Search for gravitational waves from inspiraling high-mass (non-spinning) compact binaries

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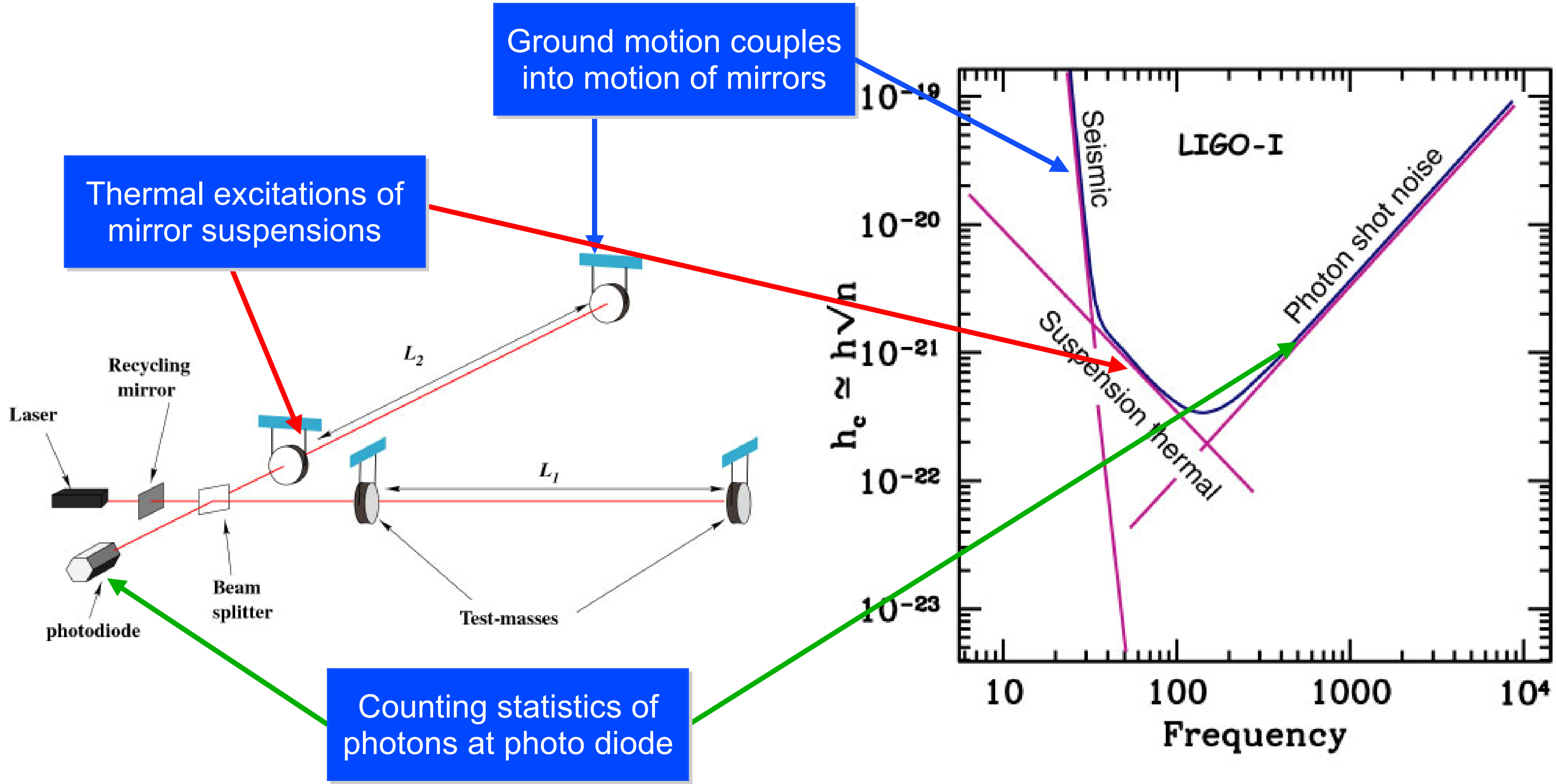
LIGO Scientific Collaboration

The LIGO Interferometers

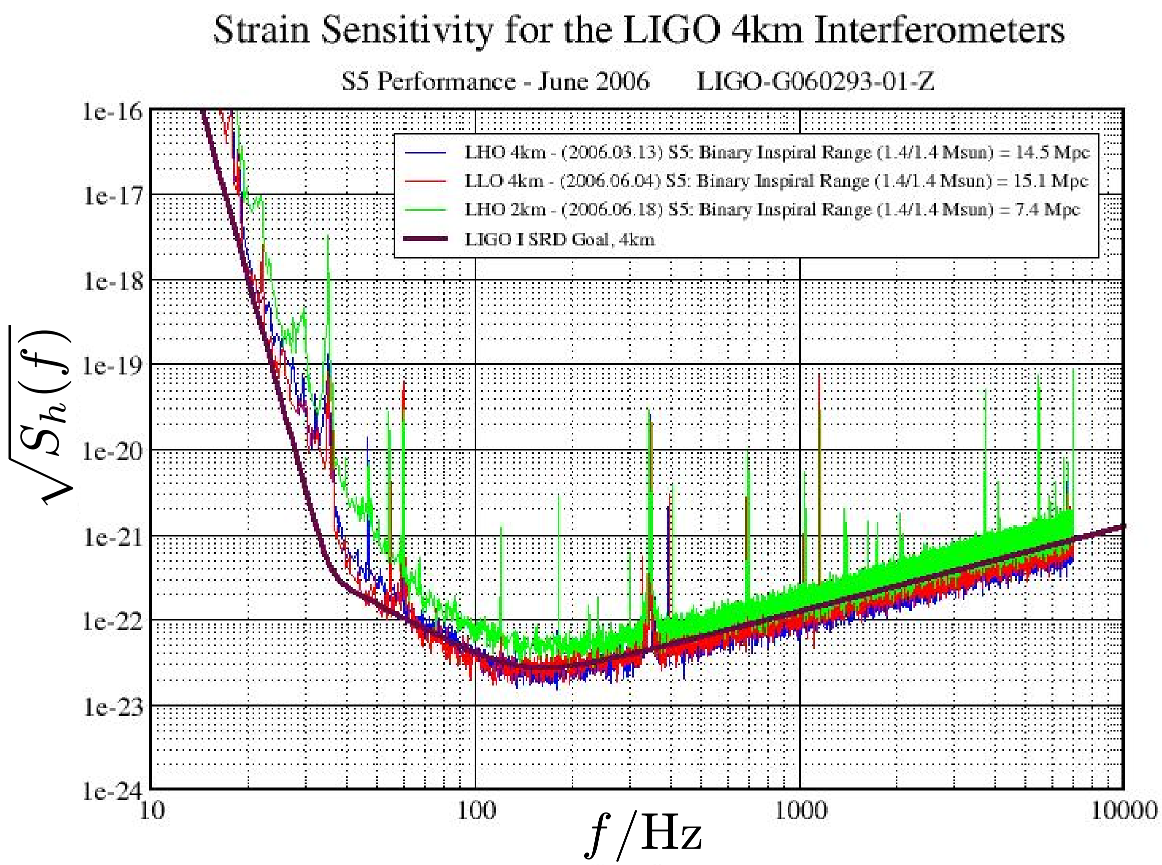
- Broad-band detector to measure distortion of spatial geometry due to passing gravitational wave from astrophysical sources.
  - » Michelson interferometer with Fabry-Perot cavity optical storage arms



Current LIGO Sensitivity

LIGO Livingston, LA

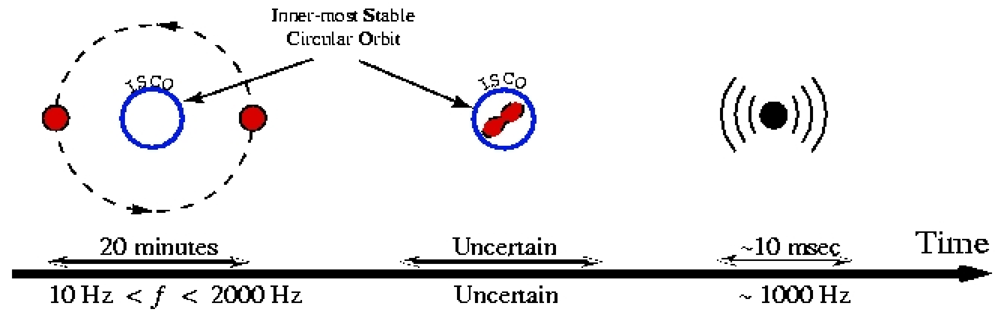
LIGO Hanford, WA



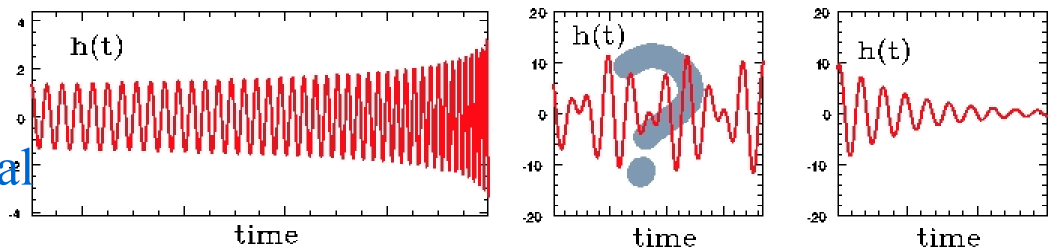
$$\langle n(f) n(f') \rangle = \frac{1}{2} S_h(f)\ \delta(f - f')$$

Binary Coalescence Waveforms

- Assume inspiral signals are (reasonably) well modeled
  - » standard matched filtering technique



- Post-Newtonian templates accurate for low mass systems in LIGO band but at higher masses post-Newtonian approximation breaks down.



- At still higher masses, inspiral searches transition into burst searches

- EOB waveforms hold good beyond ISCO upto $r \sim 3\ M_\odot$ (more bandwidth for high mass systems)

LIGO is sensitive to NS / BH inspirals $M \leq 100\ M_\odot$

Matched Filtering with EOB templates

- Detector output contains noise and a possible inspiral signal $x(t) = n(t) + h(t;\vec{\mu})$
  - » Assume signal's functional form is known accurately : EOB waveforms
  - » Signal's parameter is not known *a-priori*

- Matched filter

$$\rho(t;\mu_i) = 4\left|\int_{f_l}^{f_u} \tilde{x}(f)\,\frac{\tilde{h}^*(f;\mu_i)}{S_h(f)}\,e^{2\pi i f t}\,df\right|$$

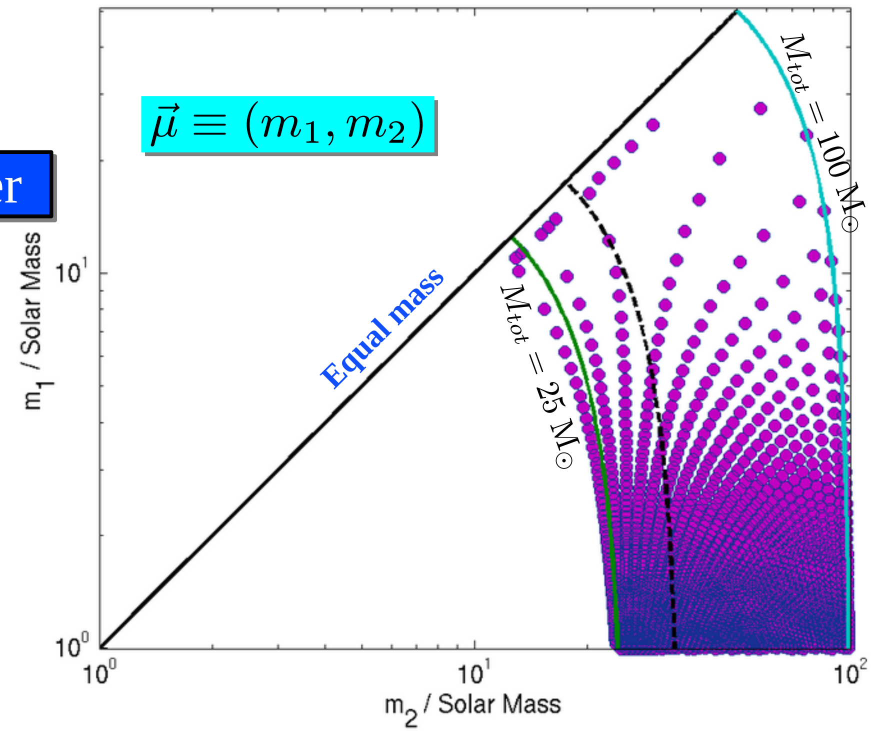
filter

data

- Maximize filter output over all parameters

$$\Lambda = \max_{t,\vec{\mu}}\,[\rho]$$

  - » This is the detection statistic.
  - » Threshold with care



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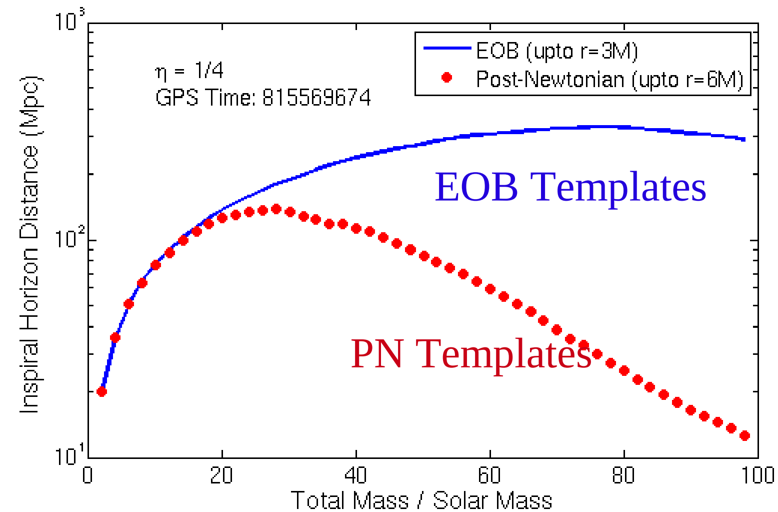
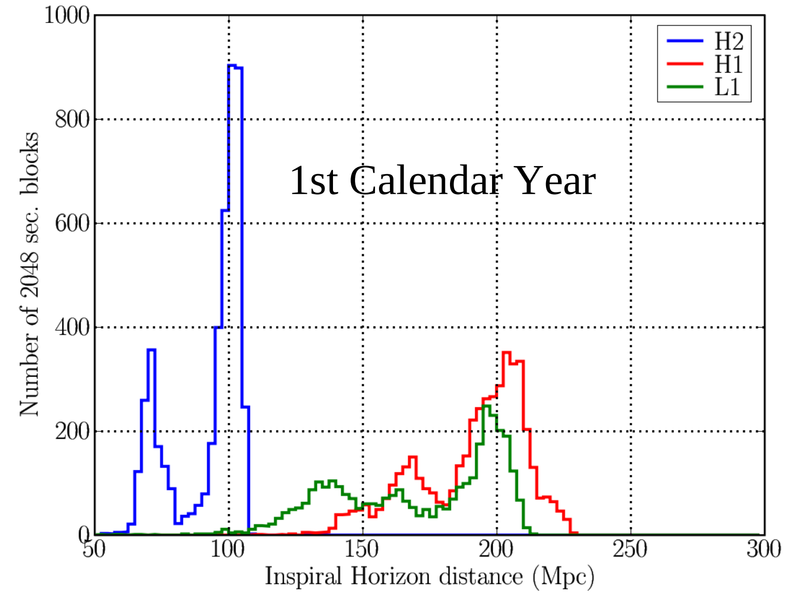
EOB templates for high-mass systems

- EOB templates are well suited for high mass CBC search
  - » Higher bandwidth for high mass systems
- Larger band-width is good for inspiral search
  - » Inspiral Horizon Distance increases (improvement in mass reach)
  - » Useful for signal based consistency tests to reject false alarms

$$d \propto \frac{A(m_1, m_2)}{\rho} \times \int_{f_l}^{f_u} \frac{|\tilde{h}(f)|^2}{S_h(f)}\, df$$

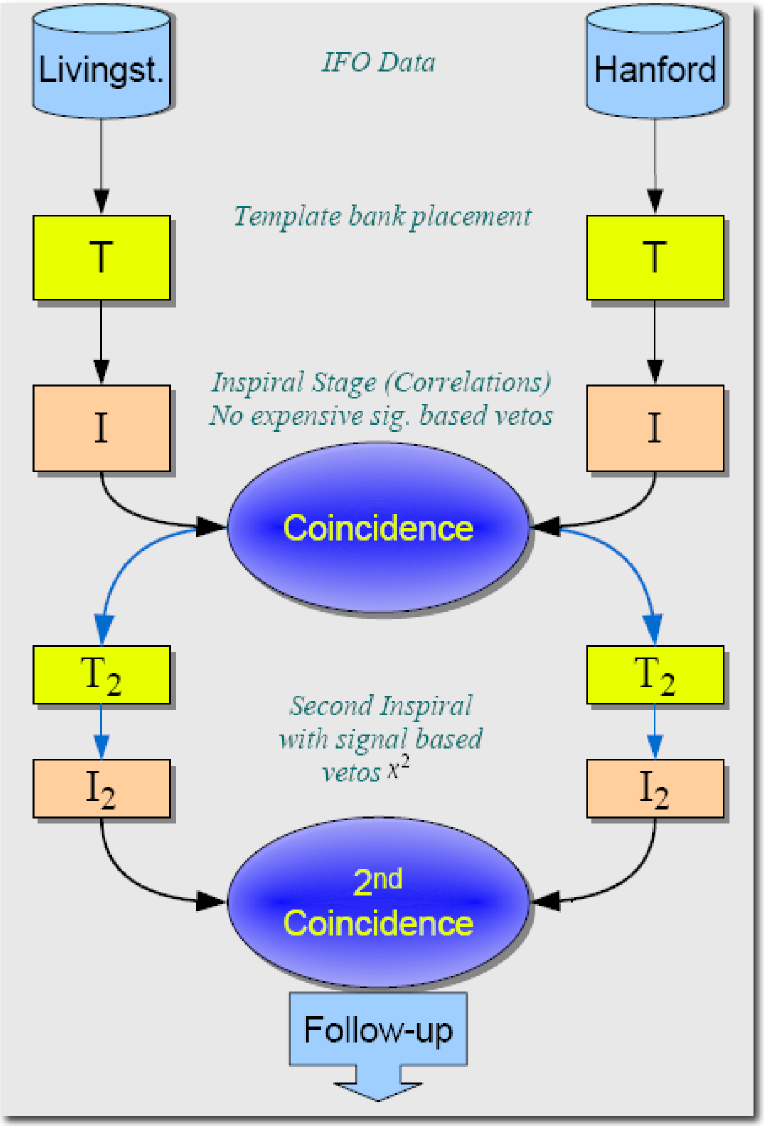
- Optimally oriented binary
  - » snr fixed at 8
  - » $|\tilde{h}(f)|^2 \sim f^{-7/3}$



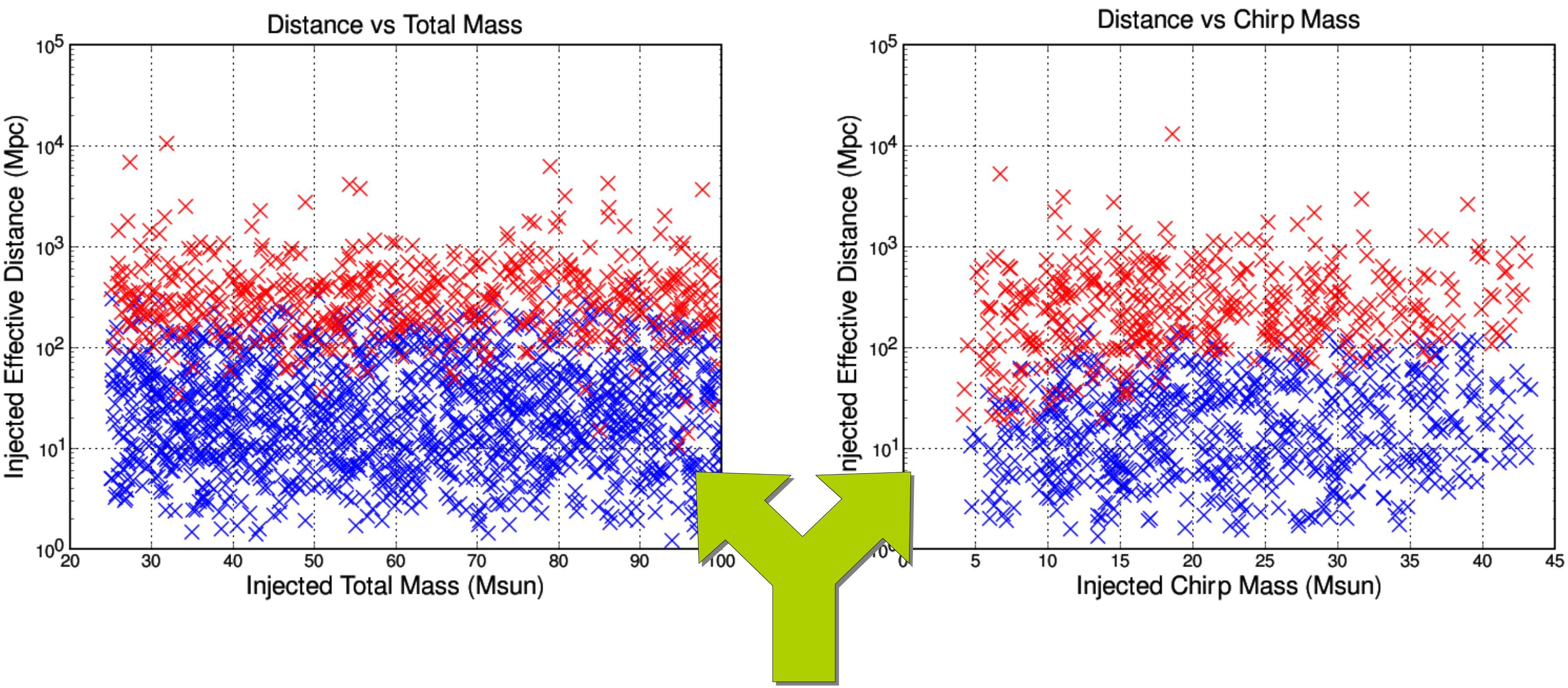


Monte-Carlo Injection Studies

- A large number of software injections are injected in data which are then parsed through the data-analysis pipeline.
  - Helps us tune the optimum value of the pipeline parameters
  - Understand pathologies of the data and/or detection algorithm (from the missed injection)
  - Quantify the efficiency of the pipeline as a function of distance to the compact binary systems.
  - Pipeline has many tunable parameters
- Try to optimize on
  - Detection efficiency
    - Compare injected / reconstructed signal
  - Reduction in false alarm probability
  - Arrive at the optimum value of parameters

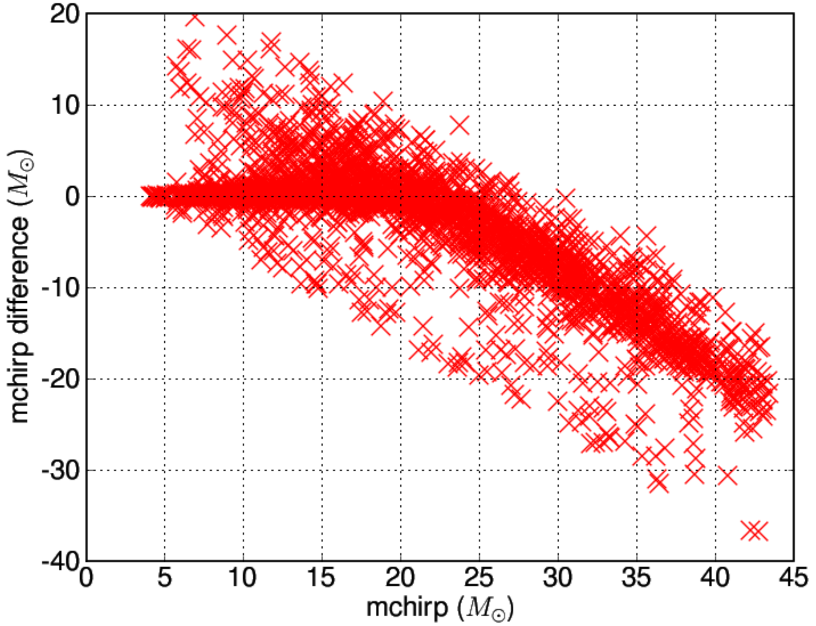


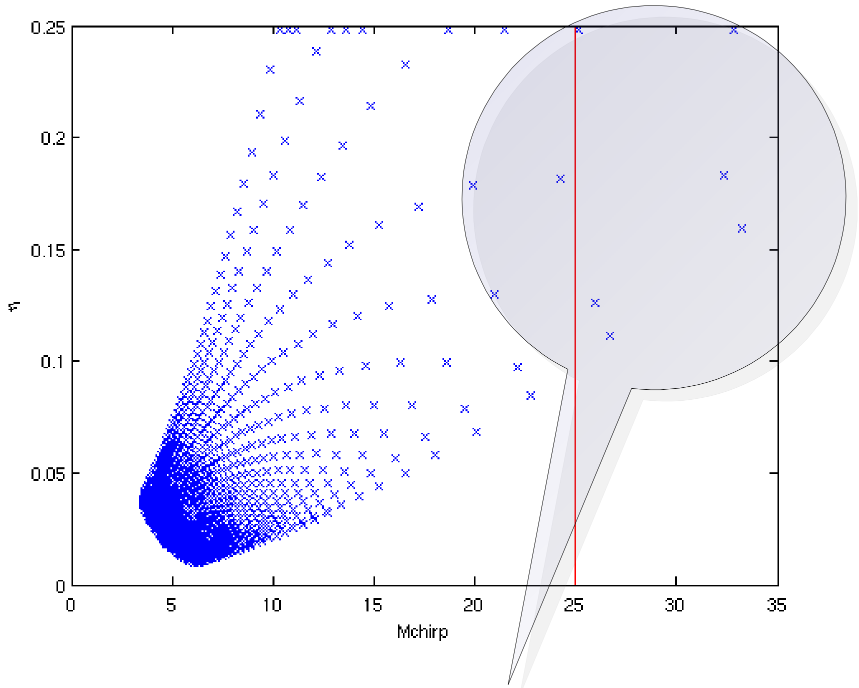
Distance Reach



Nearby asymmetric high-mass injections are missed by our pipeline

Parameter Estimation



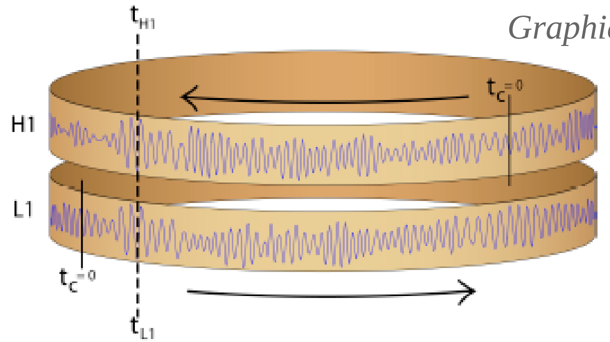


Systematic bias
in reconstructed parameters

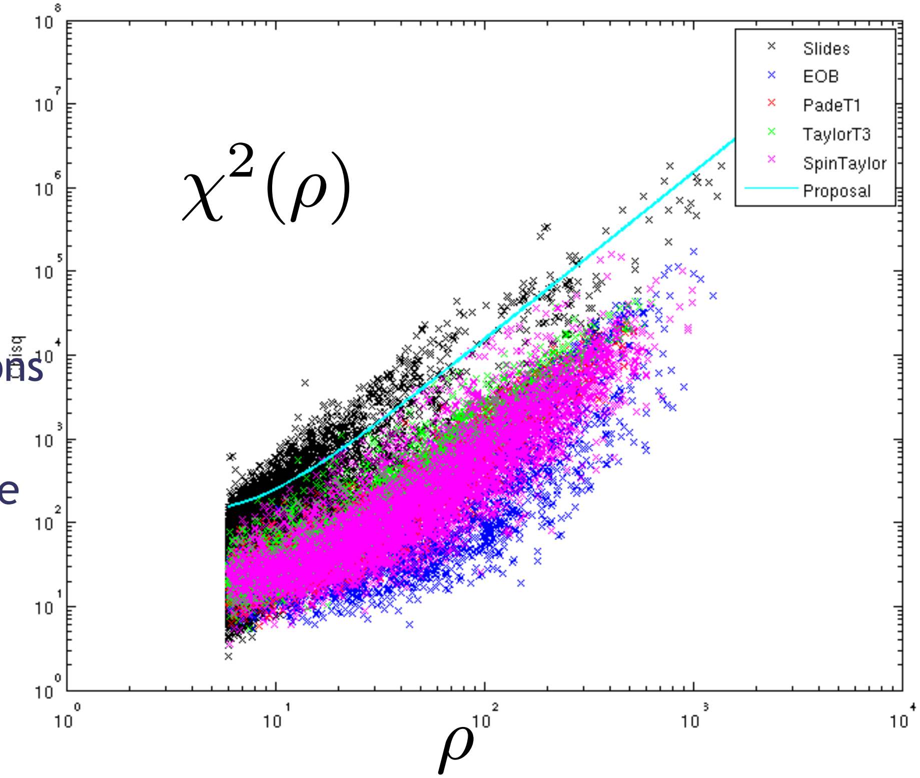
Sparse density of templates
in parameter space

Signal based veto

Graphics: Becky Tucker



- Triggers from separate instruments are slid *wrt* each other
  - » Accidental coincidences
  - » Could not have arisen due to true gravitational wave event
  - » Estimate of our background



- Signal based vetoes help us reduce accidental coincidences
  - » Separate background from injections
  - » Improve confidence of detection
  - » Monte-Carlo injections help us tune the pipeline to reject accidental coincidences

Conclusion

- Mature inspiral data analysis pipeline
  - » Science runs S1 through S4 analyzed
  - » Astrophysical upper-limit results have been published.
  - » S5 1 year analysis in progress
    - Low mass search
    - High mass search
- High mass search employing EOB templates
  - » Can be integrated up-to light ring (beyond standard PN templates)
  - » Injection studies under way to tune the pipeline to be most efficient for high-mass systems.
- Pipeline tuning under way
  - » Unprecedented data quality in terms of band-width and integration time
  - » New search, new methods, new problems ?
    - Apply lessons learnt in the low mass search to this new search
  - » Rapid progress to automate the procedure