GEO 600 Future

Jim Lough for the GEO team

GEO 600

MAX-PLANCK-GESELLSCHAFT

LSC

Leibniz Universität Hannover

CARDIFF UNIVERSITY

Universitat de les Illes Balears

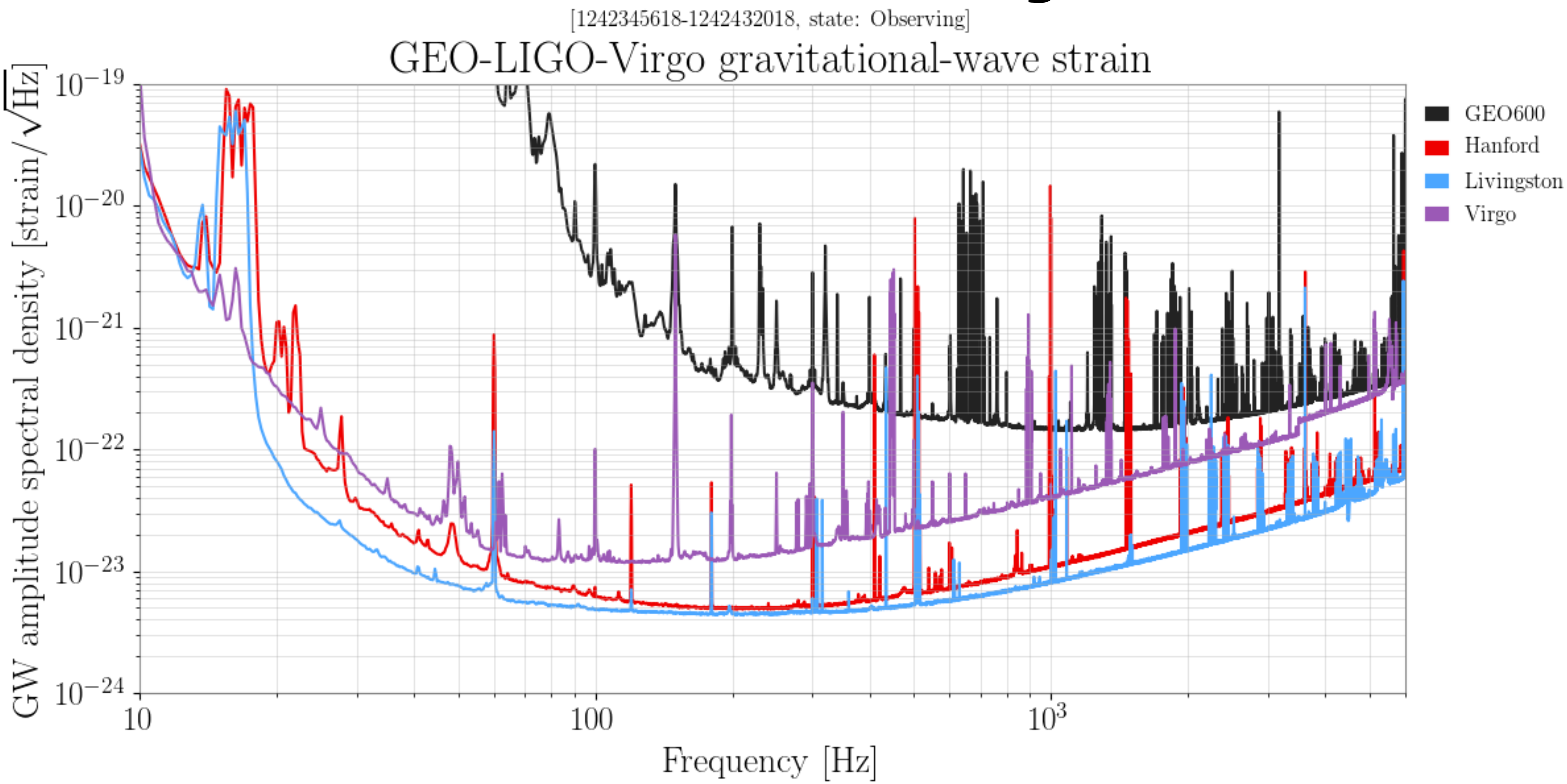
Facility overview

- Construction began in 1995 (groundbreaking)
- Installation began in 1998
- same core optics
- switch from 98% to 90% signal recycling mirror in 2011

History of Pioneering Technologies

- Lasers
- Glasgow suspensions - monolithic
- Signal Recycling/ Extraction
- Thermal Compensation
- Electrostatic Actuators
- Squeezing

Sensitivity



GEO data most recently used in postmerger analysis:

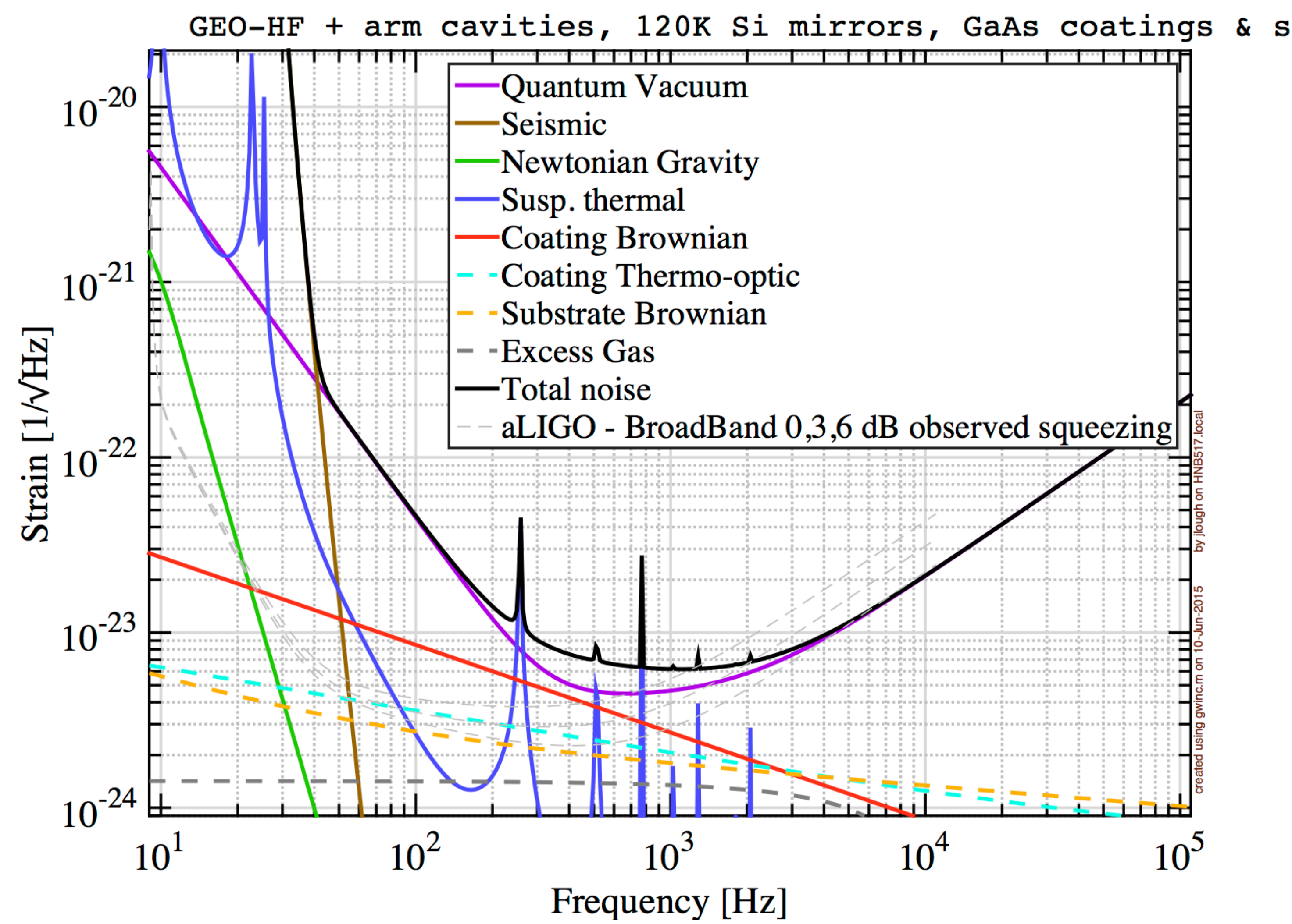
Properties of the Binary Neutron Star Merger GW170817

B. P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration)

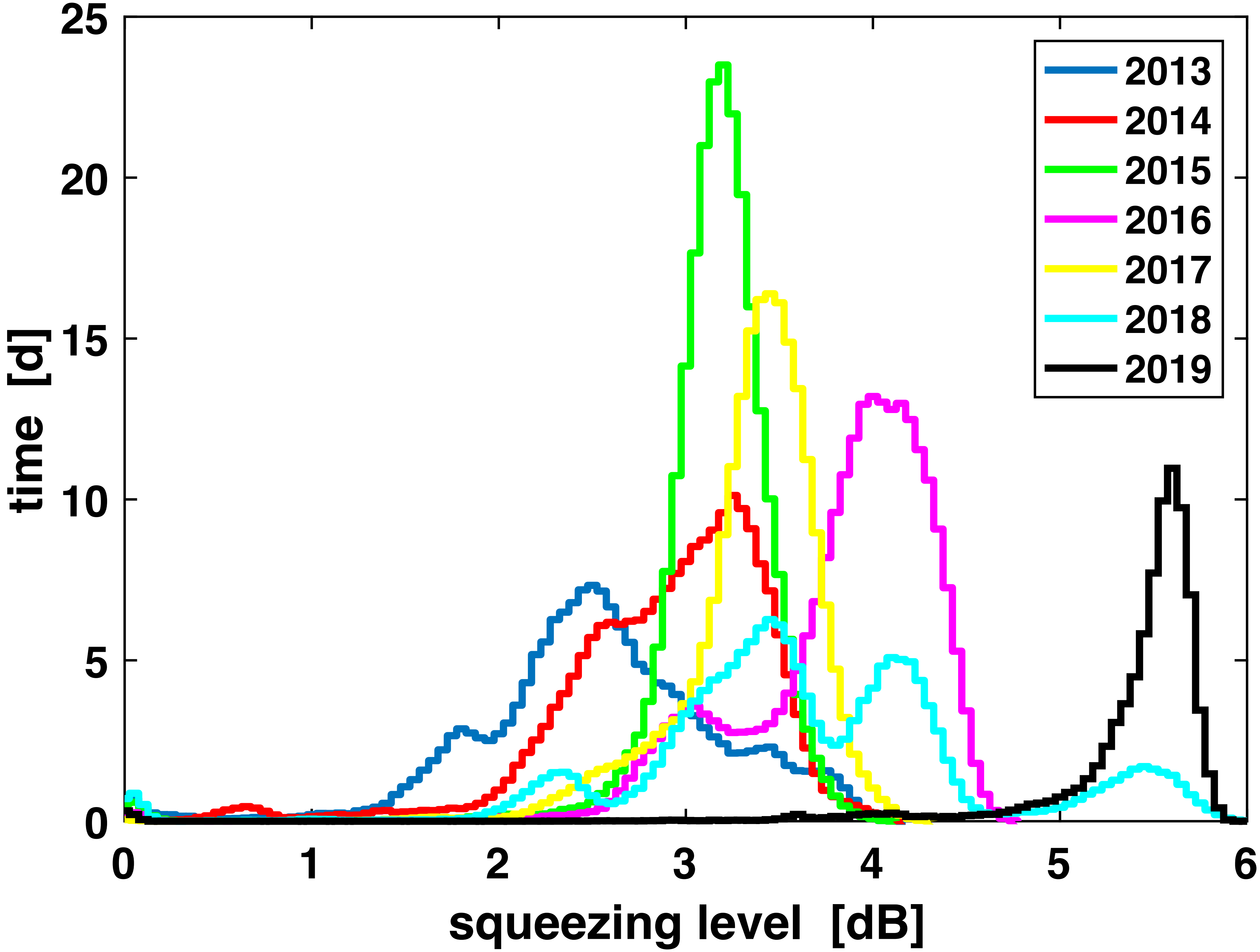
Phys. Rev. X **9**, 011001 – Published 2 January 2019

Sensitivity

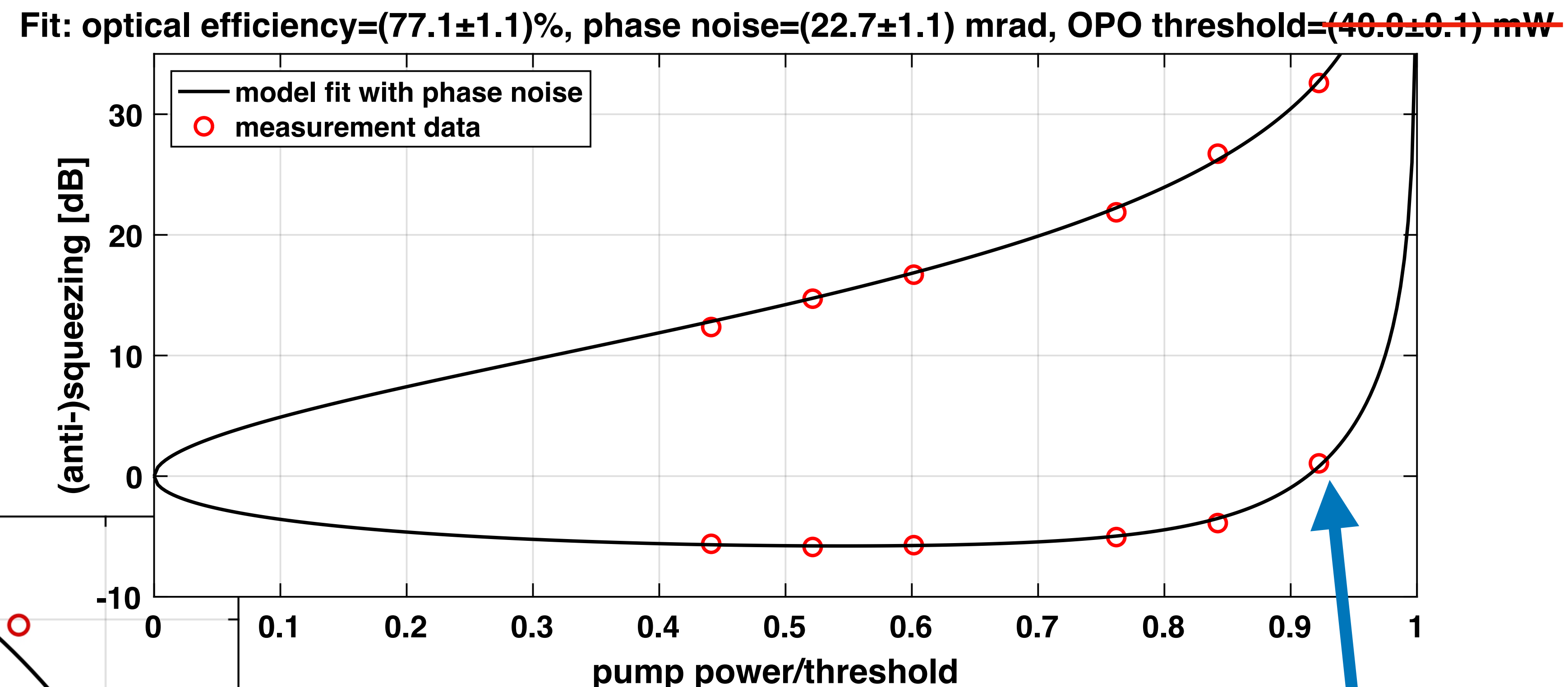
- No plans for competitive sensitivities
- In 2015, we decided to NOT pursue this route ->
  - or any other major sensitivity upgrades
- Pursuing technologies applicable to high frequency sensitivity



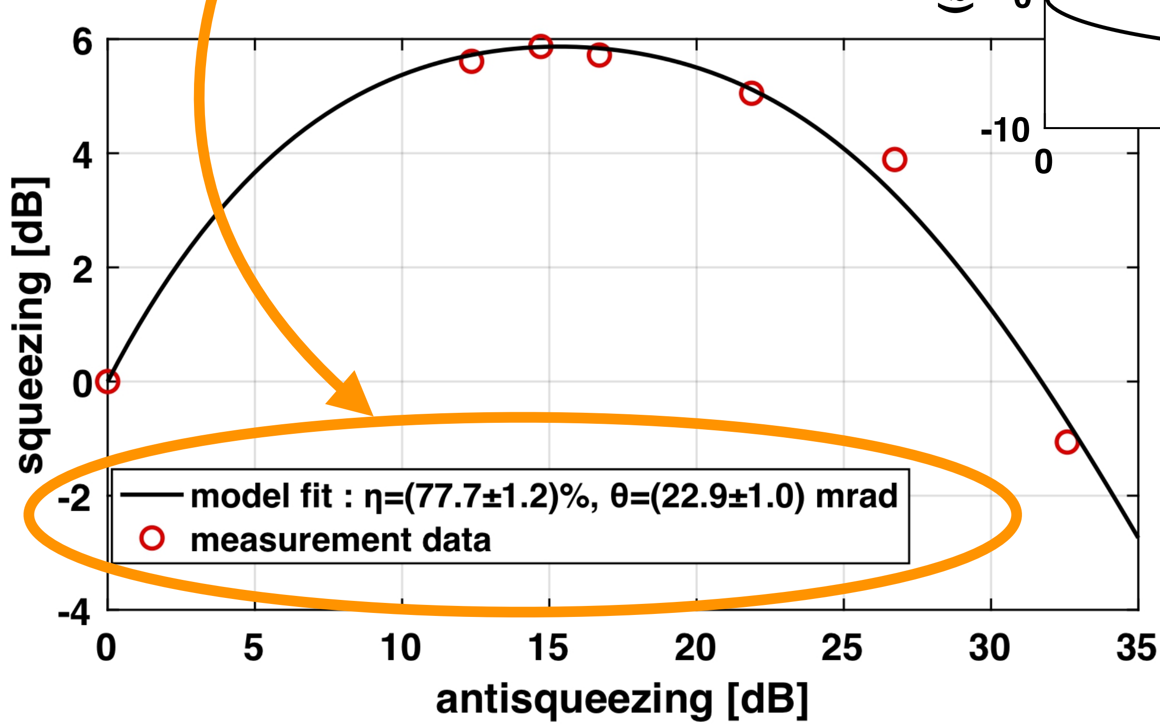
Squeezing


25
20
15
10
5
0
time [d]
0
1
2
3
4
5
6
squeezing level [dB]
2013
2014
2015
2016
2017
2018
2019

Squeezing



sqz. vs asqz. better because it removes nonlinearity in green power to gain



Phase noise contributions

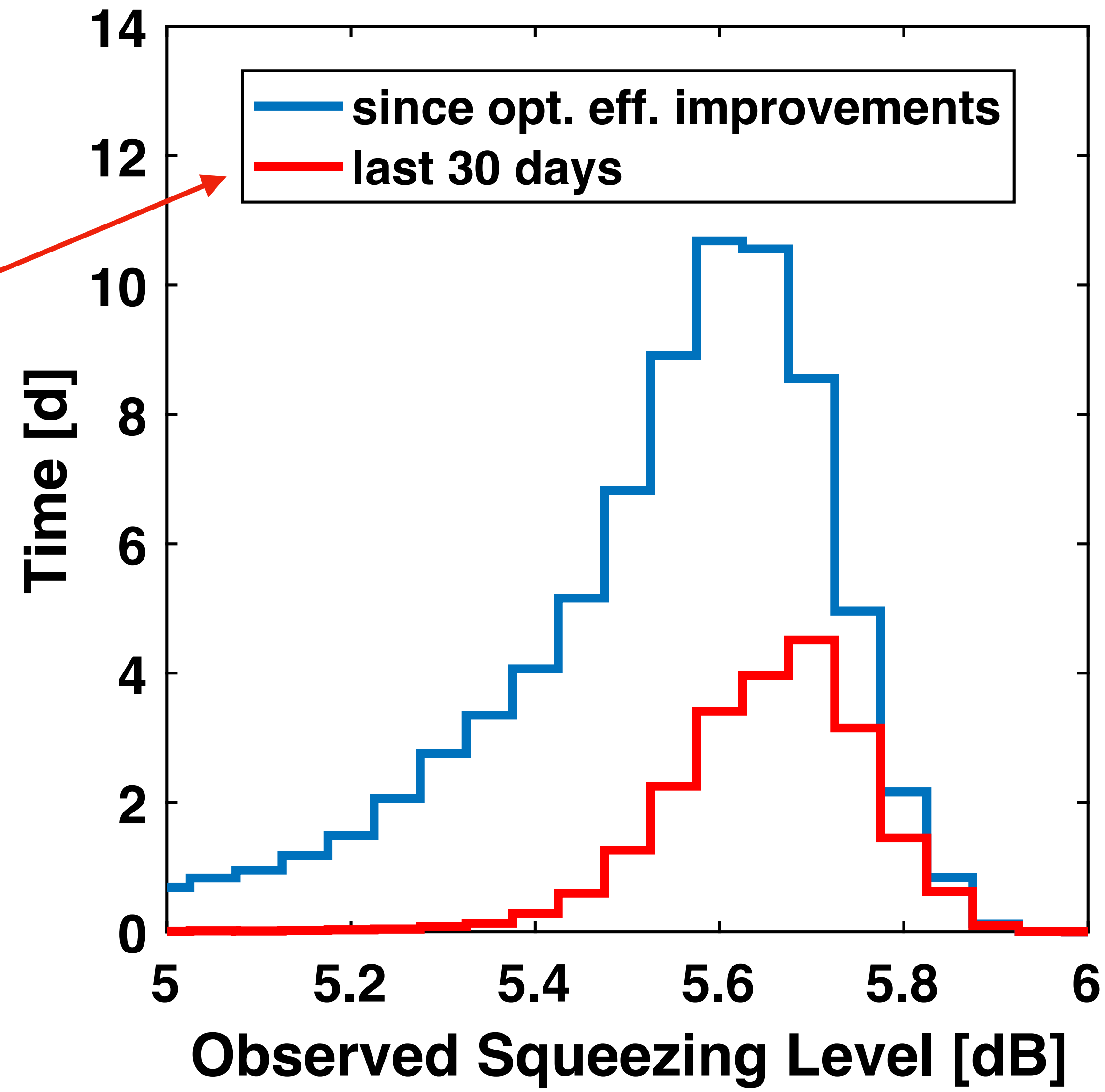
- rf sidebands
- fiber noise from main laser
- sensing noise
- OPA intrinsic is very low

anti squeezing due to phase noise alone!

Tons of nonlinear gain to estimate phase noise

Squeezing

- reduction in squeezing variations
- thermal drifts can cause
    - changes in the phase matching in the OPA
        - new control loop to improve stabilization of the phase matching
    - reduction of isolation of faraday isolators
        - locked the phase of the backscatter light to reduce technical noise impact - in conjunction with optical efficiency improvements

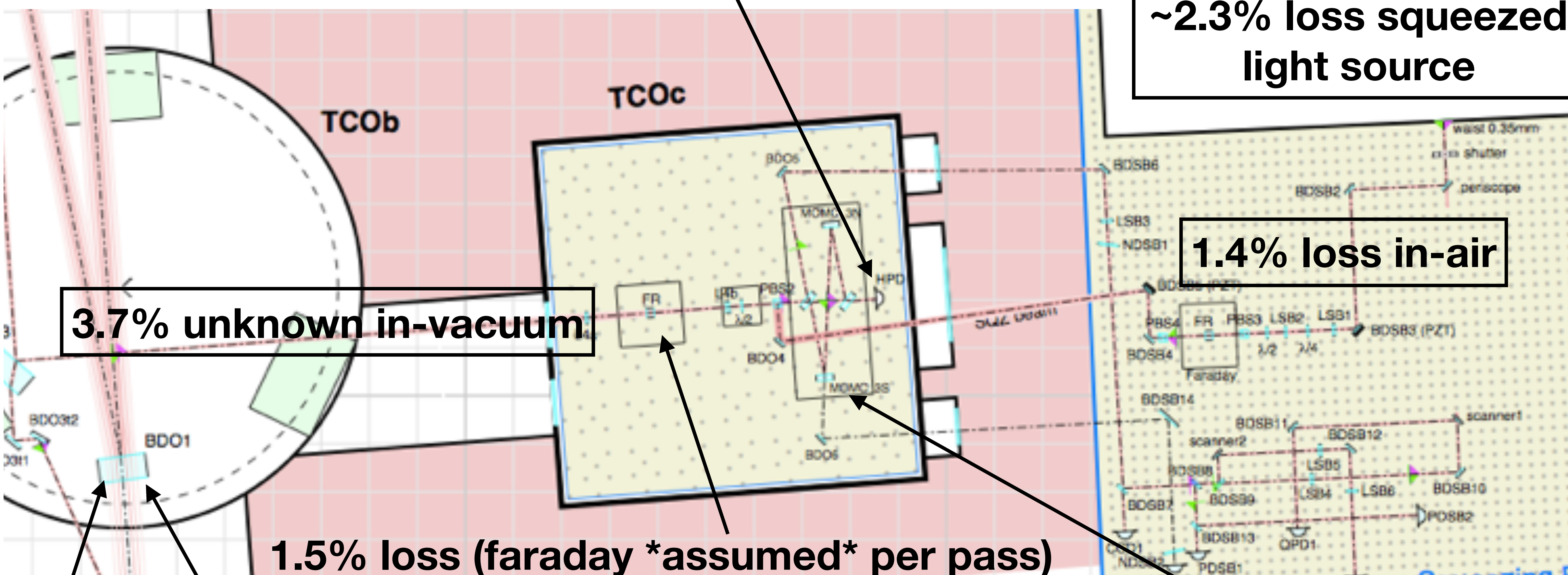


future

Optical Loss

~1.5% loss PD q.e. and reflection

~2.3% loss squeezed light source



1.4% loss in-air

3.7% unknown in-vacuum

1.5% loss (faraday *assumed* per pass)

3.2% loss (astigmatism)

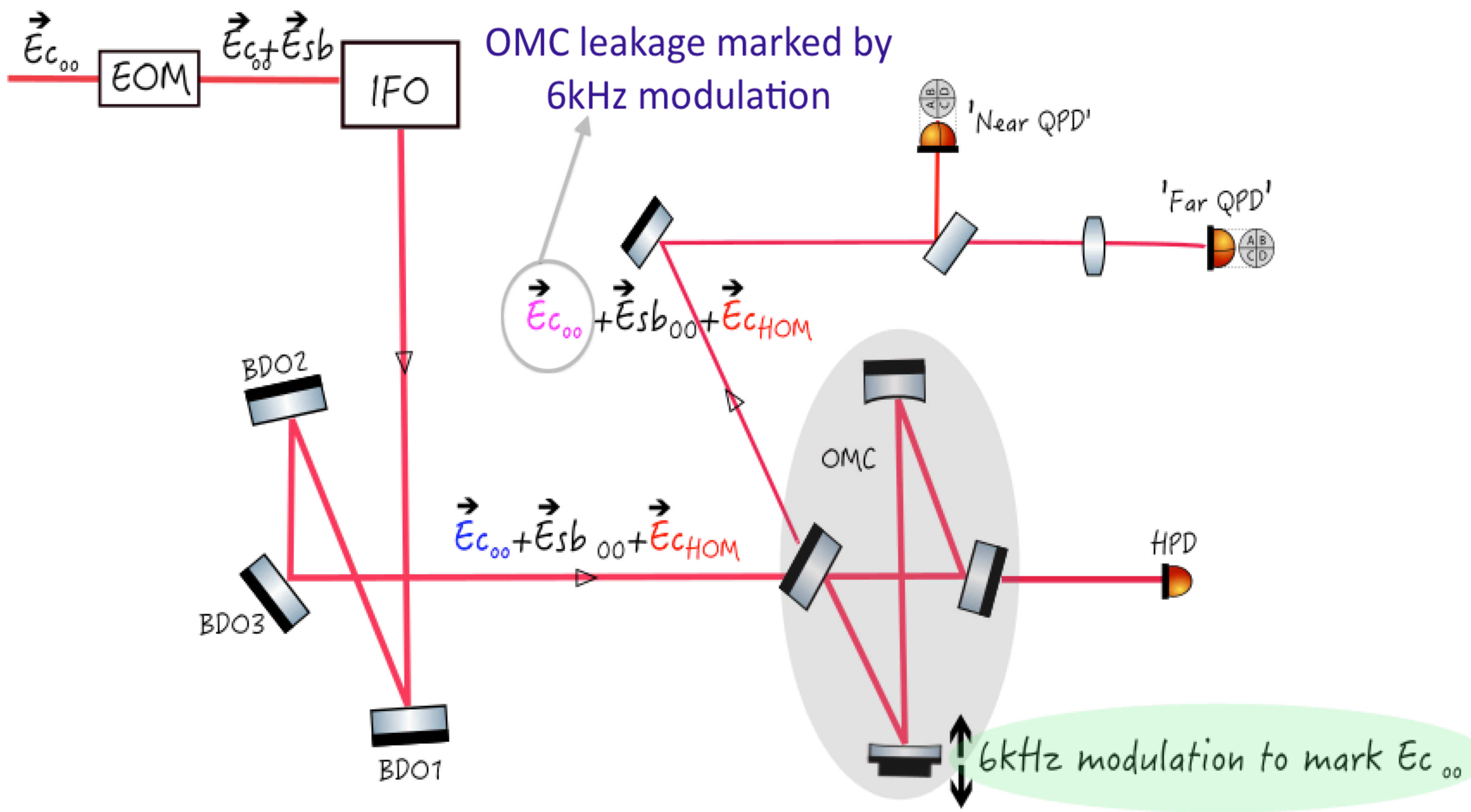
2% loss (coating)

3% loss (reflection from OMC)

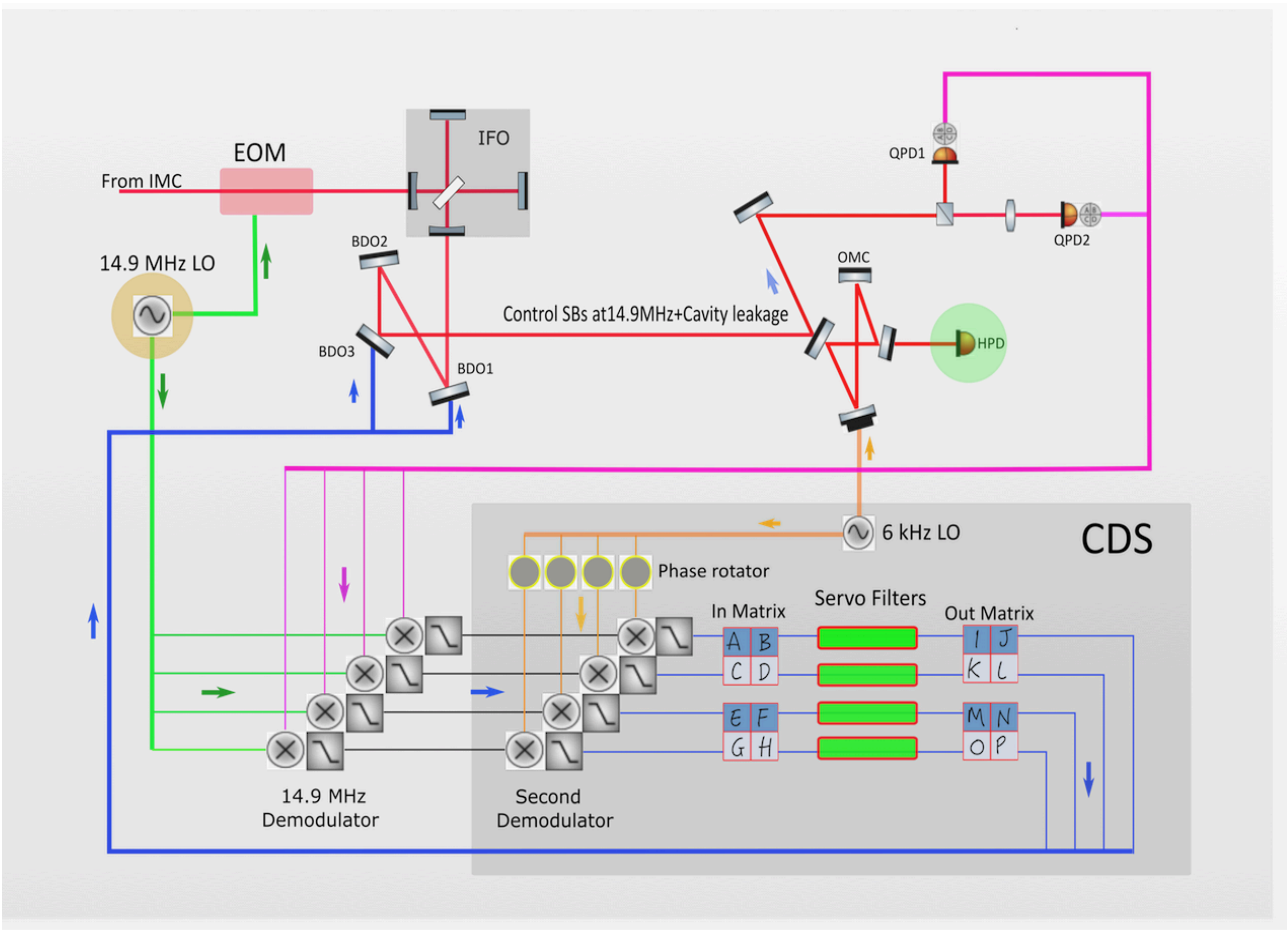
→ ~3.8% unaccounted for

MDWS

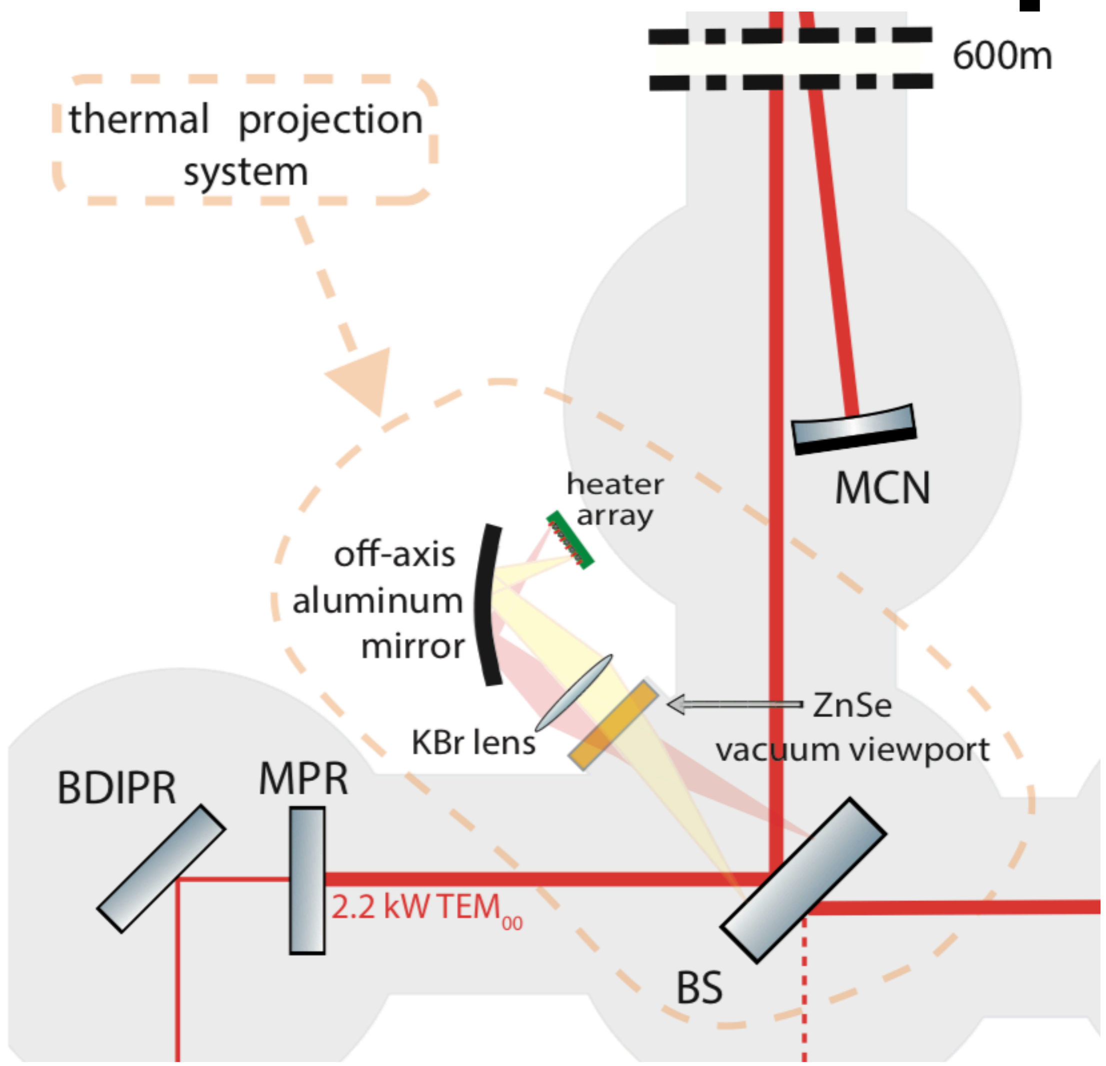
- higher bandwidth lock
- Autoalignment of OMC to michelson sidebands
- squeezing also aligned to michelson sidebands
- No dithering required (dithering = optical loss)

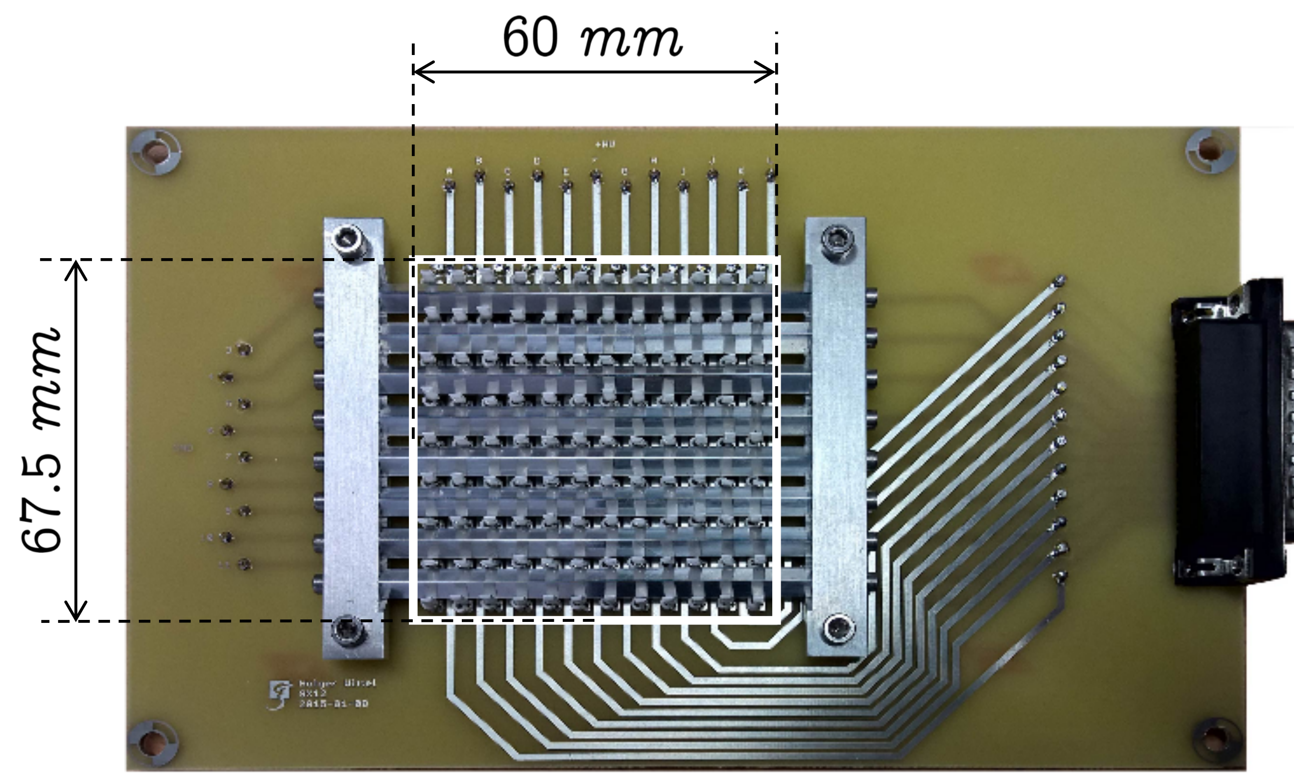


MDWS Control

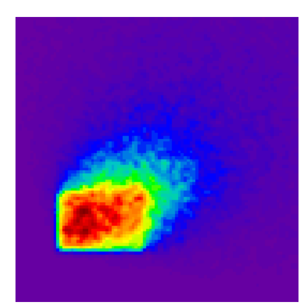


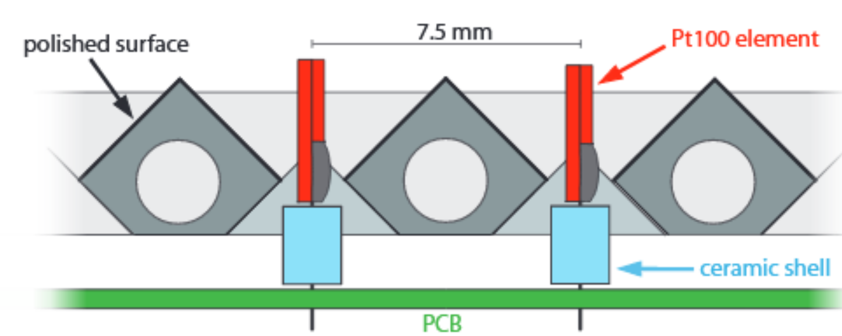
Beamsplitter Thermal Compensation





(a) Photograph of the heater array.

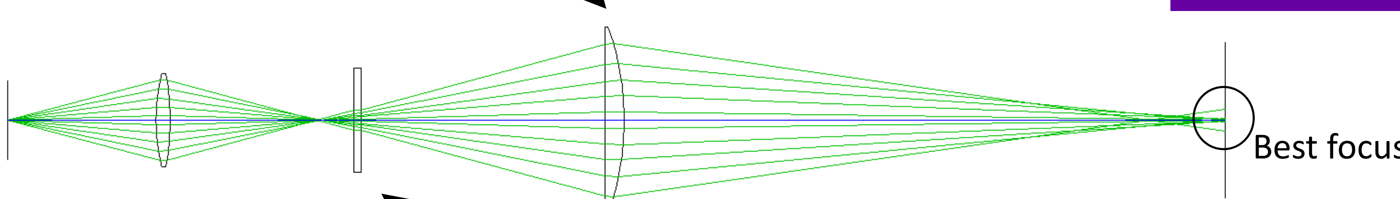




(b) Cross section of the heater array.

Fig. 2. Photograph and cross section of the heater array.

new optical system



vacuum viewport

30% contrast improvement so far

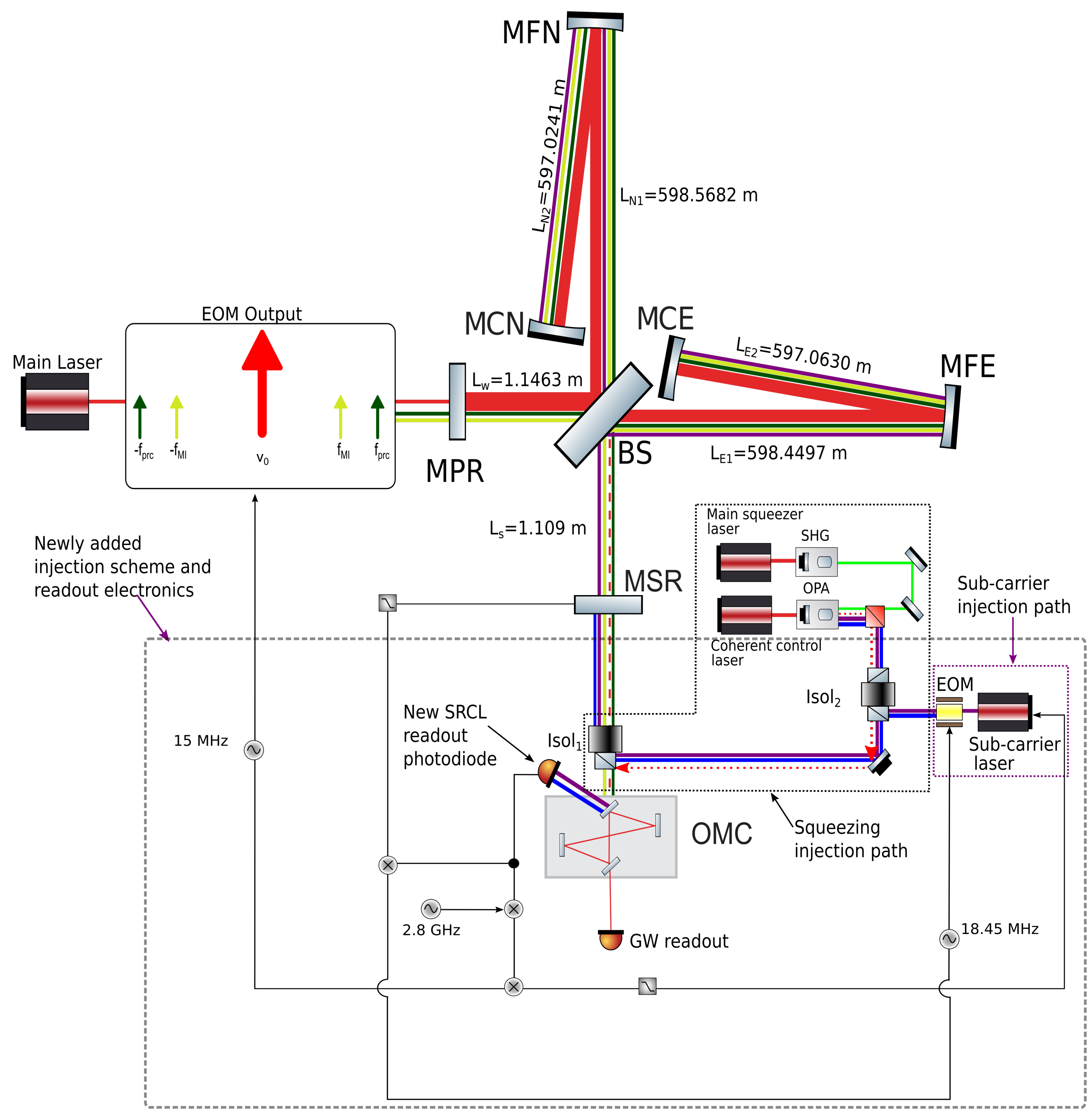
H. Wittel, et al. "Matrix heater in the gravitational wave observatory GEO 600," Opt. Express 26, 22687-22697 (2018)

Signal Recycling Control

Vaishali Adya

Concept

- Up to several hundred Hz, GEO 600 observes length noise arising from control of the signal recycling mirror, technical noises and a mystery noise.
- Inject a subcarrier through the output port offset by N*FSR with RF modulation.
- Reflected from the squeezer OPA for injection into the interferometer



Concept paper for control of Einstein Telescope : underway

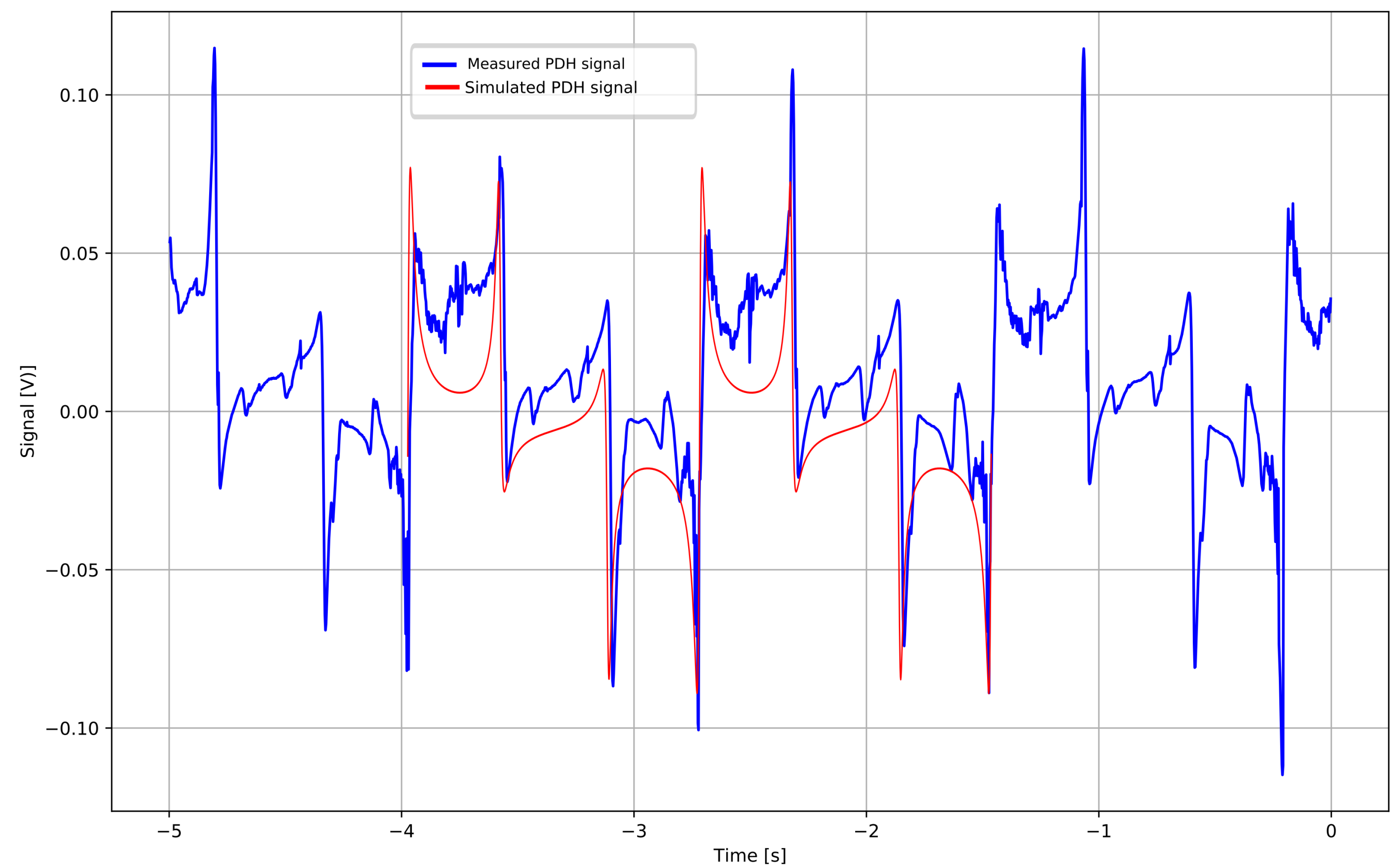
Signal Recycling Control

Vaishali Adya

GEO logbook : 8122

Results

- All electronics in place and phase lock loop between the subcarrier laser and the interferometer beam established.
- The error signals obtained for the SRCL control with this scheme looks promising*.



* Conditions apply : slightly noisier than expected, sharp spikey features

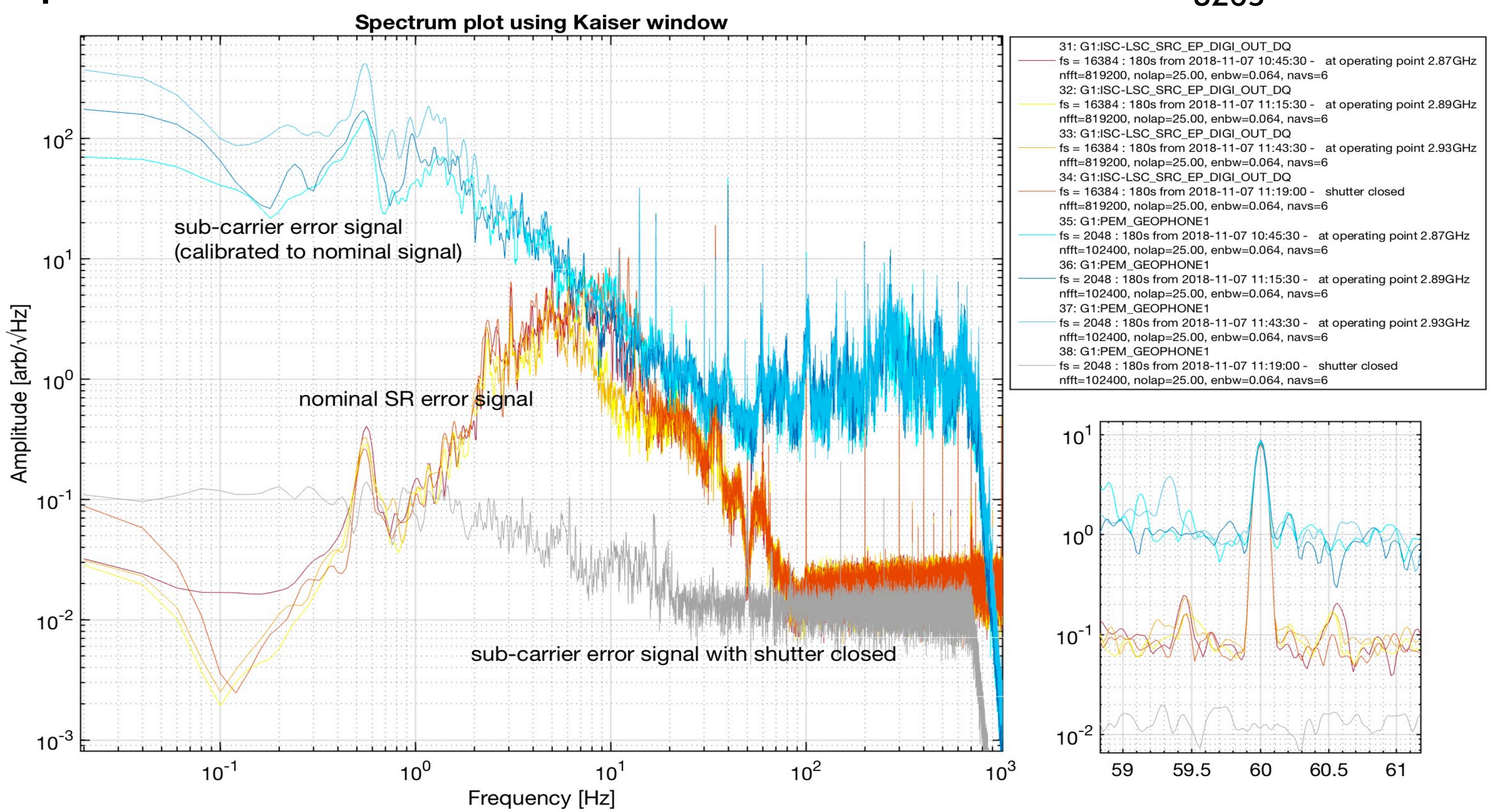
Signal Recycling Control

Vaishali Adya

Debugging part 1

GEO logbook : 8263

- Transfer function from the old signal-recycling error point compared to the in-loop spectra of old and new signals
- Reasonably flat at mid frequencies, higher optical gain compared to old signal, as predicted by the model

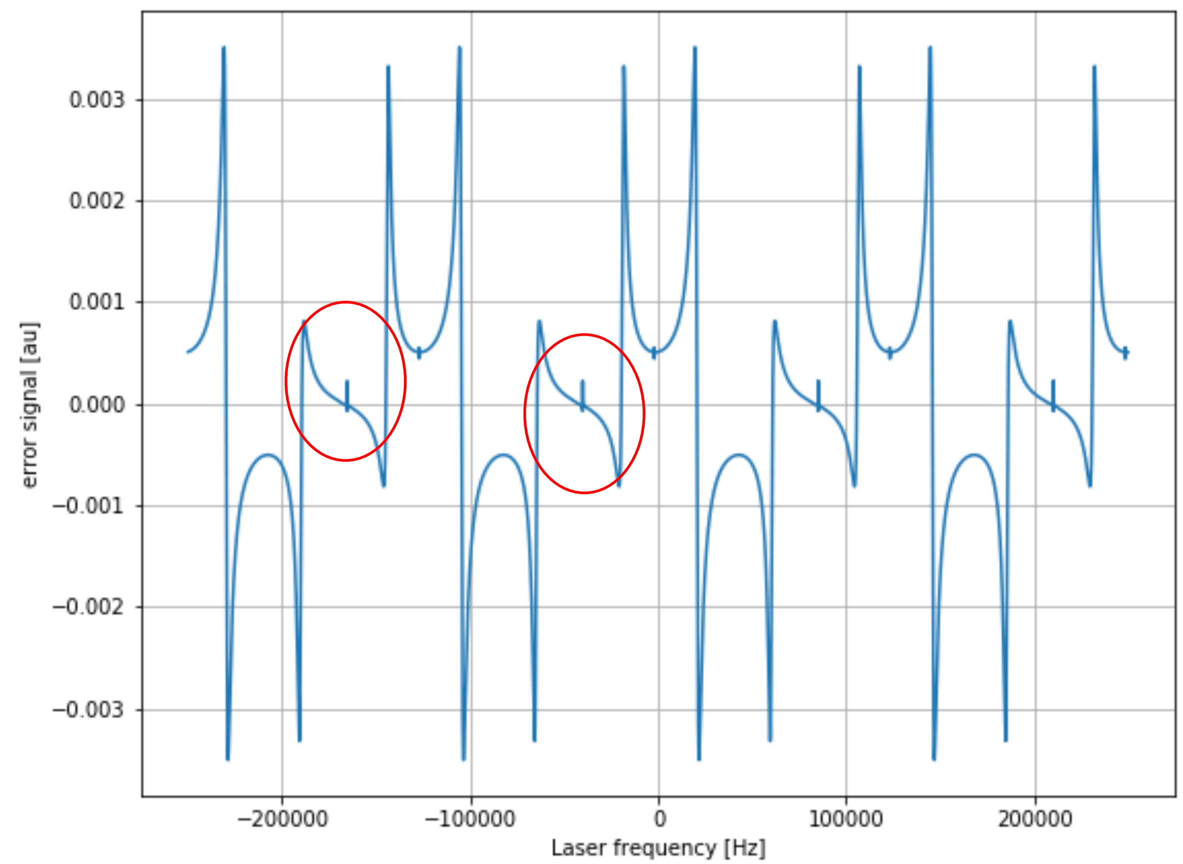


Signal Recycling Control

Vaishali Adya

Re-visiting the modelling

- Reproduced some of the features with a finesse model
- Coupling from the PRC via the Schnupp asymmetry coming from a difference in lengths used in the optical model
- Position of offending peaks : l_{prc}-l_{src}
- Height of the peaks : schnupp coupling



Signal Recycling Control

Vaishali Adya

Plans for the SRC control experiment

- Re-visit OptoCad model for lengths to be used in the Finesse model

⬇

- Change sub-carrier frequency to eliminate PRC coupling

⬇

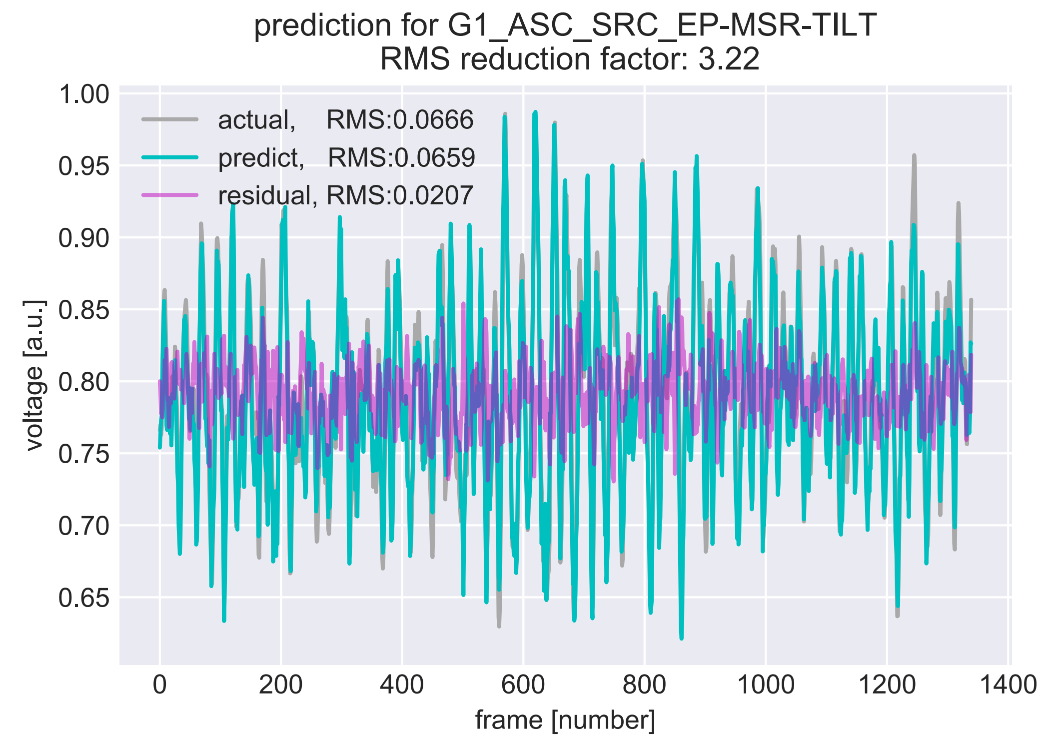
- Re-do noise measurements i.e. impact on ‘h’

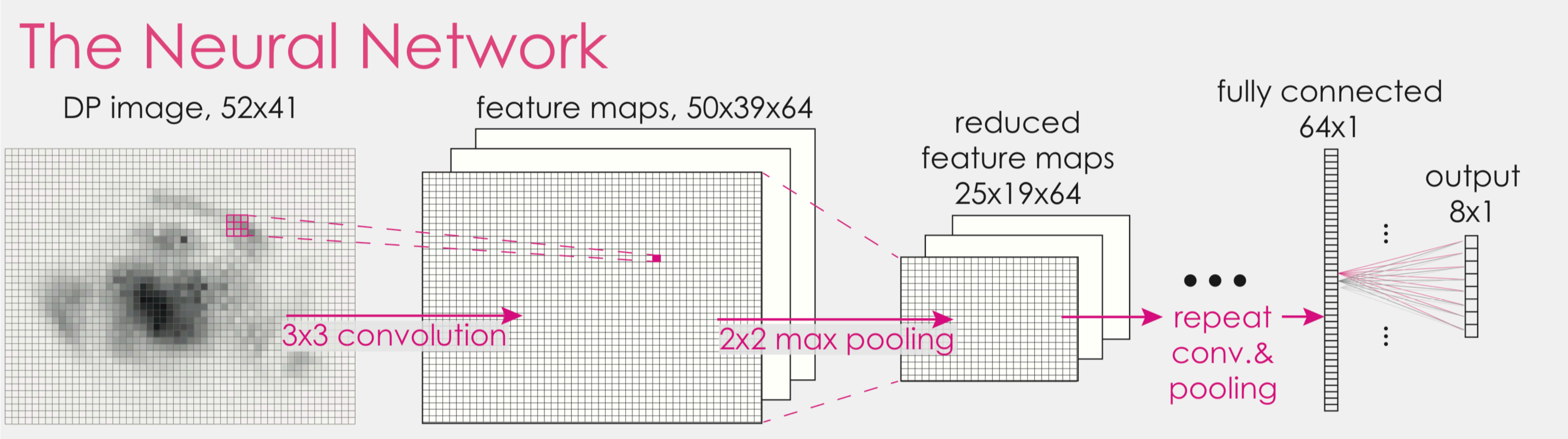
⬇

- Insert squeezing into the interferometer

Controls

- Adaptive feedforward
- Machine Learning!
- Bilinear couplings in signal recycling (See Nikhil's poster!)

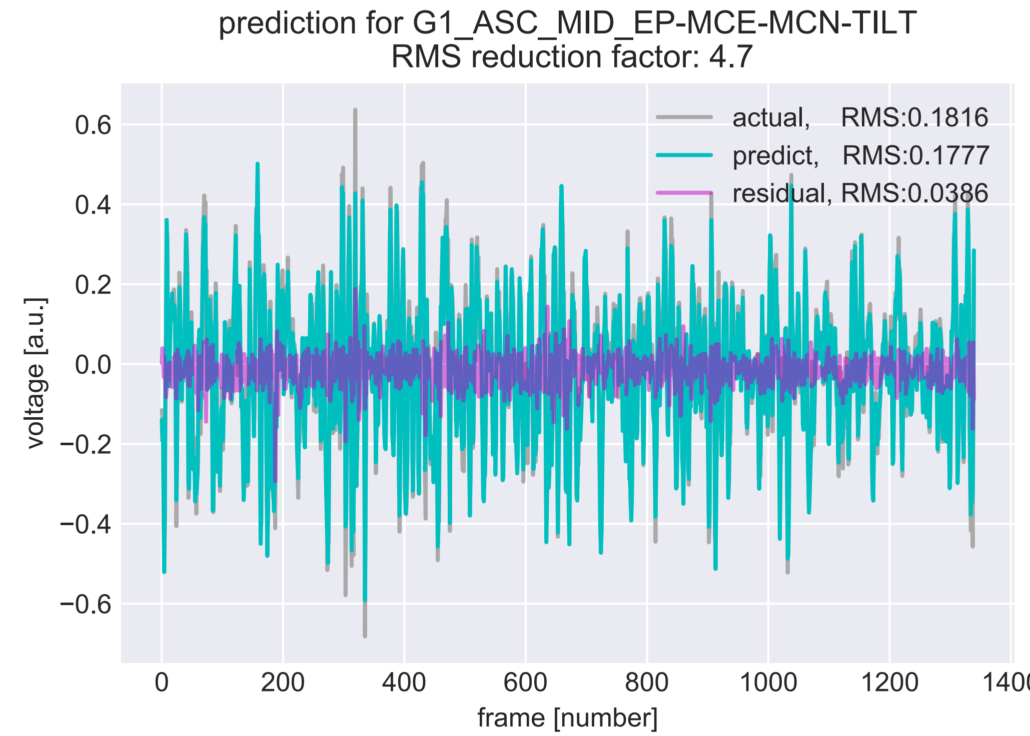


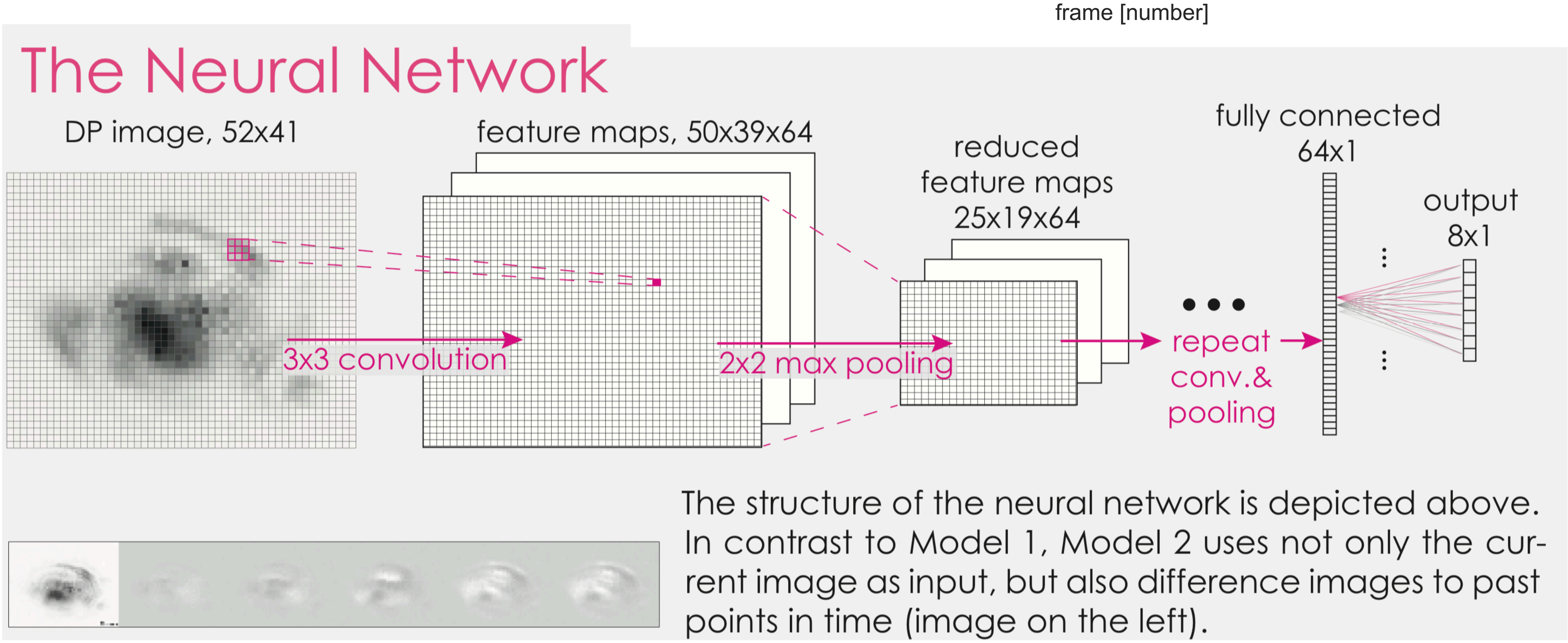


The structure of the neural network is depicted above. In contrast to Model 1, Model 2 uses not only the current image as input, but also difference images to past points in time (image on the left).

Controls

- Adaptive feedforward
- Machine Learning!
- Bilinear couplings in signal recycling



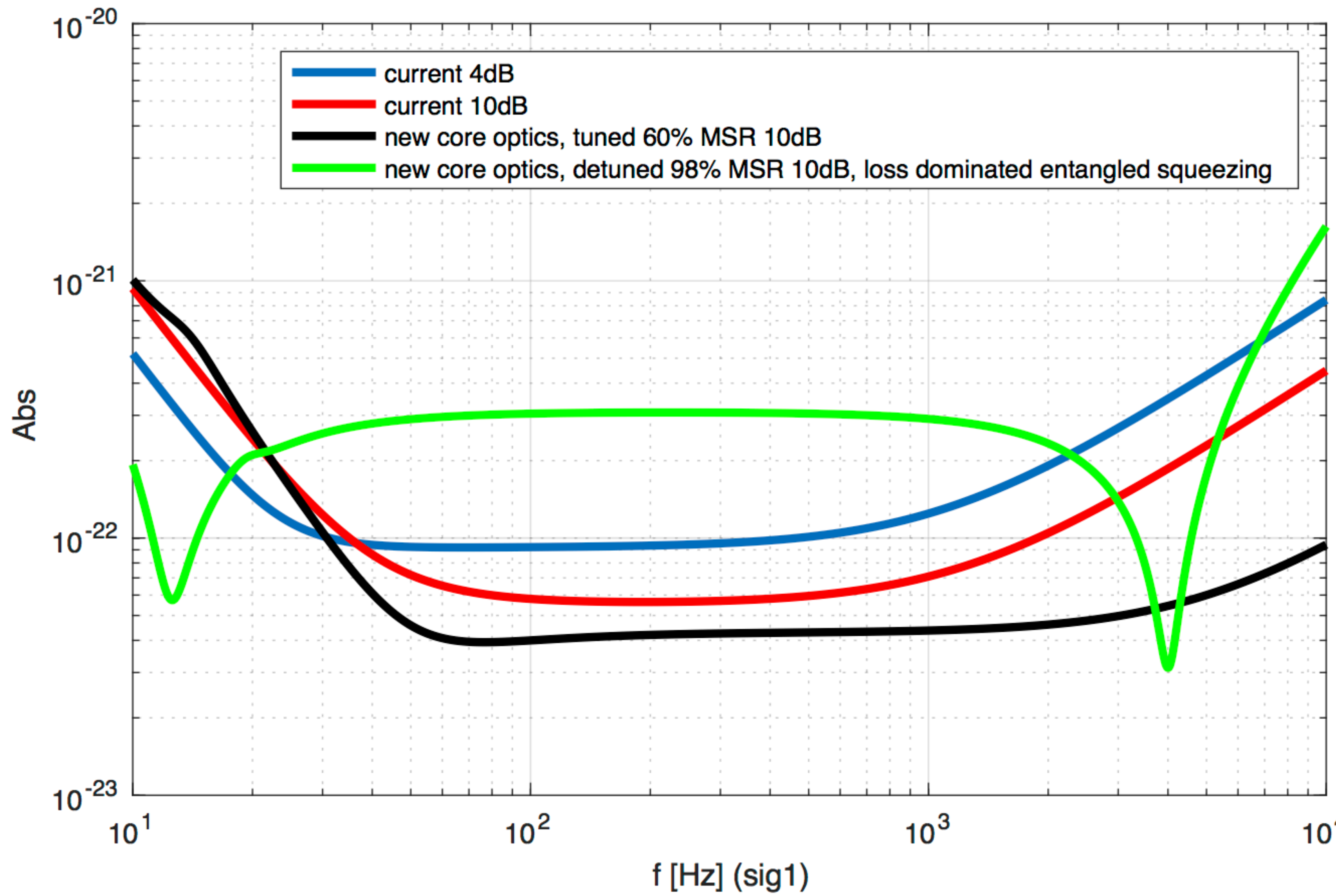


Plans (high level)

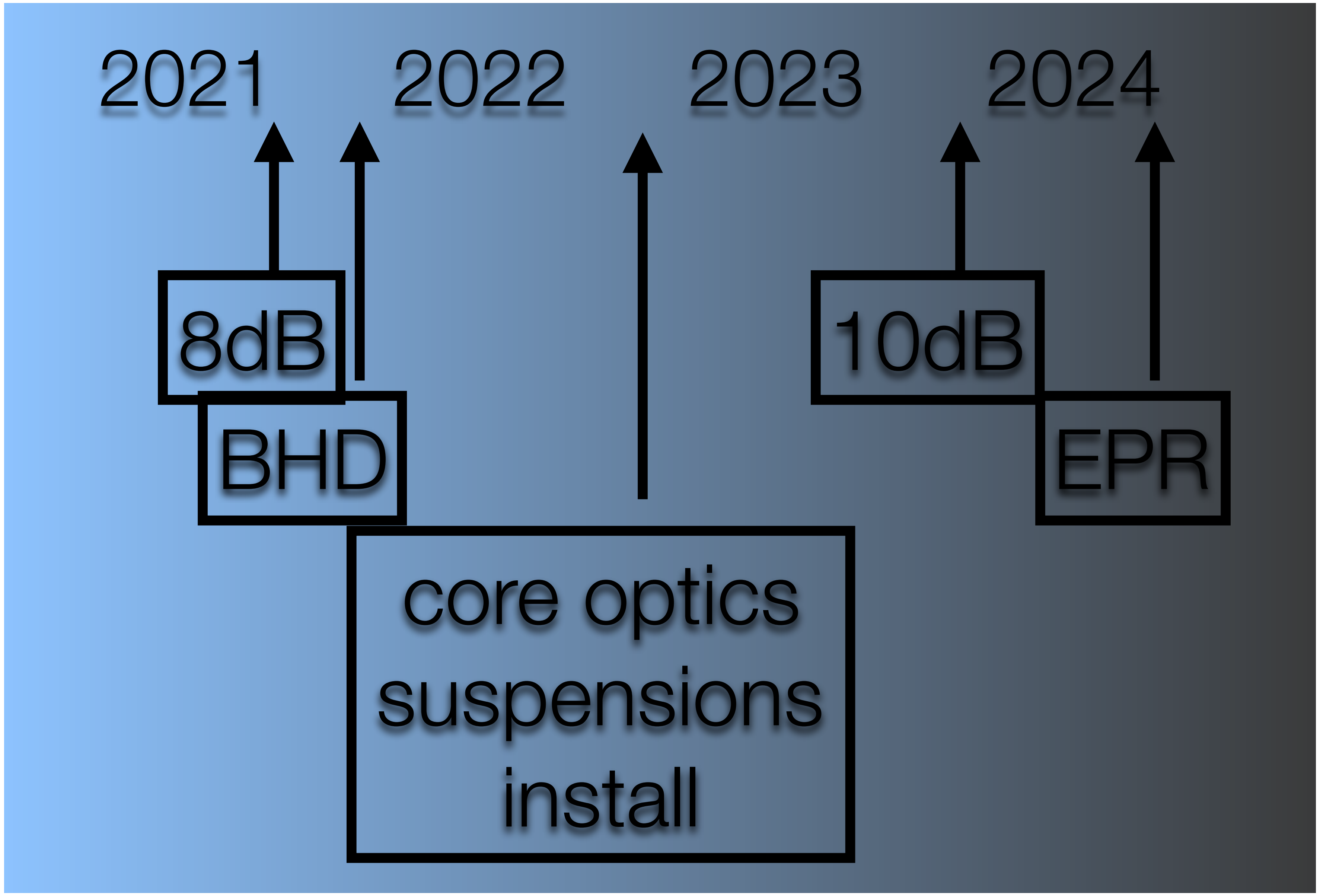
- Astrowatch as long as it makes sense
- GEO 600 as a full scale testbed
- Applications to fully functional gravitational-wave detector
- Technologies to enhance high frequency sensitivity
  - fancy quantum schemes
    - need new core optics and balanced homodyne readout
  - EPR entanglement on a detuned GEO? not certain

EPR sensitivity

- On detuned detector EPR "squeezes" without reducing bandwidth
- penalty of 3dB or more



Potential Timeline for Upgrades



less certain →

Thanks!

3 departures

plus Fabio Bergamin, Nikhil Mukund, Séverin Nadji