

What do GW150914 and GW151226 tell us about Extreme Gravity?

Kent Yagi
Princeton University

Testing Gravity 2017
Vancouver, Jan. 26th 2017

What do GW150914 and GW151226 tell us about Extreme Gravity? ~Testing Kerr Hypothesis~

Kent Yagi
Princeton University

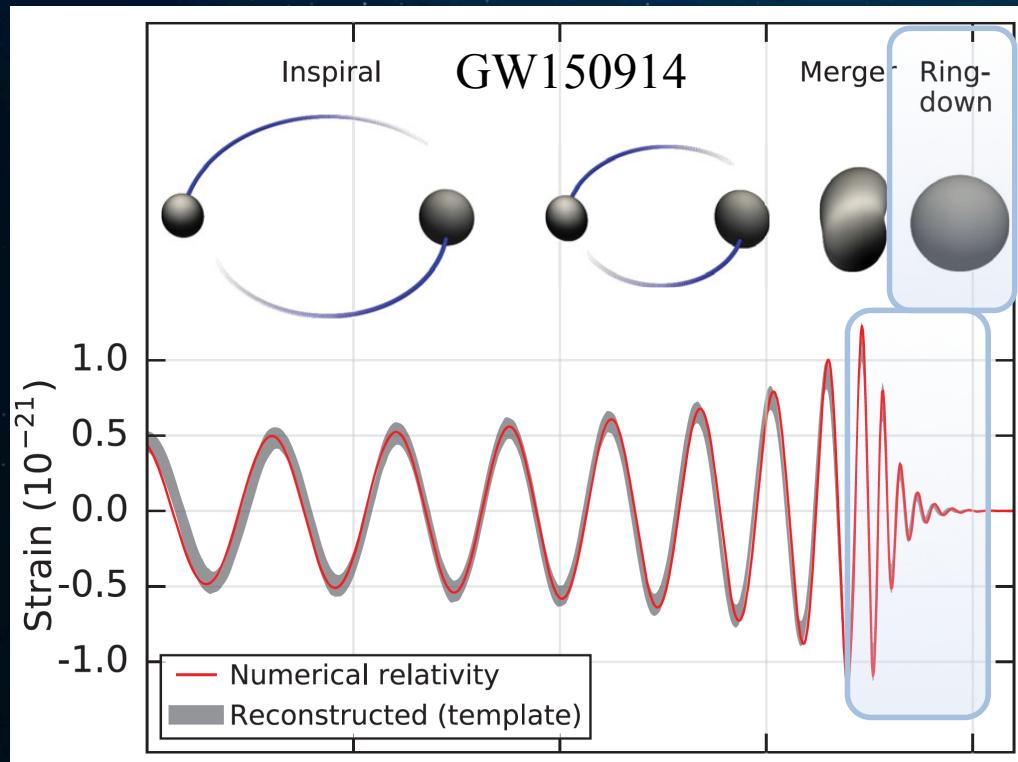
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Black Hole Spectroscopy

black hole **no-hair** property

ringdown frequency: $f_{\ell m}(M, \chi)$

damping time: $\tau_{\ell m}(M, \chi)$



[LVC (2016) GW150914 detection]

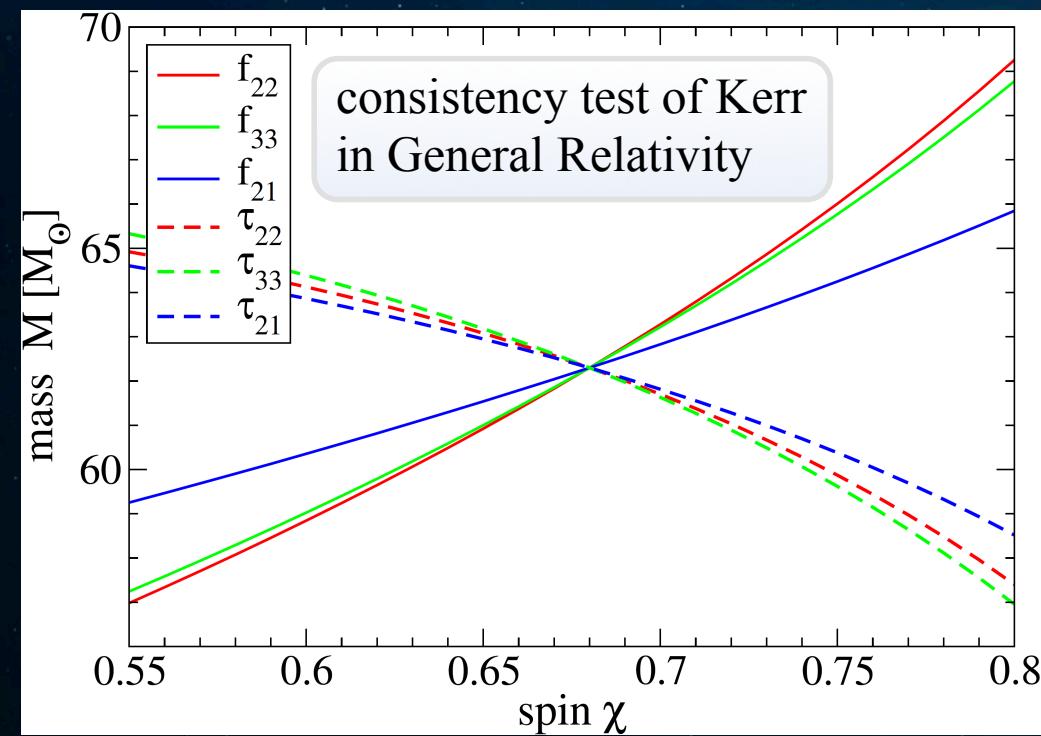
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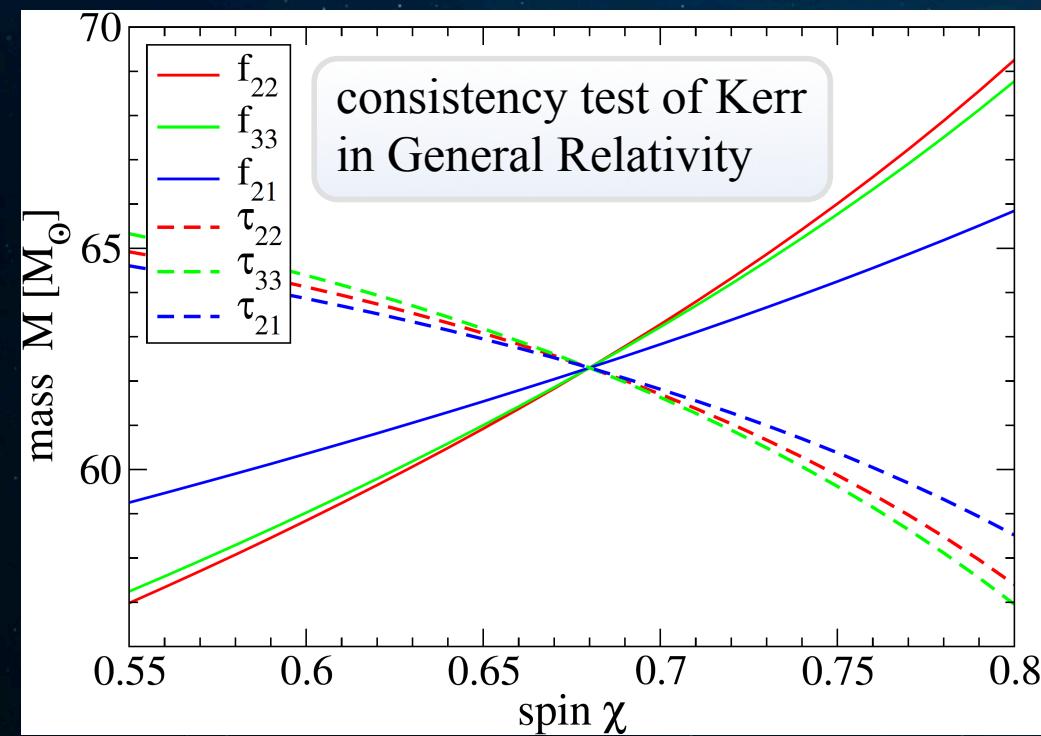


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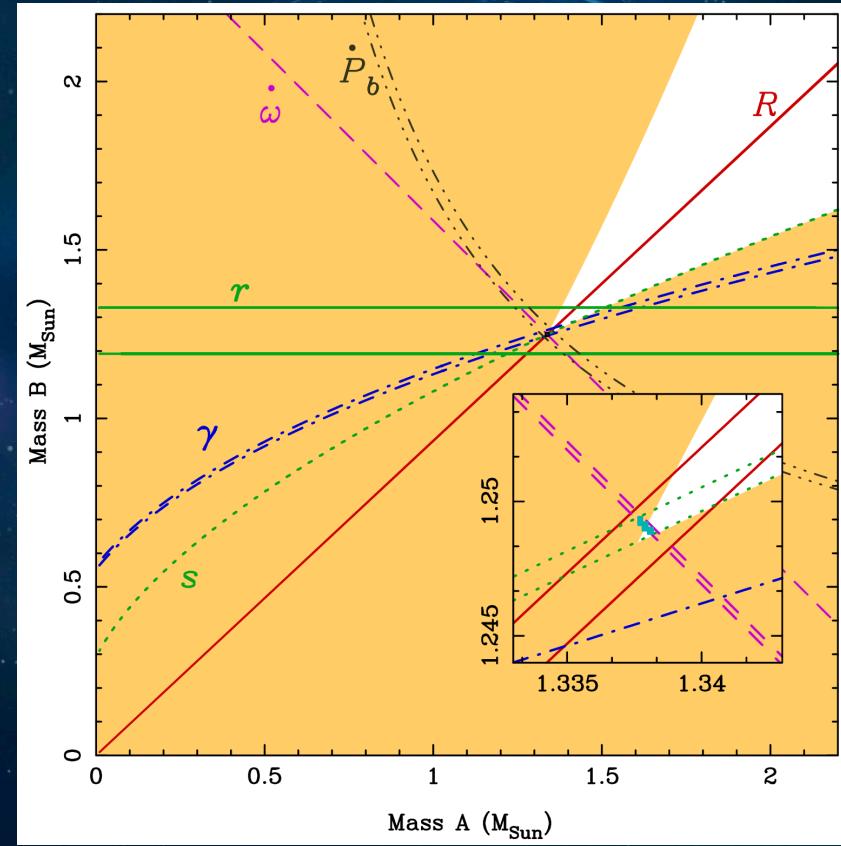
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Double Binary Pulsar

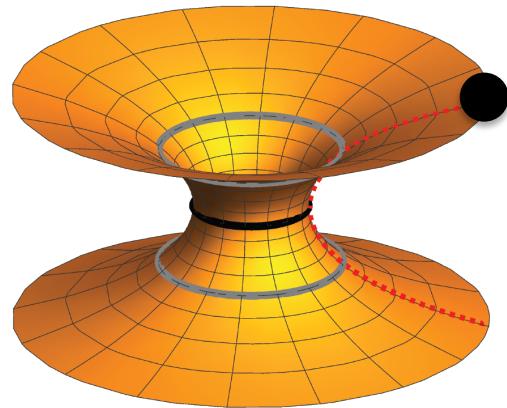


[Kramer & Wex (2009), Wex (2014)]

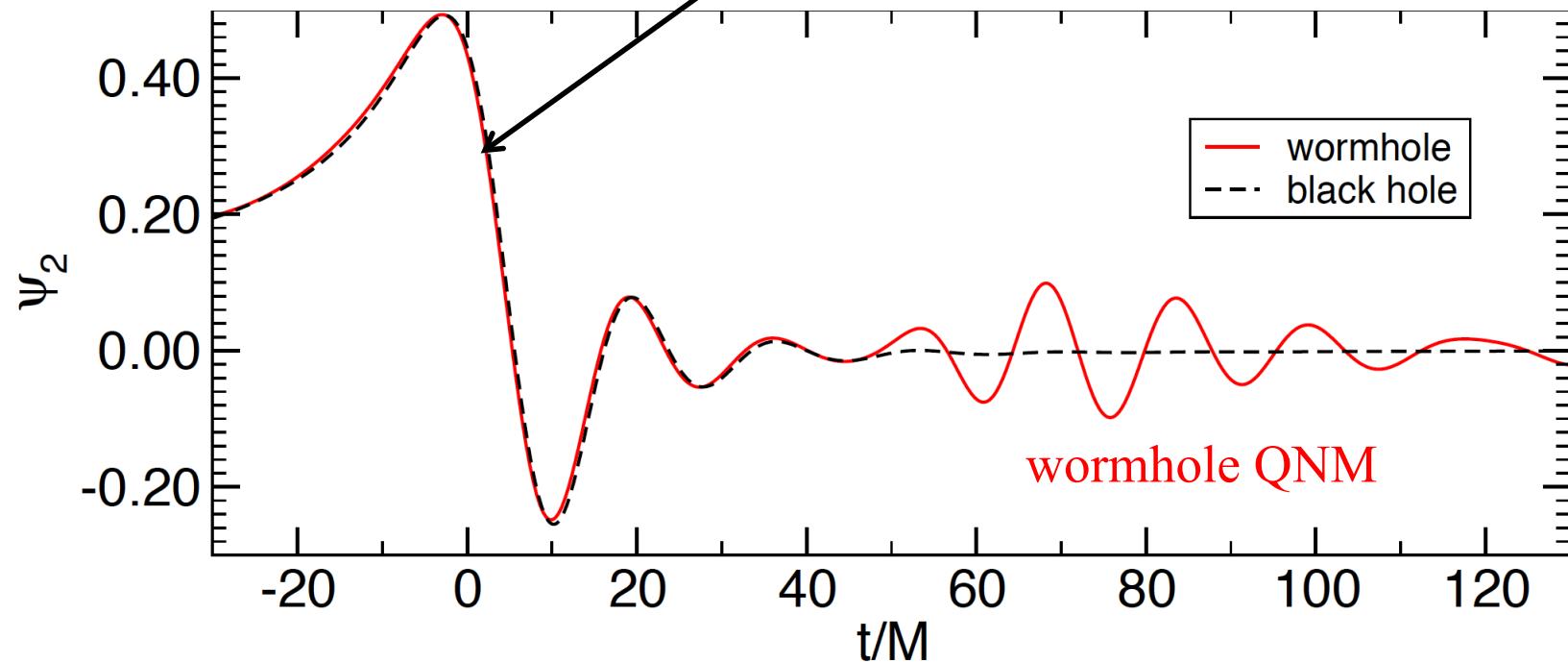
Secondary Modes & Exotic Objects

wormholes

[Cardoso et al. (2016)]



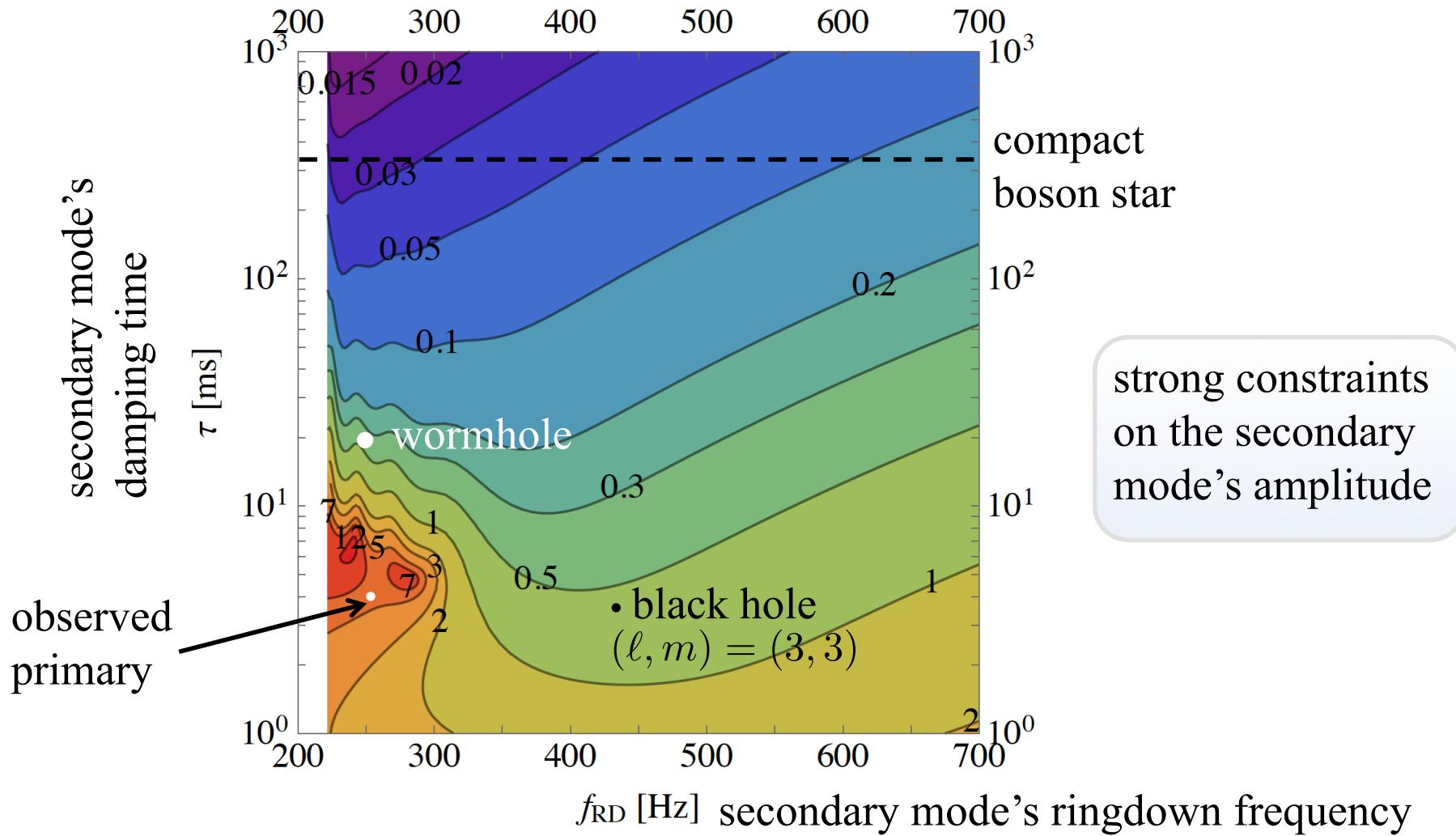
primary oscillation similar to
black hole **quasi-normal mode**
(QNM)



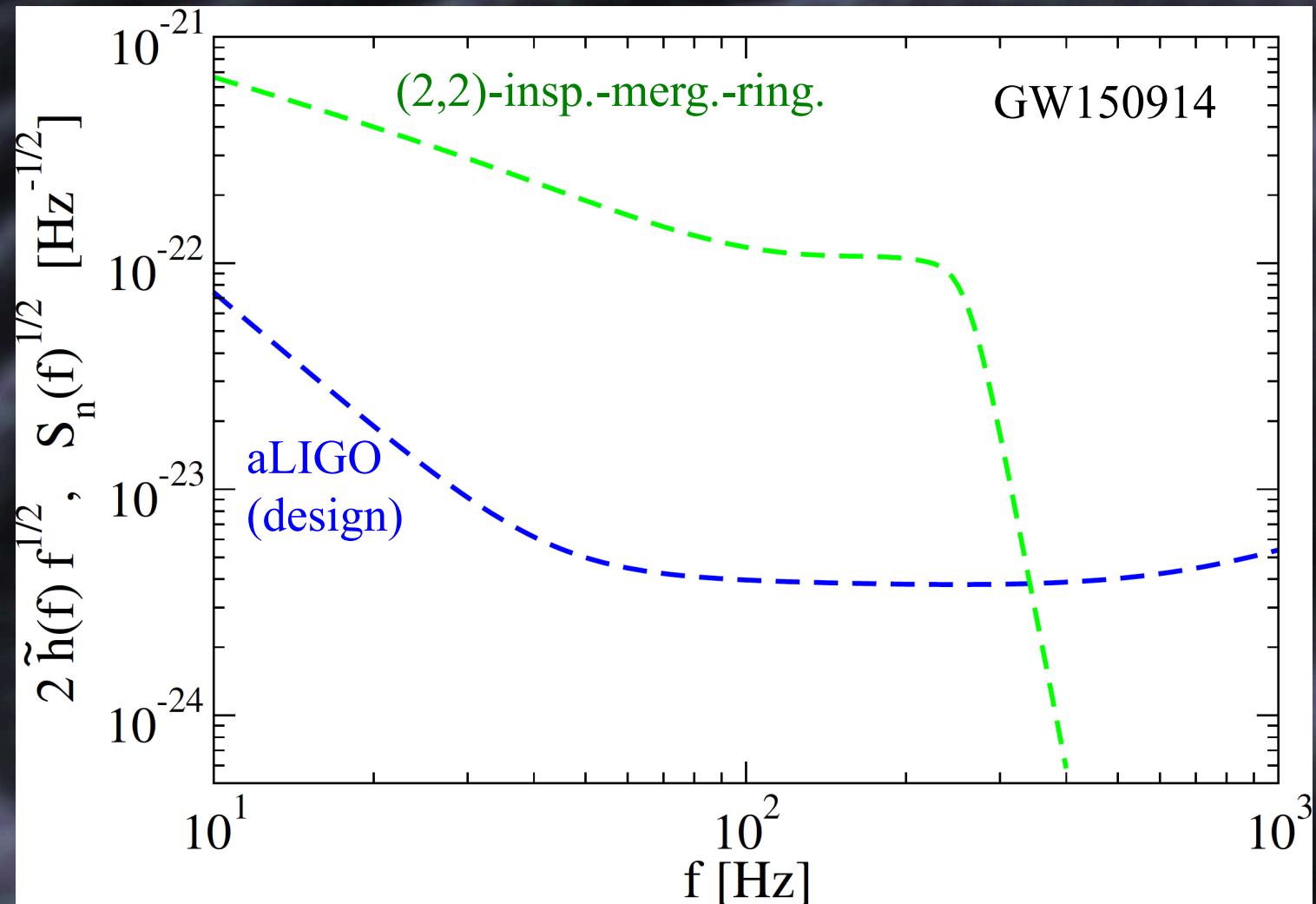
GW150914 Bounds on Secondary Modes

bounds on the secondary mode amplitude
relative to the observed primary one

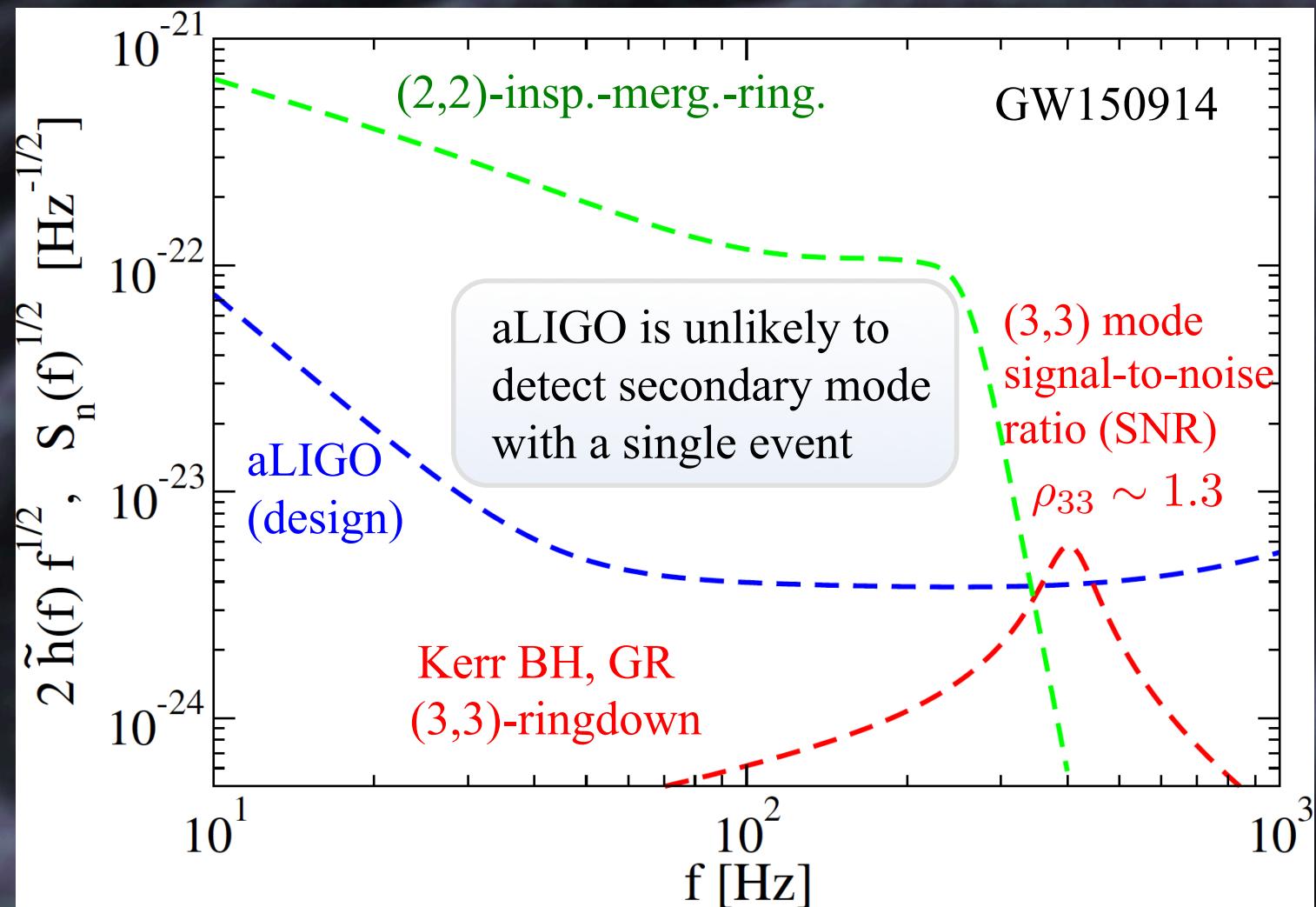
[Yunes, KY & Pretorius (2016)]



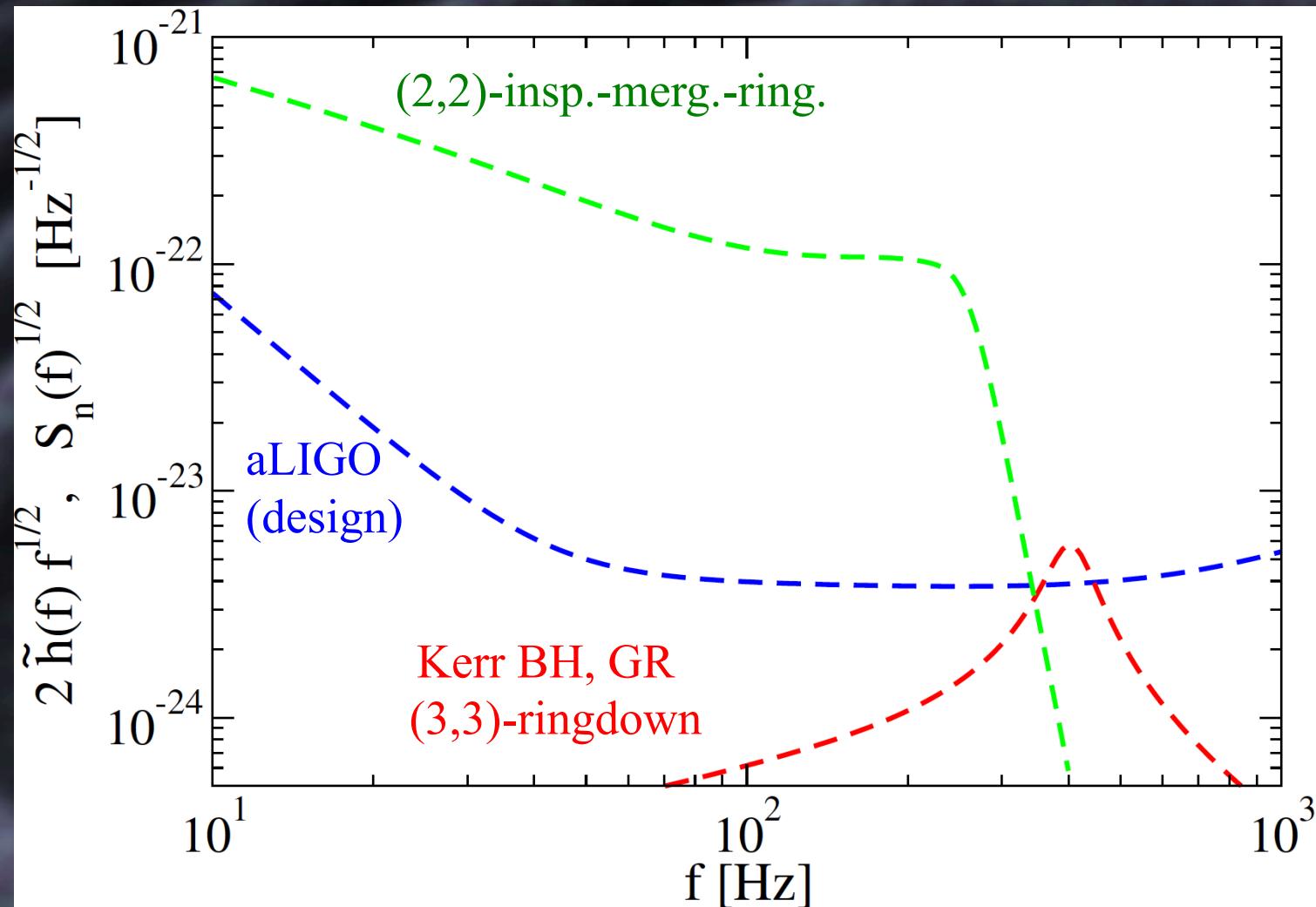
Will we detect BH secondary mode with aLIGO?



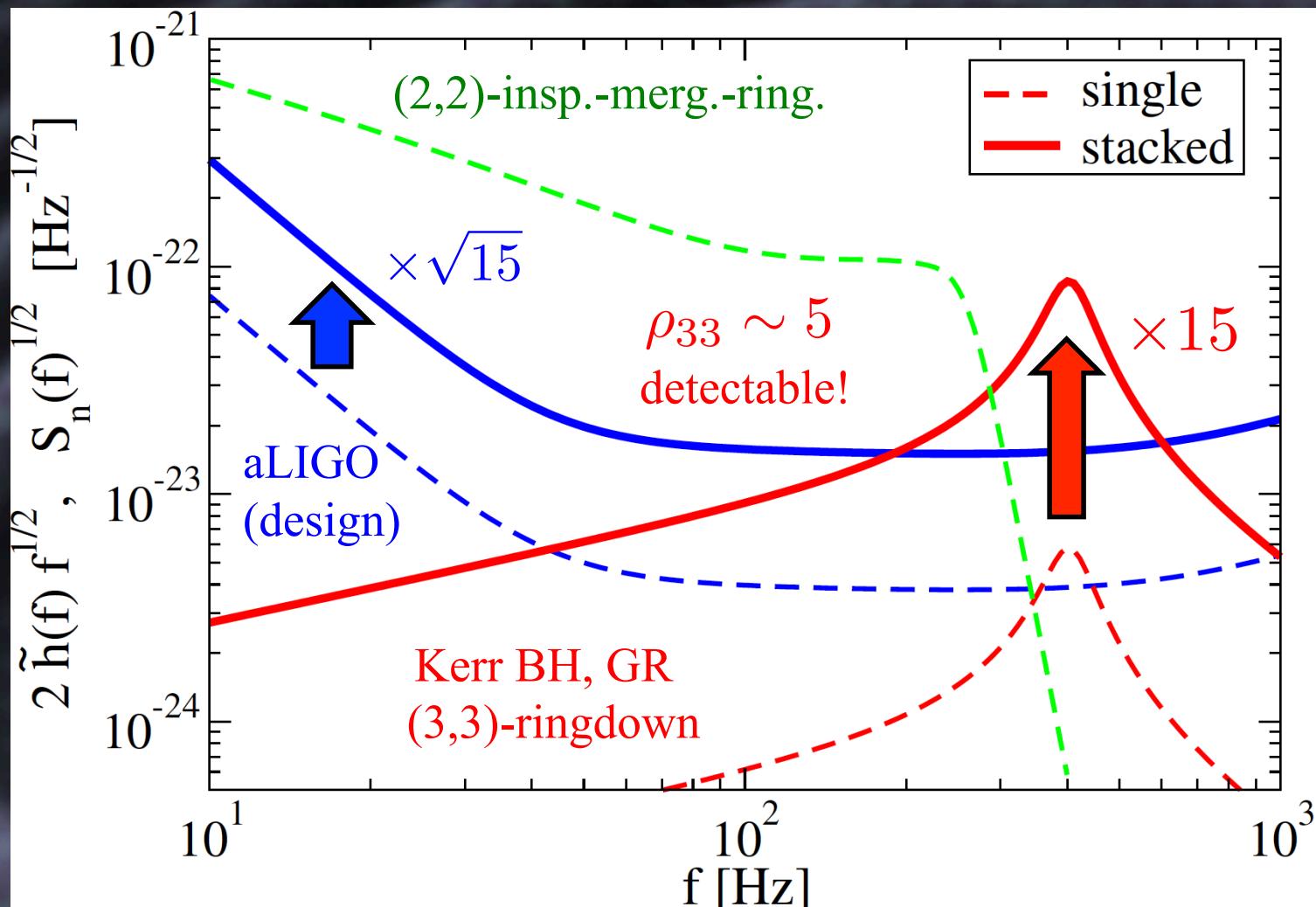
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Stacking 15 Identical Events



Stacking 15 Identical Events



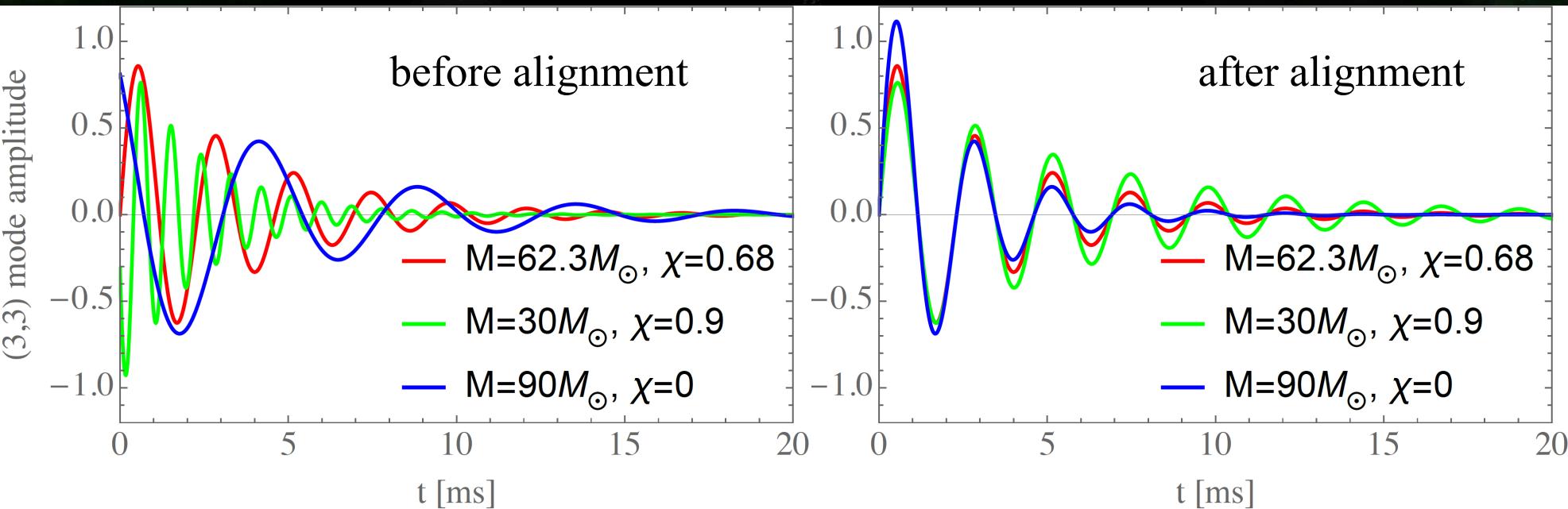
coherent mode stacking



\sqrt{N} improvement in SNR

Coherent Mode Stacking

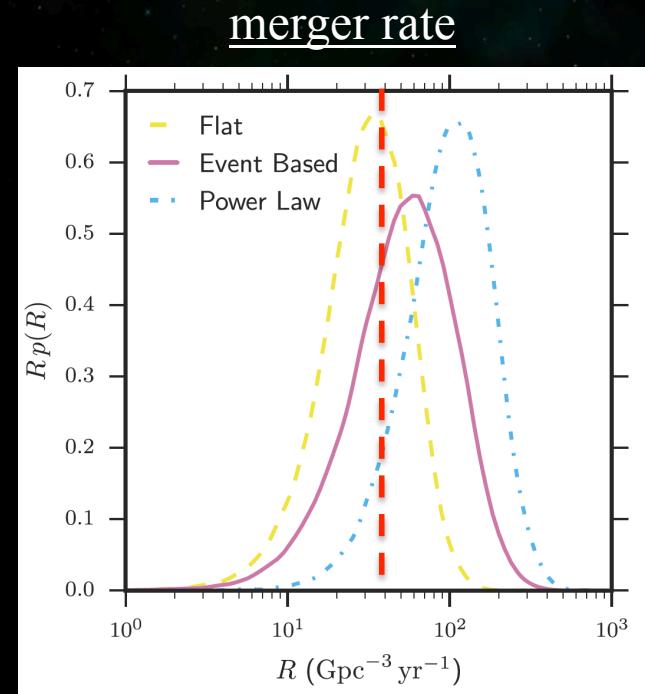
- Events **not identical** in reality
- Need to **align** the waveform phase by **scaling/shifting** in time
- Use the **dominant** mode information (including inspiral) to predict the secondary mode of each event assuming the remnant is a Kerr black hole in General Relativity



Monte Carlo Simulations

[Yang, KY, Blackman, Lehner, Pretorius, Paschalidis, Yunes (2017)]

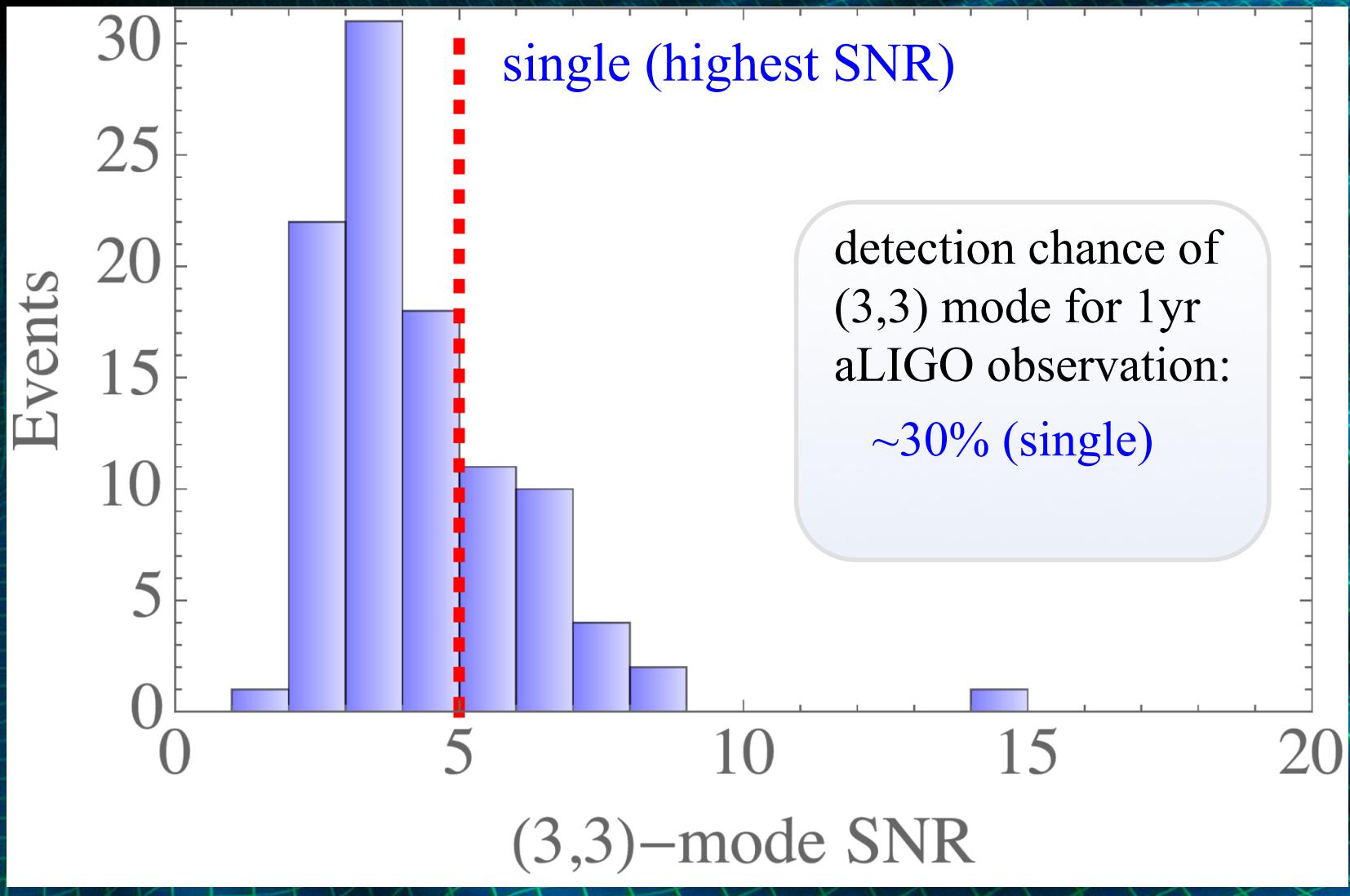
- initial mass: uniform in $[10, 50] M_{\odot}$
- initial spin: 0
- merger rate: $40 \text{ Gpc}^{-3} \text{ yr}^{-1}$
- observation time: 1yr
- # of runs: 100
- slight **reduction** in signal-to-noise ratio due to
 - incomplete alignment due to parameter uncertainties
 - subtraction residual of the dominant mode



[LVC (2016) BBH O1]

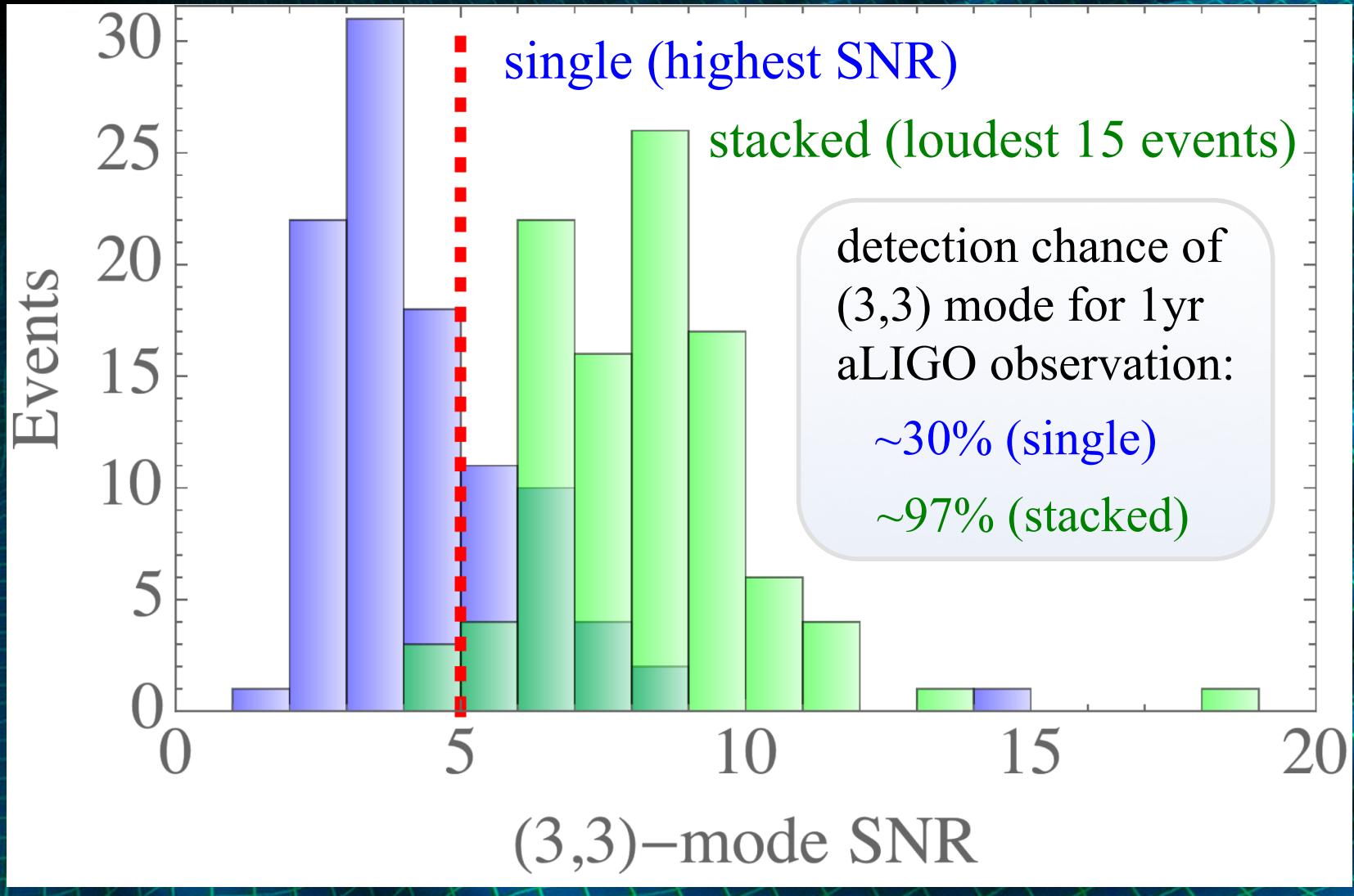
Single vs Stacking

[Yang, KY, Blackman, Lehner,
Pretorius, Paschalidis, Yunes (2017)]

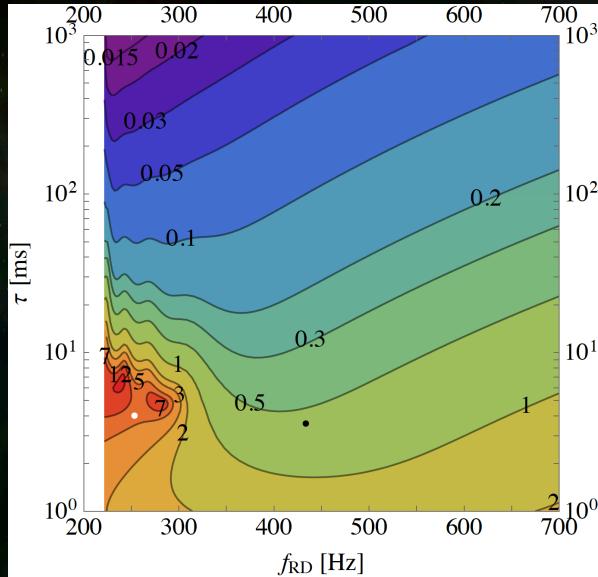


Single vs Stacking

[Yang, KY, Blackman, Lehner,
Pretorius, Paschalidis, Yunes (2017)]



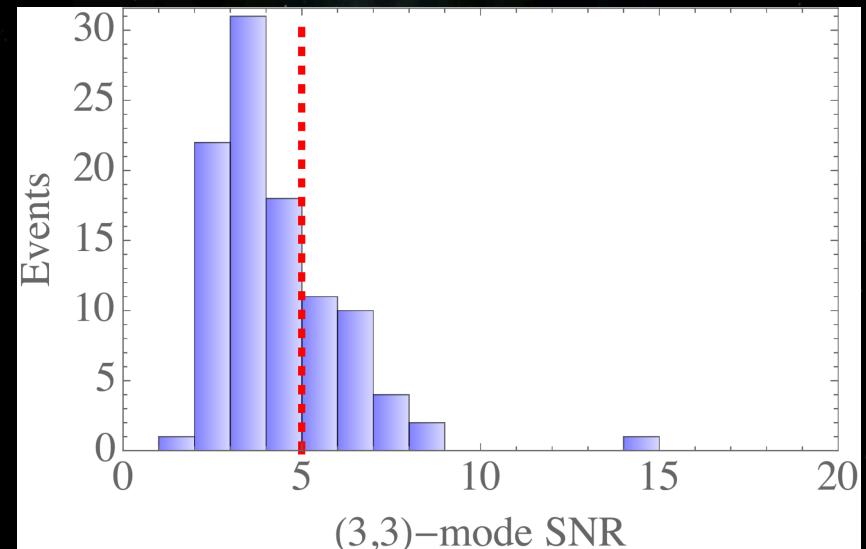
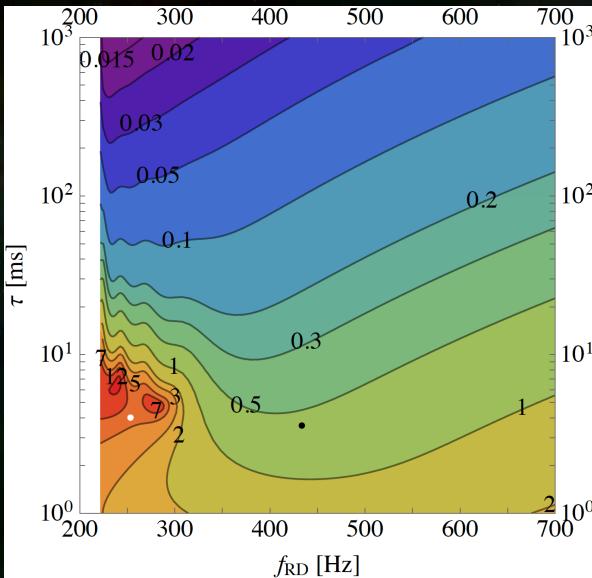
Takeaway



Single Event

- small secondary mode amplitude with GW150914

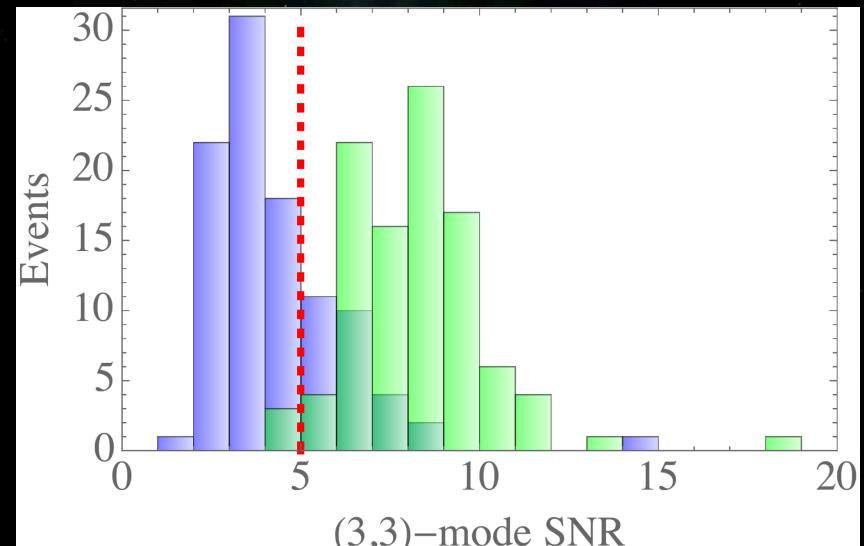
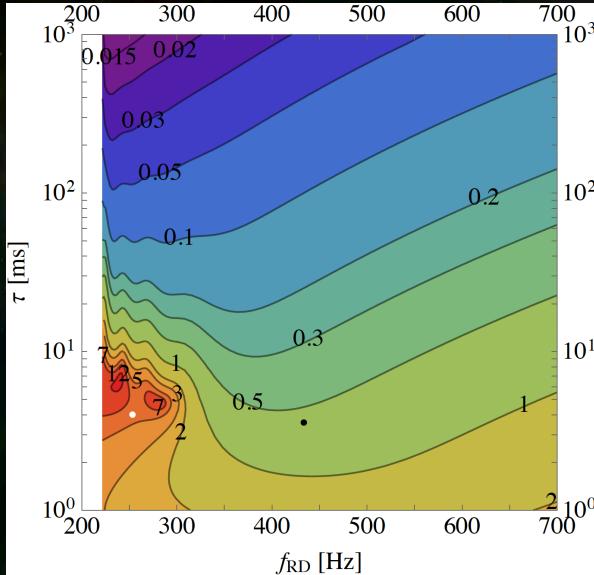
Takeaway



Single Event

- small secondary mode amplitude with GW150914
- aLIGO **unlikely** to detect secondary mode

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Single Event

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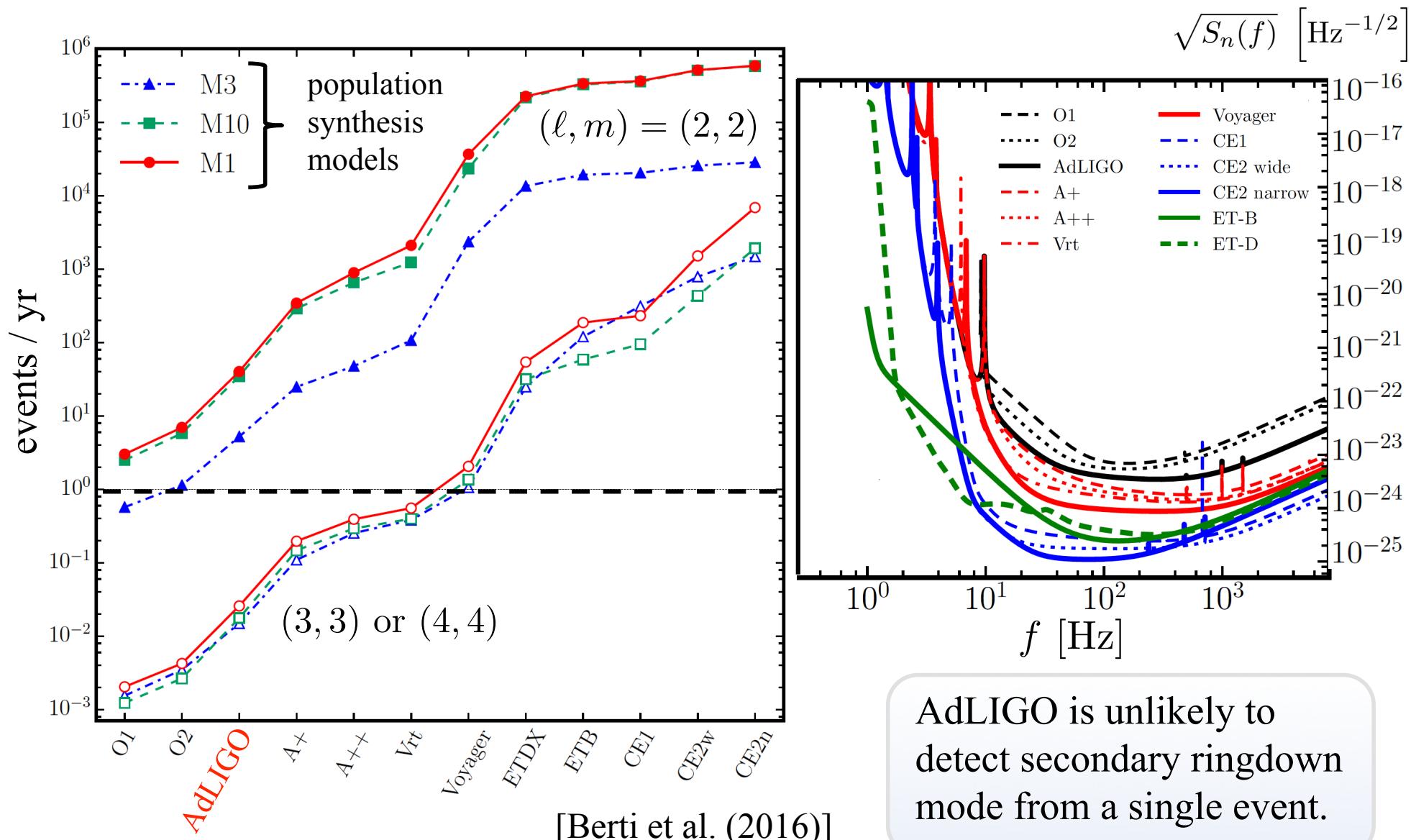
Coherent Mode Stacking

- aLIGO **likely** to detect secondary mode

THANK YOU!!

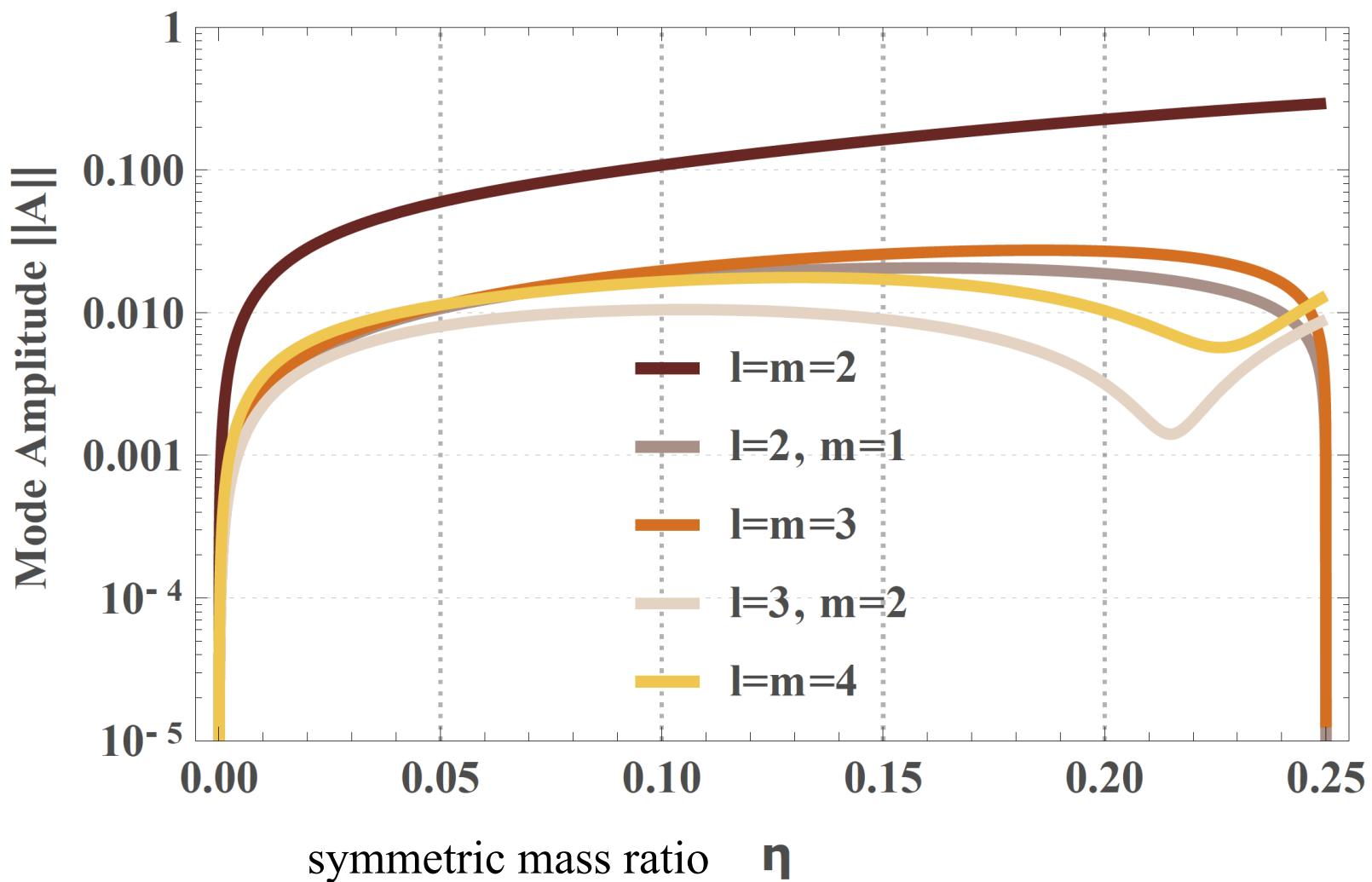
Back Up

When will we detect the secondary mode?

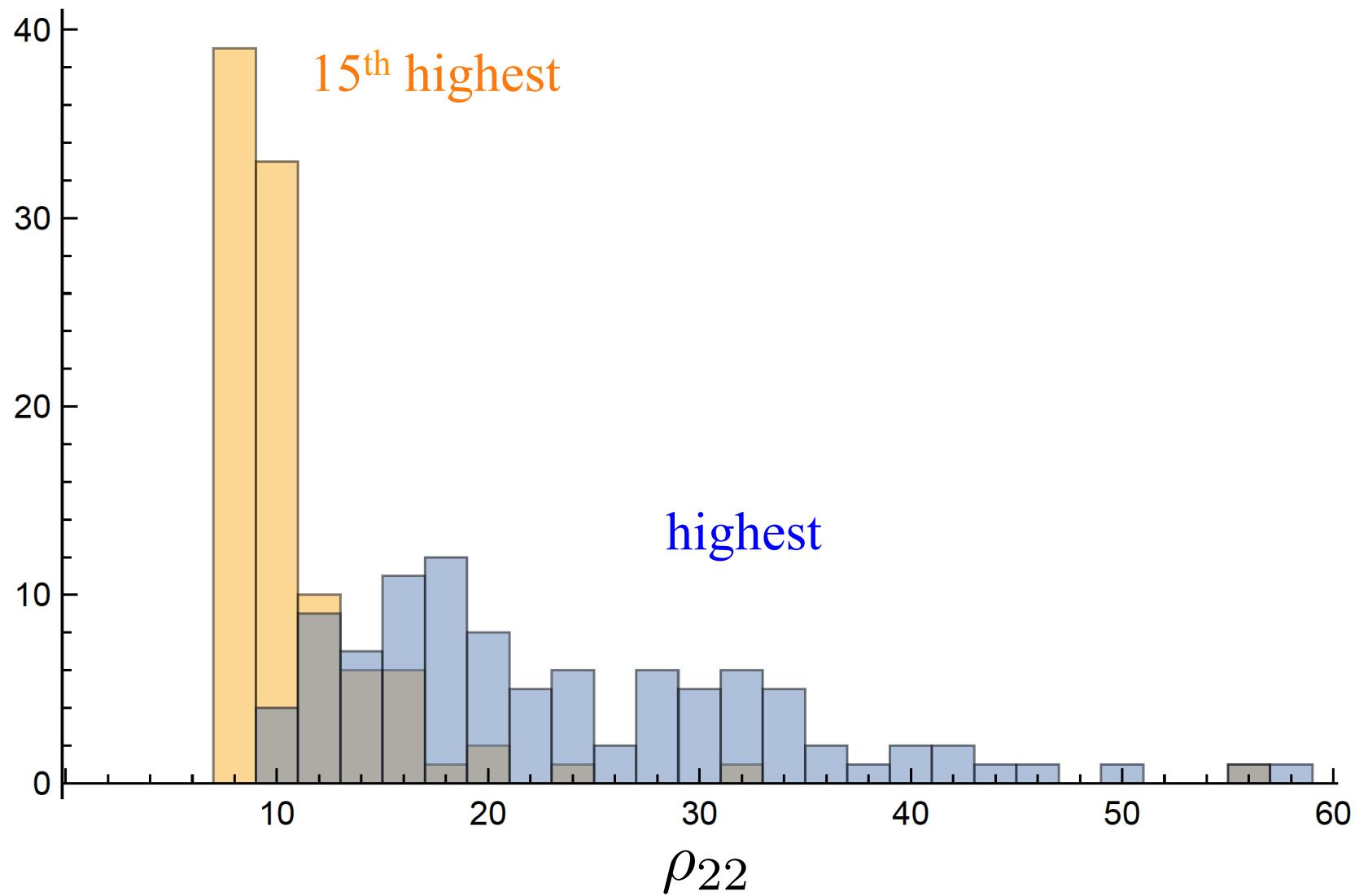


Ringdown Mode Amplitude

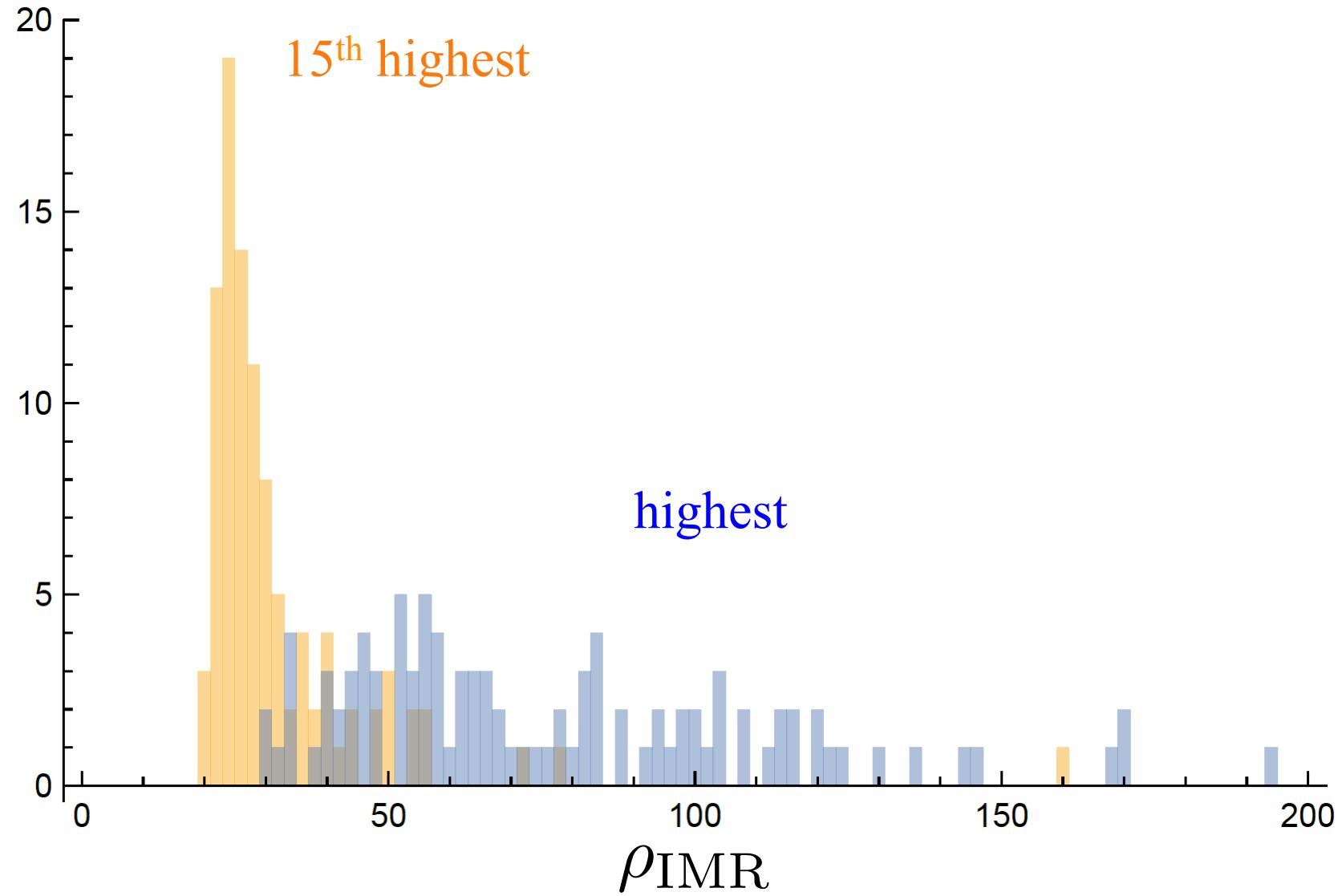
[Bhagwat et al. (2016)]



(2,2) SNR Distribution



total SNR Distribution

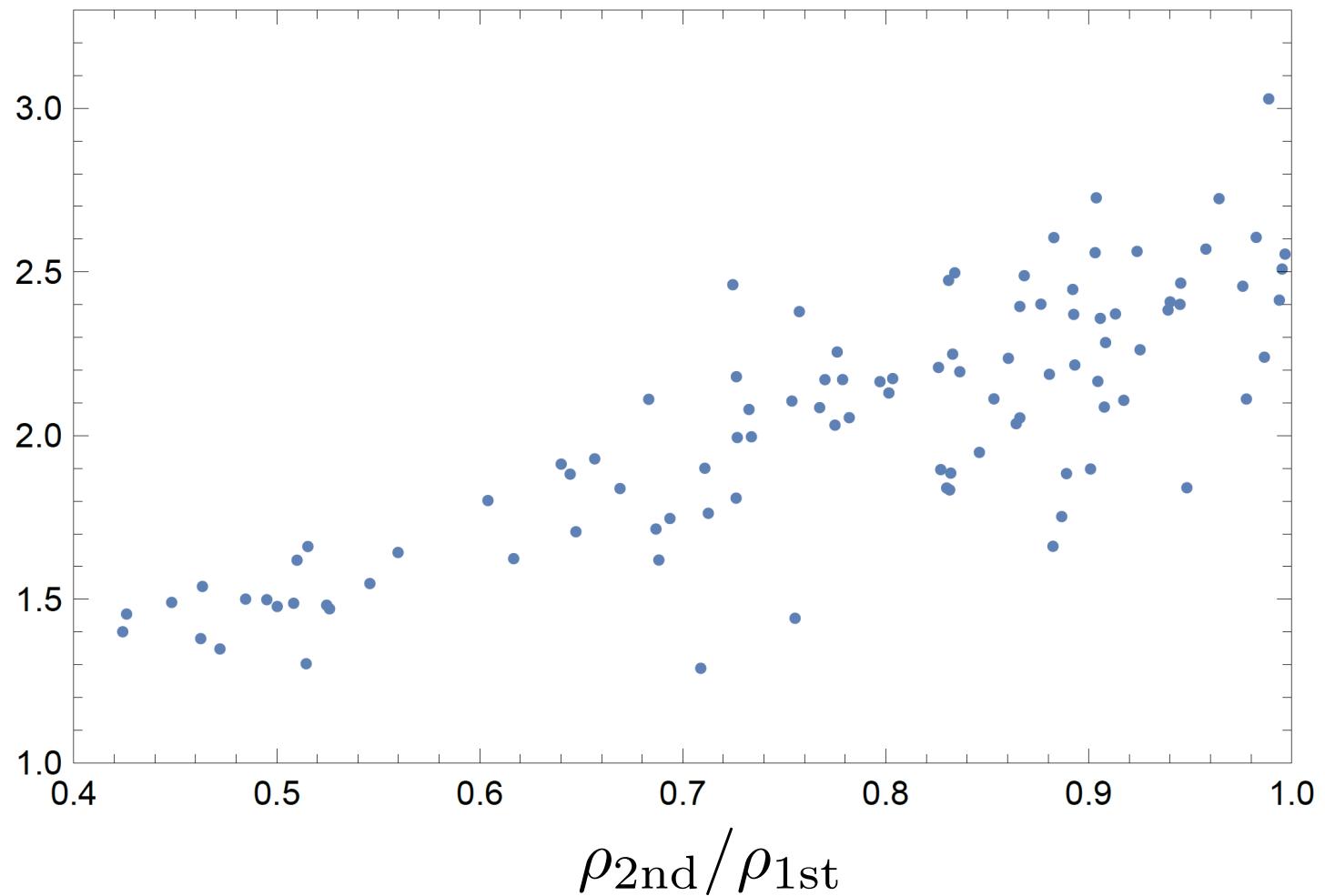


SNR Improvement via Stacking

$$\sqrt{15} \sim 3.9$$

[Yang, KY et al. (2017)]

$\rho_{\text{stack}}/\rho_{\text{1st}}$



Phase Uncertainties

[Yang, KY et al. (2017)]

