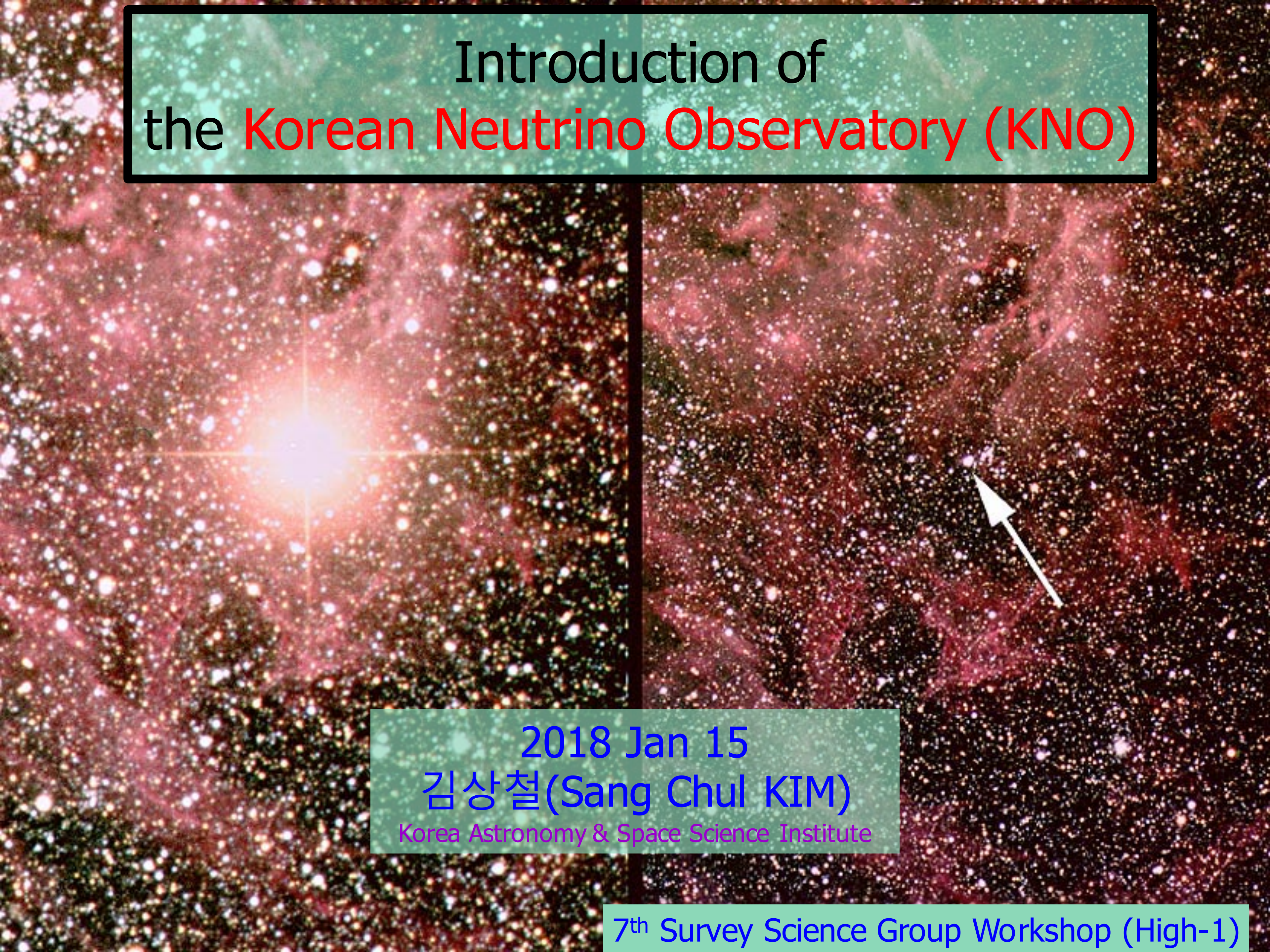


Introduction of the Korean Neutrino Observatory (KNO)

2018 Jan 15

김상철(Sang Chul KIM)

Korea Astronomy & Space Science Institute

7th Survey Science Group Workshop (High-1)

Introduction of the Korean Neutrino Observatory (KNO)

Korean Neutrino Telescope (KNT)
2nd Hyper-Kamiokande (HK)

SNU : Soo-Bong Kim, Seon-Hee Seo
KASI : Sang-Hyeon Ahn, Jeong-Sook Kim, Sang Chul KIM, Soon-Wook Kim, Hong Soo Park
KNU : Myeong-Gu Park, Tae Seog Yoon
SNU : Sung-Chul Yoon
UNIST : Kyujin Kwak, Dongsu Ryu

7th Survey Science Group Workshop (High-1)

Neutrinos from stellar nucleosyntheses

Proton-proton (pp) fusion chain :

1st step : $^{1}H + ^{1}H \rightarrow ^{2}H + e^{+} + \nu_e$ ($\rightarrow$1.44 MeV)

2nd step : $^{2}H + ^{1}H \rightarrow ^{3}He + \gamma$ ($\rightarrow$5.49 MeV)

3rd step : $^{3}He + ^{3}He \rightarrow ^{4}He + ^{1}H + ^{1}H$ ($\rightarrow$12.9 MeV)

CNO Cycle :

$^{12}C + ^{1}H \rightarrow ^{13}N + \gamma$

$^{13}N \rightarrow ^{13}C + e^{+} + \nu_e$

$^{13}C + ^{1}H \rightarrow ^{14}N + \gamma$

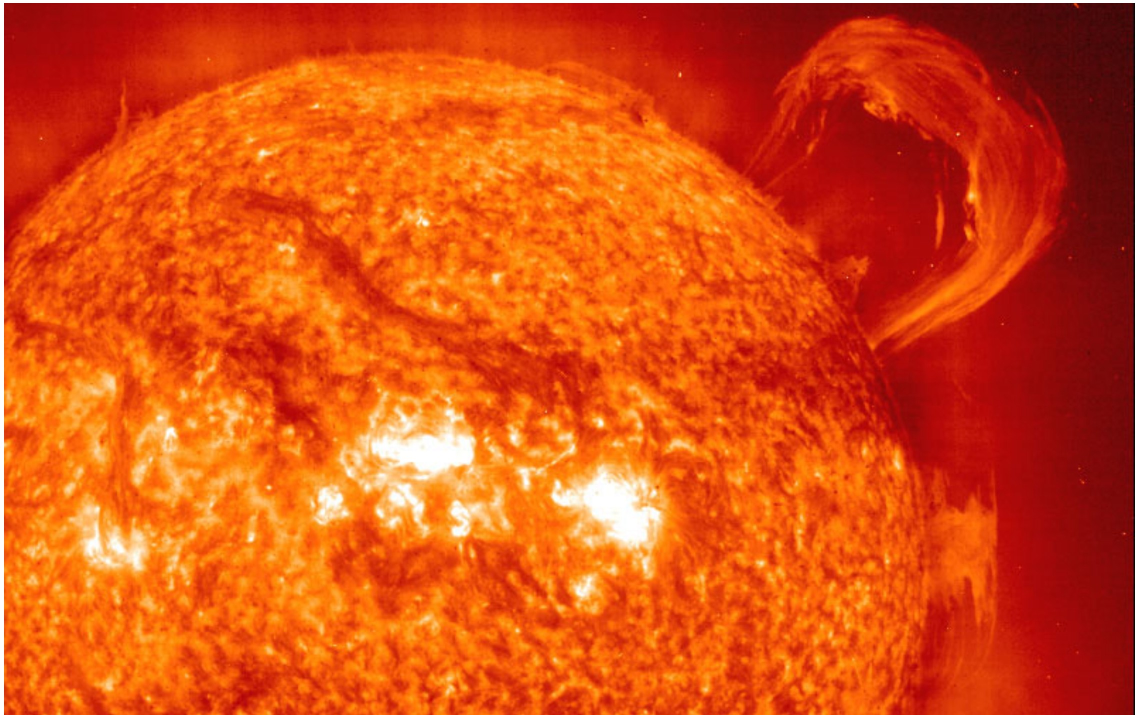
$^{14}N + ^{1}H \rightarrow ^{15}O + \gamma$

$^{15}O \rightarrow ^{15}N + e^{+} + \nu_e$

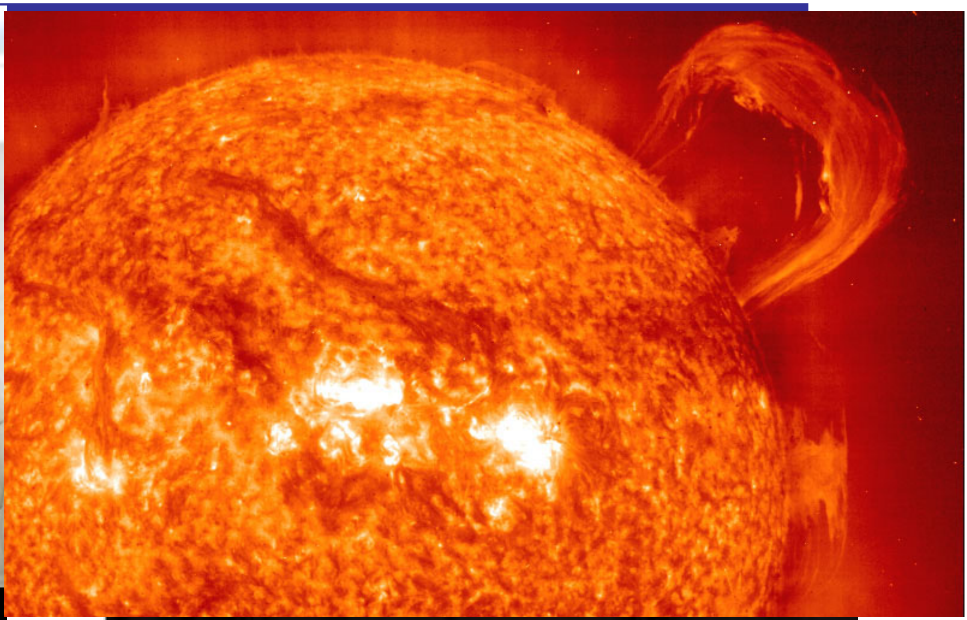
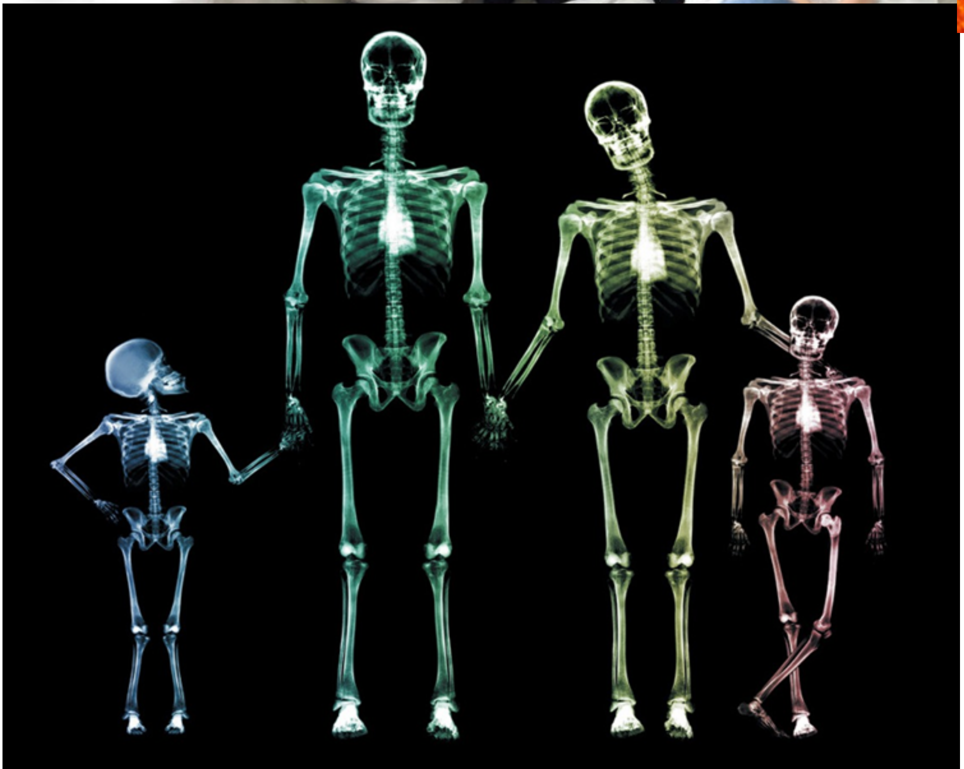
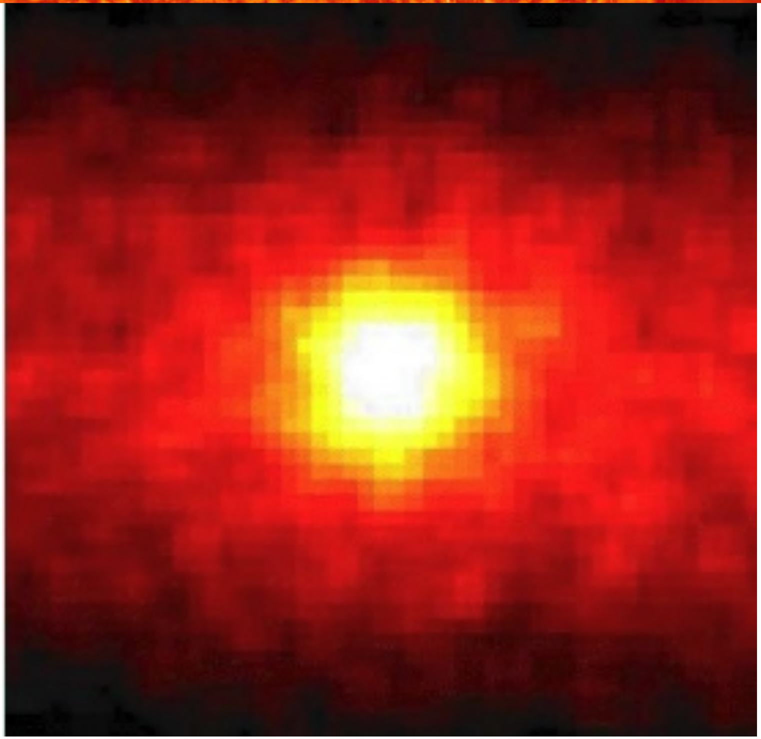
$^{15}N + ^{1}H \rightarrow ^{12}C + ^{4}He$

β^{+} decay : $p \rightarrow n + \beta^{+} +$

※ $\beta^{+} = e^{+}$ (positron)



“Observation of the solar center’

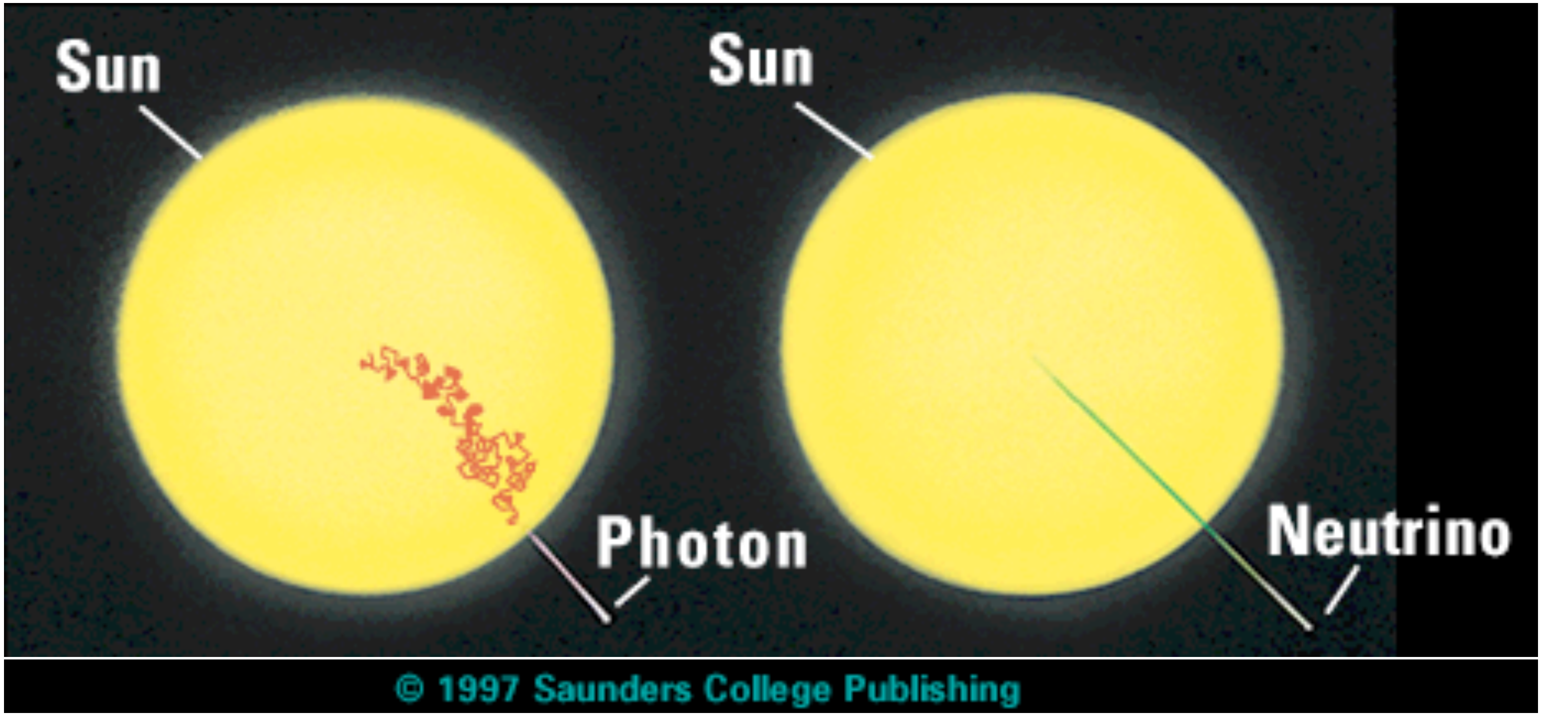





Photon, neutrino – escape from the Sun's interior

Photon and neutrino – travel times out of the center of the Sun

10^4 -10^5 yr 2 sec

"Random walk"



Neutrinos from Supernovae (SNe)

- Neutrinos come out first from the core collapse (CC)
- Neutrino telescope can give fast alert to optical and other λ observatories
- supernova energy
  - 99% comes as neutrinos
  - $\sim$1% comes as kinetic energy
  - $\sim$0.01% optical emission

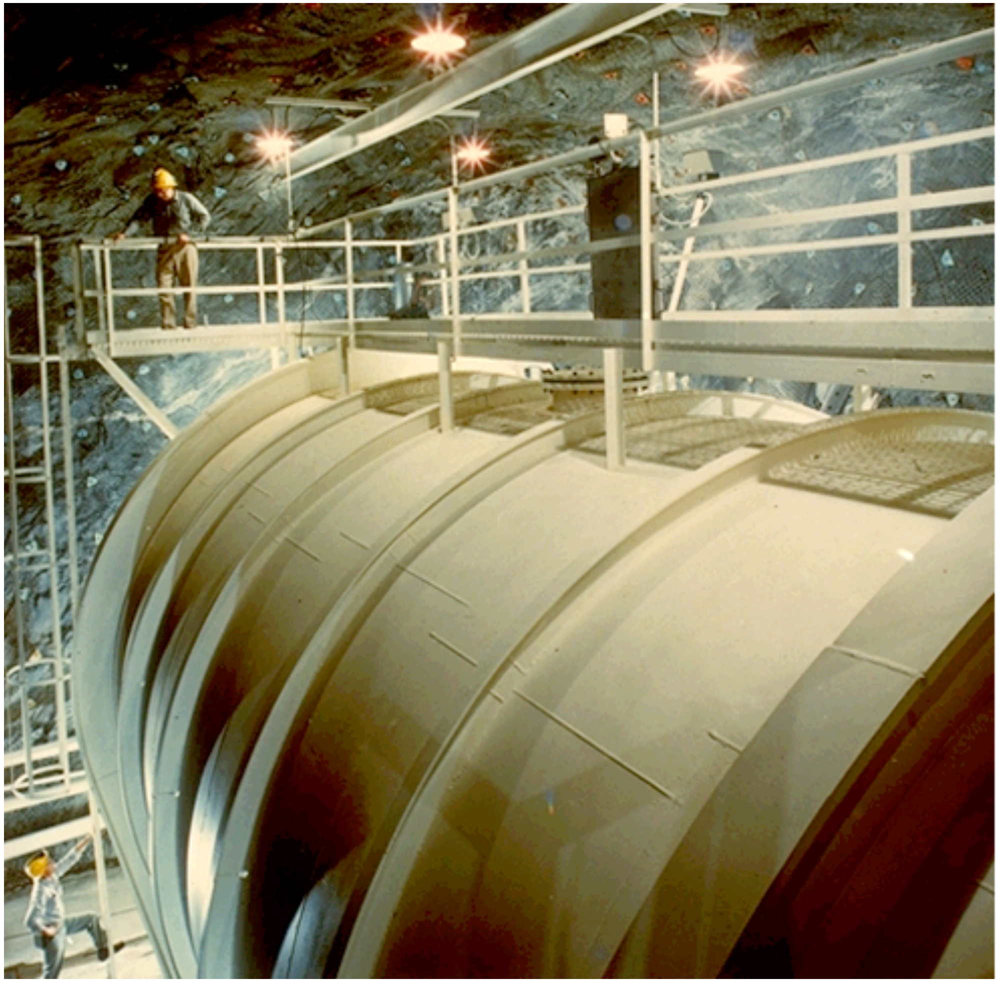
Neutrino – interaction with matters

- 3.5×10^{12} neutrinos penetrate 1 cm^2 earth surface / sec, but no interaction!
- Mean free path $\approx 10^9 M_\odot \sim 10^{10} \times R_\odot \sim 300$ pc
- Characteristic size : $r^2 = n \times 10^{-33}\ cm^2$
  ($n=3.2$ for ν_e, $n=1.7$ for ν_μ, $n=1.0$ for ν_τ)

Solar neutrino detector

- $\approx 2 \times 10^{38}$ neutrinos are being emitted from the Sun / sec

The first Solar neutrino detector



http://www.astronomynotes.com/starsun/s4.htm

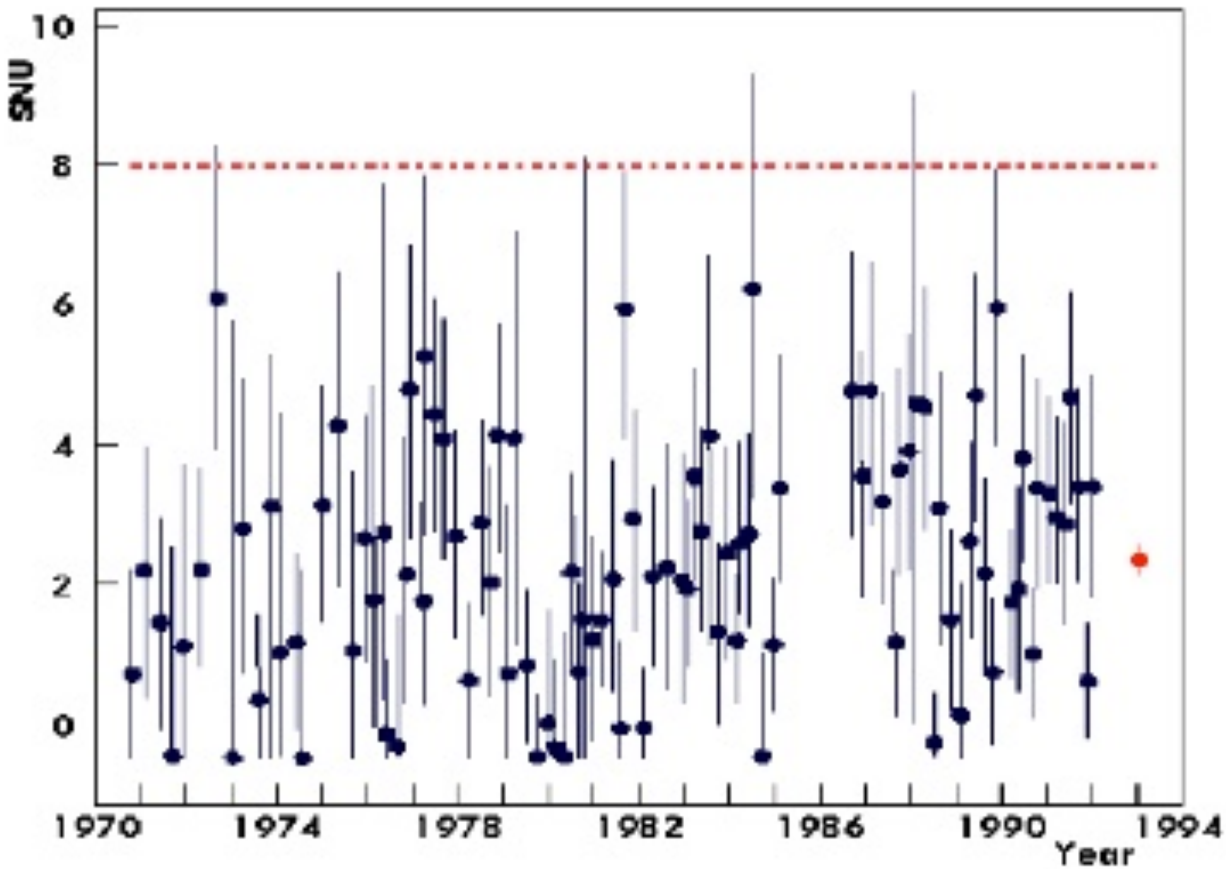
1960s
Raymond Davis Jr. (U of Pynnsylvania)
John N. Bahcall :
Homestake mine, 1500m underground
(Lead, South Dakota, USA)

- 600 tons of liquid Chlorine ($C_2\,Cl_4$)

$\nu_e + {}^{37}Cl \rightarrow {}^{37}Ar + e^+$

N(Cl atoms) ~ 2×10^{30}
→ $\geq$ 10 Ar atoms

Solar neutrino measurement



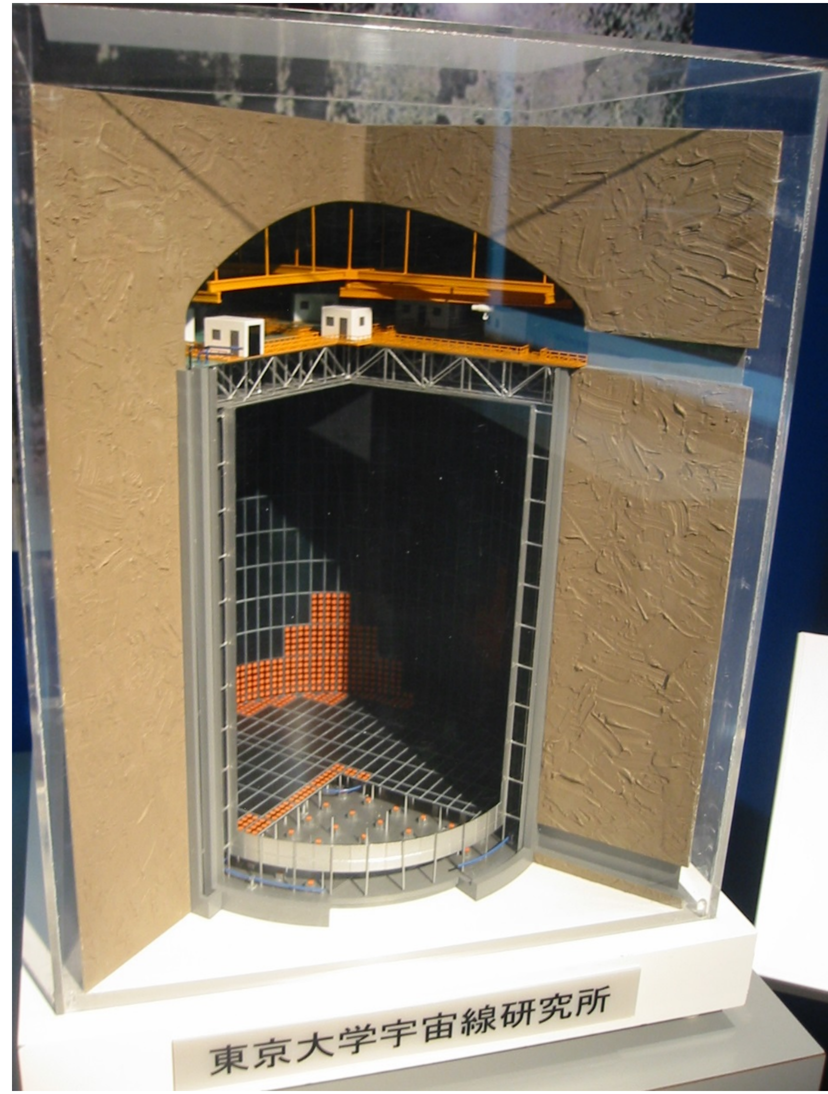
- Measured values ~ 1/3 of the estimation from the standard solar mode (by John N. Bahcall)
  → Solar neutrino problem

http://mulli2.kps.or.kr/~pht/11-11/021108.htm

Water Cherenkov neutrino detector – KamiokaNDE

Kamioka (神岡) Neutrino Detection Experiment

Construction : 1982 – 1983 April
Operation : 1983 - 1996
Cylindrical tank – 3000 tons of pure water
16.0m height, 15.6m diamter
1,000 × 50 cm diameter phtomultiplier tubes (PMTs)



https://en.wikipedia.org/wiki/Kamioka_Observatory

Gifu Prefecture (기후 현, ぎふけん)
岐阜県 Gifu-ken

Kamioka Observatory
1000m underground

Under Mount Ikeno (near the city of Hida-shi 飛騨市/飛驒市)

Water Cherenkov neutrino detector– Kamiokande II

- Upgrade → operation since 1985
- Observed solar neutrinos
- Observed 11 neutrinos from Supernova (SN) 1987A – 50 kpc (163,000 ly) away in the Large Magellanic Cloud

- Masatoshi Koshiba (小柴 昌俊) – 2002 Nobel Prize in Physics (w/Raymond Davis Jr., Riccardo Giacconi) for his work directing the Kamoka experiments, and in particular for the first-ever detection of astrophysical neutrinos

(1914-)

Raymond Davis Jr.

Prize share: 1/4

(1926-)

Masatoshi Koshiba

Prize share: 1/4

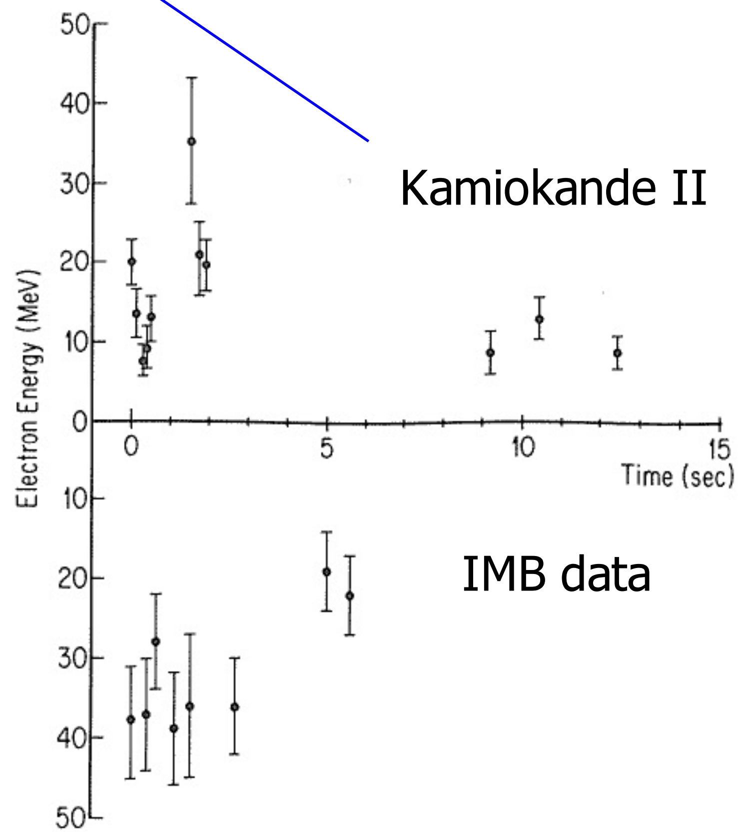
(1931-)

Riccardo Giacconi

Prize share: 1/2

Raymond Davis Jr. and Masatoshi Koshiba *"for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos"* and the other half to Riccardo Giacconi *"for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources".*

http://www.nobelprize.org/nobel_prizes/physics/laureates/2002/



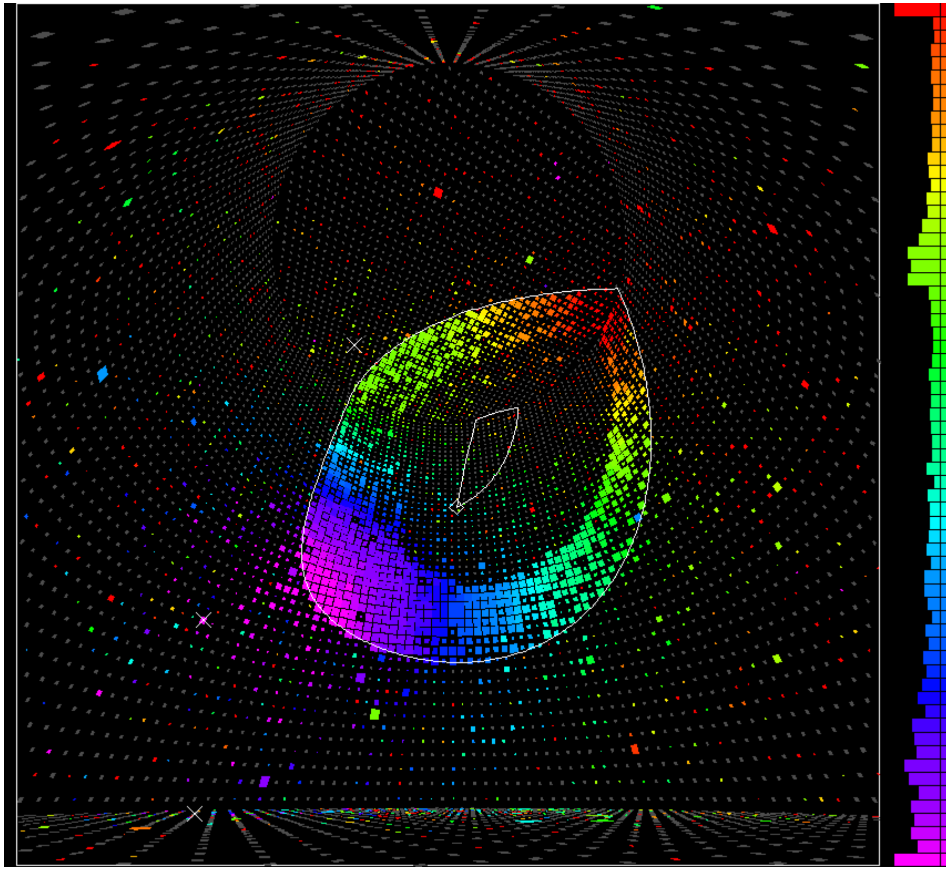
10^{58} Neutrinos from SN 1987A

1987 Feb 23, 07h 35m 35s (UT)

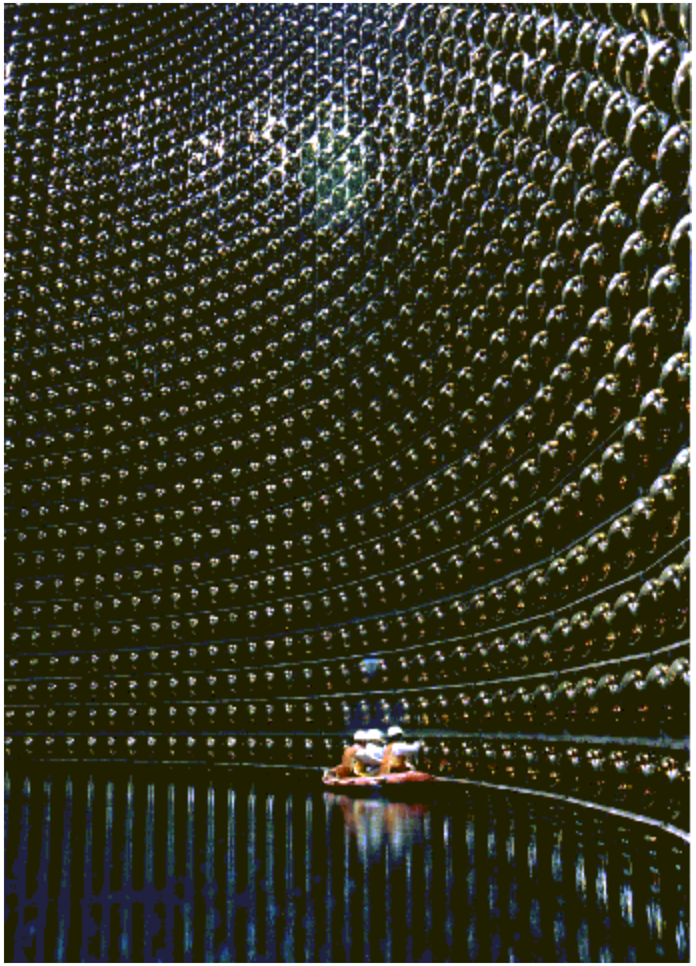
http://mulli2.kps.or.kr/~pht/11-11/021108.htm

Super-Kamiokande (Super-K) : Water Cherenkov detector

Neutrino event in Super-Kamiokande



スーパーカミオカンデ detector



- Approved in 1991, total $100M
- Operation since 1996
- 50,000 tons of ultra-pure water
- Cylinder - 41.4m tall, 39.3m diameter
- Inner detector : 11,146 photomultiplier tubes (diameter 50 cm)
- Outer detector : 1,885 PMTs (diameter 20 cm)
- 1000m underground

http://www.phy.olemiss.edu/~cavaglia/courses/Astr_325/complementary.html

Neutrino oscillation → mass

- Bruno Pontecorvo (1957) suggested masses and oscillation
- 1998 atmospheric ν → discovery of oscillation, which means neutrinos have mass!

※ oscillation among the three flavors : ν_e, ν_μ, ν_τ

The Nobel Prize in Physics 2015

Photo: A. Mahmoud
Takaaki Kajita
Prize share: 1/2

Photo: A. Mahmoud
Arthur B. McDonald
Prize share: 1/2

The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and Arthur B. McDonald *"for the discovery of neutrino oscillations, which shows that neutrinos have mass"*

From Carsten Rott

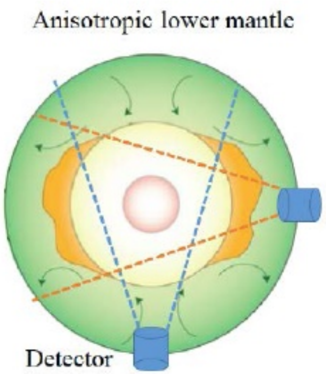
Neutrino research – Current scientific Goals

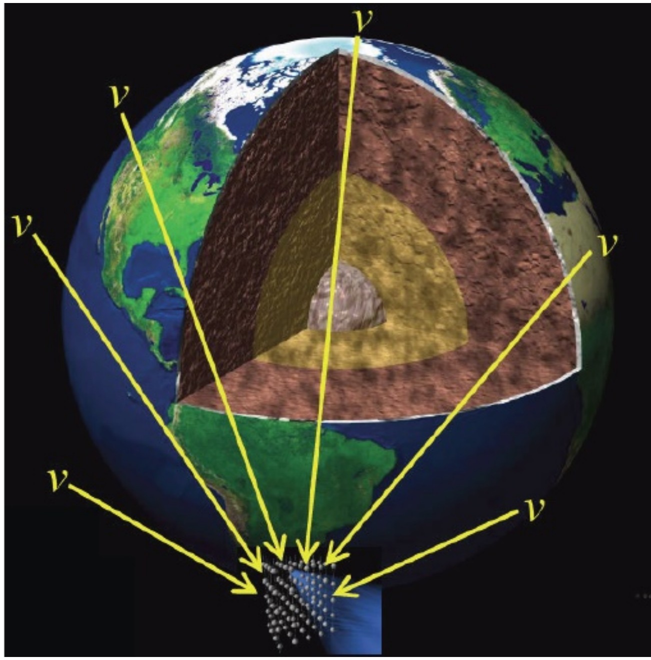
- Neutrino oscillations : Majorana/Dirac particle, ν_e, ν_μ, ν_τ – Mass Hierarchy (mass ordering, if $m_3^2 > m_1^2$), Leptonic CP violation (CP asymmetry) phase measurement, θ_{23} Octant, Non-standard neutrino interaction, ⋯

  - exact mass/energy　　Why matter dominate our Universe?

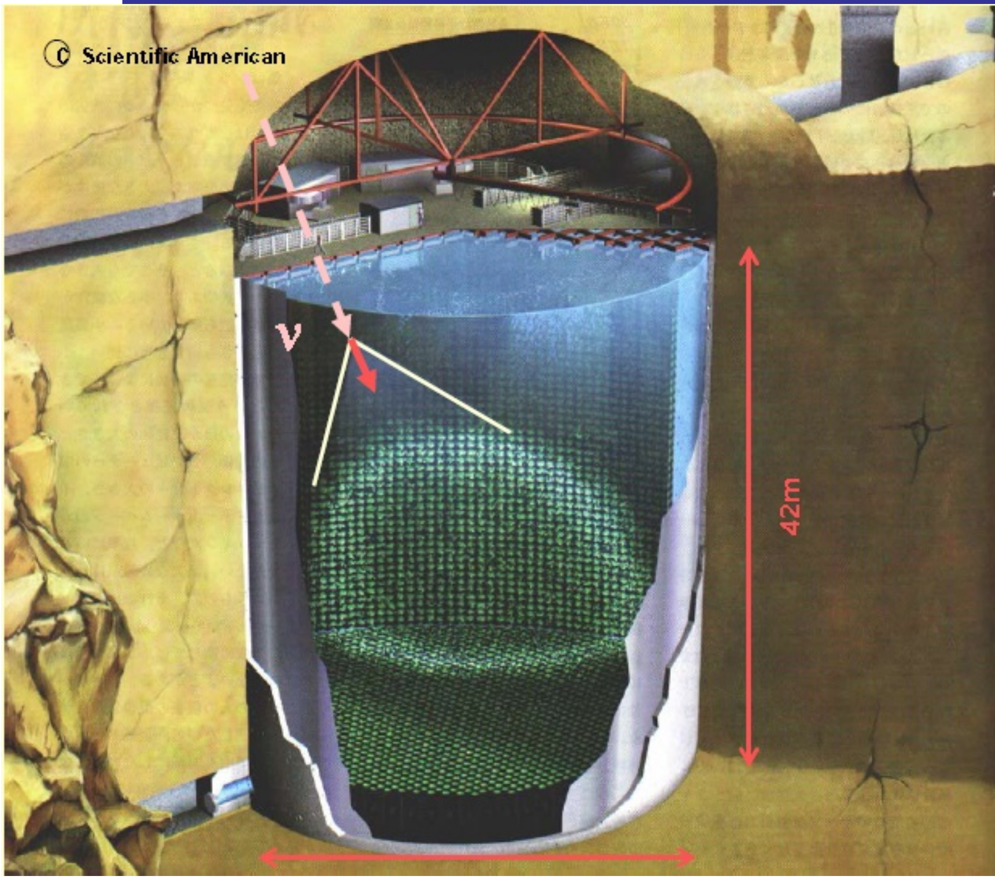
- Nucleon (proton) decay discovery to reveal Grand Unification Theory (GUT) : $p \rightarrow e^+\pi^0$, $p \rightarrow K^+\overline{\nu}$, ⋯
- Atmospheric neutrino reseach
- National underground research facility

- Neutrino astrophysics :
- Solar neutrinos (±10% CNO cycle neutrinos, Z/X value of the Sun, Day-Night asymmetry, Seasonal variation)
- Supernova neutrinos
- Supernova Relic Neutrino (SRN)
- Weakly Interacting Massive Particles (WIMPs) dark matter searches
- ν geo physics (Earth matter density profile, average composition (Z/A) along the path)



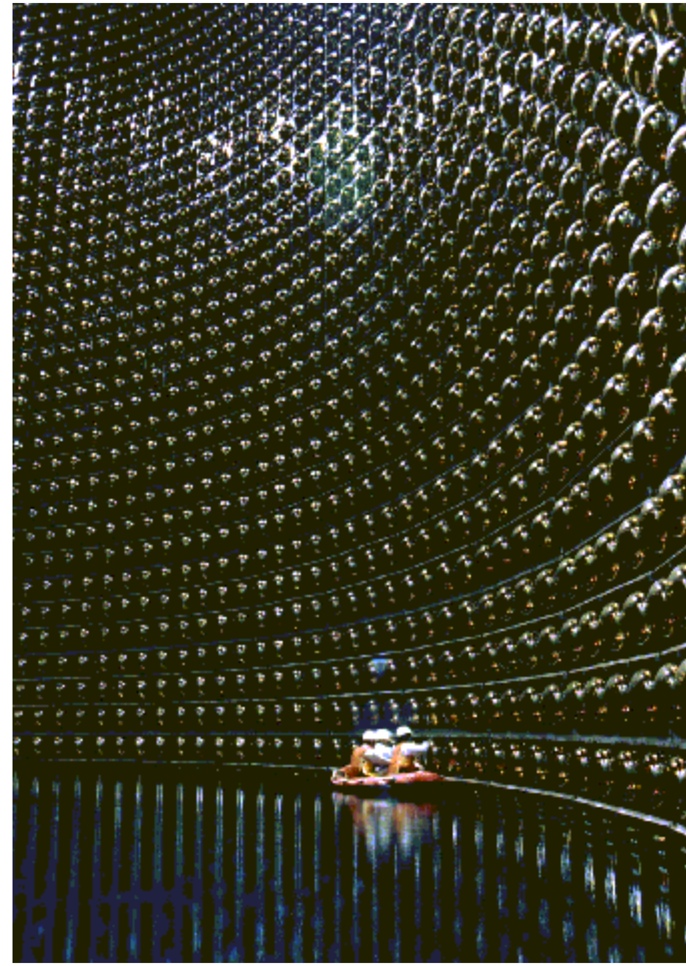


Super-Kamiokande (SK) → Hyper-Kamiokande (HK)



39m

Super-Kamiokande detector

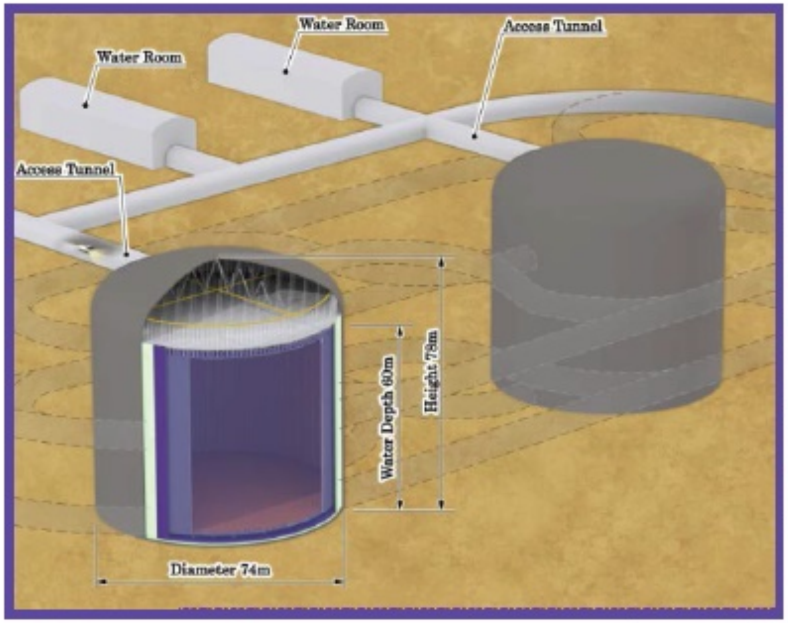


- Approved in 1991, total $100M
- Operation since 1996
- 50,000 tons of ultra-pure water → 500,000 tons, 10^{12} KRW → 2 × 250,000 tons, 5 × 10^{11} KRW
- Cylinder - 41.4m tall, 39.3m diameter
- Inner detector : 11,146 photomultiplier tubes (diameter 50 cm)
- Outer detector : 1,885 PMTs (diameter 20 cm)
- 지하 1000m

http://www.phy.olemiss.edu/~cavaglia/courses/Astr_325/complementary.html

Hyper-Kamiokande (HK)

Inauguration: Jan. 2015



Hyper-K

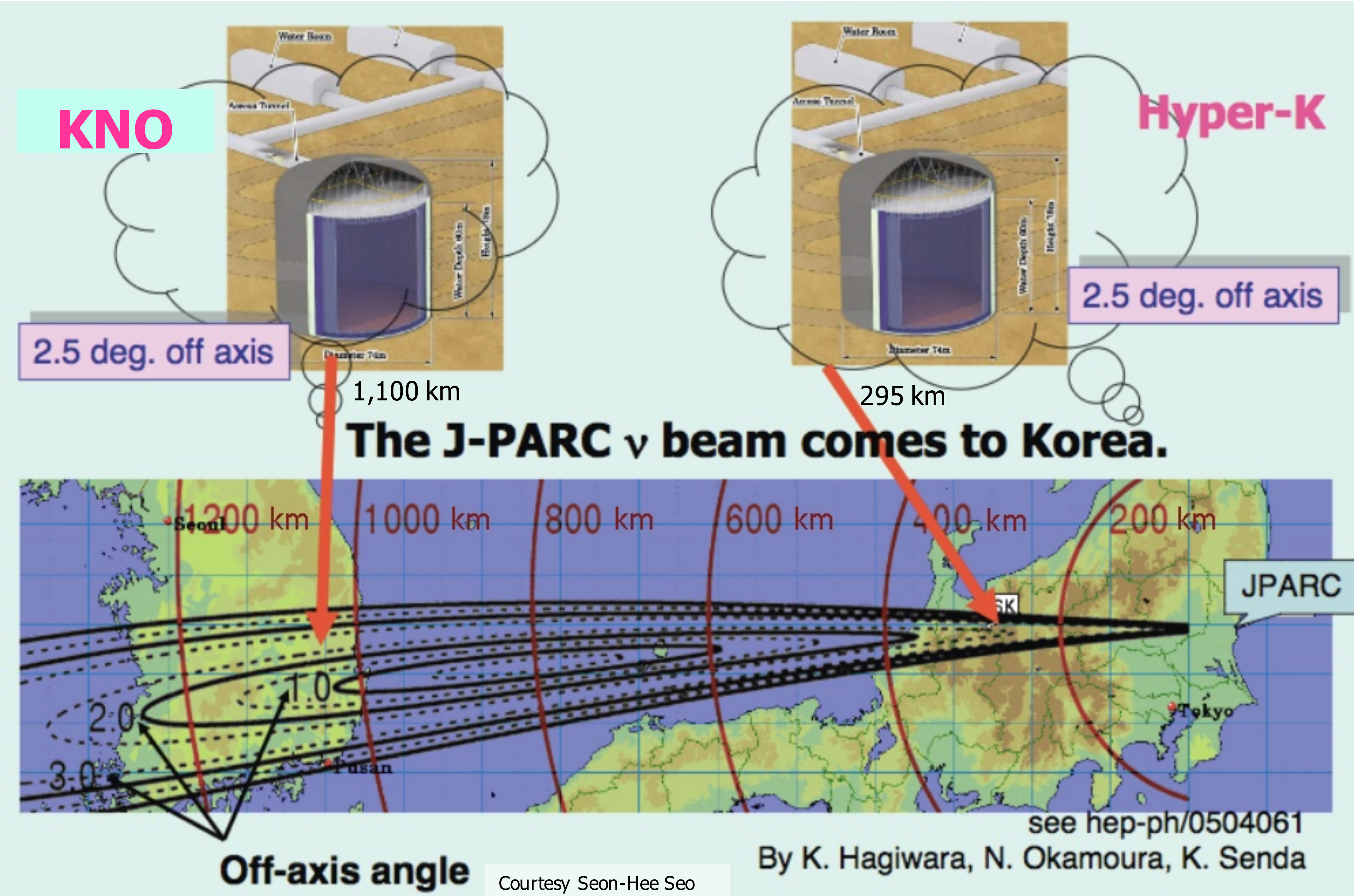
J-PARC
가속기연구소

Hyper-K proto-collaboration : 14 countries, ~300 members are growing

- J-PARC (Japan-Proton Acceleration Research Complex) at Tokai-city, Ibaraki prefecture
- 30 GeV (kinetic energy) proton beam, 470 kW power

Korean Neutrino Observatory (KNO) and Hyper-Kamiokande (HK)

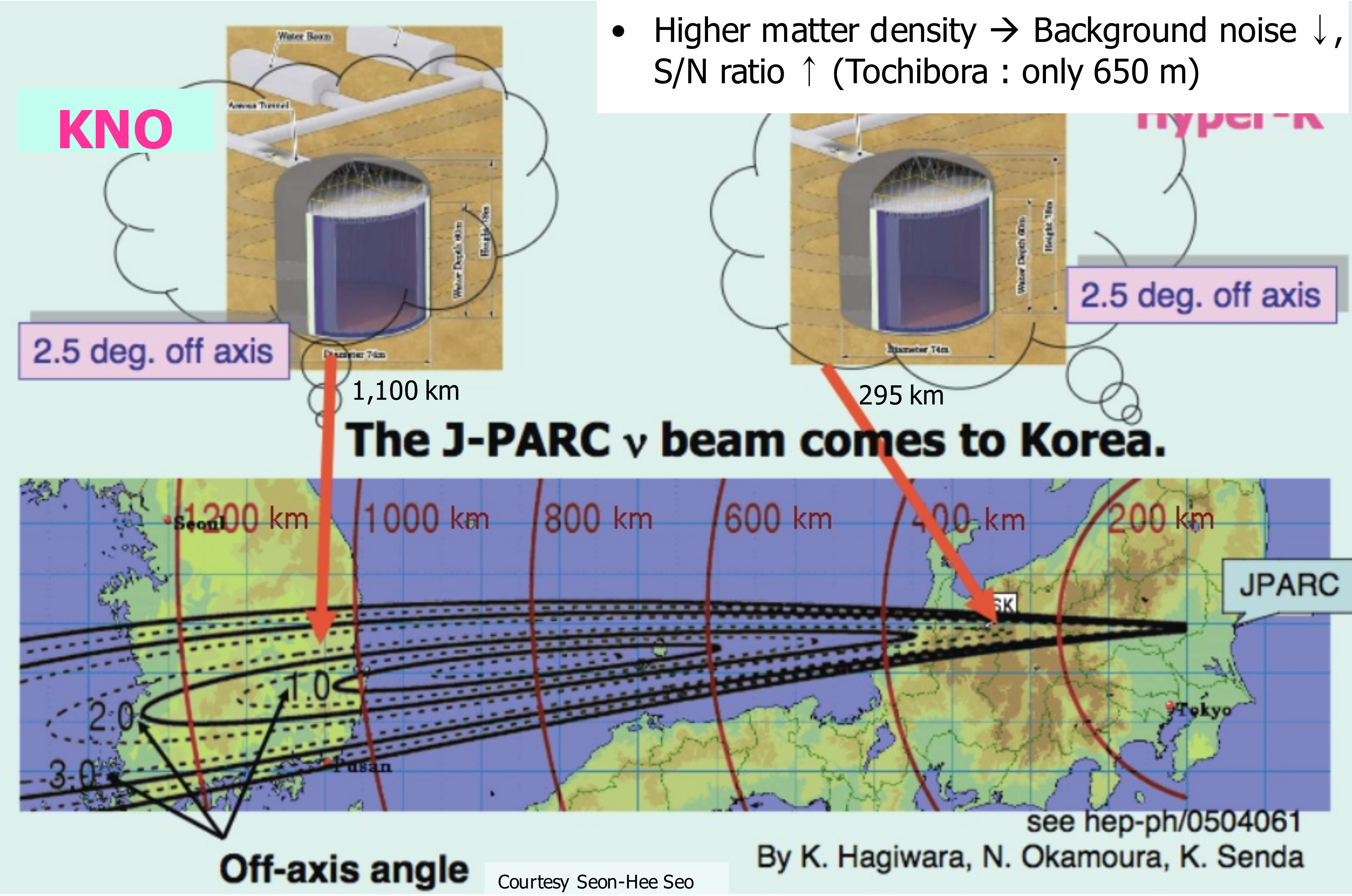
- KNO's longer baseline → oscillation efficiency increases (But, not too long distance…)



Courtesy Seon-Hee Seo

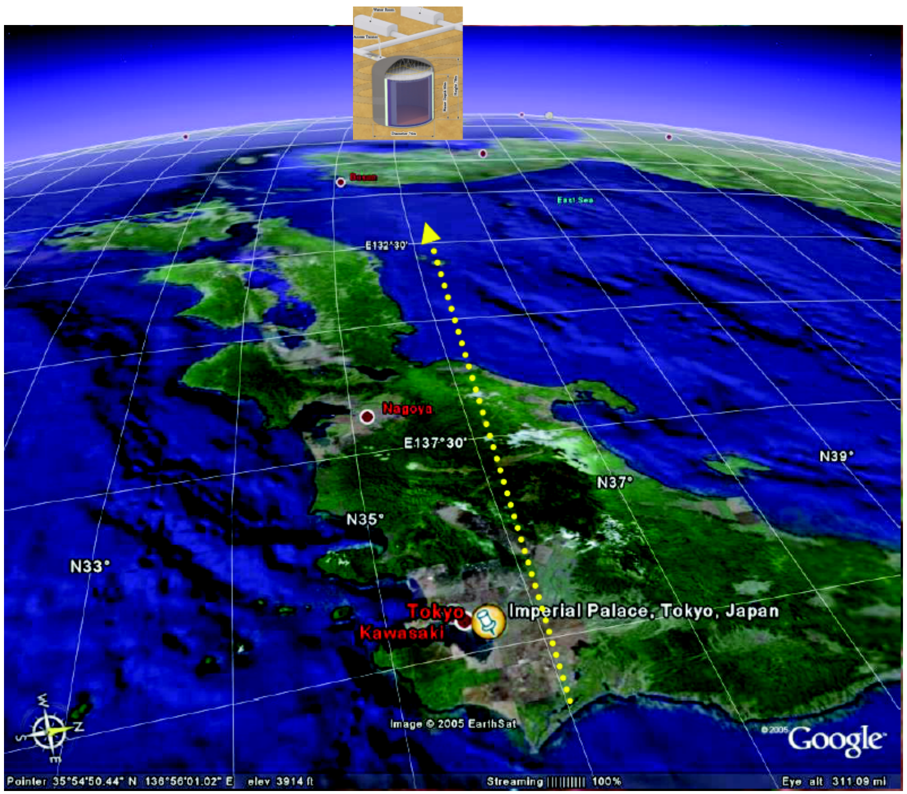
Korean Neutrino Observatory (KNO) and Hyper-Kamiokande (HK)

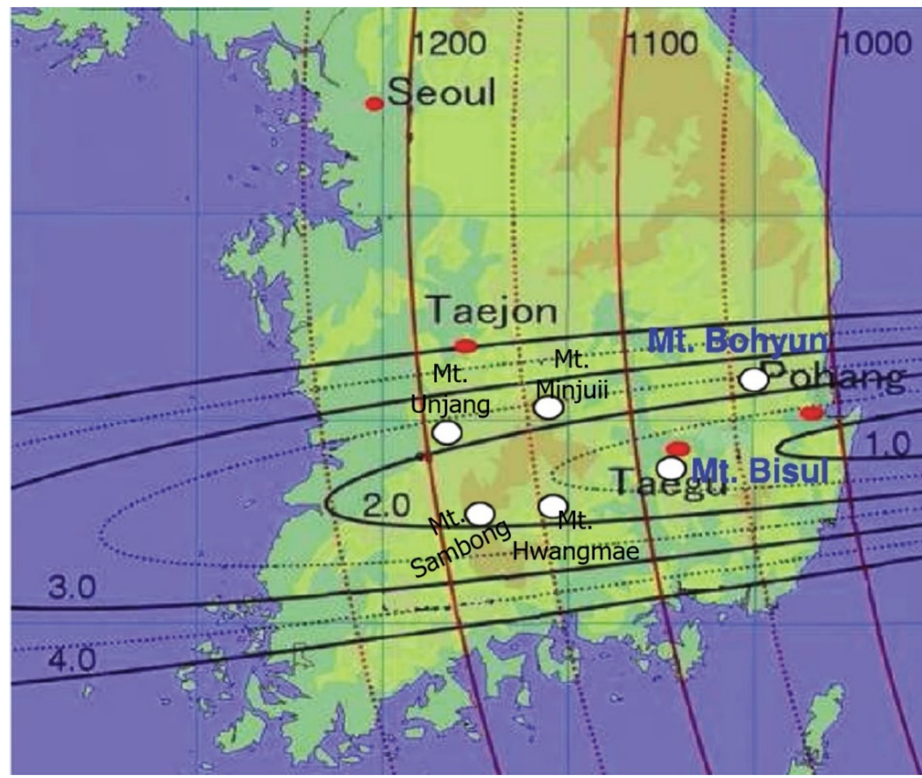
- KNO’s longer baseline → oscillation efficiency increases (But, not too long distance…)
- Higher matter density → Background noise ↓, S/N ratio ↑ (Tochibora : only 650 m)



Candidate Sites

- Six sites selected from many possibilities
- Two best sites : Mt. Bisul near Daegu and Mt. Bohyun near Youngcheon





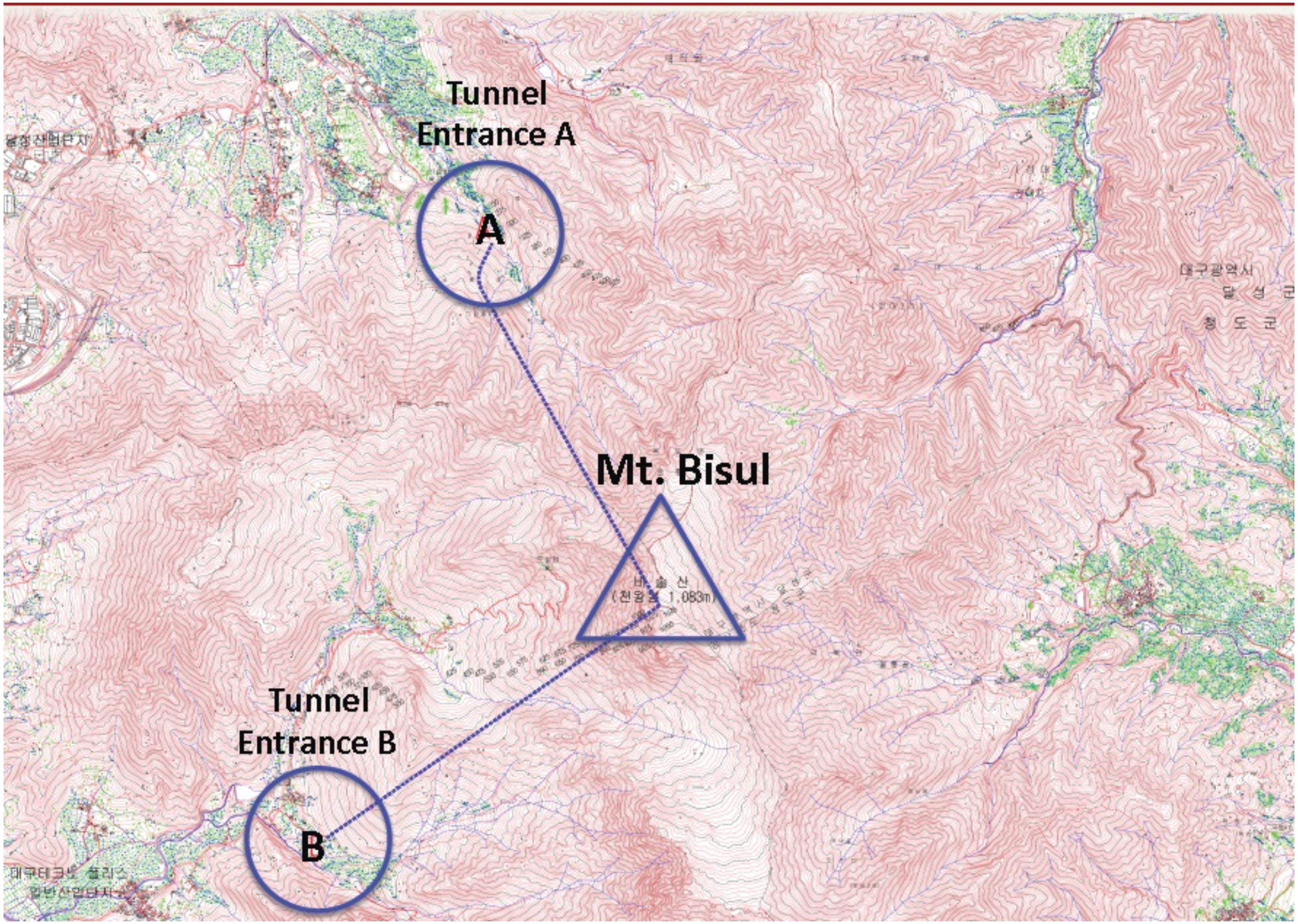
From Soo-Bong Kim

Candidate sites in Korea

- Site candidates for a second oscillation maximum detector in Korea
  - baselines with 1,000 – 1,200 km
  - 1.0° - 2.5° off axis beam directions
  - 1,000 m high mountains with hard granite rocks

Site	Height	OAB	Baseline	Rock composition
Mt. Bisul	1084 m	1.3°	1088 km	Granite porphyry(화강반암), andesitic breccia(안산 각력암)
Mt. Hwangmae	1113 m	1.9°	1141 km	Flake granite(파편 화강암), porphyritic gneiss(반상 편마암)
Mt. Sambong	1186 m	2.1°	1169 km	Porphyritic granite(반상 화강암), biotite gneiss(흑운모질 편마암)
Mt. Bohyun	1124 m	2.3°	1043 km	Granite(화강암), volcanic rocks(화산암), volcanic breccia(화산 각력암)
Mt. Minjuii	1242 m	2.4°	1145 km	Granite(화강암), biotite gneiss(흑운모질 편마암)
Mt. Unjang	1125 m	2.2°	1190 km	Rhyolite(유문암), granite porphyry(화강반암), quartz porphyry(석영 반암)

Mt. Bisul at Dalsung (1084m high)

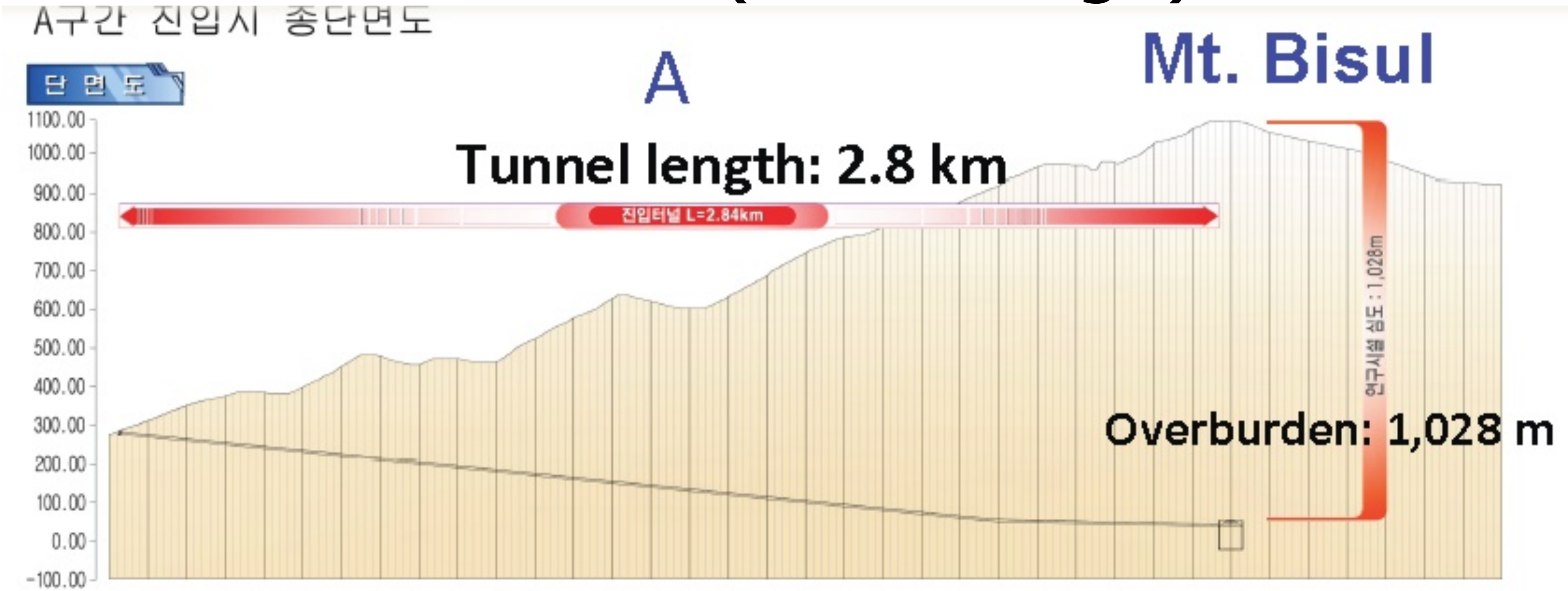


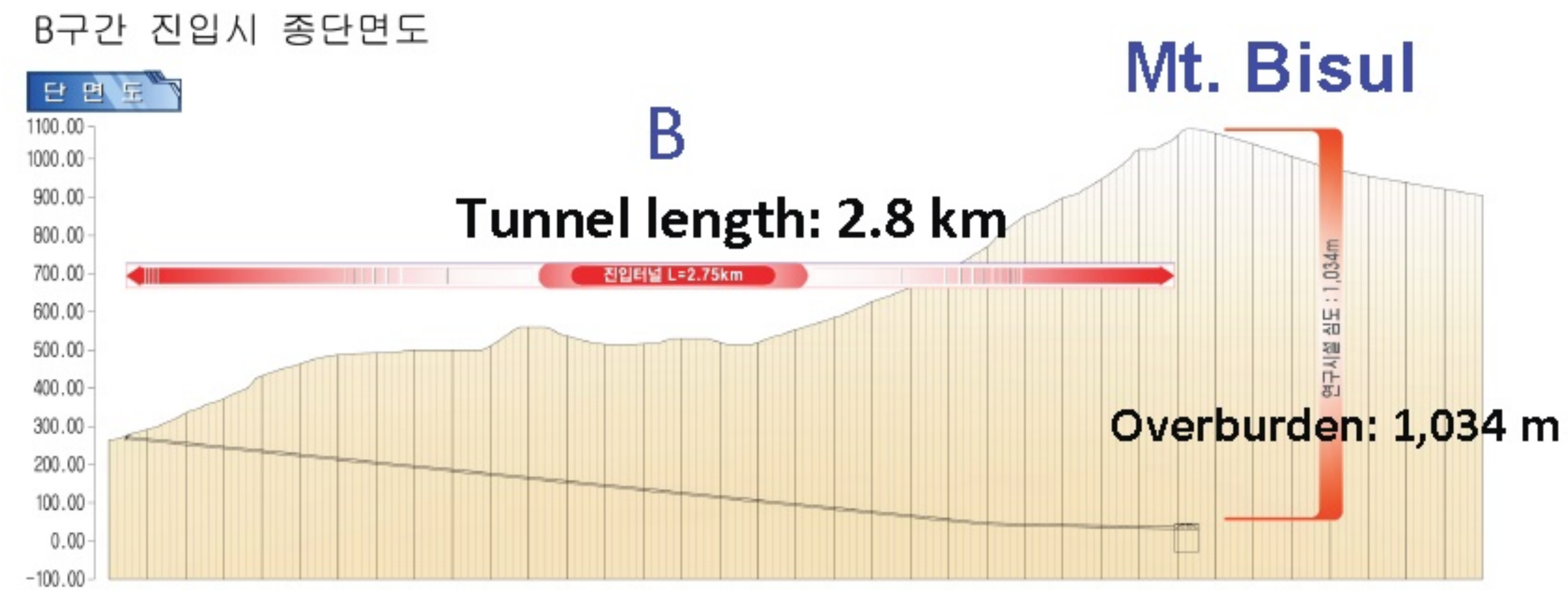
Latitude N 35° 43′ 00″

Longitude E 128° 31′ 28″

Courtesy Seon-Hee Seo

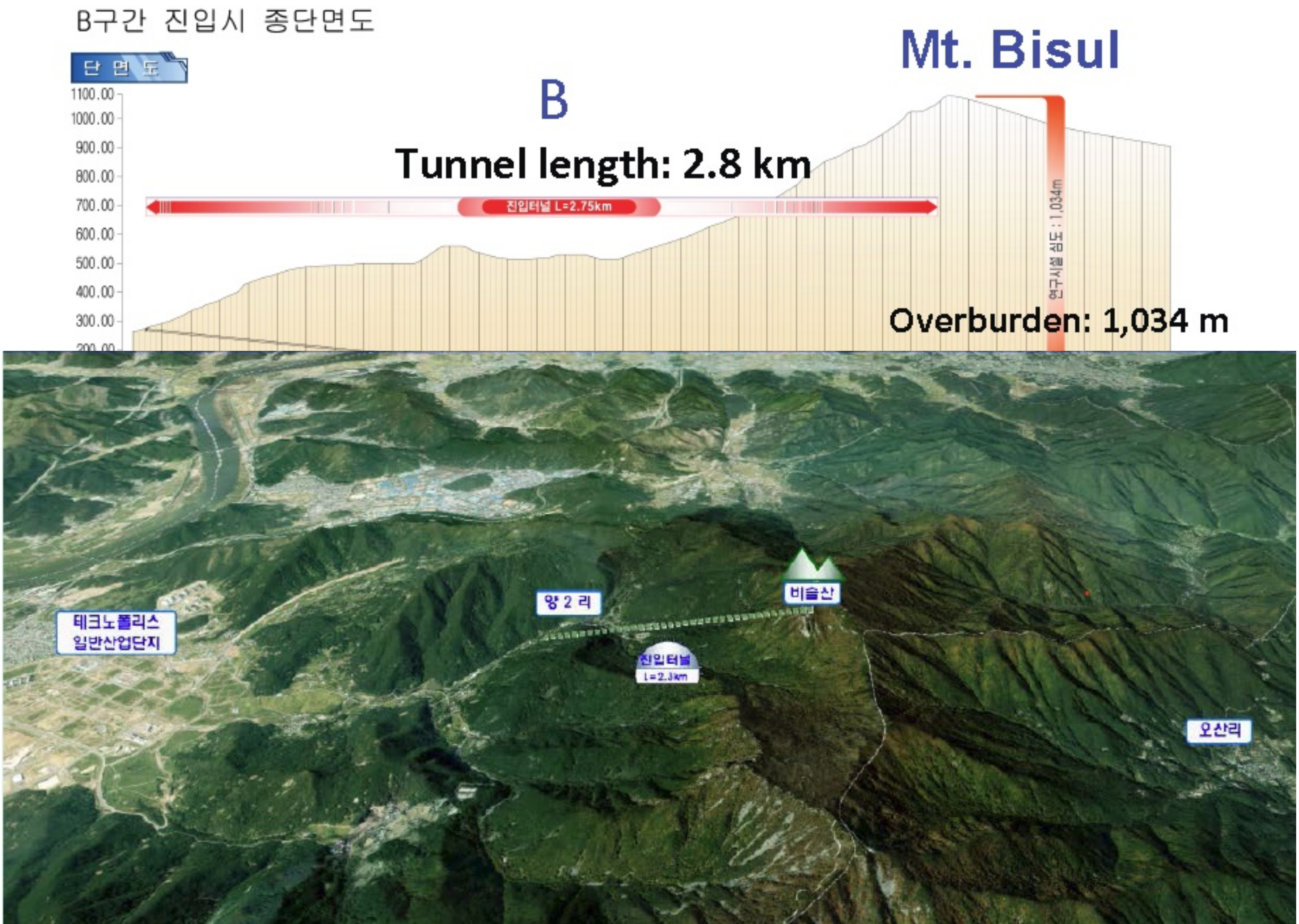
Mt. Bisul (1084m high)



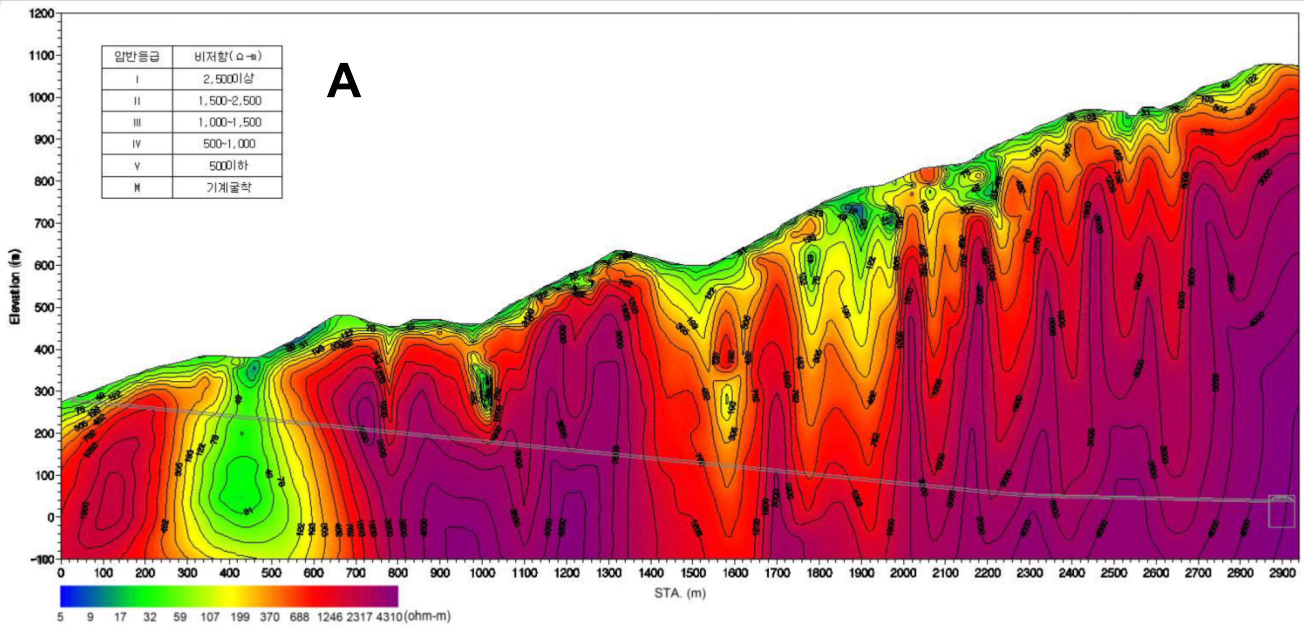


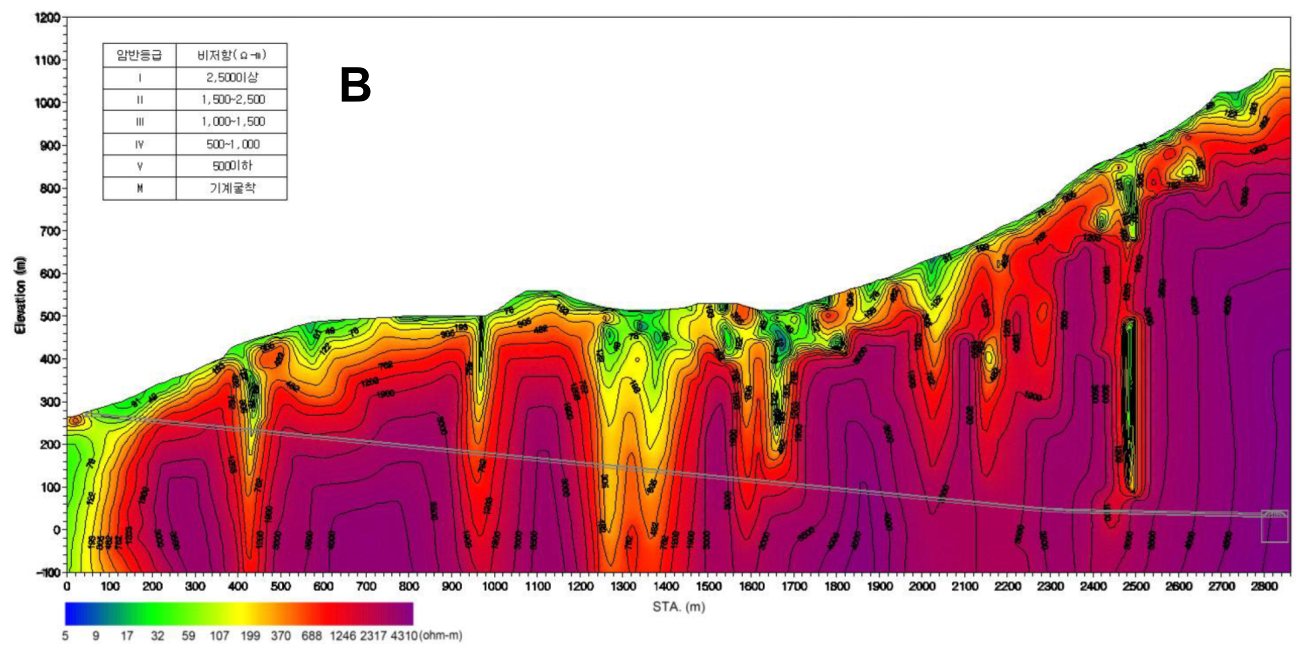
Courtesy Seon-Hee Seo

Mt. Bisul (1084m high)



Mt. Bisul – Rock solidity (A and B)





Class : 1 or 2
(out of 7)

Mt. Bohyun at Youngcheon (1124m high)

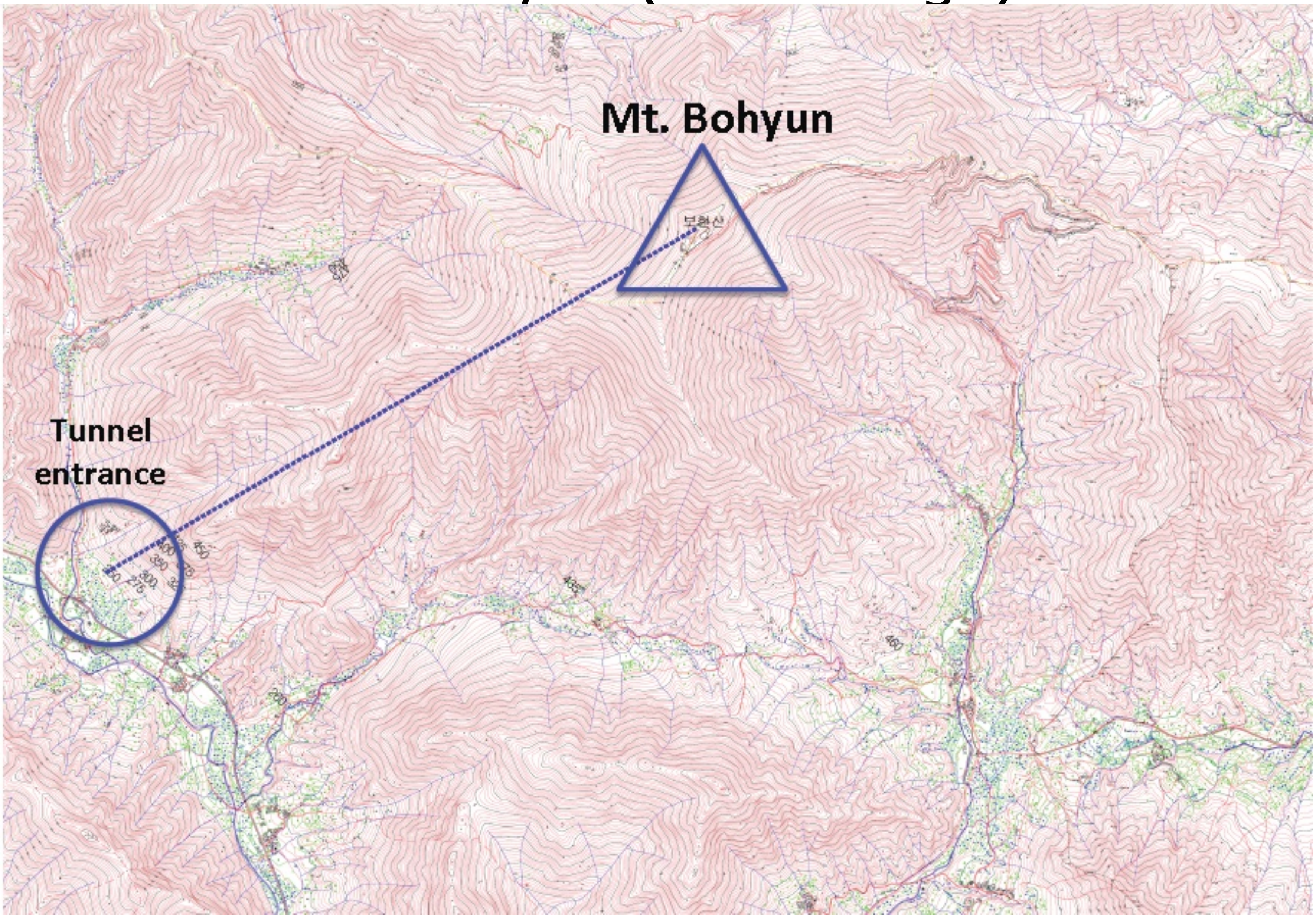
- Baseline : 1040 km, 2.2° off-axis beam

Courtesy Seon-Hee Seo

Latitude N 36° 09′ 47″

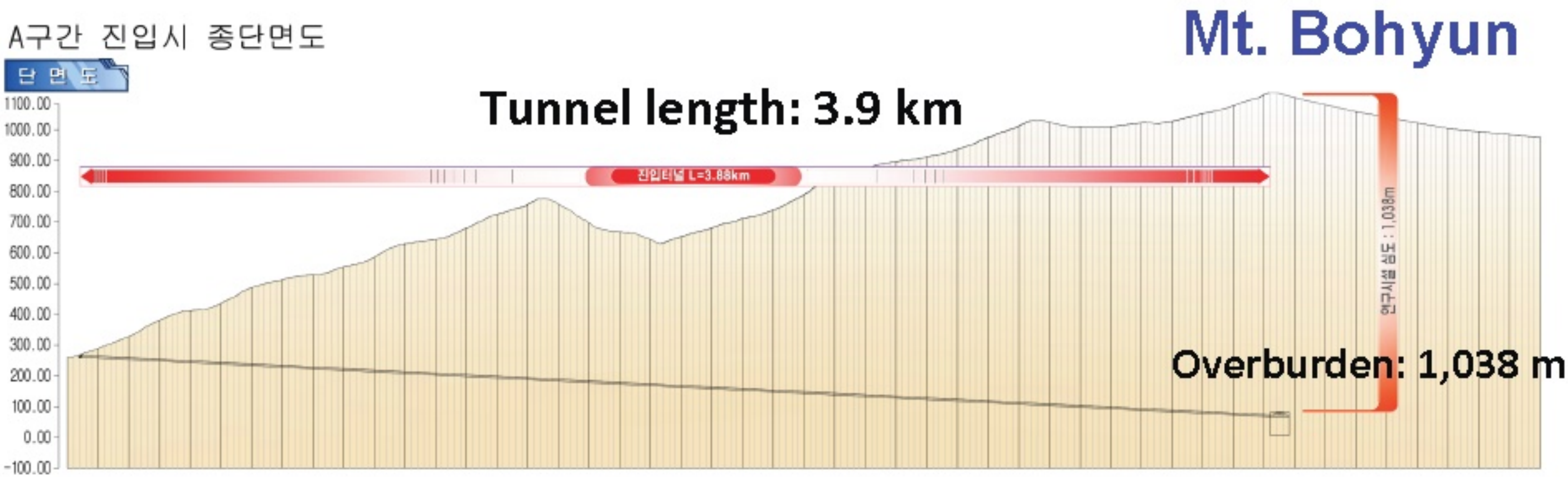
Longitude E 128° 58′ 26″

Mt. Bohyun (1124m high)



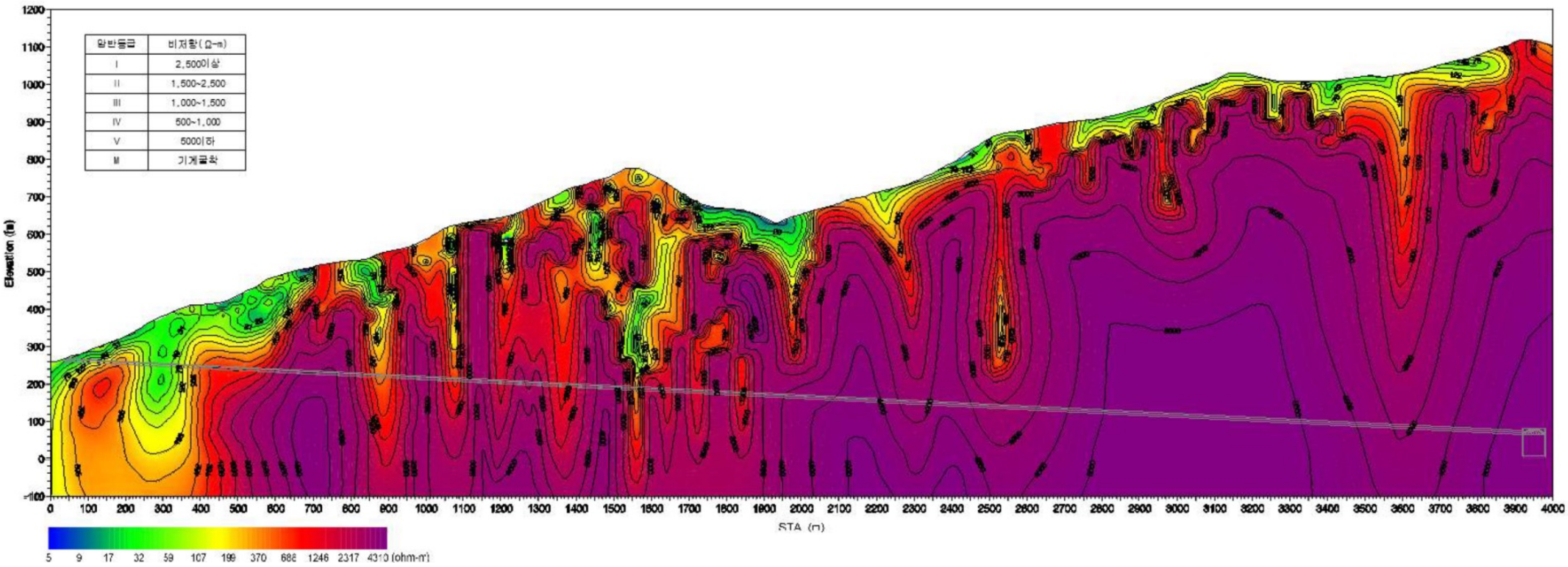
Courtesy Seon-Hee Seo

Mt. Bohyun (1124m high)



Courtesy Seon-Hee Seo

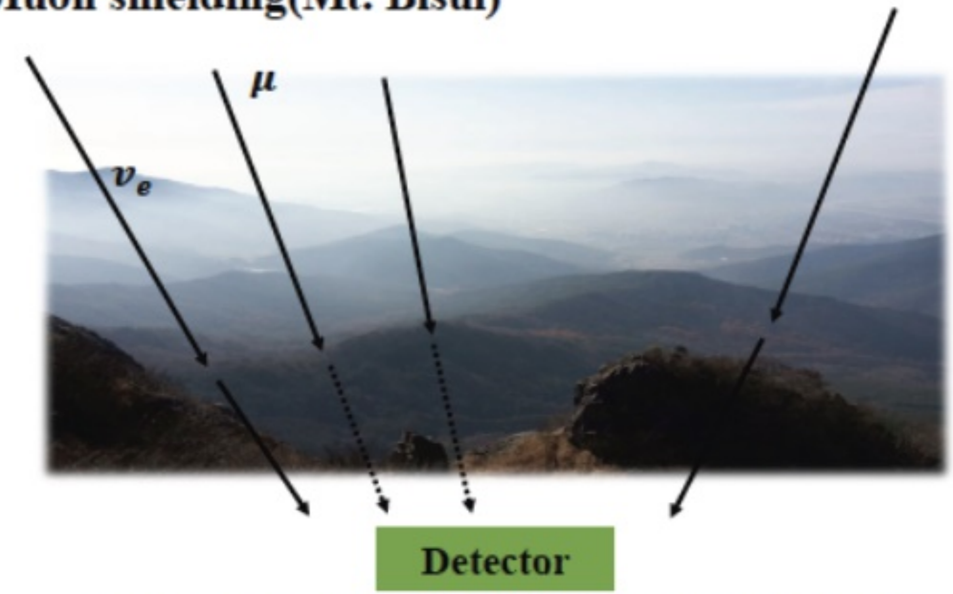
Mt. Bohyun – Rock solidity



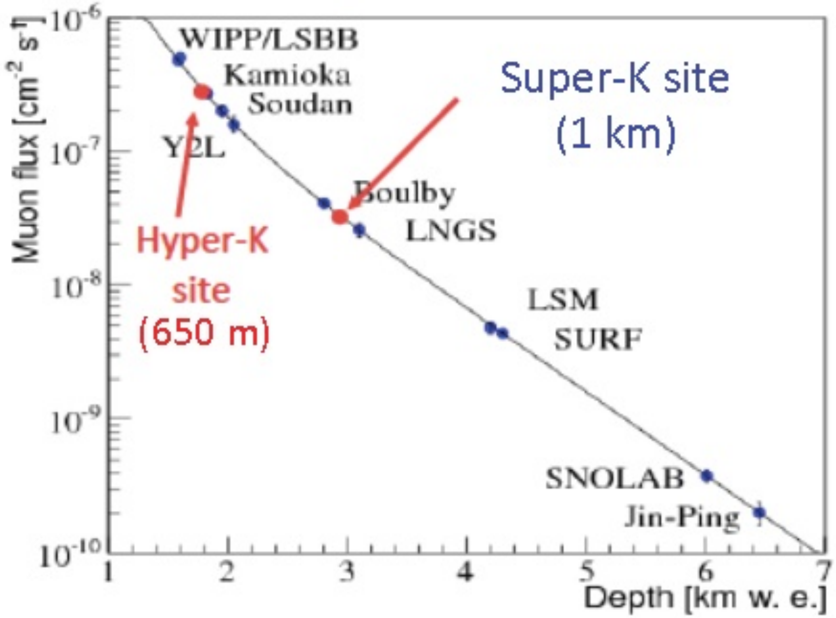
Deeper site – Low background noise

- Deeper site → lower muon flux, lower spallation background
- Two geographical separation → signal coincidence, degeneracy break-up

Muon shielding(Mt. Bisul)



Due to the detector being located deep underground,
The background level is decreased



Muon flux to each laboratory

Courtesy Seon-Hee Seo

KNO White Paper
2016 November 21

arXiv:1611.06118

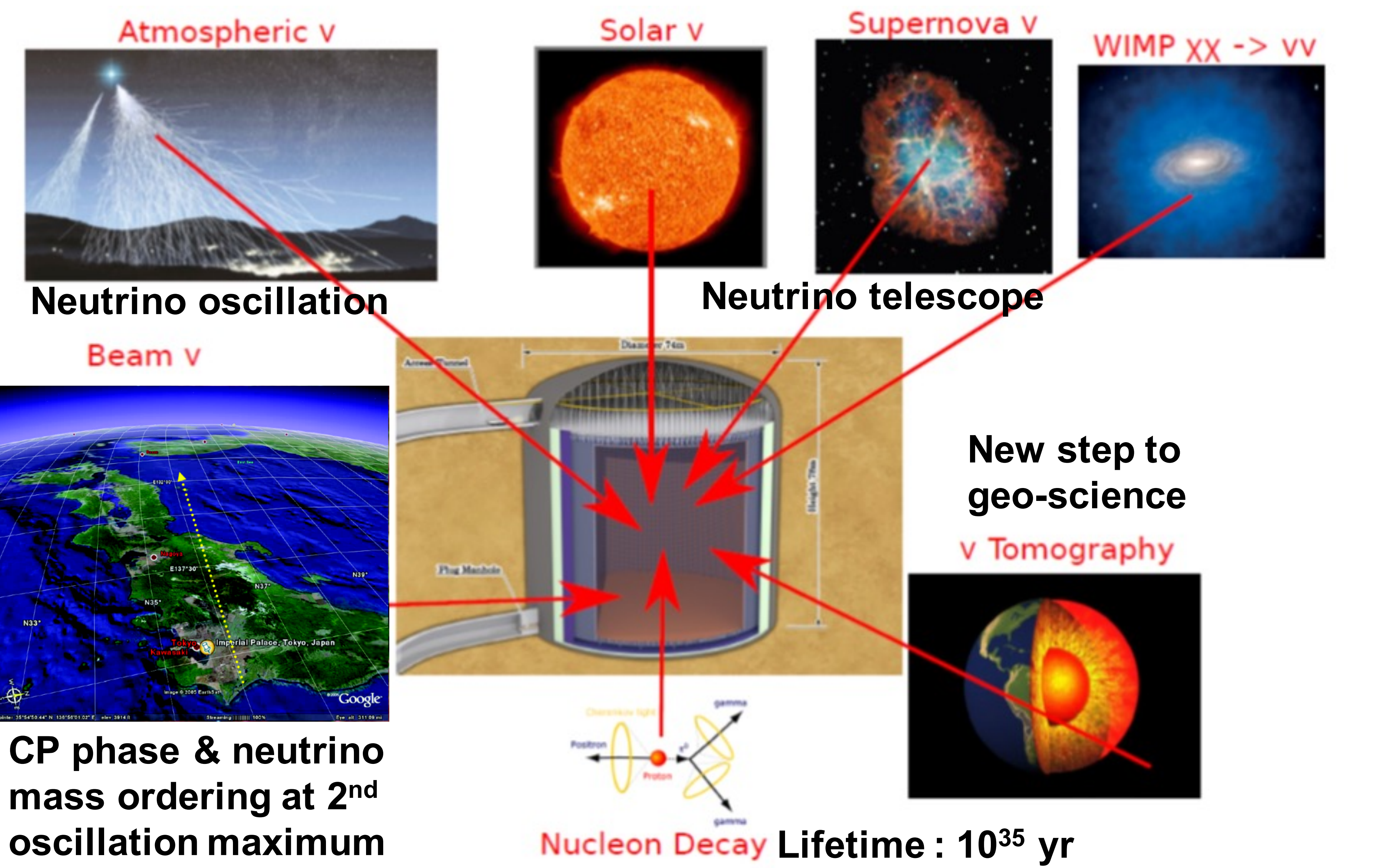
(60 pages)

Physics Potentials with the Second Hyper-Kamiokande Detector in Korea

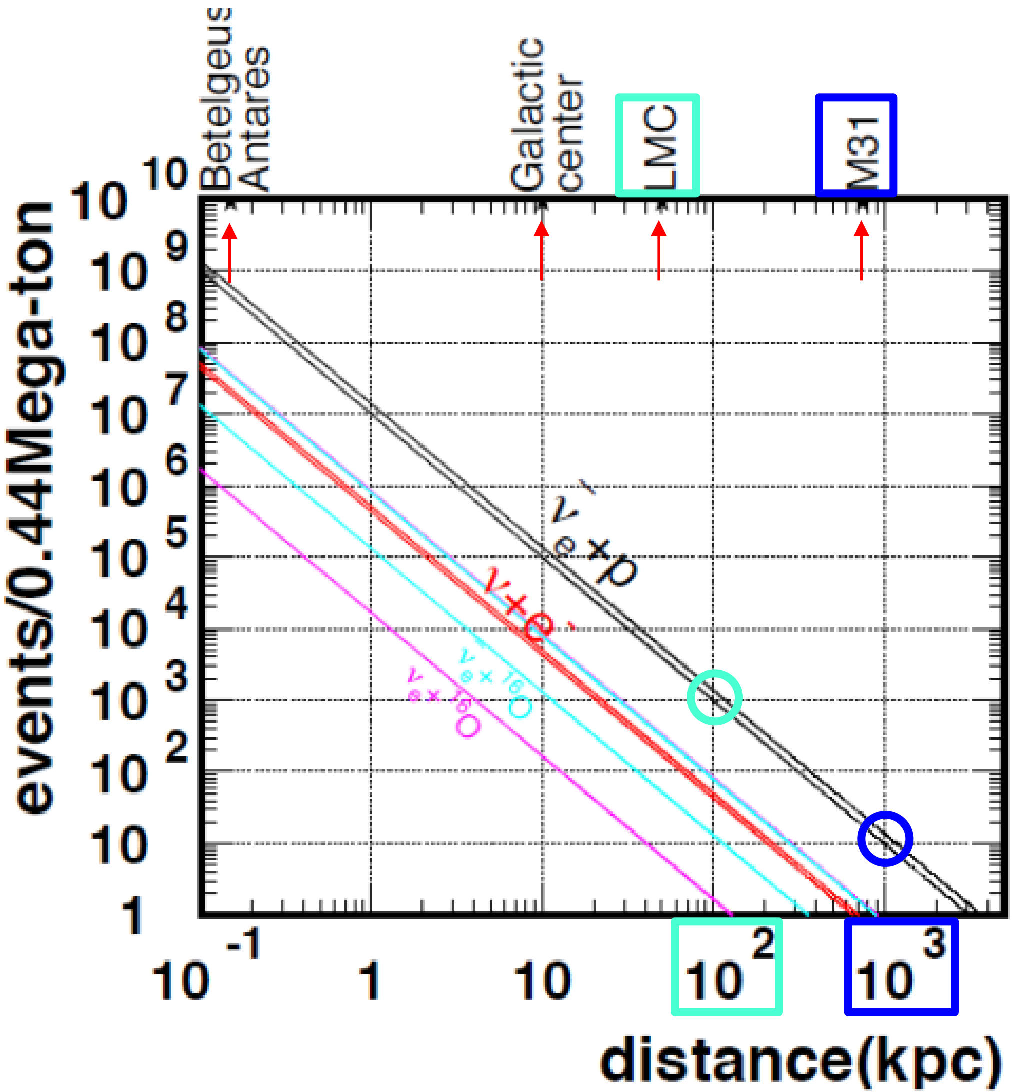
(Hyper-Kamiokande Proto-Collaboration)

K. Abe,[57,59] Ke. Abe,[24] H. Aihara,[59,60] A. Aimi,[18] R. Akutsu,[58] C. Andreopoulos,[28,43] I. Anghel,[21] L.H.V. Anthony,[28] M. Antonova,[20] Y. Ashida,[25] M. Barbi,[44] G.J. Barker,[66] G. Barr,[40] P. Beltrame,[11] V. Berardi,[16] M. Bergevin,[3] S. Berkman,[2] T. Berry,[45] S. Bhadra,[73] F.d.M. Blaszczyk,[1] A. Blondel,[12] S. Bolognesi,[6] S.B. Boyd,[66] A. Bravar,[12]

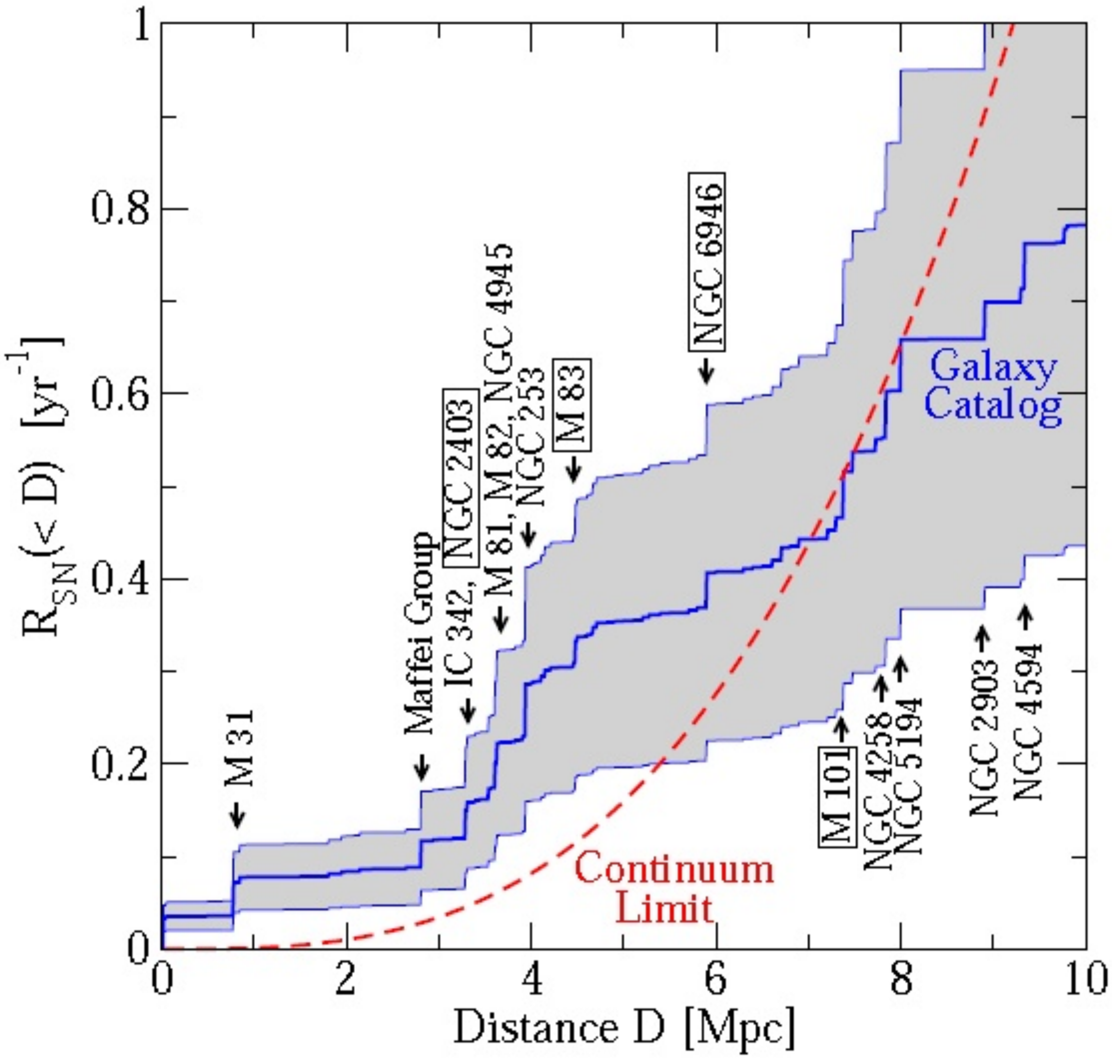
Science Goals



SN burst observation by HK



CC SN Rate

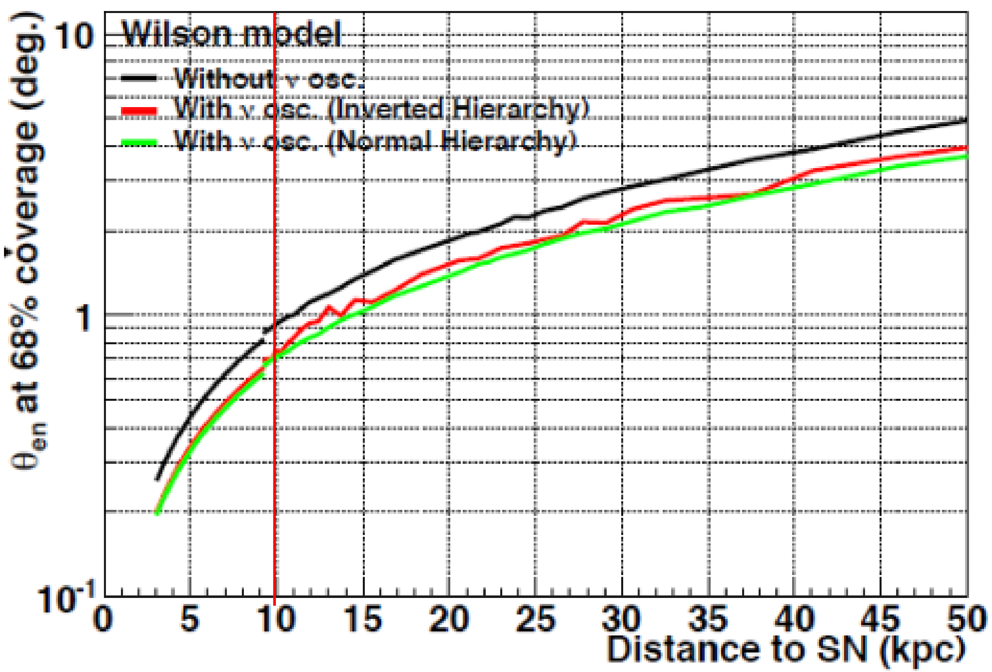


Ando et al. (2005, PRL, 95, 171101)

SN burst – Position accuracy

	SK	SK-Gd	HK	HK-Gd
Error Circle	6°	3°	1.4°	0.6°

※ Gadolinium trichloride ($GdCl_3$) addition (0.2%)
→ increases detection efficiency (J. F. Beacom & M. R. Vagins 2004 Phys. Rev. Lett. 93, 171101)



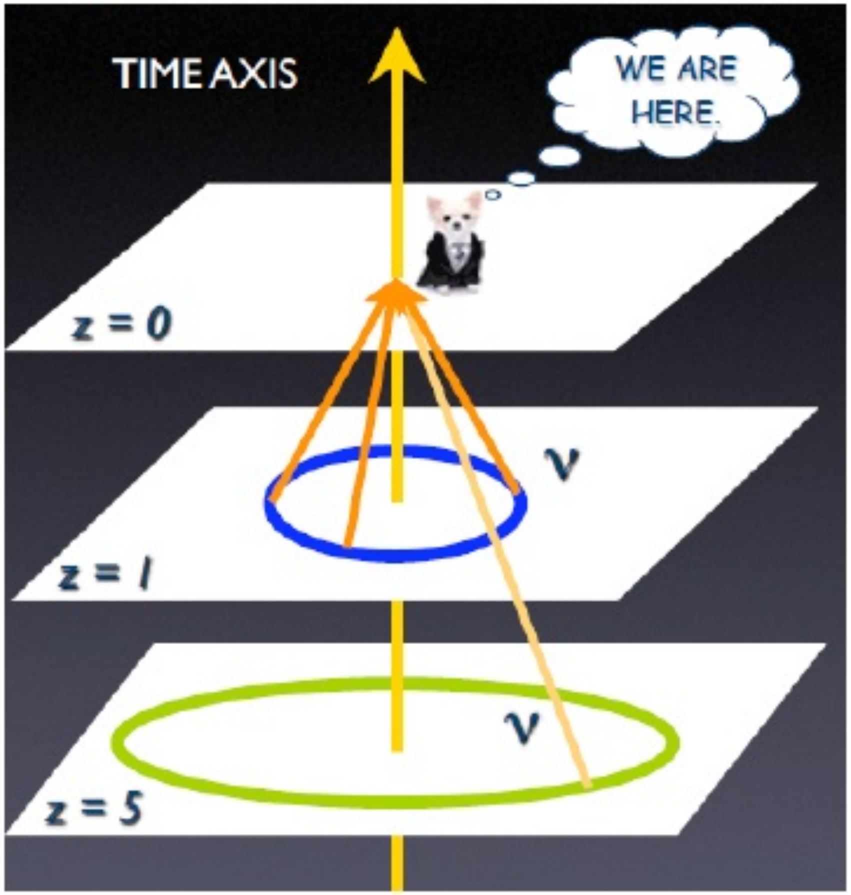
~1 degree at 10kpc

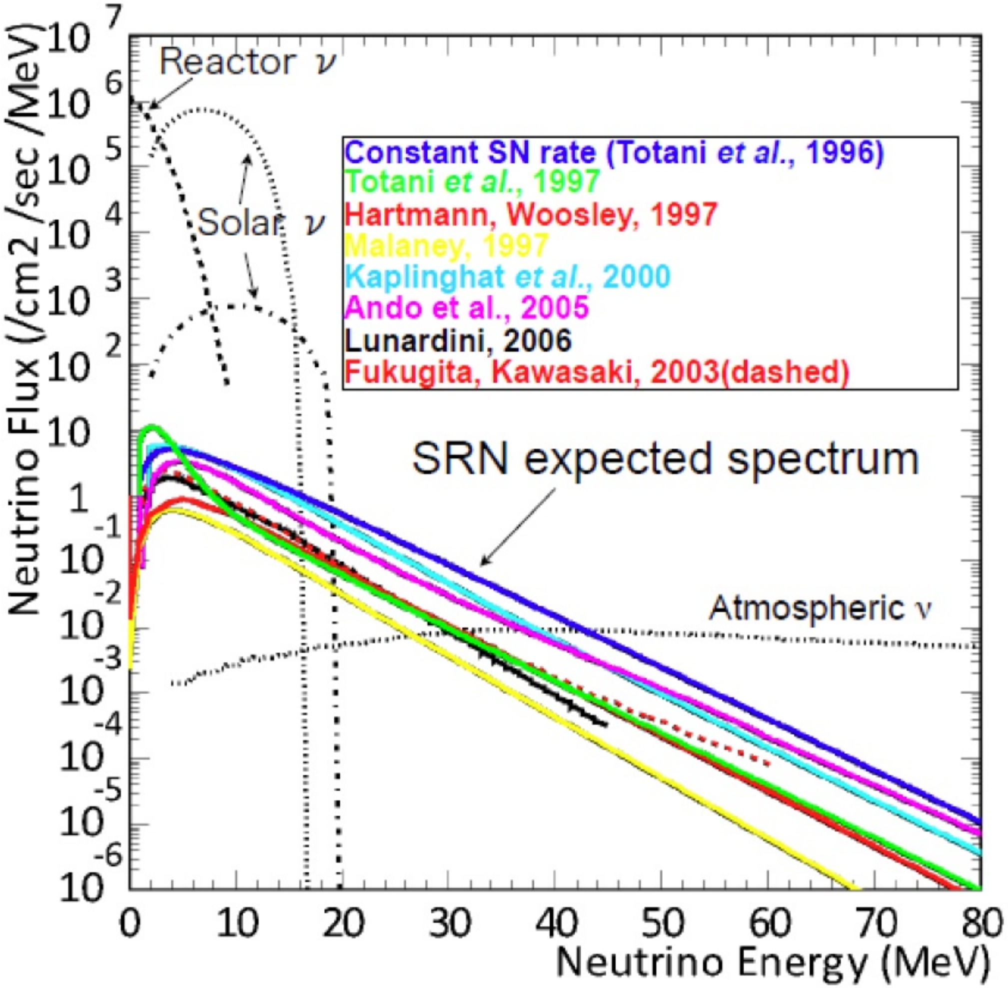
Supernova Relic Neutrino (SRN)

- SRN : Neutrinos emitted from past SNe since the beginning of the Universe

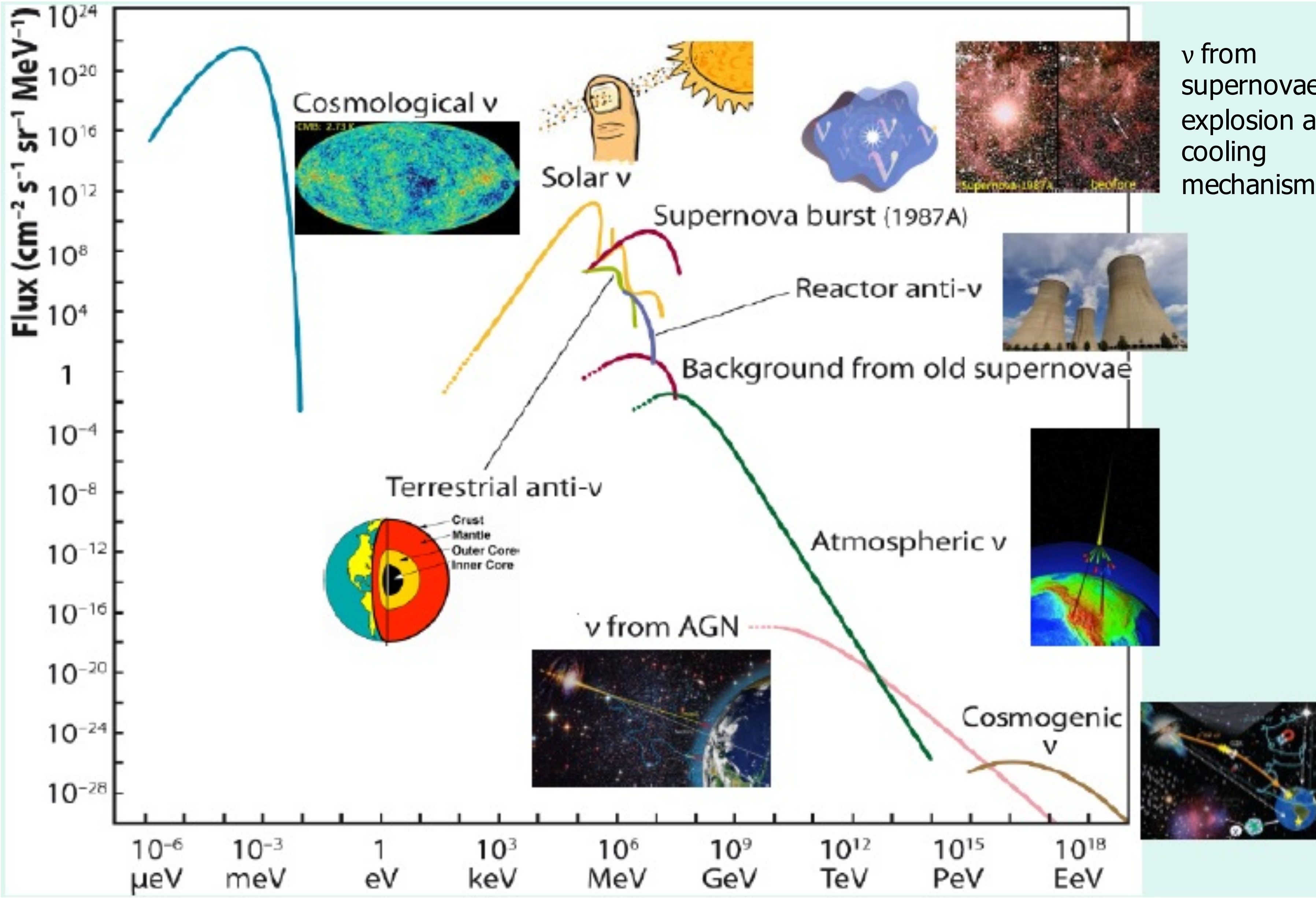
→ SRN energy spectrum measurement, history of SN bursts

S.Ando





Neutrino Sources



ν from supernovae → explosion and cooling mechanisms

Courtesy Soo-Bong Kim

SNEWS:
SuperNova Early Warning System

- http://snews.bnl.gov/
- A network of 7 neutrino detectors
  - Borexino, Daya Bay, KamLAND, HALO, IceCube, LVD, Super-Kamiokande
  - began automatic operation in 2005
  - reports gather + identify SNe at Brookhaven National Laboratory
    → need signals at ≥ 2 detectors within 10 seconds
- To make early warning for CC SNe from the Milky Way, or nearby galaxies (e.g. LMC, Canis Major dwarf)
- Neutrino pulses from SN 1987A – arrived 3 hours before the photons

Neutrino research - Astronomical applications

- Solar neutrino
- Nearby massive stars during very late evolutionary stages – we can look into the "core" directly and study the stellar interior.
- Core-collapse supernovae in the Milky Way or Galaxies in the Local Group (~long Gamma-Ray Burst)

  - early alert, multi-λ obs, explosion mechanism, NS cooling, BH formation
  - behind the bulge, behind the Sun, w/large extinction, failed SNe
  - good sensitivity → larger distance (~Mpc)
- NS + NS merger → short GRB + kilo nova
- NS + BH merger → short GRB
- WD + WD merger → collapse to a NS without a bright SN
- Supernova relic neutrinos (SRN : Neutrinos produced by all of the SN explosions since the beginning of the Universe) – esp. below 20 MeV (~100 events in 10 years)

  → SRN energy spectrum measurement, history of SN bursts
- Cosmic ray spallation – atmospheric neutrinos
- Dark Matter – Weakly Interacting Massive Particles (WIMP)

- KNO can serve as a Neutrino Telescope for >30 years

Project Status

- 2017 July : Selected to be in the Japanese government (MEXT) large-project roadmap
- 2017 Fall : Budget request to the Japanese government (5×10^{11} KRW)

- Korea : Efforts on physics/astronomy community endorsement
- Writing a proposal to the Korean government ($\sim2\times10^{11}$ KRW)
- Form an organization of “KNO Project Group”

PyeongChang 2018™

Thank you.

Plan

- Efforts on physics/astronomy community endorsement
- Writing a proposal for the government
- Form an organization of “KNO 추진 사업단”

KNO 추진 사업단

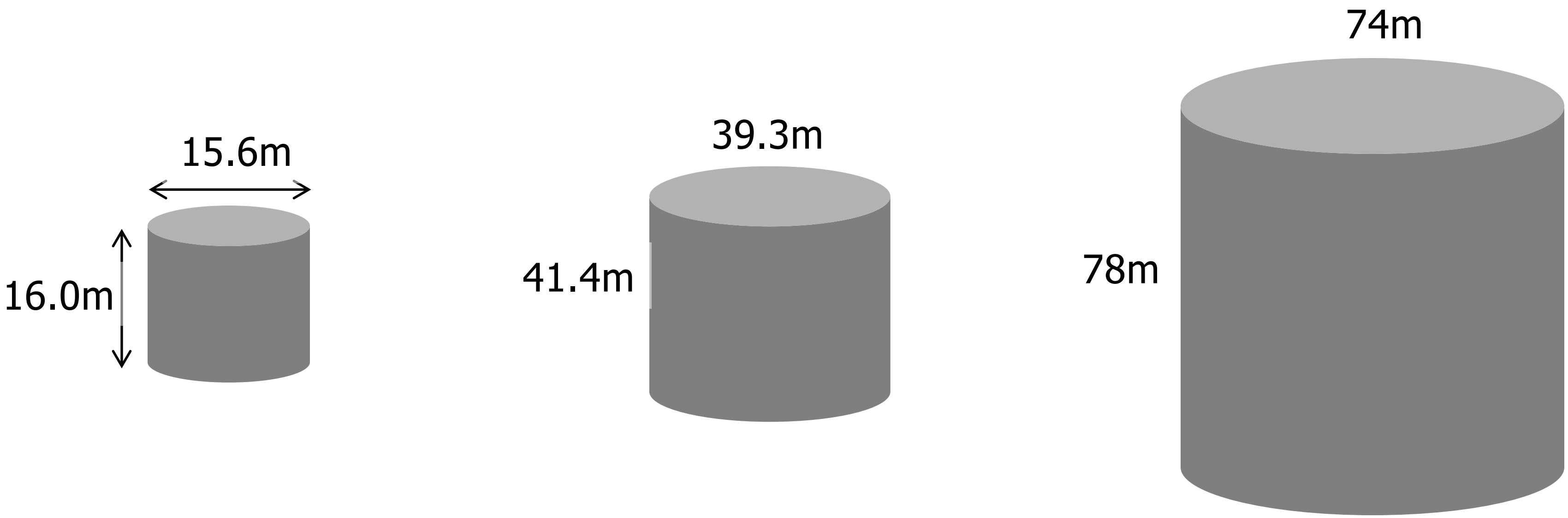
- **지하시설 구축 및 예산 확보**
  (지하시설 구축, 지자체 지원, 예산확보 노력)
- **KNO 검출기 그룹**
  (검출기 설계, 제작, 운영에 관한 연구팀)
- **KNT (Korean Neutrino Telescope) 그룹**
  (중성미자 망원경의 천문학 연구팀)
- **중성미자 및 입자물리 그룹**
  (중성미자와 입자물리에 관한 연구팀)
- **핵 천체물리 그룹**
  (핵과 천체물리에 관한 연구팀)
- **국제협력 그룹**
  (하이퍼카미오칸데 국제공동연구진과의 협력 및 국제연구진 참여 확대)
- **대외홍보 그룹**
  (KNO의 학문적 중요성과 기대효과에 대한 대외 홍보 노력)

3 Generations of Kamiokande

Kamiokande (1983-1996)
3,000 ton

Super-Kamiokande (1996-)
50,000 ton

Hyper-Kamiokande (~2026-)
2×260,000 ton



Water depth
= 60m

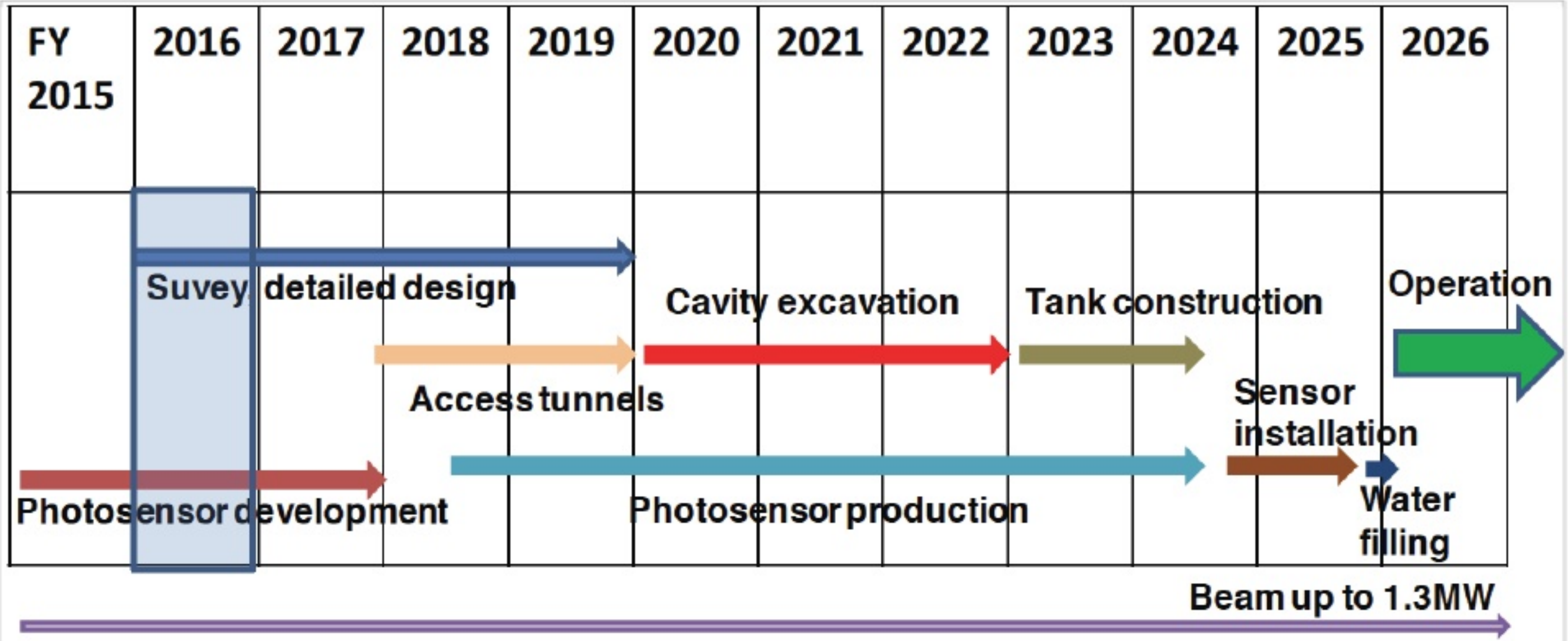
1000 PMTs

Inner detector :
11,146 (D=50 cm)

Outer detector :
1,885 (D=20 cm)

ID : ~40,000

Hyper-K Schedule



- Assuming funding from 2018
- The 1st detector construction in 2018~2025
  - Cavern excavation: ~5 years
  - Tank (liner, photosensors) construction: ~3 years
  - Water filling: 0.5 years

Courtesy Seon-Hee Seo