Theoretical Predictions for Mergers of NS-NS, BH-NS and BH-BH Binaries

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– LIGO/Virgo upper limits on merger rates

– BH natal kicks

– Evolutionary initial conditions

(the very limited and brief overview...)

Predictions: double compact object merger rates

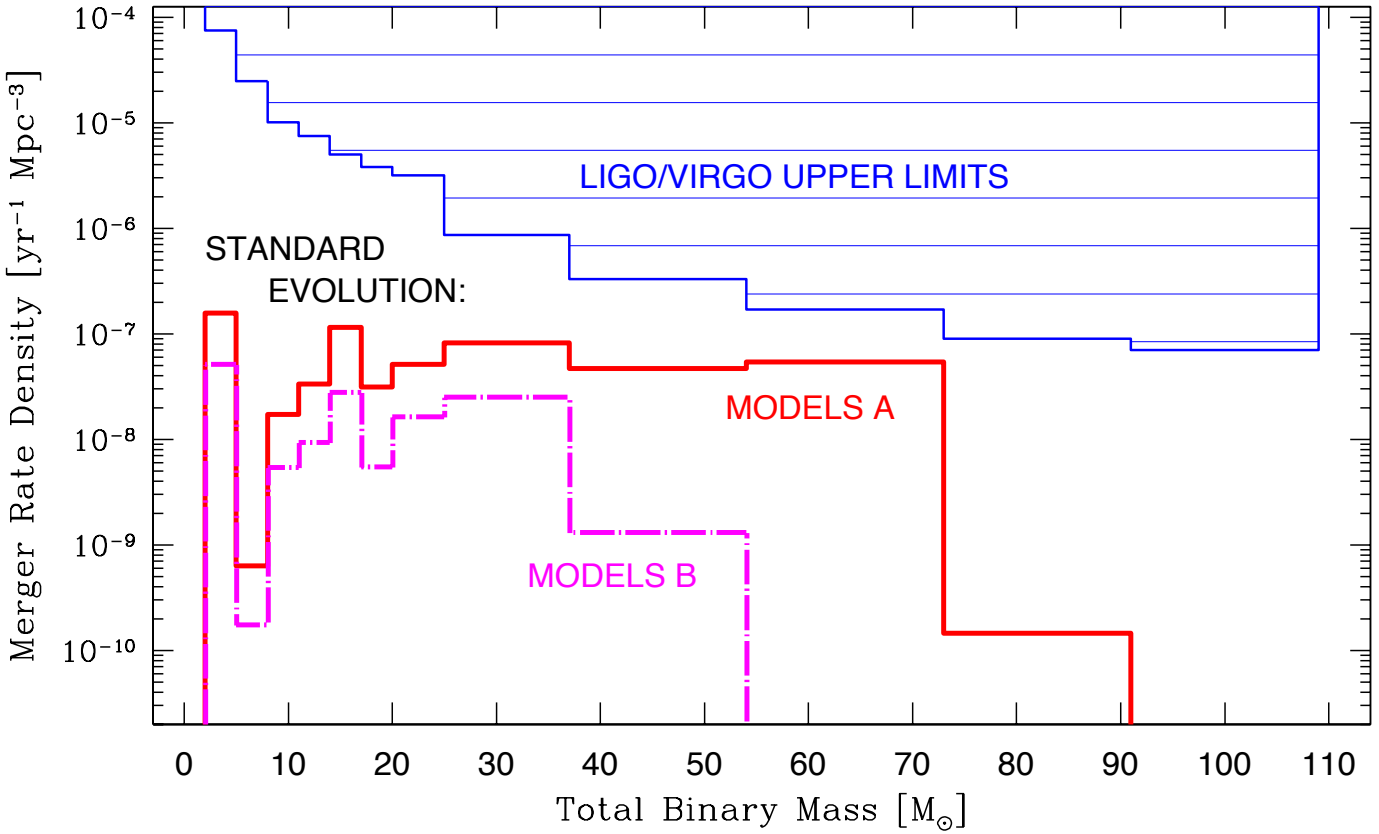
Evolutionary Prediction Uncertainties:

- initial conditions: IMF, q, $P_{\rm orb}$, e, $f_{\rm binary}$, Z (yes, this one too...)
- single star evolution: winds + mixing: radius?
- binary CE evolution: development criteria + survival?

- NS/BH mass: distribution and extent?
- NS/BH natal kicks: high or low?

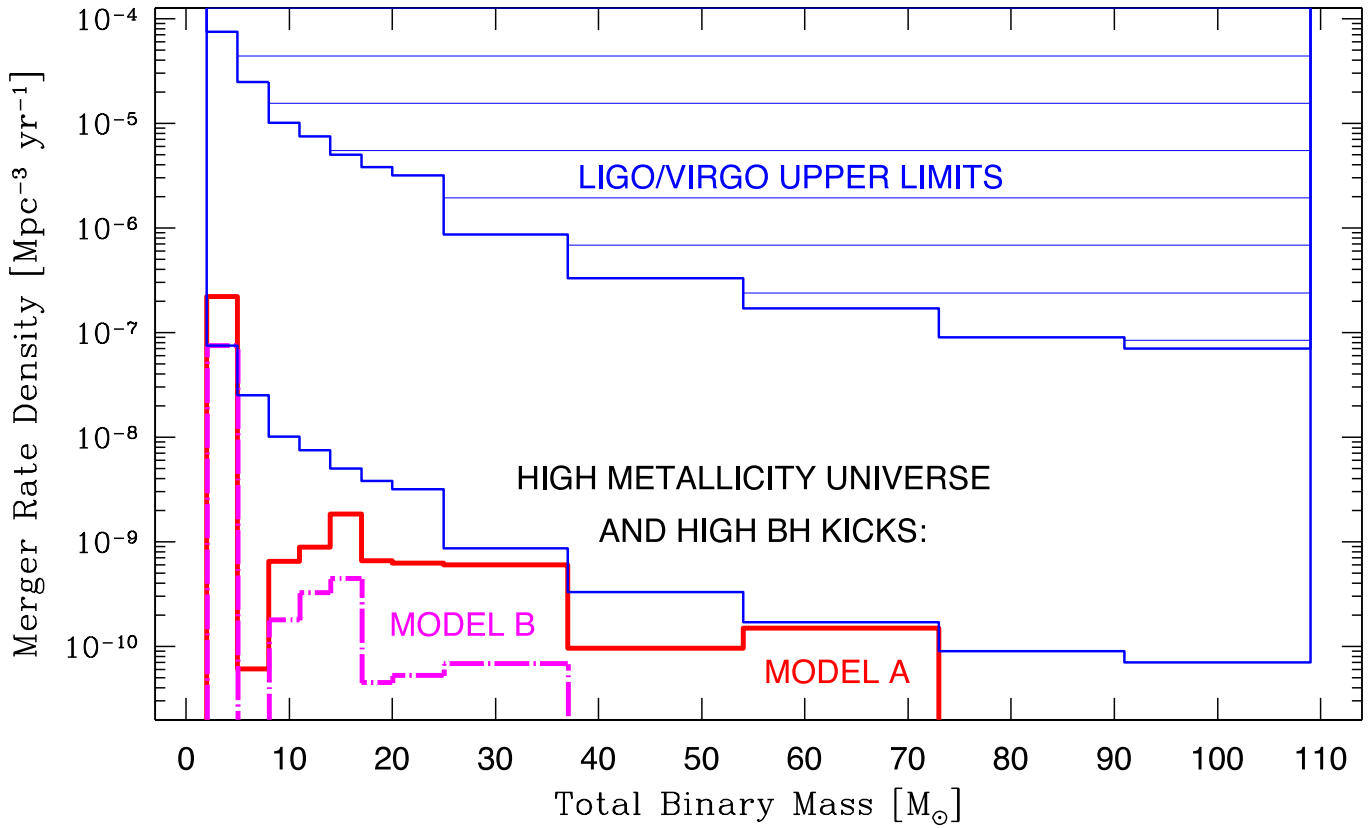
Predicted Rates vs LIGO/Virgo upper limits ->

LIGO/Virgo CURRENT UPPER LIMITS



Small change in LIGO/Virgo sensitivity will bring physical constraints...
or detections.

LIGO/Virgo FUTURE (???) UPPER LIMITS



Upgrade to advanced LIGO/Virgo sensitivity may not bring BH-BH detections...
but will provide constraints (alas degeneracies).

BH Natal Kicks

BH natal kicks decrease with BH mass... (or so it is claimed)

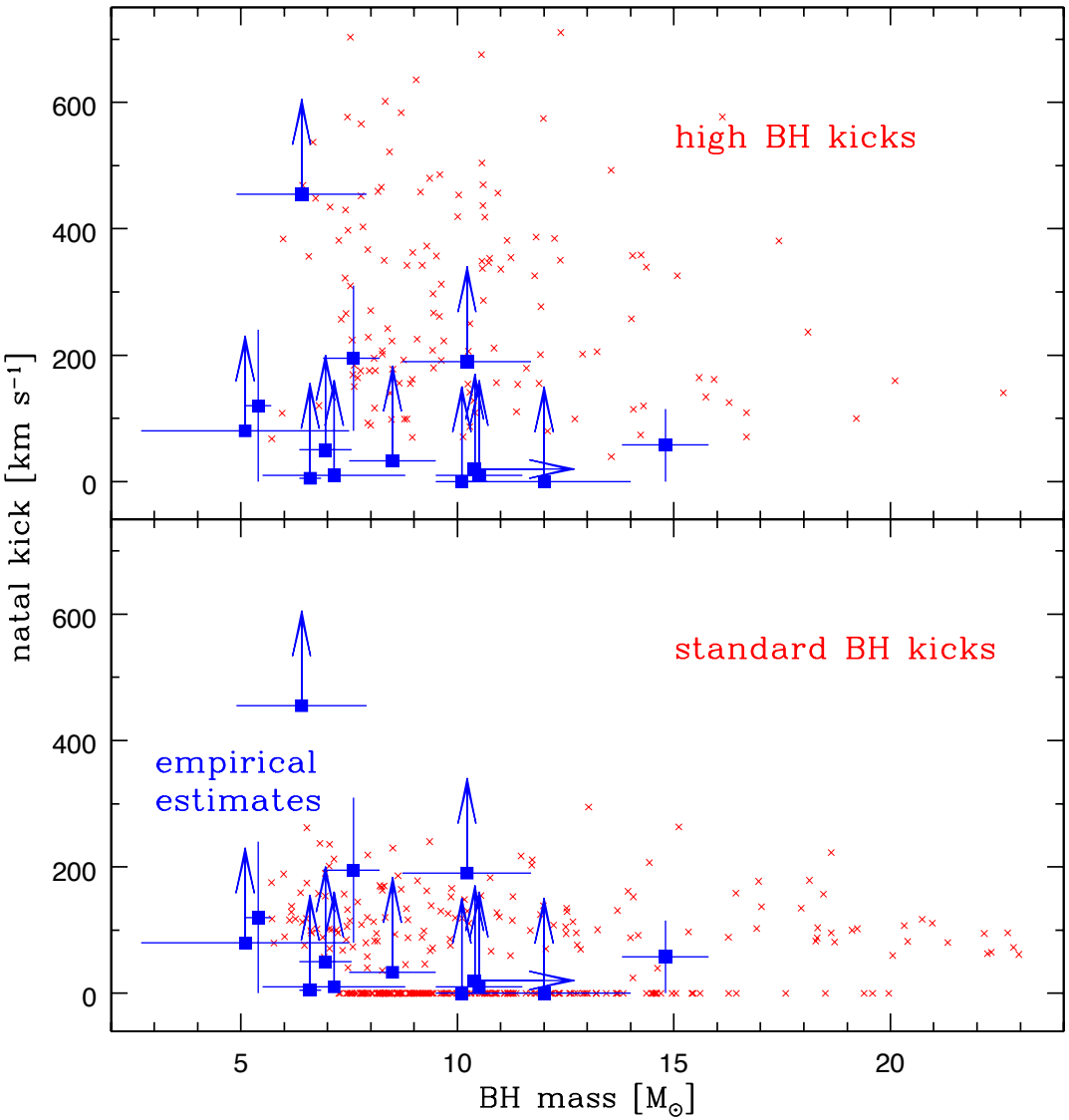
Let's do the following exercise:

- collect empirical data on (Galactic) BH natal kicks: 14 points
- evolve Galactic population of BH systems:
  – with high BH kicks (1D $\sigma = 265$ km/s)
  – with "standard" BH kicks (decreasing with BH mass)
- select X-ray binaries with short periods (observed)
- plot both models against empirical data

Constraints on BH kicks ->

(mostly from Serena Repetto and Northwestern group + Wong et al.)

BH Natal Kicks



no EM constraint
on BH kick mechanism...

potential science
for aLIGO/Virgo

Initial Conditions for Massive Binary Evolution

Initial conditions for massive stars are poorly known and merger rates may sensitively depend on adopted distributions... (or so it is said)

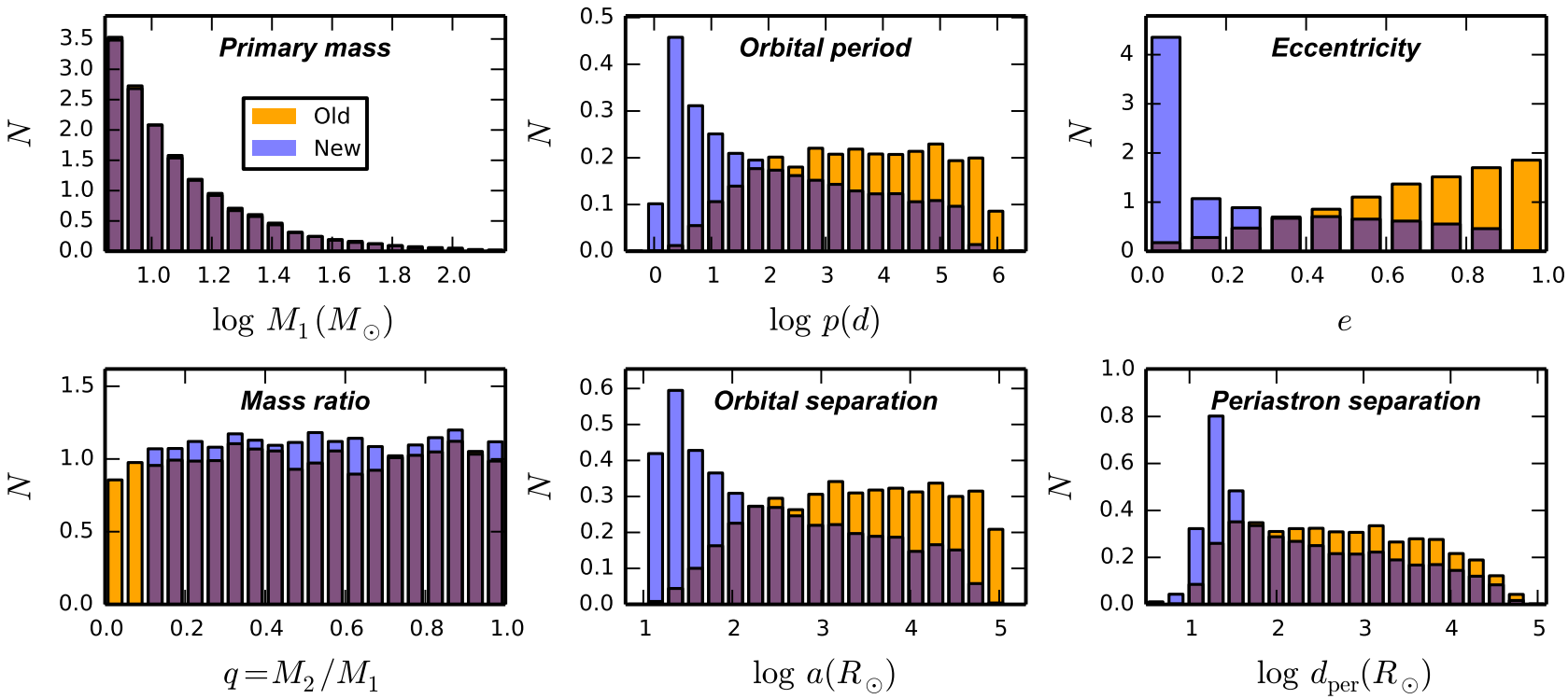
Sana et al. (2012): have provided a very realistic estimates of initial conditions for massive stars...

Let's do the following exercise:

- pick a single/binary evolution model
- evolve massive binaries:
  – with so far adopted initial distributions
  – with new Sana et al. 2012 distributions
- compare merger rates for NS-NS/BH-NS/BH-BH systems

how large are the changes? (Selma de Mink et al. ->)

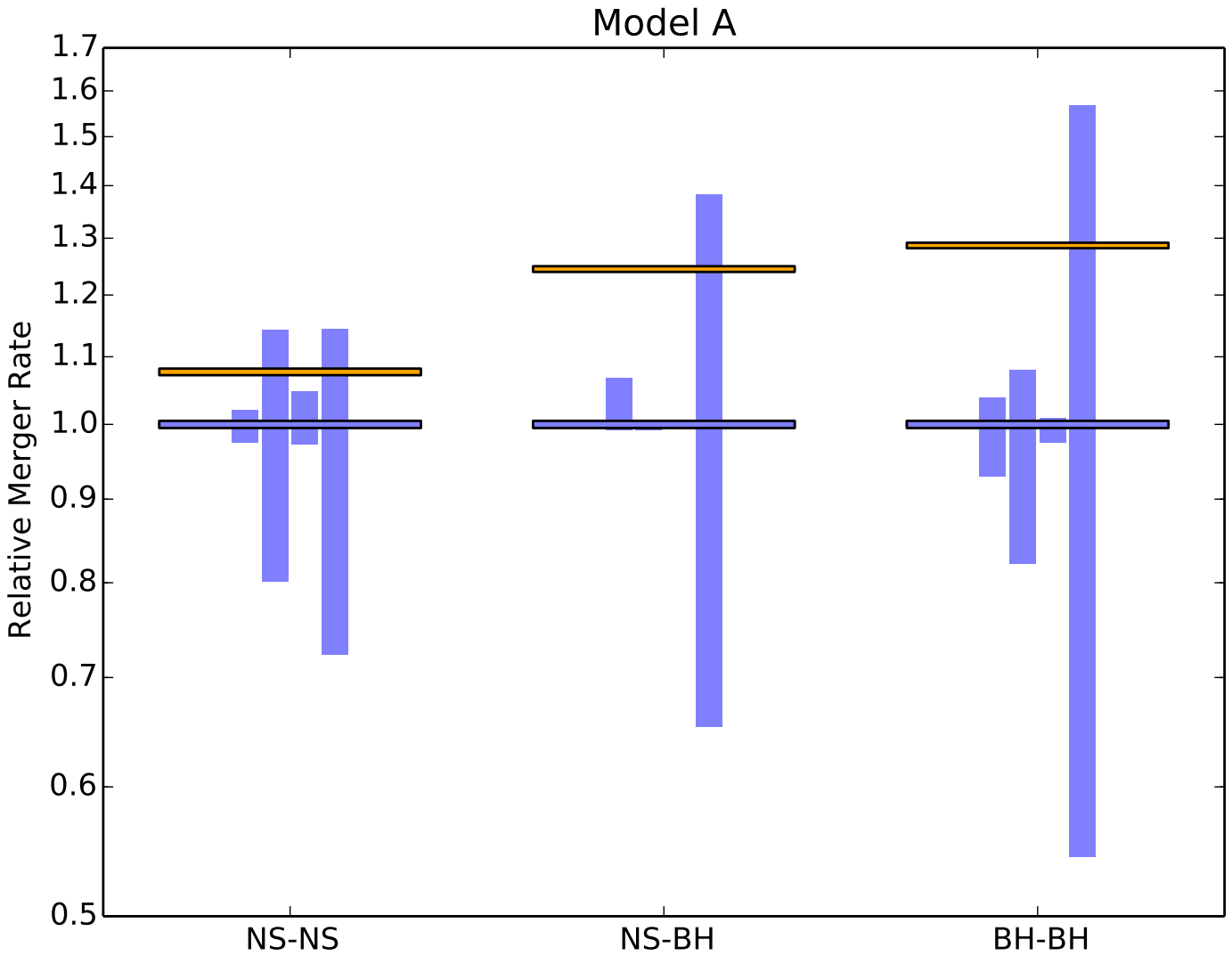
Initial Conditions for Massive Binary Evolution



– no changes for initial binary component masses (IMF and mass ratio)

– very different initial distributions for: orbital period and eccentricity

Initial Conditions for Massive Binary Evolution



"no" change in merger rates...

entire set of uncertainties eliminated!

Conclusions

- not much is known about double compact objects
  ($\sim$ 6 close NS-NS and no BH-NS nor BH-BH systems)
- predictions are burdened with heavy uncertainties
  (both for single and binary star evolution)
- evolutionary science studies are hard, but not impossible...
  – elimination of parameters (e.g., initial distributions)
  – identifying cases that depend only on 1 parameter
  (i) NS/BH mass gap: supernova physics
  (ii) BHs with mass above 100 $\mathrm{M}_{\odot}$: stellar expansion
  – study of parameter degeneracies (e.g., BH-BH case)

if we do not detect any BH-BH mergers:
1) high BH kicks
2) restricted CE development
3) inefficient tides + large winds

Observations: known double compact objects

- BH-BH: not observed (but IC10 X-1, NGC300 X-1: $\lesssim 1000\ \mathrm{yr}^{-1}$)
- BH-NS: not observed (Cyg X-1: $0.01\ \mathrm{yr}^{-1}$, Cyg X-3: $0.1\ \mathrm{yr}^{-1}$)
- NS-NS: 9 Galactic systems. 6 are close binaries: $\sim$ *few* yr^{-1}

Phone #	t_{mrg}/Gyr	$M_{\mathrm{ns},1}/M_\odot$	$M_{\mathrm{ns},1}/M_\odot$	Comment
1) J0737-3039	0.09	1.34	1.25	field (double pulsar)
2) B2127+11C	0.22	1.36	1.35	cluster
3) J1906+0746	0.30	1.25	1.37	field
4) B1913+16	0.33	1.44	1.39	field
5) J1756-2251	1.7	1.34	1.23	field
6) B1534+12	2.7	1.33	1.35	field

– Empirical Galactic merger rate $\sim$ 1-100 Myr^{-1} (O'Shaughnessy et al. 2014)
population synthesis predictions: $\sim$ 2-50 Myr^{-1} (Dominik et al. 2012)

– low contribution from cluster NS-NS binaries (kicks/low esc. velocity)