aLIGO Past and Future

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For Joint ET/LIGO future Meeting, September 2017

Is aLIGO relevant for ET?

- From the technical/programmatic side Not very:
  - » No Civil Construction
  - » Small budget ($200M)
  - » Small science audience sufficed
- From the ‘enabling’ side, rather useful:
  - » Started up the ’post detection’ phase
- What lessons to learn? I’ll mention topics – please ask questions

What elements helped aLIGO succeed?

- **…to meet time and budget plans?**
  - » Robust request to NSF
    - – Engineering cost, manpower, time estimates
    - – Senior engineering review (and increases)
    - – Management review (and increases)
    - – Monte-Carlo approach to estimating how much of the contingency estimate to include
  - » Robust response from funding agencies
    - – NSF accepted the basis of estimate, but said ‘never any more’
    - – STFC, Max Planck, ARC all significant help
  - » Program environment
    - – Designed own reviews, safety program, etc.
    - – Paid for labor and equipment, and could trade between the two
    - – Full ‘earned value’ cost reporting required, expensive!

What elements helped aLIGO succeed?

- **…to start out well technically?**
  - » Good system engineering flowdown of requirements
  - » Prototyping of ideas around the world; very collaborative environment
  - » Models of various kinds – parts in detail, top-level
  - » Prototyping of 'brassboards' – similar to first articles
  - » Testing of first articles in real vacuum chambers installed by real technicians with real analysis of the results: can we meet requirements for the performance?
  - » Schedule which allowed some iteration (e.g., SEI system first prototype was 'everything can be aligned'; 2nd was 'nothing can be adjusted'
- **…to run pretty well as a project? Leadership team of…**
  - » Professional project manager
  - » Engineer
  - » Scientist

What helped aLIGO quickly reach an interesting sensitivity?

- The design and testing described on the previous page, and…
- **More testing:**
  - » Of assembled parts
  - » Of sensors/motors/cables in production with statistics
  - » Of electronics with actual cables in actual lengths
  - » Of complete assemblies outside of the vacuum
  - » Of complete assemblies in the vacuum
- Assembly by previous initial LIGO operators/engineers who were building the machine they would operate as operators and engineers – total ownership of the results

- (need to fold in AdVirgo's excellent commissioning success to make generalizations)

aLIGO Timeline – an existence proof

- 1990's: very active R&D and table-top demonstrations
- 1999: white paper with a conceptual design, a few important open questions (test mass material, laser technology); Lab cost and schedule estimate
- 1999: NSF acknowledges that this is a feasible plan and they support it being developed into a proposal
- 2000-2005: larger scale prototypes, 'v0.8' style prototypes
- 2003: Proposal formally submitted to the NSF (final approval in 2007)
- 2005-2010: preliminary designs, some final designs
- ★ **Meet NSB start criteria: Initial LIGO at design sensitivity, one year run**
- 2008: funding starts for Advanced LIGO Project
- 2014: Project complete
- 2015: Two detectors functioning at 1/3 final sensitivity, ~50% joint uptime

- From 1995 to 2015: 20 years

Initial LIGO Timeline – maybe more relevant

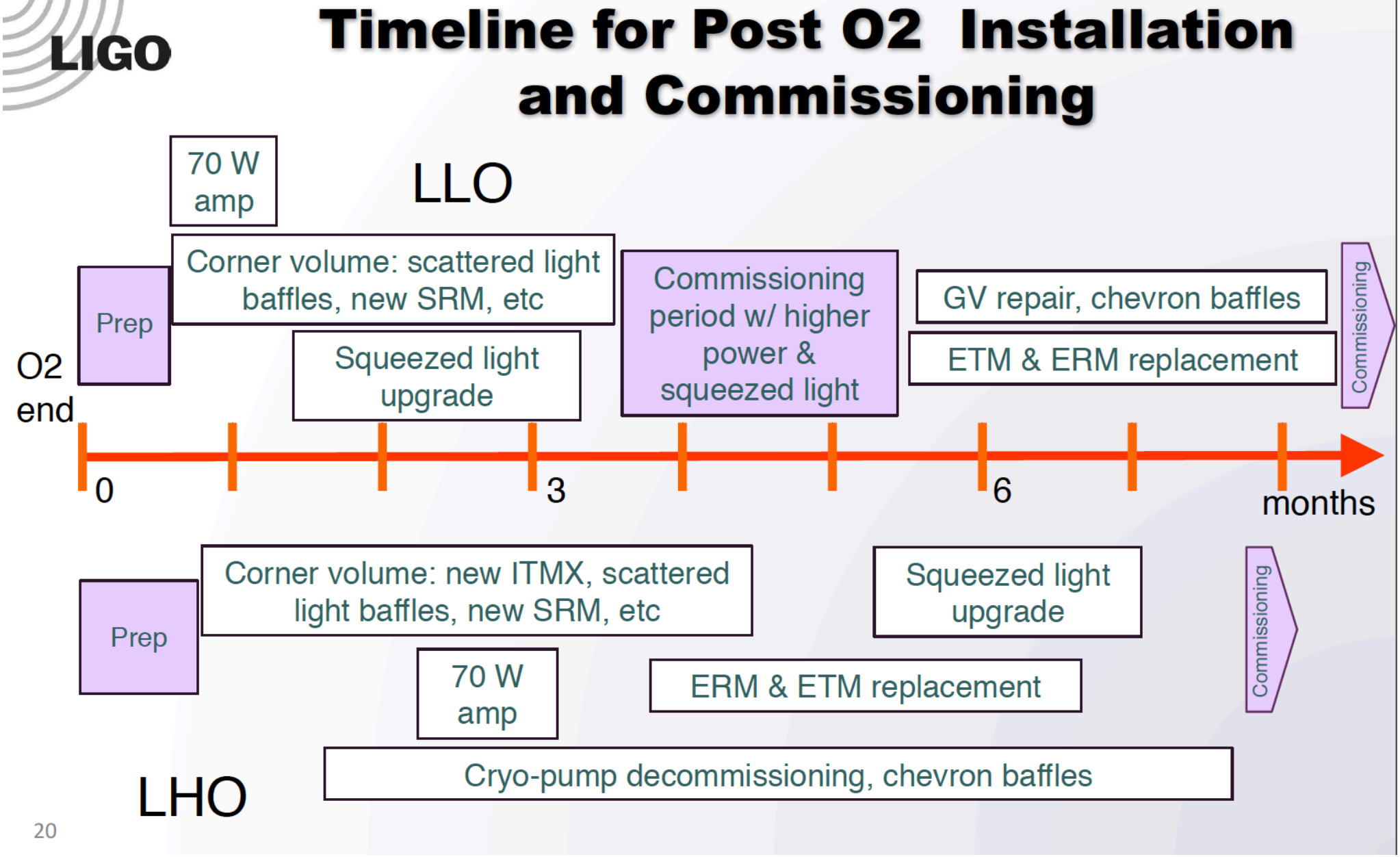
- 1978 Proposal to make an industrial study
- 1989 Proposal to the NSF
- 1992 Site selection
- 1993 Beam Tube Contract signed
- 1994 Site Groundbreaking
- 1999 Vacuum systems 'accepted'
- 2000 First lock
- 2002 First Science Run
- 2010 Design sensitivity science run completed

- ~20 years for the infrastructure to come into being
- ~25 years to good science data
- If we are e.g., at the '1978' level of maturity for 3rd gen…
  - » 2037 completed infrastructure
  - » 2042 good science data

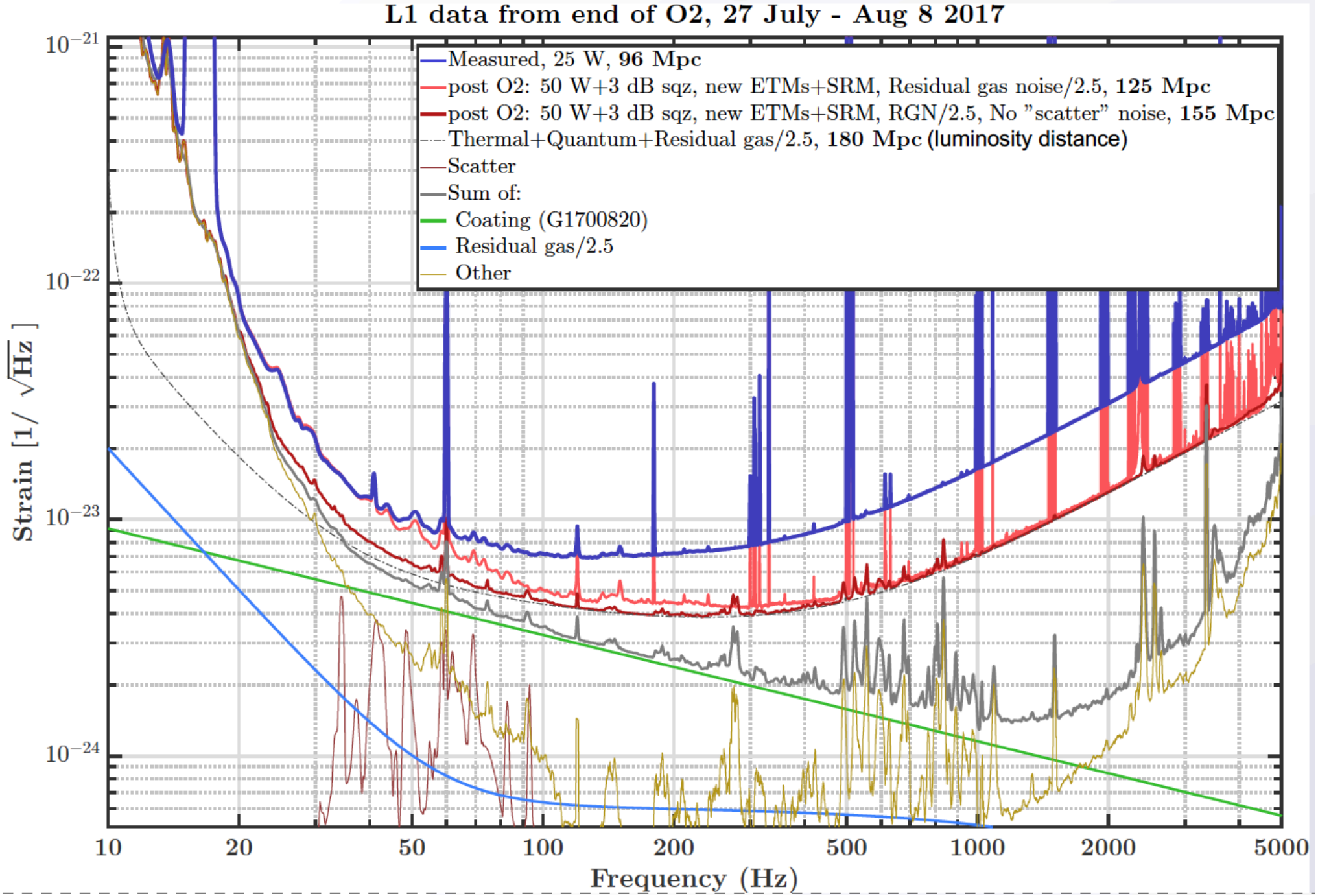
Back to Advanced LIGO: Near-term plan for O3?

- What's the near-term plan for aLIGO for O3?
  - 1 year (or more if needed)
  - ~1.3-1.5 LLO, factor ~2 LHO
  - (factor ~2+ for AdV)
- Things we plan to address:
  - Scattered light
  - Difficulty of working with high-power lasers
  - RF and Digital electronics getting into signal chain
  - Mystery noise (squeeze film damping? ESD actuators?)
- Things we should be addressing in addition:
  - Documentation
  - Remote access to the instrument state
  - Inclusiveness in Commissioning

From Valera Frolov's talk at LVC



Noise Projection



aLIGO Upgrades: +, ++, +++… ‘modest’ cost, ‘modest’ downtime

- A+ now well defined; possible submission in one year
- Freq. Dep. Squeezing
- Installation of ‘better’ mirrors
  - » Lower loss, scatter
  - » Lower thermal noise
- Maybe other bits and pieces
- ~1.7 greater reach for BNS
  - » ×5 in rate
  - » 2022 or so completion

- Later…
- Increasing mirror mass, Extending suspension length (ok, not so modest…)
- **…clearly can keep busy till 2025**

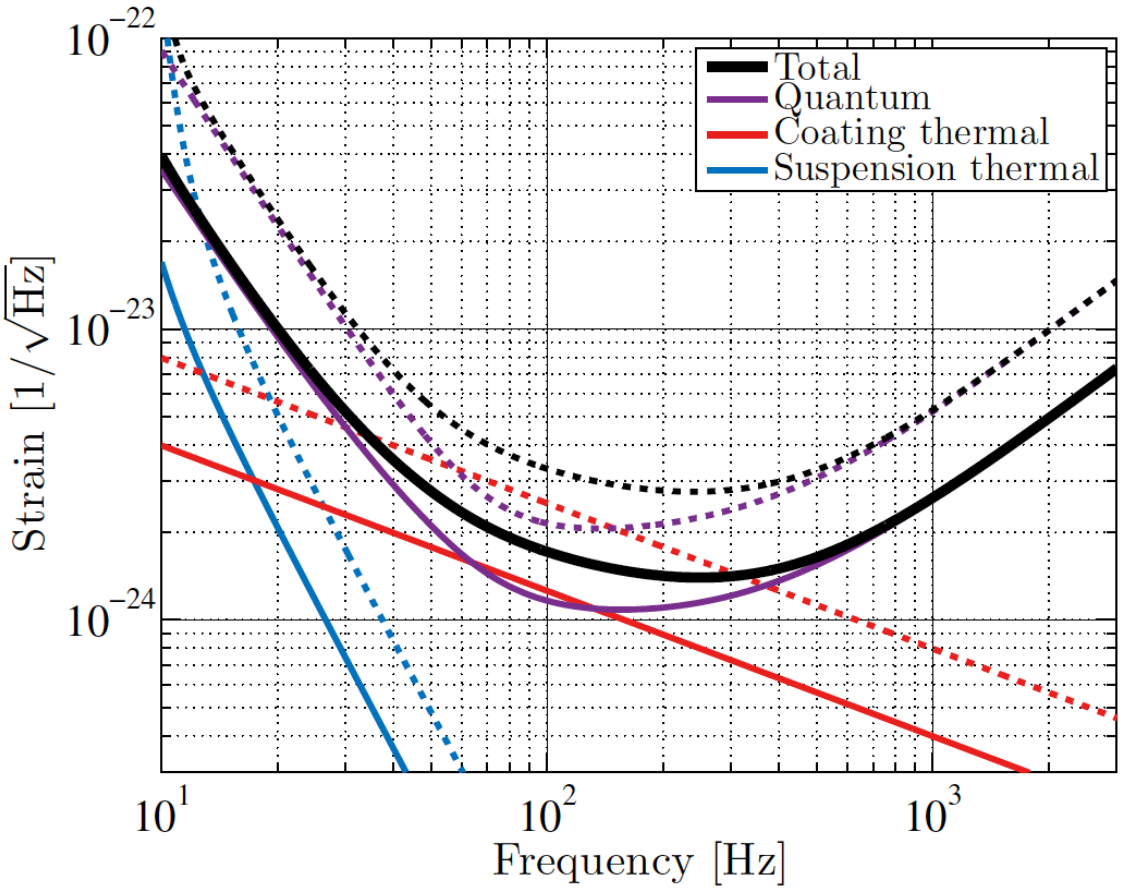


FIG. 1. Strain sensitivity of a possible upgraded Advanced LIGO interferometer. Improved thermal noise (factor of two), improved quantum noise (16 m filter cavity and 6 dB of measured squeezing at high frequency) and heavier test masses (also a factor of two) are shown. The equivalent Advanced LIGO curves are shown as dashed lines.

Voyager scale Upgrade

- Some approach to another step up; several concepts in discussion
- Dennis Coyne and Eric Gustafson made an educated guess for the cost and time required for a Cryogenic, Silicon, Voyager-style instrument for the current LIGO facilities, and re-using what one can
- Extrapolated from the aLIGO experience for both cost and time.
- Costs: ~$100M, using US accounting
- Timing with hopes for start dates and resignation for the later pace:
  - » End-2016 NSF review of Concept, NSF go-ahead mid-2017
  - » Design through PDR, Construction proposal to NSF end 2019
  - » Construction award end of 2021 (if ★ …)
  - » 3 years Fabrication,
  - » 2 years installation
  - » 1 year integration
  - » **Commissioning begins at the end of 2027**

  } ~4 years with no observation
- What's the science lifetime of this upgrade? 10 years? That determines…:
  - » **When do we want to see an ET/LUNGO operating?**

Tensions in the Cold Voyager path

- Time down for a given observatory
  - » Have to assume we do a staged upgrade of the instruments, with the other partners in the network continuing observations
  - » What scale of upgrade in the 'Voyager' epoch will be well motivated in terms of the science and the downtime?
- Time to first observation
  - » First guess for a cryogenic Voyager Observing Run is ~2028
  - » Will the 'Advanced+++' detectors be interesting until then?
- Quasi-parallel or slightly time-shifted request for ~10^8 and ~10^9
  - » Is there a community to support this pair of investments?
  - » Is there an optimization of draws from the bank in terms of timing?
  - » Is a $10% 'prototype' a good investment to control final costs?
- Can it be better to skip the 'cold Voyager' phase?
  - » Can we find more 'modest' upgrades with 'modest' downtime?
  - » Science Objective: Bring in the earliest readiness date for an ET/LUNGO scale observatory, reduce downtime
  - » Funding Objective: Decrease sum of draws from funding agencies

Recycling (of slides, that is): A rough timeline to critique

(stolen from Evans, G1401081)