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Building the Third Generation of Gravitational Wave Detectors: Thoughts about Science, $, €

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Historical Gestation Periods for US GW Detectors

- Initial LIGO
  - **1983** MIT and Caltech jointly present results of the km-scale interferometer study to NSF. Receive endorsement by NSF committee on new large programs in physics.
  - **1990** The US National Science Board (NSB) approves the LIGO construction proposal, which envisions Initial LIGO followed by Advanced LIGO.
  - **1994-1995** Site construction begins at the Hanford and Livingston locations.
  - **2002** The first coincident operation of Initial LIGO interferometers with the GEO600 interferometer.
  - **2006** Initial LIGO design sensitivity achieved.
- Advanced LIGO
  - **1999** The LSC Concept Paper for Advanced LIGO completed.
  - **2003** LIGO Laboratory submits proposal to NSF for Advanced LIGO proposal.
  - **2006** NSF conducts review of Advanced LIGO Construction.
  - **2008** Advanced LIGO Construction is funded by NSF.
  - **2014** Advanced LIGO Construction completed.
  - **2015** Advanced LIGO begins science operations

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- Advanced LIGO → 16 years
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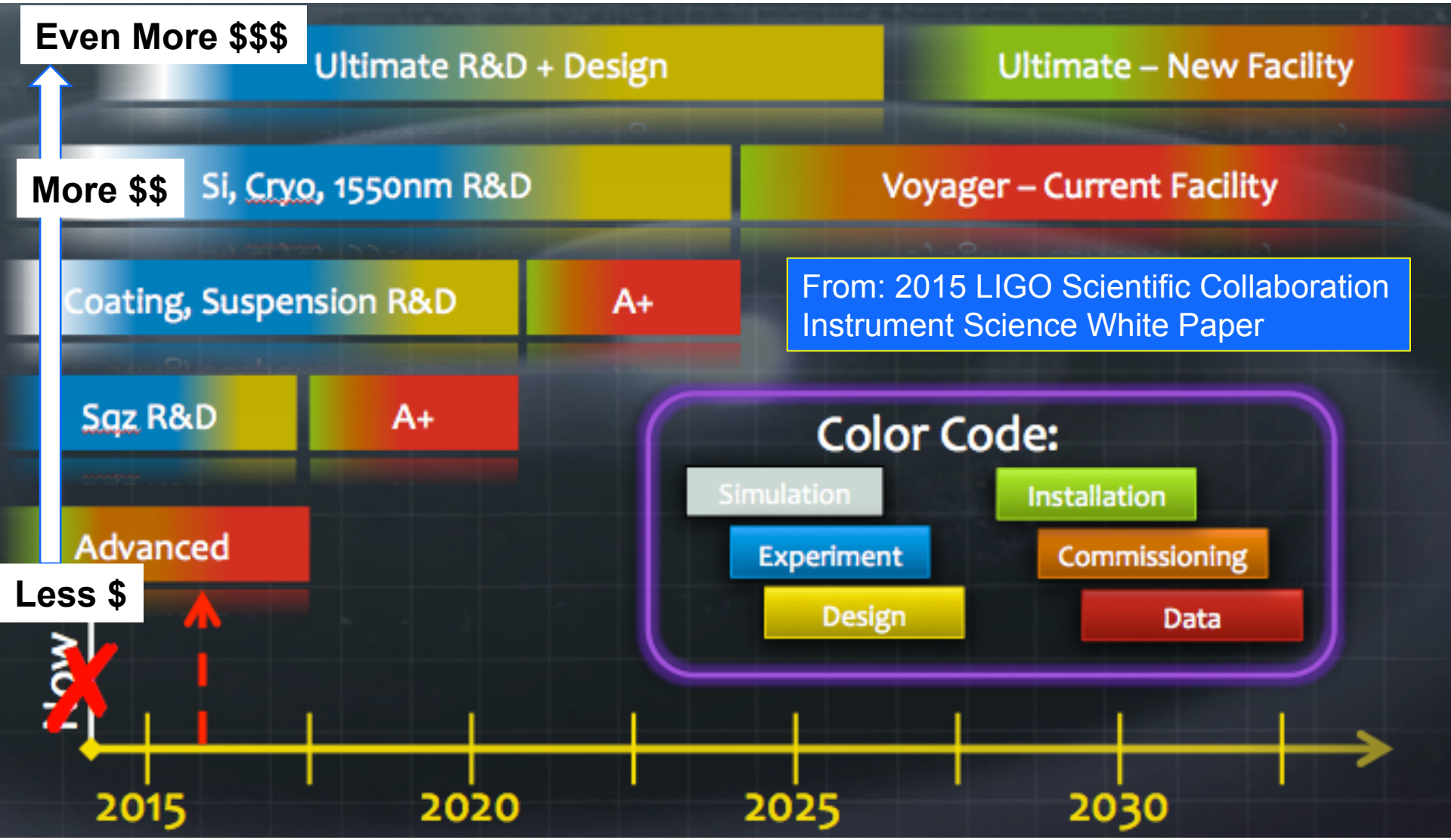
The Terrain in the Next Few Years

- The advanced detectors should make detections in the 2016-2018 frame
- The nature of the classes of detected sources will provide valuable input (but not completely dictate) the science case for a 3G detector network
- *More importantly, the window of GW astronomy will open, moving us into the arenas of frontier strong field physics, high energy astrophysics, multi-messenger astronomy*

- ***The case for proposing a 3G detector will never be as good as it is in the next few years!***

The Best of All Worlds?



'Current versus Future Facilities' versus 'Current & Future Facilities'

- Start with rough estimates of the costs
  - **Guess:** Upgrades of two detectors in current facilities: $100-$150M (in 2016 $)
  - **Guess:** New facilities with new detectors: $1- 1.5B (in 2016 $)
- Exploiting sensitivity limits of current facilities (including facility modifications) is *by far* the lower cost option
  - Supports a '3X' improvement using current LIGO facilities
  - Caveat: LIGO Observatories are showing signs of aging and will likely need a substantial refurbishment of the vacuum system in the next 5 years
- A new 'CE-class' observatory with 10 or 20 or 40 km arm lengths will require a new site
  - Both Hanford and Livingston are constrained by local development, land ownership, environmental constraints
  - Neither the Hanford or Livingston sites are 'great' from an environmental standpoint (seismic, wind, …)
- R&D themes are common for Cosmic Explorer and Voyager
  - Coatings (it's always about the coatings), lasers, cryogenics, NN, …
- Given time scales and costs (Voyager $150M funding in 2020; CE $1.5B in 2030), optimistically it *might* be possible to do both

Prerequisites for funding a US 3G detector

- *Essential* Advanced LIGO must reach its design sensitivity
  - #1 -- because it provides proof that we understand and can tame the noises in 2G interferometers
  - #2 -- it will demonstrate to funding agencies that we can deliver on our design goals
- *Essential* The science case for 3G detectors must be extremely well developed given what we know at the time of the proposal
- *Essential* The community will have to prepare their respective funding agencies that big projects are being planned
  - It can take 5 years to get a project 'queued up' into the NSF Major Research Equipment and Facilities Construction budget
- *Essential (for Cosmic Explorer)* An external evaluation must be conducted by a panel of experts
  - Is the science case sufficiently strong for a 3G detector?
  - Is the technology development mature?
  - Is their preliminary costing and project planning, or is there a path
  - ….
- *Nice to Have* International planning and coordination
  - May be essential for CE-class project
- *Nice to Have* Support from an outside community
  - They support GW science because it adds to their science
  - For the GW community, it's the astronomers, perhaps nuclear physicists

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Science Case for 3G detectors

The case for a 3G detector begins with science:

- **What capability can you achieve? What science can you do with that capability? What will it cost?**
- **These questions are all linked, and have to be iterated right up until the construction proposal is submitted**

- ET Design Study provides a good basis for a 3G science case, but must be refined as we know more
- A network analysis considering number, sites, and hybrid 2/3G network is essential (a la Sathya)

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Agency Coordination

- In the US, agencies (NSF) will follow scientific community desires …
- … subject to boundary conditions
  - » Boundary Condition #1: available agency budgets and budget projections (dictated by US Congress)
  - » Boundary Condition #2: agency priorities (eg, applied vs fundamental science)
- NSF has established the Gravitational Wave Agency Correspondents group to lay the groundwork for establishing coordination among agencies that support ground-based GW research
  - » Current membership: NSF, ARC (Australia), CNRS (France) , INFN, DFG
    - – Indian DAE membership pending
  - » A working group, ie, no Directors, Presidents, Chiefs
  - » This group has met once, primarily to introduce themselves
- My impression: the GWAC is ‘standing by’ to respond to community driven inputs and ‘pushes’

External Evaluation by Blue Ribbon Panels

- In the US, blue ribbon panels play a critical role in informing agencies on science priorities and road mapping how a specific field will develop
- Two primary routes: 1) field-specific NRC studies & 2) Decadal Surveys

1. **National Research Council studies**
   - NRC is formally part of the US National Academies of Science, Engineering, and Medicine
   - Studies are both comprehensive and intensive
     - 10-15 members, membership is a mix of scientists from within the community and objective outsiders
   - Agencies must request and fund them (cost: up to $500k)
2. **Decadal Surveys**
   - Astronomy and various fields of Physics conduct Decadal Surveys
     - Initial LIGO was endorsed in a 1986 physics decadal survey
   - Decadal Surveys carry different weights in Physics & Astronomy
     - In Astronomy, they are treated with *biblical reverence* (although they aren't always followed by agencies due to funding constraints)
     - In Physics, they are useful as inputs to physics funding priorities

- **A large Cosmic Explorer class project will almost certainly have to go through one of these two routes**

Funding a New Facility in the US: the $1B+ ask

- The US National Science Foundation has funded LIGO since the mid 1980s
- Funding breaks down into two categories:
  - Construction: building of the LIGO Observatories and initial and Advanced LIGO detectors
  - Operations and Maintenance: funding to run the detectors, maintain the facilities, LSC science program, sustaining engineering and R&D, outreach
- NSF has never funded a $1B+ one shot construction project (to my knowledge)
  - Atacama Large Millimeter Array Construction funded by NSF: $526M
  - Remaining funds came from European Southern Observatory
- The US Department of Energy is the other agency that *could in principle* fund LIGO
  - Joint funding of LSST, DUSEL (abandoned)

Considerations in formulating the Global 3G Network

- First generation GW interferometers were independently designed and constructed.
  - LIGO, Virgo, GEO
  - We were competitors at the time
- Second generation GW detectors had some elements of coordination …
  - Advanced LIGO had US, UK, German, Australian contributions
- … but by and large were independently designed and built
- We now collaborate on the analysis of GW data
  - LIGO-Virgo agreement (2007), LV pre-agreement (2013)

- **For 3G, the GW community intends to 'go big'**
- The scale of the project (at least two 10+ km class interferometers) may require coordination across collaborations/projects to take advantage of 'economies of scale'
- Advantages of coordination
  - (At least partial) homogeneity in design and construction
  - Coordinated site selection for optimal network design
  - Makes best use of distributed expertise
- Disadvantages of (or challenges in) coordination
  - Requires establishment of robust management structure, necessitating giving up some control by partners
  - Requires robust system engineering, establishment of standards, interface control, quality assurance program, …
- ***Major challenge may be synchronization of US/European/Japanese plans for 3G upgrades***

Questions? Answers! And Speculations.

A) **hat funding avenues exist for ~$1B scale projects?**

In the US, NSF funds ground-based GW detector science and facility development. NSF has never done a $1B-class project. DOE is a possibility, but will require NSF buy in and handshaking between NSF and DOE

B) **what recent examples do we have to help us form successful proposals?**

Advanced LIGO is an example of how to structure a ~ $200M proposal. At the $1B+ level, best example is LSST, which is a joint NSF/DOE program.

For international projects, high energy physics leads the way (eg, ILC design study). The Thirty Meter Telescope is an other example. Examples of problematic international projects also exist – ITER is the best example

Questions? Answers and Speculations

C) Funding - how and when to decide on a global 3rd gen. scenery? We will need a good understanding of options and probability of funding levels. How to deal with the uncertainty?

We probably have two years to decide on paths forward and level of coordination

D) What near-term activities should be put in motion from the standpoint of strategy?

Development of the science case for ET, Voyager, CE detectors is the essential prerequisite

More working level meetings (eg, 'Dawn' meeting, GWADW) to continue coordination and planning

E) What are the next actions in this domain?

Discussions of funding wedges for mid-scale (Voyager) and large-scale (CE) upgrades in the US

Suggestion: a representative from the US community should 'embed' in ET development program to facilitate coordination

GWIC should establish a 3G working group to establish coordination, be able to interact with funding agencies, understand who the competition is …