Future Natural-Source Neutrino Experiments

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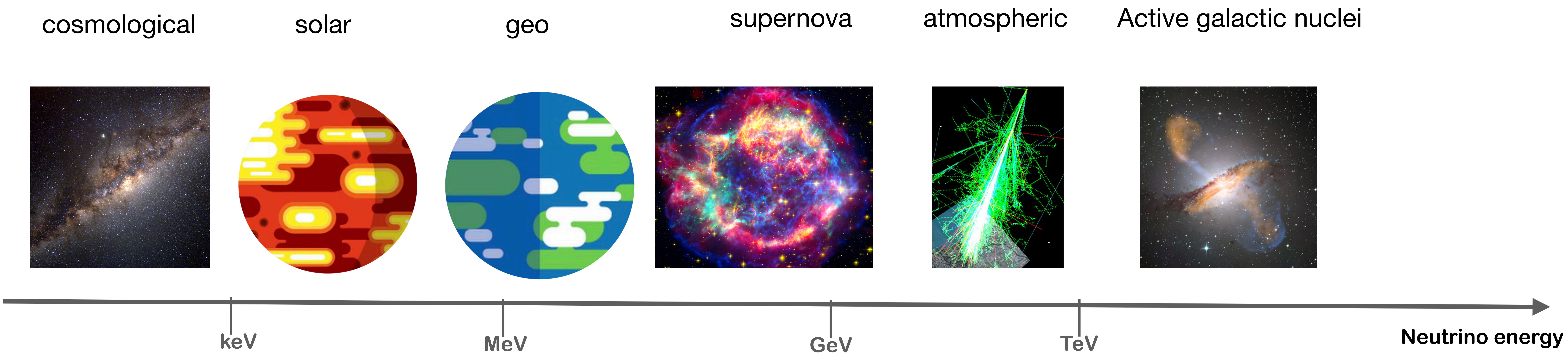
Where to look



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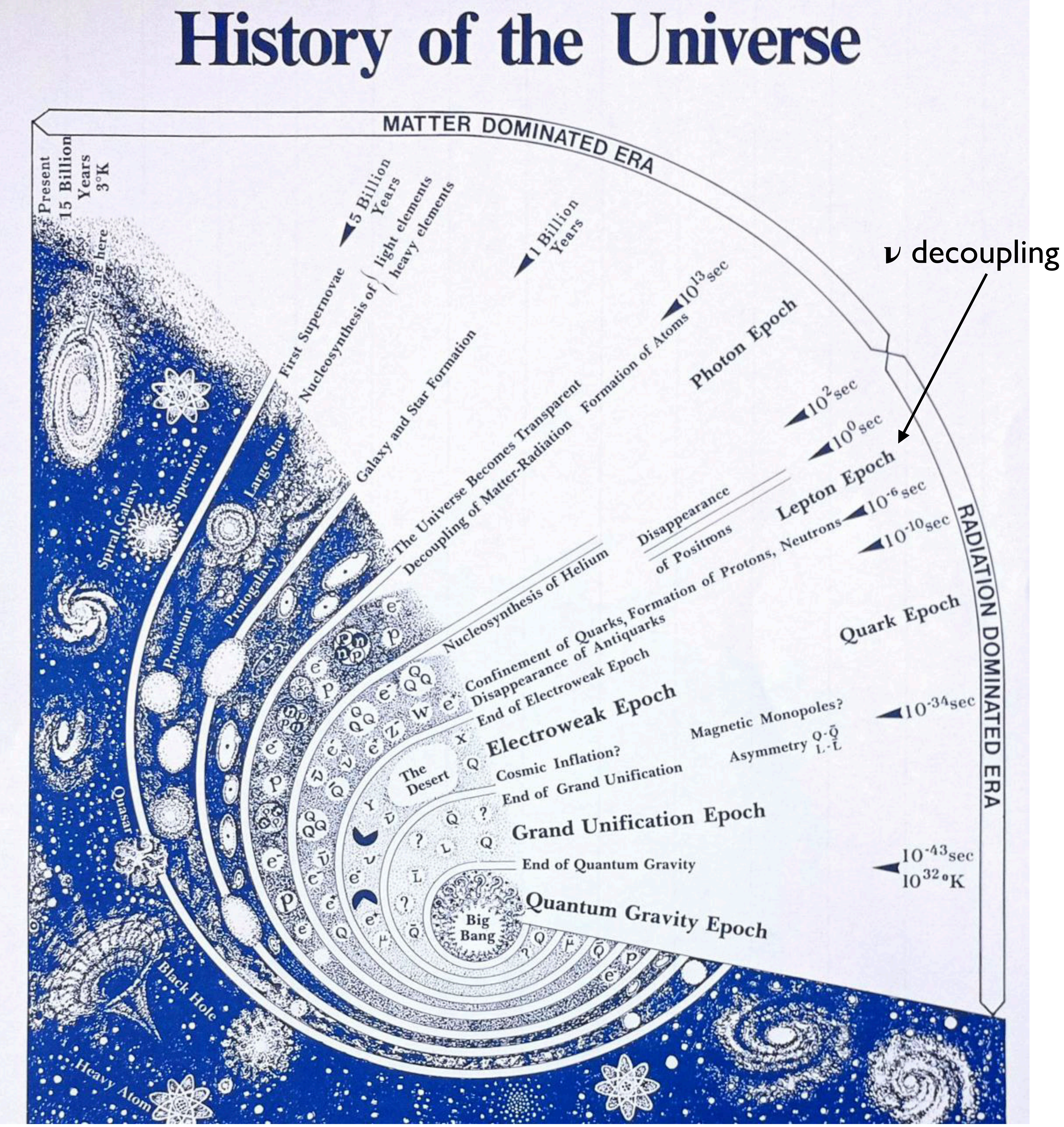
Cosmological neutrinos

Neutrinos created in the early moments of the Big Bang

- Very low-energy neutrinos
- Below detection threshold of current experiments
- Provide a window into the 1st second
- Significant test of standard cosmology
- Absolute mass scale ($m_\nu < 0.8$ eV KATRIN)
- Mass ordering (50 $meV < m_{light} \simeq m_e$ or m_τ)



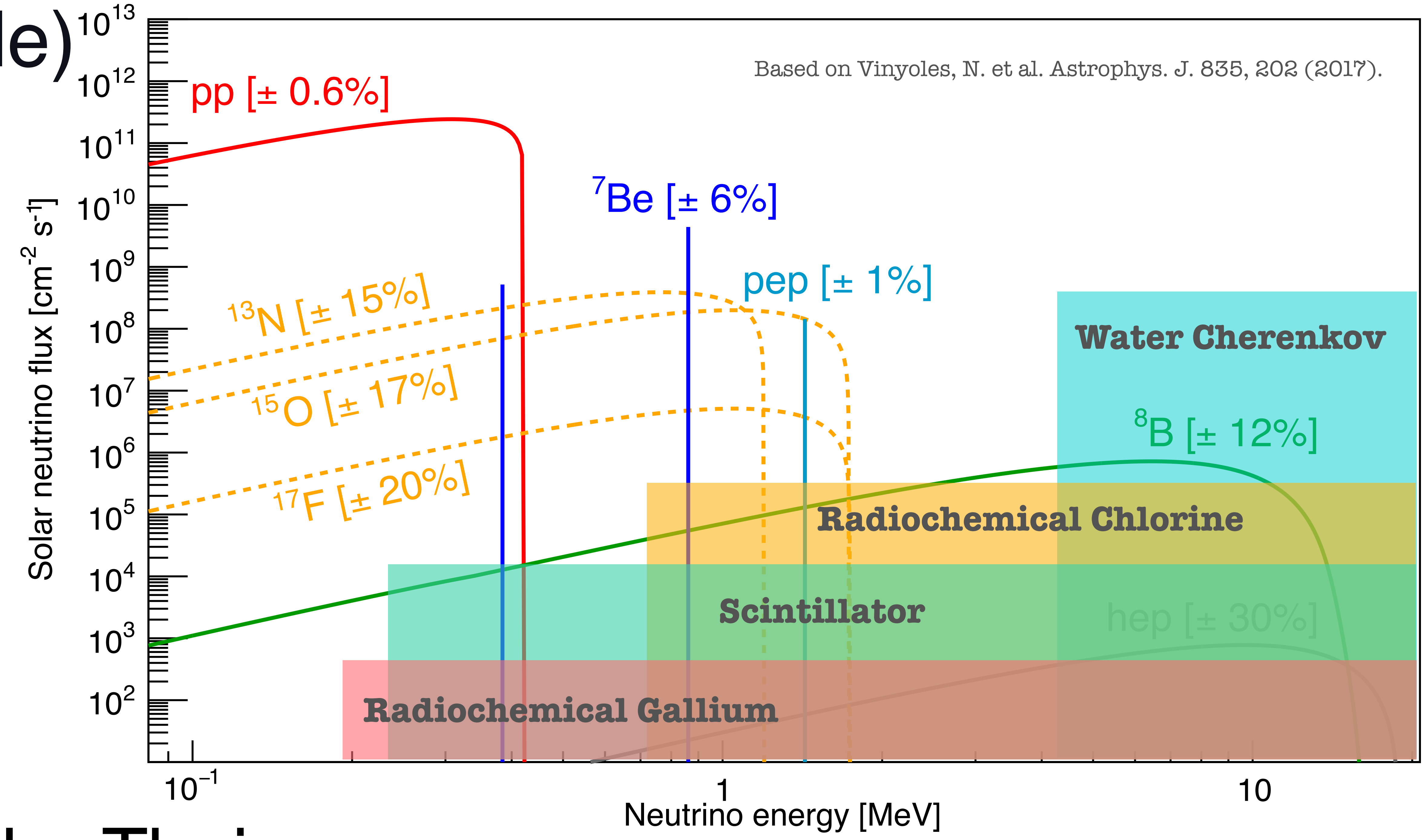
PTOLEMY aims to detect cosmic neutrino background on a long term
The detector prototype at LNGS (distribute atomic tritium on a solid state substrate (e.g. graphene))

Solar neutrinos

$$4p \rightarrow ^4\text{He} + 2e^+ + 2\nu_e$$

Released energy ~26 MeV

- CNO neutrinos (directionality based background rejection, solar metallicity puzzle)
- ^{8}B solar neutrinos high-statistics, low-threshold spectral shape-> new physics in the MSW-vacuum transition region, e.g. sensitivity to non-standard interactions
- Precision low-energy measurements (pp, pep)-> sun luminosity



Experiments: SNO+, Super/Hyper-Kamiokande, Theia

Requirements: Cleanliness, depth,

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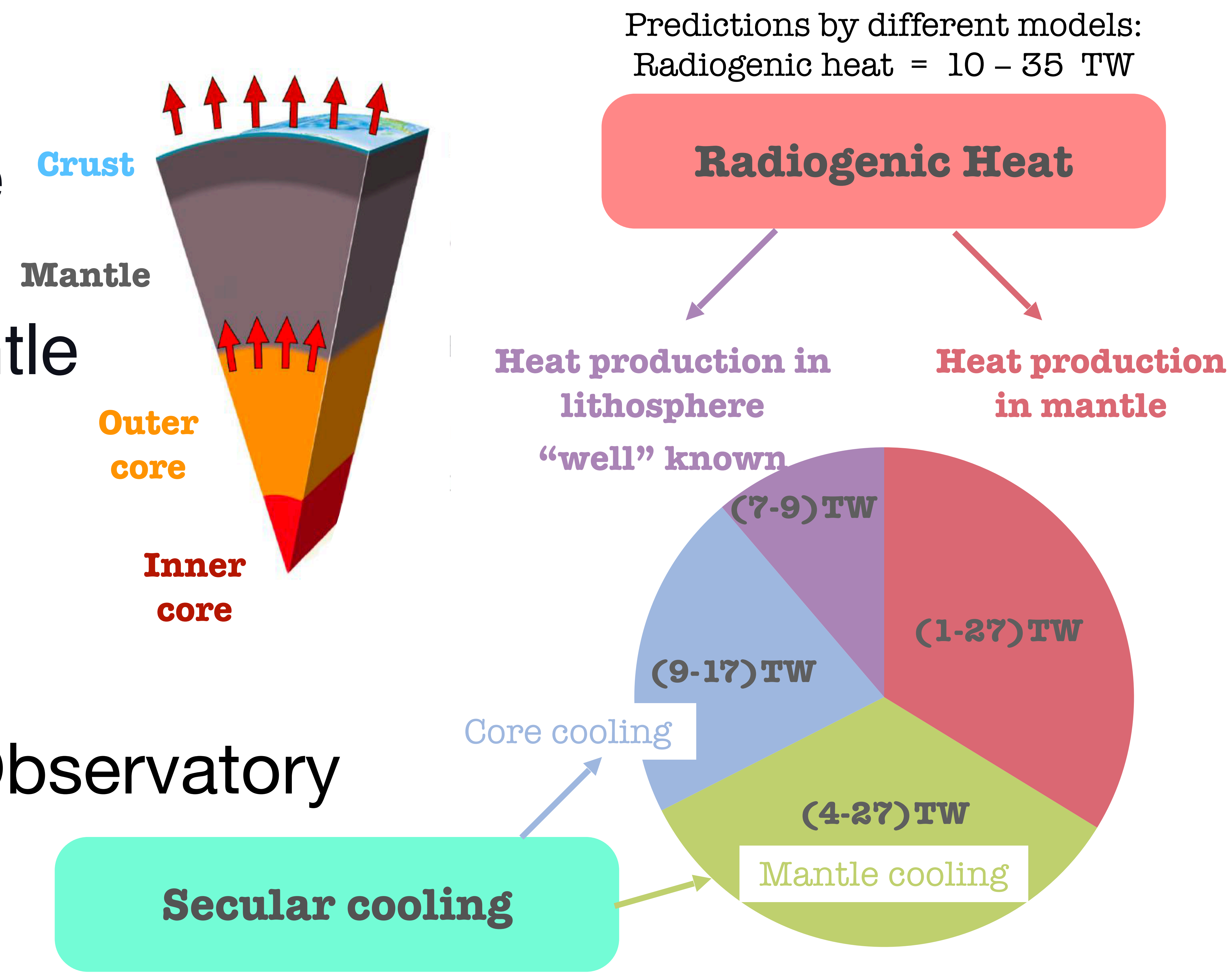
Geoneutrinos

- Only two measurements in the world at the moment
- More locations, more sensitivity to the mantle signal



Experiments: JUNO, Theia, Ocean-Bottom Observatory

Requirements: Depth, low-energy threshold

Supernova Neutrinos

- DSNB neutrinos: Diffuse, isotropic flux of ν from all SN explosions in the Universe. (not yet experimentally observed)

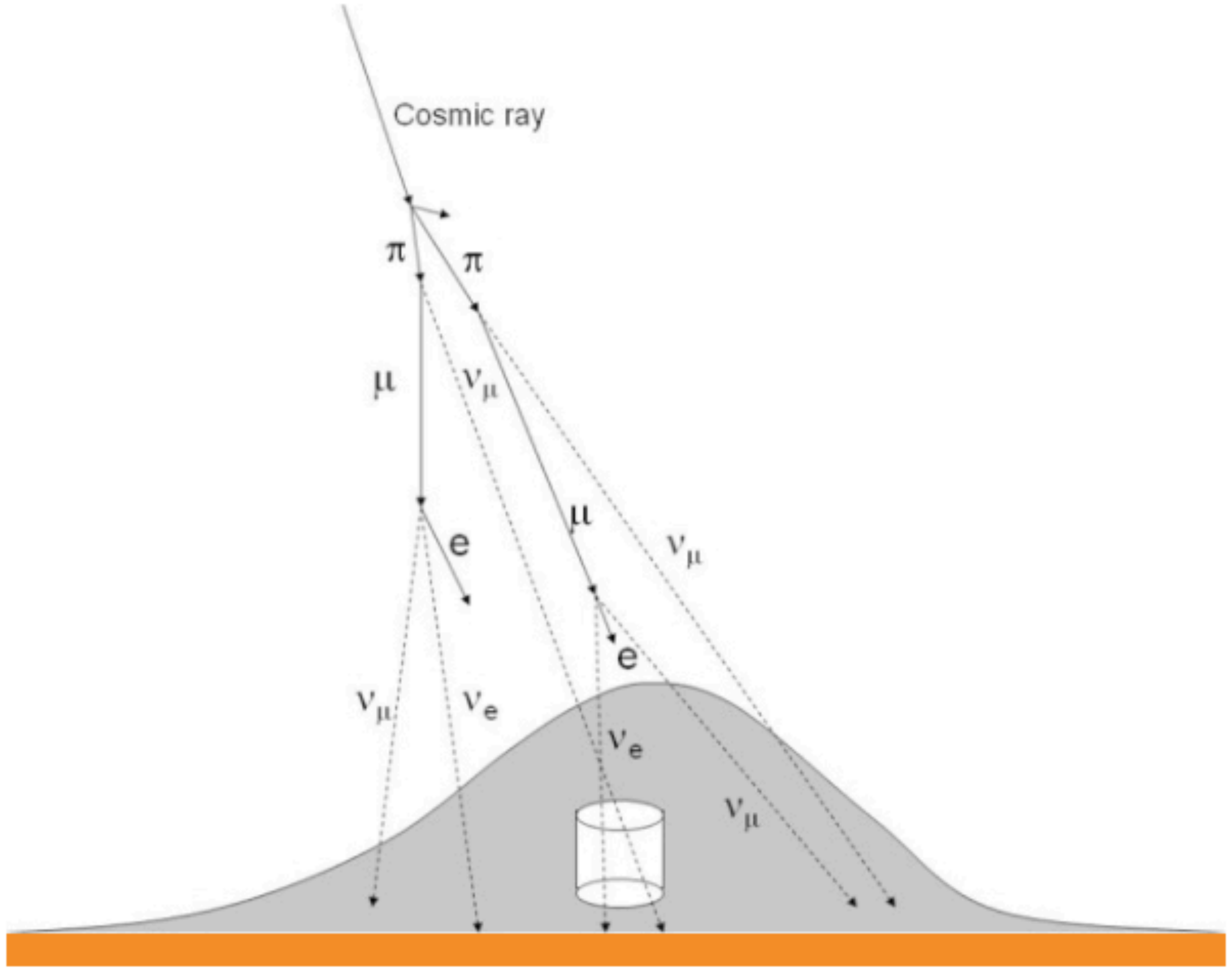
- Supernova burst (only one observed: SN1987A)
- dynamics of the core collapse (neutronization, reheating, proto-neutron star cooling)
- the properties of the neutrinos themselves (mass hierarchy, absolute mass scale, collective oscillations)

Experiments: SNO+, JUNO, Super/Hyper-Kamiokande, Dune, Theia

Requirements: Size

Atmospheric Neutrinos

- Neutrinos produced in cosmic ray showers
- Oscillation parameters
- Tau-neutrino cross sections
- Geotomography



Experiments: JUNO, DUNE, Hyper-K, Theia

Requirements: Depth, size

Extragalactic neutrinos

- The origin of high energy neutrinos and the birthplace of cosmic rays
- The physics of cosmic accelerators: neutrino flavour, energy spectrum, and BSM
- Cosmogenic neutrinos: GZK neutrinos and cosmic ray composition
- Cross sections at high energies

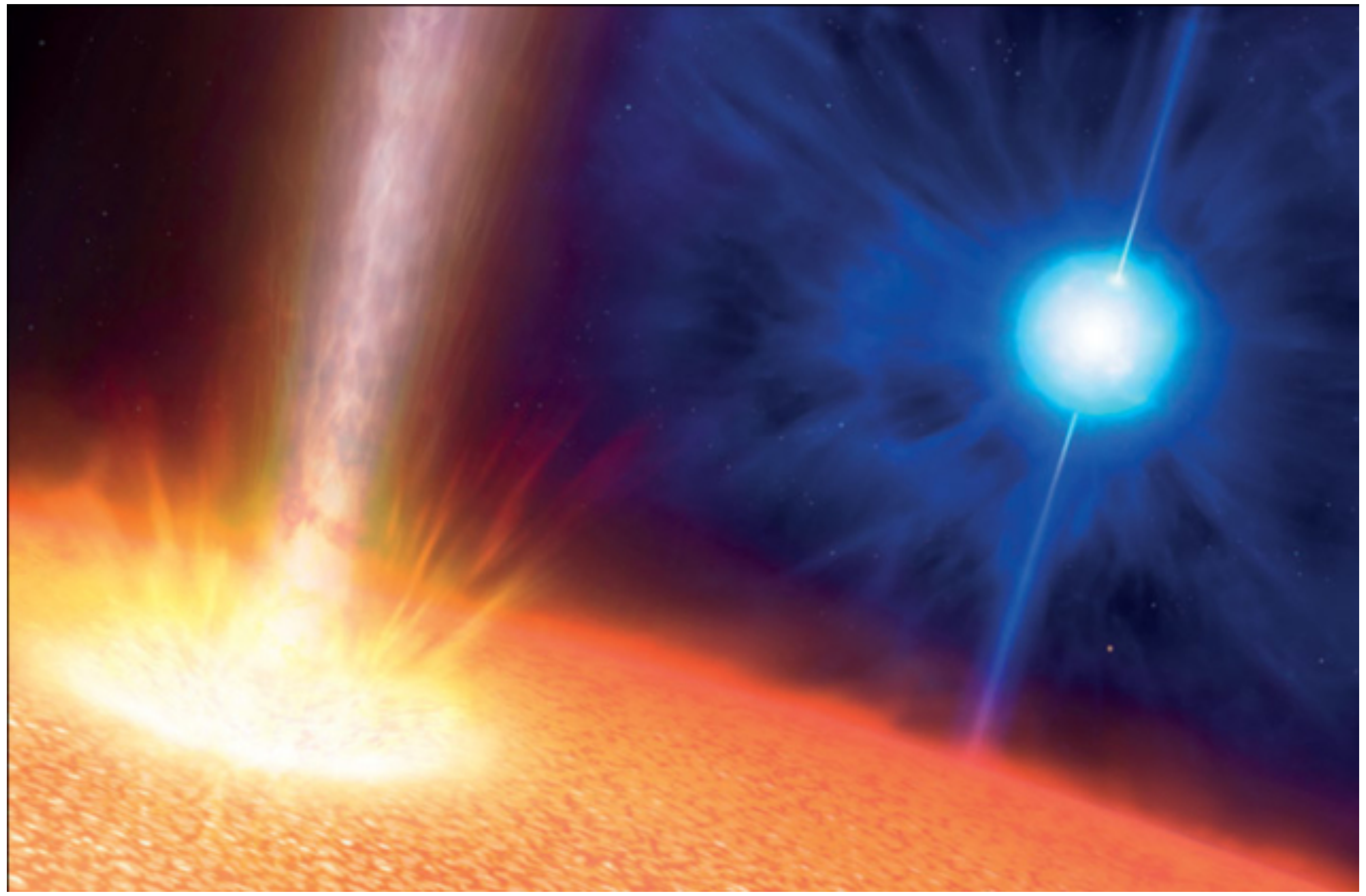
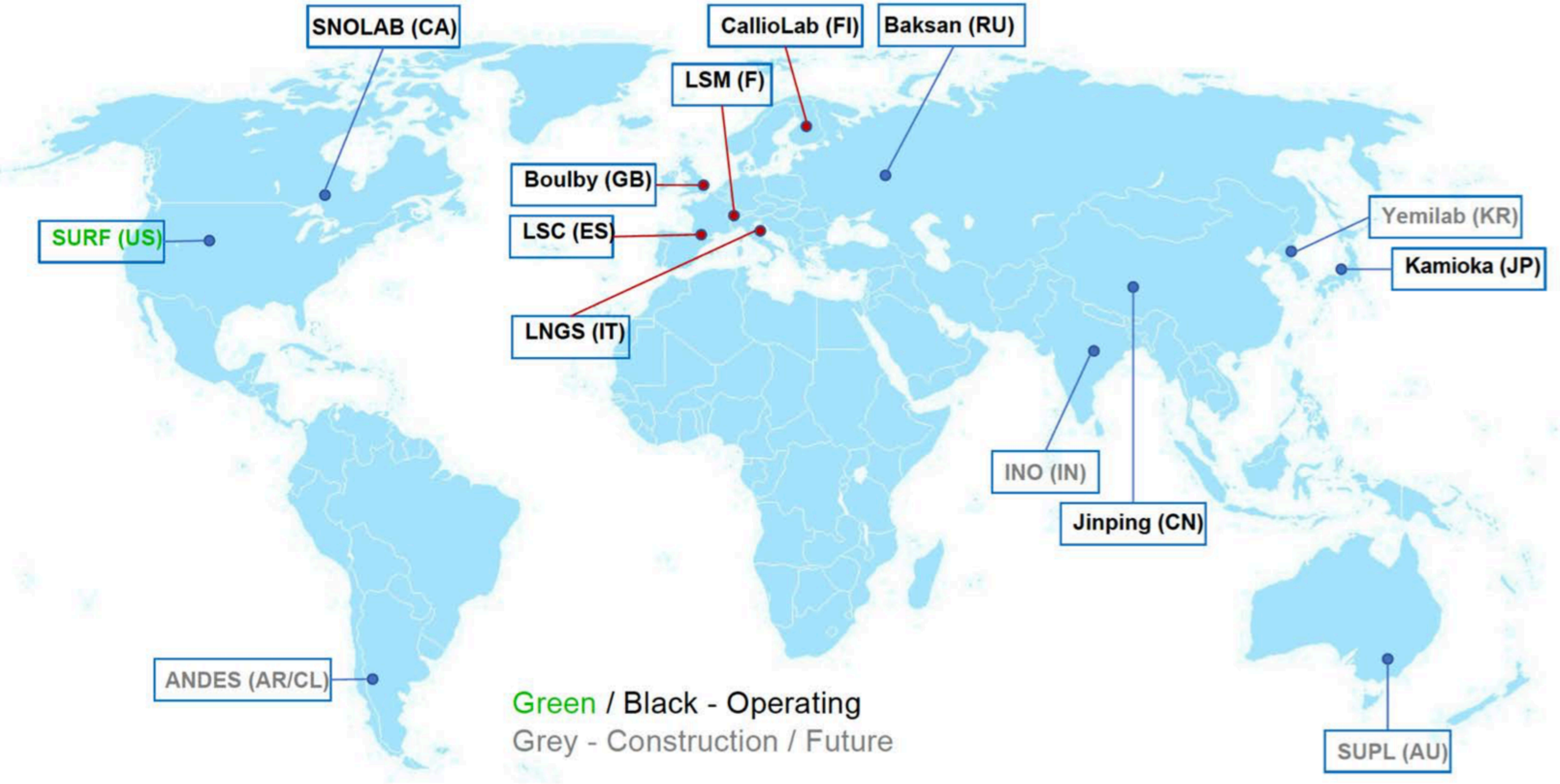


Image credit: Mark A Garlick, University of Warwick.

Experiments: IceCube, Hyper-Kamiokande

Requirement: Very large volume

From where to look



Non underground honorary mentions:

Ice Cube, KM3NET, ANTARES, Ocean Bottom Detector

Credit: C.J Virtue A Tour of International Underground Facilities & Science: Today and Tomorrow

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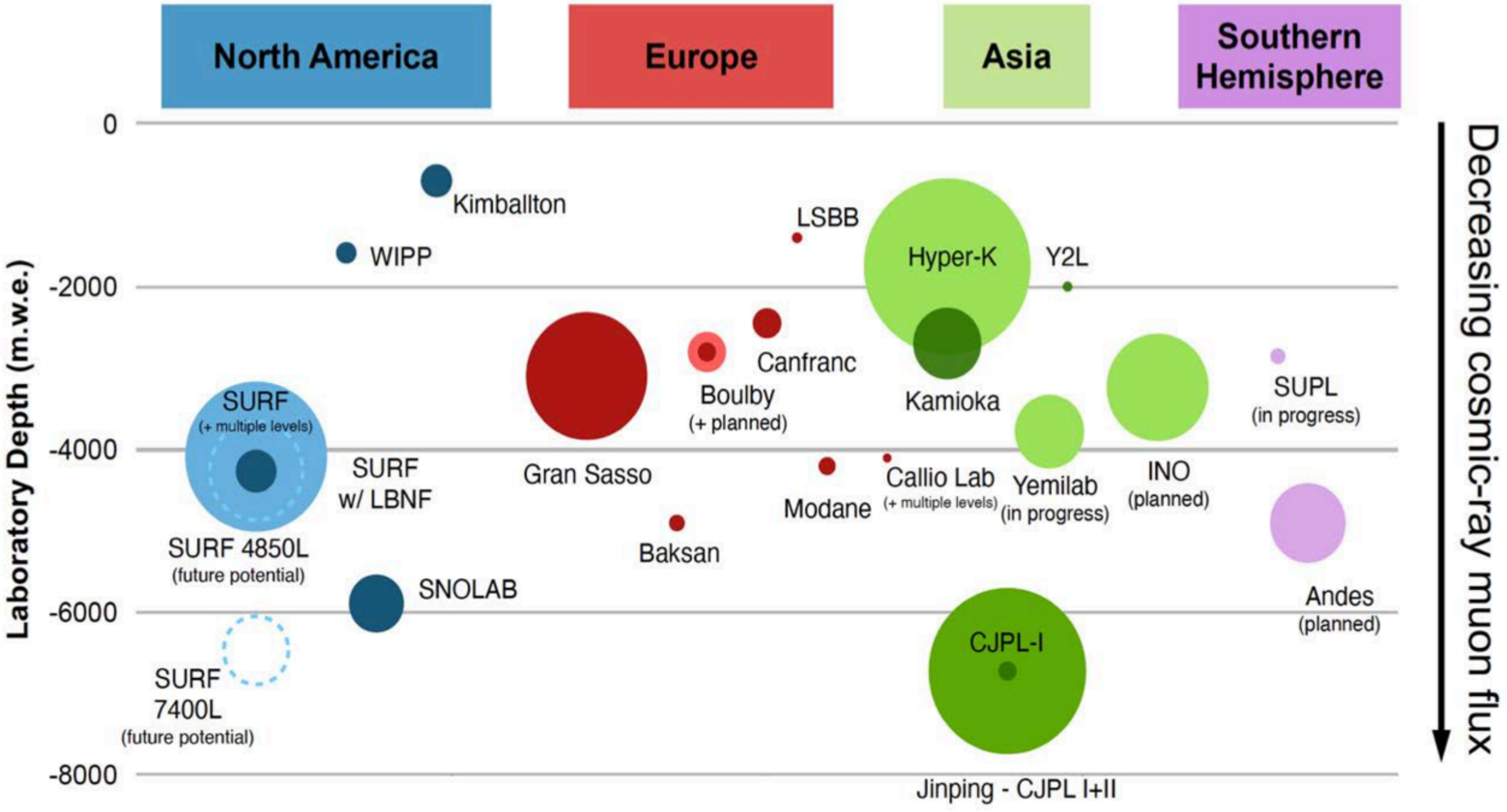
The effect of depth



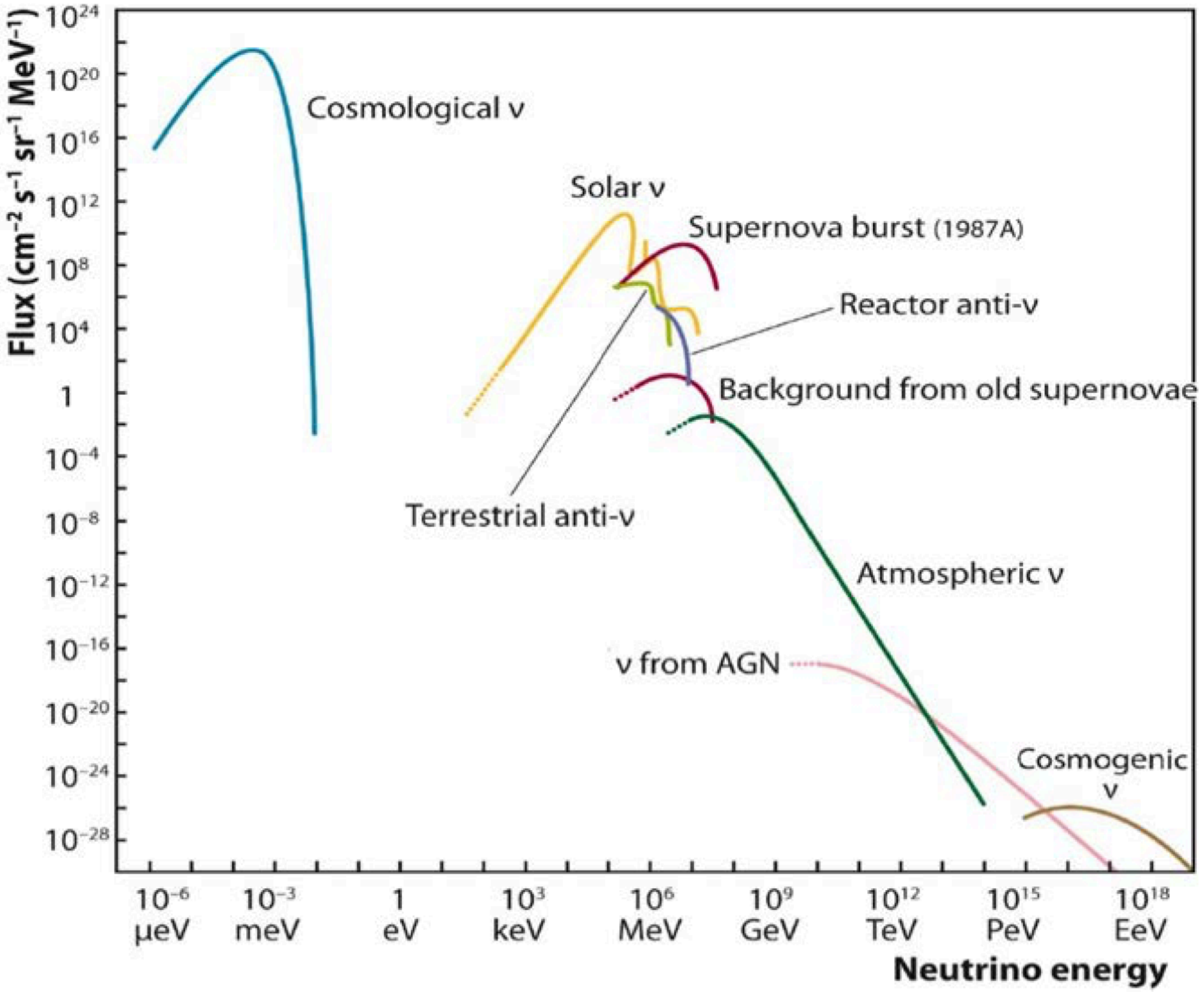
Note: Circles represent volume of science space

Frontrunners: Jinping, SNOLAB

Decreased muon flux-> reduced neutron flux

Important for solar, geo

The effect of volume



Frontrunners: SURF, Hyper-K

Important for atmospheric, supernova, extragalactic neutrinos

Accessing more rare events, high precision measurements -> more opportunities

Cleanliness: Surroundings and the target

Frontrunners: LNGS

Borexino: 10^{-19} g/g of both ^{232}Th and ^{238}U, landmark in liquid scintillator detectors

Current/upcoming LS: JUNO, SNO+

Current/upcoming Water: Super-K, Hyper-K

Hybrid: Jinping, THEIA

Liquid argon: DUNE

Other thoughts:

Options for Isotopic loading, e.g. ^{7}Li for solars , Gd for neutron capture

Solid-state experiments and Noble liquid (XENONnT), e.g. no intrinsic C14 background

Need of different locations & different approaches

Probing the different locations of geoneutrino flux

Combined studies of astrophysical events

High-statistics co-detection of neutrinos and antineutrinos with different targets

Opposite sides of the Earth -> Earth matter effects

Conclusions

- Broad physics program, many opportunities for first-time observations, and precise neutrino property measurements with natural sources neutrinos
- Rich variety in underground laboratories around the world
- Increasing available experiment space
- Control/Reducing the radon levels
- Using the existing know-how, expanding to the new approaches.