GWADW Online 2021

GWADW2021 Gravitational Wave Advanced Detector Workshop

17-21 May 2021
remote

Quantum Noise and Optical Configuration *WORKSHOP*

Conveners:
Martina De Laurentis (University of Naples ‘Federico II’ - INFN) ,
Sebastian Steinlechner (Maastricht University & Nikhef)

INFN NSF

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Quantum Noise and Optical Configuration WORKSHOP

***Session I*:** May 19th ,h 23.00 CEST- May 20th 1.00 CEST

SESSION I (1st and 2nd hour)

Status of Quantum Noise Reduction
in current Gravitational Waves Detectors

SESSION II (3rd and 4th hour)

Advanced QNR technologies and
High Frequency Detectors

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Quantum Noise and Optical Configuration WORKSHOP

***Session I*: Status of Quantum Noise Reduction System in the operating Gravitational Waves Detectors**

May 19th ,h 23.00 CEST- May 20th 1.00 CEST

1

Yuhang Zhao (ICRR, The University of Tokyo),

Status of the frequency dependent squeezed vacuum source development at TAMA

2

Valeria Sequino (Università degli Studi di Napoli "Federico II" and INFN sez. Napoli),

Marco Vardaro (Institute for High-Energy Physics, University of Amsterdam and NikHef)

Injection and control of Frequency Dependent Squeezing in Advance Virgo Plus

3

Naoki Aritomi (National Astronomical Observatory of Japan)

Demonstration of length control for a filter cavity with coherent control sidebands

4

Jon Richardson (Caltech) , Rana Adhikari (Caltech)

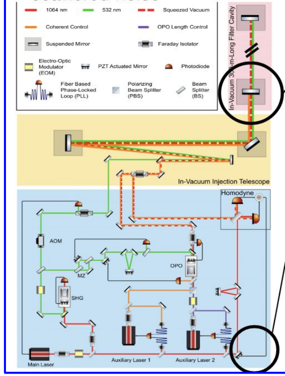
Optimizing Interferometer Design for Squeezed Light

Status of the frequency dependent squeezed vacuum source development at TAMA

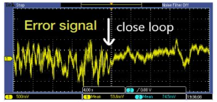
ZHAO, Yuhang (ICRR); ARITOMI, Naoki;

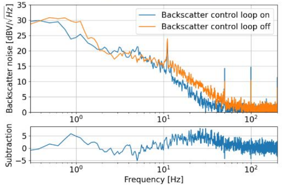
Low frequency noise investigation

- A loop was designed and demonstrated to be able to reduce back scattered noise



- **To control squeezing phase:**
  - Drive filter cavity input mirror
  - Drive phase shifter





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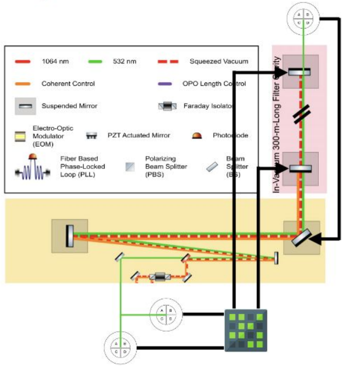
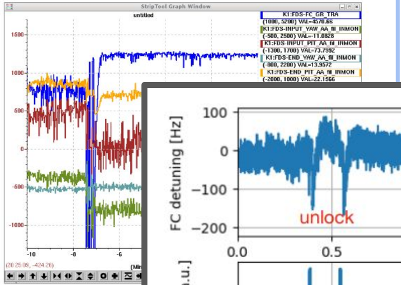
Filter cavity auto-alignment

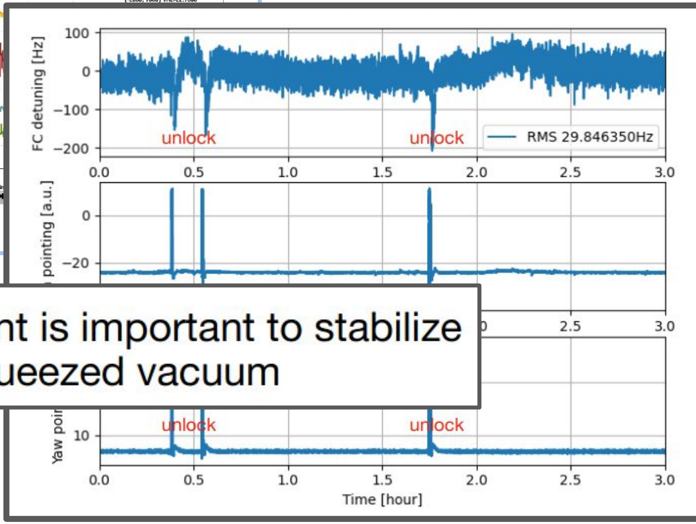
- A green beam auto-alignment to filter cavity system was successfully implemented based on wavefront sensing



- The IR auto-alignment is achieved simultaneously with green because of their overlap



- The IR resonance can be kept decently after a green beam pointing loop implementation



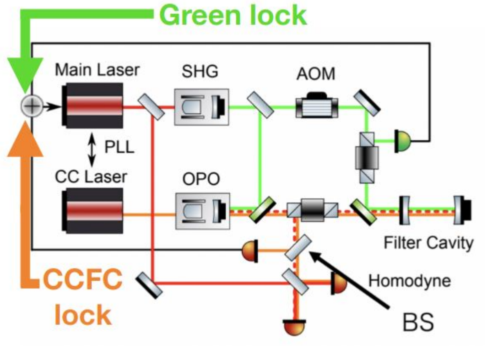
Longterm stability: filter cavity auto-alignment is important to stabilize the filter cavity alignment and detuning for squeezed vacuum

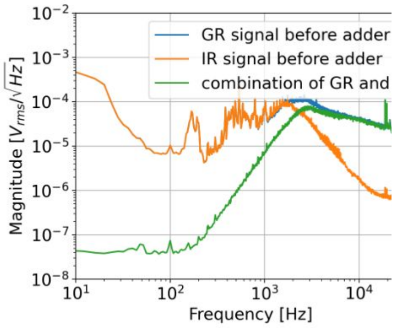
Demonstration of length control for a filter cavity with coherent control sidebands

Naoki Aritomi (National Astronomical Observatory of Japan)

Filter cavity new length control

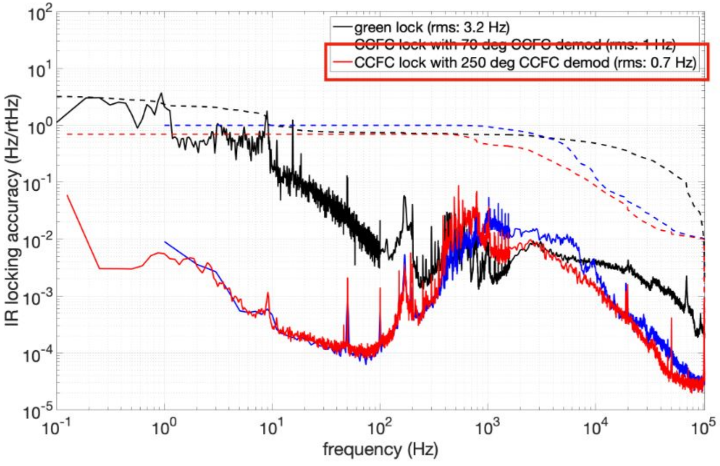
- A pre-stabilized coherent control field reaching filter cavity with one sideband on-resonance and the other off-resonance, which tells us the filter cavity mirrors differential length information





- This loop reduces IR length noise by introducing small length noise for GR

- A in-loop check of the IR length noise shows less than 1Hz noise is achieved



Injection and control of Frequency Dependent Squeezing in Advanced Virgo Plus

V. Sequino and M. Vardaro
on behalf of the Virgo-AEI collaboration

AdV+ Filter cavity

Parallel to the ITF North Arm

CAVITY MIRRORS

- diameter d=15 cm;
- radius of curvature RoC= 558 m;
- round-trip losses l< 40 ppm

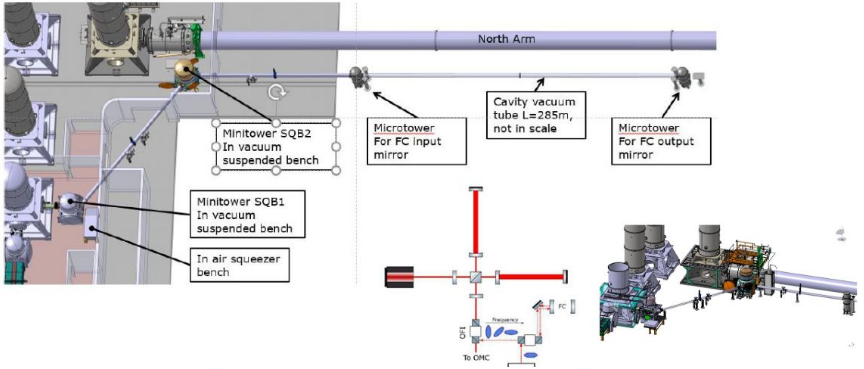
AdV+ required squeezing angle rotation: 20-30 Hz

Need for a cavity linewidth of the same order

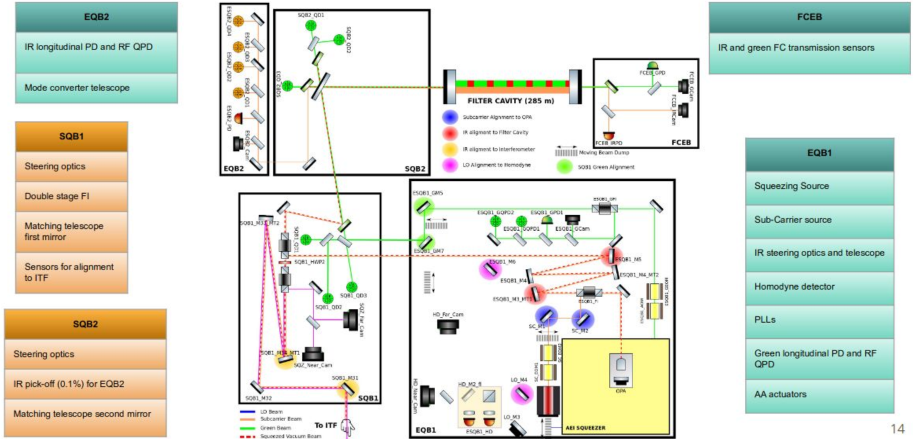
- length L=285 m;
- finesse F=11000 (@1064 nm)

The cavity must be **detuned** with respect to the frequency of the squeezed beam:

- Locking with an external IR laser (Sub Carrier)
- Locking with green (F=100 @532 nm)



Overall conceptual design



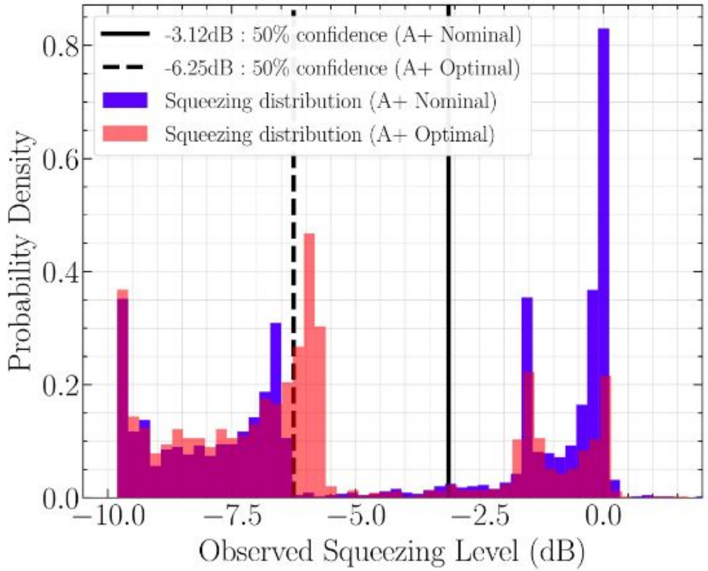
LIGO-G2101095

Optimizing Gravitational-Wave Detector Design for Squeezed Light

Jonathan Richardson
Caltech and LIGO Laboratory

May 18, 2021

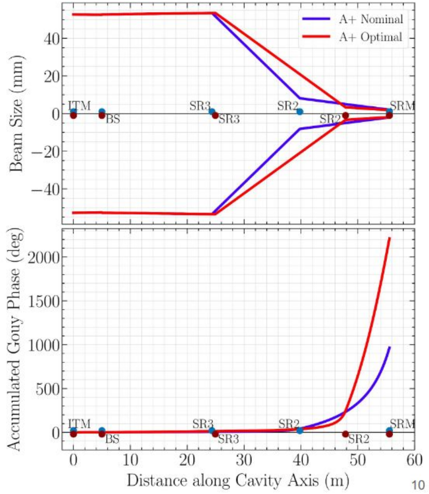
Ratio of median shot noise reduction factors: **1.43**



Optimal SRC design

Nominal versus optimal SRC parameters:

Parameter	A+ Nominal	A+ Optimal
SR3 radius of curvature	35.97 m	48.13 m
SR2 radius of curvature	-6.41 m	-3.34 m
SRM radius of curvature	-5.69 m	-36.41 m
Beamsplitter to SR3 length	19.37 m	19.96 m
SR3 to SR2 length	15.44 m	22.89 m
SR2 to SRM length	15.76 m	7.71 m



Quantum Noise and Optical Configuration WORKSHOP

Session II: Advanced QNR technologies and High Frequency Detectors

May 21th, 6.00-8.00 CEST

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Teng Zhang (University of Birmingham)
A broadband xylophone configuration with sloshing Sagnac interferometers

Roman Schnabel (Universität Hamburg)
Mitigation of back-scattered light by dual balanced-homodyne readout

Carl Blair (University of Western Australia)
White Light Signal Enhancement

Eugene Polzik (Copenhagen University)
Towards broadband quantum noise reduction in GWIs using an atomic noise eater

Ken-ichi Harada (Tokyo Institute of Technology)
Optical-parametric signal-amplification for a high-frequency gravitational-wave detector

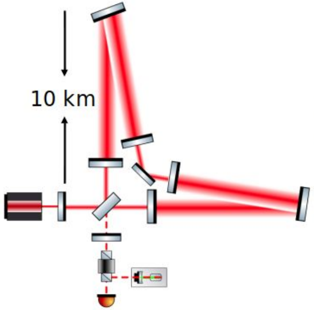
Nancy Aggarwal (Northwestern University)
Science case and design considerations for a GW detector in the 10 - 300 kHz band

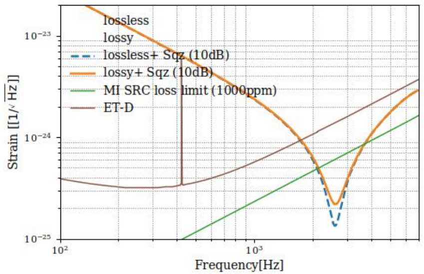
A broadband xylophone configuration with sloshing Sagnac interferometers

Teng Zhang, Denis Martynov, Haixing Miao

GWADW, 2021.05.20

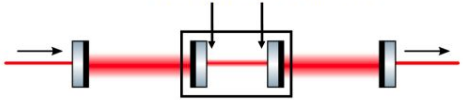
A pure HF detector

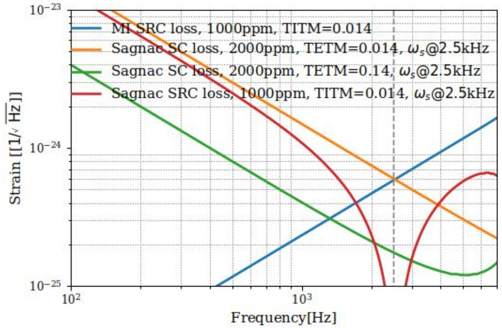




Arm power	SC power/ BS power	Arm length	SC length	ITM T	ETM T	SRM T
3MW	5	20km	800m	0.014	0.14	0.1

New loss limit





In addition, the SC loss is free of loss from BS compared with Michelson SRC loss.

Mitigation of back-scattered light by dual balanced-homodyne readout

Roman Schnabel
Institut für Laserphysik & Zentrum für Optische Quantentechnologien

Best data for back-scatter modelling

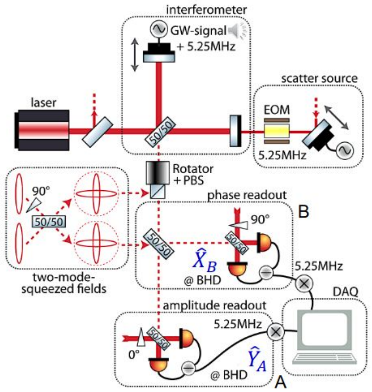
→ half of GW-signal lost.

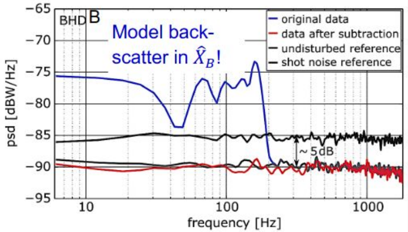
$\theta = 0$

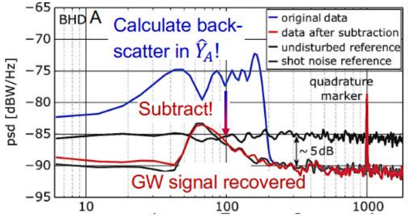
Zero data for back-scatter modelling

→ no GW-signal lost.

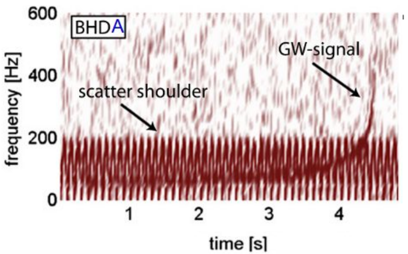
Proof of principle demonstration

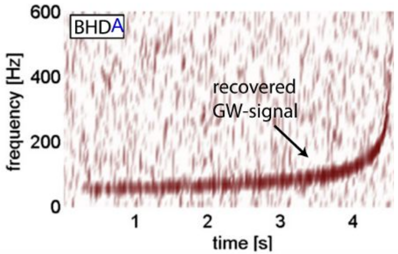






[M. Ast, S. Steinlechner, R. Schnabel,





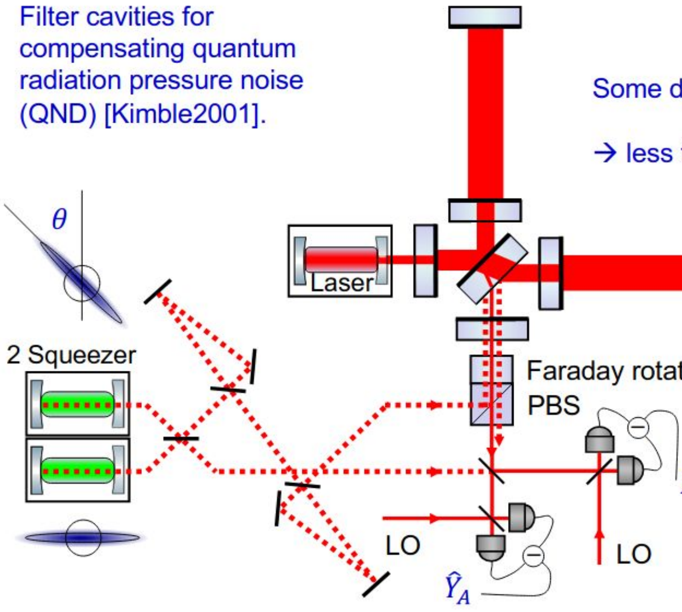
ET with Dual Balanced-Homodyne Readout

Filter cavities for compensating quantum radiation pressure noise (QND) [Kimble2001].

$\theta = 90°$

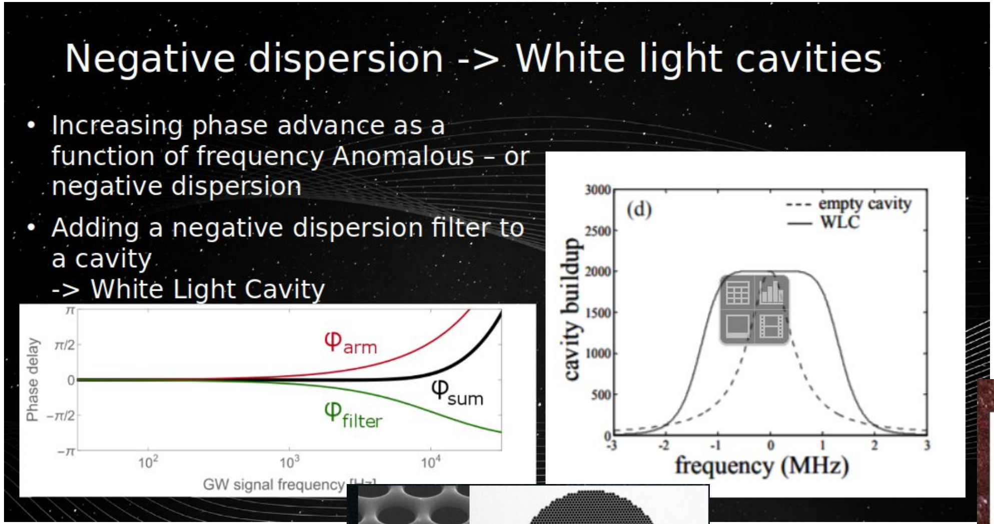
Some data for back-scatter modelling

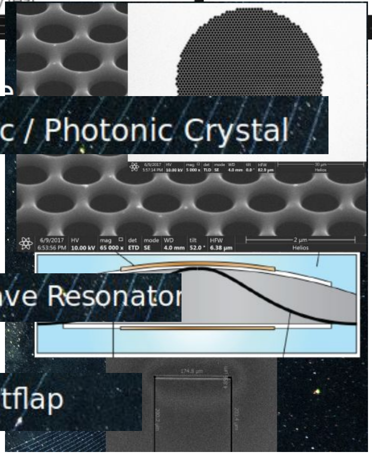
→ less than half of GW-signal lost.



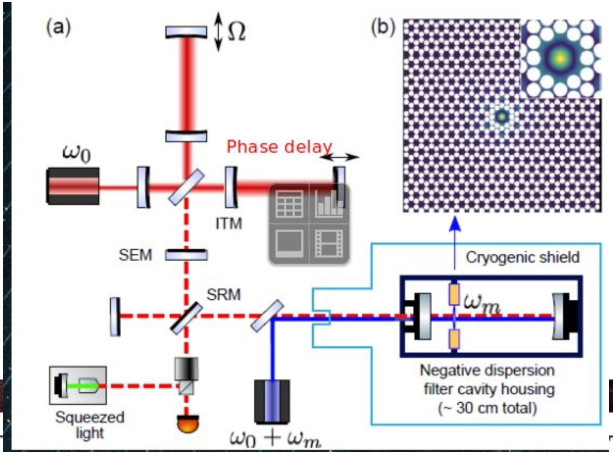
$$\hat{X}_{B,\theta} = \hat{Y}_B \sin\theta + \hat{X}_B \cos\theta$$

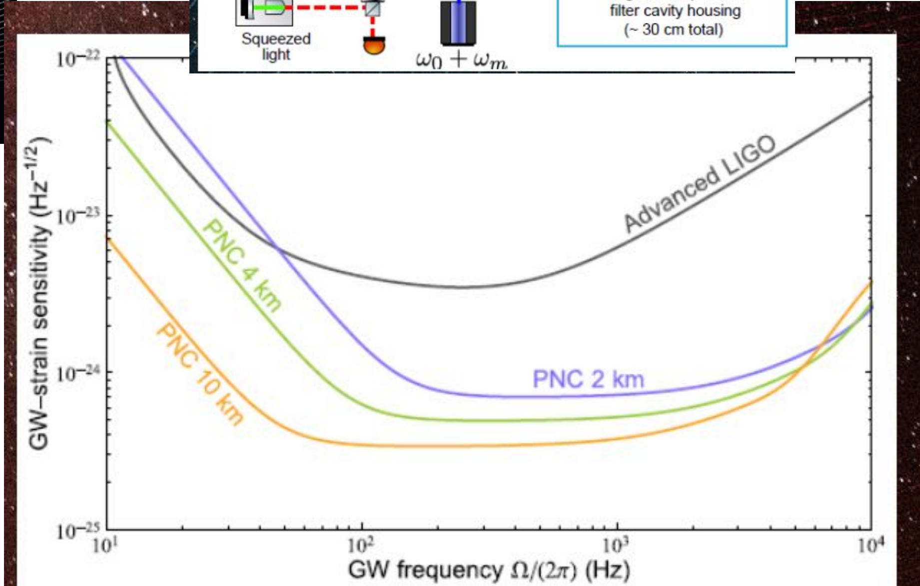
C. Blair: White Light Signal Enhancement

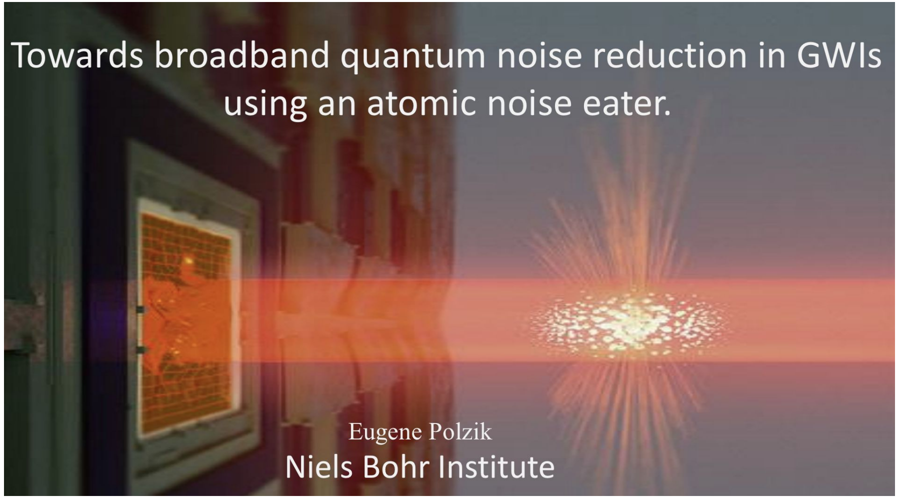




- Phononic / Photonic Crystal
- Bulk Acoustic Wave Resonator
- Optically Diluted Catflap

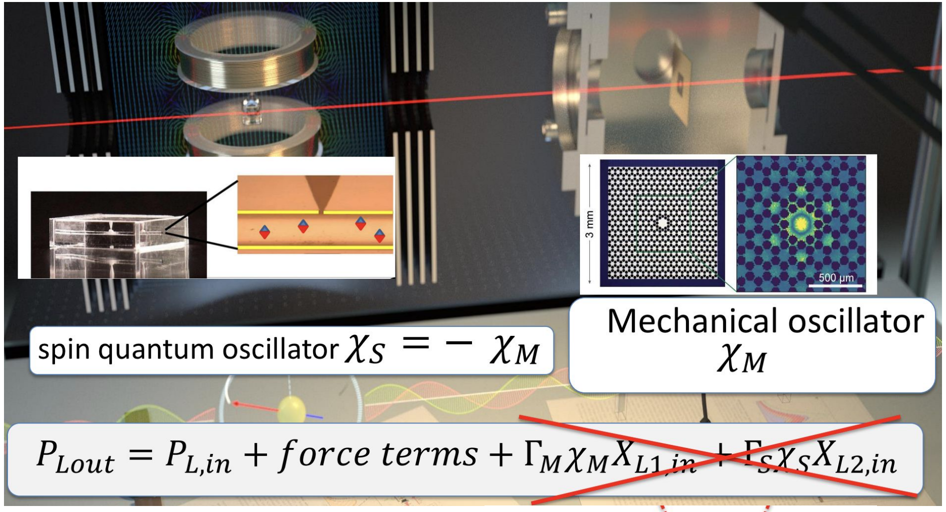


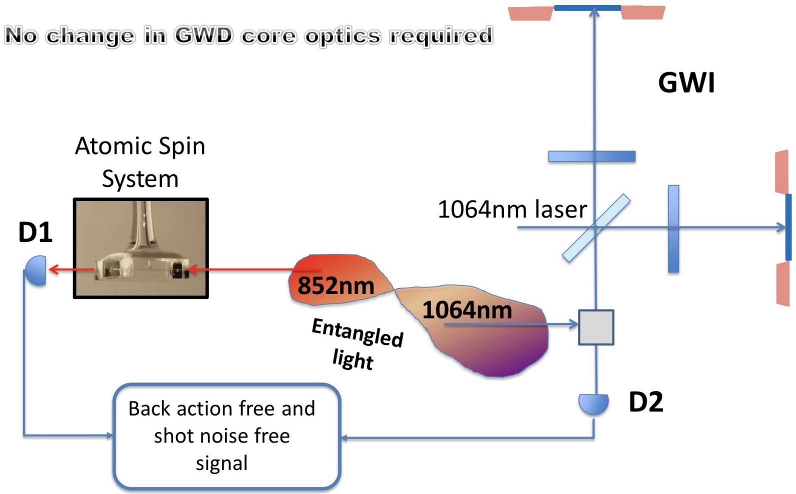




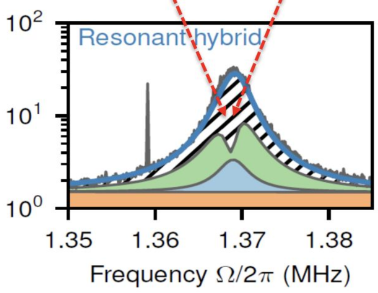
$$X_-(t) = X(t) - X_0(t) = X - X_0 + \frac{Pt}{m} - \frac{P_0 t}{-m} = X_- + \frac{P_+ t}{m}$$

$$[\hat{X}_-, \hat{P}_+] = 0 \;\Rightarrow\; \Delta X_- \Delta P_+ \geqslant 0 \;\Rightarrow\; [\Delta X_-(t)]^2 \geqslant 0 \quad \text{(EPR)}$$





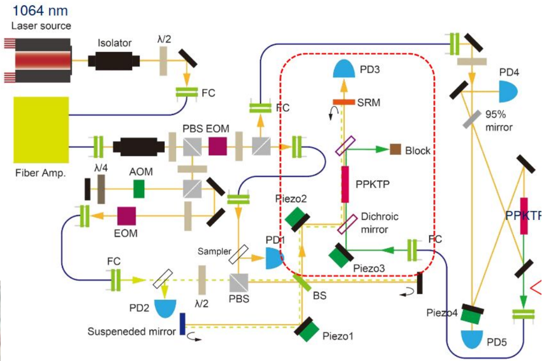
6dB reduction of quantum back-action demonstrated in membrane + atoms system

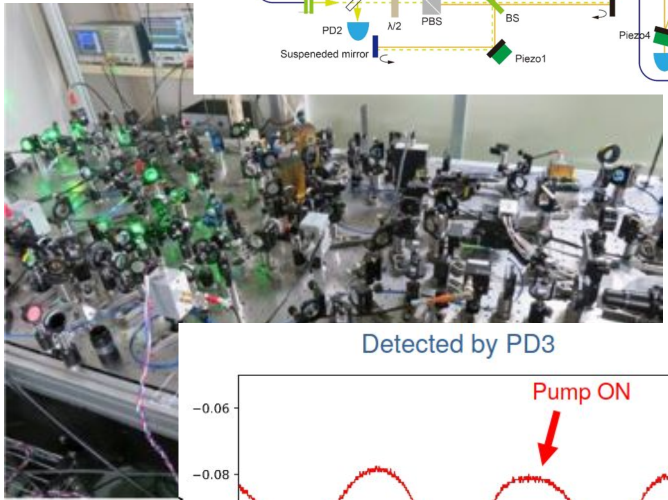


Optical-parametric signal-amplification for a high-frequency gravitational-wave detector

Department of physics, Tokyo Institute of Technology, Japan

Ken-ichi Harada

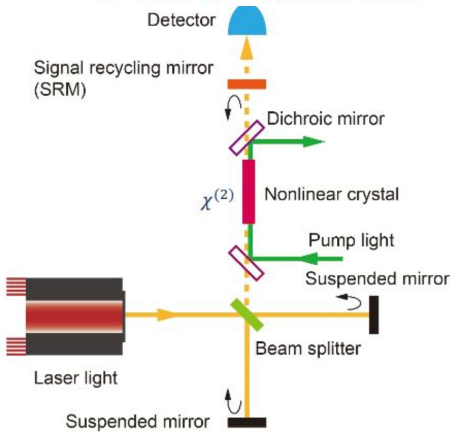


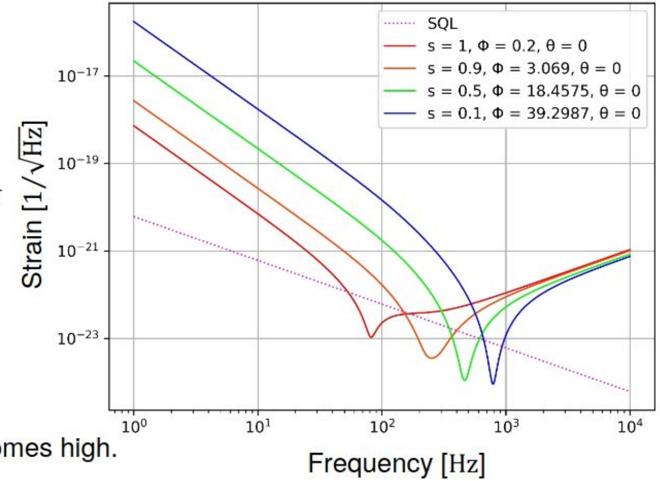


Sensitivity of signal recycling Michelson interferometer (SRMI) with OPA

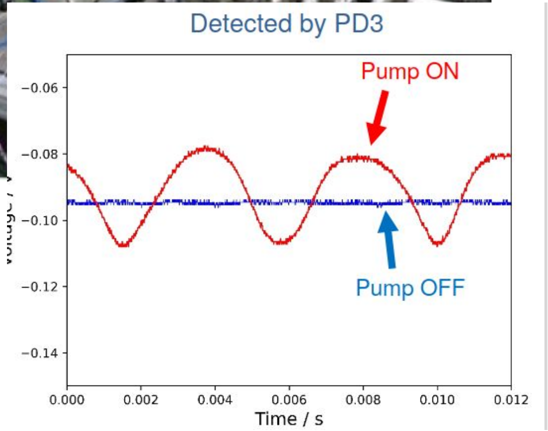
The detuned phase of SR → Optical Spring generates

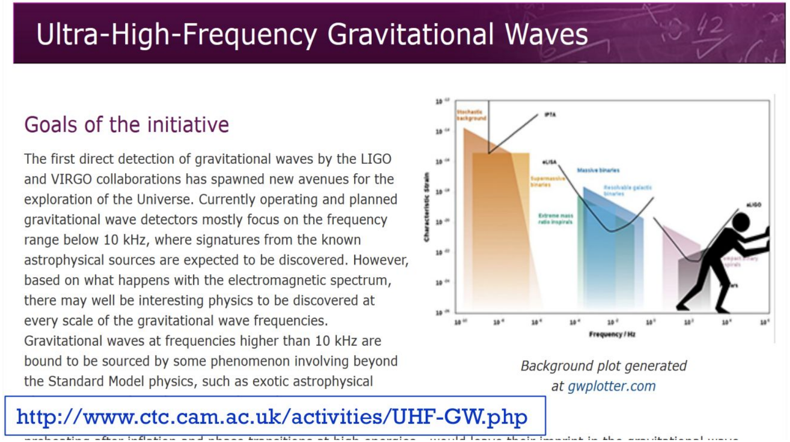
OPA → The resonance frequency of OS is high.





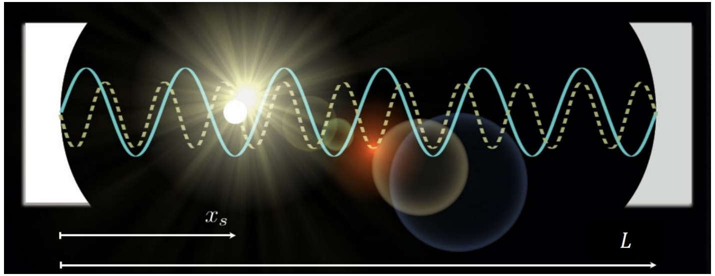
When the pump power is high,
the optical spring frequency becomes high.





- proposed new design with 20x sensitivity
- new limits on BH superradiance and primordial BHs

- Miniature GW detector
- Based on optical trapping/levitation
- Tunable resonance in the 10-300 kHz range
- limited by gas damping and photon recoil



Quantum Noise and Optical Configuration WORKSHOP

MAIN TOPICS and OUTCOME

Quantum noise and optical configurations discussion

Shared experience and thoughts on a variety of topics:

➔ current influence of phase noise, and stability of locking schemes for frequency-dependent squeezing

➔ influence of back-scattered light, and in-vacuum OPOs

➔ is the mode-matching loss limited by sensors or by controls?

Quantum Noise and Optical Configuration WORKSHOP

MAIN TOPICS and OUTCOME

GWADW Online 2021

Advanced quantum-optics techniques:
pushing for higher and lower frequencies!

Good progress on a wide variety of schemes!

➔ quantum-technology to remove noise from scatter source

➔ new ideas for a broadband quantum-noise reduction and back-action free interferometry

➔ pushing the high-frequency limits of current detectors by adding dispersive elements

➔ beyond interferometry: levitating detectors for the 10s of kHz

Quantum Noise and Optical Configuration WORKSHOP

MAIN TOPICS and OUTCOME

Special thanks to all the speakers!!!!