Title: Coherently searching for spinning compact binary coalescences

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URL: http://pirsa.org/10060069

Abstract: In this talk we present the motivation behind our implementation of and results from a coherent search for spinning compact binary coalescences. Our method uses the Physical template family of waveforms which describe binaries where only one of the objects has spin. In addition we discuss the possibility of extending thissearch to incorporate template waveforms for precessing black hole mergers derived from numerical relativity.

Spin

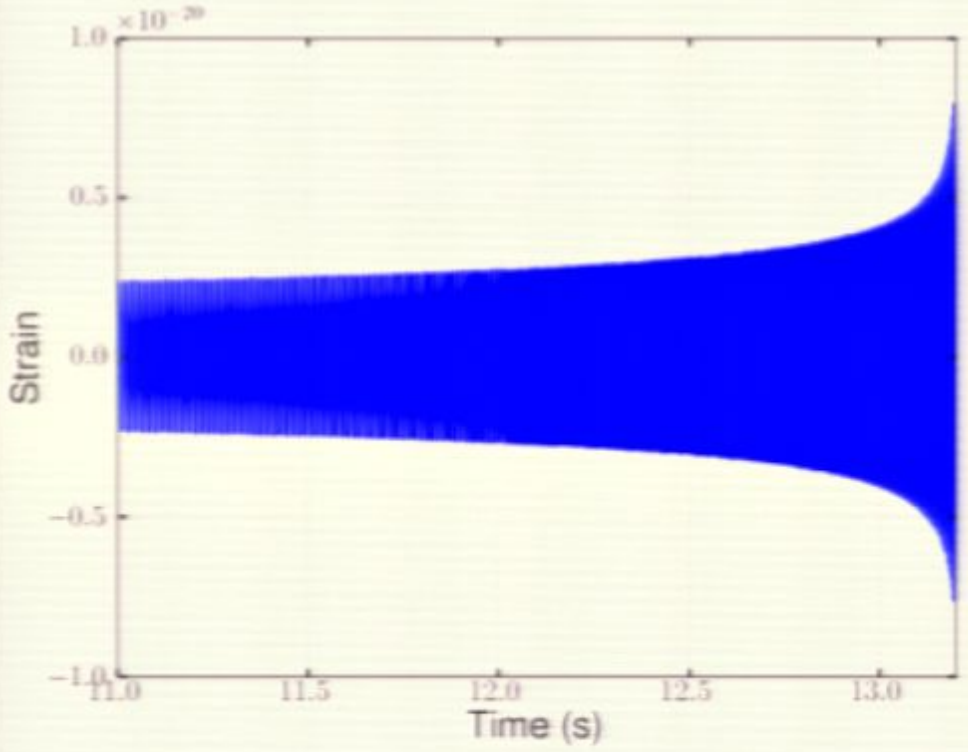
- Including spin adds 6 additional parameters required to describe the waveform
  - Covering the full spin space with NR/hybrid waveforms is a big task.
  - It is also a challenge to search this space
- I'll discuss a few reasons why it's difficult and how we're trying to get past these

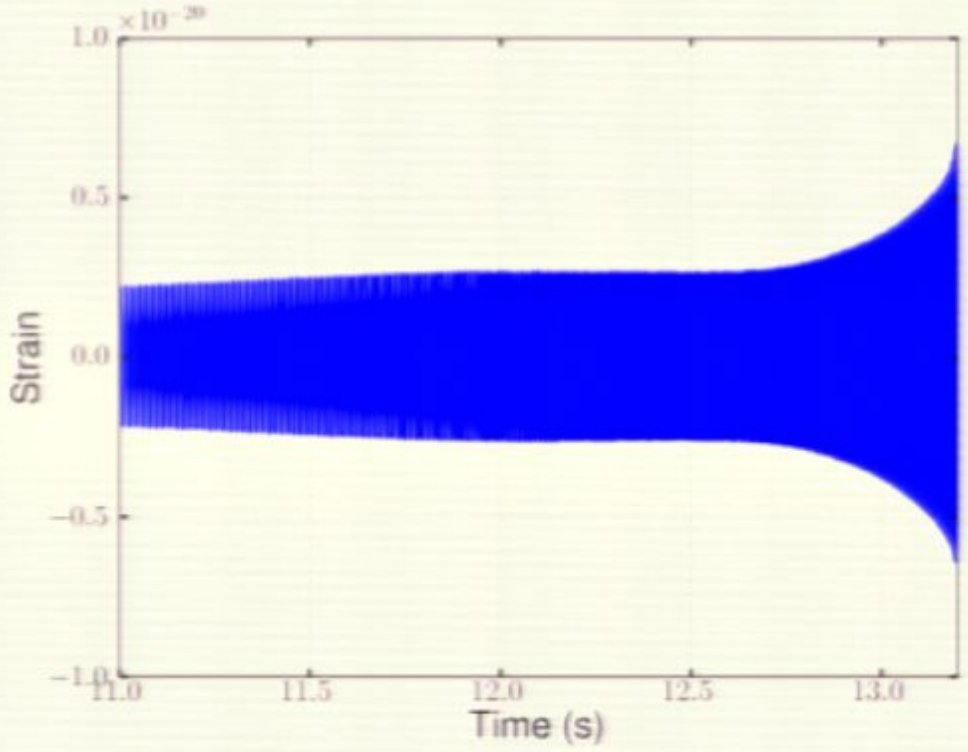
Binary Orientation

- For non-precessing systems, changing orientation can
  - Rescale the waveform: $A(D,\iota, \Psi,\phi)$
  - Change the overall phase: $\varphi_0(D,\iota, \Psi,\phi)$
  - Well known methods to maximize over amplitude and phase
  - More complex if higher harmonics are included
- For precessing systems, changing orientation gives very different waveforms

Face on waveforms

Neutron Star (1.4 $M_\odot$) – Black Hole (10 $M_\odot$)





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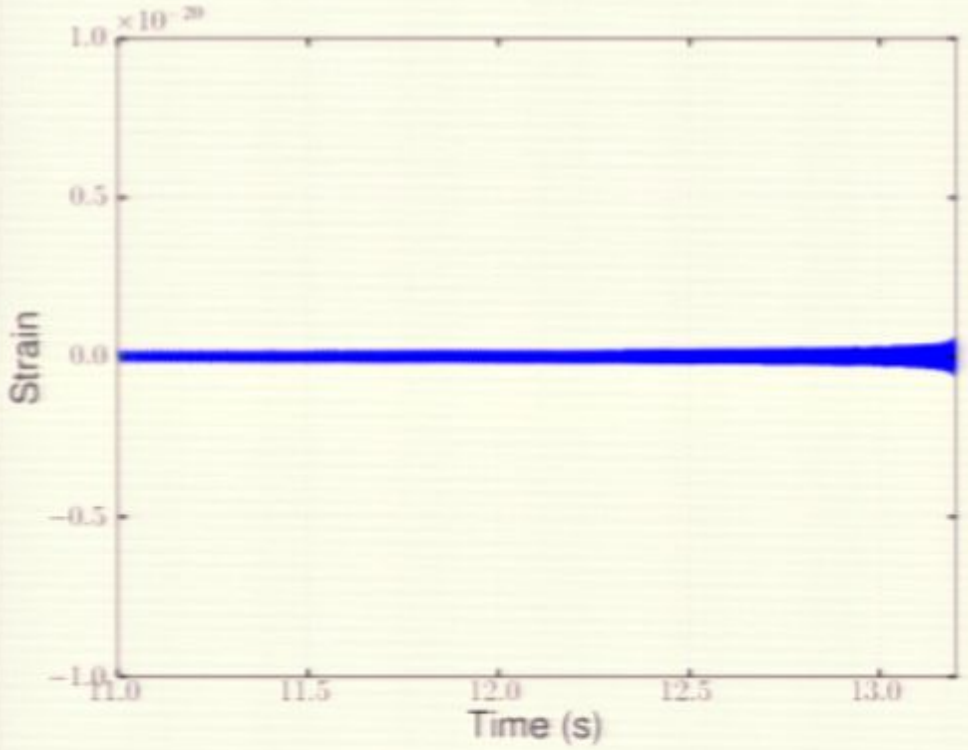

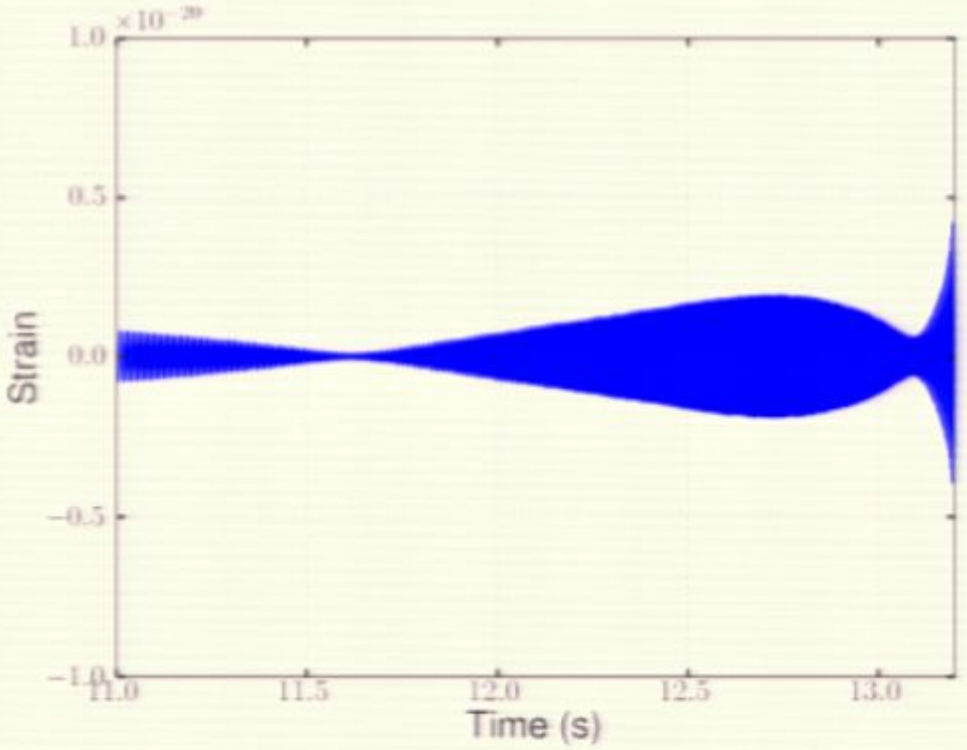

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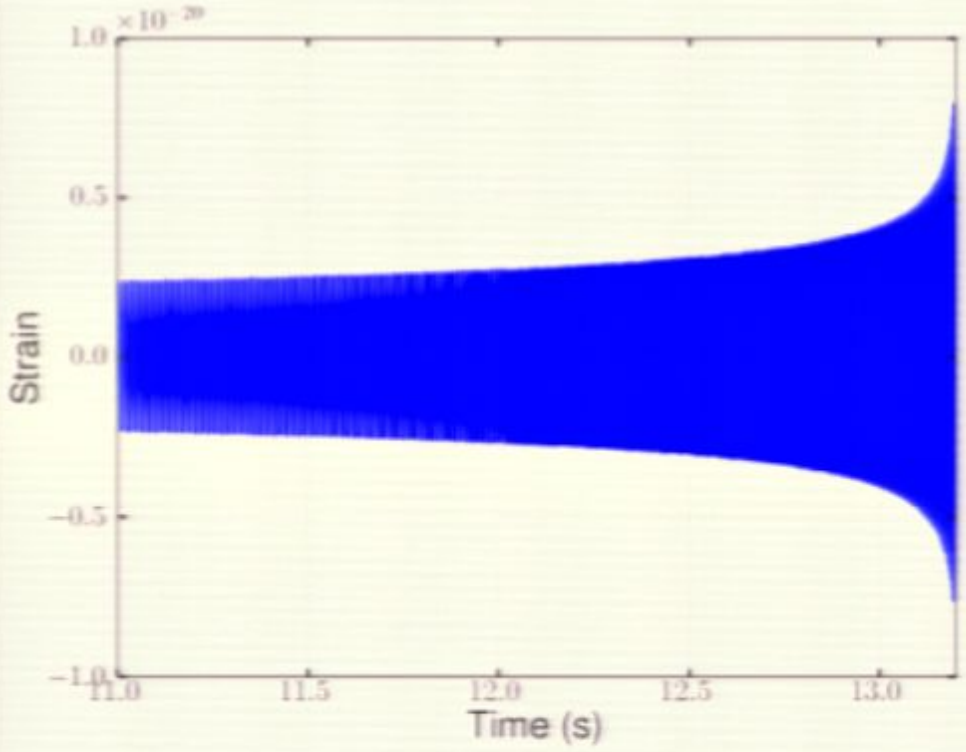

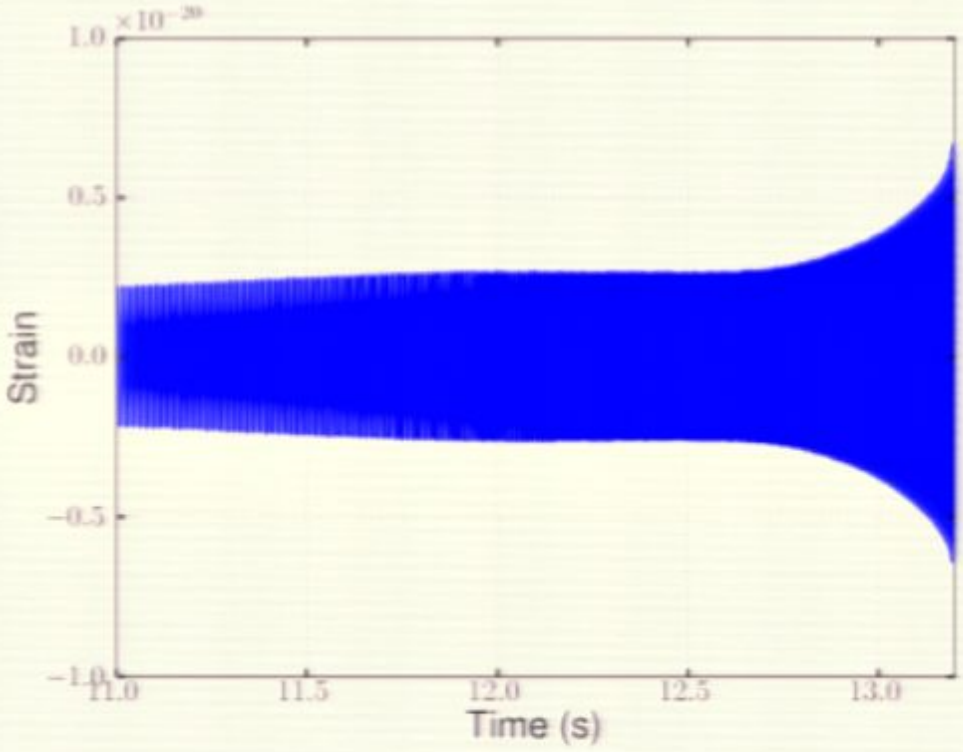

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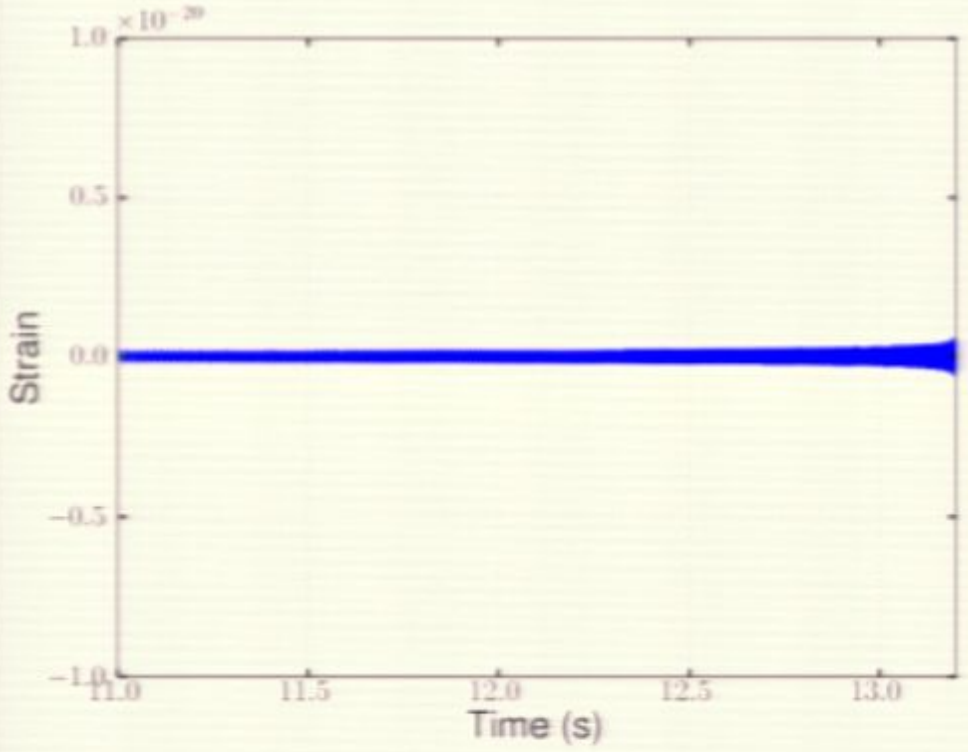

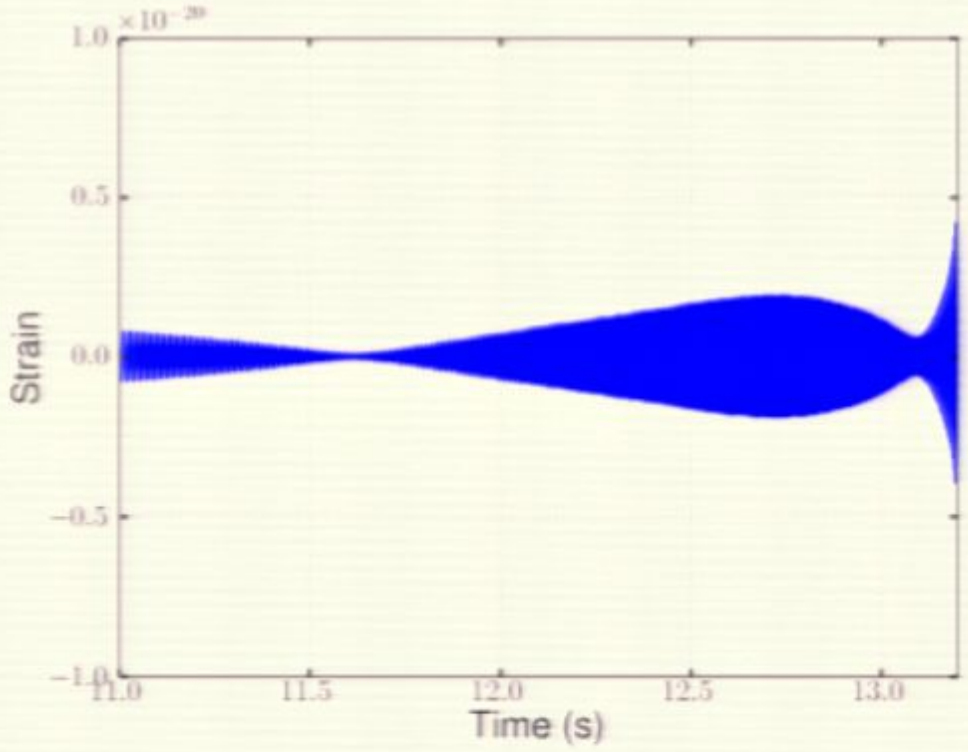

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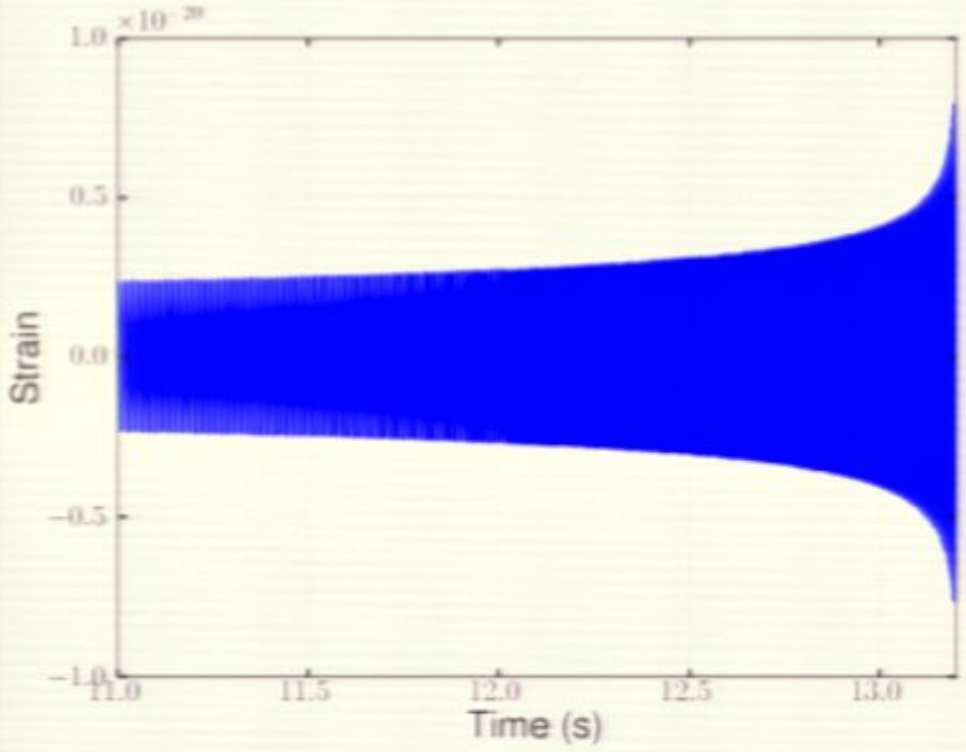

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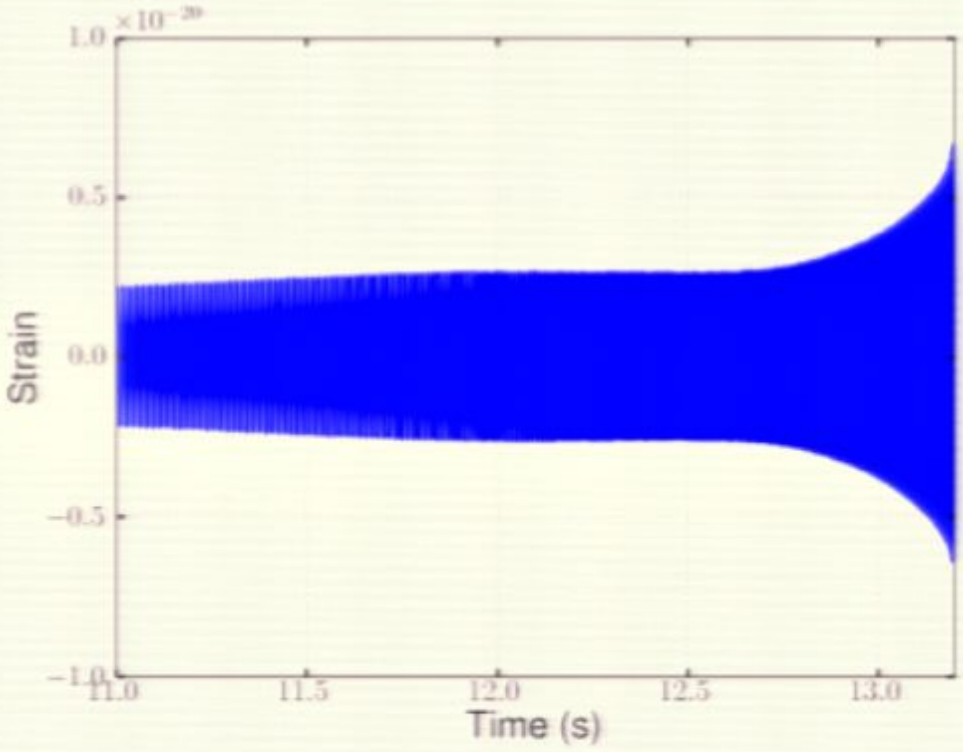

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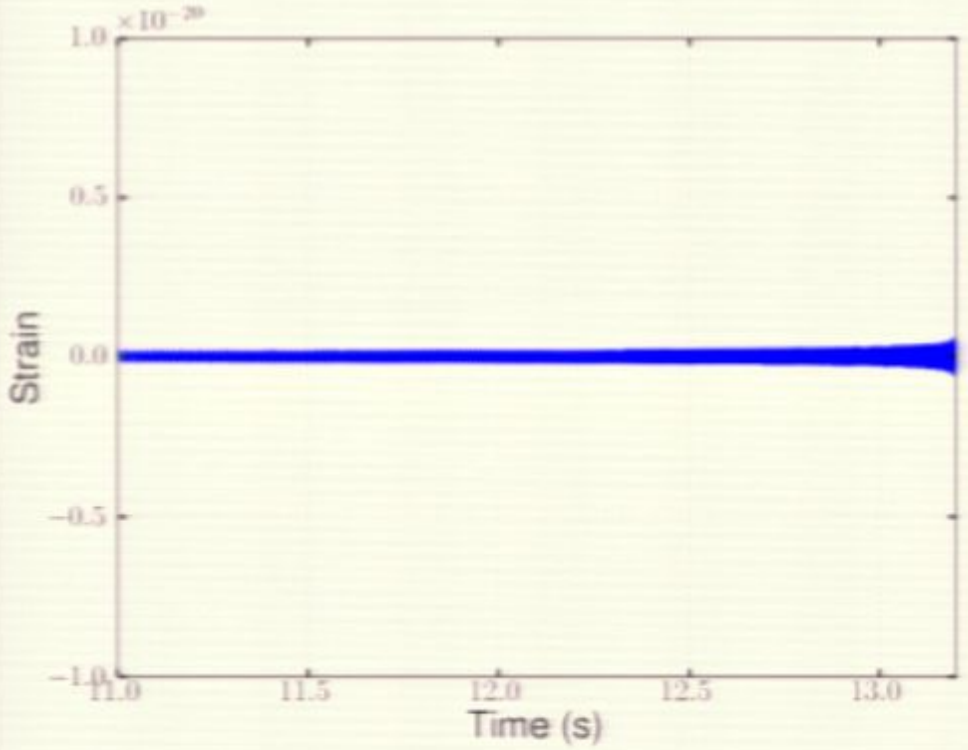

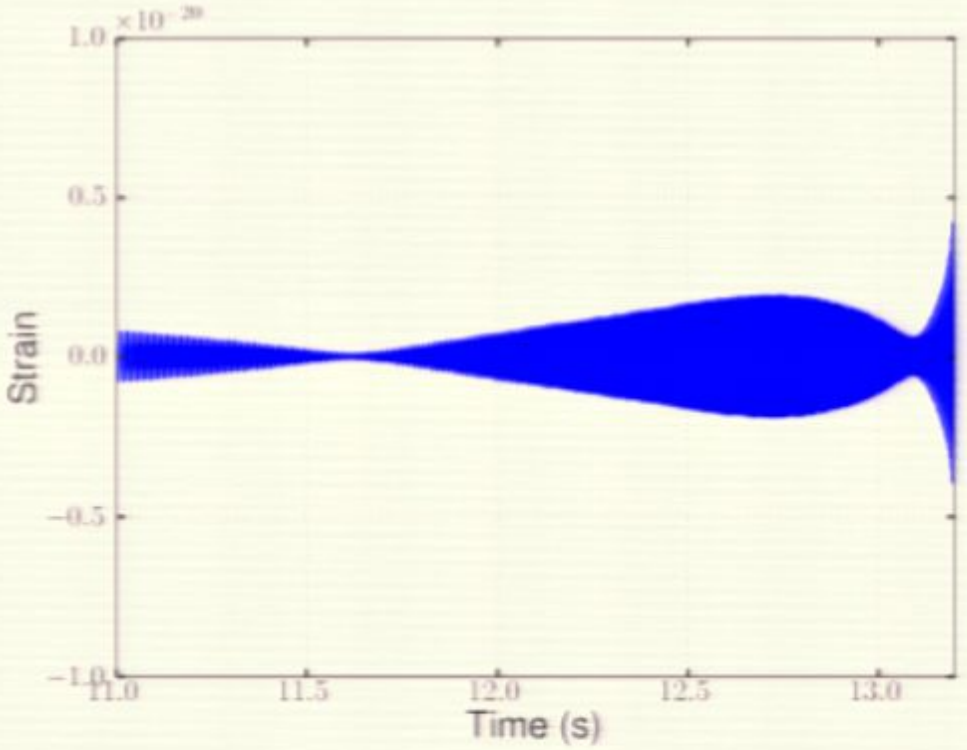

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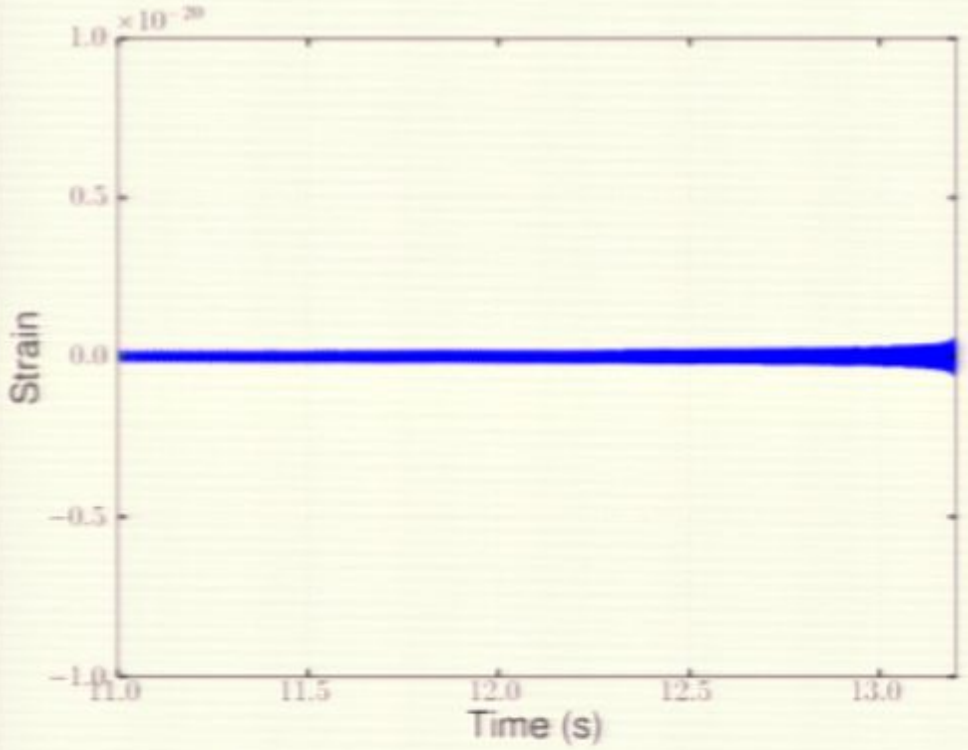

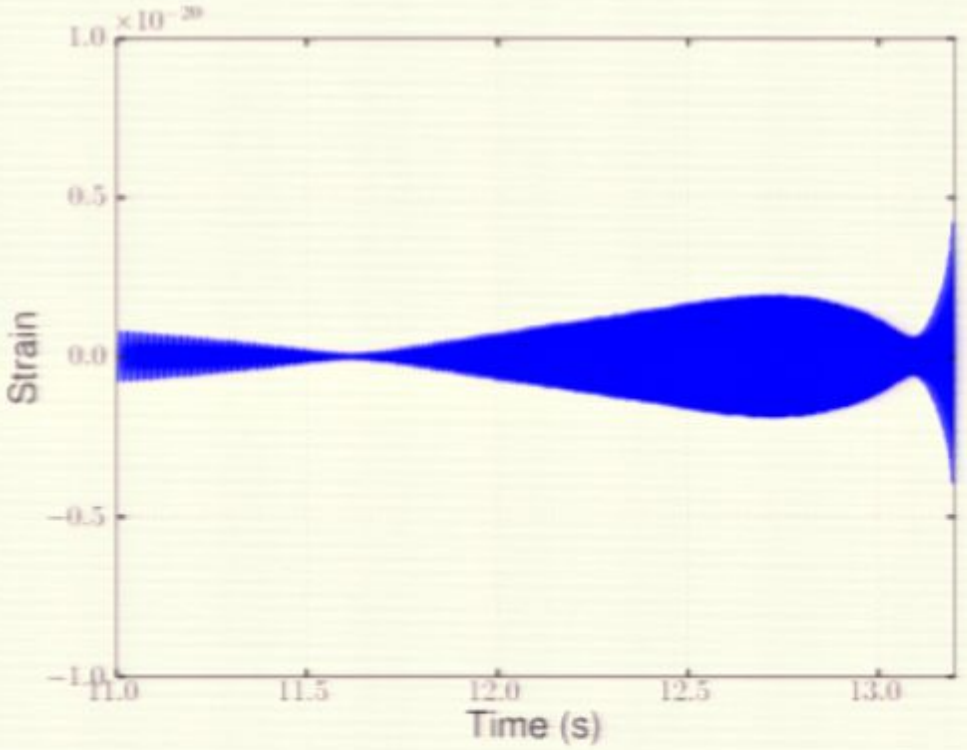

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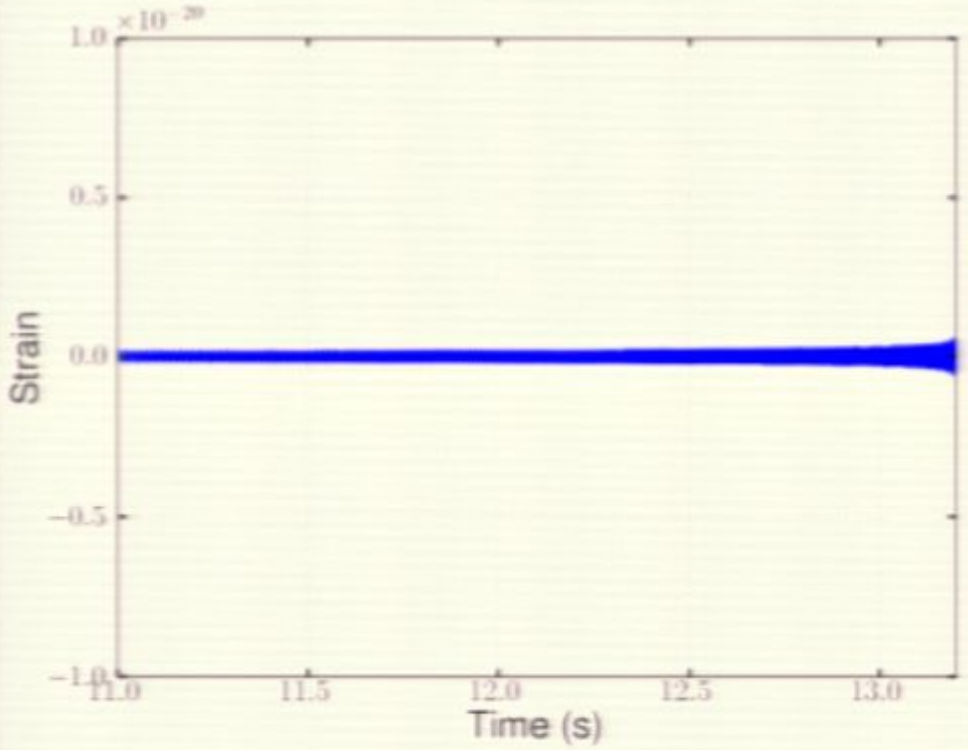

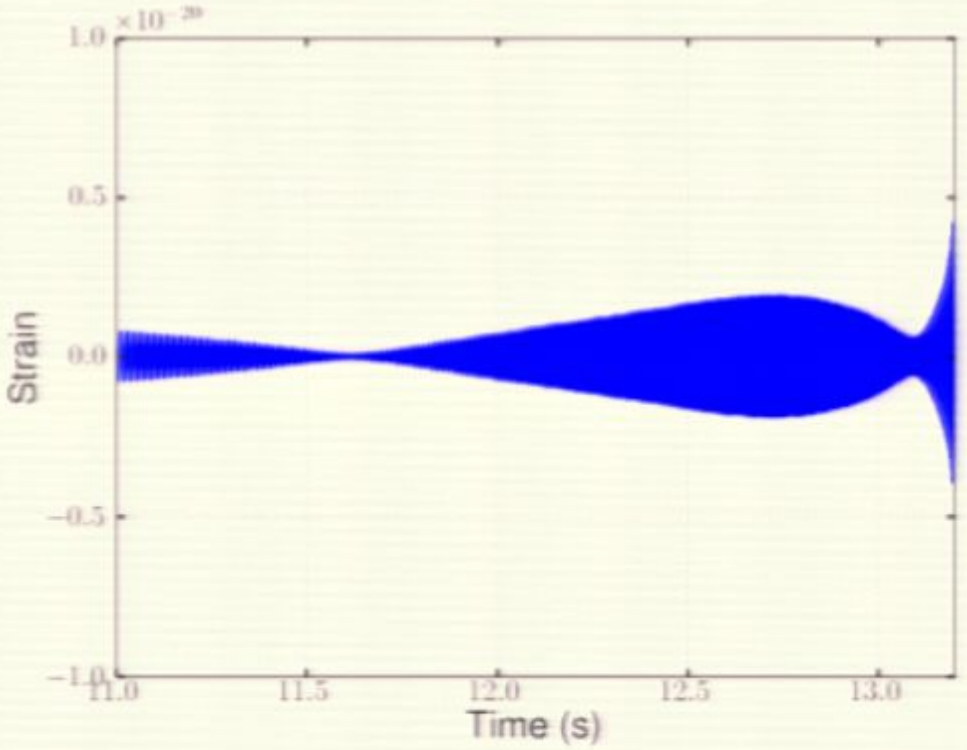

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Searching

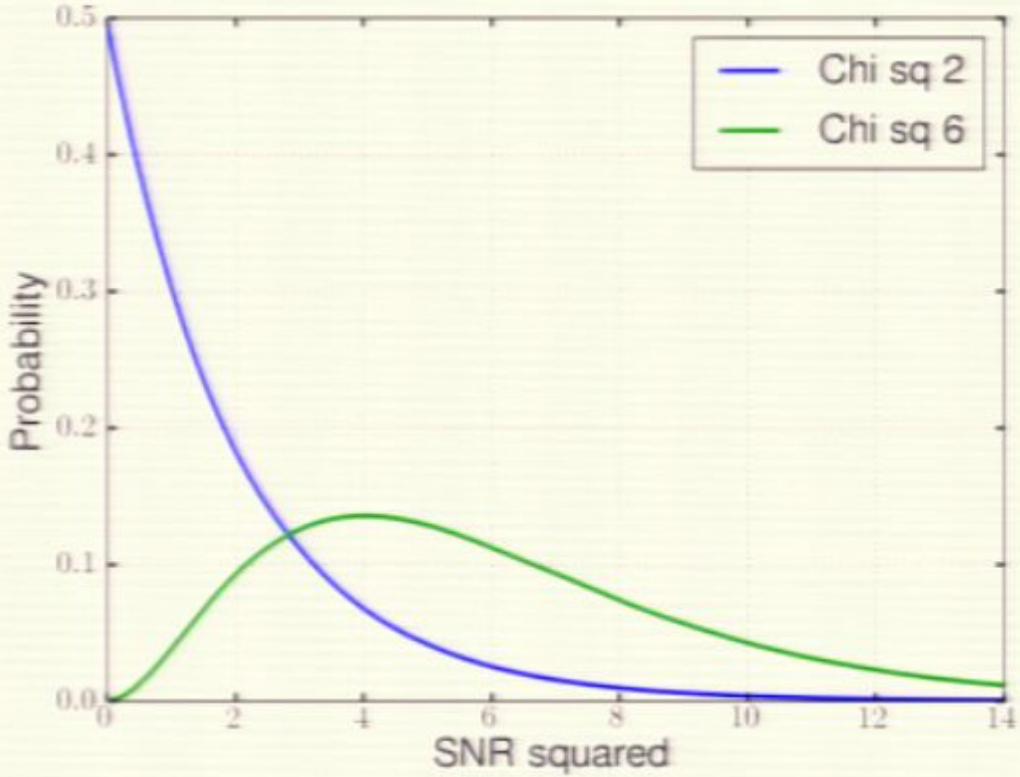
- To date, it's not possible to do the full coherent 15 parameter search using, e.g. brute force, MCMC, nested sampling, …
- We are using the Physical Template Family (Pan et al, PRD,69,104017; Fazi PhD Thesis)
  - Single spin waveforms, ideal for unequal mass systems, e.g. NS-BH
  - Good overlap with double spin systems (Buonanno et al, PRD 70,104003)
  - Use analytical tricks to reduce parameter space

Maximizing over parameters

- Restrict to dominant harmonic
  - 5 waveform components Y_{2-2}, …, Y_{22}
  - 4 parameters determine these amplitudes (D, ι, Ψ, ϕ)
  - Maximize freely over Y_{2m}, even though there is a constraint (Pan et al, PRD,69,104017)
  - Additionally, if precession is slow, maximize over the initial "spin-orbit" phase
  - Analytically remove 5 parameters!

What's the cost?

- Non-spinning search, SNR is χ^2 distributed, 2 degrees of freedom
- For PTF search, SNR is approx χ^2 distributed, 6 degrees of freedom
- Spin search requires a higher SNR threshold to achieve same false alarm rate



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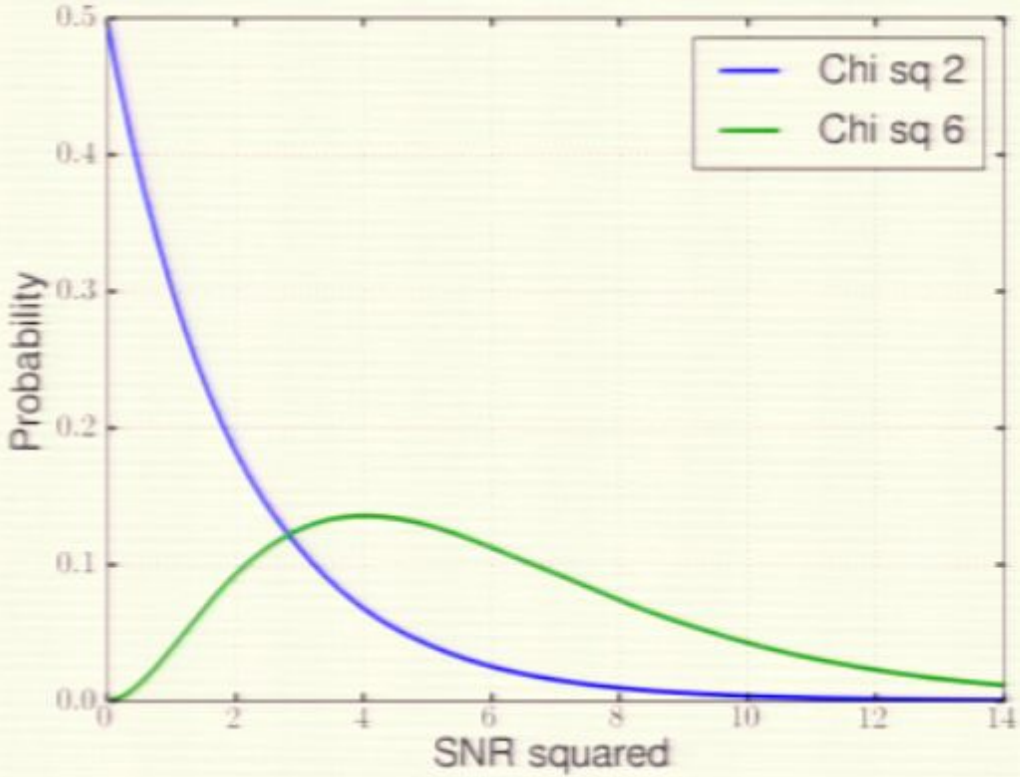
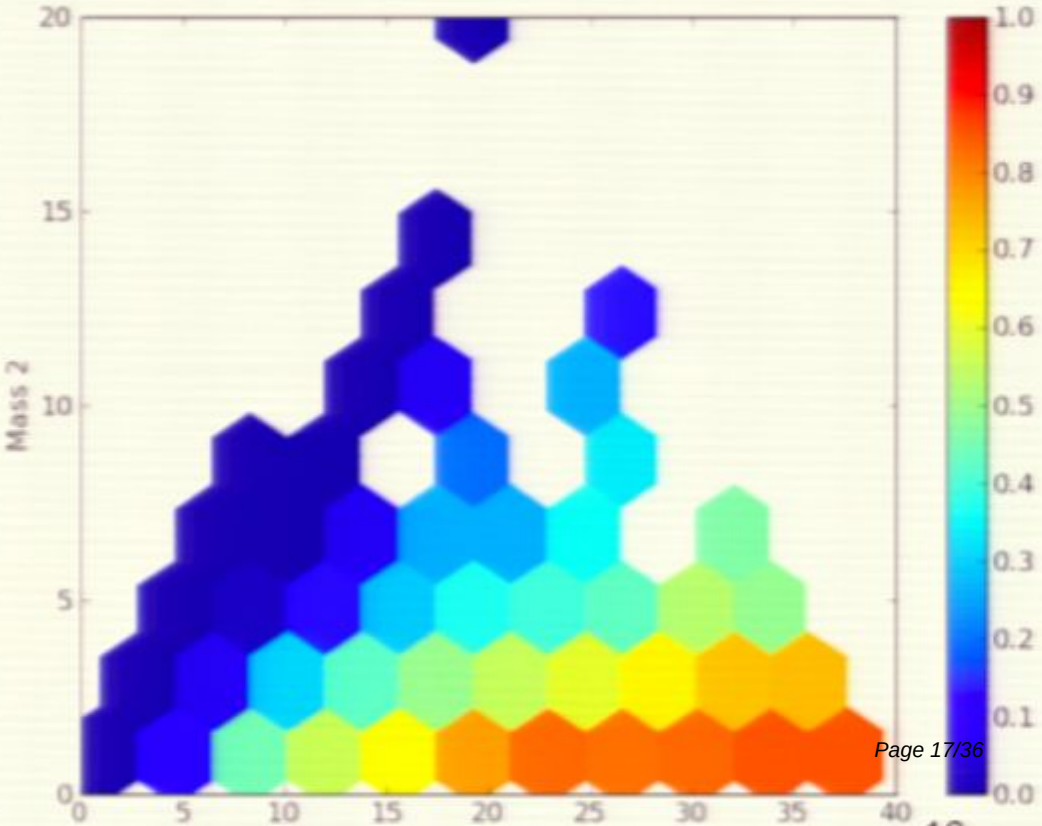


Is it worth it?

- For mildly precessing systems, can do better by only searching for Y_{22}, Y_{2-2} components
  - Lose some SNR, but lower false alarm rate
  - Increase the expected number of detectable signals



fraction of templates with significant precession

Template Space

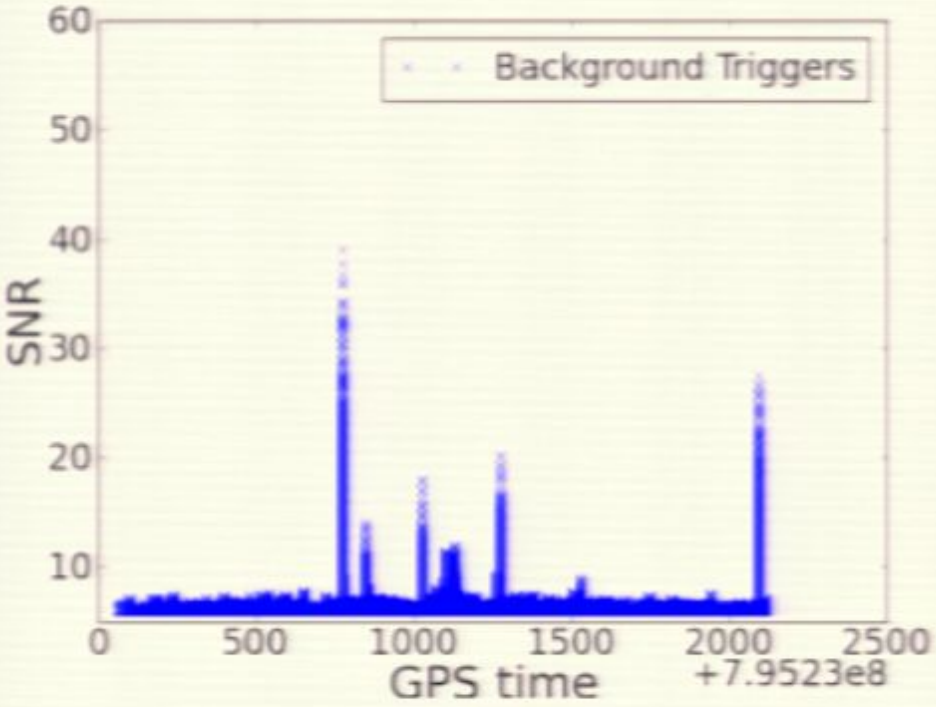
- After maximization, have 4 dimensions to template: (m_1, m_2, $|\mathbf{S}|$, $\mathbf{S}.\mathbf{L}$)
- Metric on this space is highly dependent on maximized parameters (D,ι, Ψ,ϕ)
  - Complicates template placement
    - For now, use non-spinning m_1, m_2 bank with fixed spin space gridding
  - Difficult to use metric in coincidence tests
    - Perform a coherent analysis

Coherent Analysis

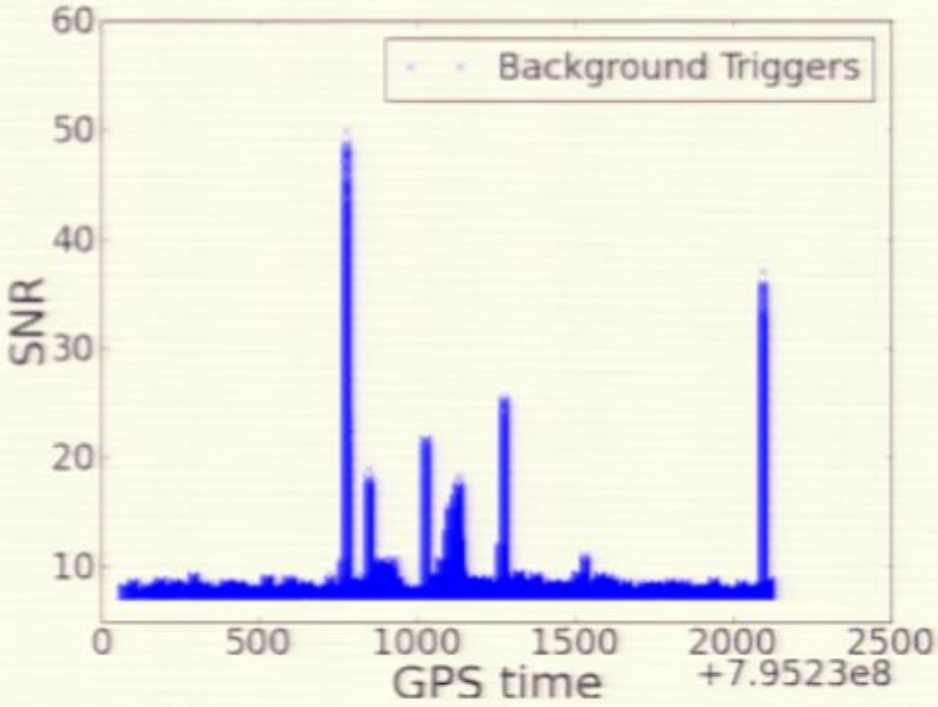
- Combine data coherently from all detectors
  - Search for signals in this data
  - Addition of spin doesn't really complicate this
- Coherent combination allows for new signal consistency tests
  - E.g. Null stream
- Implemented a coherent spinning search for externally triggered events (e.g. GRBs)
  - Ran on a "fake" GRB in LIGO's S4 data

Results – SNR

Non precessing templates



Precessing templates



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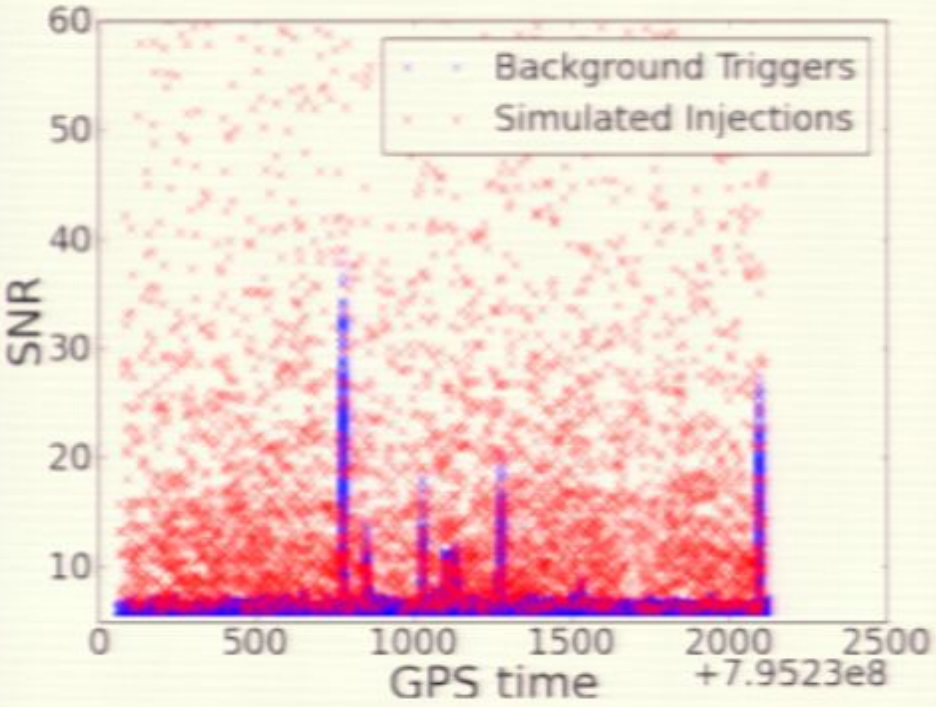

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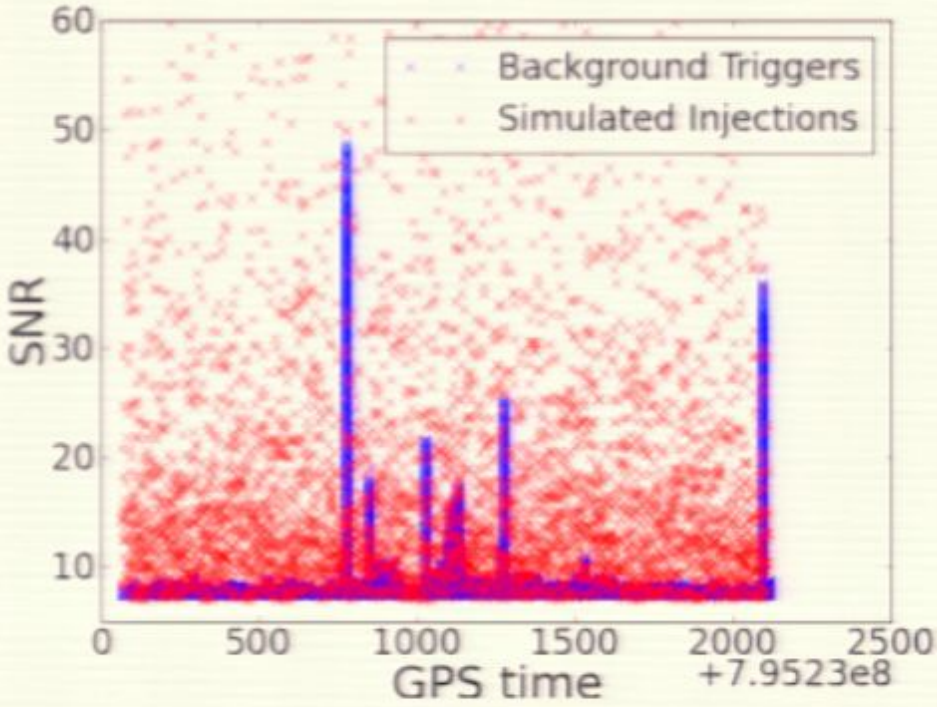
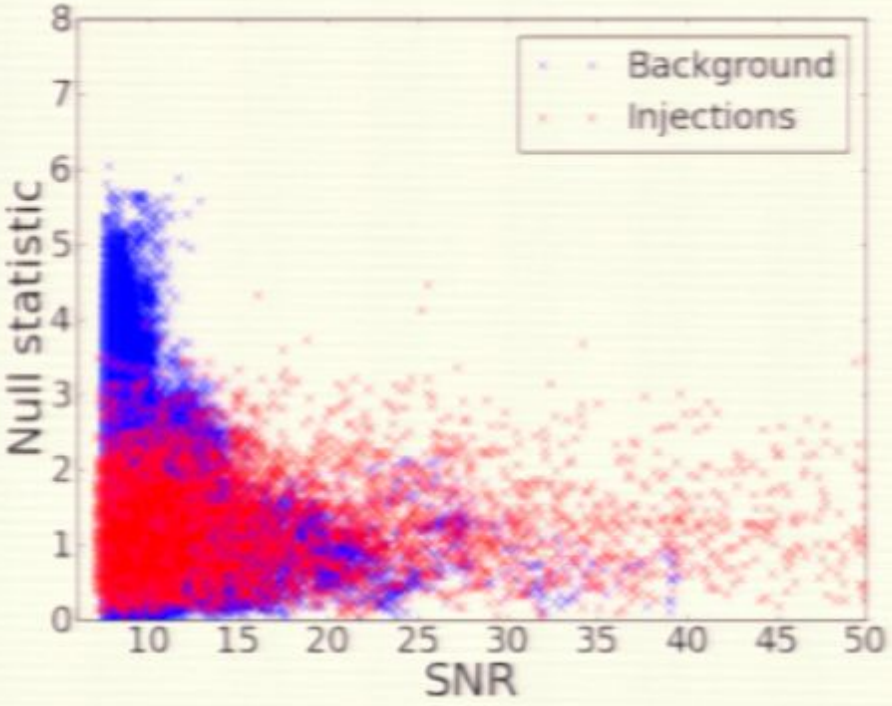


Glitch Rejection

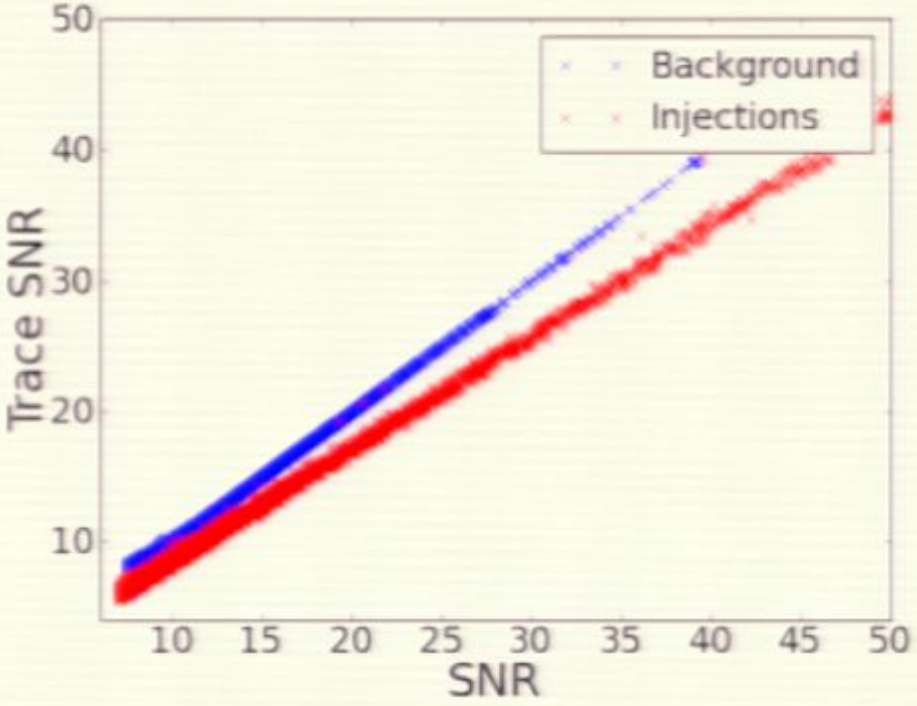
- Null Stream
  - Gravitational waves have 2 polarizations
  - With 3 or more detectors, can construct a data stream which will have no signal
  - Glitches may still appear in the null stream
- Trace SNR
  - Coherent SNR involves single detector terms and cross terms between detectors
  - Glitches often in a single detector
  - Compare single detector "trace SNR" to SNR
- "Familiar" χ^2 tests also implemented

Glitch Rejection

Null Stream



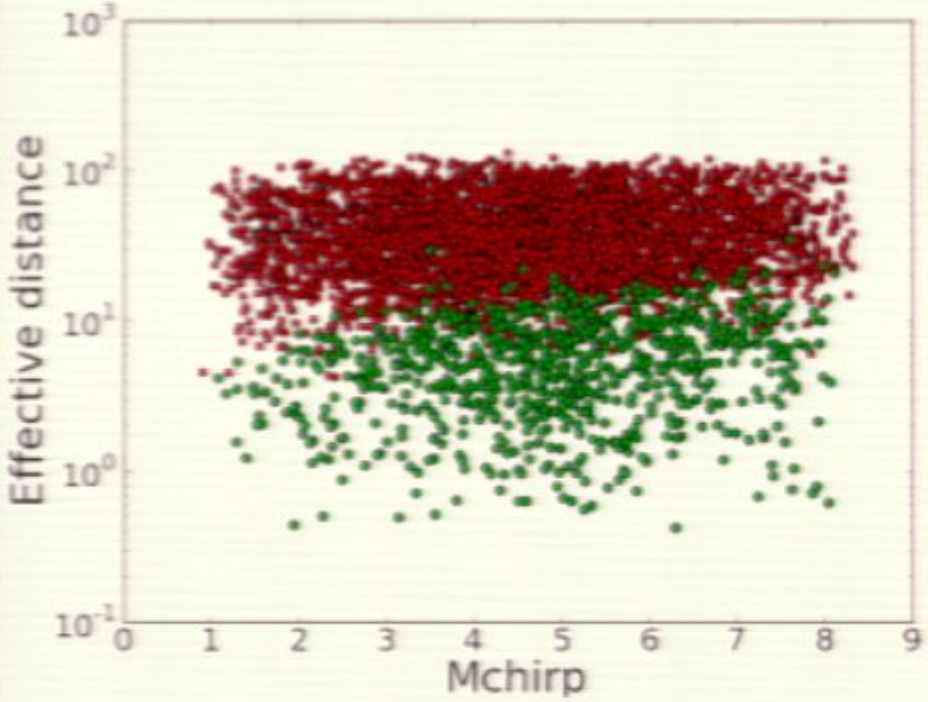
Trace SNR



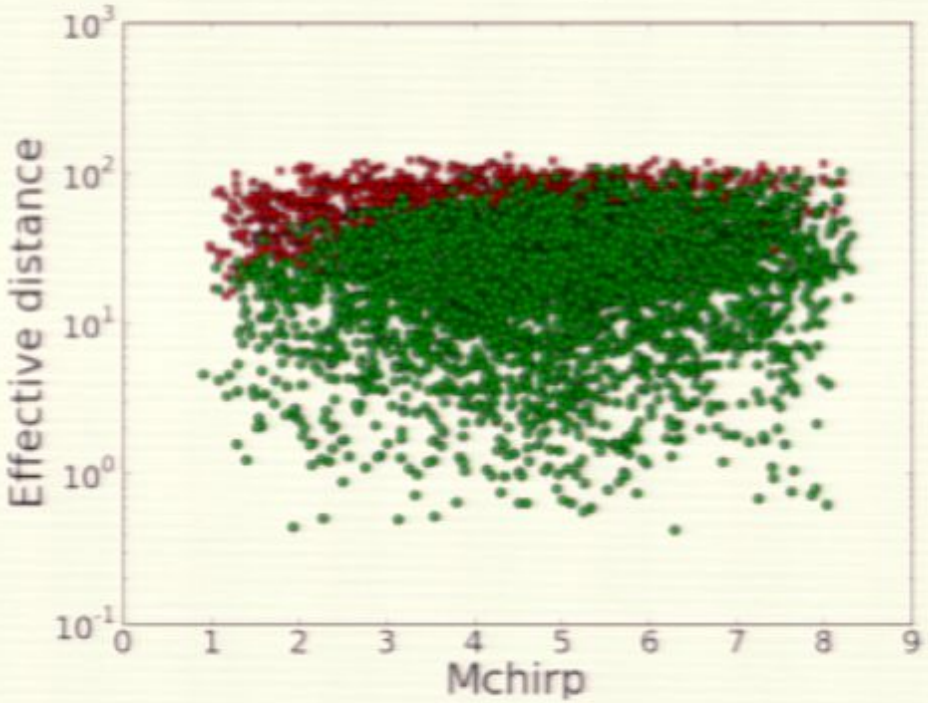
Results

Green: Simulated signals louder than all background

SNR only



SNR, Null Stream, Trace SNR

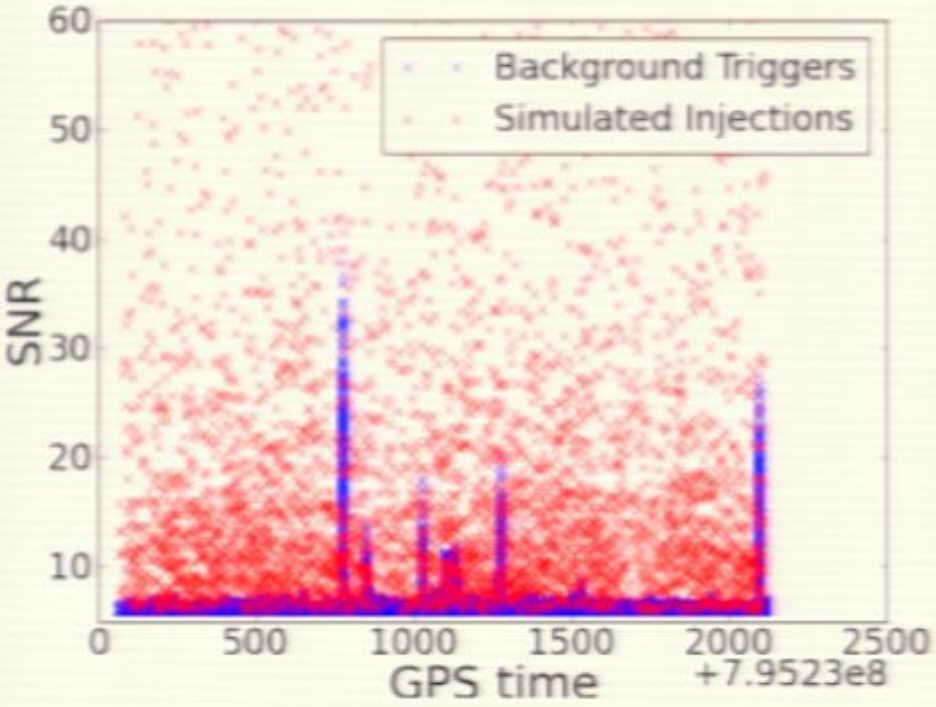


Conclusions

- Spin greatly complicates searches.
  - Need efficient ways of spanning the spin space.
- Have developed a targeted, coherent search for spinning systems.
  - Need to identify regions of parameter space where it outperforms non-spinning search
- Many of the methods discussed would extend to full precessing waveforms.
  - Difficult to also include higher harmonics

Results – SNR

Non precessing templates



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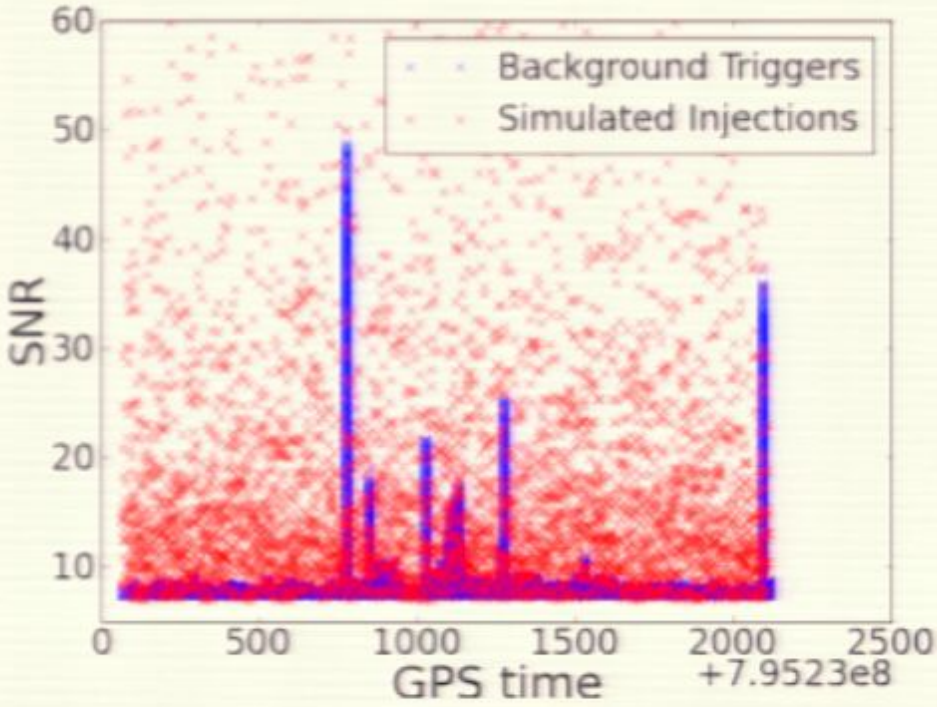

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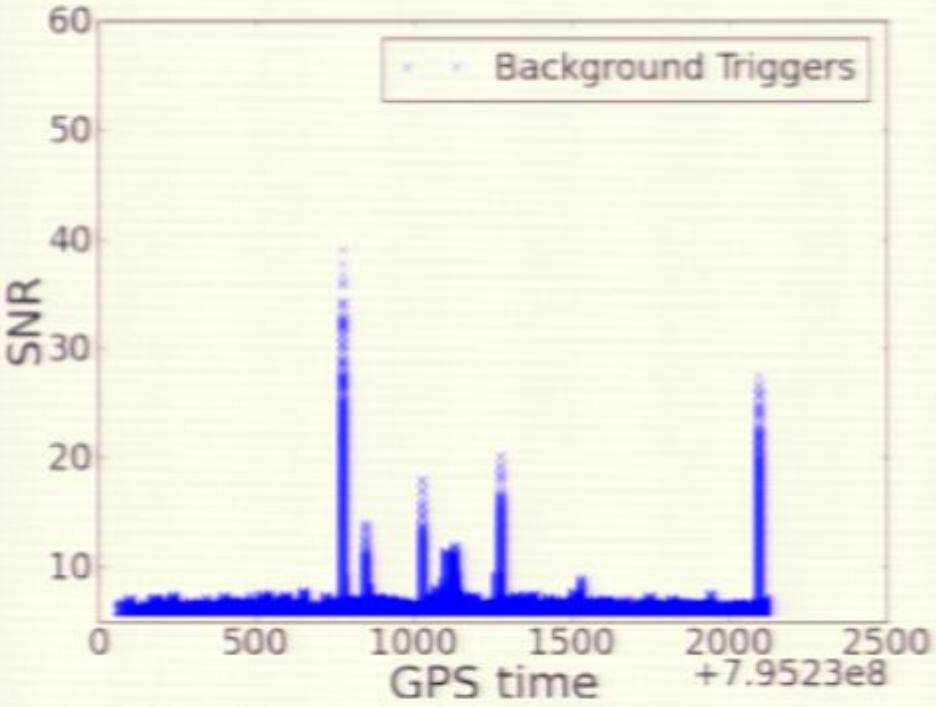

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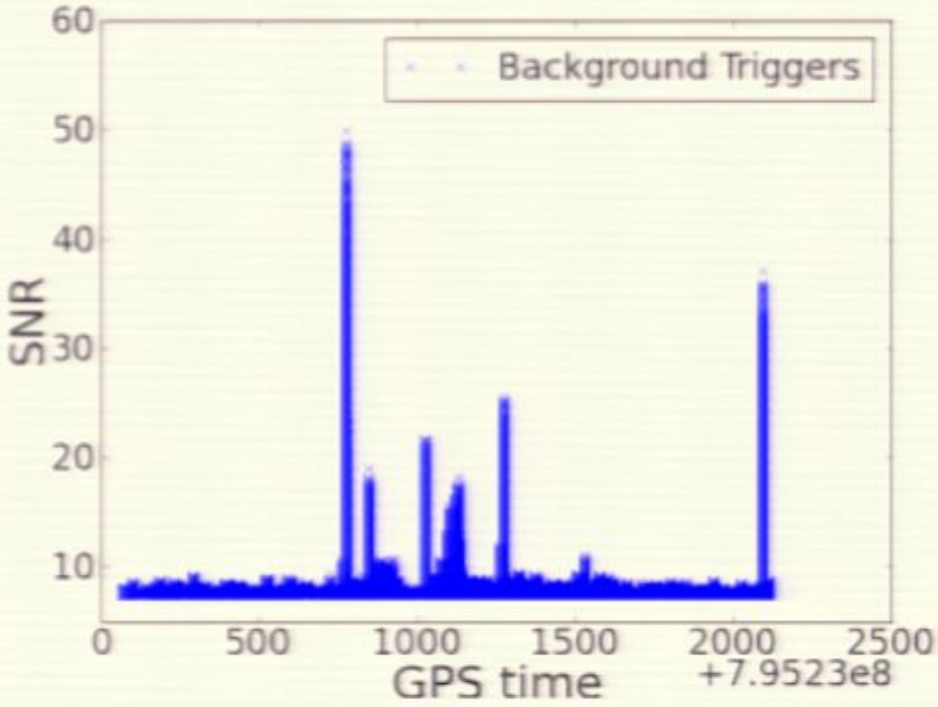

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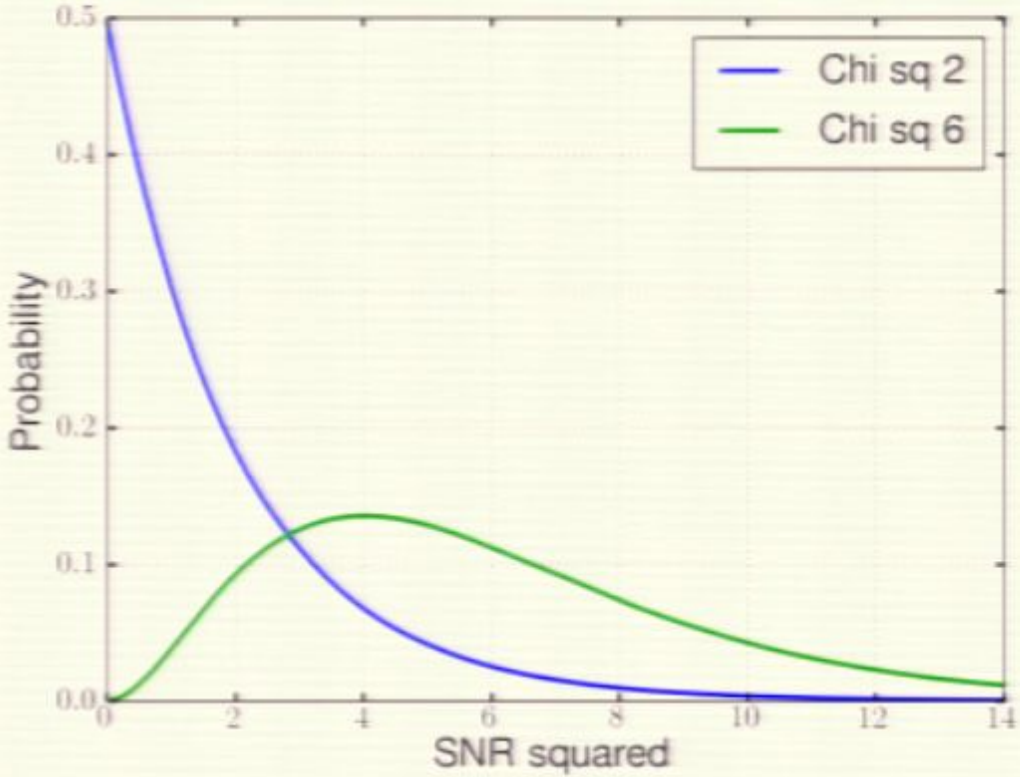

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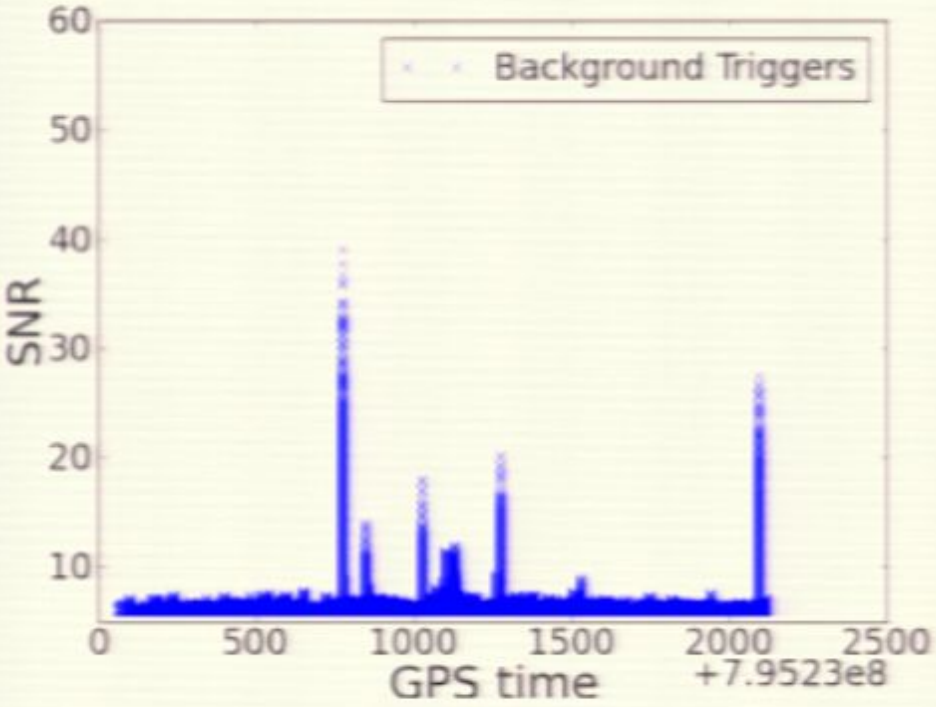

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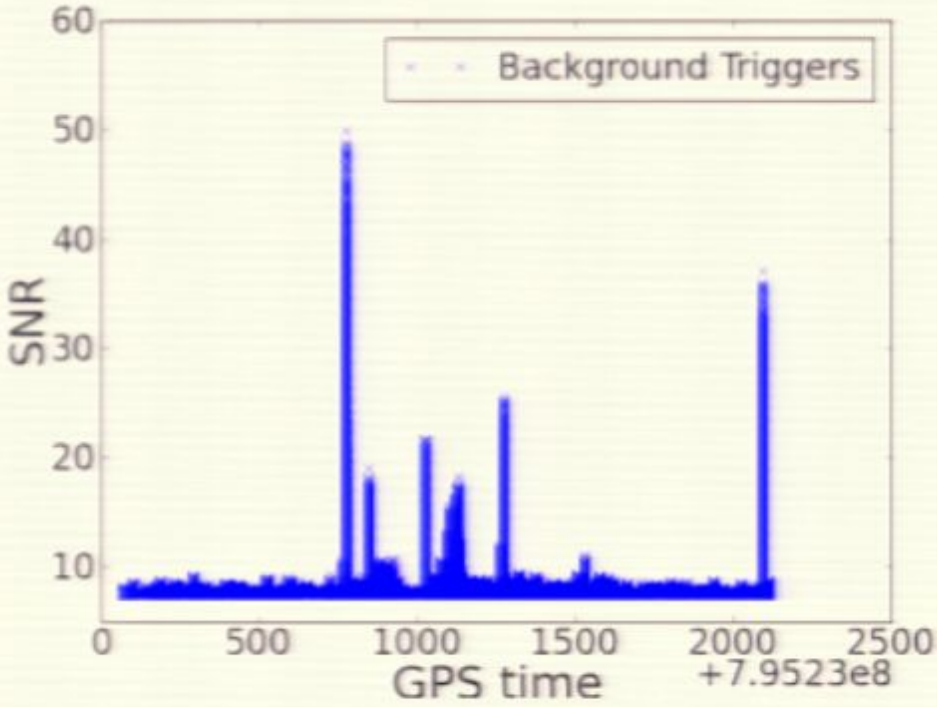

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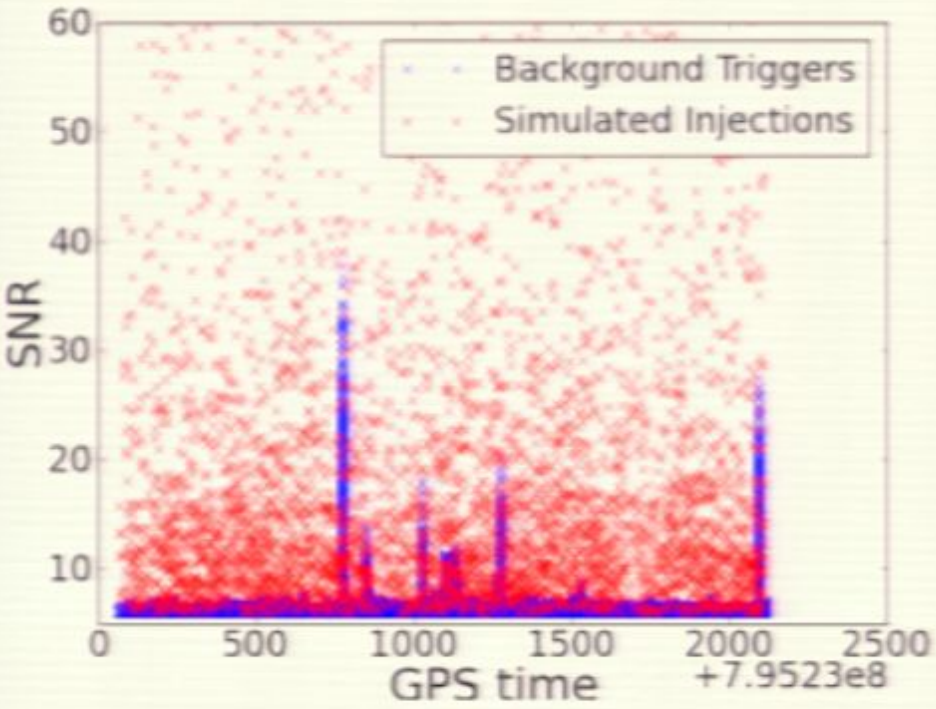

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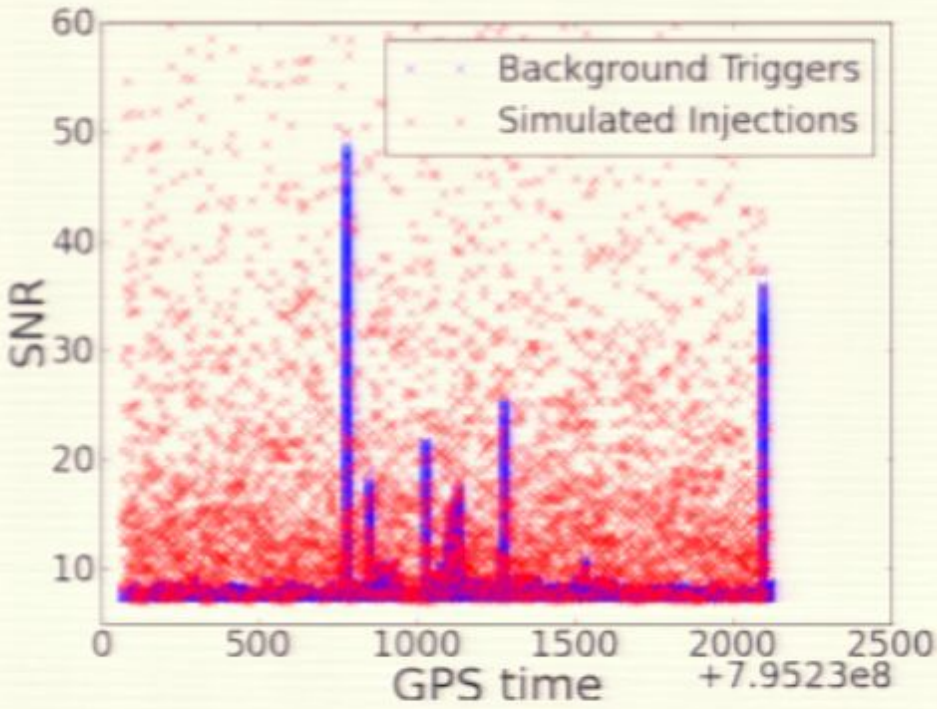

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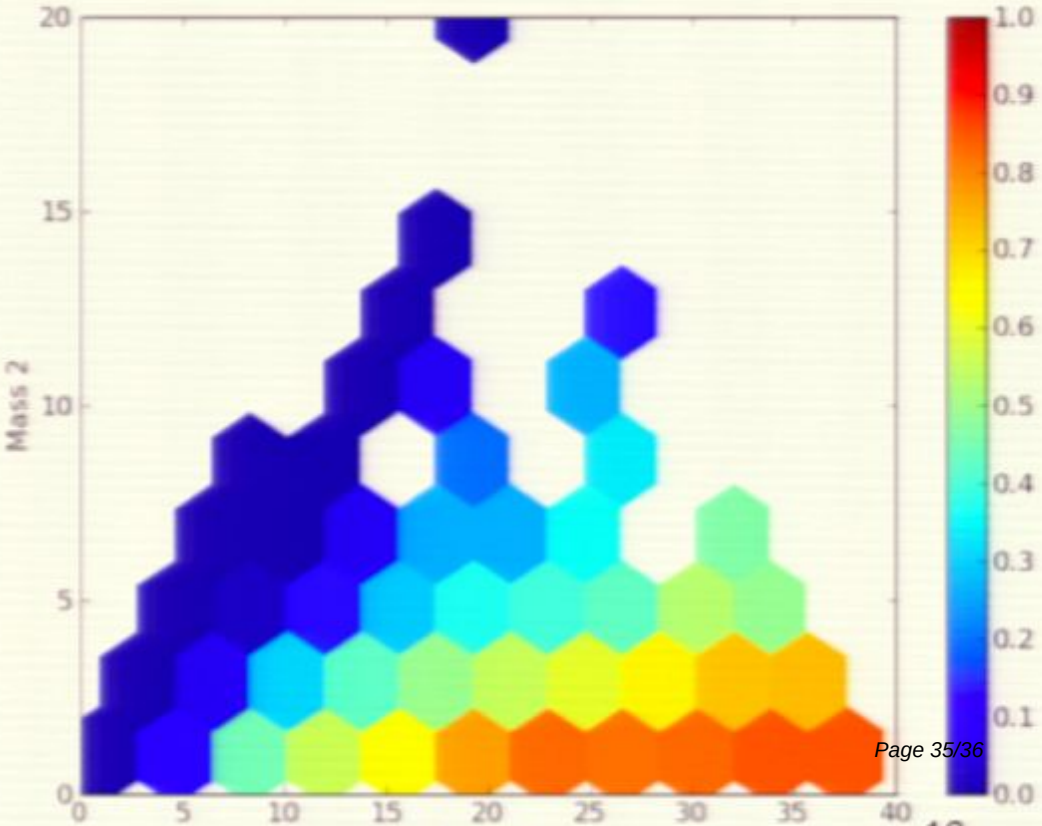

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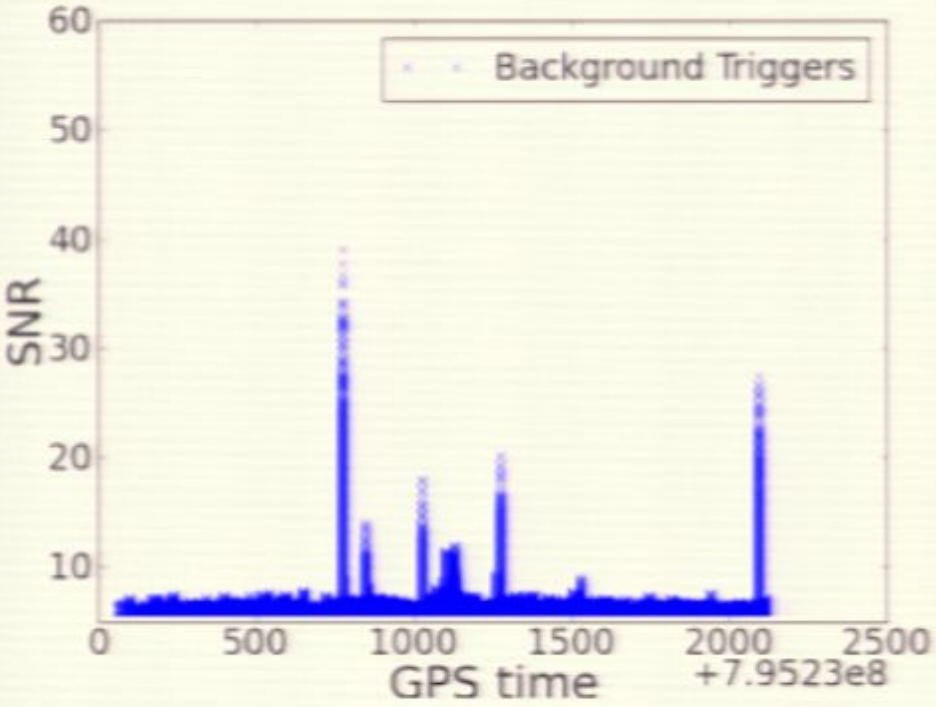

Precessing templates