
# *LIGO*

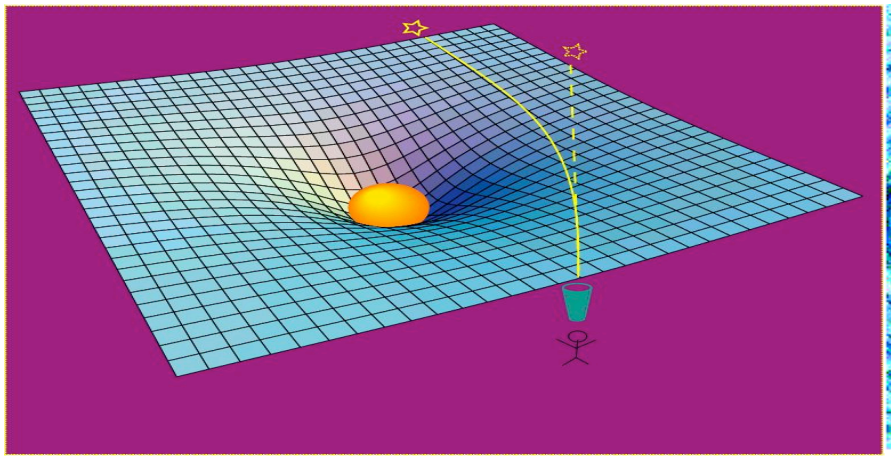
## *Laser Interferometer Gravitational Wave Observatory*

Talk for PMA Chair Council
Jay Marx, LIGO Laboratory Executive Director
April 30, 2008

LIGO-G080275-00-A

# Scientific goals of LIGO-

- Discover the gravitational waves predicted by General Relativity

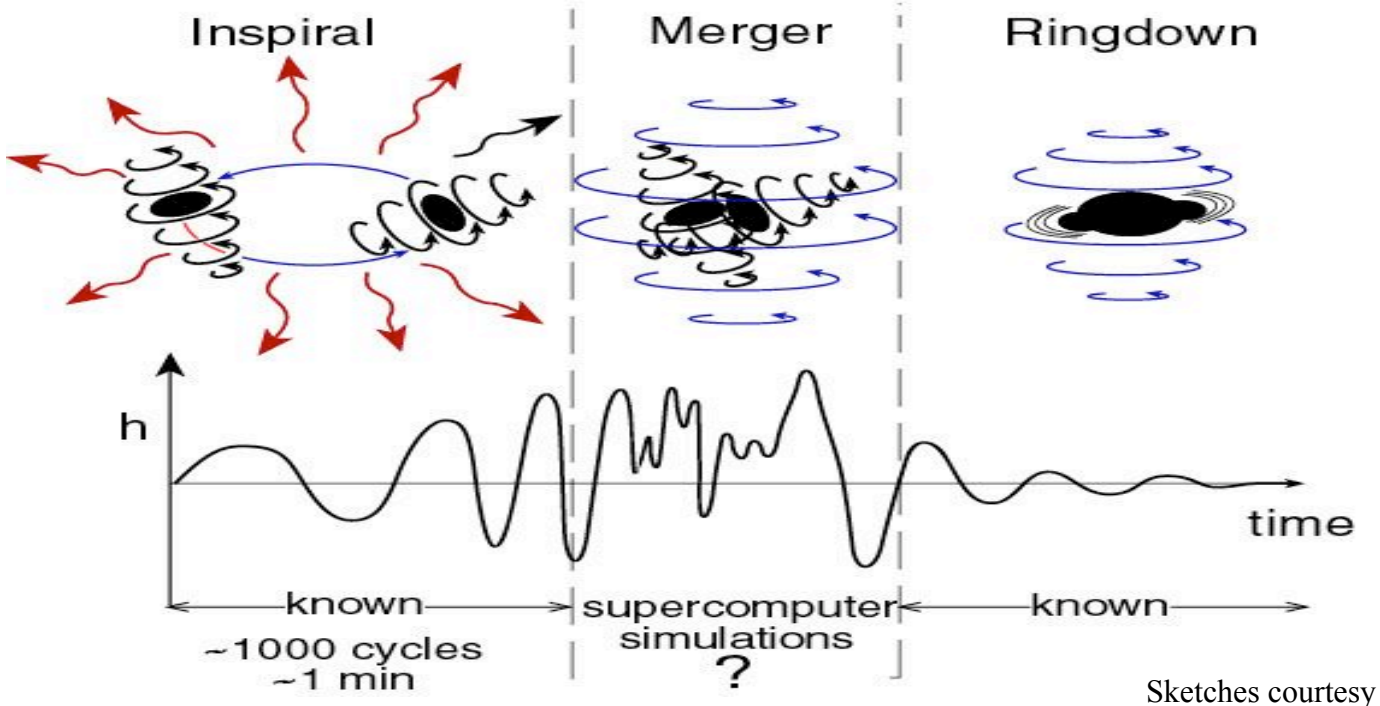


Mass warps the fabric of space.
Moving mass can dynamically warps space producing waves in the fabric.
These waves propagate outward from the source at the speed of light.

- Use gravitational waves to pioneer a new window on the universe-- gravitational wave astronomy

# *Gravitational waves provide new view of heavens*

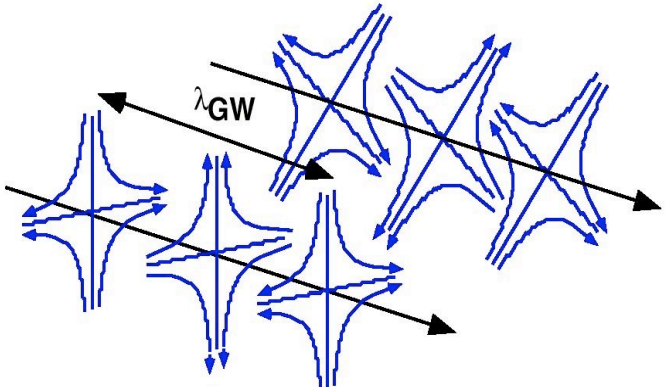
- Are not absorbed by matter- can "see" astrophysical sources that are hidden from view with traditional astronomical "eyes" (light, x-rays, gamma rays)
- Can "see" objects that don't emit light- e.g. black holes
- Information about the source of the waves in encoded in the shape of the waves

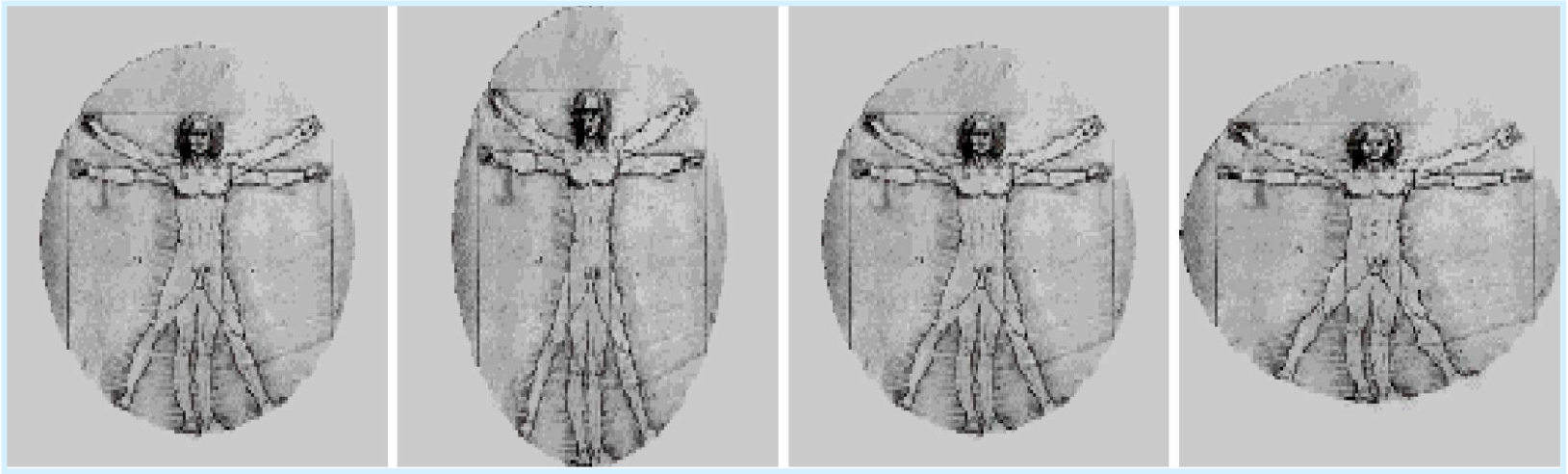



Sketches courtesy of Kip Thorne

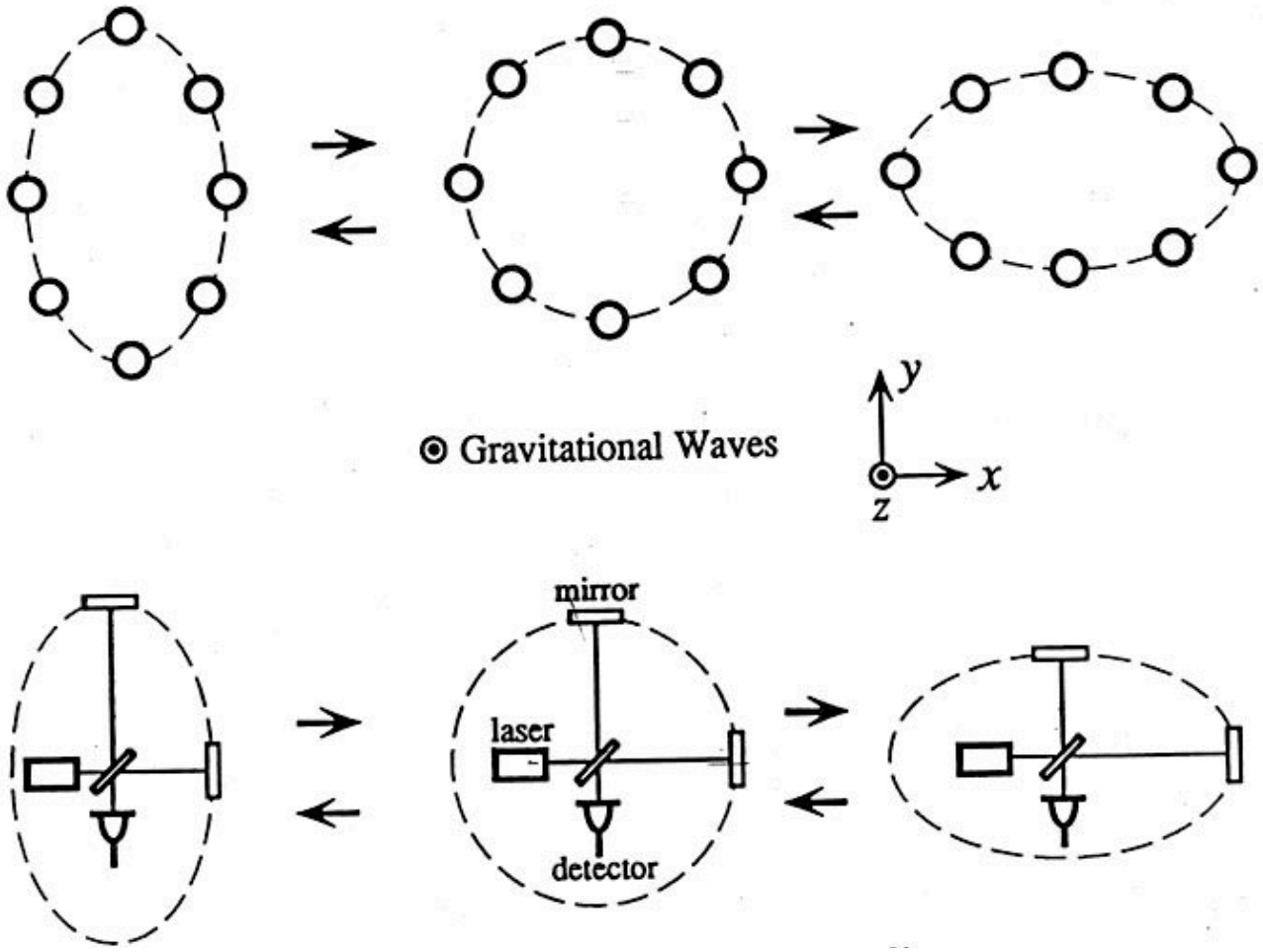
# *The key to observing gravitational waves*

- Waves alternatively
  stretch & compress space-time,
  perpendicular to propagation
  direction



# *Gravitational waves can be seen with an instrument sensitive to changes in length*



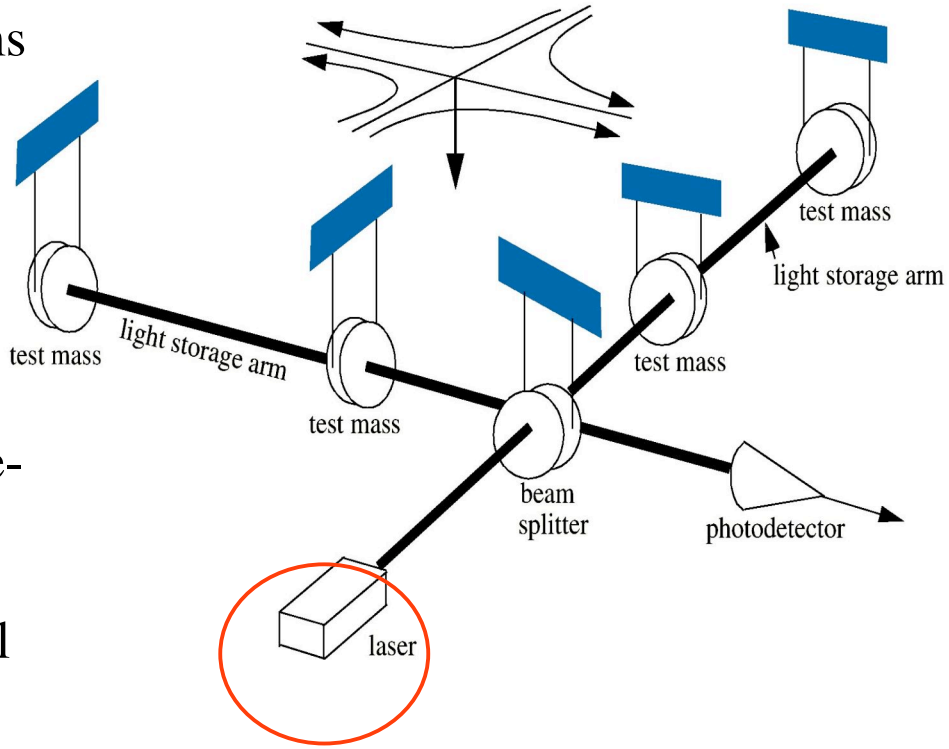
# *Detecting GWs with Precision Interferometry*

• Interferometry allows us to determine relative distance between test masses (mirrors) in 2.5 mile long L-shaped arms with *incredible* accuracy (~$10^{-18}$ m)

• Suspended mirrors act as markers tied to the fabric of space-time

• A passing gravitational wave alternately stretches (compresses) space-time and thus the arms.

• Due to light interference, a differential stretch/compress gives a time varying signal at the photodetector




*Gravitational waves can be seen with an instrument sensitive to changes in length*

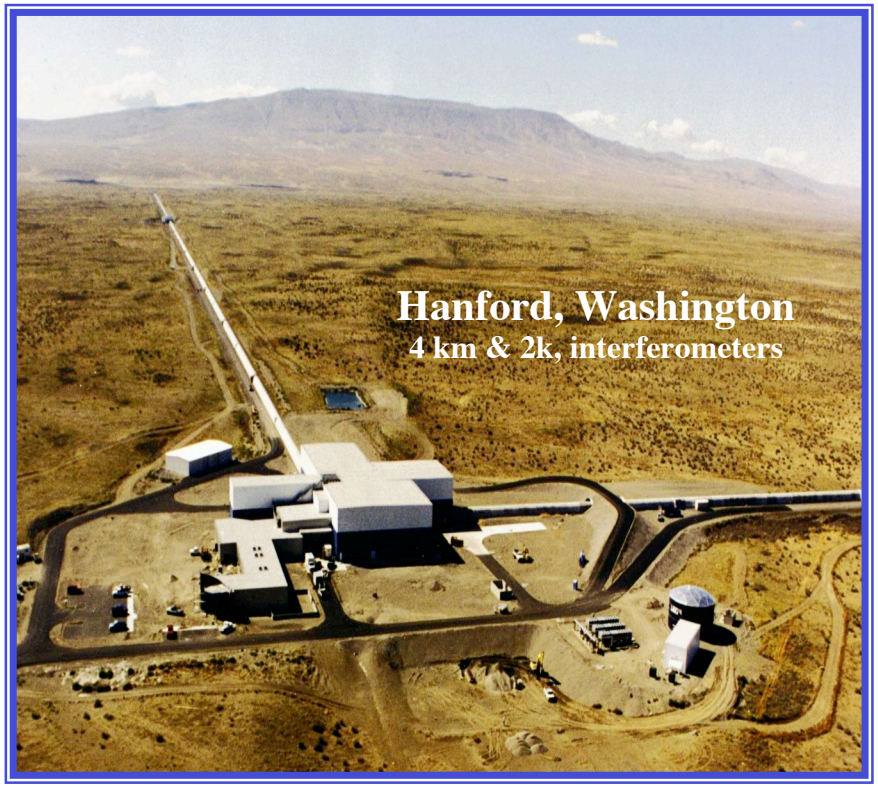
**Movie showing how LIGO works**


# *The challenge of measuring gravitational waves*

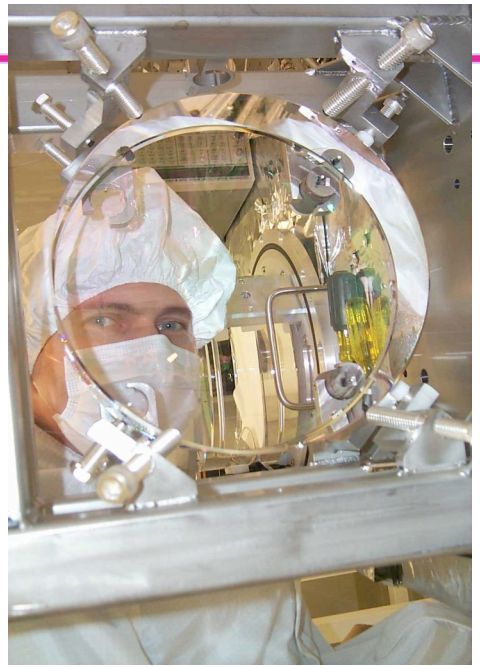
- Gravitational waves from even the strongest cosmic sources are very weak when they reach earth (strain ~ $10^{-22}$)
- To see them LIGO must be *sensitive to differential change in arm length of ~$10^{-18}$ m*
  - See change of 1/1000 the size of a proton over 2 1/2 miles!!!
  - Like measuring distance to nearby stars with accuracy of a hair's width
- If successful can search for signals from many fascinating astrophysical sources--
  - Inspiraling neutron star and black hole pairs,
  - Collapsing supernovae,
  - Pulsars-- rotating neutron stars
  - The Big Bang,
  - the unknown.

# *Realizing this concept-The LIGO Observatory*

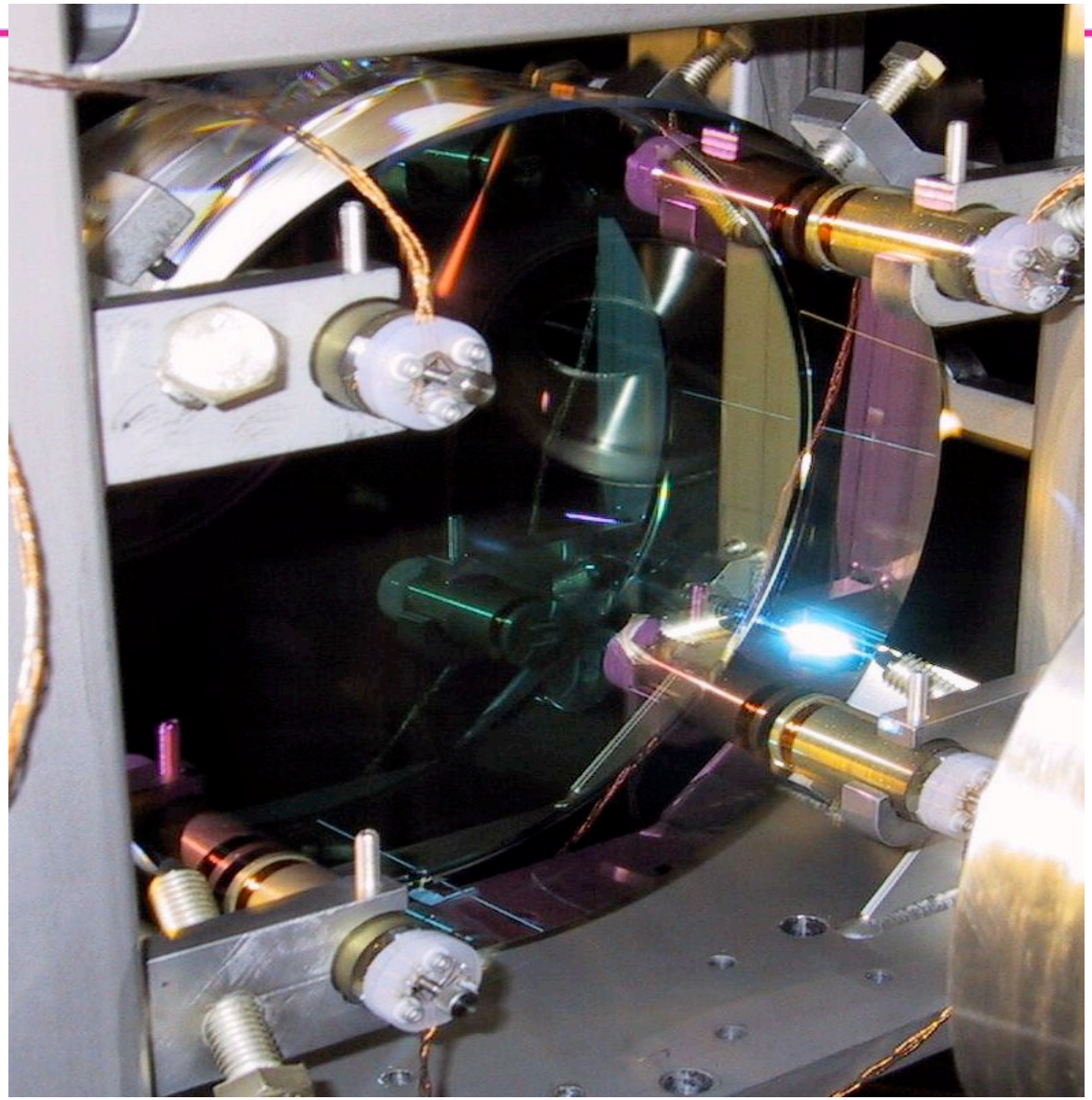
- Widely spaced (3000 km) kilometer-scale interferometers
  - so not fooled by tiny signal due to local disturbance--
  - Hanford Washington and Livingston Louisiana




# *Some LIGO hardware*

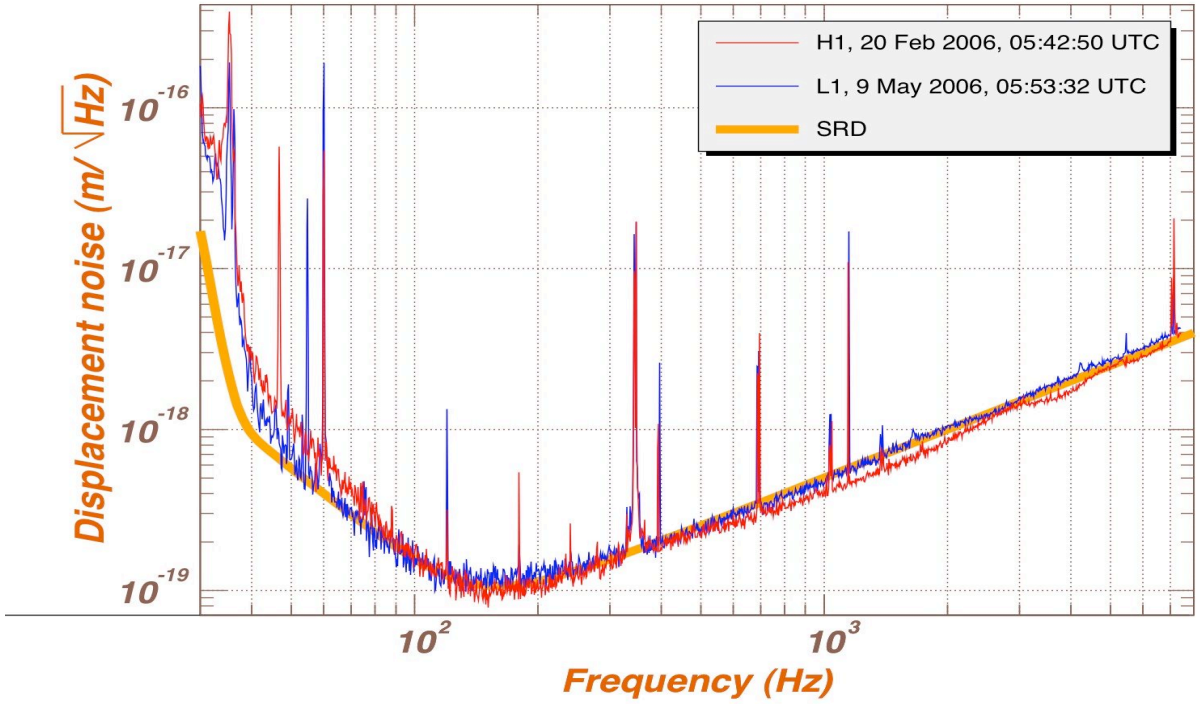


# *Core optics and control actuators*



# *The challenge of measuring gravitational waves*

- After 5 years of intense effort to reduce noise by ~ 3 orders of magnitude,
- LIGO's design sensitivity of ~$10^{-18}$ m was reached in 2005--a great achievement.

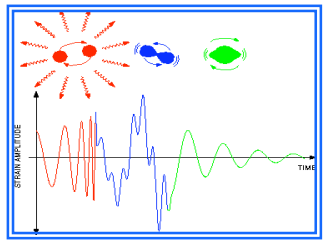



# *LIGO today*

- In October 2007 LIGO completed 2-year long science run at better than design sensitivity--
  - » Proof that LIGO works, can be operated at the exquisite sensitivity required for long periods of time
  - » Sensitive enough to "see" merging neutron star pairs >50 million light years away
  - » and merging black hole pairs >400 million light years away
- No GW waves detected yet (as expected)
- Interesting scientific results being published

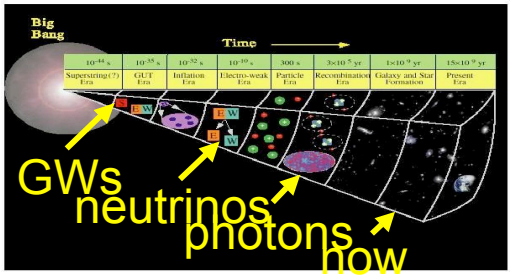
# *Examples of interesting results from limits*

- **Binary neutron stars or black holes coalescing**
  - » In Milky Way sized galaxy
    - – for 1.4 $M_o$ NS-NS happens less often than once every 50 years
    - – for 5.0 $M_o$ BH-BH happens less often than once every 250 years




- **Pulsars-- spinning neutron stars that spindown**
  - » For Crab pulsar determine that less than 7% of energy lost in spindown goes into GWs
  - » Limits on pulsar ellipticity ~ $10^{-6}$ (1 cm bump on 10 km size object)

- **GWs from the Big Bang** (data from previous run)
  - » Fraction of the energy density in the universe in GW (in 50-150Hz frequency band) is less than 65 parts per million



# *Example of triggered search*
## *Gamma Ray Burst on February 1, 2007*

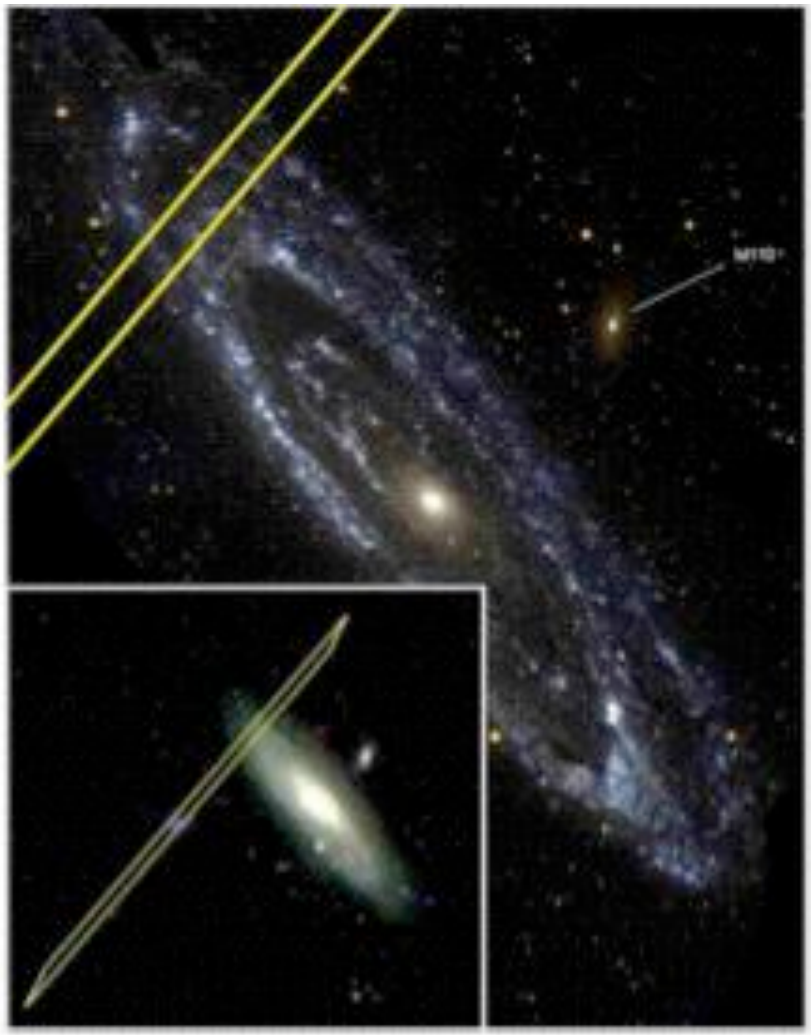
* Few second-long gamma ray burst seen by x-ray satellite in direction of Andromeda galaxy- 2 million light years away

* Mechanism-- merging pair of neutron stars or something else?

* If merging pair in Andromeda, LIGO would have seen a very big signal because our range is >50 million light years

* Saw nothing-- event is due to another mechanism or located far beyond Andromeda.

* This result got a lot of attention in the astronomy community

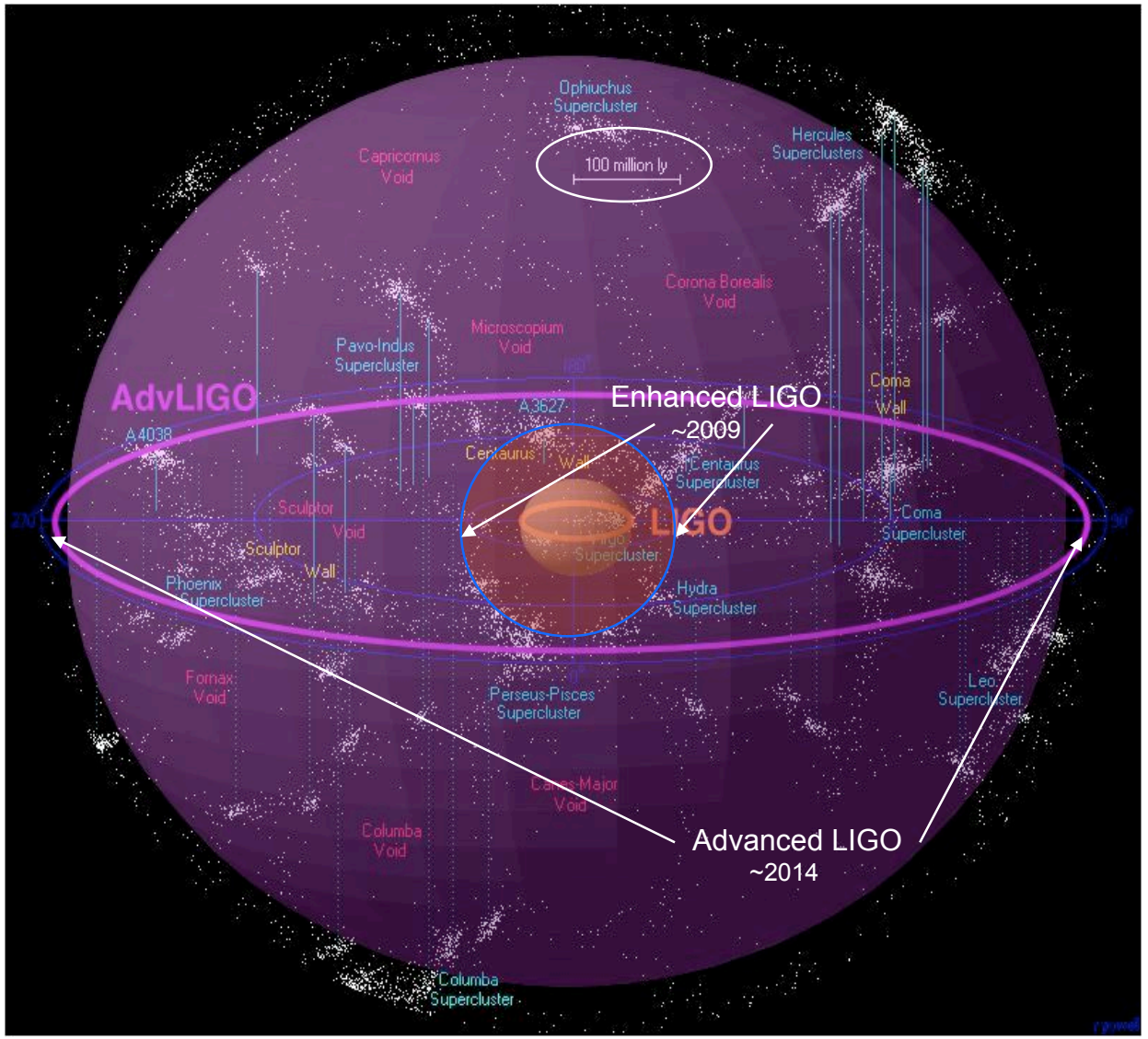



# *The future-Probing deeper into the cosmos*

- Near term- Enhanced LIGO (~double LIGO's sensitivity)
  - » Increase # galaxies in range by factor of 8
  - » Begin science run in 2009
  - » Discovery probability-moderate (maybe 30-50%)
  - » Lead by R. Adhikari, new Caltech Asst. Professor

- Longer term--Advanced LIGO project (~10x sensitivity)
  - » The big step forward for the field
  - » 1000 times more galaxies in range-- no question of discovery
  - » In ~ 2014 expect ~1 signal/day or /week
  - » Will usher in era of gravitational wave astronomy

# *The future-- Probing deeper into the cosmos*



# *The big news*

BBC News (4/17/08)-

"The next phase in physics' great 21st century quest- to detect gravitational waves-- has been approved"

On March 31, 2008 the National Science Board approved:

- Funding for Advanced LIGO construction
  - » $205.11 for the project including $32.75 for FY08
  - » Construction formally started on April 1, 2008
- Funding for the operations of LIGO Laboratory for FY2009 through FY2013.
  - » $150M for the 5-year grant
  - » Caltech invited to submit renewal proposal for additional 5 years--
    - – no recompetition until 2018!!


# *"Sociology"---LIGO is BIG SCIENCE*

- **LIGO = LIGO Laboratory + the LIGO Scientific Collaboration**

- **LIGO Laboratory-** managed by Caltech under a cooperative agreement with NSF
  - ~180 people, headquartered at Caltech with observatories in Louisiana and Washington State & a group at MIT
  - Annual operating budget ~$33M (in FY07, funded by NSF)
  - Operates the observatories, does R&D, analyses data and publishes science results, manages and executes LIGO projects

- **LIGO Scientific Collaboration**
  - ~500 scientists from 45 institutions worldwide (including Caltech)
  - With LIGO Lab, does R&D, analyses data and publishes science results
  - LSC has been integrated into the LIGO Lab management structure

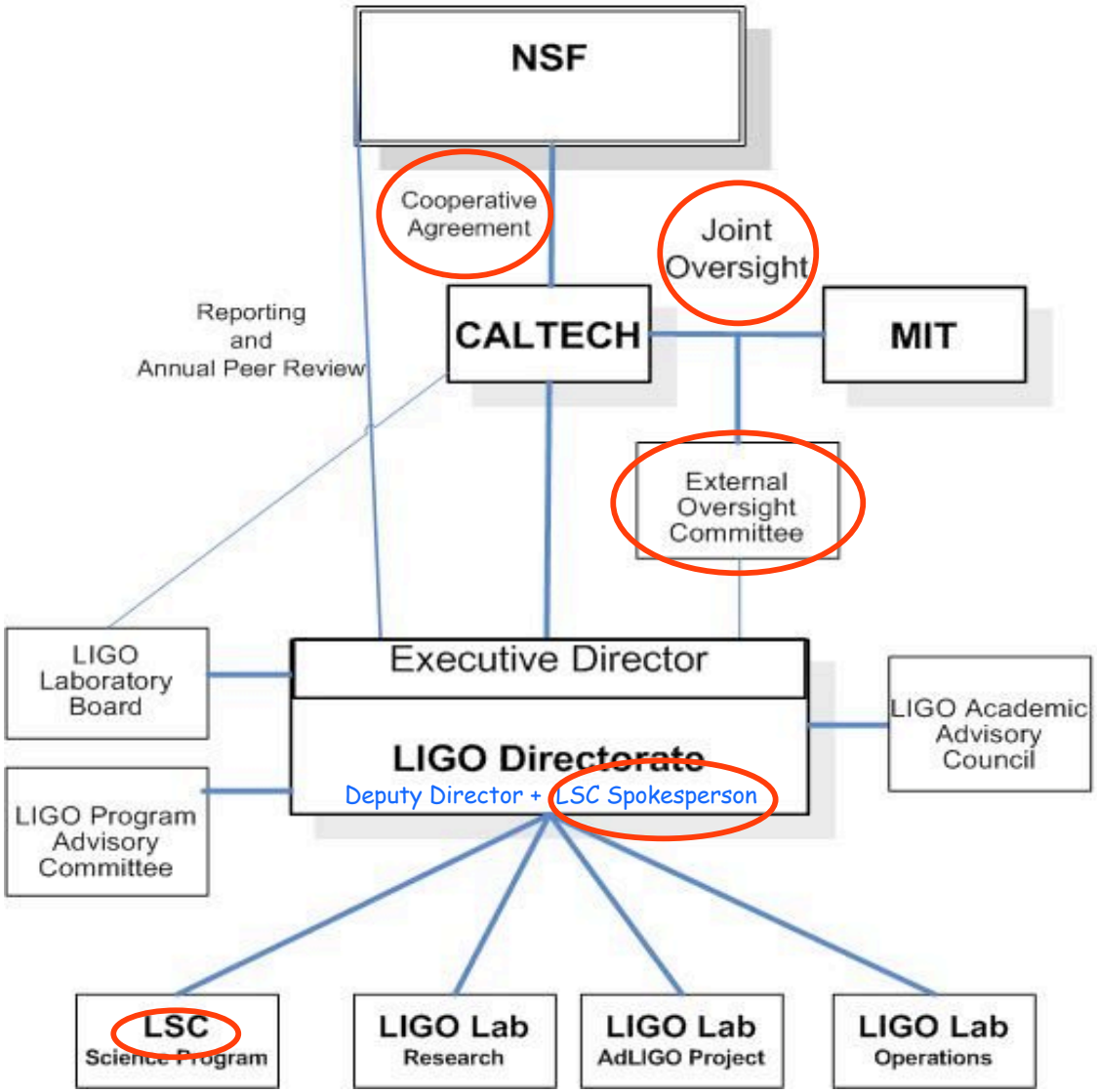

# *How much has/will NSF invest in LIGO?*

## Over 1 billion dollars

- Since start of construction start in 1995: $520M
- Funding for FY2009-FY2015: $390M[1]

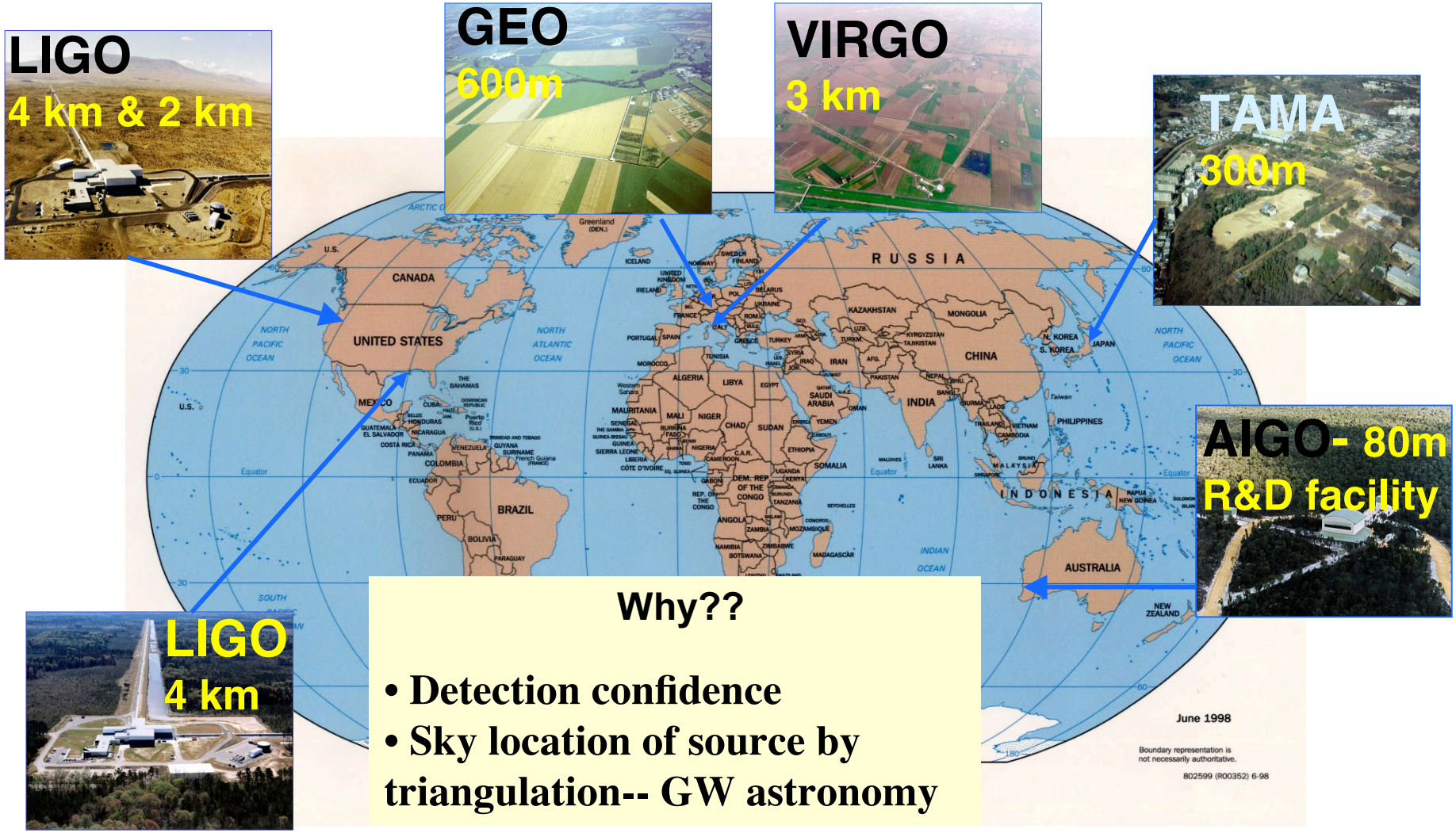
1-- Operations under new Cooperative Agreement, Advanced LIGO construction and estimated operations funding in 2015

# LIGO Organization



# *The international scene*

## *Goal-a global network of interferometers*




# *Status of the global network*

- Being developed under LIGO's leadership
- GEO (Germany & U.K.) and LIGO carry out all observing and data analysis as one team, the LIGO Scientific Collaboration (LSC).
- LSC and Virgo (Italy, France, Netherlands, Poland) have begun collaborative data analysis and joint run planning.
- This collaboration is open to other interferometers when they reach the sensitivity levels to contribute scientifically-
  - » e.g. possible future Japanese and Australian projects

# *LIGO Science Education Center*

*On the LIGO Livingston Louisiana site*

- *Flagship of LIGO's public education program--*
  - Opened October 2007
  - Focus-training science teachers & exposing students to basic physics concepts
  - Partners-- Southern University, LA State Board of Regents, SF Exploratorium

# *Hanford Observatory- very active education and outreach program*

- Bring public out to “touch and see” science in the making
- Help schools with teacher training, internships and school tours
  - » In 2006-7--- ~3000 visitors to site including ~1000 K-12 students
  - » Public lectures, astronomy nights, student workshops, etc.


# *LIGO at Caltech-- people*

- ~90 LIGO Lab people on campus (and ~30 at each observatory site)
  - » Includes 10 postdocs
  - » Also, ~ 10 grad students and ~20 summer students (SURF and REU)
- 6 members of Professorial Faculty involved with LIGO-
  - » Rana Adhakari
  - » Barry Barish (ret)
  - » Yanbei Chen
  - » Ken Libbrecht
  - » Kip Thorne
  - » Alan Weinstein
- And 3 members of the Research Faculty
  - » Curt Cutler
  - » Jay Marx
  - » Stan Whitcomb


# *LIGO connections with other Caltech programs*

- Numerical relativity through TAPIR (Kip's group)
  - Apply Caltech brains and lots of computing power to numerically solve Einstein's equations of General Relativity
  - Essential to solve inverse problem--decode information carried on gravitational waves
  - Successful GW astronomy depends on this
- Astronomy through NSF Frontier Physics Center
  - Proposed to NSF by team from PMA
  - Learn how to extract most interesting astrophysics and astronomy from "seeing" sources through different kinds of eyes--
    - light (with telescopes), x-rays and gamma rays with satellites, radio-waves with antennae, and gravitational waves with LIGO


# *Take-home messages*

- LIGO is the world-leading program in Gravitational Wave science--Caltech led and nurtured
- The recently completed science run at design sensitivity was a big success & science results are being published
- With Enhanced and then Advanced LIGO, LIGO will observe GWs and then pioneer the new field of GW astronomy
  - » Advanced LIGO fund approved and construction started April 1, 2008
  - » New 5-year operations grant for FY2009-FY2013 approved
- A coordinated international network is evolving under LIGO's leadership
- LIGO makes important educational contributions at Caltech and in the public sector.

# *Closing remarks…*

- The future for LIGO will be very exciting
- The opening of the field of gravitational wave astronomy by LIGO will provide a new view of the cosmos