Status of LIGO

Keita KAWABE, LIGO Hanford Observatory/Caltech for the LIGO Scientific Collaboration
• Who we are
  – Introduction to LIGO and LSC
• Where we are at now
  – Status of Current Science Run (S5)
  – Detector Performance etc.
• Future
Who We Are
Who We Are

- **Laser Interferometer Gravitational-Wave Observatory**
- **Funding:** NSF
- **Operation:** Caltech-MIT
- **2 observatories, 3 detectors**
  - Hanford (LHO), 4km & 2km, (30+ local staffs)
  - Livingston (LLO), 4km, (30+ local staffs)
- **CIT/MIT staffs outside of site** (more than 100)
- **LIGO Scientific Collaboration (LSC),** a body carrying out the scientific program of LIGO (about 570 as of now, all over the world)
LIGO Hanford Observatory (LHO)
H1 : 4 km arms
H2 : 2 km arms
Desert in north west, Washington

LIGO Livingston Observatory (LLO)
L1 : 4 km arms
Swamp in gulf coast, Louisiana

3000 km, 10 ms
Detection concept

- Compare the travel time of photons in orthogonal directions using laser interferometer

- Power-recycled,
- Michelson IFO,
- Fabry-Perot arms
  - 4km (or 2km)
Initial LIGO Core Optics

- **Substrate: SiO2**
  - 25cm diam x 10cm thick
  - Homogeneity < 5x10^{-7}
  - Internal mode Q factor > 2x10^6

- **Polishing**
  - Surface uniformity < 1nm rms
  - Radius of curvature matched < 3%

- **Coating**
  - Scatter < 50ppm
  - Absorption < 2ppm
  - Uniformity < 10^{-3}
Core Optics Suspension
and Vibration Isolation

Vibration-isolated chambers using stack

HAM Chamber

BSC Chamber

Core Optics Suspension
Where We Are At Now
Where We Are At Now

- 4 Science Runs (S1-S4) in the past
- S5, starting Nov/04/2005, is still ongoing
  - The last run with the current configuration
  - At design sensitivity (or better) for all 3 IFOs
  - Close to the end: 2007/Oct/01 00:00:00 UTC
    - Will accumulate one year's worth of 3-IFO coincidence by then
  - Coincident run with GEO and VIRGO
    - Sometimes 5-fold coincidence
LIGO History


Inauguration
First Lock

4K strain noise
$10^{-17}$ $10^{-18}$ $10^{-20}$ $10^{-21}$ $10^{-22}$

at 150 Hz [Hz$^{-1/2}$]

4k Best NS-NS range in Mpc
(1.4 Msun, all-sky average, S/N=8)

6.5 7.7 12 15.1 16.3

Science (3 IFOs)
Joint coincidence run

S1 S2 S3 S4 S5

TAMA, GEO TAMA, GEO, Allegro GEO, Allegro, Auriga GEO VIRGO

S5 end
A Little about Detector Noise Limit

- Shot noise (and radiation pressure noise)
- Thermal motion of mirror and suspension
- Seismic motion
- Gravity gradient
- Residual gas
- Many, many technical noise not shown here
  - Electronics etc.
Strain Sensitivity of the LIGO Interferometers

S5 Performance - May 2007  LIGO-G070366-00-E

Design target \( (10^{-22} / \text{sqrtHz}, 100\text{Hz BW}) \)
3 IFOs running well:
Recent control room screen

- 12 hr trend of NS-NS inspiral range
NS–NS binary range from the start of S5

Duty factor from the start of S5
Anticipated Sources in LIGO's Band
(And corresponding LSC Search Groups)

- **Periodic sources**
  - Binary pulsars, spinning NS, low mass X-ray binaries
  - Example of upper limits (targeted)
    - \( h_0 < 4.8 \times 10^{-26} \) (PSR J1623-2631)
    - \( \varepsilon < 1.1 \times 10^{-7} \) (PSR J2124-3358)
    - Crab pulsar: *observational GW emission upper limit is smaller than the spin-down derived limit*

- **Coalescing compact binaries**
  - NS-NS, NS-BH, BH-BH
  - Physics regimes: Inspiral, merger, ringdown
  - Numerical relativity is essential to interpret GW waveform
  - \( \sim 16 \text{Mpc} \) (1.4-1.4 *M\odot*, all-sky, S/N=8)
Anticipated Sources in LIGO's Band (Continued)

- **Burst**
  - e.g. Supernovae with asymmetric collapse
  - Abrupt, uncharacterized impulse.
  - Ex) Upper limit:
    - \( E_{GW} \sim 0.1 \, M_\odot \) at 20 MpA (153 Hz case, untriggered)
    - \( E_{GW} \sim 10^{-7} \) to \( 10^{-8} \, M_\odot \) (SGR1806-20 at 5-10 kpA)

- **Stochastic background**
  - Primordial Big Bang (t = \( 10^{-22} \) sec)
  - Cross correlation of signals in pairs (LHO-LLO, LHO-LHO)
  - Ex.) First upper limit all-sky map of stochastic point source for S4
BTW, We Need Interaction With Non-GW Researchers

- Knowledge from any other means/channels
  - better GW source model etc.
  - trigger with location information (e.g. GRB/SWIFT) etc.
- GW detection might also impact underlying physics of observed objects
  - e.g. non axi-symmetry and NS equation of state
- NS specialists: please don't leave until the end of this talk (conference ad alert!).

Control room screenshot for GRB alert

www.astroscu.unam.mx/neutrones/NS-Picture/NStar/NStar_LS.gif
I'm afraid I don't have time to talk about these

- Many observational results for S4 and earlier were already published.
  - Please go to http://www.ligo.org
- Some analysis are going on for S4 and S5.
  - Some already appeared in conference talks.
  - Again http://www.ligo.org
S5 summary

- Design sensitivity requirement met by all 3 IFOs.
- Good duty factors.
- As of Sep/10/2007, about 97.3 % of 1-year (~355 days) 3-coincidence data has been accumulated.
  - Already more than 1-year 2-site coincidence (accomplished July 2007)
- End of S5 date set: 2007/Oct/01 00:00:00 UTC
  - We'll very likely accumulate more than 1 year worth of 3-coincidence data.
- We'll be ready for the next step very soon!
LIGO Future

- S5, 1yr data, with design sensitivity
  - Hundreds of galaxies in range, detection possible

- Enhanced LIGO
  - Operation in 2009
  - 8 times more galaxies in range, 8 times more detection probability

- Advanced LIGO project (~200M$)
  - Construction start expected in FY08
  - 1000X more galaxies in range
  - Expect ~1 signal/day- 1/week in ~2014
Mid-term Enhancement Plan

- Realistic, modest upgrade of initial LIGO detectors
- Early commissioning of advanced LIGO technologies
  - One high power laser module, allowing us to inject 30+ W (instead of 7-8 W)
    - DC readout with output mode cleaner
    - Better thermal compensation
- Another ~1-year run, S6, before AdLIGO
Advanced LIGO

Initial Interferometers
- Open up wider band
- Reshape Noise
- Quadruple pendulum: Silica optics, welded to silica suspension fibers

Advanced Interferometers
- Active vibration isolation systems
- High power laser (180W)
- Advanced interferometry
- Signal recycling
AdLIGO Suspension Prototype
Example of AdLIGO Noise

- Newtonian background, estimate for LIGO sites
- Seismic ‘cutoff’ at 10 Hz
- Suspension thermal noise
- Test mass thermal noise
- Unified quantum noise dominates at most frequencies for full power, broadband tuning
LIGO Conclusion

- LIGO is close to an end of S5 run with excellent performance
- Data analyses ongoing
- Ready for the next step
  - LIGO enhancement (operation 2009)
  - Advanced LIGO expected to detect GW on a regular basis (in 2014)
Global Network of GW Detectors in the Future

- GW detection for astronomy
  - Higher detection confidence
  - Better localization of sources
  - Better polarization decomposition of the wave
- All of these necessitates multiple detectors around the world!
Global Network of GW Detectors in the Future

AdLIGO (two sites)

LIGO

EGO - GEO

GEO600

Virgo

LIGO

TAMA300

LCGT

AIGO(3k?)

AIGO(80m)
Network of Terrestrial and Space GW Detectors in the Future

AdLIGO (two sites)

LISA

http://lisa.nasa.gov
Courtesy NASA/JPL-Caltech

DECIGO

EGO - GEO

http://lisa.nasa.gov
Courtesy S.Kawamura

AIGO(80m)

LIGO

GEO600

Virgo

TAMA300

LCGT

AIGO(3k?)
Advertisement 1: 2\textsuperscript{nd} Annual NS/LSC Meeting

http://www.ligo-wa.caltech.edu/~mlandry/NSMeet/Oct07/

- Oct/20/2007, Albert Einstein Institute in Hannover, Germany.
- A meeting between neutron star experts and gravitational wave researchers searching for continuous wave.
- “spin evolution, braking indices, crusts, magnetic fields, population studies, new surveys, and anything else that could affect detectability of gravitational waves.”
Advertisement 2: Pulsar analysis using your PC!

- All-sky pulsar GW search
  - computer intensive, bound by CPU power.
- You can help by taking part in Einstein@Home!
- Distributed computing with SETI@Home technology.
- Really easy with Windows, Linux and OSX.
- 55000 active users, 70+ TFLOPS
- http://einstein.phys.uwm.edu/

Pretty screensaver!
HEPI: Hydraulic External Pre-Isolator

Early implementation of AdLIGO technique

LIGO-G070617-00-D: KAWABE K., 2007/Sep/11 TAUP2007, Sendai
HEPI performance

Allows L1 to lock during “typical” noisy days

Locking threshold

The latest: reducing the stack modes
TCS: Thermal Compensation System

- Heat optics using CO2 laser
  - to counter the wave front distortion caused by the absorption of interferometer beam in the substrate
Thermal lens effect and TCS

Thermal lens effect controlled/compensated by CO2 laser

CO2 laser

Carrier

Sideband

AS port

CO2 heating

Sideband images

Common heating

carrier

90mW

180mW

Best match

Servo controlled

LIGO-G070617-00-D: KAWABE K., 2007/Sep/11 TAUP2007, Sendai