LIGO-G040205-00-E

Status of LIGO Searches for Binary Inspirals

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For the Inspiral Analysis Working Group
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The LSC Inspiral Analysis Working Group

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Collaboration tools:

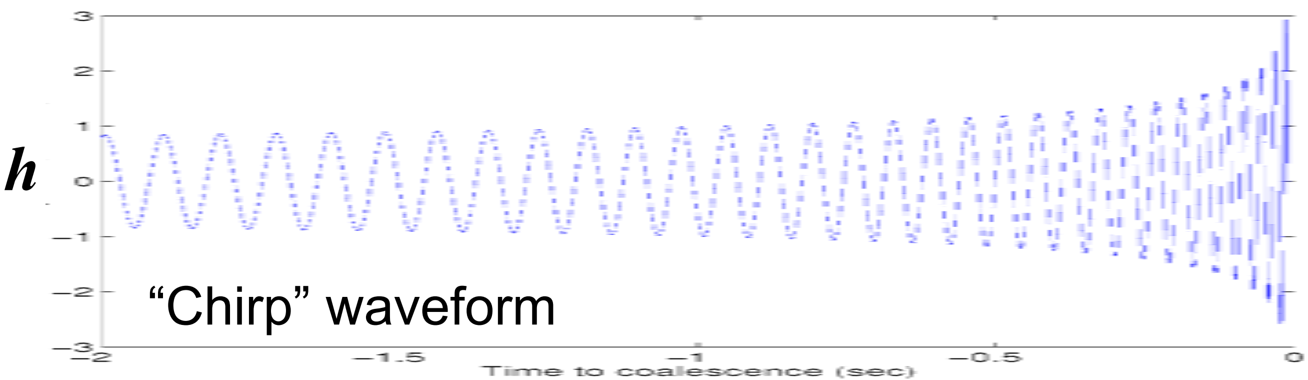
- Email mailing list
- Web-based electronic notebook
- Weekly teleconference
- Occasional face-to-face meetings

Target Sources

Compact binary system

Each object a neutron star or a black hole (up to ~50 $M_{\odot}$)

Orbit decays due to emission of gravitational radiation



In LIGO frequency band (40–2000 Hz) for a short time just before merging: anywhere from a few minutes to ≪1 second, depending on mass

Waveform is known accurately for low masses, but not for higher masses, especially if there is spin

Overview of Inspiral Search Technique (1)

Use matched filtering in frequency domain

Data

Template

$$z(t) = 4 \int_0^{\infty} \frac{\tilde{s}(f)\ \tilde{h}^*(f)}{S_n(f)}\ e^{2\pi i f t}\ df$$

Noise power spectral density

Look for maxima of $|z(t)|$ above some threshold ➔ "triggers"

Check consistency of signal with expected waveform

Divide template into p parts, calculate $\chi^2(t) = p \sum_{l=1}^{p} \| z_l(t) - z(t)/p \|^2$

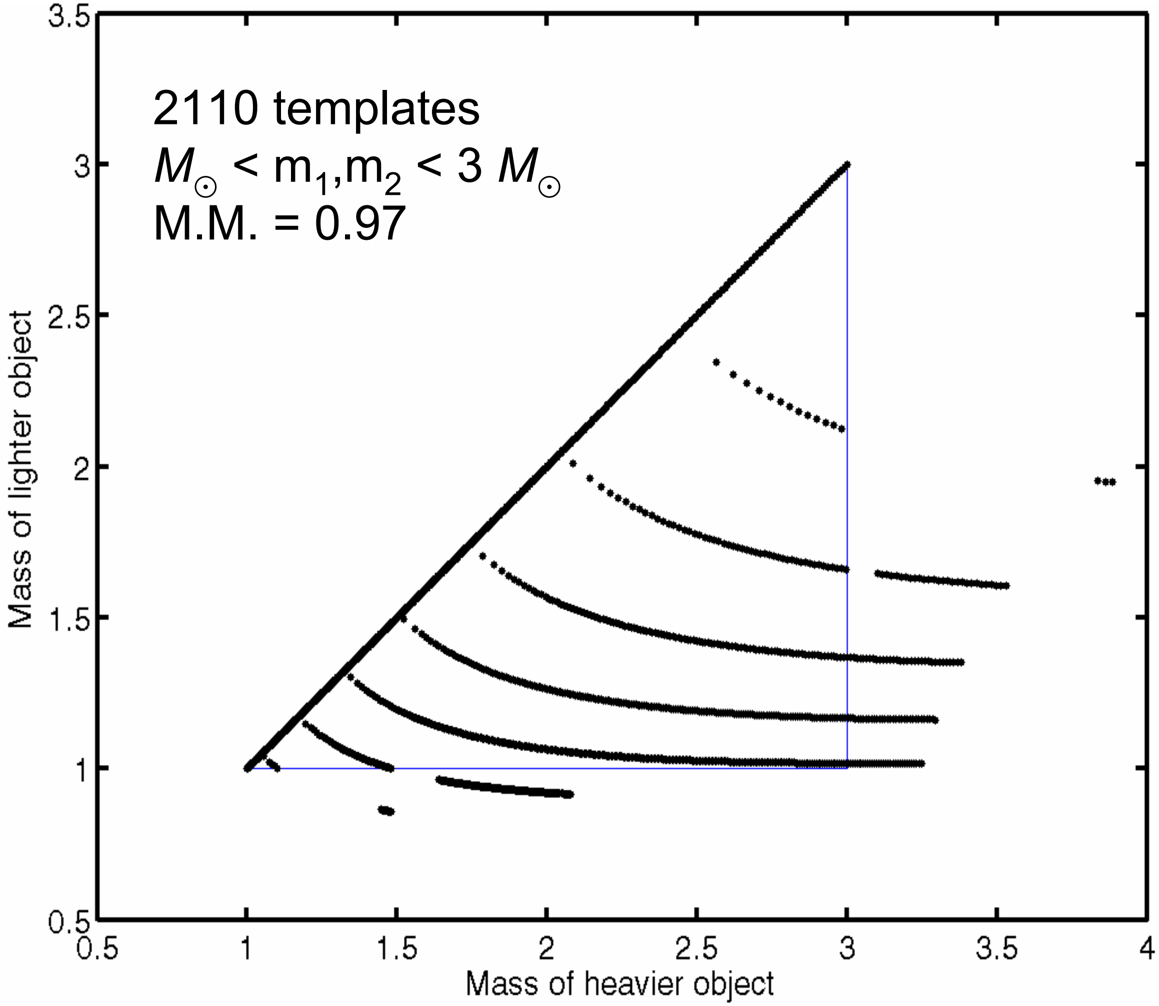
Other waveform consistency tests are being considered

Overview of Inspiral Search Technique (2)

Use a bank of templates to cover parameter space

Require a certain "minimal match" with all possible signals

Process data in parallel on many CPUs

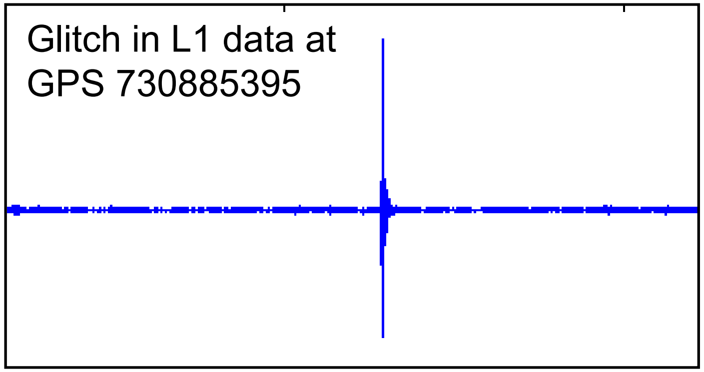


Overview of Inspiral Search Technique (3)

Process only good data, based on data quality checks

Validate search algorithm with simulated signals

Use auxiliary channels to veto environmental / instrumental glitches



Require coincidence to make a detection

- Consistent time, signal parameters in multiple interferometers
- Eventually, will do coherent analysis

… or set an *upper limit* on event rate

Binary Neutron Star Search Using S1 Data

Binaries with component masses between 1 and 3 $M_\odot$

2nd-order post-Newtonian waveforms are reliable; spin effects negligible

Visible range for 1.4+1.4 $M_\odot$ (optimally oriented, with SNR=8):

L1 ~175 kpc ← Milky Way and Magellanic Clouds
H1 ~38 kpc
H2 ~35 kpc

Analyzed 236 hours of data when L1 and/or H1 was running

Use "maximum-SNR" statistical method to set an upper limit

Efficiency of search calculated by Monte Carlo

Simple spatial model; mass distribution from population synthesis model

Result (90% C.L.): Rate < 170 per year per MWEG

To appear in Phys. Rev. D; gr-qc/0308069

[Milky Way Equivalent Galaxy]

Binary Neutron Star Searches in Progress

LIGO-only search using S2 data

Max. visible range:	L1:	~1.6 Mpc	← Reaches M31, M33
(for 1.4+1.4 $M_\odot$)	H1:	~0.8 Mpc	← Barely reaches M31, M33
	H2:	~0.6 Mpc	

Using coincident data from L1 running at same time as H1 and/or H2

345 hours of data processed using automated "pipeline"

Estimate background by sliding times of LHO triggers relative to LLO

Analysis is basically complete, being tidied up

Plan to present result at APS Meeting in May

Joint analysis of LIGO S2 + TAMA DT8

Will use rest of LIGO S2 data (~700 hours)

Will exchange trigger data, look for coincident triggers

Binary Neutron Star Search in Planning Stage

Search using LIGO+GEO S3 data

Max. visible range:	H1: **up to ~10 Mpc**
(for 1.4+1.4 $M_\odot$)	L1: ~2.5 Mpc ← Reaches M31, M33
	H2: ~2 Mpc
	GEO:~50 kpc?

Starting to see into the universe, but only with one detector so far

Have not analyzed this data yet

Three-site coherent analysis is interesting but challenging

Binary Black Hole MACHO Search

Galactic halo mass could consist of primordial black holes with masses ≲1 $M_\odot$

Some would be binaries inspiraling within the age of the universe

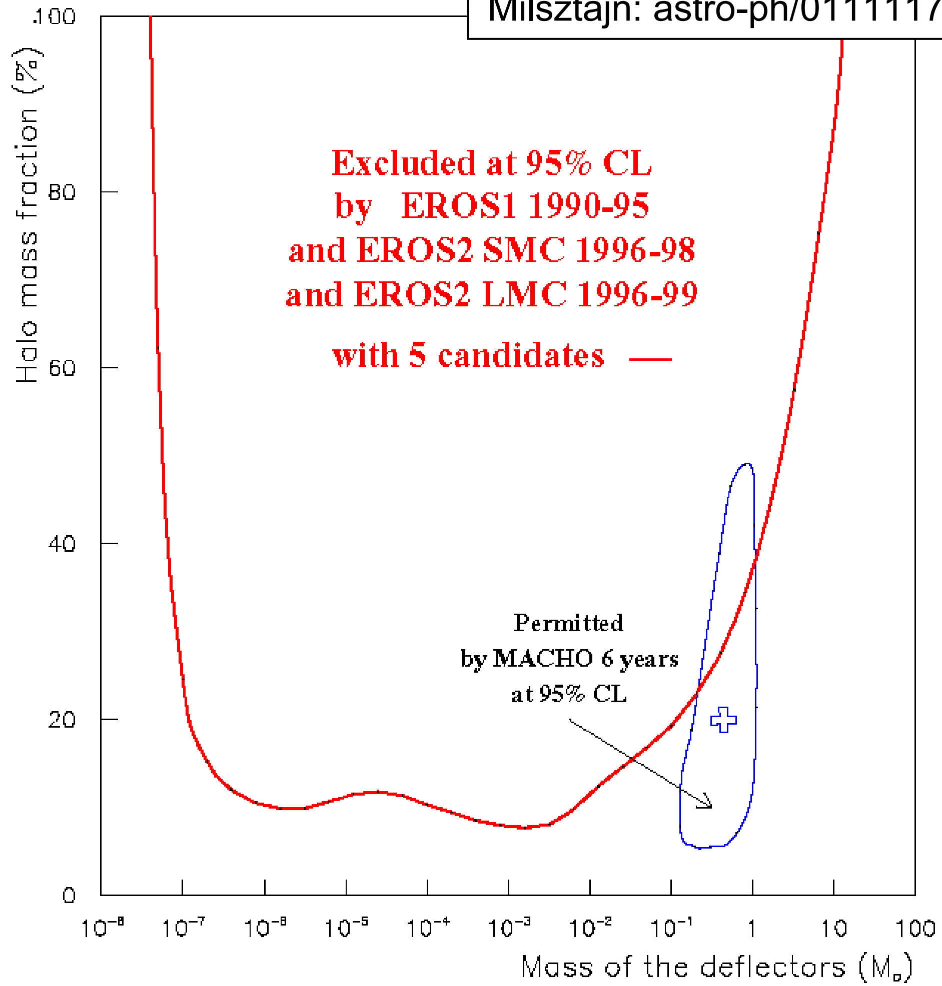
Simple extension of binary neutron star search

S2 data being analyzed now

Mass range limited by available CPU

Probably can go down to m = (0.25~0.3) $M_\odot$

Milsztajn: astro-ph/0111117



Templates for Non-Spinning Binary Black Hole Systems

Waveforms not known exactly

Post-Newtonian expansion breaks down while in LIGO frequency band

Use matched filtering with "BCV detection template family"

Buonanno, Chen, and Vallisneri, Phys. Rev. D **67**, 024016 (2003)

Fourier-domain templates h_{eff}

$$\left\| h_{eff}(f) \right\| = f^{-7/6}\,(1-\alpha\, f^{2/3})\;\; \theta(f_{cut} - f)$$

$$\arg\left[h_{eff}(f)\right] = 2\pi f t_0 + \phi_0 + \psi_0\, f^{-5/3} + \psi_{3/2}\, f^{-1}$$

Template parameters: $\psi_0,\ \psi_{3/2}, f_{cut}$ (analytically maximize over others)

Can achieve good matching to various model waveforms

Adiabatic, non-adiabatic, stationary phase, effective-one-body, …

Taylor vs. Padé expansions

Templates for *Spinning* Binary Black Hole Systems

Spin complicate waveforms considerably

- Precession ➔ phase and amplitude modulation
- Introduces several additional signal parameters

BCV have treated this in the adiabatic-inspiral limit

- Phys. Rev. D **67**, 104025 (2003)
- Continue “detection template family” approach
- Introduce sinusoidal phase modulation
- Leads to a manageable parameter space

Also shown to be good for black hole–neutron star systems

Searches in Progress for Higher-Mass Binary Systems

Search for non-spinning systems using S2 data

Target masses: 3+3 to 20+20 $M_\odot$

BCV1 templates and bank generation have been implemented in LIGO Algorithm Library (LAL)

S2 “playground” data has been processed

Issue: how to perform a χ^2 test for very short signals

Plan to have results this summer

Plan to search for spinning systems in S3 data

Software development and studies of bank generation issues are in progress

Summary

Binary neutron star search published using S1 data

Currently pursuing several topics using S2 and S3 data

- More sophisticated analysis pipelines
- Combined analysis with other interferometer projects
- Lower- and higher-mass systems

Interferometers are getting sensitive enough to see binary systems out into the universe !