Results from LIGO Observations

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on behalf of the

LIGO Scientific Collaboration

LIGO-G060363-00-Z

Introduction

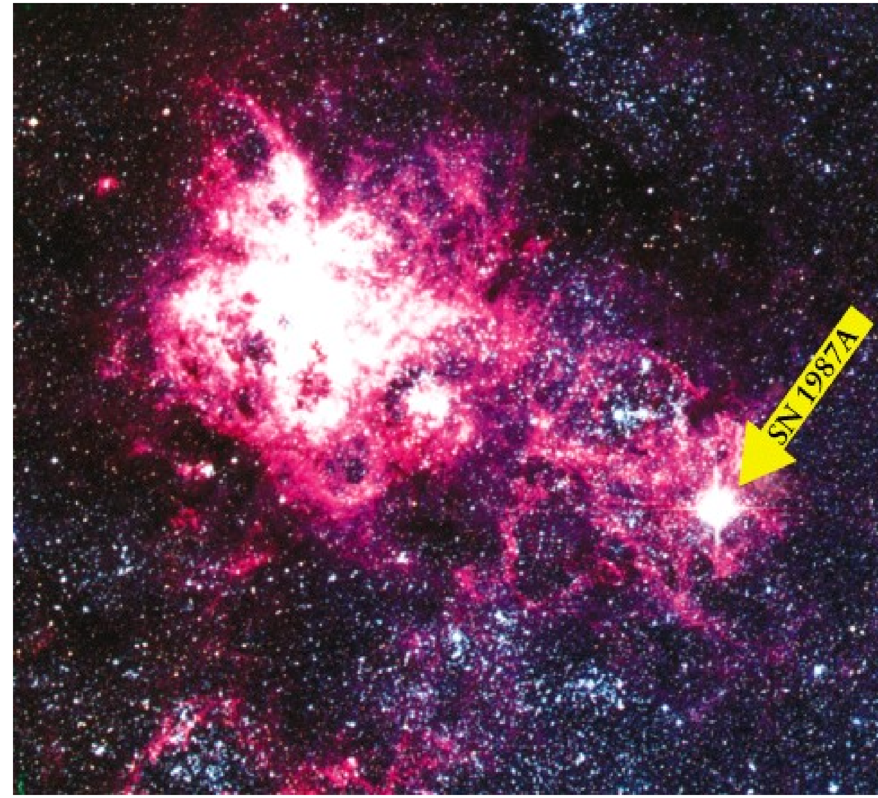
- Overview of LIGO searches for gravitational wave transients
  - Signals lasting from a few ms to a few minutes
- Broadly split into two categories:
  - Well modelled sources
    - Binary inspiral, black hole ringdown, cosmic string cusps
  - Unmodelled sources
    - BH merger, core-collapse supernovae, GRB engines, ...
- No GW identified so far, but upper limits are becoming astrophysically interesting.

Outline

- Gravitational wave bursts
  - Unmodelled bursts
  - Astronomically triggered searches
- Coalescing binaries
  - Binary neutron stars
  - Binary black holes

Gravitational Wave Bursts

- Produced during cataclysmic events involving stellar-mass (1-100 $M_{\odot}$) compact objects:
  - Core-collapse supernovae
  - Accreting/merging black holes
  - Gamma-ray burst engines
  - Unexpected ...

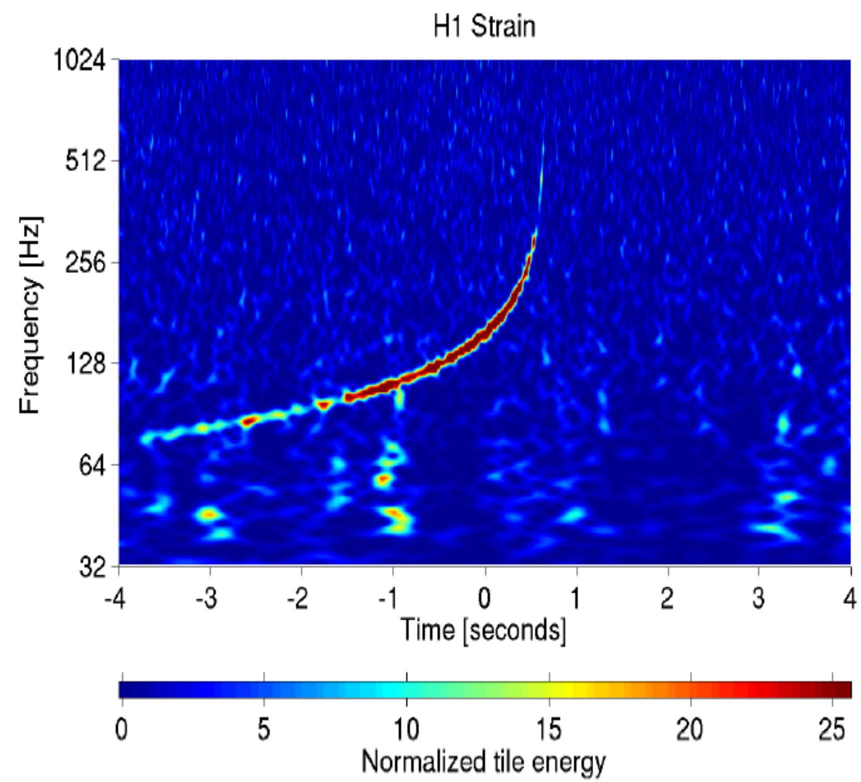


- Probe interesting new physics and astrophysics:
  - dynamical gravitational fields, black hole horizons, matter at supra-nuclear density, ...
- Uncertain waveforms complicate detection.

Excess power detection

- Look for transient increase in power in some time-frequency region:
  - Minimal assumptions about signal
  - Duration: 1 to 100 ms
    - Characteristic time scale for stellar mass objects
  - Frequency: 60 to 2,000 Hz
    - Determined by detector's sensitivity
  - Many different implementations
    - Fourier modes, wavelets, sine-Gaussians
    - Multiple time/frequency resolutions
    - Provide redundancy and robustness

Simulated binary inspiral signal in S5 data



Consistency Checks

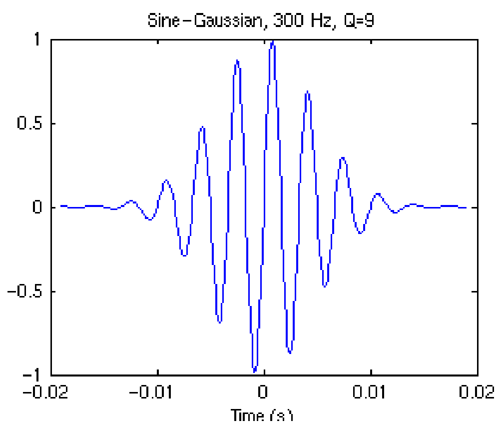
- Require time and frequency coincidence in three LIGO detectors.
- Follow up coincidences with:
  - Amplitude consistency between co-located H1-H2 detectors
  - Cross correlation of data from pairs of detectors
  - Check environmental and auxiliary channels for:
    - Earthquakes, airplanes, trains, instrumental misbehaviour, ...
  - Remove times of poor data quality
  - Veto events associated to known noise sources
- Compare remaining events with background estimated by repeating analysis with large time shifts of detector data.

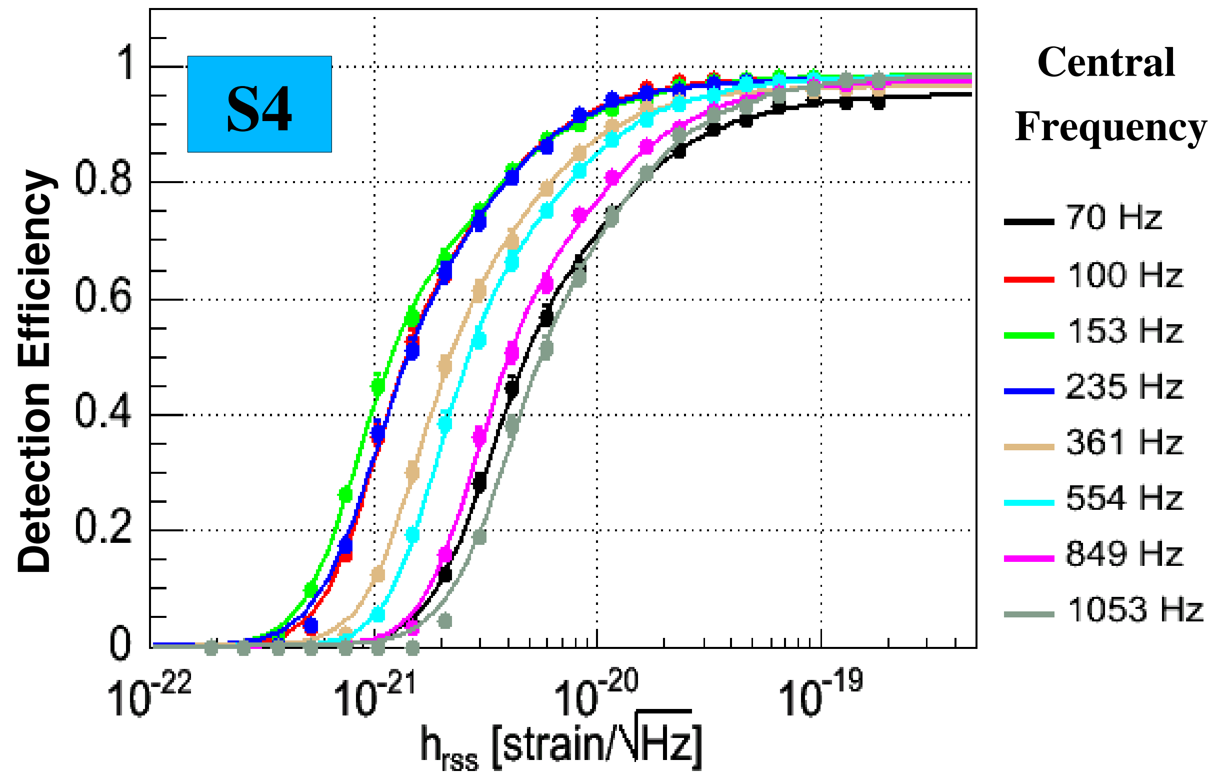
Burst Search Results

- Analysis of data from first three science runs (S1-S3) complete:
  1. B. Abbott et al. (LSC), *First upper limits from LIGO on gravitational wave bursts.* Phys. Rev. D **69**, 102001 (2004).
  2. B. Abbott et al. (LSC), *A Search for Gravitational Waves Associated with the Gamma Ray Burst GRB030329 Using the LIGO Detectors.* Phys. Rev. D **72**, 042002 (2005).
  3. B. Abbott et al. (LSC), *Upper Limits on Gravitational Wave Bursts in LIGO's Second Science Run.* Phys. Rev. D **72**, 062001 (2005)
  4. B. Abbott et al. (LSC), T. Akutsu et al. (TAMA), *Upper Limits from the LIGO and TAMA Detectors on the Rate of Gravitational-Wave Bursts.* Phys. Rev. D **72**, 122004 (2005)
  5. B. Abbott et al. (LSC), *Search for gravitational wave bursts in LIGO's third science run.* Class. Quant. Grav. **23**, S29-S39 (2006)
- Results from S4 being finalised.
- S5 search in progress.

Detection Efficiency

- Evaluate efficiency ϵ by adding simulated GW bursts to the data.
  - Example waveform



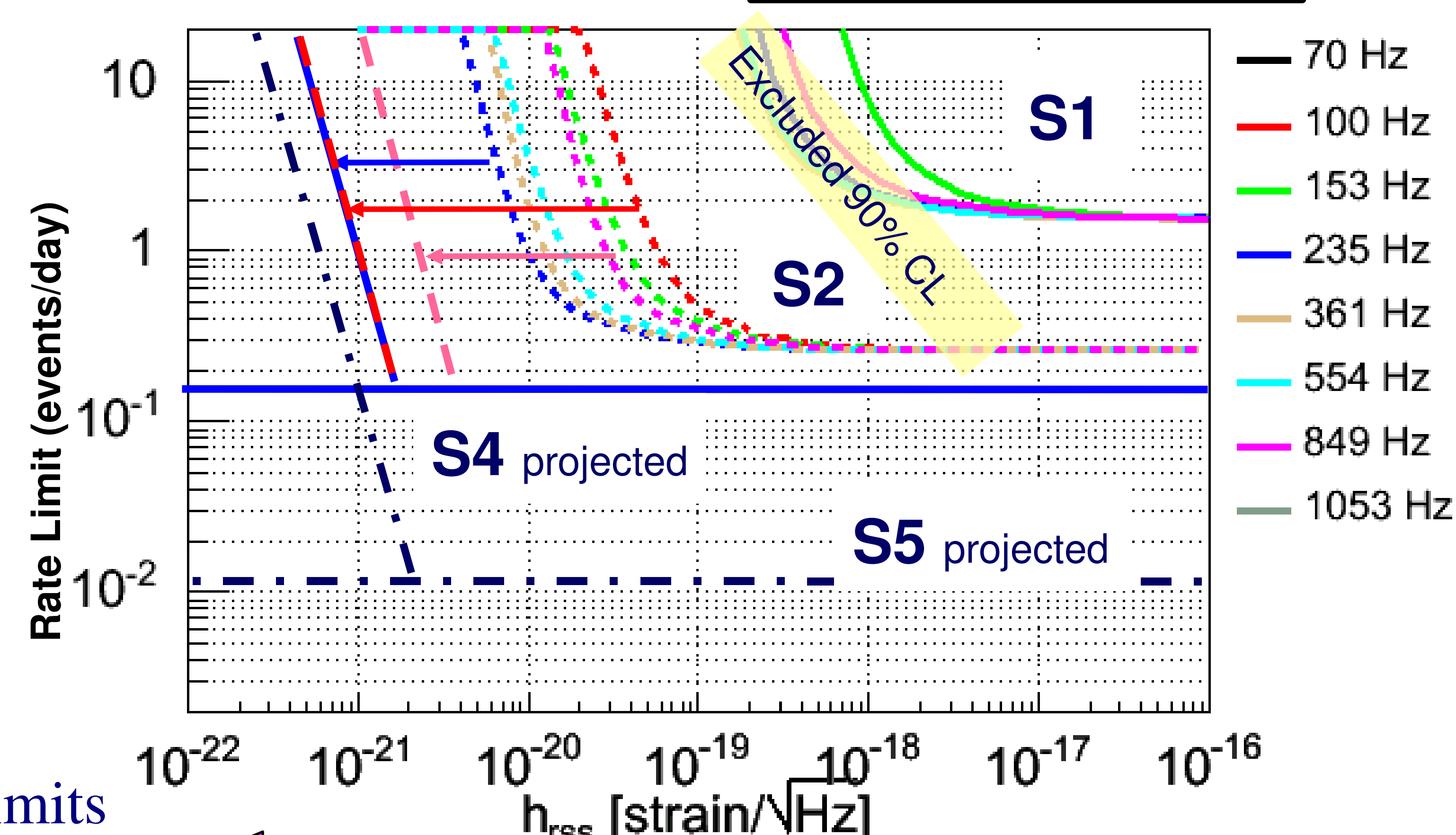


- S5 sensitivity: minimum detectable in band energy in GW
  - $E_{GW} > 1\ M_{\odot}$ @ 75 Mpc
  - $E_{GW} > 0.05\ M_{\odot}$ @ 15 Mpc (Virgo cluster)

Upper Limits

- No GW bursts detected through S4
  - set limit on rate vs signal strength.

$$R \propto \frac{1}{\epsilon(h_{\rm rss})\, T}$$



Lower rate limits from longer observation times

Lower amplitude limits from lower detector noise

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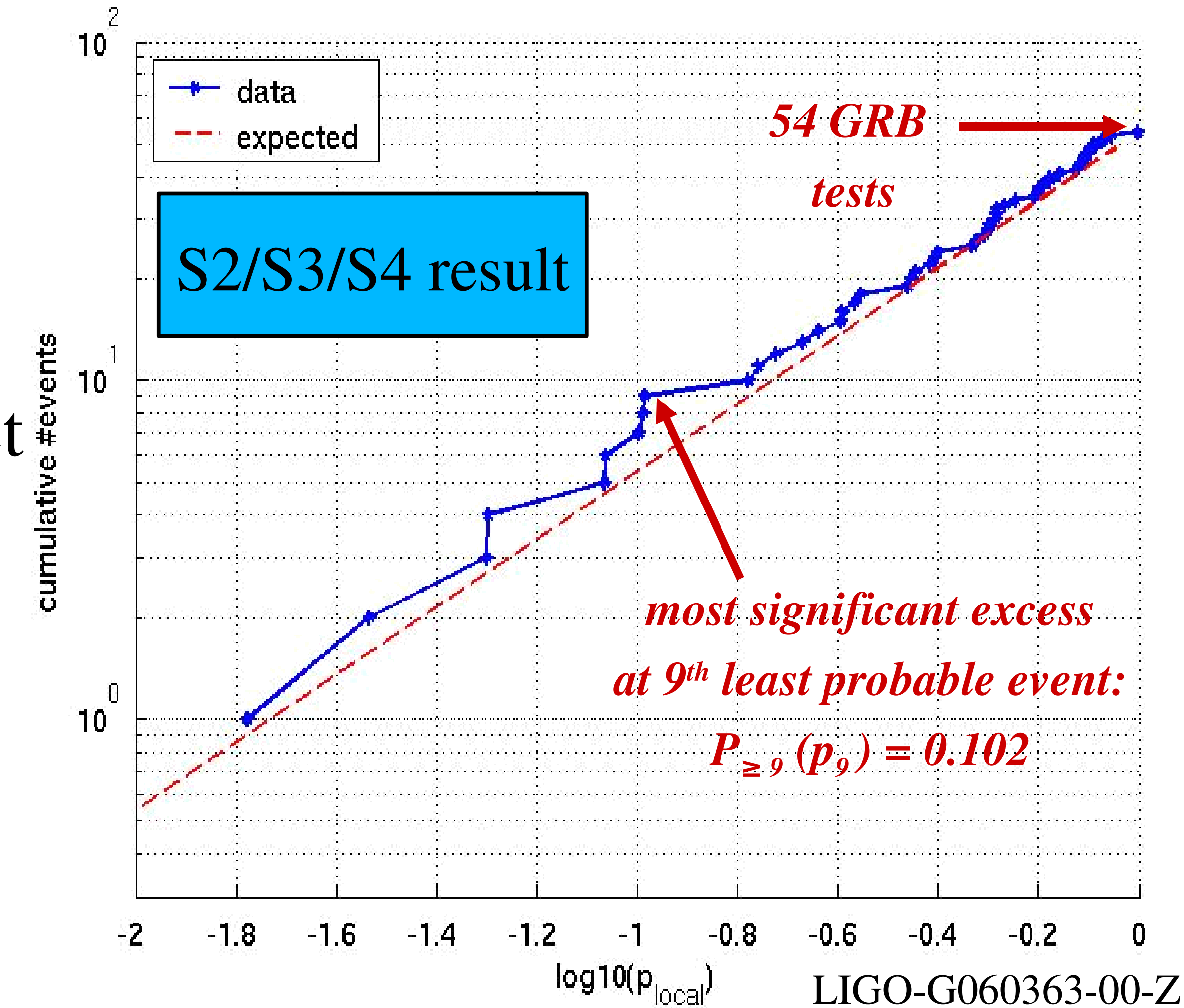
Triggered Searches

- Follow up times around interesting astronomical triggers, particularly gamma-ray bursts
  - Compare results with those from time shifts
- No loud signals seen
- Look for cumulative effect
  - Use binomial test to compare to uniform distribution
- No significant difference from expectation

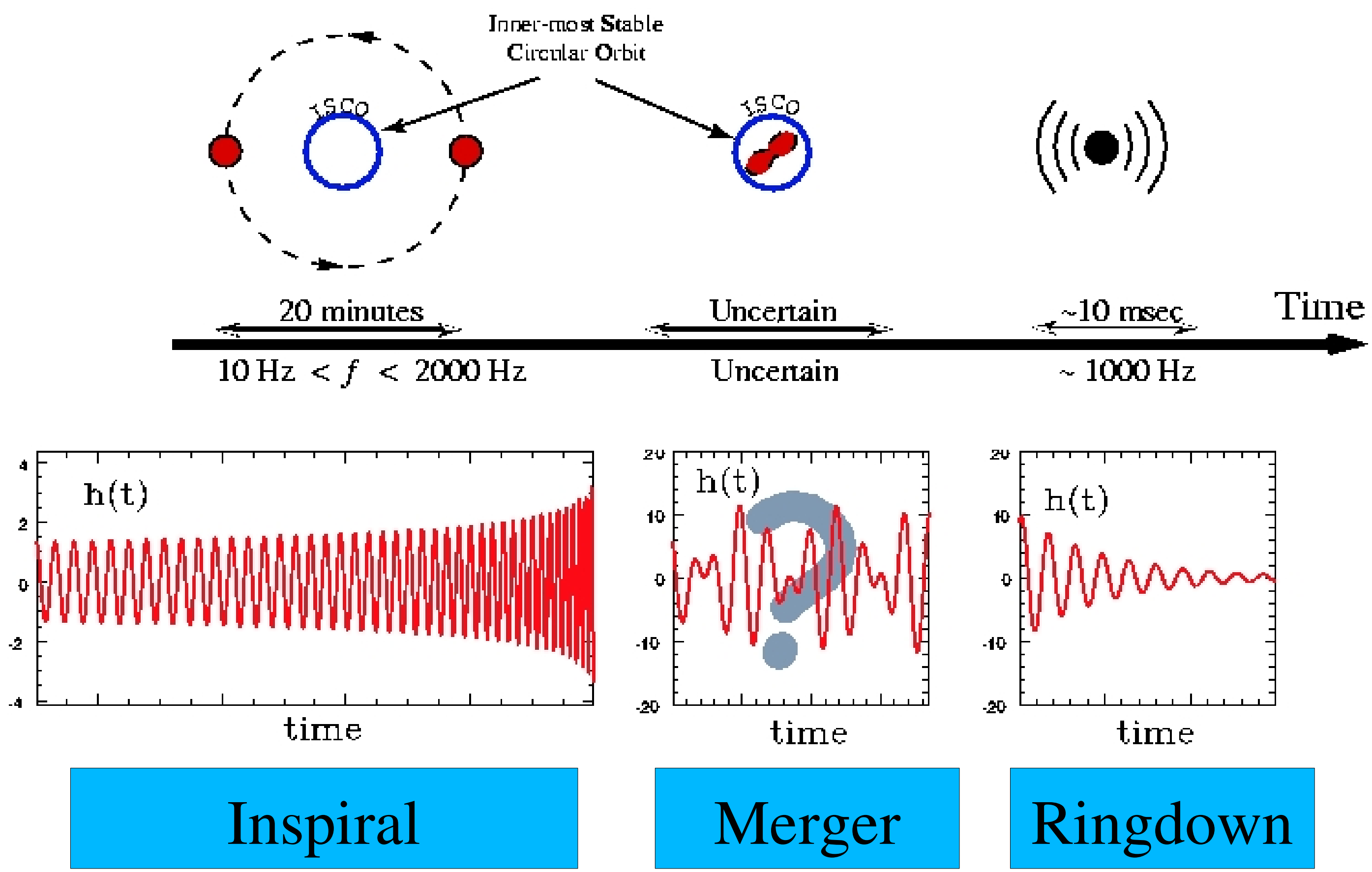


Outline

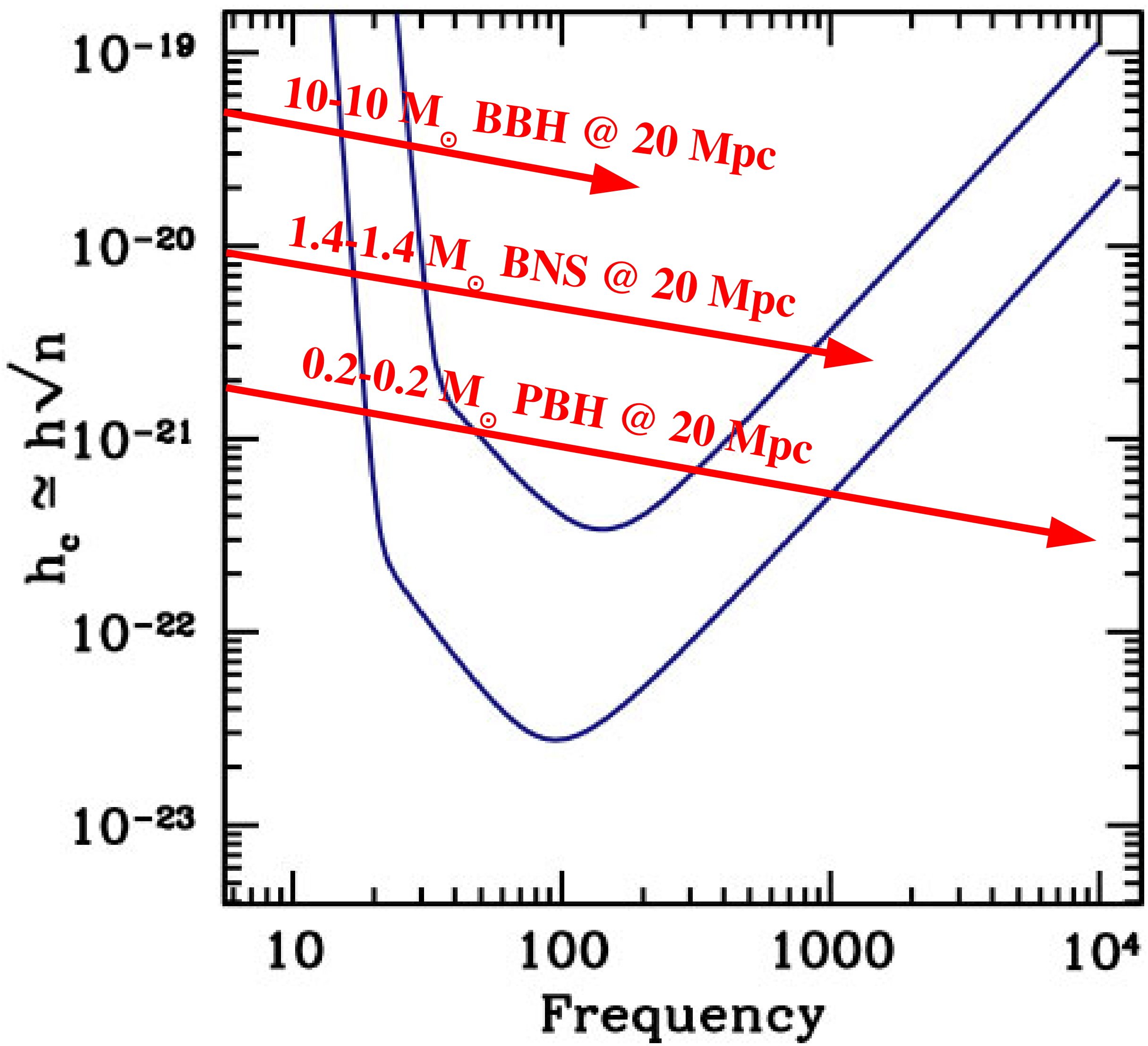
- Gravitational wave bursts
  - Unmodelled bursts
  - Astronomically triggered searches
- Coalescing binaries
  - Binary neutron stars
  - Binary black holes

Coalescing Binaries

- LIGO is sensitive to gravitational waves from neutron star and black hole binaries

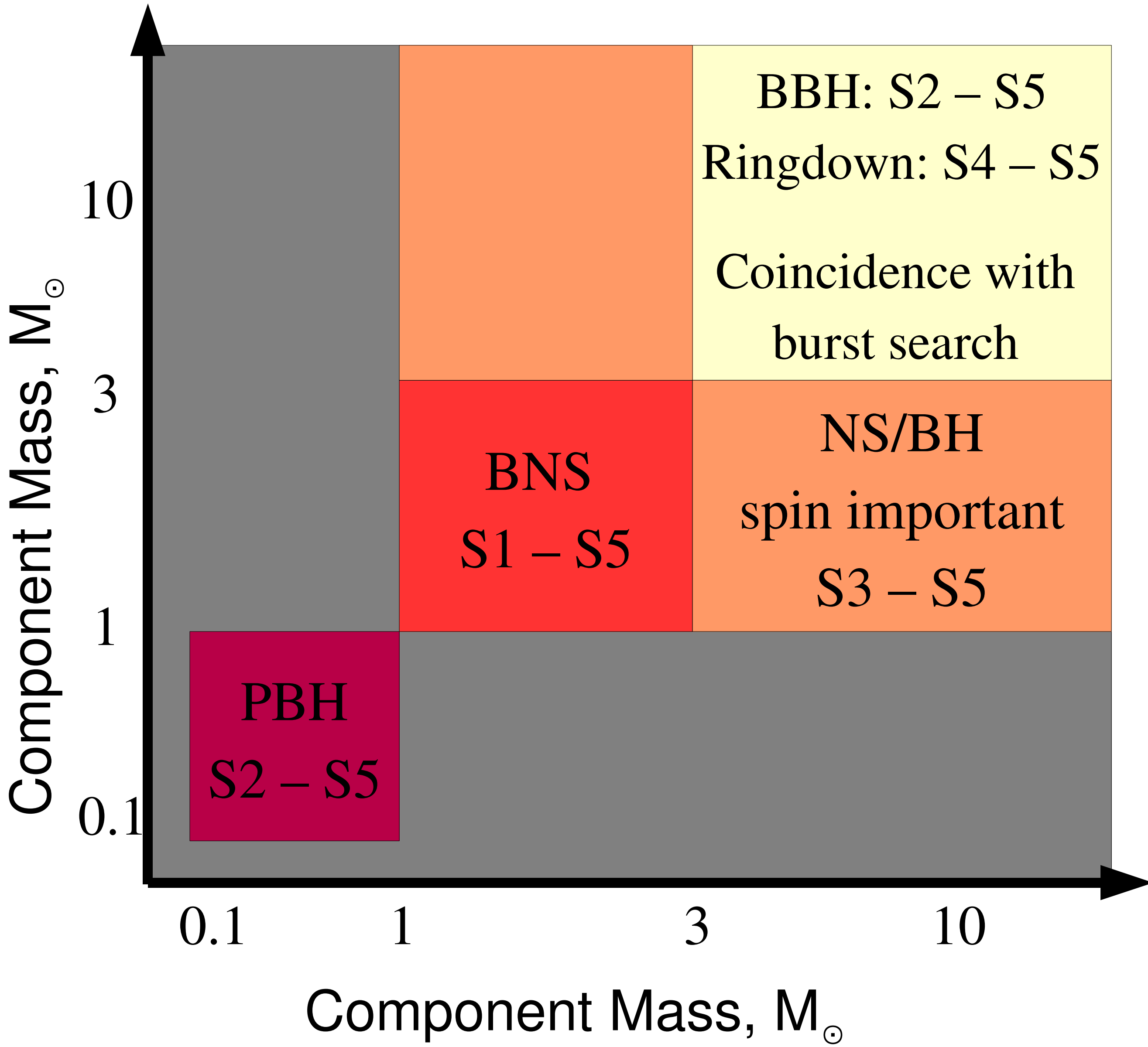


Target Sources



- Use templated search
  - Require waveform consistency
- Use detection templates for higher masses
- Require time and mass coincidence between 2 or more detectors
- Data quality/followup similar to burst searches

Target Sources

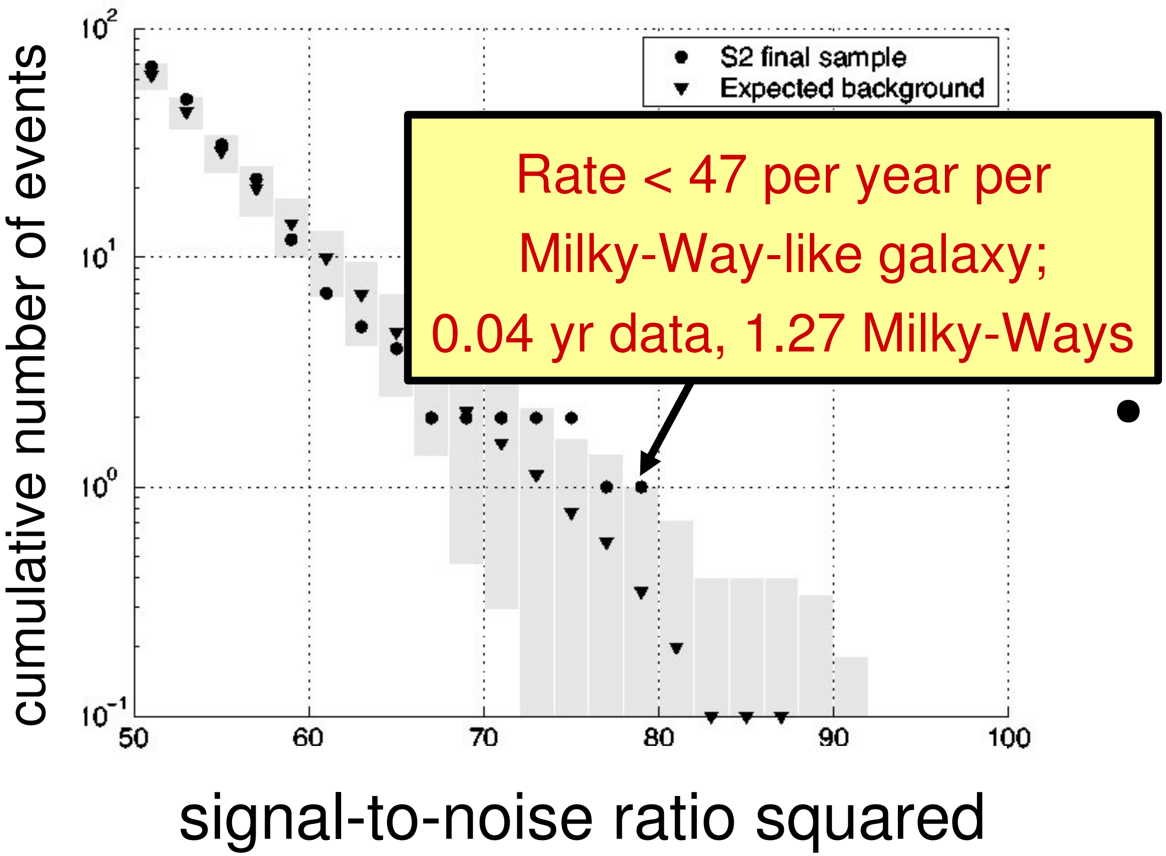


- Binary Black Hole
  - Estimates give upper bound of 1/year for LIGO during S5
- Binary Neutron Star
  - Estimates give upper bound of 1/3 year for LIGO during S5

Binary Neutron Stars

S2 Observational Result

Phys. Rev. D. 72, 082001 (2005)



- S3 search complete
  - Under internal review
  - 0.09 yr of data
  - ~3 Milky-Way like galaxies for 1.4 – 1.4 $M_\odot$
- S4 search complete
  - Under internal review
  - 0.05 yr of data
  - ~24 Milky-Way like galaxies for 1.4 – 1.4 $M_\odot$

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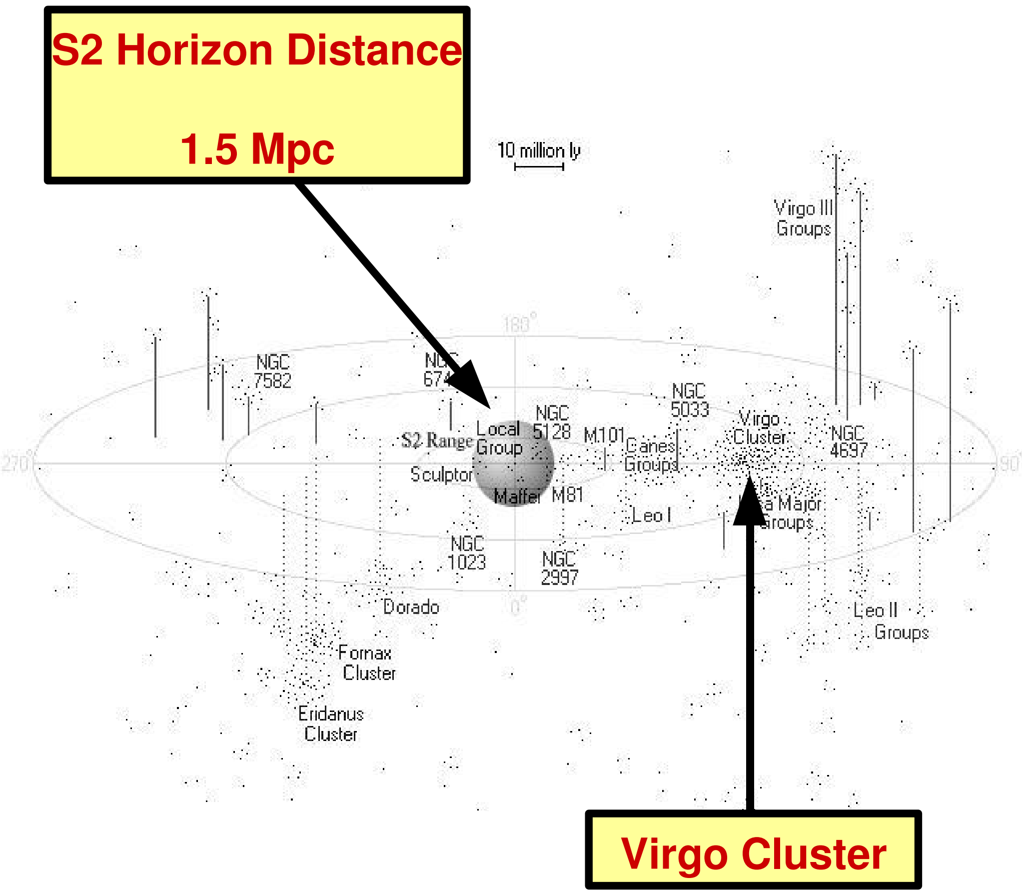
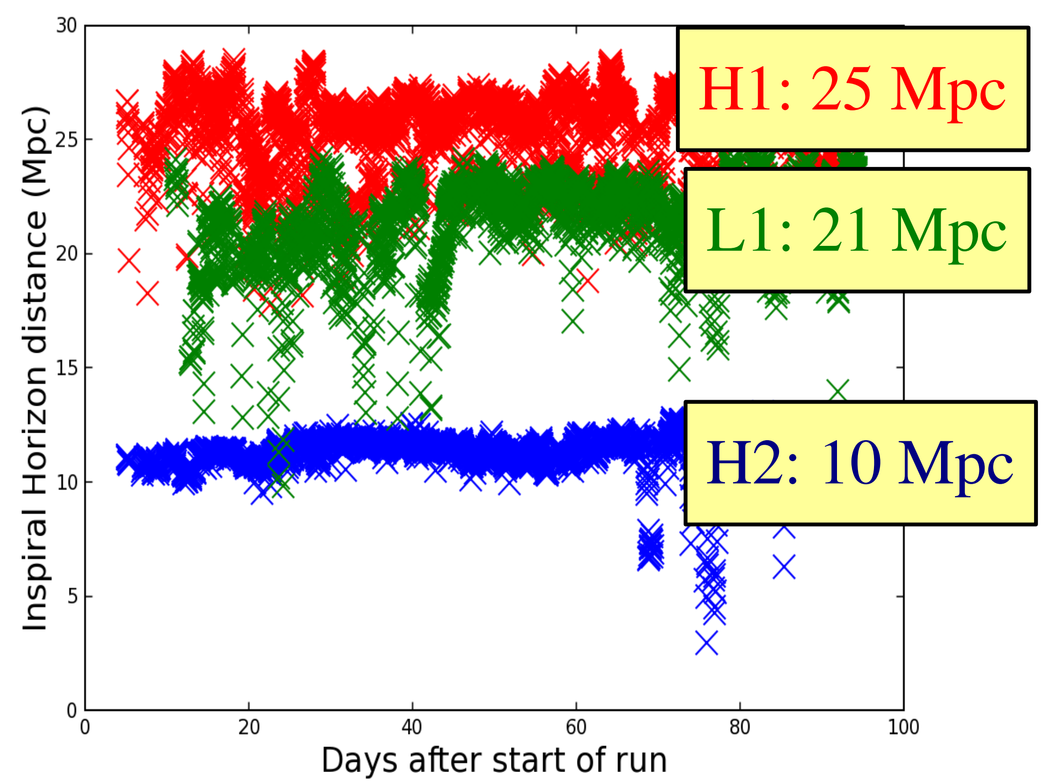
S5 Binary Neutron Stars

- First three months of S5 data have been analyzed



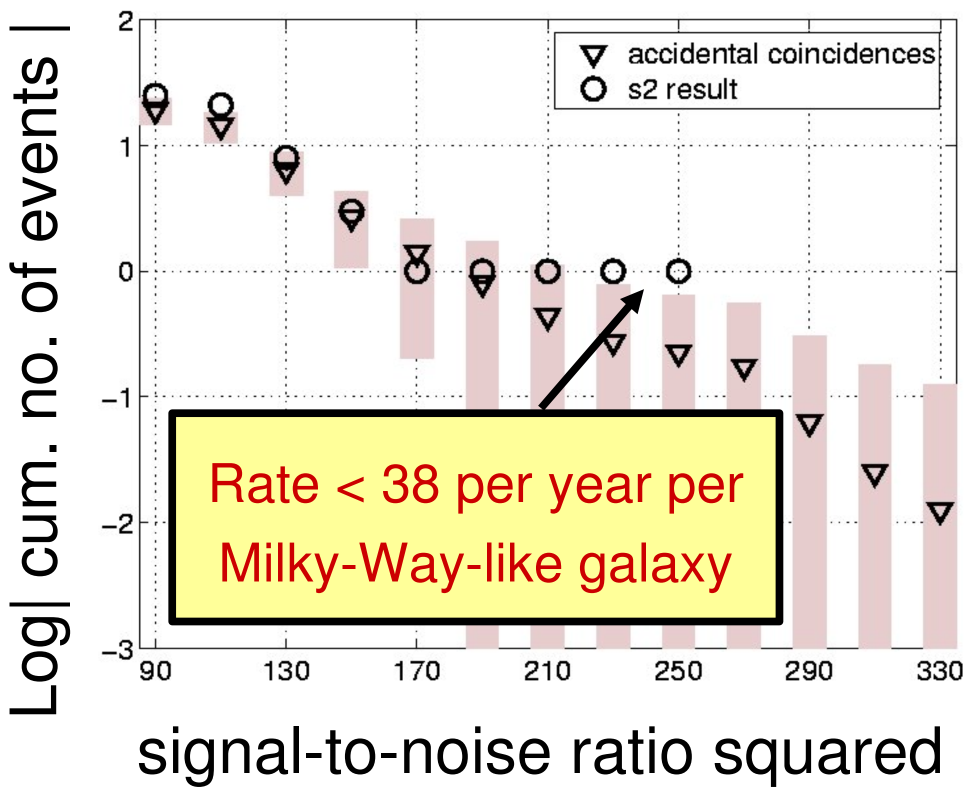
- Horizon distance
  - Distance to 1.4-1.4 $M_\odot$ optimally oriented & located binary at SNR 8



Binary Black Holes

S2 Observational Result

Phys. Rev. D. 73, 062001 (2006)

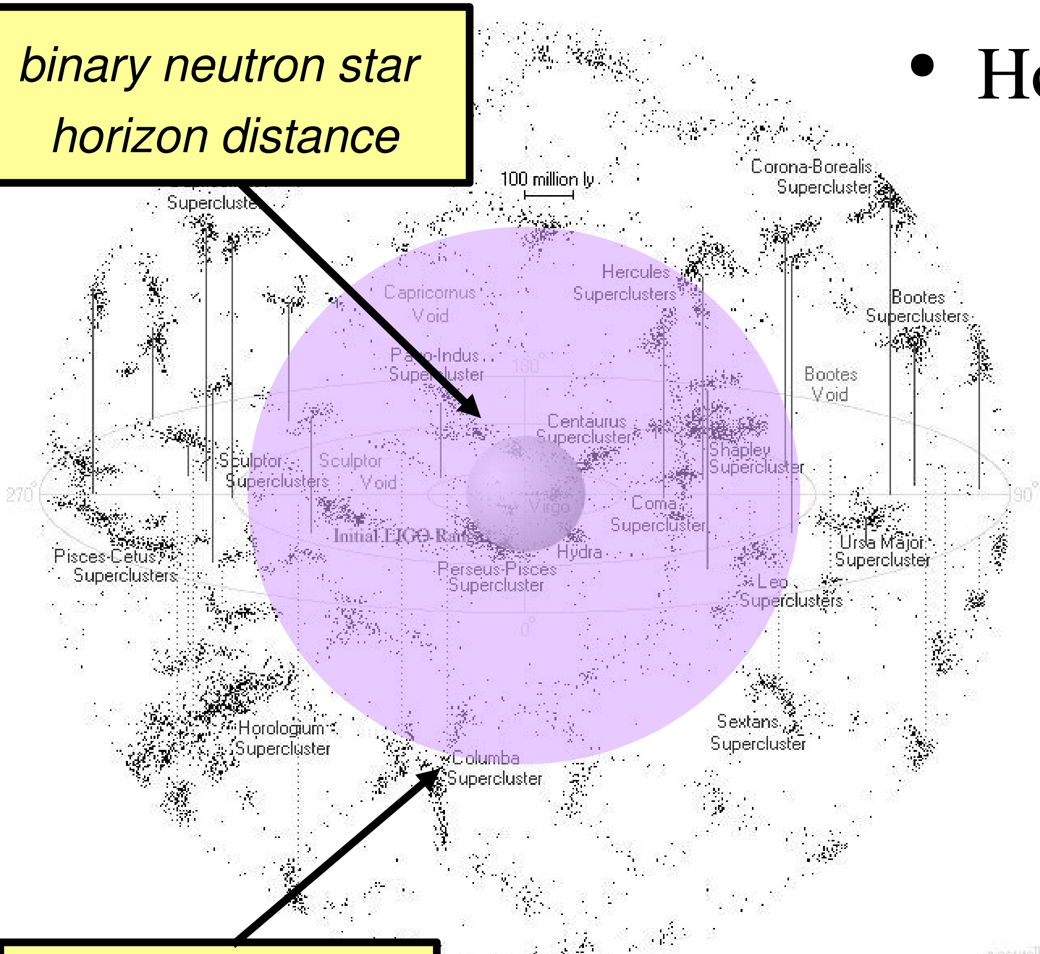


- S3 search complete
  - Under internal review
  - 0.09 yr of data
  - ~5 Milky-Way like galaxies for 5-5 $M_\odot$
- S4 search complete
  - Under internal review
  - 0.05 yr of data
  - ~150 Milky-Way like galaxies for 5-5 $M_\odot$

S5 Binary Black Holes

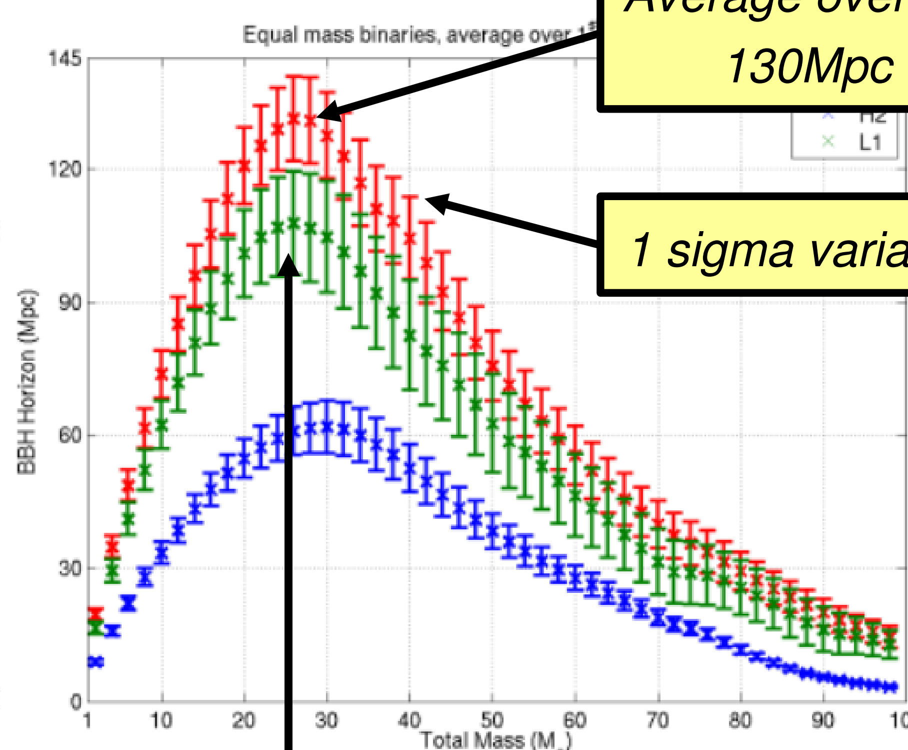
- Horizon distance vs mass for BBH

binary neutron star horizon distance



binary black hole horizon distance

Average over run 130Mpc



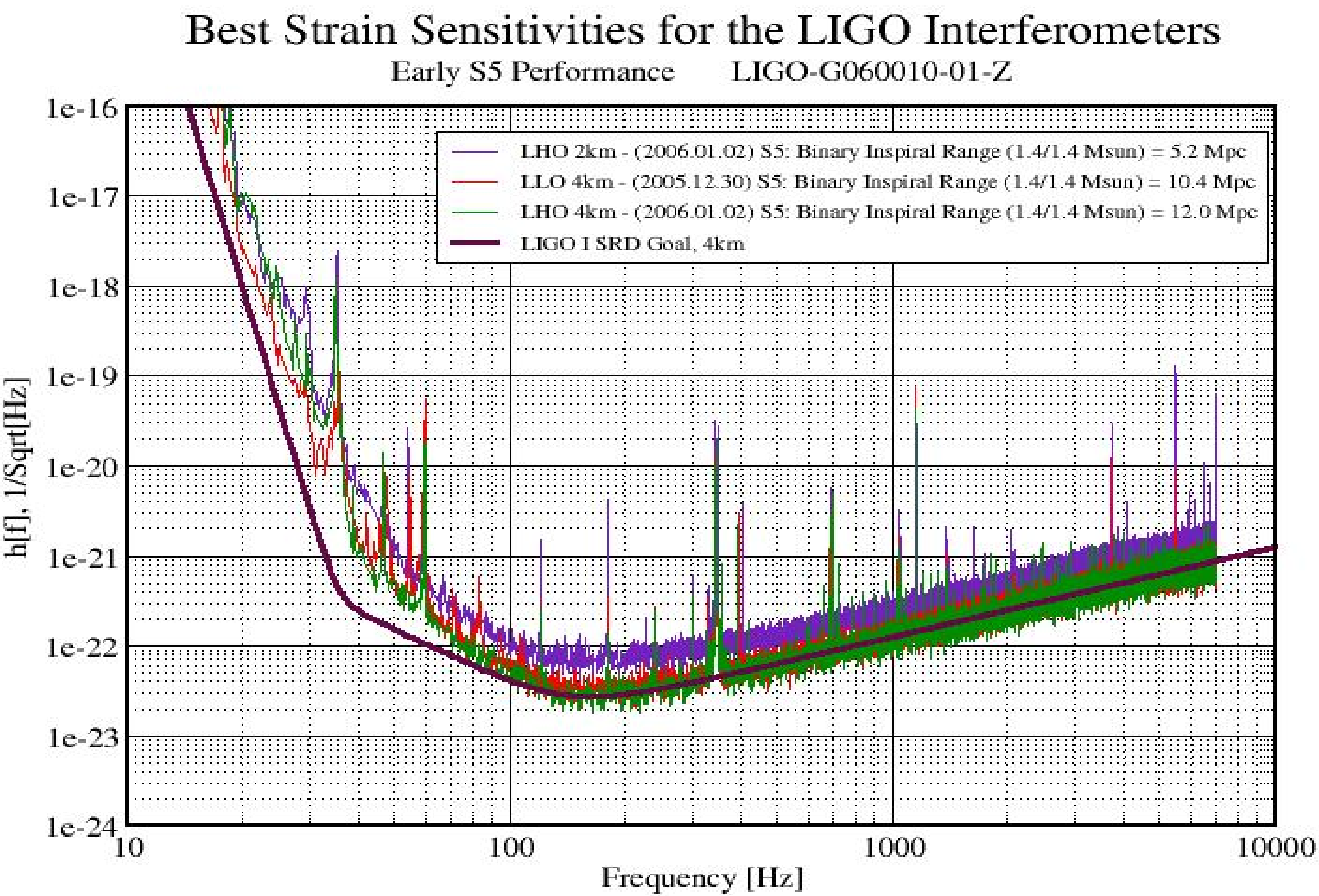
1 sigma variation

Peak at total mass ~ 25$M_\odot$

Conclusions

- Analysis of LIGO data is in full swing
  - In the process of acquiring one year of coincident data at design sensitivity.
  - "Online" analysis & follow-up provide rapid feedback to experimentalists.
  - Results from fourth and fifth LIGO science runs are appearing.
- Burst searches
  - Rate and amplitude sensitivites continue to improve
    - Minimum detectable in-band energy: $E_{GW} \sim 1\ M_{\odot}$ at r ~100 Mpc.
- Inspiral searches
  - S5 sensitivity makes this an exciting time for gravitational wave astronomy and astrophysics.

Looking Forward



Looking Forward