Optical Simulations and Upgrade Efforts for the LIGO 40m IFO and Cooperation with Neutrino Observatories on Supernovae Observations

A Proposal to the NSF by
The California State University Dominguez Hills
Elementary Particles and Relativity Group

December 12, 2000, at LIGO Ninth PAC Meeting

by Kenneth S. Ganezer

LIGO-G000420-00-D

Members of CSUDH EPRG

Kenneth S. Ganezer	Dept. of Physics (Super-K, IMB)
William E. Keig	Dept. of Physics (part time CSUDH and full-time Compton Community College; Super-K)
Samuel L. Wiley	Dept. of Physics (Emeritus)
George A. Jennings	Dept. of Mathematics
Frederic Brulois	Dept. of Mathematics

CSUDH EPRG and Med.Apps. Of Physics; Funding

NSF PHY 9208472. Solar Neutrinos at IMB; Past

NSF PHY 9514150. Solar Neutrinos and Nucleon Decay S-K;

NSF PHY 0071656. Neutrino Oscillations, Neutrino Astronomy and Nucleon Decay at Super-Kamiokande; 7/01-7-04; Funded includes Postdoctoral Researcher.

NIH Current funding for Medical Imaging Design; 4/99-4/01

NIH S06 GM 08156-22; Pending $800K; New Med. Imaging Tech using γ-rays and CZT and acoustics and new material models of bone; start 4/01- 4/05 includes Postdoctoral Researcher.

California State University Dominguez Hills and CSU.

- 8500 on-campus students.
- 3000 students in off-campus nursing program.
- Wide Spectrum of Student groups; 63.3% females, average age of undergrads is 29 years.
- Ethnicity is about 25% Caucasian American, 30% African American, 31% Hispanic American, and 12%.
- Asian or Pacific Islander American.
- 11 Physics Majors in BS program in 2000-2001 AY; 55% Hispanic American, 35% African American
- 2.25 Bachelors Degrees per year.
- No CSUDH Physics Grad Program; But we Supervise MS Students from Nearby CSU, Long Beach.
- Caltech and CSUDH are on opposite ends o f Harbor (110) Freeway ; We are near the Southwest end of 110.
- CSU is largest Univ. System in US, trains 80% of K-12 teachers and 72% of Nurses in CA
- CSU becoming more research oriented; For example Extra-Solar planet discovery of San Fran. State, UCB, and Swiss group; Joint doctoral programs; startup money for new faculty; many new faculty new Channel Islands, Monterey Bay, and San Marcos Campuses; tidal wave of students expected in next 5 years.

CSUDH/EPRG NSF PROPOSAL CONTAINS THREE “TASKS”.

- **Optical Simulations for Upgraded Caltech 40m** IFO Including Imperfect Optics.
- **Participation in the construction of the upgraded 40m IFO**; including building at CSUDH and installation at the 40m of a Physical Environment Monitoring System (PEM).
- **Neutrino-Gravity Wave-Electromagnetic Correlations from Supernovae** in coordination with early warning networks.

Figure-1. (compiled by Lisa Goggin, Caltech Sumer 2000 SURF student). A schematic of the upgraded 40m. The lengths between various optical elements are given.
This figure also contains the beam amplitude radius at various optical elements, and their radii of curvature.

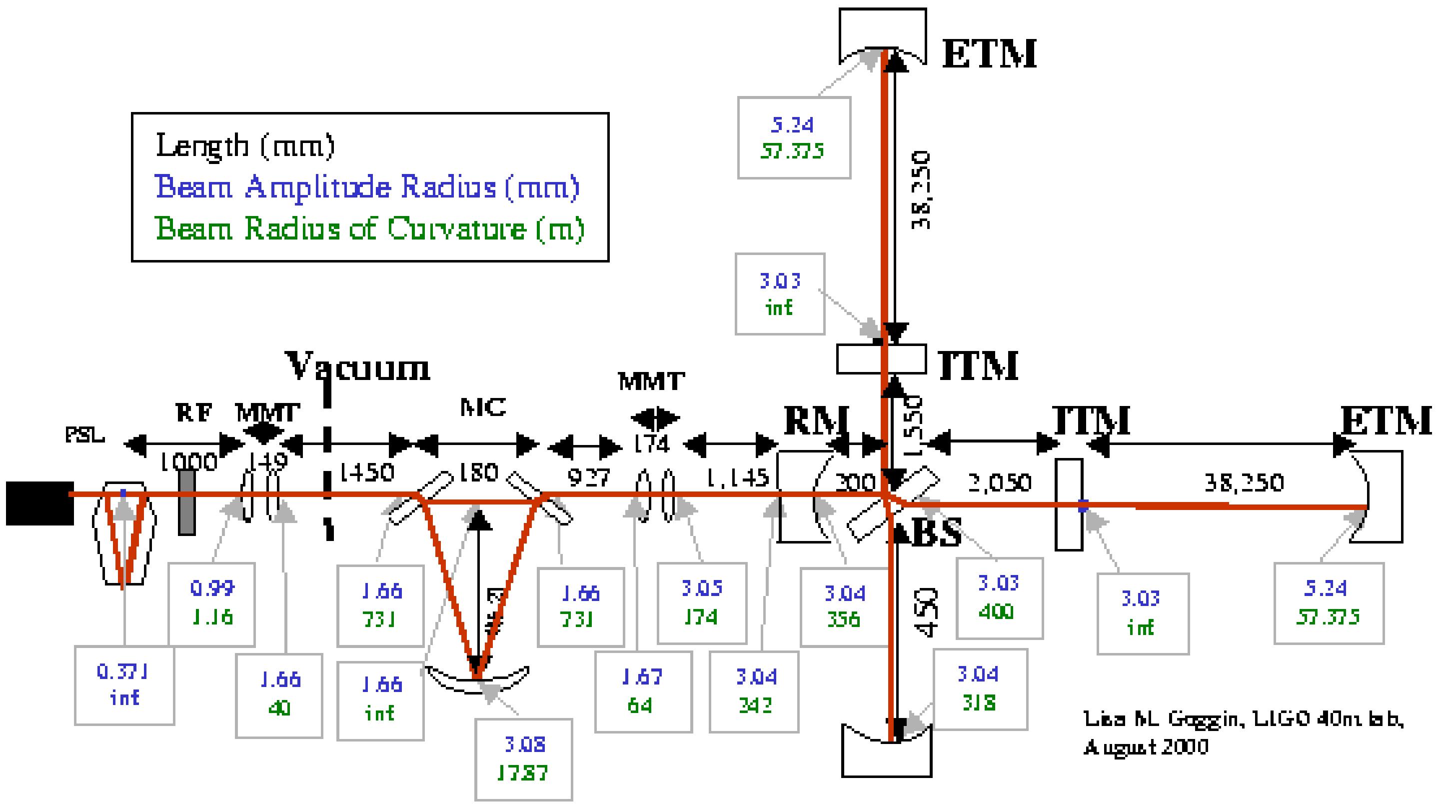


Figure-2 Noise Curves for the 40m and for LIGO II (from LIGO Document M 990288 A-M)

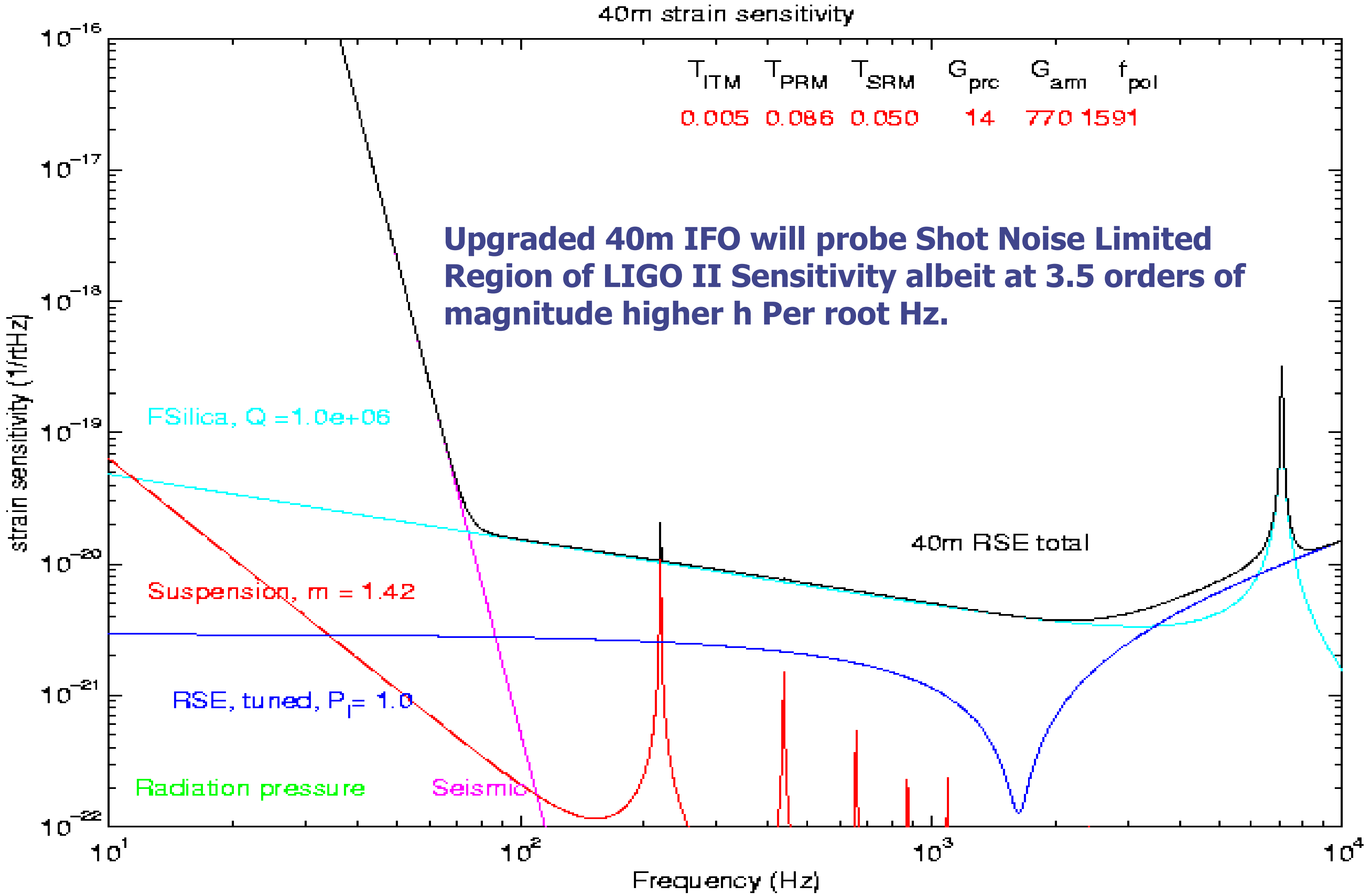


Figure-2 Noise Curves for the 40m and for LIGO II
(from LIGO Document M 990288 A-M)

LIGO II

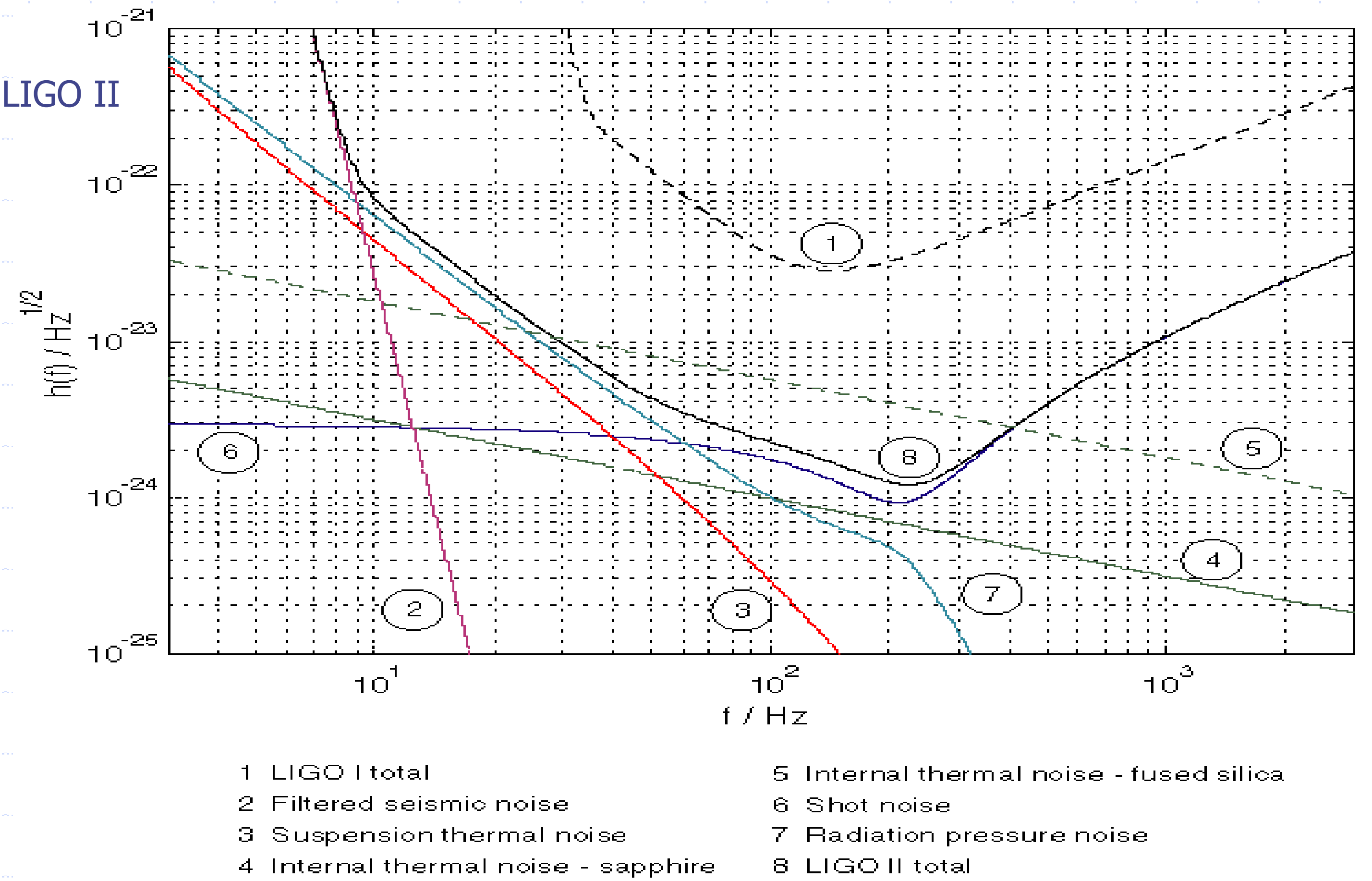


Figure 2 *Noise Anatomy of LIGO II.*

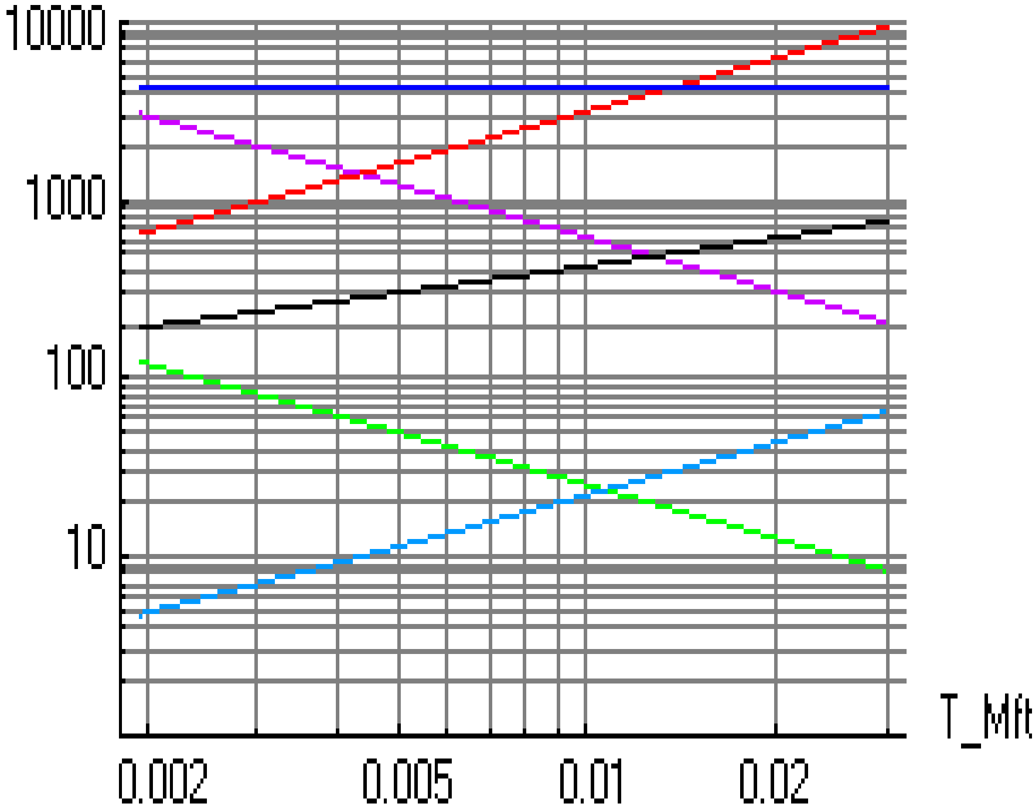
Optical Simulations for 40m

Simulations using FFT code (of Bochner and others)

- .Imperfect Optics; will involve FFT MPI code on CACR Beowulf
- RSE; Broadband and Narrowband (tuned) various schemes
- Add MC and MMT
- Thermal Effects
- GW Sidebands According to Proposed Schemes
- Sapphire Optics
- Help Caltech 40m Group to Look into Control Using Twiddle and E2E
- Model Possible Advanced LIGO Configurations

Work So Far With FFT And Near Term Plans

1. We have run the single recycling FFT mode to calculate Six parameters as a function of T_{ITM} any one of which can be used to drive design. Our results of full FFT relaxation calculation are consistent with simple analytical calculations
2. We will do similar calculations for the dual recycling upgraded 40m configuration. Have fixed minor problems with DR FFT code from repository
3. Are modifying DR FFT to run under MPI and make any modifications needed to run SR FFT under MPI.
4. Will take 4 versions of FFT; single workstation and MPI SR and DR versions and set up as single code. Different executables will be compiled under different c++ options.



Graph of Transmittivity of ITM versus finesse, τ_S, f_{pole}, Arm-Carr00, PRC- Carr00, and h(f).

Abscissa has T_{ITM}Ordinate contains the following
With various units

1. Finesse in **Purple**
2. τ_S = storage time in ms in **Green**.
3. Fpole-arm in Hz in **Red**.
4. Carrier TEM_{00} gain in in-line FP arm in **Dark Blue**.
5. Carrier TEM_{00} gain in PRC in **Bright Blue**
6. Strain sensitivity (h(f)) multiplied by 10^{24} in **Black**

Figure-3. Graphs of the Trasmittivity of the ITM versus various parameters for the 40m in a LIGO-I like configuration. These plots were obtained by the CSUDH group using FFT.

Our Role in Construction of Upgraded 40m IFO

In near future New Vacuum System, Output Chambers, PSL, 12m suspended mass mode cleaner, 4” optics, CDS control system will be installed.
In longer term new Output chamber for signal mirror, SM optics suspension, control strategy for all optical components, M-Z IFO sideband and possibly LIGO II SUS and SEI will be used.
Also a hardware prototype for LIGO-II RSE will be ready for testing by 2002

We will participate in planning and carrying out the construction.

Physical Environment Monitoring System Will be Constructed At CSUDH in Duplicate; One PEM will be installed, after Testing at Caltech 40m by CSUDH

40m PEM will Include

SUN Station with VME crate
Microphones (audible and infrasonic)
Geophones
Seismometers and Accelerometers
Magnetometers
Weather Measuring Devices

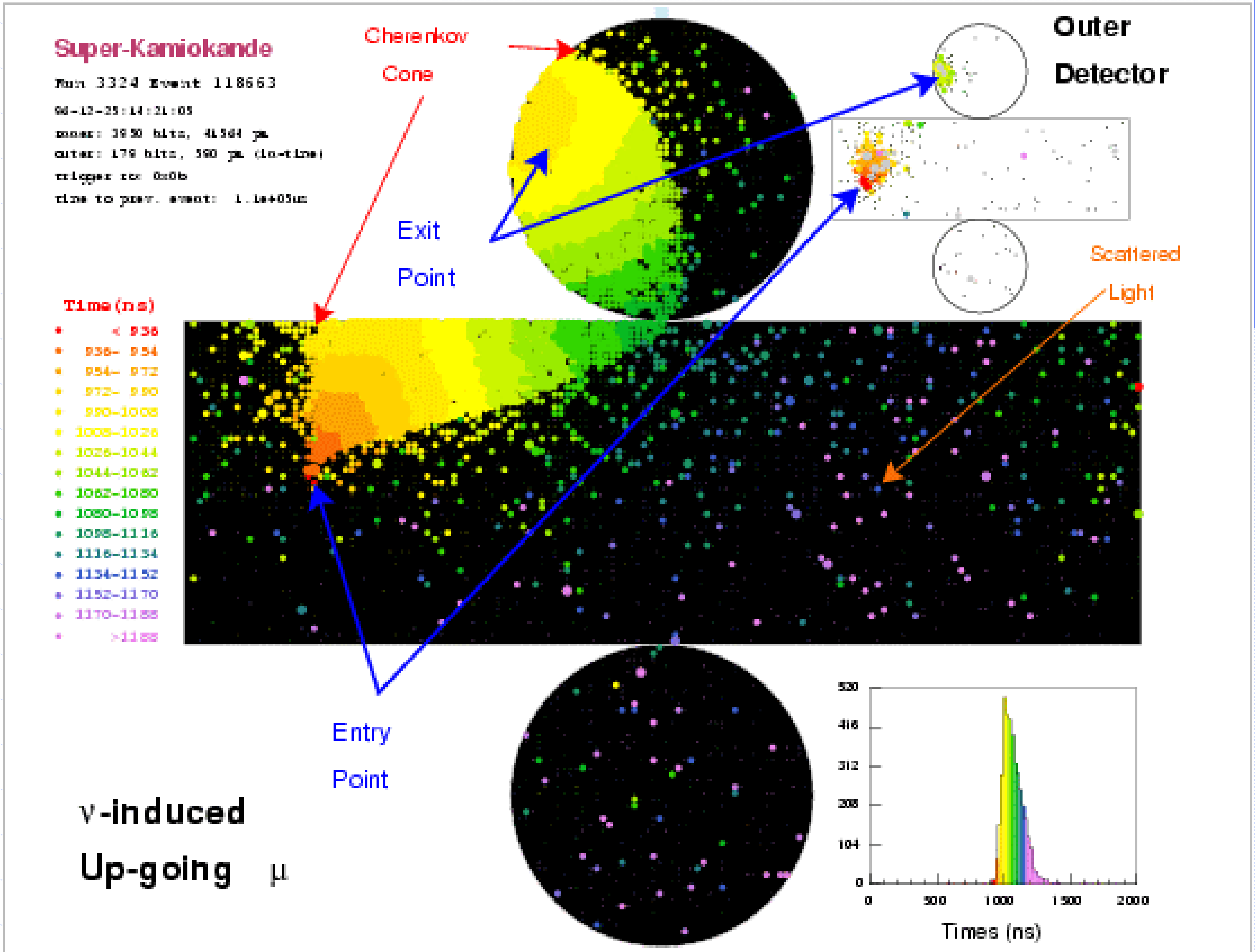
It will add to CSUDH infrastructure for Physics and Other Sciences.

Three types of neutrino experiments using natural sources may provide useful

Correlations with Gravity waves.

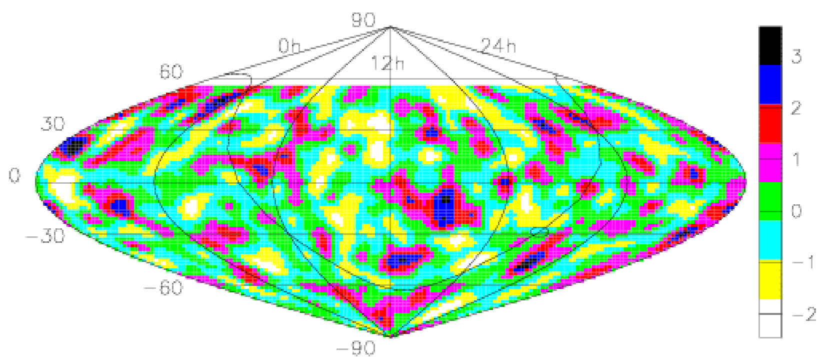
1. Low Energy (50MeV or less) from Supernovae that are usually studied in conjunction with Solar Neutrinos.
2. Studies of intermediate Energy (E< 10 GeV) Neutrinos. These Experiments are designed for atmospheric neutrinos
3. Studies of High Energy (E> 10 GeV) Upward-Stopping or Through-Going Muon (or Tau) Neutrinos.

Super-Kamiokande Studies All Three Types of Neutrinos

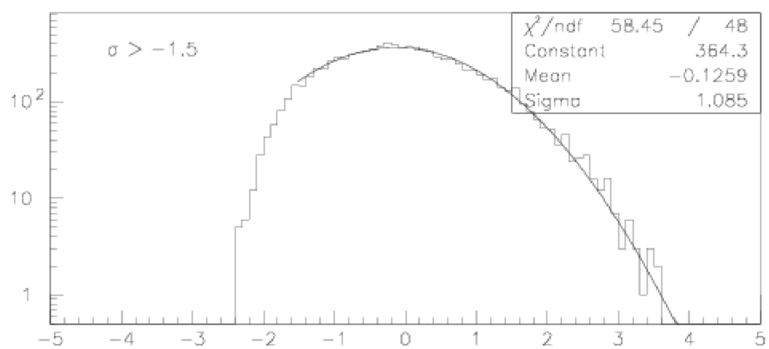

Super-Kamiokande
Run 3324 Event 118663
trigger id: 0x0b
time to prev. event: 1.1e+05us
Cherenkov
Cone
Exit
Point
Outer
Detector
Scattered
Light
Time (ns)
< 936
936- 954
954- 972
972- 990
990-1008
1008-1026
1026-1044
1044-1062
1062-1080
1080-1098
1098-1116
1116-1134
1134-1152
1152-1170
1170-1188
>1188
Entry
Point
520
416
312
208
104
0
0
500
1000
1500
2000
Times (ns)
ν-induced
Up-going μ

SK Upward-Going Muon Flux Limit

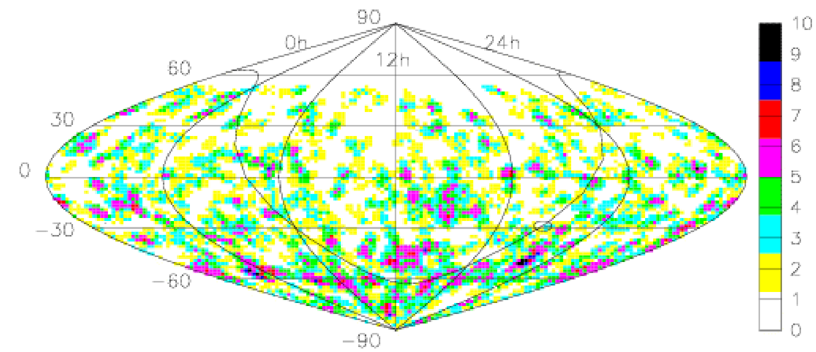
Source name	upmu observed (in 4° cone)	noise expected	Accept. (cm^2)	Flux Limit ($cm^{-2}\ s^{-1}$)
Cyg X-1	6	1.6	4.1×10^6	2.8×10^{-14}
Cyg X-3	1	1.7	3.5×10^6	1.3×10^{-14}
Her X-1	1	1.7	4.1×10^6	1.1×10^{-14}
Sco X-1	2	2.4	6.9×10^6	8.7×10^{-15}
Vela X-1	5	2.6	8.6×10^6	1.2×10^{-14}
Crab N.	0	1.5	5.1×10^6	4.8×10^{-15}
3C273	2	2.0	6.5×10^6	9.2×10^{-15}
Per A	1	1.7	3.4×10^6	1.3×10^{-14}
Vir A	1	1.7	5.7×10^6	7.8×10^{-15}
Coma cl.	2	1.4	4.7×10^6	1.3×10^{-14}
Gemminga	3	1.7	5.4×10^6	1.4×10^{-14}
G.C.	3	2.1	7.6×10^6	9.9×10^{-15}
Mrk 421	1	1.8	3.8×10^6	1.2×10^{-14}
Mrk 501	1	1.8	3.6×10^6	1.2×10^{-14}



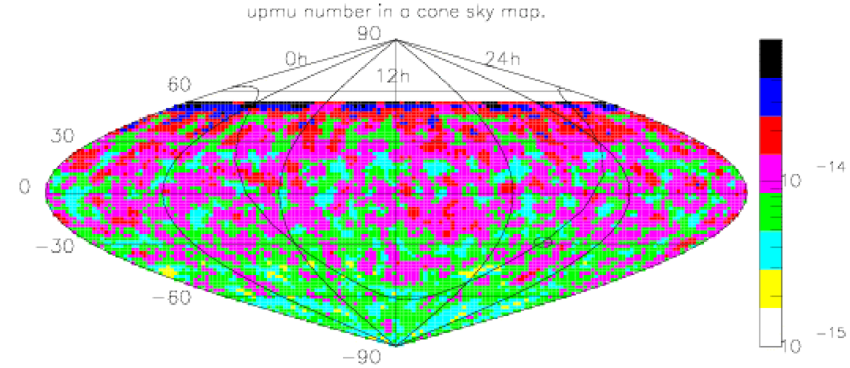
SD upmu skymap in equitorial coordinate.



weighted skymap SD distribution.



upmu number in a cone sky map.



upmu flux limit sky map (upmu, 90 % CL)

The LIGO-SNEWS (Supernova Early Warning System) Connection

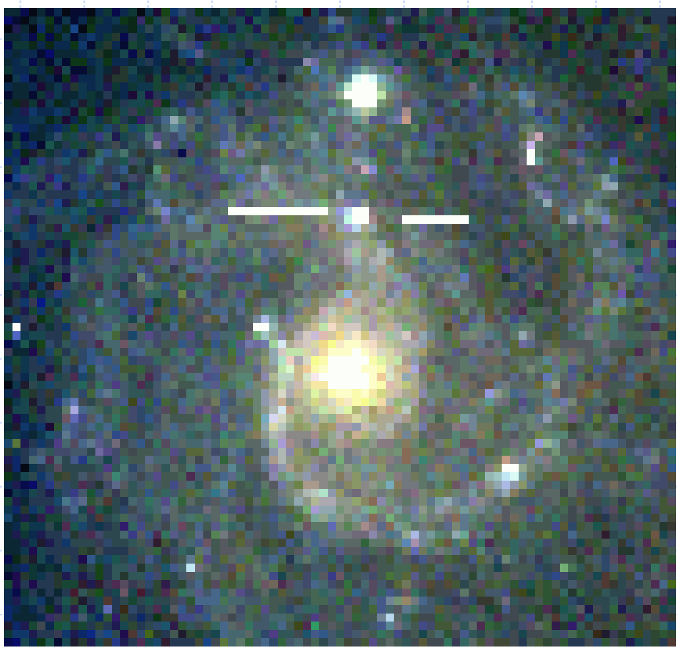
The LIGO-SNEWS group submitted a LSC Software proposal, which outlines the milestones for LIGO to receive and eventually issue SNEWS alarms.

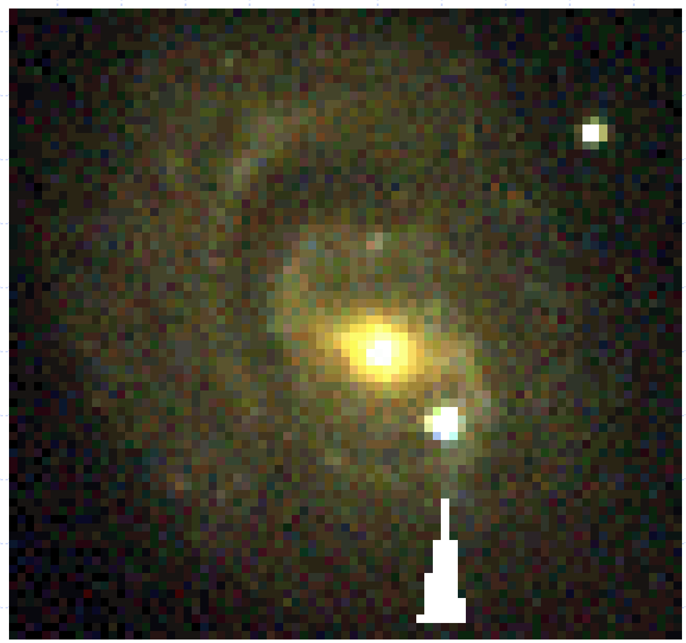
SNEWS is designed to provide much needed advance notice to optical and other supernovae sensitive observatories of a possible supernova.

Pointing is important. For an SN at 10 Kpc Super-K will detect 4400 mostly Quasi-elastic neutrino interactions. Directional Information from 200 elastic scattering interactions yields an angular resolution of 2-5 degrees. Reconstruction could be done quickly enough to provide directional information in early warning through modification of Super-K software and intra-collaboration agreements. CSUDH LCS/Super-K group will work this out.

Neutrino detectors (Super-K) are sensitive to nearly all Supernovae in the Milky Way and its Satellites including those that are optically obscured. Estimate by A. Burrows is one SN per 20 years.

Supernovae are seen by optical observers and occasionally, if nearby by neutrino telescopes





Neutrino and Gravity Wave Measurements are Complementary

Use Neutrinos to Point and Verify and Gravity Waves Eventually for Maximum Range. A "Natural" Partnership

GW detectors need verification from neutrino experiments to distinguish a real signal from possible unknown noise sources and for pointing.

Eventually GW detectors will have better filters and a longer range (50 Mpc to the Virgo Cluster and further) for SNs. There is currently a great uncertainty in the precise form and strength of an SN GW signal.

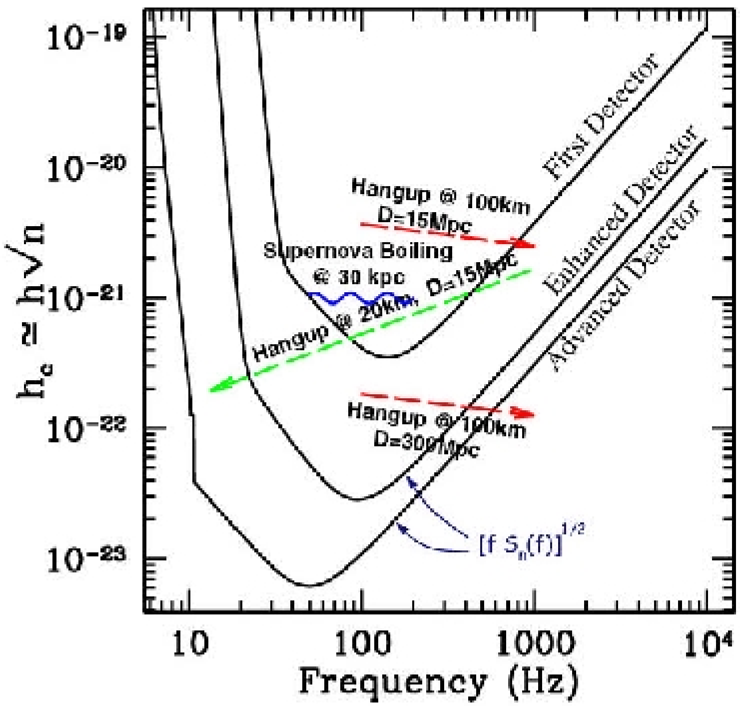
Arnaud et. al. has applied a collection of SN gw waveform envelopes and 9 different filters to create a near real-time SN trigger for VIRGO

Interferometers

astrophysical sources

SN1987A

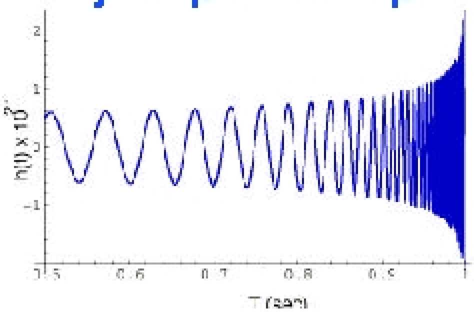
sensitivity to burst sources



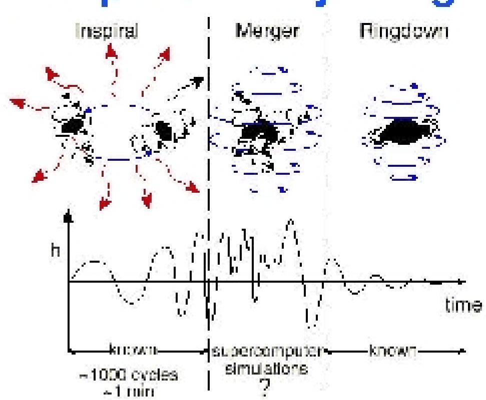
Interferometers

astrophysical sources

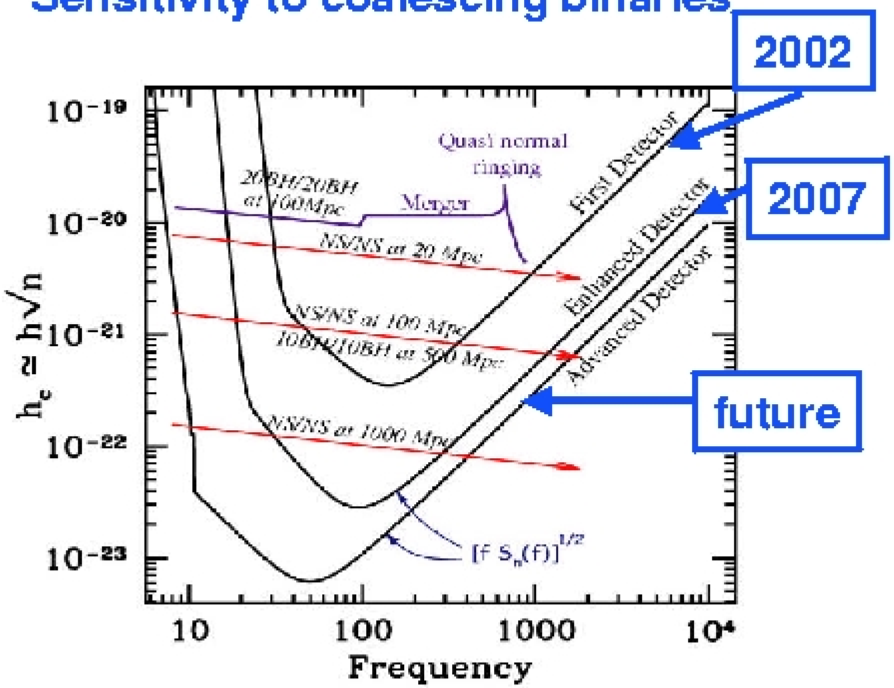
Binary inspiral 'chirp' signal



Compact binary mergers



Sensitivity to coalescing binaries



The Entry of LIGO into SNEWS has several considerations.

1. **False Alarm rates:** These are greatly reduced when coincidences are used since detector specific noise sources are highly unlikely to produce coincidences of two or more detectors. Indeed coincidences among gravity wave detectors will be used to verify detections and to reduce false alarm rates.

2. **A near real time** supernova alarm will be difficult to formulate, but there are promising techniques available.

3. Early GW detectors may have comparable range as existing neutrino detectors (Super-K can detect a SN from as far away as the Andromeda galaxy.)

Summary

Under our NSF Proposal, CSUDH Elementary Particles and Relativity Group, CSUDH/ EPRG would work on

1. Simulations for the upgraded 40m.
2. Participation in Construction of the upgraded 40m including Responsibility for 40m PEM
3. Correlating Neutrino and GW measurements. In particular correlations between Super-K, SNEWS, and LIGO.