The Analysis of Binary Inspiral Signals in LIGO Data

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Outline

- Background of Compact Binary coalescence (CBC) work
- Matched filtering
- Instrumental and environmental vetoes
- Analysis pipeline
- Science goals

Background

Four data analysis working groups

- The Compact Binary Coalescence (CBC) Group
- The Burst Analysis Working Group
- The Continuous Wave (or Periodic Sources) Search Group
- The Stochastic Background Working Group

GWs from coalescence of compact binary systems

- Identify GW from compact binary sources in the detector data;

  Estimate the waveform parameters.

- GWs sweep upward in frequency and amplitude. The binary orbits shrinks.

  The period of the orbit is reduced.

  ---Inspiral phase of the binary system

GWs from coalescence of compact binary systems

- Post-Newtonian waveforms are accurate below ~700(2.8$M_{\square}$/M_{total})Hz

- LIGO: Optimal sensitivity for these sweeping signals: 40-800 Hz

- Numerical relativity:

  BBH: on the verge of yielding accurate waveforms.

  BNS: not successes so far(2007/06/11).

Matched Filtering

- A matched filter: correlates a known signal, or template, with an unknown signal to detect the presence of the template in the unknown signal. … (www.wikipedia.org)

- The matched filter: optimal linear filter for maximizing the signal to noise ratio (SNR) in the presence of additive stochastic noise.

Matched Filtering

- The waveforms of expected events can be parameterized by the m_1 , $m_{2.}$ -→template bank
- h(t): template waveform
  $S_n(f)$: noise power spectral density
  s(t): detector output
- Trigger: significant correlation between s(t) and h(t)

Matched Filtering

- Complex output:

$$z(t) = 4\int_{f_{\rm low}}^{f_{\rm final}} \frac{\tilde{s}(f)^*\tilde{h}(f)e^{2\pi i f t}}{S_n(f)}df,$$

- The template normalization:

$$\sigma^2 = (\tilde{h}(f), \tilde{h}(f)) \equiv 4{\rm Re}\int_{f_{\rm low}}^{f_{\rm final}} \frac{\tilde{h}(f) * \tilde{h}(f)}{S_n(f)}df$$

- SNR:

$$\rho = \frac{|z|}{\sigma}.$$

Matched Filtering

- SNR is not adequate detection statistic in non-stationary, non-Gaussian noise, since spurious signals may cause events of environmental or instrumental origin.
- Additional signal consistency checks: χ^2 time-frequency discriminator.
- An orthogonal complete set of *p* templates $h(f)_i$

$$(\tilde{h}(f)_i, \tilde{h}(f)_j) = \frac{\delta_{ij}}{p}$$

$$\sum_{i=1}^{p} (\tilde{h}(f)_i, \tilde{h}(f)_i) = 1\,.$$

Matched Filtering

- A signal (that perfectly matches h(f) at ρ) would be expected to have ρ/p SNR in each projection $h(f)_i$

$$\chi^2 = p \sum_{i=1}^{p} (\Delta\rho_i)^2 .$$

$$\Delta\rho_i = \rho_i - \rho/p$$

- In Gaussian noise: $\langle\chi^2\rangle = 2p-2$

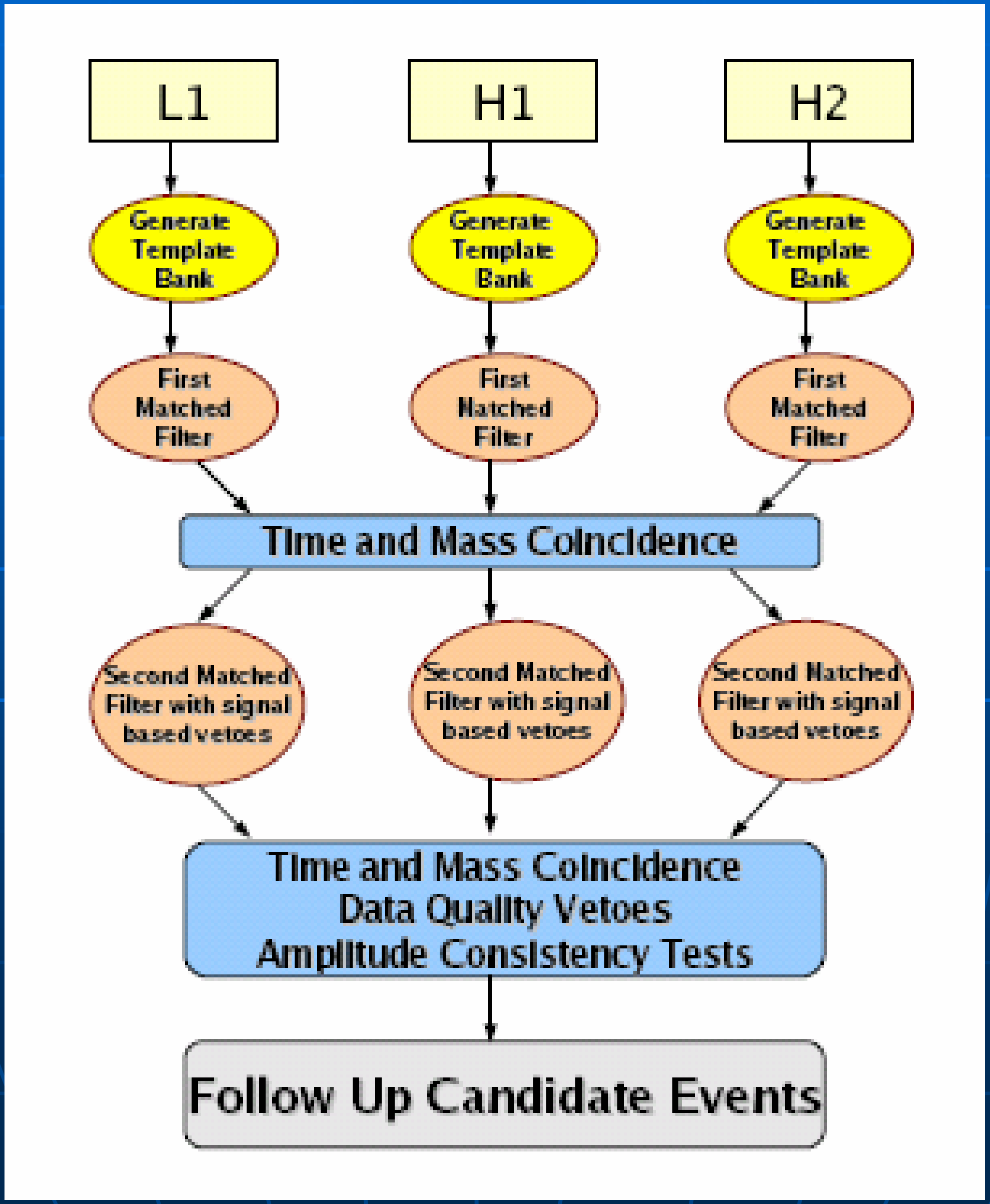
- Consider slight mismatch between templates:

$$\xi^2 = \frac{\chi^2}{p + \rho^2\delta} \le \xi^{*2},$$

Instrumental and environmental vetoes

- Category 1 is based on whether or not the IFO is in Science Mode.
- Category 2 includes times when known instrumental effects cause false alarms (such as calibration dropouts and injections)
- Category 3 includes veto flags with statistically significant correlations but more signal based, with less clearly explained mechanisms
- Category 4 covers suspect times without clear physical or statistical correlation to inspiral triggers, but still times where data is suspect in some way

Analysis pipeline



Science Goals

- Estimate the rate of compact binary inspiral.
- Measure the masses, spins. Develop a catalog of binaries.
- Determine the energy content of GWs during the merger of BBH.
- Test alternative theories of gravity.
- Bound the mass of the graviton.
- Test strong field predictions of analytical and numerical relativity.
- …

References

- Gravitational Wave Data Analysis by the LSC and Virgo: Science Goals, Methods, Status, and Plans (2007 edition) DRAFT as of 2007/06/11. The LSC-Virgo Data Analysis Working Groups, the Data Analysis Software Working Group, the Detector Characterization Working Group and the
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- http://www.phy.olemiss.edu/cgi-bin/gr/ligowiki.cgi/

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Thanks!