Compact Binaries as Sources for Ground-Based Gravitational-Wave Detectors

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with thanks to members of the CBC group of the LVC for feedback

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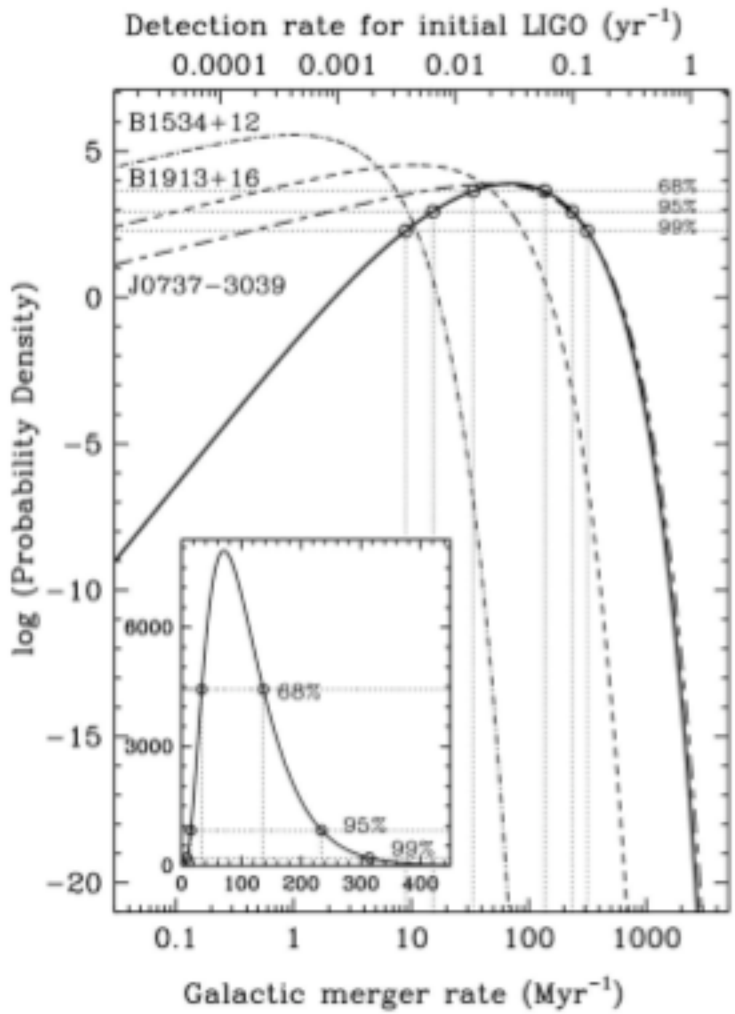
Introduction

- All astrophysical rates estimates depend on limited observations and/or models with many ill-understood parameters, and are still significantly uncertain at present
- Ground-based interferometric detectors (LIGO, Virgo, GEO 600, AIGO, LCGT) are sensitive @ tens/hundreds Hz: ideal for detecting NS-NS, NS-BH, BH-BH binaries
- Rates predictions from:
  - extrapolation from observed sample of compact binaries
  - isolated binary-evolution simulations
  - dynamical formation models
  - intermediate-mass-black holes ?
- Instrument sensitivity and conversion to detection rates

Observed NS binaries 1

- Best NS-NS merger-rate estimates come from observed Galactic binary pulsars
- Small-number statistics: out of eight binary pulsars, only four systems should merge in a Hubble time under radiation reaction; are these representative?
- Selection effects unclear, particularly pulsar luminosity distribution (could change rates by a factor of ~10)
- Uncertainties in age of pulsar, beaming factor, etc.
- [Phinney 1991; Narayan et al. 1991; Kim et al. 2003, 2006; Kalogera et al., 2004]

Observed NS Binaries 2

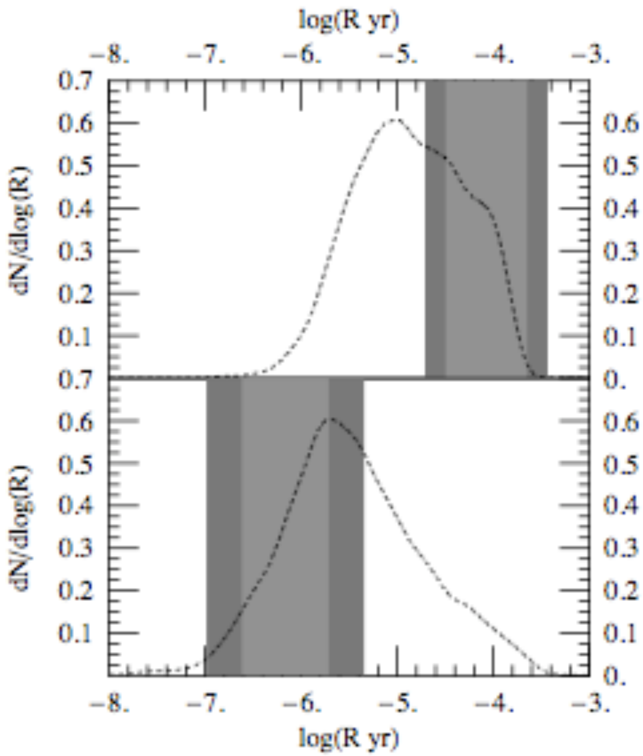


[Kalogera et al., 2006]

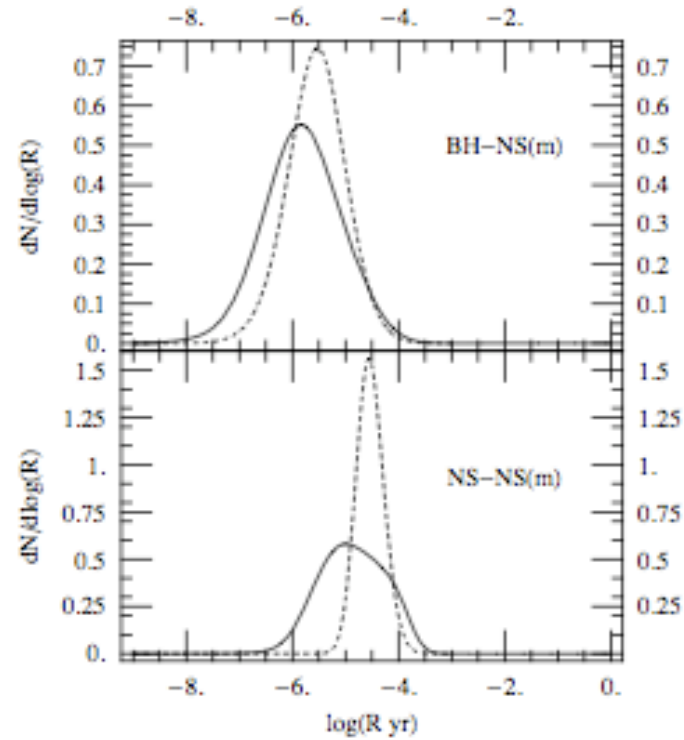
Population synthesis 1

- No observed NS-BH or BH-BH binaries
- Predictions based on population-synthesis models for isolated binary evolution
- Thirty poorly constrained parameters, including seven important ones (e.g., winds, birth kicks)
- Constraints from observations (binary pulsars, supernovae, etc.)
- Complicated simulations with StarTrack (Belczynski et al.) or similar codes, average over models that satisfy constraints
- [O'Shaughnessy et al., 2005, 2008]

Population Synthesis 2



Constraints from observed binary pulsars



BH-NS and NS-NS rate/MWEG predictions

[O'Shaughnessy et al., 2008]

Dynamical Formation

- BH-BH mergers in dense black-hole subclusters of globular clusters
  - [O'Leary, O'Shaughnessy, Rasio 2007]
  - Predicted rates 10^{-4} to 1 per Mpc^3 per Myr
  - Plausible optimistic values could yield 0.5 events/year for Initial LIGO
- BH-BH scattering in galactic nuclei with a density cusp caused by a massive black hole (MBH)
  - [O'Leary, Kocsis, Loeb, 2008]
  - Based on a number of optimistic assumptions
  - Predicted detection rates of 1 to 1000 per year for Advanced LIGO
- BH-BH mergers in nuclei of small galaxies without an MBH
  - [Miller and Lauburg, 2008]
  - Predicted rates of a few X 0.1 per Myr per galaxy
  - Tens of detections per year with Advanced LIGO

Rates per Galaxy

Source	R_{low}	R_{re}	R_{pl}
NS-NS (L_{10}^{-1} Myr^{-1})	0.6	50	500
NS-BH (L_{10}^{-1} Myr^{-1})	0.03	2	60
BH-BH (L_{10}^{-1} Myr^{-1})	0.06	0.2	20

- In simplest models, coalescence rates are proportional to stellar-birth rates in nearby spiral galaxies, so we quote rates in units of L_{10} (blue-light luminosity of 10^{10} Suns)
- However, this does not properly account for delay of coalescence relative to star formation (esp. elliptical galaxies)

LIGO sensitivity

$$\dot{N} = R \times N_G$$

(merger rate) =
(merger rate per L10) *
(Ng in L10's)

$$\rho \equiv \sqrt{4 \int_0^{f_{\rm ISCO}} \frac{|\tilde{h}(f)|^2}{S_n(f)} df}$$

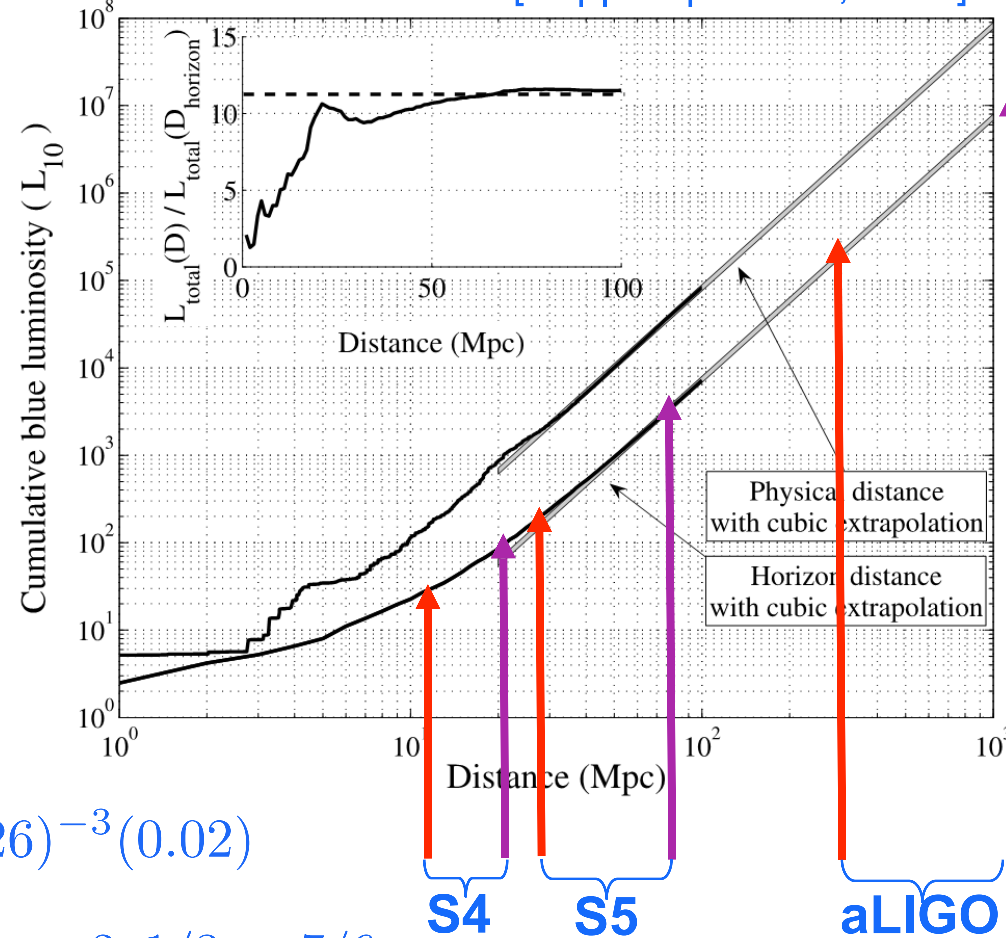
$$\rho(D_{\rm horizon}) \equiv 8$$

1/2.26 -- sky and orientation averaging; 0.02 L_{10} per Mpc^3

$$N_G\ (\mathrm{L}_{10}) = \frac{4}{3}\pi \left(\frac{D_{\rm horizon}}{\rm Mpc}\right)^3 (2.26)^{-3}(0.02)$$

$$|\tilde{h}(f)| = 2/D * (5\mu/96)^{1/2}(M/\pi^2)^{1/3} f^{-7/6}$$

[Kopparapu et al., 2008]

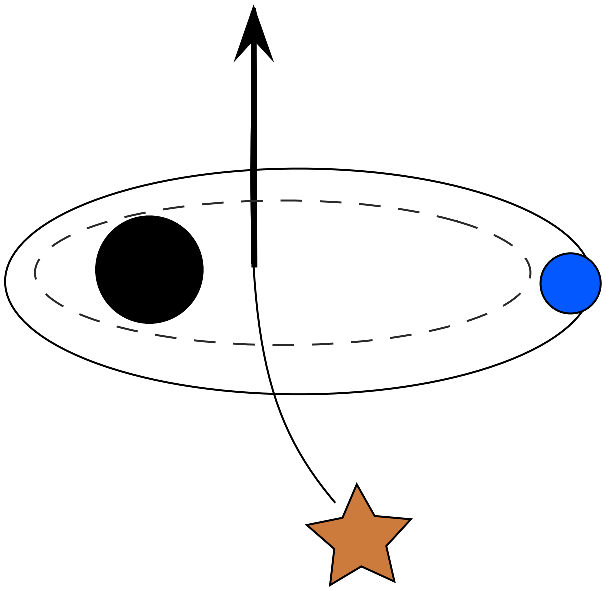


Detection Rates

IFO	Source	$\dot{N}_{\rm low}$ $\rm yr^{-1}$	$\dot{N}_{\rm re}$ $\rm yr^{-1}$	$\dot{N}_{\rm pl}$ $\rm yr^{-1}$
Initial	NS-NS	2×10^{-4}	0.02	0.2
	NS-BH	9×10^{-5}	0.006	0.2
	BH-BH	2×10^{-4}	0.009	0.7
Advanced	NS-NS	0.4	40	400
	NS-BH	0.2	10	300
	BH-BH	0.5	20	1000

Inspirals into IMBHs

- Intermediate-mass-ratio inspirals into IMBHs: a few per year with Advanced LIGO? [IM, Brown, Gair, Miller, 2008]



- IMBH-IMBH mergers in globular clusters: 0.1 to 1 per year with Advanced LIGO? [Fregeau, Larson, Miller, O'Shaughnessy, Rasio, 2006]

Why do we care?

- Rates predictions can help to determine which searches we should focus resources on, and to decide what detector configurations should be selected
- Observed rates can be compared with models to determine important astrophysical parameters (see next talk by Richard O'Shaughnessy for one aspect of this)
- As detector sensitivity improves, even upper limits can be useful in constraining model space and, thus, parameter space for birth kicks, common-envelope efficiency, winds, etc.