LIGO Science Reach

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Introduction

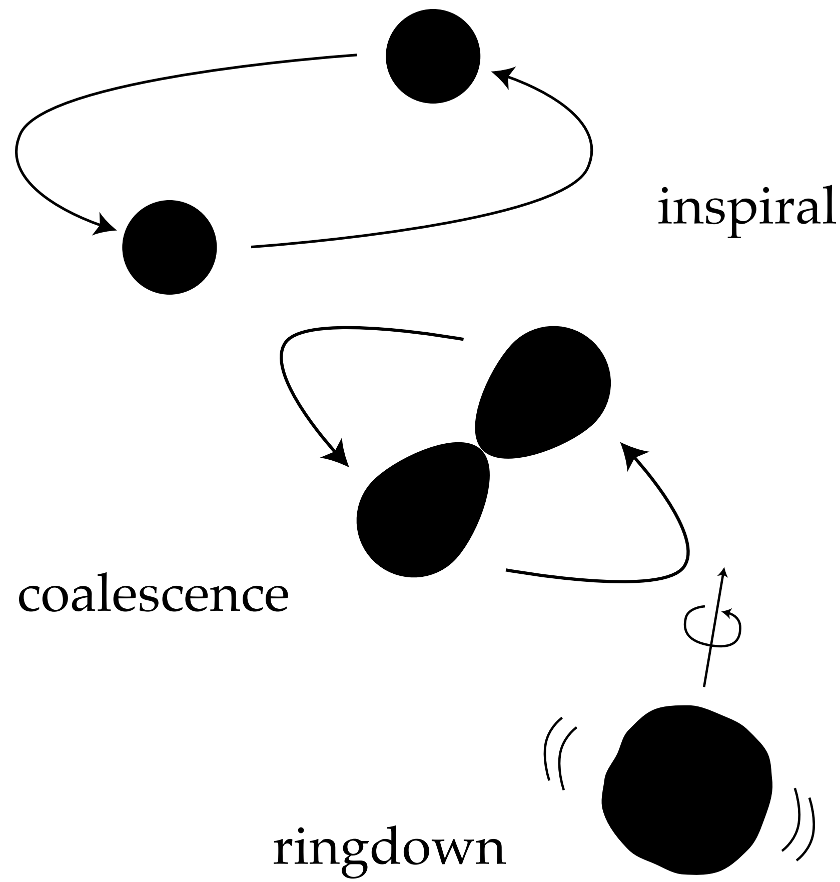
- What is "science reach"?
  - Instrument sensitivity to target science
  - What kind of science, can we expect with first, second generation LIGO instrumentation?
- Conservative approach
  - Focus where speculation can be minimized
  - Miss out on most exciting prospects!
- Outline
  - LIGO I, II baseline recap
  - Compact binary inspiral
  - Stochastic gw signal
  - γ-ray bursts
  - Core-collapse supernovae
  - Summary

LIGO baseline recap

- LIGO I
  - Fixed configuration
  - Peak "sensitivity"
    - $3 - 6 \times 10^{-23}/\mathrm{Hz}^{1/2}$ in 75 – 500 Hz band
- LIGO II
  - Configurable
    - Broad or narrow band operation on a per-IFO basis
  - Peak sensitivity: broadband
    - $1.5 - 3 \times 10^{-24}/\mathrm{Hz}^{1/2}$ in 150 – 600 Hz band
  - Peak sensitivity: narrowband
    - Limited by substrate thermal noise

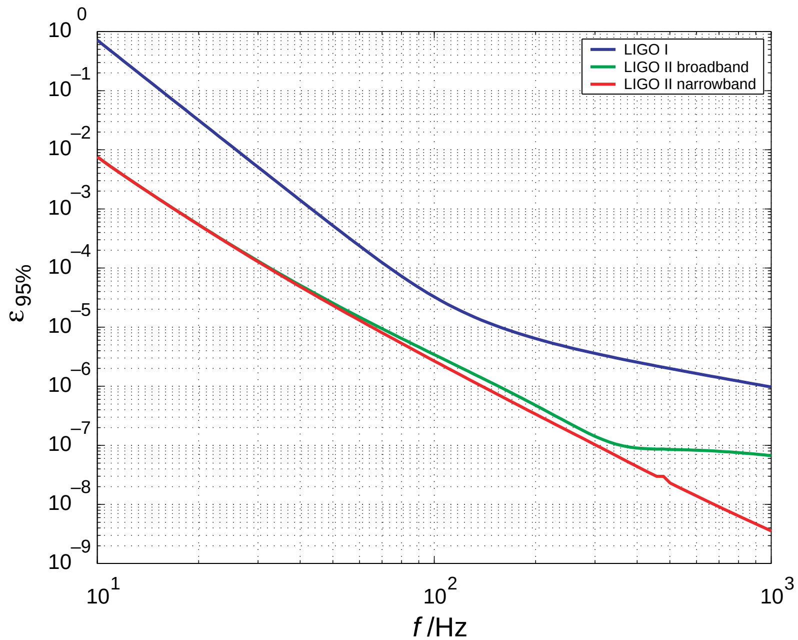
Binary Inspiral

- Reach: Survey volume
  - Distance r such that observed rate is $4\pi r^3 n/3$
  - Allow for luminosity function, cosmology, etc.
- Parameters
  - $M = 1.4+1.4\ M_\odot$ binaries
    - $r \sim M^{5/6}$ for $M<10M_\odot$
  - Expected false rate
    - $< 10^{-4}/y$
    - Corresponds to S/N ~ 8
  - $r_{\mathrm{LIGO\ I}} = 14$ Mpc
  - $r_{\mathrm{LIGO\ II}} = 200$ Mpc
  - x ~ 1.5 for coherent sum



Periodic Signals

- Focus on pulsars
  - $f_{gw} = 2f_{pulsar}$
  - $h \propto \varepsilon = (\Delta I / I)$
- Reach: upper limit on ε
  - 1 yr observation
  - *10 Kpc* distance
  - Declination average
  - Significance: 95%
- Theoretical prejudice
  - $\varepsilon < \sim 10^{-6}$
    - From pure Coulumb lattice crust strength
- Observational constraints
  - $\varepsilon < \sim 10^{-8}$ for *old* (recycled) pulsars



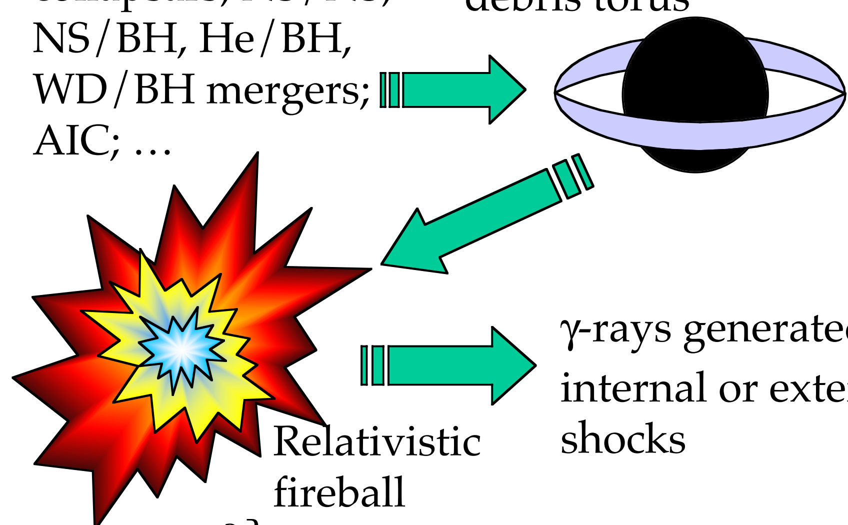
Stochastic Signals

- Single IFO can't separate between signal, noise
- Reach: Limit on Ω_{GW}
  - GW energy density, as fraction closure density, per log bandwidth
  - 99% significance
  - 1/3 yr observation
- LIGO I: $3.3\mathrm{x}10^{-6}/h^2$
- LIGO II: $2\mathrm{x}10^{-9}/h^2$

- Two detectors respond ~coherently when $\lambda > d$
  - LHO-LLO: c/d=100 Hz
  - LLO-ALLEGRO: c/d >> KHz
- Theoretical prejudice:
  - Inflation: $\Omega_{GW} \sim 10^{-14}$
  - Comic Strings: $\Omega_{GW}\sim10^{-11}$
- In-band observational constraints:
  - N.synthesis: $\Omega_{GW} \sim 10^{-5}$

γ-ray bursts

- γ-ray burst triggered by formation of ~$M_\odot$ bh
  - Expect grav.-wave burst
- Individual grav.-wave bursts not detectable
  - Distance, amplitude, etc., conspire against
- Look for statistical association:



$$h^2_{\mathrm{Det}} < h^2_{95\%} = \begin{Bmatrix} \left(1.35\times10^{-22}\right)^2 \\ \left(2.5\times10^{-23}\right)^2 \end{Bmatrix} \left(\frac{T}{0.2\mathrm{s}}\frac{1000}{N_{\mathrm{on}}}\right)^{1/2} \quad \begin{matrix} \text{LIGO I} \\ \text{LIGO II} \end{matrix}$$

  - LIGO II bound equiv to ~$0.3M_\odot$ in grav.-waves at $z = 1/2$

Core-collapse supernovae

- Assume:
  - LIGO II observation of extra-galactic SN
    - Light curve fixes collapse to within 1h
  - LIGO I observation in galactic neighborhood
    - Neutrinos fix collapse to within 1s
  - Waveform unknown
    - Focus on detector-detector x-correlation
  - 1 KHz signal bandwidth

- Reach:
  - Mass fraction ε converted to gravitational waves
- LIGO II:
  - $\varepsilon_{95\%} < 24\%$ for SN at 15 Mpc
    - Expected rate 3/y
- LIGO I:
  - $\varepsilon_{95\%} < 2\mathrm{x}10^{-4}$ for SN at 55 Kpc
    - Expected rate 1/30y
- Theoretical prejudice
  - $\varepsilon < 10^{-7} - 10^{-8}$

Summary

- LIGO I bounds the possible
  - Bound outside estimates on inspiral rates
  - Upper limits probes prejudice on pulsar crust strength upper bound
  - Improve in-band limit on stochastic GW background
  - Possible physical bound on SN efficiency

- LIGO II challenges theory
  - Observe several NS/NS inspirals per year
  - Measure deformation of nearby pulsars
  - Improve limits on stochastic background
  - Maybe explore γ-ray burst model
  - Physical bound on SN efficiency