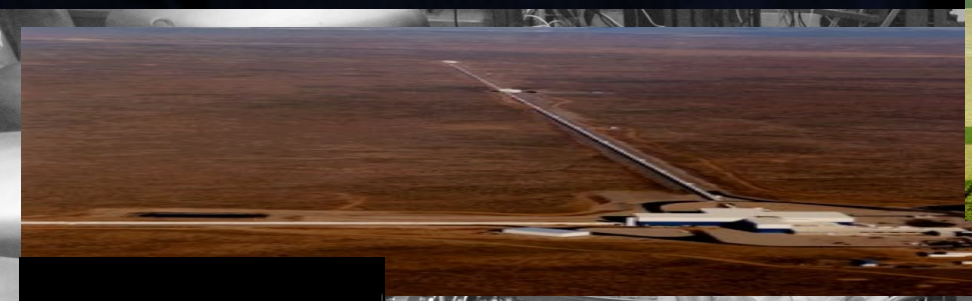
H.Grote, AEI
GWADW
Elba, May 2013

S q e e z i n g
for Future Generation Detectors



Potential of Squeezing: Lower Quantum Noise

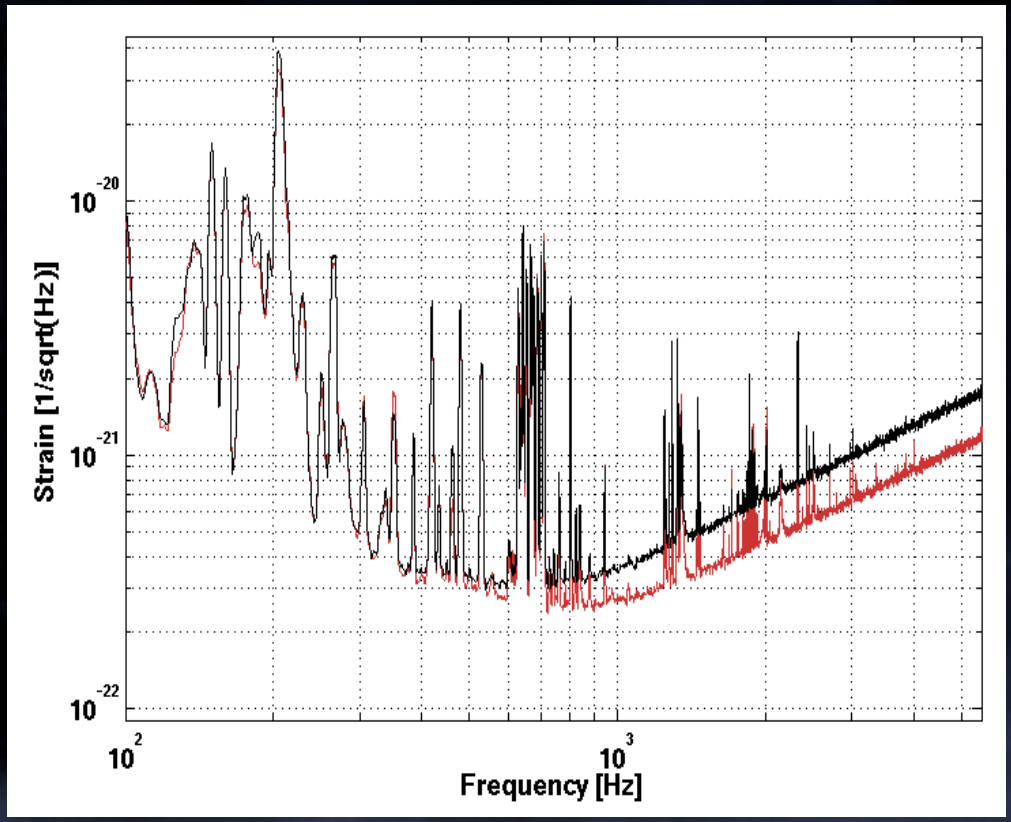
- 2nd Generation detectors (Adv LIGO, Adv Virgo, KAGRA) are likely to use squeezing as upgrade sooner or later
- 3rd Generation (LIGO RGB, ET) from the beginning

How many dBs ??

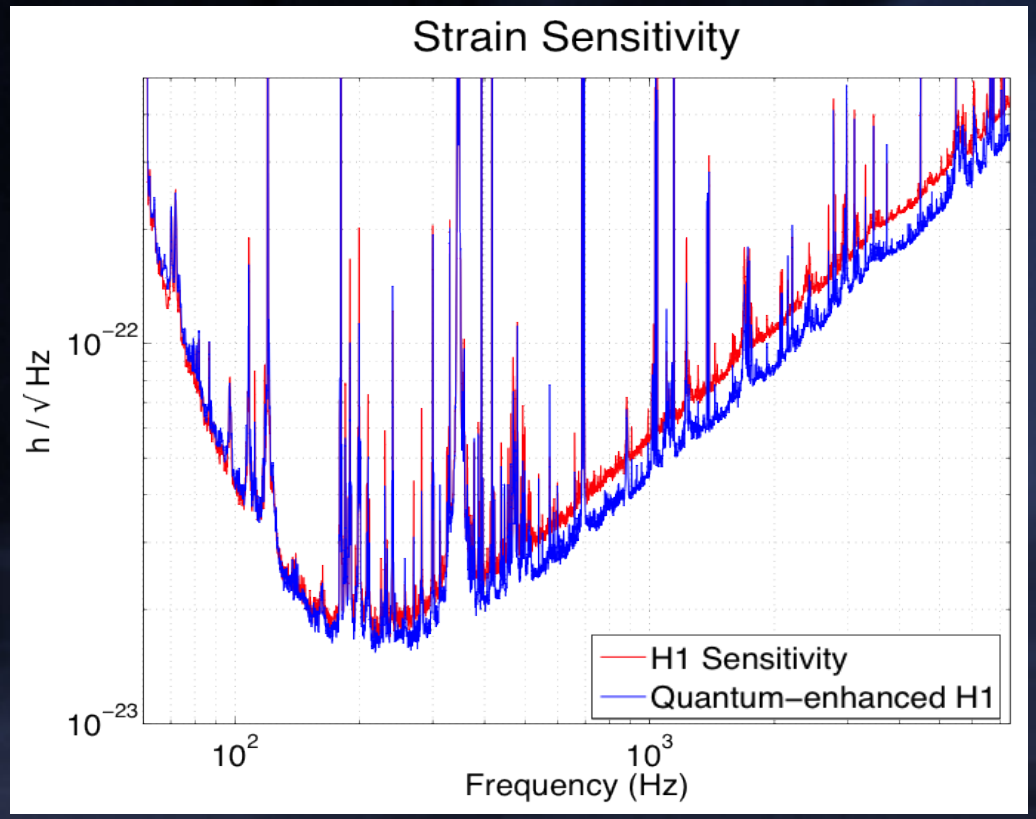
And at which Frequency ??

Ligo Scientific Collaboration: G1, H1

G1, GEO600 (2010, ongoing):
3.5dB, >400Hz



H1, LIGO Hanford (2011):
2.2dB, >150Hz

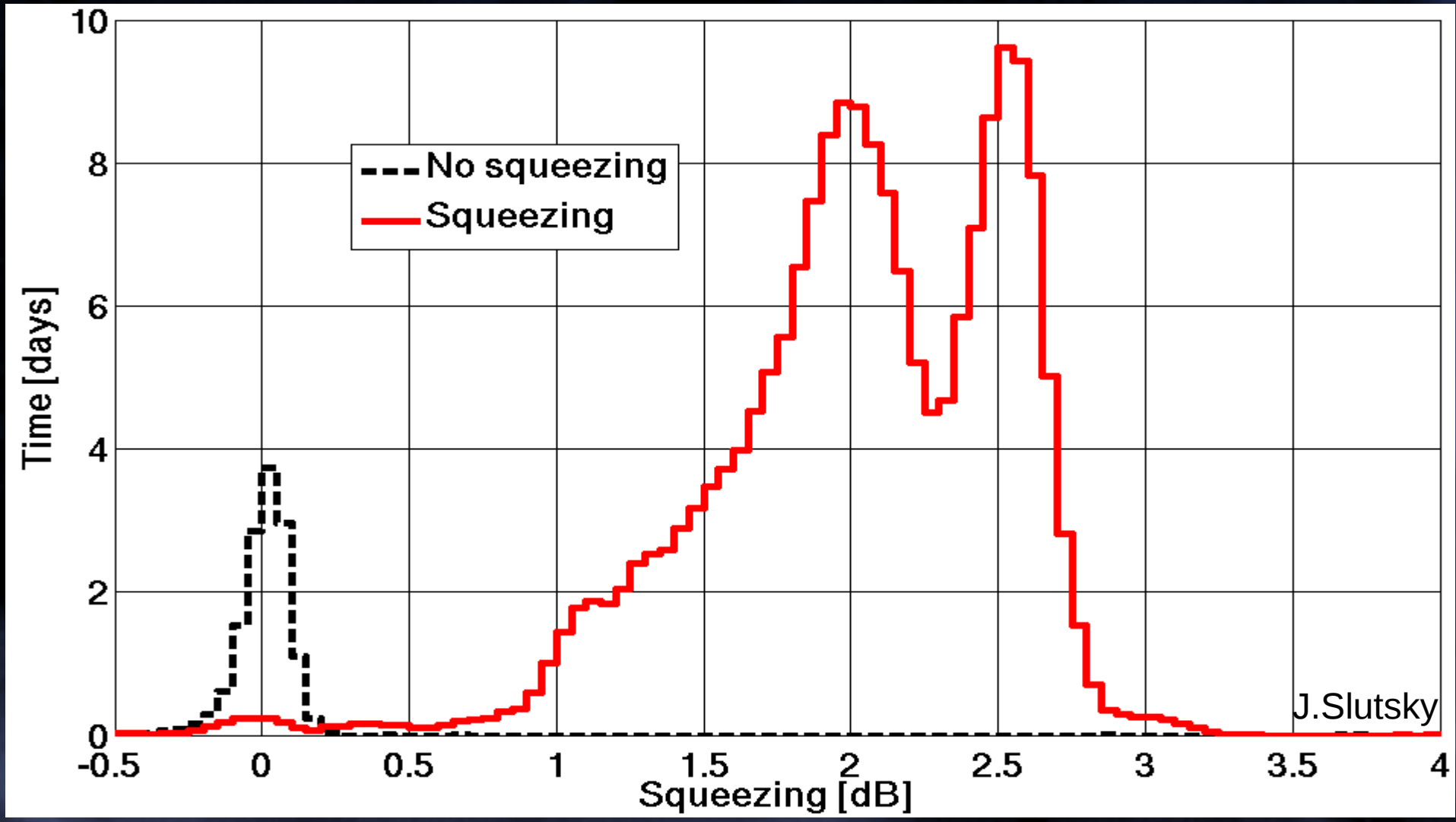


- long term reliability and automation
- glitch/gaussianity analysis
- different control signals

- back-scatter analysis
- phase noise analysis

SQZ performance Nov 2011- Oct 2012

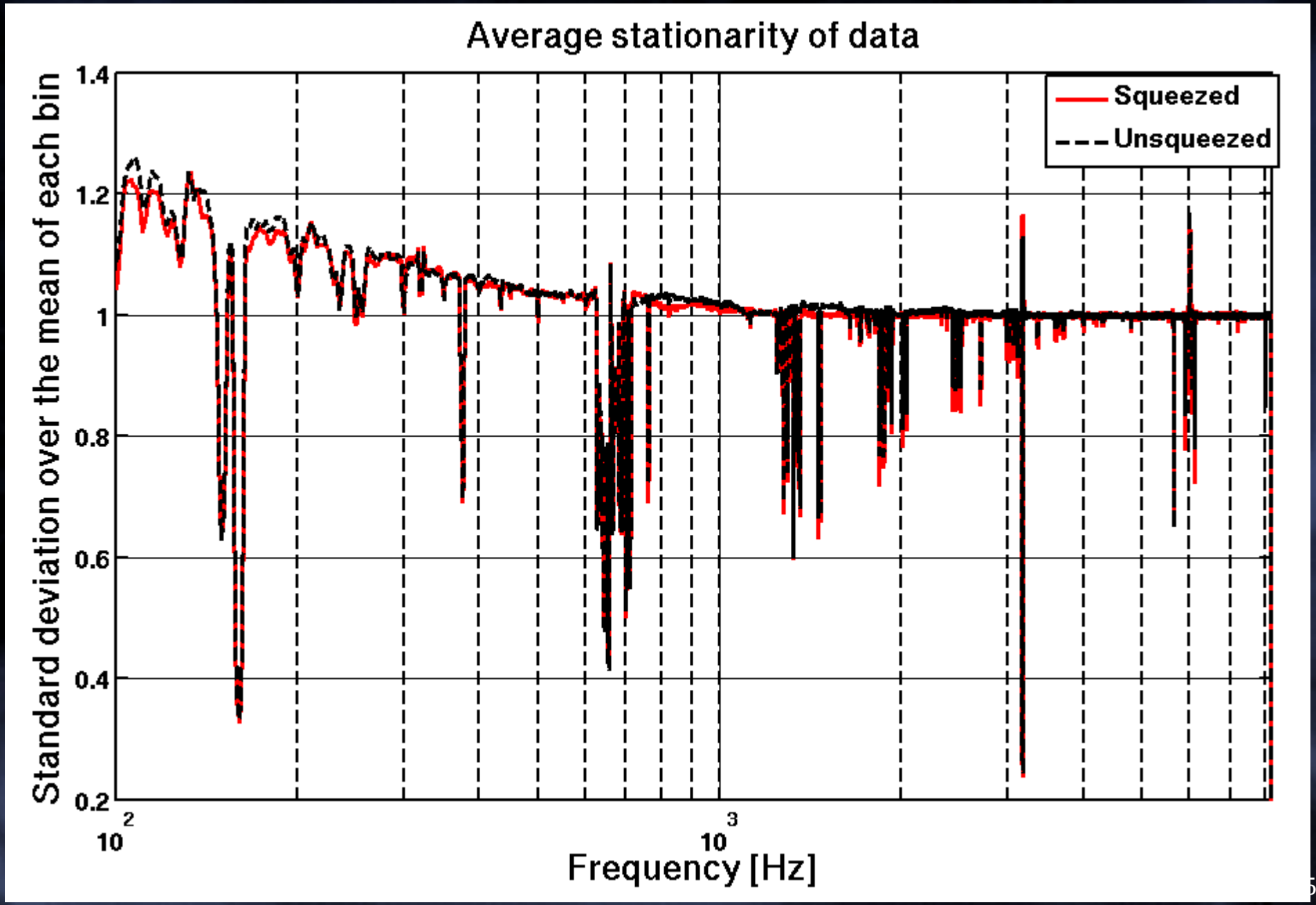
Dither lock/ CC combination, Autoalignment for 2DOF, OMC-trans signal



Science time: 68%, with squeezing: 90%

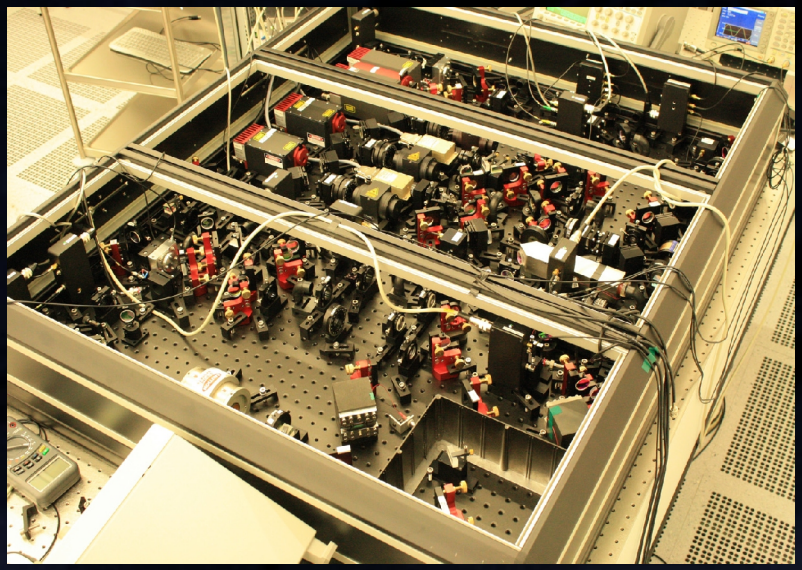
PRL 110, 18001 (2013)

2 x 33h Squeezing On/Off Comparison



J. Slutsky

Why not more than ~3dB yet ?

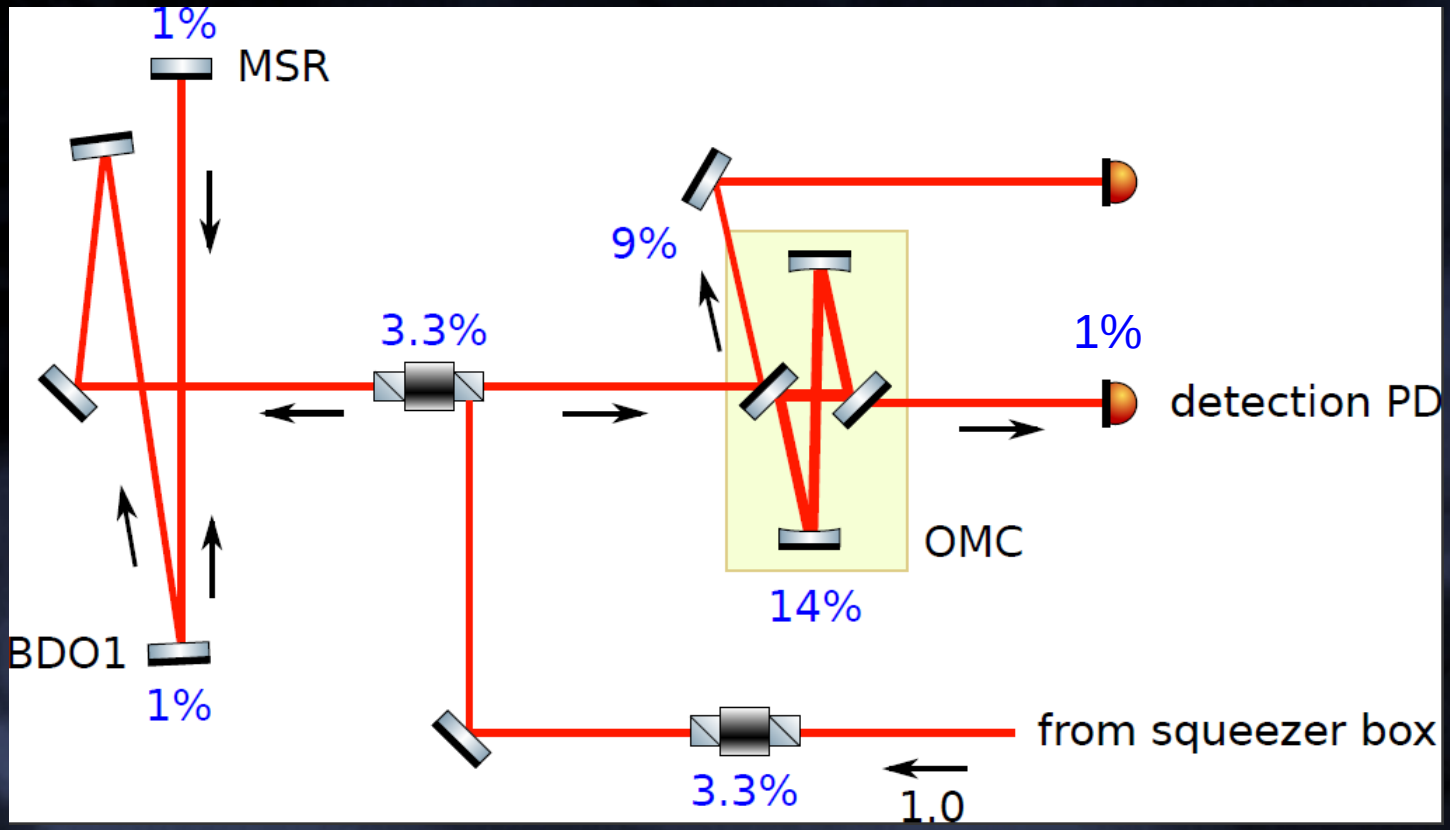


>~ 10dB
When detected on local homodyne detector

But:
Only ~3dB so far on GW IFOs:
-More optics (losses), more cavities (modematching)
-More complex paths (alignment, phase-noise)

Optical loss

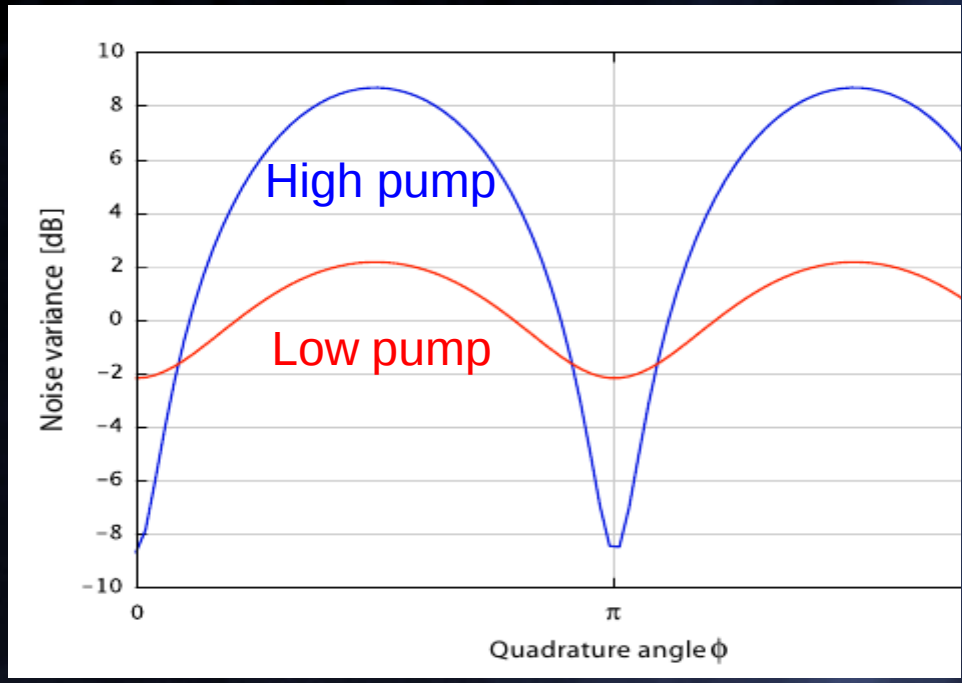
- OMC Loss (G1:14%, H1:20%) → we can do better!
- Modematching (SQZ to IFO, IFO to OMC, 8-30%)
- Faraday isolators (G1: 3.3%, mainly Pol. Beamsplitters!)



Total efficieny:
~0.65
As measured with bright beam.

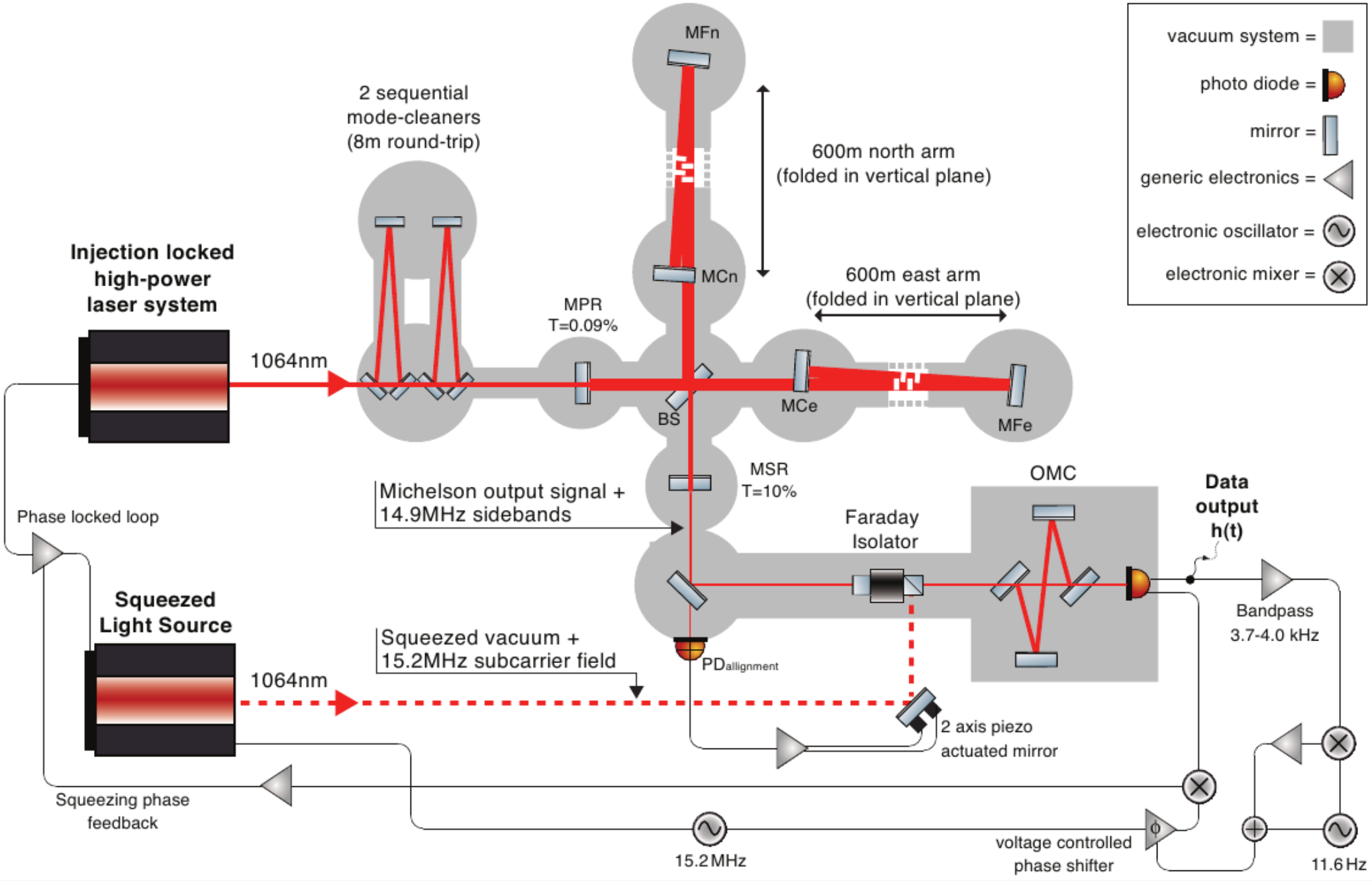
BUT: Different condition (MM to IFO , alignment)

Phase (Quadrature) Noise

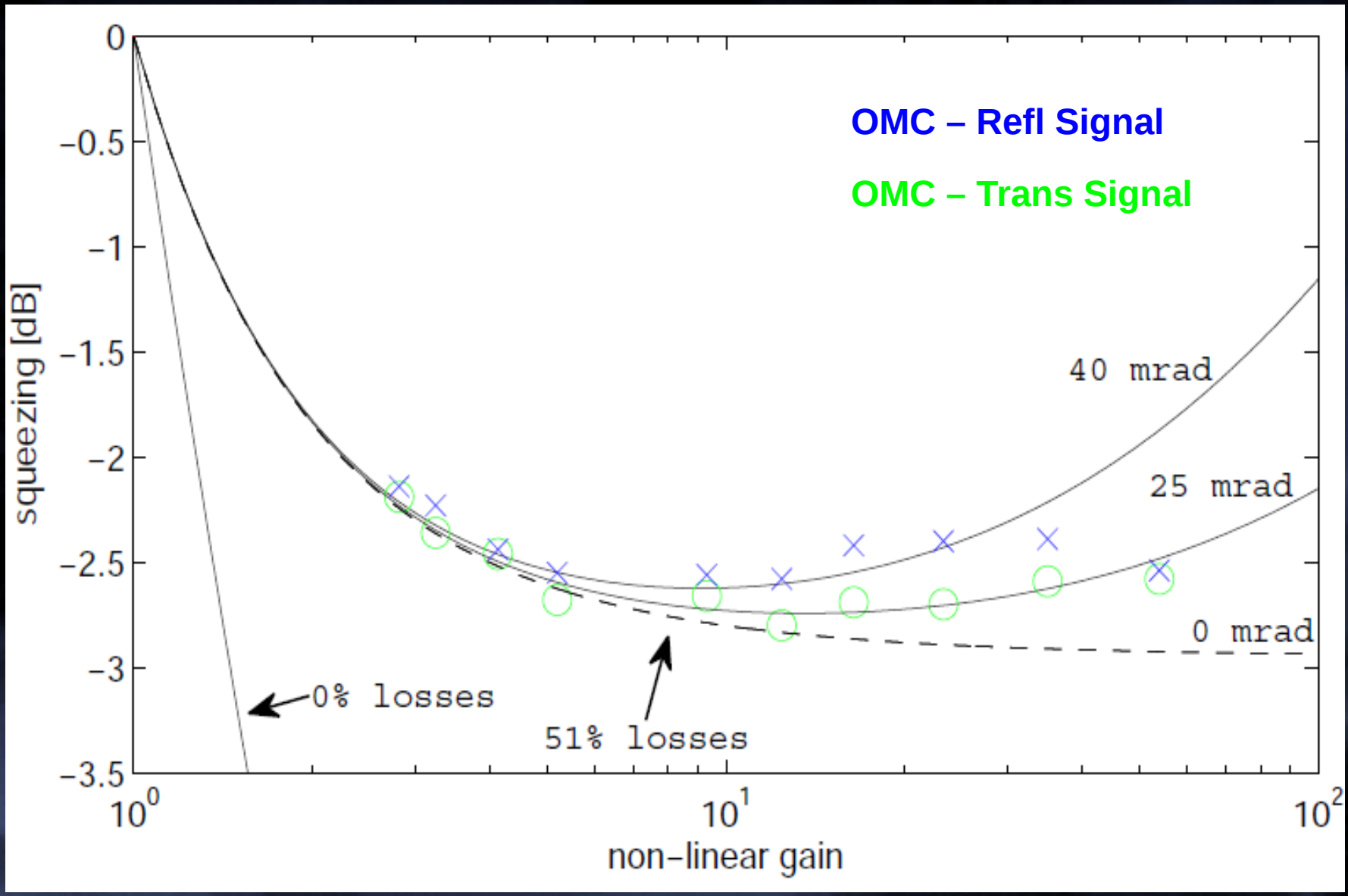


- Source:
  - OPO length noise (H1)
  - OPO temp. fluct.
  - Technical noises
- IFO:
  - Propagation, IFO Pendulums
  - IFO RF sidebands (G1)
  - Phase Sensing (Alignment, Technical)

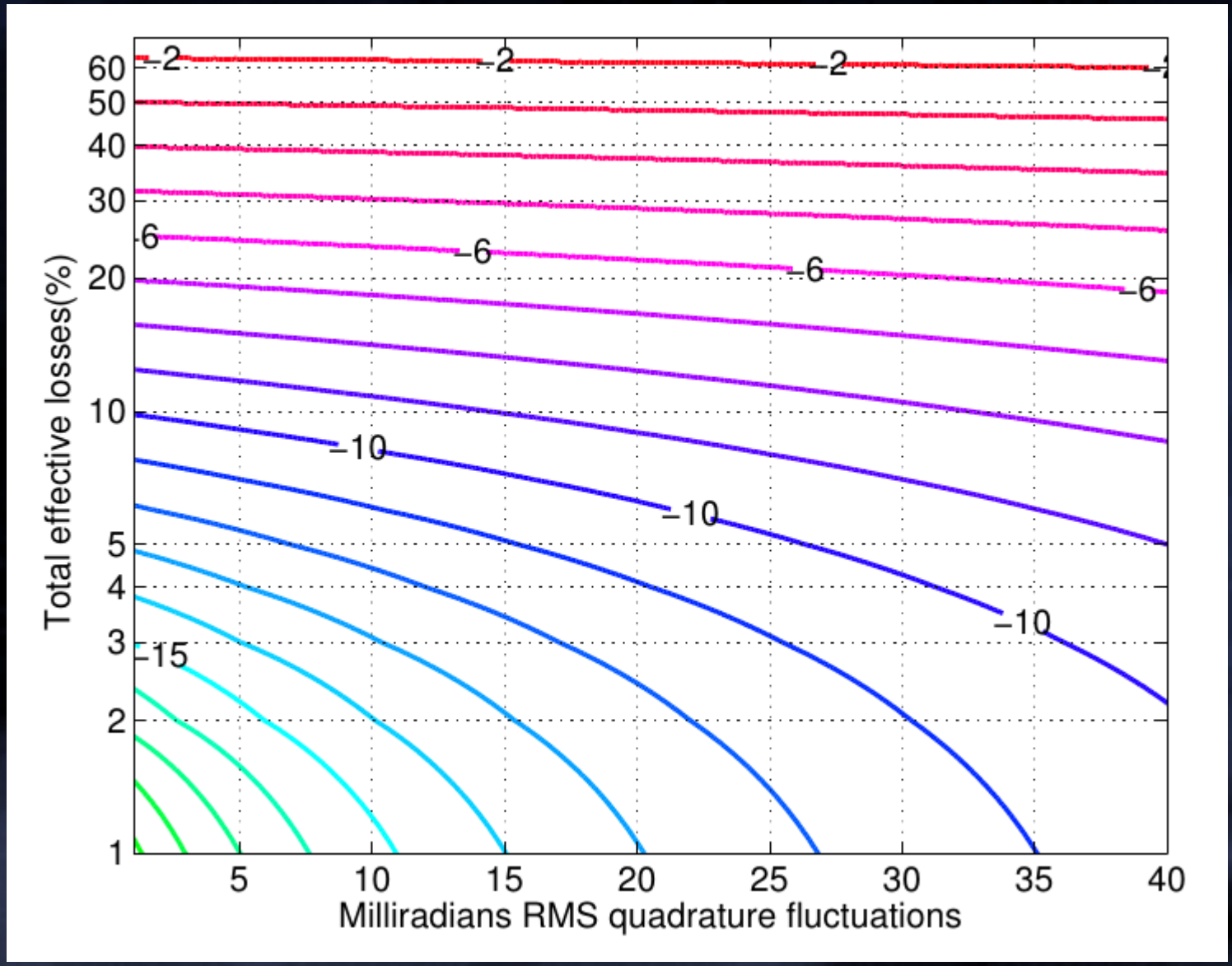
SUM: ~40 mrad


vacuum system =
photo diode =
mirror =
generic electronics =
electronic oscillator =
electronic mixer =
MFn
2 sequential
mode-cleaners
(8m round-trip)
600m north arm
(folded in vertical plane)
Injection locked
high-power
laser system
MCn
MPR
T=0.09%
600m east arm
(folded in vertical plane)
1064nm
BS
MCe
MFe
MSR
T=10%
OMC
Michelson output signal +
14.9MHz sidebands
Phase locked loop
Faraday
Isolator
Data
output
h(t)
Squeezed
Light Source
Bandpass
3.7-4.0 kHz
Squeezed vacuum +
15.2MHz subcarrier field
1064nm
PDallignment
2 axis piezo
actuated mirror
Squeezing phase
feedback
15.2MHz
voltage controlled
phase shifter
11.6Hz

Phase noise measurement ('out-of-loop')

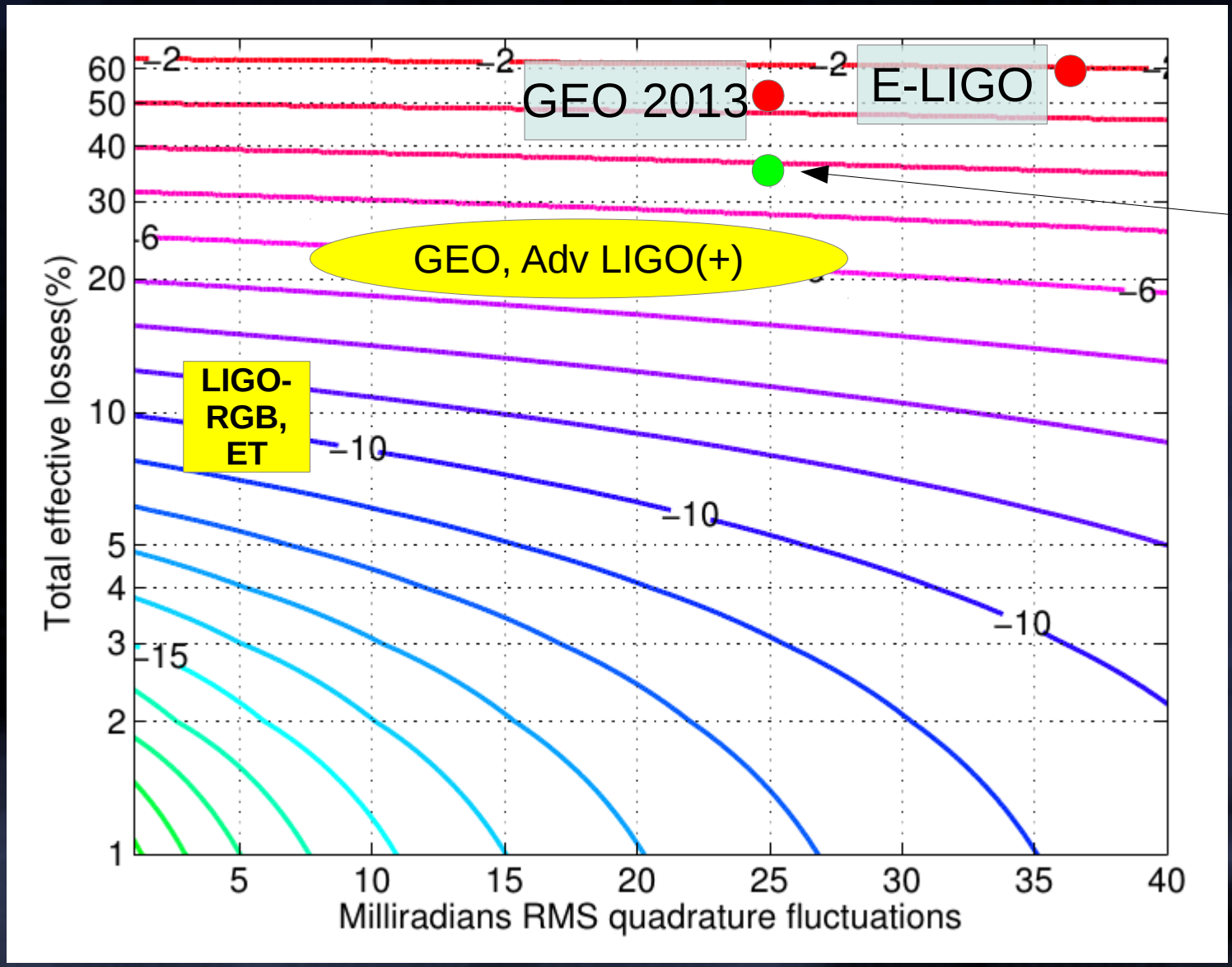


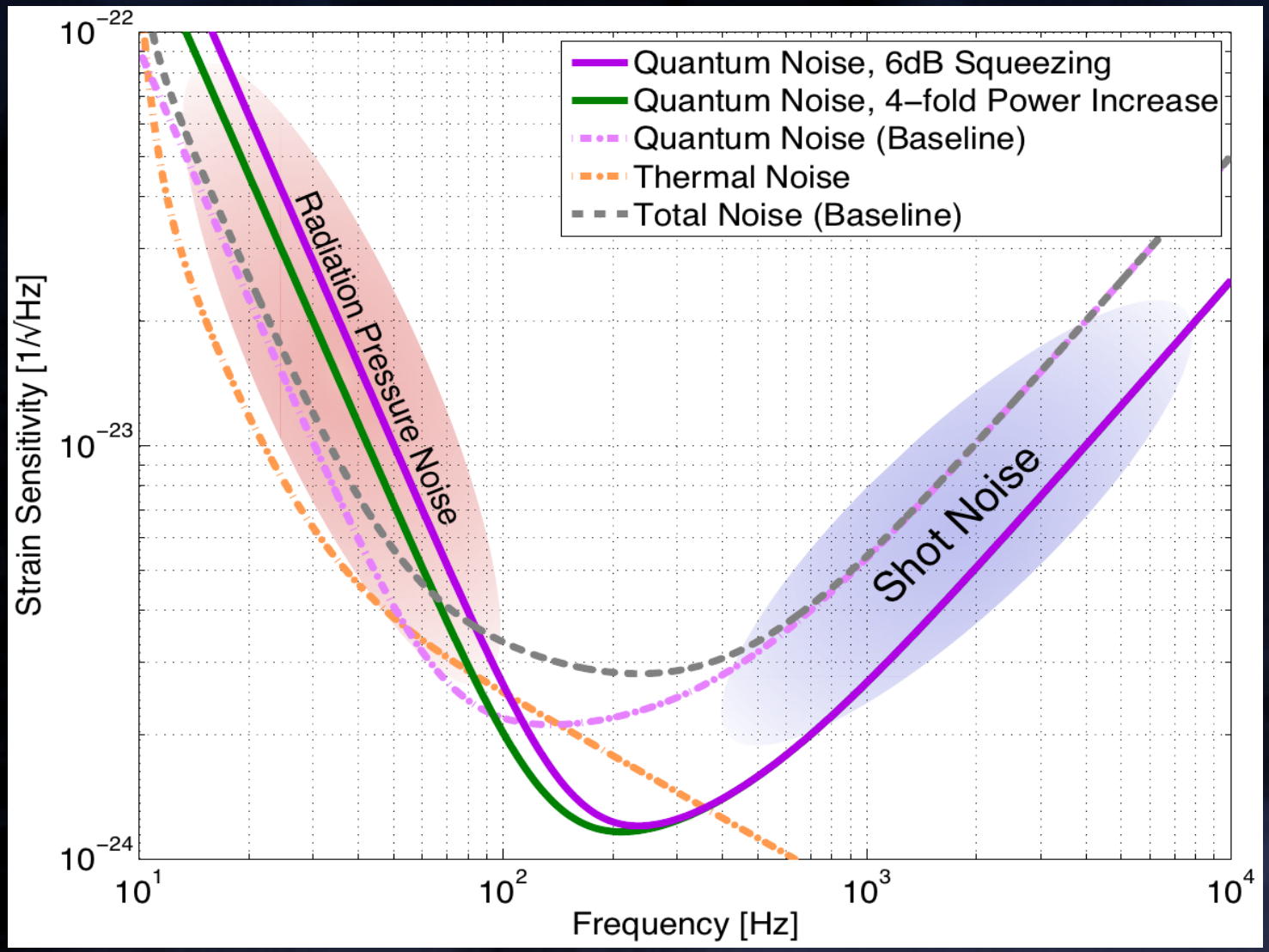
Otical Loss and Phase Noise



S.Dwyer

Optical Loss and Phase Noise





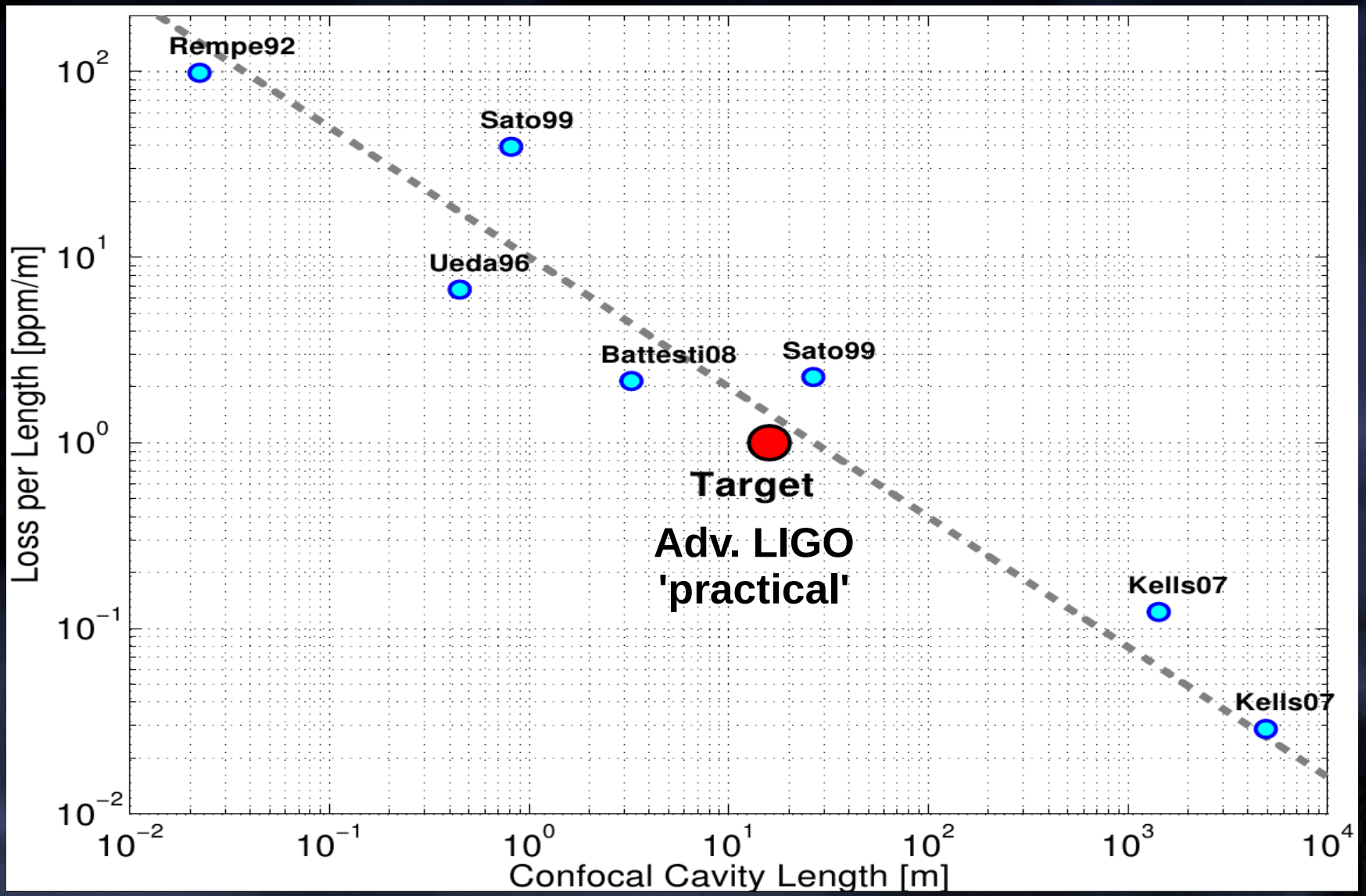
BUT:

M.Evans / MIT group

... at which Frequency ??

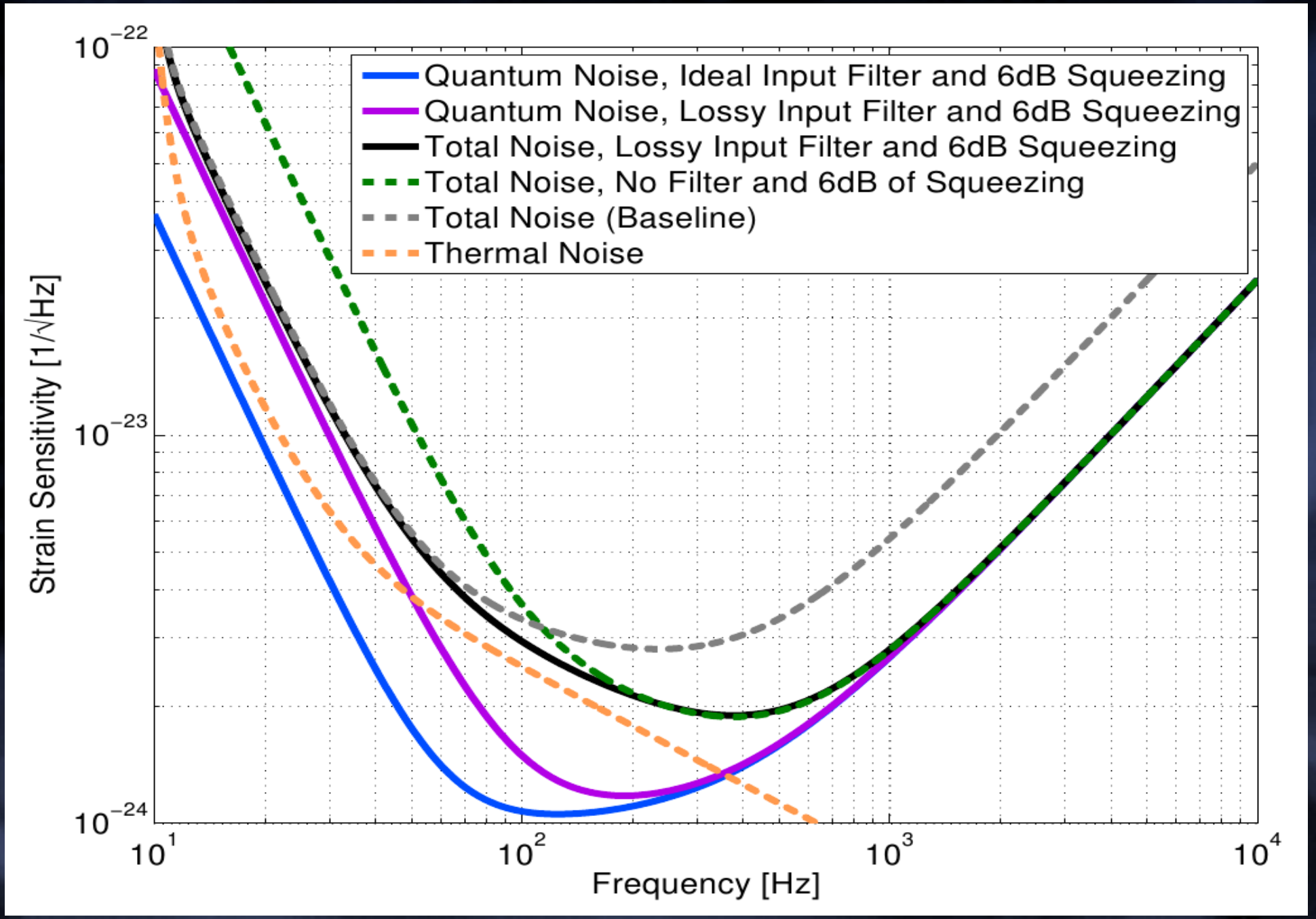
(Input) Filter cavity

Filter Cavity
Does Length Help? → Yes: ~L^-2/3



MIT

A practical approach for AdvLIGO(+)



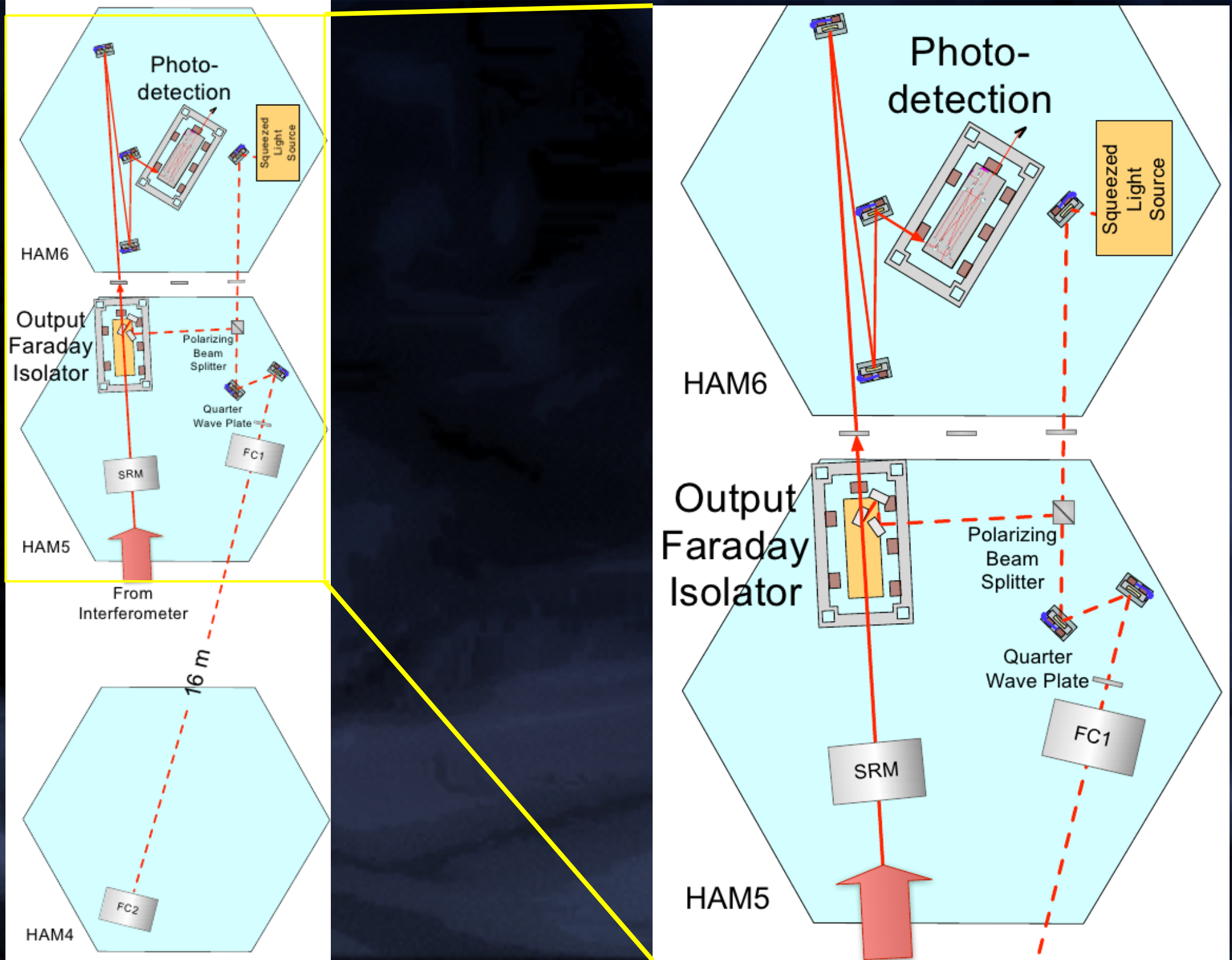


Photo-
detection
Squeezed
Light
Source
HAM6
Output
Faraday
Isolator
Polarizing
Beam
Splitter
Quarter
Wave Plate
FC1
SRM
HAM5
From
Interferometer
16 m
FC2
HAM4
Photo-
detection
Squeezed
Light
Source
HAM6
Output
Faraday
Isolator
Polarizing
Beam
Splitter
Quarter
Wave Plate
FC1
SRM
HAM5

Research Topics

Short term

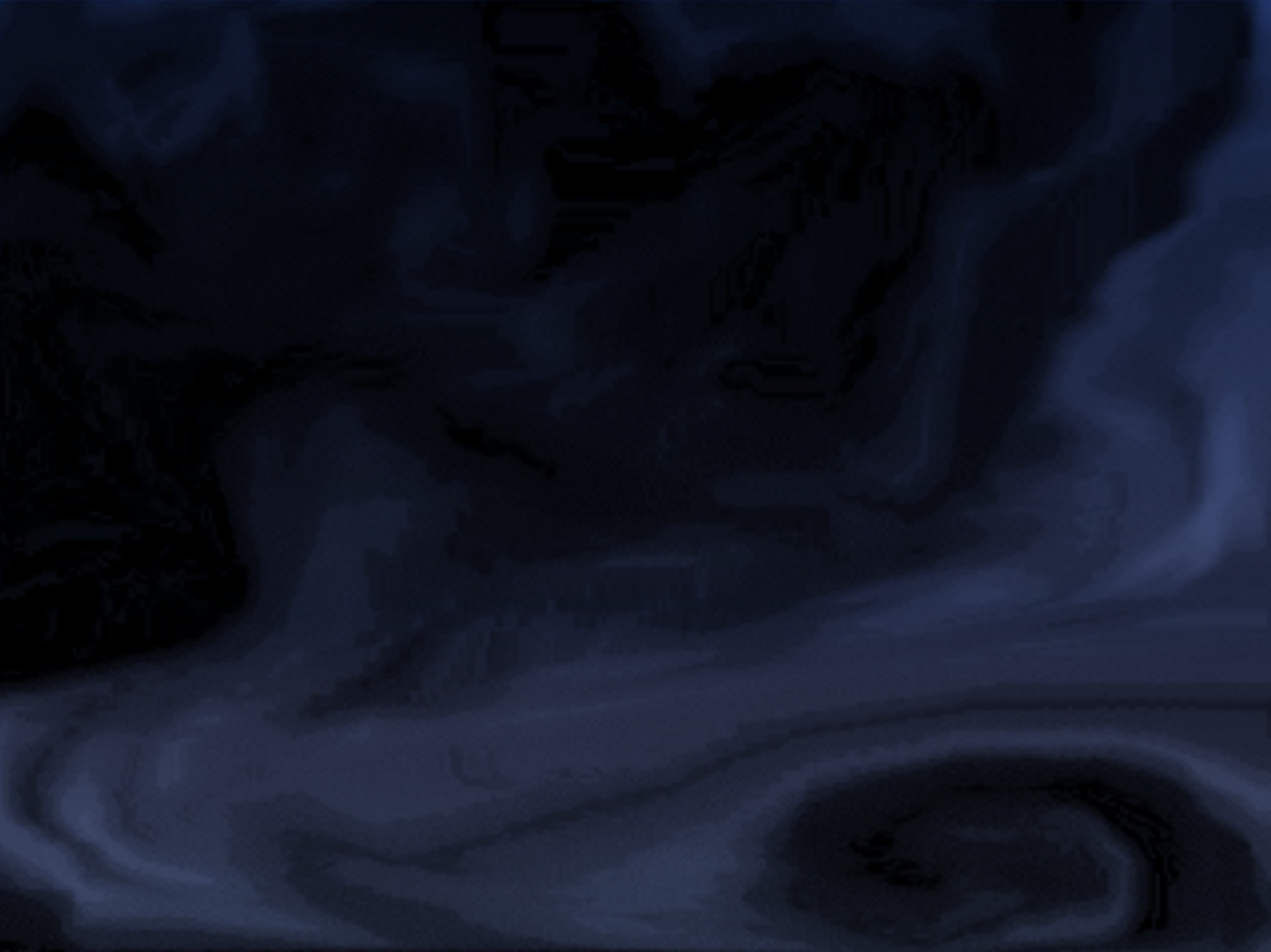
- Control: OMC trans. signal, phase-noise, RF+DC readout
- Automatic alignment (OMC refl.)
- Mode matching and HOM

Medium term (6dB for Adv(+))

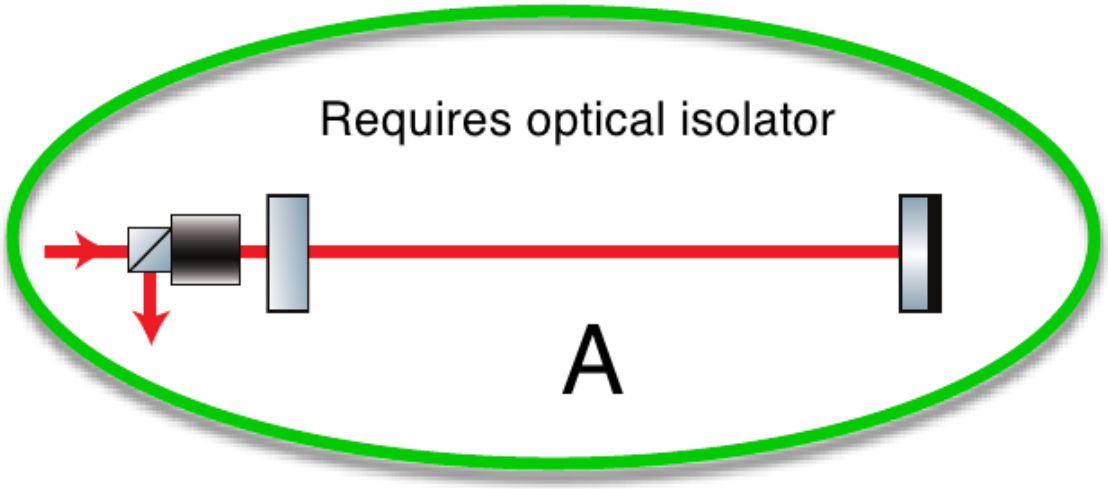
- Filter cavities:
- Short design for Adv(+)
- Losses
- HOM
- Control (e.g. green?)

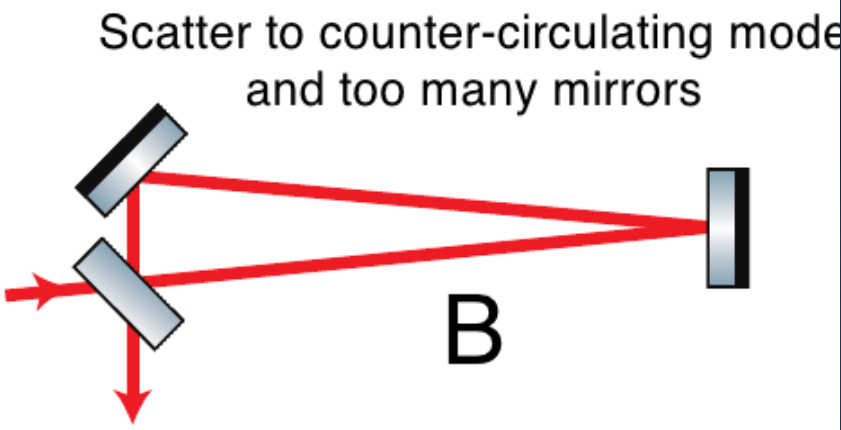
Longer term (~10dB for L. RGB, ET)

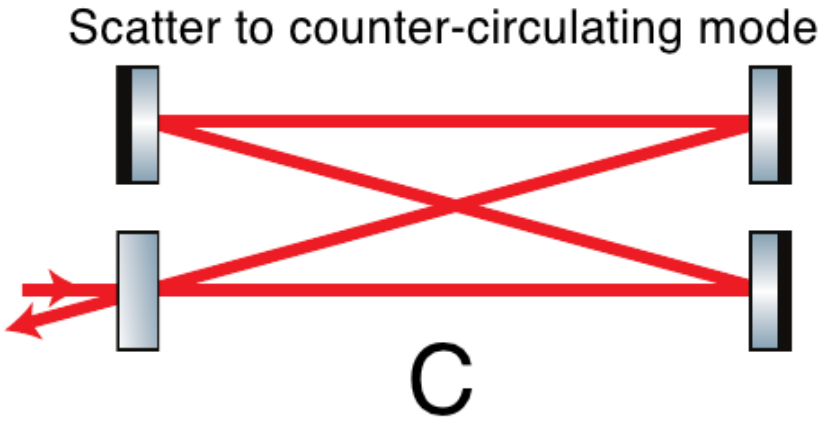
- Better PBSs (<0.2%Loss) and other optics
- Extremely good modematchings (>~99%)
- Longer filter cavities
- Squeezing source in vacuum? And/or very good control signals

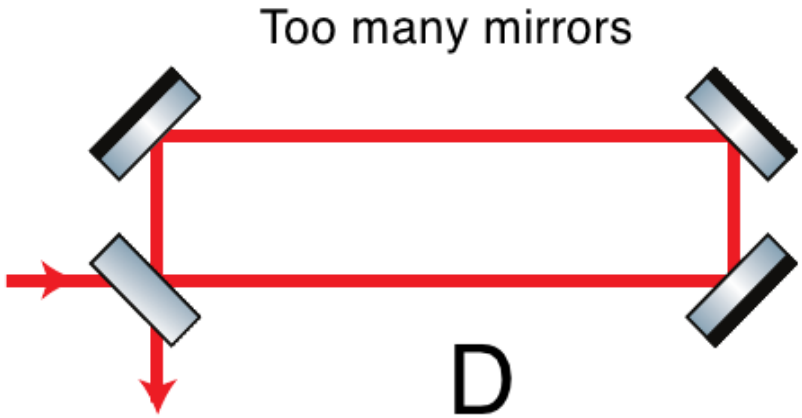


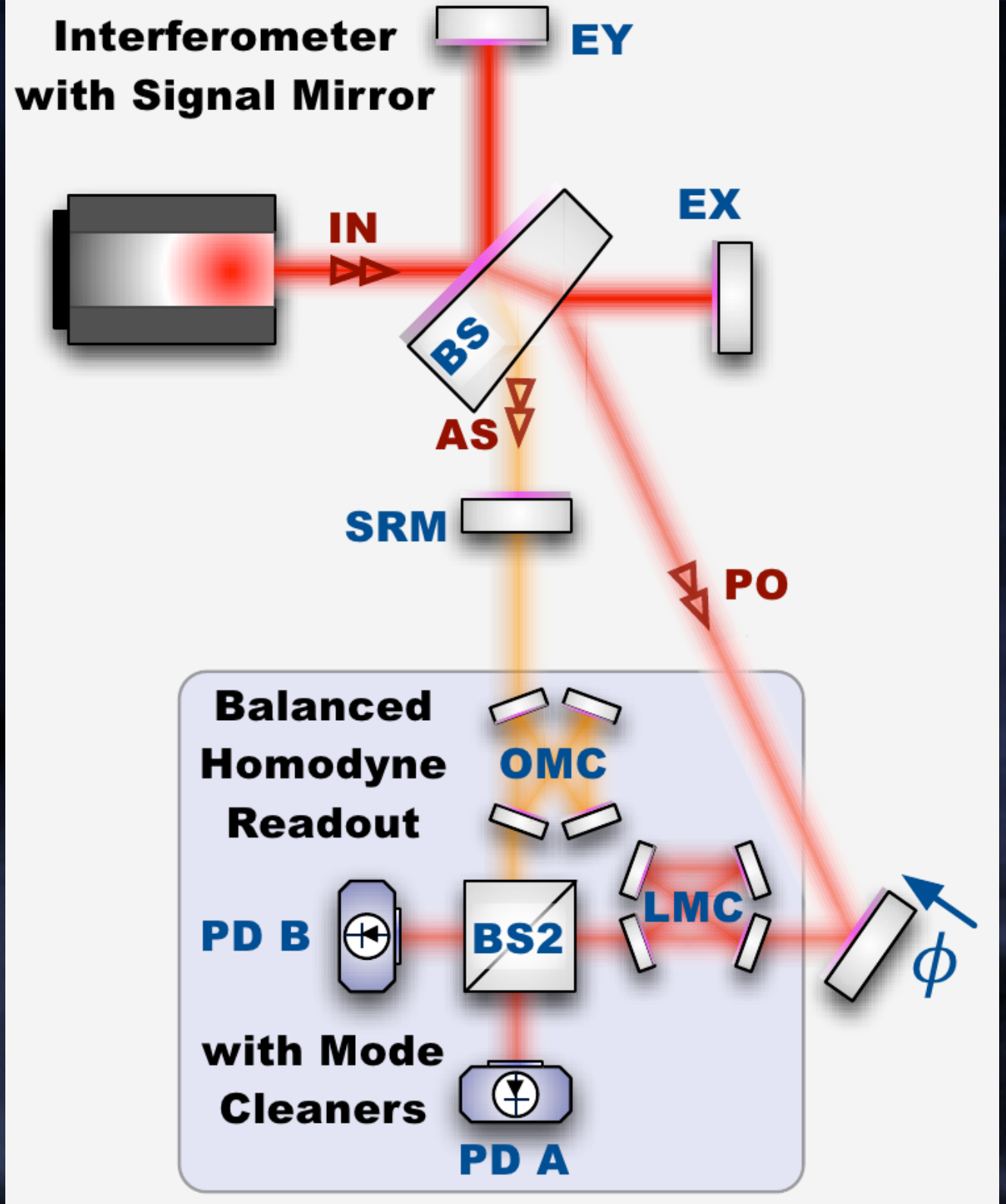
What type of Filter Cavity ?










Interferometer
with Signal Mirror
EY
EX
IN
BS
AS
SRM
PO
Balanced
Homodyne
Readout
OMC
PD B
BS2
LMC
ϕ
with Mode
Cleaners
PD A

The Quantum Future (1 dB/year)
(L. Barsotti, 2012)

Long term stability (alignment, OPO temperature, sqz phase,..)
macroscopic losses

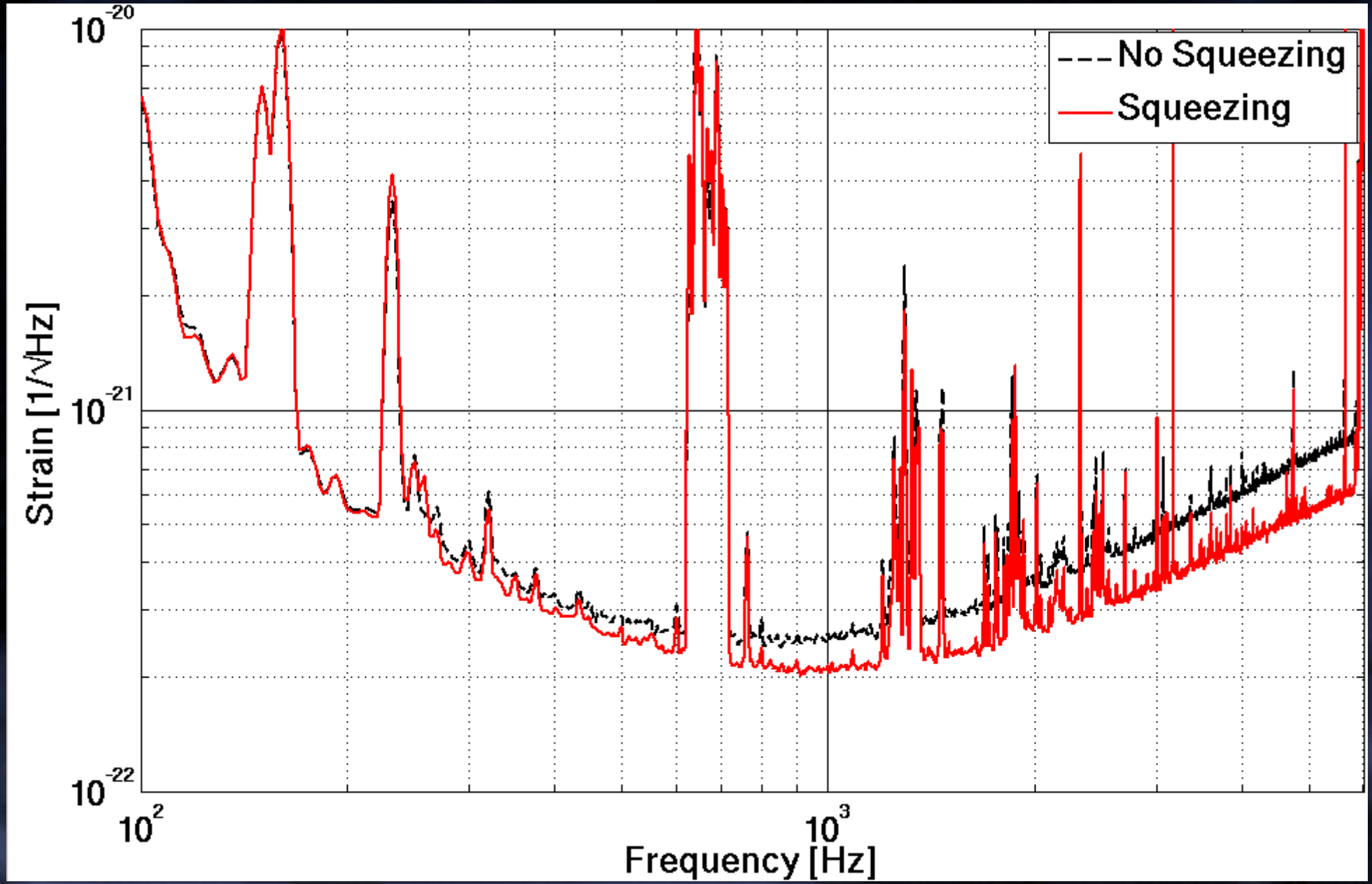
1-2% losses in Faradays, >98% mode matching, OMC > 99%

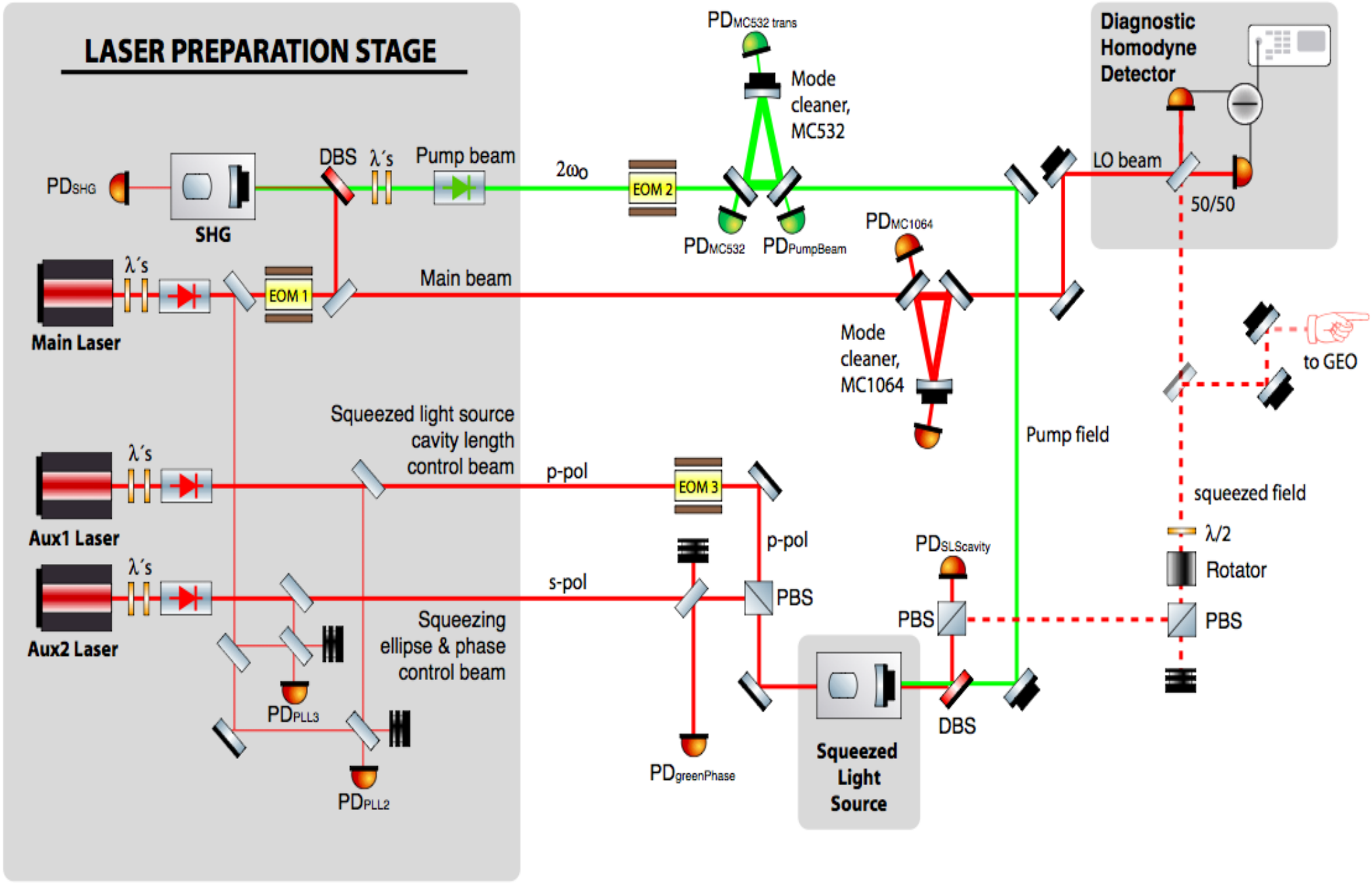
Filter cavity to mitigate additional quantum noise at low frequency

Everything <<1% losses (Faradays, OPO, OMC , IFO, ..)
Filter cavities to beat radiation pressure noise

...or some new idea!

Recent: ~2.8dB


No Squeezing
Squeezing
Strain [1/√Hz]
10^-20
10^-21
10^-22
10^2
10^3
Frequency [Hz]


LASER PREPARATION STAGE
PDSHG
SHG
DBS
λ´s
Pump beam
2ωo
EOM 2
PDMC532 trans
Mode cleaner, MC532
PDMC532
PDPumpBeam
Diagnostic Homodyne Detector
LO beam
50/50
PDMC1064
Mode cleaner, MC1064
Main Laser
λ´s
EOM 1
Main beam
to GEO
Pump field
Squeezed light source cavity length control beam
p-pol
EOM 3
Aux1 Laser
λ´s
p-pol
PBS
s-pol
PDSLScavity
PBS
squeezed field
λ/2
Rotator
PBS
Aux2 Laser
λ´s
Squeezing ellipse & phase control beam
PDPLL3
PDPLL2
PDgreenPhase
Squeezed Light Source
DBS