Neutrino Astrophysics

Ryan Nichol

UK Input to
European Strategy

Neutrino Astrophysics

Ryan Nichol

UK Input to
European Strategy

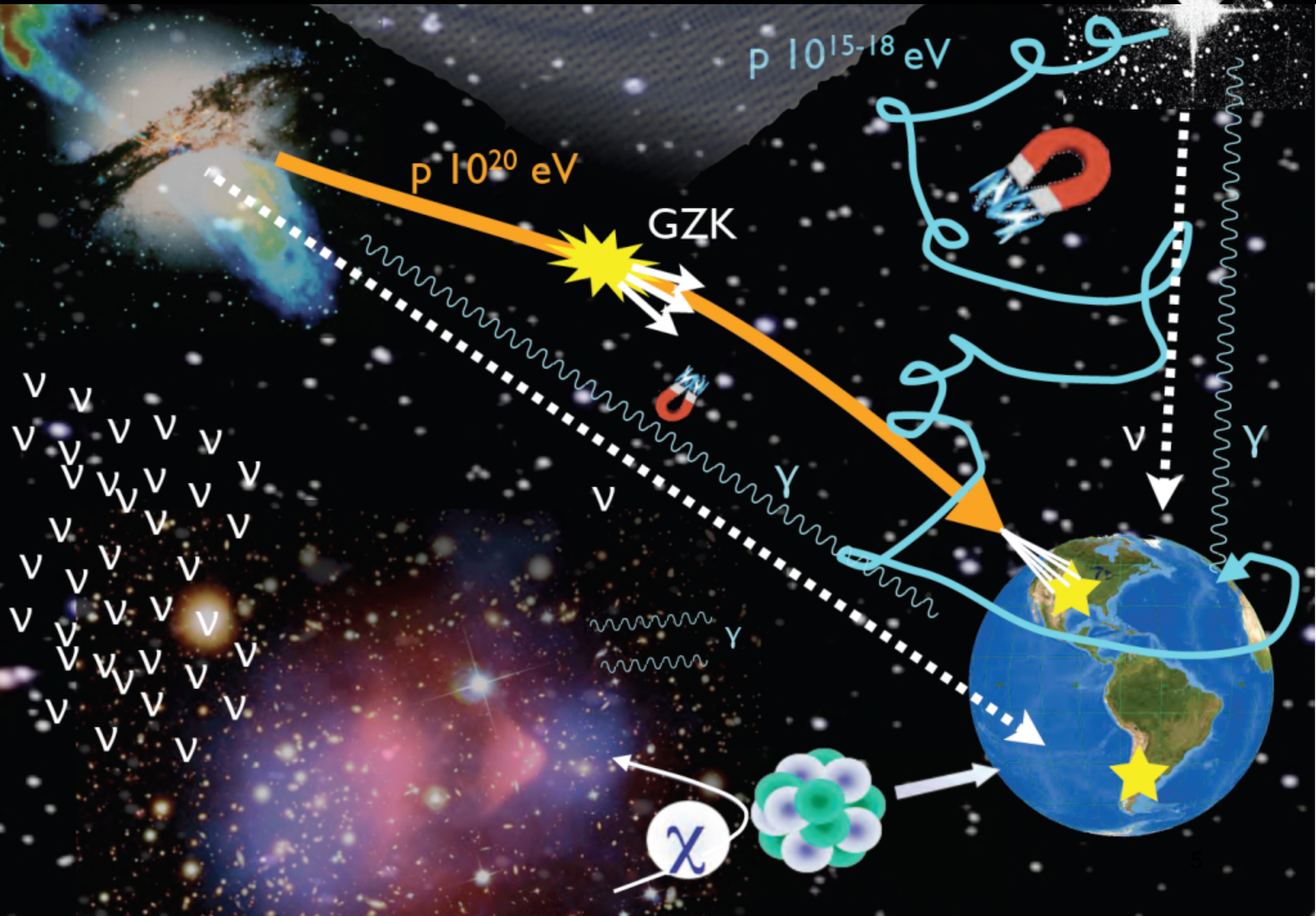
Highly cited papers

- Higgs Discovery (2012)
  - 8000+ citations
- Atmospheric neutrino oscillations (1998)
  - 5000+ citations
- Top quark discovery (1995)
  - 3000+ citations
- Solar neutrino oscillations (2002)
  - 3000+ citations
- Kaon CP violations (1964)
  - 3000+ citations
- Reactor antineutrino [KamLAND] (2003)
  - 2000+ citations
- Gravitational Waves (2016)
  - 2000+ citations
- c-quark discovery (1974)
  - 2000+ citations
- Solar neutrino [Homestake] (1968-1998)
  - 2000+
- Z discovery (1983)
  - 2000+
- Positron excess [PAMELA] (2008)
  - 1900+
- Reactor neutrino theta_13 (2012)
  - 1900+
- b-quark discovery (1977)
  - 1900+
- W-discovery (1983)
  - 1800+
- Z width (2005)
  - 1700+
- Proton spin crisis (1989)
  - 1700+
- LSND anomaly (2001)
  - 1700+
- Parity non conservation (1957)
  - 1600+
- LUX Dark Matter (2013)
  - 1500+
- g-2 (2006)
  - 1500+
- SN1987a neutrinos (1987)
  - 1500+
- Weak neutral current (1973)
  - 1500+
- Charmomium (2003)
  - 1400+
- B-Bbar oscillation (1987)
  - 1300+
- nu_mu -> nu_e (2011)
  - 1300+
- Accelerator neutrino oscillation (2002)
  - 1100+
- Muon neutrino discovery (1962)
  - 1100+
- DAMA/Libra (2008-)
  - 1000+
- Pentaquark [LEPS] (2003)
  - 1000+
- Neutron EDM (2006)

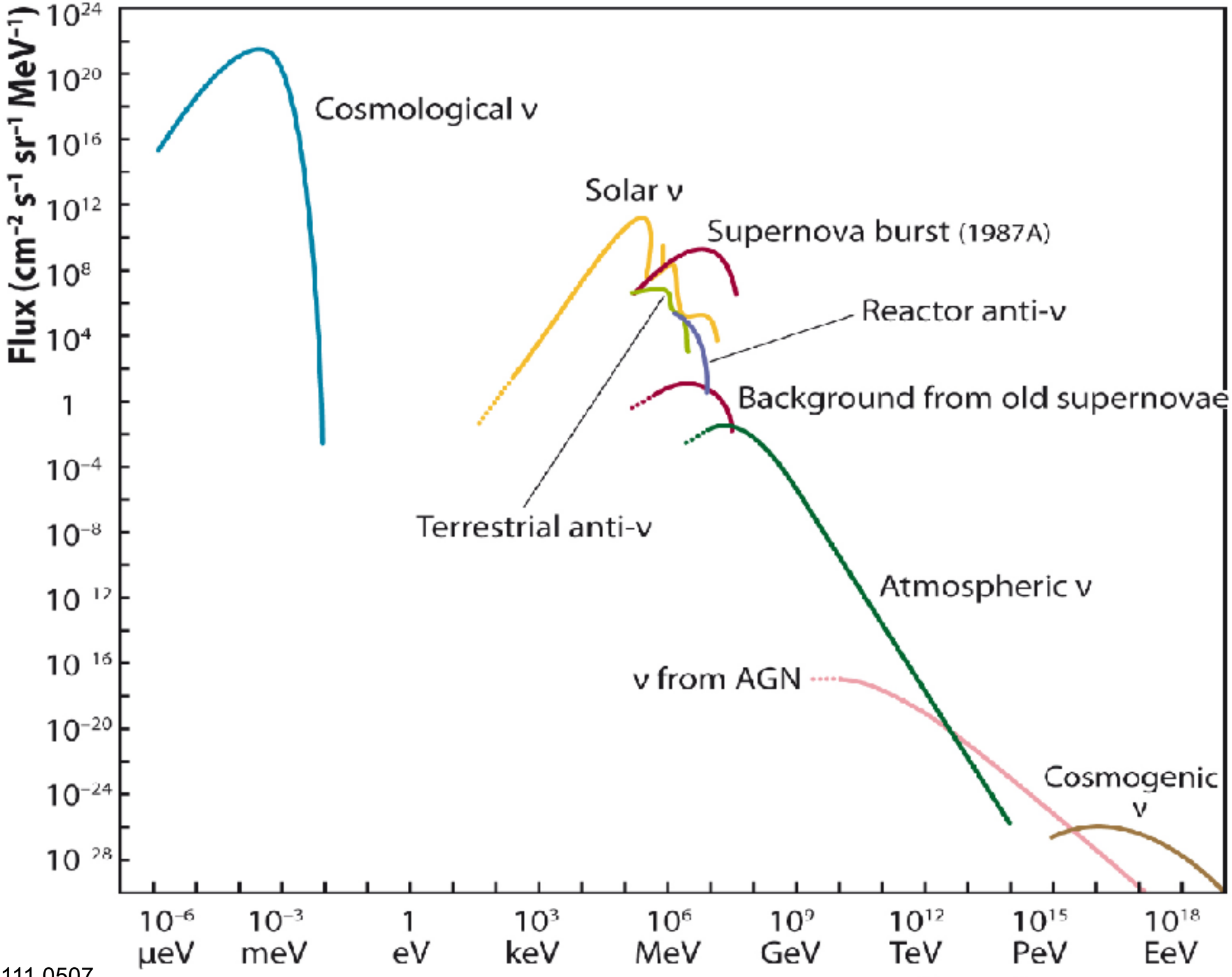
Highly cited papers

- Higgs Discovery (2012)
  - 8000+ citations
- Atmospheric neutrino oscillations (1998)
  - 5000+ citations
- Top quark discovery (1995)
  - 3000+ citations
- Solar neutrino oscillations (2002)
  - 3000+ citations
- Kaon CP violations (1964)
  - 3000+ citations
- Reactor antineutrino [KamLAND] (2003)
  - 2000+ citations
- Gravitational Waves (2016)
  - 2000+ citations
- c-quark discovery (1974)
  - 2000+ citations
- Solar neutrino [Homestake] (1968-1998)
  - 2000+
- Z discovery (1983)
  - 2000+
- Positron excess [PAMELA] (2008)
  - 1900+
- Reactor neutrino theta_13 (2012)
  - 1900+
- b-quark discovery (1977)
  - 1900+
- W-discovery (1983)
  - 1800+
- Z width (2005)
  - 1700+
- Proton spin crisis (1989)
  - 1700+
- LSND anomaly (2001)
  - 1700+
- Parity non conservation (1957)
  - 1600+
- LUX Dark Matter (2013)
  - 1500+
- g-2 (2006)
  - 1500+
- SN1987a neutrinos (1987)
  - 1500+
- Weak neutral current (1973)
  - 1500+
- Charmomium (2003)
  - 1400+
- B-Bbar oscillation (1987)
  - 1300+
- nu_mu -> nu_e (2011)
  - 1300+
- Accelerator neutrino oscillation (2002)
  - 1100+
- Muon neutrino discovery (1962)
  - 1100+
- DAMA/Libra (2008-)
  - 1000+
- Pentaquark [LEPS] (2003)
  - 1000+
- Neutron EDM (2006)
  - 1000+

Big Picture (from Johannes Blümer)

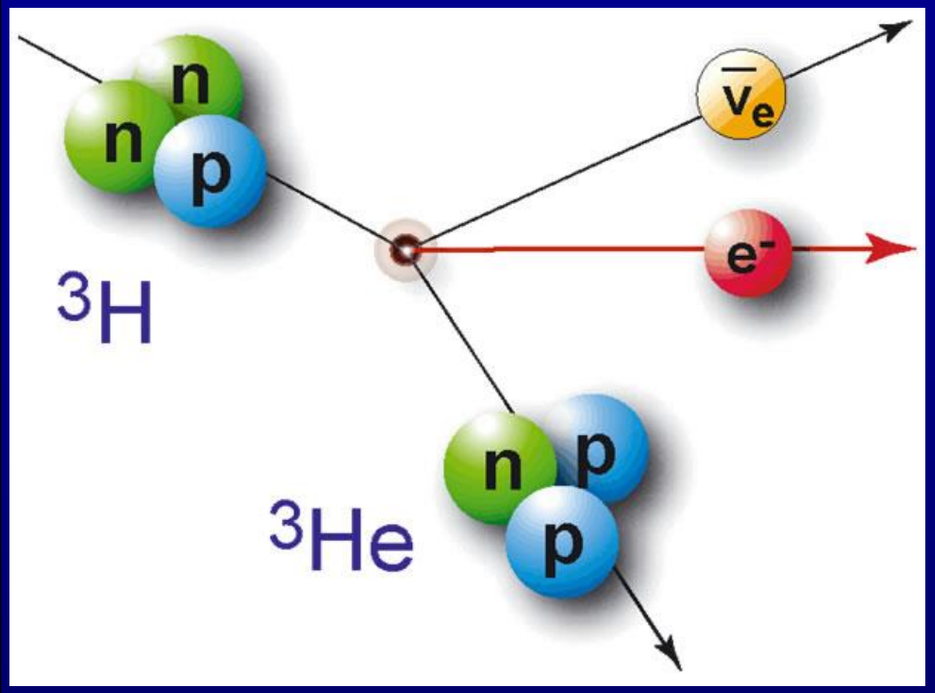


Neutrino Universe



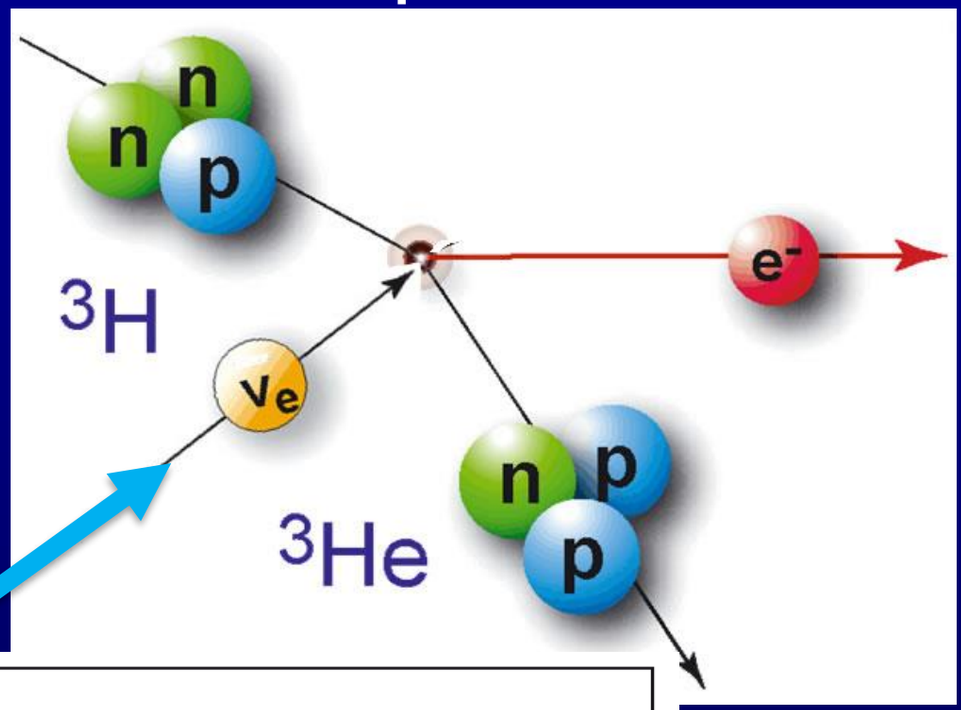
arXiv:1111.0507

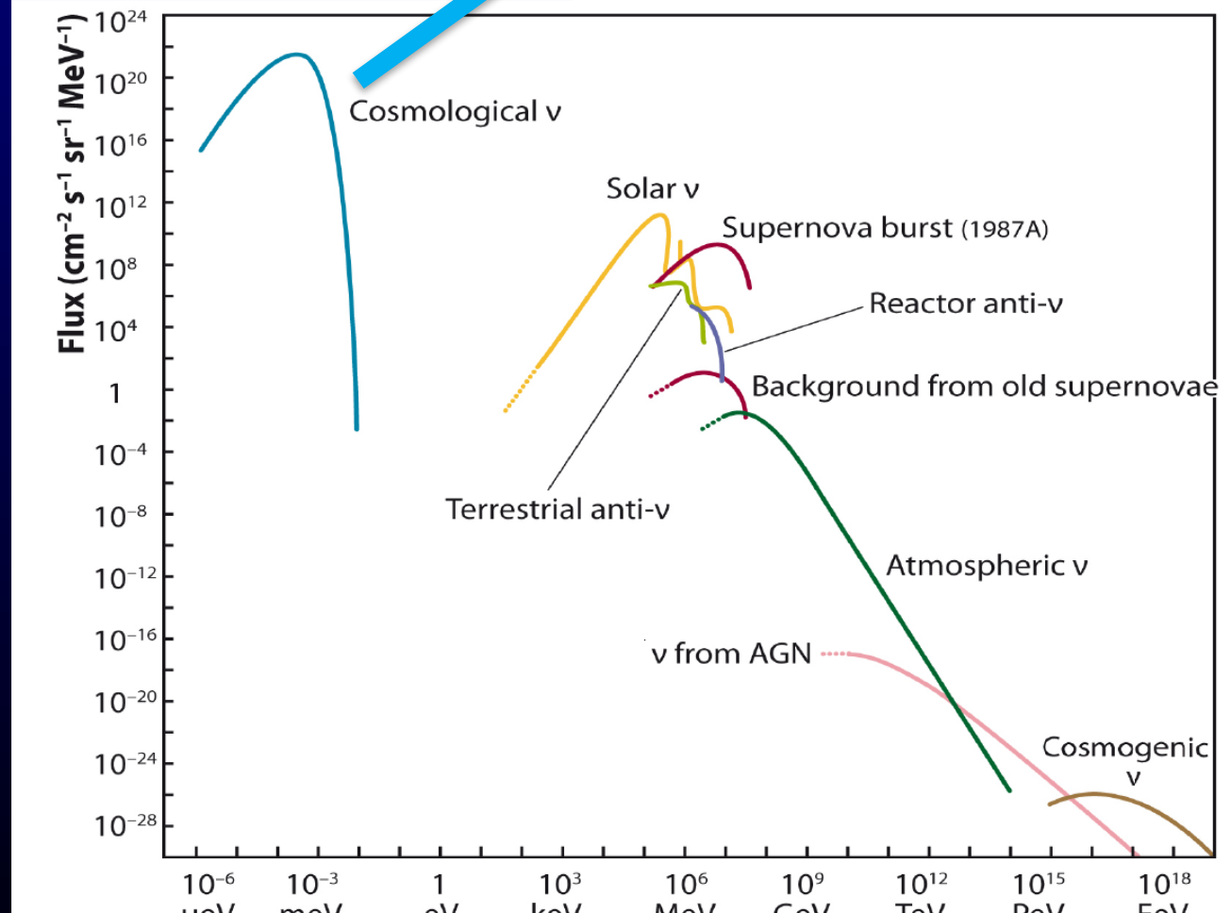
Tritium β-decay and Neutrino Capture



Tritium β-decay
(12.3 yr half-life)

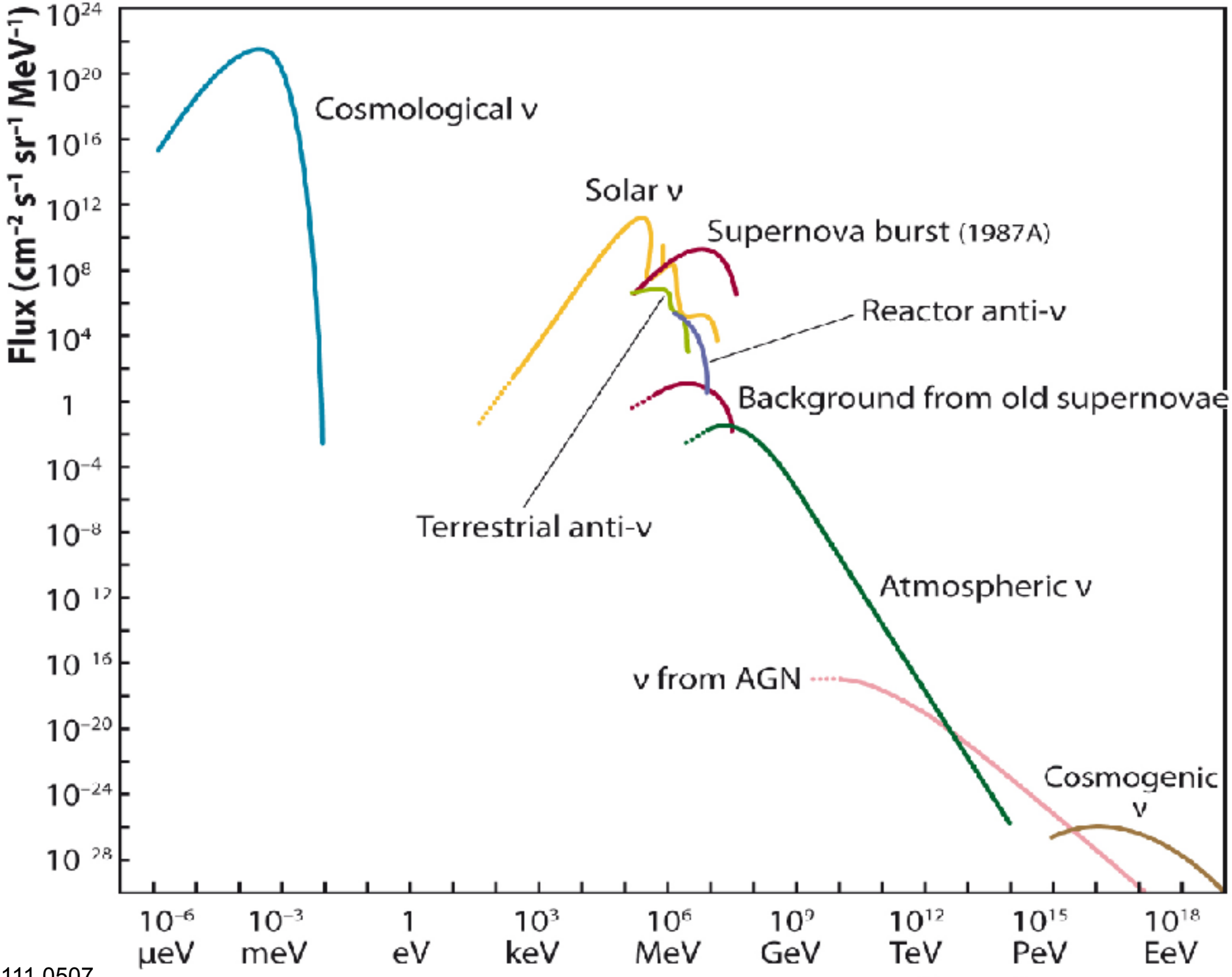
Neutrino capture on Tritium





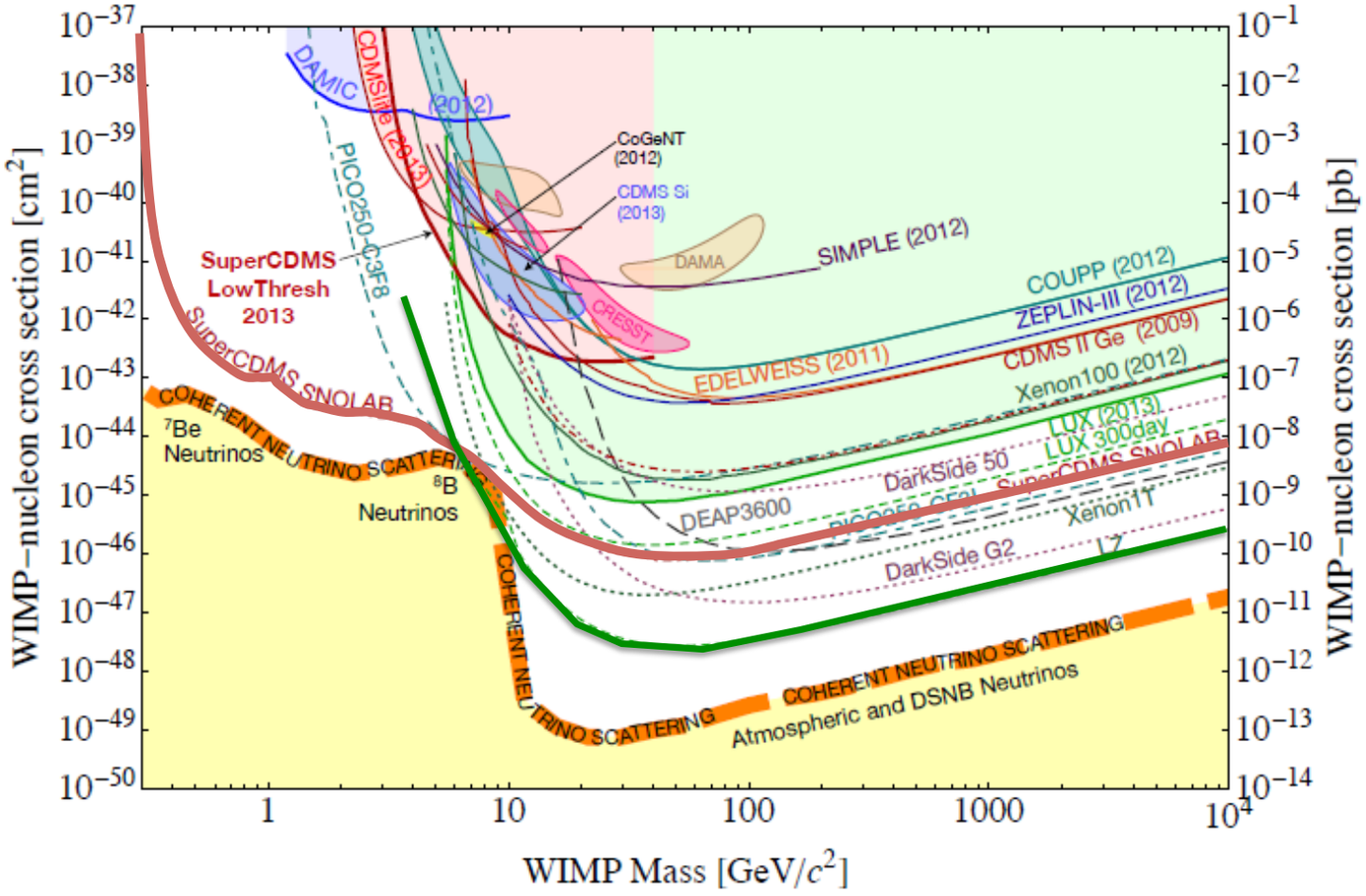
PTOLEMY, Chris Tully
https://indico.cern.ch/event/640340

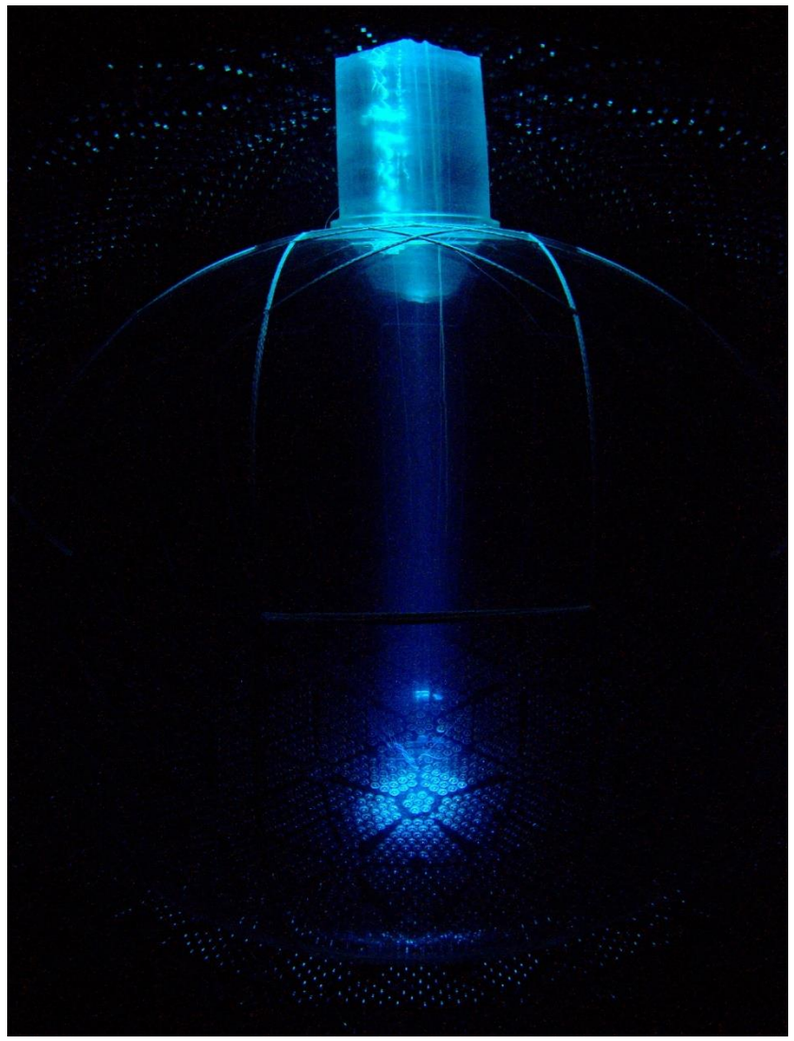
Neutrino Universe



arXiv:1111.0507

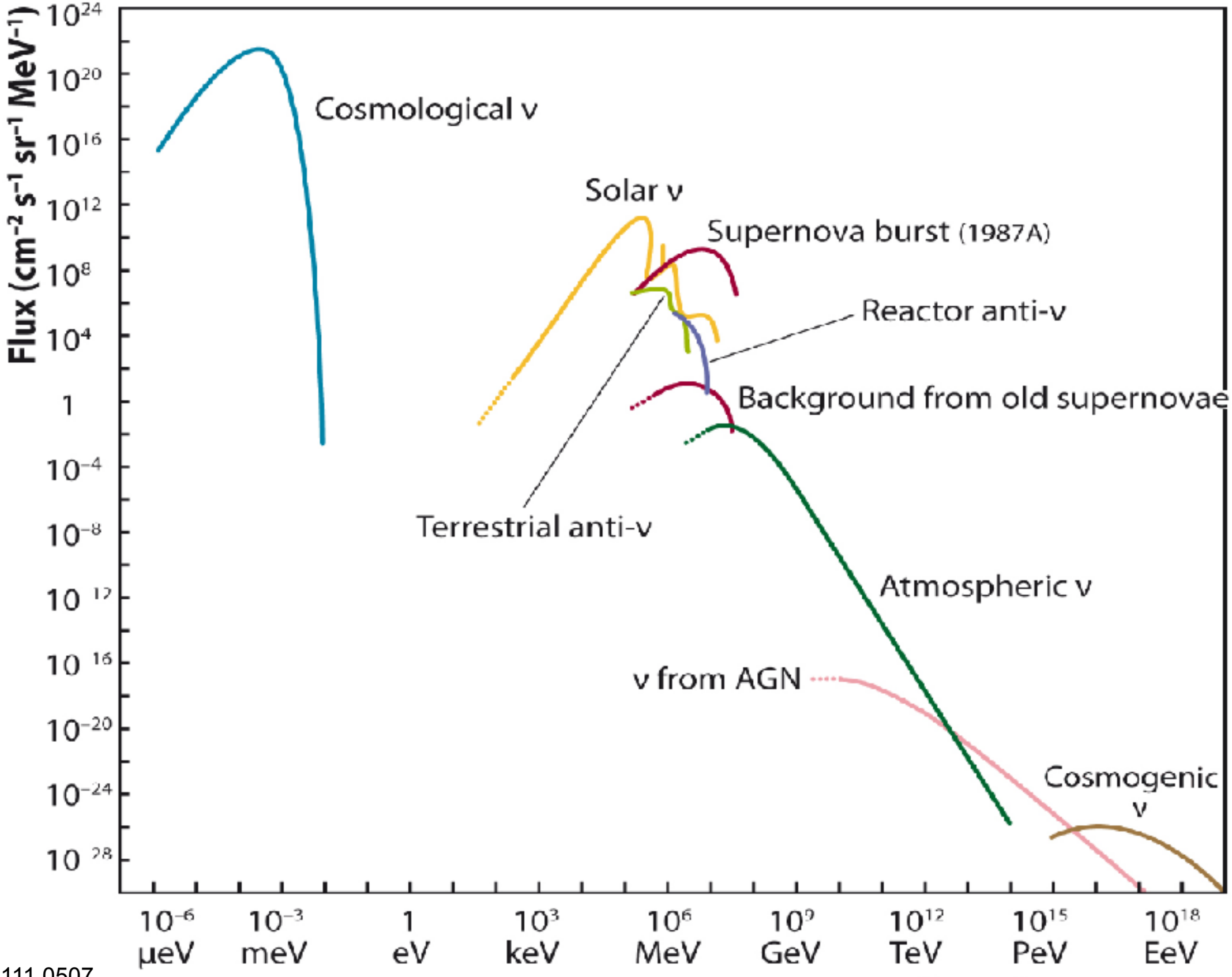
Solar Neutrinos





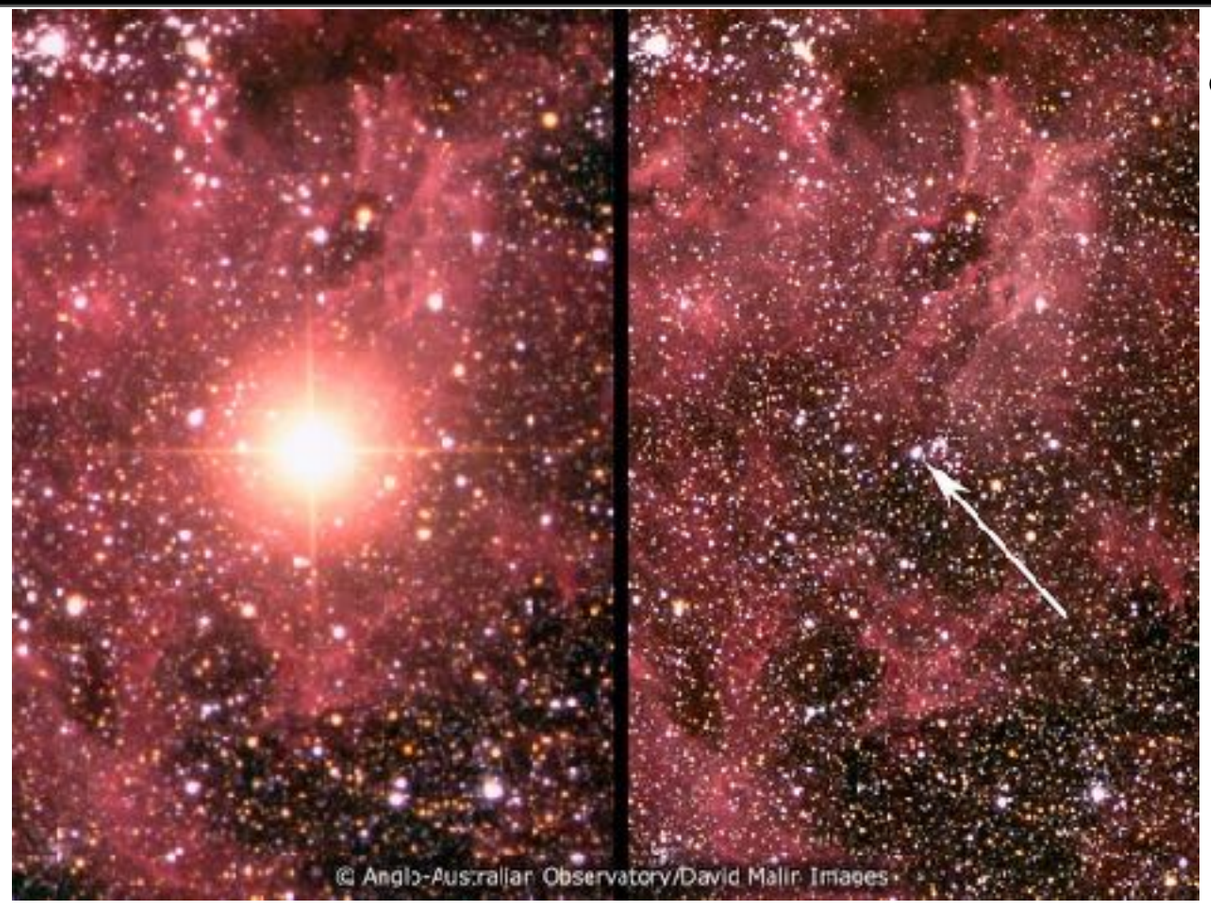
HYPER K

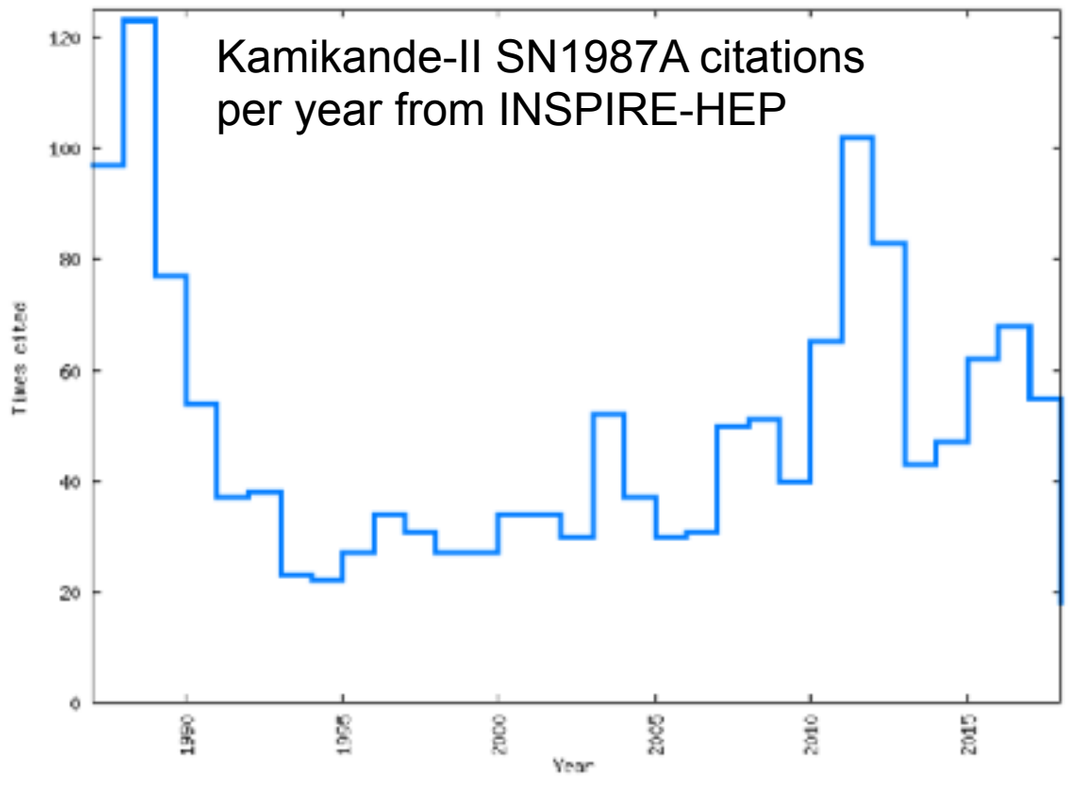
Neutrino Universe



arXiv:1111.0507

Aside: Super Nova Neutrinos

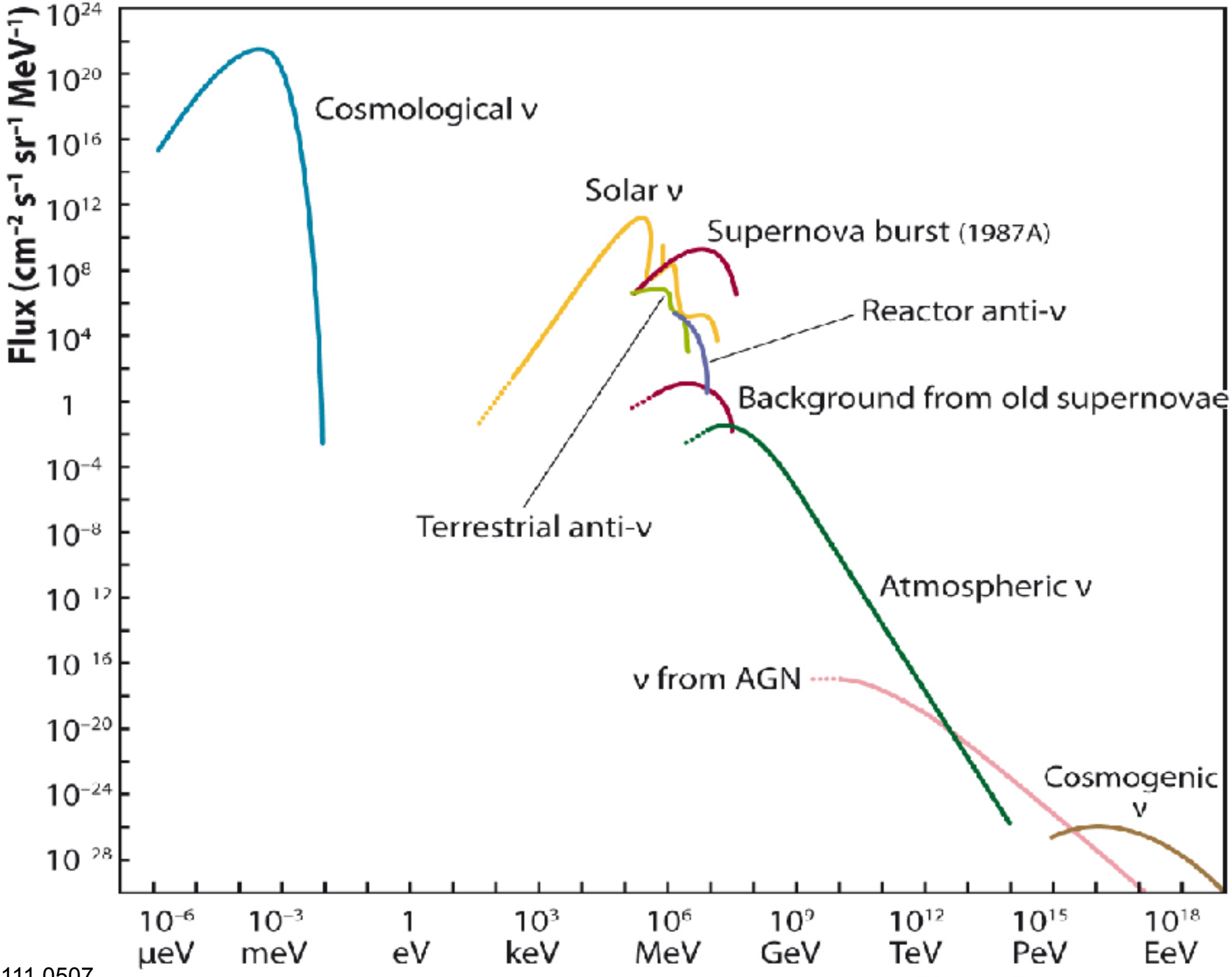




* before 2011, excluding solar

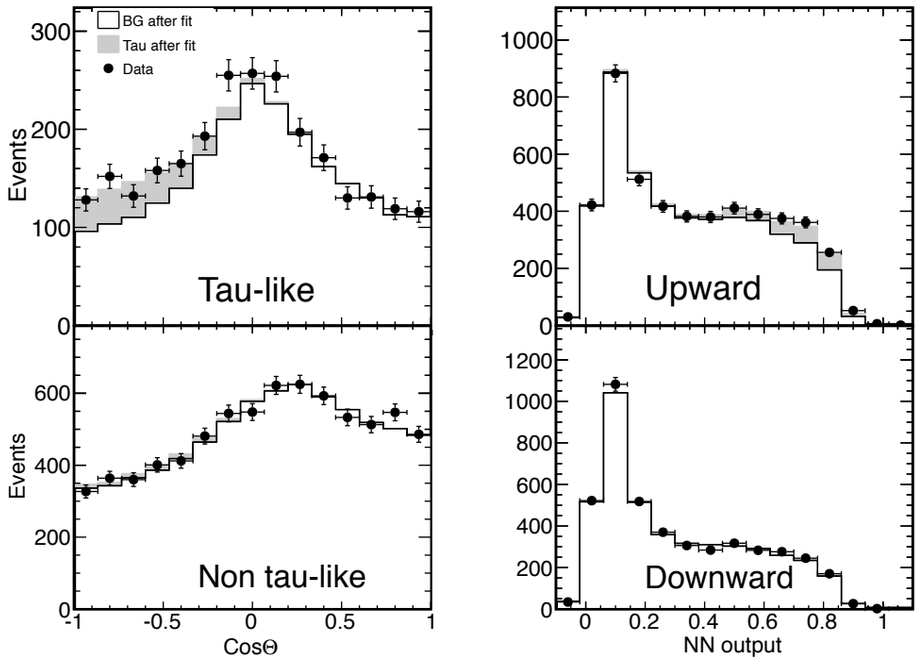
- SN1987A
  - 24 neutrino events detected by Kamikande-II, IMB and Baksan
  - Learned about
    - Supernova collapse mechanisms
    - Neutrinos feel gravity (similarly to photons)
    - Neutrino mass < 23eV from time of flight dispersion
    - Neutrinos are not charged
    - Limits on non-neutrino weakly interacting particles
    - Axion bounds
    - Neutrino mixing and oscillations
    - Exotic neutrino disappearance

Neutrino Universe

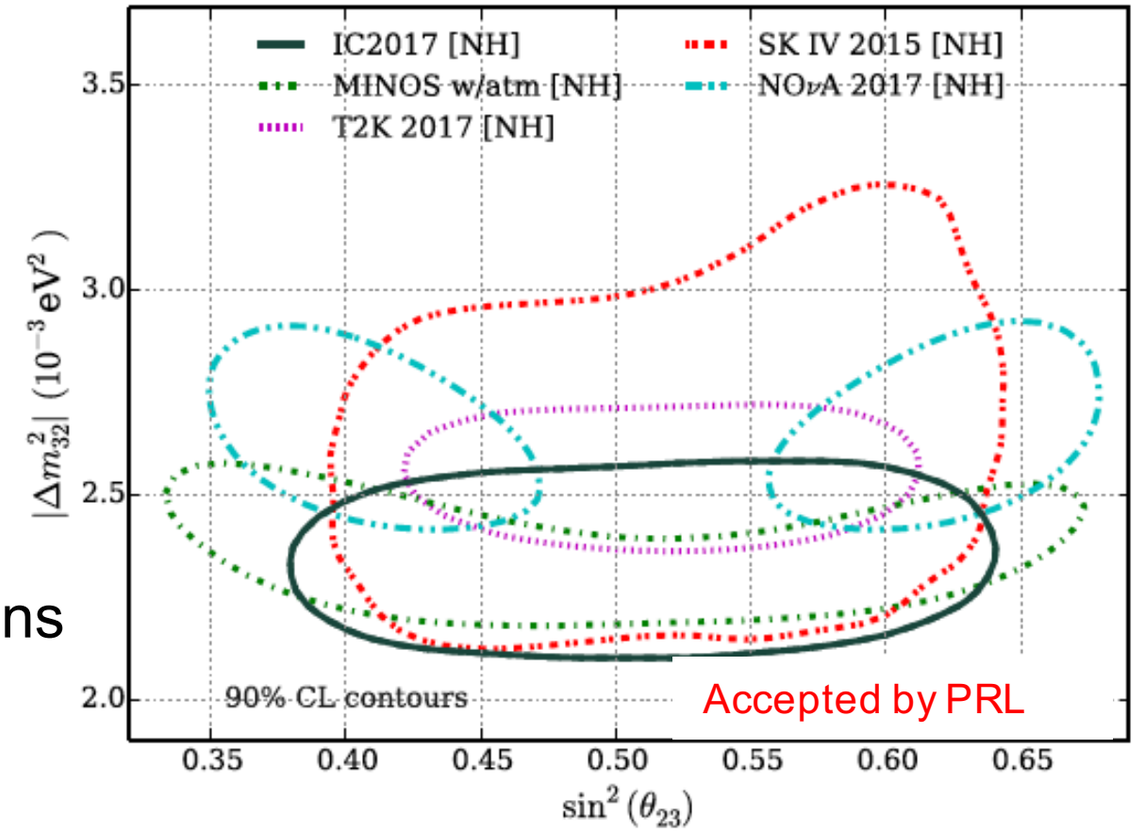


arXiv:1111.0507

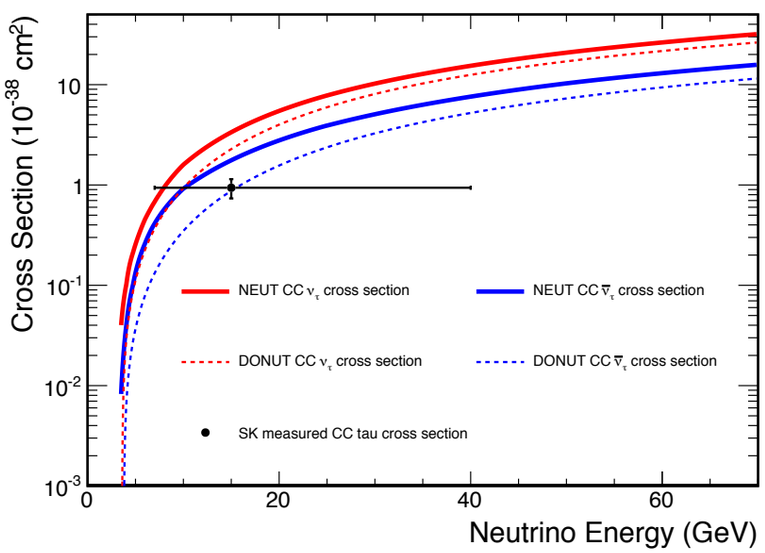
Atmospheric Neutrinos

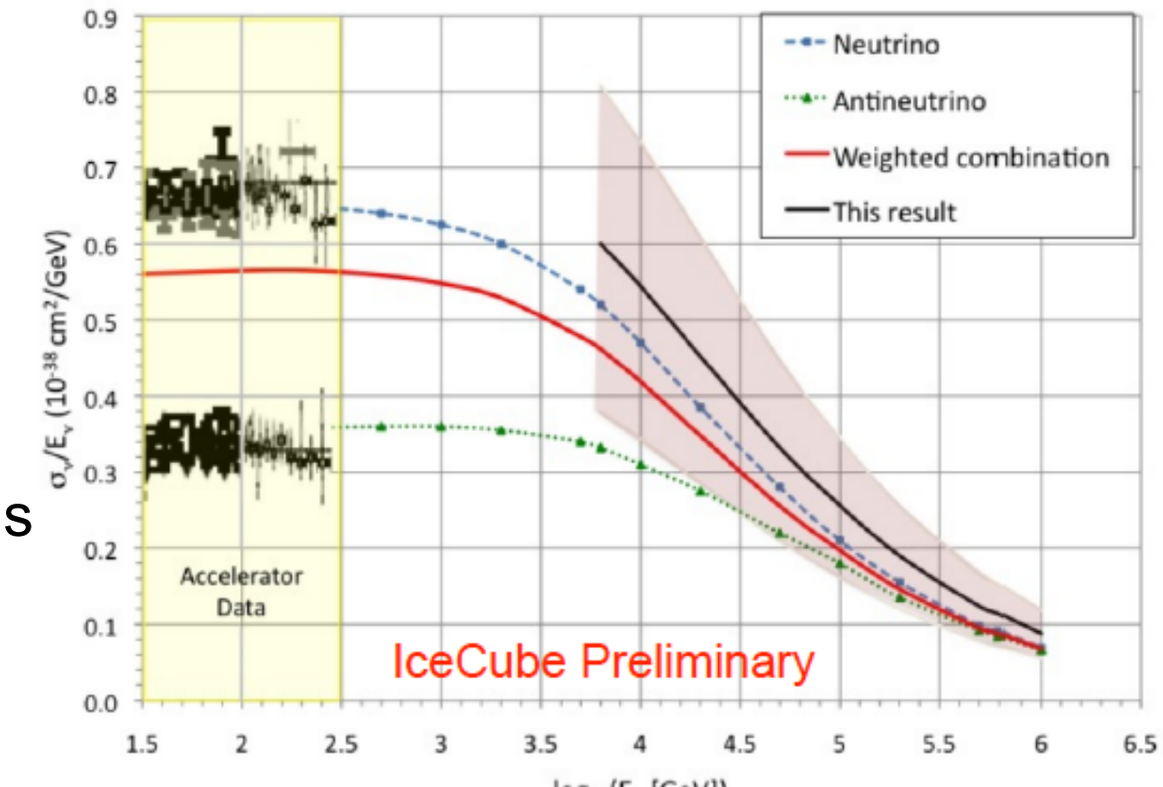


Oscillations

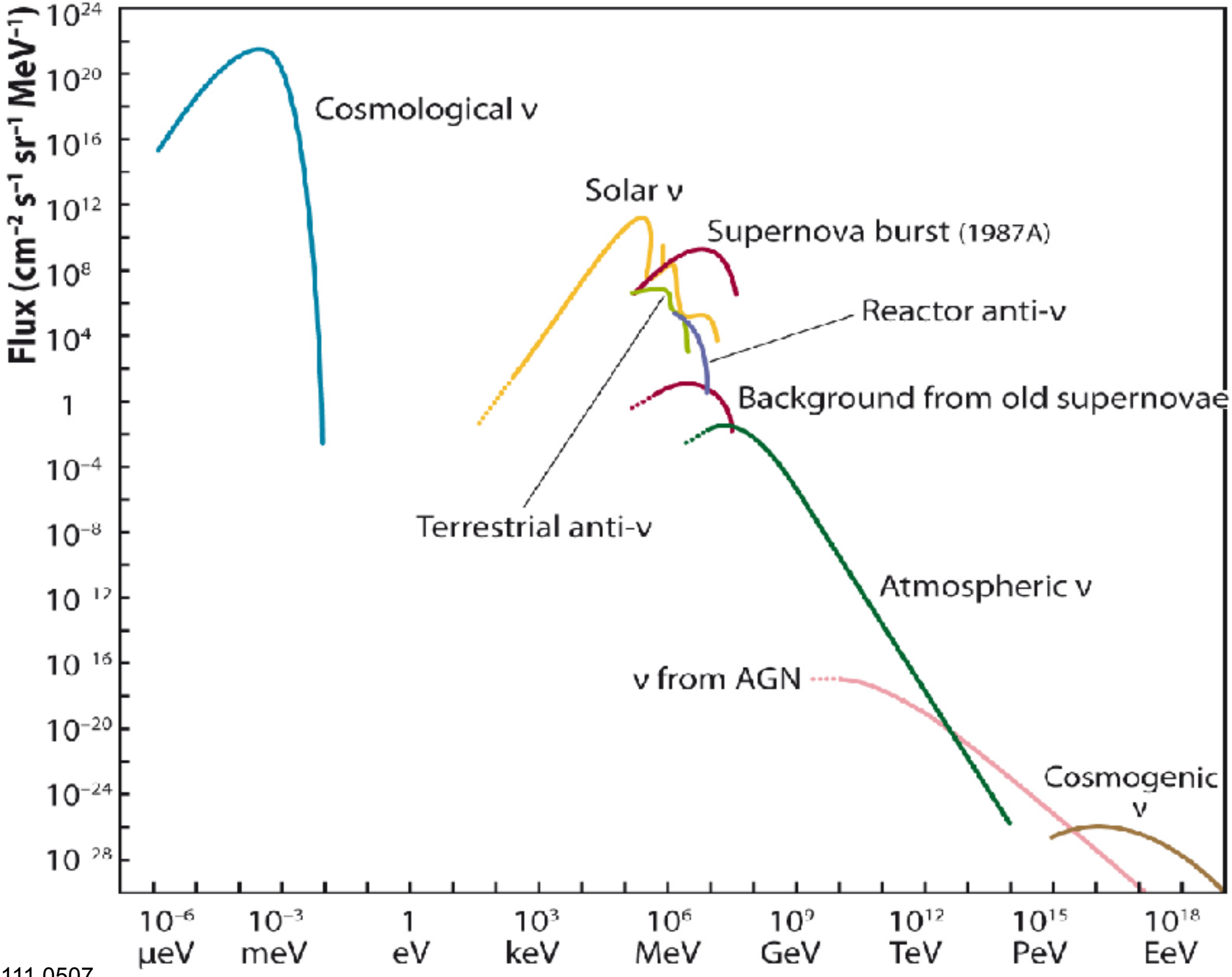


Cross-sections

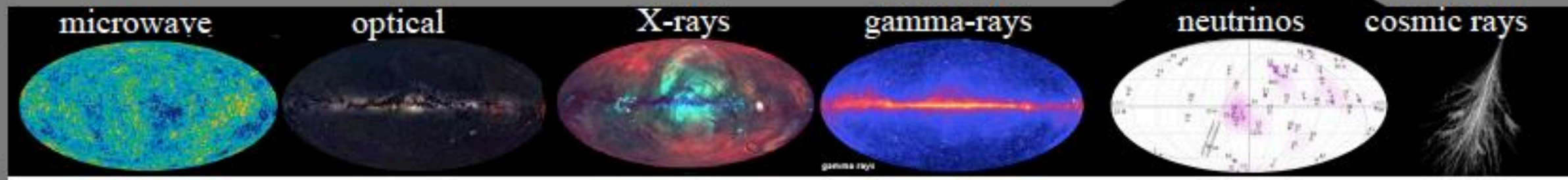




Neutrino Universe



arXiv:1111.0507



cosmological max of star formation

nearest Blazar

nearest Galaxy

Galactic Center

terra incognita:
only revealed by
neutrinos

Gravitational waves - ripples in space-time

Distance [Mpc]

10^{4} 10^{3} 10^{2} 10^{1} 10^{0} 10^{-1} 10^{-2} 10^{-3}

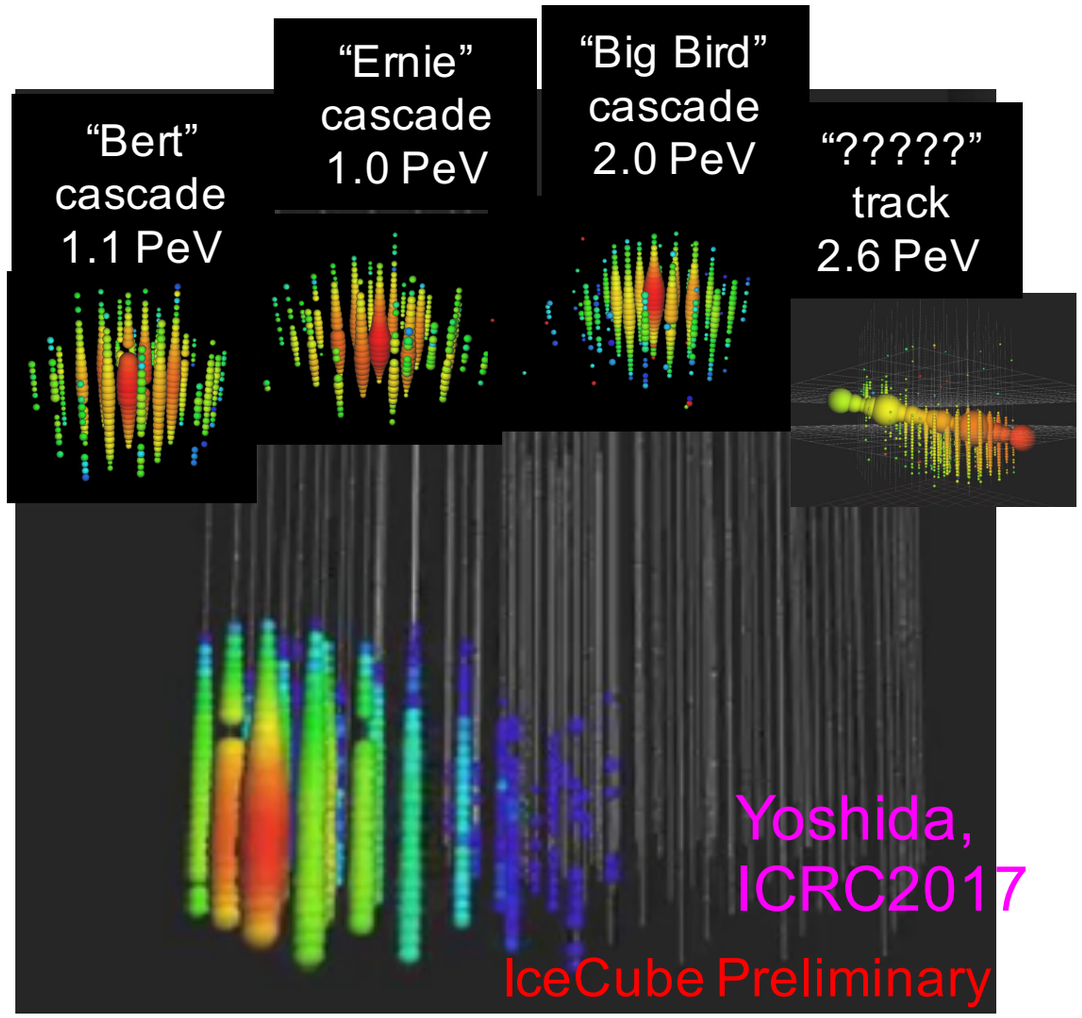
10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} 10^{8} 10^{10} 10^{12} 10^{14} 10^{16} 10^{18} 10^{20}

Energy [eV]

- 20% of the Universe is opaque to the EM spectrum
- non-thermal Universe powered by cosmic accelerators
- probed by gravity waves, neutrinos and cosmic rays

IceCube

- IceCube detected 5th PeV neutrino (name: ?????)
  - Cascade type
  - ~2.7 PeV (the highest energy)
  - unlikely to be cosmogenic neutrino



- They are selling new IC170922 t-shirts
  - Point source candidate?
  - Blazar coincidence?

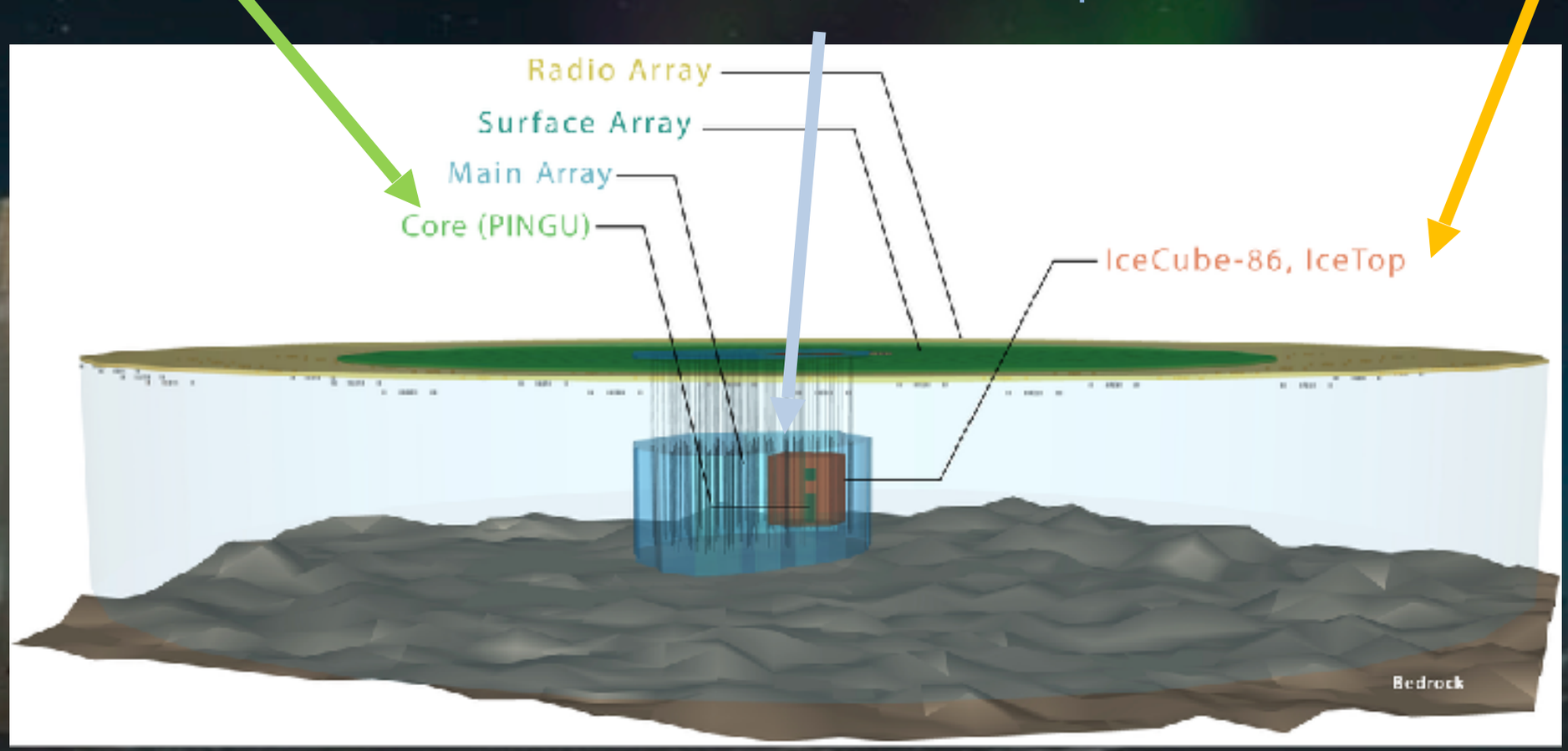
Future: IceCube-Gen2

IceCube-Gen2 covers particle physics from MeV to EeV with real discovery potential

PINGU (GeV)
- ~20m spacing dense array
- neutrino mass ordering

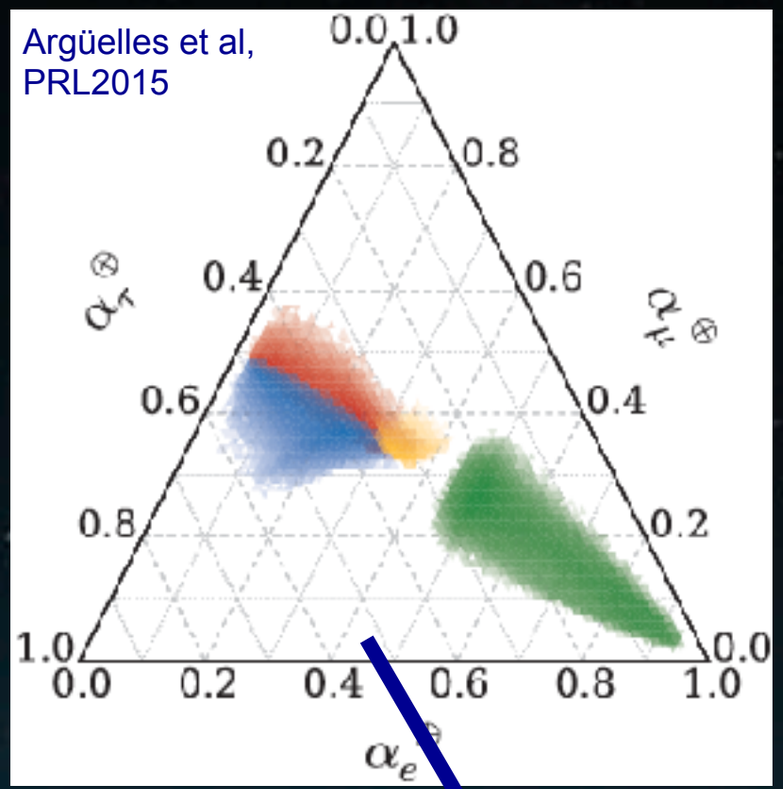
Main array (TeV-PeV)
- 120 new strings, 80 DOMs per string
- 240m separation to cover x8 volume
- x2 QE PMTs, and/or new photo-sensors

Askaryan Radio Array (EeV)
- GZK neutrinos



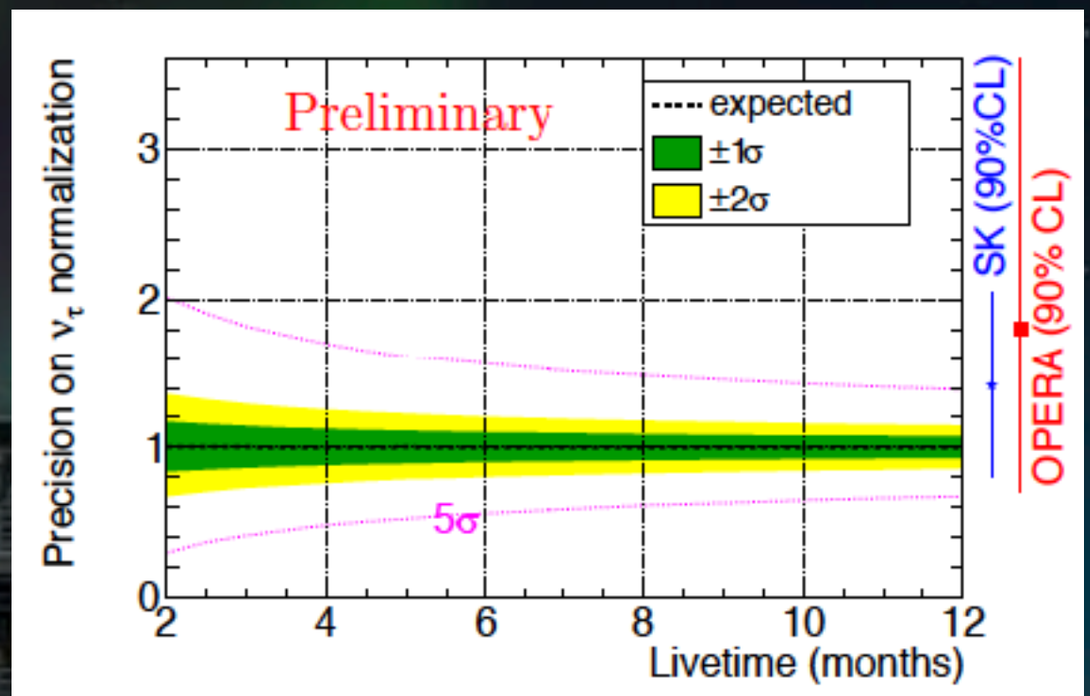
ICECUBE GEN2

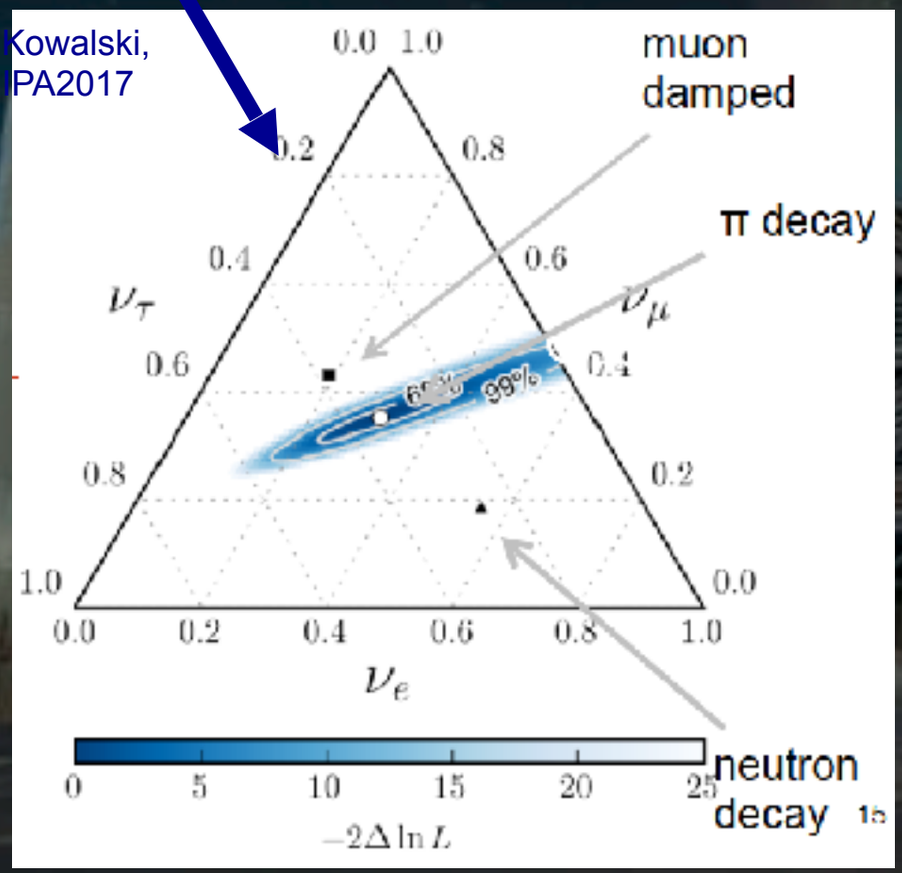
Physics of IceCube-Gen2



Astrophysical neutrino flavour
- very sensitive to new physics such as neutrino decay, non-standard interaction, quantum gravity, etc

Lepton unitarity triangle
- High statistics τ appearance to test of lepton unitarity





Unlimited list of science!
- low mass dark matter
- neutrino mass ordering
- multi-messenger astronomy, etc

ICECUBE GEN2

IceCube-Gen2 in UK

Manchester: J. Evans, S. Söldner-Rembold, S. Wren
Oxford: S. Sarkar
Queen Mary: T. Katori, S. Mandalia

IceCube data analysis
- Mass ordering analysis on DeepCore
- Test of quantum gravity

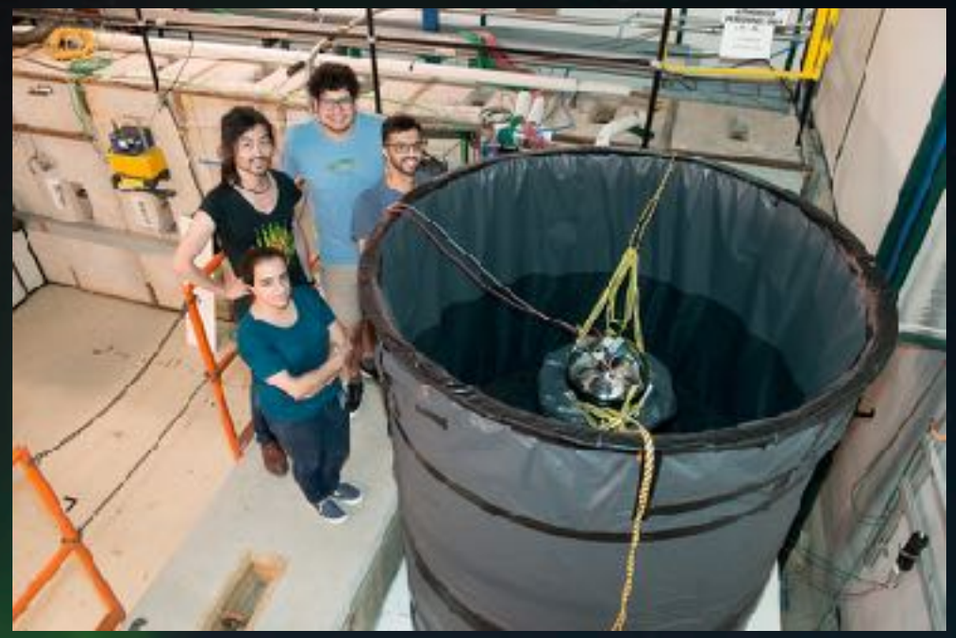
Software development
- Atmospheric flux systematics — Evans et al, PRD95(2017)023012
- Hadronization systematics — Katori et al, JPhysG42(2015)115004
- PINGU fast oscillation analysis code — paper in preparation

Hardware
- FEB firmware development
- DOM Fermilab beam test — paper in preparation

Analysis coordination
- Gen2 low E convener (Justin Evans)

On top of these, there is a large theory contribution from Oxford (Subir Sarkar)

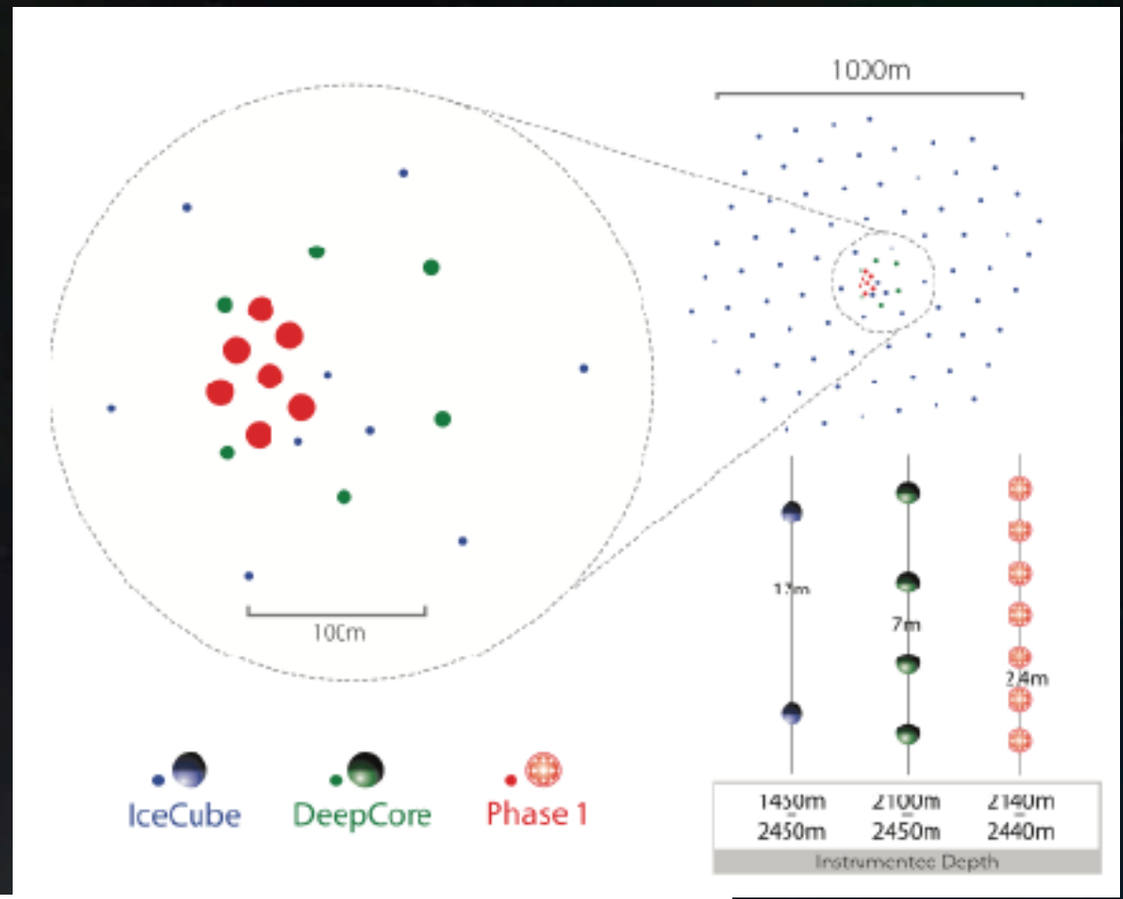
LHCb for prompt-ν production, JHEP02(2016)130
High energy neutrino cross section, JHEP08(2011)042
etc

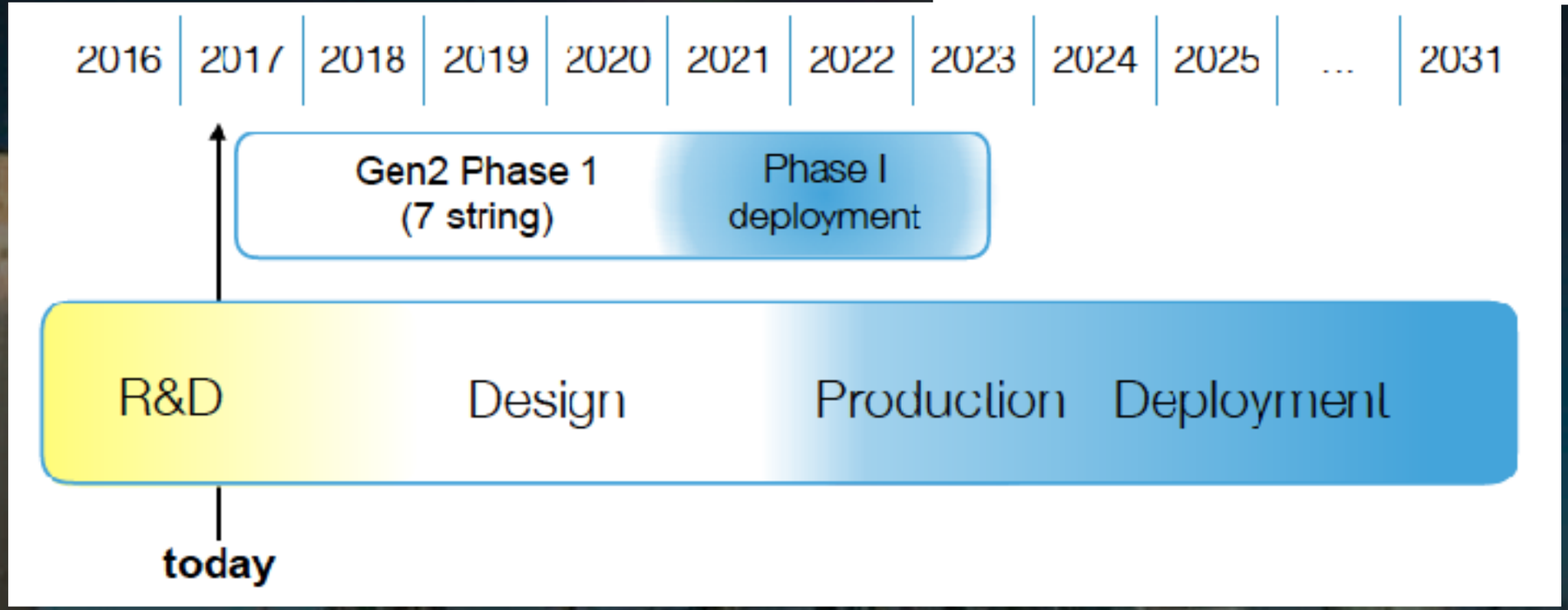


IceCube-Gen2 phase I

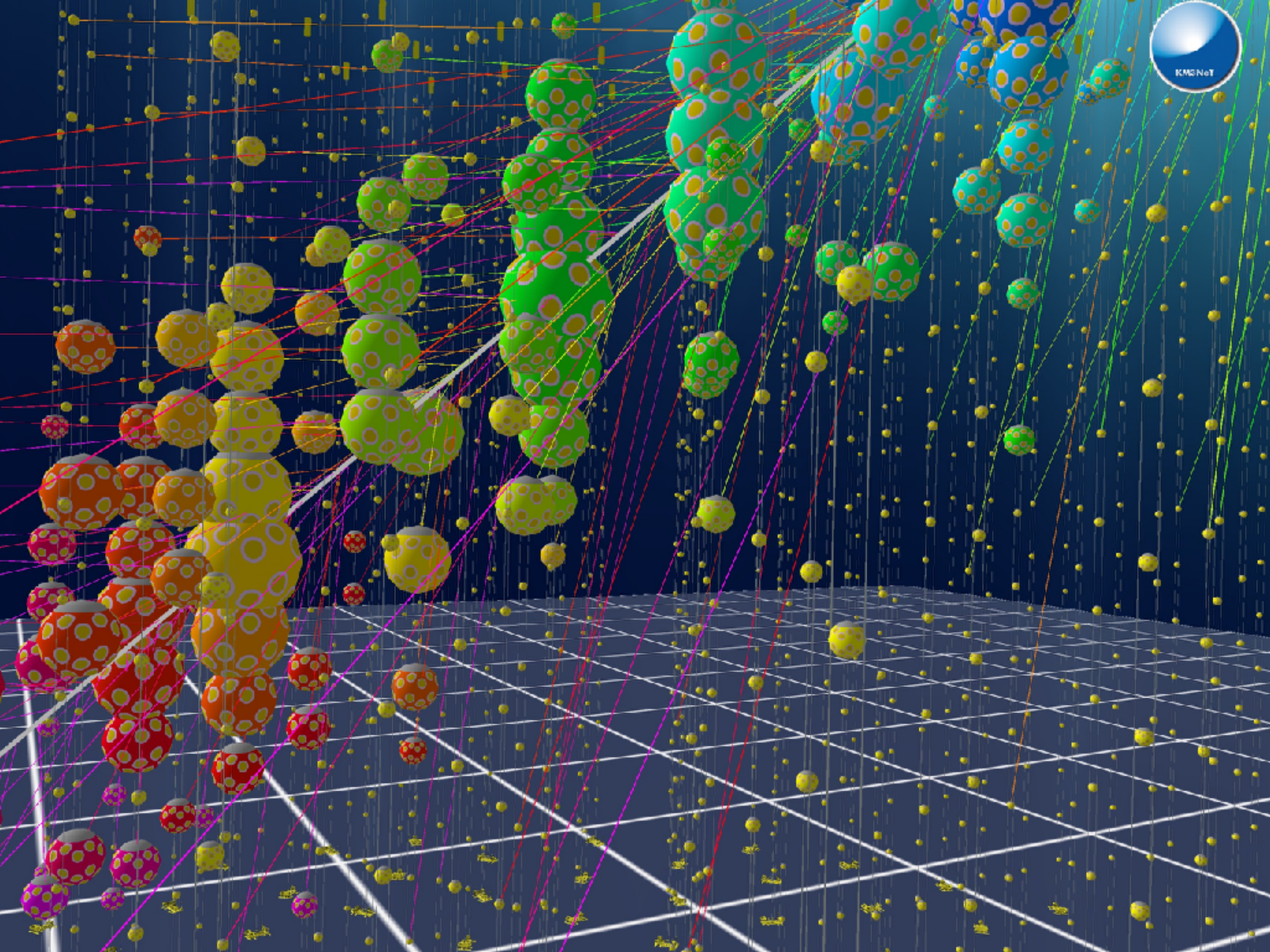
Staged approach
- Phase I includes 7 close strings to focus on ν_τ appearance (unitarity triangle)
- Proposal submitted to NSF, received with favor

PINGU: A vision for neutrino and particle physics at the South Pole
arXiv:1607.02671,JPhysG44(2017)054006
IceCube-Gen2: A vision for the future neutrino astronomy
arXiv:1412.5106

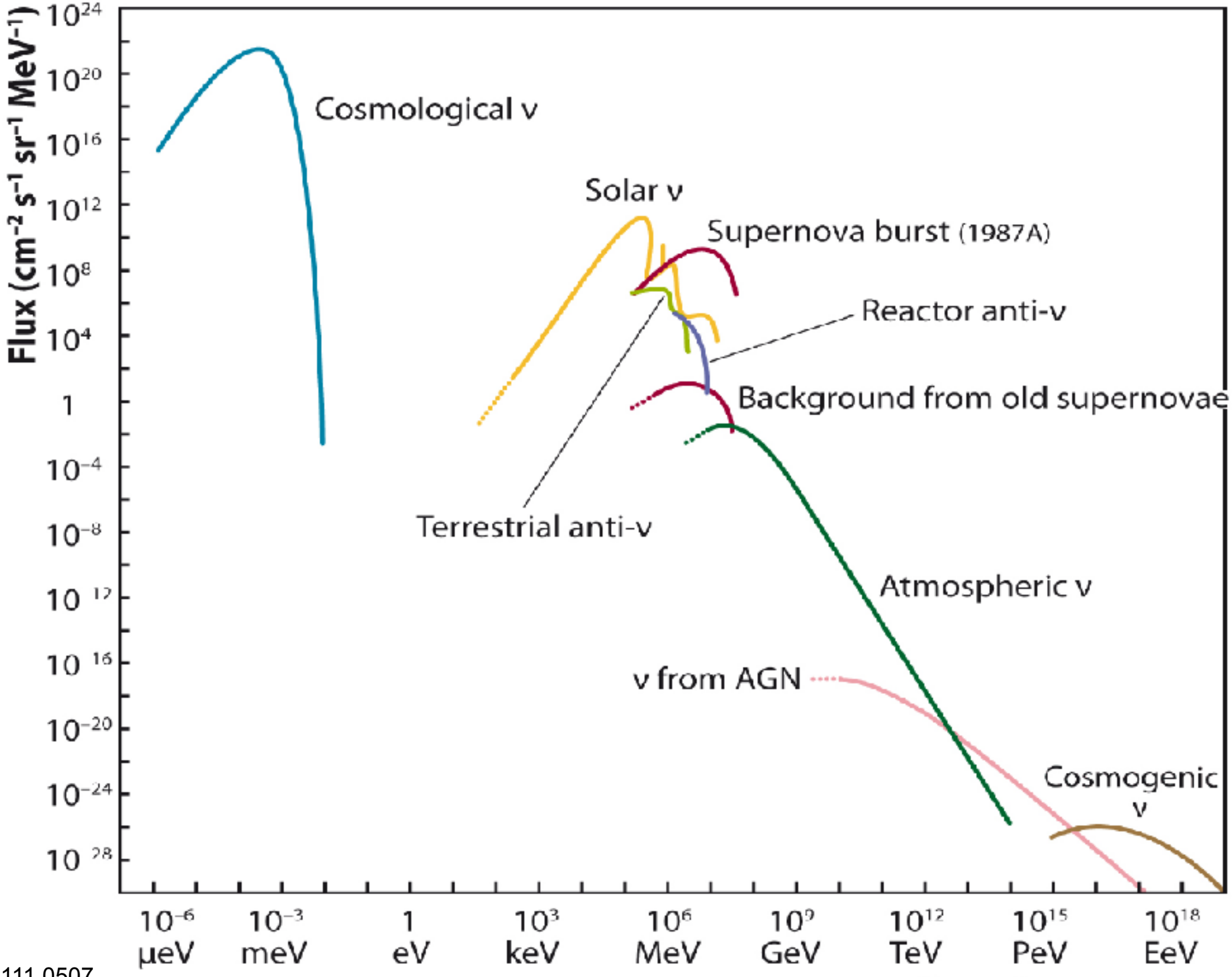




Thank you for your attention!


KMD NoT

Neutrino Universe



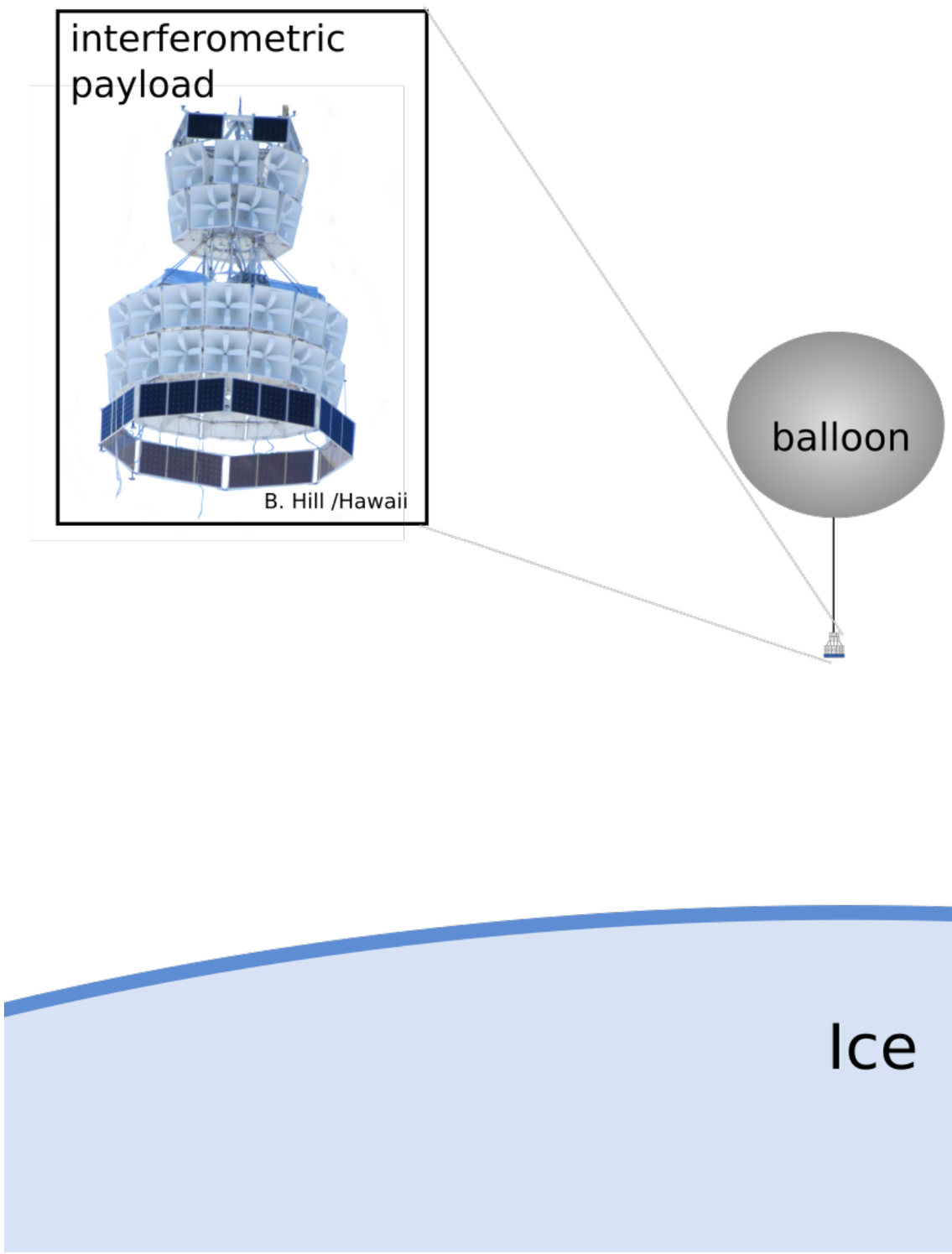
arXiv:1111.0507

UCL

ANITA

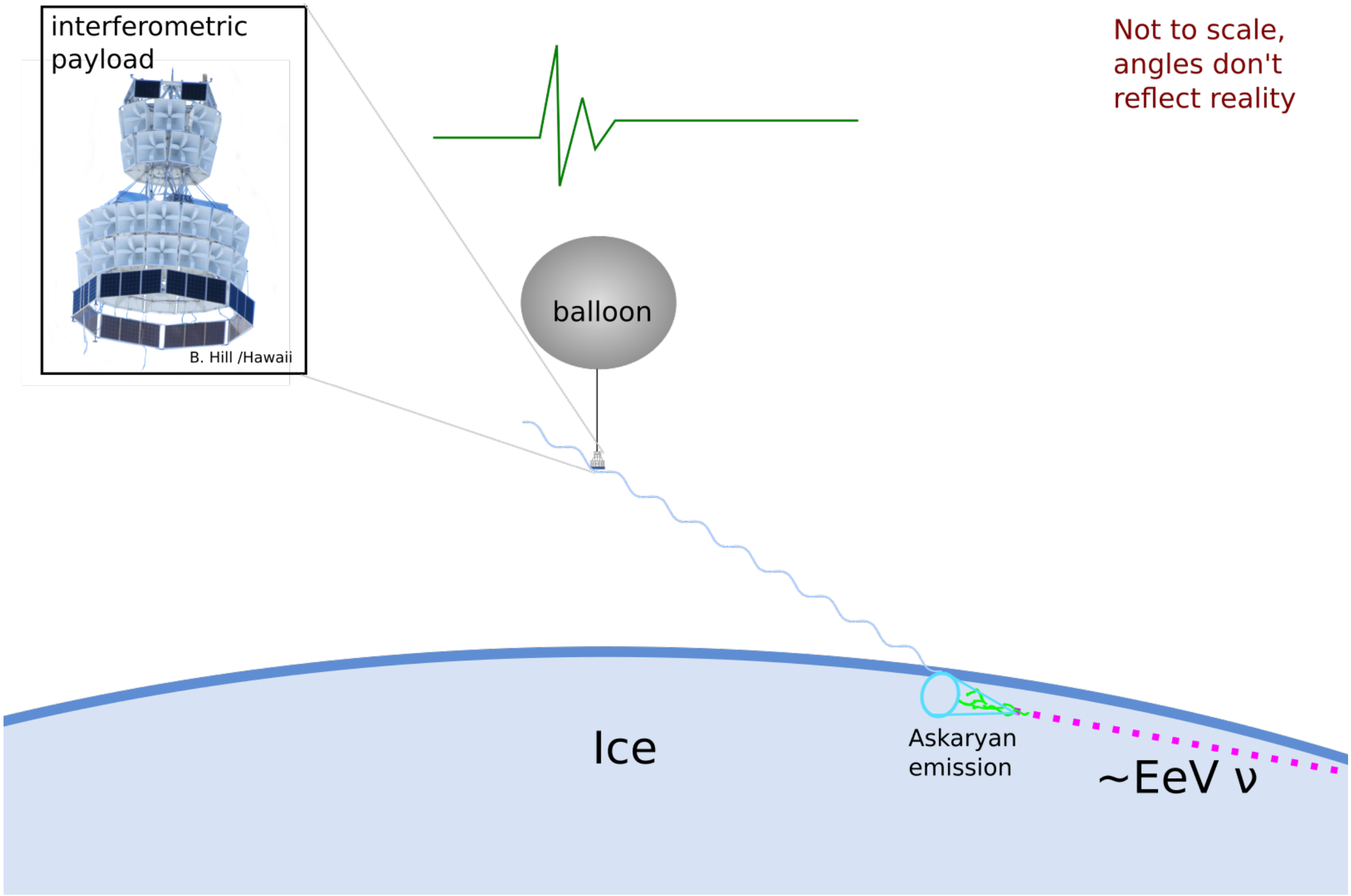
Photo: H. Schoorlemmer , University of Hawaii

Concept



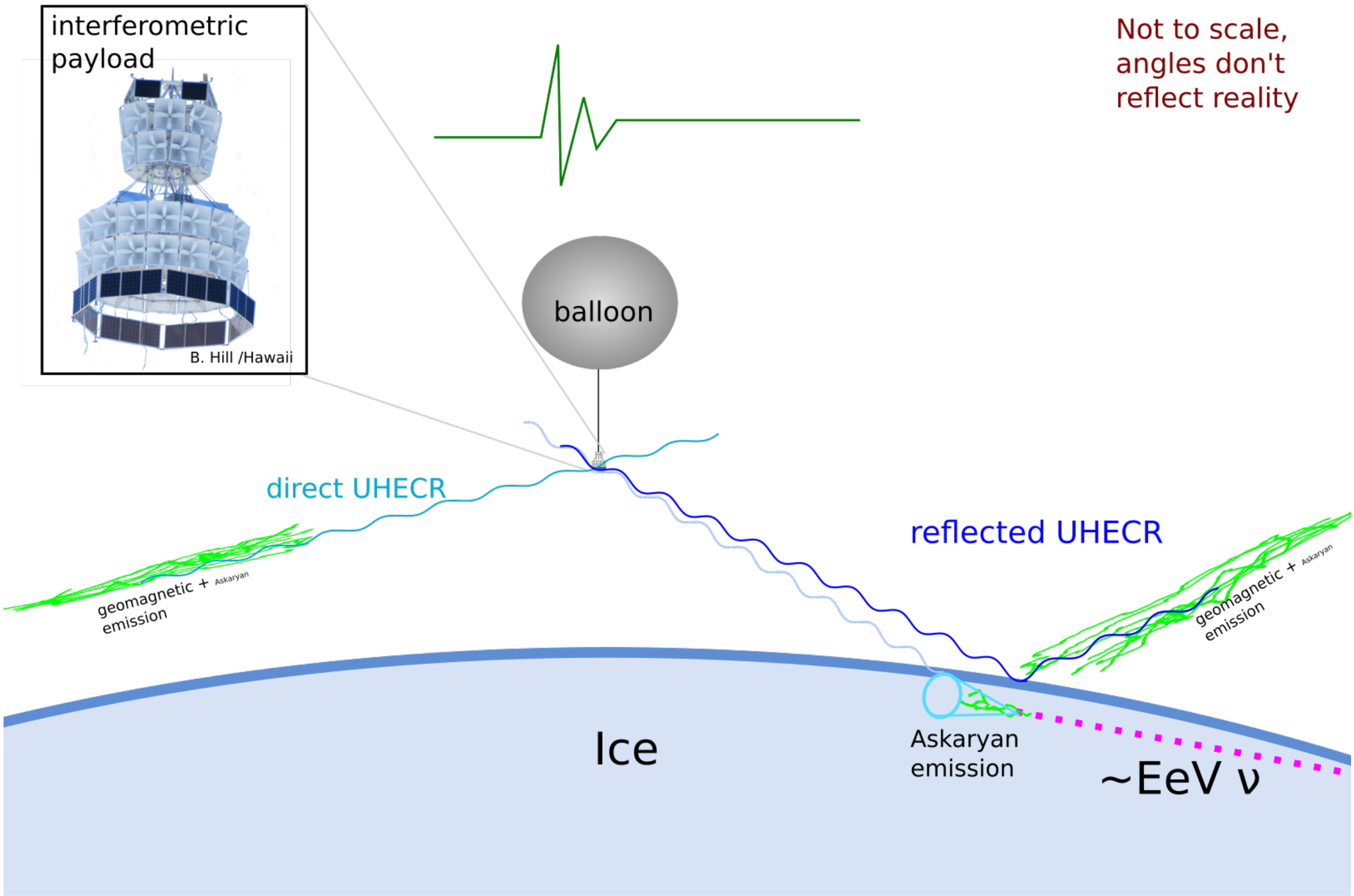
Not to scale, angles don't reflect reality

Concept



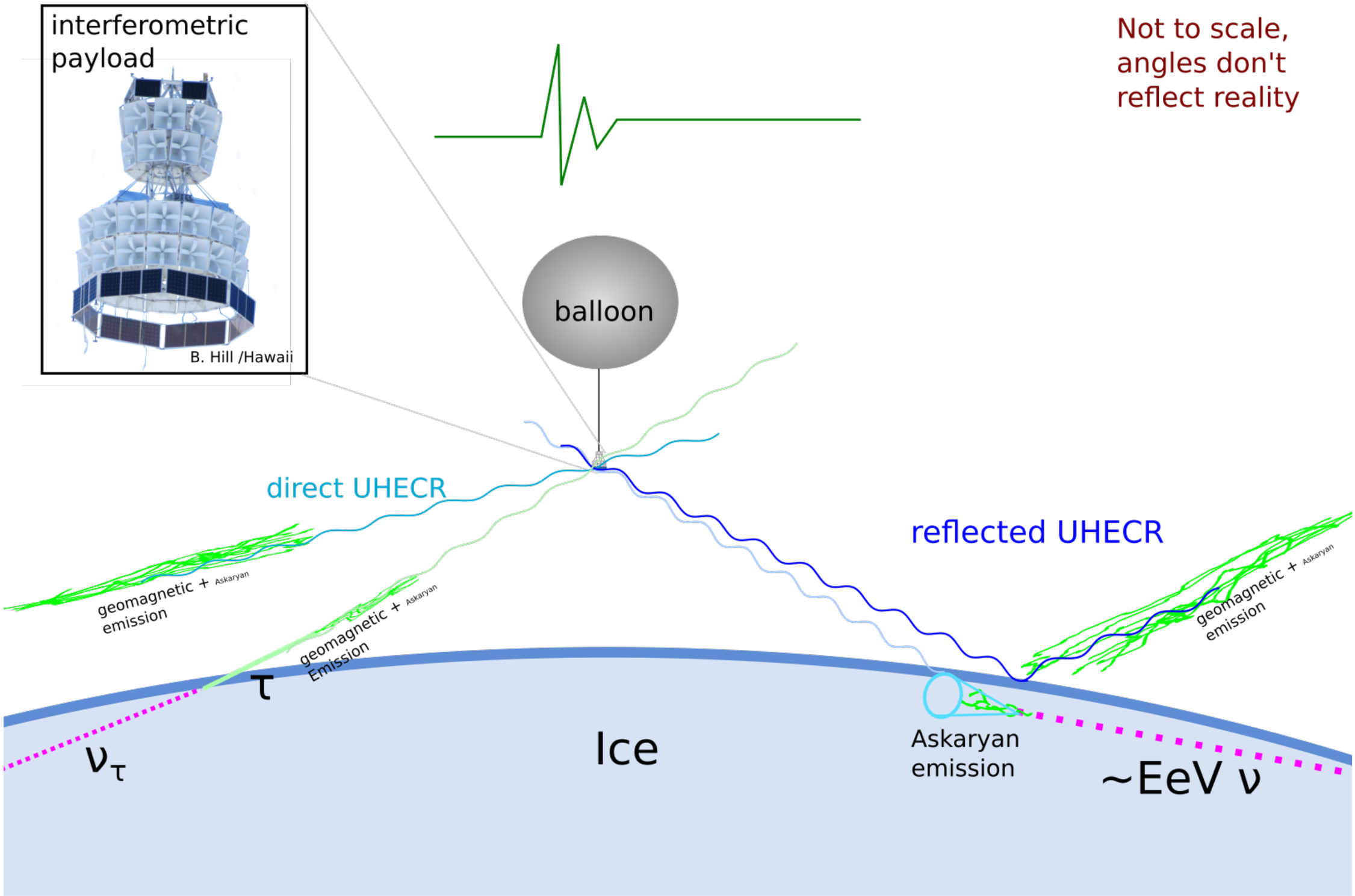
Not to scale, angles don't reflect reality

Concept



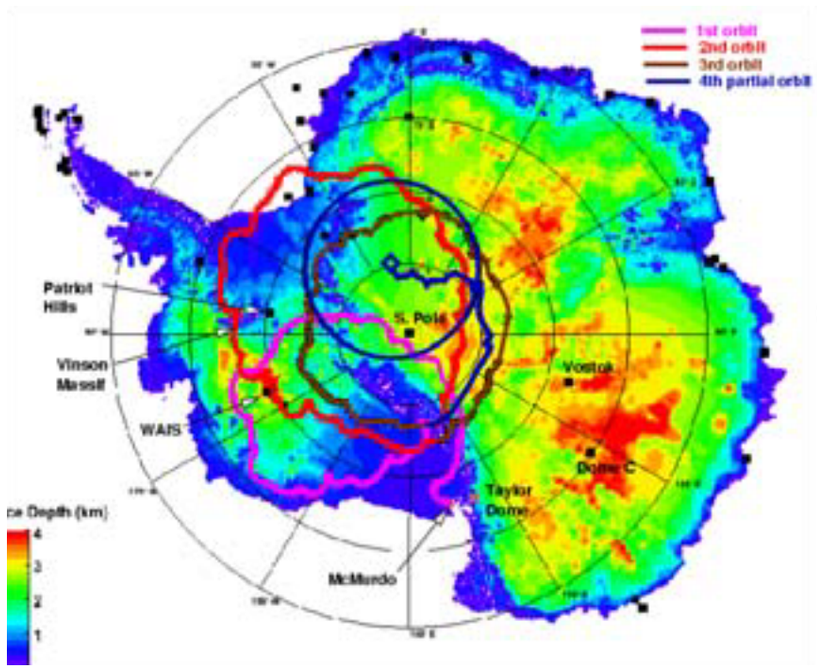
Not to scale, angles don't reflect reality

Concept



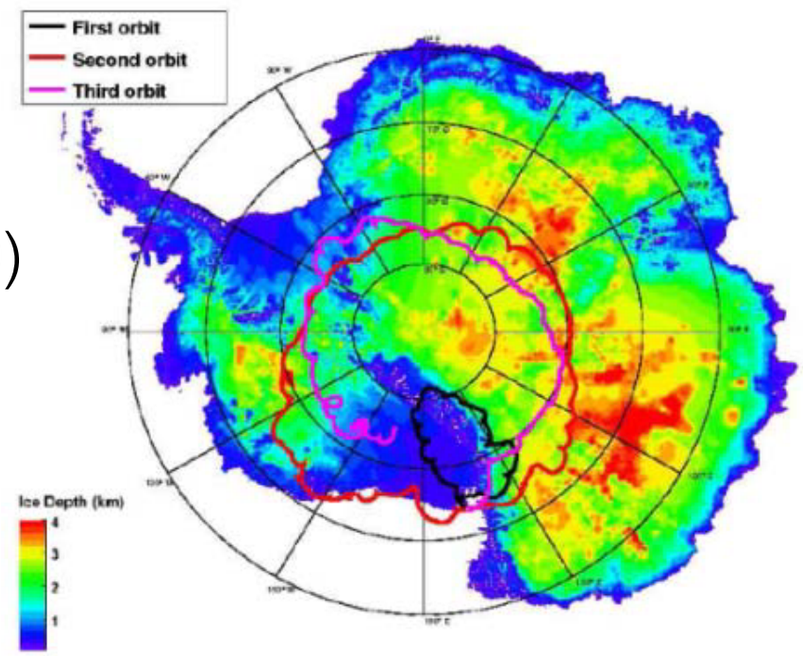
Not to scale, angles don't reflect reality

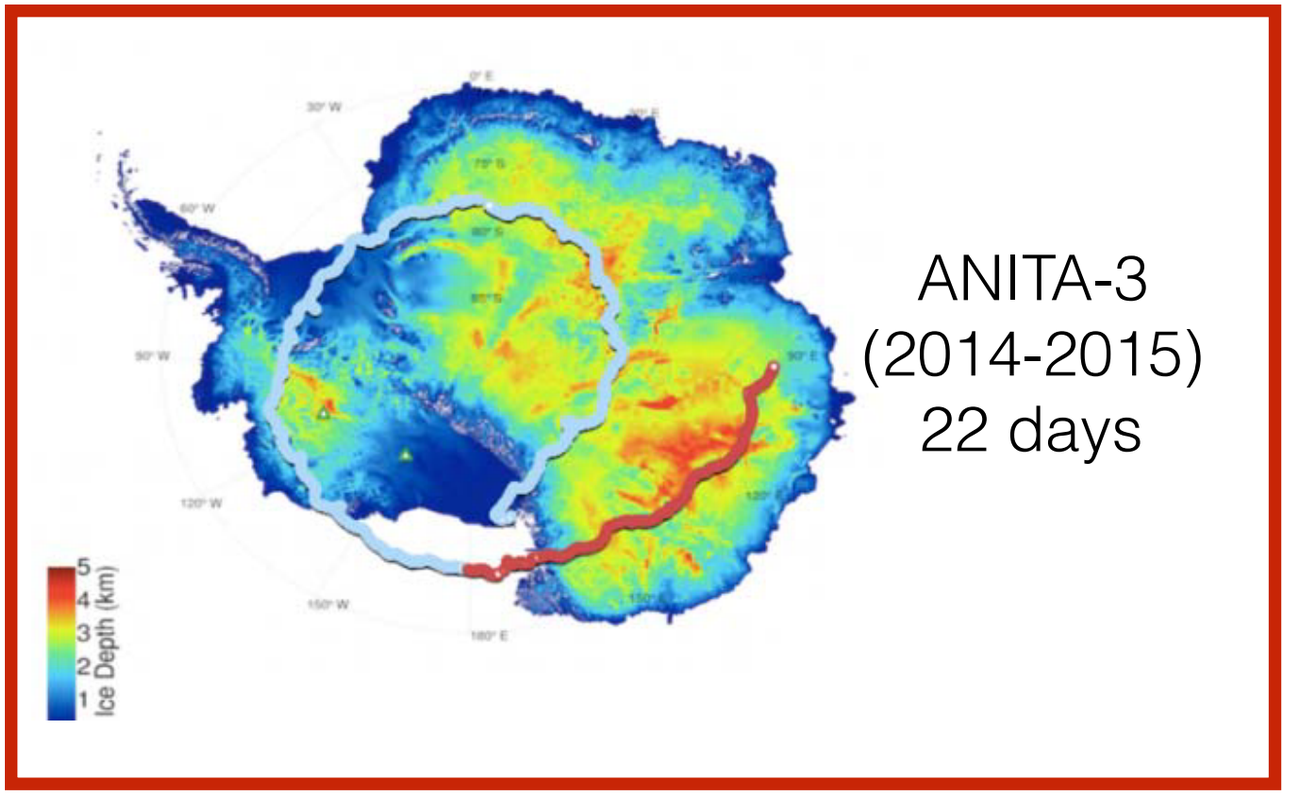
ANITA Flights



ANITA-1
(2006-2007)
35 days

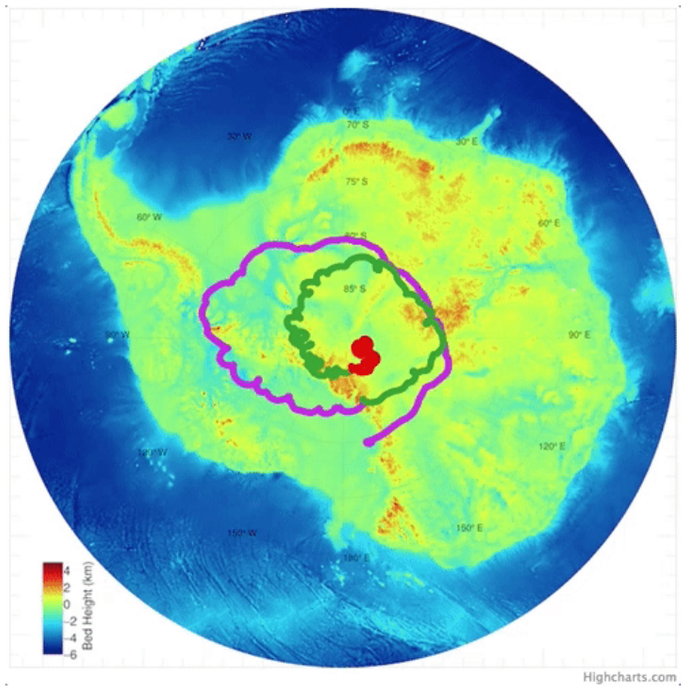
ANITA-2
(2008-2009)
30 days





ANITA-3
(2014-2015)
22 days

ANITA-4
(2016)
30 days

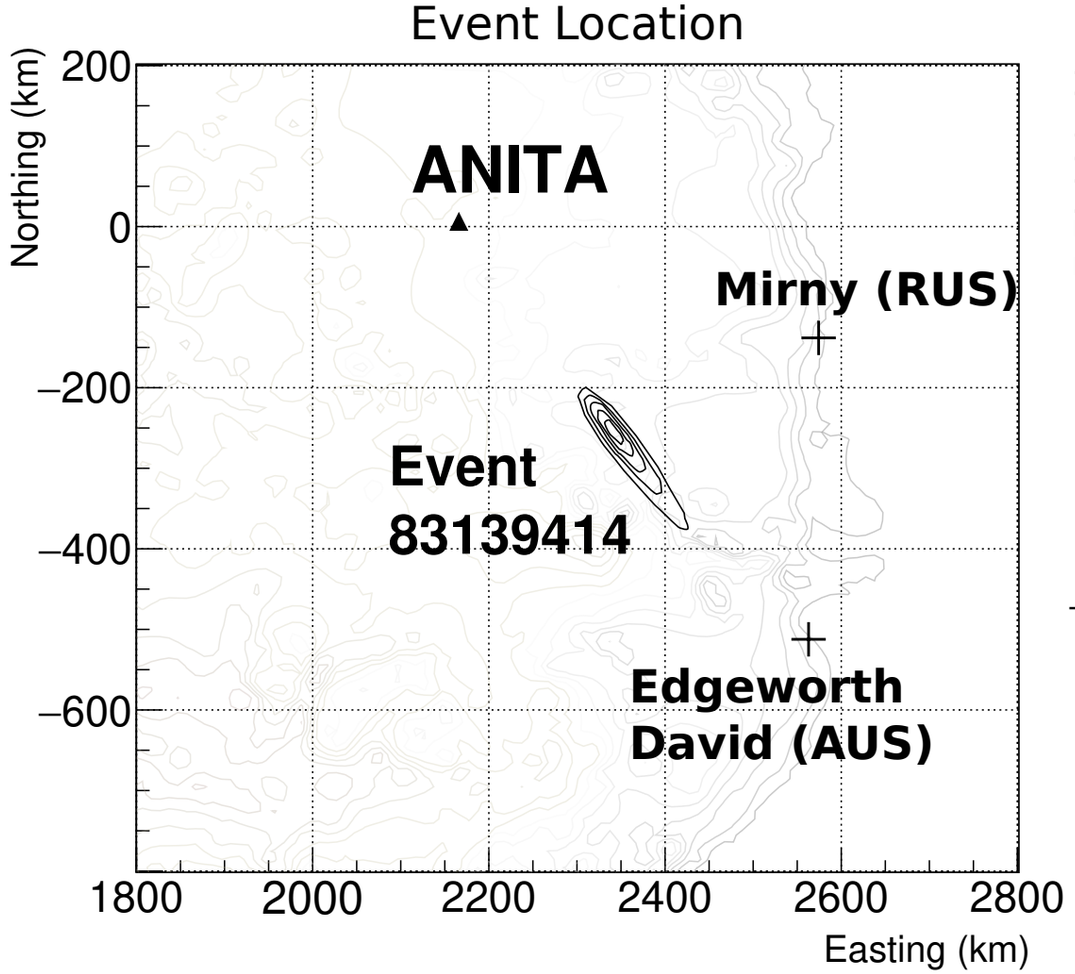


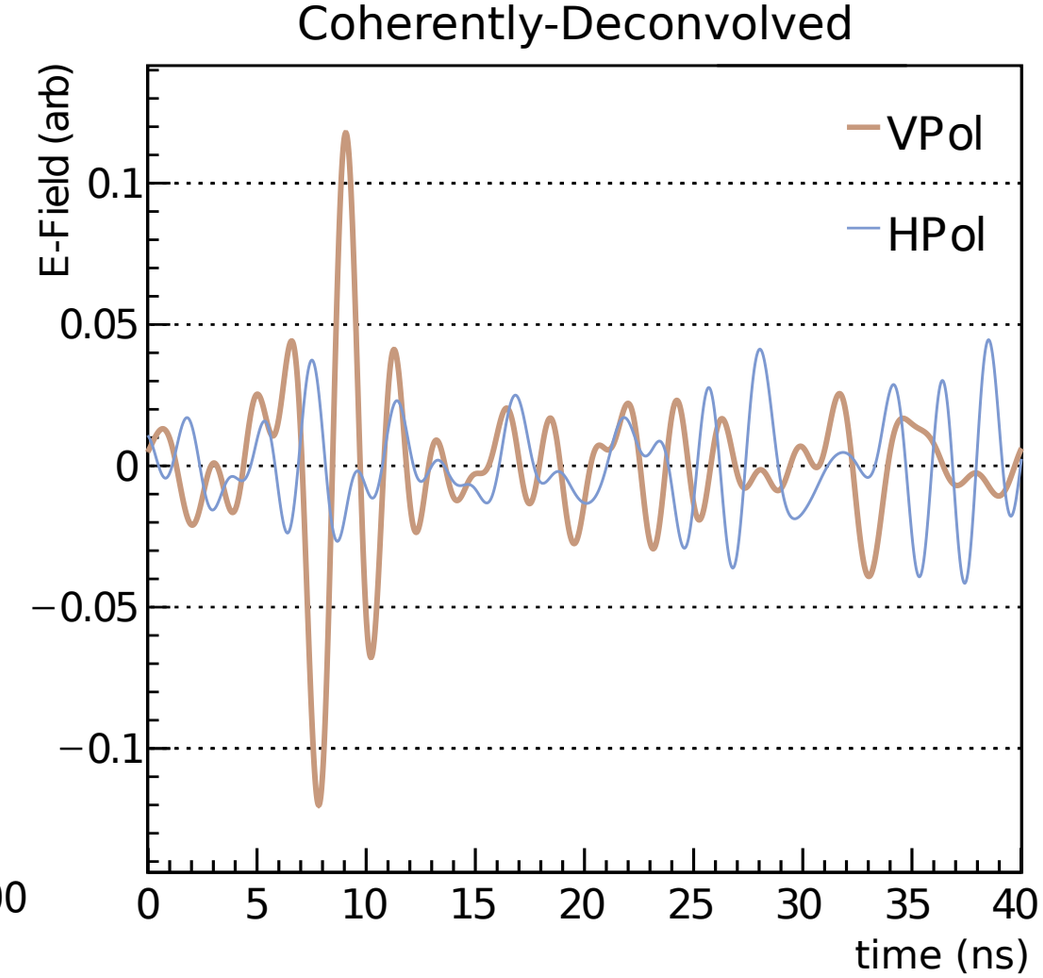
ANITA-3 Results

- New diffuse neutrinos search from ANITA-3
  - arXiv 1803.02719

Constraints on the diffuse high-energy neutrino flux from the third flight of ANITA

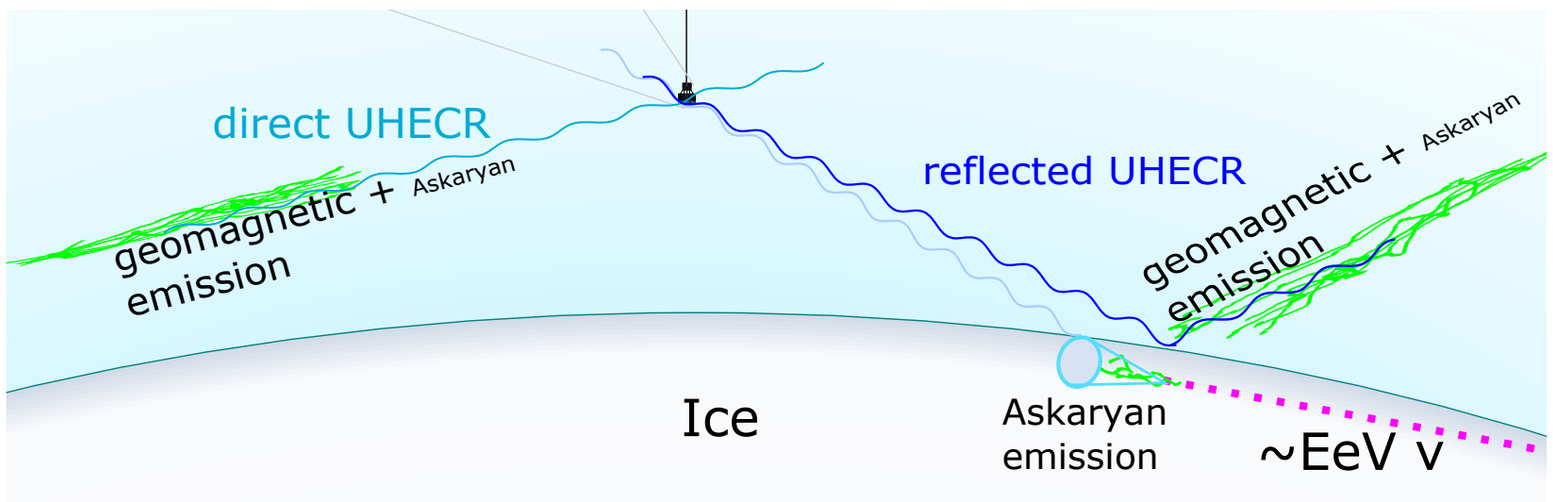
P. Allison, O. Banerjee, L. Batten, J. J. Beatty, K. Bechtol, K. Belov, D. Z. Besson, W. R. Binns, V. Bugaev, P. Cao, C. C. Chen, C. H. Chen, P. Chen, J. M. Clem, A. Connolly, L. Cremonesi, B. Dailey, C. Deaconu, P. F. Dowkontt, B. D. Fox, J. W. H. Gordon, P. W. Gorham, C. Hast, B. Hill, S. Y. Hsu, J. J. Huang, K. Hughes, R. Hupe, M. H. Israel, K. M. Liewer, T. C. Liu, A. B. Ludwig, L. Macchiarulo, S. Matsuno, C. Miki, K. Mulrey, J. Nam, C. Naudet, R. J. Nichol, A. Novikov, E. Oberla, S. Prohira, B. F. Rauch, J. M. Roberts, A. Romero-Wolf, B. Rotter, J. W. Russell, D. Saltzberg, D. Seckel, H. Schoorlemmer, J. Shiao, S. Stafford, J. Stockham, M. Stockham, B. Strutt, M. S. Sutherland, G. S. Varner, A. G. Vieregg, S. H. Wang, S. A. Wissel

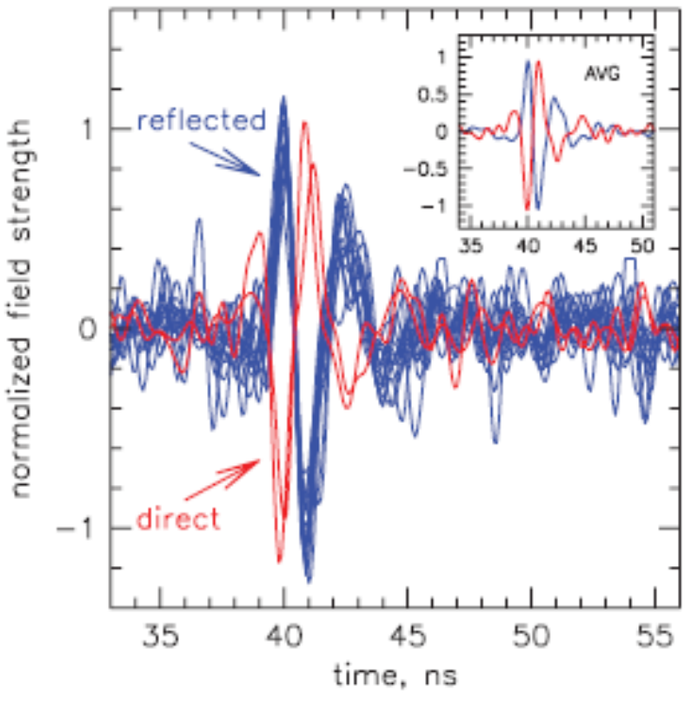




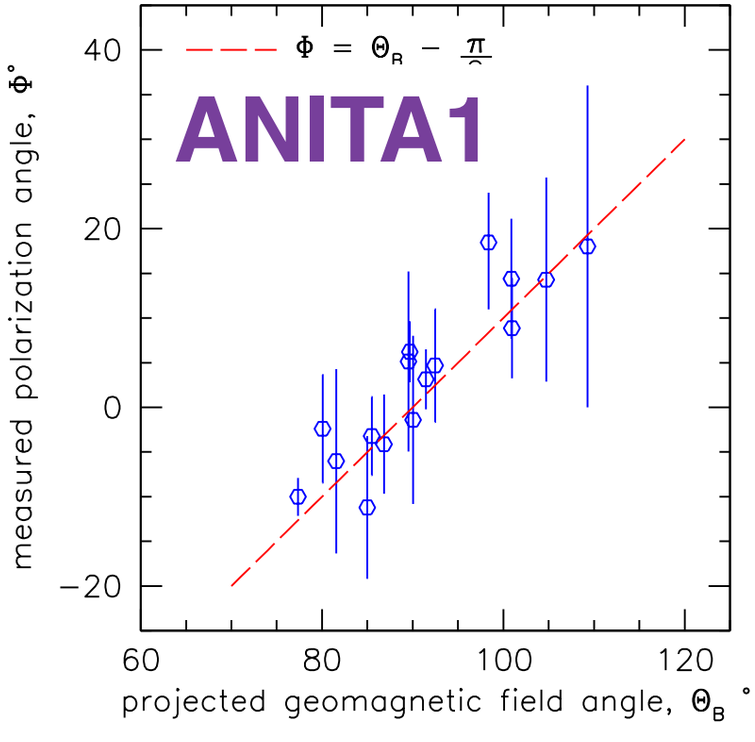
UHECR

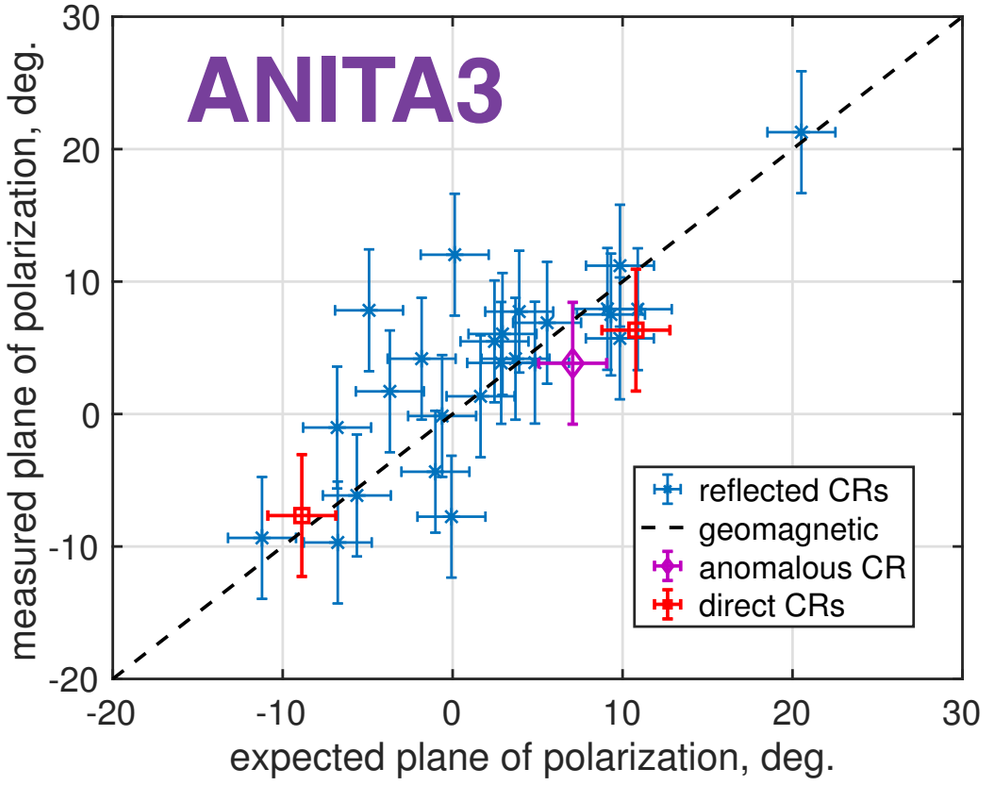
ANITA1: 16 UHECR
 14 reflected + 2 direct
ANITA-2: 2 UHECR
 H-pol trigger was off
ANITA-3: 25 UHECR
ANITA-4: analysis in progress





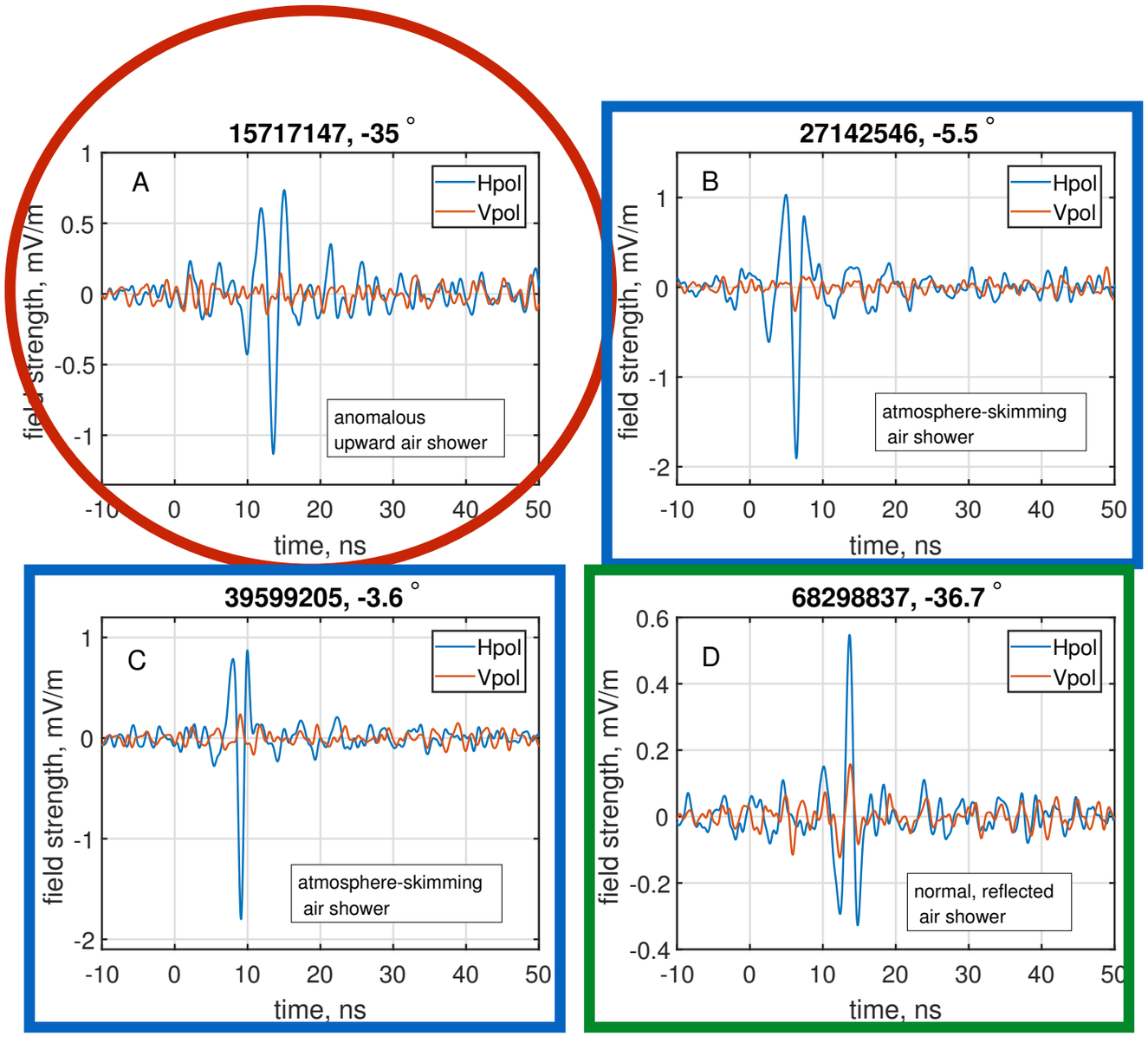
PRL 105, 151101 (2010)

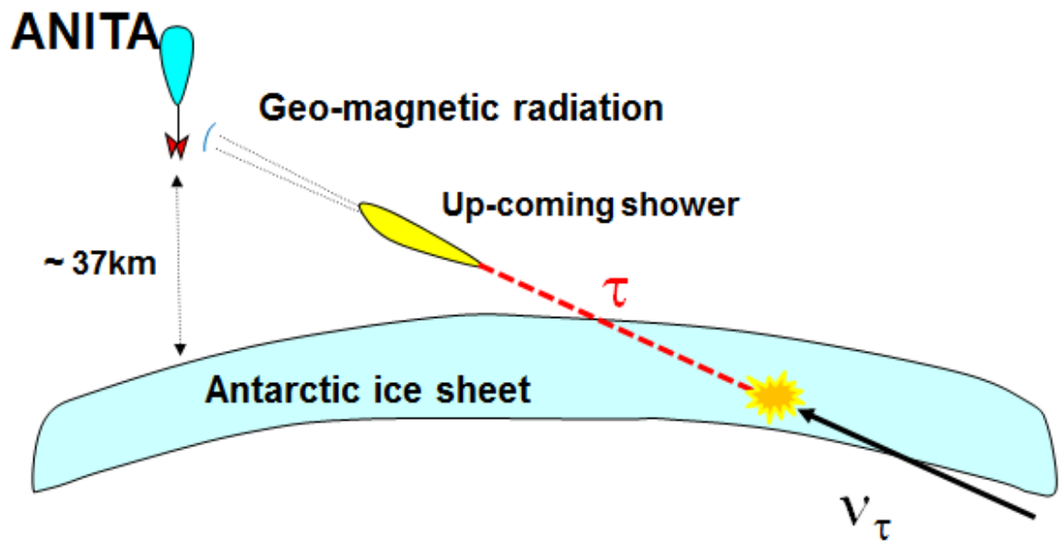




arXiv:1803.05088 [astro-ph.HE]

And ANITA-3 mystery event





Direct Cosmic Rays

Reflected Cosmic Rays

NEW PHYSICS ?

Chord length: 5500-7000 km (20-30,000km water equivalent)
1600km SM interaction length @ 1 EeV

Background estimate < 10^{-2}

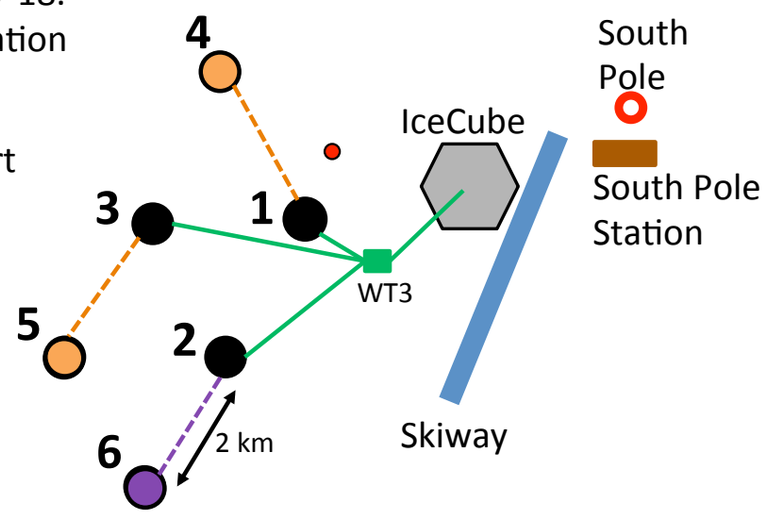
Future Radio

Deployed ARA Station

Instrumentation deployment in 17 / 18. Site / road preparation in 16 / 17.

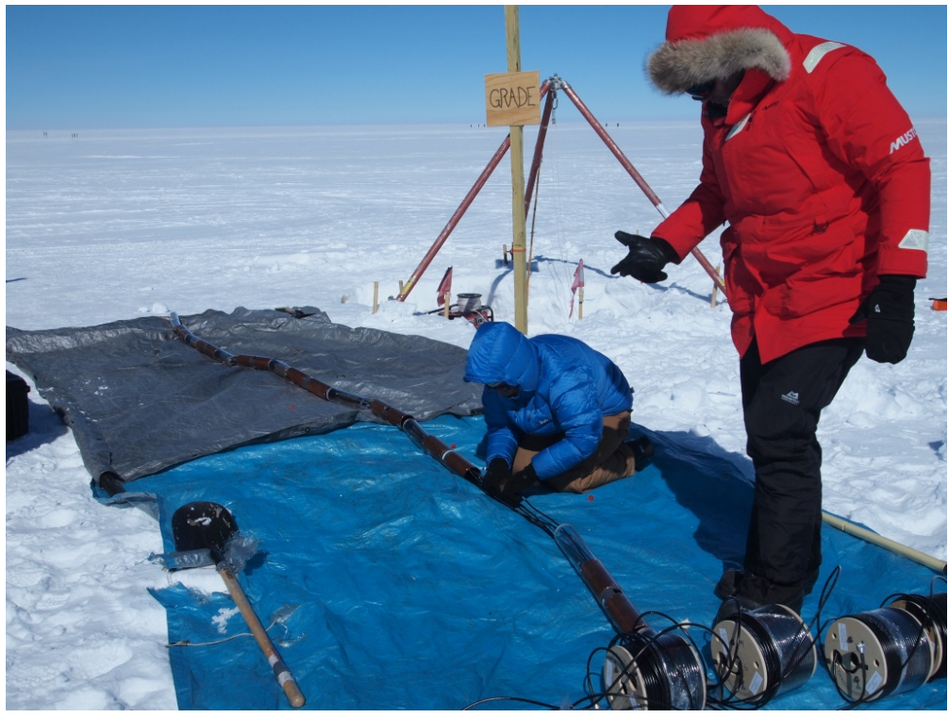
Potential if support is available

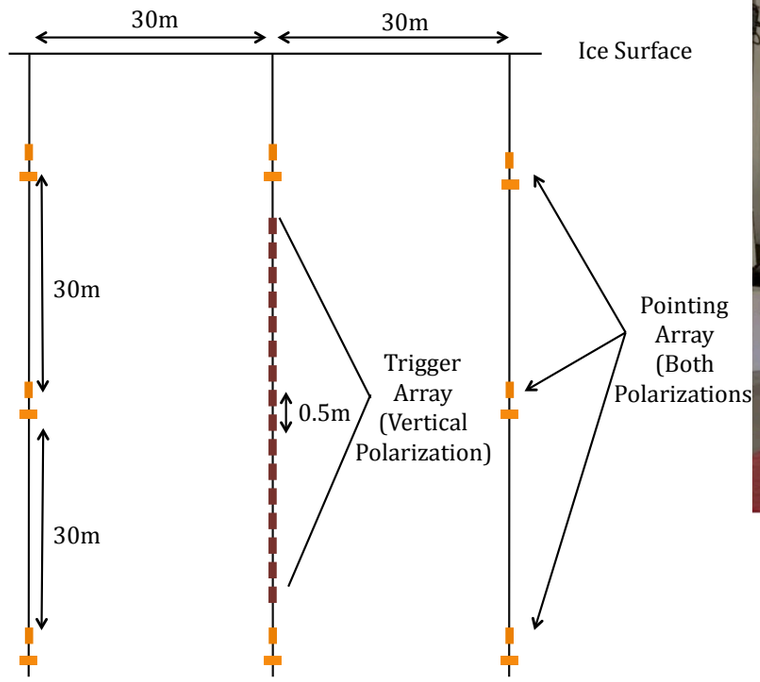
ARA6



EVA

Greenland Neutrino Observatory





Questions?

- What consensus / conflicts (on what should be done in longer term European HEP) are there in this area?
- What are the experimental possibilities? Are different scenarios already envisaged?
  - IceCube is a tremendous success, the science case for IceCube-Gen2 (both the high and low energy extensions) are clear
  - Some version of KM3NeT will exist
  - Small experiments (i.e. ANITA) have discovery potential
  - Hard to disentangle politics
- What are the choices for the strategy? What can the UK agree to input?
  - Astroparticle physics should be mentioned
- What are the potential developments in this field? How do they relate to fundamental physics questions?