Searching for Gravitational-Wave Signatures of Compact Binary Coälescences w/LIGO & Virgo

John T. Whelan
john.whelan@astro.rit.edu

Rochester Institute of Technology
(for the LIGO Scientific Collaboration & the Virgo Collaboration)

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Outline

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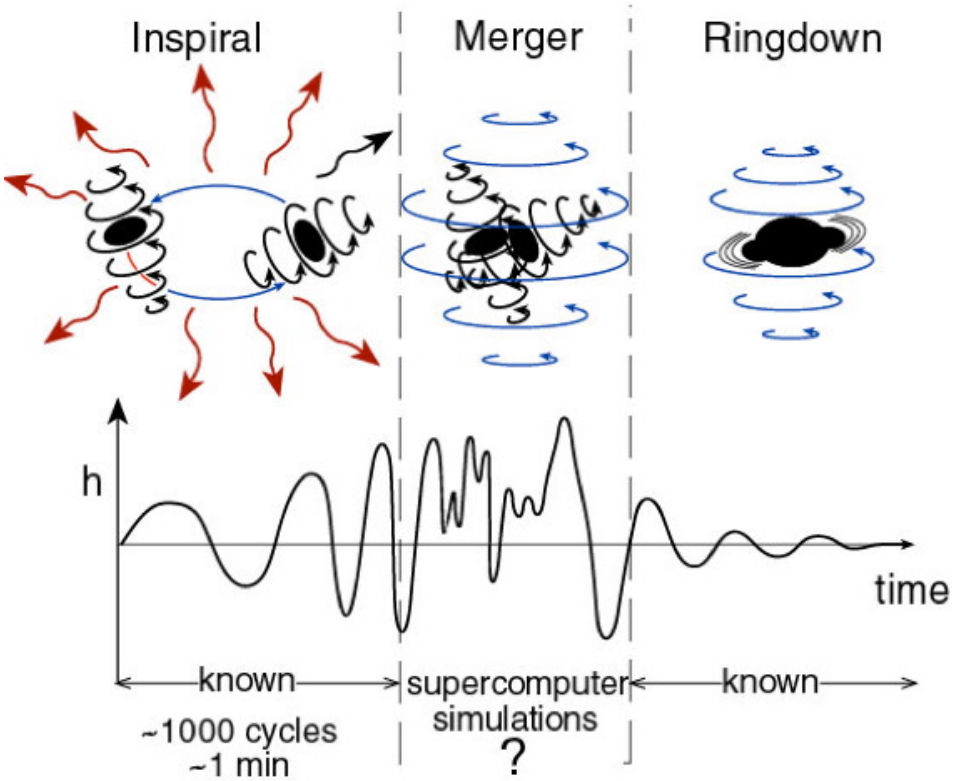
Template Waveforms

- Inspiralling binaries produce well-modelled GW signals; Search with pattern-match filter
- Compact object binary coälescence consists of inspiral / plunge / merger / ringdown



Cartoon by Kip Thorne

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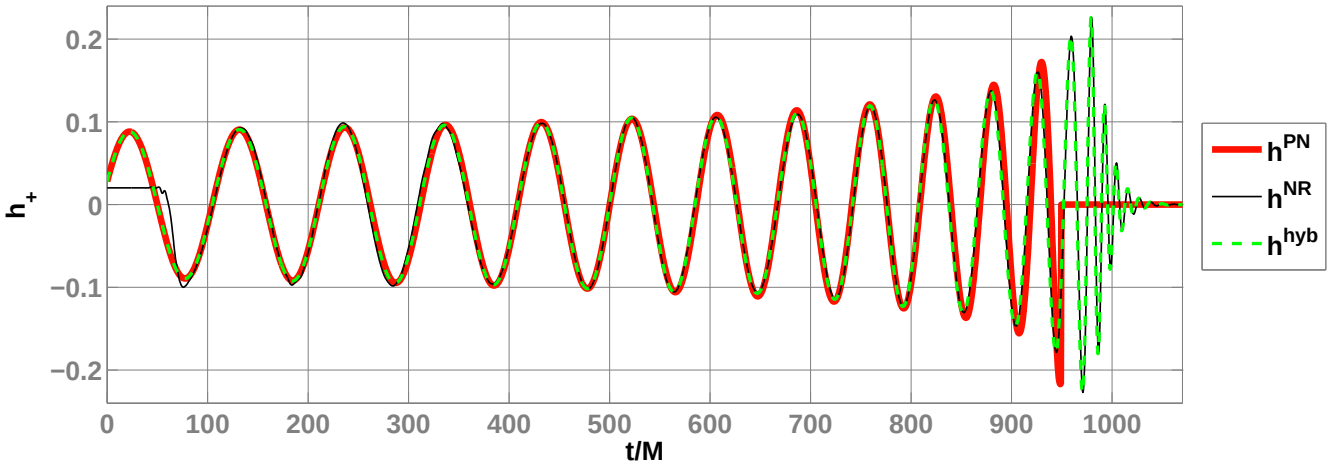


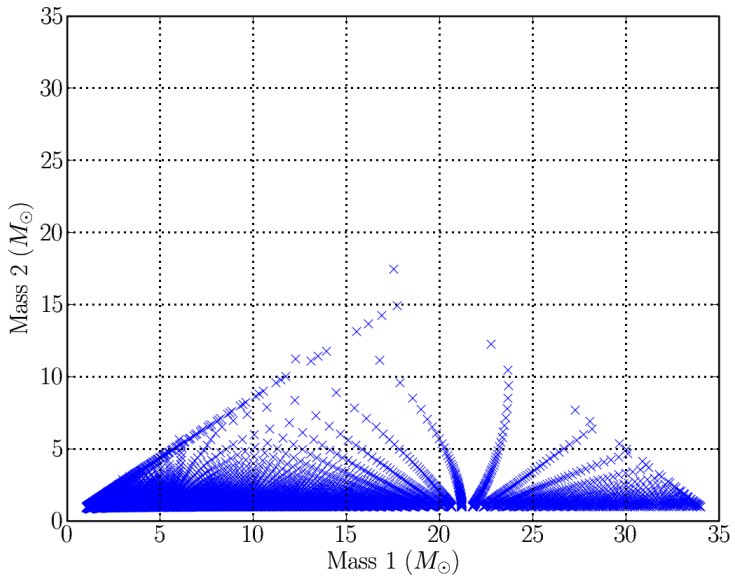
Ajith et al, *CQG* **24**, S689 (2007)

Template Waveforms

- Compact object binary coälescence consists of inspiral / plunge / merger / ringdown
- For first part of inspiral, orbits not too relativistic
  can expand in powers of $\frac{v}{c} \longrightarrow$ post-Newtonian methods
  Can estimate orb vel from Kepler's 3rd law: $v \approx (\pi GMf)^{1/3}$
  - Low Mass $\longrightarrow$ plunge @ high freq
    $1.4M_\odot/1.4M_\odot$ NS/NS binary has $v \approx 0.3c$ @ 800 Hz;
    PN OK in LIGO band
  - High Mass $\longrightarrow$ plunge @ low freq
    $10M_\odot/10M_\odot$ BH/BH binary has $v \approx 0.4c$ @ 200 Hz;
    merges in LIGO band
- Different template families used for different mass ranges

Matched Filtering GW Data

- Match-filtered signal-to-noise ratio measures how well template "fits" data: $\rho \sim \int df \frac{x^*(f)h(f)}{S_n(f)}$
- Time series for each set of param (e.g., m_1 & m_2) values
- Lay out parameter choices in template bank to get good overlap w/possible signals



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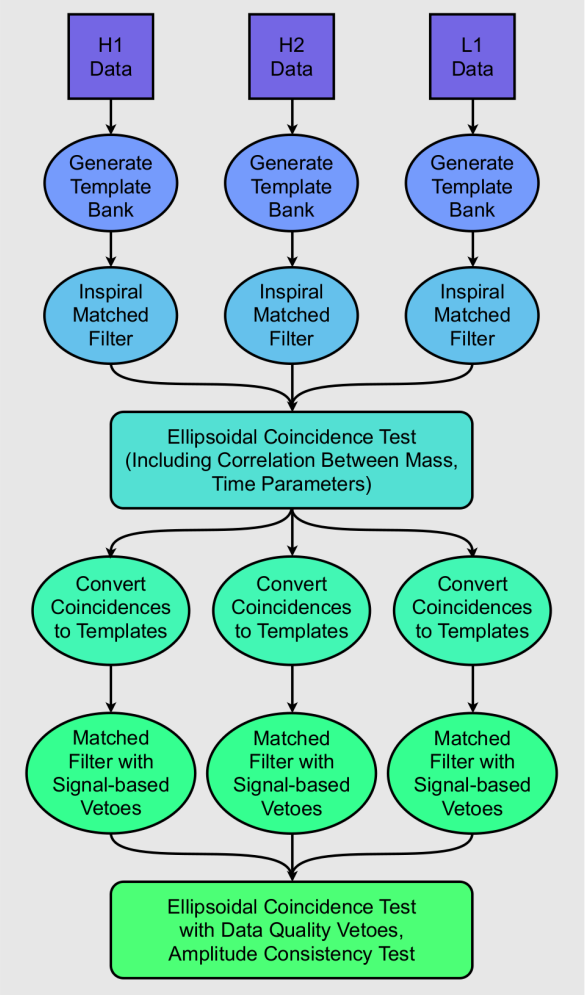
Reducing Accidental Triggers

- Ideally, high SNR triggers would be likely GW events
- Real GW data has glitches etc
  which lead to non-Gaussian noise triggers;
  apply several strategies to deal with this:
  - Set low initial SNR threshold;
    population of noise triggers helps to find background level
  - Suppress triggers w/bad spectral match using $\rho_{\text{eff}}(\rho, \chi^2)$
  - Look for triggers **coïncident** in time & masses
    between **multiple detectors**
  - Some regions of tmplt space produce more false alarms;
    use false alarm rate or likelihood ratio rather than eff SNR
    to compare triggers from different mass regions

LSC CBC Search Pipeline



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Estimating BG with Time Shifts

- Most triggers in each GW detector are noise; multi-detector coïncidences are candidate events
- Estimate rate of accidental coïncs w/time shift: Introduce unphysical relative time shift btwn detectors ($\gg$ light travel time) e.g.:

Slide #	...	−3	−2	−1	1	2	3	...
LHO shift (sec)	...	0	0	0	0	0	0	...
LLO shift (sec)	...	−15	−10	−5	5	10	15	...
Virgo shift (sec)	...	−45	−30	−15	15	30	45	...

- LHO 4km & 2km detectors have correlated noise triggers; shifting relative to each other would underestimate BG

Estimating BG for Triggered Searches

- GW searches w/external triggers (e.g., GRBs) have well-defined "on-source" time
- Can estimate BG by counting coïncs @ "off-source" times
- Allows use of H1-H2 (LHO 4km & 2km) coïncs

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S5/VSR1 Untriggered Searches

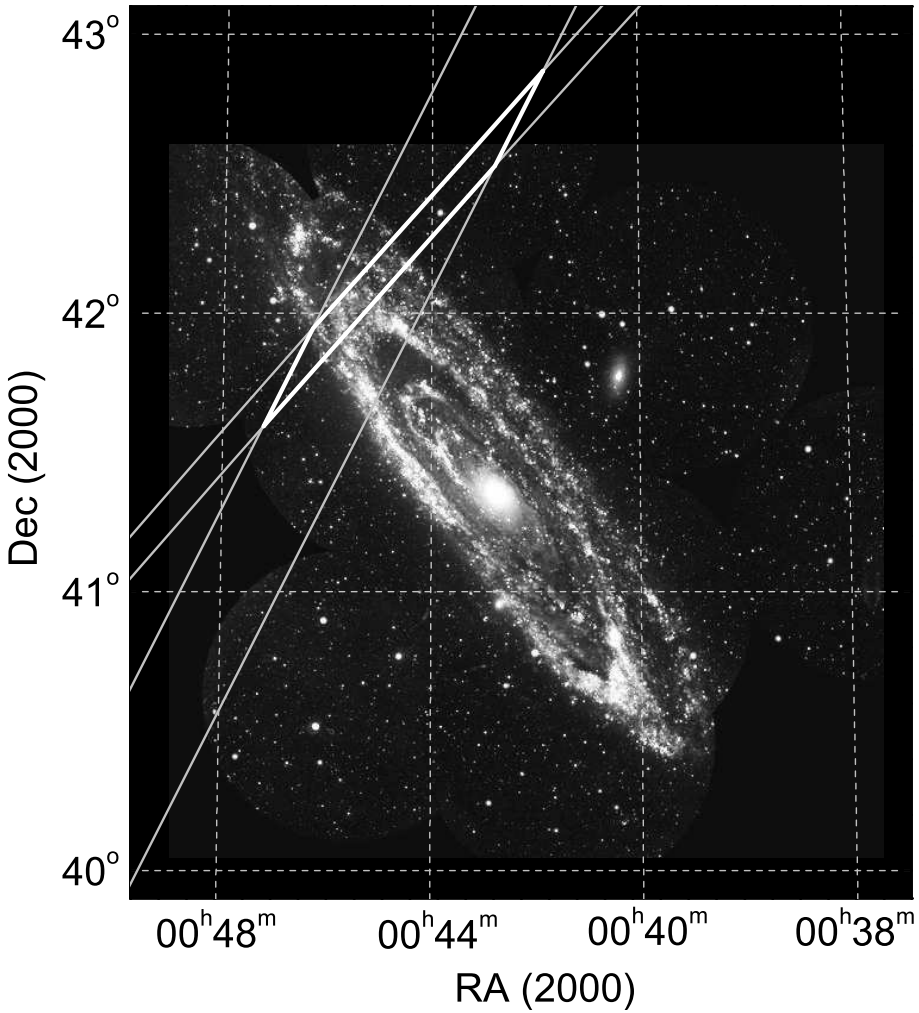
- Low-mass ($2M_\odot \leq (m_1 + m_2) \leq 35M_\odot$) CBC search in 1st 18 months of LIGO S5 Data: no GWs seen; limits on event rates ($L_{10} = 10^{10} L_{B,\odot}$; MWEG $\equiv 1.7 L_{10}$):
  - $1.4 \times 10^{-2} L_{10}^{-1} \mathrm{yr}^{-1}$ on BNS ($1.4M_\odot/1.4M_\odot$)
  - $7.3 \times 10^{-4} L_{10}^{-1} \mathrm{yr}^{-1}$ on BBH ($5M_\odot/5M_\odot$)
  - $3.6 \times 10^{-3} L_{10}^{-1} \mathrm{yr}^{-1}$ on BHNS ($1.4M_\odot/5M_\odot$)
  - arXiv:0901.0302 & LIGO-G0900354
- Under internal review:
  - Low-mass CBC search in last 6 months of S5 + Virgo VSR1
  - High-mass ($25M_\odot \leq (m_1 + m_2) \leq 100M_\odot$) CBC search in LIGO S5, using templates w/merger & ringdown
  - Status reports in LIGO-G0900058 & LIGO-G0900371
- In progress: search for BH ringdowns

S5/VSR1 GRB-Triggered Searches

- BNS or NSBH CBC: (one) progenitor model for short GRBs (See O'Shaughnessy talk yesterday LIGO-G0900450)
- 33 short GRBs during S5/VSR1;
  22 while two or more of the four LIGO/Virgo detectors a (LHO 4km, LLO 4km, LHO 2km, Virgo) were taking science-quality data
- Results of triggered searches for these GRBs under internal review
- Status report in LIGO-G0900368
- One case of special interest: GRB070201 . . .

GRB070201

- 2007 Feb 1: short GRB whose error box overlapped spiral arm of M31 (770 kpc away)
- LHO 4 km & 2 km detectors operating & sensitive to CBC out to 35.7& 15.3 Mpc
- No GW seen; rule out CBC progenitor in M31 w/$>$ 99% conf
- *ApJ* **681**, 1419 (2008)



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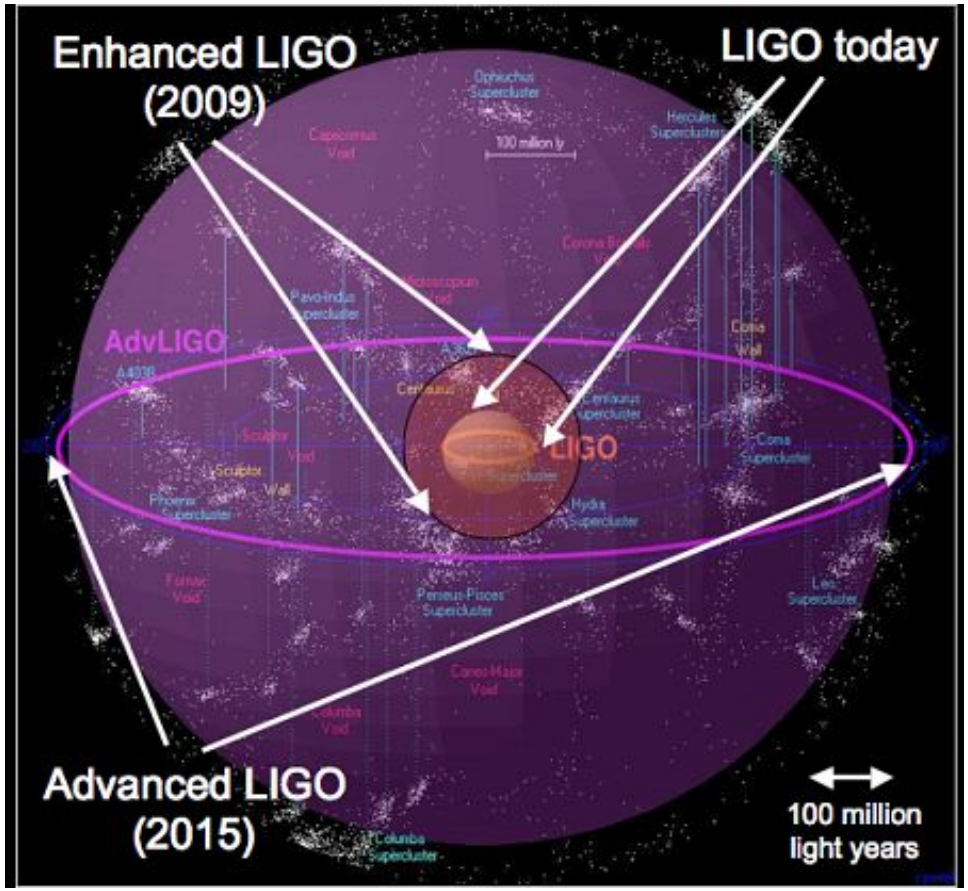
Enhanced and Advanced LIGO



Credits: Image by Beverly Berger; Cluster Map by Richard Powell

S6/VSR2

- Run to start soon w/"enhanced" LIGO & Virgo detectors
- Improved sensitivity $\longrightarrow$ probe greater space(time) volume
- Comparible detectors @ 3 sites: triangulate sky location
- Potential to use GW candidates as triggers for EM obs
  but latency is an important challenge
  (see upcoming Amaldi presentations)

Summary

- Search for compact binary coälescence (inspiral-merger-ringdown) w/matched filter
- Characterize real-world background with multi-detector coïncidence
- Searches so far untriggered or triggered by GRBs
- GW event candidates potential triggers for EM observations