Supernova neutrinos

J Tseng
Neutrino Summer School
UC Santa Barbara
7 July 2026

NASA, ESA, Allison Loll/Jeff Hester (ASU). Ack: Davide De Martin (ESA/Hubble)

Lectures

1. What's a supernova?
2. What do neutrinos have to do with supernovae?
3. What can we learn from supernova neutrinos?
4. Observing supernova neutrinos
   a. Diffuse supernova neutrino "background" (DSNB)
5. The next Galactic core-collapse supernova

Chapter 4

Observing supernova neutrinos

Galactic core-collapse supernova rate

- The bad news: from a survey of historical records, nearby observations, massive stars, neutron star birthrate, ^{26}Al abundance, rate is 1.63 ± 0.46 per century (Rozwadowska, Vissani, Cappellaro, *New Astron* 83 (2021) 101498)

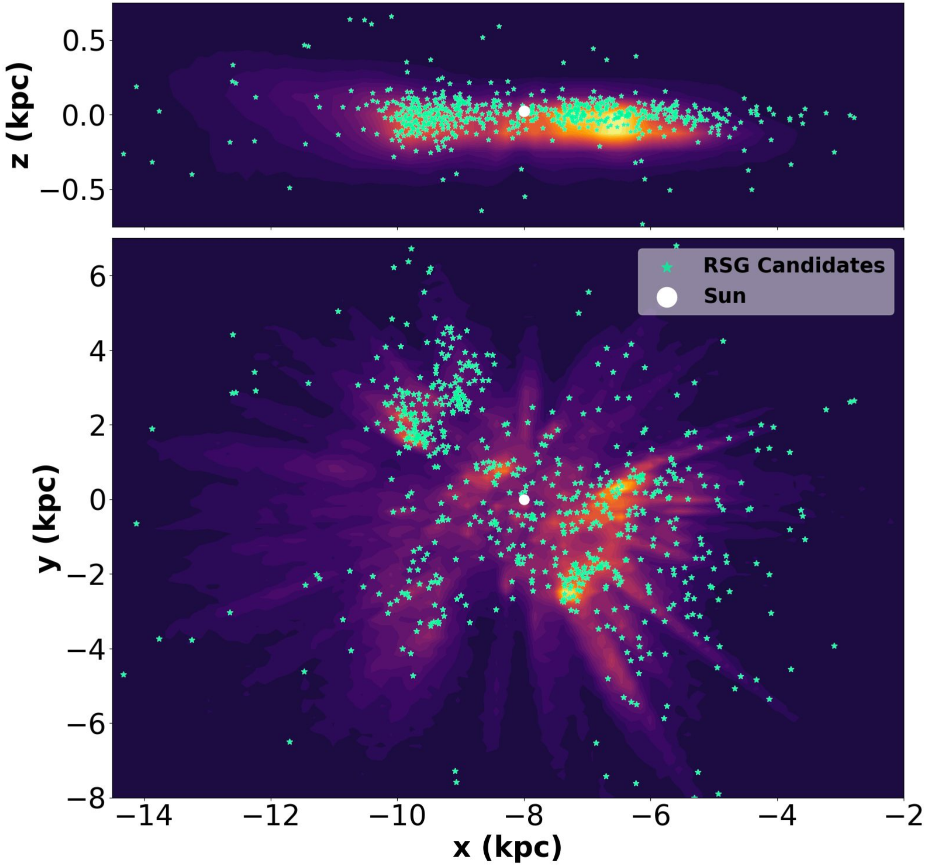
Galactic CCSN are extremely rare but also extremely rich in physics!

- Can we anticipate which stars might collapse?
  - Identify nearby massive stars…

S Healy et al., MNRAS 529, 3630 (2024)

Red supergiants

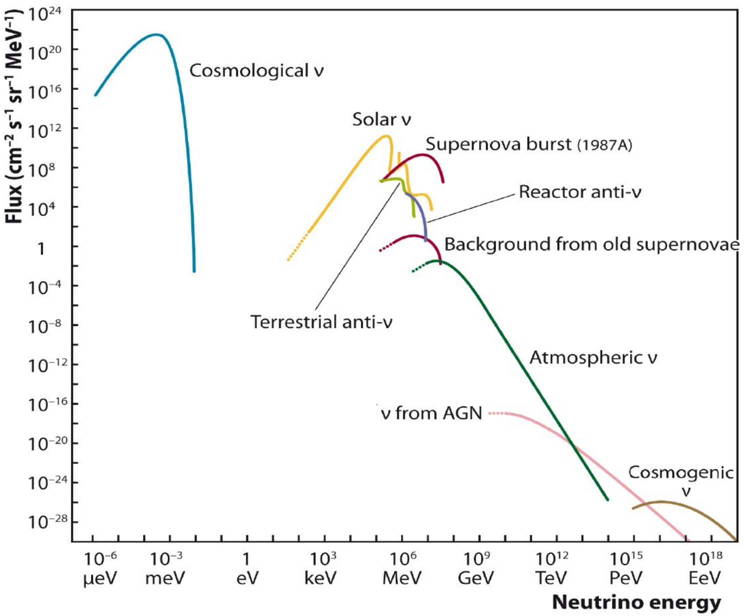
- Catalog of 578 “highly probable” + 62 “likely” nearby red supergiants
  - Compared to stellar density from Gaia DR3
- If we can tell the direction to a supernova, we can focus on detailed observations of a few candidates
  - If we can estimate the distance, can narrow down even further

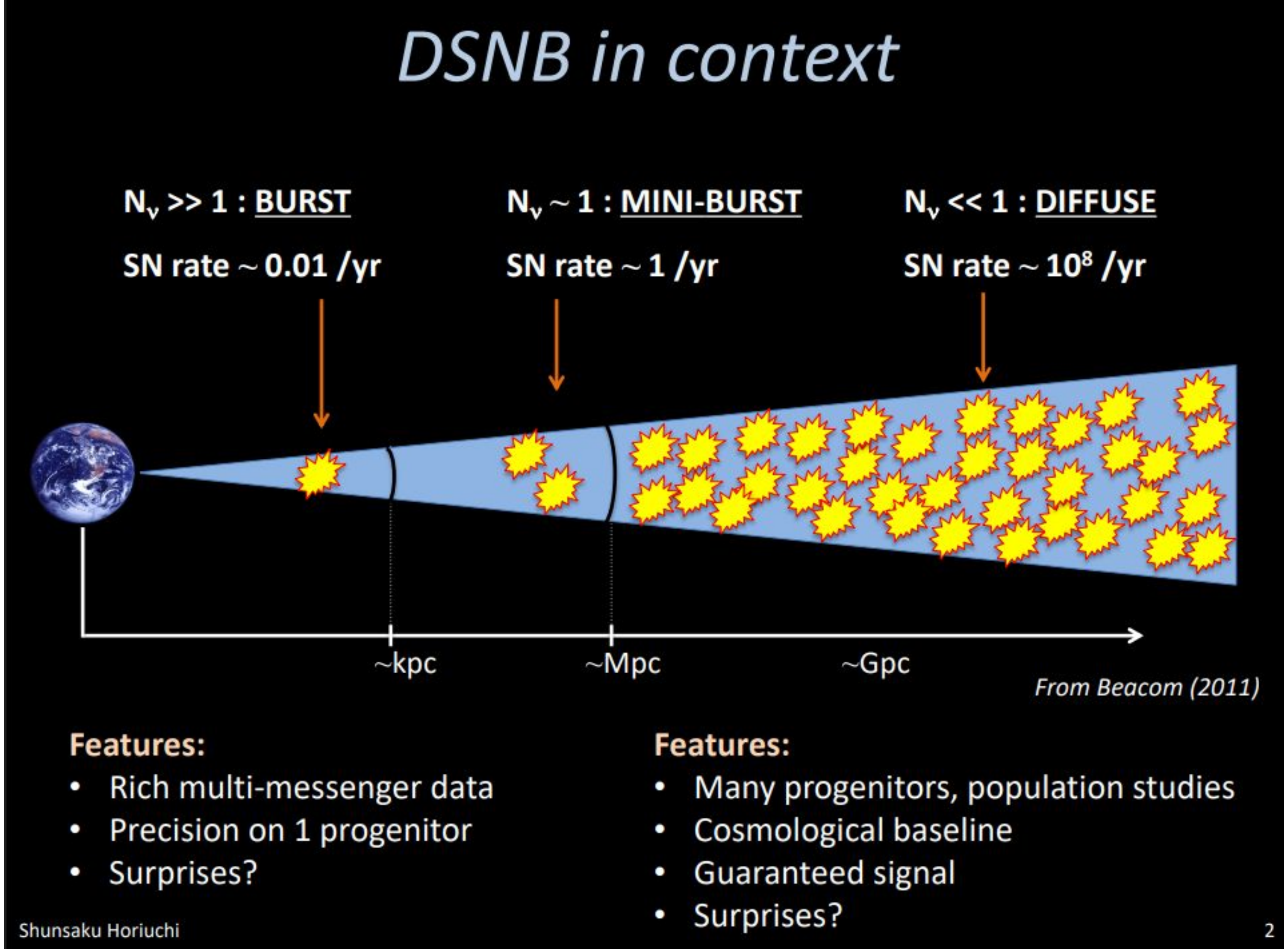


- Mass ~14$M_\odot$
- Radius ~700$R_\odot$
- Distance ~0.15 kpc
- Big stars tend to be inhomogeneous

Diffuse Supernova Neutrino "Background" (DSNB)

- Stars collapse everywhere in the Universe
- Neutrinos travel a *long* distance
- Can we observe them?
- What can we learn from them?





S Horiuchu, SNvD@LNGS 2023

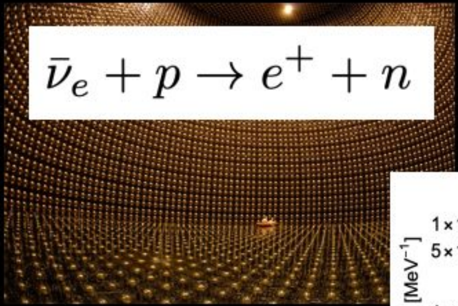
DSNB: ingredients

$$R = N_t \int dE\, \sigma_{\rm IBD} \int dz\, c \frac{dN}{dE'}(1+z) R_{CC}(z) \left|\frac{dt}{dz}\right|$$

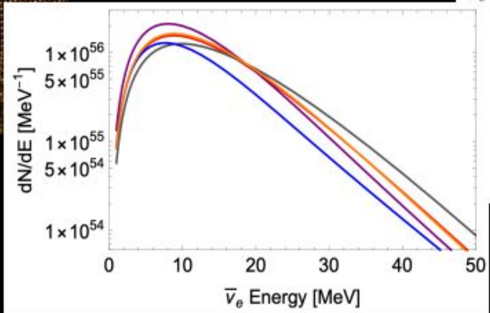
Neutrino detector capabilities

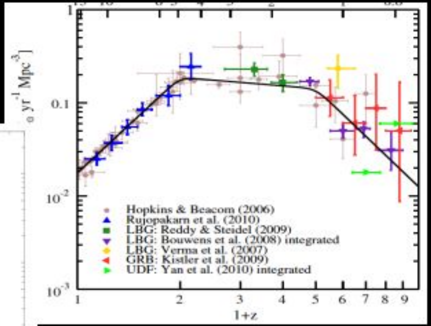
Time-integrated neutrino emission

Rate of massive star core collapse



$$\bar{\nu}_e + p \rightarrow e^+ + n$$





Shunsaku Horiuchi

3

DSNB challenges

$$R = N_t \int dE\, \sigma_{\rm IBD} \int dz\, c \frac{dN}{dE'}(1+z) R_{CC}(z) \left| \frac{dt}{dz} \right|$$

1. What is the true core-collapse rate?

2. What is the time-integrated neutrino emission?
   - For exploding Fe core collapses
   - Diversity in neutrino emissions
   - Other effects

3. Rates & detections (backgrounds)

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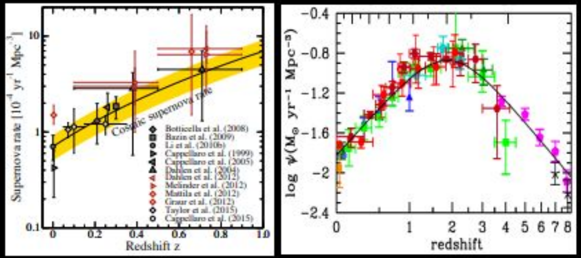
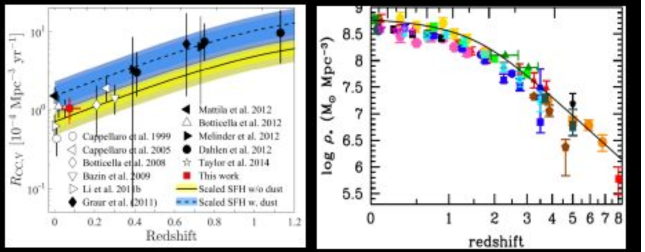
First take away

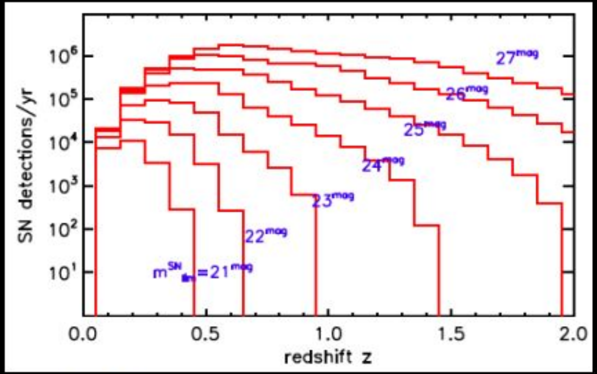
Are we confident core collapses are occurring? **Yes**



How certain are we about the rate? **To factor ~2**



Plus, orders of magnitude more core-collapse supernovae expected by LSST (2025~).



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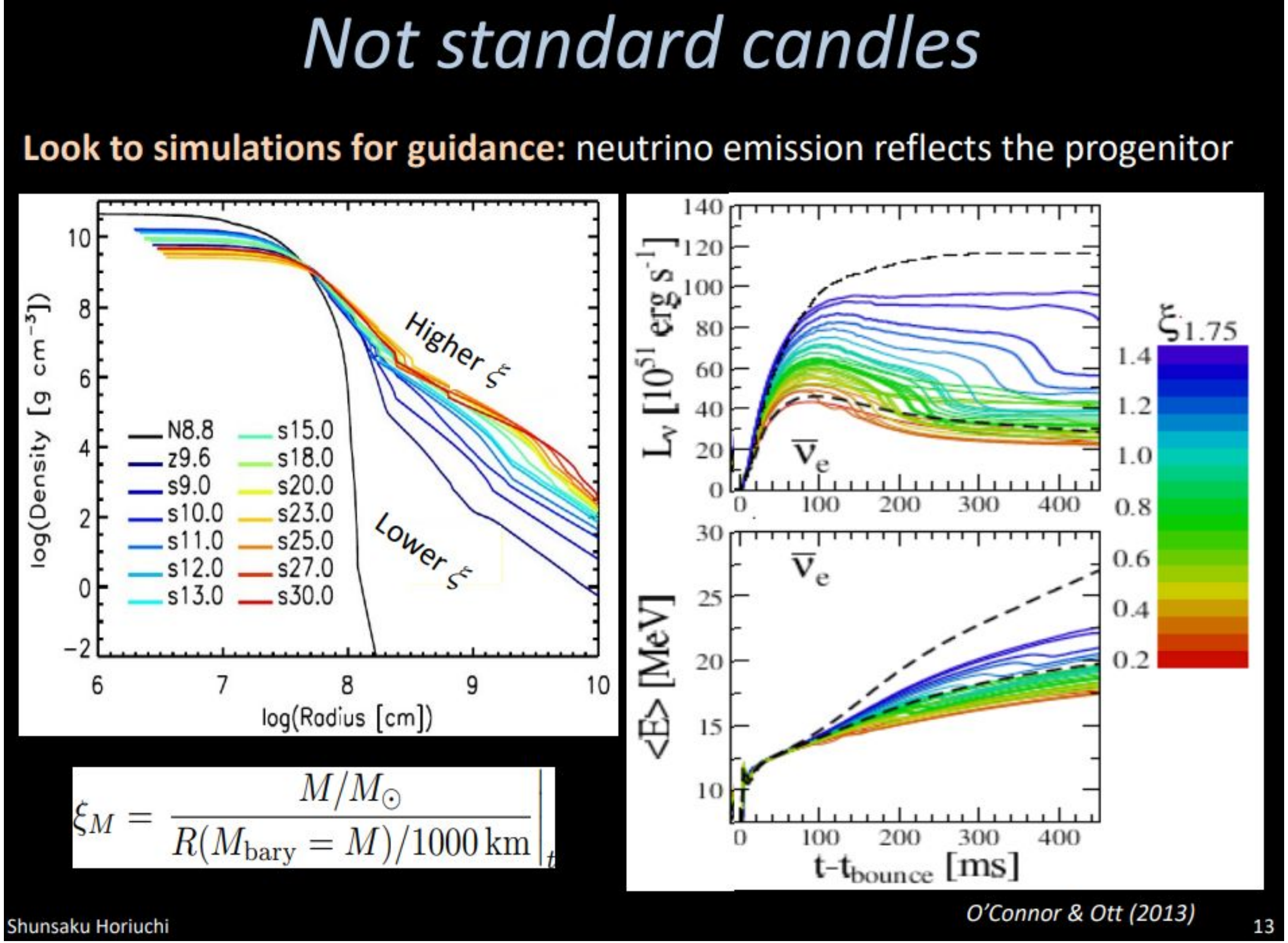
Lien & Fields (2009)

11

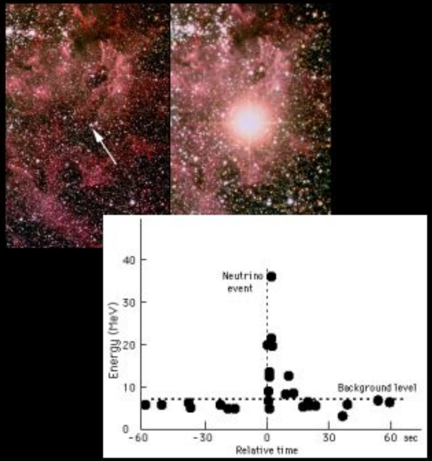


Don't forget missing SN (e.g., failed to explode)

Second take away

Are we confident core collapses are emitting neutrinos?

Yes



Are we certain about the time-integrated neutrino signal?

Still many dependences to study, eg, progenitors

CC & explosion details

cooling phase treatments

BH contribution

Other effects…

These are what we want to test with the DSNB

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26

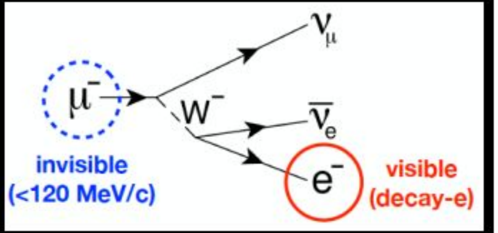
Relevant backgrounds

1. Neutrinos

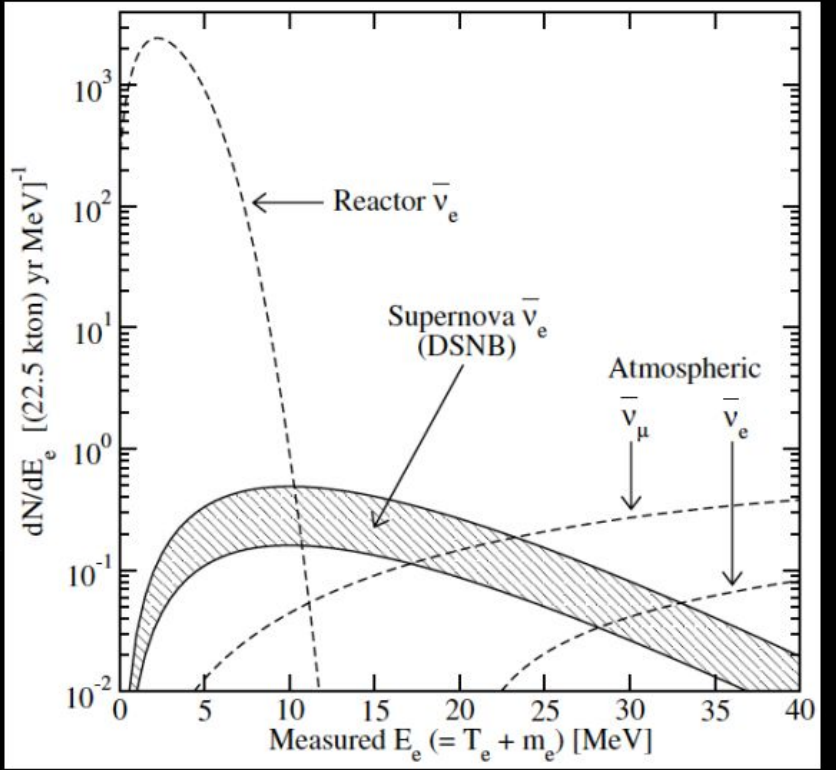
- Reactor neutrinos
- Atmospheric neutrinos

2. Non-neutrinos

- Invisible muon decays



- CR μ spallation products
- Atmospheric neutrino related



Beacom & Vagins (2004)

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31

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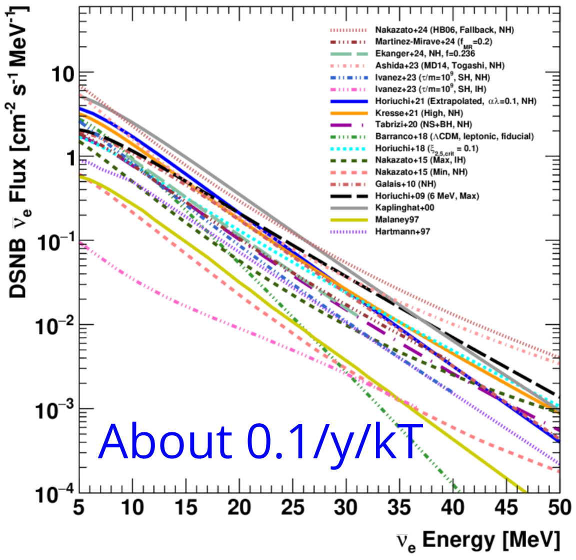
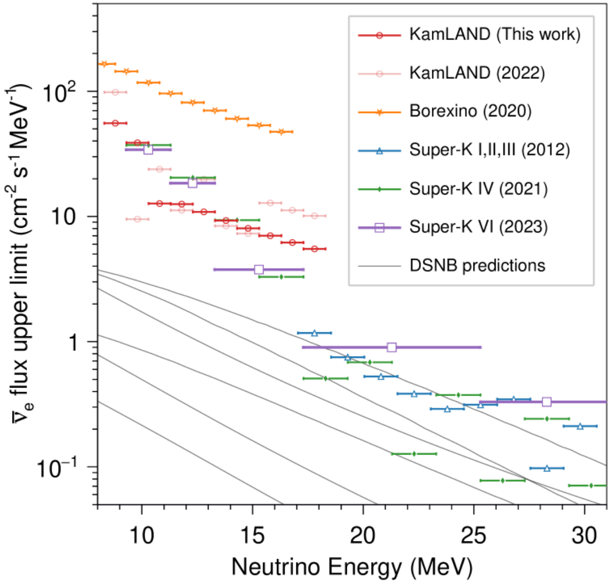
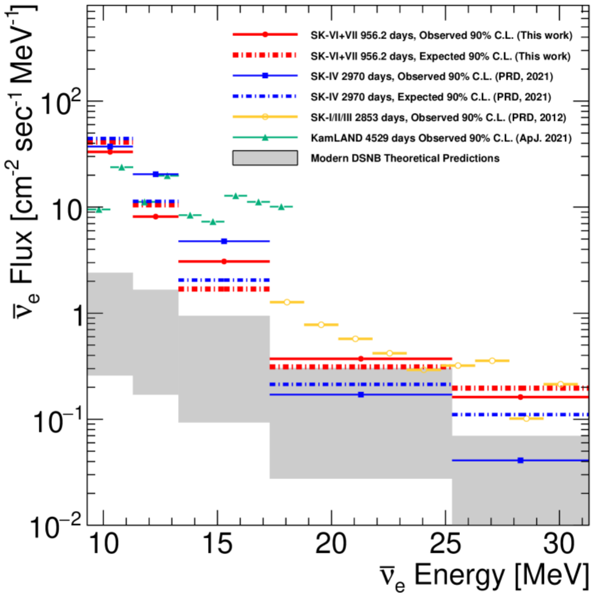
DSNB search

Predictions





KamLAND, Arxiv:2606.29381, 30 June 2026

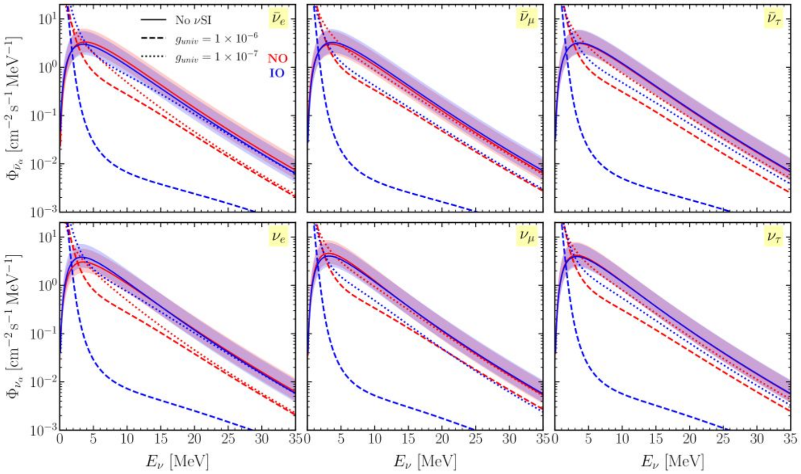


Super-Kamiokande, arxiv:2511.02222

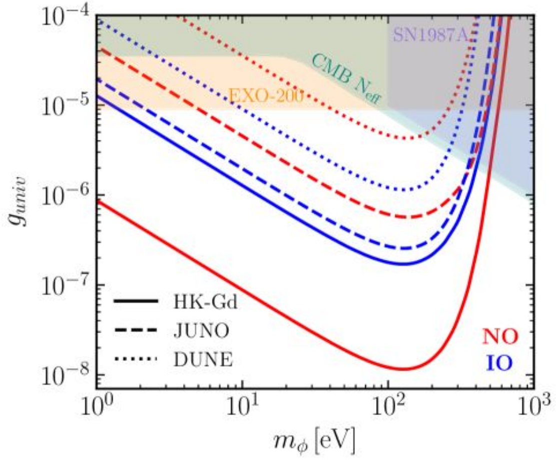
P Bharadwaj, U Chattopadhyay, DK Ghosh, A Sarker, arxiv:2606.22898

DSNB-CνB with secret neutrino interactions

- Resonant scattering of DSNB (> 10 MeV) off cosmic relic neutrinos (CνB) via scalar-mediated non-standard neutrino self-interactions

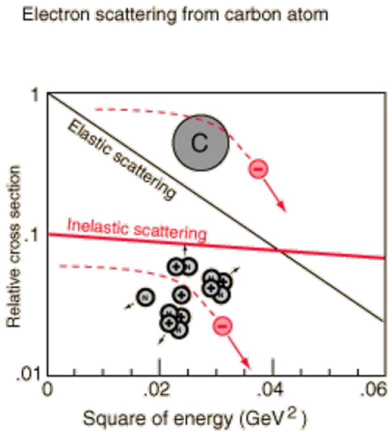


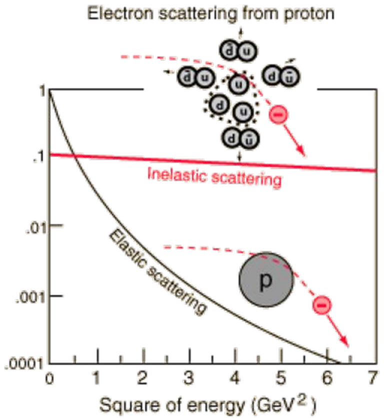
Spectra with 100eV mediator mass

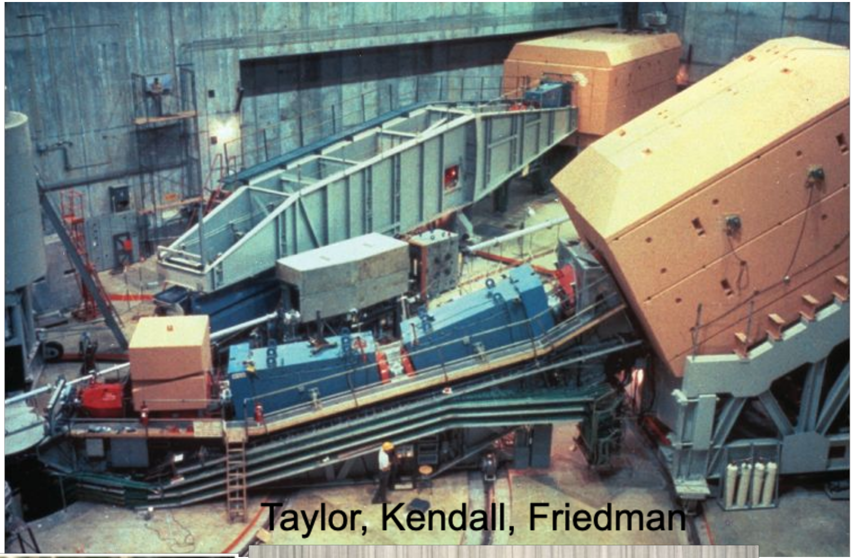


3σ exclusion, universal coupling

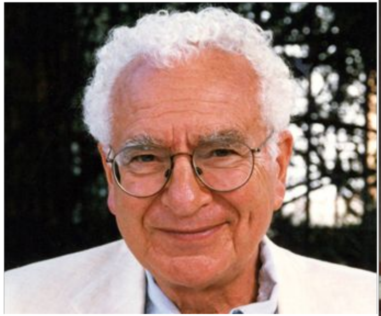
Interlude: deep inelastic (quasi-elastic) scattering & quarks



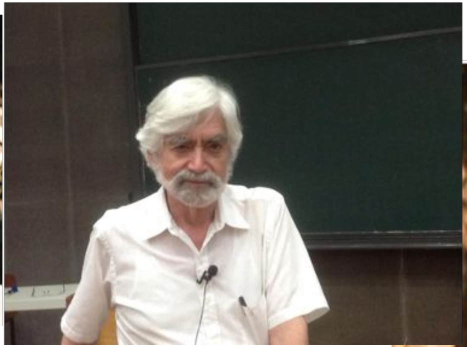




Gell-Mann



Zweig

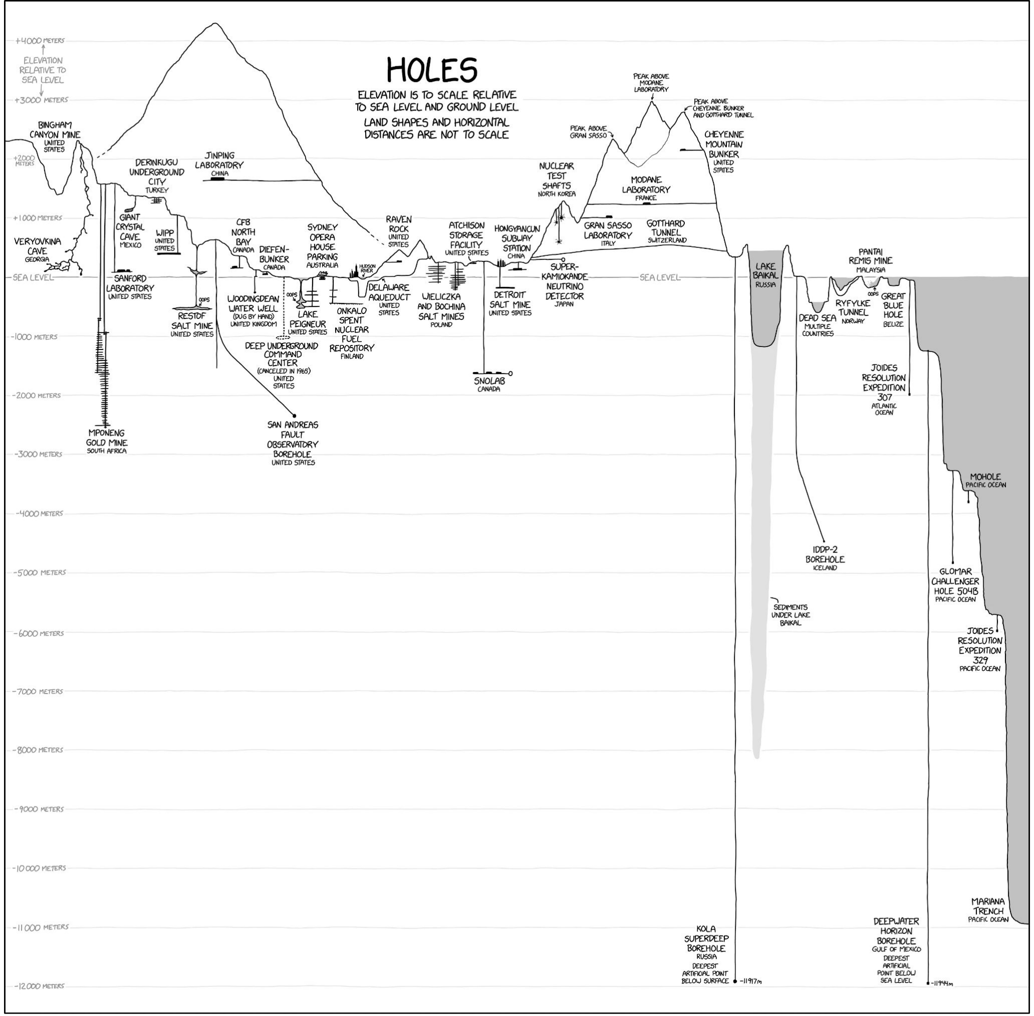


Bjorken

Taylor, Kendall, Friedman

Direct detection of supernova burst

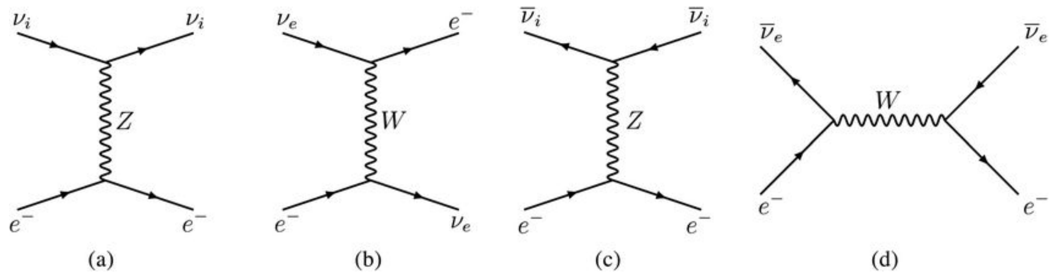
Step 1. Dig.



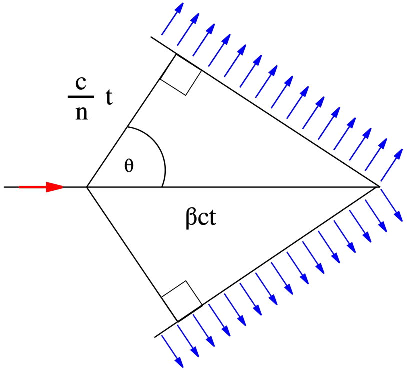
Randall Munroe,
Xkcd, 1(3?) July 2026

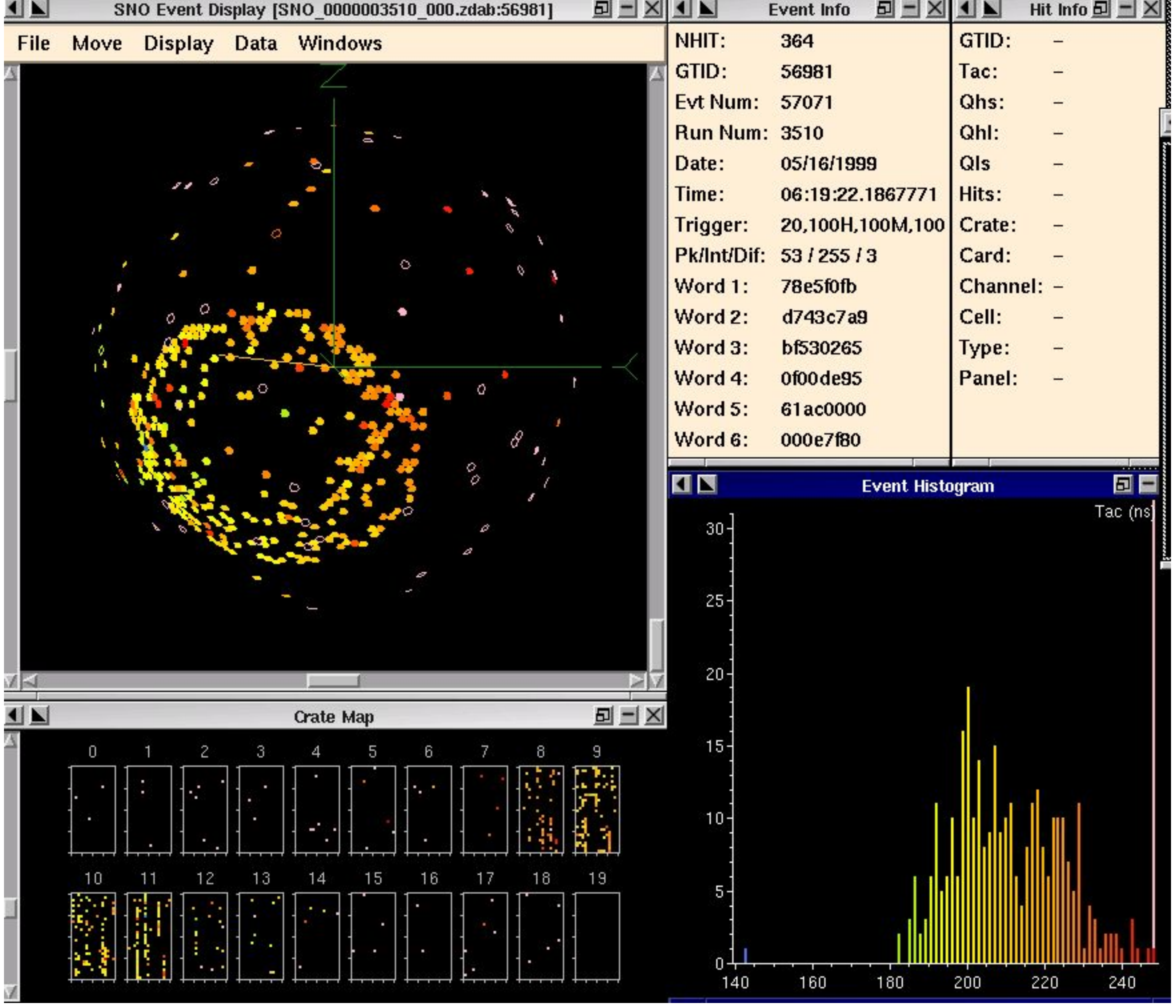
Elastic scattering off electrons

- Incoming neutrino imparts energy to an atomic orbital electron



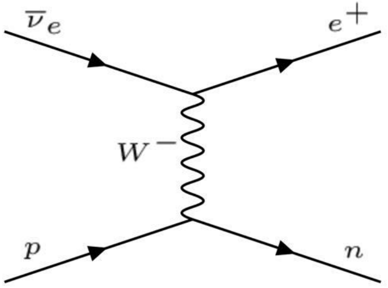
- If enough energy, electron velocity > speed of light in medium (e.g., water)
  $\rightarrow$ Cherenkov radiation

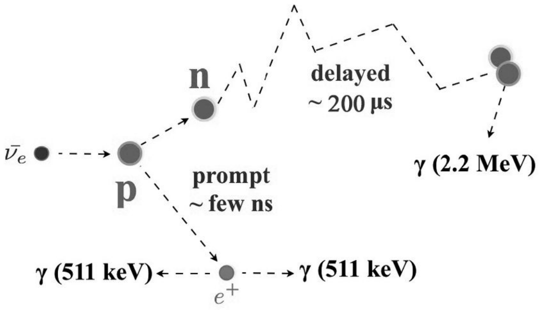


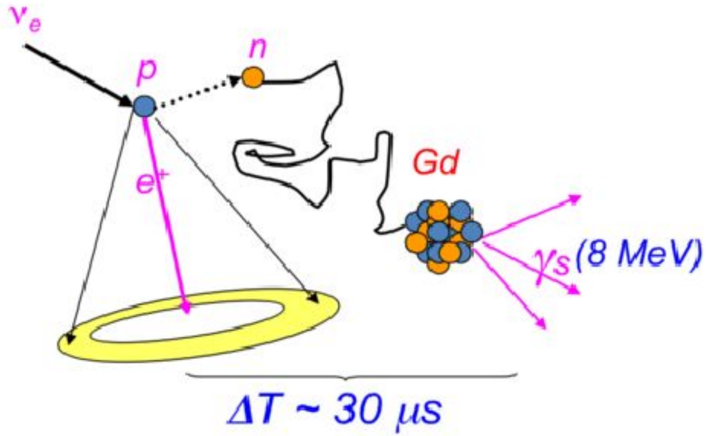


Water Cherenkov detector

Inverse beta decay







Ideally, detect coincidence between e^+ event and n absorption
→ much reduced backgrounds

Other interaction channels

- There's more than just protons (hydrogen nuclei) and electrons
- Everything happens - or, anything which can happen will happen
    - Same can be said about backgrounds!
- Supernova burst is so intense, must also consider sub-dominant channels
- Neutrinos can also interact with heavy nuclei around the detector, with scattering products propagating into detector

Interaction channels

SNO+: 780t organic liquid scintillator

Reaction	Yield
NC: $\nu p \to \nu p$	429.1 ± 12.0
CC: $\bar{\nu}_e p \to e^+ n$	194.7 ± 1.0
CC: $\bar{\nu}_e\ {}^{12}\mathrm{C} \to e^+\ {}^{12}\mathrm{B}_{gs}$	7.0 ± 0.7
CC: $\nu_e\ {}^{12}\mathrm{C} \to e^-\ {}^{12}\mathrm{N}_{gs}$	2.7 ± 0.3
NC: $\nu\ {}^{12}\mathrm{C} \to \nu'\ {}^{12}\mathrm{C}^*(15.1\ \mathrm{MeV})$	43.8 ± 8.7
CC/NC: $\nu\ {}^{12}\mathrm{C} \to\ {}^{11}\mathrm{C}$ or ${}^{11}\mathrm{B}+X$	2.4 ± 0.5
νe elastic scattering	13.1

SNO+, Adv HEP 2016 (2016) 6194250

Super-Kamiokande:
32kt water Cherenkov + Gd

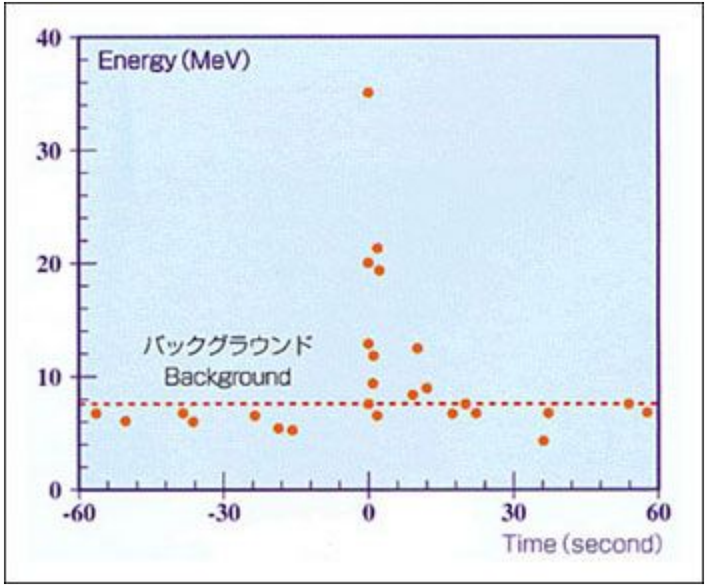
Reconstructed	Hüdepohl			Fischer			Tamborra		
	No Osc.	NMO	IMO	No Osc.	NMO	IMO	No Osc.	NMO	IMO
IBD ($\bar{\nu}_e$)	1936	1939	1935	1186	1260	1437	2505	2283	1786
ES (ν_e)	38	39	39	22	29	26	46	33	37
ES ($\bar{\nu}_e$)	9	8	8	5	6	6	12	10	8
ES (ν_x)	12	12	12	9	8	8	10	12	12
ES ($\bar{\nu}_x$)	10	10	10	7	7	7	8	9	10
^{16}O CC (ν_e)	7	19	16	3	17	13	35	58	51
^{16}O CC ($\bar{\nu}_e$)	19	20	21	9	11	17	62	58	49
^{16}O NC (ν_e, ^{15}N)	0	0	0	0	0	0	0	0	0
^{16}O NC ($\bar{\nu}_e$, ^{15}N)	0	0	0	0	0	0	0	0	0
^{16}O NC (ν_x, ^{15}N)	0	0	0	0	0	0	0	0	0
^{16}O NC ($\bar{\nu}_x$, ^{15}N)	0	0	0	0	0	0	0	0	0
^{16}O NC (ν_e, ^{15}O)	0	0	0	0	0	0	0	0	0
^{16}O NC ($\bar{\nu}_e$, ^{15}O)	0	0	0	0	0	0	0	0	0
^{16}O NC (ν_x, ^{15}O)	0	0	0	0	0	0	0	0	0
^{16}O NC ($\bar{\nu}_x$, ^{15}O)	0	0	0	0	0	0	0	0	0
total	2031	2037	2041	1241	1338	1514	2678	2463	1953

Super-K, arxiv:2403.06760

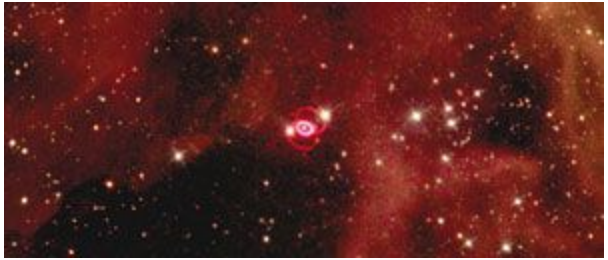
Data: SN1987A

23 Feb 1987

Kamiokande



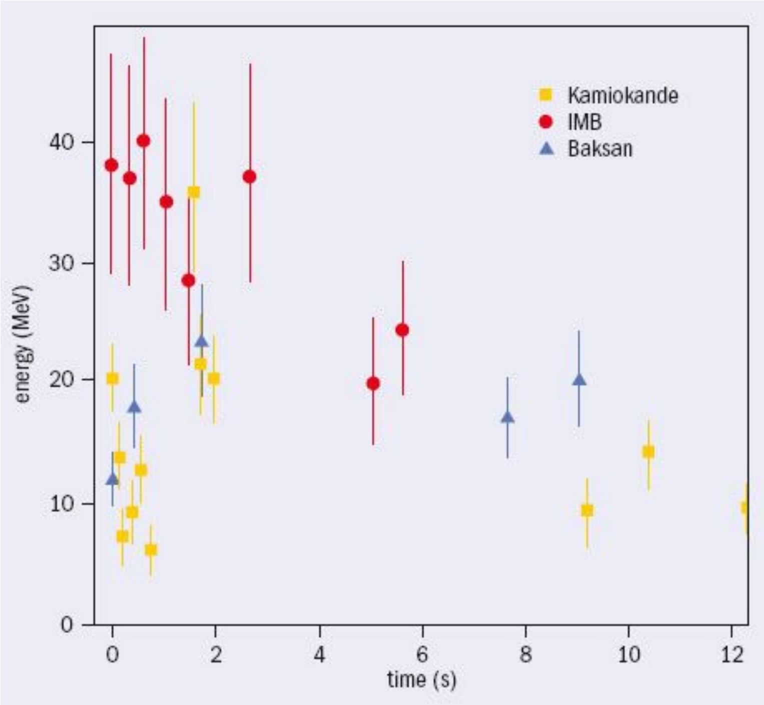
2-3 hours later:
Ian Shelton
(Toronto)
Oscar Duhalde
(Las Campanas)
Albert Jones
(AAVSO)

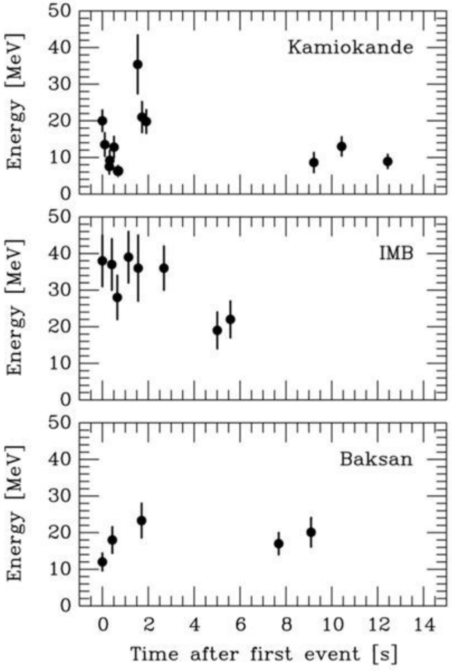


HST, 1990’s

Before/after images © Anglo-Australian Observatory / David Malin

SN1987A neutrinos around the world





Kamiokande-II (Japan)
Water Cherenkov detector
2140 tons
Clock uncertainty ± 1 min

Irvine-Michigan-Brookhaven (US)
Water Cherenkov detector
6800 tons
Clock uncertainty ± 50 ms

Baksan Scintillator Telescope
(Soviet Union), 200 tons
Random event cluster ~ 0.7/day
Clock uncertainty $+2/-54$ s

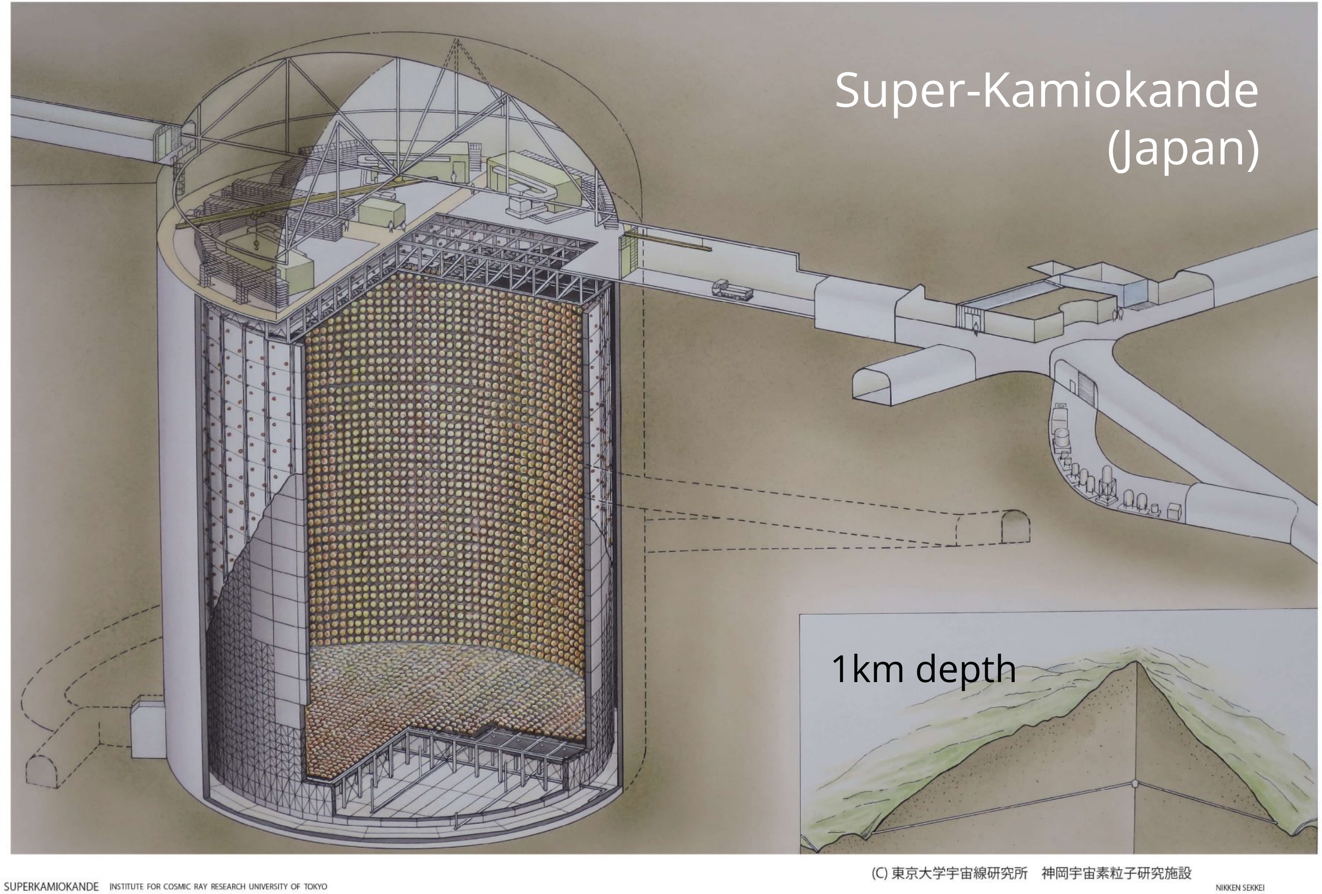
Within clock uncertainties, all signals are contemporaneous

Georg Raffelt, MPI Physics, Munich — Neutrinos in Astrophysics and Cosmology, NBI, 23–27 June 2014

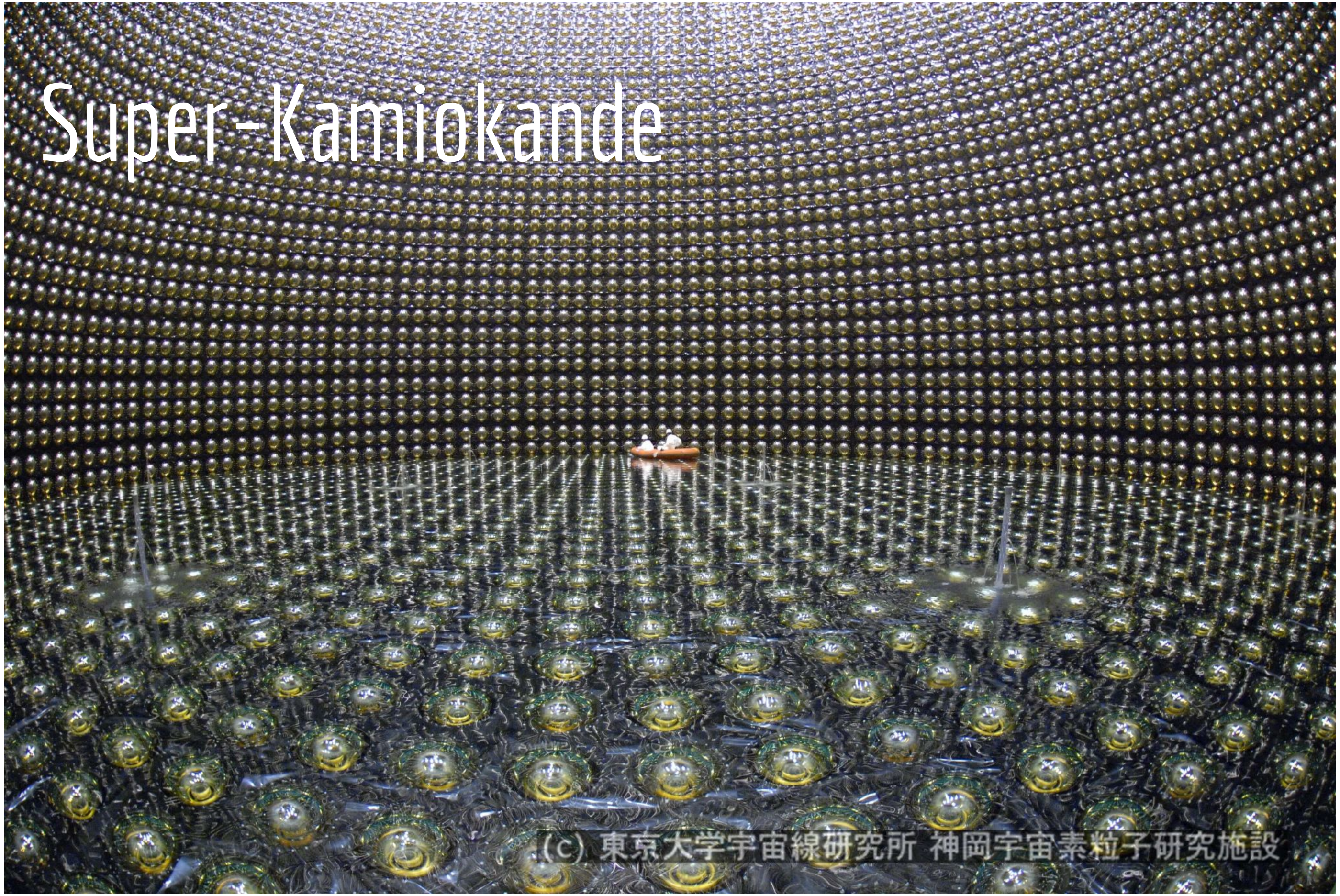
Modern neutrino detectors: the good news

- It’s easier to synchronize clocks across the globe with GPS
- Neutrino detectors are bigger and more capable than in 1987
- There is a greater diversity among neutrino-sensitive detectors

Super-Kamiokande (Japan)



Super-Kamiokande



Ultra-
pure
water

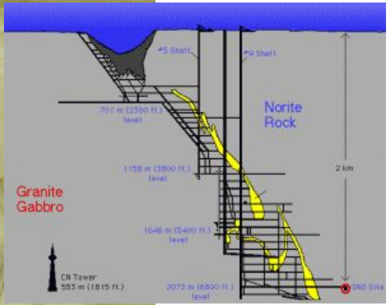
From https://www-sk.icrr.u-tokyo.ac.jp/en/sk/experience/gallery/

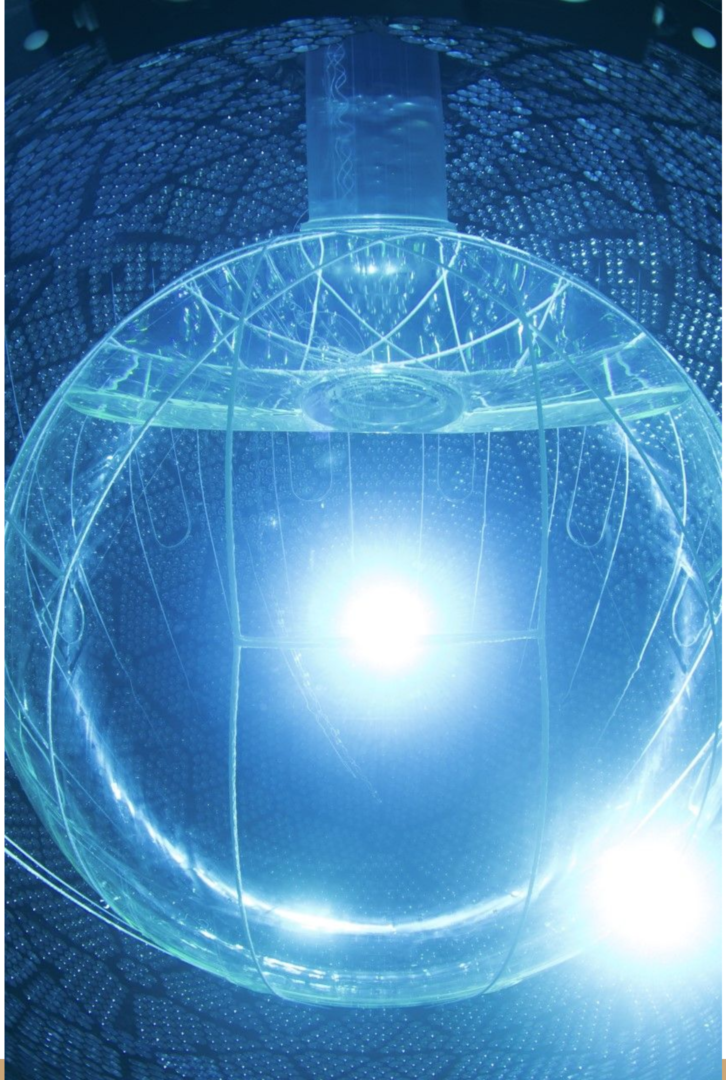
Over 5x bigger than Super-Kamiokande

Under construction

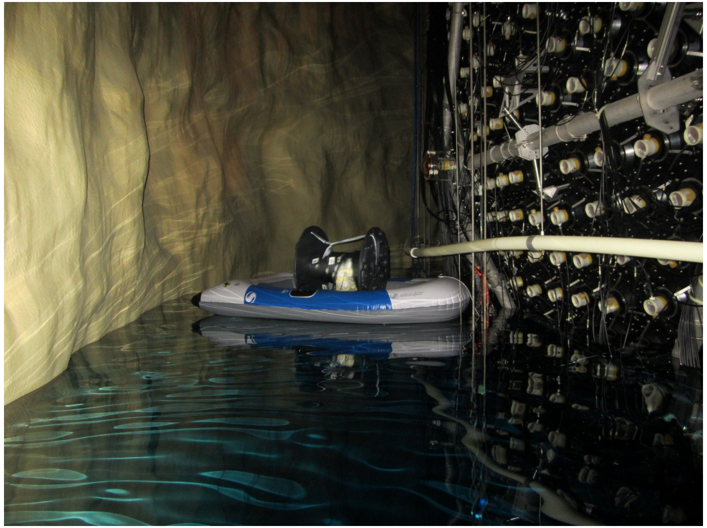
(Could see neutrinos from Andromeda!)

SNO+

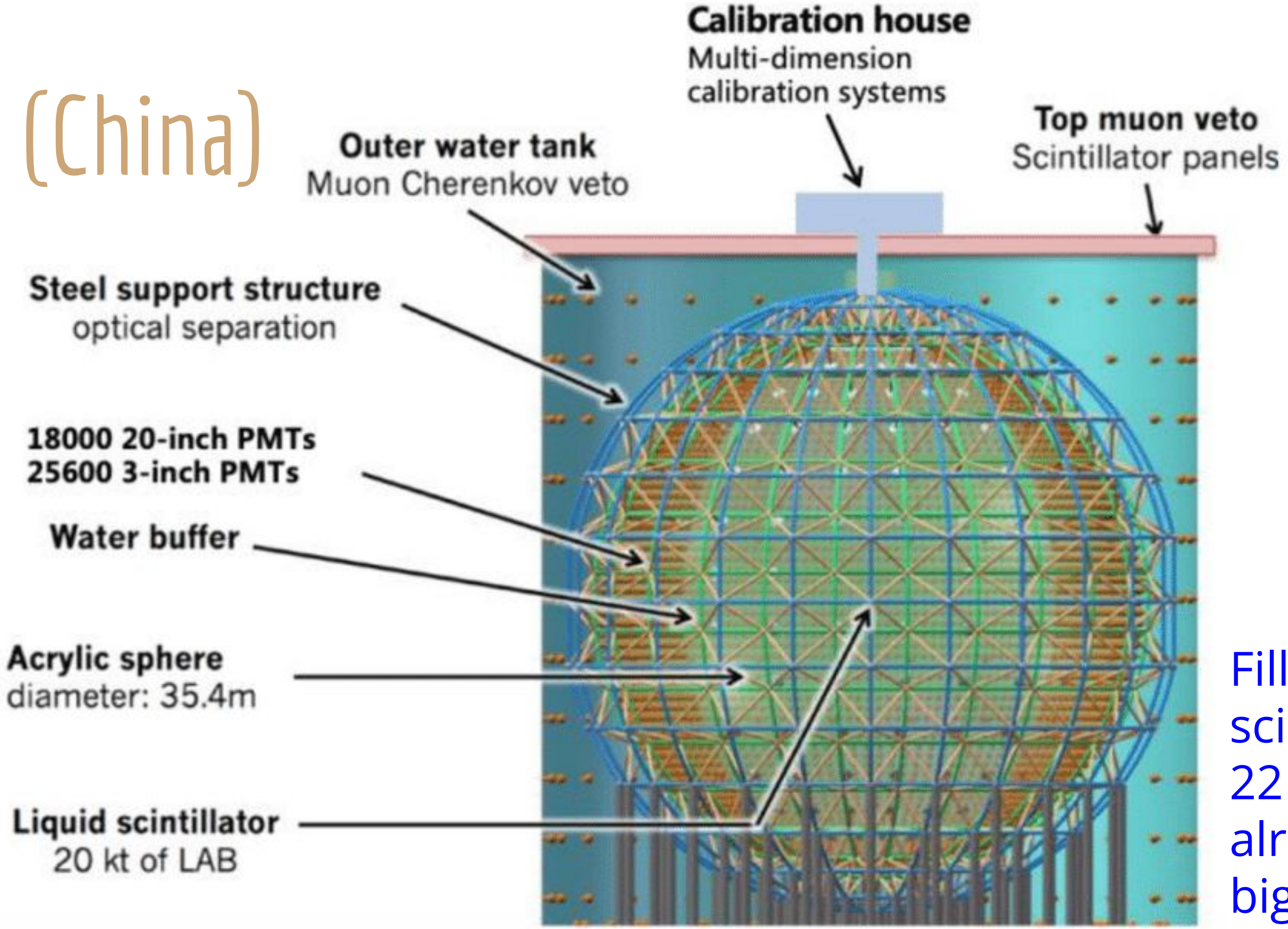

#5 Shaft
#9 Shaft
Norite Rock
701 m (2300 ft.) level
1158 m (3800 ft.) level
2 km
Granite Gabbro
1646 m (5400 ft.) level
CN Tower 553 m (1815 ft.)
2073 m (6800 ft.) level
SNO Site



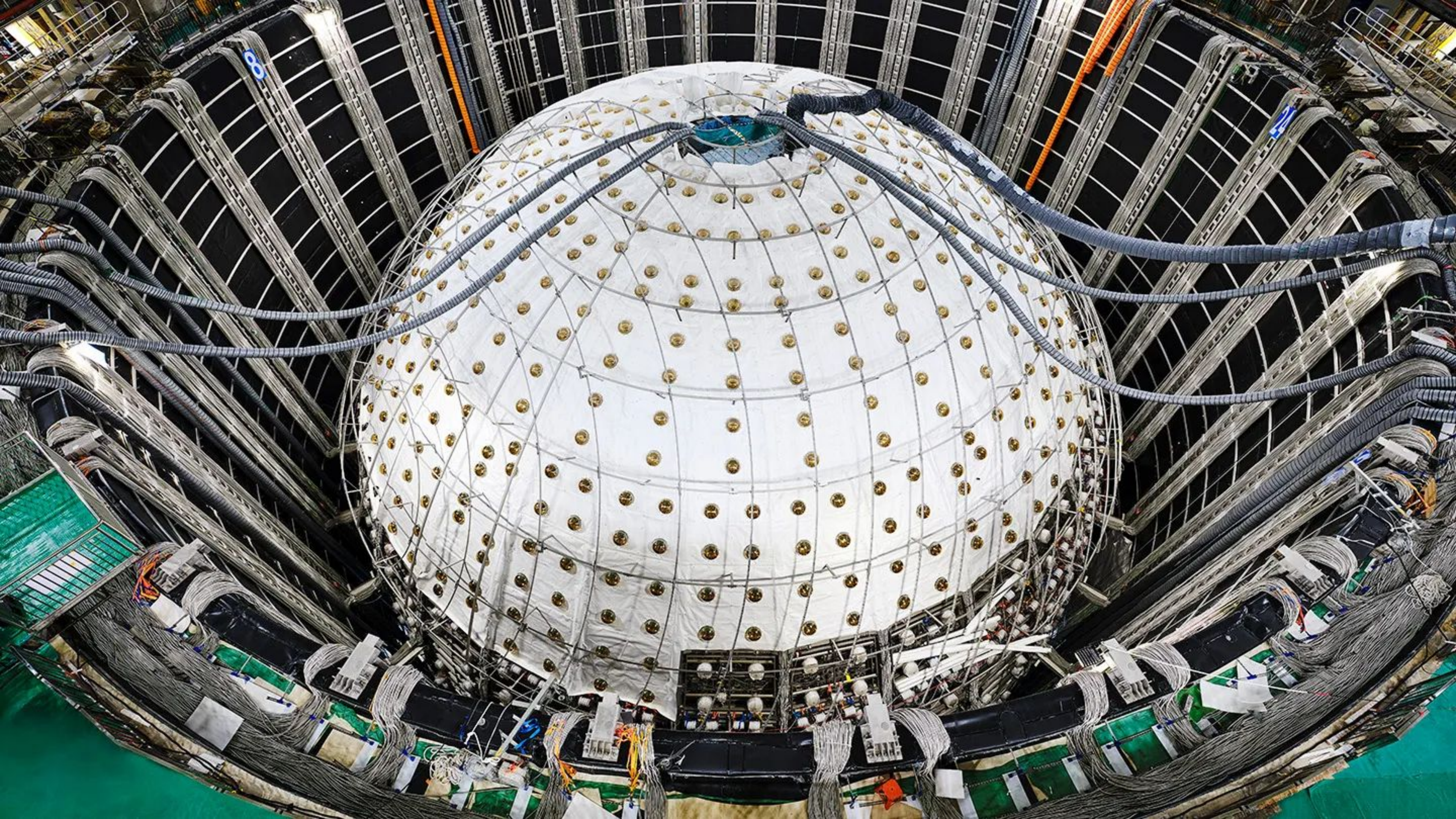
Not your [average] undergraduate physics lab (though it's still underground)



JUNO (China)

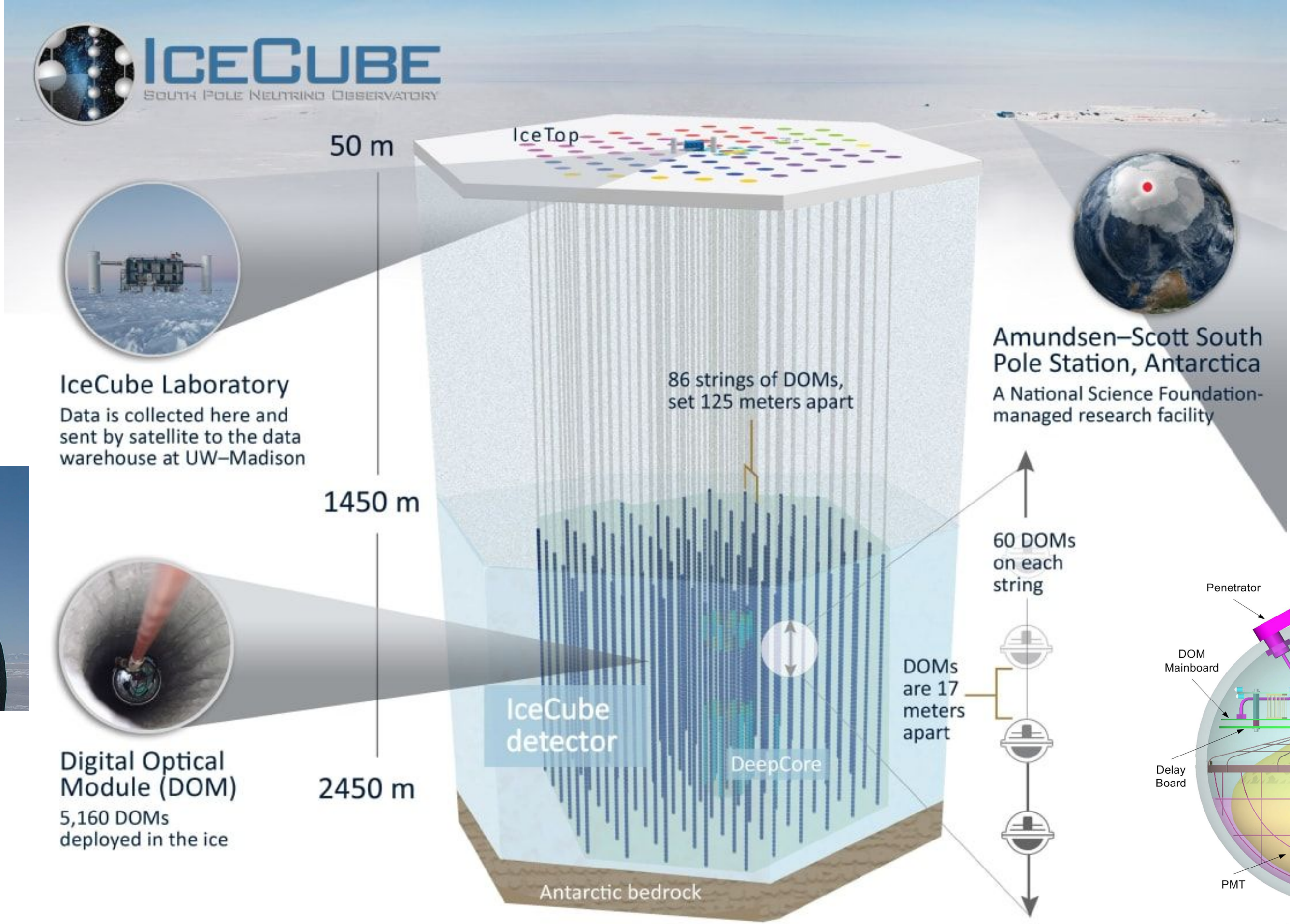


Filled with liquid scintillator 22 Aug 2025, already making a big impact

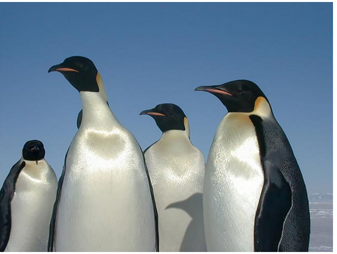

8

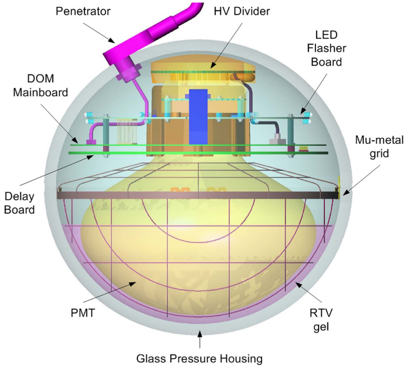
New neutrino detector types

- Neutrino telescopes
  - Designed for high-energy (>1 TeV) neutrinos
- Heavy elements
  - Liquid noble elements
  - Lead
- Dark matter direct detection
  - Liquid noble elements: large A, low thresholds



ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY
IceTop
50 m
1450 m
2450 m
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
86 strings of DOMs, set 125 meters apart
IceCube detector
DeepCore
Antarctic bedrock
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
60 DOMs on each string
DOMs are 17 meters apart



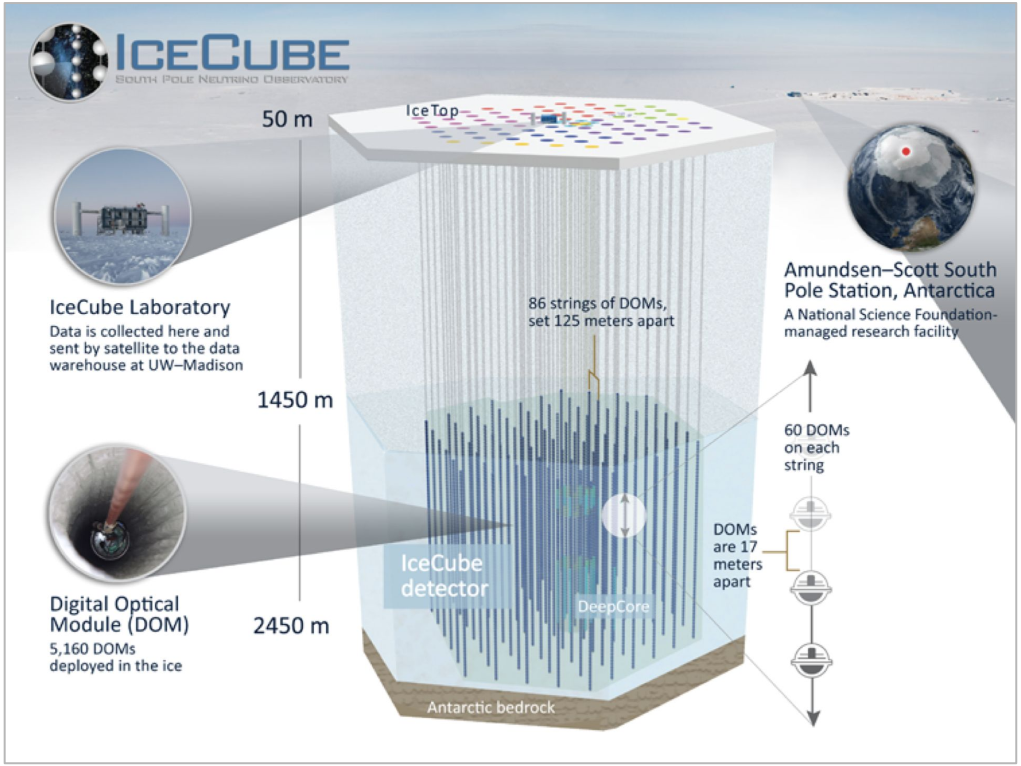


Penetrator
HV Divider
LED Flasher Board
DOM Mainboard
Mu-metal grid
Delay Board
PMT
RTV gel
Glass Pressure Housing

Detecting Neutrinos with IceCube

IceCube Neutrino Observatory: the world's largest particle detector.

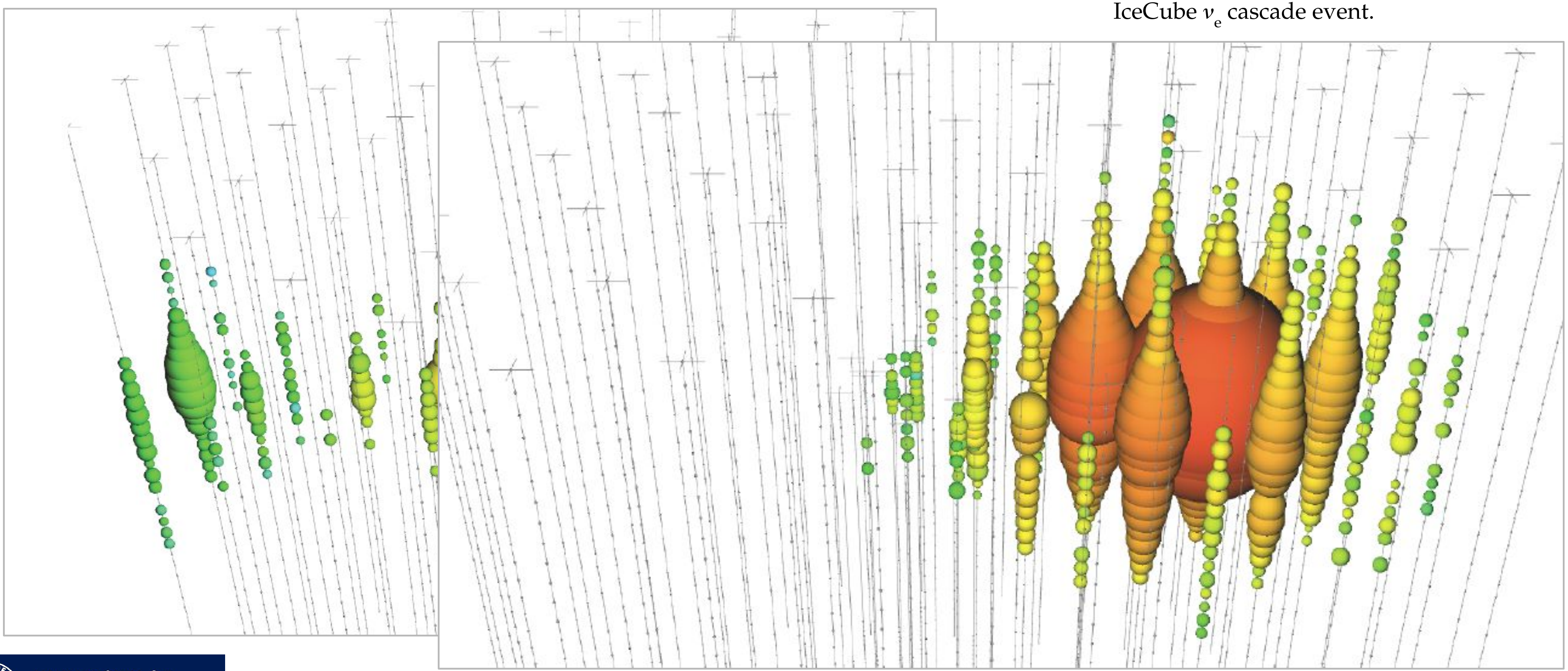
- Design goal: observe origins of high-energy cosmic rays and astrophysical neutrinos.
- 5,160 single-PMT Digital Optical Modules (**DOMs**) buried in clear ice 1.4-2.4 km under South Pole.
- ~100,000 **atmospheric** neutrino candidates per year, > 5 GeV.
- Localized **astrophysical** neutrino candidates, > 100 TeV: ~1 month^{-1}.



Astrophysical Neutrino Candidates

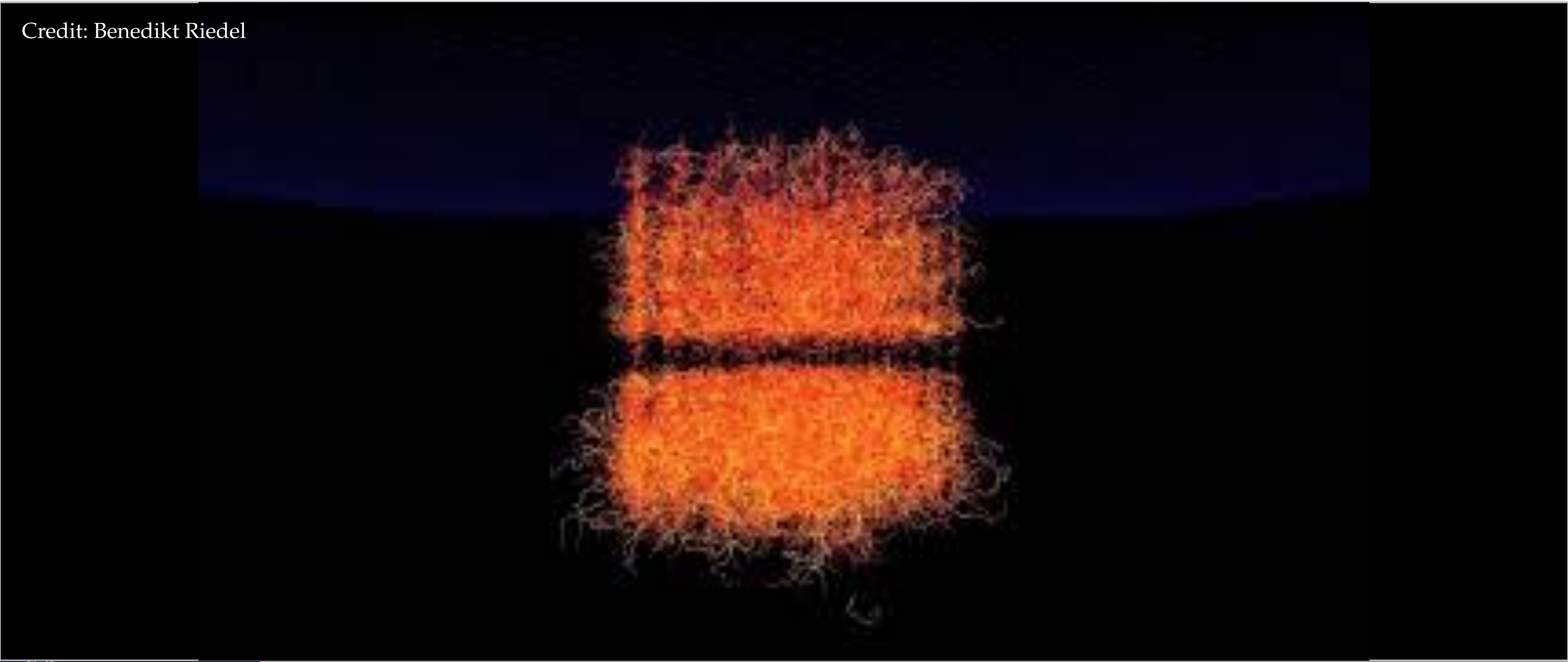
IceCube ν_μ track event.

IceCube ν_e cascade event.

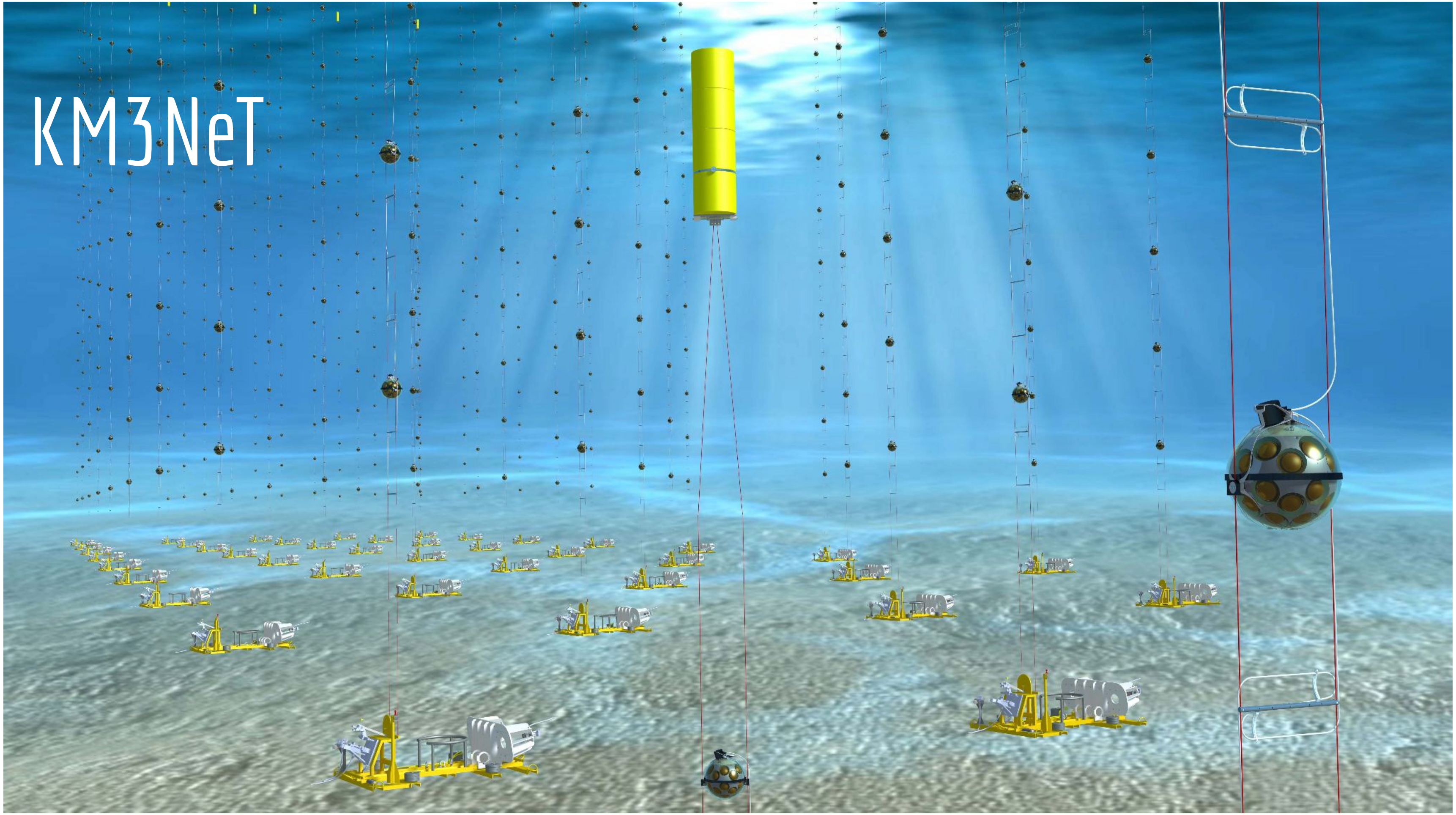


From S BenZvi, SNvD@LNGS (1 June 2023)

CCSN MeV ν Signal in IceCube



KM3NeT



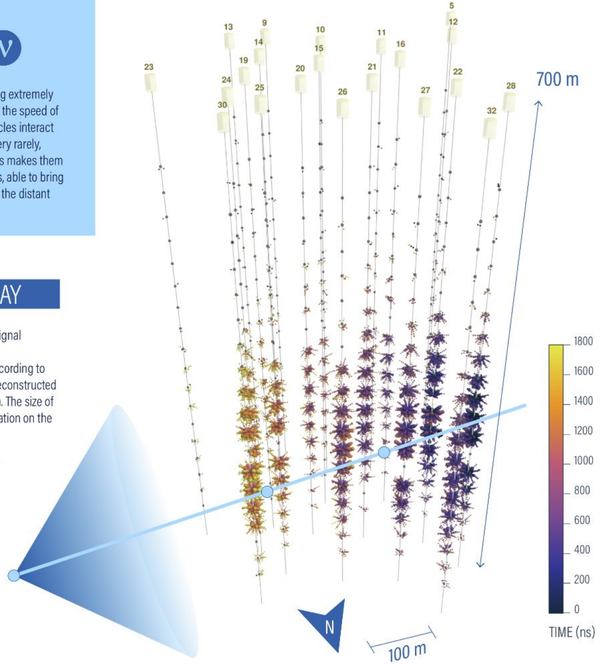
THE RECORD NEUTRINO

NEUTRINOS ν

With no electric charge, being extremely light and travelling almost at the speed of light, these elementary particles interact only weakly, and therefore very rarely, with matter. Their elusiveness makes them valuable cosmic messengers, able to bring us unique information about the distant universe.

THE EVENT DISPLAY

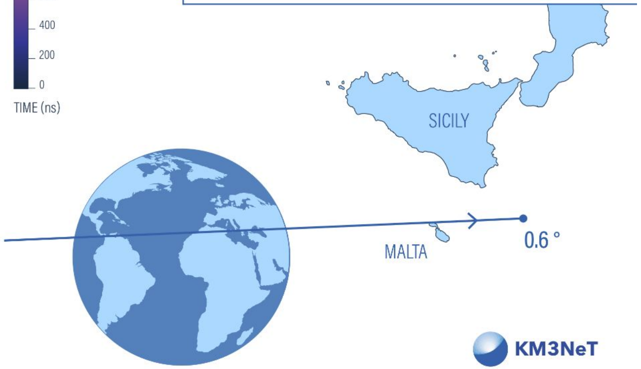
A view of the KM3-230213A signal detected by KM3NeT.
The spheres are coloured according to the detection time and the reconstructed track of the particle is shown. The size of the blue cone gives an indication on the amplitude of the signal.



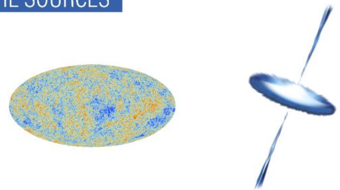
On 13 February 2023, at a depth of 3450 metres off the coast of Sicily, in Italy, the ARCA detector of the KM3NeT submarine neutrino telescope recorded an extraordinary signal: produced by a neutrino with a record energy of about 220 PeV, corresponding to 220 million billion electronvolts. This signal, named KM3-230213A, provides the first evidence that neutrinos with such extreme energies exist in the universe.

KM3-230213A IDENTIKIT

The cosmic neutrino plunged into the Mediterranean Sea and crossed the Malta continental shelf with an inclination of 0.6° above the horizon. During this journey, it travelled almost at the speed of light and interacted with an atomic nucleus, generating an ultra-relativistic muon, which crossed the whole detector.



THE SOURCES



The origin of the ultra-high energy neutrino could have been one of the cataclysmic events that animate our universe, such as an active galactic nucleus or a gamma-ray burst. Or it could be a neutrino generated by the interaction of an ultra-high energy cosmic-ray particle with the cosmic background radiation that permeates the universe.

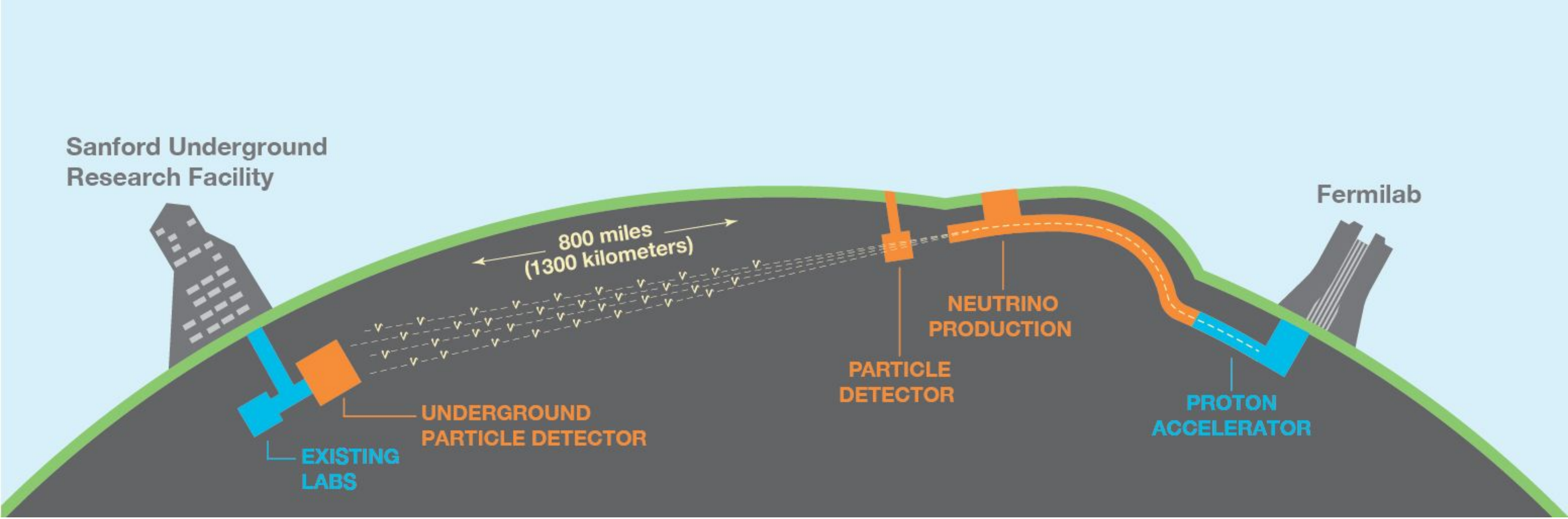
KM3NeT

Co-funded by the European Union

DUNE

Primarily sensitive to ν_e via Ar scattering and coherent elastic neutrino-nucleus scattering (CEνNS)

www.dunescience.org



Helium and Lead Observatory
Astronomically patient

At SNOLAB as well

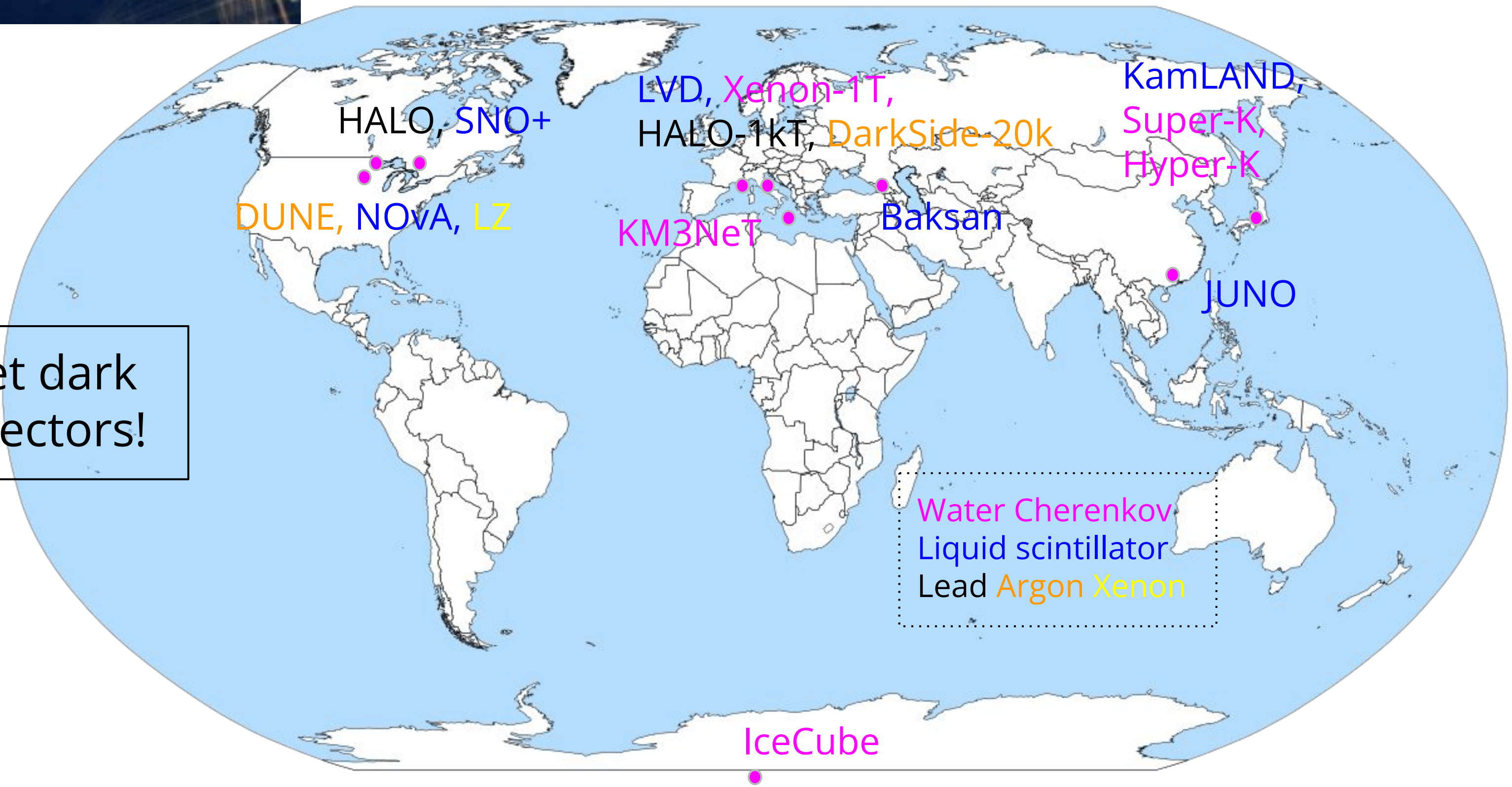
$\nu_e + \mathrm{Pb} \rightarrow e^- + \mathrm{Bi}^*$
$\mathrm{Bi}^* \rightarrow \mathrm{Bi} + \gamma + n$
$^3\mathrm{He} + n \rightarrow {}^3\mathrm{H} + p$

Operating since 2012

Expect only a few events, but…

Low maintenance. May outlast all the other detectors.

SNEWS
SUPERNOVA EARLY WARNING SYSTEM



Don’t forget dark matter detectors!

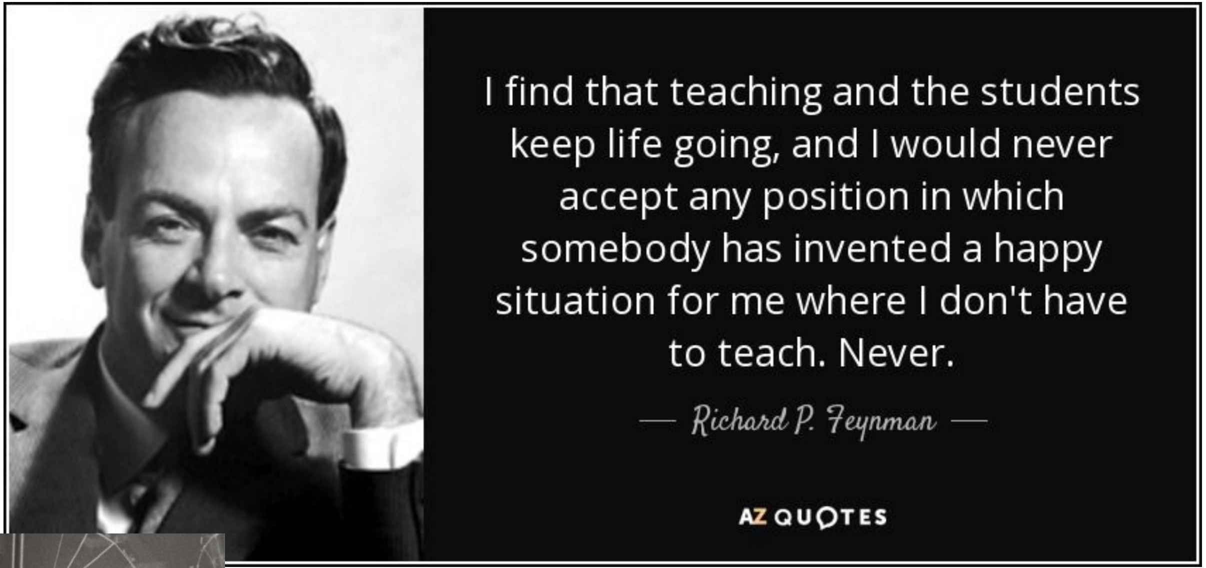
Event yields

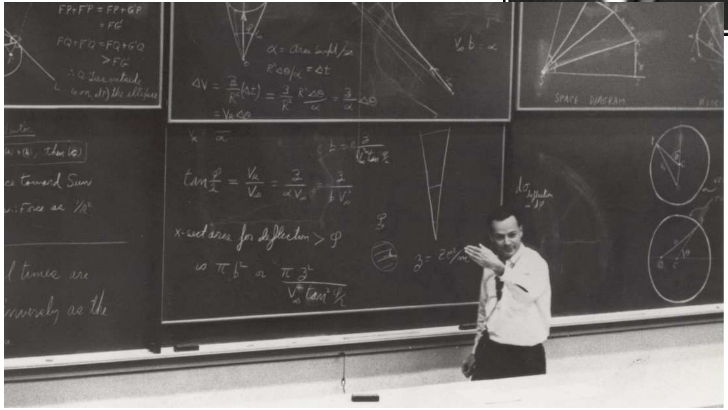
Primary channels, SN at 10kpc

Experiment	Type	Mass [kt]	Location	$11.2\,M_\odot$	$27.0\,M_\odot$	$40.0\,M_\odot$
Super-K	$H_2O/\bar{\nu}_e$	32	Japan	4000/4100	7800/7600	7600/4900
Hyper-K	$H_2O/\bar{\nu}_e$	220	Japan	28K/28K	53K/52K	52K/34K
IceCube	String/$\bar{\nu}_e$	2500*	South Pole	320K/330K	660K/660K	820K/630K
KM3NeT	String/$\bar{\nu}_e$	150*	Italy/France	17K/18K	37K/38K	47K/38K
LVD	$C_nH_{2n}/\bar{\nu}_e$	1	Italy	190/190	360/350	340/240
KamLAND	$C_nH_{2n}/\bar{\nu}_e$	1	Japan	190/190	360/350	340/240
Borexino	$C_nH_{2n}/\bar{\nu}_e$	0.278	Italy	52/52	100/97	96/65
JUNO	$C_nH_{2n}/\bar{\nu}_e$	20	China	3800/3800	7200/7000	6900/4700
SNO+	$C_nH_{2n}/\bar{\nu}_e$	0.78	Canada	150/150	280/270	270/180
NOνA	$C_nH_{2n}/\bar{\nu}_e$	14	USA	1900/2000	3700/3600	3600/2500
Baksan	$C_nH_{2n}/\bar{\nu}_e$	0.24	Russia	45/45	86/84	82/56
HALO	Lead/ν_e	0.079	Canada	4/3	9/8	9/9
HALO-1kT	Lead/ν_e	1	Italy	53/47	120/100	120/120
DUNE	Ar/ν_e	40	USA	2700/2500	5500/5200	5800/6000
MicroBooNe	Ar/ν_e	0.09	USA	6/5	12/11	13/13
SBND	Ar/ν_e	0.12	USA	8/7	16/15	17/18
DarkSide-20k	Ar/any ν	0.0386	Italy	-	250	-
XENONnT	Xe/any ν	0.006	Italy	56	106	-
LZ	Xe/any ν	0.007	USA	65	123	-
PandaX-4T	Xe/any ν	0.004	China	37	70	-

SNEWS2, New J Phys 23 (2021) 3, 031201

Interlude


I find that teaching and the students keep life going, and I would never accept any position in which somebody has invented a happy situation for me where I don't have to teach. Never.
— Richard P. Feynman —
AZ QUOTES



Detecting supernova neutrinos: summary

- Inverse beta decay and electron elastic scattering remaining the most important detection channels
  - Intensity of burst will also raise other channels
  - Overlap of events within trigger/coincidence windows can be an issue
- New detectors newly or coming online are larger and more capable than ever before
  - New detector types: neutrino telescopes, lead, noble liquids
  - Channels specific to electron neutrinos, to complement IBD anti-νe → flavor separation
  - Dark matter detectors can also contribute important data
- Now, let’s put them together!

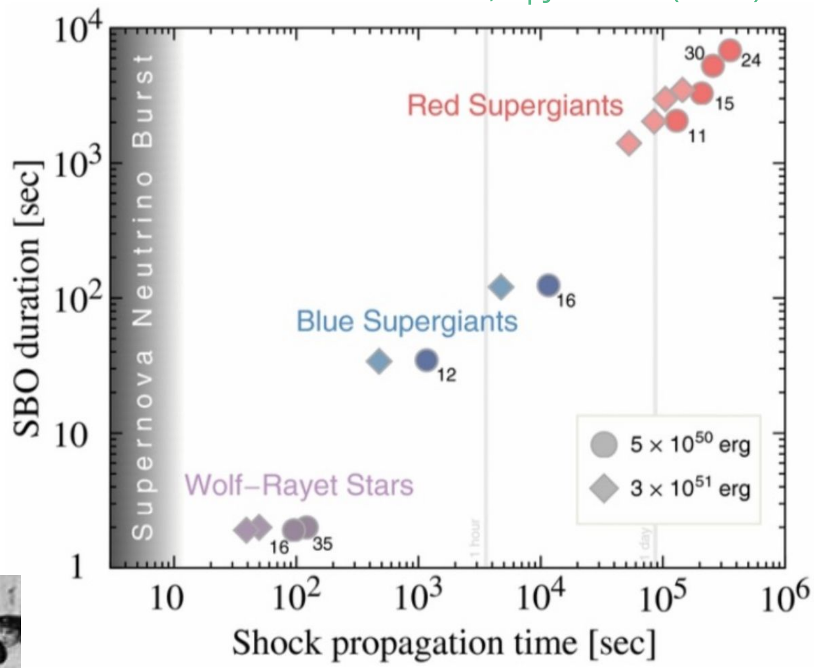
Chapter 5

The next Galactic core-collapse supernova

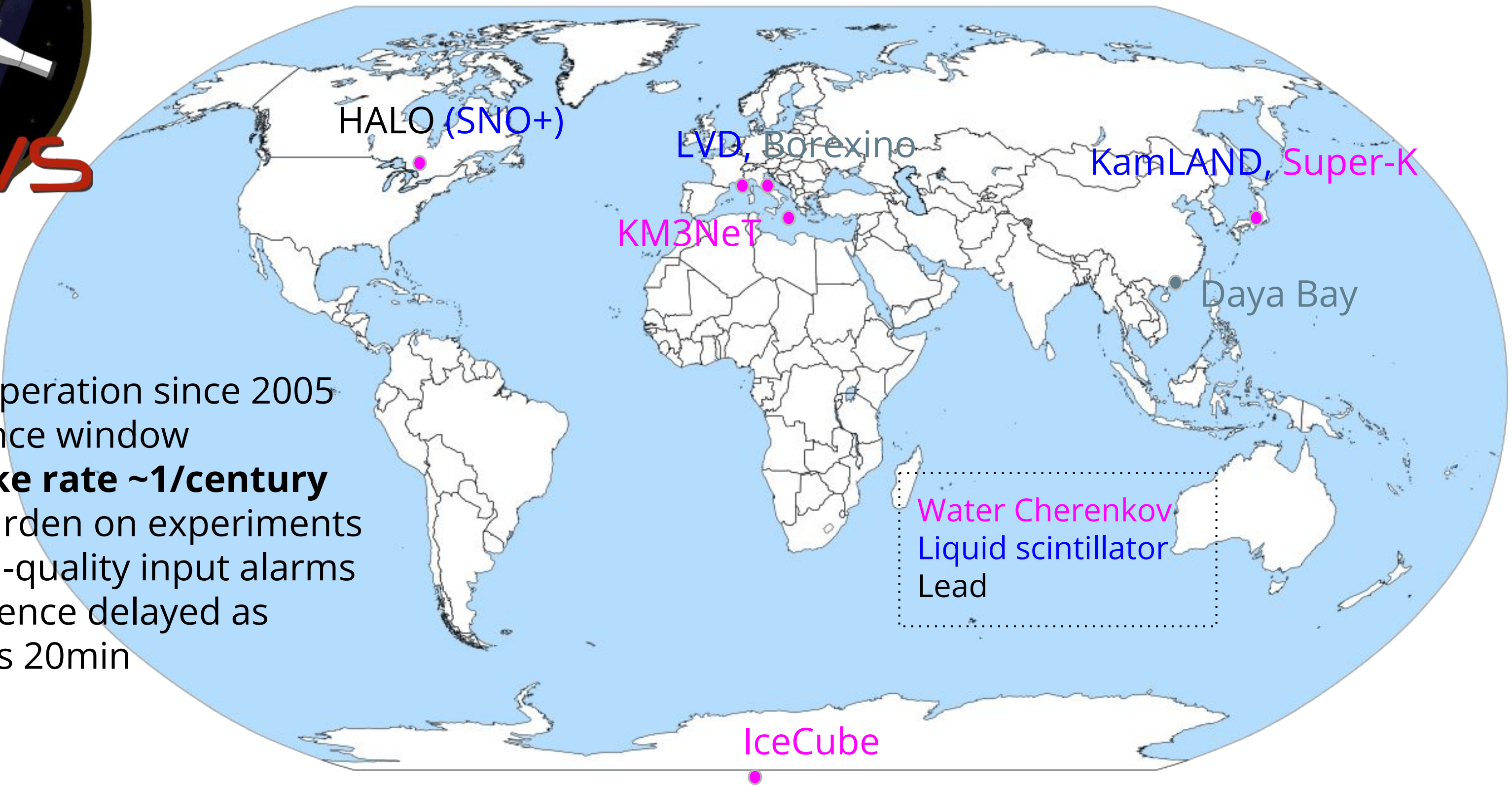
Race against time

- Neutrinos are the starting gun
- The race takes place once in a lifetime
  - You don't know when
  - You don't know how long it lasts
  - You want all hands on deck:
    every possible radiation and wavelength

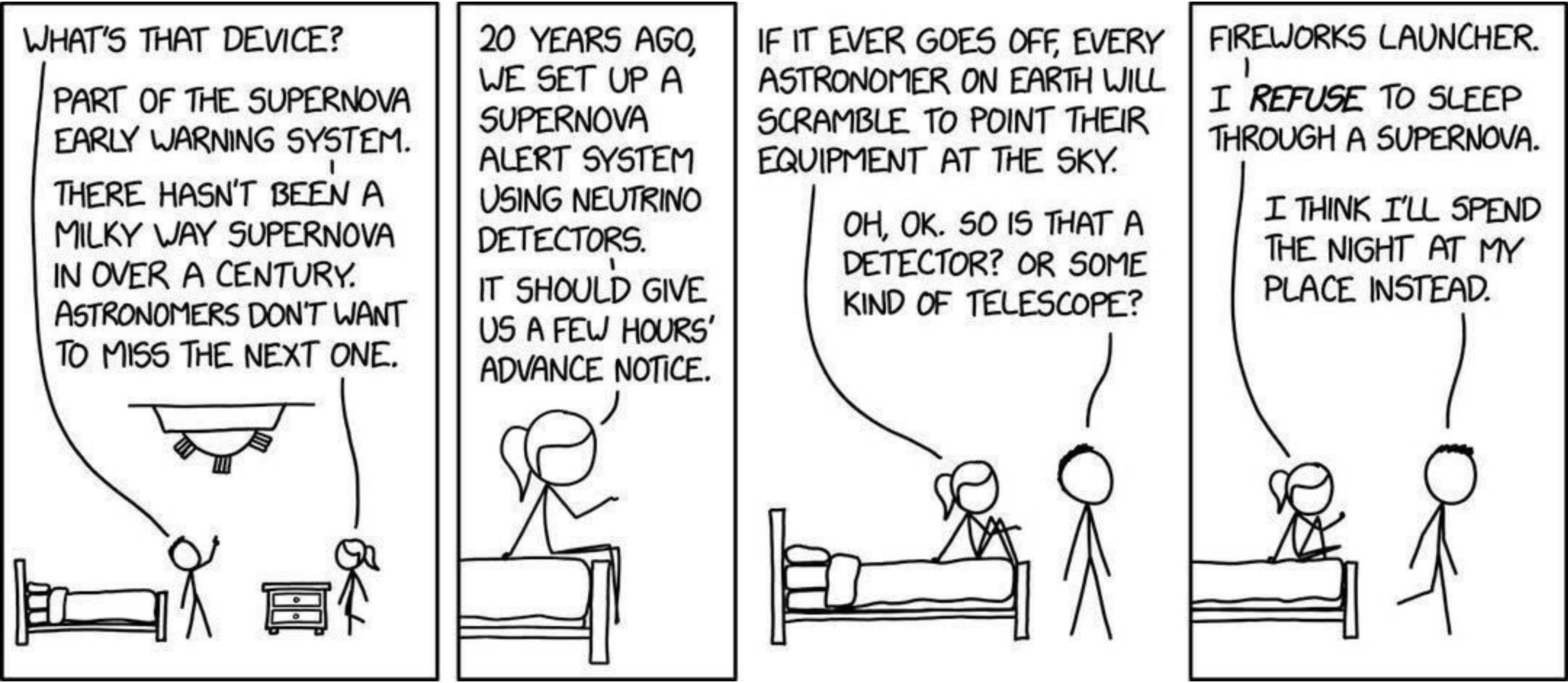
Kistler et al, ApJ 778:81 (2013)



Current members



- Automated operation since 2005
- 10s coincidence window
- **Expected fake rate ~1/century**
  - High burden on experiments for high-quality input alarms
  - Coincidence delayed as much as 20min

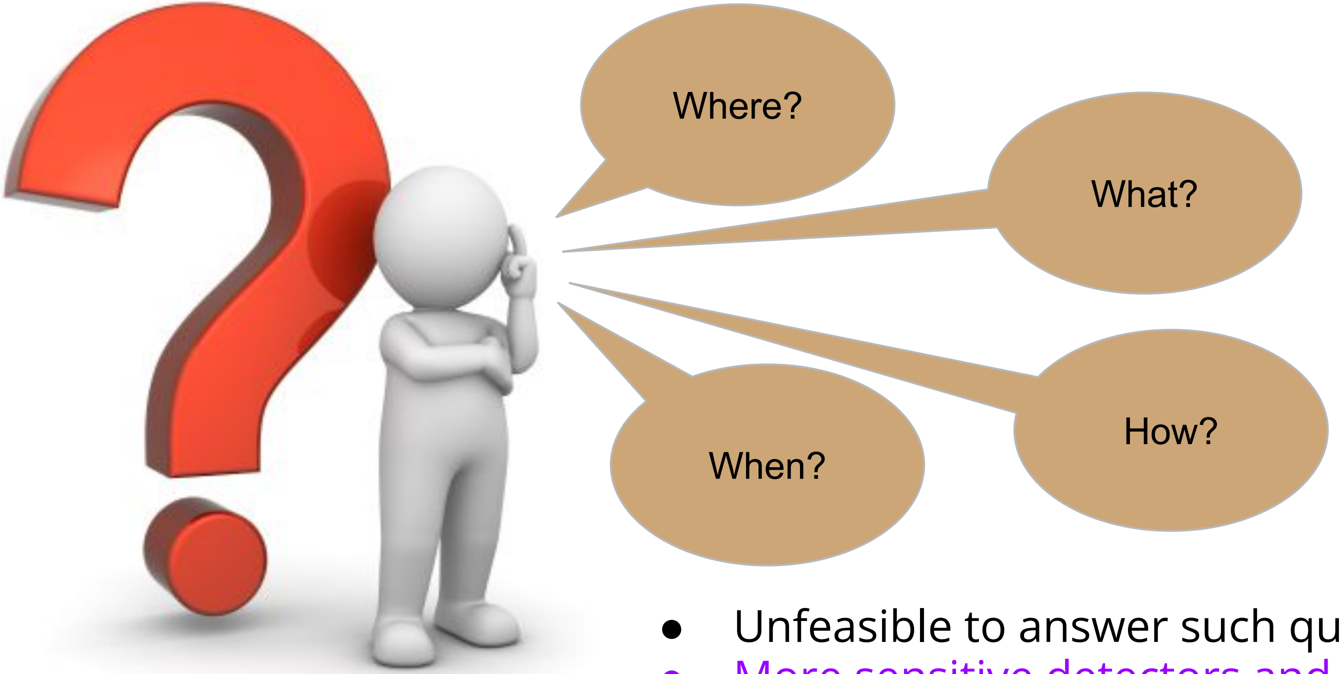


Randall Munroe, xkcd

SNEWS risks

- With fake rate ~ 1/century (and no galactic SN since 2005)...

Coincidence - what then?



- Unfeasible to answer such questions in 2005
- More sensitive detectors and techniques...

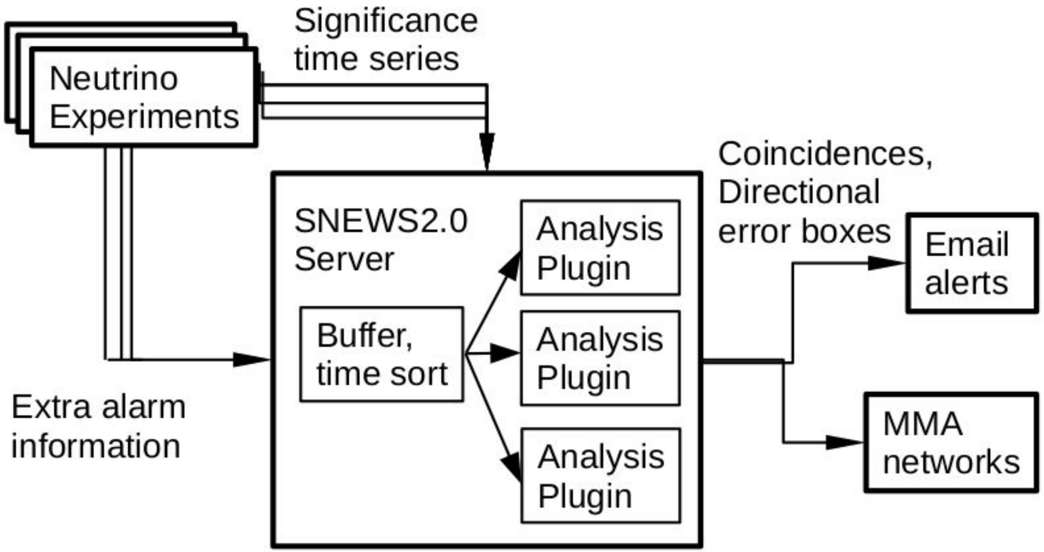
SNEWS2: goals

- Reduce threshold for generating alerts
  - Aim for false alarm rate ~1/month: firedrills, “proof of life”, backgrounds
- Reduce alert latency
- Provide pointing information
- Implement a pre-supernova alert
  - Build on KamLAND monitoring experience
- Develop a follow-up strategy to prepare the astronomy community
- Engage amateur astronomers and citizen science communities

Whitepaper: S Al Kharusi et al., New J Phys 23 (2021) 3, 031201

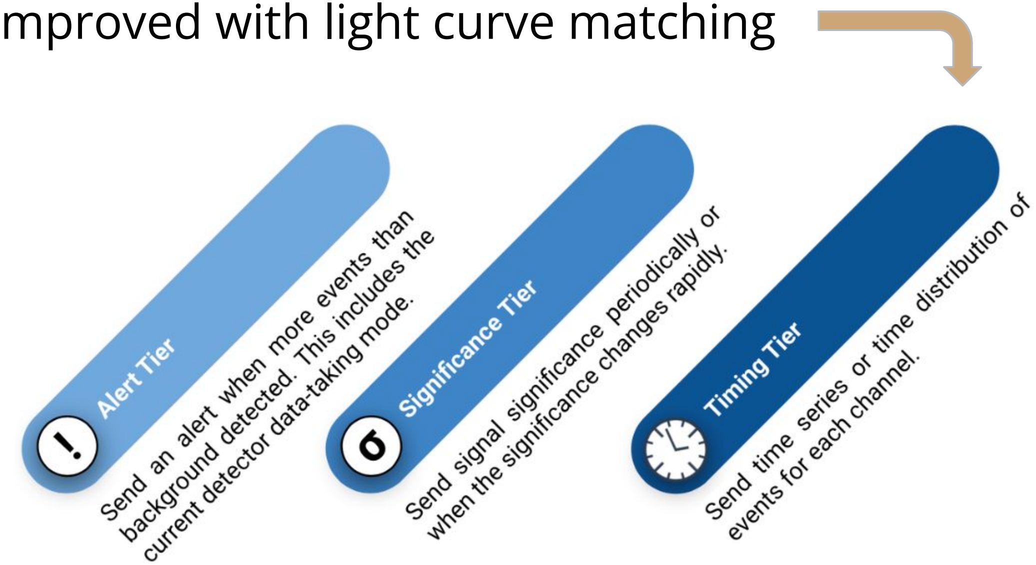
SNEWS2 calculations (pointing+)

- Provide rapid calculation of observationally relevant quantities
- Direction
- Distance
- Features

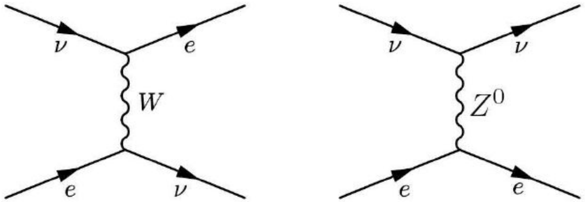


Where: direction strategies

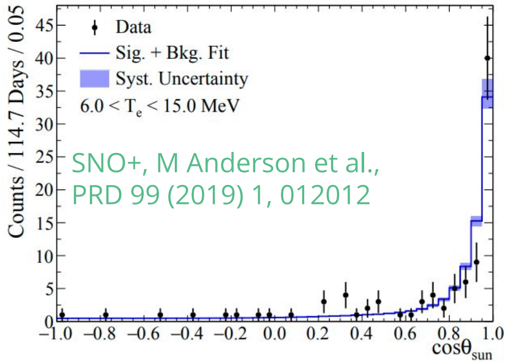
- Electron elastic scattering
- Triangulation (multilateration) with burst timing
- Triangulation improved with light curve matching



Electron elastic scattering (EES)

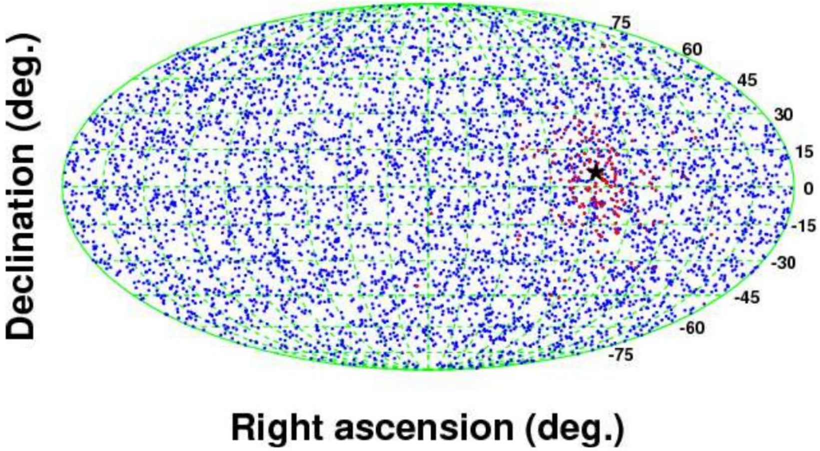


- Small fraction of SN neutrino interactions
  - Inverse beta decay background (if no n tagging)
- Super-Kamiokande (32kT):   4.3 - 5.9° at 10kpc



arxiv:2604.07702

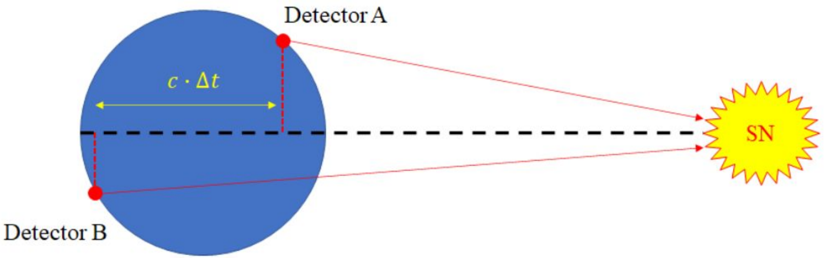
Super-K, K Abe et al 2016;
See also arxiv:2403.06760



- SK pointing in ~90s
- Hyper-K (220kT): 1 - 1.3°
- DUNE (40kT, 10kT): 4.3°, 8.6°

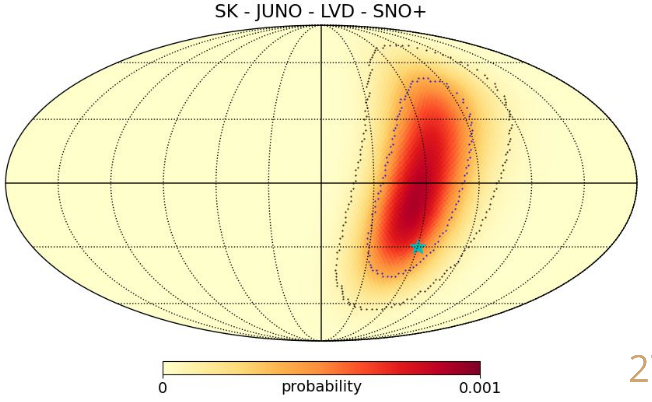
arxiv:2407.10339

Burst timing



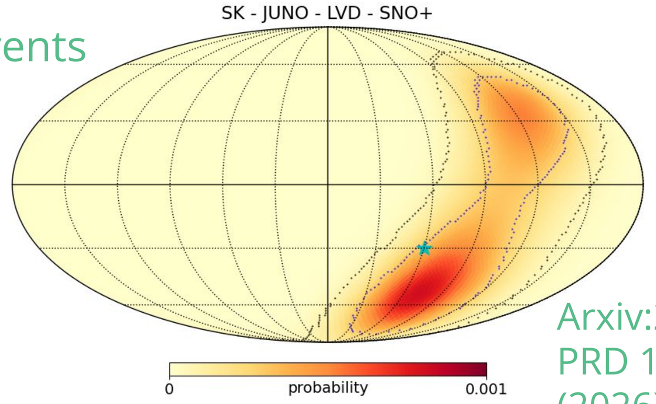
- Coincidence within 10s
- Maximum time difference between arrival times ~40ms
- Just need to use the first few events at each detector
- Very fast, but less precise
  - Good to start slewing telescopes

Need to be careful:
- Detector clocks synchronized
- Agree on definition of burst time



Using first events method

$27M_\odot$ progenitor

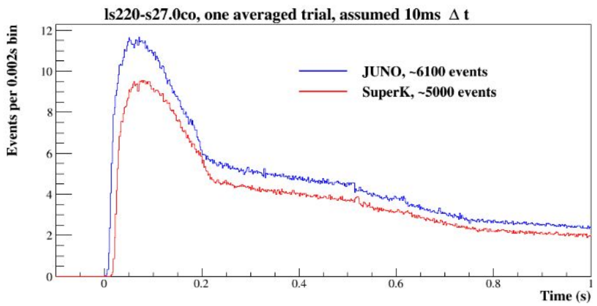


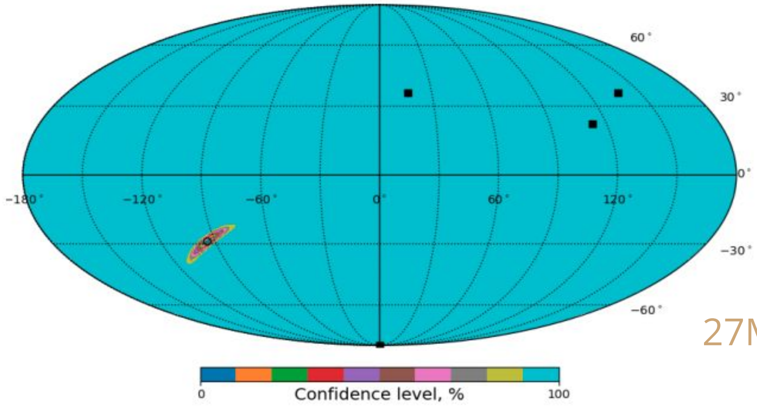
Arxiv:2410.11984, PRD 113, 063005 (2026)

Time series matching

- Improve Δt for pairs of comparable time series, e.g., of IBD events
  - Cross correlation, χ^2, other metrics
  - Most statistical power from rapid changes in flux

IceCube+JUNO+HK+KM3NeT



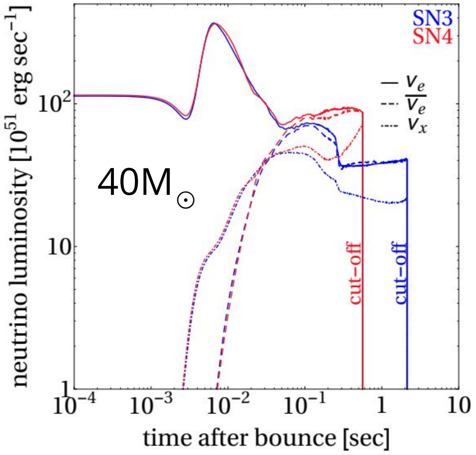


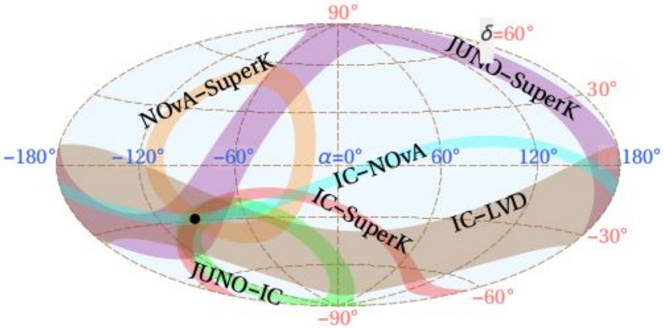
$27M_\odot$ progenitor

Coleiro et al., EPJ C 80 (2020) 9, 856

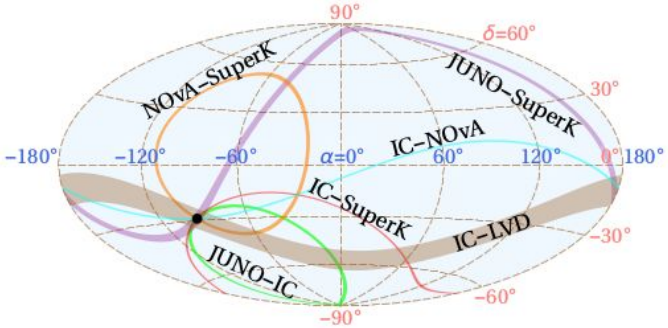
Time series matching

- Most rapid change: black hole formation
- Illustrative improvement in 1σ contours





Neutron star formation

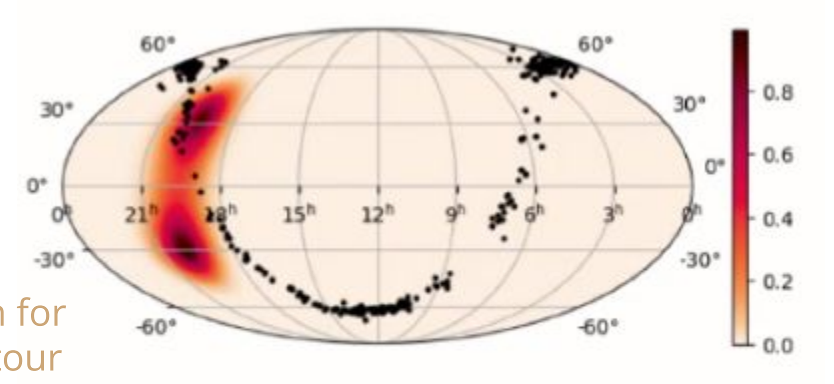


Black hole formation

Brdar, Lindner, Xu, JCAP 04 (2018) 025, based on Garching CCSN models

Direction: result

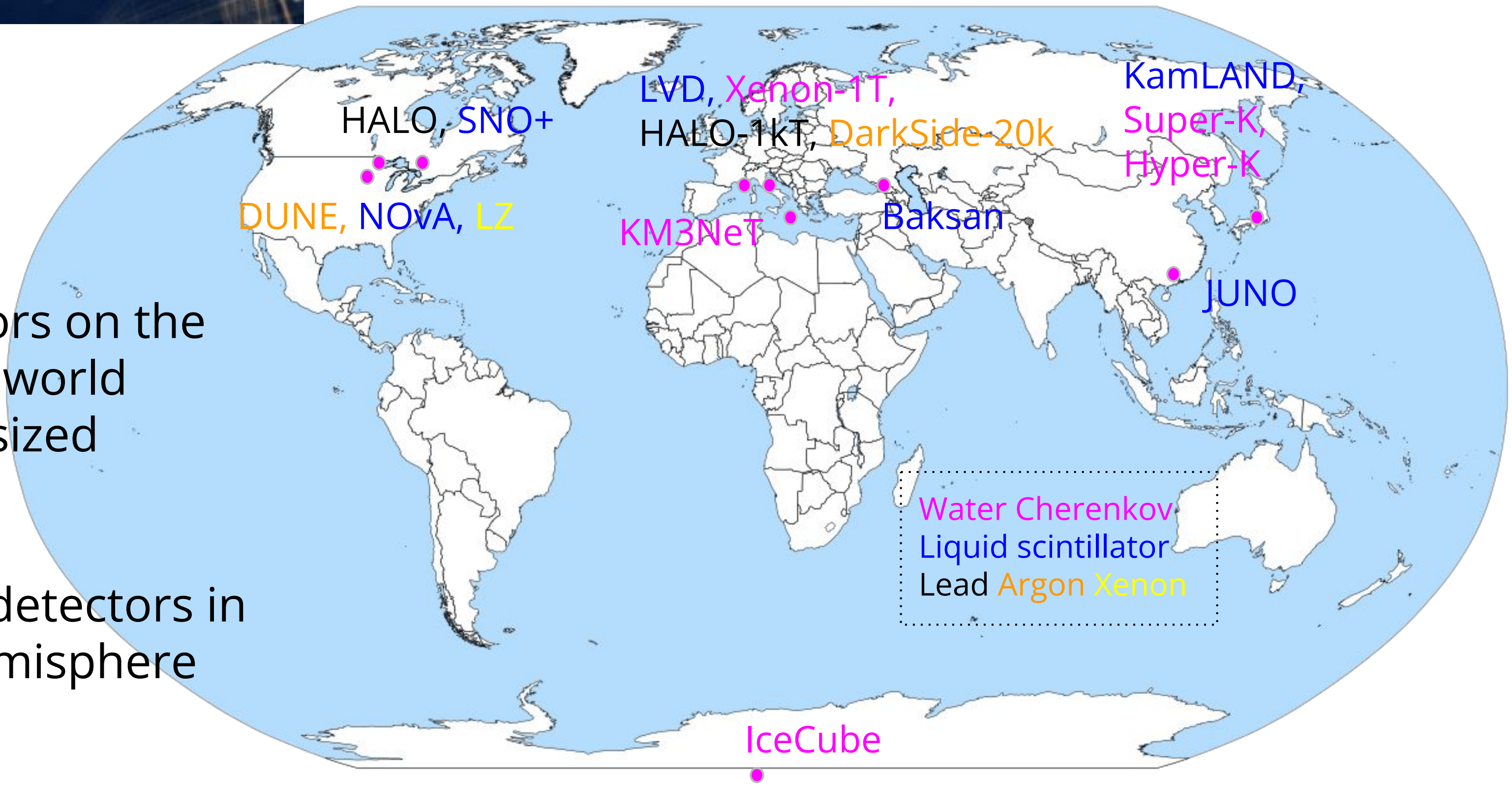
- Successive improvement as experiment data comes in
    a. Burst times → rough triangulation
    b. Time distributions → improved triangulation
    c. Experiment pointing using EES → likely to dominate in the end
- Report pointing as a skymap of confidence levels
  - superimpose on candidate stars



Sample result - deliberately chosen for big, non-trivial contour

SNEWS
SUPERNOVA EARLY WARNING SYSTEM

Helps to have detectors all over the world



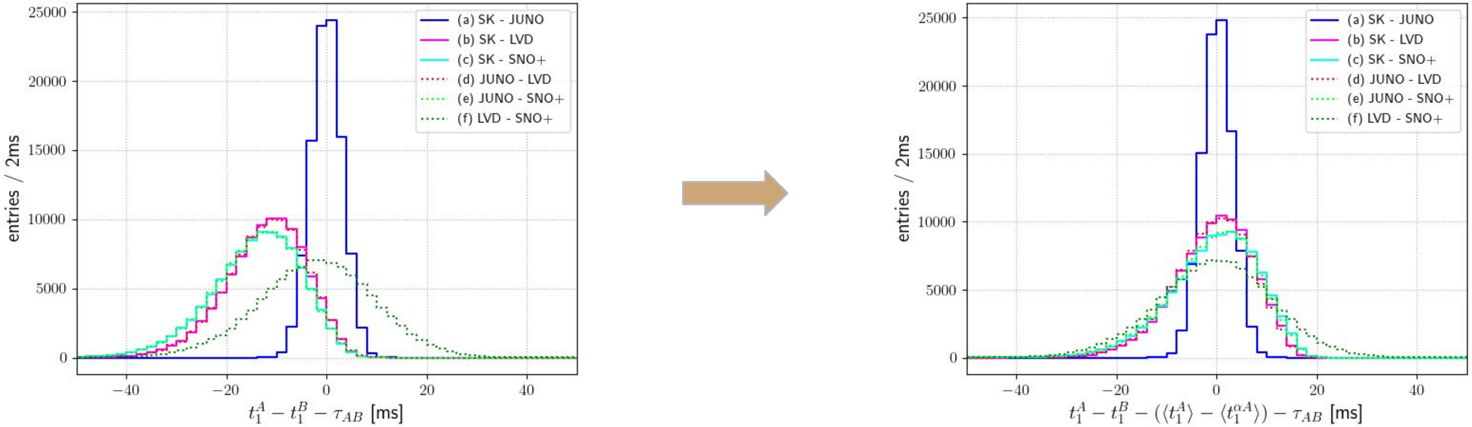
Small detectors on the other side of world make an outsized contribution

Note lack of detectors in Southern Hemisphere

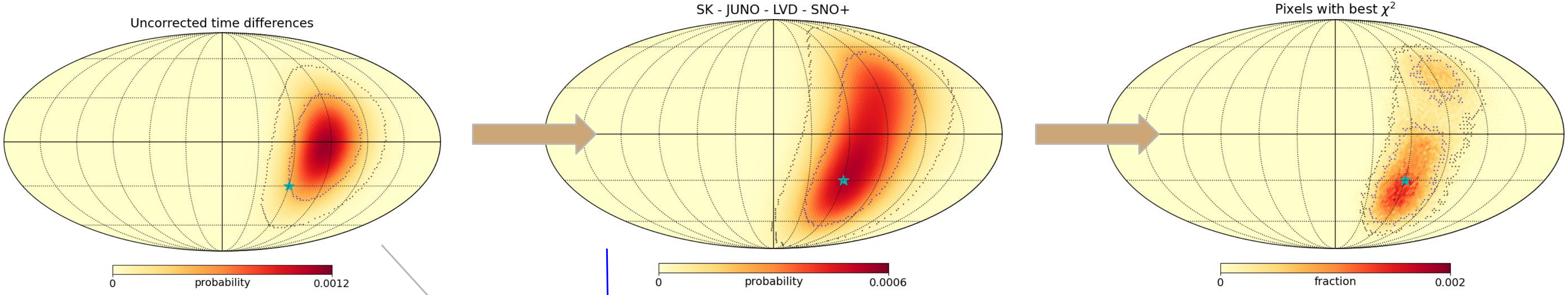
First-events method

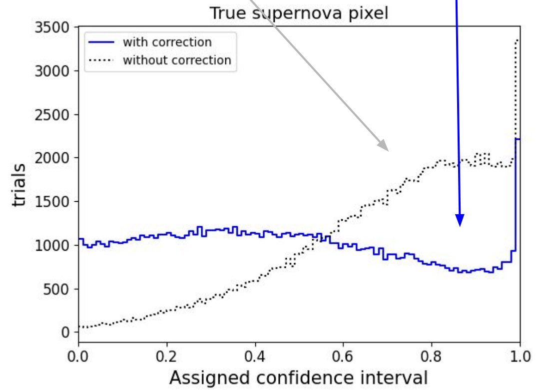
arxiv:2410.11984, PRD 113, 063005 (2026)

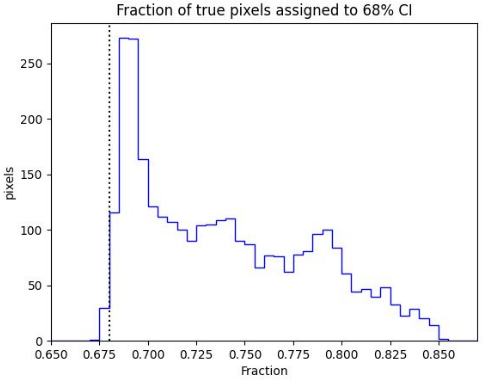
- Use neutrino lightcurve from one reference detector to de-bias first observed event times at other detectors
- Estimate uncertainty directly from data
  - Follow-up observation/optical discovery should be guided by reasonable confidence regions



Confidence regions (first events method)



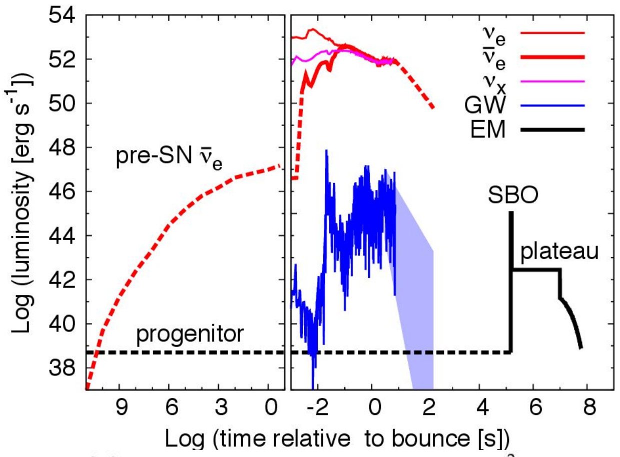




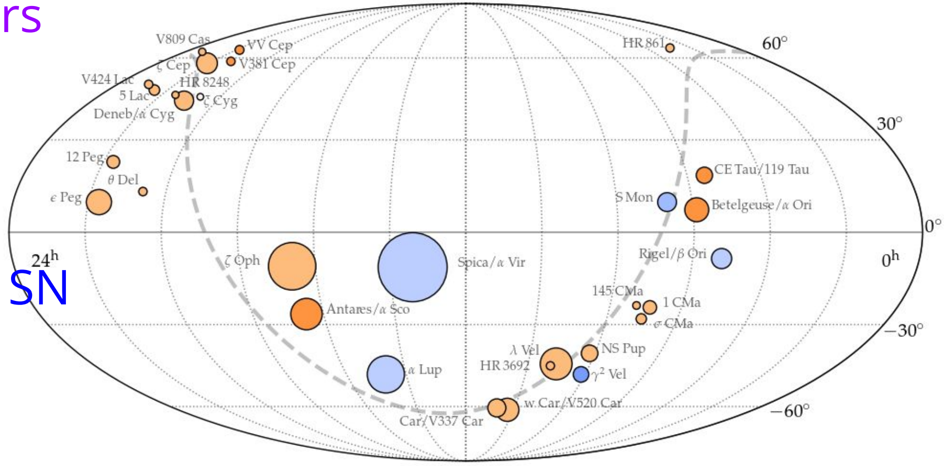
Method gives reasonable though slightly conservative confidence regions

Pre-supernova neutrinos

- Late-stage silicon burning emits at increasing rate
- Detectable for stars up to 1kpc
- Can increase warning time by hours
  - KamLAND pioneered publishing a pre-supernova significance
  - SuperK sensitivity: ApJ 935, 40 (2022)
  - SNO+, JUNO, HyperK will do this too
- IBD events may also point back to SN (but limited # of candidates)



Nearby Galactic CCSN Candidates: Marker Area ∝ (Source Distance)$^{-2}$

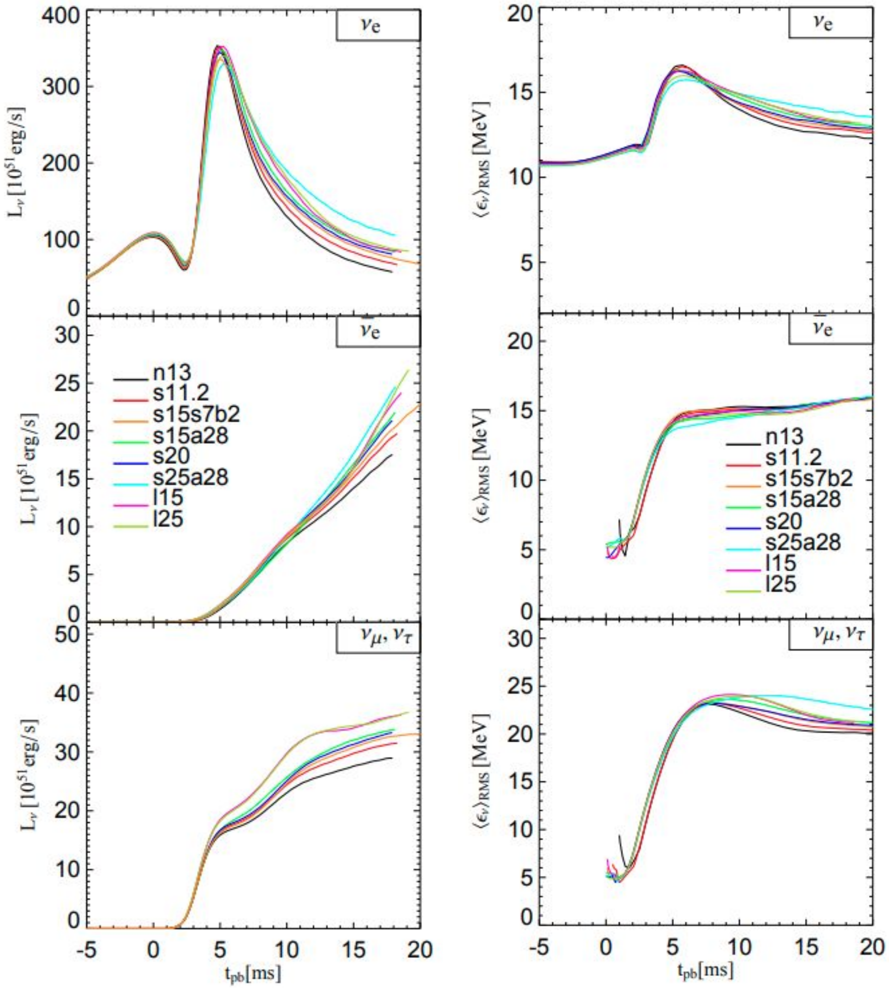


Mukhopadhyay et al., 2020

Distance

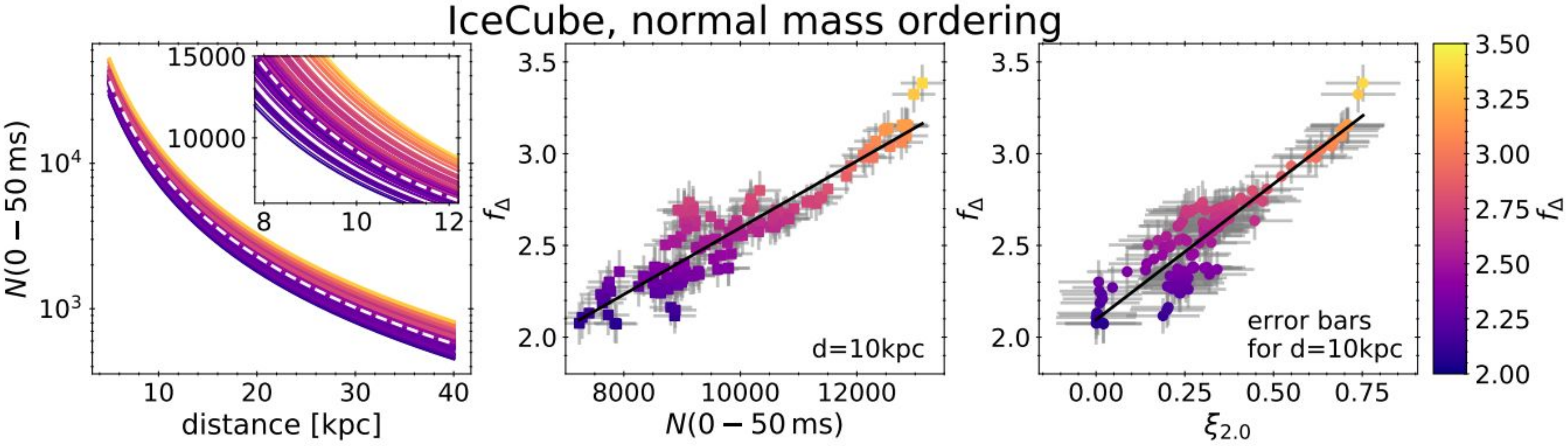
Kachelriess et al., PRD71 (2005) 063003

- Neutronization burst (ν_e) self-limited by electron captures
  - Potential standard candle, stable vs progenitor mass
  - Yield can be used to estimate distance to SN
- 1MT water Cherenkov detector
  - Average 112 EES events at 10kpc
  - 5% uncertainty on distance
- SNO+ and JUNO should also get a sizable number of proton elastic scattering events



Distance

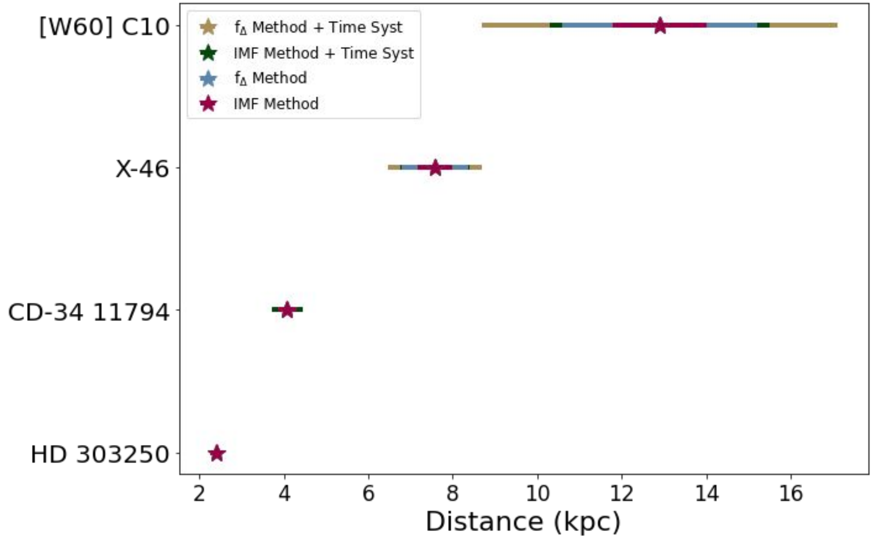
- Anti-ν_e yield ratio of (100,150)ms / (0,50)ms related to "compactness"
  - Can also be related to mass → similar sensitivity, smaller detectors using IBD

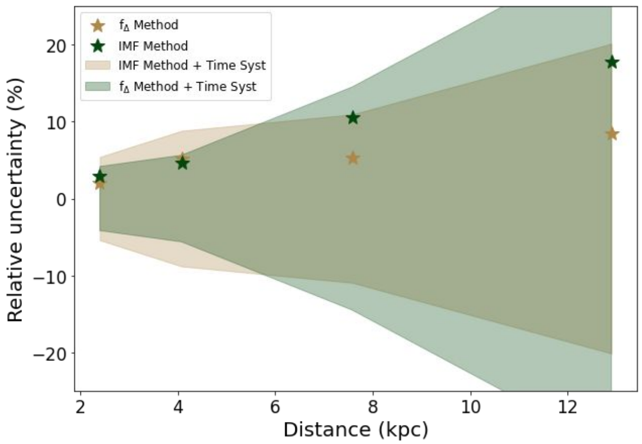


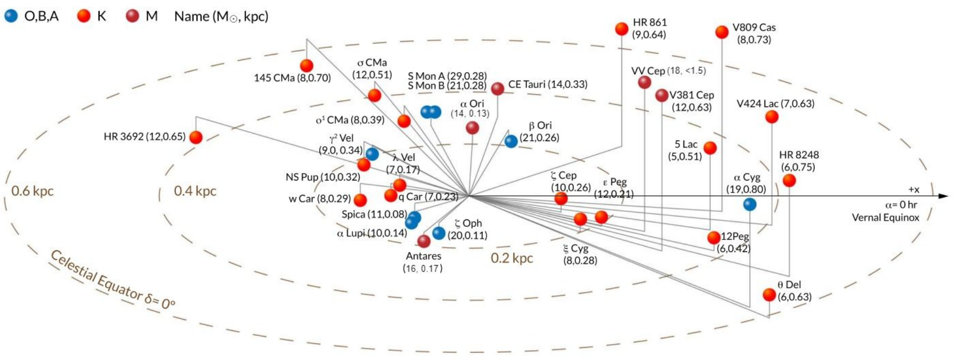
Segerlund et al., arxiv:2101.10624 (2021)

Distance

S Healy et al., MNRAS 529, 3630 (2024)





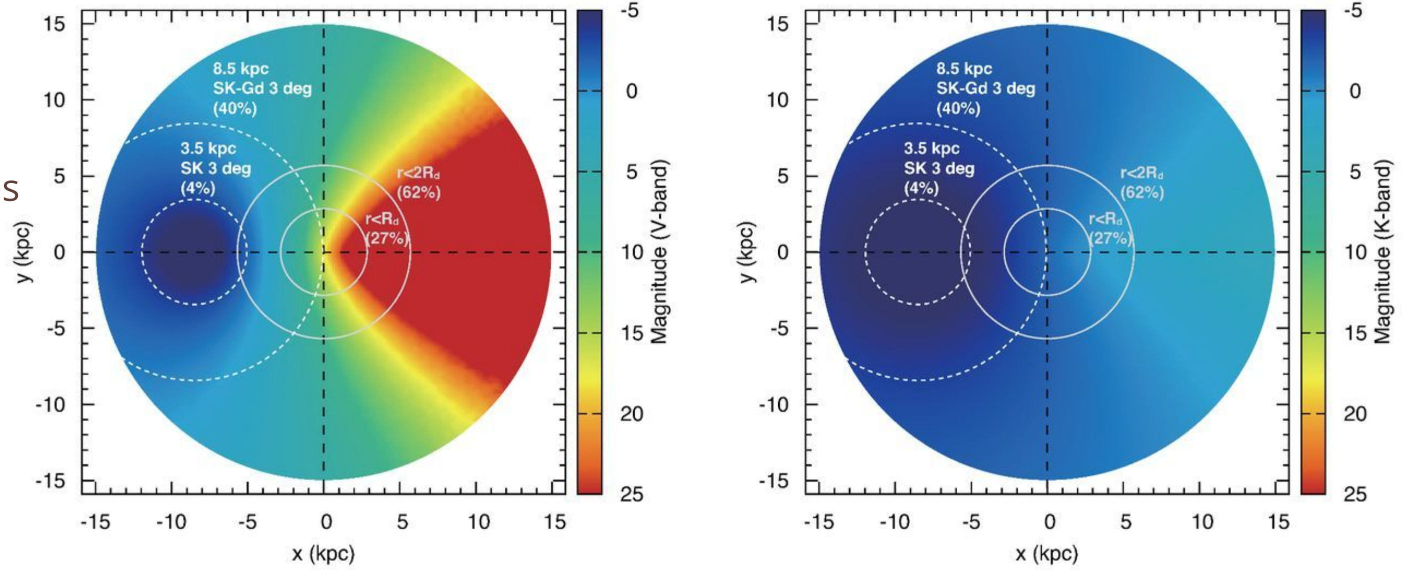


CCSN candidates < 1kpc from Earth
(Stanley Joseph, Wikipedia, CC BY4)

Why is distance relevant?

K Nakamura et al., MNRAS 461 (2016) 3296

Optical magnitudes (plateau)



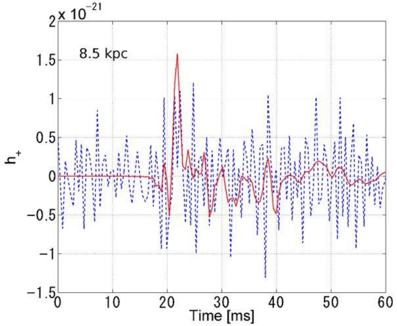
Near IR magnitudes (plateau)

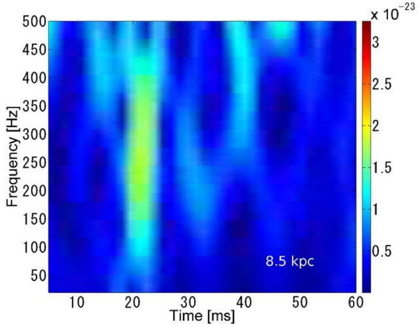
SK pointing (% galactic CCSN rate)

- Sizable fraction of the galaxy obscured by dust
- May change optimal observation strategy

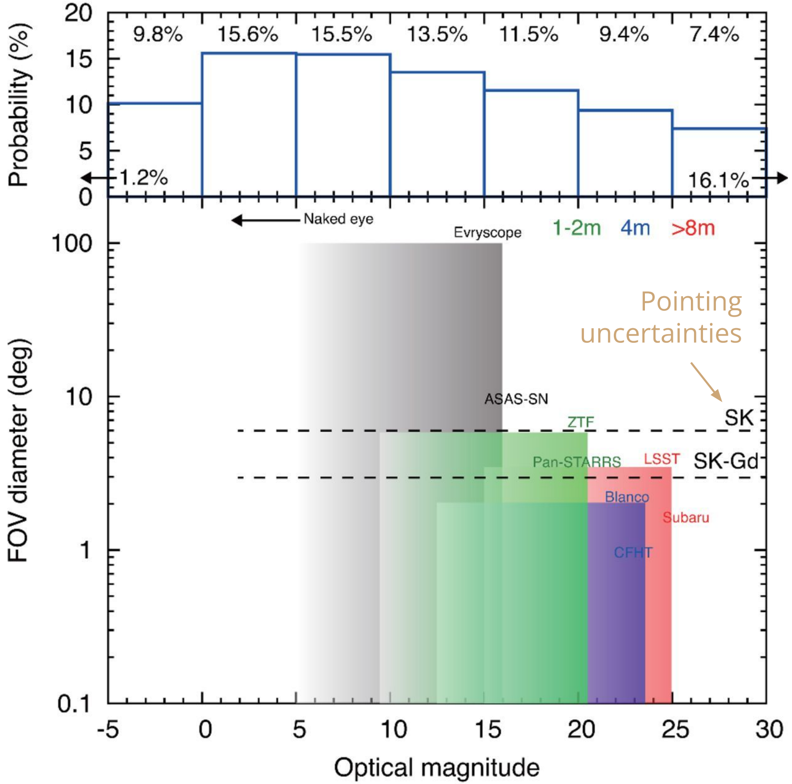
Multiple messengers

- Electromagnetic: telescopes will see late minutes/hours later
- Gravitational waves: large uncertainties, may be lost in noise if not pinned down by neutrino times
- Neutrino flux ~ $1/R^2$: only (near) galactic supernovae will give an identifiable yield





Distribution of galactic CCSN (IIP) by plateau magnitude, incl dust attenuation



K Nakamura et al., MNRAS 461 (2016) 3296

SN at LSST

LSST Science Collaboration and LSST Project 2009, *LSST Science Book* v2, arxiv:0912.0201

- Roughly 1000 supernovae discovered in history
  - Many by surveys, e.g., Sloan Digital Sky Survey
  - By far most outside the Galaxy
- LSST (Vera Rubin Observatory) will survey whole Southern sky every ~4d
- First look released 23 June 2025
- **10-year survey began 30 June 2026**
- Should observe 1M SN per year - by far most outside galaxy
- ~50% should be CCSN
- Large field view should assist finding a Galactic supernova

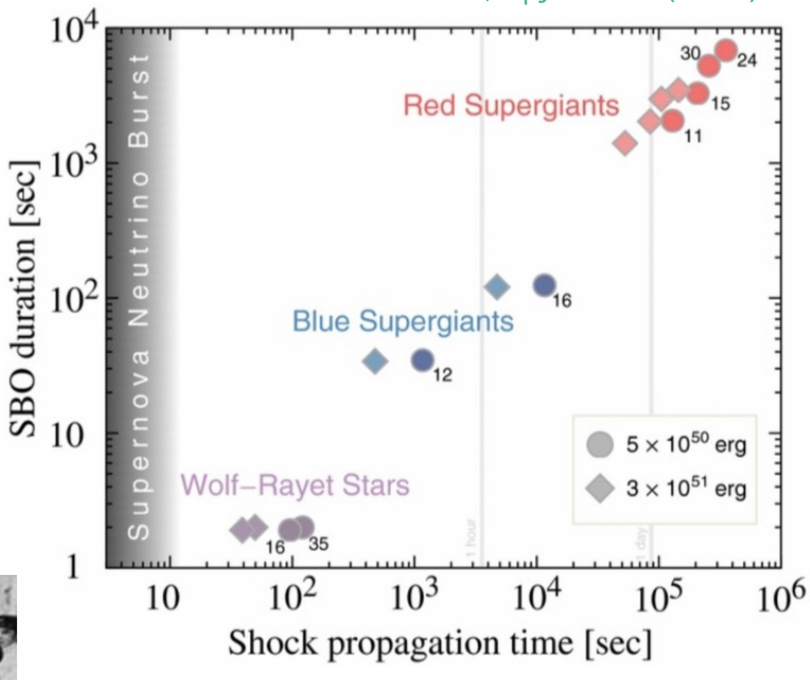
Follow-up communities

- American Association of Variable Star Observers
  - Recording amateur observations since 1911
  - Played critical role in early observations of SN1987A
  - Developing narrowfield search strategies
- Global Rapid Advanced Network Devoted to the Multi-messenger Addicts
  - Network of robotic telescopes
  - Experienced with follow-up, amateur astronomer engagement
- Engage with fire drills and preparation

Race against time

- Neutrinos are the starting gun
- The race takes place once in a lifetime
  - You don't know when
  - You don't know how long it lasts
  - You want all hands on deck:
    every possible radiation and wavelength

Kistler et al, ApJ 778:81 (2013)



Conclusion

- Neutrinos from a galactic core-collapse supernova could yield a rich harvest of physics on fundamental questions
- A galactic CCSN is very rare, so must make the most of the opportunity

- Neutrinos start the race to get the most bang out of a galactic CCSN
- SNEWS has been providing automatic coincidence detection since 2005
- SNEWS2 aims not only to detect coincidences, but provide critical information to guide follow-up in the observer community

SNEWS
SUPERNOVA EARLY WARNING SYSTEM