9: Prospects for Advanced LIGO and Advanced Virgo

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with help from
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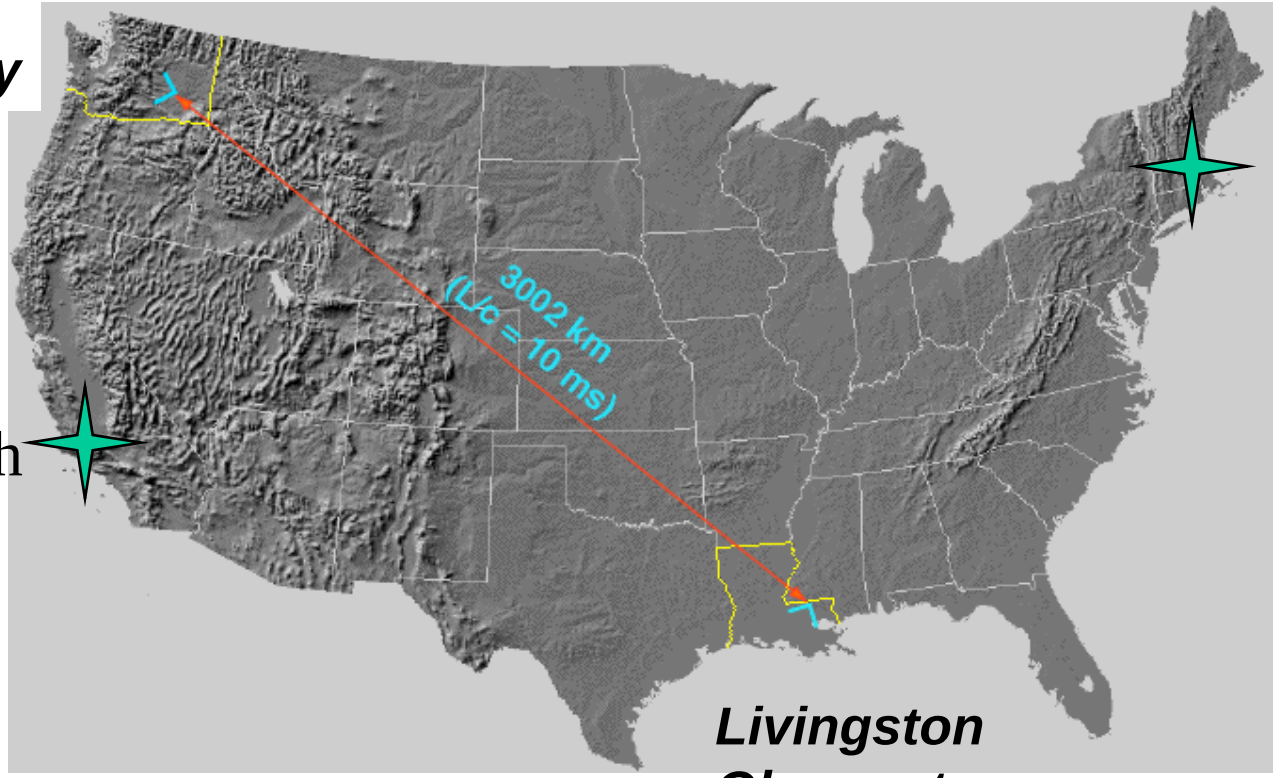
My lectures during this School

1. Overview of gravitational waves and sources
2. Interactions of waves and detectors
3. Shot noise and radiation pressure noise
4. Theory of linear systems
5. Vibration isolation (passive)
6. Thermal noise
7. Optics of Fabry-Perot cavities
8. Feedback control systems
9. **Advanced LIGO, Advanced Virgo**
10. Future detectors in space

LIGO Laboratory Sites

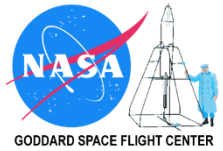
Laser Interferometer Gravitational-wave Observatory (LIGO)

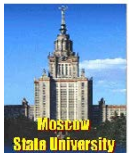


LIGO Scientific Collaboration

LIGO

LSC





UNIVERSITY OF MINNESOTA

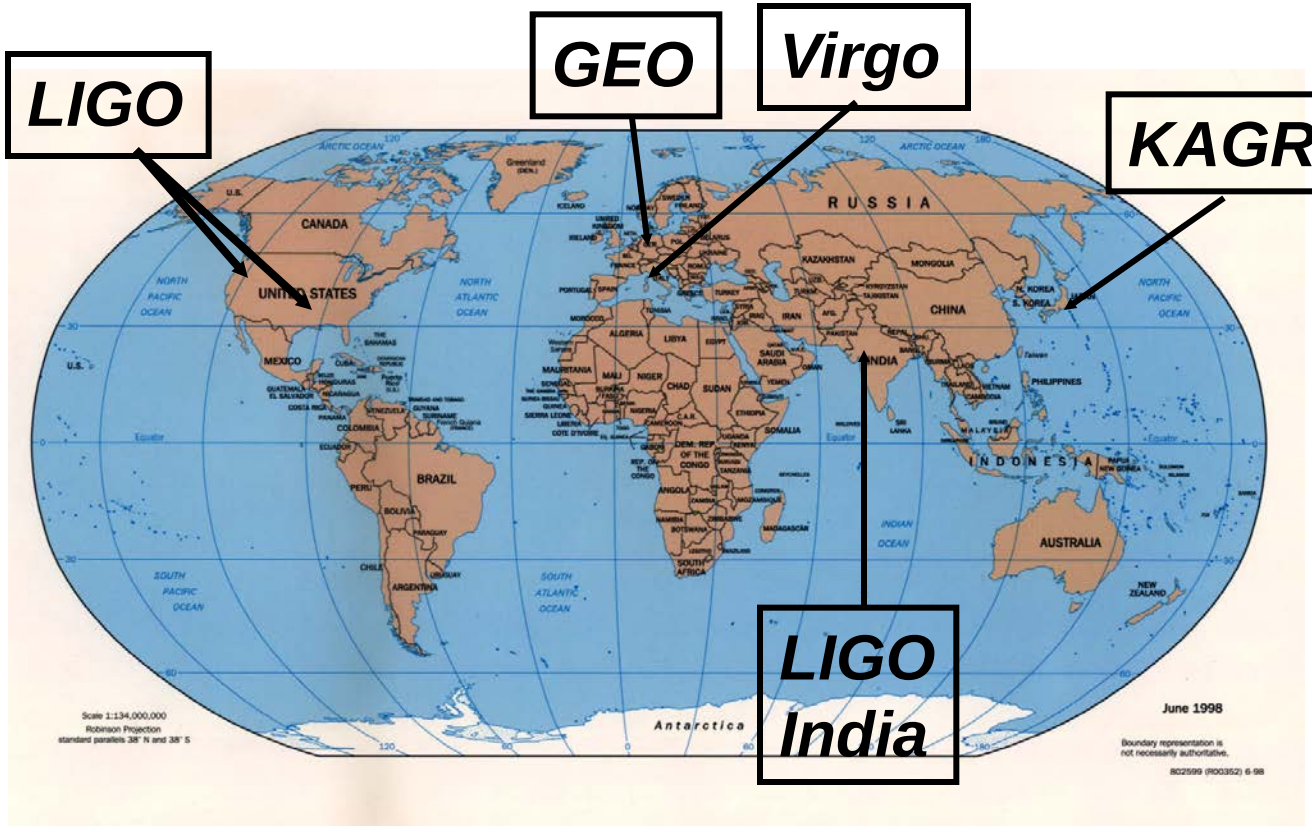
Science & Technology Facilities Council
Rutherford Appleton Laboratory

Universität Hannover

GEO 600

An International Network of Interferometers

Simultaneously detect signal (within msec)



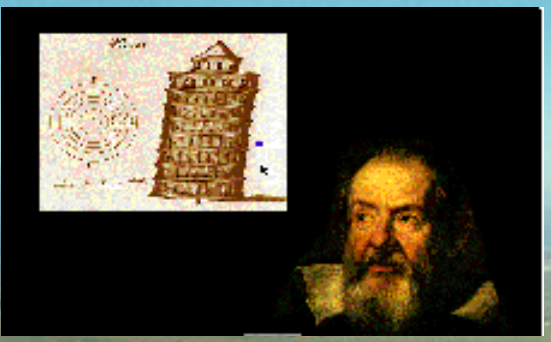
detection confidence

locate the sources

decompose the polarization of gravitational waves

VIRGO

EGO



- LAPP - Annecy
- INFN - Firenze/Urbino
- INFN - Frascati
- IPN - Lyon
- INFN - Napoli
- OCA - Nice
- ESPCI - Paris
- LAL - Orsay
- INFN - Perugia
- INFN - Pisa
- INFN - Roma

NIKHEF - Amsterdam (joining)

Inaugurated July 2003

Advanced LIGO's reach

Observations with initial LIGO did not discover any signals.

Not too surprising: We know abundance of NSB's, and knew we couldn't see far enough.

The design of initial LIGO was conservative. Plan was to upgrade to a more sensitive design.

Probability of finding a signal improves as the cube of the distance to which we can detect.

aLIGO goal: ensure detection of NSB's.

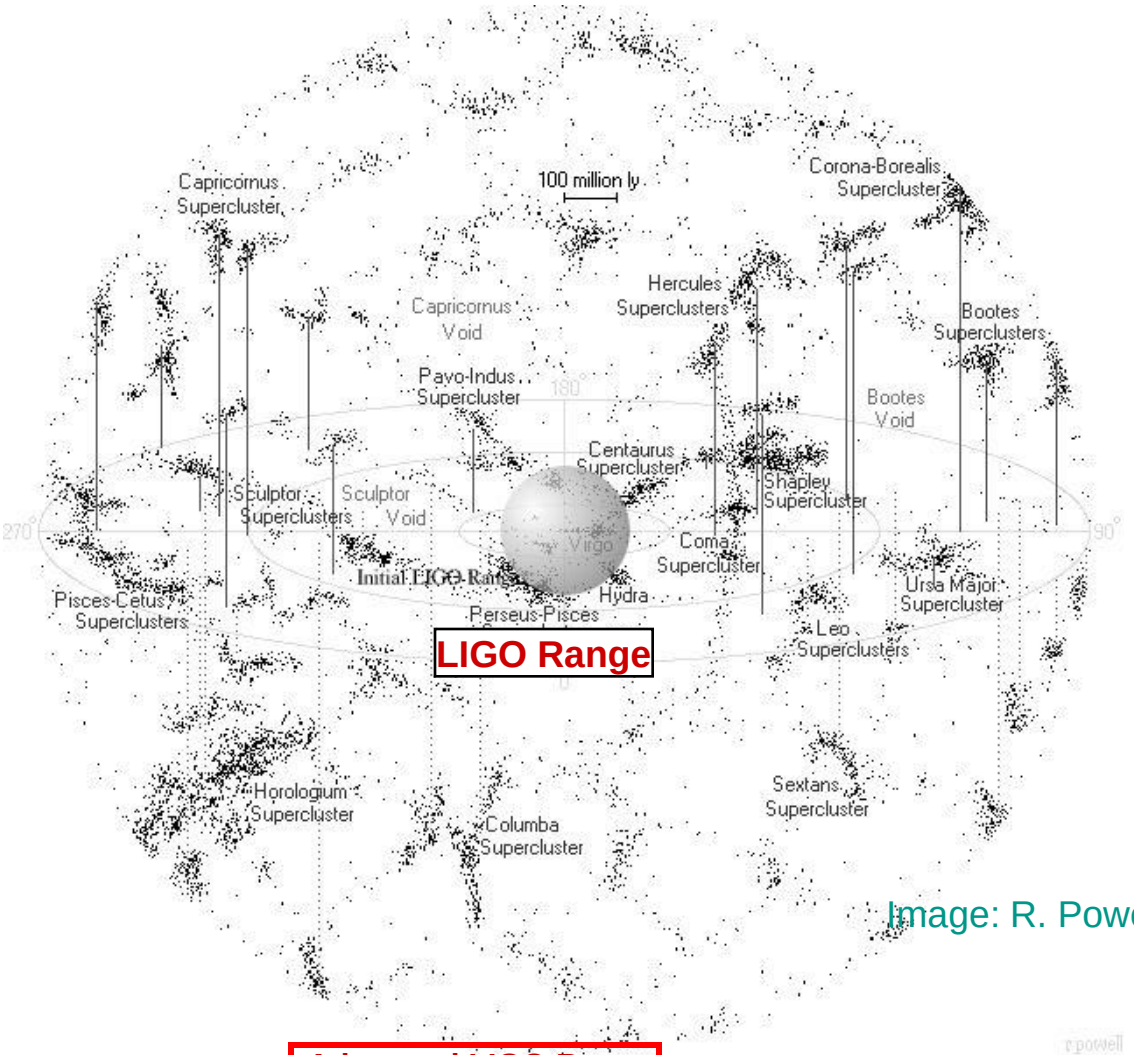


Image: R. Powell

Event rate estimates

TABLE V: Detection rates for compact binary coalescence sources.

IFO	Source[a]	N_{low} yr^{-1}	N_{re} yr^{-1}	N_{high} yr^{-1}	N_{max} yr^{-1}
Initial	NS-NS	2×10^{-4}	0.02	0.2	0.6
	NS-BH	7×10^{-4}	0.004	0.1	
	BH-BH	2×10^{-4}	0.007	0.3	
	IMRI into IMBH			< 0.001[b]	0.01[e]
	IMBH-IMBH			10^{-4}[d]	10^{-2}[e]
Advanced	NS-NS	0.4	40	400	1000
	NS-BH	0.2	10	300	
	BH-BH	0.4	20	1000	
	IMRI into IMBH			10[b]	300[e]
	IMBH-IMBH			0.1[d]	1[e]

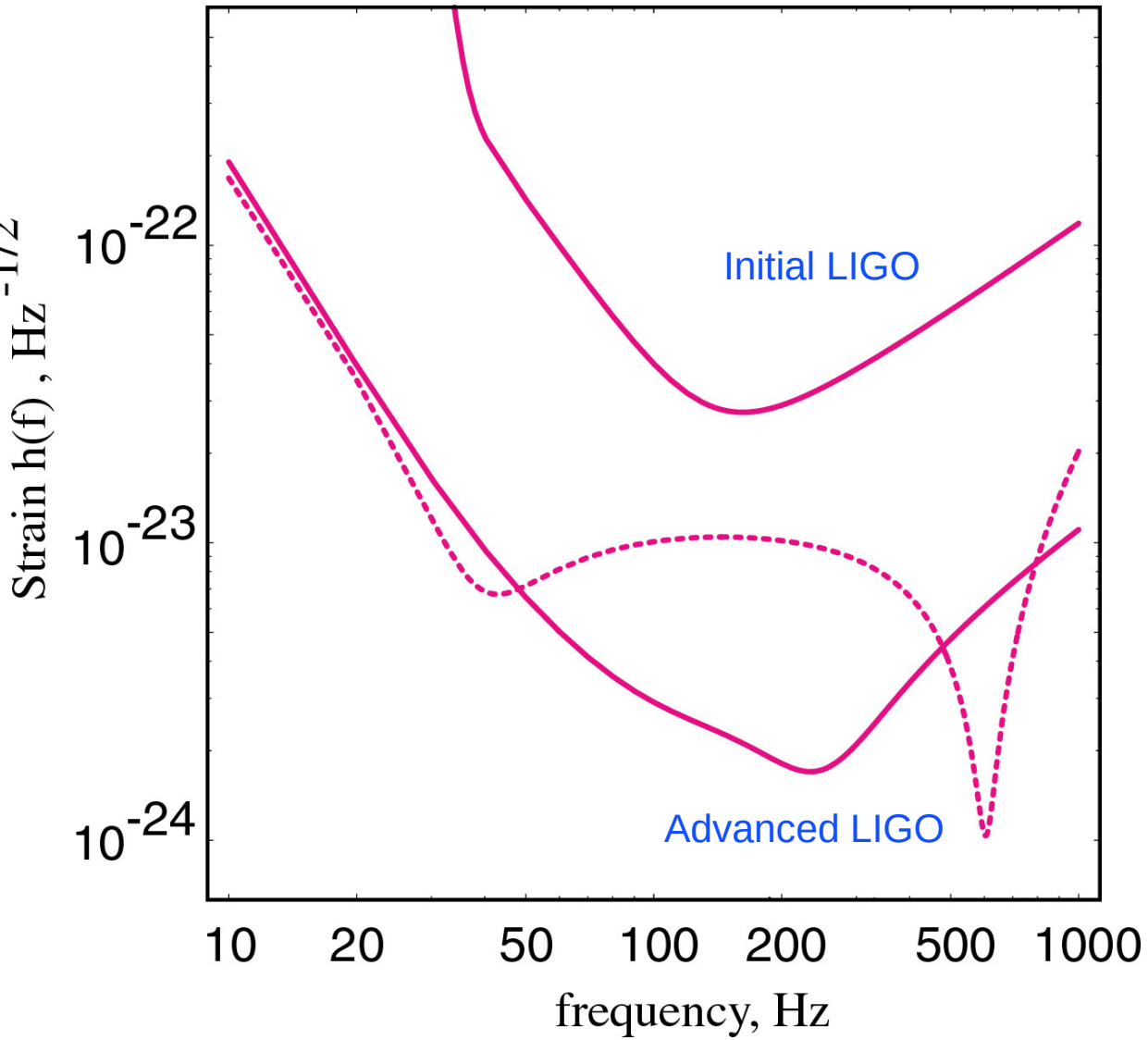
Coming Soon: Advanced LIGO

Much better sensitivity:

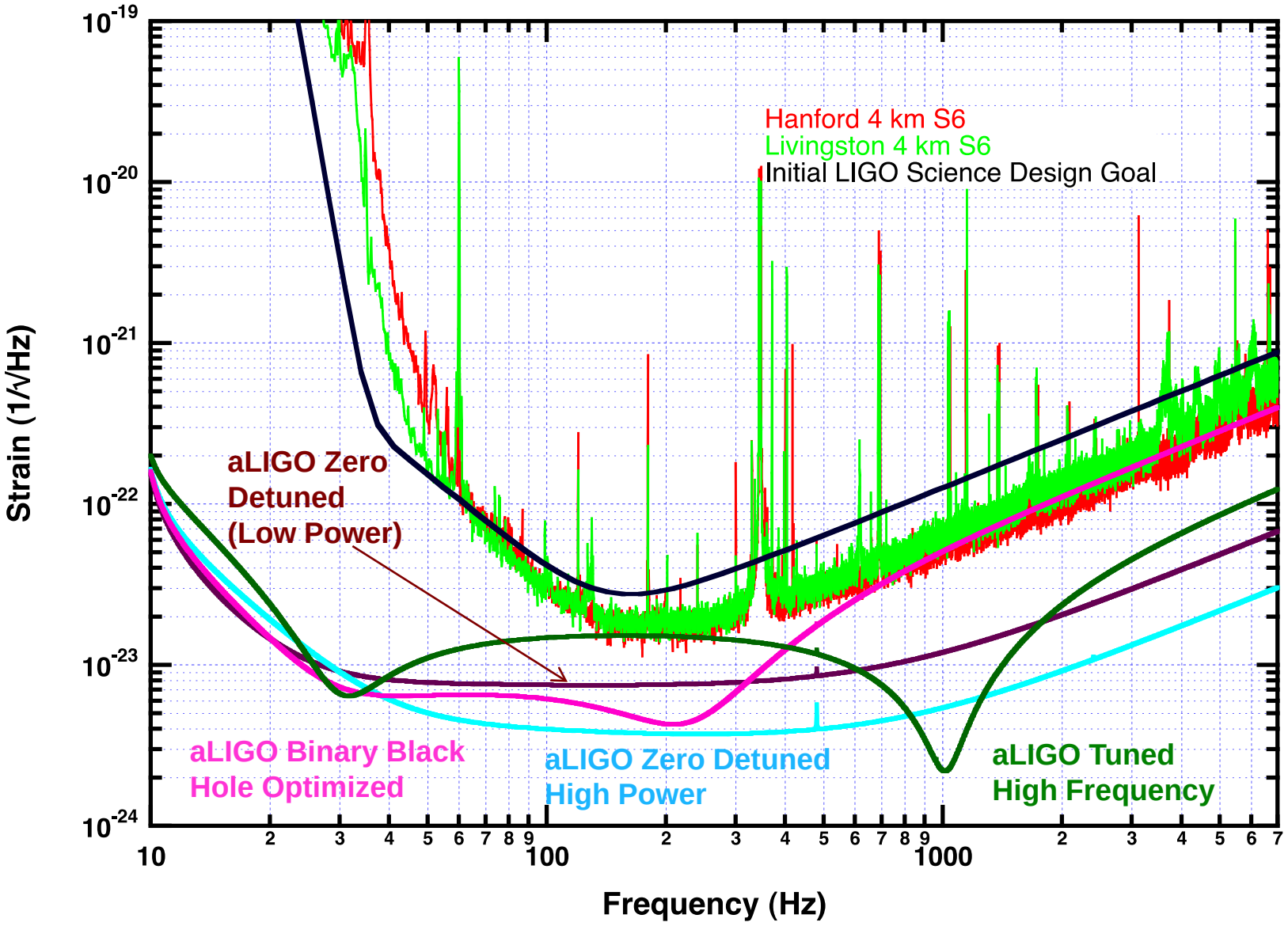
- ~10x lower noise
- ~4x lower frequency
- tunable

Through these features:

- Fused silica multi-stage suspension (U.K.)
- ~20x higher laser power (Germany)
- Active seismic isolation
- Signal recycling
- Quantum engineering
  rad'n pressure *vs.* shot noise



Advanced LIGO Sensitivity



aLIGO optical response can be tuned in many ways

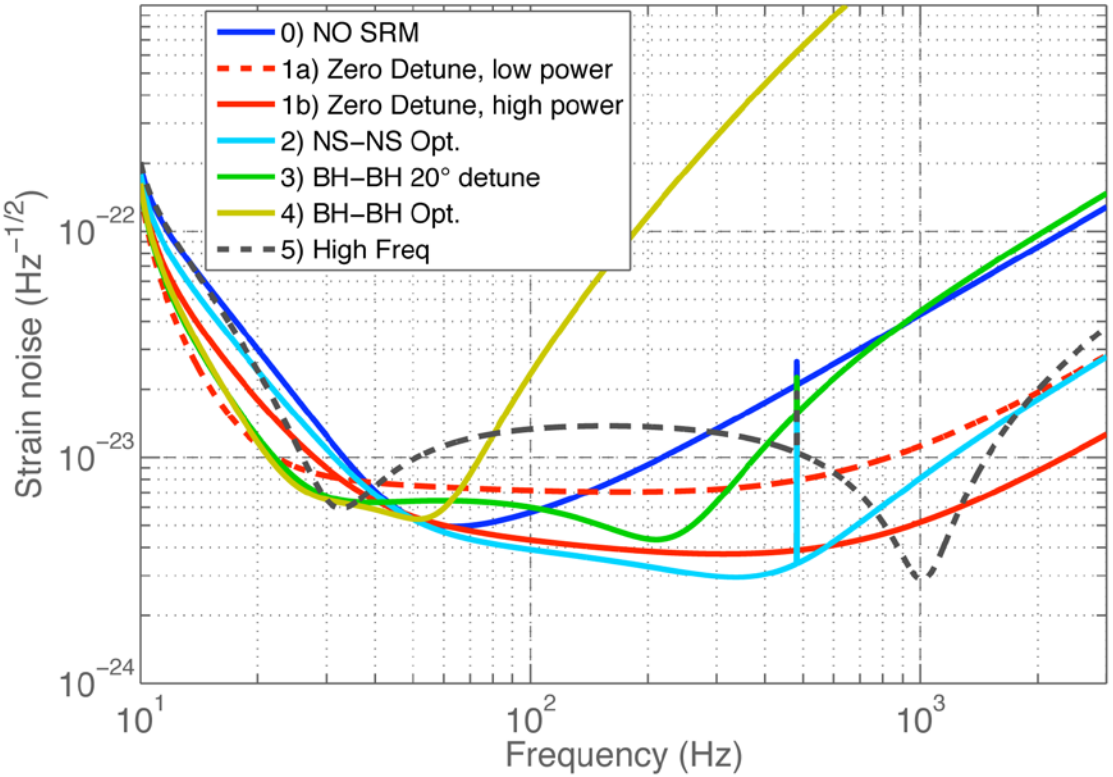
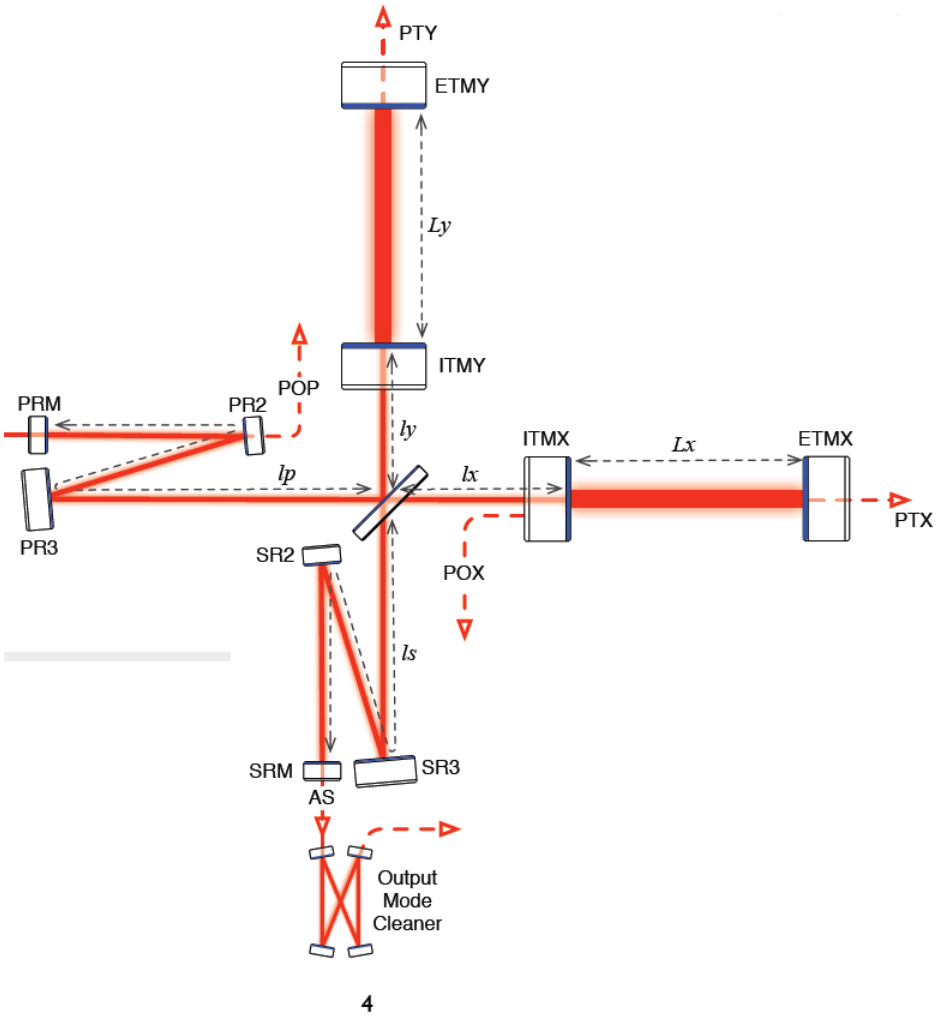


Figure 1: Proposed modes of operation for the Advanced LIGO interferometers. See text for description of the modes.

Advanced LIGO Overview

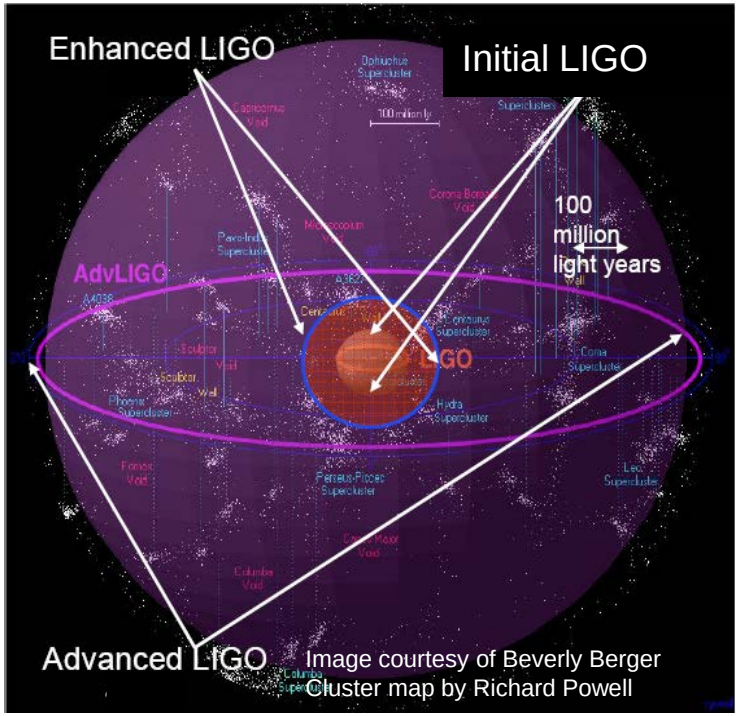
What is Advanced?

Parameter	*Initial LIGO*	*Advanced LIGO*
Input Laser Power	10 W (10 kW arm)	180 W (>700 kW arm)
Mirror Mass	10 kg	40 kg
Interferometer Topology	Power-recycled Fabry-Perot arm cavity Michelson	Dual-recycled Fabry-Perot arm cavity Michelson (stable RC)
GW Readout Method	RF heterodyne	DC homodyne
Optimal Strain Sensitivity	3 x 10^{-23} / rHz	Tunable, better than 5 x 10^{-24} / rHz in broadband
Seismic Isolation Performance	f_{low} ~ 50 Hz	f_{low} ~ 12 Hz
Mirror Suspensions	Single Pendulum	Quadruple pendulum

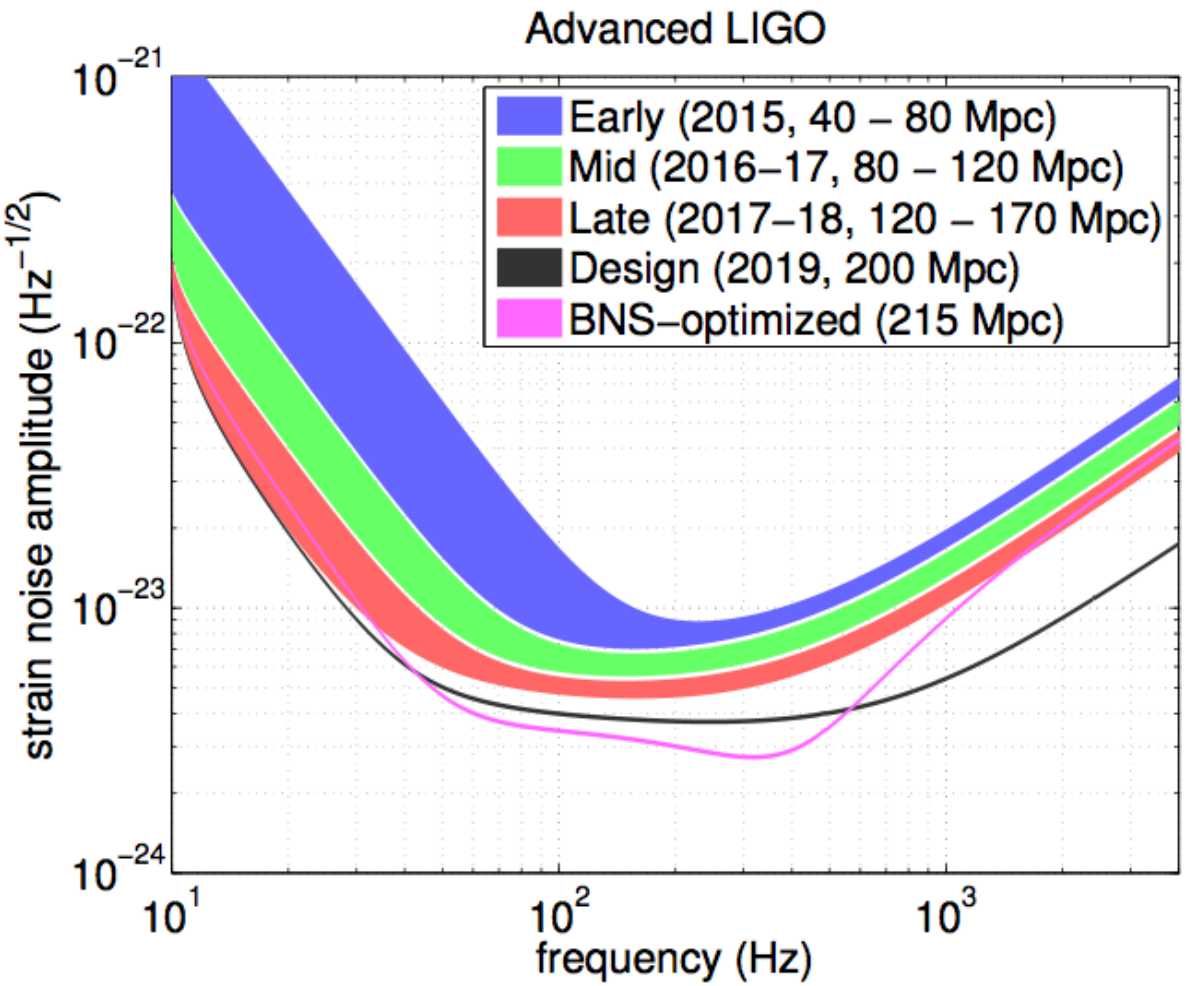


Advanced LIGO

- A complete redesign and rebuild of the LIGO interferometers
  - 10x more sensitive →1000x more volume probed
- Advanced LIGO funded by NSF in April 2008
  - 7 year construction project, planned end in March 2015
- $205.1M in funding from NSF
- Capital contributions from international partners
  - Science and Technology Facilities Council, UK ($14M), Max Planck Society, Germany ($14M), Australian Research Council ($1.7M)
- Three interferometer upgrade: Original plan to place 2 interferometers @ Hanford and 1 @ Livingston has been modified to place 1 each @ Hanford and Livingston and store third interferometer for construction in India late this decade
- Construction by LIGO Laboratory with participation by member groups of the LIGO Scientific Collaboration
- Project-wise, ~ 87% complete
  - Through most of the subsystem assembly, testing, and installation
  - Through some of the more complex integrated testing phase
- ***On time and on budget for completion in March 2015***

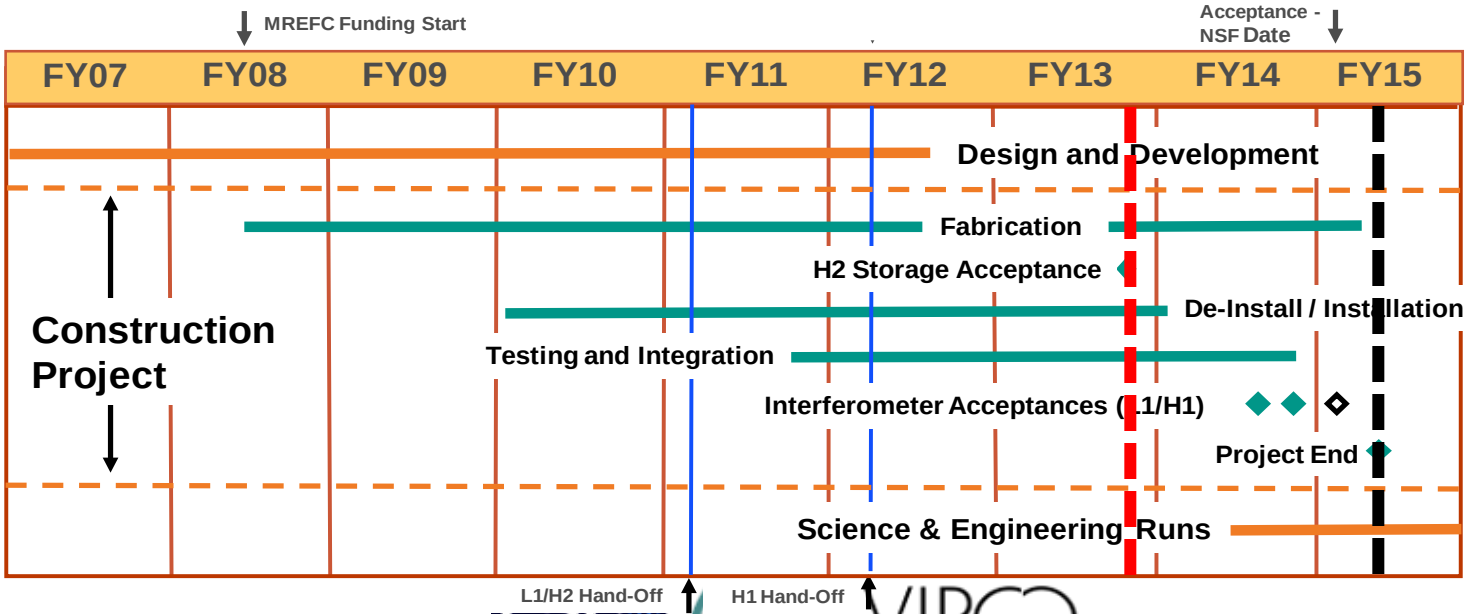


Advanced LIGO Projected Sensitivity Evolution



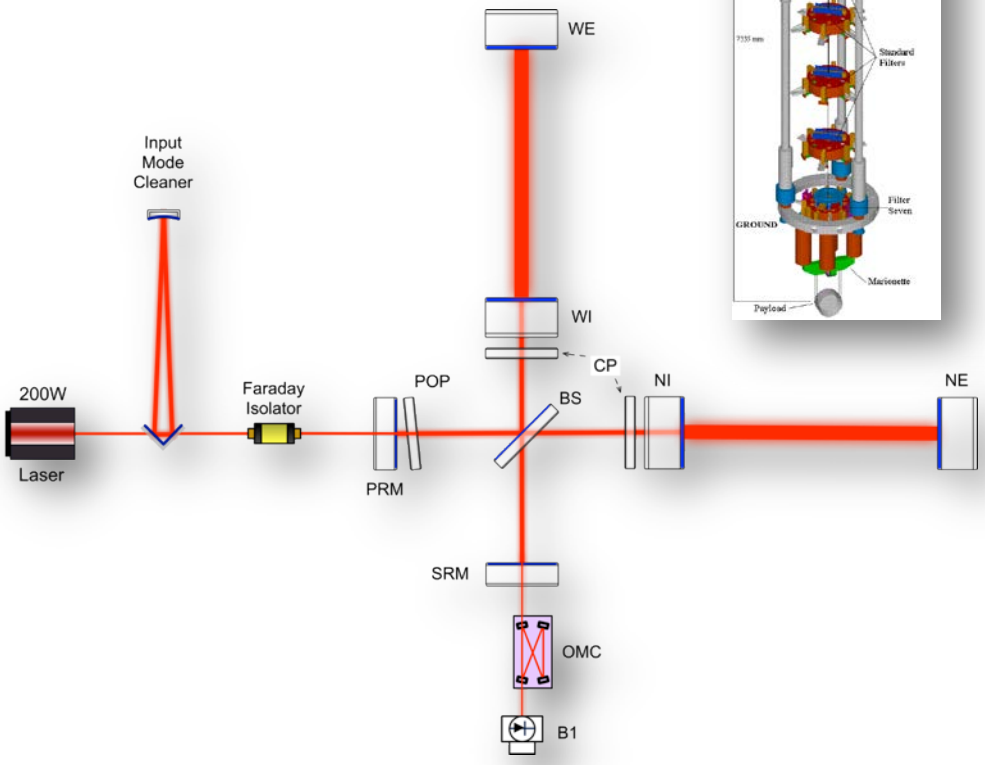
Timeline From Now to Advanced LIGO Science Operations

- Formal hand-off of the interferometers to observatory operations requires each to interferometer lock for 2 hours
- We expect both Hanford and Livingston interferometers to be turned over to observatory operations in late 2014
  - ***Very important point: hand-off does not imply astrophysically interesting sensitivity***
- Advanced LIGO Project formally ends March 2015 after installation of storage and analysis computers
- **The inaugural Advanced LIGO science run will take place after interferometers have been tuned to reach 'good sensitivity' → likely the latter half of 2015**



Advanced Virgo Design

- Main improvements w.r.t. Virgo
  - larger optical beams
  - More massive mirrors
  - higher quality optics
  - Better thermal control of aberrations
  - 200W fiber laser
  - signal recycling
- Already proven: vibration isolation by Virgo superattenuators
  - performance demonstrated
  - large experience gained with commissioning at low frequency



Advanced Virgo Projected Sensitivity Evolution