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LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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Quarterly Science & Integration Meeting 20, 21 May, MIT		
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Quarterly Science & Integration Meeting

20, 21 May 1996, MIT

Agenda - Day 1 (Times are EDT)

0900 - 1200

- Report (and discussion) from the working group on Data Analysis Scenarios and Flows -- Vogt/Bork/Blackburn/Zucker/

1200 - 1300

- Lunch

1300 - 1430

- Report (and discussion) on the working group on IFO Diagnostics -- Weiss/Spero/Raab

1430 - 1600

- Report on activities leading to the continuing R&D proposal to the NSF -- Weiss/Vogt

1600 - 1700

- Report on LIGO / VIRGO Data Formats Meeting -- Lazzarini
- Follow-up discussions with Mours -- Blackburn/Bork



Quarterly Science & Integration Meeting

20, 21 May 1996, MIT

Agenda - Day 2 (Times are EDT)

0900 - 0940

- Civil Construction - Coles/Stapfer

0940 - 1040

- Beam Tube System - Jones
- Mini bake status - Althouse
- BT /Baffle alignment tolerancing - Lazzarini

1040 - 1055

- BREAK

1055 - 1140

- Vacuum Equipment System - Worden

1140 - 1230

- Lunch



Quarterly Science & Integration Meeting

20, 21 May 1996, MIT
Agenda - Day 2 (Times are EDT)

1300 - 1320

- Detector Systems Design - Shoemaker

1320 - 1350

- Missions of 40 m research program - Spero

1350 - 1400

- BREAK

1400 - 1420

- Performance of 40 m interferometer, related to LIGO goals -Spero

1420 - 1440

- ISC design - Zucker

1440 - 1515

- PNI status/update - Saha

1515

- MIT Facilities tours



**Report (and discussion) from
the working group on Data
Analysis Scenarios and Flows**

Vogt/Bork/Blackburn/Zucker

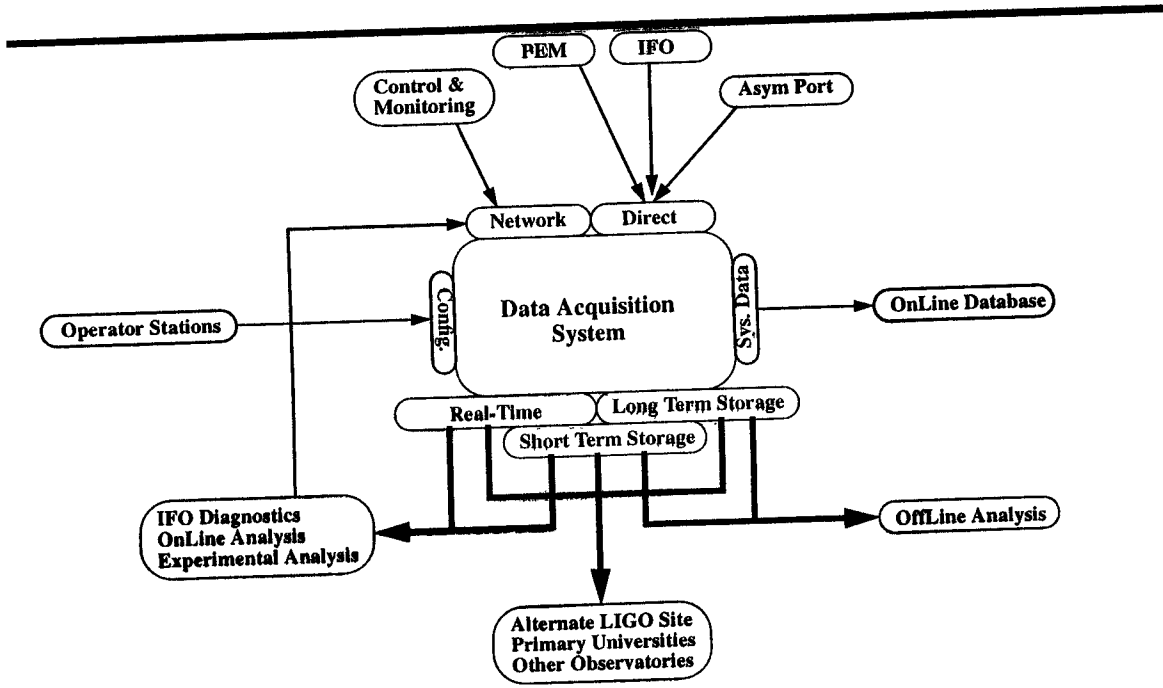
**20 May, 1996
0900-1200**

Science & Integration Meeting
MIT
May 1996

DATA ANALYSIS SCENARIOS

- ① System Overview
- ② Data Flow Down
- ③ Master Tape
- ④ Data Analysis
- ⑤ IBM UNIV. GRANT Program

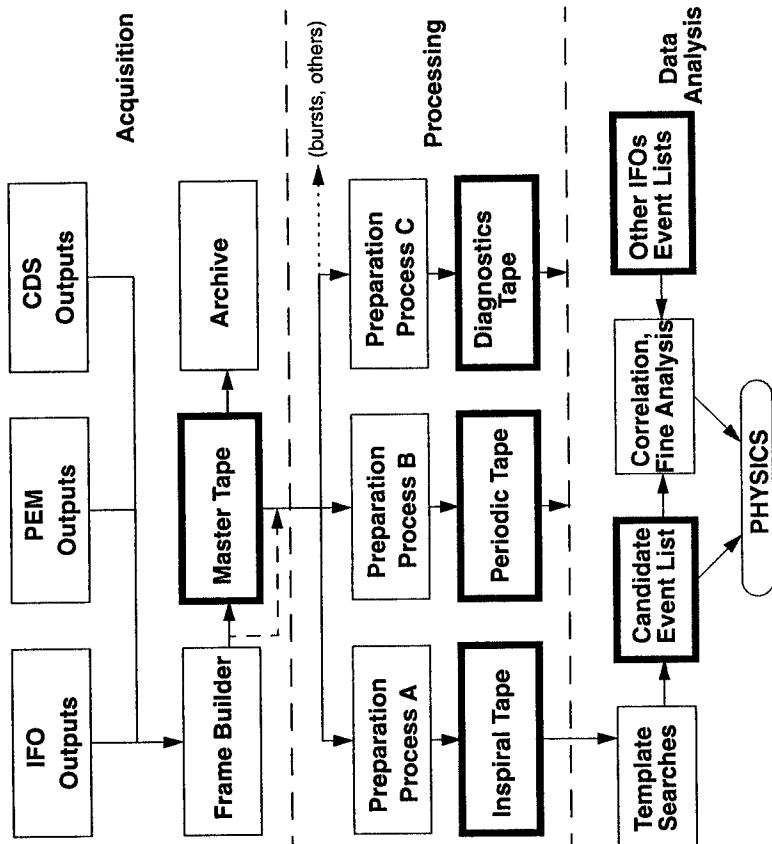
DAQ System Interfaces



LIGO DATA TAPE

Science & Integration Meeting - MIT May 1996

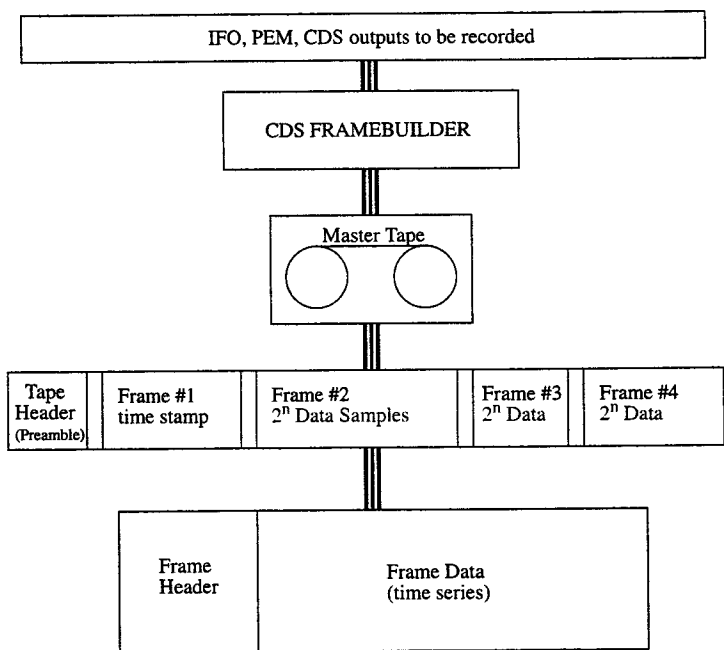
• "Very" Simple Data Flow Concept



LIGO DATA TAPE

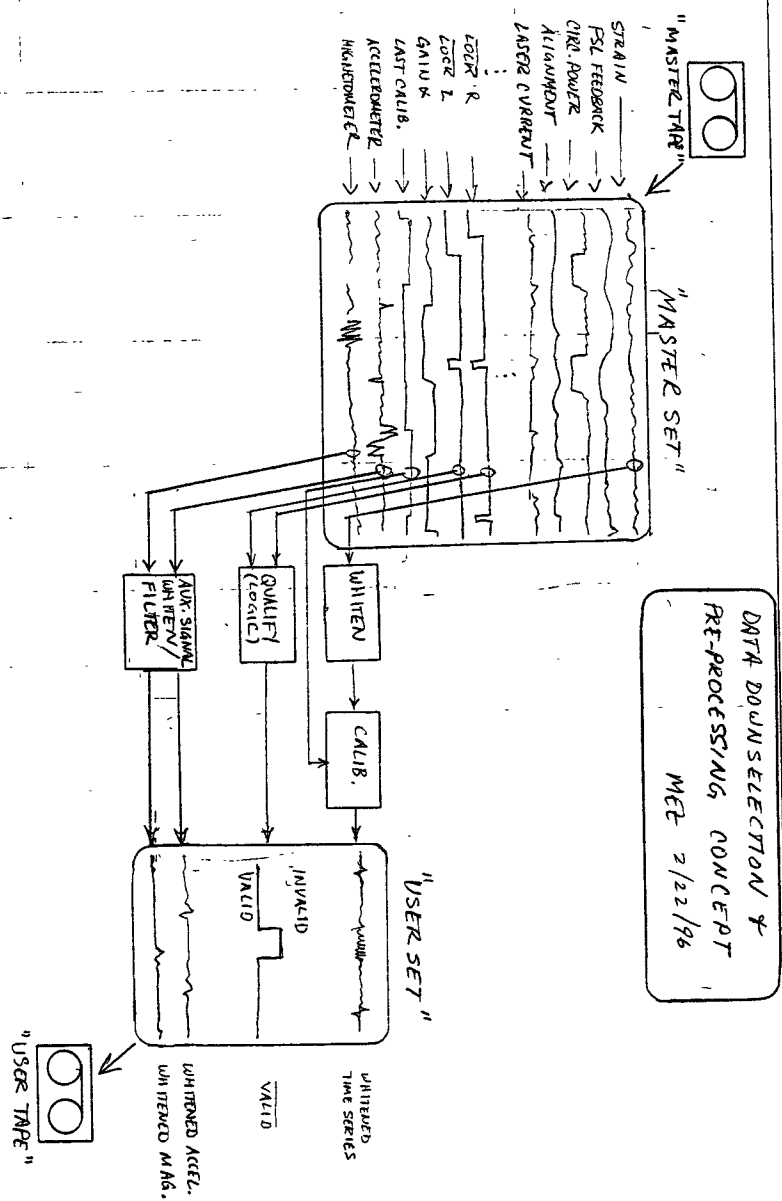
Science & Integration Meeting - MIT May 1996

• "Very" Preliminary Master Tape Concept



ZUCKER 2/3

FIGURE 2



LATER ANALYSIS...

DO NOT WRITE IN THESE SPACES
 ALL INFORMATION CONTAINED
 HEREIN IS UNCLASSIFIED
 DATE 02-28-2002 BY 60322
 UCBAW/SAB

LIGO DATA TAPE

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• Recorded Data

The “Master Tape” will contain a complete set of interferometer data necessary to make off-line data analysis and data channel correlations possible.

- One “Master Tape” per interferometer
- Record all IFO *time series* outputs
- Record all PEM *time series* outputs
- Record all CDS *time series* outputs
- Information on the pre-A/D whitening filters used to compress the dynamic range of signals such as the strain, acoustic, accelerometer, etc.
- A quality flag or hierarchical set of flags will be written to the tape using a logical condition which may change as our understanding of the interferometer evolves. This flag will facilitate the qualification of data during analysis
- Transfer functions and IFO state vectors be written to the “Master Tape.” This information will appear in the “Master Tape” header and in a specialized frame each time these data vary outside of a TBD “dead-band.”

LIGO DATA TAPE

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• Data Structure

The structure of the data stored on the “Master Tape” will at the highest level consist of frames. The “Master Tape” will have a tape header with information pertinent to the entire tape and/or long stretches of the tape. Each frame will consist of a self describing frame header followed by the time series data from all the recorded outputs(channels).

- Frames will contain all data for a fixed intervals of time (frames may vary in byte size)
- Frames time intervals will be an fixed number of seconds and should contain a power of two number of data samples
- Frames will not be so long in time interval as to make data extraction excessively time consuming on standard data analysis computer environments looking at data from multiple interferometers.
- Frame headers will have a time stamp marker corresponding to the start/TBD time of the data contained in the frame.
- Frame headers will contain sufficient self descriptors to identify the type of frame and other TBD characteristics of the frame
- The frame header will be followed by the time series data in a TBD data format for all recorded outputs.

LIGO DATA TAPE

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• Tape Preambles

The "Tape Header" will provide at a minimum a preamble to identify the tape. These are meant to characterize either the whole tape or at least long stretches of the tape.

- Sequential Tape ID (may have encoded within, the Site & IFO number)
- Site
- IFO number
- Date (both local and GMT)
- Time (both local and GMT)
- Detector location (latitude & longitude)
- Detector arm orientation (convention needed)
- Frame Builder version
- IFO mode (recycled, dual-recycled)
- Operation mode (normal observation, research & development)
- Initial IFO state vector (~10's of kilobytes)
- Initial Transfer Functions (~10 kilobytes)
- Pre-A/D whitening filters used to reduce dynamic range
- A FLEXIBLE FORMAT that allows for expansion of this list



LIGO DATA TAPE

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• Tape Summary

The "Tape Header" will contain a pre-allocated data space for storing summary and statistical information on various characteristics of the data and the interferometer that are accumulated during the recording period for the tape.

• Data Rates

- ~6 Megabytes per second is the expected data rate / interferometer
- ~2 hours is the expected data collection time per tape (48GB / 6MB/s)

• Frame Types

The tape frame will be sufficiently general to support and completely describe variable frame types. One could propose to use special-purpose frames under the general frame structure for such things as:

- Fast IFO data (e.g. strain, laser power)
- Fast PEM data (e.g. microphone, accelerometer)
- Slow IFO data (e.g. suspension, stack signals)
- Slow PEM data (e.g. temperature, RGA pressure)
- Qualified data time span list (e.g. ignore frame 0000x, 00y00, ...)
- Measured frequency response transfer functions (e.g. strain calibrations)
- Machine state description
- Remote diagnostics & video snapshots



LIGO DATA TAPE

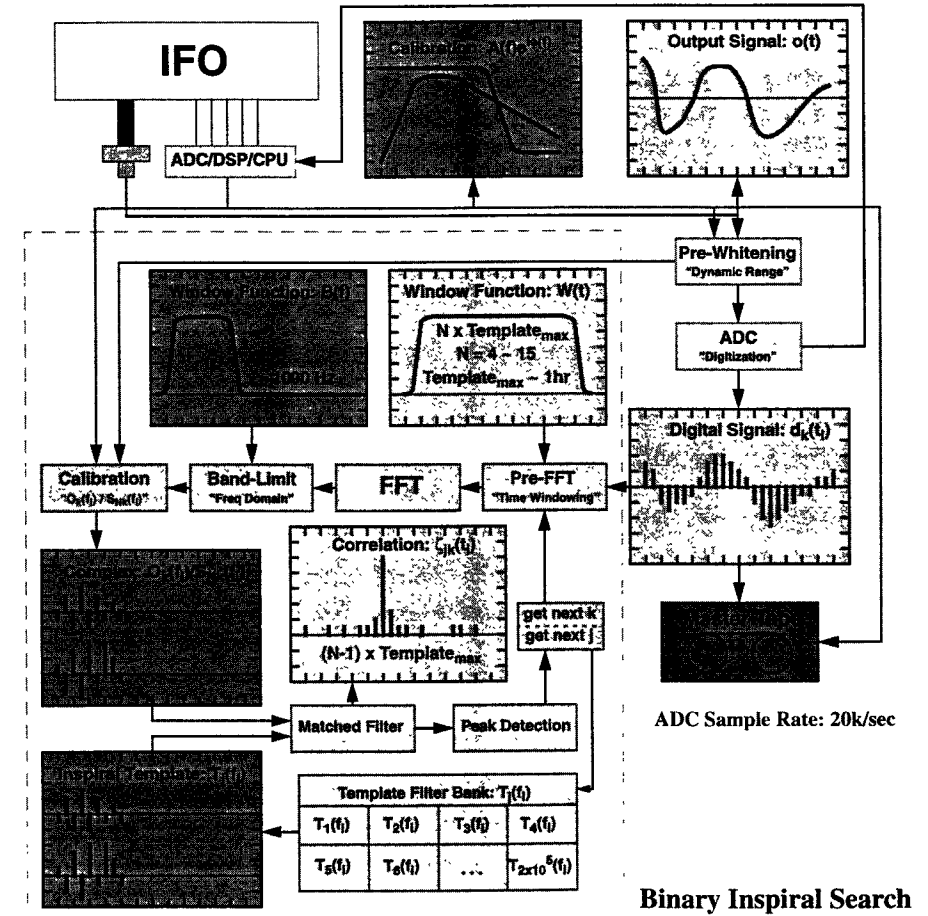
Science & Integration Meeting - MIT May 1996

Existing Formats

- HARDWARE: ascii, binary
- COMPUTER LANGUAGE: Arrays, C-structures, C++ objects
- PUBLIC DOMAIN: CDF, FITS, GRIB, HDF, netCDF, VICAR, PDS, miscellaneous graphics formats (TIFF, GIF, JPEG, FLI, CGM), SAIF, SDTS, HDS, MedFileS, CXF, JCAMP, CIF, OpenMath, GeoTIFF, DLG-3, DEM ...
- COMMERCIAL: proprietary database

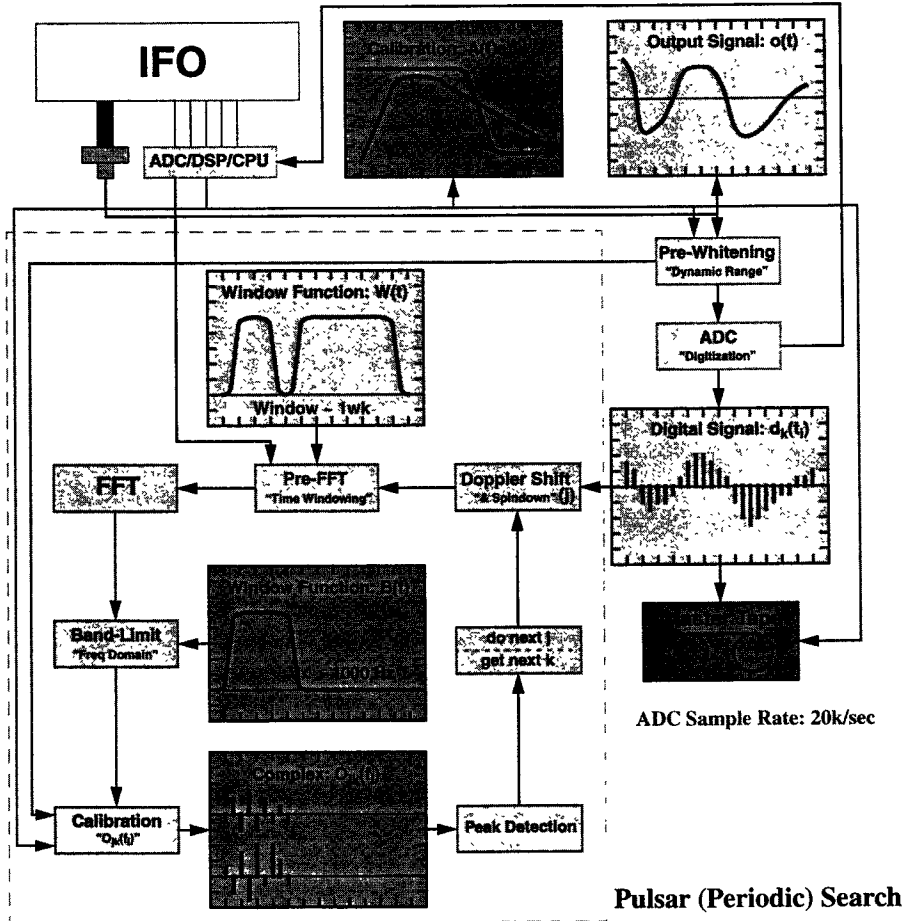
LIGO DATA ANALYSIS

Science & Integration Meeting - MIT May 1996

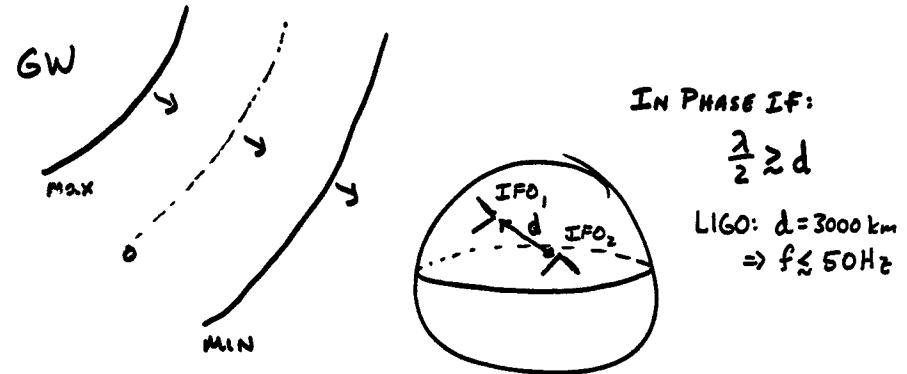


LIGO DATA ANALYSIS

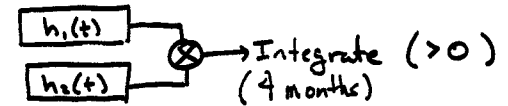
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STOCHASTIC BACKGROUND DATA ANALYSIS



Correlate signals from 2 or more detectors



Optimal Filtering (B. Allen)

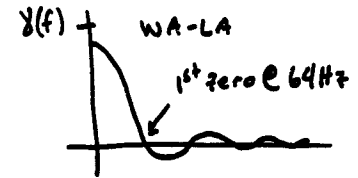
$$\int_{-\infty}^{\infty} df \tilde{h}_1(f) \tilde{h}_2(f) \tilde{Q}(f)$$

Optimal when

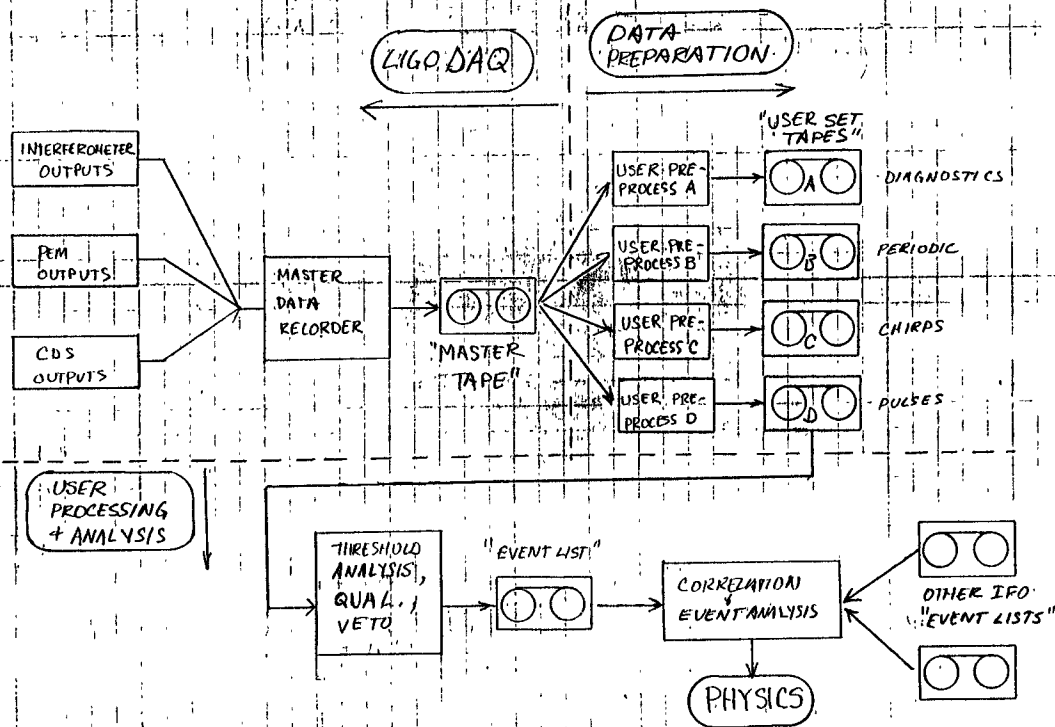
$$\tilde{Q}(f) = \frac{\gamma(f) S_{gw}(f)}{f^3 S_1(f) S_2(f)}$$

Sensitivity Reduced by factor $\gamma(f)$ (Overlap Reduction Function)

- => 1) non parallel arm alignment
- 2) signals out of phase



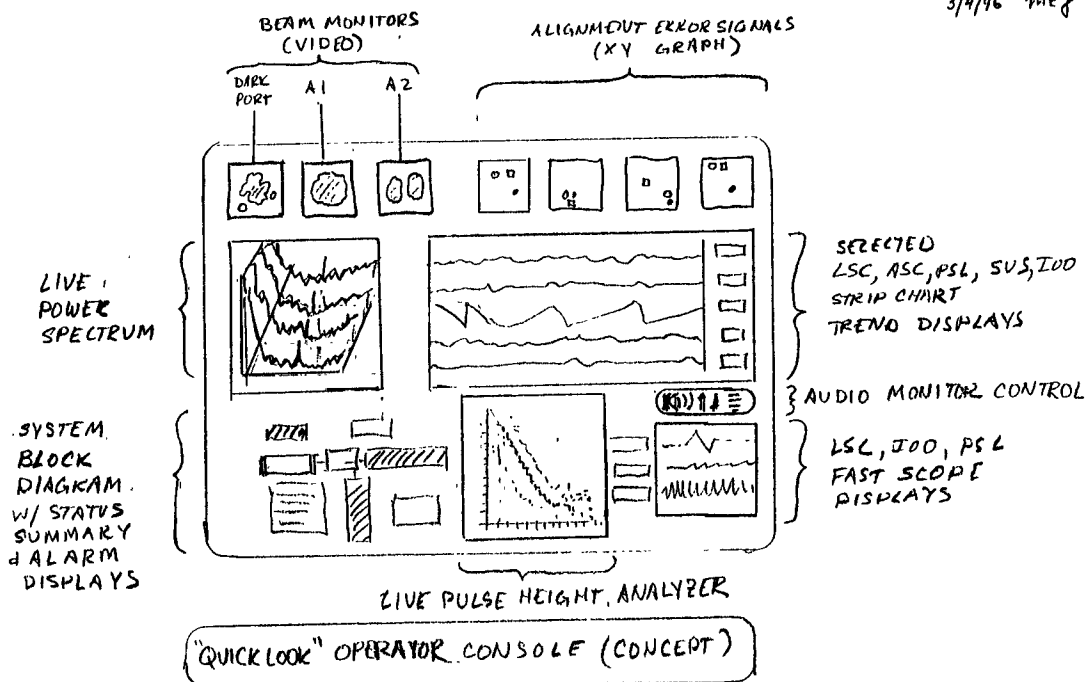
CONCEPTUAL DATA FLOW PARADIGM V. 2
 MEZ 3/7/96



WORKING GROUP ON DATA ANALYSIS...

FIGURE 1

3/3/96 MEZ
 3/4/96 MEZ



WKG GROUP ON IFO DIAGNOSTICS

FIGURE 2

ZUCKER 1/3

ZUCKER 1/1

Report (and discussion) on the working group on IFO Diag- nostics

Weiss/ Spero/ Raab

**20 May, 1996
1300-1400**

DIAGNOSTIC TESTS Functions

- Set operating points
 - ›› search for instabilities in servo loops
 - ›› determine minimum noise parameters
 - ›› determine dynamic range of an output
 - ›› determine intermodulation products due to offsets, saturations and non-linearities
- Establish sensitivity to perturbations
 - ›› determine sensitivity at an output by stimulation
 - ›› measure the noise at a sensitive point due to a specific mechanism
- Determine transfer functions and correlations
 - ›› determine transfer function between stimulus and output
 - ›› determine crosscorrelation or cross power spectrum between outputs
- Calibration of the system

DIAGNOSTIC TESTS

Concept to gain sensitivity

- Stimulation by periodic or random excitation
 - » Excitation larger than naturally occurring noise
 - » Response still linear
- Response to stimulation measured
 - » At output Z specifically sensitive to the stimulation
 - » Minimally sensitive to other noise sources
 - » Transfer function stimulation to Z output
- Transfer function of stimulation to GW output
 - » cross-correlation or cross power spectrum Z to GW output
- Noise measurement
 - » Stimulation off; cross-correlation of noise at Z with GW output
 - » Ultimately extension to full matrix solution not just diagonal terms

DIAGNOSTIC TESTS

- The tests recur :
 - » occasionally to set parameters
 - » periodically to maintain record of instrument and facility performance
 - » continuously as part of the operations data stream
- On line analysis tools
 - » plot data with adjustable axes (log and/or linear) and in different colors
 - » select data to fit to a linear, exponential or power law
 - » make χ^2 minimized fits to non-linear functions; plot: data, fit and residuals
 - » take the Fourier transform of selected data
 - » display the auto-correlation function of selected data
 - » take the cross-correlation function of selected data pairs

DIAGNOSTIC TESTS

- ›› determine the covariance of selected data pairs
 - ›› calculate the cross amplitude spectrum of selected data pairs
 - ›› calculate primitive statistical parameters of selected data: mean, variance, p-p, skewness and higher moments
 - ›› display a histogram of the probability distribution of selected data
 - ›› to make a restricted class of wavelet transforms of selected data
- Remote fast diagnostics - functions
 - ›› measurement of peak excursions to uncover saturation
 - ›› measurement of oscillation instabilities in servo loops
 - ›› direct measurement of RF signals before demodulation
 - ›› measurement of servo locking transients

DIAGNOSTIC TESTS

- Fast diagnostic signals - remote oscilloscope
 - ›› common mode cavity output
 - ›› differential mode cavity output
 - ›› common mode Michelson output
 - ›› differential mode Michelson output
 - ›› common mode cavity wavefront sensor output
 - ›› differential mode cavity wavefront sensor output
 - ›› common mode Michelson wavefront sensor output
 - ›› differential mode Michelson wavefront sensor output
 - ›› all test mass position sensor outputs
 - ›› all RF signal inputs to mixers

DIAGNOSTIC TESTS

List of tests

SENSING NOISE TESTS 1

- Test 1.1: Frequency noise in the gravitational wave band
- Test 1.2: Amplitude noise in the gravitational wave band
- Test 1.3: Amplitude noise at the sideband frequency
- Test 1.4: Amplitude noise due to unintended interferometers
- Test 1.5: Noise due to input beam position and angle fluctuations
- Test 1.6: Intermodulation products due to offsets and large amplitude deviations from null
- Test 1.7: Phase noise limits due to scattering in the beam tube

OPTIMIZATION OF OPTICAL PHASE SENSITIVITY 2

- Test 2.1: Signal to noise optimization of the RF modulation index
- Test 2.2: Mode matching into interferometer
- Test 2.3: Higher order arm cavity mode scan
- Test 2.4: Arm cavity loss measurement
- Test 2.5: Recycling cavity loss measurement
- Test 2.6: Common mode cavity fringe calibration
- Test 2.7: Differential mode cavity fringe calibration
- Test 2.8: Common mode Michelson fringe calibration
- Test 2.9: Differential mode Michelson fringe calibration
- Test 2.10: Common mode arm cavity end mirror rotation calibration
- Test 2.11: Differential mode arm cavity end mirror rotation calibration
- Test 2.12: Common mode arm cavity input mirror rotation calibration

DIAGNOSTIC TESTS

List of tests

- Test 2.13: Differential mode arm cavity input mirror rotation calibration
- Test 2.14: Beam splitter rotation calibration
- Test 2.15: Recycling mirror rotation calibration

NOISE DUE TO RANDOM FORCES 3

- Test 3.1: Suspended optical component seismic noise sensitivity - ambient/driven
- Test 3.2: Suspended optical component acoustic noise sensitivity - ambient/driven
- Test 3.3: Suspended optical component magnetic field sensitivity - ambient/driven
- Test 3.4: Suspended optical component electric field sensitivity - ambient/driven
- Test 3.5: Suspended optical component tilt sensitivity - ambient/driven
- Test 3.6: Pendulum longitudinal mode Q
- Test 3.7: Pendulum wire transverse mode Q
- Test 3.8: Pendulum wire longitudinal mode Q
- Test 3.9: Pendulum vertical to horizontal cross coupling

OPTIMIZATION TO MINIMIZE NOISE FROM RANDOM FORCES 4

- Test 4.1: Search for rotation insensitive beam position on suspended component
- Test 4.2: Search for astatic point in suspended component position controller

DIAGNOSTIC TESTS

List of tests

TESTS OF THE FACILITY/DETECTOR INTERFACE 5

Test 5.1: Correlation of residual gas pressure fluctuations with detector output

Test 5.2: Correlation of technical power fluctuations with detector output

Test 5.3: Correlation of facility power fluctuations with detector output

Test 5.4: Correlation of facility monitor flags with detector output

**Report on activities leading to
the continuing R&D proposal
to the NSF**

Weiss/ Vogt

**20 May, 1996
1430-1600**

**LIGO RESEARCH PROPOSAL
Schedule**

- R&D FUNDING FOR LIGO AT CALTECH/MIT ENDS IN 1/1997
- PROJECT WILL SUBMIT R&D PROPOSAL TO NSF IN OCTOBER 1996 (Vogt, Weiss ,+)
- NSF HAS APPOINTED A "BLUE RIBBON" PANEL TO DETERMINE NEEDS OF THE FIELD
 - >> First meeting 6/24 - 6/25/96
 - >> Committee Membership
 - William Frazer Lawrence Berkeley Lab
 - Ned Goldwasser University of Illinois
 - Boyce McDaniel - chair Cornell University
 - Pier Oddone University of California at Berkeley
 - Peter Saulson Syracuse University
 - Sydney Wolff National Optical Astronomy Observatories



LIGO RESEARCH PROPOSAL Schedule

- PRESENTATIONS BY:

- ›› LIGO

- Current state of LIGO construction
- Planning for operations and data analysis
- “White paper” on R&D
- LIGO Visitors Program

- ›› LIGO Research Community Chair

- ›› Stanford University Group

- ›› University of Florida Group

- ›› University of Colorado Group ?

- ›› Syracuse University Group ?

- HOPED FOR OUTCOME

- ›› Scientific prospects and proposal pressure draw in new funds for the field

- ›› NSF retains part of LIGO construction funding wedge



LIGO RESEARCH PROPOSAL “White Paper”

- Intent of “White Paper” is to provide pedagogy

- Scientific overview

- ›› Prospects for Gravitational wave research

- Consequence for fundamental physics of gravitation
- Consequences for astrophysics and cosmology
- Classes of sources

- ›› The initial LIGO detector

- Sensitivity
- Techniques to give confidence of detection
- Operation as part of a gravitational wave detector network

- ›› Directions for incremental improvements in the detector

$h(f)$ referenced to Initial and Advanced detector spectra shown in 1992 *Science* article

h_{rms} referenced to 3 events/year NS/NS coalescence at 20, 200, 2000 Mpc



LIGO RESEARCH PROPOSAL “White Paper”

- Double pendulum suspension
 - Electrostatic controller and elimination of magnets on final suspension stage
 - Mechanical filter for control noise
 - Improved seismic isolation
 - Reduction in sensitivity to thermal noise from final isolation stage

- Reduced internal test mass losses
 - Higher Q test mass: design and materials

- Reduced pendulum losses
 - Alternate mounting techniques
 - New flexure design and materials

- Improved seismic isolation
 - Lower spring constant springs
 - External active isolation (if not incorporated in the initial detector)

- Higher circulating power in arms
 - Higher input laser power
 - Lower loss coatings on test mass mirrors



LIGO RESEARCH PROPOSAL “White Paper”

- » Directions for qualitatively new detectors
 - Dual recycling configurations
 - High frequency narrow band operation
 - Completely reflective configurations

- » Fundamental limits
 - Gravity gradients
 - Naive quantum limit

- LIGO operations
 - » Detector installation and qualification
 - » Diagnostic procedures and initial noise measurements
 - » Observation planning
 - data processing
 - development of data analysis strategies and algorithms
 - » The observations
 - data analysis: optimal filtering for different classes of sources
 - correlation studies of intra and inter site noise



LIGO RESEARCH PROPOSAL

“White Paper”

- Use of the large baseline facilities for related research
 - Measurement of optical scattering
 - Study of temporal fluctuations in the residual gas
 - Local geophysical measurements

• Strategy for the LIGO R&D

- » Intend to propose collaborative research programs
 - Broadening of expertise to make LIGO more productive
 - Utilization of LIGO infrastructure by collaborators
 - Provide natural entry for collaborations in the use of the LIGO long baseline system

• Rough Cost estimate and level of effort

- » LIGO scientific and engineering staff divided between R&D and operations and data analysis
 - R&D support from new proposal
 - Operations and data analysis support from operations funds

LIGO/VIRGO DATA FORMATS

Science & Integration Meeting - MIT May 1996

-
- Actions Items from LIGO/VIRGO Meeting, April 1996
 - >> Review the structure of the proposed VIRGO FORMAT
 - >> Investigate the structure of public domain data formats
 - >> Isolate the VIRGO format read/write software into a “library”
 - >> Distribute this new VIRGO format library to LIGO for testing
 - >> Evolve VIRGO format -> LIGO/VIRGO format
 - >> Document format and library
 - >> Meet to finalize technical aspects of format in August
 - >> Finalize LIGO/VIRGO data format in September in Annecy



1 of 8

LIGO-G950000-00-M

**Report on LIGO/VIRGO
Data Formats Meetings**

Lazzarini

**20 May, 1996
1600-1700**