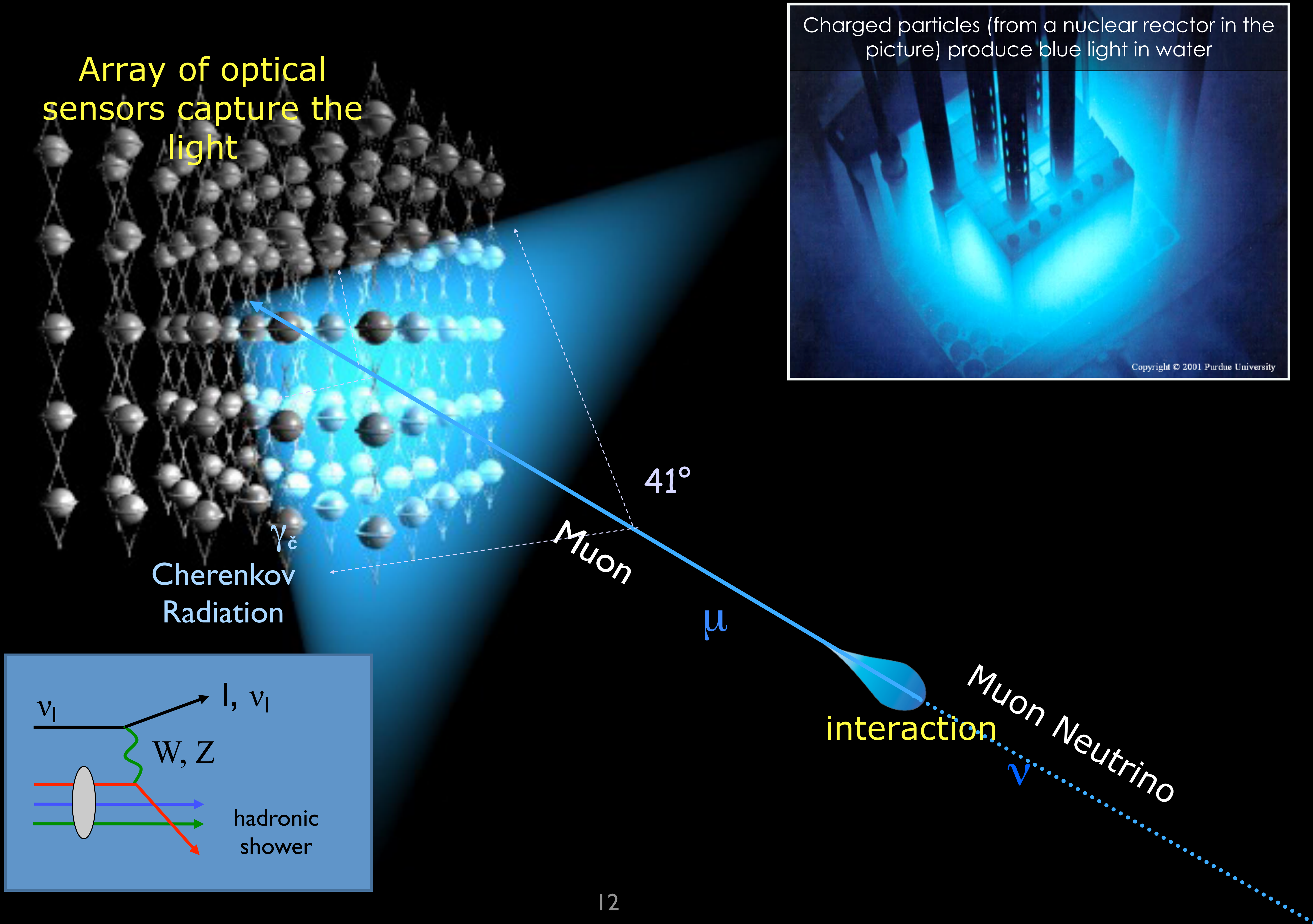
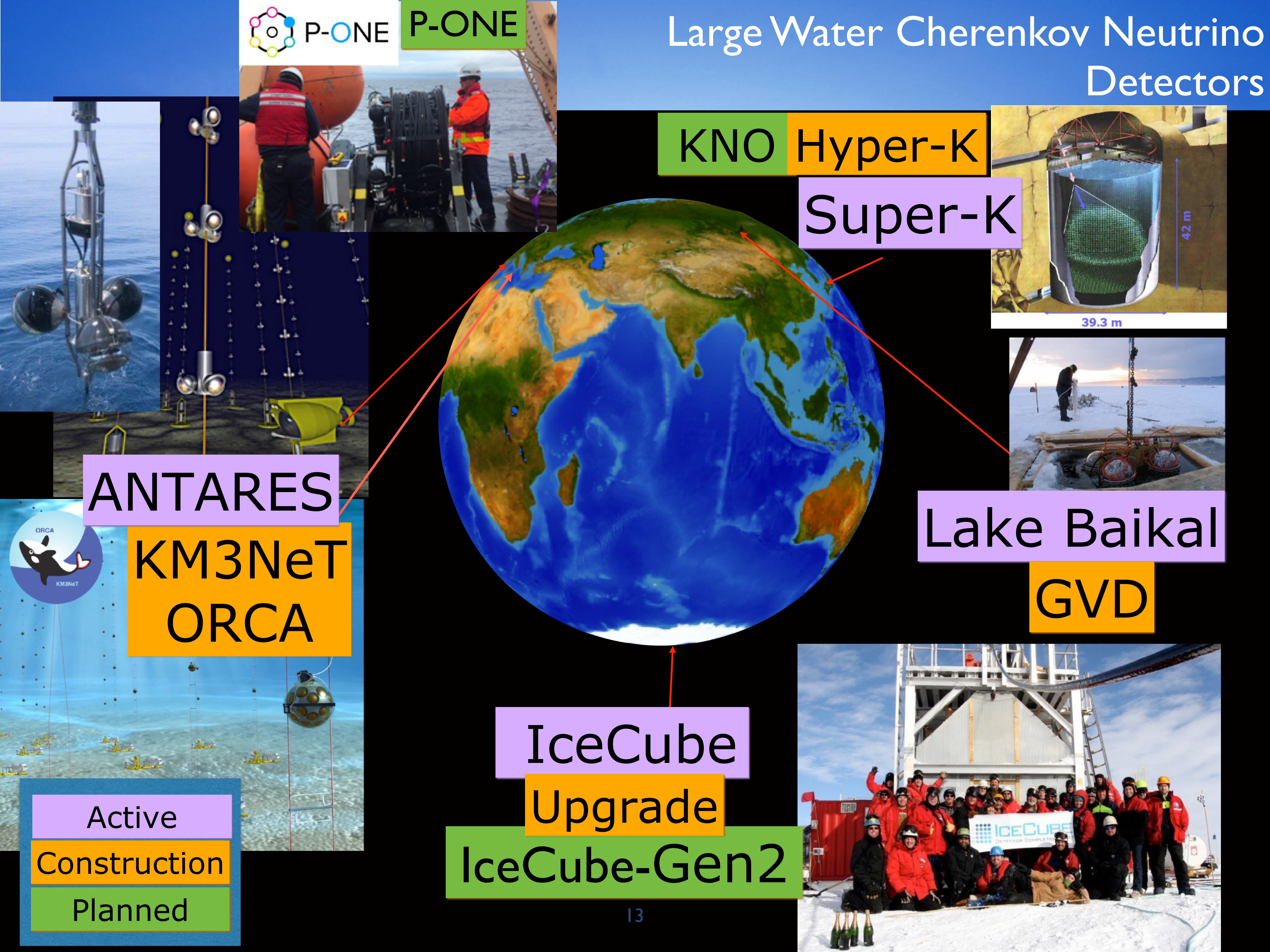
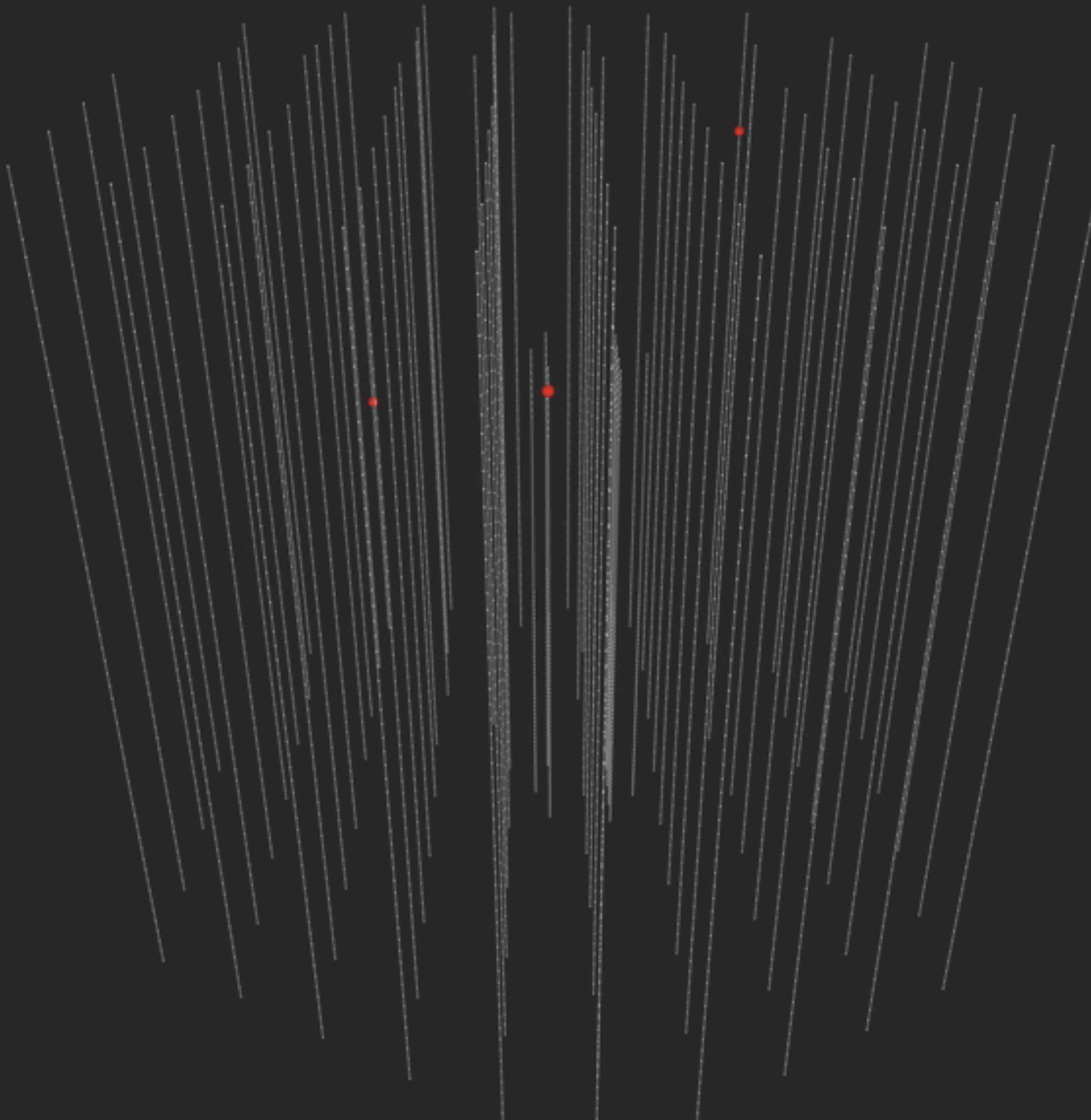
Neutrino Telescopes

Principle of an optical Neutrino Telescope

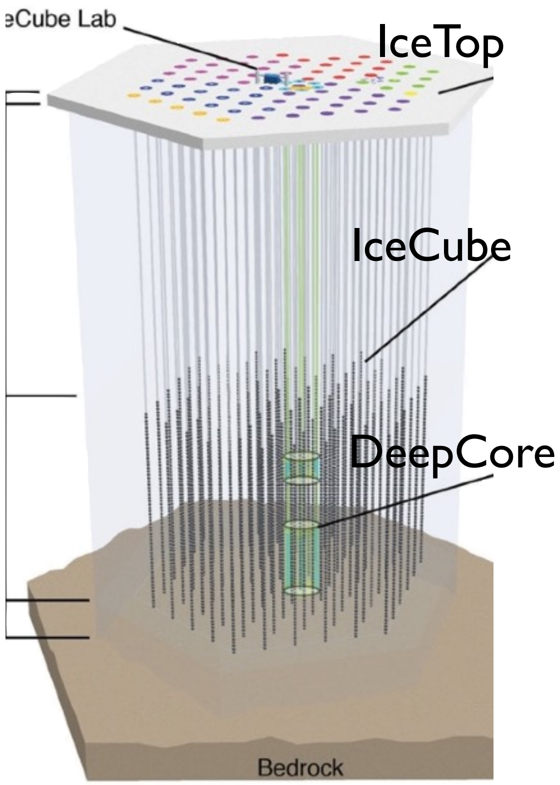


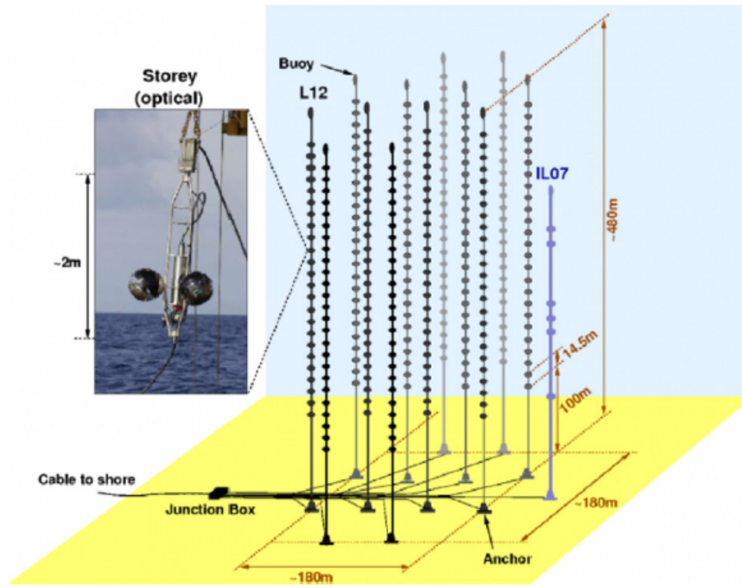
Large Water Cherenkov Neutrino Detectors

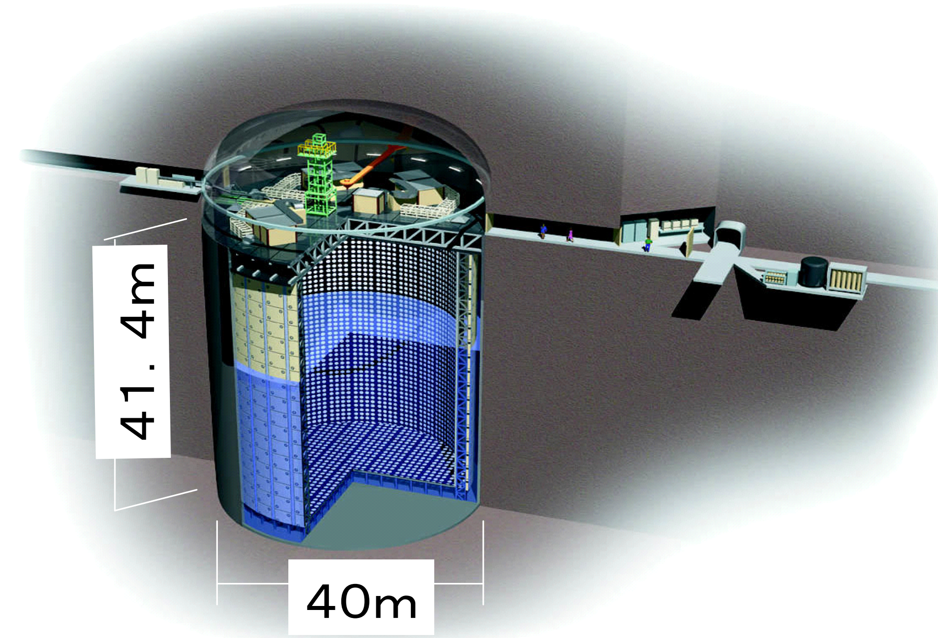




Atmospheric Neutrino Telescopes / Detectors







- **IceCube** at the Geographic South Pole
- 5160 10"PMTs in Digital optical modules distributed over 86 strings instrumenting ~1km³
- Physics data taking since 2007 ; Completed in December 2010, including **DeepCore** low-energy extension

- **ANTARES** is located at a depth of 2475 m in the Mediterranean Sea, 40 km offshore from Toulon
- Consists 885 10"PMTs on 12 lines with 25 storeys each.
- Detector was competed in May 2008 ; Phyiscs data taking since 2007

- **Super-Kamiokande** at Kamioka uses 11K 20" PMTs
- 50kt pure water (22.5kt fiducial) water-cherenkov detector
- Operating since 1996

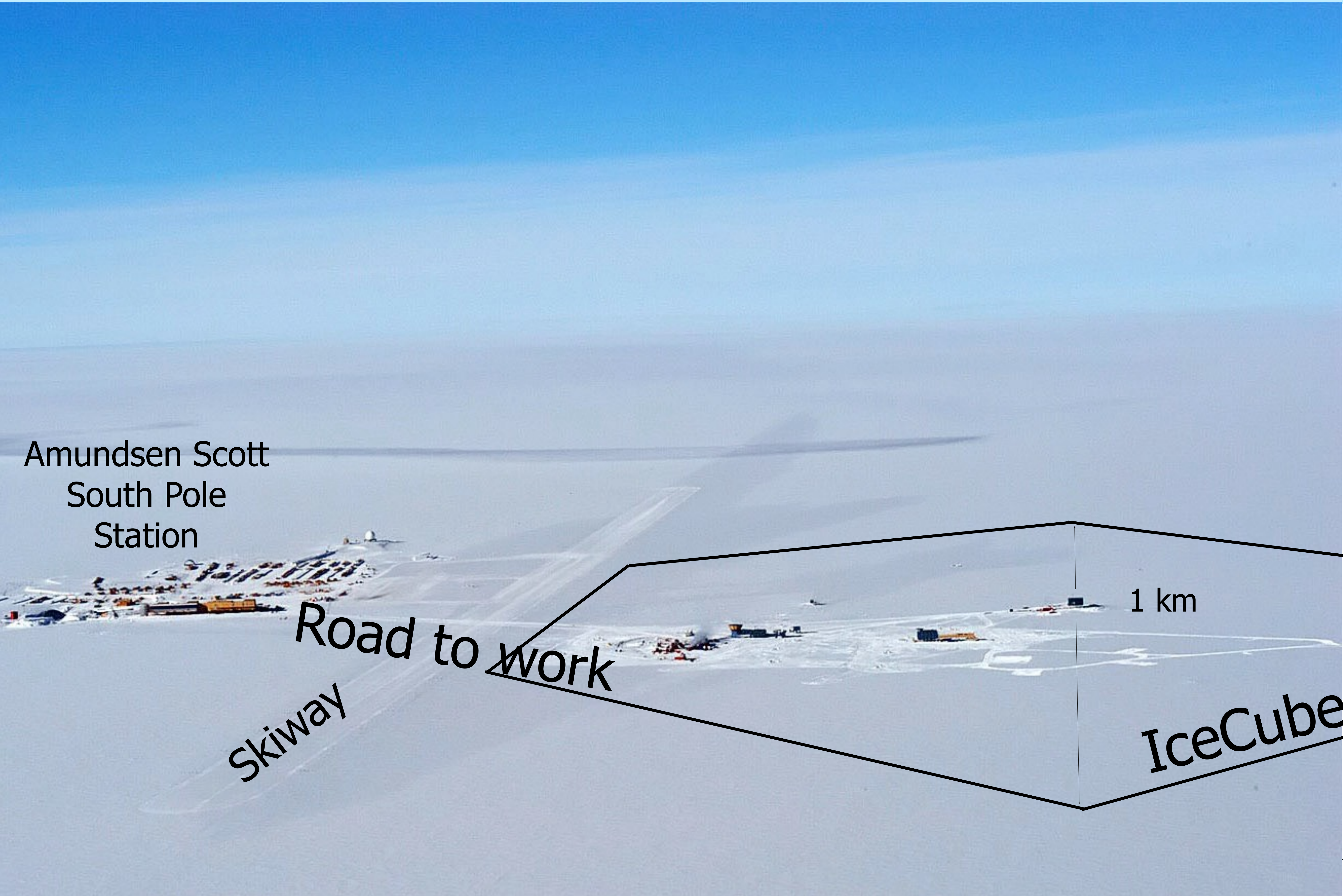
Detect Cherenkov light from neutrino interaction products

Main backgrounds: Atmospheric neutrino, atmospheric muons (down-going)

The IceCube Neutrino Telescope


SOUTH
90
SOUTH POLE
NSF
JARY 1. 2008

Laboratory at the South Pole



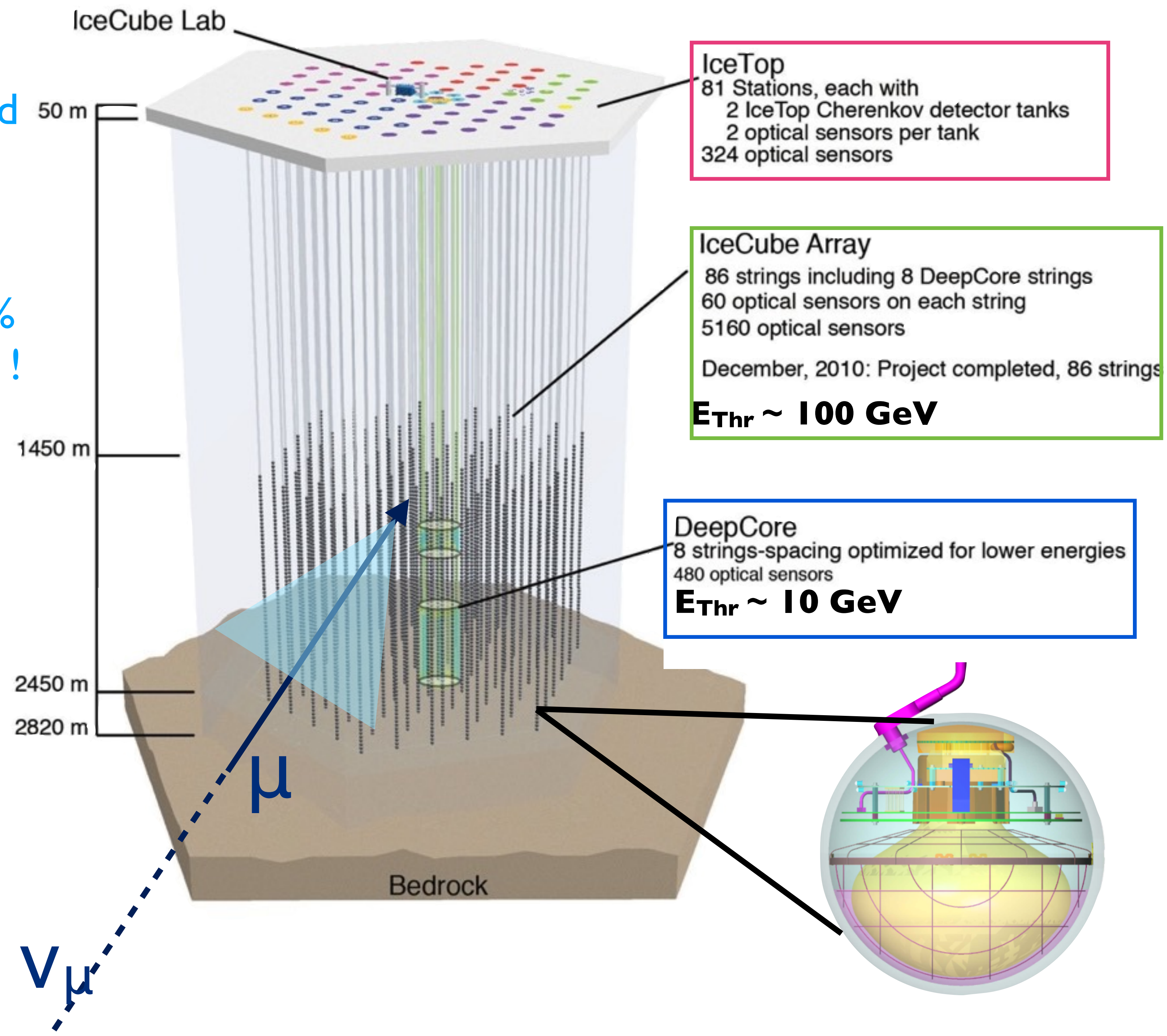
The IceCube Neutrino Telescope

- Gigaton Neutrino Detector at the Geographic South Pole
- 5160 Digital optical modules distributed over 86 strings
- Completed in December 2010
- Extremely stable: >99% uptime and 98% of sensor modules in perfect condition !
- Neutrinos are identified through Cherenkov light emission from secondary particles produced in the neutrino interaction with the ice

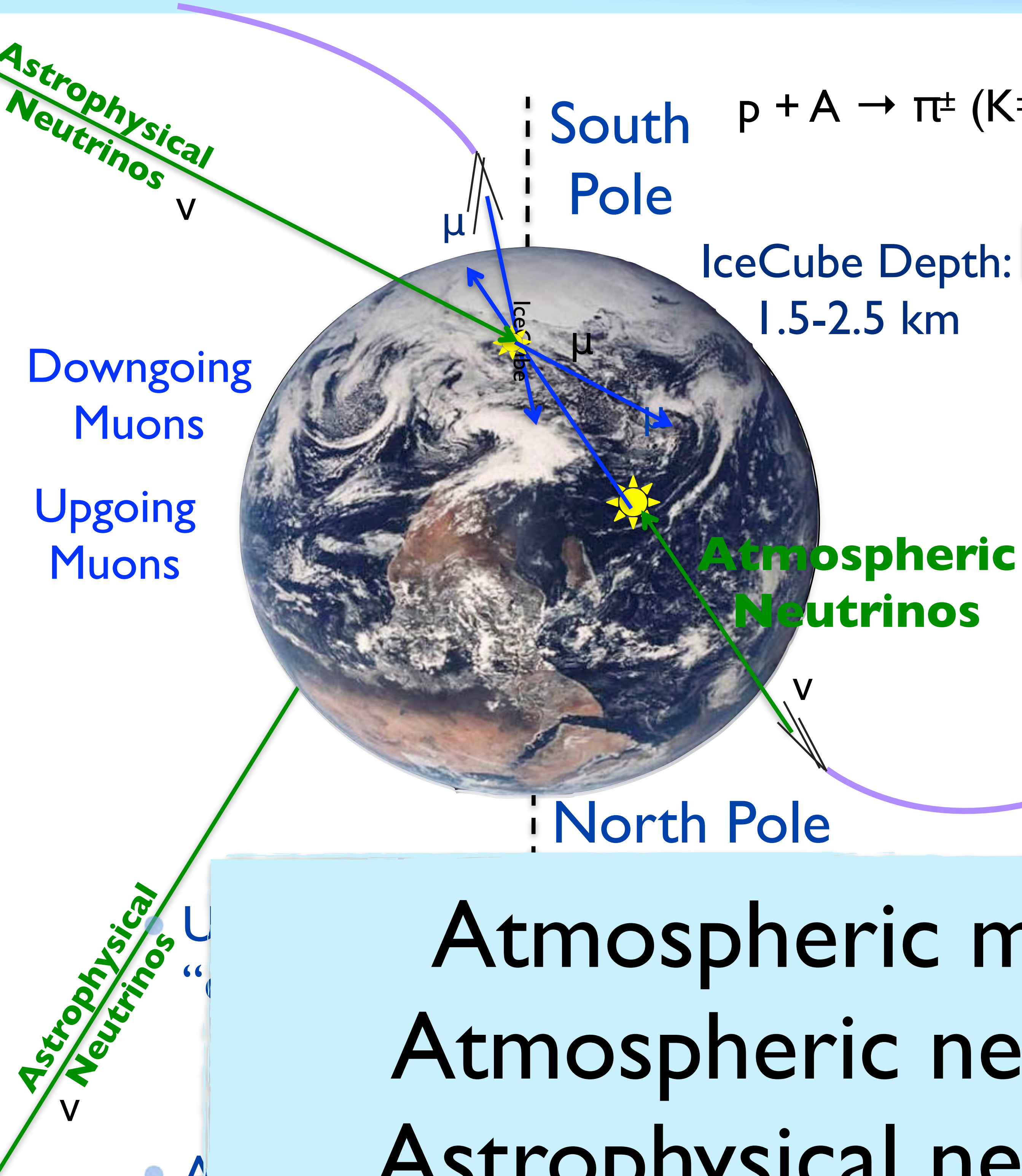
〈이 기사는 2014년 01월 06일자 신문 23면에 게재되었습니다.〉

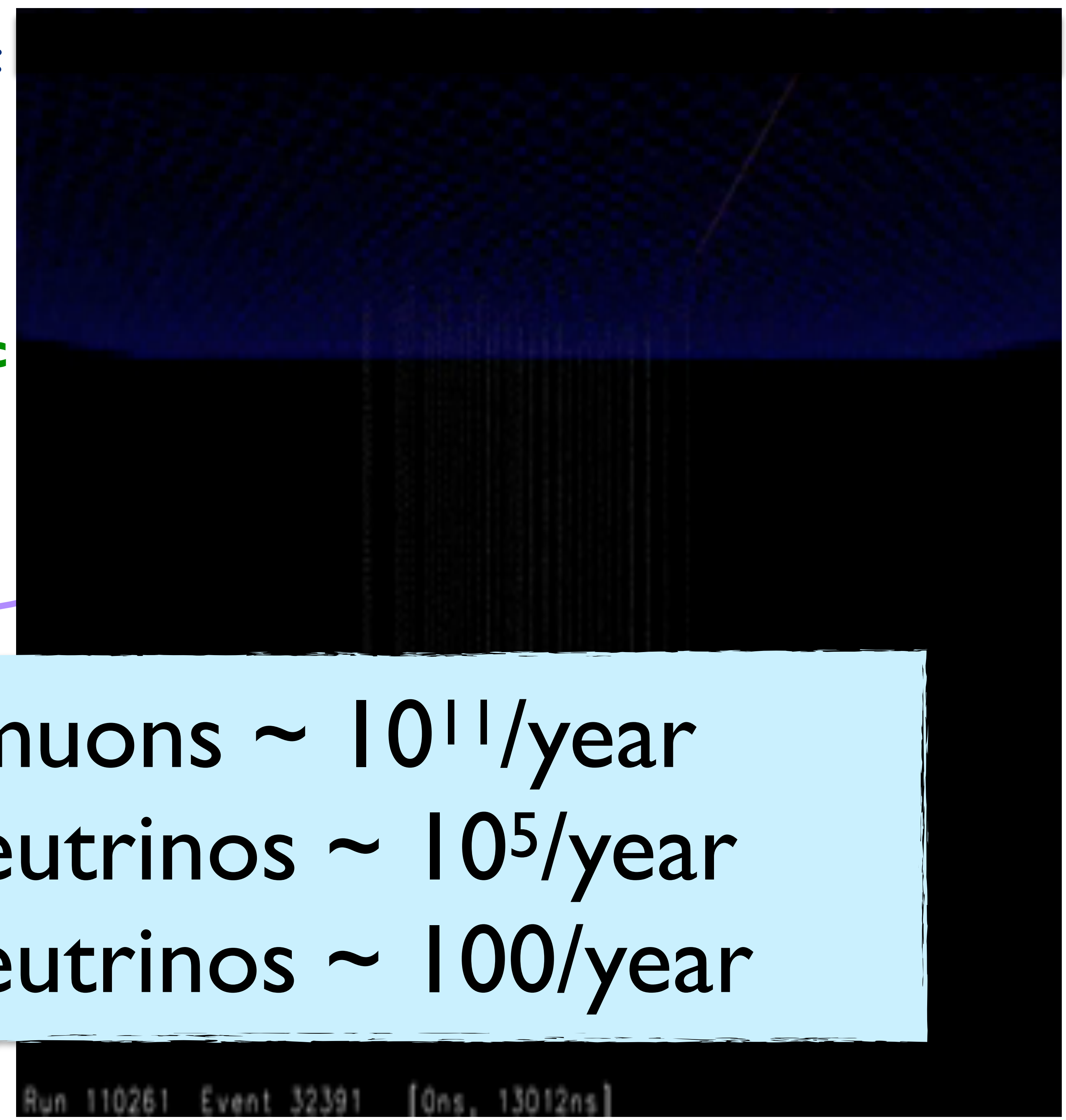
“한국 ‘세계적 리더’ 될 좋은 기회”

기초과학 투자 의지 활발, 한국에 새 연구 터전 둥지.. 연구자·학생 영입해 연구



Signals in IceCube





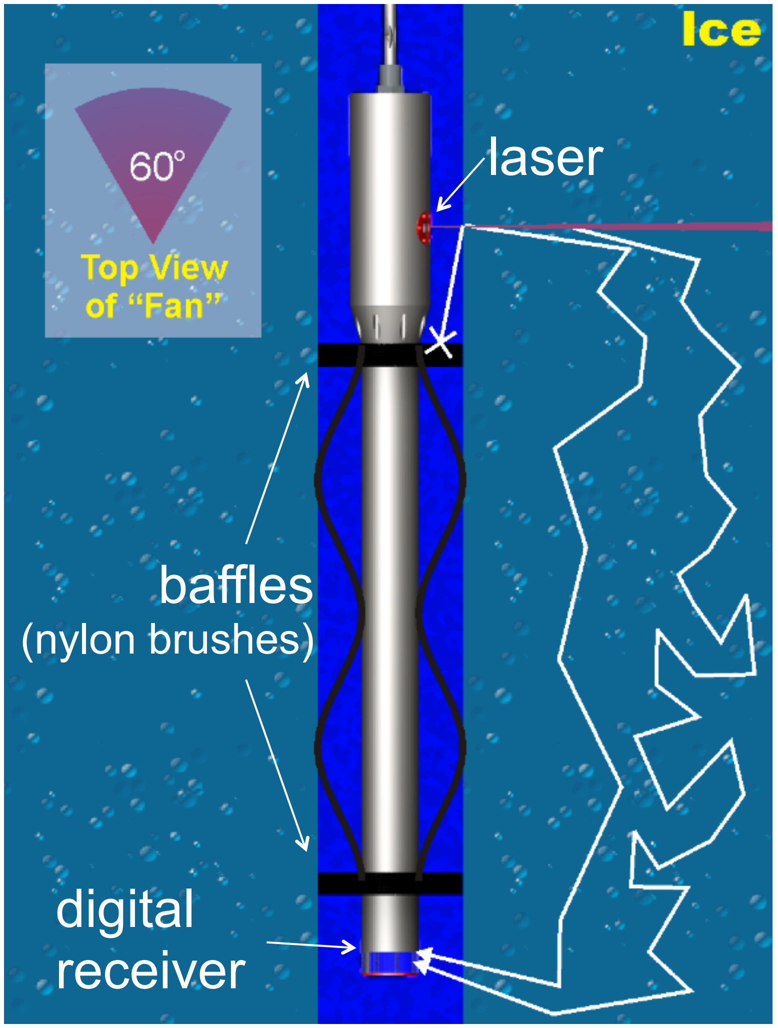
Atmospheric muons ~ 10^{11}/year

Atmospheric neutrinos ~ 10^{5}/year

Astrophysical neutrinos ~ 100/year

extra terrestrial neutrino fluxes

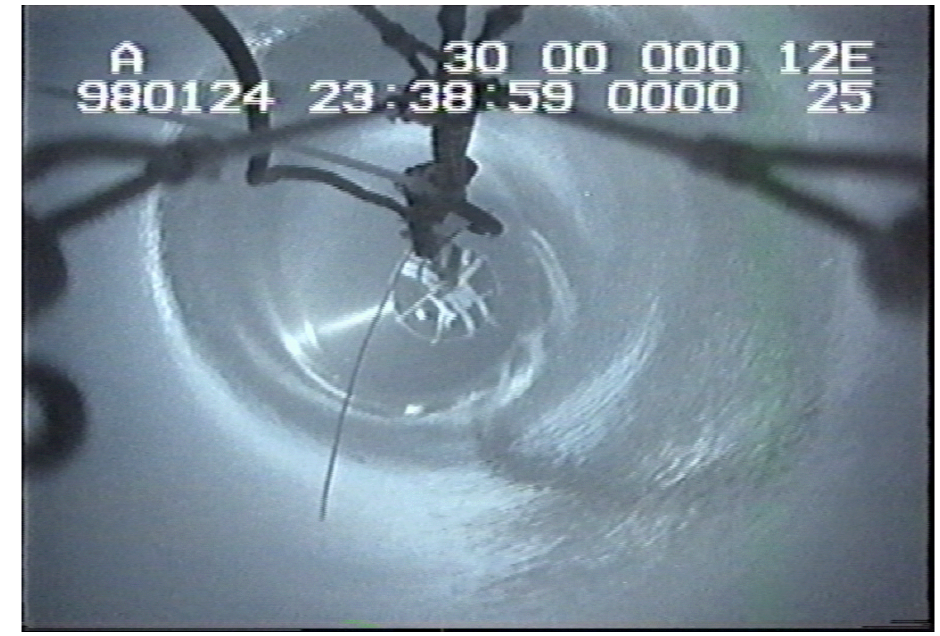
The Ice

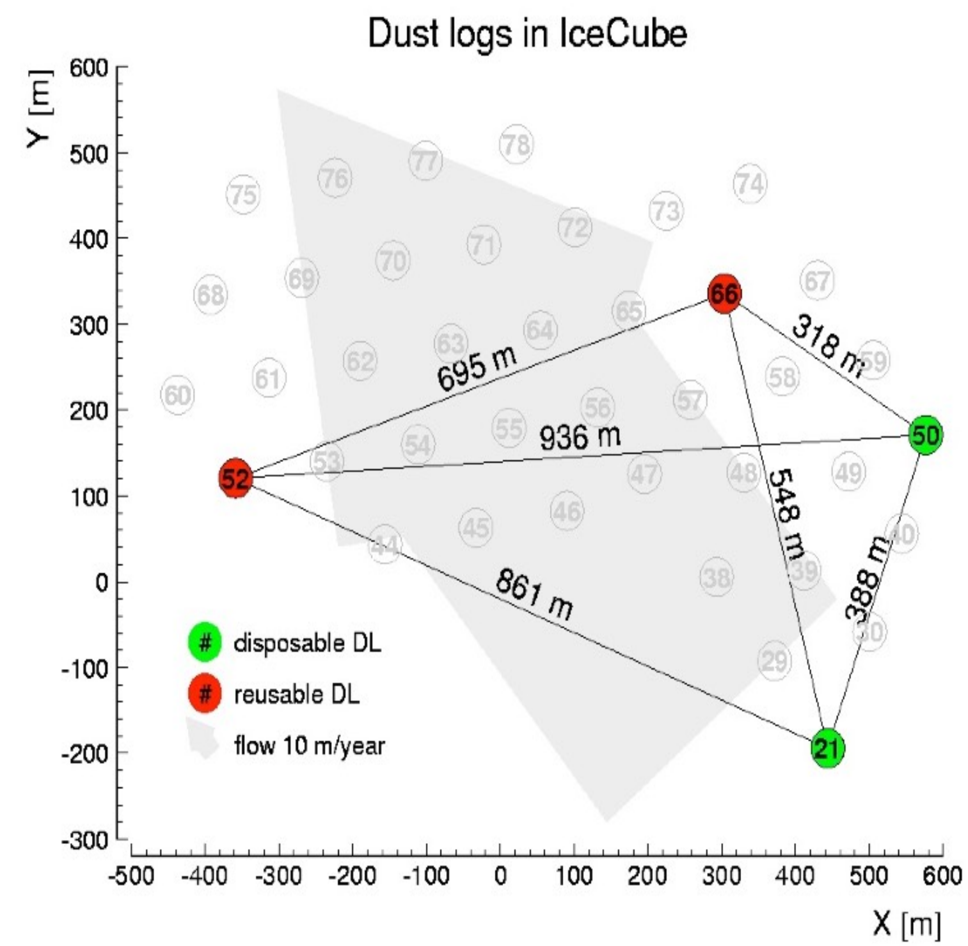


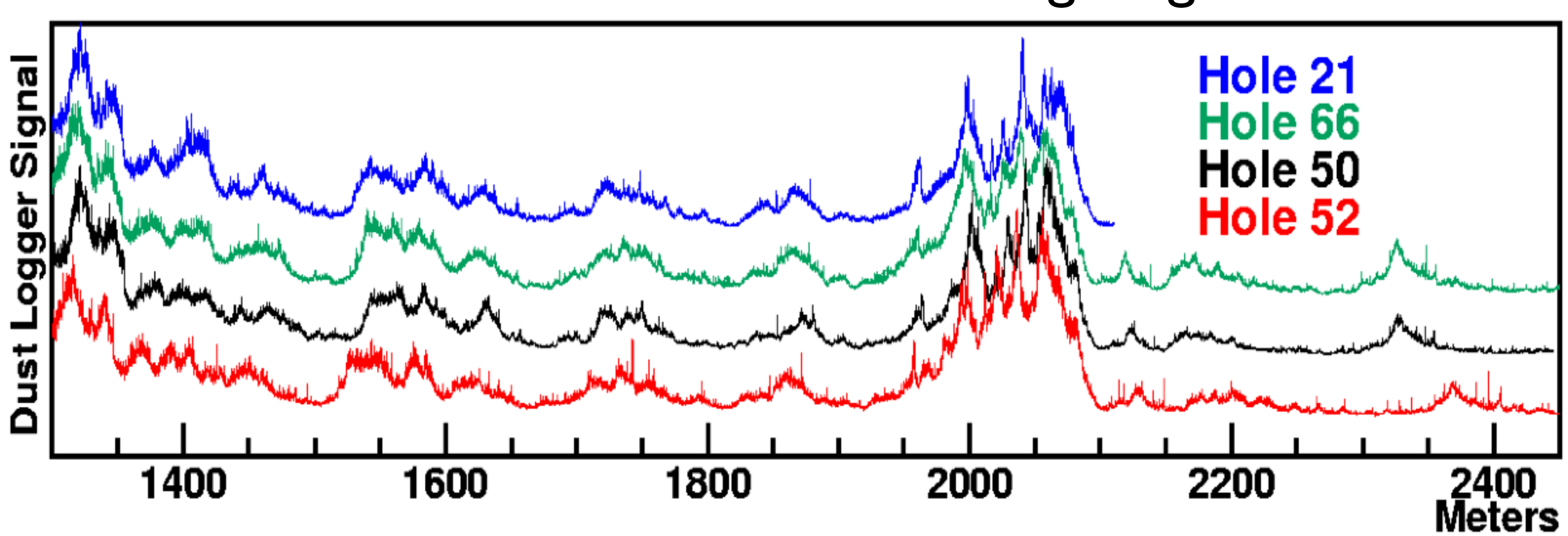
Major calibration efforts resulted in a very precise understanding of the ice surrounding the IceCube detector

- Calibration Sources:
  - 12 LED flashers on each DOM
  - In-Ice Calibration Laser
  - Cosmic Rays
  - One pair of Camera DOMs

absorption length ~ 210m
scattering length ~20-40m







DISCO: An optical instrument to calibrate neutrino detection in complex media

PROCEEDINGS OF SCIENCE

Volume 444 - 38th International Cosmic Ray Conference (ICRC2023) - Neutrino Astronomy & Physics (NU)

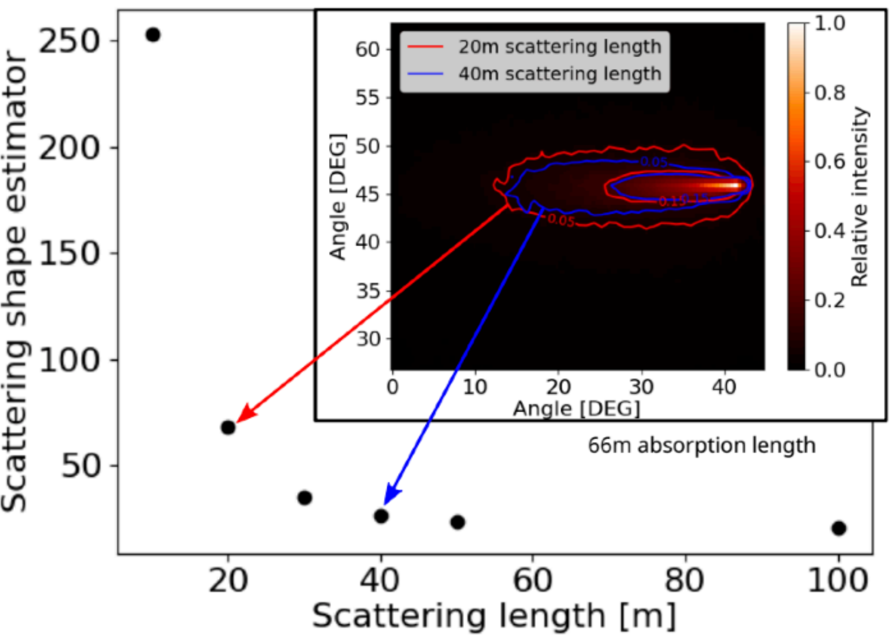
PoS-ICRC2023-1139

DISCO: An optical instrument to calibrate neutrino detection in complex media

C. Rott*, S. BenZvi, M. DuVernois, K. Golden, B. Jones and C. Toennis

Full text: pdf

Pre-published on: August 09, 2023



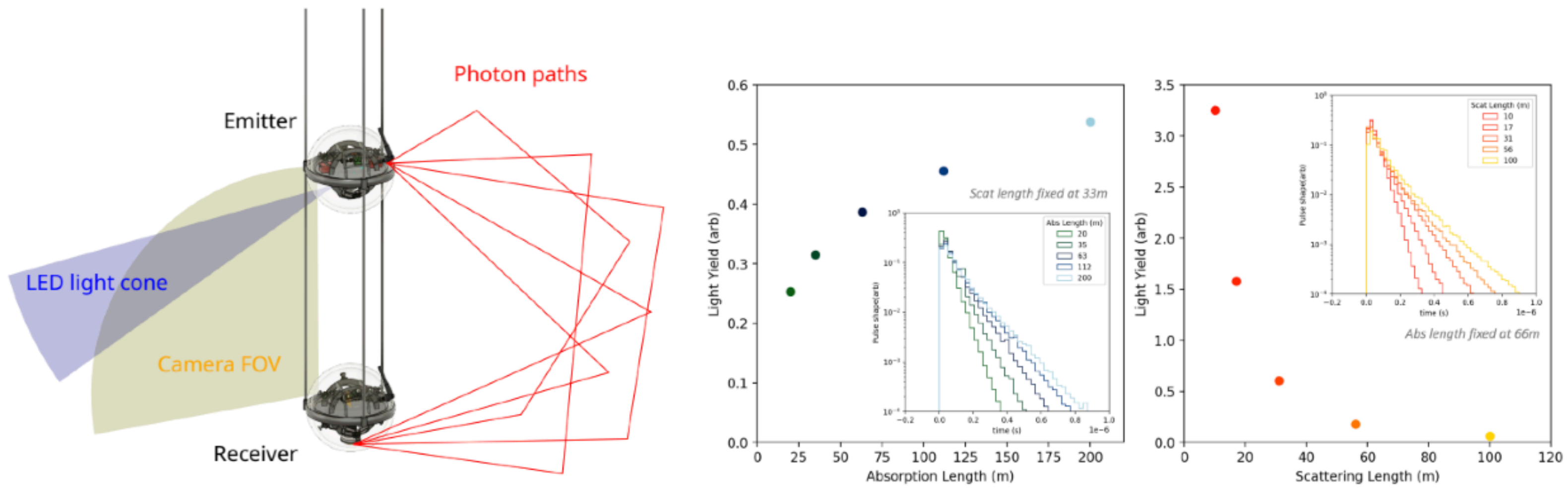


Figure 1: Left: Concept of DISCO. LED light cone observed by cameras (left side) and Laser observed by the PMT logging system (right side). Right: Absorption and scattering effects on pulse shape and returned light intensity for the pulsed laser measurement.

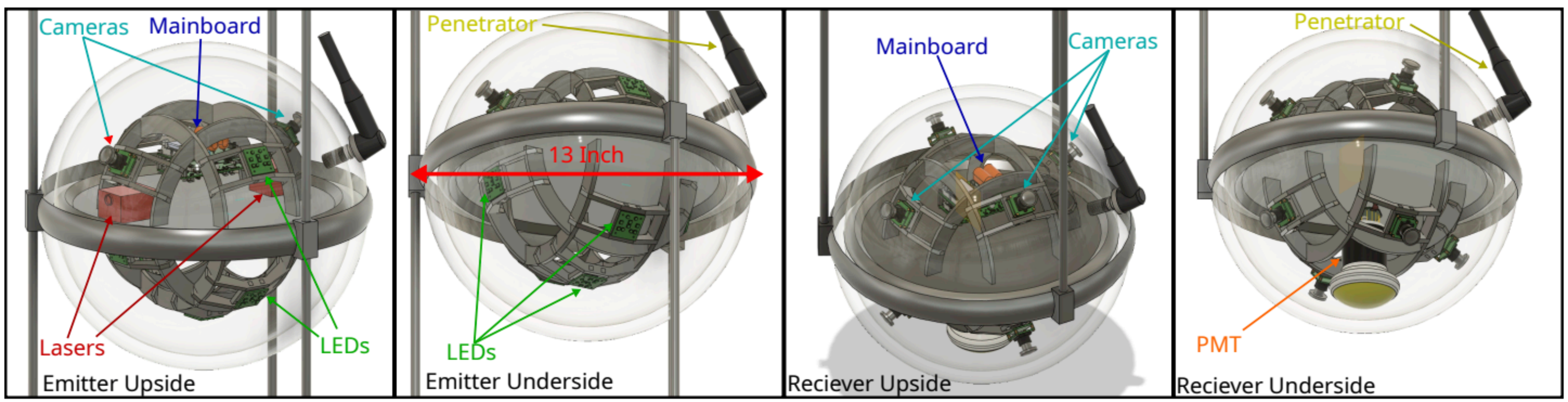


Figure 2: A 3D model of the basic design concept for the emitter and receiver module.

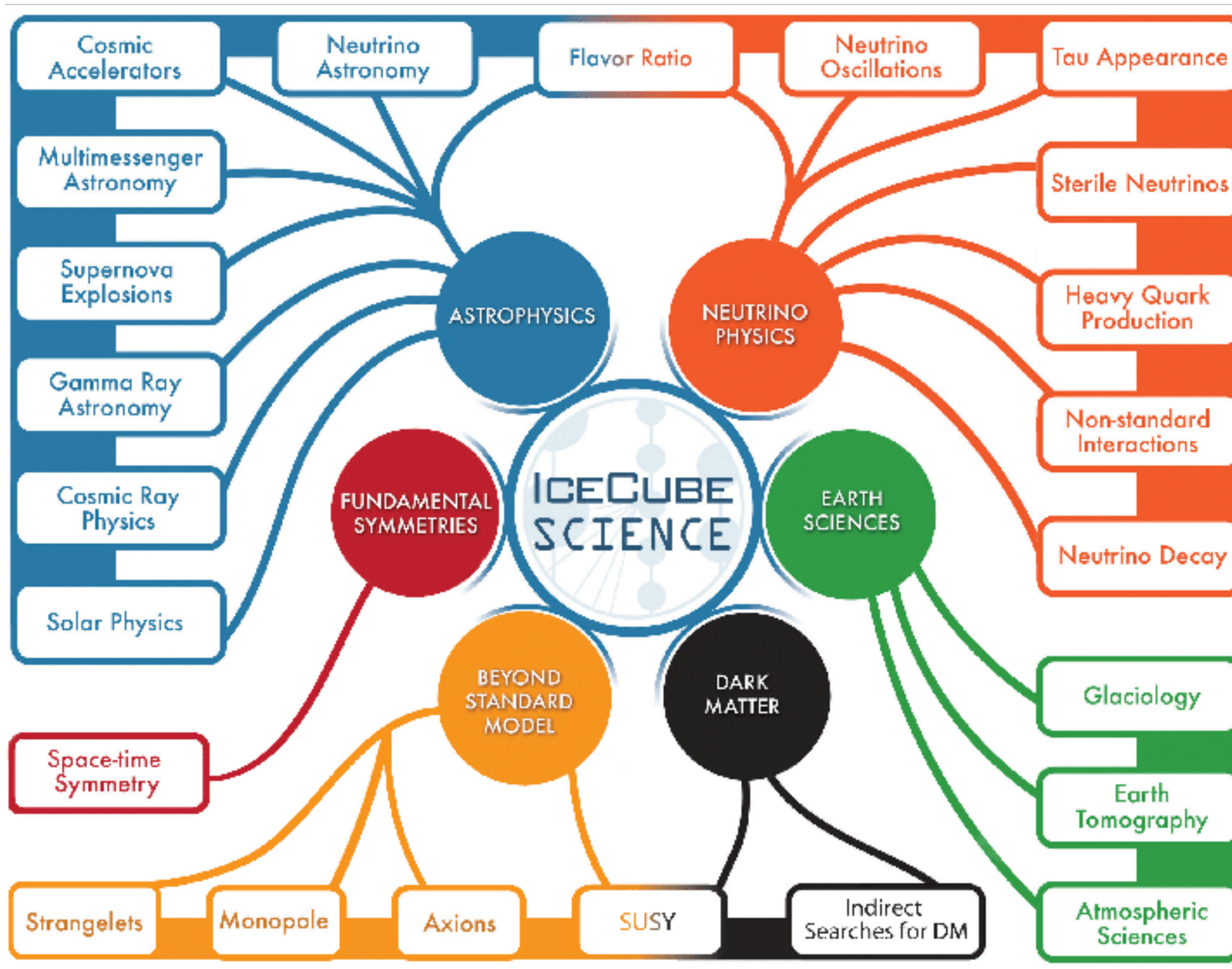
Selected Results and Science Program

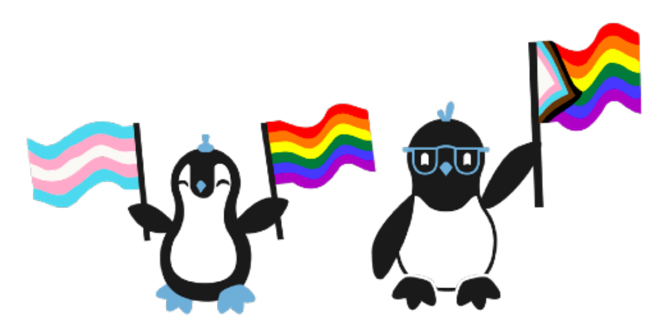
Neutrino Telescope Science

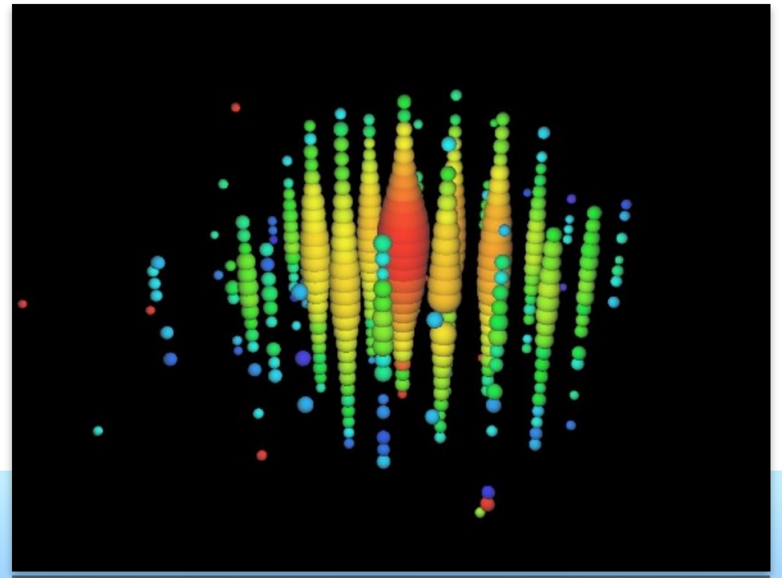
Scientific Scope

- ASTROPHYSICS & NEUTRINO SOURCES
  - Point sources of ν's (SNR, AGN …), extended sources
  - Transients (GRBs, AGN flares …)
  - Solar Atmospheric Neutrinos
  - Diffuse fluxes of ν's (all sky, cosmogenic, galactic plane …)
- BSM PHYSICS & DARK MATTER
  - Indirect DM searches (Earth, Sun, Galactic center/halo)
  - Magnetic monopoles
  - Violation of Lorentz invariance
- PARTICLE PHYSICS
  - ν oscillations, sterile ν's
  - Charm in CR interactions
  - Neutrino Cross Sections
- COSMIC RAY PHYSICS
  - Energy spectrum around "knee", composition, anisotropy
- SUPERNOVAE (galactic/LMC)
- GLACIOLOGY & EARTH SCIENCE

Very diverse science program, with neutrinos from 10GeV to EeV, and MeV burst neutrinos



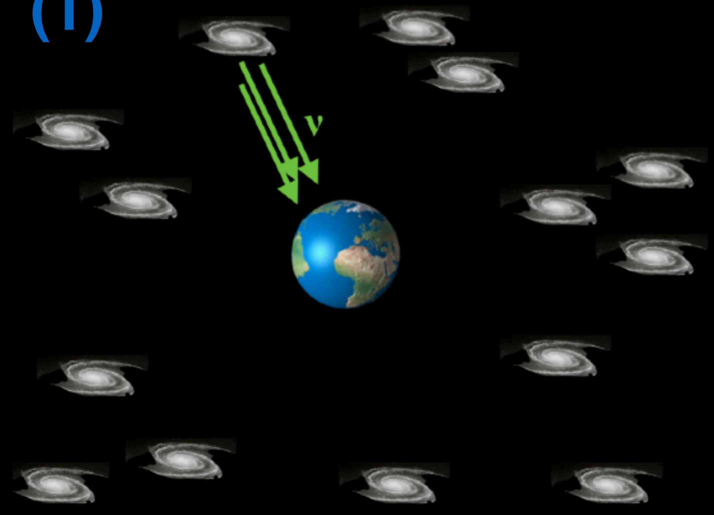




Astro-physical Neutrino Search

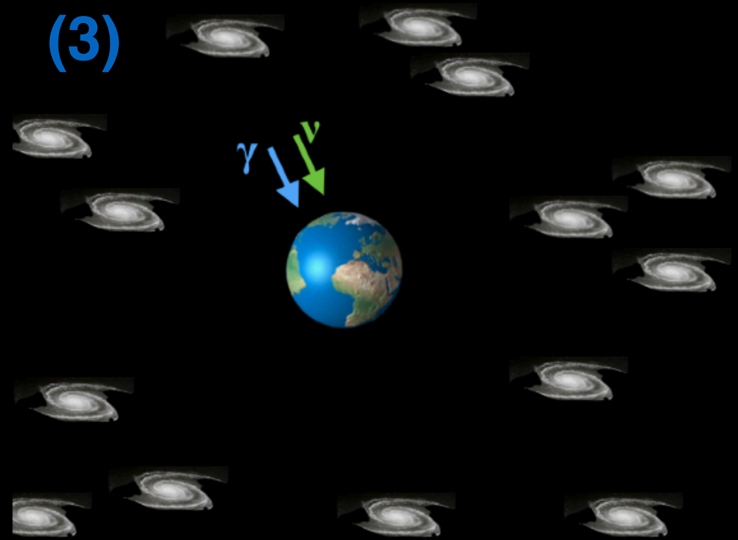
Finding astrophysical neutrinos

(1)

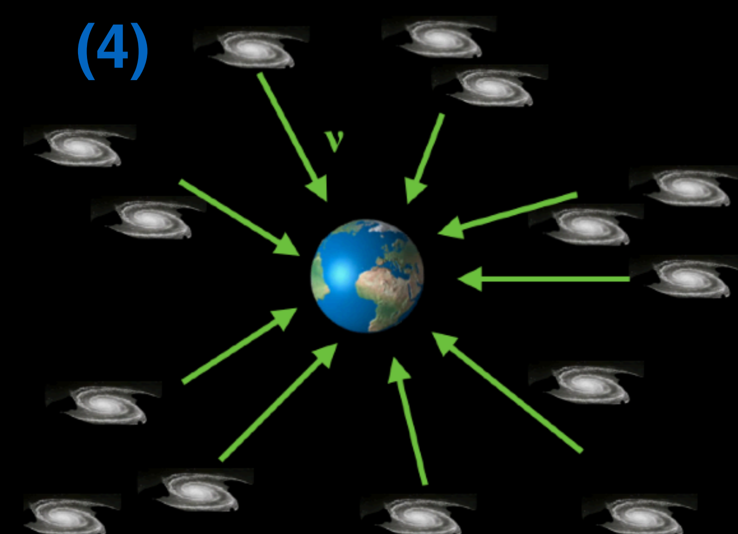


(2)

(3)



(4)



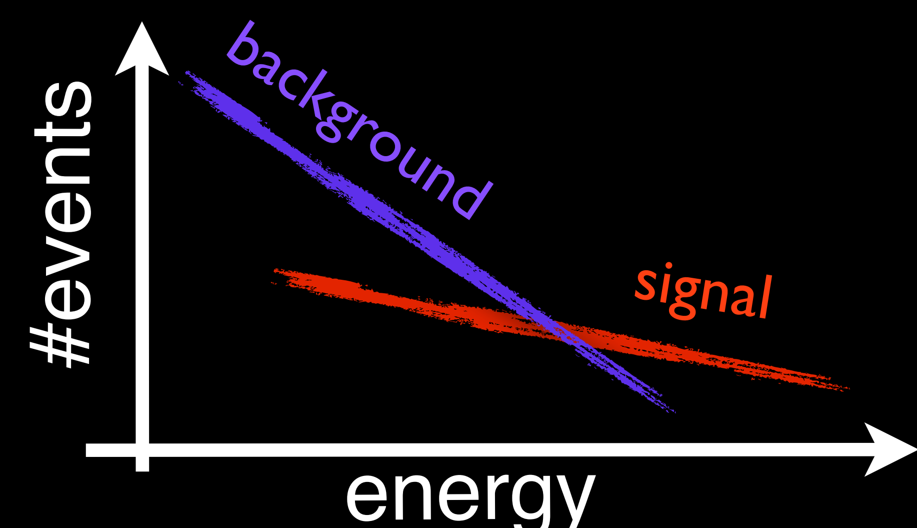
(1) Point source search
- Search for clustering of neutrinos from point in the sky

(2) Transient source search
- Search for spacial and temporal clustering of neutrinos

(3) Multi-messenger search
- Search for a coincidence between neutrino and other messenger particles spacial at particular time and location

(4) Diffuse search
- Search for spectral feature, inconsistent with atmospheric background predictions

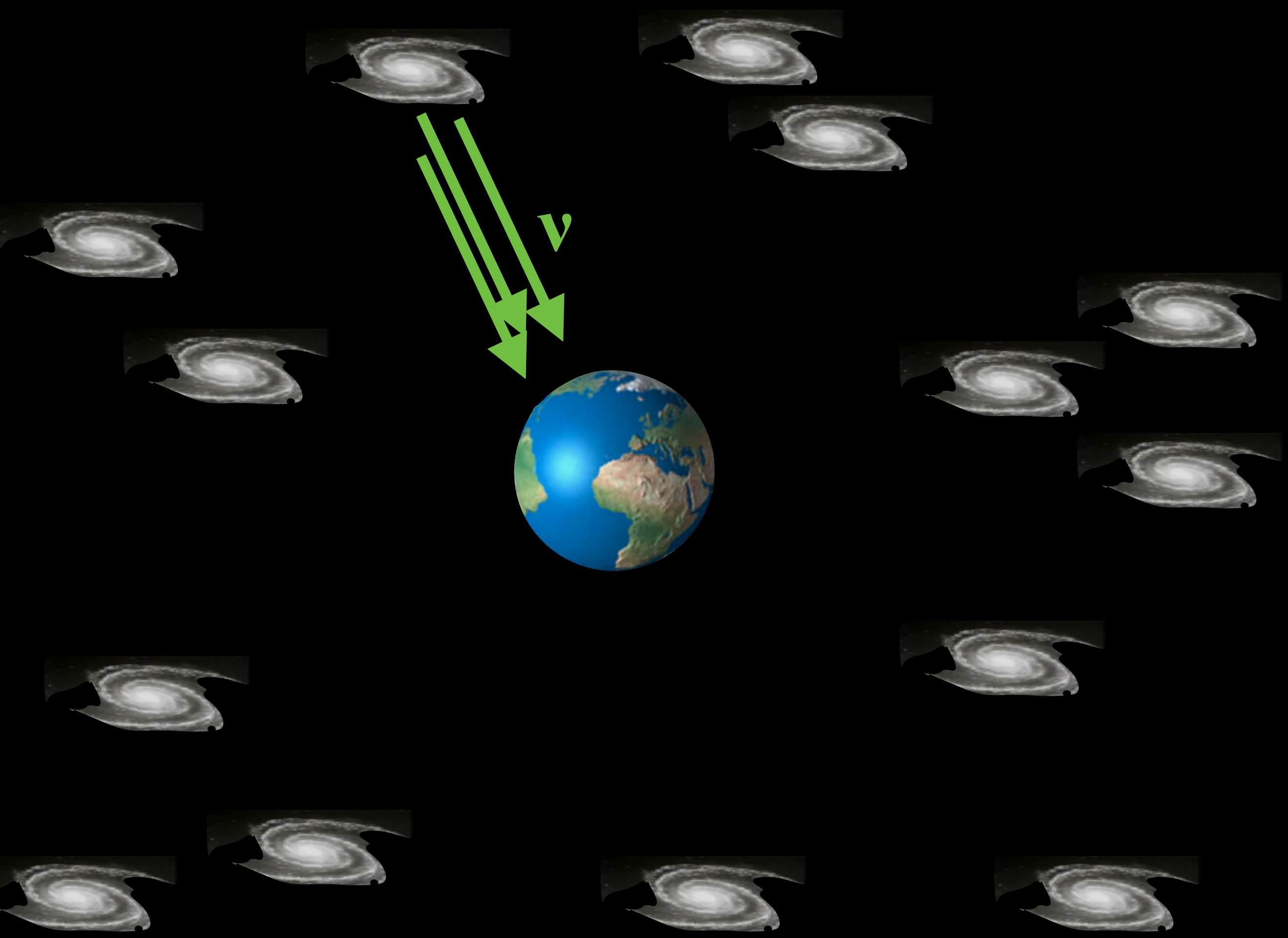
…. + various combinations and



Finding astrophysical neutrinos

How to find astrophysical neutrinos ?

Finding astrophysical neutrinos



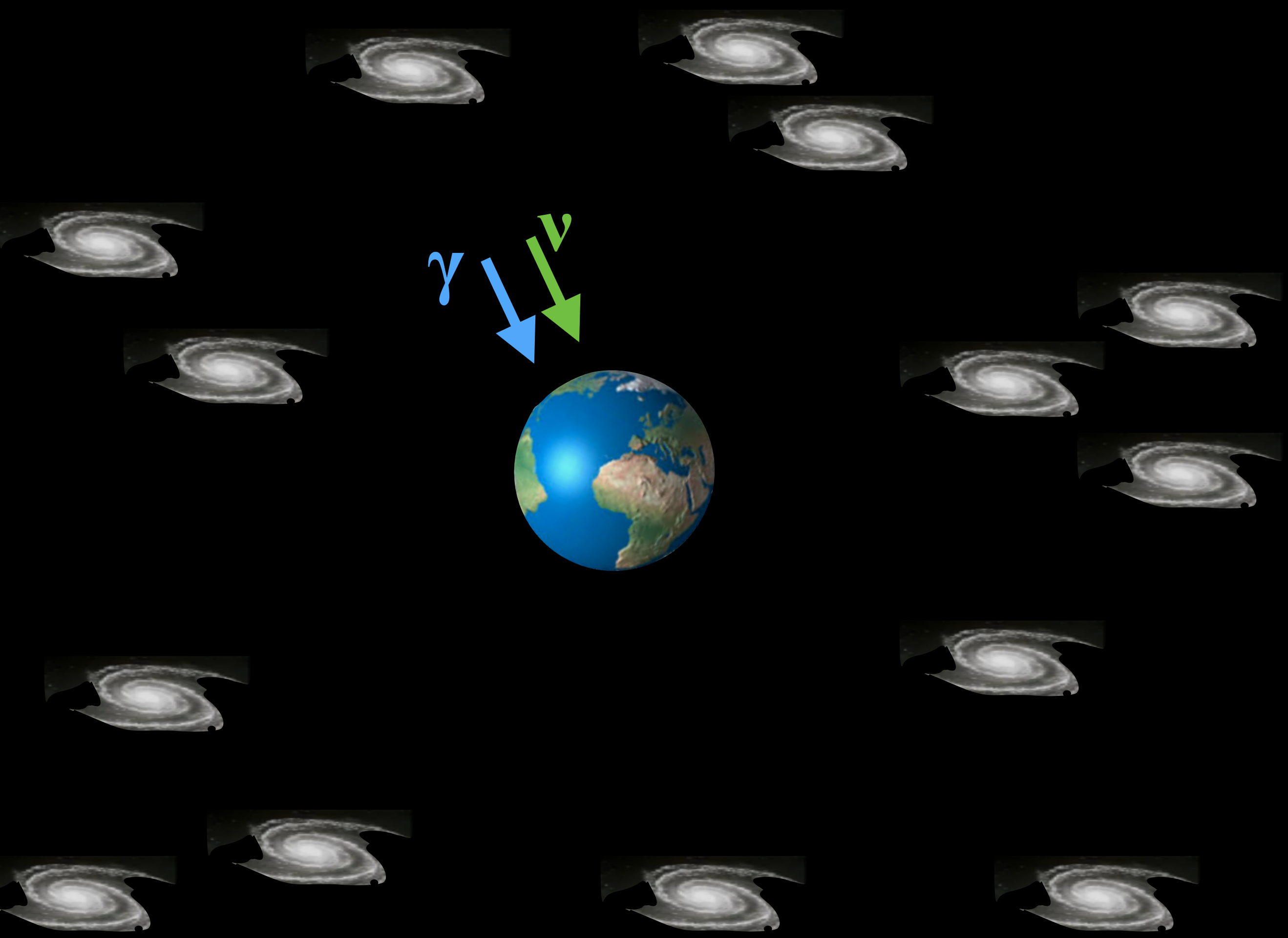
Point source search

- search for clustering of neutrinos from point in the sky

Finding astrophysical neutrinos

Transient source search

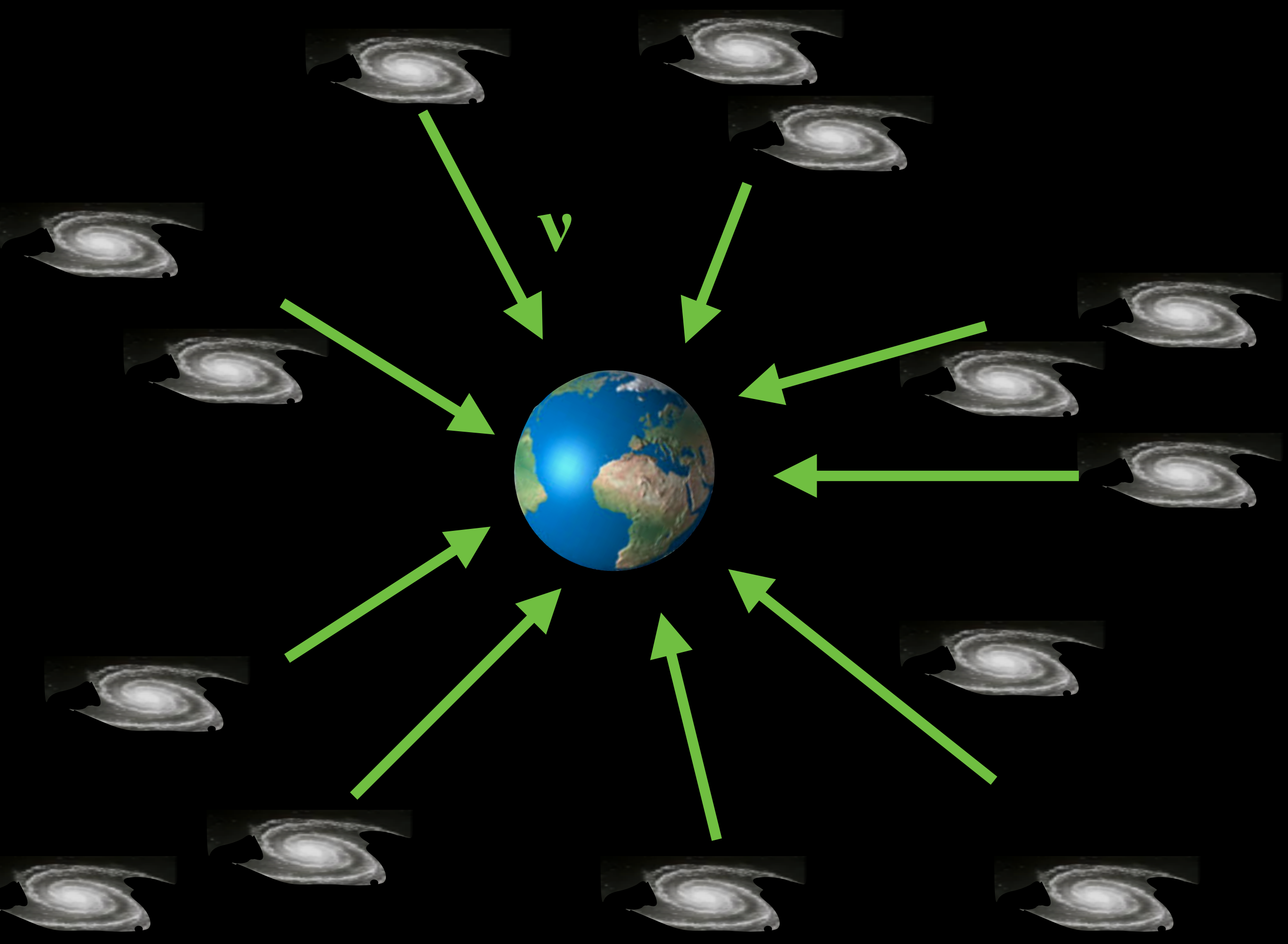
- search for spacial and temporal clustering of neutrinos



Multi-messenger search

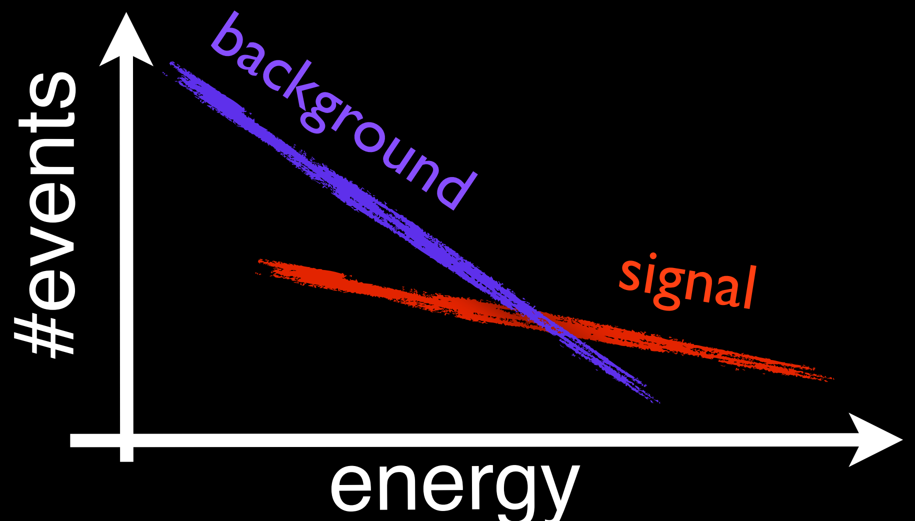
- search for a coincidence between neutrino and other messenger particles spacial at particular time and location

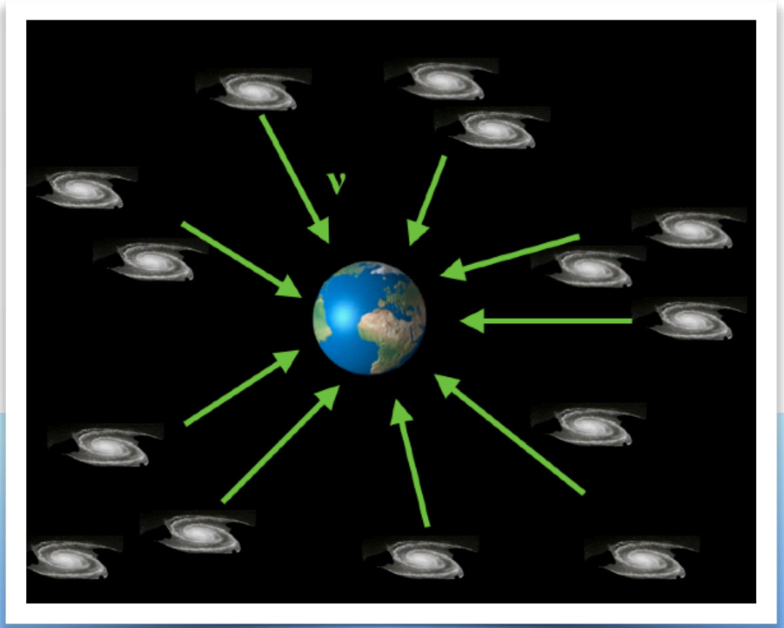
Finding astrophysical neutrinos



Diffuse search

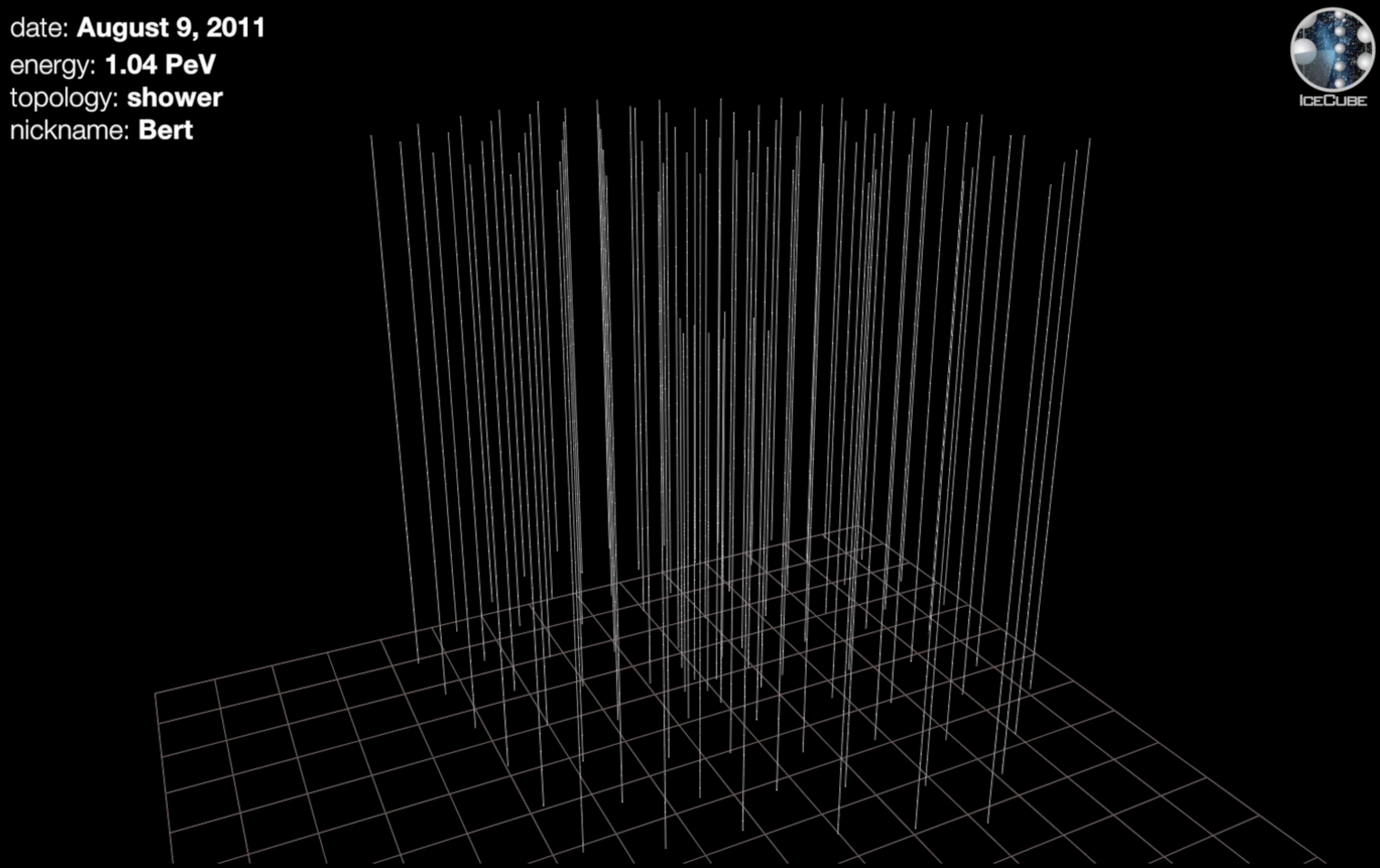
- search for spectral feature, inconsistent with atmospheric background predictions





Diffuse Neutrino Flux Search

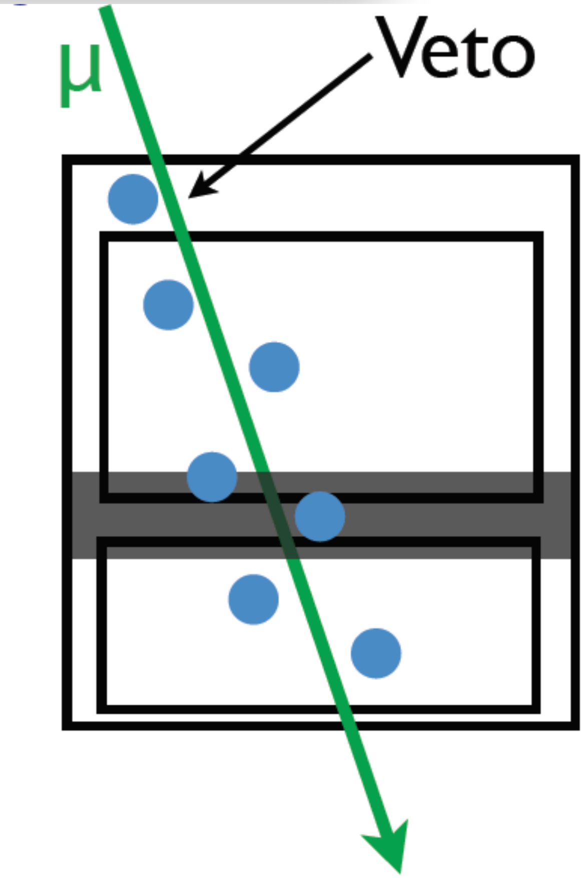
A cosmic neutrino interacts INSIDE the detector: it is too energetic to be produced in the atmosphere



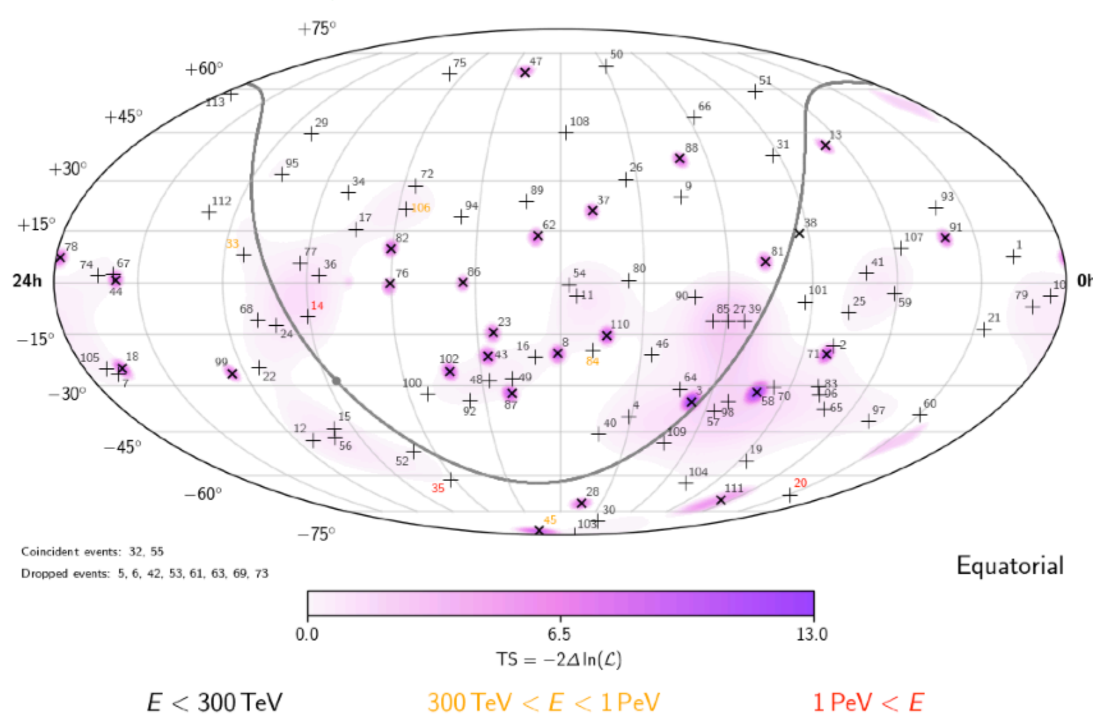
> 300 optical sensors; > 100,000 photons; 2 nanosec time resolution

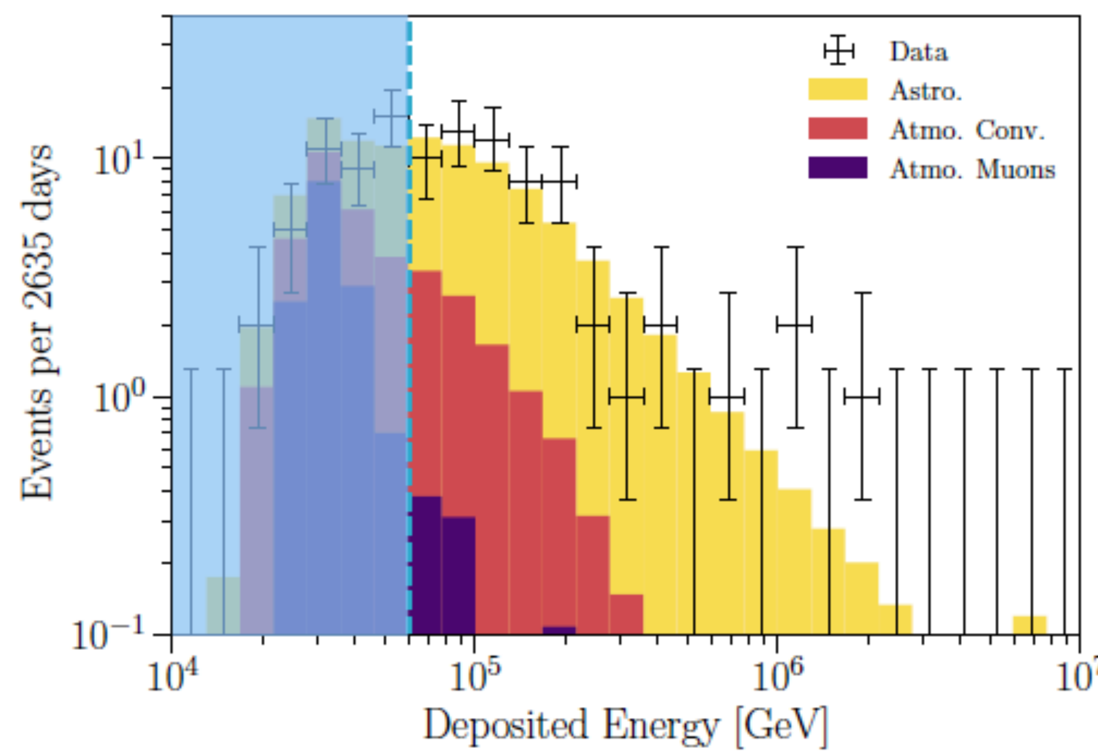
Observation of high-energy astrophysical neutrinos

IceCube Collaboration, *Science 342, 1242856 (2013)*,
IceCube Collaboration, *Phys. Rev. Lett 113, 101101 (2014)*
IceCube Collaboration arXiv:2011.03545

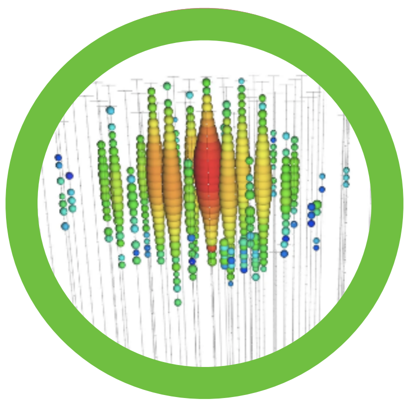


- Search for High-Energy Starting Events (HESE)
  - Efficient reject atmospheric backgrounds
  - Discovery of astrophysical neutrinos

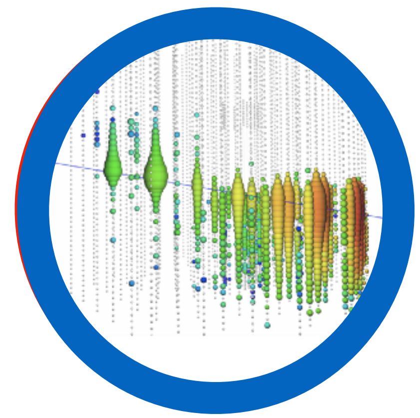




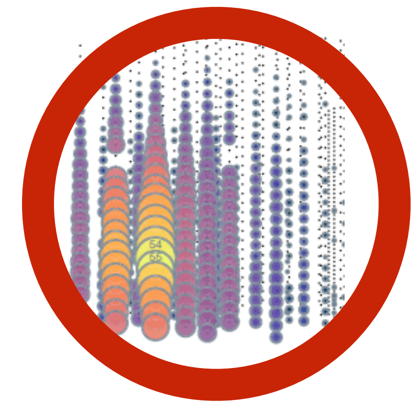
Astrophysical Neutrino Flux



High-energy starting events (HESE)
Interaction vertex in the detector, All flavor, all sky

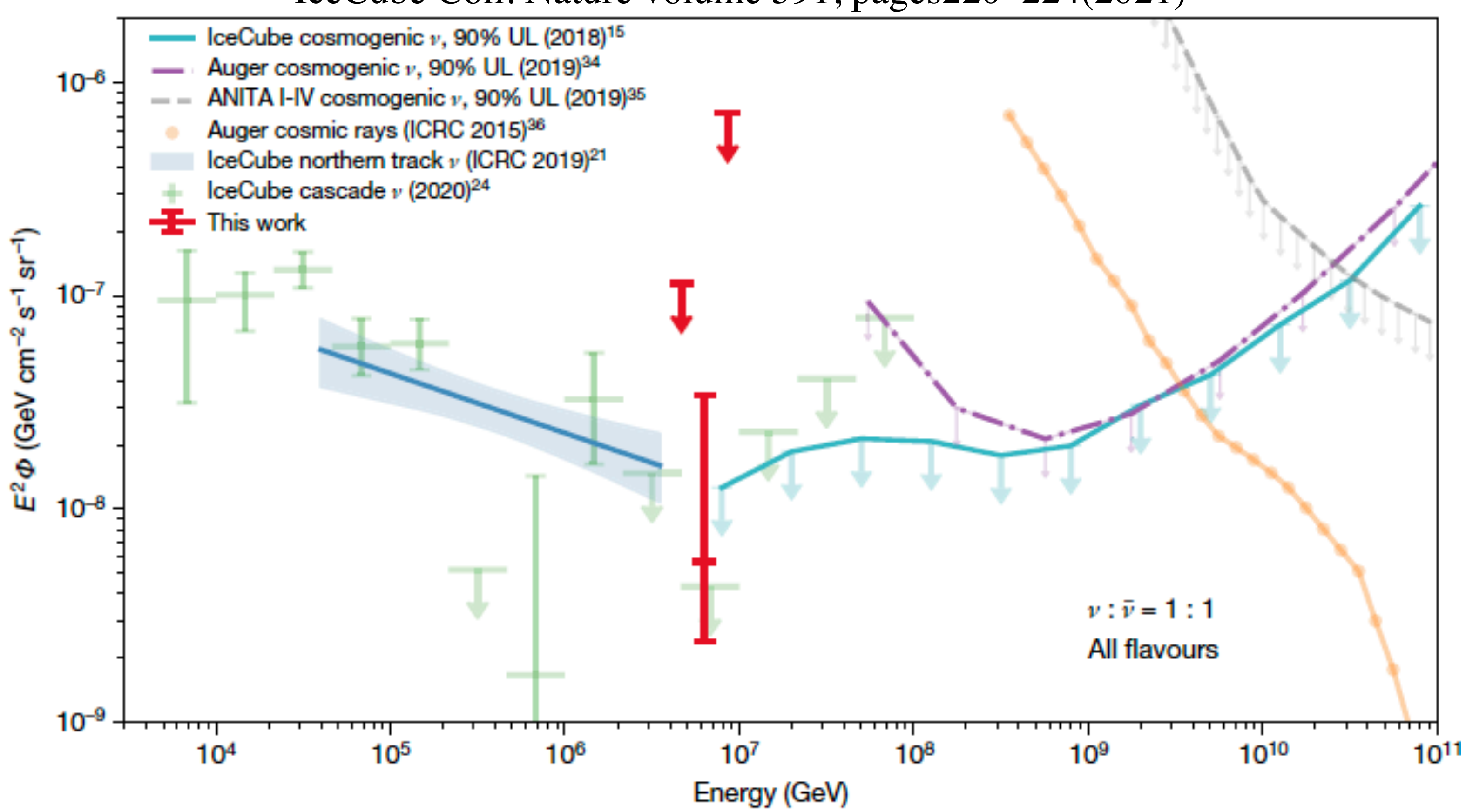


Up-going tracks
Muon-dominated
Northern sky

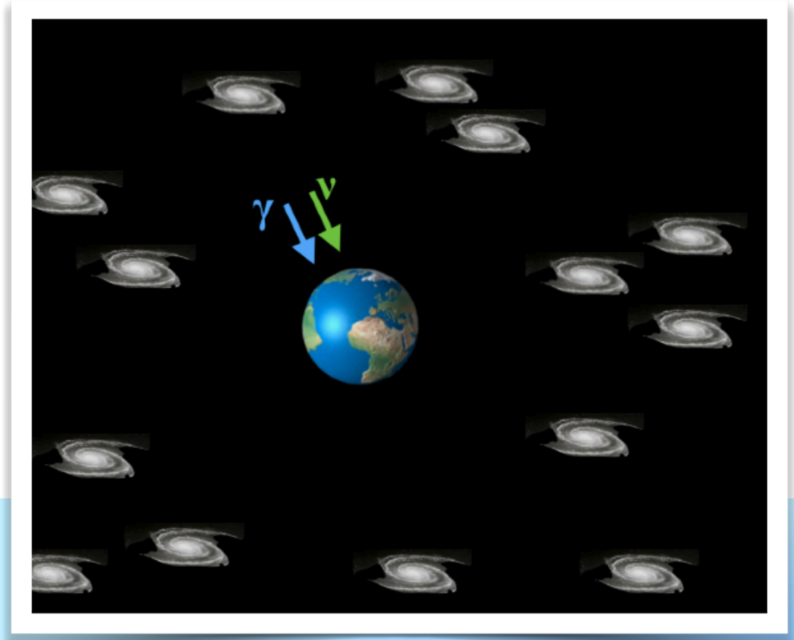


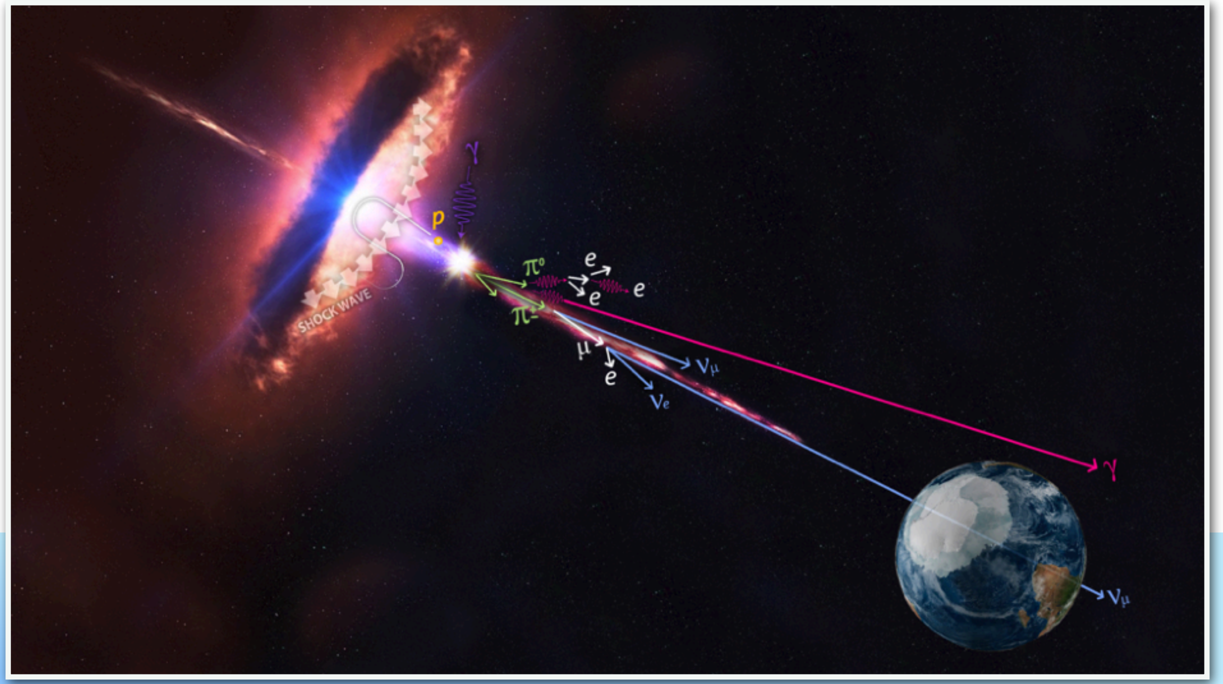
PeV energy partially contained events (PEPE)
Interaction vertex near the edge of the detector, All flavor, all sky

IceCube Coll. Nature volume 591, pages220–224(2021)



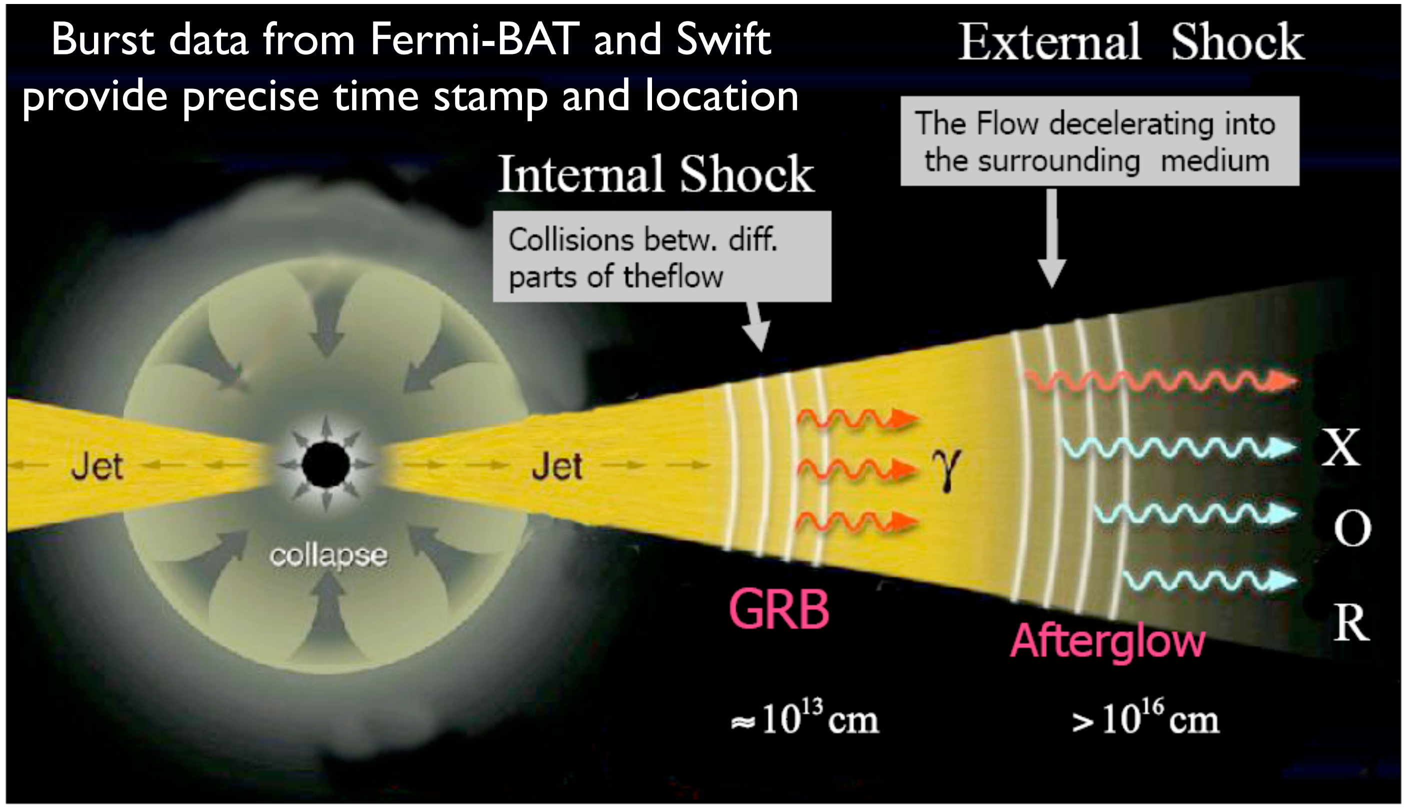
- **Astrophysical flux in the 20 TeV - 9PeV range**
- **Various channels and analysis methods**





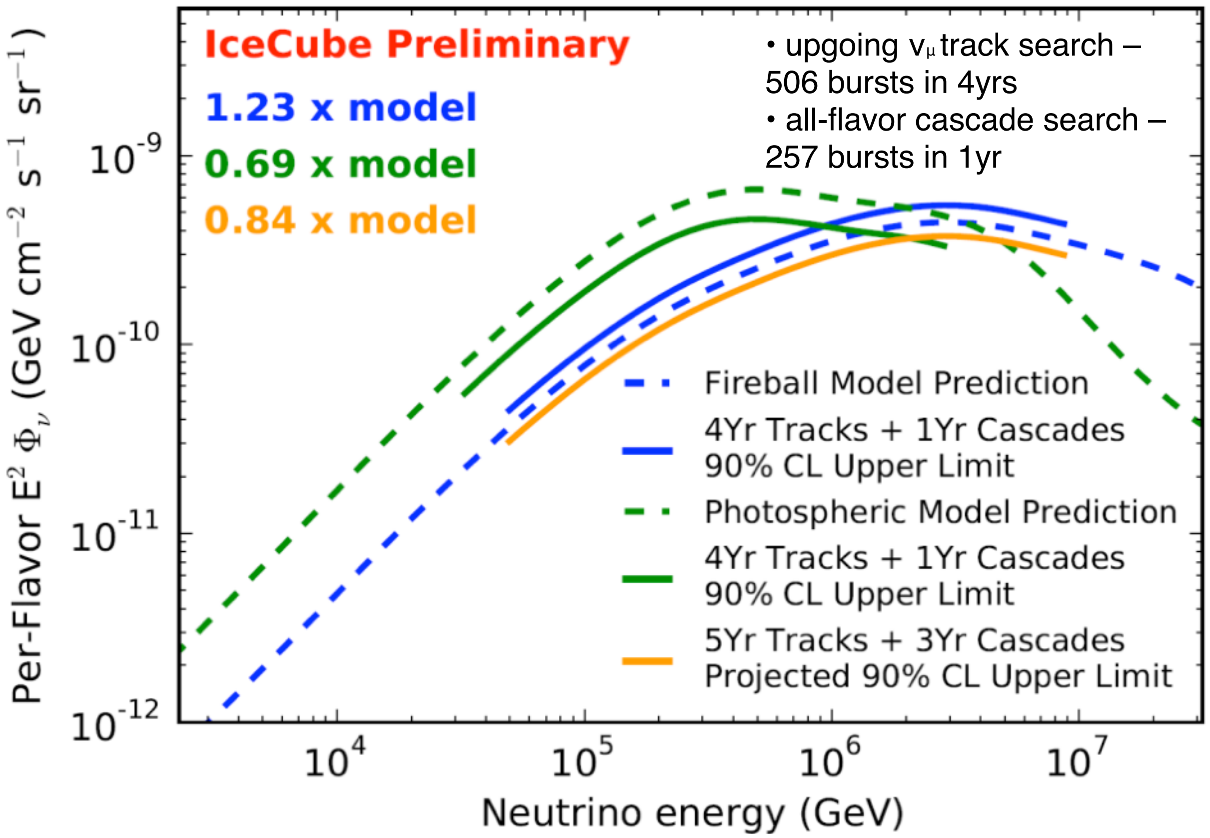
Multi-messenger Neutrino Astronomy and IceCube-170922A

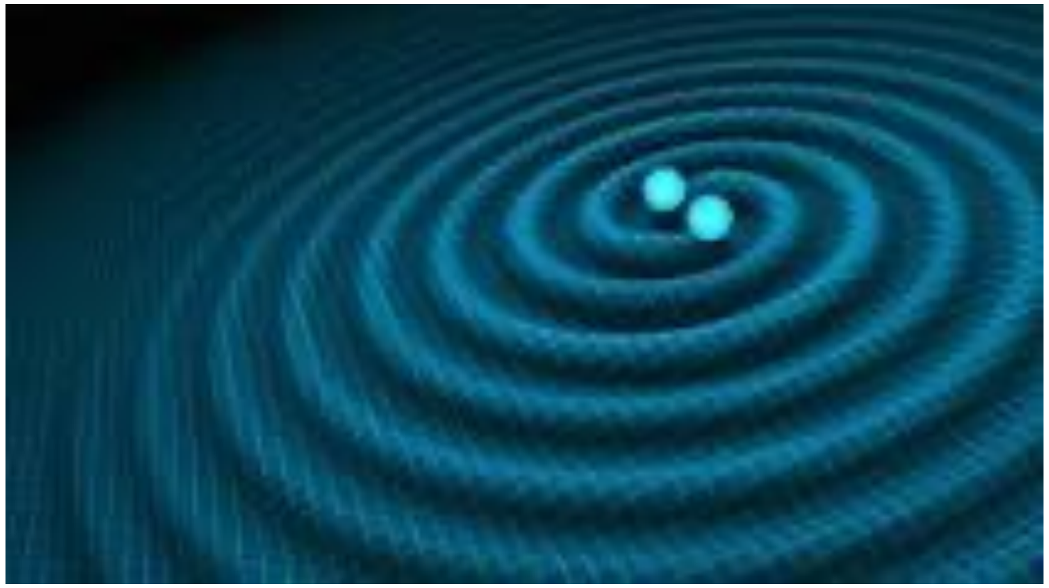
Transient Searches



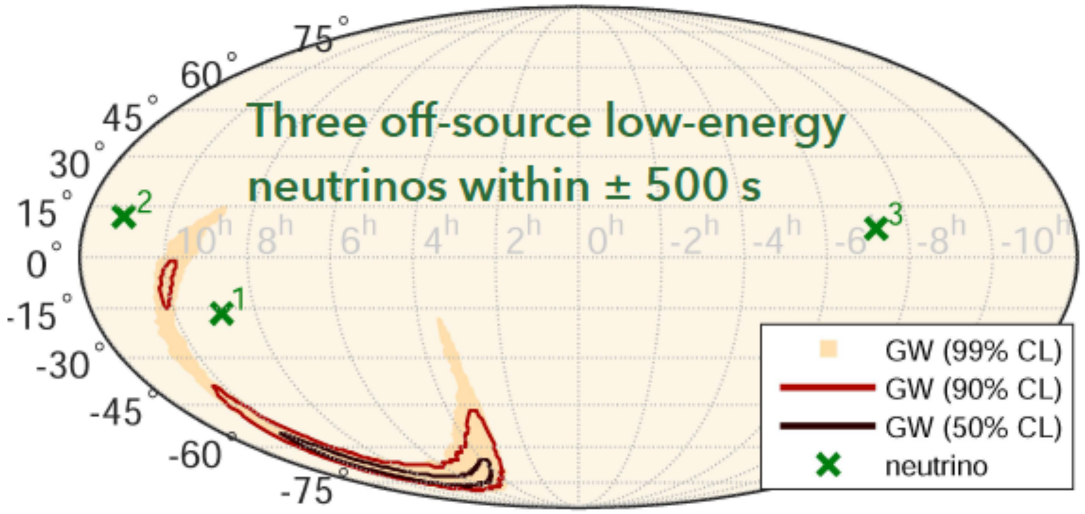
IceCube Collaboration - Nature Vol **484**, 351 (2012)

no coincidence found





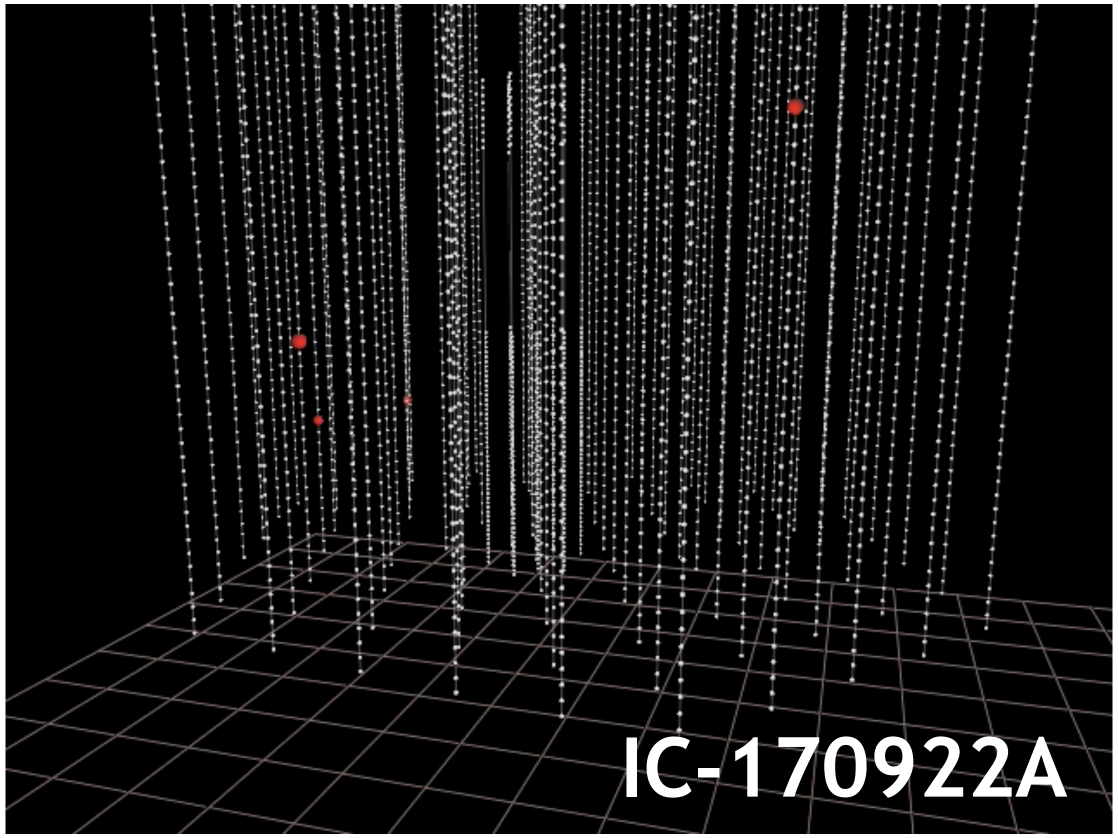
ANTARES Collaboration, IceCube Collaboration, LIGO Scientific Collaboration, Virgo Collaboration [arXiv:1602.05411]

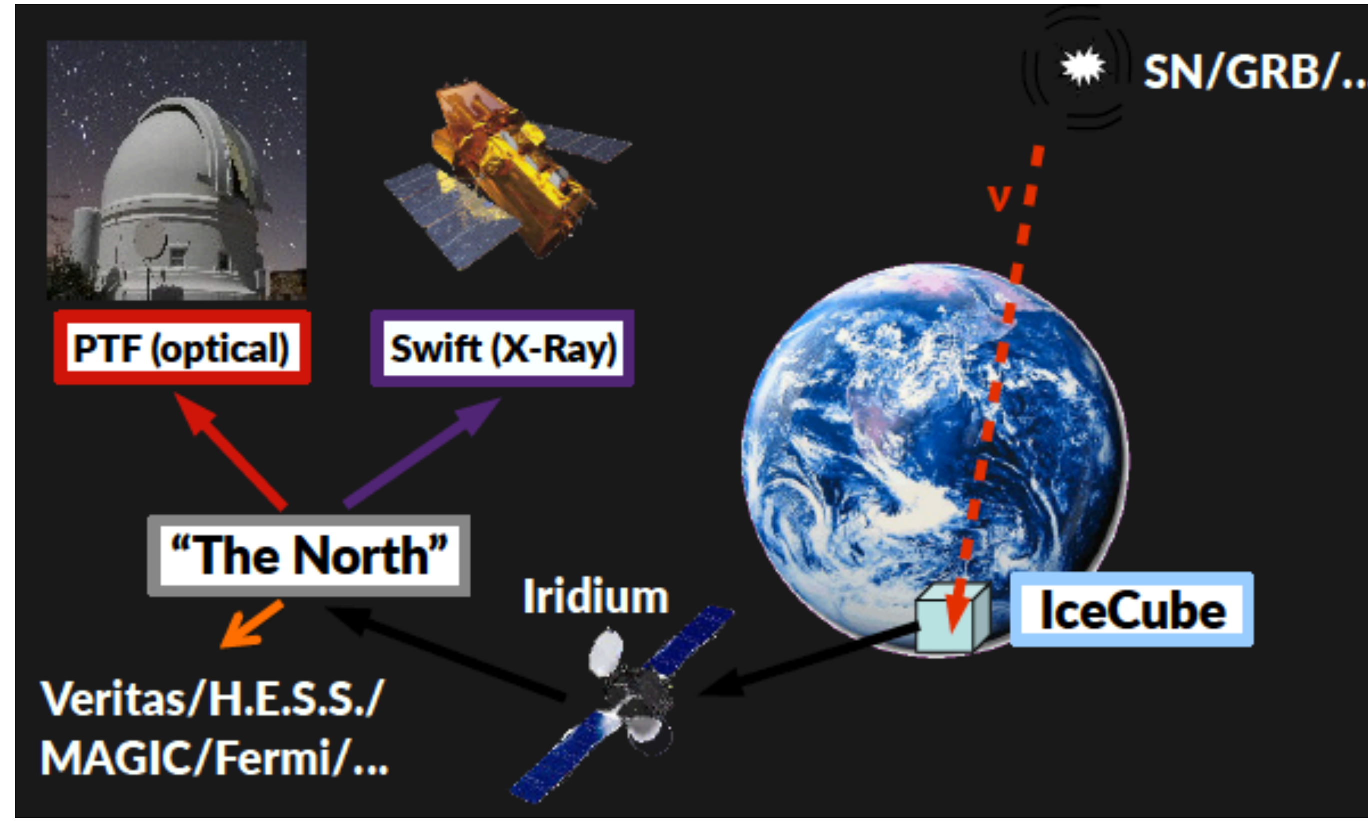


- Follow up on LIGO Gravitational Wave GW 150914
  - No neutrino association observed

Astropart. Phys. 92 (2017) 30
A&A 607 (2017) A115

IceCube-170922A

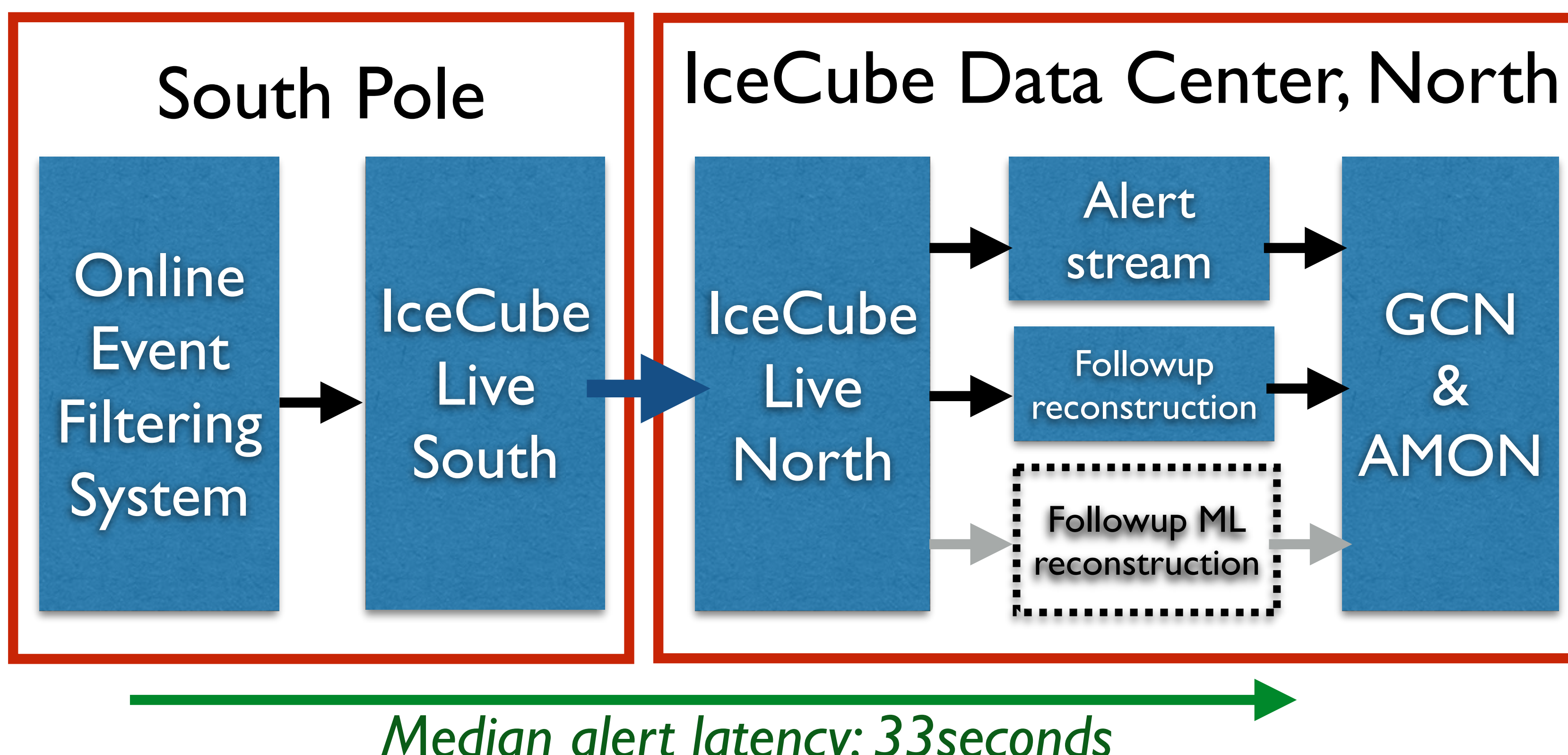




Real-time alerts

- Good angular resolution (0.5° - 2° 90% of events)

Updated alerts	Gold	Bronze
Signalness	> 50%	>30%
Expected signal/yr	6.6	2.8
Expected bkgd/yr	6.1	14.7

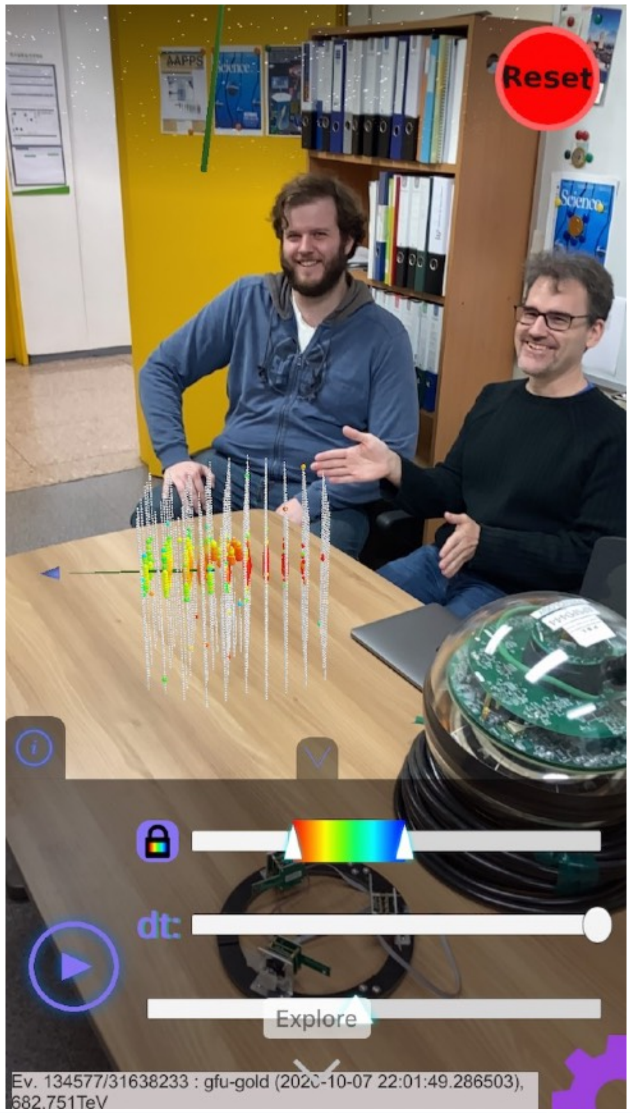


Astropart. Phys. 92 (2017) 30

A&A 607 (2017) A115

IceCube-170922A

IceCuBeAR - https://icecube.wisc.edu/news/view/776



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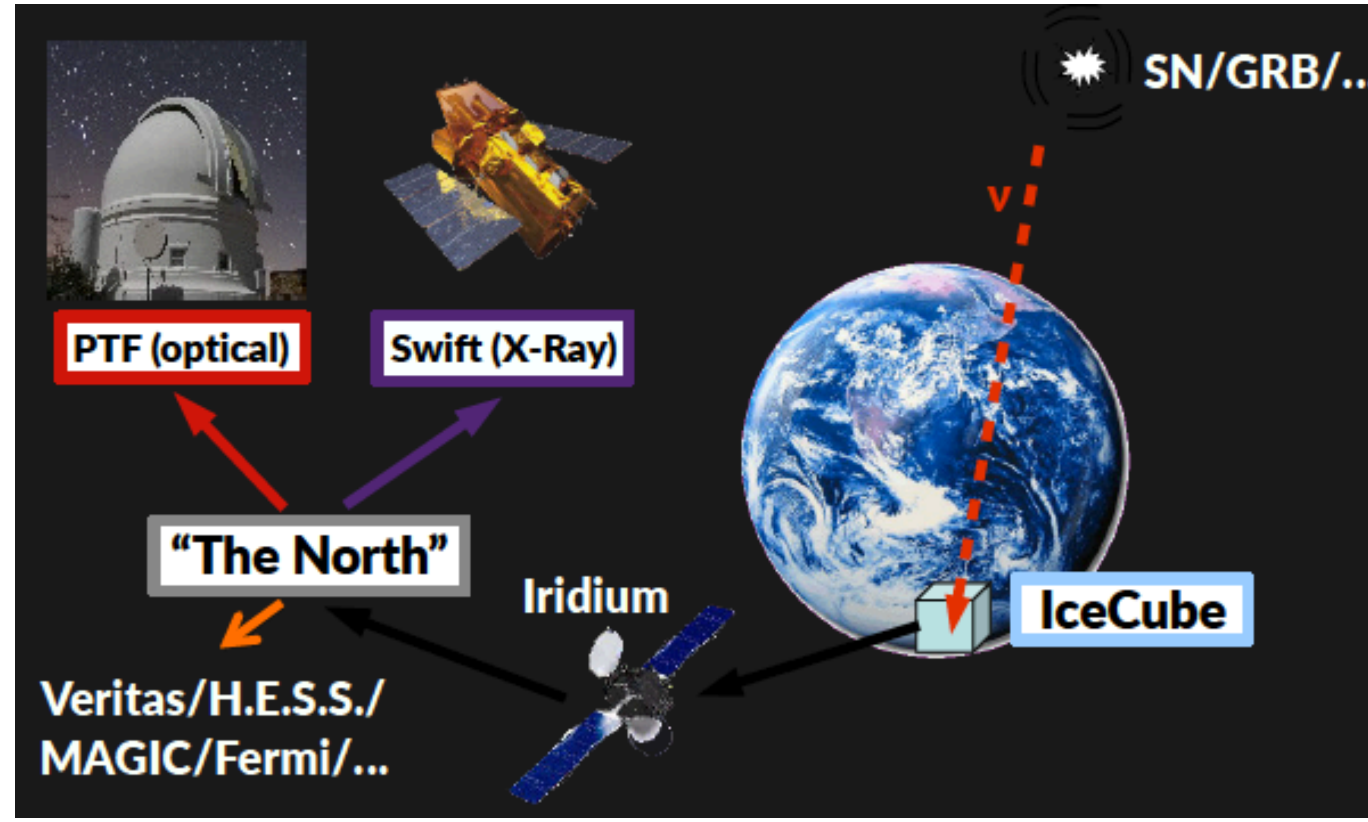
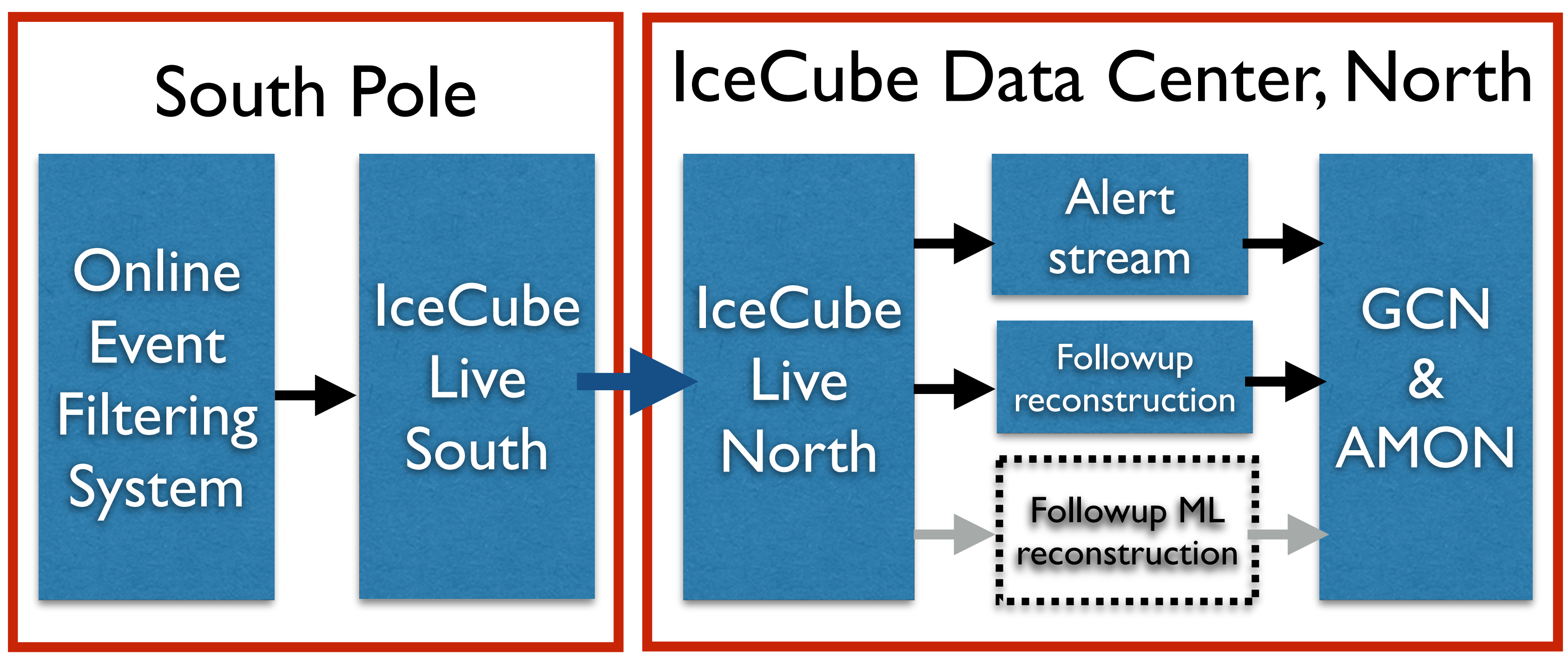
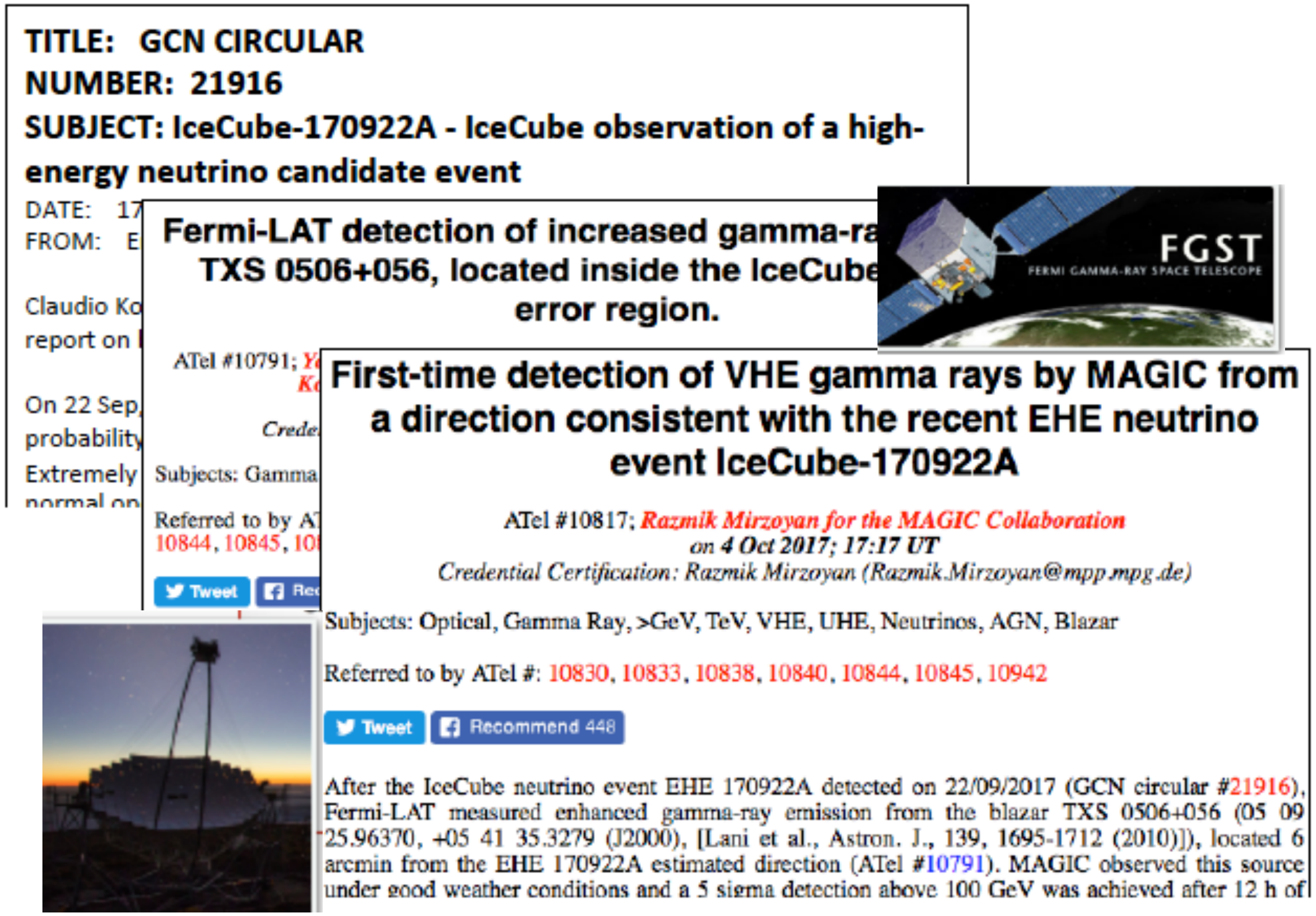




Median alert latency: 33seconds

Astropart. Phys. 92 (2017) 30
A&A 607 (2017) A115

IceCube-170922A & TXS 0506+056


TITLE: GCN CIRCULAR
NUMBER: 21916
SUBJECT: IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
DATE: 17
FROM: E
Claudio Ko
report on
On 22 Sep
probability
Extremely
normal on

Fermi-LAT detection of increased gamma-ra
TXS 0506+056, located inside the IceCube
error region.
ATel #10791; Y
Crede
Subjects: Gamma
Referred to by AT
10844, 10845, 10
Tweet Rec

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

Referred to by ATel #: 10830, 10833, 10838, 10840, 10844, 10845, 10942

Tweet Recommend 448

After the IceCube neutrino event EHE 170922A detected on 22/09/2017 (GCN circular #21916), Fermi-LAT measured enhanced gamma-ray emission from the blazar TXS 0506+056 (05 09 25.96370, +05 41 35.3279 (J2000), [Lani et al., Astron. J., 139, 1695-1712 (2010)]), located 6 arcmin from the EHE 170922A estimated direction (ATel #10791). MAGIC observed this source under good weather conditions and a 5 sigma detection above 100 GeV was achieved after 12 h of

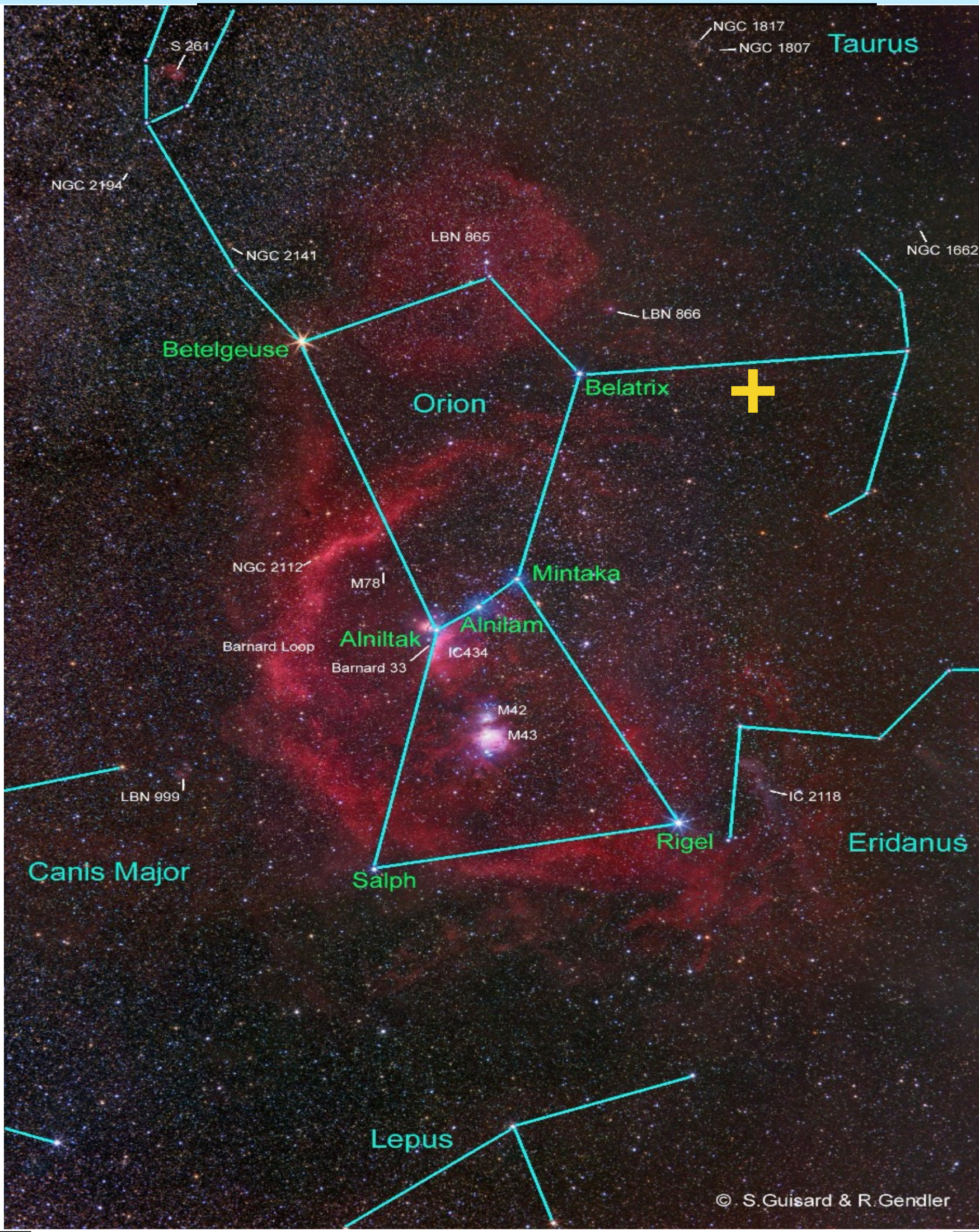
- September 22, 2017: a neutrino alert issued by IceCube
- Fermi-LAT and MAGIC identify a spatially coincident flaring blazar (TXS 0506+056)
- Very active multi-messenger follow-up from radio to γ-rays

IceCube-170922A

Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

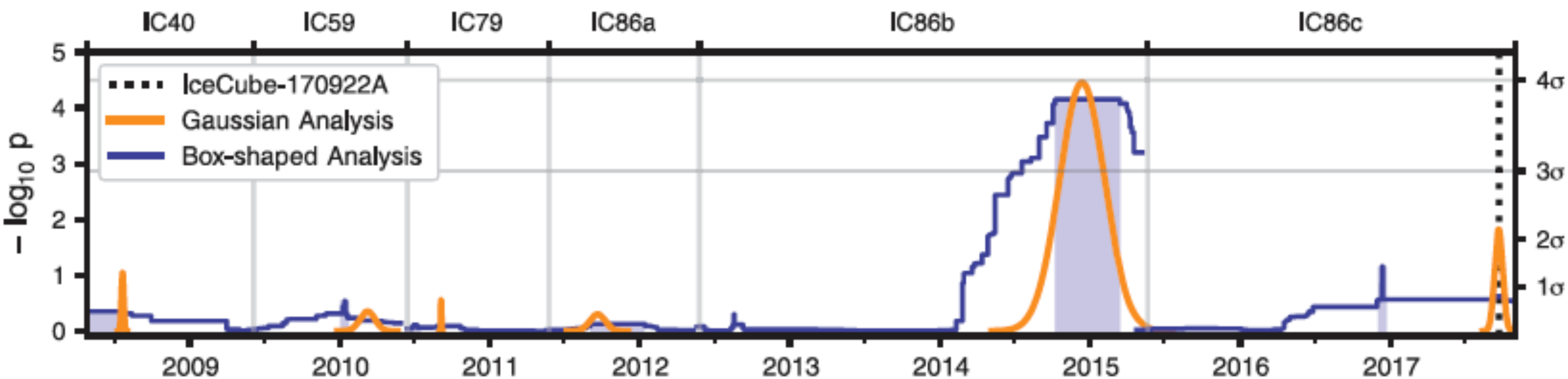
The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*, ASAS-SN, HAWC, H.E.S.S., *INTEGRAL*, Kanata, Kiso, Kapteyn, Liverpool Telescope, Subaru, *Swift/NuSTAR*, VERITAS, and VLA/17B-403 teams*†

- Chance probability of a Fermi-IceCube coincident observation: ~**3σ** (determined based on the historical IceCube sample and known Fermi-LAT blazars)
- Time-integrated neutrino spectrum is approximately $E^{-2.1}$
- **TXS 0506+056 redshift determined to be z=0.3365** (S. Paiano et al. ApJL 854.L32(2018))
- Time-average luminosity about an order of magnitude higher than Mkn 421, Mkn 501, or 1ES 1959+605

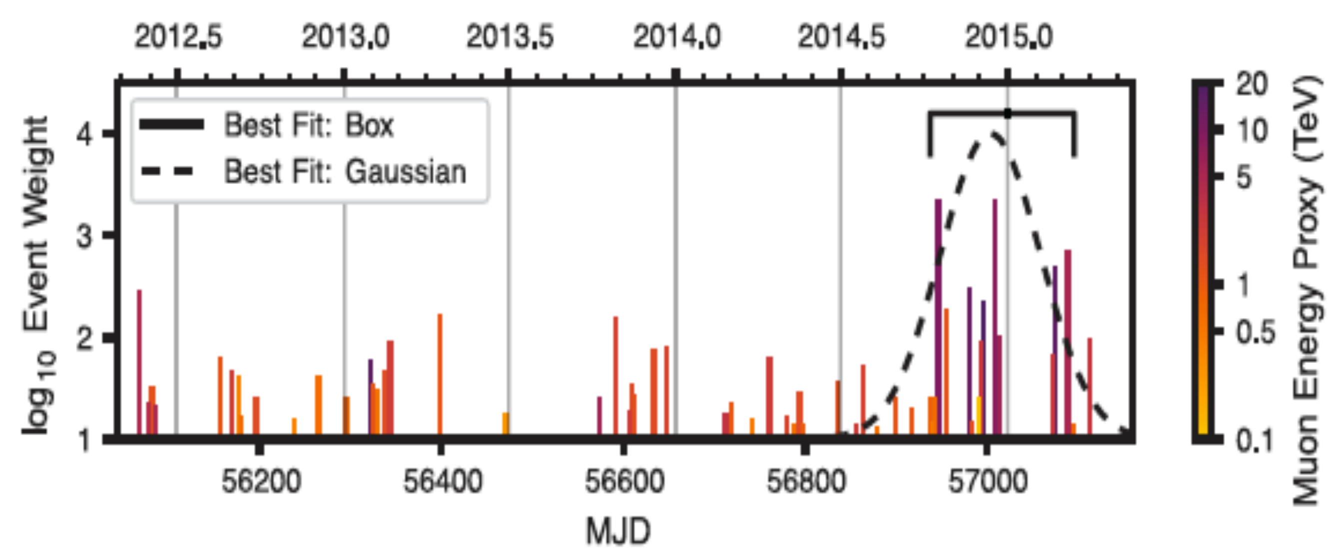


Science 361 (6398), 147-151.

IceCube-170922A



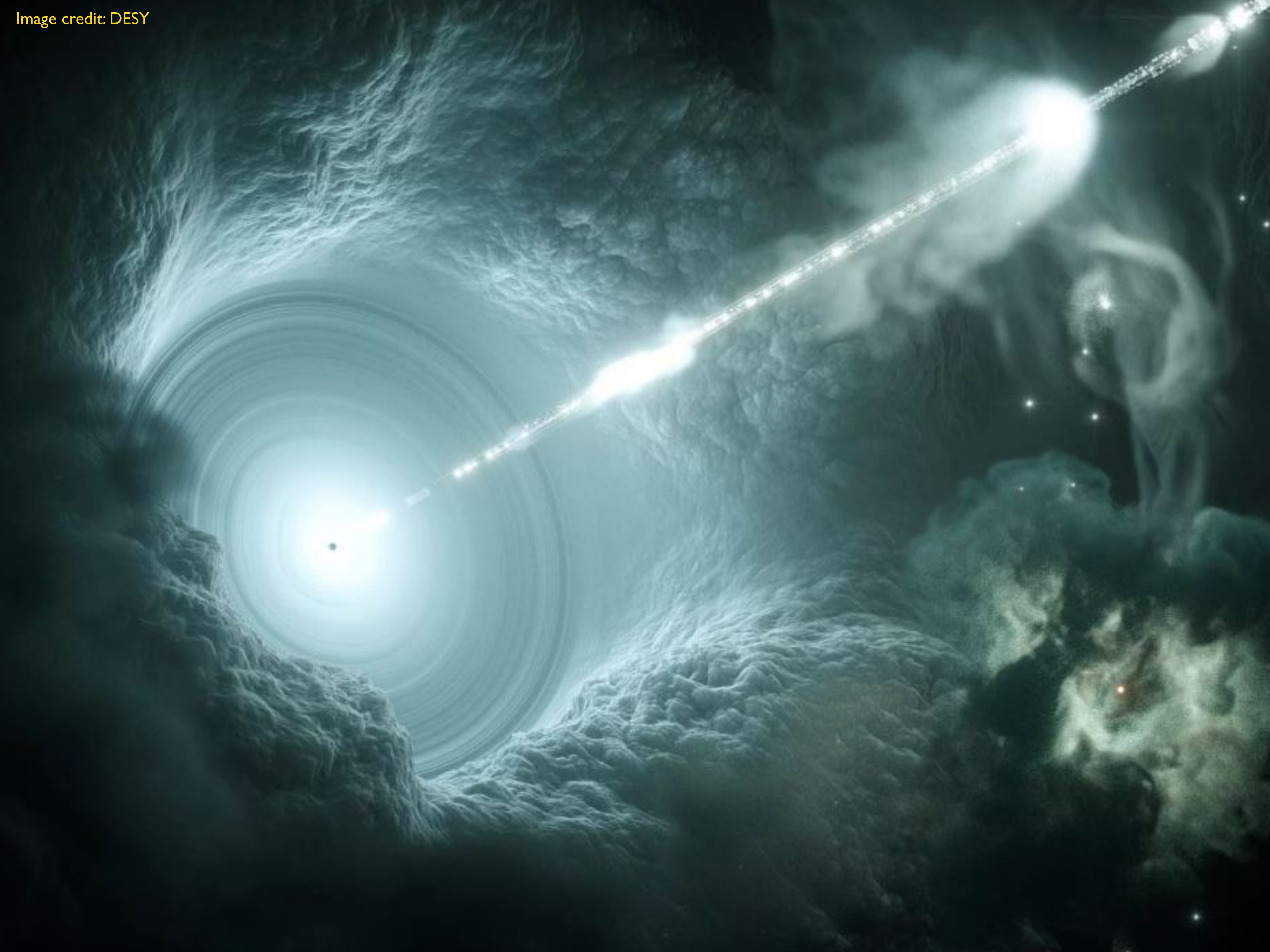
- 9.5 years of archival data was evaluated in direction of TXS 0506+056
- An excess of 13±5 events above background was observed during Sep 2014 - March 2016
- Inconsistent with background only hypothesis at **3.5σ** level (independently of the **3σ** associated with IceCube-170922A alert)



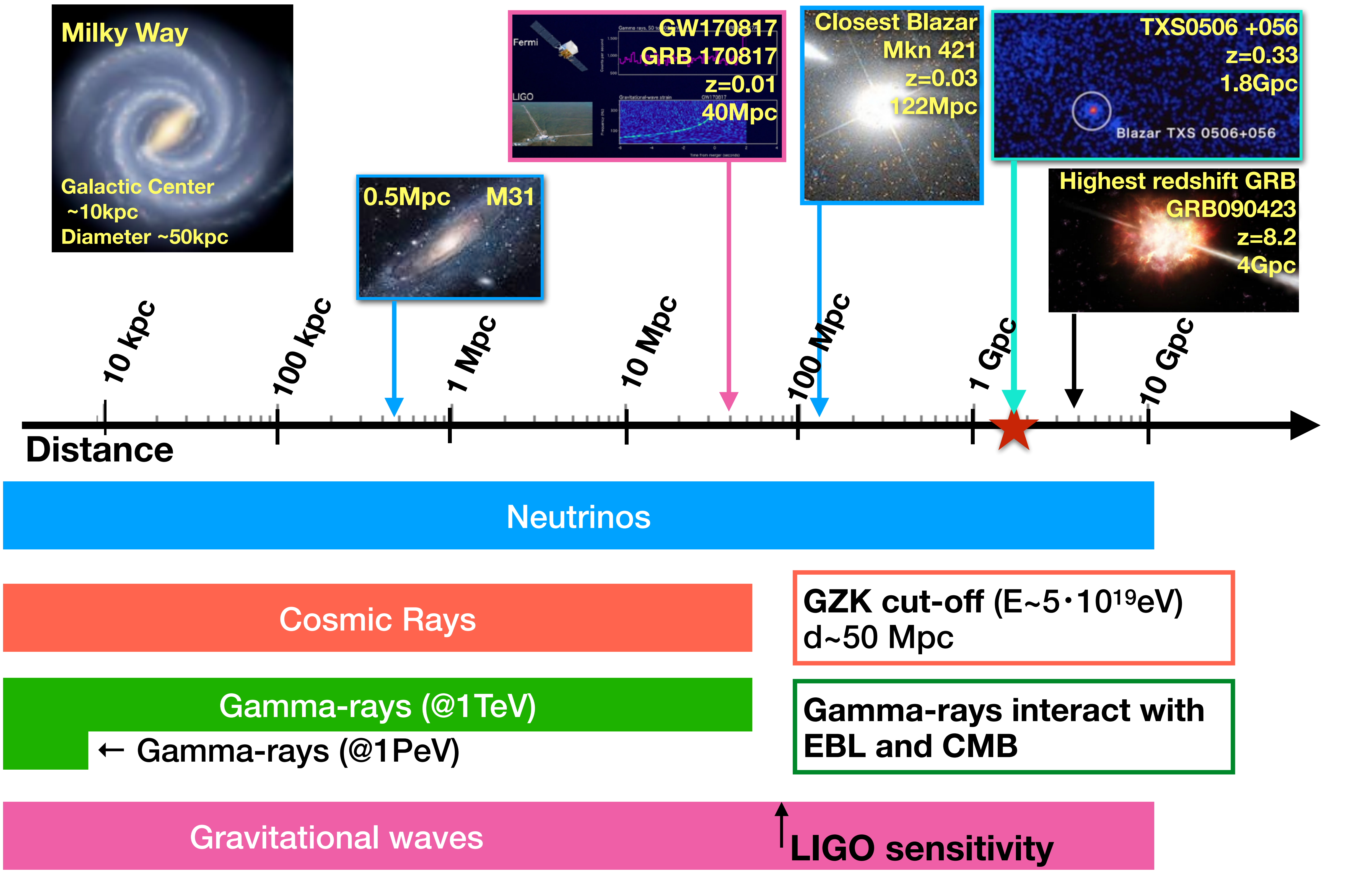
Time-independent weight of individual events during the IC86b period.

However: Maximum contribution of the 2LAC blazars to the observed astrophysical neutrino flux to be 27% or less between around 10 TeV and 2 PeV [IceCube Astrophys.J. 835 (2017) no.1, 45]

Image credit: DESY



Distance scales …

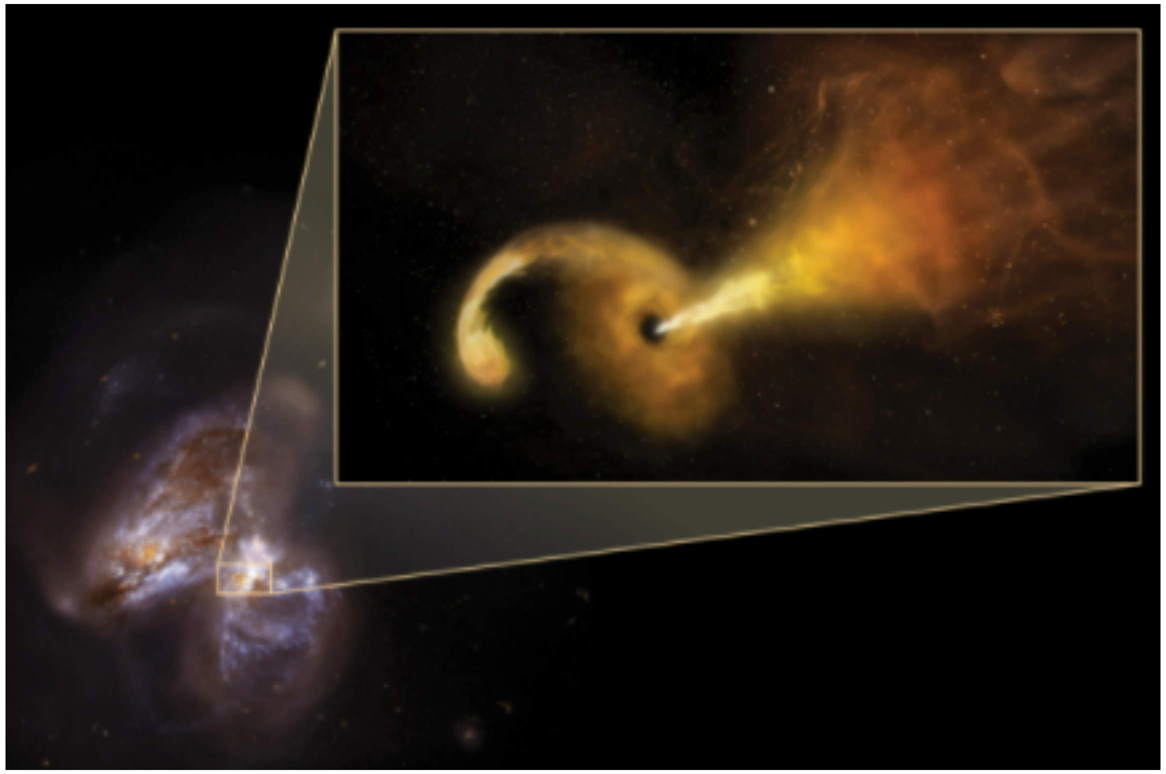


Note: Distant sources also allow to test rare interactions K.Choi, J.Kim, **C.Rott** PRD 2019

1 pc = 3.26 ly

Other candidate sources

- **Tidal Disruption Event (AT2019dsg)**
  - Radio-emitting tidal disruption event, AT2019dsg, with a high energy neutrino
  - Identified as part of ZTF (Zwicky Transient Facility) follow up of IceCube-191001A (19/10/01)
  - The probability of finding any coincident radio-emitting tidal disruption event by chance is 0.5% (Stein, R. et al. **Nat Astron (2021)**.)
  - see also W.Winter https://arxiv.org/pdf/2005.06097.pdf
    - AT2019dsg (z=0.05 / 230Mpc) / E=200TeV IC-191001



Artist illustration of the TDE example for image of the galaxy Arp299B …. Credit: NRAO/AUI/NSF/NASA/STScI