# GR14 Conference
# Florence, Italy August,1995

**LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY**

# STATUS OF LIGO

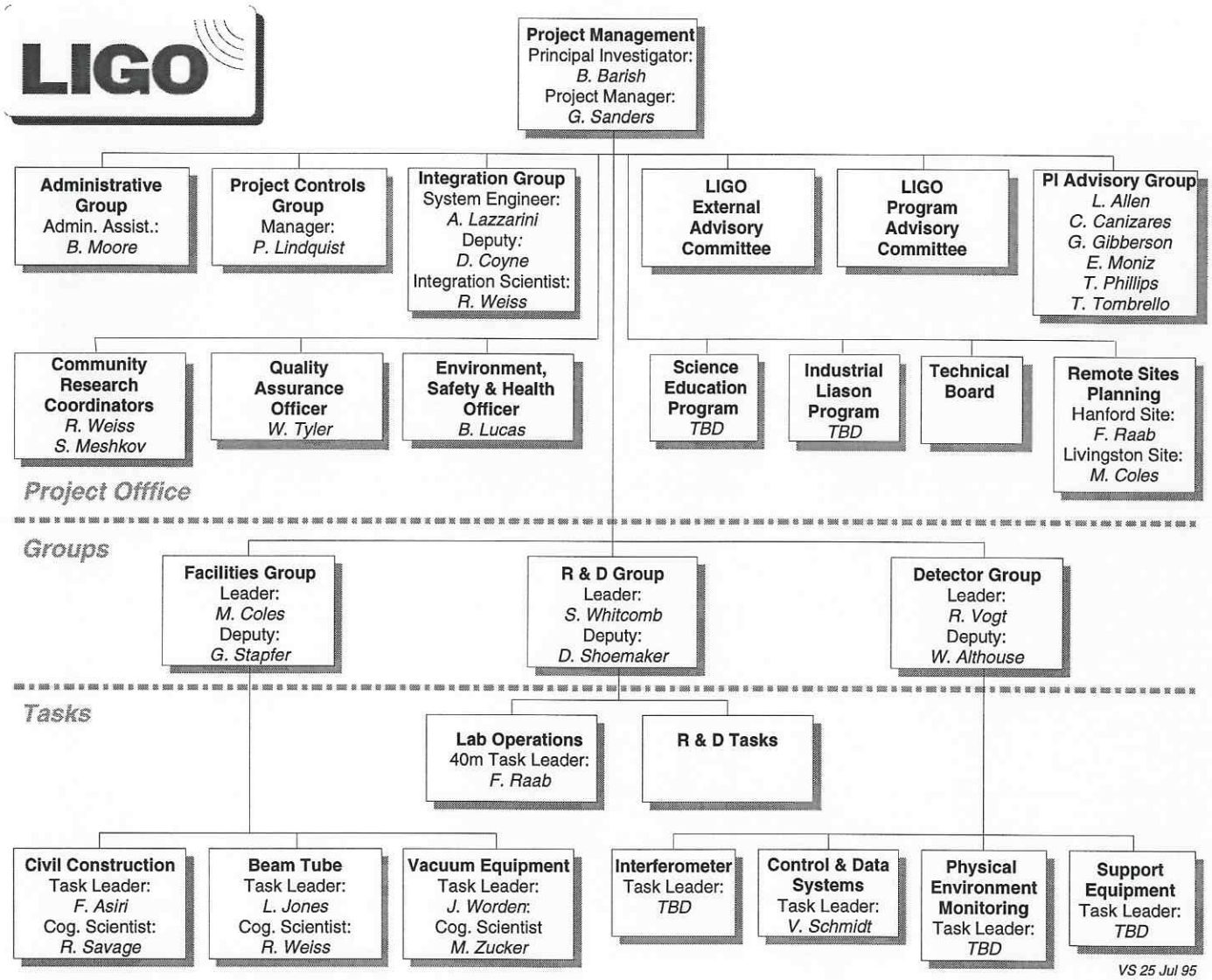

GARY SANDERS

CALIFORNIA INSTITUTE OF TECHNOLOGY

# OVERVIEW

- LIGO DESIGN
- MAJOR LIGO SYSTEMS
  - CIVIL CONSTRUCTION
  - BEAM TUBE SYSTEMS
  - VACUUM EQUIPMENT
  - DETECTOR SYSTEMS
  - R&D
- LIGO RESEARCH COMMUNITY

# LIGO ORGANIZATIONAL STRUCTURE



# LIGO DESIGN

- OBSERVATORY CHARACTERISTICS
  - TWO SITES: HANFORD, WASHINGTON & LIVINGSTON, LOUISIANA
  - TWO 4KM INTERFEROMETERS & ONE 2 KM INTERFEROMETER (HANFORD)
  - ARMS ORIENTED "PARALLEL" TO ONE ANOTHER
  - COINCIDENT OBSERVATIONS AMONG ALL THREE INTERFEROMETERS
  - INITIAL SENSITIVITY: $h_{rms} \leq 10^{-21}$ WITHIN 100 HZ BAND CENTERED AT MAXIMUM SENSITIVITY
  - OBSERVATORY EXTENSIBILITY:
    - EVENTUAL EXPANSION TO 9 INTERFEROMETERS
    - LIMITING SENSITIVITIES:
      - Naturally occurring gravity gradients (at lowest frequencies)
      - Scattered light phase noise (in the mid-frequency range)
      - Residual gas phase noise (at the highest high-frequencies)

# LIGO SITES

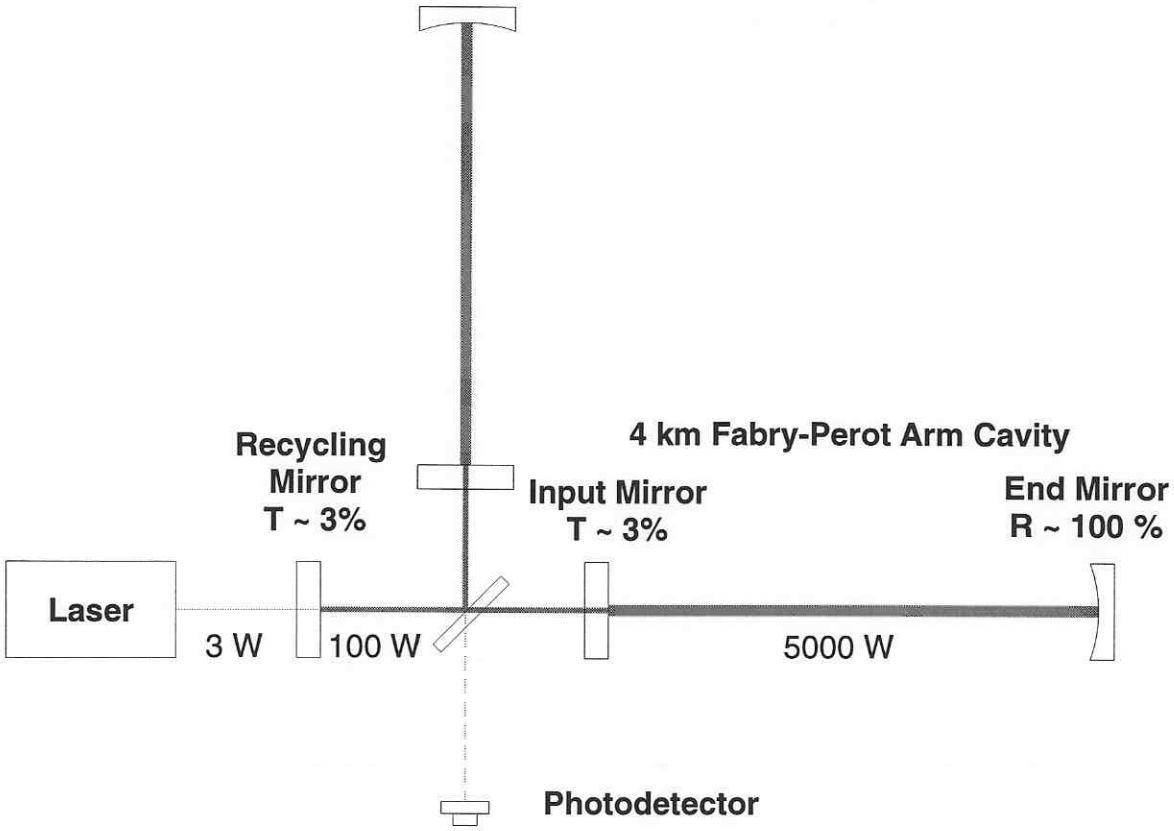

HANFORD, WASHINGTON

- LOCATED ON U.S. DOE RESERVATION
- TREELESS, SEMI-ARID HIGH DESERT
- APPROX. 25 KM FROM RICHLAND, WA (POPULATION :140,000)

LIVINGSTON, LOUISIANA

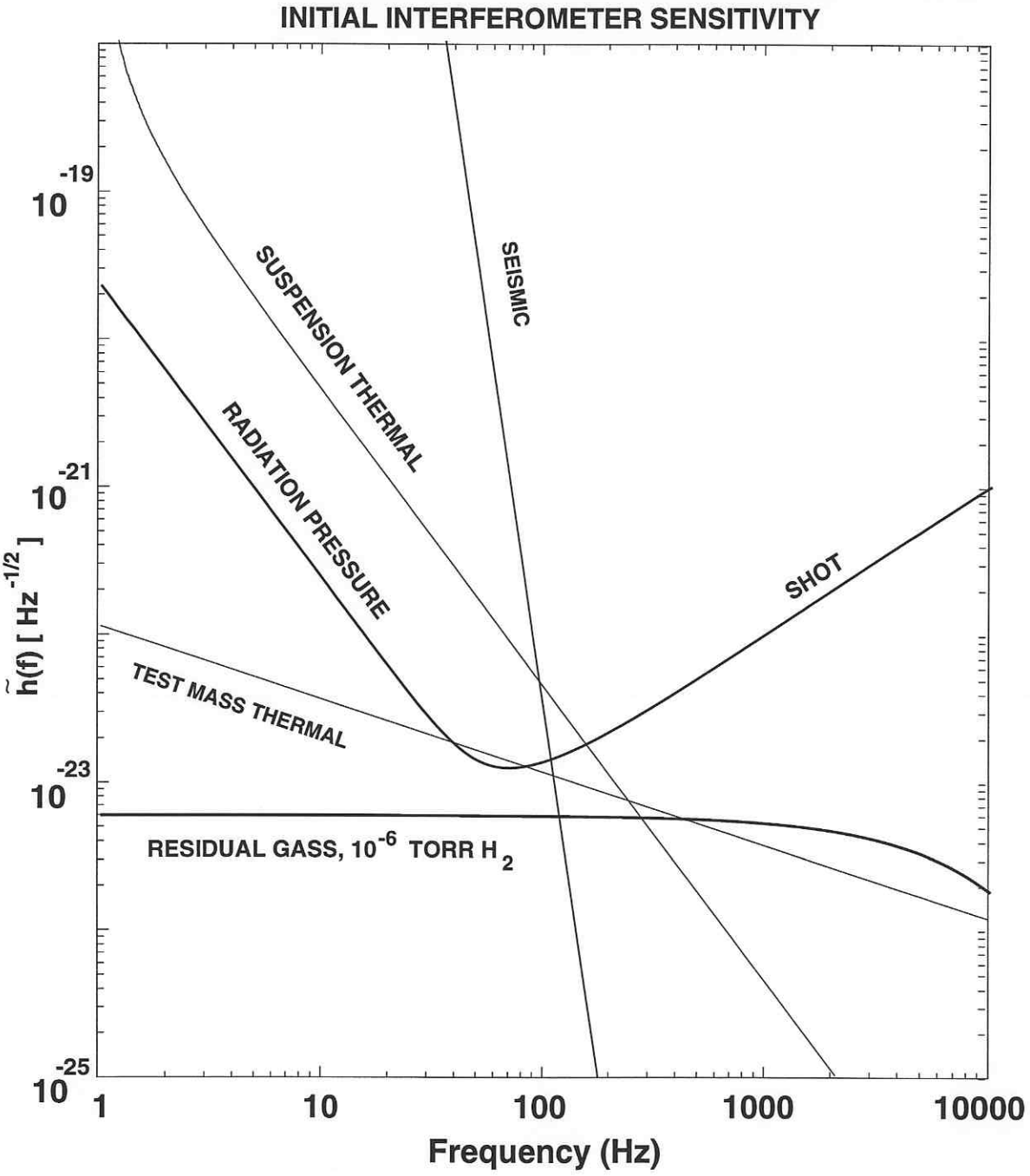
- LOCATED IN FORESTED RURAL AREA
- MIXED FOREST; LOW-LYING; POOR DRAINAGE
- APPROX. 50 KM FROM BATON ROUGE, LA (POPULATION :450,000)

# INITIAL INTERFEROMETER CONFIGURATION

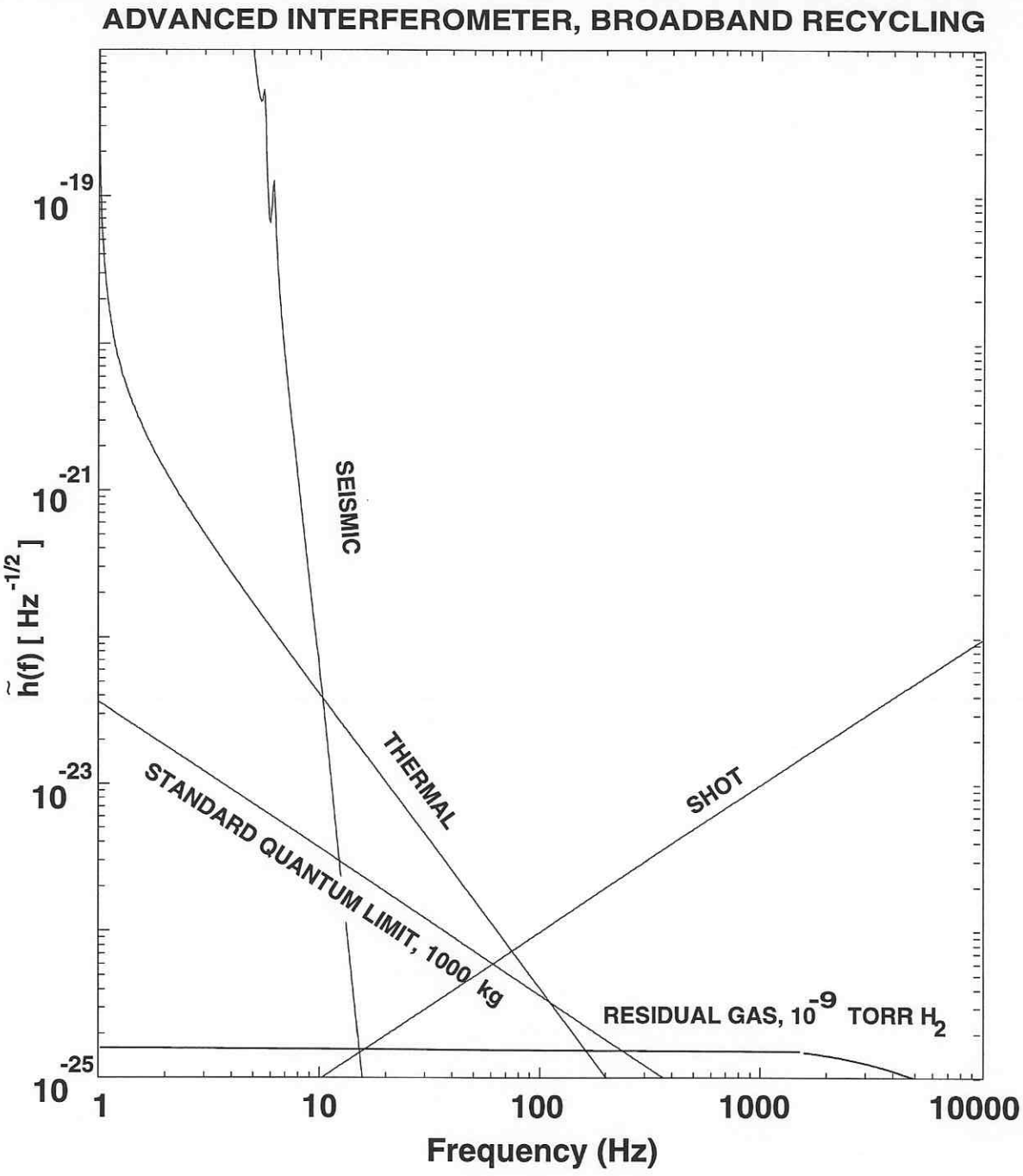



- FABRY-PEROT ARM CAVITIES
- MODEST INPUT POWER (2 - 3 W)
- INITIAL LASER: $Ar^+$ $\lambda = 0.5145$ μm POWER RECYCLING
- MODEST RECYCLING FACTOR ( $\gamma \sim$ **30X**)
- MODEST CAVITY FINESSE ( $\eta \sim$ **50** )

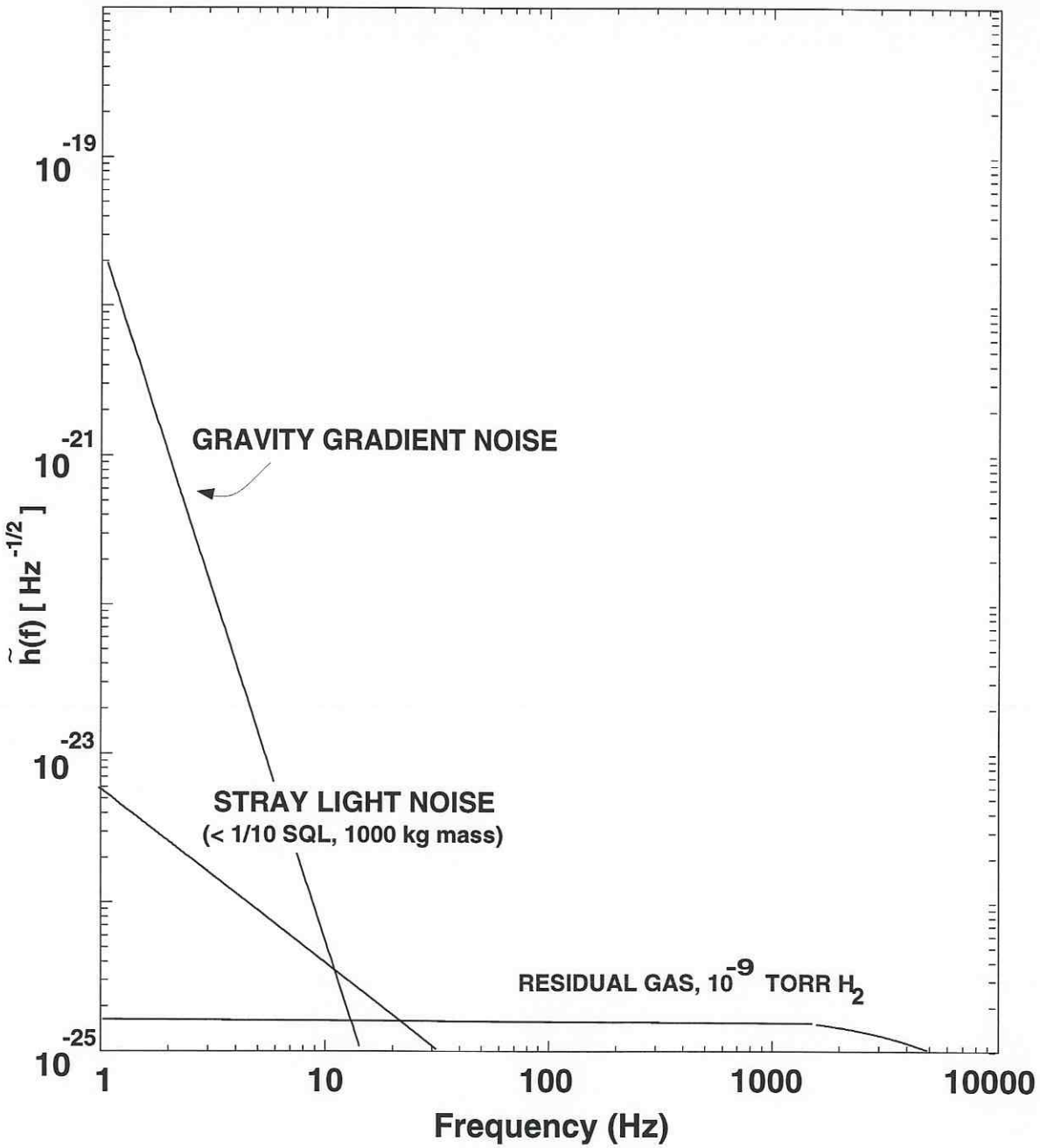
# INITIAL DESIGN PERFORMANCE GOAL



# ADVANCED DESIGN PERFORMANCE GOAL



# LIMITING PERFORMANCE DUE TO FACILITIES



# LIGO DESIGN (cont.)

- OBSERVATORY EXTENSIBILITY (CONT.):
  - EXTREME CARE IN DESIGNING QUIET FACILITIES
    - site selection
    - design considerations
  - APERTURE & BAFFLING DESIGNED TO MINIMIZE SCATTERED STRAY LIGHT
  - VACUUM CHARACTERISTICS OF BEAM TUBES AND VACUUM EQUIPMENT DESIGNED TO PROVIDE ULTRA-HIGH VACUUM OPERATING CONDITIONS.

## • OPERATIONAL CONSIDERATIONS

- ASTROPHYSICAL RESEARCH
  - HIGH ON-LINE AVAILABILITY
  - MULTIPLE MODES OF OPERATION:
    - 3X ; $T_{online} > 75\%$
    - 2X: (WA-LA); $T_{online} > 85\%$
    - 1X: $T_{online} > 90\%$
- ALLOCATION OF OBSERVING TIME BY PI/PAC/NSF
- TIME FOR DEVELOPMENT OF IMPROVED DETECTORS

# LIGO DESIGN (cont.)

- DATA FORMATS
  - COMPATIBILITY WITH OTHER GRAVITATIONAL WAVE DETECTORS & PARTICLE DETECTORS
  - SAMPLE RATE AND PRECISION COMMENSURATE WITH SCIENTIFIC MISSIONS
- ENABLING RESEARCH & FACILITIES
  - LONG-TERM DEVELOPMENT OF ADVANCED DETECTORS
  - UNIVERSITY-BASED INTERFEROMETER FACILITIES
  - LIGO RESEARCH COMMUNITY

# MAJOR LIGO SYSTEMS

# CIVIL CONSTRUCTION

# CIVIL CONSTRUCTION

- CHARACTERISTICS
  - INFRASTRUCTURE
    - LARGE AND CLEAN LABORATORY (CLEAN CONSTRUCTION PRACTICES; HIGH BAY)
    - BEAM TUBE ENCLOSURES TO PROTECT THIN-WALLED TUBE
    - OFFICE SPACE/LABORATORY SPACE TO ACCOMMODATE STAFF AND VISITORS
    - ROADS, FOUNDATIONS, STRUCTURES, ETC.
  - REQUIREMENTS
    - REMOTE SITES WITH SEISMIC STABILITY -- THICK SLAB
    - FEW INTERNAL NOISE SOURCES, EMI/EMF BACKGROUNDS, ETC.
    - CLEANLINESS

# CIVIL CONSTRUCTION

- STATUS (cont.)
  - BOTH SITES UNDER DEVELOPMENT & IMPROVEMENT;
  - WASHINGTON SITE
    - GRADED TO FINAL TOPOGRAPHY
    - NOW AWAITING SETTLEMENT BEFORE PROCEEDING WITH BUILDING CONSTRUCTION
  - LOUISIANA SITE
    - LOGGED AND CLEARED
    - GROUND BREAKING TOOK PLACE 7 JULY
  - INITIAL CONCEPTUAL DESIGN OF FACILITIES DEVELOPED BY LIGO

# CIVIL CONSTRUCTION

## • STATUS (cont.)

- ARCHITECTURAL & ENGINEERING FIRM COMPLETING THE CONCEPTUAL DESIGN AND DEFINING REQUIREMENTS
  - RALPH M. PARSONS CO.
  - BEAM TUBE ENCLOSURE CONCEPT COMPLETE AND BEING DESIGNED
  - FACILITY CONCEPTUAL DESIGN AT 100% COMPLETENESS (6/30/95)
  - FULL DESIGN REVIEW IN 11/95
- A&E WILL OVERSEE CONSTRUCTION OF FACILITIES AT BOTH SITES

# MAJOR LIGO SYSTEMS

# BEAM TUBES

# BEAM TUBES

- CHARACTERISTICS
  - MODULE LENGTHS OF 2 KM
  - TUBE DIAMETER - 1.22 M (1 M CLEAR APERTURE AFTER BAFFLING)
  - BAFFLING TO REDUCE SCATTERED LIGHT PHASE NOISE
  - VERY LOW ALLOWED AIR LEAKAGE:
    $F < 10^{-9}$ ATM CC/S, HE
  - VERY LOW OUTGASSING:
    - $P_{ADVANCED} < 10^{-9}$ TORR (ALL RESIDUALS);
    - $J[H_2]$: $< 10^{-13}$ TORR LITERS/$CM^2$/S
      $J[H_2O]$:$< 10^{-15}$ TORR LITERS/$CM^2$/S
    - PARTIAL PRESSURES FOR CO + $CO_2$ + $H_{2N}C_N$ + ... MUST BE EVEN LOWER
  - QUALITY CONTROL AND CLEANLINESS MUST BE PURSUED DILIGENTLY THROUGHOUT FABRICATION AND INTEGRATION PROCESS

# BEAM TUBES

- STATUS
  - DESIGN & QUALIFICATION PHASE AWARDED TO CHICAGO BRIDGE & IRON IN 8/93
  - FINAL DESIGN REVIEW COMPLETED 4/94
  - PROTOTYPE FABRICATION - COMPLETE 5/95
    - QUALIFICATION TEST 1/95 - 3/95
    - DEMONSTRATED SUCCESSFUL CLEANING PROCEDURE
    - DEMONSTRATED SUCCESSFUL LEAK TEST PROCEDURE
      - SPIRAL WELDS
      - JOINT WELDS
      - BELLOWS EXPANSION JOINT
      - $F < 10^{-11}$ ATM CC/S
    - DEMONSTRATED SUCCESSFUL BAKEOUT PROCEDURE
      - RESIDUAL OUTGASSING RATES FOR $H_2$, $H_2O$ BELOW REQUIRED LEVELS:
      - $H_2$: $< 10^{-13}$ TORR LITERS/$CM^2$/S
        $H_2O$: $< 10^{-15}$ TORR LITERS/$CM^2$/S
      - RESIDUAL OUTGASSING RATES FOR $CO_2$, $H_{2N}C_N$ BELOW MINIMUM ACCEPTABLE RATES;

# BEAM TUBES

- PRODUCTION OF 16 KM TUBES FOR LIGO
  - QUALIFICATION TEST REVIEW HELD 4/95
  - REVIEW BOARD ENDORSED ALL ASPECTS OF TESTS DEMONSTRATING READINESS FOR PRODUCTION
  - RFP FOR PRODUCTION PHASE ISSUED 1 JUNE 1995
  - REVIEWING PROPOSAL RECEIVED IN JULY
  - CONCURRENT RESEARCH INTO BAFFLING MATERIAL OPTICAL PROPERTIES AND BAFFLE MECHANICAL DESIGN

# MAJOR LIGO SYSTEMS

# VACUUM EQUIPMENT

# VACUUM EQUIPMENT

- CHARACTERISTICS
  - THE LIGO VACUUM *SYSTEM* (VACUUM EQUIPMENT + BEAM TUBES) PROVIDES:
    - A CLEAR APERTURE FOR THE INTERFEROMETERS --VERY LARGE APERTURE GATE VALVES TO ISOLATE 1.22 M BEAM TUBES
    - A CLEAN ENVIRONMENT FOR THE PRECISION OPTICS.
    - A LOW PRESSURE IN ORDER TO MINIMIZE DIFFRACTION AND ACOUSTIC COUPLING.
    - EXTENSIVE CONTROLS AND MONITORING EQUIPMENT TO ENSURE SAFE OPERATION
    - LARGE PUMPING SPEEDS AND VOLUMES -- BEAM TUBE PUMPING SOLELY FROM 4KM ENDS
  - THE LIGO VACUUM *SYSTEM* WILL BE THE WORLD'S LARGEST HIGH PERFORMANCE VACUUM SYSTEM WITH A PUMPED VOLUME OF ROUGHLY 20,000 $M^3$
  - MOSTLY CONVENTIONAL VACUUM HARDWARE

# VACUUM EQUIPMENT (cont.)

- STATUS
  - SPECIFICATIONS DEFINED -- SCIENCE REQUIREMENTS REVIEW 8/95
  - RFP FOR DESIGN PHASE AND FABRICATION PHASE ISSUED 12/95
    - 3-MONTH EFFORT TO COMPLETE SYSTEM DESIGN
  - TWO CONTRACTORS SELECTED FOR DESIGN PHASE
    - CHICAGO BRIDGE & IRON
    - PROCESS SYSTEMS INTERNATIONAL, INC.
  - DESIGN STUDY FROM 4/1/95 - 6/28/95
  - PDRs HELD AT CALTECH 26, 27 JUNE 1995
  - PROCESS SYSTEMS INTERNATIONAL, INC. SELECTED LAST WEEK

# MAJOR LIGO SYSTEMS

# DETECTOR

# DETECTOR SYSTEM

- CHARACTERISTICS
  - BASELINE CONFIGURATION EMPLOYS PROVEN TECHNIQUES
    - 40M AND 5M SCALE SYSTEMS (AT CIT & MIT)
    - OPTICS EXPERIMENTS ON RECOMBINATION AND RECYCLING BEING PERFORMED IN R&D
    - PRECISION ENGINEERING
  - COLLABORATIVE STUDIES WITH INDUSTRY TO DEVELOP MIRROR COATING AND POLISHING TECHNOLOGIES
  - BUILT-IN DESIGN FLEXIBILITY FOR LATER IMPROVEMENTS AS R&D RESULTS BECOME AVAILABLE
    - DUAL WAVELENGTH COATINGS TO PERMIT CHANGE FROM $Ar^+$ TO Nd:YAG LASER TECHNOLOGY
  - PASSIVE & ACTIVE SEISMIC ISOLATION
  - ADVANCED CONTROL & DATA SYSTEM USING STATE-OF-THE-ART LAN/WAN ARCHITECTURES

# DETECTOR SYSTEM (cont.)

- STATUS
  - DETECTOR DESIGN UNDER WAY
  - KEY INITIAL DESIGN REVIEWS HELD:
    - PRESTABILIZED LASER SUBSYSTEM
      - DESIGN READINESS REVIEW IN 2/95
      - PRELIMINARY DESIGN READINESS REVIEW 6/95
      - PROTOTYPE SYSTEM BEING READIED FOR 40 m INTERFEROMETER INTEGRATION
    - ALIGNMENT CONTROL SYSTEM DESIGN READINESS REVIEW HELD 5/95
    - SUSPENSION SUBSYSTEM DESIGN READINESS REVIEW HELD 6/95
    - CORE OPTICS COMPONENTS DESIGN READINESS REVIEW TO BE HELD IN 7/95
    - MODE-CLEANER PROTOTYPE BEING READIED FOR INSERTION INTO 40 M SYSTEM
    - ACTIVE SEISMIC ISOLATION (STACIS SYSTEM FROM BARRY CONTROLS, INC.) SUCCESSFULLY DEMONSTRATED AT MIT

# DETECTOR SYSTEM (cont.)

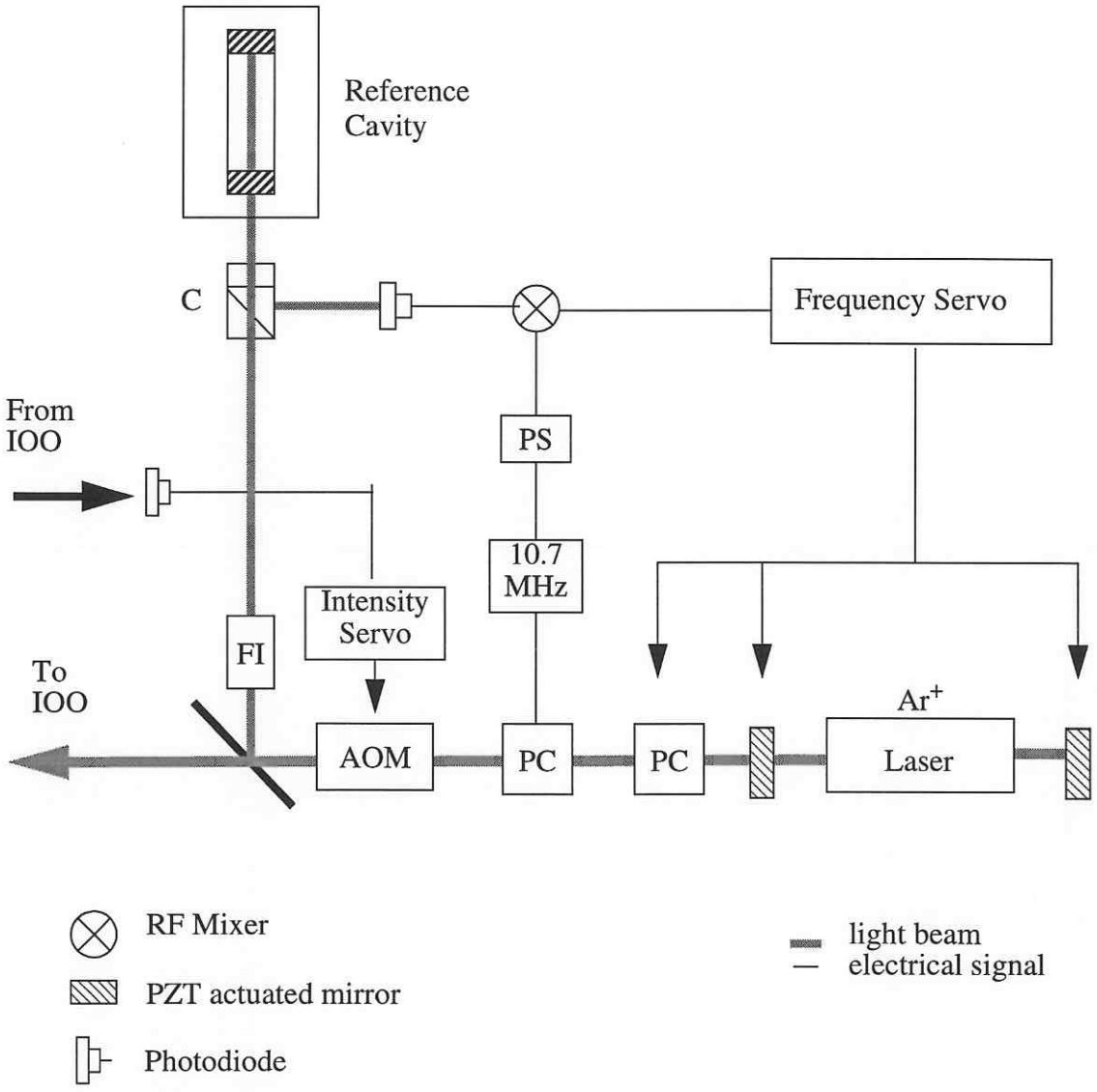
## PRESTABILIZED LASER (PSL)

- CHARACTERISTICS
  - PROVIDES SINGLE-MODE, SINGLE-FREQUENCY BEAM > 4 W TO INPUT OPTICS SUBSYSTEM
  - SERVO LOOPS TOP STABILIZE LIGHT:
    - FREQUENCY STABILIZATION TO <1 Hz/$\sqrt{\text{Hz}}$ @ 100 Hz (GAIN OF $10^5$)
    - INTENSITY (AMPLITUDE) FLUCTUATIONS < $10^{-7}$ W/$\sqrt{\text{Hz}}$ @ 100 Hz (GAIN OF $10^3$)
    - BEAM ANGULAR JITTER TO < 200 μrad/$\sqrt{\text{Hz}}$ @ 100 Hz
    - POLARIZATION FLUCTUATIONS IN THE BEAM TO < $10^{-6}$ 1/$\sqrt{\text{Hz}}$ @ 100 Hz
  - PSL IS BUILT AROUND A CUSTOMIZED COMMERCIALLY AVAILABLE $Ar^+$ LASER
    - LIGO IS PRESENTLY CONDUCTING A TRADE STUDY EVALUATING DESIRABILITY/FEASIBILITY OF ADOPTING SOLID STATE LASER TECHNOLOGY TO REPLACE PLASMA TUBE LASER [Nd:YAG 10 w @ 1.064 μm or 5w @ 0.532 μm]

# DETECTOR SYSTEM (cont.)

## PRESTABILIZED LASER (PSL)

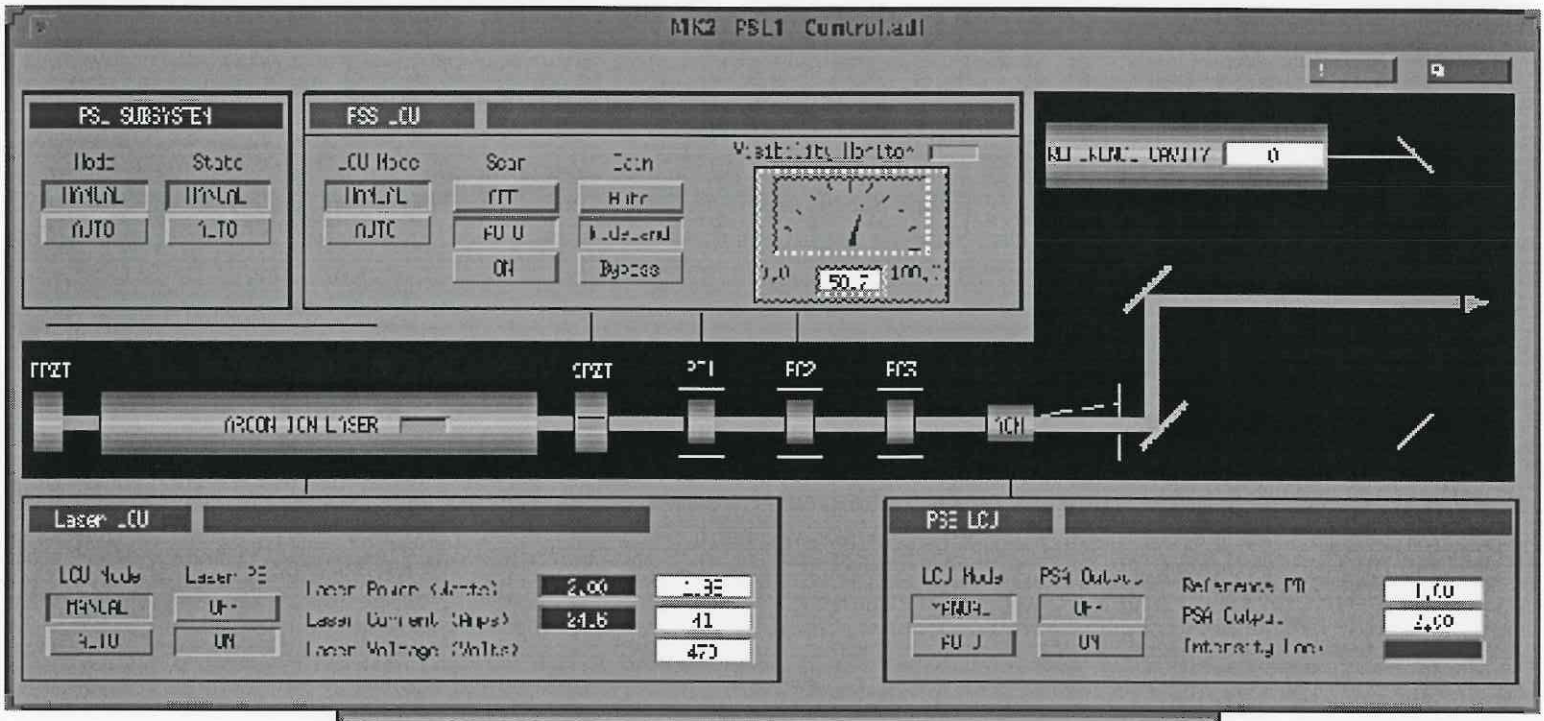
PC: Pockels Cell
AOM: Acousto Optical Modulator
FI: Faraday Isolator
C: Optical Circulator
PS: Phase Shifter

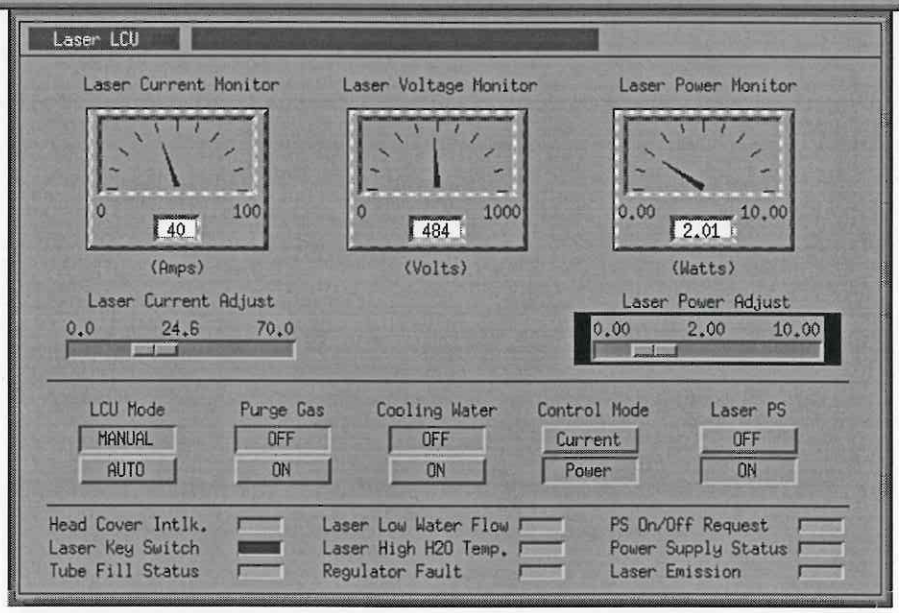


# DETECTOR SYSTEM (cont.)
## PRESTABILIZED LASER (PSL)

- STATUS
  - FREQUENCY & INTENSITY SERVOS OPERATIONAL UNDER LIGO-TYPE COMPUTER CONTROL (CDS SYSTEM)
  - PSL INTERFACE USES EPICS-BASED CONTROL SYSTEM:
    - LASER CONTROL
    - SERVO CONTROL
    - DATA MONITORING & ARCHIVAL
    - ALARM HANDLING
  - PSL PROTOTYPE TESTING UNDERWAY (6/95 - 9/95)
    - NOISE PERFORMANCE
    - AVAILABILITY
    - ENVIRONMENTAL SENSITIVITY
      - SEISMIC NOISE
      - ACOUSTIC NOISE
      - THERMAL VARIATION

# DETECTOR SYSTEM (cont.)
# PRESTABILIZED LASER (PSL)



# MAJOR LIGO SYSTEMS

# RESEARCH AND DEVELOPMENT

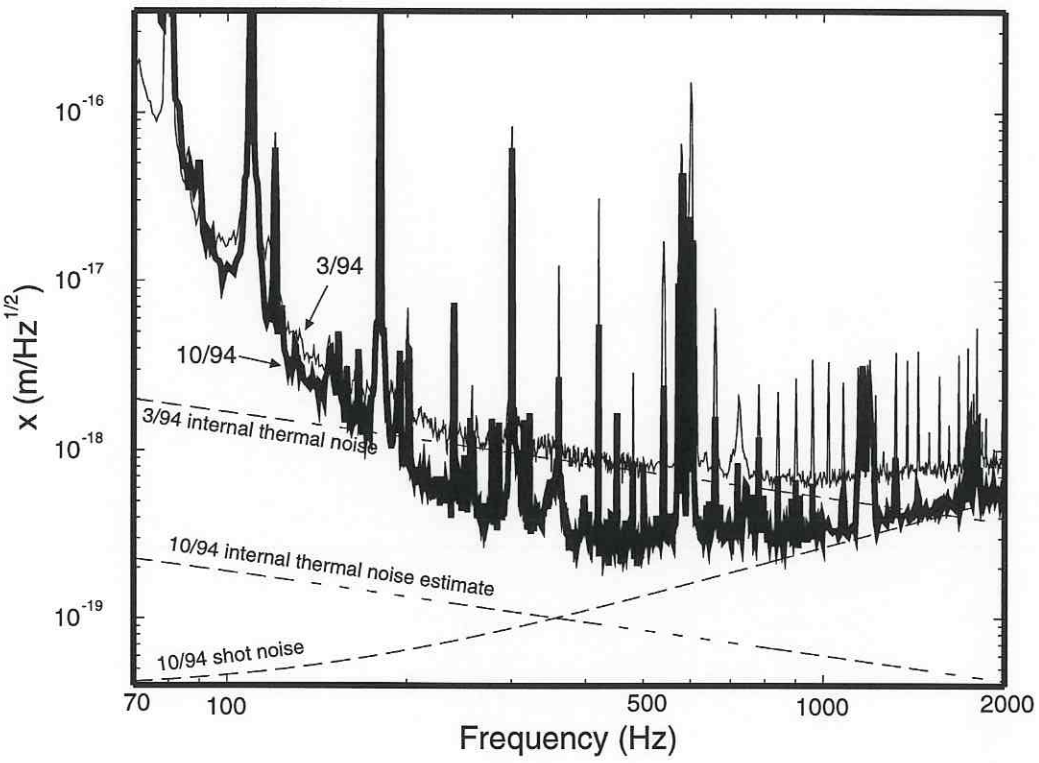
# RESEARCH & DEVELOPMENT

- OBJECTIVES
  - PHASED TIME LAG BETWEEN R&D TASKS WHICH DEMONSTRATE ENABLING TECHNOLOGIES AND DETAILED TASKS FOR LIGO DETECTOR DESIGNS:
    - THERMAL NOISE INVESTIGATIONS
      - SUSPENSIONS
      - SEISMIC STACKS
      - TEST MASSES
    - OPTICAL CONFIGURATION DEFINITION STUDIES
      - RECOMBINATION;
      - POWER RECYCLING;
    - PHASE NOISE STUDIES AT HIGH RECYCLING POWER
    - ALIGNMENT SENSING & CONTROL;
    - LENGTH SENSING & CONTROL;
    - ACTIVE/PASSIVE SEISMIC ISOLATION
  - VALIDATING DESIGN PROTOTYPES:
    - TRIANGULAR MODE CLEANER
    - PRESTABILIZED LASER SUBSYSTEM
  - LONGER-TERM EFFORT TO ESTABLISH FOUNDATIONS FOR FUTURE INTERFEROMETER ADVANCES

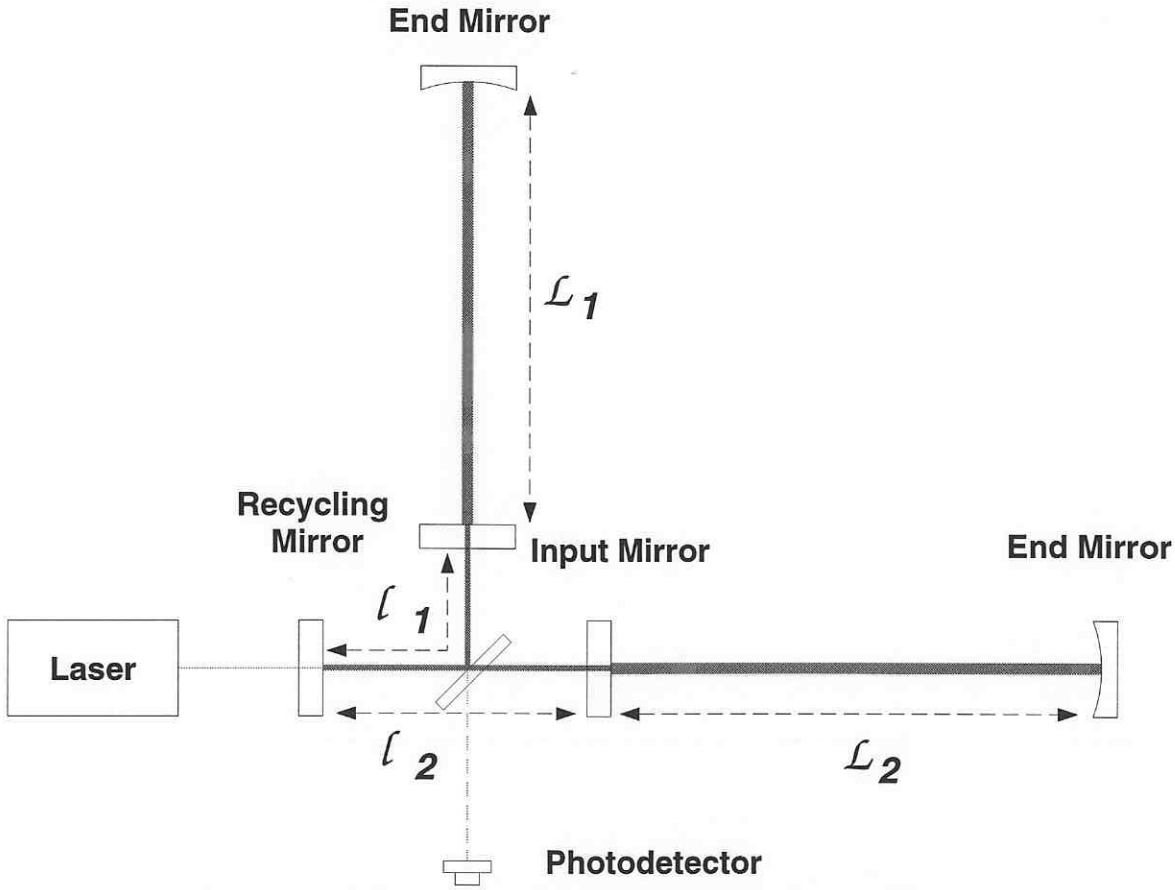
# RESEARCH & DEVELOPMENT
## THERMAL NOISE STUDIES

- THERMAL NOISE OF SUBSTRATE, PENDULUM SIGNIFICANT FOR LIGO
  - NO DIRECT EXPERIMENTAL OBSERVATIONS TO VERIFY MODELS
  - OPPORTUNITY TO OBSERVE IN 40M BY CHANGE OF MASSES
- THERMAL NOISE IN COMPOUND MASSES CAREFULLY CALCULATED
  - GOOD AGREEMENT WITH 40 M DATA
- NEW MONOLITHIC MASSES STUDIED SEPARATELY
  - ATTENTION TO COUPLING OF CONTROL/SENSING MAGNETS/FINS, SUSPENSION WIRES,...
  - INSTALLED INTO 40M FALL OF 1994
- LATEST (AND BEST) SPECTRUM TO DATE CONSISTENT WITH THERMAL NOISE MODEL

# RESEARCH & DEVELOPMENT
## THERMAL NOISE STUDIES



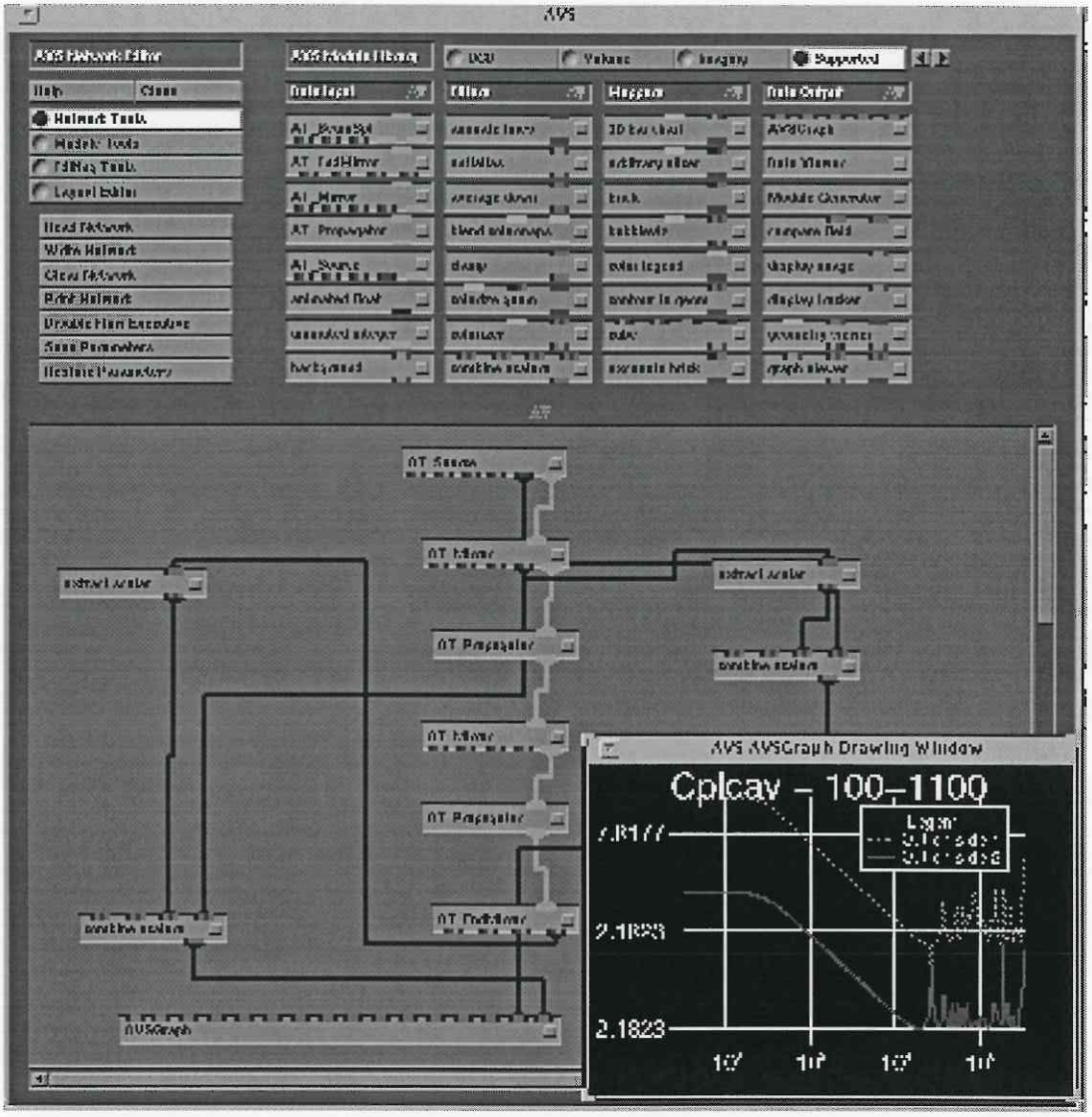
# RESEARCH & DEVELOPMENT
## OPTICAL CONFIGURATION STUDIES




- MUST CONTROL AT LEAST FOUR DEGREES OF FREEDOM:
  - PLACEMENT OF SIGNAL-SENSING ELEMENTS
  - PHOTODETECTORS AND MODULATORS
- CONCURRENT TRADE STUDY BEING CONDUCTED FOR OPTICAL CONFIGURATION
- MODIFYING THE 40M TO SUPPORT R&D STUDIES

# INTERFEROMETER CONFIGURATION DEFINITION

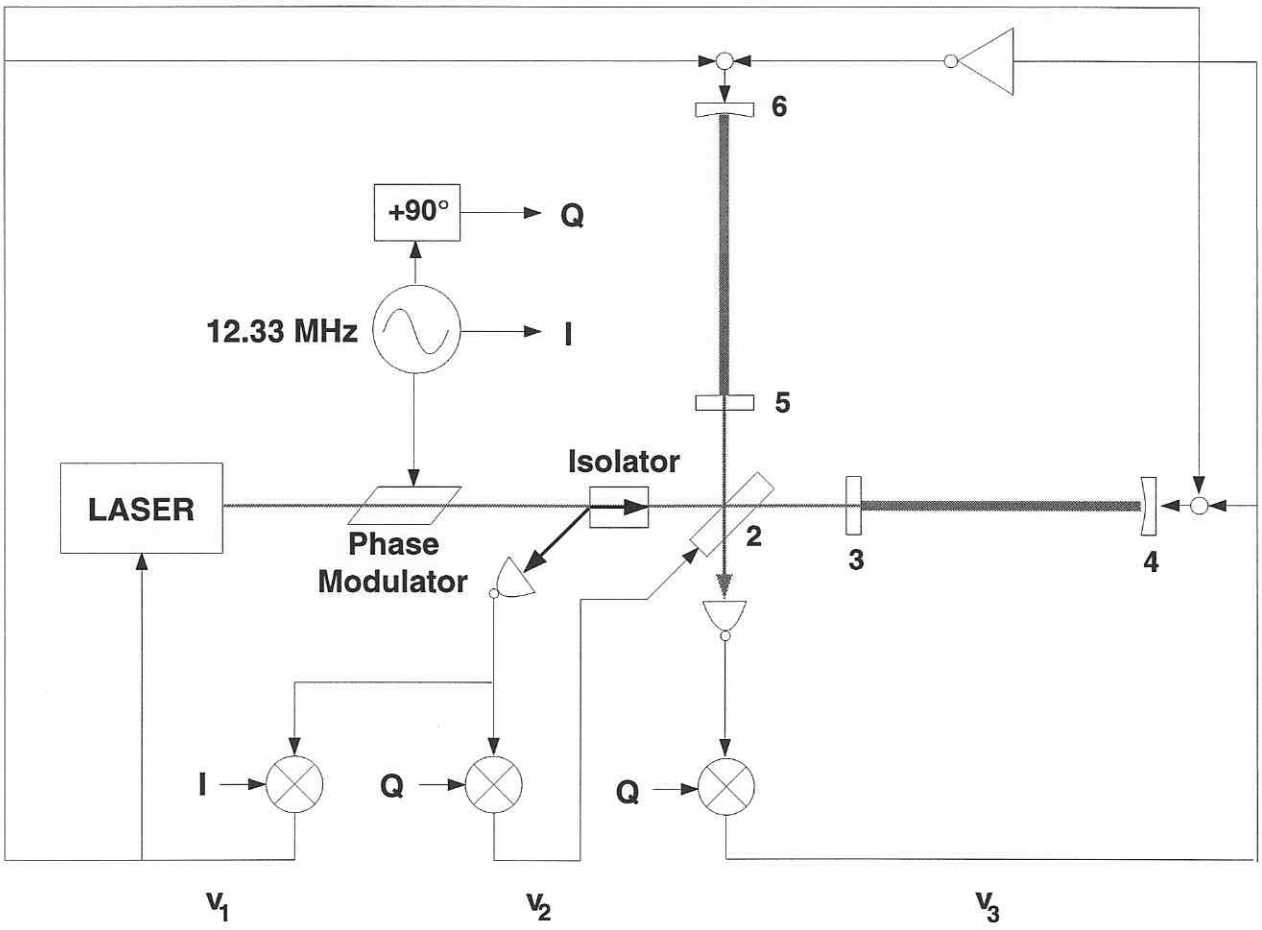
## MODELING



# RESEARCH & DEVELOPMENT
## OPTICAL CONFIGURATION

- RECOMBINATION & POWER RECYCLING
  - MODELING OF LIGO WELL ADVANCED
  - EAGER TO HAVE EXPERIMENTAL VERIFICATION
    - LARGE & SMALL SIGNAL INTERFEROMETER DYNAMIC RESPONSE FUNCTIONS
    - IMPROVED COMMON-MODE NOISE REJECTION FOR DISPLACEMENT STUDIES
  - STATUS:
    - SERIES OF SMALL-SCALE EXPERIMENTS TO VALIDATE DIFFERENT ASPECTS OF MODELS COMPLETE (DOCTORAL THESES)
    - ARM ASYMMETRY INTRODUCED FOR MODULATION TECHNIQUE
    - SYSTEM HAS ACQUIRED LOCK AND ARMS HAVE BEEN RESONANT
    - PRESENTLY IN SHAKEDOWN TO REPEAT PREVIOUSLY ACHIEVED LEVEL OF NOISE PERFORMANCE
    - RECYCLING WILL FOLLOW ONCE RECOMBINED SYSTEM IS FULLY CHARACTERIZED

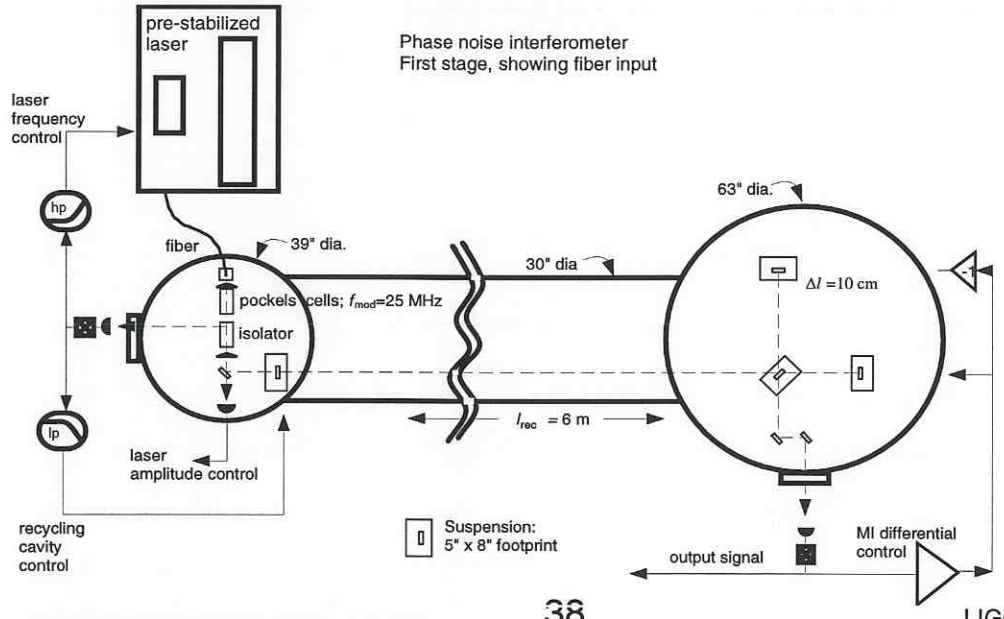
# RESEARCH & DEVELOPMENT
## OPTICAL CONFIGURATION




- RECOMBINED CONFIGURATION COMPLETE: FIRST LOCK ACQUISITION ACHIEVED MAY/JUNE
- PRESENTLY UNDERGOING SHAKEDOWN TO RECOVER SENSITIVITY ACHIEVED EARLIER

# RESEARCH & DEVELOPMENT
## PHASE NOISE RESEARCH

- OBJECTIVES:
  - DISPLACEMENT SENSITIVITY STUDY UNDER WAY WITH 40M FACILITY
  - LIGO REQUIRES HIGH PHASE SENSITIVITY (< $10^{-10}$ RAD/$\sqrt{\text{Hz}}$ )
    - BEST TO DATE ACHIEVED WITH 1W OF OPTICAL POWER ( <$10^{-9}$ RAD/$\sqrt{\text{Hz}}$ @ MPI/GARCHING)
    - LIGO REQUIRES ROUGHLY 75W
  - PHASE NOISE STUDIES WILL DEMONSTRATE REQUIRED SENSITIVITY
    - CONFIRMS UNDERSTANDING OF SHOT NOISE
    - NEED TO SOLVE TECHNICAL PROBLEMS (PHOTODETECTOR IRRADIANCES)
    - NON-RECYCLED MICHELSON CONFIGURATION INITIALLY TO BE USED (1 W) ; RECYCLING TO BE ADDED (15 W) ; MODE CLEANER WILL EVENTUALLY BOOST POWER TO 70 W.



# RESEARCH& DEVELOPMENT
## PHASE NOISE RESEARCH

- STATUS
  - SYSTEM HAS BEEN INTEGRATED AT MIT
  - INCLUDES ACTIVE ISOLATION SYSTEM FROM BARRY CONTROLS, INC. (STACIS) BEING EVALUATED FOR EVENTUAL INCLUSION INTO LIGO
  - IN-AIR INTERFERENCE HAS BEEN OBSERVED
  - BEING READIED FOR EVACUATION AND SHAKE-DOWN TESTING

# RESEARCH & DEVELOPMENT
## ALIGNMENT SENSING & CONTROL

- ALIGNMENT REQUIREMENTS FOR LIGO
  - INTERFEROMETER USES $TEM_{00}$ LIGHT
  - REQUIRE GOOD OVERLAP BETWEEN INPUT LIGHT, OPTIC AXIS
  - HIGH CONTRAST IN MICHELSON INTERFERENCE
  - LEADS TO REQUIREMENT OF $<10^{-7}$ RADIANS ALLOWED MIS-ALIGNMENT
  - OR... <1% (POWER) EXCITATION OF $TEM_{01}$ MODE
- ALIGNMENT SENSING
  - PHASE MODULATION OF THE LIGHT
  - SIMILAR TECHNIQUES TO THE GW READOUT SYSTEM
  - SPATIALLY SENSITIVE DETECTORS, PLACED AT CRITICAL POINTS
  - SENSES PHASE SHEAR IN THE BEAMS IN THE INTERFEROMETER
  - SUBTLE RELATIONSHIP BETWEEN SENSORS AND MIRROR ANGLES

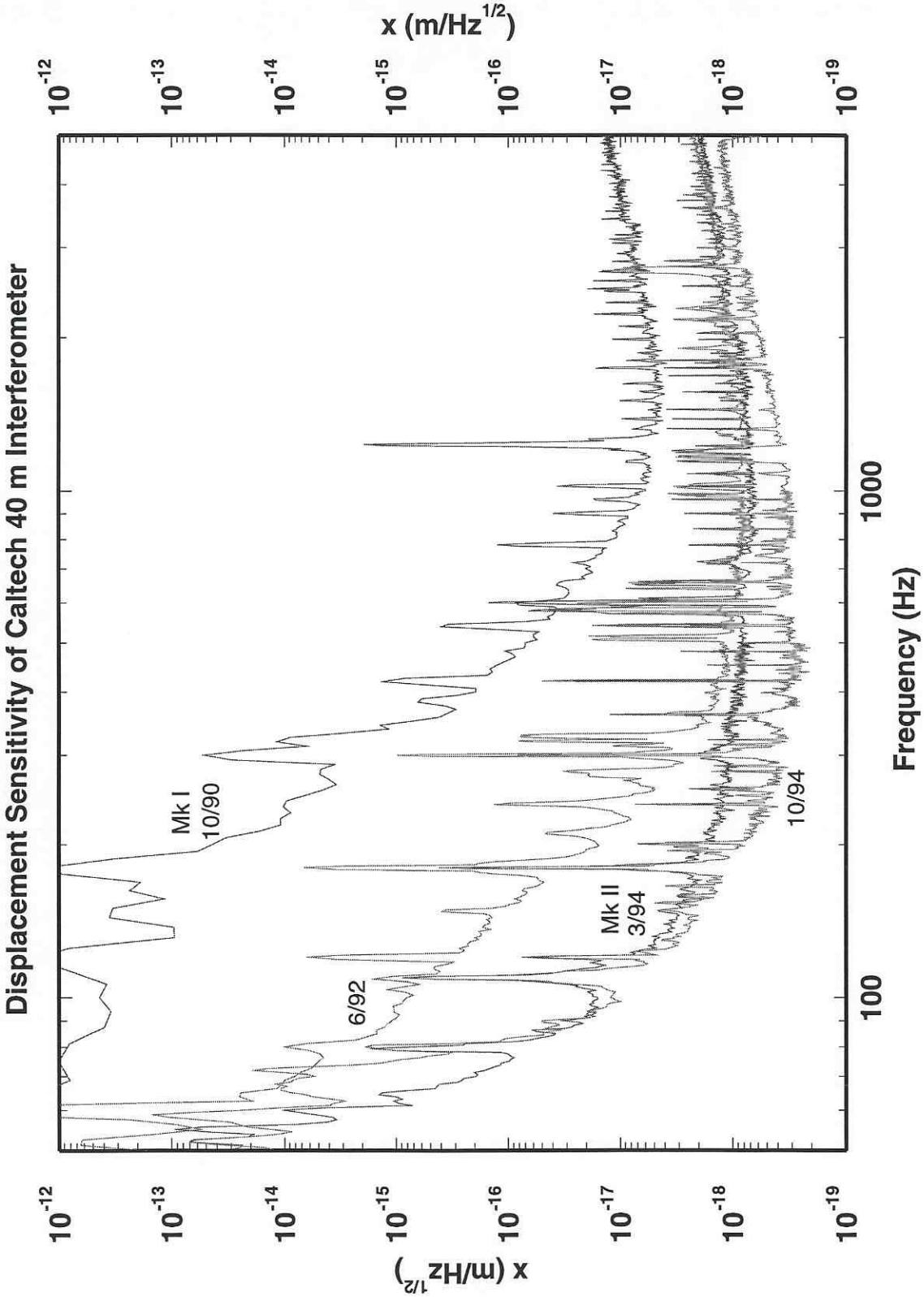
# RESEARCH & DEVELOPMENT
## PHASE NOISE RESEARCH

- STATUS
  - SYSTEM HAS BEEN INTEGRATED AT MIT
  - INCLUDES ACTIVE ISOLATION SYSTEM FROM BARRY CONTROLS, INC. (STACIS) BEING EVALUATED FOR EVENTUAL INCLUSION INTO LIGO
  - IN-AIR INTERFERENCE HAS BEEN OBSERVED
  - BEING READIED FOR EVACUATION AND SHAKE-DOWN TESTING

# RESEARCH & DEVELOPMENT
## ALIGNMENT SENSING & CONTROL (cont.)

- MODELING THE ALIGNMENT SENSITIVITY AND SENSING SYSTEM
  - USE MATRIX TECHNIQUES AND SCATTER TO ESTIMATE OFF-DIAGONAL RELATIONSHIPS
    - BREAK LIGHT INTO $TEM_{00}$, $TEM_{01}$ MODES, PARAXIAL APPROXIMATION
    - PROVIDES BOTH REQUIREMENTS AND DETAILED DESIGN INFORMATION
- EXPERIMENTAL VERIFICATION OF MODEL
  - SUB-SCALE EXPERIMENT WITH COMPLETE LIGO LENGTH, ANGLE READOUT CONFIGURATION
  - QUANTITATIVE RESULTS EXPECTED IN EARLY '96

# IMPROVEMENTS IN 40m INTERFEROMETER SENSITIVITY



# RESEARCH & DEVELOPMENT

- STATUS
  - SEISMIC NOISE ISOLATION
    - PASSIVE SEISMIC STACK UNDERSTOOD
    - SOFTER ELASTOMER SPRINGS WILL BE USED (RTV VS VITON)
    - SITE CHARACTERISTICS VERY QUIET AND CHARACTERIZED
    - BASELINE DESIGN FOR DETECTOR WILL MEET LIGO GOAL
  - THERMAL NOISE
    - PHYSICAL PROCESSES HAVE BEEN IDENTIFIED AND CHARACTERIZED
    - SUSPENSION REQUIREMENTS RELAXED IN FAVOR OF TIGHTER INTERNAL MODE REQUIREMENTS
    - BASELINE DESIGN FOR DETECTOR WILL MEET LIGO GOAL
  - SHOT NOISE
    - LIGO GOAL IS 10X BETTER THAN DEMONSTRATED TO DATE
    - REQUIRES CHARACTERIZATION AND INTEGRATION OF DIFFERENT ELECTRO-OPTICAL COMPONENTS AND SUB-SYSTEMS -- CIT/40M ; MIT/5M FACILITIES:
      - RECYCLING
      - RECOMBINATION
      - HIGHER POWER

# LIGO RESEARCH COMMUNITY

# LIGO RESEARCH COMMUNITY

## LIGO COLLABORATIVE PROGRAM

- PURPOSE AND GOALS
  - TO ENHANCE THE PROBABILITY OF THE (EARLY) SUCCESSFUL DETECTION OF GRAVITATIONAL WAVES (GW) AND TO OPEN THE FIELD OF GW ASTROPHYSICS
  - TO INCREASE PARTICIPATION OF RESEARCHERS IN THE SCIENTIFIC & TECHNICAL CHALLENGES OF GW DETECTION
  - TO DEVELOP A RESEARCH COMMUNITY FOR THE LIGO FACILITIES (BOTH SITES & UNIVERSITY RESOURCES)
  - TO ENHANCE THE EFFECTIVENESS OF THE SCIENTIFIC CONSTITUENCY FOR THE FIELD OF GW ASTROPHYSICS

# LIGO RESEARCH COMMUNITY

## COMMUNICATION WITH SCIENTIFIC COMMUNITY

- ORGANIZATION OF SESSIONS/PRESENTATIONS ON GW DETECTION AT MEETINGS OF SCIENTIFIC & TECHNICAL SOCIETIES
  - APS (4/94)
  - SNOWMASS APS PLANNING MEETING FOR PARTICLE & NUCLEAR ASTROPHYSICS (7/94)
  - MARCEL GROSSMAN MEETING (7/94)
  - OPTICAL SOCIETY OF AMERICA ANNUAL MEETING (10/94)
  - ASPEN WINTER PHYSICS CONFERENCE SERIES (1/95)
  - INTERNATIONAL MEETING ON GENERAL RELATIVITY & GRAVITATION (7/95)
  - ASPEN WINTER PHYSICS CONFERENCE SERIES (1/96)
  - CORAL GABLES CONFERENCE (1/96)

# LIGO RESEARCH COMMUNITY

## COMMUNICATION WITH SCIENTIFIC COMMUNITY (cont.)

- LIGO-HOSTED TOPICAL WORKSHOPS ON TECHNOLOGIES RELEVANT TO GW DETECTION & TOPICAL WORKSHOPS ORGANIZED BY LIGO, VIRGO, GEO600, AIGO, AND LIGO AFFILIATES:
  - THERMAL NOISE (1/94)
  - COALESCING BINARY WAVEFORMS & DATA ANALYSIS (1/94)
  - BEAM TUBE BAFFLE DESIGNS AND ANALYSES (1/95)
  - OPTICS, MODELING, FABRICATION, TESTING
  - INTERFEROMETER CONFIGURATIONS
  - DATA ANALYSIS (WINTER '95)
  - SEISMIC ISOLATION
  - LASER SOURCES
  - APPLICATIONS OF SQUEEZED LIGHT

# LIGO RESEARCH COMMUNITY
## COMMUNICATION WITH SCIENTIFIC COMMUNITY (cont.)

- WWW ON-LINE LIGO RESEARCH RESULT & PROJECT STATUS
- WWW ON-LINE PUBLICATIONS LIST **http: //www.ligo.caltech.edu**


- LIGO FACILITIES INTERFACE DOCUMENT

# LIGO RESEARCH COMMUNITY

## ORGANIZATIONAL STRUCTURE

- LIGO PRE-PROGRAM ADVISORY COMMITTEE (LPPAC)
  - SELF-DISSOLVING GROUP
    - FORMED BY LIGO MANAGEMENT WITH NSF CONCURRENCE
    - COMPOSED OF INDIVIDUALS EXPERIENCED IN GW RESEARCH, OPERATION OF SCIENTIFIC FACILITIES
    - MEMBERS:
      - P. SAULSON (SYRACUSE UNIVERSITY) - -CHAIR
      - L.S. FINN (NORTHWESTERN UNIVERSITY)
      - A. GIAZOTTO (UNIVERSITY OF PISA/VIRGO)
      - J. HALL (JILA)
      - W. HAMILTON (LSU)
      - C. PRESCOTT (SLAC)
      - A. RUEDIGER (MPI-GARCHING/GEO)
  - ADVISES LIGO:
    - COMPOSITION, CHARTER, & ROLE OF THE LIGO PROGRAM ADVISORY COMMITTEE (LPAC) WHICH WILL REPLACE IT
    - ASSISTS IN SETTING UP LIGO EXECUTIVE COMMITTEE (OVERSEES LIGO RESEARCH COMMUNITY ACTIVITIES)
    - PROPOSES EXTERNAL ADVISORY COMMITTEE (EAC)
      - PROVIDES TECHNICAL ADVICE TO LIGO PI RE: LIGO UPGRADES& OTHER TECHNICAL ISSUES

# LIGO RESEARCH COMMUNITY

## ORGANIZATIONAL STRUCTURE (cont.)

- LIGO PROGRAM ADVISORY COMMITTEE (LPAC)
  - WILL ADVISE LIGO MANAGEMENT ON:
    - EVALUATION OF PROPOSALS BY POTENTIAL COLLABORATORS
    - SCHEDULING & PHASING OF INSTALLATION OF DETECTORS, OBSERVATIONAL PROGRAMS,& FUTURE ENHANCEMENTS; FOR OTHER FACILITY USES BY INTERNAL & EXTERNAL RESEARCHERS
    - SCHEDULING & PHASING OF FUTURE ENHANCEMENTS FOR THE FACILITIES
    - LIGO DATA ANALYSIS PROGRAM
    - COORDINATION OF OBSERVATIONS WITH OTHER GRAVITATIONAL WAVE & ASTRONOMICAL FACILITIES
    - INTERNATIONAL COLLABORATIONS FOR DEVELOPING TECHNOLOGIES & JOINT OPERATIONS

# LIGO RESEARCH COMMUNITY

## ORGANIZATIONAL STRUCTURE (cont.)

- LIGO RESEARCH COMMUNITY:
  - SCIENTIFIC & ENGINEERING BODY WITH INTERESTS IN GW DETECTOR RESEARCH TO BE CARRIED OUT BY LIGO
  - INTERNAL & EXTERNAL MEMBERSHIP
  - PARTICIPANTS IN COLLABORATIVE PROGRAMS OF RESEARCH & DEVELOPMENT
    - (E.G., INFORMAL GROUP ON SOURCES, WAVEFORMS, & COMPUTATIONAL ALGORITHMS, FORMED AT THE COALESCING BINARY WORKSHOP IN 1/94 -- MEETING NOW FOR 2ND TIME)
- LIGO EXTERNAL RESEARCH COORDINATOR
  - INTERNAL (TO LIGO) POINT OF CONTACT FOR INDIVIDUALS WISHING TO CARRY OUT COLLABORATIVE PROGRAMS WITH LIGO
  - WILL ADVISE POTENTIAL COLLABORATORS AND DIRECT THEM TO KNOWLEDGEABLE & INTERESTED PERSONS WITHIN LIGO PROGRAM OFFICE

# LIGO RESEARCH COMMUNITY

## ORGANIZATIONAL STRUCTURE (cont.)

- MODES OF COLLABORATION WITH LIGO
- INDIVIDUALS:
  - VISITORS
    - BRIEF PERIODS OF RESEARCH & STUDY AT THE UNIVERSITIES (CIT/MIT)
    - LIGO TEAM MEMBERS VISIT OTHER INSTITUTIONS FOR BRIEF PERIODS
  - RESEARCH INDEPENDENT OF, BUT RELEVANT TO LIGO (E.G. ADVANCED DETECTORS)
  - RESEARCHERS INTERESTED IN ENABLING TECHNOLOGY DEVELOPMENT FOR LIGO ITSELF:
    - HARDWARE
    - SOFTWARE
    - MODELS
  - RESEARCHERS INTERESTED IN DEVELOPING NEW ADVANCED DETECTORS FOR EVENTUAL INSTALLATION ON LIGO
  - DATA USERS: MINING OF ARCHIVED DATABASES
  - RESEARCHERS INTERESTED IN MAKING JOINT/ COORDINATED ASTROPHYSICAL SEARCHES WITH LIGO

# LIGO RESEARCH COMMUNITY

## ORGANIZATIONAL STRUCTURE (cont.)

- INSTITUTIONS:
  - MEMORANDA OF UNDERSTANDING (MOUs)
  - CALTECH RELATIVITY THEORY GROUP (THORNE) - COMPLETE
    - SOURCE IDENTIFICATION & ALGORITHM DEVELOPMENT
  - AUSTRALIAN CONSORTIUM FOR INTERFEROMETRIC GRAVITATIONAL ASTRONOMY (ACIGA) - COMPLETE
    - DISPLACEMENT SENSORS FOR INITIAL LIGO TEST MASS STABILIZATION
  - CU/JILA (BENDER) - IN PROCESS
    - LOW FREQUENCY ISOLATION PROJECT
  - VIRGO - IN PROCESS
    - TECHNOLOGY EXCHANGES; JOINT DEVELOPMENT & ANALYSES
  - PENN STATE GRAVITATIONAL PHYSICS GROUP (CUTLER) - PENDING
    - DATA ANALYSIS & MODELING
  - EXTANT BUT TO BE RE-WRITTEN:
    - SAULSON (SYRACUSE)
    - FINN (NORTHWESTERN)
    - STANFORD
    - BRAGINSKY (MSU)
- ACTIVITIES WOULD REQUIRE PROPOSALS TO LPAC/NSF/FUNDING AGENCIES FOR REVIEW &