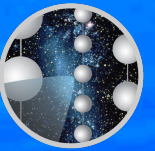


# Review of Neutrino Astrophysics with IceCube

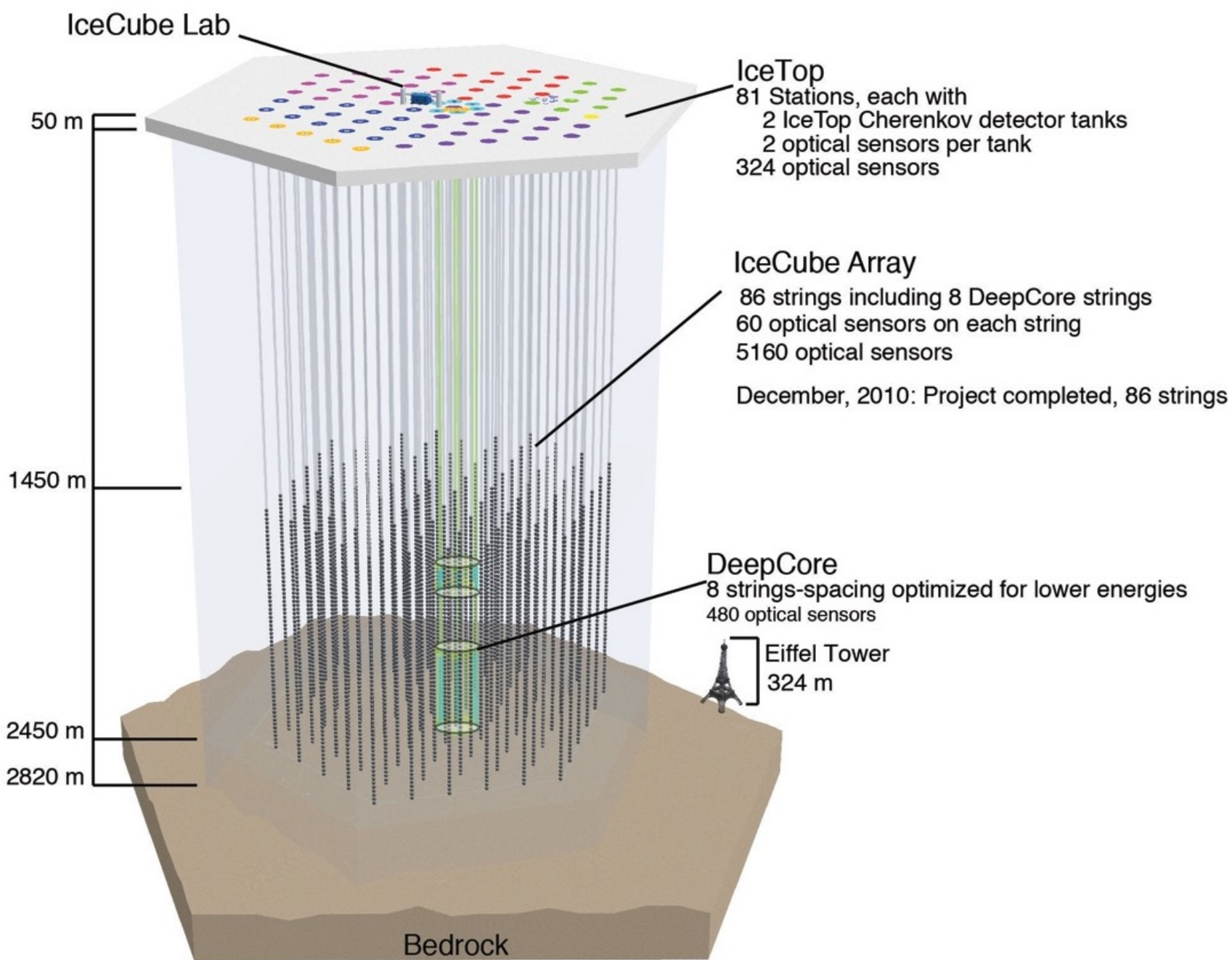
Ignacio Taboada  
Georgia Institute of Technology



ICECUBE







# IceCube: a km<sup>3</sup> scale detector at the South Pole

Operating in full configuration since May 2011

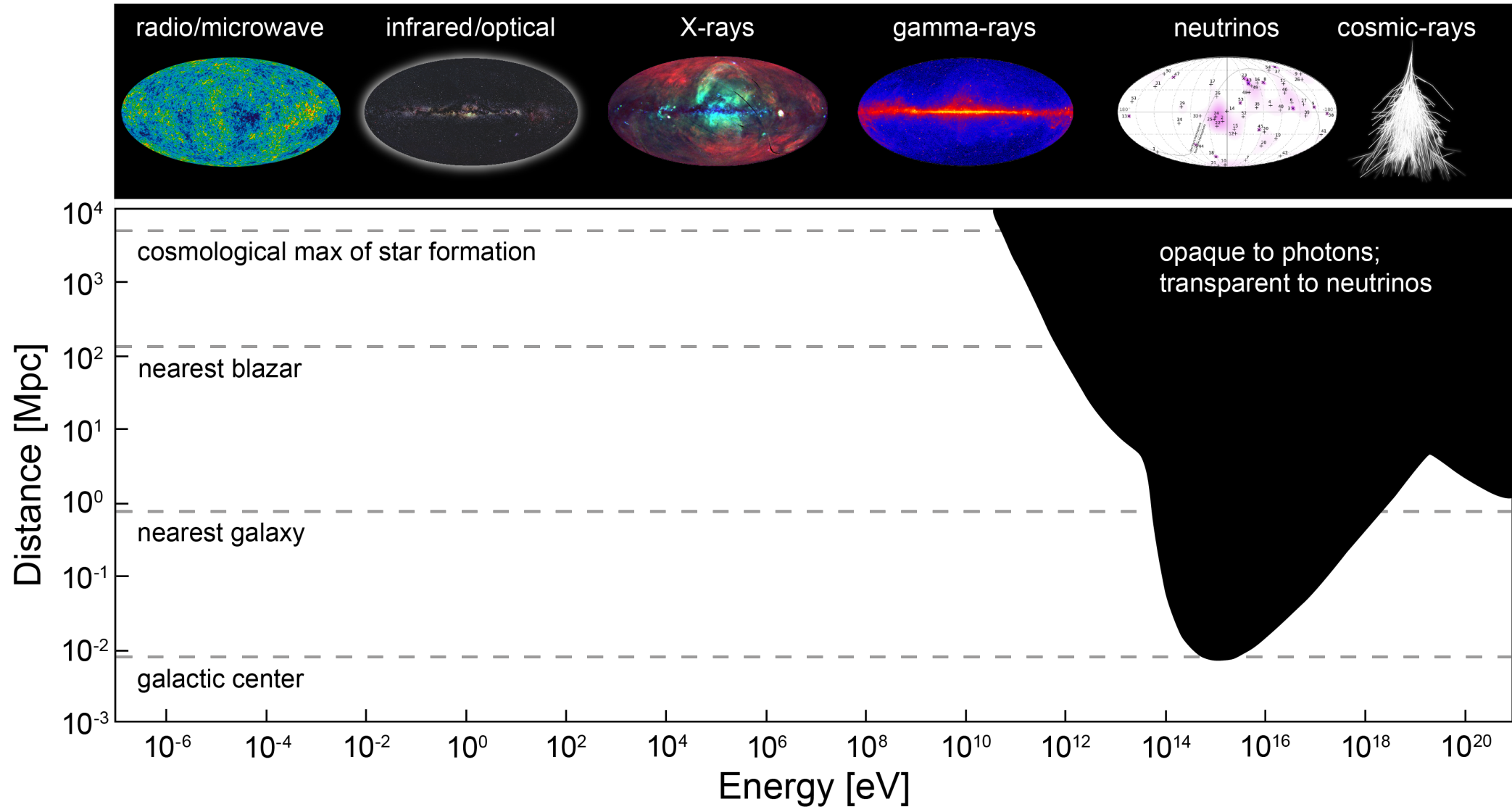


~99% of DOMs currently operational

>99% uptime

4 $\pi$  sr survey

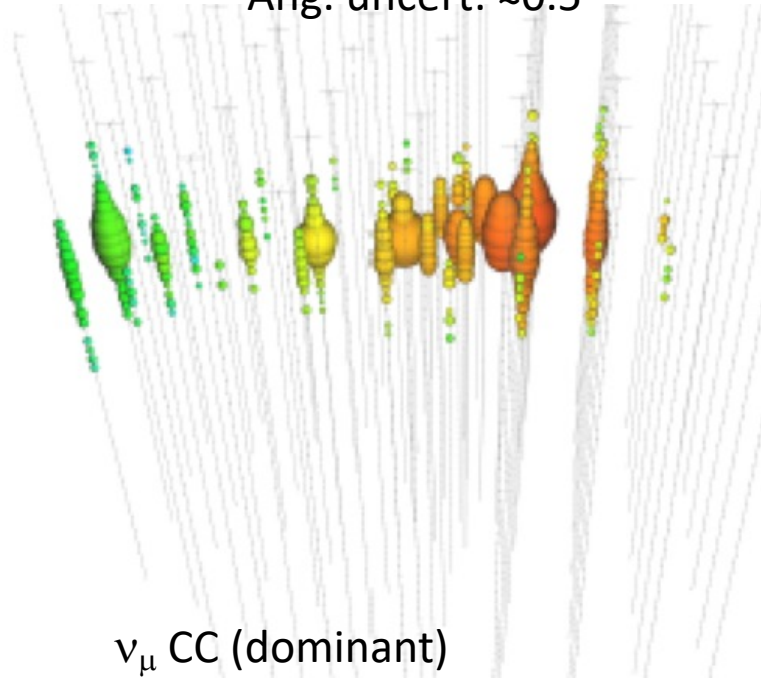
# Why Neutrino Astronomy?



# Neutrino signatures

## Tracks

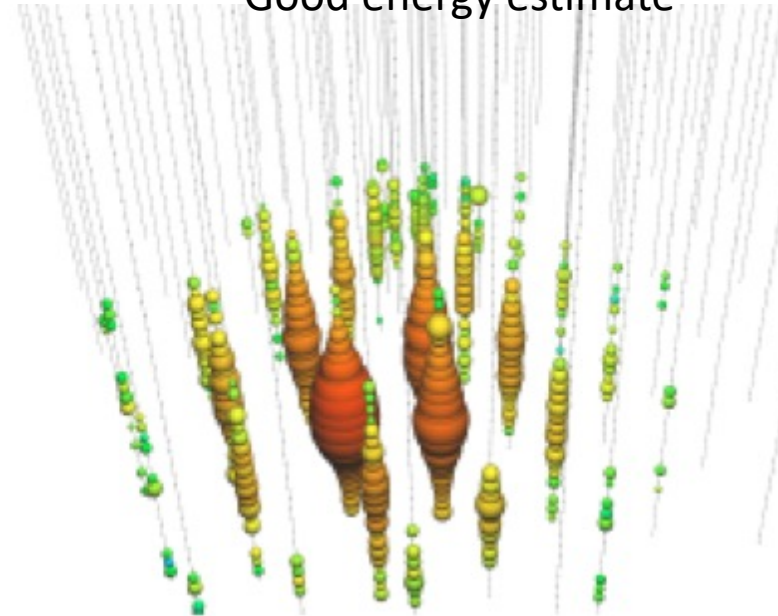
“Traditional  $\nu$  astro channel”  
Ang. uncert:  $\approx 0.5^\circ$



$\nu_\mu$  CC (dominant)  
 $\nu_\tau$  CC;  $\tau$  decaying into  $\mu$  (minor)

## Cascades / Showers

Ang. uncert:  $\approx 3-15^\circ$   
Good energy estimate



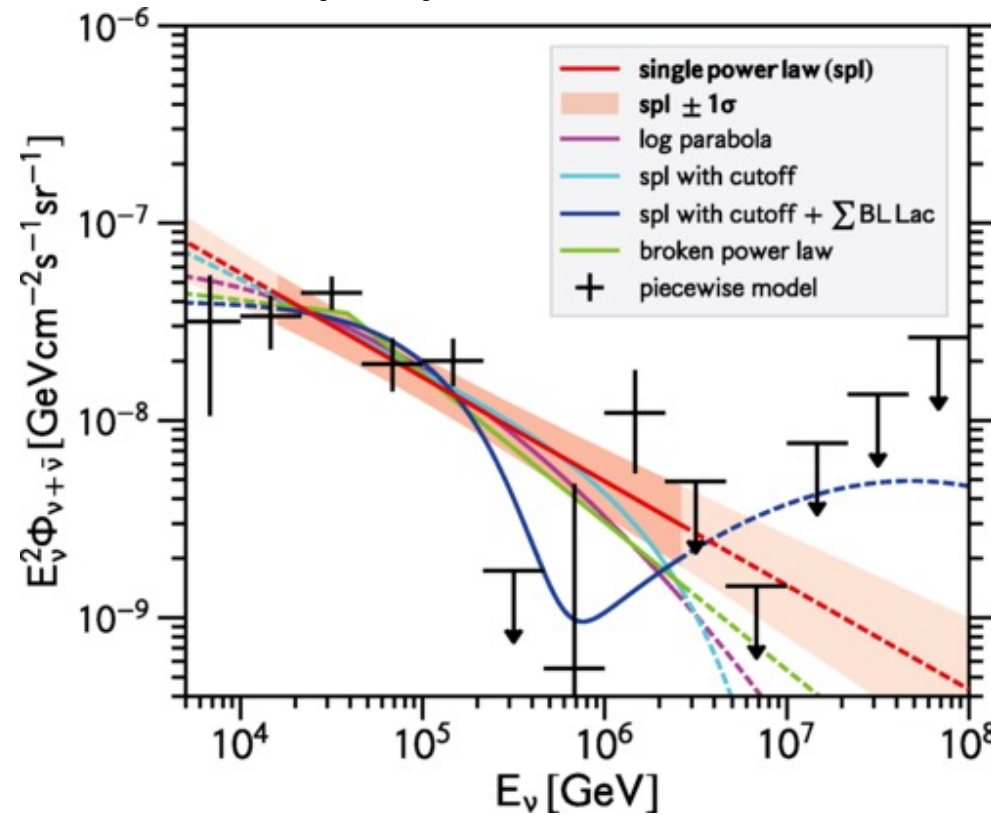
All other CC/NC/Glashow  $\nu$   
interaction (\*)

JINST 16 (2021) P07041  
JINST 9 (2014) P03009

Astro  $\nu$  : Atm  $\nu$  : Atm  $\mu$   
1 :  $10^4$  :  $10^{10}$

(\*) Actually  $\nu_\tau$  CC interactions may  
have complicated topologies

# A diffuse flux of astrophysical neutrinos



PRL 125 (2020) 121104

Observed with multiple methods between  $\sim 10$  TeV and  $\sim 10$  PeV.

Isotropic  $\rightarrow$  extragalactic

Consistent with standard neutrino oscillations over astrophysical baselines



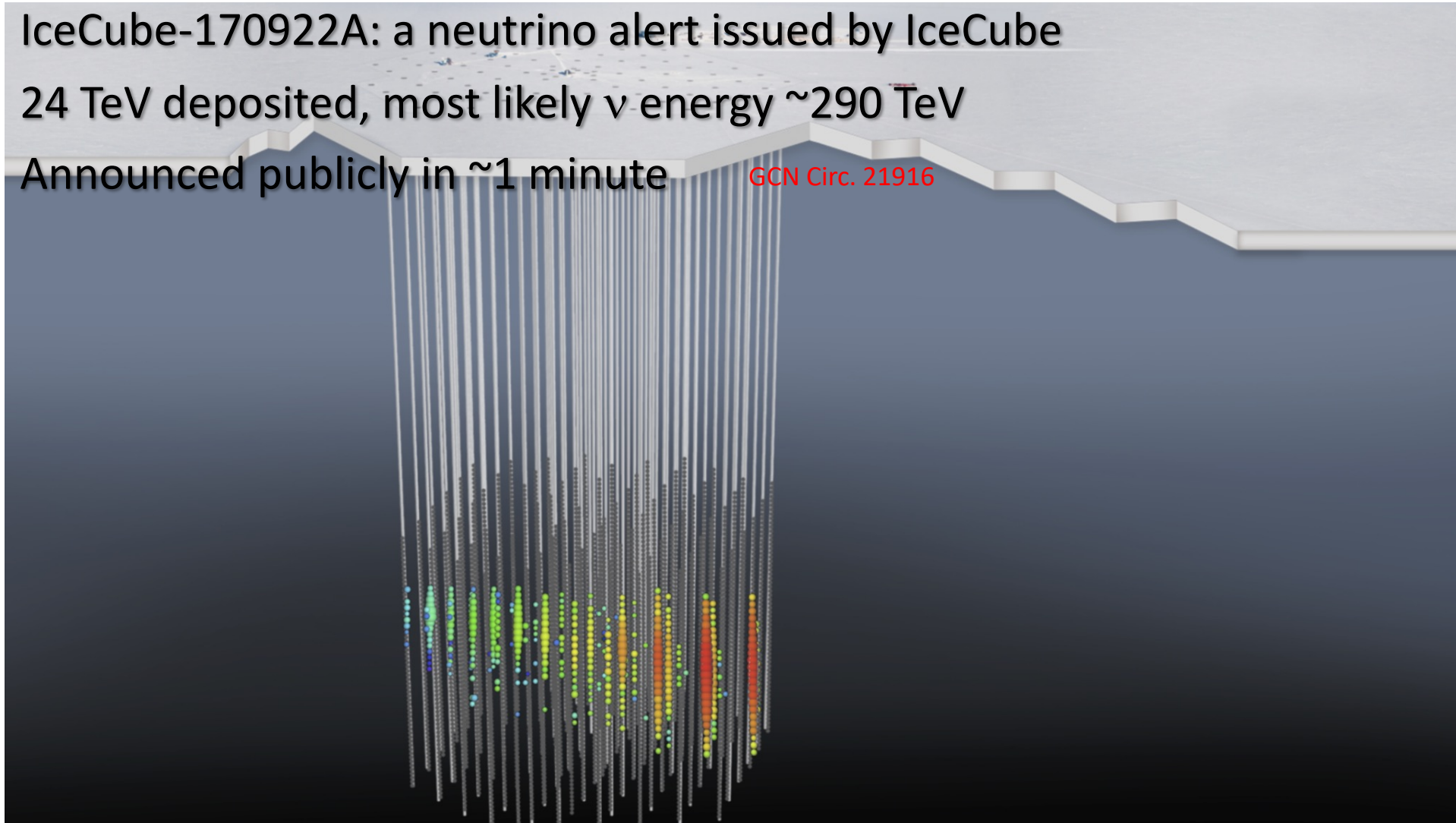
# TXS 0506+056: A candidate neutrino source

IceCube-170922A: a neutrino alert issued by IceCube

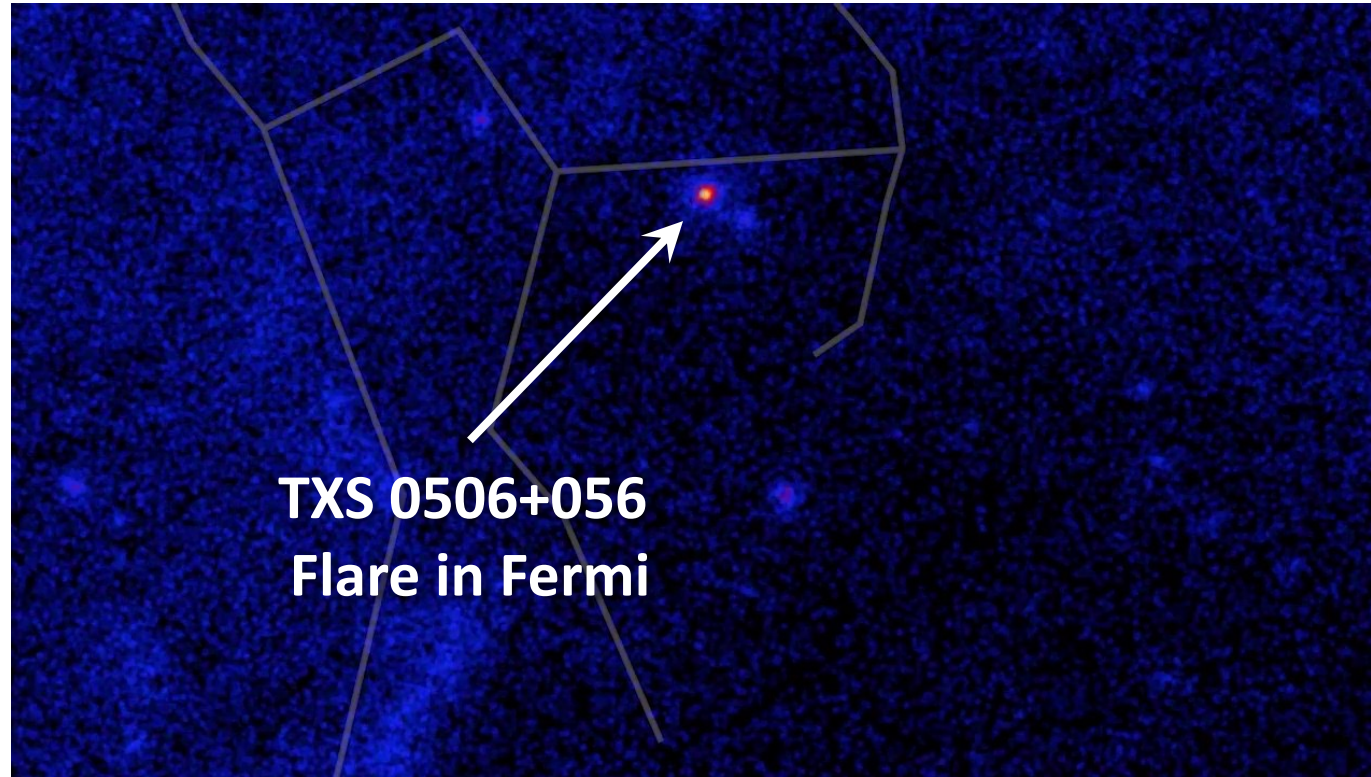
24 TeV deposited, most likely  $\nu$  energy  $\sim 290$  TeV

Announced publicly in  $\sim 1$  minute

GCN Circ. 21916



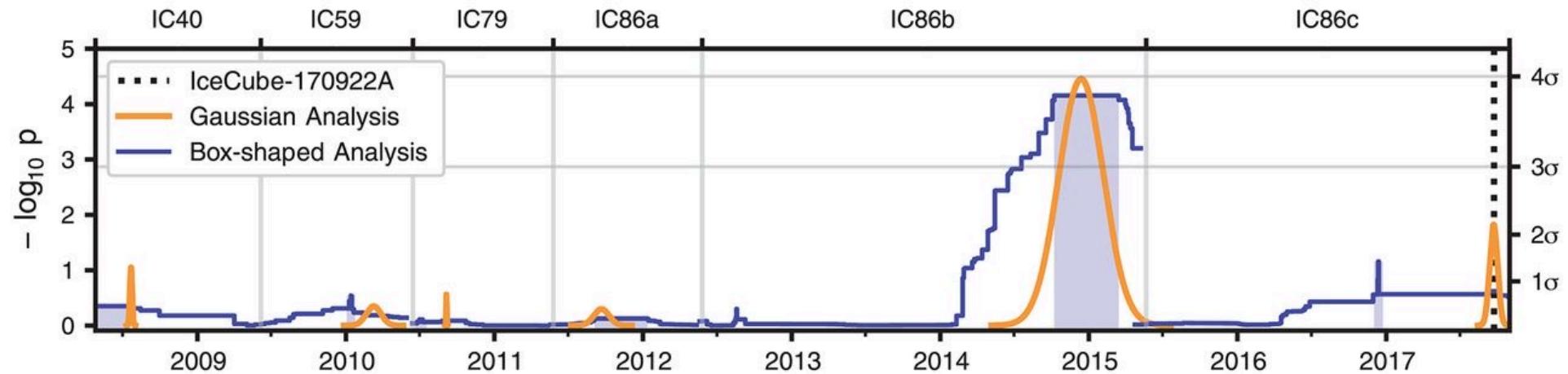
# TXS 0506+056: A candidate neutrino source



Fermi and MAGIC identify a spatially coincident flaring blazar, TXS 0506+056  
Accidental correlation ruled out at  $3\sigma$ .

Science 361 (2018) eaat1378

# TXS 0506+056: A candidate neutrino source



3.5  $\sigma$  evidence for a neutrino flare in late 2014 – early 2015 (long before IceCube-170922A)

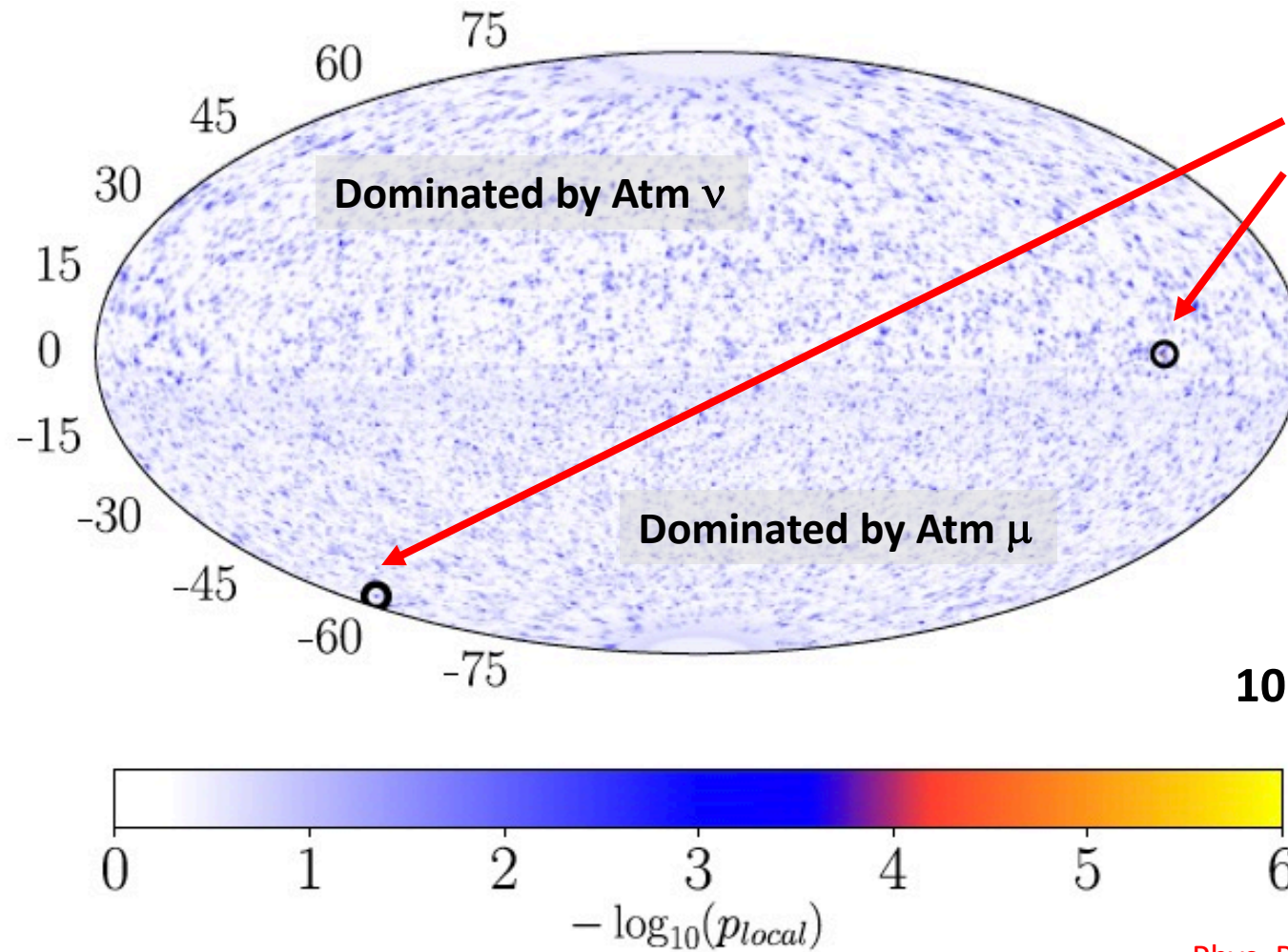
- 158 day duration (box)
- 110 day duration (Gaussian)

13 excess neutrinos above atmospheric background

[Science 361 \(2018\) 147-151](#)



# Neutrino point sources: self correlation



Most Significant  
Hotspots

Post-trial P- values:

$9.9 \times 10^{-2}$  (North)

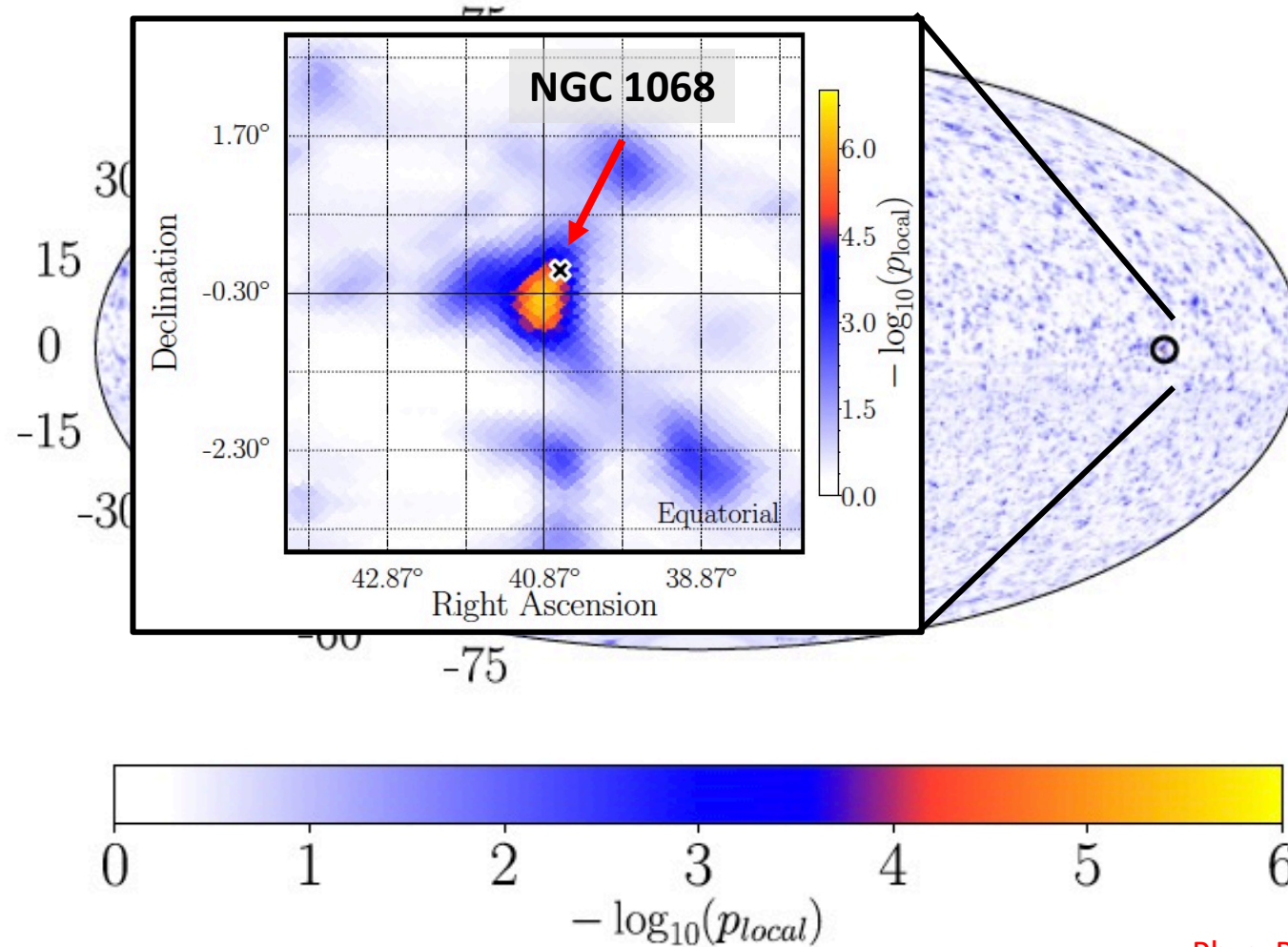
0.75 (South)

Results use

10 years of IceCube data

Phys. Rev. Lett. 124 (2020) 051103

# Neutrino point sources: source list



Most significant object, out of 110 likely  $\nu$ -emitters, correlated with IceCube data:

## NGC 1068

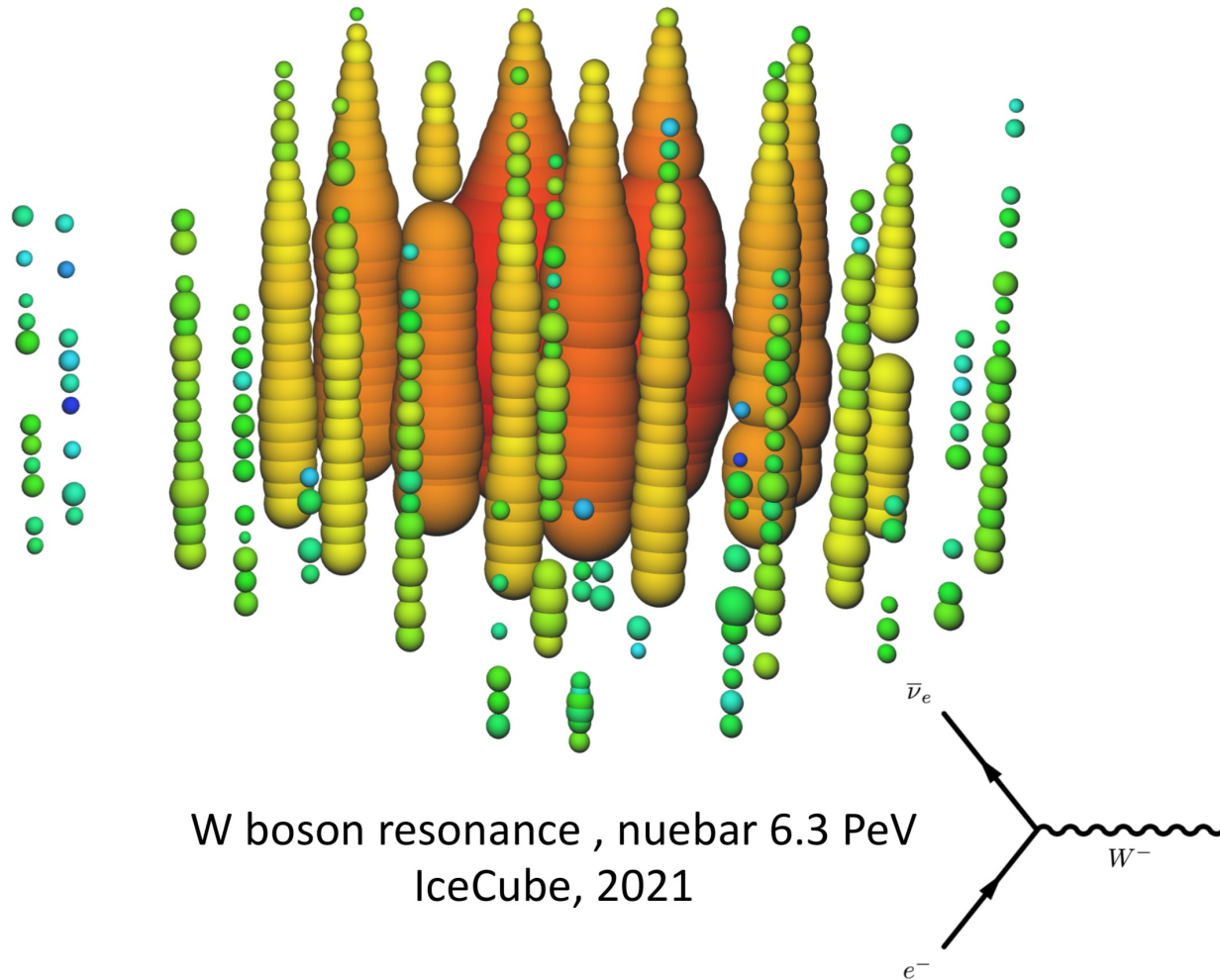
Post-trial:  $2.9 \sigma$  ( $4.1 \sigma$  pre-trial)

Within  $0.3^\circ$  of most likely northern hotspot

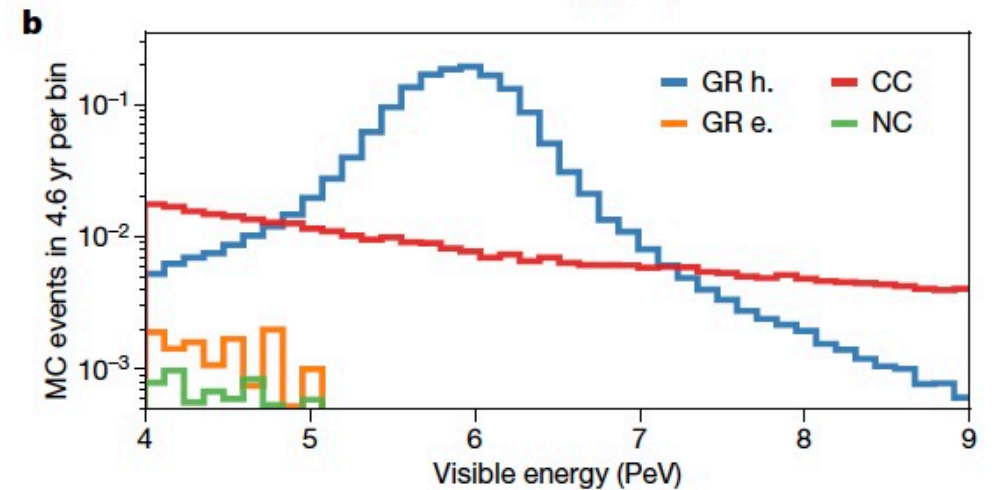
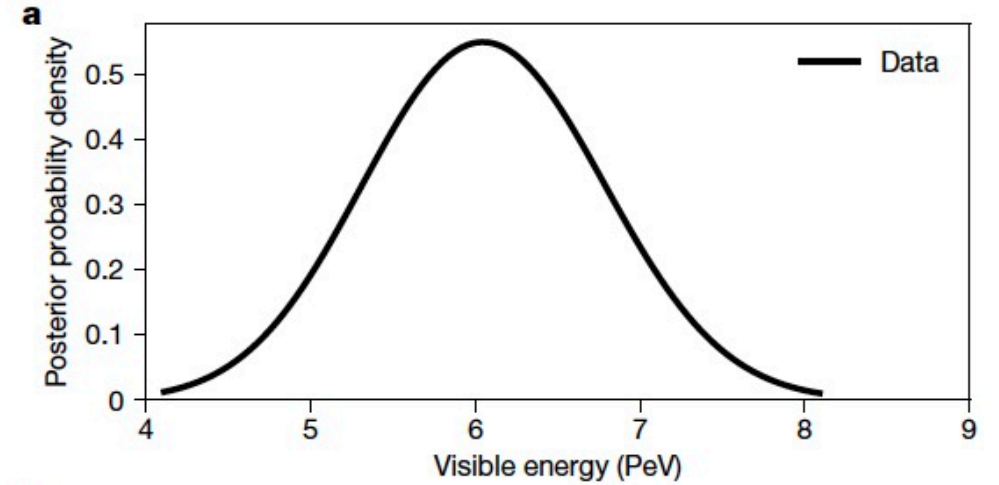
NGC 1068 is a starburst and a Seyfert II galaxy.

Phys. Rev. Lett. 124 (2020) 051103

# A neutrino at the Glashow-resonance energy



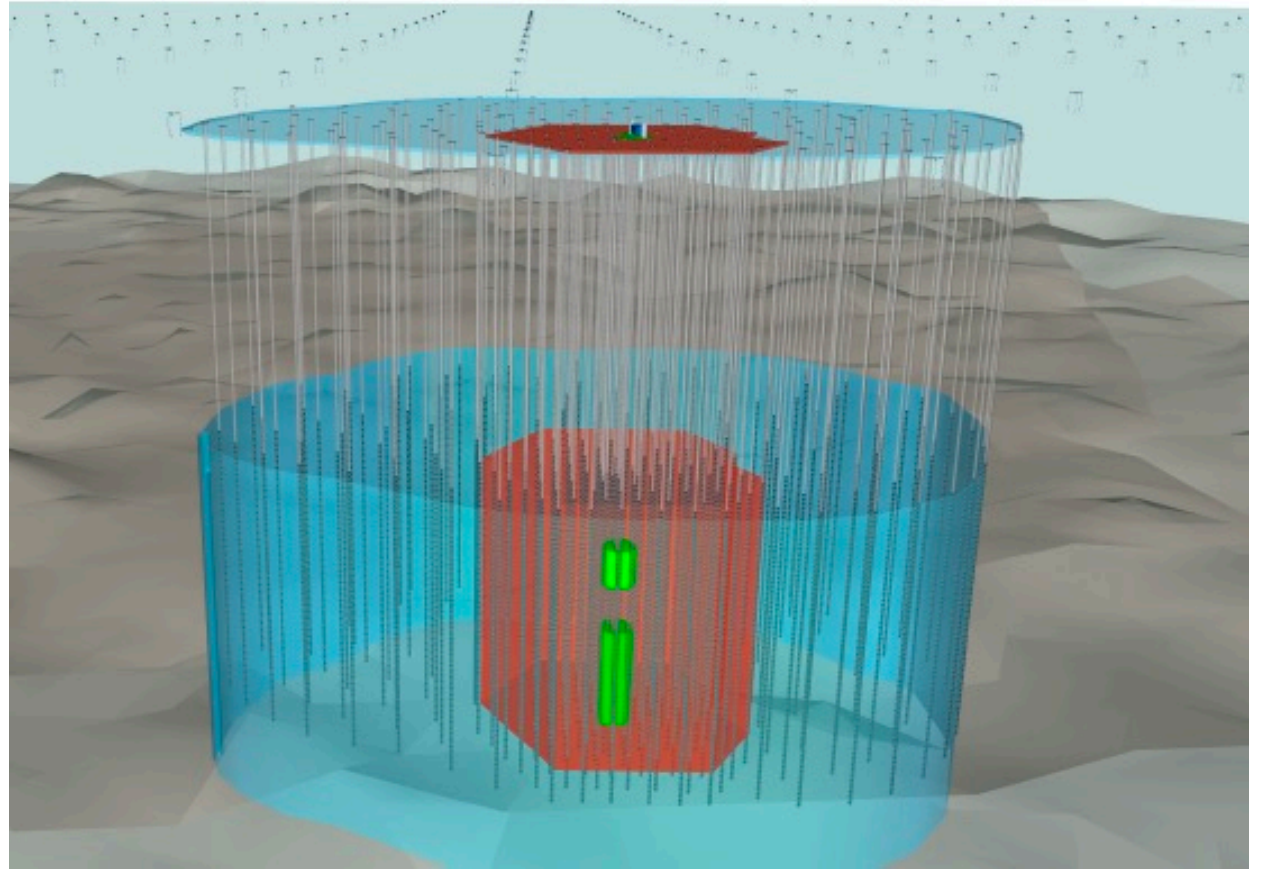
Cascade reconstructed energy:  $6.05 \pm 0.72$  PeV



Nature 591 (2021) 220–224



# IceCube-Gen2



J.Phys.G 48 (2021) 6, 060501

8x the instrumented volume of IceCube

One order of magnitude more astrophysical neutrinos

5x better sensitivity to point sources

# Thank you!

## THE ICECUBE COLLABORATION

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

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**GERMANY**  
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icecube.wisc.edu