Gravitational Waves

The Status of LIGO

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Neutron Star Binary Coalescence

Method	*Our Galaxy*	*Distance for 3/yr*
Progenitor Death Rate	~1/1000 yr	130 M.L.yr
Binary Pulsar Searches and Discoveries	$\sim 1/10^{5\pm1}$ yr	600 M.L.yr.
Ultra-conservtive Limit from Binary Pulsar Searches	$\sim 1/10^{7}$ yr	3000 M.L.yr

International Effort - Gravitational Waves

- Techniques
  - » Resonant Bar Detectors
  - » Large Scale Interferometers
- International Interferometer Effort
  - » U.S. -- LIGO (Two Sites)
  - » Europe -- VIRGO (One Site)

  plus, smaller efforts
    - – Germany, Japan, Australia
- Combination yields
  - » Reliable detection
  - » Pointing to source
  - » Decomp. of grav wave polarizations
  - » Evolution of sensitivity
- Time Scale
  - » Approximately year 2000

Forces Exerted by a Gravitational Wave

If Detector Size << Wavelength
(4 km) (300-30,000km)

Then: Quadrupolar Lines of Force

+ Polarization   x Polarization

Gravitational Wave Emission

Russell Hulse and Joseph Taylor

PSR 1913 + 16

17/sec

Timing of Pulsars

8 hr

Timed to ~50 μsec

Since discovery, observed period gradually speed up

- 10 sec in 15 years
- growing quadratically in time

Due to loss of orbital energy, from emission of gravitational waves

LIGO
Scientific Mission

- Direct Detection of Gravitational Waves

  Neutron Binary Coalescence
  (Last 15 minutes of Hulse/Taylor
  in 100 Million Years)

  » Test General Relativity in Strong Field and High Velocity Limit
  » Measure Polarization and Propagation Speed

LIGO Long Range Goals

- "New Tool" to Explore the Universe
  - » Final Coalescence of Binary Systems
    - – Neutron Star/Neutron Star

      Design Benchmark: last 15 min; 20,000 cycles 600MLyr
    - – Black-hole/Black-hole or /Neutron Star
  - » Supernovae
    - – Axisymmetric in our galaxy
    - – Non-axisymmetric ~300MLyr
  - » Early Universe
    - – Vibrating Cosmic Strings
    - – Vacuum Phase Transitions
    - – Vacuum Fluctuations from Planck Era
  - » The Unknown

Gravitational Wave Detection Strategy

- Interferometer Sensitivity
  - » R&D Program
    - – Technology Development
    - – Demonstration Experiments
  - » Engineering Implementation
    - – Precision Engineering Design
    - – Quality Control
- Two Sites - Three Interferometers
  - » Single Interferometer ~50/hr
    - – non-gaussian level
  - » Hanford (Doubles) ~1/day
    - – correlated rate (x1000)
  - » Hanford + Livingston <0.1/yr
    - – uncorrelated (x5000)

LIGO Project

- Detector
  - » Detection Strategy
  - » Interferometers
- R&D
  - » Noise Sources and Sensitivity
  - » Demonstration Experiments
- Major Facilities
  - » Beam Tube
  - » Vacuum Systems
  - » Civil Construction
- Status and Plans

Civil Construction

- Characteristics
  - » Structures, Foundation, Roads, etc
    - – Large and Clean Laboratory Bldgs
    - – Beam Enclosures
    - – Office/Lab Space
  - » Requirements
    - – Seismic Stability, Noise Sources, etc
    - – Cleanliness

- Status and Plans
  - » Both Sites Acquired
    - – Grading - Wash; Clearing in Lousiana
  - » Design/Const. Management
    - – Awarded to Parsons (Nov 95)
  - » Conceptual Design -
    - – 90% A&E received 4/95
    - – Trade Studies; Value Engineering

LIGO Facilities
Civil Construction

- A & E Contract
  - » R. M.. Parsons -- initiated Jan 95
  - » scope: design and construction management for buildings, enclosures, offices etc
  - » requirements for seismic stability, noise sources, cleanliness
  - » conceptual design approved in July for scope consistent with LIGO budget
  - » final design proceeding as "design to cost"

- Status of Construction
  - » Both sites acquired; no major problems remain
  - » Washington:
    - – rough grading completed; settling
  - » Louisiana:
    - – cleared and grubbed;
    - – pipeline reconfigurations solved and underway
    - – rough grading bids received, begin soon

Vacuum Equipment

- Characteristics
  - » Enormous Volume (~20,000 m^3)
  - » Mostly Standard Vac. Equipment
    - 1st stage roughing - Atm -> 0.1 torr
    - 2nd stage roughing - 0.1 torr ->10^{-6} torr
    - Steady State - Ion/getter pumps.
  - » Large Gate Valves (4ft diam)
    - access and flexibility
  - » Controls and Monitoring
- Status and Plans
  - » Specifications Defined
    - Science Review Complete - Aug '95
  - » RFP for Design and Manufacturing
    - CBI and PSI awarded design contracts
    - Down-select 6/95

LIGO Facilities
Vacuum Equipment

- Characteristics
  - » mostly standard vacuum equipment
    - 1st stage roughing atm -> 0.1 torr
    - 2nd stage roughing 0.1 torr -> 10^{-6} torr
    - steady state - ion/getter pumps
  - » large gate valves (4 ft diam)
    - access and flexibility
  - » controls and monitoring

- Status
  - » Science requirements and review 6/94
  - » RFP issued for design contract only
  - » Two competitive contracts awarded (CB&I, PSI)
  - » Final design and manufacturing
    - down select (6/95) to PSI
    - cost ($39.1M), including change control actions is about $2M under budget
    - approved by NSF and contract awarded!!

Beam Tube

- Characteristics
  - » Arm Lengths - 4km
  - » Tube Diameter - 4 ft
  - » Initial Detector
    - – 10^{-6} torr Hydrogen; 10^{-7} torr Water
  - » Advanced Detectors
    - – 10^{-9} torr Hydrogen; 10^{-10} torr Water
  - » Quality Control
    - – (materials, welding, cleaning, etc)

- Status and Plans
  - » Design Contract was with CBI
    - – Final Design Report Accepted (6/94)
  - » Qualification Test
    - – 130 ft Section - success (4/95)
  - » Contract Options

LIGO Facilities

Beam Tube

- Characteristics:
  - » length = 4 km (4 arms)
  - » diameter = 4 ft
  - » volume = 20, 000m^3

- Design Contract with CBI
  - » Design report accepted
    - – thin wall stainless spiral weld structure
    - – 65 foot sections with bellow
    - – quality control in material selection, welding, cleaning, etc
  - » Qualification test -
    - – 130 ft section assembled, cleaned, baked and tested -- achieved design

- Construction contract
  - » Negotiate option with CB&I, but be prepared to compete
  - » Status -- final price agreed; negotiating detailed scope; contract soon.
  - » Cost (~ $40M) is about $5M over budget

Beam Tube Enclosure

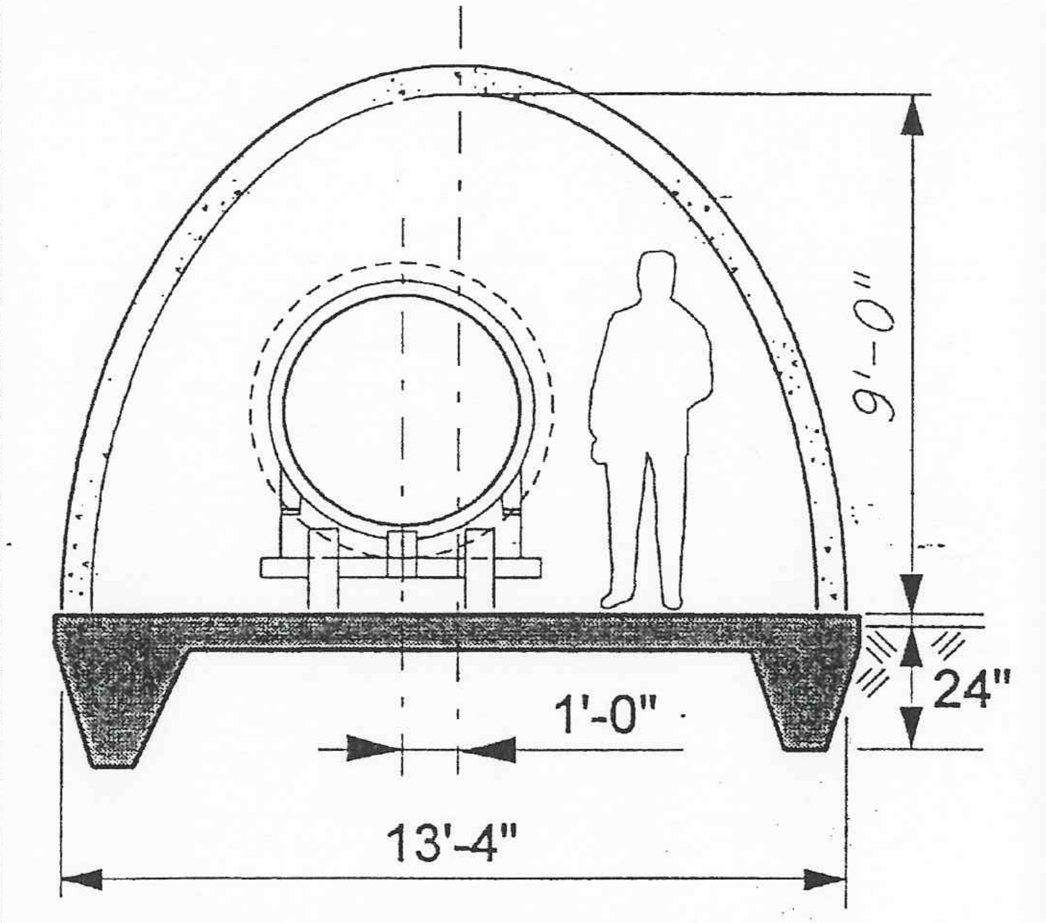

Figure 2.1-1 -- Cross Section of Design Baseline at Hanford

LIGO Detectors
R&D Program

- Sensitivity
  - » main features of 40 m spectrum understood
  - » monolithic test masses improve sensitivity

- Demonstration Experiments
  - » optical recombination demonstrated on 40 m
  - » acquisition locking with LIGO controls
  - » MIT phase noise experiments underway

- Pre- [detector design freeze]
  - » Program testing directed at tasks that could effect design over the next two years

- Post- [detector design freeze]
  - » Program directed at improved sensitivity; experience running an interferometer facility

R&D Program

- Overview
  - » Demonstration Experiments
    - – Technical: Suspensions; Optics, Servos, ..
    - – Sensitivity: Displacement, Phase Noise
  - » Priorities for Detector Design Freeze
  - » Operations: Reliability, Stability
  - » Develop Advanced Techniques
    - – Active Seismic Isolation
- Progress and Plans
  - » Optics, Test masses, Mirrors, etc
  - » 40m Displacement Results

LIGO Detectors
Lasers

- Working decision to switch to Nd:YAG lasers for LIGO
  - » Study initiated in May '95; study and discussion meetings during summer, decision in Sept '95
  - » YAG chosen for reliability and because it is the most direct path toward high power (improved sensitivity)
  - » Switch now to invest all our resources toward final laser type and to build optics at longer wavelength.
  - » Now developing plan to integrate into LIGO baseline
    - – acquire low power Nd:YAG soon and stabilize
    - – install in 40 m to test in interferometer
    - – design/acquire laser with LIGO power and test
    - – integrate into detector design
  - » official change control action when plan is developed and cost/schedule impact understood

LIGO Detectors
Integration/System Eng.

- Science Goals for initial and improved detectors
- Establish Systems Requirements
  - » First draft document
- Modeling
  - » environment - AVS
  - » end to end model - underway
  - » lock acquisition, optics, etc
  - » help final design and understand performance
- Interfaces
  - » facilities, detector

LIGO Detectors
Detector Implementation

- Detector baseline established for Costing (9/94). This baseline is 'consistent' with sensitivity goals.

- Detector requirements being established from sensitivity goals

- Detector Implementation Plan (1/95)
  - » Two Groups
    - – interferometer (mechanical/optical systems)
    - – control data systems (electronics, controls, data)
  - » Design over next two years (now underway)
    - – design requirements for subsystems
    - – interfaces
    - – preliminary designs
  - » Development work
    - – mirror coatings, etc
  - » Final design and construction

LIGO Status and Plans
Conclusions

- The LIGO Project
  - » We are still growing rapidly and entering into major contracts
  - » We are strictly building to cost
  - » The coming year should see most major contracts established and actual construction of facilities well underway
  - » technical considerations for civil construction and vacuum systems mostly in hand
- Detector design
  - » development and design phase
  - » develop design and reconcile with requirements
- Detailed site planning underway
  - » staffing and organization
  - » plan for installation, commissioning and operations
- Outside community being included, informed and organized