# LIGO Roadmap Musing

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**For Joint ET/LIGO future Meeting, February 2016**


# Questions

a) What are the current instrument timelines for initial operation and incremental upgrades

b) What plausible timelines do we see for major observatories in the US and in Europe

c) What are the key questions that need to be pursued to firm up timelines

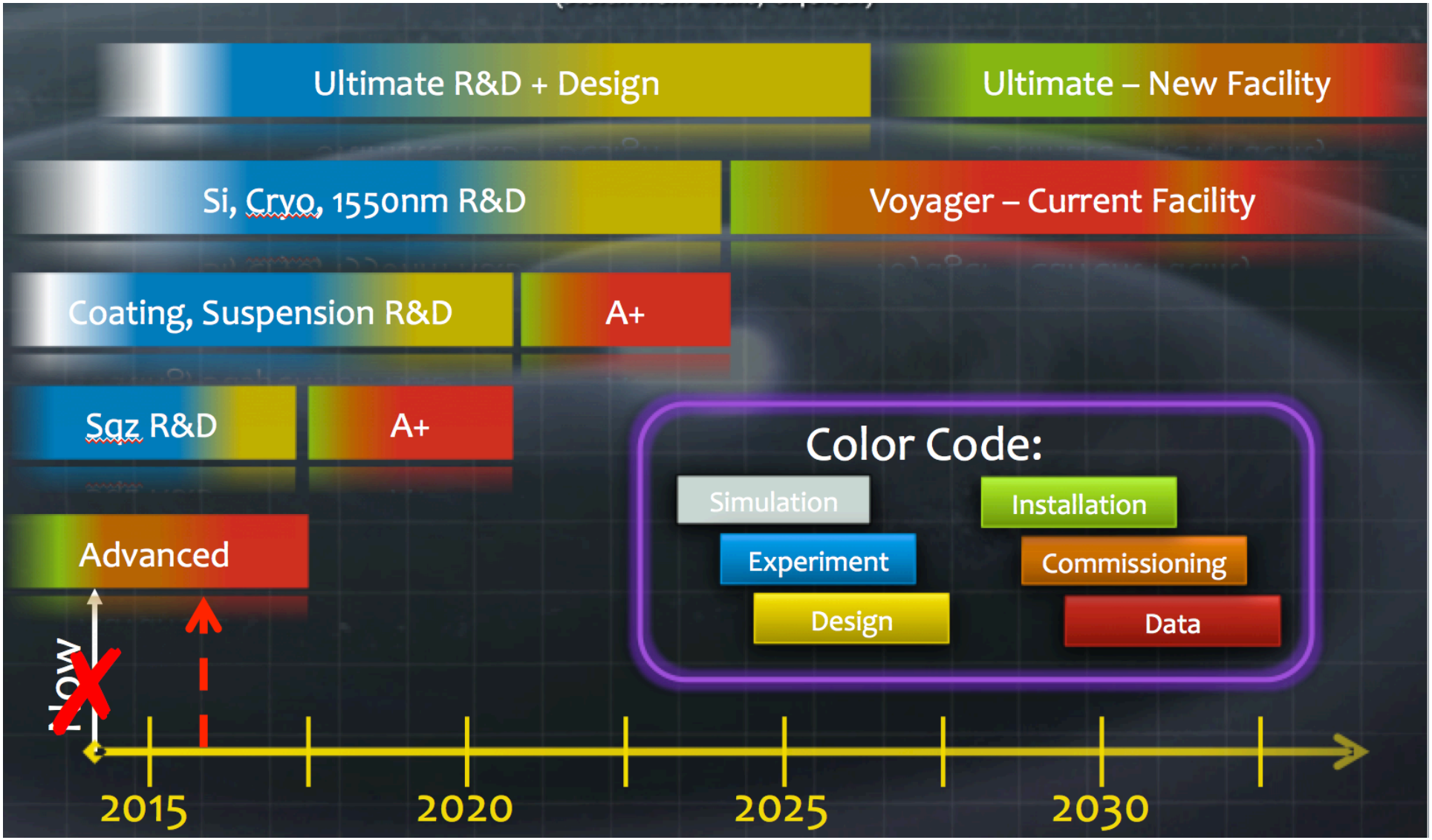
d) what are the next actions in this domain?


# Credits and Caveats

- Thoughts on roadmaps for LIGO detectors have been discussed many times in many places
- Draws from work by many; Mike Zucker just talked to this issue in the Lab; Dennis Coyne and Erik Gustafson have worked some on ‘Voyager’ cost and schedule; Paper by Miller et alia; cover slide stolen from Dave
- No consensus represented by my slides! Just things I thought useful for discussion.
  - (i.e., expect a lively set of critiques and questions from LIGO folk!)

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

(stolen from Evans, G1401081)



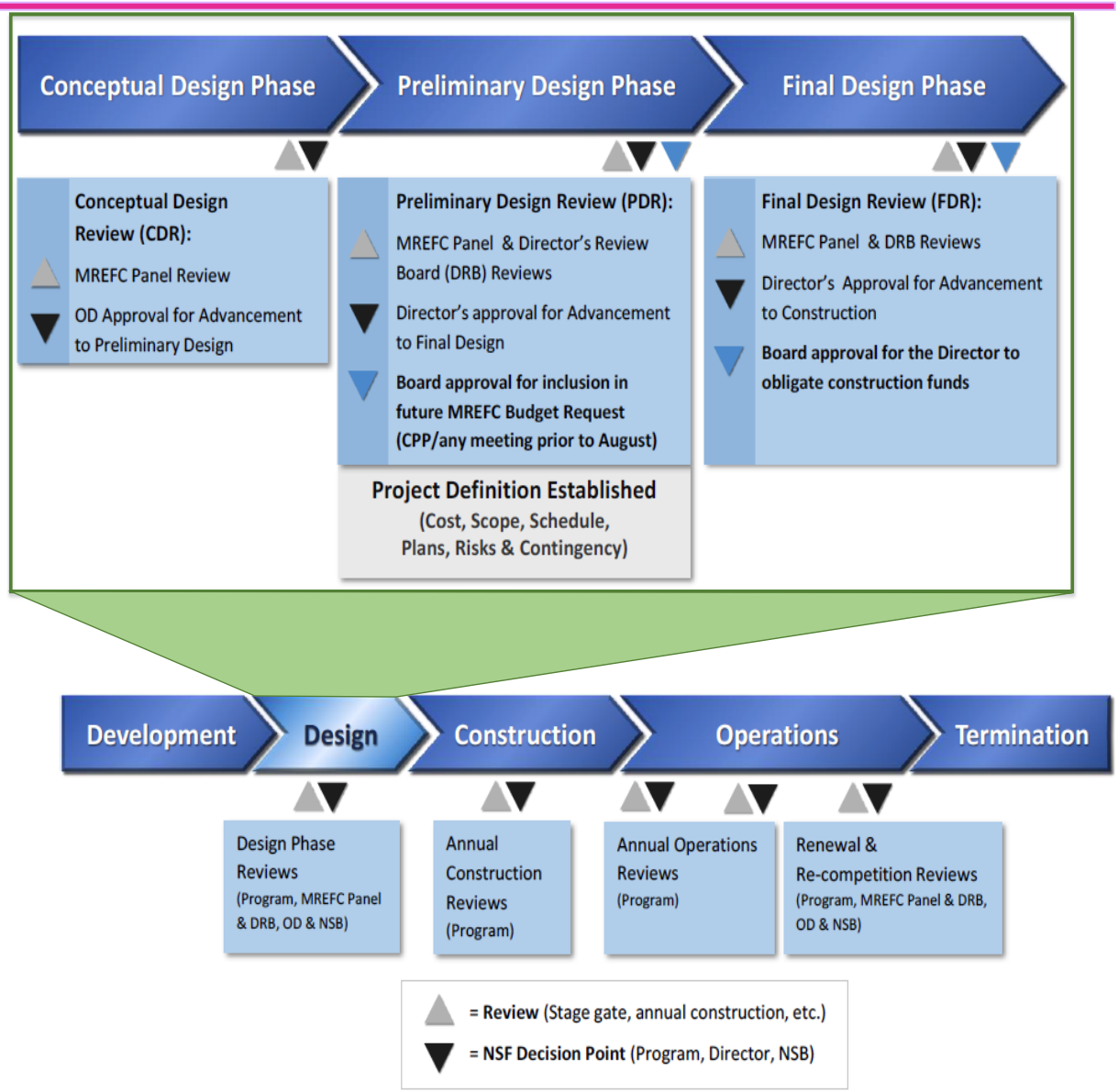

# aLIGO Timeline – an existence proof

- 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**
- If we are e.g., at the '1995' level of maturity for 3rd gen….could guess 2036.

# (new) NSF process for Projects

- Has become more complex than it was for aLIGO
- Much more NSF participation
- E.g., management of reviews
- Can expect to continue to see ★ milestones presented as prerequisites to moving forward



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

- Fixing whatever is limiting the sensitivity at this time!
- Use of squeezed Light
  - » Frequency independent ~now
  - » Frequency dependent – possibly between O2-O3
- Tiltmeters; NN/seismic feed-forward array
- Vertical/roll damping; additional vertical springs here and there
- Installation of ‘better’ mirrors
  - » Lower loss, scatter
  - » Lower thermal noise
- Increasing mirror mass, Extending suspension length (ok, not so modest…)
- **…clearly can keep busy till 2025**

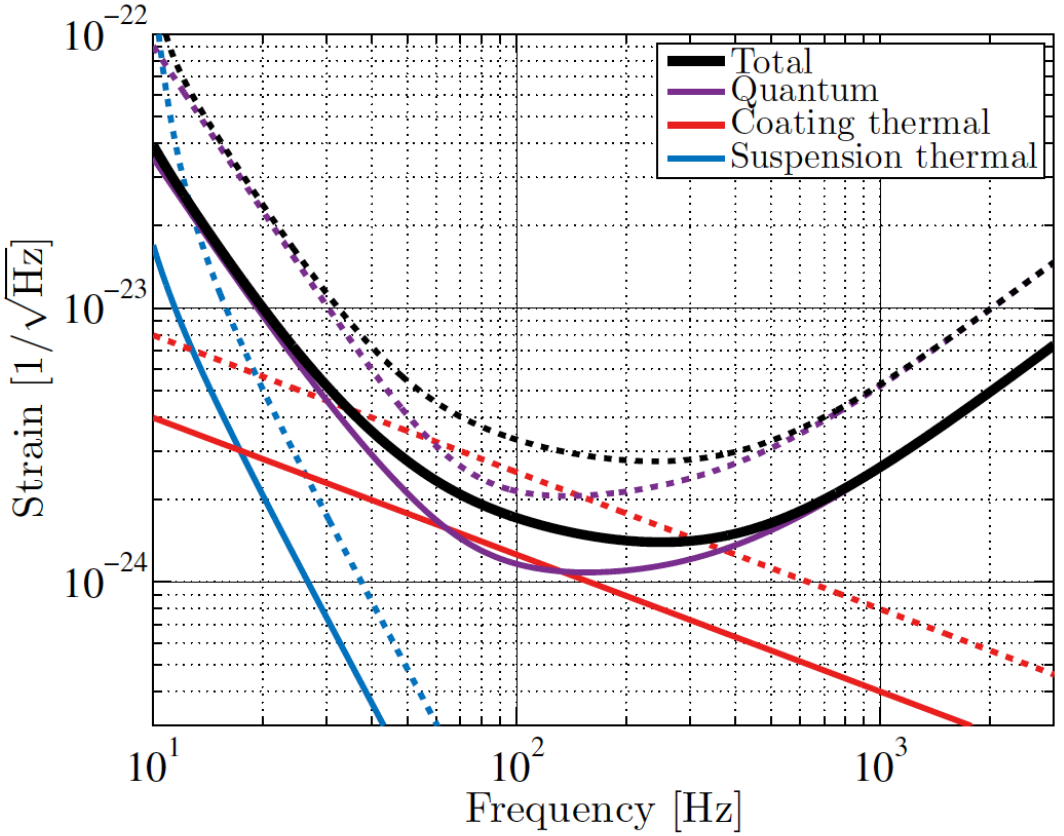



FIG. 1. Strain sensitivity of a possible upgraded Advanced LIGO interferometer. Improved thermal noise (factor of two), improved quantum noise (16 m filter cavity and 6 dB of measured squeezing at high frequency) and heavier test masses (also a factor of two) are shown. The equivalent Advanced LIGO curves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


# LIGO Lab thoughts on 3rd gen

- Starting to talk (Mike Z) about how to make real substantive progress
  - » The ET study really brought the European effort forward; emulate this
  - » Can't be done in 'spare time' with 'spare people'
- May apply to the NSF for supplemental funding for this domain
- Proposal elements of a ~3 year plan might be this sort of mix:
  - » Voyager design study
  - » LUNGO design study
  - » Amorphous Si coatings, Crystal coatings
  - » 40m conversion → 2 $\mu$m, Si
  - » LASTI cryo test
  - » Si optics & lasers
- Proposal Objectives:
  - » Science motivation, conceptual designs, engineering & cost frameworks for aLIGO+, Voyager and CX/LUNGO/ET
  - » Directed R&D to resolve strategic issues and inform designs
  - » Systems-level integrated design and trade studies
  - » Systems-level integrated testing of critical technologies


# Timeline for a US great observatory, with a Voyager-scale upgrade in series

- Can't do much better at this time than copy-and-paste the timeline for Voyager, pushed out some number of years and stretched to account for:
  - » Civil construction
  - » Overall scale and need to establish the project in the funding process
- Need to have a compelling argument; N.B.: our scientific results, and #(astronomy customers), grow with time to motivate a ~$bn expense
- Guess we need to show success with a Voyager-class upgrade, so no construction before ~2030, but everything can be ready including designs
  - » I have confidence R&D can deliver by then
- So, Timing:
  - » End-2026 NSF review of Concept, NSF go-ahead mid-2027
  - » Design through PDR, Construction proposal to NSF end 2028
  - » Construction award end of 2030 (if ★ )
  - » 3 years Fabrication – **here in parallel with Civil Construction**
  - » 2 years installation
  - » 1 year integration
  - » Commissioning begins at the end of **2037 – 10 years after a Voyager**


# Timeline for a US great observatory, **no** Voyager-scale upgrade in series

- Same point of departure for Great Observatory project duration
- Again, Need to have a compelling argument – our data, and astronomy customers, grow with time to motivate a ~$bn expense; **can we achieve that without a Voyager-scale instrument and resulting data?**
- Timing w/out Voyager may be limited by our instrument R&D bearing fruit, full-scale prototype tests, and the like; guess 6 years from ~ now
- So, Timing, pulled in without a Cold Voyager in series:
  - » End-2022 NSF review of Concept, NSF go-ahead mid-2023
  - » Commissioning of new Observatory begins at the end of **2033**
  - » ~4 years earlier without a Cold Voyager, but so much guesswork….

- The naïve aLIGO extrapolation suggested 2036 if we start now
- **The uncertainty in the dates is greater than the difference with/without Voyager; probably is sooner without the change in wavelength and cryogenics if funding is adequately motivated by the science to date**


# Questions, answers, questions…

a) What are the current instrument timelines for initial operation and incremental upgrades

- » No new information – we believe we can improve the aLIGO (and AdV) performance substantially (x2) with modest funds

b) What plausible timelines do we see for major observatories in the US and in Europe

- » Some guesses offered in these slides

c) What are the key questions that need to be pursued to firm up timelines

- » Do we pursue a cold-Voyager-class upgrade? Can we satisfy our science customers until 2034 with only modest improvements ($10-$30M) and small down-time per ifo?


# Questions, answers, questions…

d) What are the next actions in this domain?

- » Resolve the intermediate-upgrade scenario from a science perspective – not urgent, but ultimately important
- » Seek feedback from funding agencies and non-GW community: **What** results from the field will be required to make a ~$bn investment compelling?
  (I think we can make the technology in time)
- » Ask ourselves: **When** can we deliver those results?
  Sets date for start ★ of bulk funding
- » **Start working as a global team with near-term deadlines**; whether we make 1,2, or 3 Great observatories, and if they are identical or not, we'll get more support from the community and the funding agencies this way

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