

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

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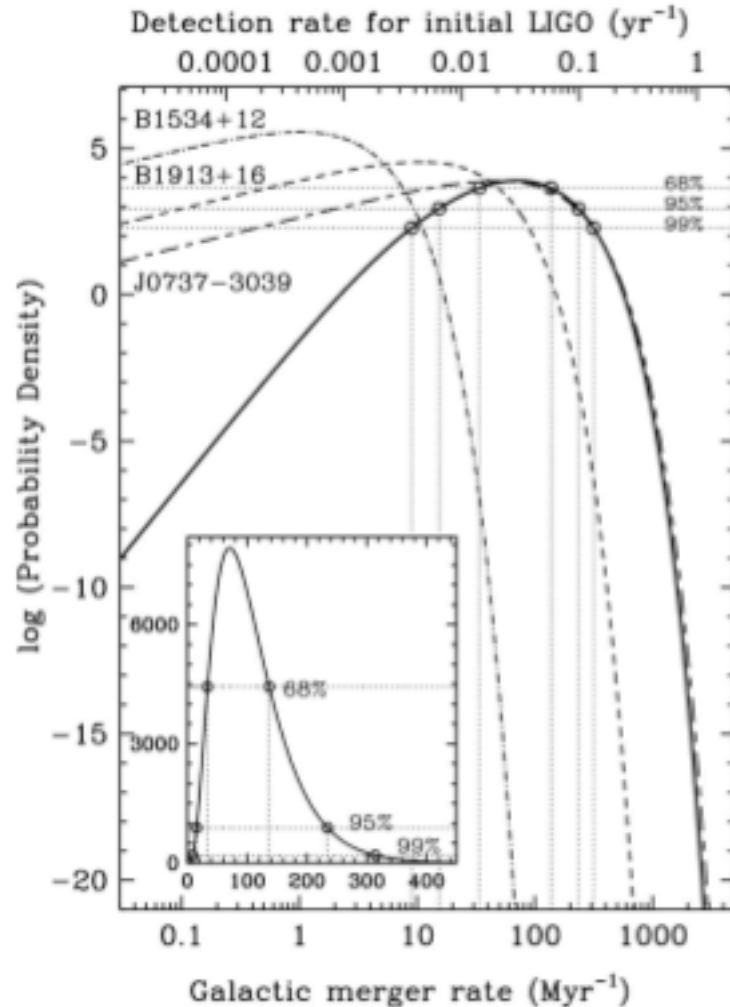
with thanks to members of the CBC group of the LVC for feedback

LIGO-G0900506-v4

Introduction

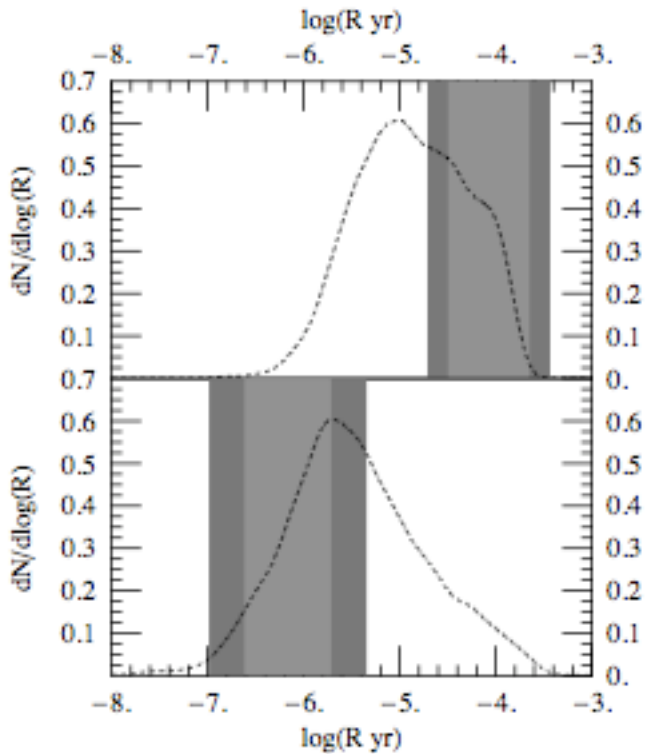
- All astrophysical rates estimates depend on limited observations and/or models with many ill-understood parameters, and are still **significantly** uncertain at present
- Ground-based interferometric detectors (LIGO, Virgo, GEO 600, AIGO, LCGT) are sensitive @ tens/hundreds Hz: ideal for detecting 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

- 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]

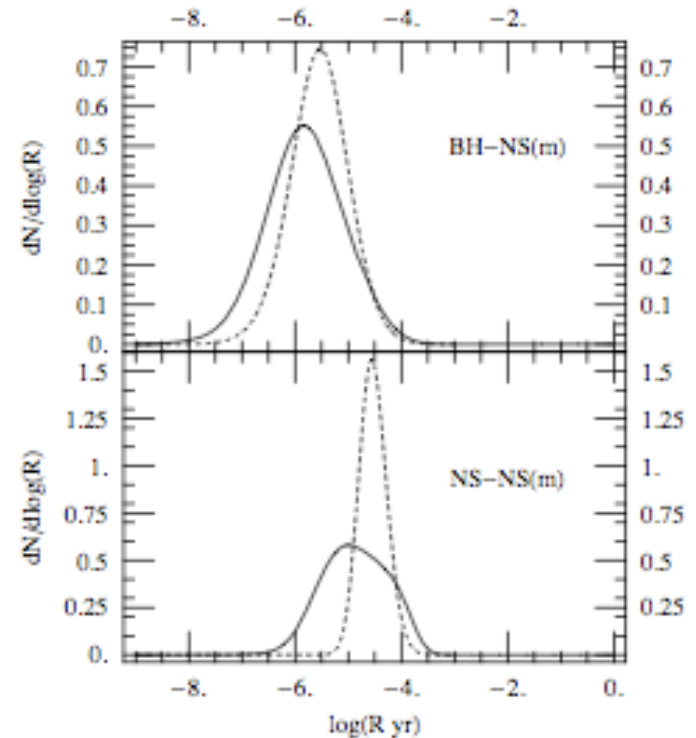


[Kalogera et al., 2006]

- 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]



Constraints from
observed binary pulsars



BH-NS and NS-NS
rate/MWEG predictions

[O'Shaughnessy et al., 2008]

- 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 $\times 0.1$ per Myr per galaxy
 - » Tens of detections per year with Advanced LIGO

Source	R_{low}	R_{re}	R_{pl}
NS-NS ($L_{10}^{-1} \text{ Myr}^{-1}$)	0.6	50	500
NS-BH ($L_{10}^{-1} \text{ Myr}^{-1}$)	0.03	2	60
BH-BH ($L_{10}^{-1} \text{ Myr}^{-1}$)	0.006	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)

[Kopparapu et al., 2008]

$\dot{N} = R \times N_G$
 (merger rate) =
 (merger rate per L10) *
 (N_G in L10's)

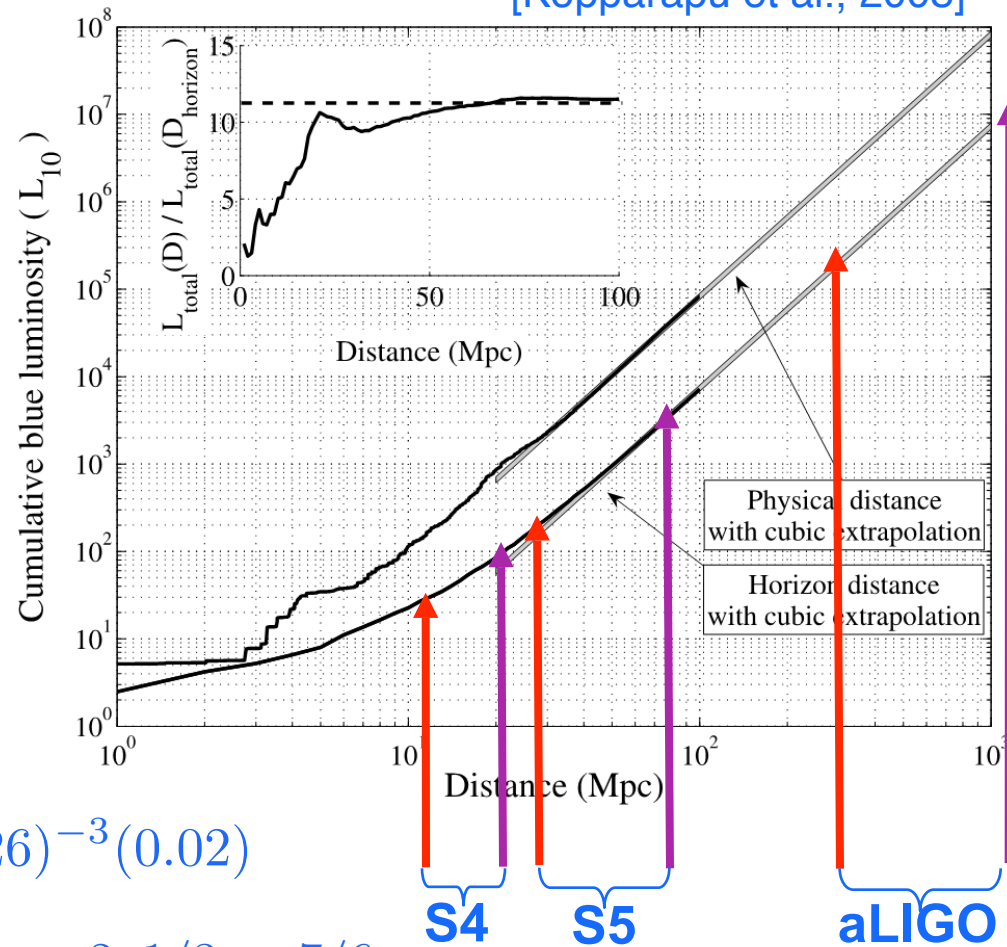
$$\rho \equiv \sqrt{4 \int_0^{f_{\text{ISCO}}} \frac{|\tilde{h}(f)|^2}{S_n(f)} df}$$

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

1/2.26 -- sky and orientation averaging; 0.02 L₁₀ per Mpc³

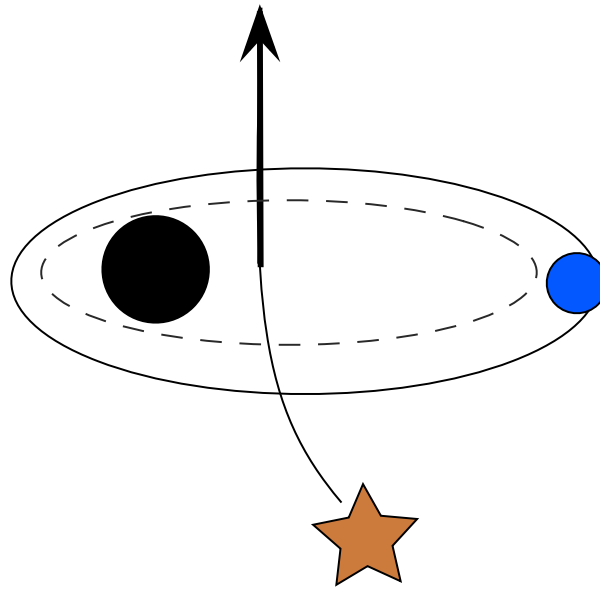
$$N_G(L_{10}) = \frac{4}{3} \pi \left(\frac{D_{\text{horizon}}}{\text{Mpc}} \right)^3 (2.26)^{-3} (0.02)$$

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



IFO	Source	\dot{N}_{low} yr^{-1}	\dot{N}_{re} yr^{-1}	\dot{N}_{pl} 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

- 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]

- 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.