Gravitational Wave Detection

With Initial and Advanced LIGO

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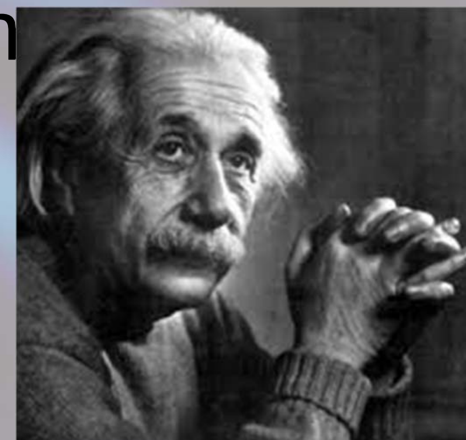
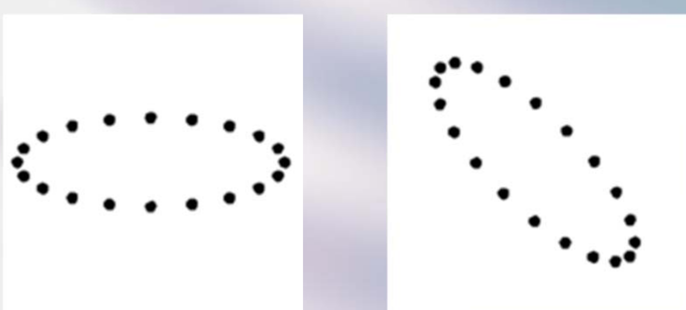
Gravitational Waves

- Gravitational waves are a prediction of Einstein's theory of gravity
- Similar to electromagnetic waves (light) from Maxwell's equations

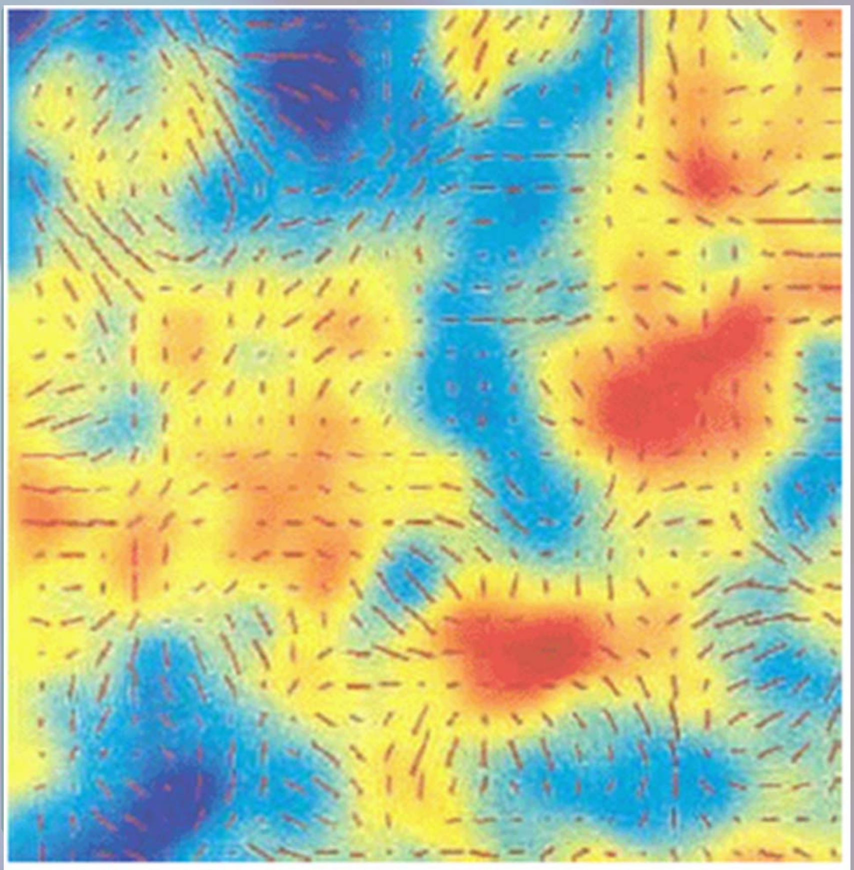


- Two major differences
- Spin two (tensor) shape
- Much smaller amplitude
  - Strain $\frac{\Delta L}{L} \cong 10^{-22}$
  - Kilometer baseline, subnuclear length changes



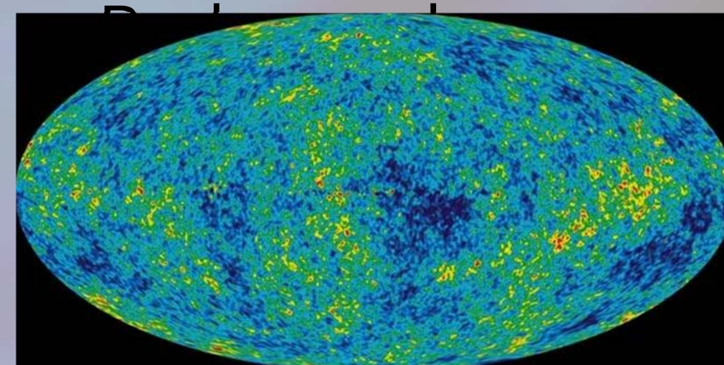
Indirect Evidence for GW

- Known binary neutron star binaries will merge within 100 million years
- Hulse and Taylor observation
  - Change in orbit of neutron star binary
- BICEP2 result
  - If it holds up, gravitational waves from Bing Bang

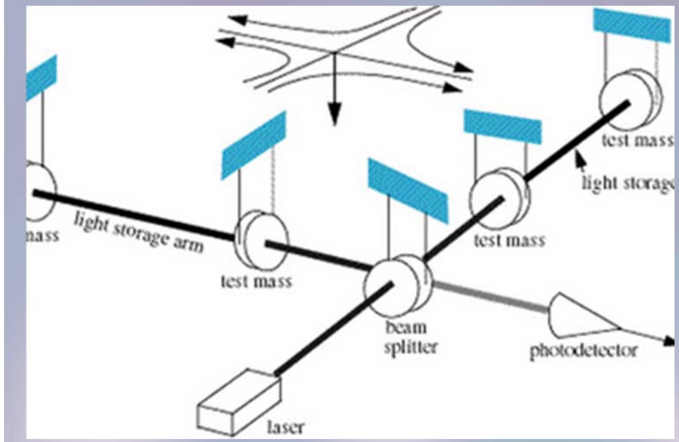


Direct Gravitational Wave Sources

	Short Duration	***Long Duration***
Modeled	Compact Body Inspirals	Periodic Sources
Unmodeled	Bursts	Stochastic



LIGO Interferometers



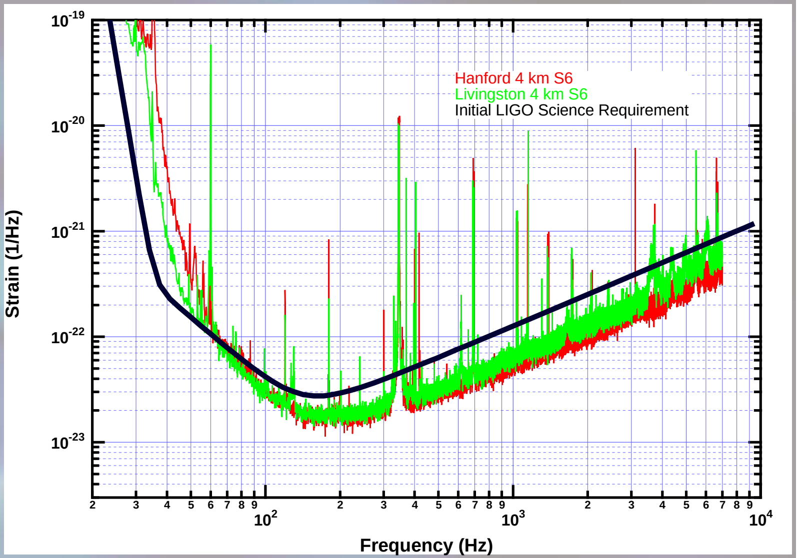
- Modern gravitational wave detectors use interferometers
- Sense tiny motion of mirrors
- L shape for tensor waves

- US has two sites
  - Livingston, Louisiana (LLO) and Hanford, Washington (LHO)
- 4 kilometer-long beam tubes
  - Entire 8 km length in vacuum
  - Low seismic noise environment

Initial LIGO

- Science data 2002 – 2010
  - Over full year coincident
- Bandwidth 40 – 3000 Hz
- Exceeded sensitivity goal

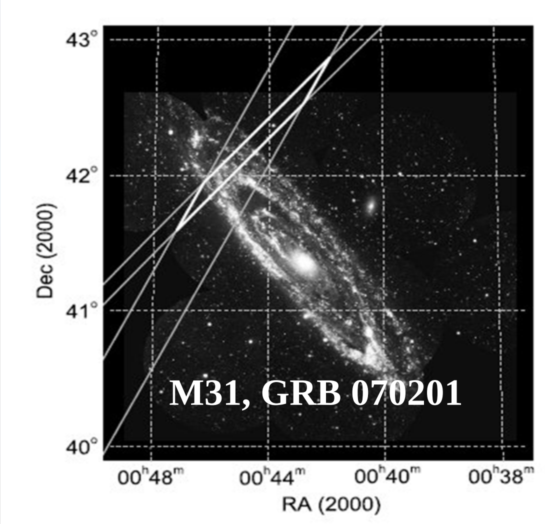
$$\frac{\Delta L}{L} = 2 \times 10^{-22}$$

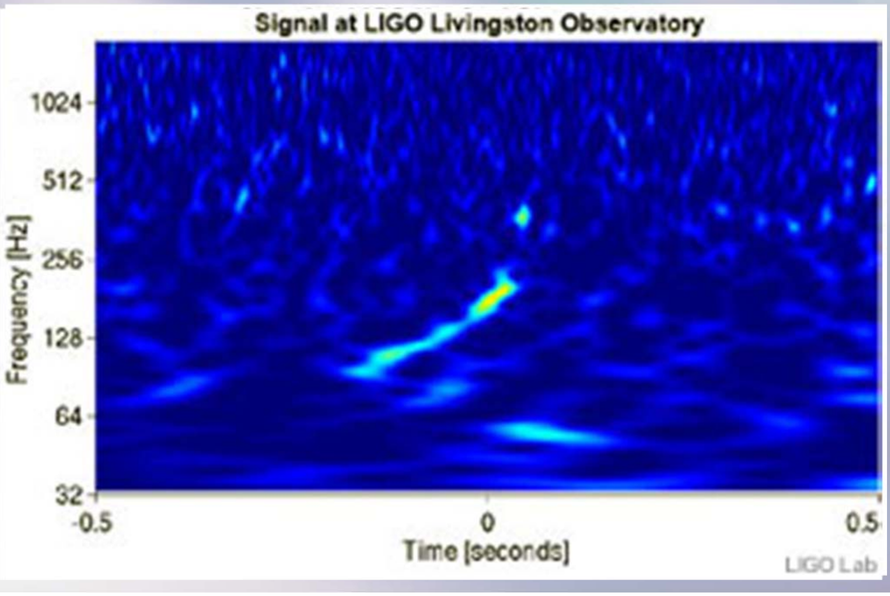


- 3 detectors. 2×4 km/1×2 km
- 20 W Nd:YAG laser
- 10 kg silica optics
- Steel wire suspensions

Initial LIGO Astrophysics: Burst and Inspiral Sources

- Gama ray bursts (GRBs) may be compact body inspirals
- Short GRBs 050311 and 070201
  - Locations in galaxies M81 and M31
  - Inspiral excluded at >98%

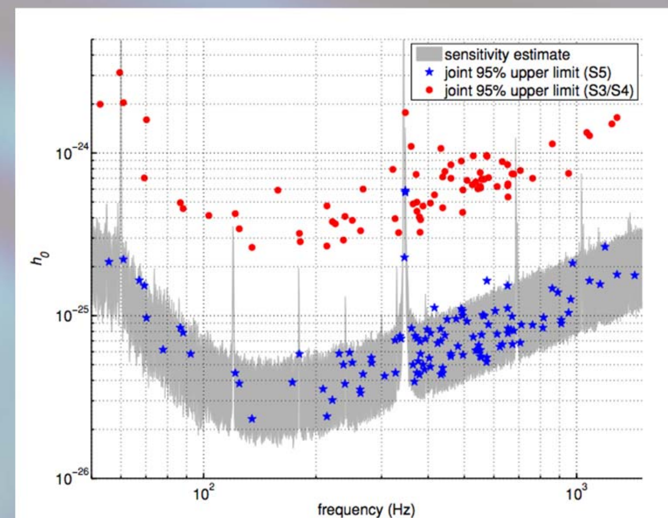


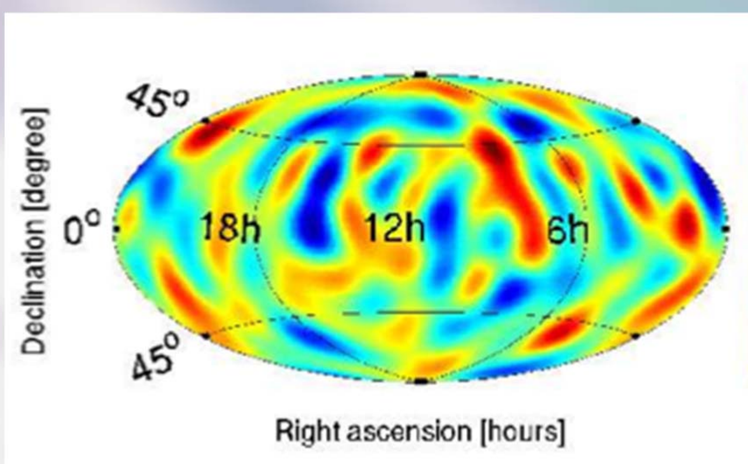


- GW100916
  - Consistent with compact body inspiral
  - Blind injection done to test analysis process

Initial LIGO Astrophysics: Pulsars and Stochastic

- Pulsars can give continuous GW from asymmetric rotation
- Crab pulsar $E_{GW} < 0.02\ E_{total}$
- Ellipticity limit in 116 pulsars
  - Lowest upper limit $\epsilon < 7 \times 10^{-8}$

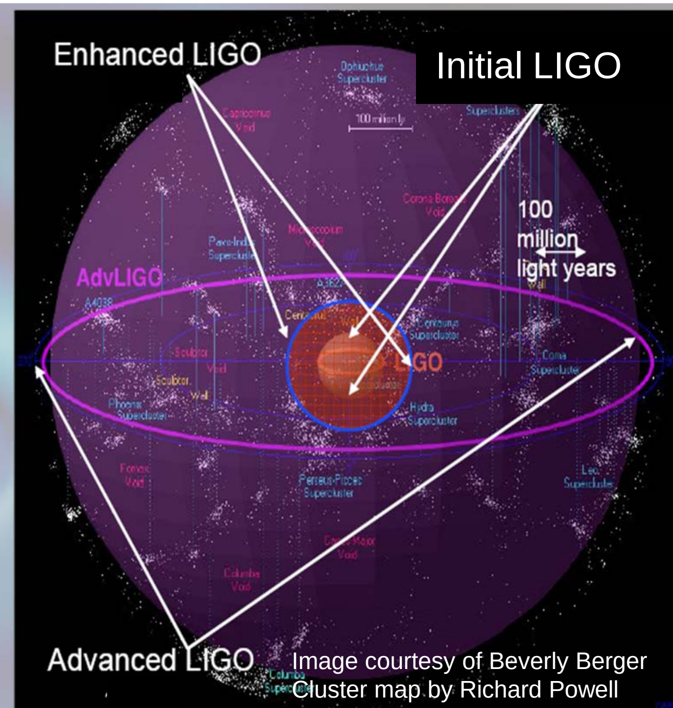




- Stochastic GW from primordial background
- $\Omega_0 < 6.9 \times 10^{-6}$
  - Nucleosynthesis limit 10^{-5}
- Limits on point sources

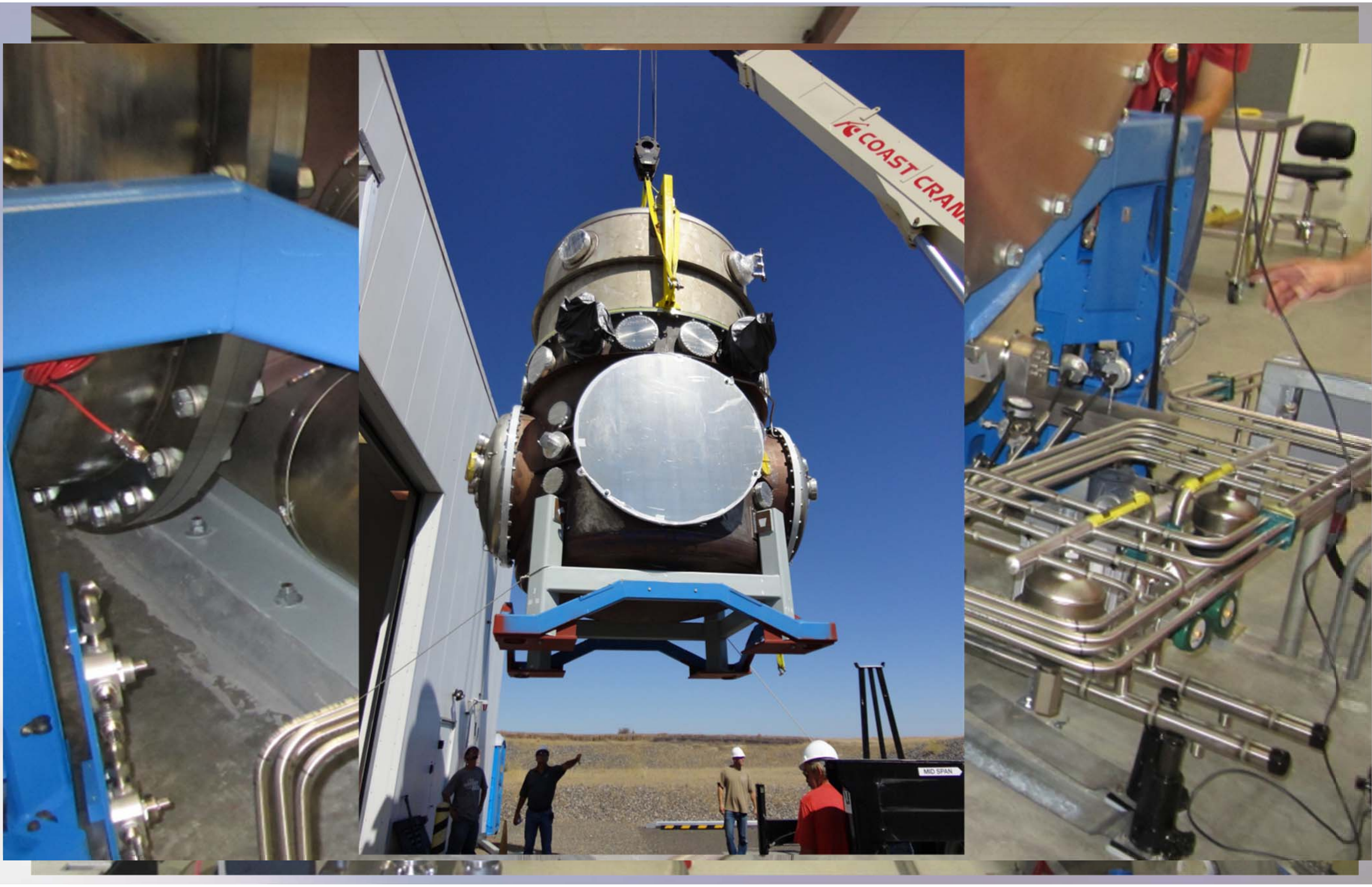
Advanced LIGO

- Goal: 10X sensitivity
  - 10 – 5000 Hz
  - 200 Mpc NS inspiral range
  - Inspirals possible ~ 1/month
  - One day with Adv LIGO = a few years with initial LIGO



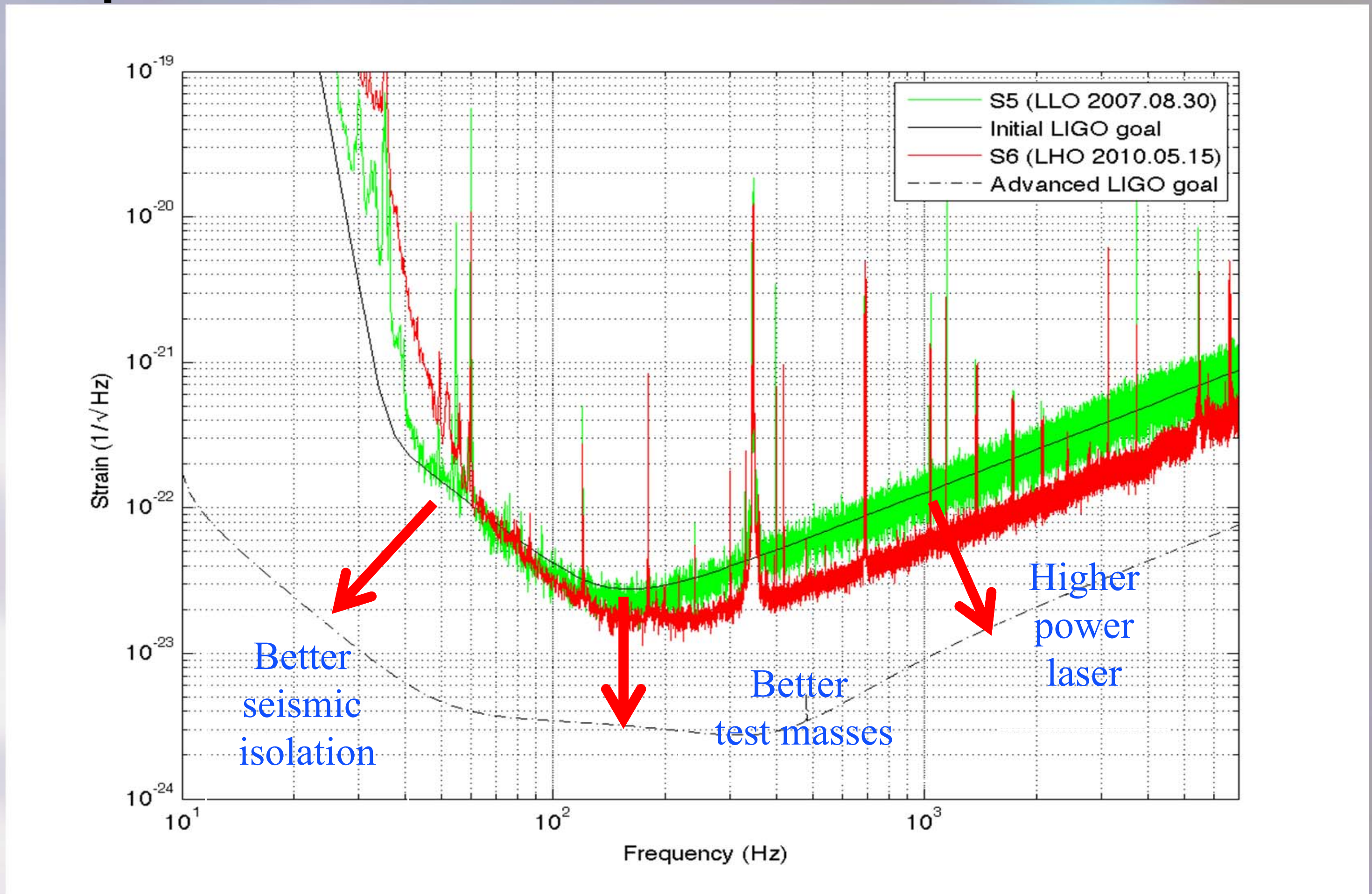
- Project began 2008
  - Installation started 2010
  - Building three interferometers
  - Installation finishing this year

Advanced LIGO Installation

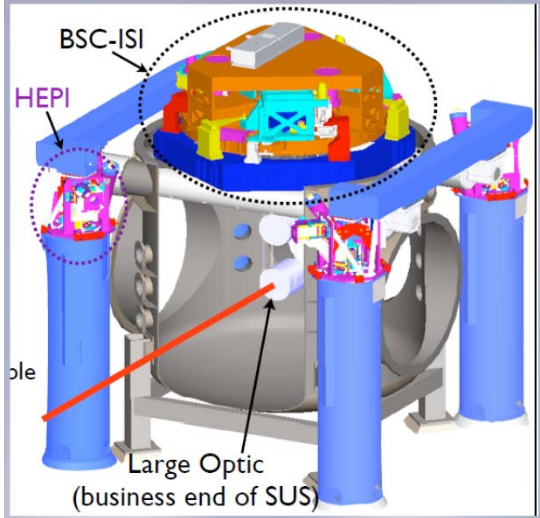


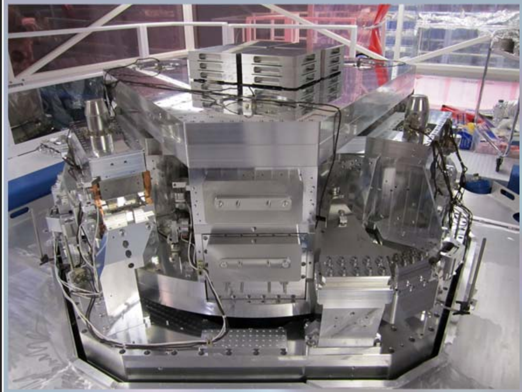
Advanced LIGO Sensitivity

Limited by Earth motion, thermodynamics, and quantum mechanics

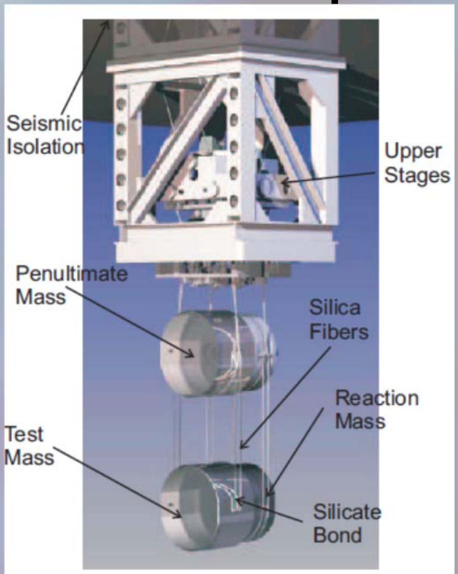


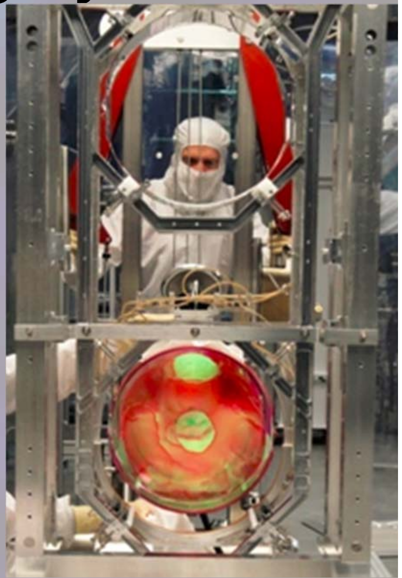
Advanced LIGO Seismic Isolation and Suspension





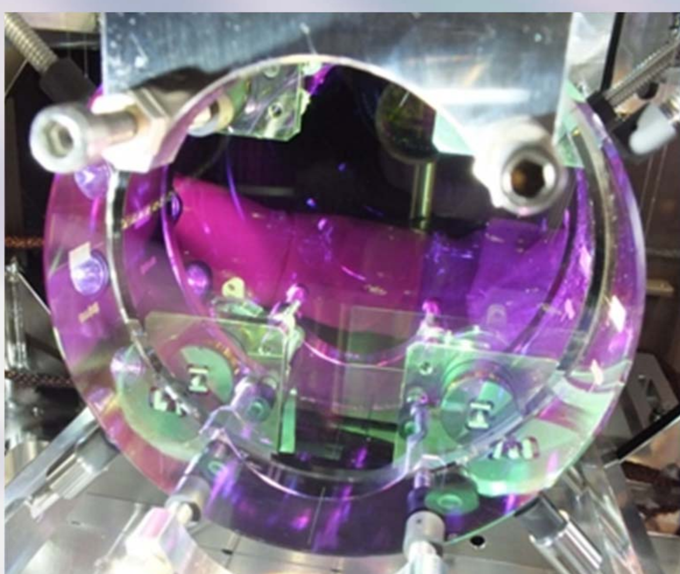
- Seismic isolation
  - Hydraulic preisolator external to vacuum
  - In vacuum, two stage, 6 DOF active mass/spring system
- Quadruple suspension
  - Based on GEO600 triples
  - Seismic noise reduction $^1/_{f^8}$ above pendulum f
  - Final stage silica fibers to reduce thermal noise

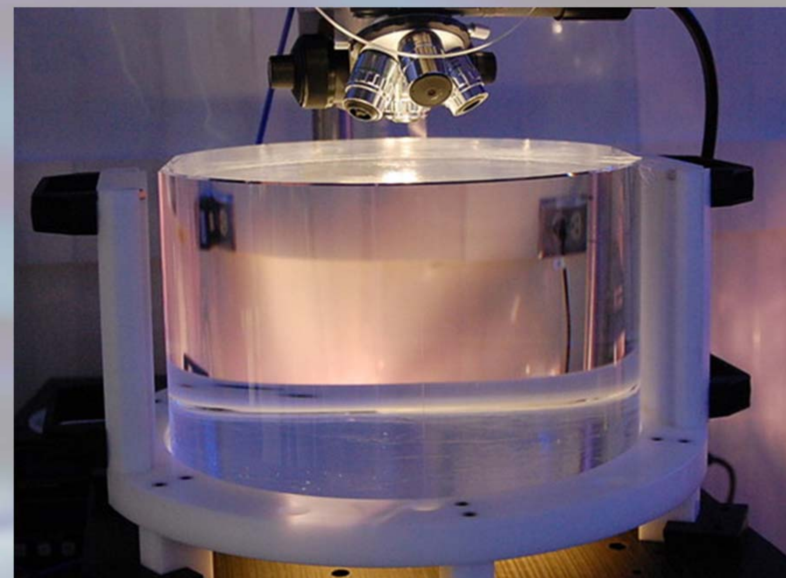




Advanced LIGO Mirrors and Coatings

- Fused silica optics
  - 40 kilograms
  - Very low absorption
  - Monolithic connection to suspension



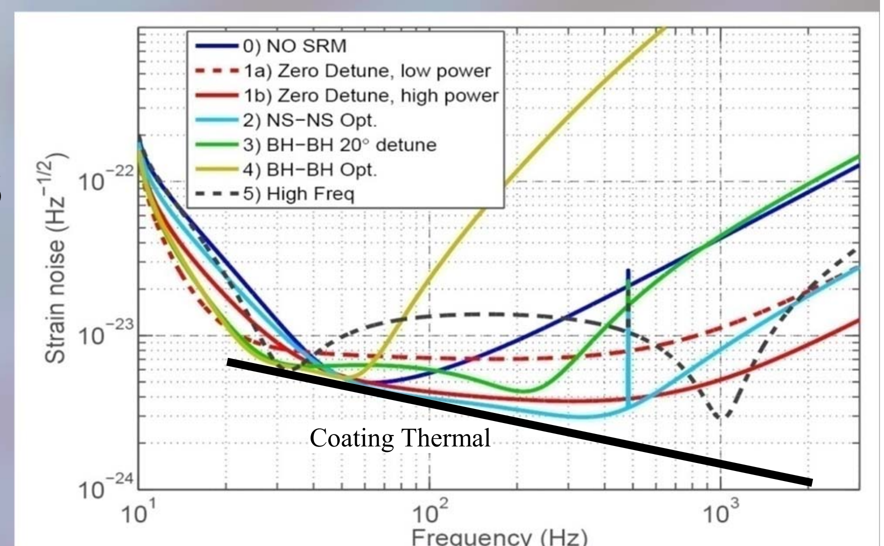


- Optical coatings
  - 34 centimeter diameter
  - 5-6 cm beam spot
  - Very low absorption
  - Low thermal noise

Advanced LIGO Laser and Interferometry

- Laser
  - Nd:YAG 1064 nm
  - Three stage NPRO
  - 180 Watts
  - Shot noise limited

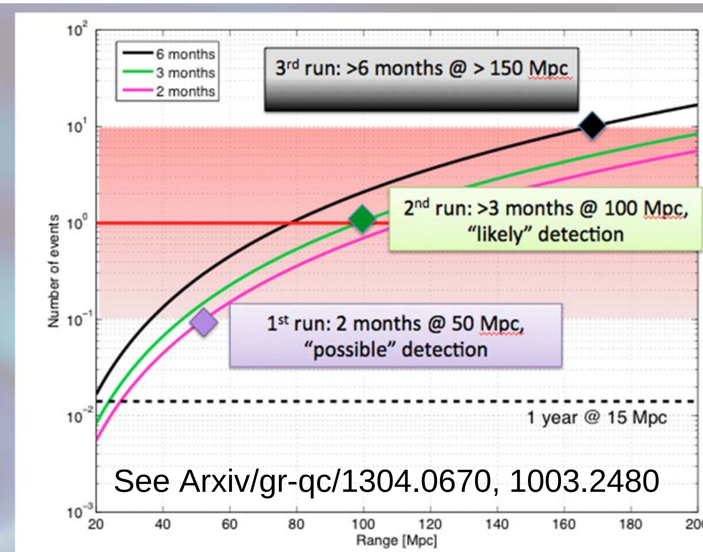
- Interferometer
  - Power recycling increases arm power to 800 kW
  - Signal recycling to tune sensitivity curve

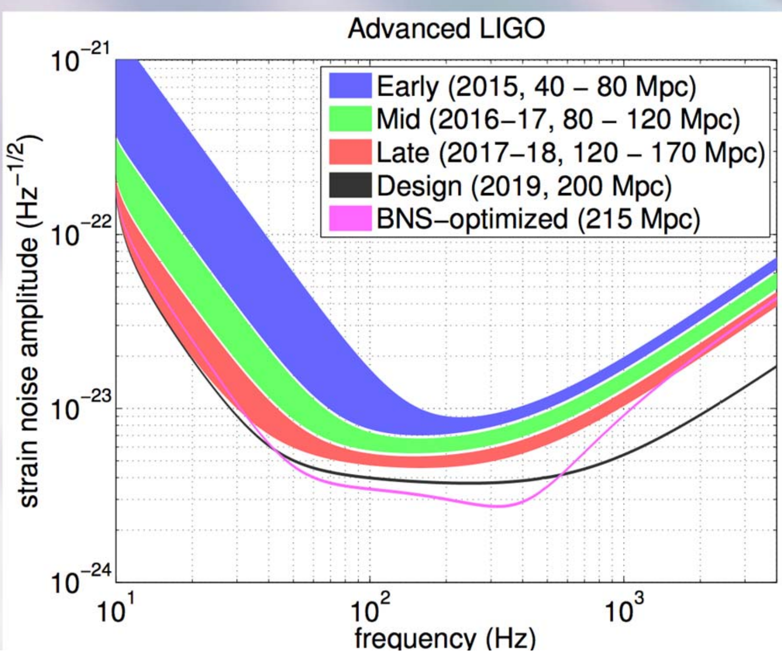


LIGO

Status and Science Plans

- 90% complete by budget
- Remaining activities
  - Finish installation at LHO
  - Testing at both LLO and LHO
  - Computer procurement

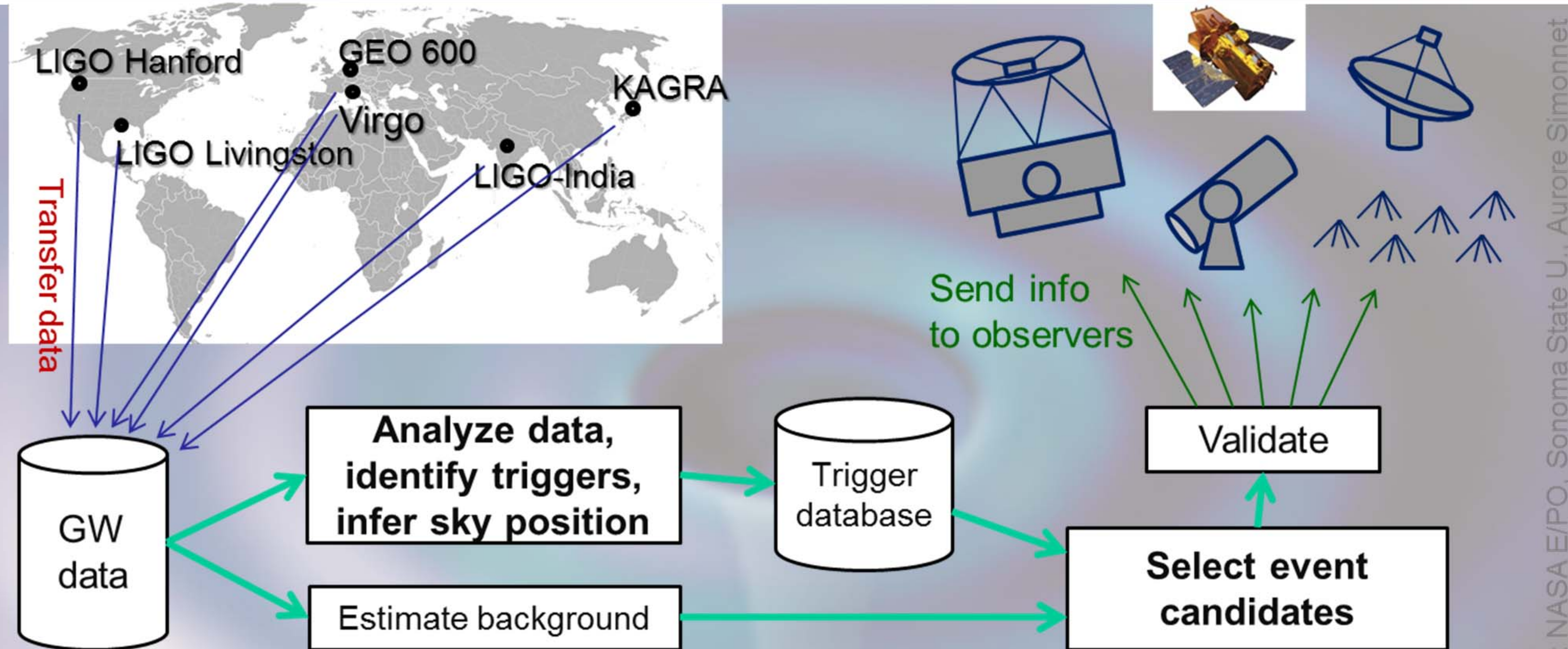




Goal: Direct detection century after Einstein's 1916 GW paper

Date	**Length**	**Sensitivity**
Late 2015	3 months	40-80 Mpc
2016/2017	6 months	80-120 Mpc
2017/2018	9 months	120-170 Mpc
2019	Full year	200 Mpc

Multimessenger Astronomy

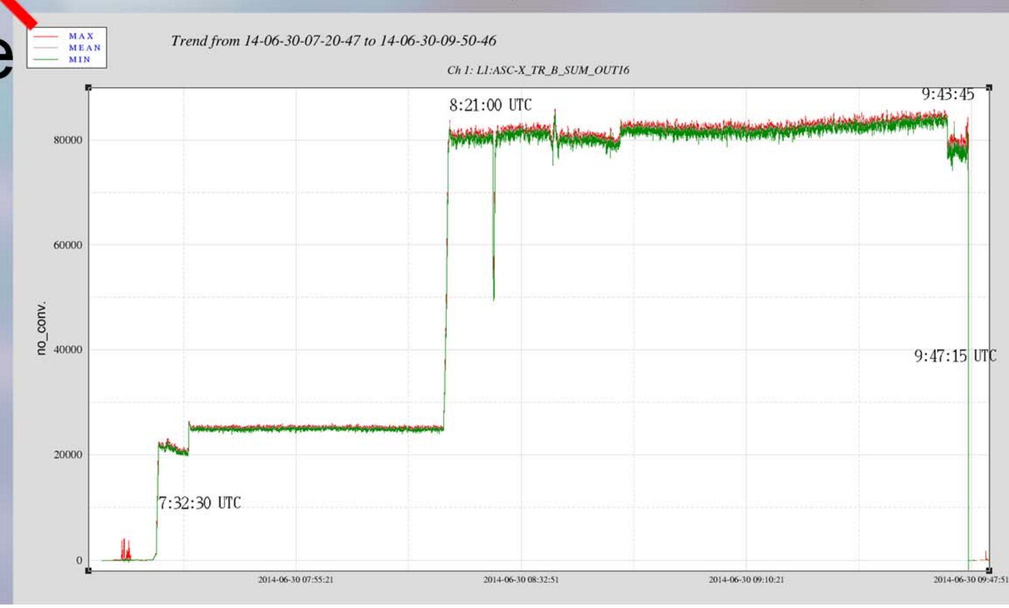


- Low latency data analysis happening as data comes in → Generate triggers
- Increase confidence in GW detection
- More precise sky location, better understanding

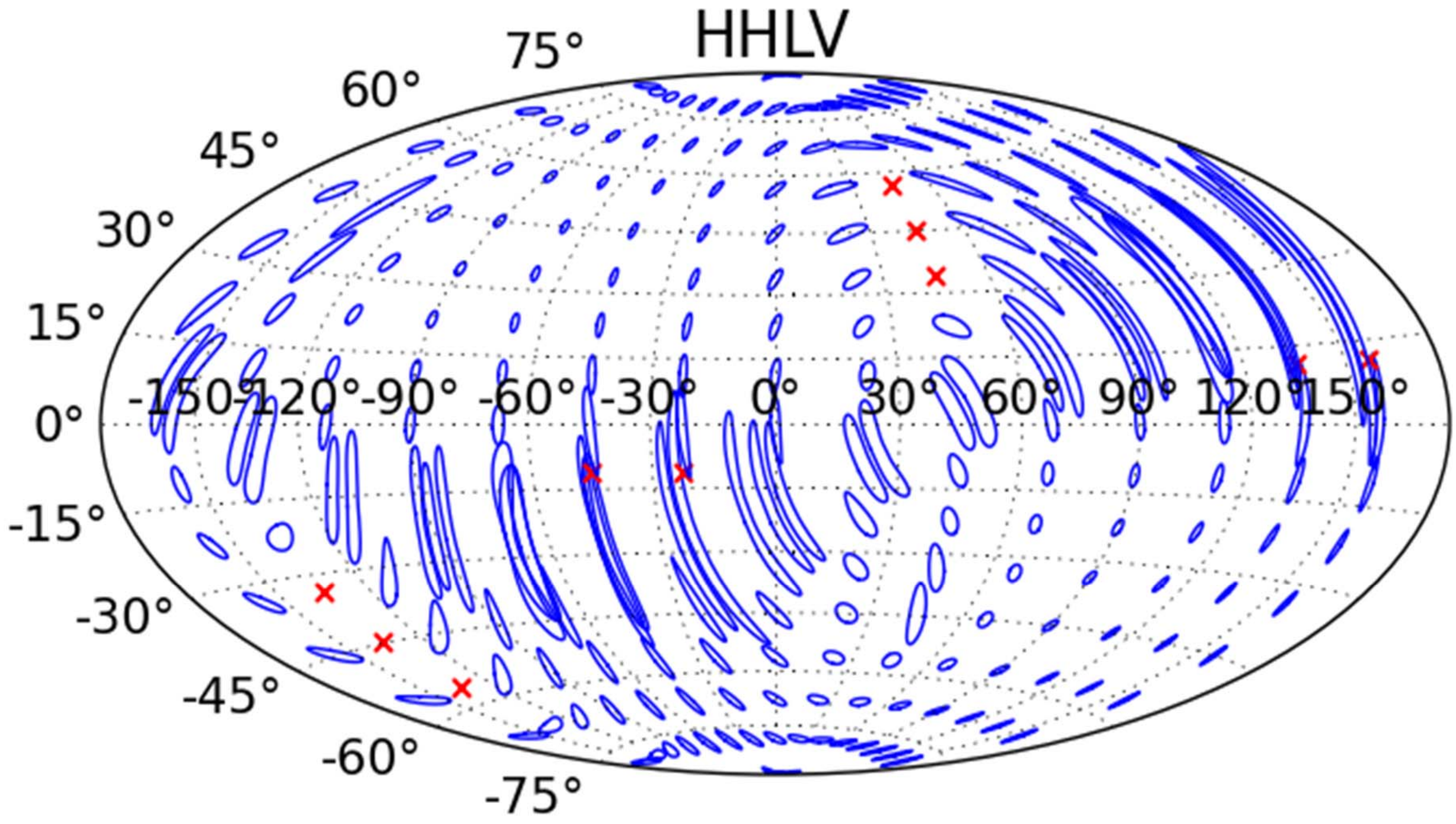
Livingston is Locked and Accepted

- Livingston interferometer has locked for more than 2 hours (135 minutes)
  - June 30, 2014
  - Now commissioning
  - When Hanford locks for > 2 hours, late 2015, construction phase

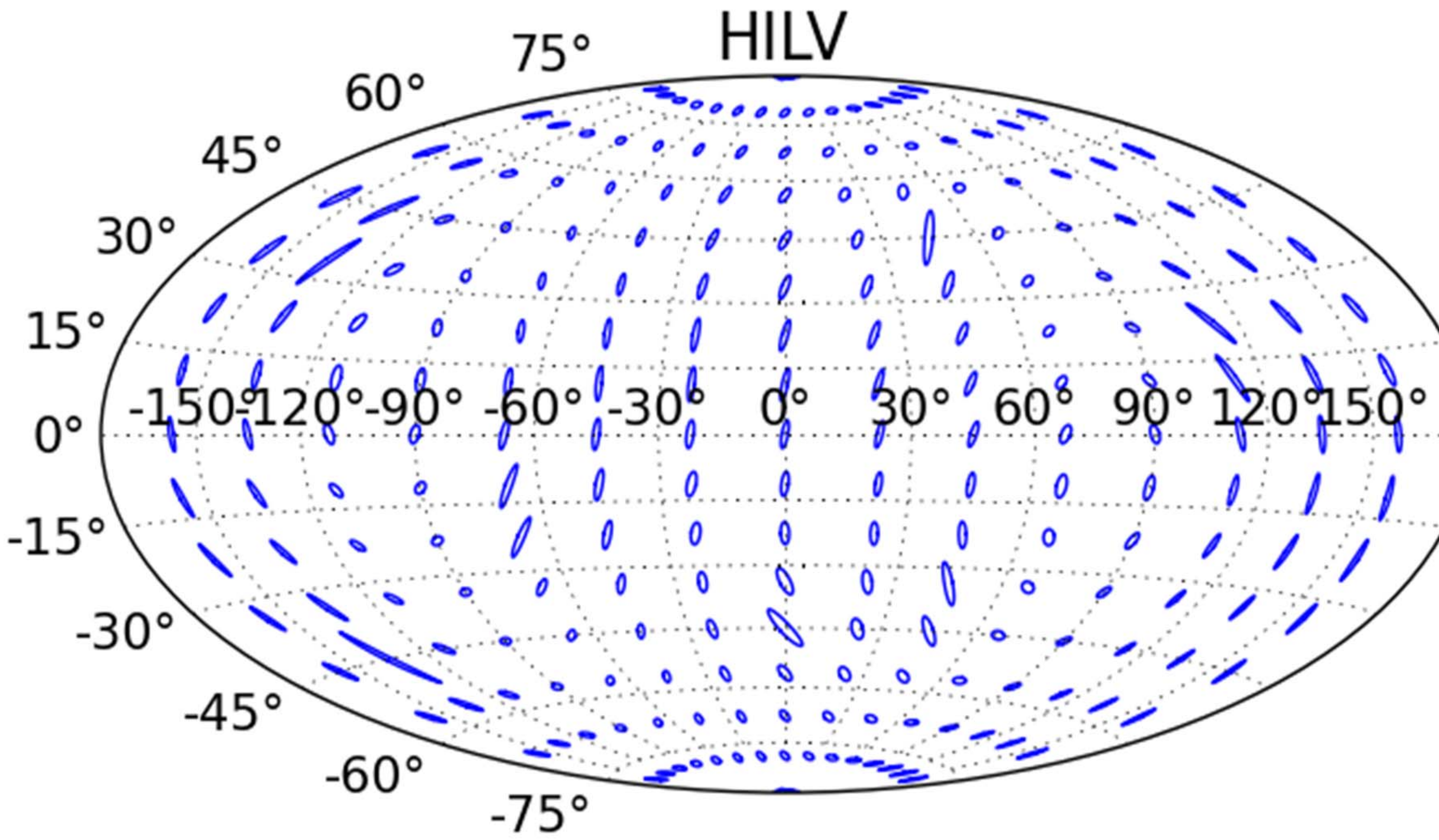
NG NEWS
S FOR 2 HOURS



Worldwide Network



LIGO India

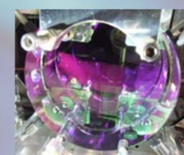


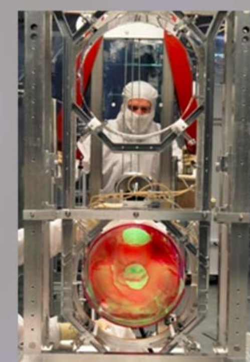
HILV
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
-150° -120° -90° -60° -30° 0° 30° 60° 90° 120° 150°

Conclusion

- Initial LIGO complete
  - Validated technology
  - Contributed to astrophysics but no detections

- Advanced LIGO
  - Installation in US nearly complete
  - Lower noise technology→10X sensitivity
  - Science runs begin 2015, detections likely





- LIGO India
  - Expect approval soon
  - Improve sky positioning of sources