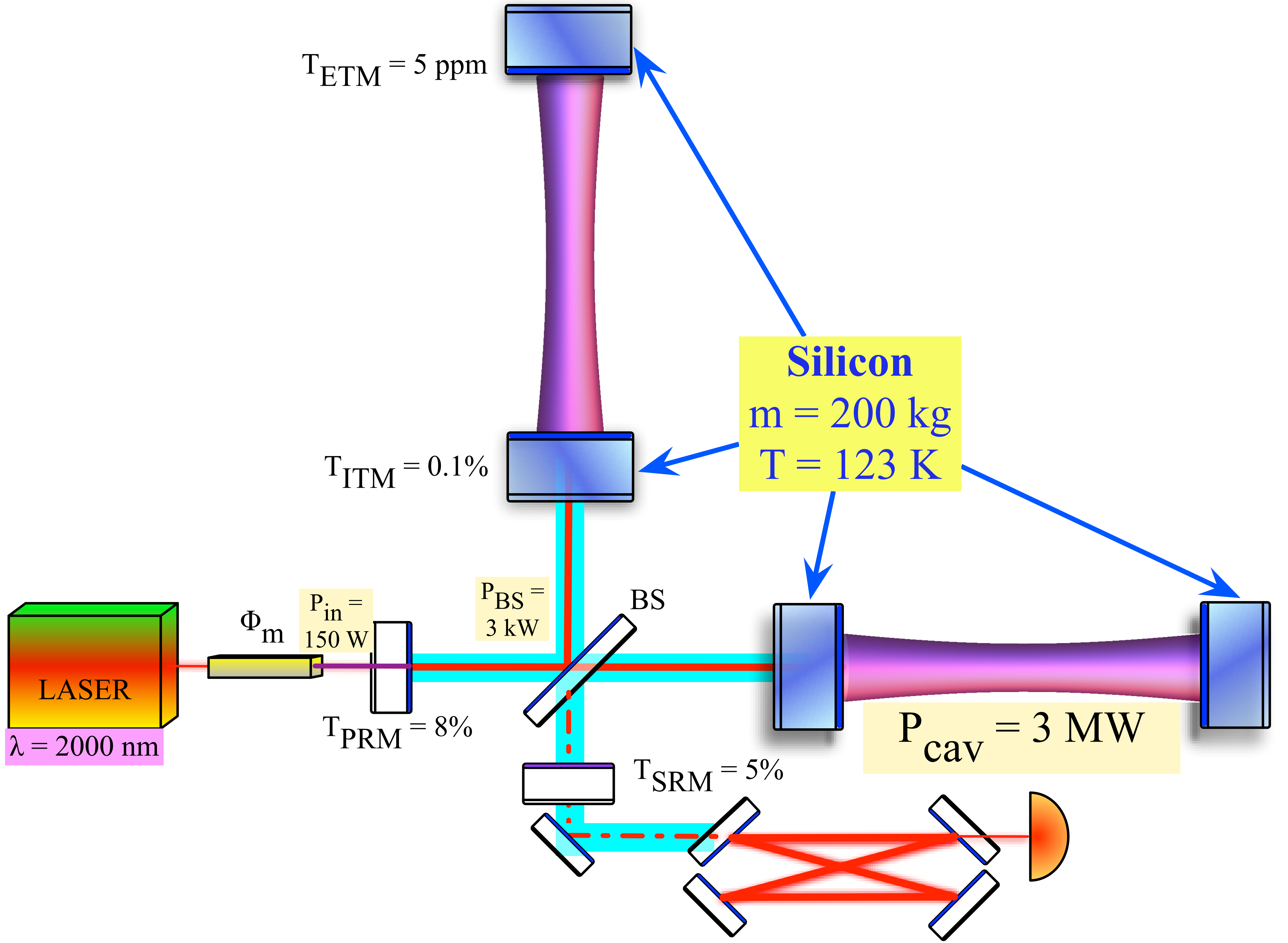
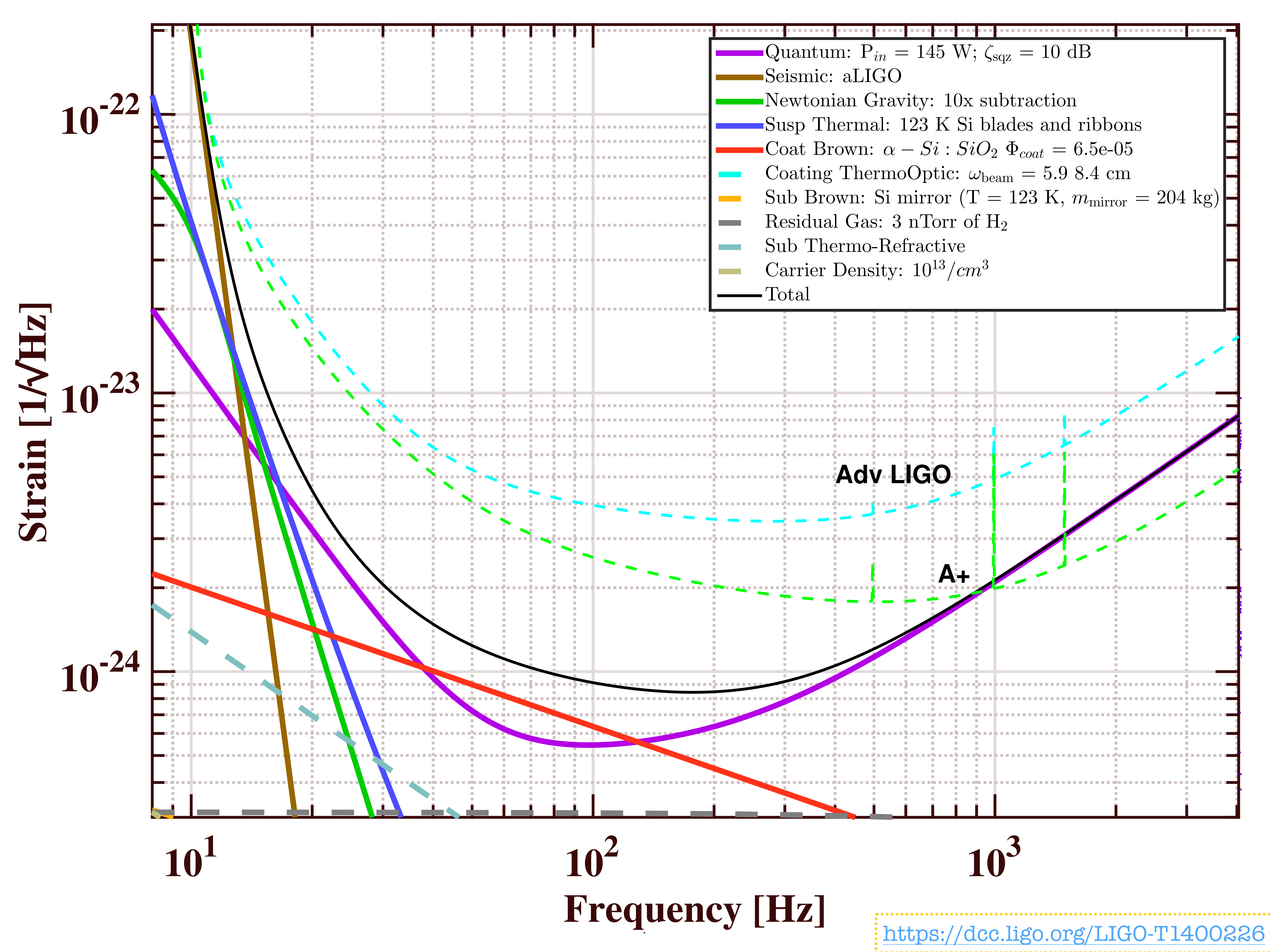
LIGO Voyager

Rana Adhikari
Caltech

https://dcc.ligo.org/LIGO-G1601461



T_ETM = 5 ppm
Silicon
m = 200 kg
T = 123 K
T_ITM = 0.1%
P_BS = 3 kW
BS
Φm
P_in = 150 W
LASER
λ = 2000 nm
T_PRM = 8%
P_cav = 3 MW
T_SRM = 5%

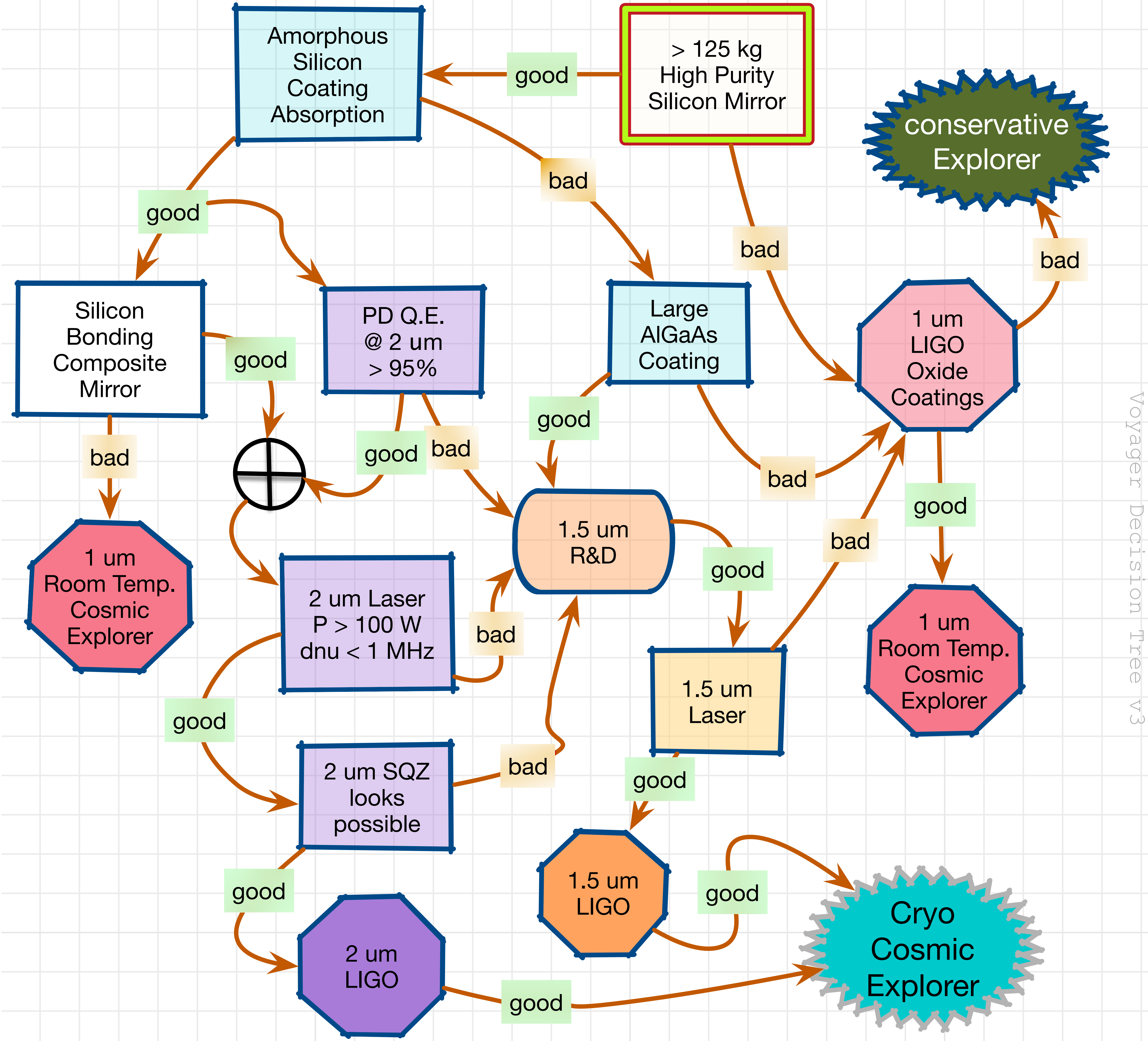


Quantum: P_{in} = 145 W; ζ_{sqz} = 10 dB
Seismic: aLIGO
Newtonian Gravity: 10x subtraction
Susp Thermal: 123 K Si blades and ribbons
Coat Brown: $\alpha - Si : SiO_2$ Φ_{coat} = 6.5e-05
Coating ThermoOptic: ω_{beam} = 5.9 8.4 cm
Sub Brown: Si mirror (T = 123 K, m_{mirror} = 204 kg)
Residual Gas: 3 nTorr of H_2
Sub Thermo-Refractive
Carrier Density: $10^{13}/cm^3$
Total
Adv LIGO
A+
10^{-22}
10^{-23}
10^{-24}
Strain [1/√Hz]
10^1
10^2
10^3
Frequency [Hz]
https://dcc.ligo.org/LIGO-T1400226

Sub-Systems

- Silicon Mirrors: 140-**200 kg**, mCZ
- Coatings: a-Si/SiO_2 or others
- *Wavelength Choice: 1.55 - 2.1 microns*
- Cryogenics: 123 K (for zero CTE), radiative (non contact) cooling
- Lasers (~2 micron): P_{PRM} ~ 140 W, P_{ARM} ~ 3 MW
- Thermal Compensation: Silica compensation plates only (CO2 lasers, no ring heaters; no heating of test mass)
- Photodiode Quantum Efficiency: 80 -> 99% for 2 micron

Draft Whitepaper: https://dcc.ligo.org/LIGO-T1400226



Evans,
Barsotti,
Adhikari
Nov 2015

200 kg Silicon Mirror

- P_{abs} < 5 W (goal); P_{coat} = alpha*3MW; P_{sub} = d_thick*alpha*P_{BS} (1W ~> 10 ppm/cm)

- 3 ppm/cm (FZ): FZ max diameter ~ 20 cm

- mCZ from SEH can get 10-20 kOhm in wafers after high T annealing (to trap oxygen)

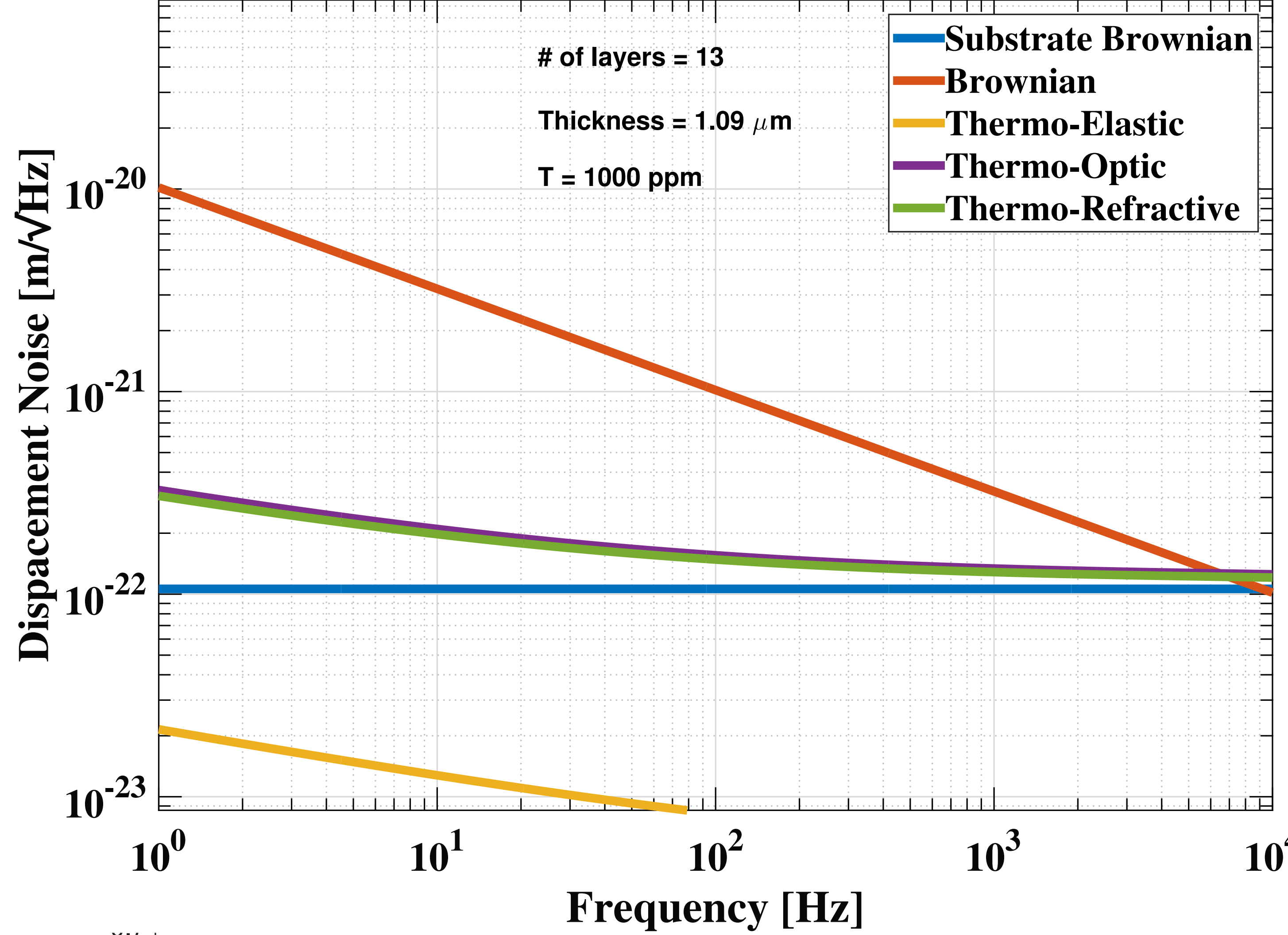
- samples acquired, absorption measurements in progress (< 2 ppm)

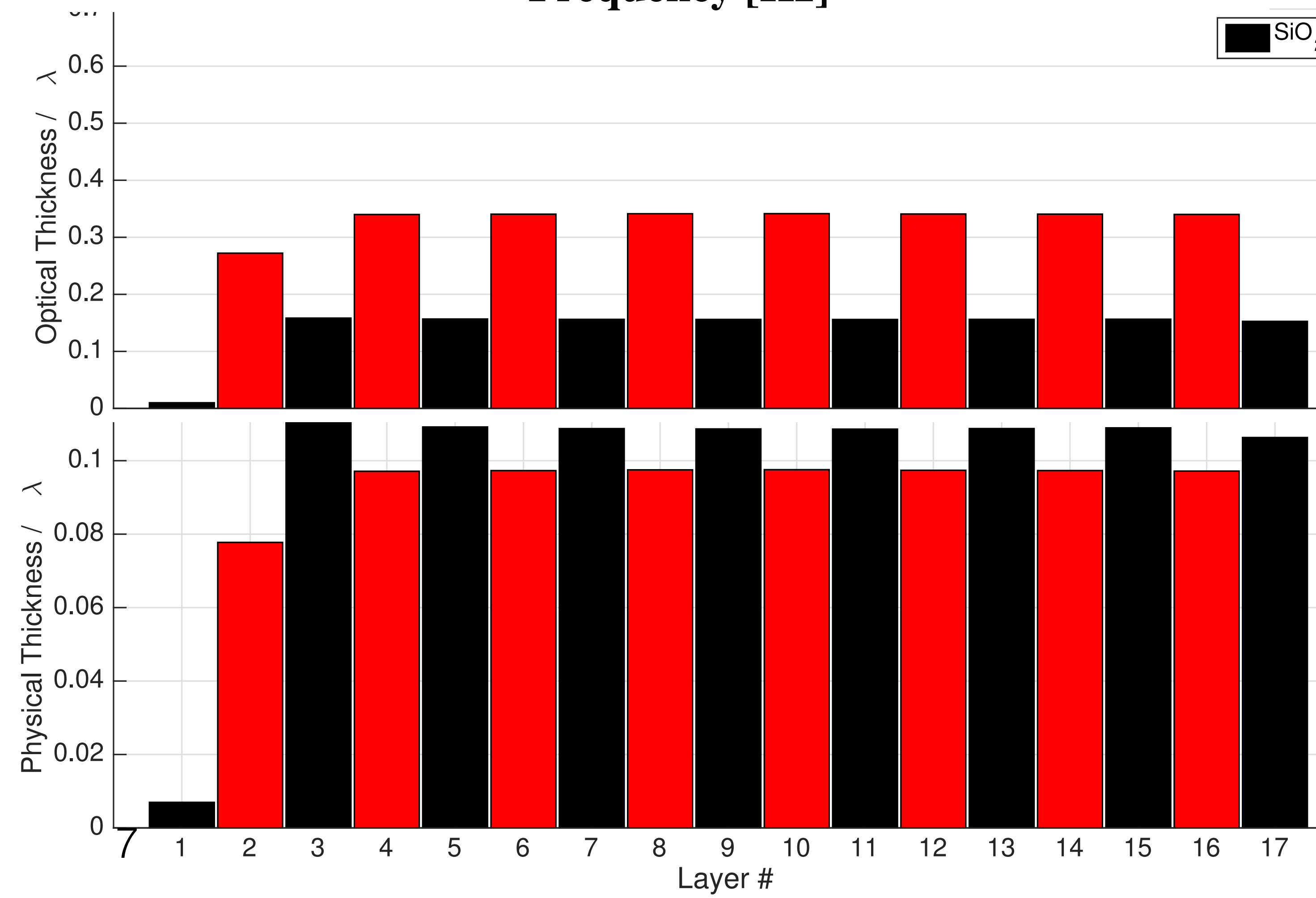
- SEH Japan will make 45 cm diameter mCZ

- how to sequence all of the annealing? Different processes for substrates, coatings.

Coatings

- **a-Si / SiO_2 baseline**
- Pohl, Hellman data
- Glasgow IBS results
- Evidence of high T deposition leading to low friction due to high surface mobility*
- high T deposition with IBS this year
- lower absorption in a-Si (1-5-2 microns) (Glasgow)



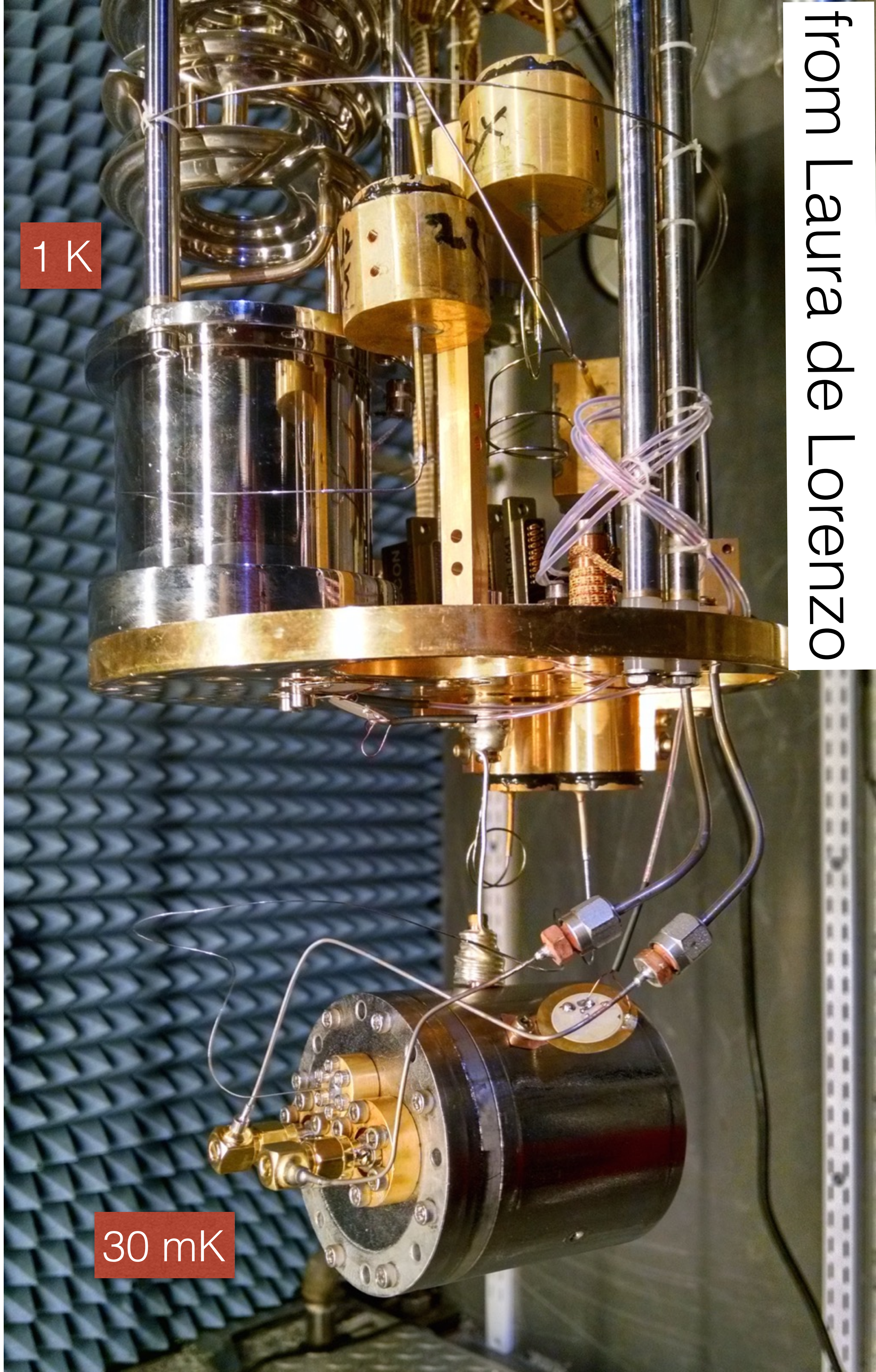


*Physics Today (Jan 2016): http://arxiv.org/abs/1512.03540

serious Cryogenics

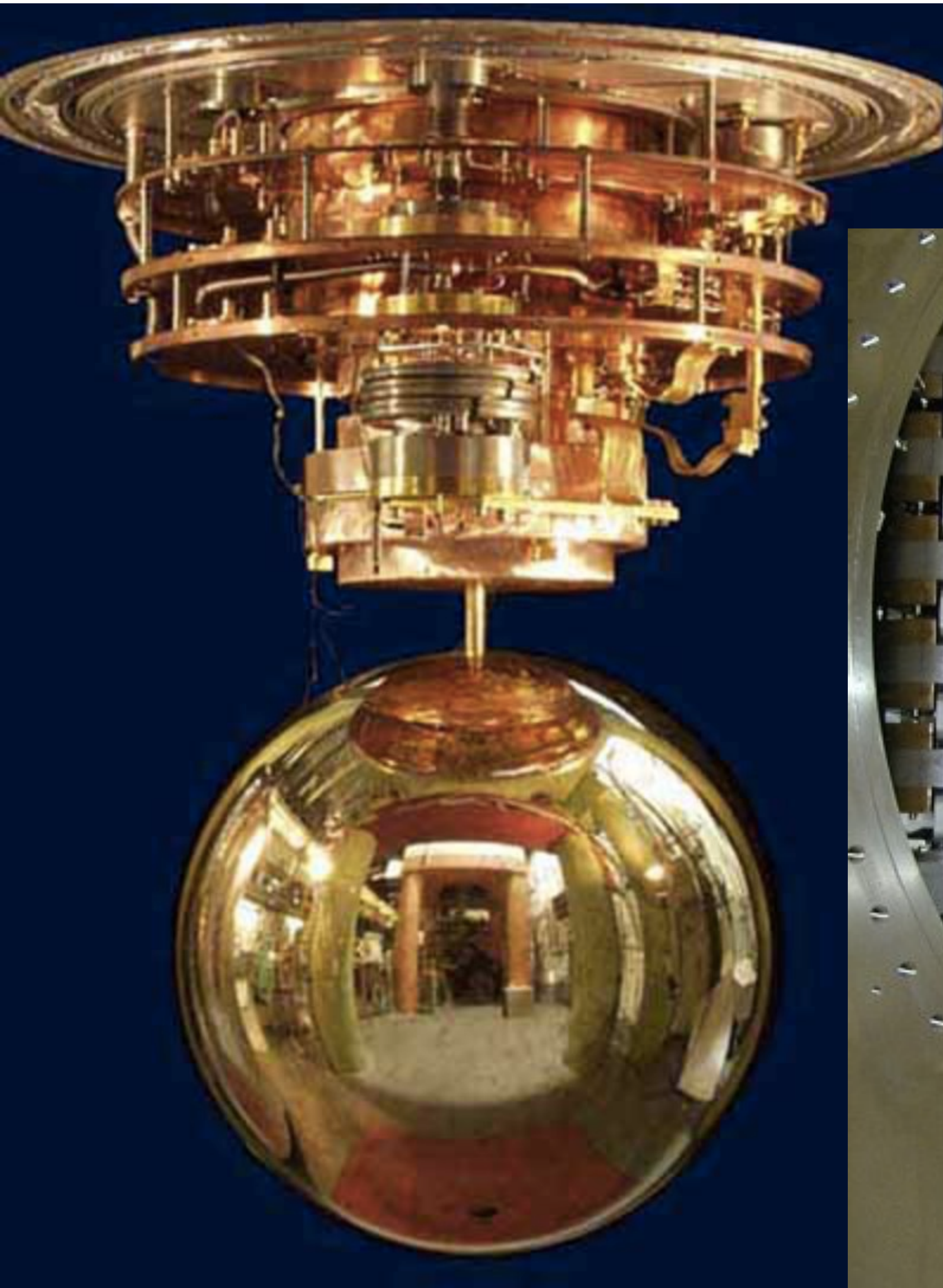
Liquid Helium
Resonant ‘Bar’
at **Caltech** (Schwab)

4 cm Niobium cavity
filled with
Superfluid ^{4}He
Q ~ 100 million



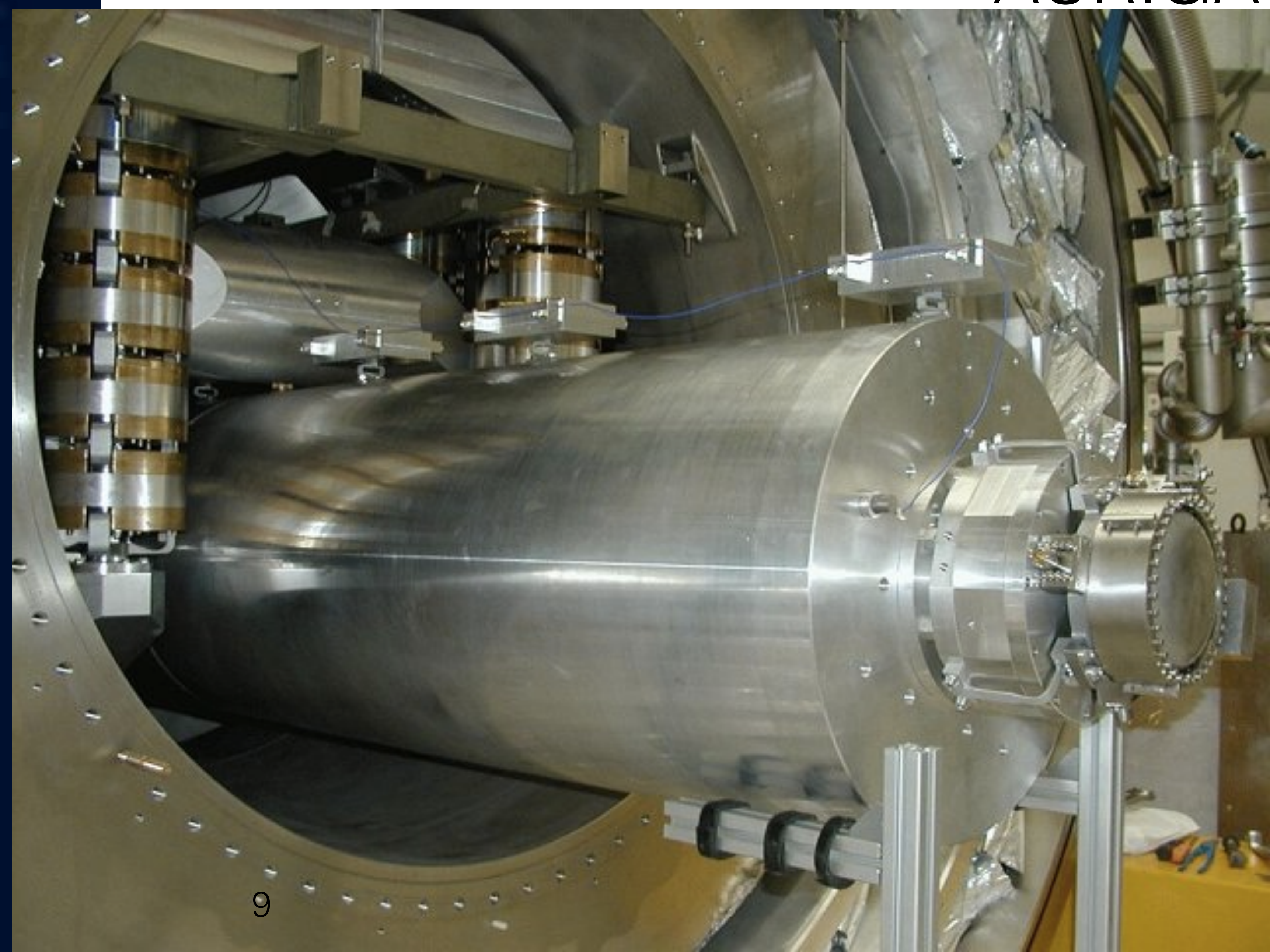
serious Cryogenics

Large GW Detectors < 10 K
care taken to filter seismic
& minimize upconversion



miniGRAIL
@ Leiden

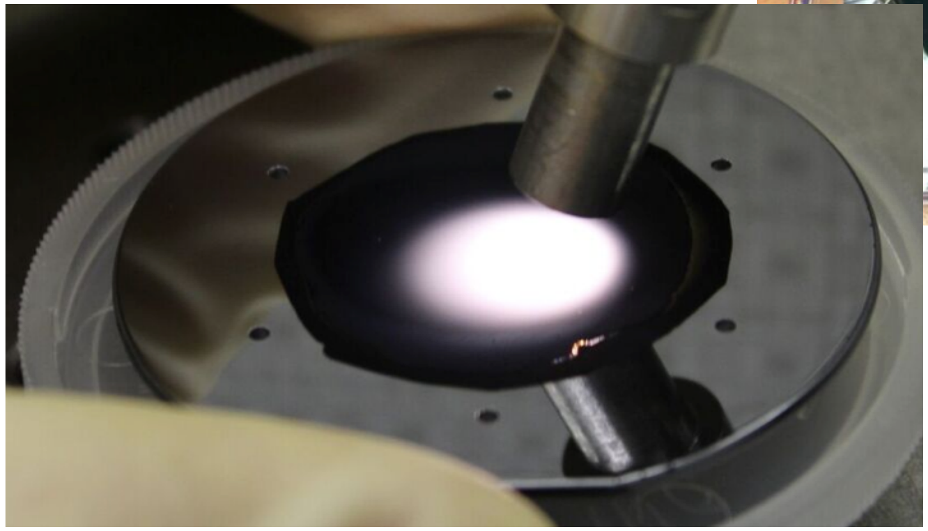
AURIGA



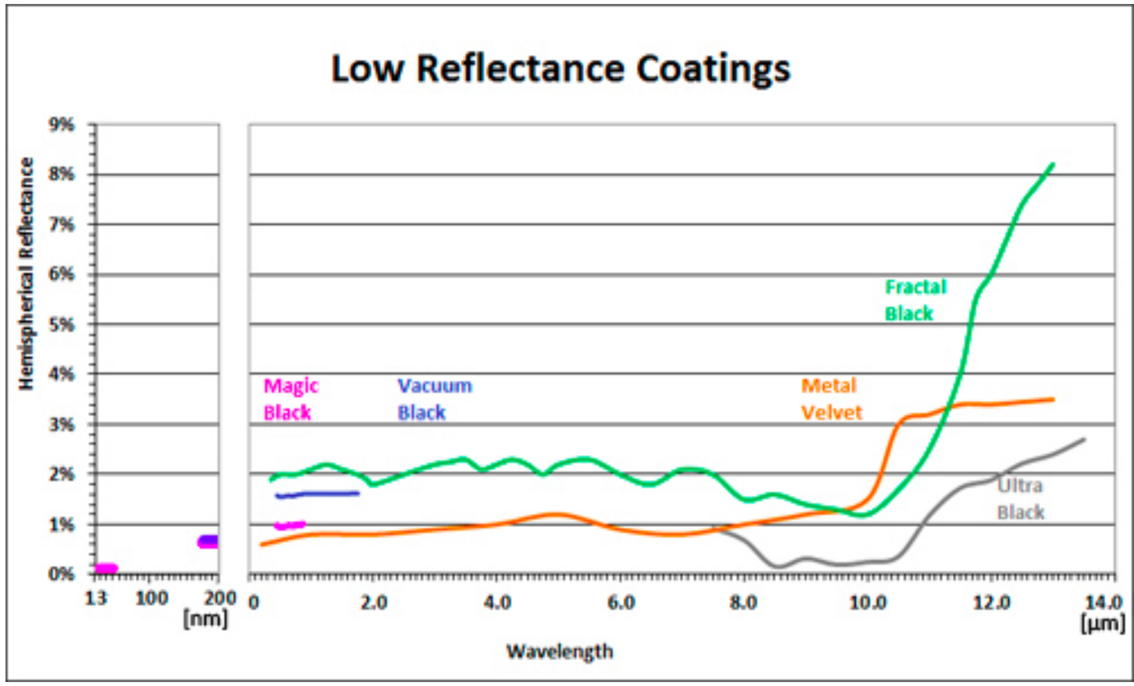
Cryogenics

- No serious issues here; this is **<u>NOT</u>** like CERN or KAGRA or dilution fridges
- ~10 W heat extraction capability in steady state
- Prelim mech drawing & backscatter analysis done (Stanford/CIT engineers).
- Vibration from cryogenics no worse than existing cryo pumps.
- How to do initial cool down? Heat switches?

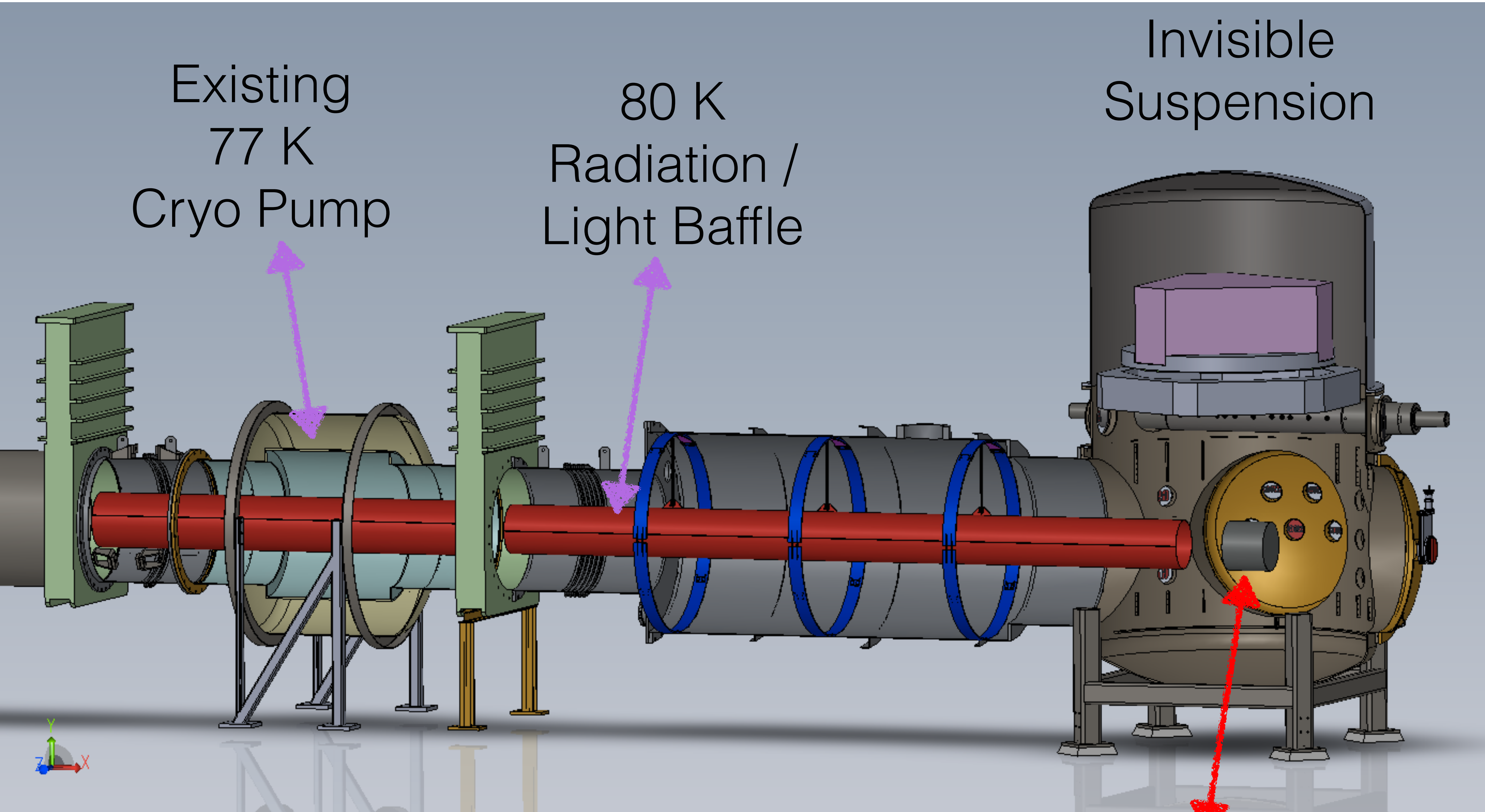
Surrey Nanosystems



John Hagopian / NASA Goddard



Acktar Black

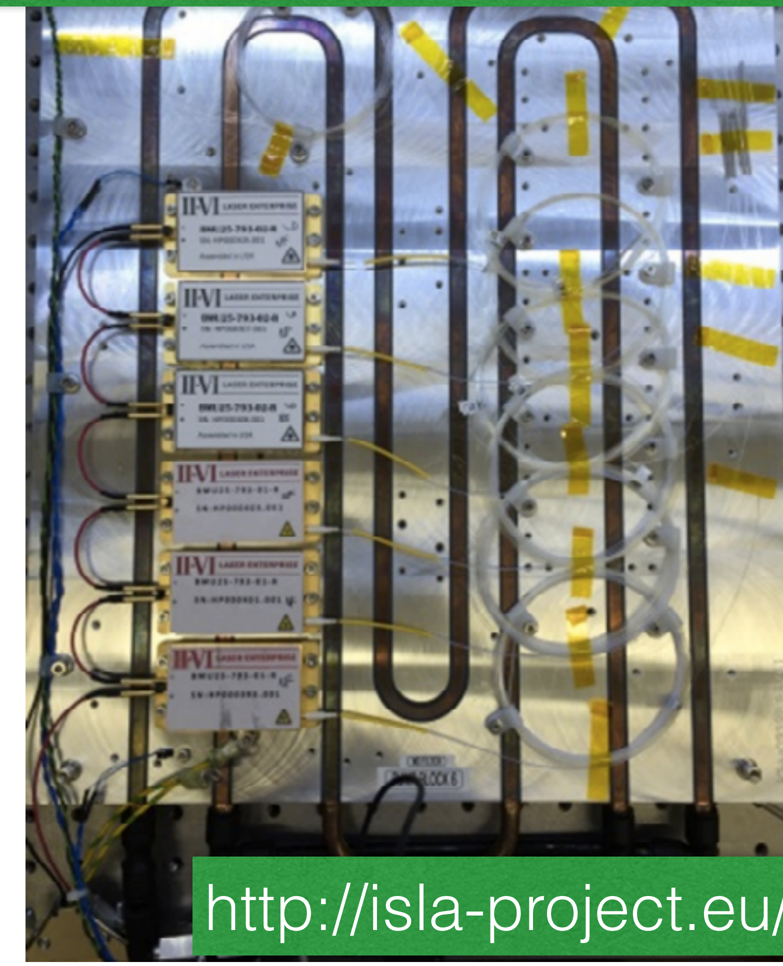


123 K
Test Mass

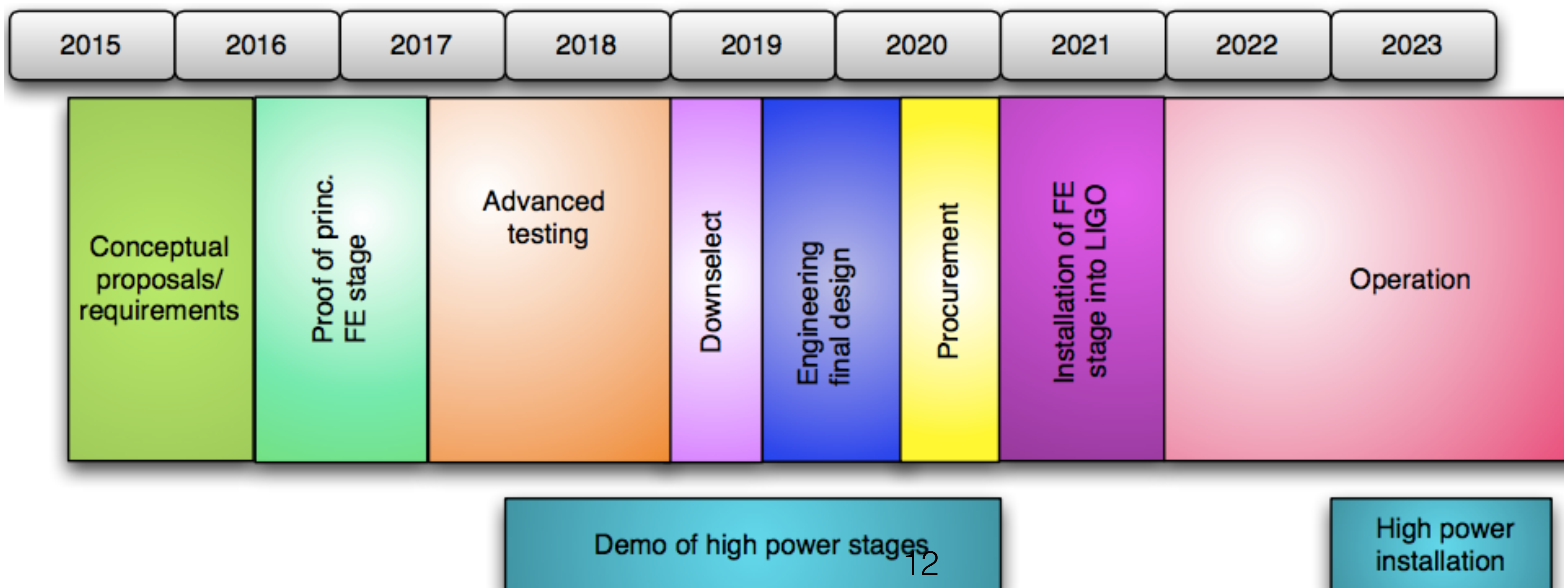
2 micron lasers

- Tm:YAG, Ho:YAG commercial lasers exist (low power, low noise, or high power, high noise)
- Adelaide lasers (Veitch LVC talk)
- Testing at CIT this summer

EU Funded 2 micron laser study

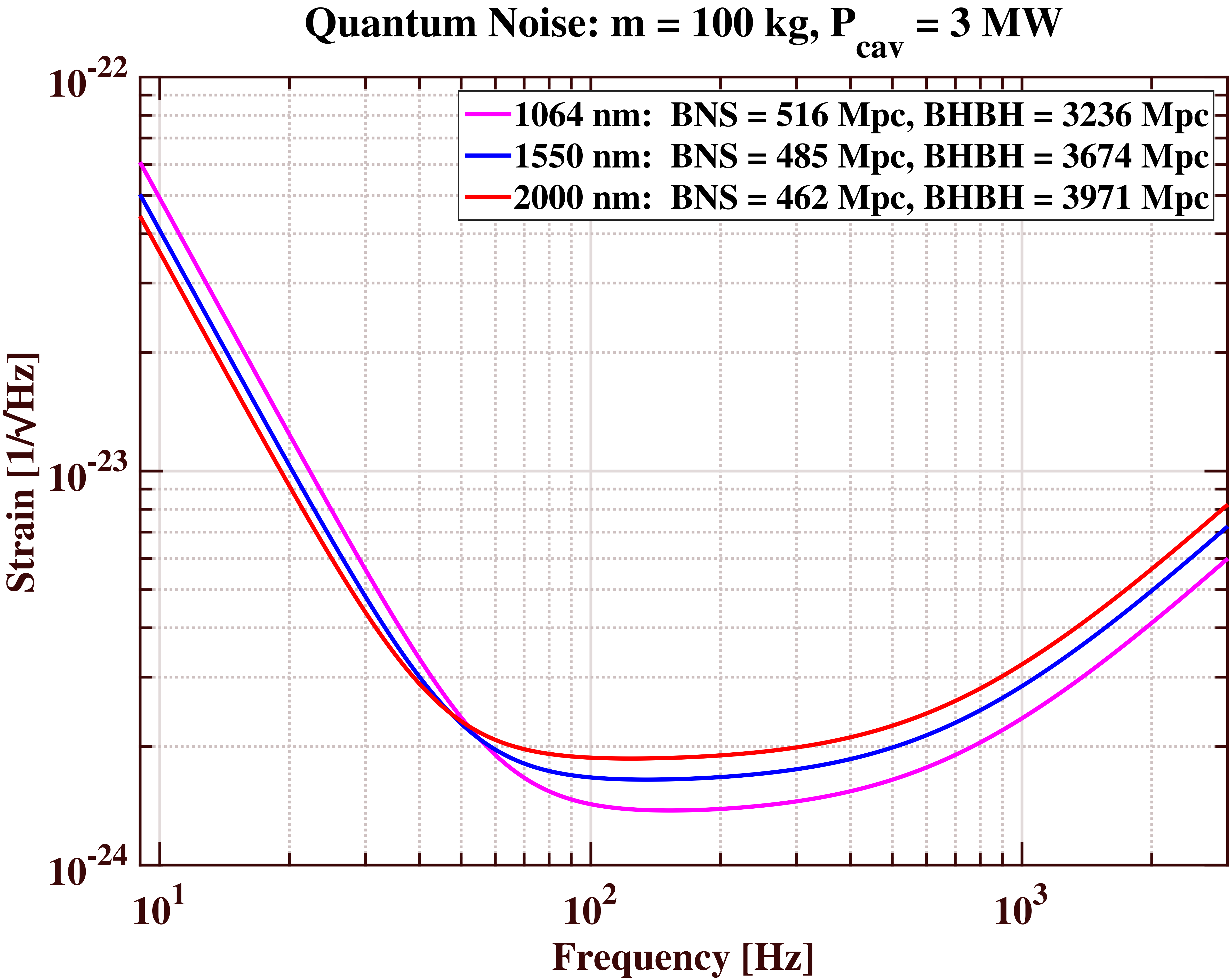


Laser dev Timeline



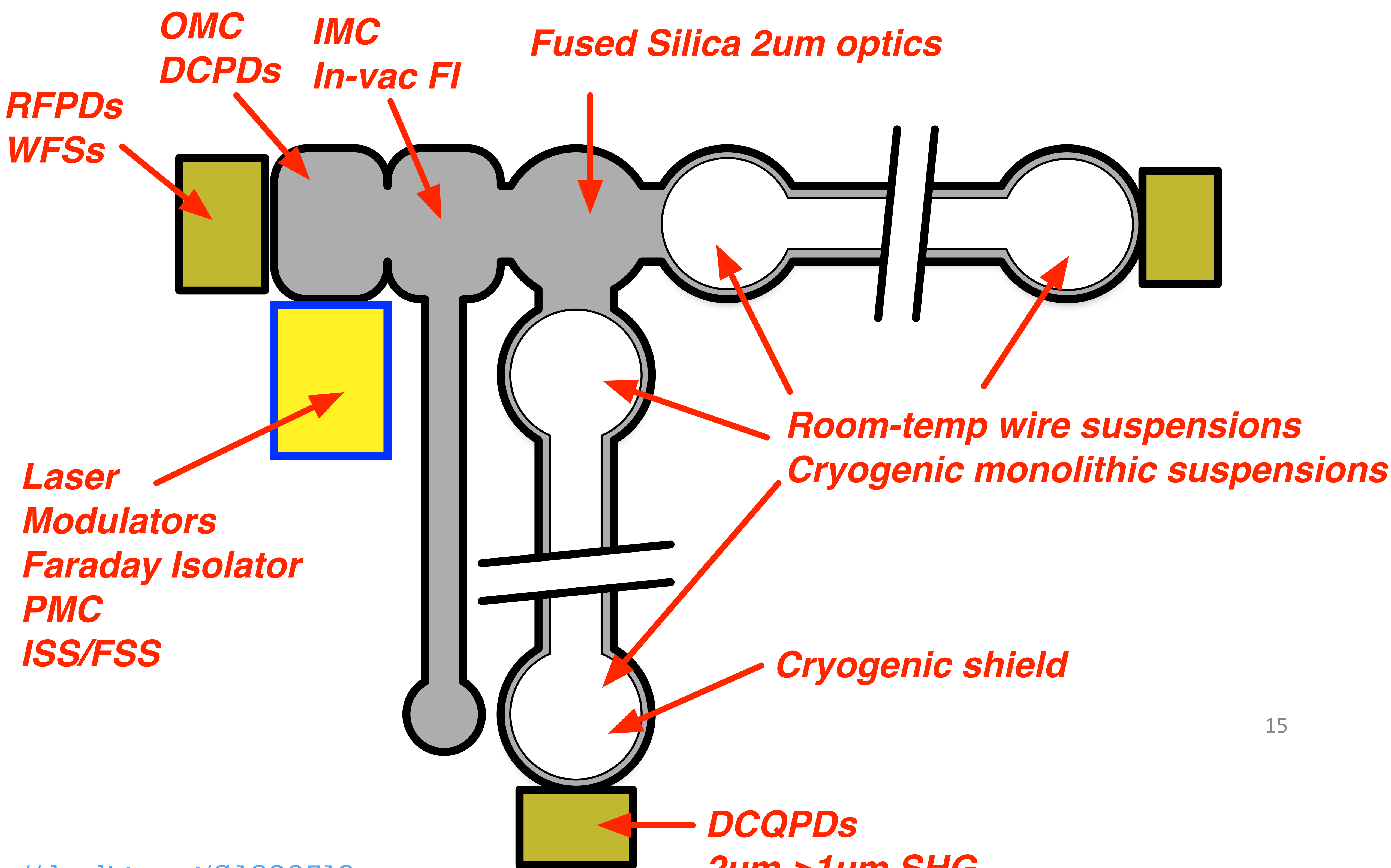
Wavelength Choice

- We know and like 1064 nm. Lots of experience.
- Many new issues with 1.5 - 2.1 microns.
- ~200 W lasers feasible with 1.8 - 2.1 microns
- PD QE > 80% today. No showstoppers yet.
- Scatter loss decreases with wavelength; quantum noise improvement. Increases ultimate reach assuming we solve "*nuisance*" losses (FI, OMC, MM, PBS, clipping, alignment, viewports, etc.)

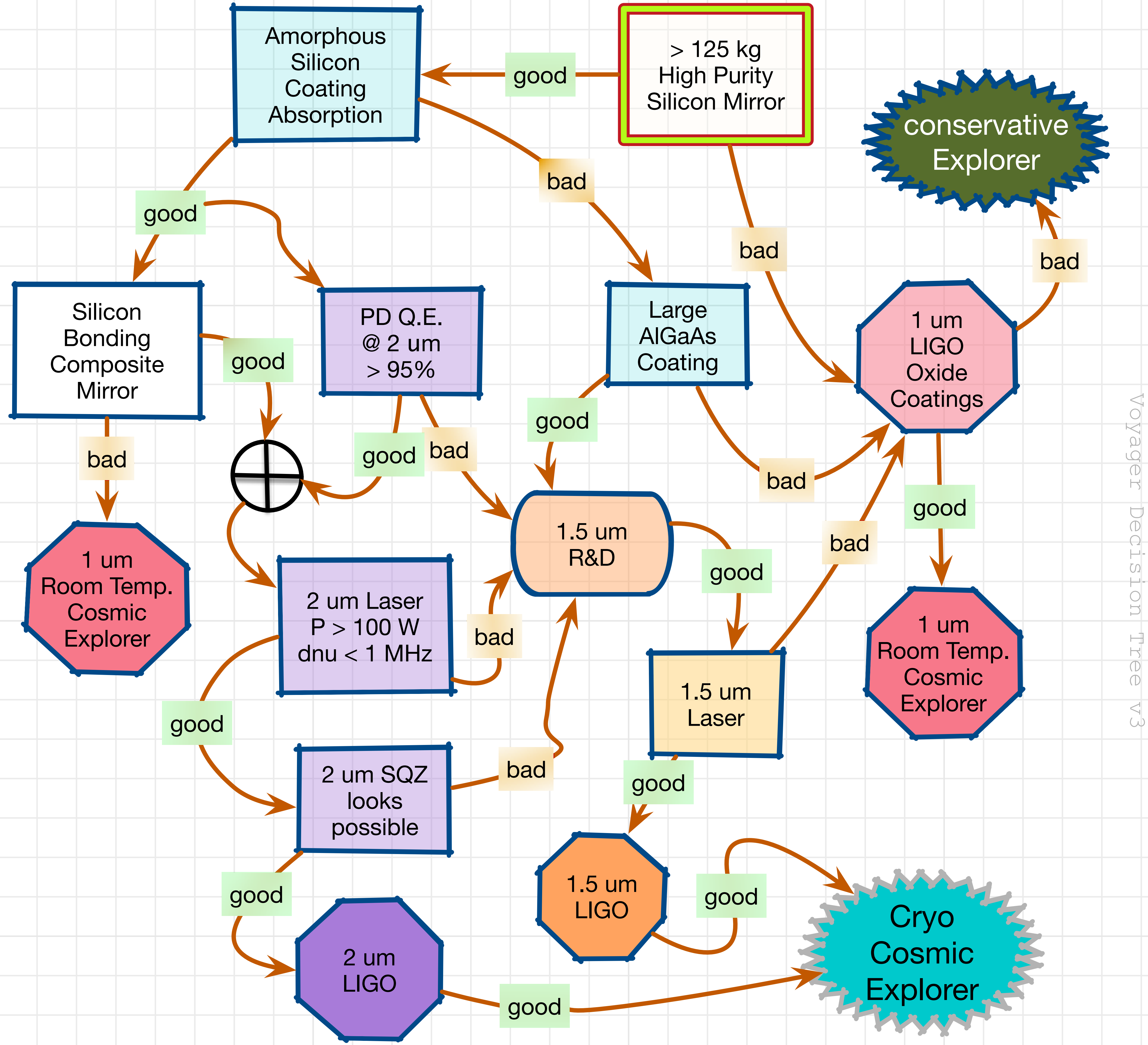


1 MW @ 1064 nm ~ 2 MW @ 2128 nm

Prototype Facility



https://dcc.ligo.org/G1600510


Amorphous Silicon Coating Absorption
> 125 kg High Purity Silicon Mirror
conservative Explorer
good
bad
bad
bad
good
Silicon Bonding Composite Mirror
PD Q.E. @ 2 um > 95%
Large AlGaAs Coating
1 um LIGO Oxide Coatings
good
good
bad
good
bad
bad
1 um Room Temp. Cosmic Explorer
1.5 um R&D
good
bad
good
2 um Laser P > 100 W dnu < 1 MHz
bad
1.5 um Laser
1 um Room Temp. Cosmic Explorer
good
bad
2 um SQZ looks possible
good
good
1.5 um LIGO
good
2 um LIGO
Cryo Cosmic Explorer
good
Voyager Decision Tree v3