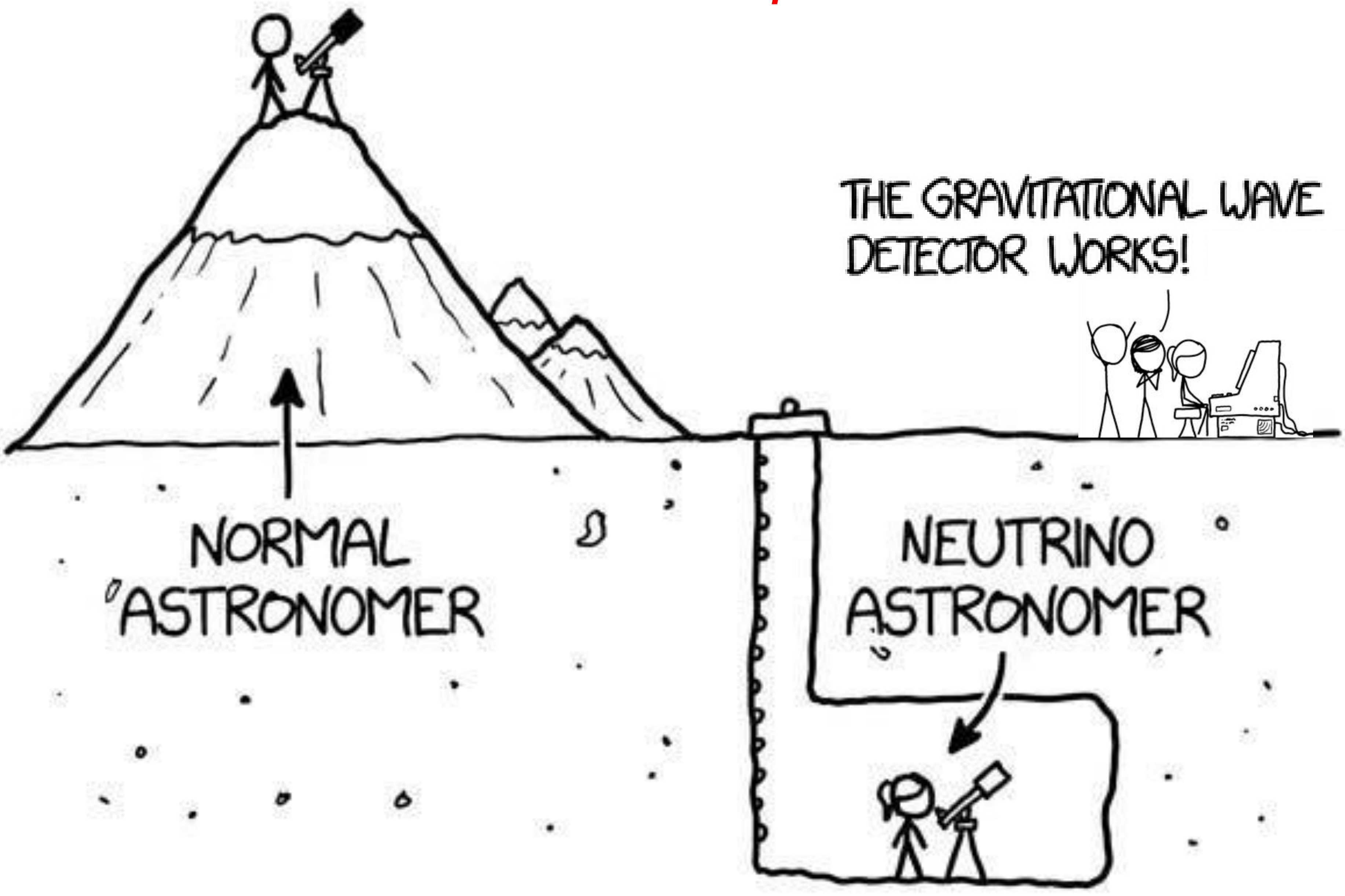
# Multi-Messenger Astronomy at Hyper-Kamiokande


Mark Vagins
Kavli IPMU, UTokyo


Workshop on Multi-messsenger Astrophysics
@ Fall Meeting of APS DNP and JPS

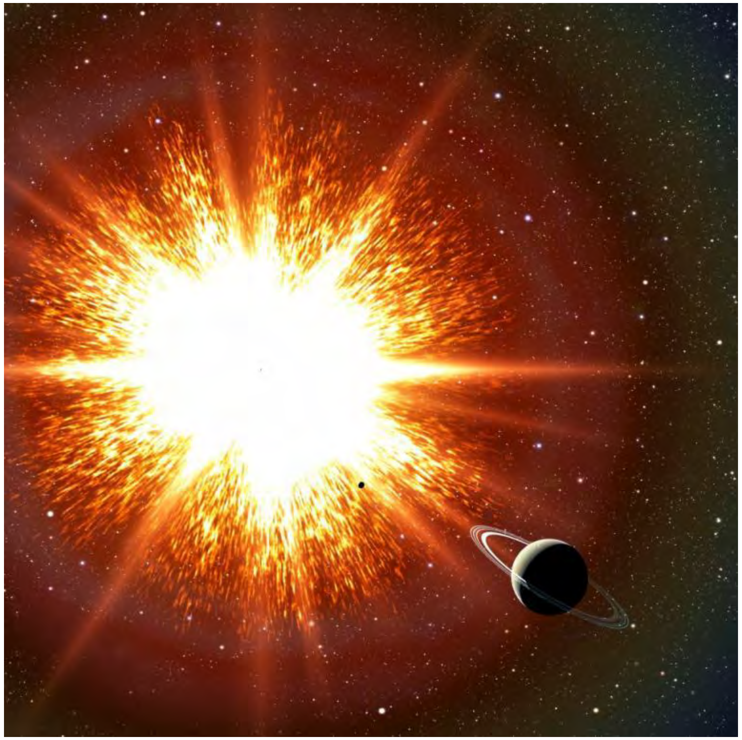
Hilton Waikoloa Village November 26, 2023

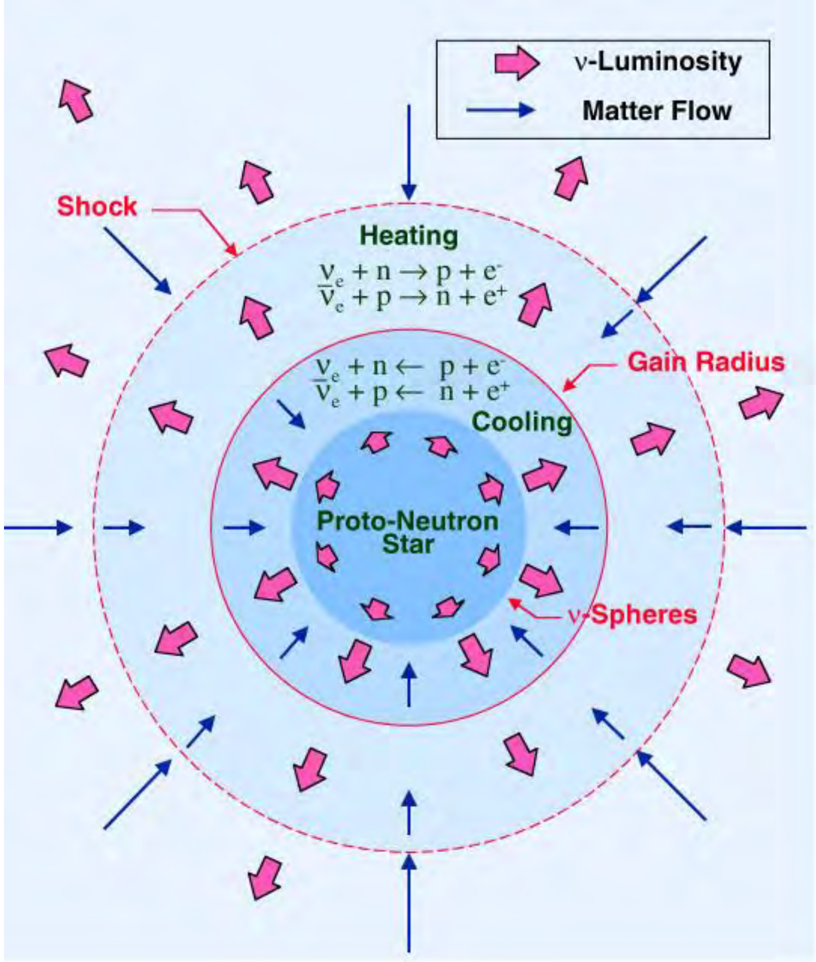
***This workshop in a nutshell…***



A core-collapse supernova is
a nearly perfect "neutrino bomb".

Within ten seconds of collapse it releases >98% of its huge energy (equal to **10**$^{12}$ hydrogen bombs exploding per second since the beginning of the universe!) as neutrinos.






Neutrinos, and possibly gravitational waves, provide the only windows into core collapses' inner dynamics.

# A long time ago, in a (neighbor) galaxy far, far away…

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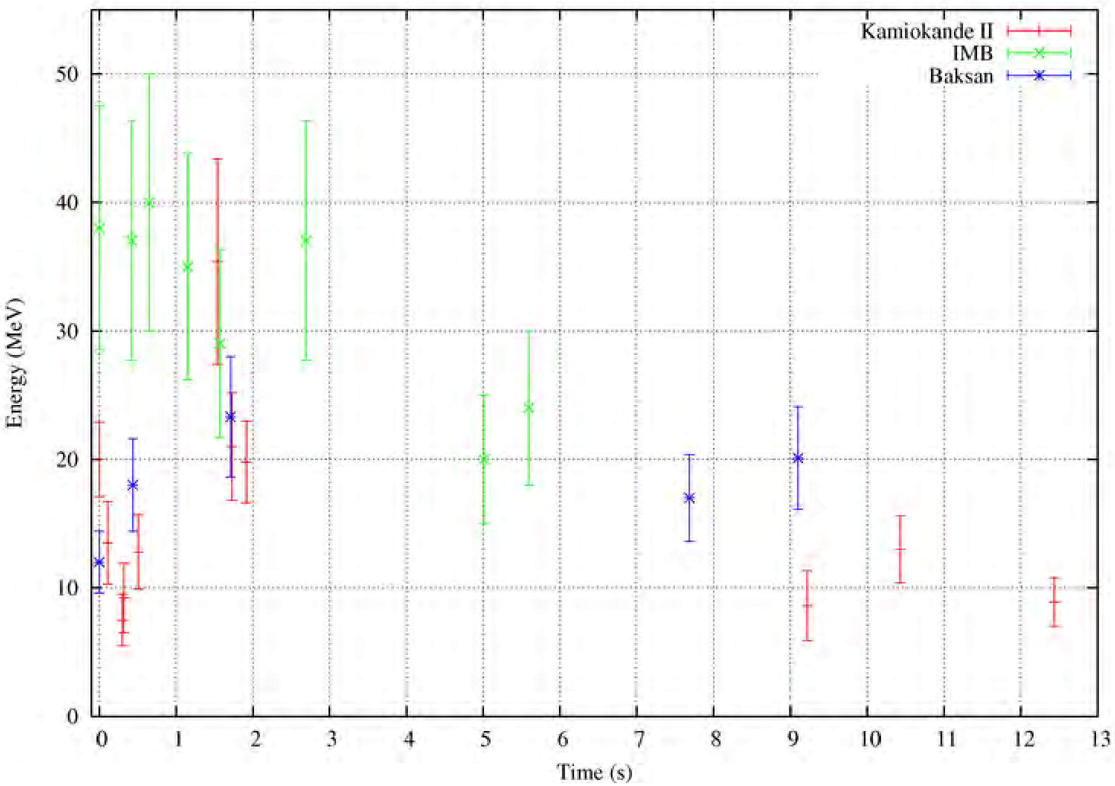
Kamiokande

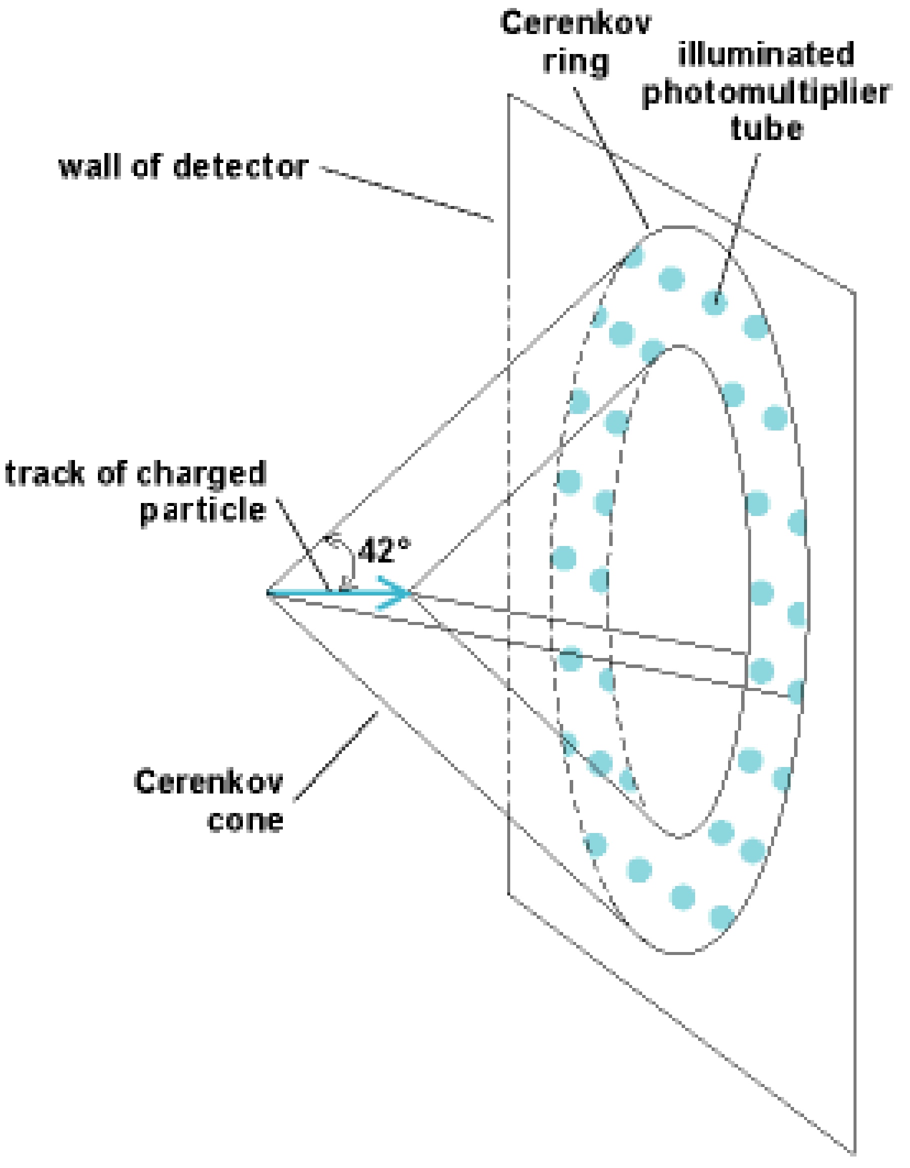

IMB

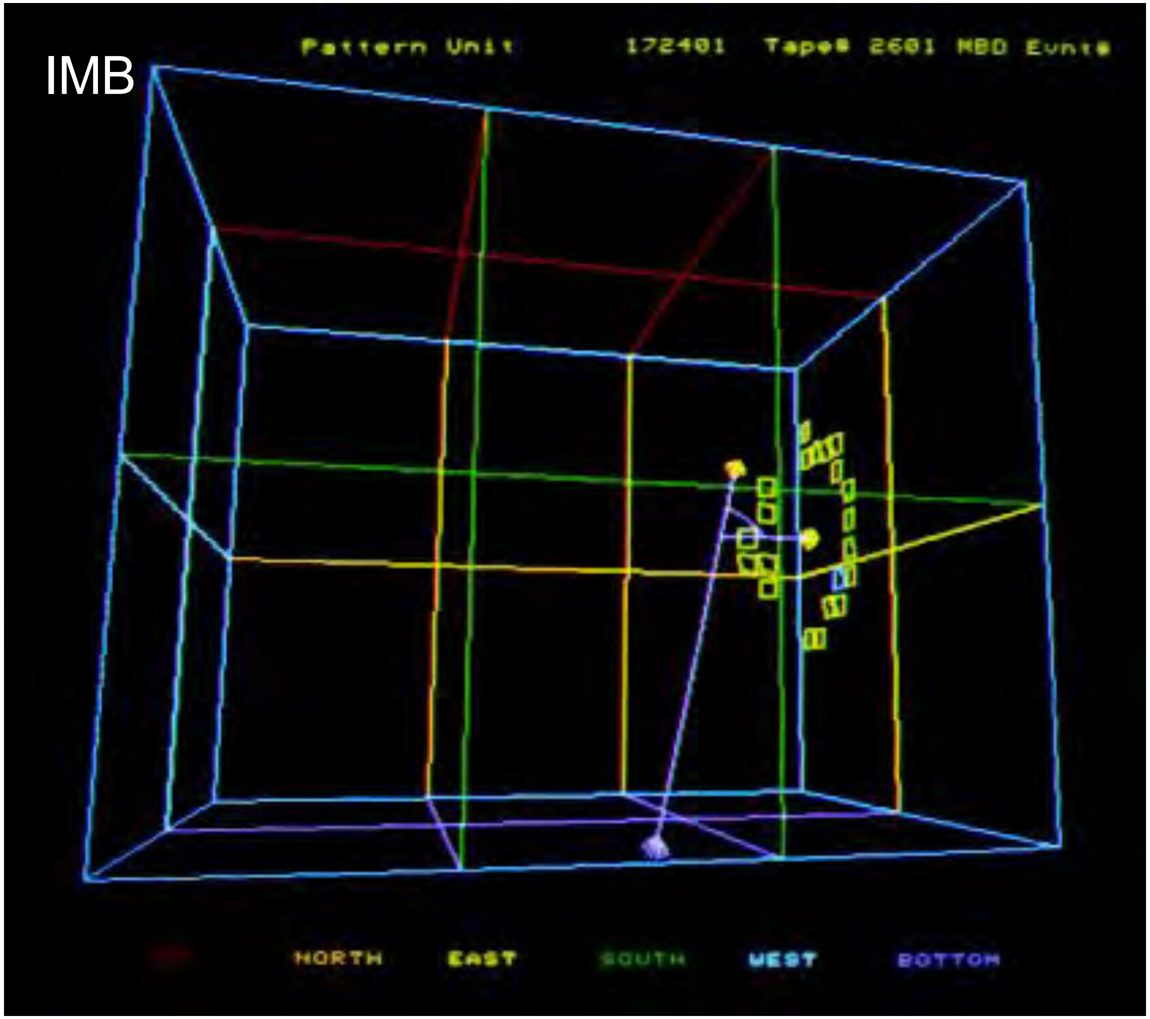

Kamiokande II
IMB
Baksan
Energy (MeV)
Time (s)
0
10
20
30
40
50
0
1
2
3
4
5
6
7
8
9
10
11
12
13


Baksan

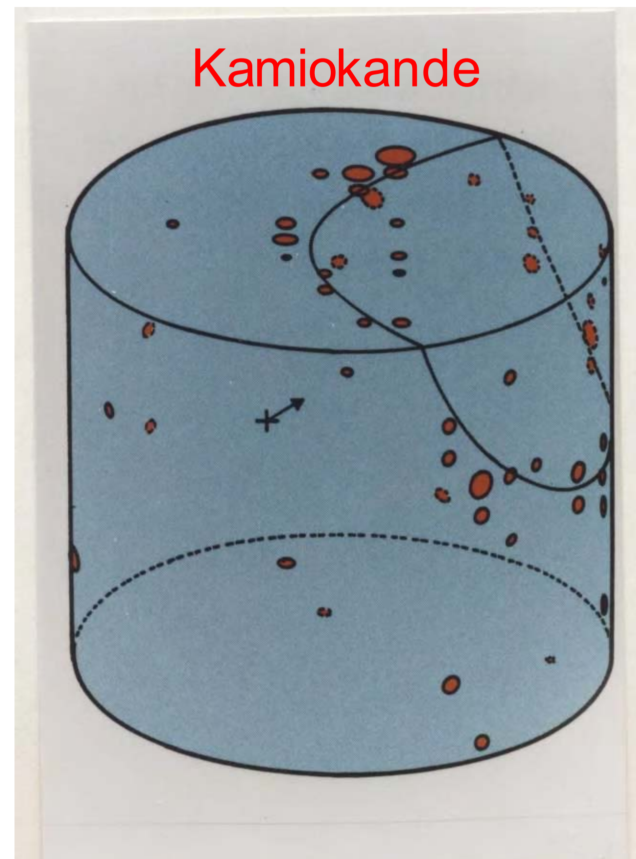
Water Cherenkov detectors' principle of operation:

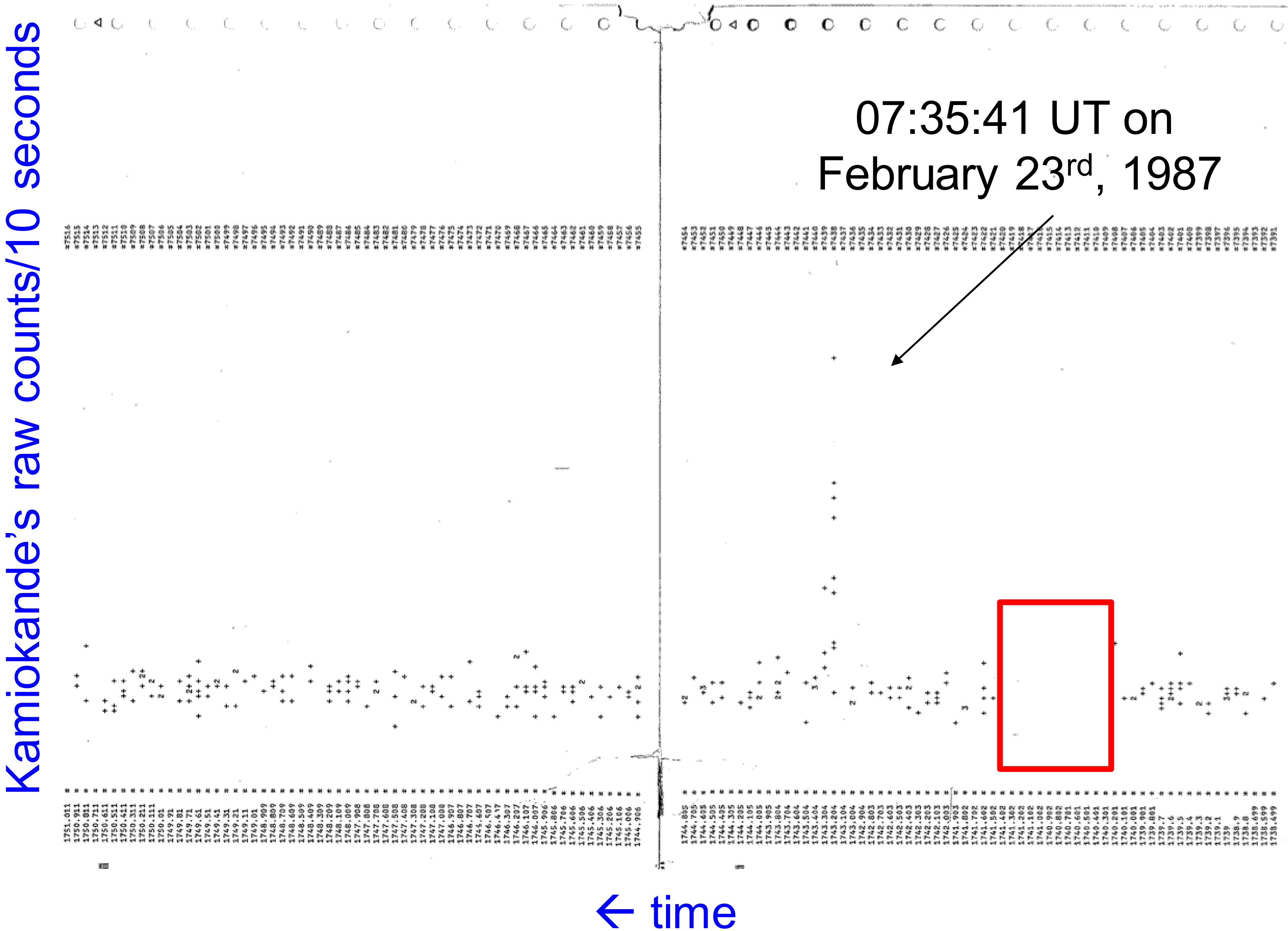
Relativistic charged particles make rings of light on the inner wall of the detector. The rings are then imaged by photomultiplier tubes.






Actual supernova neutrino events!




Kamiokande's raw counts/10 seconds
07:35:41 UT on
February 23rd, 1987
← time

Based on the handful of supernova neutrinos which were detected that day, approximately <u>one theory paper has been published every ten days</u>…

*…for the last <u>thirty-six years!</u>*

In 2002, Masatoshi Koshiba would win the Nobel Prize in physics for observing the neutrinos from SN1987A with Kamiokande.

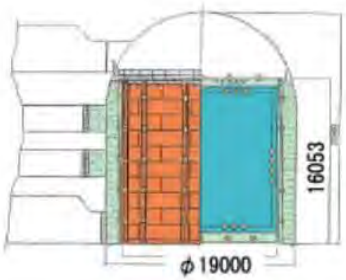
## Kamiokande =
## Kamioka Nucleon Decay Experiment

Both IMB and Kamiokande had been built to discover proton decay based on SU(5) predictions.

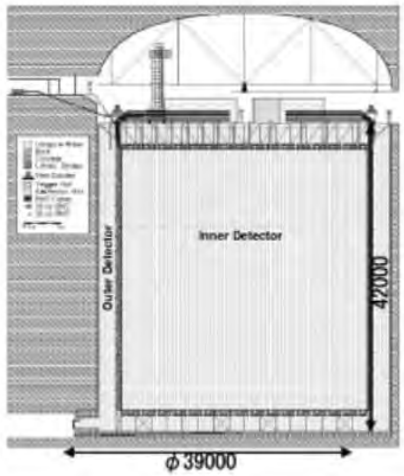
## Super/Hyper-Kamiokande = Super/Hyper Kamioka Neutrino Detection Experiment

We’re still looking for proton decay, but now neutrinos – atmospheric, solar, and supernova – are the undisputed stars of the show!

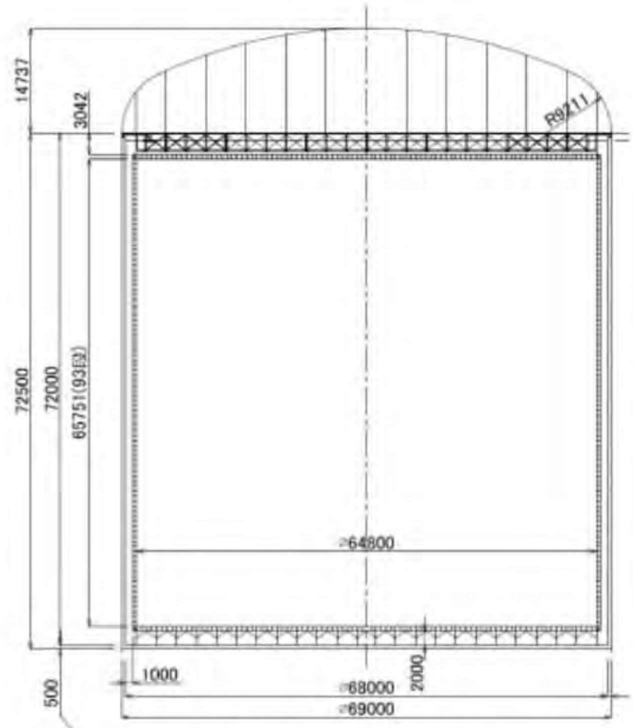
# When collecting neutrinos, size definitely does matter!




Kamiokande
(1983-1996)




Super-Kamiokande
(1996-present)




Hyper-Kamiokande
(to be started in 2027)

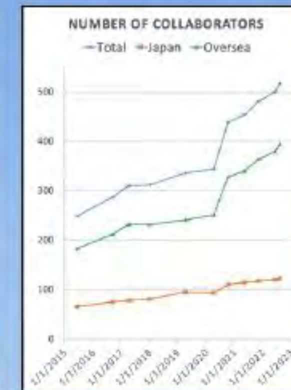
3 kilotons → 50 kilotons → 258 kilotons

(1 kt fiducial) → (22.5 kt fiducial) → (178 kt fiducial)

# HYPER-K COLLABORATION

**Broadening of the international collaboration**

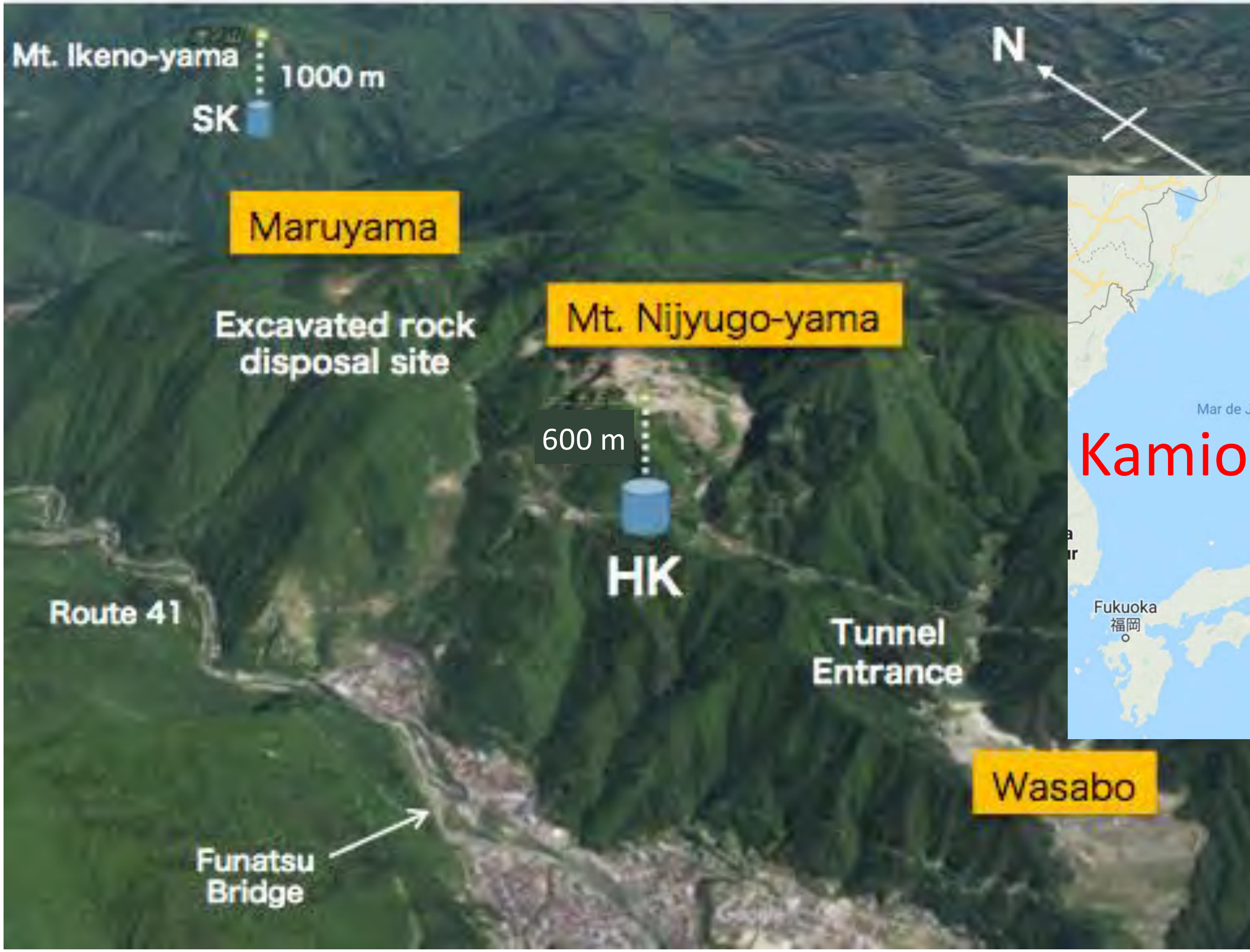
~600 collaborators (incl. 25% of Japanese), 22 countries, and 102 institutes. Funding secured in several countries.



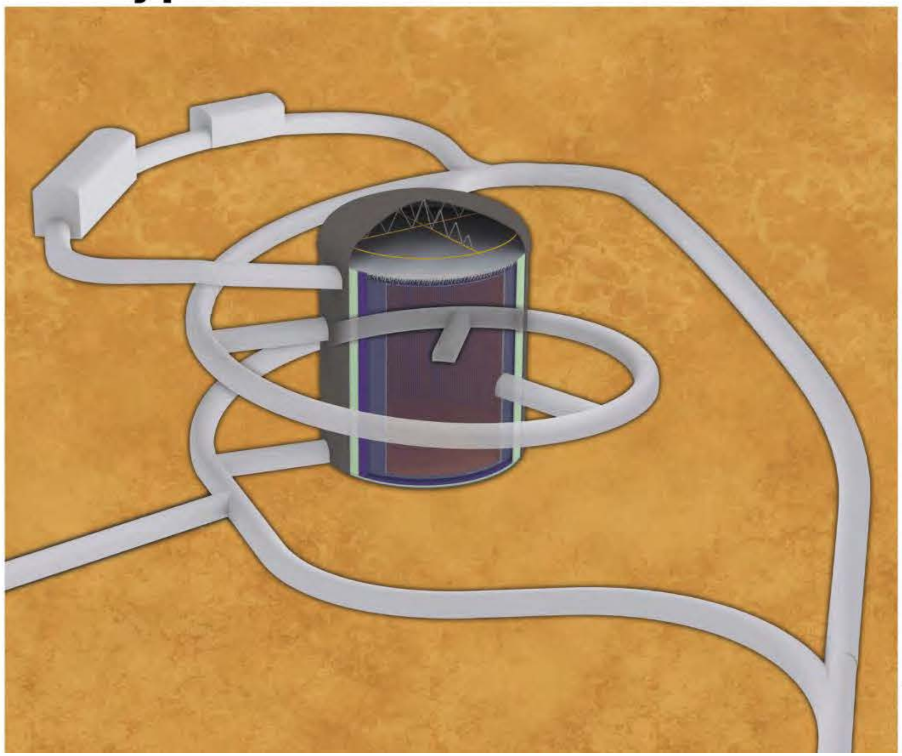

March 2023, 1st in-person Collaboration Meeting @ Toyama

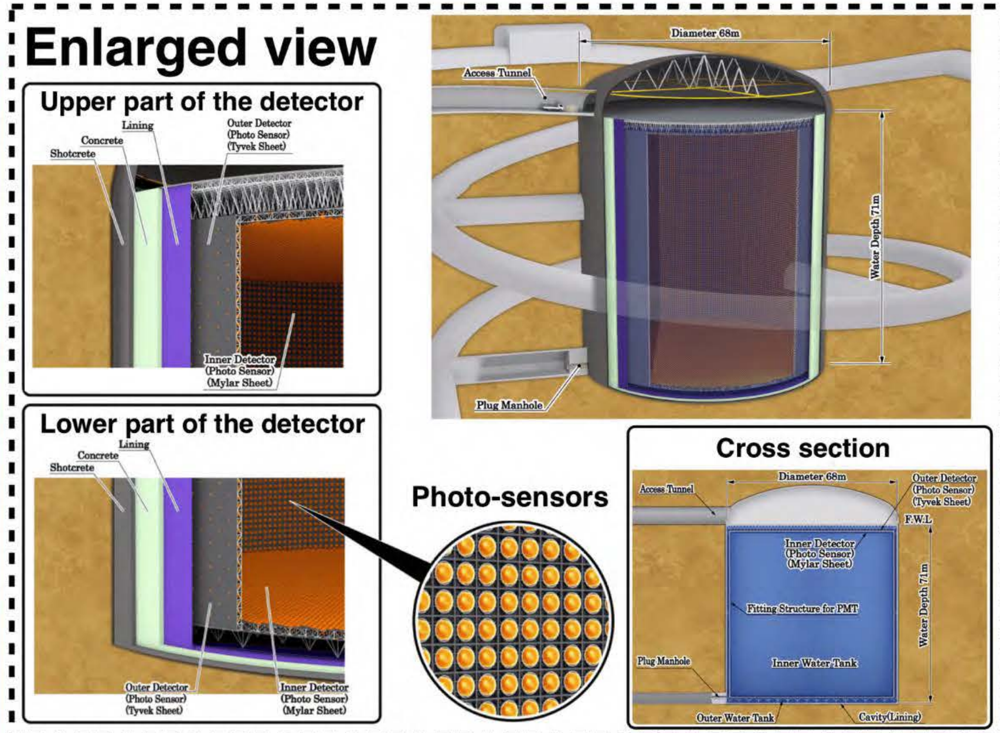
# Hyper-K Detector Location

- 8 km south of Super-K
- 295 km from J-PARC and 2.5 deg. off-axis beam (same as Super-K)
- 600 m rock overburden




# Schematic view of Hyper-Kamiokande detector

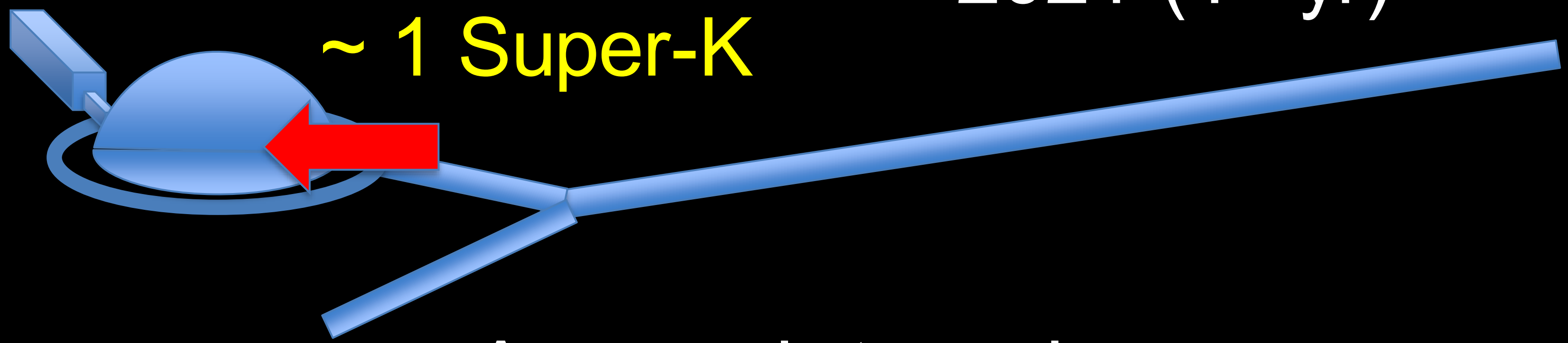




# Construction history

Dome section
2023 (3rd yr)

Access tunnel
2021 (1st yr)




Approach tunnel
2022 (2nd yr)


**Approved as a project in April 2020, Hyper-Kamiokande rock excavation is proceeding on schedule. All access tunnels have been dug, as well as the 69-meter-wide by 21-meter-tall dome, and the cavernous (1st) water system room.**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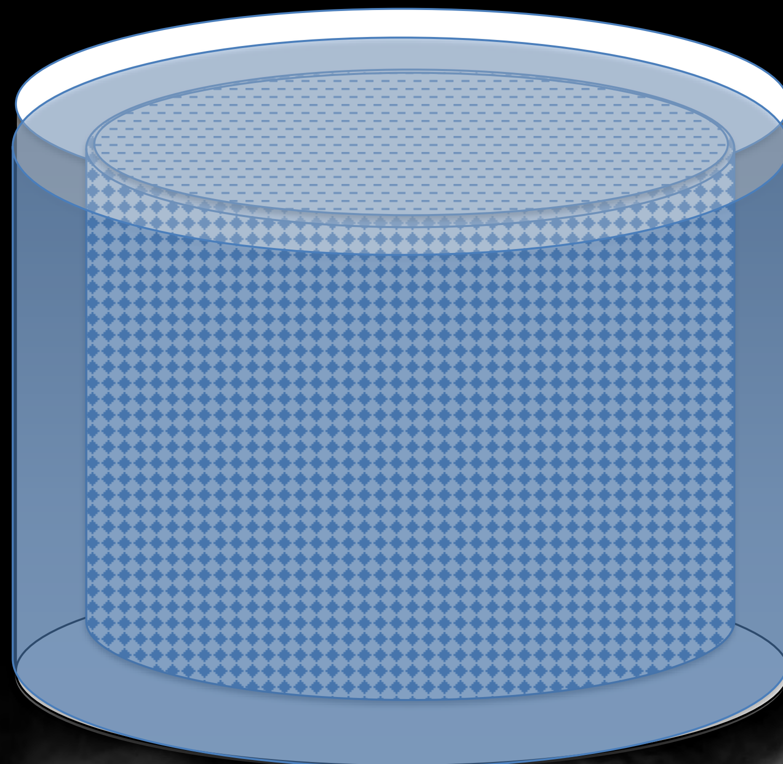
# PMT production for Hyper-K is also underway

Screening of ~20,000 50-cm tubes is being conducted both at Hamamatsu and Kamioka

# Construction plan

# Construction plan

Photosensor installation
2026 (6th yr)



Water
Filling
&
DAQ
start
2027

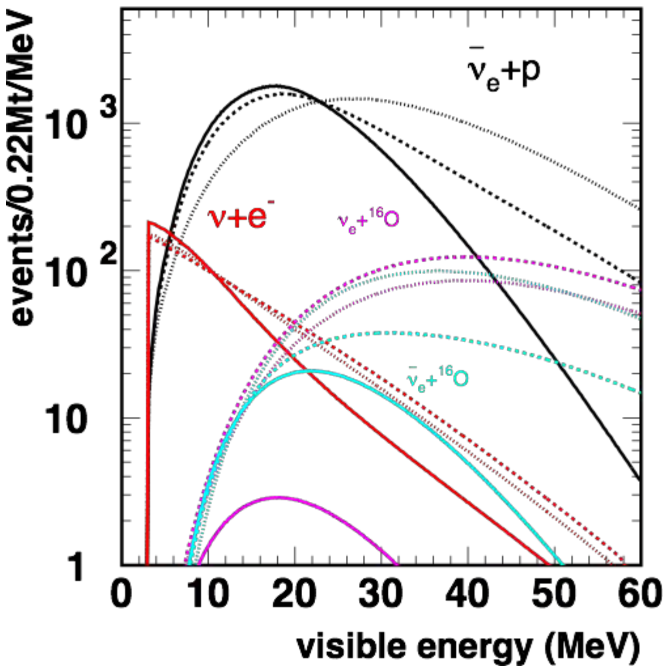
Stainless lining
2025 (5th yr)

# Astrophysics: Supernova ν in Hyper-K

## Main detection channels

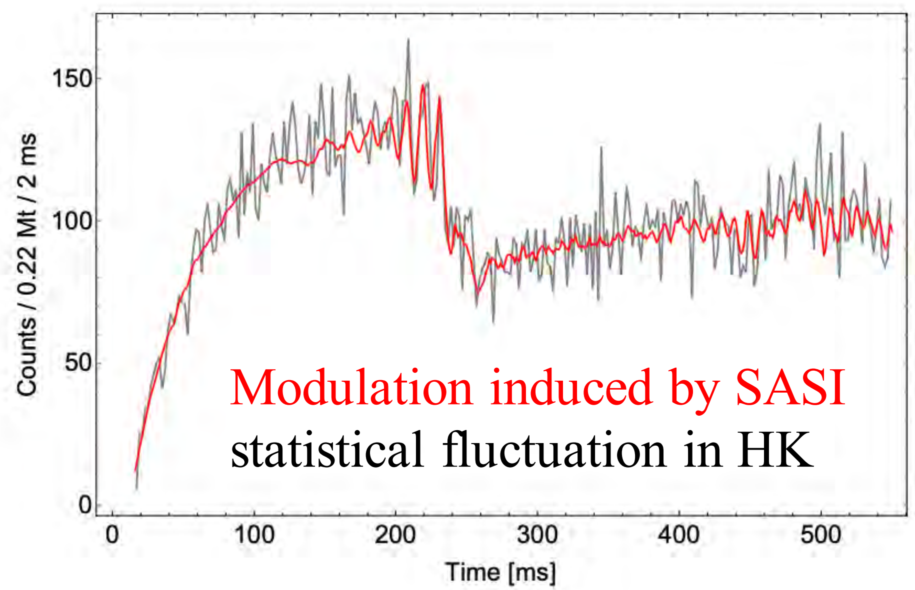
| | | |
|---|---|---|
| Inverse beta decay | $\overline{\nu}_e + p \rightarrow e^+ + n$ | E > 1.8 MeV |
| ν-e scattering | $\nu + e^- \rightarrow \nu + e^-$ | |
| $\nu_e$ $^{16}$O CC | $\nu_e + {}^{16}\mathrm{O} \rightarrow e^- + {}^{16}\mathrm{F}^{(*)}$ | E > 15 MeV |
| $\overline{\nu}_e$ $^{16}$O CC | $\overline{\nu}_e + {}^{16}\mathrm{O} \rightarrow e^+ + {}^{16}\mathrm{N}^{(*)}$ | E > 11 MeV |

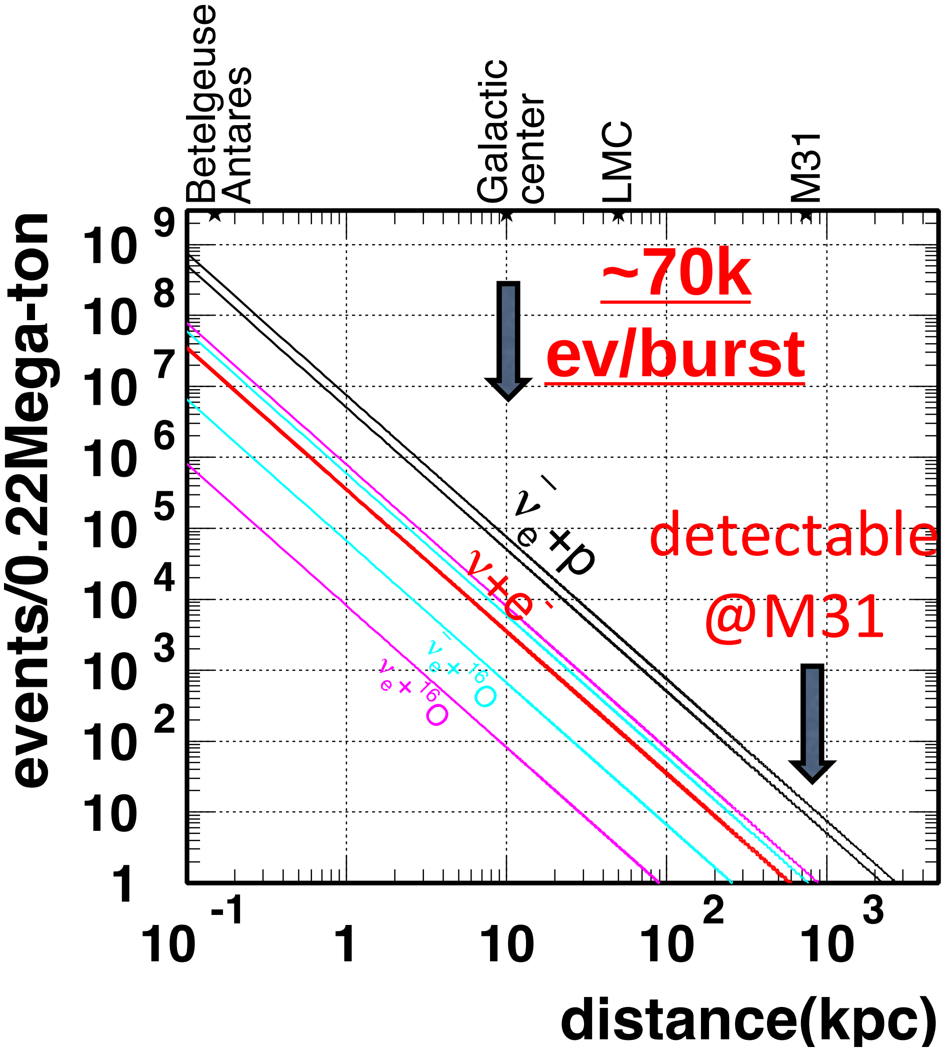
Total energy spectrum

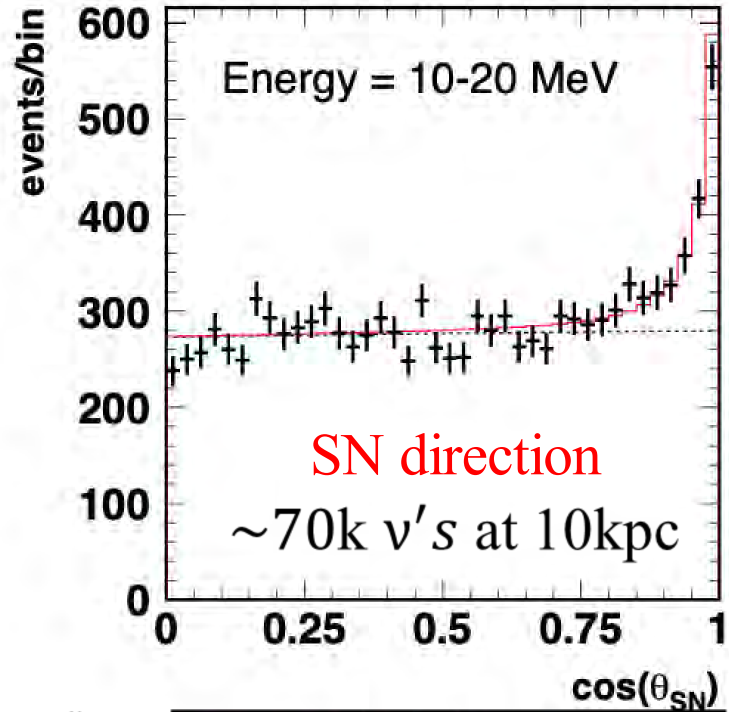


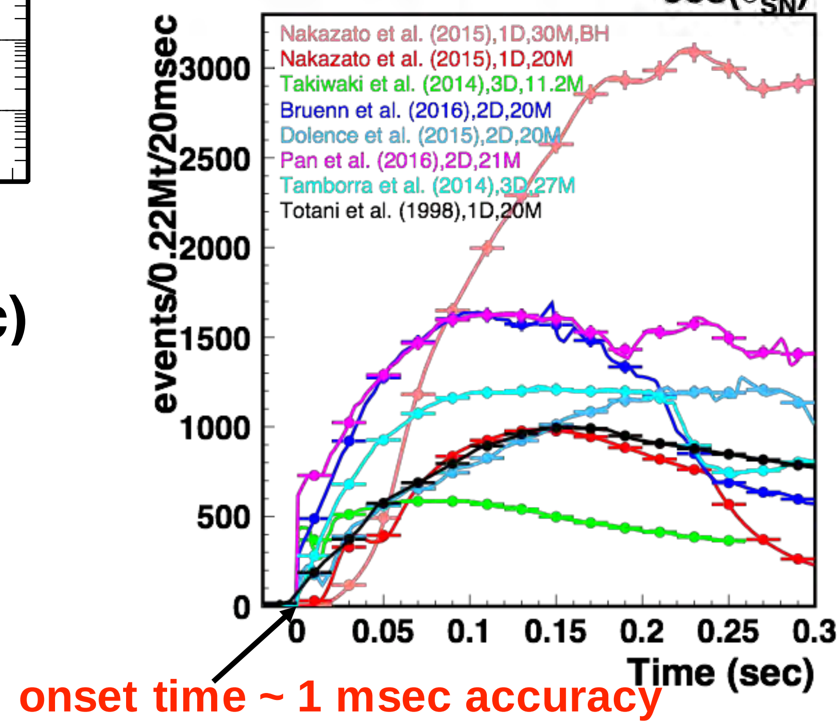

Time modulation of event rate

galactic supernova at 10 kpc (our $r_{gal}$= 8 kpc)





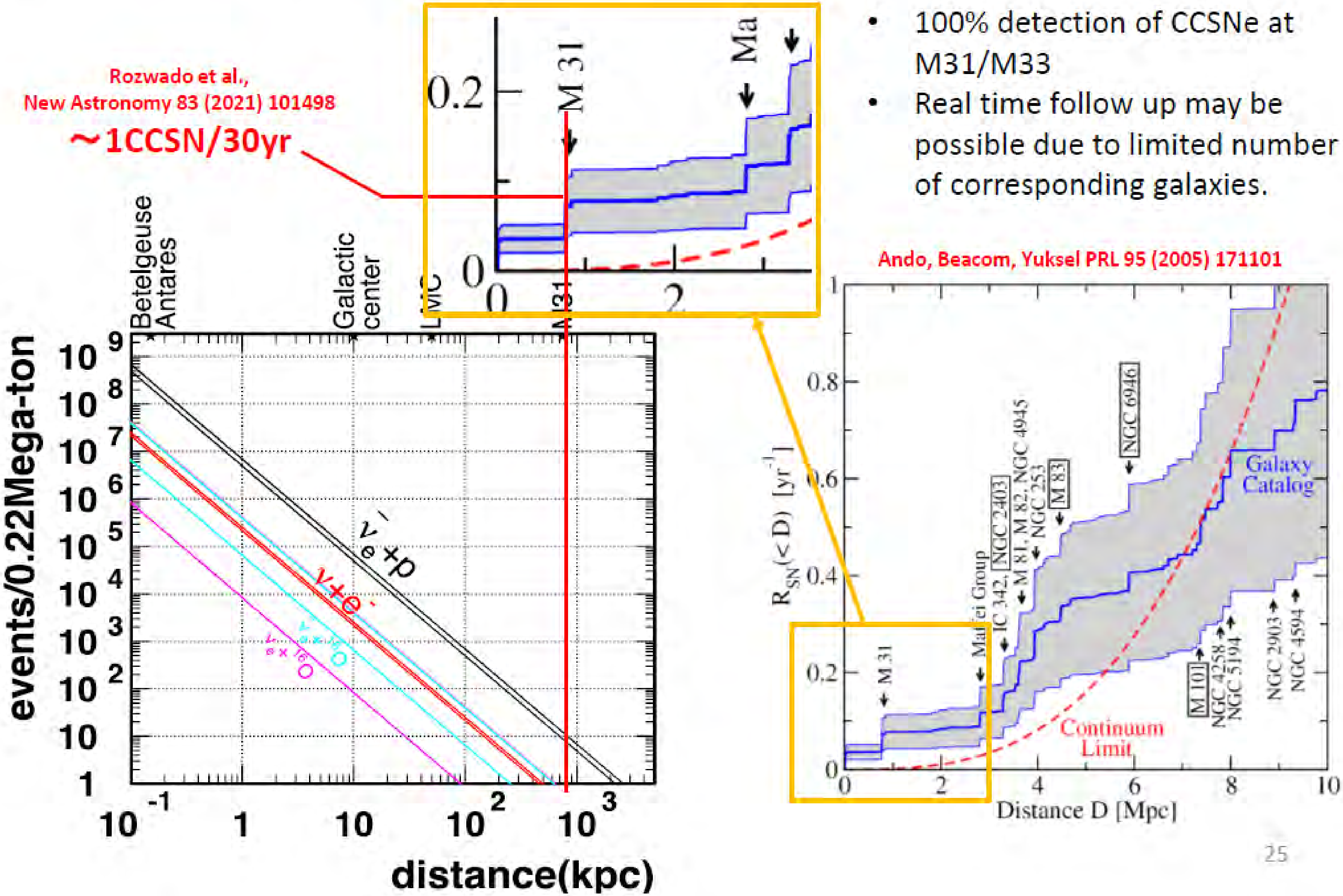

**~70k events/burst**

- explosion mechanism,
- BH/NS formation,
- alert with 1° pointing

# Supernova Neutrino Detection

**Heart of the multi-messenger astronomy with HK: 8.4 times larger effective mass than SK**

- 100% detection of CCSNe at M31/M33
- Real time follow up may be possible due to limited number of corresponding galaxies.

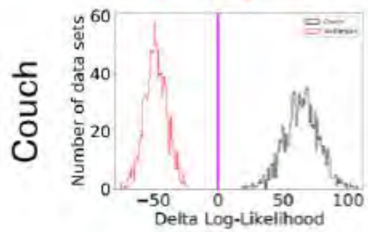


# Supernova Model Discrimination

- To understand explosion mechanism, need to compare observation with simulations.
- 5 representative models are compared by using energy & time of events detected 20-520ms after core bounce.
  - Full detector simulation
  - Unbinned likelihood
- Model discrimination is surely possible at LMC (50kpc).

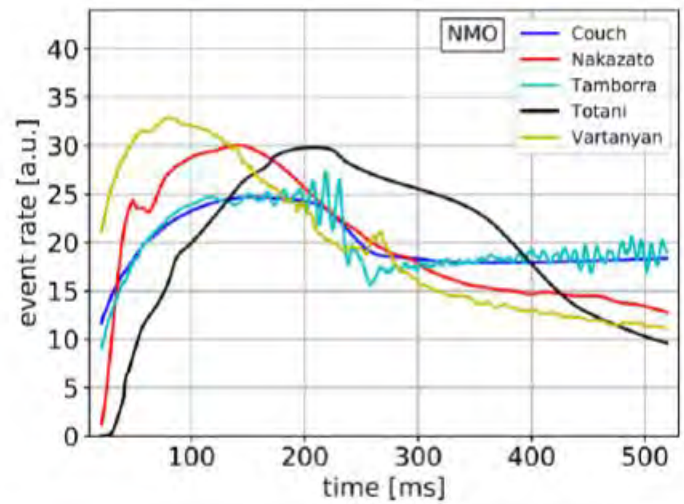
An example (300ev)

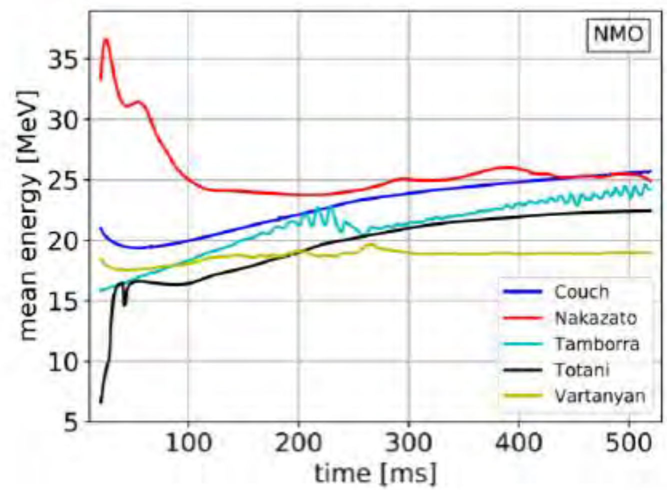
Vartanyan



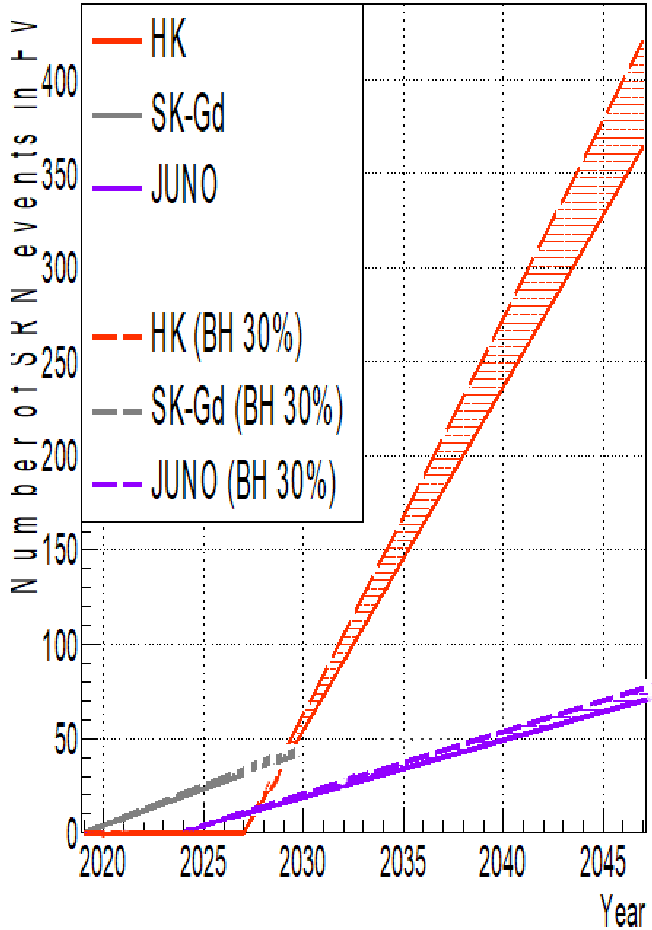

| Model | Normal Mass Ordering | | |
|---|---|---|---|
| | $N_{10\ \mathrm{kpc}}$ | $d_{100}$ | $d_{300}$ |
| Totani | 20021 | 141 kpc | 82 kpc |
| Nakazato | 17978 | 134 kpc | 77 kpc |
| Couch | 27539 | 166 kpc | 96 kpc |
| Vartanyan | 10372 | 102 kpc | 59 kpc |
| Tamborra | 25025 | 158 kpc | 91 kpc |

HK Collab., ApJ 916:15, 2021



# Expected number of DSNB events in HK




Conditions

**SK-Gd (22.5 kton $H_2O$ + Gd)**

Low energy threshold : 10 MeV
neutron tagging by Gd-loading

Started data-taking in 2020

**Aim for the first discovery**

**JUNO (20 kton LS)**

Low energy threshold : 12 MeV

Start data-taking in 2024

**Hyper-K (187 kton $H_2O$)**

Energy threshold : 16 MeV?

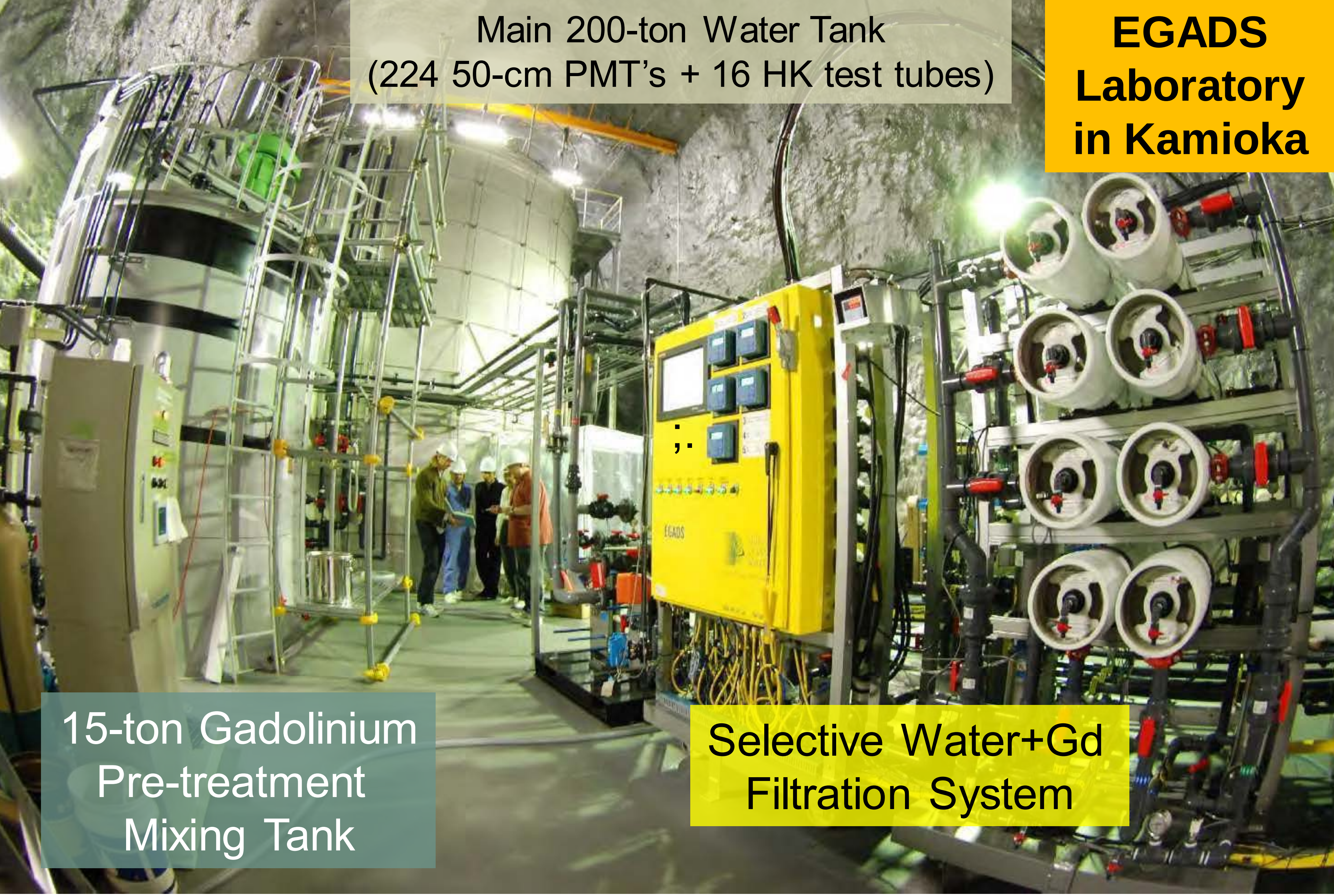
Start data-taking in 2027

**Aim for the precise flux and energy spectrum measurement**

**~4 events/yr in HK w/ H tag**

- Stellar collapse
- Star formation rate
- Heavy element synthesis

Adding gadolinium to HK is being preserved as a future upgrade option → >10 DSNB events/yr




**Worldwide, over ¥十五億 ($10M) has been spent developing and proving the viability of the Beacom+Vagins Gd-in-water concept.**

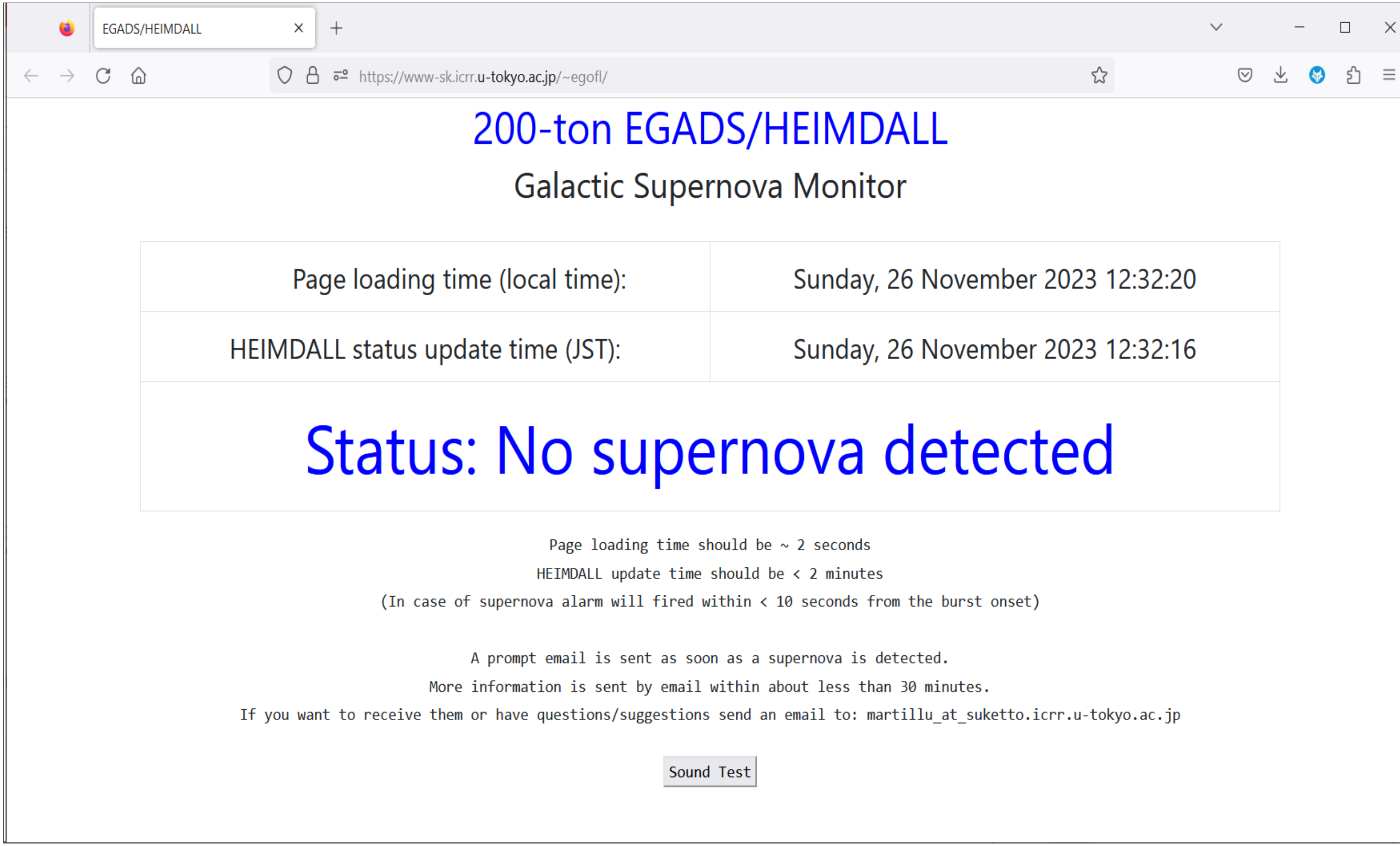
With an R&D program of mostly long-duration tests, EGADS also functions as a dedicated, Gd-loaded SN detector. <u>Its realtime alerts are open to the public.</u>

~90,000 ν events @ Betelgeuse

~40 ν events @ G.C.

<u>EGADS is now the lowest latency SN neutrino detector in the world.</u> We'll send out an announcement within <u>***a few seconds***</u> of a MW SN neutrino burst's arrival!

https://www-sk.icrr.u-tokyo.ac.jp/~egofl/



EGADS/HEIMDALL

https://www-sk.icrr.u-tokyo.ac.jp/~egofl/

# 200-ton EGADS/HEIMDALL

## Galactic Supernova Monitor

| | |
|---|---|
| Page loading time (local time): | Sunday, 26 November 2023 12:32:20 |
| HEIMDALL status update time (JST): | Sunday, 26 November 2023 12:32:16 |
| **Status: No supernova detected** | |

Page loading time should be ~ 2 seconds

HEIMDALL update time should be < 2 minutes

(In case of supernova alarm will fired within < 10 seconds from the burst onset)

A prompt email is sent as soon as a supernova is detected.

More information is sent by email within about less than 30 minutes.

If you want to receive them or have questions/suggestions send an email to: martillu_at_suketto.icrr.u-tokyo.ac.jp

Sound Test

Sorry, but there was no Milky Way supernova while I was preparing my talk last night!

So, thank you
for having me
here today.

In Hawaii – unlike
in Japan – my usual
choice of clothing
actually looks normal.

Let’s keep
watching the
skies together and
so put all the SN
messengers to work!