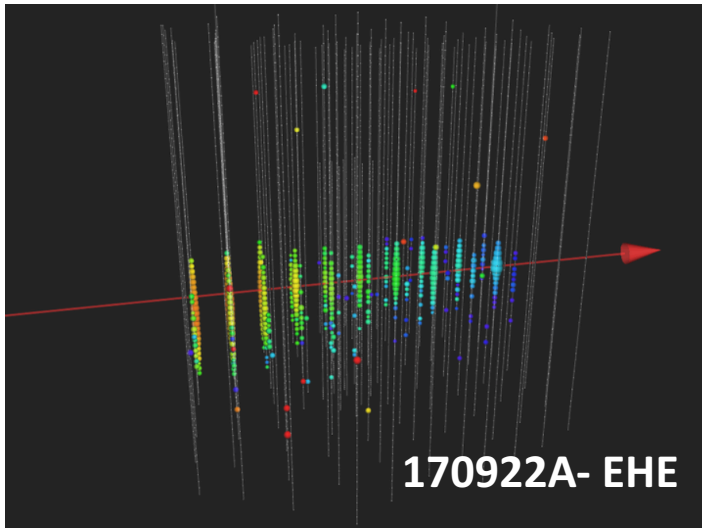
Size of IceCube's "Big Bird" high energy event

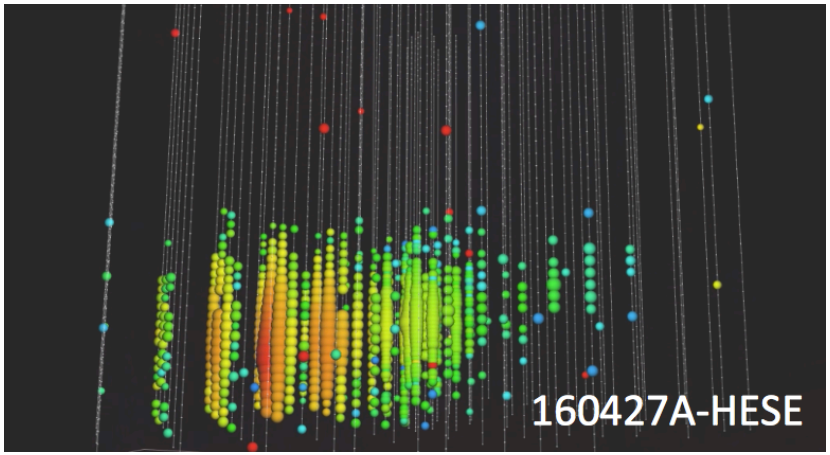


Public real-time alerts sent via GCN

EHE alerts: high energy, through-going muons induced by neutrinos. Tracks only. Expect ~4-5 alerts/year (~2 of which are background)

HESE alerts: high energy events that start in the detector. Currently only tracks. Expect ~3-4 alerts/year (~2-3 of which are background)





Also, multiplet alerts sent privately to partners for optical and gamma follow-up

GCN webpage: https://gcn.gsfc.nasa.gov