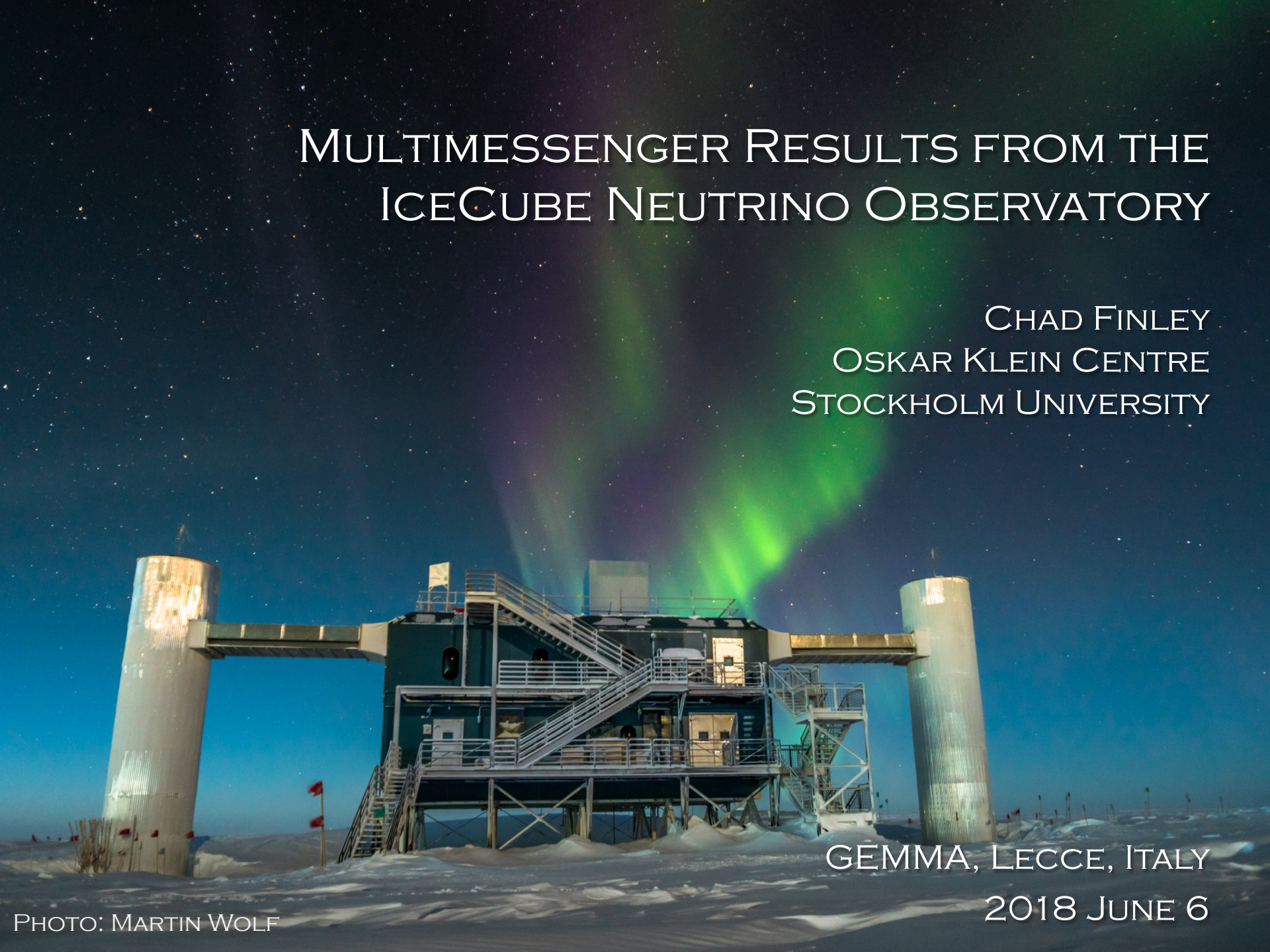
Multimessenger Results from the IceCube Neutrino Observatory

Chad Finley
Oskar Klein Centre
Stockholm University



GEMMA, Lecce, Italy
2018 June 6

Photo: Martin Wolf

Neutrino Astronomy

SN1987A

Supernova neutrinos

IceCube

Extra-galactic neutrino flux

eV keV MeV GeV TeV PeV EeV ZeV

10^0 10^3 10^6 10^9 10^{12} 10^{15} 10^{18} 10^{21}

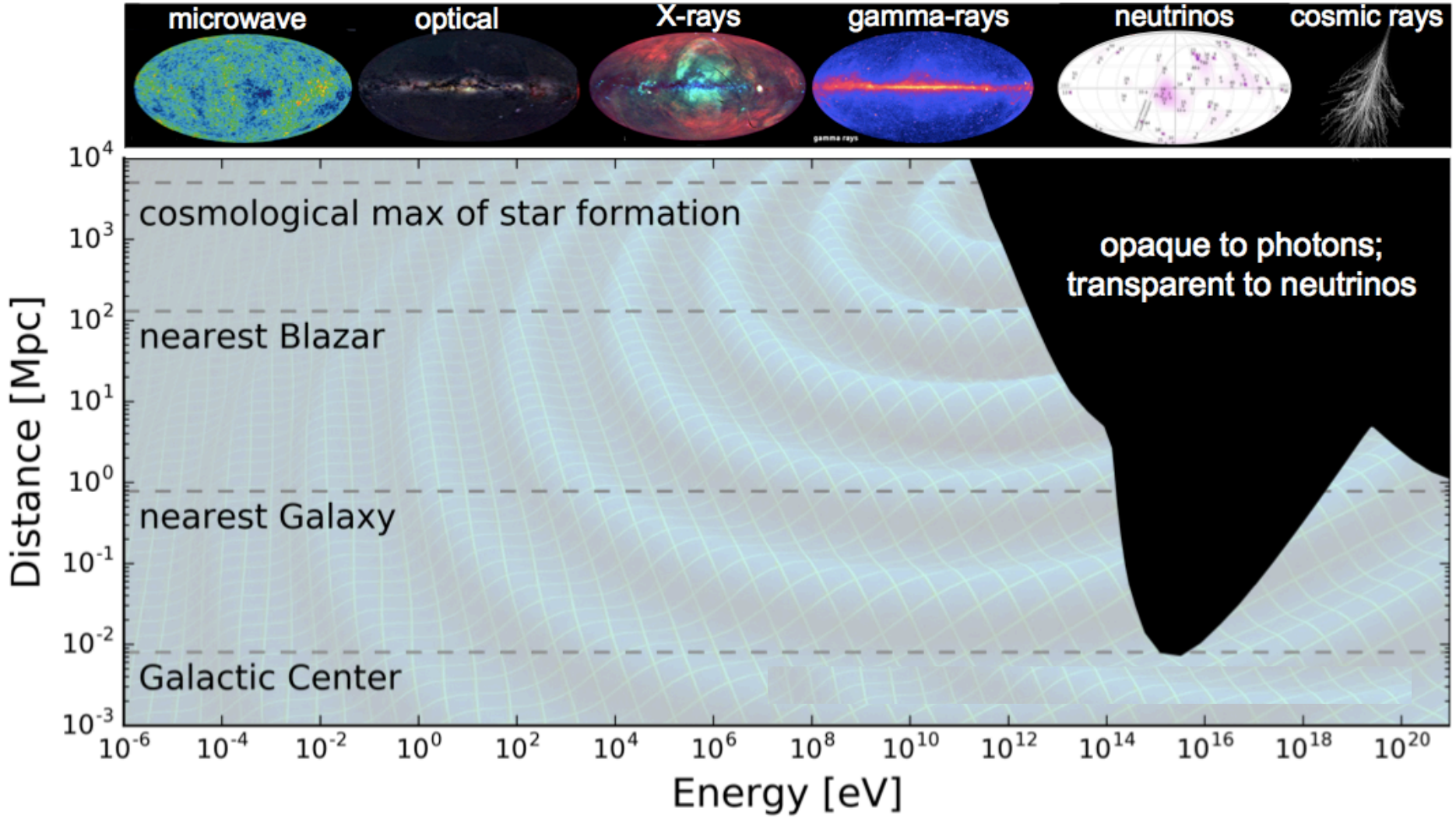
Cosmic rays

Infrared Optical Ultra-violet X-ray Gamma-ray

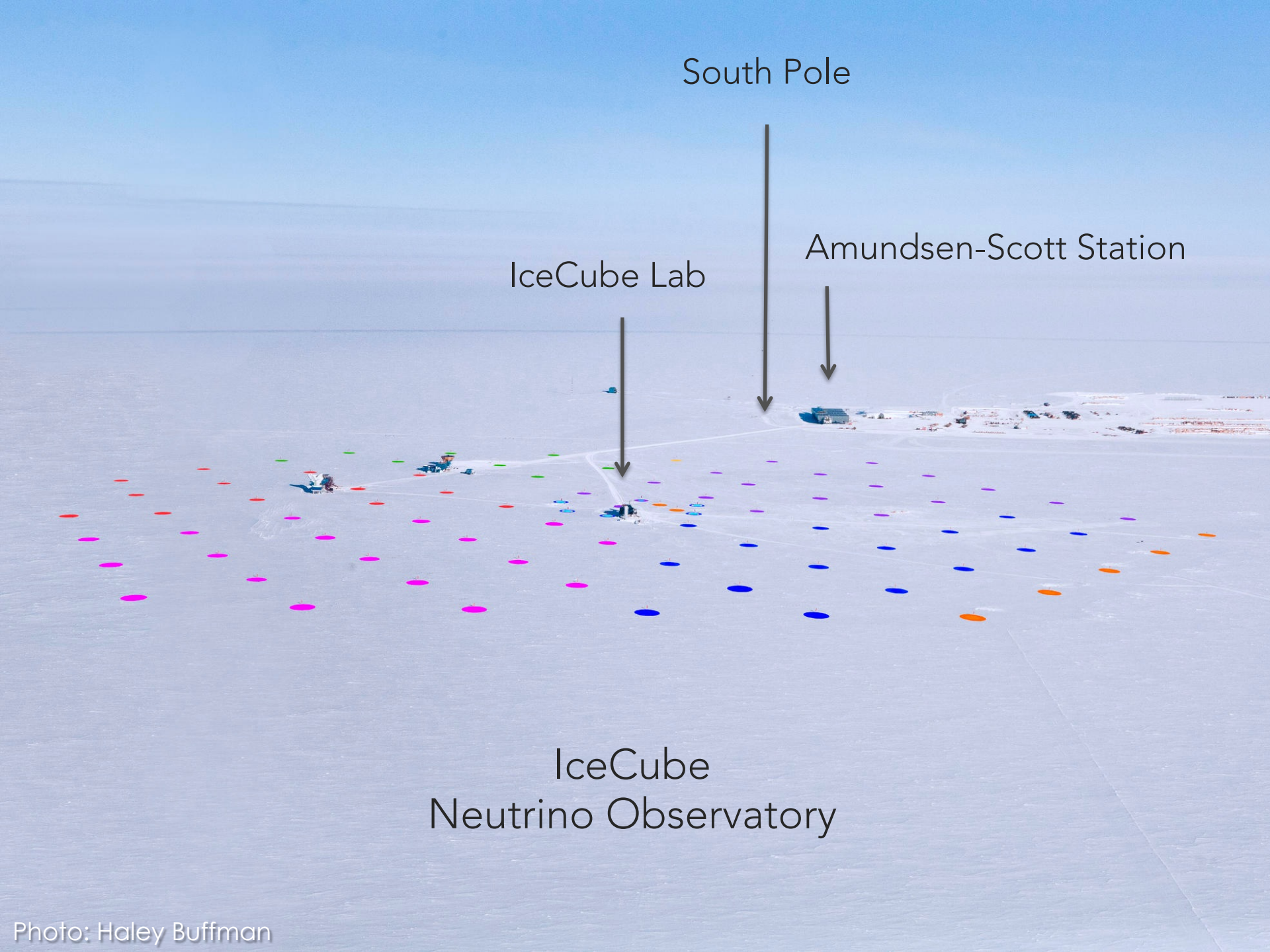
Extragalactic gamma-rays attenuated at high energies

Neutrino Astronomy is a High-Energy Window

Marek Kowalski



12 countries — 49 institutes — 300 scientists


South Pole
Amundsen-Scott Station
IceCube Lab
IceCube
Neutrino Observatory
Photo: Haley Buffman

IceCube Neutrino Observatory

86 strings

60 Optical Modules per string

5 160 total modules in Ice

1 km^3 = Gigaton instrumented volume

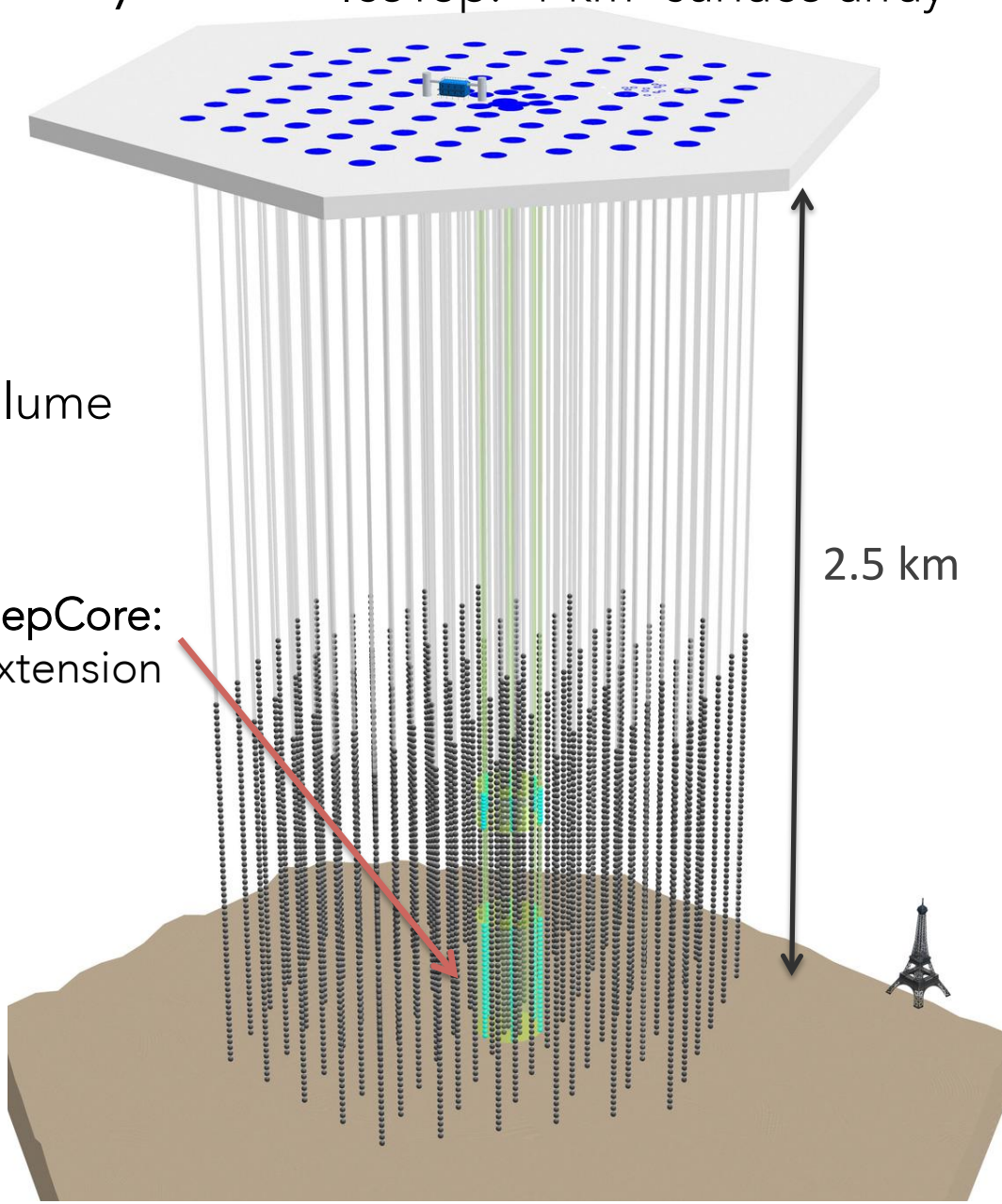
Began full operations May 2011

Highly stable operation.

Since 2014: livetime > 99%

clean-uptime 97-98%

(analysis-ready, full-detector data)

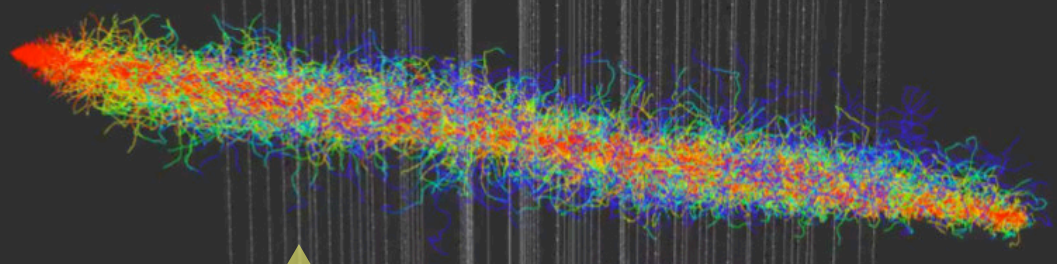


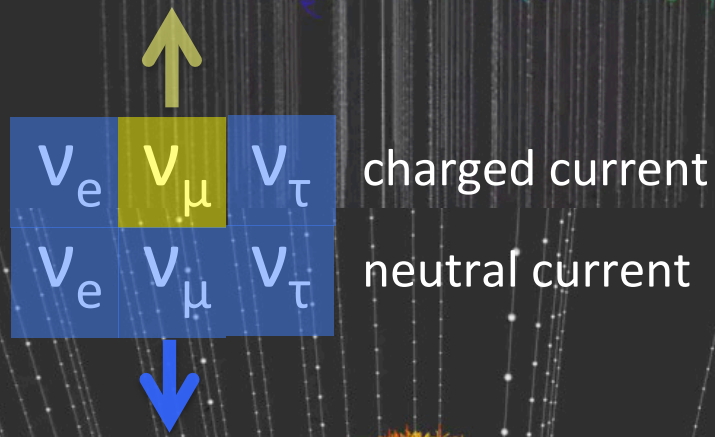
Photons produced by Neutrino Interactions

Tracks

Energy measured:
lower bound

Good pointing:
0.2° - 1°

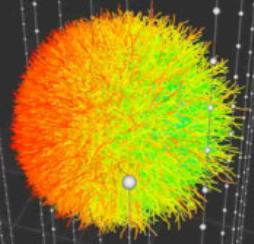


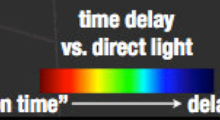


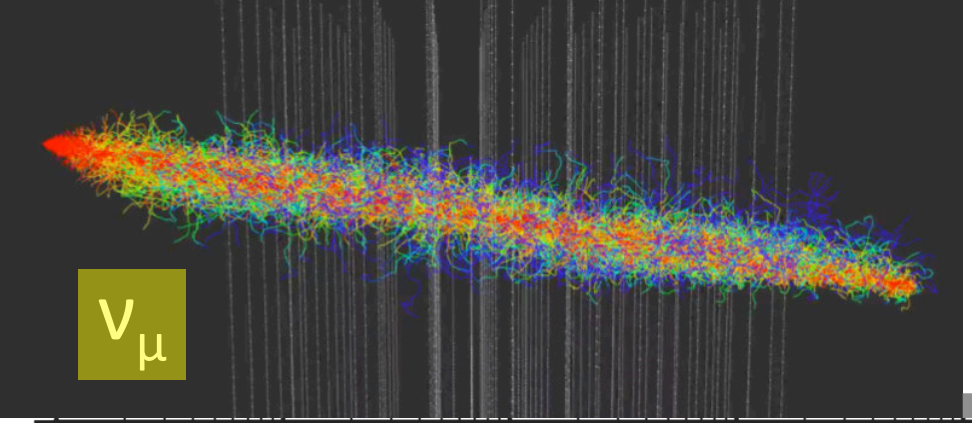
Cascades

Good energy
resolution, 15%

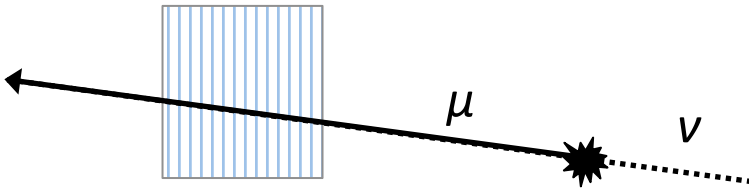
Some pointing,
10° - 15°







measured $E_{muon} < E_{neutrino}$



ApJ 833(2016)1,3
2012-2015 sample

Background Atmospheric Neutrinos
~ 70 000 neutrinos / year

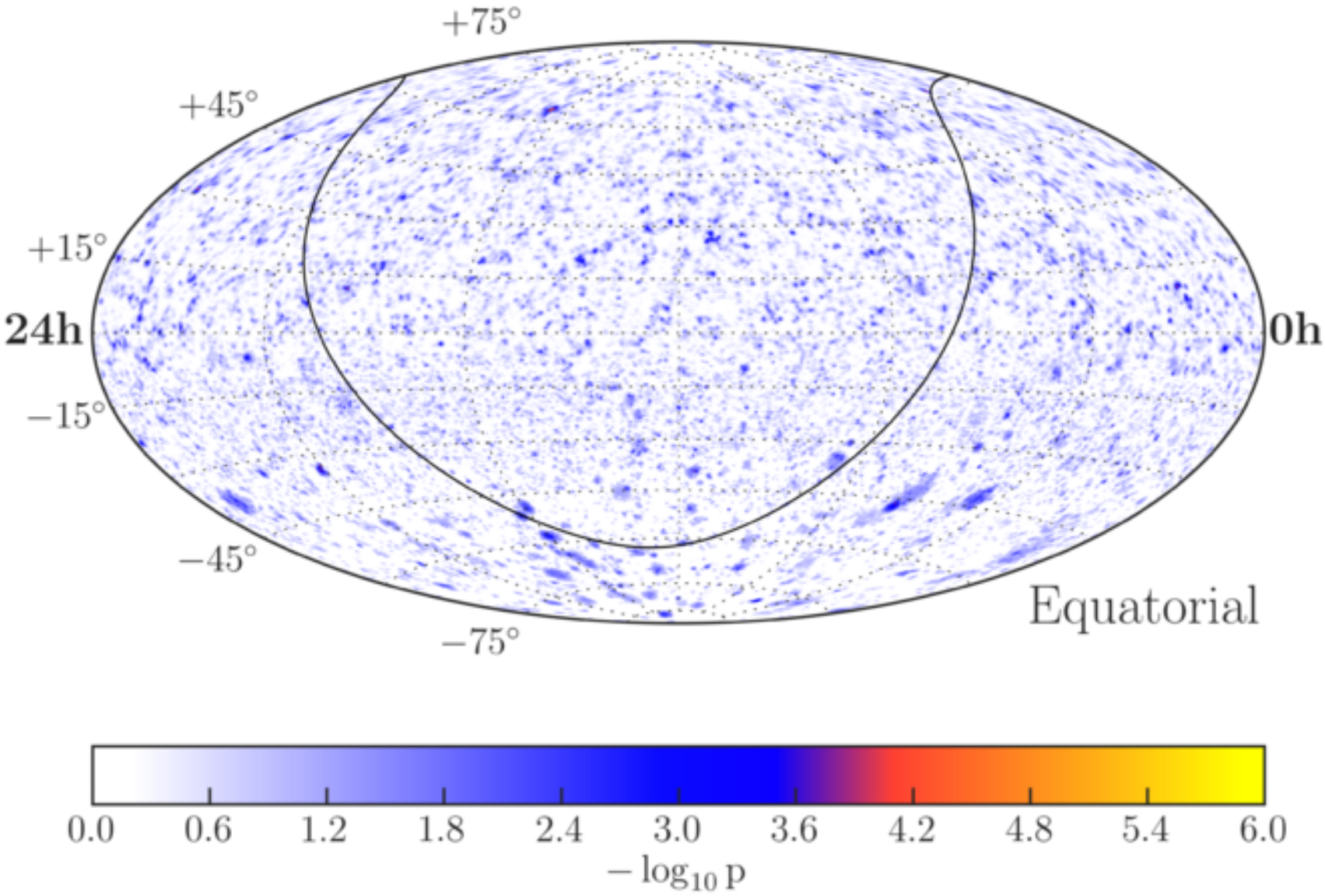
$E^{-2.1}$ astrophysical
neutrino flux
(~ 100 neutrinos / year)

Above 100 TeV, an all-sky astrophysical neutrino flux is observed in multiple channels at > 5σ.
Here is how it appears in the muon-neutrino channel.

10^3 10^4 10^5 10^6 10^7

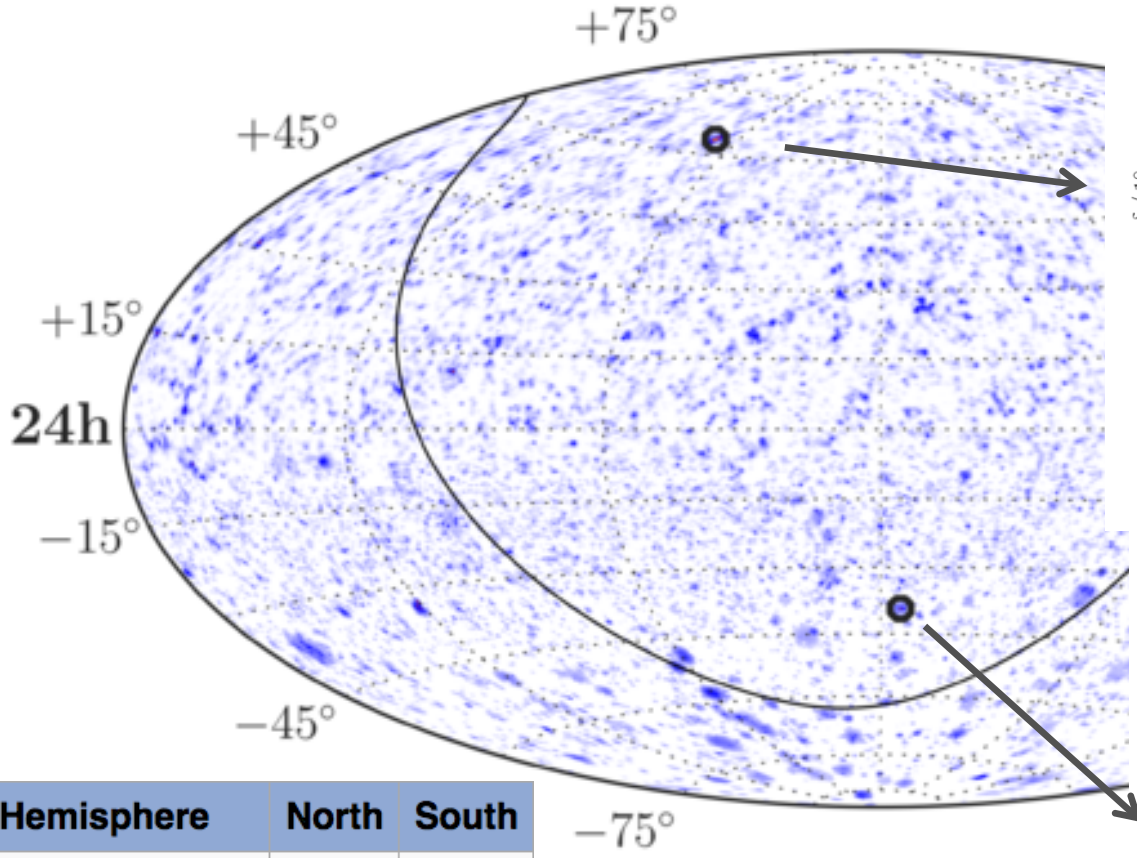
Muon Energy Proxy/GeV

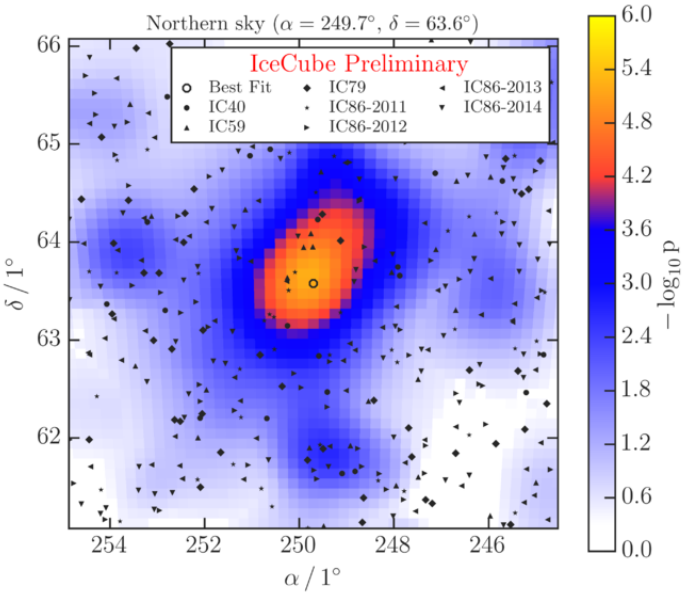
IceCube 7-year Point Source Search

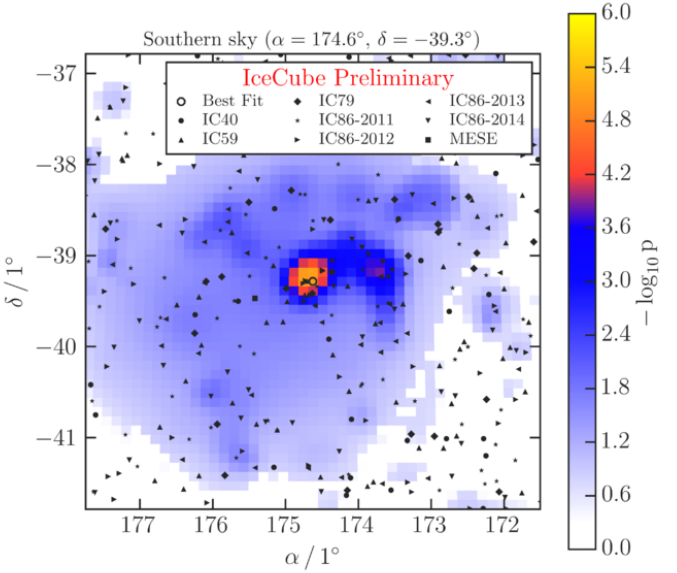


ApJ 835 (2017) 2, 151

IceCube 7-year Point Source Search



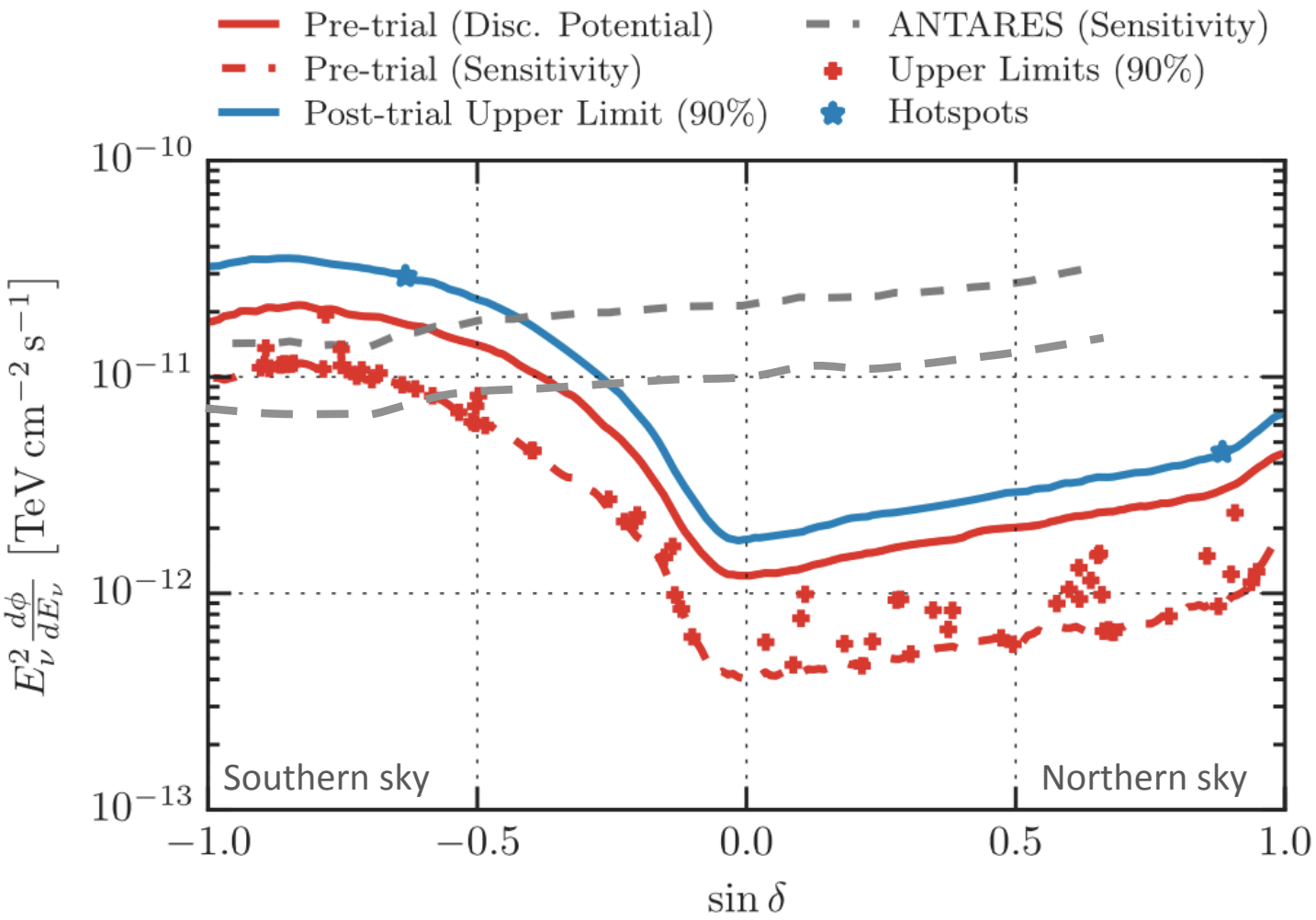




Hemisphere	North	South
N_Sources	27.22	15.54
Gamma	1.95	2.84
Test statistic	18.99	20.26
-log10(Pre-Trial P)	5.24	5.33
Post Trial P	44%	39%

ApJ 835 (2017) 2, 151

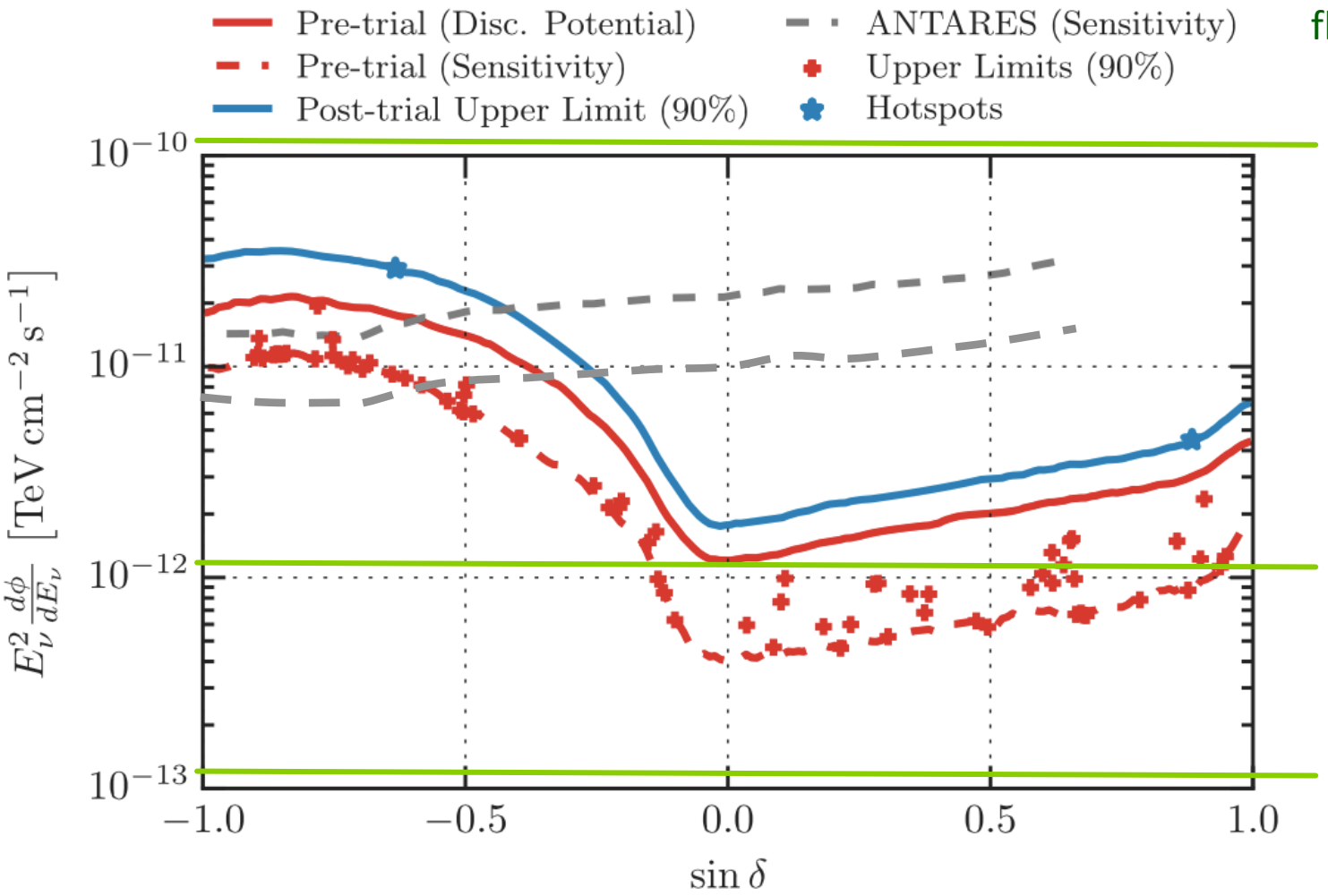
IceCube 7-year Point Source Search



ApJ 835 (2017) 2, 151

Relating All-sky Diffuse and Point Source fluxes

Point-source equivalent flux if the total astrophysical flux came from:



one point in the sky

100 points in the sky

1000 points in the sky

ApJ 835 (2017) 2, 151

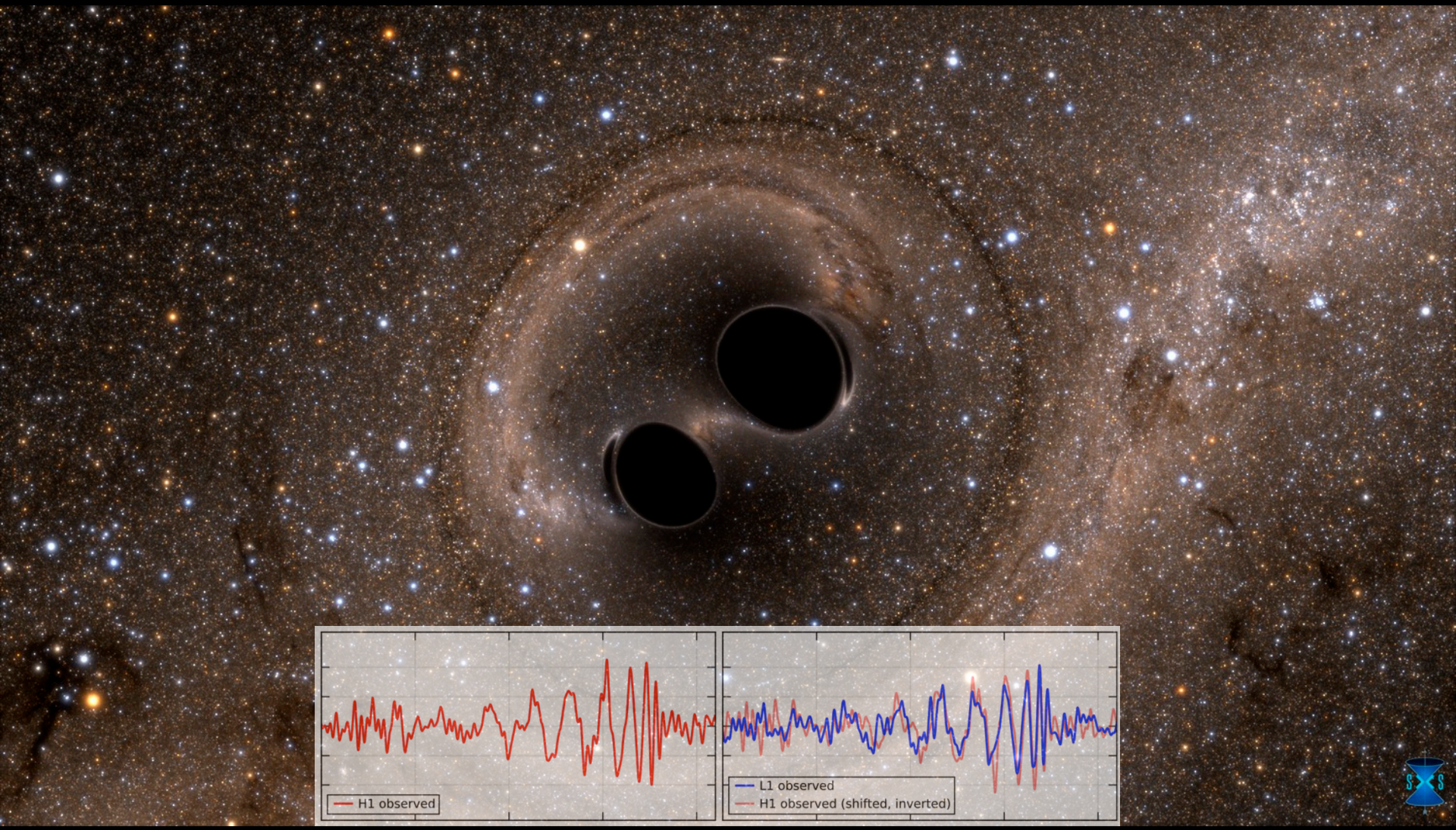
Joint Multimessenger Searches

IceCube has ~ 99% uptime and records data from all sky continuously

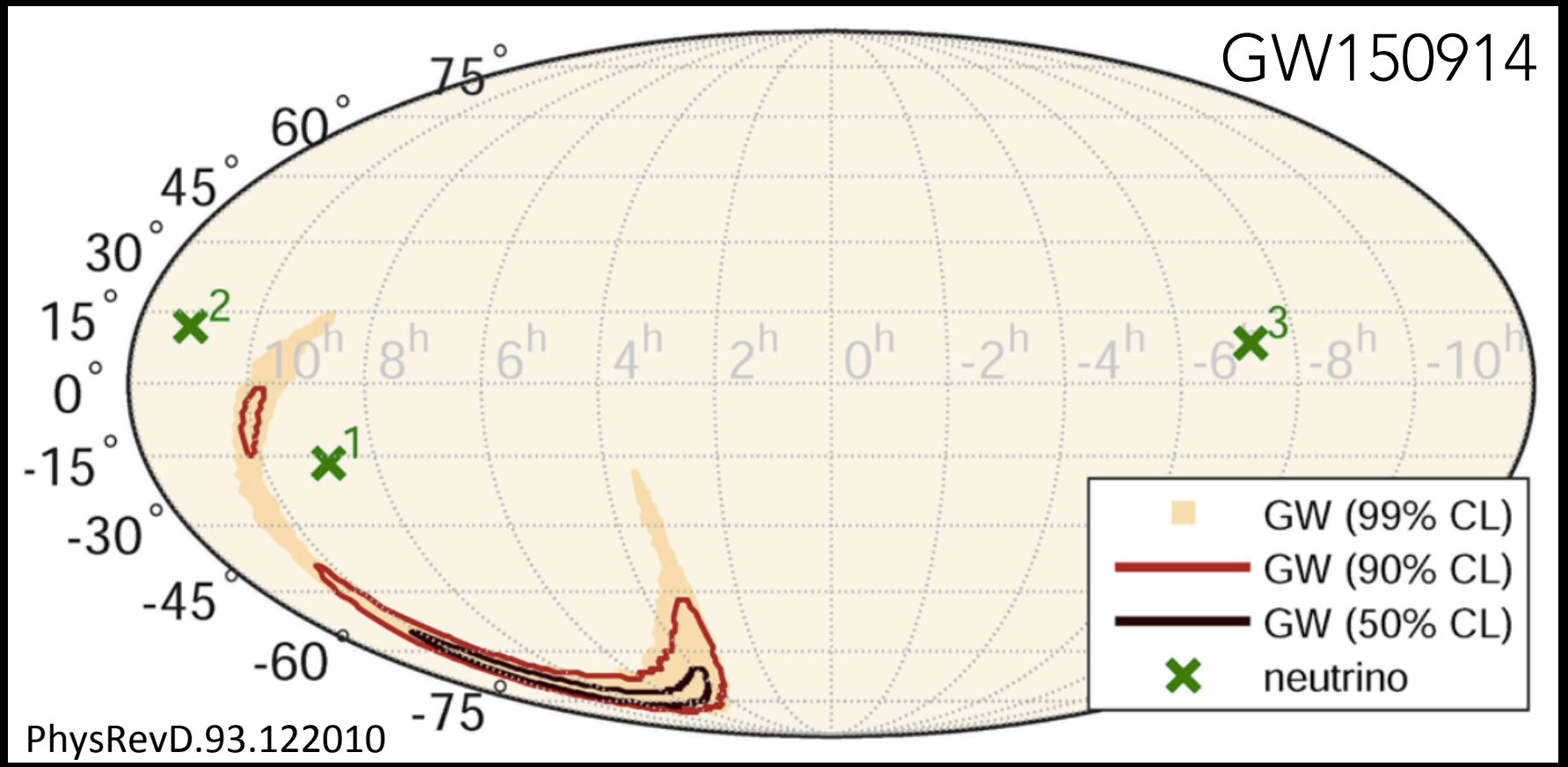
→ Events can be reconstructed quickly and transmitted northward, < 1 min

→ Can look back at data recorded earlier for any direction

- Fast-response to GW or EM alerts
- Offline coincidence searches
- Sending neutrino alerts


H1 observed
L1 observed
H1 observed (shifted, inverted)

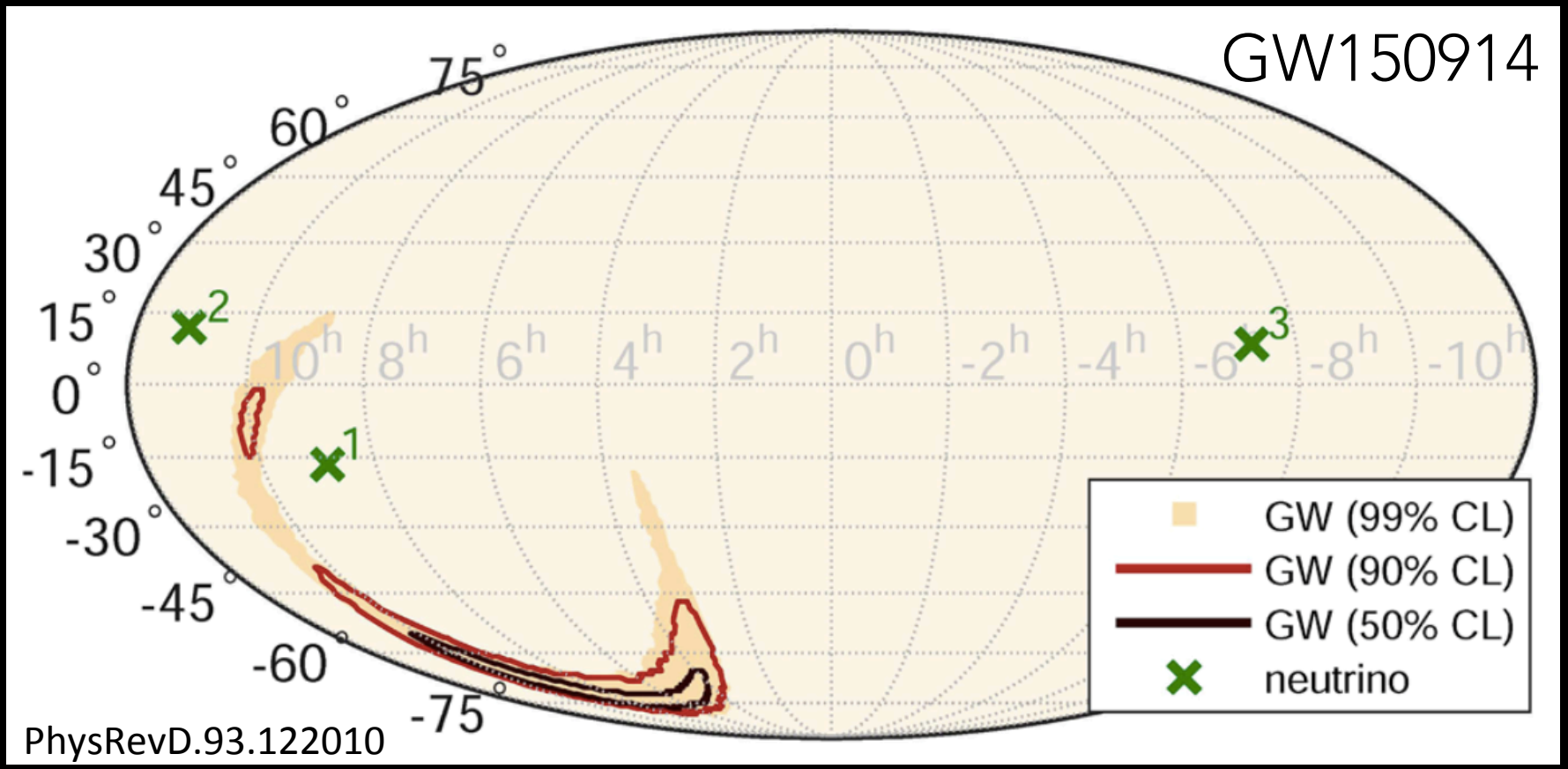
GW150914 – Binary Black Hole Merger



±500 second search window

No.	ΔT [s]	RA [h]	Dec [°]	σ_{μ}^{rec} [°]	E_{μ}^{rec} [TeV]	Fraction
1	+37.2	8.84	−16.6	0.35	175	12.5%
2	+163.2	11.13	12.0	1.95	1.22	26.5%
3	+311.4	−7.23	8.4	0.47	0.33	98.4%

GW150914 – Binary Black Hole Merger



Localization of neutrino direction ~ 1°

No.	ΔT [s]	RA [h]	Dec [°]	σ_μ^{rec} [°]	E_μ^{rec} [TeV]	Fraction
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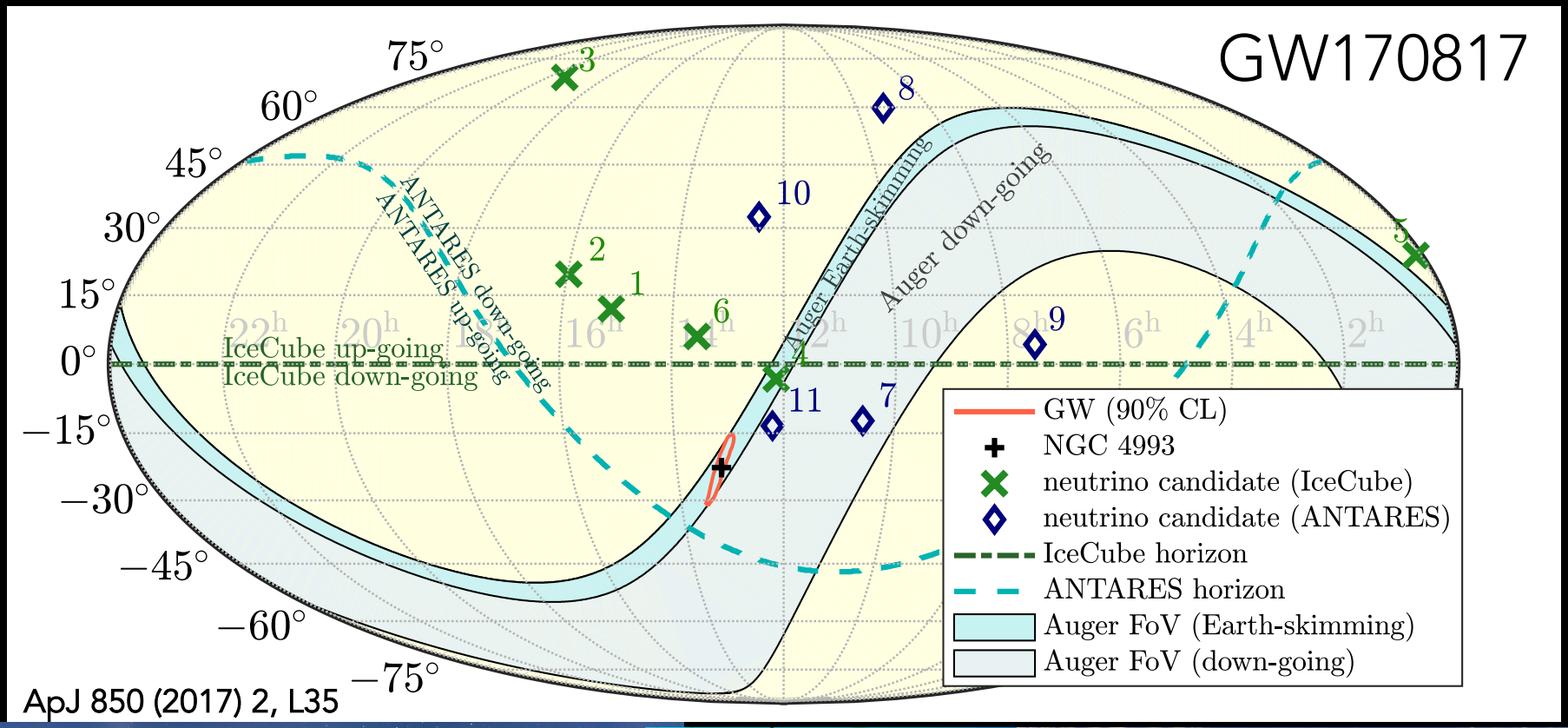
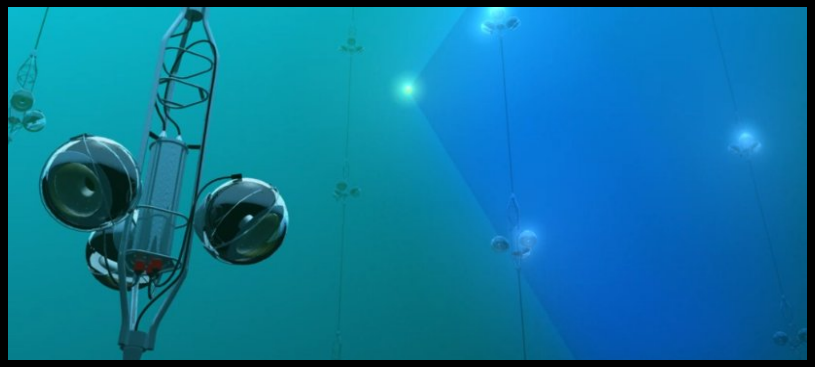
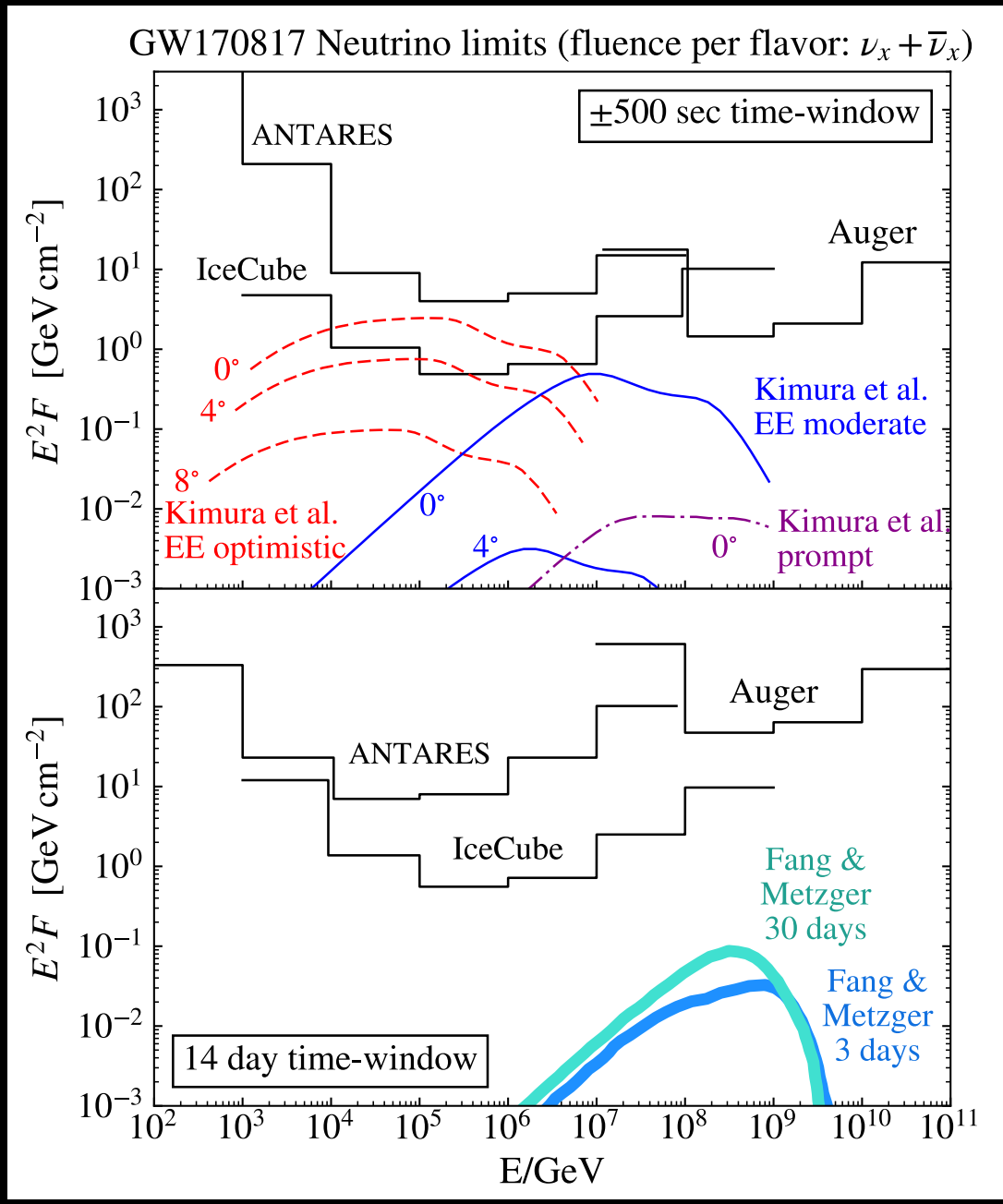
GW170817 – Binary Neutron Star Merger







Antares, Auger, IceCube, LIGO-Virgo Observatories, A. Albert et al., ApJ 850 (2017) 2, L35

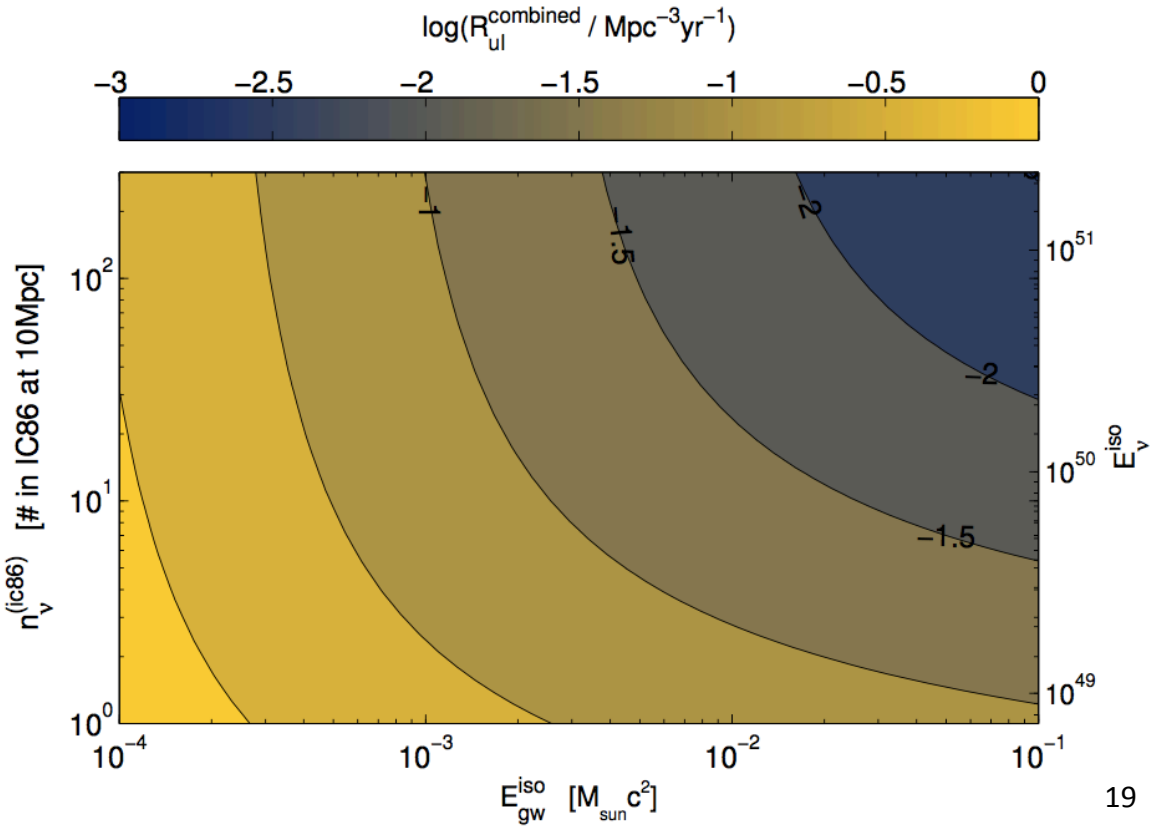
Joint sub-threshold analysis with initial LIGO-Virgo

IceCube, LIGO, Virgo
PRD 90, 102002 (2014)

# of strings	Start	End
22	May 2007	Apr 2008
59	May 2009	May 2010
79	May 2010	May 2011

Initial LIGO-Virgo and partial IceCube detector:

Joint GW+nu source rate upper limit –
as a function of isotropic-equivalent GW emission E_iso, and neutrino emission n_nu



Joint sub-threshold analysis with initial LIGO-Virgo

IceCube, LIGO, Virgo
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22	May 2007	Apr 2008
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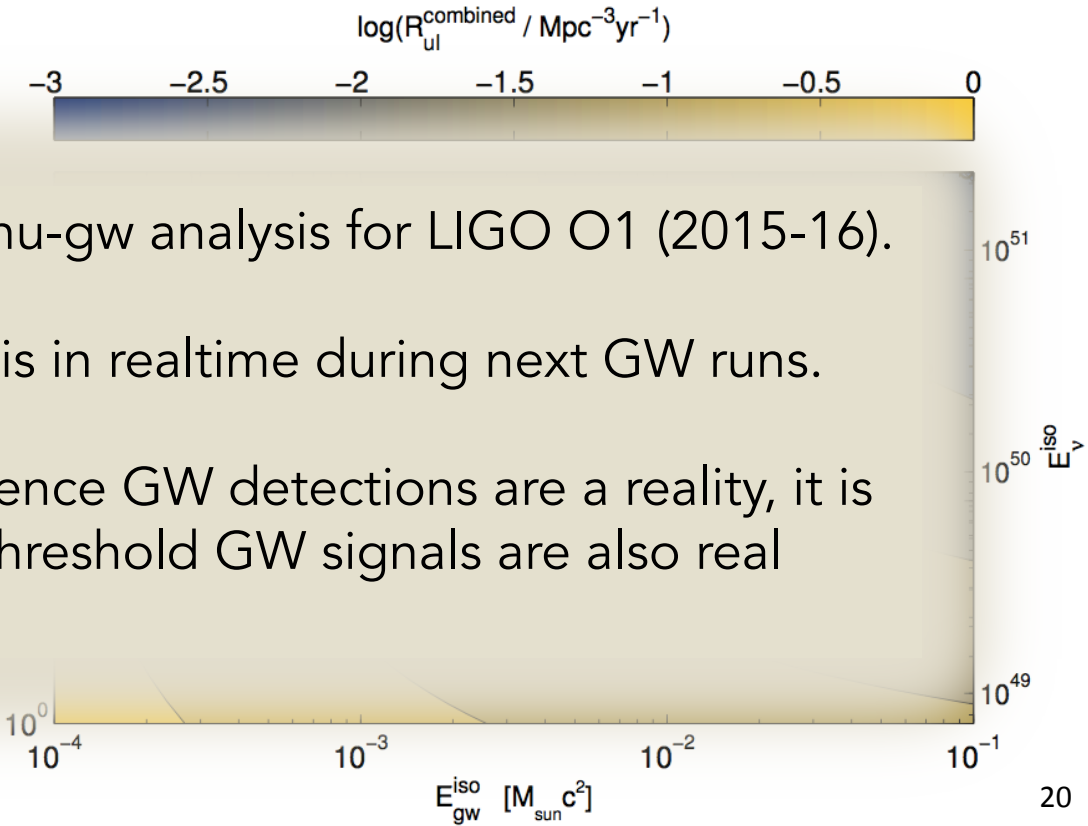
Joint GW+nu source rate upper limit of the Initial LIGO detectors isotropic

Now: Finalizing joint nu-gw analysis for LIGO O1 (2015-16).

Possible to run analysis in realtime during next GW runs.

Now that high-confidence GW detections are a reality, it is likely that some sub-threshold GW signals are also real events.



IceCube Realtime Public Alerts

Astropart. Phys. 92 (2017) 30

Operating since April 2016. Transmitted via AMON, GCN.

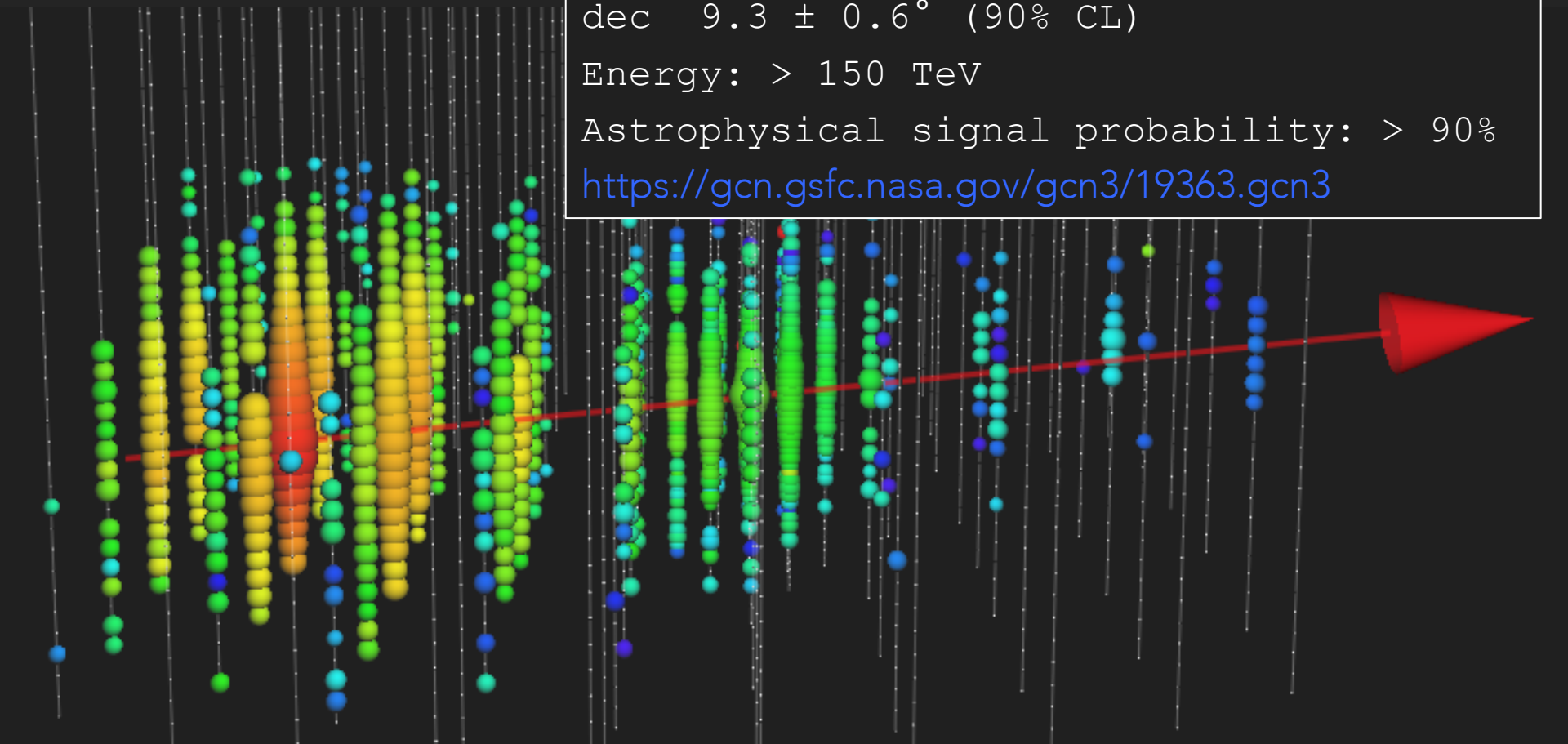
Typical latency from event until public GCN alert: < 1 min

6-8 alerts per year

Example (first event):

```
IceCube-160427A
r.a. 240.6 ± 0.6° (90% CL)
dec  9.3 ± 0.6° (90% CL)
Energy: > 150 TeV
Astrophysical signal probability: > 90%
```

https://gcn.gsfc.nasa.gov/gcn3/19363.gcn3



Alert event IceCube-170922A and the blazar TXS 0506+056

Date: 22 Sept 2017

RA: 77.43° (-0.80°/+1.30° 90% CL)
Dec: 5.72° (-0.40°/+0.70° 90% CL)

Energy (prelim. reported est.): > 120 TeV

TITLE: GCN CIRCULAR
NUMBER: 21916
SUBJECT: IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
DATE: 17/09/23 01:09:26 GMT
FROM: Erik Blaufuss at U. Maryland/IceCube <blaufuss@icecube.umd.edu>

Claudio Kopper (University of Alberta) and Erik Blaufuss (University of Maryland) report on behalf of the IceCube Collaboration (http://icecube.wisc.edu/).

On 22 Sep, 2017 IceCube detected a track-like, very-high-energy event with a high probability of being of astrophysical origin. The event was identified by the Extremely High Energy (EHE) track event selection. The IceCube detector was in a normal eutrino r, produce a muon

Date: 28 Sept 2017

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; *Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration*
on 28 Sep 2017; 10:10 UT
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

Date: 4 Oct 2017

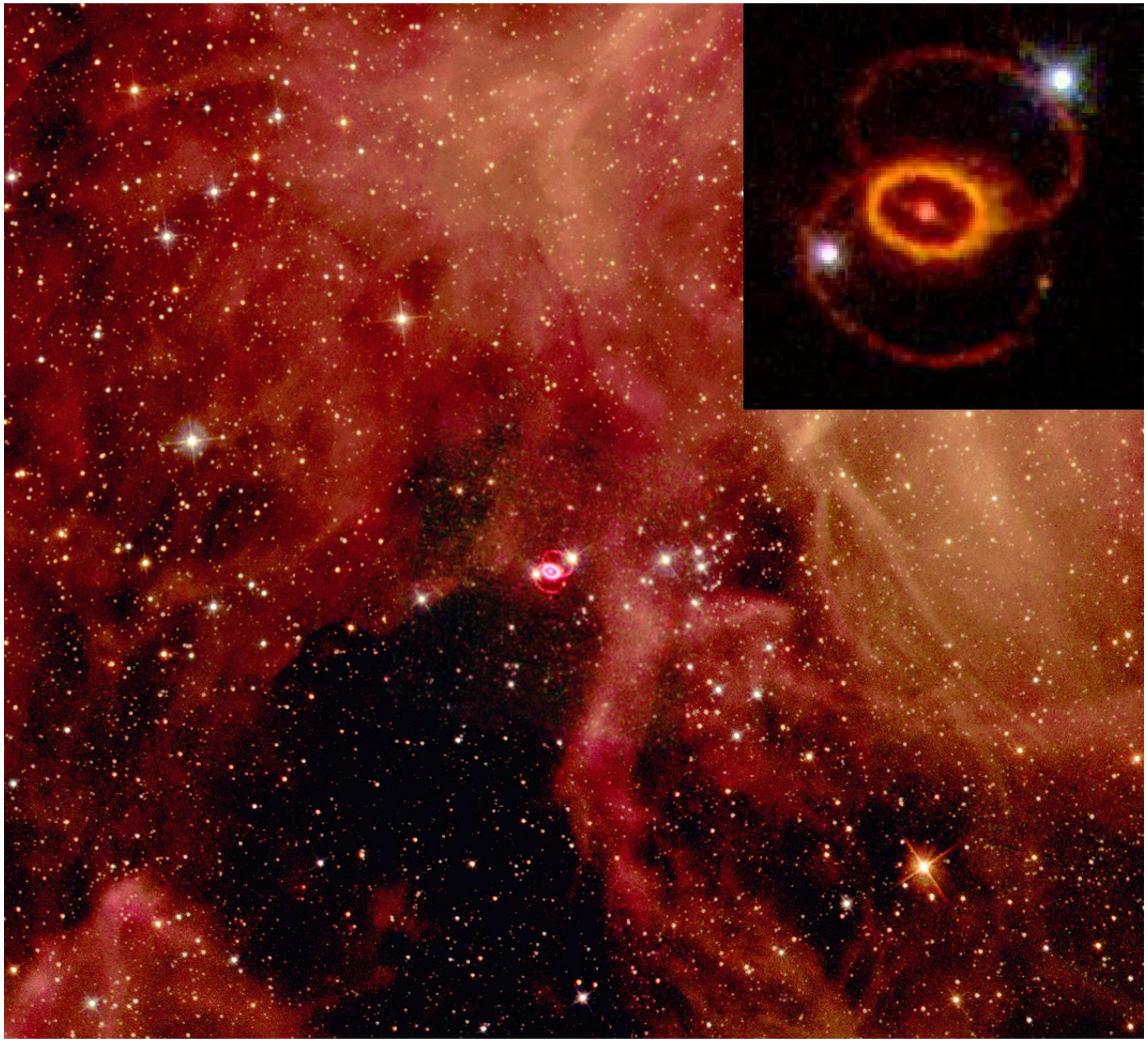
First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

ATel #10817; *Razmik Mirzoyan for the MAGIC Collaboration*
on 4 Oct 2017; 17:17 UT
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Optical, Gamma Ray, >GeV, TeV, VHE, UHE, Neutrinos, AGN, Blazar


Photo: Martin Wolf
All-sky high-energy neutrino flux is observed
May be connected to powerful particle accelerators, but not identified yet
Stay tuned!
IceCube Collaboration

EXTRA

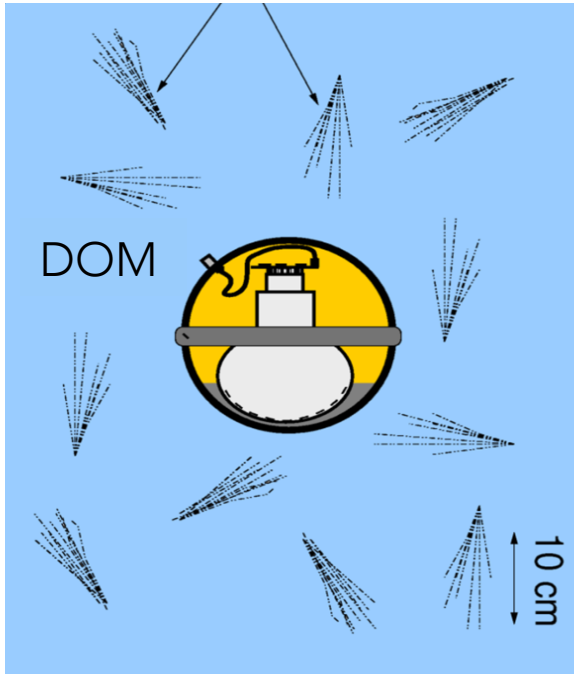


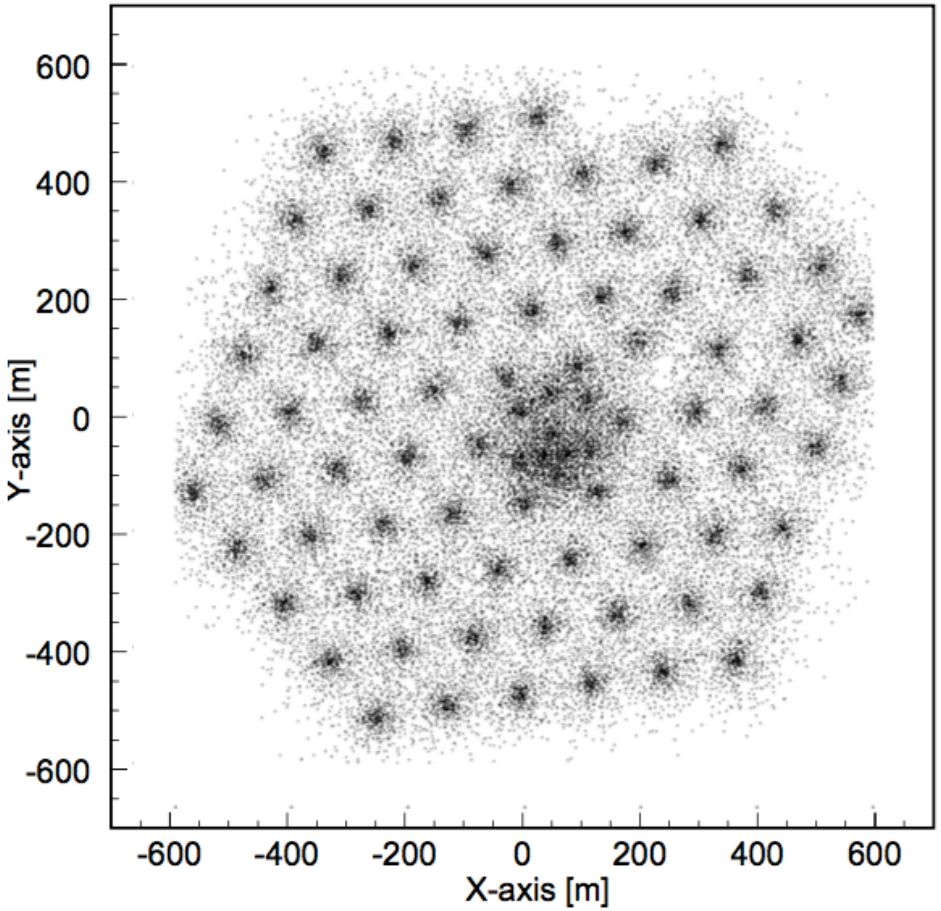
Supernova Neutrino Detection

The produced positron is emitted almost isotropically.

Short paths of MeV positrons do not create enough Cherenkov photons for detectable "tracks." But they increase the **noise rate**.

10-20 MeV positrons





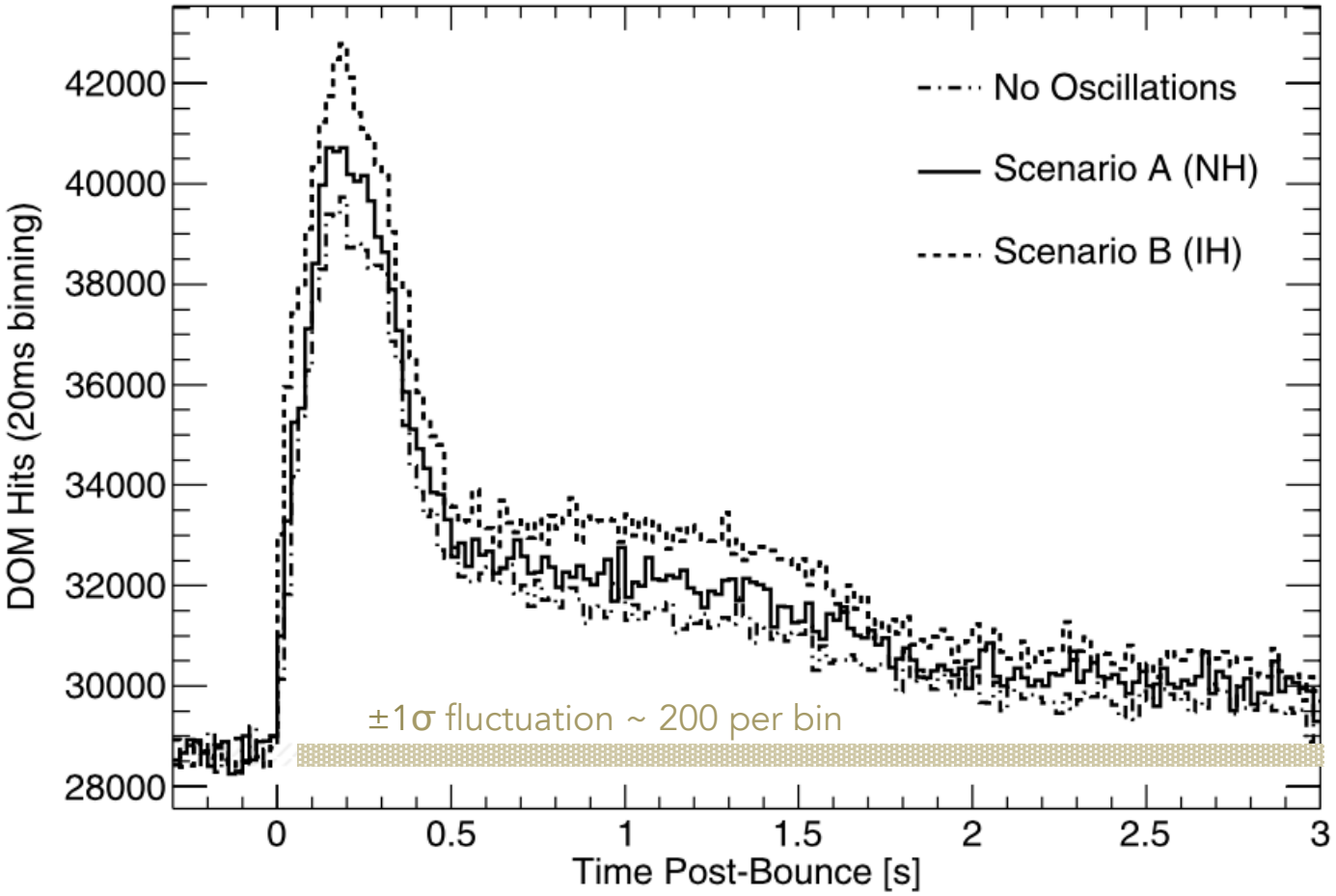
GEANT3 simulation of detected neutrino inverse beta decay interaction vertices

IceCube Coll., A&A 535 A109 (2011)

Supernova Neutrino Detection: Typical

Global noise rate in IceCube:
1.4 MHz

29K per 20ms bin

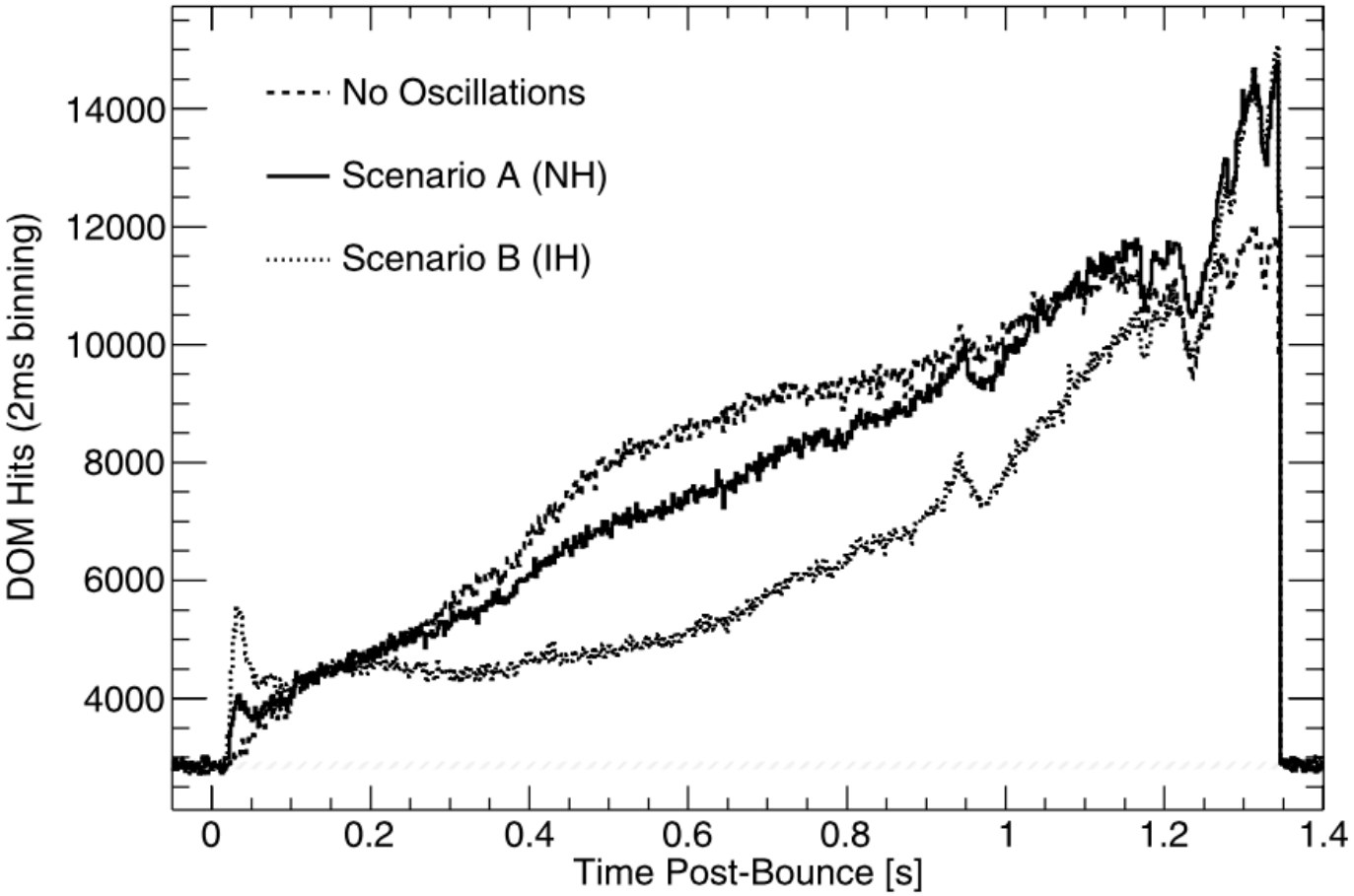


Expected rate distribution for SN at 10 kpc

IceCube Coll., A&A 535 A109 (2011)

Supernova Neutrino Detection: Exotic

Formation of black hole



Expected neutrino signal from the gravitational collapse of a non rotating massive star of 40 solar masses into a black hole at 10 kpc distance

IceCube Coll., A&A 535 A109 (2011)

SNEWS: SuperNova Early Warning System

Automated system.

Receive candidate alerts, establish coincidence, send public alert < 10 sec.

Seven neutrino experiments currently involved:

- Super-K (Japan)
- LVD (Italy)
- Ice Cube (South Pole)
- KamLAND (Japan)
- Borexino (Italy)
- Daya Bay (China)
- HALO (Canada)