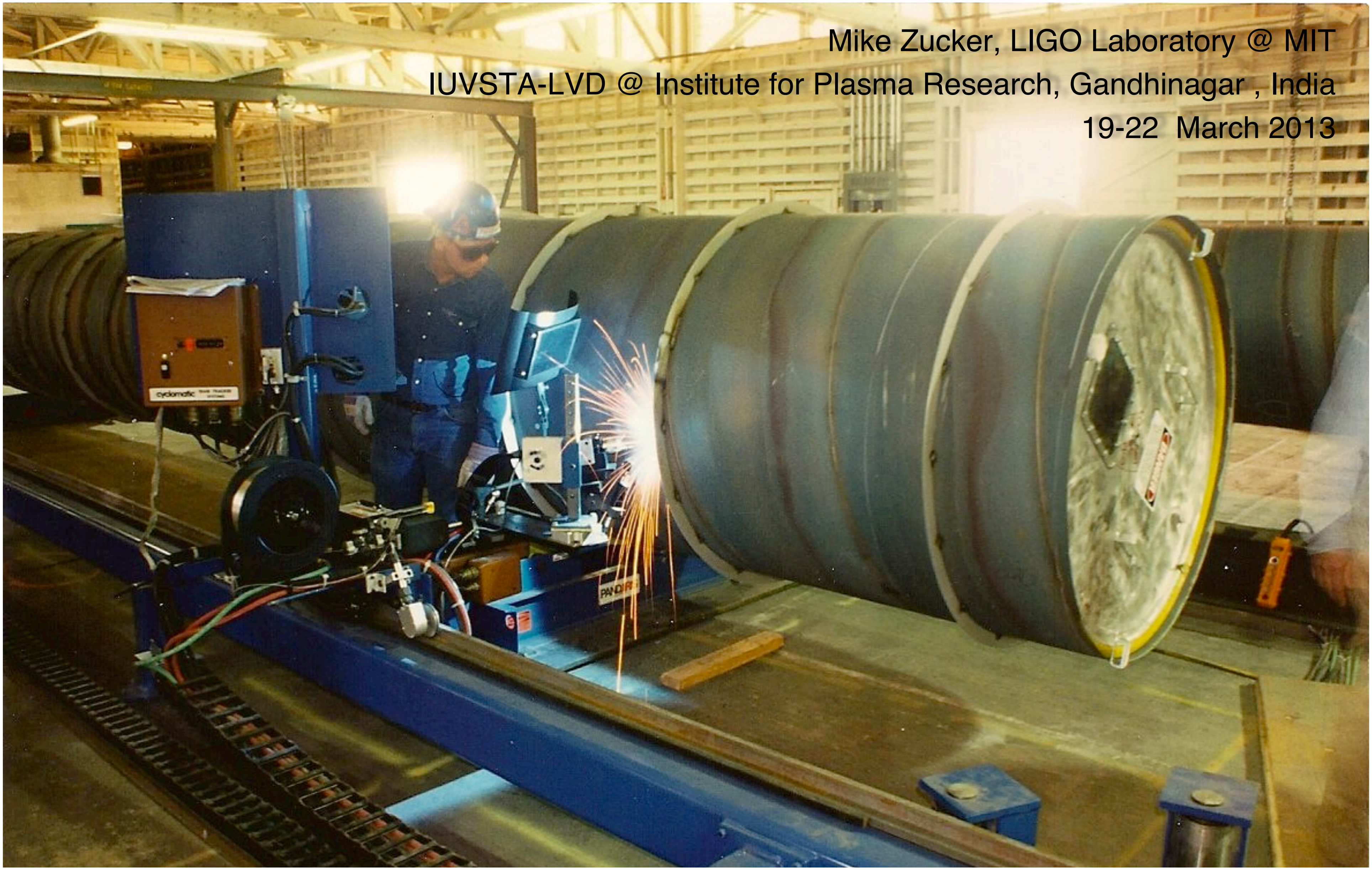
The LIGO Vacuum Equipment and Beam Tubes: Retrospective and Prospective



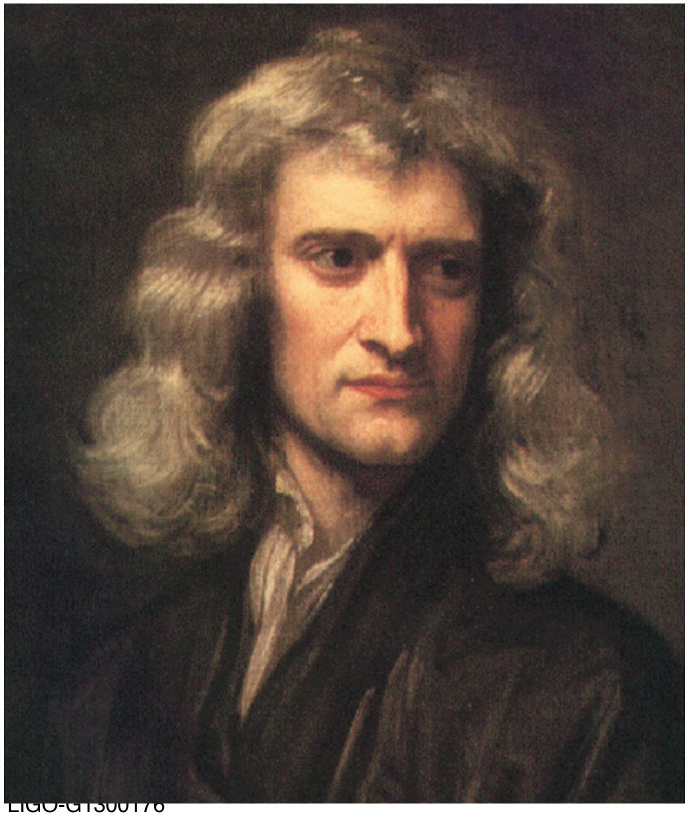
Mike Zucker, LIGO Laboratory @ MIT
IUVSTA-LVD @ Institute for Plasma Research, Gandhinagar , India
19-22 March 2013

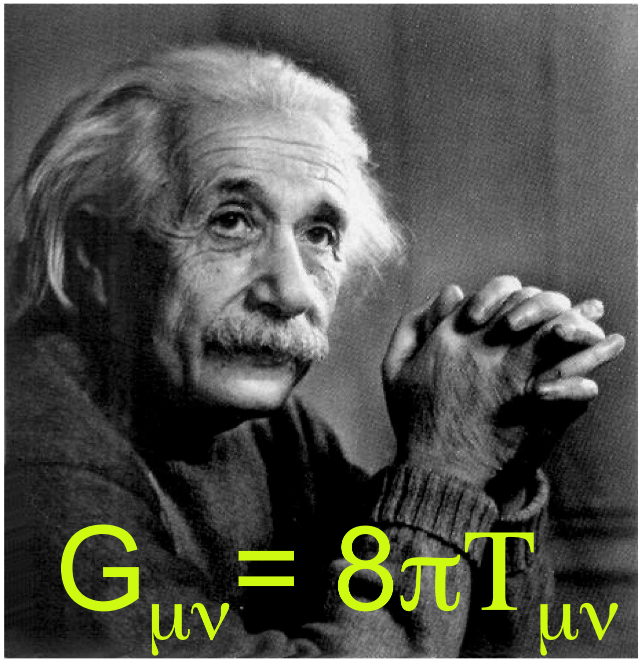
Outline

- About LIGO and LIGO India
- Vacuum Requirements & Constraints
- Vacuum Equipment
- Beam Tubes
- Paths for Improvement

Why must there be gravitational waves?

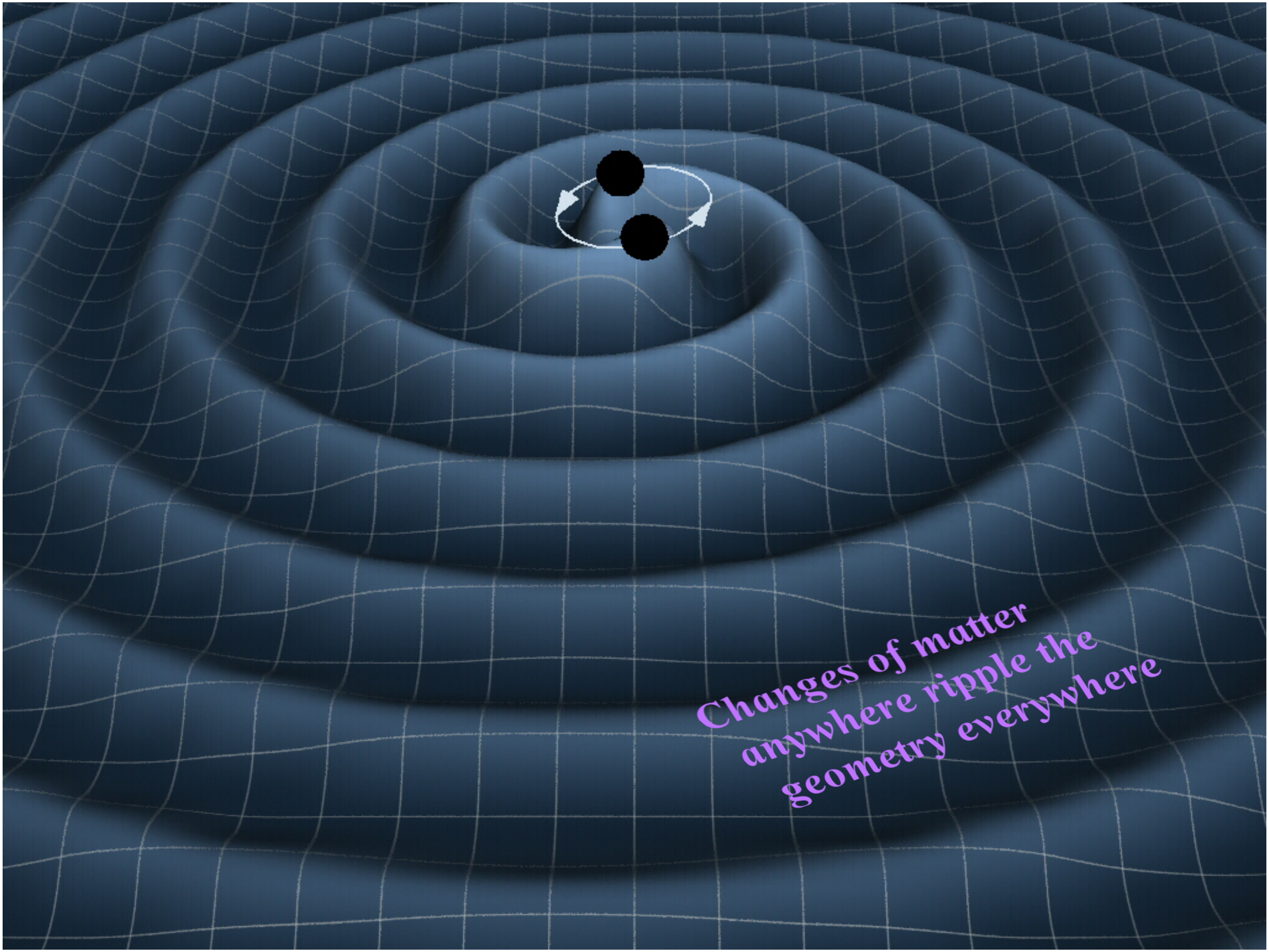
Newton's puzzle:
"instantaneous action at a distance"



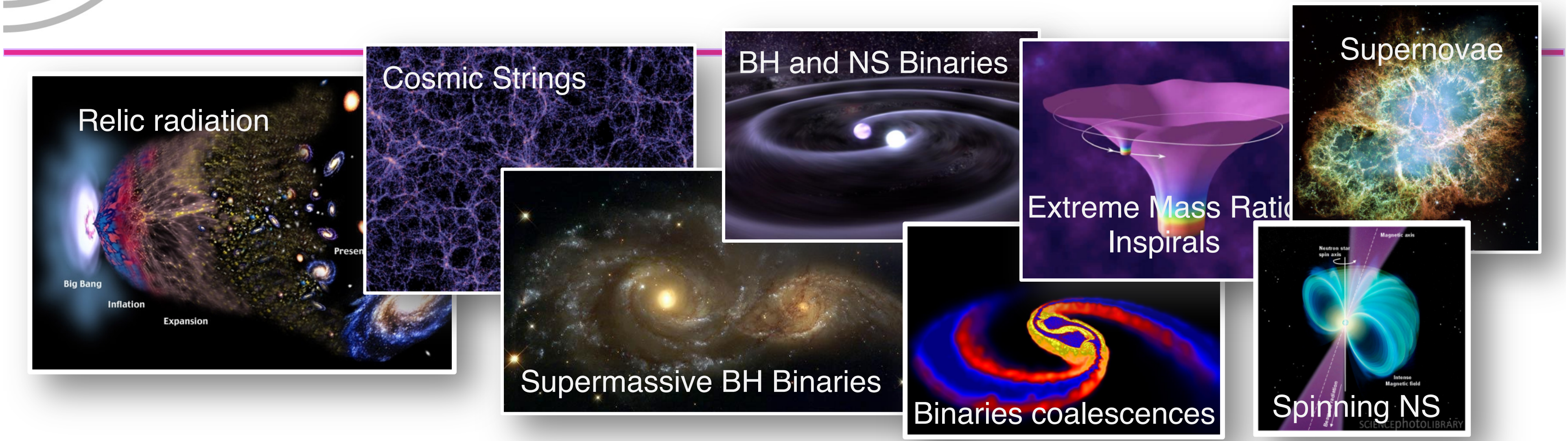


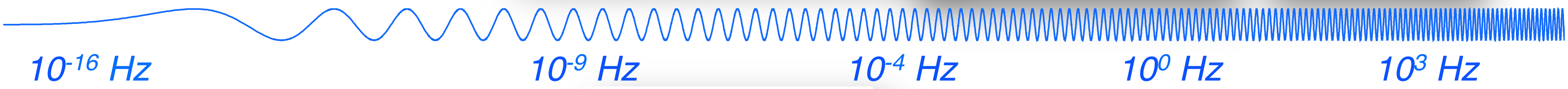
$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$

General Relativity
Spacetime itself is a medium
Geometry carries information


Changes of matter
anywhere ripple the
geometry everywhere

The GW Spectrum



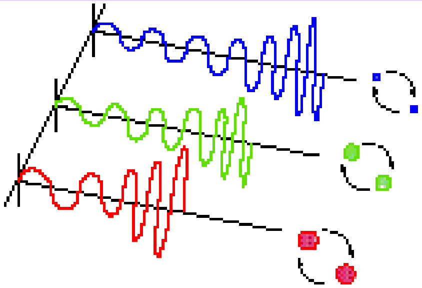


Inflation Probe | Pulsar timing | Space detectors | Ground interferometers

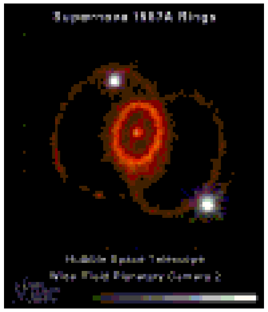
Laser
Interferometer
Gravitational
Wave
Observatory

Some Expected Astrophysical Sources

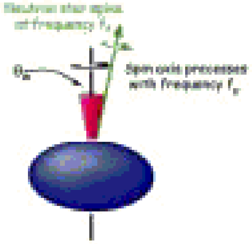
- Compact binary inspiral: “chirps”
  - **NS-NS, NS-BH, BH-BH**



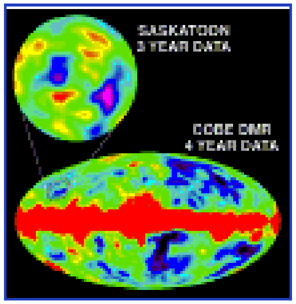
- Supernovas or GRBs: “bursts”
  - **GW signals observed in coincidence with EM or neutrino detectors**



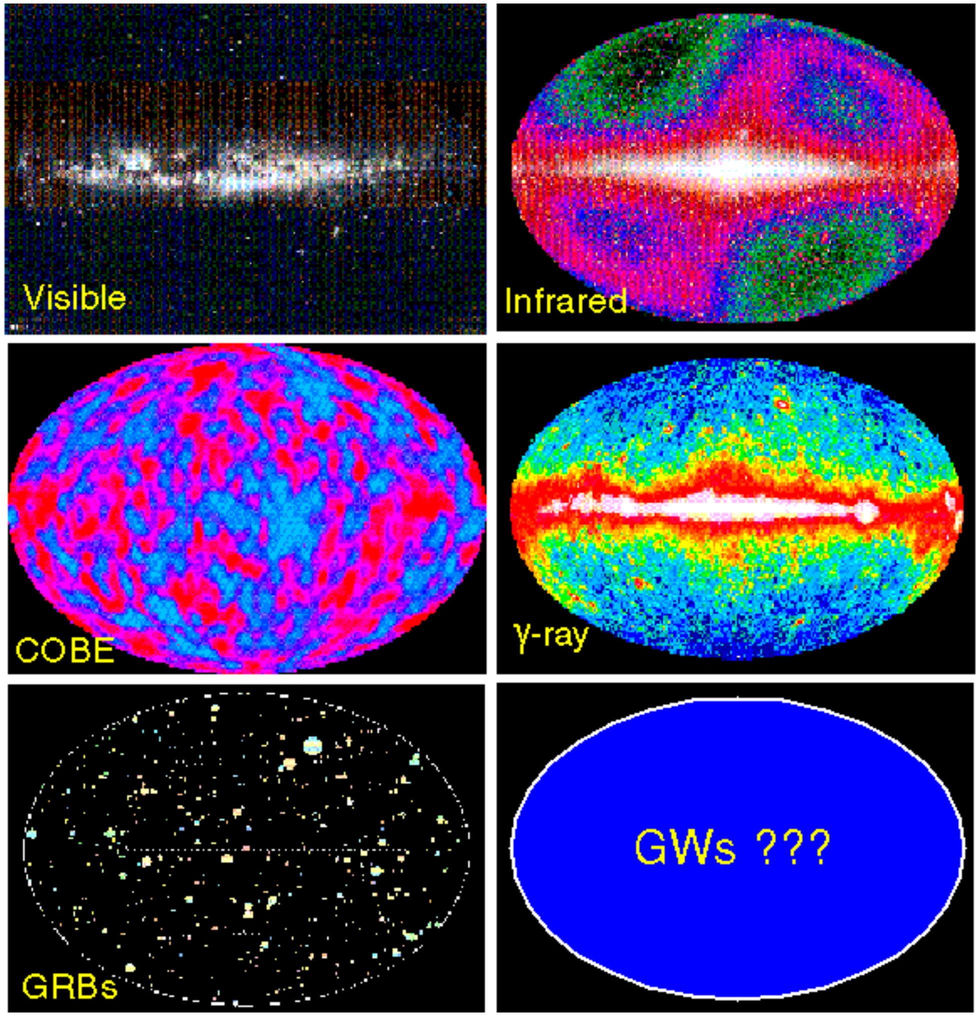
- Pulsars in our galaxy: “periodic waves”
  - **Rapidly rotating neutron stars**
  - **Modes of NS vibration**

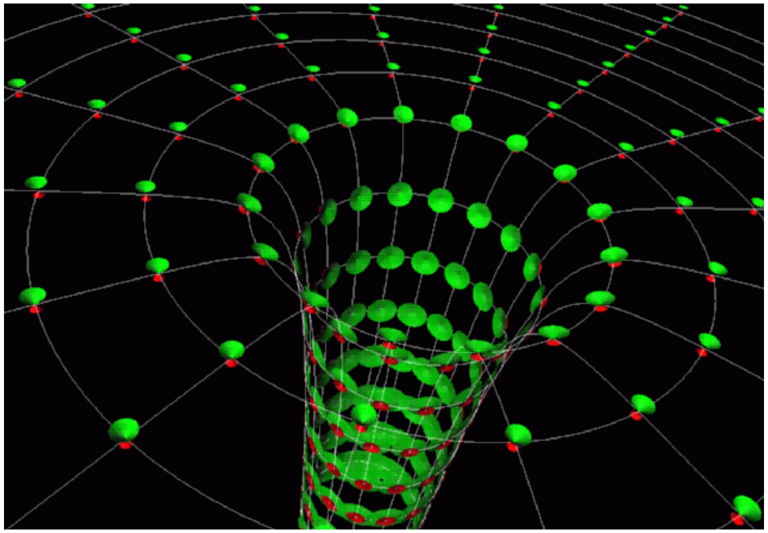


- Cosmological: “stochastic background”
  - **Probe back to the Planck time (10^{-43} s)**



A New ‘Sense’- A New Universe





Gravitational Waves will provide complementary information, as different from what we know as sound is from sight.

Great promise, but a great challenge…

A wave's strength is characterized by its *strain*

$$h = \Delta L / L$$

We can calculate the expected strain at Earth for, say, an orbiting binary system;

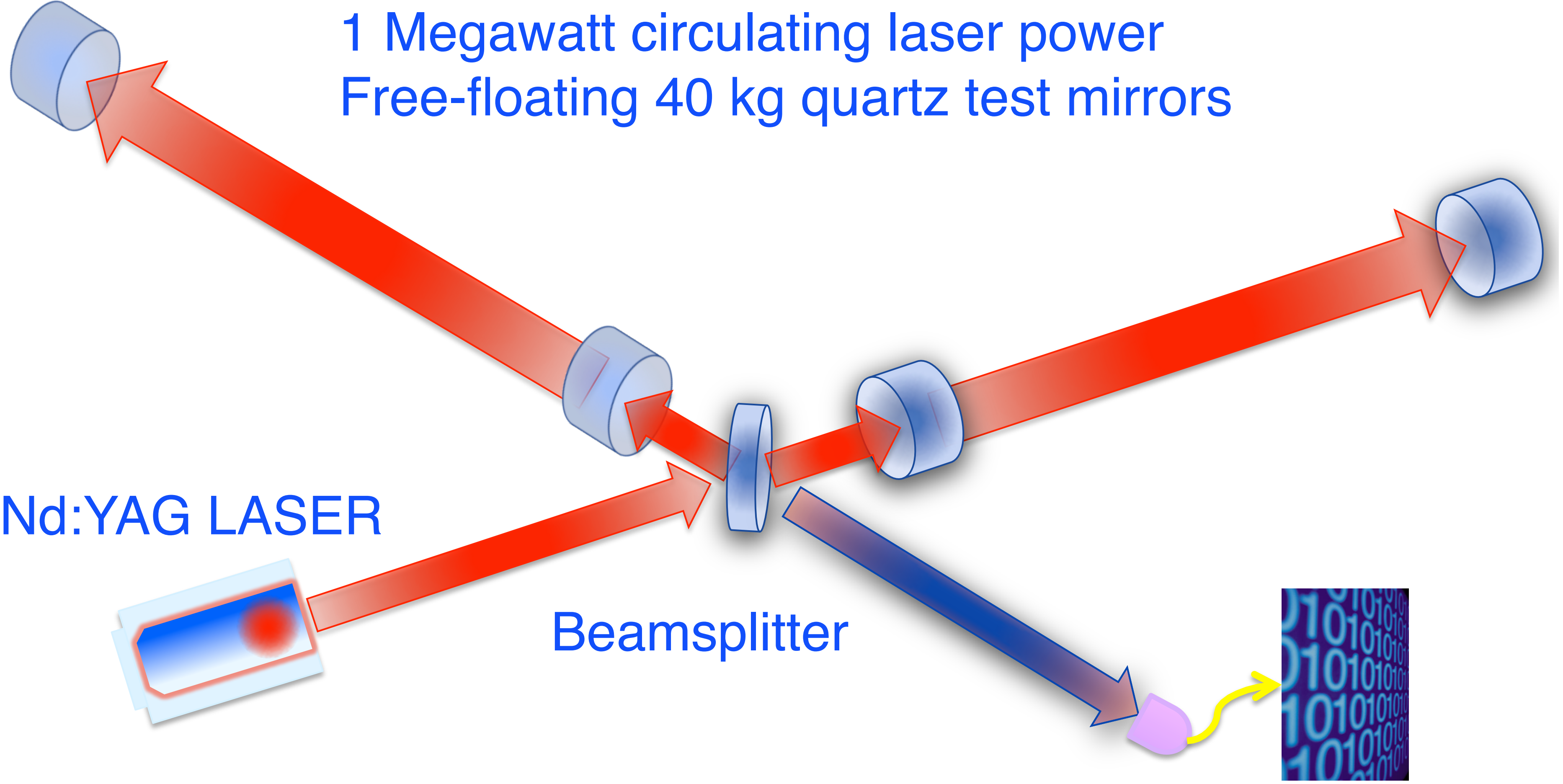
$$|h| \approx 4\pi^2 G M R^2 f_{orbit}^2 / c^4 r \approx 10^{-21} \left(\frac{R}{20\mathrm{km}}\right)^2 \left(\frac{M}{M_\Theta}\right) \left(\frac{f_{orbit}}{400\,\mathrm{Hz}}\right)^2 \left(\frac{10\mathrm{Mpc}}{r}\right)$$

If we make our interferometer 4,000 meters long,

$$\Delta L = h \times L \approx 10^{-21} \times 4{,}000\, m \approx 10^{-18}\, m$$

Laser Interferometer Gravitational-Wave Detector

4 kilometer long “arm” cavities
1 Megawatt circulating laser power
Free-floating 40 kg quartz test mirrors

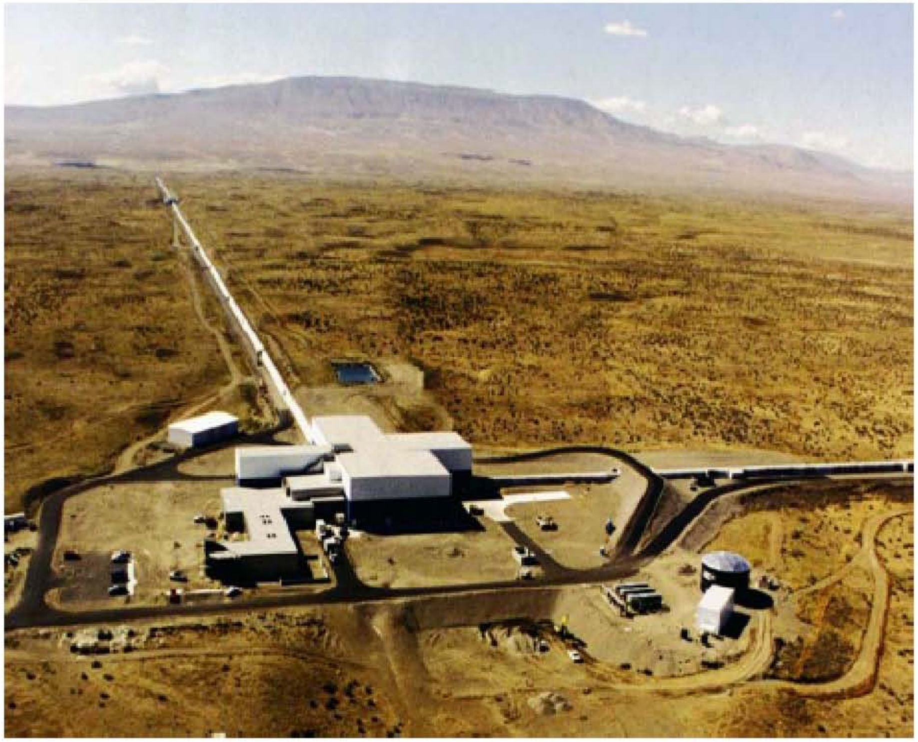


Nd:YAG LASER

Beamsplitter

Photodetector

LIGO Observatory Sites



LIGO Hanford Observatory [LHO]

26 km north of Richland, WA

2 km + 4 km interferometers in same vacuum envelope

LIGO Livingston Observatory [LLO]

42 km east of Baton Rouge, LA

Single 4 km interferometer

LIGO

LIGO Scientific Collaboration

LSC

MICHIGAN

UNIVERSITY OF MARYLAND 18 56

indigo

LIGO INDIA

UNIVERSITY OF STRATHCLYDE

LOYOLA UNIVERSITY NEW ORLEANS

ACIGA

MONTANA STATE UNIVERSITY

РАН

IUCAA

UNIVERSITY OF WASHINGTON

SYRACUSE UNIVERSITY FOUNDED AD 1870

清華大學
Tsinghua University

TRINITY UNIVERSITY

San José State UNIVERSITY

UNIVERSITY of WISCONSIN
UWMILWAUKEE

ANU
THE AUSTRALIAN NATIONAL UNIVERSITY

부산대학교
PUSAN NATIONAL UNIVERSITY

THE UNIVERSITY OF WESTERN AUSTRALIA

1754

UNIVERSITY of GLASGOW

NASA
GODDARD SPACE FLIGHT CENTER

Università degli Studi del Sannio

LSU

UTB TSC

R·I·T

THE UNIVERSITY OF MELBOURNE

KiSTi

Andrews University

SOUTHEASTERN

Moscow State University

CALIFORNIA INSTITUTE OF TECHNOLOGY 1891

NORTHWESTERN UNIVERSITY

HANYANG UNIVERSITY 한양 1939

UNIVERSITY OF CAMBRIDGE

THE UNIVERSITY OF ADELAIDE AUSTRALIA

PAN

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LELAND STANFORD JUNIOR UNIVERSITY 1891

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY

UNIVERSITY OF MASSACHUSETTS AMHERST 1863

LUND UNIVERSITY

ISI

UNIVERSITY of NEW HAMPSHIRE

PENNSTATE 1855

SIGILL. COLL. CARLETON NORTHFIELD, MINN. A.D. 1866

GEO 600

CARDIFF UNIVERSITY

CALIFORNIA STATE UNIVERSITY FULLERTON

WASHINGTON STATE UNIVERSITY

국가수리과학연구소
National Institute for Mathematical Sciences

UIB Universitat de les Illes Balears

UF UNIVERSITY of FLORIDA

PI PERIMETER INSTITUTE

CITA-ICAT

SEOUL NATIONAL UNIVERSITY

1848 The University of Mississippi

CHARLES STURT UNIVERSITY

UNIVERSITY OF ROCHESTER

NAOJ

University of Southampton

UNIVERSITY OF MINNESOTA

HOBART AND WILLIAM SMITH COLLEGES

Universität Hannover

SOUTHERN UNIVERSITY And Agricultural & Mechanical College

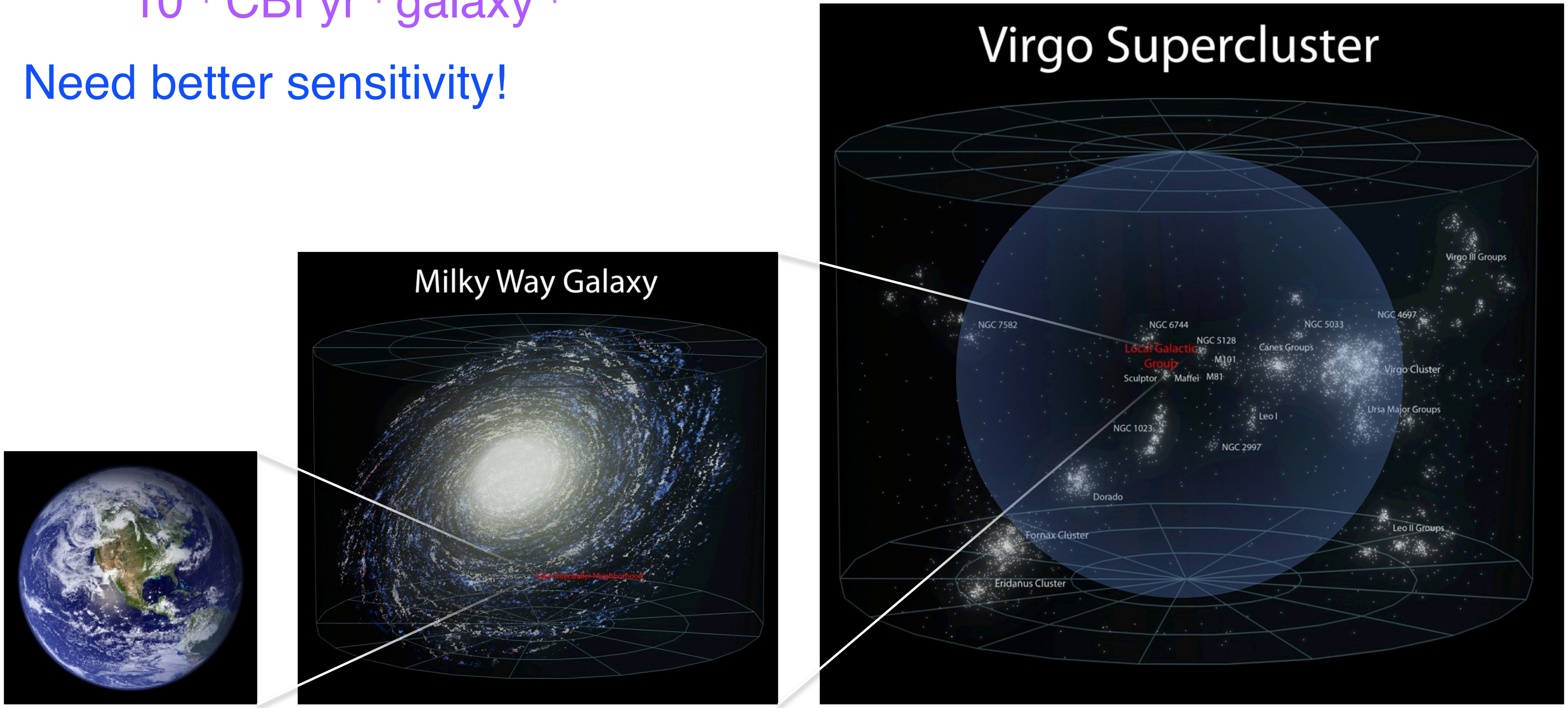
Science & Technology Facilities Council
Rutherford Appleton Laboratory

No Confirmed Detections Yet…

- First generation detectors reached about 100 galaxies
- Current predictions in range of

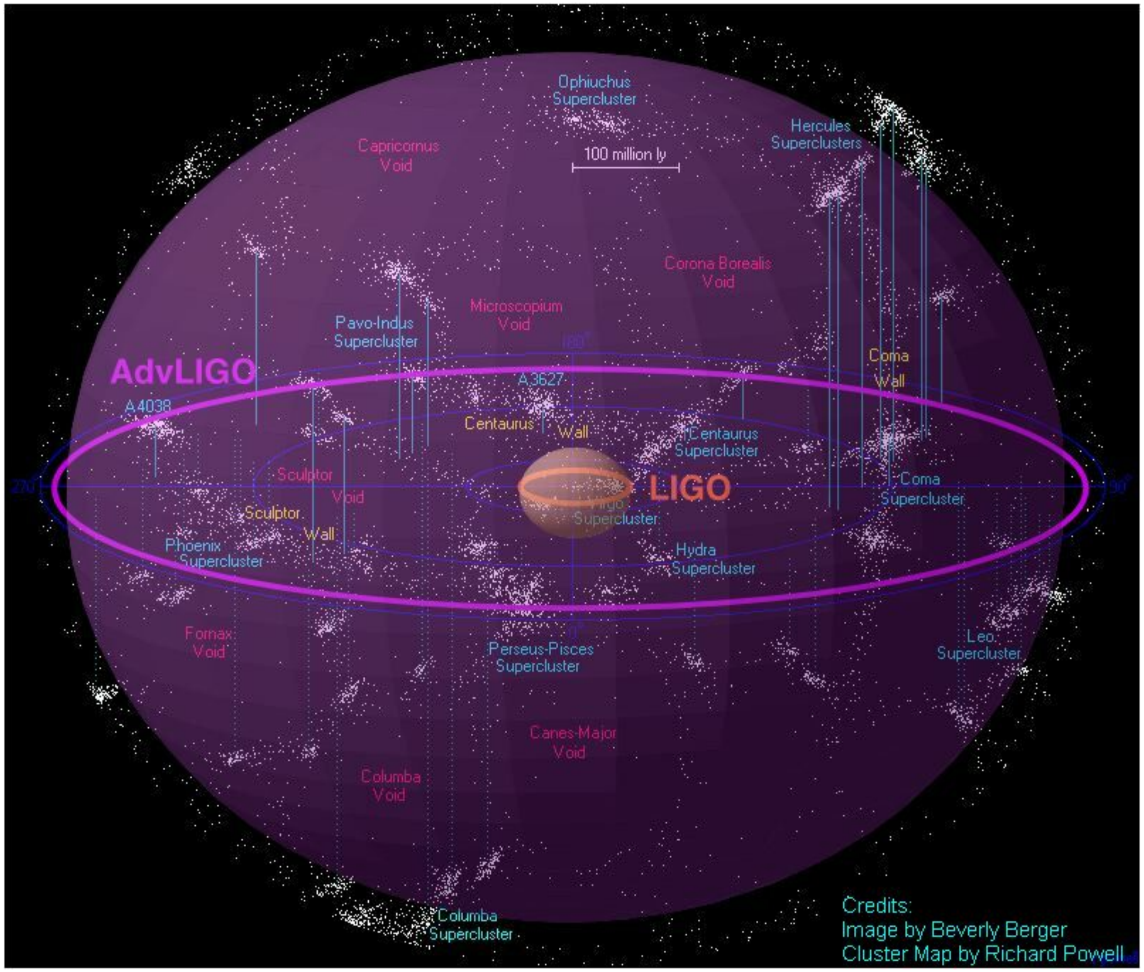
  10^{-4} CBI yr^{-1} galaxy^{-1}

- Need better sensitivity!



Advanced LIGO

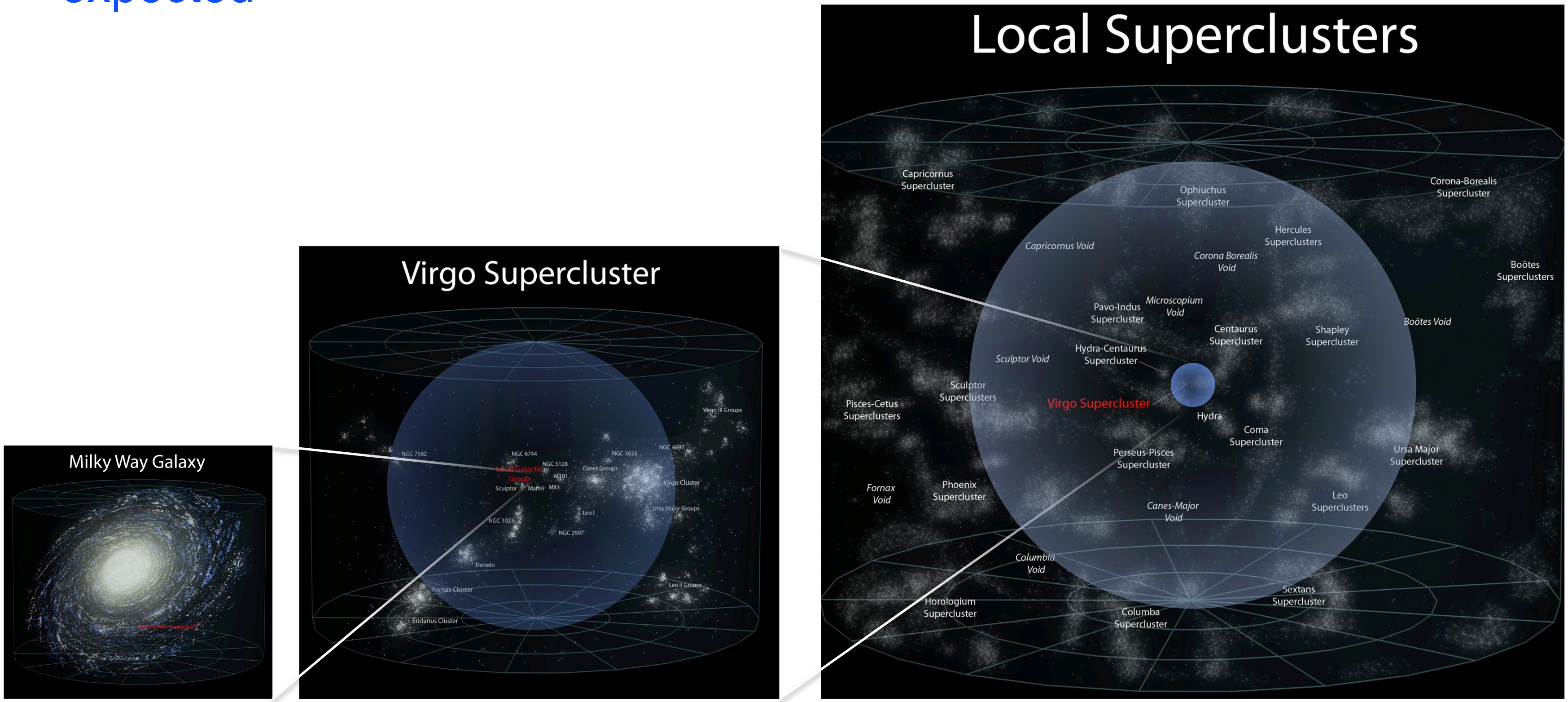
- Initial detectors completed in 2000
- Design sensitivity achieved 2005
- Ran ~ 2.5 years
  - No confirmed detection
- Facilities, vacuum system designed to be compatible with "ultimate" future interferometers
- Advanced LIGO detector upgrade funded '08, now being installed
  - Design 10x more sensitive
  - 1,000x greater observable volume (or event rate)



Credits:
Image by Beverly Berger
Cluster Map by Richard Powell

Advanced LIGO:
10x More Range

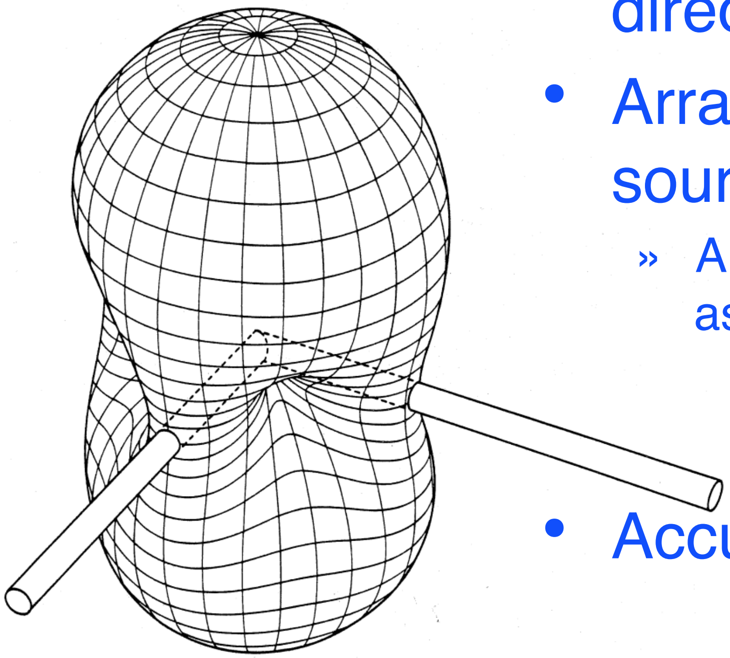
- Advanced detectors will reach about 100,000 galaxies
- Roughly 1 CBI event per month expected



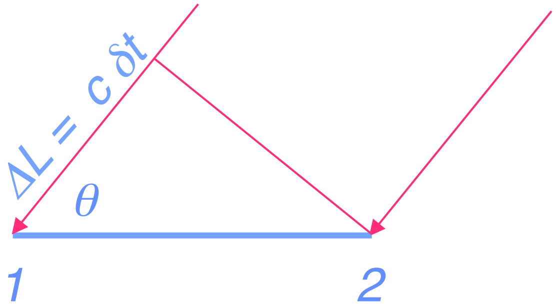
Initial LIGO Range

Advanced LIGO Range

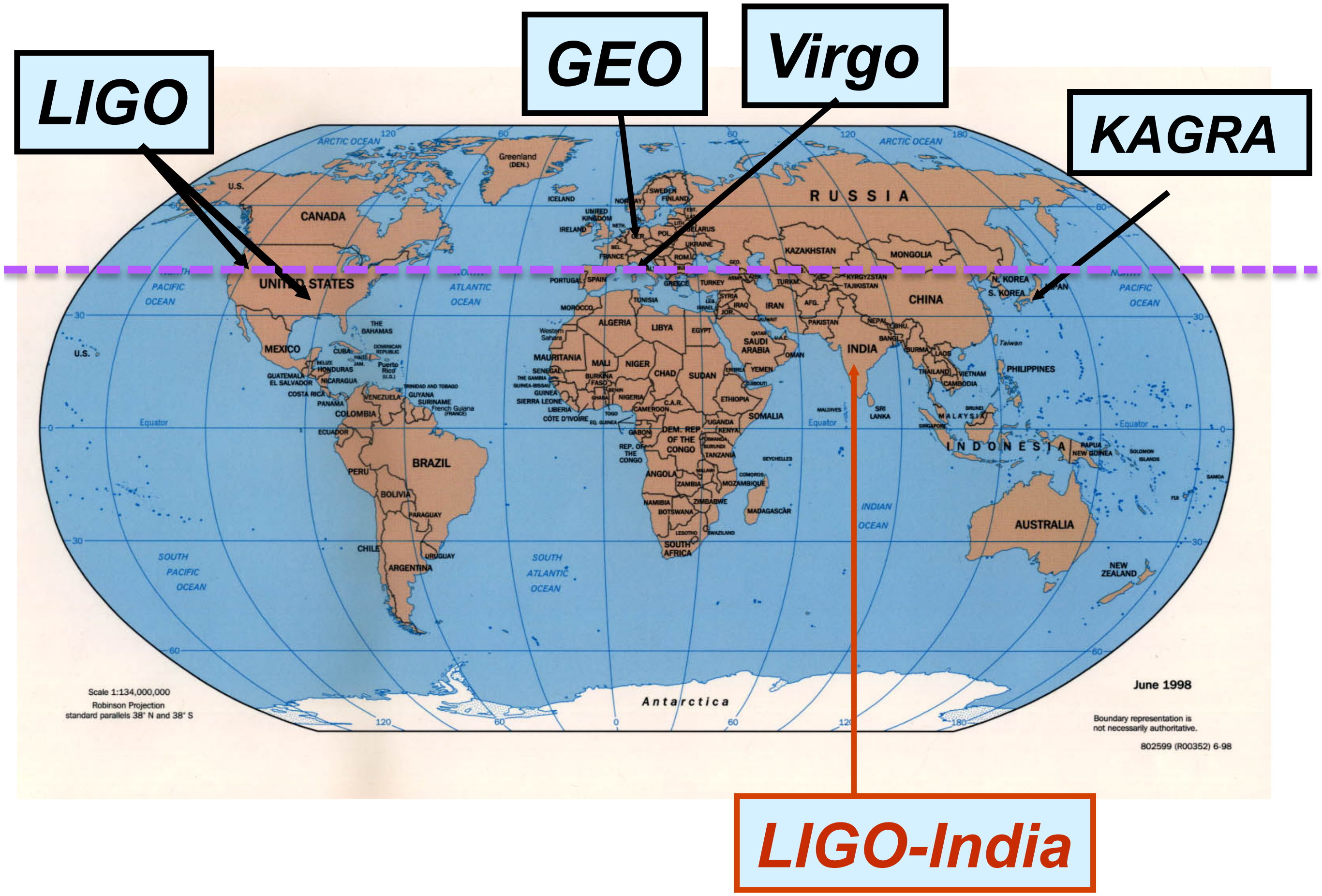
Source Localization and MultiMessenger Astrophysics



- GW detectors are nearly omni-directional
- Array working together can determine source location
  - Analogous to “aperture synthesis” in radio astronomy
- Accuracy tied to diffraction limit



Future Global Detector Network



LIGO

GEO

Virgo

KAGRA

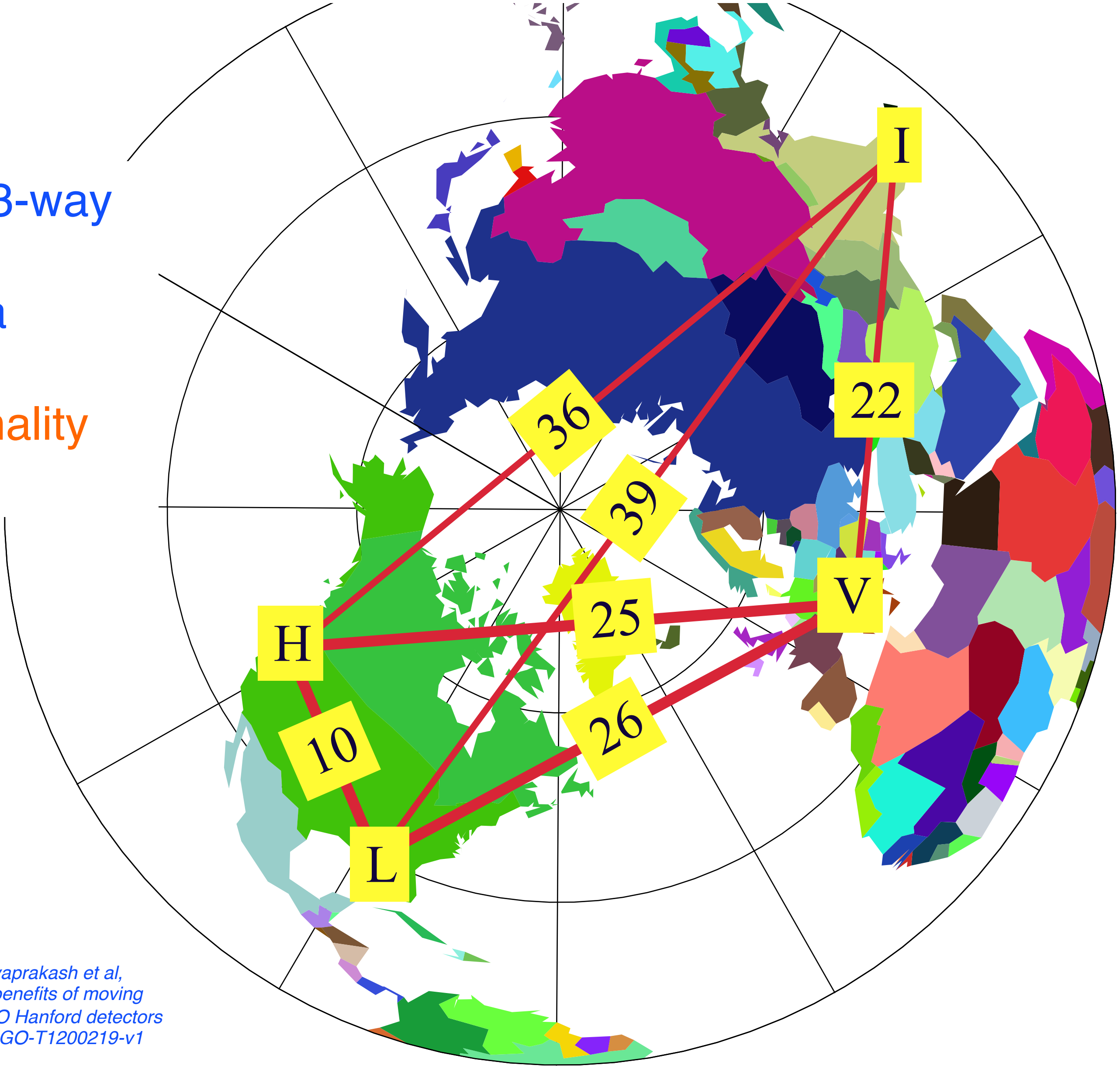
LIGO-India

US, Europe and Japan detectors are close to co-planar—not optimal

India site out of plane breaks degeneracy, improving sky coverage

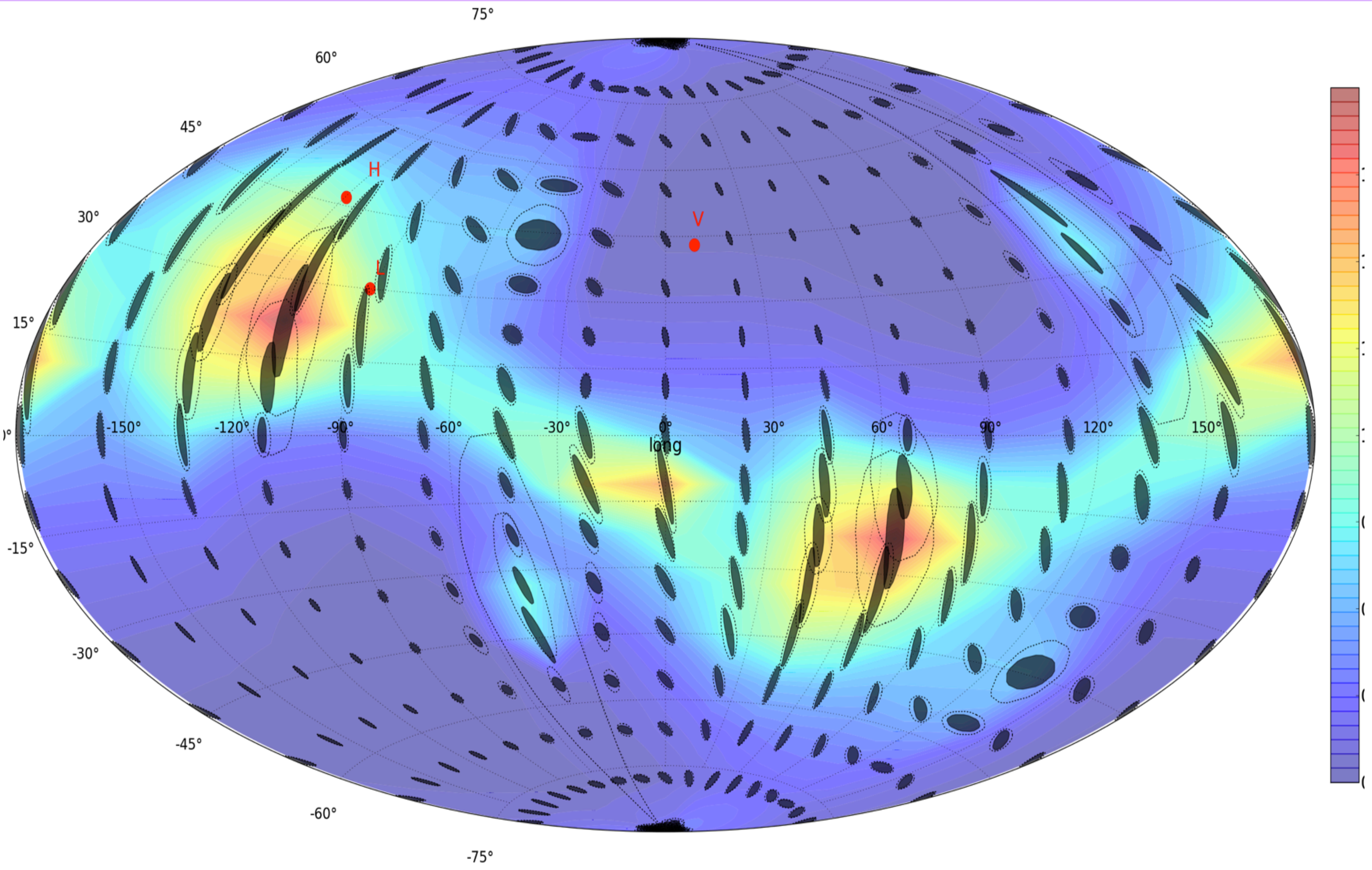
A Network with LIGO India, LIGO US and Virgo

- HLVI contains four 3-way networks
- Baselines with India are1.5x longer
- ~ 4x better directionality (for given SNR)

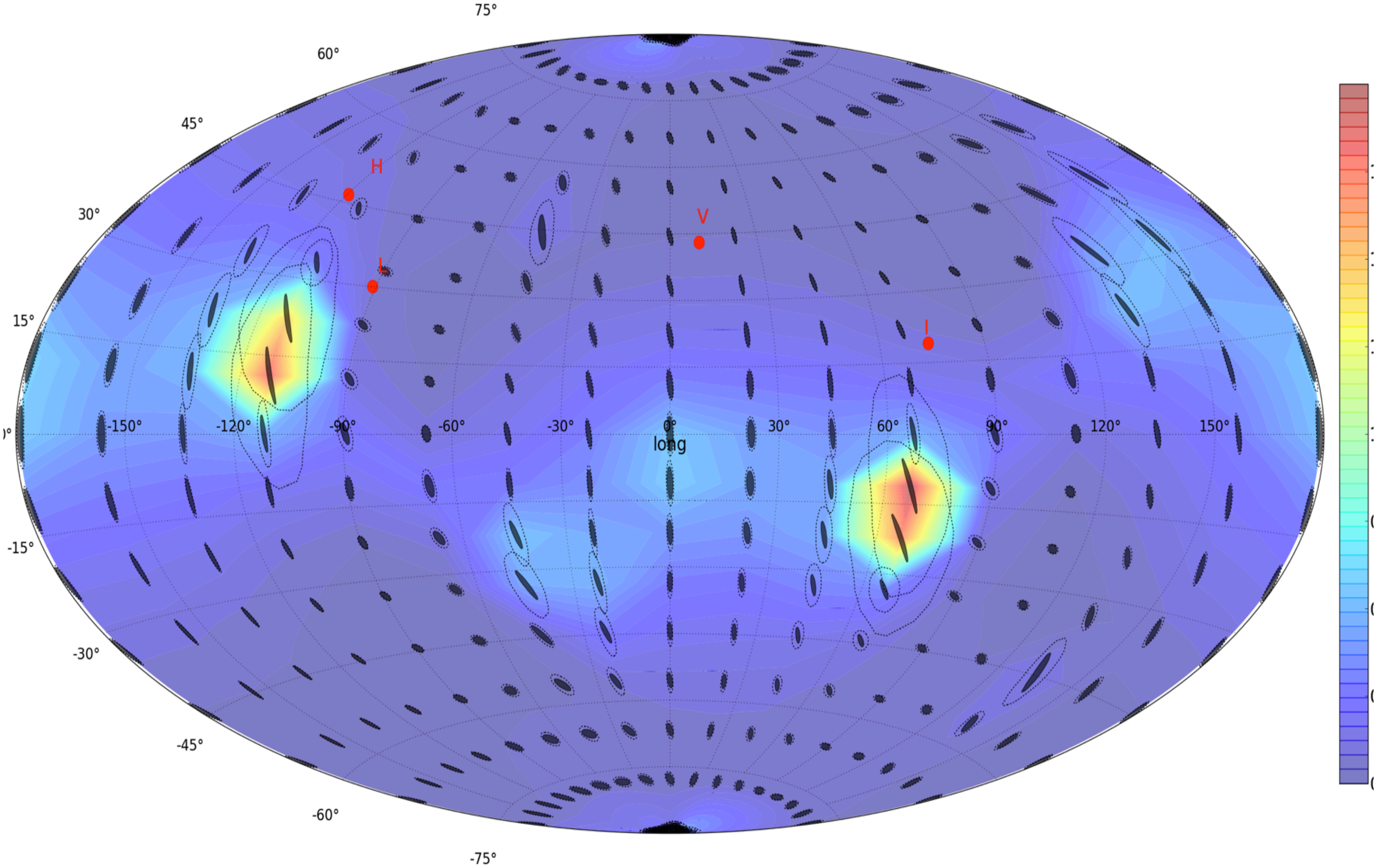


B. S. Sathyaprakash et al, 'Scientific benefits of moving one of LIGO Hanford detectors to India', LIGO-T1200219-v1

Timing Errors without LIGO-India



Timing Errors with LIGO-India



LIGO India Core Team

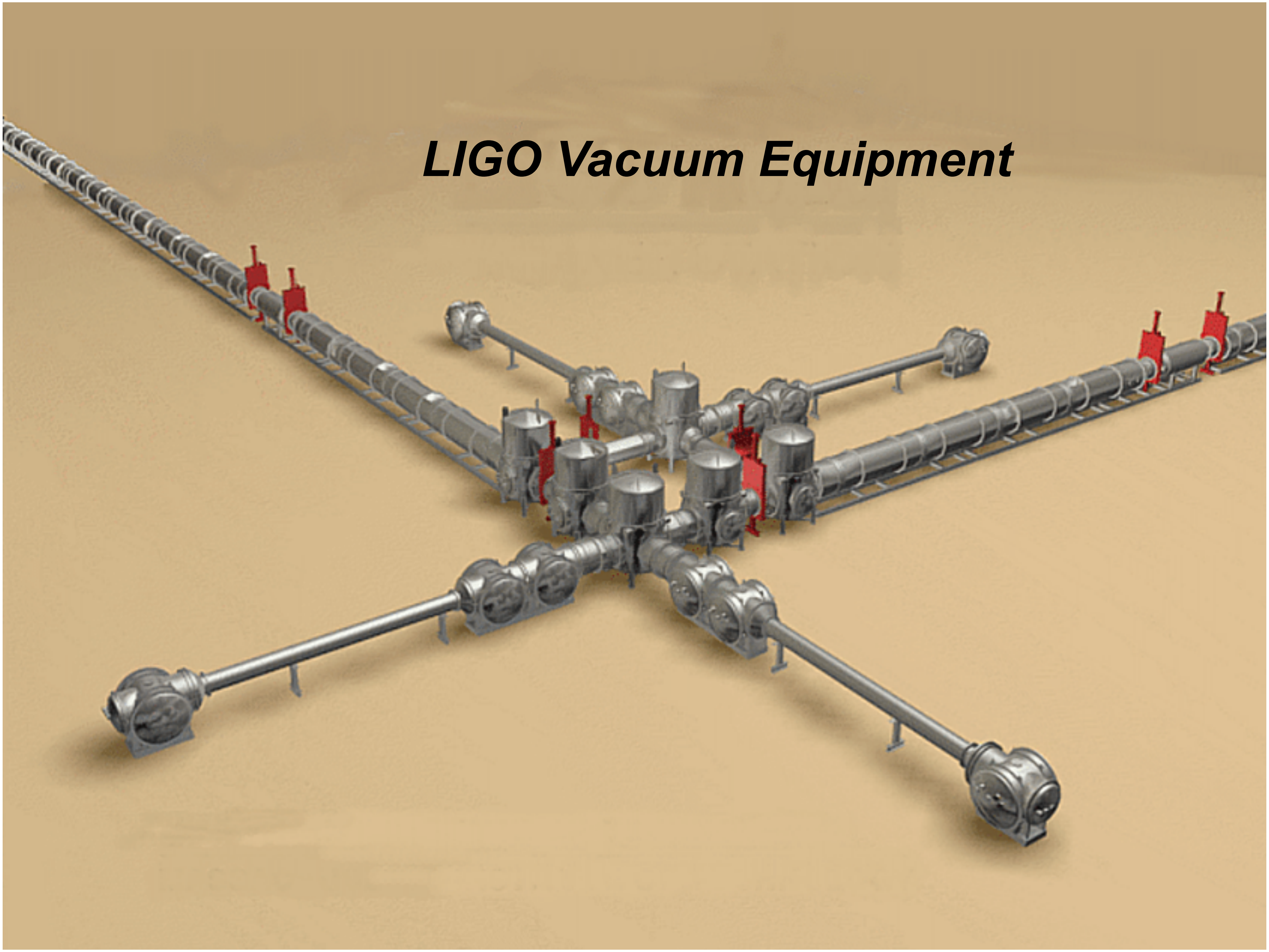
IPR, Gandhinagar – Facilities, Beam Tubes, Vacuum Equipment, Controls

RRCAT, Indore – Interferometer Optimization, Installation, Commissioning

IUCAA, Pune – Site survey, Astrophysical Data Analysis & Computing

LIGO-US WILL CONTRIBUTE COMPLETE INTERFEROMETER PLUS TECHNOLOGY TRANSFER AND TECHNICAL SUPPORT

LIGO Vacuum Equipment



LIGO Really Has Two Vacuum Systems

"Vacuum Equipment:" Chambers, pumps, instruments

- Houses detector apparatus
- Isolation (valves), access (doors)
- Electrical, mechanical, optical penetrations
- Pumping & instrumentation
- Somewhat "conventional"
- *F:A* ~ 10^{-2} $ls^{-1}cm^{-2}$

Beam tubes

- A long hole in the air;

  Never to be vented
- Highly "unconventional"
  - 20 million liters (per site)
  - 600 million cm^2 (per site)
  - 200 l/s char. conductance
  - *F:A* ~ 10^{-5} $ls^{-1}cm^{-2}$

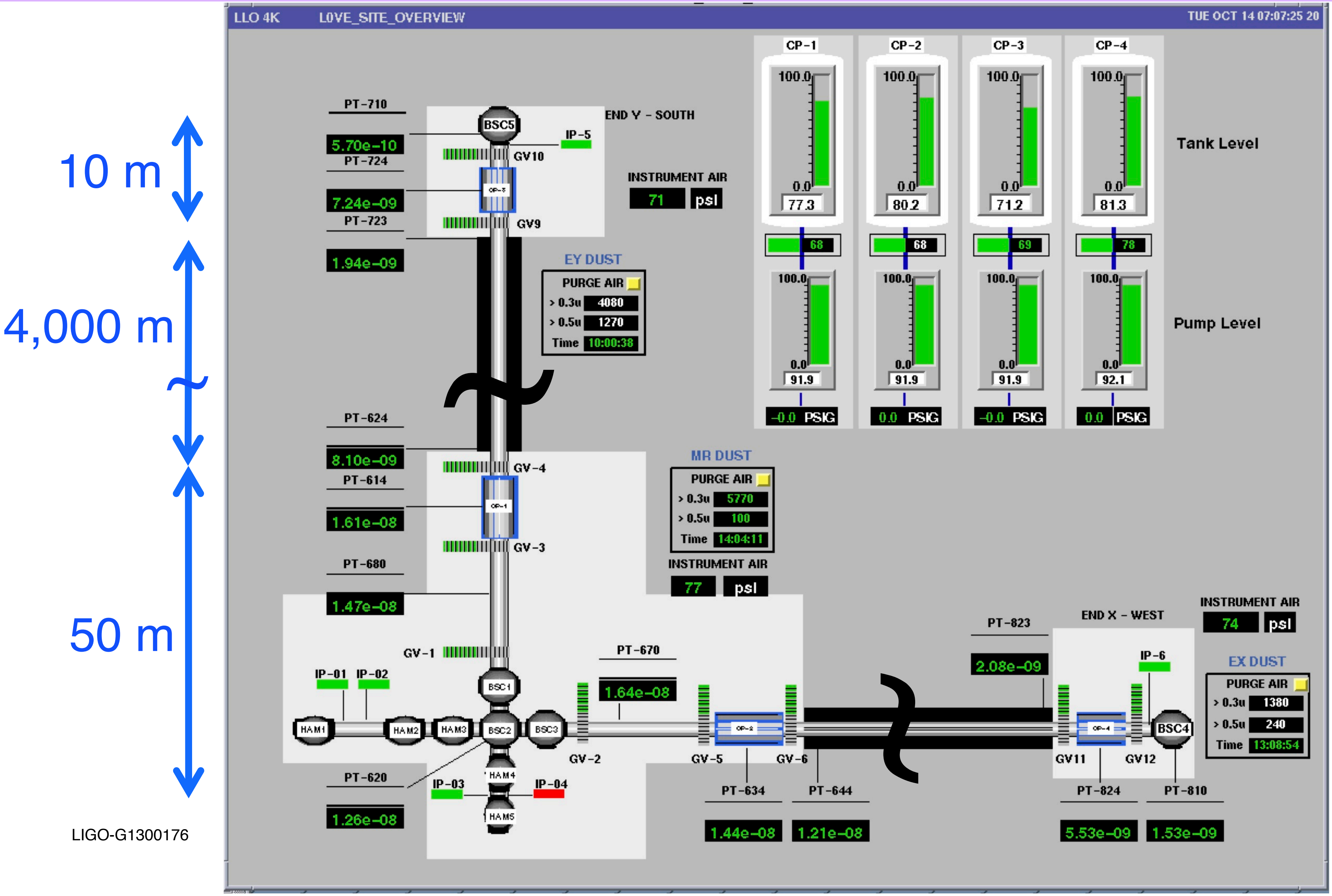
LIGO Vacuum Requirements

(partial list)

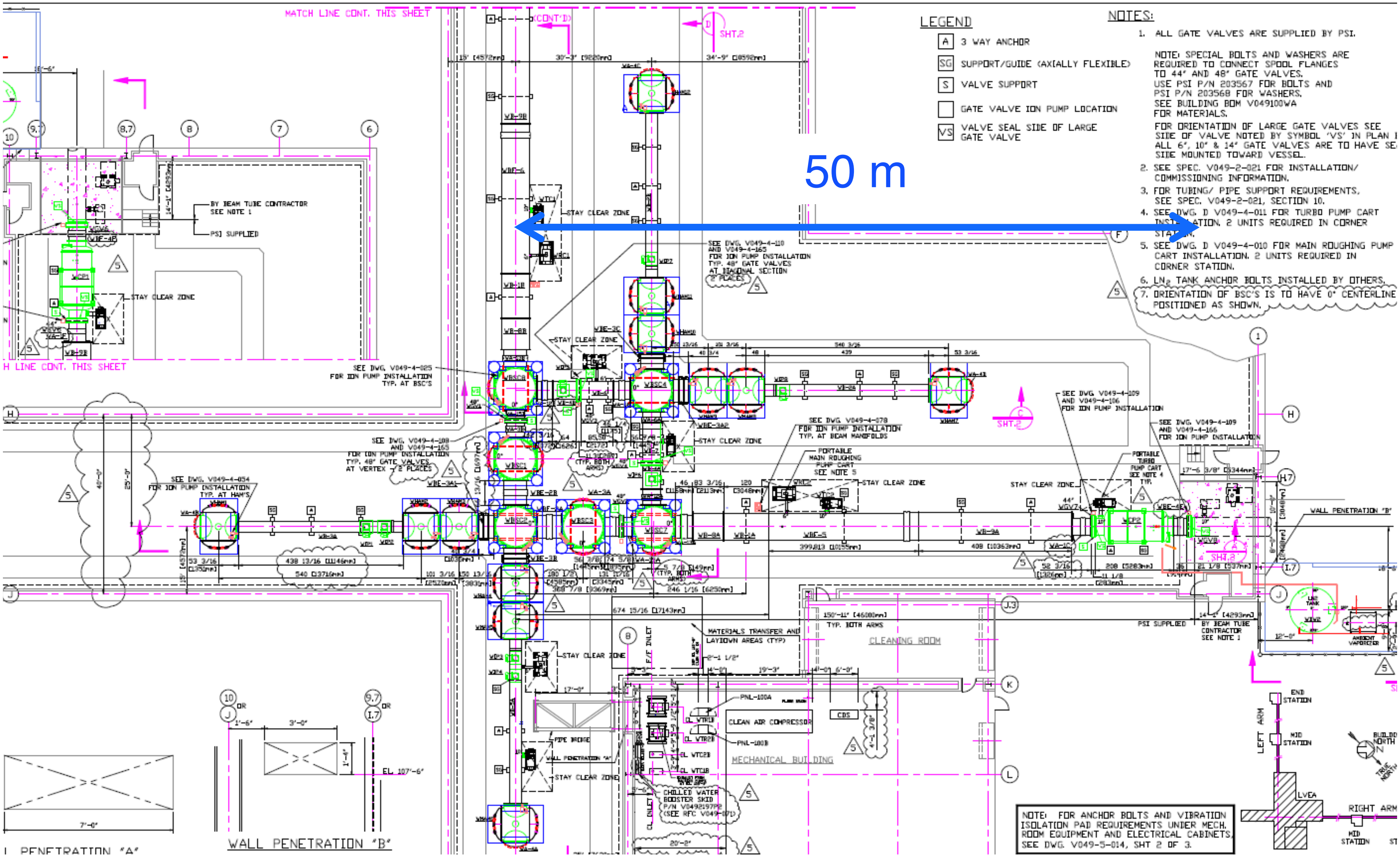
- Light scattering phase noise from residual gas
  - Function of molecular polarizability, transit speed and partial pressure
  - Primary goals for beam tubes:
    - ➔$P(H_2) < 10^{-9}$ Torr
    - ➔$P(H_2O) < 10^{-10}$ Torr
- Contamination of optics
  - Mirror absorption < 0.1 ppm
  - Hydrocarbons: < 1 monolayer/10 years
    - ➔Aggressive cleaning and vacuum bake of every component
  - Particles: < one 10 μm particle on any mirror
    - ➔ISO Class 5 or better cleanroom protocol for worker access, internal components, surface exposure
- Vibration-free environment
    - ➔No mechanical, turbo or closed-cycle cryo pumps in steady state operation

NB: Unlike accelerator, plasma, or aerospace applications, we have no radiation, thermal, or ion loading ; in LIGO outgassing is passive at ambient temperature

Vacuum System Schematic



Corner Station Layout



LEGEND

A	3 WAY ANCHOR
SG	SUPPORT/GUIDE (AXIALLY FLEXIBLE)
S	VALVE SUPPORT
☐	GATE VALVE ION PUMP LOCATION
VS	VALVE SEAL SIDE OF LARGE GATE VALVE

NOTES:

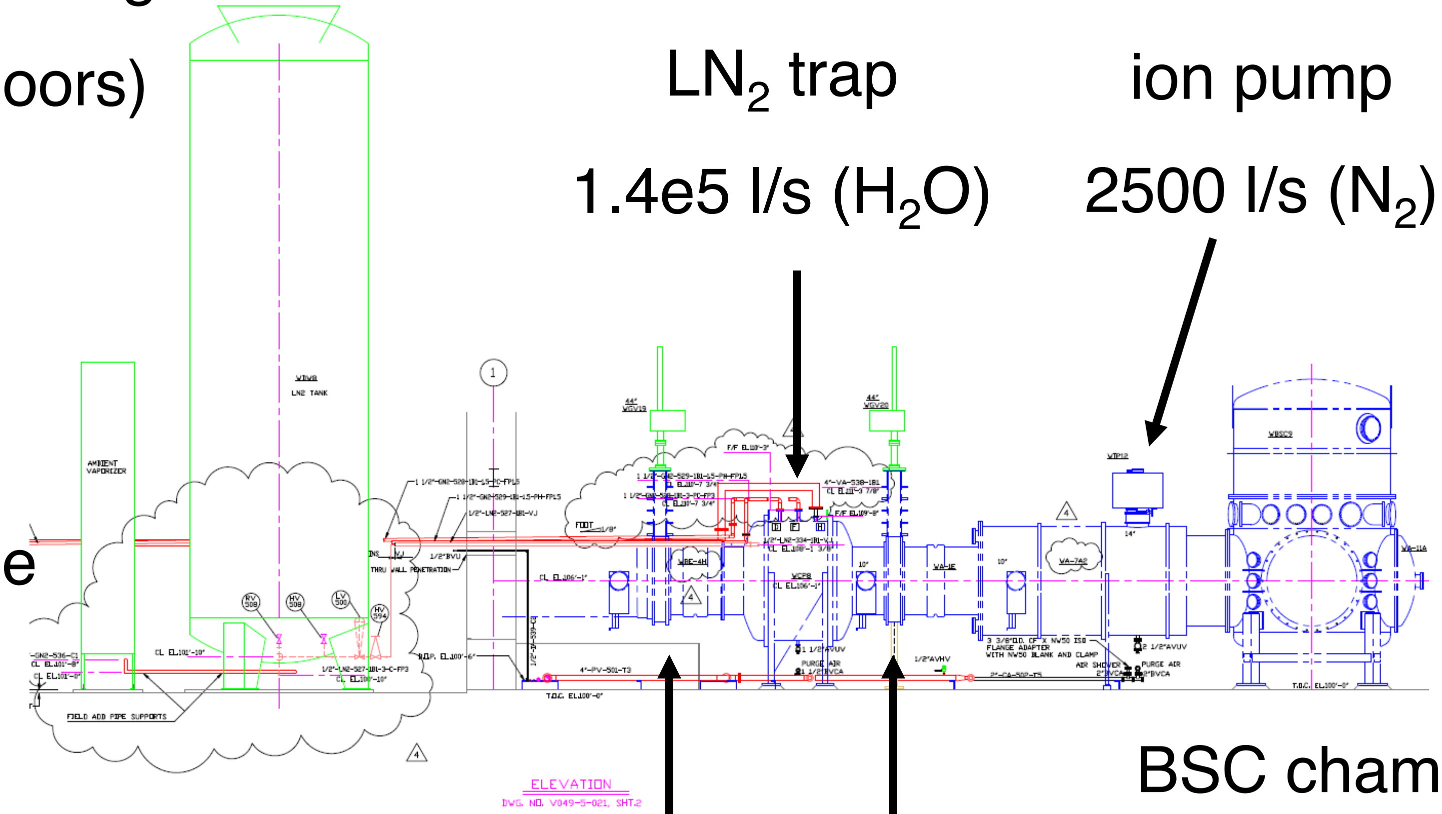
1. ALL GATE VALVES ARE SUPPLIED BY PSI.

   NOTE: SPECIAL BOLTS AND WASHERS ARE REQUIRED TO CONNECT SPOOL FLANGES TO 44" AND 48" GATE VALVES. USE PSI P/N 203567 FOR BOLTS AND PSI P/N 203568 FOR WASHERS. SEE BUILDING BOM V049100WA FOR MATERIALS.

   FOR ORIENTATION OF LARGE GATE VALVES SEE SIDE OF VALVE NOTED BY SYMBOL 'VS' IN PLAN I ALL 6", 10" & 14" GATE VALVES ARE TO HAVE SE SIDE MOUNTED TOWARD VESSEL.
2. SEE SPEC. V049-2-021 FOR INSTALLATION/ COMMISSIONING INFORMATION.
3. FOR TUBING/ PIPE SUPPORT REQUIREMENTS, SEE SPEC. V049-2-021, SECTION 10.
4. SEE DWG. D V049-4-011 FOR TURBO PUMP CART INSTALLATION. 2 UNITS REQUIRED IN CORNER STATION.
5. SEE DWG. D V049-4-010 FOR MAIN ROUGHING PUMP CART INSTALLATION. 2 UNITS REQUIRED IN CORNER STATION.
6. LN_2 TANK ANCHOR BOLTS INSTALLED BY OTHERS.
7. ORIENTATION OF BSC'S IS TO HAVE 0° CENTERLINE POSITIONED AS SHOWN.

NOTE: FOR ANCHOR BOLTS AND VIBRATION ISOLATION PAD REQUIREMENTS UNDER MECH. ROOM EQUIPMENT AND ELECTRICAL CABINETS, SEE DWG. V049-5-014, SHT 2 OF 3.

End Station Arrangement



LN$_2$ storage

(outdoors)

Coaxial

LN$_2$ trap

1.4e5 l/s (H_2O)

ion pump

2500 l/s (N_2)

beamtube

BSC chamber

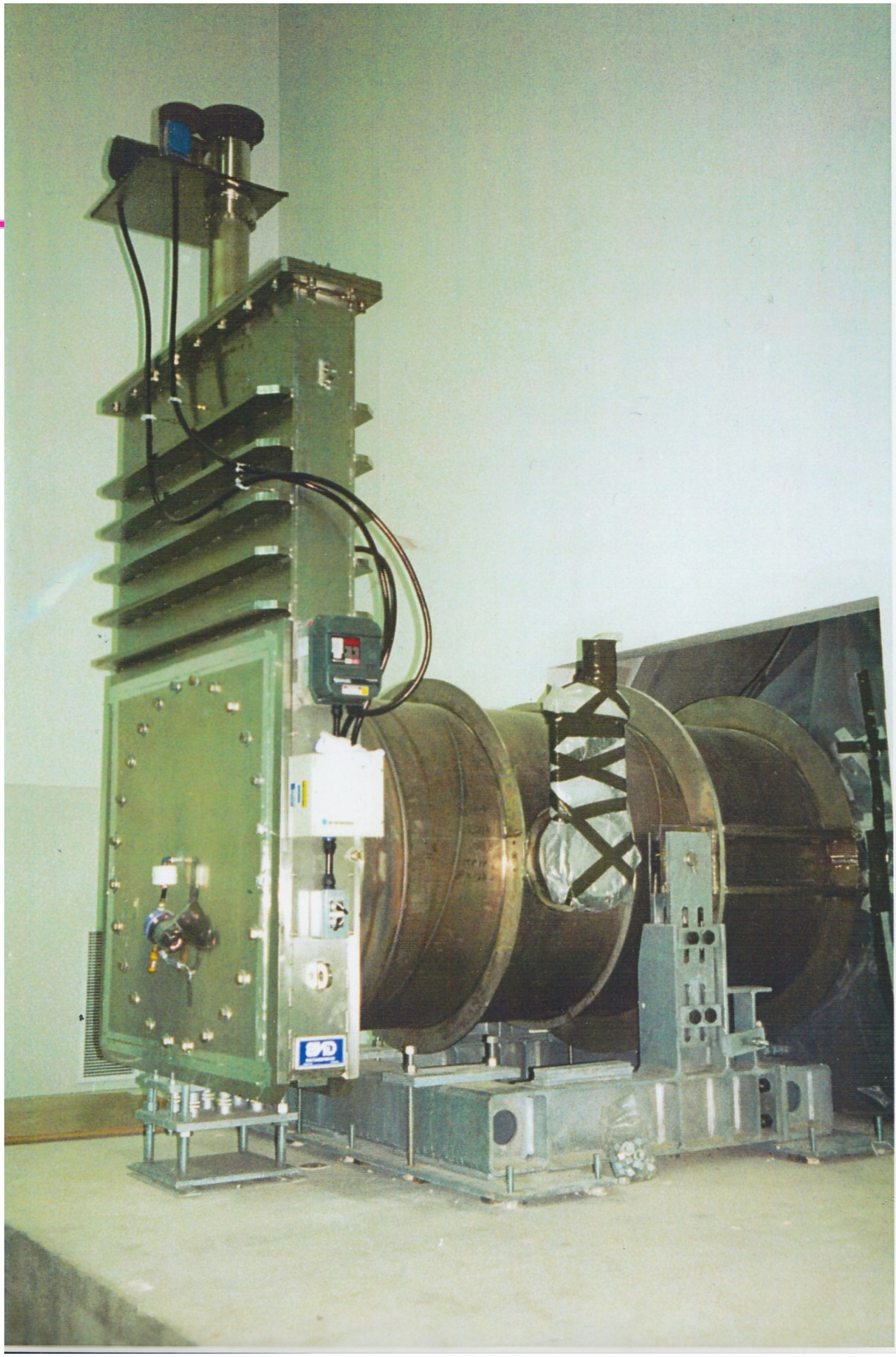
1.2m Ø gate valves

Beamtube Gate Valves

- 40” & 44” ID gate valves to isolate beamtubes, sections, LN2 traps
- Double O-ring gates & bonnet seals with pumped annulus*
- Two actuator varieties: *electric* (ballscrew) and *pneumatic* (cylinder)
- Custom design by GNB Corp.

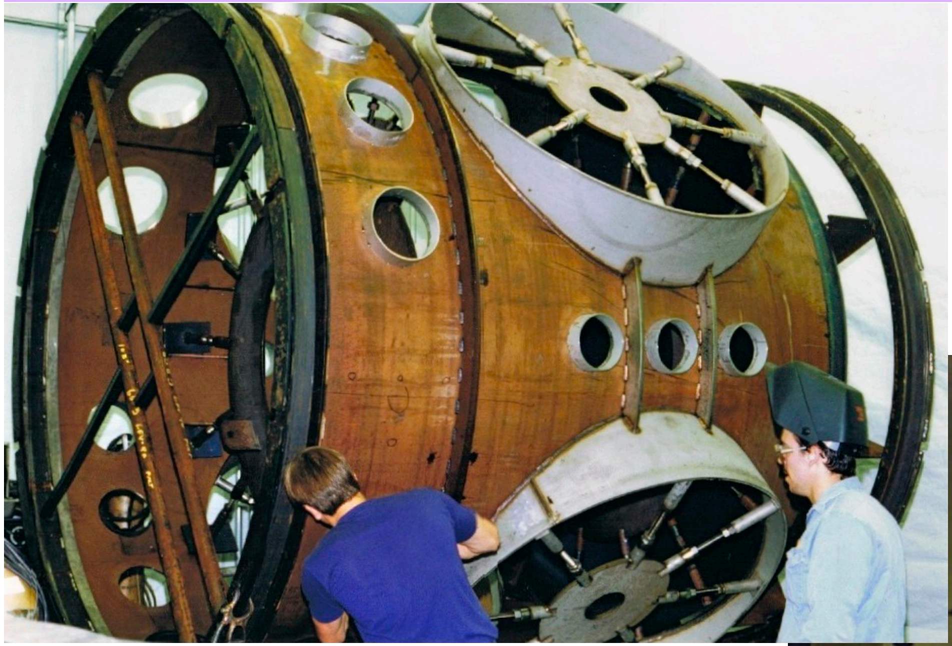
** Principal volume is vulnerable when gate is open!*

- In US, we installed beam tubes first to allow time for bakeout
- VE contractor supplied valves & pumps to tube contractor



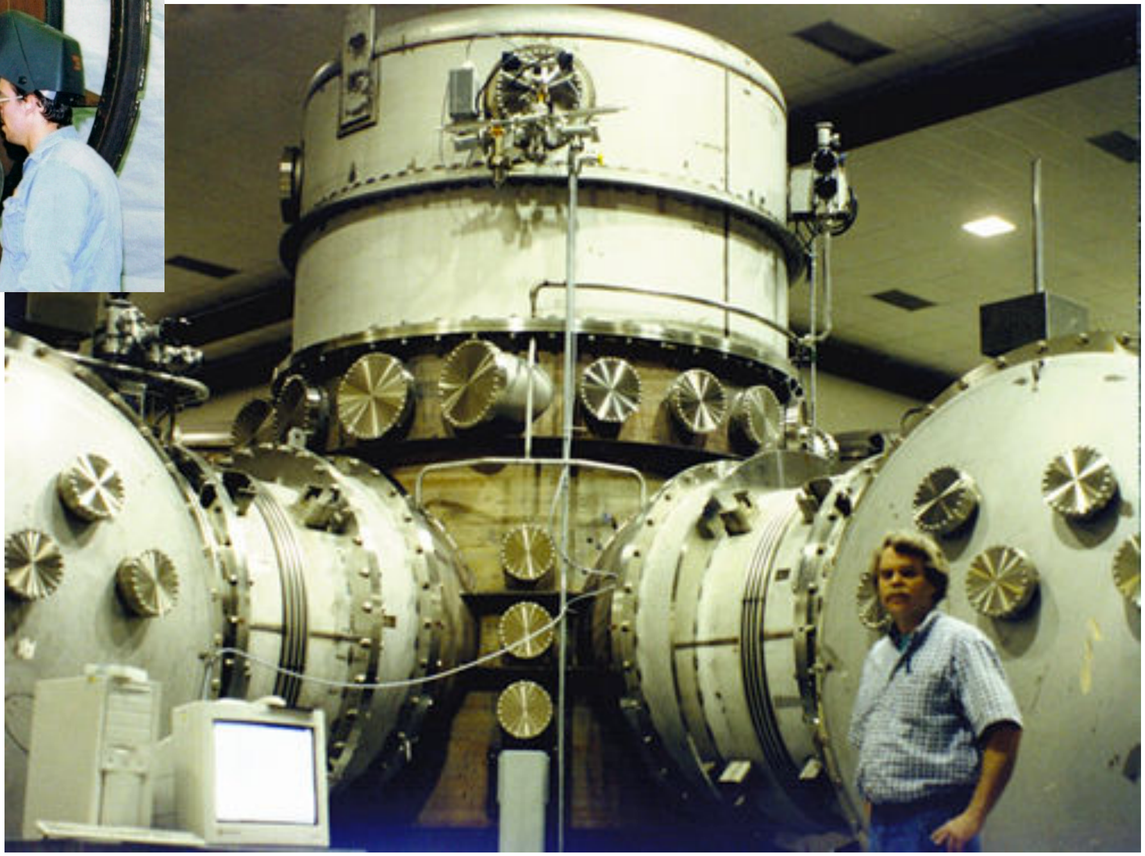
BSC chamber

(Basic Symmetric Chamber)



- 2.8m Ø x 5.5m h for large cavity optics
- Upper third is a removable dome
- Thin (10-15mm) 304L SS shell with welded stiffeners, F&D heads
- Combination of GTAW and plasma welding
- Major weldments stress-relieved*

  *NOTE SURFACE FINISH!

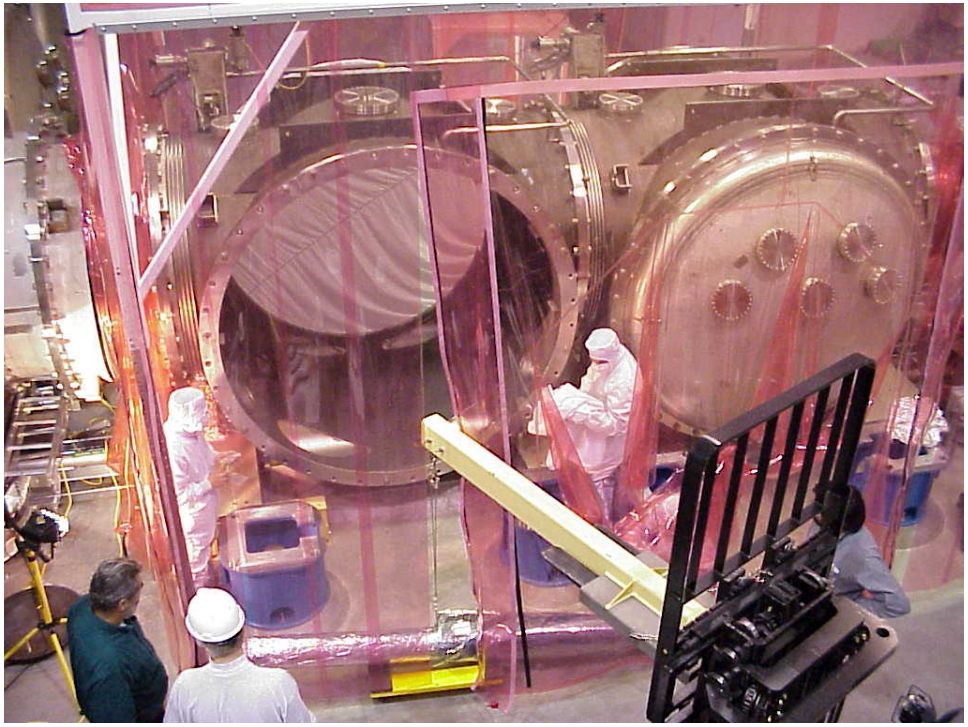


- Ports < 35cm Ø: ConFlat^{TM}
- Ports > 35cm Ø: Dual O-ring
  - Treated Viton elastomer
  - DRY (no grease)
  - Isolated pumped annulus between inner and outer seal
  - Permeation and damage tolerant

In Situ Chamber Bakeout

Particulate control: movable ISO Class 5 cleanrooms

- Part of VE contract due to special features required for chamber access

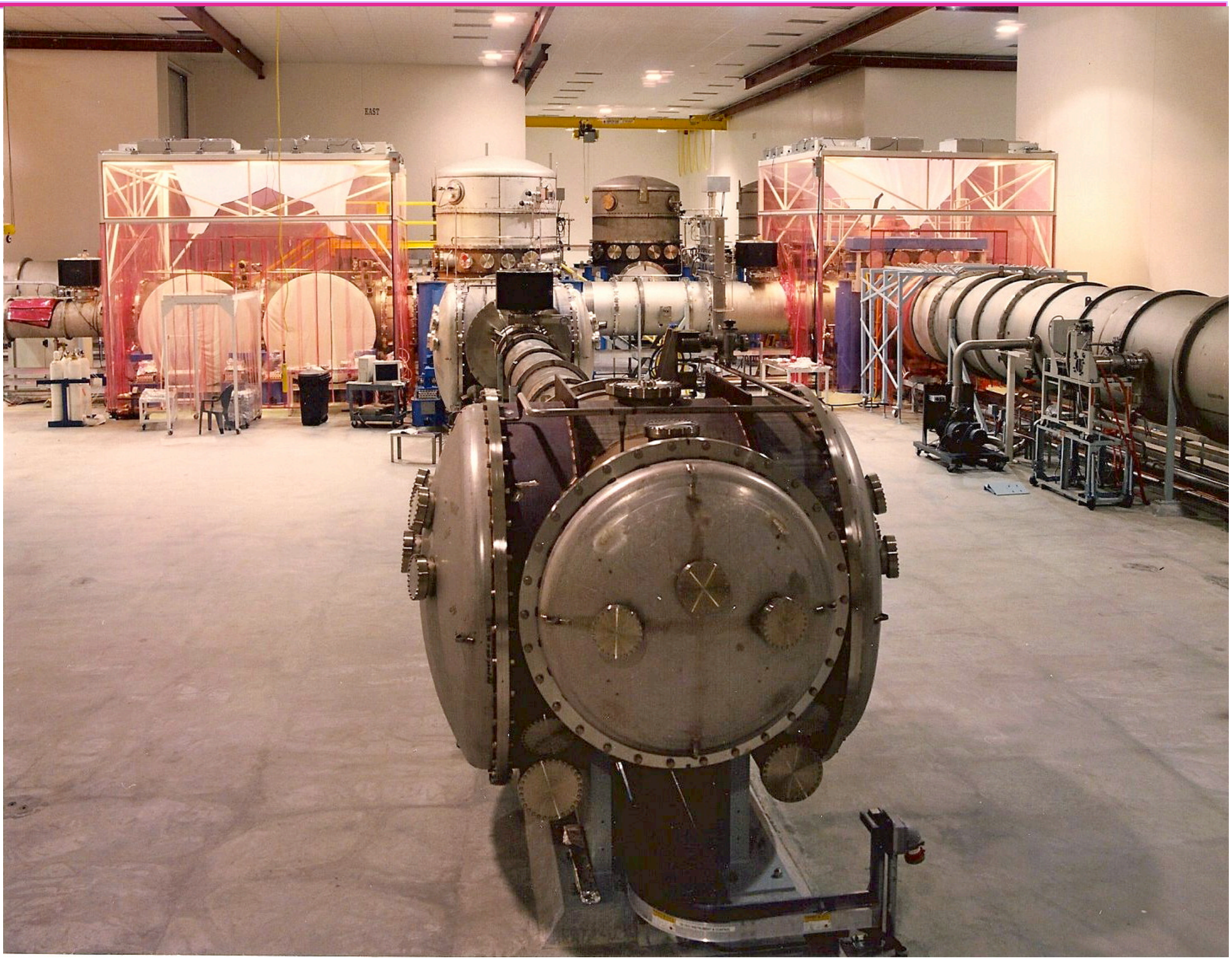


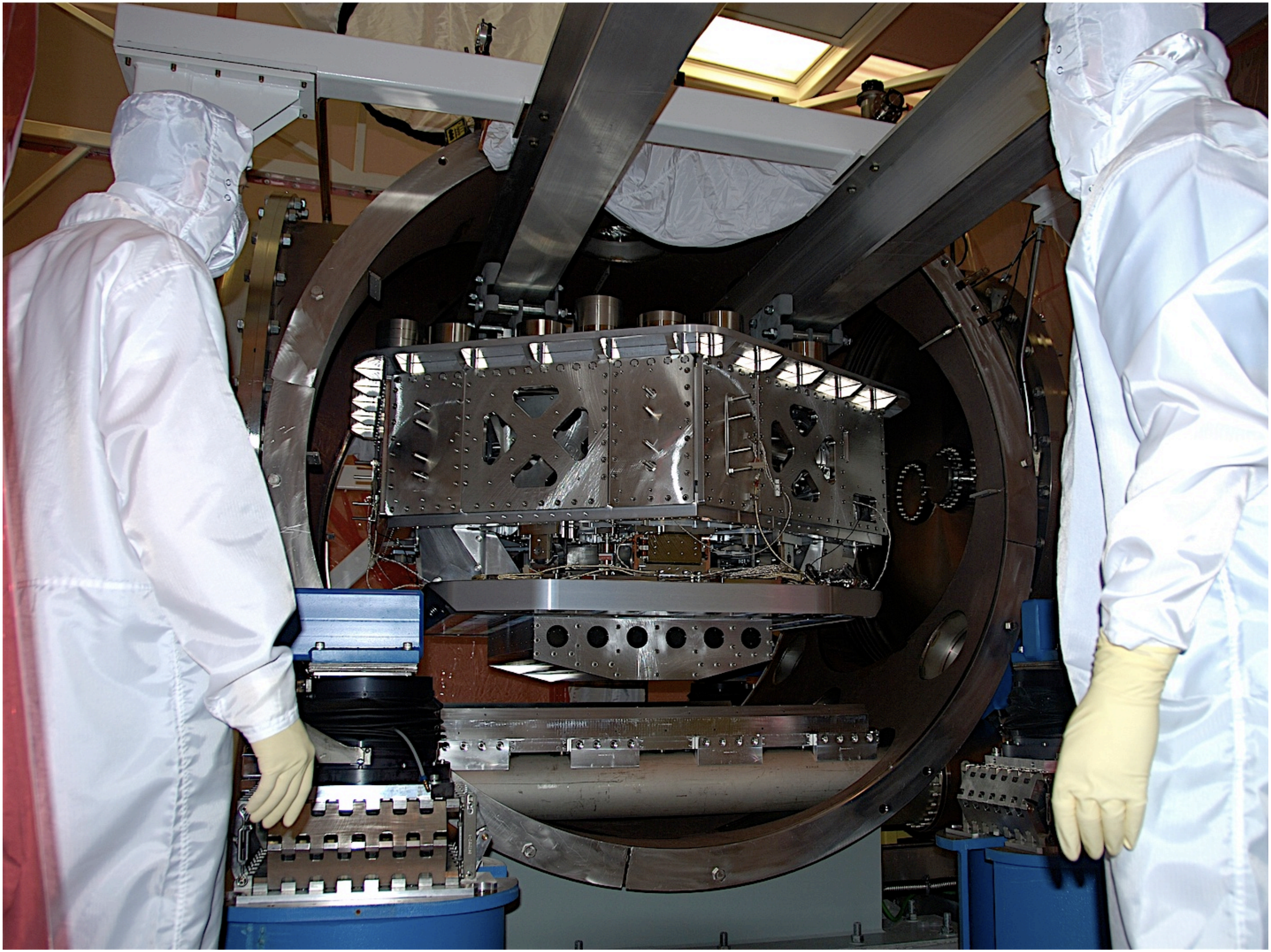
BSC Equipment Installation

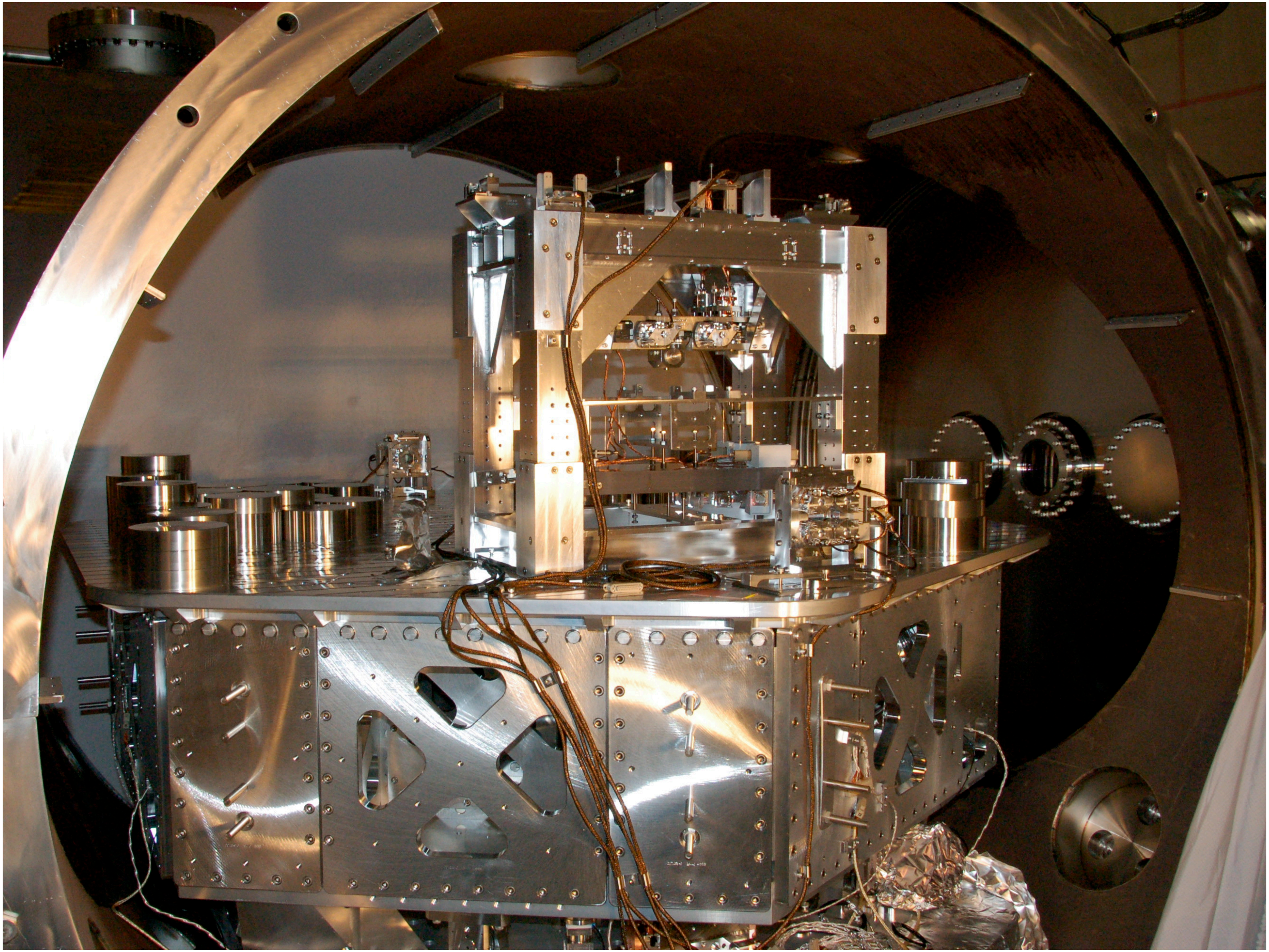
HAM chamber

(Horizontal Access Module)

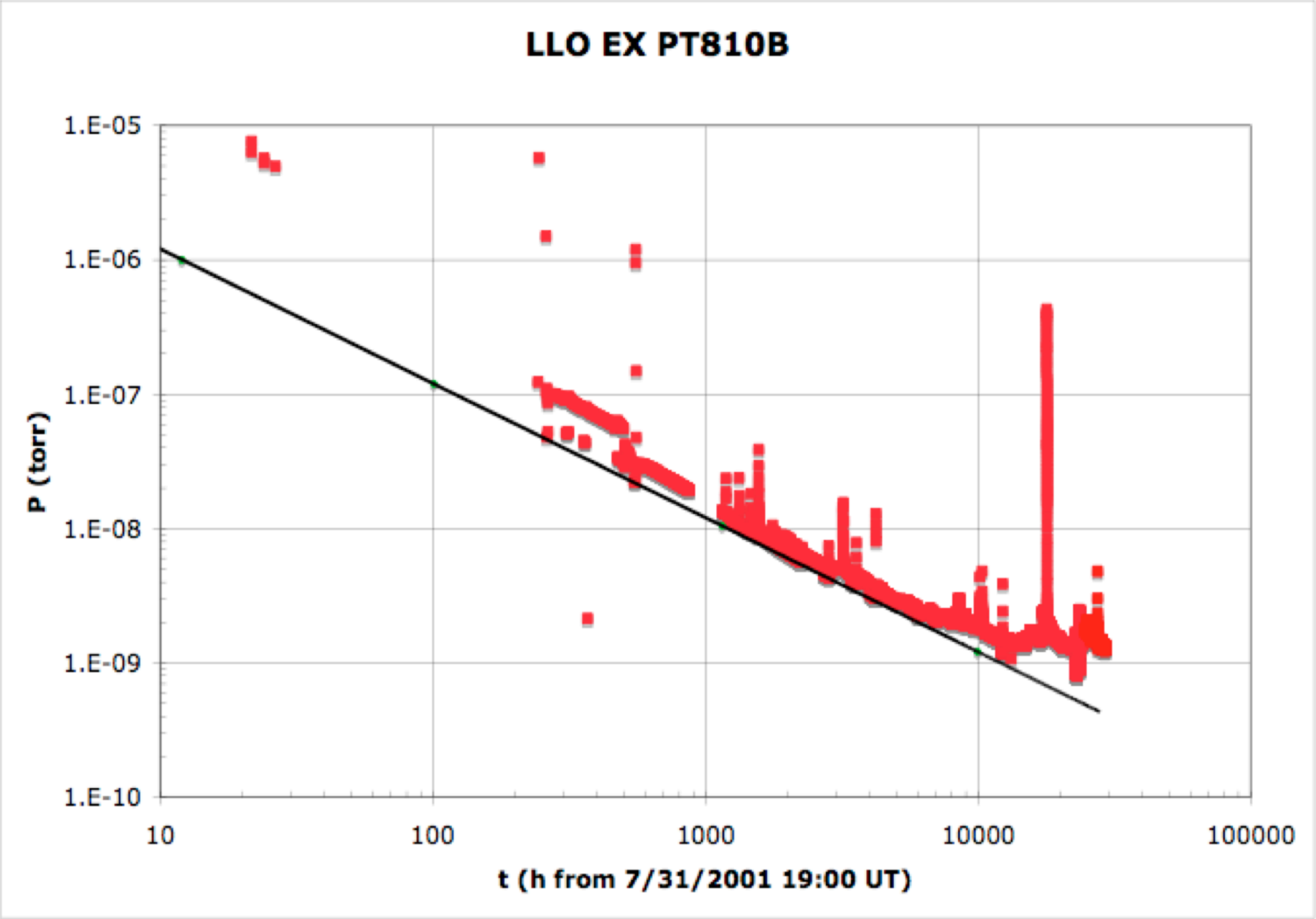
- House complex input/output optics
- 2.1m Ø x 2m w
- More than 70% of area is removable access doors





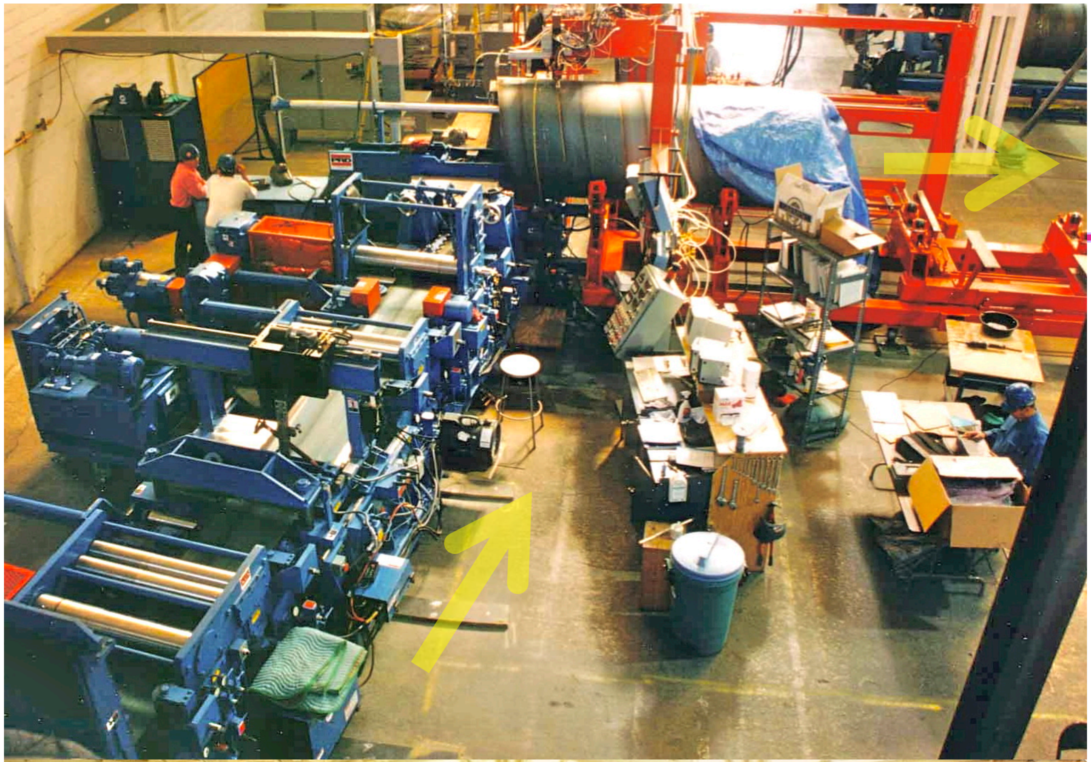


End Station Pressure Evolution after Backfill

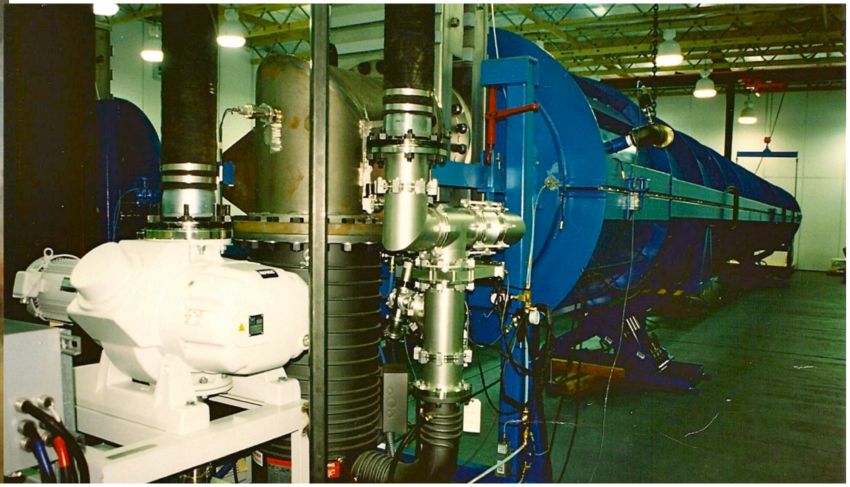


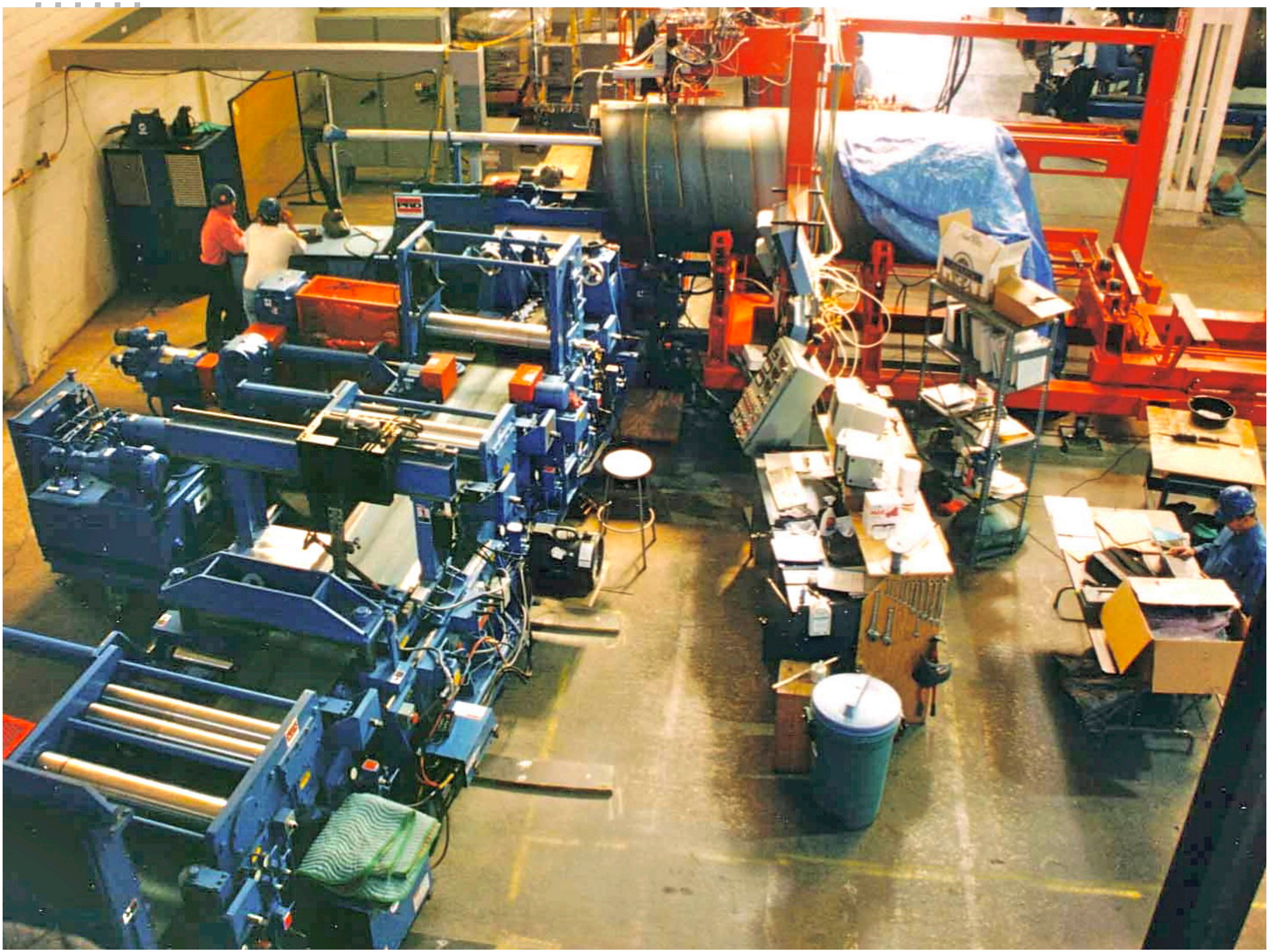
L

Beam Tubes



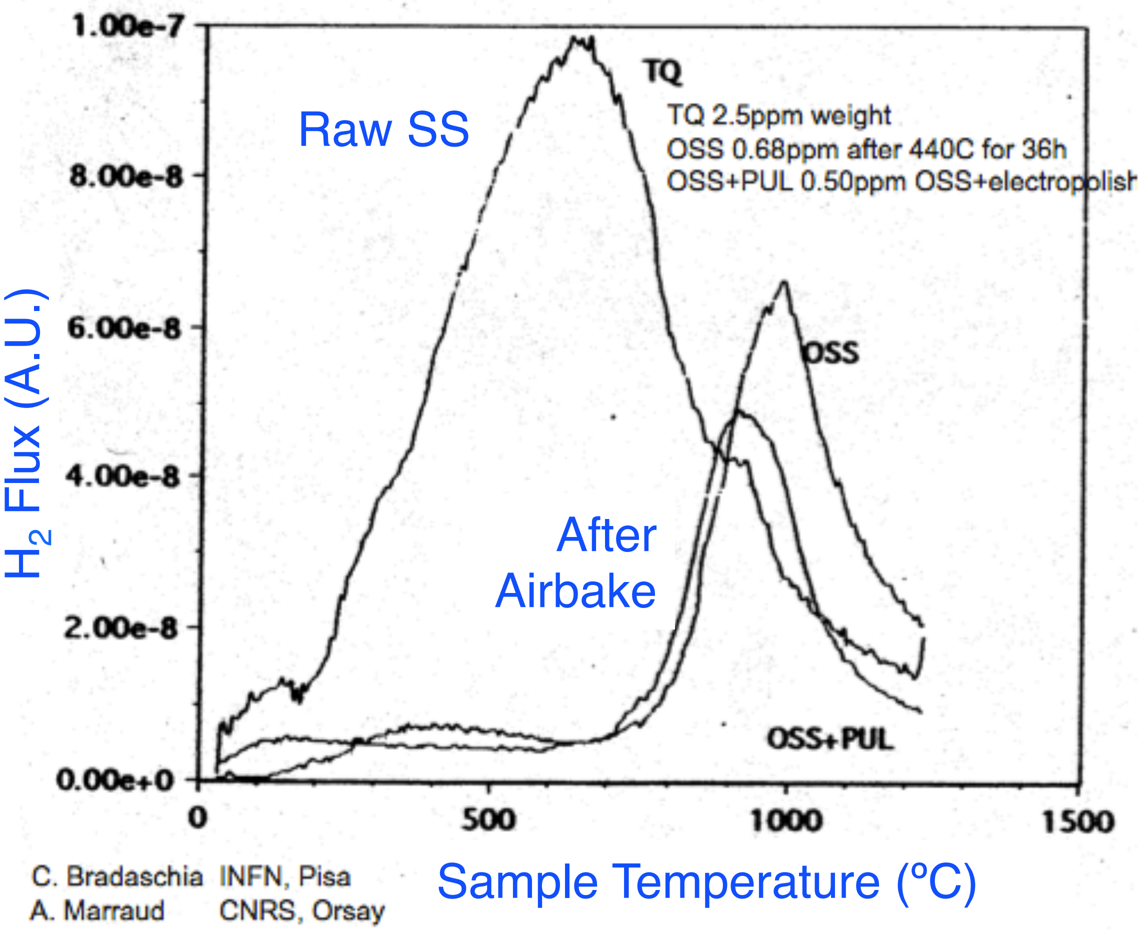
- 304L SS, 3.2 mm thick with external stiffeners
- raw coiled stock air baked 36h @ 455C to deplete hydrogen
    - » $J_{H2} < 1e\text{-}13$ Tl/s/cm^2
    - » permits ultimate P without distributed pumps
    - » process developed by LIGO
- prepared coil spiral-welded into 1.2m tube on modified culvert mill
- 16m sections cleaned, leak checked, and capped
- FTIR analysis to confirm HC-free
- sections field butt-welded together in travelling clean room
- Over 50 linear km of weld—





Depleting H from raw SS before fabrication: An economical alternative to high T vacuum bakeout

- SS sheet from mill is baked in air 36 hours at 455 °C
- (Hotter treatment deemed inadvisable due to carbide formation)
- Total dissolved hydrogen is reduced ~ 3x
- Remaining H is tightly bound, high activation T
- Care is required in welding to avoid re-introduction of H



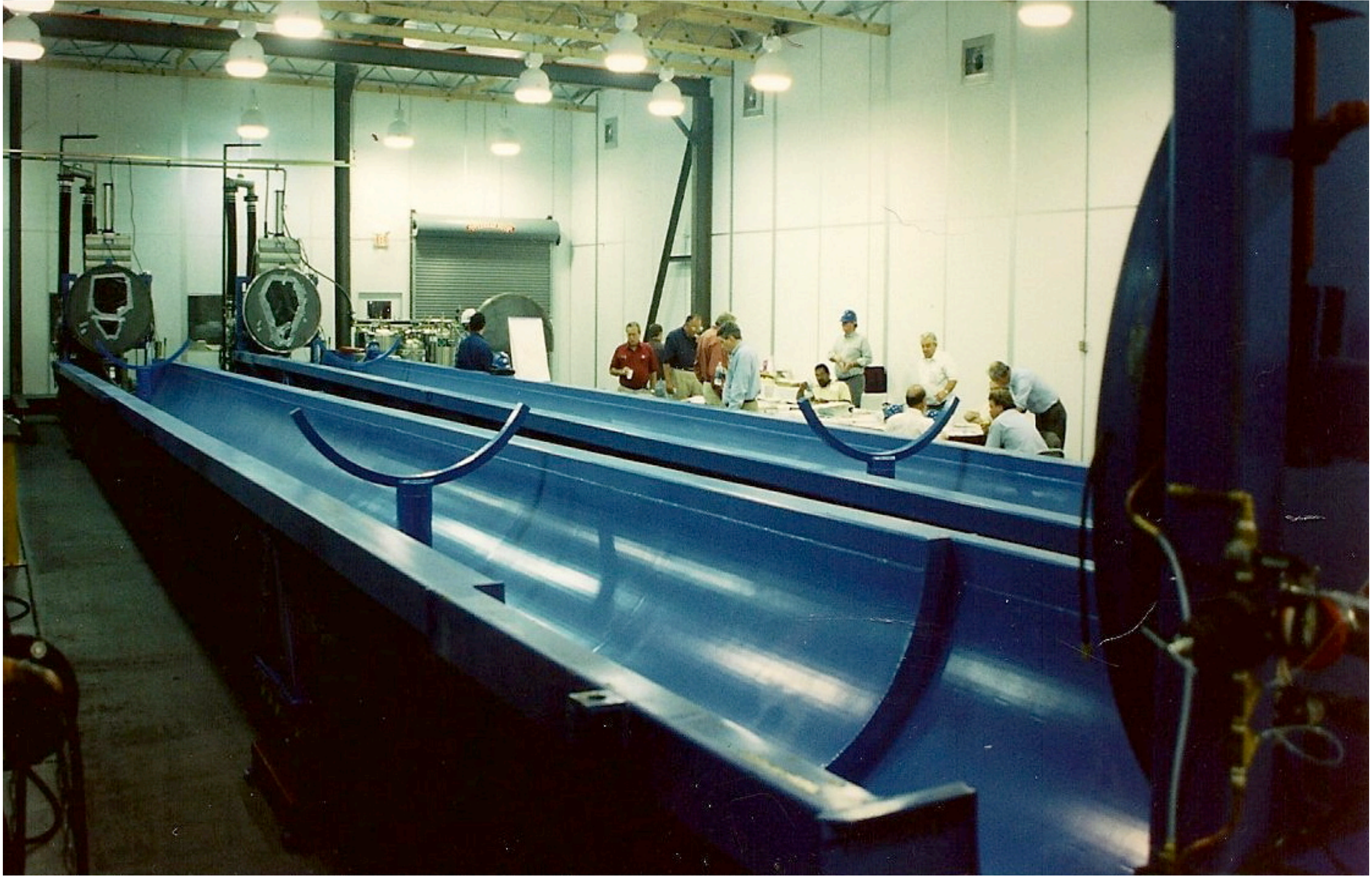
data courtesy of Virgo

Cleaned with pressurized hot water and detergent

QA by FTIR sampling

Leak Test "Coffin"

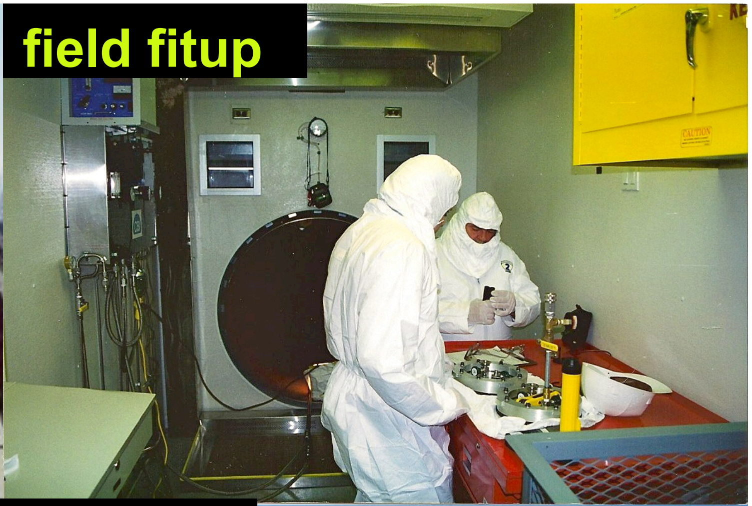
Leak Test "Coffin"



Beam Tube Field Assembly


transport


position


field fitup


butt weld


leak check


next section

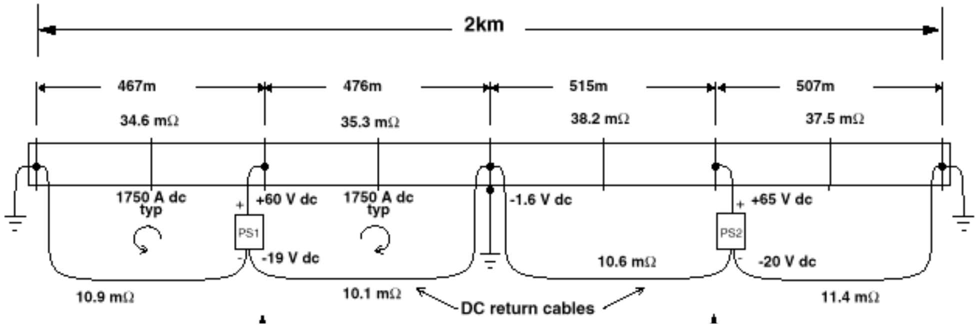
Tube Assembly

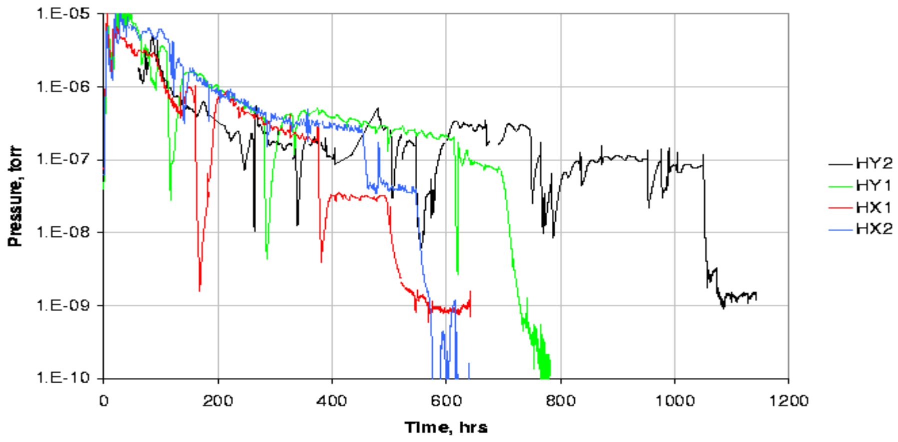
- Field butt weld made in movable shelter
- Internal “dam” shields inside of weld with inert gas
- Dam is later filled with He for leak test
- Finally, garbed worker crawls in to remove dam & place optical baffles

Welding Shelter

I^2R Bakeout to Desorb Water

- Glass wool insulation
- I_{DC} = 2,000 A
- ~ 3 weeks @ 160ºC
- Final $J_{H20} < 2e\text{-}17$ Tl/s/cm^2
- Tubes never to be vented





How Often do you get a Second Chance??
Some Updates Under Study for LIGO India

- Move to “conventional” large gate valve design ?
  - Reduce cost with single 0-ring gate seal, metallic bonnet seal?
  - Increase reliability with “standard product”?
  - Reduce complexity of two actuator styles
- Remove oxide from stress-relieved vessel walls?
  - Oxide patina was good for suppressing IR scatter, good for vacuum performance, but began to flake off with age– had to be removed!
  - Considering conventional treatments such as passivation or electropolish
- Is spiral-welding still the most economical tube construction?
- Are there alternative ways to achieve ultralow dissolved hydrogen?
- Should we upgrade monitoring & instrumentation along tubes?
- Should we consider 316L in place of 304L for higher corrosion resistance?
- Should we consider flanging or other means to reversibly isolate tube sections after installation?

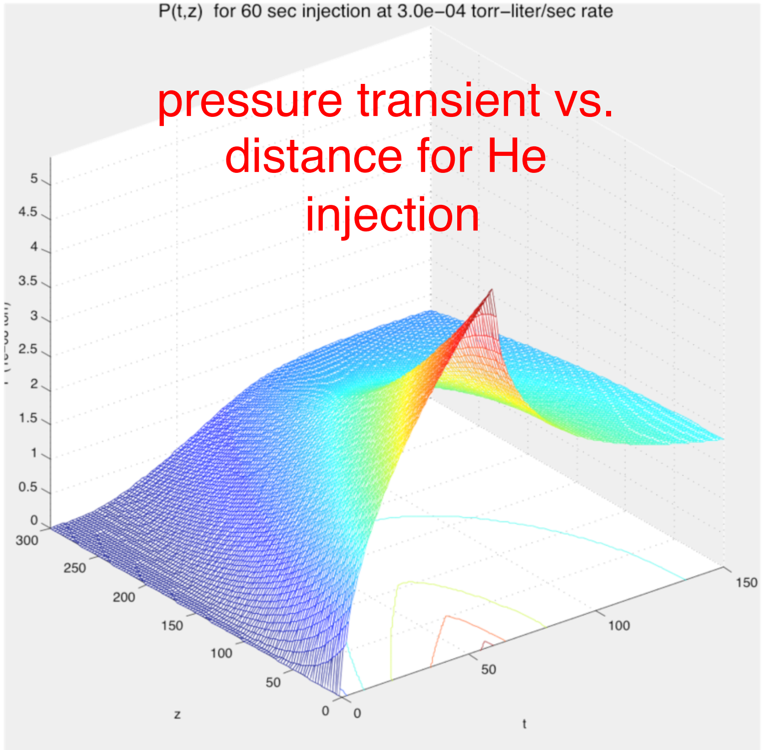
Cautionary Tale:
The LLO Y Beamtube Leak

- Discovered only late last year, but…
- Reconstruct *t*=0 in 2008, *F* = 2.5e-4 torr-liter/sec (!)
  - » Unnoticed due to sparse instrumentation, masked by detector outgassing
  - » Approximately 1e5 x specification; *MUST BE REPAIRED*
    - – Legacy of water vapor deposited since '08 may persist, even after repairs
- Localized near Y midpoint by gradient methods
- Followed by He MSLD test: VERY DIFFICULT ON THIS SIZE SYSTEM !
- At least *4 distinct leaks* discovered to date, in at least 3 zones
  - » Confirms this is no fluke or isolated defect, but a progressive problem
  - » Most likely a spectrum of sources will be found
  - » Largest breach is now sealed but about 1e-5 torr-liter/sec remains unaccounted for
- Those discovered to date coincide with
  - » Welds (both a spiral weld and a stiffener fillet), plus
  - » Animal residues (mice or mud wasps; emit "corrosion accelerants"), plus
  - » Local history of persistent water incursion
- Team (incl. yours truly) has been assigned to find, repair, prevent recurrence
  - » Outside metallurgical & welding specialists under contract
  - » Additional diagnostics on known leaks, representative fab samples
  - » Too soon to reliably bound full $ and schedule impact!


mouse latrine


evacuated temporary cover


mud dauber nest



pressure transient vs. distance for He injection


B →

Final Remarks

- LIGO facilities are among the largest high-vacuum systems ever built, and have stringent requirements
- Novel and cost-effective methods were developed to meet these challenges successfully in the US
- In trouble-free operation over a decade, LIGO is now installing second-generation instruments in Louisiana and Washington
- A third identical interferometer was built and is now designated for India when the site is available
- With benefit of hindsight, new technology, and Indian innovation, we believe the LIGO India vacuum system will be even better!

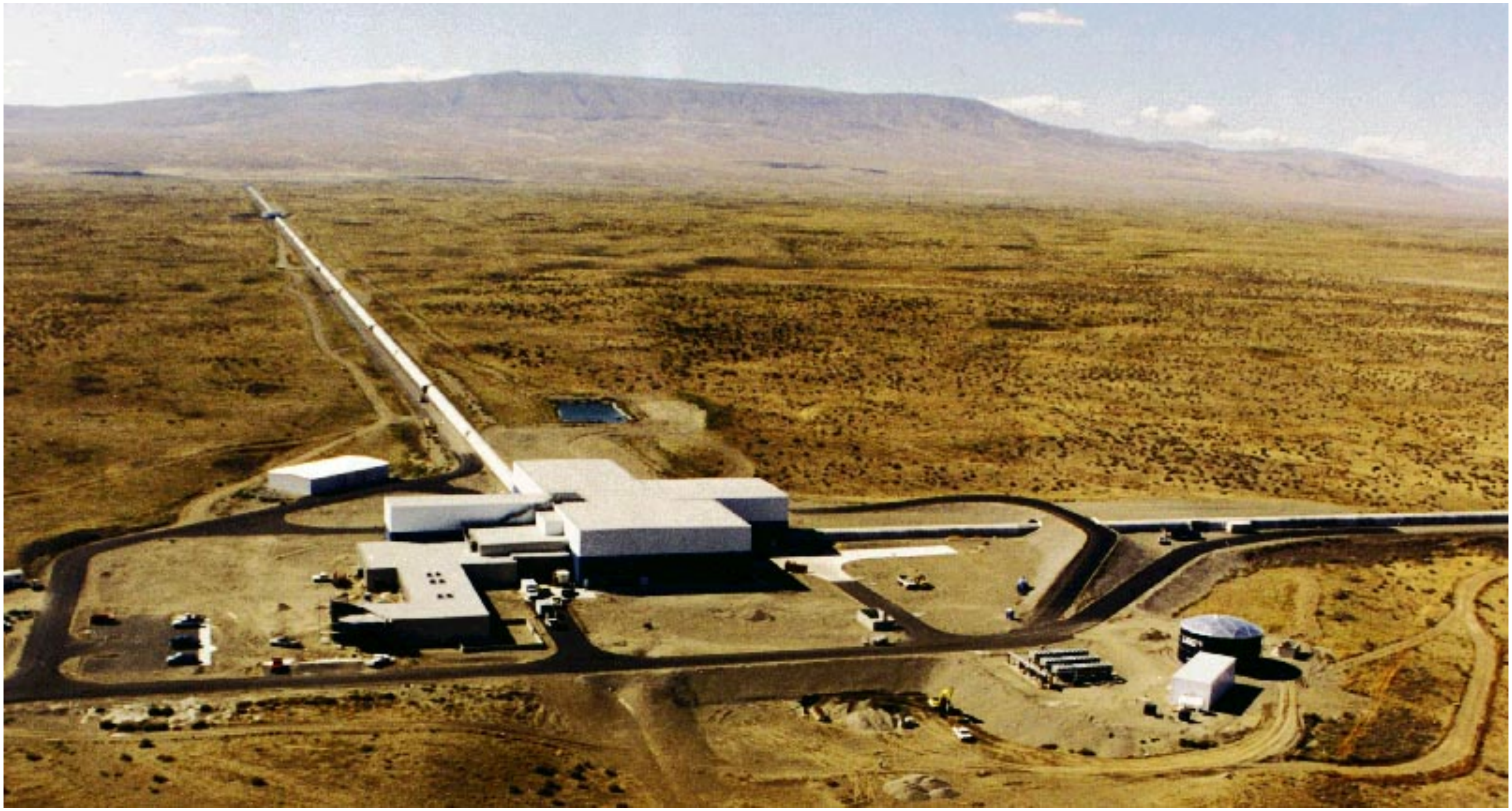
Thank you IUVSTA!

Thank you IPR!

--Reference Slides--

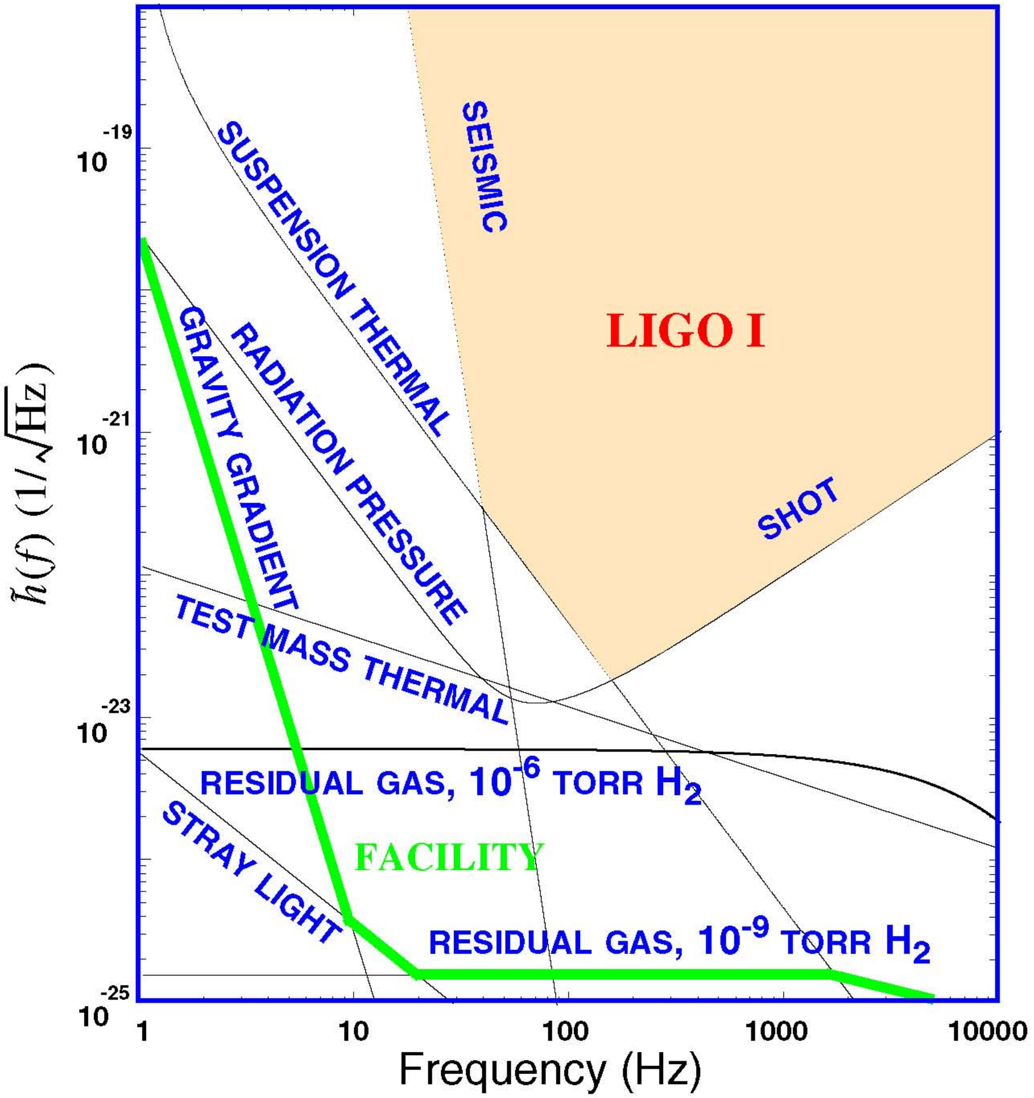
LIGO
Livingston Observatory

LIGO
Hanford Observatory



Limits to Sensitivity

- First detectors reached design sensitivity in 2005
- Now installing Advanced detectors
- Vacuum requirement $<10^{-9}$ torr H_2 $<10^{-10}$ torr H_2O



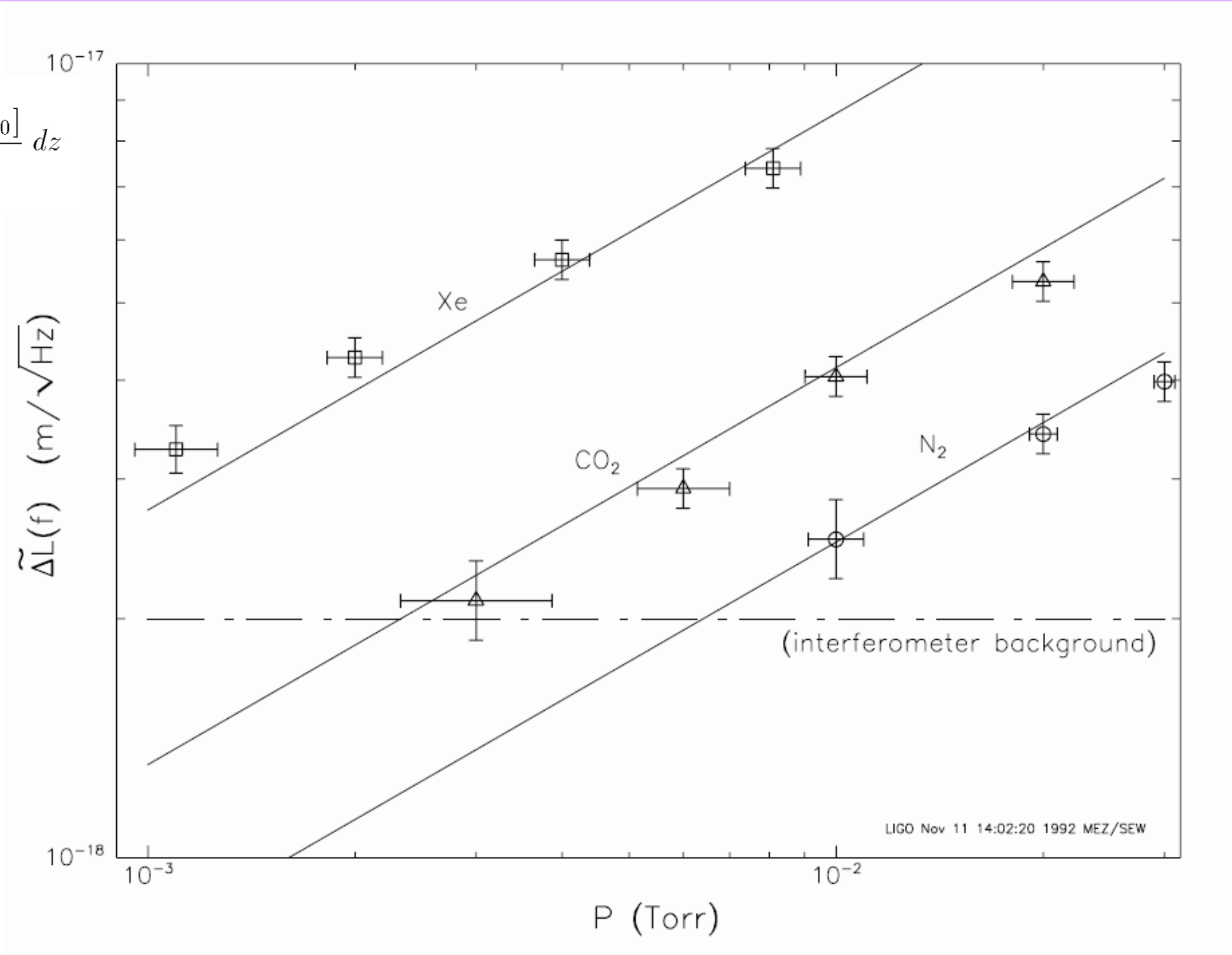
Residual Gas Index Fluctuation Noise

$$S_L(f) = \frac{4\rho(2\pi\alpha)^2}{v_0}\int_0^{L_0} \frac{\exp\left[-2\pi f\, w(z)/v_0\right]}{w(z)}\, dz$$

$$\Delta\tilde{L}(f) \equiv \sqrt{\bar{S}_{\Delta L}(f)} = \sqrt{2S_L(f)}$$

ϱ = gas number density (~ pressure)
α = optical polarizability (~ index)
w = beam radius
v_0 = most probable thermal speed
L_0 = arm length
ΔL = arm optical path difference

Statistical model verified by interferometer experiment



S. Whitcomb and MZ, *Proc. 7th Marcel Grossmann Meeting on GR,*
R. Jantzen and G. Keiser, eds. World Scientific, Singapore (1996).

Residual Gas Pressure Limits in Beam Tubes

To avoid optical phase noise in laser path

$$h(f) = 4.8\times10^{-21} R\left(\frac{x}{H_2}\right)\sqrt{\langle P(torr)\rangle_L}$$

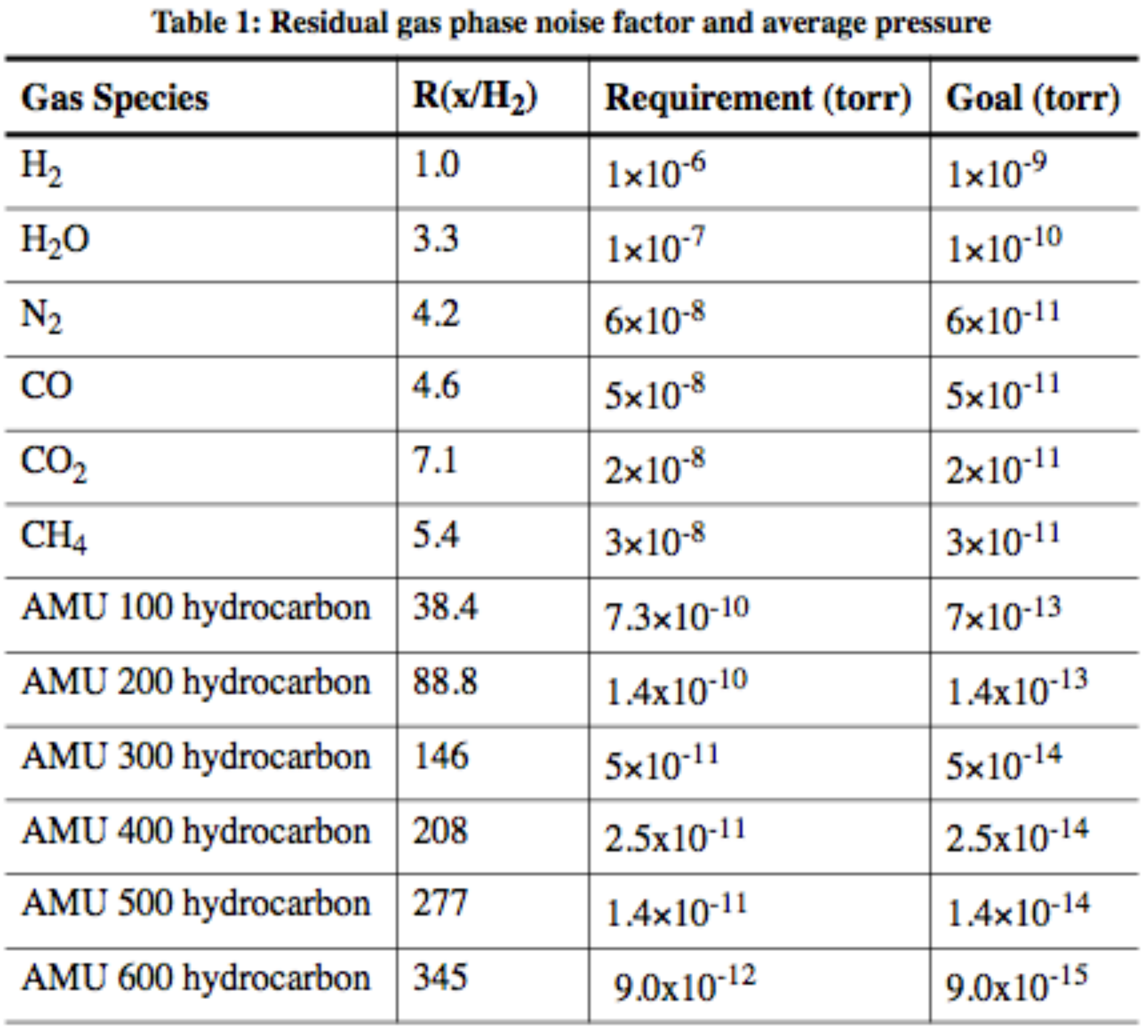
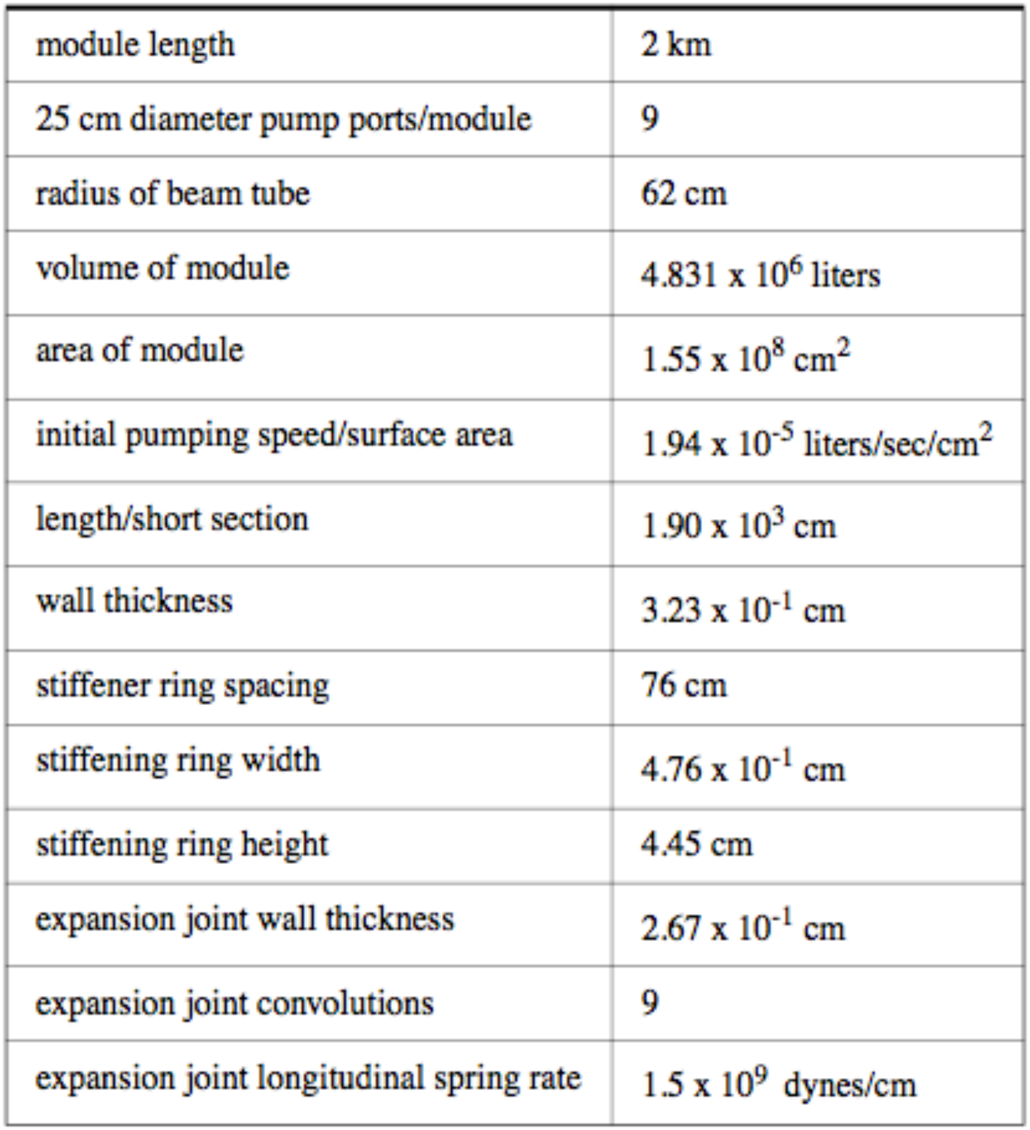


Table 1: Residual gas phase noise factor and average pressure

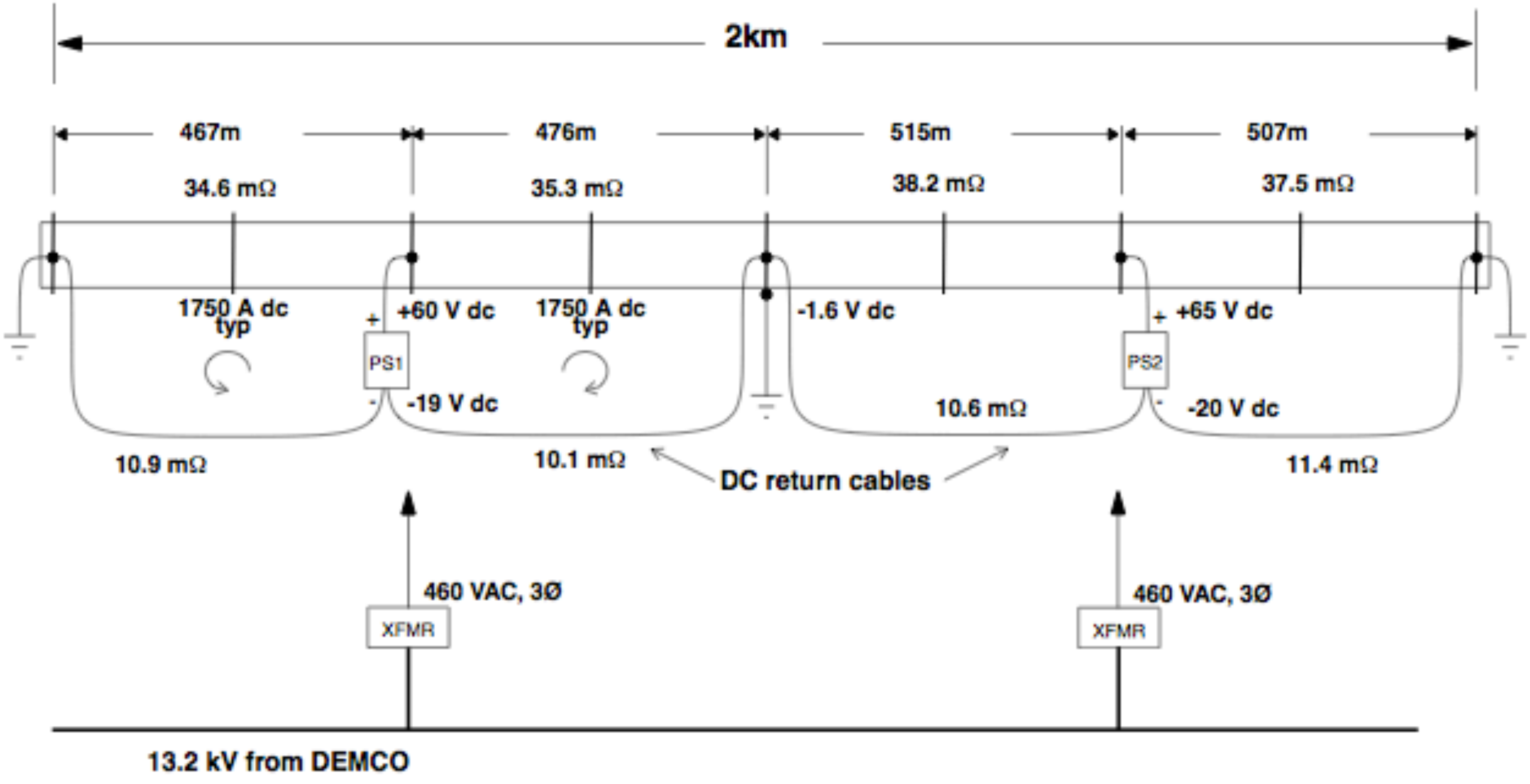
Gas Species	$R(x/H_2)$	Requirement (torr)	Goal (torr)
H_2	1.0	1×10^{-6}	1×10^{-9}
H_2O	3.3	1×10^{-7}	1×10^{-10}
N_2	4.2	6×10^{-8}	6×10^{-11}
CO	4.6	$5x10^{-8}$	$5x10^{-11}$
CO_2	7.1	2×10^{-8}	2×10^{-11}
CH_4	5.4	3×10^{-8}	3×10^{-11}
AMU 100 hydrocarbon	38.4	7.3×10^{-10}	7×10^{-13}
AMU 200 hydrocarbon	88.8	$1.4x10^{-10}$	$1.4x10^{-13}$
AMU 300 hydrocarbon	146	$5x10^{-11}$	$5x10^{-14}$
AMU 400 hydrocarbon	208	$2.5x10^{-11}$	$2.5x10^{-14}$
AMU 500 hydrocarbon	277	1.4×10^{-11}	1.4×10^{-14}
AMU 600 hydrocarbon	345	$9.0x10^{-12}$	$9.0x10^{-15}$

Beam Tube Properties



module length	2 km
25 cm diameter pump ports/module	9
radius of beam tube	62 cm
volume of module	4.831×10^6 liters
area of module	1.55×10^8 cm^2
initial pumping speed/surface area	1.94×10^{-5} liters/sec/cm^2
length/short section	1.90×10^3 cm
wall thickness	3.23×10^{-1} cm
stiffener ring spacing	76 cm
stiffening ring width	4.76×10^{-1} cm
stiffening ring height	4.45 cm
expansion joint wall thickness	2.67×10^{-1} cm
expansion joint convolutions	9
expansion joint longitudinal spring rate	1.5×10^9 dynes/cm

BEAM TUBE BAKEOUT ELECTRICAL HEATING POWER



2km

467m
476m
515m
507m

34.6 mΩ
35.3 mΩ
38.2 mΩ
37.5 mΩ

1750 A dc typ
+60 V dc
1750 A dc typ
-1.6 V dc
+65 V dc

PS1
PS2

-19 V dc
-20 V dc

10.9 mΩ
10.1 mΩ
10.6 mΩ
11.4 mΩ

DC return cables

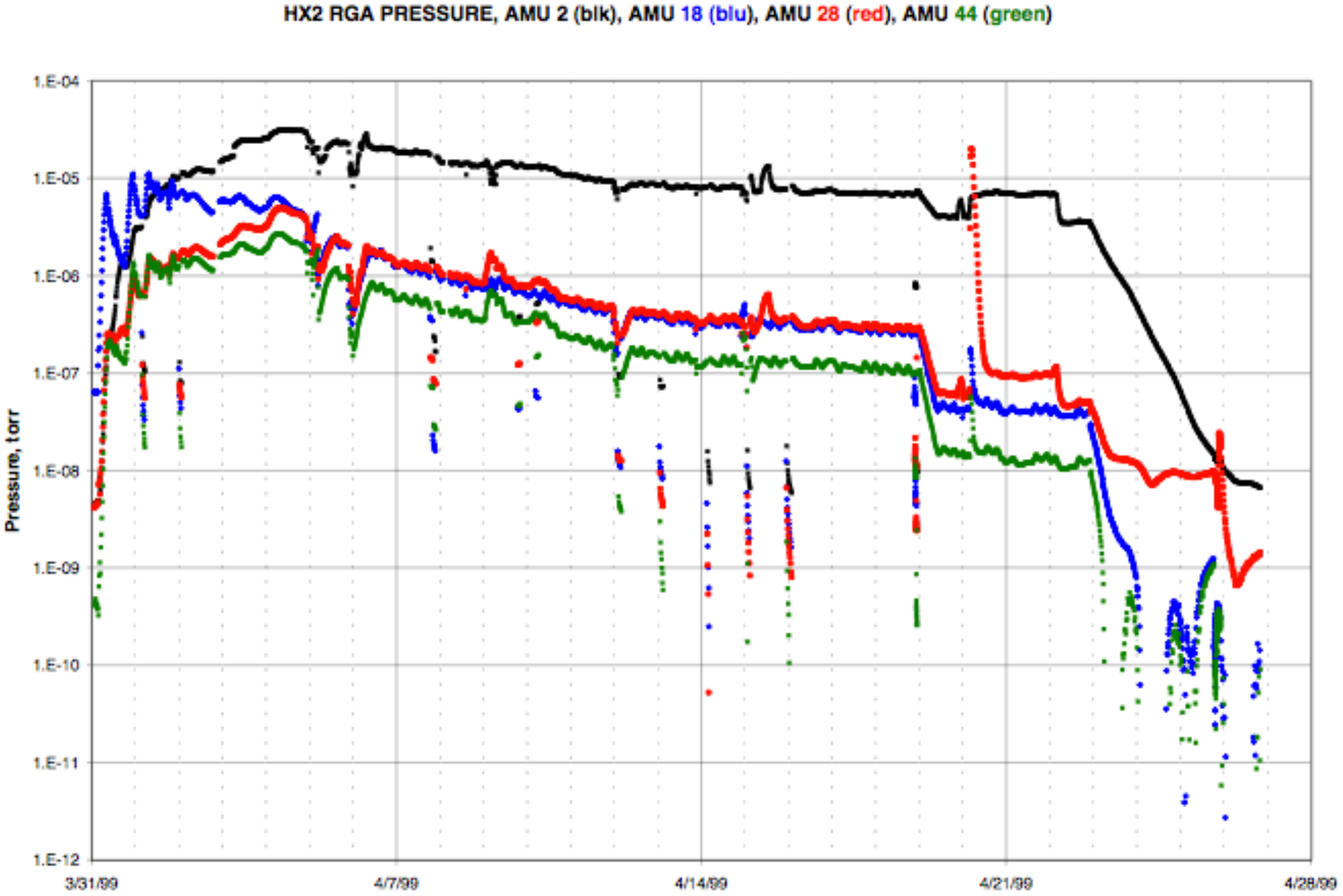
460 VAC, 3Ø
460 VAC, 3Ø

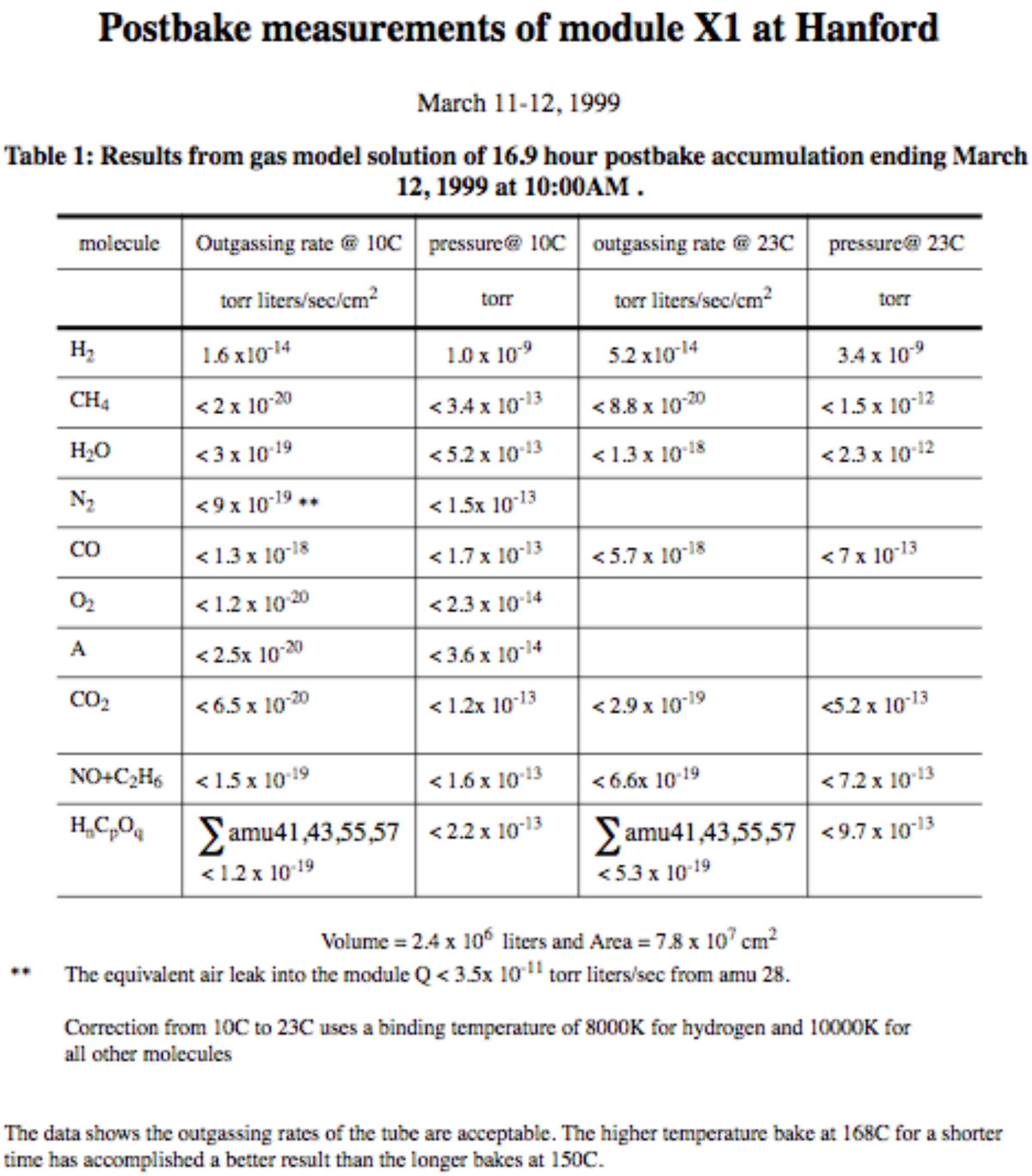
XFMR
XFMR

13.2 kV from DEMCO

Legend: XFMR Power Transformer PS Low voltage, high current DC power supply

Pressure evolution for major species during 160ºC beam tube module bakeout





Postbake measurements of module X1 at Hanford

March 11-12, 1999

Table 1: Results from gas model solution of 16.9 hour postbake accumulation ending March 12, 1999 at 10:00AM .

molecule	Outgassing rate @ 10C	pressure@ 10C	outgassing rate @ 23C	pressure@ 23C
	torr liters/sec/cm^2	torr	torr liters/sec/cm^2	torr
H_2	1.6 x10^{-14}	1.0 x 10^{-9}	5.2 x10^{-14}	3.4 x 10^{-9}
CH_4	< 2 x 10^{-20}	< 3.4 x 10^{-13}	< 8.8 x 10^{-20}	< 1.5 x 10^{-12}
H_2O	< 3 x 10^{-19}	< 5.2 x 10^{-13}	< 1.3 x 10^{-18}	< 2.3 x 10^{-12}
N_2	< 9 x 10^{-19} **	< 1.5x 10^{-13}		
CO	< 1.3 x 10^{-18}	< 1.7 x 10^{-13}	< 5.7 x 10^{-18}	< 7 x 10^{-13}
O_2	< 1.2 x 10^{-20}	< 2.3 x 10^{-14}		
A	< 2.5x 10^{-20}	< 3.6 x 10^{-14}		
CO_2	< 6.5 x 10^{-20}	< 1.2x 10^{-13}	< 2.9 x 10^{-19}	<5.2 x 10^{-13}
$NO+C_2H_6$	< 1.5 x 10^{-19}	< 1.6 x 10^{-13}	< 6.6x 10^{-19}	< 7.2 x 10^{-13}
$H_nC_pO_q$	$\sum$amu41,43,55,57 < 1.2 x 10^{-19}	< 2.2 x 10^{-13}	$\sum$amu41,43,55,57 < 5.3 x 10^{-19}	< 9.7 x 10^{-13}

Volume = 2.4 x 10^6 liters and Area = 7.8 x 10^7 cm^2

** The equivalent air leak into the module Q < 3.5x 10^{-11} torr liters/sec from amu 28.

Correction from 10C to 23C uses a binding temperature of 8000K for hydrogen and 10000K for all other molecules

The data shows the outgassing rates of the tube are acceptable. The higher temperature bake at 168C for a shorter time has accomplished a better result than the longer bakes at 150C.

Beam Tube Bakeout Results

	Outgassing Rate corrected to 23 °C torr liters/sec/cm^2 (All except H_2 are upper limits)					
molecule	**Goal***	**HY2**	**HY1**	**HX1**	**HX2**	
H_2	4.7	4.8	6.3	5.2	4.6	$\times 10^{-14}$
CH_4	48000	< 900	< 220	< 8.8	< 95	$\times 10^{-20}$
H_2O	1500	< 4	< 20	< 1.8	< 0.8	$\times 10^{-18}$
CO	650	< 14	< 9	< 5.7	< 2	$\times 10^{-18}$
CO_2	2200	< 40	< 18	< 2.9	< 8.5	$\times 10^{-19}$
$NO+C_2H_6$	7000	< 2	< 14	< 6.6	< 1.0	$\times 10^{-19}$
$H_nC_pO_q$	50–2†	< 15	< 8.5	< 5.3	< 0.4	$\times 10^{-19}$

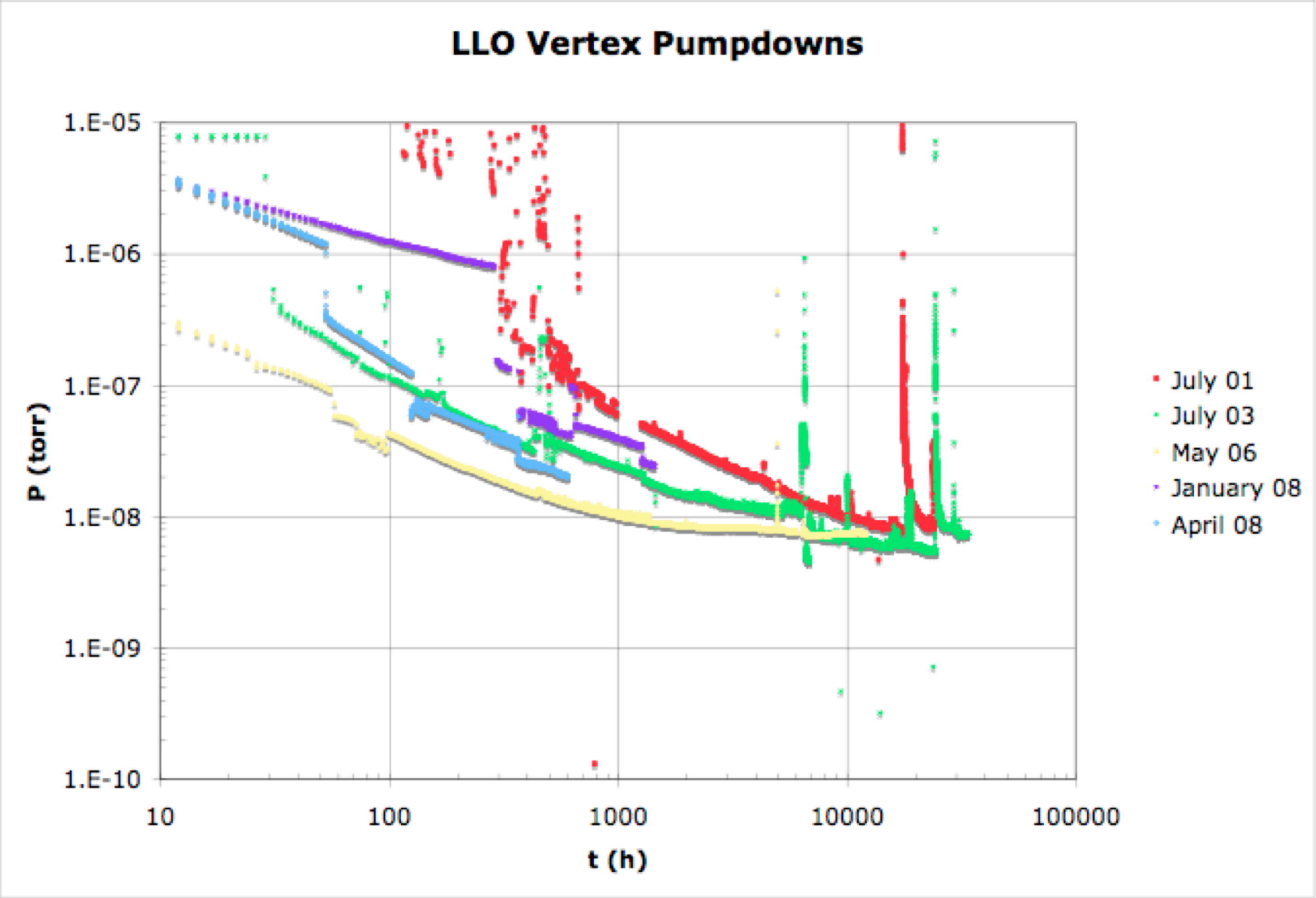
air leak	1000	< 20	< 10	< 3.5	< 16	$\times 10^{-11}$ torr liter/sec

*Goal: maximum outgassing to achieve pressure equivalent to 10^{-9} torr H_2 using only pumps at stations

†Goal for hydrocarbons depends on weight of parent molecule; range given corresponds with 100–300 AMU

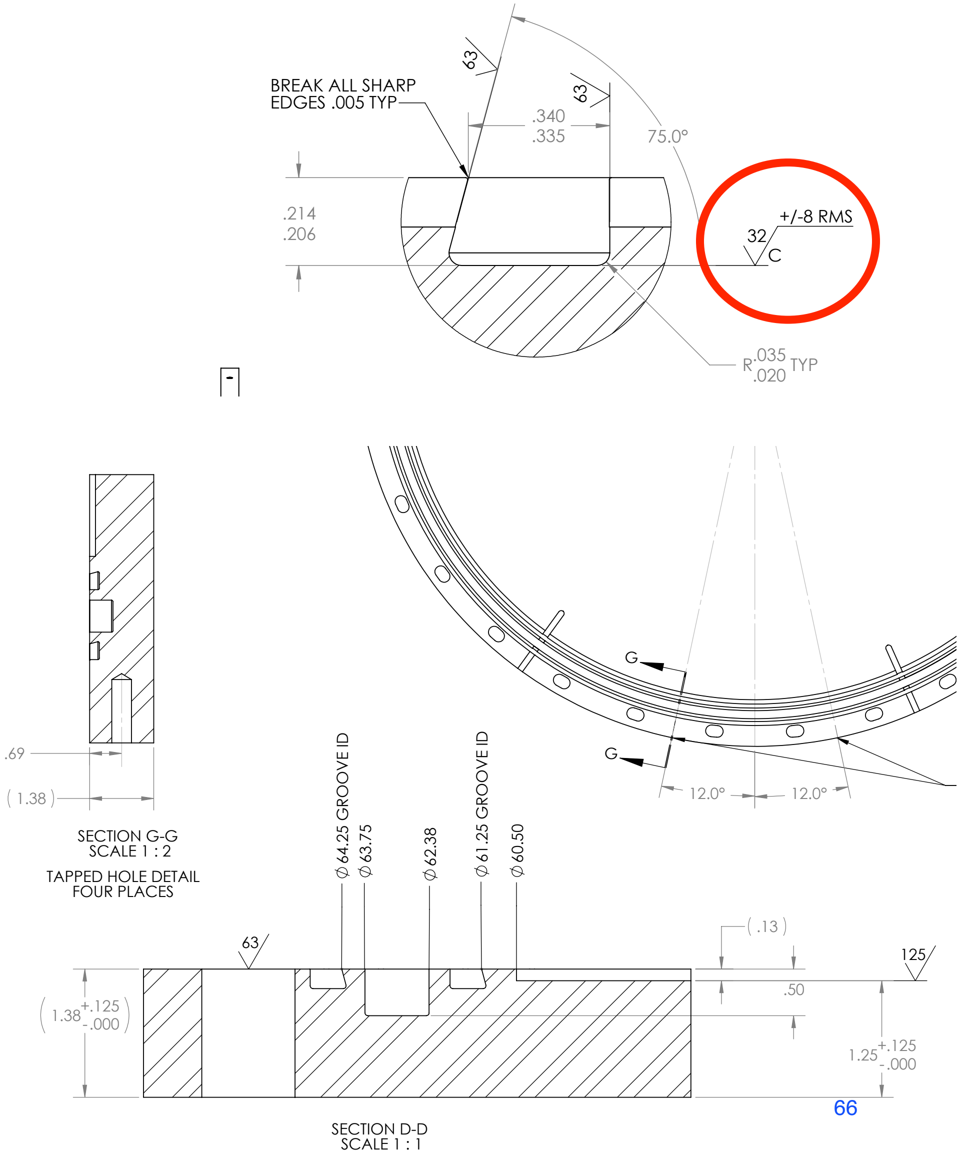
5/24/99 wea

Vertex Pressure Evolution after Backfill



Large Flange Design

- Dual “dry” o-ring
- Pumped annulus between
- (independent of main volume, except in open gate valve)
- Seal faces single-point machined
- Controlled circumferential 32 µinch “tooth” finish
- Custom Viton (Flourel) cord formulation (55 gallon min. order)
- Cleaned & baked after molding to remove volatile compounds and mold release wax



SECTION G-G
SCALE 1 : 2
TAPPED HOLE DETAIL
FOUR PLACES

SECTION D-D
SCALE 1 : 1

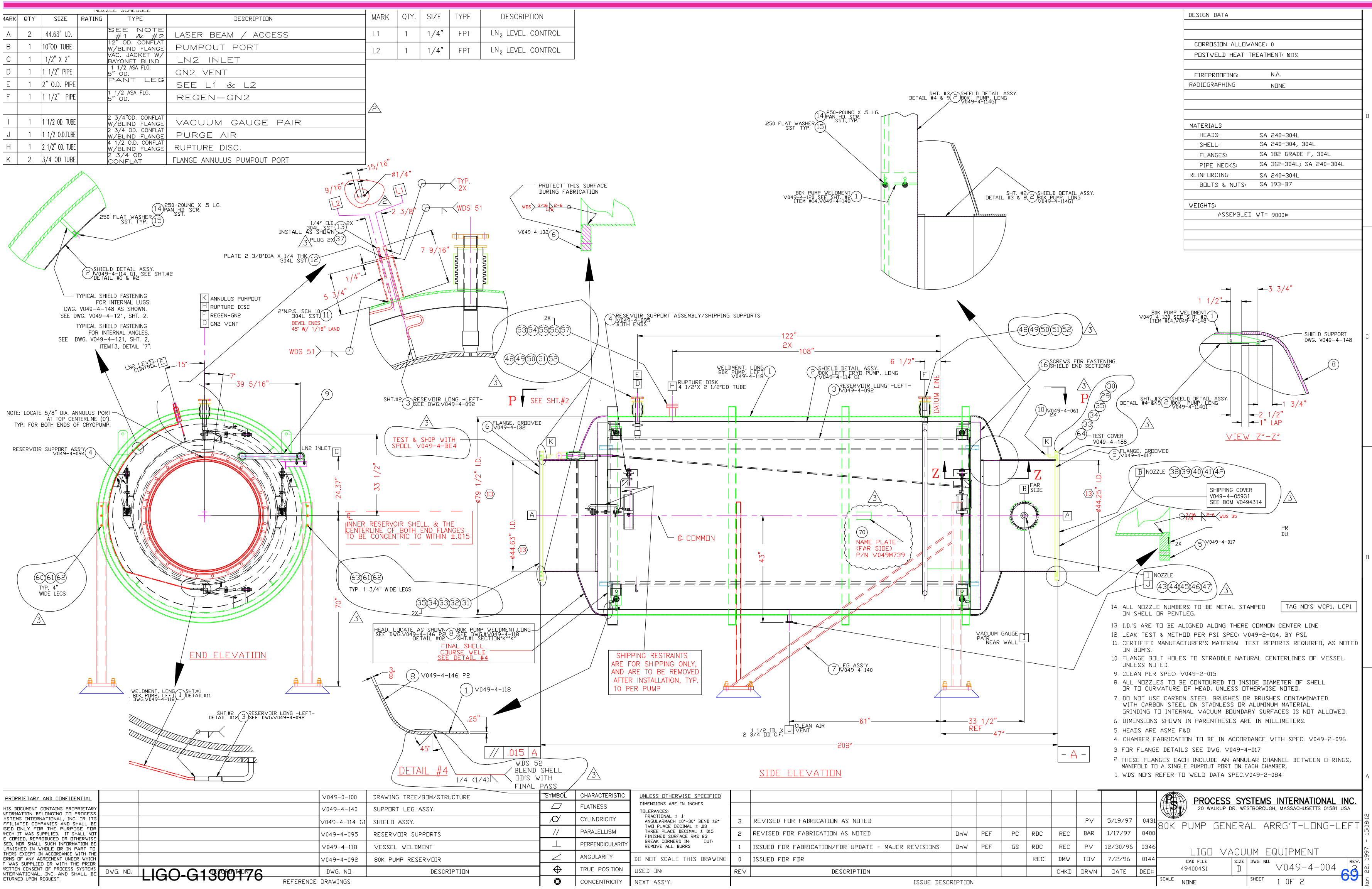
Pumping

- All “dry” pumping
- Initial evacuation by blowers & maglev turbomolecular pumps
- Maintained by noble diode ion pumps and coaxial LN_2

80K LN_2 Cryopump

- Special “low vibration” design
  - LN2 reservoir suspended by compliant springs with Flourel dampers
  - Dual-phase liquid delivery (horizontal vacuum-jacketed lines) maintain continuous liquid and vapor flow without slugging
  - Sloped “chute” introduces new liquid to reservoir
  - Reservoir shape & free surface area designed to preclude boiling
  - Continuous level control (PID with differential pressure level sensor)
- Low-emissivity aluminum cold surface
- Low-emissivity tube liners reduce thermal flux
- Outdoor storage dewars refilled periodically by truck delivery

Cryopump Design



NOZZLE SCHEDULE

MARK	QTY	SIZE	RATING	TYPE	DESCRIPTION
A	2	44.63" I.D.		SEE NOTE #1 & #2	LASER BEAM / ACCESS
B	1	10"OD TUBE		12" OD. CONFLAT W/BLIND FLANGE	PUMPOUT PORT
C	1	1/2" X 2"		VAC. JACKET W/ BAYONET BLIND	LN2 INLET
D	1	1 1/2" PIPE		1 1/2 ASA FLG. 5" OD.	GN2 VENT
E	1	2" O.D. PIPE		PANT LEG	SEE L1 & L2
F	1	1 1/2" PIPE		1 1/2 ASA FLG. 5" OD.	REGEN-GN2
I	1	1 1/2 OD. TUBE		2 3/4"OD. CONFLAT W/BLIND FLANGE	VACUUM GAUGE PAIR
J	1	1 1/2 O.D.TUBE		2 3/4 OD. CONFLAT W/BLIND FLANGE	PURGE AIR
H	1	2 1/2" OD. TUBE		4 1/2 O.D. CONFLAT W/BLIND FLANGE	RUPTURE DISC.
K	2	3/4 OD TUBE		2 3/4 OD CONFLAT	FLANGE ANNULUS PUMPOUT PORT

MARK	QTY.	SIZE	TYPE	DESCRIPTION
L1	1	1/4"	FPT	LN_2 LEVEL CONTROL
L2	1	1/4"	FPT	LN_2 LEVEL CONTROL

DESIGN DATA

CORROSION ALLOWANCE: 0	
POSTWELD HEAT TREATMENT: NOS	
FIREPROOFING:	N.A.
RADIOGRAPHING	NONE
MATERIALS	
HEADS:	SA 240-304L
SHELL:	SA 240-304, 304L
FLANGES:	SA 182 GRADE F, 304L
PIPE NECKS:	SA 312-304L; SA 240-304L
REINFORCING:	SA 240-304L
BOLTS & NUTS:	SA 193-B7
WEIGHTS:	
ASSEMBLED WT= 9000#	

TAG NO'S WCP1, LCP1

14. ALL NOZZLE NUMBERS TO BE METAL STAMPED ON SHELL OR PENTLEG.
13. I.D.'S ARE TO BE ALIGNED ALONG THERE COMMON CENTER LINE
12. LEAK TEST & METHOD PER PSI SPEC: V049-2-014, BY PSI.
11. CERTIFIED MANUFACTURER'S MATERIAL TEST REPORTS REQUIRED, AS NOTED ON BOM'S.
10. FLANGE BOLT HOLES TO STRADDLE NATURAL CENTERLINES OF VESSEL. UNLESS NOTED.
9. CLEAN PER SPEC: V049-2-015
8. ALL NOZZLES TO BE CONTOURED TO INSIDE DIAMETER OF SHELL OR TO CURVATURE OF HEAD, UNLESS OTHERWISE NOTED.
7. DO NOT USE CARBON STEEL BRUSHES OR BRUSHES CONTAMINATED WITH CARBON STEEL ON STAINLESS OR ALUMINUM MATERIAL. GRINDING TO INTERNAL VACUUM BOUNDARY SURFACES IS NOT ALLOWED.
6. DIMENSIONS SHOWN IN PARENTHESES ARE IN MILLIMETERS.
5. HEADS ARE ASME F&D.
4. CHAMBER FABRICATION TO BE IN ACCORDANCE WITH SPEC. V049-2-096
3. FOR FLANGE DETAILS SEE DWG. V049-4-017
2. THESE FLANGES EACH INCLUDE AN ANNULAR CHANNEL BETWEEN O-RINGS, MANIFOLD TO A SINGLE PUMPOUT PORT ON EACH CHAMBER,
1. WDS NO'S REFER TO WELD DATA SPEC.V049-2-084

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REFERENCE DRAWINGS

DWG. NO.	DESCRIPTION
V049-0-100	DRAWING TREE/BOM/STRUCTURE
V049-4-140	SUPPORT LEG ASSY.
V049-4-114 G1	SHIELD ASSY.
V049-4-095	RESERVOIR SUPPORTS
V049-4-118	VESSEL WELDMENT
V049-4-092	80K PUMP RESERVOIR

SYMBOL	CHARACTERISTIC
⏥	FLATNESS
⌭	CYLINDRICITY
//	PARALELLISM
⊥	PERPENDICULARITY
∠	ANGULARITY
⌖	TRUE POSITION
◎	CONCENTRICITY

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .1
ANGULARMACH ±0°-30' BEND ±2°
TWO PLACE DECIMAL ± .03
THREE PLACE DECIMAL ± .015
FINISHED SURFACE RMS 63
BREAK CORNERS IN: OUT:
REMOVE ALL BURRS
DO NOT SCALE THIS DRAWING
USED ON:
NEXT ASS'Y:

ISSUE DESCRIPTION

REV	DESCRIPTION					CHKD	DRWN	DATE	DEO#
3	REVISED FOR FABRICATION AS NOTED						PV	5/19/97	0431
2	REVISED FOR FABRICATION AS NOTED	DmW	PEF	PC	RDC	REC	BAR	1/17/97	0400
1	ISSUED FOR FABRICATION/FDR UPDATE - MAJOR REVISIONS	DmW	PEF	GS	RDC	REC	PV	12/30/96	0346
0	ISSUED FOR FDR				REC	DMW	TDV	7/2/96	0144

PROCESS SYSTEMS INTERNATIONAL INC.
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80K PUMP GENERAL ARRG'T-LONG-LEFT

LIGO VACUUM EQUIPMENT

CAD FILE 494004S1 | SIZE D | DWG. NO. V049-4-004 | REV. 3
SCALE NONE | SHEET 1 OF 2

Jan 22, 1997 - 15:08:12