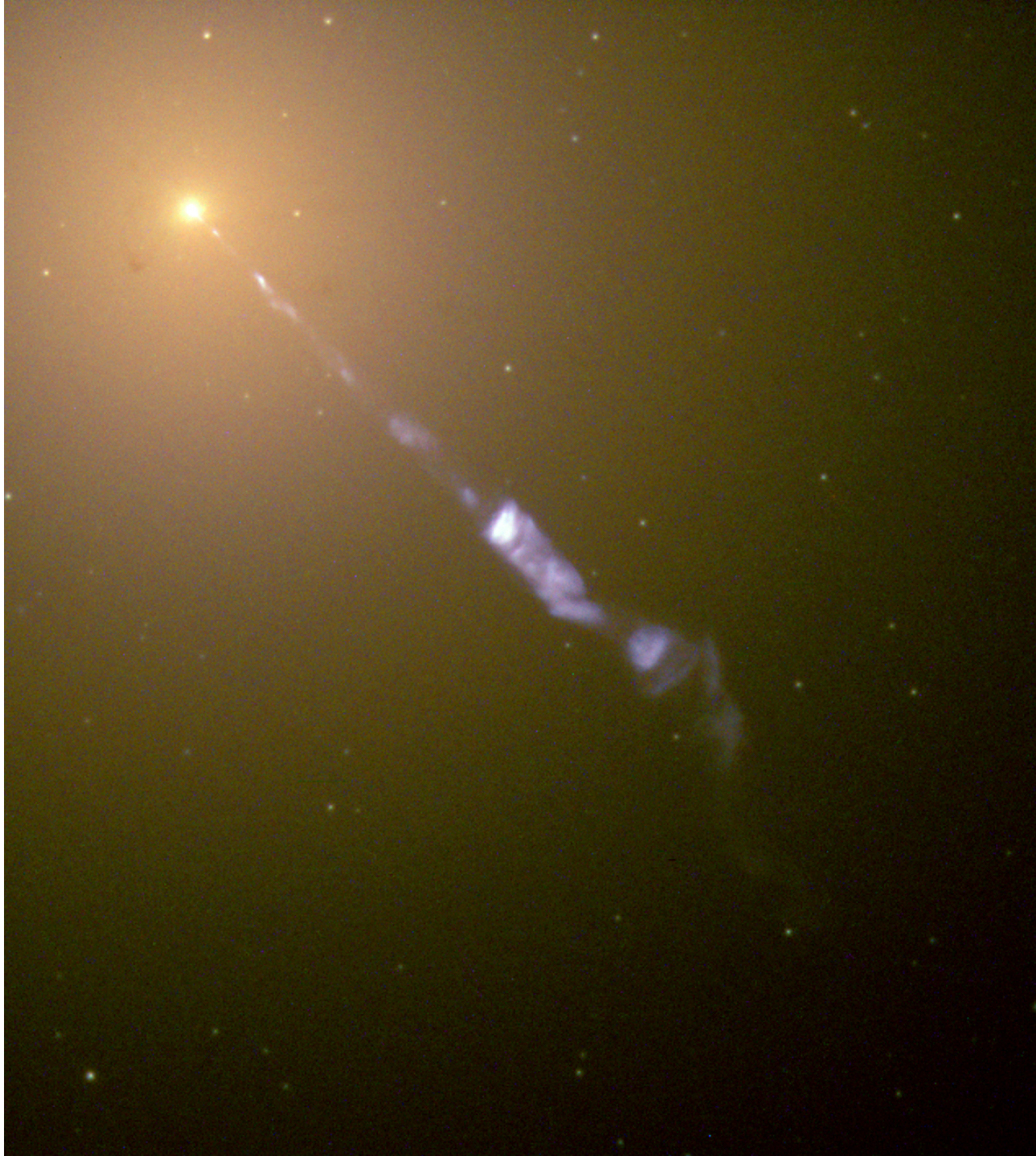
PHY 7097 | Modern Astrophysics

Lecture XX.

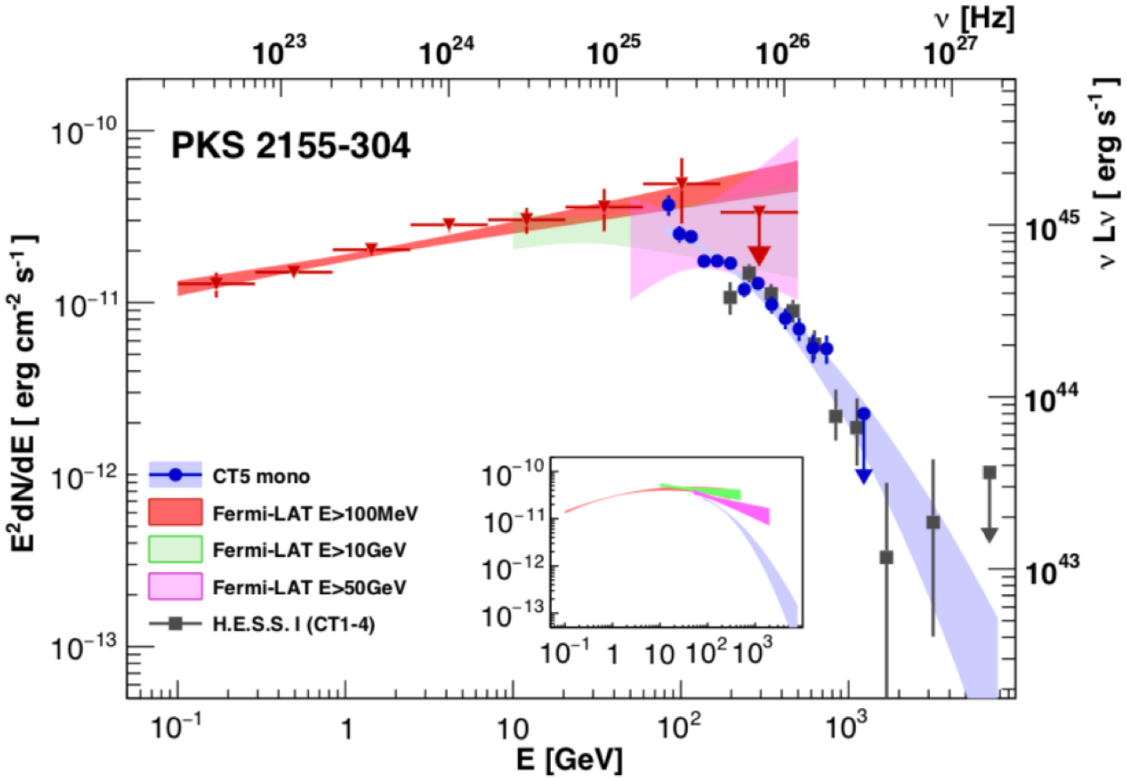
Astrophysical particle acceleration

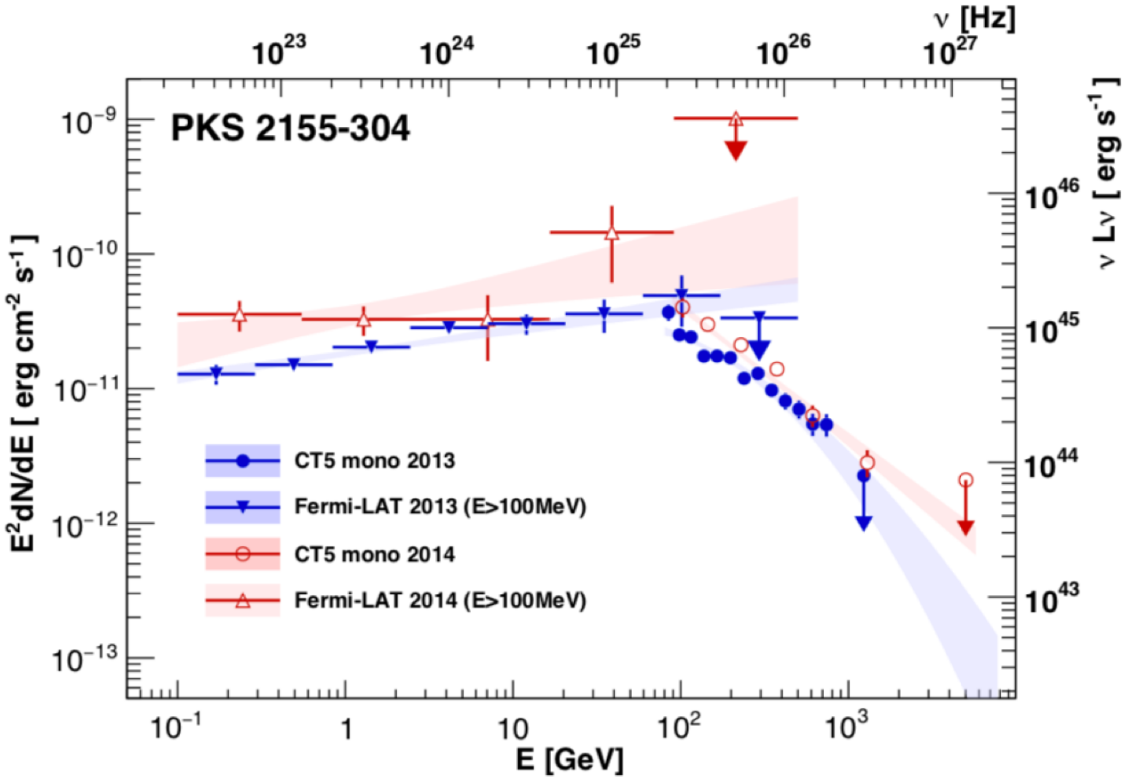


Imre Bartos | Spring 2018

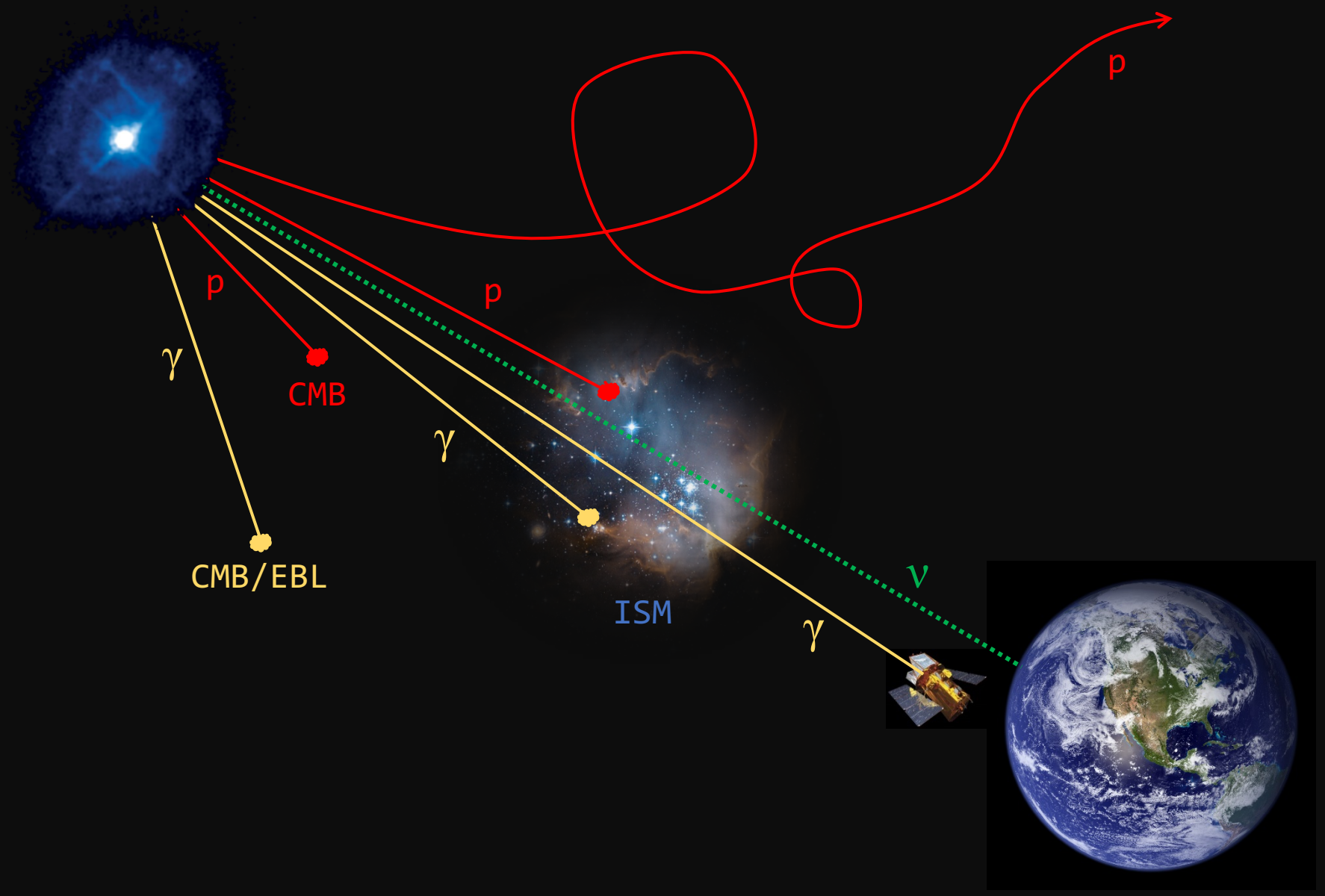
Gamma-rays

Blazar spectrum consistent with Fermi acceleration (up to some cutoff)

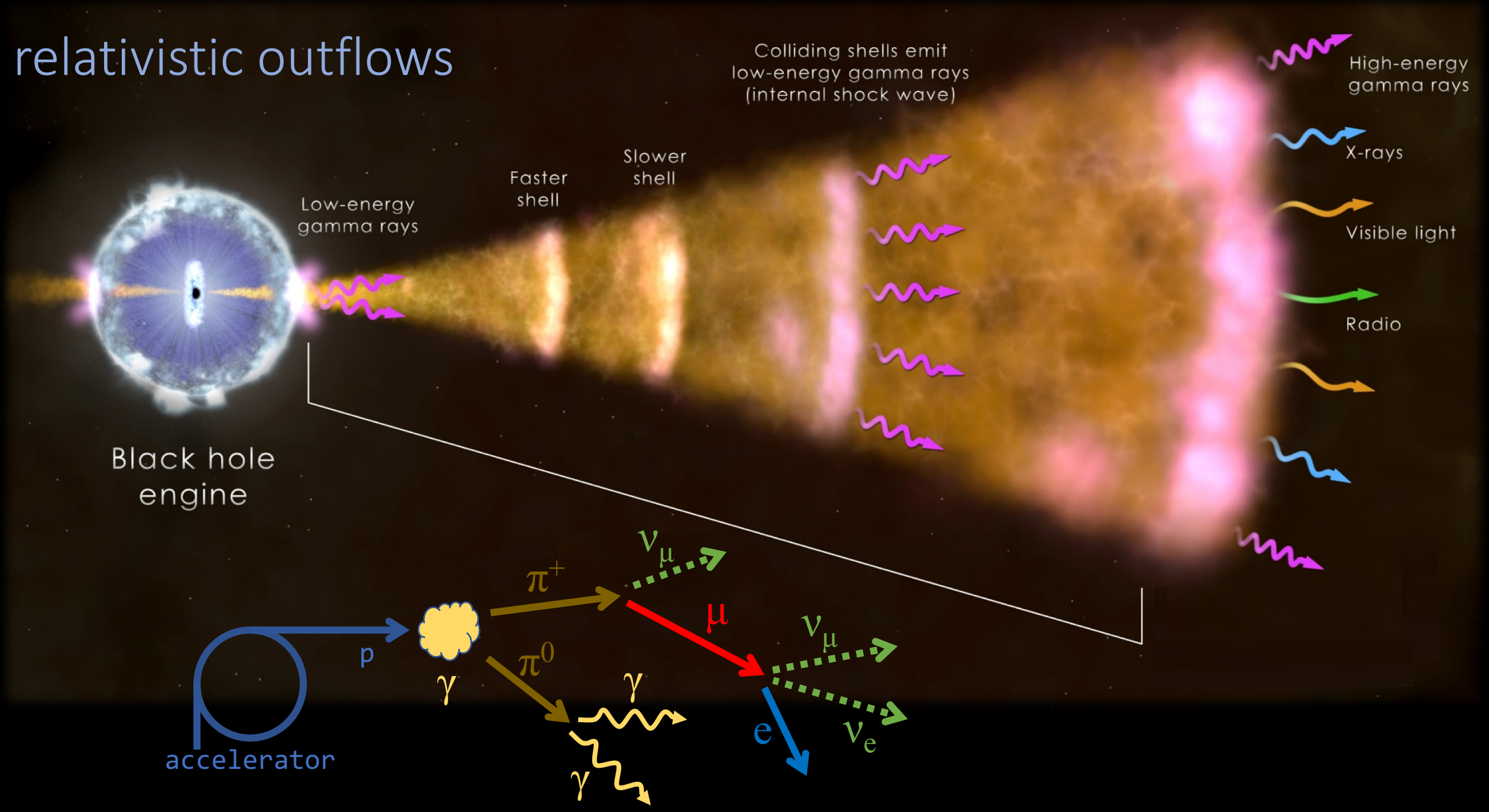




difficulty finding the origin

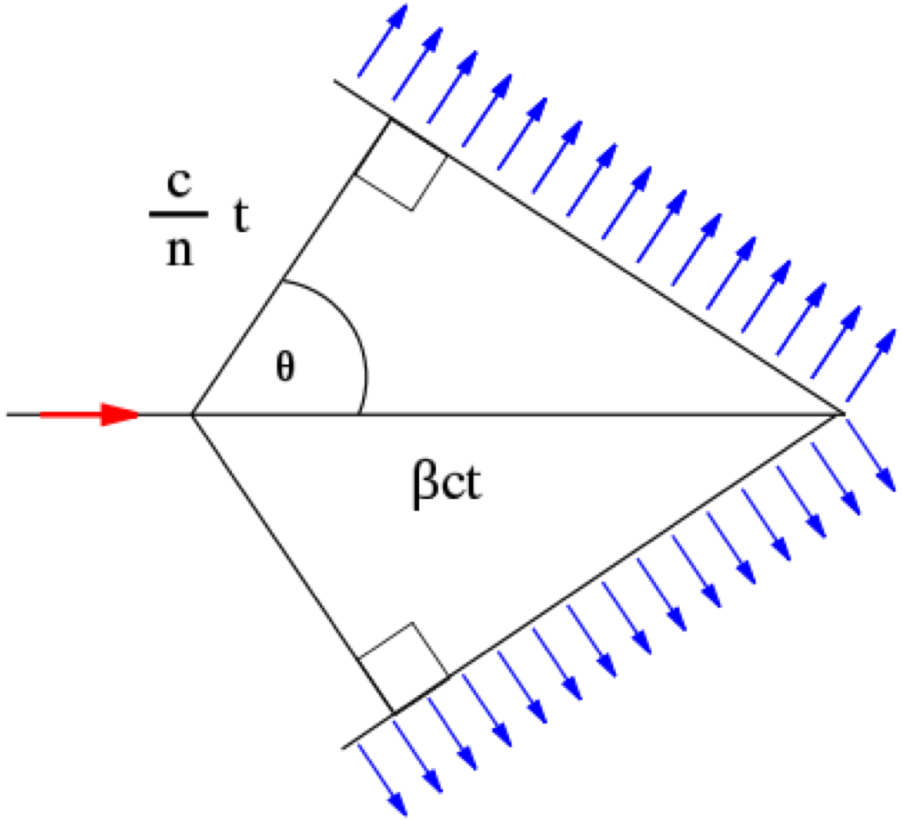


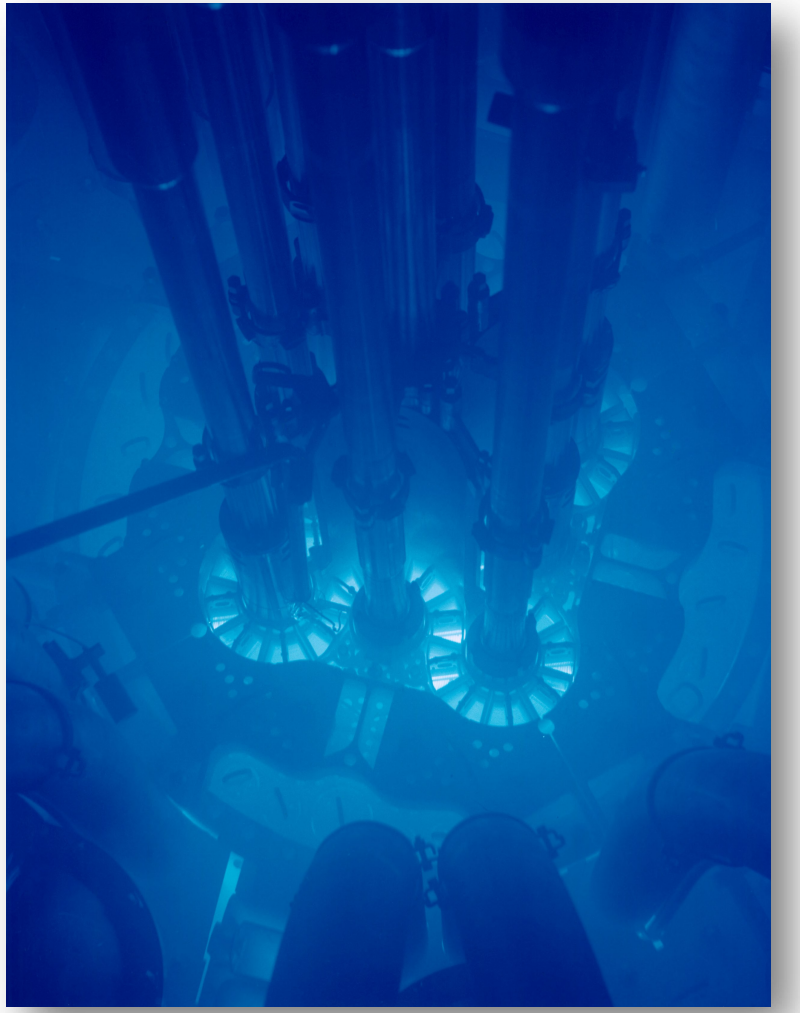
relativistic outflows



Cherenkov radiation

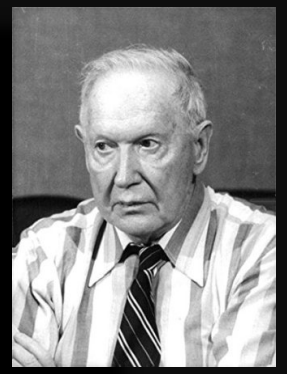
Charged particle passes through medium at speed faster than the speed of light in the medium *(in water the speed of light is 0.75c).*

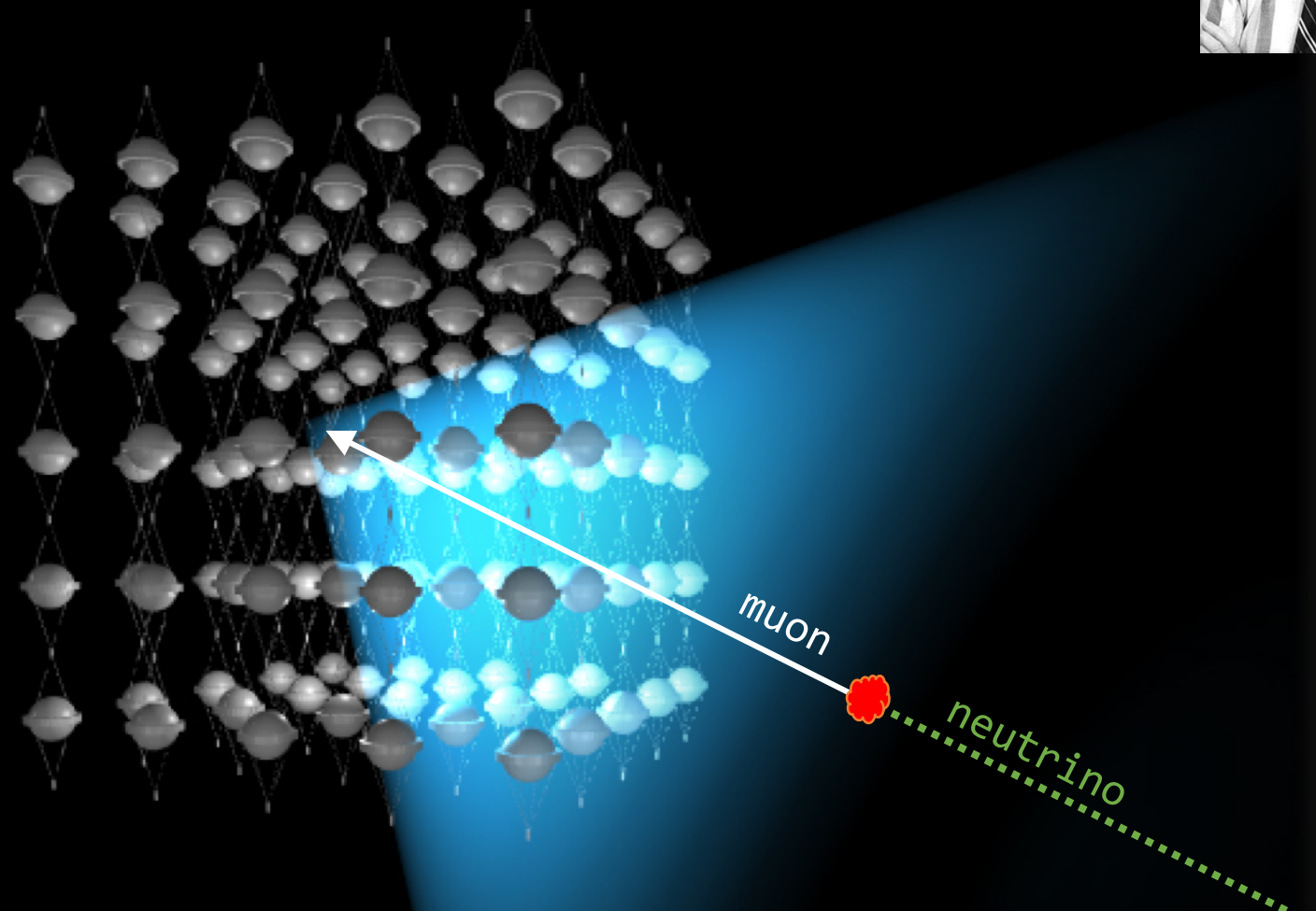




high-energy neutrino detection

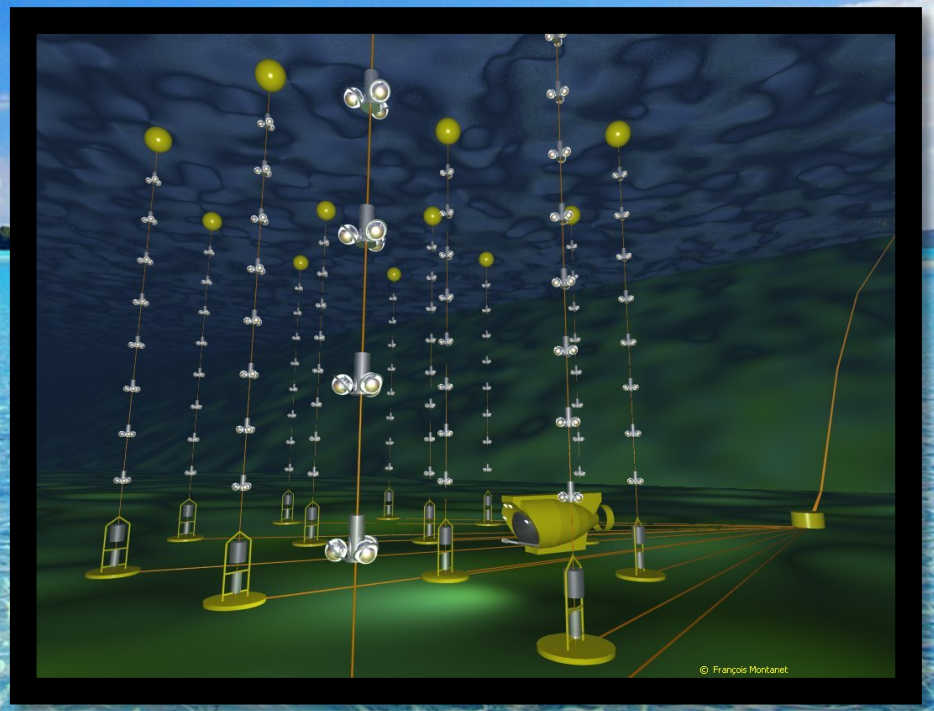
Moisey Markov (1960): we propose to install detectors deep in a lake or in the sea and to determine the direction of charged particles with the help of Cherenkov radiation.



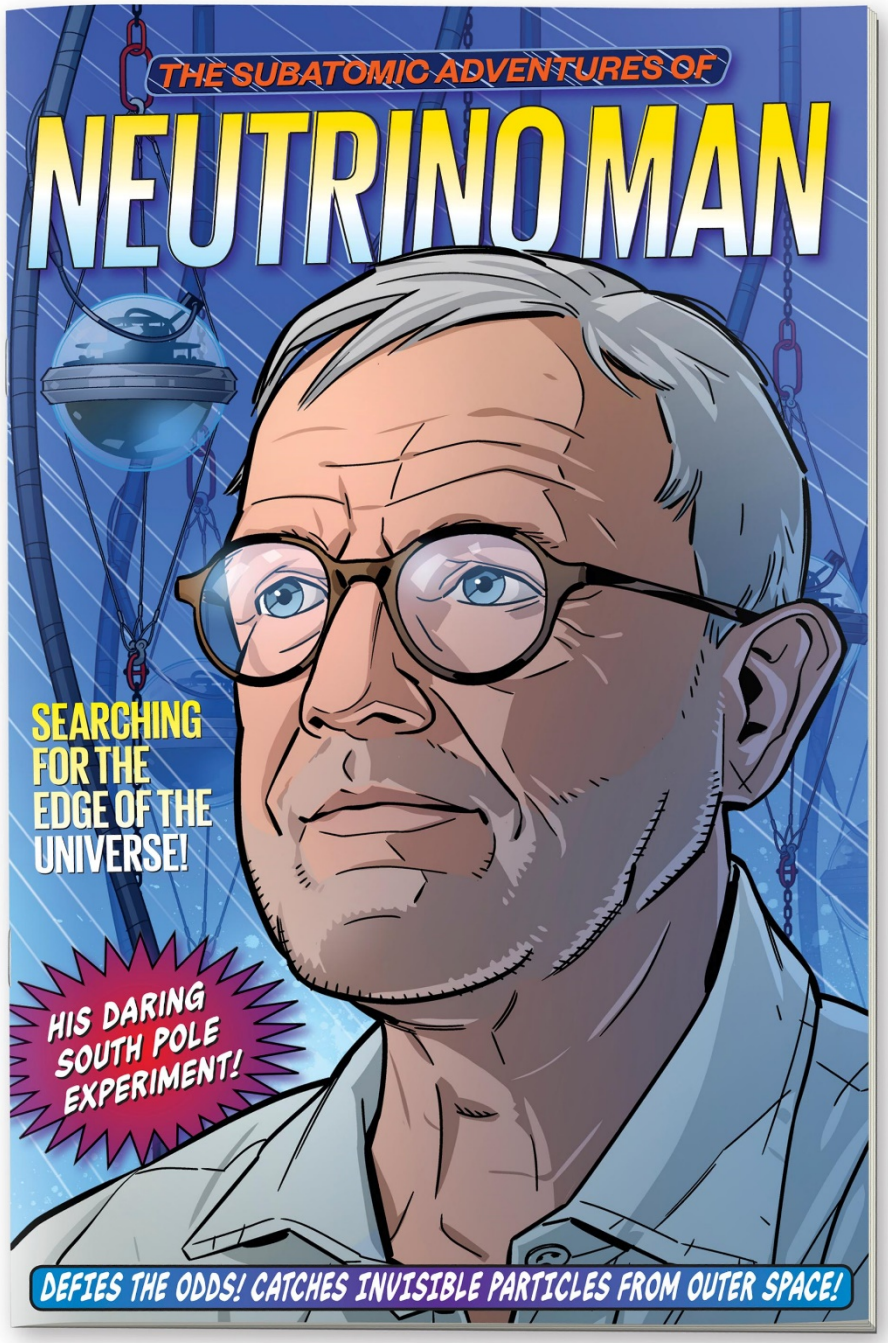


lattice of photomultipliers

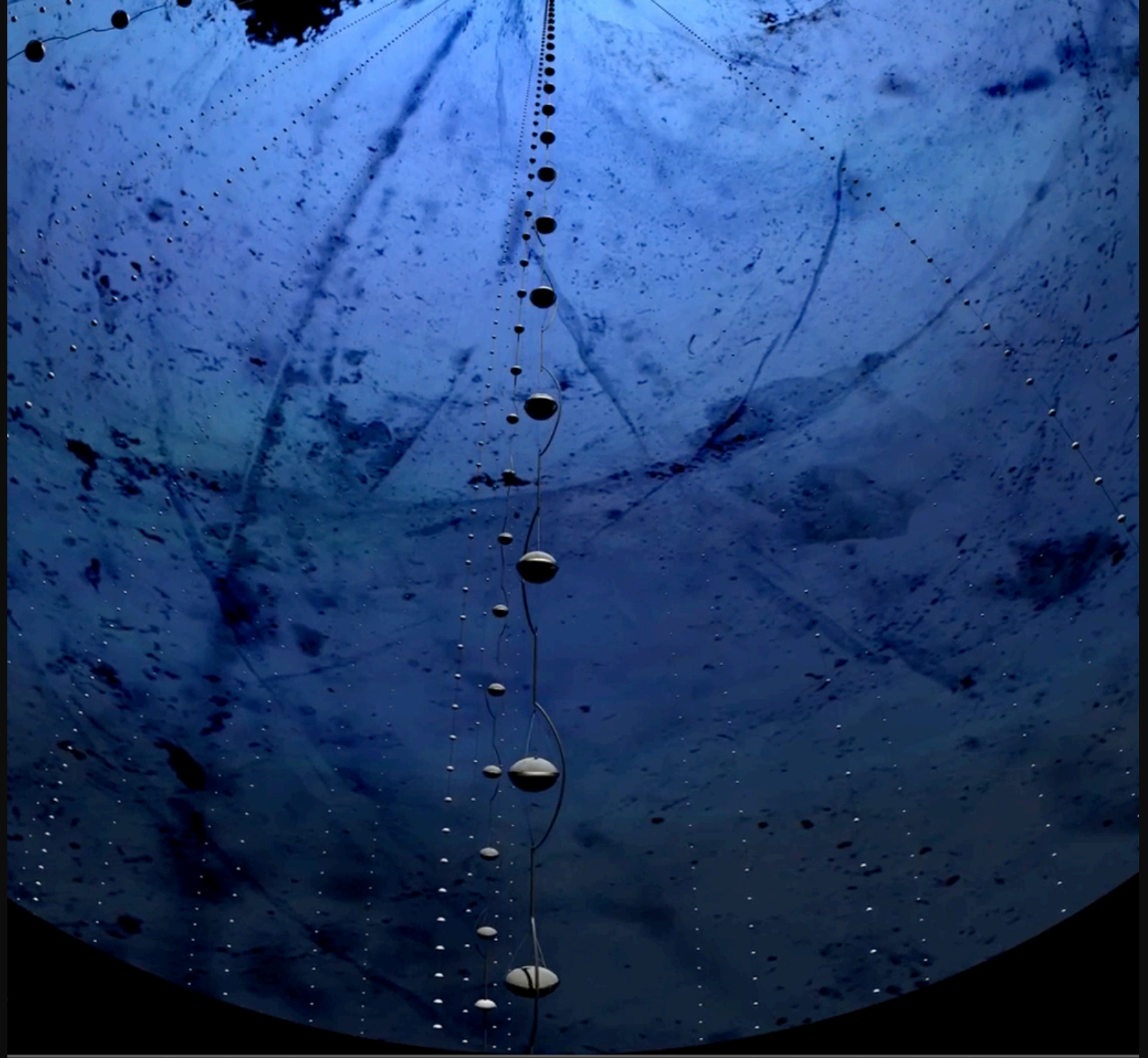
DUMAND *(Deep Underwater Muon And Neutrino Detector)*

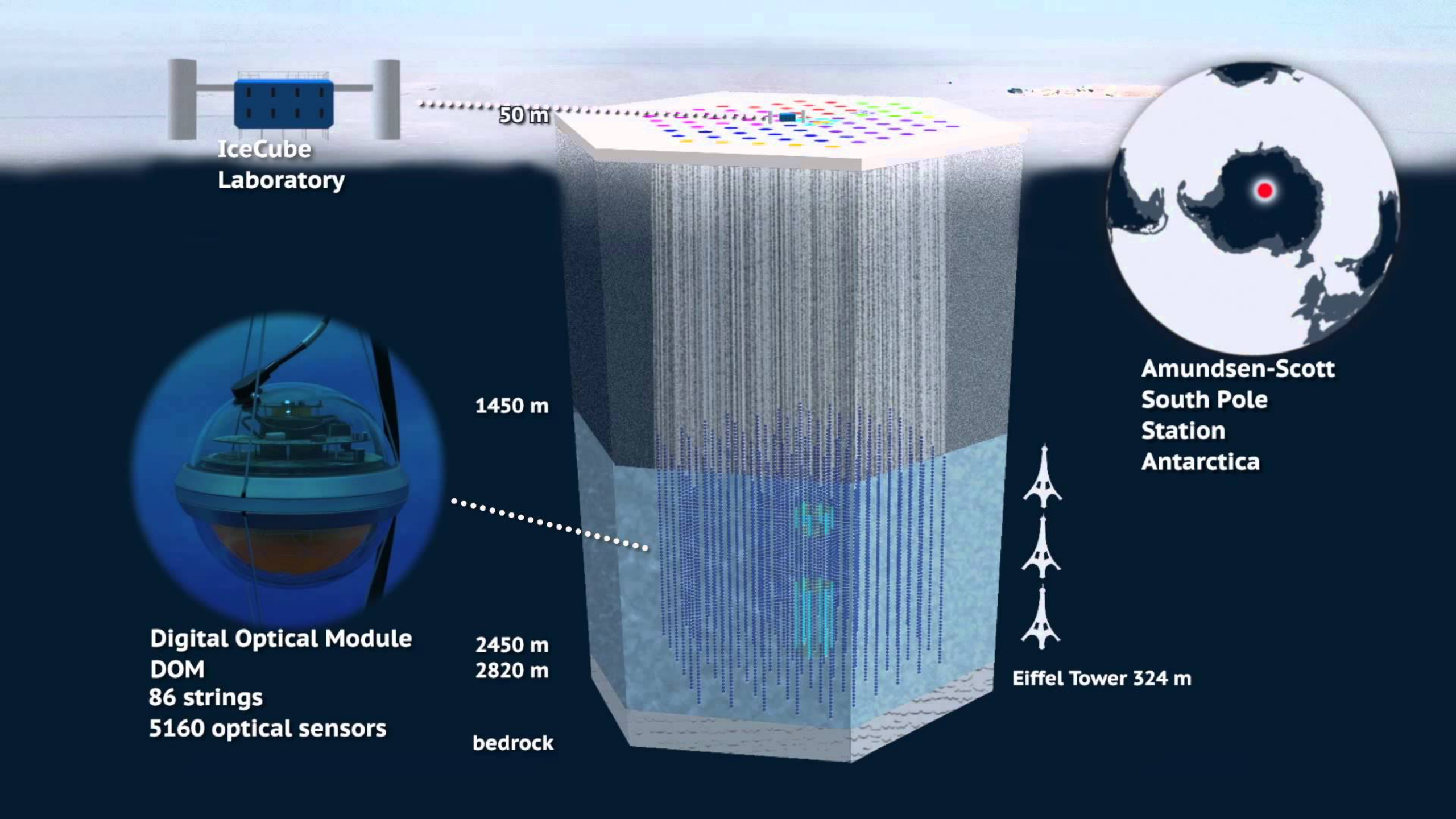


1976–1995

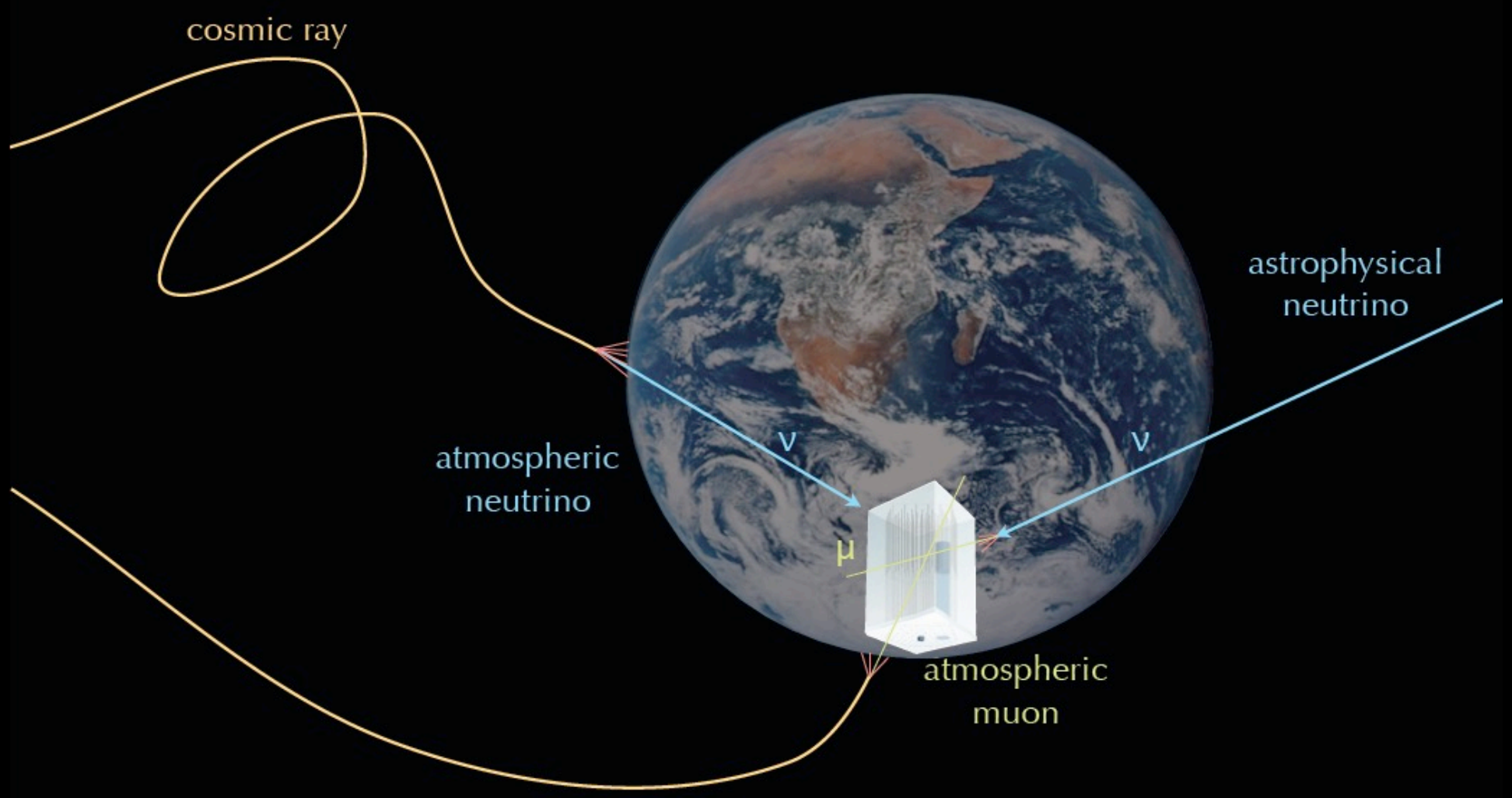

THE SUBATOMIC ADVENTURES OF
NEUTRINO MAN
SEARCHING FOR THE EDGE OF THE UNIVERSE!
HIS DARING SOUTH POLE EXPERIMENT!
DEFIES THE ODDS! CATCHES INVISIBLE PARTICLES FROM OUTER SPACE!


ultra-transparent ice below 1.5 km

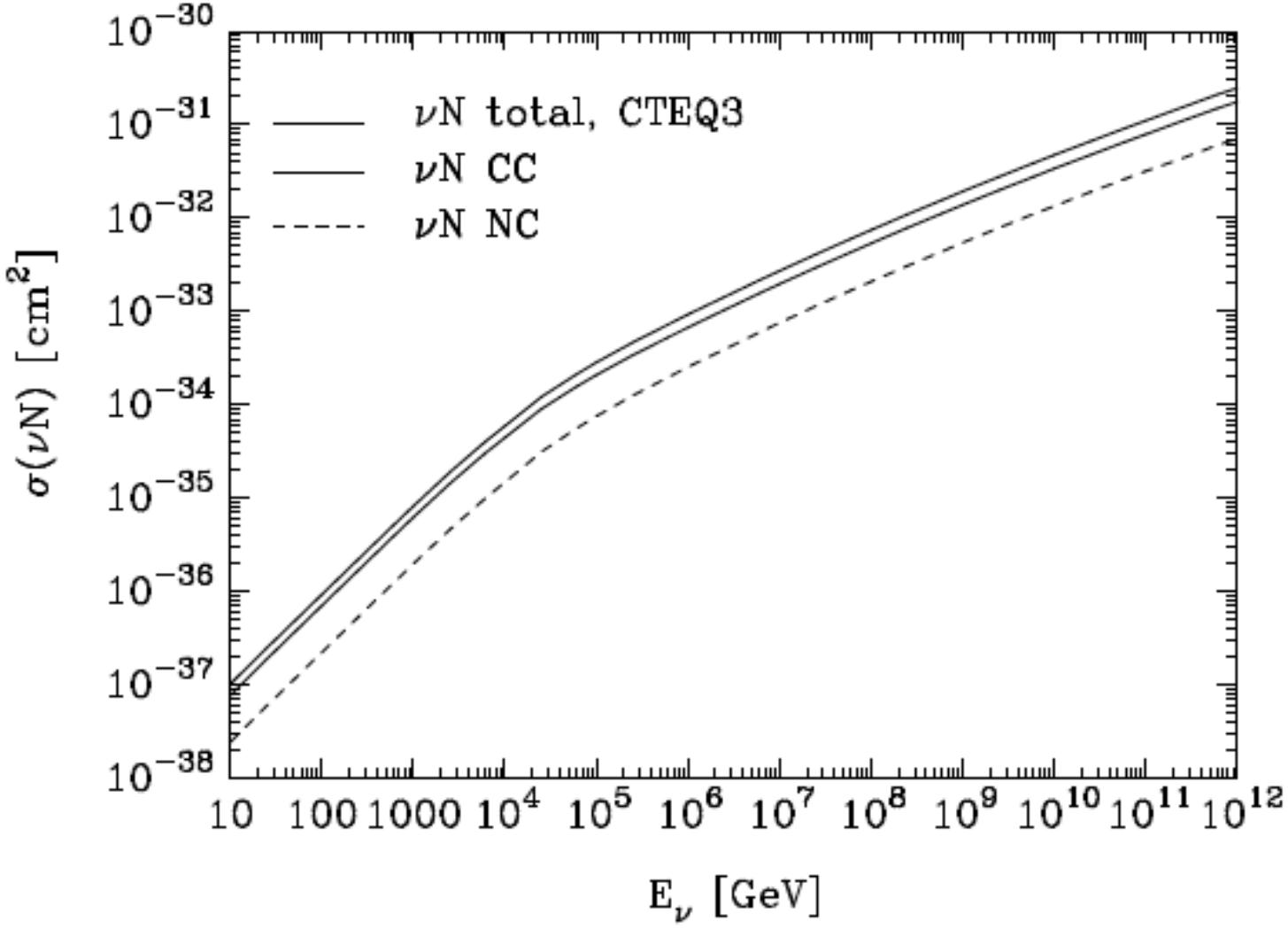



IceCube
Laboratory
50 m
1450 m
2450 m
2820 m
bedrock
Digital Optical Module
DOM
86 strings
5160 optical sensors
Eiffel Tower 324 m
Amundsen-Scott
South Pole
Station
Antarctica

Signals and Backgrounds



Neutrino cross section



What fraction will cross the Earth at 10 TeV energy? (the energy of the LHC)

$$\frac{\mathrm{d}\Phi}{\mathrm{d}z} = -n\sigma\Phi$$

$$\Phi = \Phi_0 \mathrm{e}^{-n\sigma z}$$

(pp cross section at 10 TeV --- ~10^{-25} cm^2)

A PATH TO MARS

BOEING

BUILDING BLOCKS

Production

1

Space Launch System (SLS)

Heavy lift launch system that transports crew and all elements from Earth to space enabling the path to Mars.

Production

2

Orion

Crew transportation vehicle that carries humans from Earth to in-space habitats and back.

Early Development

3

Transit Habitat

The primary crew living quarters, the habitat has all the systems necessary to keep the crew healthy.

Early Development

4

Deep Space Tug

The tug moves in-space elements to other locations, utilizing solar electric and chemical propulsion.

Concept

5

Mars Lander/ Heat Shield

The heat shield is needed to enter the Martian atmosphere so the lander can perform a propulsive landing.

Concept

6

Mars Ascent Vehicle

A small crew vehicle that carries crew to the surface of Mars (with the lander) and back to space and is also a small habitat for short stays.

1 + 2

SLS and Orion

Primary transportation capabilities established

Today

Low Earth Orbit Missions

ISS is a testbed for deep space hardware and operations

2 + 3 + 4

Exploration Habitat

Key systems demonstrated

2 + 3 + 4

Mars Transit Vehicle

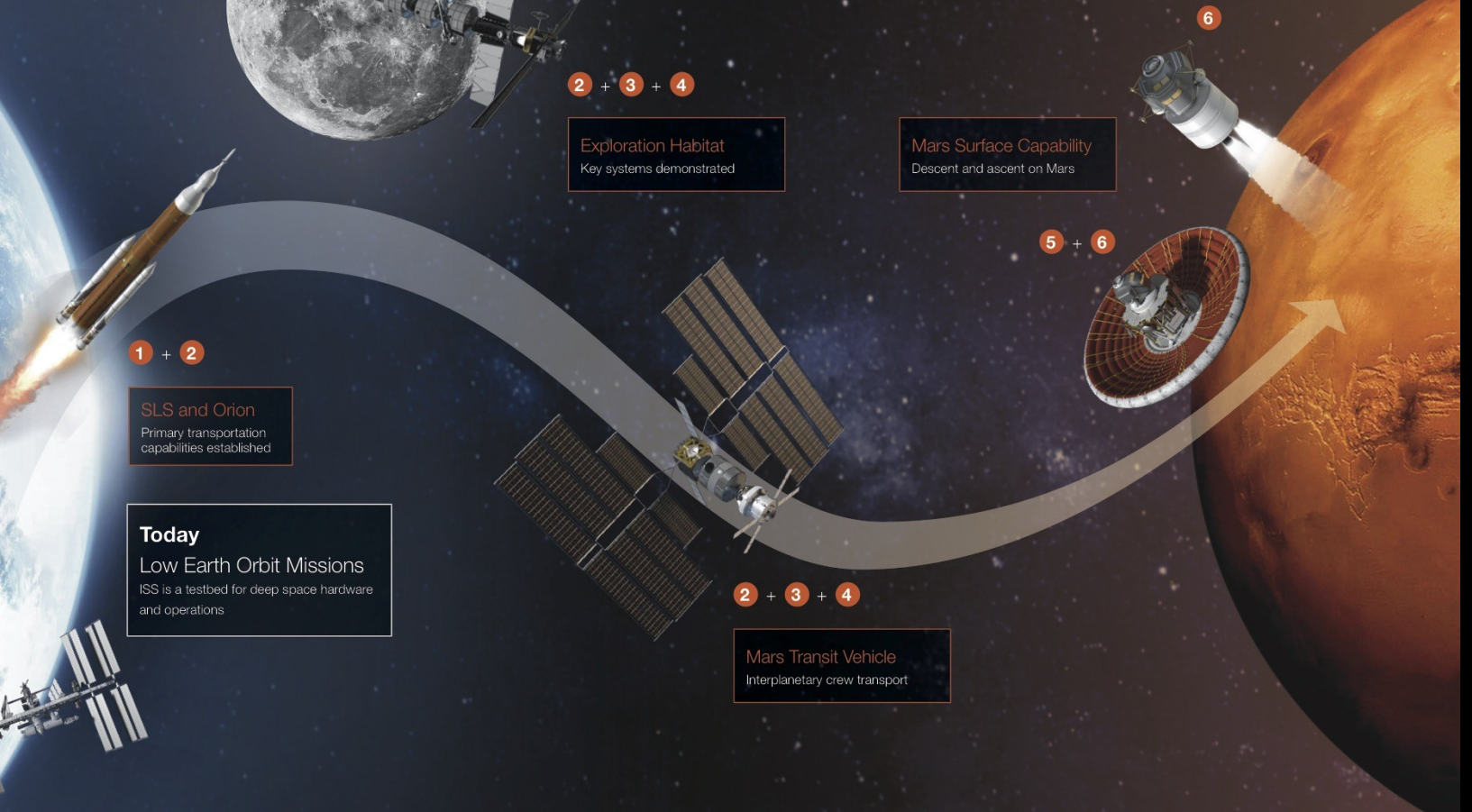
Interplanetary crew transport

6

Mars Surface Capability

Descent and ascent on Mars

5 + 6



2020s

1. Proving Ground Missions

Initial missions near the moon demonstrate important space systems and demonstrate early elements of the Mars transportation vehicles.

Early 2030s

2. Mission to Mars Vicinity

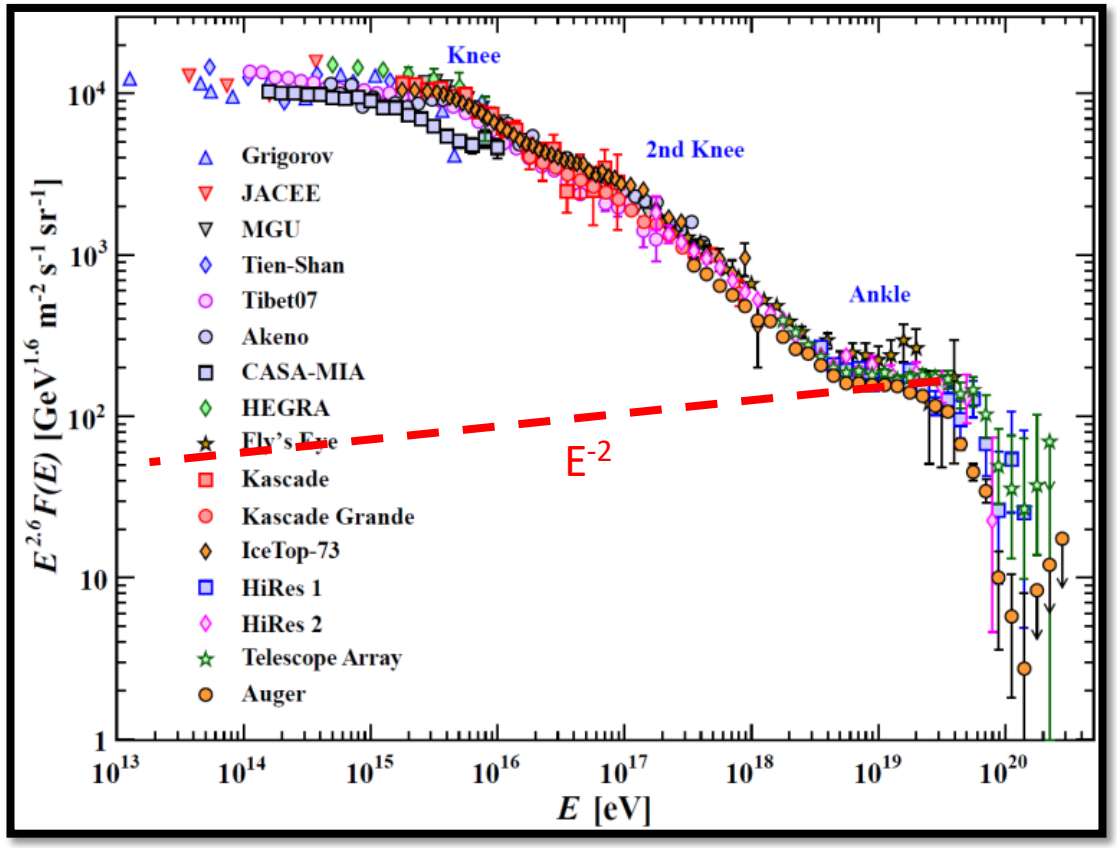
The vehicles and systems validated in cislunar space are used for missions to Mars orbit, proving capabilities for transit to Mars.

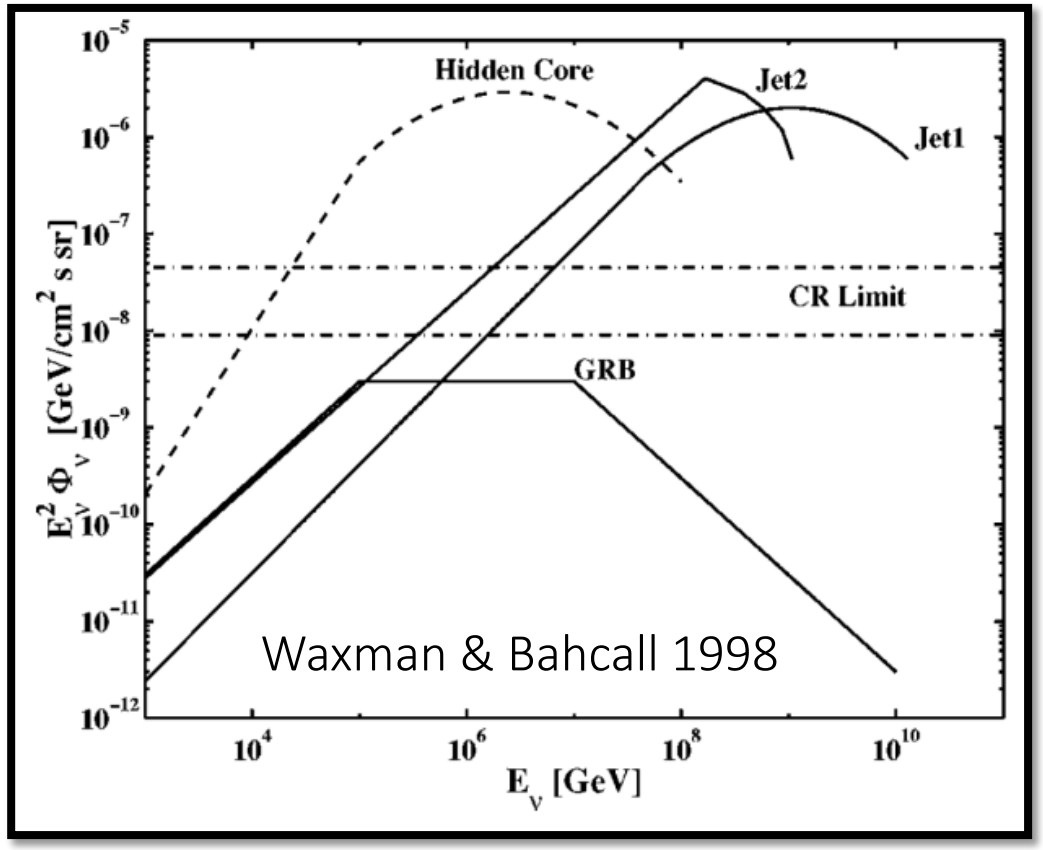
Mid to Late 2030s

3. Mars Surface

Future development capabilities for landing and ascent on Mars will enable Mars surface exploration.

Waxman-Bahcall upper bound

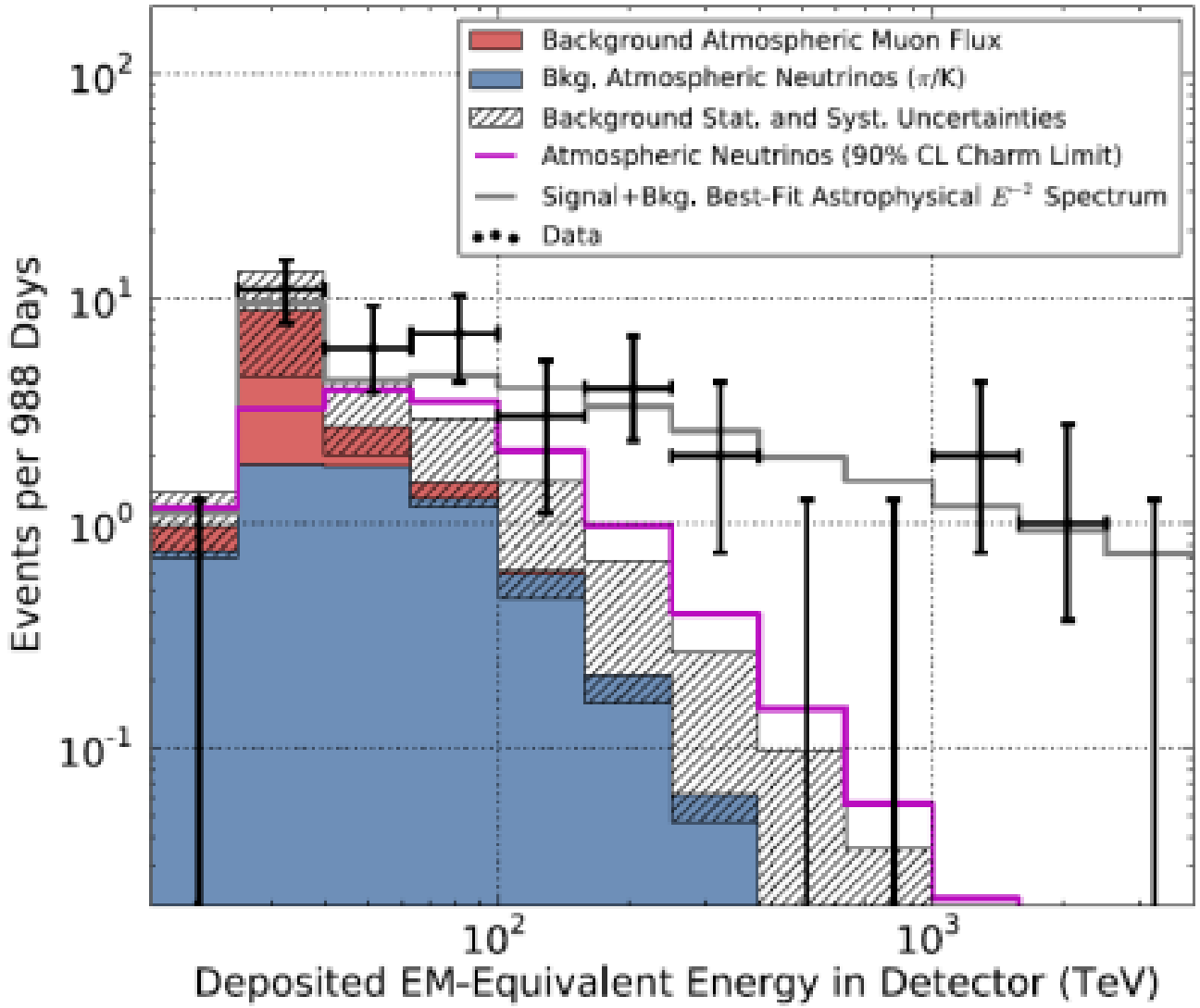




Extragalactic cosmic rays should eventually collide with gas and produce high energy neutrinos. What will be the neutrino flux if the extragalactic flux

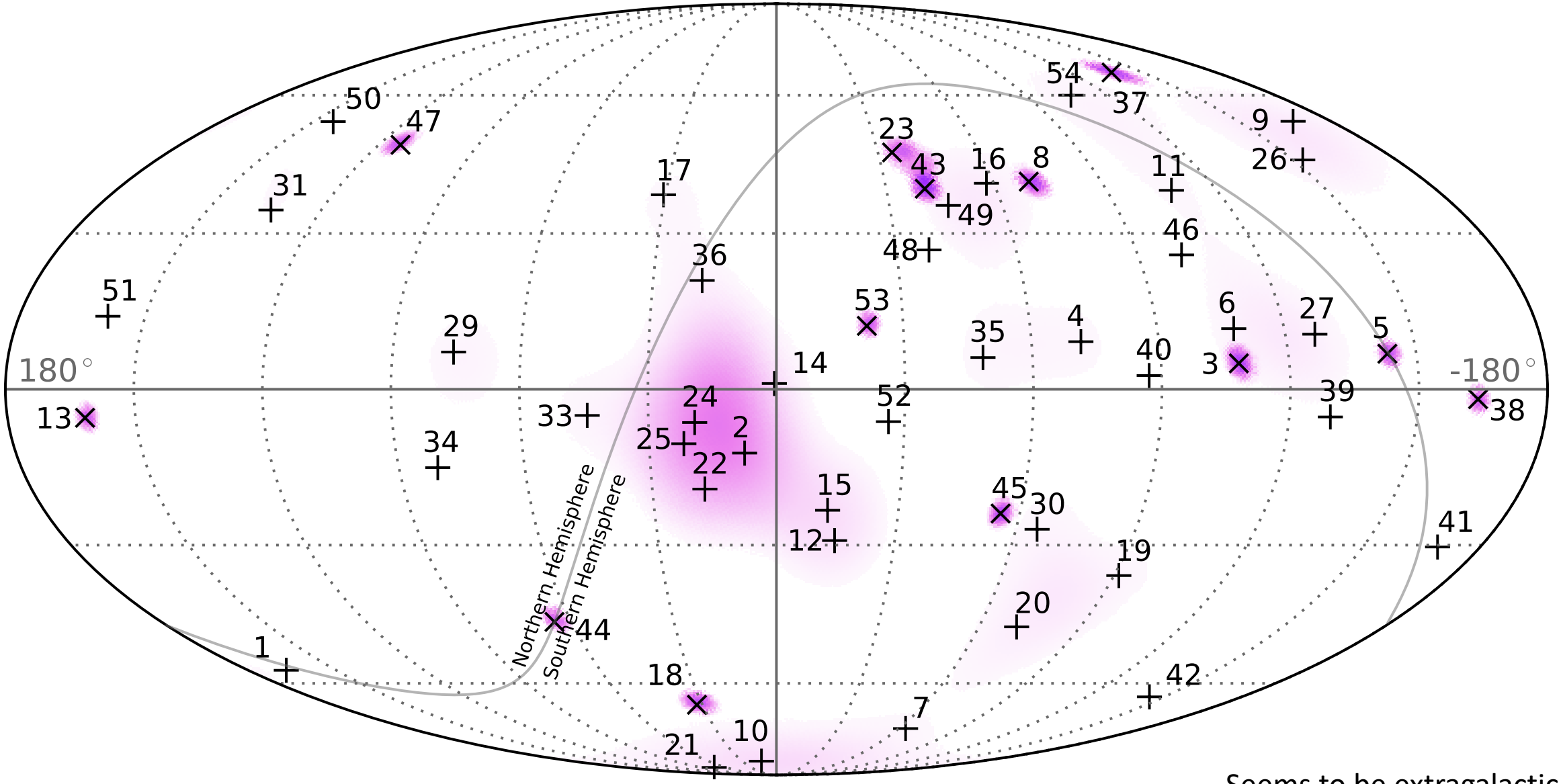
- follows a Fermi spectrum and
- continues down to lower energies?

Discovery of “diffuse” astrophysical neutrino flux



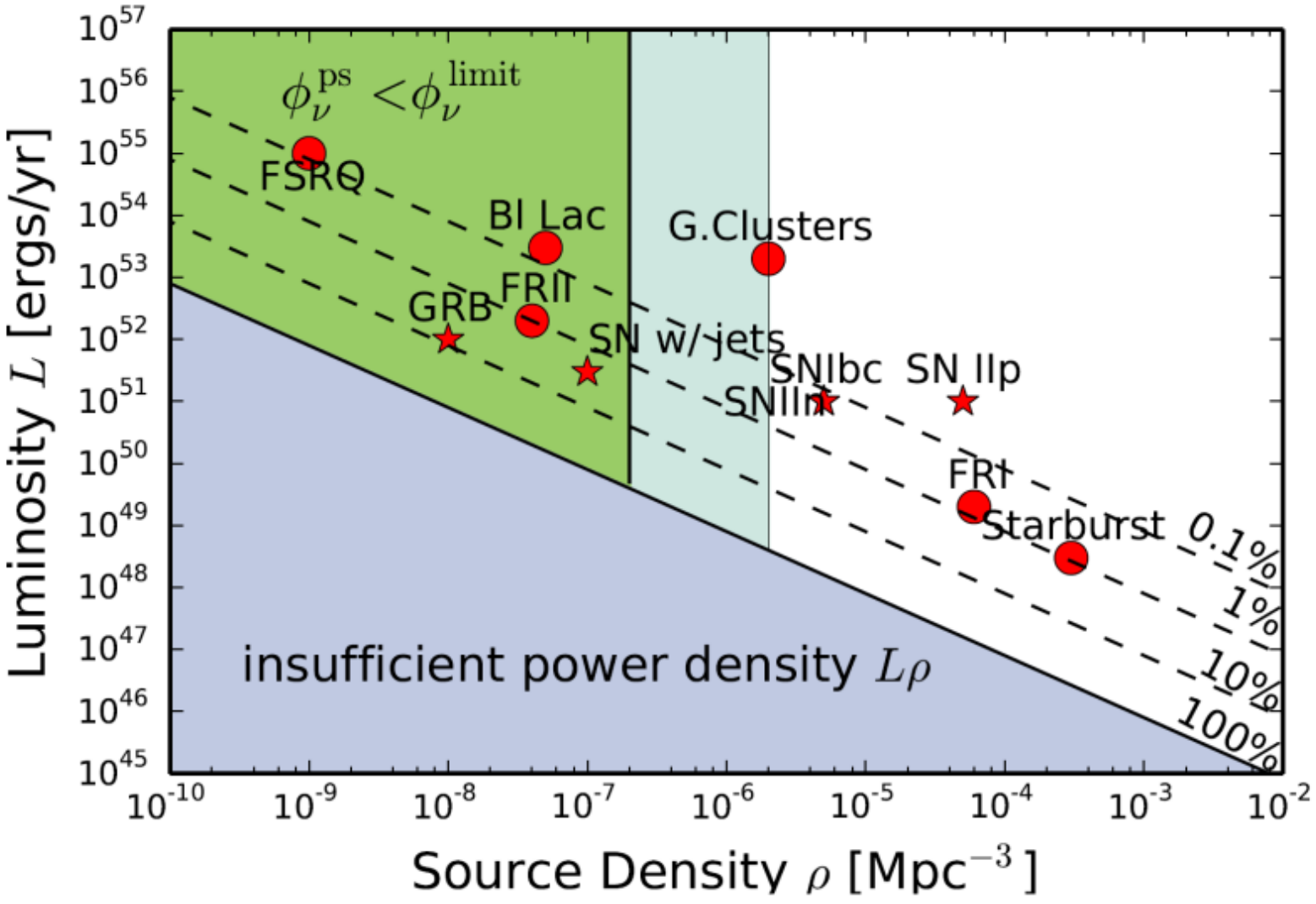
- Excess neutrino flux over expected background at >100 TeV
- No identified source
- Spectrum consistent with Fermi process

Detected high-energy neutrinos (>100 TeV)



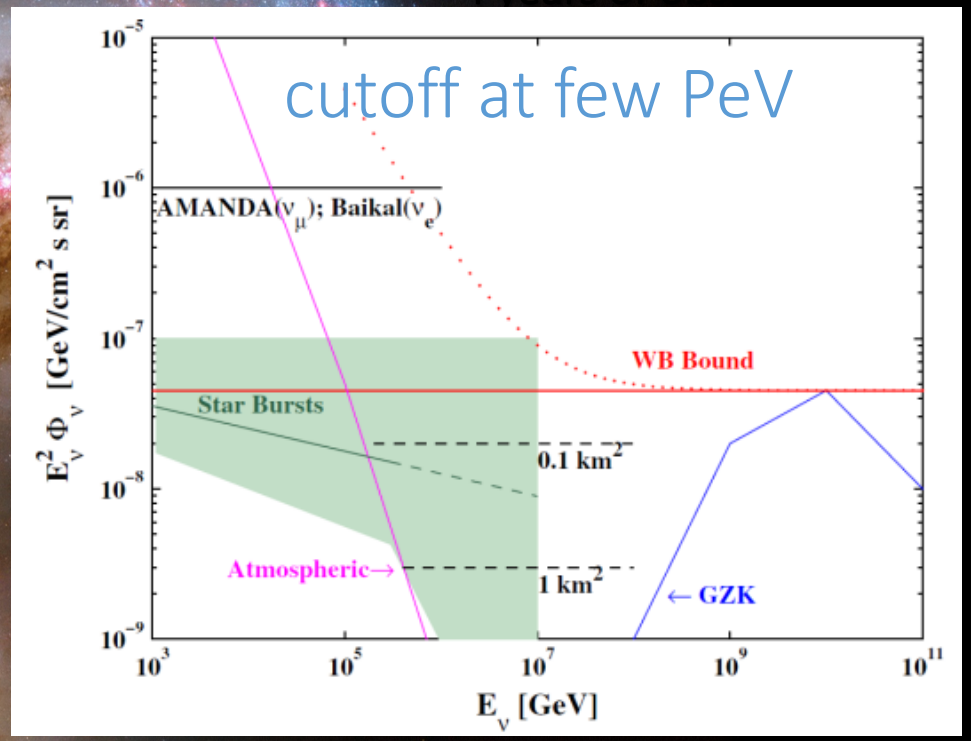
Seems to be extragalactic

Waxman-Bahcall upper bound



Lack of neutrino doublets rules out “rare, bright” sources.

starburst galaxies?



Loeb & Waxman 2006

cosmic ray calorimeters.

high-star formation → cosmic ray injection

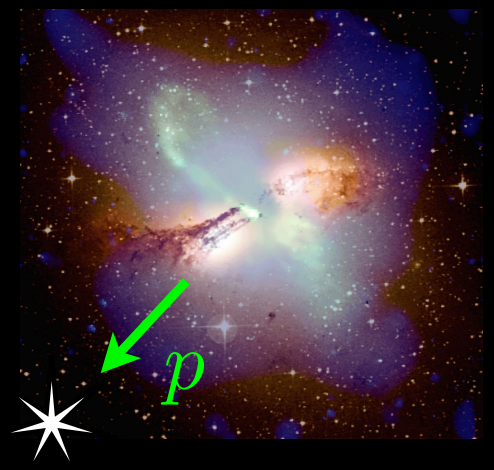
strong magnetic fields → traps cosmic rays longer

dense ISM → CRs interact.

gamma rays

hadronic gamma rays?

$\pi^+ = \pi^- = \pi^0$

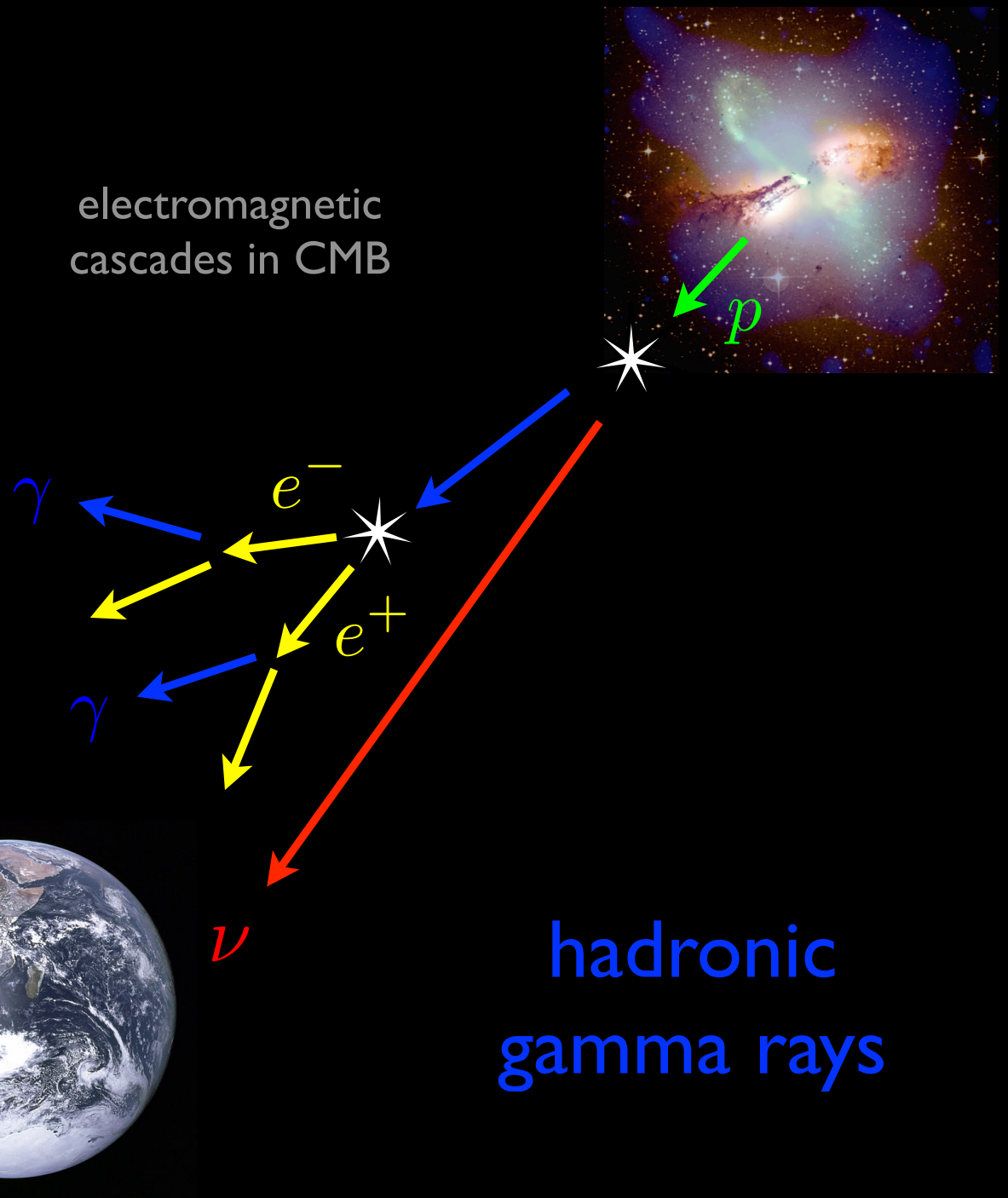


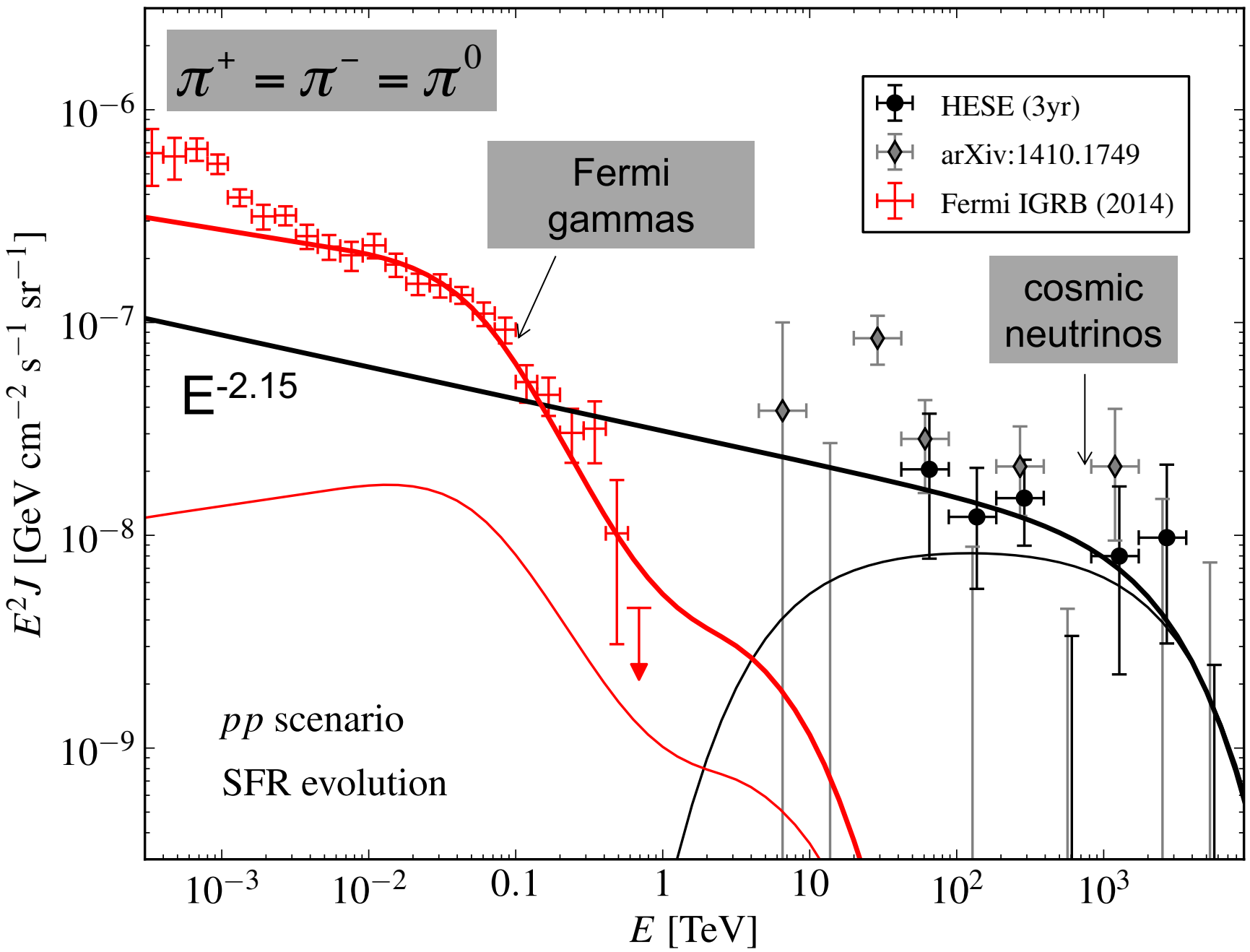
γ

ν

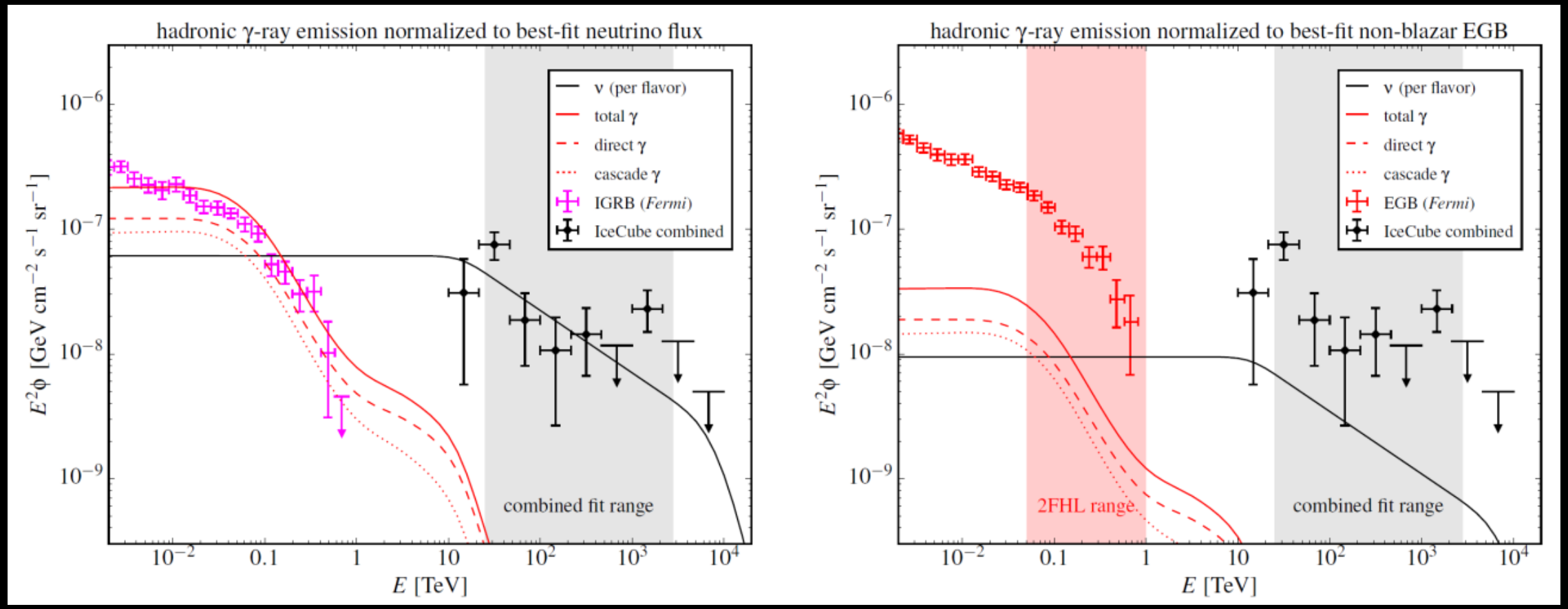
hadronic
gamma rays

gamma rays


electromagnetic
cascades in CMB
p
γ
e^-
e^+
γ
ν
hadronic
gamma rays


$\pi^+ = \pi^- = \pi^0$
HESE (3yr)
arXiv:1410.1749
Fermi IGRB (2014)
Fermi gammas
cosmic neutrinos
$E^{-2.15}$
pp scenario
SFR evolution
$E^2 J$ [GeV cm^{-2} s^{-1} sr^{-1}]
E [TeV]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-3}
10^{-2}
0.1
1
10
10^2
10^3

gamma-ray + neutrinos

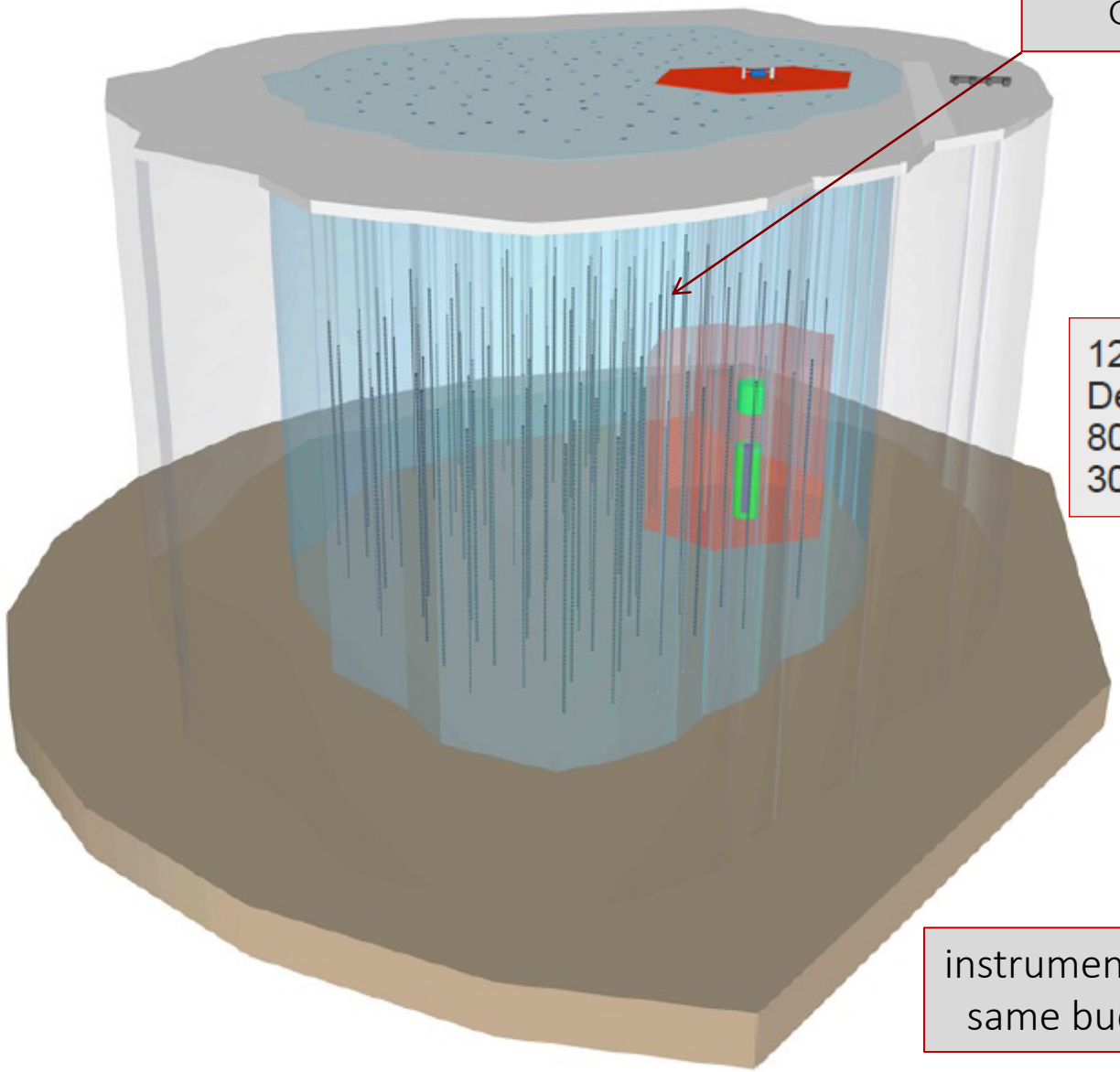


Bechtol+ 2015

non-blazar diffuse gamma-ray flux
limited by Fermi-LAT to ~15%

need more multimessenger observations!

beyond IceCube



PINGU infill
40 strings
GeV threshold

120 strings
Depth 1.35 to 2.7 km
80 DOMs/string
300 m spacing

instrumented volume: x 10
same budget as IceCube

The IceCube Gen2 Facility