

Wishes/Thoughts/Maps/Plans on Experimental Gravitation in Taiwan

- Grand Landscape in Basic Physics
- TEXONO's Existing Programs & Evolution/Transition/Expansion
- Experimental Gravitation Research in Taiwan
 - ⚡ History, Cast, Menu
 - ⚡ Program Overview, Highlights, Status *[What?]*
 - ⚡ Challenges, Strategies & Plans *[How?]*

Henry T. Wong / 王子敬



Academia Sinica / 中央研究院

August 2023



The Grand Landscape [大視野]



📖 Fundamental Conflict between the Universe comprehended via
Gravitation [General Relativity – Macroscopic] Vs
Particle Physics [Standard Model – Microscopic]

微觀(粒子作用) 與 宏觀(重力現象) 在
實驗數據 與 理論基礎 的 矛盾

- ☑ Experimental Data (Observations)
- ☑ Theoretical Formulation

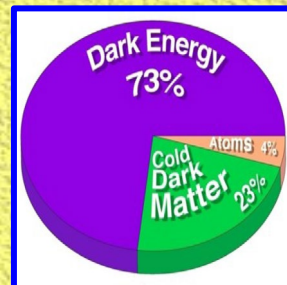
⇒ **Mainstream Interpretation:**

~95% of the Energy Density of the Universe is not understood ??

📖 Gravitation stands out in our lack of/incomplete understanding

⇒ IOP to make a serious attempt into – **AND take lead in Taiwan on --**

“How to Confront Gravitation Physics”



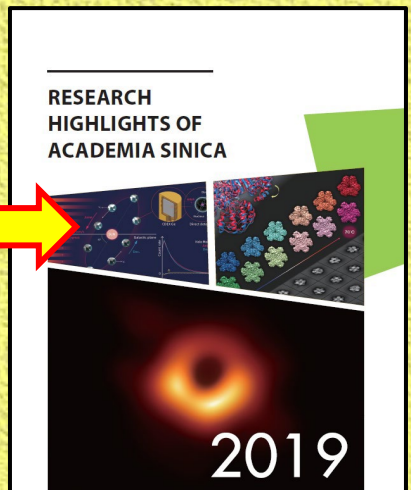
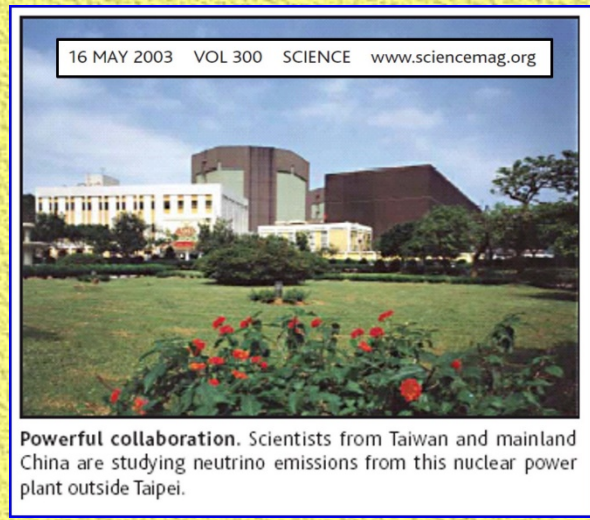
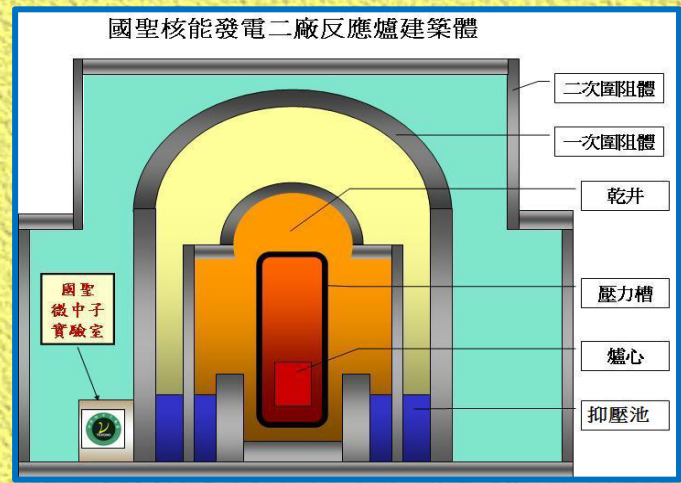
From My Comfort Zone



Taiwan EXperiment On Neutrino — History and Prospects

International Journal of Modern Physics A
Vol. 33, No. 16 (2018) 1830014 (30 pages)
© World Scientific Publishing Company
DOI: 10.1142/S0217751X18300144

Henry Tsz-King Wong
Institute of Physics, Academia Sinica, Taipei 11529, Taiwan
htwong@phys.sinica.edu.tw



Annual Review of Nuclear and Particle Science
Annu. Rev. Nucl. Part. Sci. 2017. 67:231–51

The China Jinping Underground Laboratory and Its Early Science

Jian-Ping Cheng,¹ Ke-Jun Kang,¹ Jian-Min Li,¹ Jin Li,¹ Yuan-Jing Li,¹ Qian Yue,¹ Zhi Zeng,¹ Yun-Hua Chen,² Shi-Yong Wu,² Xiang-Dong Ji,³ and Henry T. Wong⁴

Facing Our Next Mountain



TEXONO Program (Ongoing) : Move On, Pass On, Re-Invent, Re-Define

🔧 TEXONO.ν @KSNL etc.

- Reactor decommissioned 2023, operation till 2025 towards DM & νN
- Continue low threshold HPGe Prototyping (expecting another jump soon)
- Options of moving [O(100eV) ECGe's] to external labs to continue
 - ❌ Scientifically Optimal: ~~Kalinin Reactor, Russia, X10 ν flux~~ !!! XXXXX !!!
 - ✅ Sanmen Reactor, China, headed by *Yang Litao (T-G3)*, X1.5 ν-flux



🔧 TEXONO.DM @CDEX @CJPL [headed by Yue Qian, T-G2]

- ✅ Many recent good Phys. Rev. analysis results by *COMPETENT* students!
- ✅ 14-m diameter cryostat commissioned 2023
- ✅ Plan: $0\nu\beta\beta$ grade background control for DM searches
- ✅ Ton-scale Ge “World-Experiment” for $0\nu\beta\beta$, much hampered by world's events



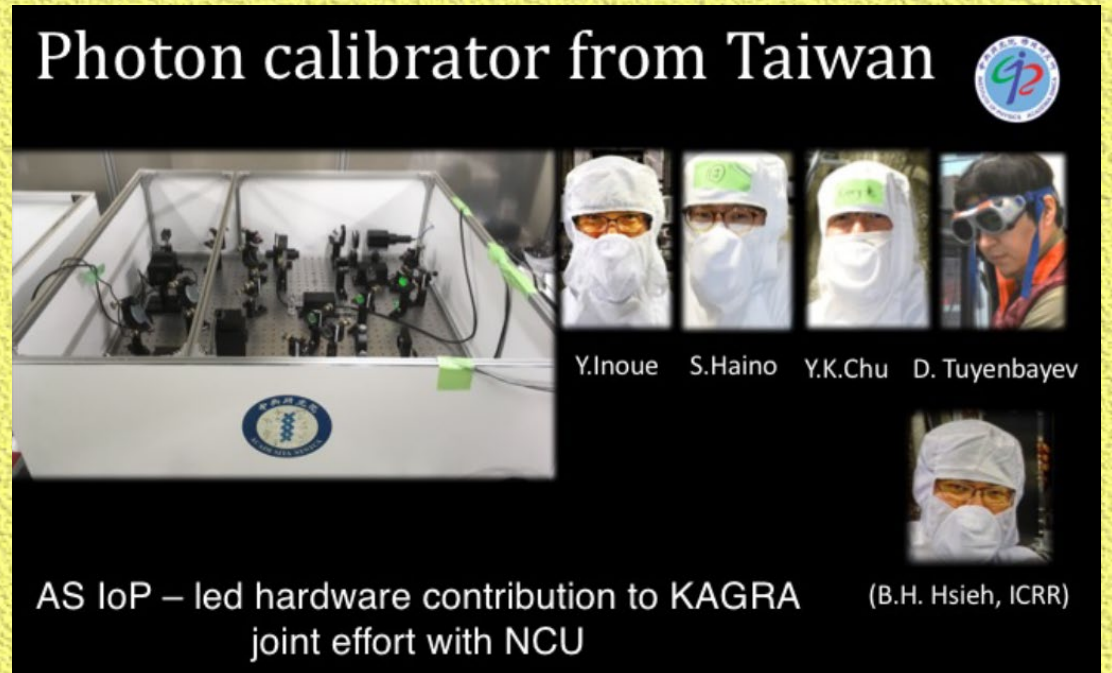
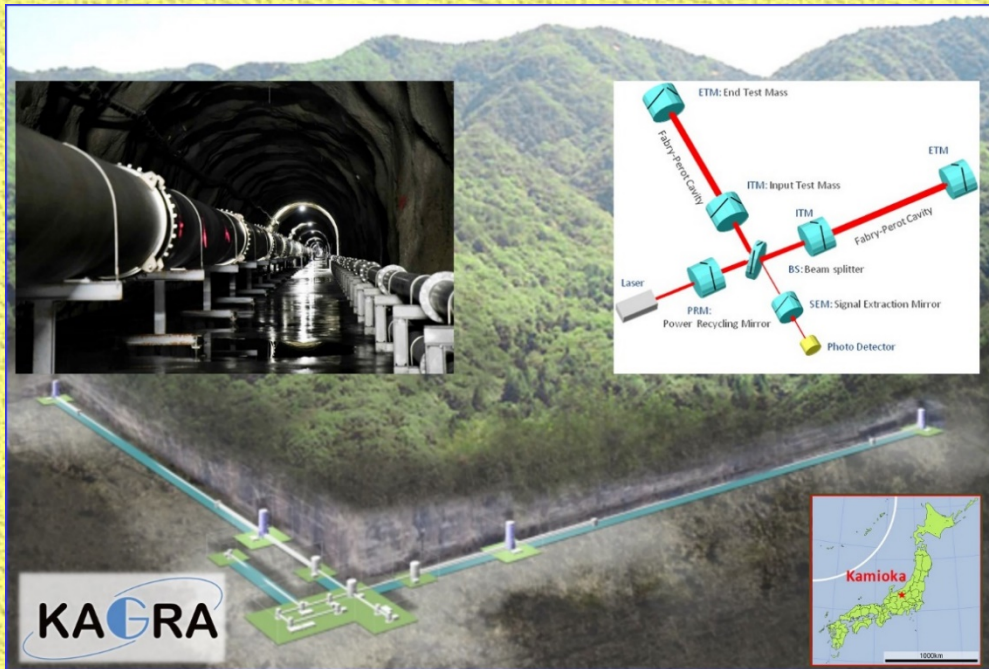
🔧 TEXONO.Th

- ✅ Active and rich program, collaborating *ASIOP-Theory, NTU, NDHU*
- ✅ *L. Singh (CUSB, T-G3), M. Deniz (DEU, T-G2)* and teams at forefronts.

i.e. TEXONO-ν, DM, Th - Require Only Positions & Brain-Power & minor equipment

Experimental Gravitation in Taiwan

- Early table-top BSM-GR experiments at NTHU (Ni...)
- Sada Haino (AS) initiated KAGRA in TW (since ~2016)
- Expanding teams & communities: *NCU, NTHU, NTNU, TKU + Theorists*
- AS @ KAGRA: *Calibration Leading Group (Laser, Gravity), High-Power Lasers, Computing Resources*
- Other TW@KAGRA: *Quantum Optics (NTHU), Analysis (Astro, Cosmo..)*



TEXONO.Gravitation

(since ~2018; ~15 members 2023)

- ✓ Yuki Inoue (NCU, AS)
- ✓ Chao Shiuh 趙煦 (NTHU)



CHRONOS



CHRONOS May 2023

✓ RAs & Students joined KAGRA Calibration

- ✗ Analysis of “PCAL” (photon calibrator) data (till 2021)
- ✗ Constructed “GCAL” 1.0 (gravity calibrator) at AS

✓ AS+NCU approved to join LIGO June 2021:

✗ LIGO: significantly more advanced in hardware; relevant R&Ds at frontiers.

✗ Official LIGO listed:

- ✓ Take over NTHU Mirror Coating Expertise and Facilities and NG-R&D

🔔 *TW's only facility directly linked to a Nobel Prize !*

- ✓ Calibration software & analysis

✗ R&D Items (Target: seek LIGO-endorsement):

- ✓ NG-GW techniques with Cryogenics
- ✓ “GW System Test Facility” for future GWs @ ASGRAF
- ✓ “Get into” analysis GW public and internal data

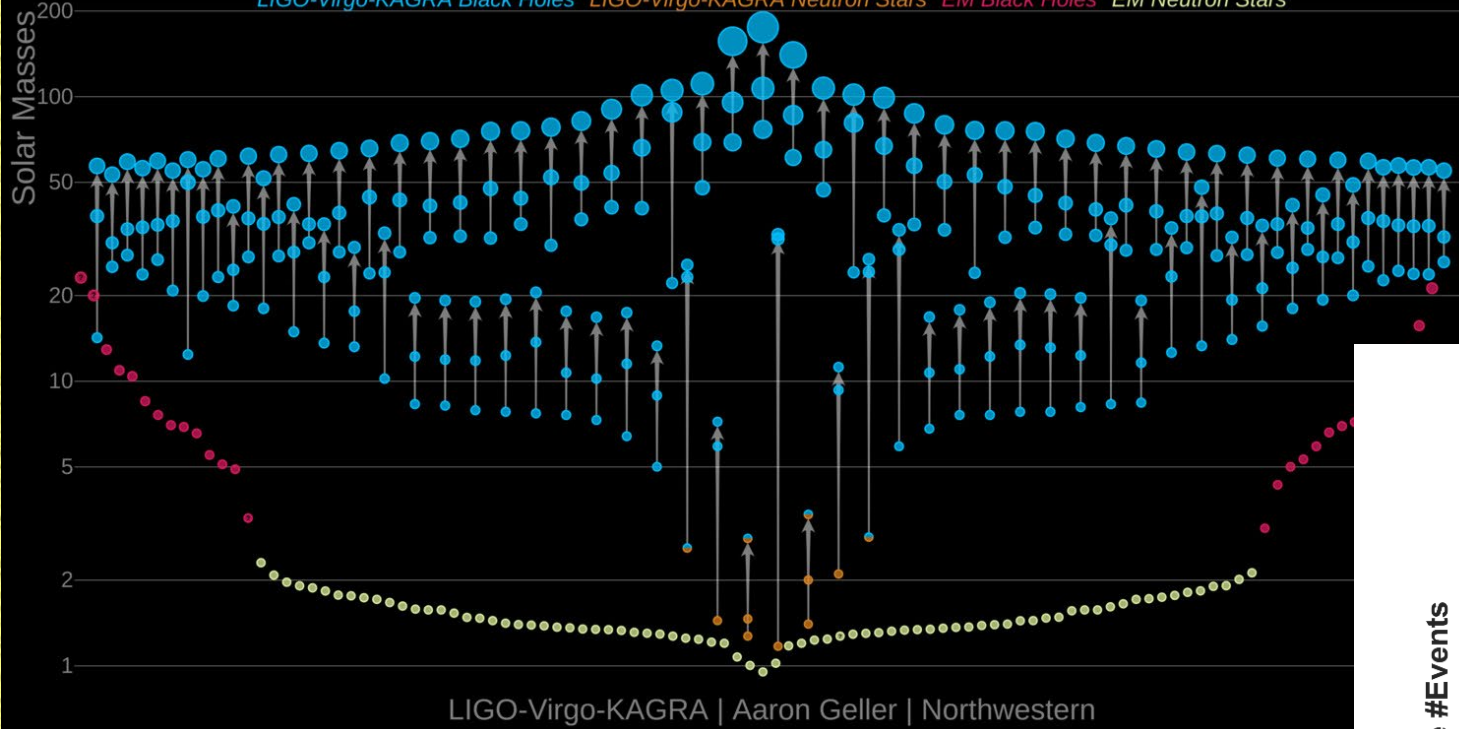
✓ Domestic CHRONOS Project



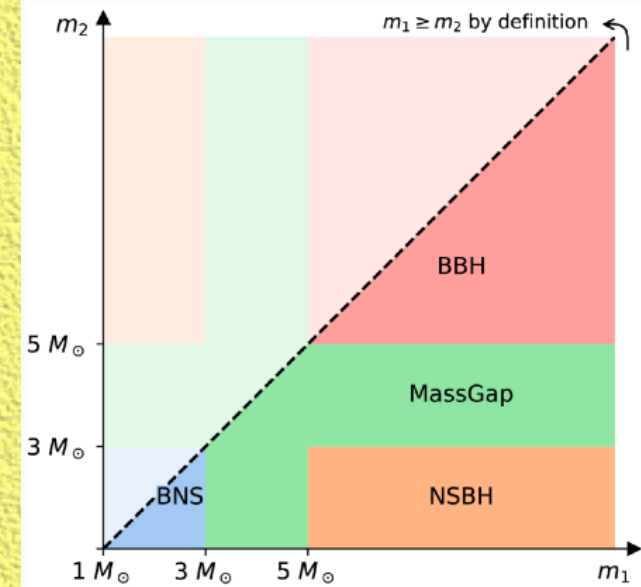
Gravitational Astronomy Summary: LIGO & VIRGO (O1-3)

Masses in the Stellar Graveyard

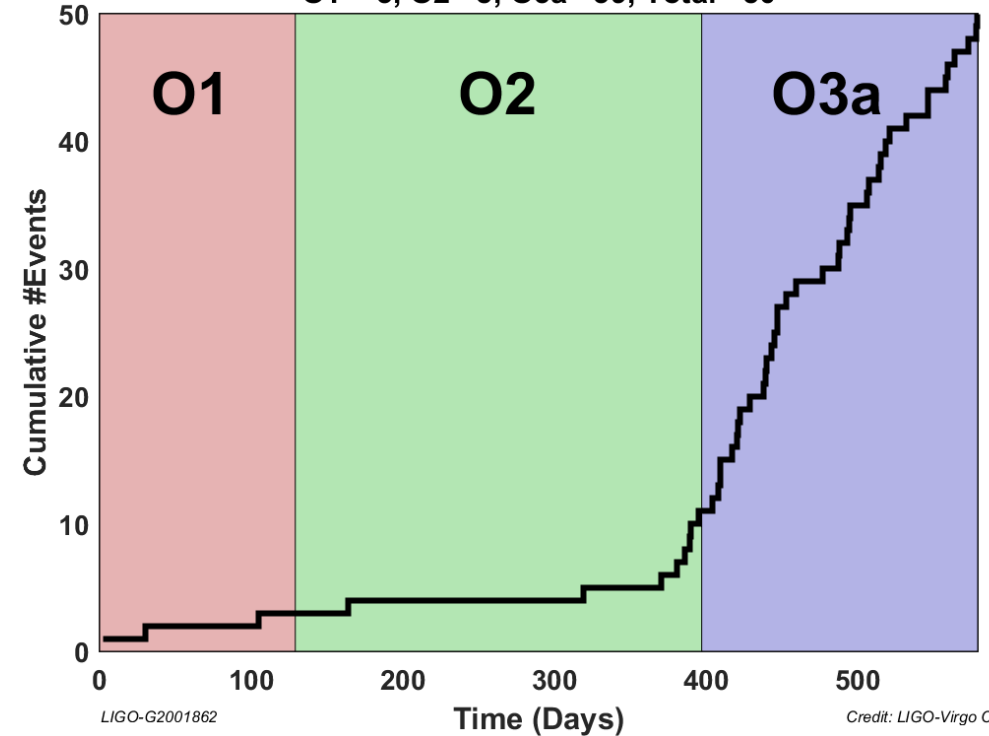
LIGO-Virgo-KAGRA Black Holes LIGO-Virgo-KAGRA Neutron Stars EM Black Holes EM Neutron Stars



LIGO-Virgo-KAGRA | Aaron Geller | Northwestern



Cumulative Count of Events
O1 = 3, O2 = 8, O3a = 39, Total = 50



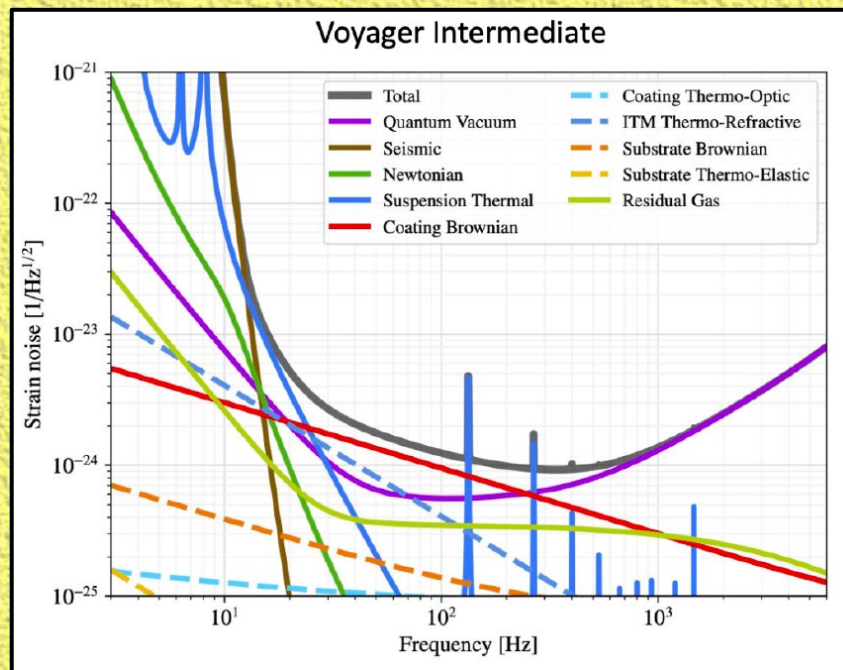
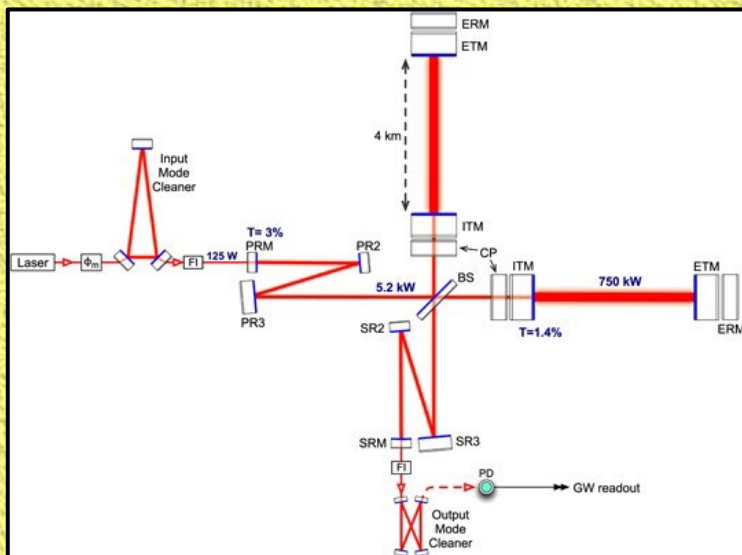
LIGO-G2001862

Credit: LIGO-Virgo Collaboration

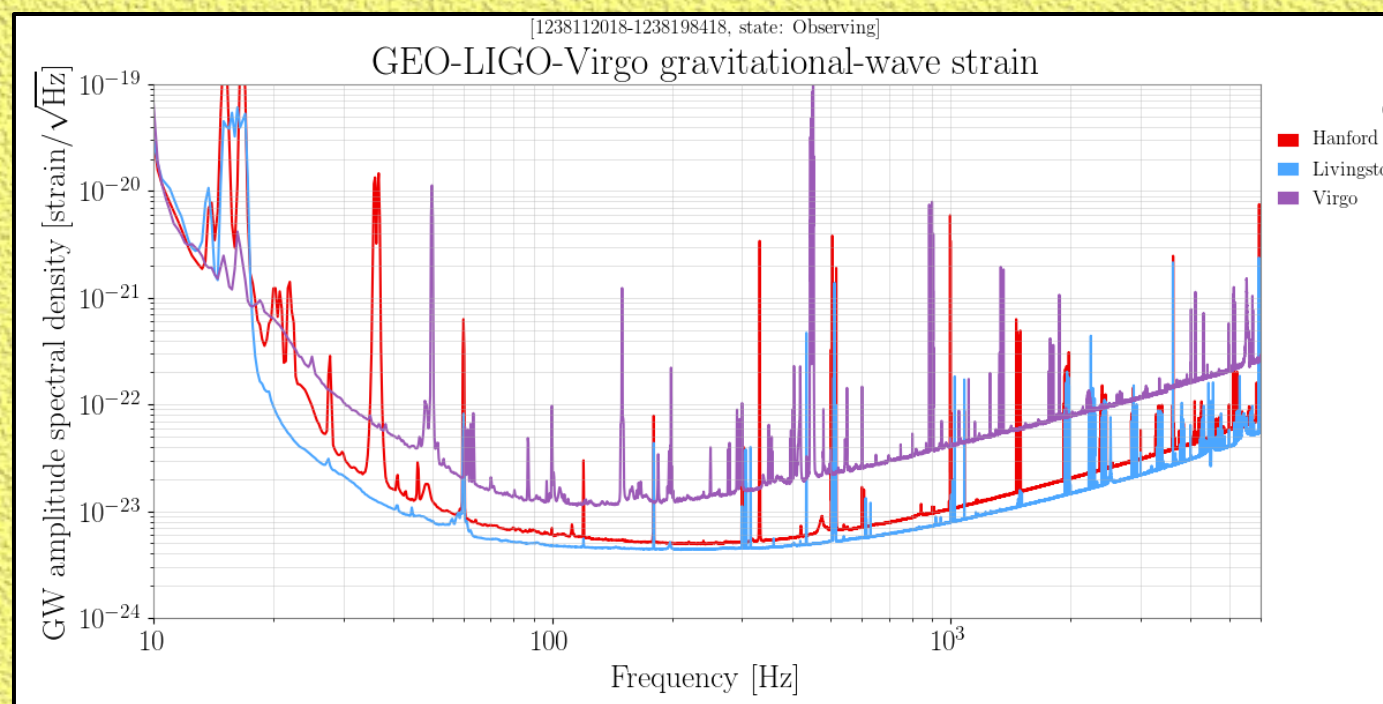
... as of 2021



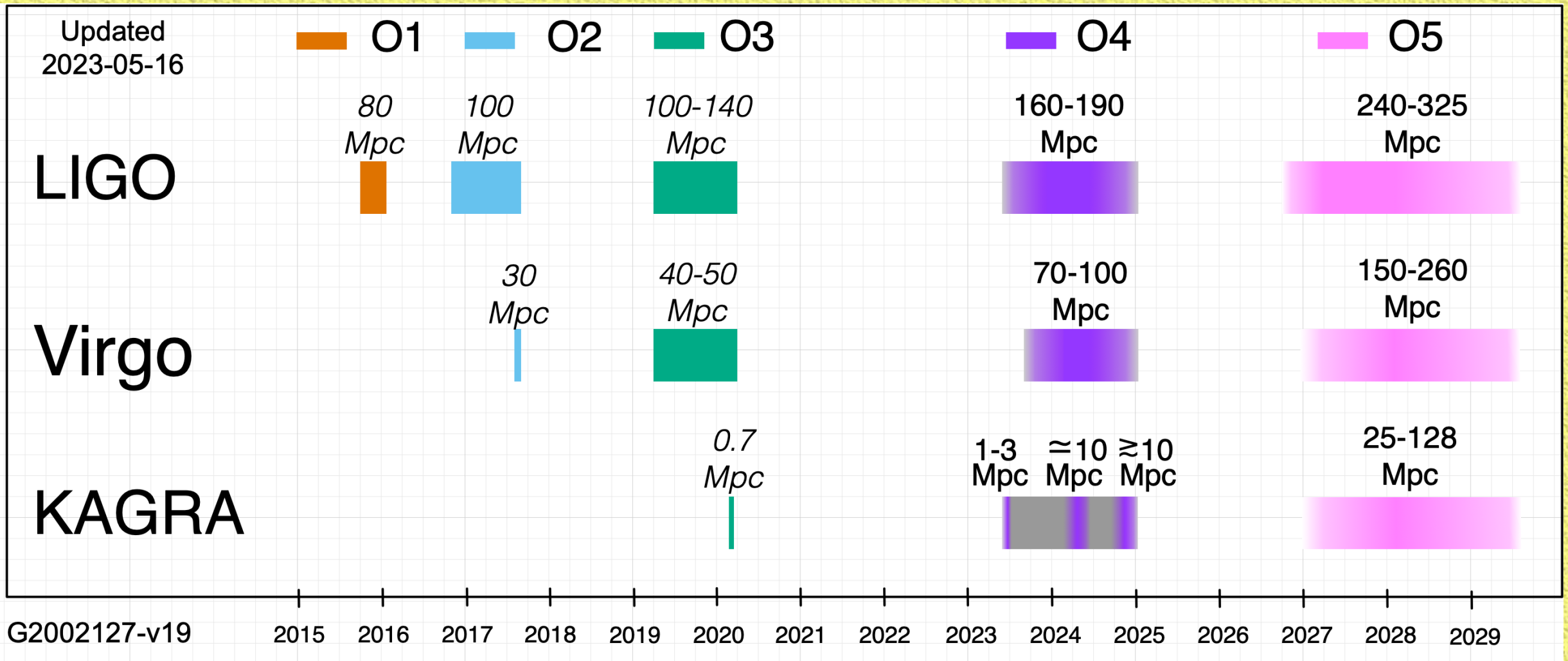
Dual recycling Fabry Perot Michelson Interferometer



Each Noise Component is
a Body of Learning and
Research Subject



LVK Observing Runs



Sensitivity: Binary Neutron Star range for a single-detector SNR threshold of 8

LIGO O5 sensitivity improvement -- primarily from **mirror coating noise**, still in the development





Research Projects Menu:

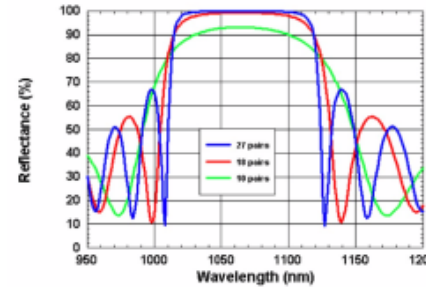
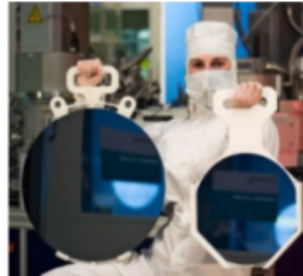
- Mirror Coating & Characterization for NG (Cryo) GW.
- Cryogenic Techniques for NG (Cryo) GW
- GW Optics System
- Calibration Data Analysis & NG Modelling
- Theory Flavor Subjects
 - GW Detector Sensitivities (Noises)
 - BSM Particle and Gravitation in GW
 - Stochastic Background Analysis
 - Earthquake in GW
- Homegrown CHRONOS Project

Mirror Coating & Characterization for NG-GW (Cryogenic)

NTHU Facilities:

- ✓ Measurements of mechanical & optical loss
- ✓ Silicon Coating System at TSRT
- ✓ Both room & cryogenic temperature

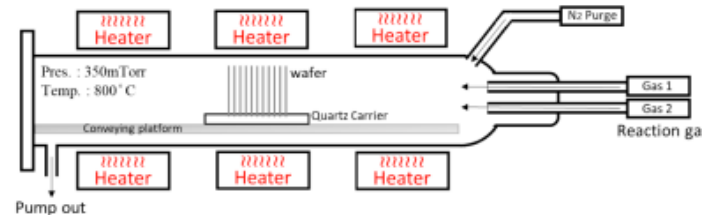
DEVELOPMENT OF LARGE COATING TECHNIQUE



Uniformity check

TSRI

MATERIAL DEVELOPMENT



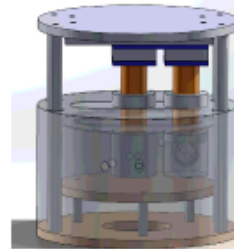
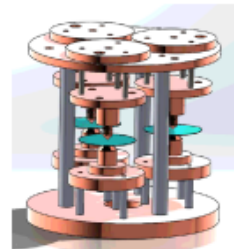
Improvement of fabrication process of high low coating

TSRI

DEVELOPMENT OF CRYOGENIC CHARACTERIZATION SYSTEM

Cryogenic Mechanical loss measurement system

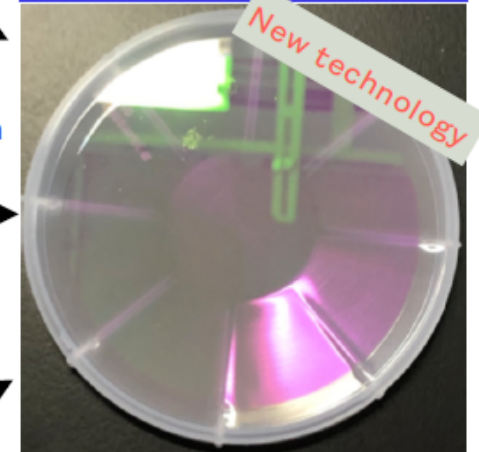
Cryogenic Optical loss measurement system



Measurement of loss at cryogenic temperature

NTHU→AS

6 INCH CRYOGENIC COATING TECHNOLOGY

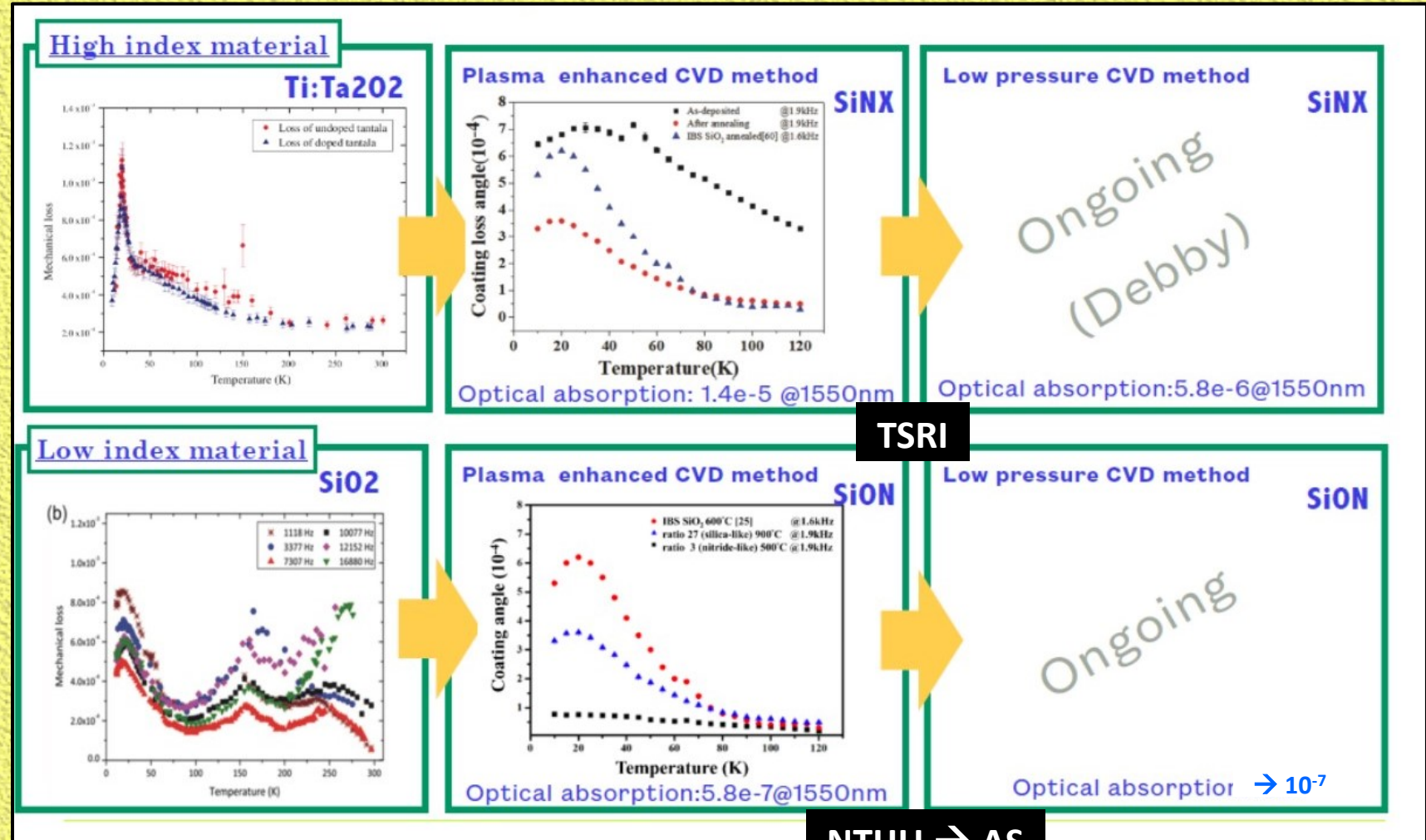
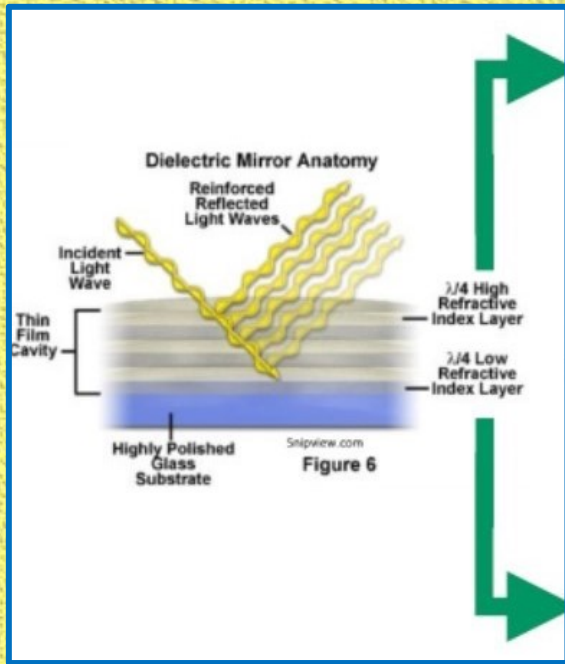


Requirement: $K \sim 10^{-7}$ (@100K)

Number of layer: >70 (CHRONOS)

The Issues:

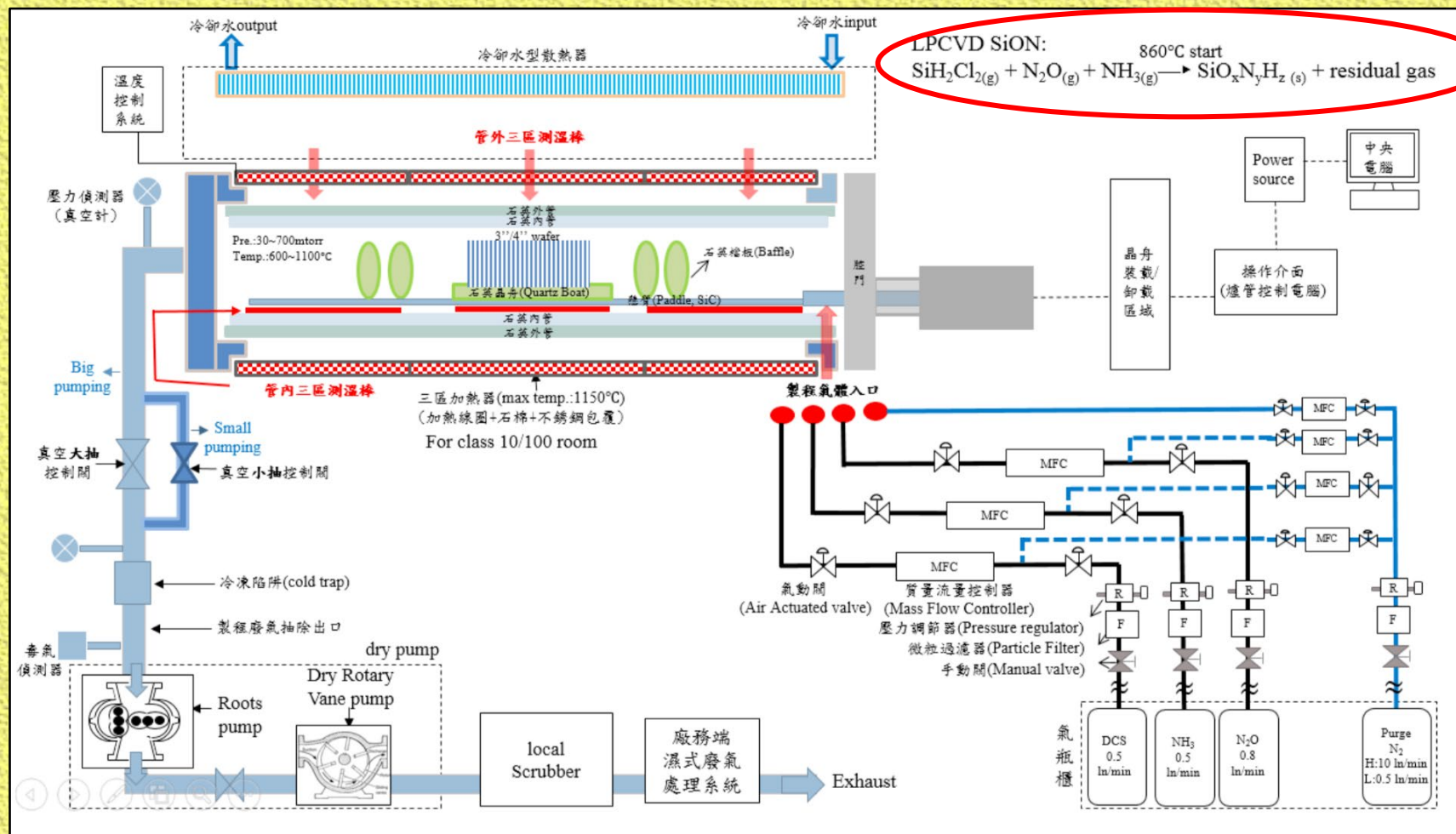
- Low Temperature → different mirror material, different optimal laser wavelength
- Large Optical Loss at Low Temperature for current materials
- Mirror Noise : main contribution to sensitivity budget



TSRI

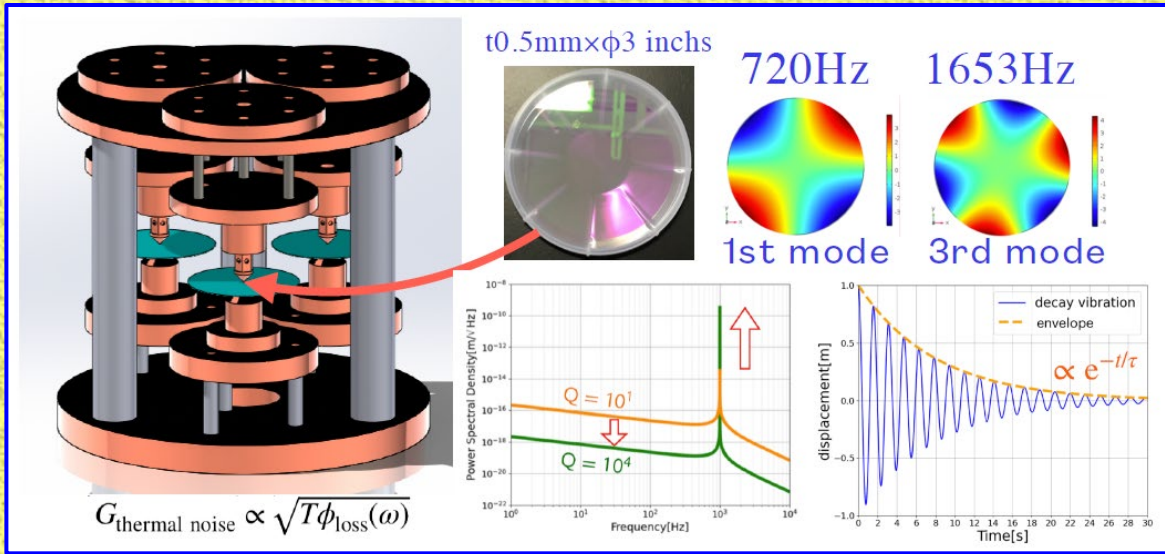
NTHU → AS

Low Pressure Chemical Vapor Deposition (LPCVD) Facility @



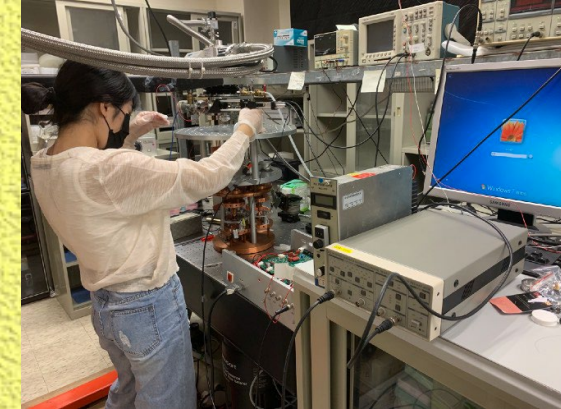
- ✓ NTHU team is a long time user; AS taking over
- ✓ AS is building a new N₂O gas line **NOW**, for SiON coating
- ✓ Need to learn how to effectively work there

Cryogenic Coating Characterization Facility at AS



Gentle Nodal Suspension (GNS) System

- Mechanical Loss Measurement at Cryogenic Temperature
- Being Commissioned @ AS



Cryogenic photo-thermal common-path interferometry system

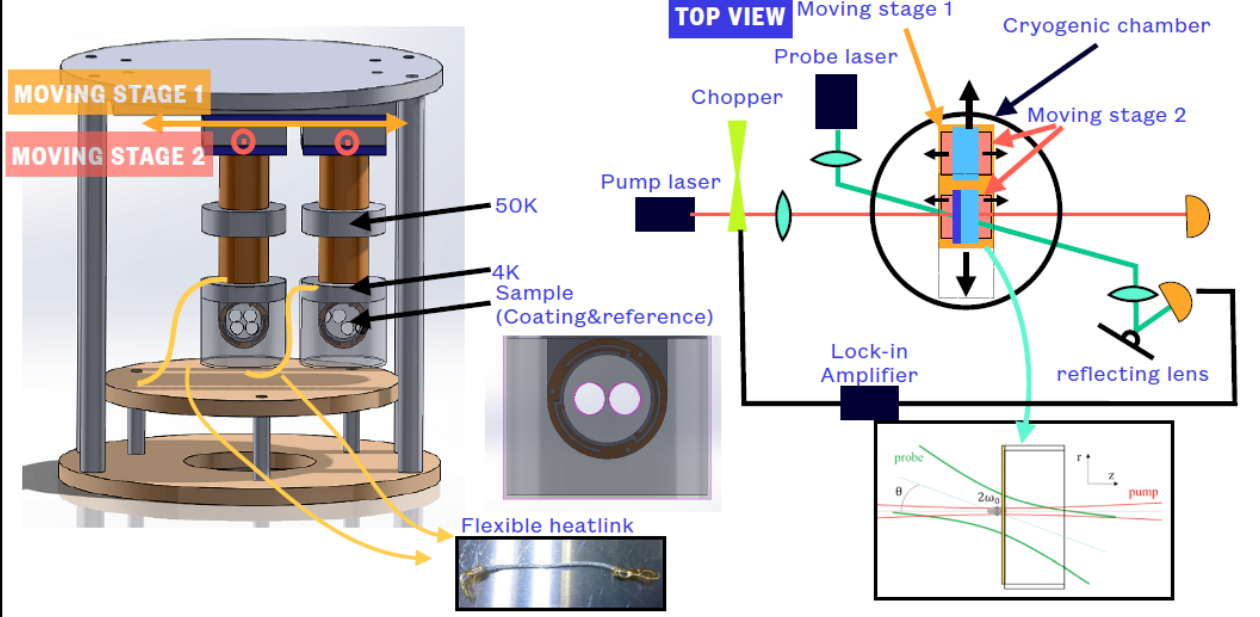
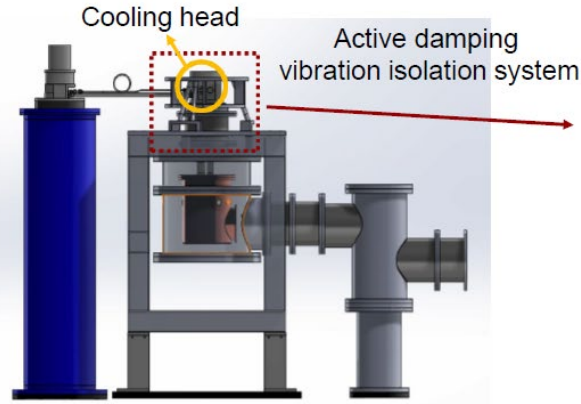
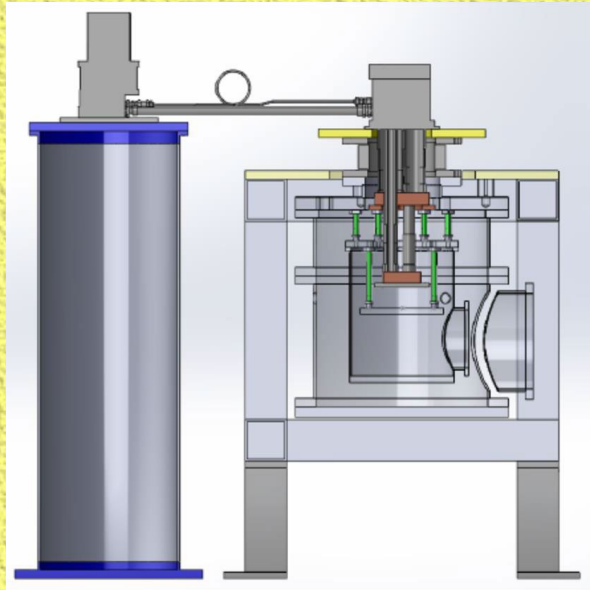


Photo-Thermal Common-Path Interferometry (PCI) System

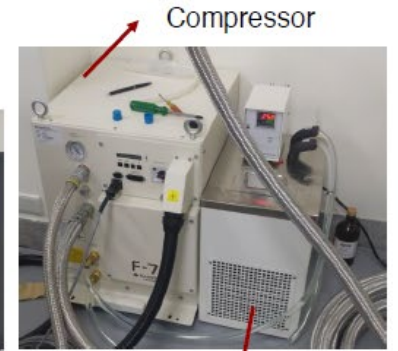
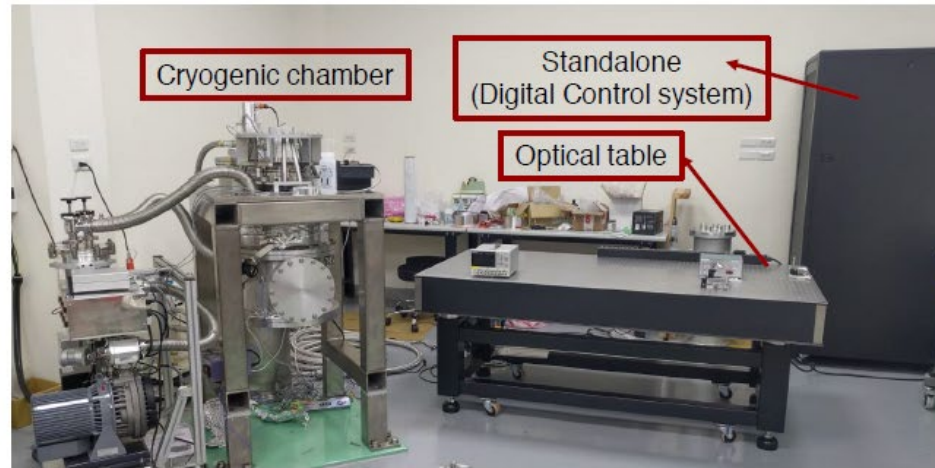
- Optical Loss Measurement at Cryogenic Temperature
- After GNS commissioned @ AS

Cryogenic Techniques and Systems at AS

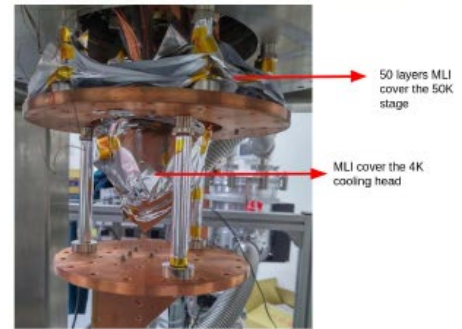
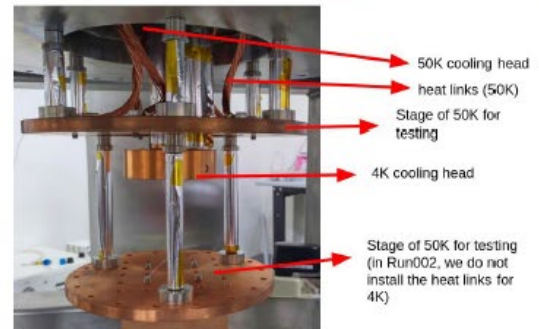
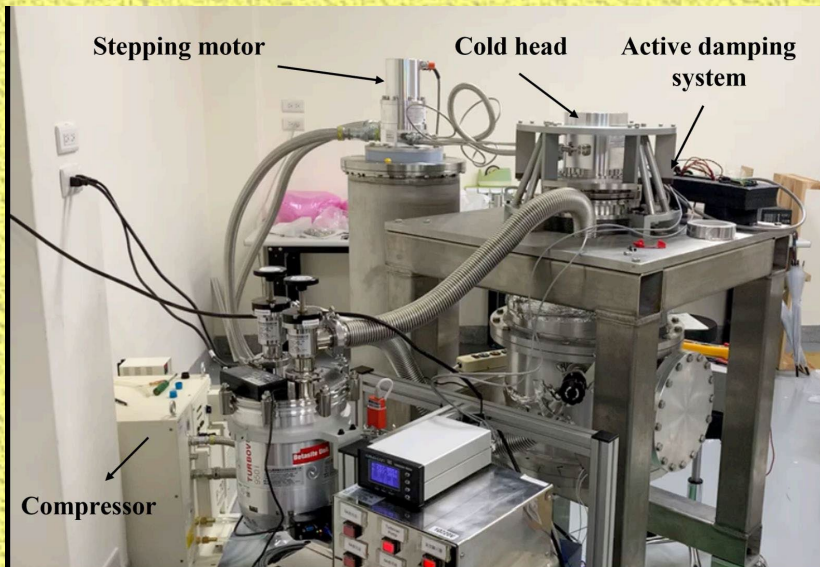


Credit: Masaya Hasegawa (KEK)

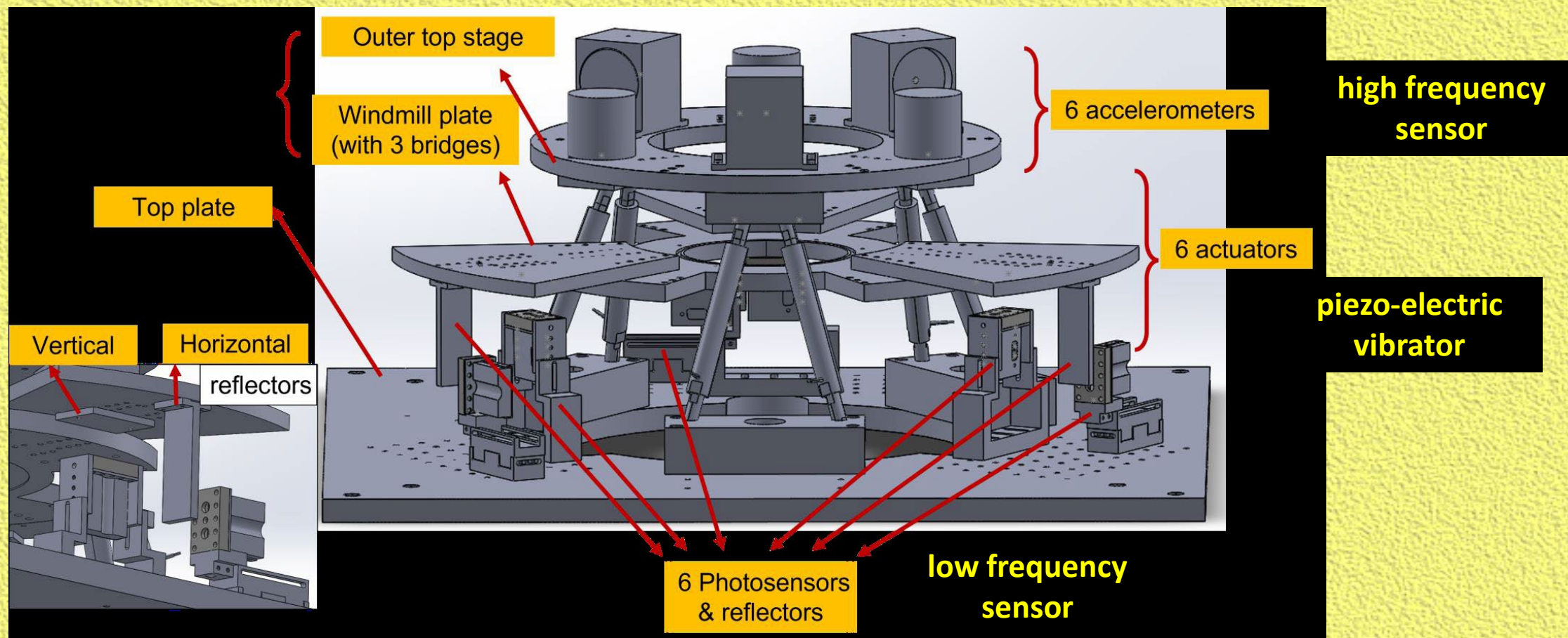
■ Optical table and standalone server are prepared



Chiller (to be upgraded to be more powerful)



Cryogenic Active Vibration Isolation System at AS





國立成功大學
物理學系

Jan 2023

碩士學位論文

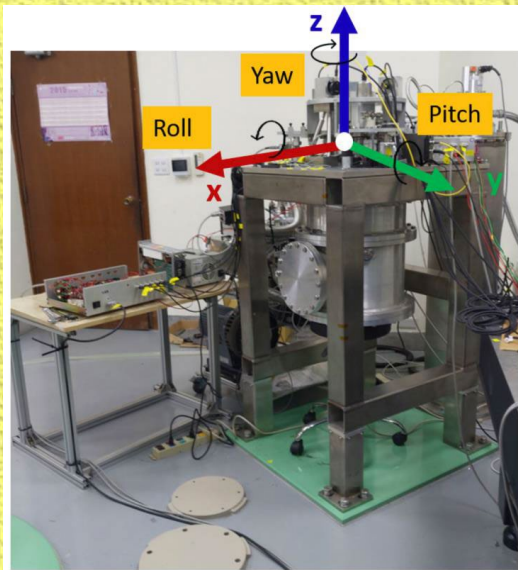
使用於重力波探測器的低溫系統與主動阻尼減震系統的研究

Study of the cryogenic system and active vibration isolation system for gravitational wave detection



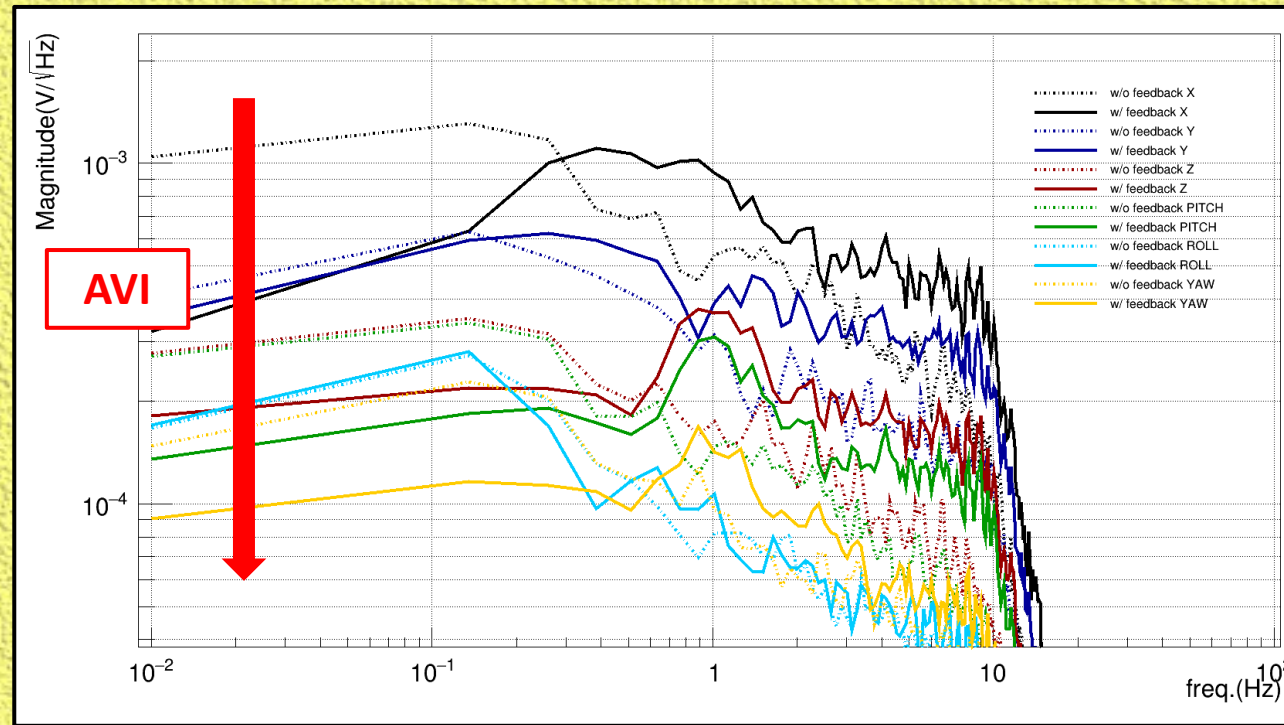
研究生：許翔傑
學號：L26094077

指導教授：楊毅教授
共同指導教授：王子敬教授



After complex maths and analysis

$$\begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ P_1 \\ P_2 \\ P_3 \end{bmatrix} = \begin{bmatrix} -1.11536 & 0.643951 & 0.178633 & 0.477491 & -0.136855 & -0.643951 \\ 1.11536 & -0.643951 & 0.178633 & -0.120226 & -0.481947 & 0.643951 \\ 1.11536 & 0.643951 & 0.178633 & -0.120226 & 0.481947 & -0.643951 \\ -1.11536 & -0.643951 & 0.178633 & 0.477491 & 0.136855 & 0.643951 \\ 0 & -1.2879 & 0.178633 & -0.357266 & -0.345092 & -0.643951 \\ 0 & 1.2879 & 0.178633 & -0.357266 & 0.345092 & 0.643951 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ Pitch \\ Roll \\ Yaw \end{bmatrix}$$



Active feedback vibration isolation of cryogenic chamber for gravitational wave experiment

Daiki Tanabe (Academia Sinica)

2023.07.21

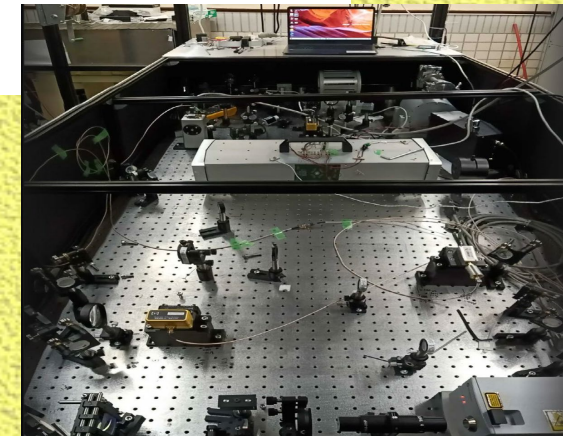
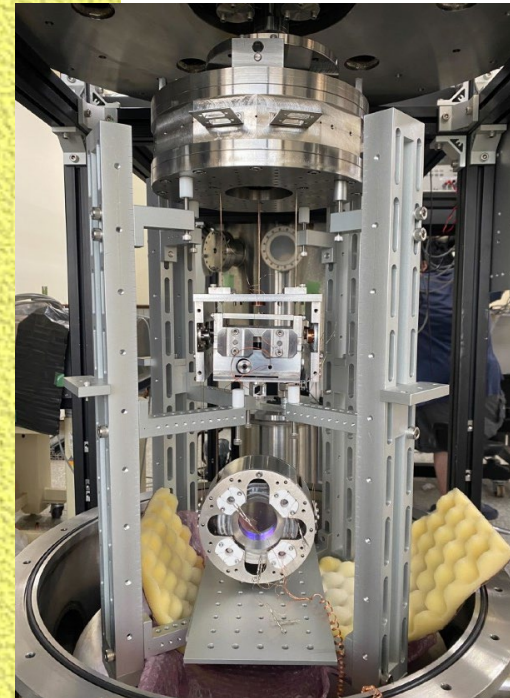
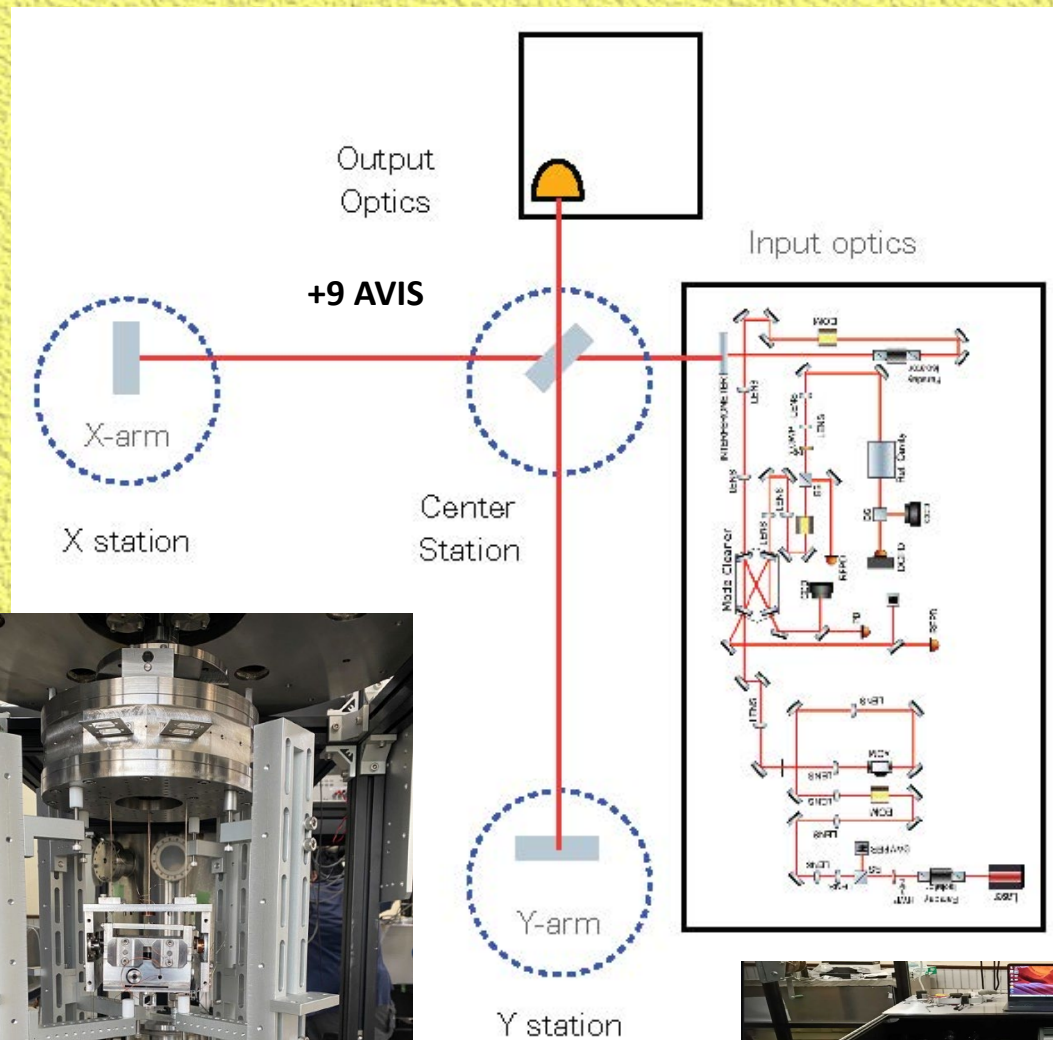
QUP LTD cluster mini-workshop



🏆 First Step towards First (?) Demonstration of Active Vibration Isolation in Cryogenic System !
[Room temperature AVI is a showcase technology advance in LIGO]

Michaelson Interferometer System @NCU

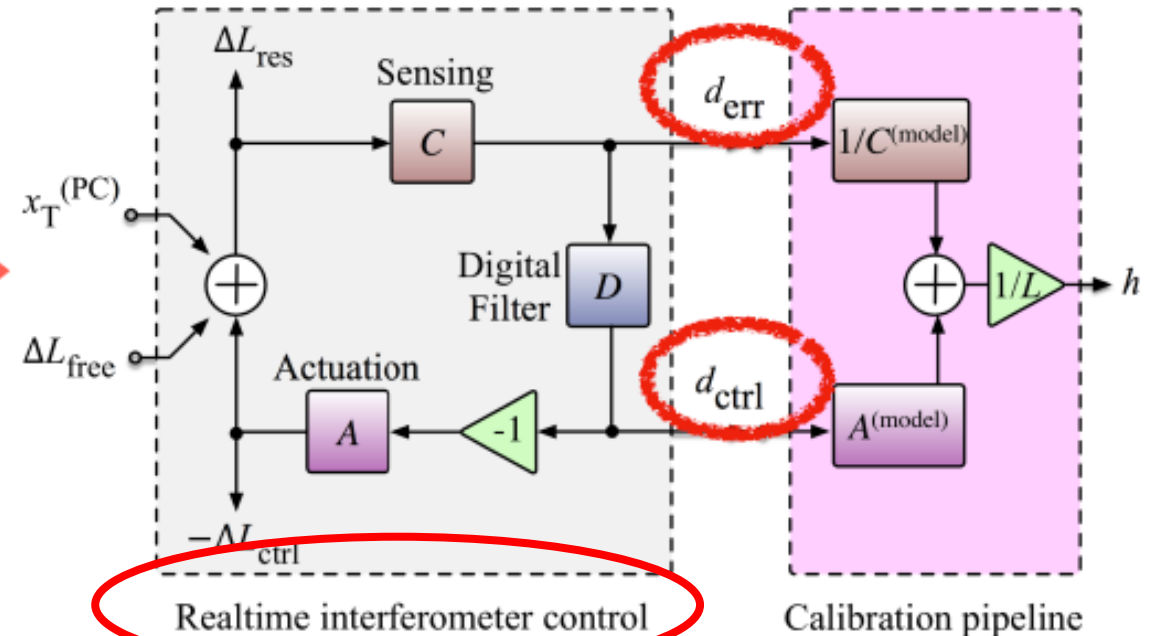
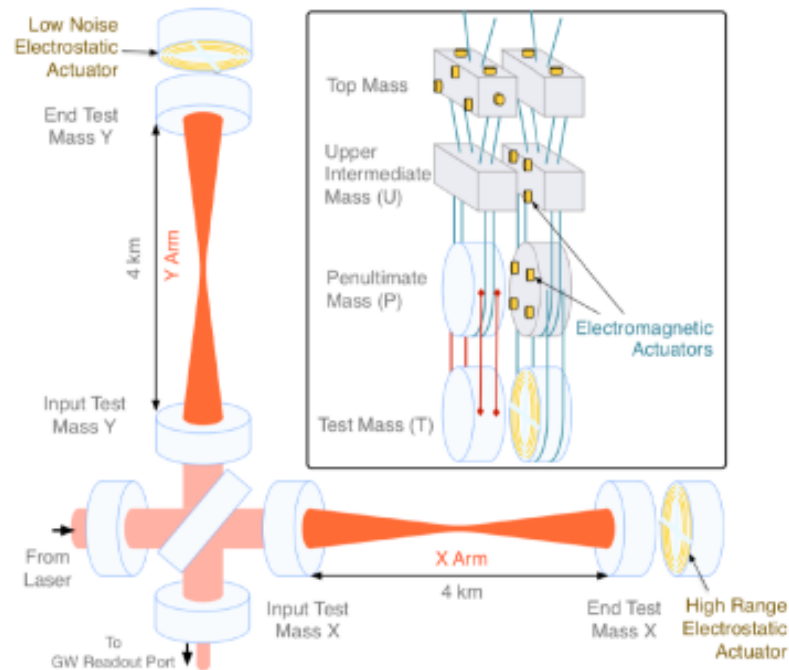
- Acquire tools & skills
- Prepare to future Cryogenic operation
- Platform for future R&Ds, e.g. Sagnac Interferometer



Theory & Analysis

- **Calibration** (*“Feedback Control” Theories → “Transfer Functions”*)
 - Modeling of Interferometer [*~HEP’s GEANT*] → systematic error
 - Data analysis pipeline, upgrade software
 - NG (O5) modeling code development
- **Sensitivities:** (*Theory of Noise & Suppression*)
 - Theories & Models of Individual Components
 - Error Propagation
 - Applications to CHRONOS & IFs @ NCU
- **Physics:**
 - DM & BSM Models @ GW [*DP -- PRD2023*]
 - Non-Newtonian Gravity with GCAL [*paper soon*]
 - Analysis of LIGO Public Data (*DM with NTHU M. Spinrath*)
 - ☑ Turn “Sensitivity Projection” to “Measurement Limits”
 - Stochastic Background analysis pipeline
(*with TKU GC. Liu @ KAGRA; KW Ng@ASloP*)
 - Earthquake Science in GW (*on shelf, after summer student studies*)

Modeling of Interferometer



- ✓ One main difference with high energy physics experiments
- ✓ Another one: continuous data taking



A Homework

Novel Features:

- ✓ Crossed Torsion Bar at 4K ;
- ✓ GW signatures as angular velocity
- ✓ Measured by “Sagnac” Speed meter

Merits:

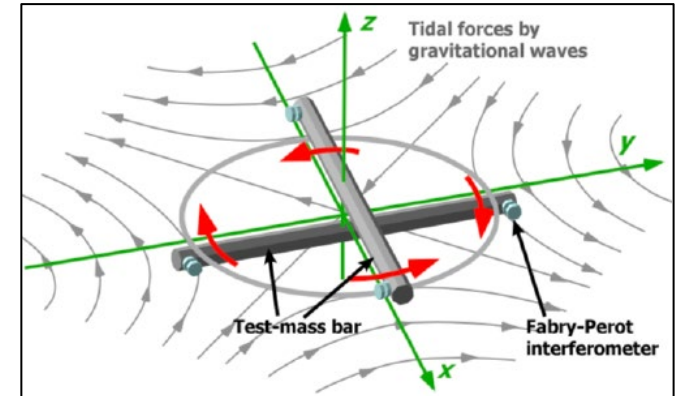
- ✓ new 0.1 Hz (deci-hertz) sensitivity window
- ✓ 10X10 m² lab space requirements [NG GW O(10 km)]

Platform for future GR/GW

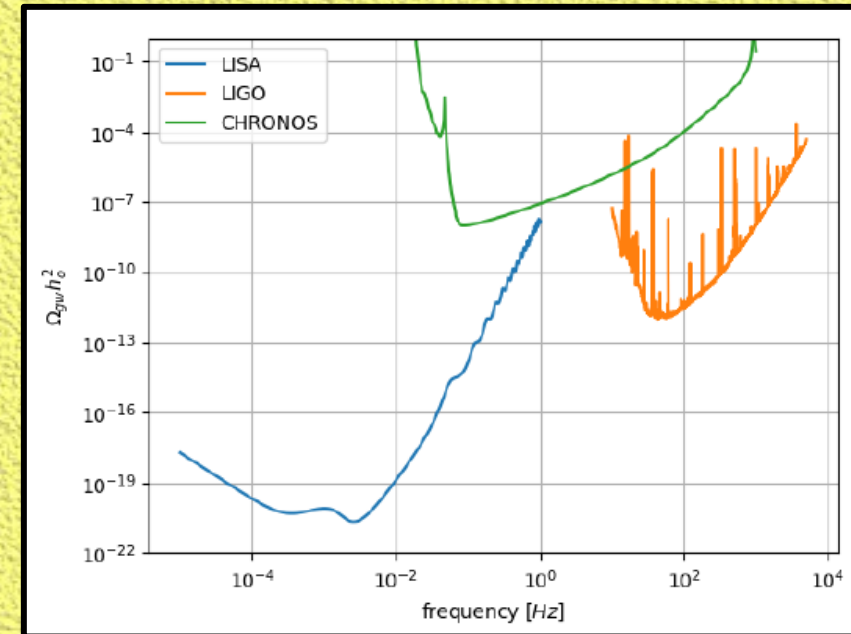
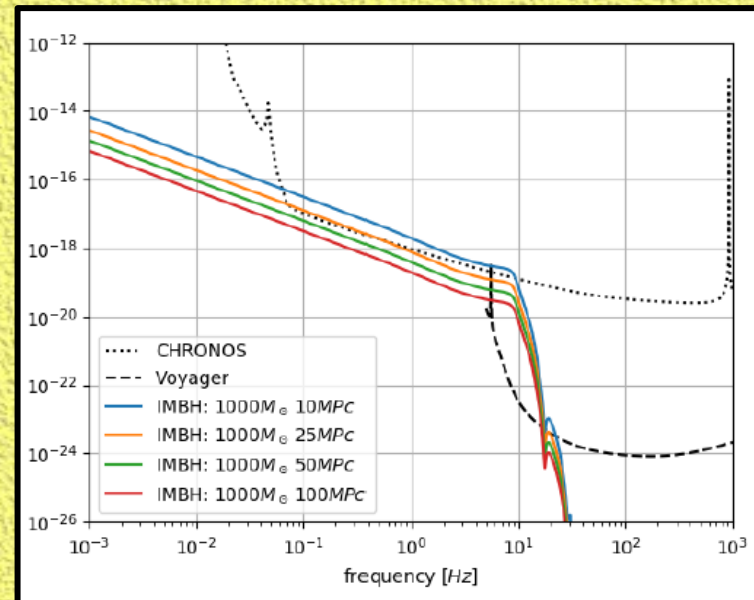
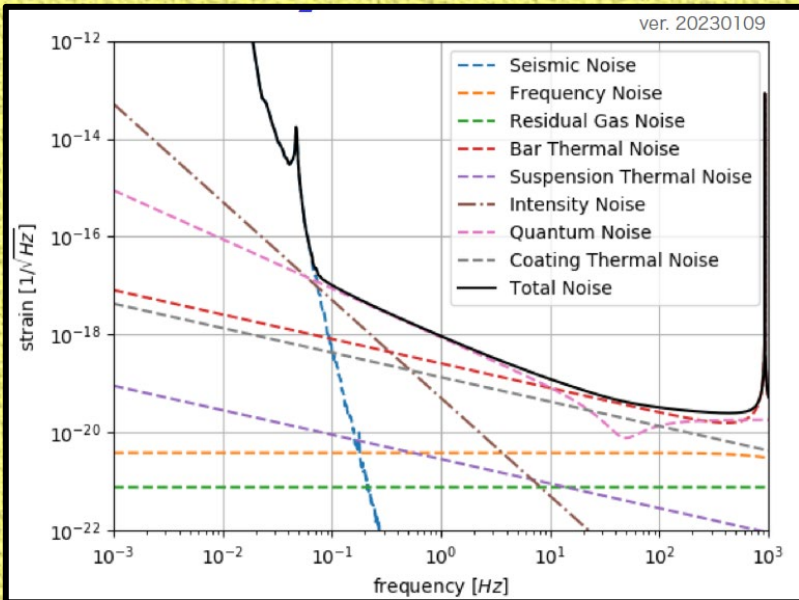
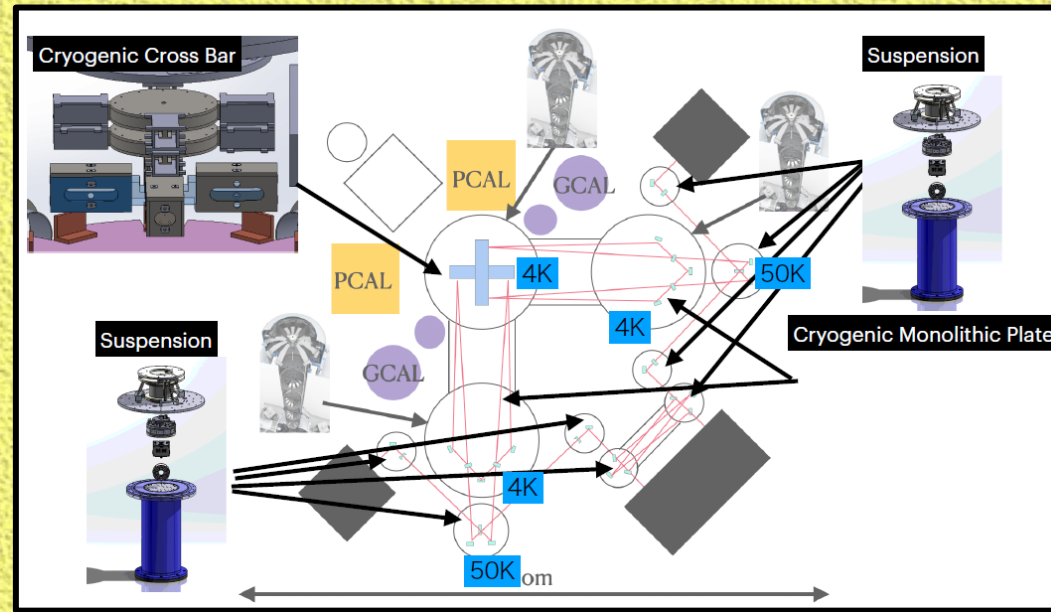
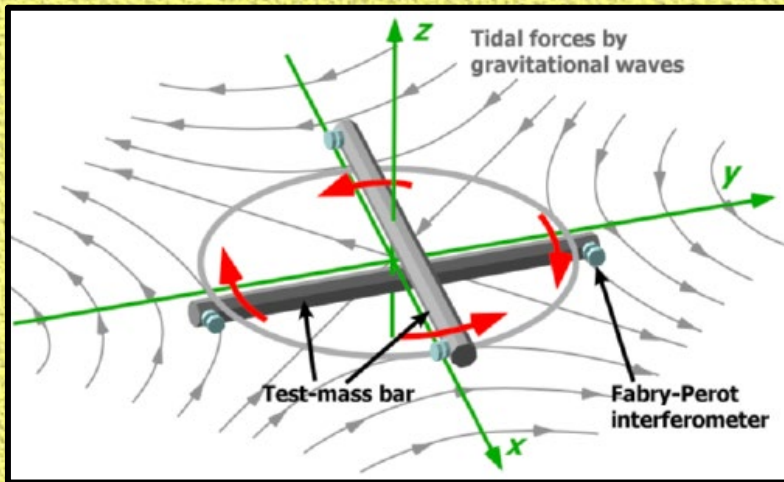
- ✓ Homework and learning (wide spectrum of skills)
- ✓ acquire technical expertise (cryogenics[AS], optics[NCU])
- ✓ learn/explore science (intermediate mass Black Hole; BSM; Earthquake....)

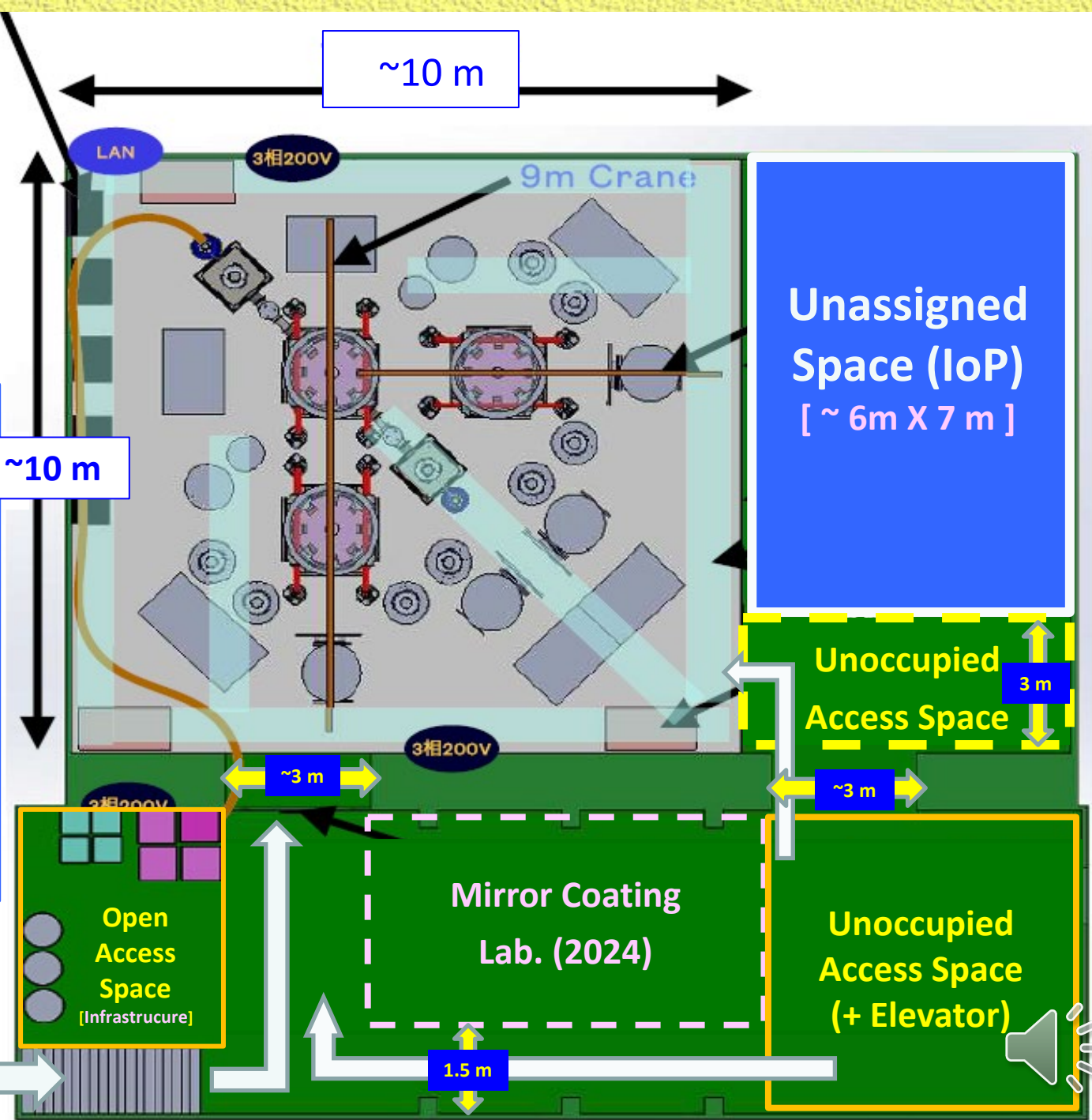
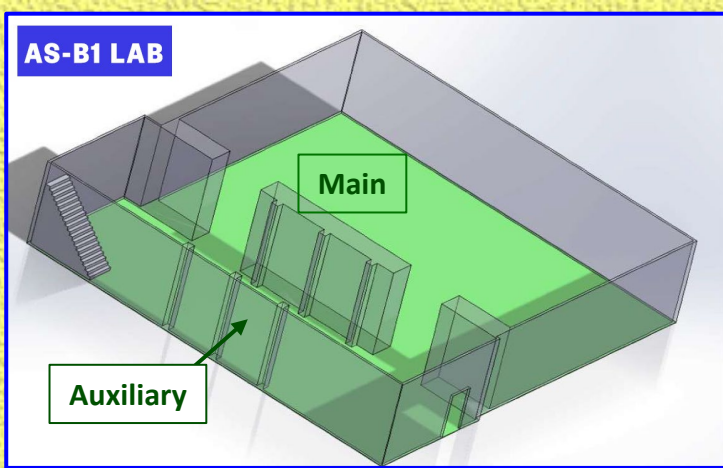
Status and Approaches

- ✓ Doing Homework (current priority still at LIGO-GW)
- ✓ Propose and Build ONLY after Homework & Rigorous R&D



CHRONOS





ASGRAF (AS Gravitation Facility):

- IOP B1 10X10 m²
- Clean Room Spec @ C-10000
- Menu (Plans):
 - Mirror & Cryo & VIS Research
 - Move NTHU Lab (2024)
 - GW “System” Test Facility
 - Future CHRONOS prototype

Walk-In Possible with Hand-Held Equipment



as of 2023/7/18



Heartfelt *Thanks* to
IoP for Support





Missing (Struggling):

■ Turn tools and skills into

➤ Established Facilities & Projects

[reproduce what XXX accomplished N years ago]

➤ Matured Research Programs

[challenge what XXX is doing now or has not yet done]

■ Immature/Developing Eco-system: Unstable Manpower and Teams

■ Operation still at Learning Curve

→ *e.g. what can be realistically achieved in a given time.*

Achieved:

■ Get into the leading GW program, eye-opening, expand connection

➤ (too-)frequent meetings

➤ a student posted 3-months at L-Hanford, make friends

➤ Students analyzing O4 data real-time now ..!

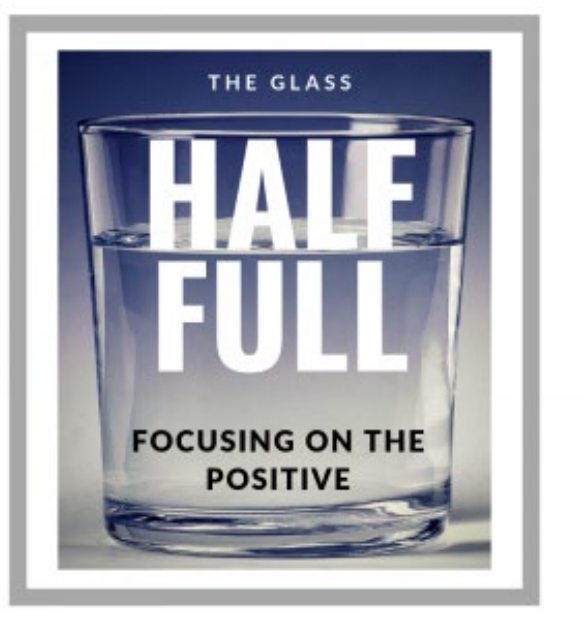
■ Learned and installed **A LOT OF** (new) physics, skills and tools

■ Already engaging in some frontier research

■ Training (Thesis) & Exposure (to the Big Boys) of students

■ Connect TW HEP Theorists to leading GW data

■ Lectures and Promotions in Universities.



Challenges, Plans, Strategies (Personal Bias):

■ Natural Scale: Taiwan, not ASloP

■ *MY* Focuses & Themes:

➤ A *Physics* Program – multi & diverse/balance projects

⇒ Instrumentation (Domestic) + Software + Operation + Physics/Science

➤ Build multi-institute, multi-disciplinary teams

Broad Programs, Teams, Ecosystems -- beyond GW, beyond LIGO ;

⇒ let/help the team members get visible in LIGO first

➤ Broad Landscape & Perspectives,

⇒ let the team members handle/master the technical details

■ Hope to Connect

➤ Physics subjects beyond mainstream GW astrophysics,

☑ particle physics and cosmology

☑ esp. the missing energy-density problem

☑ leave astrophysics to professionals

➤ TW experimental HEP resources & expertise

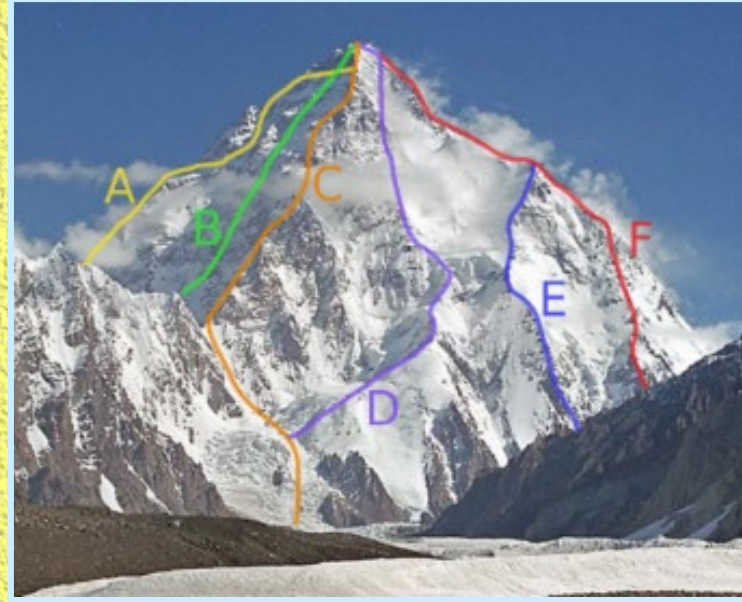
➤ IoP expertise in semiconductors & cryogenics

➤ Resources from TEXONO & CDEX (ν & DM) teams

Wishes on Personnel

- Participation/Consultation of Domestic Engineering Team(s)
 - Mirror Coating & Characterization: techniques, chemistry, literature, TW semiconductor eco-system etc.
 - Cryogenic techniques
 - 🏆 **Much room/necessity to collaborate with IoP QMP teams**
- Participation of new Junior Faculty from a different university
- Participation of International Groups
 - **Testing the water:** TEXONO Turkish group
- Connections and Working with HEP Theory Groups
 - **Currently:** M Spinrath (NTHU), CR Chen (NTNU): BSM+DM; GC Liu (TKU), KW Ng (AS) SBGW

期待：依然精彩



Despite Challenges from being Outside our Comfort Zone, Recall the *Rewarding Journeys* than “*WE*”, together, have successfully gone through

