CONTROLS CONSIDERATIONS FOR NEXT GENERATION GW DETECTORS

CONTROLS WORKSHOP

GWADW

26 MAY 2016

LIGO-G1601213-V1

AGENDA

- Introduction (<30 min)
  - Brief description/reminder of next gen concepts (A+, CV, CE, ET)
  - Some thoughts on controls challenges, considerations for discussion
- Open Discussion/Brainstorming (~60 min)
  - Controls challenges for each next generation concept, e.g.
  - Common/general controls issues
- Goals
  - List of controls problems to be addressed
  - Suggested plans of attack
  - Plan to follow up with the CSWG (volunteer teams and regular review)

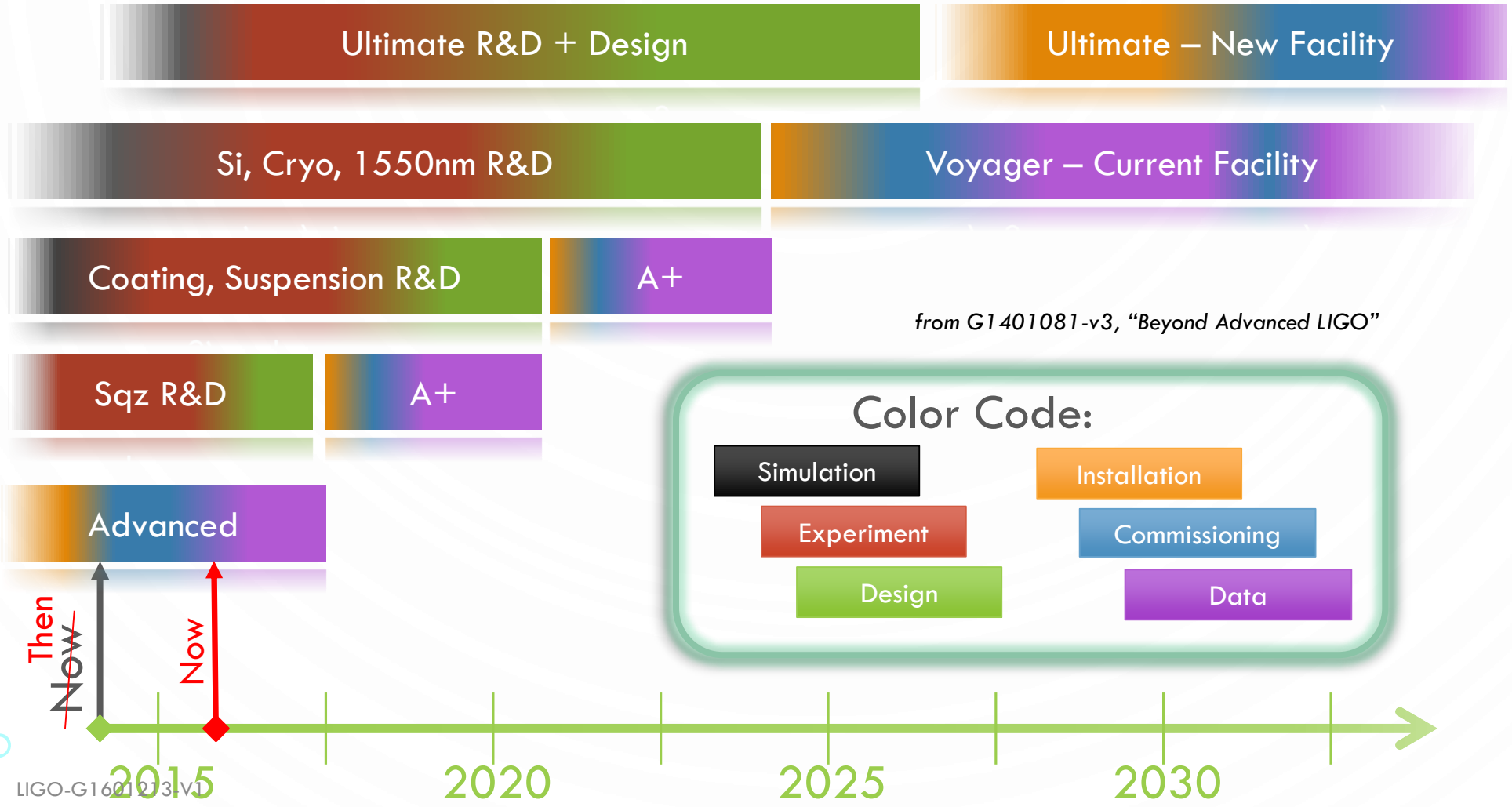
NEXT GENERATION DETECTORS … moving targets

- Advanced LIGO plus (A+)
  - aLIGO plus quick, near-term upgrades with modest budget and goal of 2x aLIGO range
  - References: P1400164 and G1600663
- VIRGO plus (V+)
  - Reference: G. Cagnoli's talk at GWADW 2016
  - Similar to aLIGO in scope
- KAGRA+
- Cryogenic Voyager (CV) (aka blue design)
  - Reference: T1400226 and R. Adhikari, Rev. Mod. Phys. 86, 121 (2014)
  - Replace aLIGO, use same facilities, Silicon @120K, ~1.5 microns, 4x aLIGO range
- Cosmic Explorer (CE) (e.g. LUNGO)
  - Reference: P1400147
  - New facility and detector
  - KISS (minimize technology development)
- Einstein Telescope (ET)
  - Reference: M. Abernathy et al., "Einstein gravitational-wave telescope conceptual design study," ET-0106C-10 (2011)
  - Underground, Xylophone configuration
  - Cryogenic, 1550 nm, detuned Signal recycling for ET-LF
  - High power (500 W) with LG 33 modes for ET-HF
  - Controls: G1500819

A BRIEF OVERVIEW WITH CONTROLS IN MIND …

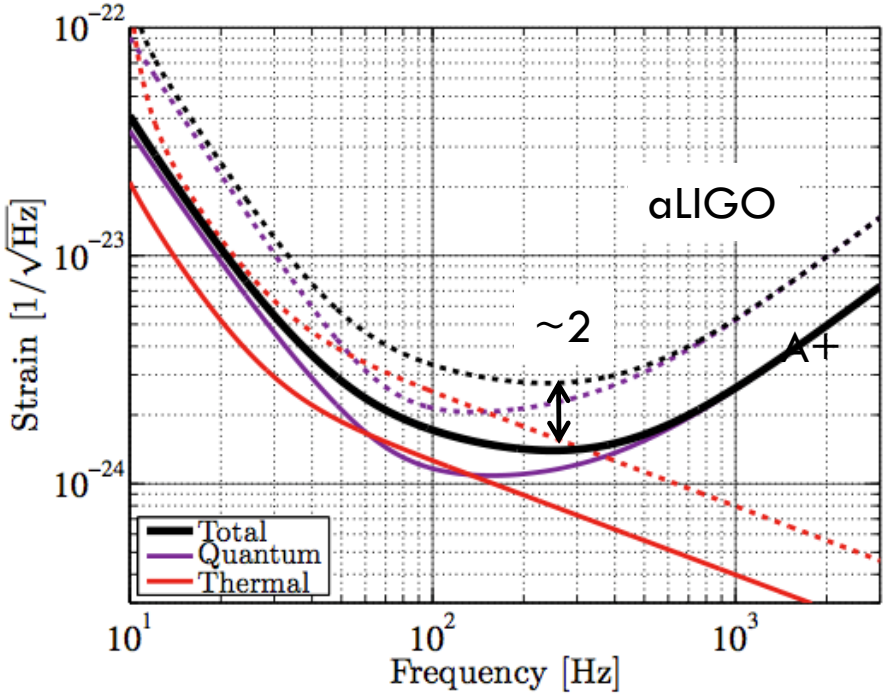
- with apologies to our VIRGO and KAGRA colleagues (due to my ignorance on their systems), let's first consider
  - A+
  - CV
  - CE
- and then discuss similarities/differences for
  - KAGRA+
  - VIRGO+
  - ET

TIMELINE FOR LIGO



A+

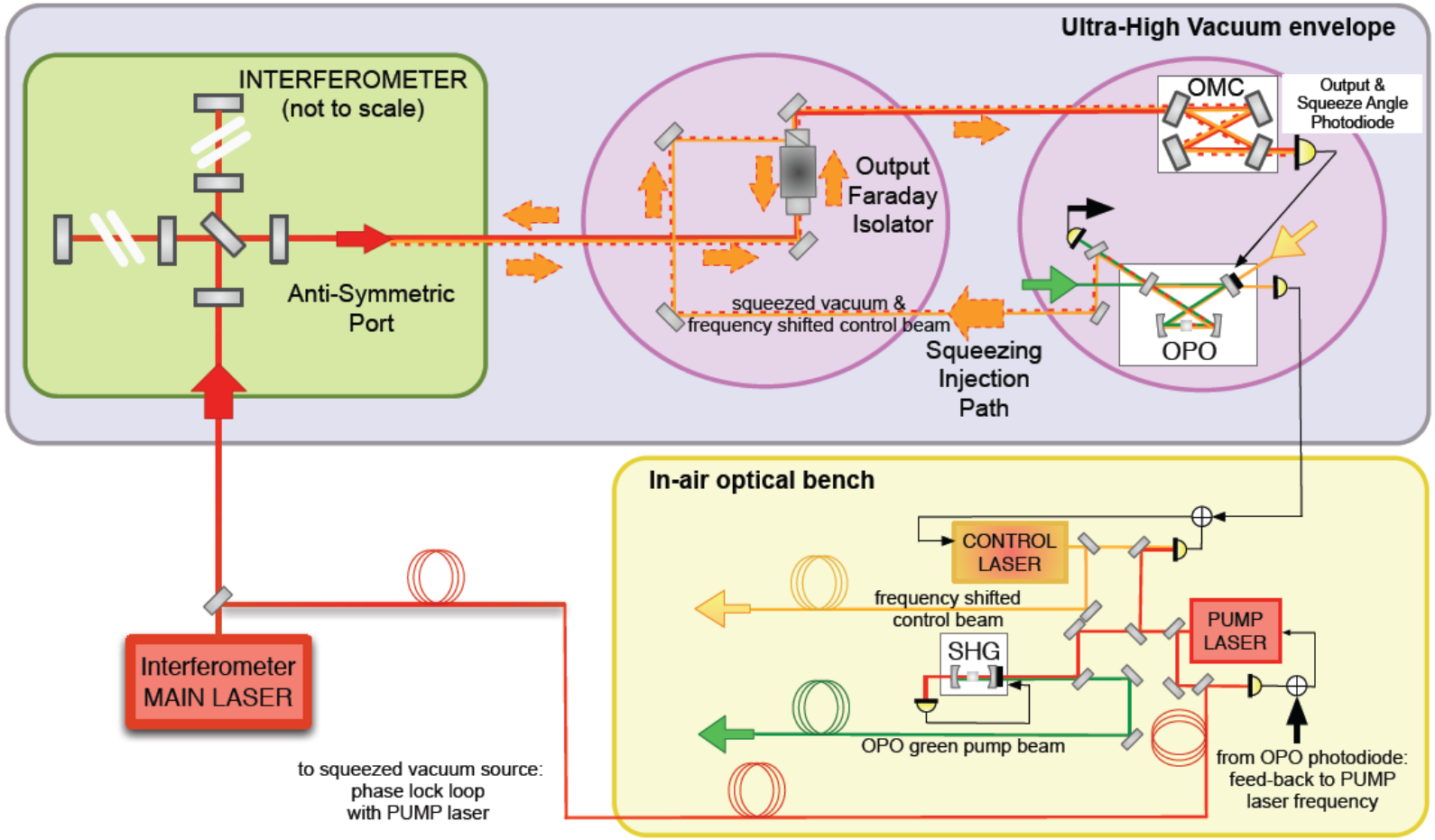
- aLIGO plus:
  - Frequency-dependent squeezing (P1600121,)
    (16m filter cavity, then ~100m cavity)
  - Lower optical loss
    (Faraday isolator, high QE PDs, larger beamsplitter, …)
  - Improved optical mode matching to cavities
  - Balanced homodyne readout
    (BHR, for reduced noise, see P1300184)
  - Newtonian noise cancellation
  - Lower thermal noise (lower loss TM coatings or larger beams)
  - Lower TM bounce mode frequency & reduced suspension thermal noise
    (longer suspension, thinner fibers)



A+ CONTROLS IMPLICATIONS

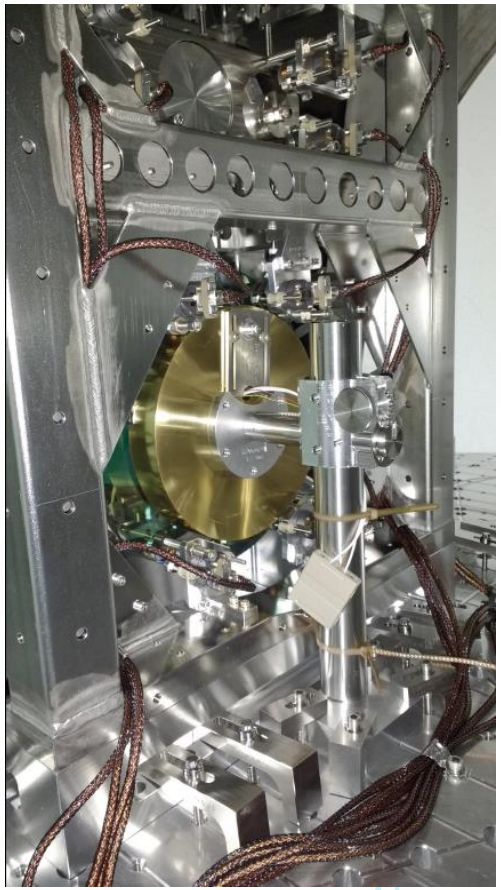
- Any unique or new controls challenges with frequency-dependent, squeezed light injection? … or 'just' more loops?
- Were the controls issues all resolved in eLIGO?

from P1600121



A+ CONTROLS IMPLICATIONS

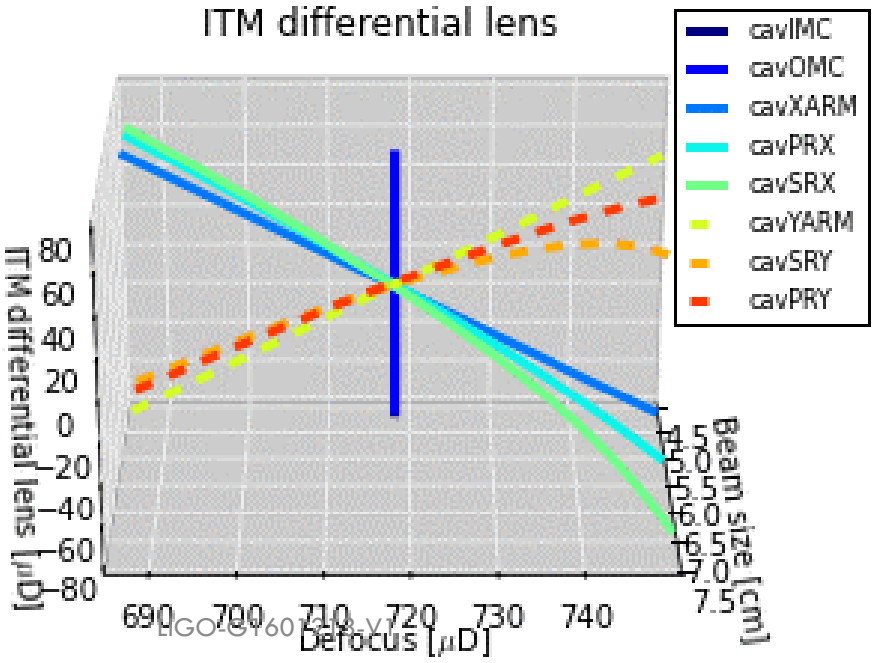
- Improved optical mode matching → Adaptive mode-matching
  - Actuators:
    - ROC only (e.g. aLIGO SR3 ROC actuator)
    - ROC & Astigmatism (e.g. Peltier heater G1600678)
    - Macroscopic translation?
  - Sensing?
    - Poor observability of mode parameters (waist size/position or Guoy phase)?
    - Are existing wavefront sensors adequate?
    - Should we add bullseye sensor(s)?



A+ CONTROLS IMPLICATIONS

- Improved optical mode matching → Adaptive mode-matching
  - Control
    - Mode matching is a nonlinear system with nonlinear cross-couplings (Perreca & Fulda, G1600770)
    - Type and magnitude of mode matching correction depends on the magnitude of actuation and the state of other actuators

beam size (Δw) and defocus (ΔS) changes at BS location to characterize actuator effect



Actuation matrix example

from G1600770

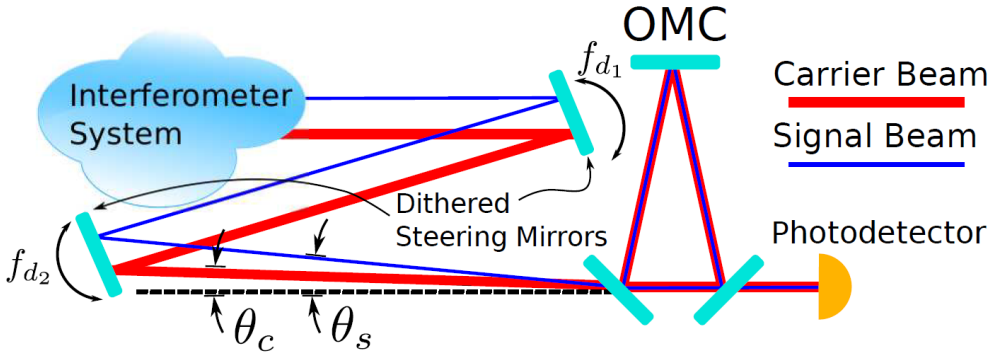
	PRC w	PRC S	SRC w	SRC S	ARMs w	ARMs S	IMC w	IMC S	OMC w	OMC S
PRM	4.54	5.86m	0.00	0.00	0.00	0.00	-1.29	-1.07	0.00	0.00
PR2	-45.01	-58.50m	0.00	0.00	0.00	0.00	-2.11	-55.88	0.00	0.00
PR3	-3.32k	-4.32	0.00	0.00	0.00	0.00	-19.92	-4.30k	0.00	0.00
SRM	0.00	0.00	-5.10	-6.33m	0.00	0.00	0.00	0.00	875.22m	1.11
SR2	0.00	0.00	-128.90	-159.89m	0.00	0.00	0.00	0.00	-2.79	-99.52
SR3	0.00	0.00	-5.46k	-6.77	0.00	0.00	0.00	0.00	-19.56	-4.29k
ITMTL	-3.19k	4.14k	-5.25k	4.14k	-5.01	4.15k	0.00	0.00	0.00	0.00
ITM	-2.31k	3.00k	-3.81k	3.00k	-1.83k	3.00k	0.00	0.00	0.00	0.00
ETM	0.00	0.00	0.00	0.00	3.77k	4.68	0.00	0.00	0.00	0.00
OM1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	163.75m	551.87m
OM2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	508.86m	-886.31m
OM3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-222.38m	-453.39m

A+ CONTROLS IMPLICATIONS

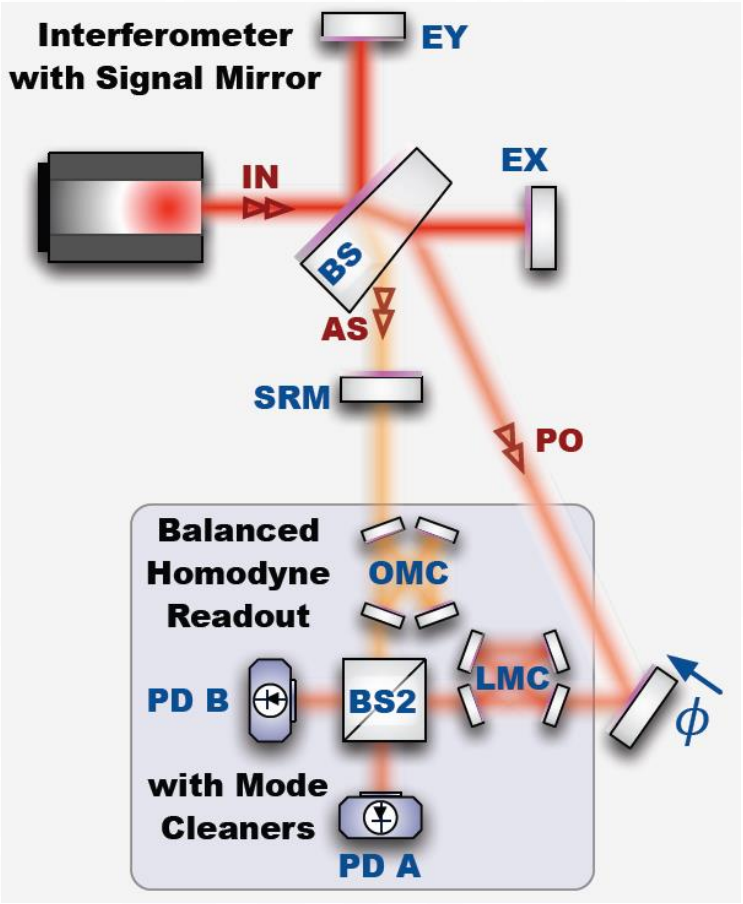
- Improved optical mode matching → Adaptive mode-matching
  - Control
    - Genetic algorithm for optimization (esp. if HOM are controlled)?
    - Predictive model (e.g. Kalman filter) to accommodate thermal transients due to lock losses?

A+ CONTROLS IMPLICATIONS

- BHR → Beacon alignment of the OMC (control without a LO field) (P1100025)
  - A solved (in principle) controls problem? – "just" need to demonstrate?
  - What sensor/measurement or metric is used to adjust the LO phase in BHR?
  - Perhaps machine learning techniques can be applied to achieve these adjustments?



from P1300184



from P1300184

A+ CONTROLS IMPLICATIONS (CONTINUED)

- Lower thermal noise TM coatings → is ALS dichroic coating a significant coating design constraint?
  - ALS design to accommodate non-optimal finesse, or
  - Suspension point interferometer instead of ALS?
  - Does SPI offer advantages over ALS (e.g. operation in low noise state)?

A+ CONTROLS IMPLICATIONS (CONTINUED)

- Lower TM bounce mode freq. → Suspension redesign with global control considerations
  - Insure all dof are observable and controllable (e.g bounce & roll)
  - Consider implementing redundant sensing and control to increase reliability & improve estimated
  - Consider optomechanical design to minimize pitch/length coupling at penultimate mass

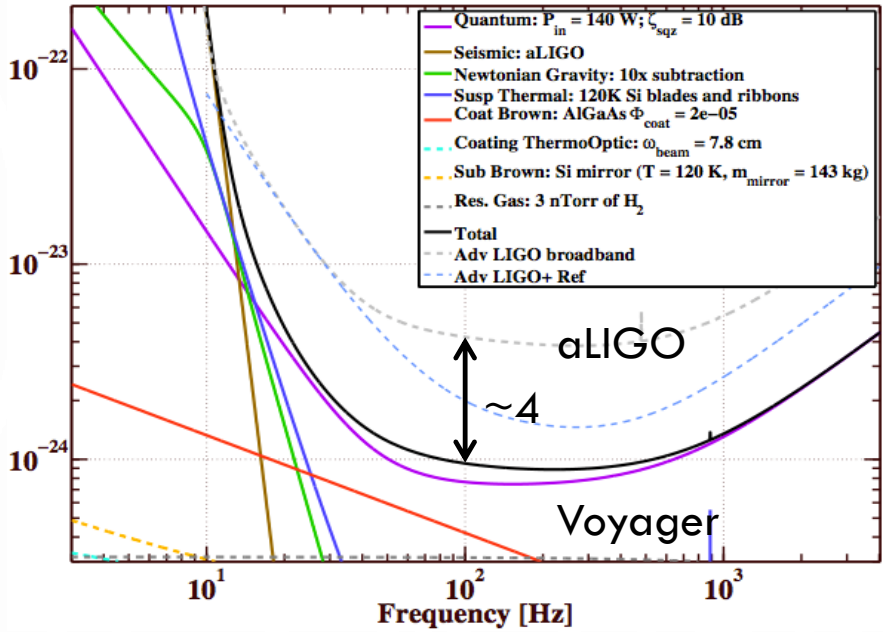
A+ CONTROLS IMPLICATIONS (CONTINUED)

- Real-time servo tracking a source/signal
  - Adjusting SRC detuning?
  - Adjusting SRM transmission? (with a variable transmission RM?)
  - Adjusting LO phase in BHR?
  - Perhaps machine learning techniques can be applied to achieve these adjustments

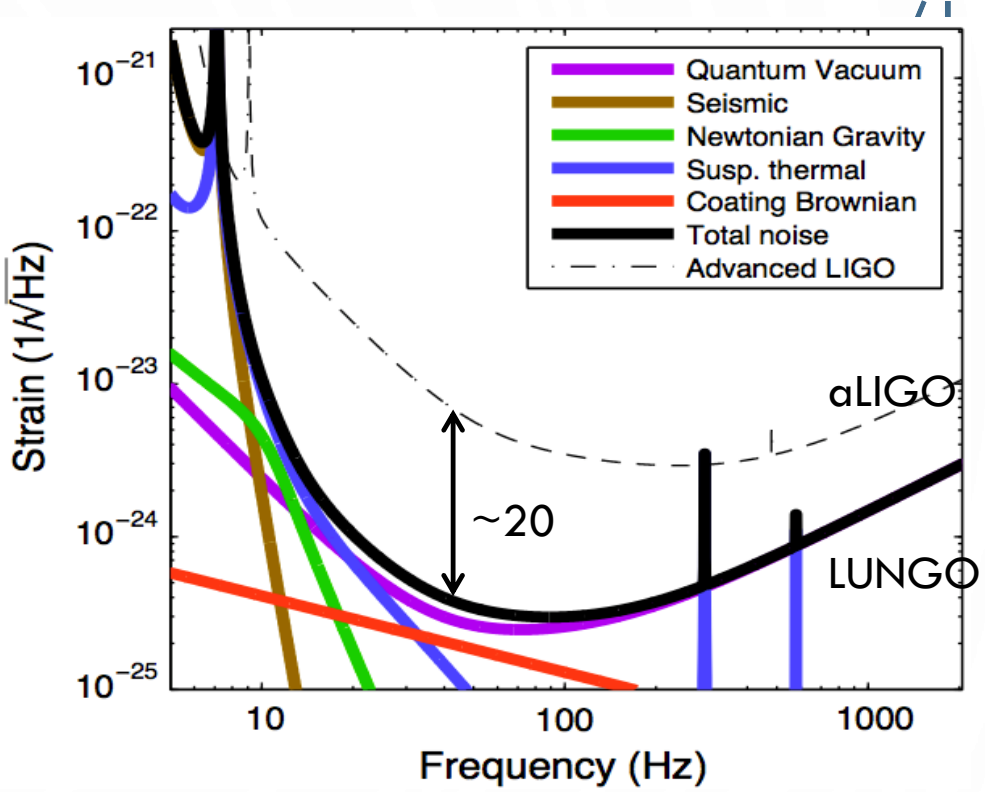
CRYOGENIC VOYAGER

- aLIGO plus A+ plus:
  - Heavier (150kg) Silicon TMs @123K, with Si ribbons
  - ~2.0 micron wavelength
  - Low temperature (123K) TMs

→ no new controls challenges beyond A+



COSMIC EXPLORER/LUNGO



- aLIGO plus A+ plus:
  - 40km arms
  - Longer filter cavity (1km)
  - Longer suspension (1m)
  - Larger beams on TMs (11.6 cm)
- By definition, CE is (was?) no new technology, 'just' longer arms, …
- Angular stability tradeoff with g-factor for long arms
  - Is there a driver to improve angular stability, or will we stick with demonstrated aLIGO performance to date?

GENERAL CONSIDERATIONS

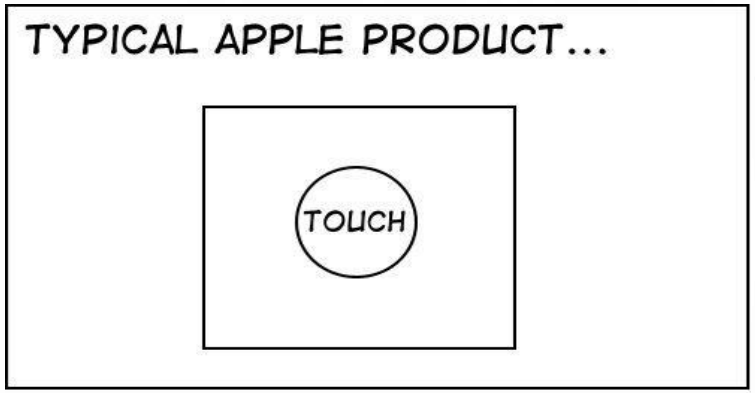
- Complete observability and controllability for all degrees of freedom (dof)
  - Higher upfront cost, but less cost during commissioning
  - Helps with fault tolerance (graceful degradation)
  - Can always abandon if not needed to reduce complexity and improve reliability
  - e.g. Bounce & roll modes of the aLIGO quad suspension
  - Other examples?
- Improved data munging tools (more of a DetChar than controls issue)
  - Imposing rigor and infrastructure for self-defined DAQ signals?
  - Improved means to query database over broken lock stretches?
- Improved transfer function fitting tools (including estimates of uncertainty)
  - Leveraging off of the models for experiment/measurement design
  - Using the (validated) models to extrapolate to unmeasured (or poorly measured) couplings or dofs

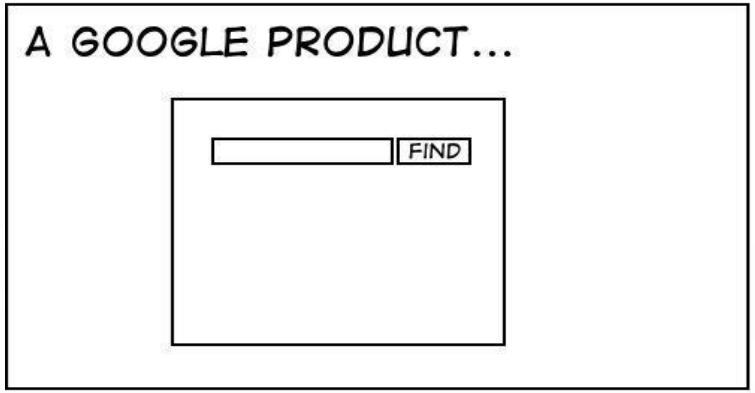
GENERAL CONSIDERATIONS

- Sideband/modulation and readout scheme for Observable interferometer length dof
  - Sensing matrix for ET (G1500819), what about for A+, CV, CE …?
- Same for angular dof?
- Adequacy or shortcomings of current simulation models

GENERAL CONSIDERATIONS (CONTINUED)

- Control & Data Systems (CDS) Architecture?
  - Likely requires custom ADC & DAC designs
    - Low noise, high dynamic range
    - Projects could leverage off shared design & development?
  - Continue to leverage off of HEP community (EPICS), or explore alternatives?





GW DETECTOR CONTROLS GUI …