

Session: errors not to be made again  
*The beauty of hindsight:* a discussion of mis-steps in

# KAGRA

National Astronomical Observatory of Japan

**Tomo Akutsu**

For the KAGRA collaboration





# Summary of the questionnaires

I made questionnaires to several people about the errors not to be made again.  
I also interviewed some of the people as well.

- Mirror fall (PR3)
- Started evacuation before closing vacuum chambers completely
- EXA optical table levitated at iKAGRA
- Many viewport leaks
- Groundwater: PSL room, corner station, both arms and so on.
- Accidents during tunnel excavation
- Frost in the cryostats (cavity finesse, oplev sum ...)
- Wrong direction wedge (SRM installation)/ the transmitting beam went away
- Explosion of a viewport window
- Sudden blackout/ planned blackout but unwanted
- VIS design: accessibility to all parts; maintenance capability of the payloads, should wipe the suspension's wires otherwise dirty. Mirror hanging/assembly jig. Winch redesign.
- Magnetizable screws to fix plates for eddy current damping... failed and replaced.
- Pieces of thermal insulator scattered in the tubes
- Electric car in snow
- Avalanche
- BS oplev fall
- Purchase mistake/miscommunication (IP)
- Neck of maraging rods/ redesigned.
- Mis-interfacing: length of type-A's wire and cryopayload
- Need more GV's in the couner station
- No maraging blades -> can be produced in Japan
- Maraging blades broken -> re-produced (高橋さんいわくいつぞやのf2f)
- Suspension drop
- Injury: pressed a finger; top plate of PR3
- Human drop: working around IYC
- Finger prints on a very high quality viewport
- Rotten parts stocked for a long time
- Darkside of internationalization; first- and third-angle projections, inch/mm, drawings and screws; some large parts were once made in the wrong understanding.
- Wastefulness: designed/manufacture eventually-unused instruments, so much. (iKAGRA end suspensions, iKAGRA transmission monitors, iKAGRA telescope for AS port)
- Mis-strategy: Type-Bp: budget required for Type-Bp eventully equals the original Type-B suspensions. Increasing numbers of types made things very complicated. (inner frame, traverse...)
- Screw Gall: SUS to SUS very sticky. SDC, BUMAX w chemical were used finally, but still need careful. Screw-gall cannot be avoided even with those. Ag-coated is the best for anti-galling, but dusty so avoided around mirrors. (By Takahashi). He also estimated maybe the workers got matured?
- Easily pick up wrong parts. After assembled, found the fact; attaching a drawing number to each pack of the parts... it is an obvious solution, but at the first time most of people underestimated it. Those who believed such careful treatment was important were mostly even persecuted, stop ped saying so, and got off from our project one by one.
- Retapping of bolt anchor holes for the oplev pylons.
- The end of the X-arm tunnel; no exits. Even no air holes to the tunnel. Small amount of portable oxygen tanks. The volume of each portable tank is not enough for a person to run through a 3-km way. Still half-baked.
- Different definition of "clean" something " among each research and/or company workers.; walking outside of the clean booth wearing clean suits...
- the chambers are too narrow;

Ok, I would like to just pick up some topics.



# Contents

- Interfacing issues
- Environmental issues
- Accidents/injuries
- Mechanical issues
- Vacuum/cryogenic issues
- Life with contractors



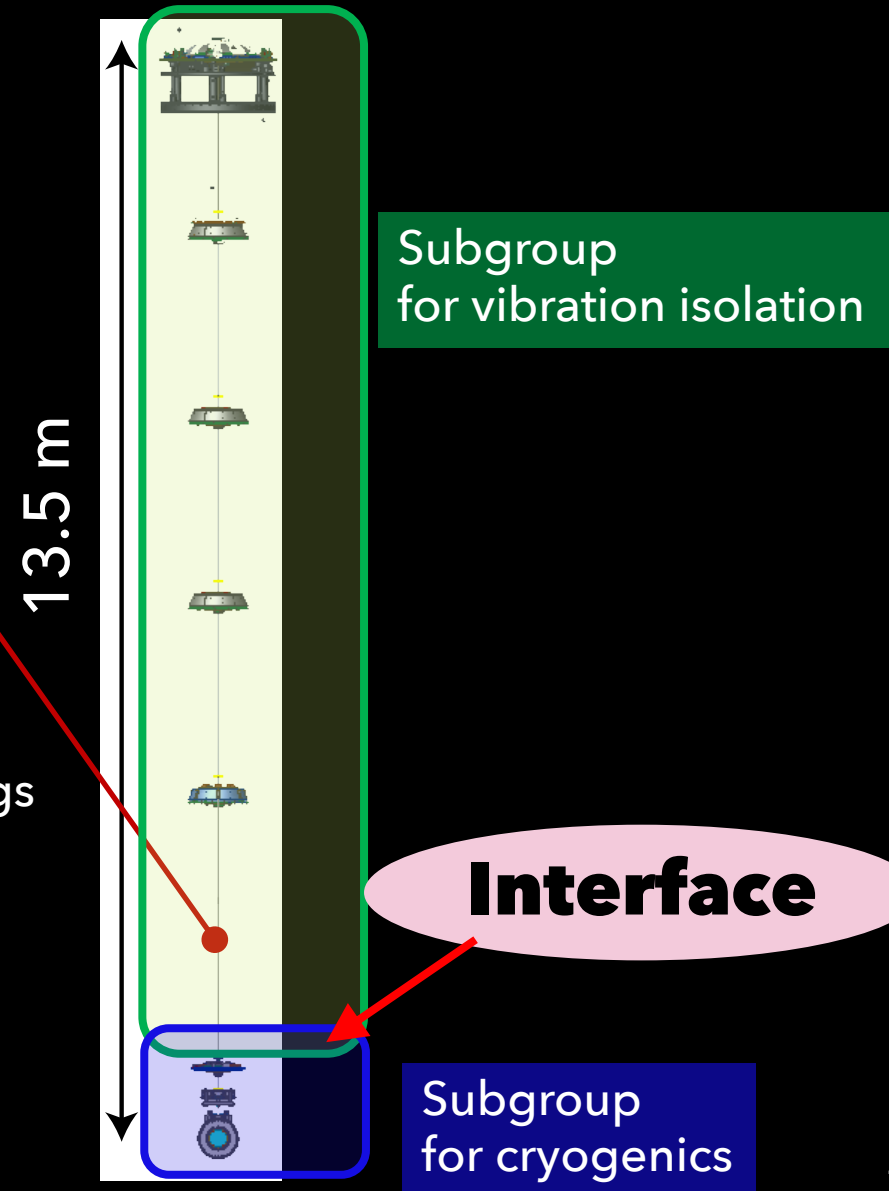
# Interfacing failures

- Breaking down to subgroups would be the key to construct a huge system.
- But the interface control is critical.

An example: we *finally* realized this on 18<sup>th</sup> May 2017 at the final timing of their integration.

Too long wire (~10 cm)

- We used different versions of the drawings each other.
- No system engineers.
- No interface control documents.





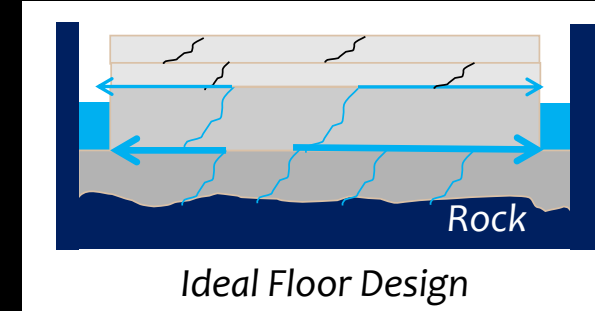
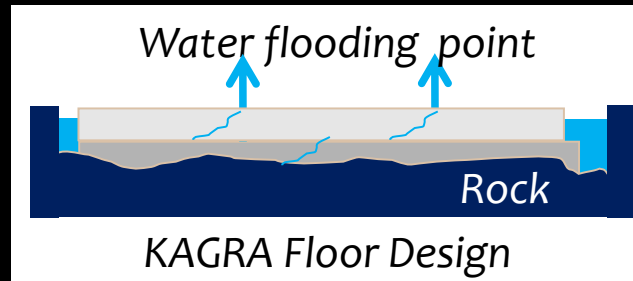
# Contents

- Interfacing issues
- Environmental issues
- Accidents/injuries
- Mechanical issues
- Vacuum/cryogenic issues
- Life with contractors



# Groundwater in the PSL clean room

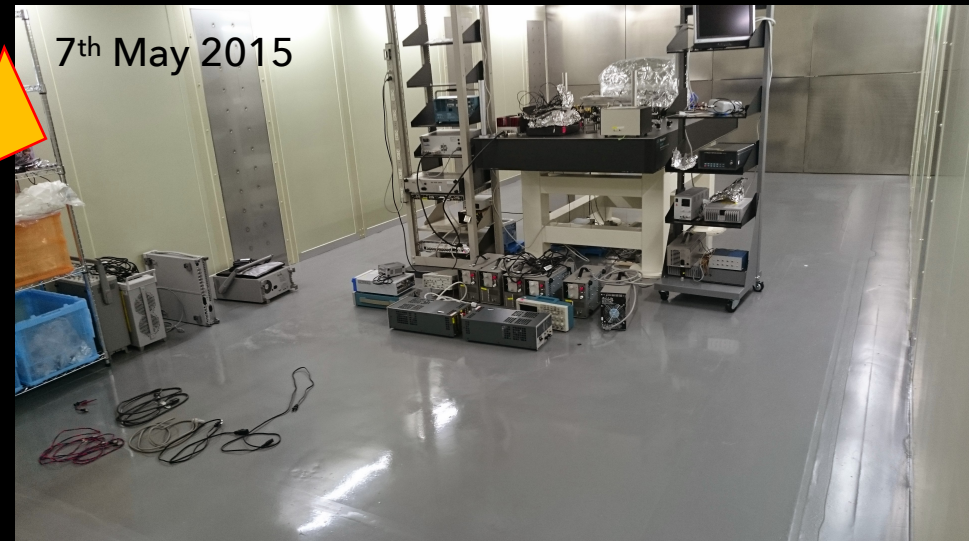
Miyoki, JGW-G1910154 →



- Note: you can find groundwater and rain everywhere in the tunnel!
- This is just an example of the (endless) fights from Dec 2014 to Apr 2015.



# Groundwater in the PSL clean room



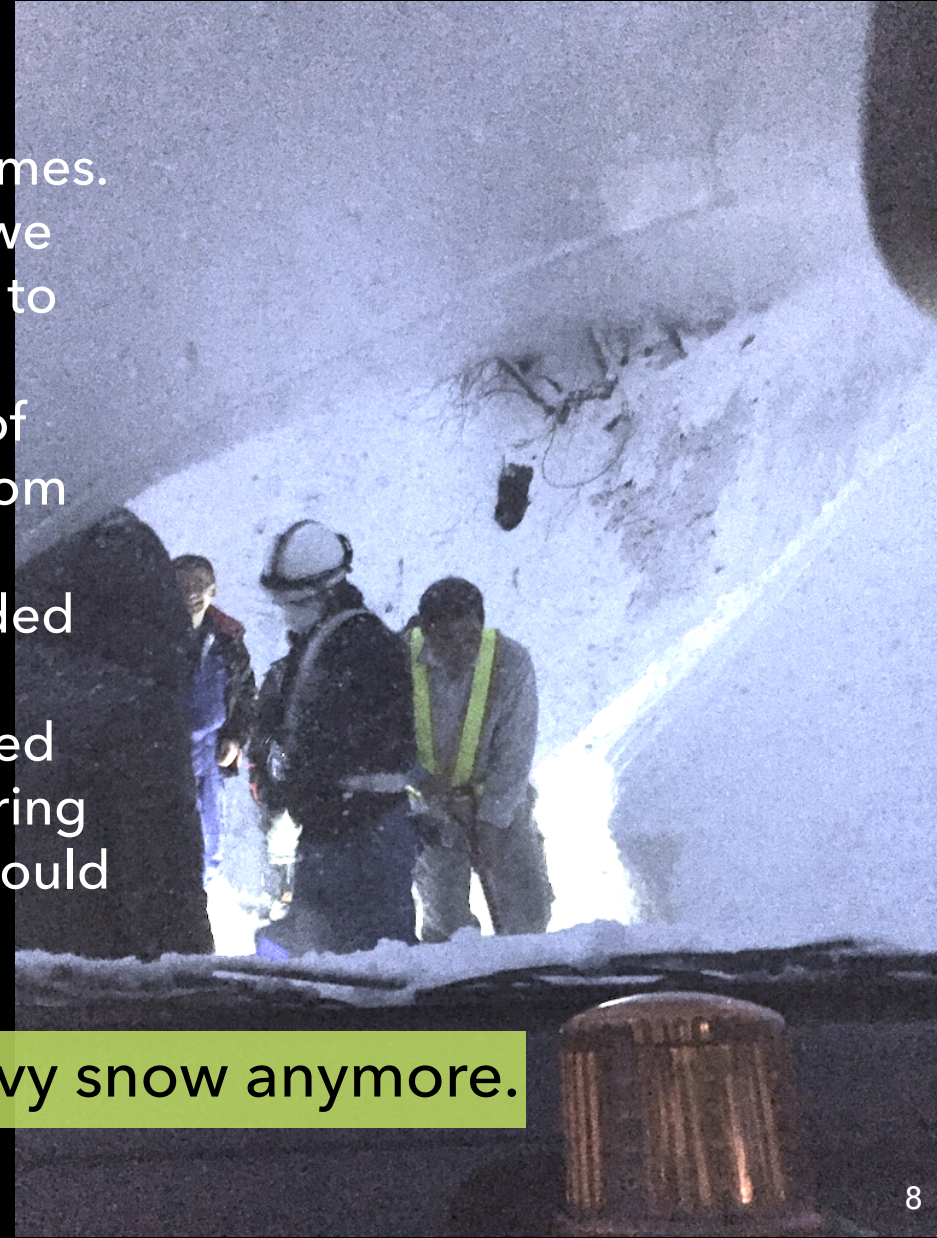
Built new drainages



# Electric car stuck in heavy snow

An example: 16<sup>th</sup> Jan 2017

- E-cars are useful in the tunnel; no fumes.
- On the day, due to heavy snowing, we stopped the works earlier, and tried to drive back from the tunnel.
- The car was trapped in a heavy fall of snow, and small avalanches came from the right.
- We tried to dig out the car, but needed to wait for arrival of a snowplow.
- In the car, the heater should be turned off to keep the battery of the car during the waiting; otherwise the battery would be running out in the low temp.



We don't use electric cars in heavy snow anymore.

# Blackouts in the tunnel

Some (unplanned) power outages happened so far.  
An example: 18<sup>th</sup> Nov 2017 (Sat)

- A power line to the tunnel was accidentally shorted.
- Not only the KAGRA tunnel but also the other tunnels.
- Pumps for groundwaters stopped .
  - Several numbers of battery-driven pumps were brought into the tunnel.

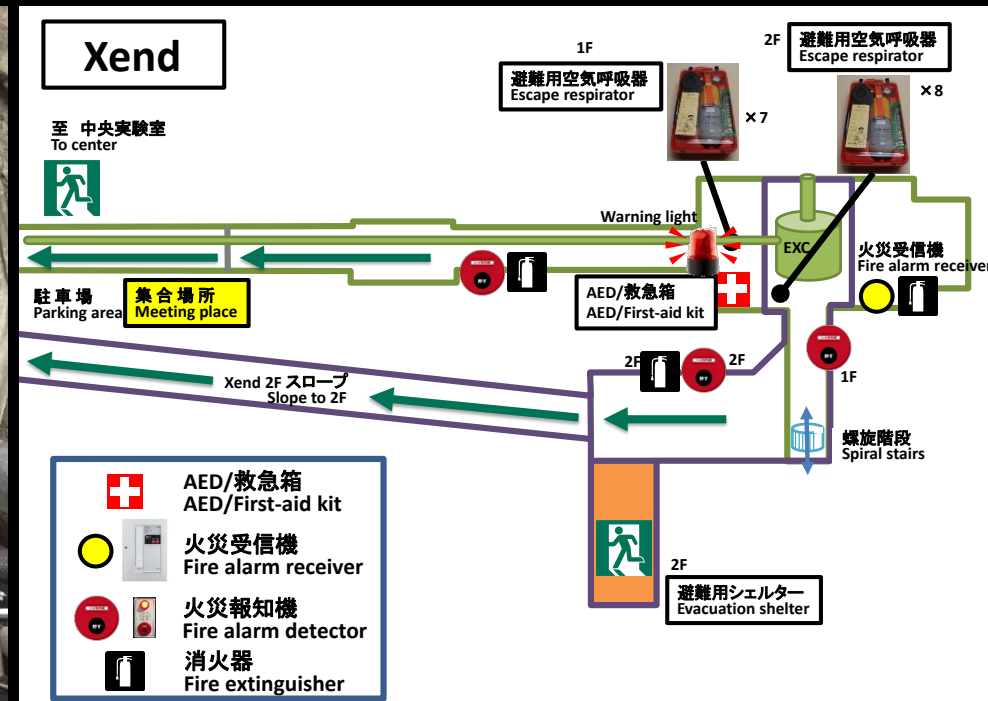
The critical infrastructures should not be left "ad-hoc"-ish.



# The tunnel

- The tunnel has a dead-end at the end of the X-arm; not escapable.
- The number of portable air tanks (respirators) are limited.
- The volume of the tank would not be sufficient for 3-km running; usable for only 10-min walking, 5-min running. (ref: I take 12 mins by E-assisted bike + walk.)

From JGW-M1910164-v2 "KAGRA Safety"



# Traps of cost cut

From S. Miyoki, the chief of facility subgroup of KAGRA

## 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.

<https://indico.ego-gw.it/event/12/timetable/>

The 1st KAGRA-Virgo-3G Detectors Workshop, Italy, Feb 16th 2019

# Contents

- Interfacing issues
- Environmental issues
- Accidents/injuries
- Mechanical issues
- Vacuum/cryogenic issues
- Life with contractors



# Suspension drop

At the installation test of a suspension with a spare mirror for PR3 on 10<sup>th</sup> Dec 2015



Clean cover

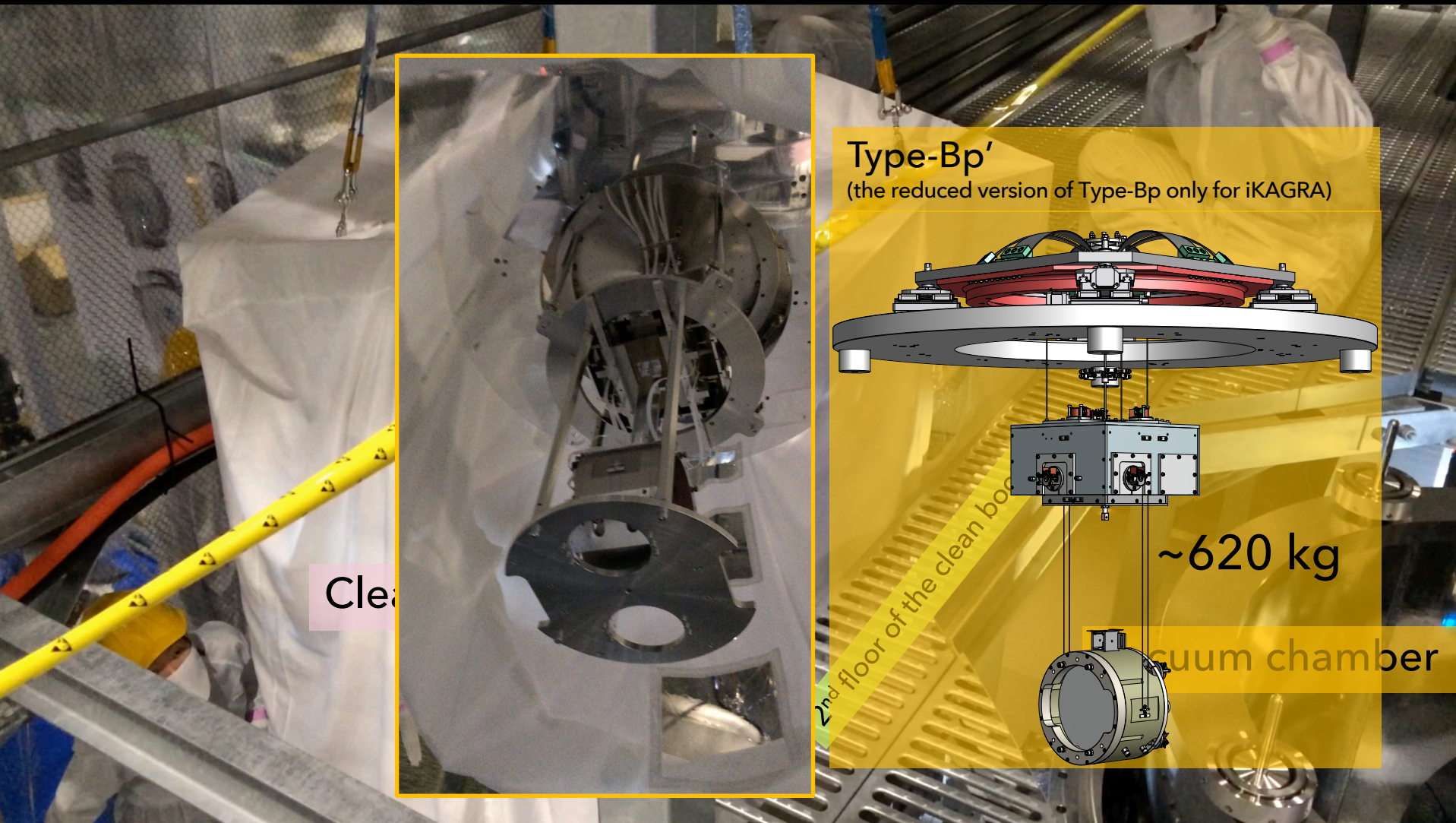
2<sup>nd</sup> floor of the clean booth

Vacuum chamber



# Suspension drop

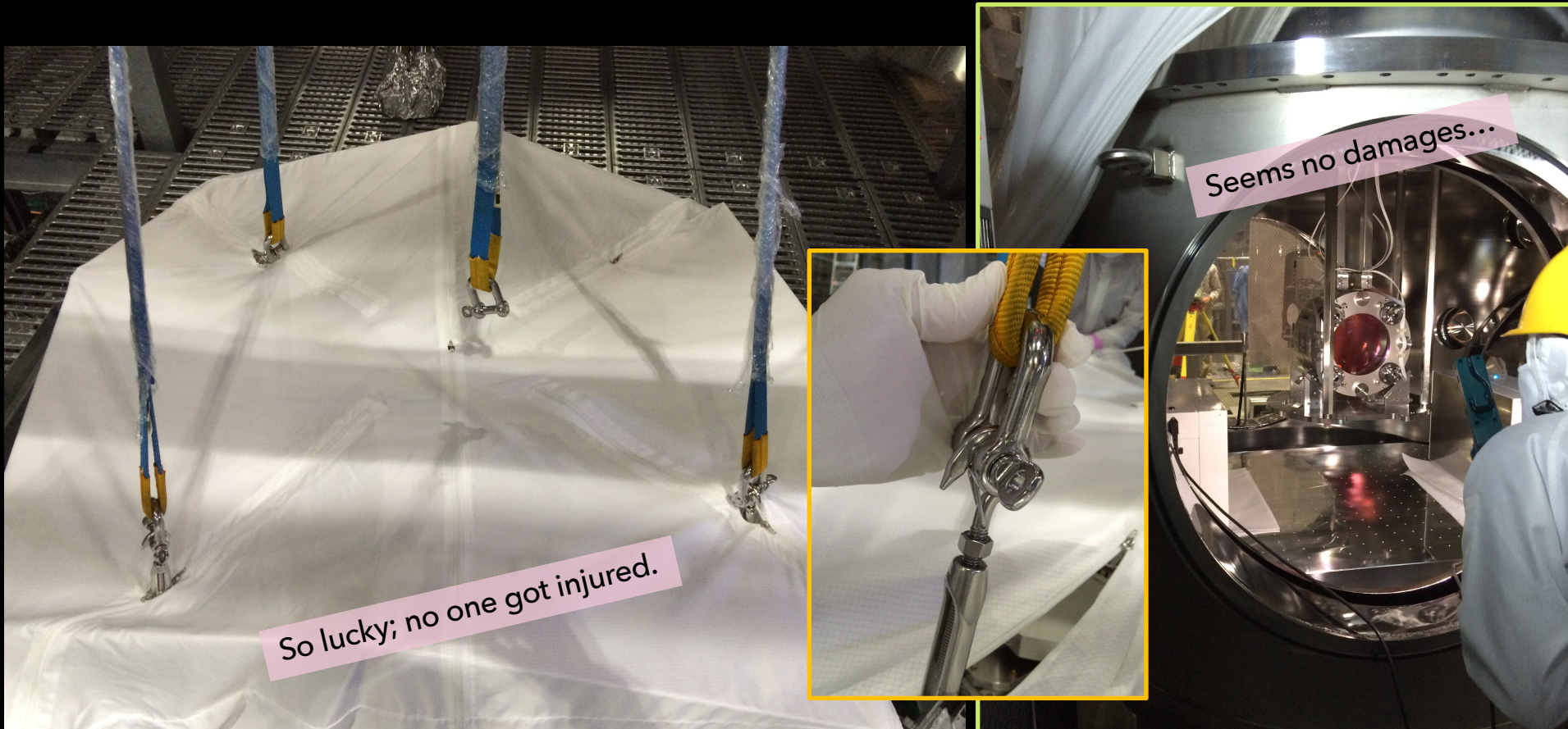
At the installation test of a suspension with a spare mirror for PR3 on 10<sup>th</sup> Dec 2015





# Suspension drop

- One of the four turnbuckles (to balance the load) suddenly unhooked during the crane work.
- The load fell ~ 1 cm and arrived (crashed!) onto the target position!



- **Mystery:** neither the turnbuckle nor the shackle seemed broken; a bad hooking from the first!?
- If so, the clean cover hid the bad hooking?? → Now we don't use such turnbuckles for these works.
- Plus, actually a pair of hook points were connected by a single sling. If the turnbuckle would have unhooked at the higher position, the paired point would lose the tension at once, and the load would swing, and caused severe injuries... again, we were so lucky. → "One hook for one sling".



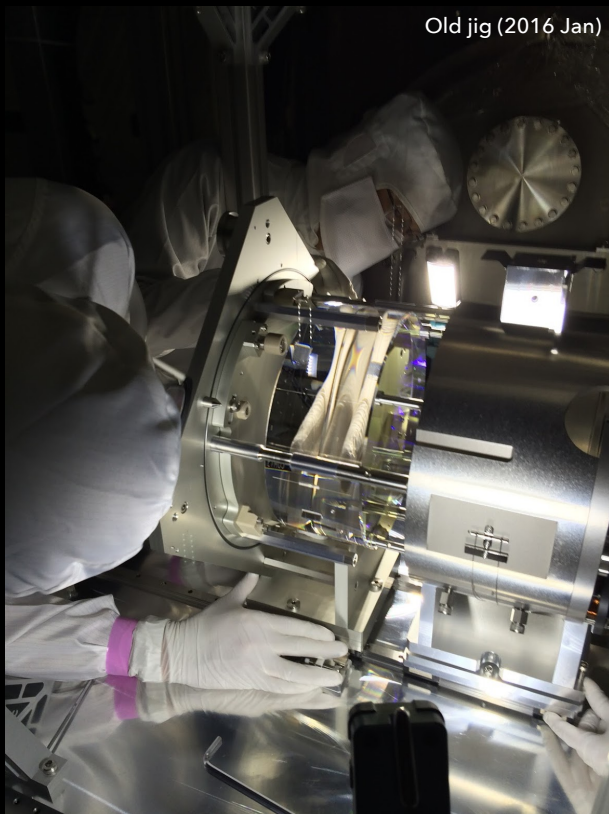
# Mirror drop

10<sup>th</sup> Nov 2016

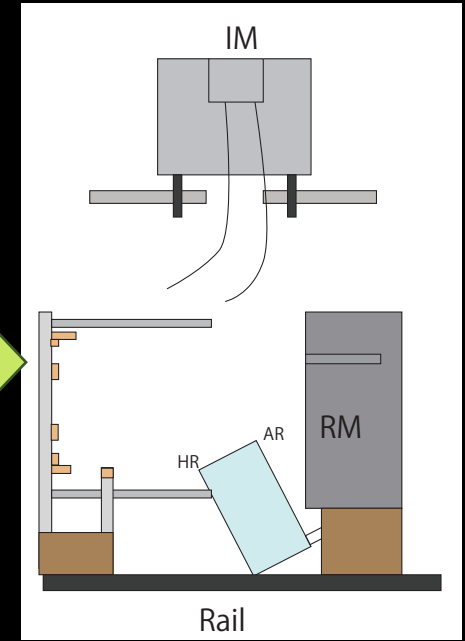
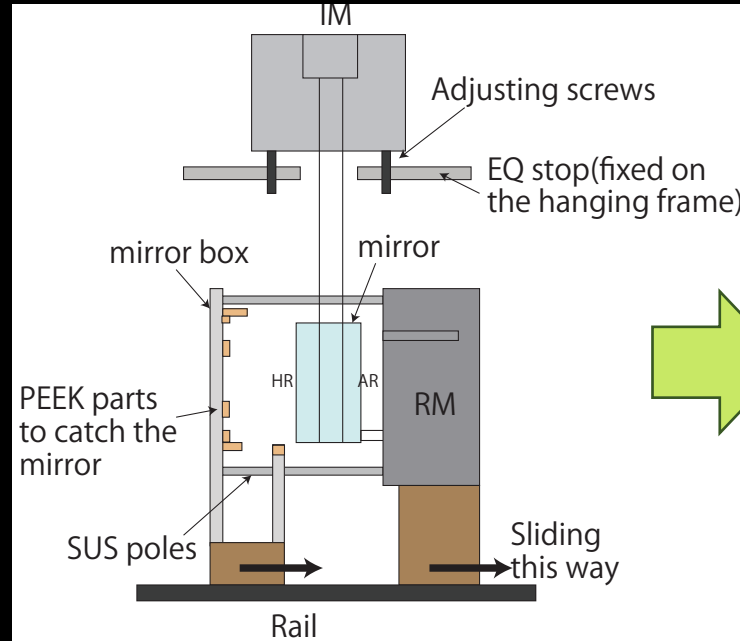
<http://klog.icrr.u-tokyo.ac.jp/osl/?r=2119>

Happened when the workers tried to detach the PR3 mirror from the suspension for the upgrade from iKAGRA to bKAGRA.

→ We stopped, and took time to modify/re-consider the jig and the procedure.



Old jig (2016 Jan)



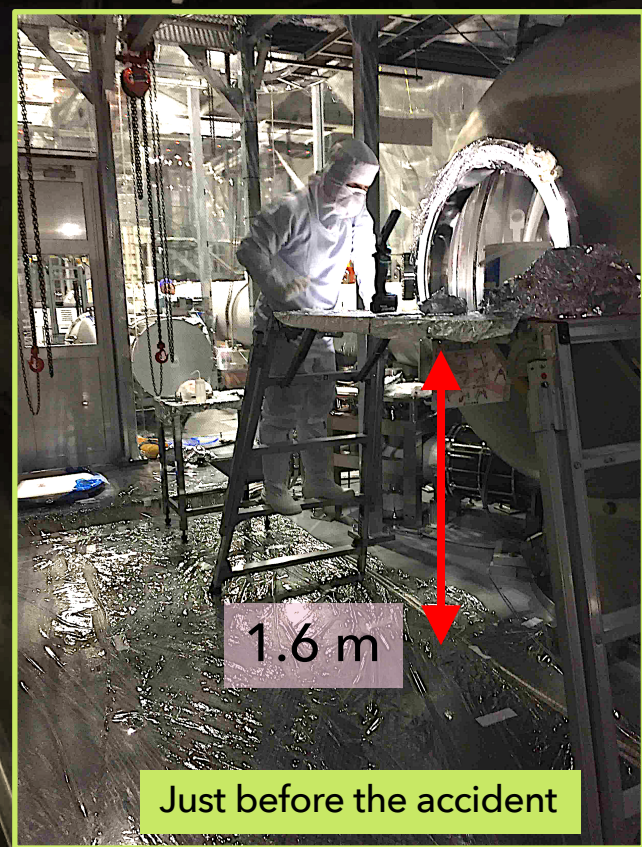
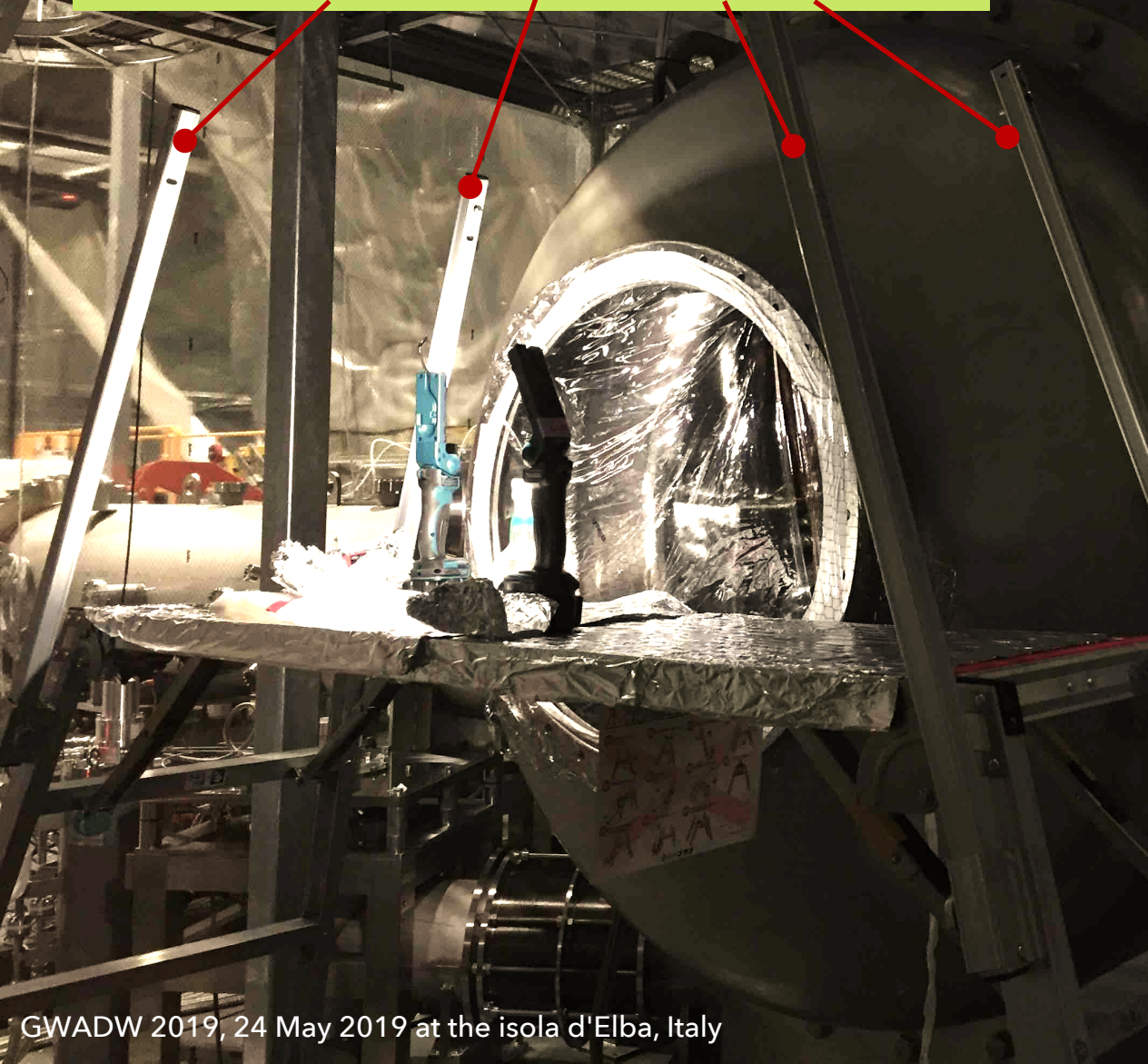


# Human drop

13<sup>th</sup> Jun 2017

So lucky: the worker did not get injured at all.

Those handles must be extended as written in the manual.



1.6 m

Just before the accident

Cryostat for ITMY

# Contents

- Interfacing issues
- Environmental issues
- Accidents/injuries
- **Mechanical issues**
- Vacuum/cryogenic issues
- Life with contractors



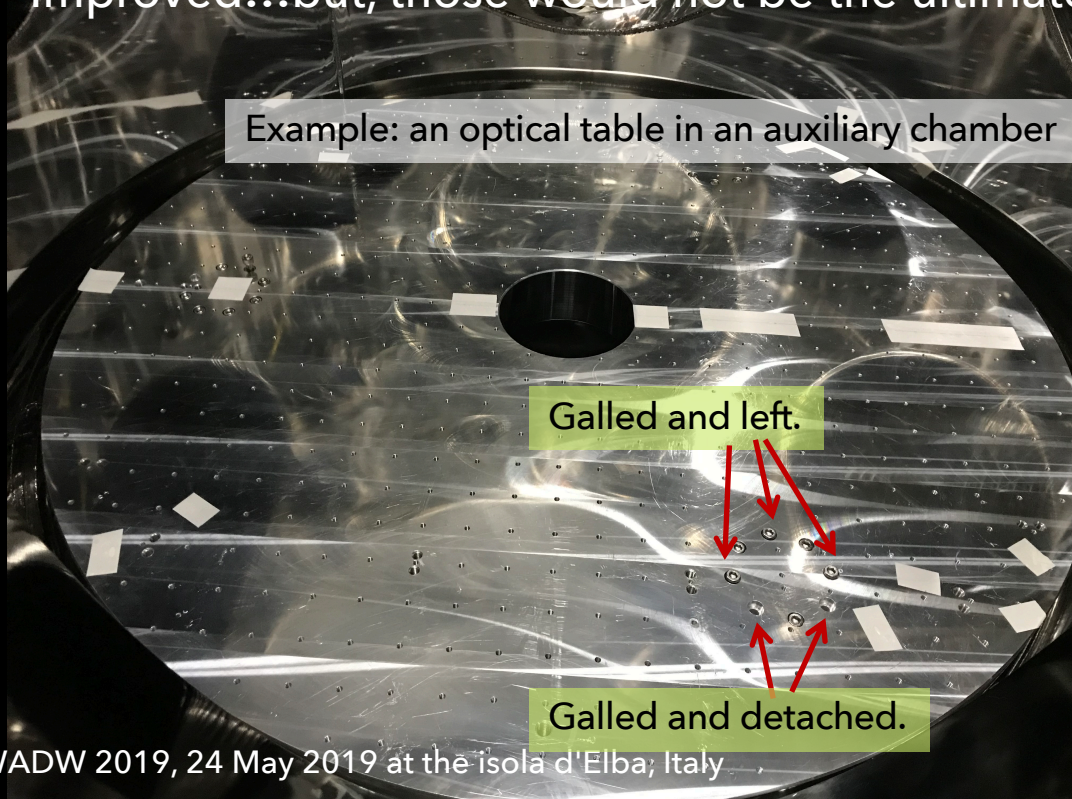
# Screw galling

A major show-stopper at the initial stage of our installation work.

- Stuffs made of the same material (metal) adhere each other easily.
- Typical: washed SUS parts with screw holes used in vacuum chambers

After some investigations...

- Screw policy <https://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/DocDB/ShowDocument?docid=5107>
- For the SUS parts, SDC clean bolts or chemical washed BUMAX109 should be used.
- Improved...but, those would not be the ultimate answers; keep investigations.



Example: an optical table in an auxiliary chamber

Galled and left.

Galled and detached.

SDC clean bolts

<http://www.sdc-tanaka.co.jp/html/product-clean.html>

国際プロジェクトKAGRAに採用

大型低温重力波望遠鏡"KAGRA"とは

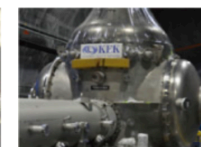
KAGRA 計画（大型低温重力波望遠鏡計画）は、ブラックホールの解明などを旨とする、「重力波の直接観測」の国際プロジェクトです。  
ノーベル賞を受賞した梶田隆章教授が所長を務める東京大学宇宙線研究所をはじめ、国立天文台や高エネルギー加速器研究機構が主導し、国内外の数多くの研究機関の研究者が参加する一大プロジェクトです。

プロジェクトへの部品提供

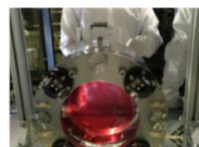
KAGRA 建設プロジェクトでは、真空装置、高出力レーザー、低温鏡など、それぞれの分野のエキスパートが最高品質の部品を提供し世界最高レベルを実現します。  
「SDCクリーンボルト」は、その品質を認められ、各種装置の部品として採用されています。



3kmに渡る真空ダクト



高真空装置



組立作業

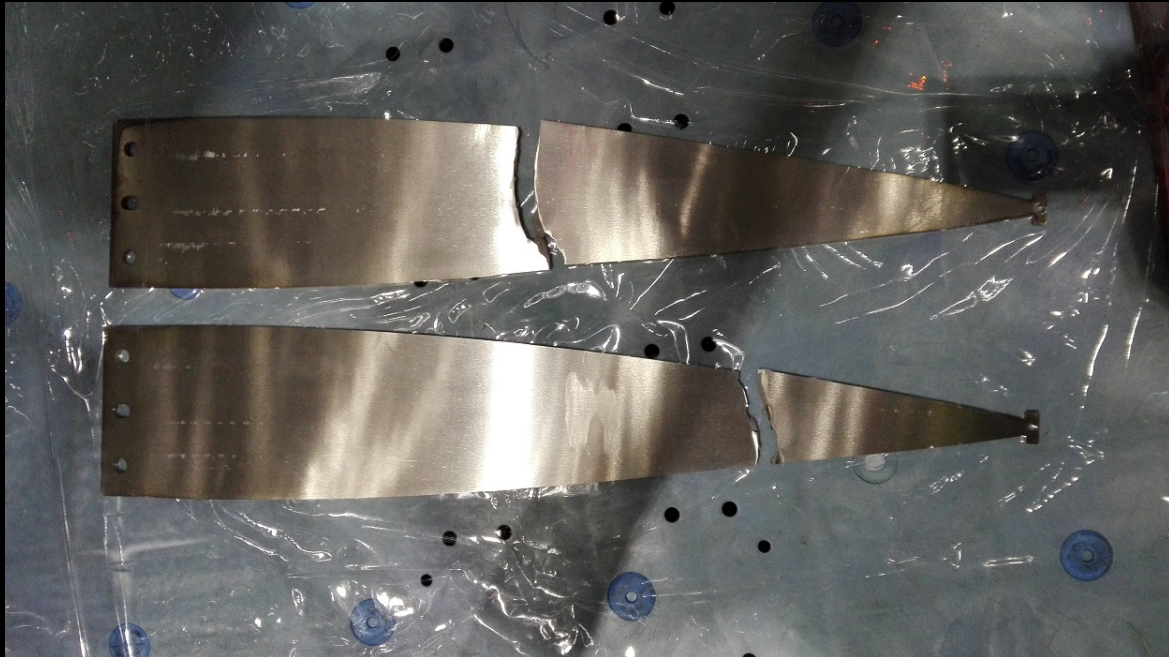
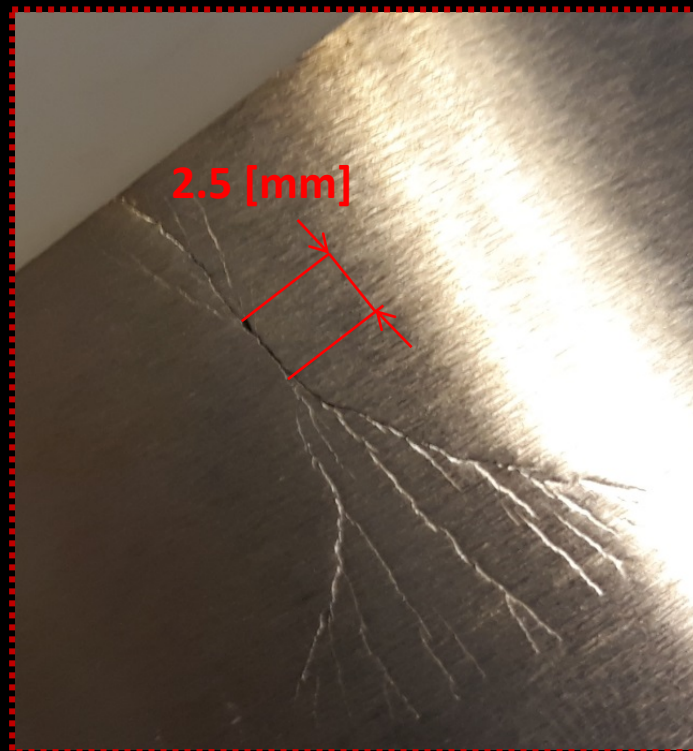
提供: 自然科学研究機構 国立天文台 および 東京大学宇宙線研究所

# Blade spring breaking

We found those on 16<sup>th</sup> Jan 2018.

- Some of thick blade springs for top GAS filters were broken or cracked.
- Imported and stocked for a long time...
- The process and why they broke have been investigated and reported.
- Replaced with new ones (in the new process) made in Japan.

JGW-G1808285  
JGW-G1808891



# Contents

- Interfacing issues
- Environmental issues
- Accidents/injuries
- Mechanical issues
- Vacuum/cryogenic issues
- Life with contractors

## Some typical accidents for vacuum

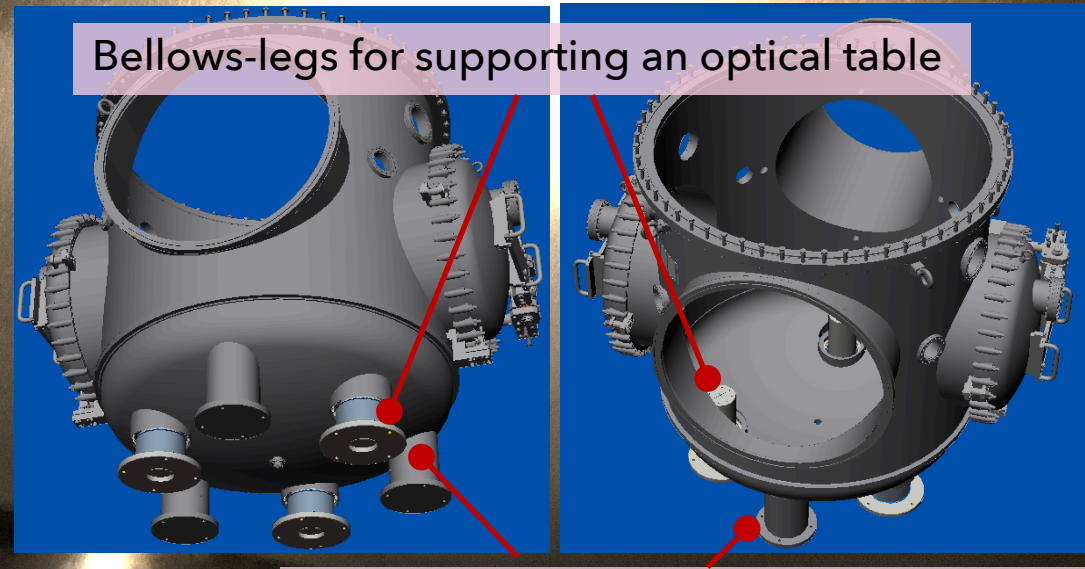
- A tentative plastic cover for a flange was absorbed.
- A tentative aluminum cover for a flange was bended.
- Storm in the chambers: thermal insulators broke into fragments.
- No gaskets and leaked very much
- Not torqued bolts and leaked very much



# Levitation

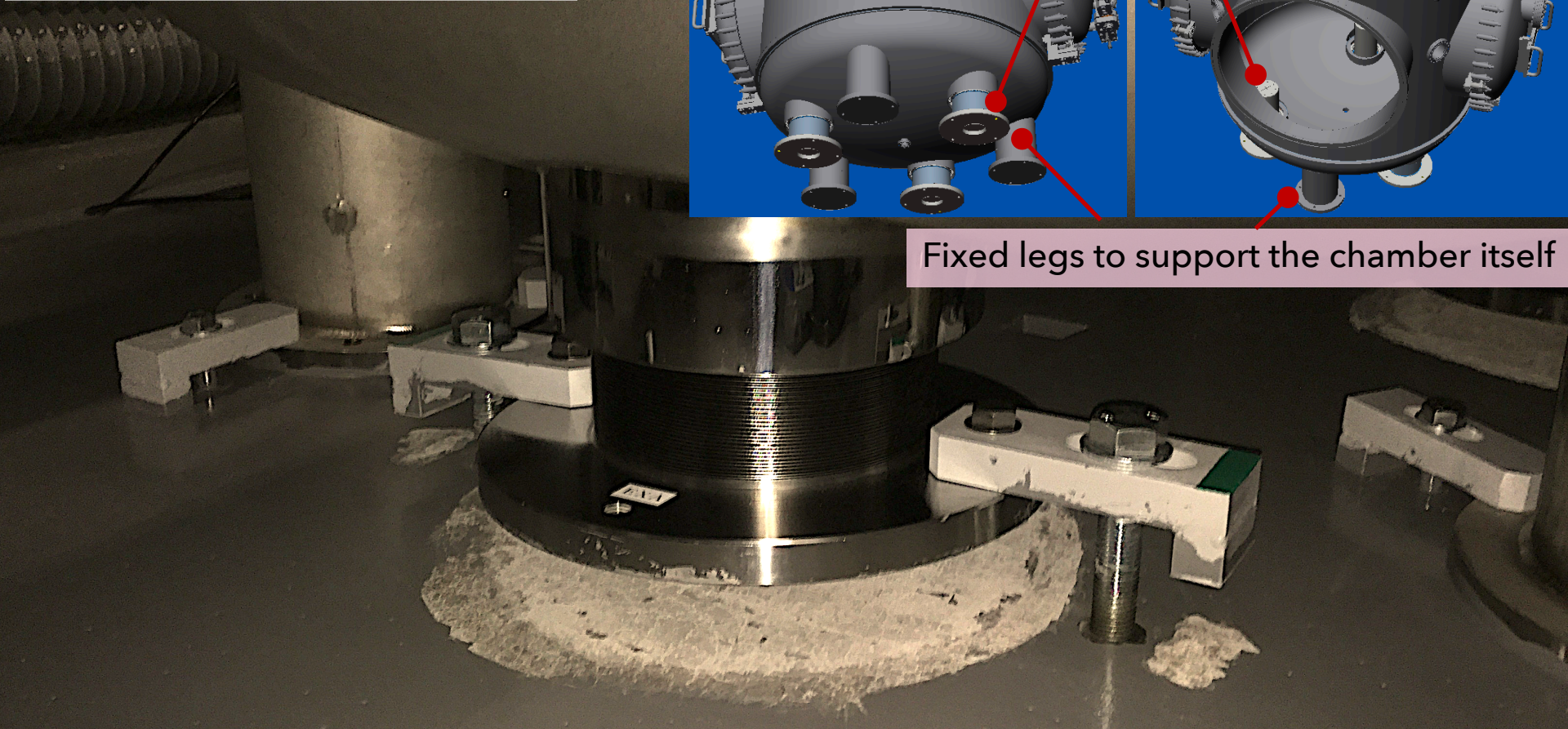
11<sup>th</sup> Mar 2016

<http://klog.icrr.u-tokyo.ac.jp/osl/?r=989>



Bellows-legs for supporting an optical table

Fixed legs to support the chamber itself



The optical table in the chamber was also floated.  
A freely suspended (iKAGRA-)ETM was on the optical table... → no damages



# Viewport explosion

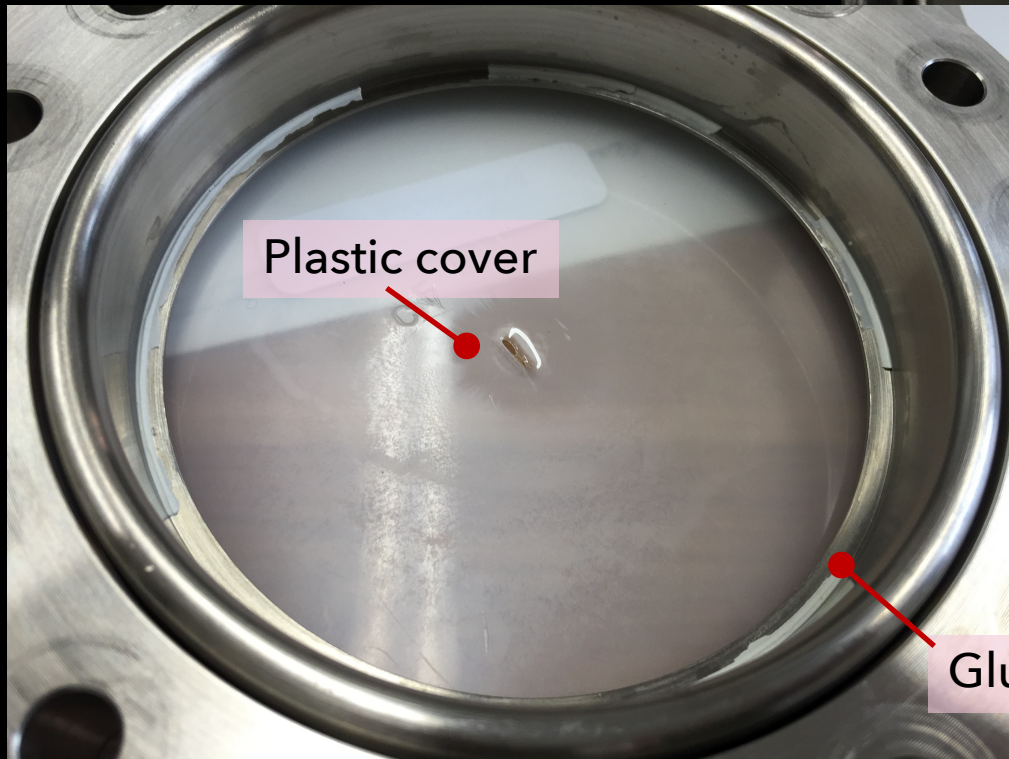
14<sup>th</sup> Mar 2016

(Not implosion)

<http://klog.icrr.u-tokyo.ac.jp/osl/?r=1347>

- We were hurry to vent the chamber, as the inside had levitated.
- No safety valves for over-pressure

Now we attach a safety valve-ish for venting.



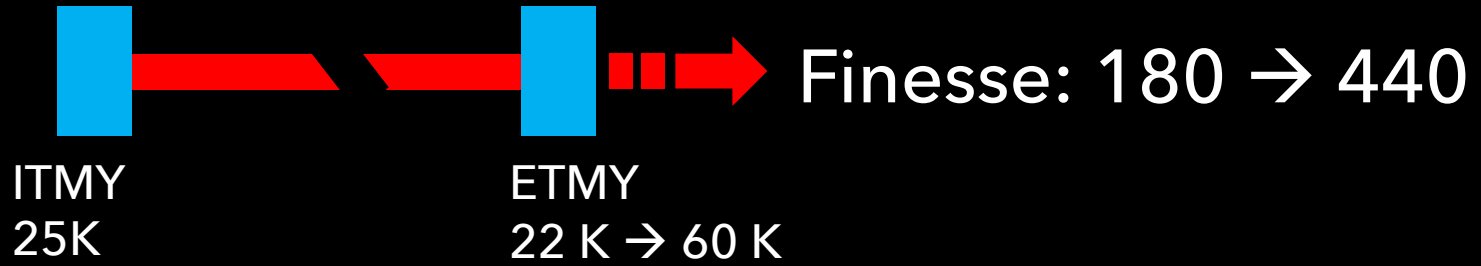


# Icing/frosting (?)

The investigation is ongoing now.

<http://klog.icrr.u-tokyo.ac.jp/osl/?r=8931>

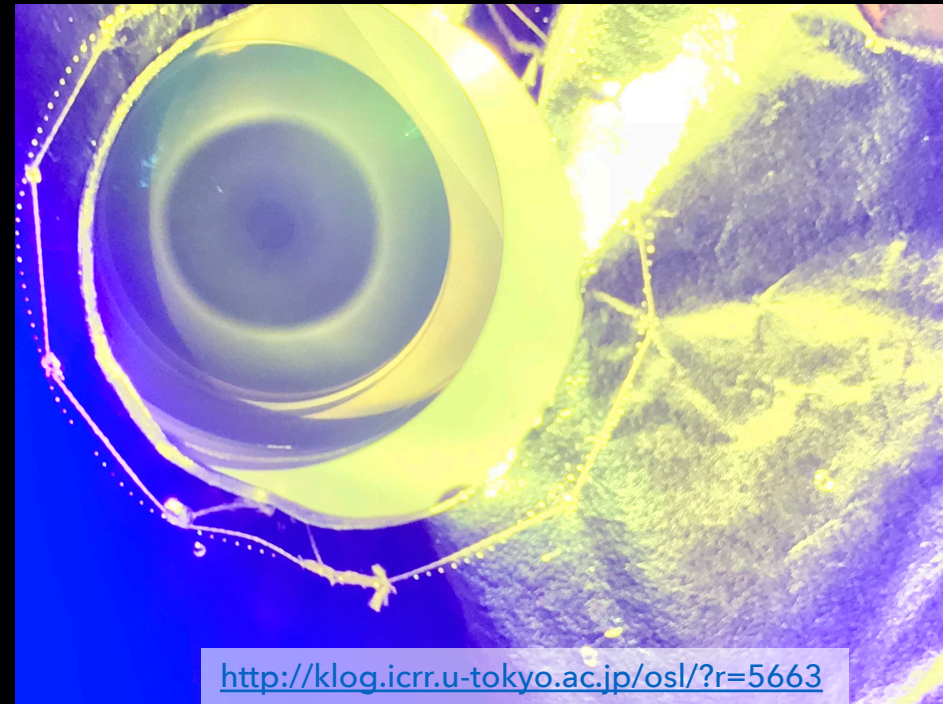
We found the finesse of the cryogenic Y-arm cavity was too low... suspected icing on the mirror(s), so started to heat up.



Ref: the Xarm's finesse has been kept  $\sim 1450$  w/ ITM@29K + ETM@150  $\rightarrow$  124K Cooling of the ETM is still on-the-way; keep observing.

Actually, icing was already observed for viewport windows for oplevs the other day.  $\rightarrow$

- In the chamber, it has been  $\sim 10^{-5}$  Pa
- If the reducing finesse is due to the icing, what made them?  $N_2$  and/or  $H_2O$ ?  $\rightarrow$  comparing the pressure monitors and temperature varying; adding mass spectrometers...
- What else?...



<http://klog.icrr.u-tokyo.ac.jp/osl/?r=5663>

Photo of a frosted window for oplev (31<sup>st</sup> Jul 2018)

# Contents

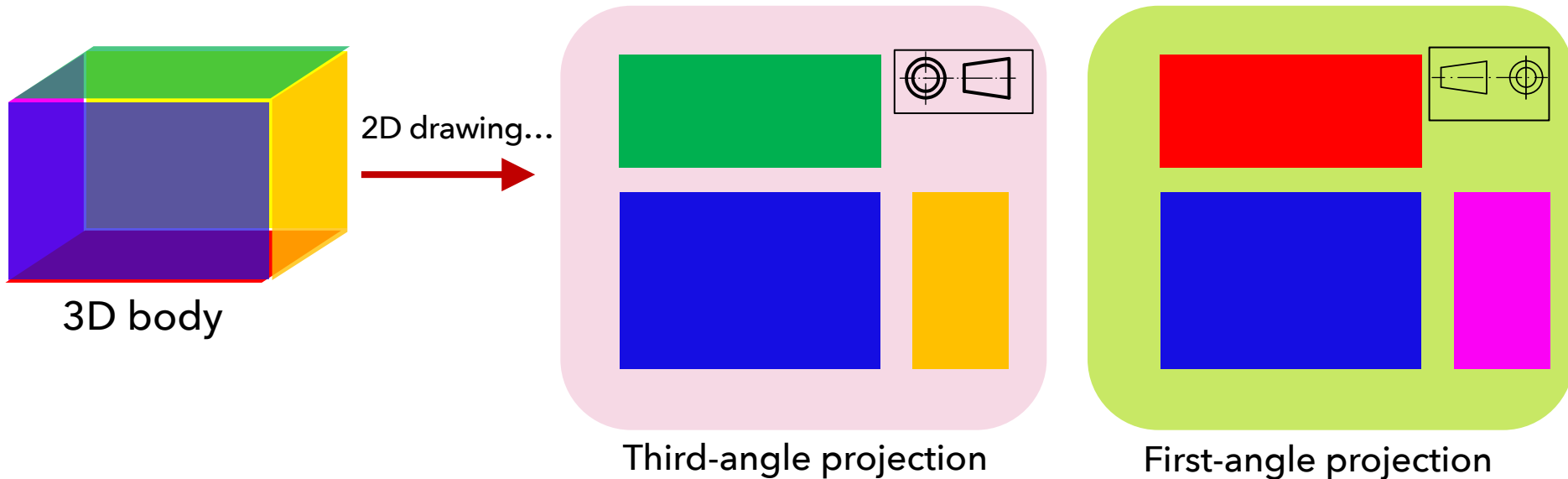
- Interfacing issues
- Environmental issues
- Accidents/injuries
- Vacuum/cryogenic issues
- Life with contractors



# Drawings

- Local manufactures (and we) *might* miss imported 2D drawings.
- We elaborated the translations for avoiding errors, but sometimes failed.

	Japan	US	Italy
Unit/screws	millimeters	inches	millimeters
Projection	3 <sup>rd</sup> angle	3 <sup>rd</sup> angle	1 <sup>st</sup> angle
Notes in	Japanese	English	Italian



# Contractors

Understand what you ordered well; monitor and/or steer them properly.

We need helps of expertized contractors for several heavy works like

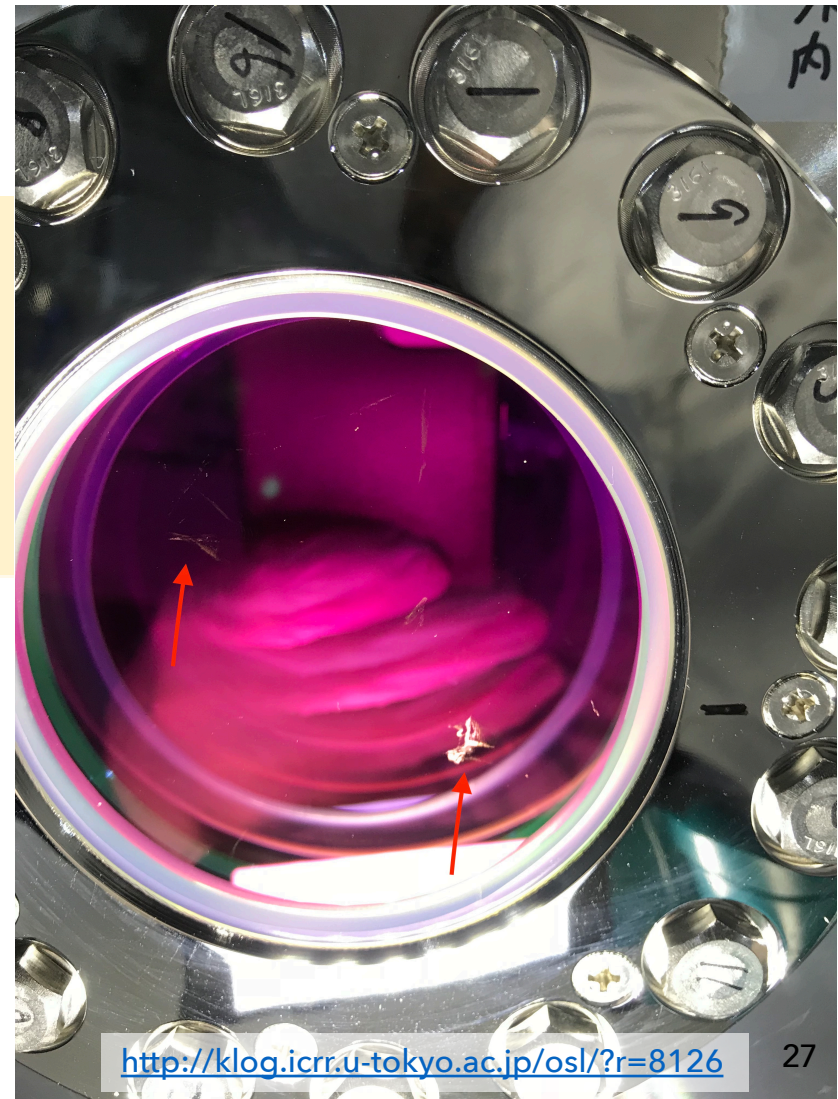
- Closing/connecting vacuum chambers/tubes,
- Bringing/moving large structures,
- Cleaning,
- And so on... to maintain the infrastructures.

Some dangerous phrases from collaborators are:

- "Don't worry, *that* would be also **common sense** to them!"
- "**They are experts** on this work, so just rely on them!"
- "**I'm not sure what/why I should monitor**, but I believe them and they would be able to do it!"

Some examples

- Worked in a clean booth without wearing clean wears.
- Went outside of the clean booth with clean wears, and then came back to the inside.
- Touched an oplev during closing vacuum tanks; the oplev was a reference for the alignment of the mirrors.
- Touched a viewport windows by a metal nozzle during the leak check.
- (?) Left dirt or finger prints on an expensive viewport window.





# What else???

