LONGER TERM OUTLOOK FOR RESEARCH AT MIT

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- THREE ELEMENTS OF FUTURE PROGRAM

  COMMISSIONING AND INITIAL OPERATIONS

  OBSERVATION PLANNING AND DATA ANALYSIS

  DEVELOPMENT OF ENHANCED AND ADVANCED DETECTORS

- REQUIRES

  ADDITIONAL FACULTY

  NEW FACILITIES

  AUGMENTED RESEARCH SUPPORT

COMMISSIONING AND INITIAL OPERATIONS

- LIGO Operations, 1997 - 2001 Plan (5/11/95)

Event	Hanford date	Livingston date
Joint Occupany	09/97	03/98
Beneficial Occupancy	03/98	09/98
Accept Vacuum Equipment	03/98	09/98
Initiate Facilities Shakedown	03/98	09/98
Initiate IFO Installation	04/98	01/99
First PSL operational	06/98	04/99
First light on beam splitter	08/98	06/99
First Recycled Michelson Resonance	11/98	08/99
First Full Interferometer Resonance	03/99	11/99
Detector Commissioned ($h_{rms} \leq 10^{-20}$)	07/00	common
Begin Normal Operations	07/00	common
Detector Design Sensitivity ($h_{rms} \leq 10^{-21}$)	11/01	common

COMMISSIONING AND INITIAL OPERATIONS

- Functions and Responsibilities
  - ›› Facilities
    - — Scientific support in test and acceptance of the beam tubes
    - — Scientific support in test and acceptance of the vacuum equipment
    - — Scientific support in acceptance of the LIGO buildings
  - ›› Detector Installation and Commissioning
    - — Interaction with vendors during construction
    - — Subsystem tests prior to installation in field
    - — Installation team for the Interferometer Sensing and Control System in conjunction with staff resident at sites
    - — Installation team for the Physical Environment Monitor System in conjunction with staff resident at sites
    - — R&D at MIT as needed to support initial detector installation in the field

COMMISSIONING AND INITIAL OPERATIONS

- ›› Detector Integration and Improvement $10^{-20} \Rightarrow 10^{-21}$
  - — Design, implement and analyse diagnostic tests
  - — Establish the sources limiting the detector noise budget
  - — Guide the development of on-line analysis techniques
  - — Advise on division of time dedicated to search vs improvement
- ›› Initial Data Analysis
  - — Plan the production of reduced data sets
  - — Couple to LIGO Research Community data analysts
  - — PhD thesis exploratory searches (tricky business)
- ›› DEAL WITH THE CRISIS THAT LIGO IS OBSERVING SIGNALS
  - — A real possibility given a factor of 100 to 1000 improvement in sensitivity and we are listening
  - — Devise additional tests to separate real signals from artifacts

OBSERVATION PLANNING AND DATA ANALYSIS

- PROGRAMMATIC ISSUES
  - ›› Project need that can be satisfied by larger community of scientists in other areas: high energy, nuclear physics, radio and x ray astronomy .....
  - ›› Near term (data formats, diagnostics) and long term (optimal filters, detection algorithm development, end - end modeling) issues
- OPPORTUNITY FOR MIT and LIGO
  - ›› New faculty position in LIGO data analysis and gravitational wave astrophysics. Strong coupling to astrophysics division and other areas of astrophysical research
  - ›› Focus the current interest in LIGO in the MIT astrophysics division
    - jointly supervised graduate student : Prof Bertschinger/LIGO
  - ›› Interact with groups at Caltech, VIRGO, GEO ... on data analysis of gravitational wave detectors
  - ›› Interact with astrophysicists using other observational methods to gain the best science

DATA STRUCTURES AND ANALYSIS

- OPERATIONS
- DIAGNOSTICS
- CALIBRATION
- ENVIRONMENTAL CORRELATION
- REDUCED DATA SETS
- DETECTOR MODELS
- SOURCE MODELS
- SEARCH STRATEGIES
- MULTIPLE DETECTOR ANALYSIS
- DETECTION CONFIDENCE
- SOURCE STATISTICS
- PHYSICS AND ASTROPHYSICS
- CONNECTION TO OTHER FIELDS

DETECTOR RESEARCH

- ENHACEMENTS TO THE INITIAL DETECTOR
  - ›› MAJOR IMPROVEMENTS FROM CONTROL OF RANDOM FORCES
  - ›› Double suspension systems
    - isolation from thermal noise of seismic isolation stage
    - improved seismic isolation
    - reduced thermal noise from internal modes
    - electrostatic controllers: smaller risk of magnetic field coupling
  - ›› Lower frequency isolation stack
    - improved seismic isolation to the gravitational gradient limit
    - damped metal spring replacement for elastomer
  - ›› Reduction of internal thermal noise
    - new test mass materials
    - methods to achieve damping at theoretical material limits
    - correlation techniques to measure the internal thermal noise

DETECTOR RESEARCH

- Improvement in the phase noise
  - ›› Increased laser power and reduction in scattering
    - 100 -- 1000 watts of 1.06 micron
    - improved coating and polishing
- ADVANCED DETECTORS
  - ›› New interferometer optical configurations
    - amplitude recycling
    - frequency tracking interferometers

DETECTOR RESEARCH

- PROGRAMMATIC ISSUES
  - ›› Many directions to take
  - ›› Collaborations needed
    - – LIGO Research Community participants a beneficial way to increase scientific and engineering capabilities
    - – Successful collaborations will most likely involve combinations of "insiders" with "outsiders"
- To maintain vitality of MIT experimental effort
  - ›› need to propose for new research support
  - ›› faculty appointment in area of precision measurements with emphasis on use of LIGO as primary research activity
  - ›› interferometer staging system
    - – size consistent with LIGO components
    - – length consistent with LIGO modulation frequencies (12-16m)
    - – in new seismically quiet location
    - – capability to carry out research on both displacement and phase noise

BACK UP SLIDES ON DATA STRUCTURES AND ANALYSIS FOR DAY II

DATA STRUCTURES AND ANALYSIS

- DIAGNOSTICS
  - ›› interferometer operating conditions
    - — state vector : binary
    - — settings table: gains, time constants
    - — long term avg vector: dc offsets
  - ›› auxiliary interferometer signals
    - — displacement signals: common and differential mode Michelson, common and differential mode cavity
    - — alignment signals: common and differential mode Michelson, common and differential mode cavity
  - ›› optical signals
    - — input light amplitude fluctuations: base band and RF
    - — input light frequency fluctuations
    - — input light position fluctuation vector
    - — input light angle fluctuation vector
    - — sideband amplitude fluctuations

DATA STRUCTURES AND ANALYSIS

  - ›› Mechanical signals
    - — Suspended mass position vectors
    - — Suspended mass angular vectors
- CALIBRATION and STIMULATION
  - ›› interferometer sensitivity and spectrum
    - — continuous differential cavity mode excitation
    - — periodic (hourly?) spectrum
  - ›› input large amplitude intensity excitation
  - ›› input large amplitude frequency excitation
  - ›› input large amplitude beam position and angle excitation
  - ›› interferometer control loop offset step - noise spectrum
  - ›› optical component large amplitude dither vectors

DATA STRUCTURES AND ANALYSIS

- ENVIRONMENTAL CORRELATION
  - local
  - site/site
  - ›› TECHNIQUE
  - veto
  - linear regression to improve signal/noise, detection confidence
  - ›› PARAMETERS
  - 3 axis seismic motion / building 0.1 < f < 10 Hz
  - 2 axis tilt / building f < 10 Hz
  - 3 axis acceleration / tank 10 < f < 1000 Hz
  - acoustic pressure / tank f < 1000 Hz
  - 3 axis magnetic fields f < 1000 Hz
  - radio frequency interference / building
  - cosmic ray muons / building t < 1 msec
  - power line fluctuations / building

DATA STRUCTURES AND ANALYSIS

  - ›› PARAMETERS (cont)
  - residual gas monitors /building /km beam tube
  - **molecular resonance absorption monitor /arm
  - **stray light monitor /km beam tube

** not in current budget

- REDUCED DATA SETS
  - ›› primary data/inteferometer/site
  - calibrated in standard units : h(t) or h(f)
  - instrument signatures removed
  - time tagged to microsecond
  - 1 to 4 x 10^9 bytes/day
  - ›› processed data/interferometer/site
  - list of interferometer state vector and environmental vetos
  - linear regression to environmental parameters
  - linear regression to ancillary interferometer signals

DATA STRUCTURES AND ANALYSIS

- SEARCH STRATEGIES
  - ›› IMPERFECT FILTERS
    - prescreening if analysis is computation intensive
    - gain statistics against signal to noise
  - ›› ONLINE FILTERS
    - reduction in stored data
    - preconceived waveforms
  - ›› BURST SEARCHES
    - threshold crossing, vetoed, event list comparisons
    - instrument and environment signatures removed, filtered cross correlation
  - ›› CHIRP SEARCHES
    - search templates (period and period derivative)
    - many detailed templates
    - χ^2 minimization using model parameters

DATA STRUCTURES AND ANALYSIS

- SEARCH STRATEGIES (cont)
  - ›› PERIODIC SOURCES
    - all frequency, selected location
    - all frequency, all location
    - amplitude spectra over total observing time (window function)
    - average of power spectra
    - search for amplitude and frequency modulation due to motion of detector
    - how to handle wandering local oscillators
    - value of data from different interferometers at same and remote locations
- STOCHASTIC BACKGROUND
    - frequency filtered cross correlation widely separated interferometers
    - frequency filtered cross correlation local interferometers
    - spatial anisotropy observations

DATA STRUCTURES AND ANALYSIS

- DETECTION CONFIDENCE
  - ›› Uncertainty in statistics of singles detection with non Gaussian noise
  - ›› Reduction to Gaussian statistics by remote coincidence
  - ›› Can one use a Neyman - Pearson hypothesis test (likelihood function) with non-Gaussian noise?
  - ›› How serious is the non-Gaussian noise in other than burst searches?
  - ›› How elaborate does a Monte - Carlo model have to be?

DATA STRUCTURES AND ANALYSIS

- LIST OF CURRENT PROBLEMS
- 1) Benefits of linear regression to environmental and ancillary interferometer signals
  - ›› Improvement in S/N Gaussian statistics
  - ›› Improvement in detection confidence
  - ›› Models for non - Gaussian noise
  - ›› Improvement as a function of correlation coefficient and noise in correlated parameters
- 2) Physics/Astrophysics bounded filters
  - ›› Dynamical limits
  - ›› Conservation laws
  - ›› Astrophysical bounds

DATA STRUCTURES AND ANALYSIS

- 3) Trigger filters (templates)
  - ›› generic filters
  - ›› increase in signal/noise and confidence of detection with more accurate filter
  - ›› is it possible to define an optimum signal processing strategy ?????
- 4) Reduced Data Sets
  - ›› Define minimum pre processing to allow data to be analysed by non-experts
  - ›› Define the signals in a reduced data set
- 5) Advantages for a periodic search using data from two sites
- 6) Stochastic background and Burst Search using data from the same site

DATA STRUCTURES AND ANALYSIS

- 7) How to use data from multiple sites
  - ›› improve detection confidence
  - ›› determine position in sky
  - ›› determine polarization of waves
- 8) Design the diagnostic tests