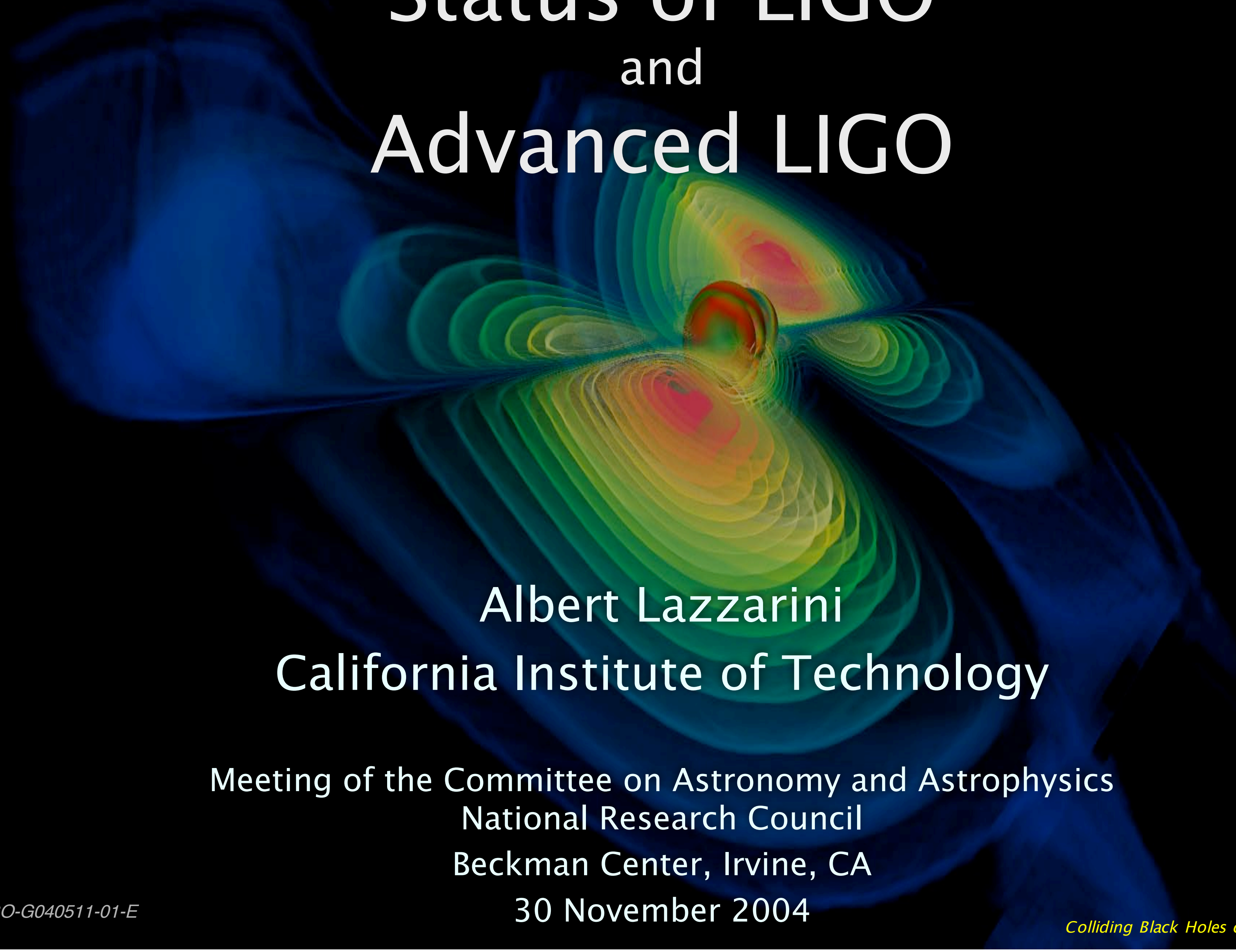
Status of LIGO
and
Advanced LIGO



Albert Lazzarini
California Institute of Technology

Meeting of the Committee on Astronomy and Astrophysics
National Research Council
Beckman Center, Irvine, CA
30 November 2004

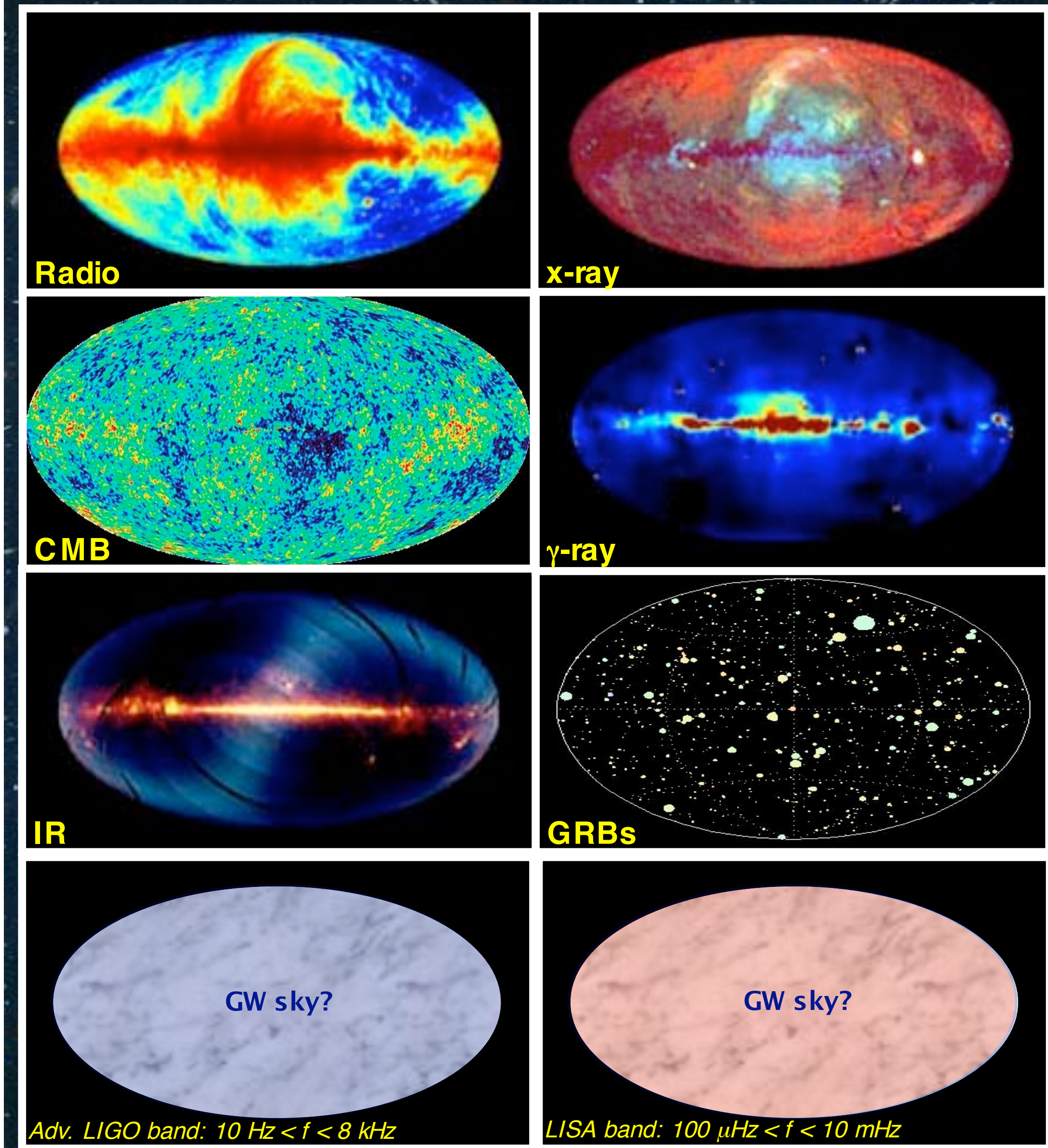
LIGO-G040511-01-E

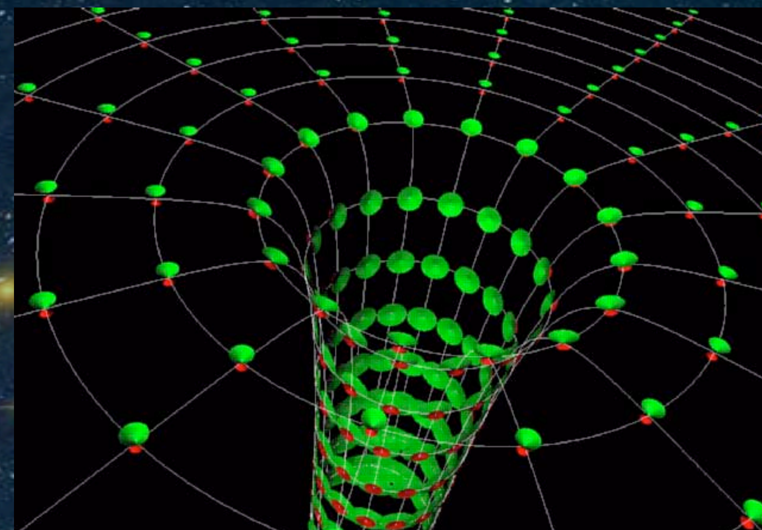
Colliding Black Holes courtesy of NCSA

Overview

- LIGO Mission
- Progress with Initial LIGO
- Status of Advanced LIGO

New Window on Universe





GRAVITATIONAL WAVES WILL GIVE A NEW AND UNIQUE VIEW OF THE DYNAMICS OF THE UNIVERSE.

EXPECTED SOURCES:

BLACK HOLES,
SUPERNOVAE, PULSARS AND
COMPACT BINARY SYSTEMS.

POSSIBILITY FOR THE UNEXPECTED IS VERY REAL!

Science Goals

- Physics
  - Direct verification of the most "relativistic" prediction of general relativity
  - Detailed tests of properties of gravitational waves: speed, strength, polarization, …
  - Probe of strong-field gravity – black holes
  - Early universe physics
- Astronomy and astrophysics
  - Abundance & properties of supernovae, neutron star binaries, black holes
  - Tests of gamma-ray burst models
  - Neutron star equation of state

A new messenger

The LIGO Observatories

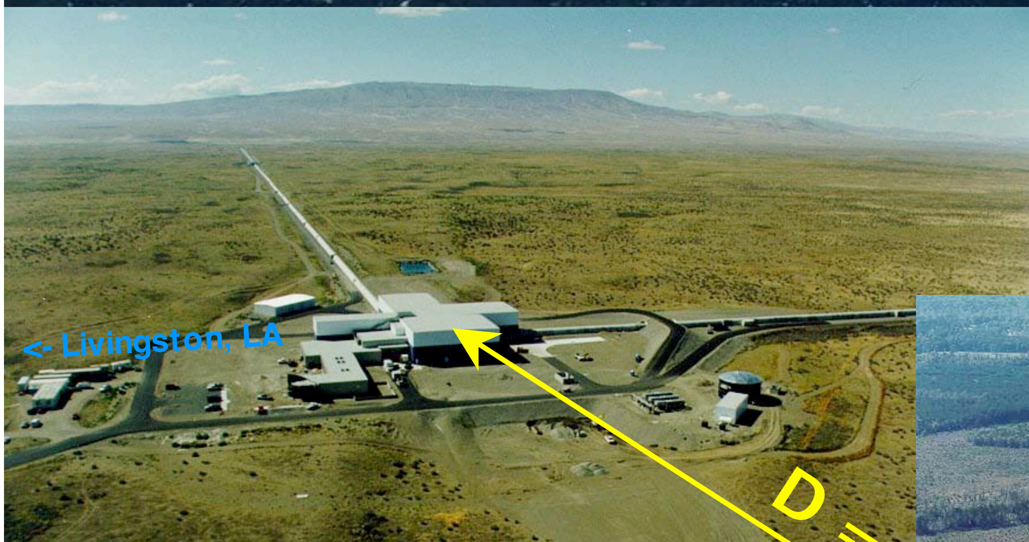
GEODETIC DATA (WGS84)

h: -6.574 m *X arm: S72.2836°W*

f : N30°33’46.419531” *Y arm: S17.7164°E*

l : W90°46’27.265294”

Livingston Observatory
Louisiana
One interferometer (4km)



Hanford Observatory
Washington
Two interferometers
(4 km and 2 km arms)

GEODETIC DATA (WGS84)

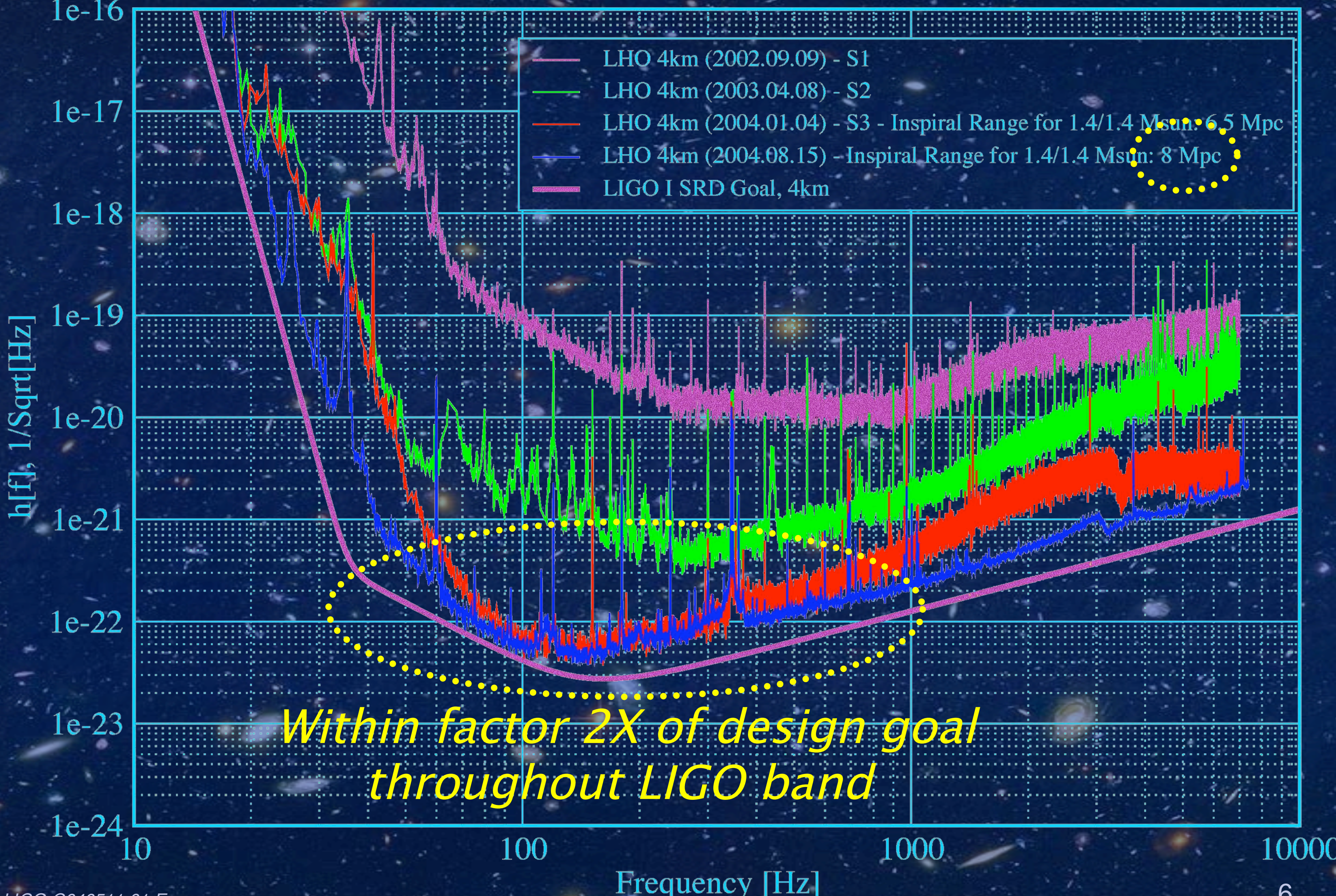
h: 142.555 m *X arm: N35.9993°W*

f : N46°27’18.527841” *Y arm: S54.0007°W*

l : W119°24’27.565681”

Strain Sensitivities for the LIGO Interferometers

H1 Performance Comparison: S1 through post S3 LIGO-G040439-00-E



The LIGO Scientific Collaboration

500 scientists at 42 institutions
27 US & 15 international

LIGO Science Has Begun

Three *Science Runs* (S1--S3) interspersed with commissioning

S1 run: ***Primarily methods papers*** – 17 days (Aug – Sep 2002)
Four S1 astrophysical searches published (*Phys. Rev. D* 69, 2004):

- Inspiraling neutron stars *122001*
- Bursts *102001*
- Known pulsar (J1939+2134) with GEO *082004*
- Stochastic background *122004*

S2 run: ***S2 analyses are mostly complete*** – 59 days (Feb – April 2003)

- Results presented at APS 2004 Spring Meeting, GR-17 (Dublin), upcoming Gravitational Wave Data Analysis Workshop (GWDAW) in Annecy, France (December 2004)

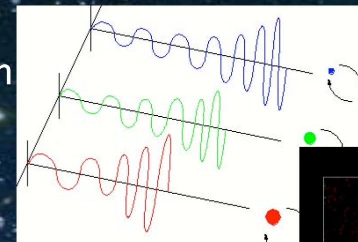
S3 run: ***Analysis is in full swing*** – 70 days (Oct 2003 – Jan 2004)

- Analysis is in full swing; preliminary results becoming available for GWDAW meeting in Annecy, France

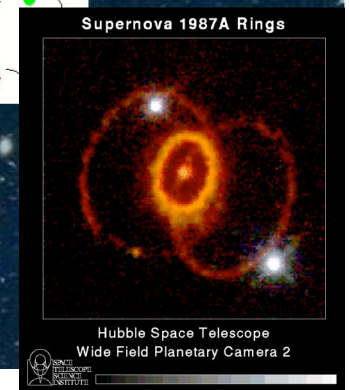
A number of drafts of S2, S3 papers under review by collaboration

Summary of latest results

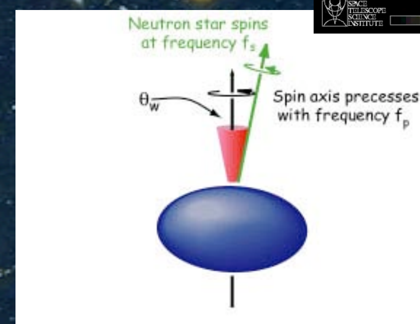
- Chirps
  - S2: 355 hours of coincident (2X, 3X) interferometer operation
  - Sensitive to D ~ 2 Mpc (N_G = 1.14 Milky Way Equiv. Galaxies)
  - $R_{90\%}$ < 50 events/year/MWEG (1 M_{sun} < $M_{1,2}$ < 3 M_{sun})



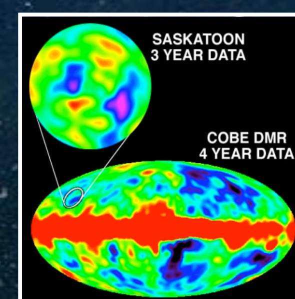
- Bursts
  - S1: 36 hours of 3X operation
  - For $h_{rss} > 10^{-18}$, $R_{90\%}$ < 2/day (limited by T_{obs})
  - Minimum $h_{rss} \sim 2 \times 10^{-19}$
  - S2: 50% detection efficiency $h_{rss} \sim 10^{-20}$



- Periodic (GW pulsars)
  - S2: 1743 hours of observations (1X, 2X, 3X) interferometer operations, targeted 28 known pulsars
  - $h_{90\%} < 1.7 \times 10^{-24}$ (J1910-5959D)
  - $\varepsilon < 4.5 \times 10^{-6}$ (J2124-3358)
  - Crab limit on $h_{90\%}$ within 30X of GW luminosity if spindown were due solely to GW emission



- Stochastic background
  - S2: 387 hours of cross-correlation measurements for H-L
  - Ω_{GW} < 0.018 +0.007/-0.003 in band 50 Hz < f < 300 Hz (preliminary)
  - S3: 240 hours of cross-correlation measurements for H-L, H-H
  - $\Omega_{GW} <\sim 5 \times 10^{-4}$ 50 Hz < f < 250 Hz
  - Plan to look for foreground sources



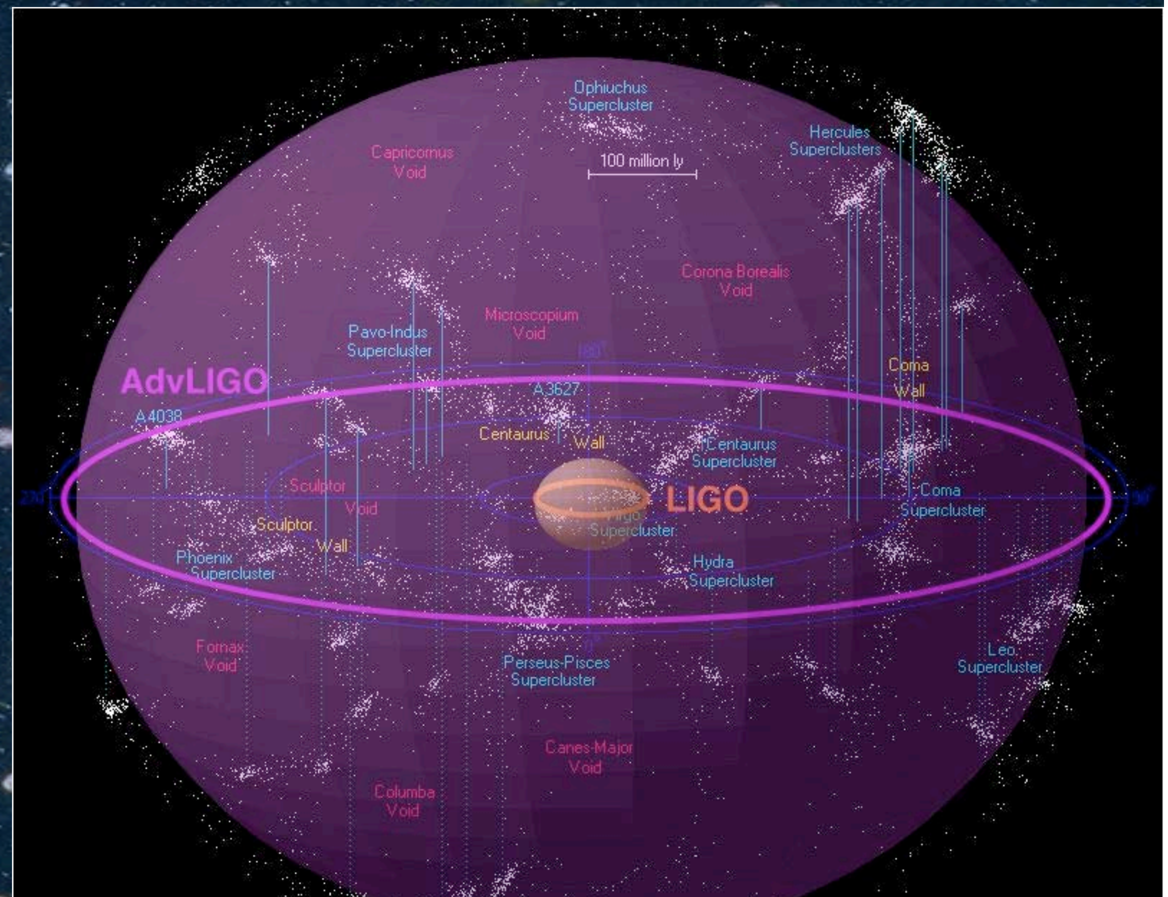
Advanced LIGO

Next phase of LIGO research plan

- National Science Board approves proposal for Advanced LIGO at 13-14 October 2004 meeting
  - Planning for Advanced LIGO is sufficiently advanced and the intellectual value of the project sufficiently well demonstrated to justify consideration by the Acting Director and the National Science Board for funding in FY 2007 or a future NSF budget request.
  - Represents planned follow-on to initial LIGO design
  - $187.2M, includes foreign (UK/Germany) participation
- 2005 - 2010: Initial LIGO Observation at design sensitivity
  - Significant observation within LIGO Observatory
  - Significant networked observation with GEO, VIRGO, TAMA
- 2007: Earliest possible time when funds arrive
  - Test Mass material, seismic isolation fabrication long leads
  - Prepare a 'stock' of equipment for minimum downtime, rapid installation
- 2010: Start initial decommissioning/installation
  - Baseline is a staggered installation, Livingston and then Hanford
- 2013: Coincident observations
  - At an advanced level of commissioning

The spacetime volume ($Mpc^3 \cdot T_{obs}$) explored in the first few hours of operating with Advanced LIGO will be comparable to 1 year of initial LIGO!

- Factor 10 better amplitude sensitivity
  - $(\text{Reach})^3 \propto$ rate
- Factor 4 lower frequency bound
- NS Binaries: for three interferometers,
  - Initial LIGO: ~20 Mpc
  - Adv LIGO: ~350 Mpc
- BH Binaries:
  - Initial LIGO: 10 M_o, 100 Mpc
  - Adv LIGO : 50 M_o, $z = 2$
- Stochastic background:
  - Initial LIGO: ~3 x 10^{-6}
  - Adv LIGO ~3 x 10^{-9}

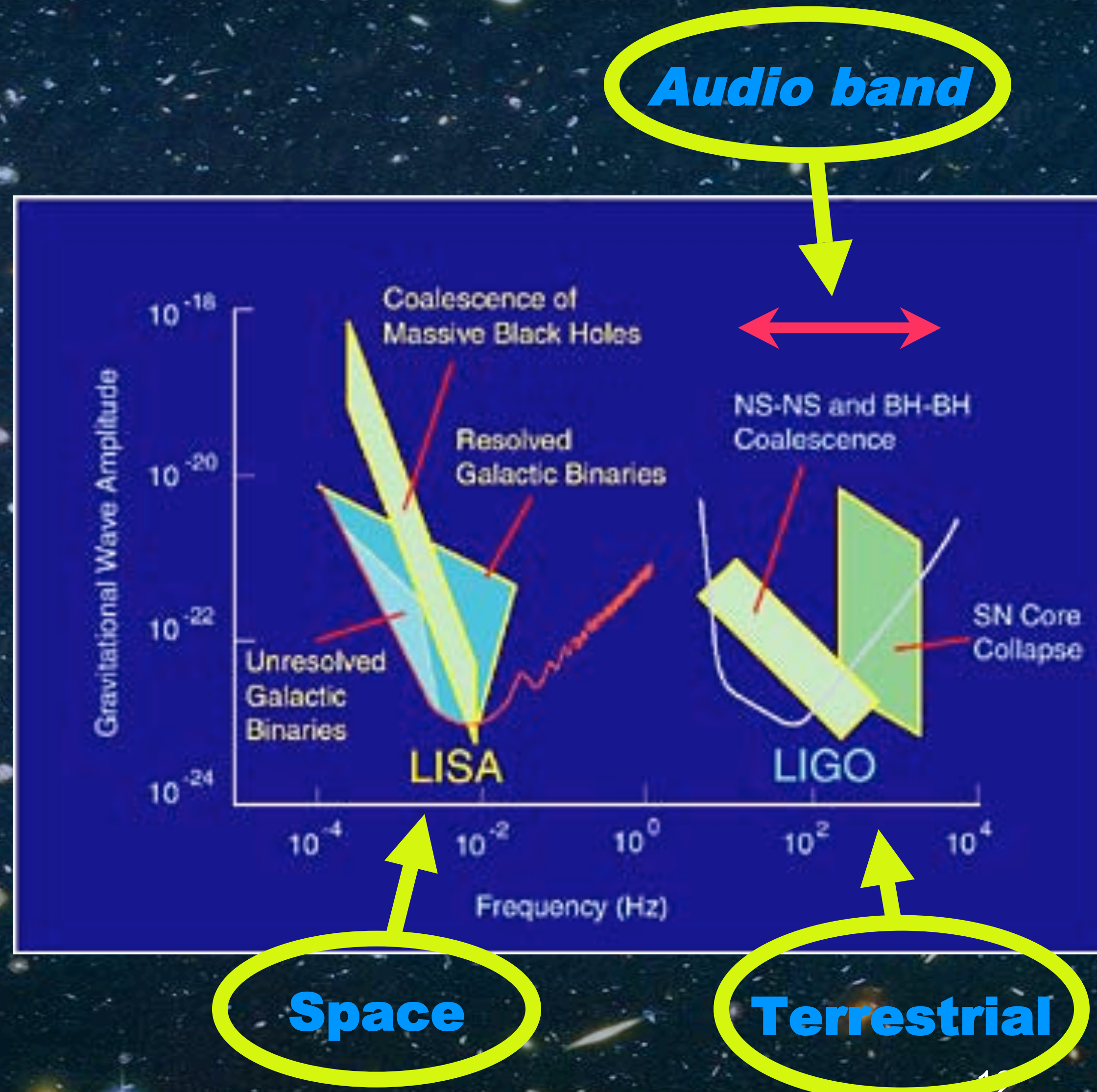


Credits:
Graphic: B. Berger/NSF
Galactic Neighborhood: R. Powell

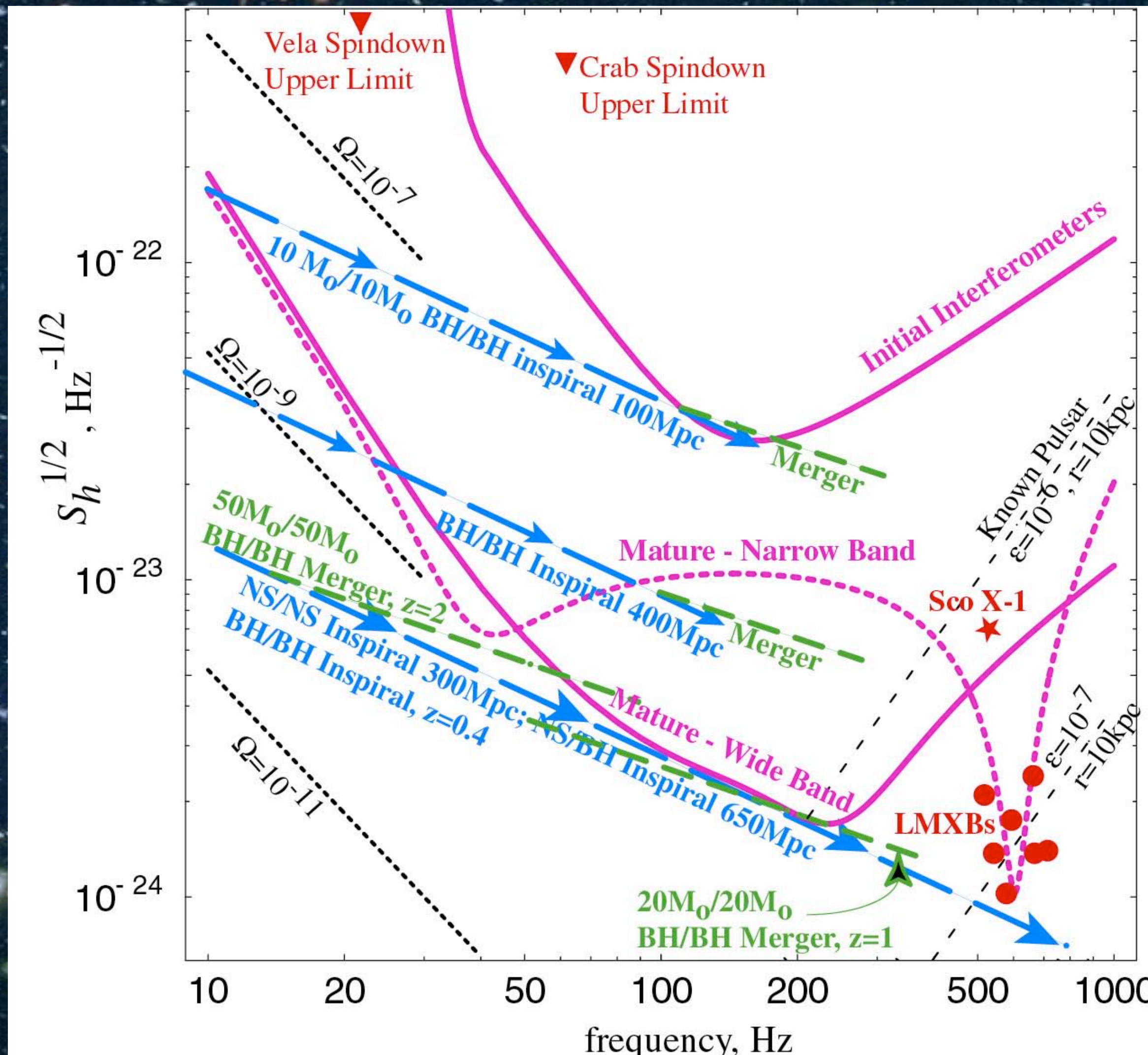
Frequency range for GW Astronomy

Dynamic range of Gravitational Waves

- Terrestrial and space detectors complementary probes
- Provide ~8 orders of magnitude coverage

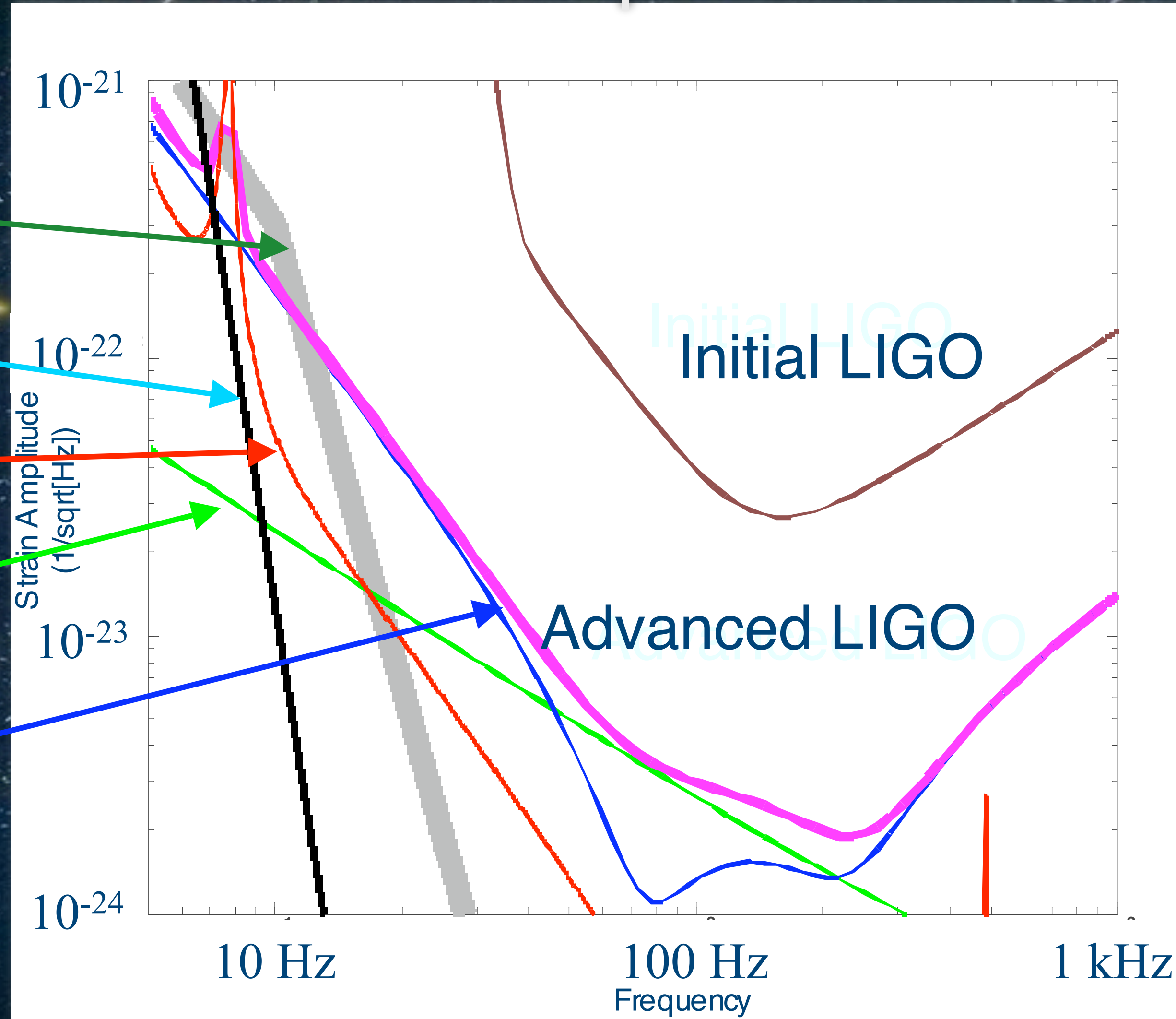


Initial and Advanced LIGO



Anatomy of the projected Advanced LIGO detector performance

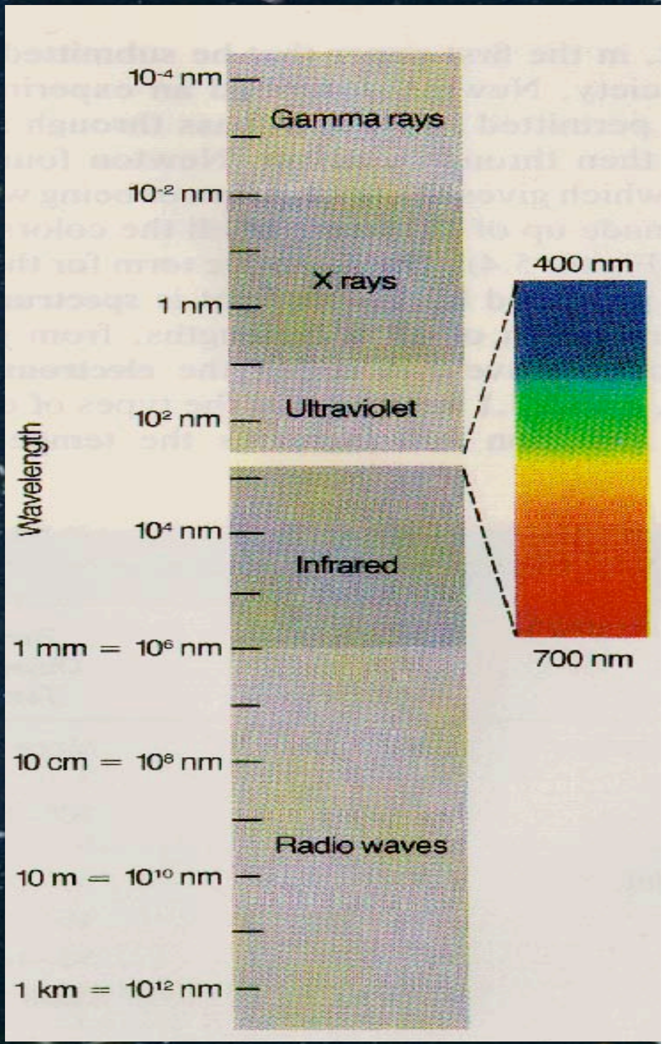
- Newtonian background, estimate for LIGO sites
- Seismic ‘cutoff’ at 10 Hz
- Suspension thermal noise
- Test mass thermal noise
- Unified quantum noise dominates at most frequencies for full power, broadband tuning

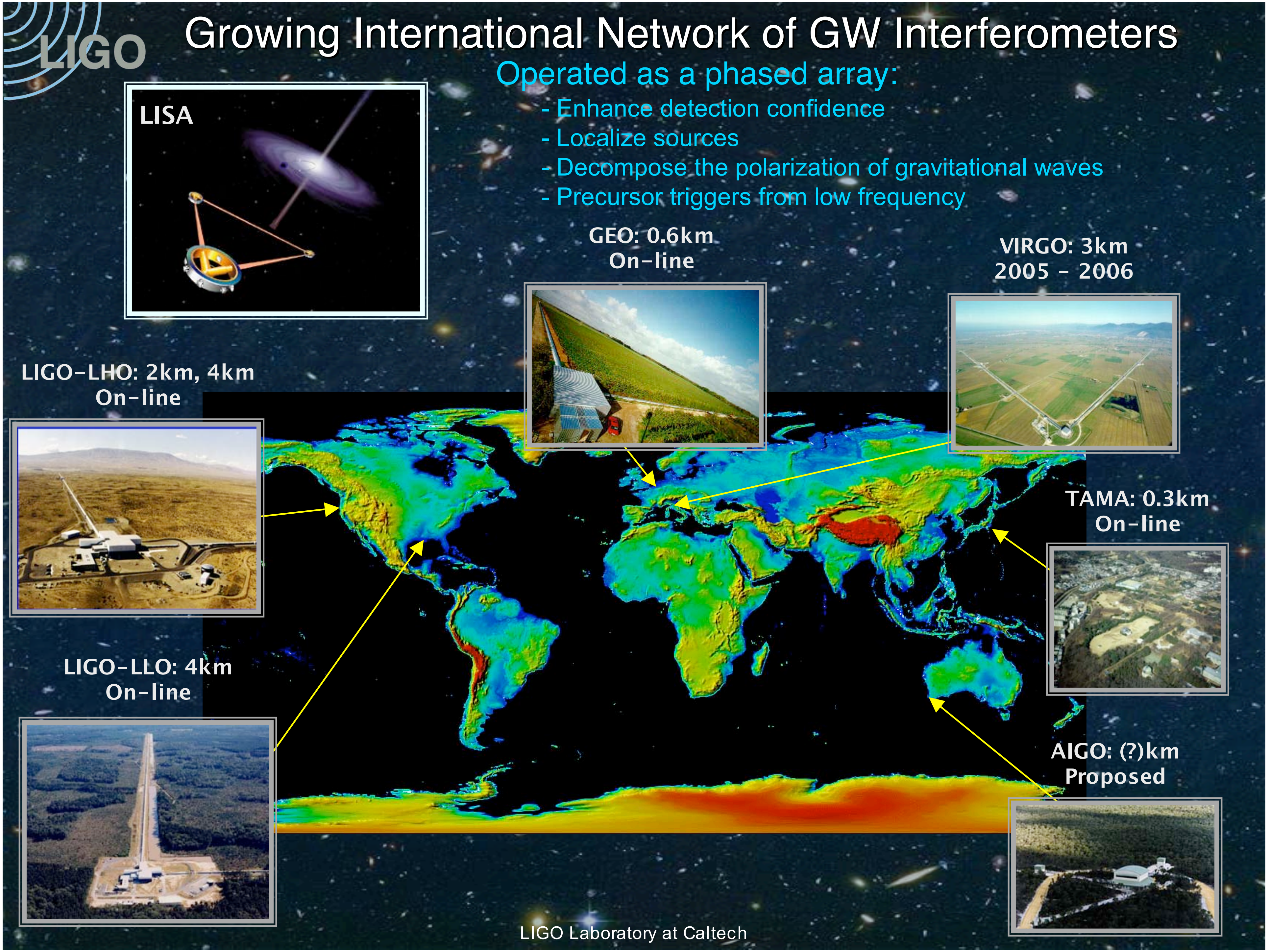


- Advanced LIGO's Fabry-Perot Michelson Interferometer is flexible – can tailor to what we learn before and after we bring it on line, to the limits of this topology

Gravitational Waves as Astrophysical Probes

- Provide *direct* information on bulk (coherent) motion of matter in most energetic events in Nature – opaque to EM
- *Space + terrestrial detectors cover 8 orders of magnitude*
  - Compare: EM -- γ-rays → radio : 16 orders of magnitude
- *High frequency (ground-based)*
  - *SNe- NS, BH formation, nuclear equation of state*
  - *Final coalescence of stellar-mass binary systems*
  - *Rapidly rotating deformed, young NS*
  - *Probes of strong gravity*
- *Low frequency (space-based)*
  - *Formation, coalescence of super-massive black holes in galactic centers*
  - *Binary systems at large separation -- coordination of observations with ground-based GW systems, EM observations*
  - *Stochastic gravity at low frequency*




LIGO
Growing International Network of GW Interferometers
Operated as a phased array:
- Enhance detection confidence
- Localize sources
- Decompose the polarization of gravitational waves
- Precursor triggers from low frequency
LISA
GEO: 0.6km
On-line
VIRGO: 3km
2005 - 2006
LIGO-LHO: 2km, 4km
On-line
TAMA: 0.3km
On-line
LIGO-LLO: 4km
On-line
AIGO: (?)km
Proposed
LIGO Laboratory at Caltech