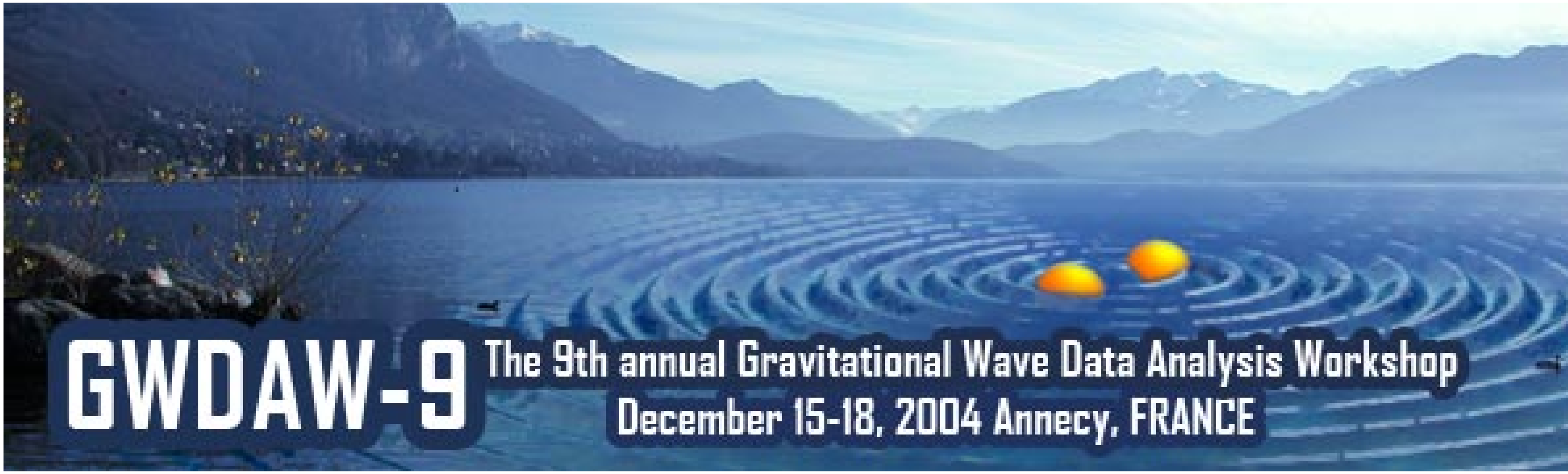

Summary of GWDAW

(Gravitational Wave Data Analysis Workshop)

Shourov Chatterji
Albert Lazzarini
Peter Shawhan
Patrick Sutton

LIGO Seminar
January 4, 2005

LIGO-G050001-02-E
(Continued in LIGO-G050003-00-Z)

Overview of GWDAW

Annual conference devoted to gravitational wave data analysis

- Originally a true workshop
- Now more like a regular conference
- ~140 participants this year

Past locations:
1996: Boston, USA
1997: Orsay, France
1998: State College (PA), USA
1999: Rome, Italy
2000: Baton Rouge, USA
2001: Trento, Italy
2002: Kyoto, Japan
2003: Milwaukee, USA

Held this year in Annecy, France

- Hosted by:

lapp — Laboratoire d'Annecy-le-vieux de Physique des Particules

Location


Paris
Marne-la-Vallée
Metz
Nancy
Karlsruhe
Pforzheim
Stuttgart
Strasbourg
Reutlingen
Ulm
Freiburg
Germany
Orléans
Mulhouse
Basel
Dijon
Besançon
Zürich
Vaduz
Bern
France
Lausanne
Switzerland
Genève
Clermont-Ferrand
Lyon
Villeurbanne
Annecy
Monza
Novara
Milano
Torino
Italy
Grenoble
Piacenza
Alessandria
Génova
Nîmes
Monaco
Castres
Aix-en-Provence
Nice
Livorno
Montpellier
Marseille
Toulon
Narbonne
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View from the Chateau

Annecy Scenes

The Program
(slightly rearranged)

Status of Ground-Based IFOs
Status of Resonant Detectors
Sources for Ground-Based Detectors
Detector Characterization
Tools for simulation, etc.
→ Peter (in this file)

Current Searches – **Stochastic**
Current Searches – **Inspiral**
→ Albert (in this file)

Poster Preview Session
Poster Viewing, with wine and cheese

Current Searches – **Pulsar**
Current Searches – **Bursts**
→ Shourov (in this file)

Multi-Detector Analysis
New and Improved Analysis Methods
Sources for Space-Based Detectors
LISA Data Analysis
→ Patrick (see LIGO-G050003-00-Z)

Slides available at http://lappweb.in2p3.fr/GWDAW9/Program.html

Status of Ground-Based Interferometers

Status of Virgo – Lisa Barsotti

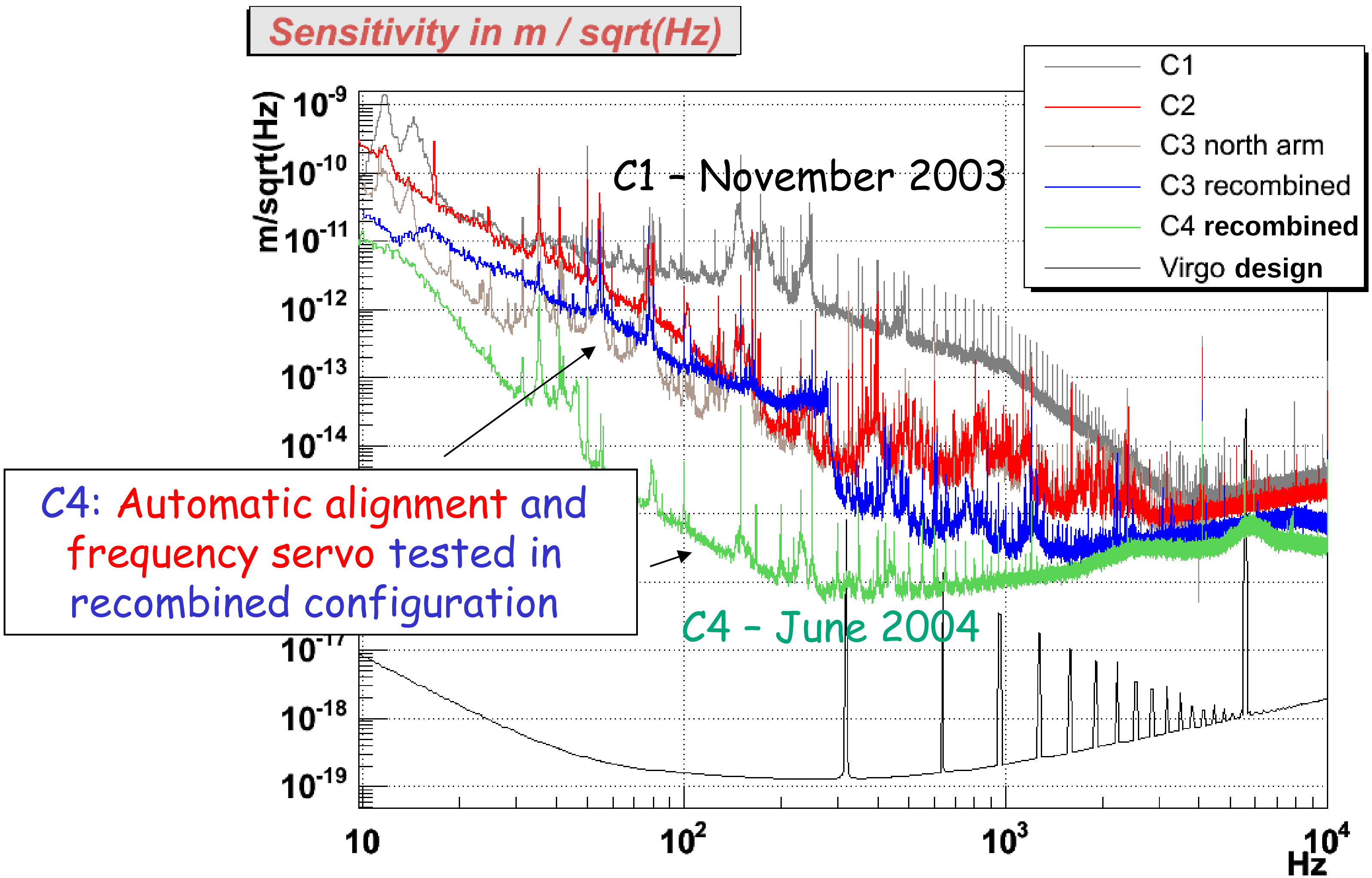
Status of TAMA data analysis – Masaki Ando

Status of LIGO – Peter Shawhan

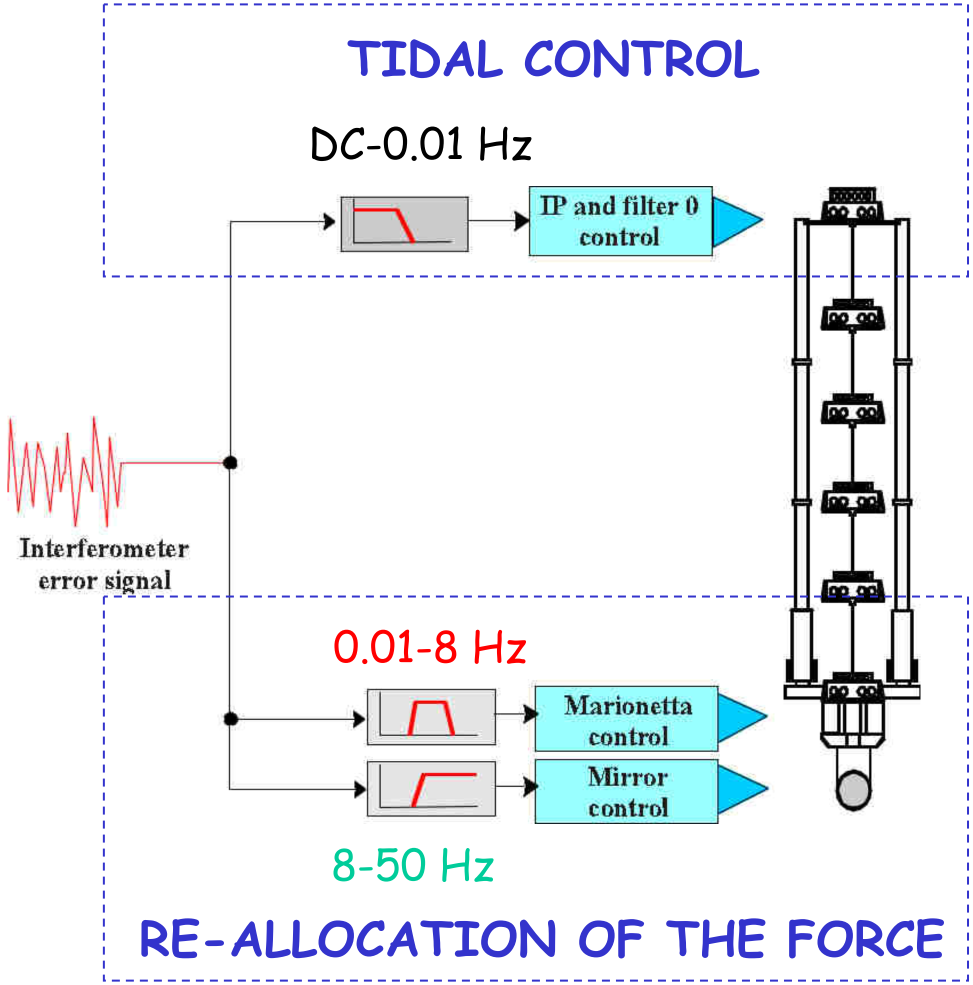
Status of GEO600 – Martin Hewitson

Sensitivity Progress

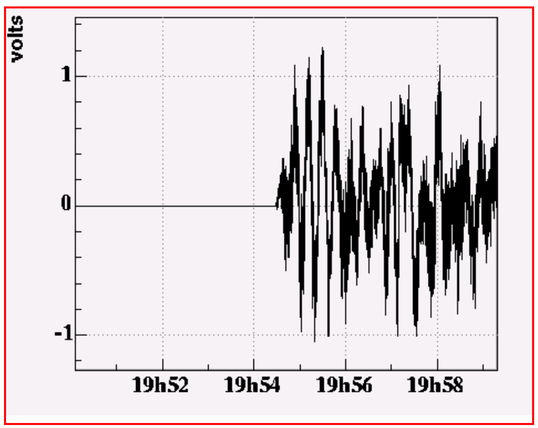
- *From a single arm to the recombined mode*



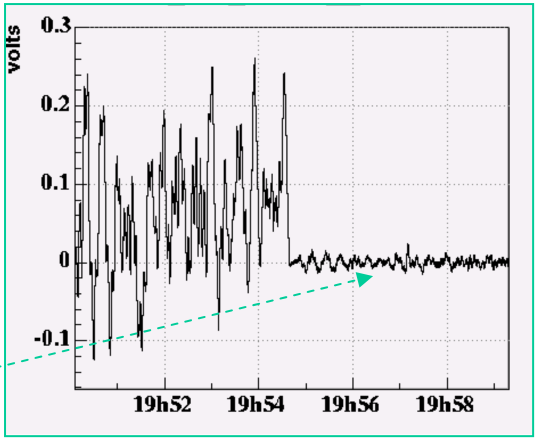
Suspension Hierarchical Control



Corrections sent to the marionette



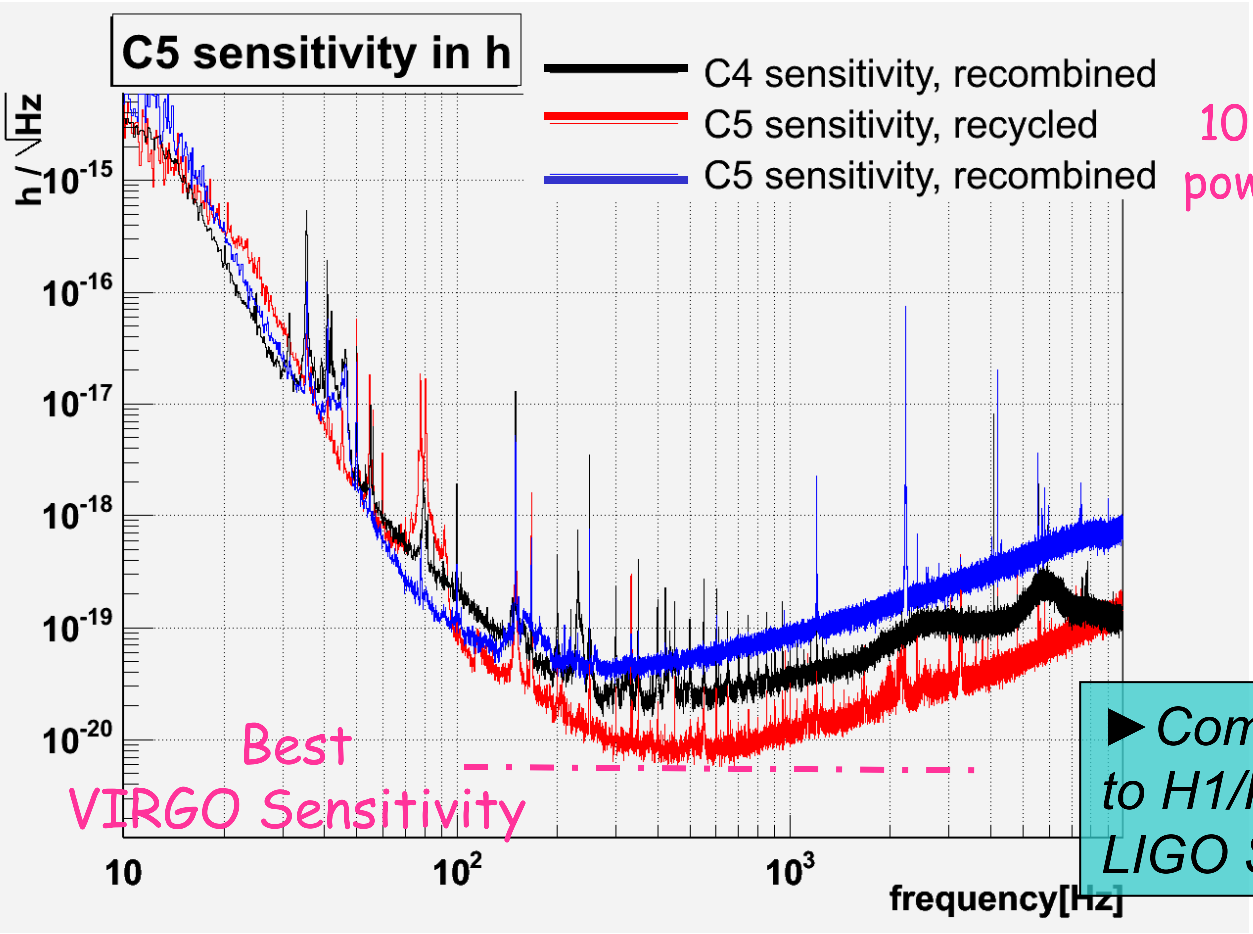
Corrections sent to the mirror



Force on the mirror reduced of a factor 20

- Switch to low noise coil drivers

Commissioning Run C5 - December 2004



10 times less power than C4

► *Comparable to H1/H2 during LIGO S1 run*

TAMA Data taking
- Observation runs -

TAMA observation runs

Data Taking		Objective	Observation time	Typical strain noise level	Total data (Longest lock)
DT1	August, 1999	Calibration test	1 night	3×10^{-19} /Hz $^{1/2}$	10 hours (7.7 hours)
DT2	September, 1999	First Observation run	3 nights	3×10^{-20} /Hz $^{1/2}$	31 hours
DT3	April, 2000	Observation with improved sensitivity	3 nights	1×10^{-20} /Hz $^{1/2}$	13 hours
DT4	Aug.-Sept., 2000	100 hours' observation data	2 weeks (night-time operation)	1×10^{-20} /Hz $^{1/2}$ (typical)	167 hours (12.8 hours)
DT5	March, 2001	100 hours' observation with high duty cycle	1 week (whole-day operation)	1.7×10^{-20} /Hz $^{1/2}$ (LF improvement)	111 hours
DT6	Aug.-Sept., 2001	1000 hours' observation data	50 days	5×10^{-21} /Hz $^{1/2}$	1038 hours (22.0 hours)
DT7	Aug.-Sept., 2002	Full operation with Power recycling	2 days		25 hours
DT8	Feb.-April., 2003	1000 hours Coincidence	2 months	3×10^{-21} /Hz $^{1/2}$	1157 hours (20.5 hours)
DT9	Nov. 2003 - Jan., 2004	Automatic operation	6 weeks	1.5×10^{-21} /Hz $^{1/2}$	558 hours (27 hours)

Detector improvement
- Noise hunting -

Noise investigation

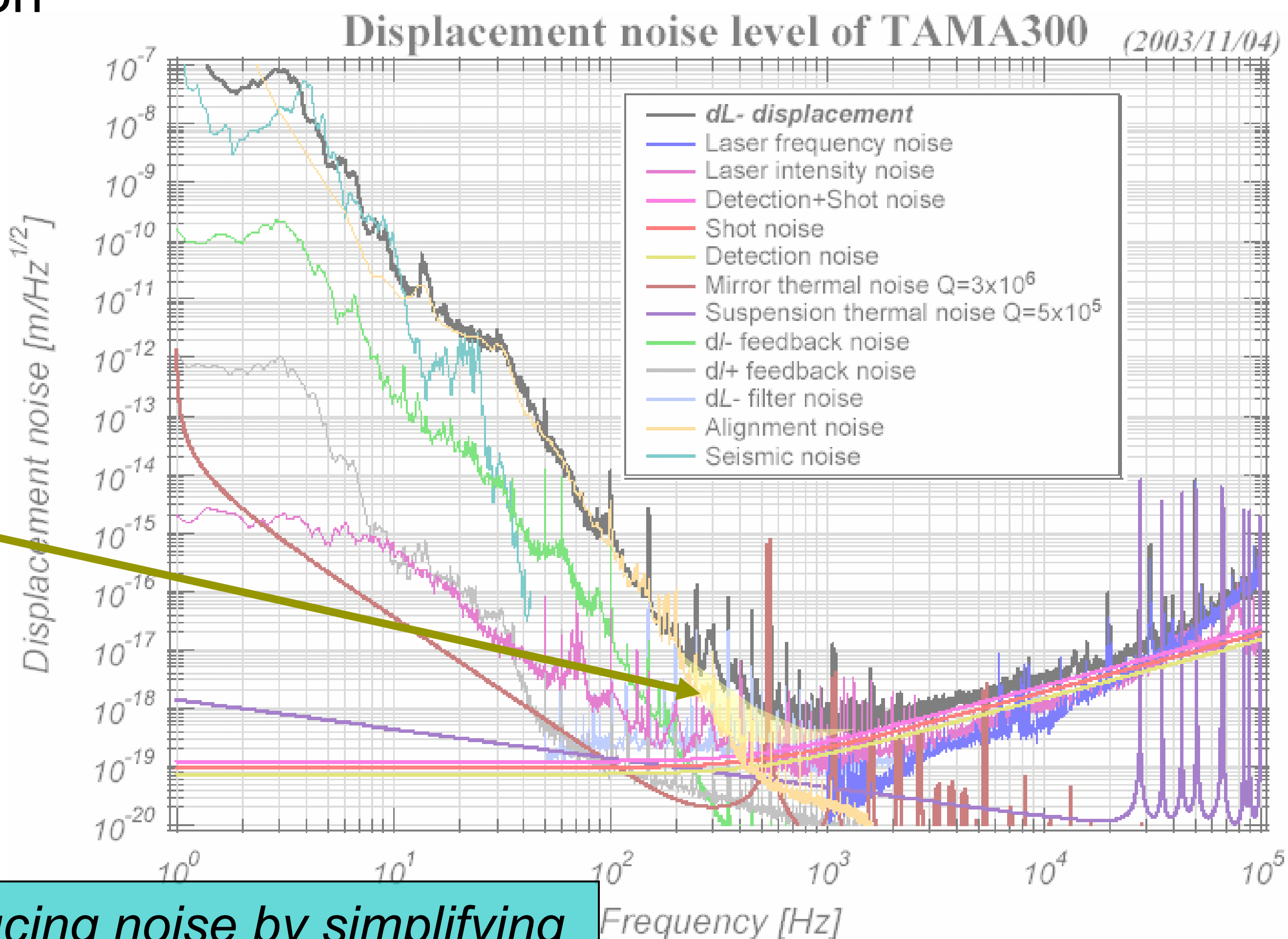
DT9 noise level

- **Seismic noise**
- **Alignment noise**
- **Shot noise**

Unidentified noise

- **Scattered light ?**
- **Beam jitter ?**
- **Laser source ?**
- **RF detection ?**
- **Electronics ?**

Noise hunting!



► *Succeeded in reducing noise by simplifying optical path, reducing scattered light*

Detector improvement
- Seismic noise reduction -

TAMA-SAS

Development for better seismic attenuation

Seismic attenuation system (SAS)

For low frequency (0.1□10Hz)

R&D with Caltech and Univ. of Pisa

Prototype test with a 3-m Fabry-Perot cavity

Expected Isolation @4Hz

10^{-8}□10^{-11} m/Hz$^{1/2}$

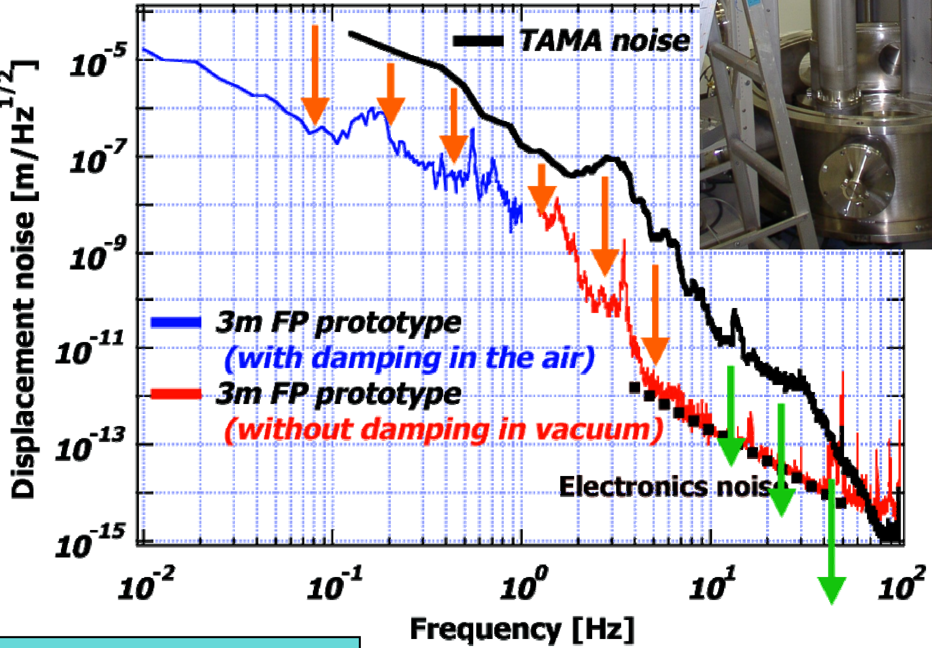
Expected RMS velocity

3.7□0.3 μm/s

Design for TAMA : fixed

Main parts : delivered

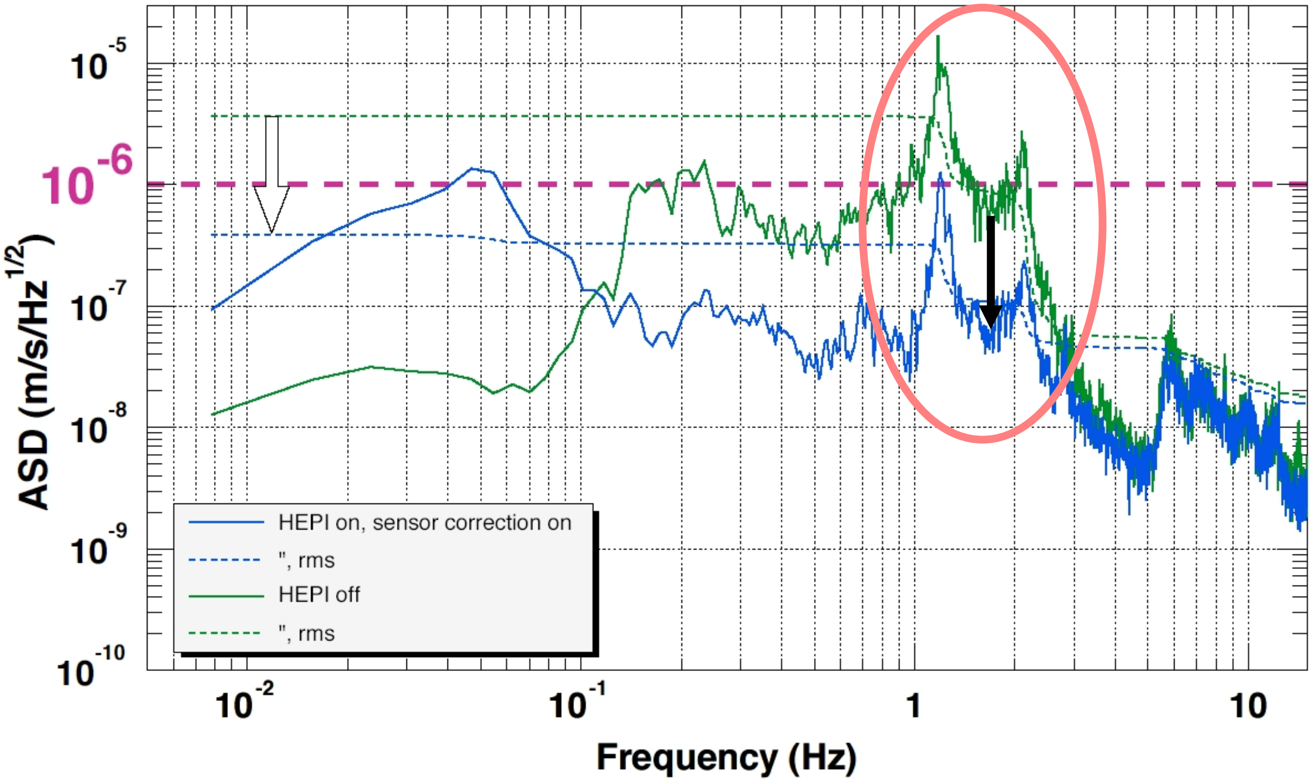
Installation in 2005



► *Will improve sensitivity at low frequency*

Active Seismic Isolation at LLO

Achieves factor of 10 reduction in the crucial frequency band and in overall rms motion



Can lock (and do commissioning work!) during daytime
Able to stay locked even when train passes nearby

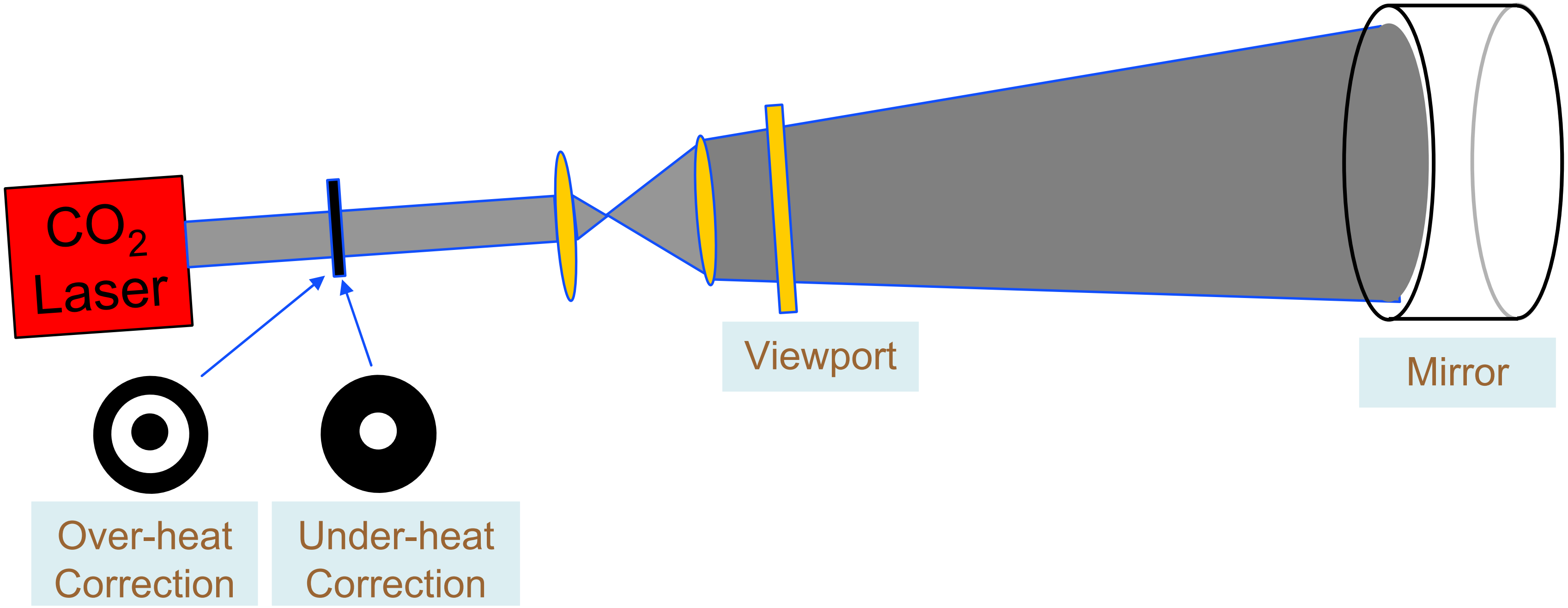
High-Power Operations at Hanford

Tuned up H1 laser to deliver 10 W

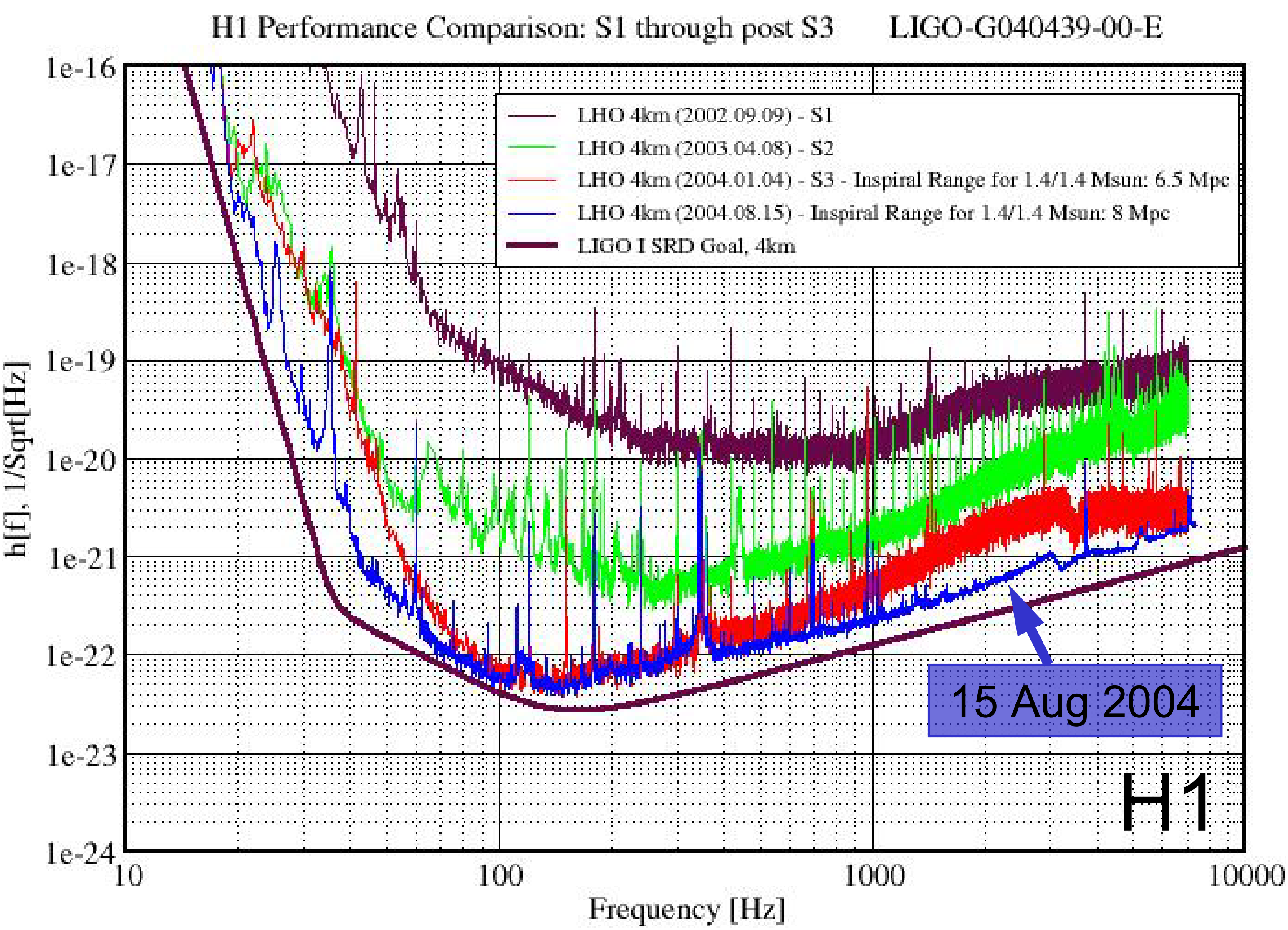
Use multiple photodetectors to handle increased light

Compensate for radiation pressure in control software

Correct thermal lensing by heating mirrors



Pushing the Sensitivity Envelope



LIGO-G050001-02-E

Operations Plan for 2005

Finish re-commissioning L1

Reach a stopping point in incremental improvements to H1

Duplicate some H1 improvements on L1 and H2

Engineering run E12

Science run S4

► *GEO will run at same time; probably TAMA too*

- Scheduled to start on February 23 and run for 4 weeks
- Performance goals: modest improvements over current best sensitivities; high duty factor for L1

Several months of commissioning

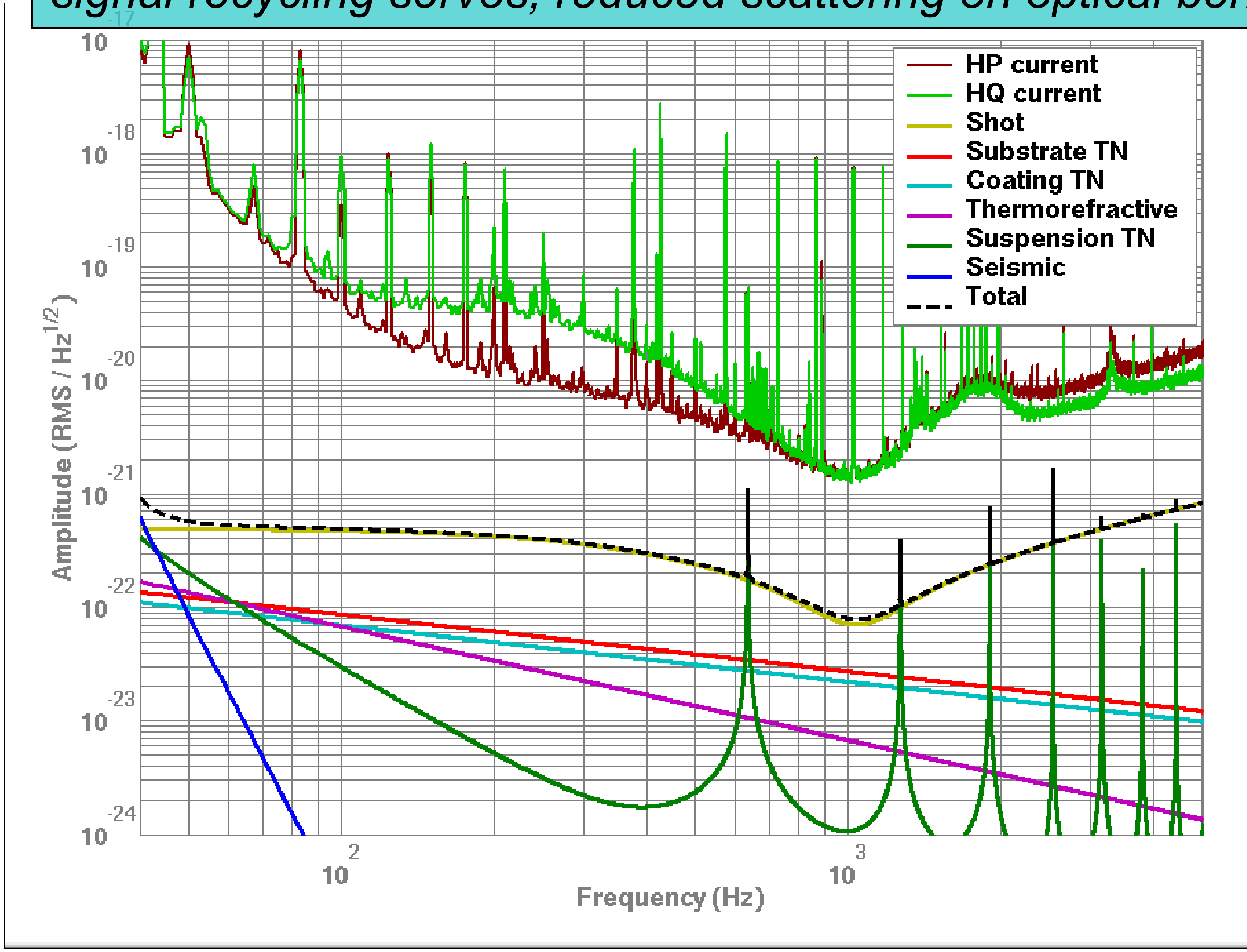
- Duplicate rest of H1 improvements on L1 and H2; improve duty factors

Science run S5

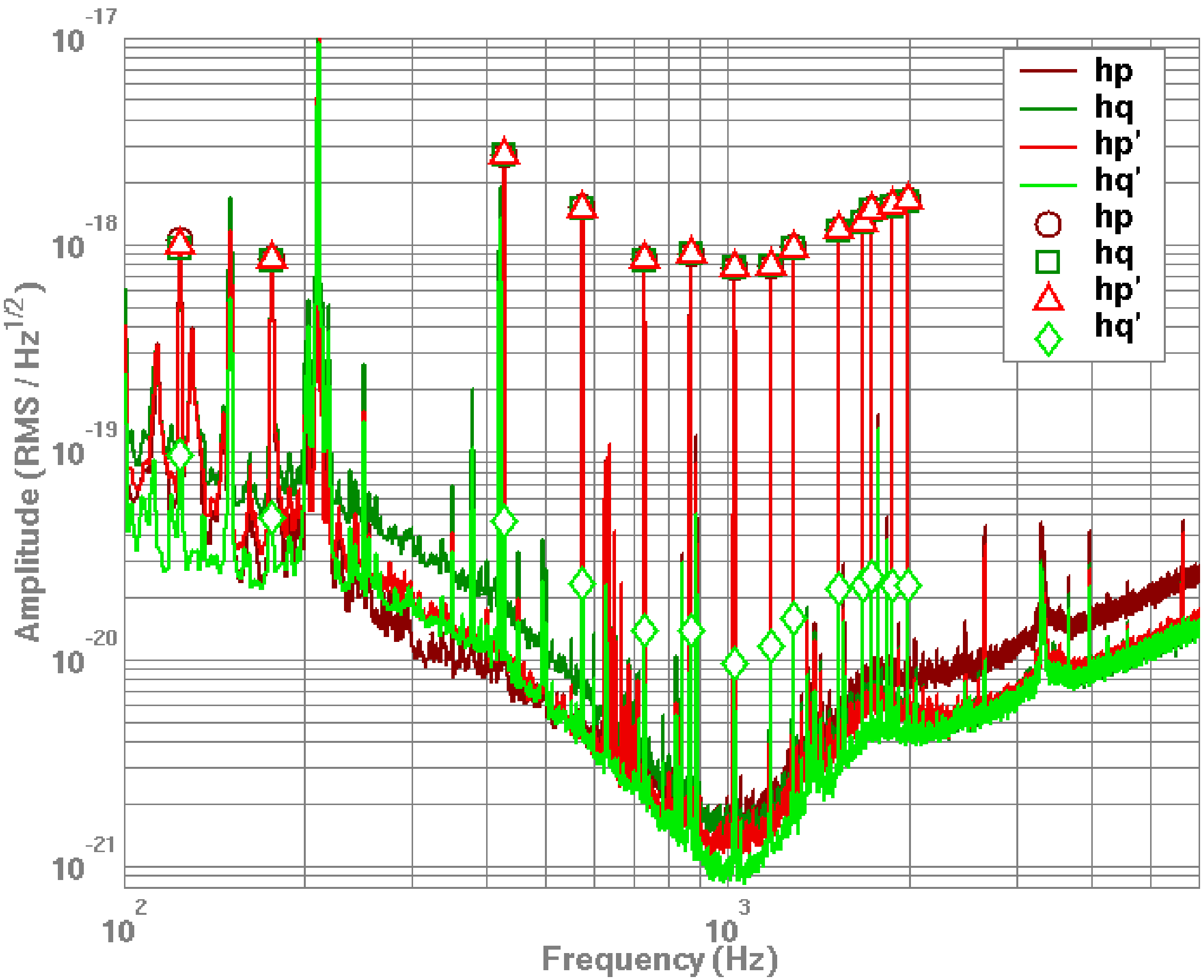
- Plan to start in the latter half of 2005
- Plan to run for extended period at design sensitivity for all 3 interferometers

Current GEO sensitivity

► *After improvements to high-power photodiode, Michelson and signal recycling servos, reduced scattering on optical bench*



Combining HP and HQ - result



► *Working out how to combine P and Q quadratures*

Simple combination:

HP' = (HP+HQ)/2
HQ' = (HP-HQ)/2

Look at calibration lines

HQ' contains almost no signal compared to HP'

Useful diagnostic for noise hunting (?)

Status of Resonant Detectors

Status of the ALLEGRO detector – Warren Johnson

Status of the AURIGA detector – Giovanni Prodi

Status of EXPLORER and NAUTILUS – Massimo Visco

ALLEGRO observing this year

(Had trouble with cryogenics in 2002 and 2003.)

Latest attempt at a fix was finished Dec 2003.

Worked! Running continuously since Feb 13, 2004.

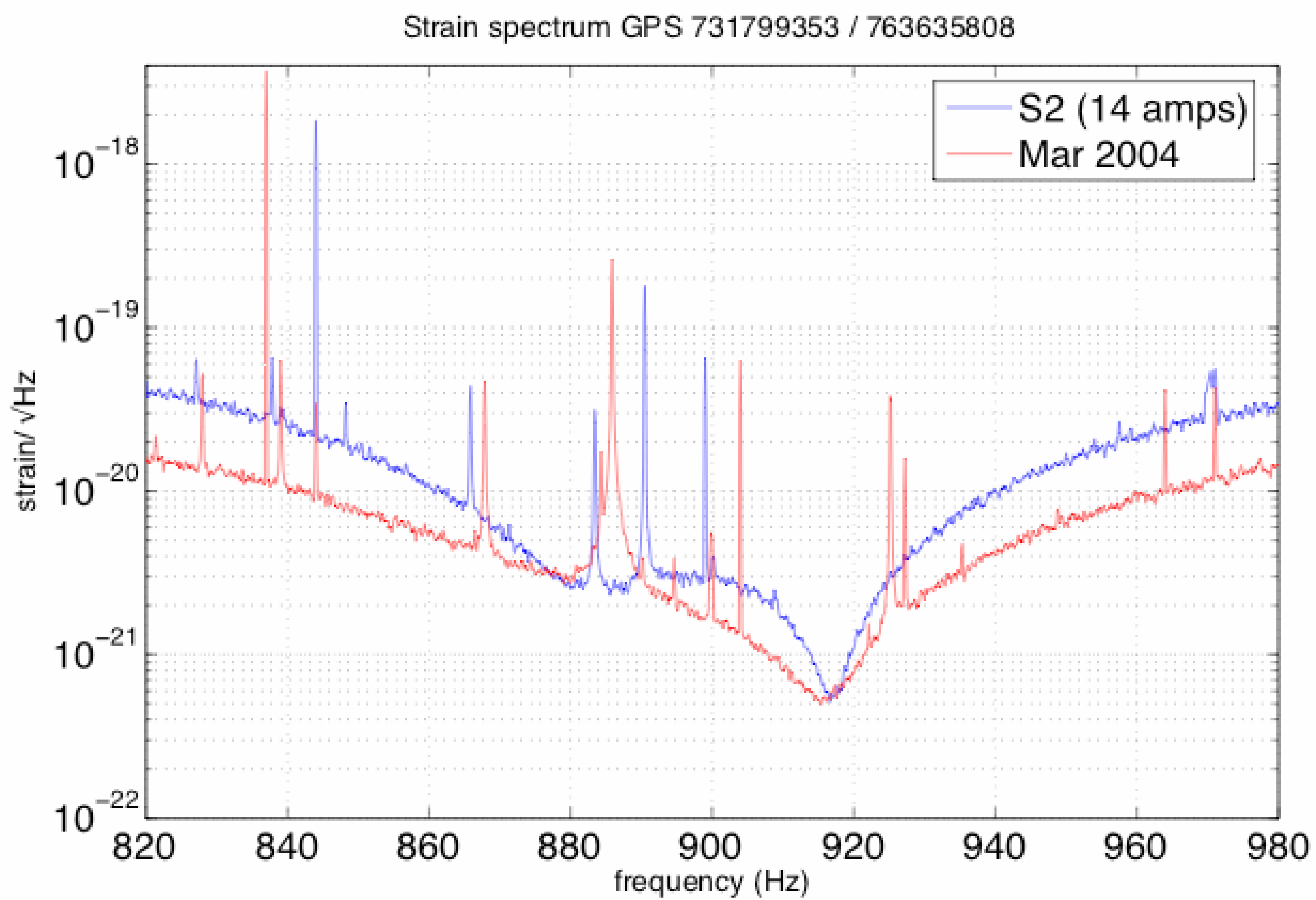
Rotated to IGEC orientation (parallel to European bars) on May 5, 2004.

So now have > 200 days available for comparison with NAUTILUS, EXPLORER, and AURIGA.

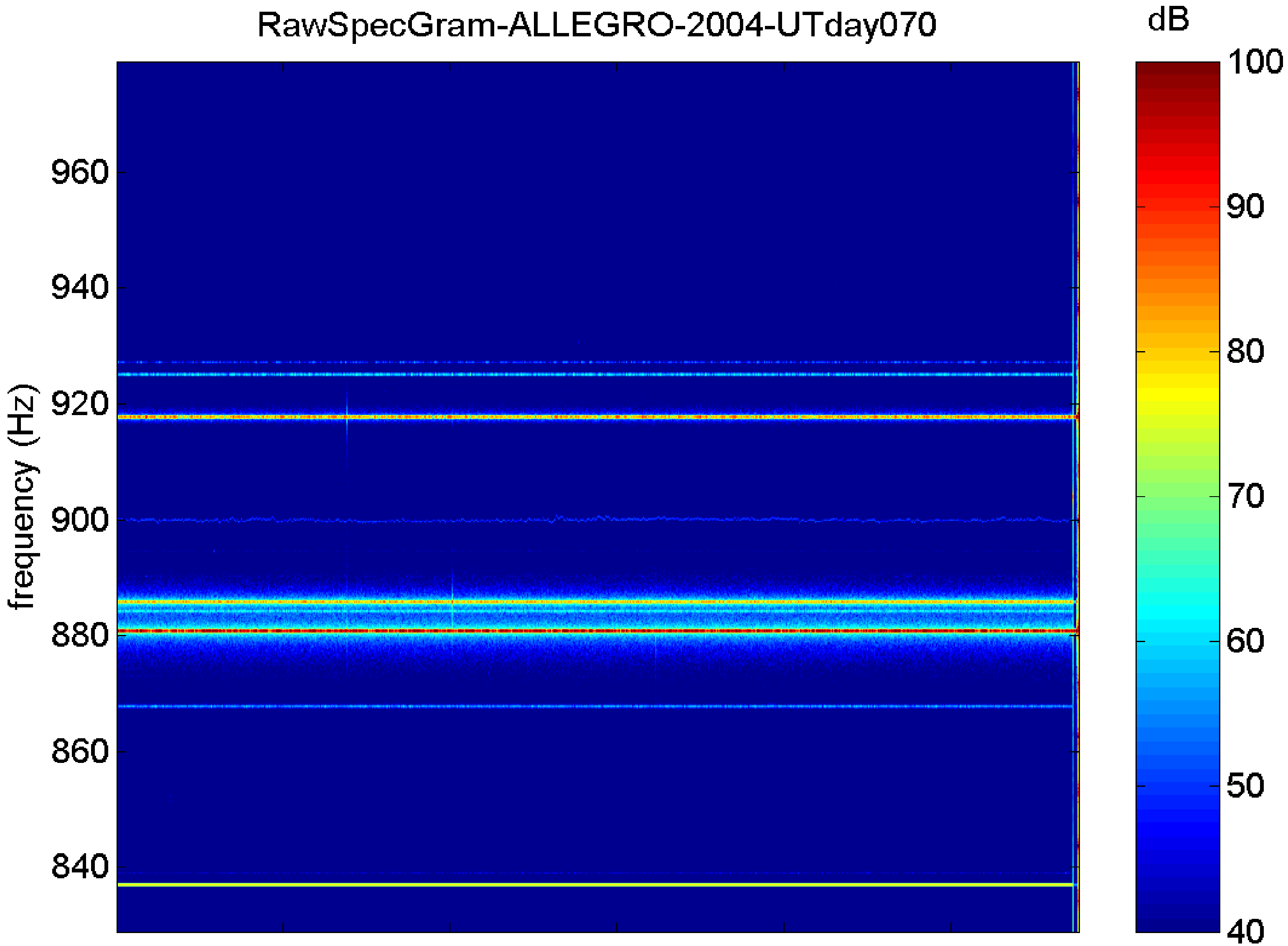
Duty factor >95% and noise improved.

► *Will continue to operate during S4, with occasional rotations*

Noise improved



Excellent stability in 2004



AURIGA run II: upgrades

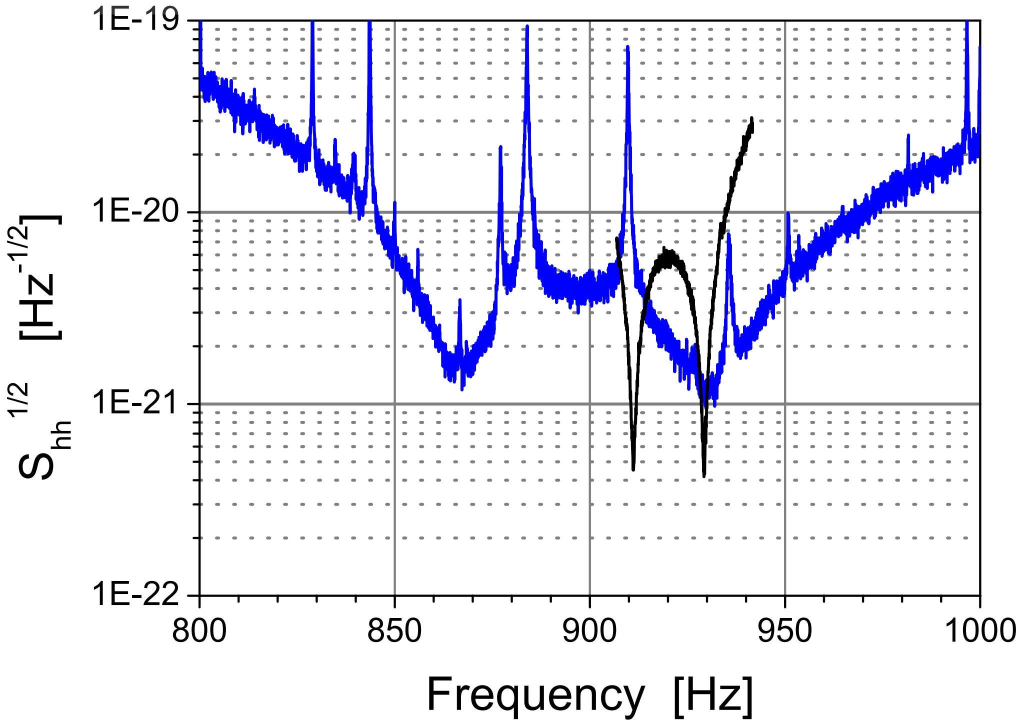
❖ **new mechanical suspensions:**
attenuation > 360 dB at 1 kHz
FEM modelled

❖ **three resonant modes operation:**
two mechanical modes
one electrical

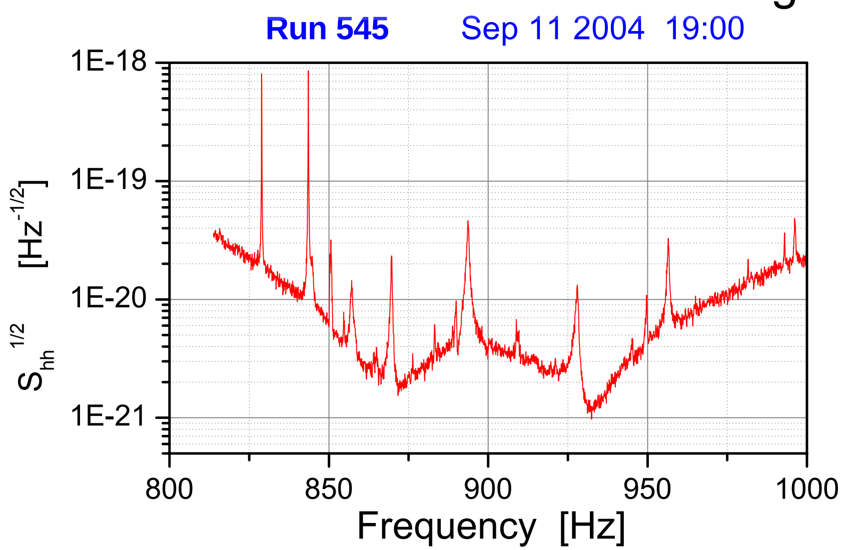
❖ **new data analysis and data acq.:**
C++ object oriented code
frame data format
Monte Carlo software injections
improved noise matching algorithm
selectable templates

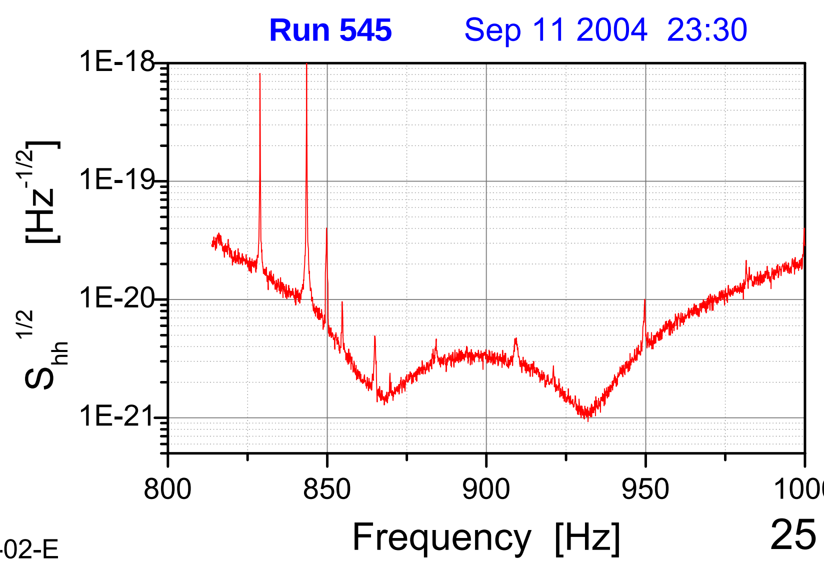
S_{hh} sensitivity **(1)**

initial operation at 4.5 K started on Dec. 24th 2003



… months of diagnostic measurements and noise hunting **…**





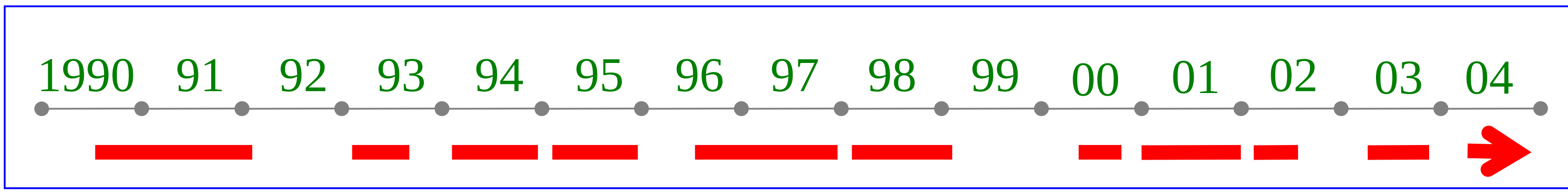
unmodeled spurious noise peaks within the sensitivity bandwidth

- not related to the dynamical linear response of the detector
- non gaussian statistics
- related to mechanical external disturbances

up-conversion of low frequency noise

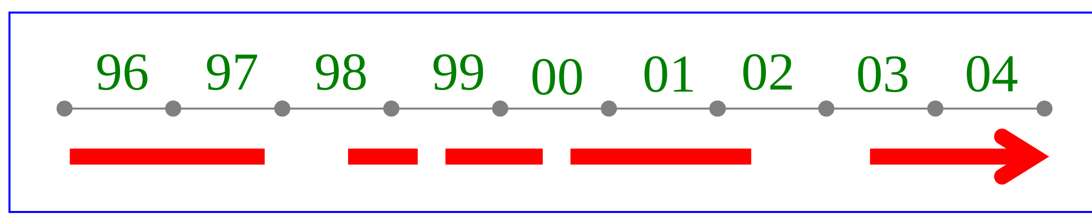
DATA TAKING DURING THE LAST 14 YEARS

EXPLORER



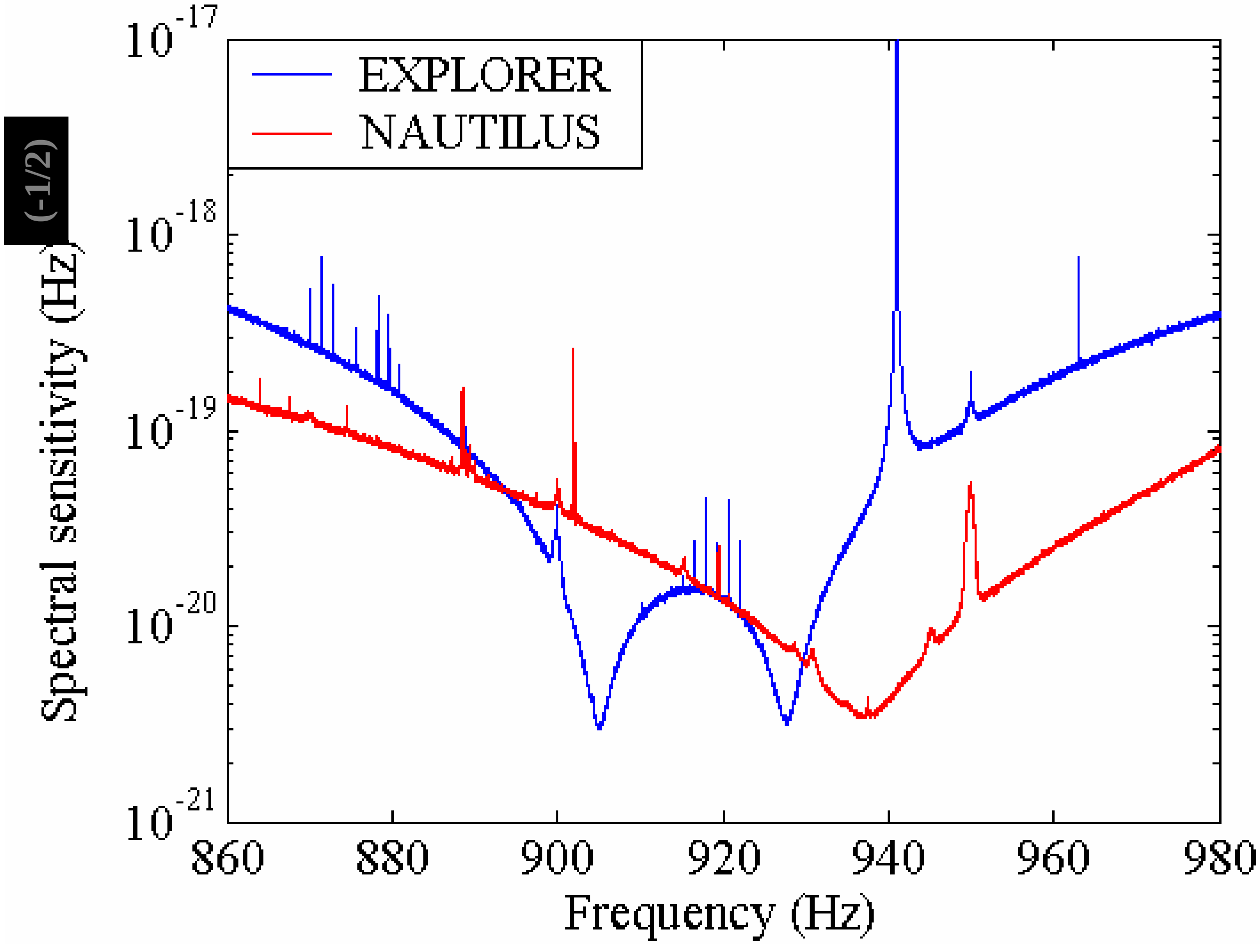
h from 10^{-18} to $4 \cdot 10^{-19}$

NAUTILUS

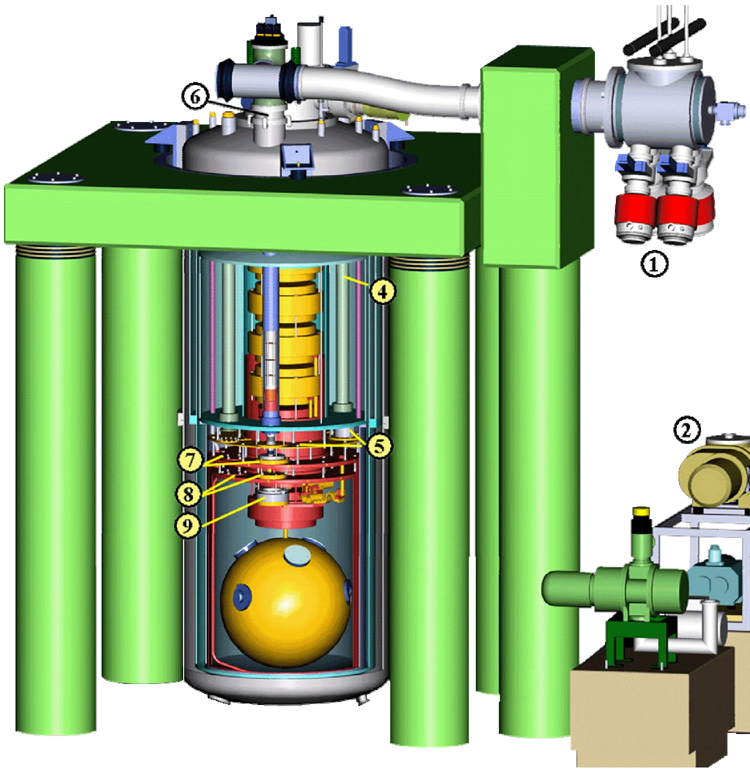


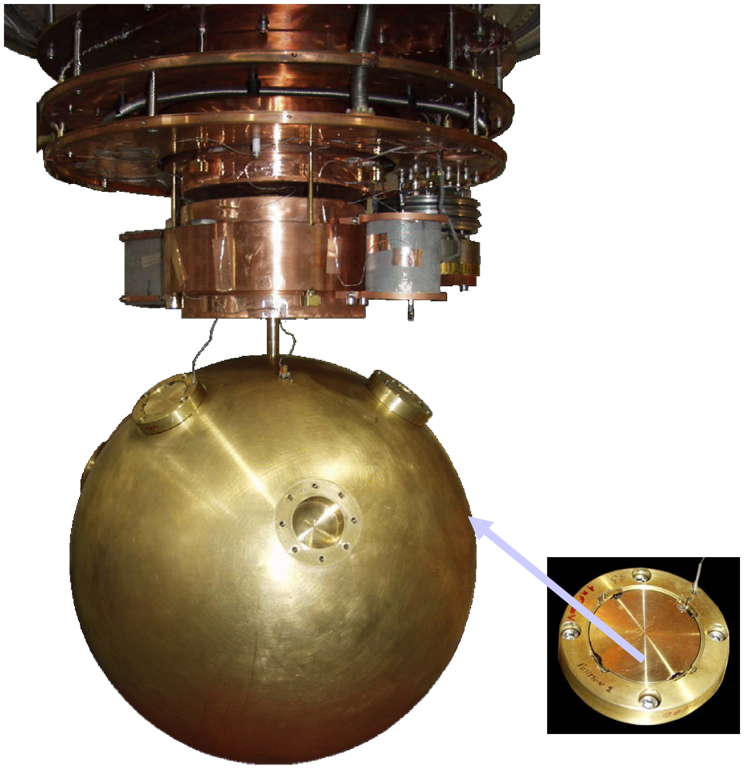
h from 10^{-18} to $3 \cdot 10^{-19}$

EXPLORER and NAUTILUS
December 11th, 2004



MINIGRAIL – NEW RUN November 2004





Ø 68 cm - 1.4 ton 3kHz

T=72mK

New cryogenic run with 3 capacitive transducers and SQUID read-out.

Sources for Ground-Based Detectors

3.5PN templates for compact binary inspiral – Luc Blanchet

3.5PN parameter estimation of inspiralling compact binaries for LIGO and VIRGO – B.S Sathyaprakash

Expected coalescence rates of NS/NS binaries for ground based interferometers – Tania Regimbau

Constraining the black hole merger rate using binary pulsar population observations – Richard O'Shaughnessy

Posters

Simulation of a population of gravitational wave-driven neutron stars – Cristiano Palomba

A new class of post-Newtonian approximants to the dynamics of inspiralling compact binaries: Test Mass in the Schwarzschild Spacetime – Craig Robinson

Detecting Kerr Binaries with P-Approximant Templates – Ed Porter

3.5PN templates for compact binary inspiral
– Luc Blanchet

Post-Newtonian expansion of inspiral waveform had been worked out to order 3.5, but with some parameters with unknown values

Need to know templates to this order to construct reliable filters for black hole inspirals (*e.g.* 10+10 Msun) for LIGO

New theoretical treatment has yielded previously-unknown values

Dimensional self-field regularization, where number of spatial dimensions is taken to be a complex number d, and then the limit $d \to 3$ is taken

Number of orbits for a 10+10 Msun binary from each term in Post-Newtonian expansion:

Newtonian	1PN	1.5PN	2PN	2.5PN	3PN	3.5PN
602	+59	–51	+6.1	–7.5	+2.2	–0.9

In the following talk, Sathya described studies of how well parameters (coalescence time, etc.) can be determined using these templates (from inverse of Fisher information matrix)

Expected coalescence rates of NS/NS binaries for ground based interferometers – Tania Regimbau

A new approach (alternative to Kalogera and collaborators)

Relies more on astronomical observations

- Star formation rate history inferred from measured ages of 552 stars
- Fraction of massive stars in binaries inferred from observations of radio pulsars

Calculation also requires some assumptions and simulations

Final estimate: 3.4×10^{-5} per year per Milky-Way-like galaxy
1 per 125 years at VIRGO design sensitivity
1 per 150 years at LIGO-I design sensitivity
1 per 26 years for LHO/LLO/VIRGO network
6 per year at Advanced LIGO design sensitivity

Constraining the black hole merger rate using binary pulsar population observations

– Richard O'Shaughnessy

Consider population synthesis simulations of binary systems with different model parameters

Check each model for consistency with two classes of binary neutron star systems with a recycled pulsar:

- *Merging* binary neutron star systems (J0737, B1915, B1534)
- *Wide* binary neutron star systems (J1811, J1518, J1829)

Yields constraints on merger rates for *other* classes of binary systems too

- Black hole – black hole
- Black hole – neutron star

Detector Characterization / Tools

Generating time domain strain data (h(t)) for the ALLEGRO resonant detector – Martin McHugh

- Crucial for LLO-ALLEGRO stochastic GW search
- Uses new calibrator mounted on end of bar

Calibration of TAMA300 data in the time domain – Souichi Telada

- Track optical gain with calibration line
- Cavity pole frequency monitored too, but didn't change
- Use IIR filters to calibrate time series
- Good in 10-3000 Hz band

LIGO calibration during the S3 science run – Michael Landry

- Frequency-domain and time-domain
- Uncertainties
- Hope to get photon calibrator working for S4

Detector Characterization / Tools (cont.)

Gravitational wave burst vetoes in the LIGO S2 and S3 data analyses – Alessandra Di Credico

Veto studies for LIGO binary inspiral triggers – Nelson Christensen

Environmental noise studies in VIRGO – Irene Fiori

- Single-arm noise contained many lines from acoustic/seismic coupling
- Suppressed in recombined running
- Tracked down coupling mechanism: power fluctuations at output of mode cleaner to to uncontrolled alignment

Searching for correlations in global environmental noise – Antony Searle

Simulation Study for Cross-Talk Noises between Two Detectors of LCGT on Detection of GW – Nobuyuki Kanda

- Plan is to have *two* interferometers at the site
- Common seismic noise does not seem to be a problem, but common noise from other sources could significantly degrade coincidence value

Detector Characterization / Tools (cont.)

Validation of realistically modelled non-stationary data
– Soma Mukherjee

Deconstruct real data into components: lines, transients, noise floor

Recombine randomly to produce realistic simulated data

Posters

NAP: a tool for noise data analysis – Elena Cuoco

A simple line detection algorithm applied to Virgo data
– Irene Fiori

Detector Characterization with AURIGA data analysis
– Francesco Salemi

Results of searches for low-mass binary coalescences using LIGO data

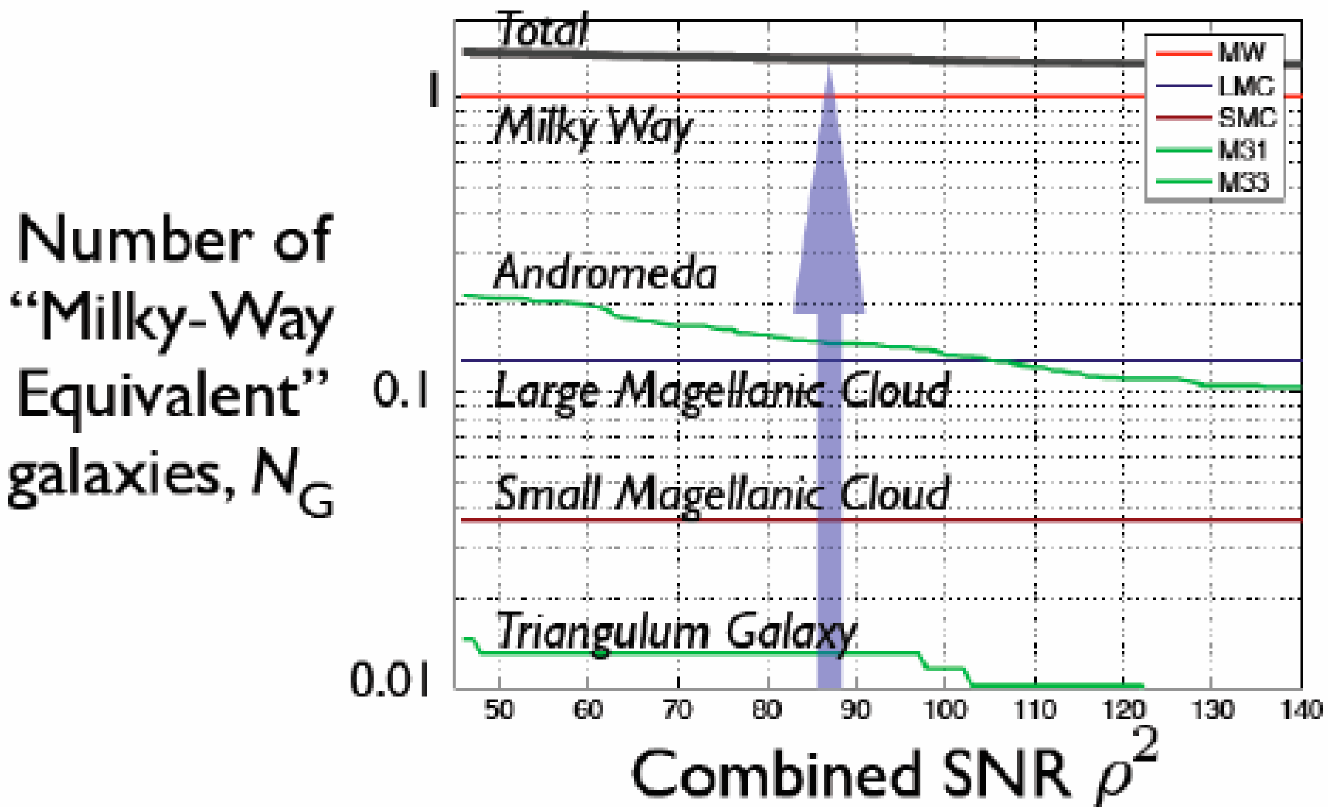
Jolien Creighton
for the LIGO Scientific Collaboration

BNS Results: Rate Limit

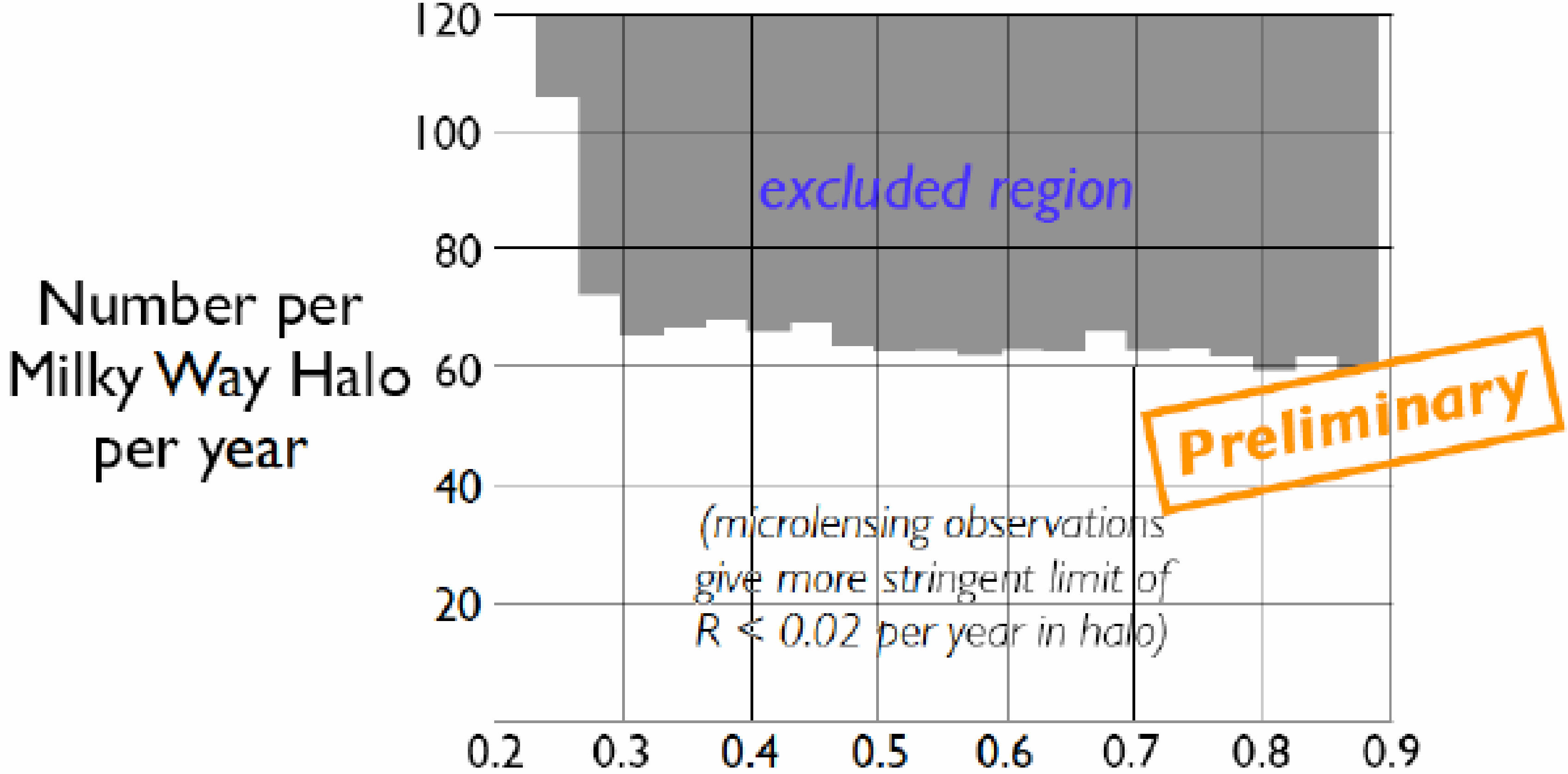
$$\mathcal{R} < 50\,\mathrm{y}^{-1}\,\mathrm{MWEG}^{-1}$$

Preliminary

(includes systematic errors, e.g. due to finite number of simulated injections)



PBBH Results: Upper Limit



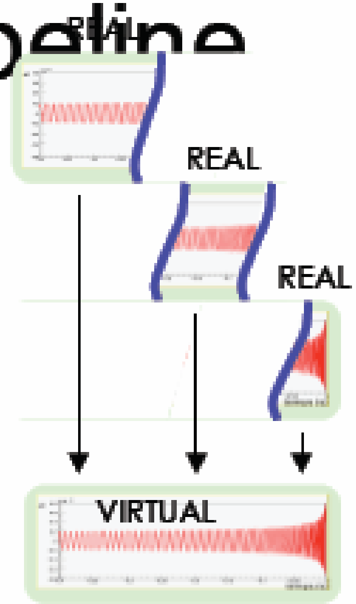
$$\left(\frac{\mathcal{M}}{M_\odot}\right)^{5/6} = \left(\frac{\mu}{M_\odot}\right)^{1/2} \left(\frac{M}{M_\odot}\right)^{1/3}$$

First Comparison Between LIGO &Virgo Inspiral Search Pipelines

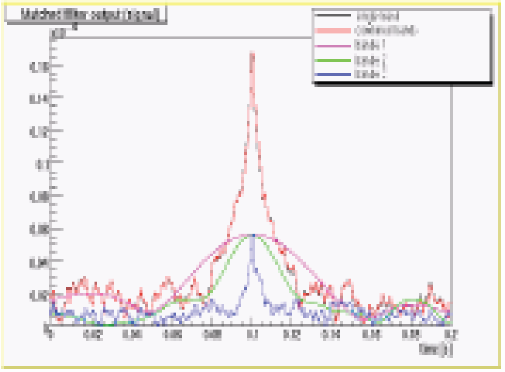
F. Beauville on behalf of the
LIGO-Virgo Joint Working Group

The Virgo Multi-band Pipeline

- Initialization
  - Spectrum (on 1800 s of noise)
  - Grid of full frequency band (VIRTUAL) templates
  - Grids of (REAL) templates for each frequency band



- Processing
  - Run synchronously each grid of REAL templates on data
    - Data chunk twice the longest REAL template
  - Check if any REAL template triggers
  - Recombine associated VIRTUAL templates



Bounding the strength of a Stochastic GW Background *in LIGO's S3 Data*

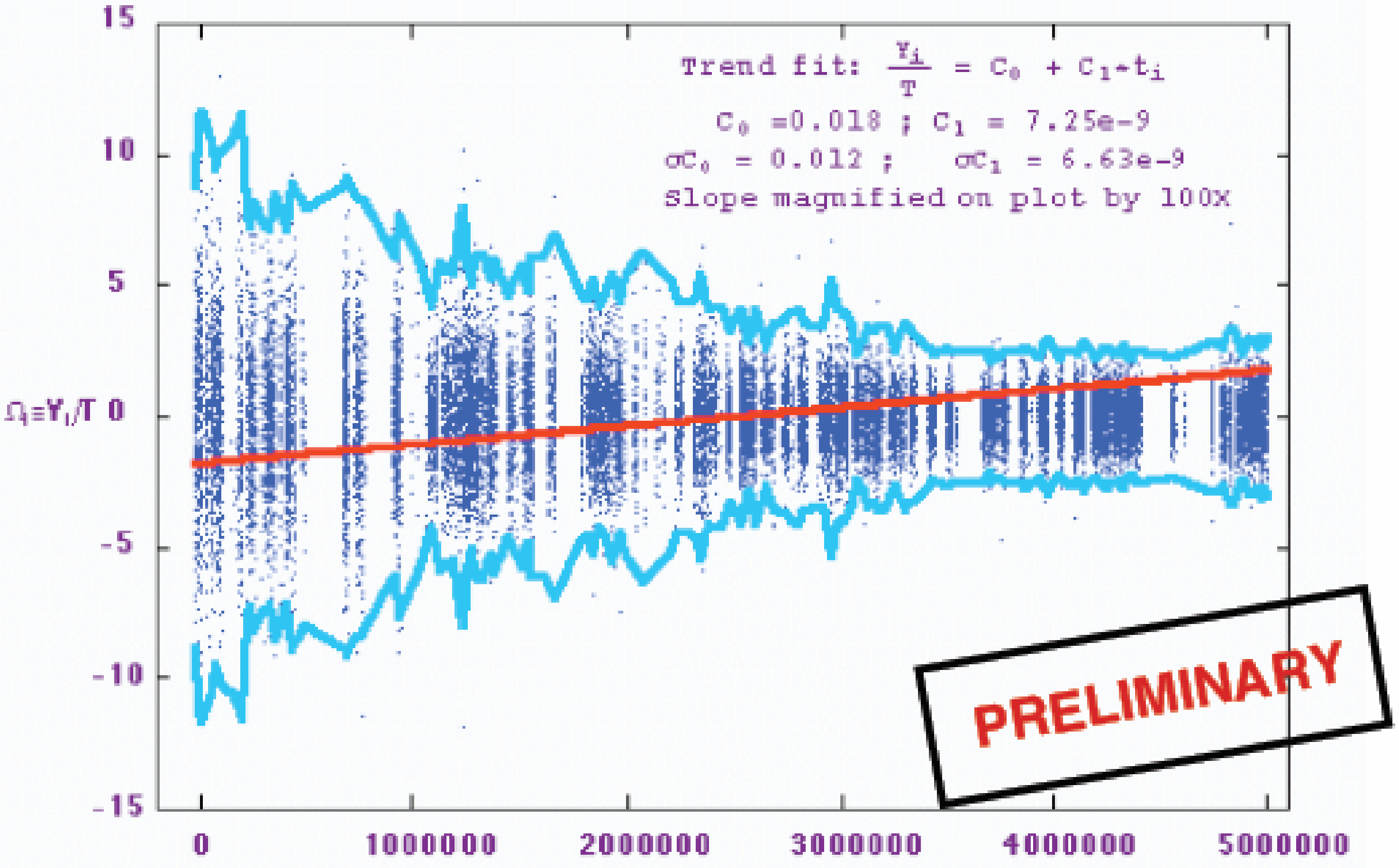
Sukanta Bose

(Washington State University, Pullman)

for the LIGO Scientific Collaboration

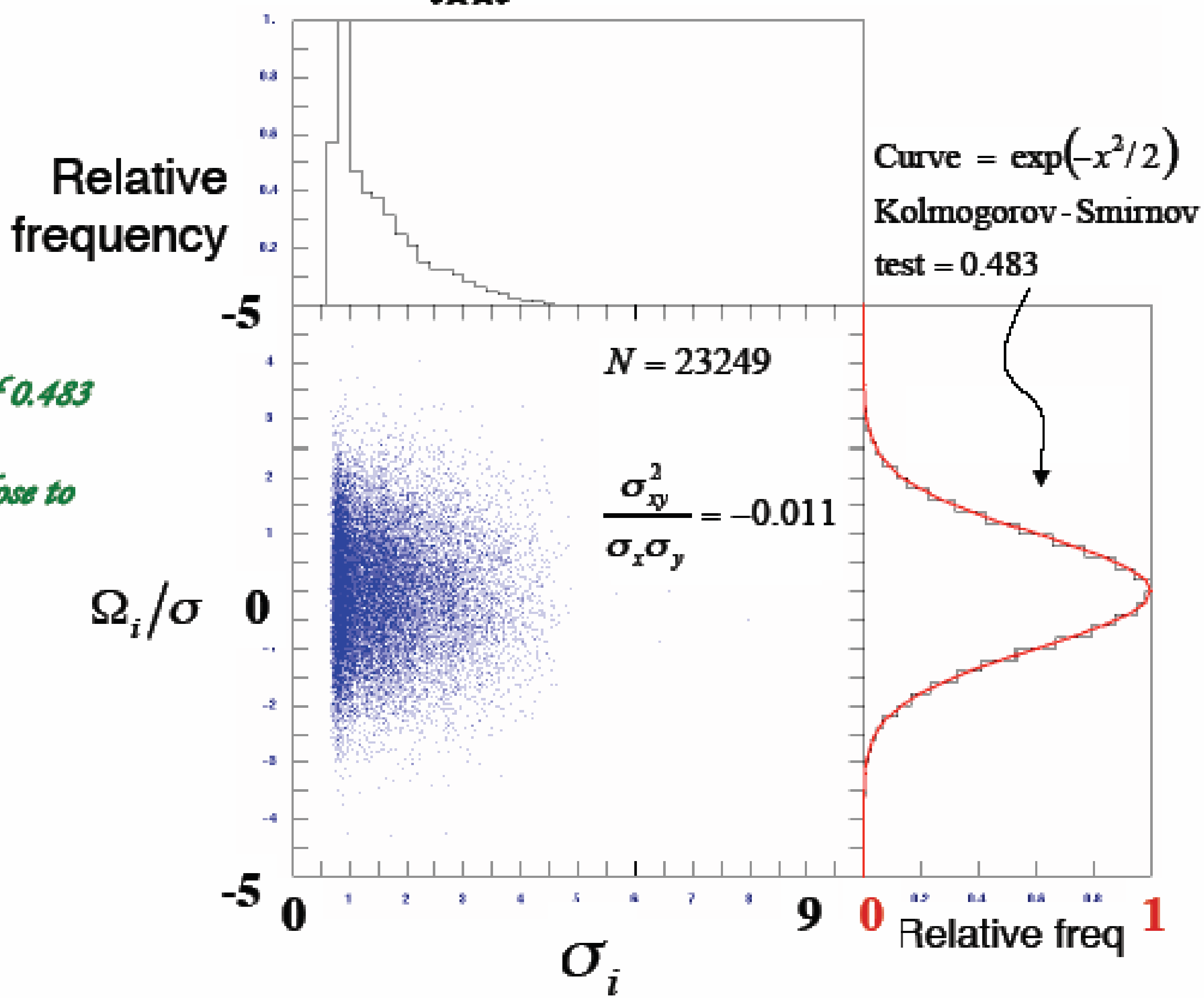
LIGO DCC No. LIGO-G050536-00-D

H1-L1 analysis:



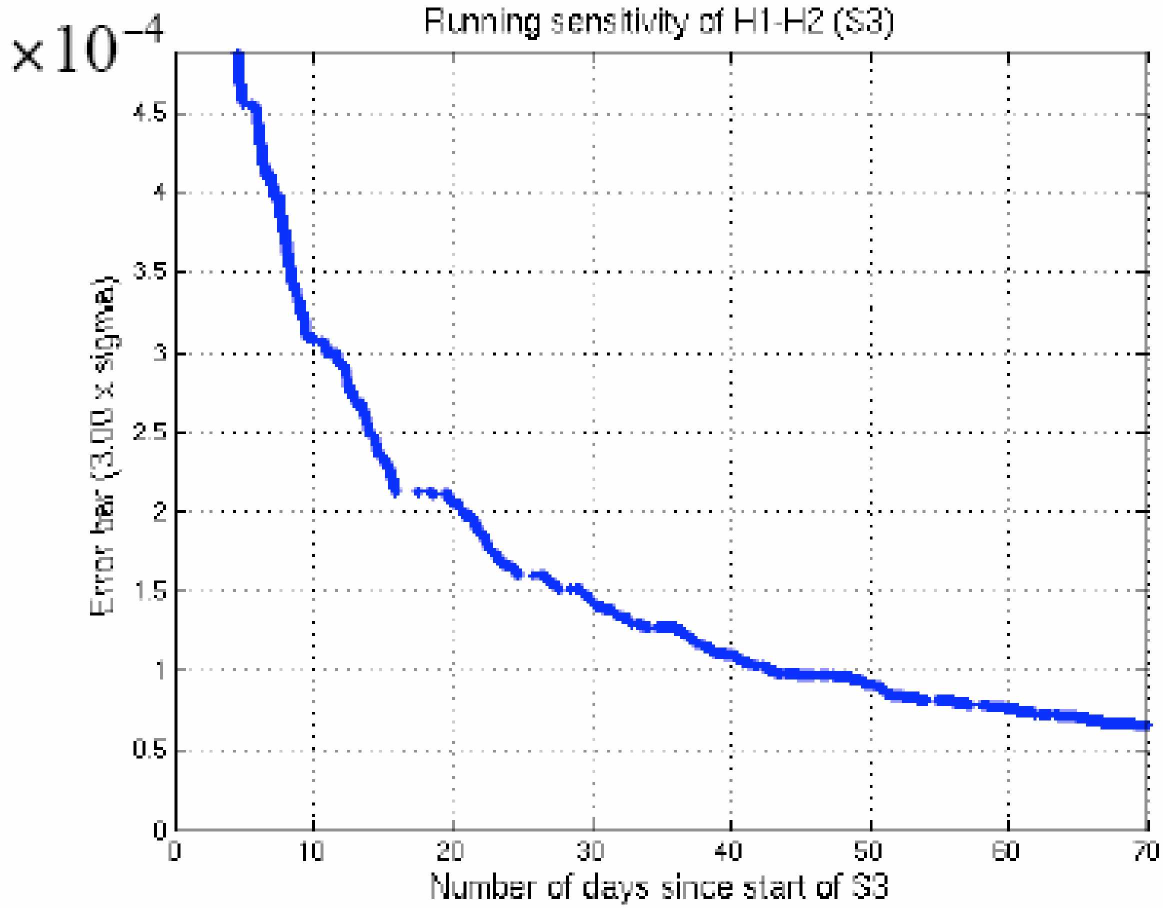
H1-L1 analysis(S2): Kolmogorov-Smirnov test

The K-S value of 0.483 implies that the distribution is close to normal.



S3 results: H1-H2

Error-estimate (+3s) plotted for the H1-H2 pair as a function of run time.



LIGO results history on $\Omega_{gw} h_{100}^2$

LIGO run	H-L	H1-H2	Freq range	Observation Time
S1*	< 23 +/- 4.6 (H2-L1)	Cross-correlated instr. noise found	40-314 Hz	64 hours (08/23/02 – 09/09/02)
S2 PRELIMINARY	< 0.018 +0.007-0.003 (H1-L1)	Cross-correlated instr. noise found	50-300 Hz	387 hours (02/14/03 – 04/14/03)
S3	??	for instrument noise in bounding W	50-250 Hz (H1-L1) 70-220 Hz (H1-H2)	L1) ~550 hrs (H1-H2) (10/31/03 01/09/04)

*[The LIGO Collaboration, PRD 69, 122004, (2004)]

Status of the LIGO-ALLEGRO Stochastic Background Search

John T. Whelan

LOYOLA UNIVERSITY NEW ORLEANS

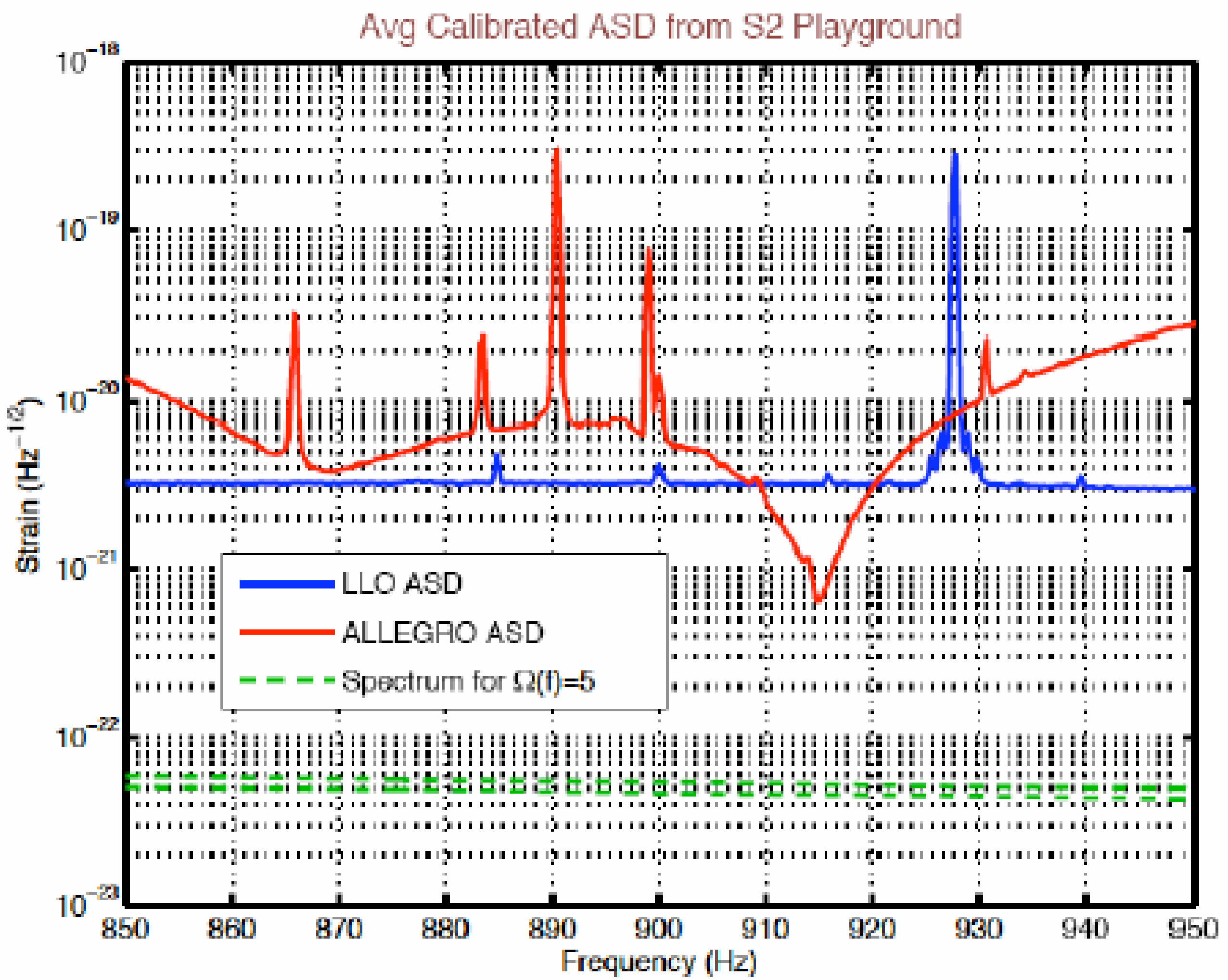
jtwhelan@loyno.edu

on behalf of the LIGO Scientific Collaboration

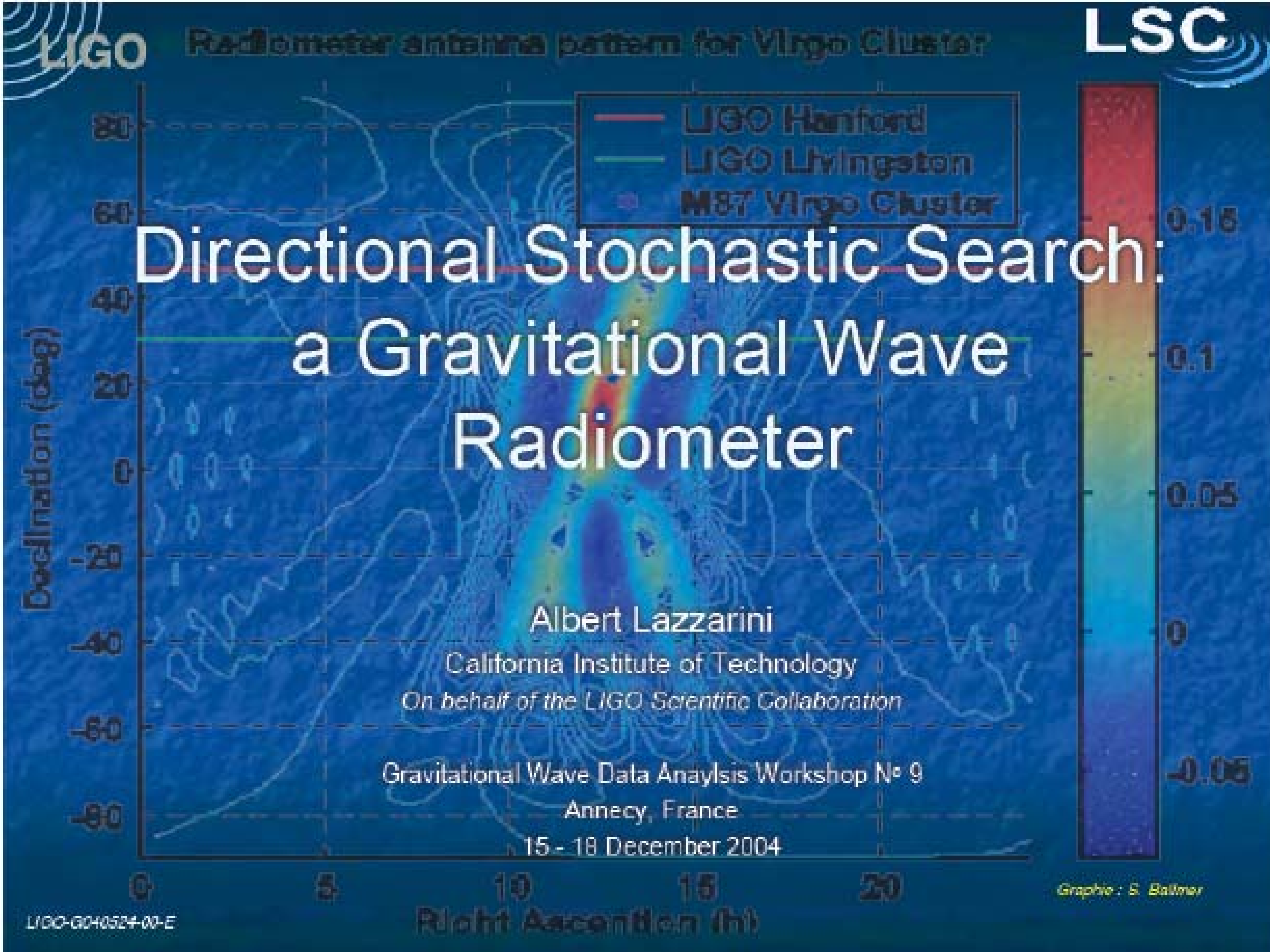
9th Gravitational Wave Data Analysis Workshop

2004 December 16

LIGO-G040525-00-Z



Avg Calibrated ASD from S2 Playground
Strain (Hz$^{-1/2}$)
Frequency (Hz)
LLO ASD
ALLEGRO ASD
Spectrum for Ω(f)=5



LIGO

LSC

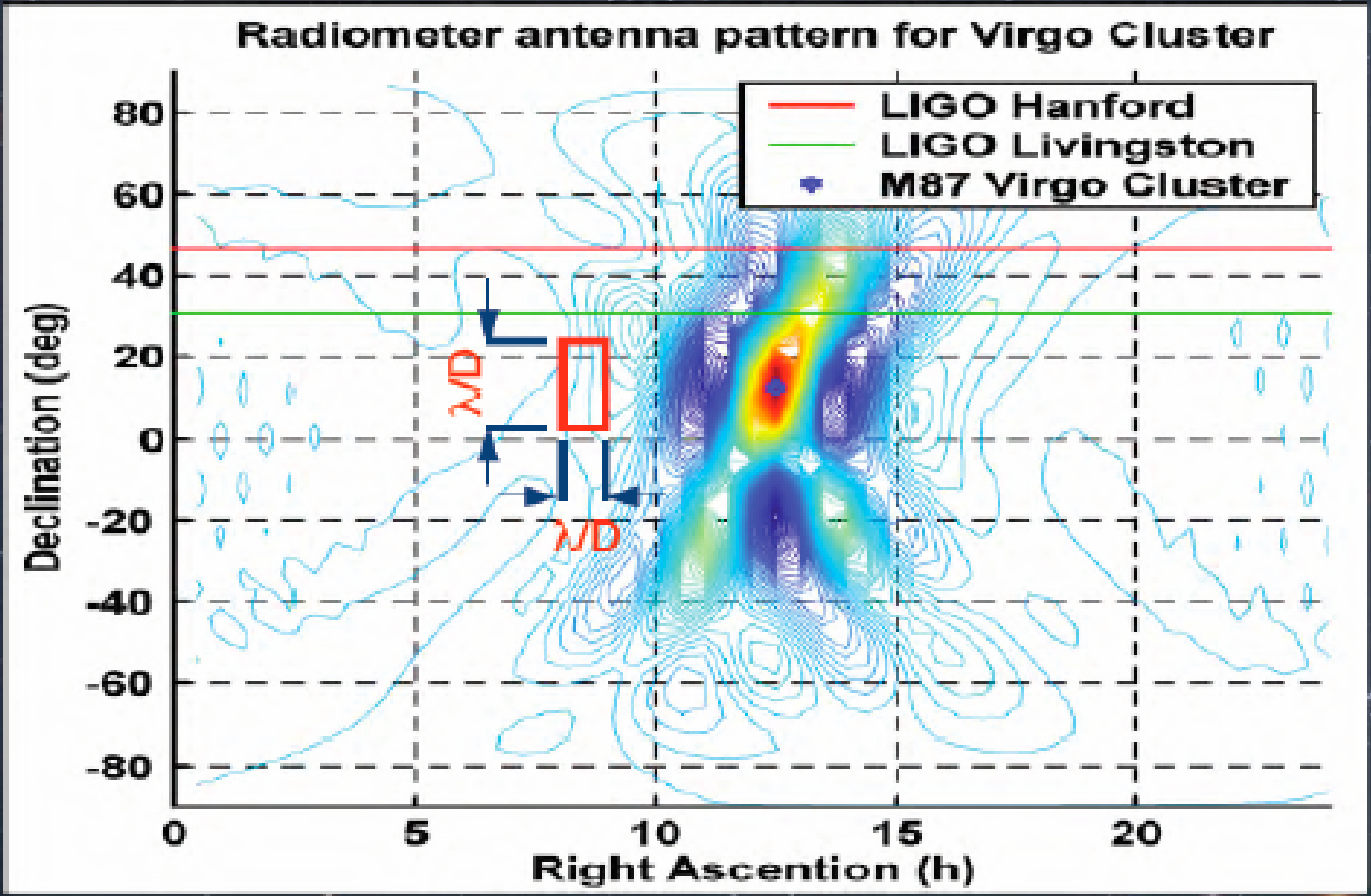
Directional Stochastic Search: a Gravitational Wave Radiometer

Albert Lazzarini
California Institute of Technology
On behalf of the LIGO Scientific Collaboration

Gravitational Wave Data Anaylsis Workshop Nº 9
Annecy, France
15 - 18 December 2004

LIGO-G040524-00-E

The antenna pattern for a flat $\Omega_{GW}(f)$ spectrum from a spatially finite source



Burst Searches

(Emphasis on presentations with astrophysical results.)

LIGO S2 Burst Search

John Zweizig for the LIGO Scientific Collaboration.

Method: Triple coincident excess power (wavelet basis) and cross-correlation.

Search: All-sky unmodelled bursts 100 to 1100 Hz.

One surviving event, correlated with airplane at Hanford.

Presented results with (and without) acoustic veto.

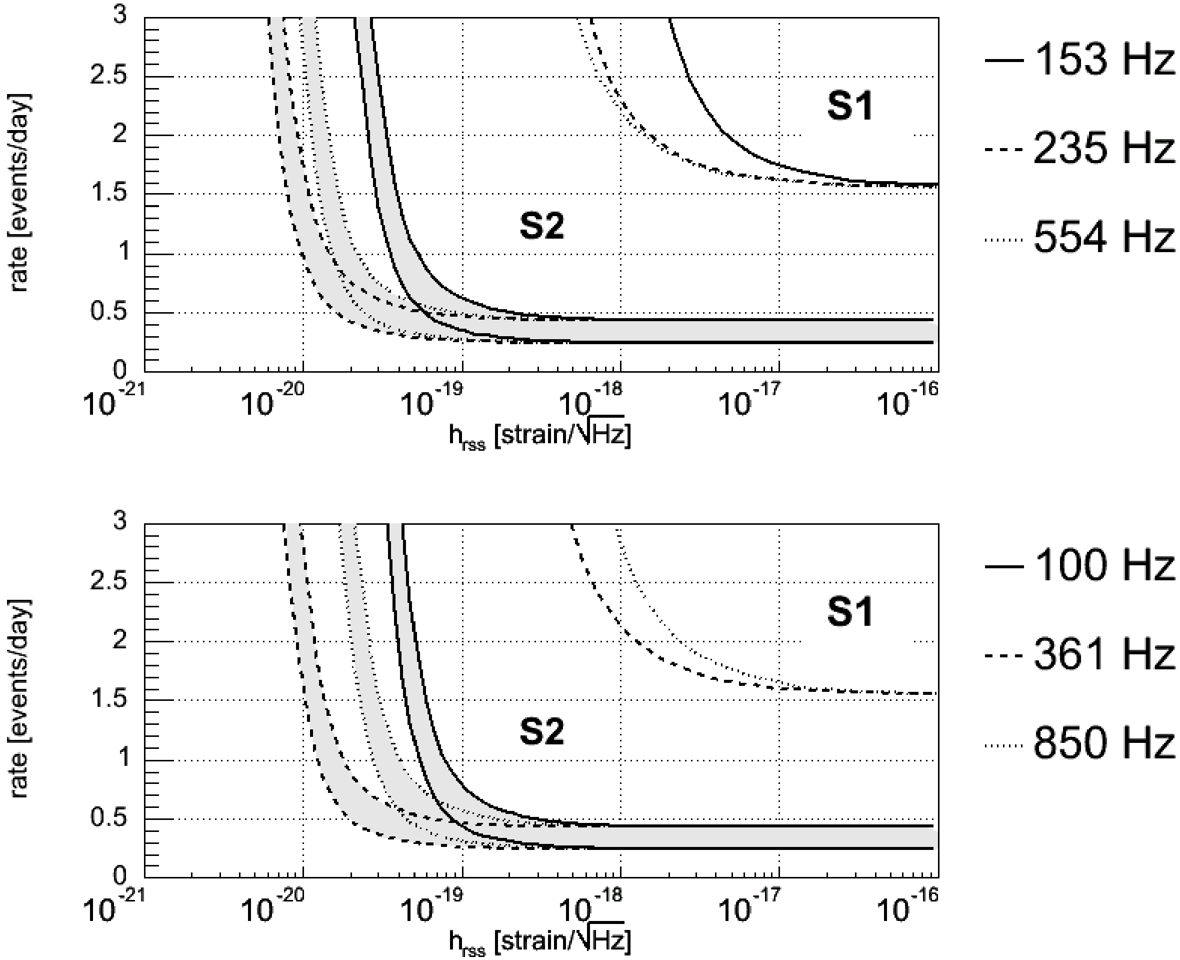
Posed acoustic veto delimna: little response

Upper limit: 0.24 (0.43) events per day at 90% confidence level.

Sensitivity: 50% detection efficiency for 235 Hz Q 9 sine-Gaussians at hrss of 1.5e-20 strain/rt(Hz).

Paper in progress.

LIGO S2 Burst Search Results (Sine-Gaussians)



TAMA DT9 Burst Search

Masaki Ando for the TAMA Collaboration

Method: single detector excess power (STFT)

Search: galactic population of supernovae (DFM)

Includes auxiliary Interferometer veto on "intensity monitor channel” (false dismissal rate 2%)

Upper limit: 6e3 events per second (90% confidence level)

Upper limit: 6e-4 solar masses per second (90% confidence level)

Paper in progress.

LIGO S2 / TAMA DT8 Surst Search

Patrick Sutton for the LIGO and TAMA collaborations

Method: triple and quadruple coincident excess power (STFT) and cross-correlation (LIGO only)

Search: unmodeled all sky 700 to 2000 Hz

No surviving events.

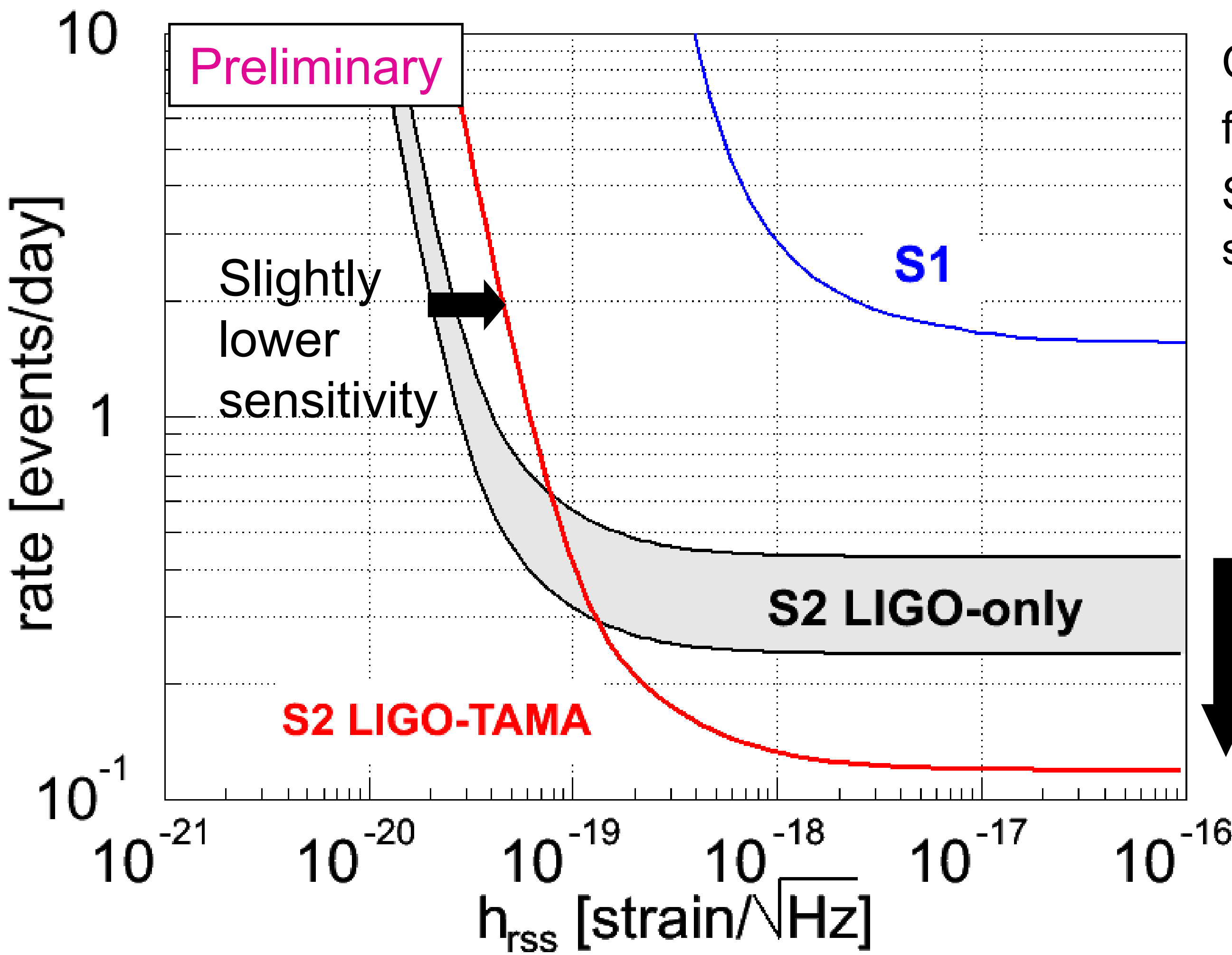
Very low event rates (1 per century) are possible.

Upper limit: 0.12 events / day (90% confidence level)

Sensitivity: 50% detection efficiency at hrss 1.8e-19 strain/rt(Hz).

Paper in progress.

Upper Limit Comparisons



Compare results for 849Hz SG to S1, S2 LIGO-only searches.

Increased observation time

The 2003 run of the Explorer-Nautilus experiment

Eugenio Coccia For the ROG Collaboration

“We report the results of the search for gravitational wave bursts from the 2003 run of the EXPLORER-NAUTILUS experiment...”

Talk not given.

Increased detector bandwidth (1 to 10Hz).

Improved timing resolution (500ms to 50ms).

Excess foreground events disappear with tighter coincidence testing.

Working to resolve discrepancy with previous results.

Not ready to present at this point.

Other Burst Talks and Posters

LIGO S3 all sky search preliminary efficiency study.

LIGO/GEO S3 preliminary efficiency study (high frequency).

LIGO S2 double coincident search using Q pipeline.

TAMA slope search for galactic supernovae.

LIGO/HETE-2 method talk.

LIGO/Virgo comparison on methods using simulated data.

CorrPower (combined cross-correlated and excess power search).

TAMA wavelet based burst search.

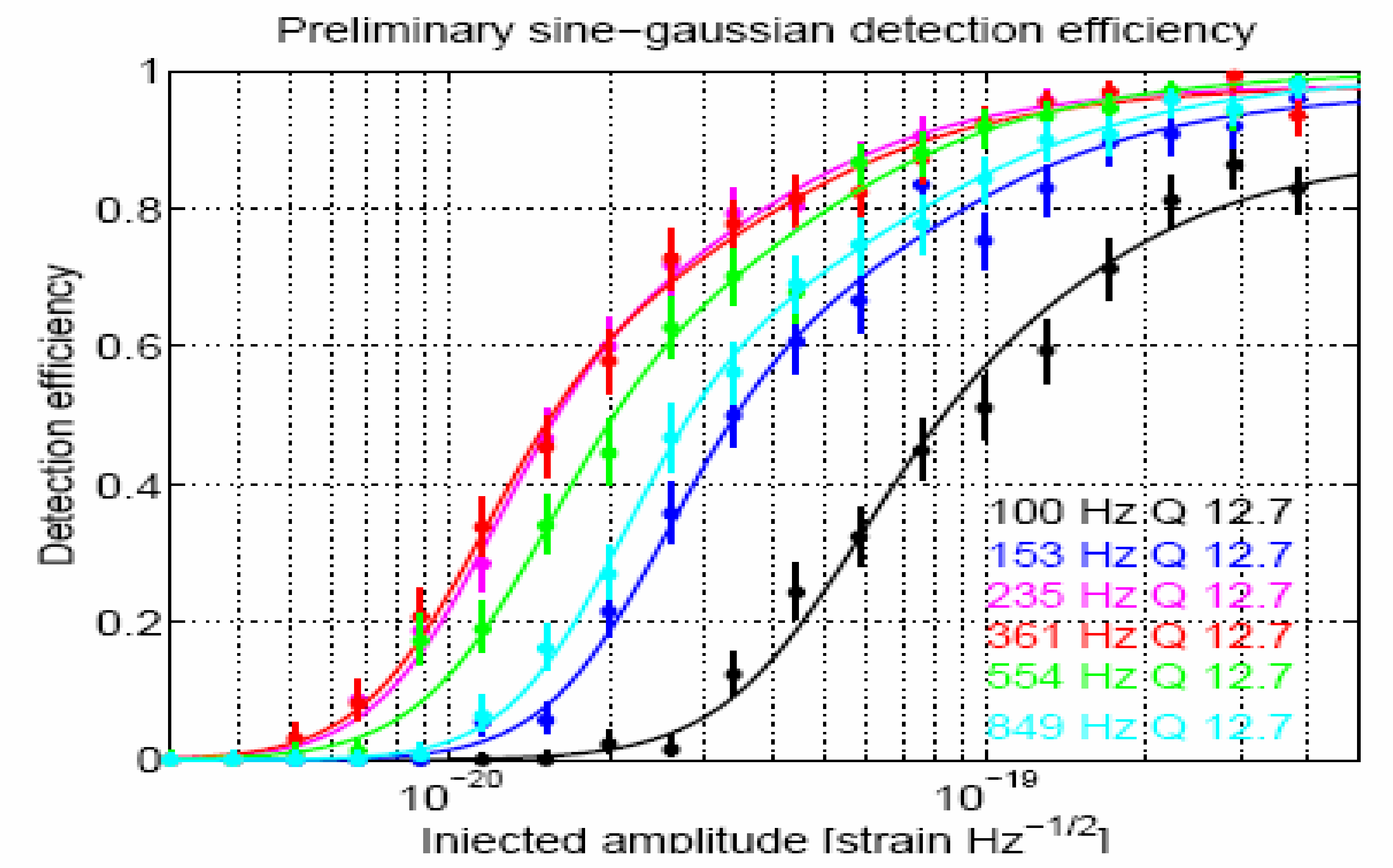
LIGO S2 vs S3 Sensitivity Improvement (Sine-Gaussians)

The table compares hrss at 50% efficiency measured in units of $10^{-20} \frac{strain}{\sqrt{Hz}}$

Freq, Hz	100	235	554	849
S2	**7.96**	**1.33**	**2.17**	**3.64**
S3	**0.94**	**0.85**	**1.27**	**2.05**

Preliminary

LIGO S2 Double Coincidence Search



Continuous Wave Searches

(Emphasis on Astrophysical Results)

Search for GW from Sco-X1 using LIGO S2 data

Chris Messenger for the LSC

Bounding the strength of gravitational radiation from SCO-X1

LIGO data from the second science run is being analyzed in order to place bounds on the strength of gravitational wave emission from the Low Mass X-ray Binary Sco X-1. This is a matched-filter search over a wide orbital parameter space and frequency band. We describe the method and pipeline that we are using and report on the status of this effort.

LIGO S2/S3 Known Pulsar Search

Matthew Pitkin for the LSC

Searching for gravitational waves from known milisecond pulsars

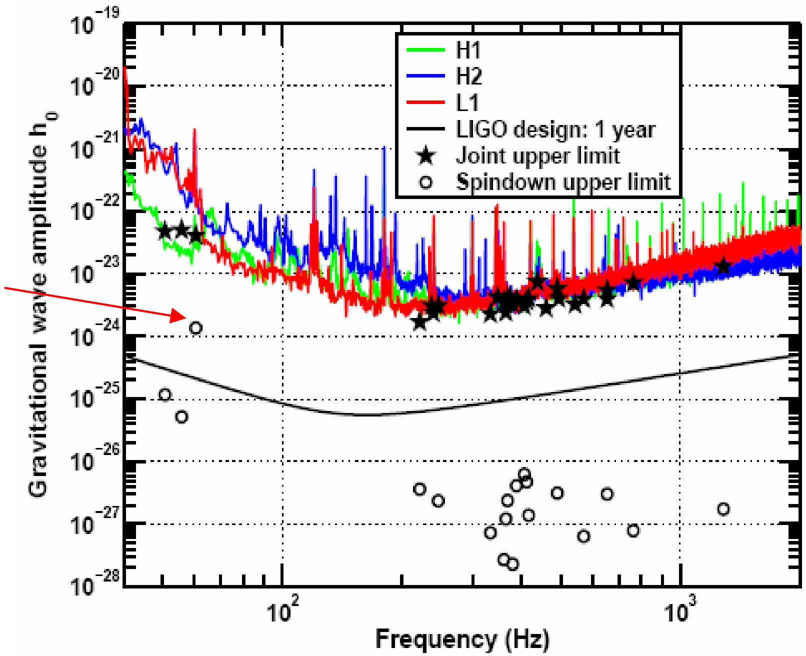
We present upper limits on gravitational wave amplitude from and neutron star ellipticity for 28 isolated pulsar using data from the second science run of LIGO. We discuss a new way of presenting such ellipticity upper limits that takes account of the uncertainties of the pulsar moment of inertia. We also present a method for searching for known pulsars in binary systems, of which there are about 80 in the sensitive frequency range of LIGO and GEO 600, that includes the system dependent binary time delays in the analysis.

LIGO S2 known pulsar search results

h_0 95% UL	Pulsars
1e-24 < h_0 < 5e-24	20
5e-24 < h_0 < 1e-23	4
h_0 > 1e-23	4

ellipticity ε	Pulsars
1e-6 < ε < 1e-5	4
1e-5 < ε< 1e-4	16
ε > 1e-4	8

Crab pulsar



- Lowest 95% UL on h_0 = 1.7e-24 (J1910-5959D)
- Lowest bound on ε = 4.5e-6 (J2124-3358)
- Crab pulsar:
  - h_0 = 4.1e-23
  - ε = 2.1e-2 (~30 times spin-down upper limit)

All-Sky Pulsar Search using LIGO S2 data

Yousuke Itoh for the LIGO Scientific Collaboration

All-sky broad band search for continuous waves using LIGO S2 data

An all-sky wide-frequency band search for continuous gravitational waves is under way on data from the second science run of the LIGO interferometers. This search uses the most sensitive and stable ten hours of data during the run. We will present an overview of the data analysis efforts completed so far with emphasis on our analysis pipeline, which includes coincidence analysis on candidates between two IFOs.

Closing Remarks

All interferometers are improving

Much interest in joint / network analysis

GWDAW-10: Brownsville, Texas, 14-17 December 2005