The star clusters that make black hole binaries across cosmic time

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(1809.01164)

Do LIGO sources form in the field?

Maybe, but significant uncertainties remain

If stellar binaries form with wide separations:

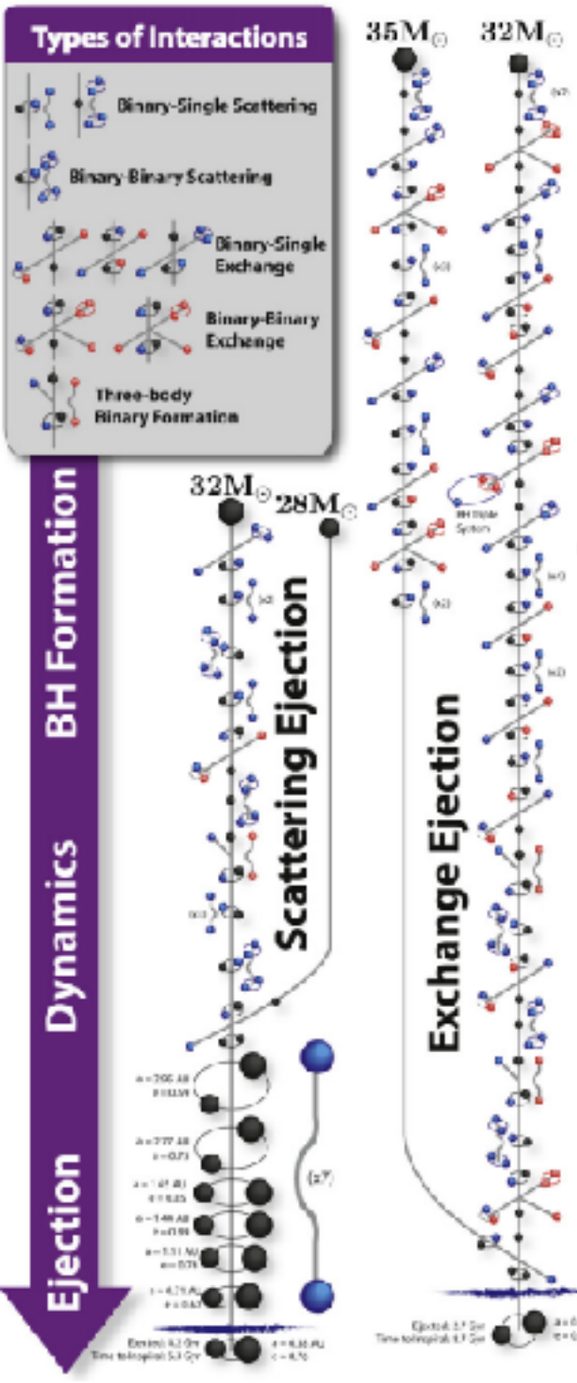
How do they shrink?
GWs only effective at ~10 Rsun

If stellar binaries form with small separations:

How do they avoid merging during stellar evolution?

(many recent papers by e.g., de Mink, Mandel, Ivanova, Mapelli, Belczynski)

Some assembly required: dynamical binary formation in star clusters



“Stars form BHs and then are introduced to a dating website”
-Ilya Mandel (Sackler conference 2018)

Dense star clusters are a prime site for dynamical interactions
Globular clusters —> low metallicity —> weak stellar winds —> massive BHs

Confirmed in many numerical simulations
(e.g., Morscher+ 15, Park+ 17, Rodriguez+ 16abcd)

But…cosmological context is important
Which cluster initial conditions should be simulated?
How does an evolving population affect the merger rate?

A cosmological model for GC formation

Analytic, merger-tree based model for formation of GC systems

GCs form when **DM halo accretes rapidly**

Number of clusters formed and properties set by **empirical galactic scaling relations**

Matches many z=0 observations: mass/metallicity distributions, GC-halo mass, age-metallicity relations…

More details: Choksi, Gnedin, & Li 2018 (1801.03515)

Model gives: GC formation times, metallicities, masses, host galaxy properties

Dynamical evolution of clusters

Apply **analytic** prescriptions for relevant timescales (modified from Antonini & Rasio 2016)

Compute all timescales for **average** BH mass in each cluster, based on cluster metallicity (Spera+ 17 initial-final mass relations, including PISN)

Cluster sizes based on local young clusters (e.g., Portegies Zwart+ 2010)

Mass-segregation of BHs

BH binary formation

via binary-single exchange or three-body interactions

Dynamical evolution of clusters

$a_{gw} > a_{ej}$

Reach GW-dominated phase in-situ

probable **in-situ** merger

BHB hardening

(via 3-body interactions)

$a_{gw} < a_{ej}$

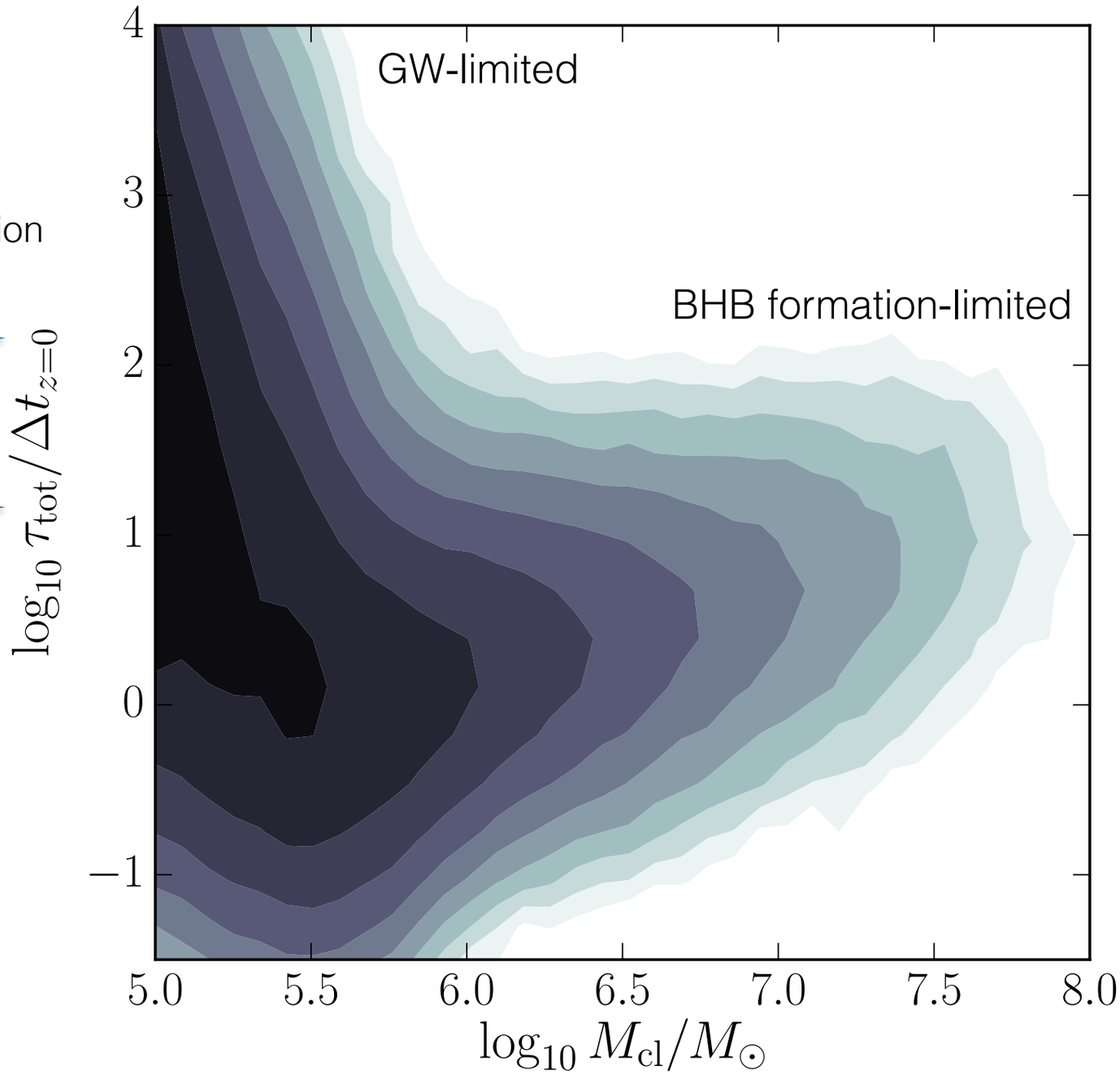
Ejected from cluster before GW regime

possible **ex-situ** merger

Time delay to mergers is typically long

time between cluster formation and z=0

total time to BHB mergers for each cluster



Internal and external timescales compete

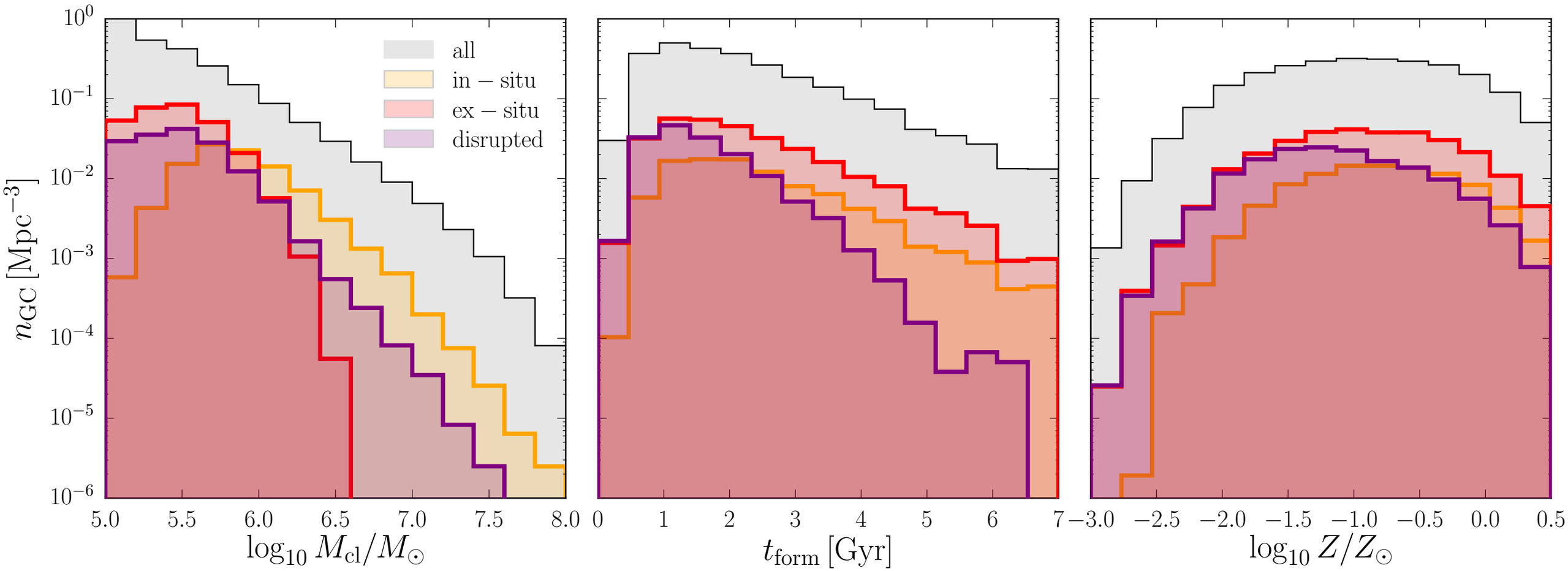
Merger and hardening timescales must be compared to:

Cluster evaporation

Dynamical friction + NSC merger

Both constrained by GC model

The star clusters that make merging black hole binaries

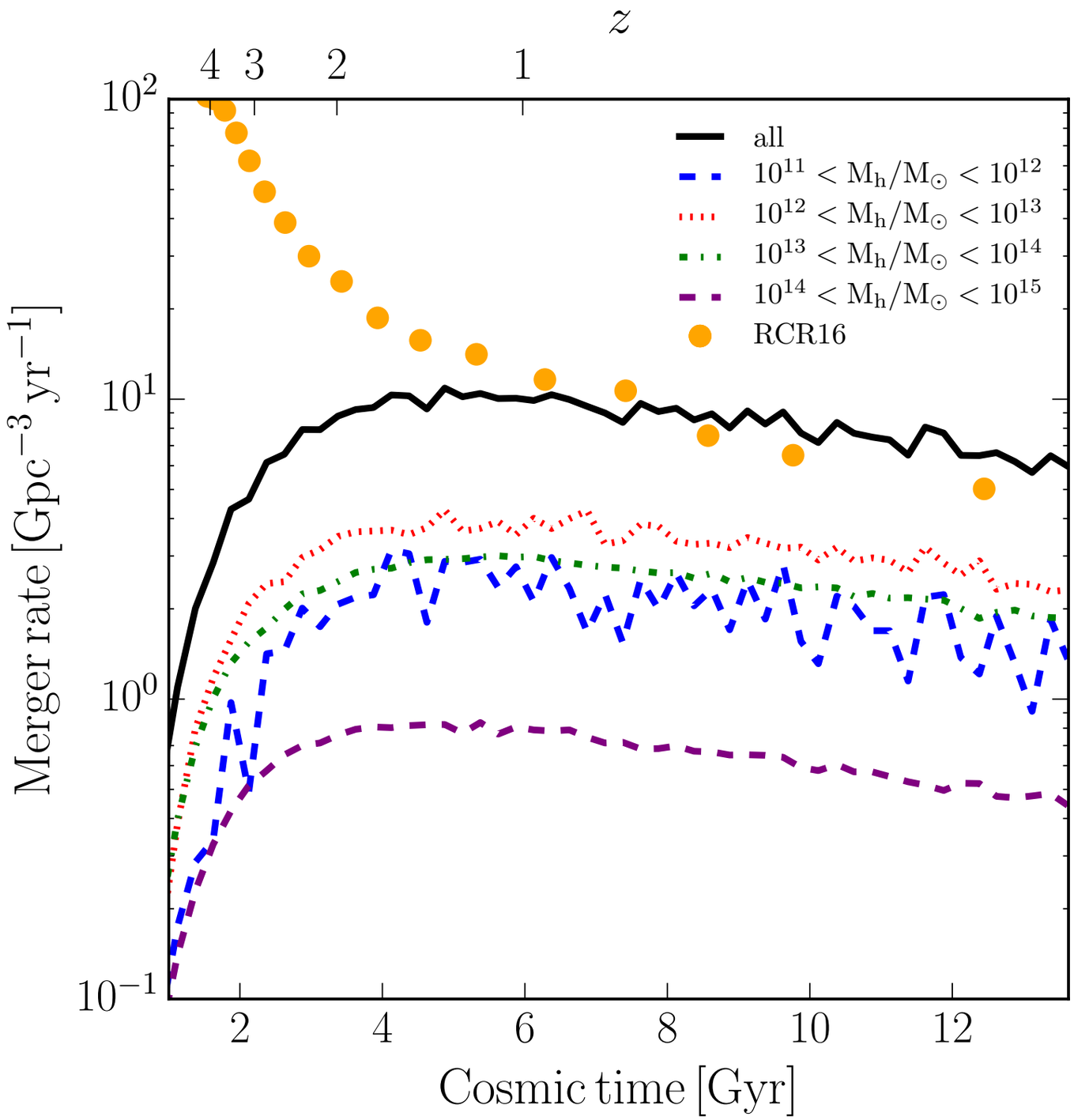


~15% of all clusters **efficiently** form merging BHBs

BHB mergers peak at M_{cl}~ $10^{5.7}$

Hosts of ejected, merging BHBs disrupted by z=0

Redshift evolution of the BHB merger rate



Summary

- Cosmological GC formation model + analytic prescriptions for dynamical evolution
- ~15% of clusters efficiently form merging BHBs
- Typical clusters have: $M \sim 10^{5.7}$, t_{form} ~ 1-2 Gyr, Z ~ 0.1 Zsun
- Dynamical channel may form >10% of observed merger rate
- Merger rate peaks at z~1.5
- ~50% of hosts of merging BHBs disrupted by z=0
- Next steps: Monte Carlo binary draw for more accurate merger rate