Squeezed Light Techniques for Gravitational Wave Detection

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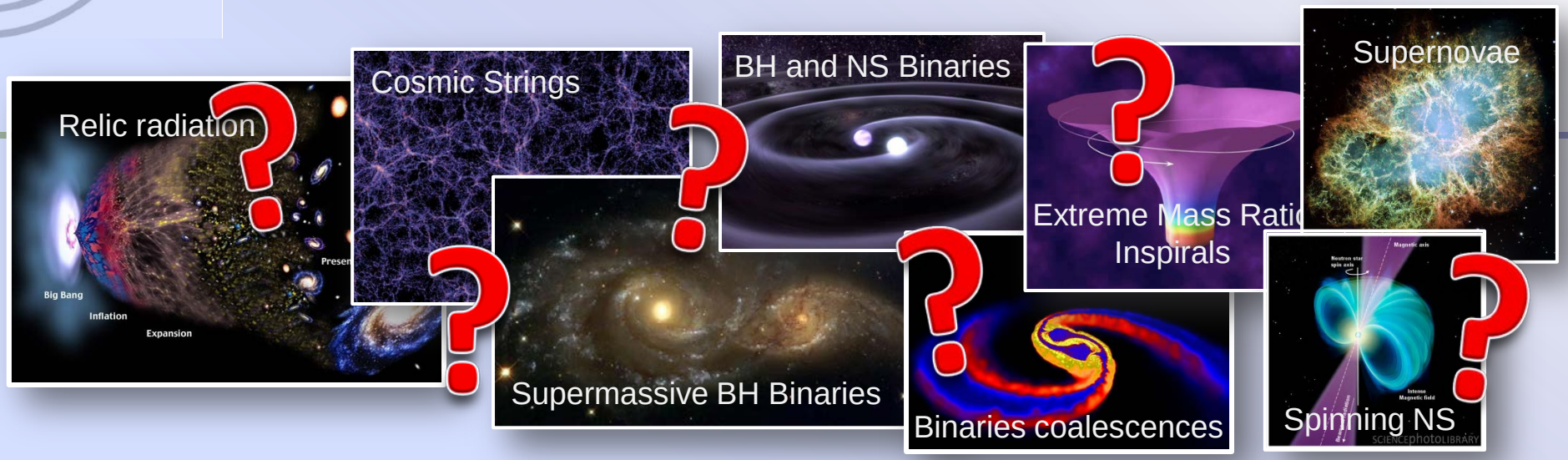
Talk at Stanford University

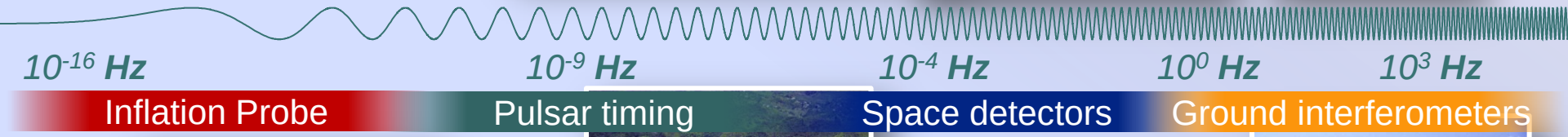
LIGO

Abstract

Several kilometer long interferometers have been built over the past decade to search for gravitational waves of astrophysical origins. For the next generation detectors intra-cavity powers of several 100 kW are envisioned. The injection of squeezed light, a specially prepared quantum state, has the potential to further increase the sensitivity of these detectors. The technology behind squeezed light production has taken impressive steps forward in recent years. As a result a series of experiments is underway to prove the effectiveness of squeezed light and to make quantum technology a valid upgrade path for gravitational wave detectors.

Gravitational Waves

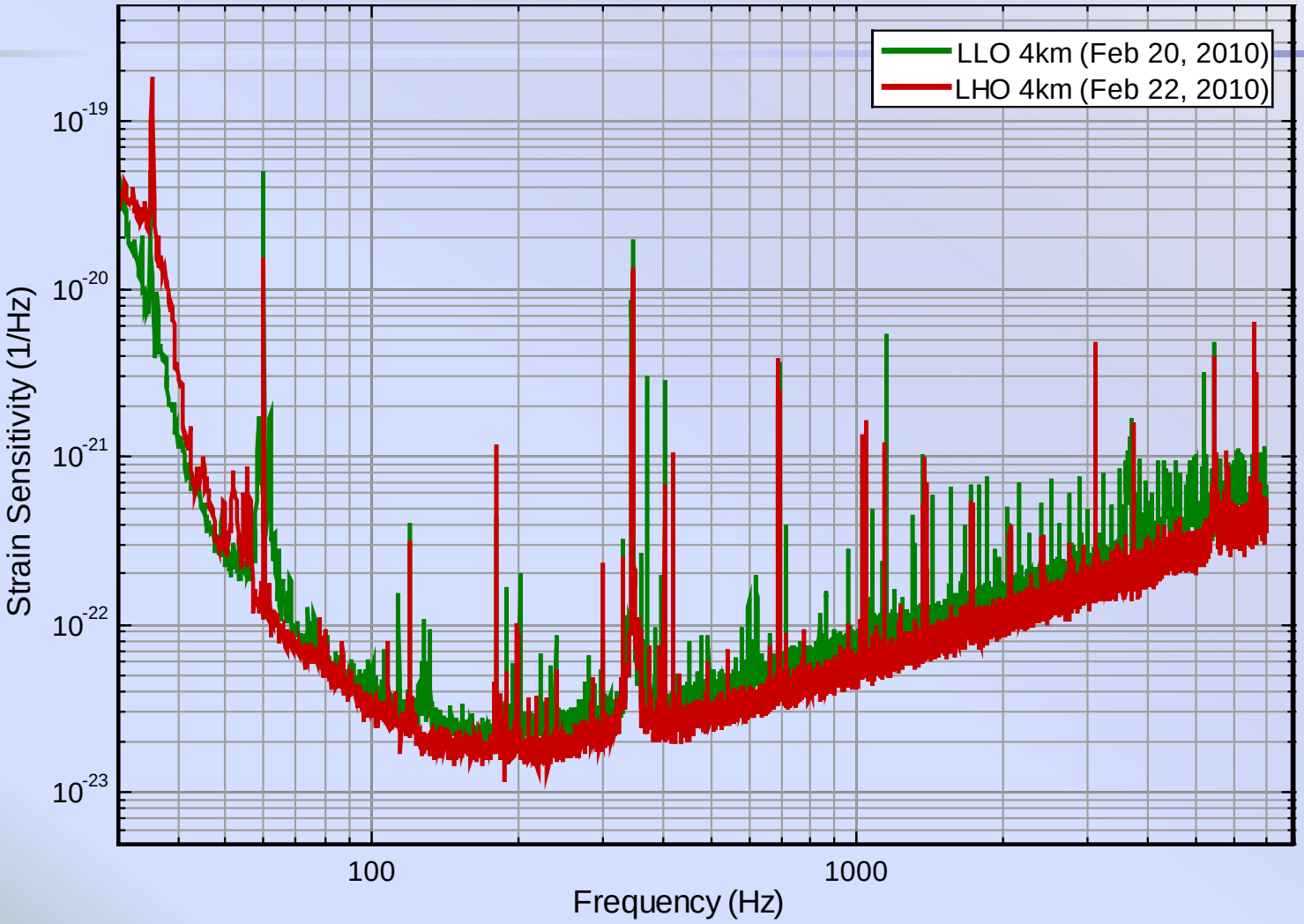




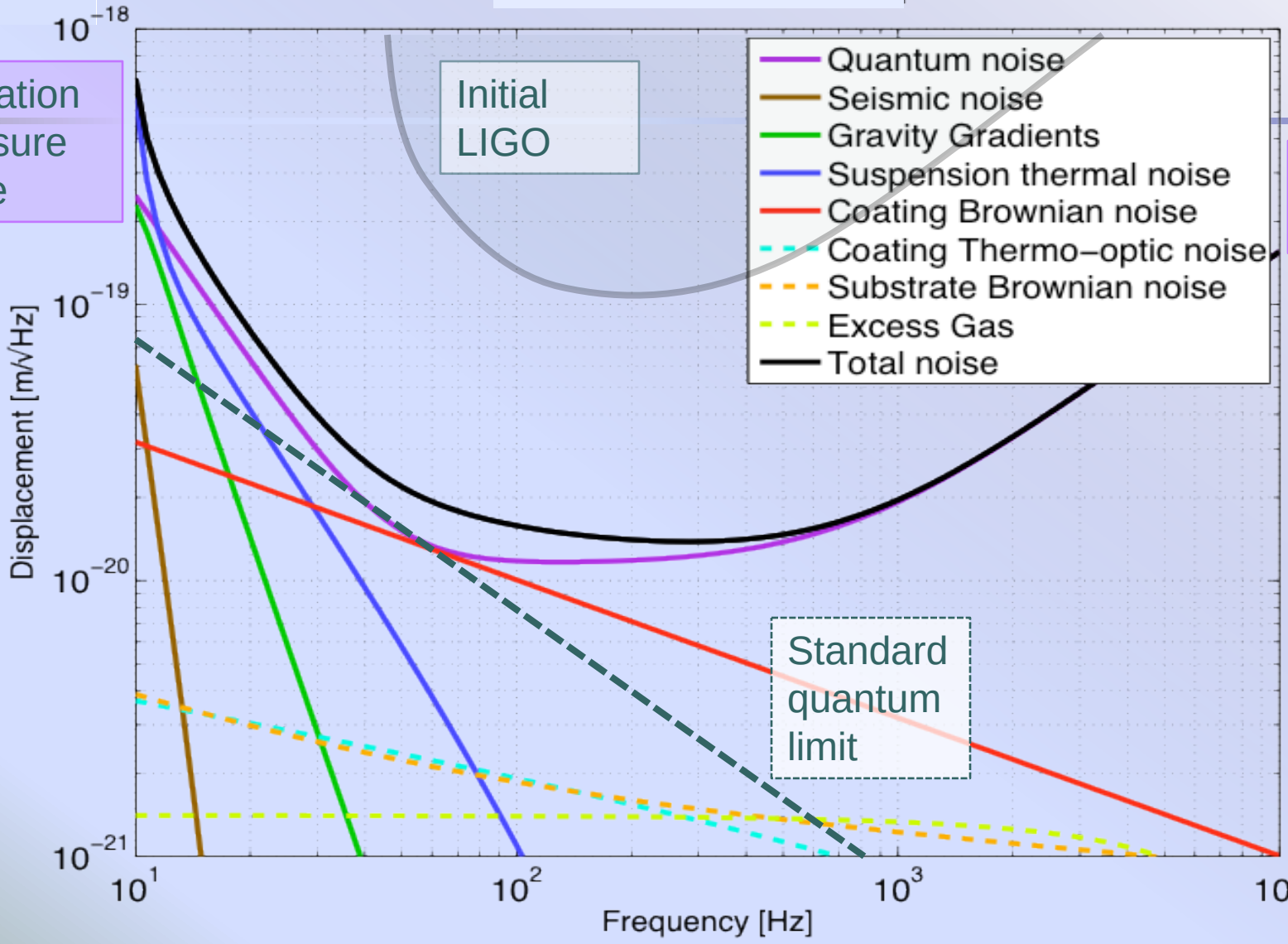
10^{-16} Hz | 10^{-9} Hz | 10^{-4} Hz | 10^{0} Hz | 10^{3} Hz

Inflation Probe | Pulsar timing | Space detectors | Ground interferometers

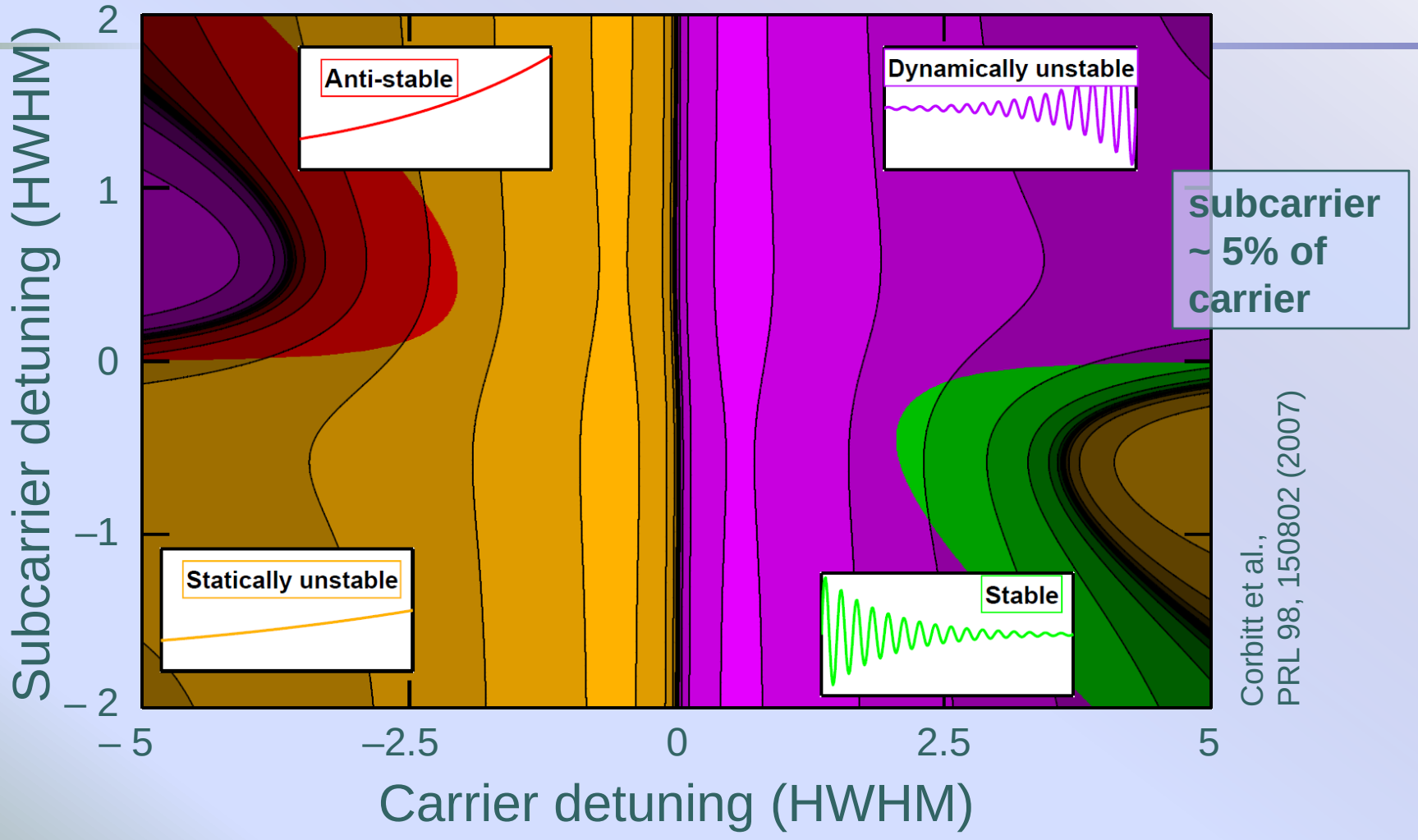
Sensitivity Sixth Science Run



Advanced LIGO Sensitivity



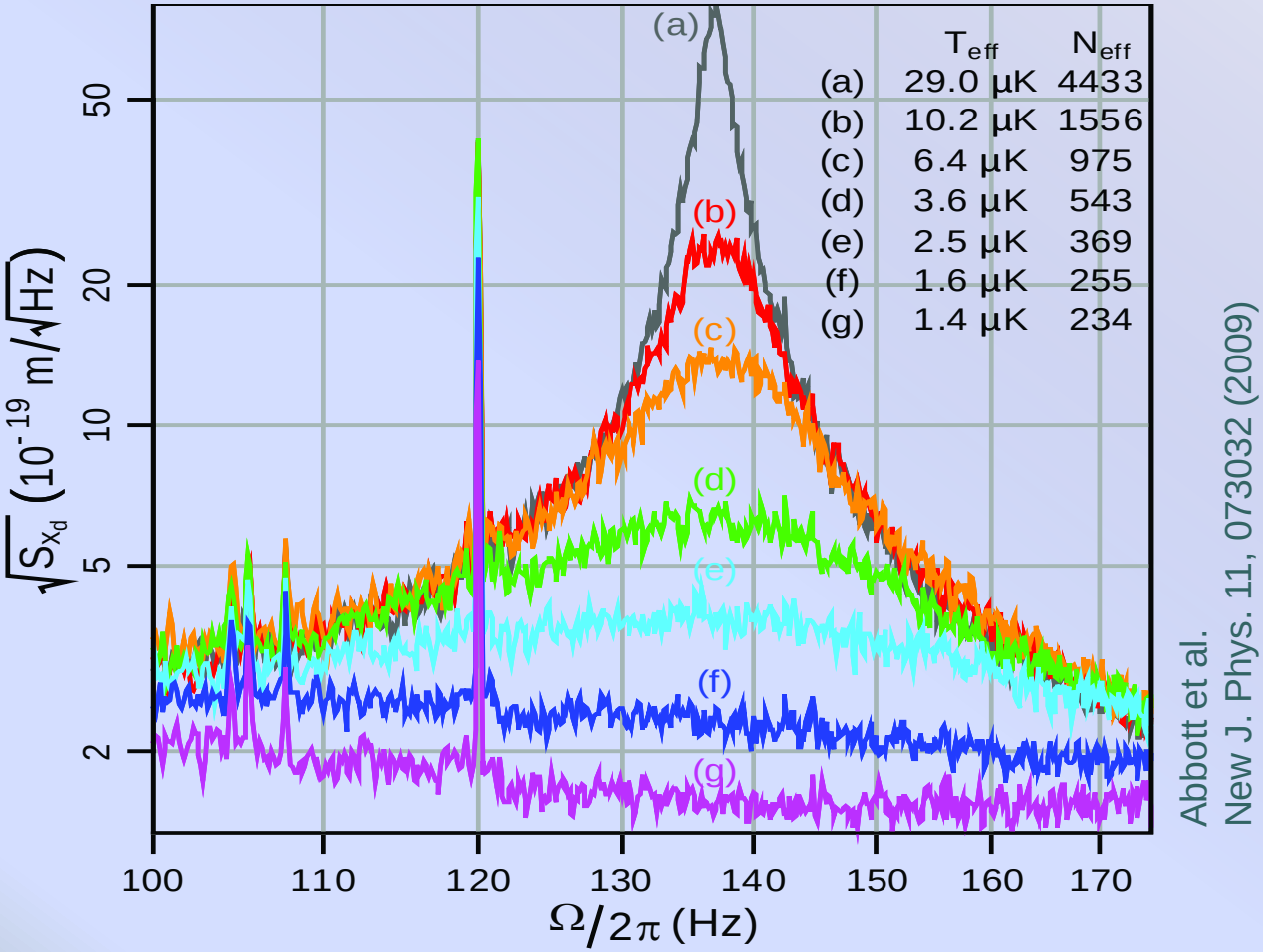
Optical Springs



subcarrier ~ 5% of carrier

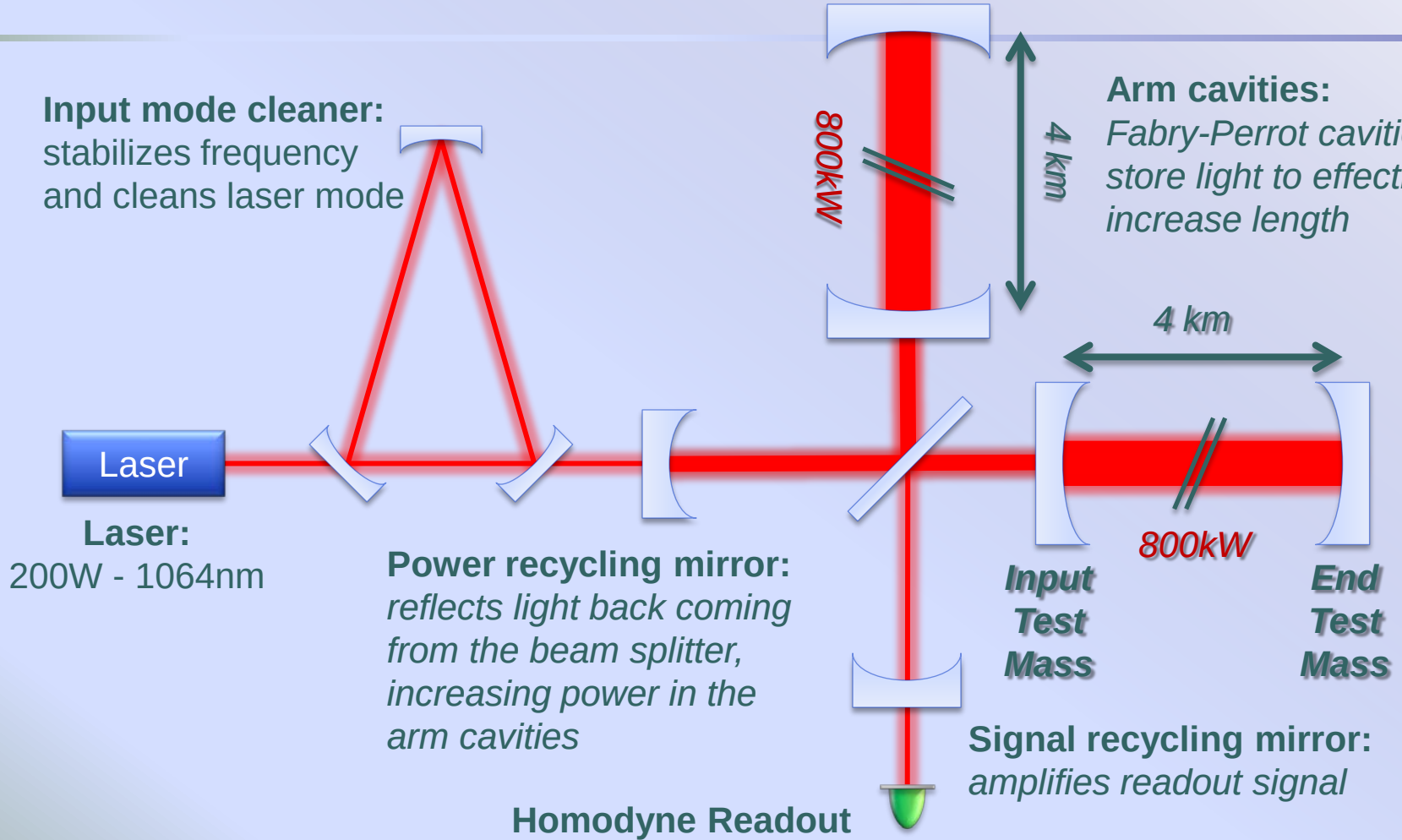
Corbitt et al., PRL 98, 150802 (2007)

Towards the Quantum Ground State

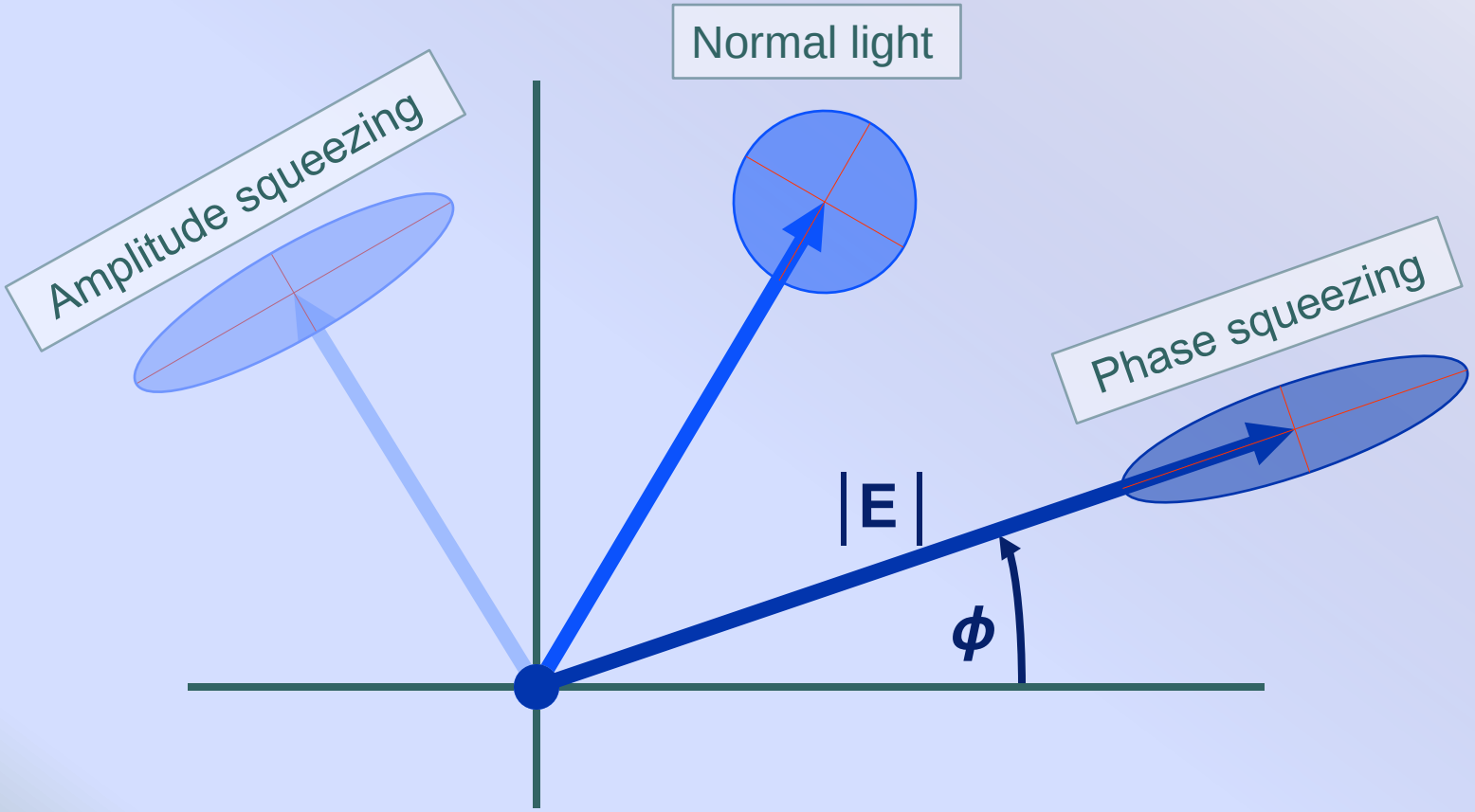


Abbott et al.
New J. Phys. 11, 073032 (2009)

The Advanced LIGO Detector



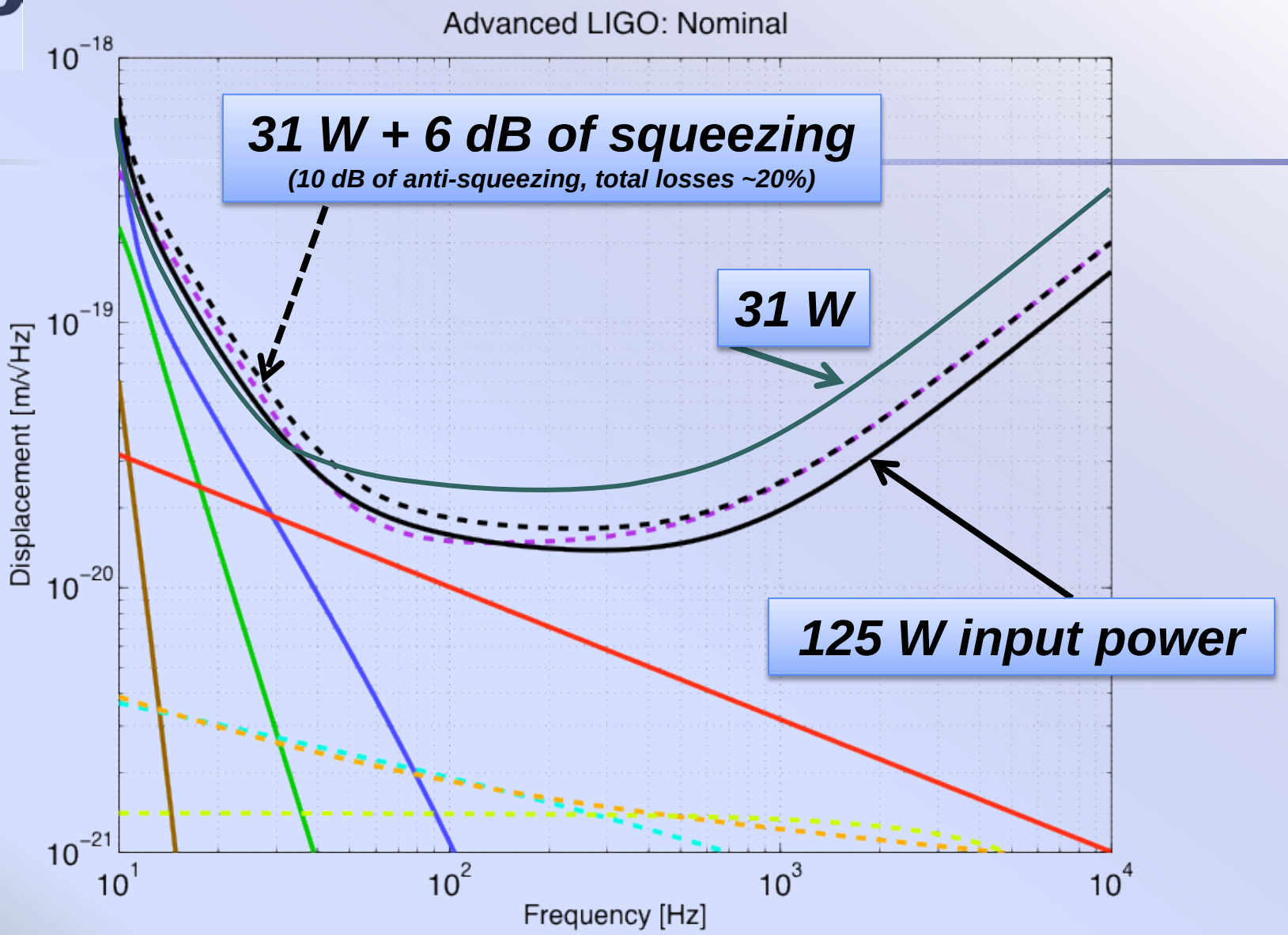
Squeezed Light

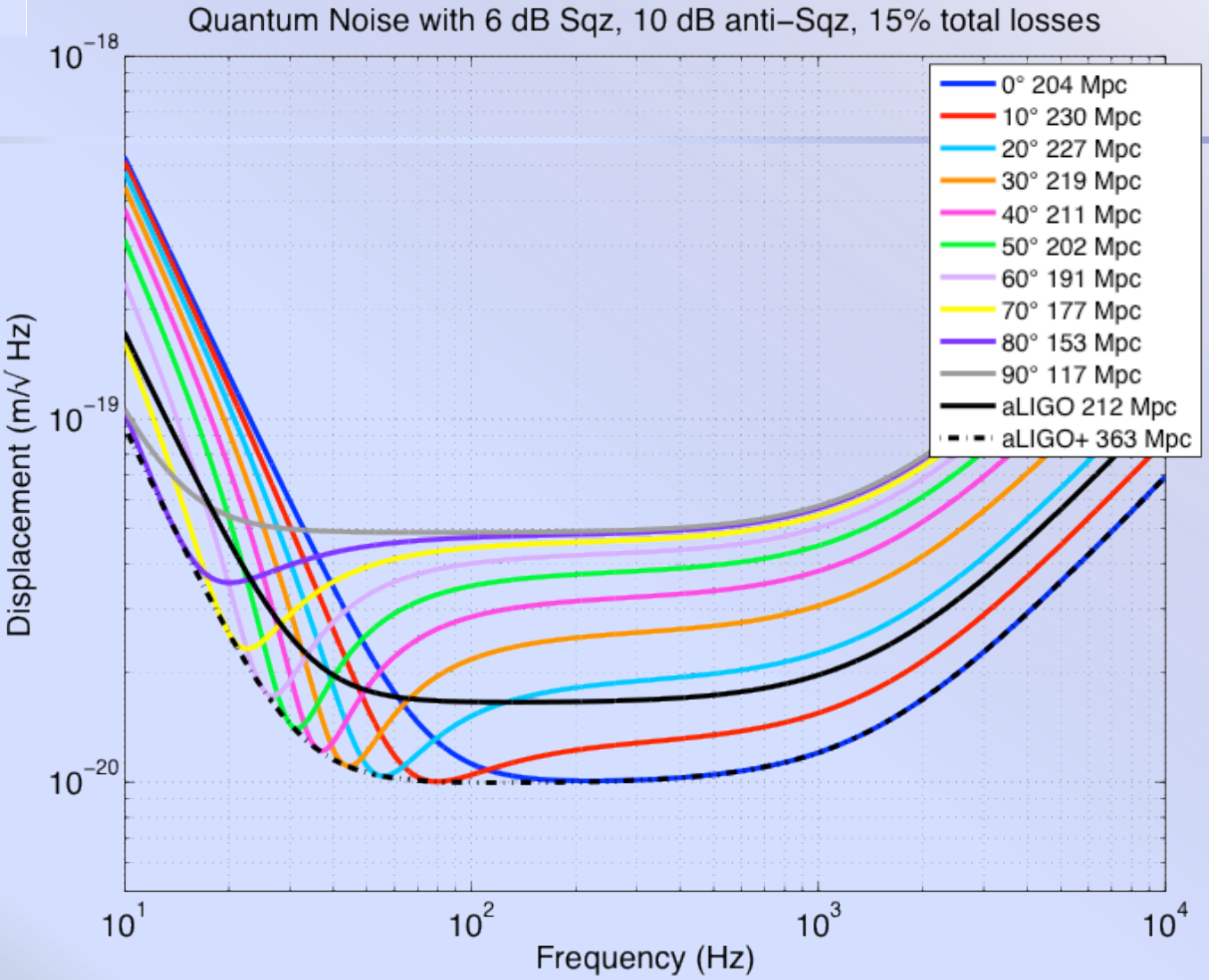


LIGO

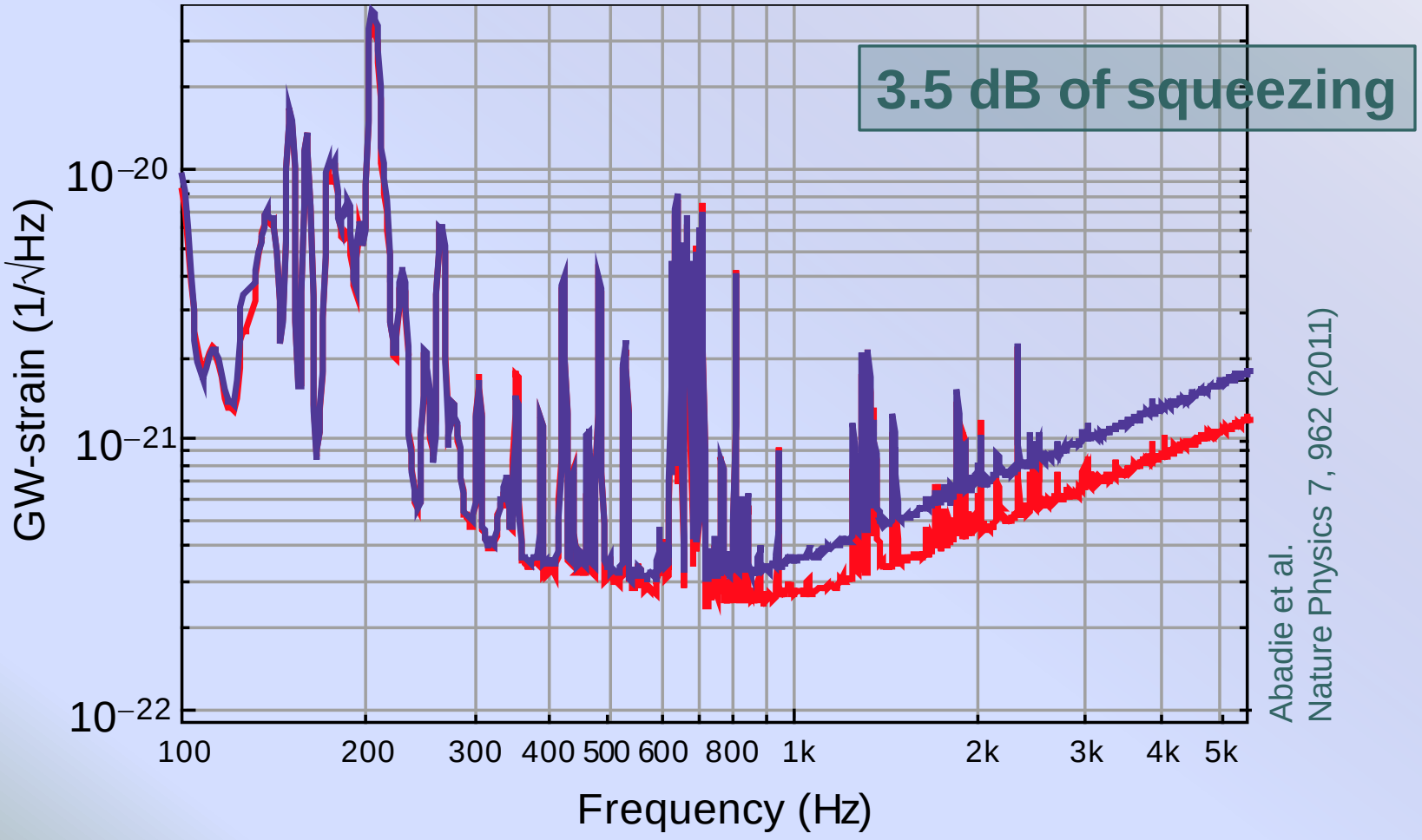
Key Insights

- Shot noise in a Michelson interferometer is due to vacuum fluctuations entering the dark port.
- Quantum noise also produces photon pressure noise.
- Injecting a specially prepared light state with reduced phase noise (relative to vacuum) into the dark port will improve the shot noise sensitivity.
- Similarly, injecting light with reduced amplitude noise will reduce the photon pressure noise.
- Non-linear optical effects can be used to generate a squeezed “vacuum” state.


Advanced LIGO: Nominal
31 W + 6 dB of squeezing
(10 dB of anti-squeezing, total losses ~20%)
31 W
125 W input power
Displacement [m/√Hz]
Frequency [Hz]
10^-18
10^-19
10^-20
10^-21
10^1
10^2
10^3
10^4


Quantum Noise with 6 dB Sqz, 10 dB anti−Sqz, 15% total losses
Displacement (m/√ Hz)
Frequency (Hz)
10^{-18}
10^{-19}
10^{-20}
10^{1}
10^{2}
10^{3}
10^{4}
0° 204 Mpc
10° 230 Mpc
20° 227 Mpc
30° 219 Mpc
40° 211 Mpc
50° 202 Mpc
60° 191 Mpc
70° 177 Mpc
80° 153 Mpc
90° 117 Mpc
aLIGO 212 Mpc
aLIGO+ 363 Mpc

Experimental Confirmation at the GEO600 Detector



The H1 Squeezer Experiment

Goals:

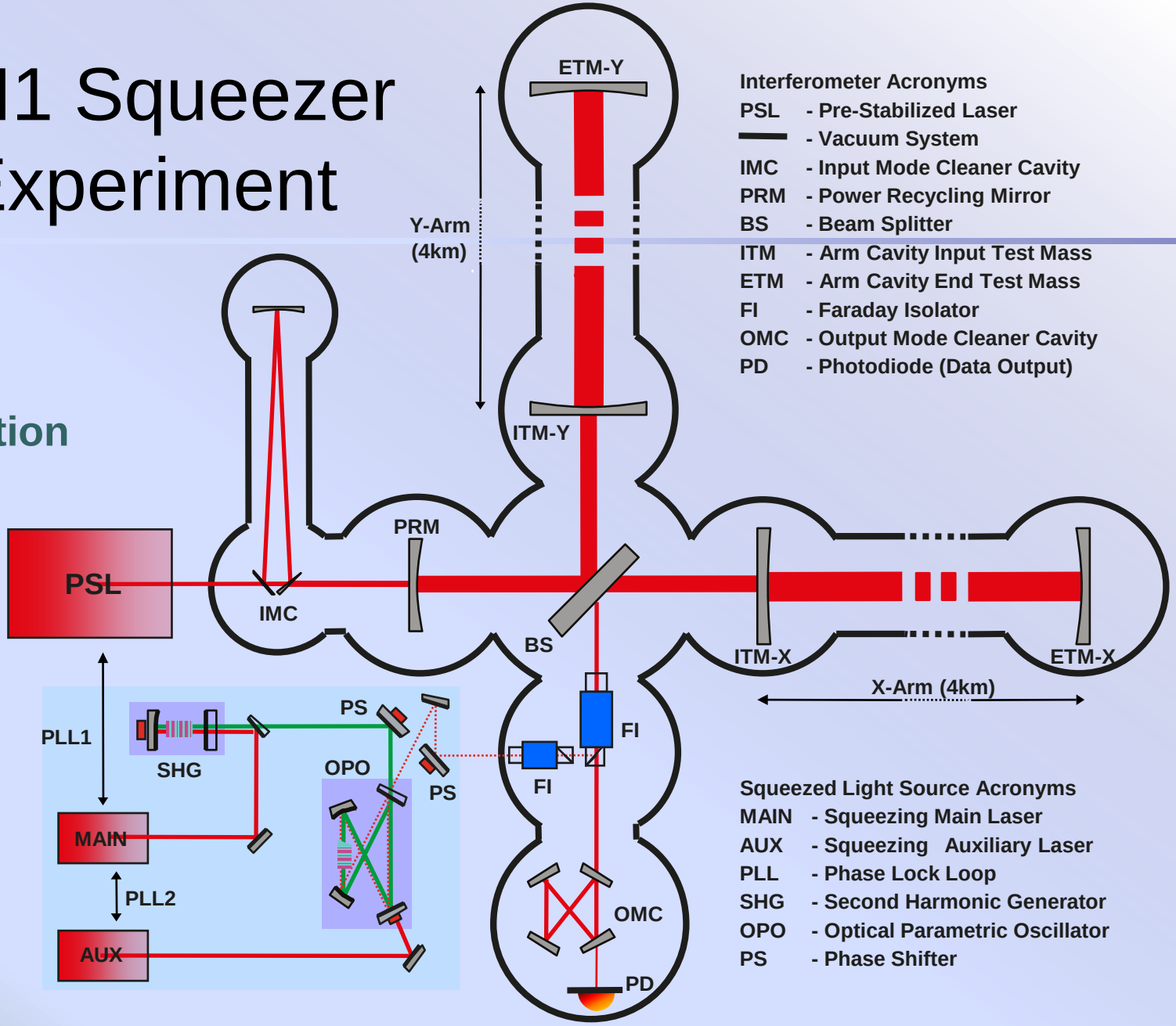
- Demonstrate 3dB of squeezing at the initial LIGO sensitivity
- Don't degrade low frequency sensitivity
- Risk mitigation for high power operations
- Pathfinder for advanced LIGO squeezer

Potential show stoppers:

- Back scattering
- Stray light
- Phase noise
- Optical losses
- Auxiliary servo noise
- Alignment jitter
- Stability

H1 Squeezer Experiment

ANU, AEI, MIT, LIGO collaboration



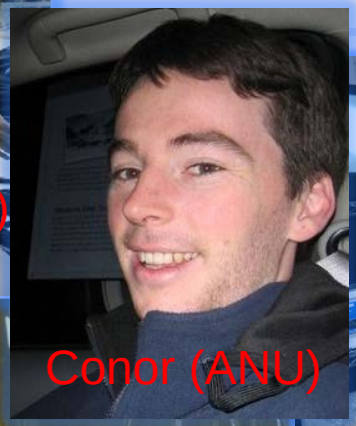
Interferometer Acronyms

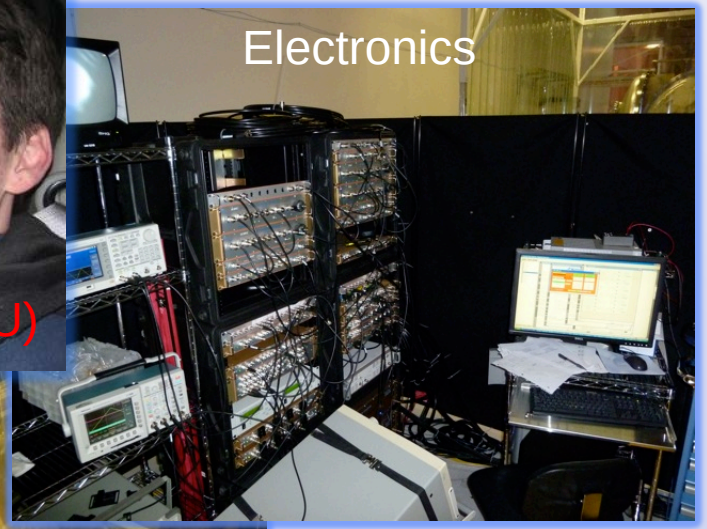
PSL	- Pre-Stabilized Laser
▬	- Vacuum System
IMC	- Input Mode Cleaner Cavity
PRM	- Power Recycling Mirror
BS	- Beam Splitter
ITM	- Arm Cavity Input Test Mass
ETM	- Arm Cavity End Test Mass
FI	- Faraday Isolator
OMC	- Output Mode Cleaner Cavity
PD	- Photodiode (Data Output)

Squeezed Light Source Acronyms

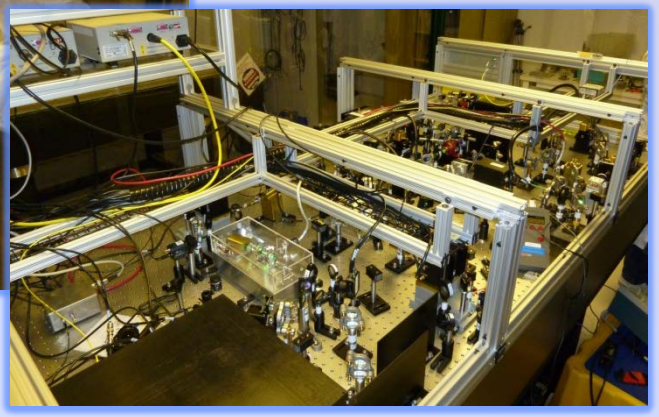
MAIN	- Squeezing Main Laser
AUX	- Squeezing Auxiliary Laser
PLL	- Phase Lock Loop
SHG	- Second Harmonic Generator
OPO	- Optical Parametric Oscillator
PS	- Phase Shifter

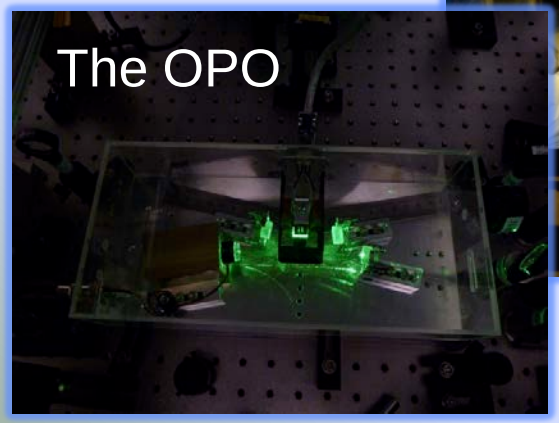
Squeezer at Hanford





Optics Table

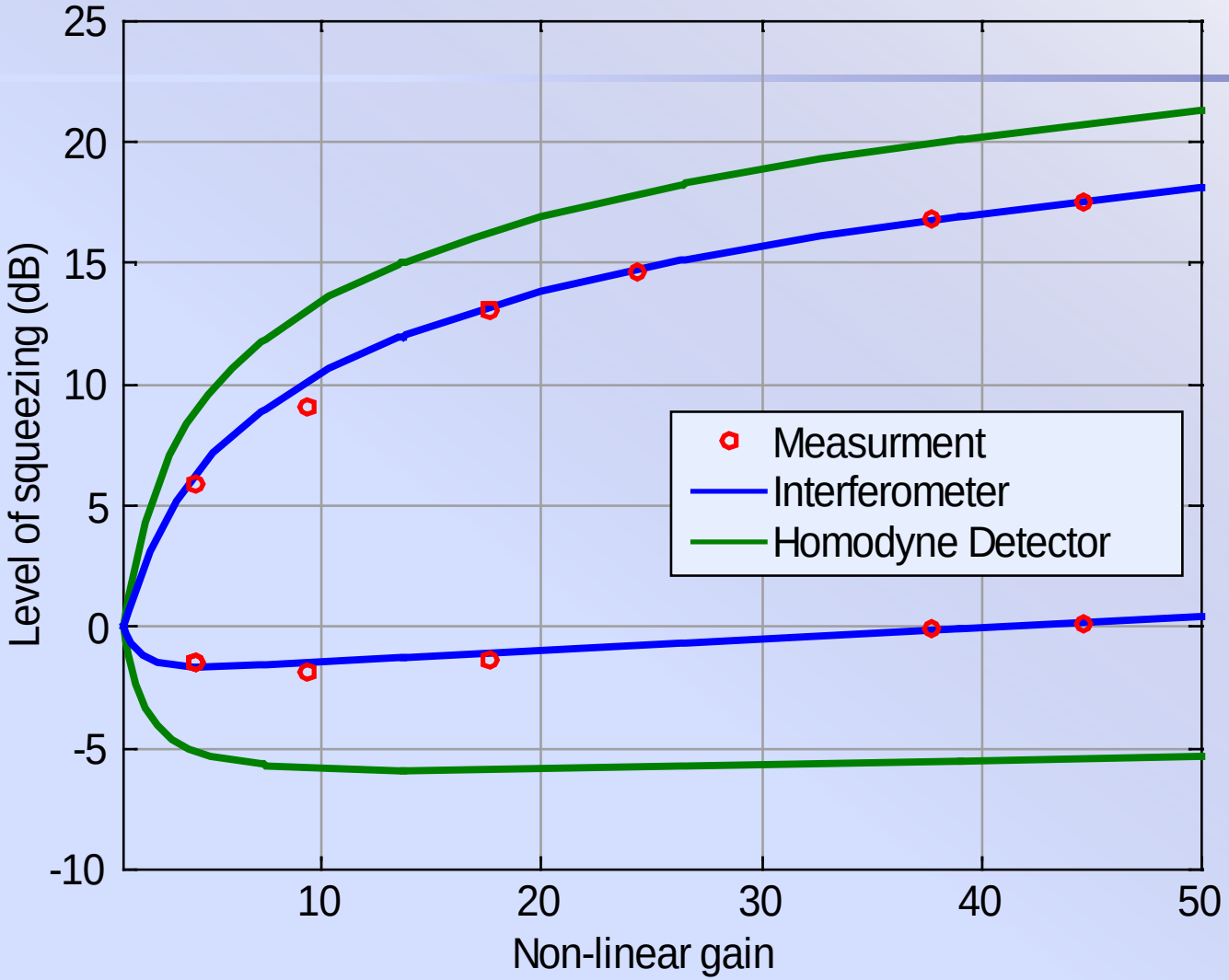




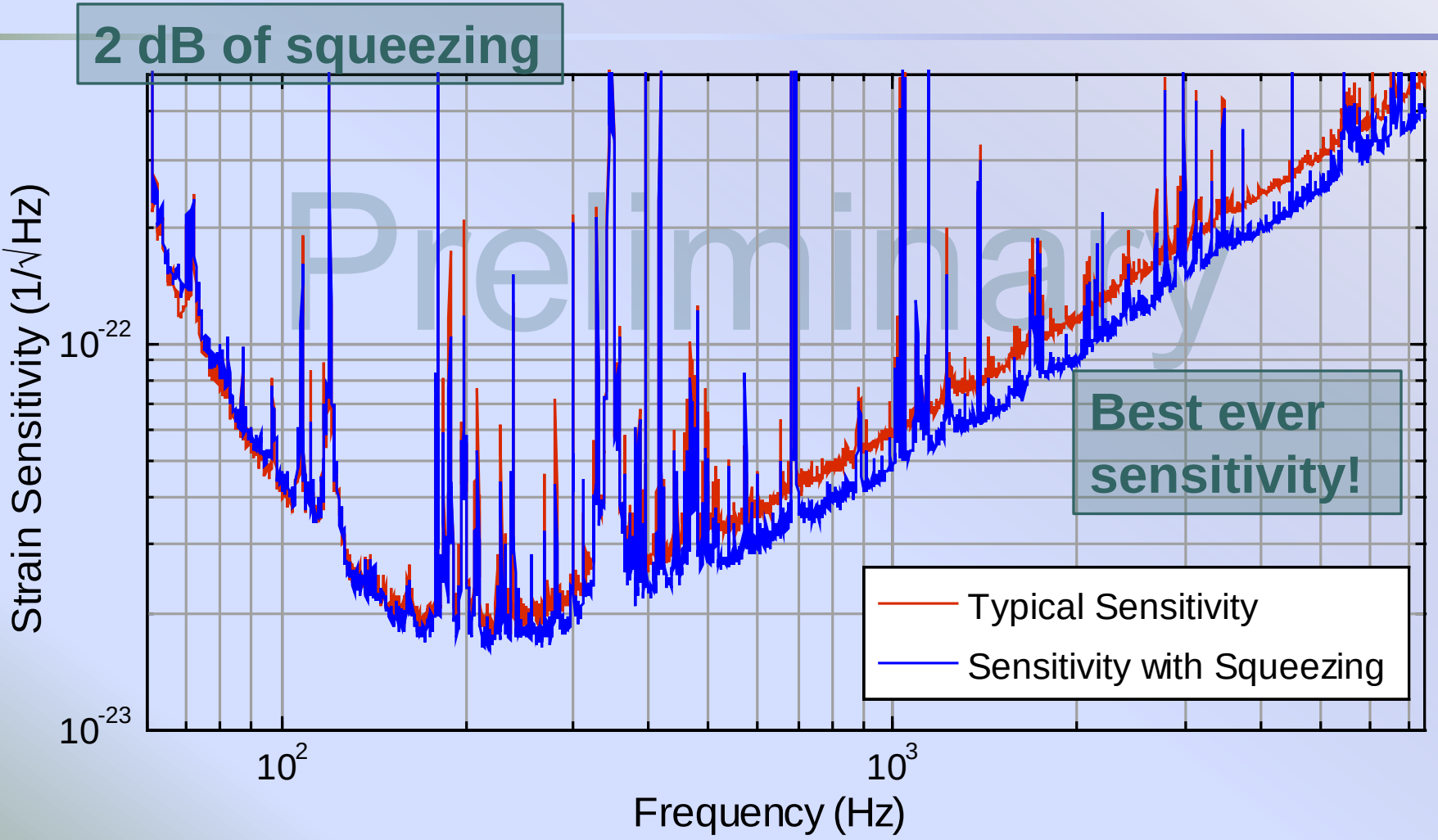
Non-Linear Gain

61% loss
5º phase noise

19% loss
1.3º phase noise



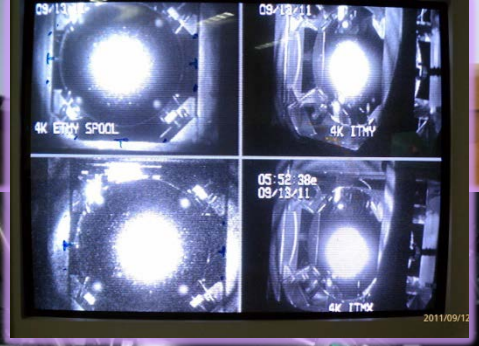
H1 Squeezed


2 dB of squeezing
Preliminary
Best ever sensitivity!
Typical Sensitivity
Sensitivity with Squeezing
Strain Sensitivity (1/√Hz)
10^-22
10^-23
10^2
10^3
Frequency (Hz)

Outlook

- GEO600/AEI will work on high performance squeezing and long term stability
- ANU continues to optimize the ring-cavity OPO
- R&D program at MIT to work on filter cavities and a low loss readout chain
- Start a design for an advanced LIGO squeezer

Squeezed light sources will be the first upgrade to advanced gravitational-wave interferometers


HAM4-S

4K ETMY SPOOL
4K ITMY
05:52:38a
09/13/11
4K ITMX
2011/09/12

2011/06/07 11:4