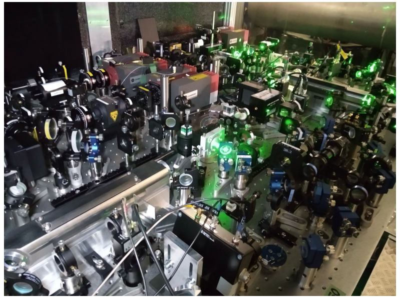
Building the Future of Gravitational Wave Astronomy in China

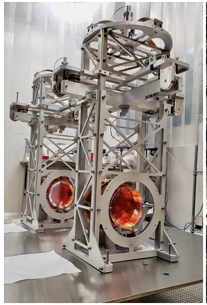
A Ground-Based Laser Interferometer and its Synergy with France

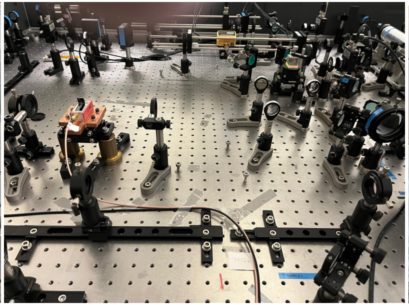
Yuhang Zhao (APC, Université Paris Cité)
(Henan Academy of Sciences*)

16th FCPPN workshop Qingdao, China 23th July, 2025

✊My past research with French researchers







Me   R. Flaminio (LAPP, CNRS)

Me and M. Barsuglia (APC, CNRS)

2016

KAGRA international workshop in BNU (organized by professor **Zong-Hong Zhu**)

BEIJING NORMAL UNIVERSITY 1902

KAGRA

2017-2020

PhD in NAOJ, working on quantum noise reduction techniques

国立天文台 NAOJ

2022-2025

Postdoc in APC, working on quantum noise reduction techniques

APC

VIRGO

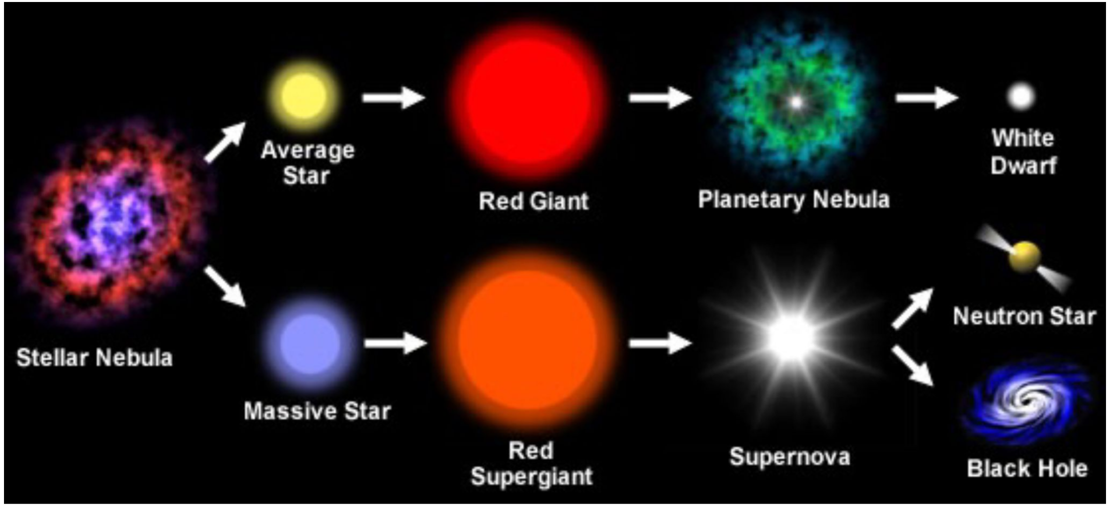
EINSTEIN TELESCOPE

🎯Outline

- Gravitational wave astronomy
- Gravitational wave detection
- Past collaboration between France and China (non-exhausitive statstics for instrumental science)
- Plan to contribute to the international community
  - Promote a ground-based laser interferometer gravitational wave observatory in China
  - Contribute to instrumental science
  - Contribute to observational science

Gravitational wave astronomy

💫 Life cycle of a star



https://www.youtube.com/watch?v=tZU3-RBzEA0, credit of this style inspired by Marco Meyer-Conde

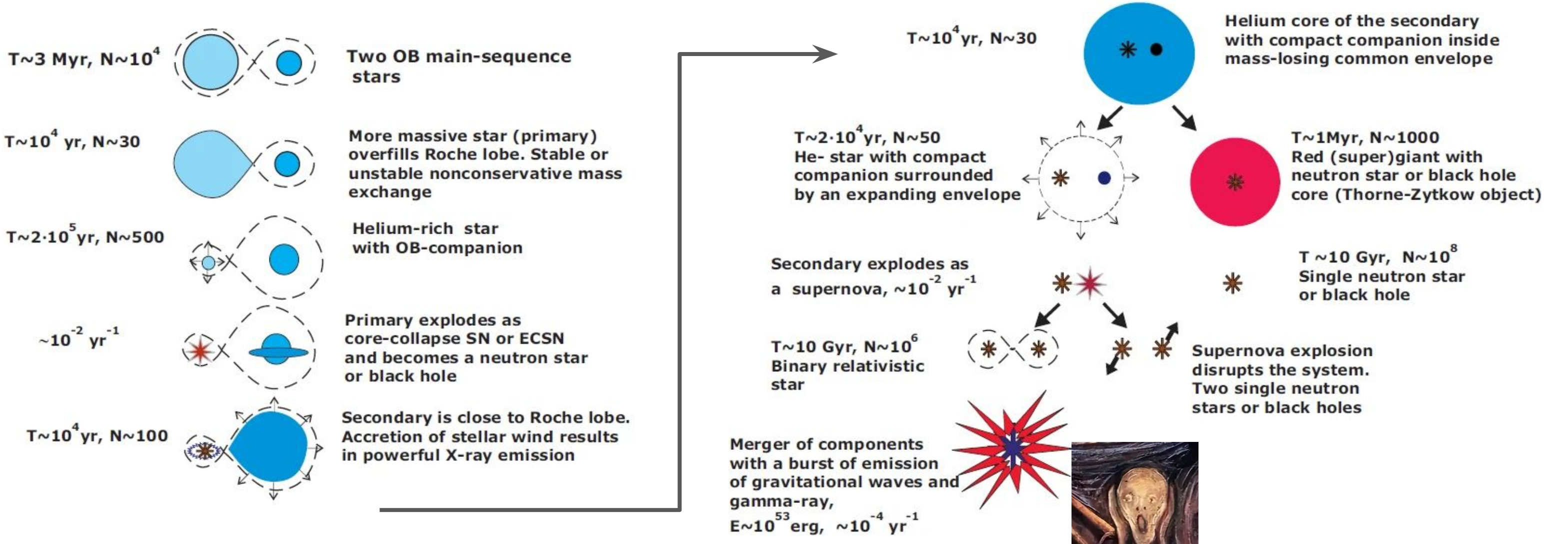
Neutron star: radius of 10-20 km, mass 1-3 solar mass

Black hole: radius of >9 km, mass >3 solar mass

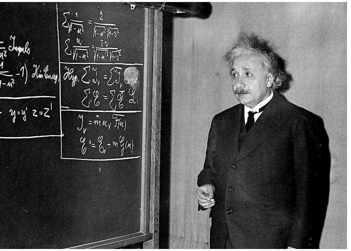
Binary system

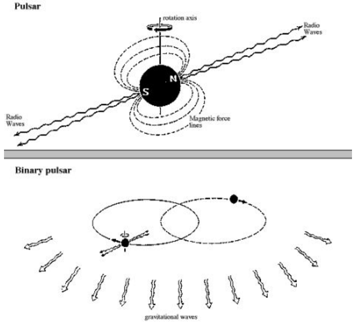
In the entire universe, roughly ⅓ to ½ of all stars are in binary or multiple systems

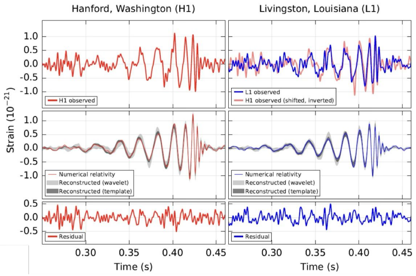
Volume 17, article number 3, Living Reviews in Relativity (2014)

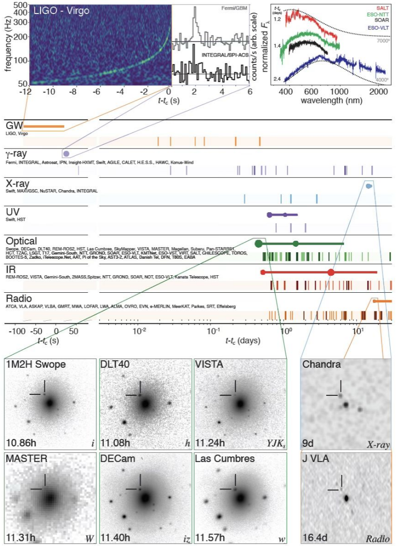


Gravitational wave milestones









1916

Einstein predicted the existence of gravitational waves

1974

Hulse-Taylor Pulsar provided the first indirect evidence of gravitational waves

1990s

large scale gravitational wave detectors were under construction (LIGO, Virgo, TAMA300, GEO600)

2015

LIGO made first direct gravitational wave detection

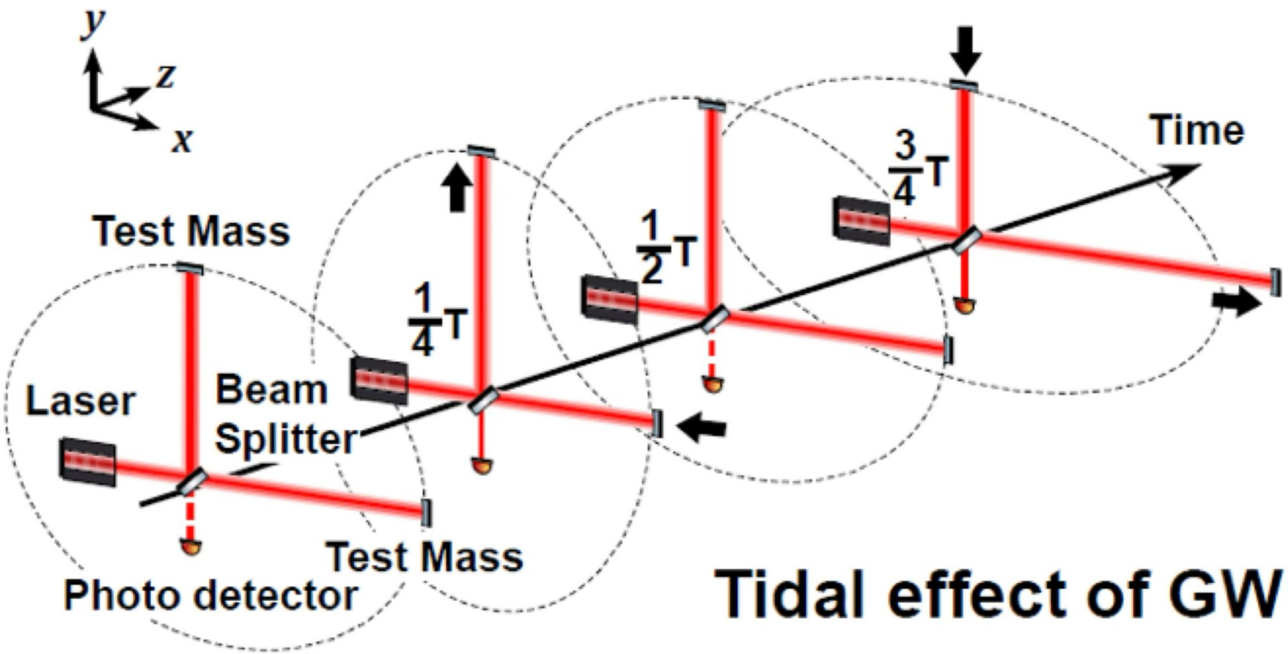
2017

LIGO and Virgo made first neutron star merger detection, with electromagnetic counterpart

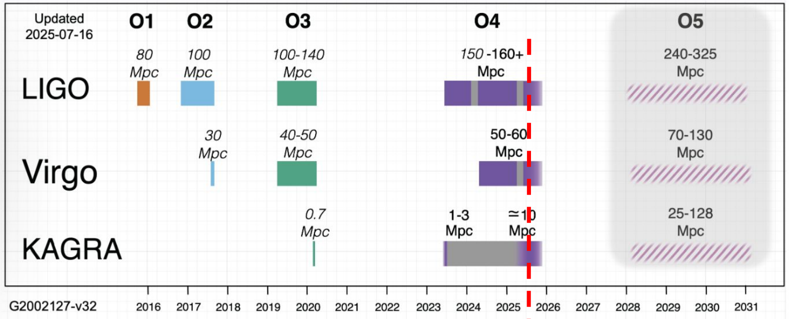
Gravitational wave detection

🔭 Gravitational wave observation

Gravitational wave > Mirror displacement > Light phase shift > Light power variation



Gravitational wave network



https://observing.docs.ligo.org/plan/#

Now

Gravitational wave observatories take alternative upgrades and observation to optimize their sensitivities

☝ State of the art technologies

Institutes

PHYSICAL REVIEW A VOLUME 13, NUMBER 6 JUNE 1976

Two-photon coherent states of the radiation field*

Horace P. Yuen

Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

(Received 26 June 1975; revised manuscript received 3 March 1976)

PHYSICAL REVIEW D VOLUME 23, NUMBER 8 15 APRIL 1981

Quantum-mechanical noise in an interferometer

Carlton M. Caves

W. K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California 91125

(Received 15 August 1980)

VOLUME 93, NUMBER 16 PHYSICAL REVIEW LETTERS week ending 15 OCTOBER 2004

Squeezing in the Audio Gravitational-Wave Detection Band

Kirk McKenzie,[1] Nicolai Grosse,[1,2] Warwick P. Bowen,[2] Stanley E. Whitcomb,[3] Malcolm B. Gray,[1] David E. McClelland,[1] and Ping Koy Lam[1,2]

[1]*Center for Gravitational Physics, Department of Physics, Faculty of Science, The Australian National University, ACT 0200, Australia*

PRL **110**, 181101 (2013) PHYSICAL REVIEW LETTERS week ending 3 MAY 2013

First Long-Term Application of Squeezed States of Light in a Gravitational-Wave Observatory

H. Grote,* K. Danzmann, K. L. Dooley, R. Schnabel, J. Slutsky, and H. Vahlbruch

LETTERS nature physics

PUBLISHED ONLINE: 11 SEPTEMBER 2011 | DOI: 10.1038/NPHYS2083

A gravitational wave observatory operating beyond the quantum shot-noise limit

The LIGO Scientific Collaboration †*

LIGO VIRGO

Industry

Mini-Circuits

Ansys

ZEMAX OPTICSBUILDER

Heraeus

RAICOL CRYSTALS An OXIDE company

Shalom EO Crystals, optics and components

ANALOG DEVICES

PI

G&H

OPTO-ELECTRONIC

nanometrics

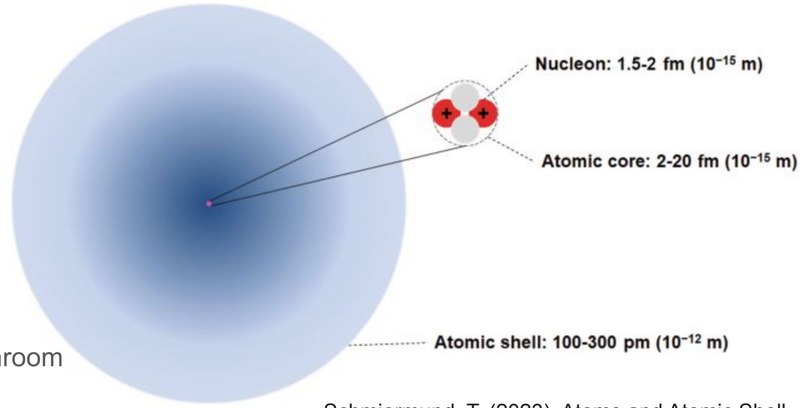
LASEROPTIK Home of high power optics and coatings

Quantic™ Wenzel

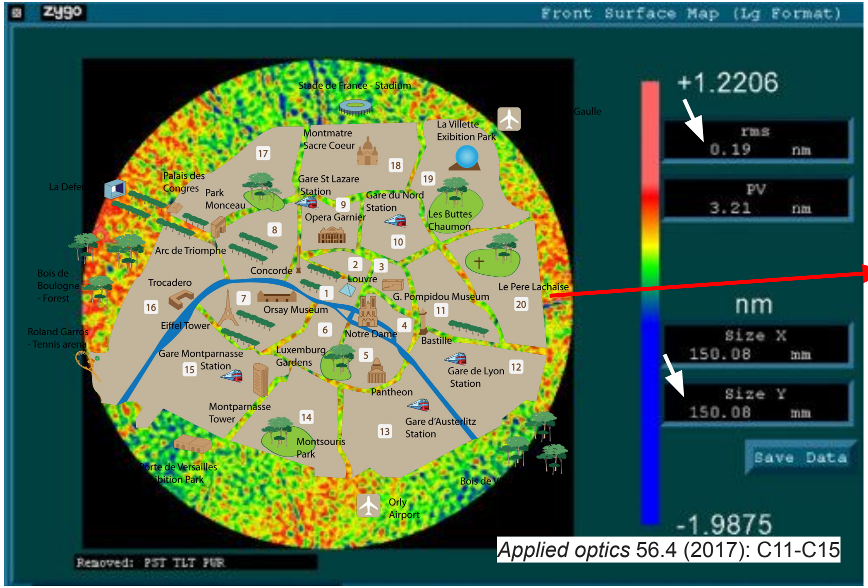
TRIOPTICS France

🫰 Orders of magnitude

Gravitational wave causes a mirror displacement with order of 10^-18 m (**one thousand times smaller than Nucleon**)



Schmiermund, T. (2023). Atoms and Atomic Shell



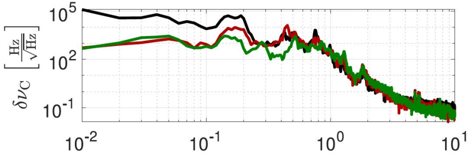
Applied optics 56.4 (2017): C11-C15

The flatness of Virgo mirror is like **allowing objects only smaller than hairs** (~10s micrometer) **in Paris** (15km)

The cleanroom used in **LMA/IN2P3, Lyon** follows this level of requirements

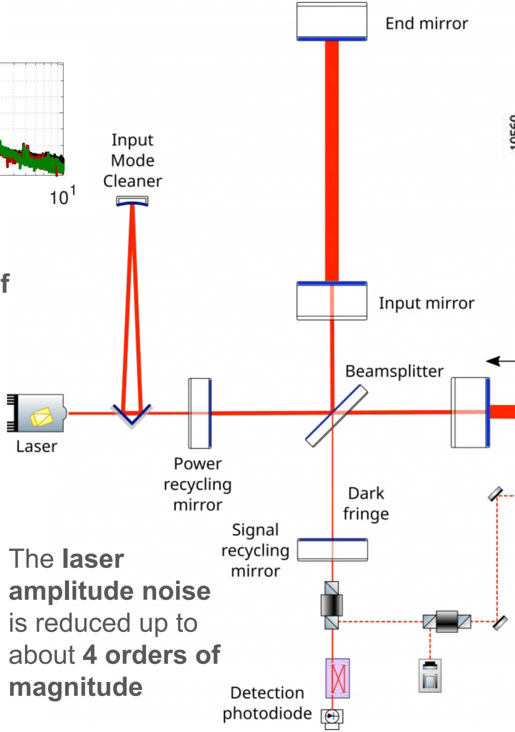
Class	>0.1 um	>0.2 um	>0.3 um	>0.5 um	>1 um	>5 um	FED STD 209E equivalent
ISO 1	10	2					
ISO 2	100	24	10	4			
ISO 3	1,000	237	102	35	8		Class 1
ISO 4	10,000	2,370	1,020	352	83		Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7				352,000	83,200	2,930	Class 10,000
ISO 8				3,520,000	832,000	29,300	Class 100,000
ISO 9				35,200,000	8,320,000	293,000	Room Air

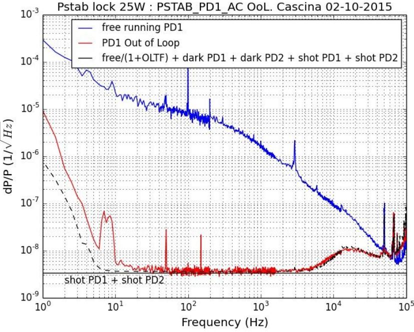
Orders of magnitude



The **laser frequency noise** is reduced up to about **2 orders of magnitude**

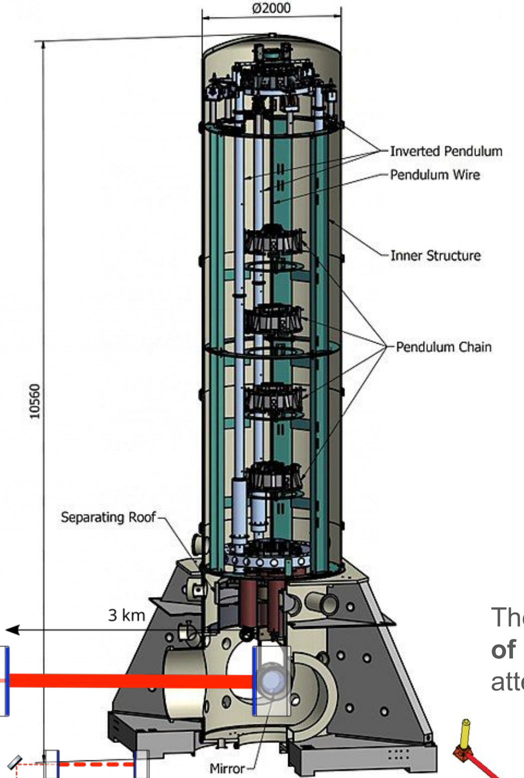
M. van Dael, et. al., Astropart. Phys. 164 (2025)

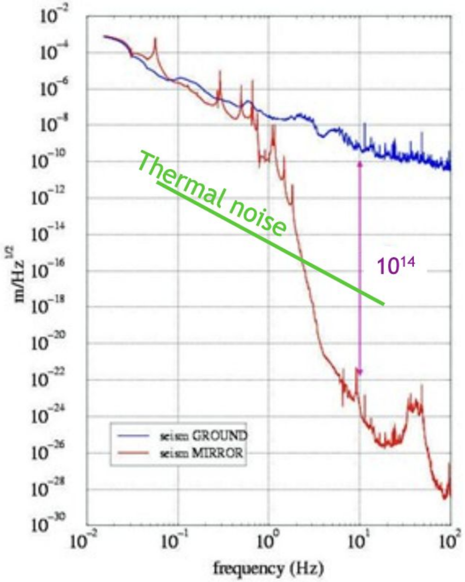




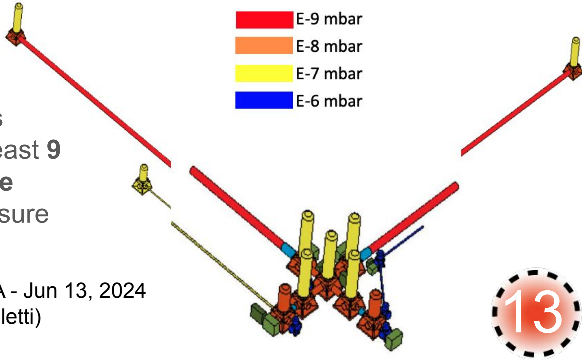
The **laser amplitude noise** is reduced up to about **4 orders of magnitude**

Artémis, l'Observatoire de la Côte d'Azur





The ground motion is reduced by **14 orders of magnitude** for mirror, using Virgo super attenuator



The **vacuum level** is evacuated to be at least **9 orders of magnitude** smaller than air pressure (~1000 mbar)

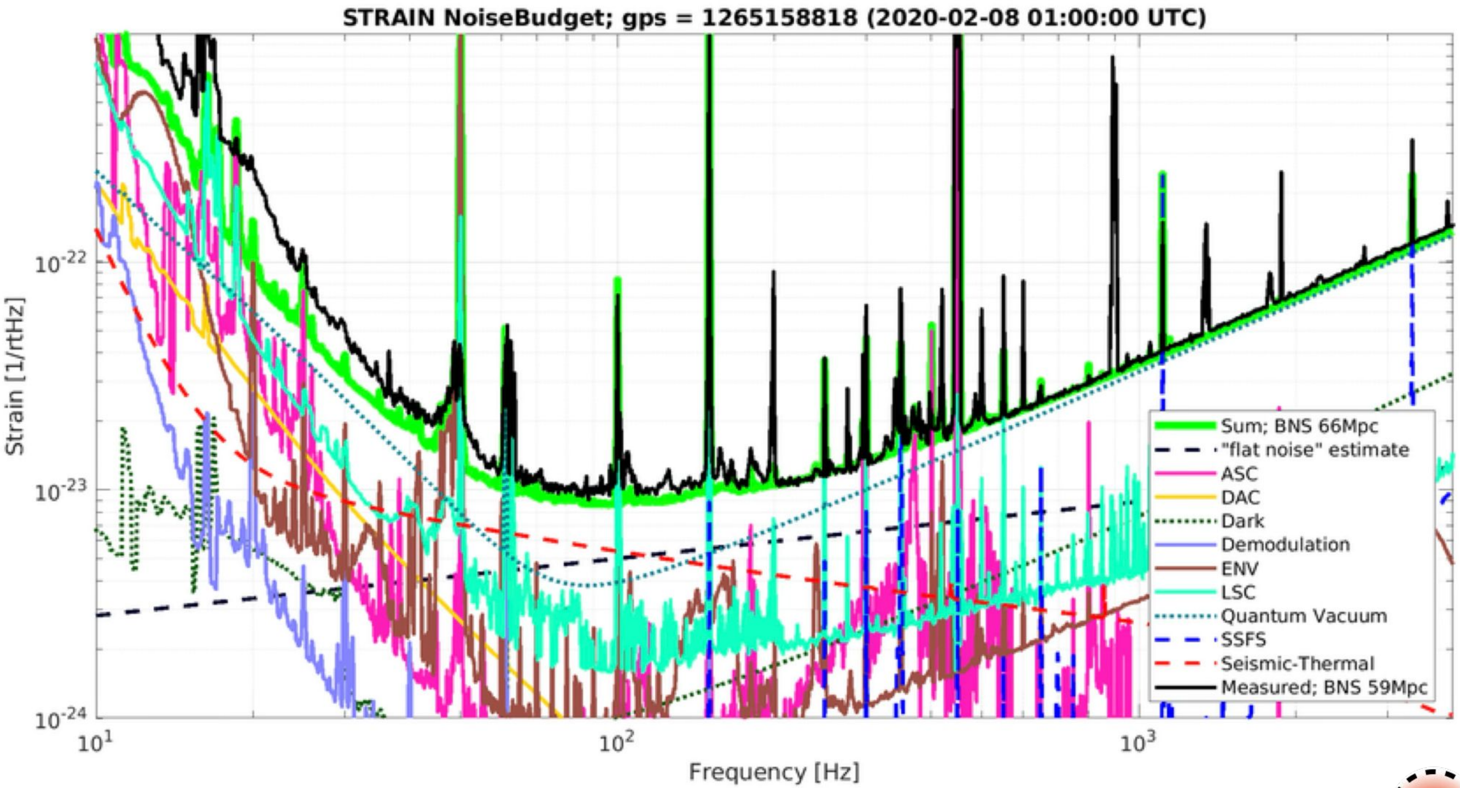
INFN LASA - Jun 13, 2024
(A. Pasqualetti)

💦An exhaustive investigation of sensitivity limitations

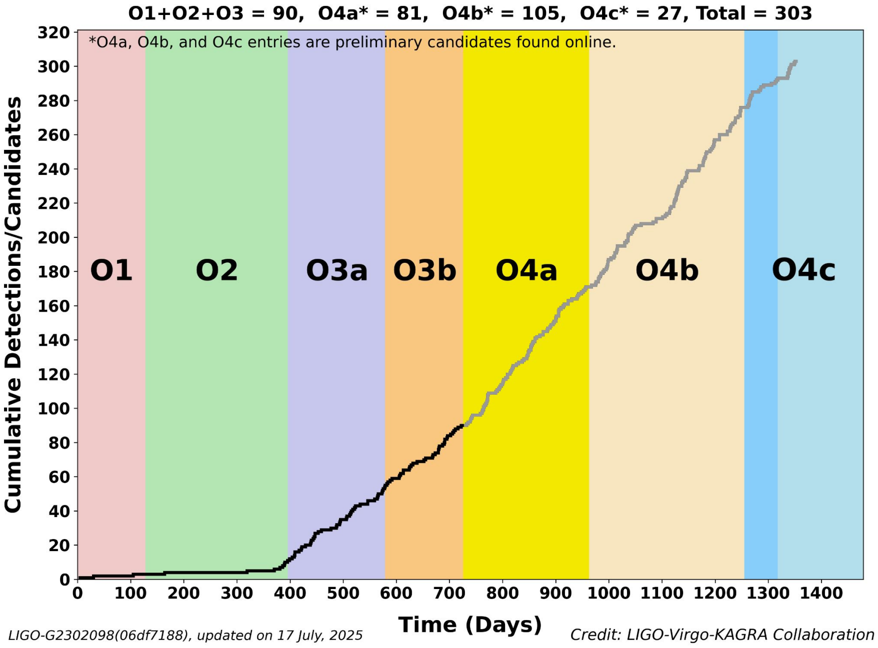
Using state of the art technologies

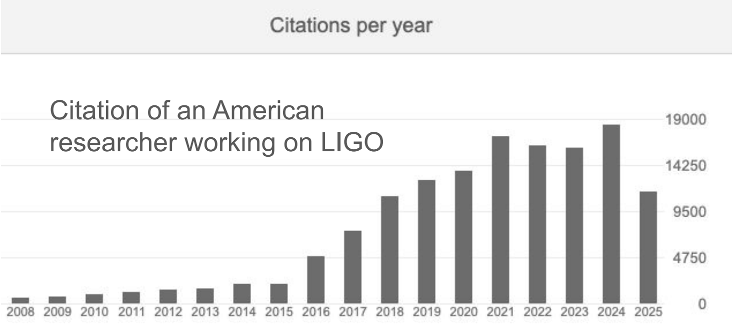
+

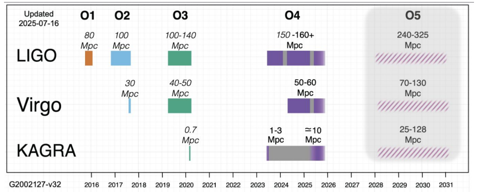
understanding of the noise contribution

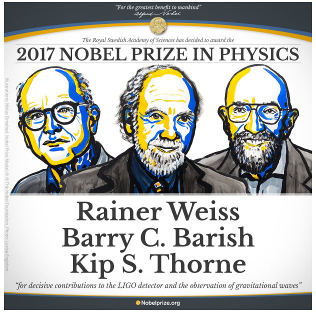


Gravitational wave detectors start to pay off









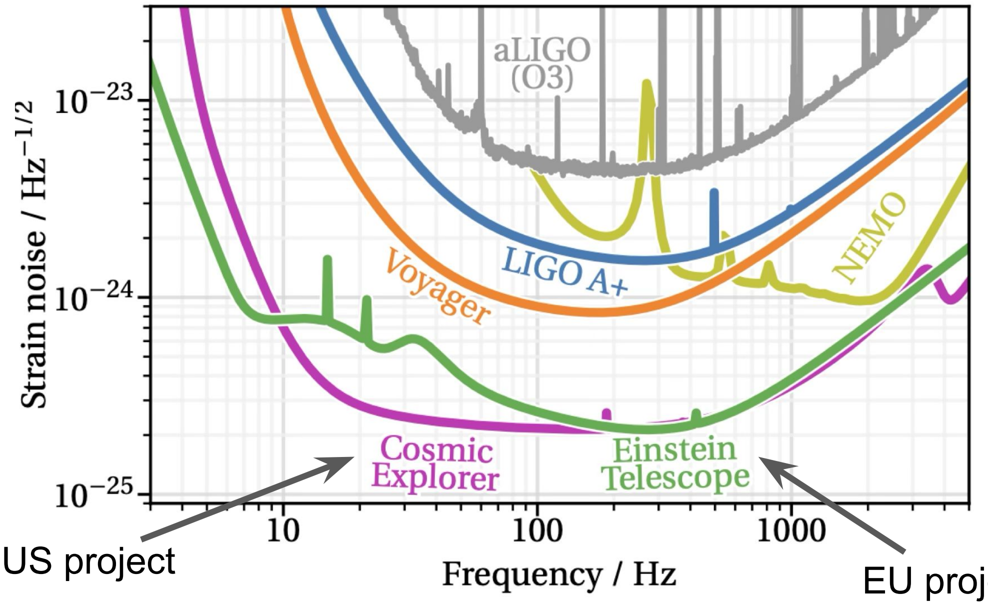
https://git.ligo.org/operations/cumulative-event-plot

Next generation detectors

Design	Preparation	Implementation	Operation

2018 2026 2035 2080

To have a substantial sensitivity improvement, new facility is mandatory

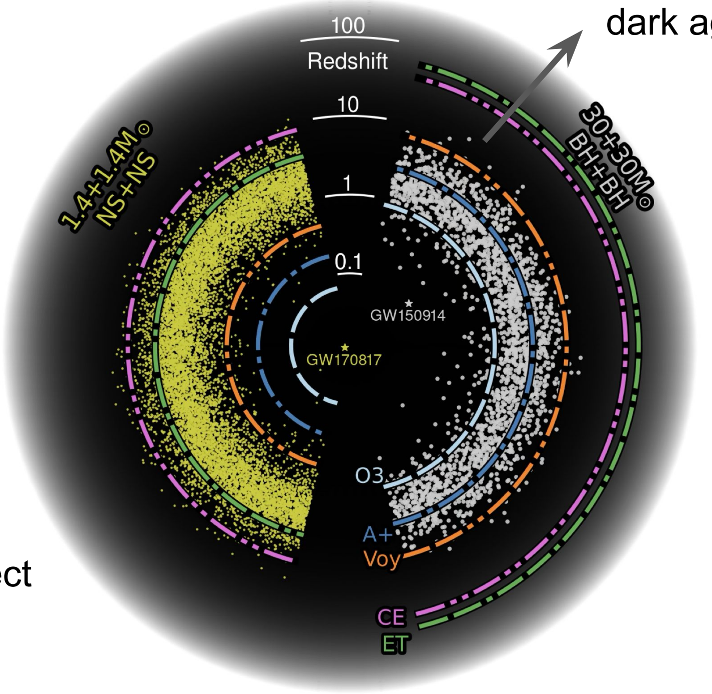


US project

EU project

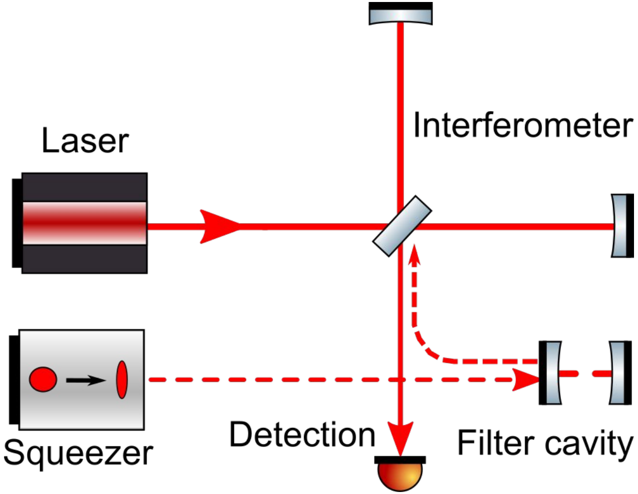
https://cosmicexplorer.org/sensitivity.html

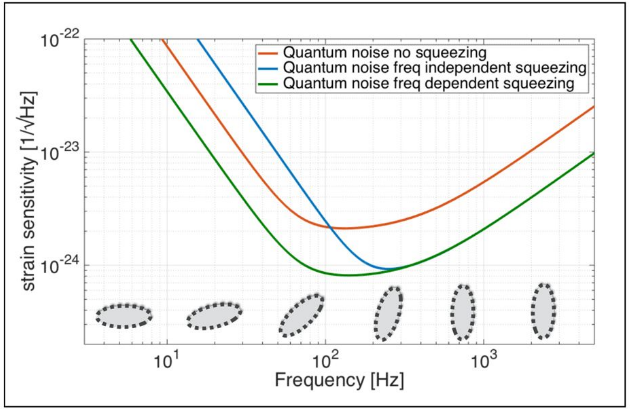
Up to the cosmological dark ages



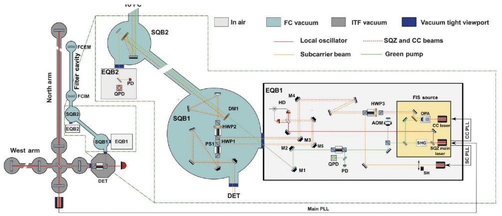
Past collaboration between France and China

✊My past research (the ones with French researchers)





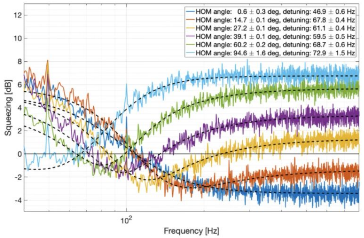
PHYSICAL REVIEW LETTERS **131,** 041403 (2023)



Contributed to **the commissioning of frequency dependent squeezed vacuum source** for Virgo detector

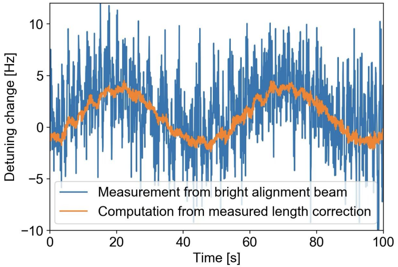
PHYSICAL REVIEW LETTERS

Editors' Suggestion | Featured in Physics



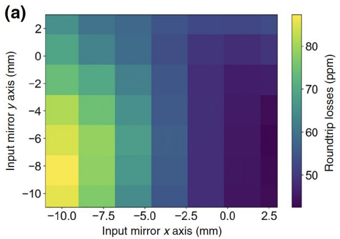
Realized **the first frequency dependent squeezed vacuum source** with rotation around 100 Hz

PHYSICAL REVIEW D



Realized filter cavity working point variation less than 10 Hz

PHYSICAL REVIEW APPLIED



Realized in-situ measurements of optical losses in hundred-meter scale cavity

✊Student visiting

Yuefan Guo

- Master student at Beijing Normal University
- Visited R. Flaminio at NAOJ (2016-2017)
- Worked on quantum noise reduction techniques for KAGRA

During 2017 and 2022, Yuefan worked on the construction of Virgo filter cavity. In the meanwhile, R. Flaminio was the upgrade coordinator of advanced Virgo plus

Applied Optics Vol. 64, Issue 17, pp. 4710-4726 (2025) • https://doi.org/10.1364/AO.555312

Optical characterization of the Advanced Virgo gravitational wave detector for the O4 observing run

Virgo Collaboration

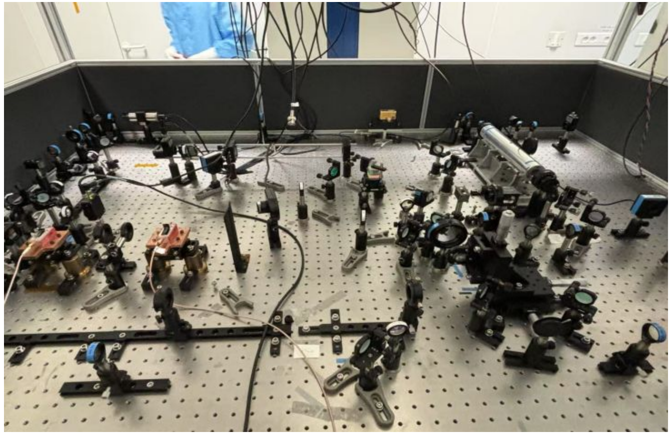
Author Information ▾ Find other works by these authors ▾

Yuefan is working now in NIKHEF as a postdoc

✊Student visiting

Fangfei Liu

- Master student at Beijing Normal University
- Visited M. Barsuglia at APC, CNRS (the second half of 2024)
- Worked on quantum noise reduction techniques for Einstein Telescope



Performance of multiple filter-cavity schemes for frequency-dependent squeezing in gravitational-wave detectors

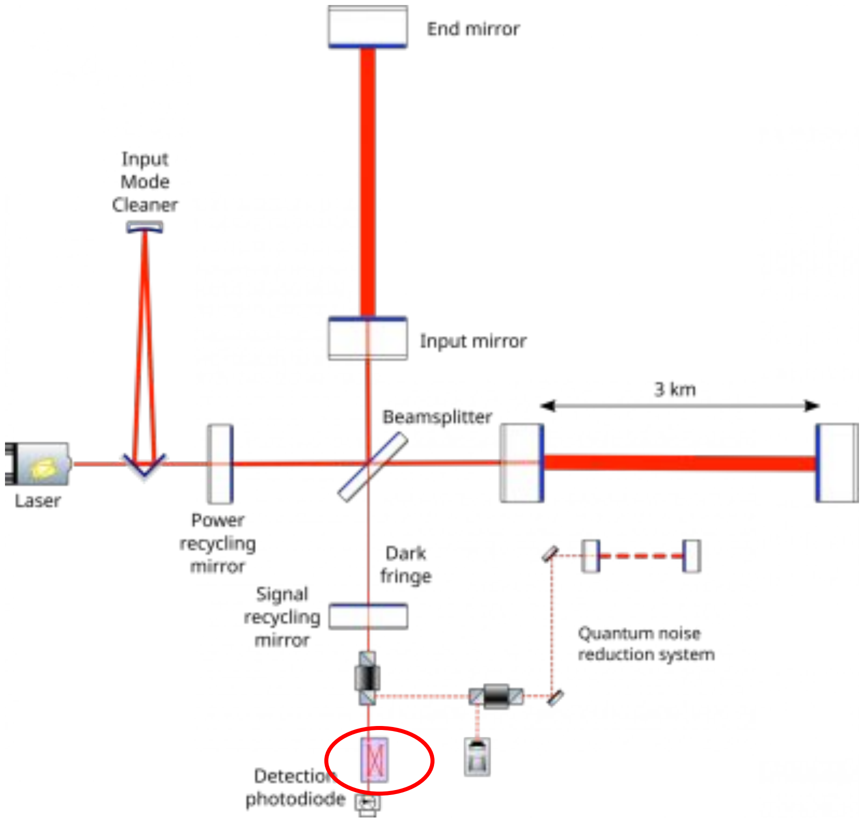
Jacques Ding,[1,2,*] Eleonora Capocasa,[1] Isander Ahrend,[1] Fangfei Liu,[1,3] Yuhang Zhao,[1] and Matteo Barsuglia[1]
[1] *Université Paris Cité, CNRS, Astroparticule et Cosmologie, F-75013 Paris, France*
[2] *Corps des Mines, Mines Paris, Université PSL, France*
[3] *School of Physics and Astronomy, Beijing Normal University, Beijing, China*
(Dated: June 12, 2025)

Fangfei has got offer to do her PhD in France!

✊Student visiting

Yuan Pan

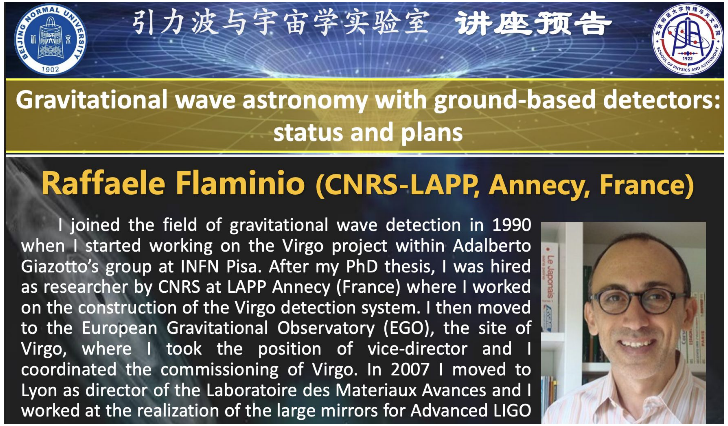
- Master student at Beijing Normal University
- Visited LAPP, CNRS for ten month in 2024
- Worked on an important device, which cleans the signal coming from the output of the laser interferometer

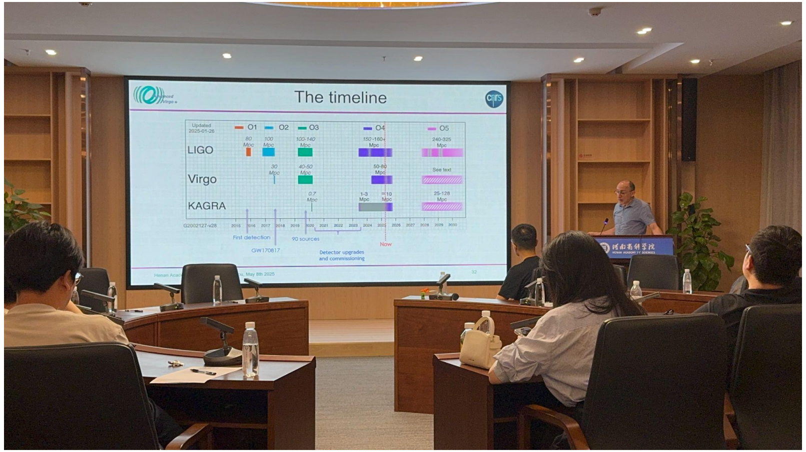


Yuan will do PhD in BNU while collaborating with LAPP.

✊Professor visiting

R. Flaminio visiting BNU and HNAS



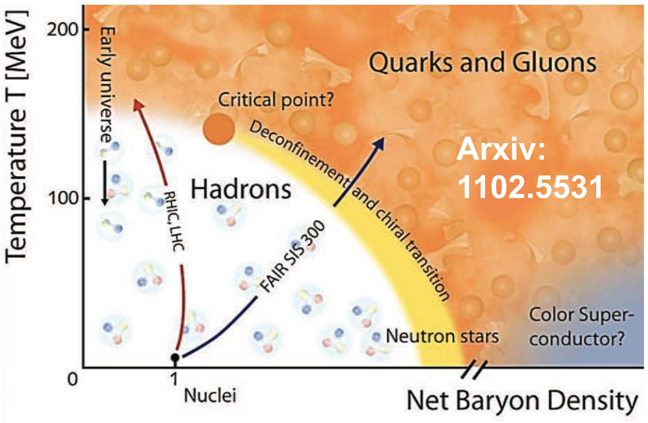


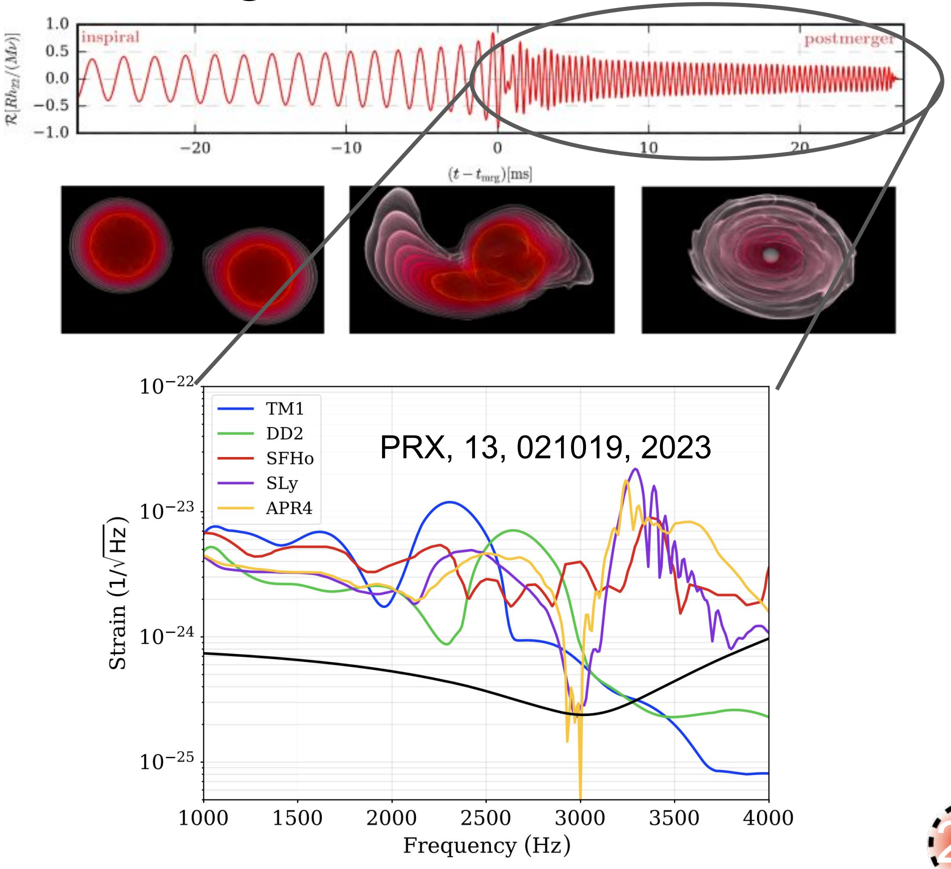
Plan to contribute to the international gravitational wave community

🌟 Interest in detecting NS-NS mergers

General Relativity and Gravitation 53.3 (2021):27

Access the **stellar particle colliders**





- Signature of phase transition in the post merger phase of NS-NS merger

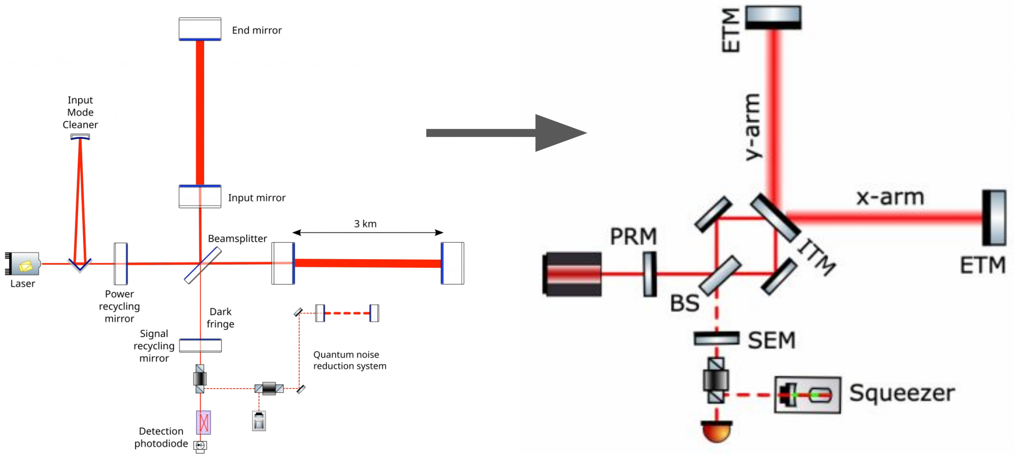
🔭Zhang Heng Telescope

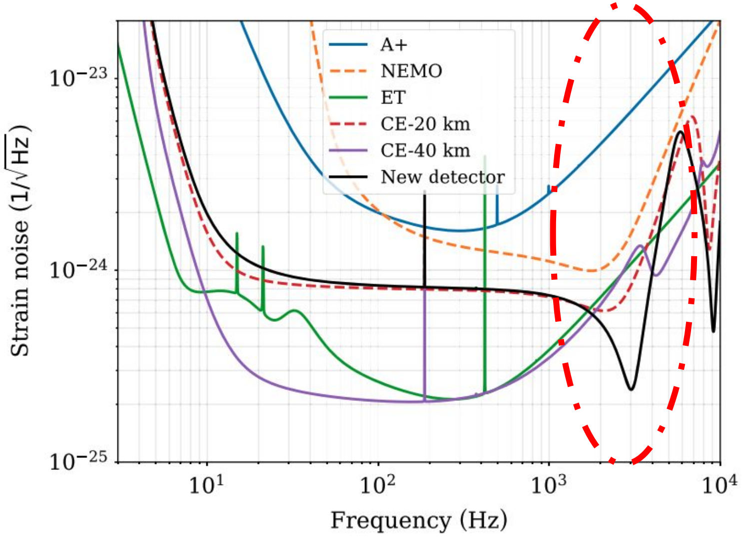
PHYSICAL REVIEW X **13,** 021019 (2023)

Gravitational-Wave Detector for Postmerger Neutron Stars: Beyond the Quantum Loss Limit of the Fabry-Perot-Michelson Interferometer

Teng Zhang,[1,2,3,*] Huan Yang,[4,5,†] Denis Martynov,[1] Patricia Schmidt,[1] and Haixing Miao[6,7,‡]

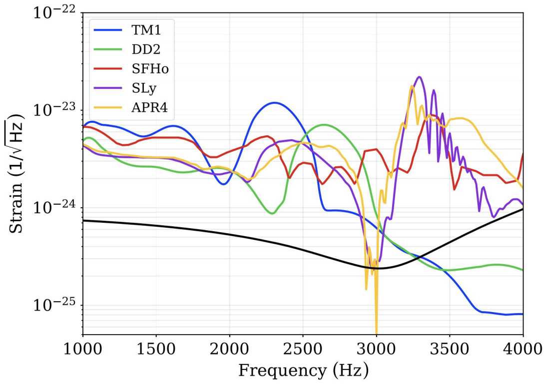
New configuration to boost high frequency sensitivity



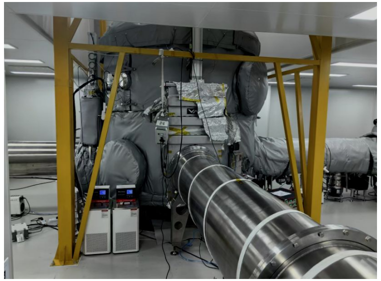


- Arm length: 25km
- Sensitive frequency: 2 kHz - 4 kHz

🔭Zhang Heng Telescope



- He Nan Academy of sciences established the institute for gravitational wave astronomy (IGWA) with the support from He Nan province
- Beijing Normal University started building a prototype since 2021



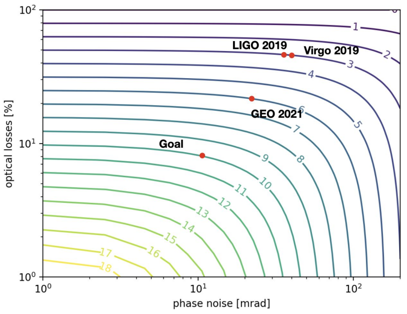
arXiv:2503.24178v2

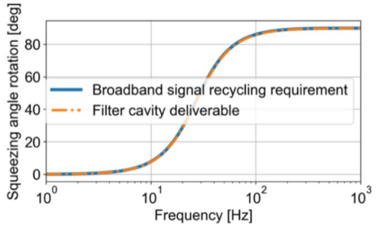
🎯Quantum noise reduction plan @ IGWA, HNAS

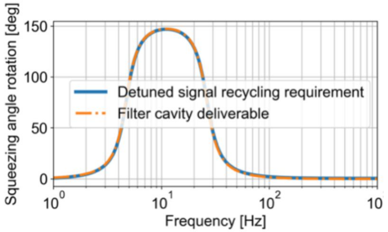
Collaboration with APC, CNRS

Goal:

- Demonstrate non-trivial frequency dependent squeezing for Einstein Telescope
- 10 dB quantum noise reduction



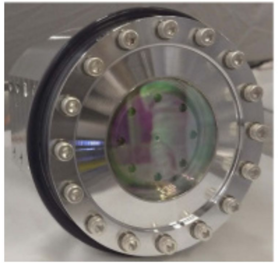


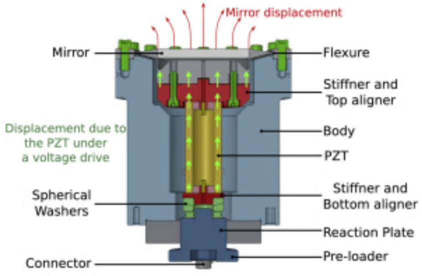


Local R&D

Goal:

- Develop a mode matching sensing and control system for a squeezed vacuum source





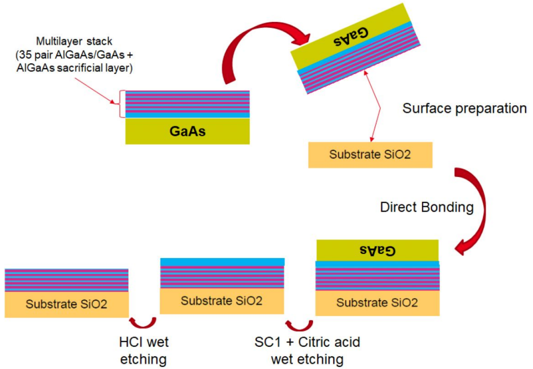
Optics Express 30.7 (2022): 10491-10501

🎯Mirror coating development plan @ IGWA, HNAS

Collaboration with LAPP, CNRS

Goal:

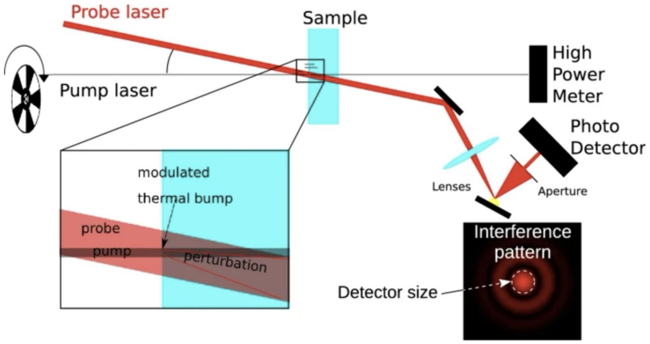
- Continue the output mode cleaner development
- Develop coating manufacturing and transferring technologies together



Local R&D

Goal:

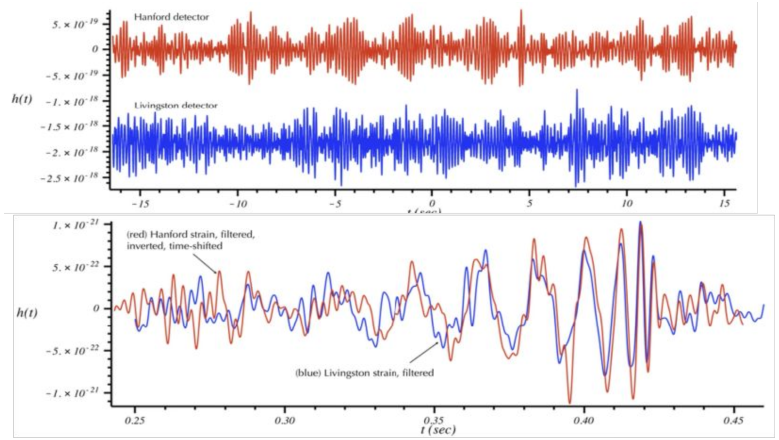
- Develop an experiment to measure the absorption of coating material
- Collaborate with other Chinese labs to develop new coatings



M. Machio, PhD thesis, 2019

🎯Observation plan @ IGWA, HNAS

Data analysis



Multi-messenger astronomy

✉️Conclusion

- There has been an effort to push for collaboration with French researchers since almost ten years to work on gravitational wave instrumentation
- Now, two students of this effort have got their PhD, another two are working closely with French researchers as PhD candidates
- We will continue this effort and hope to join the FCPPN to consolidate such tie

Thank you for your attention!