LIGO: At the Frontier of Gravitational-wave Research and Science Education*

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Southern University and A&M College
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*Work supported by NSF Grants No. PHY-0101177 and PHY-0355471;
Board of Regents Grant No. 05-231SUBR-CMSS

Percy L. Julian Luncheon Presentation
2007 NOBCCHE Annual Conference
Orlando, FL
April 4, 2007

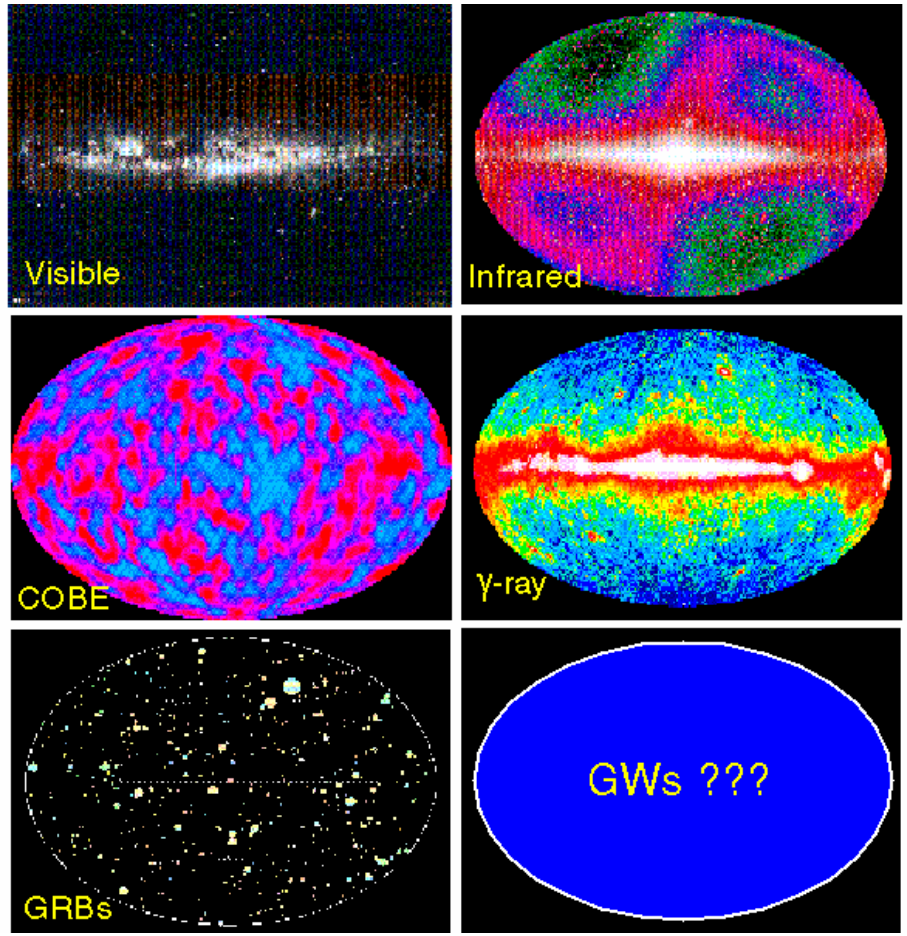
LIGO-G070392-00-Z

TALK OUTLINE

- LIGO, the experiment
  (Laser Interferometer Gravitational-wave Observatory)
- SUBR-LIGO Materials Research
- LIGO Local Educational Outreach Partnership
- Summary and Acknowledgments

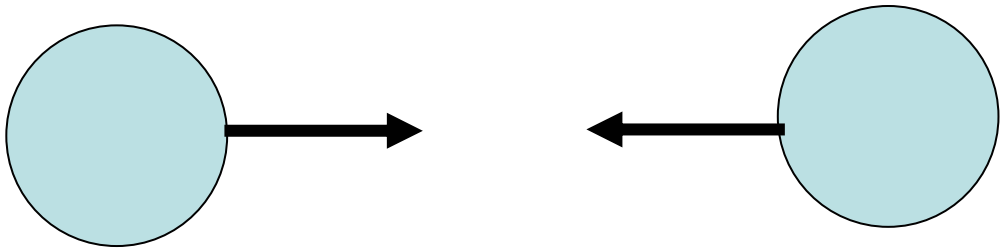
Scientific Mission of LIGO

- LIGO's quest, ~400 yrs after invention of optical astronomical telescopes, is to create a radically new way to perceive the universe, by directly listening to the vibrations of space itself
- LIGO consists of large, high-tech, earth-based, detectors that will act like huge microphones, listening for "space quakes" created by the most violent events in the universe



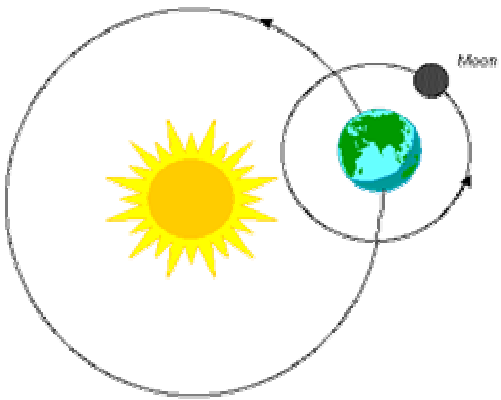
Photos courtesy of NASA.

Newton's gravitation



Newton's law: $F=Gm_1m_2/r^2$

Explains why things fall down, and planetary motion.

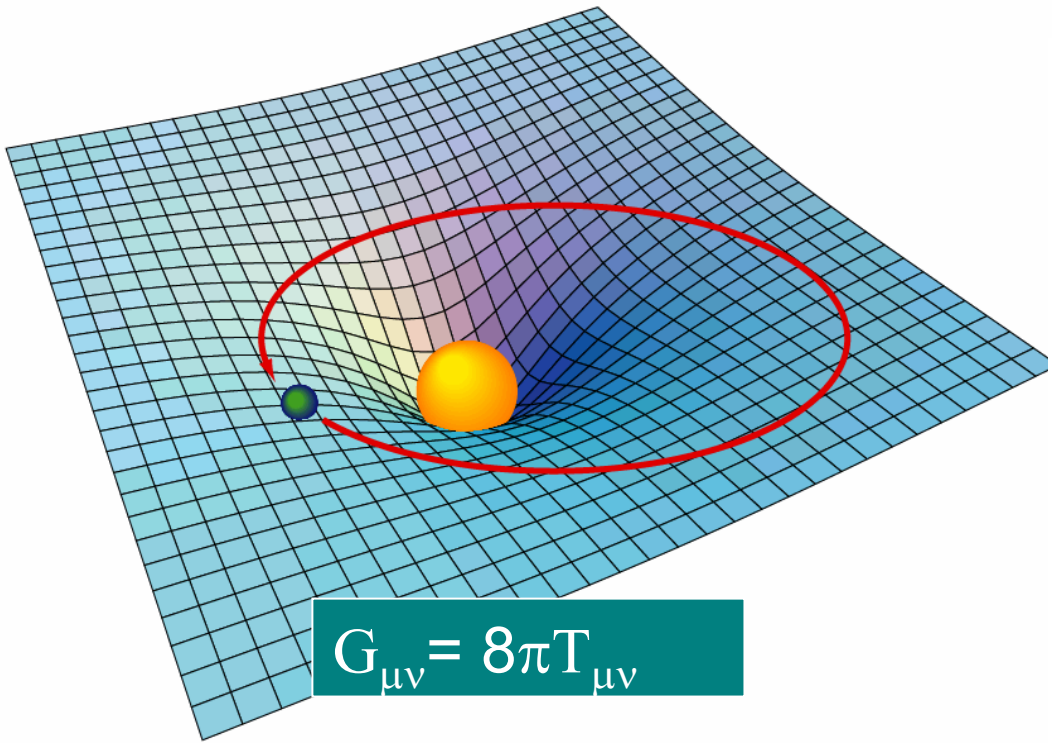


LIGO

General Relativity

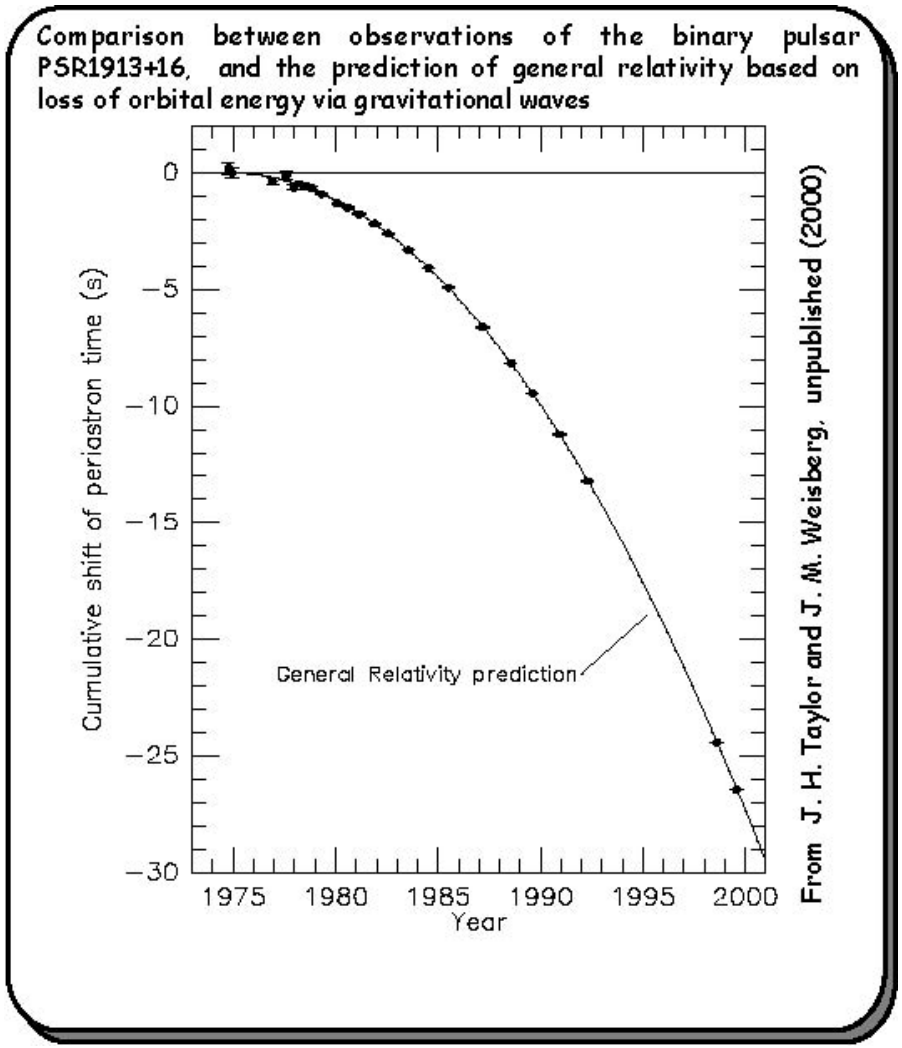
SOUTHERN UNIVERSITY And Agricultural & Mechanical College

Einstein theorized that smaller masses travel toward larger masses, not because they are "attracted" by a mysterious force, but because the smaller objects travel through space that is warped by the larger object



- Imagine space as a stretched rubber sheet.
- A mass on the surface will cause a deformation.
- Another mass dropped onto the sheet will roll toward that mass.

Hulse-Taylor Experiment

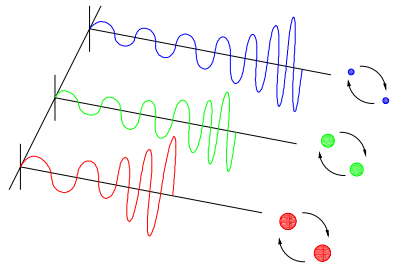


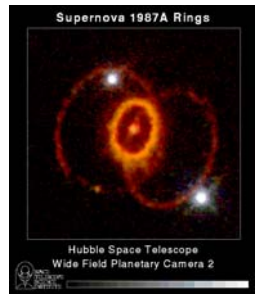
Russell Hulse and Joseph Taylor carefully observed two binary pulsar systems for more than 15 years. They determined the rate at which the orbital parameters were changing and compared these rates of change to those predicted as a consequence of the emission of gravitational radiation.

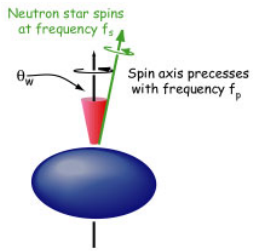
1993 Nobel Prize in Physics!

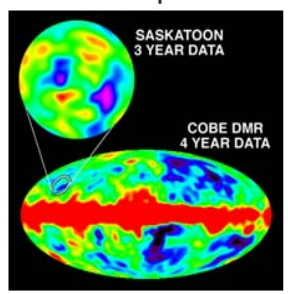
Astrophysical Sources of Gravitational Waves

- Compact binary inspiral: *"chirps"*
  - NS-NS
  - BH-BH
- Supernovae / GRBs: *"bursts"*
  - burst signals in coincidence with signals in electromagnetic radiation
  - prompt alarm (~ one hour) with neutrino detectors
- Pulsars in our galaxy: *"periodic signals"*
  - search for observed neutron stars (frequency, doppler shift)
  - all sky search (computing challenge)
  - r-modes
- Cosmological Signals *"stochastic background"*

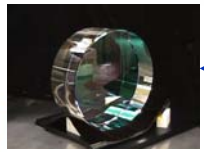




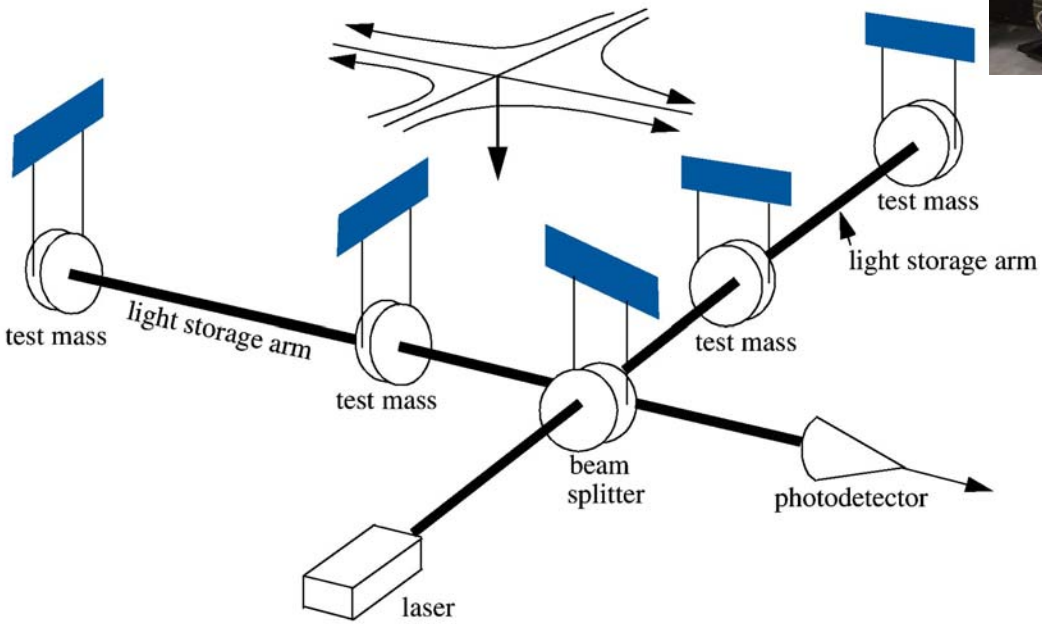




HOW ARE GRAVITY WAVES DETECTED?



suspended mirrors



$$Strain = h = \delta L/L$$

LIGO (4 km), stretch (squeeze) = 10^{-18} m will be detected at frequencies of 10 Hz to 10^4 Hz. It can detect waves from a distance of 600 x 10^6 light years

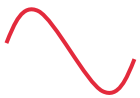
How Small is 10^{-18} Meter?

One meter, about 40 inches

÷10,000

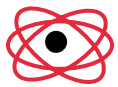
Human hair, about 100 microns

÷100



Wavelength of light, about 1 micron

÷10,000

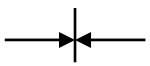


Atomic diameter, 10^{-10} meter

÷100,000

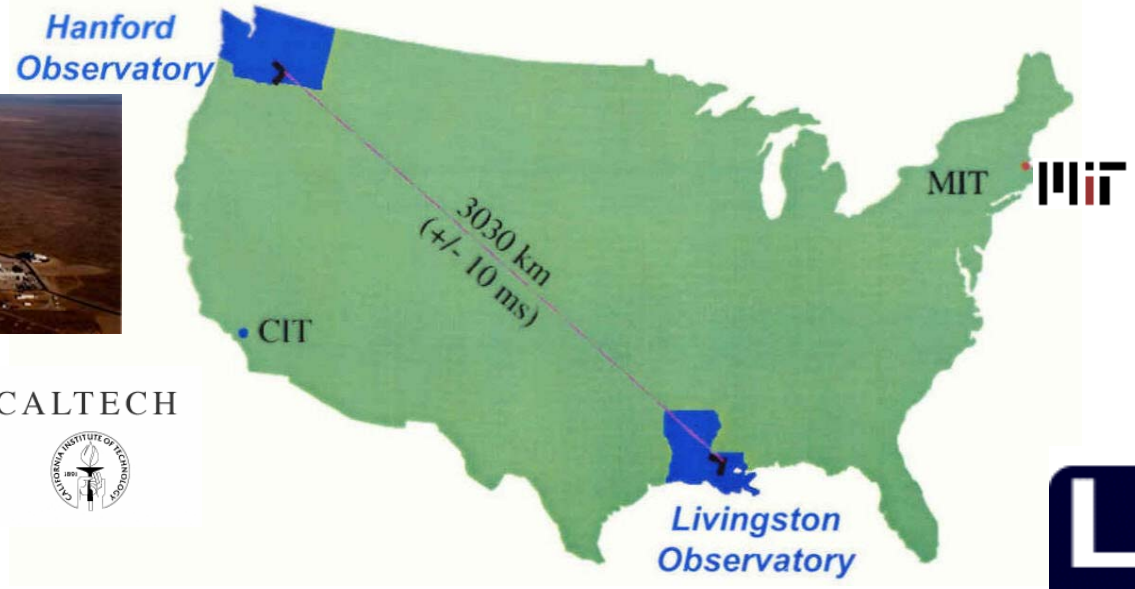
Nuclear diameter, 10^{-15} meter

÷1,000



LIGO sensitivity, 10^{-18} meter

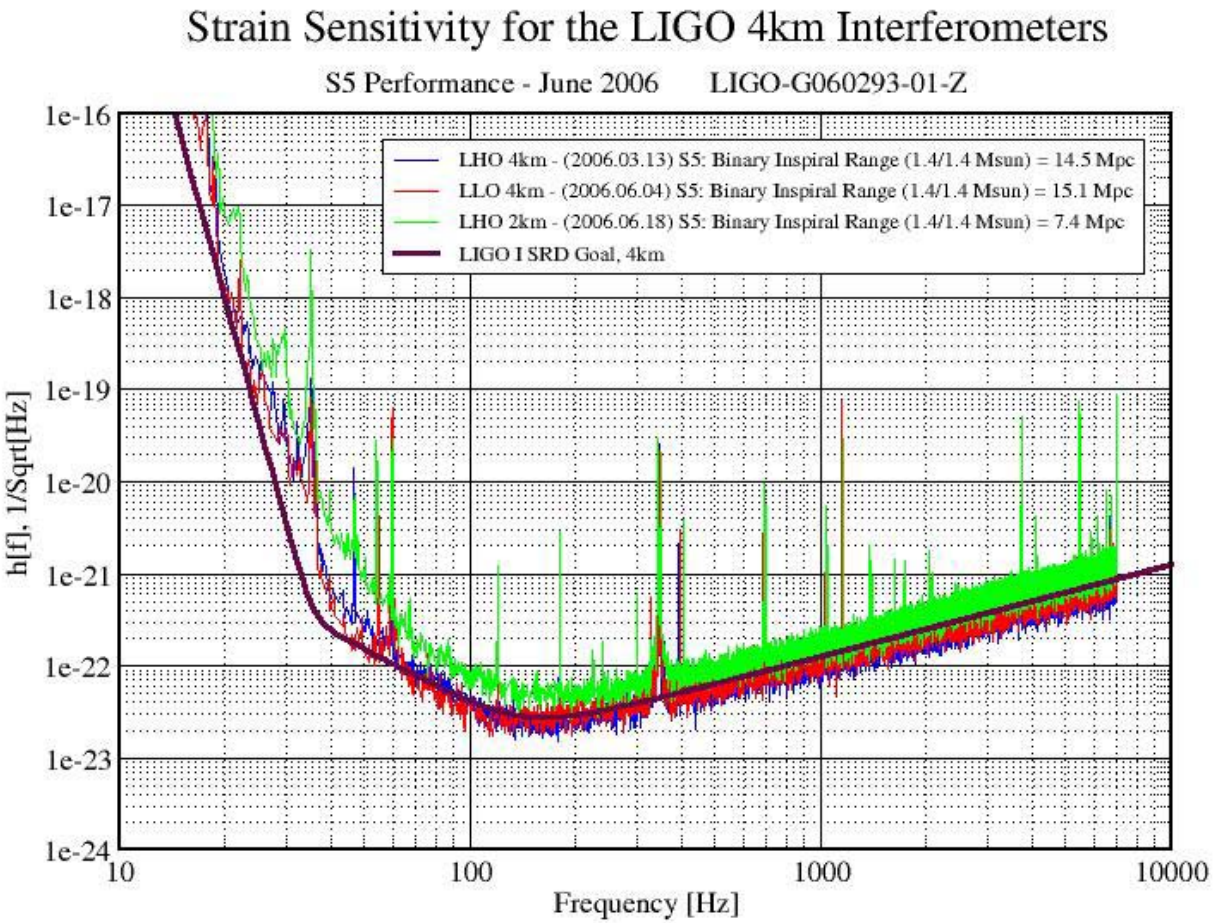
Laser Interferometer Gravitational-wave Observatory Sites



CALTECH

Funded by the National Science Foundation; operated by Caltech and MIT; the research focus for about 500 LIGO Scientific Collaboration (LSC) members worldwide.

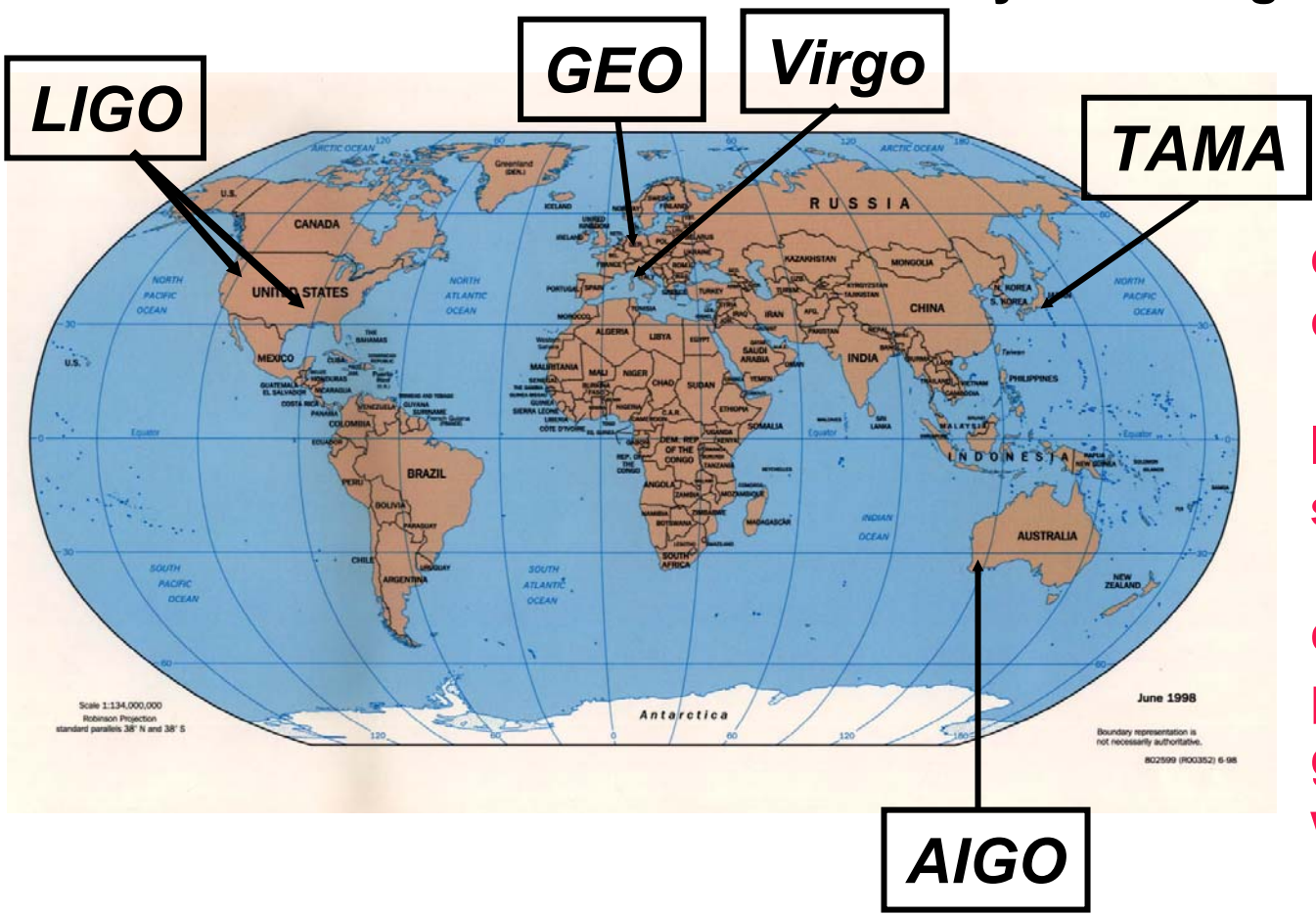
Recent Strain Sensitivity Curve



Interferometers

international network

Simultaneously detect signal (within msec)



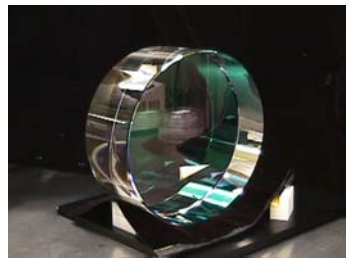
detection confidence

locate the sources

decompose the polarization of gravitational waves

Proximity of LIGO site to Southern University

SUBR Science Focus



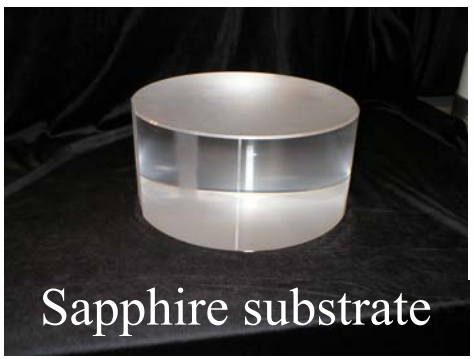
Trace element measurements in substrates and coatings

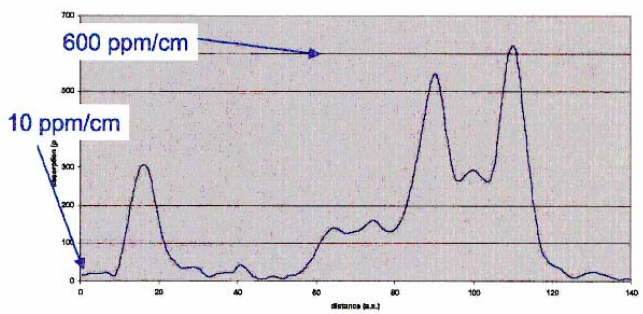
Objective:

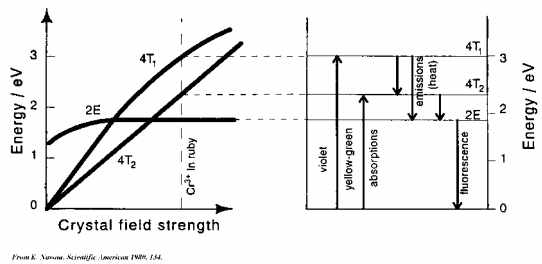
Obtain physical correlations between chemical impurities (Ti, Cr, Fe, Co, etc.) and optical absorption characteristics of materials under consideration for use as test masses and optical coatings in advanced LIGO.

HEM™ Process

Crystal Systems, Inc.







COLLABORATORS

E. E. Doomes, L.L. Henry, S. C. McGuire, M. J. Baham and E. Preddie
Department of Physics, Southern University and A&M College
Baton Rouge, LA

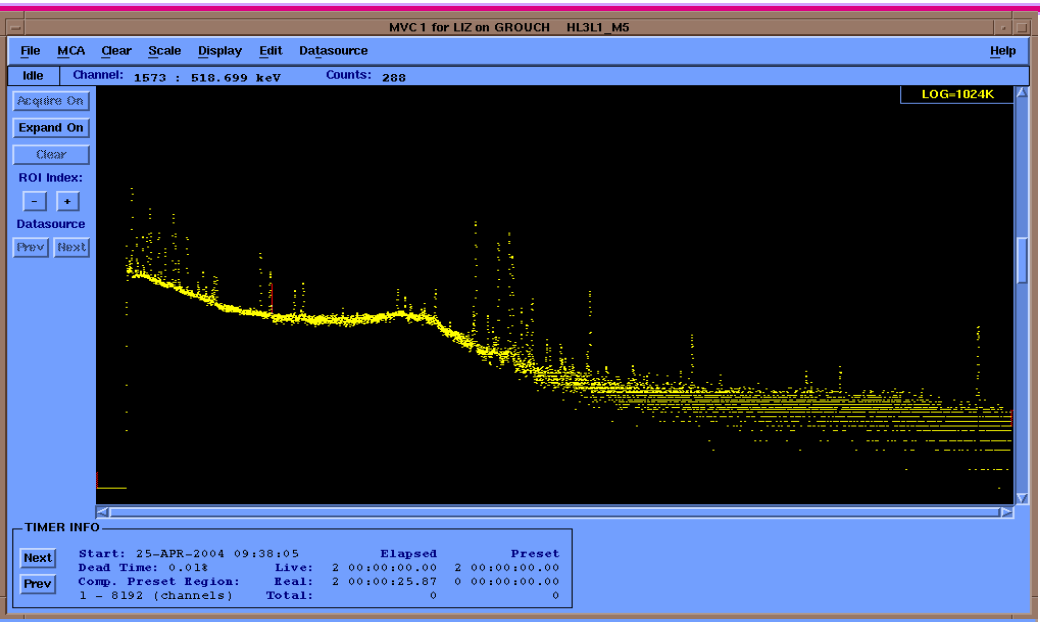
G. P. Lamaze and E. A. Mackey
NIST, Chemical Sciences and Technology Laboratory
Gaithersburg, MD

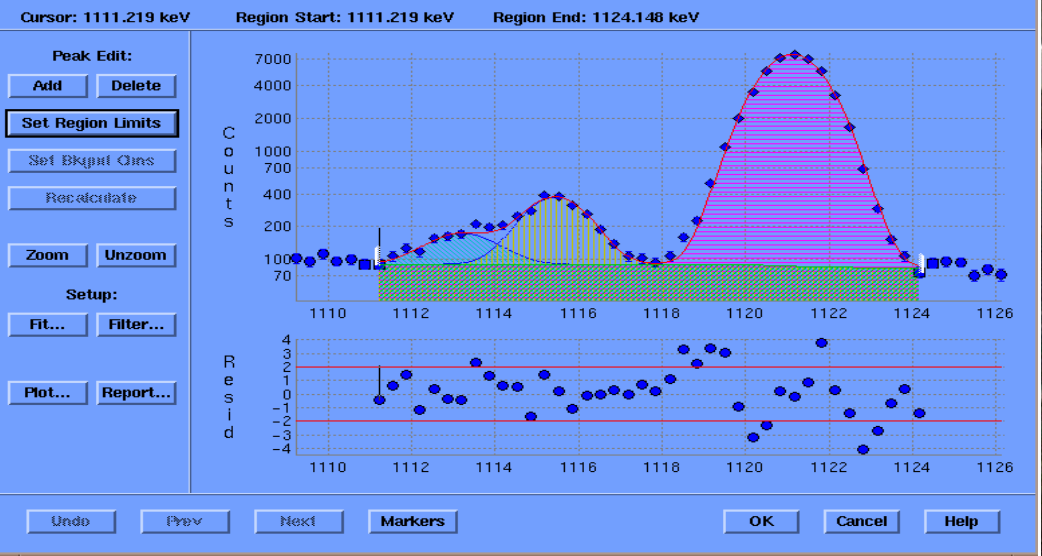
S. Brennan, K. Luening, P. Pianetta, A. Singh
Stanford Synchrotron Radiation Laboratory
SLAC/HBCU Partnership Program
Menlo Park, CA

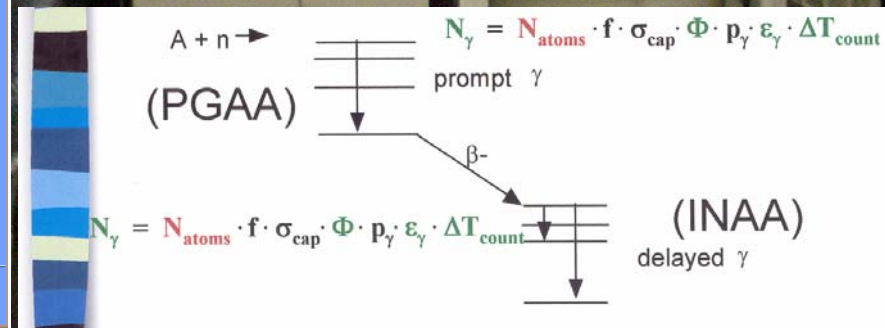
R. Tittsworth (deceased)
Center for Advanced Microstructures and Devices/LSU
Baton Rouge, LA

S. Cliff, K. H. Jackson, M. Jimenez-Cruz
Advanced Light Source
Lawrence Berkeley Laboratory
Berkeley, CA

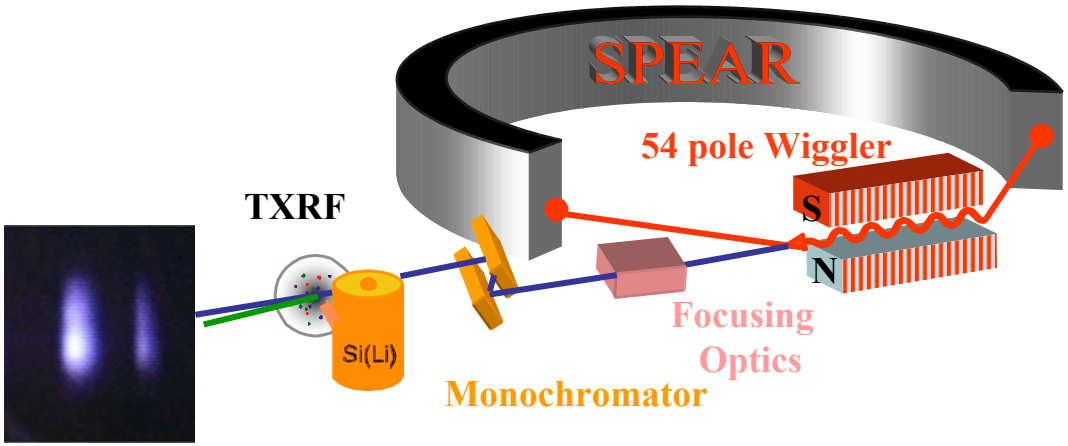
INAA γ-ray Spectroscopy at NIST







Synchrotron Radiation TXRF Facility at SSRL



Collaborators:

SSRL:

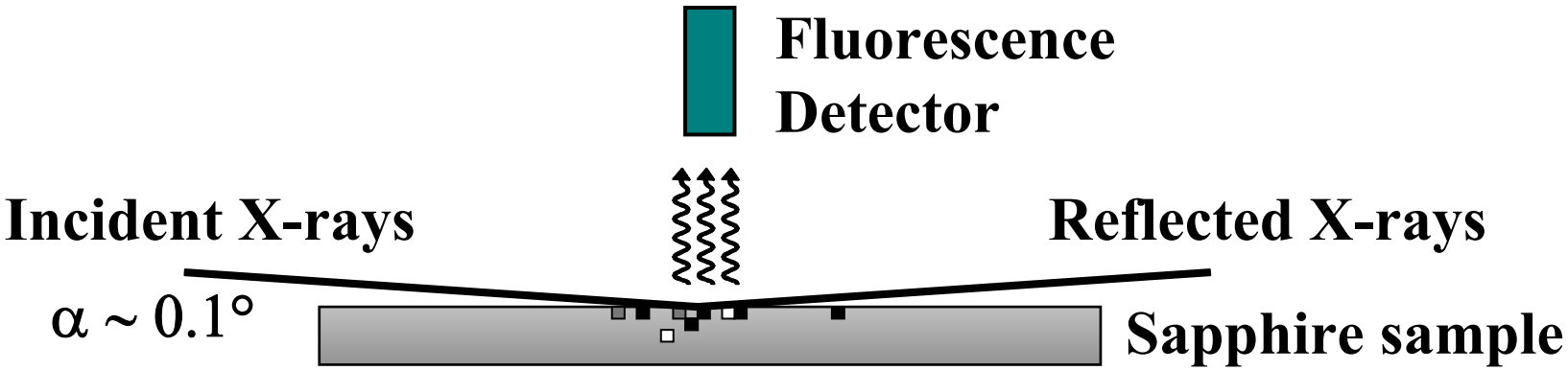
- P. Pianetta
- K. Luening
- S. Brennan
- A. Singh

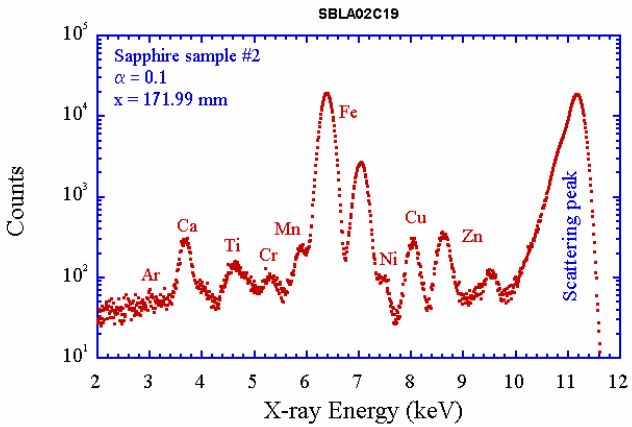
Southern Univ.

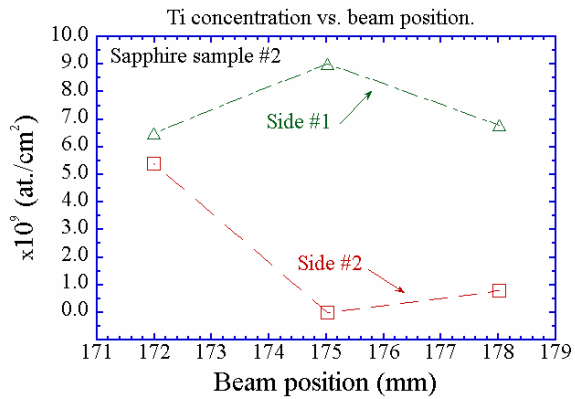
- S. C. McGuire
- M. Baham
- E. Preddie

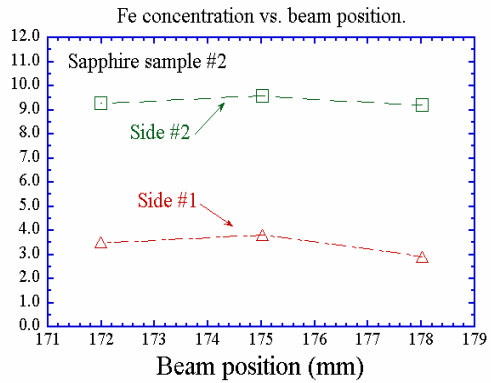
X-ray energy: 11.3 keV
Angle of incidence ~ 0.08°
Detector: Si(Li)—no parasitic peaks
Automatic critical angle measurement
Wafers: Small pieces to 200 mm
Cleanroom mini-environment

Total X-ray Reflection Fluorescence (TXRF)





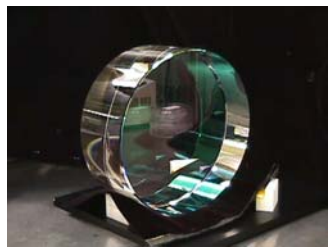




SUBR Science Focus, cont.

SUBR Physics Objective:

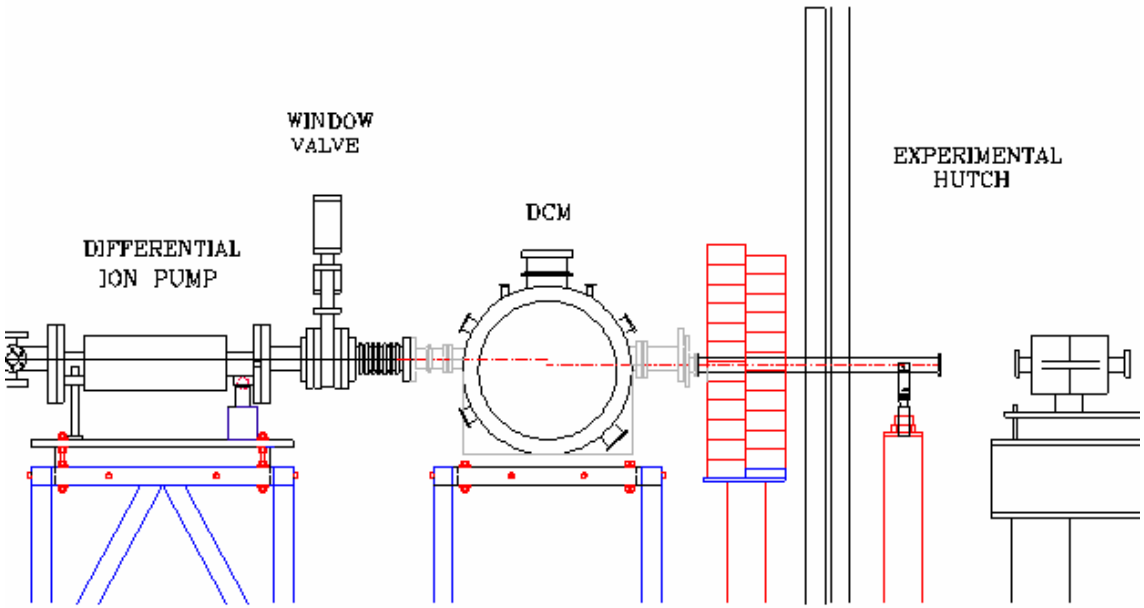
Obtain physical correlations between chemical impurities and/or dopants (Ti, Cr, Fe, Co, etc.) and optical absorption characteristics of **materials** under consideration for use as **test masses** and **optical coatings** in advanced LIGO.

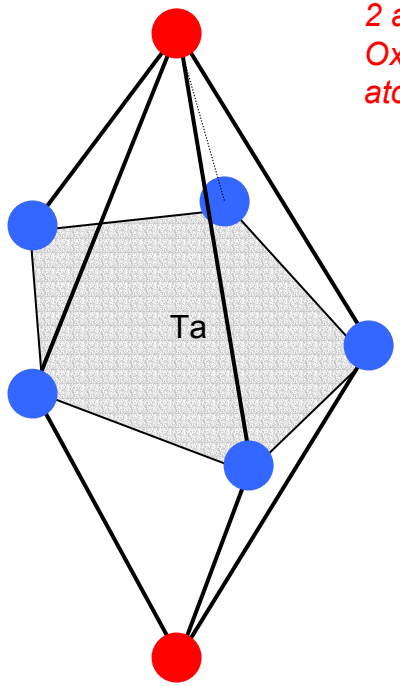


Current Focus:

Composition and chemical structure of titania (TiO_2)-doped multilayer (SiO_2/Ta_2O_5) mirror coatings.

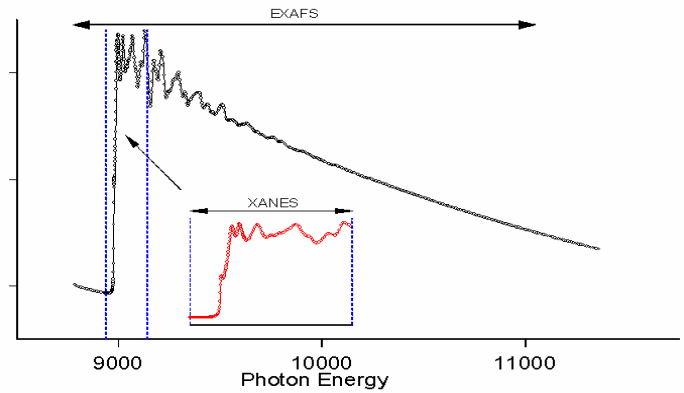
EXAFS and XANES at CAMD



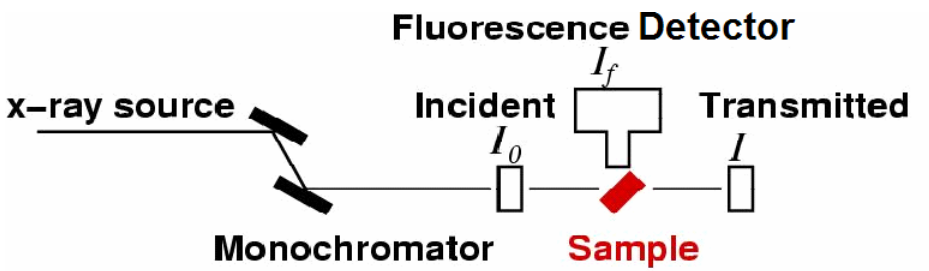


2 axial Oxygen atoms

4 in-plane Oxygen atoms



13 element Ge photon detector array



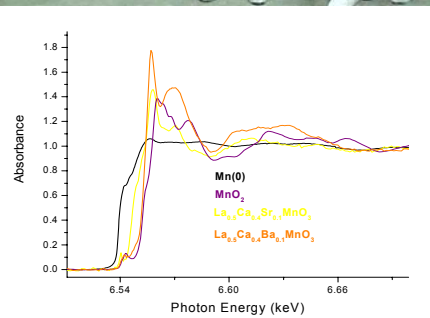
Research and Teaching

"X-ray absorption in high purity synthetic Al_2O_3 and $LaMnO_3$ -based materials"

Alex Harvey, Jr., Shelli Pace,
Laurence L. Henry and Stephen C. McGuire
Department of Physics
Southern University and A&M College,
Baton Rouge, Louisiana 70813
Center for Advanced Microstructures and Devices (CAMD)
2001 Annual Report, p. 81.

"The effects of thermal insulation due to isolation in seismic vaults"

Keisa Williams Mathis
LIGO Advisor: S. Marka
***Southern University* Honors College Thesis**
Southern University and A&M College,
Baton Rouge, LA 70813
May 2001

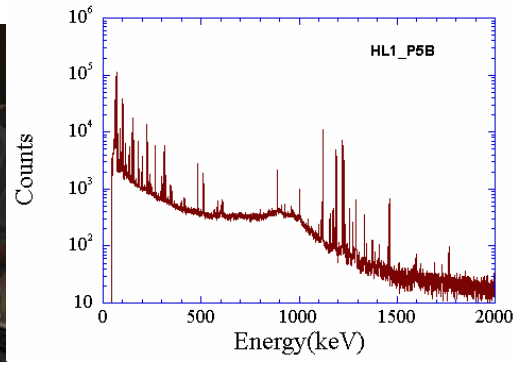


Research and Teaching

"Gamma-ray spectroscopy: modern physics aspects of gamma-ray measurement and detection"

Anthony R. Pullen

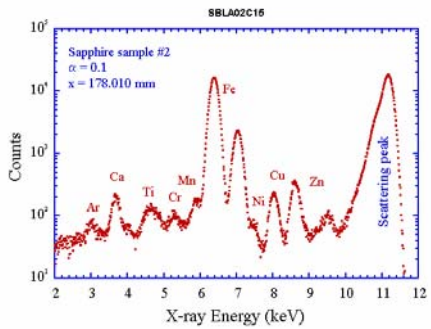
Honors Option in Physics 271, ***Modern Physics, Spring 2002.***
Southern University Honors College Report
Southern University and A&M College, Baton Rouge, LA 70813



Surface trace element characterization of synthetic single crystal Al_2O_3 at the SSRL*

S. C. McGuire[1], **M. J. Baham[1], E. Preddie[1],**
S. Brennan[2], K. Luening[2], P. Pianetta[2] and A. Singh[2]
[1]*Southern University and A&M College, Baton Rouge, Louisiana 70813*
[2]*Stanford Synchrotron Radiation Laboratory, Stanford University, Stanford, CA 94309*

* **Synchrotron Radiation Instrumentation: Eighth International Conference**, edited by T. Warwick et al., **AIP Conference Proceedings**, **No. 706**, 1182-1185 (2004).



LIGO Research Participation

SOUTHERN UNIVERSITY And Agricultural & Mechanical College

Cacey S. Stevens

California Institute of Technology
MURF Summer Intern 2006

Mentor: Eric Black

"Thermal Noise Interferometer Test Mass Coating Studies"

CALTECH

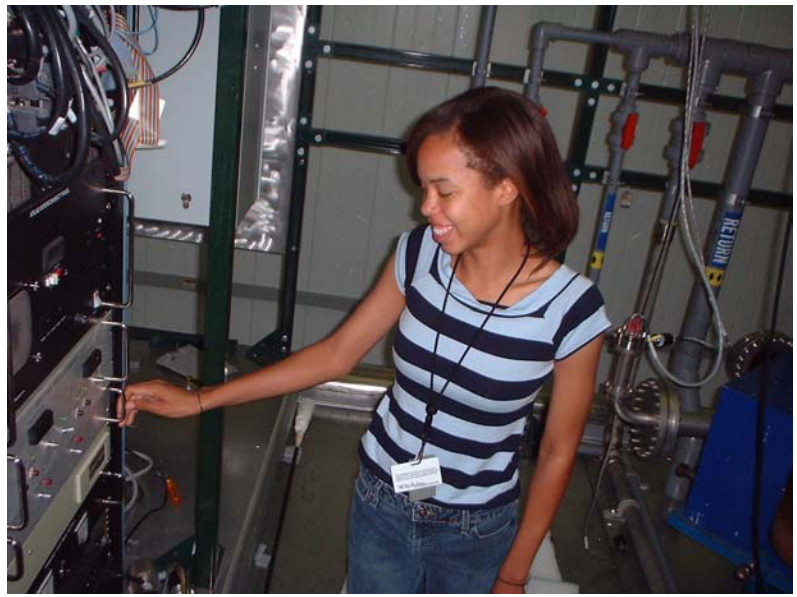


Photo courtesy of Argonne National Laboratory (DOE).

APS physics

American Physical Society
Minority Undergraduate Scholarship
Award Winner 2005-2007

LIGO Science Education Center Partnership

"Using Exhibit-Based Teaching and Learning to Enhance Science Literacy"

MISSION

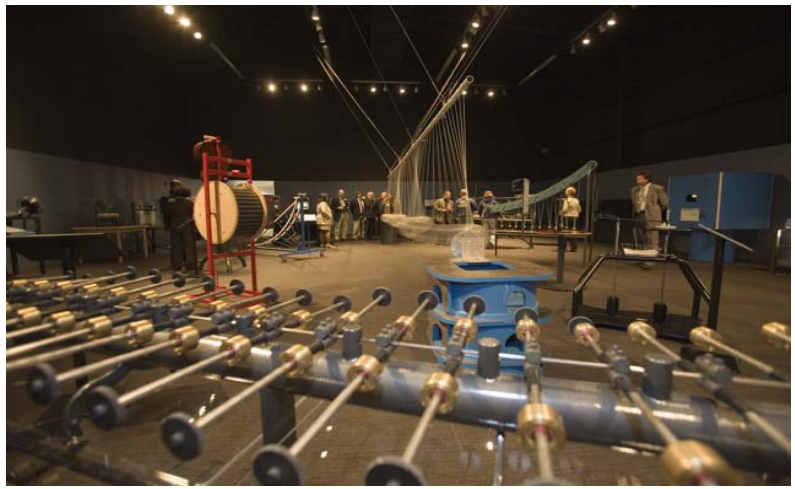
- To develop a Center at the LIGO Livingston Observatory (LLO) equipped with hands-on exhibits in LIGO-related science.

- To integrate the LLO Center, its exhibits and activities, into pre-service and in-service education at Southern University Baton Rouge (SUBR).

LIGO Outreach

LIGO Science Education Center (SEC)

"Using Exhibit-Based Teaching and Learning to Enhance Science Literacy"



LIGO Science Concepts

WAVES
Bells
Echo Tube
Theremin
Turn Off the Sky (giant polarizer)
Vibrating String (SUBR)
Water Waves
Wave Machine (suspended type)
Wave Propagation Device
Wave Upon Wave

WAVE PROPAGATION
Doppler Effect
Sound Spectrogram
Walking Beats
Watch Dog

RESONANCE
Pendulum Snake
Pendulum Table
Resonant Pendulum
Resonant Rings
Resonator (SUBR)
Ultraviolet Greenhouse

INTERFERENCE
Bridge Light
Interference Patterns
Long Path Diffraction (SUBR)
Michelson Interferometer
Soap Film Painting
Soap Films

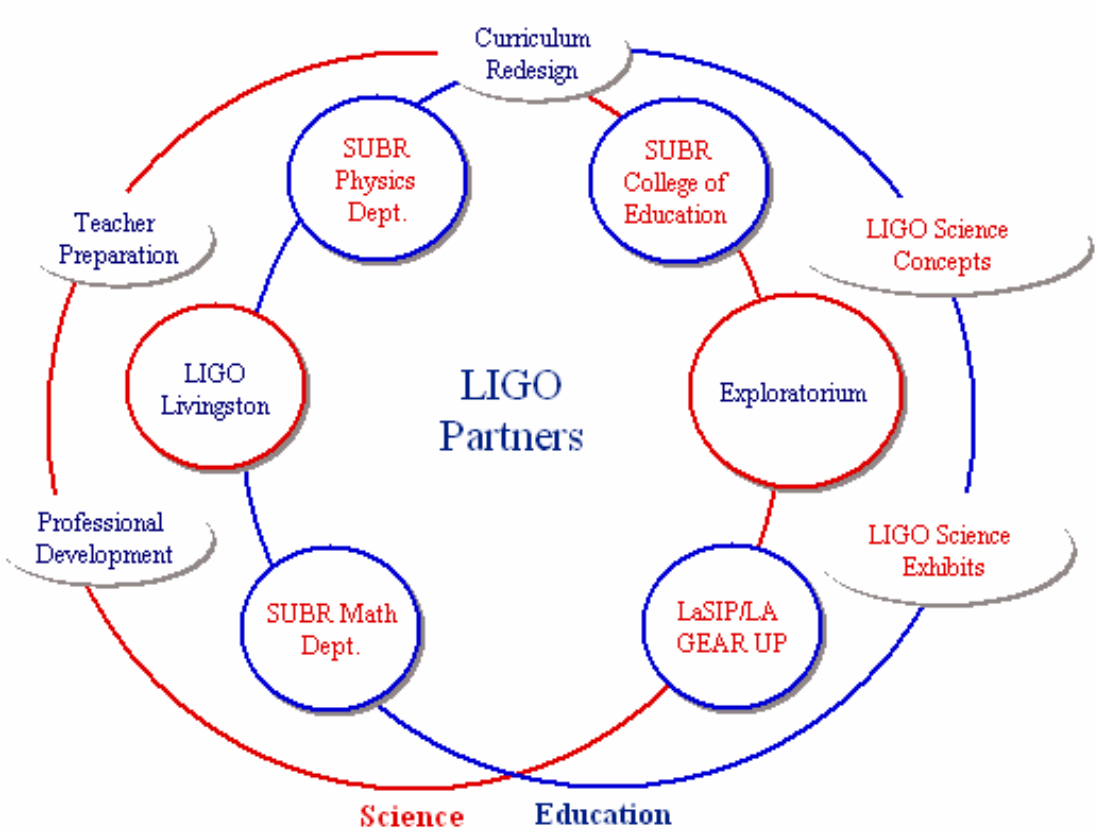
GRAVITY
Balancing Stick
Bouncing Ball
Center of Gravity
Falling Feather
Gravity Well
Gravity's Rainbow
Satellite Orbit Simulator (SUBR)

LASER AND LIGHT
C – The Light
The Light Island (SUBR)
Hologram Stuff
Inverse Square Law Model
LASER Demonstration
Spectra
Zeemann Effect

SUBR Project Goals

- The overall goal of the LIGO educational outreach project is increasing the number of certified middle and high school physical science teachers.
- Provide LIGO science professional development to in-service and pre-service teachers.
- Significantly enrich K -12 education with LIGO science concepts.
- Increase student learning gains in LIGO science.

LIGO Science Education Partners



SUBR LSC PHYSICS GROUP

S. C. McGuire
E. E. Doomes
L. L. Henry
R. B. McNair
I. Anderson
M. P. Smith

PROJECT MISE

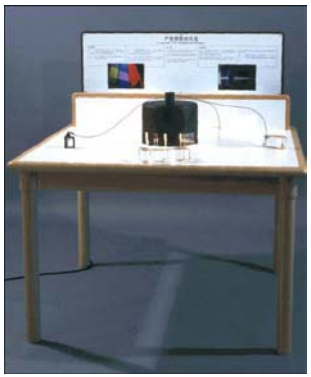
(Modeling Inquiry-Based Science Education)

J. Meyinnsse
L. Stubblefield
B. Remble
R. Peters

LIGO Outreach

A Standards-based Approach

Exploratorium Exhibits



SUBR Physics Course Inclusion

Interference	Short Description	Elements of Physics I&II,	Links to LIGO and LA Science Framework Benchmarks
Bridge Light	Monochromatic interference demonstrated	General Physics I&II,	PS-E-C2,PS-M-C4
Interference Patterns	Young's double slit experiment showing wave nature of light	Earth Science II	models basic concepts of interferometer...PS-E-C2,PS-M-C4
Long Path Diffraction	Patterns produced as a product of diffraction	General Physics I&II,	PS-E-C2,PS-M-C4
Michelson Interferometer	Mixing monochromatic waves	General Physics I&II,	models the big interferometer
Soap Film Painting	Visible light interference demonstrated	General Physics I&II,	PS-E-C2,PS-M-C4
Soap Films	Visible light interference demonstrated	Elements of Physics I&II,	PS-E-C2,PS-M-C4

LIGO Outreach

In-service teacher preparation

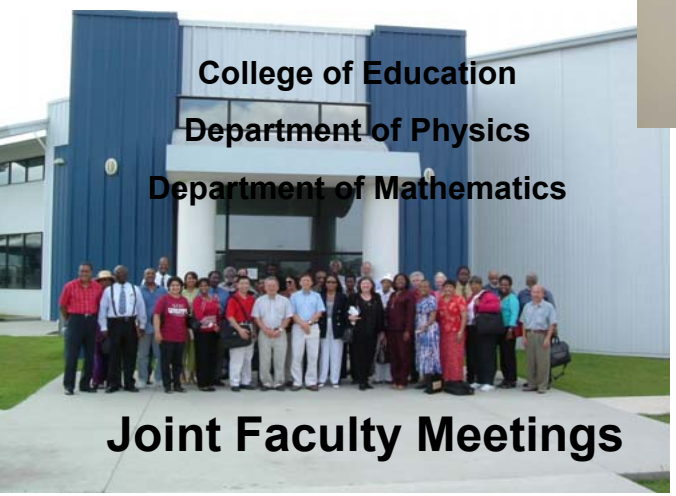

SUBR Inquiry Workshop


MISE Workshop at LLO

College of Education

Department of Physics

Department of Mathematics


Joint Faculty Meetings


SUBR Inquiry Workshop

Ongoing Activities

- Successful implementation of a program of research-based trace element measurements for advanced LIGO optics.
- Application of imaging methods to losses in coatings on fused silica in progress; Based upon atomic force microscopy.
- Physics, Mathematics and Education revisions to syllabi and integrated visits to the SUBR LIGO Science Hall and LIGO SEC.
- LIGO scientist/SUBR faculty collaborations in progress .
- Year-round SUBR Professional Development Workshops (MISE).

SUBR LIGO EDUCATIONAL OUTREACH TEAM

Mildred R. Smalley, Principal Investigator
Vice Chancellor for Research

Ivory L. Toldson, Project Director
College of Education

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Carolyn Person, Director of E-Learning; College of Education

Ken Ford, Graduate Assistant, Science and Mathematics Education Ph.D. Program

For more information see…..

LIGO Web site: http://www.ligo.caltech.edu
See for example: **Einstein's Messengers Video**

LIGO Science Education Center: http://www.ligo-la.caltech.edu

Southern University LIGO Web site: http://ligoscience.subronline.net

Einstein@home: http://einstein.phys.uwm.edu/
http://www.einsteinathome.org/

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