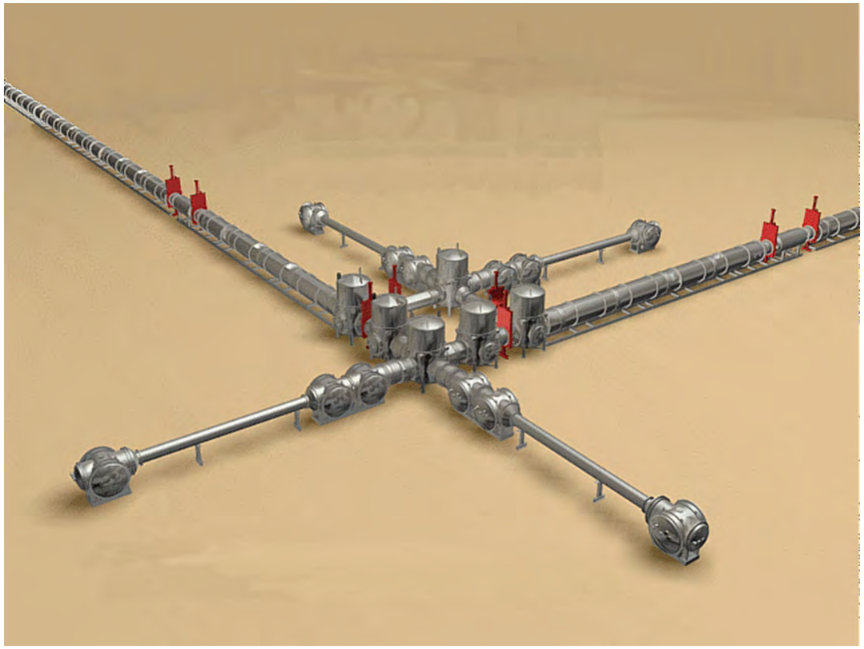
The LIGO Vacuum System and plans for LIGO-Australia



Stan Whitcomb

IndIGO - ACIGA meeting on LIGO-Australia

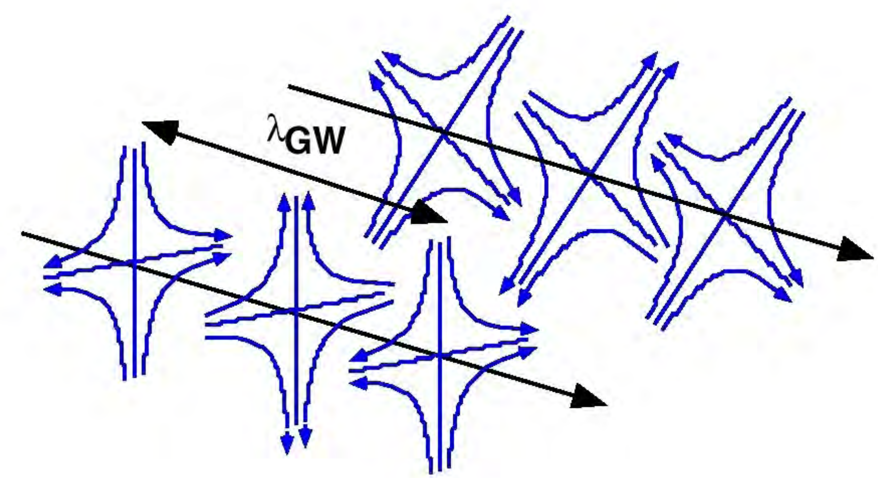
9 February 2011

LIGO-G1100108-v1

Gravitational Wave Physics

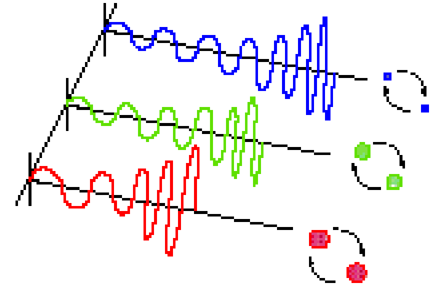
- **Einstein (in 1916 and 1918) recognized gravitational waves in his theory of General Relativity**
  - » **Necessary consequence of Special Relativity with its finite speed for information transfer**
  - » **Most distinctive departure from Newtonian theory**
- **Analogous to electro-magnetic waves (in some ways!)**
  - » **Propagate away from the sources at the speed of light**
  - » **Purely transverse waves**
  - » **Alternating stretching and shrinking of space in perpendicular directions**

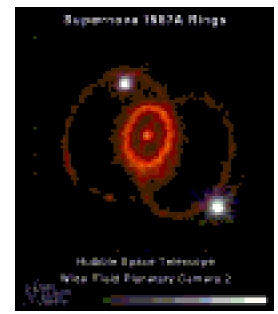
$$h = \Delta L / L$$



Astrophysical Sources for Terrestrial GW Detectors

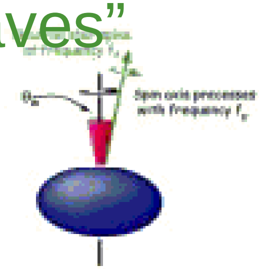
- Compact binary inspiral: "chirps"
  - » **NS-NS, NS-BH, BH-BH**



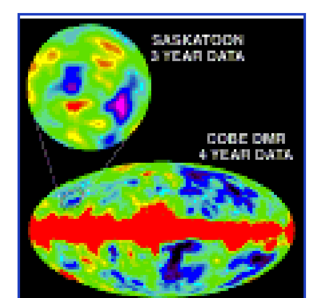


- Supernovas or GRBs: "bursts"
  - » **GW signals observed in coincidence with EM or neutrino detectors**

- Pulsars in our galaxy: "periodic waves"
  - » **Rapidly rotating neutron stars**
  - » **Modes of NS vibration**



- Cosmological: "stochastic background"
  - » **Probe back to the Planck time (10^{-43} s)**

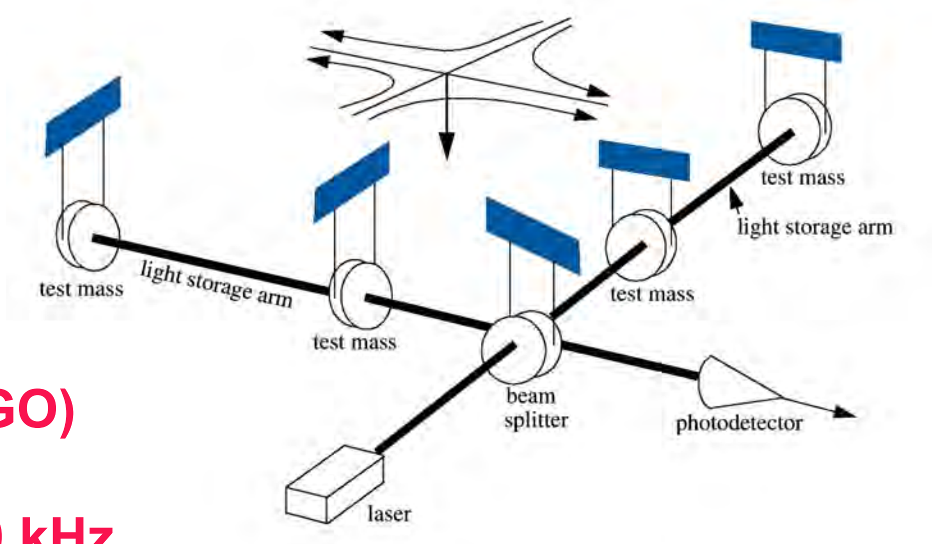


Detecting GWs with Interferometry

Suspended mirrors act as "freely-falling" test masses

in horizontal plane for frequencies $f \gg f_{pend}$

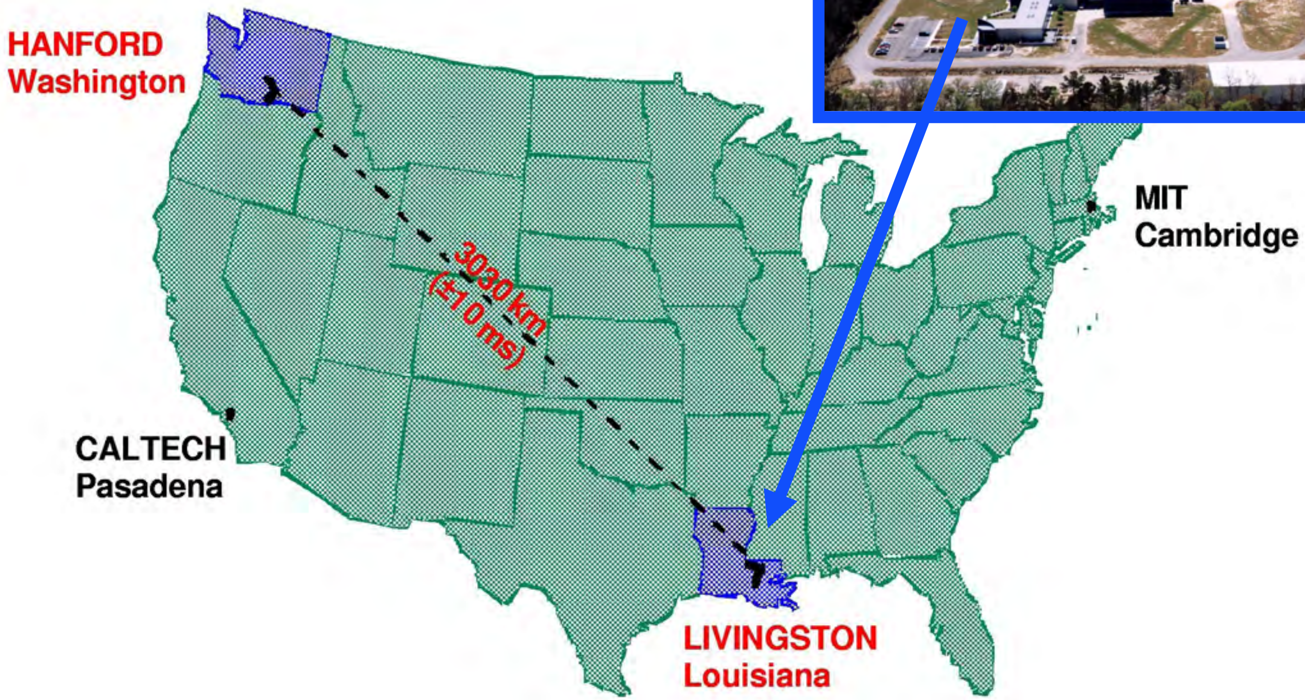
$$h = \Delta L / L$$



Terrestrial detector,
L ~ 4 km
For $h \sim 10^{-22} - 10^{-21}$ (Initial LIGO)
$\Delta L \sim 10^{-18}$ m
Useful bandwidth 10 Hz to 10 kHz, determined by "unavoidable" noise (at low frequencies) and expected maximum source frequencies (high frequencies)

LIGO Observatories

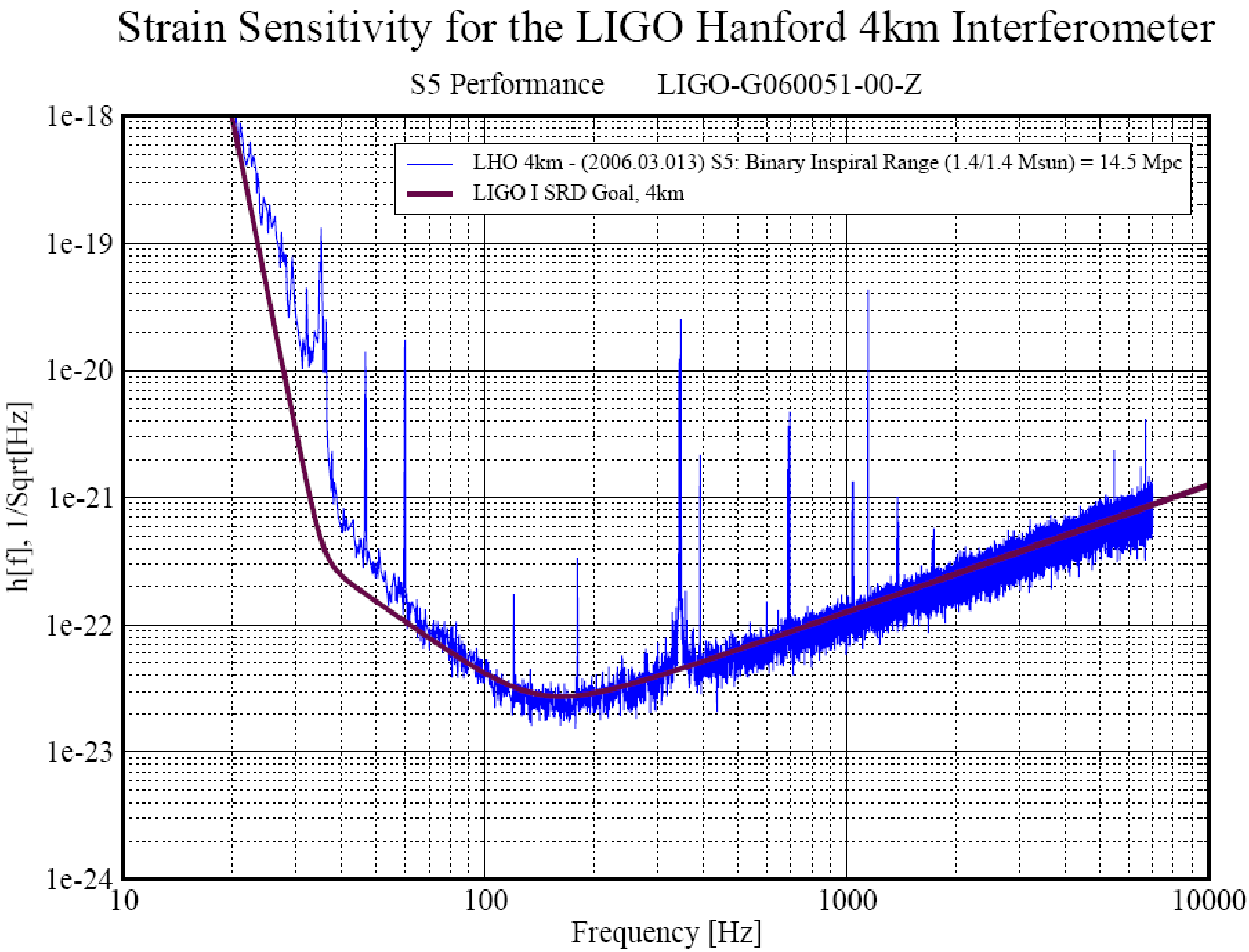
Facility Construction 1994-2000



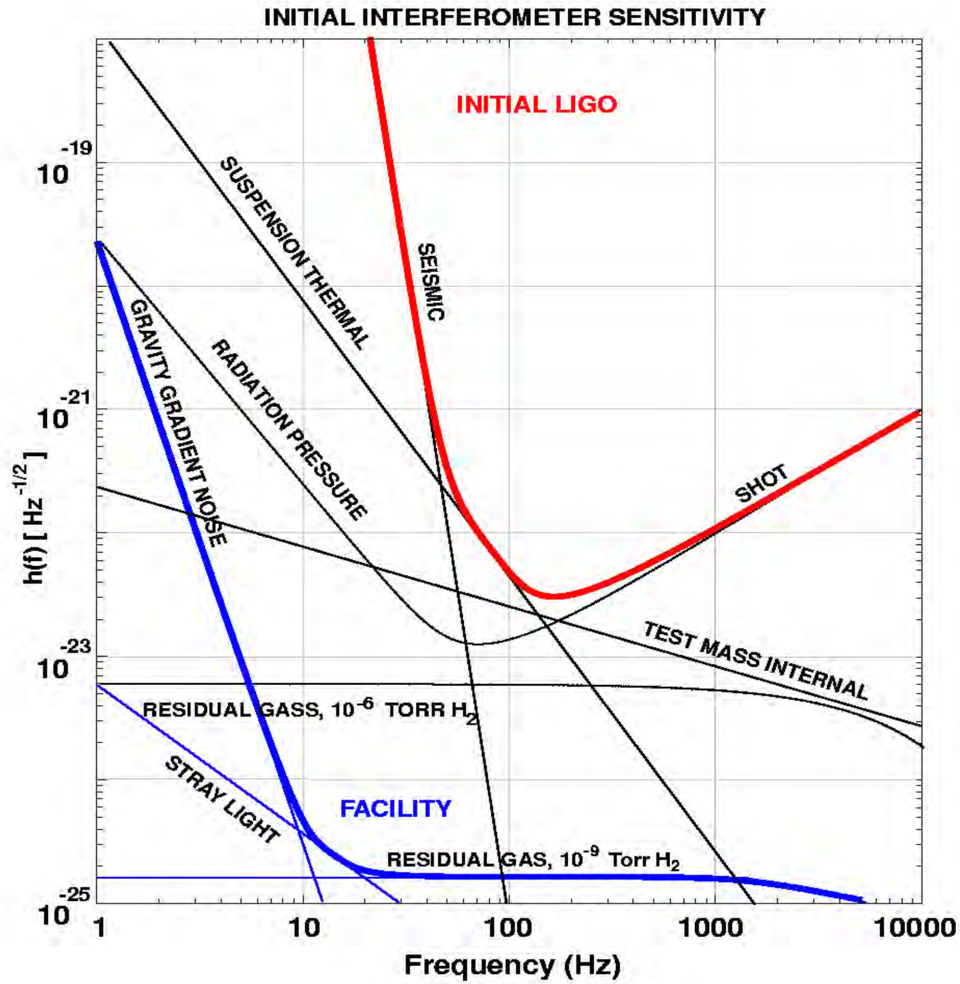
LIGO
Hanford Observatory

LIGO
Livingston Observatory

LIGO Sensitivity



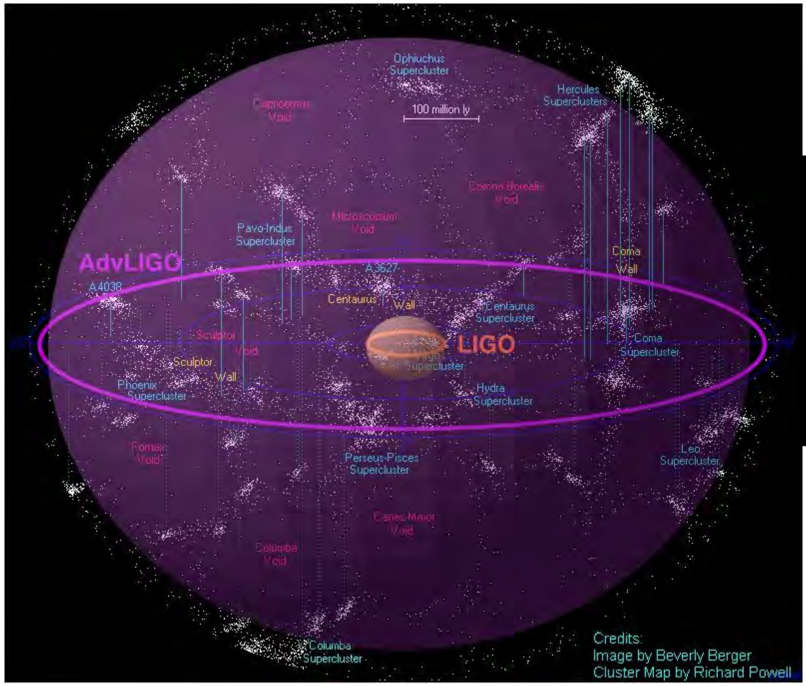
Facility Limits to Sensitivity



- Facility limits leave lots of room for future improvements
- Vacuum requirement $<10^{-9}$ torr H_2 $<10^{-10}$ torr H_2O

What's next for LIGO? Advanced LIGO

- Take advantage of new technologies and on-going R&D
  - » Active anti-seismic system operating to lower frequencies
  - » Lower thermal noise suspensions and optics
  - » Higher laser power
  - » More sensitive and more flexible optical configuration



x10 better amplitude sensitivity

⇒ x1000 rate=(reach)³

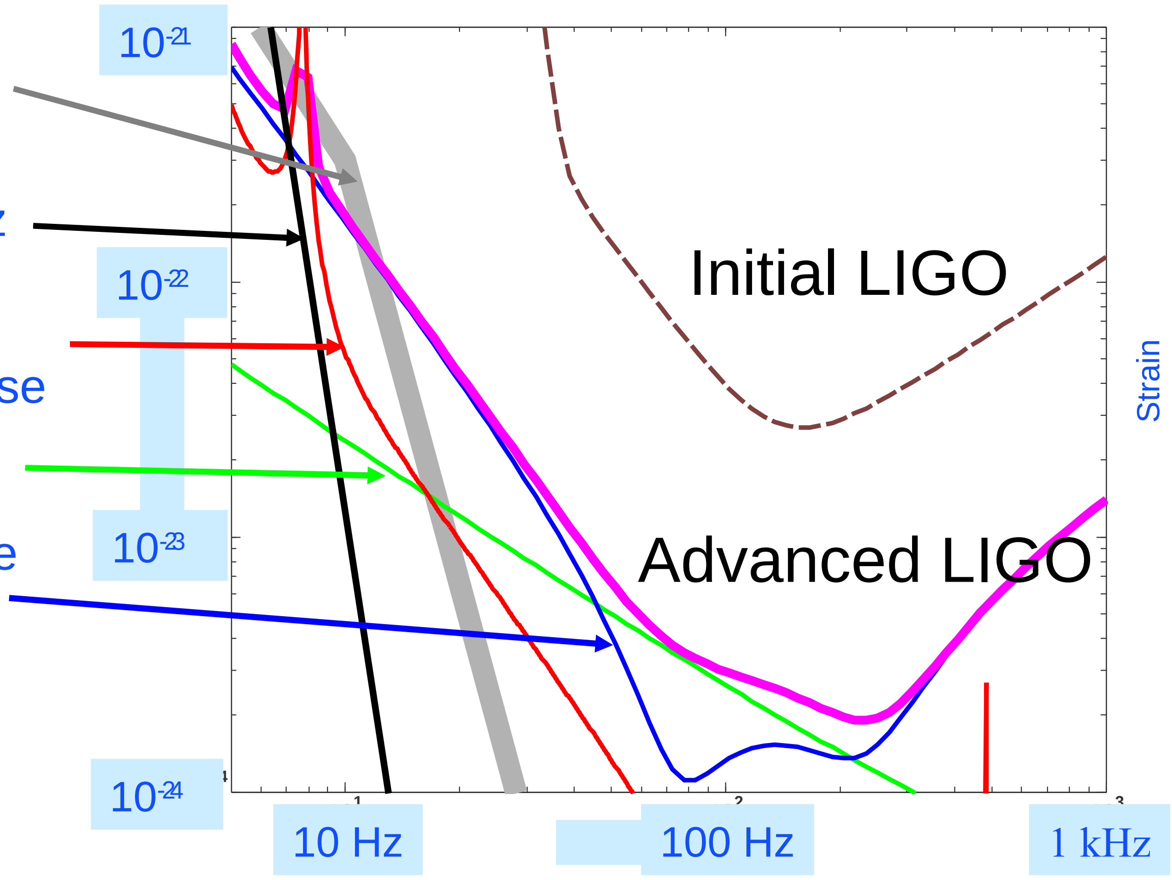
⇒ 1 day of Advanced LIGO

» 1 year of Initial LIGO !

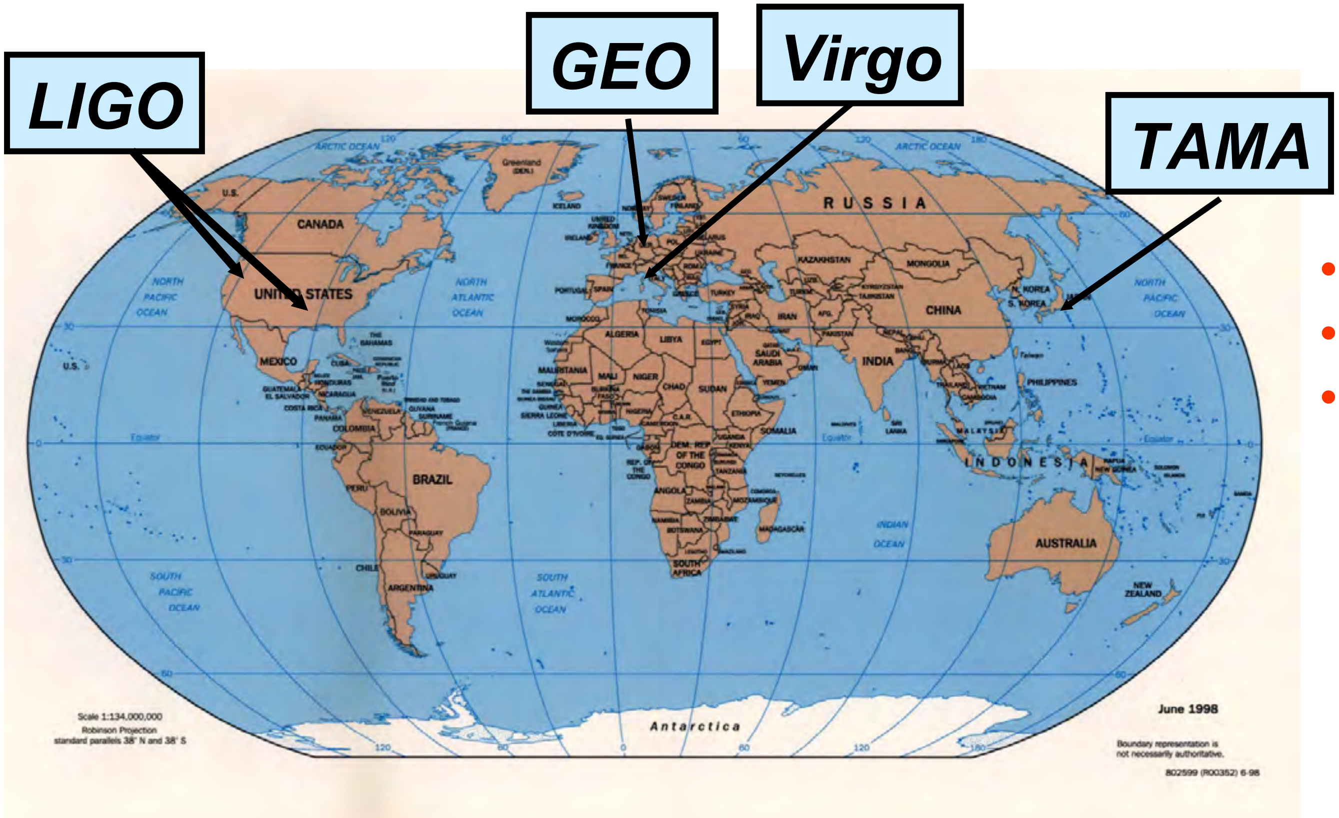
2008 start,
installation beginning 2011

Advanced LIGO Performance

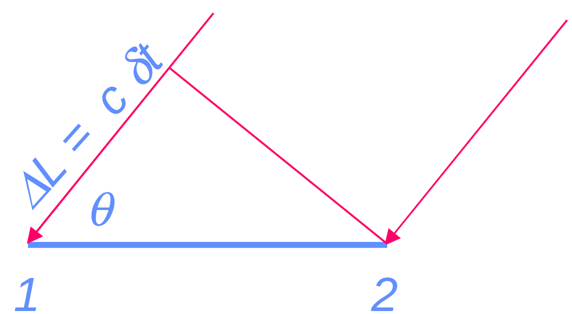
- Newtonian background, estimate for LIGO sites
- Seismic 'cutoff' at 10 Hz
- Suspension thermal noise
- Test mass thermal noise
- Quantum noise dominates at most frequencies



A Global Network of GW Detectors 2009

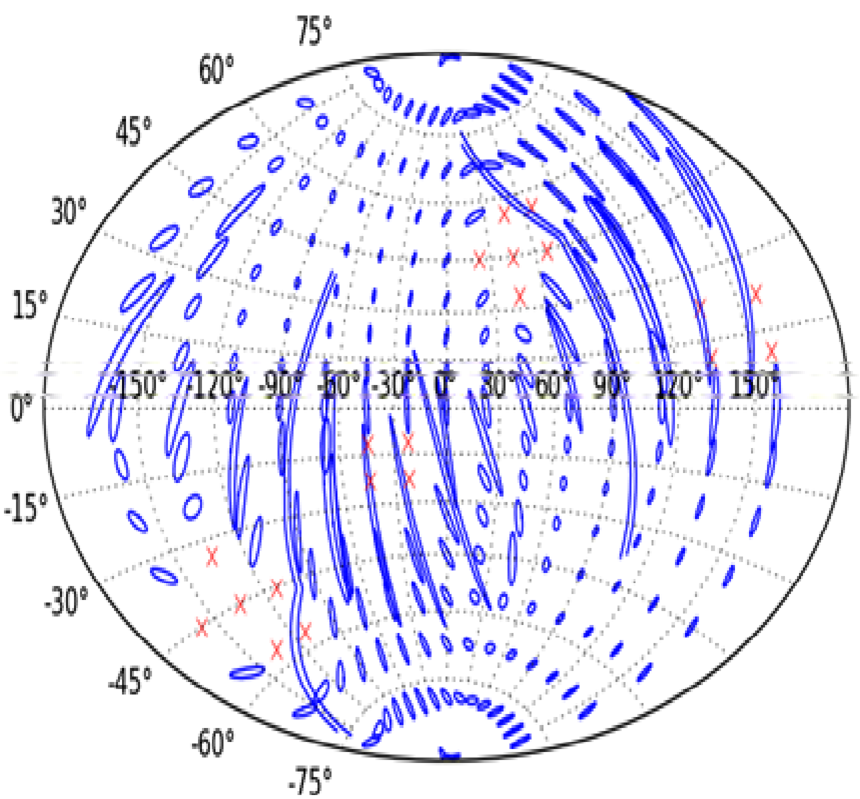


- **Detection confidence**
- **Locate sources**
- **Decompose the polarization of gravitational waves**

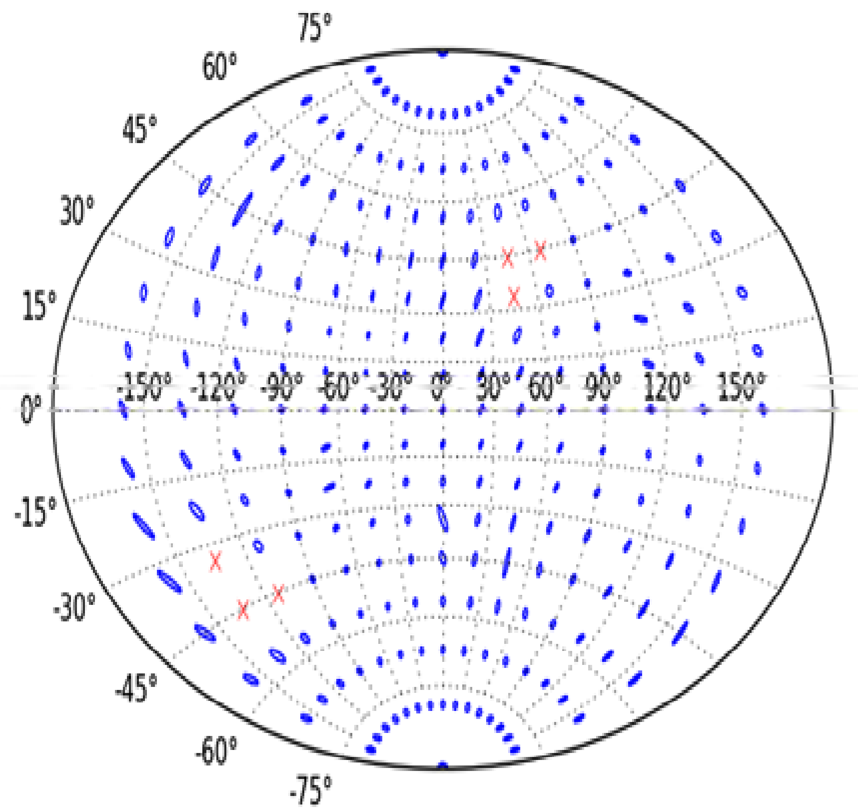


Benefits of LIGO-Australia

Determination of source sky position: NS-NS binary inspirals



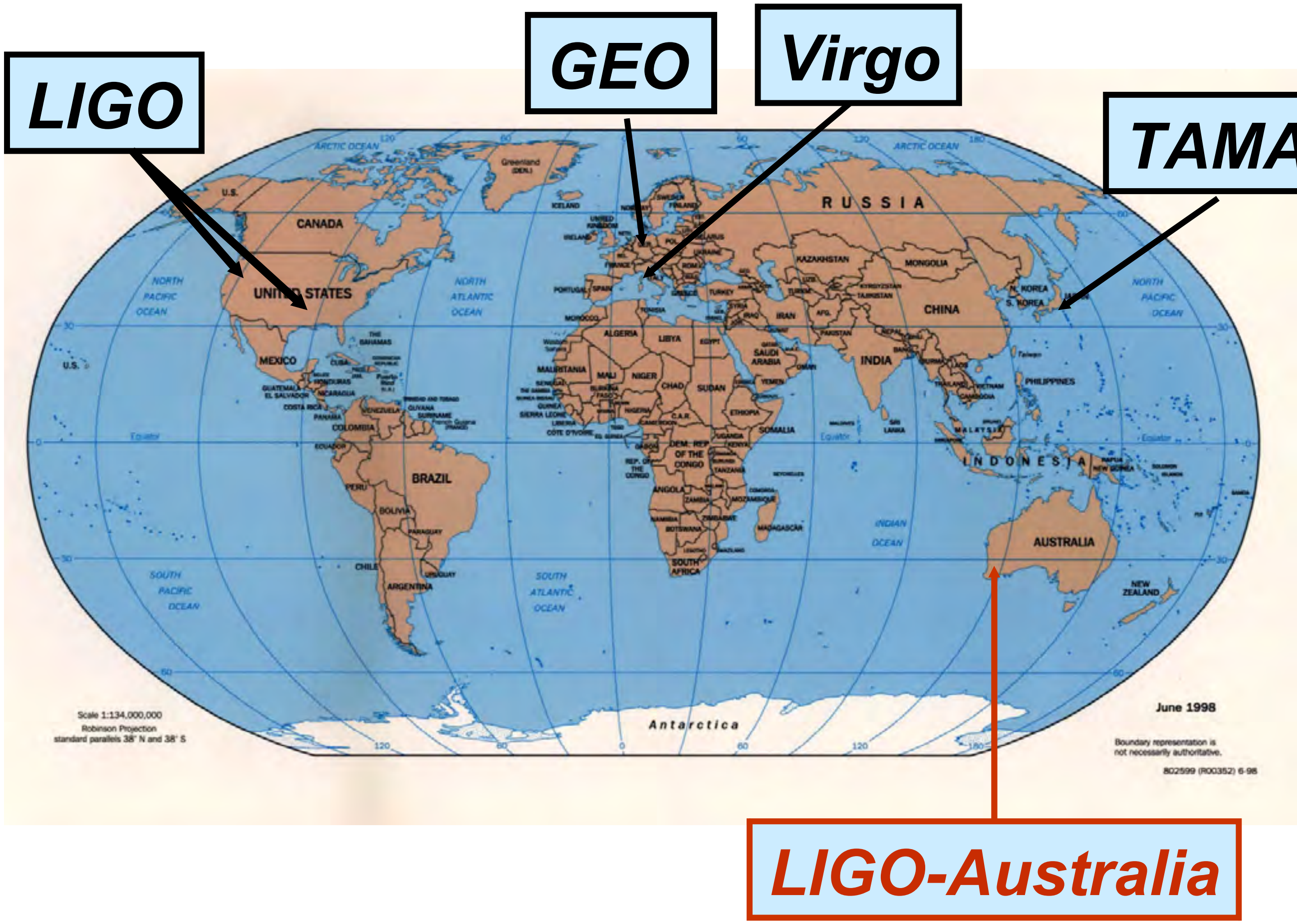
LIGO + Virgo



With LIGO-Australia

LIGO

Completing the Global Network



Southern Hemisphere detector

LIGO-Australia Concept

- A direct partnership between LIGO Laboratory and Australian collaborators to build an Australian interferometer
  - » LIGO Lab (with its UK, German and Australian partners) provides components for one Advanced LIGO interferometer, unit #3, from the Advanced LIGO project
  - » Australia provides the infrastructure (site, roads, building, vacuum system), “shipping & handling,” staff, installation & commissioning, operating costs
- The interferometer, the third Advanced LIGO instrument, would be operated as part of LIGO to maximize the scientific impact of LIGO-Australia
- Key deadline: LIGO needs a commitment from Australia by October 2011—otherwise, must begin installation of the LIGO-Australia detector at LHO

LIGO

Australia and its partners provide a facility with-

- Vacuum system
- Site, buildings

LIGO Beam Tube

- LIGO beam tube under construction in January 1998
- 16 m spiral welded sections
- girth welded in portable clean room in the field

1.2 m diameter - 3mm stainless
50 km of weld

NO LEAKS !!

Beam Tube Construction

LIGO beam tube enclosure

- minimal enclosure
- reinforced concrete
- no services

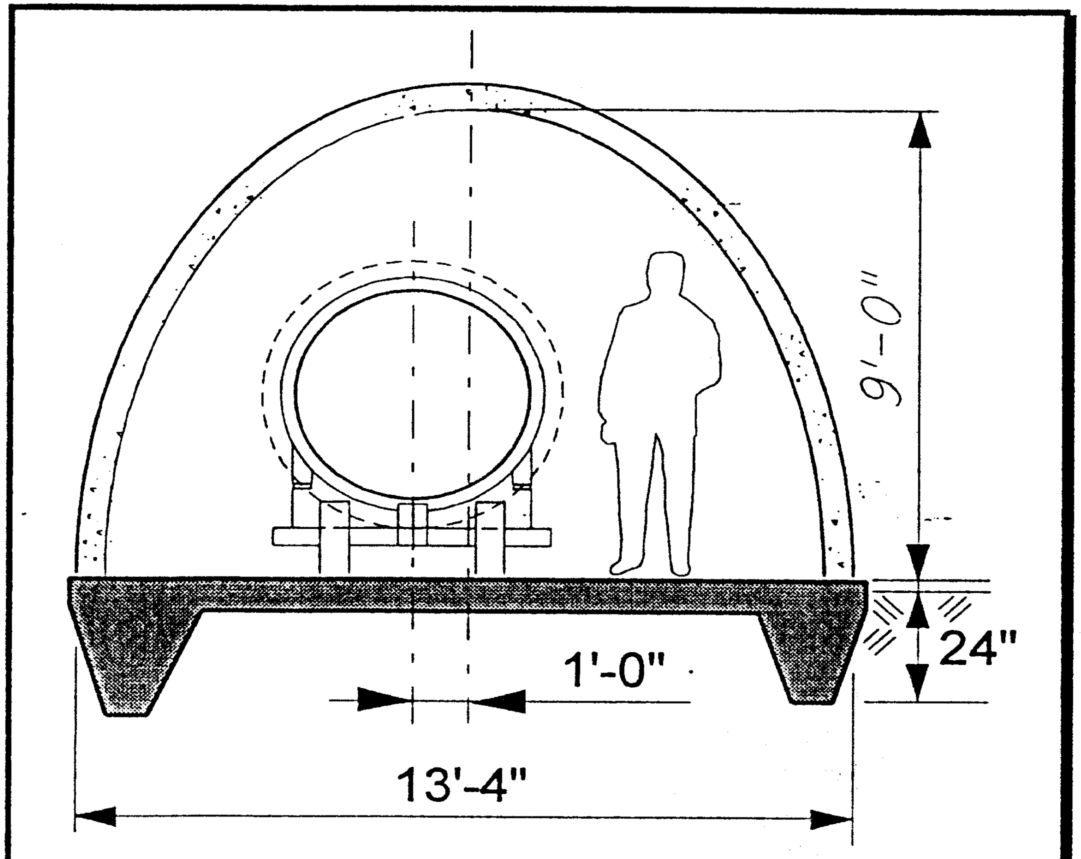
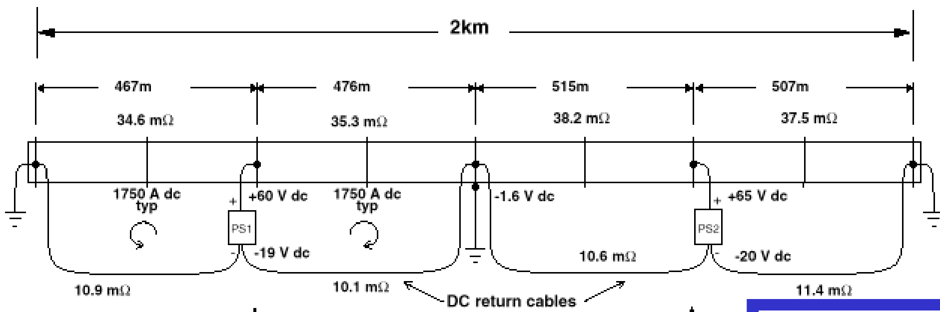
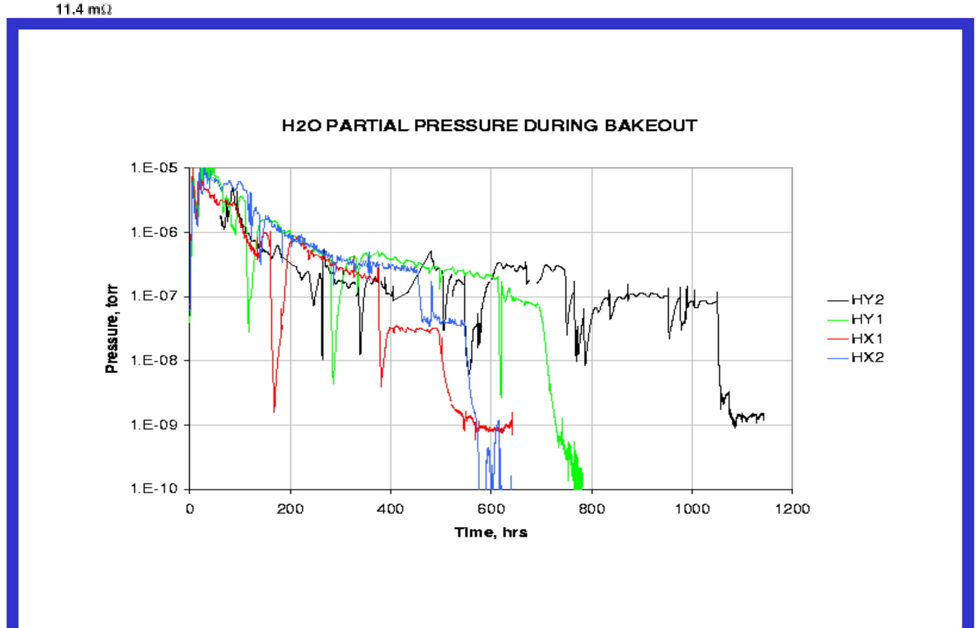


Figure 2.1-1 -- Cross Section of Design Baseline at Hanford

Beam Tube Bakeout

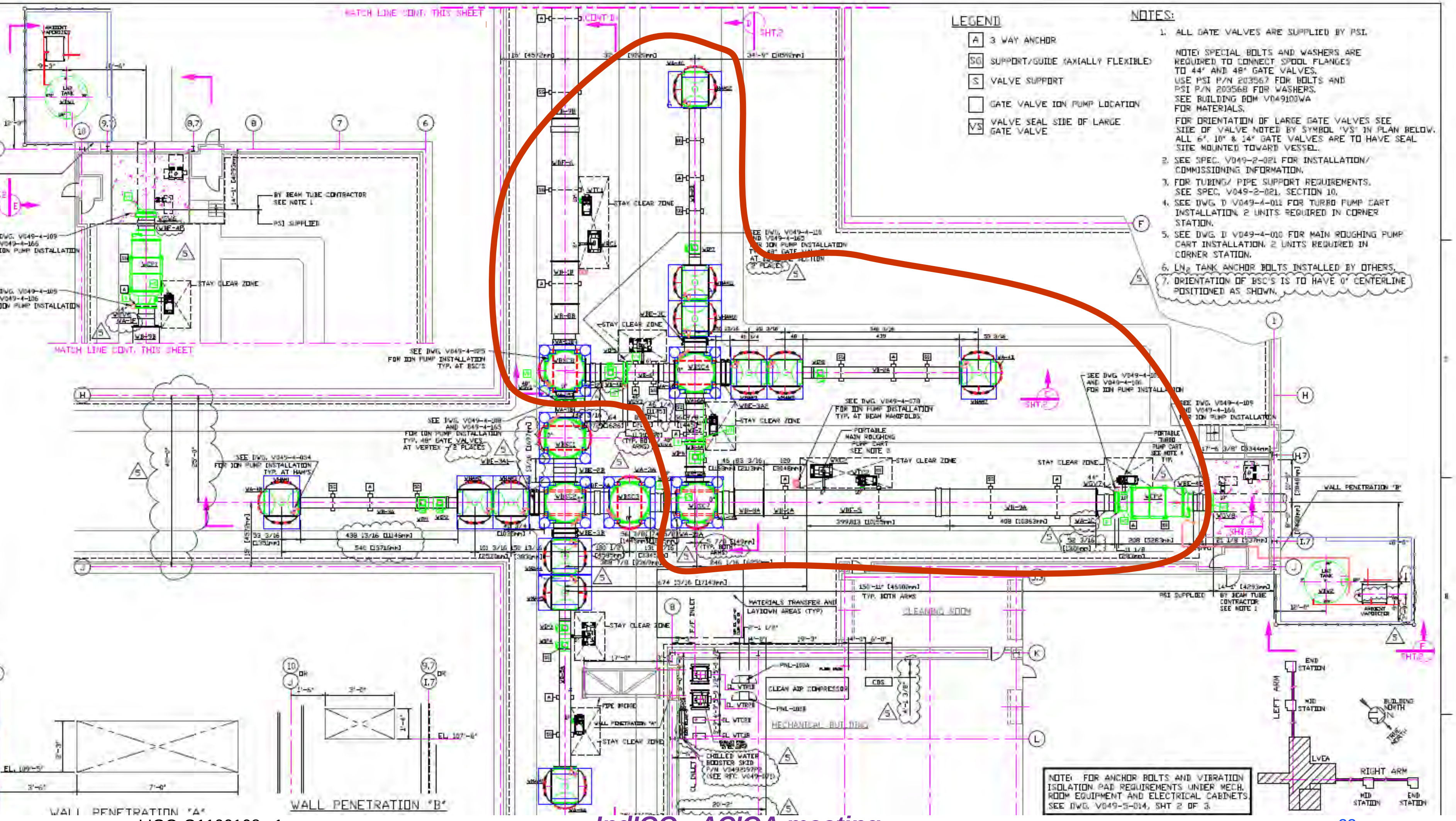


- **I = 2000 amps for ~ 1 week**
- **no leaks !!**
- **final vacuum at level where not limiting noise, even for future detectors**



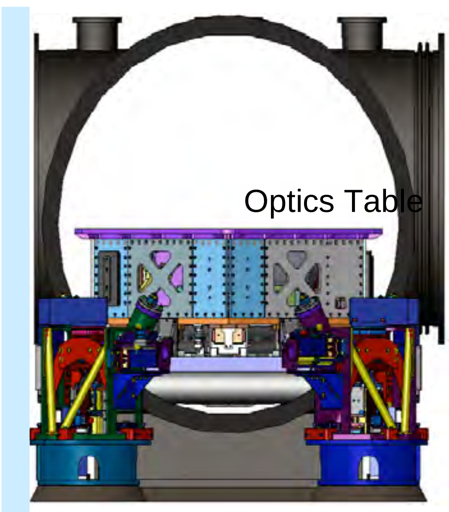
LIGO Vacuum Equipment

Corner Station Layout

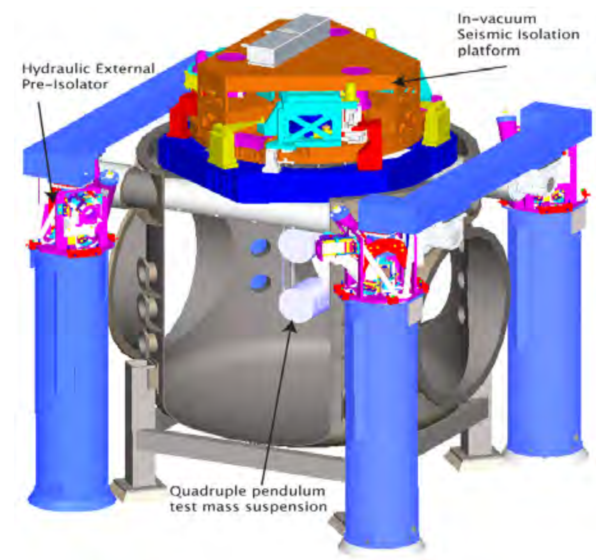


Two Chamber Types

- Main interface: Vibration Isolation System
  - » Reduce in-band seismic motion by 4 - 6 orders of magnitude
  - » Large range actuation for initial alignment and drift compensation
  - » Quiet actuation to correct for Earth tides and microseism at 0.15 Hz during observation

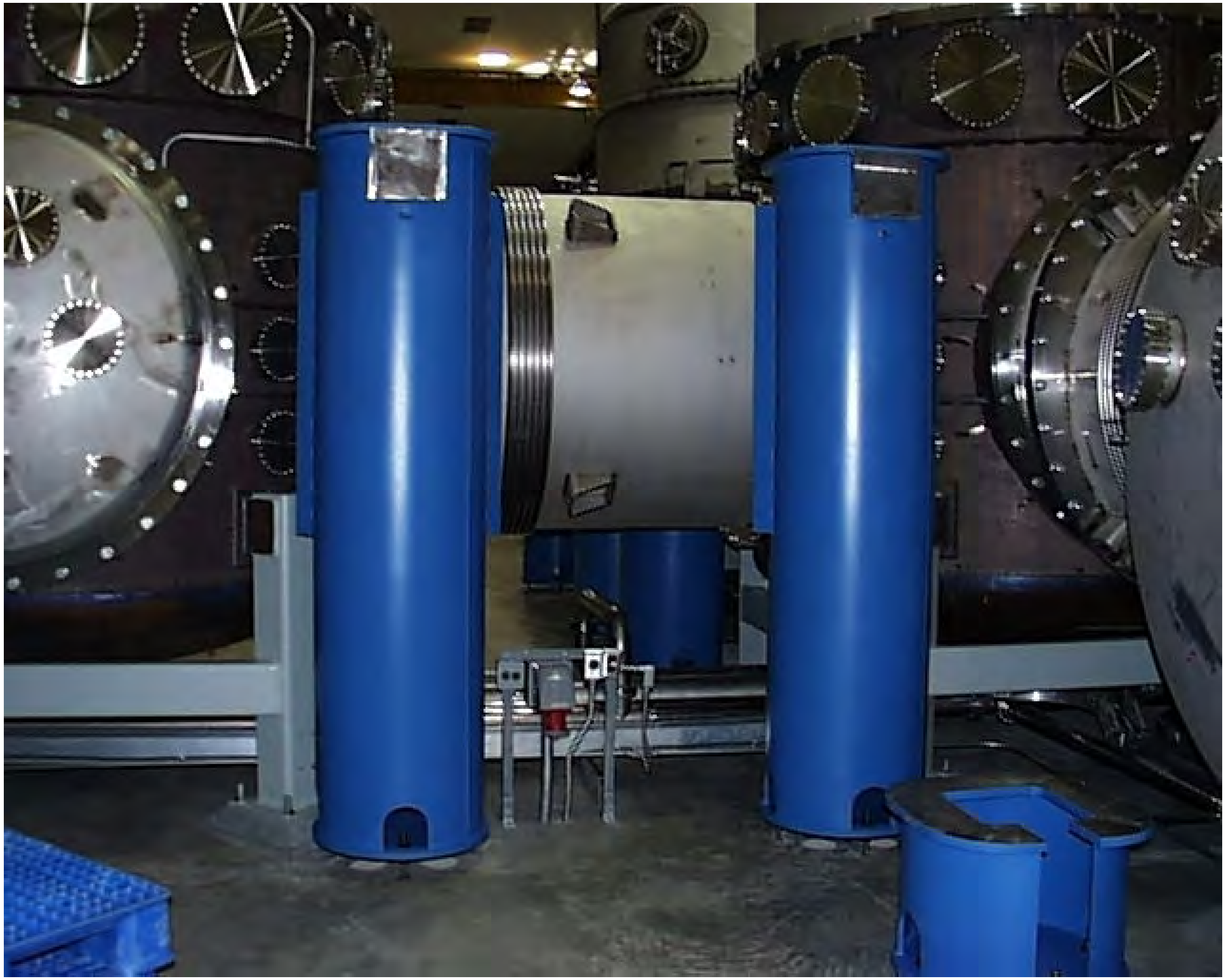


HAM



BSC

Adapters, Bellows, Spools



Fabrication and Installation

- Fabricated and cleaned off-site
- Delivered in sealed condition for alignment and installation

Corner Station Chambers

- Align, assemble, test under portable clean rooms

Beamtube Gate Valves

- Large gate valves to isolate beamtubes, LN2 traps

Pumps and Manifolds

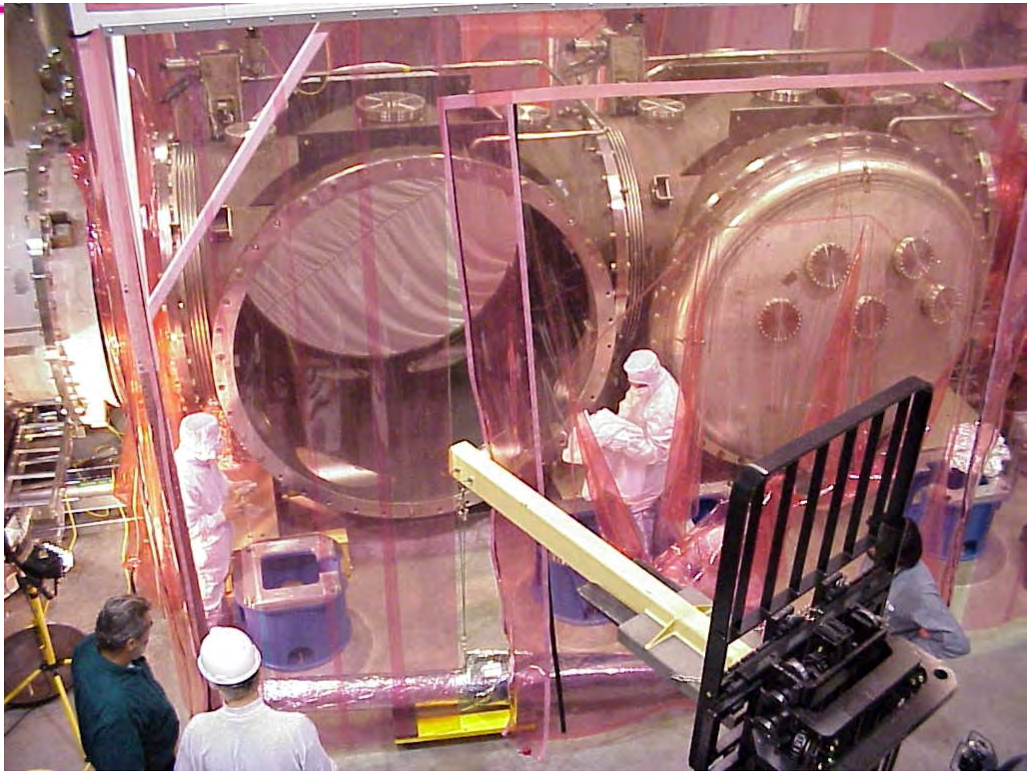
- Roughing pumps (Roots blowers) located remotely
- Ion pumps and LN2 traps located on vacuum system

Bake Out to Reduce Out-gassing

- Heating tapes and insulation for in-place bake-out

Detector Installation using Cleanrooms

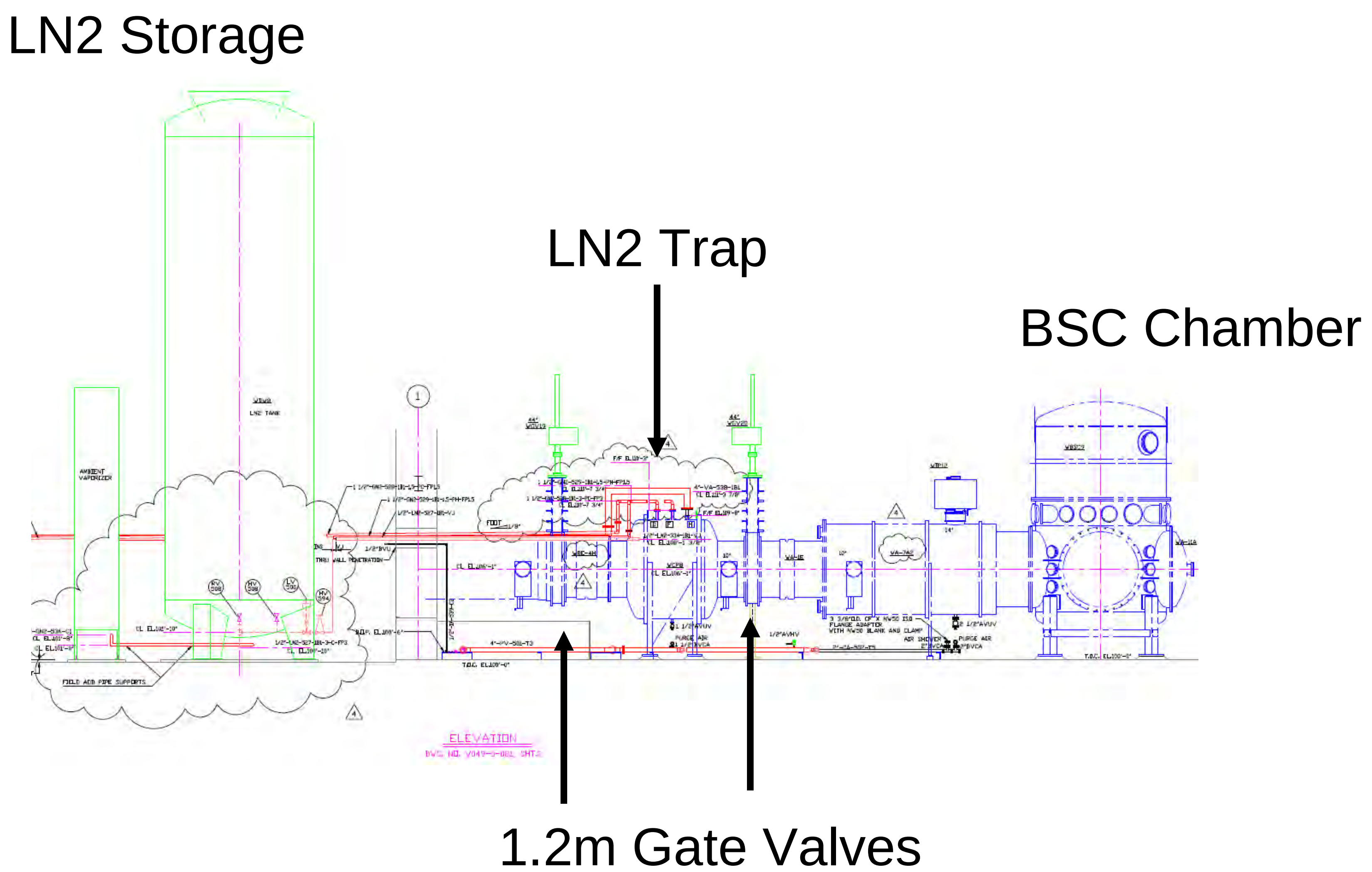
- Chamber access through large doors



HAM Chamber

Optics Installation Under Cleanroom Conditions

End Station



End Station

Final Remarks

- Vacuum system is a crucial part of LIGO
  - » Scope of Indian contribution depends on capabilities and funding
- Main challenges are leak free welds, (moderately) tight tolerances on welded structures, cleanliness
  - » BUT, it has all been done successfully!
- LIGO views our relationship with contractors on challenging projects as a partnership, not a competition