Searches for Gravitational Waves from the Inspiral of Binary Neutron Stars and Black Holes

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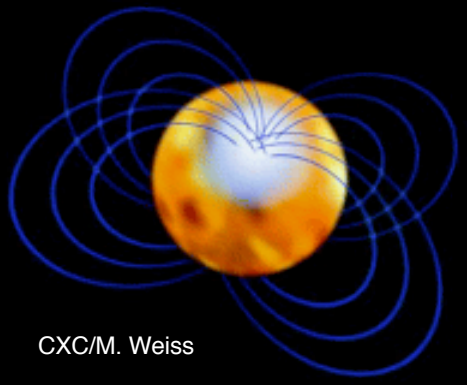
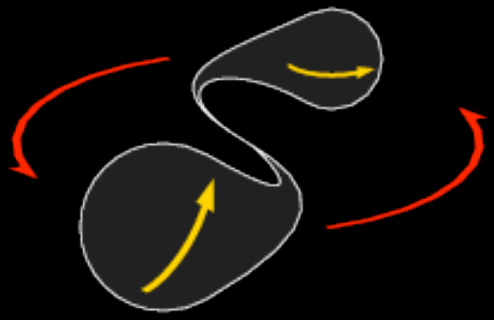
Astrophysical Sources of Gravitational Waves

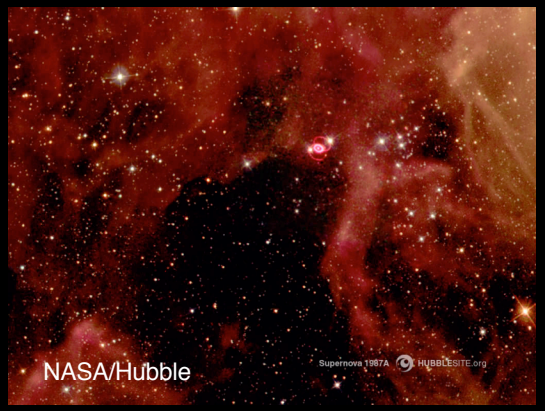


CXC/M. Weiss

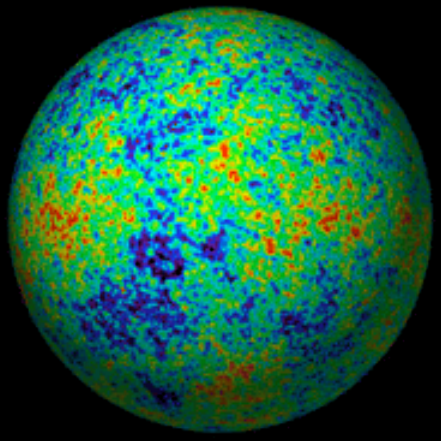
Continuous sources: Spinning neutron stars



Compact Binary Coalescence (CBC): "long bursts" of gravitational waves as stars inspiral, merge and ring down



"Short bursts:" Supernovae, transient sources, ???



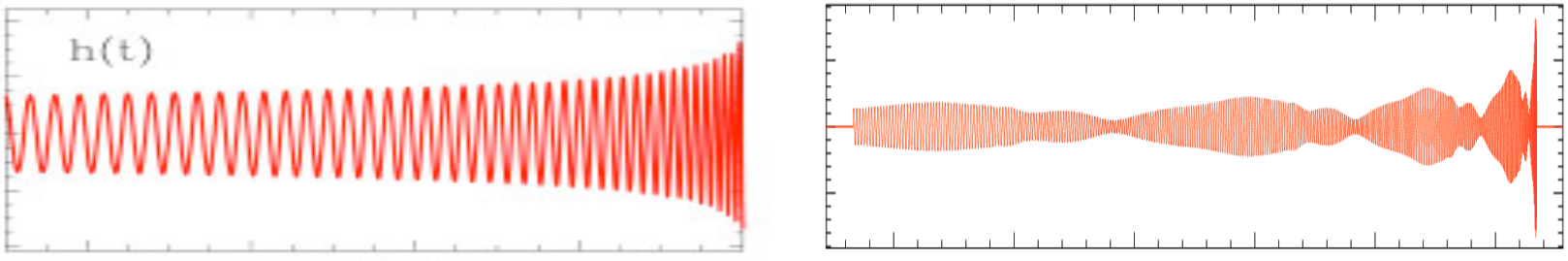
Gravitational wave backgrounds: relic radiation from the big bang

Goals of the CBC Search

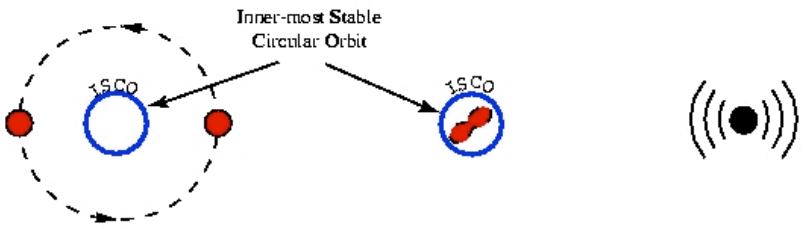
- Direct detection of two dramatic predictions of Einstein's Theory of General Relativity
  - » Gravitational Waves
  - » Black Holes
- LIGO gives us Astronomy and Physics
  - » Test models of gamma-ray burst progenitors
  - » Probe the neutron star equation of state
  - » Compact binary populations and formation rates
  - » Explore the strong field gravity of colliding black holes
  - » Speed of gravitational waves, graviton mass, etc.
- Observation of gravitational waves will open a new window on the universe

Gravitational Waves from Compact Binaries

- LIGO is sensitive to gravitational waves from binary systems containing neutron stars and black holes
- Gravitational waveform depends on masses and spins



- Gravitational Waves from Compact Binary Coalesce have three phases:



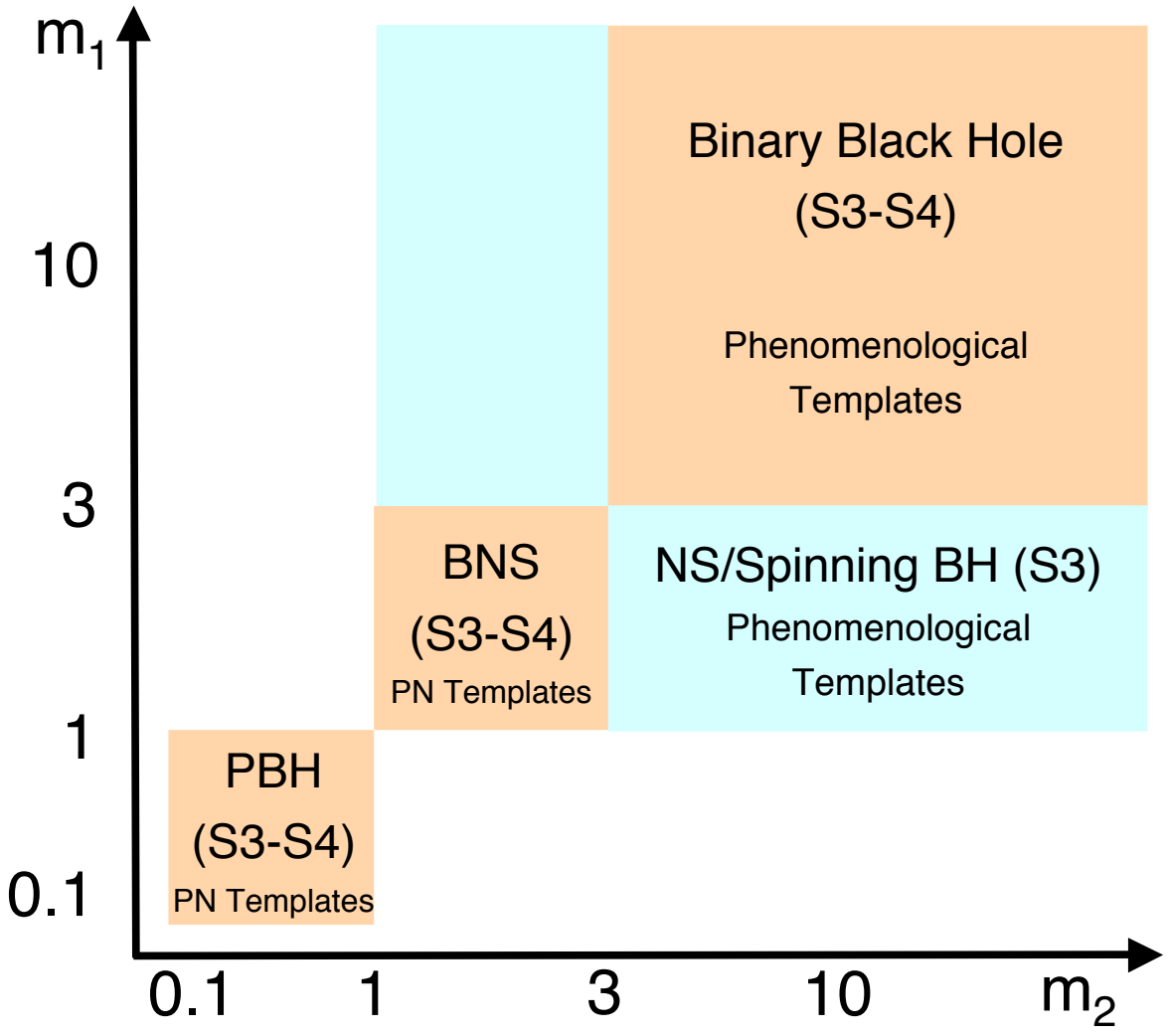
Inspiral Merger Ringdown

Astrophysical Rate Predictions

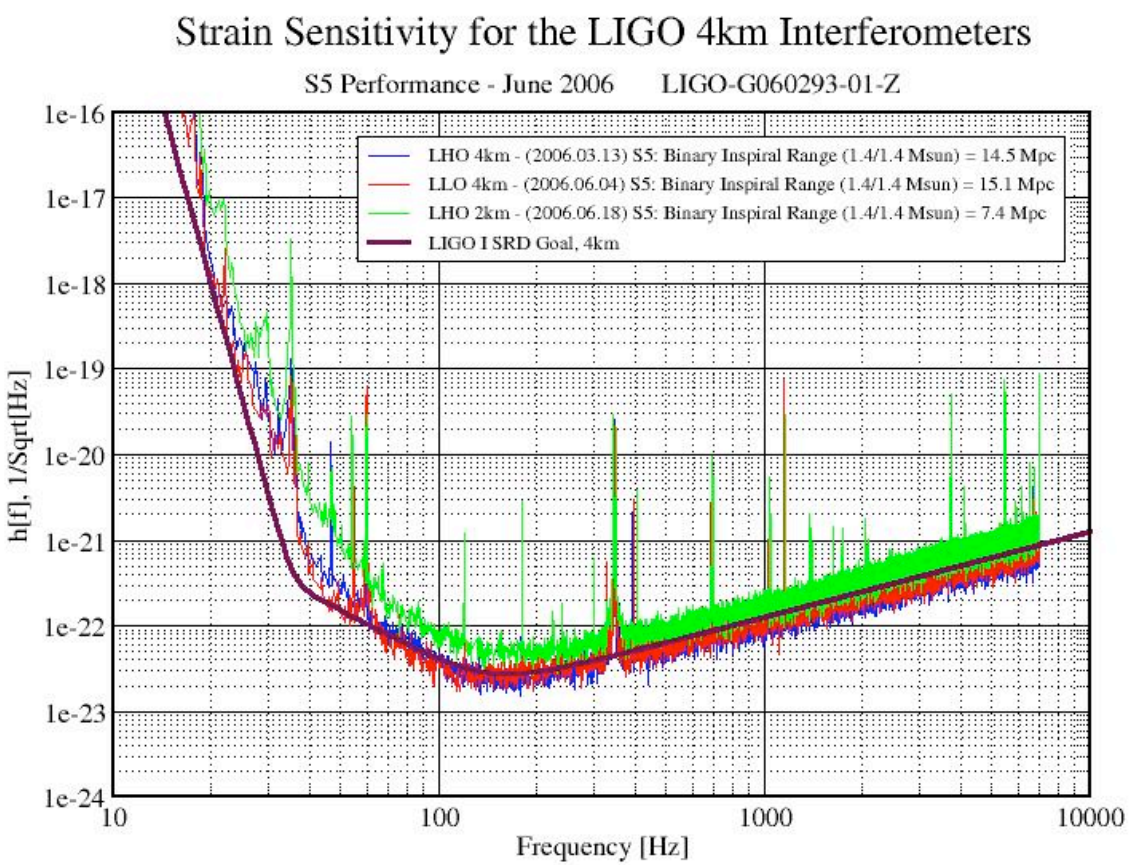
- Rate prediction from population synthesis
  - » Constrained by observing binary neutron star systems in our galaxy
  - » 1 Milky Way Galaxy = 1.7 L_{10}
- Binary Neutron Star (BNS) rates are estimated to be 5 x 10^{-5} yr^{-1} L_{10}^{-1}:
  - » 0.015/yr (Initial LIGO), 0.15/yr (Enhanced LIGO), 20/yr (Advanced LIGO)
- BNS rates could be plausibly as high as 5 x 10^{-4} yr^{-1} L_{10}^{-1}:
  - » 0.15/yr (Initial LIGO), 1.5/yr (Enhanced LIGO), 200/yr (Advanced LIGO)
- Binary Black Hole (BBH) rates are estimated to be 4 x 10^{-7} yr^{-1} L_{10}^{-1}:
  - » 0.01/yr (Initial LIGO), 0.11/yr (Enhanced LIGO), 16/yr (Advanced LIGO)
- BBH rates could be plausibly as high as 6 x 10^{-5} yr^{-1} L_{10}^{-1}:
  - » 1.7/yr (Initial LIGO), 18/yr (Enhanced LIGO), 2700/yr (Advanced LIGO)

Previous Results from LIGO Searches

- LIGO S3-S4 Analysis
  - » No GW signals found
  - » Phys. Rev. D 77, 062002 (2008)
  - » Post-Newtonian (PN) and phenomenological templates
- Primordial Black Holes (PBH)
  - » $R_{90\%} < 4.9\ yr^{-1}\ L_{10}^{-1}$
- Binary Neutron Stars (BNS)
  - » $R_{90\%} < 1.2\ yr^{-1}\ L_{10}^{-1}$
- Binary Black Holes (BBH)
  - » $R_{90\%} < 0.5\ yr^{-1}\ L_{10}^{-1}$
- LIGO S3 Neutron Star-Spinning Black Hole Search
  - » No GW signals found
  - » $R_{90\%} < 15.9\ yr^{-1}\ L_{10}^{-1}$
  - » arXiv:0712.2050



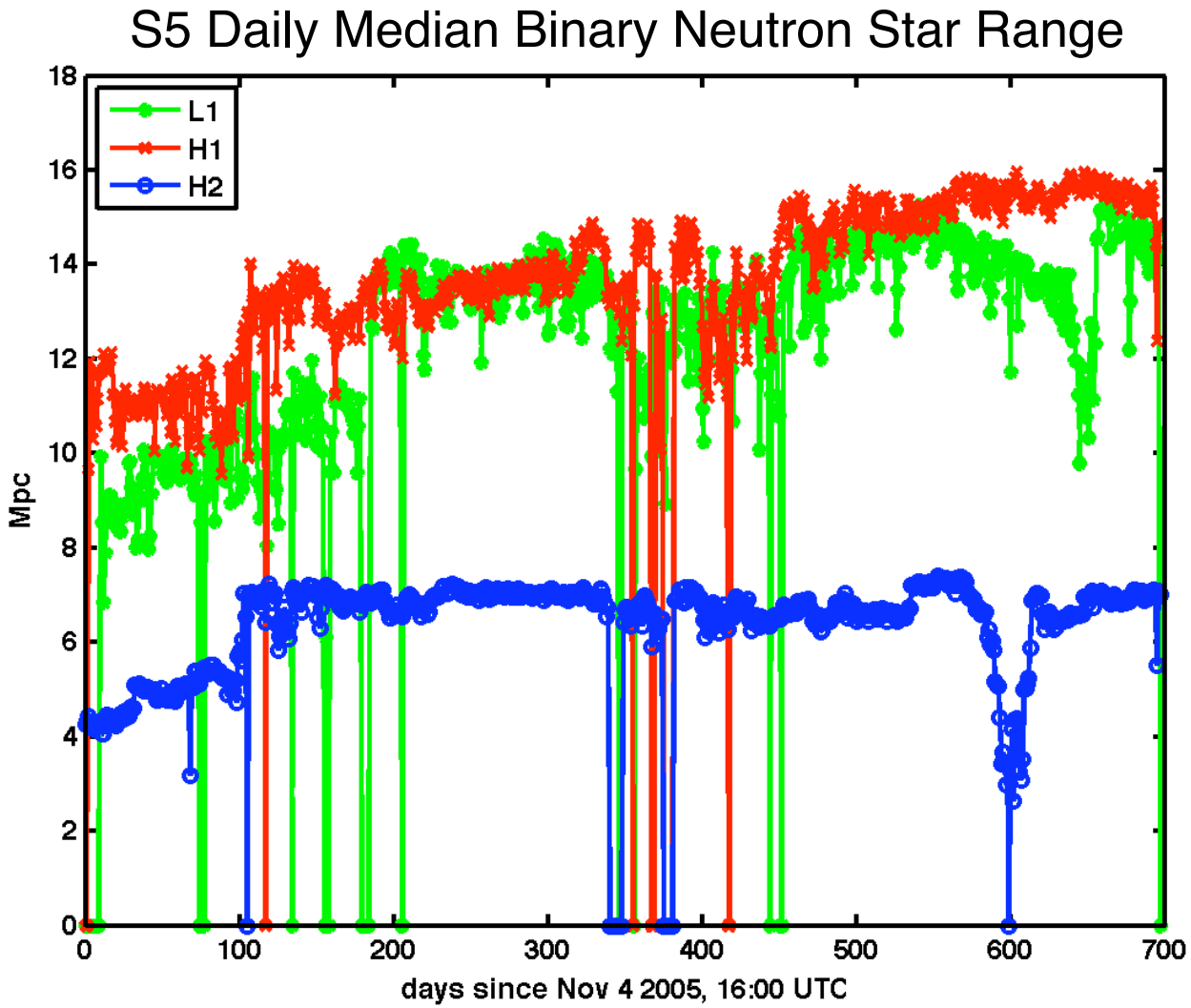
Sensitivity of the LIGO Detectors



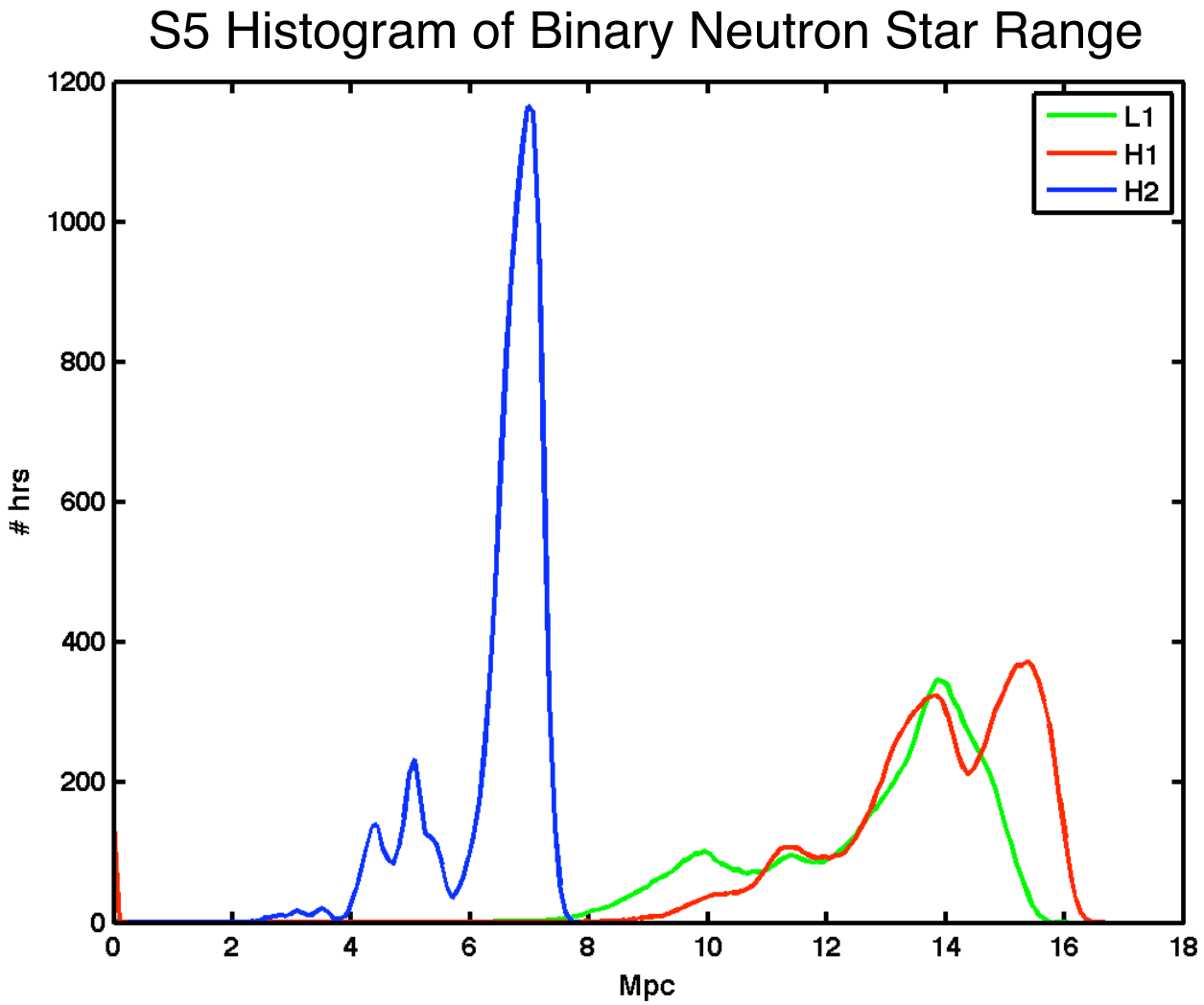
- Fifth Science Run (S5) Nov 5, 2005 - October 1, 2007
- Recorded **one year of coincident data** from the three LIGO detectors **at design sensitivity**
- Seismic wall at ~ 40Hz: S5 is sensitive to binaries with

$$M_{\rm total} \lesssim 100 M_\odot$$

S5 Binary Neutron Star Range



S5 Binary Neutron Star Range



Overview of Searches in S5 Data

- **Triggered** searches
  - » Search for gravitational waves coincident with external trigger
  - » Currently use short-hard gamma ray burst events to trigger inspiral search

- **Untriggered** searches
  - » Blind searches for gravitational waves from compact binaries
  - » Search for binaries with total mass 2 M_{sun} to 100 M_{sun}

- LIGO and Virgo started data sharing in May 2007
  - » Searches before this use LIGO data only
  - » Searches afterwards both LIGO and Virgo data (joint analysis pipeline)

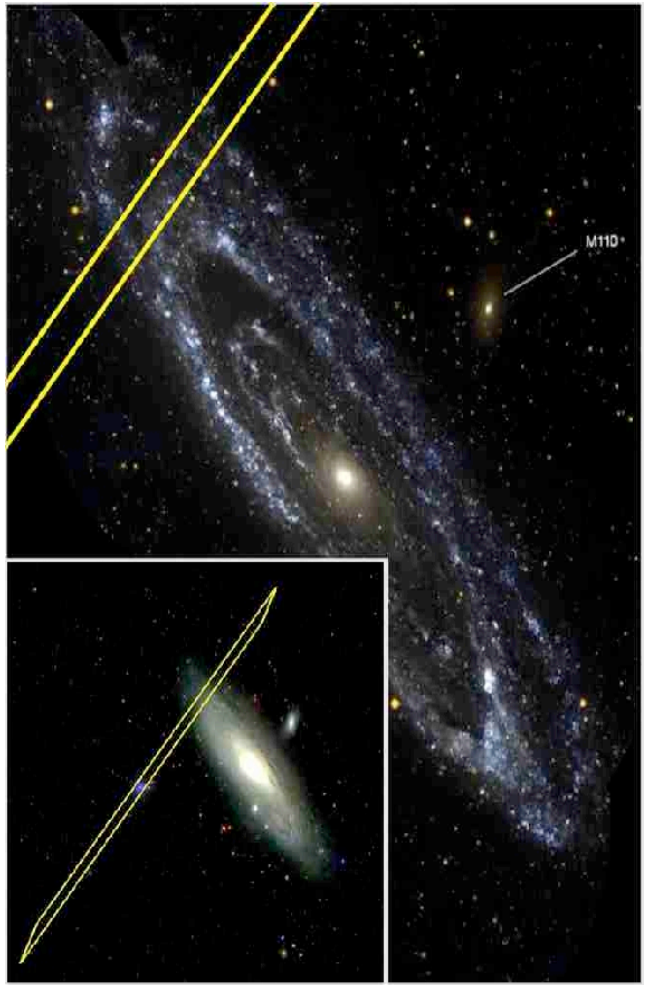
S5 Triggered Searches

- SH-GRBs are thought to have binary inspiral progenitors
- Triggered searches allow us to dig deeper into the detector noise
- Developed a triggered search pipeline to look for gravitational waves associated with a GRB trigger
  - » Has been exercised on GRB070201
- 213 Gamma Ray Bursts During S5
- 32 Short Hard Gamma Ray Bursts of which 26 have at least two LIGO detectors operating

(Talk by N. Fotopoulos Session E8)

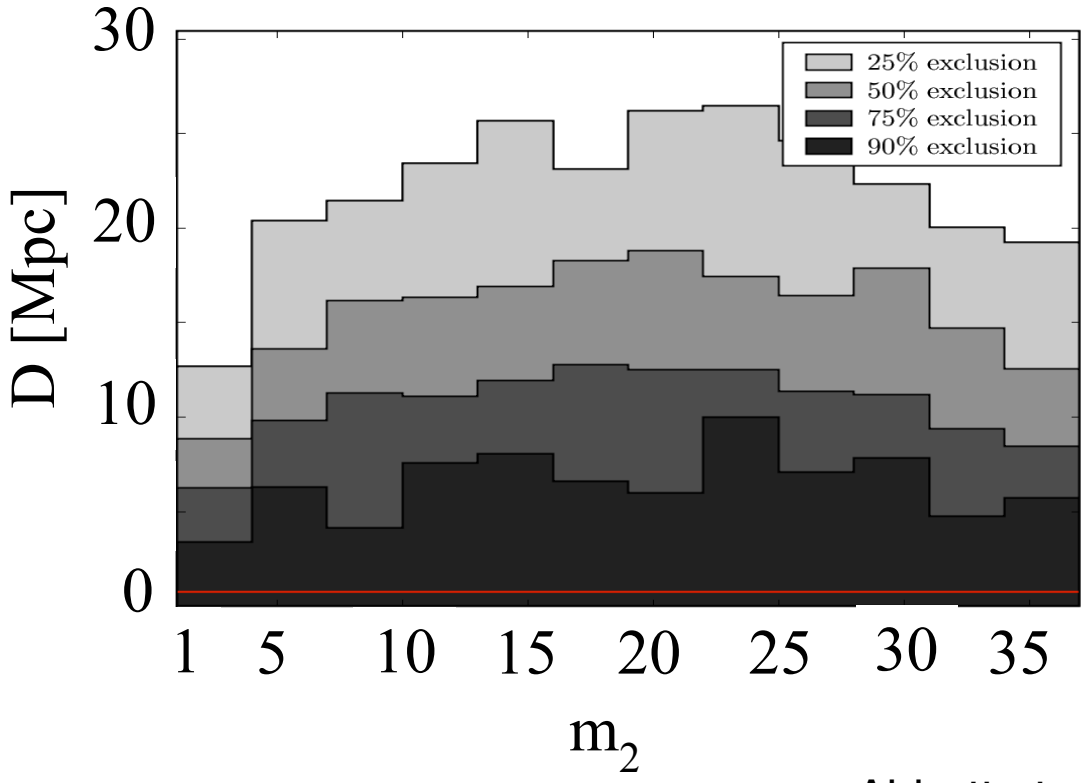
Search for GWs associated with Gamma Ray Burst 070201

- Gamma Ray Burst 070201
- Short Hard GRB located by five electromagnetic satellites
- Location error box overlaps the spiral arms of Andromeda (D ~ 770 kpc)
- LIGO Hanford detectors were operating at the time of the GRB



GRB070201 Triggered Search Result

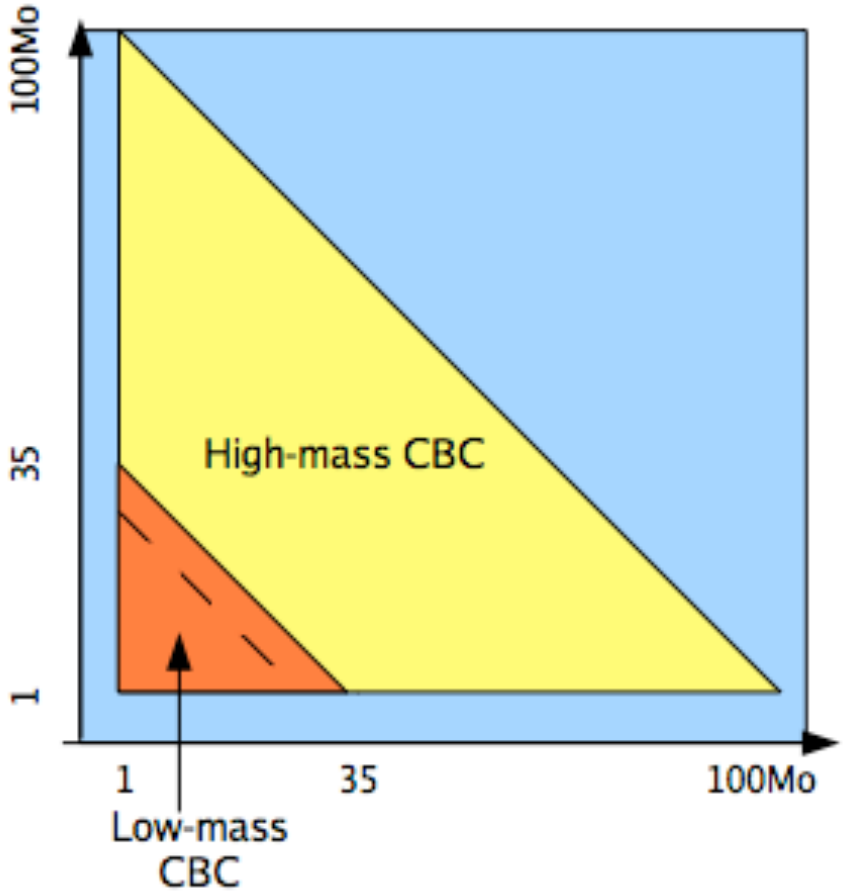
- Inspiral in Andromeda with masses 1.0 M_{sun} < m_1 < 3.0 M_{sun} and 1.0 M_{sun} < m_2 < 40 M_{sun} excluded at > 99% confidence

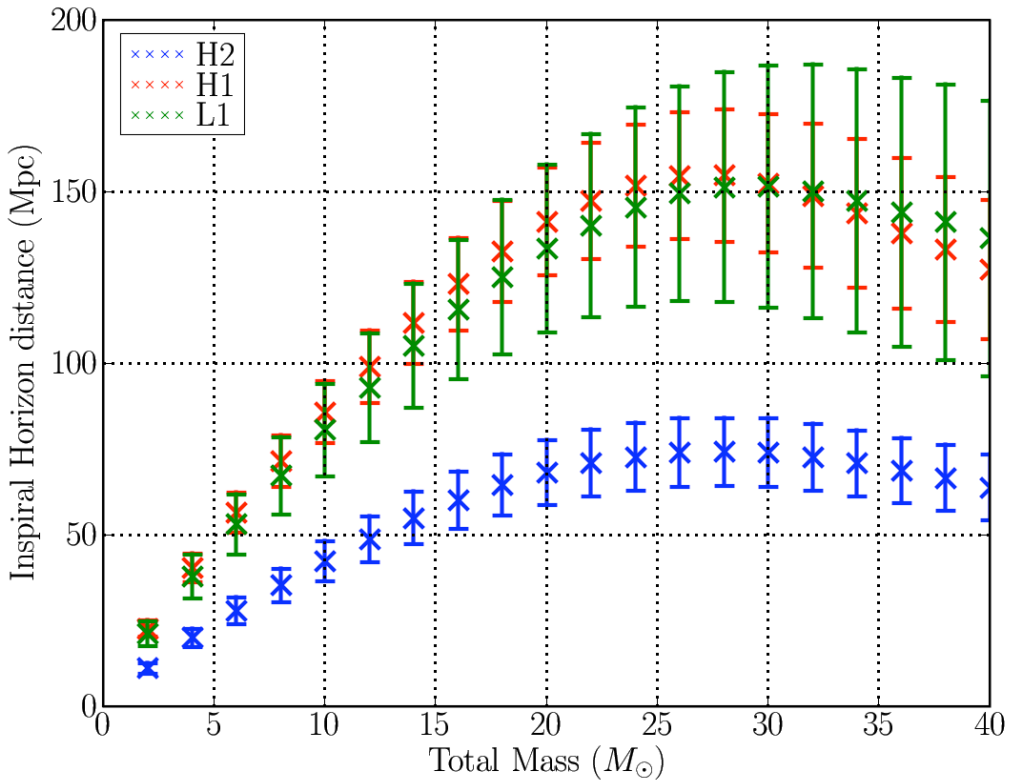


Abbott et. al. arXiv:0711.1163

Untriggered Searches

- In S5 divide sources up into “low” and “high” mass CBC





S5 Untriggered Searches

- Blind detection search for gravitational waves from CBC
- Low mass inspiral search 2 M_{sun} < M < 35 M_{sun}
  - » Use post-Newtonian templates
  - » Includes BNS, BBH and BH-NS region as single search
- High mass inspiral search 35 M_{sun} < M < 100 M_{sun}
  - » Uses Effective One Body templates which model inspiral into merger
- Search for black hole quasi-normal ringdown
  - » Sensitive to ringdowns up to ~ 500 M_{sun}

S5 First Year Search Status

- Search of first calendar year of S5 data for low mass compact binaries is complete
- Analyzed 0.5 yr of data from the three LIGO detectors
- Found our “self-blinded” hardware signal injection
- Final search result currently under collaboration review

Talk by D. Keppel, Session B10

S5 First Year Projected Sensitivity

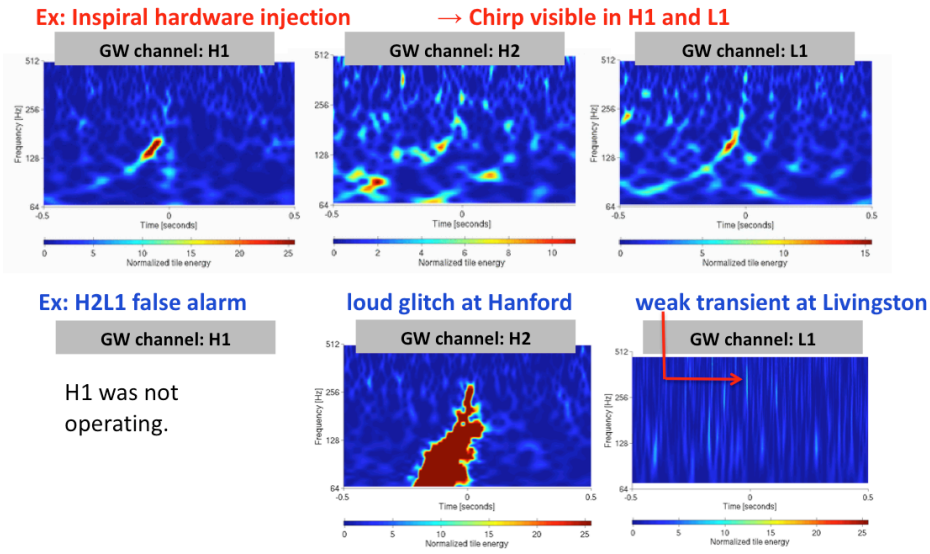
Mass range	Comp. masses (M_{sun})	Inspiral Horizon Distance (Mpc)	Mean N_G (L_{10}) (MWEG = 1.7L_{10})	$(N_G \times T)^{-1}$ (L_{10}^{-1} yr^{-1})
NS / NS	1.4 / 1.4	~ 30 Mpc	~ 200	~ 10^{-2}
NS / BH	1.4 / 5	~ 50 Mpc	~ 1000	~ 10^{-2} -10^{-3}
BH / BH	5 / 5	~ 80 Mpc	~ 4000	~ 10^{-3}

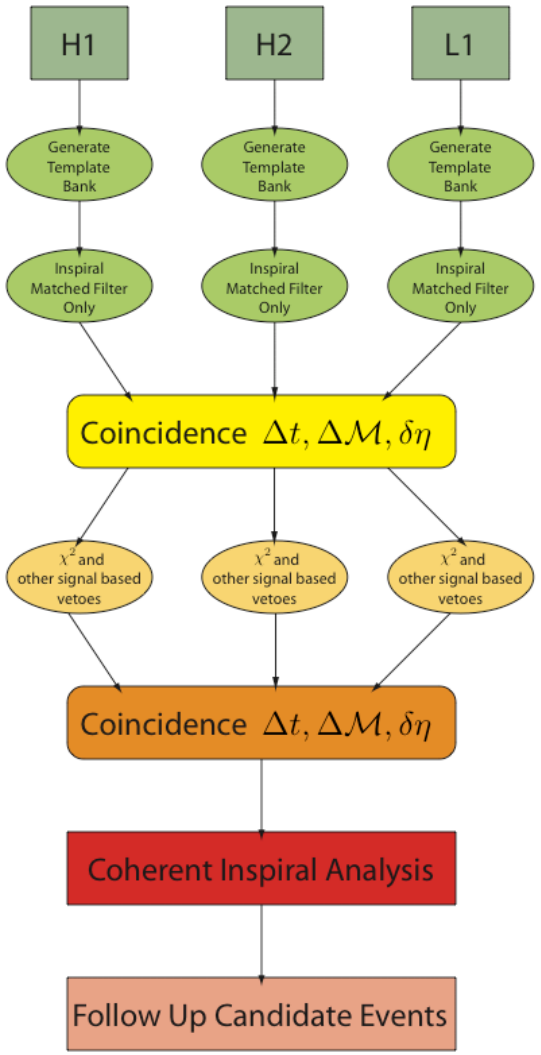
Preliminary

Talks by D. Keppel, S. Caudill, J. Slutsky, Session B10

We are getting ready for a detection…

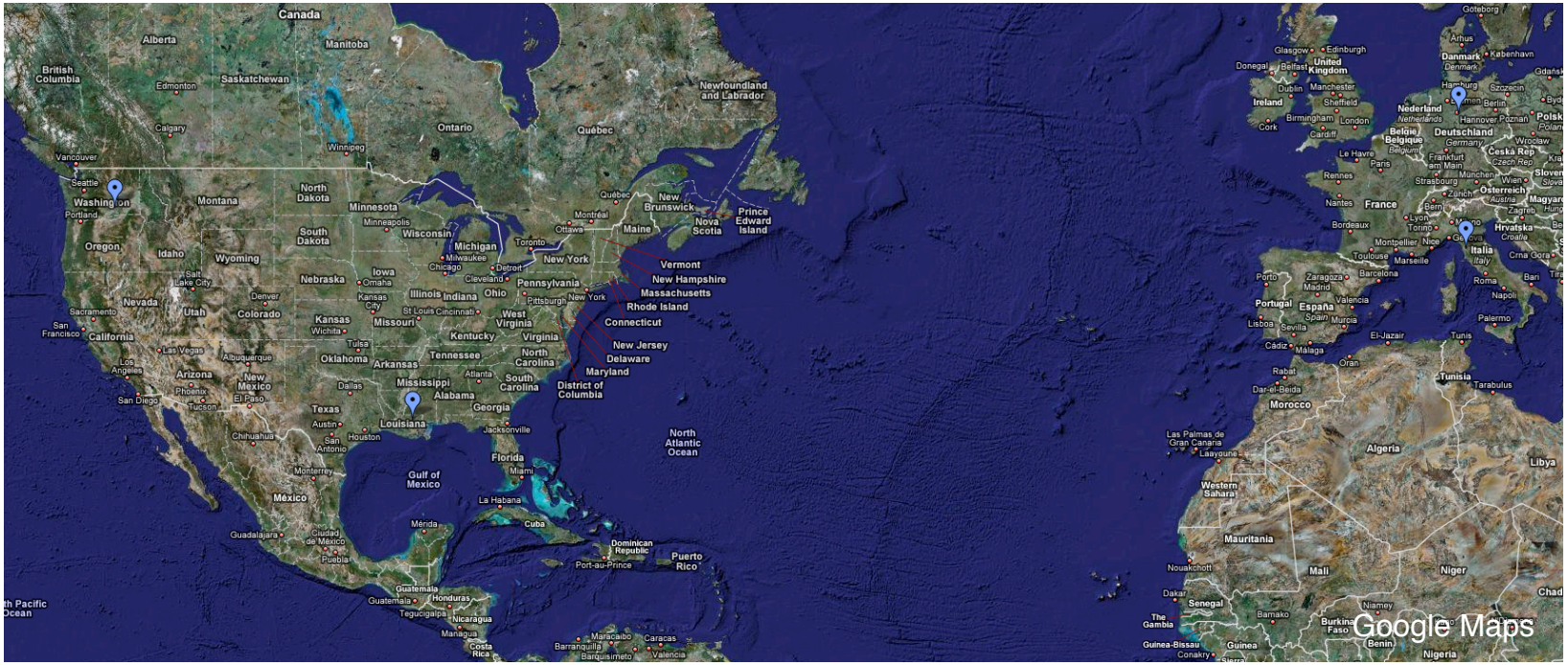
- CBC search pipeline is maturing
  - » Will take us through S5 and Enhanced LIGO
- Experience with S5 data has greatly enhanced our “detection checklist”





A World Wide Network of Detectors

- Virgo joined the S5 run in May 2007
  - » LSC and Virgo collaboration members are working together to analyze the joint LIGO-Virgo data set
- GEO and Hanford 2km detector are in “astrowatch” mode

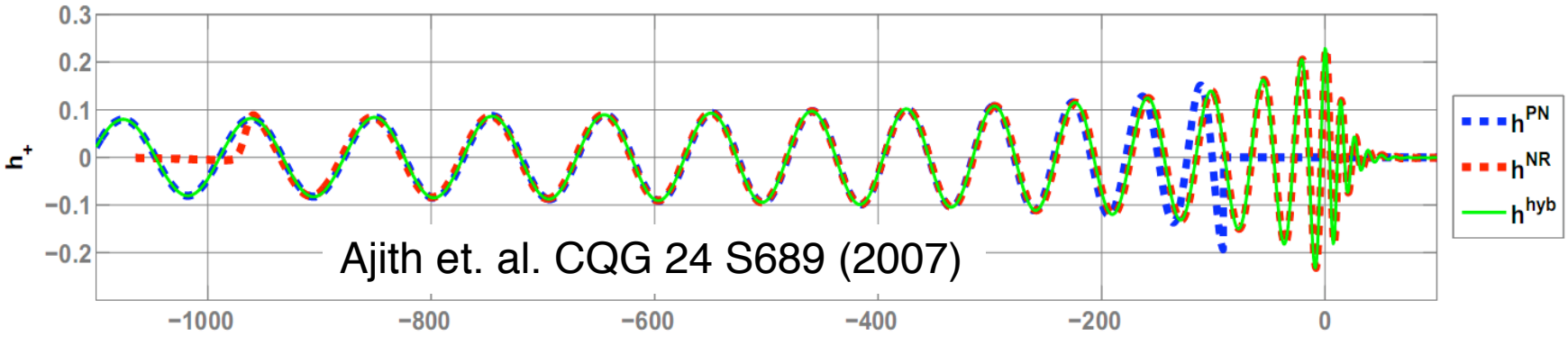


Ongoing CBC Searches

- Search for low mass signals in the second year of S5 data is well underway
- High mass search using EOB templates is ongoing
  - » Takes longer than the low mass search as search in this region is less mature
- Major Goal of CBC Group: Working towards **reducing search latency** for Enhanced and Advanced LIGO
  - » Automating as much of the analysis as possible
  - » Want to be able to react quickly to our data
  - » Looking towards gravitational wave astronomy
- Black hole ringdown search underway on S4 and S5 data

New Developments in CBC Searches

- Enhancing searches with information learned from numerical simulations
  - » e.g. hybrid PN-NR waveforms, EOB+Ringdown templates



- Establishing joint inspiral-merger-ringdown analyses
- Better incorporating the effect of spin in template searches
- Improving parameter estimation pipelines
- Looking towards coincidence with other electromagnetic triggers

Conclusions

- Analysis of S5 LIGO and Virgo data is moving rapidly
- Sensitivity of Enhanced and Advanced LIGO makes this an exciting time
- LSC and Virgo are working towards **gravitational wave astronomy** with compact binaries