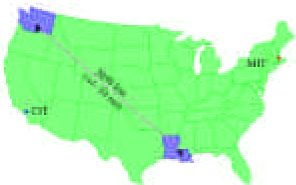
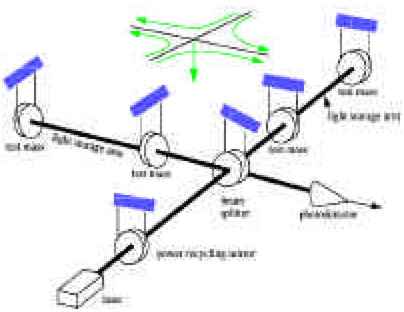
LIGO Detector Commissioning

Hanford Observatory, WA
4km and 2km IFOs



Livingston Observatory, LA
4km IFO

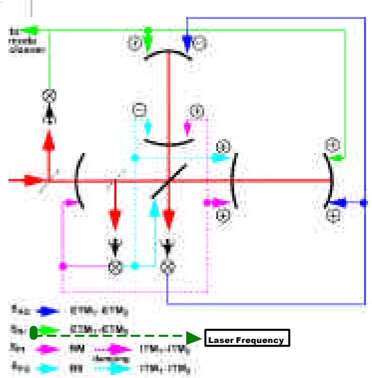


LIGO Observatory

- **Coincidence between two sites is required for confident detection**
- **Sites are widely separated to eliminate correlations**
- **Measure the direction to the source, the speed and polarization of the gravity waves**

Operational Challenges

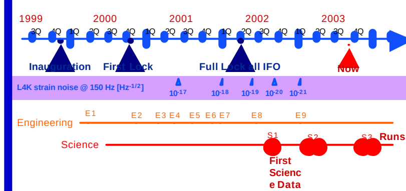
- **Attaining the resonant state for all cavities - lock acquisition. RMS length ~10^{-10} m. RMS angle ~10^{-3} rad.**
- **Control the mirror displacement at low frequencies to keep cavities on resonance. RMS ~10^{-13} m.**
- **Control the mirror angles at low frequencies to achieve stability and low noise. RMS ~10^{-8} rad.**



Control Scheme

IFO Degree of Freedom		Optical Output Port
Differential Arm Gravity Wave Channel	L_- →	Anti-Symmetric
Common Arm	$L_+ + e_1 l_+$ →	Reflected
Power Recycling Cavity	$L_+ + e_2 l_+$ →	Pick Off
Michelson	l_- →	Pick Off

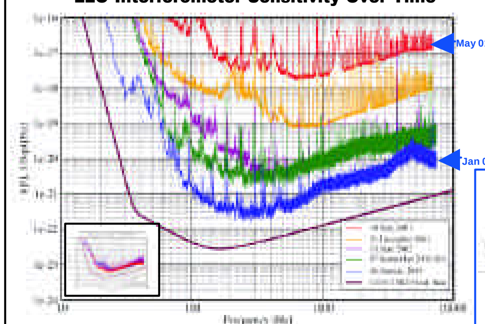
Time Line

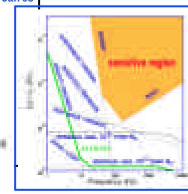


Commissioning Progress in the Last Two Years

- **Stable locking of 4-km interferometers with power recycling factors of ~40 and lock durations up to 66 hours**
- **Achievement of 10^{-13} m RMS arm length stabilization**
- **Four orders of magnitude improvement in sensitivity at 150 Hz**
- **Development of digital suspension controllers provides agility in tailoring control-loops**
- **Partial implementation of wave-front sensing & alignment control stabilizes sensitivity to within several % over 1/2-day time scales**
- **Tidal and Microseism compensation systems work**
- **Initial look at thermal-noise parameters exhibit expected properties**
- **Optical characterization of losses in long arm cavities look good**

LLO Interferometer Sensitivity Over Time





Commissioning Plans

- **Implement full angular control**
- **Increase the laser power to 10 W**
- **Seismic pre-isolation at LLO to improve the duty cycle**
- **Install acoustic enclosures around optical tables**
- **Reduce noise contribution from auxiliary degrees of freedom**

Effects of Gravity Waves on Test Masses

$$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right) h_{\mu ?} = 0$$

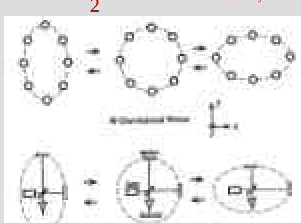
Force due to gravity wave on a test mass m

$$\vec{\mathbf{F}}_+ = \frac{1}{2} m \ddot{h}_+ (x \vec{\mathbf{e}}_x - y \vec{\mathbf{e}}_y)$$

$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$
$g_{\mu\nu}$ **is space-time metric**
$h_{\mu\nu}$ **is metric perturbation also called strain**

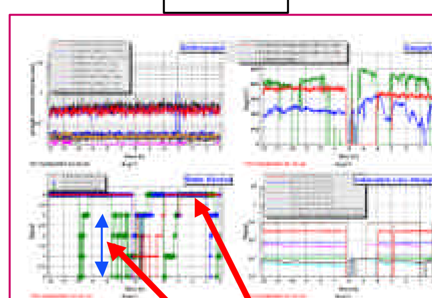
$$?_{\mu ?} = \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \qquad h_{\mu ?} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_{xx} & h_{xy} & 0 \\ 0 & h_{yx} & h_{yy} & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

flat metric **perturbation**



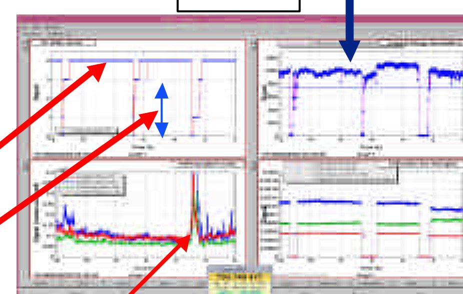
S2 Control Room Screen Shots

From LHO



- **During S2 LIGO was sensitive to the neutron star-neutron star binary inspiral events out to the Andromeda galaxy with the SNR of 8.5**

From LLO



Inspiral sensitivity
L1: ~900 kpc
H1: ~350 kpc
H2: ~200 kpc
Duty cycle
L1: 37%
H1: 74%
H2: 58%
Triple: 22%

IFO Fully Locked

Some Cavities Locked

Train

DCC #G030524-00-D