Astroparticle Physics in Hyper-Kamiokande

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Topics in Astroparticle and Underground Physics 2017

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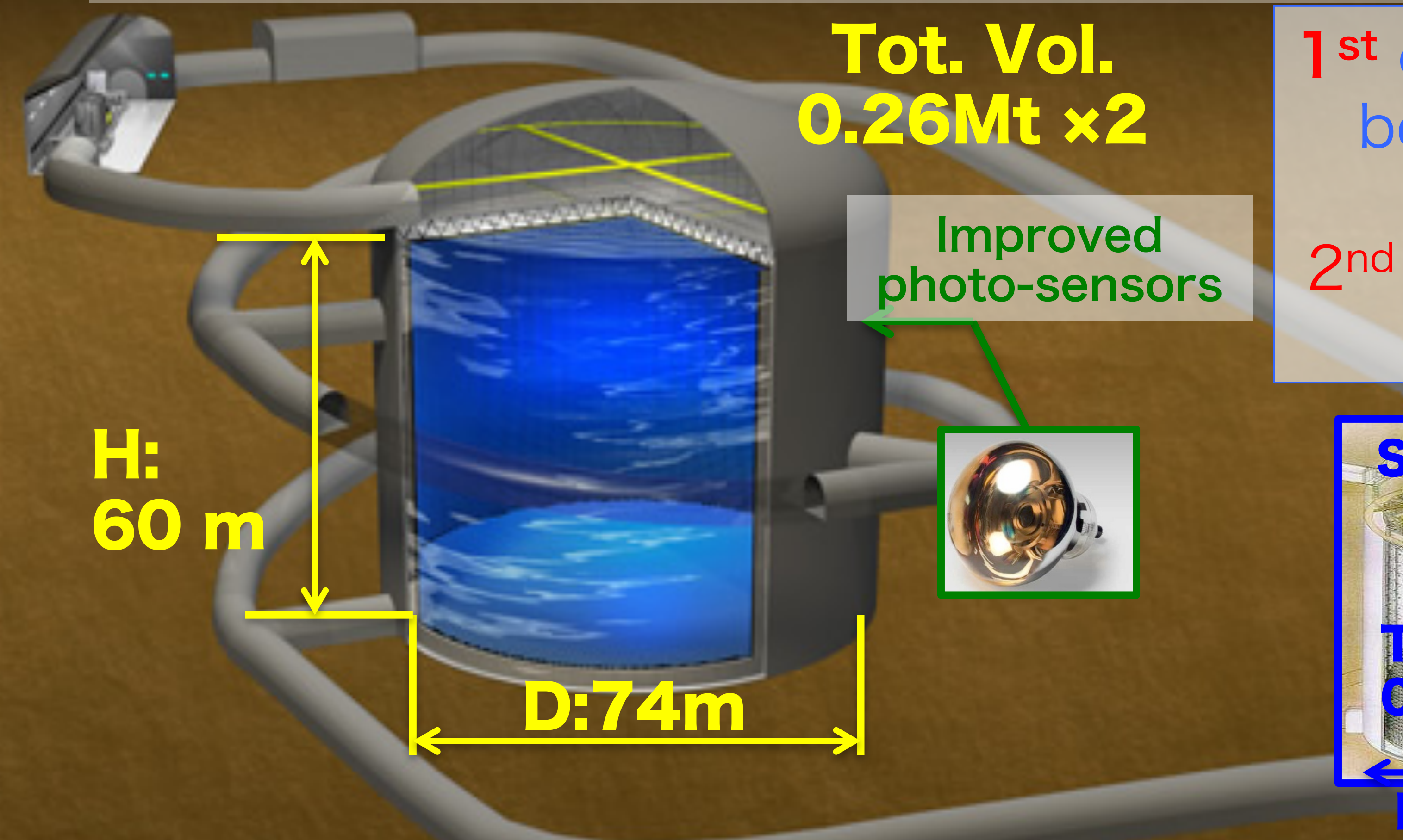
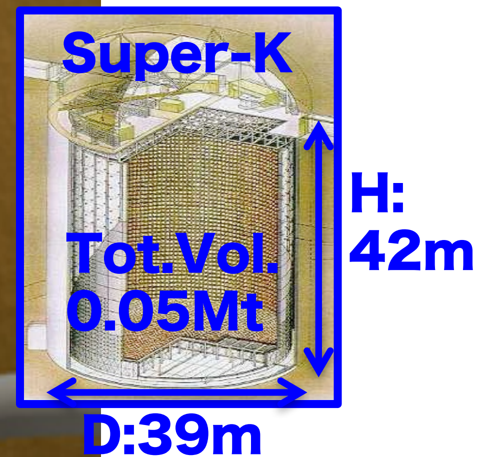
Hyper-Kamiokande Project

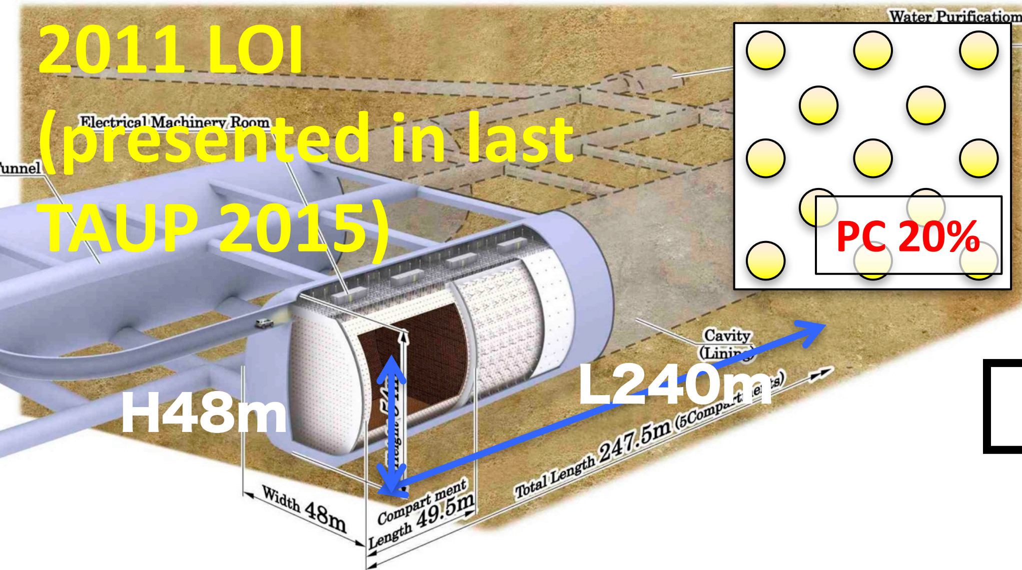


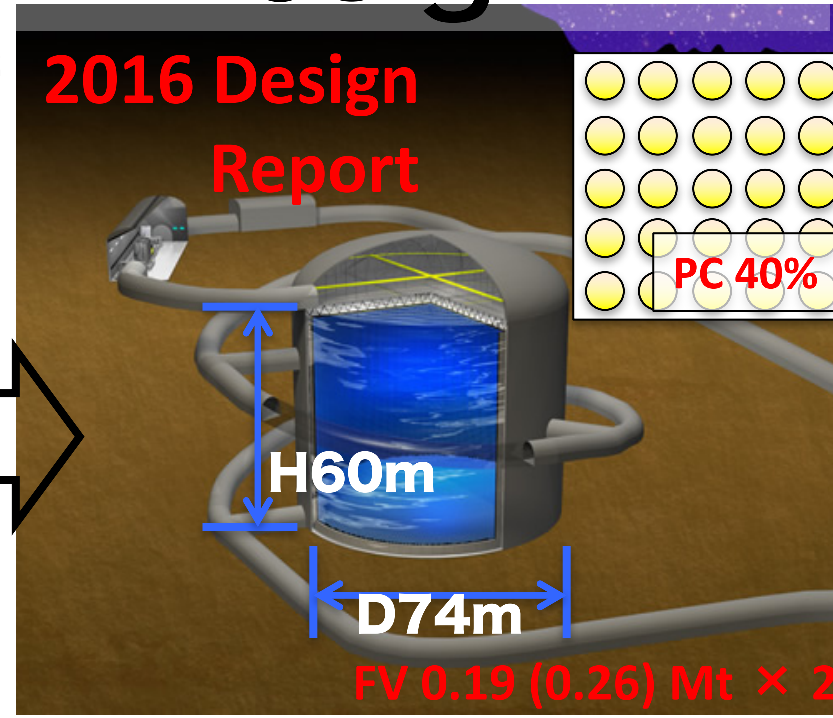
1st detector will be ready at **2026**.
2nd will be 6yrs later.



Design	Hyper-Kamiokande	Super-Kamiokande
Shape of tank(s)	2 Cylindrical tanks	1 Cylinder
No. of PMTs (ID/OD)	40,000 / 6,700 (per tank)	11,129 / 1,885
Photocathode coverage	40% (×2 efficient p.e. detection)	40%
Total / Fiducial V.	0.26 Mt / 0.19Mt (per tank)	50 kt / 22.5 kt

New Hyper-K Design





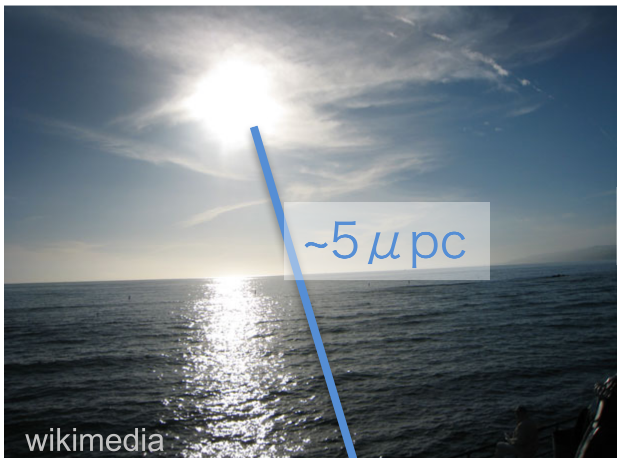
New HK detector consists of two SK-like cylinders.

- Better energy and vertex resolutions with higher photo-coverage and improved photo sensors (x2 p.e. detectable).
- 70% fiducial volume comparing to LOI design.
- Easy to build and install photo sensors.
- Deeper tank with high pressure tolerance PMT.
- At 2026, we will start the observation with 1st tank. The 2nd tank will be ready 6 years later. One candidate site is Korea.

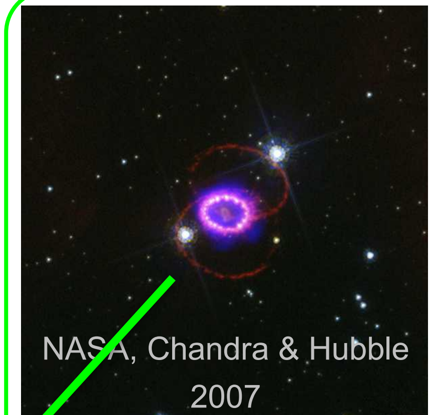
Astrophysical Neutrino at HK

Solar neutrino

- Burning processes, modeling of the Sun
- Property of neutrino

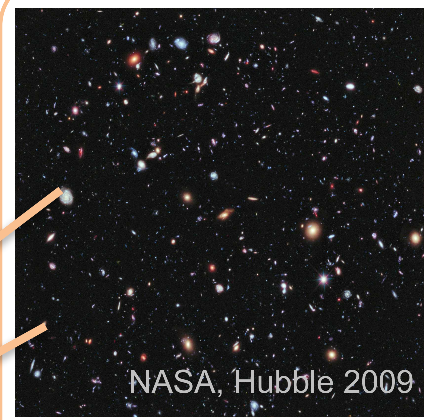


kpc ~ Mpc



Supernova ν

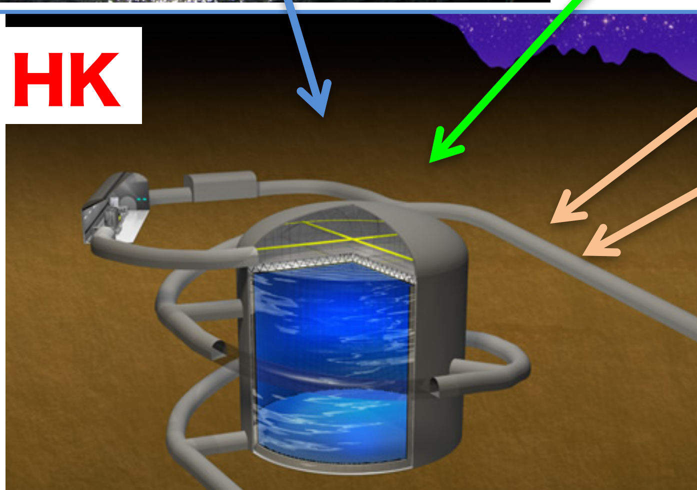
- SN explosion mechanism
- SN monitor
- Nucleosynthesis



SN relic ν

- SN mechanism
- Star formation history
- Extraordinary SNe

Mpc ~



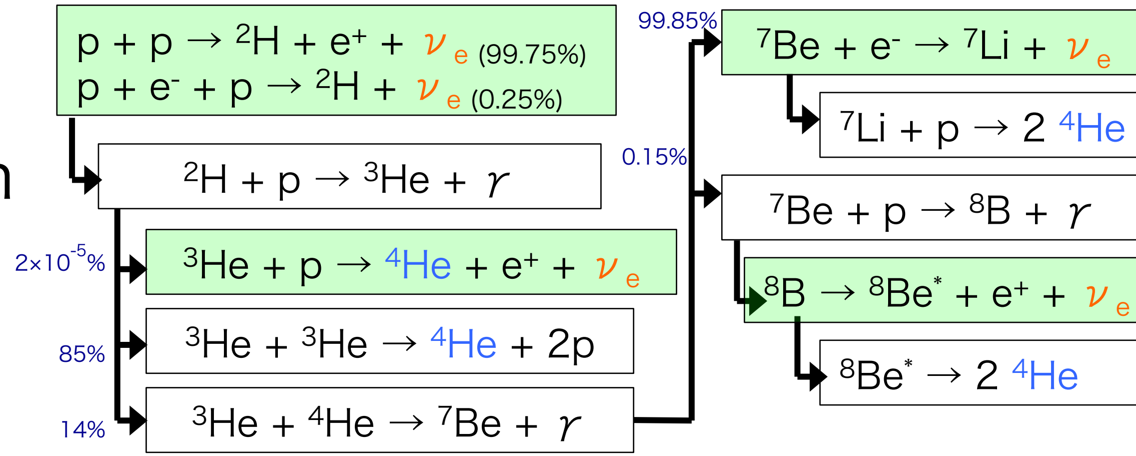
and DM annihilation, GRB ν…

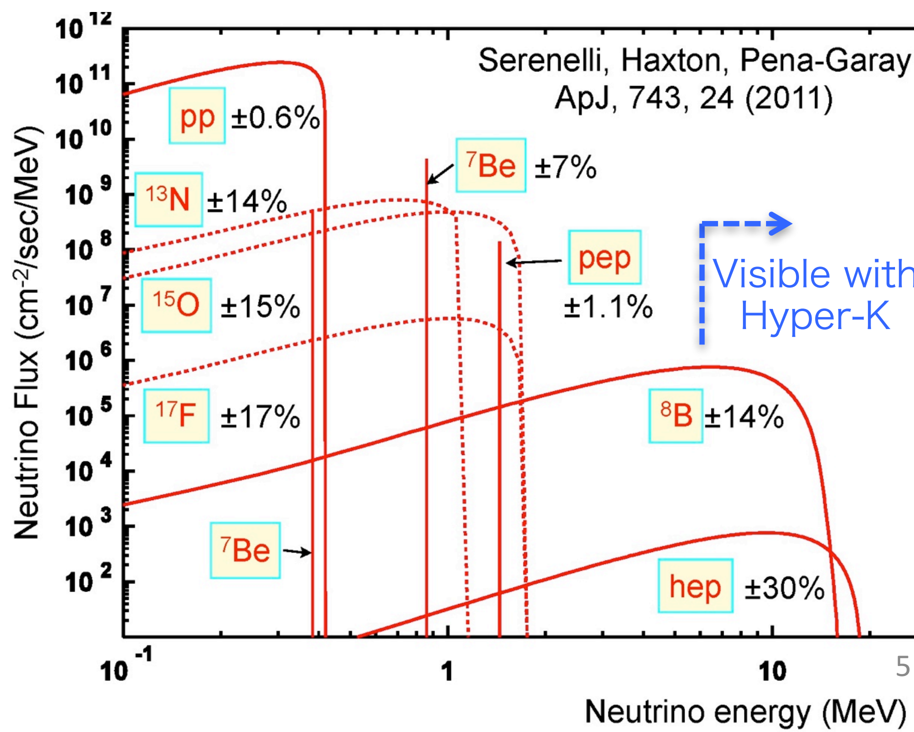
Solar neutrino

pp-chain & ν Energy specturm

- The **Sun** is burning with nuclear fusion reactions, i.e. pp-chain and CNO-cycle, emitting neutrinos.
- Only neutrinos can bring out the information of “today’s” status of solar center.
- With **Hyper-K**, a large statistics is expected :

  70 ν ev./day/tank,
  E_ν>6.5MeV
  (18 ν ev./day in SK-IV)





Solar neutrino observation

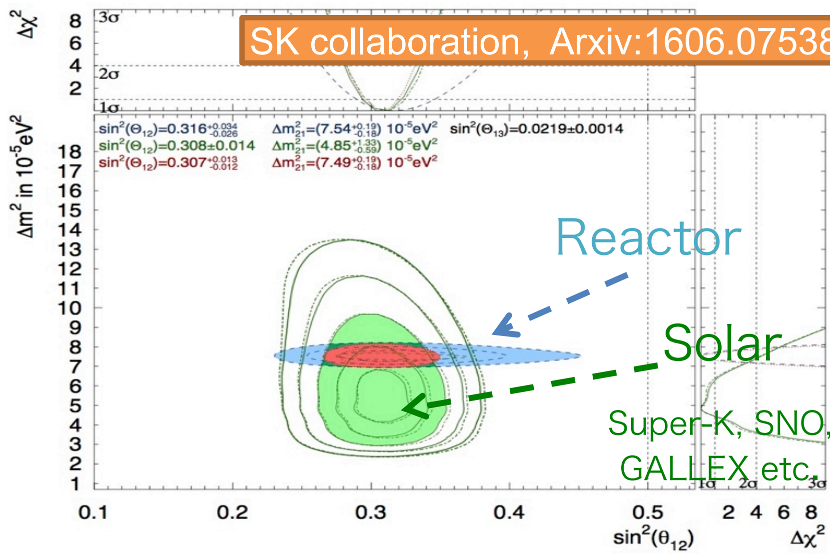
- In water detector, we observe the neutrinos with the **Cherenkov light** of the scattered electron.

$$\nu + e^- \rightarrow \nu + e^-$$

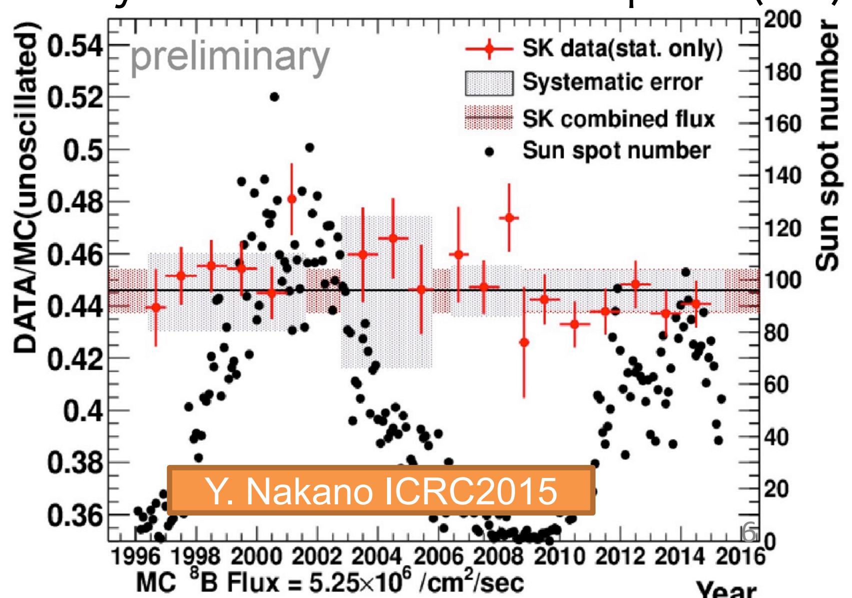
- Sensitivity to **direction** and **energy**.
- Real-time measurement.

- Importance of solar nu meas. in particle physics and astrophysics
  - Precision measurement, Δm_{21}
    - Day/Night asymmetry
  - Solar nu spectrum up-turn
  - Discovery of Hep neutrino
  - Stability/fluctuation of solar ν

Solar ν oscillation measurement



Yearly ν variation & Sun spots (SK)

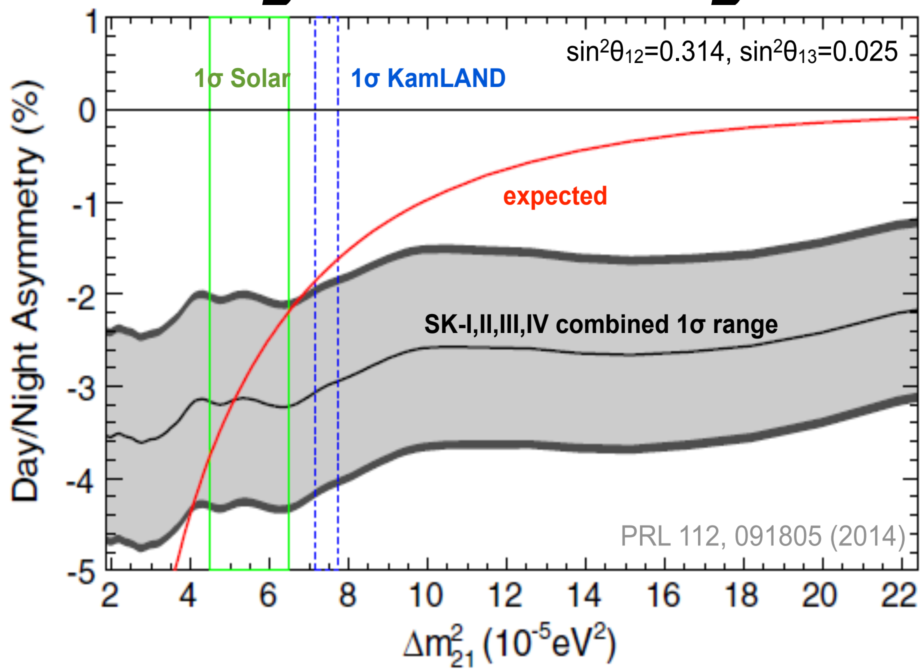


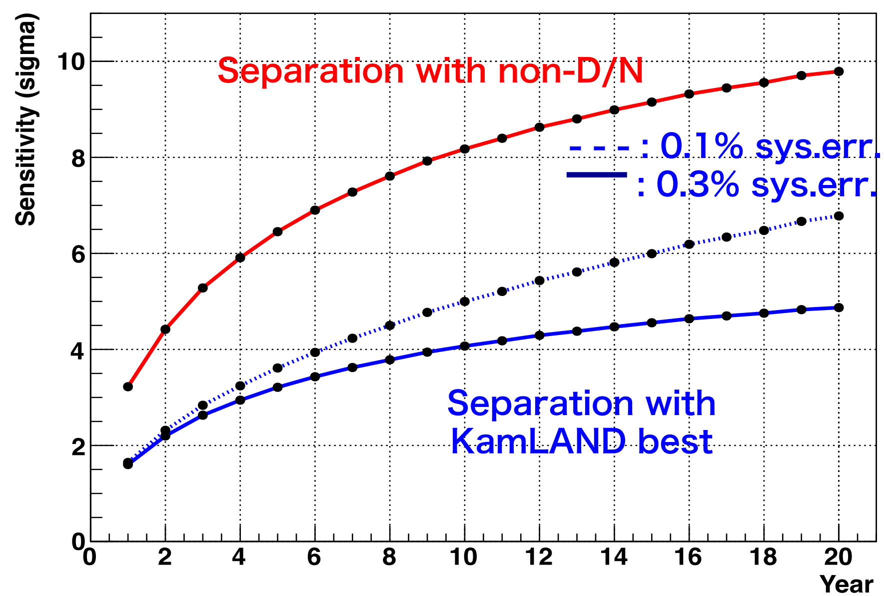
Solar Day/Night asymmetry

- **Nonzero D/N asymmetry** of solar ν caused by terrestrial matter effect is indicated by SK.
  [PRL 1212, 091805(2014)]
- The D/N asymmetry leads smaller Δm^2_{21} value in solar neutrino analysis, comparing to reactor neutrino analysis.
- With Hyper-K statistics, we can separate solar best Δm^2_{21} and KamLAND best above 4σ.
  - 10 years with 1 tank, 0.3% sys. Err.

→ CPT violation test, difference between $P_{\nu e \to \nu e}$ and $P_{\overline{\nu e} \to \overline{\nu e}}$.

→ Precise Δm^2_{21} also contributes to CPV test in HK long-baseline.

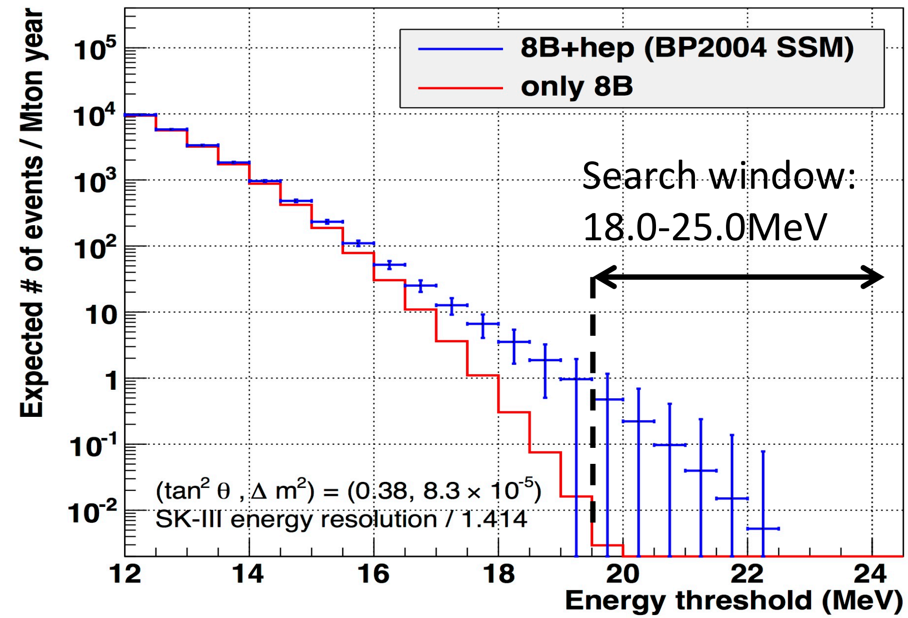




Other solar ν topics

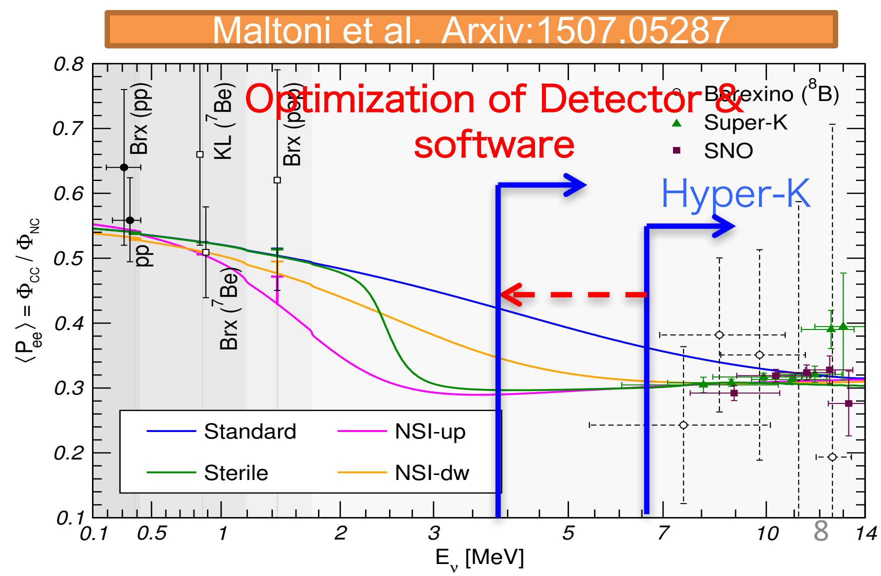
Hep process neutrino

- Undiscovered solar neutrino, with small branching ratio.
- With Hyper-K 10 years, there is chance to discover.
- → To test the solar models.
- **6.0 ev. + BG 0.5 ev.**/10y/tank



Energy spectrum up-turn

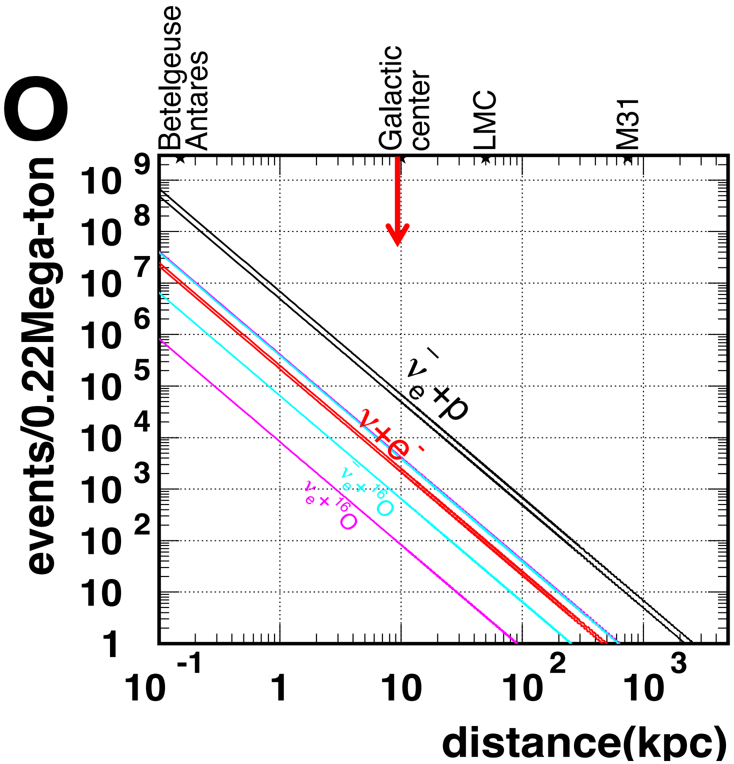
- To confirm the solar neutrino oscillation, or to see new physics beyond the SM.
  → Non-standard interaction, sterile neutrinos …
- **Separable w/ up-turn from w/o up-trun with ~3(5)** σ.
  - 4.5 (3.5) MeV threshold, 10y, 1 tank



Supernova Neutrino

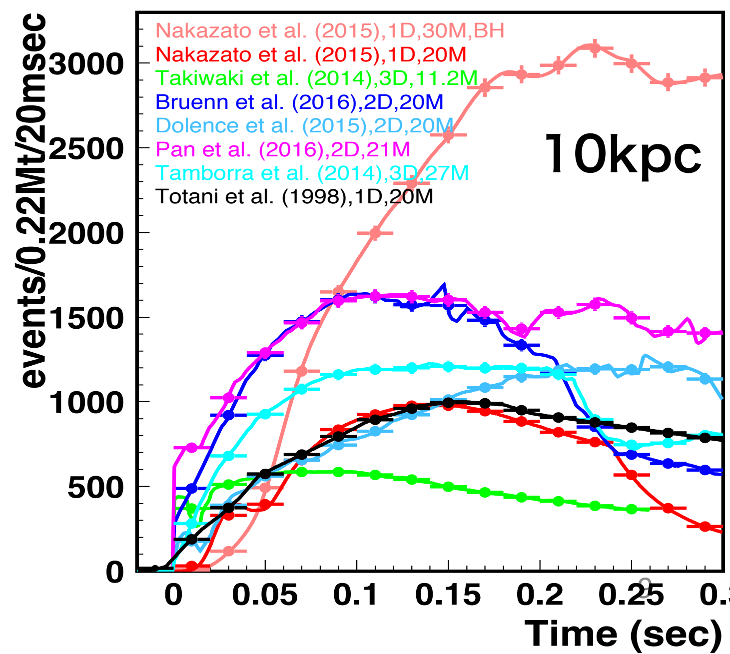
Core collapse supernova emits all kinds of neutrinos.

- **11** neutrino events by Kamiokande from SN1987A at **50kpc** (LMC).
- **50 ~ 80k events/tank** are expected in HK from SN at **10kpc** (galactic center).



Physics Motivation

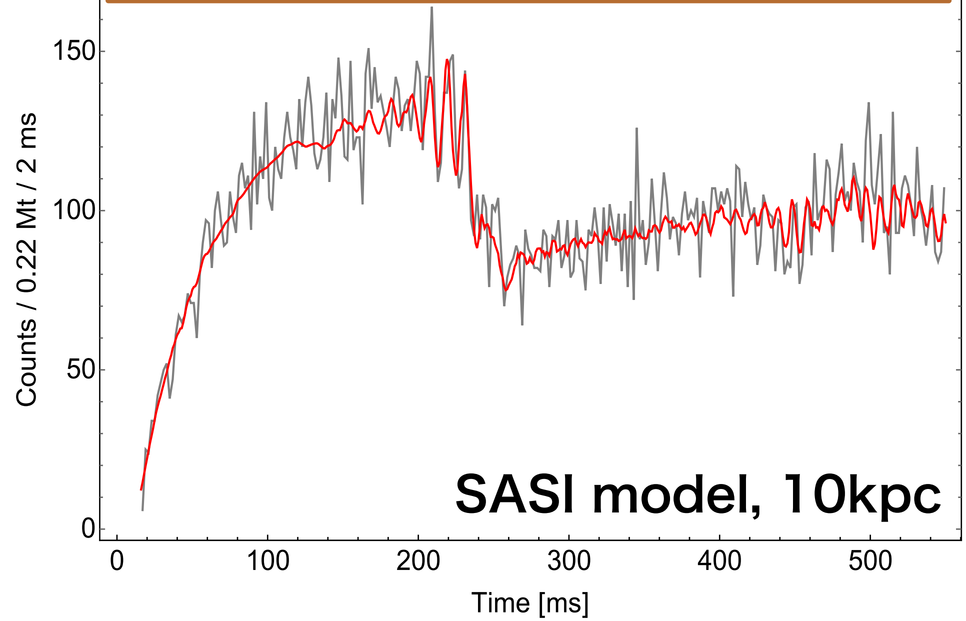
- Core collapse SN physics
  - Explosion mechanism
  - Proto-neutron star formation
  - Black hole formation
- Neutrino Physics
- Multi-messenger analysis
  - With gravitational wave, gamma-ray, X-ray, telescope…



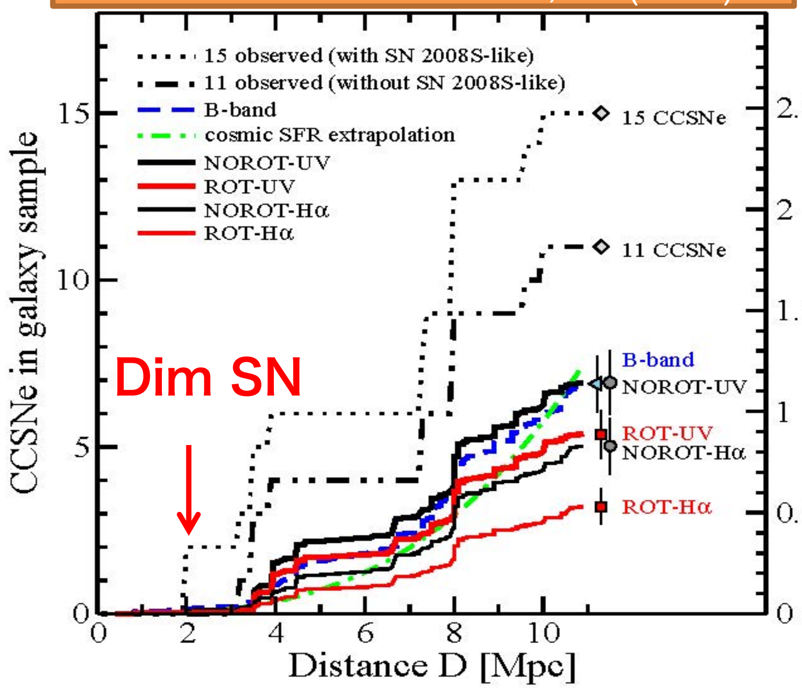
Features

- Precise SN neutrino time profile
- Energy spectrum measurement
  - Investigation of the SN mechanism (SASI/Rotation/Convection)
- Proving dim supernova/BH formation

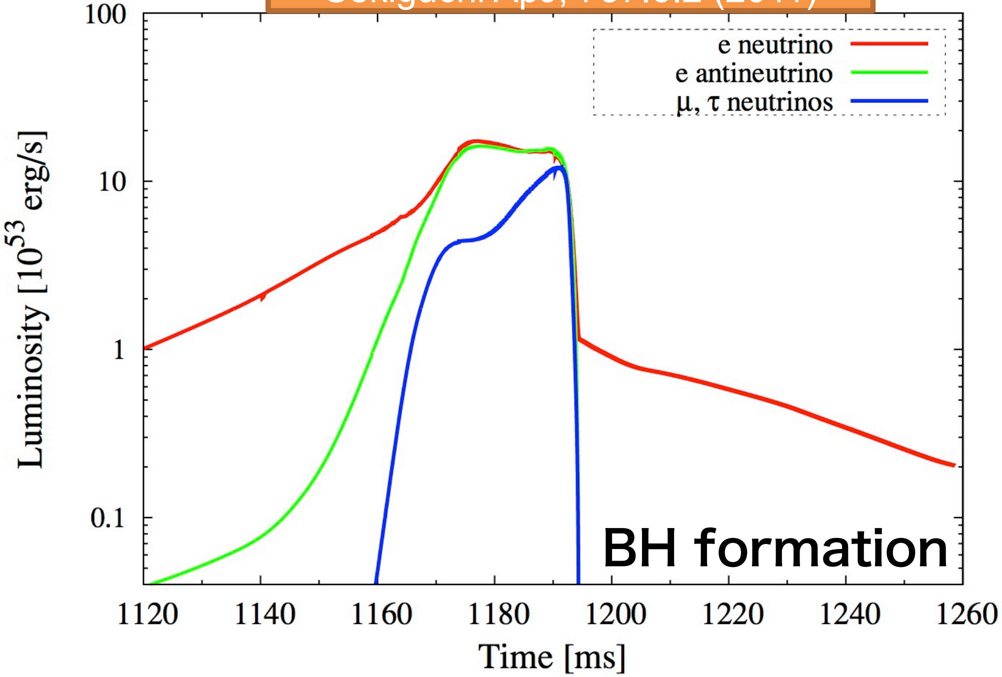
nu Flux from I. Tamborra PRL 111, 121104 (2013)



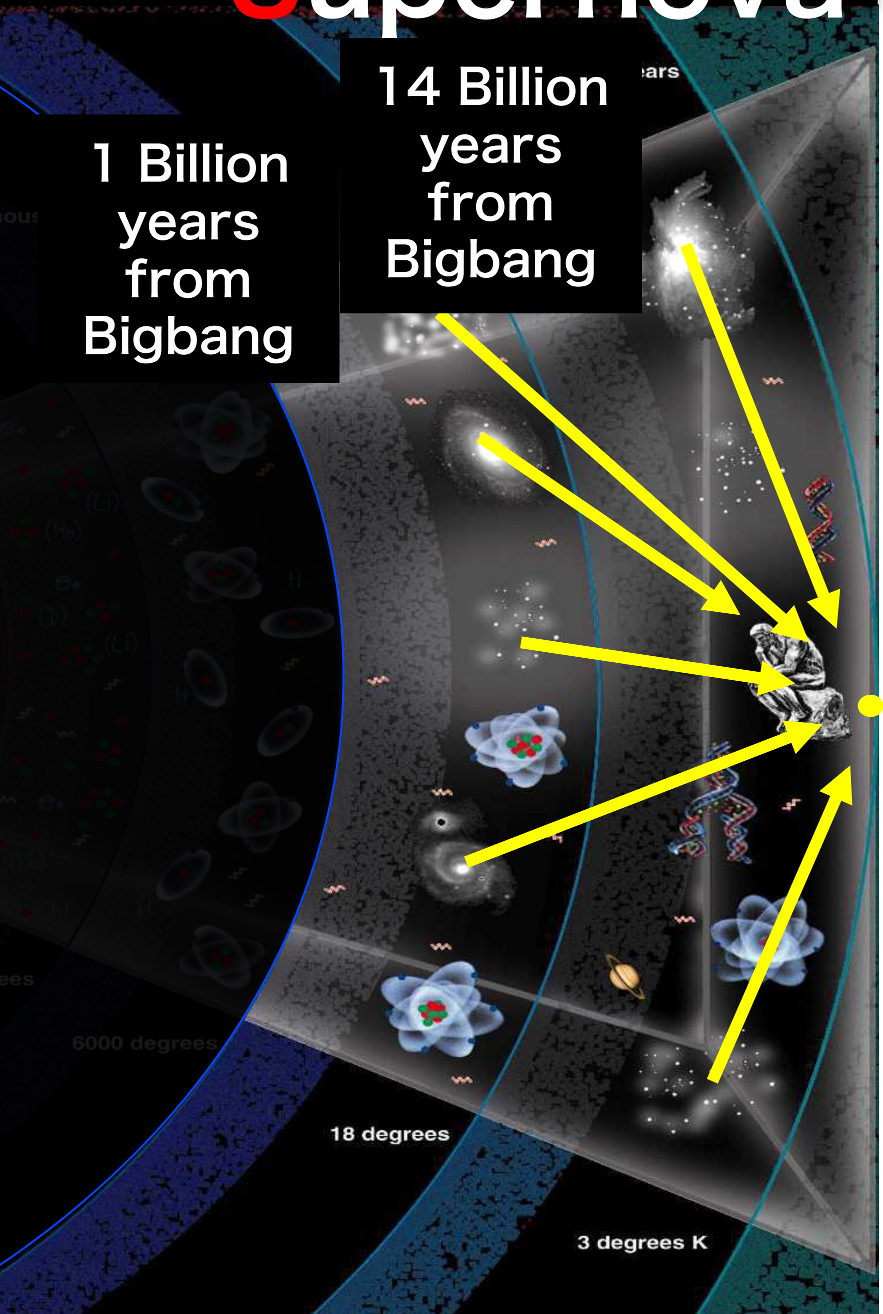
Horiuchi et al. AstroP.J769,113 (2013)



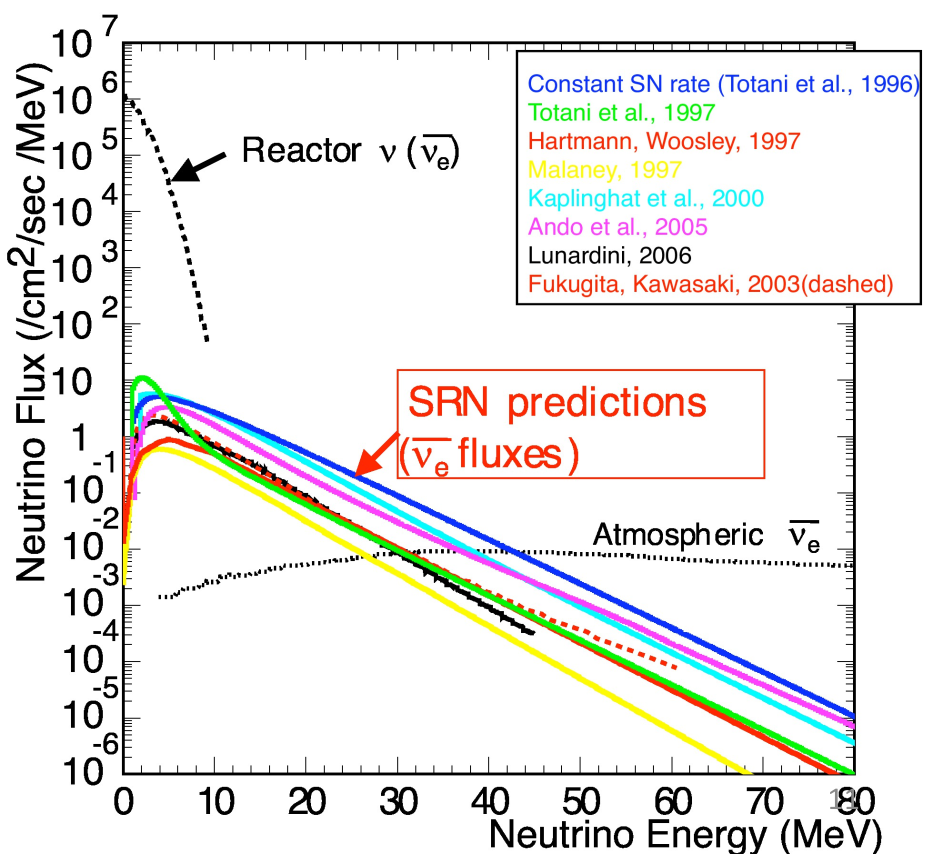
Sekiguchi ApJ, 737.6.2 (2011)



Supernova Relic Neutrino



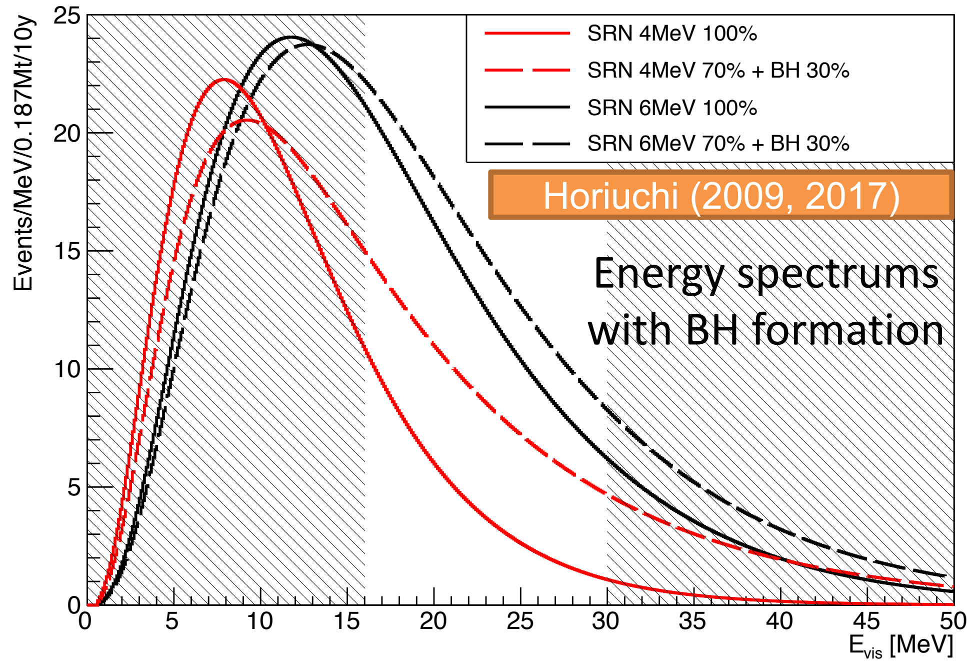
- **Supernova Relic Neutrino (SRN)** is diffused neutrinos coming from all past supernovae.
- Not discovered but **promising** source of extra-galactic neutrino.



SRN with HK

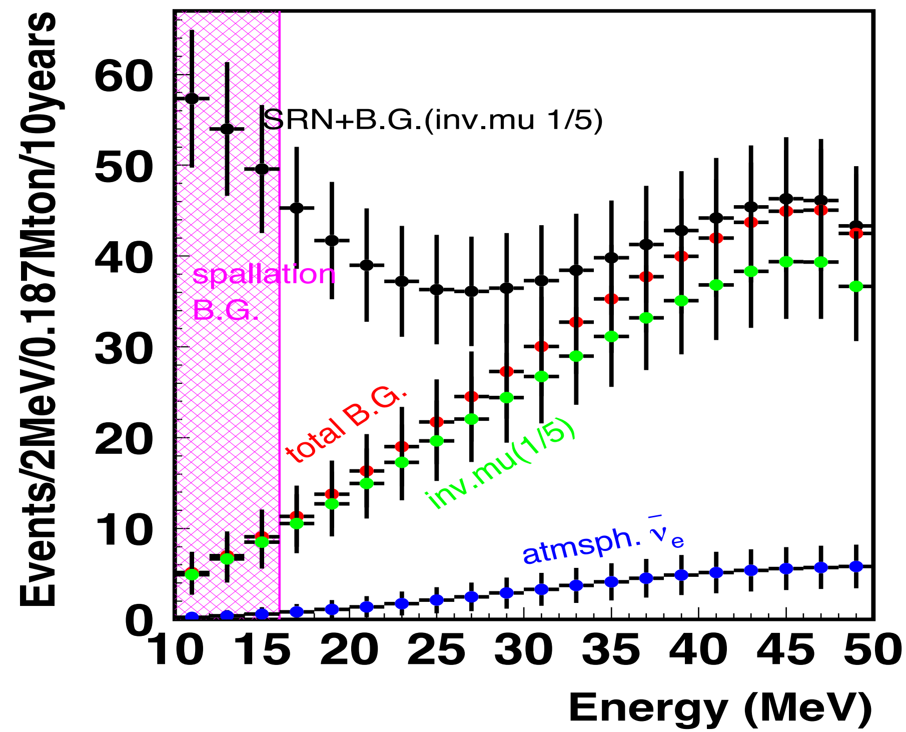
Physics of SRN

- Test of star formation rate
  - Factor ~2 discrepancy between rates of formations and SNe.
- Energy spectrum of supernova burst neutrinos
  - Temperature inside the SN
- Extraordinary SN
  - BH formation, dim supernova



SRN with Hyper-K

- SRN can be observed by HK in 10y with **~70±17** (**~98±20**) events with 1 (1^{st}+2^{nd}) tank(s).
- It is 4 (4.8) σ from nonzero
- We will go beyond the discovery and aim to measurement of SRN.



Summary

- **Hyper-K project is a next generation large water Cherenkov detector.**
  - Design Report 2016 is ready. The update is being prepared.
  - 1st HK detector will be ready at 2026. Now we're going to request the budget.
- **Astrophysical neutrino measurements is one of the features of Hyper-Kamiokande.**
  - **Solar neutrino**
    - Hep neutrino, seasonal variation, up-turn etc…
  - **Supernova neutrino**
    - Energy and time spectrum measurement, SN alarming etc..
  - **Supernova Relic Neutrino**
    - Supernova and SFR models, extraordinary SN

Hyper-Kamiokande Proto-Collaboration

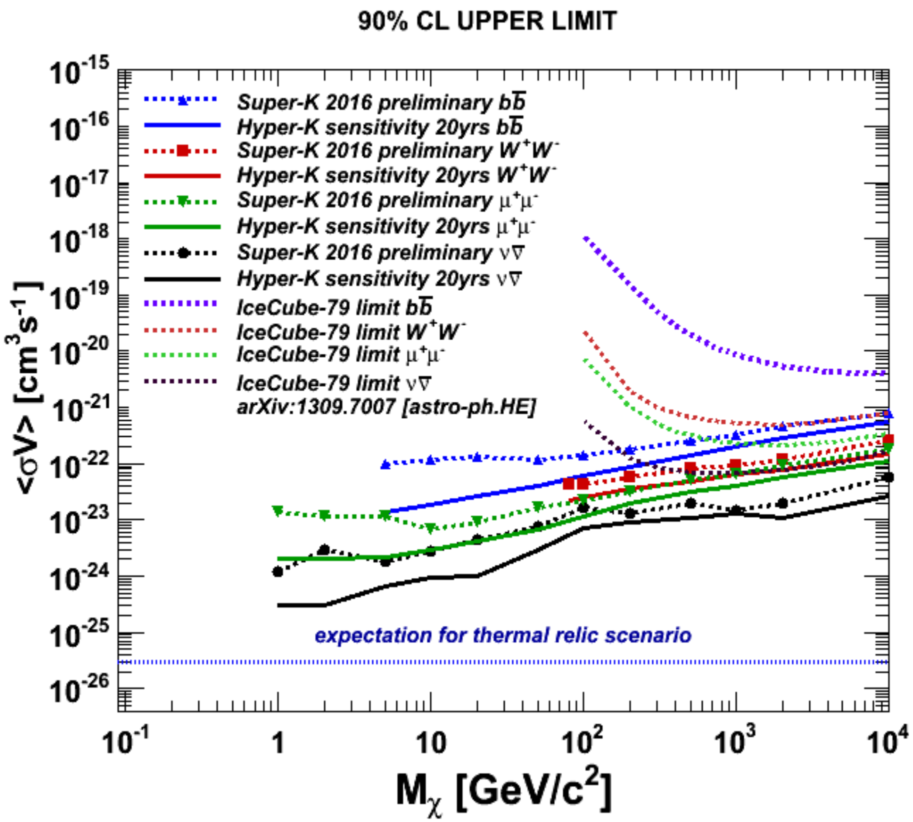
16 institutes from Japan

- Kamioka Observatory, ICRR, University of Tokyo, Japan
- Kavli IPMU, University of Tokyo, Japan
- KEK, Japan
- Kobe University, Japan
- Kyoto University, Japan
- Miyagi University of Education, Japan
- Nagoya University, Japan
- Okayama University, Japan
- Osaka City University, Japan
- Tohoku University, Japan
- Tokyo Institute of Technology, Japan
- University of Tokyo, Japan etc.

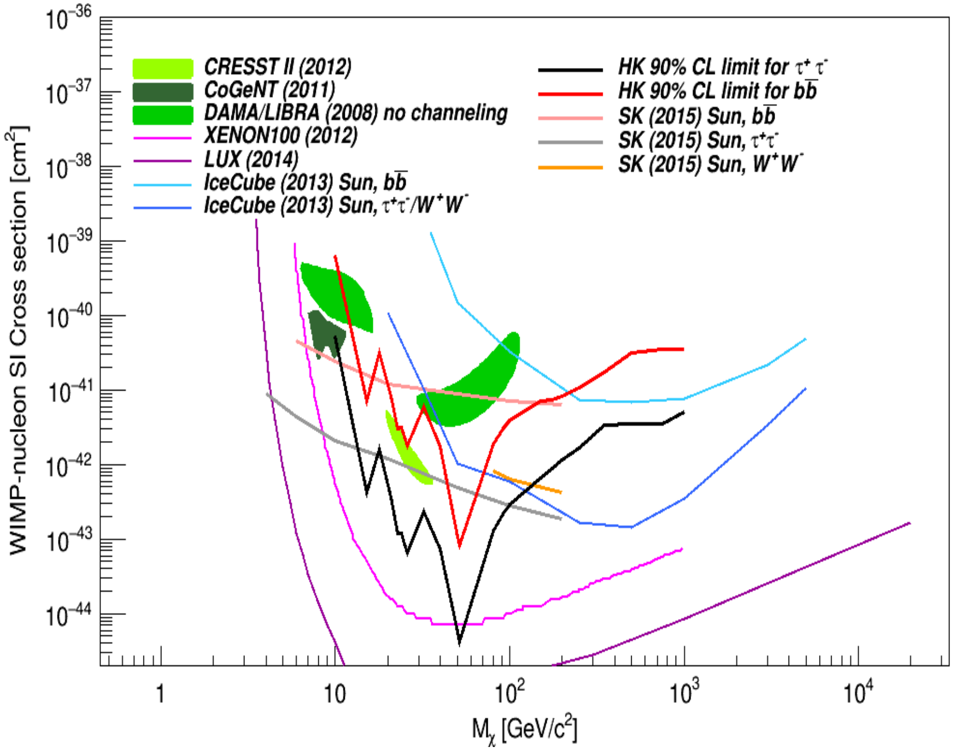
- 16 Institutes from **USA**
- 11 Institutes from **UK**
- 6 Institutes from **Canada**
- 6 Institutes from **Korea**
- 5 Institutes from **Italy**
- 4 Institutes from **Poland**
- 2 Institutes from **France**
- 2 Institutes from **Brazil**
- 1 Institute from **Russia**
- 1 Institute from **Switzerland**
- 1 Institute from **Ecuador**
- 1 Institute from **Armenia**
- 1 Institute from **Spain**

- 298 members
- 73 institutes

WIMP search



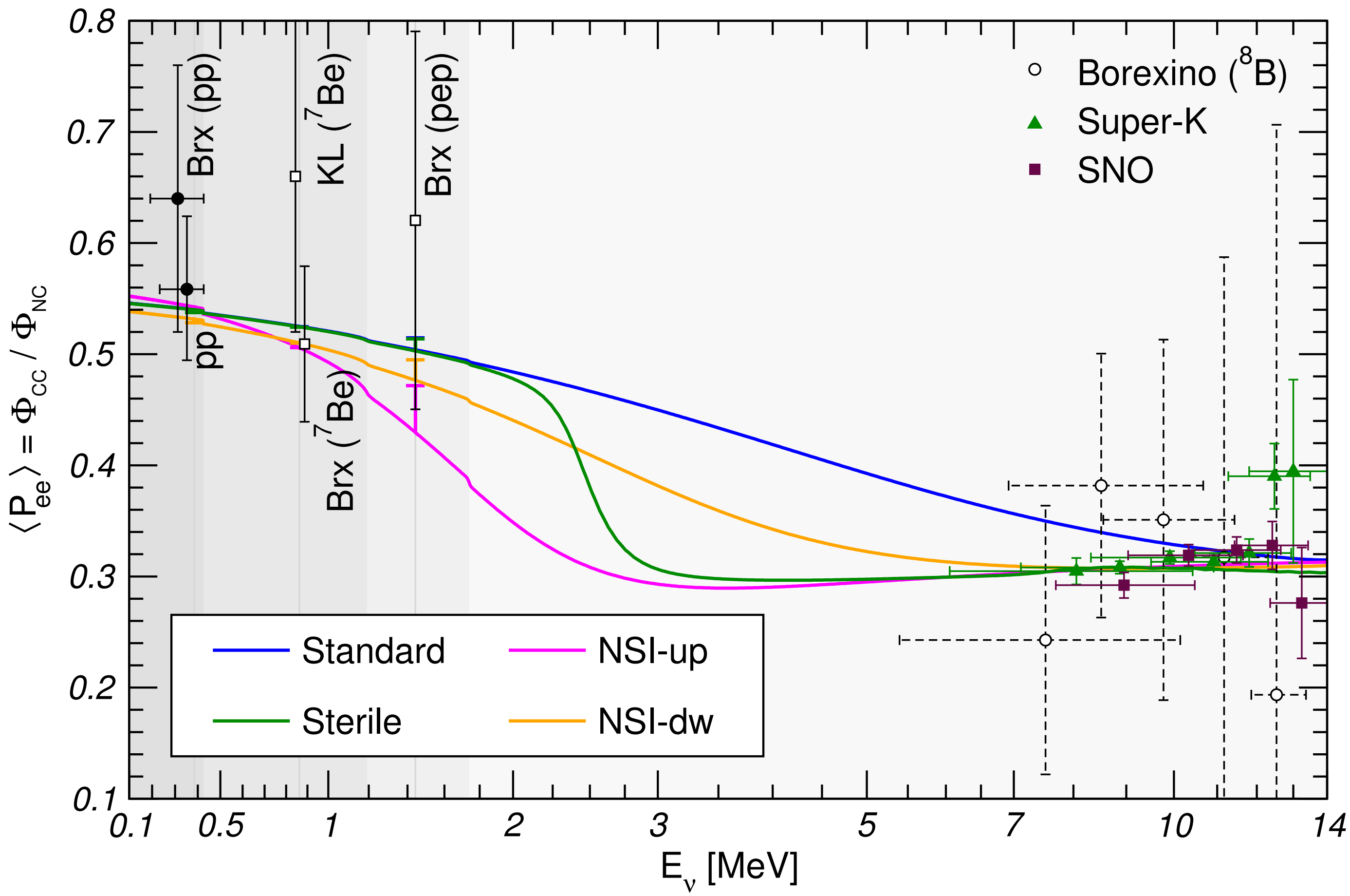
Galactic WIMP



Earth WIMP, SI

Solar neutrino upturn

Maltoni et al. http://arxiv.org/pdf/1507.05287.pdf



Solar neutrino fluxes of models.

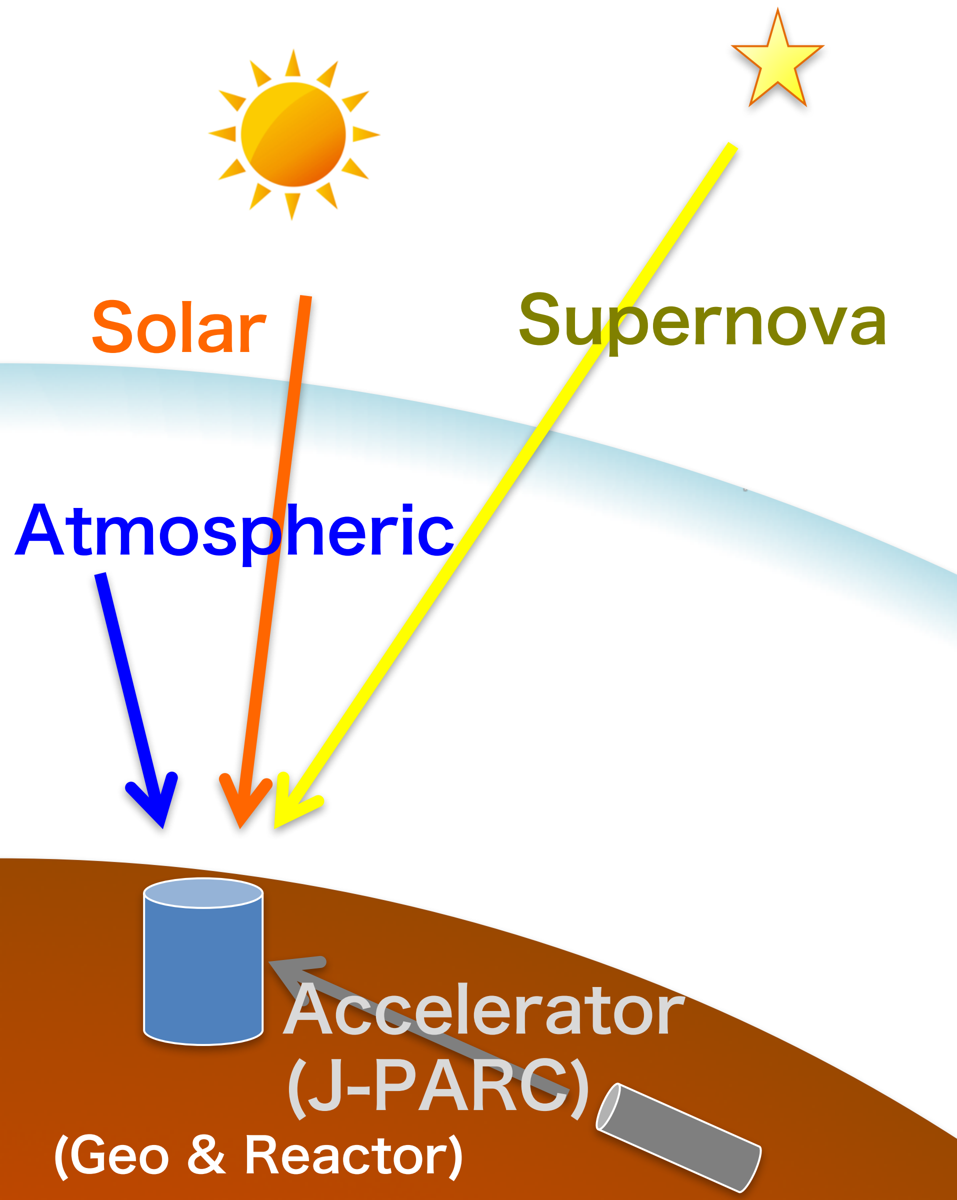
J.N. Bahcall and A.M. Serenelli, Astro. Phys. J. 621, 85 (2005)

Table 2: Predicted solar neutrino fluxes from seven solar models. The table presents the predicted fluxes, in units of $10^{10}(pp)$, $10^{9}(^{7}\mathrm{Be})$, $10^{8}(pep, ^{13}\mathrm{N}, ^{15}\mathrm{O})$, $10^{6}(^{8}\mathrm{B}, ^{17}\mathrm{F})$, and $10^{3}(\mathrm{hep})$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for the same solar models whose characteristics are summarized in Table 1.

Model	pp	pep	hep	^{7}Be	^{8}B	^{13}N	^{15}O	^{17}F
BP04(Yale)	5.94	1.40	7.88	4.86	5.79	5.71	5.03	5.91
BP04(Garching)	5.94	1.41	7.88	4.84	5.74	5.70	4.98	5.87
BS04	5.94	1.40	7.86	4.88	5.87	5.62	4.90	6.01
BS05(^{14}N)	5.99	1.42	7.91	4.89	5.83	3.11	2.38	5.97
BS05(OP)	5.99	1.42	7.93	4.84	5.69	3.07	2.33	5.84
BS05(AGS,OP)	6.06	1.45	8.25	4.34	4.51	2.01	1.45	3.25
BS05(AGS,OPAL)	6.05	1.45	8.23	4.38	4.59	2.03	1.47	3.31

Neutrino, Messenger from Nature

Source of Neutrinos



Physics of Neutrinos

- Neutrino Mixing
  - Mixing angles, Mass differences
- Difference between ν & $\overline{\nu}$
  - CPV, CPTV (Leptogenesis)
- Tiny neutrino masses
  - Mass hierarchy (See-saw mechanism)
- **Astrophysics**
  - **Prove of supernova, Sun, Earth and our universe.**
- **ν's role in nature**
  - **ν heating in supernova**