Status of Virgo and LIGO

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LIGO-G0900448

Evolution of ground-based GW detectors

- 1st generation interferometric detectors
  - Initial LIGO, Virgo, GEO600

Unlikely detection

Science data taking
Set up network observation

We are here

  - Enhanced LIGO, Virgo+

Plausible detection

Lay ground for multi-messenger astronomy

- 2nd generation detectors
  - Advanced LIGO, Advanced Virgo, GEO-HF

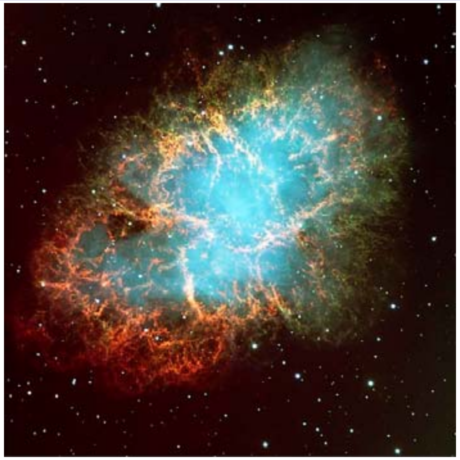
Likely detection

Routine observation
➔ GW astronomy

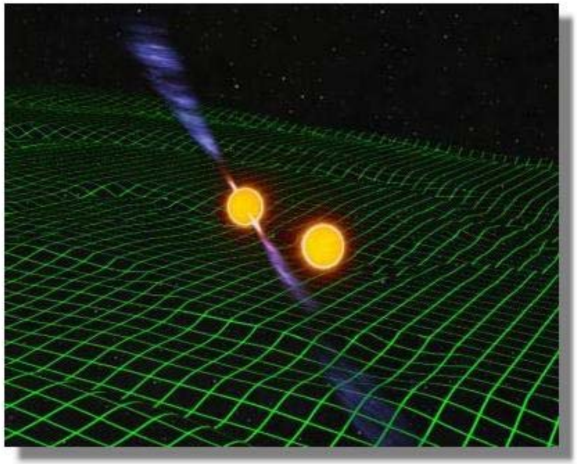
- 3rd generation detectors
  - Einstein Telescope, US counterpart to ET

Thorough observation of Universe with GW

GW sources



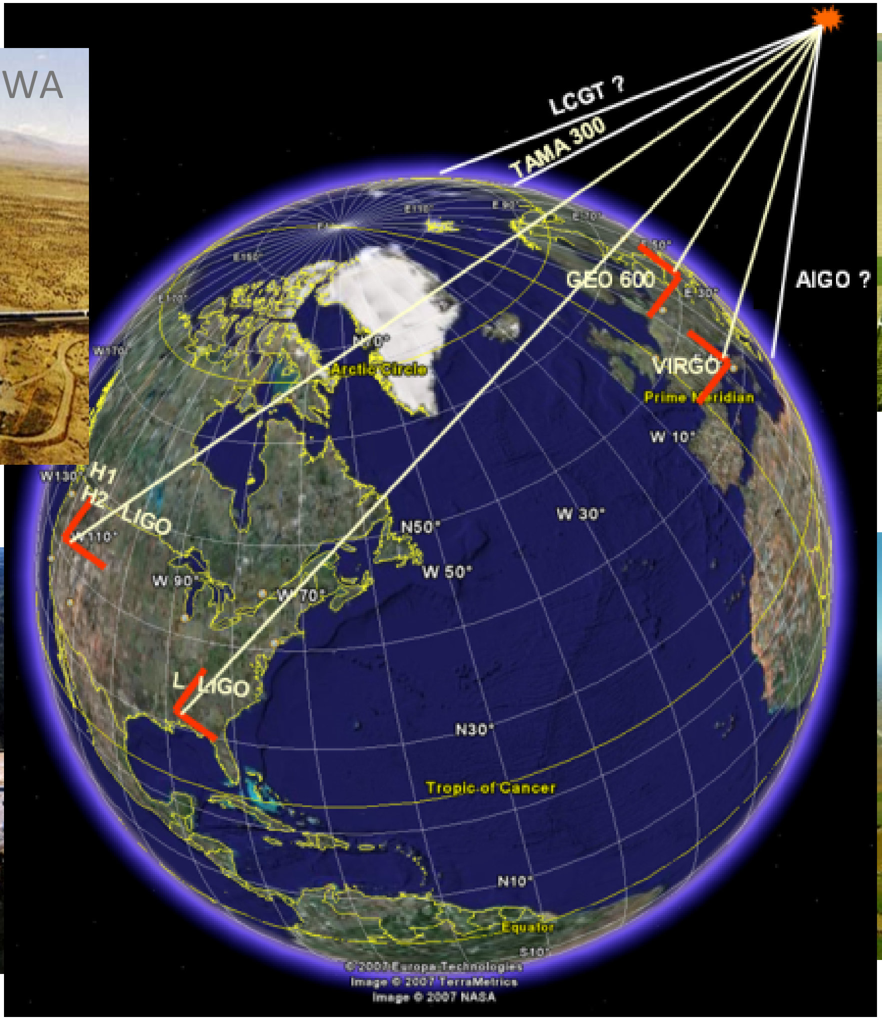
- Transient signals
  - ◆ Supernovae
  - ◆ Compact coalescing binaries
    - » BNS, BBH, NS-BH
    - » “Standard candles”



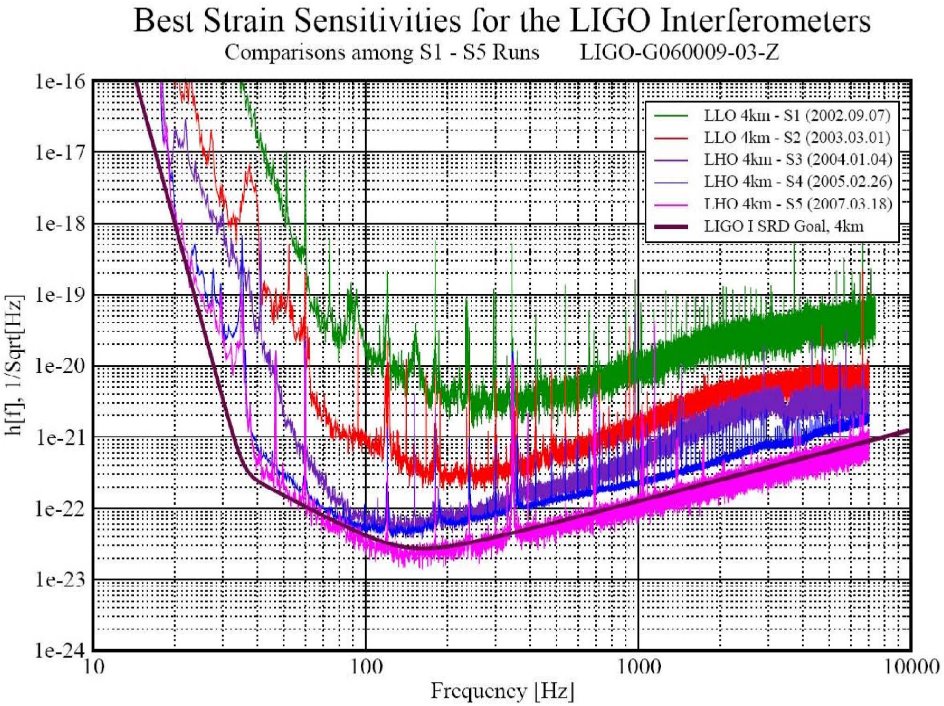
- Periodic signals
  - ◆ Rotating neutron stars
- Stochastic signals
  - ◆ Early Universe GW background

- Mechanisms producing GRB’s are likely to produce GW as well
- Several GW sources are potential sources of neutrinos

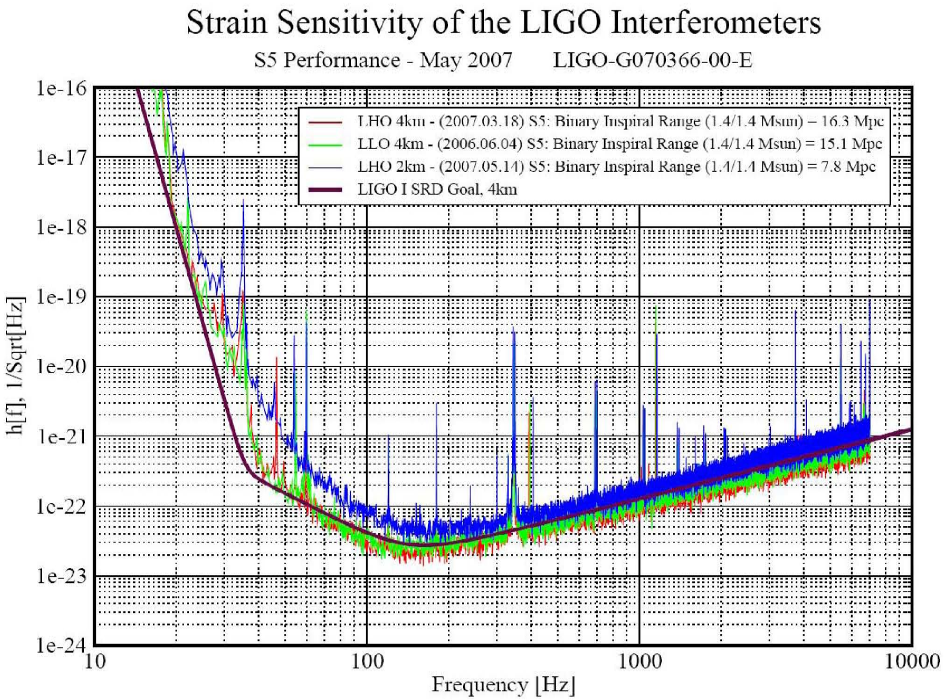
A worldwide network of detectors



Reaching design sensitivity

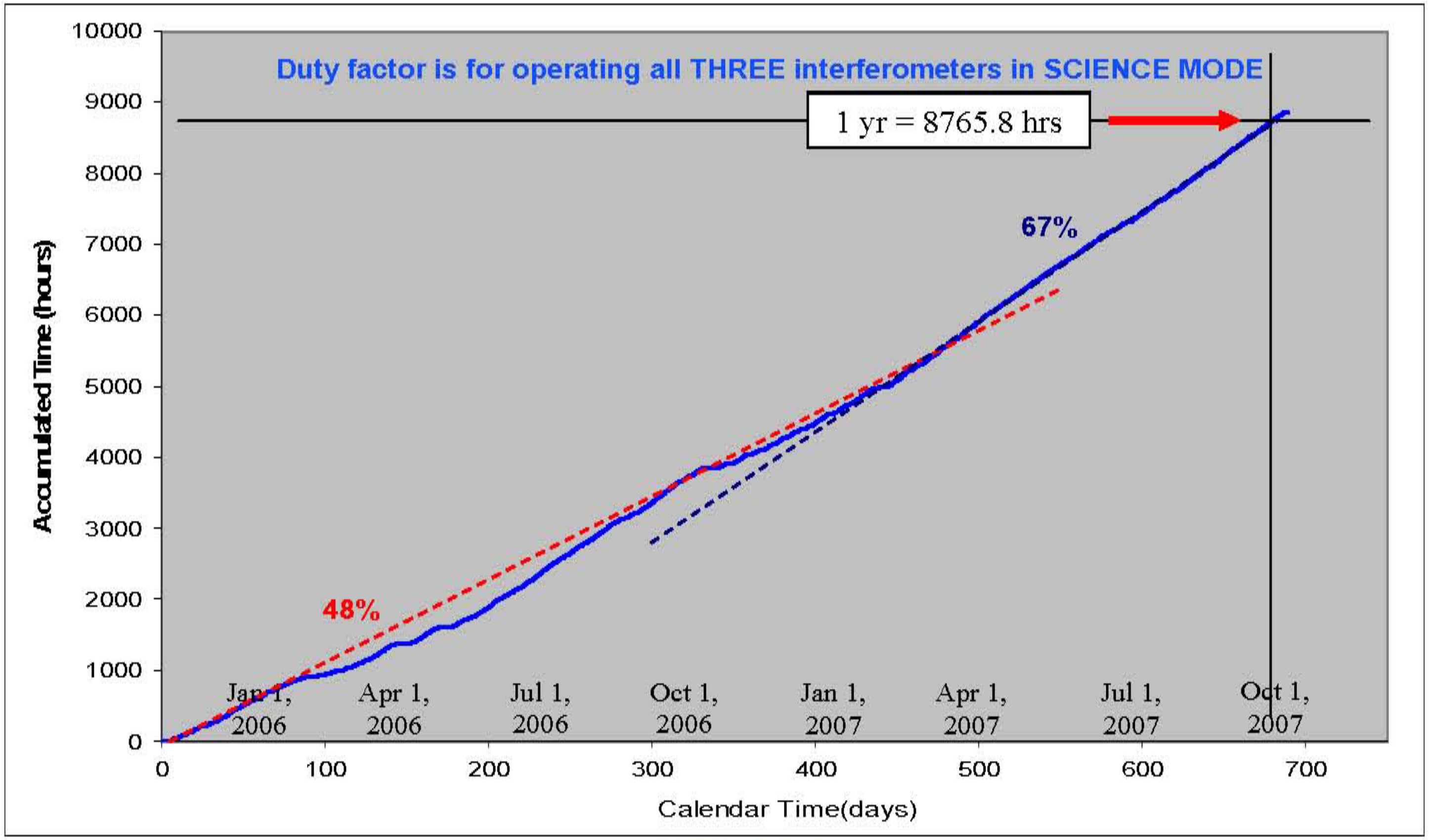


- Reaching design sensitivity has been a long process
- The LIGO detectors reached their design sensitivities for the fifth science run (S5)



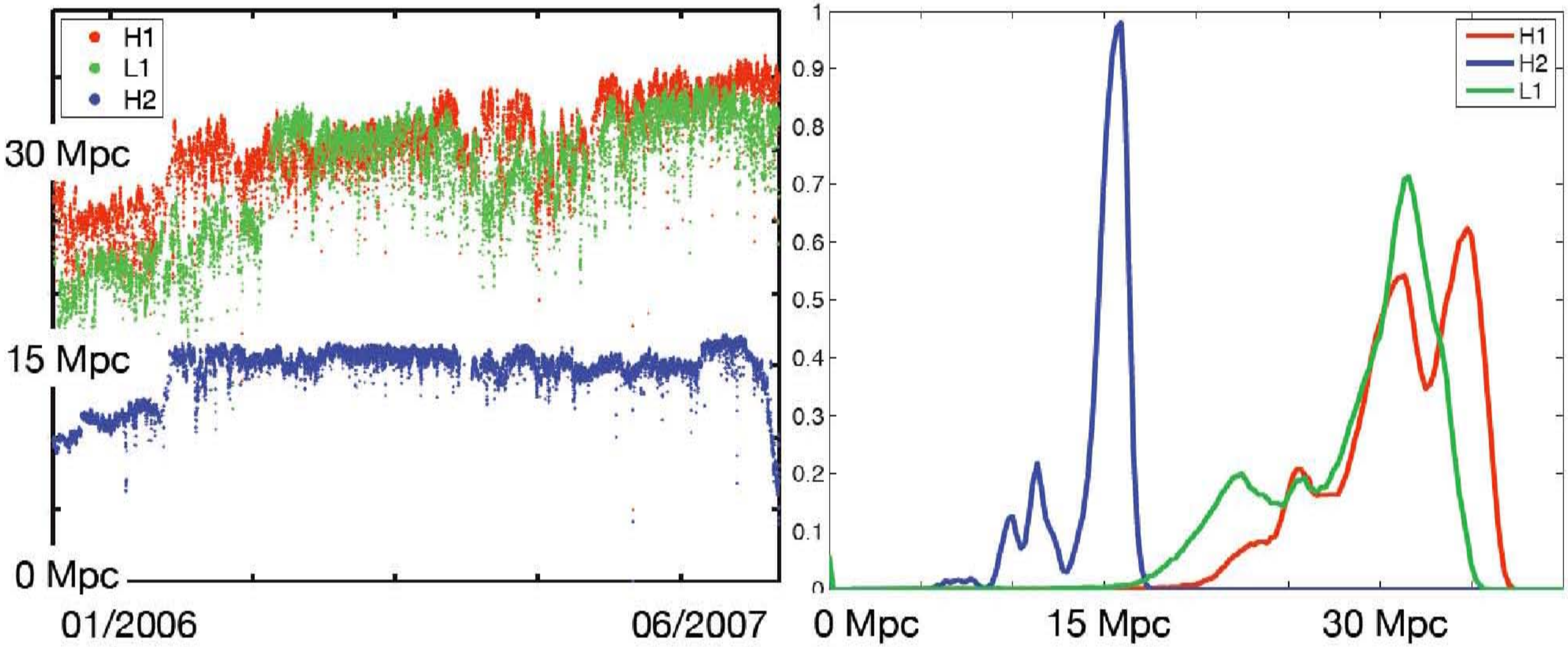
LIGO S5 (I)

- November 2005 – October 2007
- Accumulated triple-coincidence time = 1 year



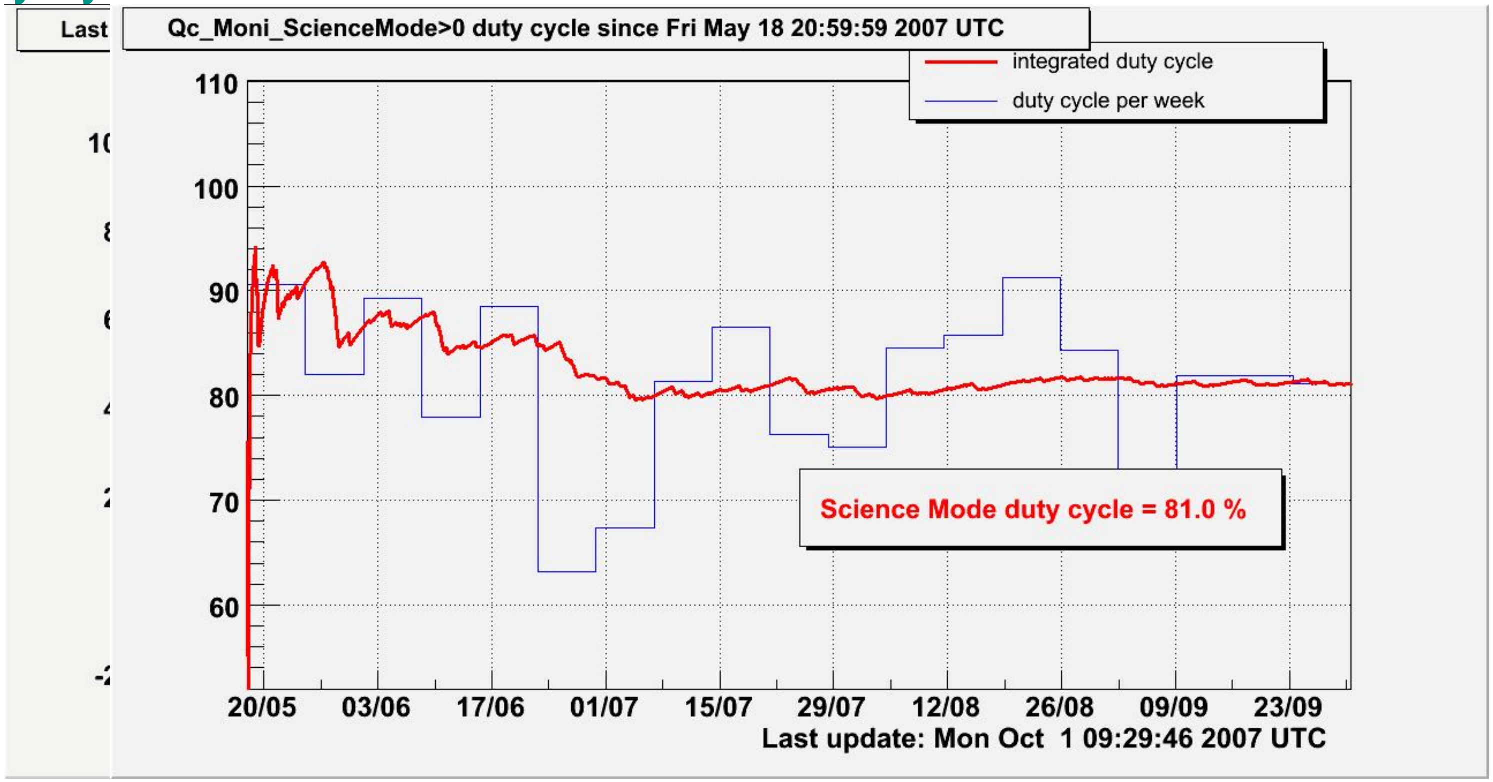
LIGO S5 (II)

- Horizon distance for (1.4,1.4) $M_\odot$ BNS
  - ◆ Distance of an optimally located and oriented source giving an SNR of 8

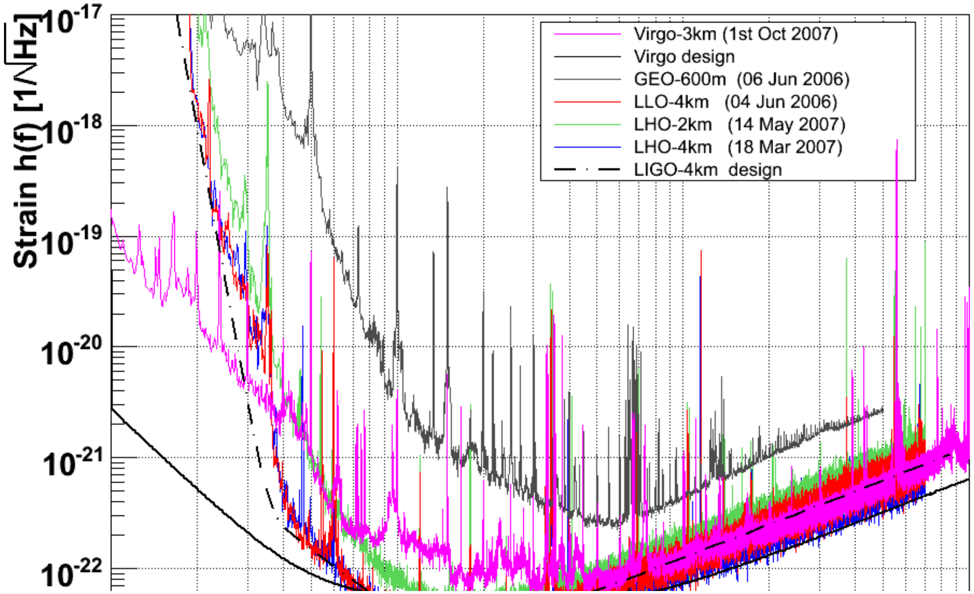


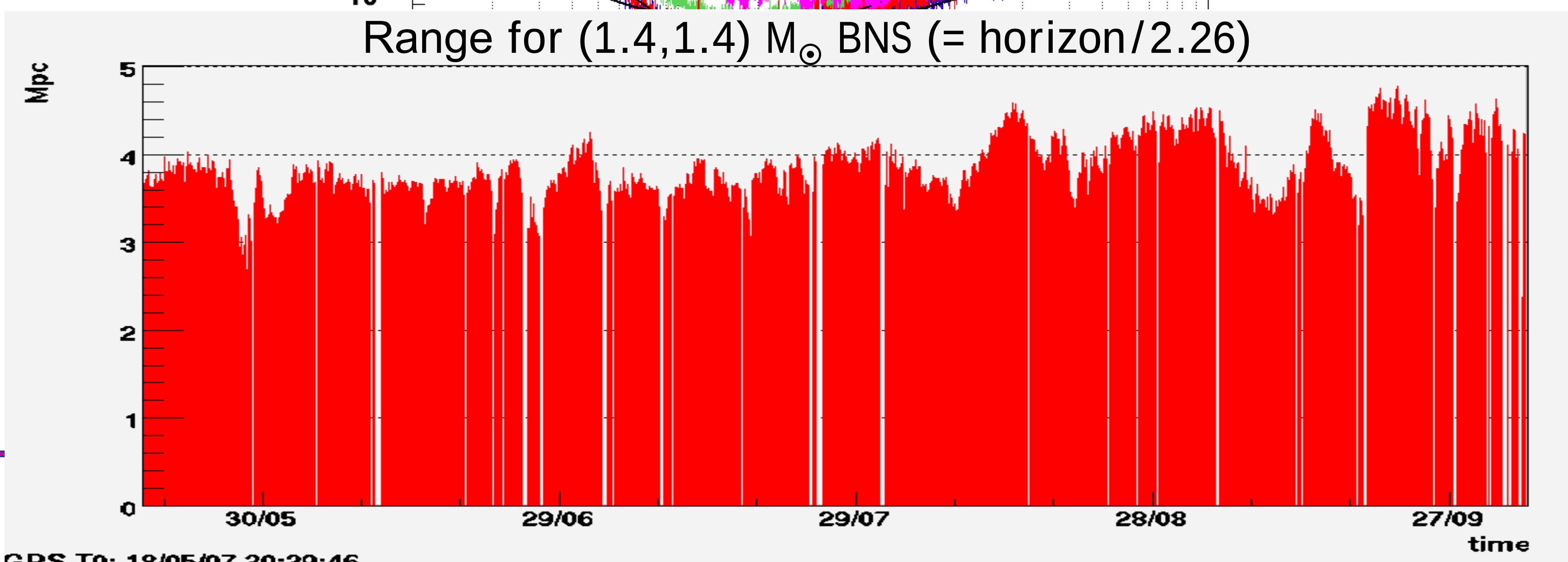
Virgo VSR1 (I)

- May 18 – October 01 2007
  - Coincident with the last months of S5
- Long locks: 20 locks > 40 hours; Longest lock 94 hours long
- Duty cycle: 81% science mode



Virgo VSR1 (II)





LIGO-Virgo agreement

- Early 2007, for three years
  - Long term spirit

> We enter into this agreement in order to lay the groundwork for decades of world-wide collaboration. We intend to carry out the search for gravitational waves in a spirit of teamwork, not competition. Furthermore, we remain open to participation of new partners, whenever

- Full data exchange started with VSR1
- Three sites are needed to extract more science

➔ Source pointing ability !

Initial detectors science impact

- The LSC has published 30 observational papers on S1 → S4
- So far, 7 papers published or submitted on S5
  - Many more to come, including joint LSC-Virgo papers

BEATING THE SPIN-DOWN LIMIT ON GRAVITATIONAL WAVE EMISSION FROM THE CRAB PULSAR

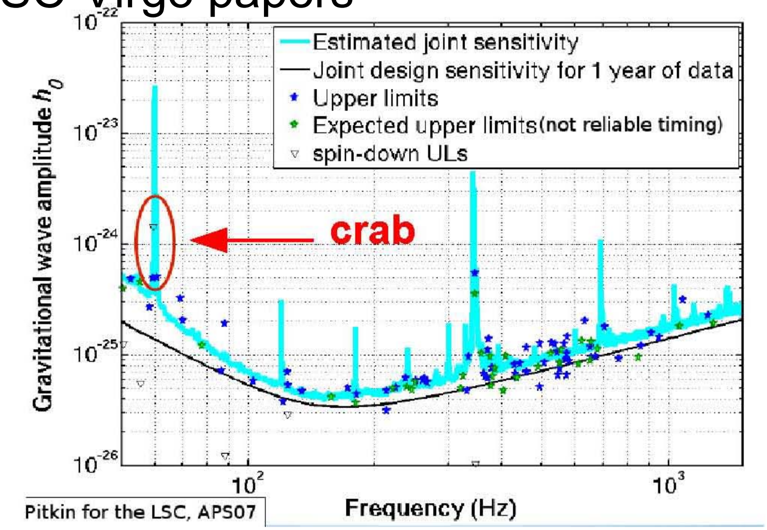
The LIGO Scientific Collaboration

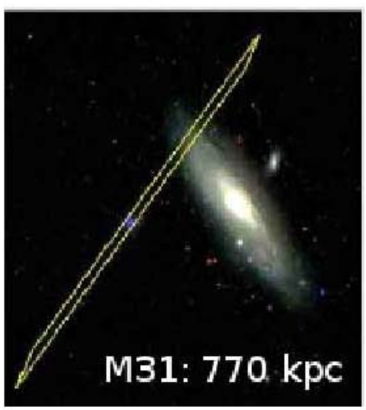
Draft version May 30, 2008

ABSTRACT

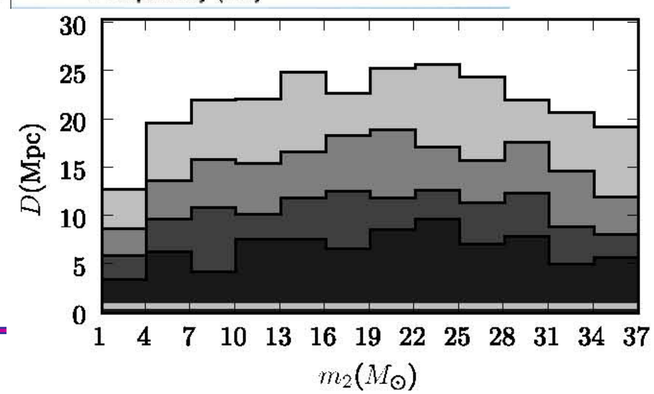
We present direct upper limits on gravitational wave emission from the Crab pulsar using data from the first nine months of the fifth science run of the Laser Interferometer Gravitational-wave Observatory (LIGO). These limits are based on two searches. In the first we assume that the gravitational wave emission follows the observed radio timing, giving an upper limit on gravitational wave emission that beats indirect limits inferred from the spin-down and braking index of the pulsar and the energetics of the nebula. In the second we allow for a small mismatch between the gravitational and radio signal frequencies and interpret our results in the context of two possible gravitational wave emission

al waves - pulsars



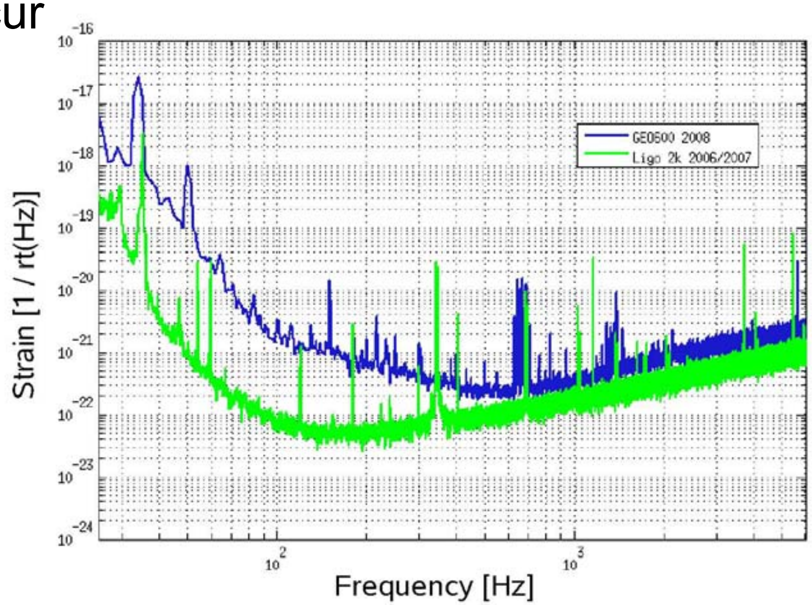


- GRB 070201
  - Merger in Andromeda?
  - No plausible GW signal found



Astrowatch

- While LIGO H1 & L1 and Virgo were being upgraded in view of S6-VSR2, LIGO H2 and GEO600 have been taking data in Astrowatch mode
  - ◆ Keep detectors up as much as possible, in order not to miss any extraordinary event that might occur
    - » e.g. a supernova in the Galaxy
  - ◆ High duty cycle achieved

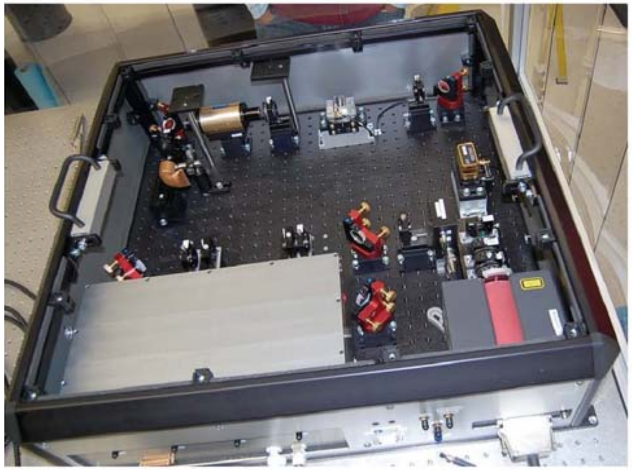


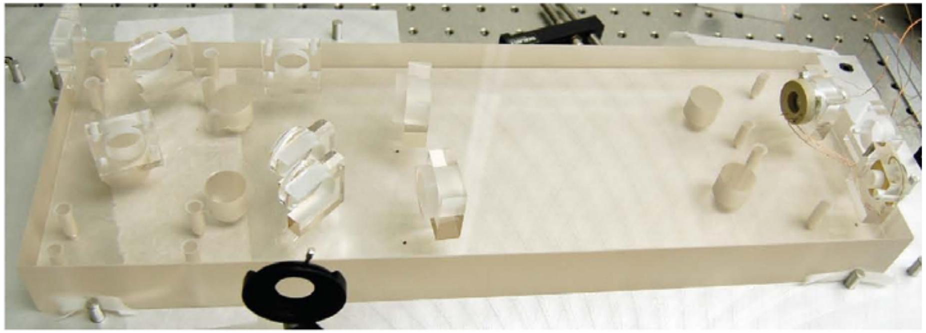
Enhanced LIGO and Virgo+

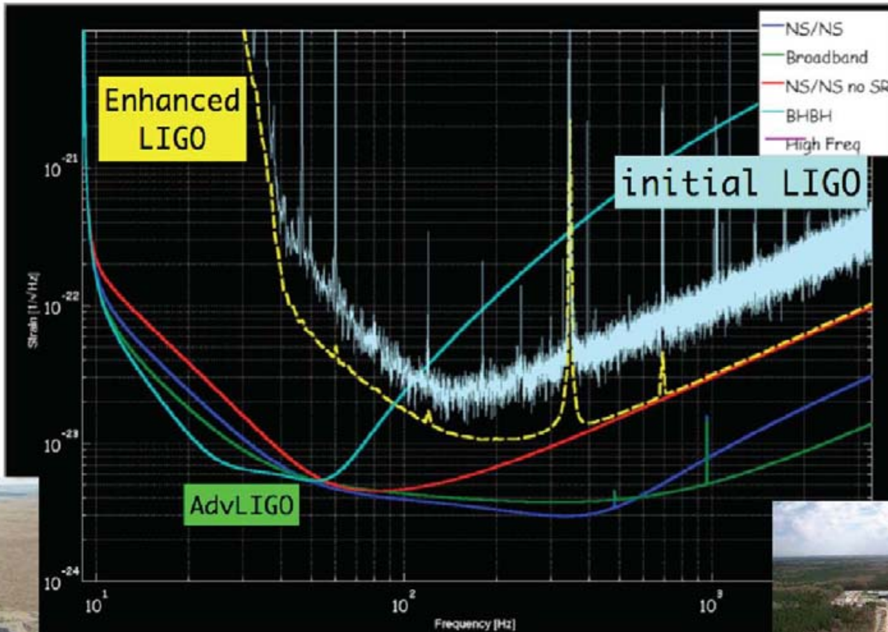
- Do "easy", "quick", and "cheap" yet significant upgrades within unchanged infrastructure
  - e.g. increase laser power
  - Aim at a factor ~2 improvement
    - An order of magnitude in the reachable volume of the Universe
    - Make detection plausible if not likely
- Include a few challenging techniques that will be needed for Advanced LIGO and Advanced Virgo
  - A step taken toward 2nd generation detectors
    - Leverage pioneering work done at GEO
  - DC detection in eLIGO
  - Monolithic suspensions in Virgo+

Enhanced LIGO

- Higher laser power: 35 W
- High power Faraday isolator
- High power thermal control of test masses
- Better magnets on test masses
- In-vacuum, active seismic isolation
- Suspended output mode cleaner
- DC readout

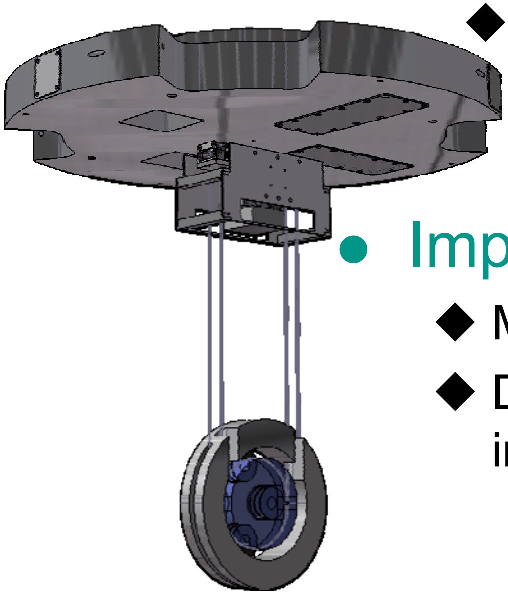


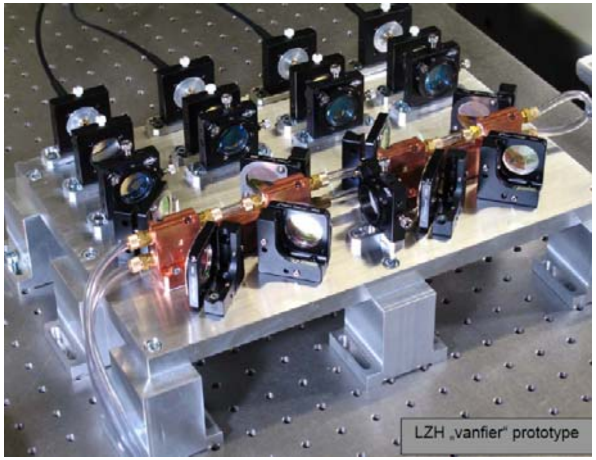




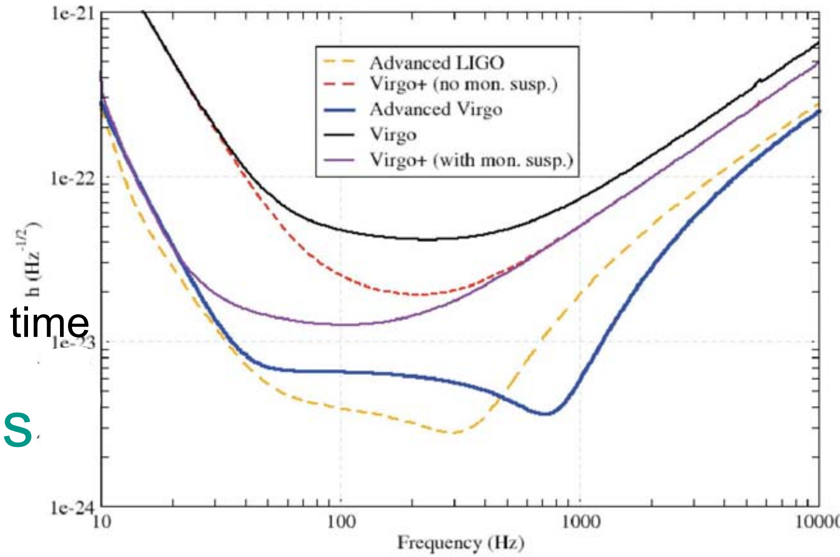
Virgo+

- Increase input power
  - Laser amplifier ➔ 50 W
  - New input mode-cleaner mirror
  - Thermal compensation system





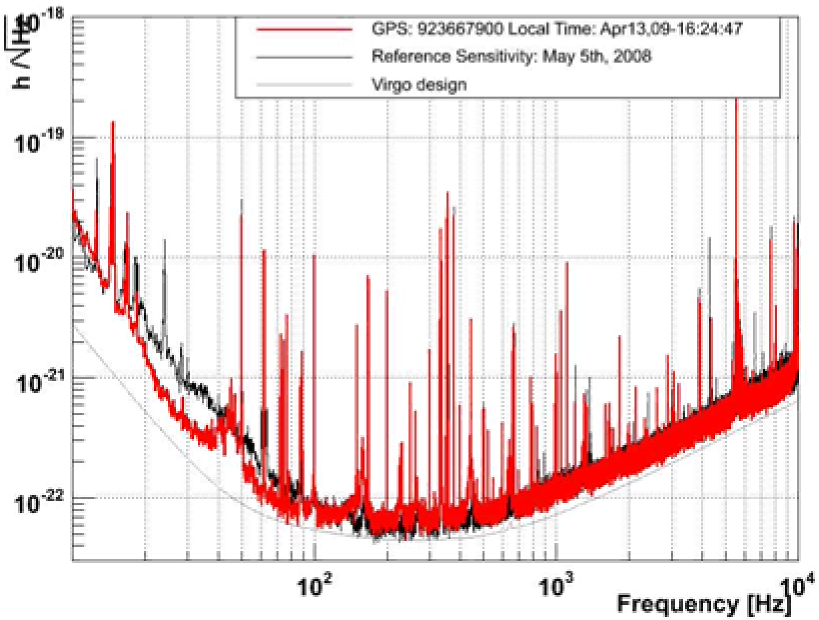
- Improve thermal noise
  - Monolithic suspensions
  - Dedicated shutdown(s) for installation during VSR2
    - » Change mirrors for higher cavity finesse at the same time

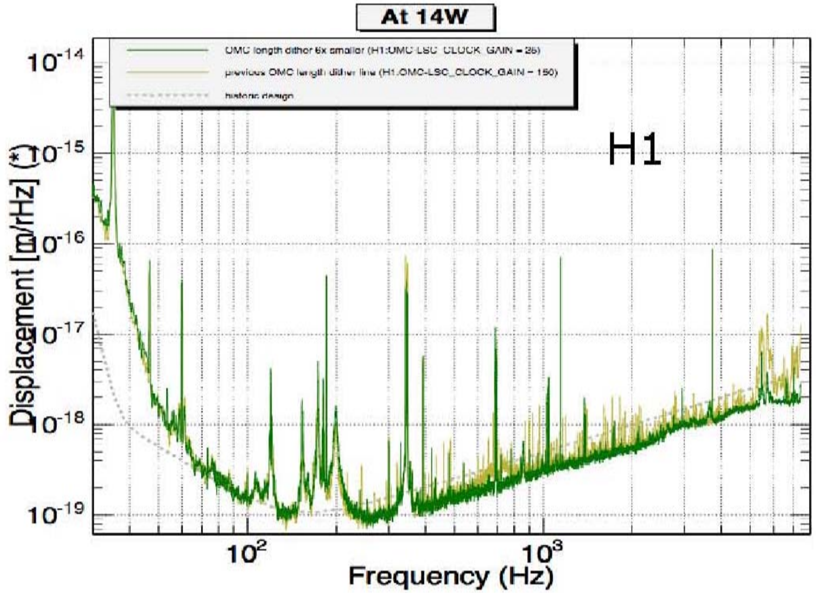


- Cut down on environmental noises
- New control electronics

Present status of enhanced detectors

- Commissioning and noise hunting effort since last fall

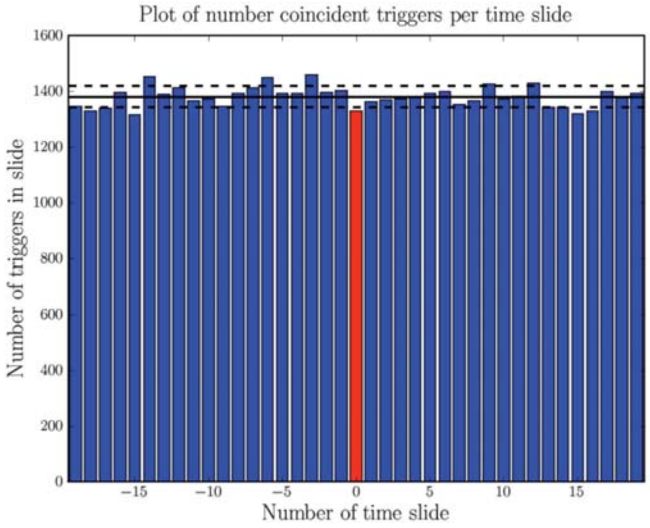




- Target date for start of runs S6 and VSR2
  - July 7th 2009

Data analysis in a nutshell

- The data are a stream of noise in which the burst and CBC searches try to identify rare and weak events
  - The noise is not Gaussian ("glitchy" detectors/environment) and not stationary
- Coincidences are our most powerful tool
  - Reduced false alarm rate
  - Background can be estimated by applying time offsets between detectors
    - » Multi-site coincident background under control
  - Efficiency of pipelines checked with hardware and software injections



- Online analyses during S6-VSR2
  - Infrastructure set up to do burst and CBC analyses with latency ≤1 hour
  - Source direction can be extracted for H-L-V triple coincidences
    - » Typical pointing accuracy ~ several degrees for signals at detection threshold
  - Candidates could be due to blind hardware injections!

Multi-messenger astronomy

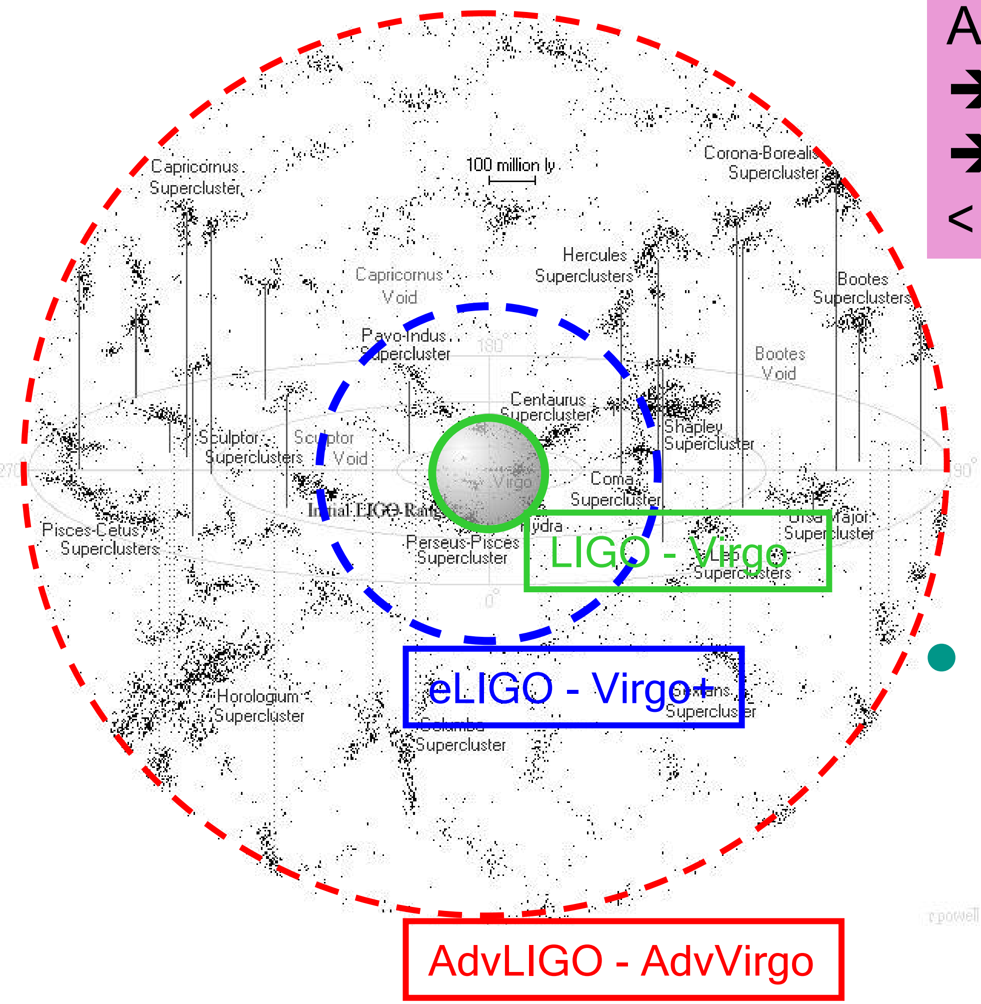
- Motivations
  - Increase confidence in GW detection
  - Extract more science from multiple observation of same event
- Already part of LIGO and Virgo data analysis
  - (Long and short) GRB triggered searches
  - All sky search for burst signals covers supernovae
    - » SN can be observed in other ways: electromagnetically, neutrinos
- Being set up
  - Broaden triggered searches making use of external data
    - » GRBs, neutrino events
  - Trigger fast follow-up of GW candidates
    - » Target of opportunity observations
    - » Wide field optical follow-up

Procedures for establishing external collaborations

The GW community is getting ready for the first detections!

Advanced detectors

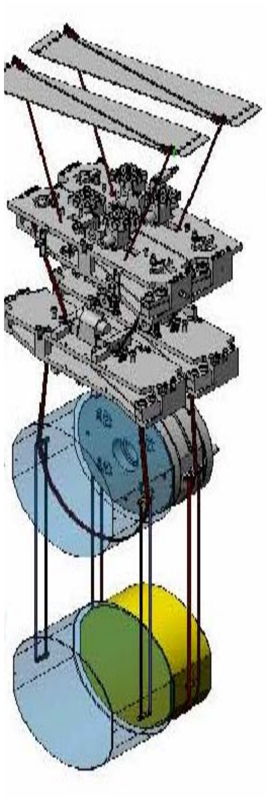
A factor **10** on the sensitivity
➔ A factor **1000** on the rate of events
➔ 1 year of initial detectors
< 1 day of advanced detectors !

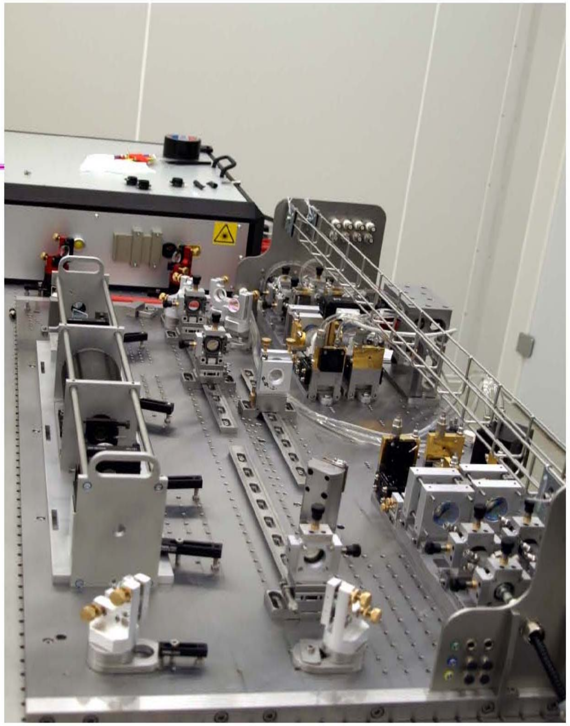


- Rate of detectable binary neutron stars coalescences
  - Initial detectors: ~ 1/100 years
  - Advanced detectors: ~ 40/year
- Binary black hole coalescences
  - Similar rates expected
  - Visible up to ~ 1 Gpc !
- Pulsars
  - Limit on ellipticity $\varepsilon \sim 10^{-8}$

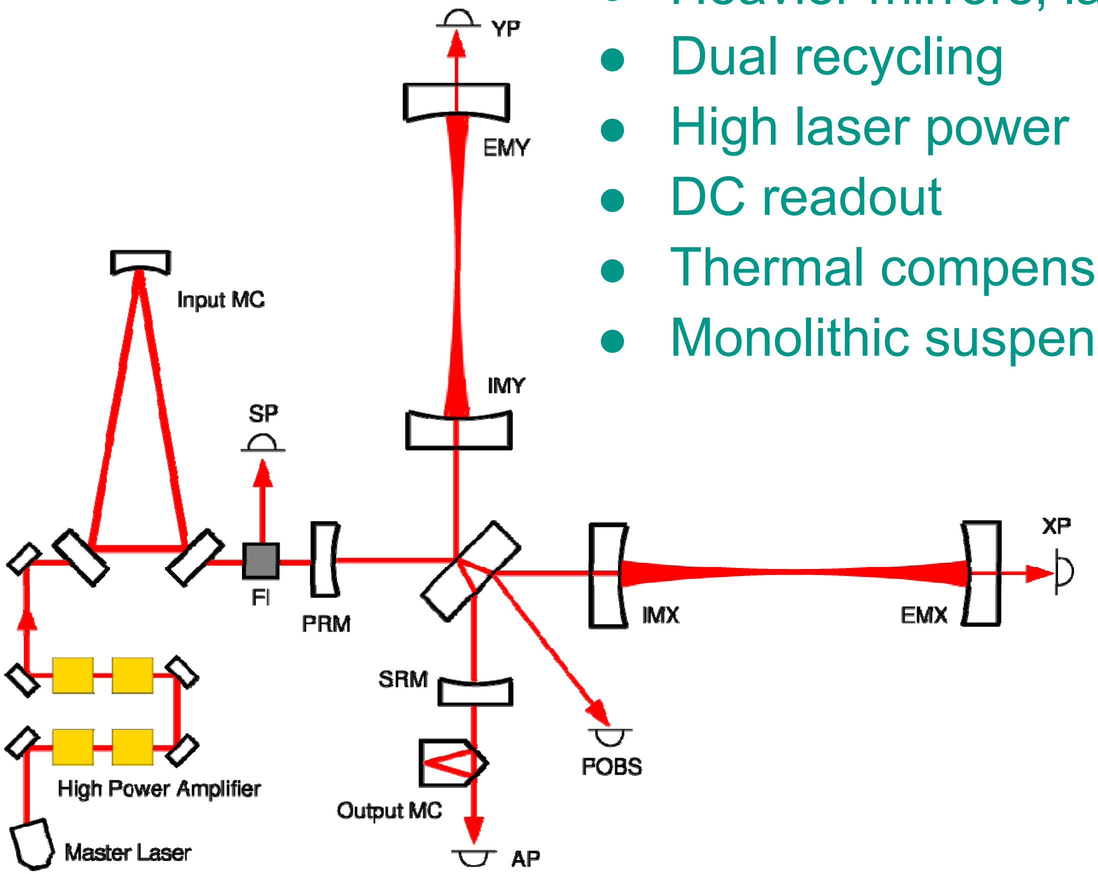
Advanced LIGO

- Active seismic isolation
- Quadruple pendulums
- Monolithic suspensions
- Signal recycling
- Increased laser power
- Adaptive thermal compensation
- DC readout
- Heavier mirrors
- Low thermal noise coatings

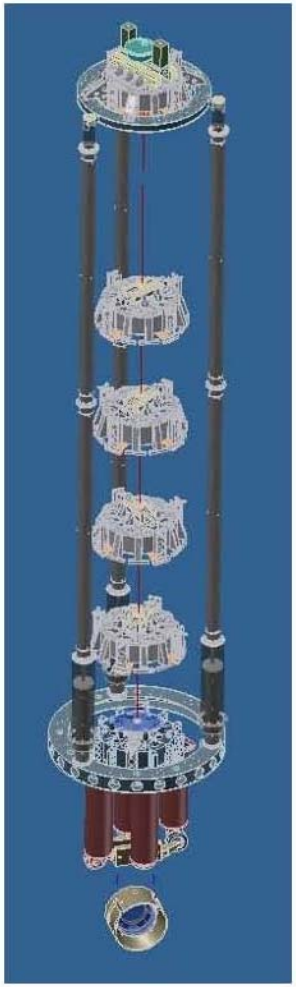




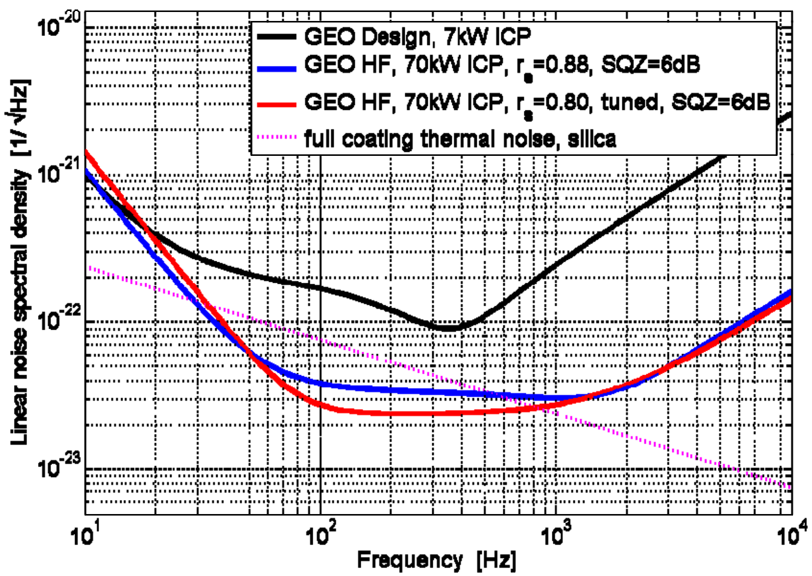
Advanced Virgo

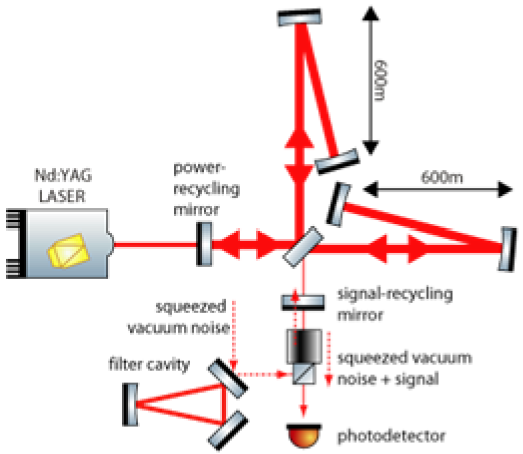


- Heavier mirrors, larger beams
- Dual recycling
- High laser power
- DC readout
- Thermal compensation
- Monolithic suspensions

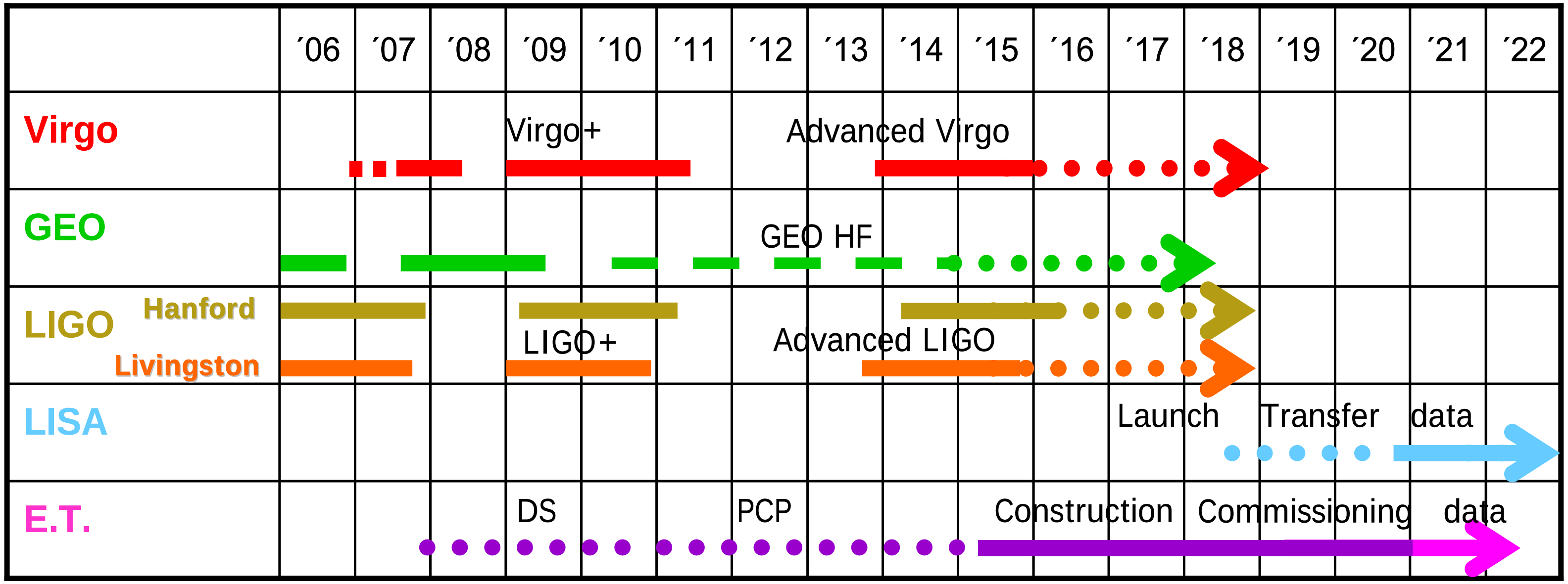


- A program of sequential upgrades
- Emphasize high frequencies
- Pioneer advanced techniques for other large interferometers
  - ◆ Tuned signal recycling and squeezing





Timeline


´06 ´07 ´08 ´09 ´10 ´11 ´12 ´13 ´14 ´15 ´16 ´17 ´18 ´19 ´20 ´21 ´22
Virgo
Virgo+
Advanced Virgo
GEO
GEO HF
LIGO
Hanford
Livingston
LIGO+
Advanced LIGO
LISA
Launch
Transfer
data
E.T.
DS
PCP
Construction
Commissioning
data

Conclusion

- LIGO and Virgo striving for first GW detection
  - Initial detectors have taken data at design sensitivity
    - » Interesting upper limits derived
  - Enhanced detectors almost ready to take data with increased sensitivity
  - Advanced detectors on track
- Multi-messenger observations are a key point
  - First detections
  - Extract full science potential from GW astronomy
  - High energy neutrinos are part of this!