WASHINGTON STATE UNIVERSITY

Estimating the parameters of coalescing black hole binaries

(non-spinning) using ground-based detectors

Sukanta Bose

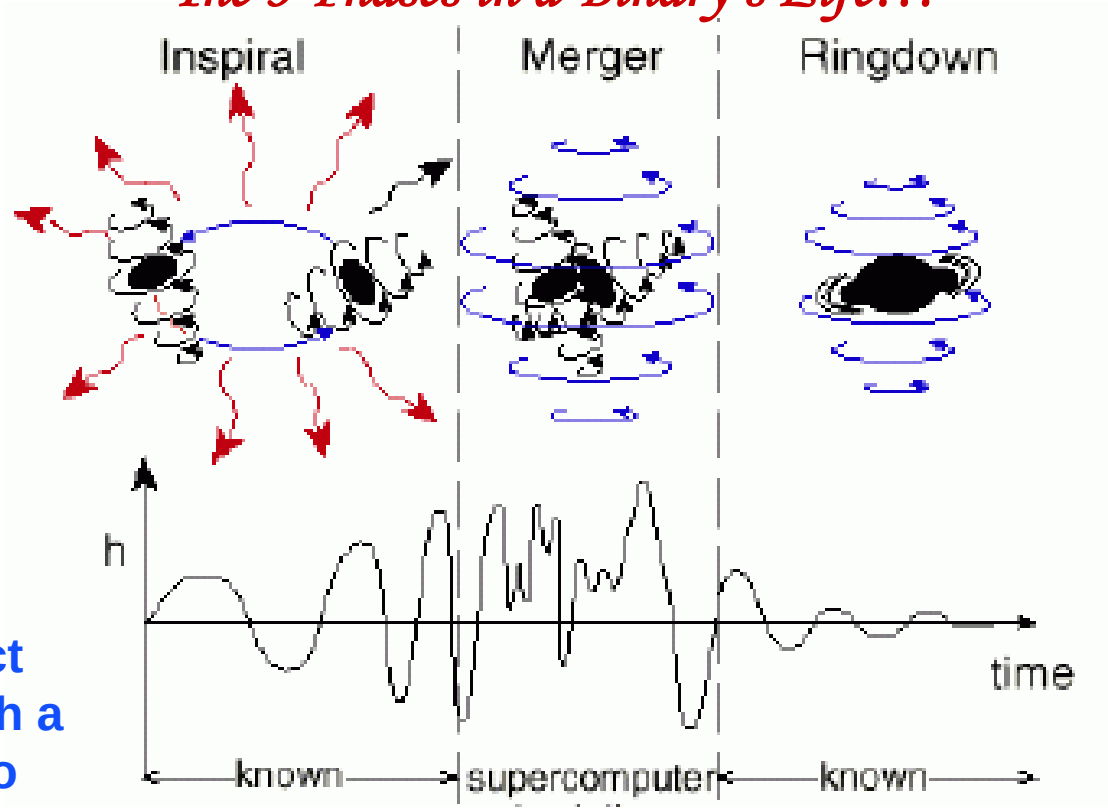
Washington State University, Pullman

In collaboration with P. Ajith (Caltech/AEI)

Based on a paper by Ajith, SB, Phys. Rev. D 79, 084032 (2009), **arXiv:0901.4936.**
(Supported in part by NSF grants PHY-0239735 & PHY-0758172)

Coalescing binary signals in earth-based detectors

The 3 Phases in a Binary's Life…

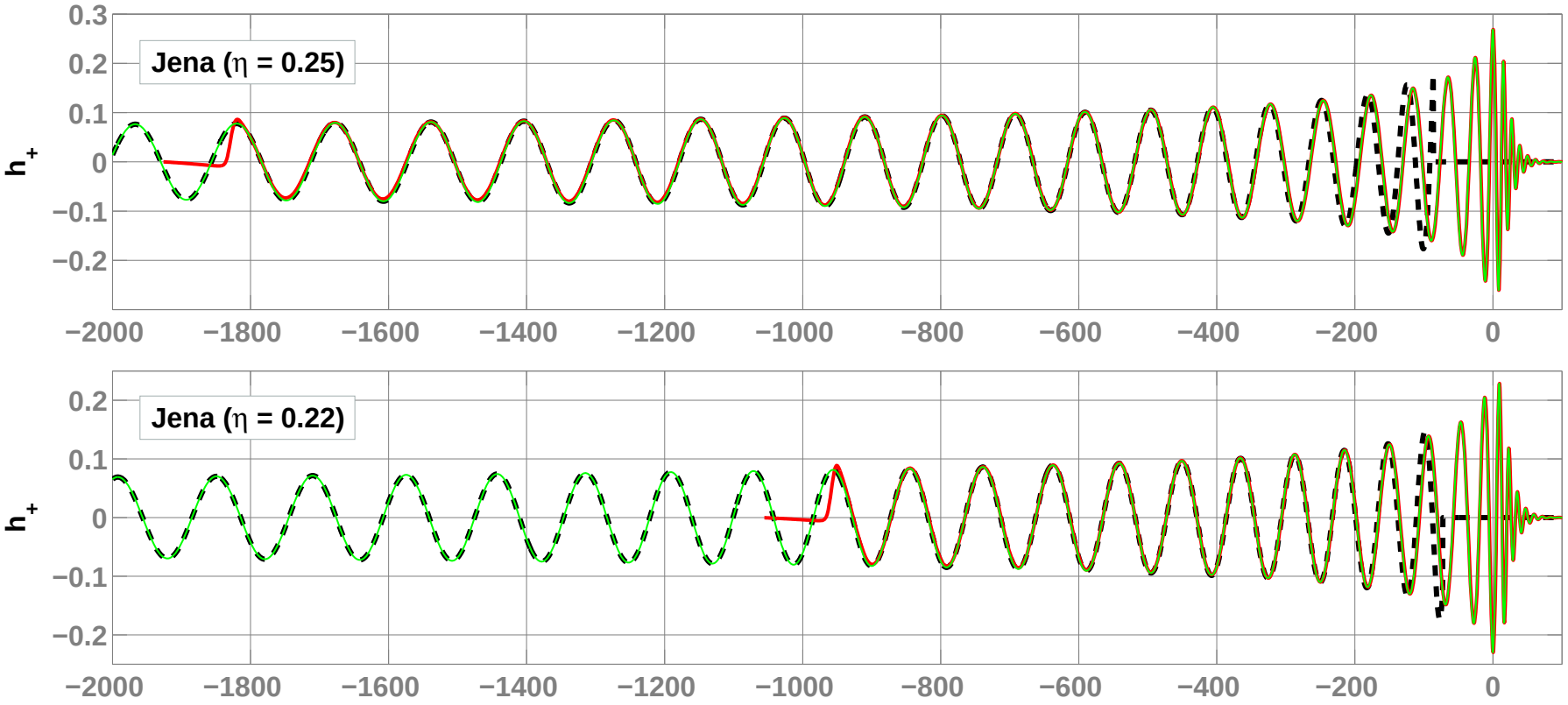


AdLIGO can detect these sources with a total mass of up to several hundred solar masses.

…lasting up to several minutes

[Figure: Courtesy of Kip Thorne]

NR-based hybrid waveforms



[P. Ajith et al, PRD '08]

WASHINGTON STATE UNIVERSITY

Astrophysical reach

- Effects of waveform extensions (data analysis):
  - Better template match,
    - Lower false-alarms / background,
      - Greater signal-to-noise ratio (SNR).
- Event rates & source “variety”: Both will increase
- Parameter estimation:
  - Can we determine both component masses?
  - Any improvements in measuring sky-localization, wave polarization, and distance?
- Provide impetus for other studies: Do IMBHs really exist? Can such binaries have electromagnetic counterparts?

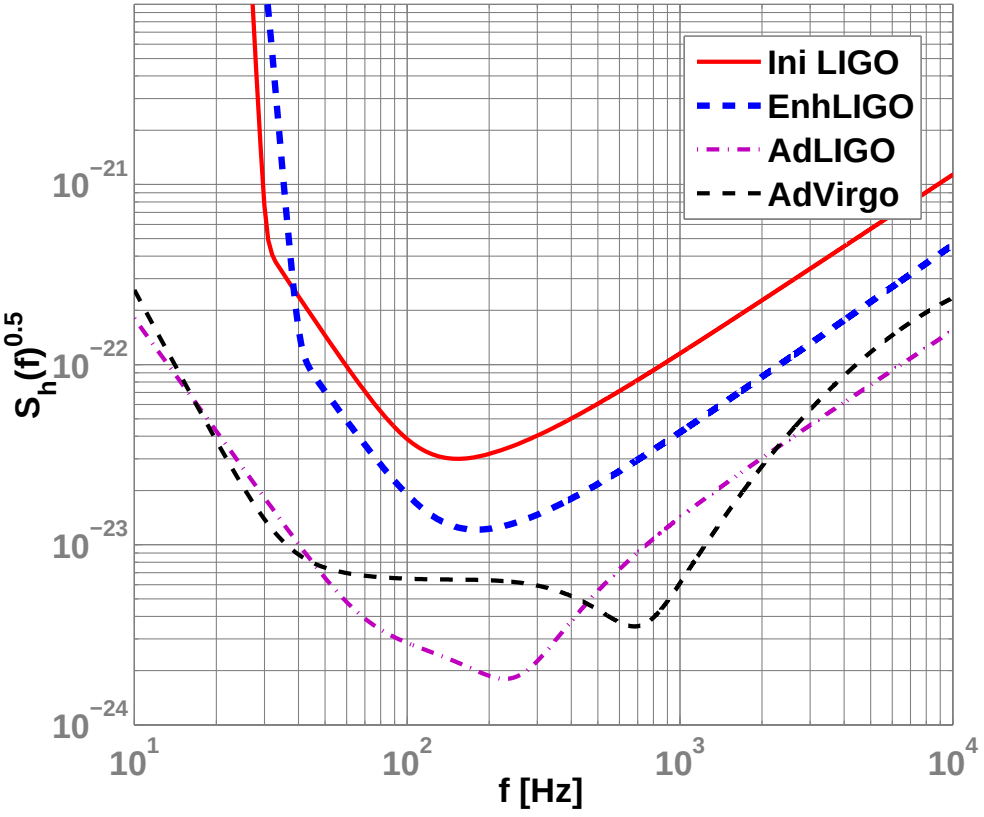
Rate estimates

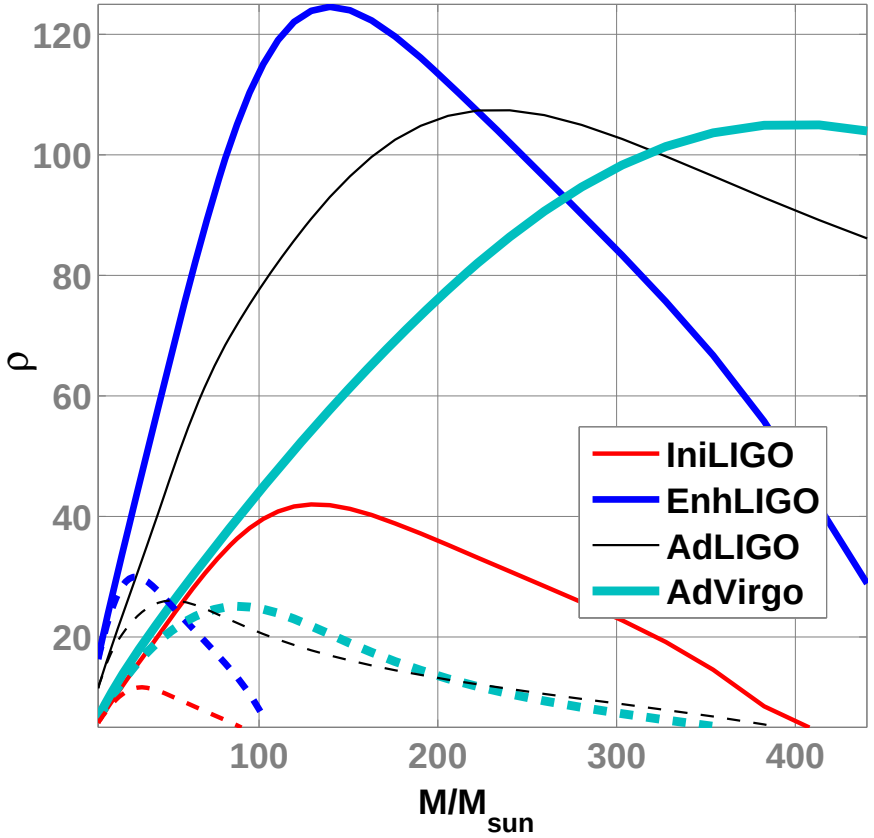
- Radio observations confirm existence of neutron star binaries:
  - » Hulse-Taylor pulsar
  - » J0737-3039 (both neutron stars are visible as pulsars)

- Stellar population modelers estimate an upper bound on BNS rates of ~ 1 in a few to several years @ LIGO-I sensitivity

- Rates for black hole binary coalescences much more uncertain
  - » Population synthesis studies suggest a likely rate of around 0.01 / 0.1 / 30 per year in LIGO-I / eLIGO / AdLIGO for stellar mass BBHs *[O'Shaughnessy et al., Astrophys. J. 633, 1076 (2005), astro-ph/0504479]*
  - » IMBH binaries: the plausible rates for LIGOI / AdLIGO detectors are 10−4 / 0.1 per year *[J. M. Fregeau et al., ibid. 646, L135 (2006), astro-ph/0605732]*
  - » Stellar-mass BHs merging with IMBHs (the so called intermediate-mass-ratio inspirals): plausible event rates for LIGOI / AdLIGO are 10−3 / 10 per year *[I. Mandel et al., arXiv:0705.0285.]*

Noise PSDs & SNRs



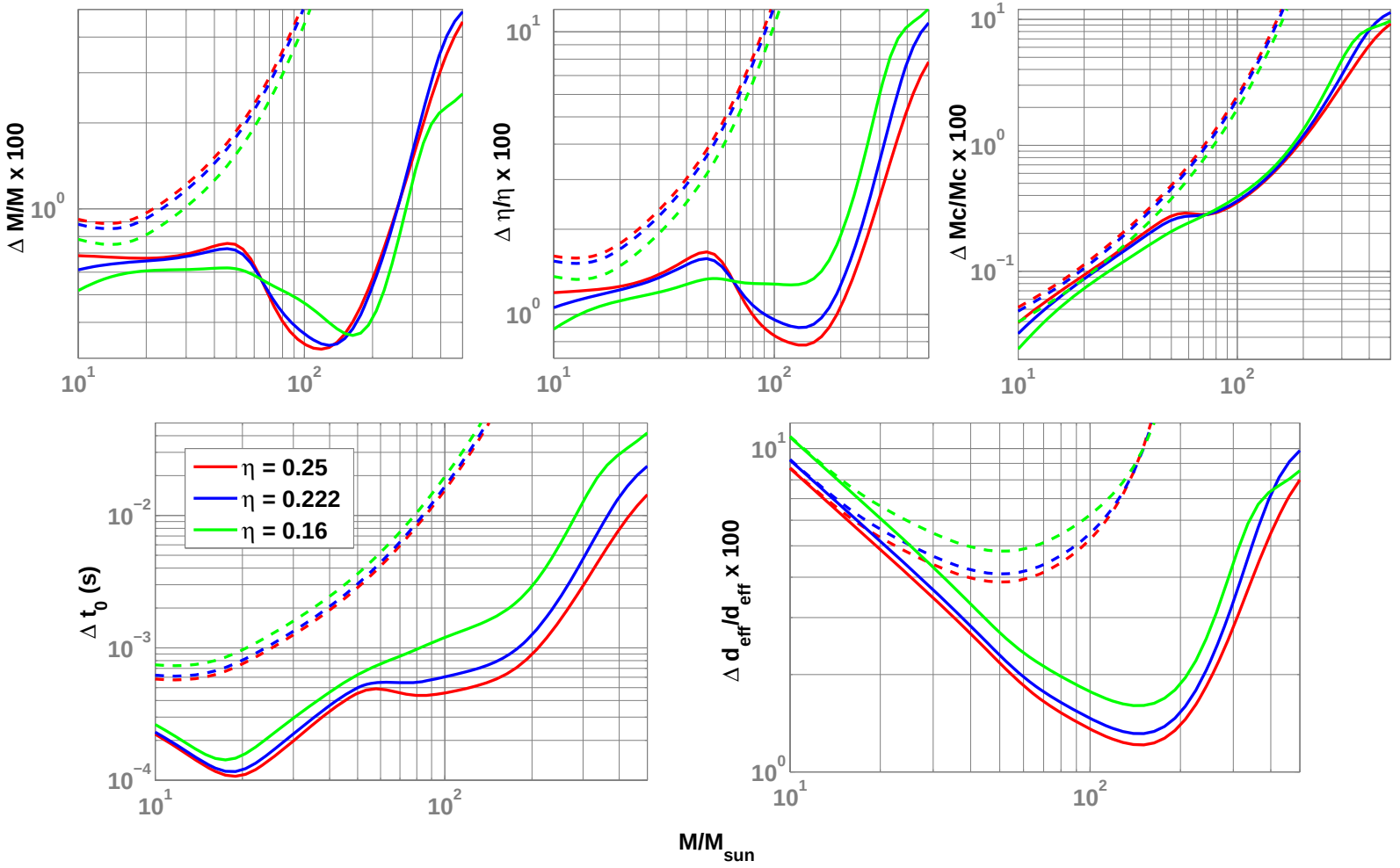


Bose, APS-Denver, 2008/05/04

The source effective distance is taken to be 100Mpc, except for AdLIGO and AdVirgo, where it is taken as 1Gpc.

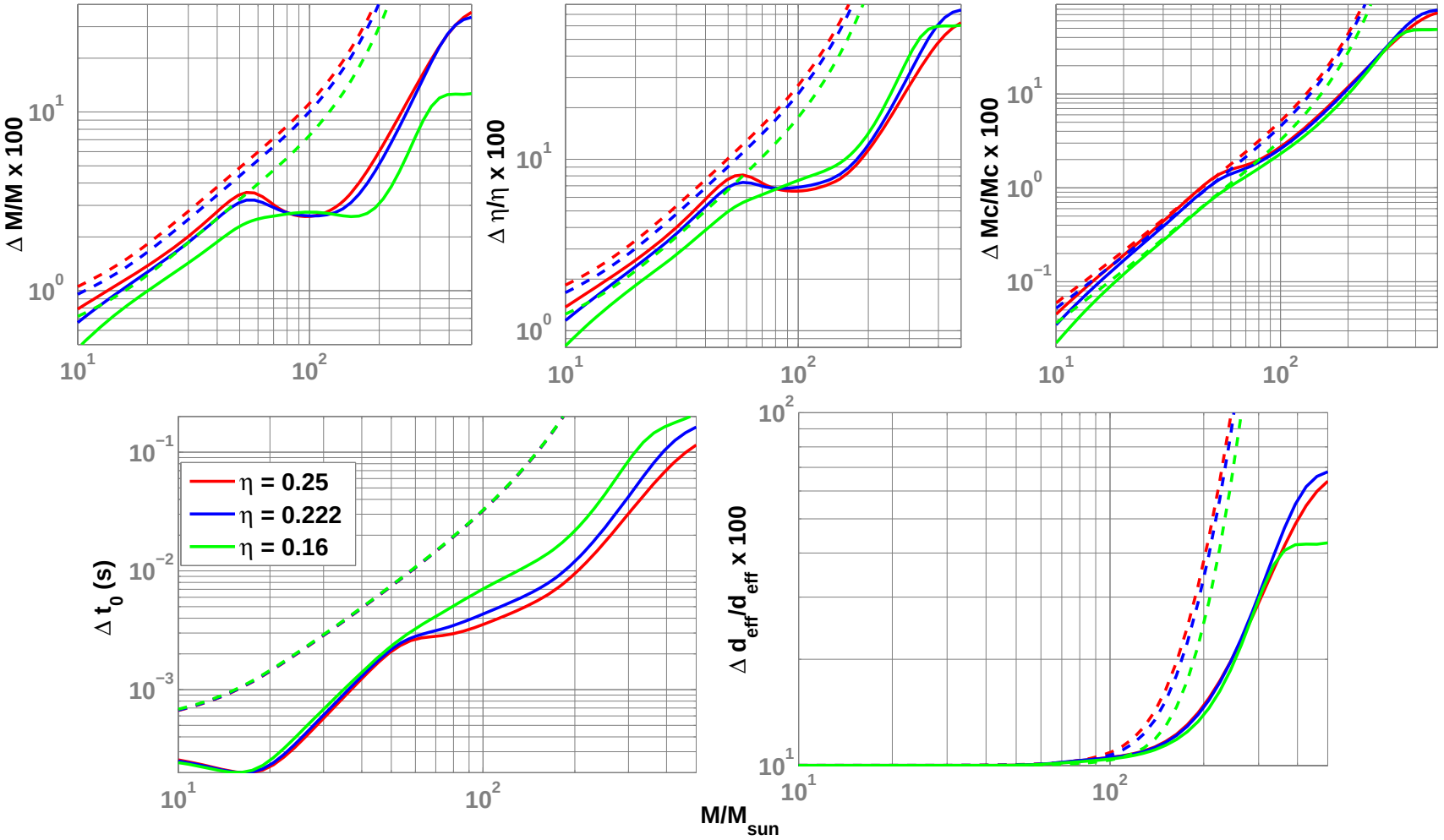
Single IFO (AdLIGO) parameter accuracies

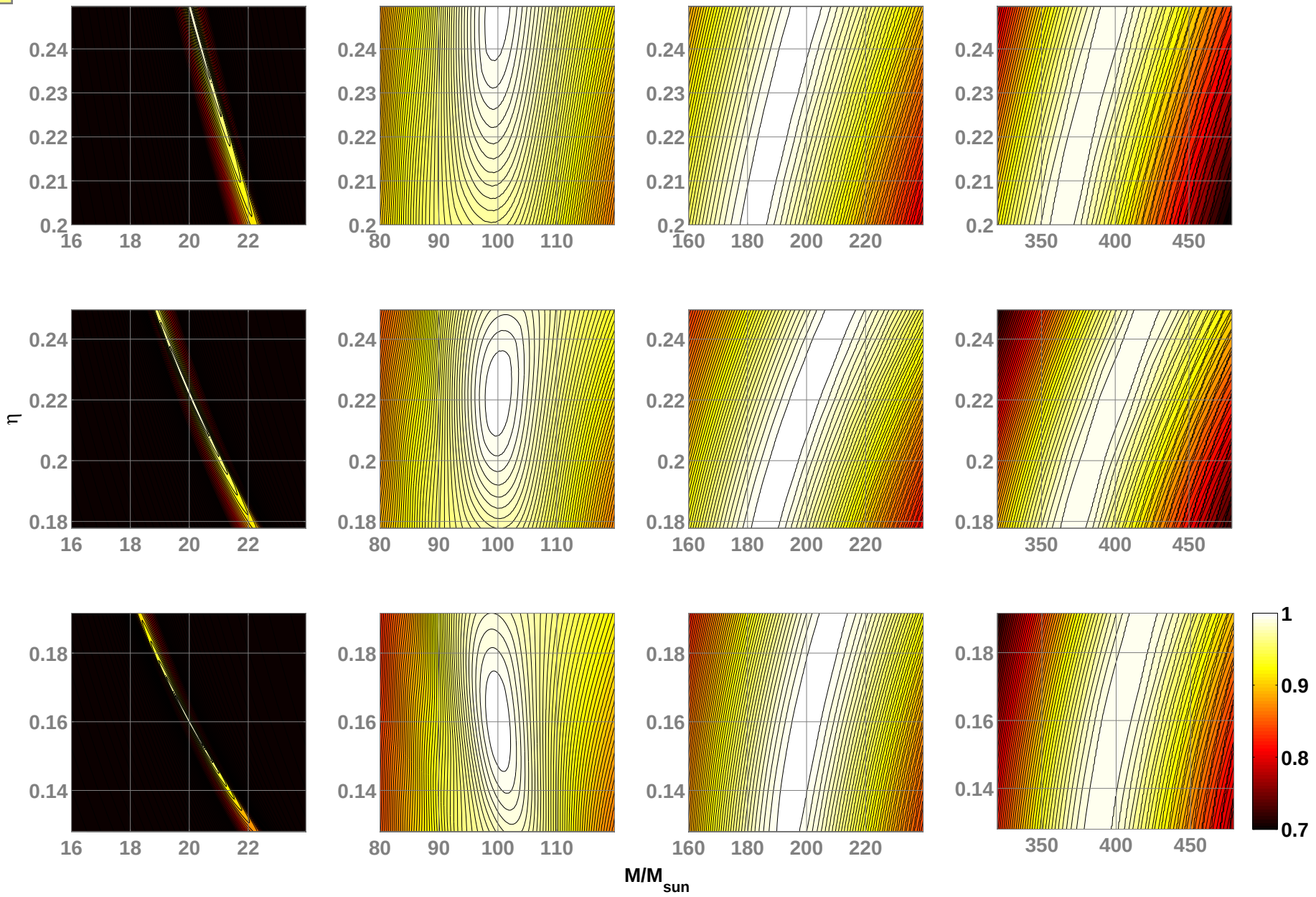
(effective distance fixed at 1Gpc)



Single IFO (AdLIGO) parameter accuracies

(SNR fixed to 10)

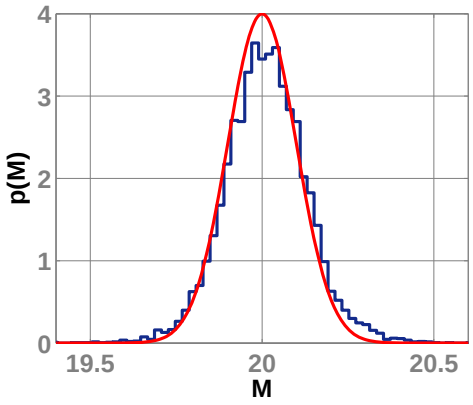


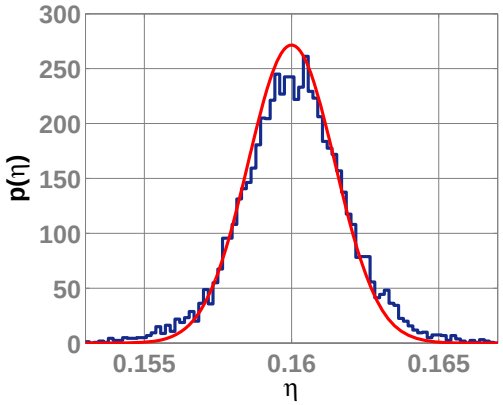


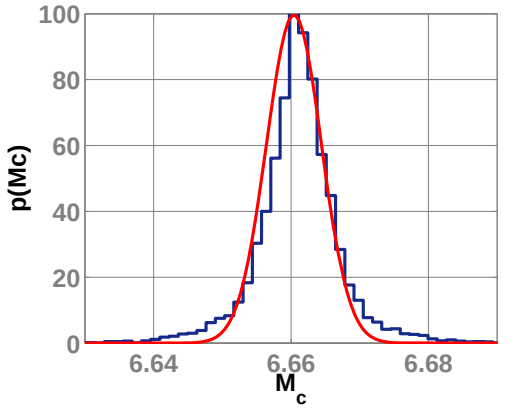
The overlap function obtained by running a template bank across twelve different target (simulated) signals.

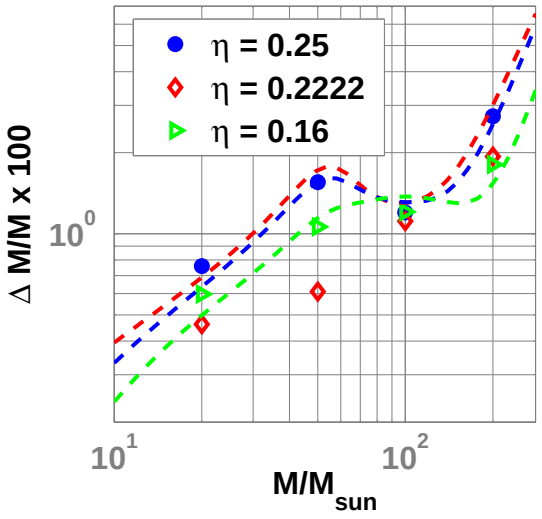
WASHINGTON STATE UNIVERSITY

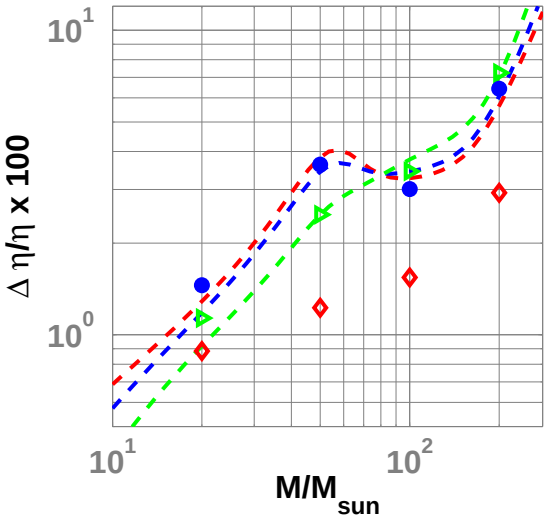
Comparing Fisher calculations with Monte Carlo simulations (SNR = 10)

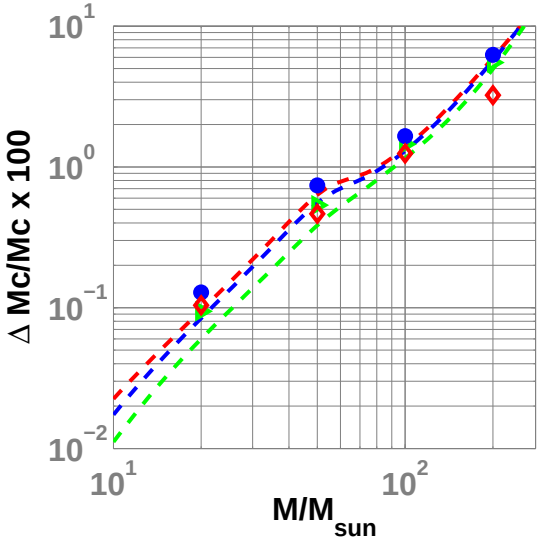


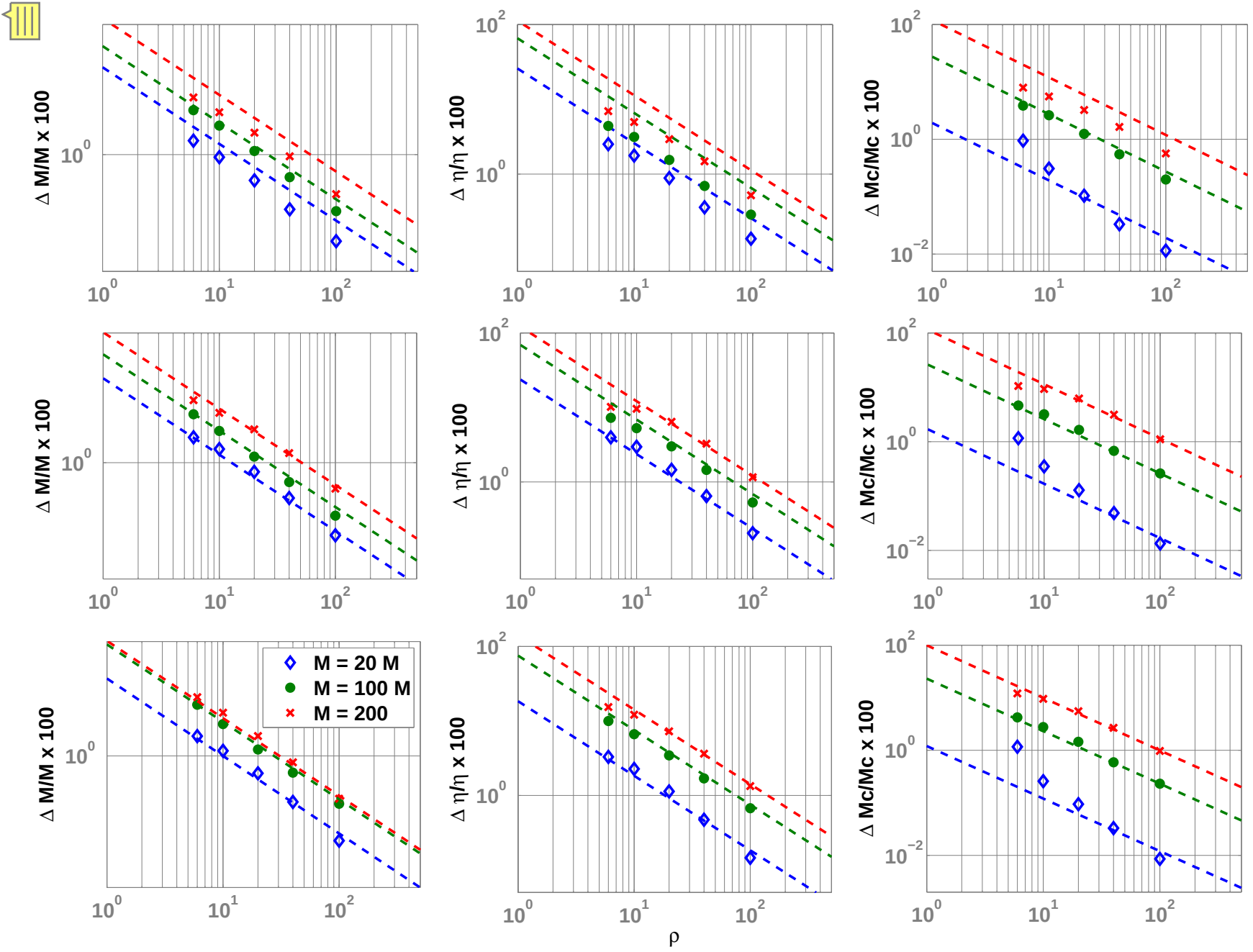






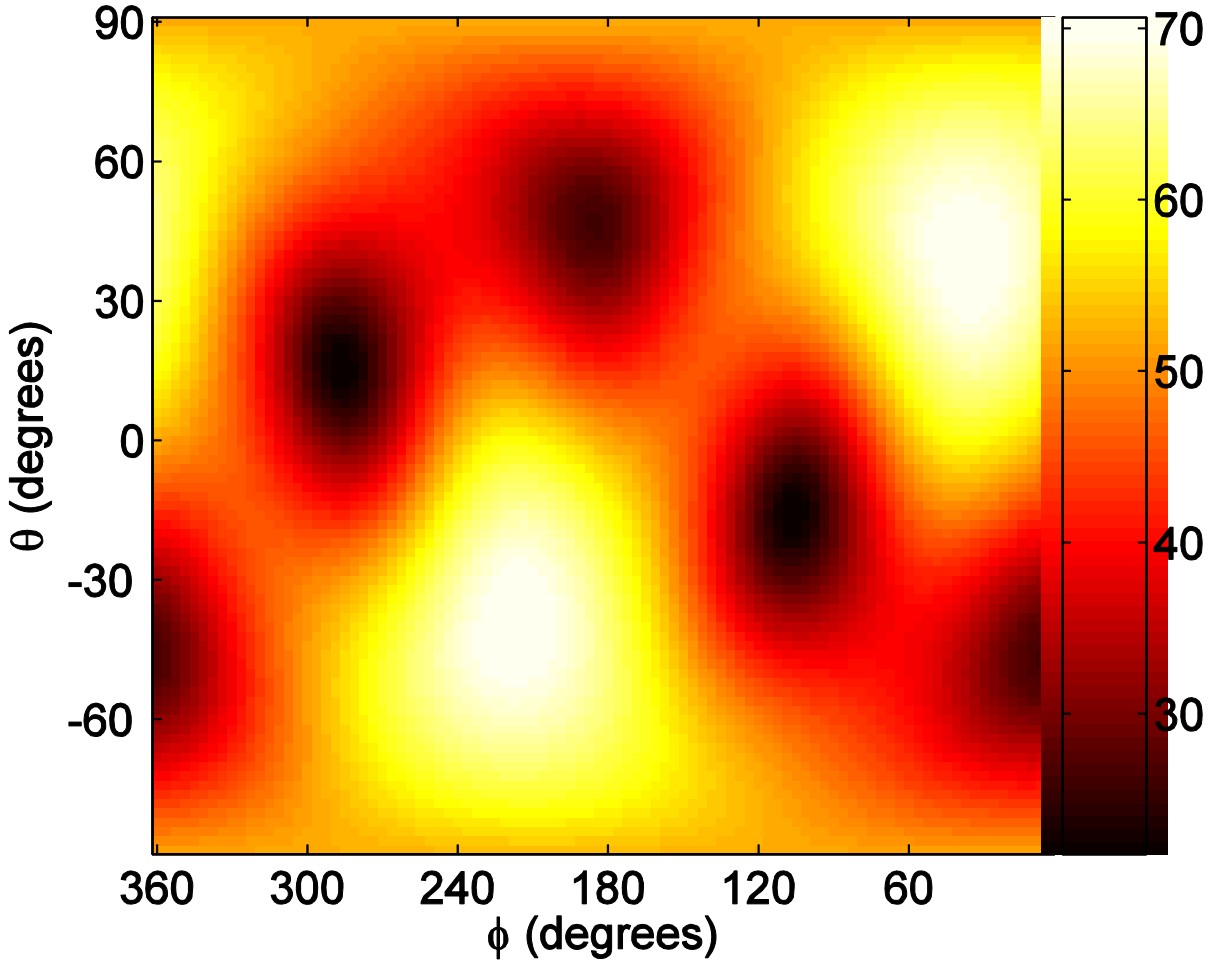





Δ M/M x 100
Δ η/η x 100
Δ Mc/Mc x 100
M = 20 M
M = 100 M
M = 200
ρ
SNR →

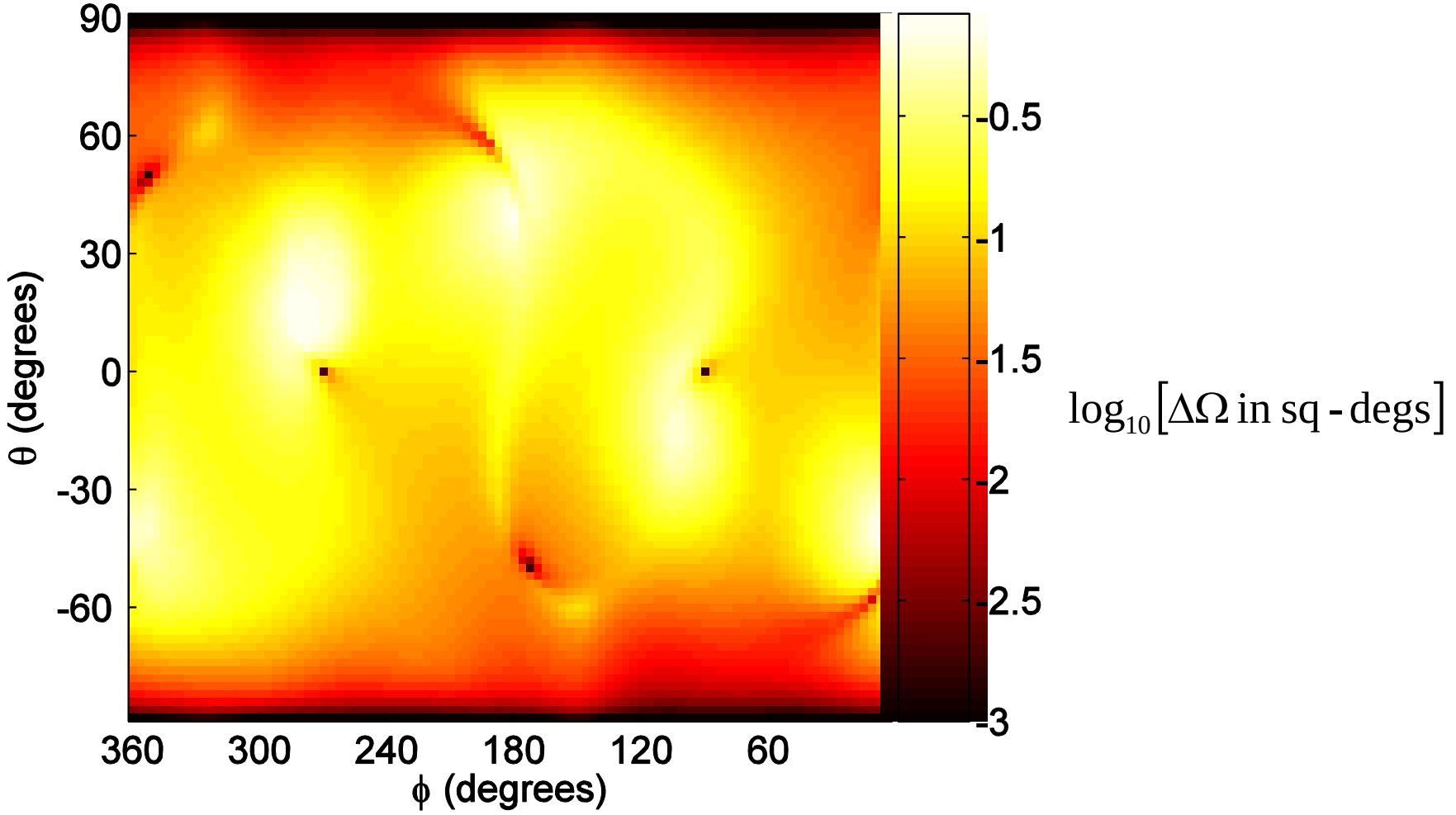
Network observations: SNR in an AdLIGO-AdLIGO-AdVirgo network

(50-50 Msun @ 1Gpc, orientation-averaged)



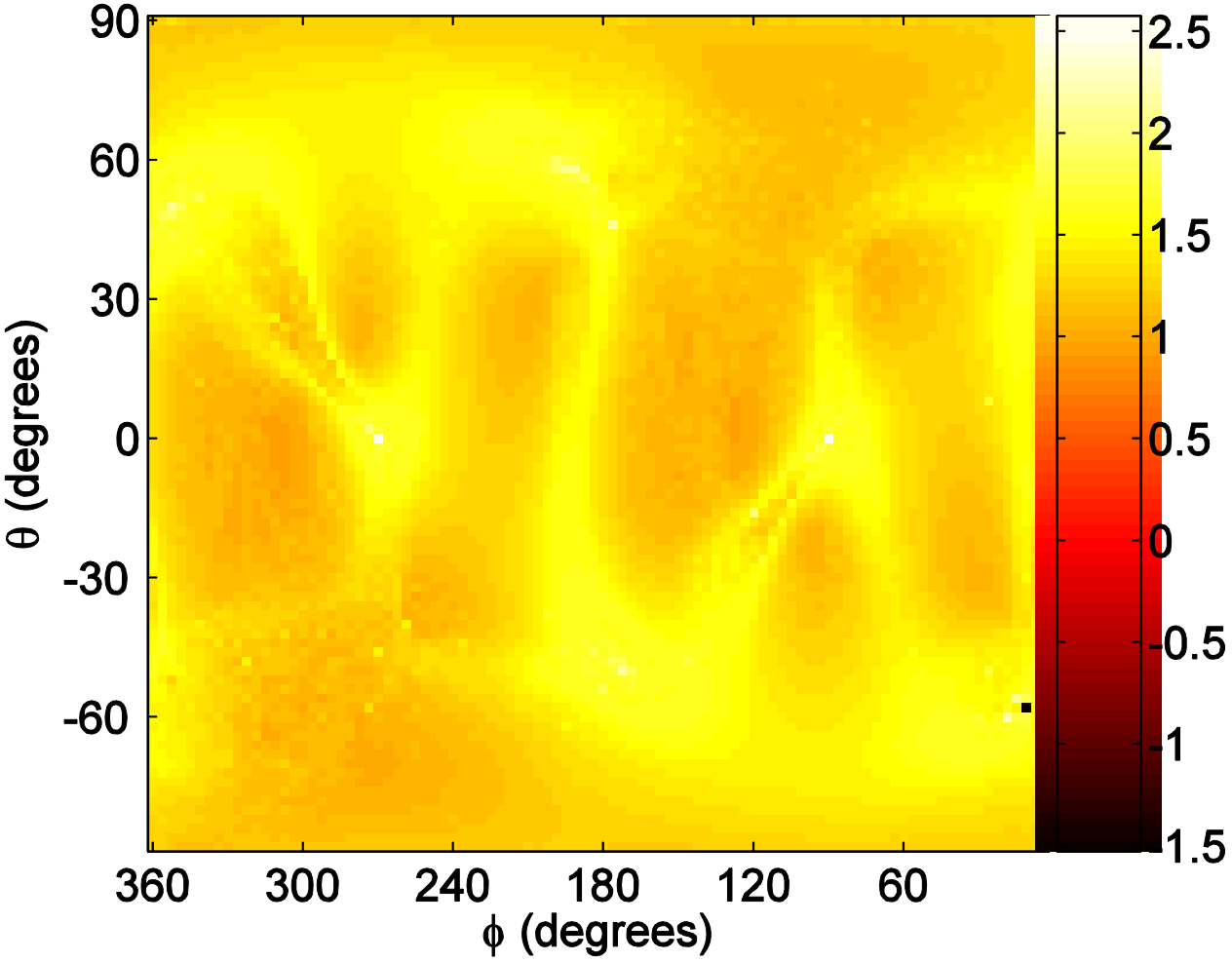
Sky-position accuracy in an AdLIGO-AdLIGO-AdVirgo network

(50-50 Msun @ 1Gpc, orientation-averaged)



Distance accuracy in an AdLIGO-AdLIGO-AdVirgo network

(50-50 Msun @ 1Gpc, orientation-averaged)



$\log_{10}[\Delta d_L / d_L \text{ in } \%]$

Sky-position: Multi-IFO (H1-L1-V1) accuracy

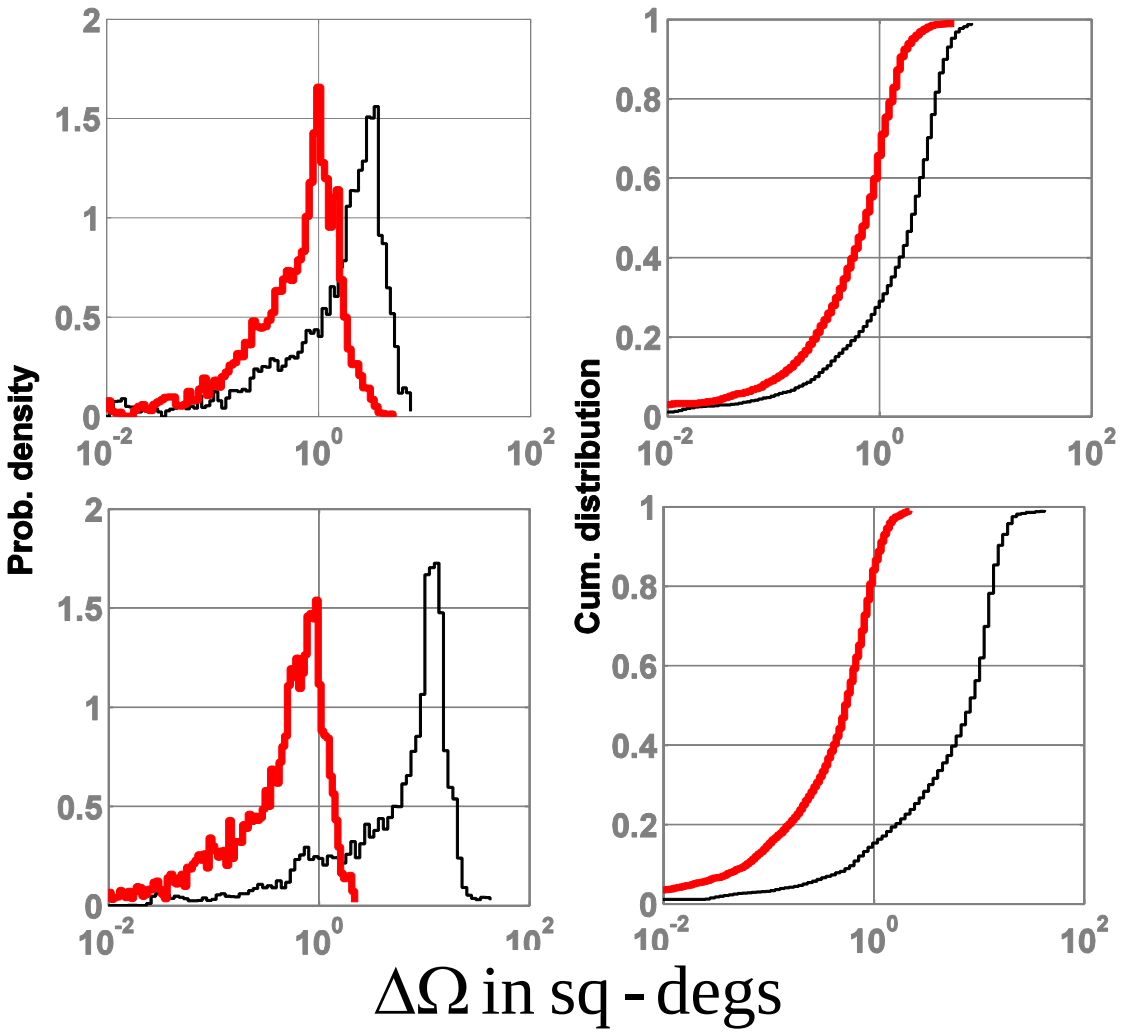
(source @ 1Gpc; observed in advanced detectors)

Inspiral-only accuracies shown in black.

Complete-waveform accuracies shown in red.

Top row: A 10-10 Msun system →

Bottom row: A 50-50 Msun system →



Sky-position: Multi-IFO (H1-L1-V1) accuracy

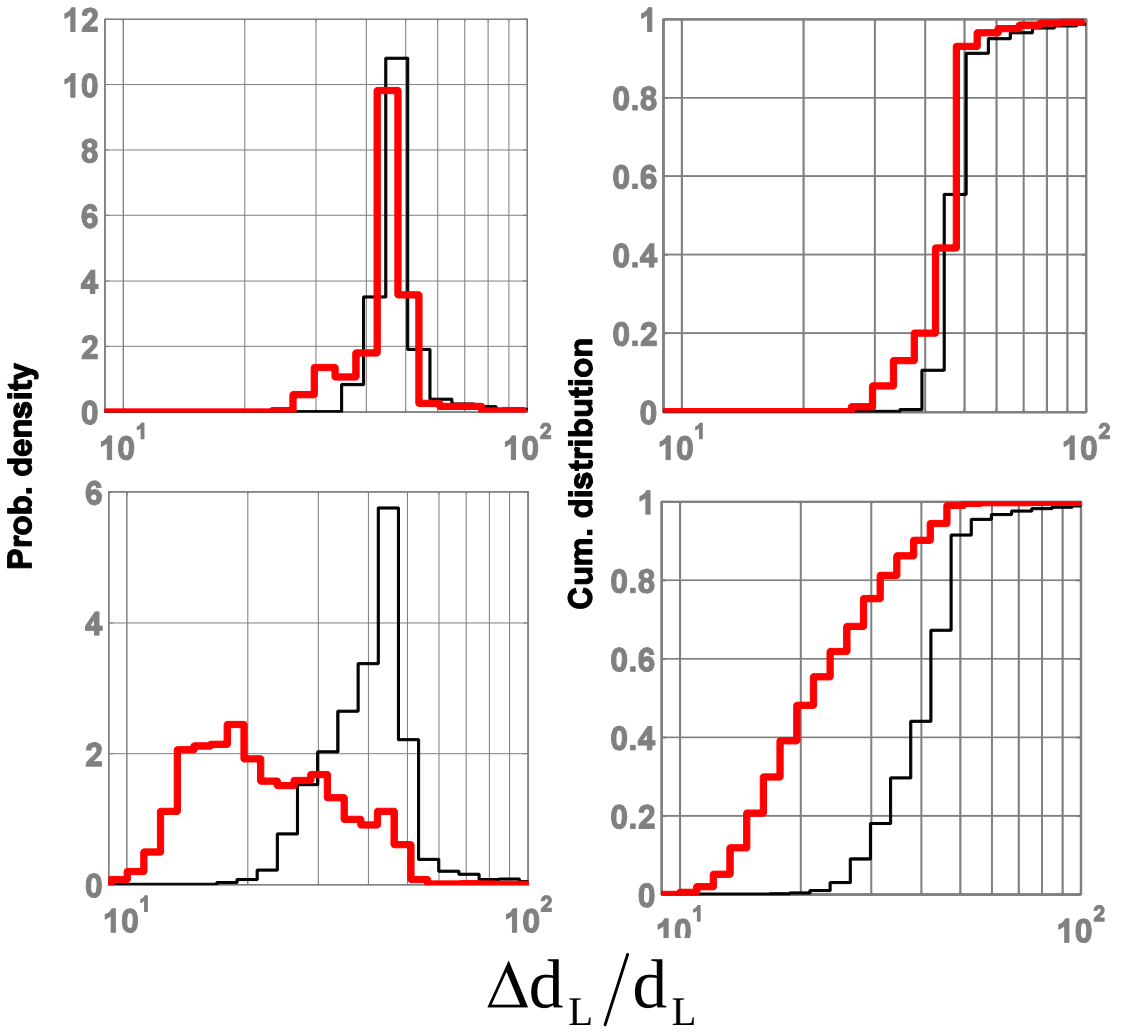
(source @ 1Gpc; observed in advanced detectors)

Inspiral-only accuracies shown in black.

Complete-waveform accuracies shown in red.

Top row: A 10-10 Msun system →

Bottom row: A 50-50 Msun system →



WASHINGTON STATE UNIVERSITY

Summary of parameter accuracies

(in advanced detectors)

Single detector estimates:

	SNR=10		$d_{eff} = 1\,\mathrm{Gpc}$	
M/M_{Sun}	M	η	M	η
20	1.38%	2.58%	0.68%	1.2%
100	0.14%	0.26%	0.22%	0.81%

AdLIGO-AdLIGO-AdVirgo estimates:

	SNR=10		$d_L = 1\,\mathrm{Gpc}$	
M/M_{Sun}	$\Delta\Omega$	$\Delta d_L/d_L$	$\Delta\Omega$	$\Delta d_L/d_L$
20	0.78	55.7%	0.70	43.2%
100	0.55	111%	0.13	23.0%