Search for Spinning Black Hole Binaries in Advanced LIGO: Parameter tuning of HACR

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8th Capra Meeting
11-14 July 2005

Overview

Goal: Detection of SBHB's in Time Frequency representation of Advanced LIGO data

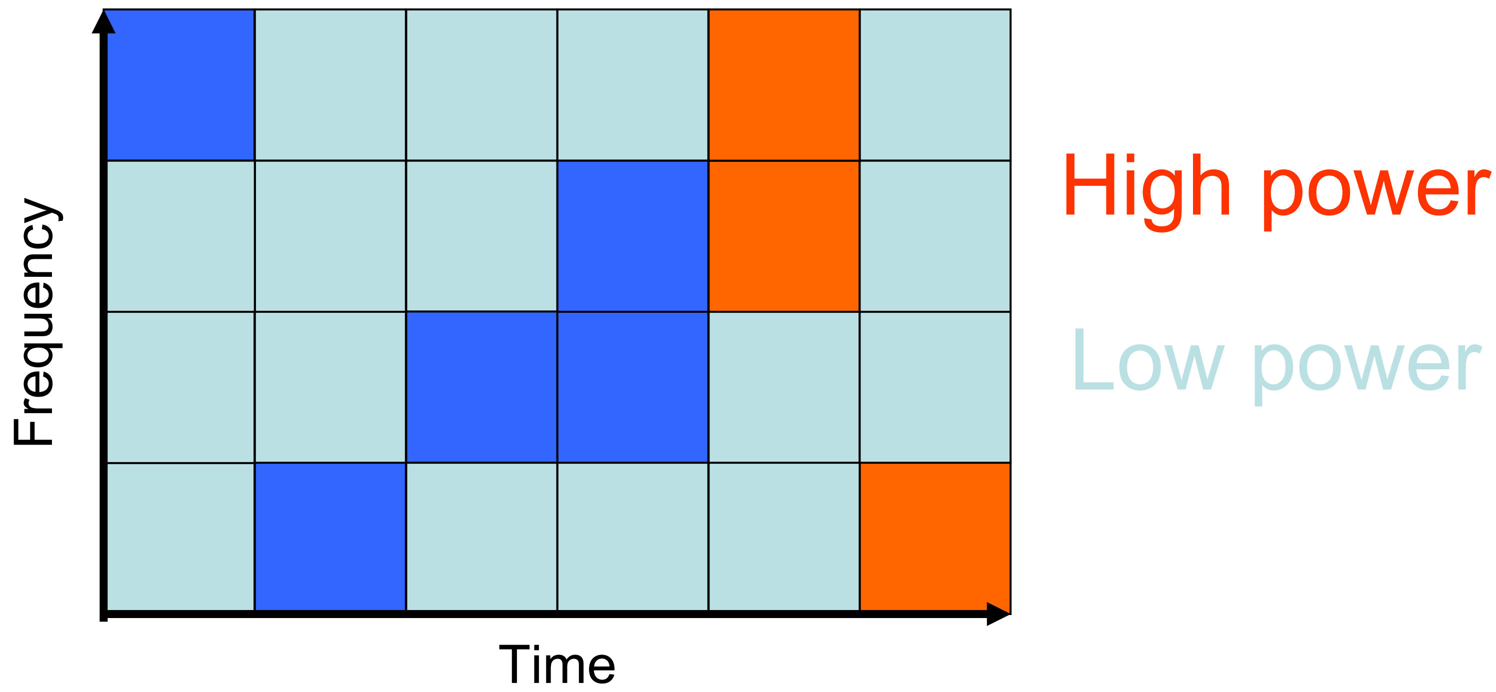
- What is HACR?
- Spinning Black Hole Binaries
- Tuning HACR in 2 steps
- Results
- Conclusions and Future Work

What is HACR?

- **H**ierarchical **A**lgorithm for **C**lusters and **R**idges written by R. Balasubramanian
- Time-frequency search
- Short bursts of excess power
- More robust than matched-filtering
- Implemented in GEO++ as HACRMon

How HACR works

1. Identify pixels with $P > \eta_{upper}$



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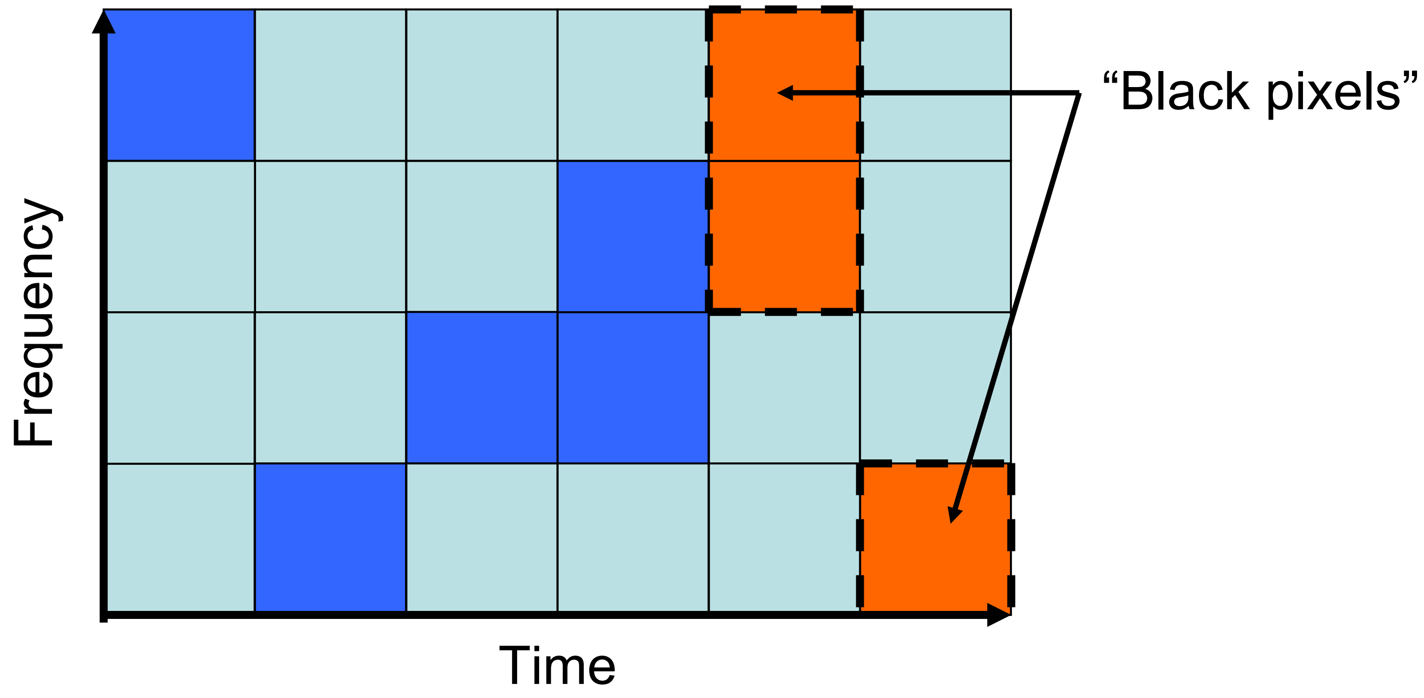
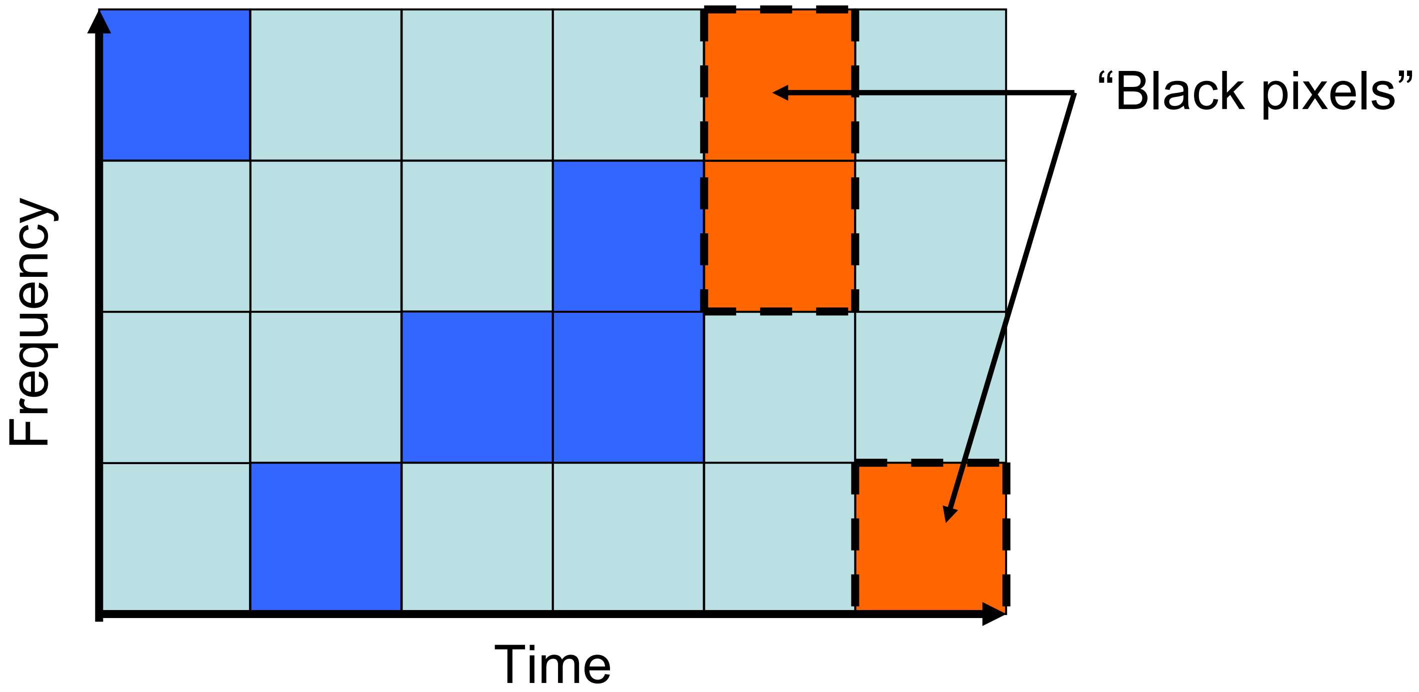


How HACR works

2. Identify neighbouring pixels with $P > \eta_{lower}$



How HACR works

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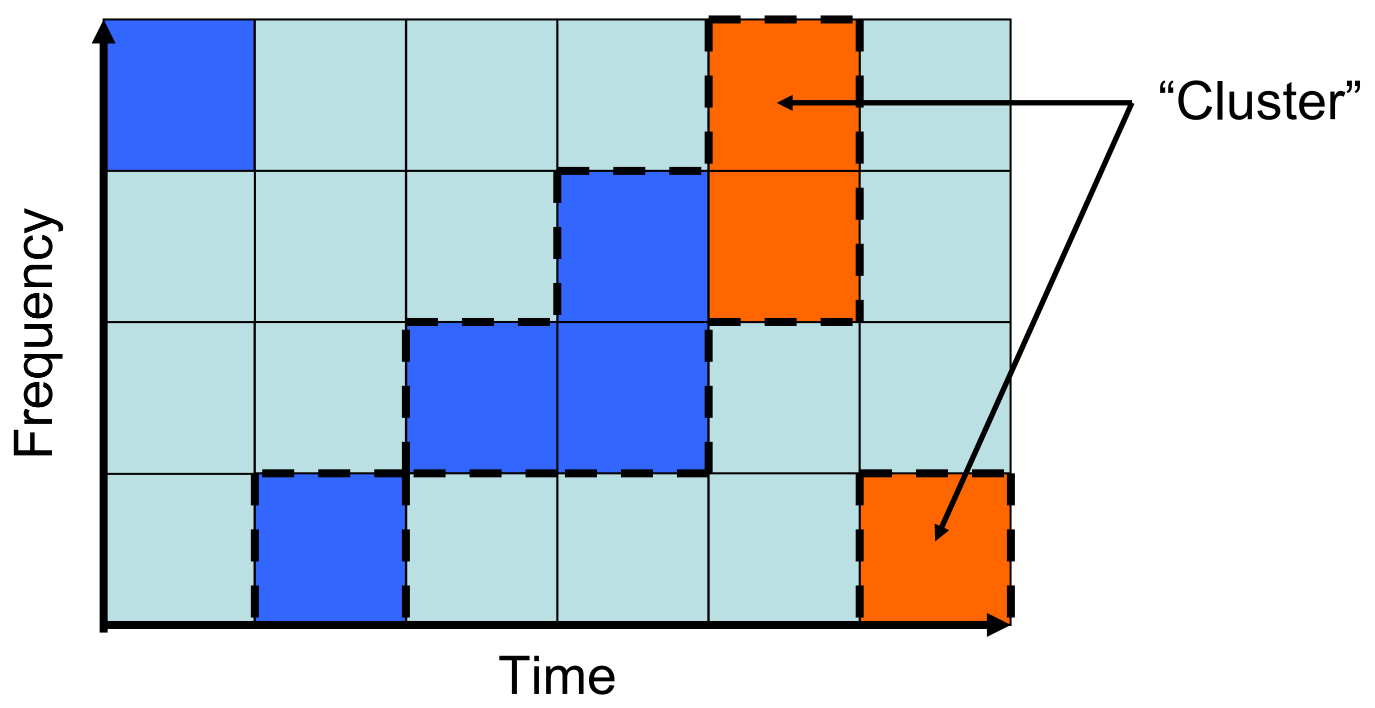
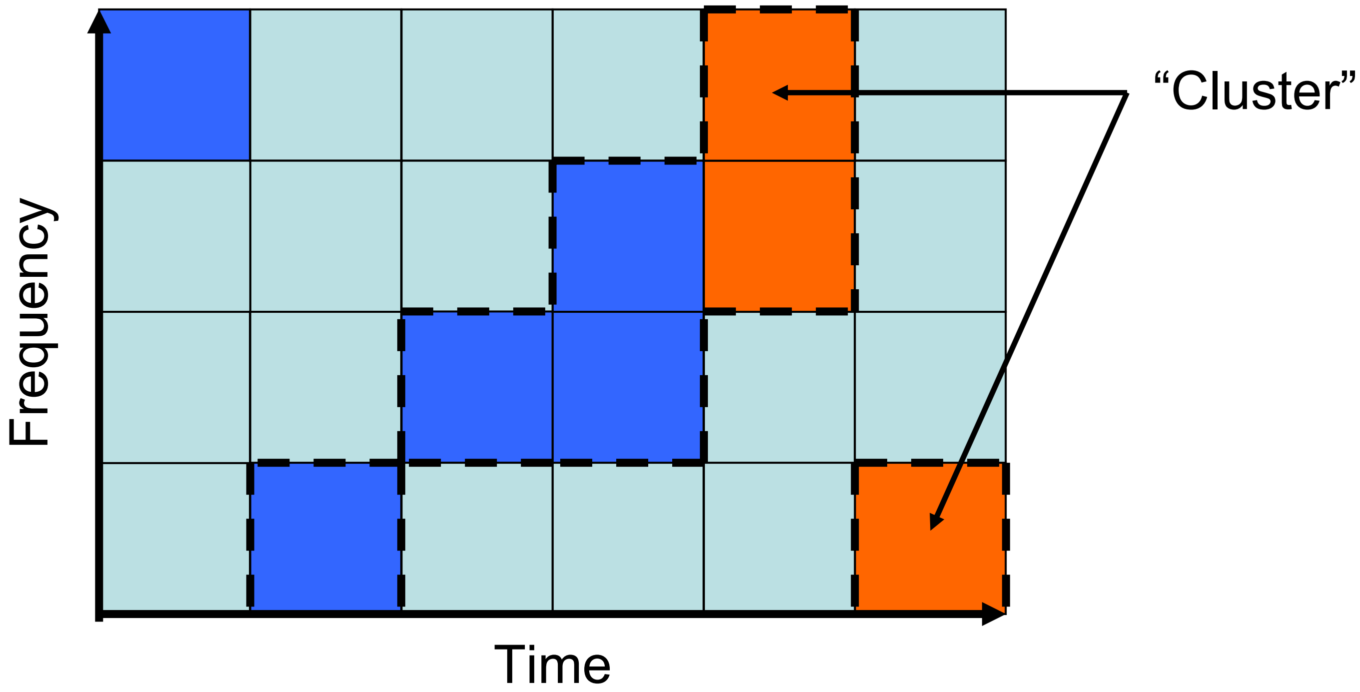


How HACR works

3. Identify clusters with $N_{pixels} > N_{threshold}$



How HACR works

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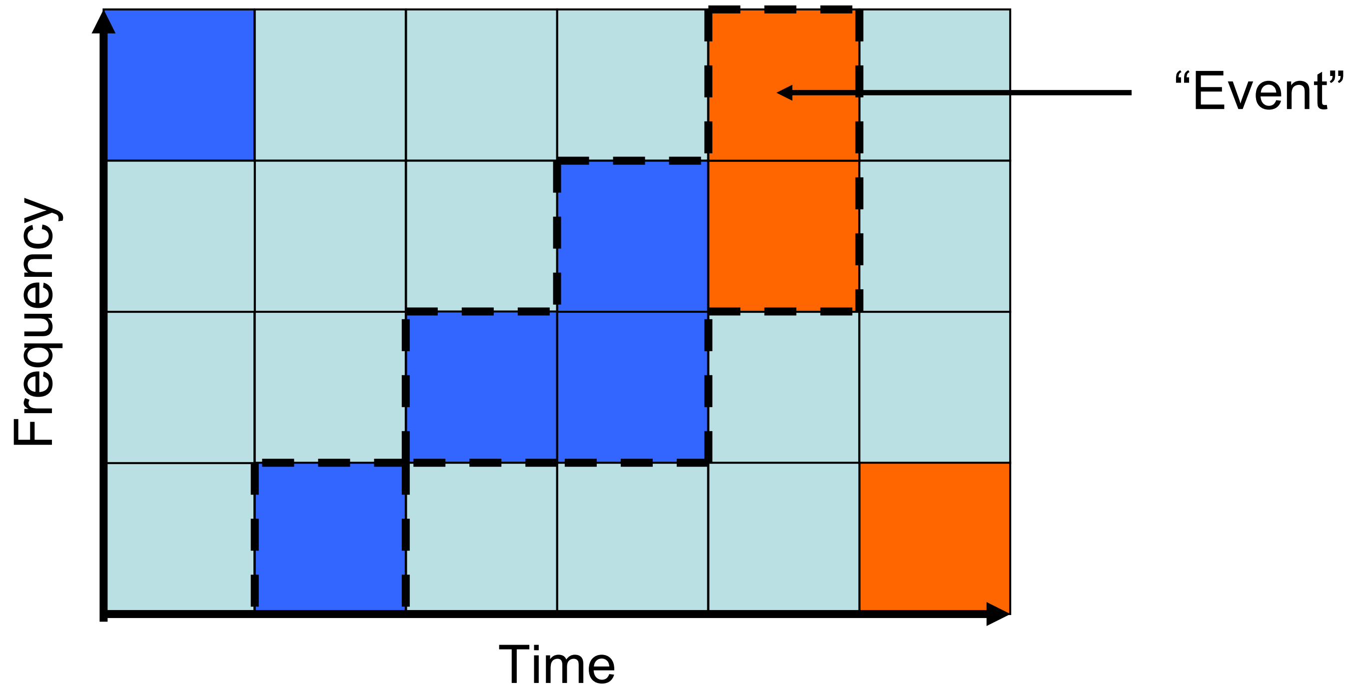
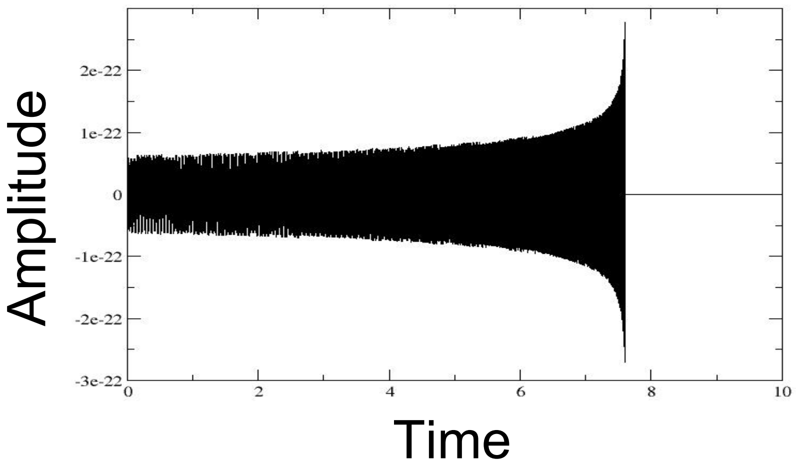
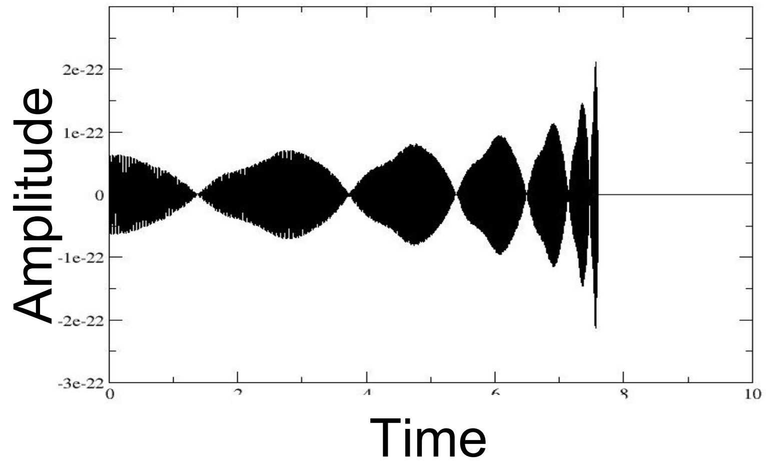


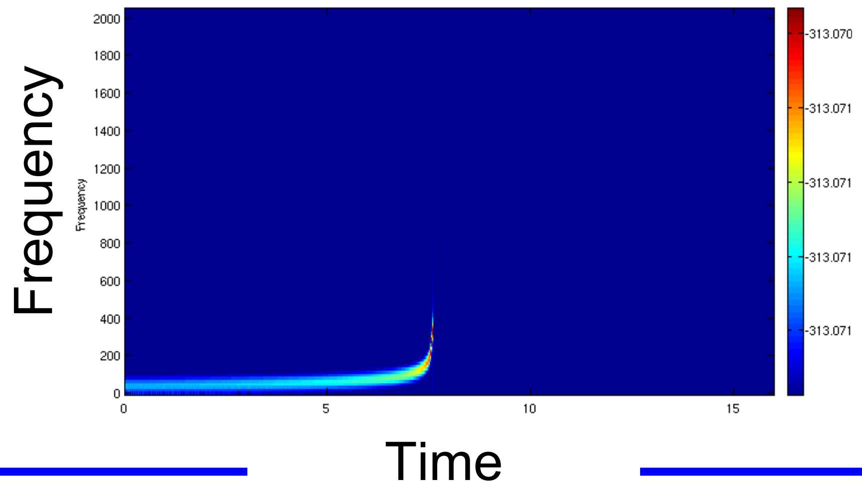
Spinning Black Hole Binaries

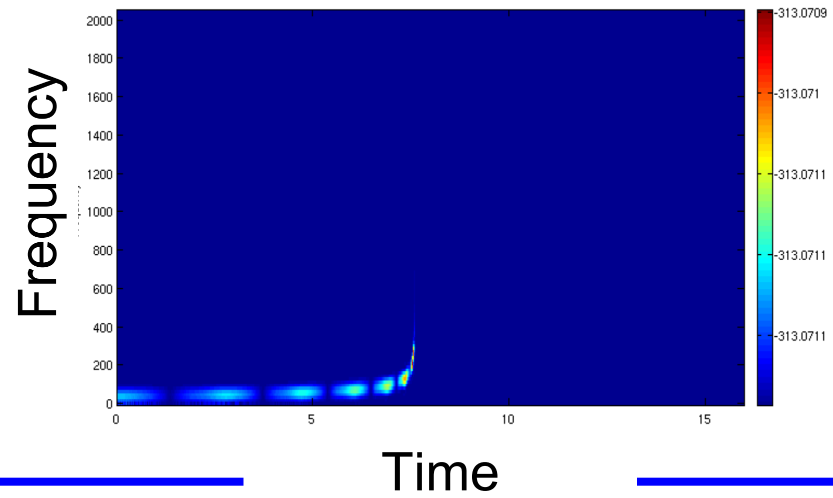
- Require 17 physical parameters to accurately describe waveform
- Spin-induced precession of orbital plane causes modulation of amplitude and phase
- Amplitude modulation causes of GW "archipelago" of clusters in TF map

Spinning Black Hole Binaries









Tuning HACR

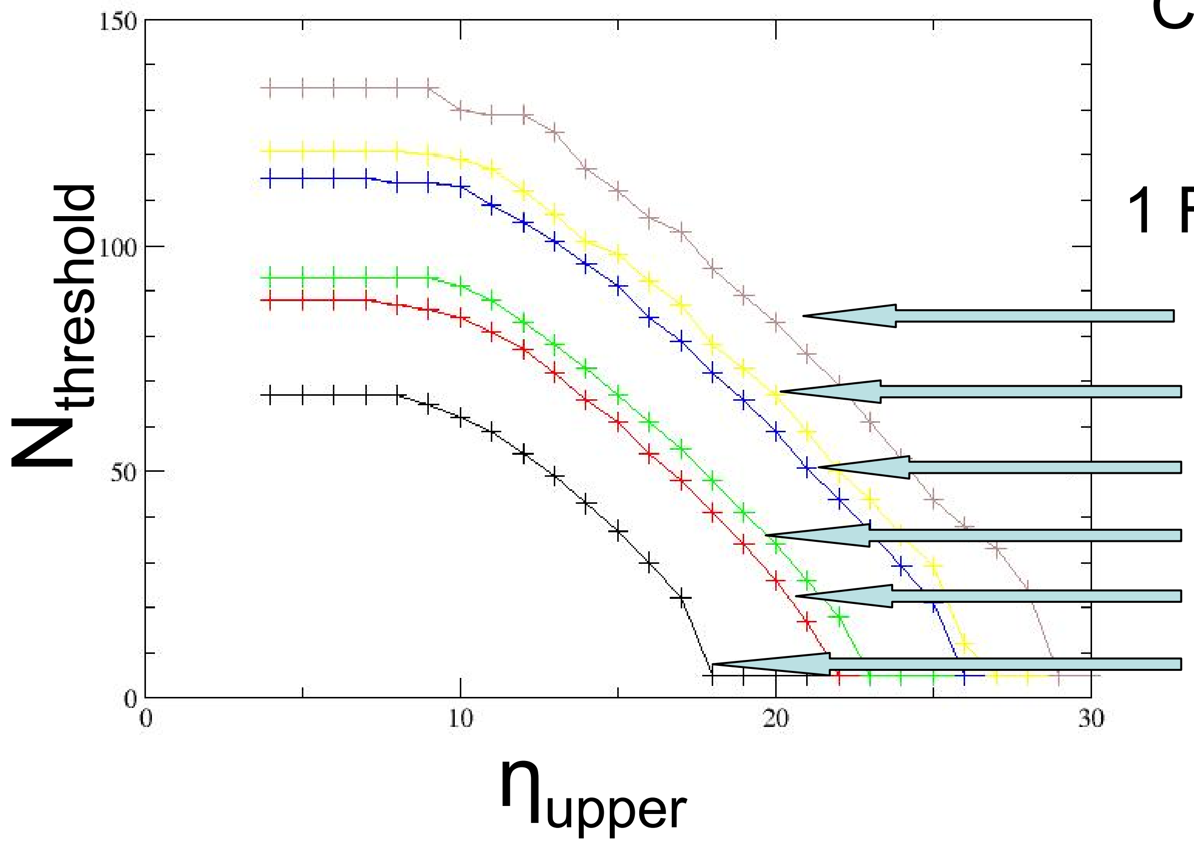
For a given false alarm rate maximise probability of detection

- 3 parameters: η_{upper}, η_{lower}, $N_{threshold}$
- Identify combinations of threshold parameters (η_{upper}, $N_{threshold}$) that produce a constant false alarm rate…
- … then for each combination of parameters measure probability of detection

False Alarm Analysis

- 100,000s of simulated Adv. LIGO data
  - Gaussian white noise convolved with Adv. LIGO PSD
- Analyse once with low values of thresholds
  - $\eta_{upper} = 4$
  - $N_{threshold} = 5$
- Store maximum-power and number of pixels for each found “event”
- For range of η_{upper} choose values of $N_{threshold}$ that give specific False Alarm rates
- Python scripts that search through a mysql database

False Alarm Analysis



Contours of constant false alarm rate

1 False alarm per…

…hour (27.8 events)

…1000s (100 events)

…10 mins (166.7 events)

…100s (1000 events)

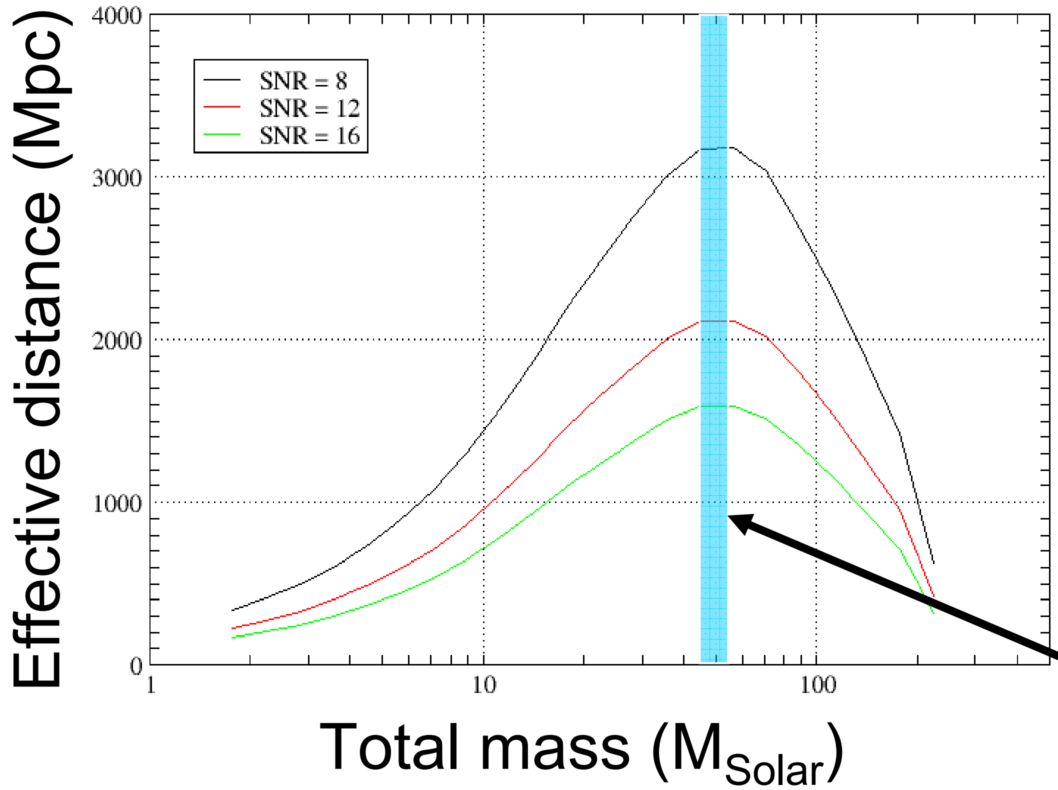
…min (1666.7 events)

…10s (10,000 events)

Injection of SBHB waveforms

- Physical waveforms
- (1-49), (10-40) and (25-25)M_{solar}
- Mass that Adv. LIGO can see furthest
- 1000 injections each with SNR = 8,12,16
- Measure number of injections recovered for each combination of (η_{upper},$N_{threshold}$)

Span of Adv. LIGO



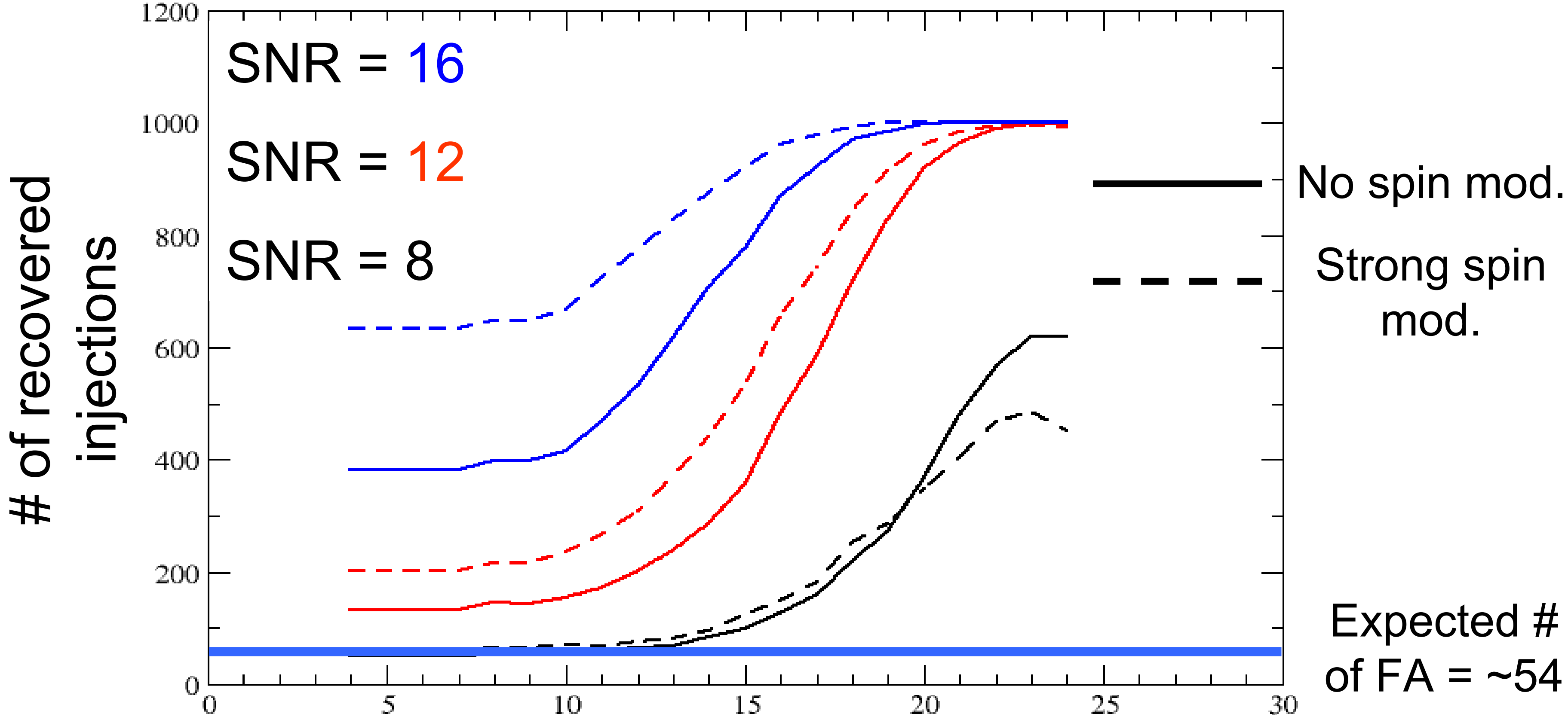
- Effective distance:

$$d = \frac{M^{5/6}}{\rho \pi^{3/2}} \left(\frac{5\eta}{6} \right)^{1/2} \left[\int_{f_{low}}^{f_{LSO}} df \, \frac{f^{-7/3}}{S_h(f)} \right]^{1/2}$$

- Equal mass binaries:
  $\eta = 0.25$

$M = 50 M_{Solar}$

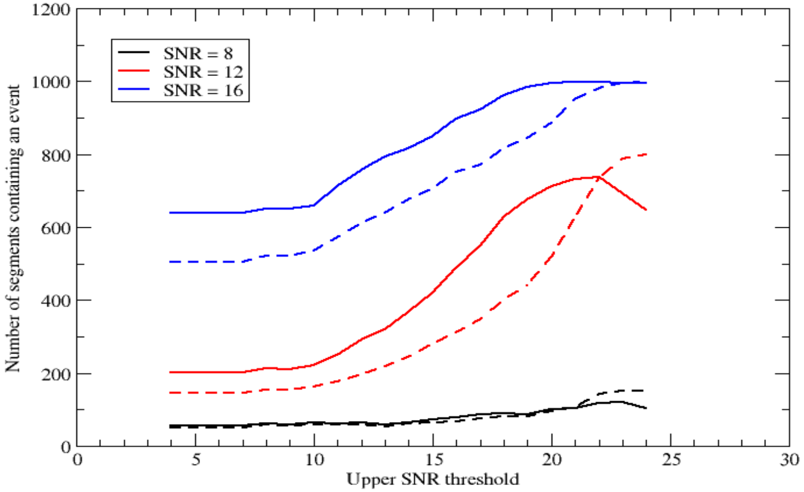
$(25\text{-}25)M_{Solar}$ Results



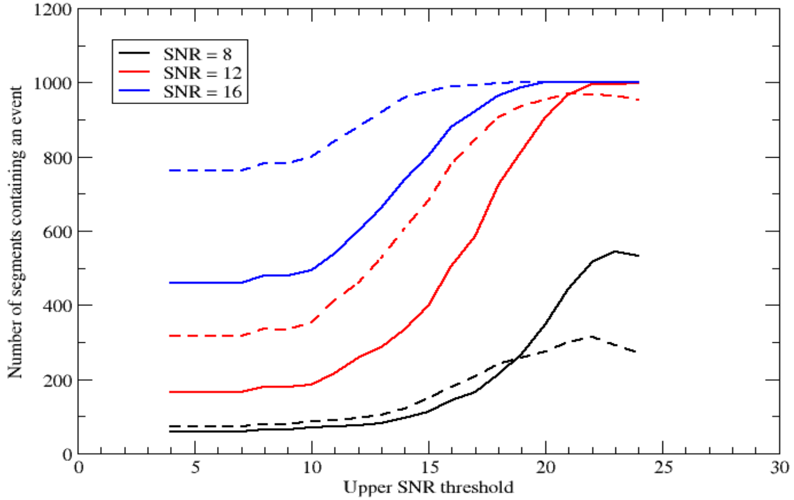
η_{upper}

(encodes corresponding $N_{threshold}$)

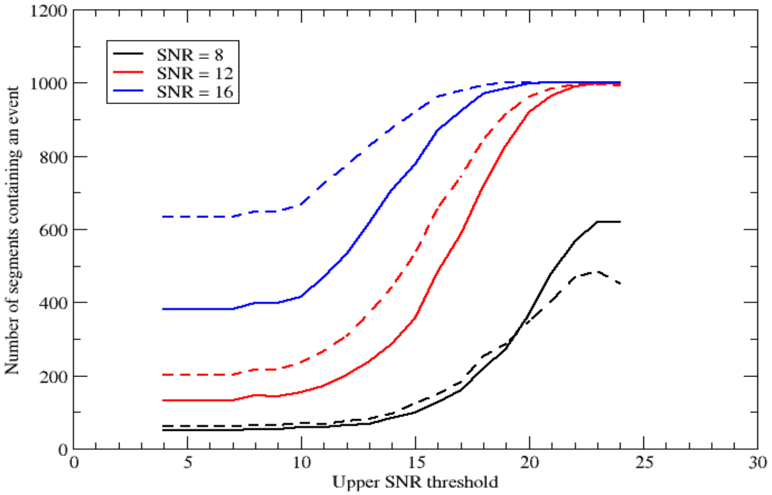
(1-49)M_{Solar}



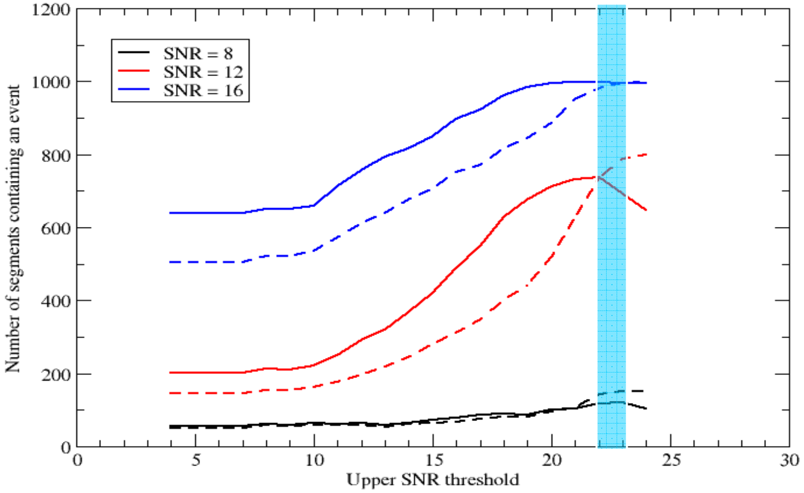
(10-40)M_{Solar}



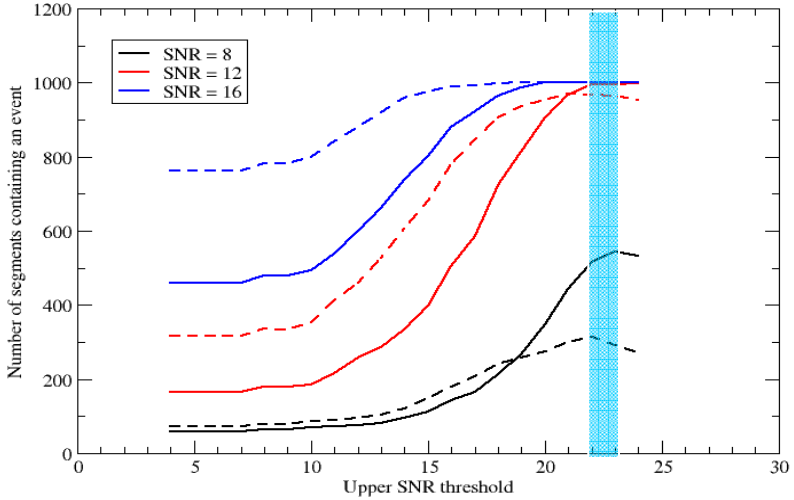
(25-25)M_{Solar}



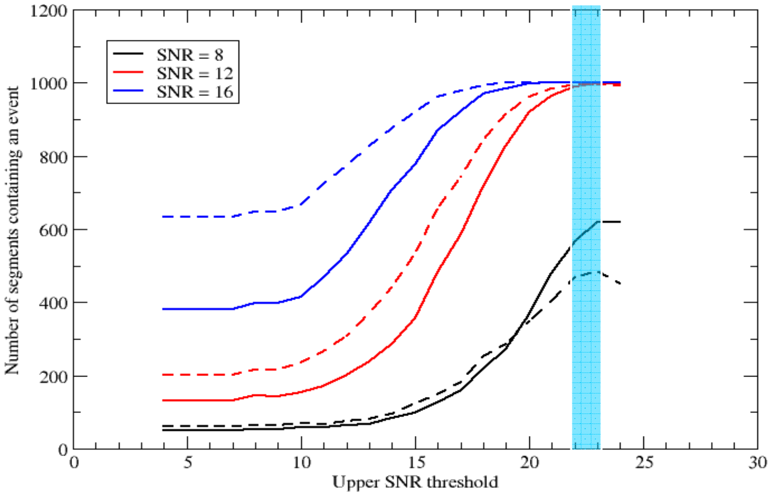
$(1\text{-}49)M_{Solar}$



$(10\text{-}40)M_{Solar}$



$(25\text{-}25)M_{Solar}$



$\eta_{upper} = 23$

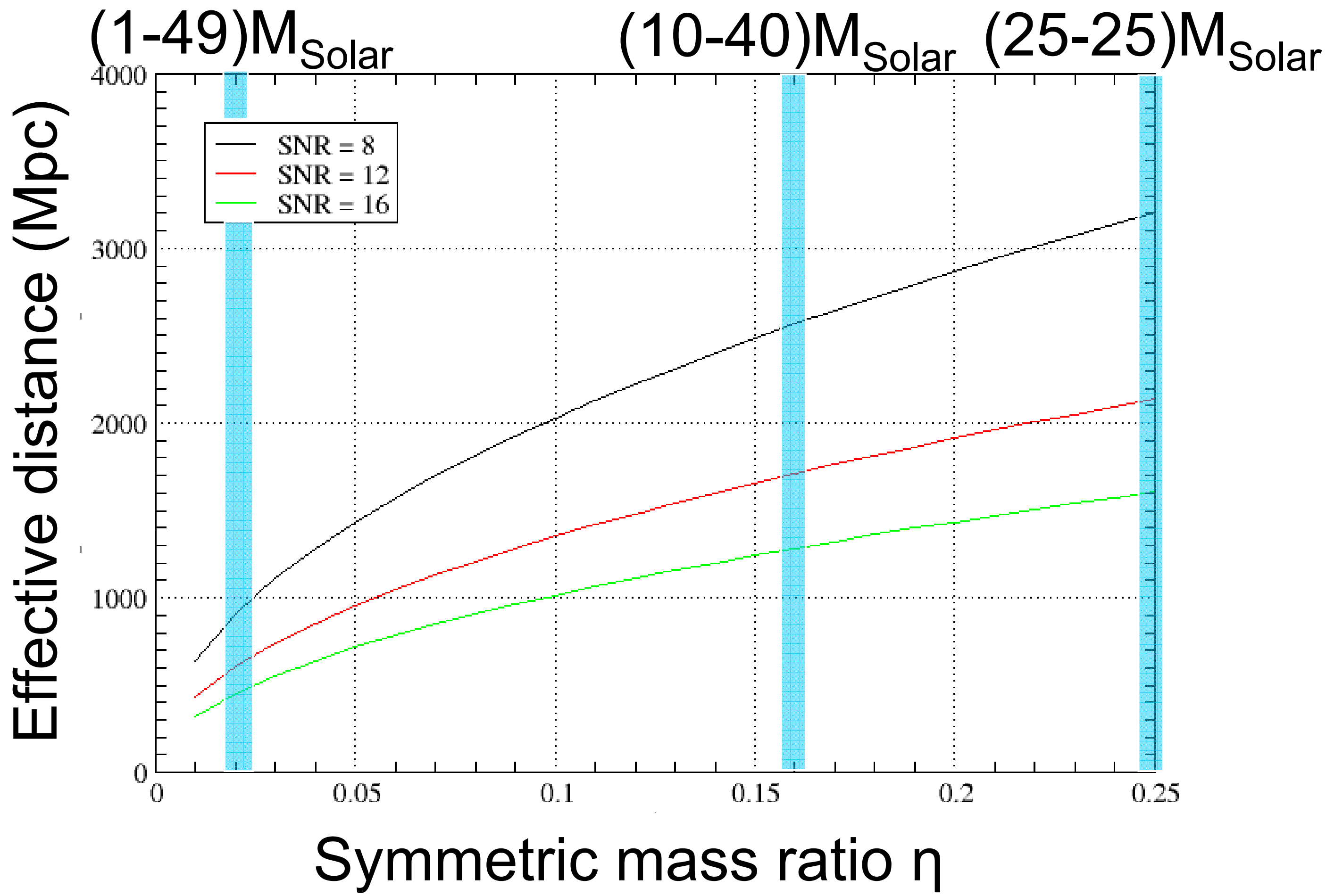
$N_{threshold} = 50$

Results and Conclusions

System	Effective distance (Mpc)		
	$\rho = 8$	$\rho = 12$	$\rho = 16$
(1-49)	898	599	**449**
(10-40)	2565	1710	1283
(25-25)	3207	**2138**	1603

- Near certain detection of all studied systems to eff. dist. ~449Mpc
- Near certain detection of (25-25)M_{Solar} binaries to eff. dist. ~2Gpc

Span of Adv. LIGO



Future Work

- Write up for PRD
- Power law pattern matching for potential event clusters
- Tune HACR for EMRI signals in LISA (with Jonathan Gair)
- Written AddSpectrogramMon for LISA++
  - Combining LISA channels