UCLouvain

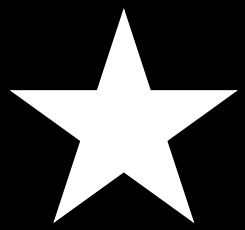
Francqui Foundation

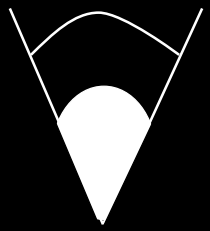
A new look on the Universe

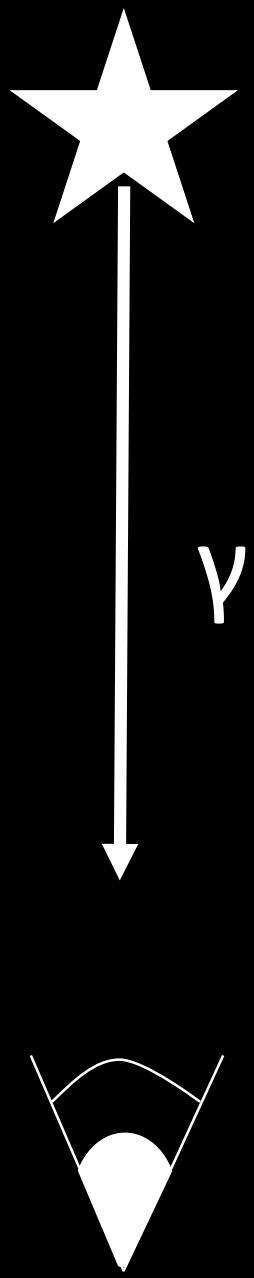
Gwenhaël De Wasseige

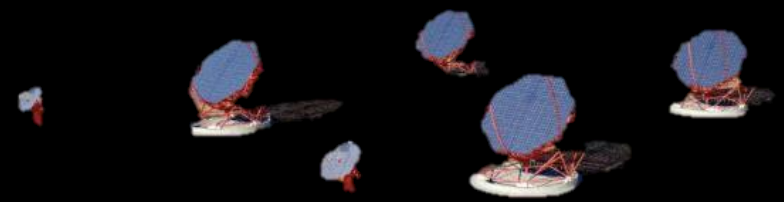
How to study the Universe?

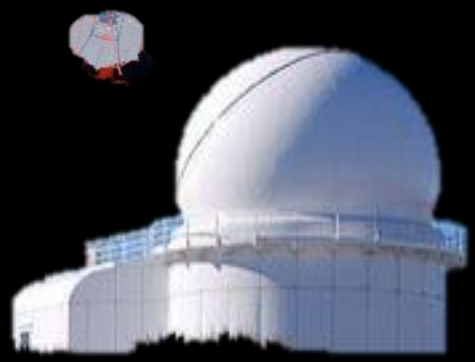
How to study the Universe?

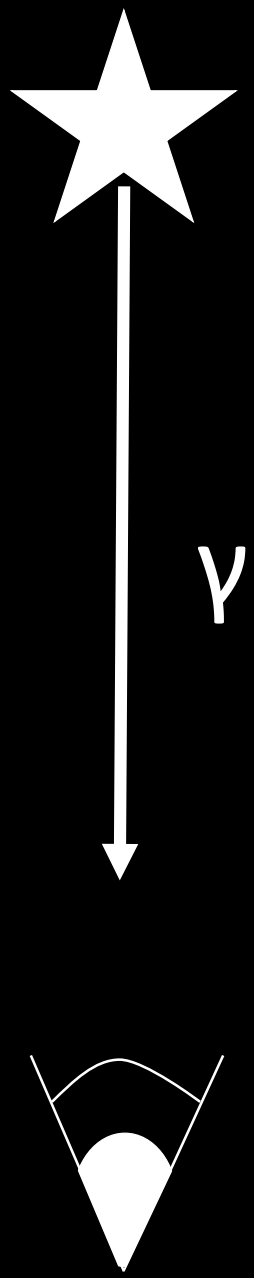





γ



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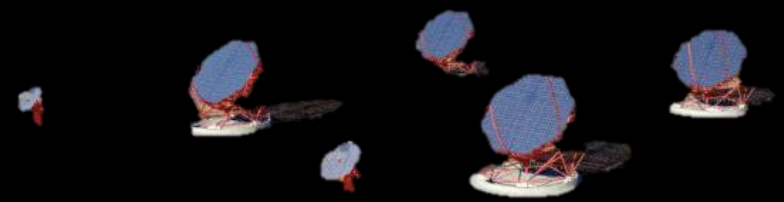
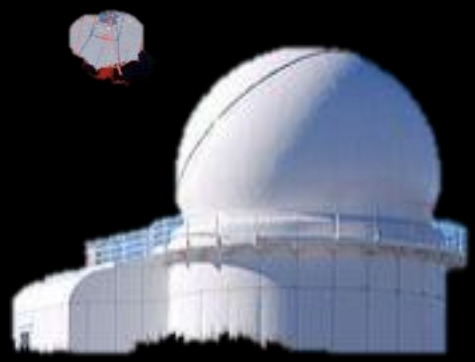
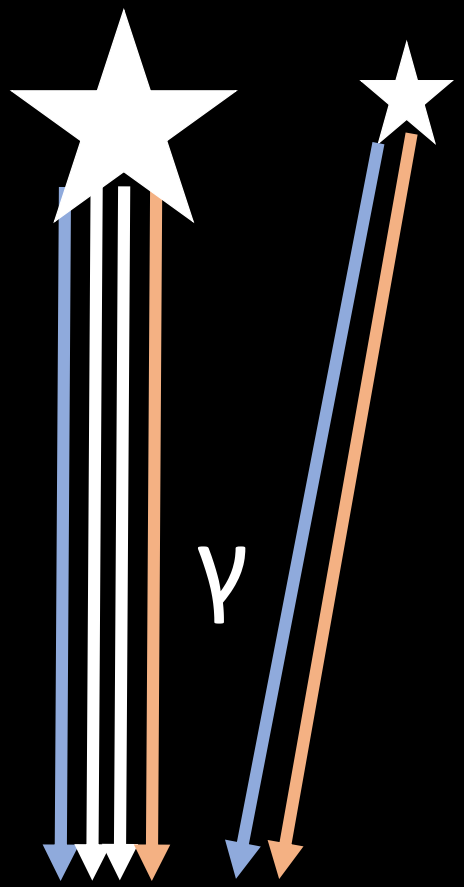
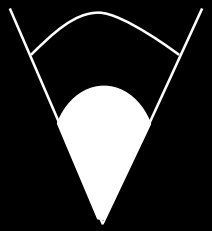
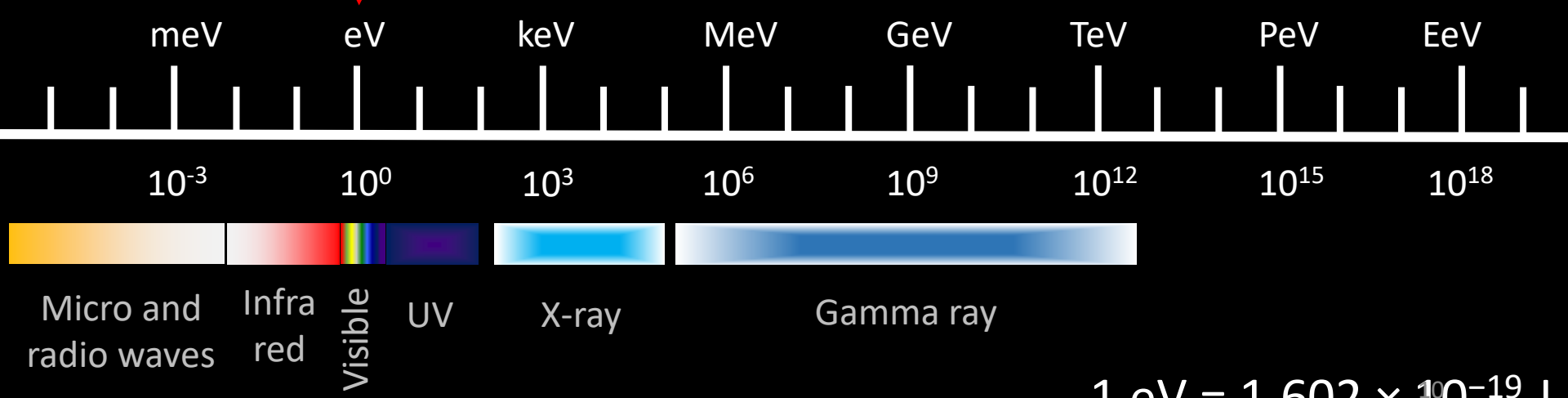


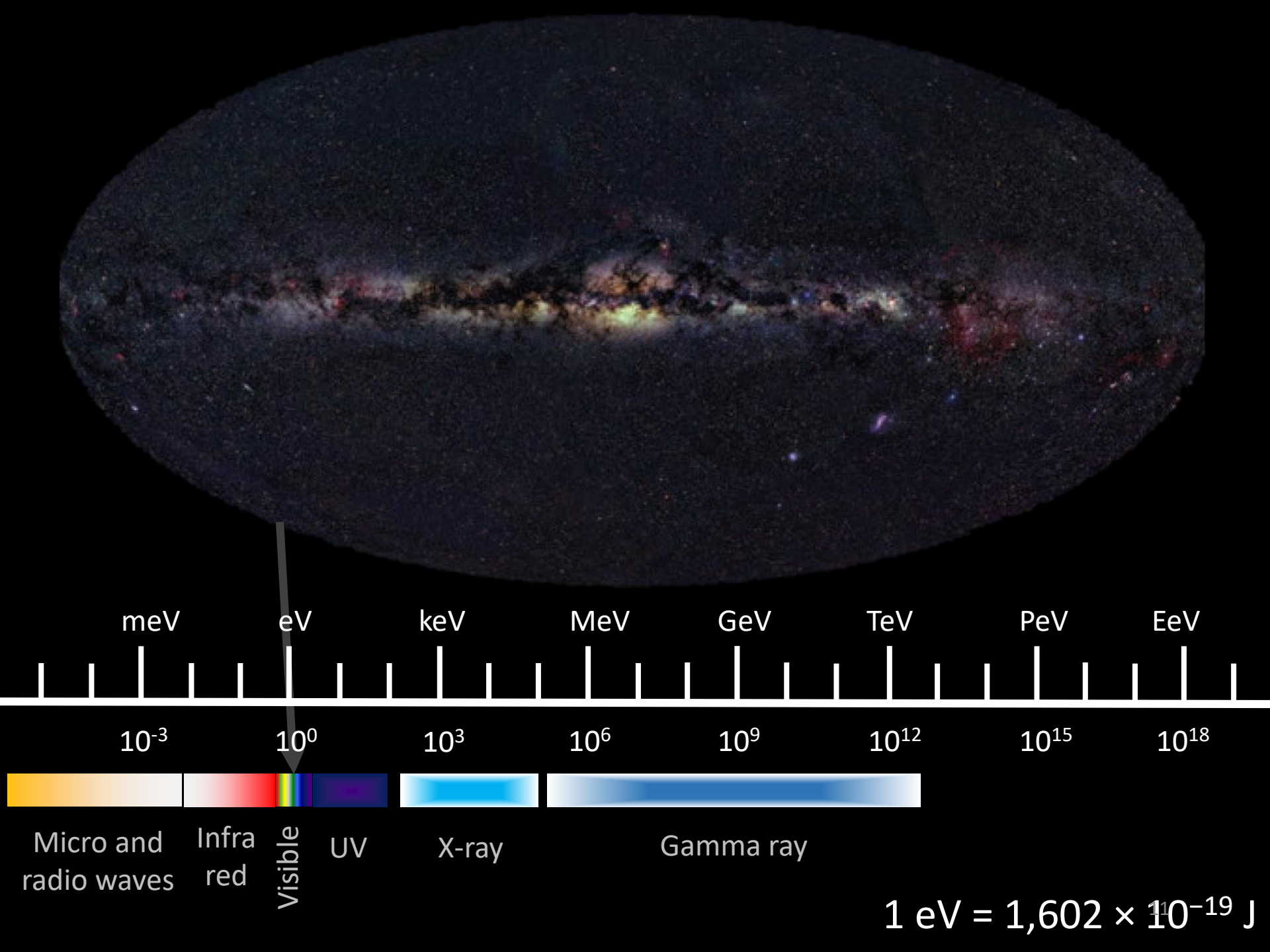



γ





$1\ \text{eV} = 1{,}602 \times 10^{-19}\ \text{J}$



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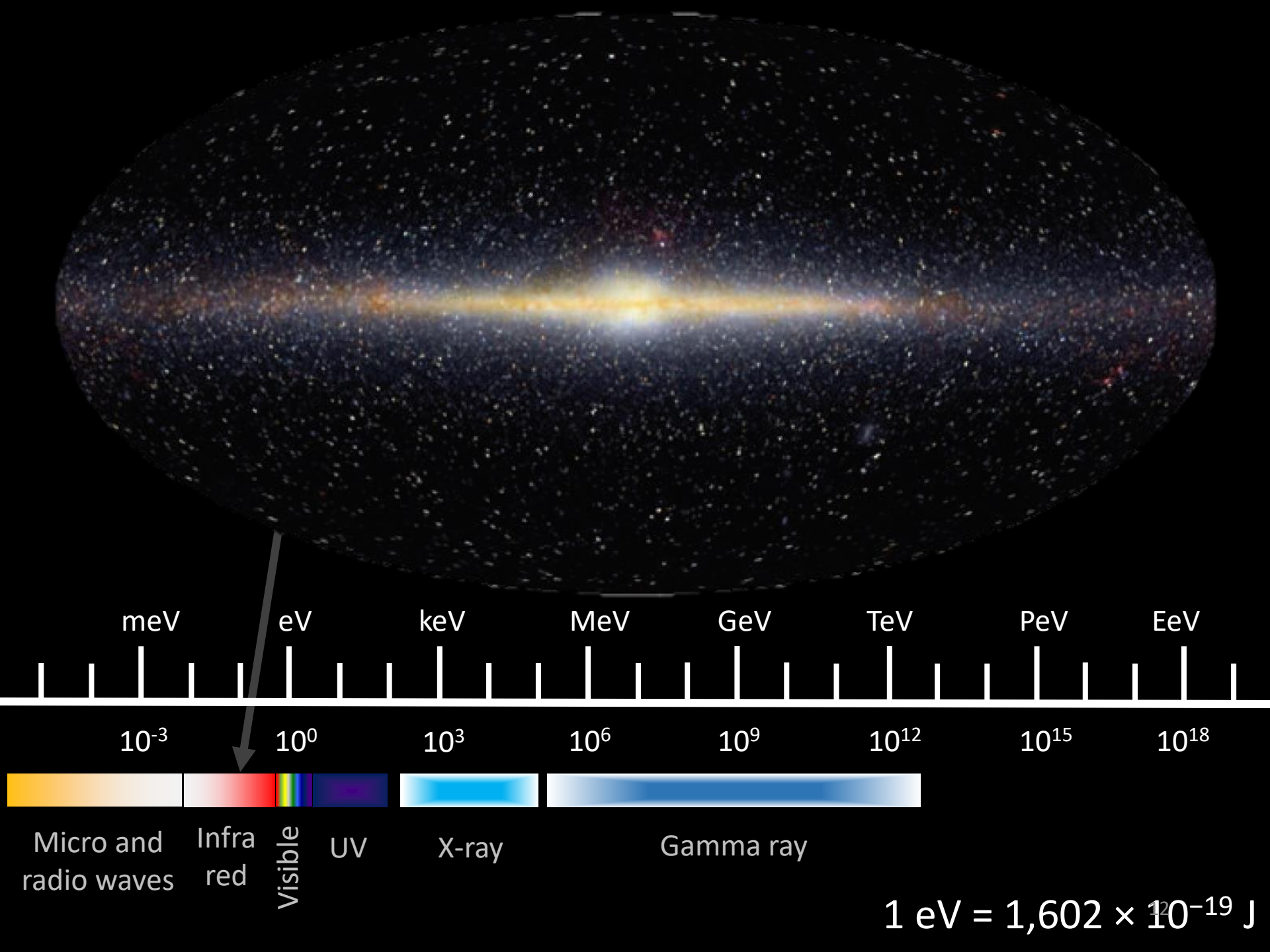

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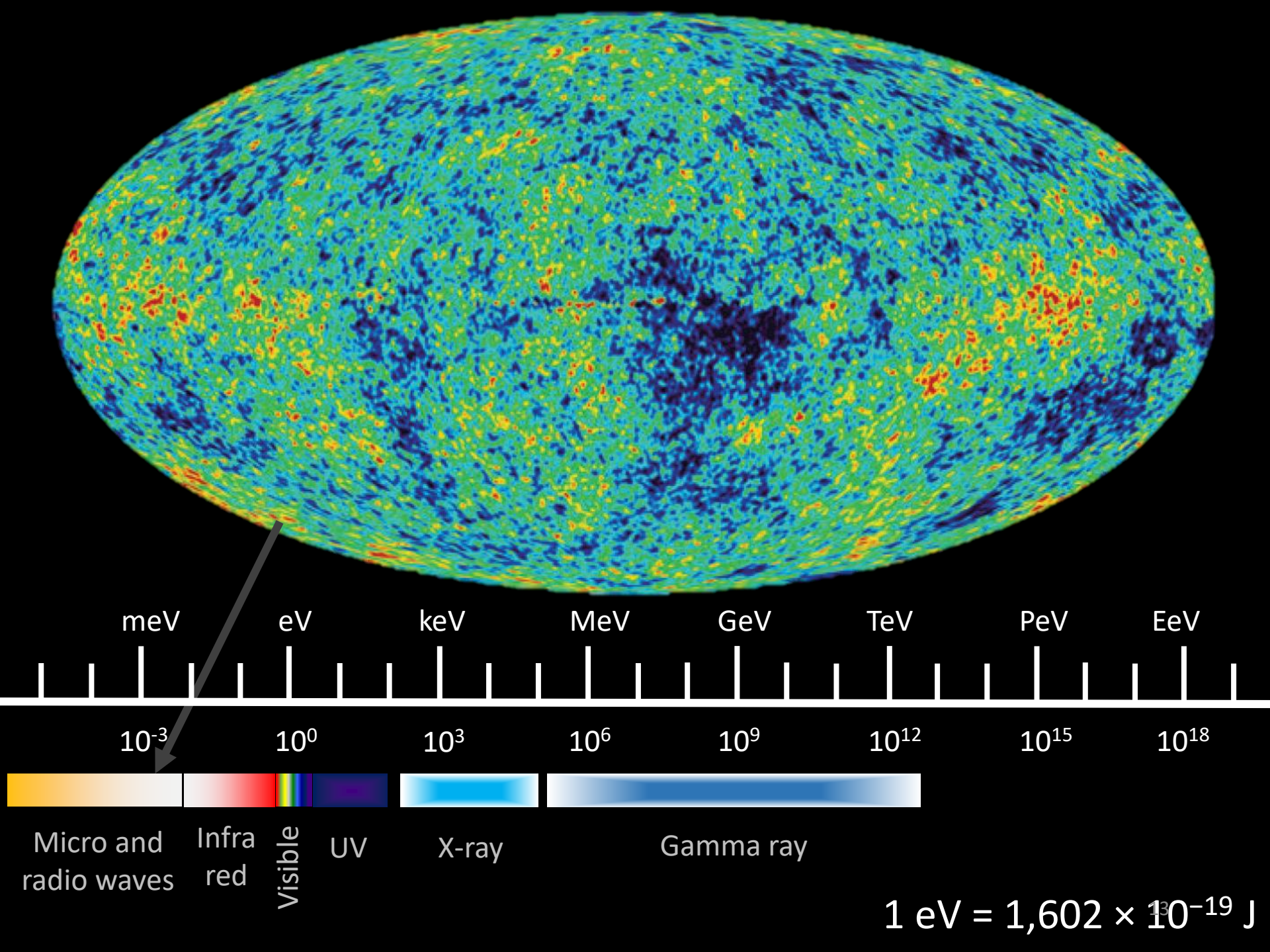

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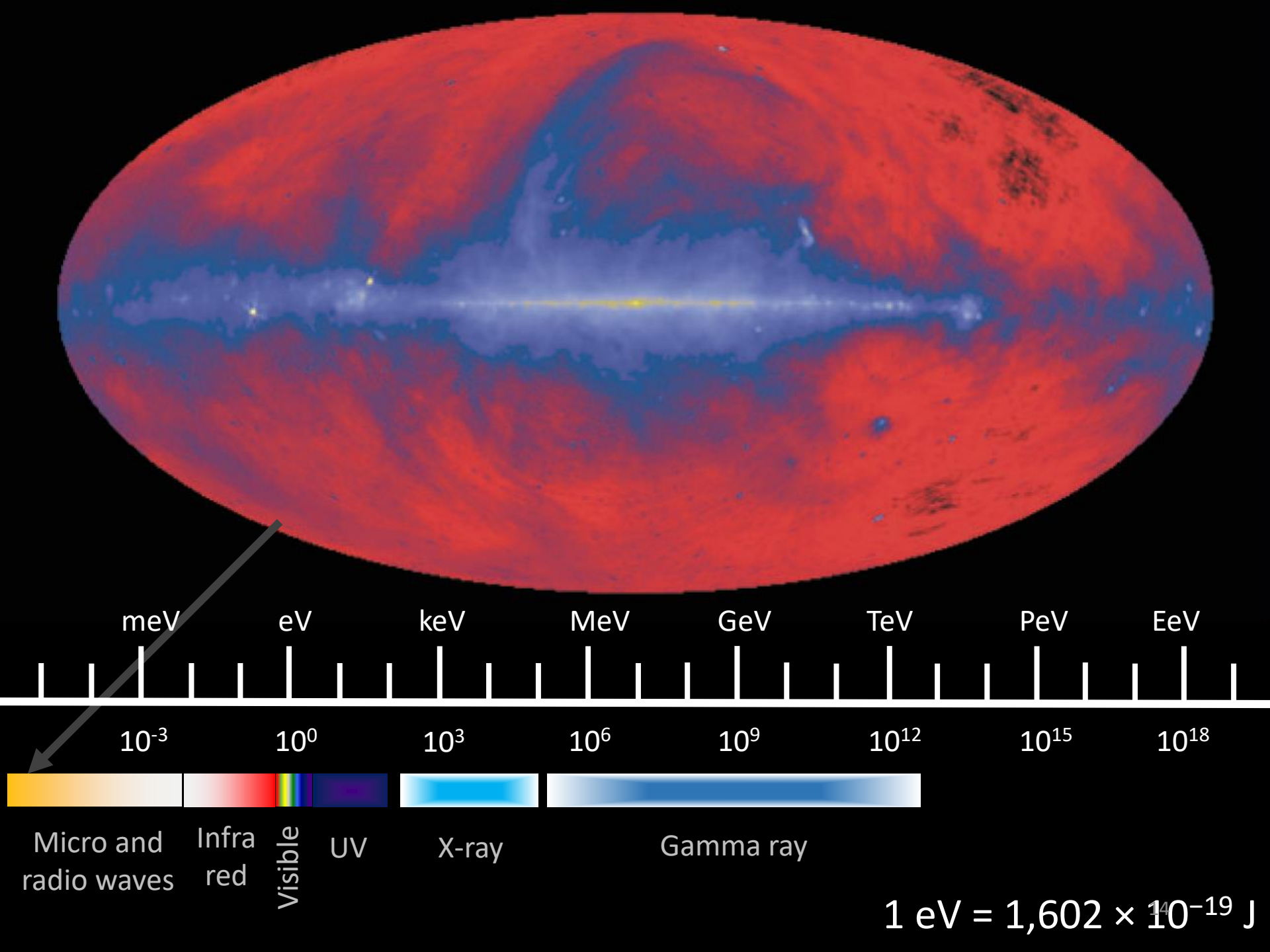

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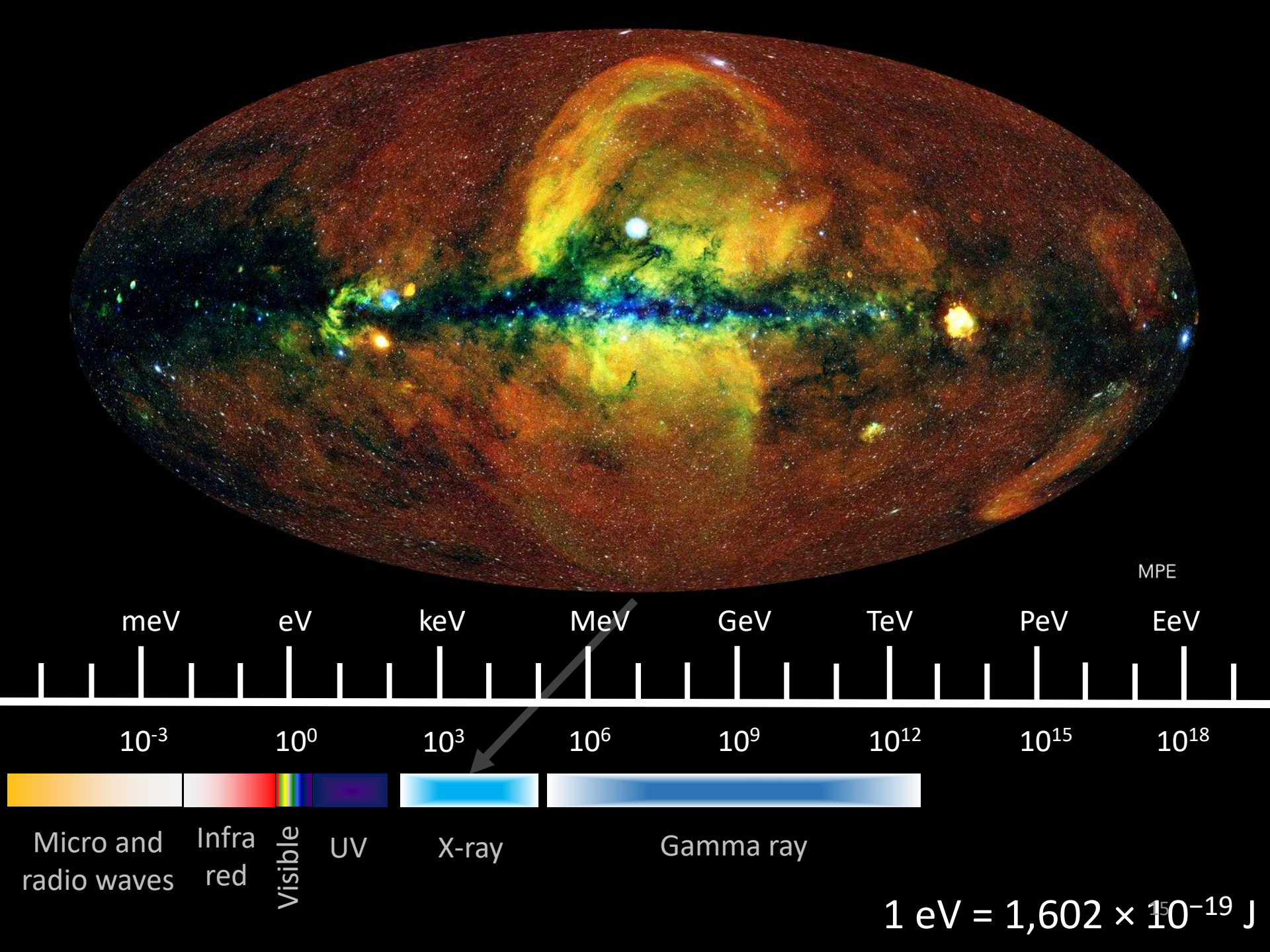

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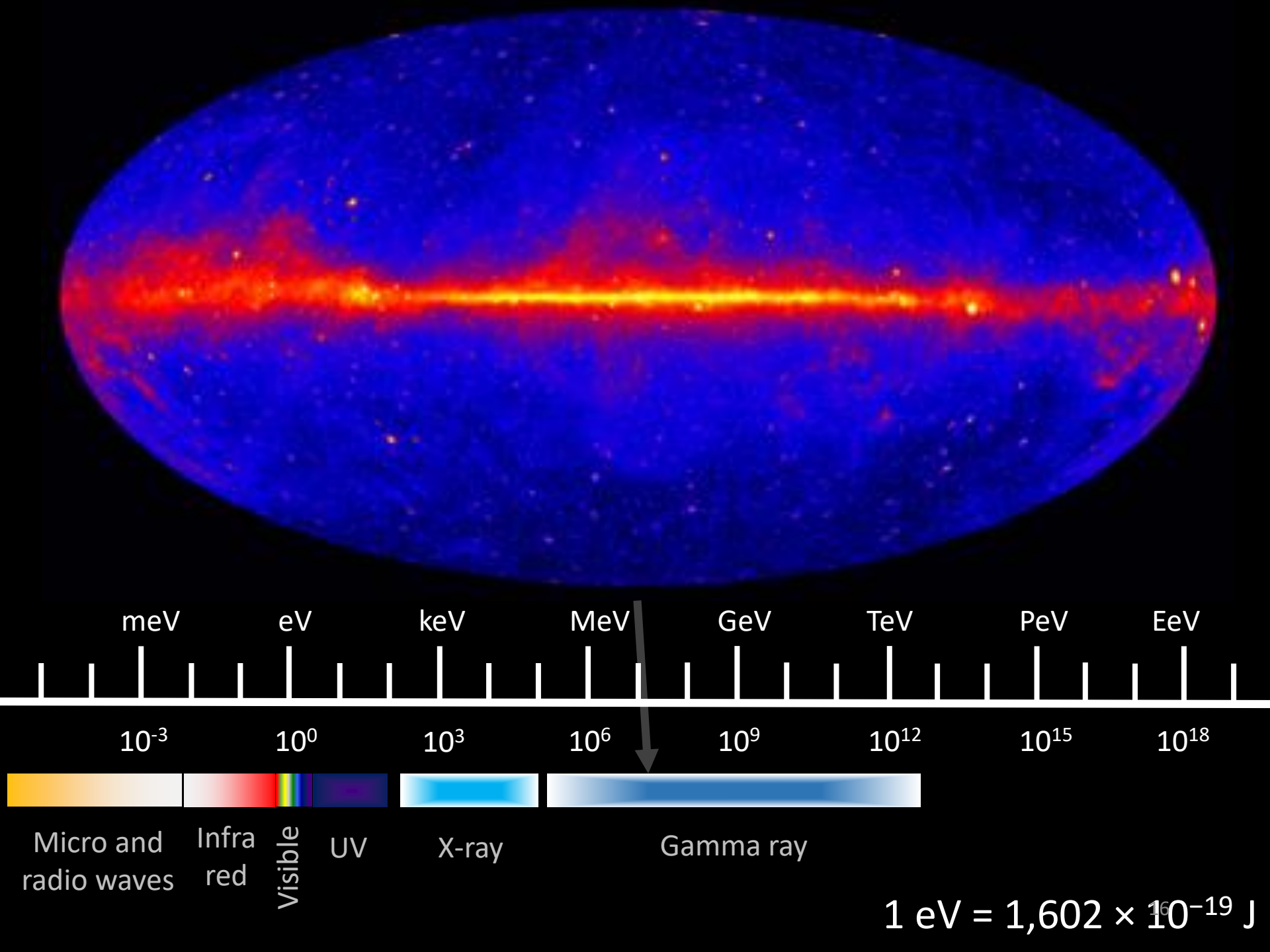

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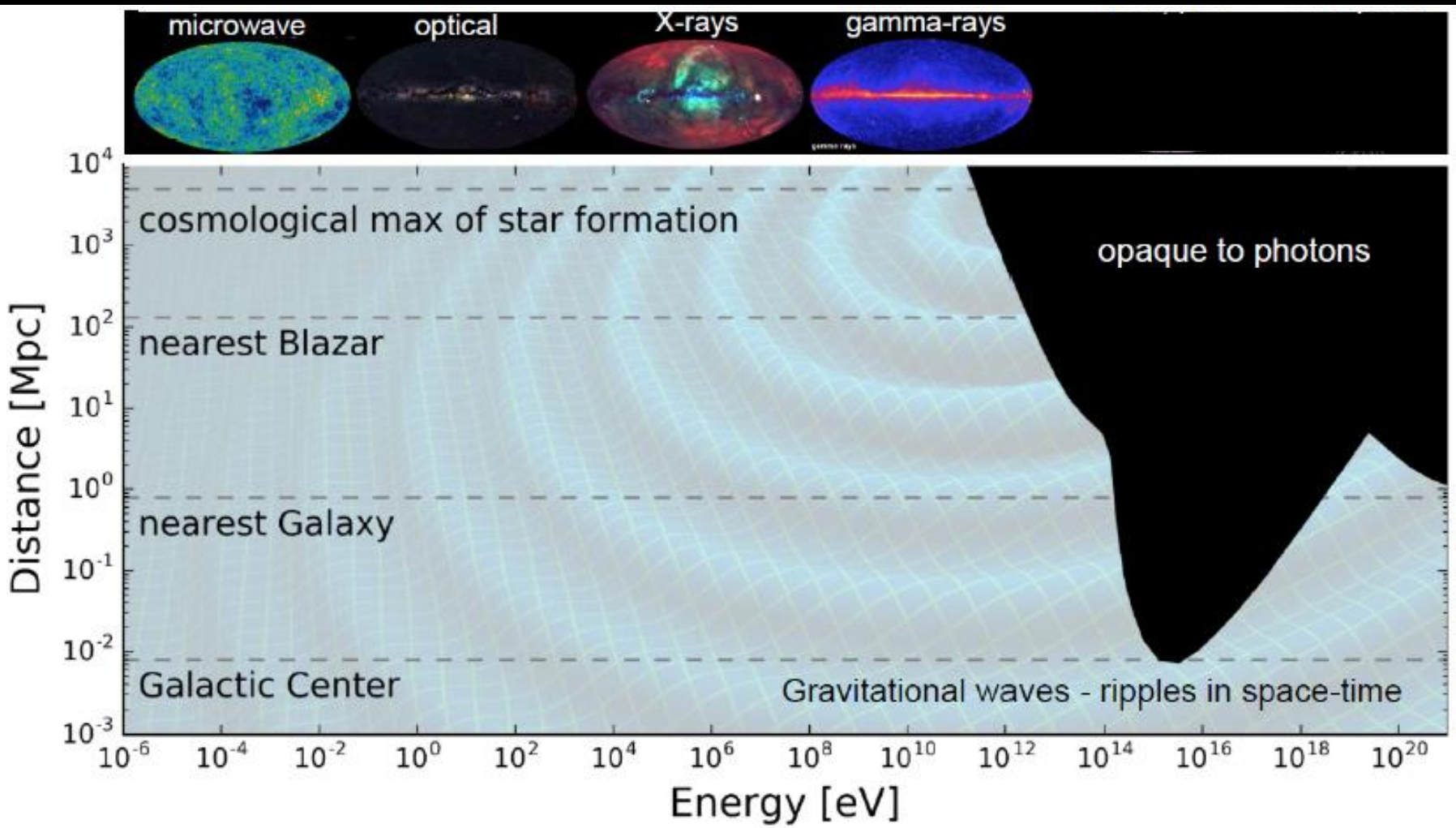
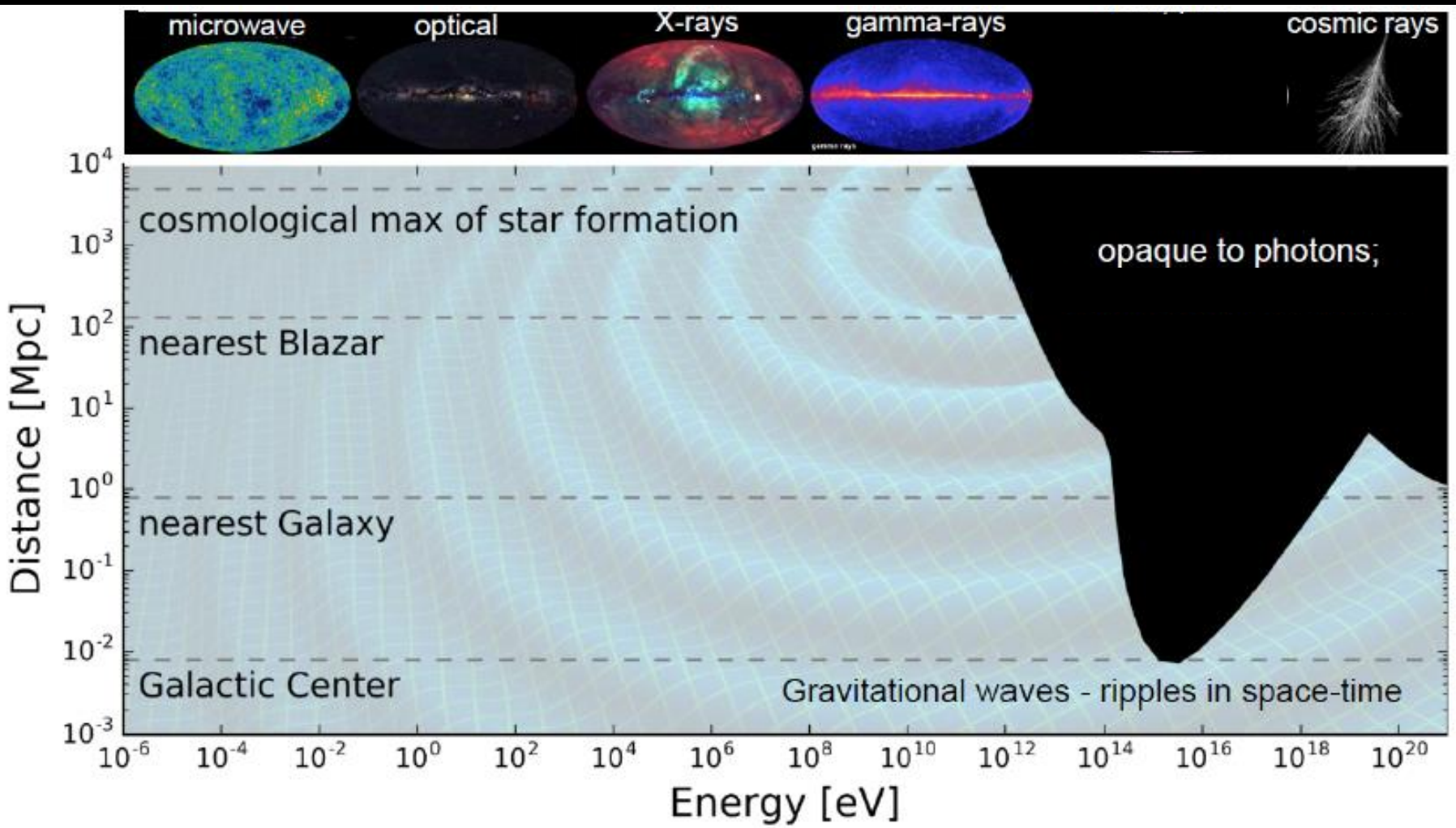


1 pc = 3,085 677 581 × 10^{16} m

= 3,2616 light-years



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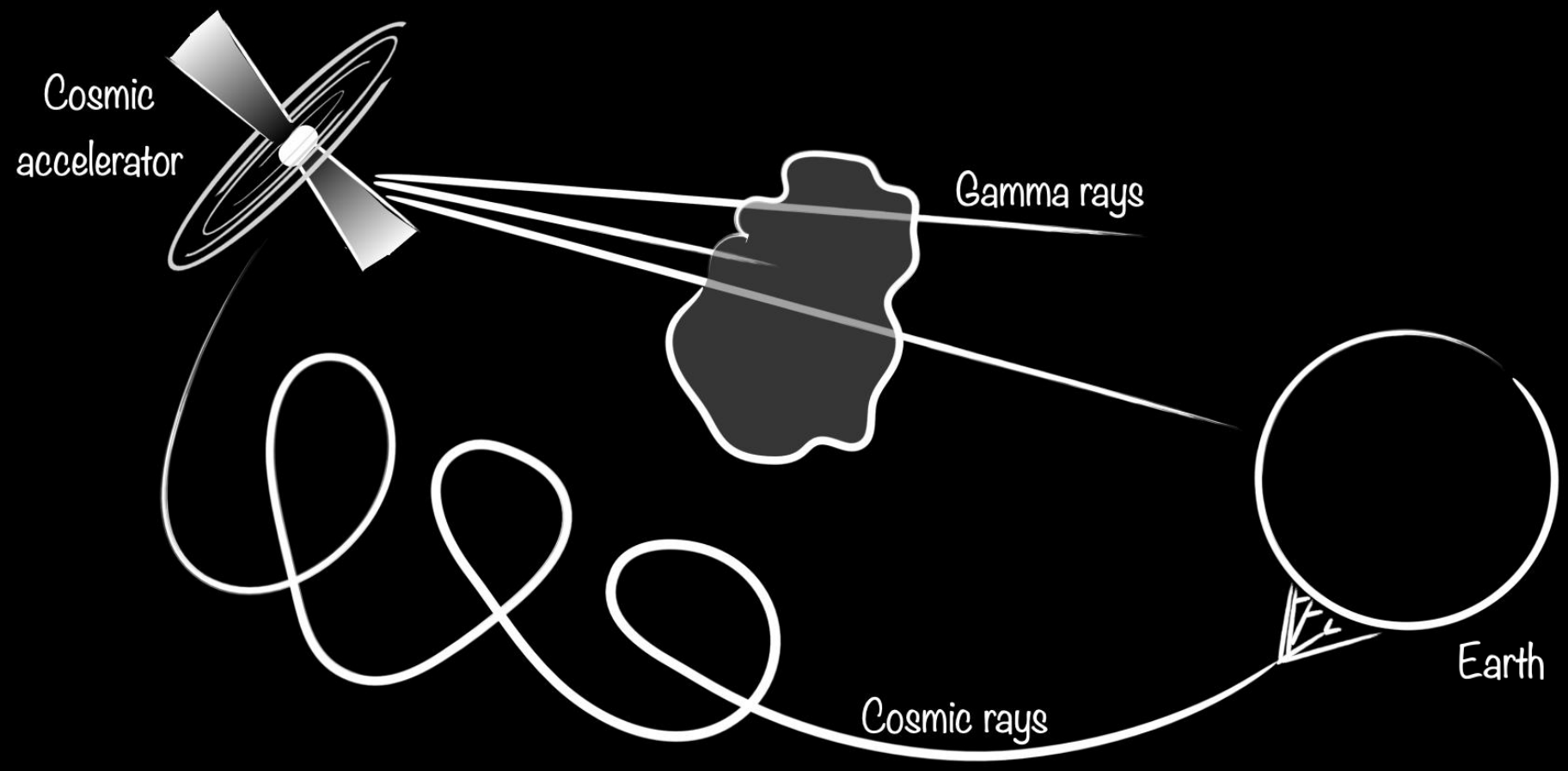
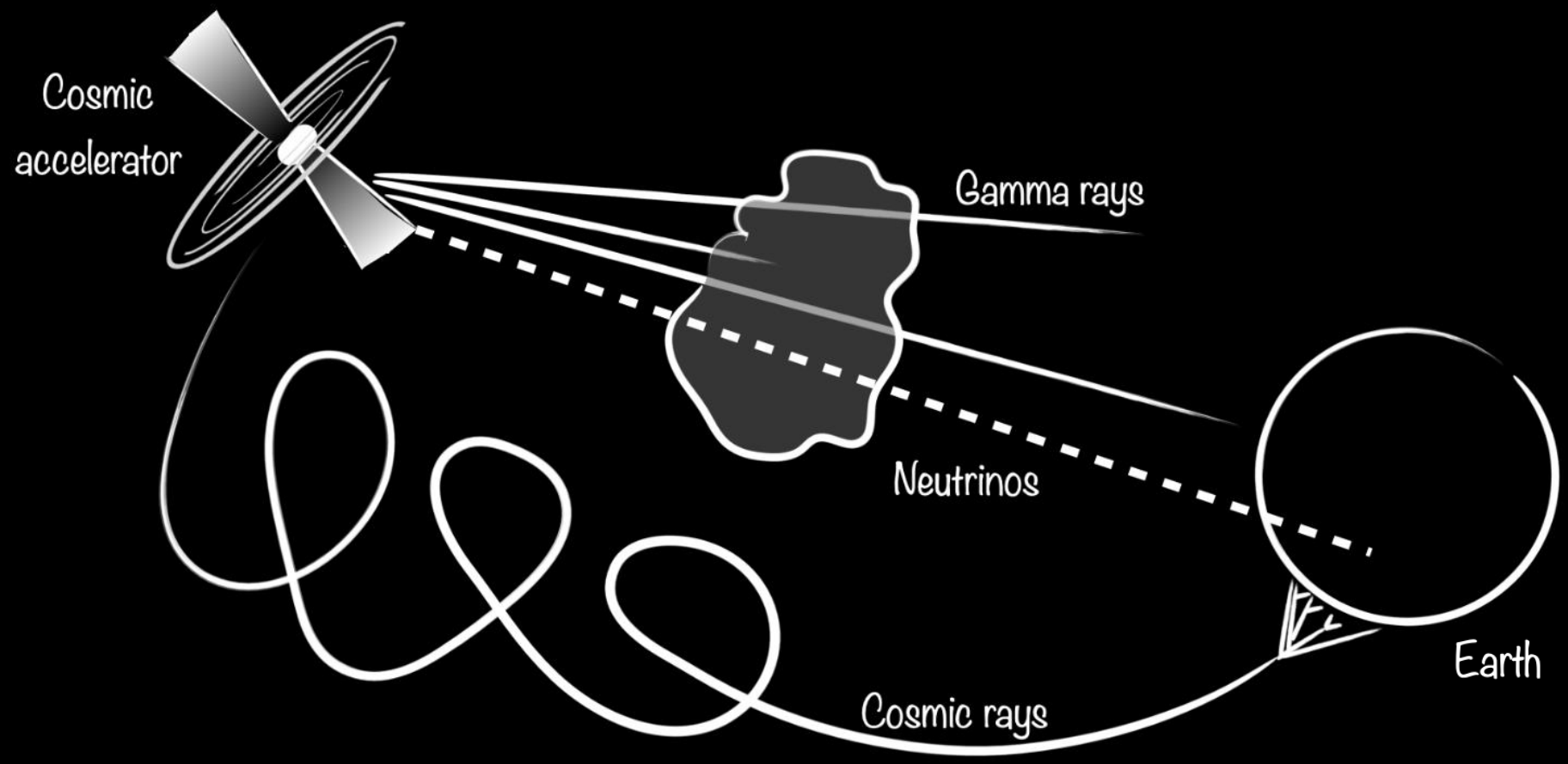

Cosmic
accelerator
Gamma rays
Earth
Cosmic rays


Cosmic
accelerator
Gamma rays
Neutrinos
Earth
Cosmic rays

Neutrinos in a few words

Elementary particles

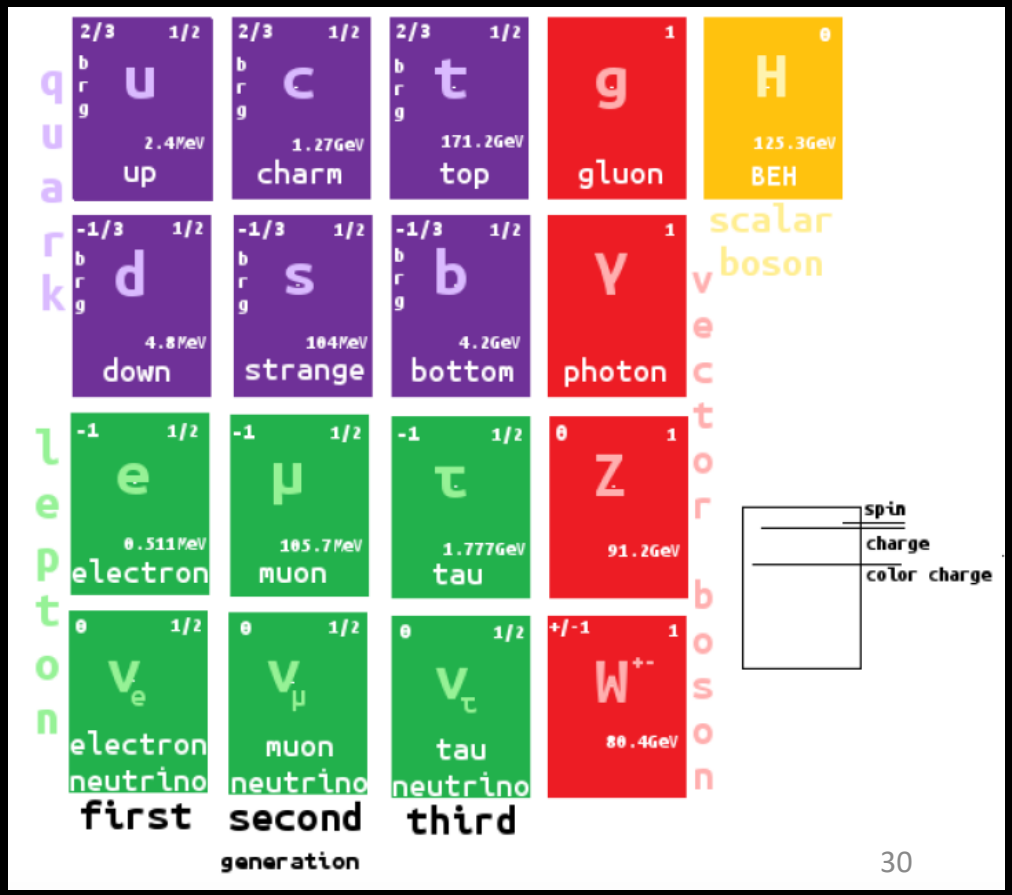
No electric charge

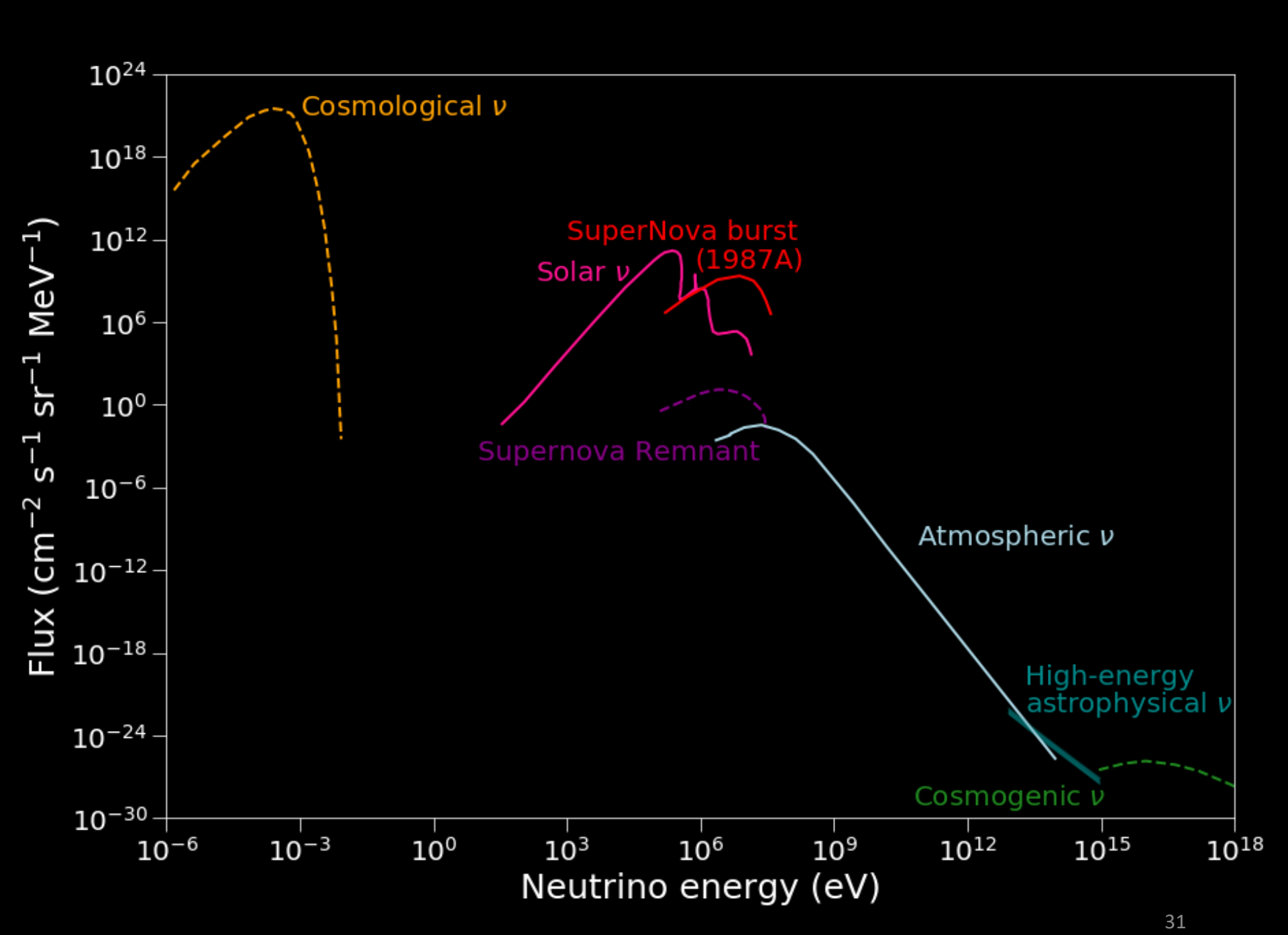
Very small cross section

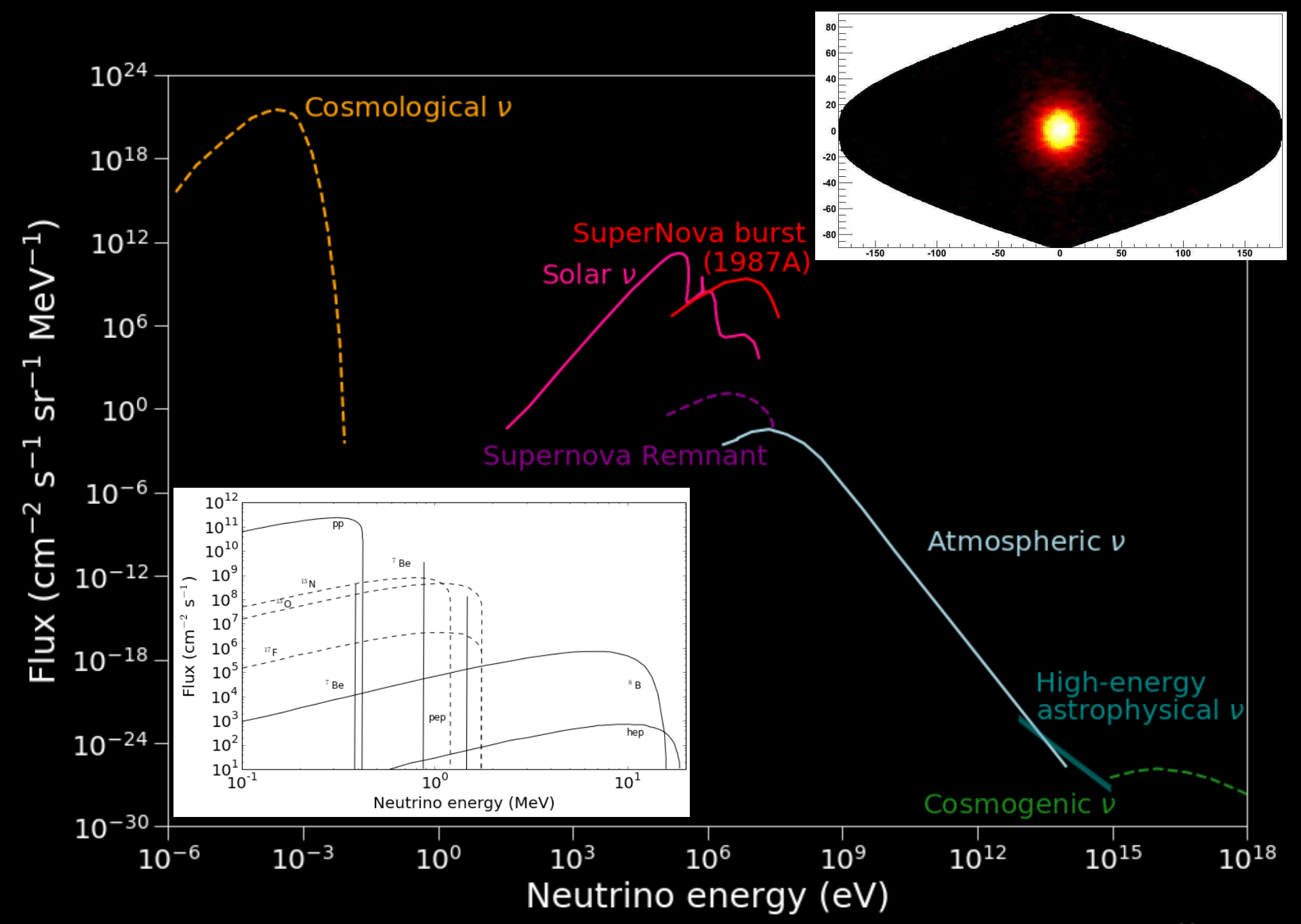
Oscillation from one flavor state to another

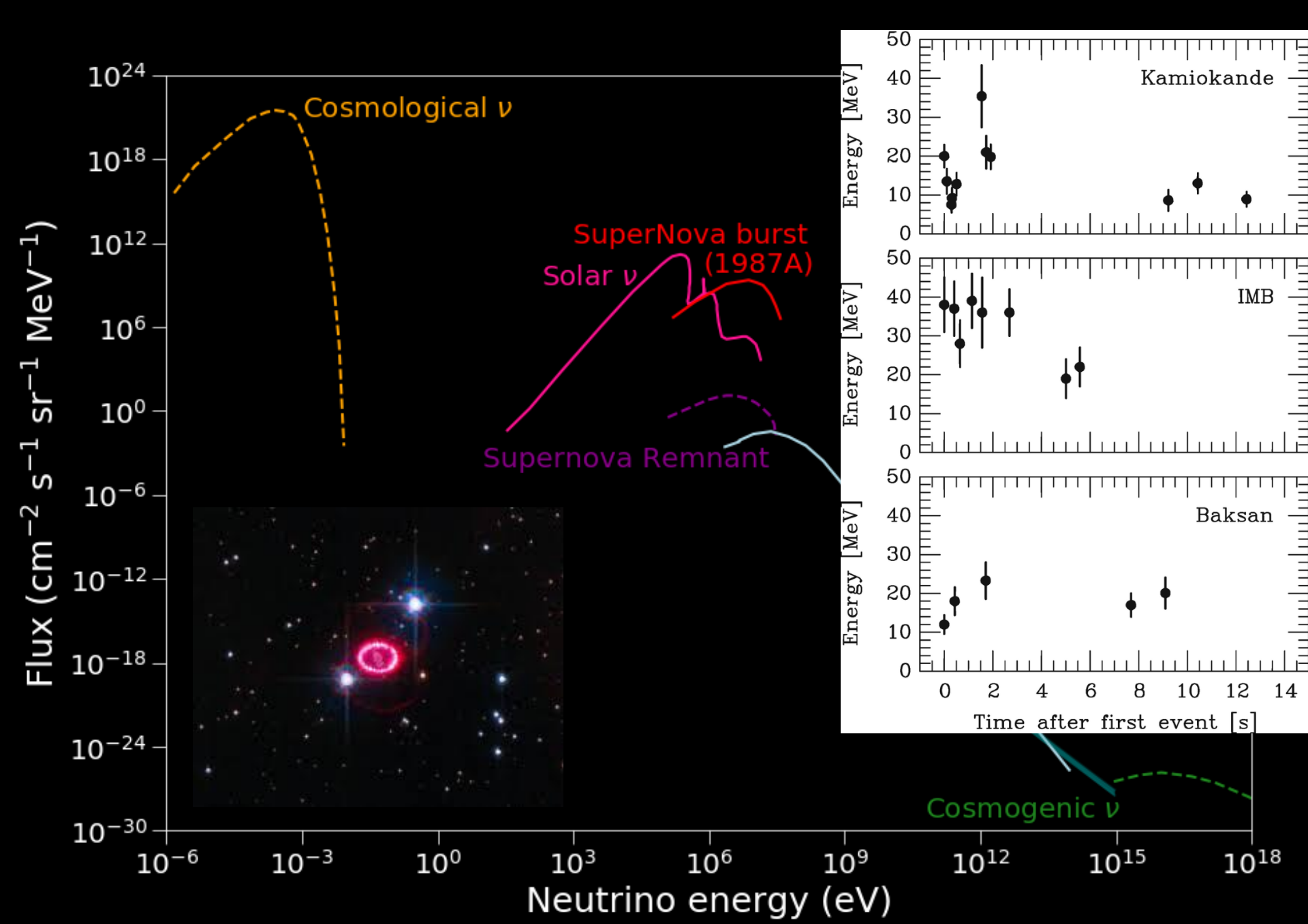
Very small but nonzero masses

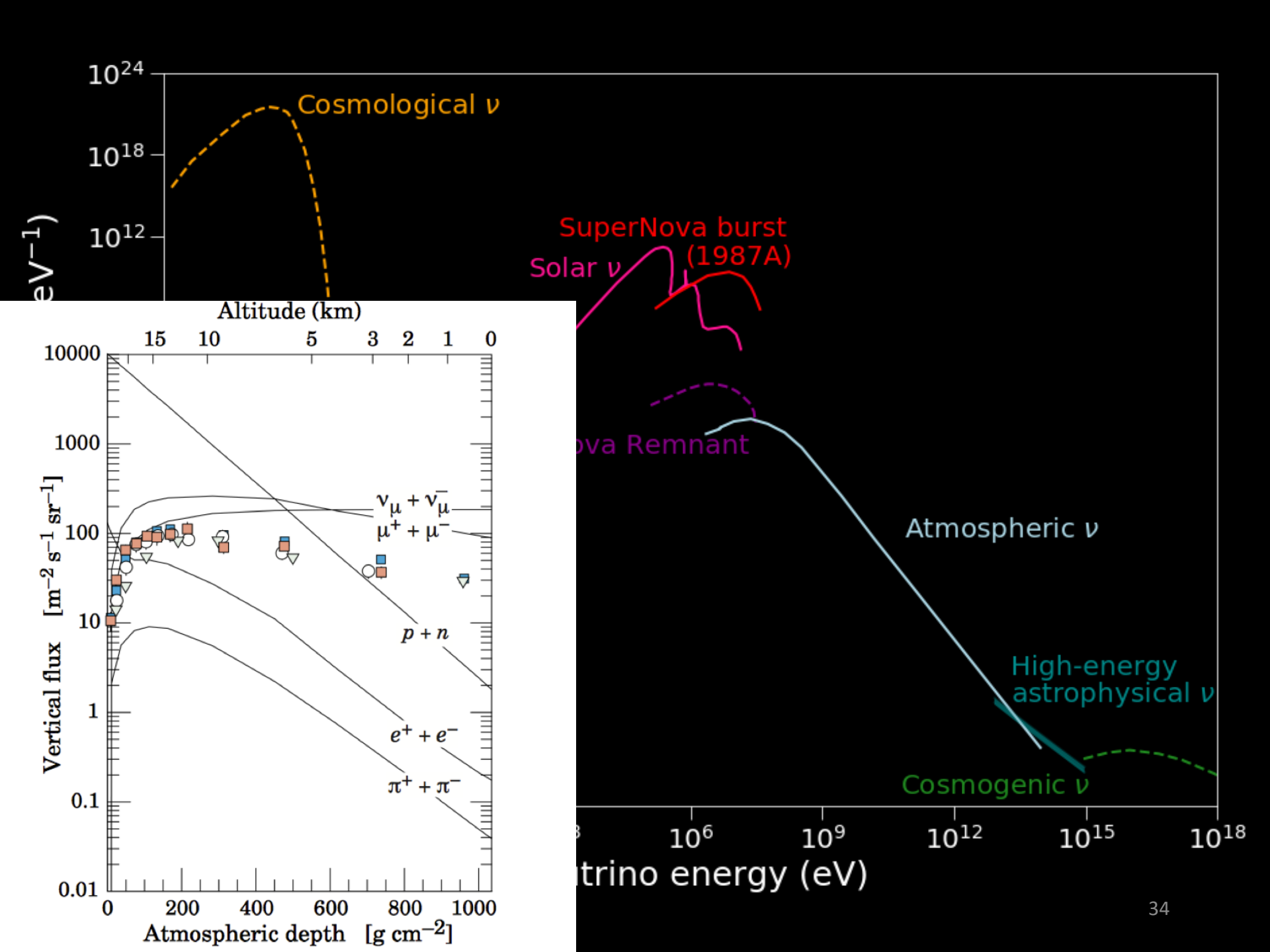
+ antiparticles

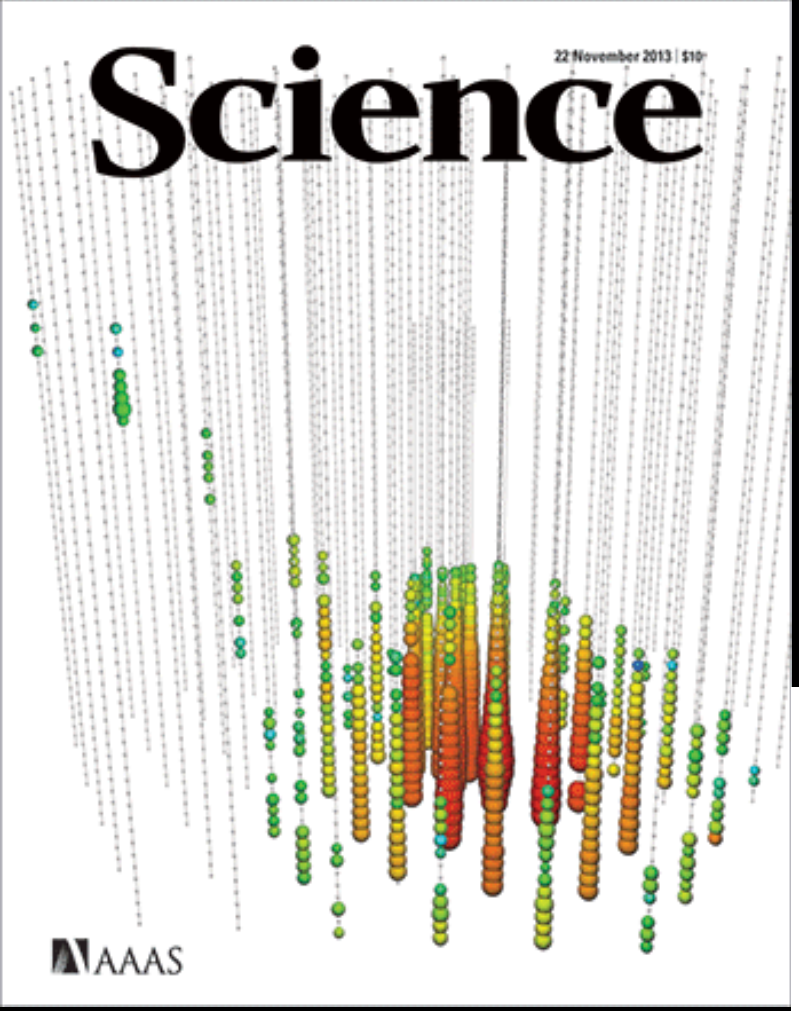



Cosmological ν
SuperNova burst
(1987A)
Solar ν
Supernova Remnant
Atmospheric ν
High-energy
astrophysical ν
Cosmogenic ν
Flux (cm^{-2} s^{-1} sr^{-1} MeV^{-1})
Neutrino energy (eV)
10^{24}
10^{18}
10^{12}
10^{6}
10^{0}
10^{-6}
10^{-12}
10^{-18}
10^{-24}
10^{-30}
10^{-6}
10^{-3}
10^{0}
10^{3}
10^{6}
10^{9}
10^{12}
10^{15}
10^{18}


Cosmological ν
SuperNova burst
(1987A)
Solar ν
Supernova Remnant
Atmospheric ν
High-energy
astrophysical ν
Cosmogenic ν
Flux (cm^{-2} s^{-1} sr^{-1} MeV^{-1})
Neutrino energy (eV)
pp
^{7}Be
^{13}N
^{15}O
^{17}F
^{7}Be
^{8}B
pep
hep
Flux (cm^{-2} s^{-1})
Neutrino energy (MeV)

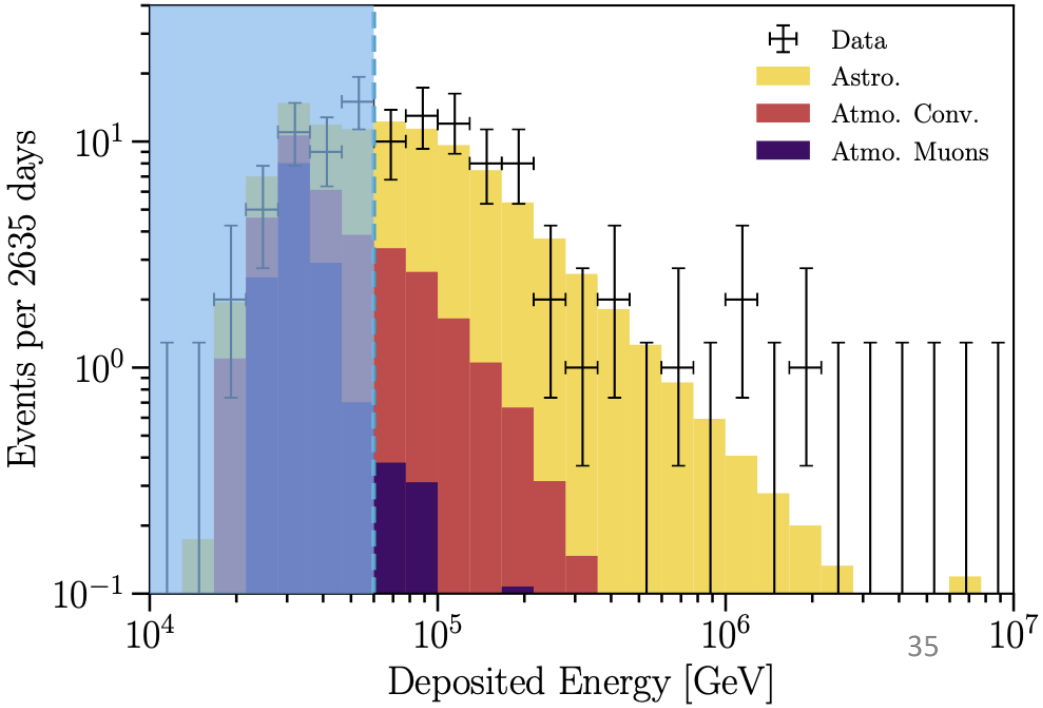

Cosmological ν
SuperNova burst
(1987A)
Solar ν
Supernova Remnant
Cosmogenic ν
Flux (cm^{-2} s^{-1} sr^{-1} MeV^{-1})
Neutrino energy (eV)
Kamiokande
IMB
Baksan
Energy [MeV]
Time after first event [s]


Cosmological ν
SuperNova burst
(1987A)
Solar ν
ova Remnant
Atmospheric ν
High-energy
astrophysical ν
Cosmogenic ν
trino energy (eV)
Altitude (km)
Vertical flux [m⁻² s⁻¹ sr⁻¹]
Atmospheric depth [g cm⁻²]
ν_μ + ν̄_μ
μ⁺ + μ⁻
p + n
e⁺ + e⁻
π⁺ + π⁻

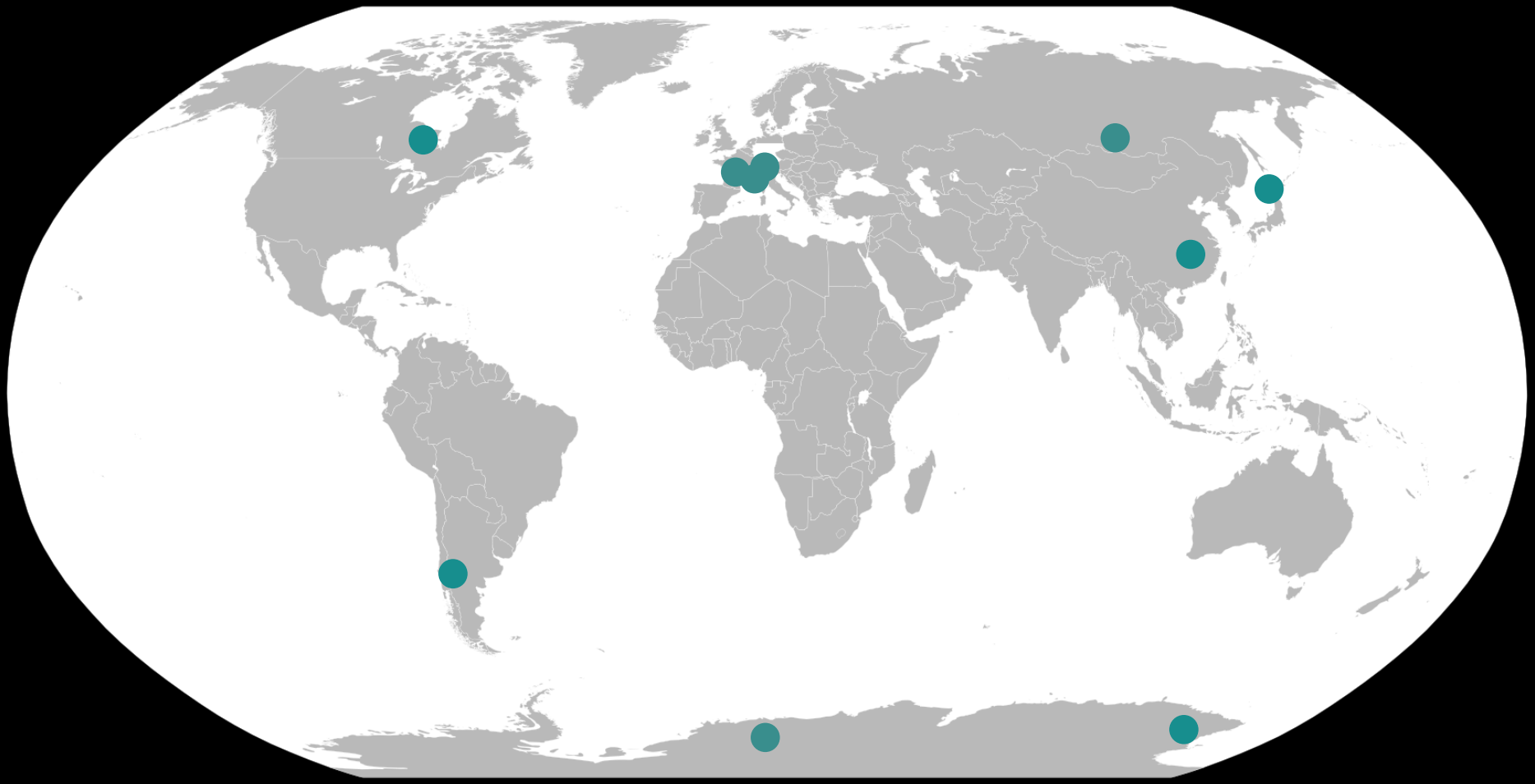


Evidence for High-Energy Extraterrestrial Neutrinos at the IceCube Detector

22 Nov. 2013

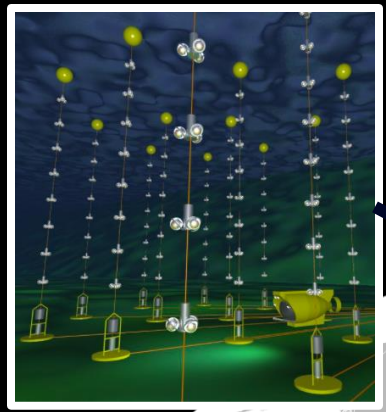


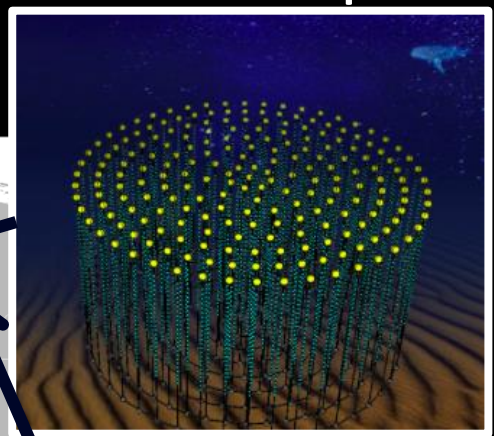
Neutrino telescopes

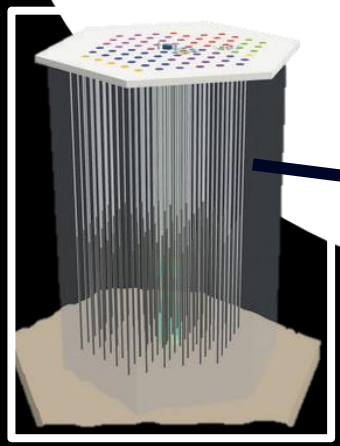


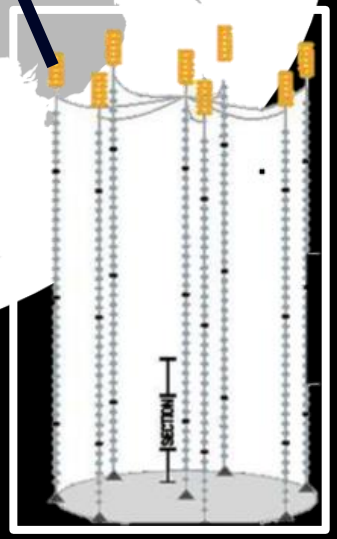
Non-exhaustive list

Neutrino telescopes





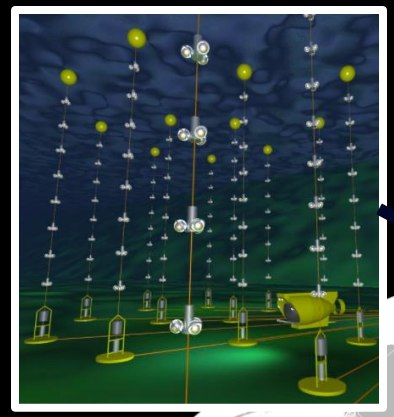


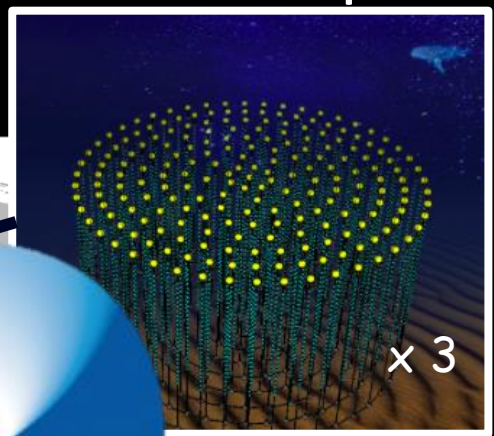


GNN
The Global Neutrino Network

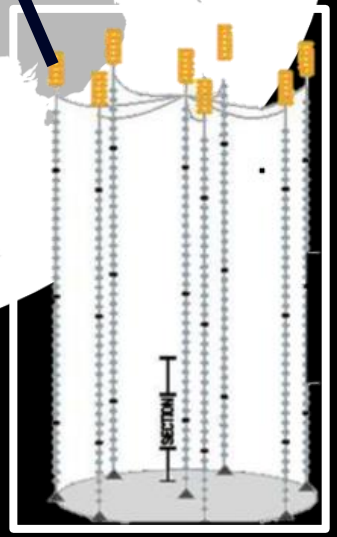
x 8

Neutrino telescopes





KM3NeT

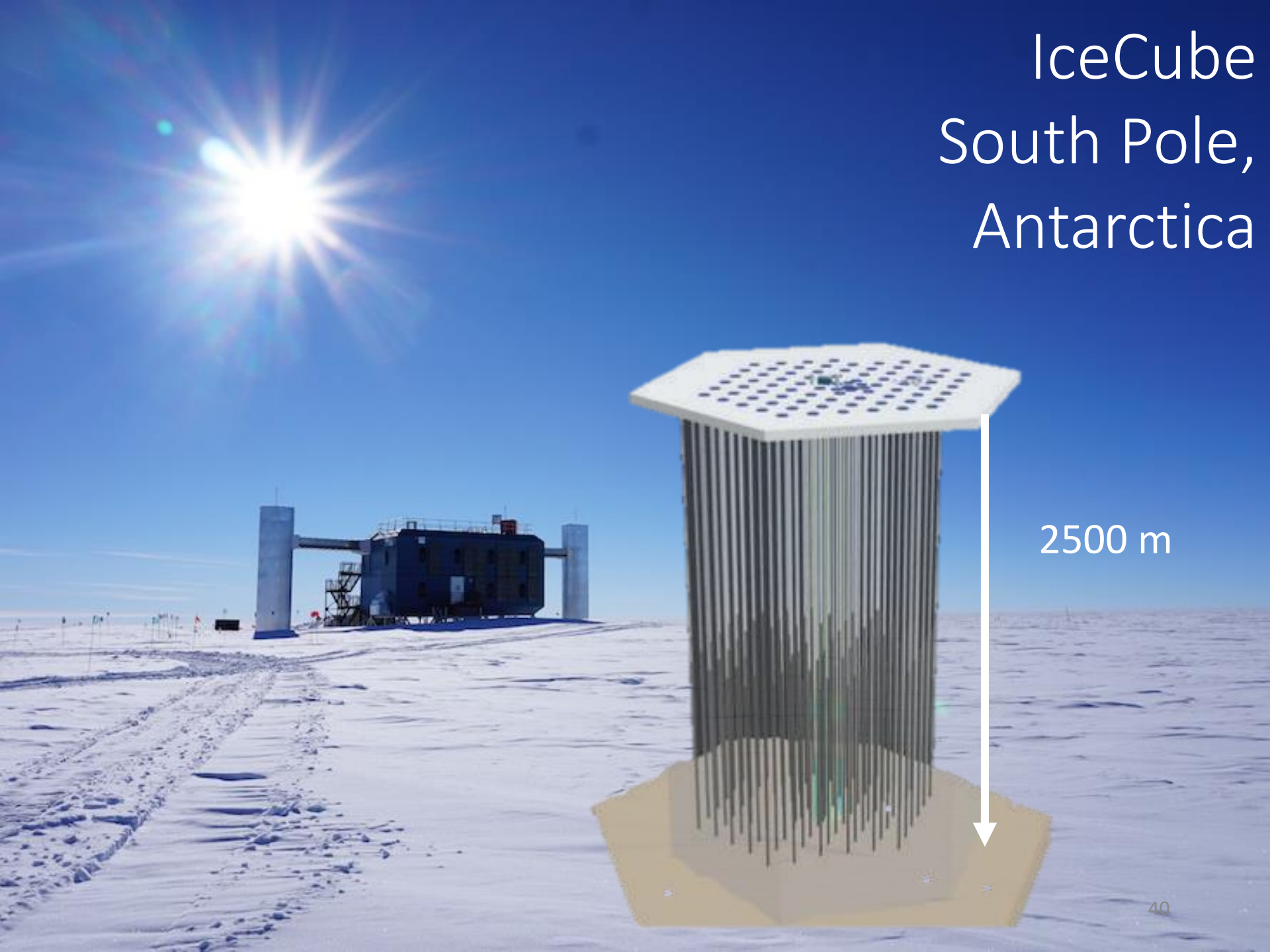


GNN
The Global Neutrino Network

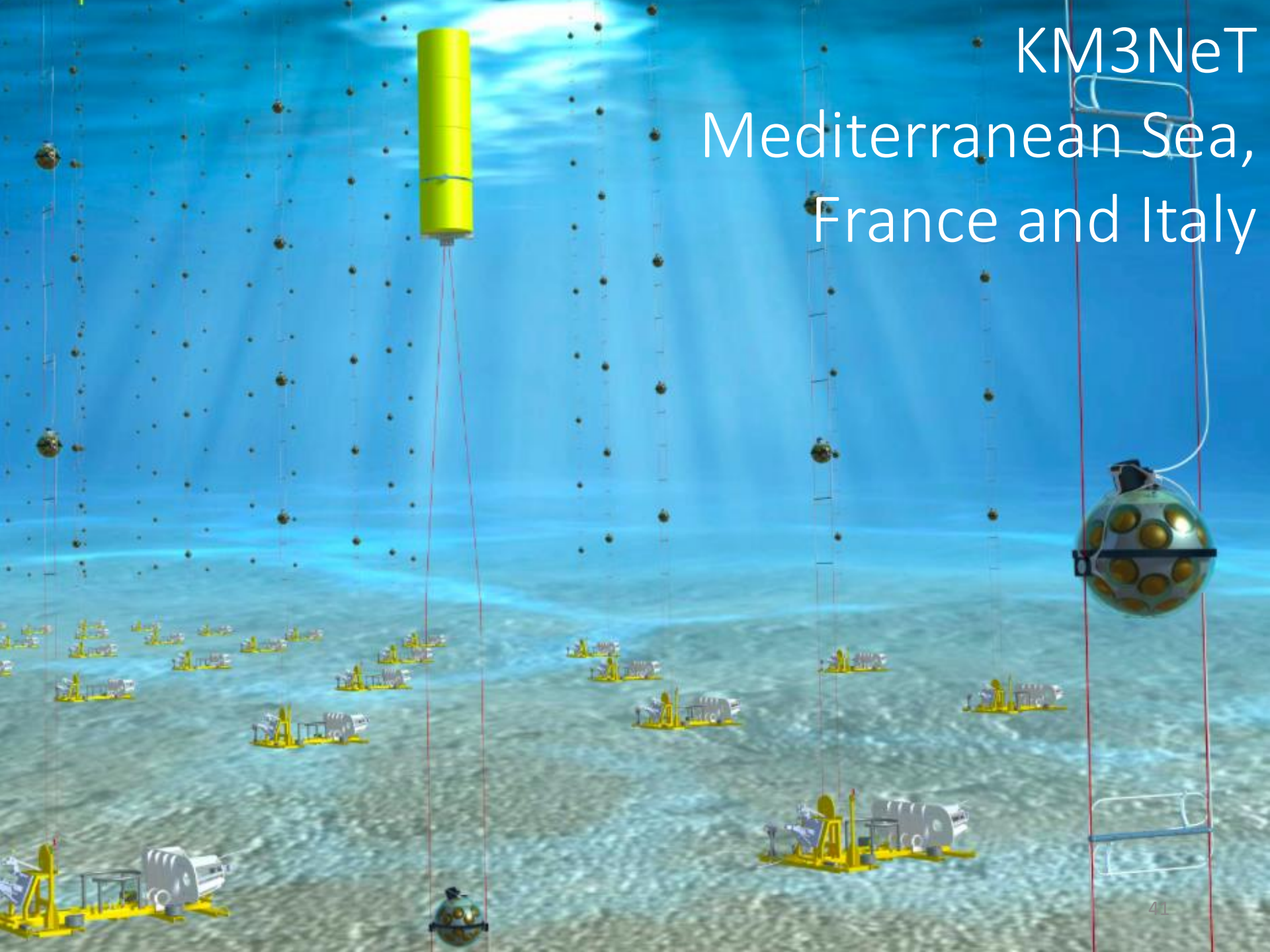
x 8

IceCube South Pole, Antarctica

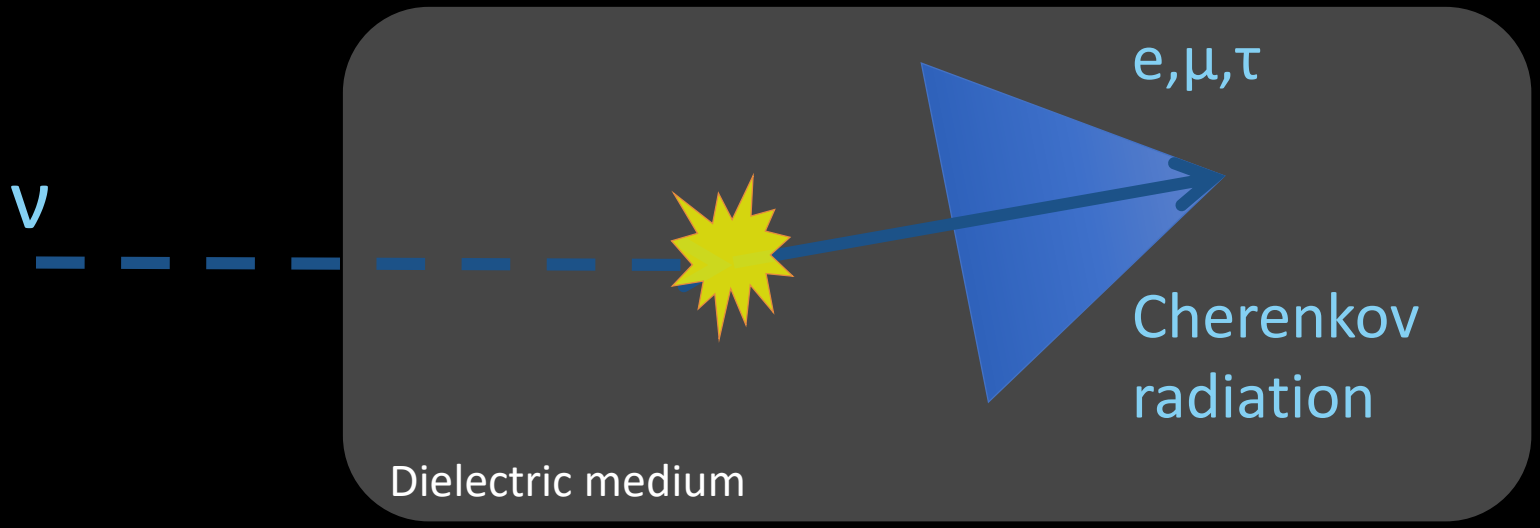
IceCube South Pole, Antarctica

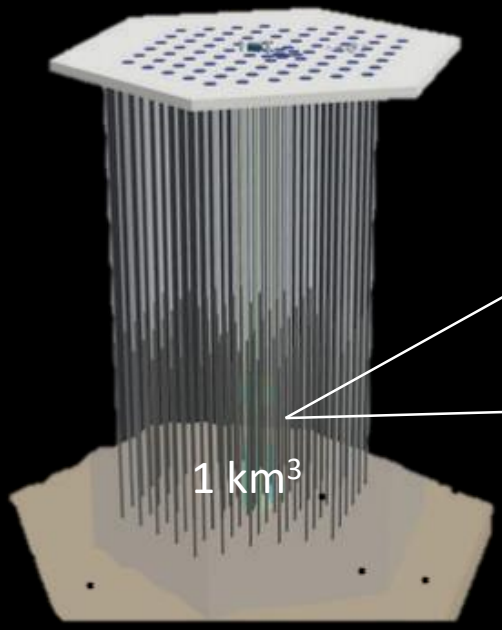


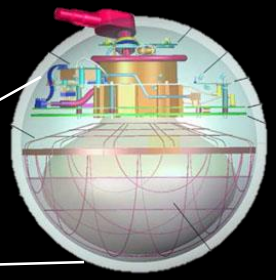
KM3NeT
Mediterranean Sea, France and Italy



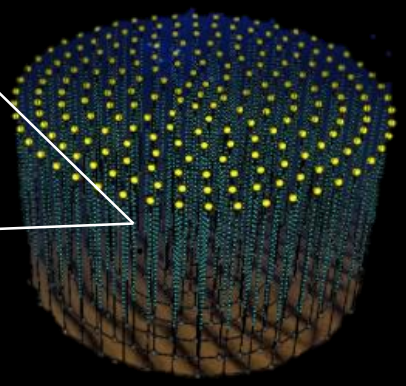
Detection strategy





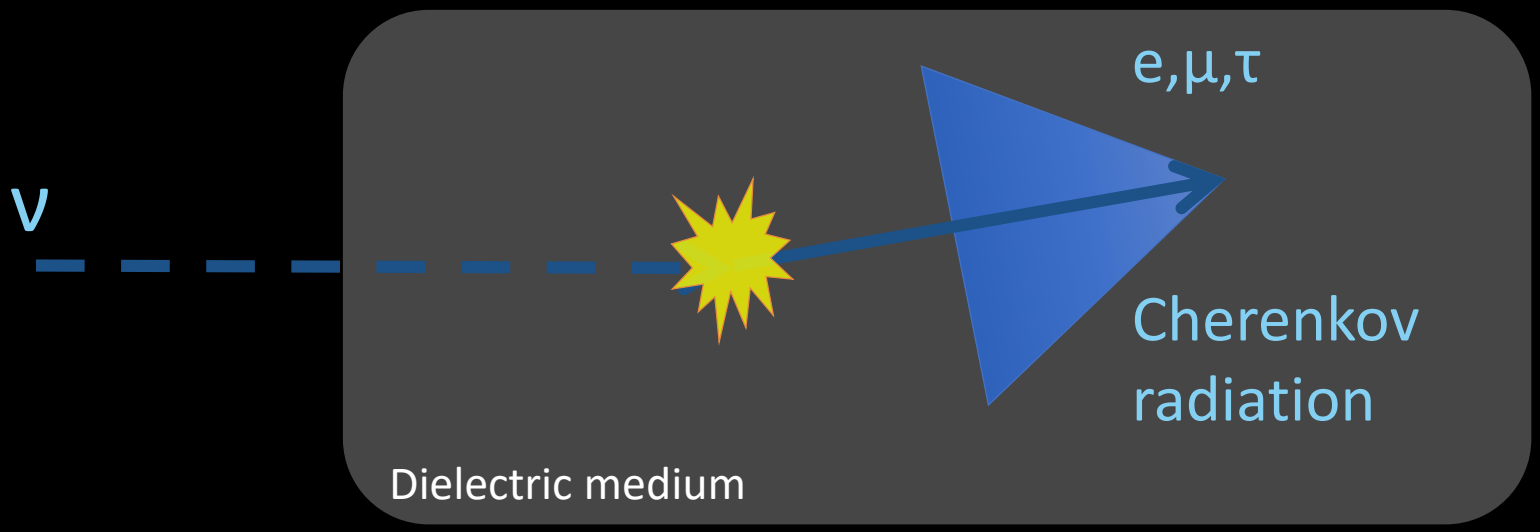


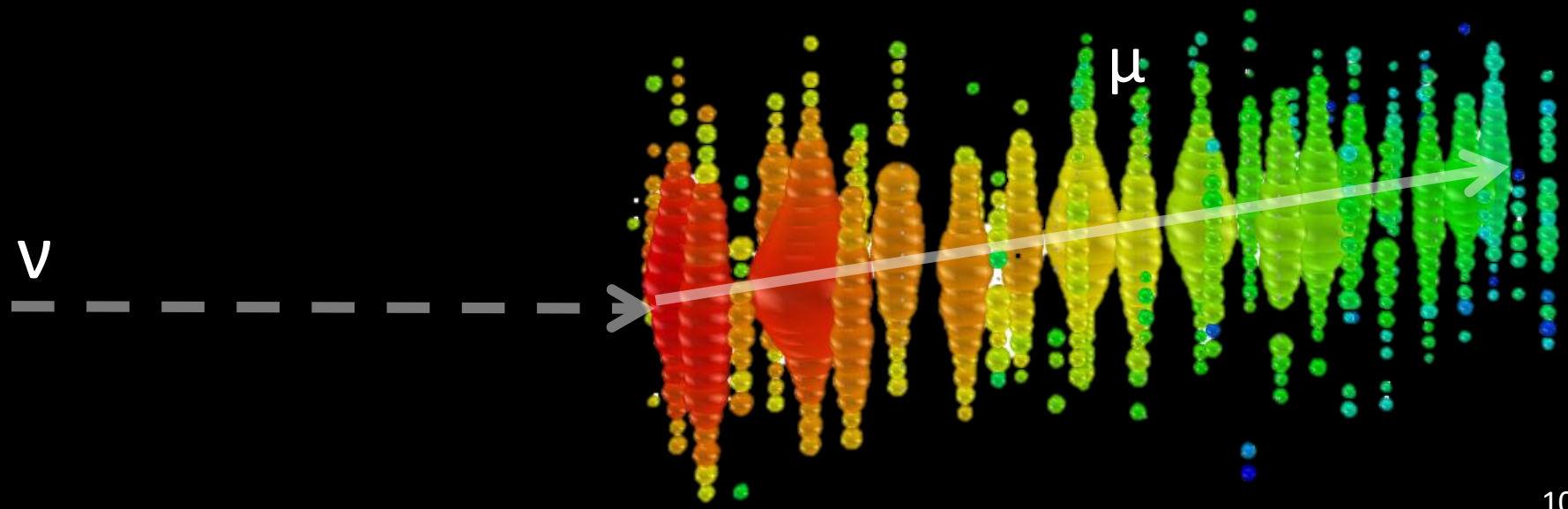
5160 sensors



2070 sensors/block
1 block ORCA
+ 2 blocks ARCA

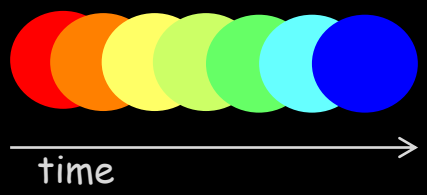
Detection strategy

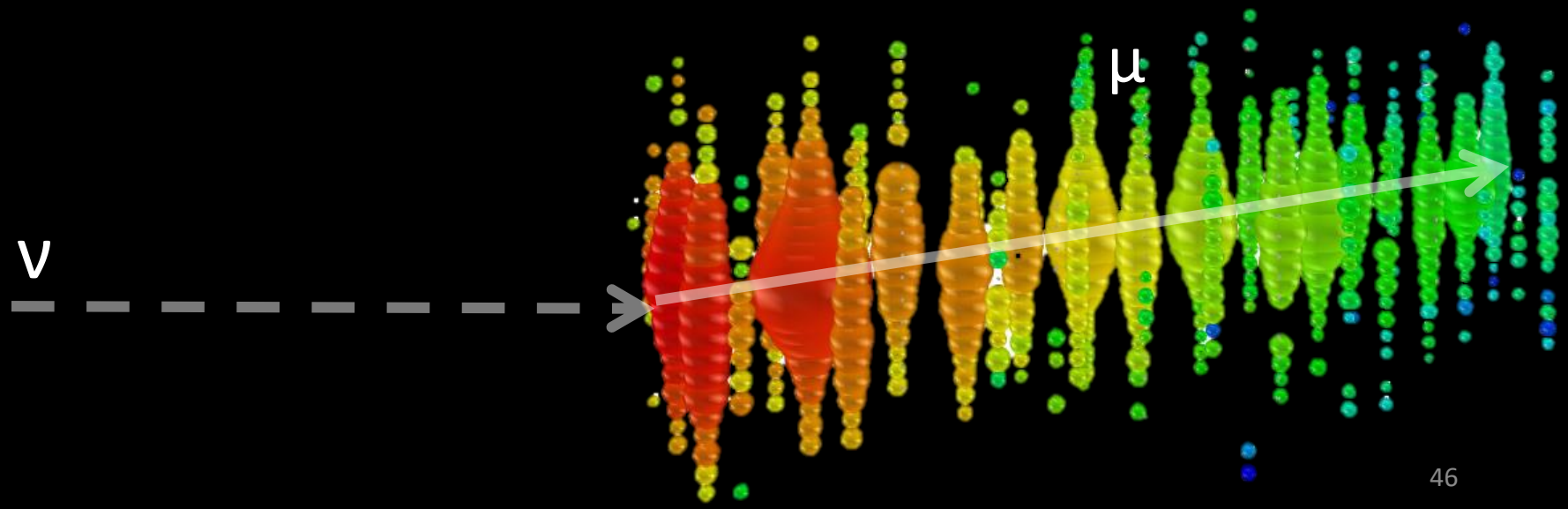


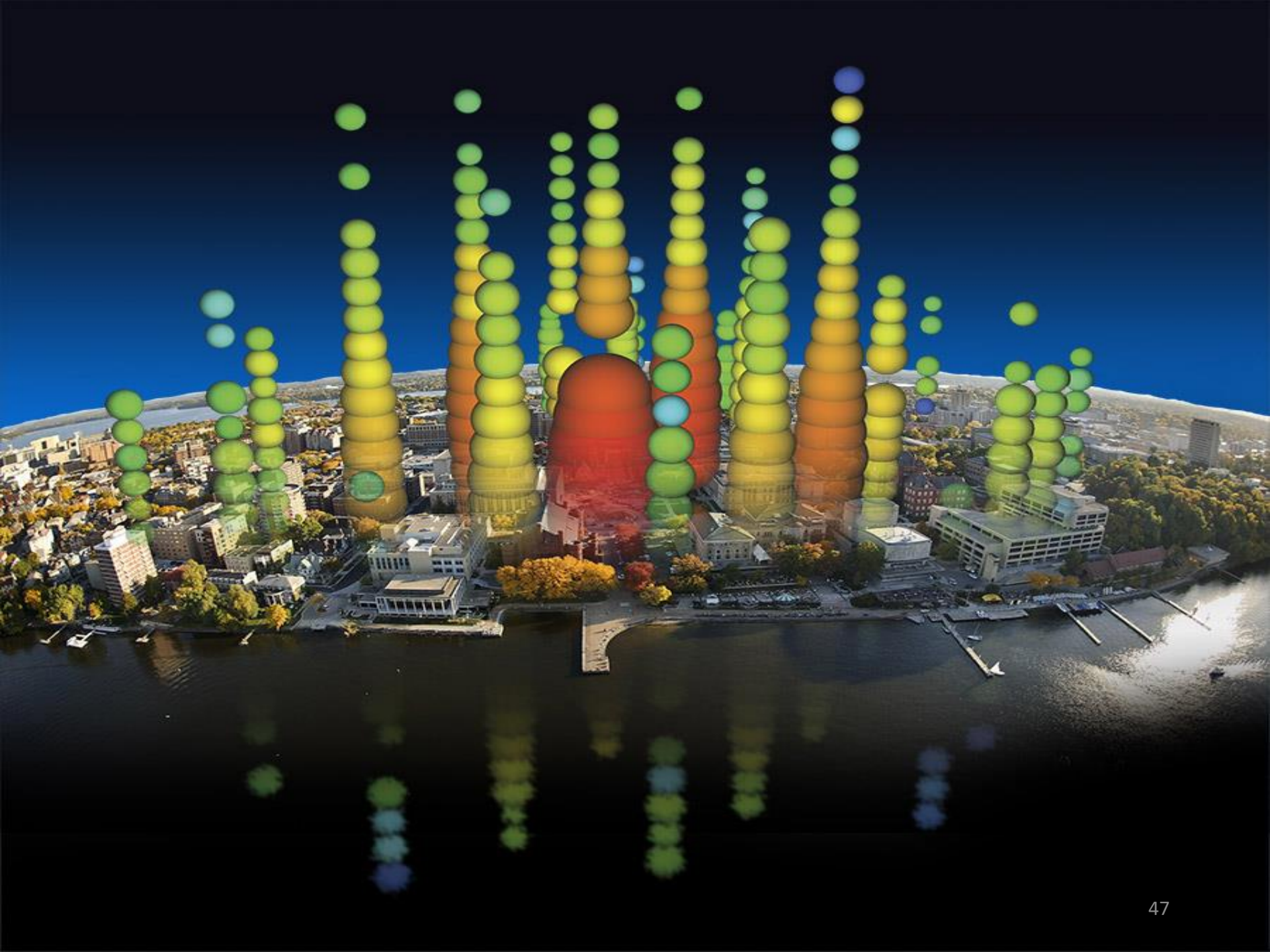


Detection strategy

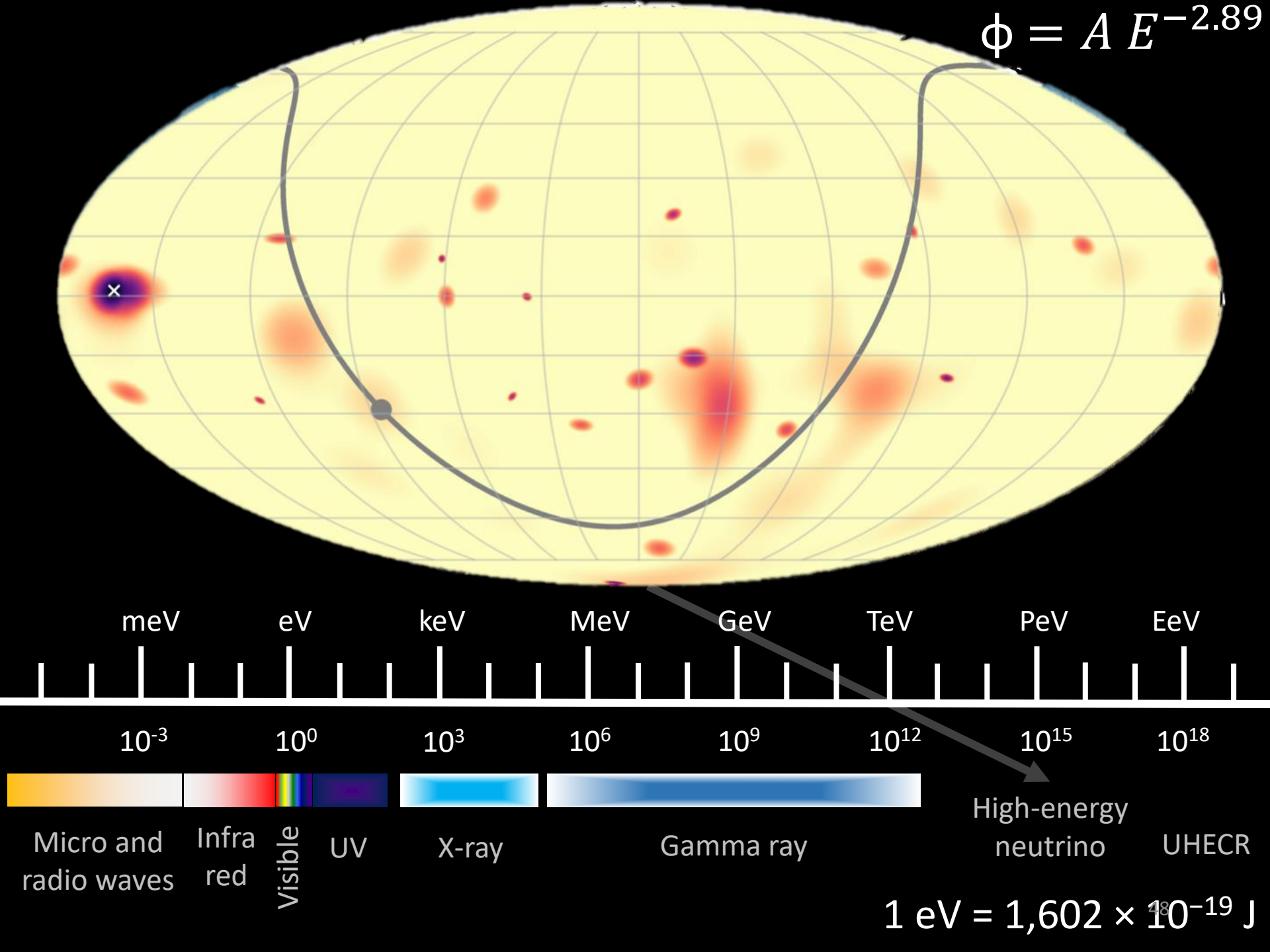
- Amount of light-> Energy
- Timing -> Direction
- Topology -> Flavor





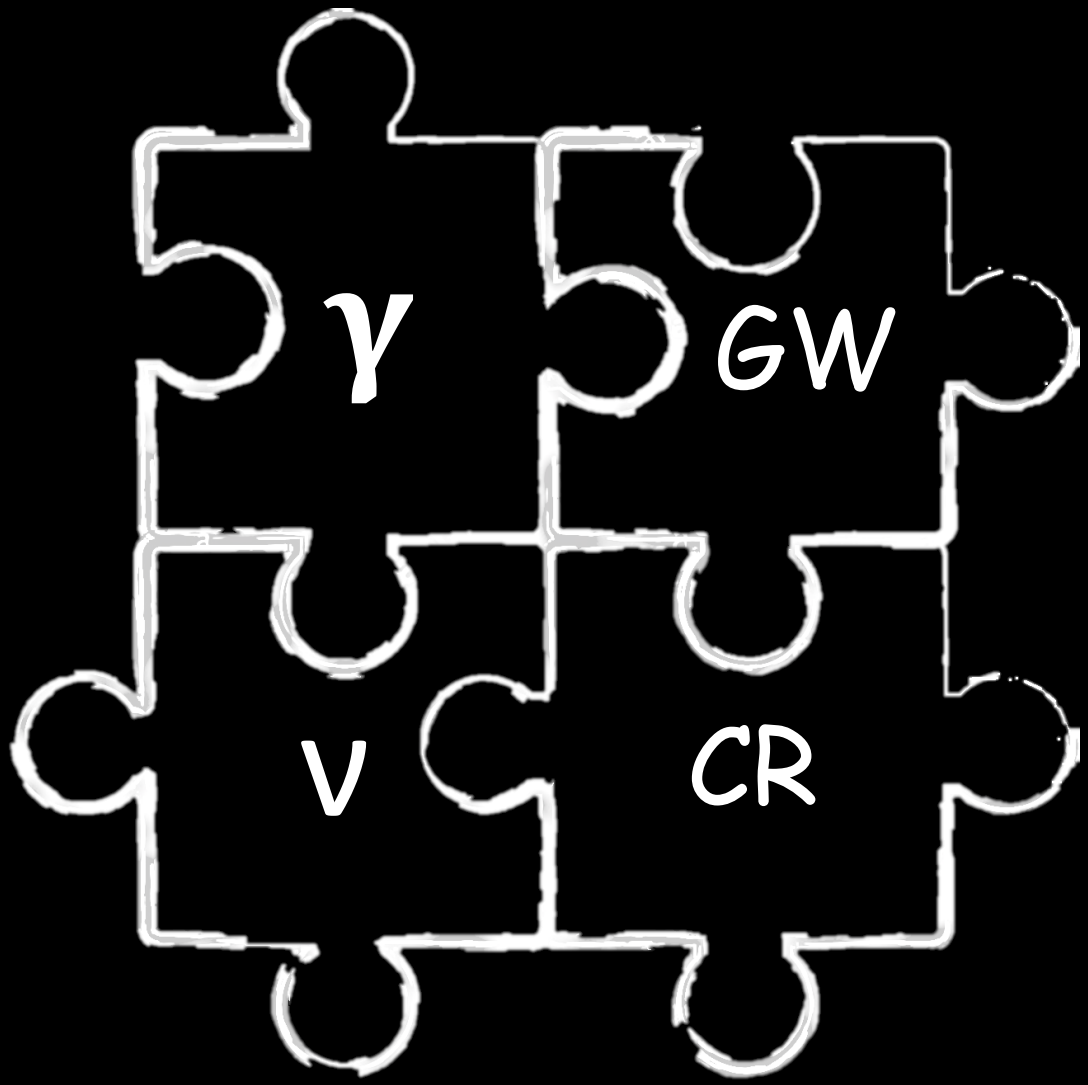


$$\phi = A\,E^{-2.89}$$



$1\ \text{eV} = 1{,}602 \times 10^{-19}\ \text{J}$

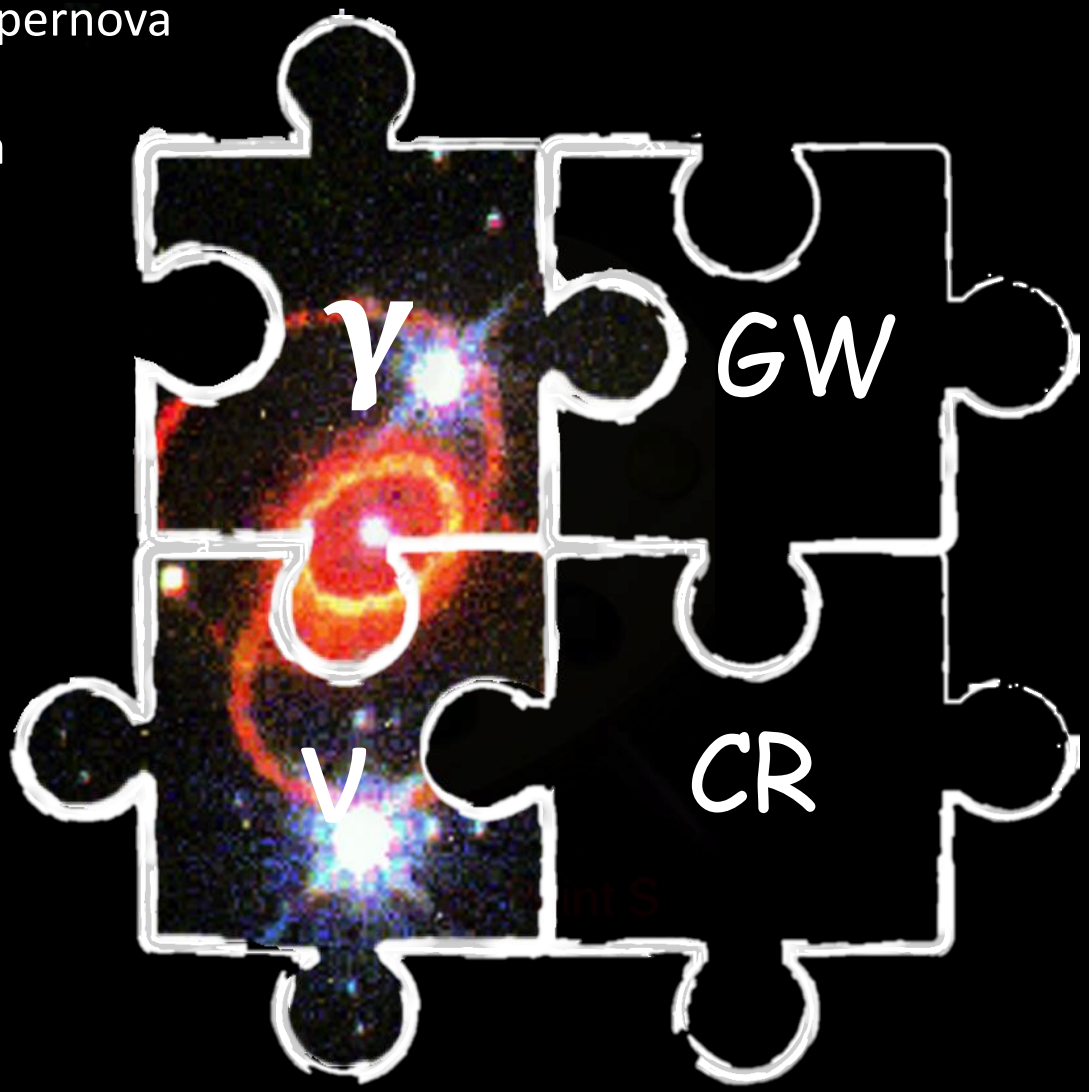
Multi-Messenger Astronomy



Multi-Messenger Astronomy

Core Collapse Supernova

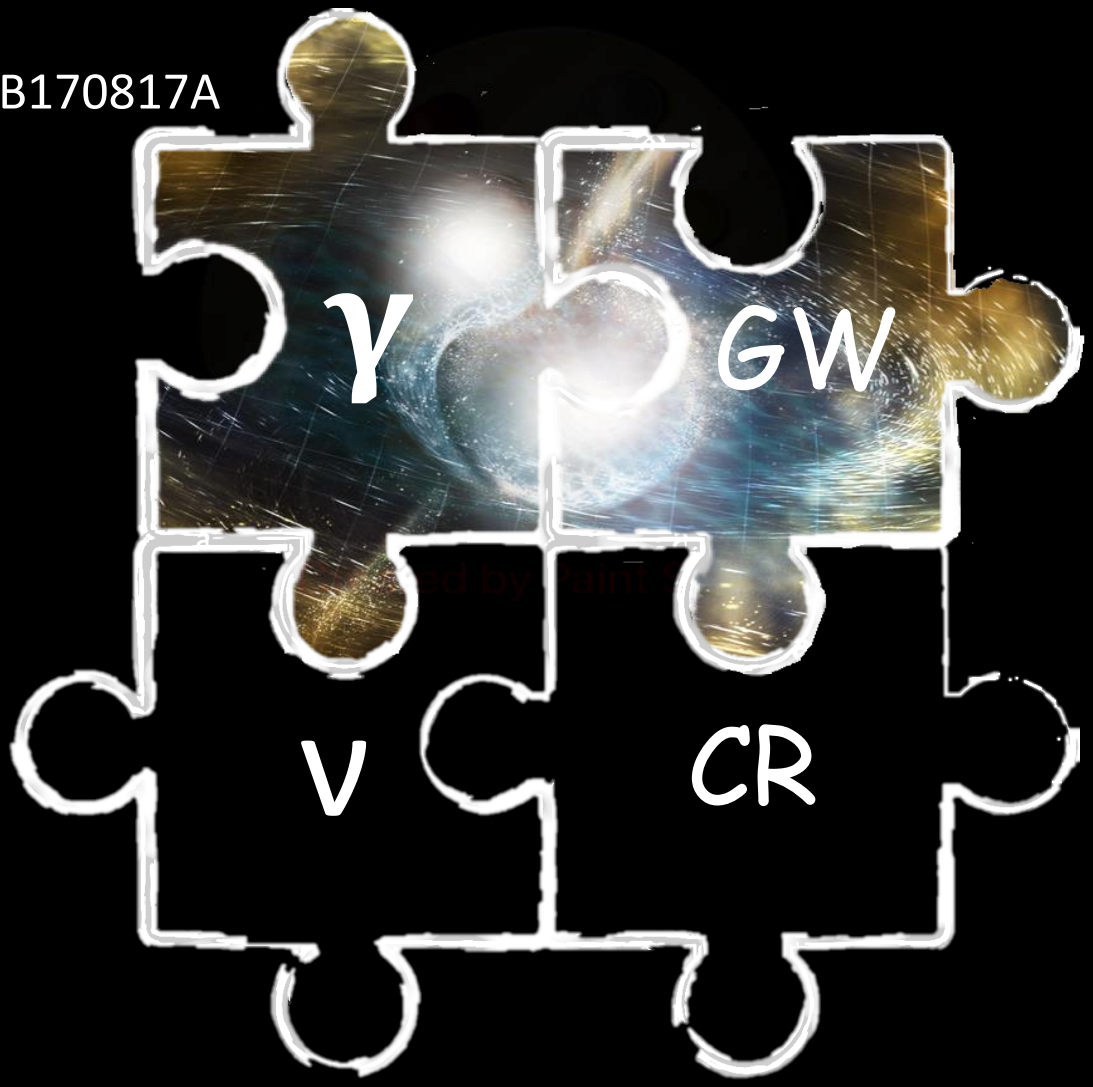
SN1987a



Multi-Messenger Astronomy

Binary neutron star merger

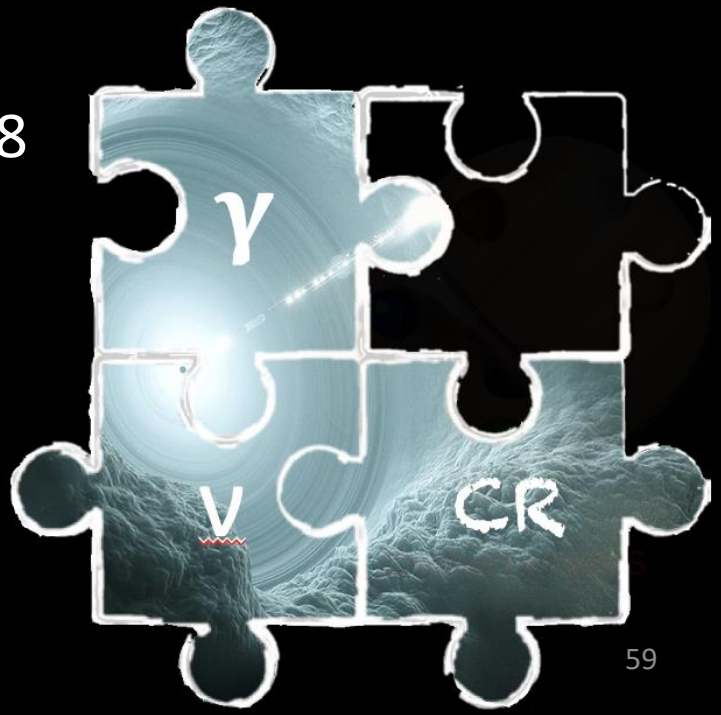
GW170817 – GRB170817A

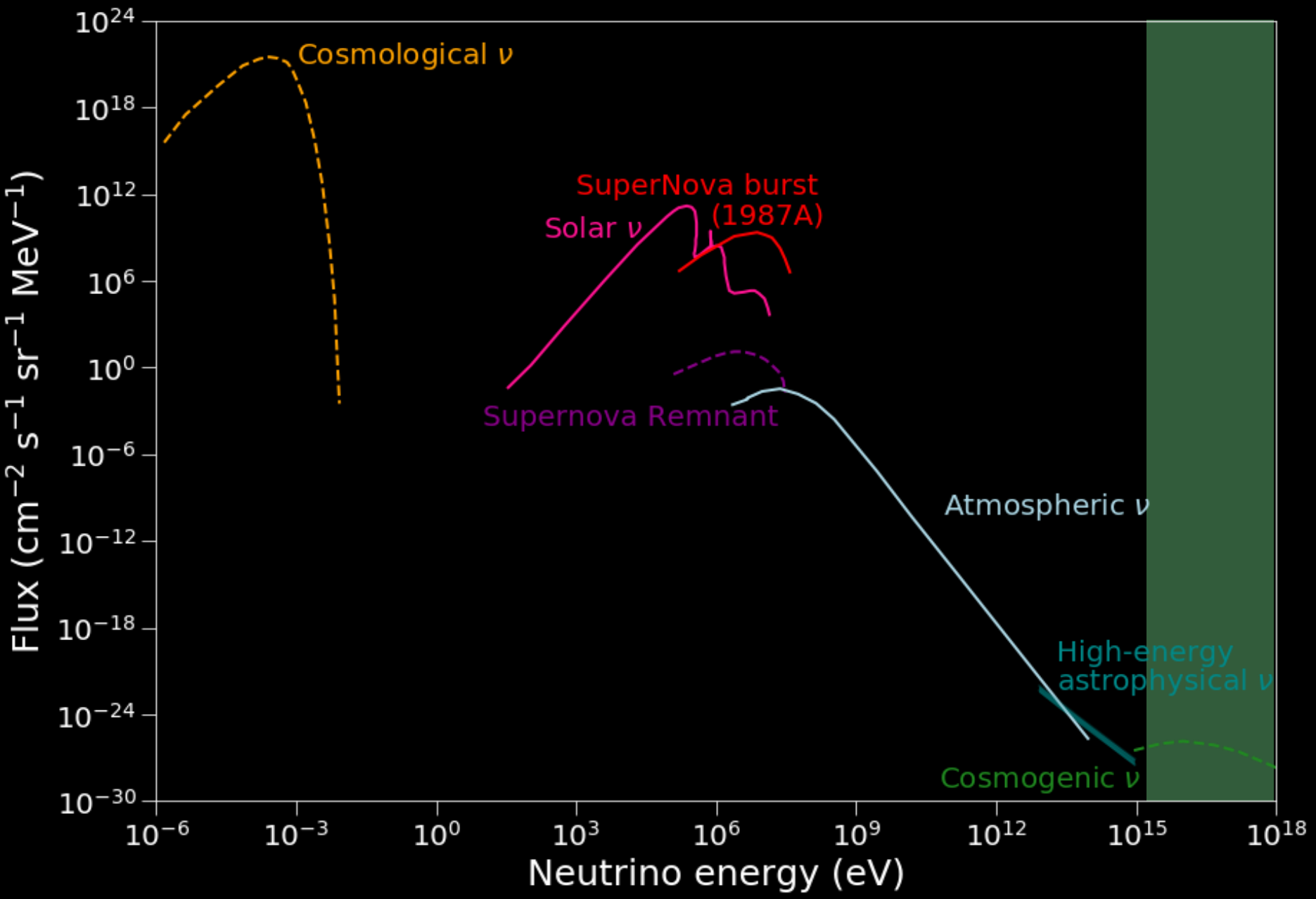


Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert

13 Jul. 2018




Cosmological ν
SuperNova burst
(1987A)
Solar ν
Supernova Remnant
Atmospheric ν
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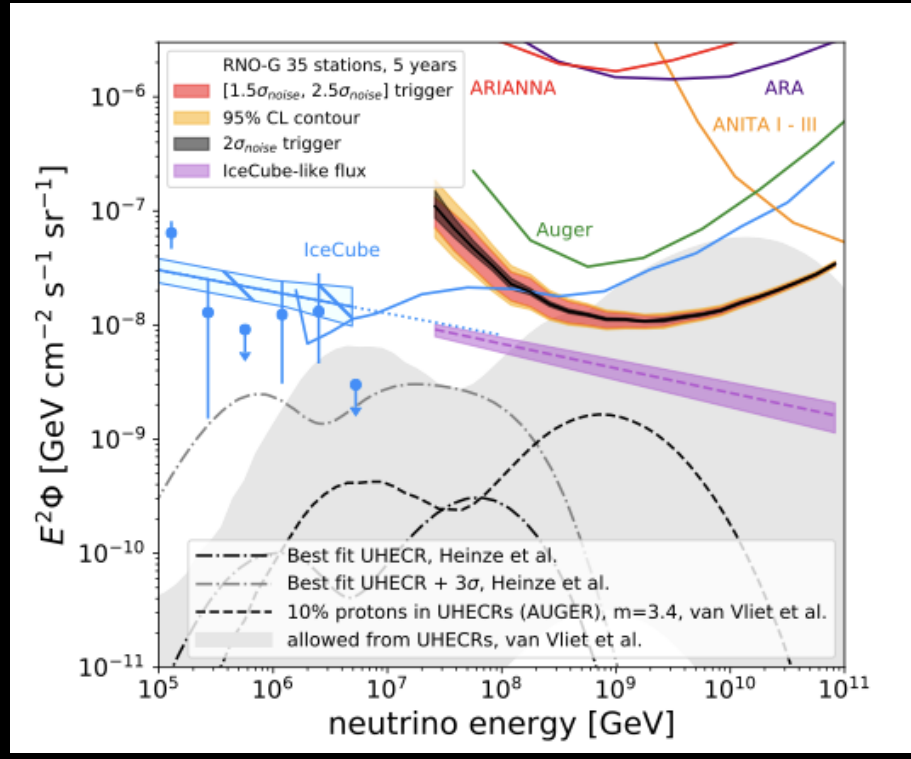
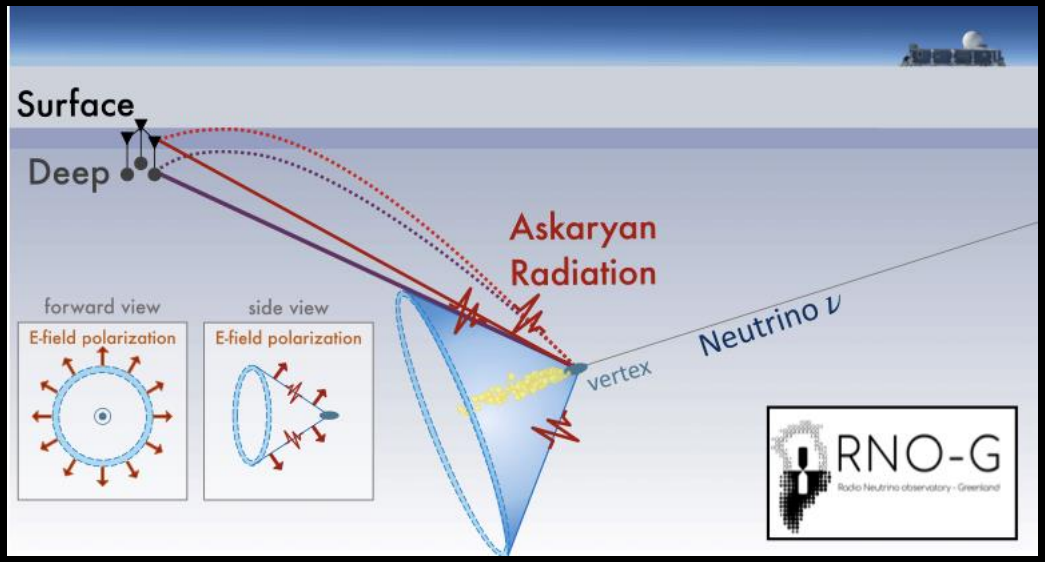
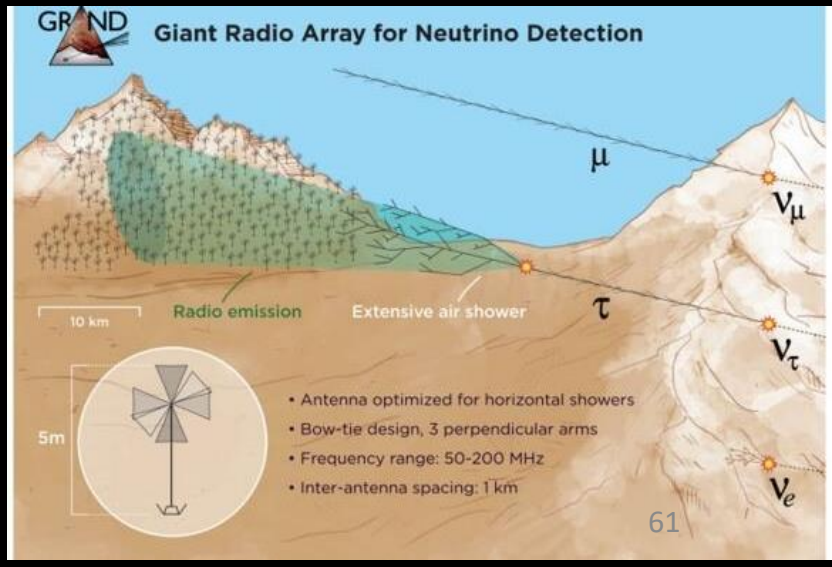
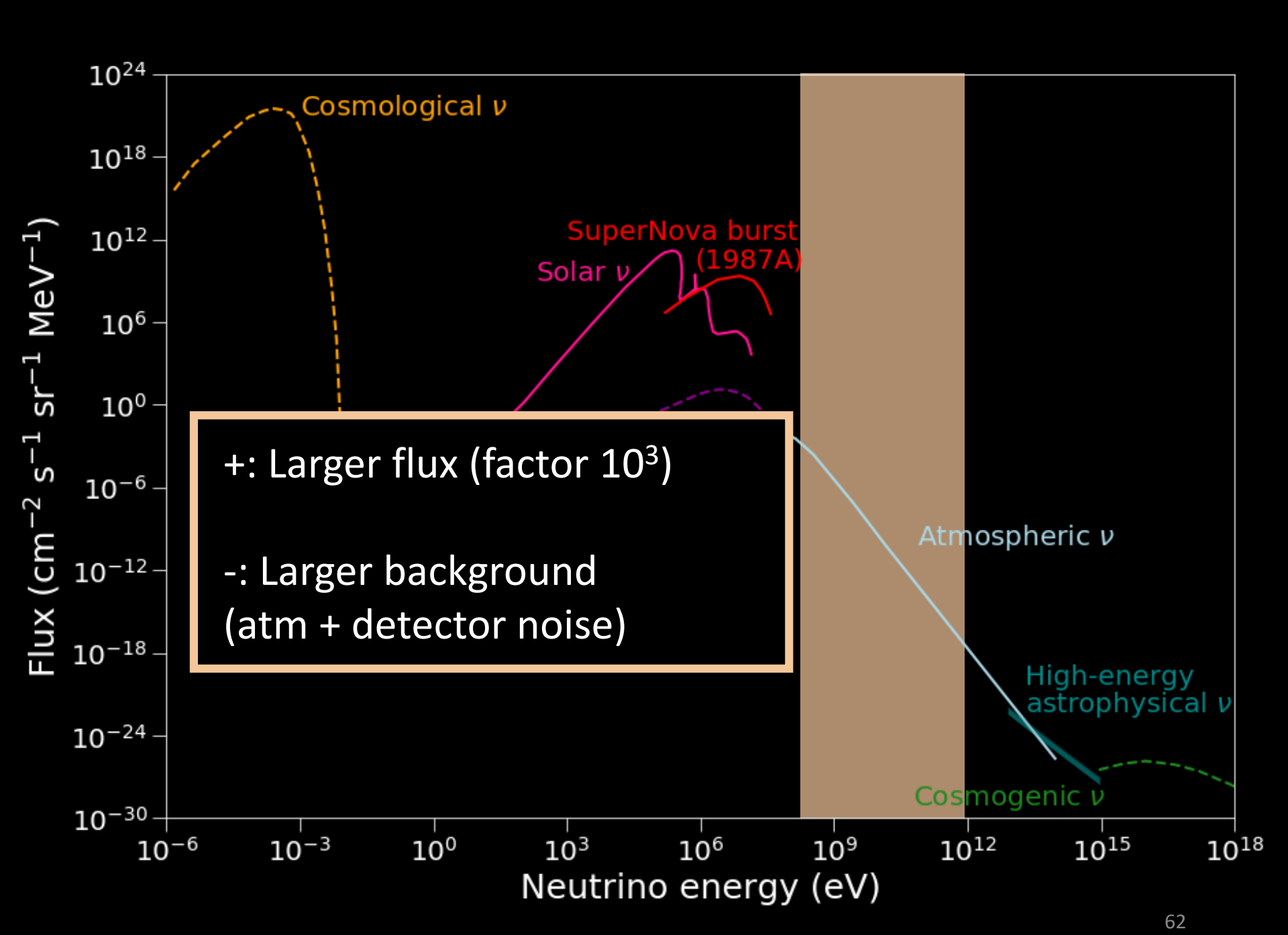
astrophysical ν
Cosmogenic ν
Flux (cm^{-2} s^{-1} sr^{-1} MeV^{-1})
Neutrino energy (eV)
10^{24}
10^{18}
10^{12}
10^{6}
10^{0}
10^{-6}
10^{-12}
10^{-18}
10^{-24}
10^{-30}
10^{-6}
10^{-3}
10^{0}
10^{3}
10^{6}
10^{9}
10^{12}
10^{15}
10^{18}


RNO-G 35 stations, 5 years
[1.5σnoise, 2.5σnoise] trigger
95% CL contour
2σnoise trigger
IceCube-like flux
ARIANNA
ARA
ANITA I - III
Auger
IceCube
Best fit UHECR, Heinze et al.
Best fit UHECR + 3σ, Heinze et al.
10% protons in UHECRs (AUGER), m=3.4, van Vliet et al.
allowed from UHECRs, van Vliet et al.
E²Φ [GeV cm⁻² s⁻¹ sr⁻¹]
neutrino energy [GeV]

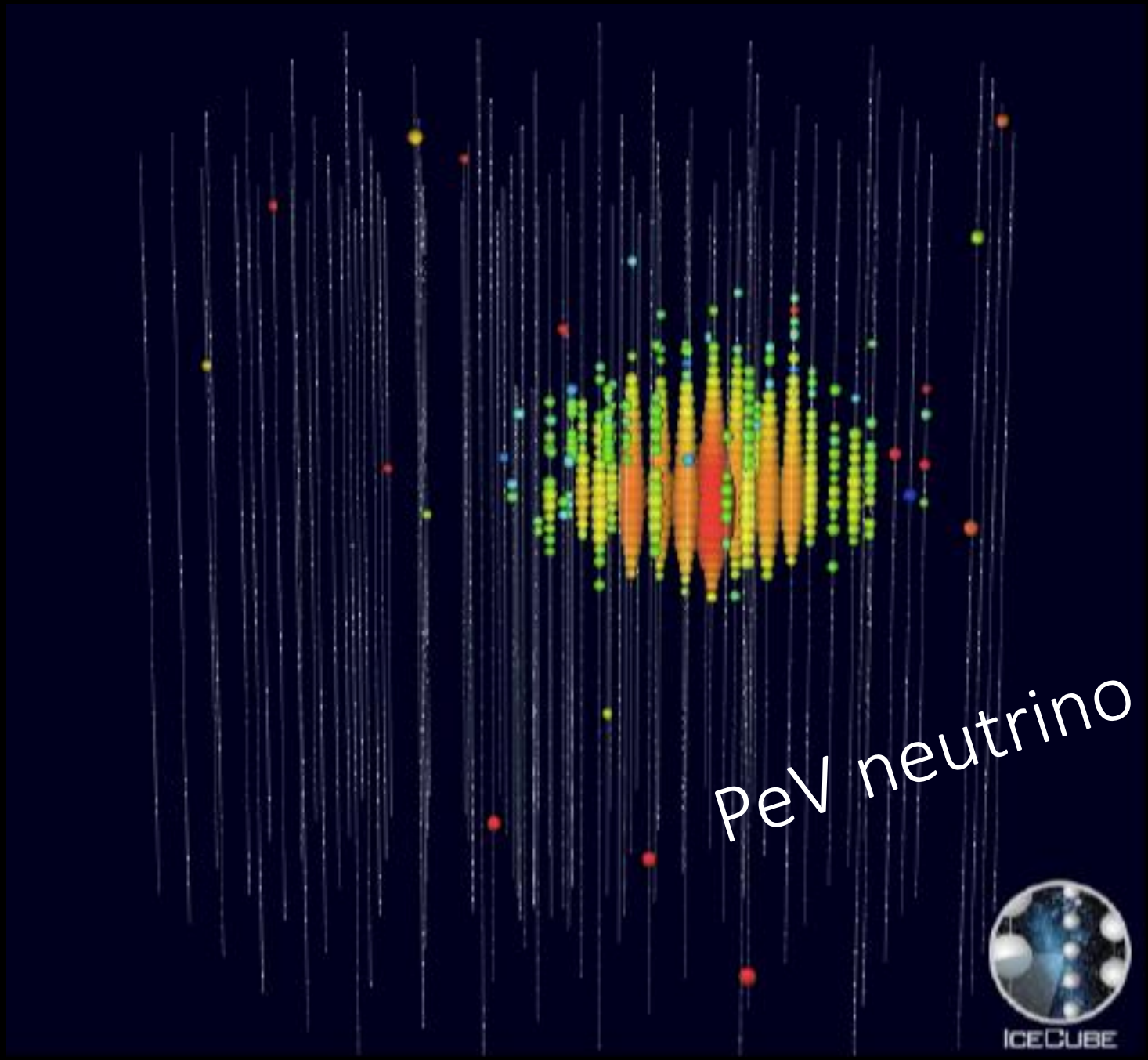

Surface
Deep
Askaryan Radiation
Neutrino ν
vertex
forward view
side view
E-field polarization
E-field polarization
RNO-G

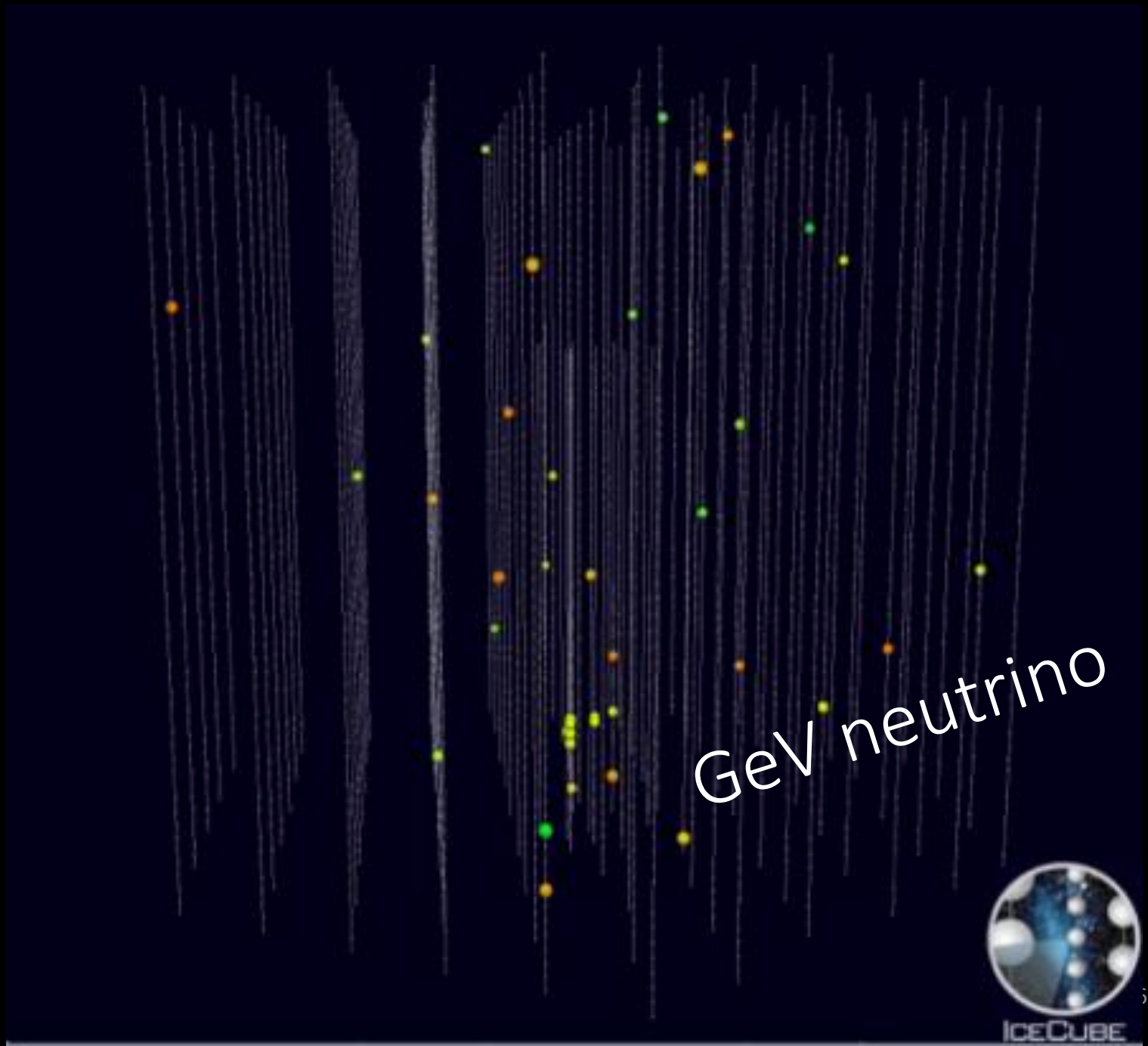

GRAND
Giant Radio Array for Neutrino Detection
μ
τ
Radio emission
Extensive air shower
10 km
5m
• Antenna optimized for horizontal showers
• Bow-tie design, 3 perpendicular arms
• Frequency range: 50-200 MHz
• Inter-antenna spacing: 1 km

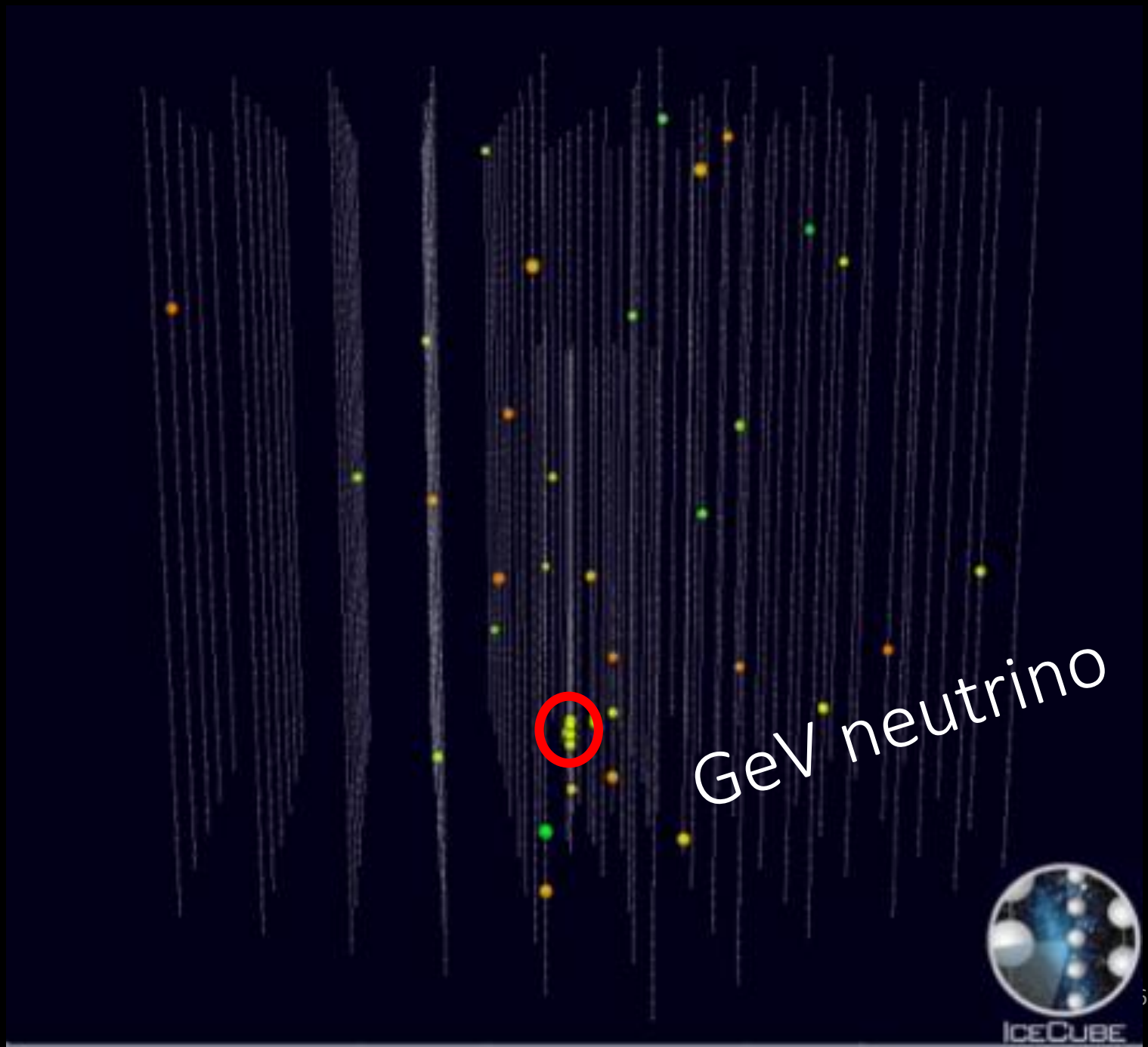


+: Larger flux (factor 10^3)

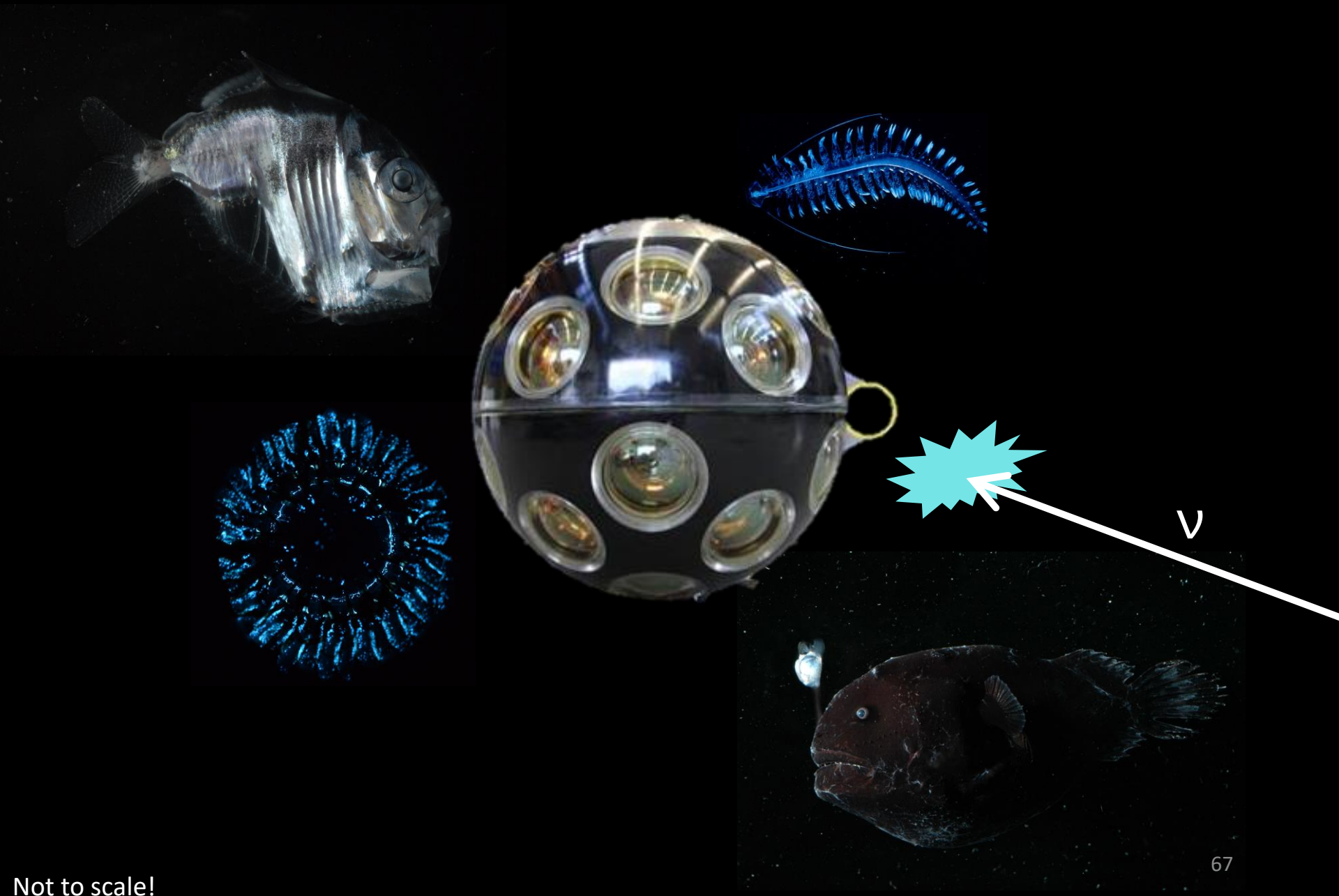
-: Larger background
(atm + detector noise)


PeV neutrino
ICECUBE


GeV neutrino
ICECUBE

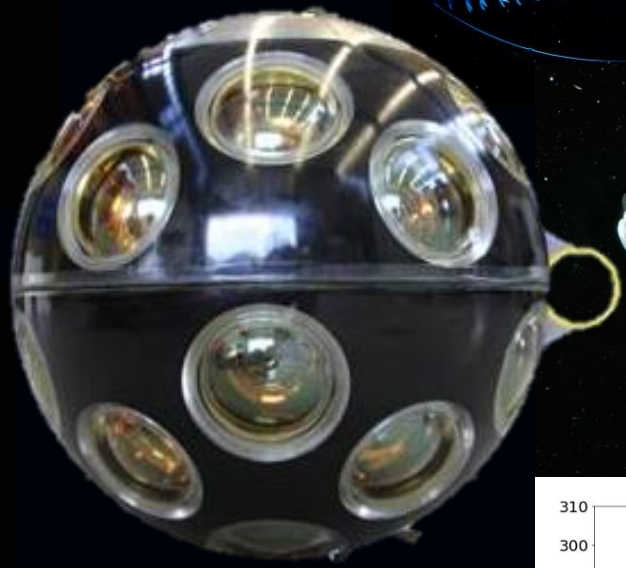

GeV neutrino
ICECUBE

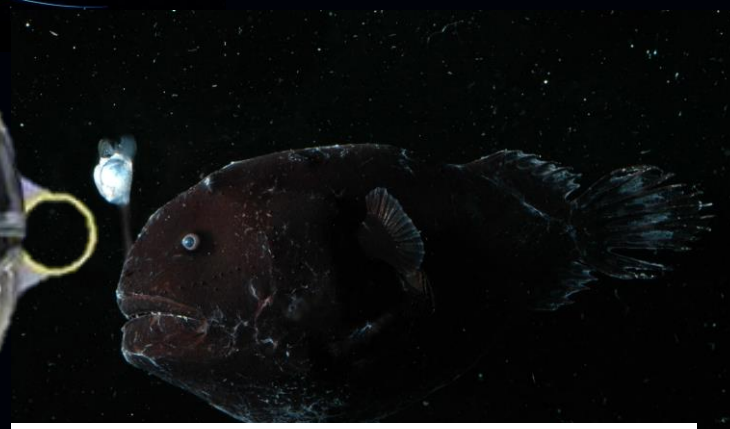
Not to scale!

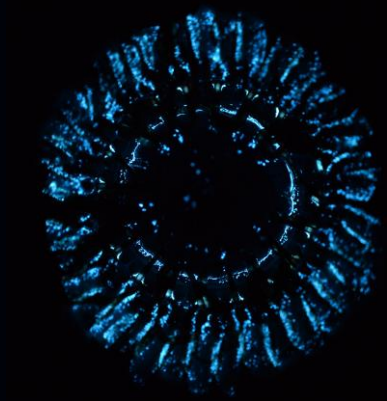


Not to scale!

Understanding the *noise* from the Deep Sea

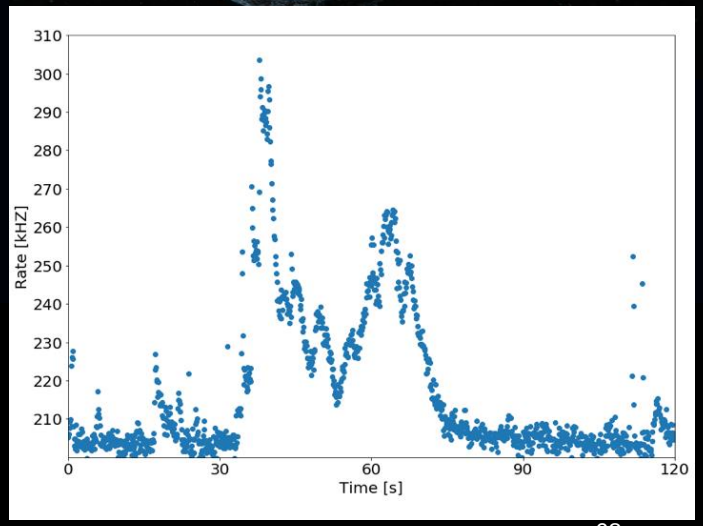


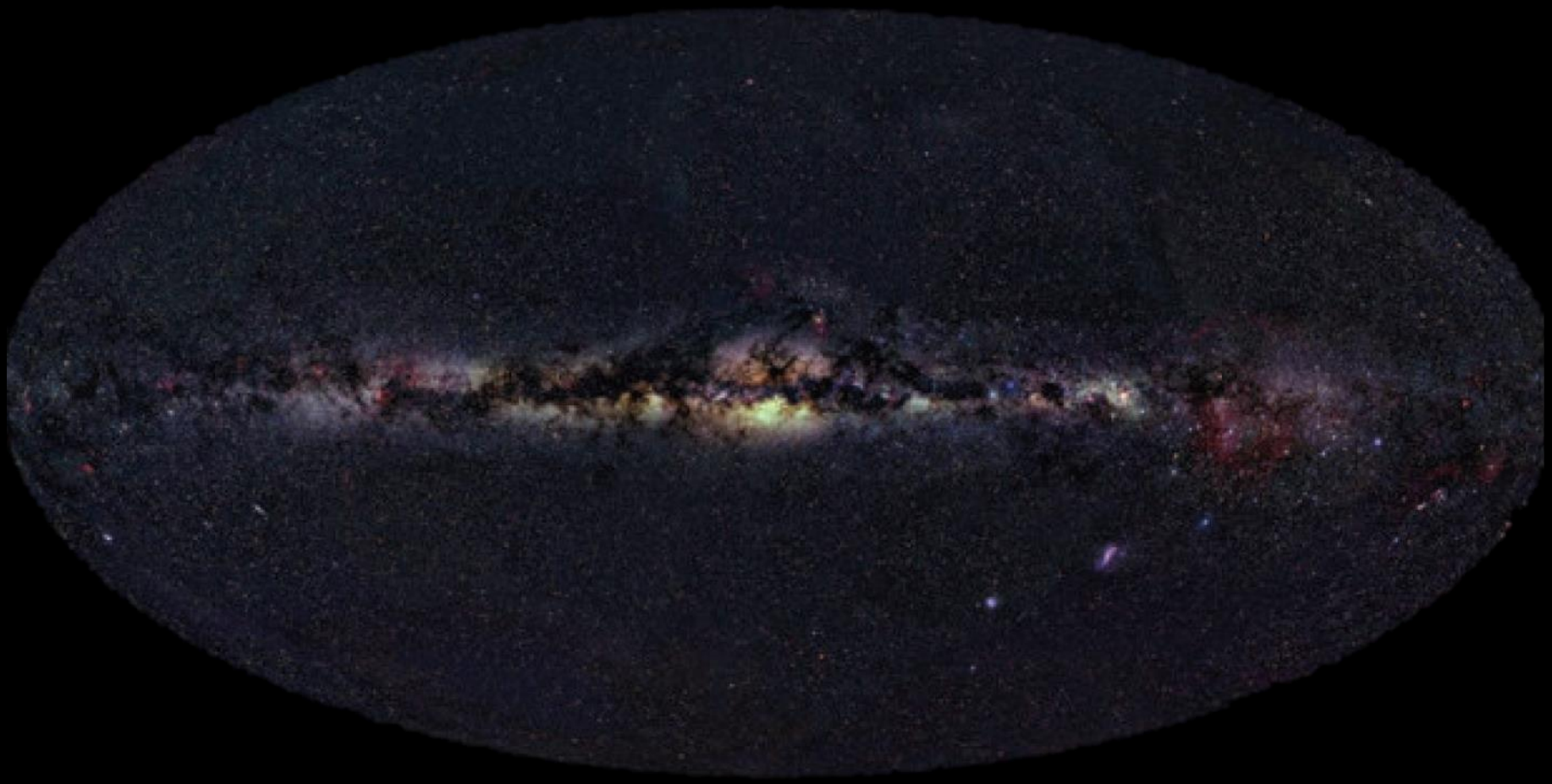




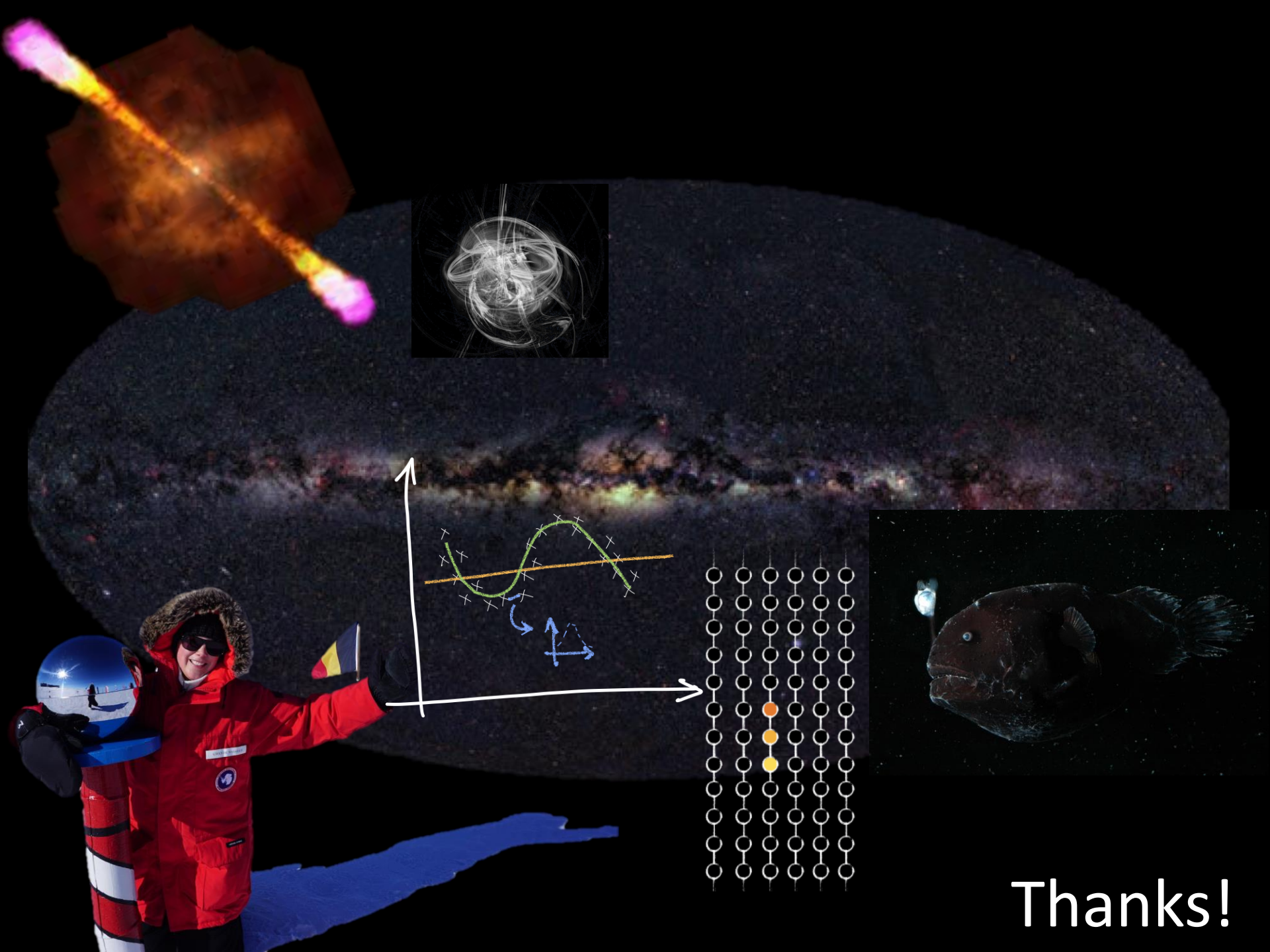
Steven Haddock/Monterey Bay Aquarium Research Institute

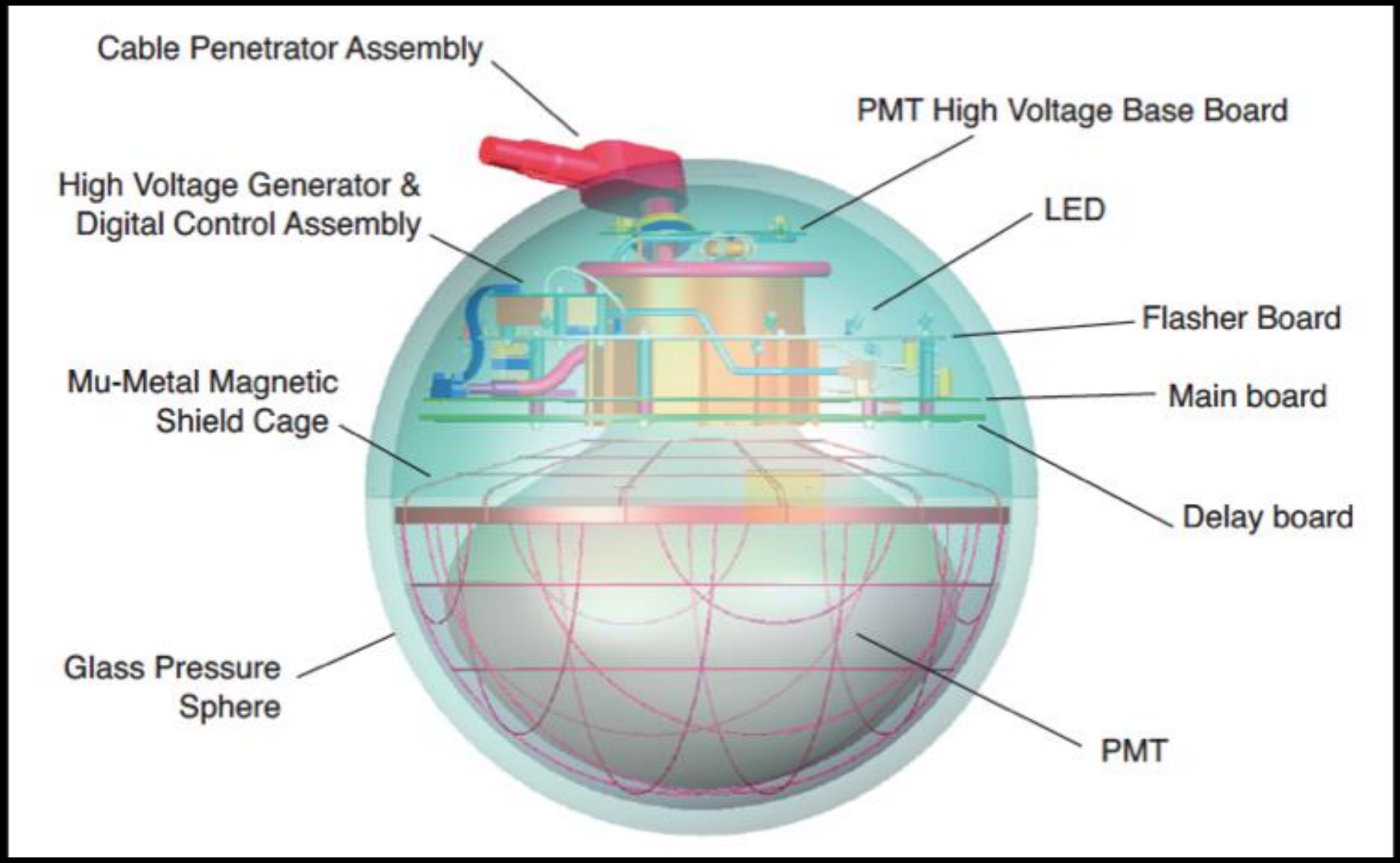
Data recorded

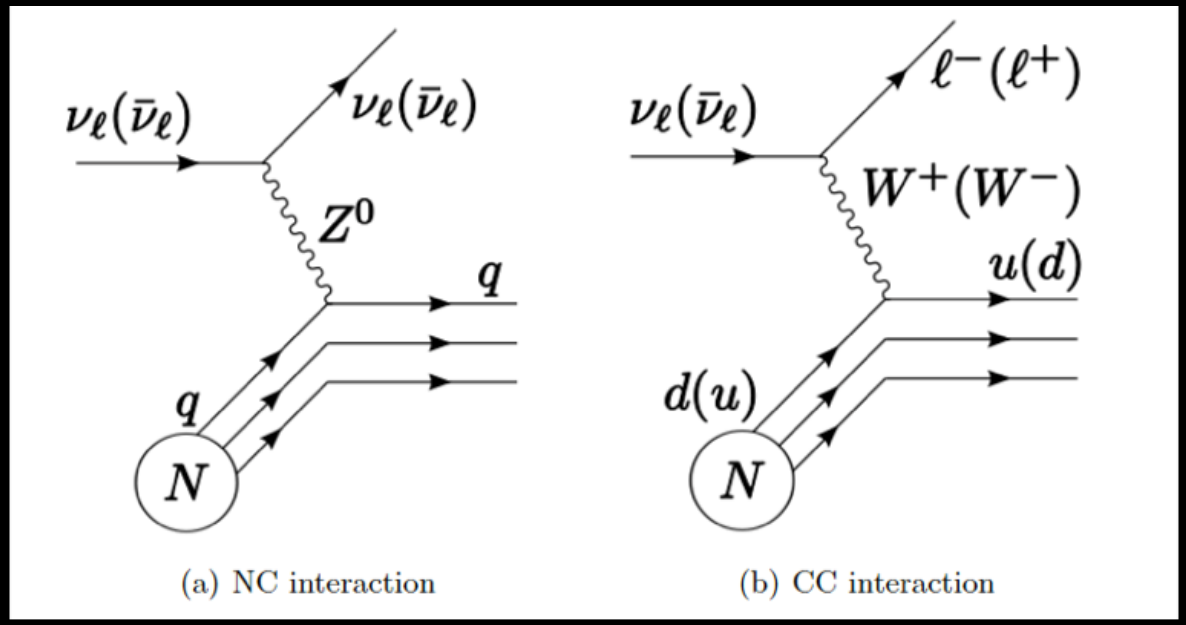




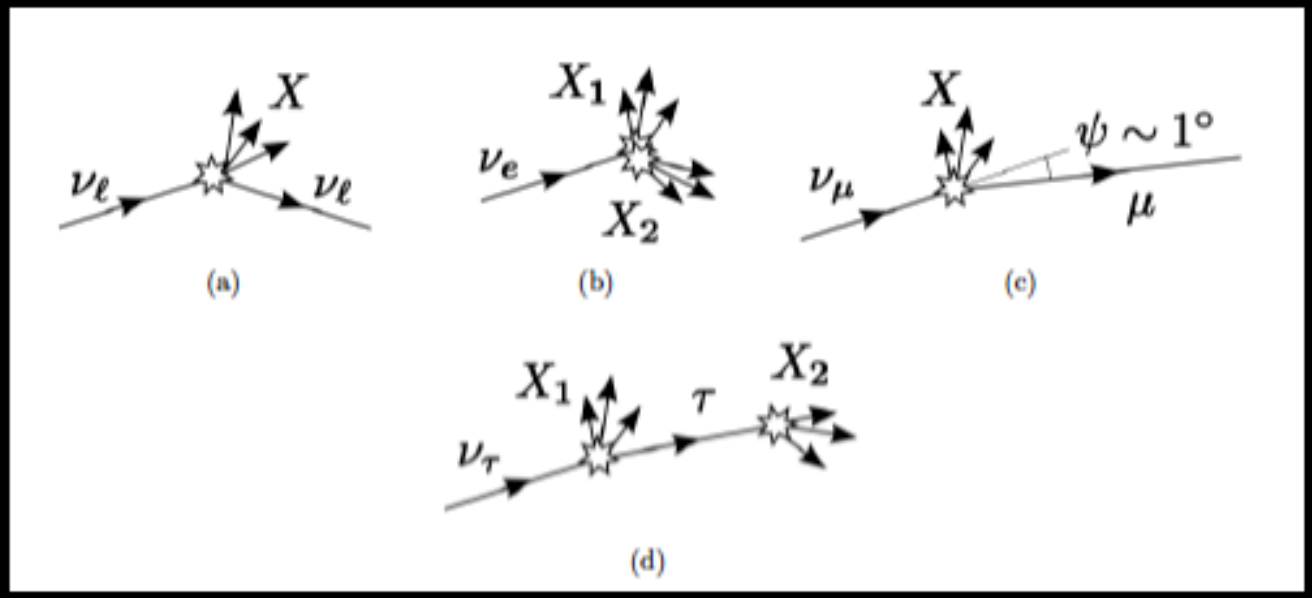
Not to scale


Thanks!

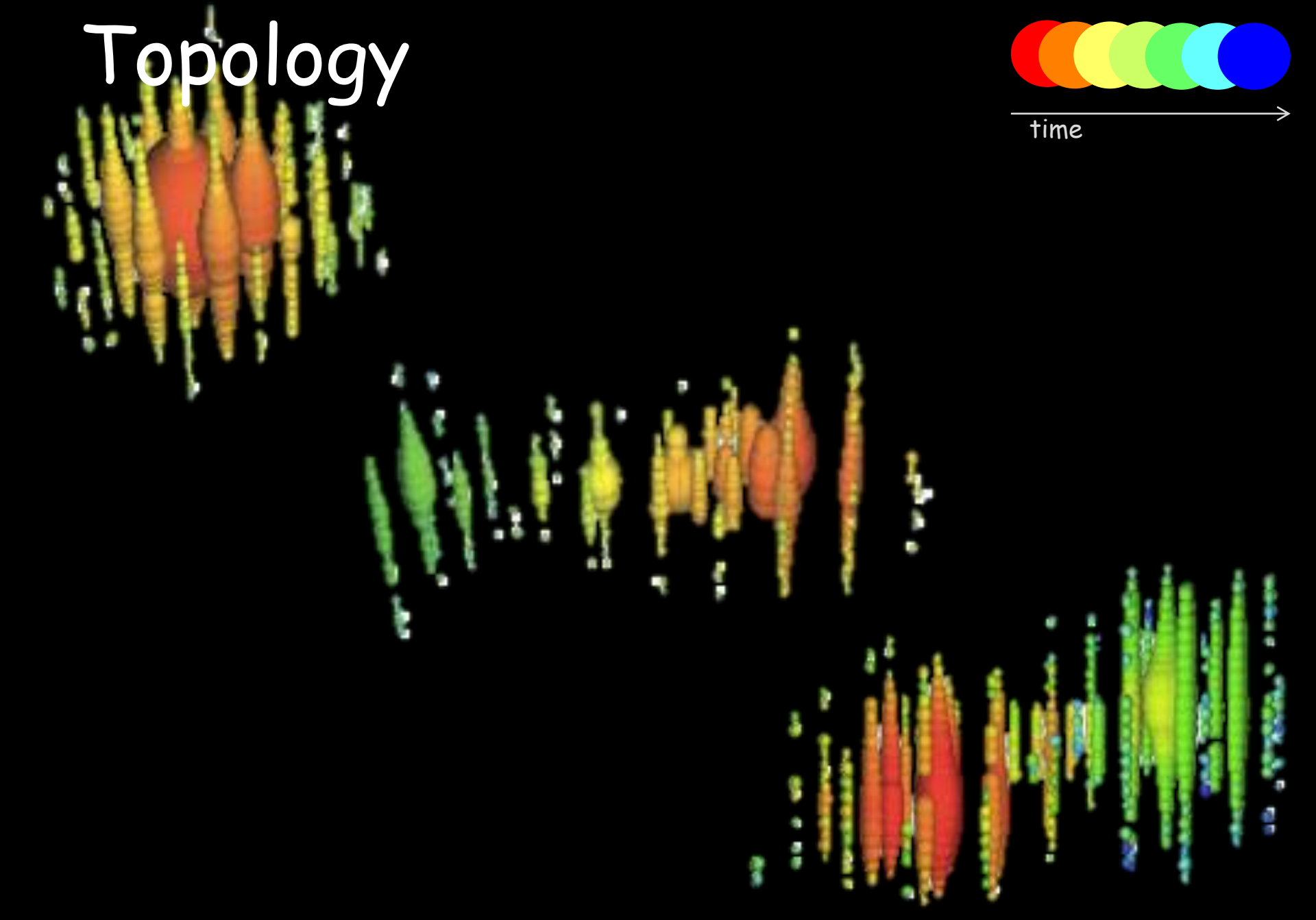

Cable Penetrator Assembly
PMT High Voltage Base Board
High Voltage Generator &
Digital Control Assembly
LED
Flasher Board
Mu-Metal Magnetic
Shield Cage
Main board
Delay board
Glass Pressure
Sphere
PMT



(a) NC interaction (b) CC interaction



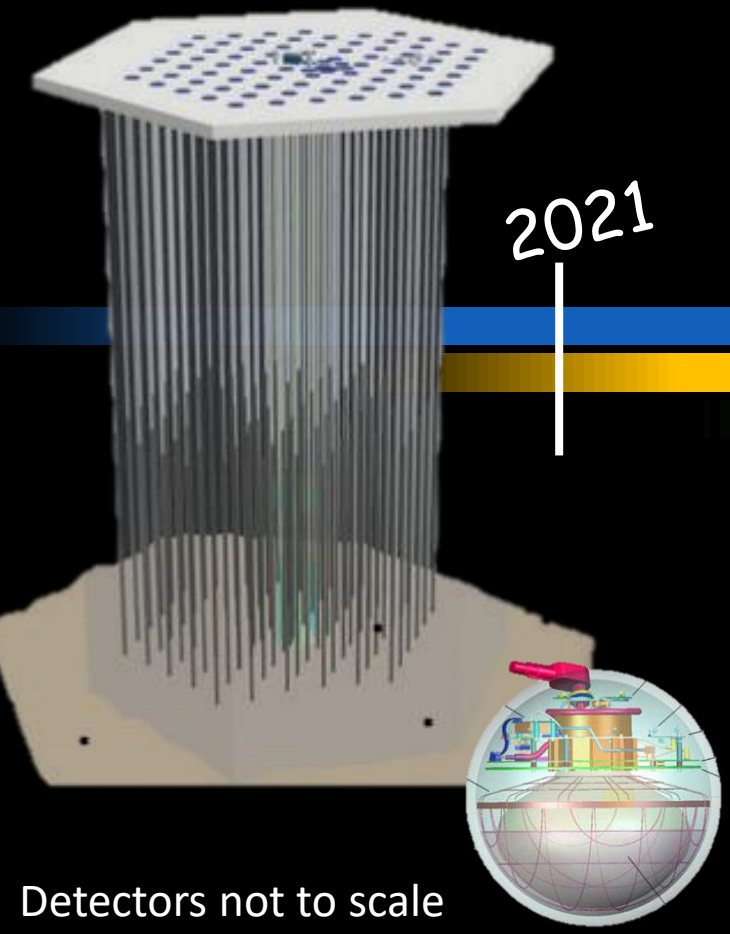
Topology



IceCube: exciting times!

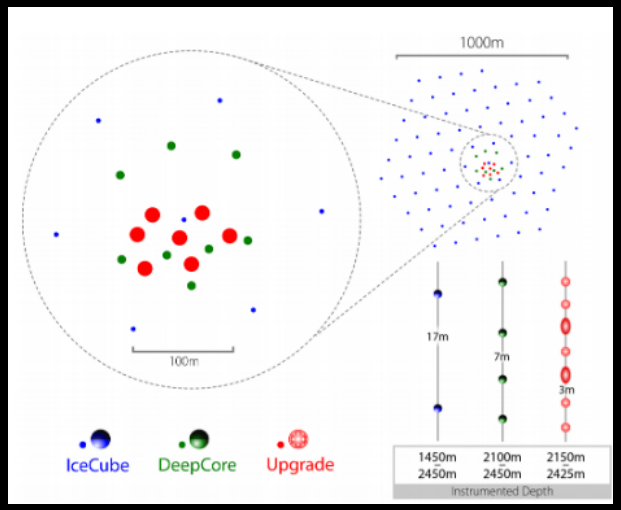
IceCube

86 strings



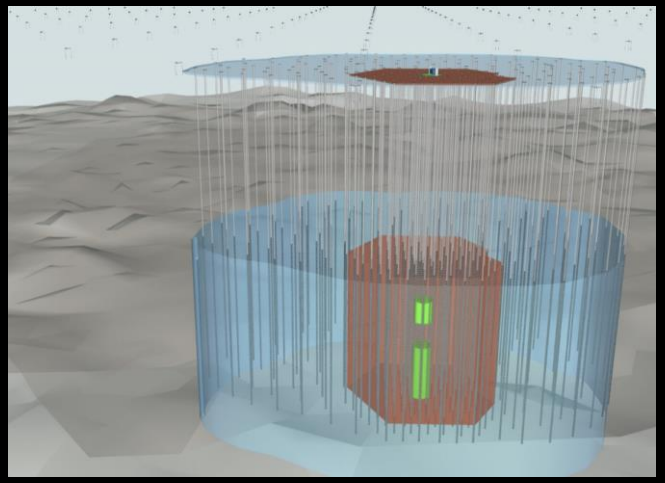
IceCube-Upgrade

7 strings



2021

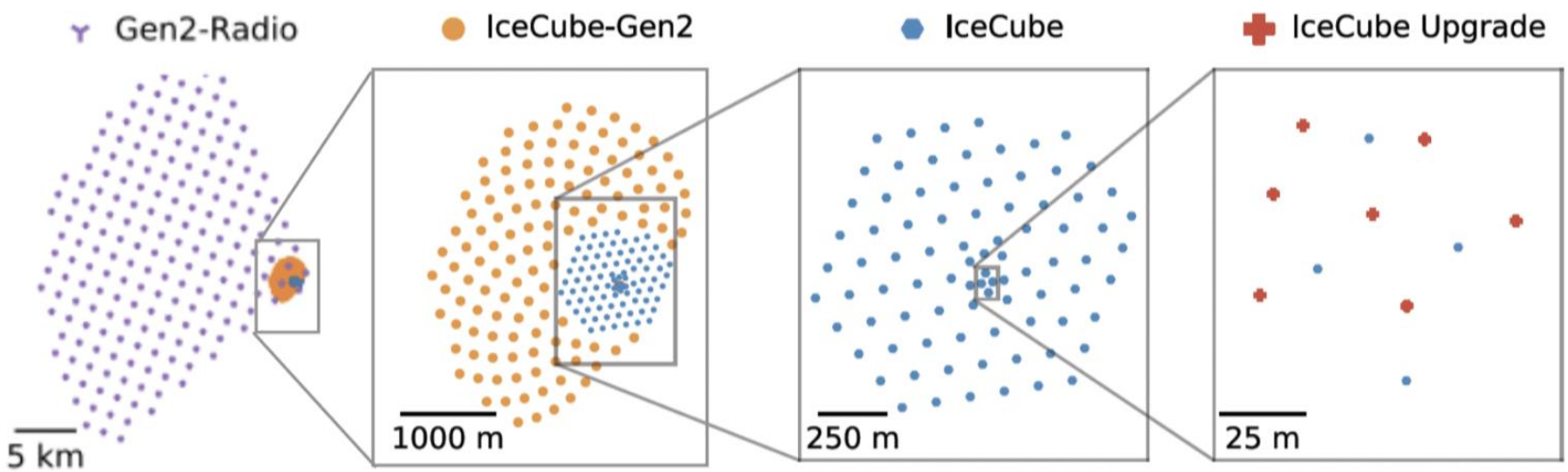
Super detector



IceCube-Gen2

Detectors not to scale

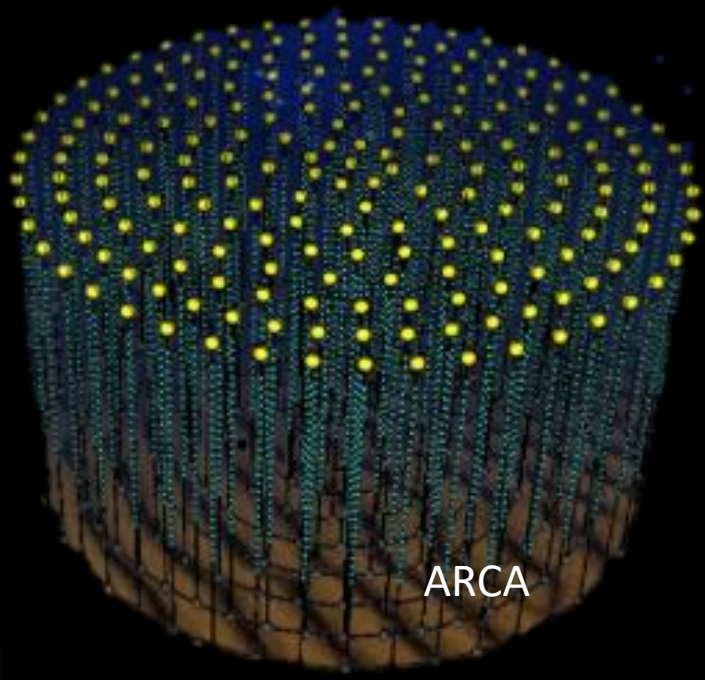
IceCube: exciting times!



EeV PeV TeV GeV

Energy

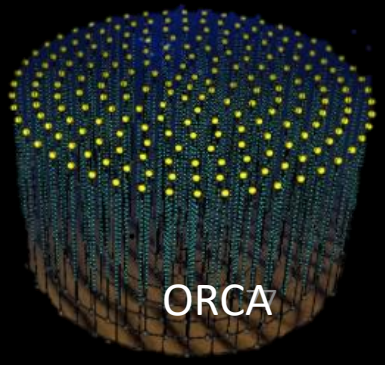
ANTARES and KM3NeT: exciting times!



More than 15 years of data taking!

2021

8 ARCA Detection Unit
6 ORCA Detection Units



Detectors not to scale

ANTARES and KM3NeT: exciting times!

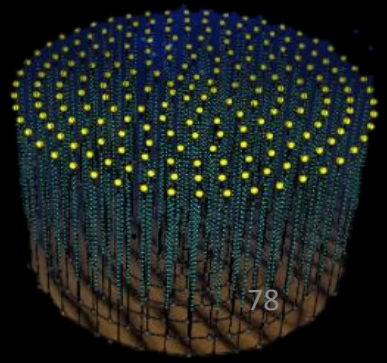
Expected for the next 6 months:

- 7 + 2-3 more ORCA DUs
- ORCA Instrumentation Unit
- 15 more ARCA DUs

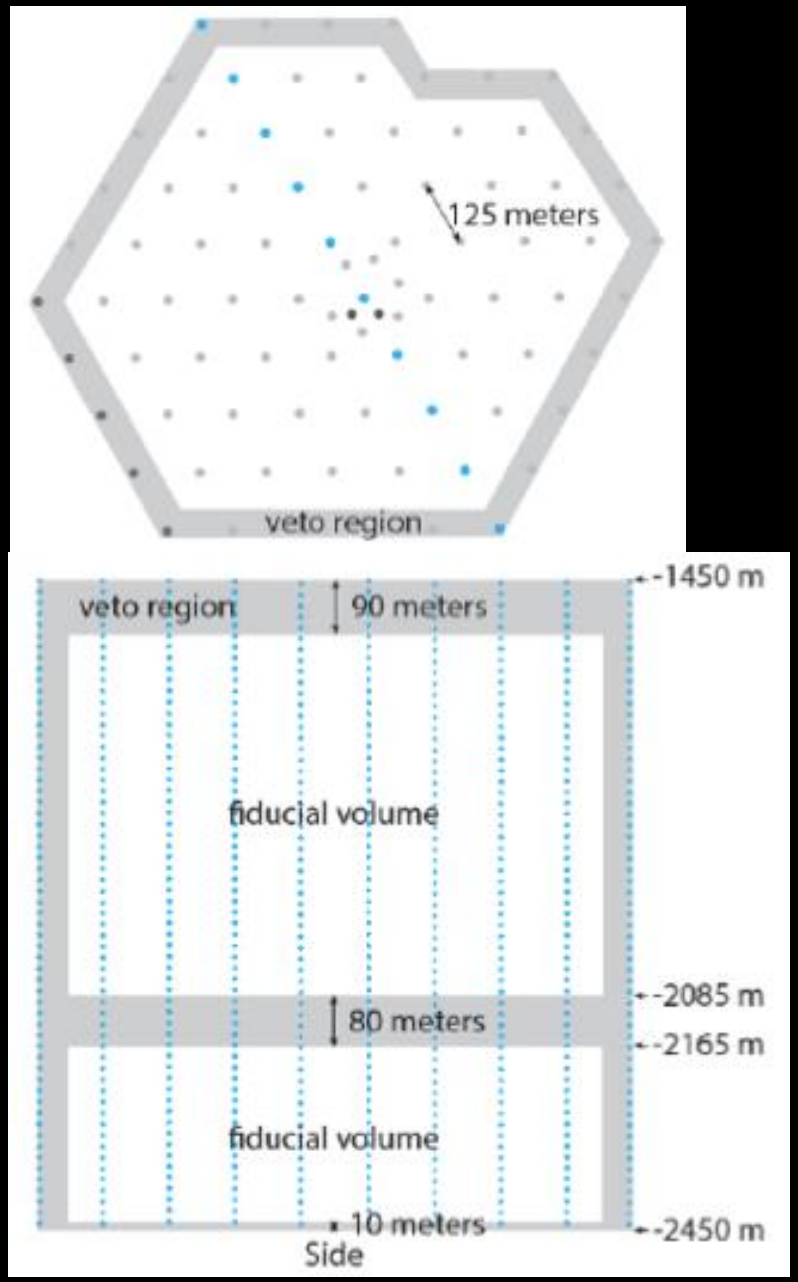
More than 15 years of data taking!

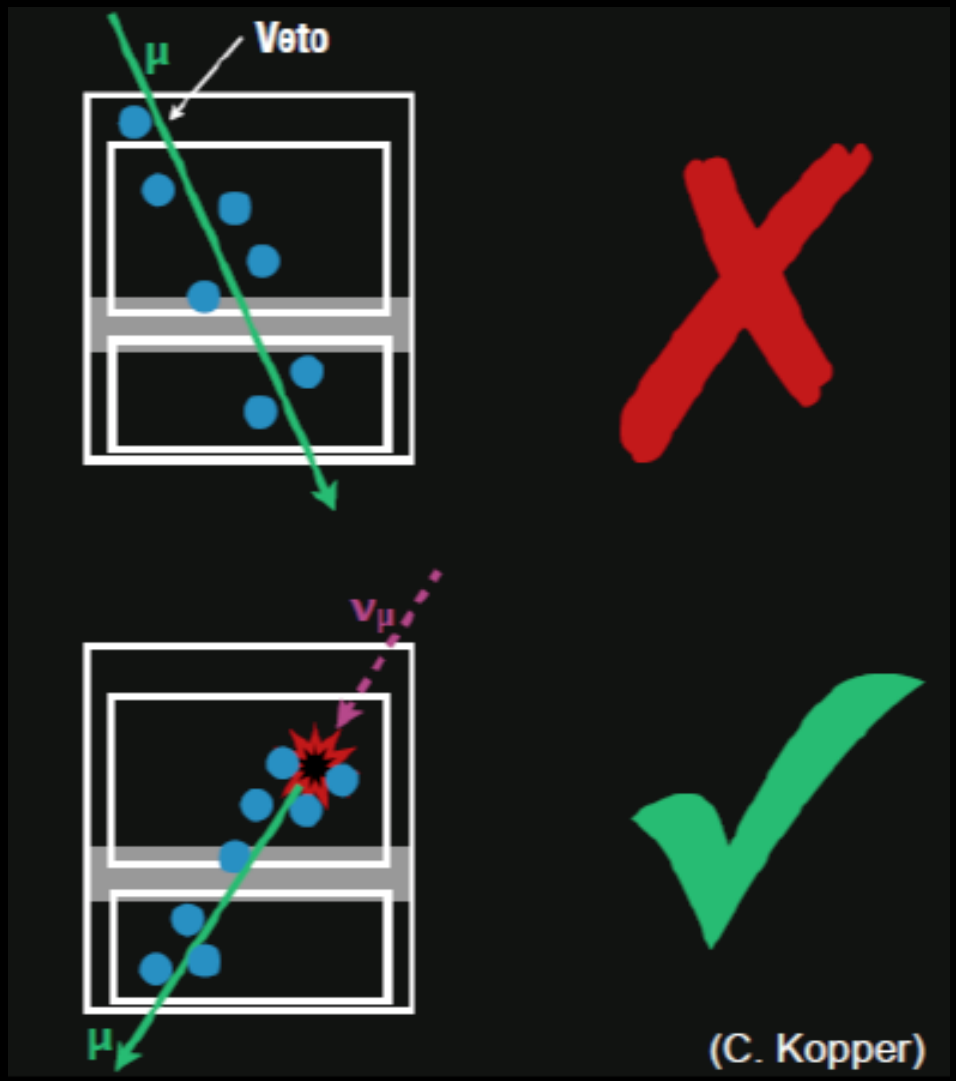
2021

8 ARCA Detection Unit
6 ORCA Detection Units



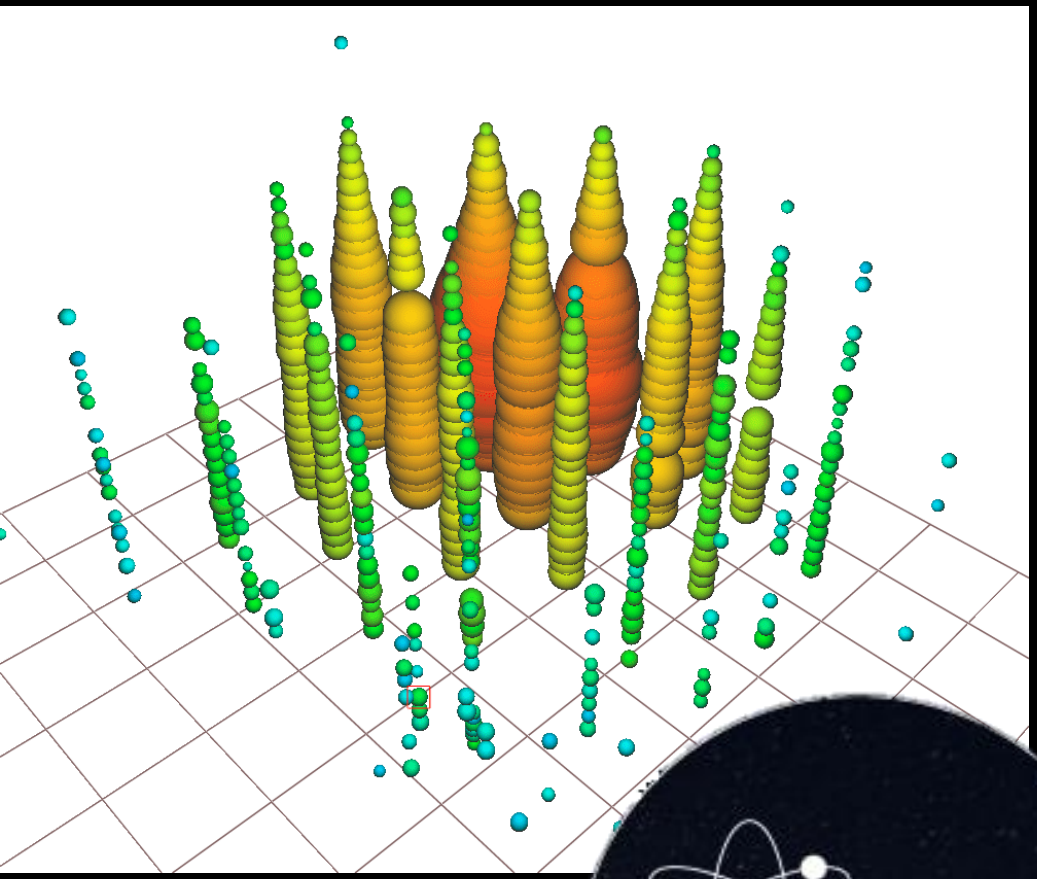
Detectors not to scale

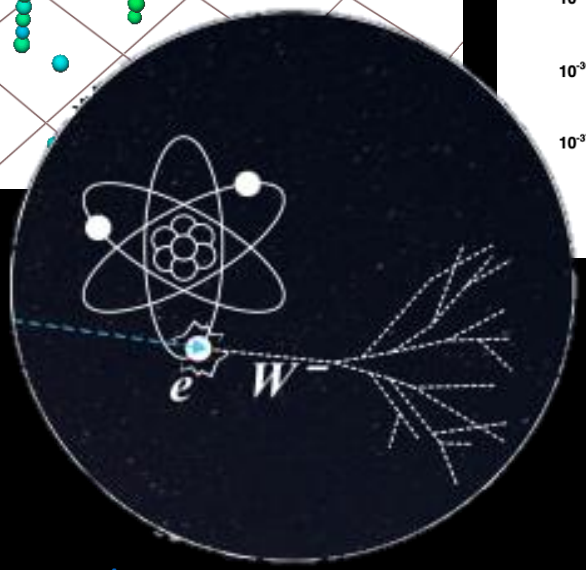

125 meters
veto region
veto region
90 meters
-1450 m
fiducial volume
-2085 m
80 meters
-2165 m
fiducial volume
10 meters
-2450 m
Side

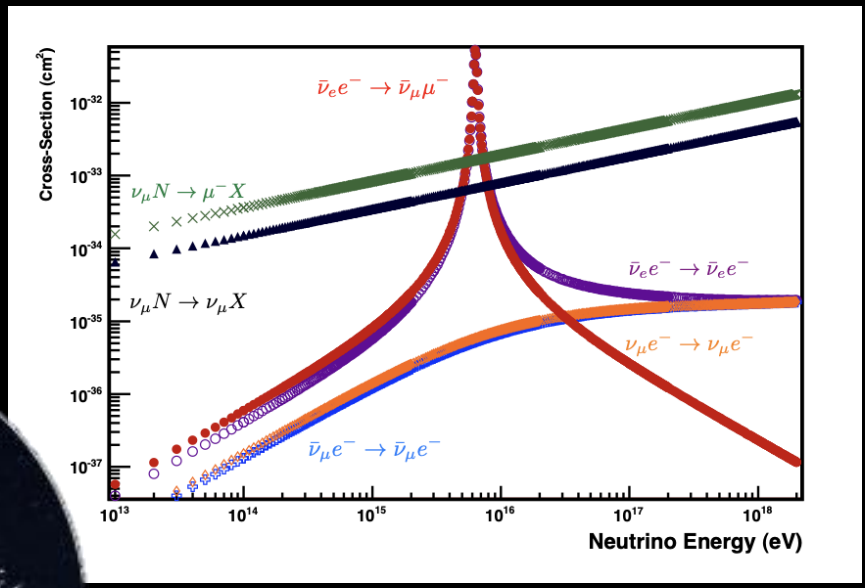

μ
Veto
νμ
μ
(C. Kopper)

First observation of a Glashow resonance event

Detection of a shower with an energy of 6.05 ± 0.72 PeV

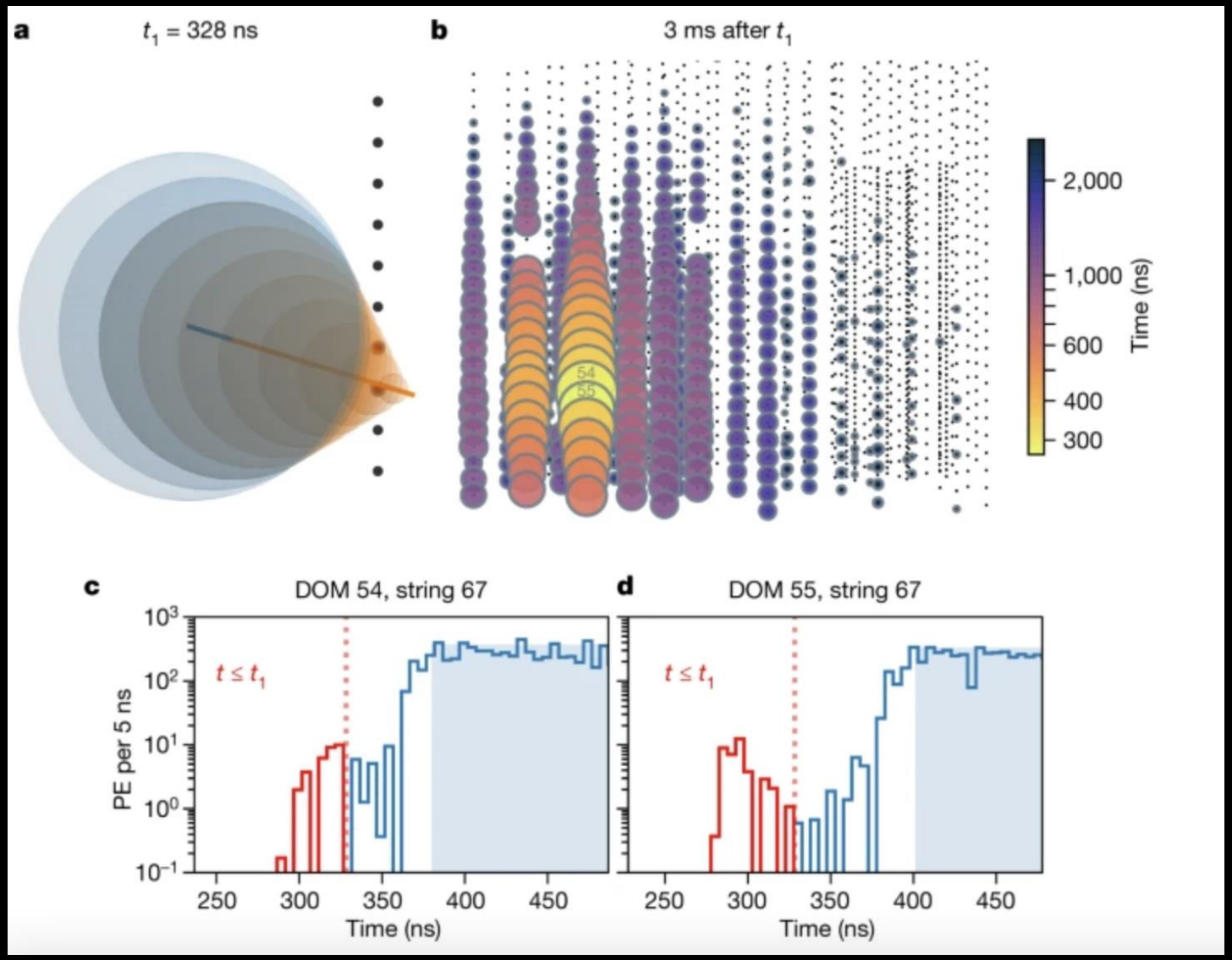




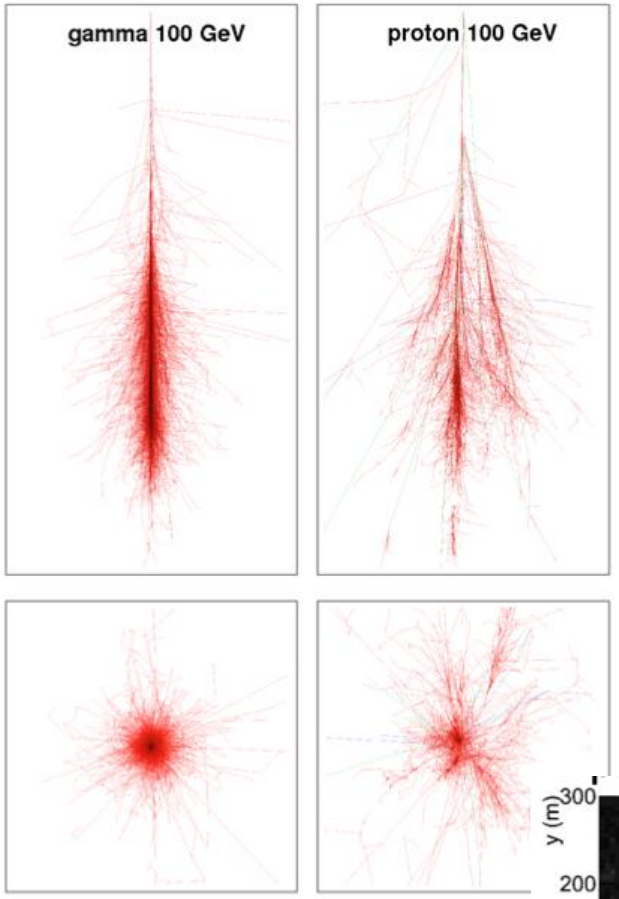


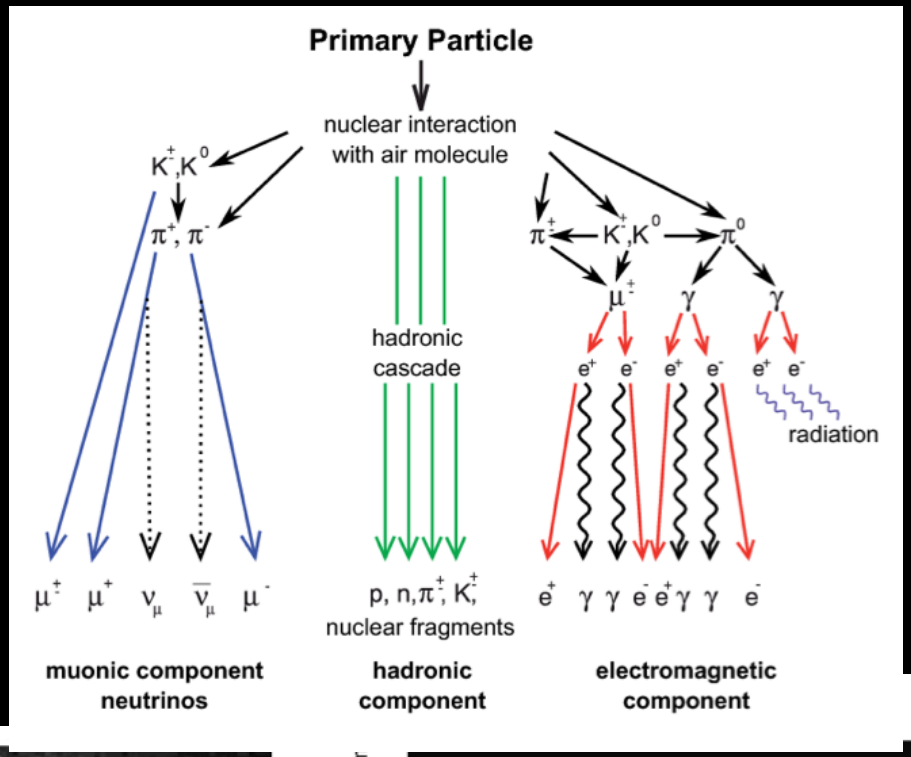
https://www.nature.com/articles/s41586-021-03256-1

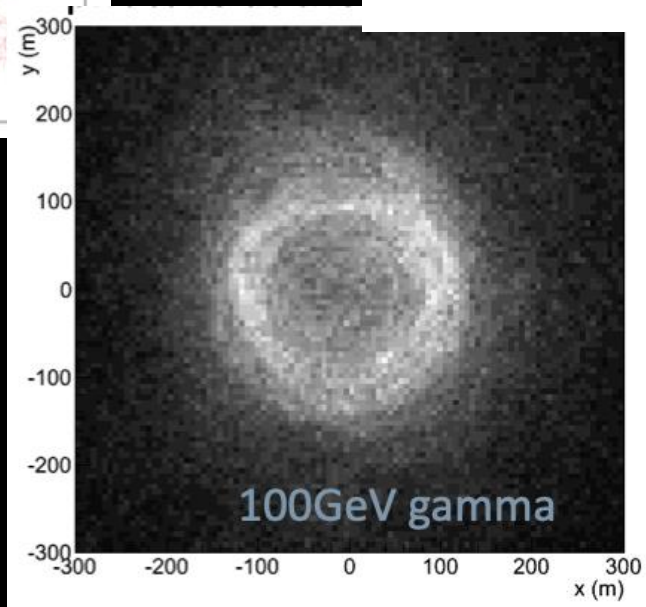
First observation of a Glashow resonance event

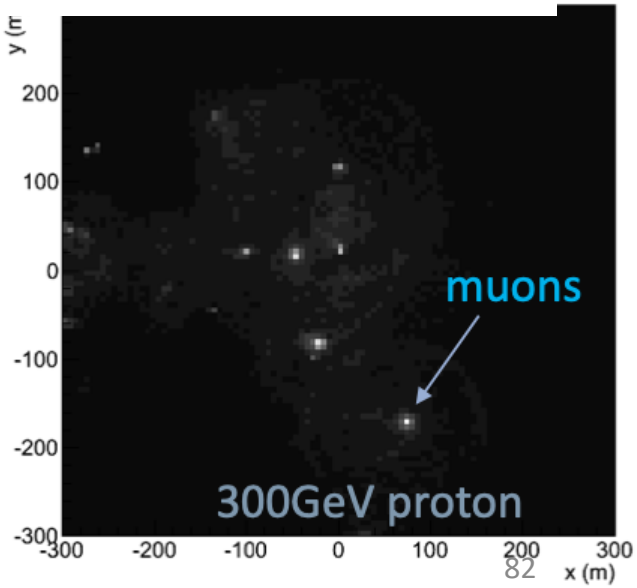


https://www.nature.com/articles/s41586-021-03256-1


gamma 100 GeV
proton 100 GeV


Primary Particle
nuclear interaction
with air molecule
hadronic
cascade
radiation
nuclear fragments
muonic component
neutrinos
hadronic
component
electromagnetic
component


100GeV gamma
y (m)
x (m)


muons
300GeV proton
x (m)

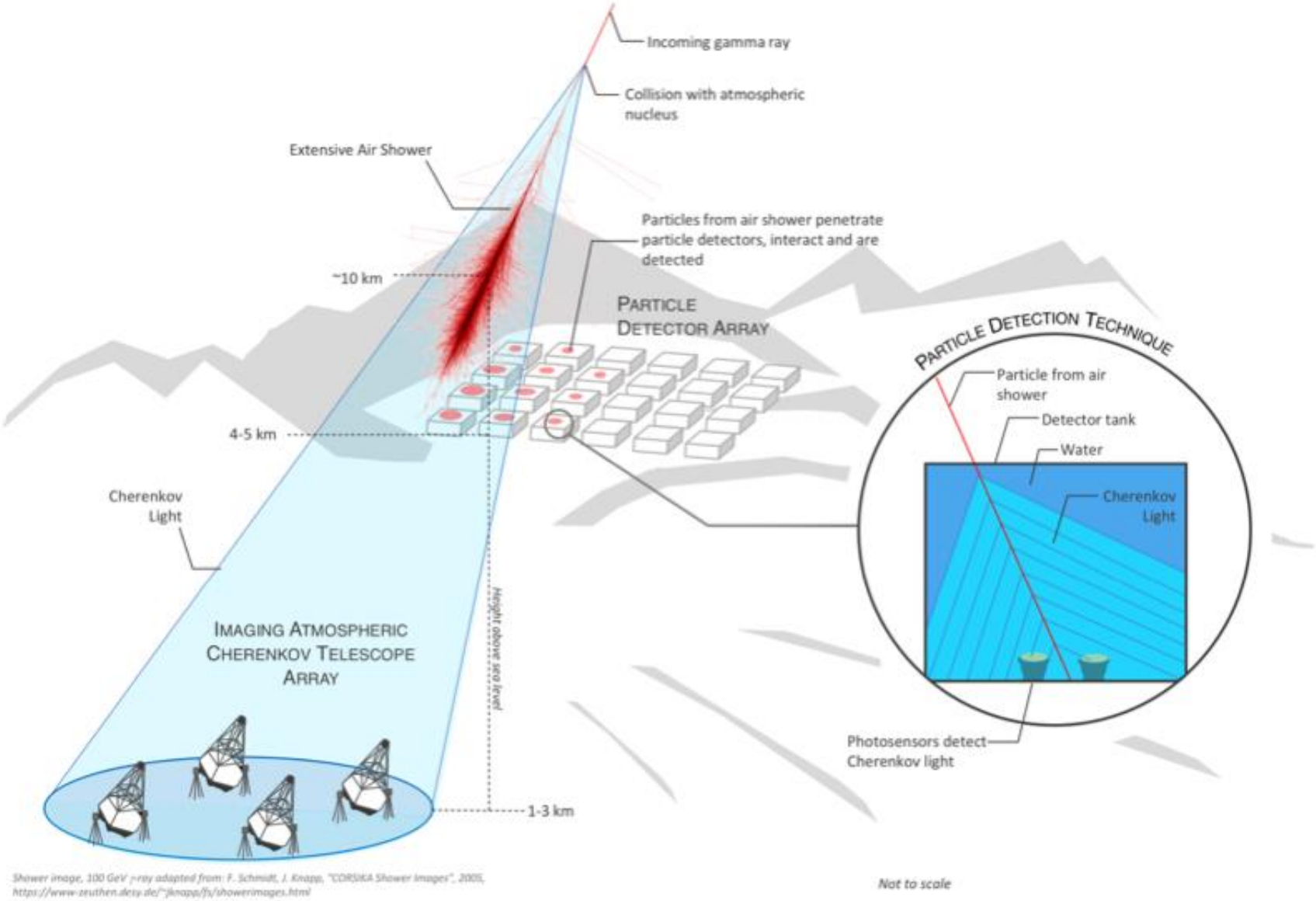
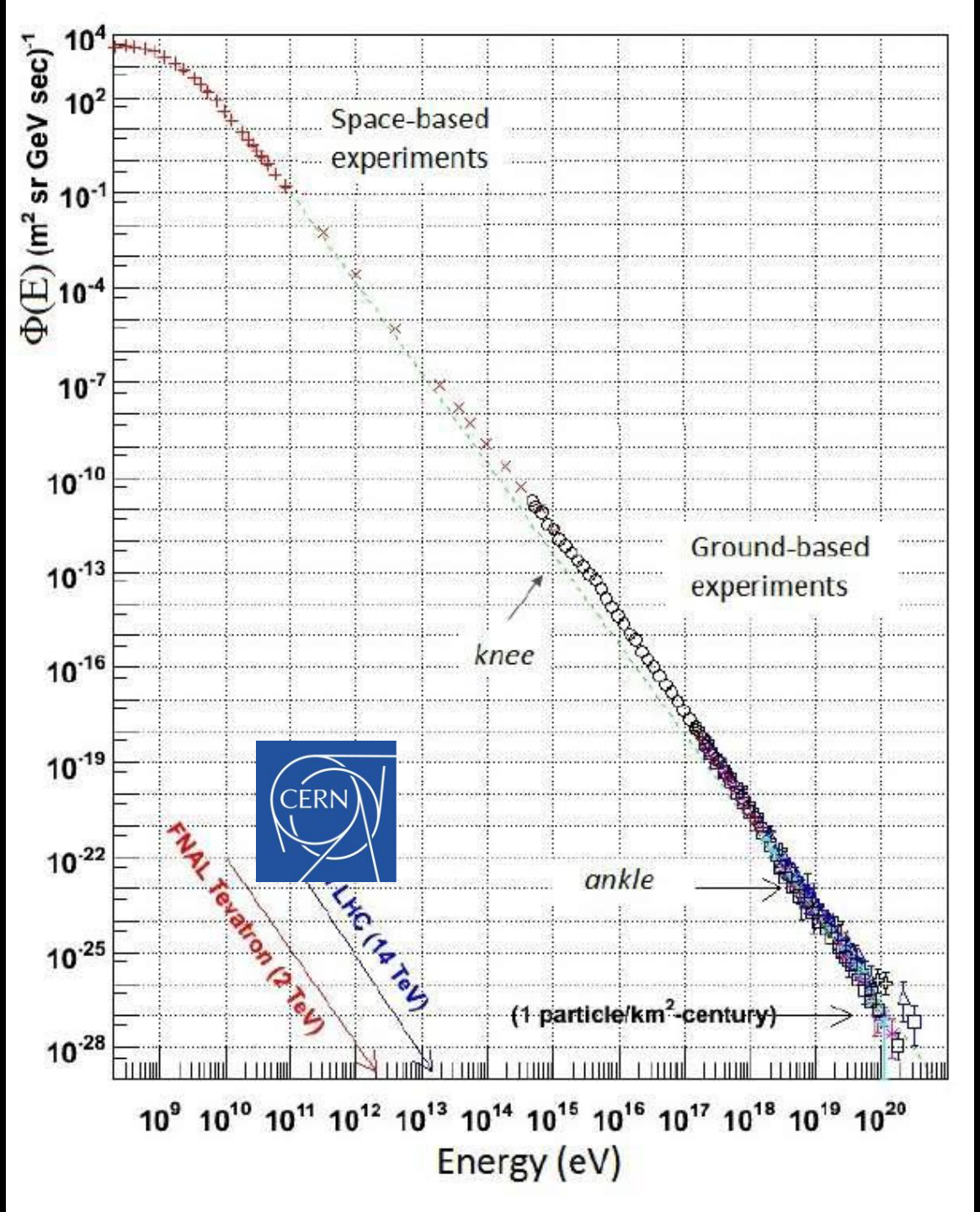


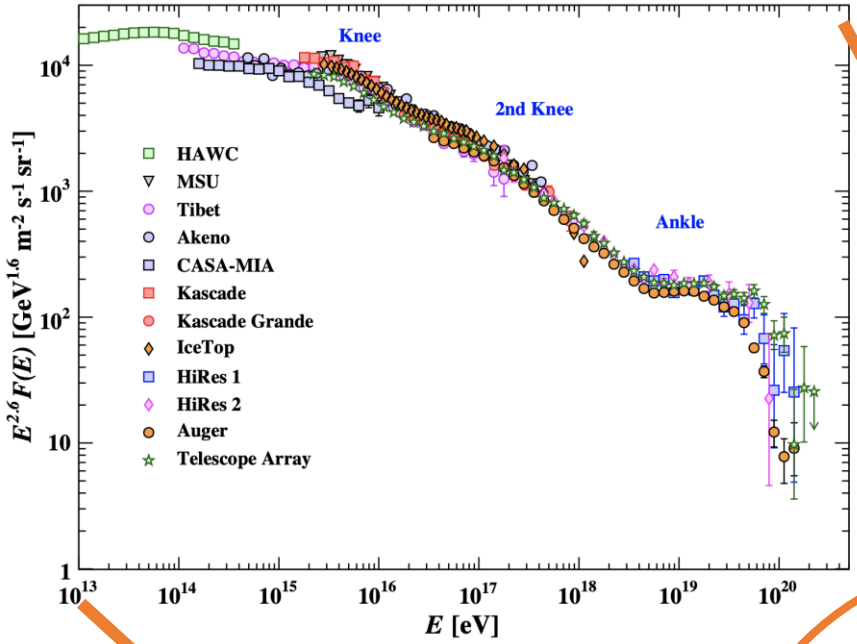
Figure 1: Schematic depiction of the two major detection methods for ground-based gamma-ray astronomy; particle detector arrays and Imaging Atmospheric Cherenkov Telescopes (IACTs) [5]. Both techniques measure the Extensive Air Showers generated by incident gamma-rays.

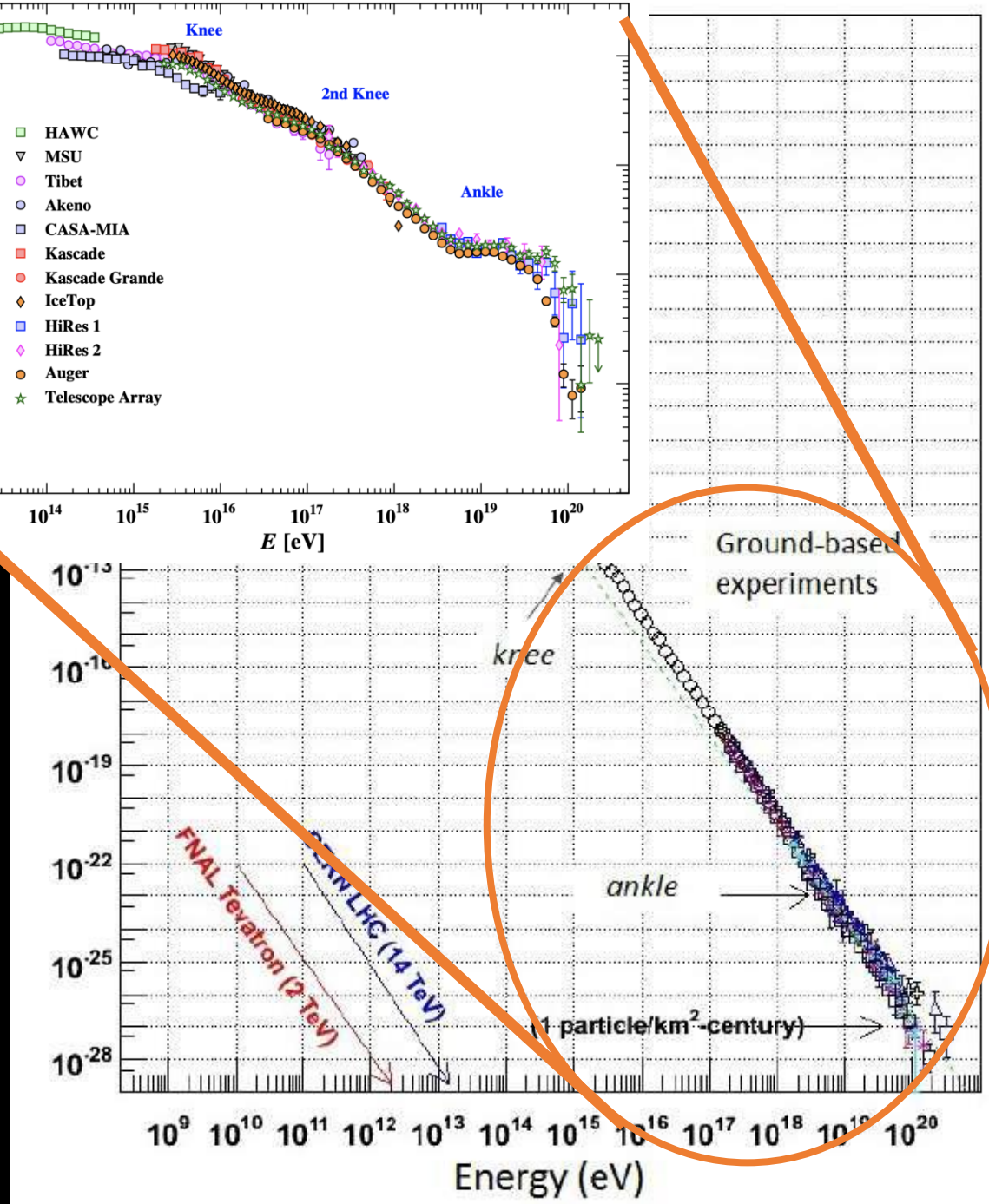
Now



- Dominated by protons or heavy nuclei
- $\phi = A\,E^{-\alpha}$

Now





- Dominated by protons or heavy nuclei
- $\phi = A\,E^{-\alpha}$
- Different α!

Neutrino searches from known sources

	Contribution to the HE ν flux
Blazars (Fermi 2LAC catalog)	< 27%
Gamma-ray burst	< 1%
Galactic plane	< 14%

What can we do to find sources?