Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

GRAVITATIONAL WAVE DETECTION

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

QUANTUM UNIVERSE ATTRACT.WORKSHOP

NOVEMBER 25TH 2025

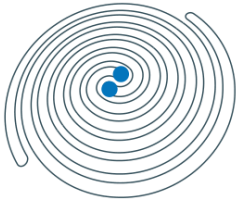
OVERVIEW OF GW ACTIVITIES IN QUANTUM UNIVERSE

PROF. DR. OLIVER GERBERDING, UNIVERSITÄT HAMBURG

BACKGROUND: THE MILKY WAY GALAXY BY DEREK ROWLEY

GRAVITATIONAL WAVES

- **Gravitational Waves** is one of the five research areas of Quantum Universe
- The experimental research is summarized in sub-area **1. Gravitational Wave Detection Techniques** (reported on here)
- Sub Area **2. Multi-Messenger Signatures of Gravitational Wave Sources** focuses on astronomy and source physics and modelling
- Sub Area **3. Gravitational Waves from the Early Universe** focuses on theory and cosmology

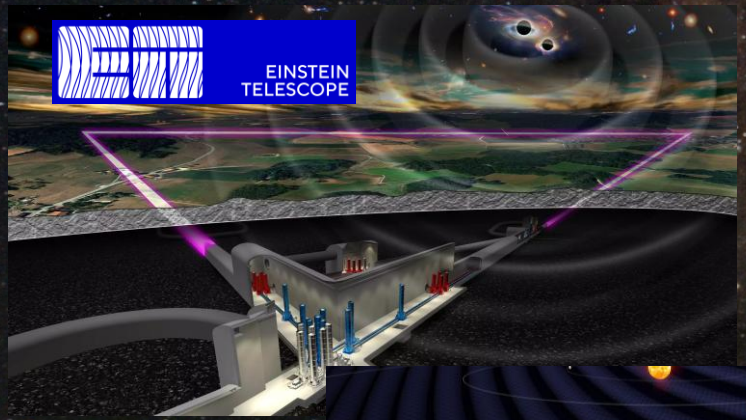


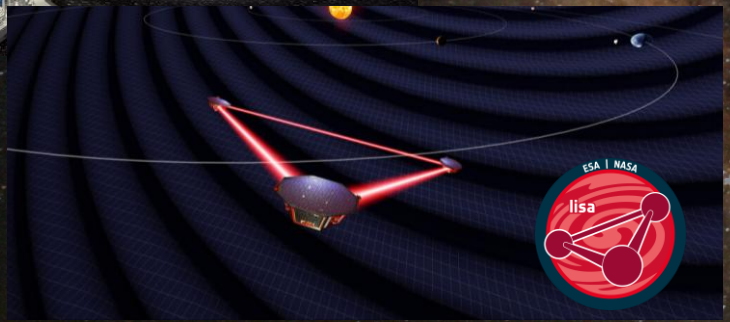
Gravitational Waves

1. Gravitational Wave Detection Techniques
2. Multi-Messenger Signatures of Gravitational Wave Sources
3. Gravitational Waves from the Early Universe

BACKGROUND: THE MILKY WAY GALAXY BY DEREK ROWLEY

MAJOR PROJECTS WE CONTRIBUTE TO



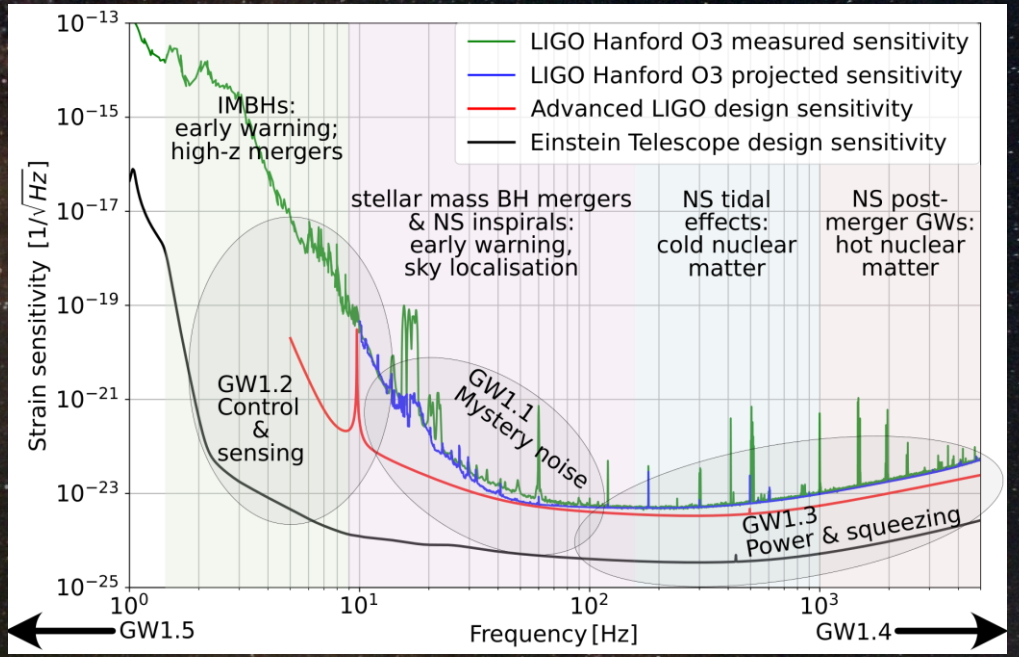


BACKGROUND: THE MILKY WAY GALAXY BY DEREK ROWLEY

GRAVITATIONAL WAVE DETECTION TECHNIQUES

Focus of QU II (we do much more!):

- Improving current ground-based detectors
- Realizing and enabling 3rd generation detectors such as the Einstein Telescope
- Investigating detection concepts for high-frequency GWs (superconducting RF cavities, nano membranes)
- Investigating ground-based mHz detection using storage rings



GW1 – Team Roman Schnabel (UHH) –
Research for the Einstein Telescope and beyond

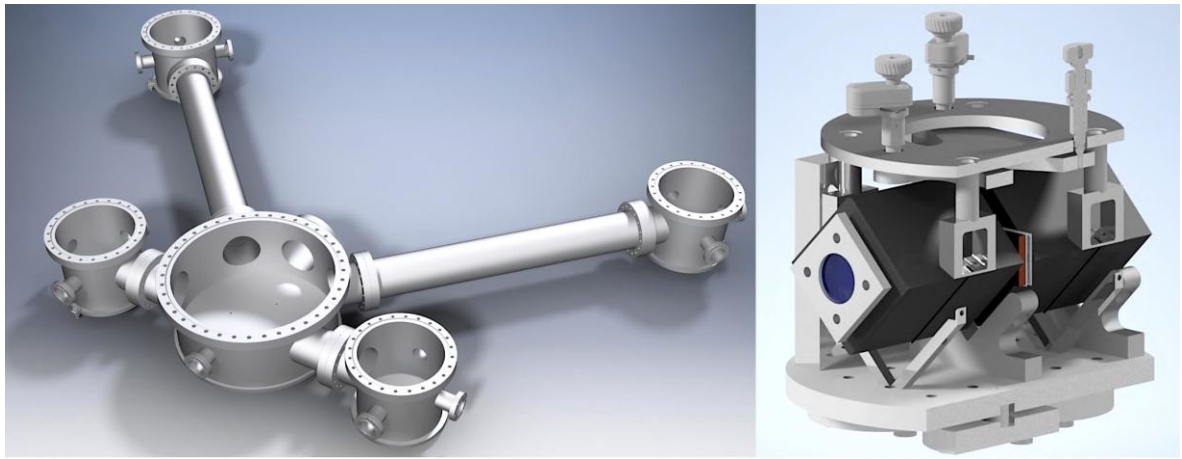
I) The Hamburg 1-m squeezed-light GW-detector prototype *Master students wanted!*

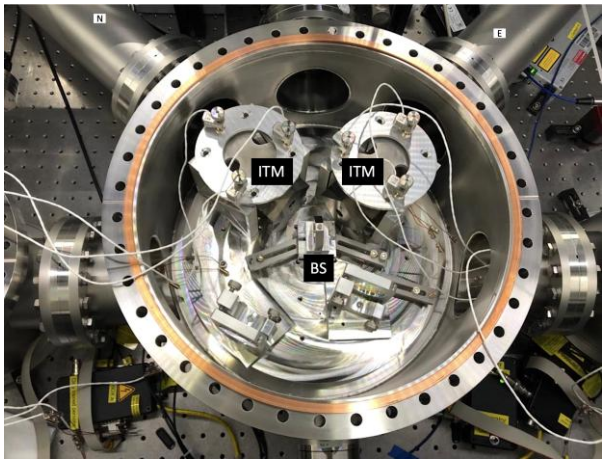
Goals: – Combining 10 dB squeezing with 100 kW of light.

– Solving the back-scatter noise problem for improved GW signals below 30 Hz.

– Establishing the new laser wavelength of 2128 nm.

– Using machine learning (ML) for isolating against seismic motion and controlling GW detectors.



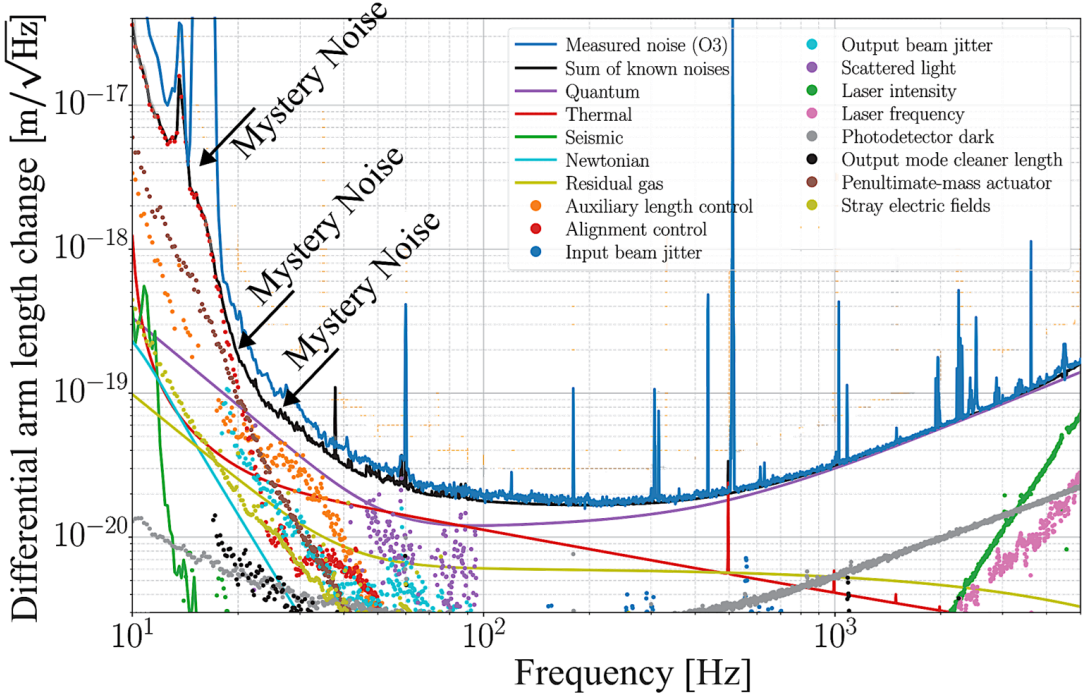


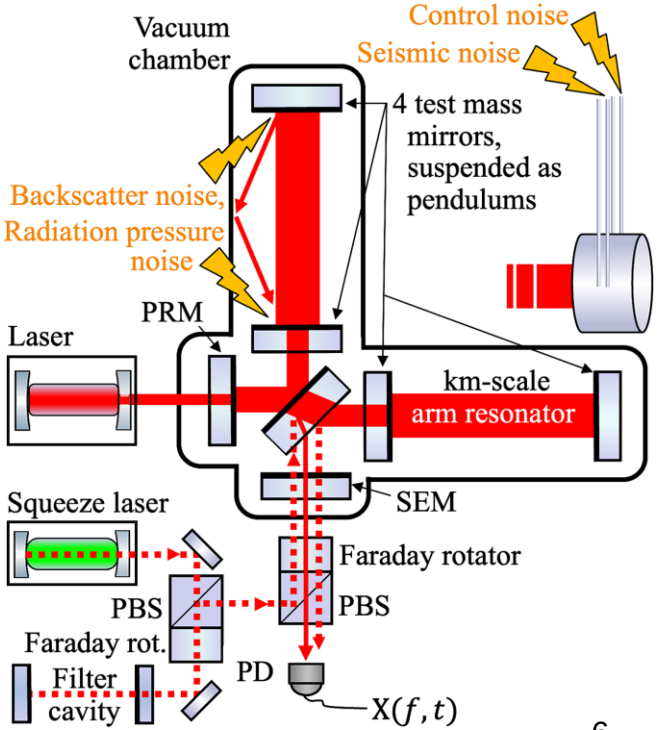
GW1 – Team Roman Schnabel / Ludwig Mathey (UHH) –
Research for the Einstein Telescope and before

II) Solving the 'Mystery Noise' Problem in GW detectors with ML/AI

Master students wanted!

Goals: – Using big data from Witness channels to learn the emergence of 'Mystery Noise', starting with LIGO.

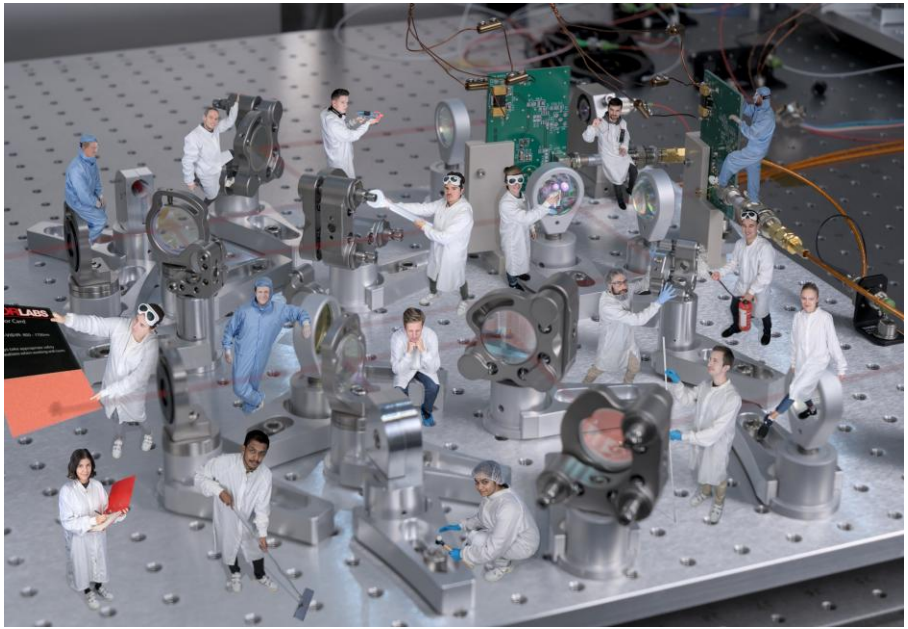




GRAVITATIONAL WAVE DETECTION GROUP LED BY O. GERBERDING

Research focus:

- Compact interferometric sensors
- Controls noise & suspensions
- Inertial sensing
- Scattered light supression
- FPGA-based phase readout and control
- Seismic networks (wave-hamburg.eu)

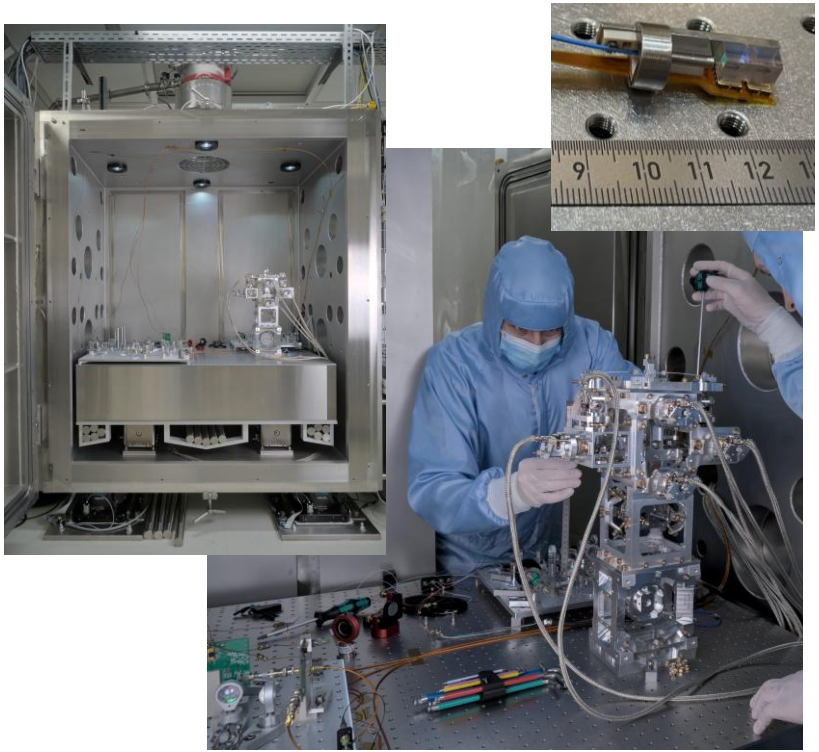


UPCOMING PROJECTS

- Postdoc position on *Multi DOF sensor experiments and modelling for low-frequency control noise reduction* (advertisement about to be released)

PhD projects with funding pending:

- *Compact interferometric sensors for ET and ET Pathfinder*
- *Pre-experiments for a large-scale ET suspension and control prototype in Hamburg*
- *Readout, control and scattered light noise readuction in compact ring laser gyroscopes*

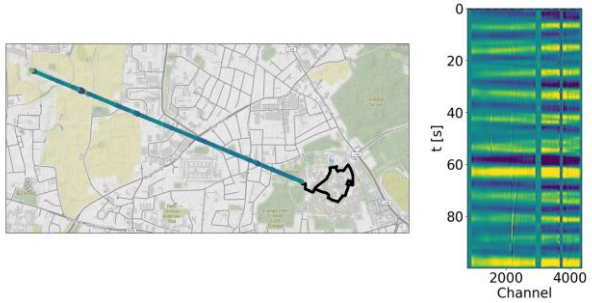


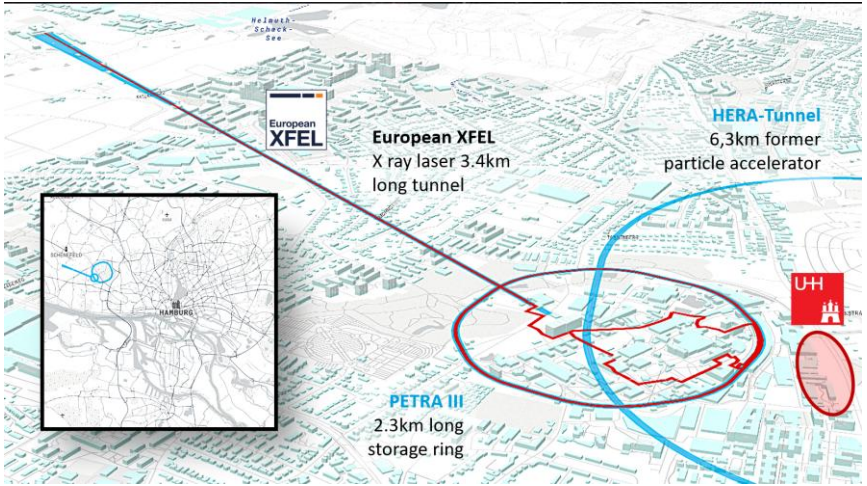
WAVE SEISMIC NETWORK INITIATIVE

Contacts: K.-S. Isleif, C. Hadziioannou (Geophysics), O. Gerberding

- Environmental noise sensing
- Predicting seismic noise
- Newtonian noise studies for ET
- On-site experiments at e.g. LIGO
- Outreach with livestreams and more

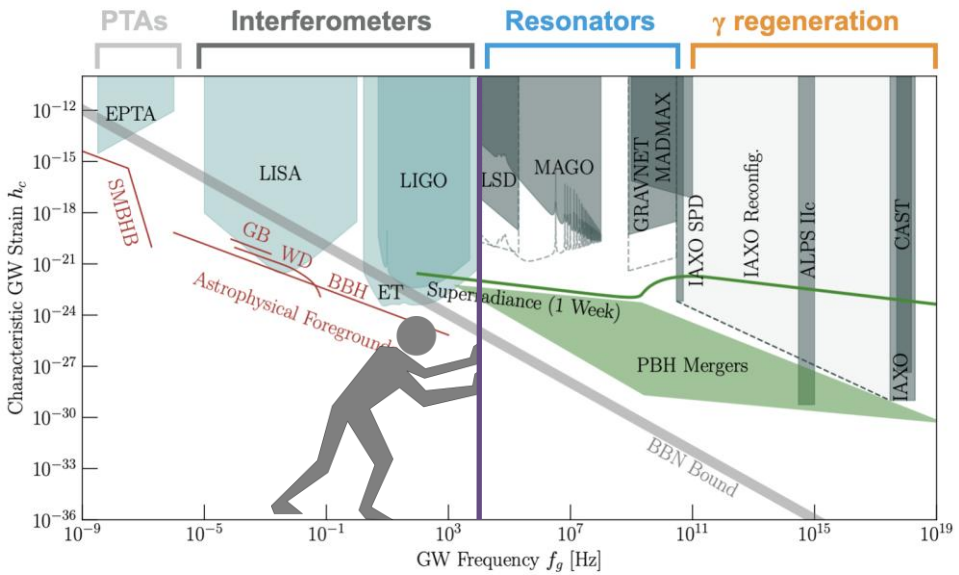
Check it out at www.wave-hamburg.eu





Opportunity to push the boundary on GWs

Gravitational Waves at Higher Frequencies



Universe expected to be populated by GWs over many decades in frequency (cf. to EM radiation)

- Extend to high frequency, complementary to LIGO/ET
- No known astrophysical objects over *O*(kHz): if detected, points to BSM physics
- High risk, high return!
- Ongoing R&D projects at DESY/UHH to establish technologies and assess feasibility

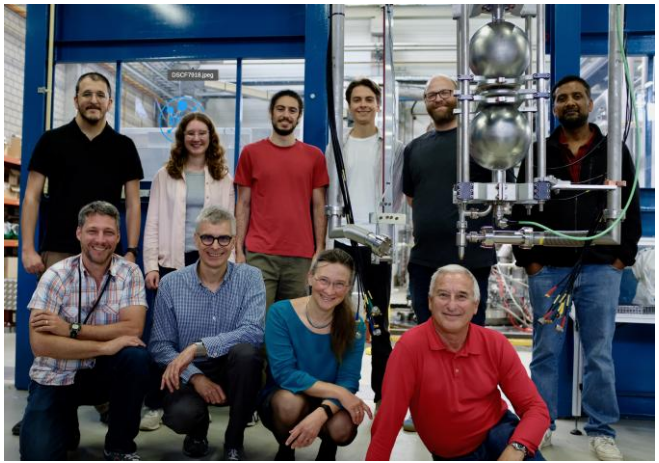
With the necessary expertise and infrastructure (e.g. cryoplatform) on-site, DESY would be an ideal place to develop and host some of these experiments

SRF cavities

Revival of the MAGO proposal

Cavities de-tuned by GW, an effect that could be detected with appropriate instrumentation

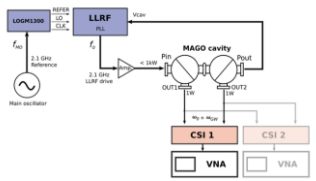
R&D at DESY/UHH in collaboration with Fermilab with the MAGO cavity (on loan from INFN)

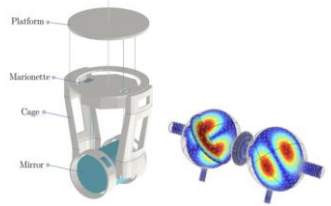


Short term goal: proof-of-principle measurement

Goals for the coming years:

- Improve further cavity control & readout
- Mitigate environmental noise with a dedicated suspension system





- Physics runs in an existing DESY cryostat with new, optimized cavities

Current experimental job openings on:

- Detailed study of the impact of superfluid helium (PhD)
- Signal readout, data acquisition and data analysis (Postdoc)

NEST (Nano-membrane Experiment for Space-time Tremors)

Goal: Detect ripples in space-time with chip-scale devices

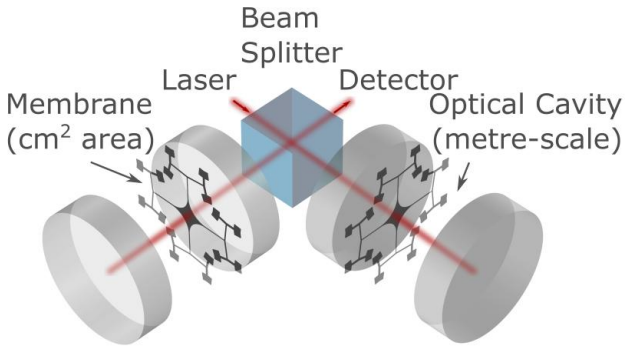
Fabricate cm^2-scale crystalline membranes & optically trap them inside Fabry-Perot cavities to search for **high-frequency gravitational waves** & **vector dark matter,** with a membrane-limited frequency range of 0.5 - 300 kHz

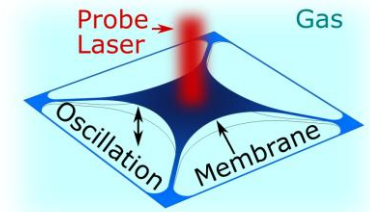
Opportunities for new team members

Contribute to membrane design and fabrication, optomechanical prototype development, data taking and analysis

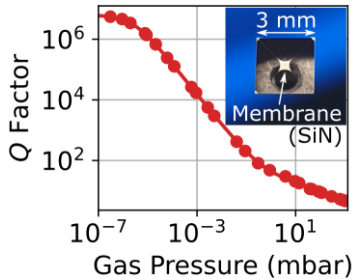
Background

- Chip-scale mechanical oscillators with ultra-low loss provide a powerful platform for precision sensing and emerging quantum technologies
- We also work on a disruptive nanomechanical gas-pressure sensor





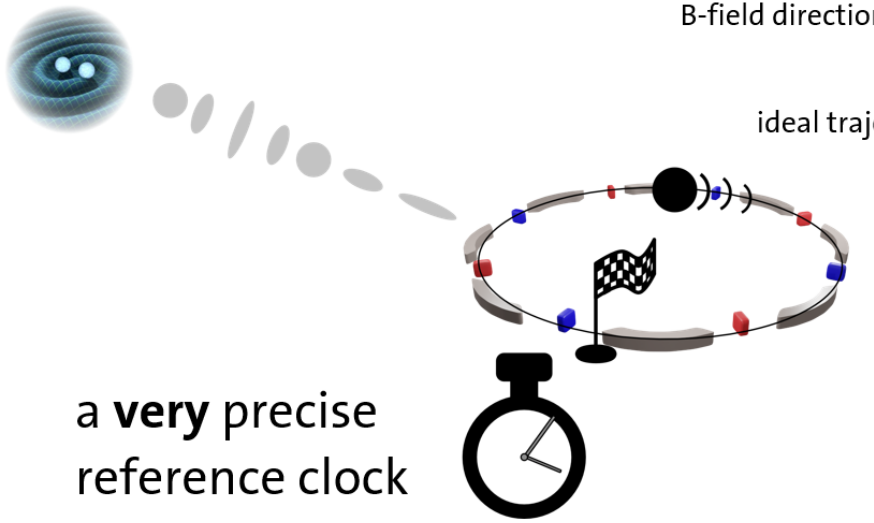
ACS Photonics, 11(4), 1438-1446 (2024)



Contact:	Axel Lindner axel.lindner@desy.de +49-40-8998-3525	Christoph Reinhardt christoph.reinhardt@desy.de +49-40-8998-5055

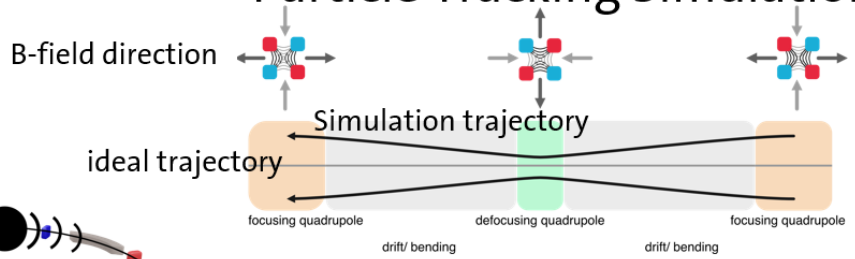
GW Detection with Storage Rings

Time-of-flight experiment

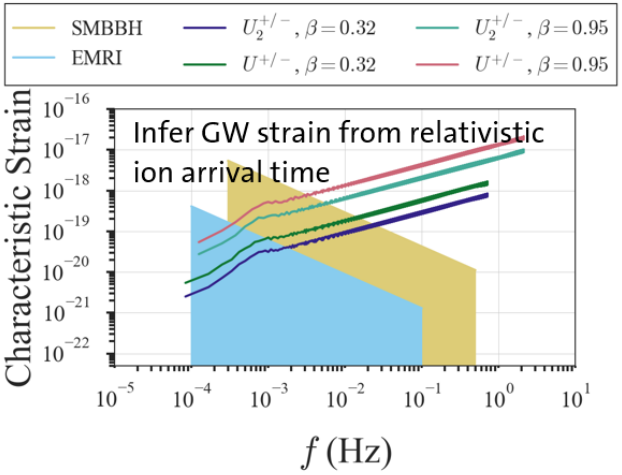


a **very** precise reference clock

Particle Tracking Simulation



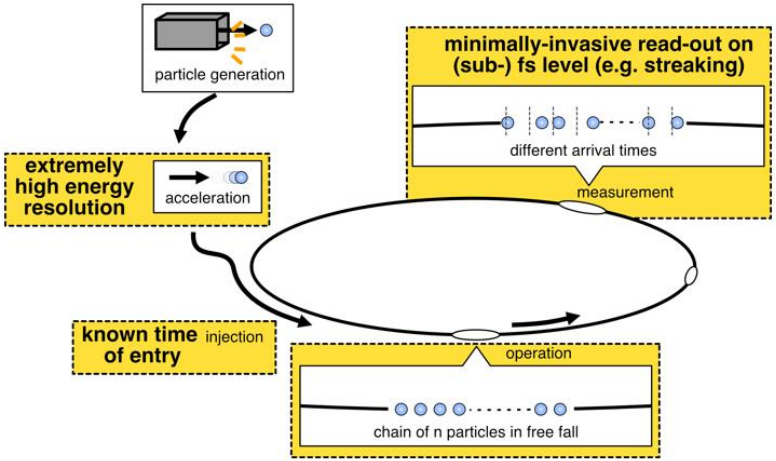
Synchrotron Radiation noise



Schmirander et al. PRD **110**, 082002 (2024)

- Particles in storage ring can circulate for minutes up to hours: **milliHertz GW With time-of-flight signal**
- Combine photon statistics with particle tracking simulation: **Synchrotron emission power noise**
- How to **quantify other noise sources**?

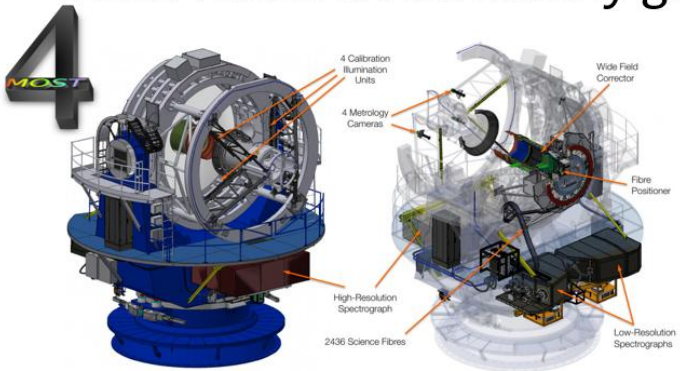
QU2 Activities



- Design and simulate experimental setup for storage ring operation and arrival time measurement **with high temporal resolution**

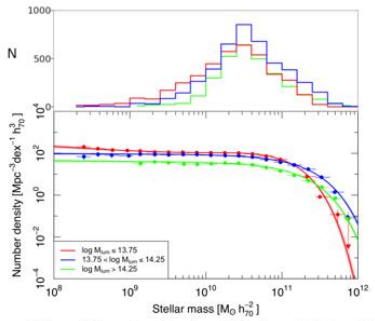
- Conduct experiment on ion **generation**, **acceleration**, **injection** and possibly read-out using attosecond streaking methods

Observational Astronomy group (J. Liske)



https://www.4most.eu/cms/gallery/

Galaxy stellar mass function



Sbaffoni et al. A&A, 696, A89 (2025)

- Study galaxy evolution using spectroscopic surveys

- Instrumentation development, e.g. 4MOST

- Develop & explore alternative concepts of mHz GW detection