Infrastructures especially Underground : the KAGRA experience

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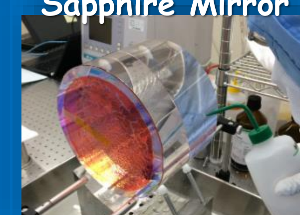
Institute for Cosmic Ray Research and KAGRA Collaboration

The 1st KAGRA-Virgo-3G Detectors Workshop, Perugia, Italy 2019

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

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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

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** - **Air** - **Electricity**
  - **Cleanroom** - **Radioactive Radon**
- **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,

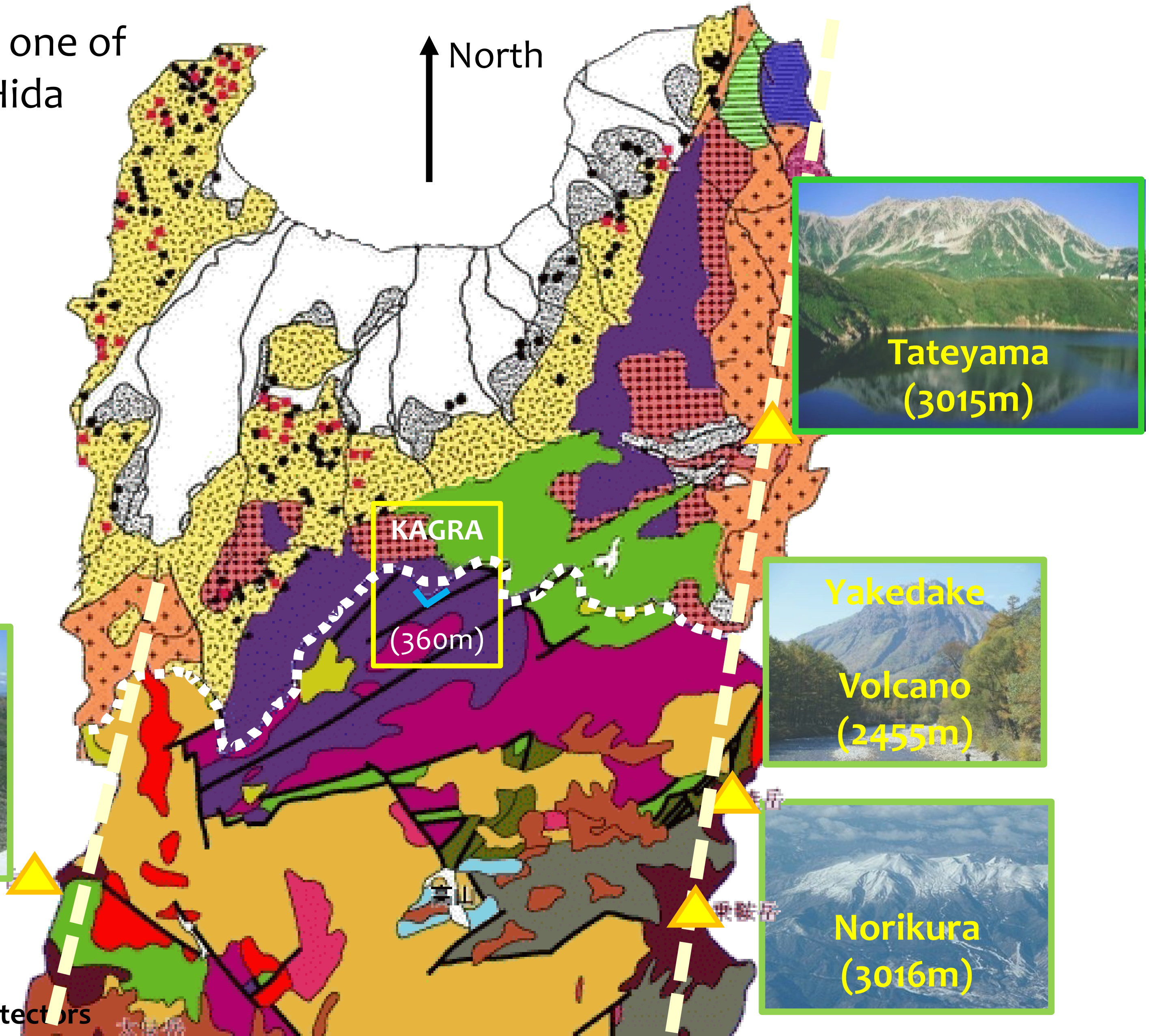
- **We found the "water" in the mountain is annoying source in many practical aspects.**
- **"Newtonian Noise" due to water flow near mirrors should be investigated. Some estimation was proposed.**
- **The word of "underground" might be better to be replaced with "on/in a hard rock bulk".**

KAGRA in "HIDA" Gneiss

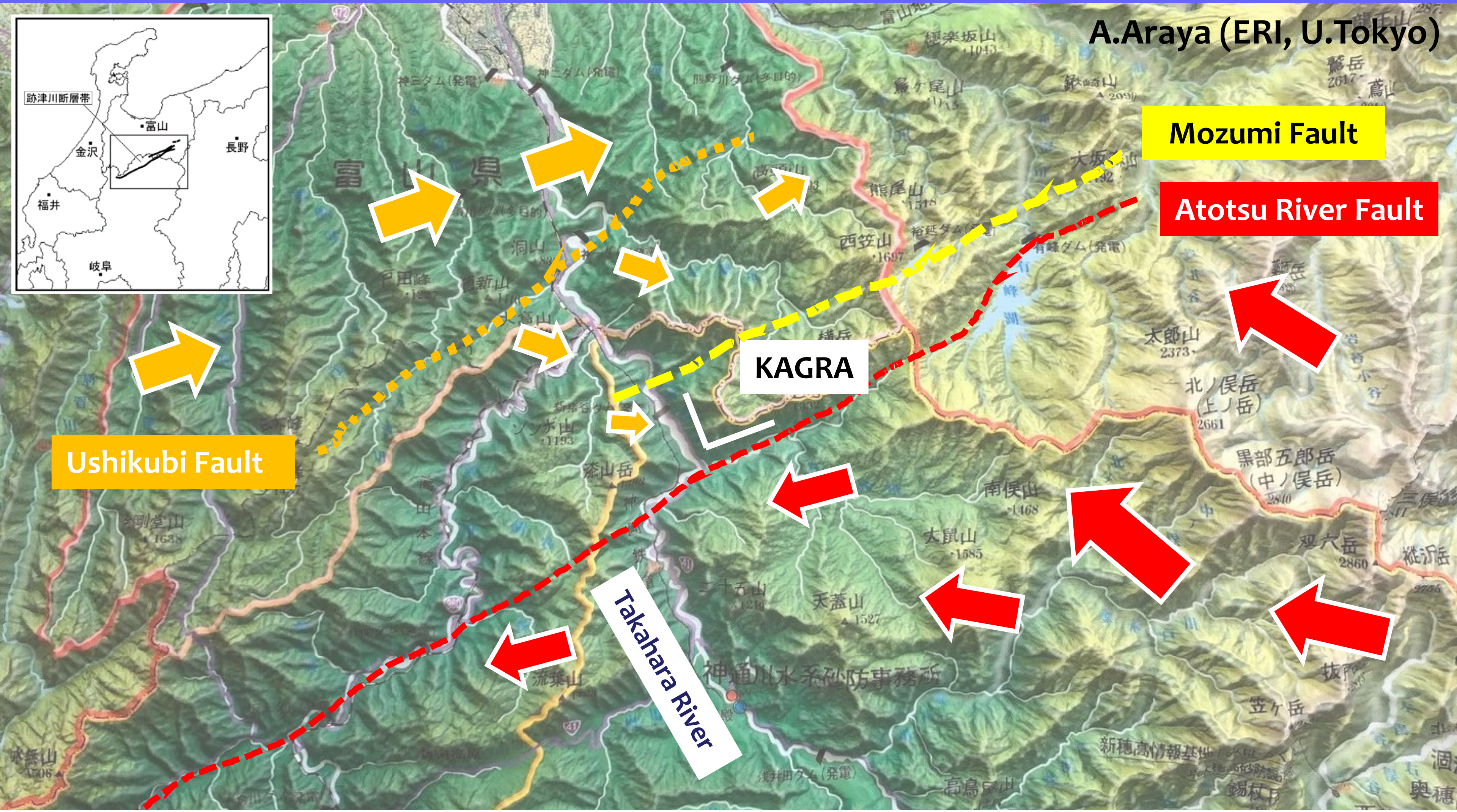
KAGRA is situated in one of the oldest rock of "Hida Gneiss" in Japan.

Hida Gneiss
(~2G years old)

Granite
(~0.2 Gyears old)



KAGRA between Two Faults



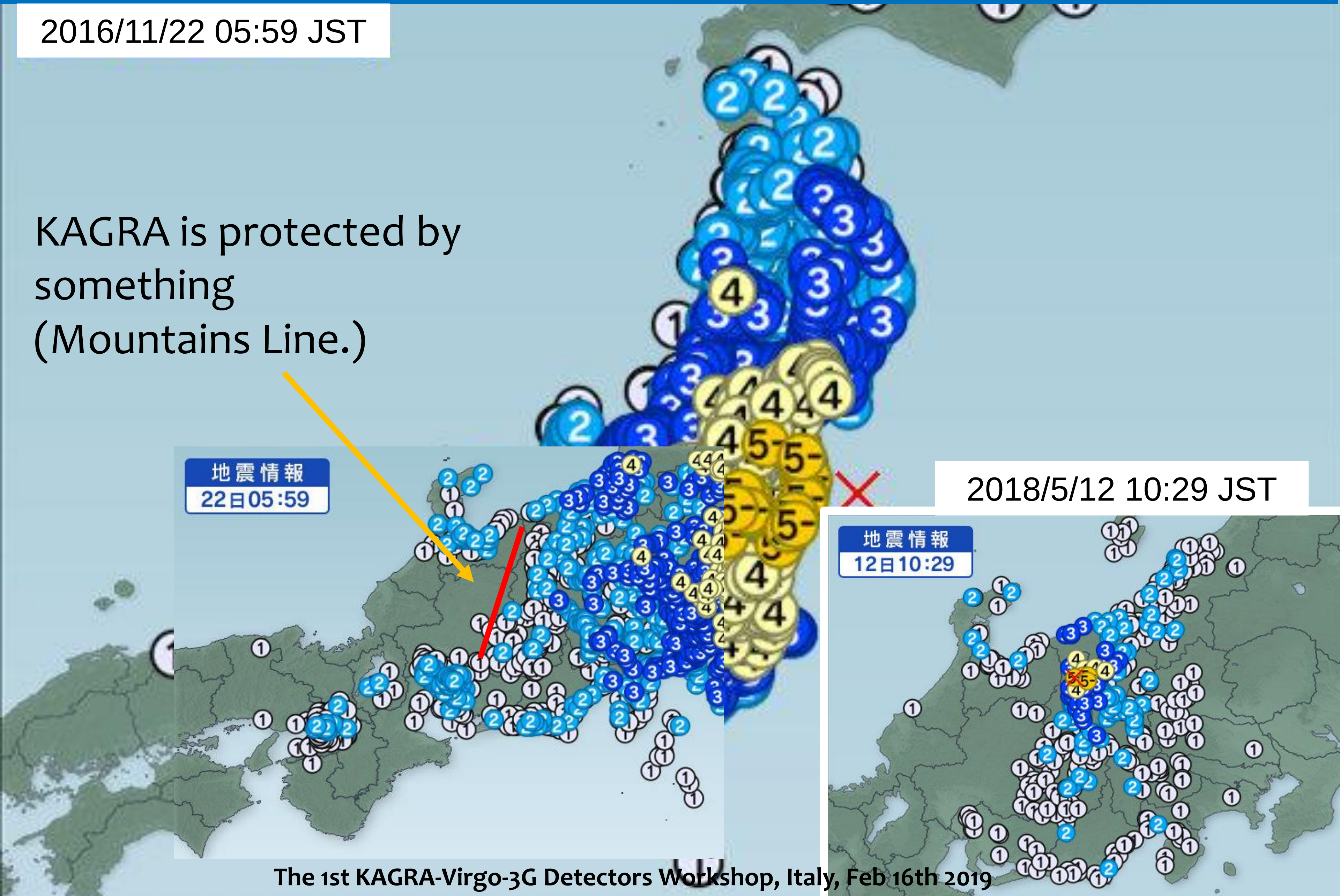
- 1 mm /year slip or creep for 3 million years.
- It made crank shape of “Takahara” river near KAGRA.

In Lucky Position Protected by Mountains

2016/11/22 05:59 JST

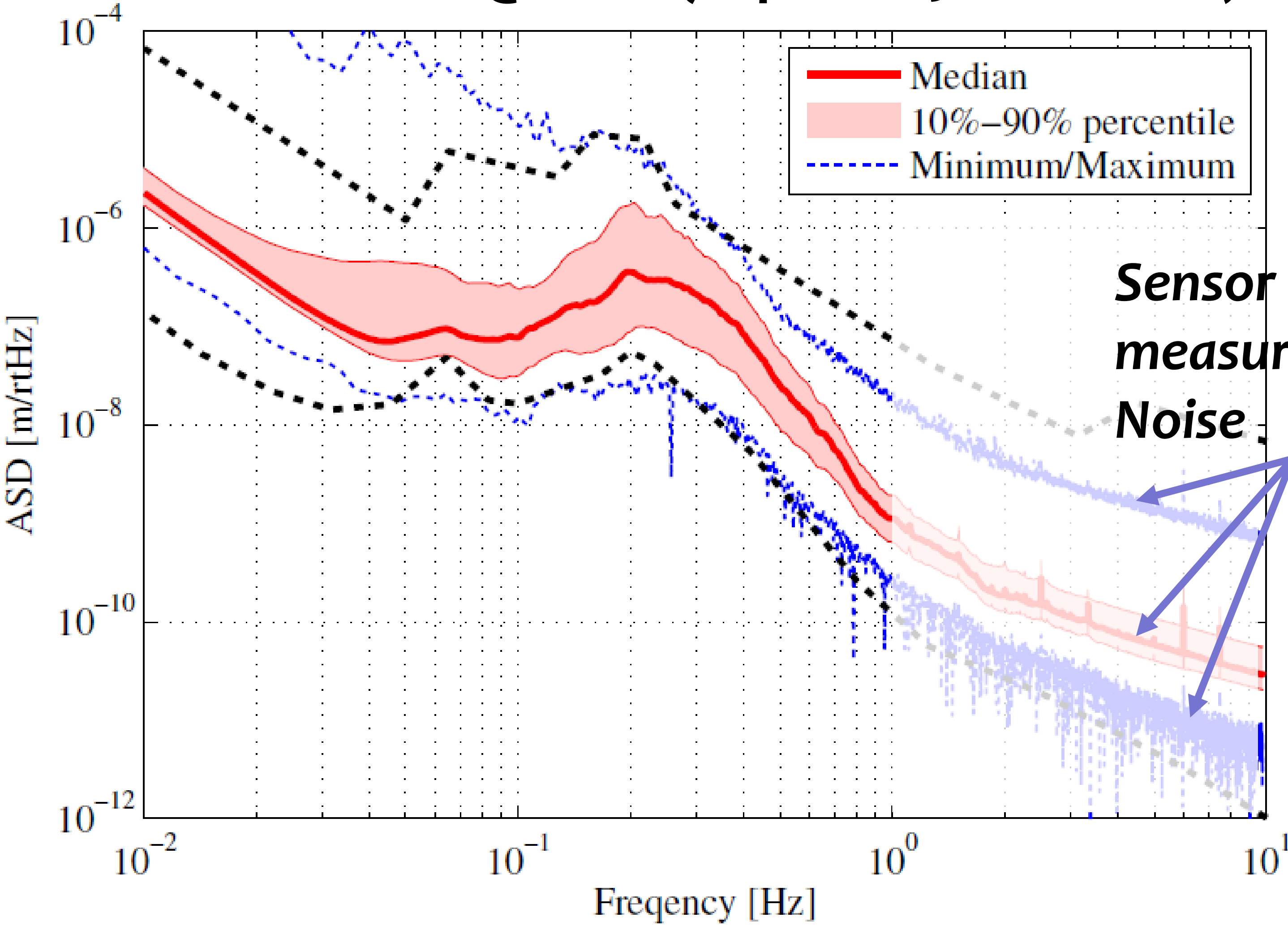
KAGRA is protected by something (Mountains Line.)

2018/5/12 10:29 JST



Kamioka Seismic Noise (< 100sec)

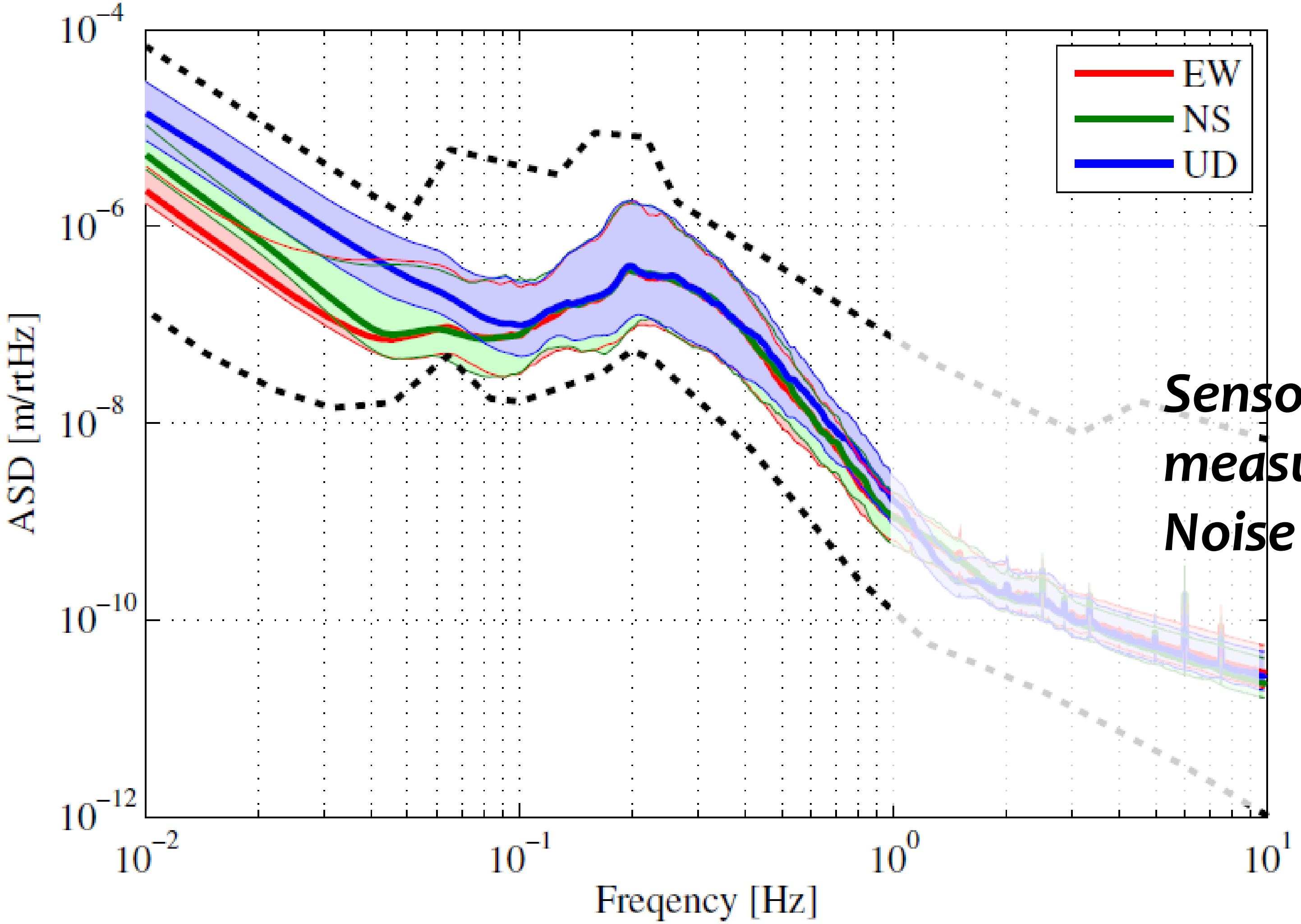
546 days data average, distribution and Max/Min by CMG-3T EW direction @ CLIO (Sept. 2009 ~ Feb. 2011)



Sensor or measurement Noise

Kamioka Seismic Noise (< 100sec)

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

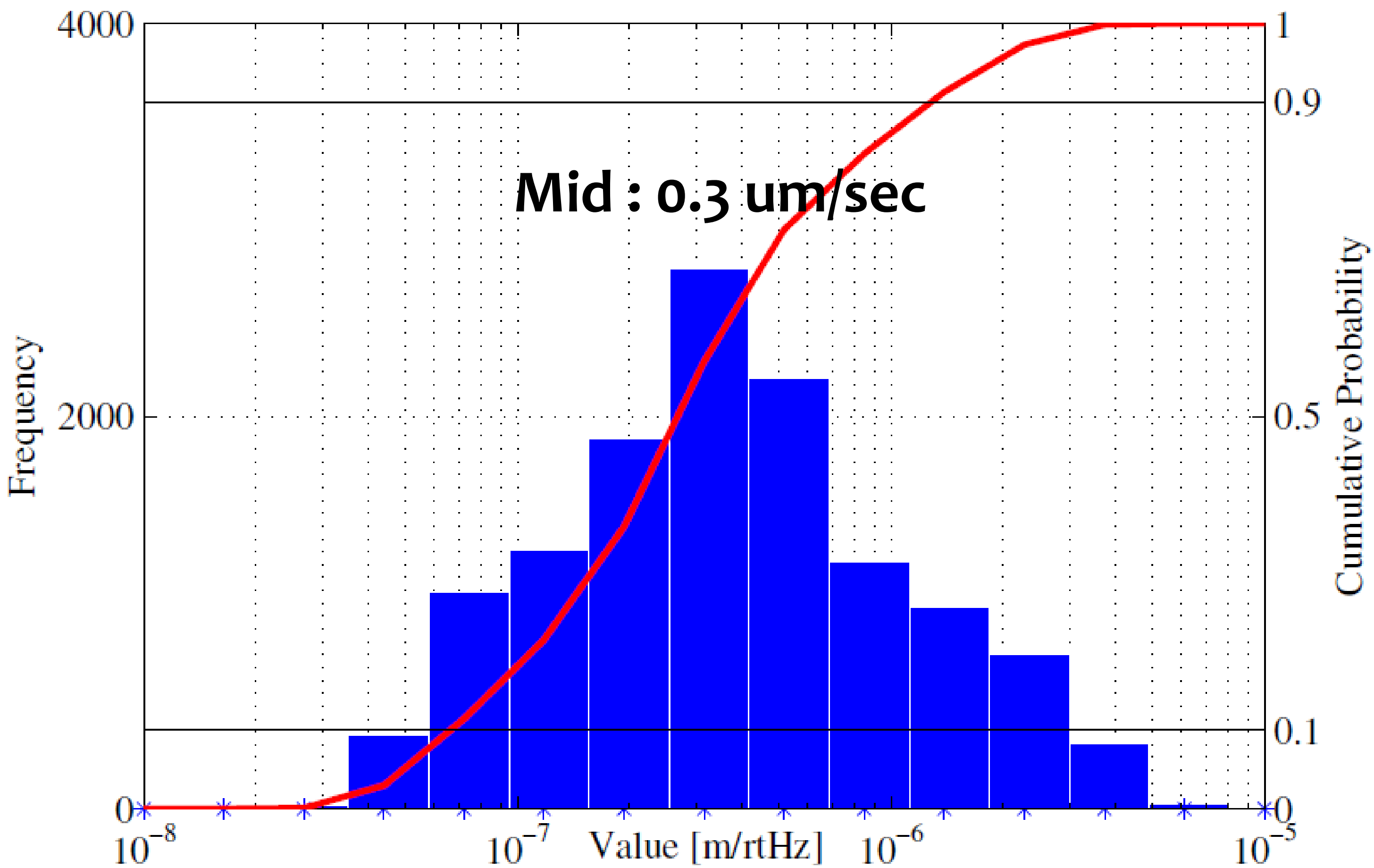


Sensor or measurement Noise

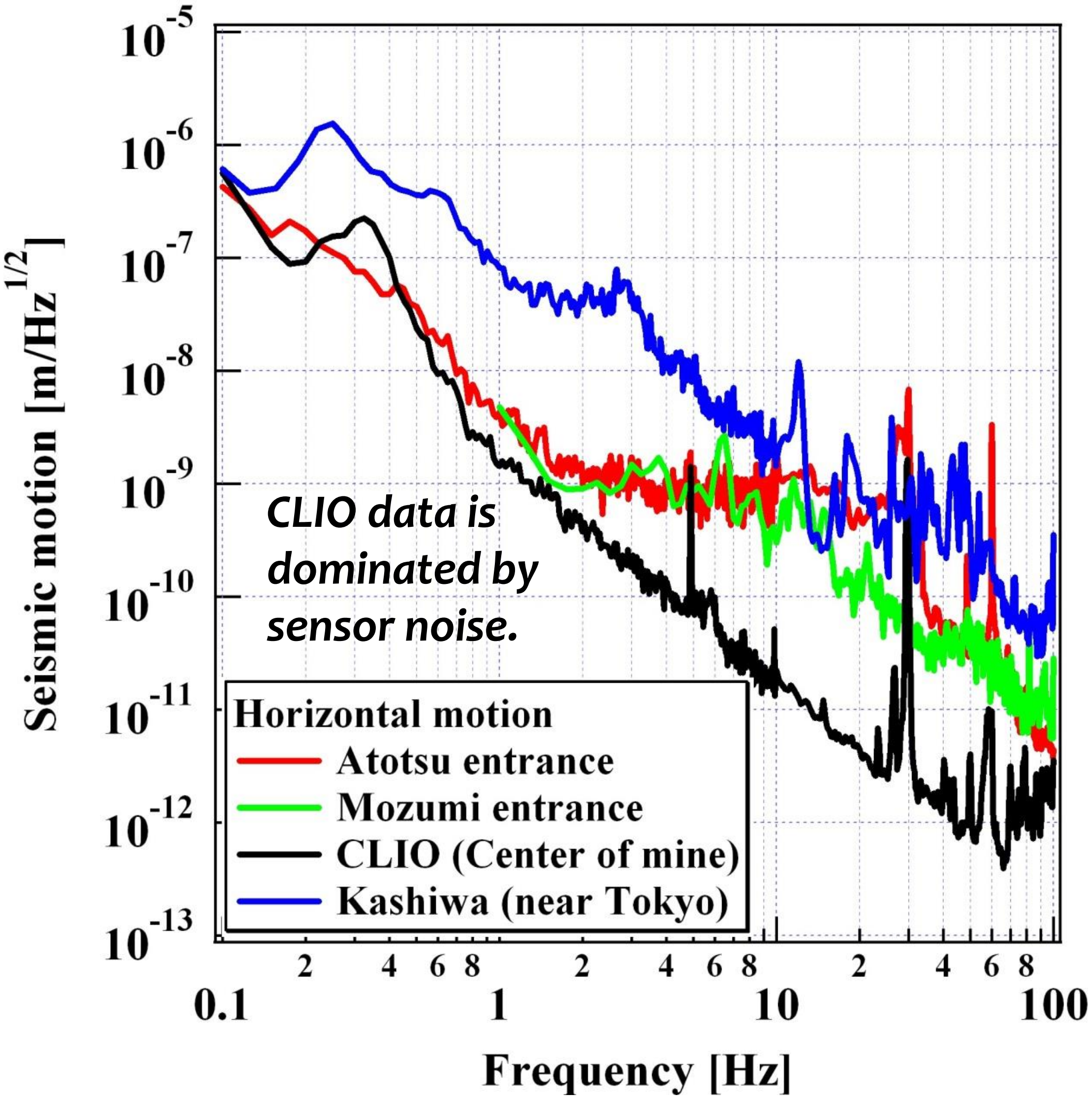
 T.Sekiguchi (U-Tokyo)

Micro Seismic Noise Level Distribution

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



Seismic Noise Comparison around KAGRA



- *f* < 1Hz

Outside(Moz,Ato) = CLIO

- 1Hz < *f* < 10Hz

Outside(Moz,Ato) > CLIO

- *f*>10Hz

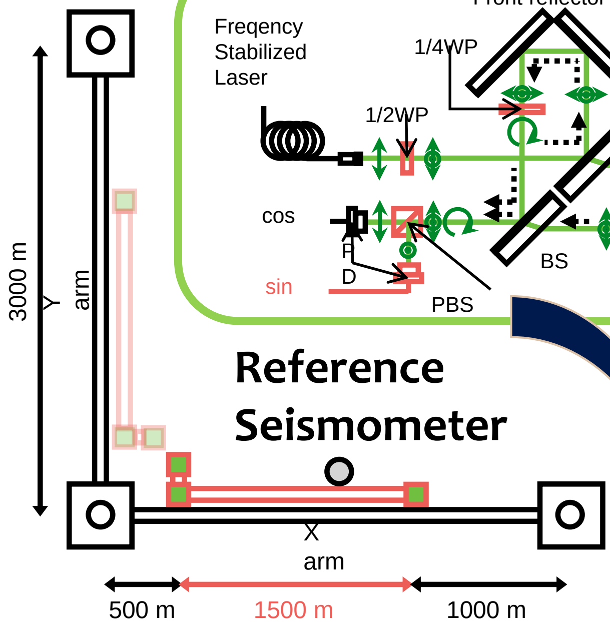
Outside(Moz,Ato) = Tokyo

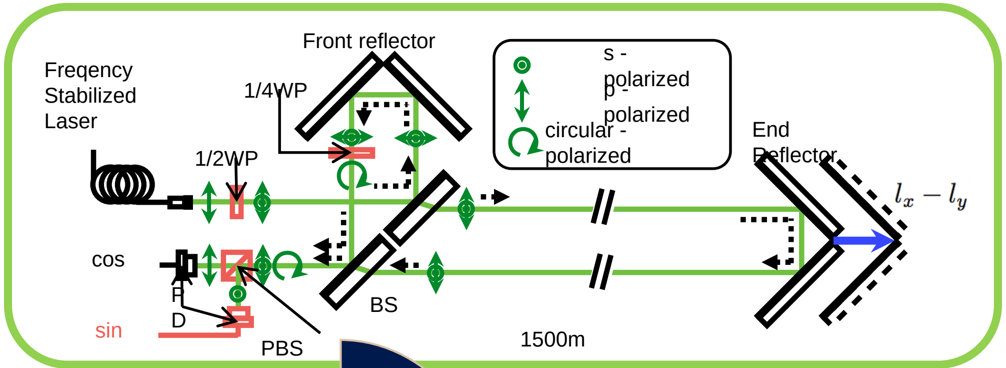
This shows that natural events such as atmospheric and ocean events dominate the seismic noise above ~ 10Hz, while human activity dominates it below ~10 Hz .

K. Yamamoto (U-Tokyo)

1500m Strain Meter in X arm

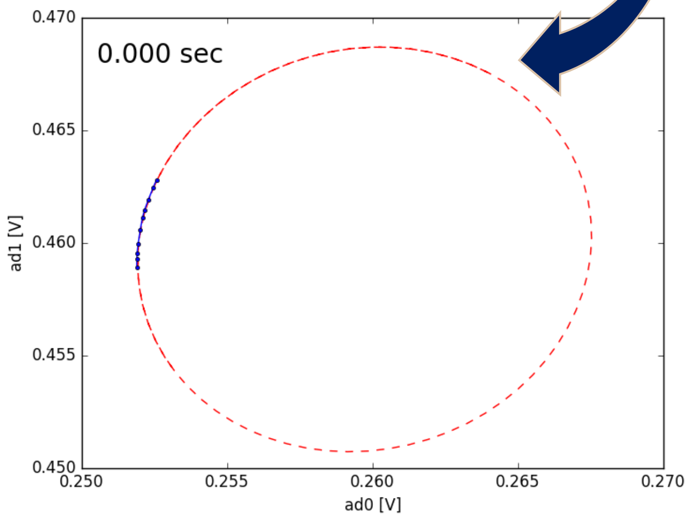
K. Miyo (U-Tokyo)

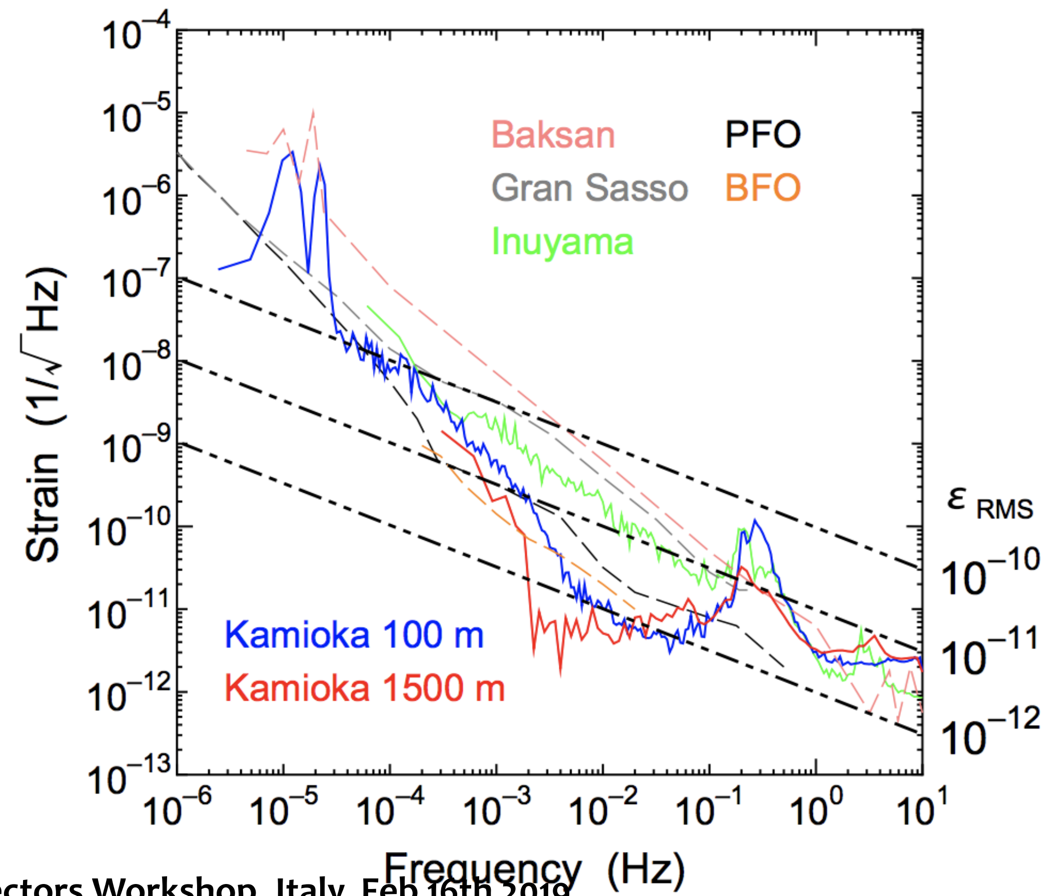




Strain meter senses differential motion between BS and a Xend mirror.

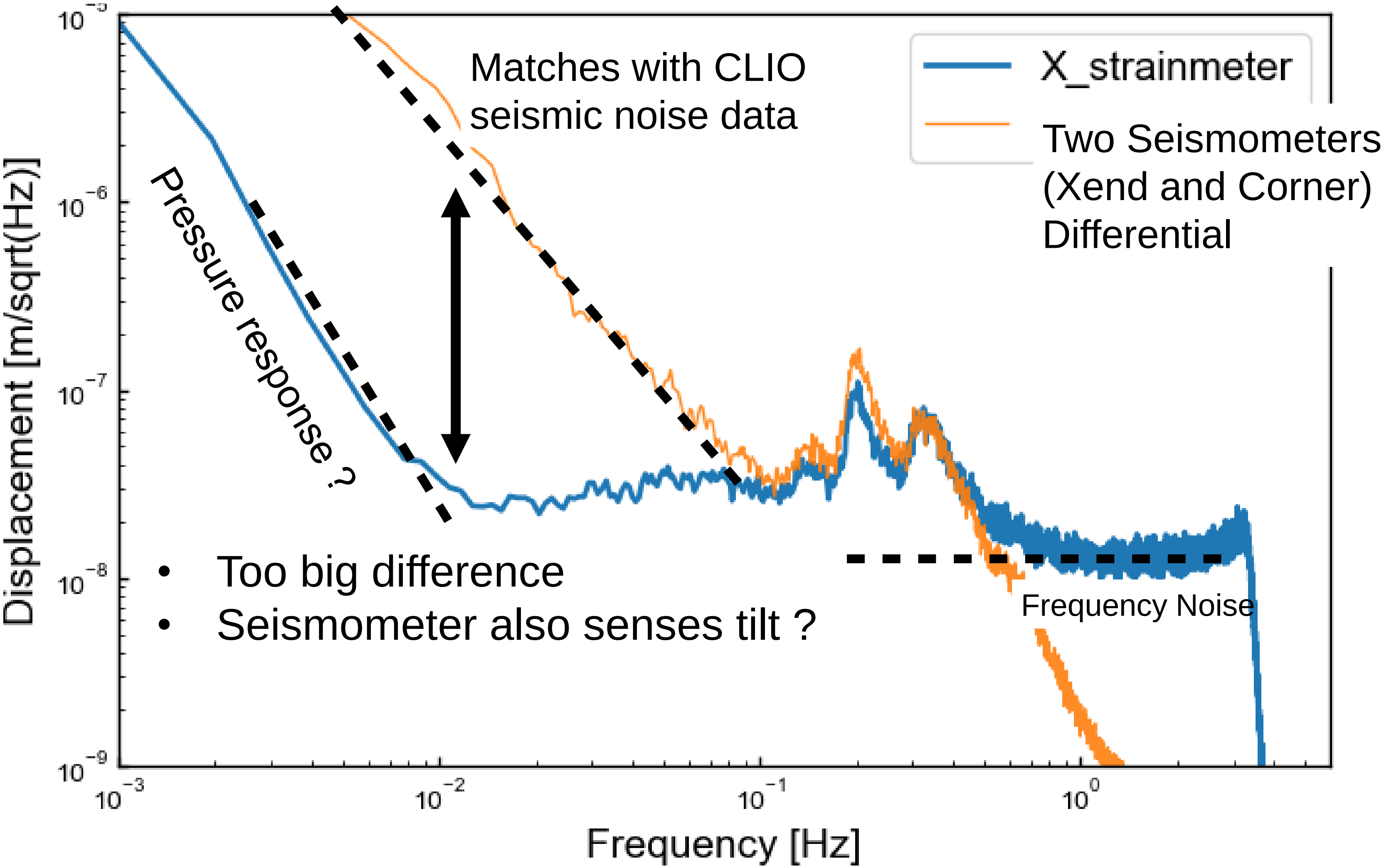
Reference Seismometer





Difference b/w ST meter and Seismometer

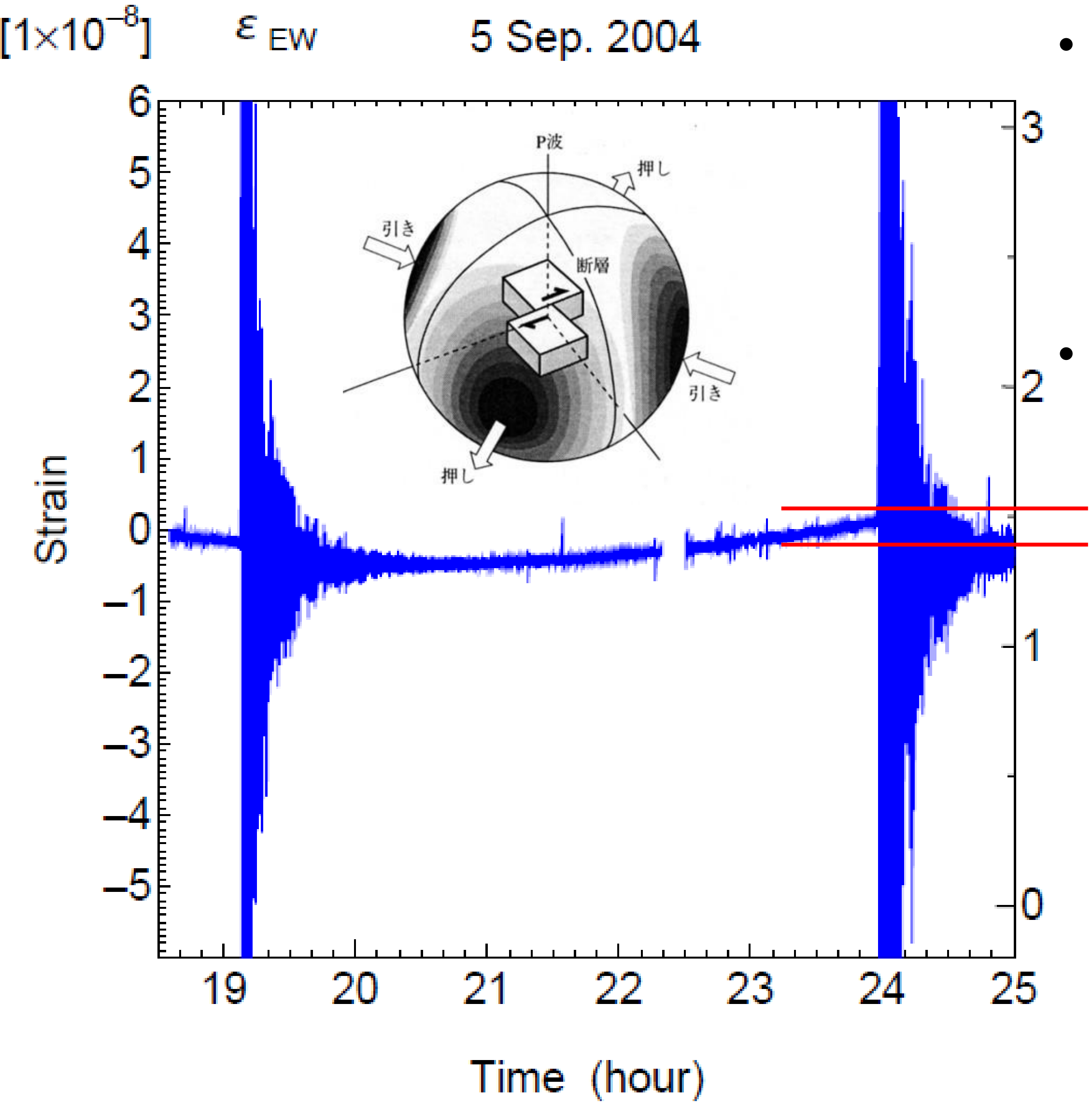
Differential Displacement by ST and Actual Seismic Noise? by Seismometer



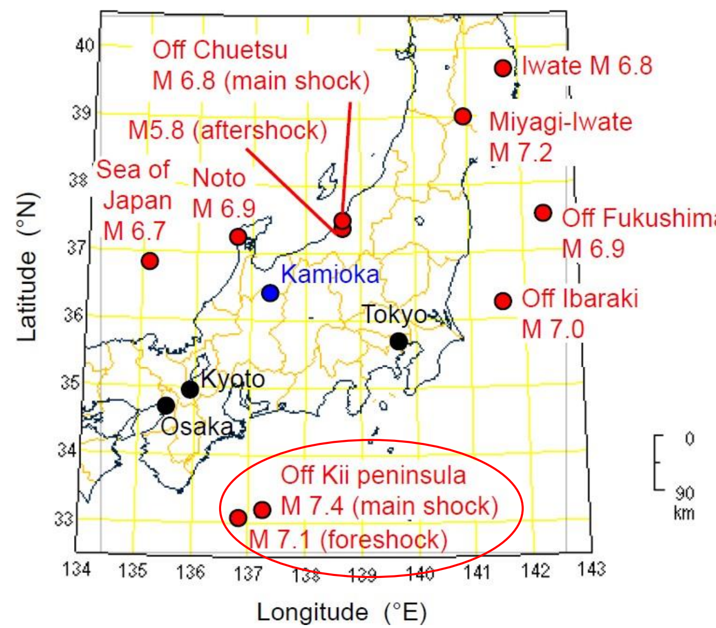
- Too big difference
- Seismometer also senses tilt ?

K. Miyo (U-Tokyo)

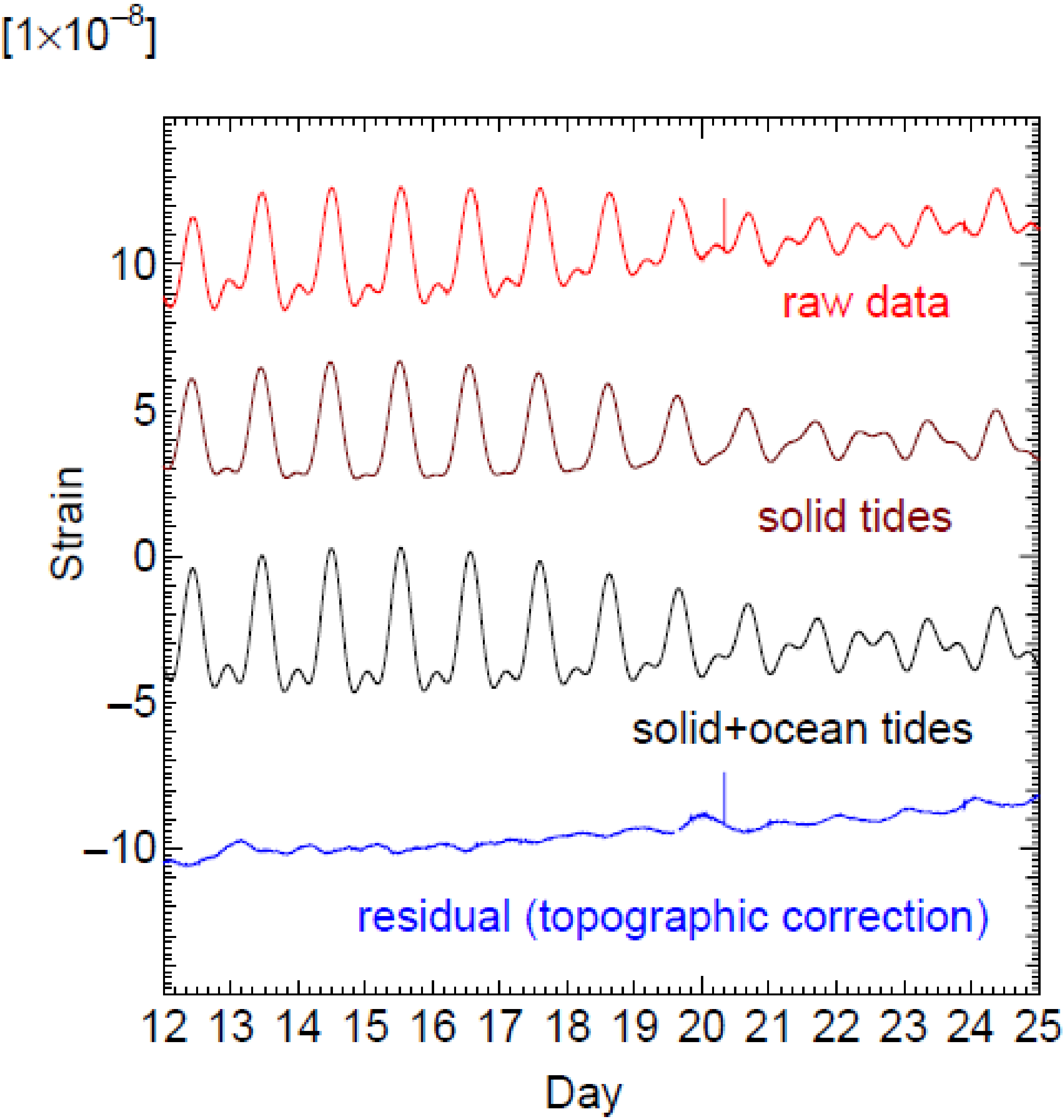
Permanent Steps



- 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.



Tidal and Local Deformation (> Days)

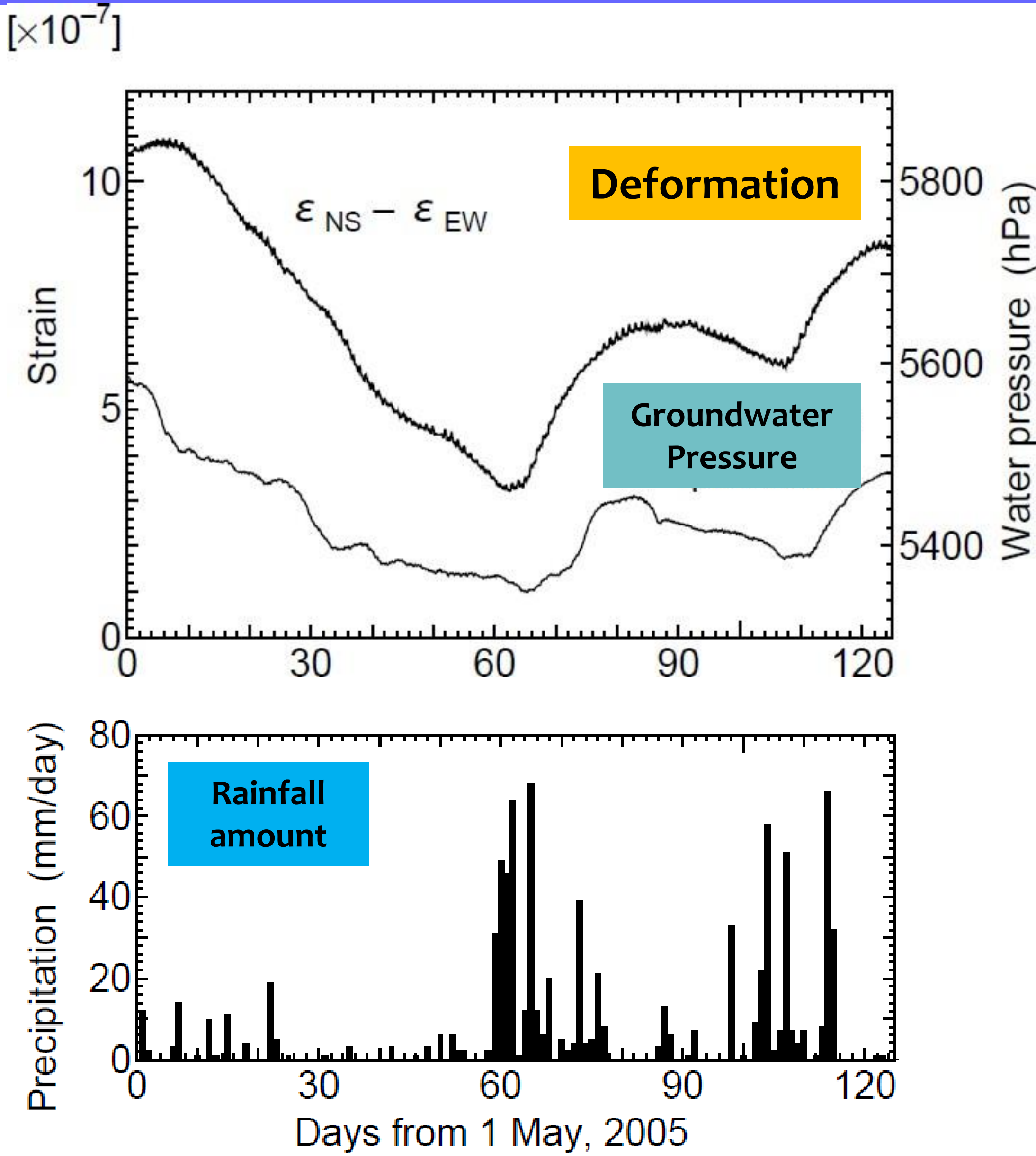


Raw data can be predicted by

(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.

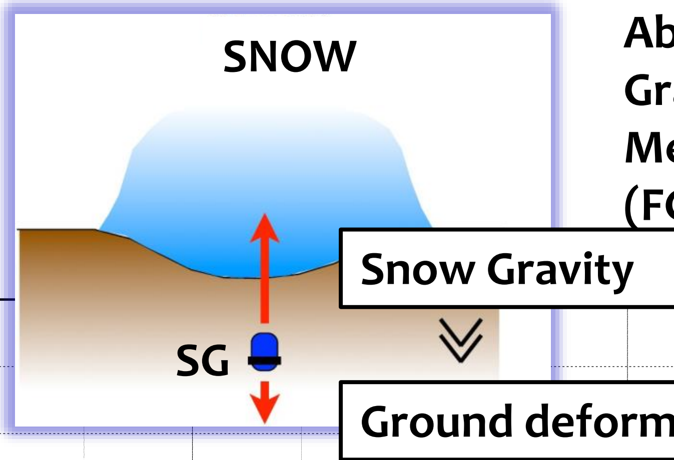
Seasonal Deformation (> Months)



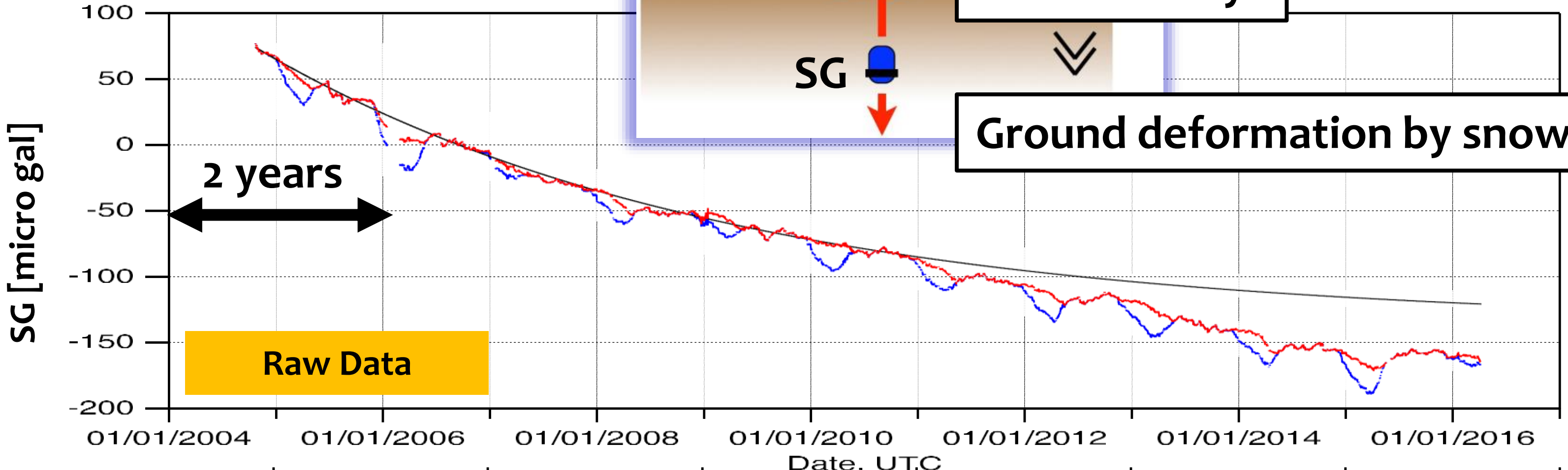
- **Snow and water in the case of KAMIOKA.**
- **Obviously ground deformation, groundwater pressure and rainfall have correlation with each other.**
- **How about gravity ??**

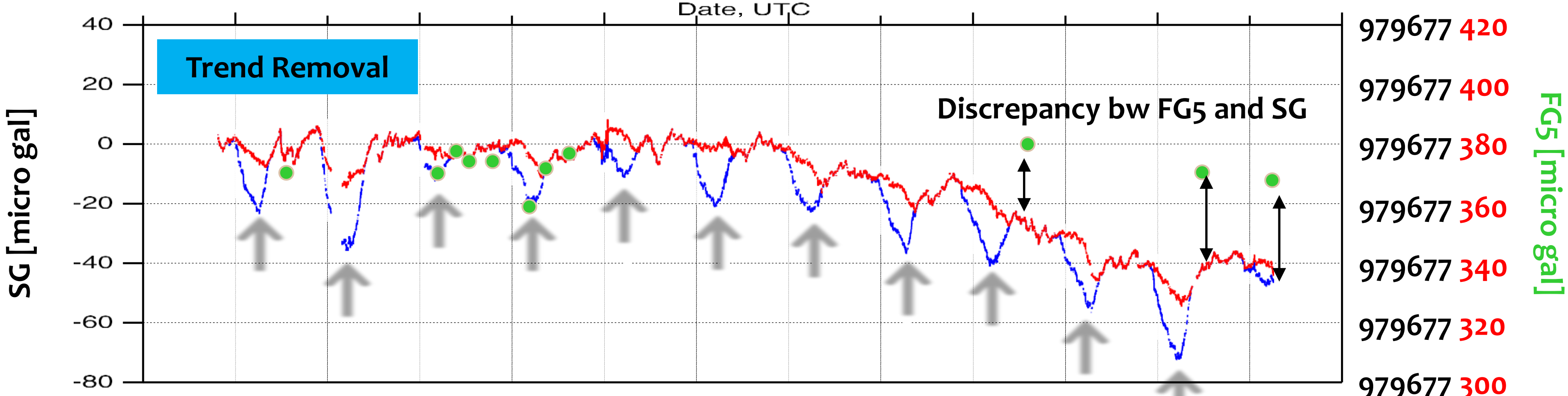
Gravity Change (>Several Months)

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



Absolute Gravity Meter (FG5)



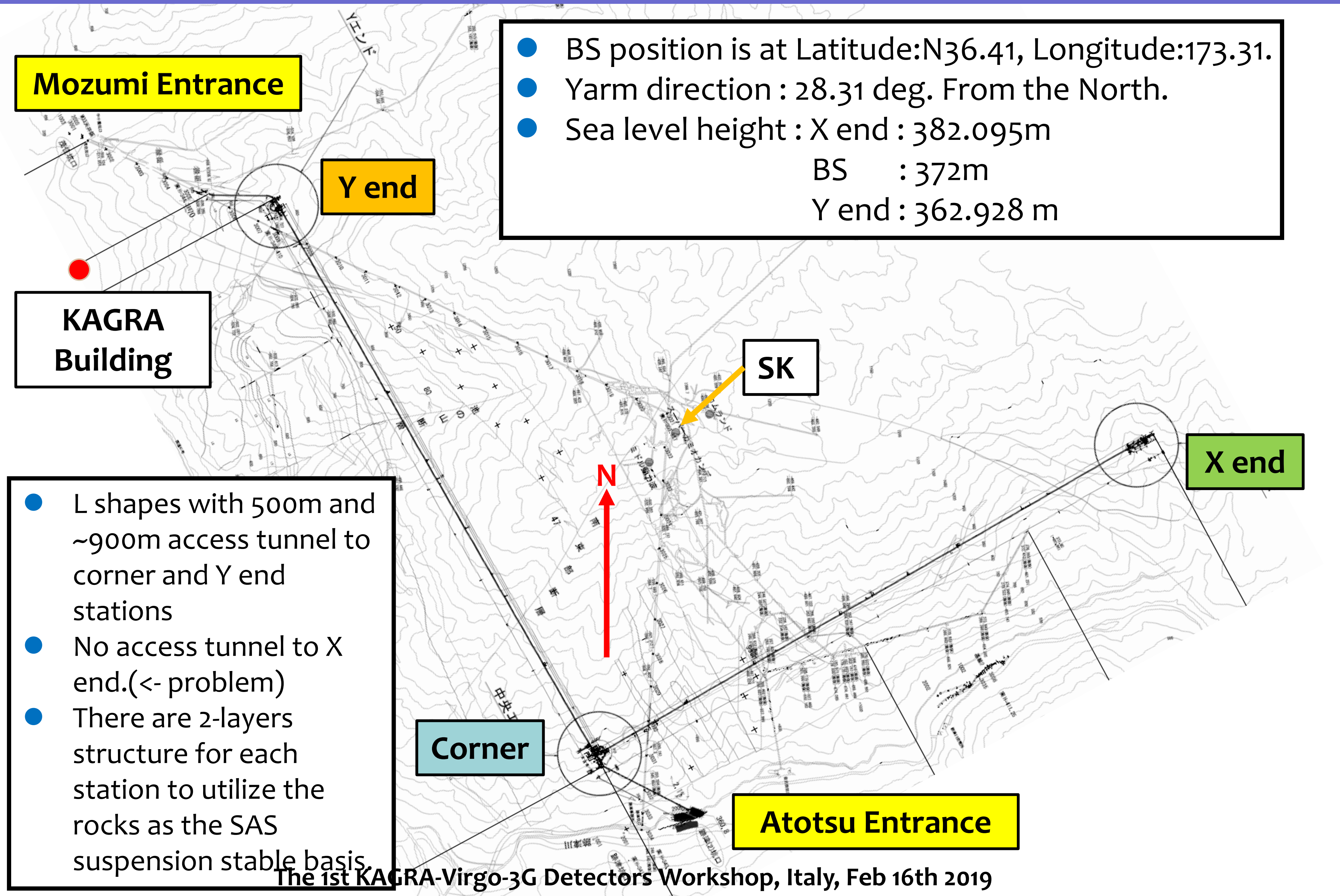


Tunnel of KAGRA

- *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.*

Very Cheap	**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)

Tunnel Position and Alignment

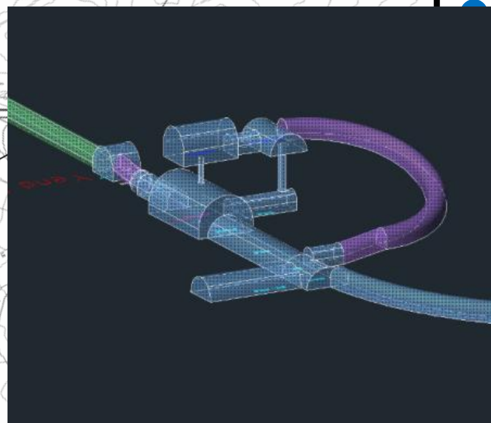


- BS position is at Latitude:N36.41, Longitude:173.31.
- Yarm direction : 28.31 deg. From the North.
- Sea level height : X end : 382.095m
  BS : 372m
  Y end : 362.928 m

- 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.

Tunnel Position and Alignment

Mozumi Entrance

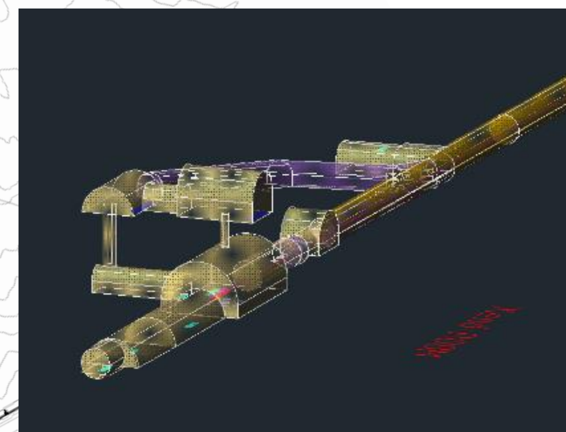


KAGRA Building

- BS position is 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

SK

N



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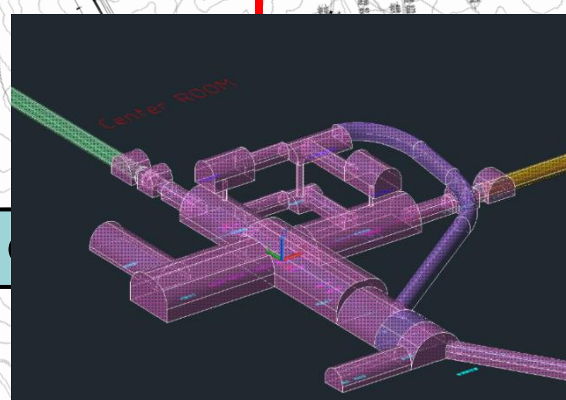
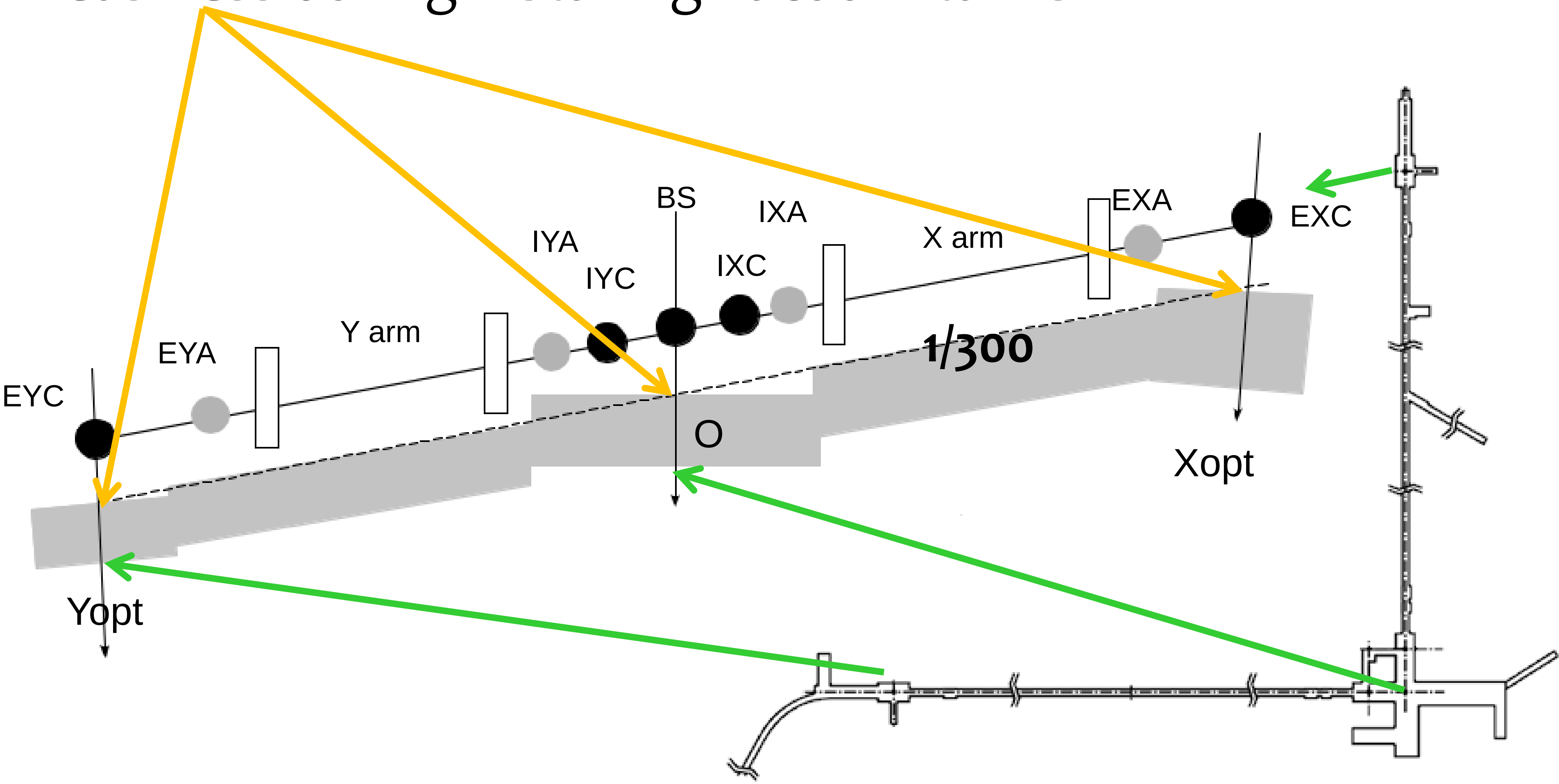


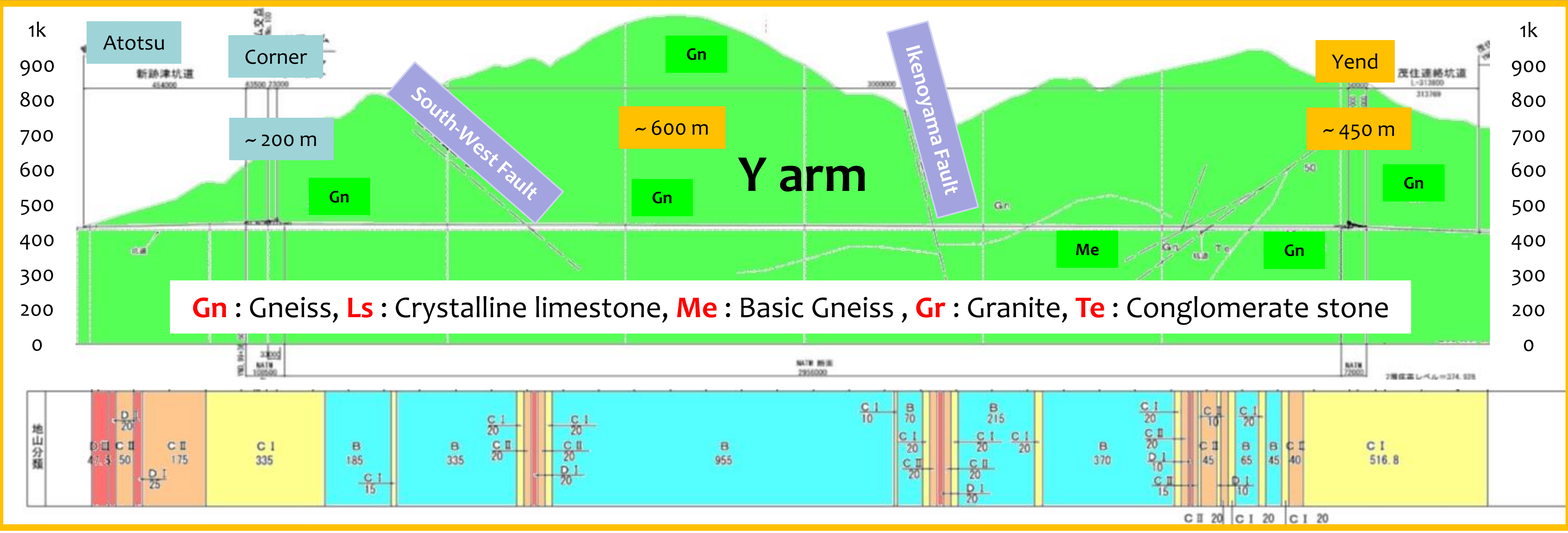
su Entrance

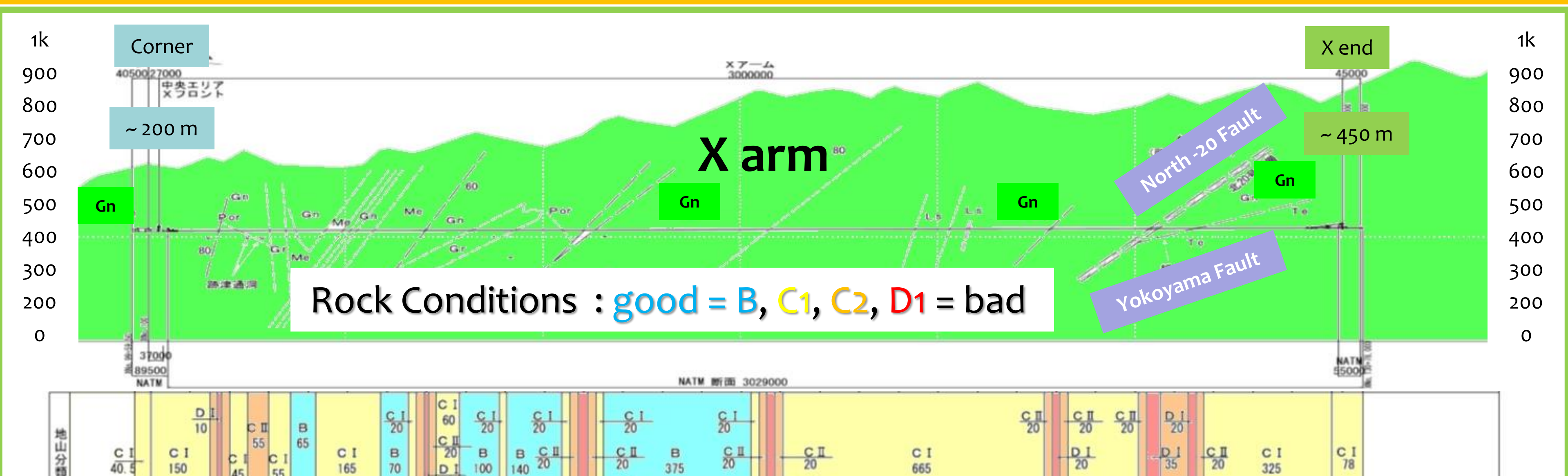
Tunnel Slope

- 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



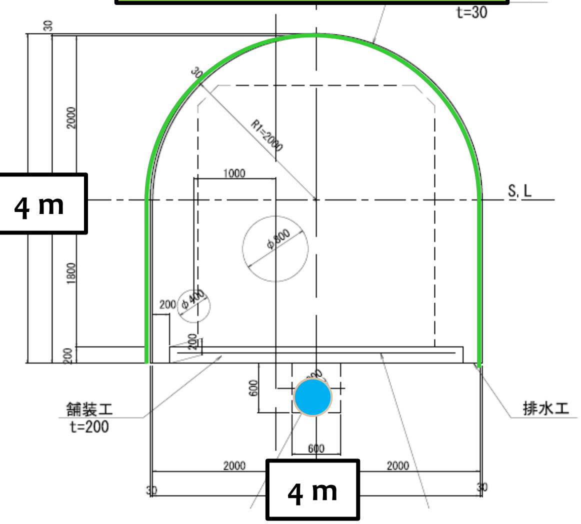
X, Y arm Tunnel Depth and Rock Conditions



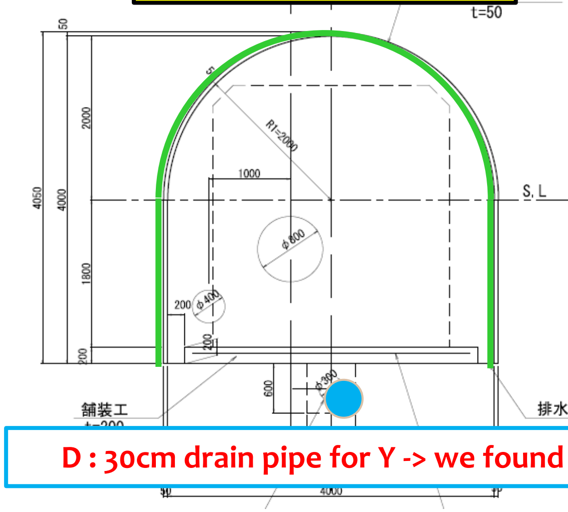


Typical Arm Tunnel Cross Section and Corner Station

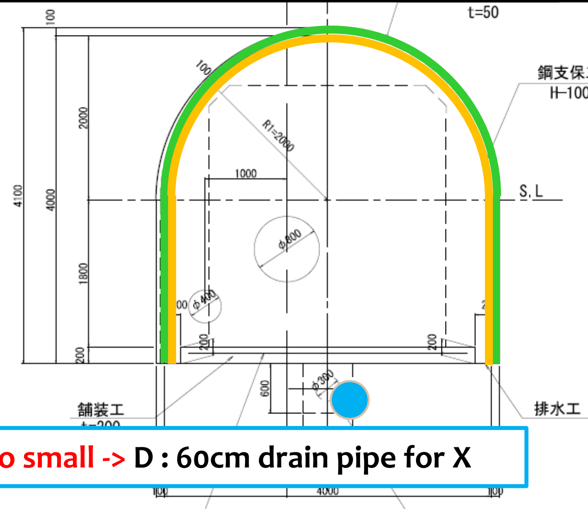
B : 3cm sprayed concrete wall



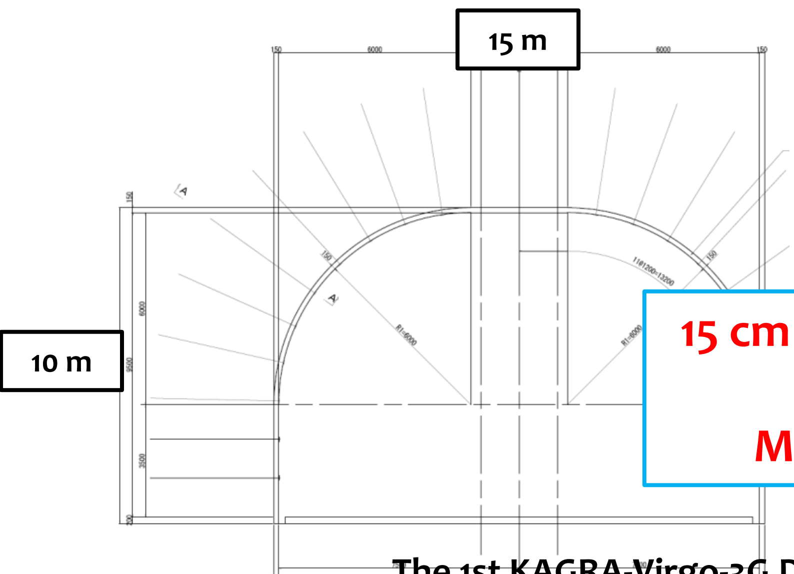
C1 : 5cm Sprayed concrete wall



C2 : 5cm sprayed concrete wall and metal arch supports

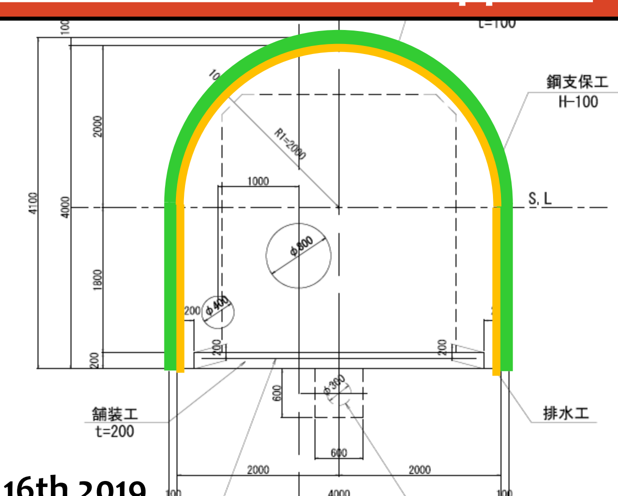


D : 30cm drain pipe for Y -> we found it is too small -> D : 60cm drain pipe for X



15 cm sprayed concrete
And
Many rock bolts

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



Heavy metal and pH of spring water during Excavation

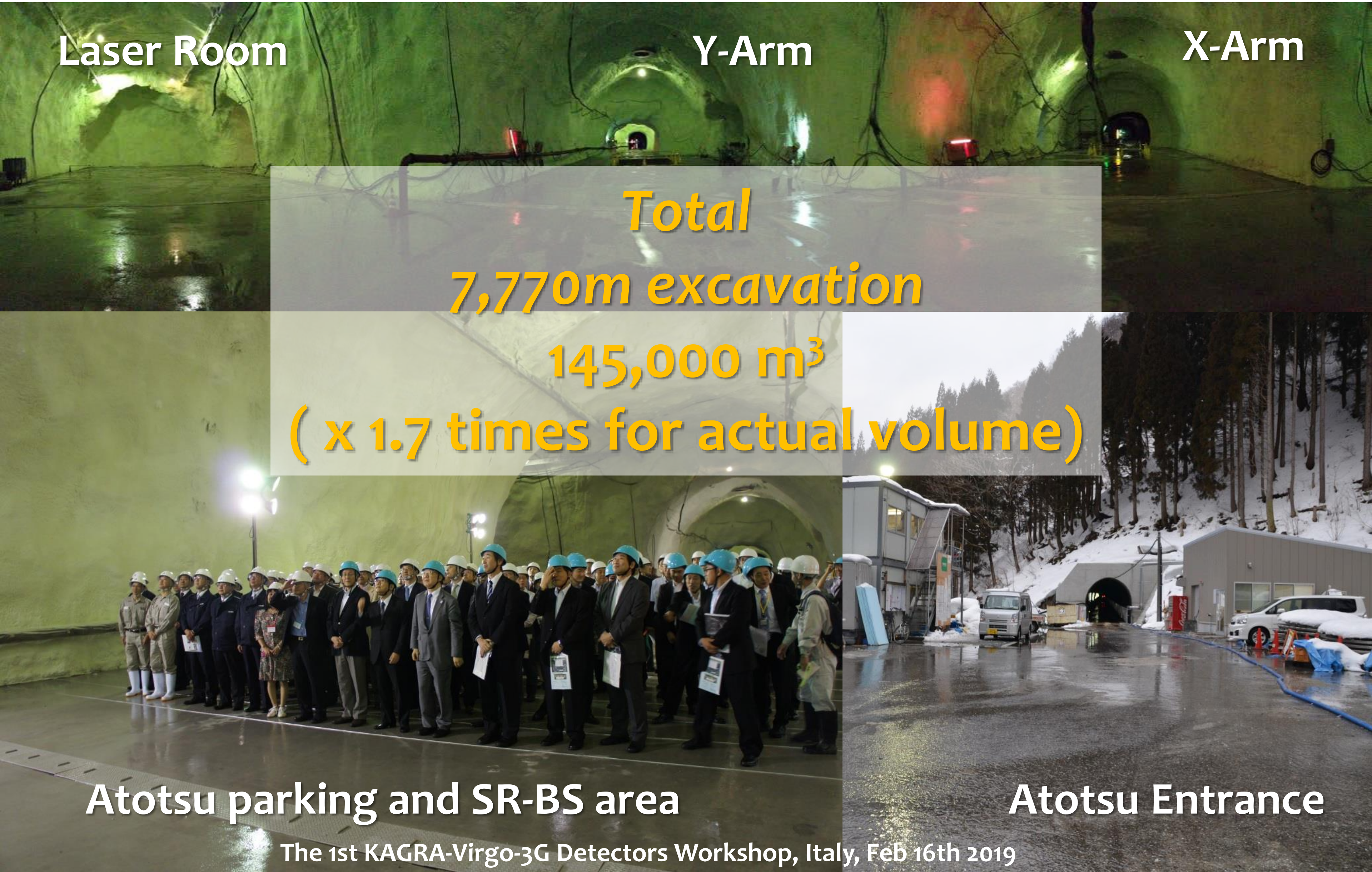
- **Serious "Cost" problem about heavy metal in rocks.**
  - *Rocks always contain heavy metals such as As, Zn, Pb, Cd, B, F, Ce, Cr, especially in KAGRA site that used to be "Zn mine".*
  - *We cannot bury them directly in some places if their content exceeds the allowed level.*
  - *Of course their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

□ **ppm level: As, Zn, Pb**

□ **ppb level: Hg**

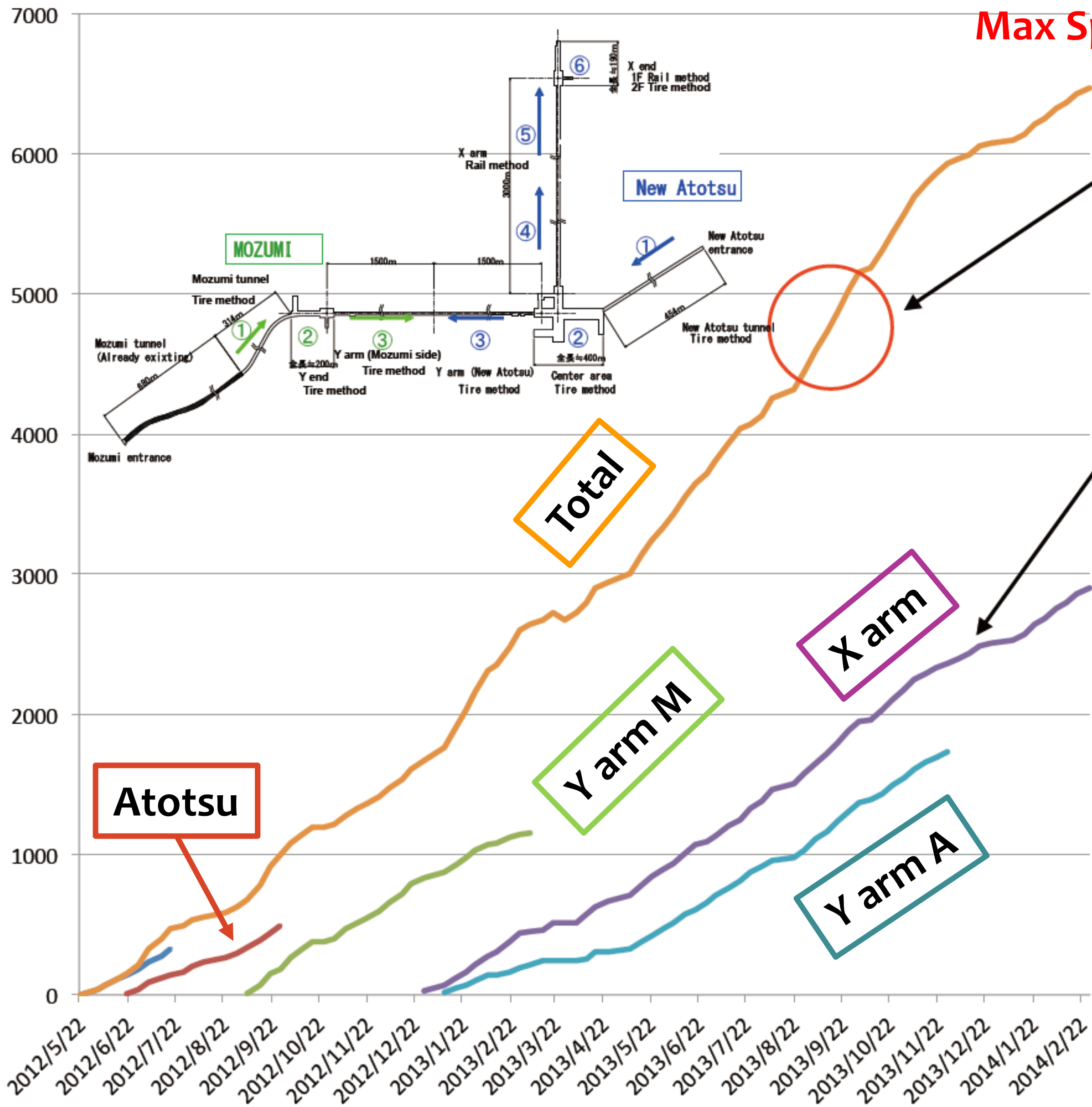
- **Another serious cost problem about alkalinity drain water.**
  - *Concrete contains CaCo3, that alkalizes spring water, not only during construction but for a long time after construction.*
  - *We cannot drain it directly in rivers and so on if its pH exceeds the allowed level.*
  - *You should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

Tunnel Completed in March 2014



Total
7,770m excavation
145,000 m^3
(x 1.7 times for actual volume)

Tunnel Excavation Speed



Max Speed in Japanese Tunnel History

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

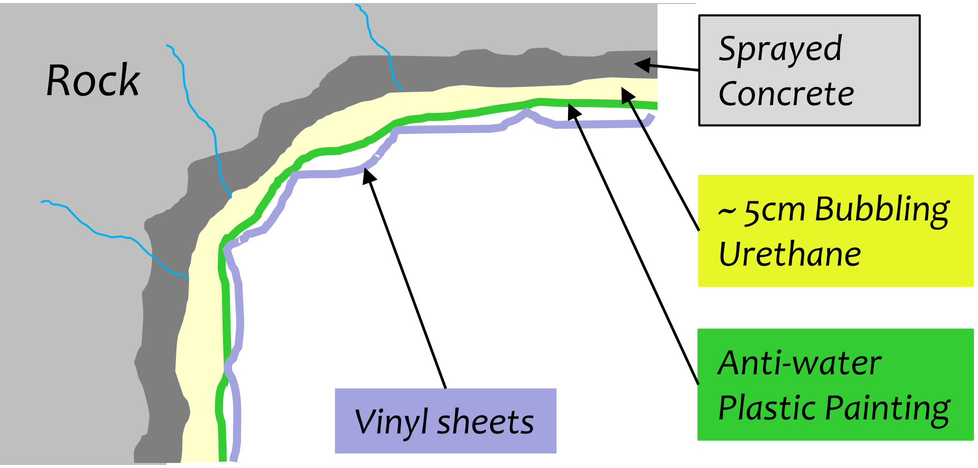
Xarm
3000m/14month=210m/month

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

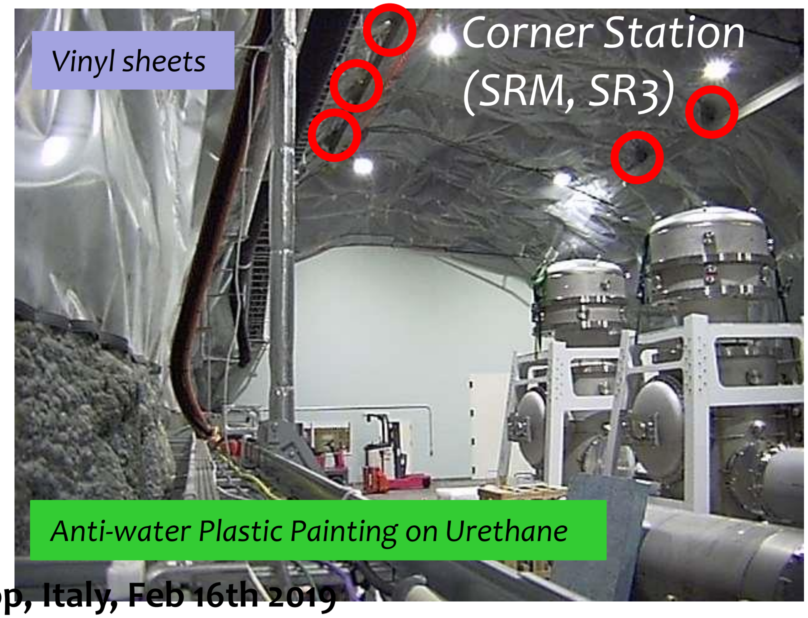
Spring Water Treatment from Walls

(1) Corner and End Stations



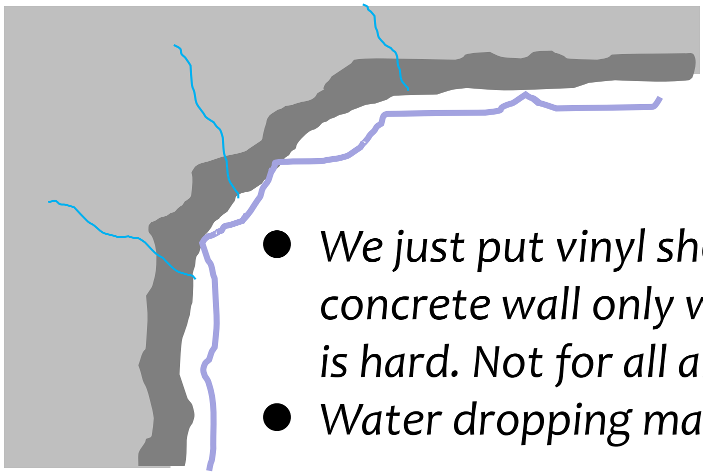
- *The water shielding method using Anti-water plastic layer on the urethane on the wall rock was selected.*
- *However, it didn't work very well. We got many water leak.*
- *We put vinyl sheets on the plastic painting.*
- *However, we could not stop water leak from anchor parts of crane and so on.*

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

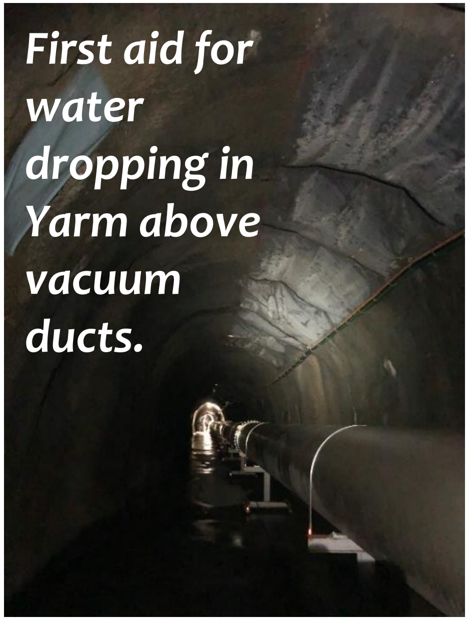


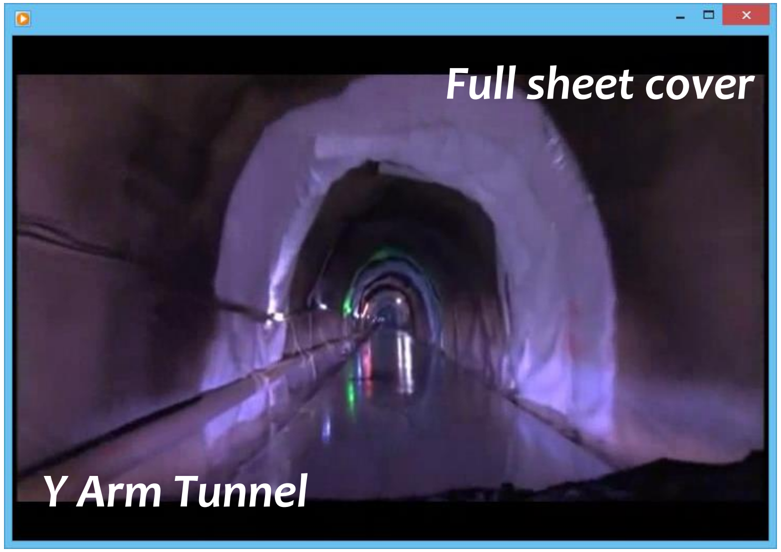
Spring Water Treatment from Walls

(2) Arm Tunnel Area



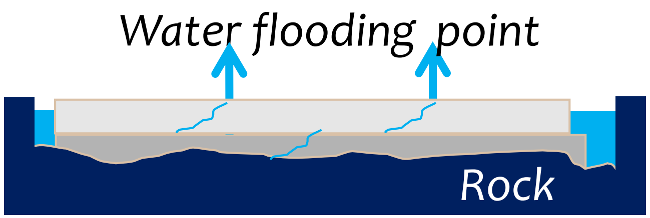
- *We just put vinyl sheets on the concrete wall only where water leak is hard. Not for all area.*
- *Water dropping make noise, maybe.*



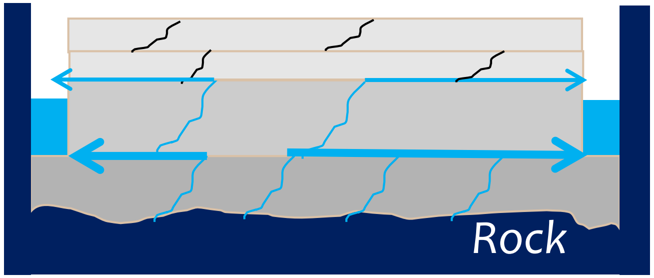


Floor Spring Water Treatment : in Stations

- 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

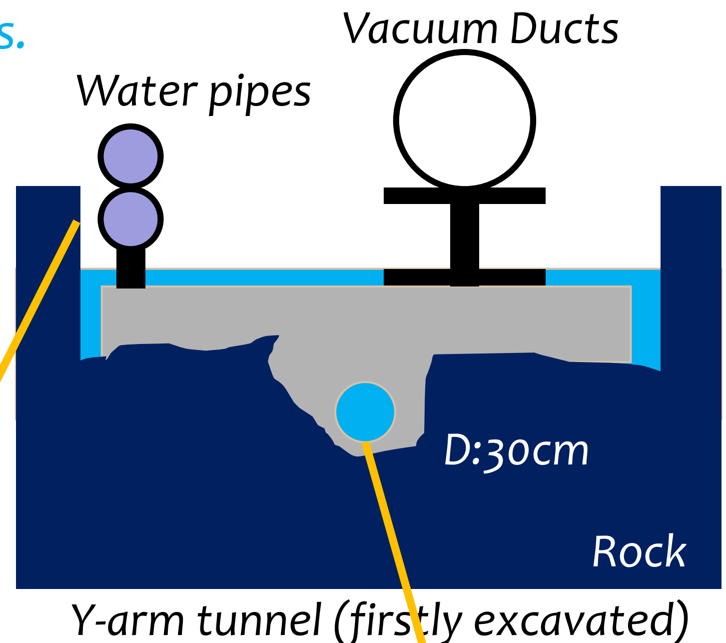


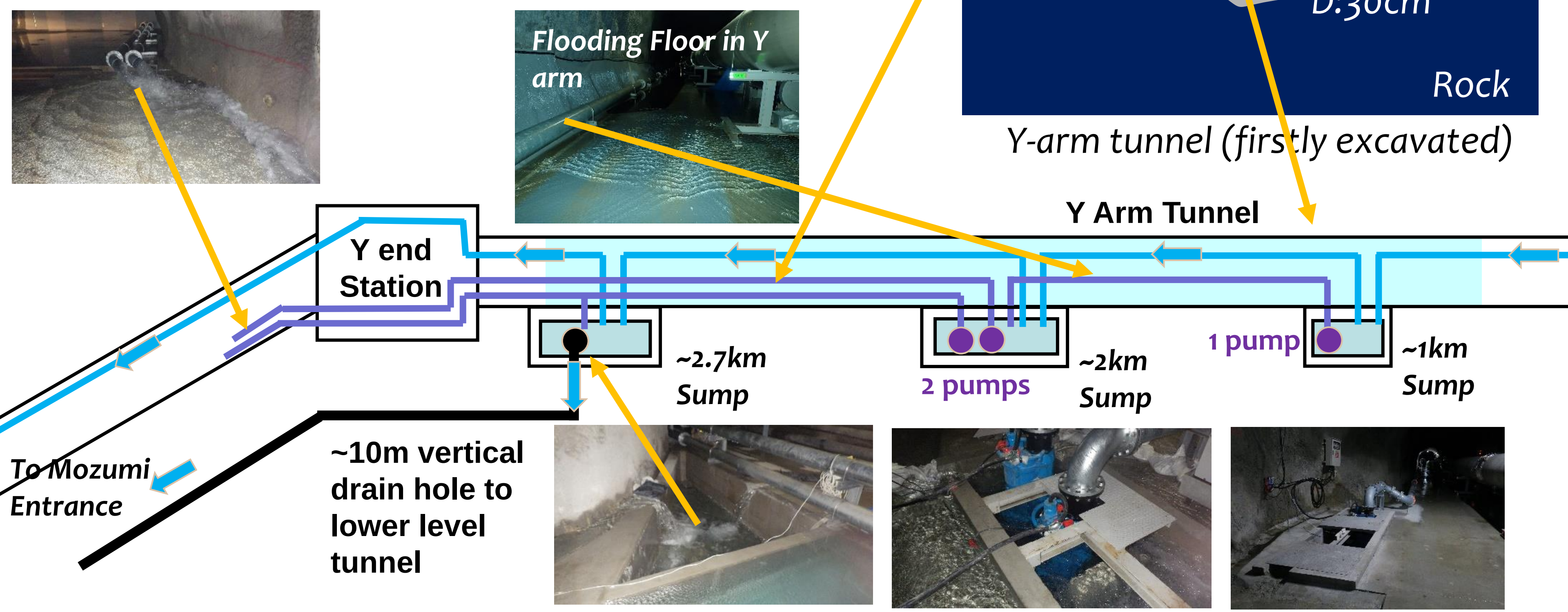
Ideal Floor Design

- 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.

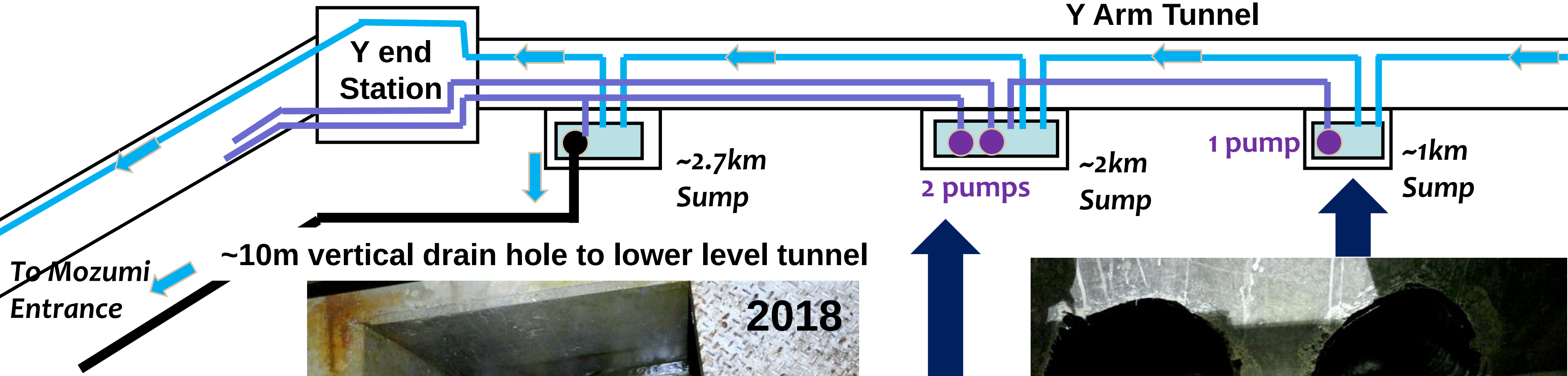
Arm Tunnel Spring Water Treatment

- *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.*





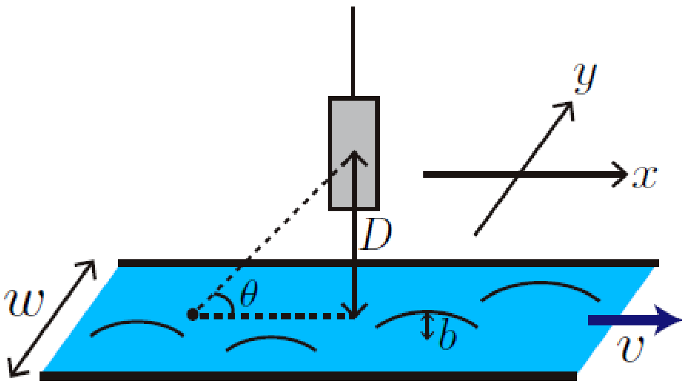
Improved Y-arm Water Transfer

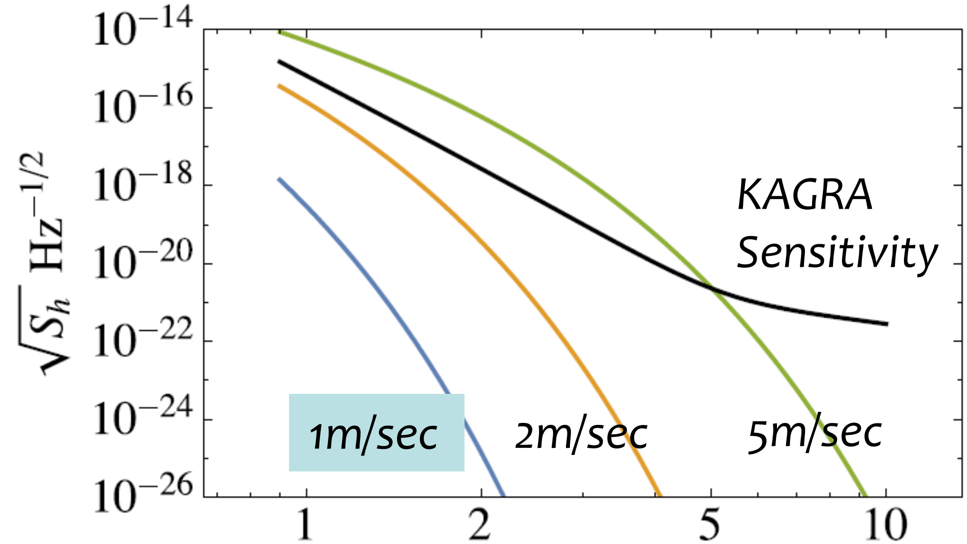


Although The amount of water was huge just after excavation in 2014, 2015, it has tendency to be constant except for the effect of snow.

Newtonian Noise from Flowing Water

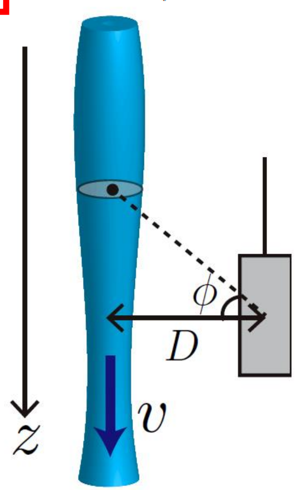
$\boxed{D = 2\,\mathrm{m}}$, $w = 0.4\,\mathrm{m}$, $\rho = 1\,\mathrm{g/cm^3}$,
$L = 3\,\mathrm{km}$, and $\delta v_\ell = 0.2\,\mathrm{m/s}$.

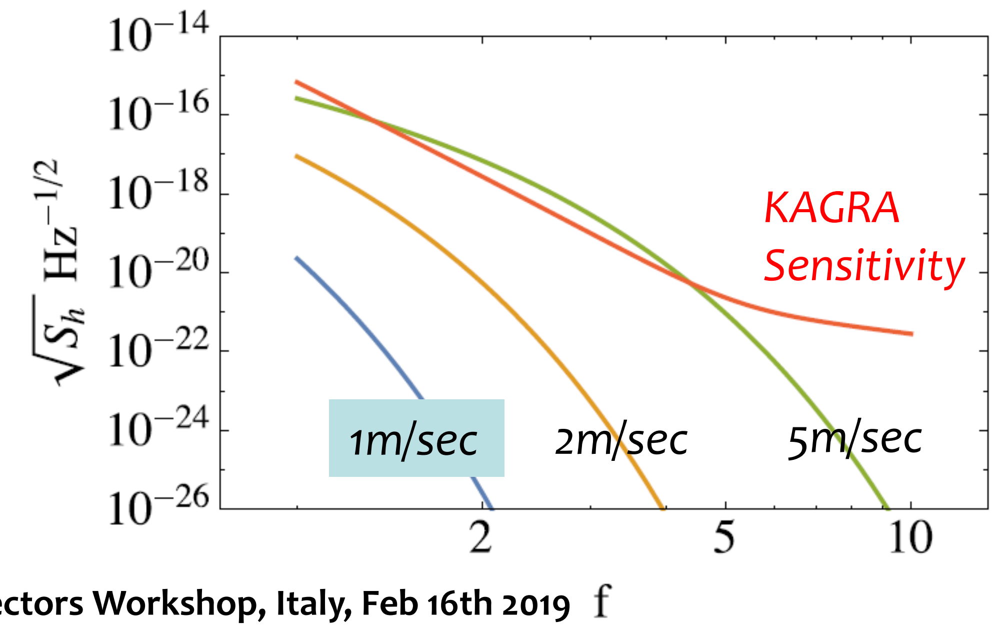




D > 5 m is actual, so less influence expected.

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

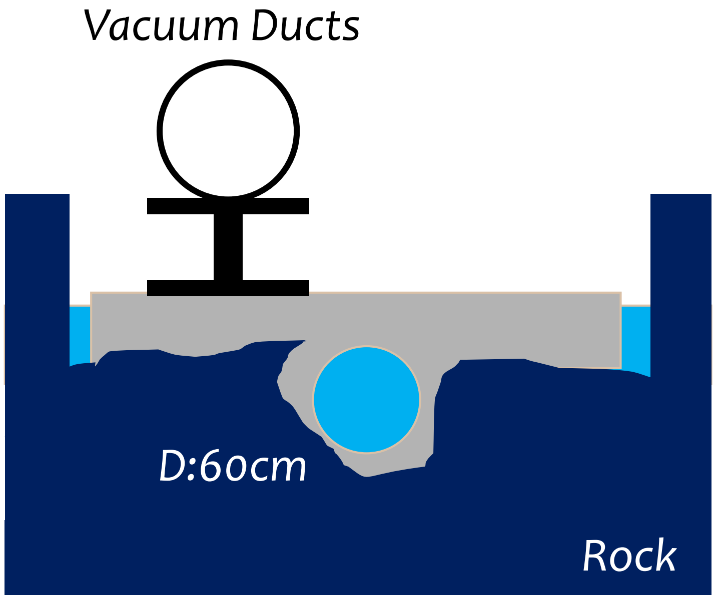




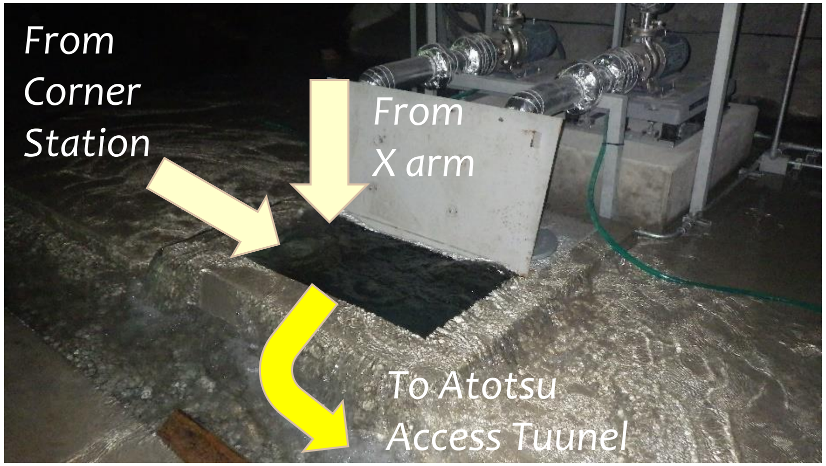
Arm Tunnel Spring Water Treatment

- *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.

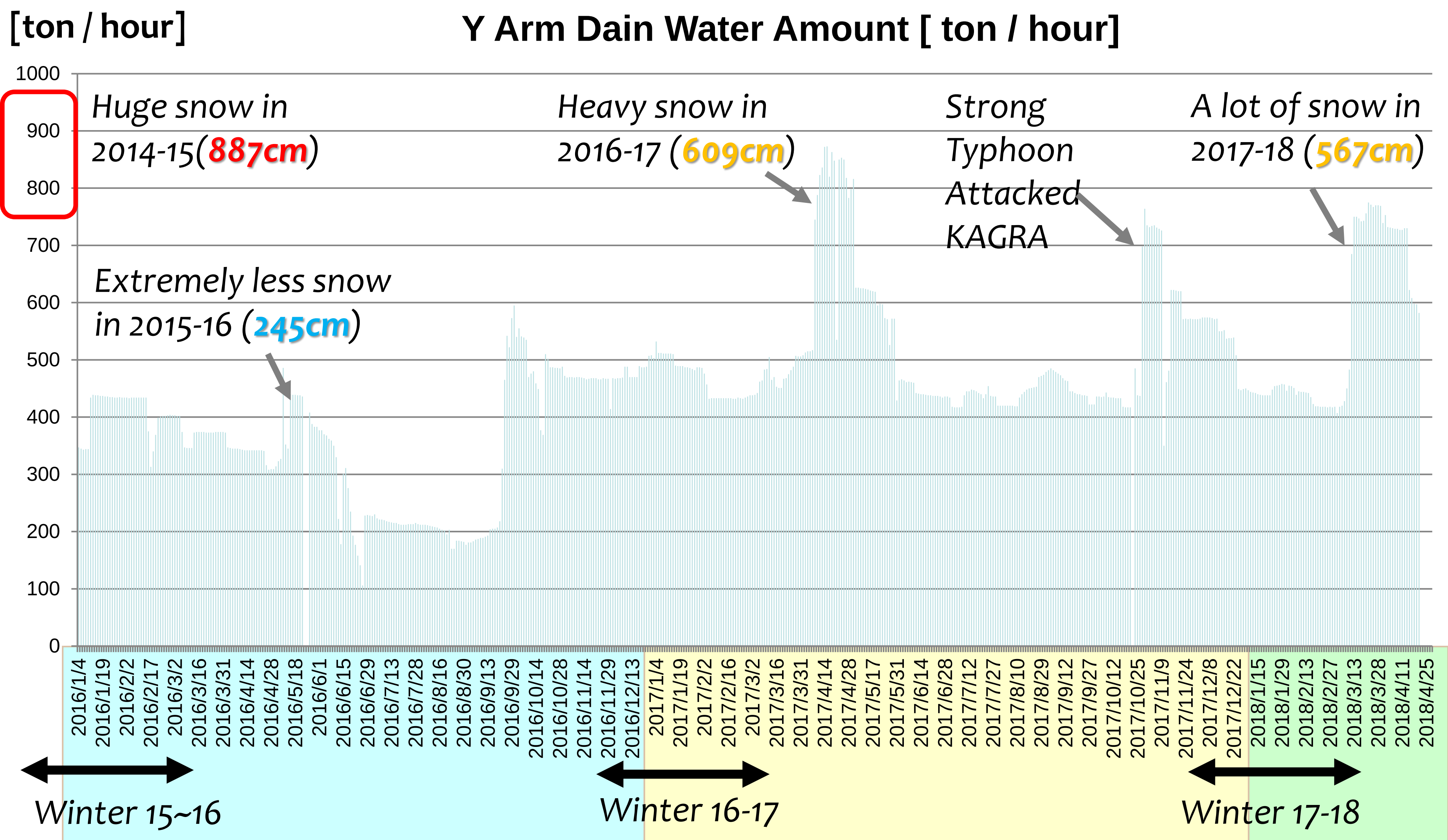


X-arm tunnel (Secondly excavated)



Spring Water Amount Depends on SNOW

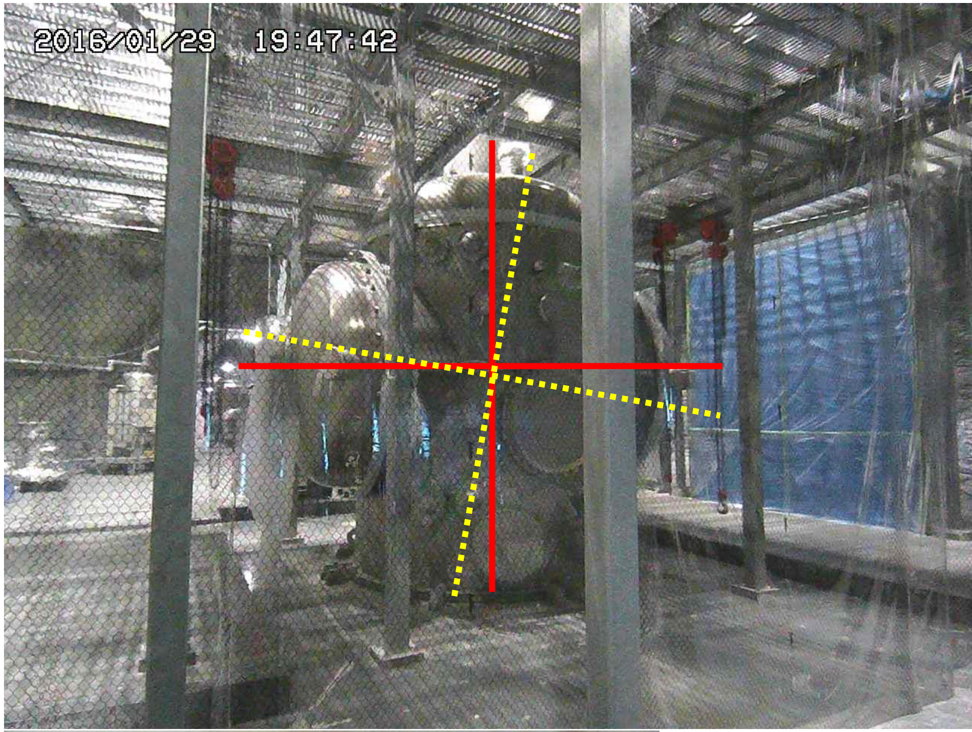
- ***Just after finishing excavation, the Y arm water became up to 1250 [ton/hour] (Total 2050 [ton/hour])***



Ground Slow Motion

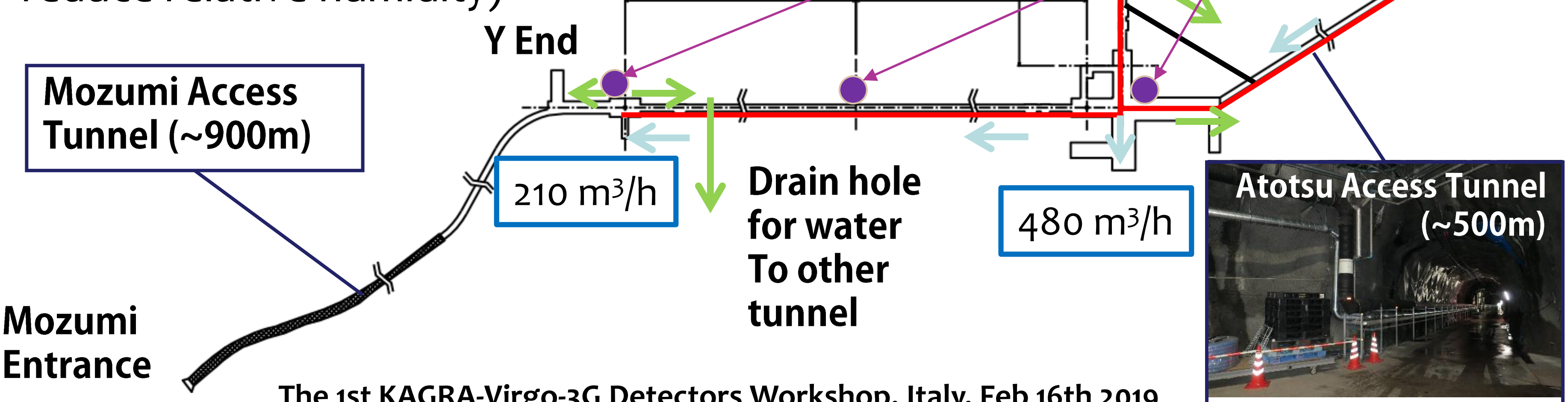
- *The tunnel was made by the NATM method. So the rock is expected to have small cracks on its surface. Because of it, uneven settlement occurred for each cryostat (12 ton)? We are now monitoring the cryostat position (2016) . -> In 2018, it seems to show no change.*

- *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, CO_2 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

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.*

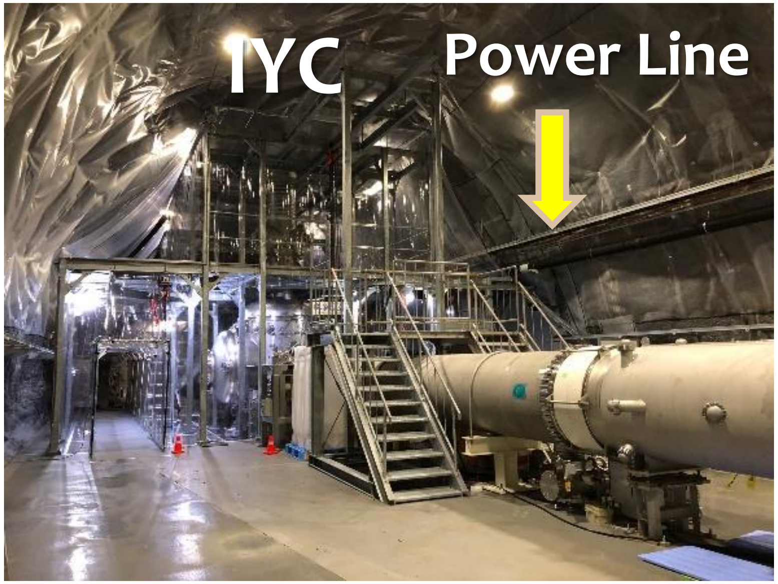
Temperature and Humidity Control

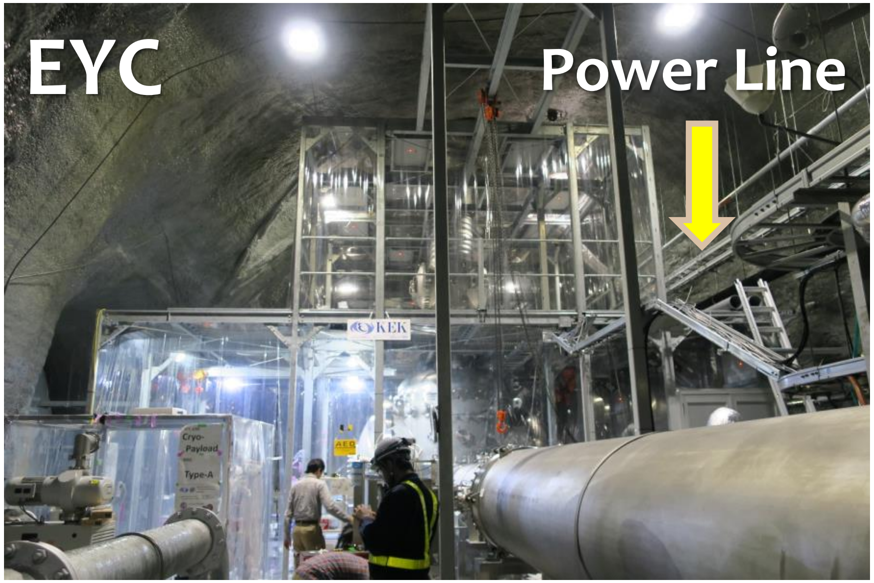
	Temperature			Humidity		
	Corner	X End	Y End,	Corner	X End,	Y end,
Natural	~ 17 C	~ 18 C	~ 14 C	>90%	~ 90%	>90%
Operation FFUs 180W, KOACHs 200W, DGS Racks ~500 W **Without no coolers**	~ 28 C ! (~200, 24, ??)	~ 28 C ! (14, 12)	~ 25 C (14, 12)	~ 65%	60~70%	70~80%
With Air Coolers air cooler with On/OFF control (using water cooling)	IXA : 16.6 IYA : 17.4 Center :24~25 Pre-R : 24~25 SR : 23.5~24.5 (20kWx4 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 (20kWx4 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 (24~25 for the corner station) as the observation mode where the minimum instruments (cool air supplier) are working. Maybe "silent" coolers should be prepared to keep temperature and relative humidity.

Electrical Equipment Issues

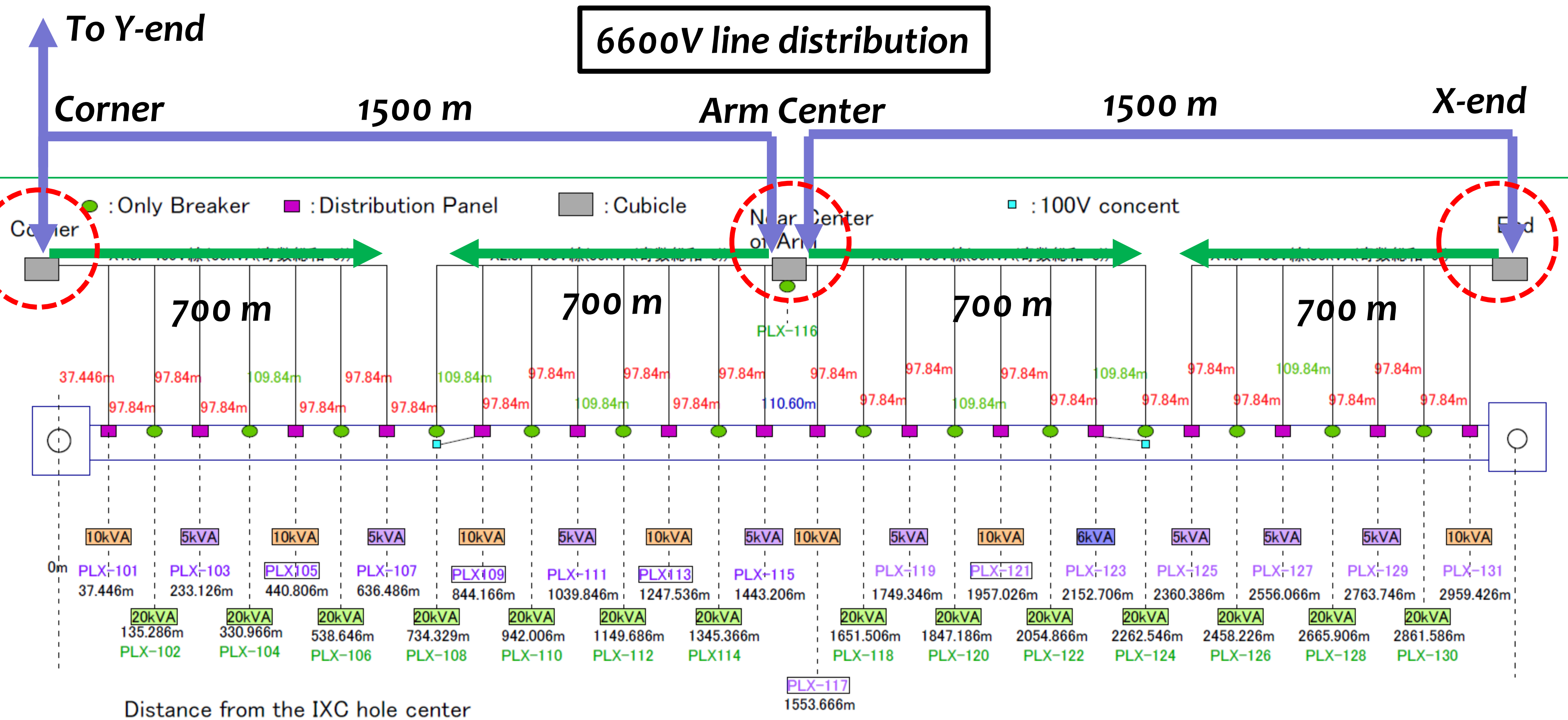
- ***Anxiety and Uncertainties***
  - *We make AC100V, 200V, ~400V from 6600V.*
  - *6600V lines go through each stations (~ 10m height) and tunnels (~ 4m) near instruments -> we don't know how much it affects as line noises ??*
  - *No place to take ground in the "Rock" tunnel. We have just ground line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





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 .*

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 O_2 (<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

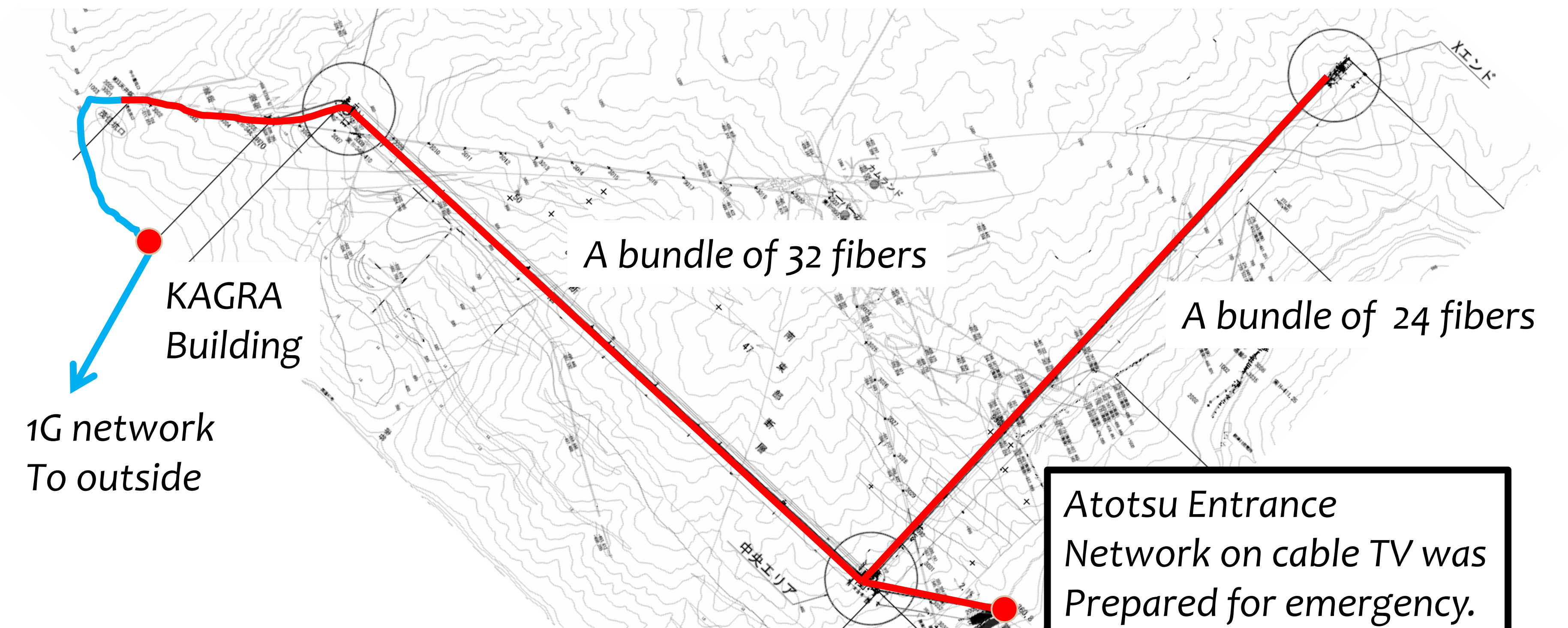
- *Many web cameras*
- *Smoke*
- *Unusual heat in the laser room*
- *O_2, CO level*
- *Water supplier operation (pumps, water level)*
- *Air fan operation (fan activation, humidity controller)*
- *High/Low voltage electrical condition (leakage, trip)*

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 prepared another network on cable TV network from Atotsu entrance.
- In the case of X arm, we have prepared a metal wire telephone line in the water ditches for emergency communication.



Summary

- Please don't repeat KAGRA's undesirable FCL design for FCL for ET and CE even if higher cost is expected.
- Key for underground usage might be "rock condition" that will houses interferometers.
- One of big problems to utilize underground is water treatment that could be one od sources to spoil NN.
- Good common mode rejection for frequency ranges below 0.1 Hz can be expected if the rock condition is good.
- Geophysical understanding for a site is important to predict the ground motion that might let IFO instable.

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