Experiences with the underground facility for KAGRA Site

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(308 collaborators (220 Japanese, 88 International))
Institute for Cosmic Ray Research and KAGRA Collaboration
GWADW2018, Alaska, USA 2018


IYC Cryostat


bKAGRA Phase1 Start


Atotsu Entrance


BS Suspension


EYC SAS


Sapphire Mirror

Thanks for Core to Core Program Again

KAGRA thanks to the following collaborators for getting a funding, core to core program for the collaboration researches and communication in GW physics and multi-messenger astronomy form FY2018 to FY2022.

USA: Caltech(LIGO) - Prof. Rana ADHIKARI
United of Kingdom: Univ. Glasgow - Prof. Sheila ROWAN
Italy: EGO/Virgo - Prof. Michele PUNTURO
France: Centre National de la Recherche Scientifique - Prof. Matteo BARSUGLIA
Australia: Swinburne University of Technology - Prof. Matthew BAILES
Germany: Max Planck Institute - Prof. Harald LUECK
China: Beijing Normal University - Prof. Zong-Hong ZHU
Taiwan: National Tsing-Hua University - Prof. Albert KONG
Korea: Sogang Univ. - Prof. Kyuman CHO
India: Inter-University Centre for Astronomy and Astrophysics - Prof. Sukanta BOSE
Vietnam: Hanoi National University of Education - Prof. NGUYEN Cao Khang
(Netherland: NIKHEF maybe from July 2018)

Contents

Although KAGRA, CLIO, SG experiences just show our local lessens, we will present what we got and suffered from…(I expect many predecessors such as Gran Sasso, SNO, CERN and so on.)

- **KAGRA Underground Geophysical Background**
- **Tunnel Excavation and Structure**
- **Treatment of**
  - **Water**
  - **Cleanroom**
  - **Air**
  - **Radioactive Radon**
  - **Electricity**
- **Safety**

Essential Merits (& Issues) of Underground

- **Out-band frequency range seismic noise at low frequency has nonlinear effect on in-band frequency range sensitivity in GWDs. So lower seismic noise in out-band is desirable.**
  - **→Smaller low-frequency motion of mirror**
  - **→ Lower gain of control system necessary**
  - **→Lower in-band noise imposed by control system**
- **We can expect Low Gravity Gradient Noise, Newtonian Noise and natural stability of temperature.**

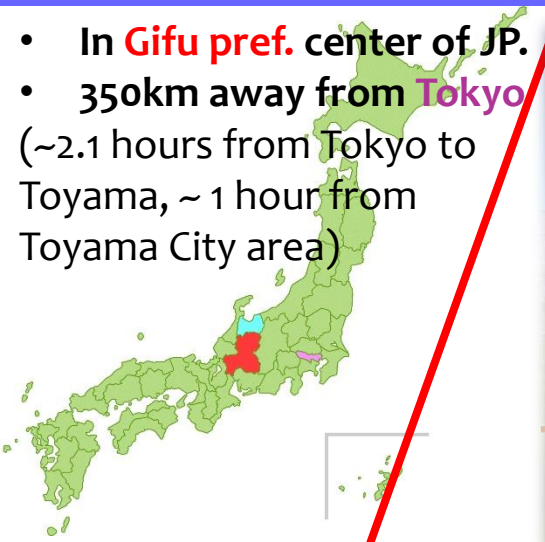
on the other hand,

- **We found the "water" in the mountain is annoying source in many practical aspects.**
- **"Newtonian Noise" due to water flow near mirrors should be investigated. Some estimation was proposed.**
- **The word of "underground" might be better to be replaced with "on/in a hard rock bulk".**

KAGRA Site (in Rock and Snow)

- **In Gifu pref. center of JP.**
- **350km away from Tokyo**

(~2.1 hours from Tokyo to Toyama, ~ 1 hour from Toyama City area)



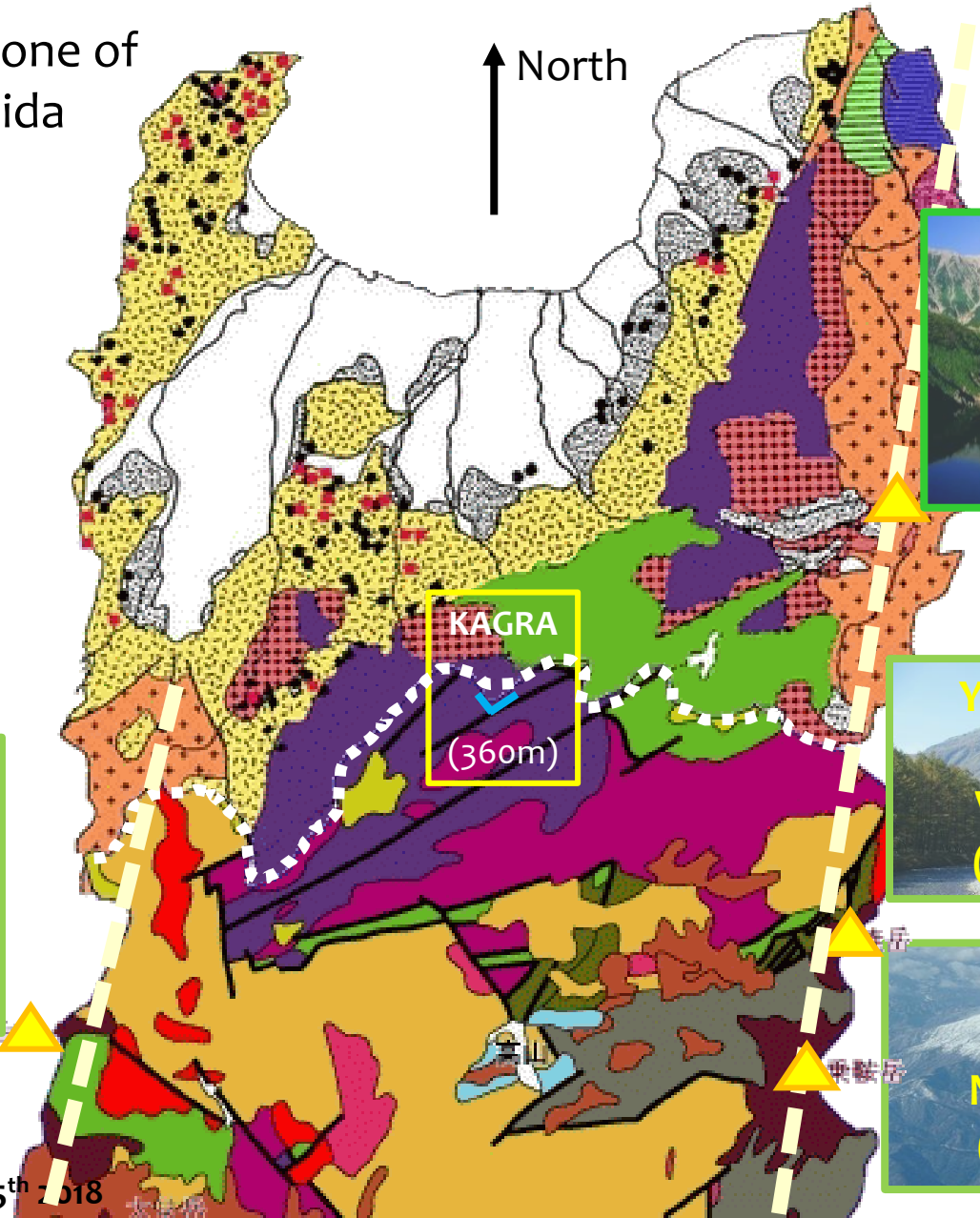
The border area between Gifu and Toyama

KAGRA in "HIDA" Gneiss

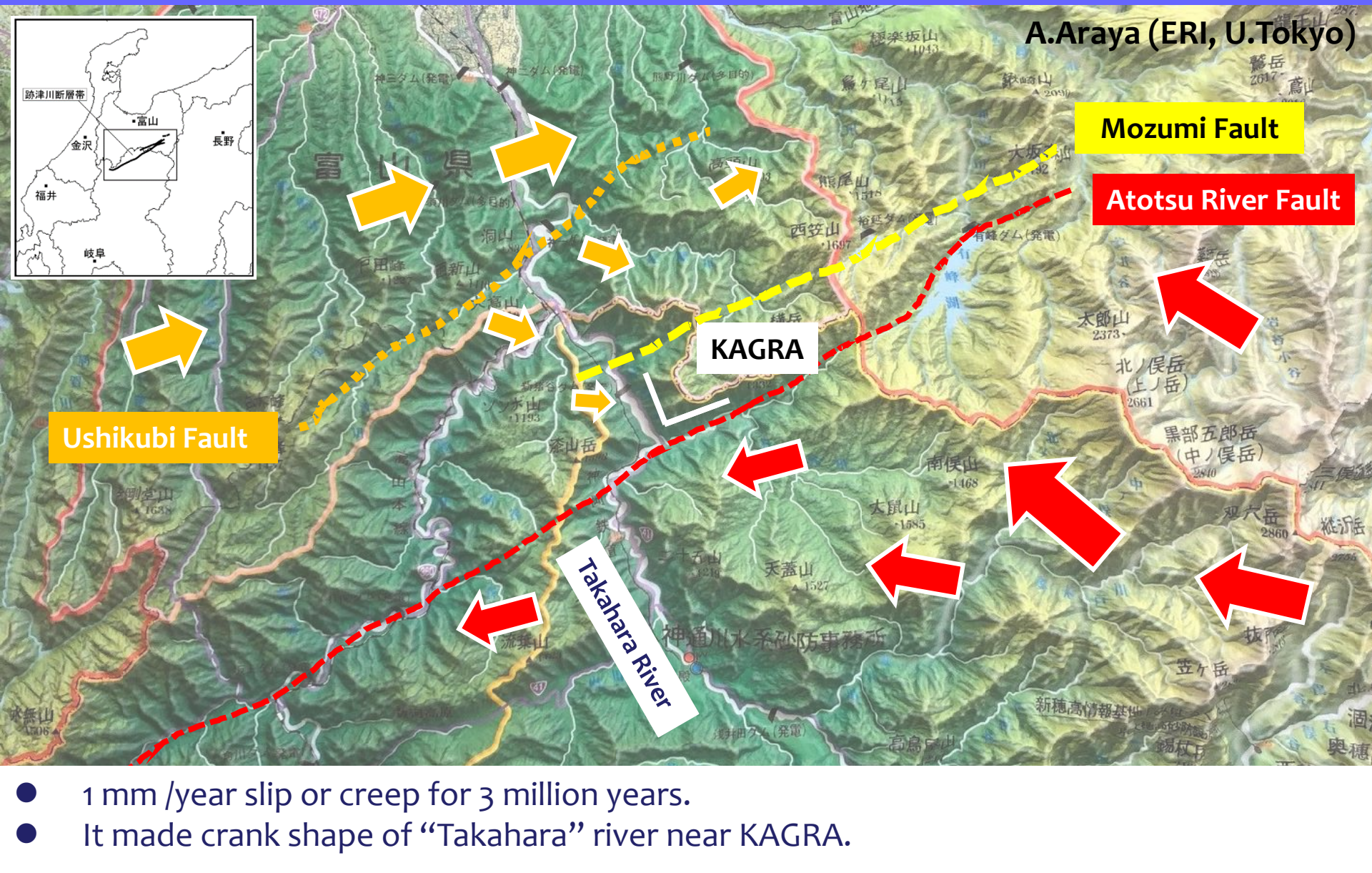
KAGRA is situated in one of the oldest rock of "Hida Gneiss" in Japan.

Hida Gneiss
(~2G years old)

Granite
(~0.2 Gyears old)



KAGRA between Two Faults

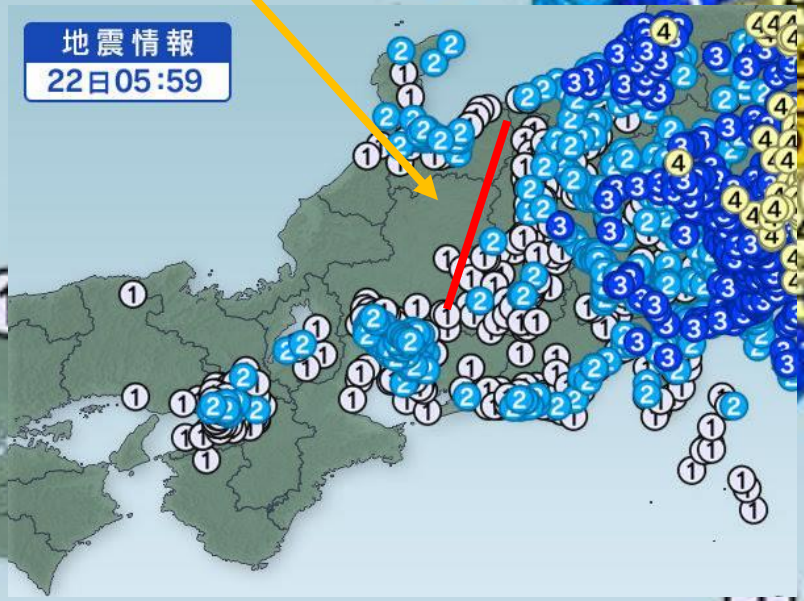


- 1 mm /year slip or creep for 3 million years.
- It made crank shape of “Takahara” river near KAGRA.

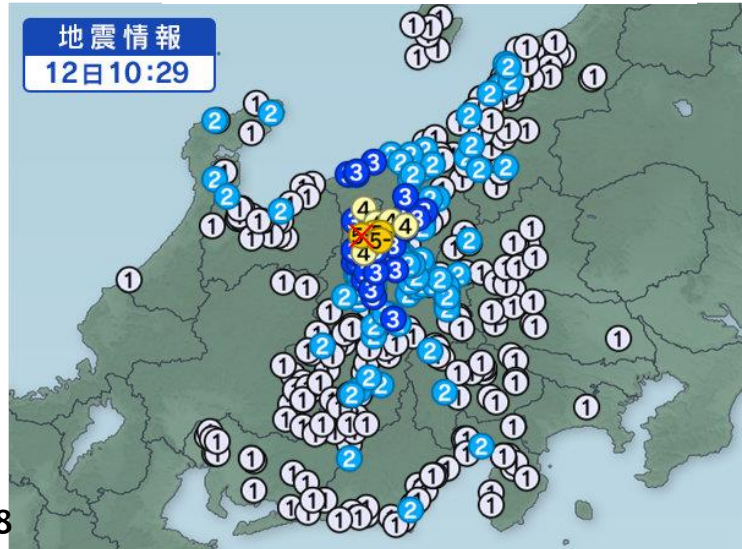
In Lucky Position Protected by Mountains

2016/11/22 05:59 JST

KAGRA is protected by something (Mountains Line.)

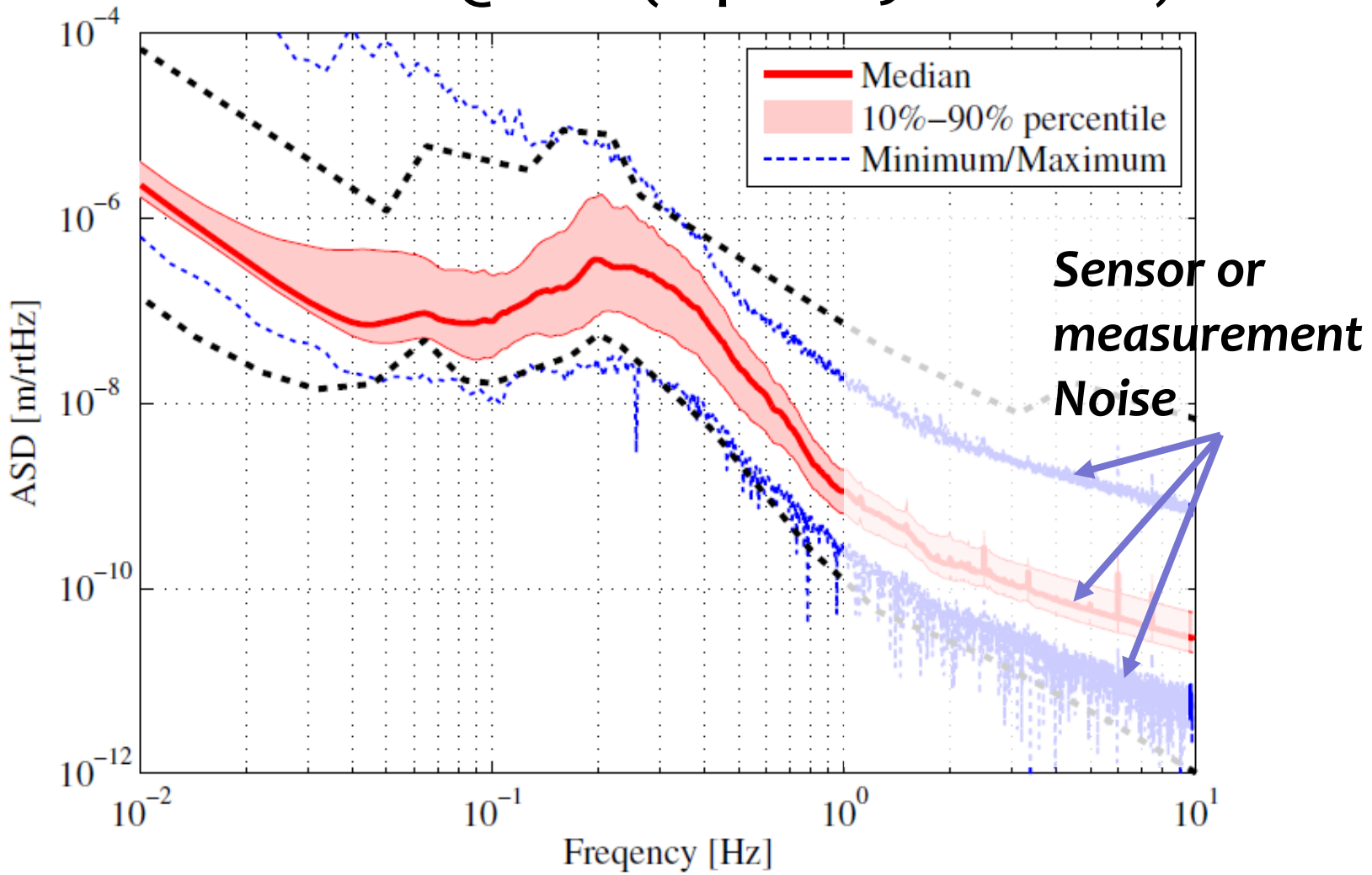


2018/5/12 10:29 JST



Kamioka Seismic Noise (< 100sec)

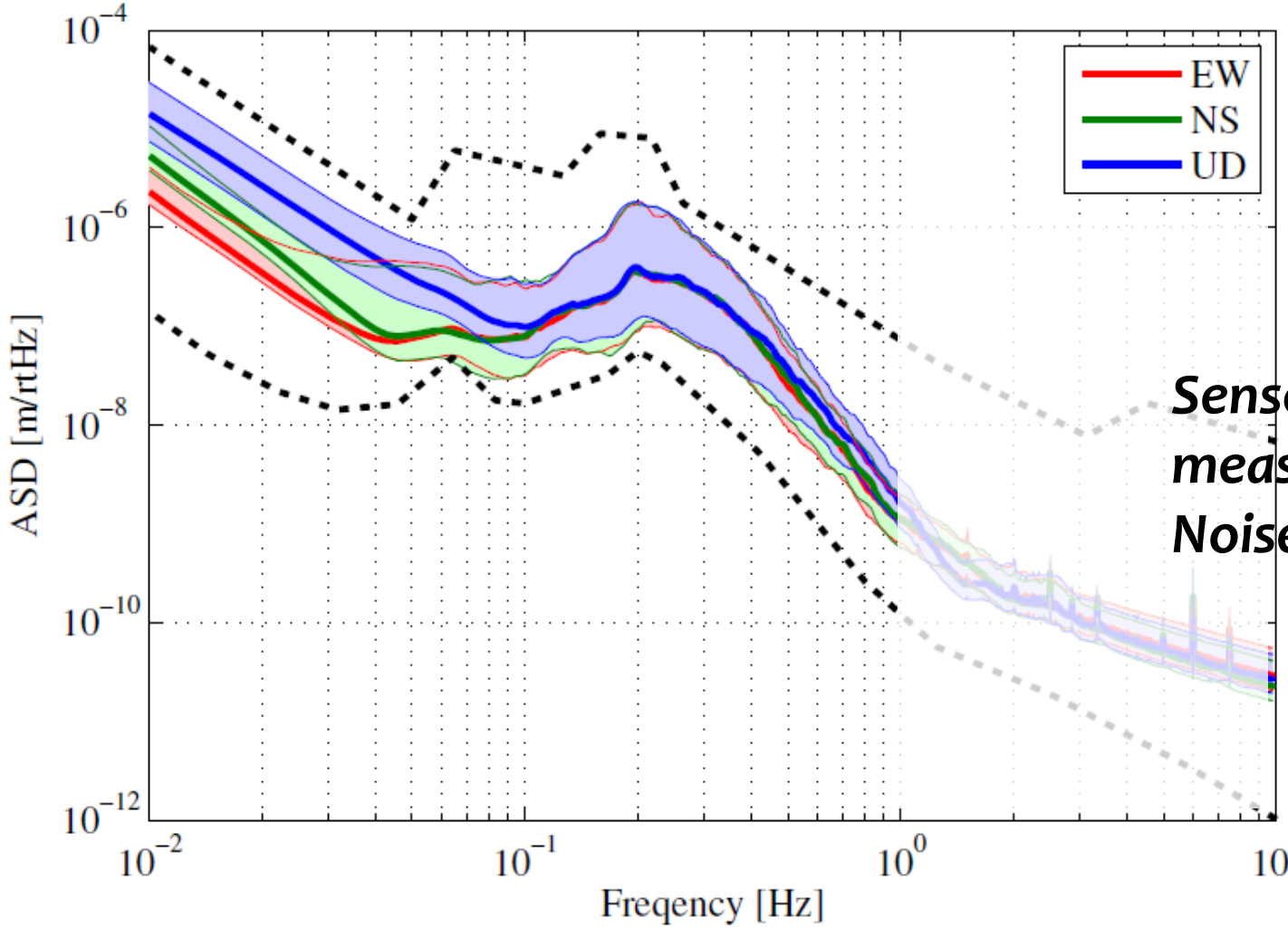
546 days data average, distribution and Max/Min by CMG-3T EW direction @ CLIO (Sept. 2009 ~ Feb. 2011)



T.Sekiguchi (U-Tokyo)

Kamioka Seismic Noise (< 100sec)

546 days data average, distribution by CMG-3T
EW/NS/UD directions @ CLIO (Sept. 2009 ~ Feb. 2011)

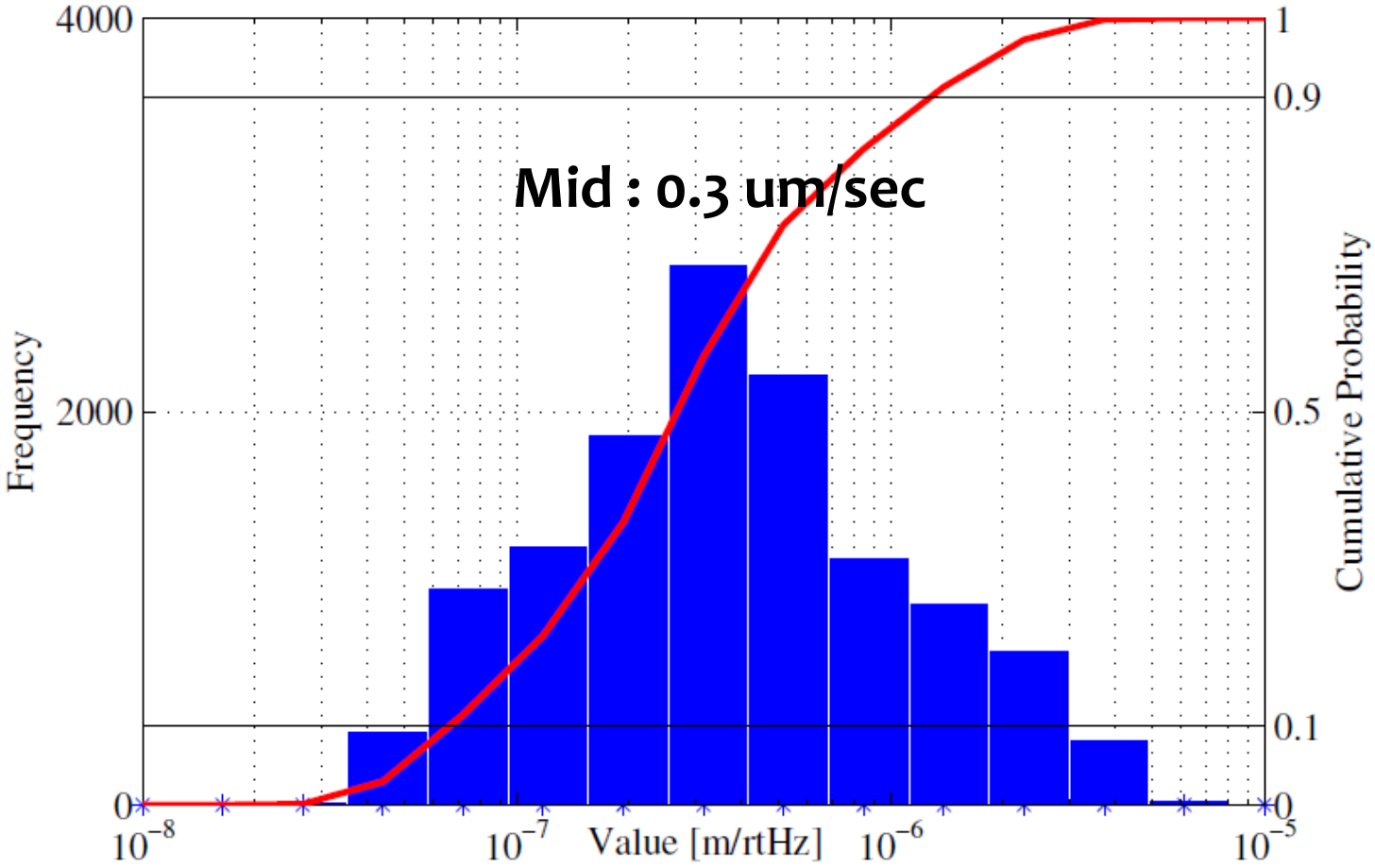


Sensor or measurement Noise

T.Sekiguchi (U-Tokyo)

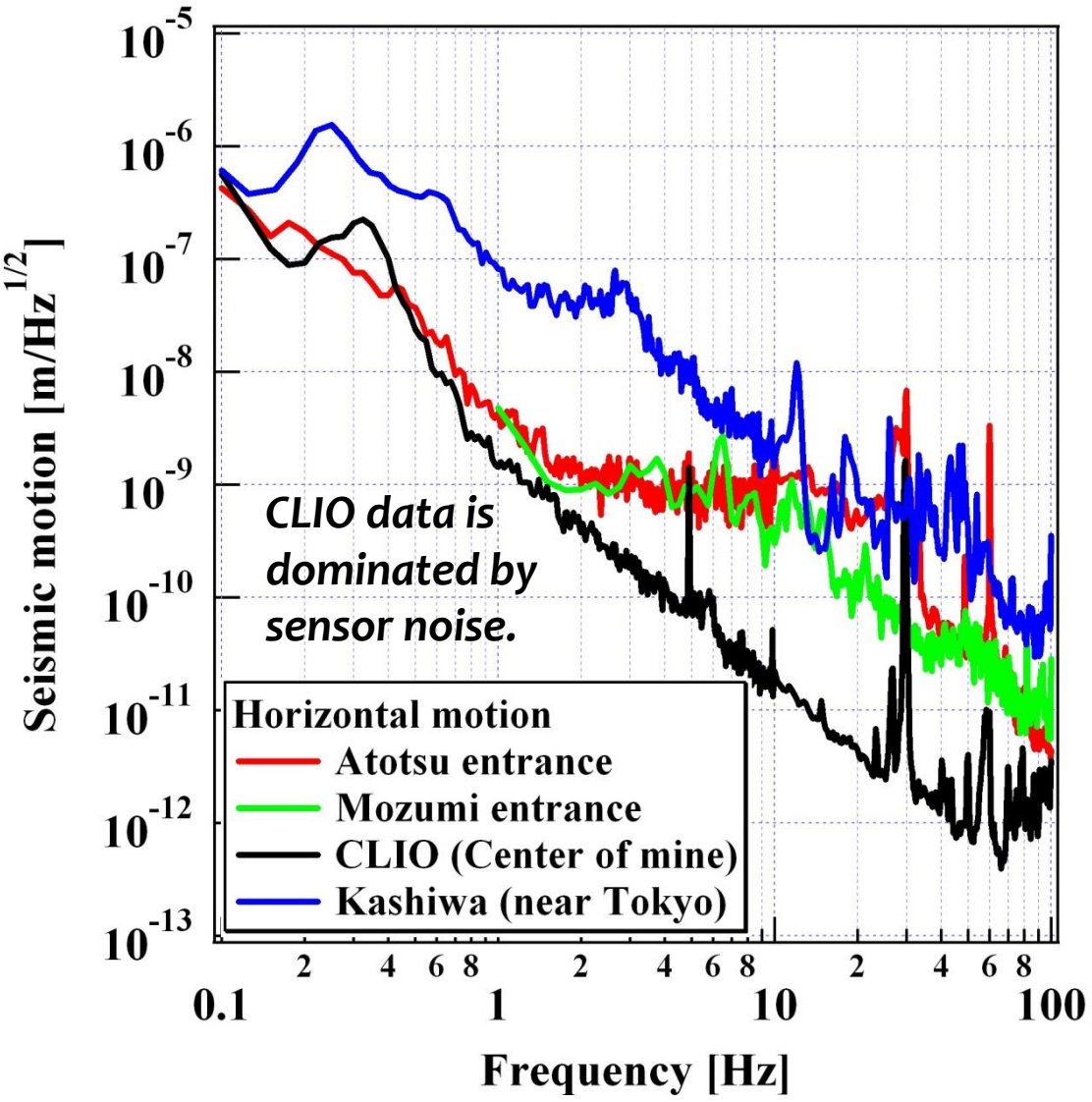
Micro Seismic Noise Level Distribution

Histogram of displacement at 0.2 Hz (Micro-seismic noise Peak)
(Sept. 2009 ~ Feb. 2011)



T.Sekiguchi (U-Tokyo)

Seismic Noise Comparison around KAGRA



- ***f* < 1Hz**

Outside(Moz,Ato) = CLIO

- **1Hz < *f* < 10Hz**

Outside(Moz,Ato) > CLIO

- ***f*>10Hz**

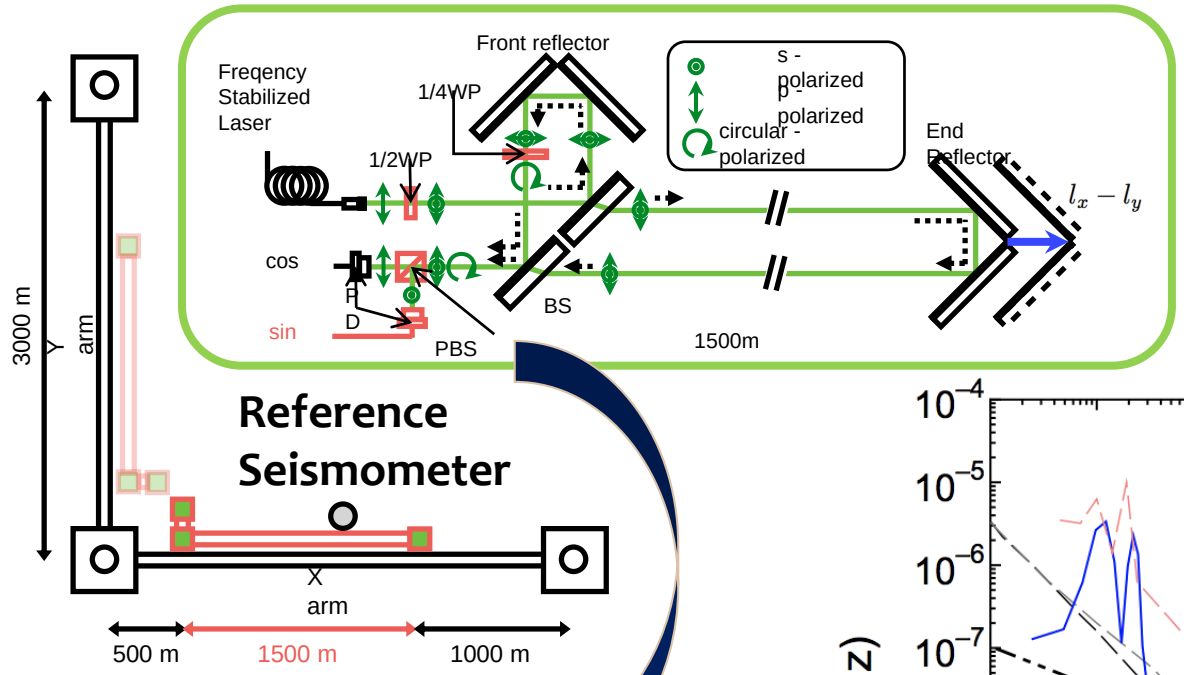
Outside(Moz,Ato) = Tokyo

This shows that natural events such as atmospheric and ocean events dominate the seismic noise above ~ 10Hz, while human activity dominates it below ~10 Hz .

K. Yamamoto (U-Tokyo)

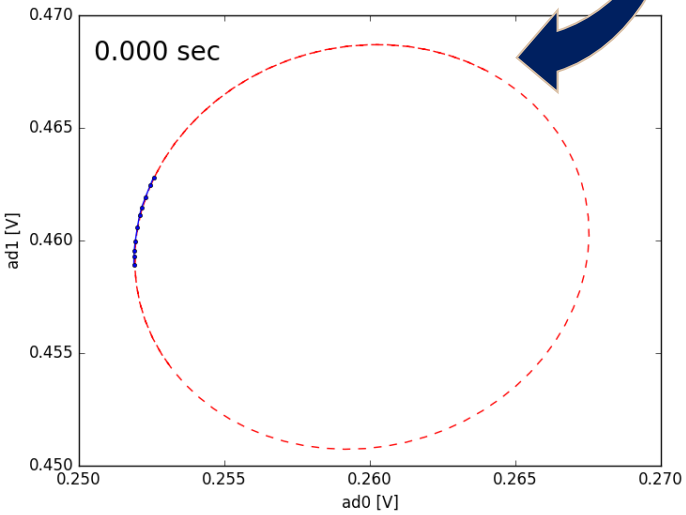
1500m Strain Meter in X arm

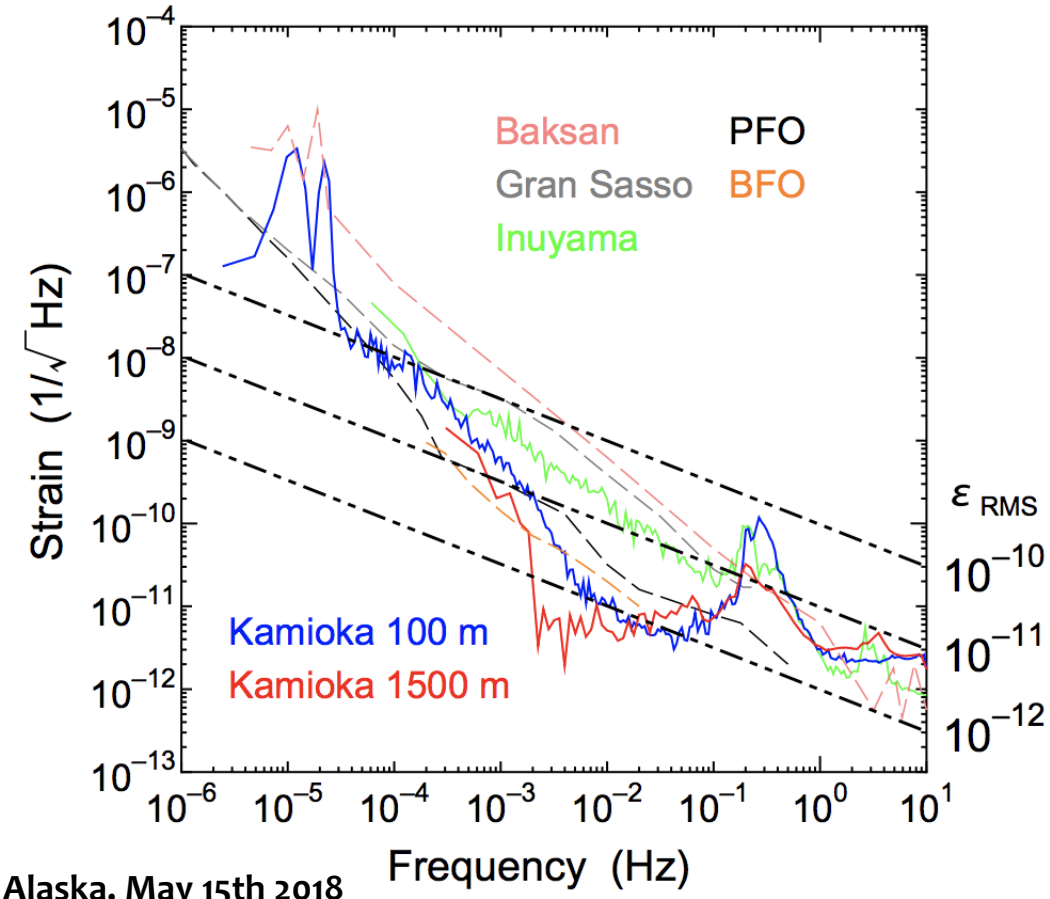
K. Miyo (U-Tokyo)



Reference Seismometer

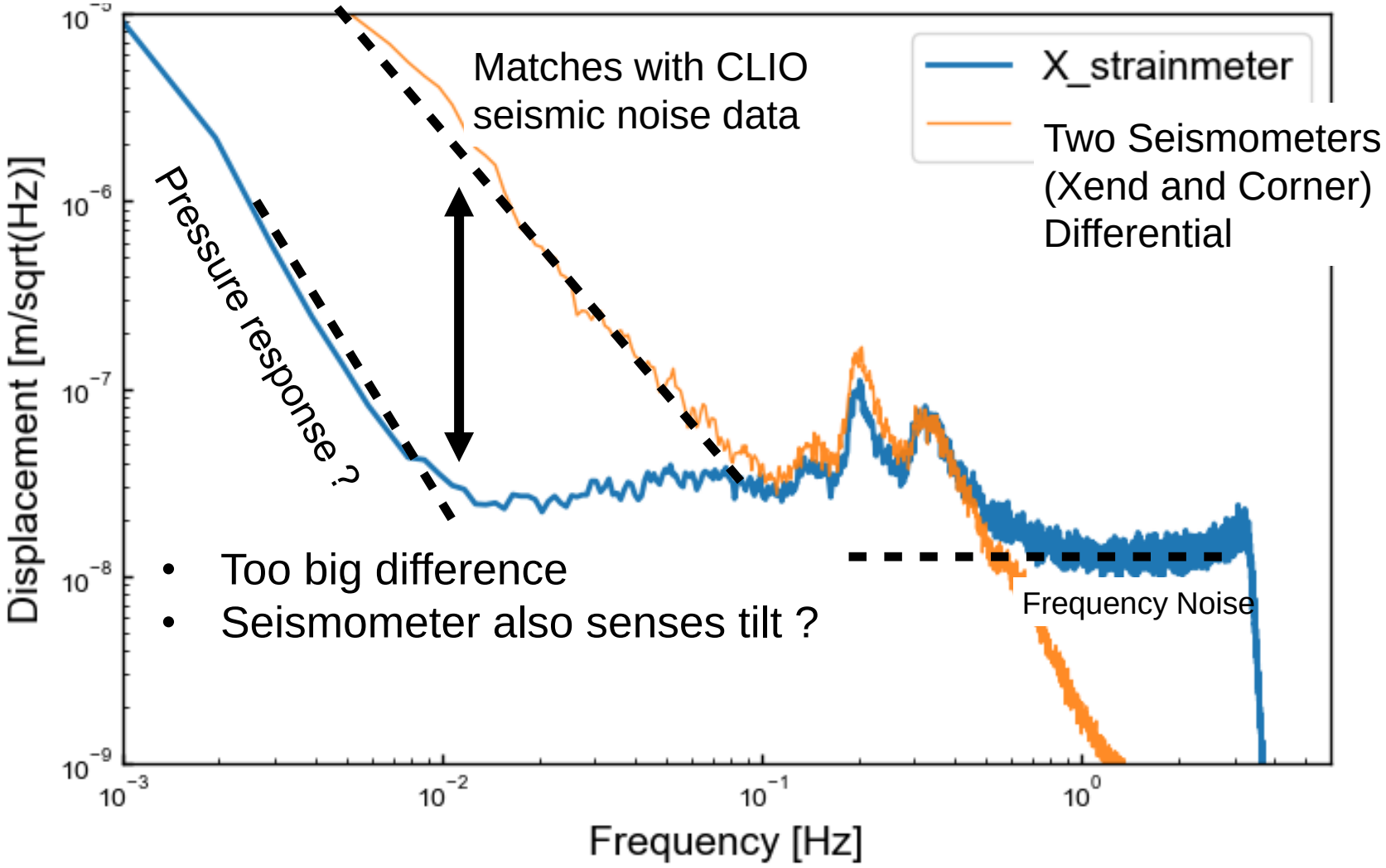
Strain meter senses differential motion between BS and a Xend mirror.





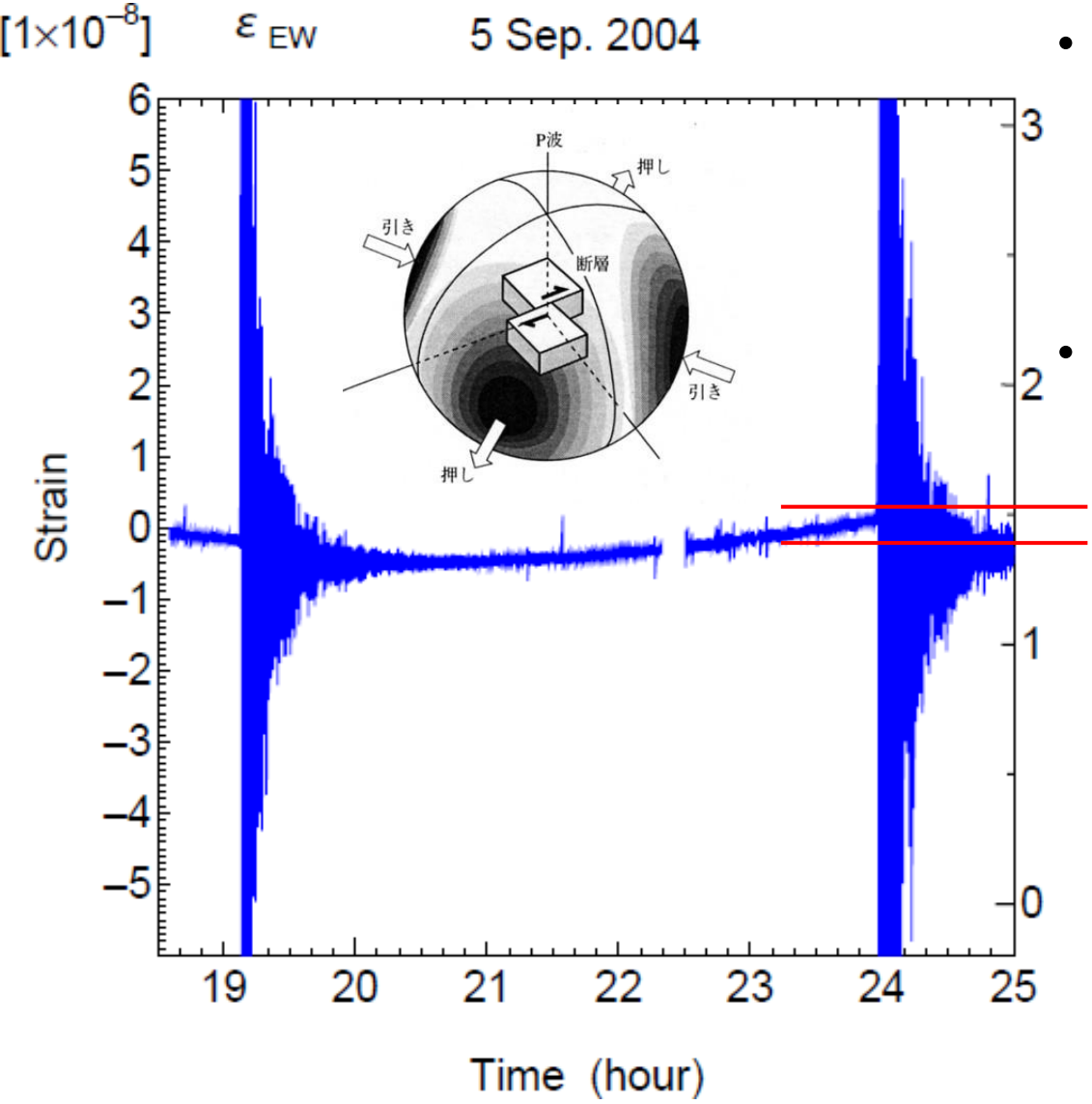
Difference b/w ST meter and Seismometer

Differential Displacement by ST and Actual Seismic Noise? by Seismometer

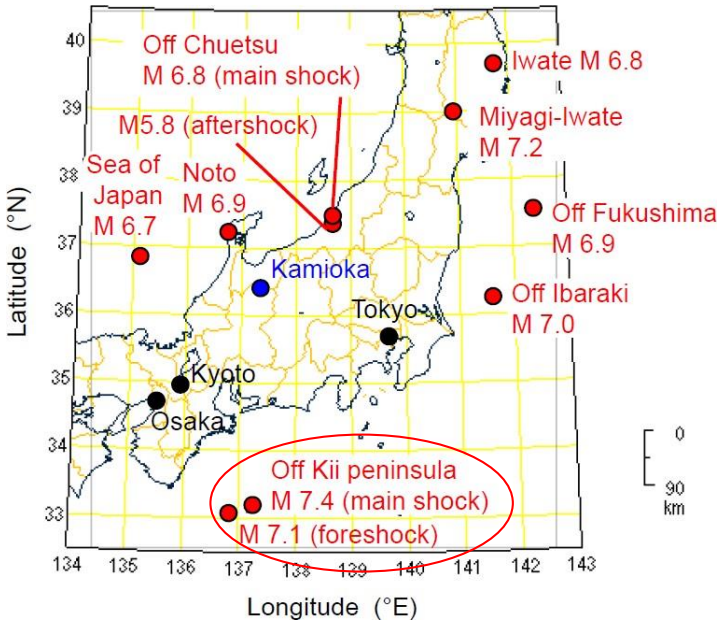


K. Miyo (U-Tokyo)

Permanent Steps

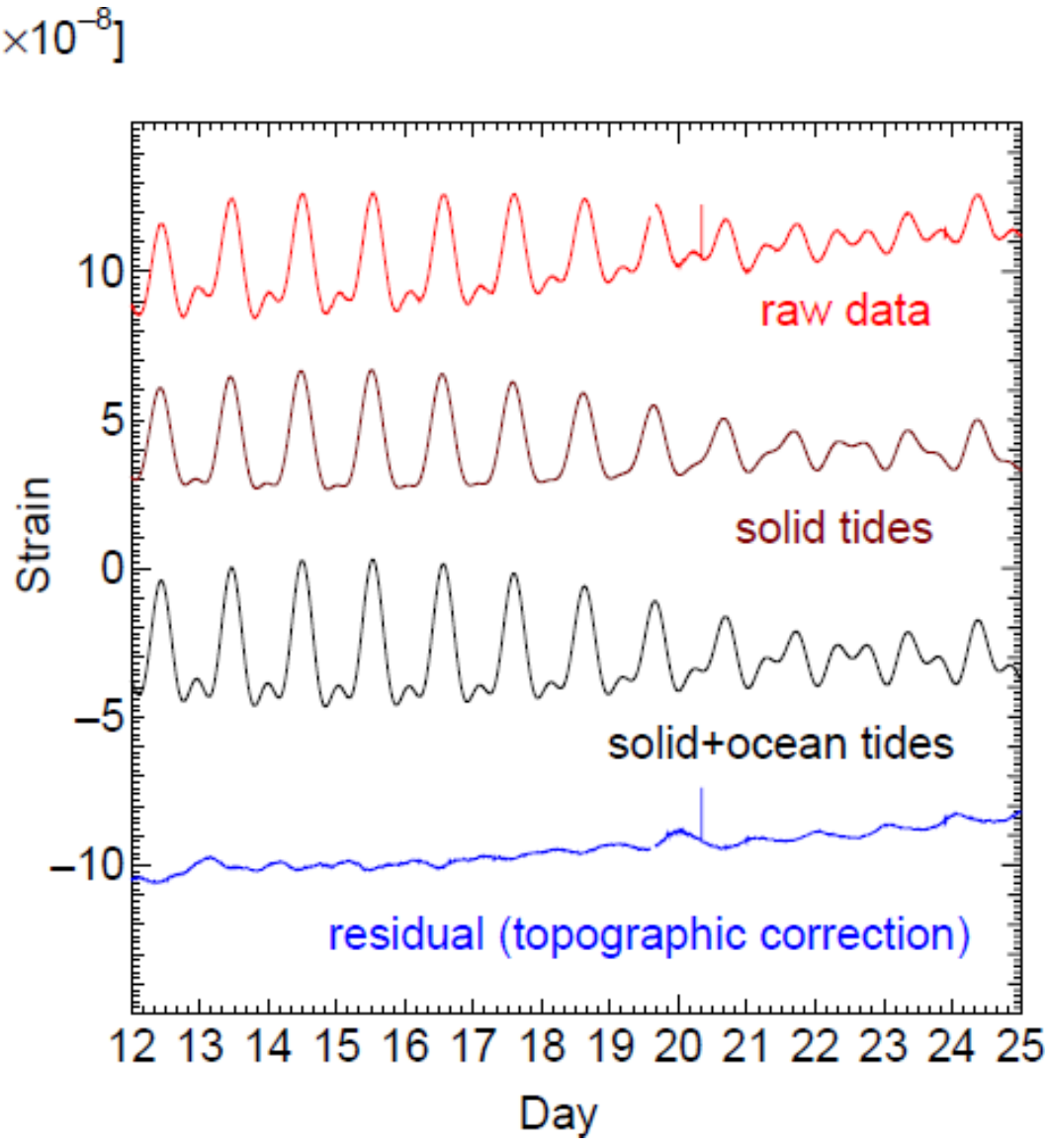


- 10^{-8} strain (1 micrometer for 100m) permanent step was observed because of M7 level Erath quakes 400km away from KAMIOKA.
- This order matched with the predicted values from its Earthquake slip model.



A.Araya (ERI, U.Tokyo)

Tidal and Local Deformation (> Days)



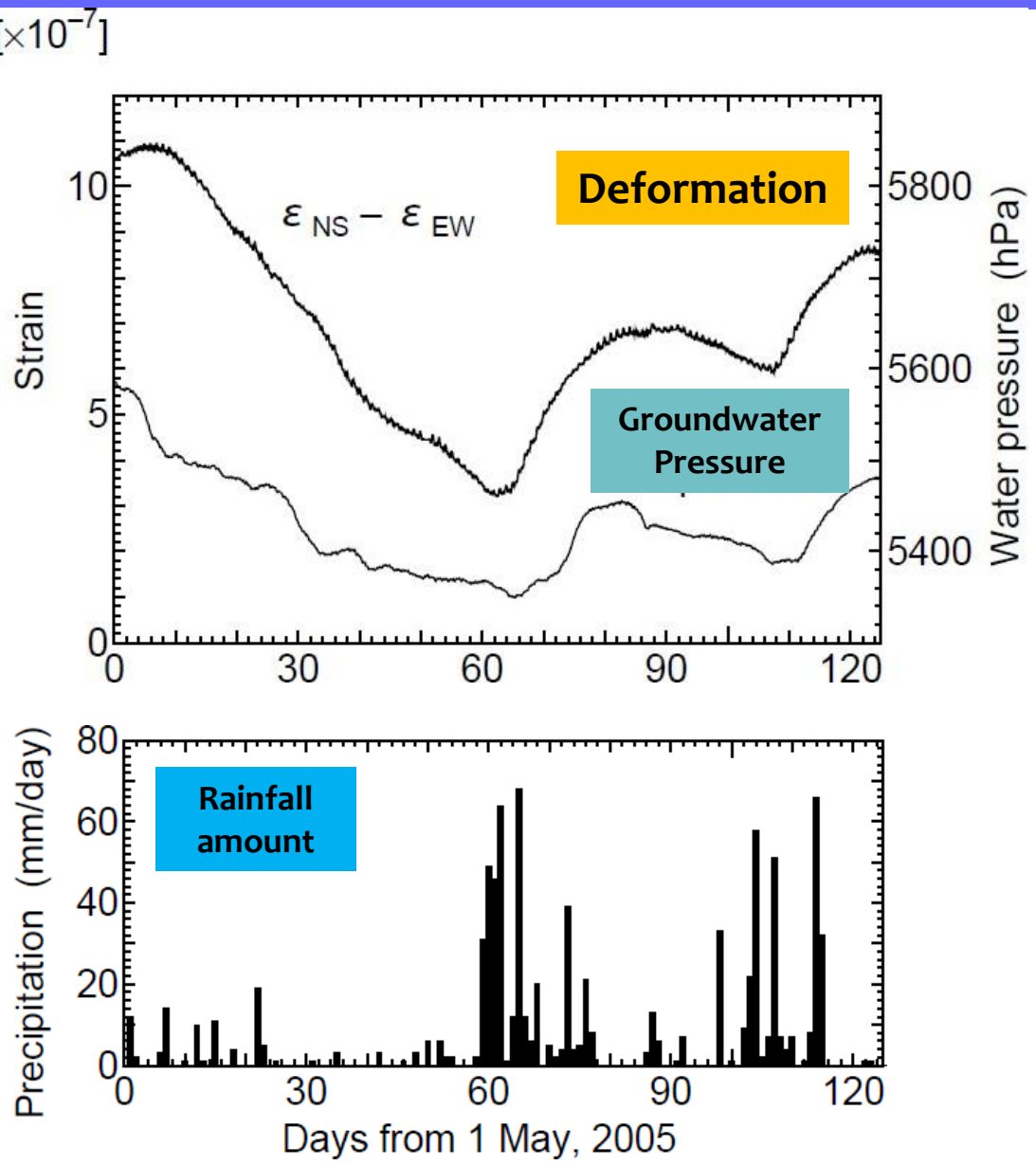
Raw data can be predicted by

(1) Standard Solid Model of the Earth
(2) Ocean Gravity Load
(3) Local deformation property

So, It is very important to obtain (3) for better characterization and the future feedforward control for KAGRA.

A.Araya (ERI, U.Tokyo)

Seasonal Deformation (> Months)

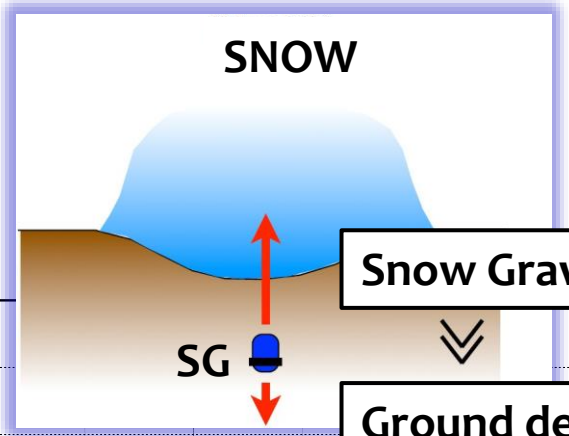


- Snow and water in the case of KAMIOKA.
- Obviously ground deformation, groundwater pressure and rainfall have correlation with each other.
- How about gravity ??

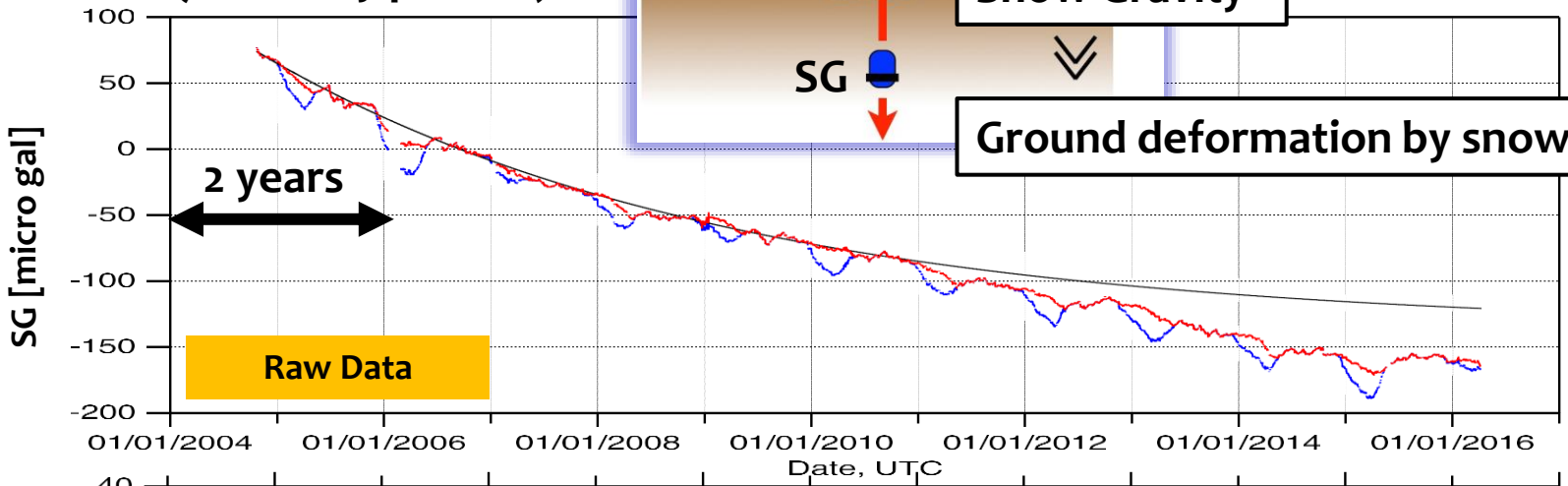
A.Araya (ERI, U.Tokyo)

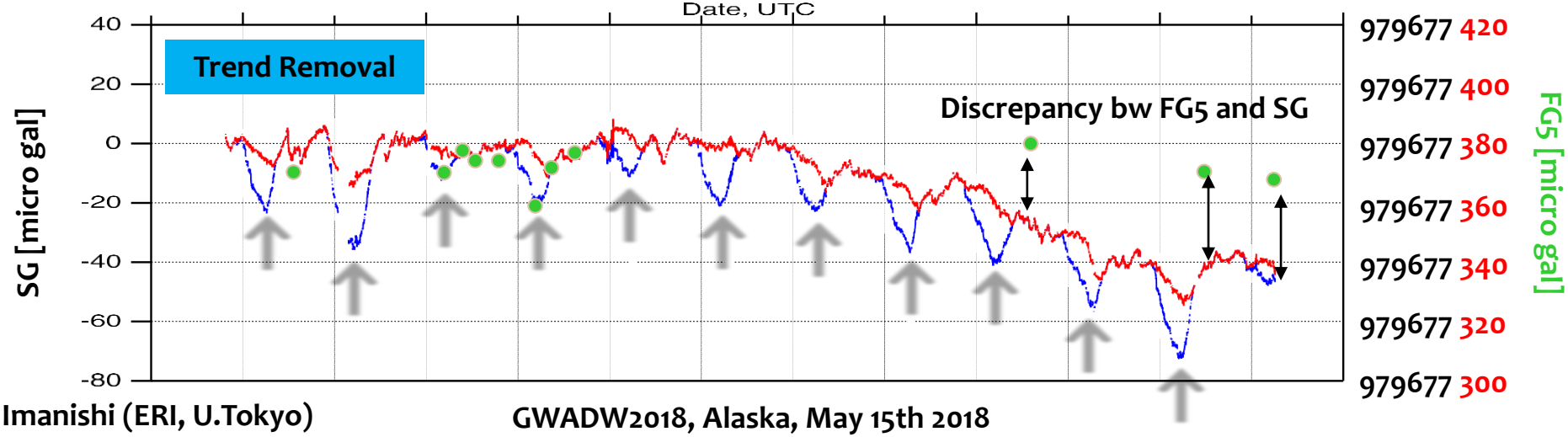
Gravity Change (>Several Months)

Superconductive Gravity Meter (SG) In the same mountain With KAGRA (relatively precise)



Absolute Gravity Meter (FG5)





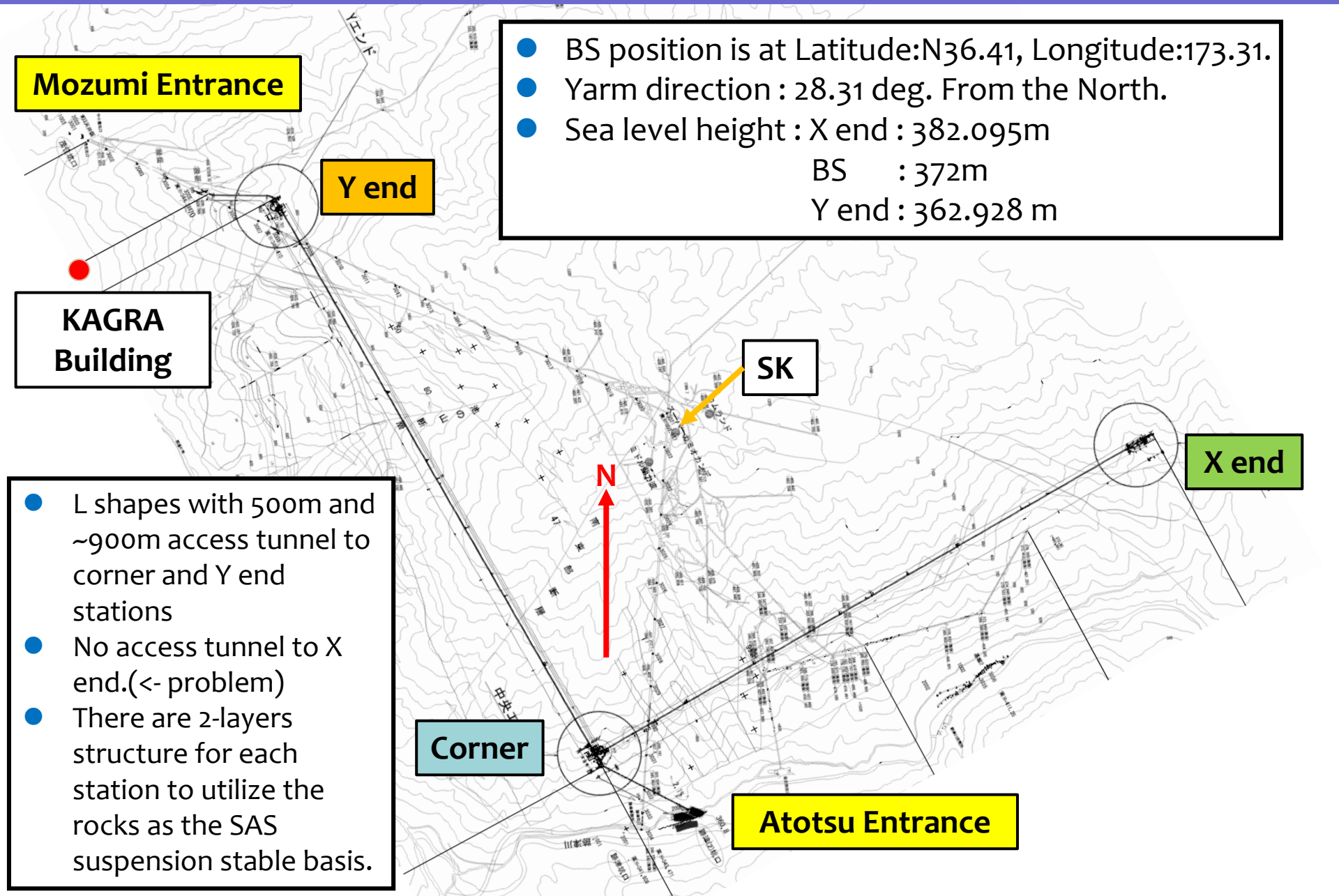
Tunnel of KAGRA

- *The stripped-down cost for KAGRA tunnel was ~28 MUSD for minimum requirements.*
- *However, additional cost was required for unexpected accident and bad ground conditions.*
- *The additional cost is acceptable at some level in M. of Land Infrastructure and Transportation, while it is not so acceptable in MEXT in Japan.*

	KAGRA	Highway (Sasago)	Rail Way (Tsugaru)	Subway (in Tokyo)
Size	4m x 4m (~7,770m)	~10m x ~8m (~4,700m)	? (~53,850m)	~6m x ~6m
Cost (USD/m)	3,600	47,900	115,000	283,000 ~167,000
	Only tunnel (NATM)	Including Infrastructure	Including Infrastructure Under Sea	Including Infrastructure (Shield Machine)

Very Cheap

Tunnel Position and Alignment



- BS position is at Latitude:N36.41, Longitude:173.31.
- Yarm direction : 28.31 deg. From the North.
- Sea level height : X end : 382.095m
  BS : 372m
  Y end : 362.928 m

- L shapes with 500m and ~900m access tunnel to corner and Y end stations
- No access tunnel to X end.(<- problem)
- There are 2-layers structure for each station to utilize the rocks as the SAS suspension stable basis.

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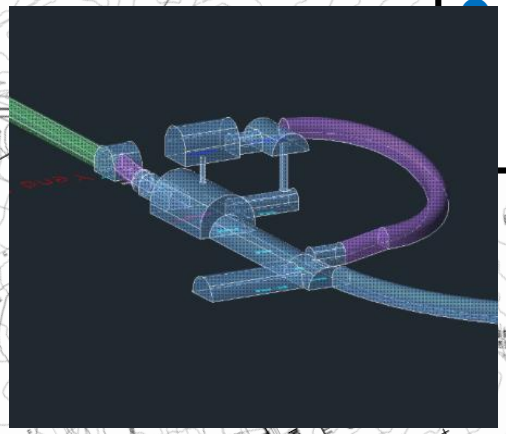
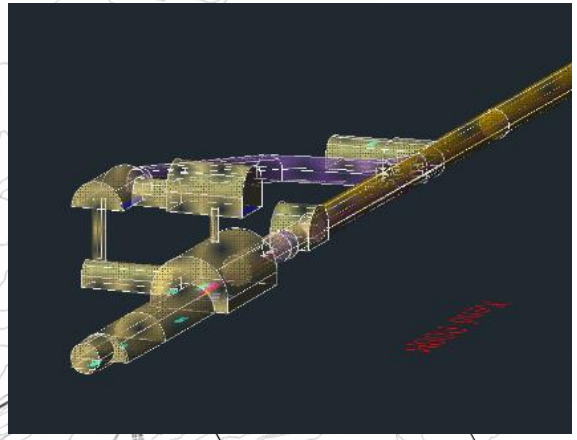
Mozumi Entrance

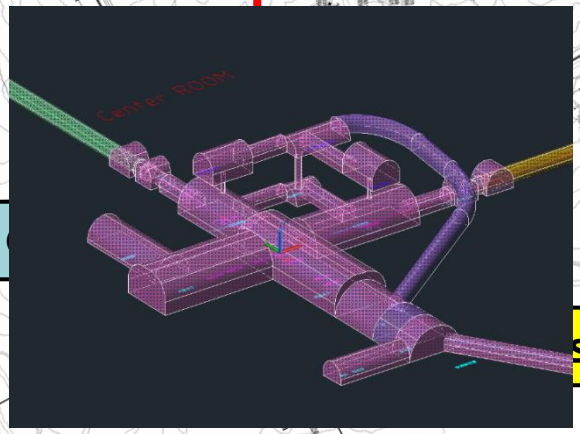


KAGRA Building

SK



N

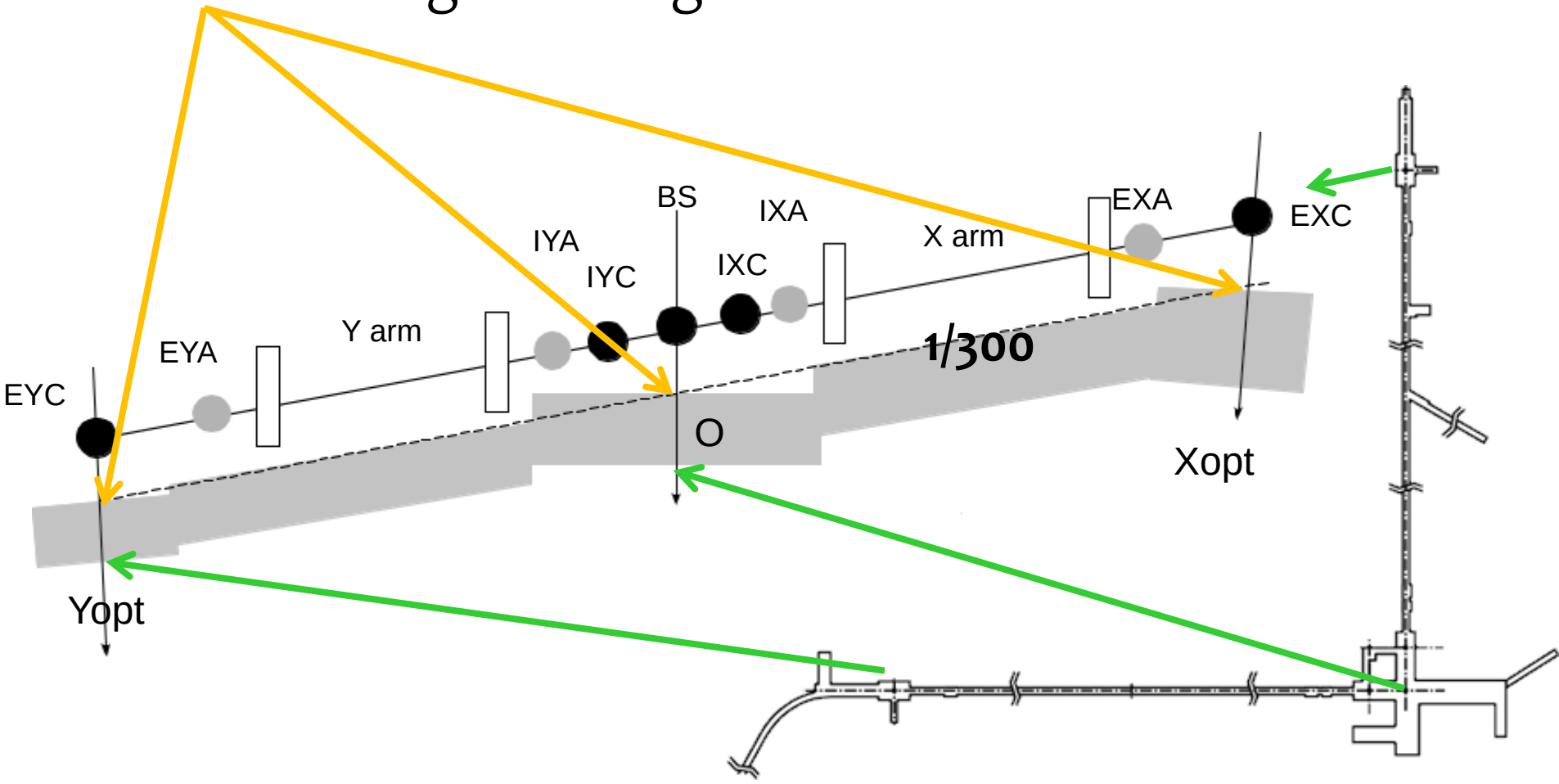


su Entrance

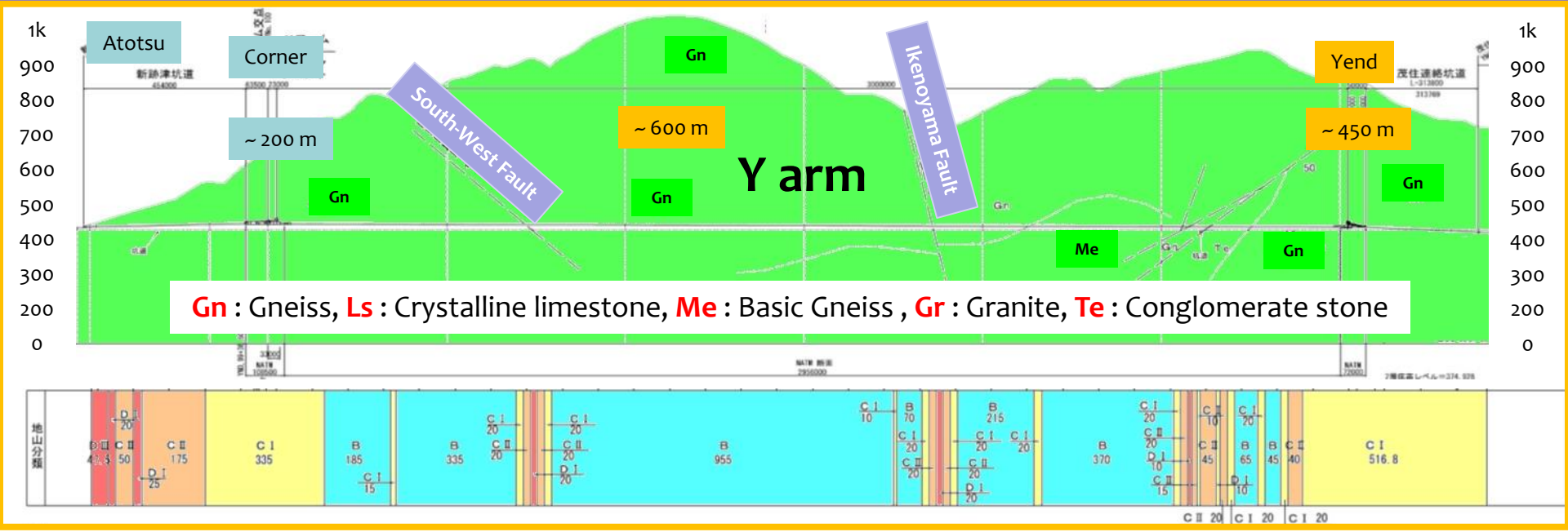
- L shapes with 500m and ~900m access tunnel to corner and Y end stations
- No access tunnel to X end.(<- problem)
- There are 2-layers structure for each station to utilize the rocks as the SAS suspension stable basis.

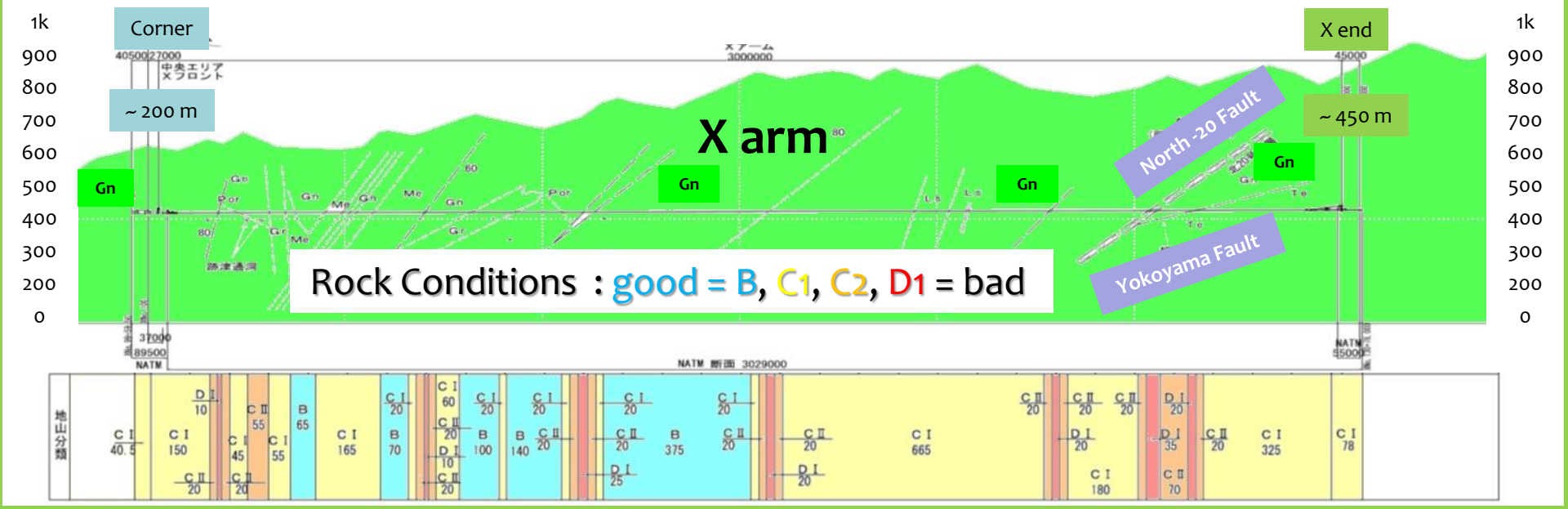
Tunnel Slope

- Slope of 1/300 was selected to drain the water to rivers.
- Horizontal planes for each station are prepared for easiness during installing vacuum tanks



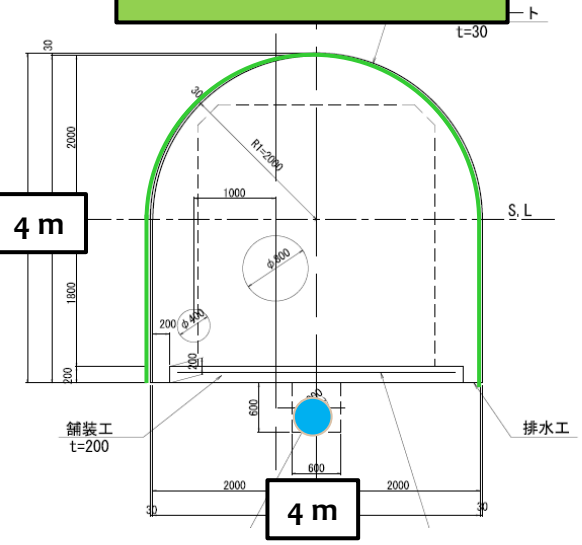
X, Y arm Tunnel Depth and Rock Conditions



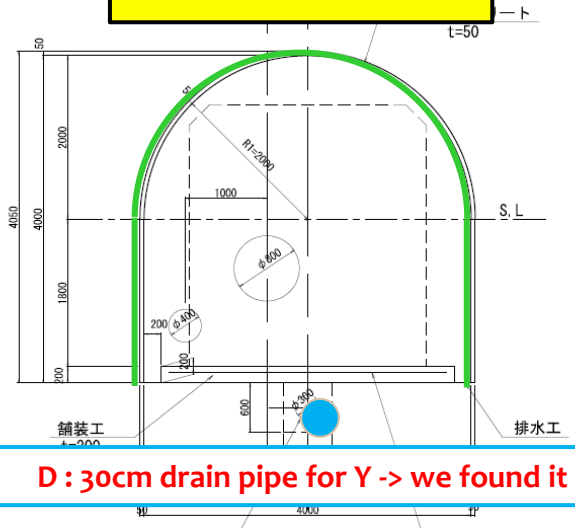


Typical Arm Tunnel Cross Section and Corner Station

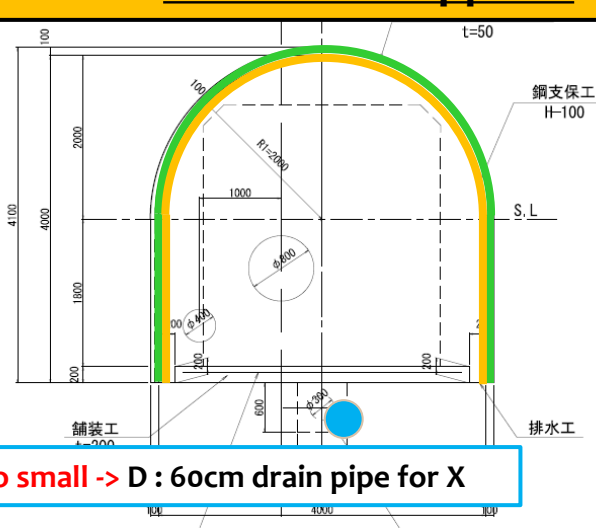
B : 3cm sprayed concrete wall



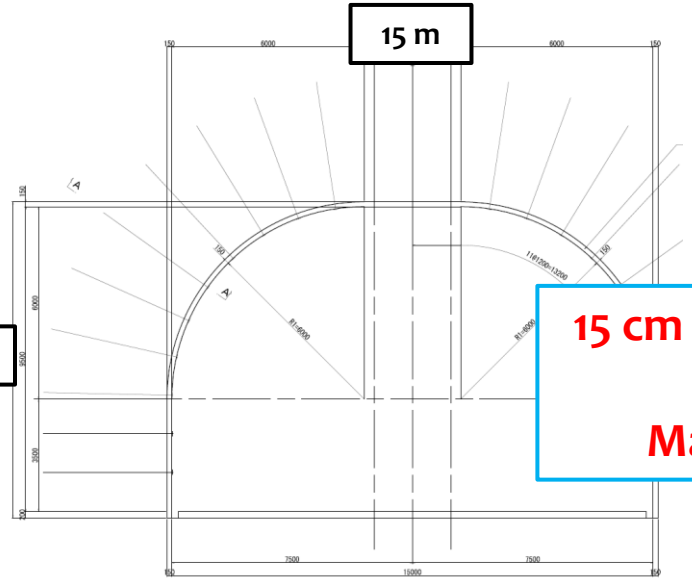
C1 : 5cm Sprayed concrete wall



C2 : 5cm sprayed concrete wall and metal arch supports

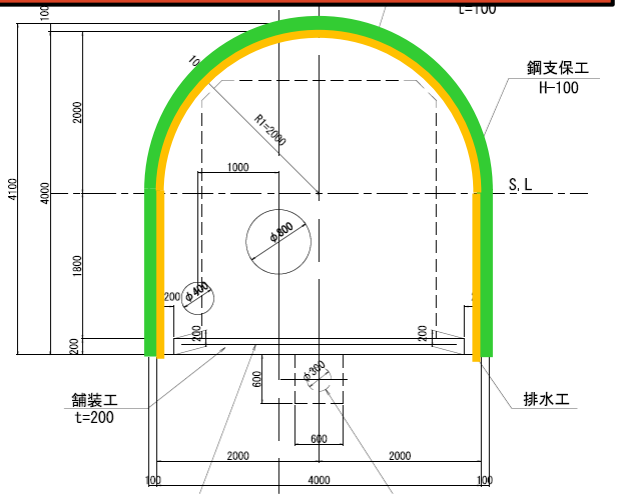


D : 30cm drain pipe for Y -> we found it is too small -> D : 60cm drain pipe for X



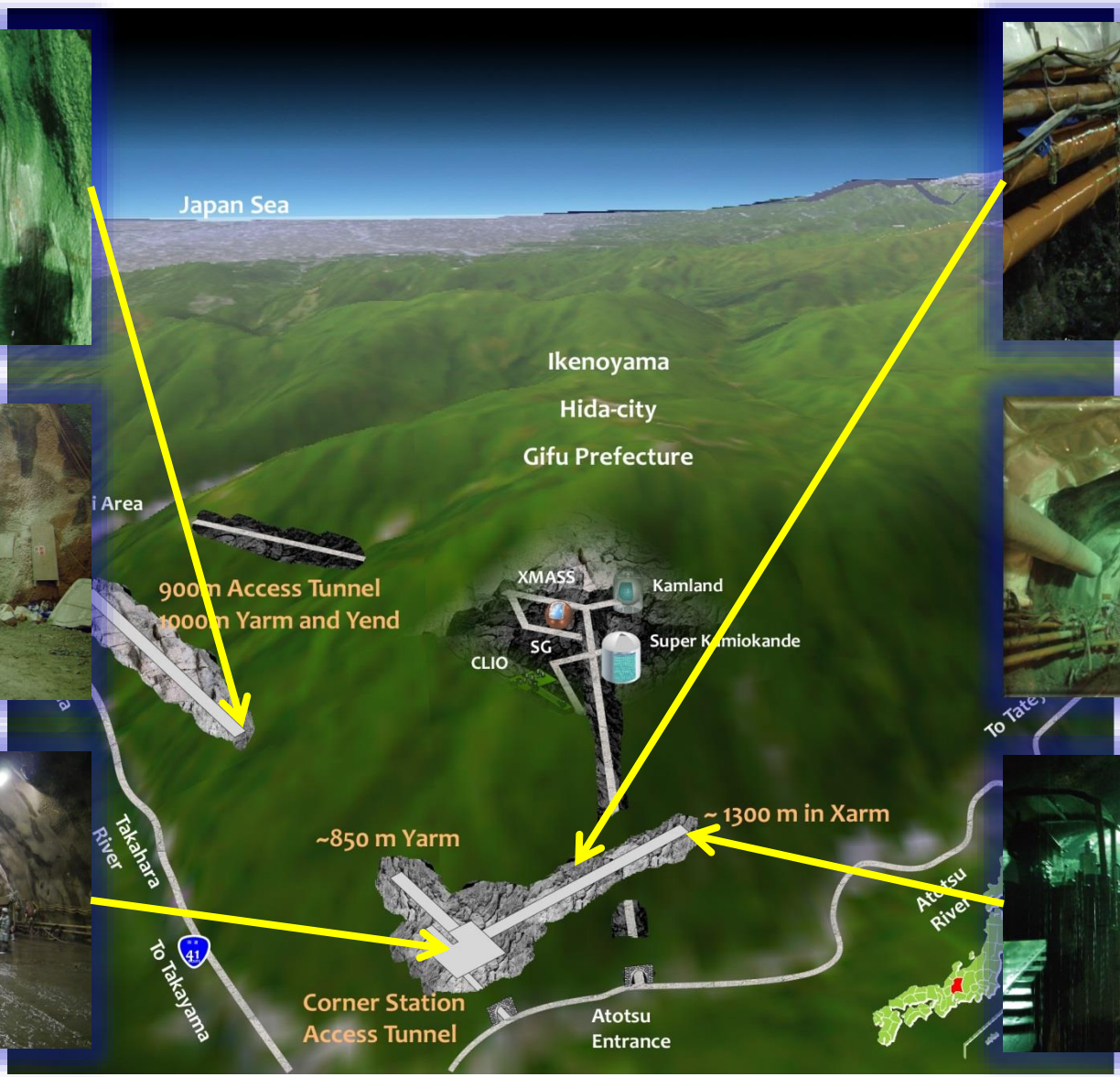
15 cm sprayed concrete And Many rock bolts

D 1 : 10 cm Sprayed concrete wall and metal arch supports



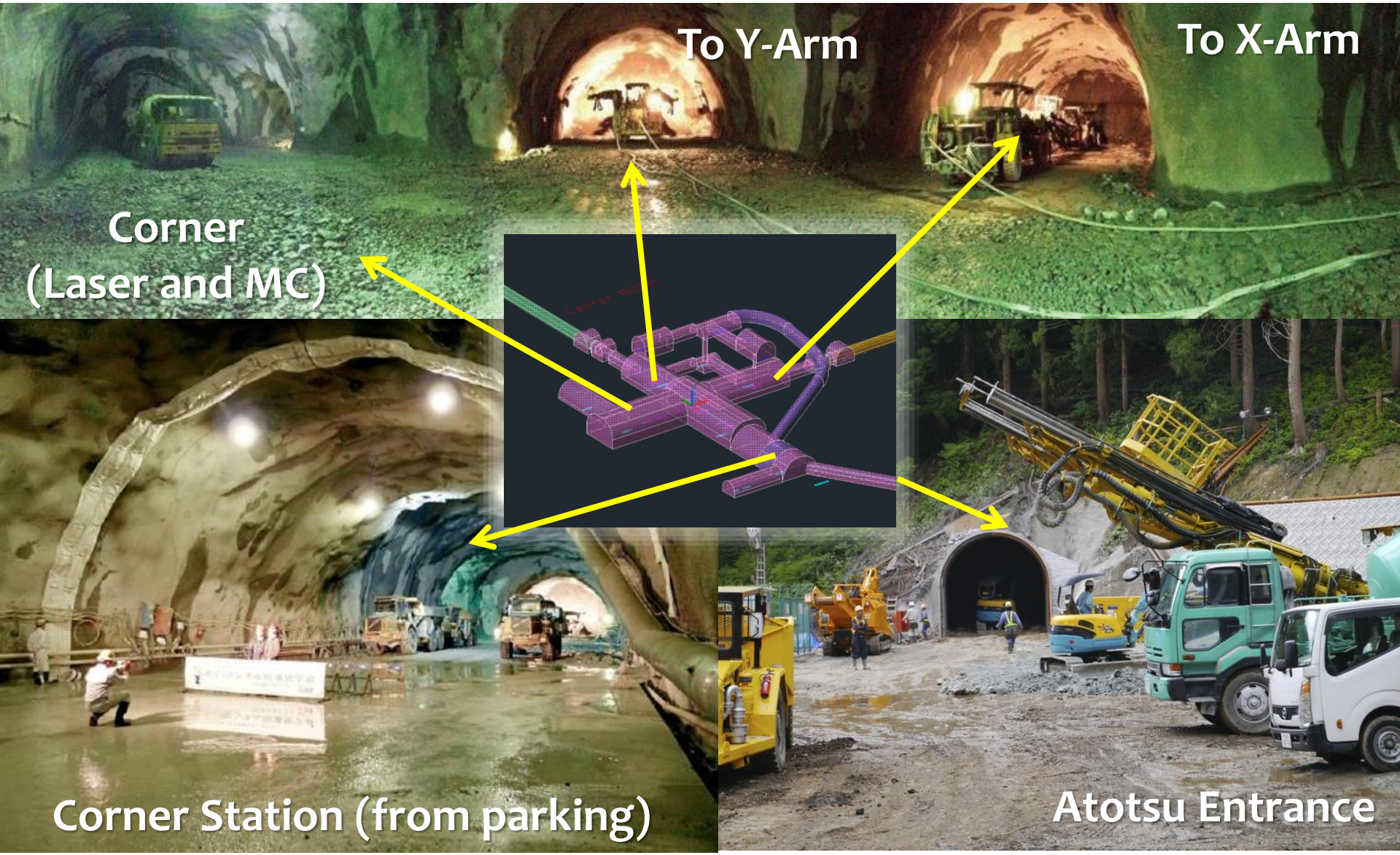
Blasting for 22 months from May 2012

Tunnel Excavation around 2013 August



Tunnel Group

Tunnel Excavation



Heavy metal and pH of spring water during Excavation

- ***Serious "Cost" problem about heavy metal in rocks.***
  - *Rocks always contain heavy metals such as As, Zn, Pb, Cd, B, F, Ce, Cr, especially in KAGRA site that used to be "Zn mine".*
  - *We cannot bury them directly in some places if their content exceeds the allowed level.*
  - *Of course their removal cost is high !*
  - *The contain level was sometimes a very little bit high in KAGRA.*

- ppm level: As, Zn, Pb
- ppb level: Hg

- ***Another serious cost problem about alkalinity drain water.***
  - *Concrete contains CaCo3, that alkalizes spring water, not only during construction but for a long time after construction.*
  - *We cannot drain it directly in rivers and so on if its pH exceeds the allowed level.*
  - *You should have to pay somewhat for neutralization by using H_2CO_3 .*

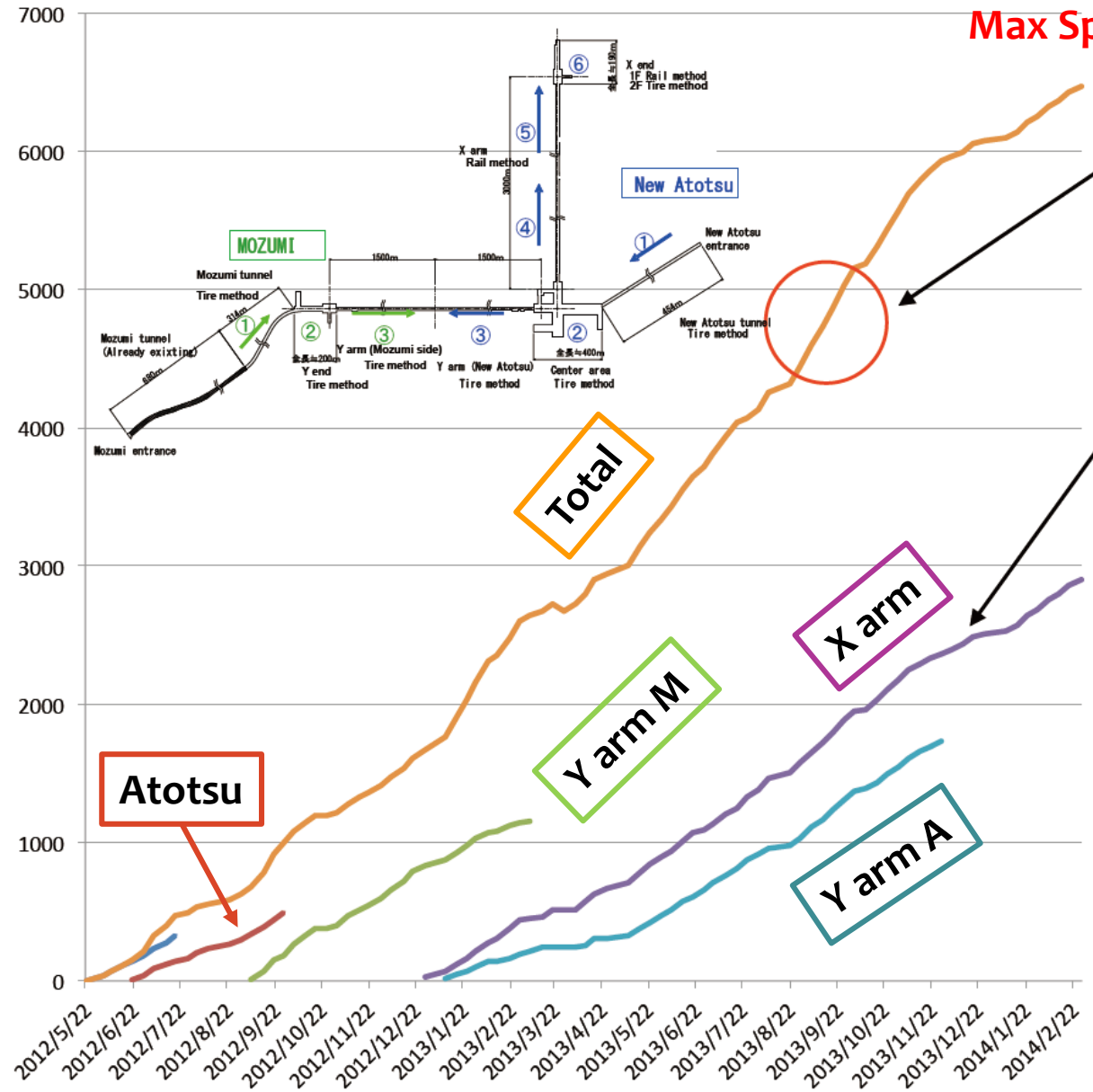
Tunnel Completed in March 2014

Total
7,770m excavation
145,000 m³
(x 1.7 times for actual volume)


Atotsu parking and SR-BS area


Atotsu Entrance

Tunnel Excavation Speed



Max Speed in Japanese Tunnel History

2013/9/1-30
Xarm: 359.4m
Yarm(down slope): 301.2m
Total: 660.6m

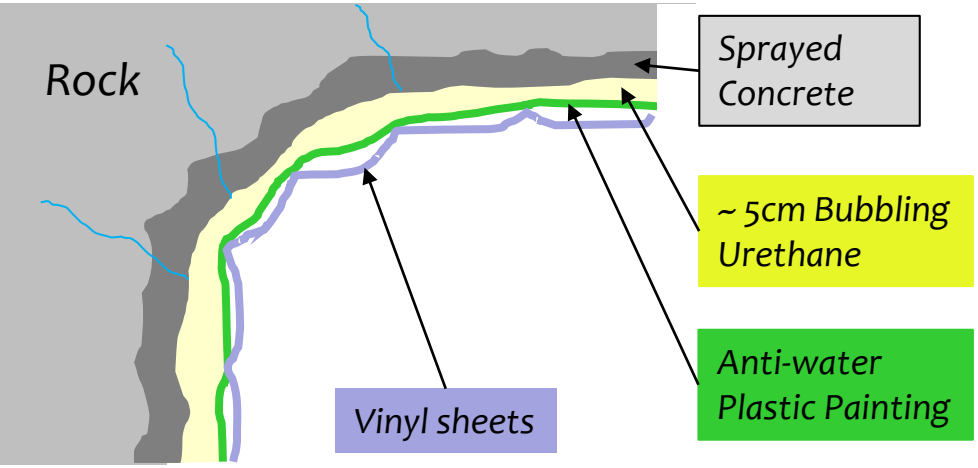
Xarm
3000m/14month=210m/month

The KAJIMA's precise blasting technique to make 4m length advancement enabled so short completion of KAGRA tunnel. This became a sample for JR's linear shinkansen tunnel.

KAJIMA CORPORATION

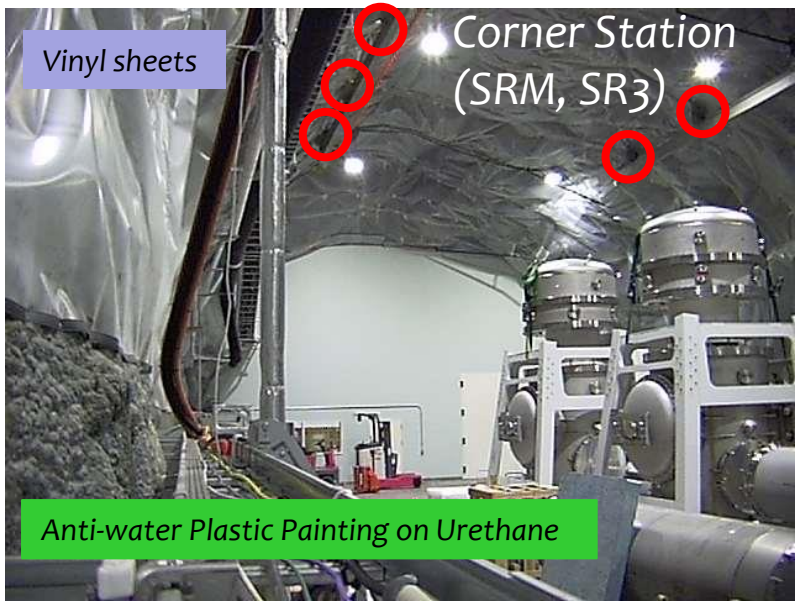
Spring Water Treatment from Walls

(1) Corner and End Stations



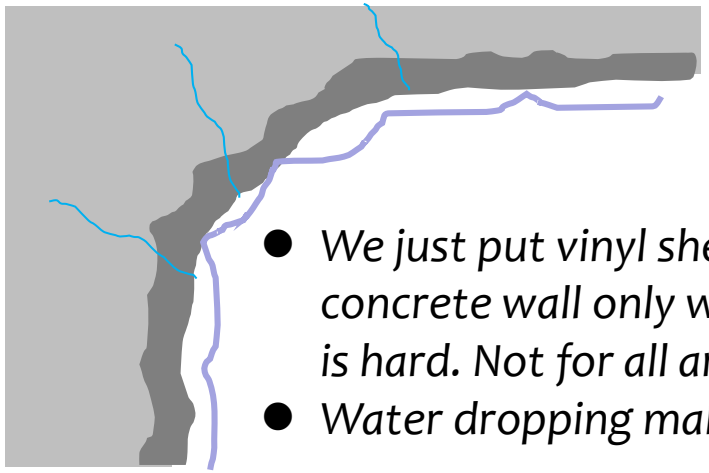
- *The water shielding method using Anti-water plastic layer on the urethane on the wall rock was selected.*
- *However, it didn't work very well. We got many water leak.*
- *We put vinyl sheets on the plastic painting.*
- *However, we could not stop water leak from anchor parts of crane and so on.*

Well designed sheet covering or shaped concrete (like a road tunnel) walls that have water shielding function should be introduced. However it costs higher.

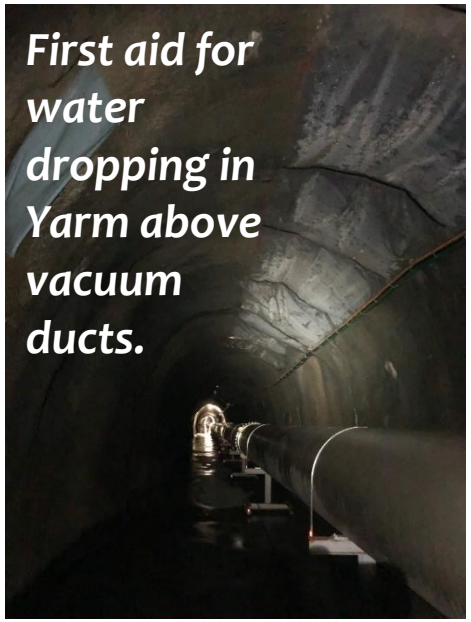


Spring Water Treatment from Walls

(2) Arm Tunnel Area

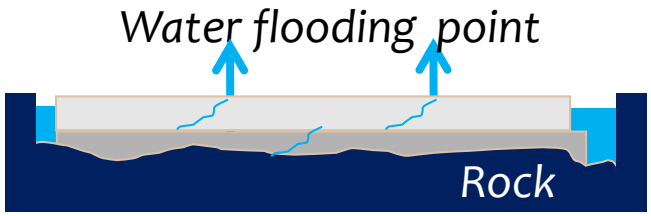


- *We just put vinyl sheets on the concrete wall only where water leak is hard. Not for all area.*
- *Water dropping make noise, maybe.*

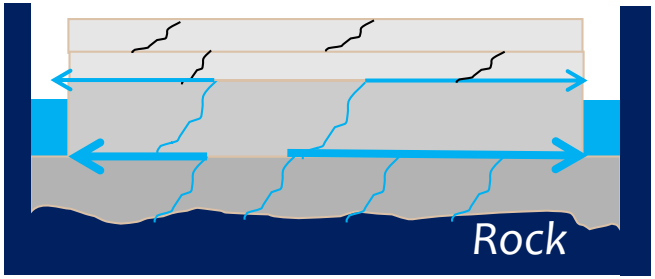


Floor Spring Water Treatment : in Stations

- *We completely missed to estimate the amount of spring water in the tunnel.*
- *Enough layers of concrete floor is necessary to reject water flooding from the floor because the concrete floor inevitably will have cracks.*
- *Deeper ditches are also desired to keep the water level lower than the bottom of the surface concrete.*

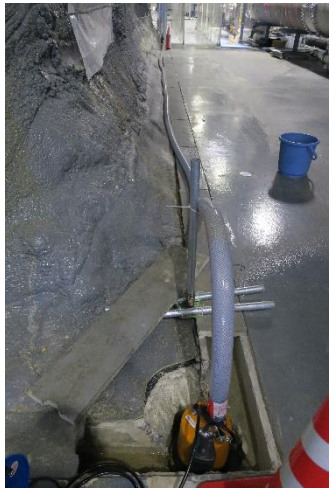


KAGRA Floor Design



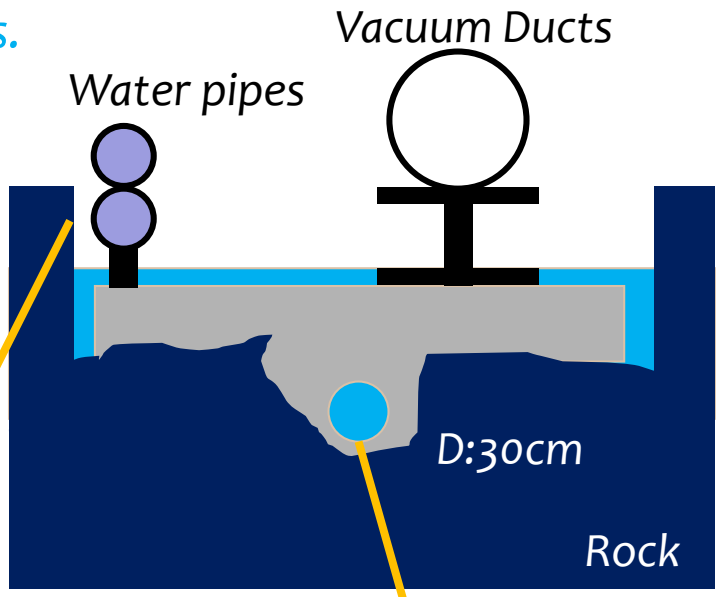
Ideal Floor Design

- *We made several deeper holes to collect waters, and put small water pumps to transfer out side the stations. So, moving pumps might be noise in the future.*

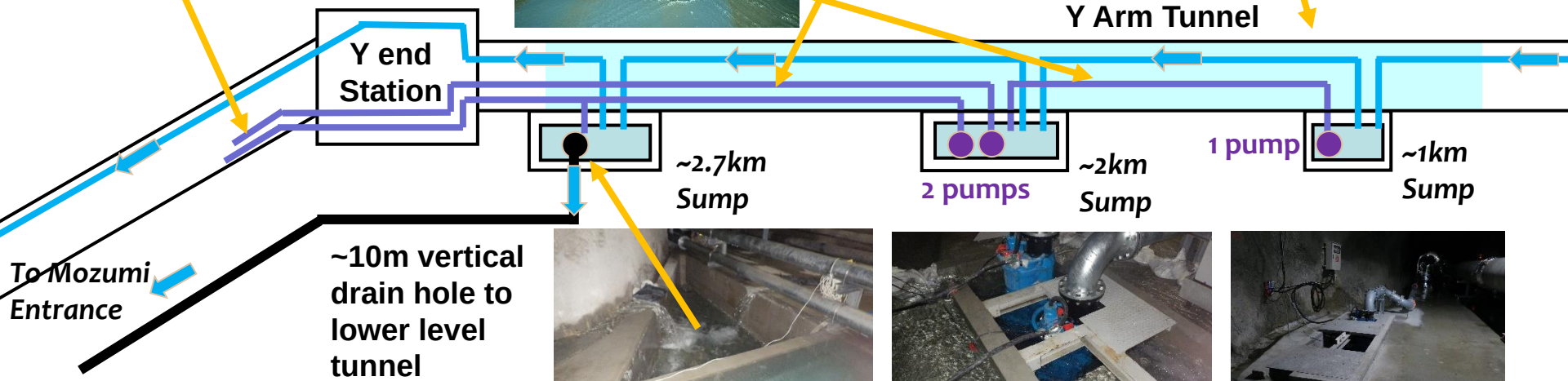


Arm Tunnel Spring Water Treatment

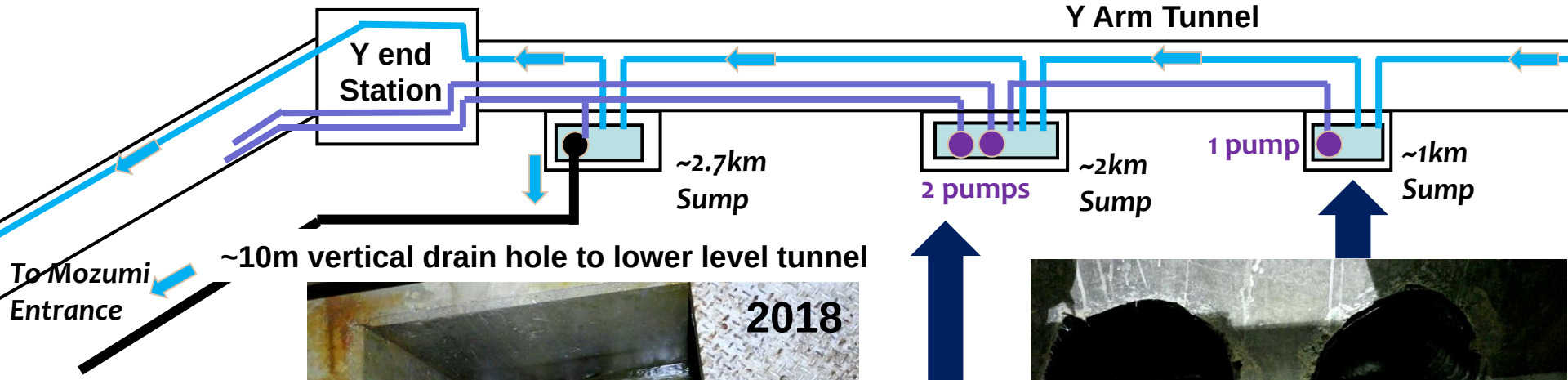
- *Water in the Yarm is a lot because of known faults.*
- *From the end of March to the end of May, the Y-arm central part (1km ~ 2.7km area from the corner station) was covered with water.*
- *To avoid flooding, KAGRA has the drain relays using water pipes (d 150mm), sumps, pumps and vertical drain hole in the only Y arm.*



Y-arm tunnel (firstly excavated)



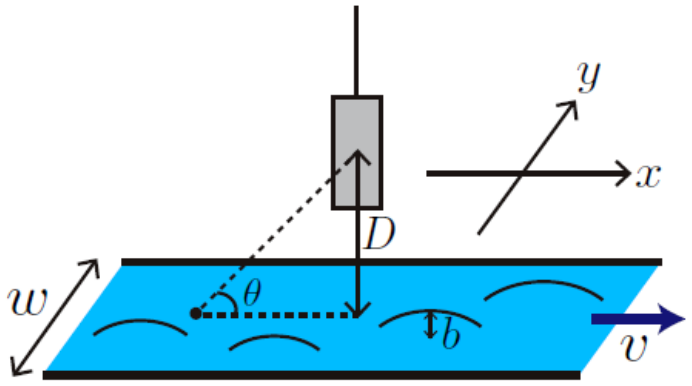
Improved Y-arm Water Transfer

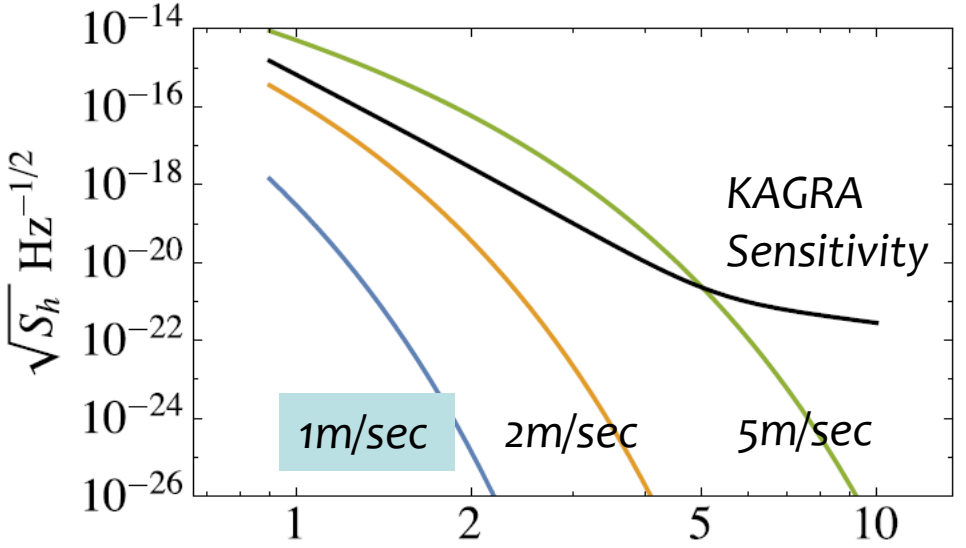


Although The amount of water was huge just after excavation in 2014, 2015, it has tendency to be constant except for the effect of snow.

Newtonian Noise from Flowing Water

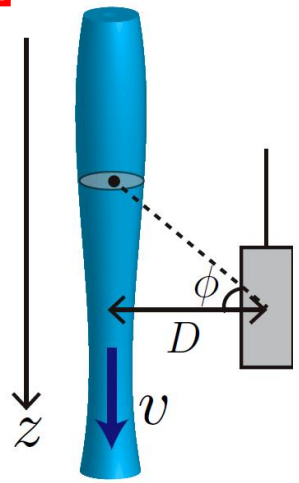
$D = 2\,\mathrm{m}$, $w = 0.4\,\mathrm{m}$, $\rho = 1\,\mathrm{g/cm^3}$, $L = 3\,\mathrm{km}$, and $\delta v_\ell = 0.2\,\mathrm{m/s}$.

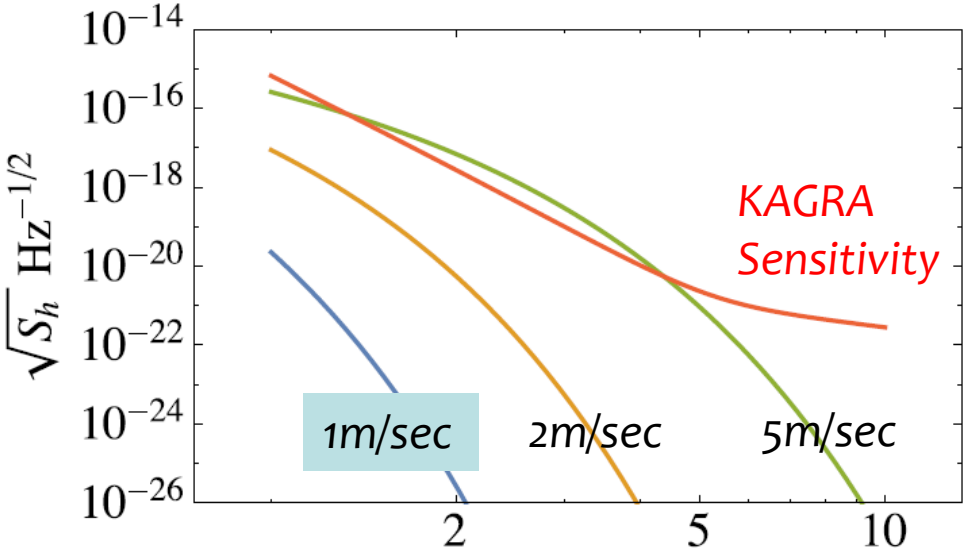




D > 5 m is actual, so less influence expected.

$D = 2\,\mathrm{m}$, $\rho = 1\,\mathrm{g/cm^3}$, $L = 3\,\mathrm{km}$,

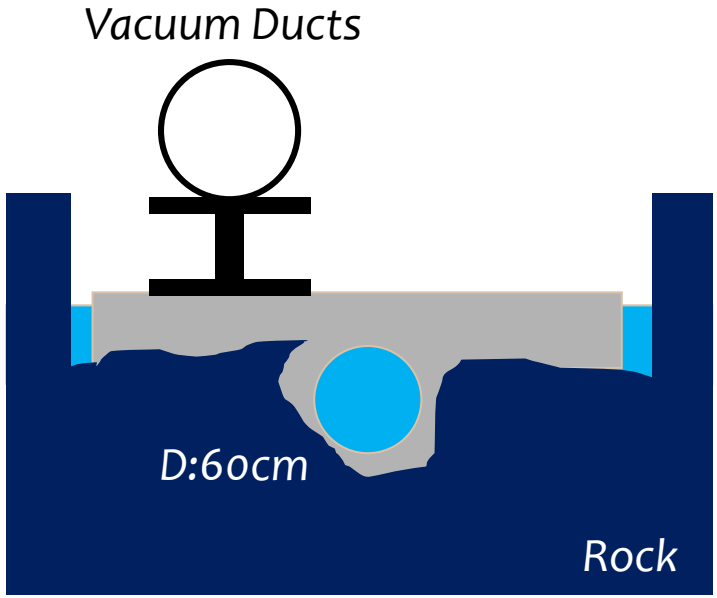




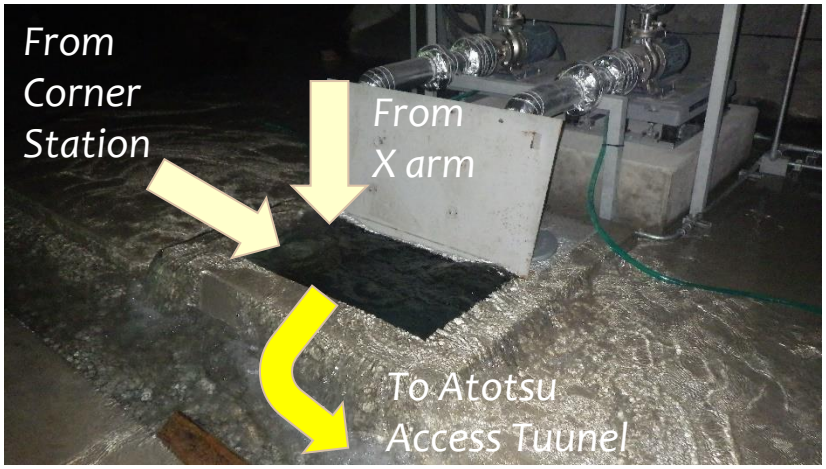
Arm Tunnel Spring Water Treatment

- *In X arm, we put a larger drain pipe under the floor, then we could avoid flooding.*
- *The water from this X arm is transferred to the drain pipe in the Atotsu access tunnel.*
- *Because the drain pipe is insufficient below floors in the access tunnel, there is flooding in the access tunnel.*

It is important to design how to drain water systematically.

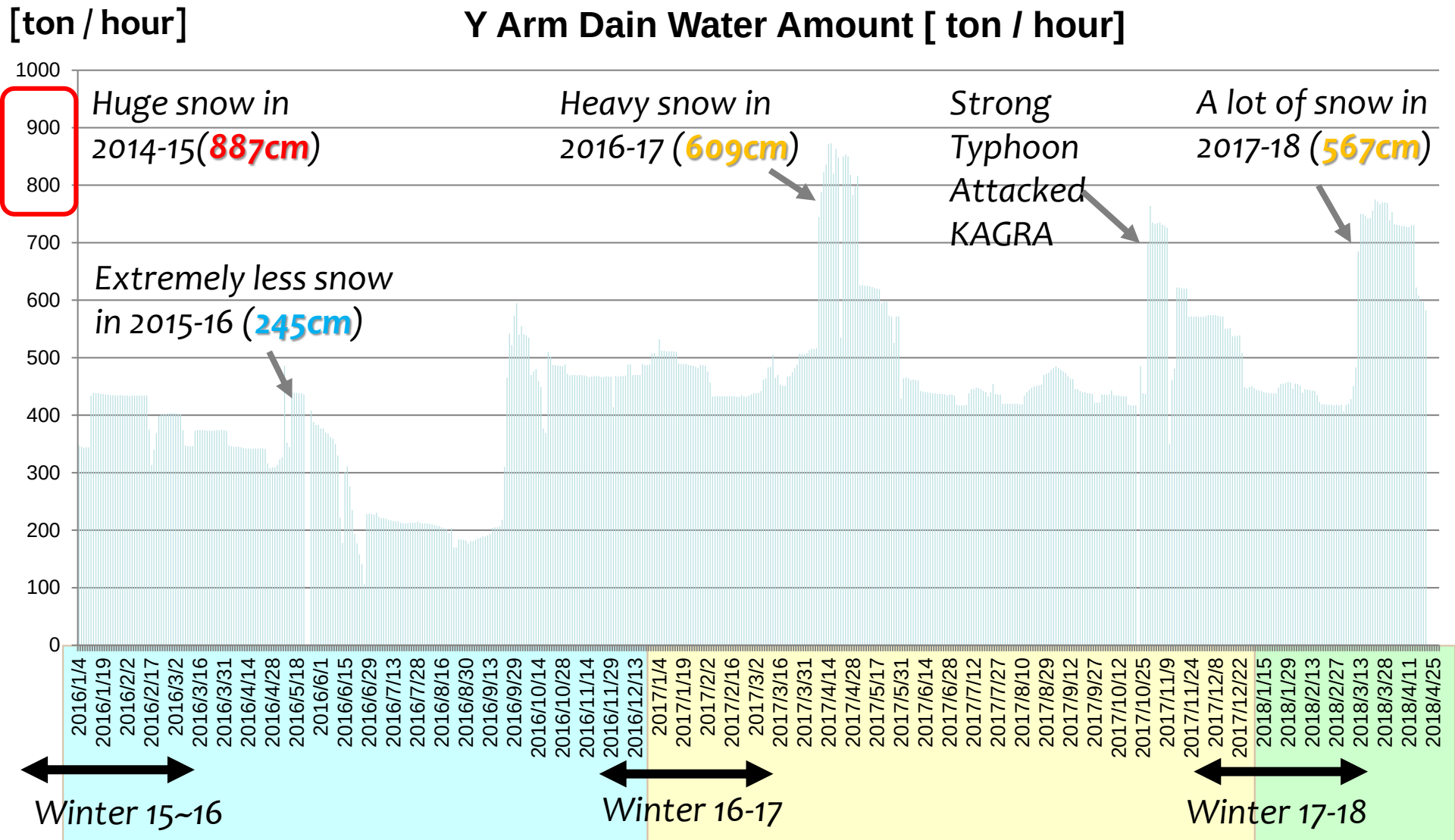


X-arm tunnel (Secondly excavated)



Spring Water Amount Depends on SNOW

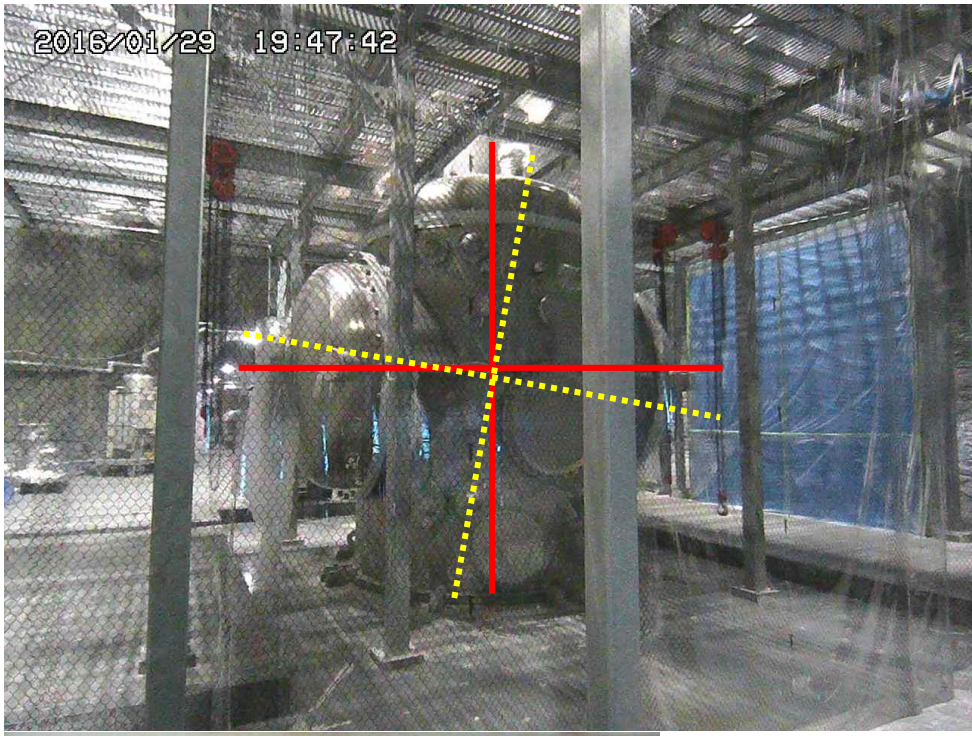
- *Just after finishing excavation, the Y arm water became up to 1250 [ton/hour] (Total 2050 [ton/hour])*

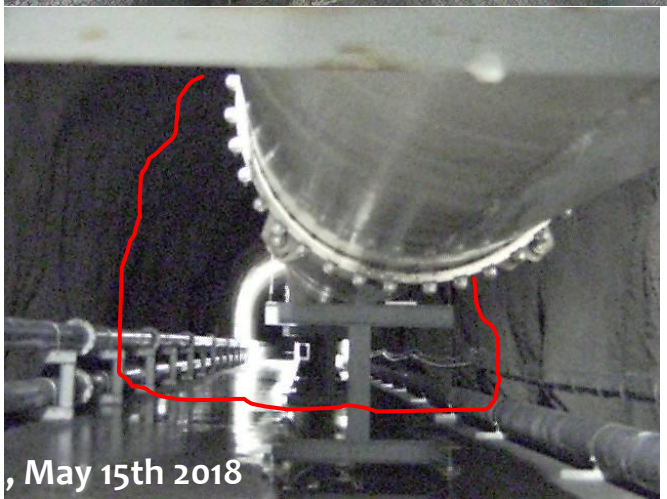


Ground Slow Motion

- *The tunnel was made by the NATM method. So the rock is expected to have small cracks on its surface. Because of it, uneven settlement occurred for each cryostat (12 ton)? We are now monitoring the cryostat position (2016) . -> In 2018, it seems to show no change.*

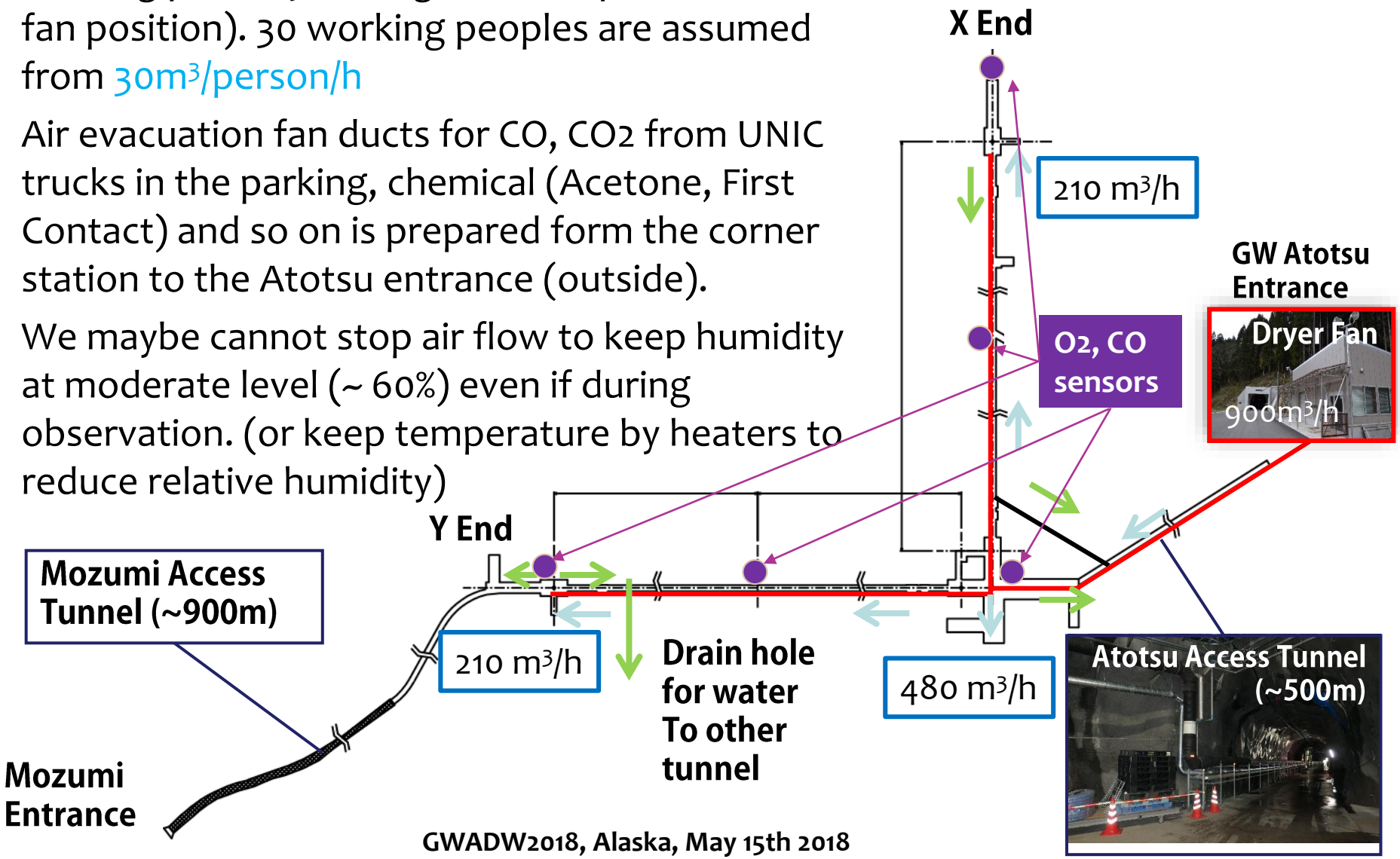
- *The known dislocation where the KAGRA tunnel crosses is now monitored. Even if the tunnel surface was covered with 5cm concrete, we found several cracks there (2016). -> In 2018, it also seems to stop.*





Air (O2, CO2, CO) and Sensors

- 900m³/h for all stations (guaranteed at the blowing point by setting the 5kPa pressure at the fan position). 30 working peoples are assumed from 30m³/person/h
- Air evacuation fan ducts for CO, CO2 from UNIC trucks in the parking, chemical (Acetone, First Contact) and so on is prepared form the corner station to the Atotsu entrance (outside).
- We maybe cannot stop air flow to keep humidity at moderate level (~ 60%) even if during observation. (or keep temperature by heaters to reduce relative humidity)



Vehicles free from CO

Bw. Building and KAGRA Parking

In Arms and Access Tunnel

Electrical Assist Bicycle in Arms

Rn Gas

- *As you, especially European people, know, high Rn gas level expected from stone and underground.*
- *Super KAMIOKANDE group prepared for anti-Rn gas sheets on all the surfaces of rock walls mainly for reducing background, and introduce a lot fresh air from outside.*

- *According to one report in Europe, every 100 Bq/m^3 enhances the lung cancer rate by 16%.*

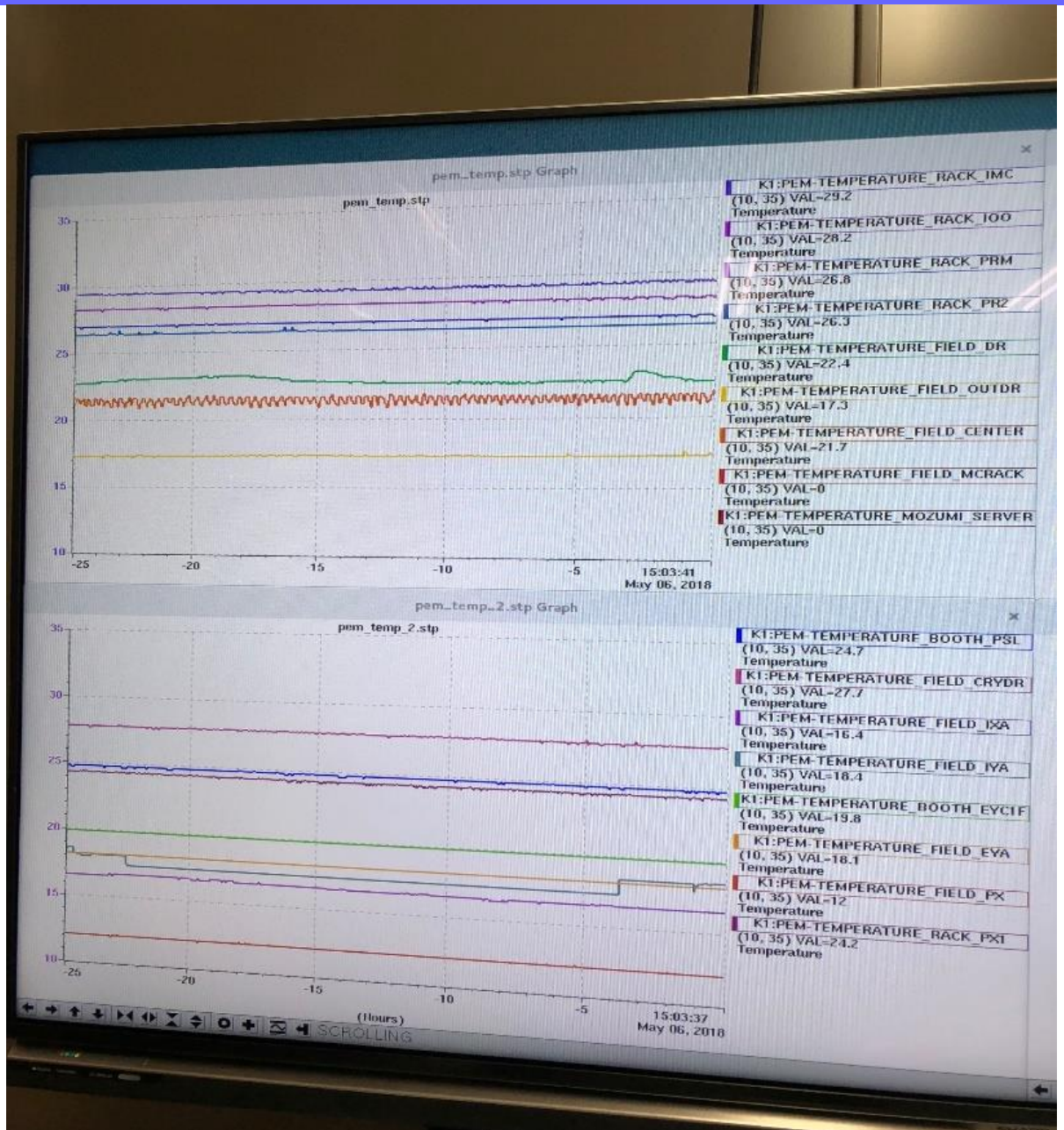
- *The present air injection is not enough to reduce in KAGRA.*

Temperature and Humidity Control

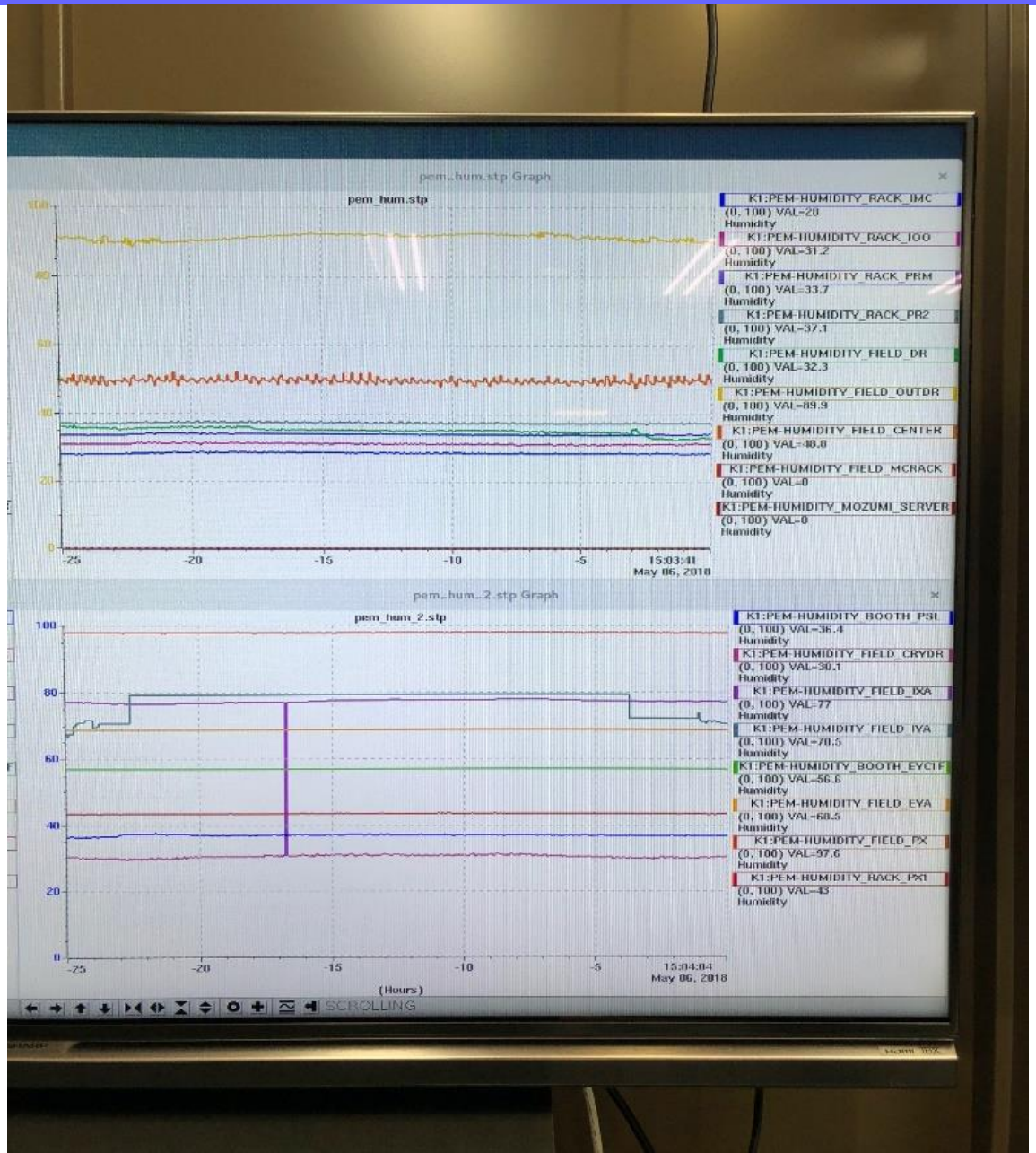
	Temperature			Humidity		
	Corner	X End	Y End,	Corner	X End,	Y end,
Natural	~ 17 C	~ 18 C	~ 14 C	>90%	~ 90%	>90%
Operation FFUs 180W, KOACHs 200W, DGS Racks ~500 W **Without no coolers**	~ 28 C ! (~200, 24, ??)	~ 28 C ! (14, 12)	~ 25 C (14, 12)	~ 65%	60~70%	70~80%
With Air Coolers air cooler with On/OFF control (using water cooling)	IXA : 16.6 IYA : 17.4 Center : 21.4 Pre-R : 17.3 SR : 23~22.5 (20kWx3 air coolers) Stability : ~0.1C	EXC : ~ 25 (5kWx1 air coolers)	EYA : 18.1 EYC 1F : 19.9	IXA : 78 IYA : 80~65? Center : 48~52 Pre-R : 88~93 SR : 34~37 (20kWx3 air coolers)	EXC : ~ ?	EYA: 68 EYC1F: 57

- Temperature change does affect the GAS filters conditions.
- Humidity control is also important to keep instruments healthy.
- We should set the target temperature as the observation mode where the minimum instruments(heat supplier) are working. Maybe “silent” heaters should be prepared to keep temperature and relative humidity.

Temperature Variation and Stability

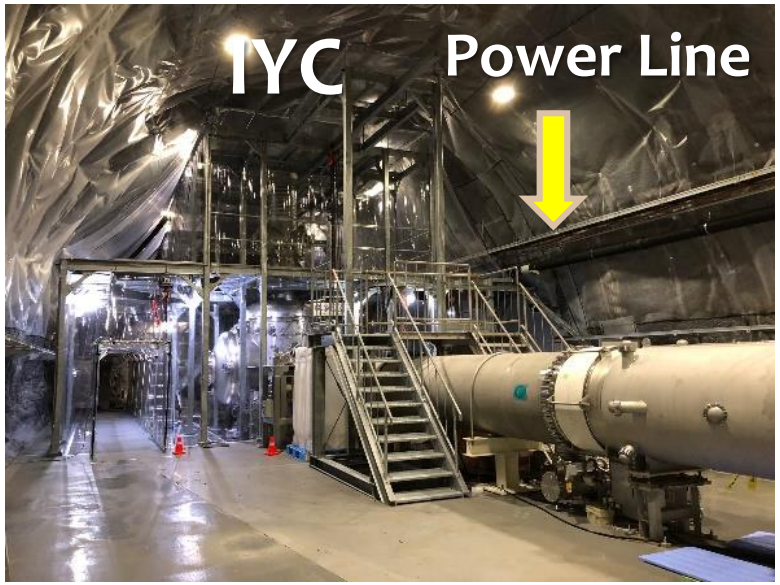


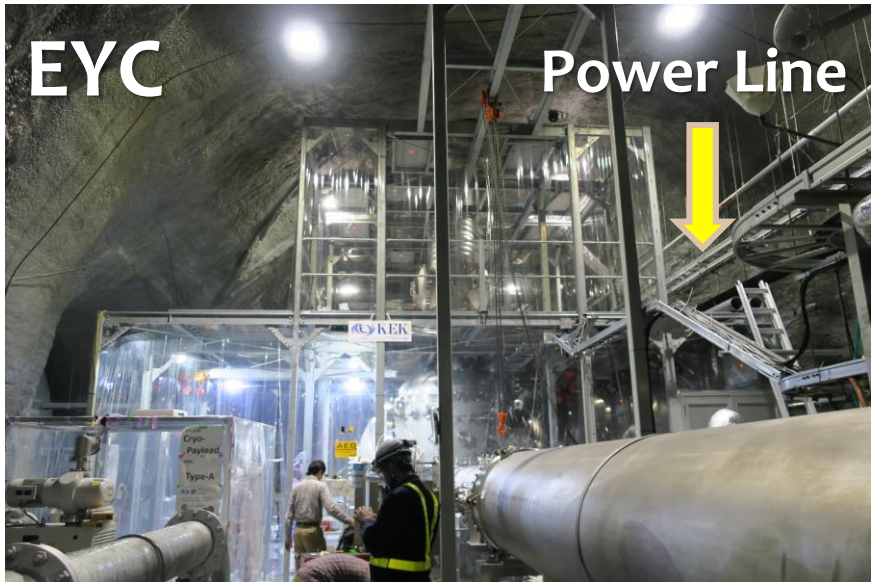
Temperature Variation and Stability



Electrical Equipment Issues

- ***Anxiety and Uncertainties***
  - *We make AC100V, 200V, ~400V from 6600V.*
  - *6600V lines go through each stations (~ 10m height) and tunnels (~ 4m) near instruments -> we don't know how much it affects as line noises ??*
  - *No place to take ground in the "Rock" tunnel. We have just ground line for power line (not for measurement). -> Water maybe cannot be ground. Vacuum ducts ?*





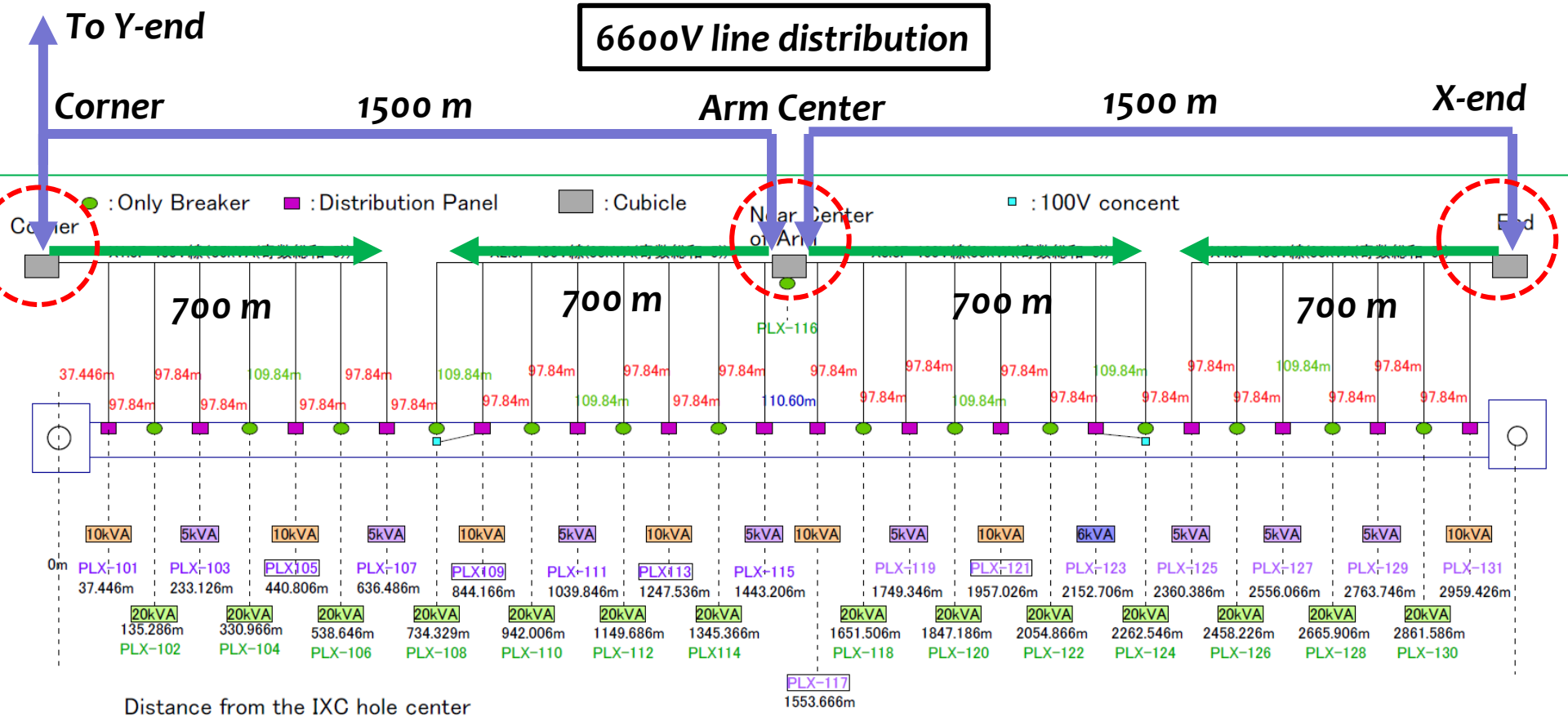
Electrical Equipment Issues

- ***Anxiety and Uncertainties***
  - *We don't know How much humidity can be kept during observation if we minimize the operation of instruments including FFUs that generate heat and reduce "relative humidity" in each station. At least, we knew that if there was no heating up in the corner station due to power outage, "clouds" appeared because 100% humidity.*

  - *We prepared emergency power units and additional power line from Atotsu entrance to keep dry air introduction and water pumps' operation. Recent electrical cars can be used as cheap emergency power units.*

Cost Reduction of Power Line

- *We need AC100V, or AC200V in "long" arms for vacuum pumps, remote monitoring.*
- *You should know that the power line is "copper" that is expensive metal, and that a longer cable requires "fat diameter" to keep target voltage.*
- *Many cubicles that generate ~400V from higher voltage at every 1 ~ 1.5km can reduce cost compared long and fat cables that supply low voltage with less cubicles.*



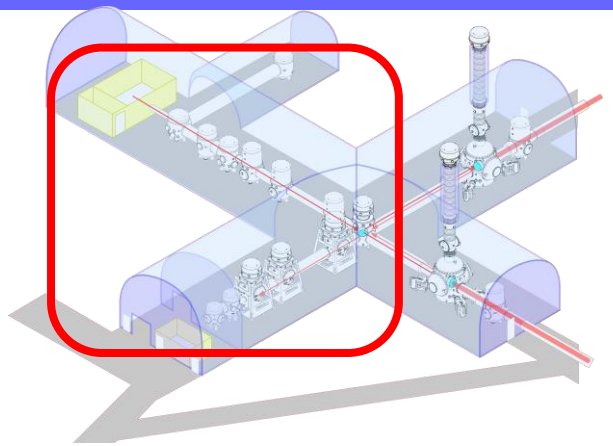
Water for Cryo-coolers and Laser

- *KAGRA requires a lot of industrial level water for cryo-coolers (ex. 12 units in the corner station) and a laser.*
- *Total 400 litters / min (for corner station) are required including air coolers and so on.*
    - *Around the KAGRA site, there is no such quality water public supplier because the site is isolated.*
    - *Even the village including KAGRA and SK buildings is using the spring water that comes from the mountain that housing SK, KAGRA.*

- *KAGRA prepared a precipitation purification equipment inside KAGRA to supply water that satisfies the requirement for cryo-coolers and laser from the spring water.*
- *Although, Ph. Is a little bit high, no Ph. Adjustment .*

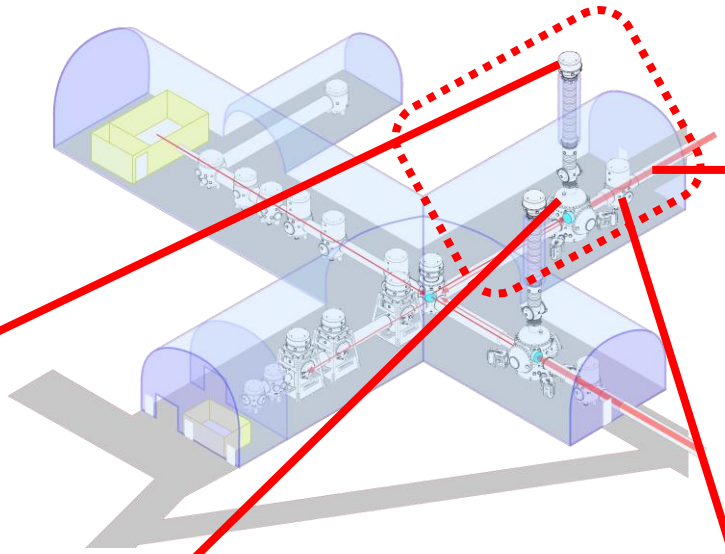
Clean Environment (IOO in Corner)

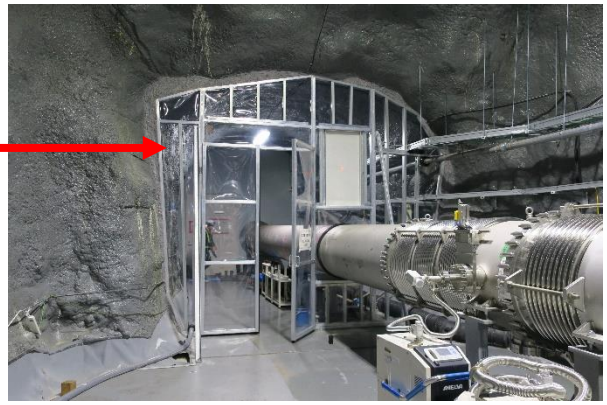
- *Dry air from the fan room (outside the KAGRA tunnel) is not cleanly filtered at all.*
- *All vacuum tanks and laser are housed in clean booths*



Clean Environment (Yarm in Corner)

IYV for SAS Base





Buffer zone to reject dirty air from arm to come into the corner/end station area.

IYC (1F, 2F) Sapphire ITMY and its suspension housing

IXC, EYC, EXC, have same set of tanks and clean booths.

IYA for ITMY surface monitoring

ISO Class definition for Air

KOACH (Ferina) →
ULPA →
HEPA →
Office Room →

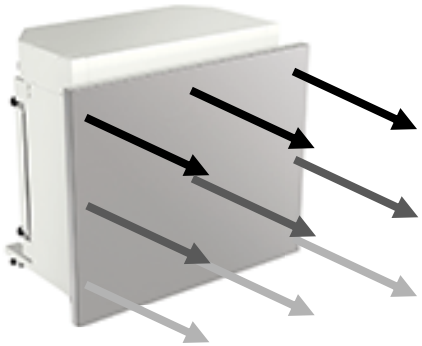
Class	maximum particles/m^3						FED STD 209E equivalent
	≥0.1 μm	≥0.2 μm	≥0.3 μm	≥0.5 μm	≥1 μm	≥5 μm	
ISO 1	10	2.37	1.02	0.35	0.083	0.0029	
ISO 2	100	23.7	10.2	3.5	0.83	0.029	
ISO 3	1,000	237	102	35	8.3	0.29	Class 1
ISO 4	10,000	2,370	1,020	352	83	2.9	Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1.0×10^6	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7	1.0×10^7	2.37×10^6	1,020,000	352,000	83,200	2,930	Class 10,000
ISO 8	1.0×10^8	2.37×10^7	1.02×10^7	3,520,000	832,000	29,300	Class 100,000
ISO 9	1.0×10^9	2.37×10^8	1.02×10^8	35,200,000	8,320,000	293,000	Room air

- *Before, ISO class 1 costs high, requires well designed housing, takes time to be constructed, and is not easy to be replaced.*
- *KOACH (Ferina Filter) drastically solved all these problems.*
- *However, ULPA : - 1,500USD / unit, KOACH: ~30,000 USD/unit (List Price)*

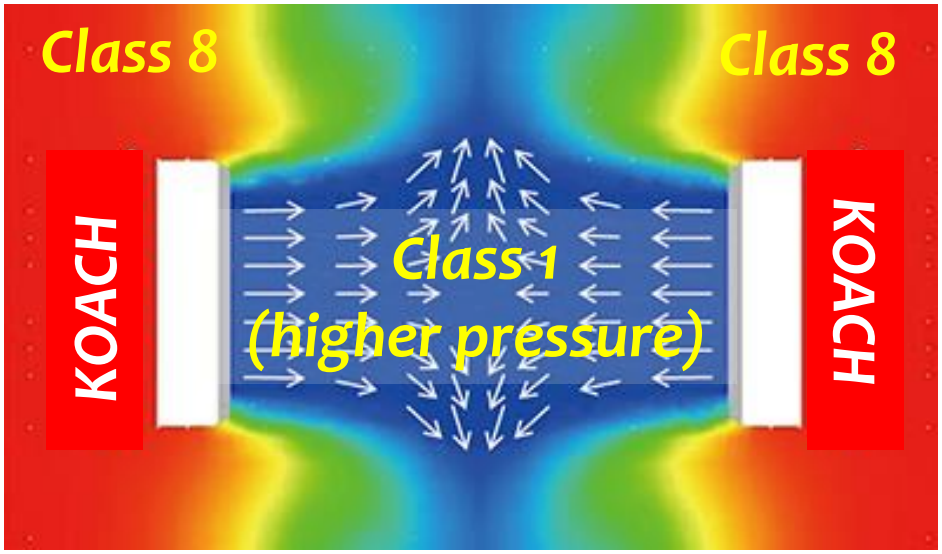
ISO Class 1 area generated by “KOACH”

- *Laser Room for high power laser handling.*
- *(IE)(XY)C 1F area for sapphire mirror handling.*

KOACH (KOKEN inc.)



Not Turbulence but Parallel flow !! (0.3 m /sec)

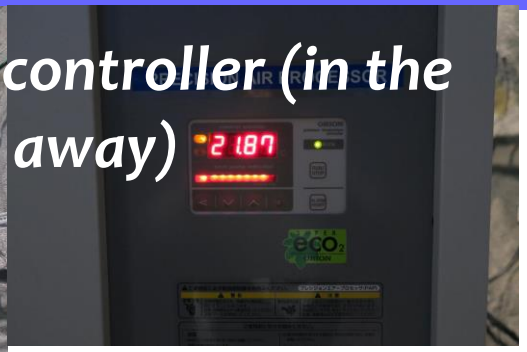


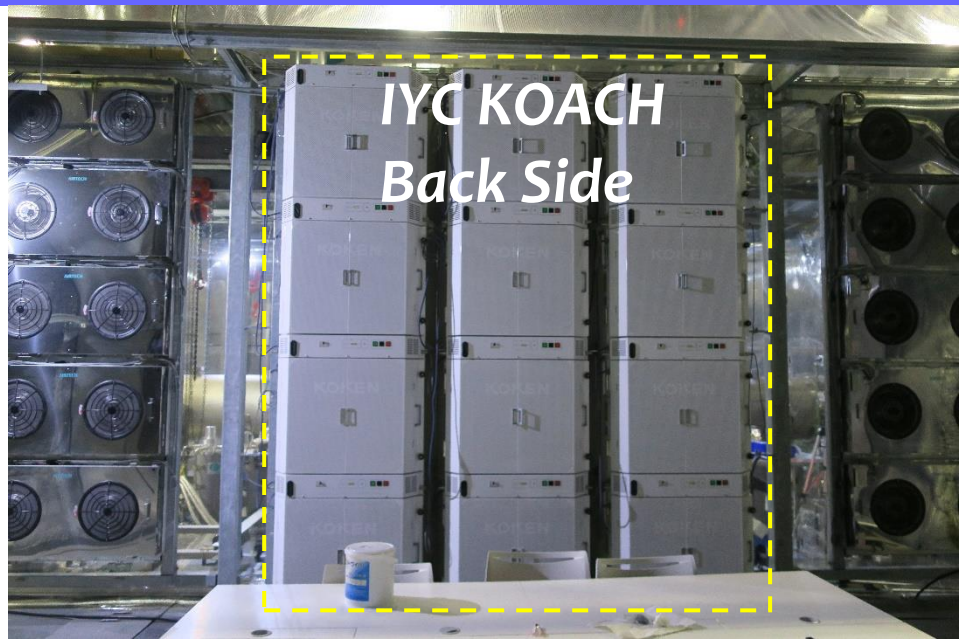
- *Parallel flow enables a boundary between clean area and dirty area, and air pressure offset inside.*
- *Pre-Filter, HEPA Filter and* ***FERINA Filter*** *can generate ISO Class 1 air directly from class 8 -9 dirtiness.*

- *Stacking easily enables ISO class 1 area extension.*

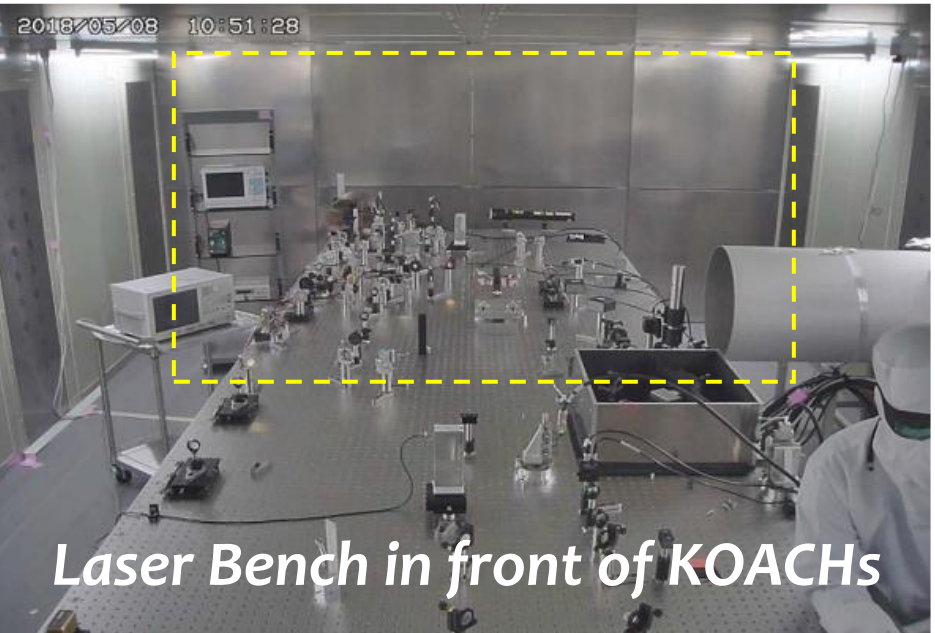
KOACHs in Laser and (IE) (XY) C area

Precise Temp. controller (in the future, moved away)





IYC KOACH
Back Side



Laser Bench in front of KOACHs

IYC KOACH Front Side behind IYC

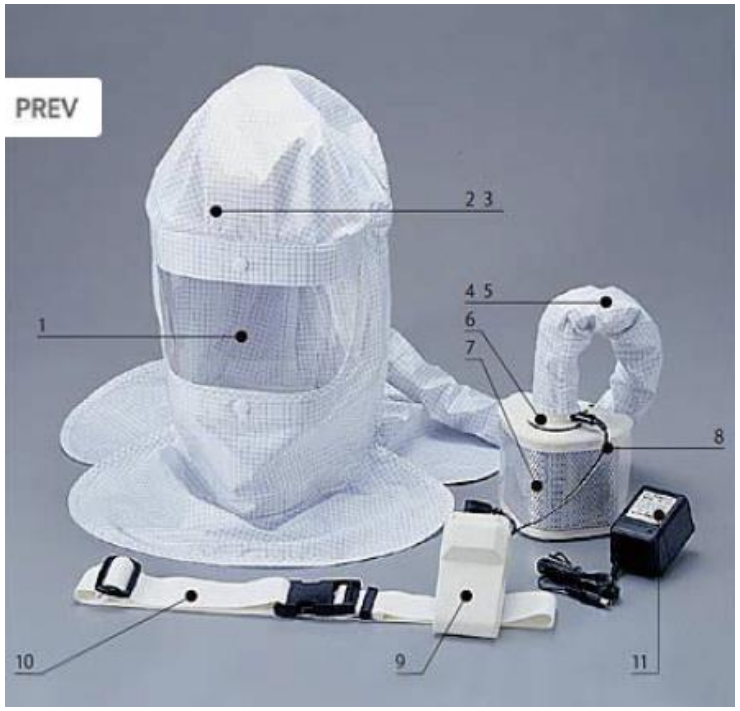
Cloths and Gloves never satisfies Class1

- *On the other hand, there is no class definition for cloths and gloves.*
- *So, actual cleanness is dominated by your under wears, cloths, gloves and activities. (Actually, the clean class for cleaning or preparation for them is 4 at most.)*
- *Air tightness is required for low dust, however enhances temp. and humid. Inside. So, air conditioning is important.*
- *We should always remind to take a position on the leeward of instruments.*

Recommended under wears

Best wearing up to now

Air filter to filter the dusty air inside the suit



Safety and Monitoring

LIFE Threatening Events

- Fire -> Static smoke sensor monitoring
  In any cases, obey the escaping rule including shelter at X-end that has no escaping road except for the X arm tunnel.
- Low O2 (<19%), high CO (>50ppm) -> Static and mobile sensor monitoring
  Rechecking rule using no warning sensor,
  if true, obey the escaping rule with masks.
- Organic solvent -> obey national laws for usage and disposal with draft chambers.

Monitoring

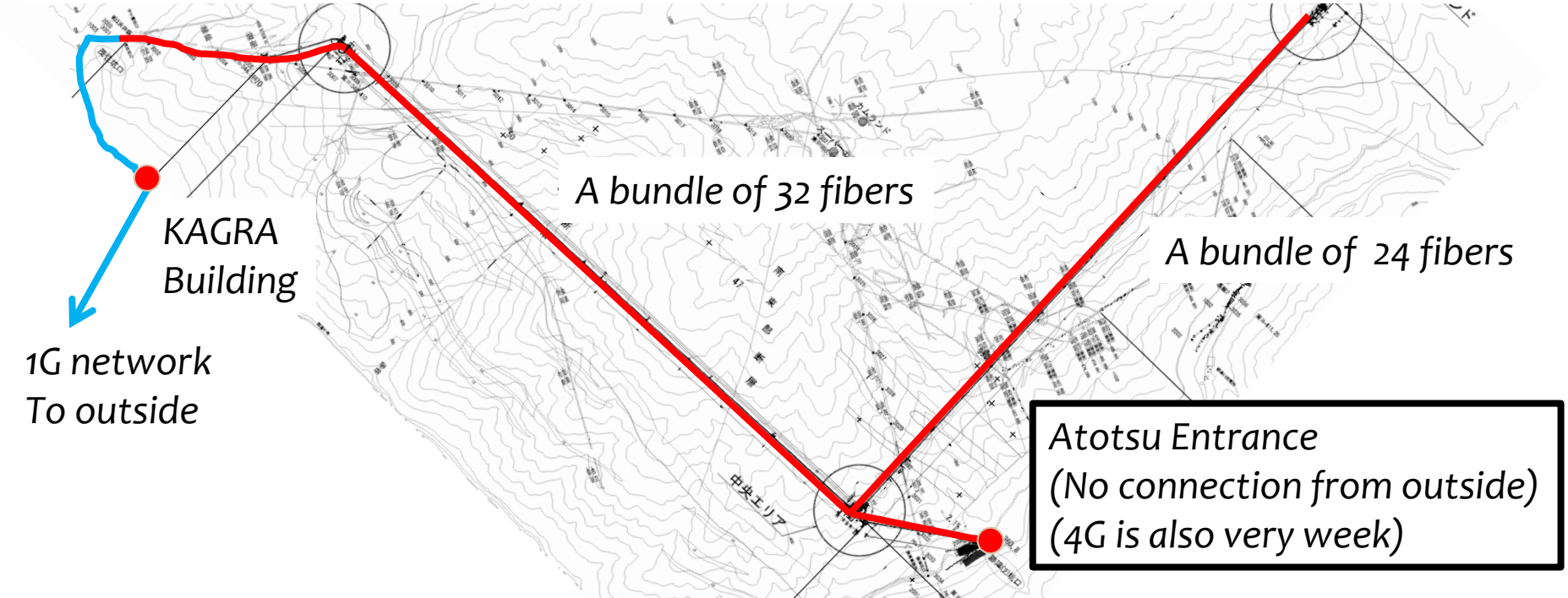
- Many web cameras
- Smoke
- Unusual heat in the laser room
- O2, CO level
- Water supplier operation (pumps, water level)
- Air fan operation (fan activation, humidity controller)
- High/Low voltage electrical condition (leakage, trip)

All event warning are sent via e-mail and
We correspond according to contact network.

Safety and Monitoring

Safety and Monitoring strongly depends on the only one optical fiber from the KAGRA Building to the corner station through Mozumi and Y-arm tunnel (total ~ 5km).

- *For redundancy, we should prepare another fire protected optical fiber in the same route or another connection points for internet such as Atotsu entrance.*
- *In the case of X arm, we have prepared a metal wire line in the water ditches for emergency communication.*



Acknowledgement

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KAKENHI

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THE UNIVERSITY OF TOKYO

ICRR
Institute for Cosmic Ray Research
University of Tokyo

LIGO

VIRGO

EGO EUROPEAN GRAVITATIONAL OBSERVATORY

NRF National Research Foundation of Korea

KiSTi www.kisti.re.kr Korea Institute of Science and Technology Information