

Black Hole Binary Formation through Stellar Dynamics in Globular Clusters

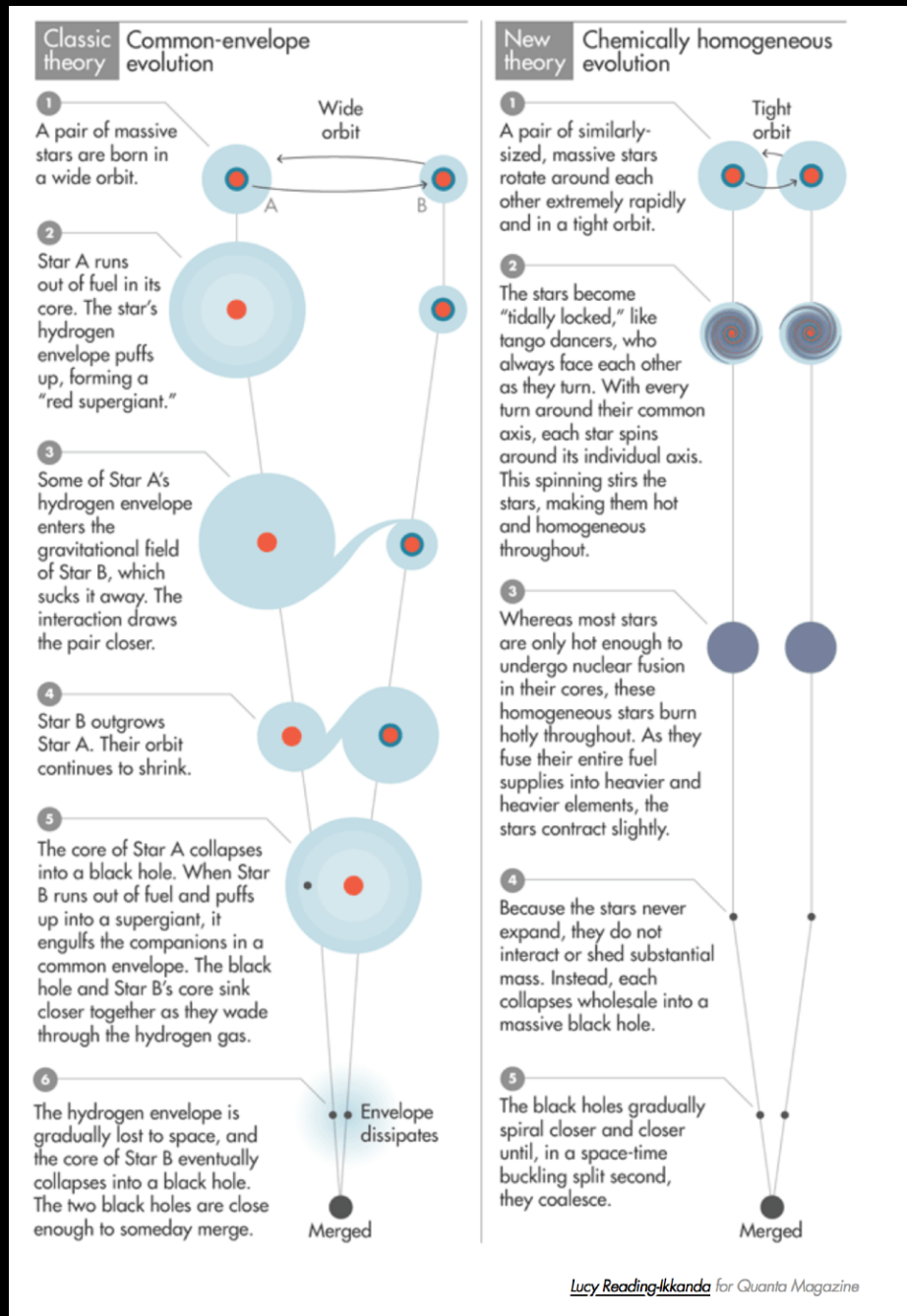
Fred Rasio

CIERA

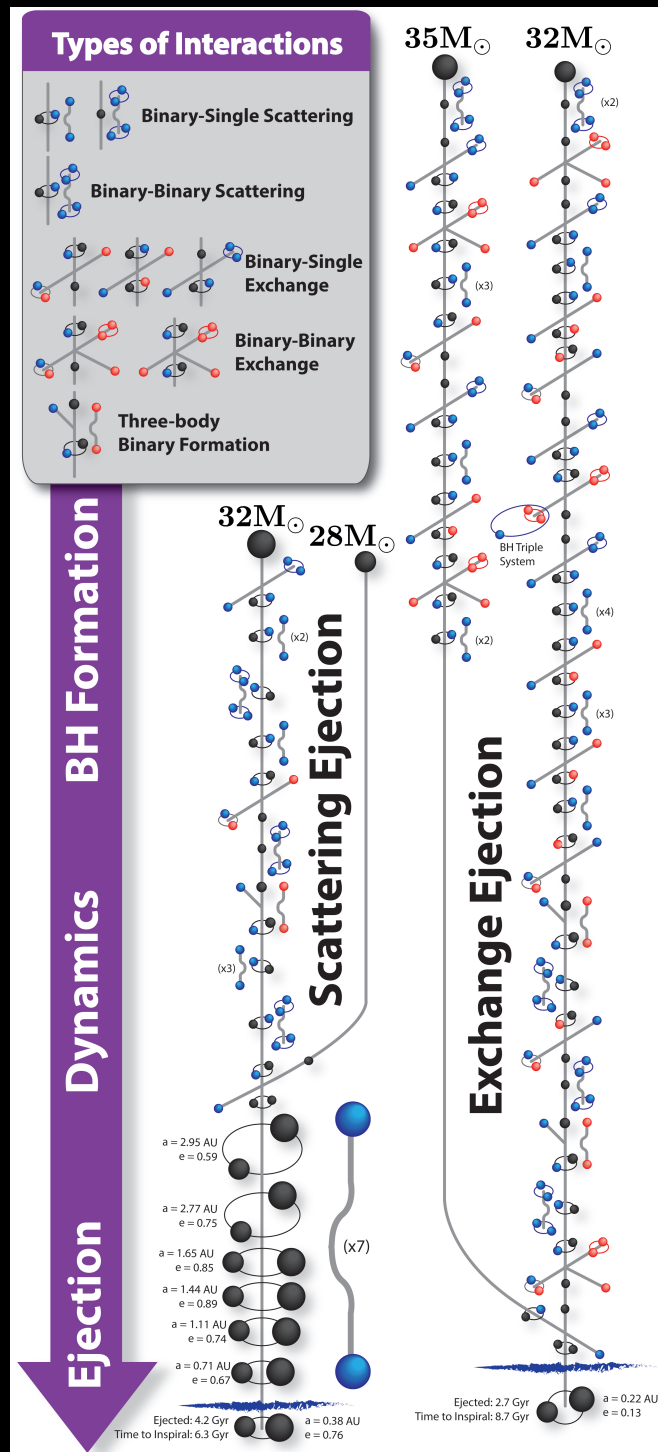
Northwestern University

2018 Sackler Conference on
Gravitational Wave Astrophysics

Binary evolution vs Dynamics:



(Many recent papers by Belczynski, de Mink, Ivanova, Mandel, Mapelli, Marchant, O'Shaughnessy, etc.)

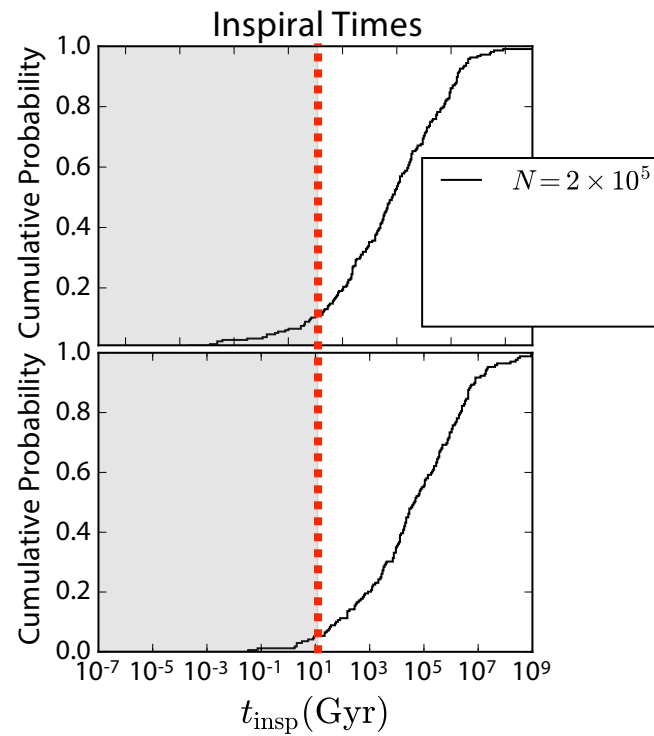
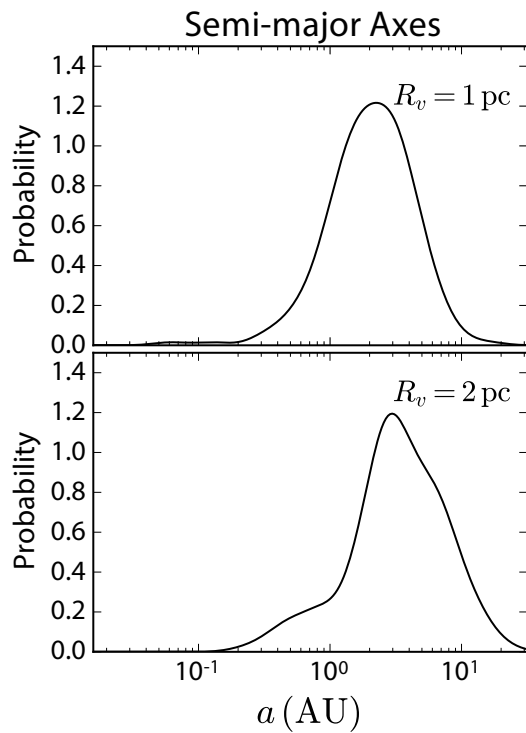


(from Rodriguez et al. 2016, ApJL, 824, L8)

Black Holes in Globular Clusters

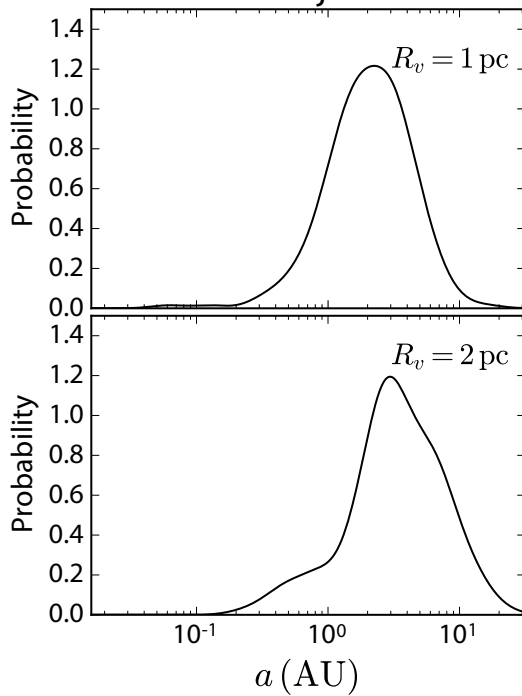
- Growing observational evidence (ULXs, breaks in XLFs, several good candidates in MW GCs ← Giesers et al. 2018 got first dynamical mass measurement!)
- Expected to form in large numbers ($\sim 10^{-3}$ N BHs per N stars) and initially retained in GCs (Belczynski et al. 2006; Fryer et al. 2012)
- Large numbers of BHs may be retained in GCs for their entire lifetimes (Breen & Heggie 2013; Morscher et al. 2013, 2015; Heggie & Giersz 2014)
- May determine overall GC structural parameters (Kremer et al. 2018)
- Key physical process: mass segregation leading to central dense core of BHs undergoing strong chaotic interactions, hardening and ejecting binary BHs (Portegies Zwart & McMillan 2000; Rodriguez et al. 2015, 2016)

Why Globular Clusters?

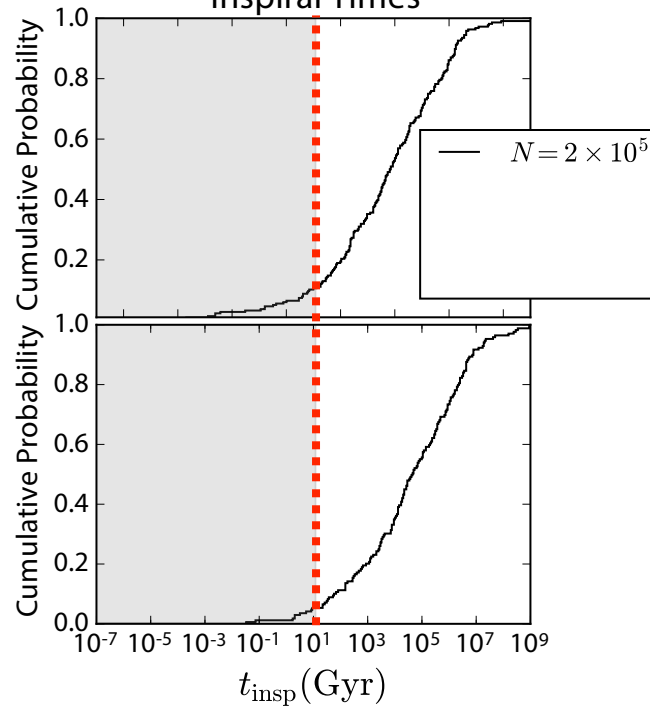


Why Globular Clusters?

Semi-major Axes

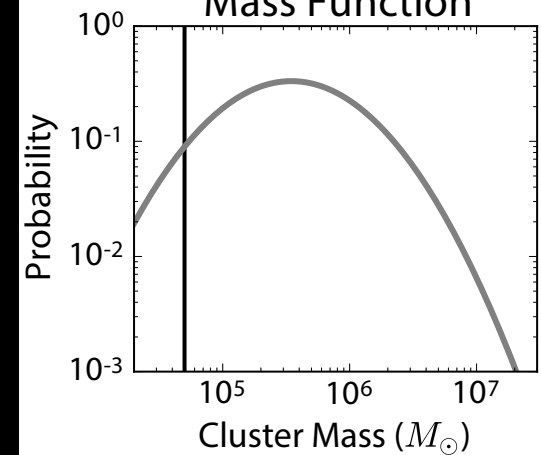


Inspiral Times



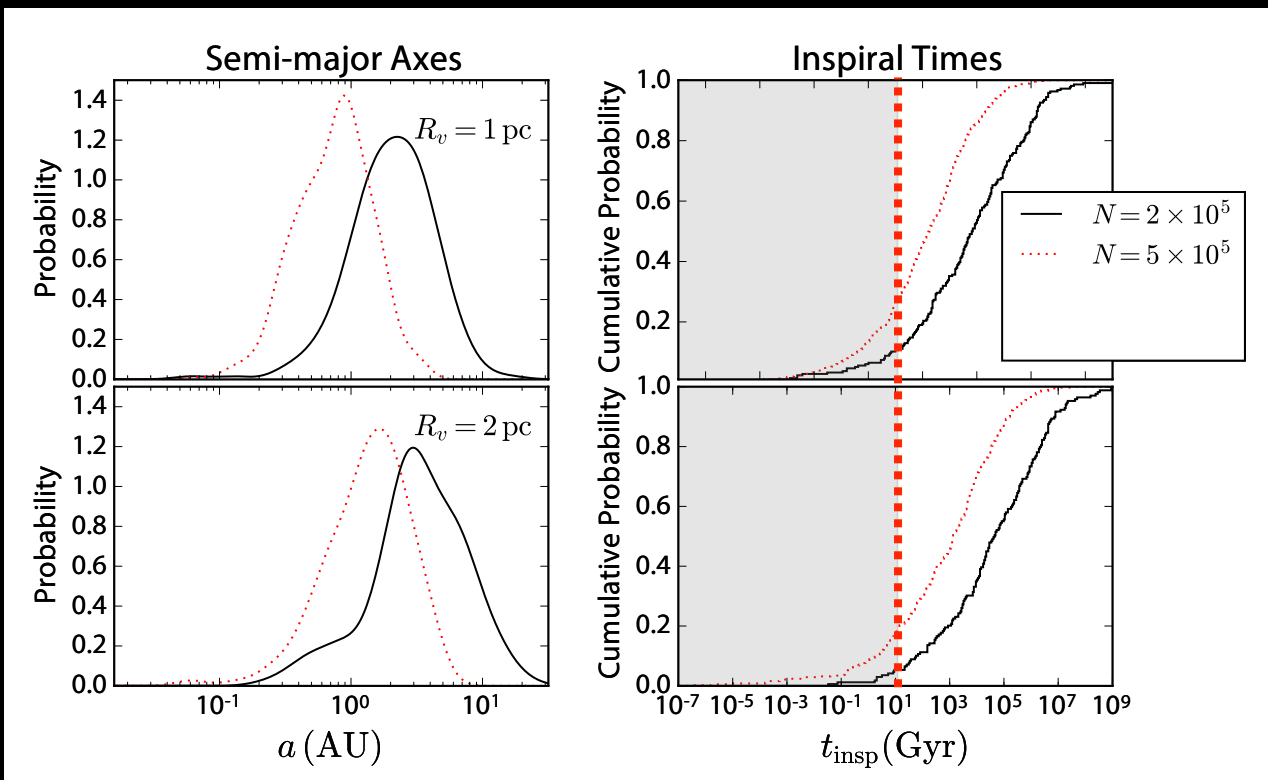
from Harris, 2014

Globular Cluster Mass Function

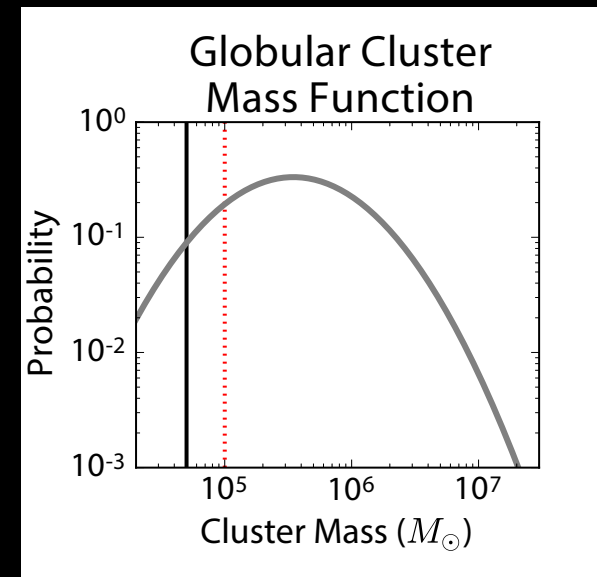


Cluster Mass (M_{\odot})

Why Globular Clusters?

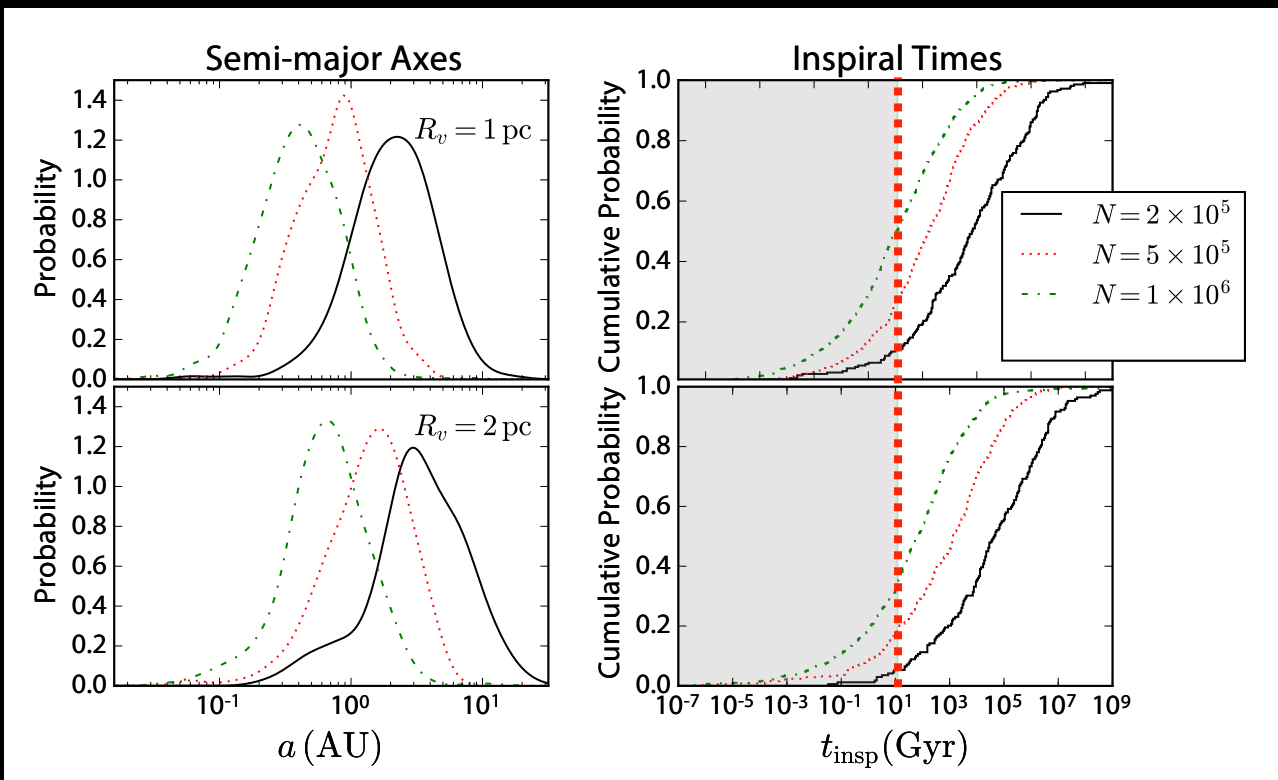


from Harris, 2014

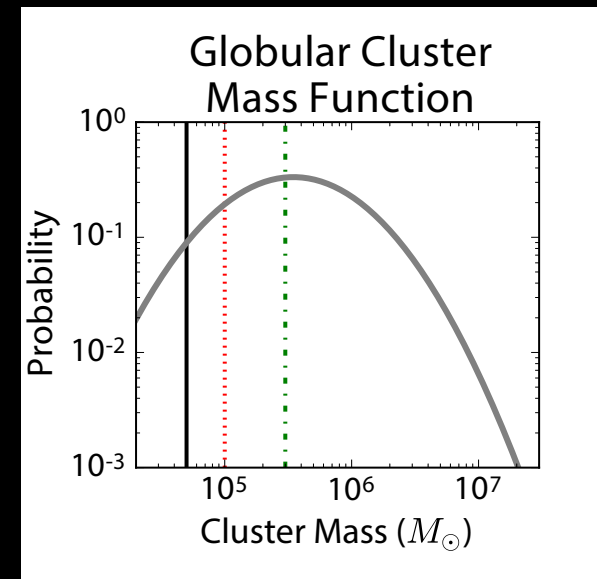


Cluster Mass (M_{\odot})

Why Globular Clusters?

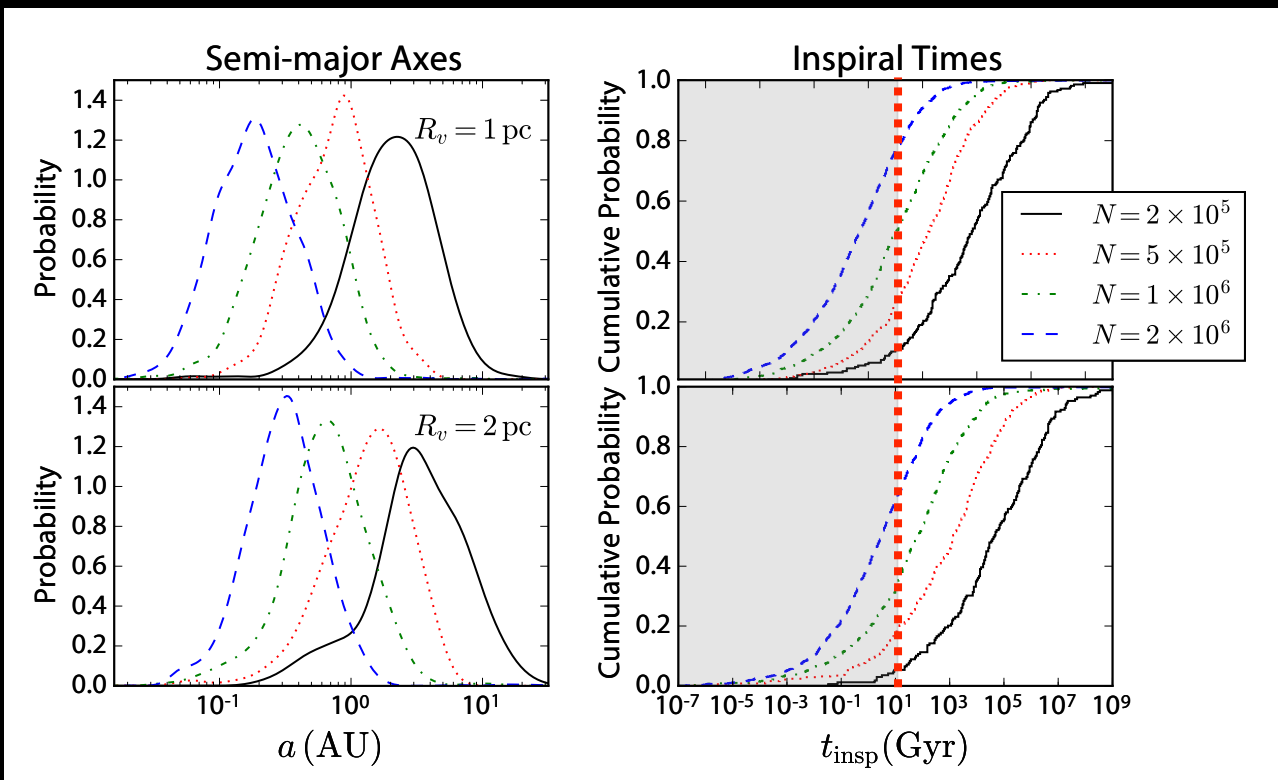


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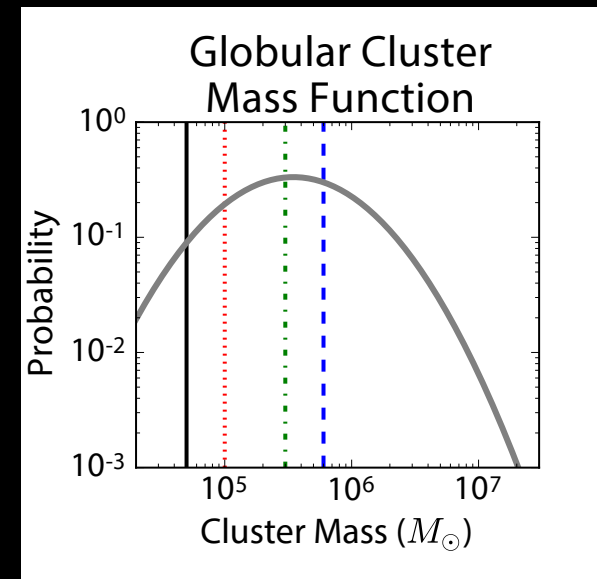


Cluster Mass (M_{\odot})

Why Globular Clusters?



from Harris, 2014



Cluster Mass (M_\odot)

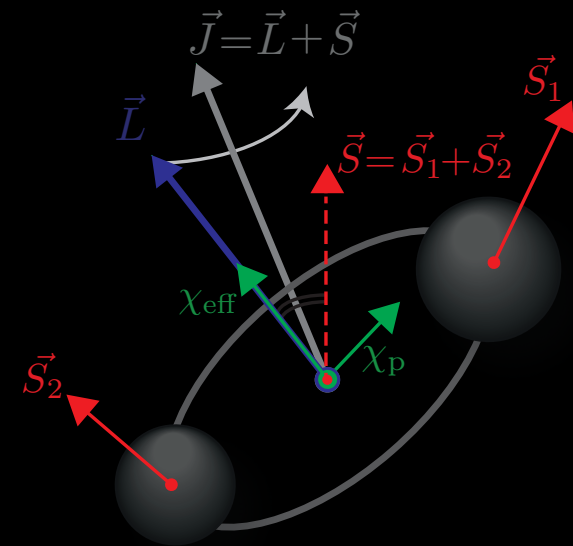
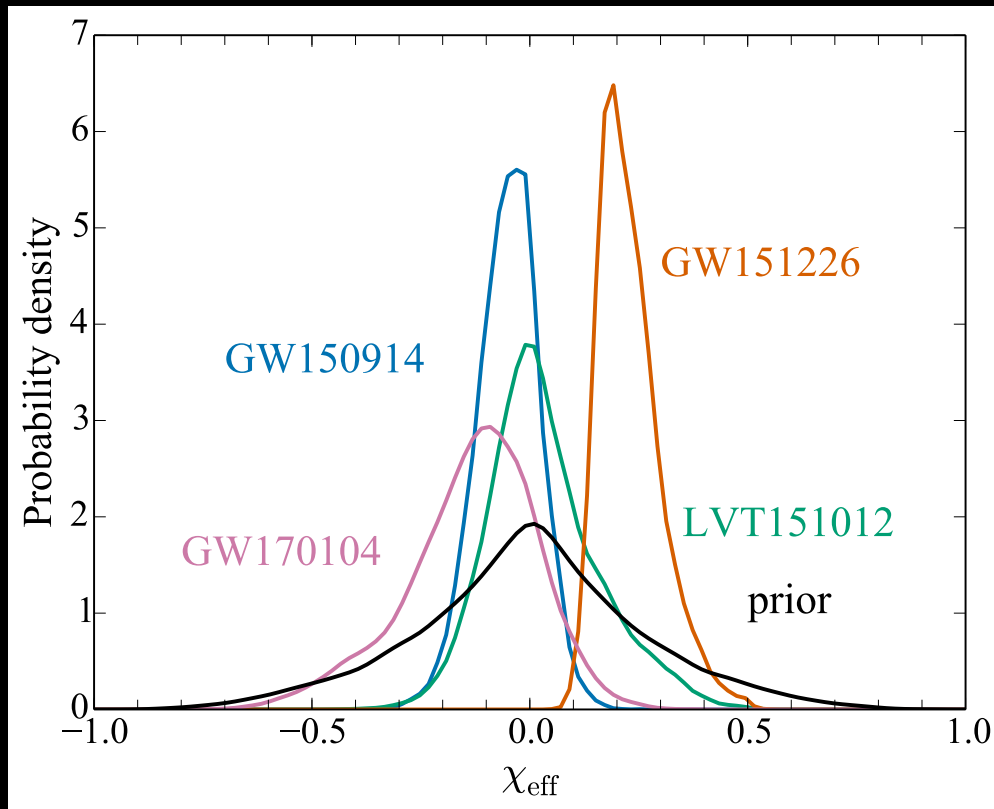
Binary Evolution vs Dynamics

- **Merger rates** (High enough? Too high? Agree with empirical value?)
- **Masses and mass ratios** (Different classes? Metallicity dependence?)
- **Eccentricity** (Decays during inspiral!)
- **Spins** (Magnitudes? Alignment with binary axis?)

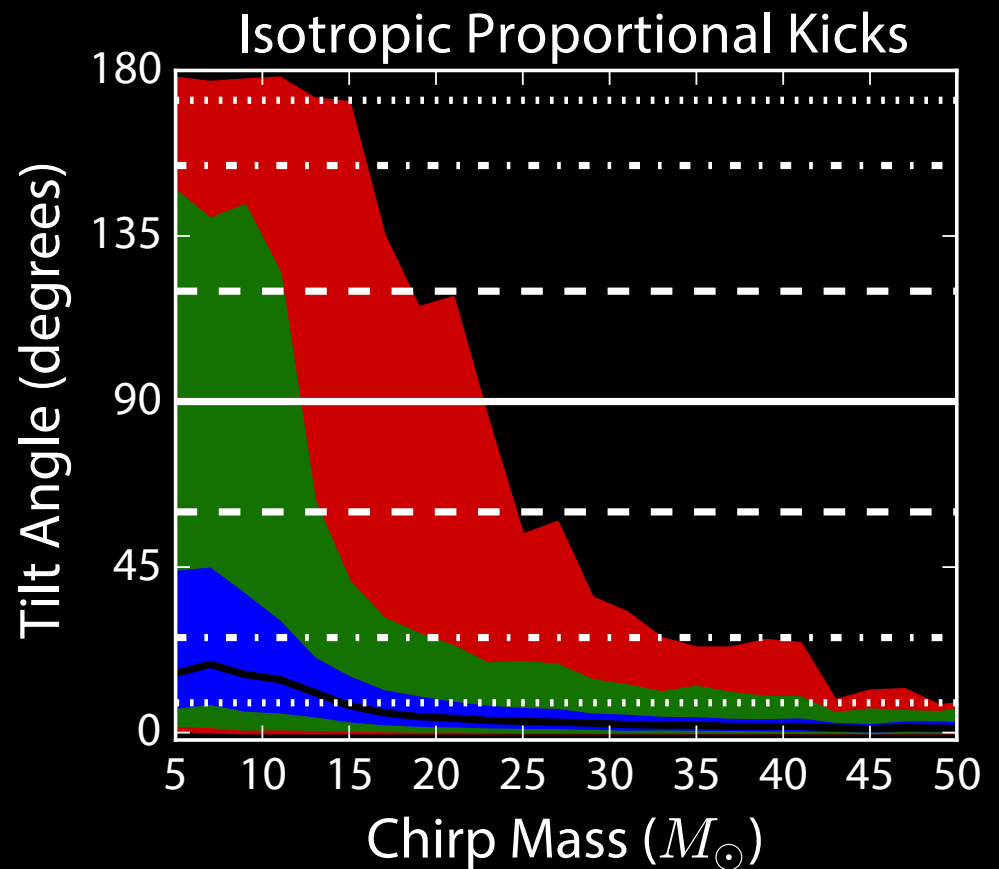
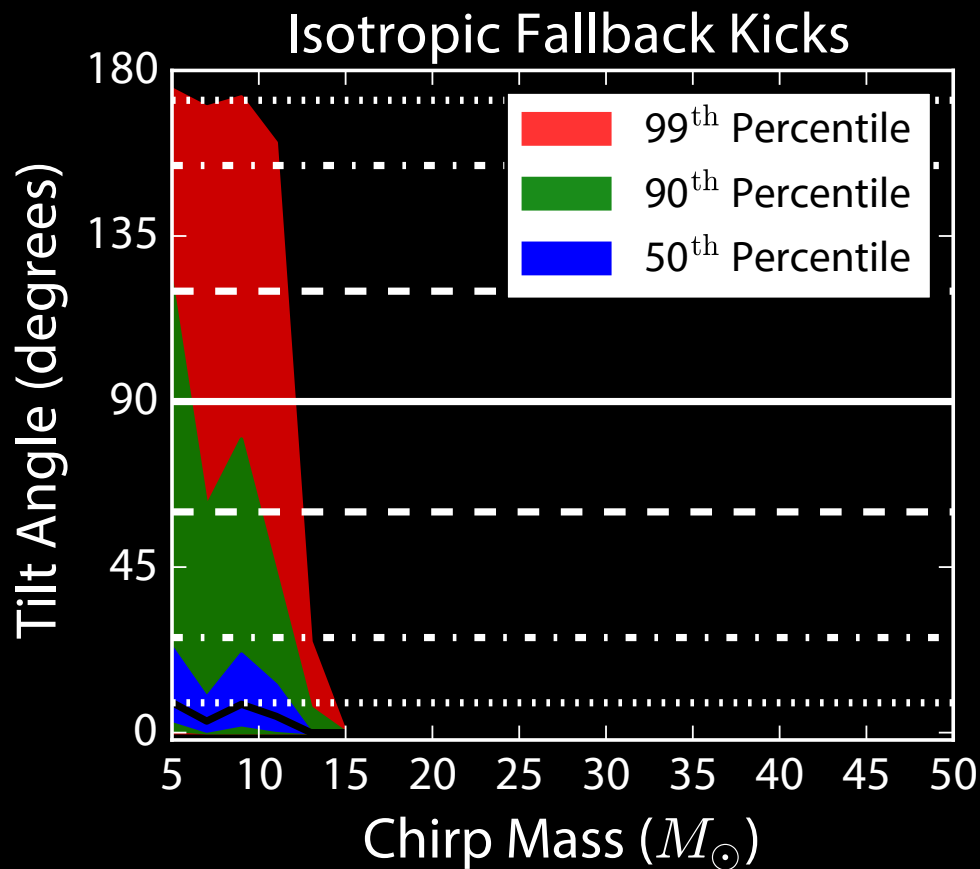
Binary Evolution vs Dynamics

- Merger rates ← highly uncertain
- Masses and mass ratios ← maybe after
hundreds of detections (Zevin et al. 2017, ApJ, 846, 82)
- Eccentricity ← with LISA for sure; maybe also with
LIGO (Breivik et al. 2016, ApJL, 830, L18; Rodriguez et al. 2018 PRL, 120, 151101)
- Spins ← most promising! (Rodriguez et al. 2016, ApJL, 832,
L2; Farr et al. 2017, Nature, 548, 426)

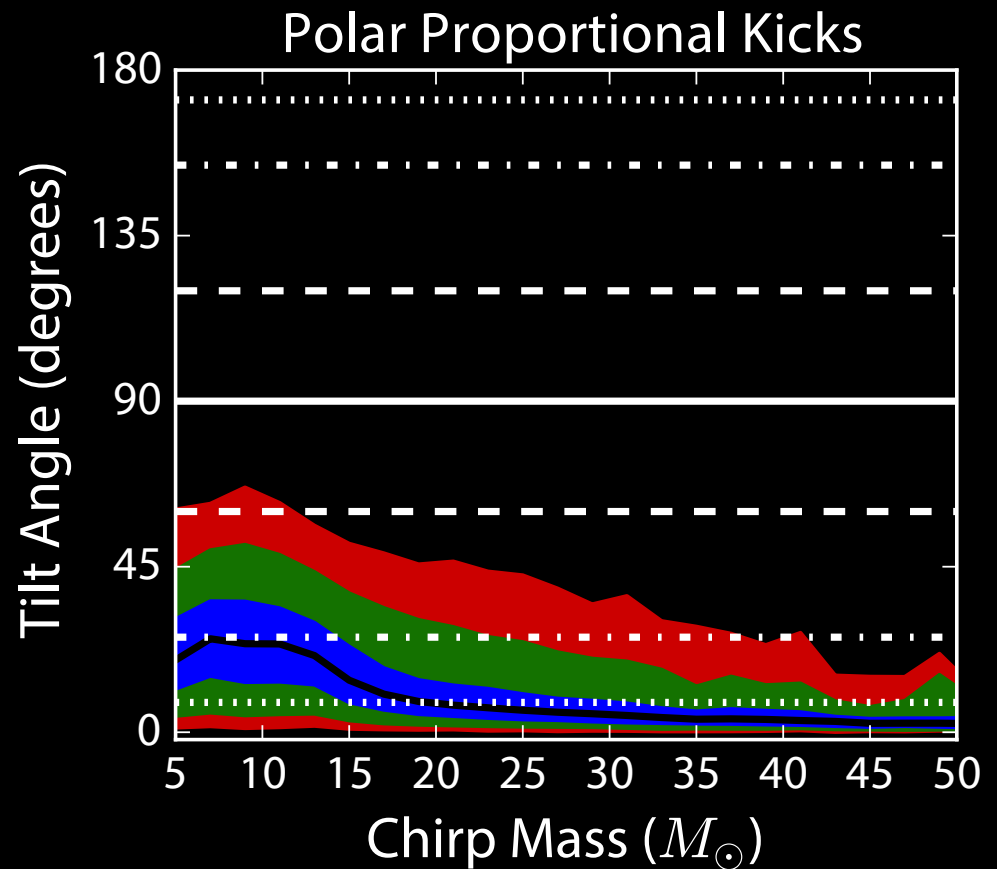
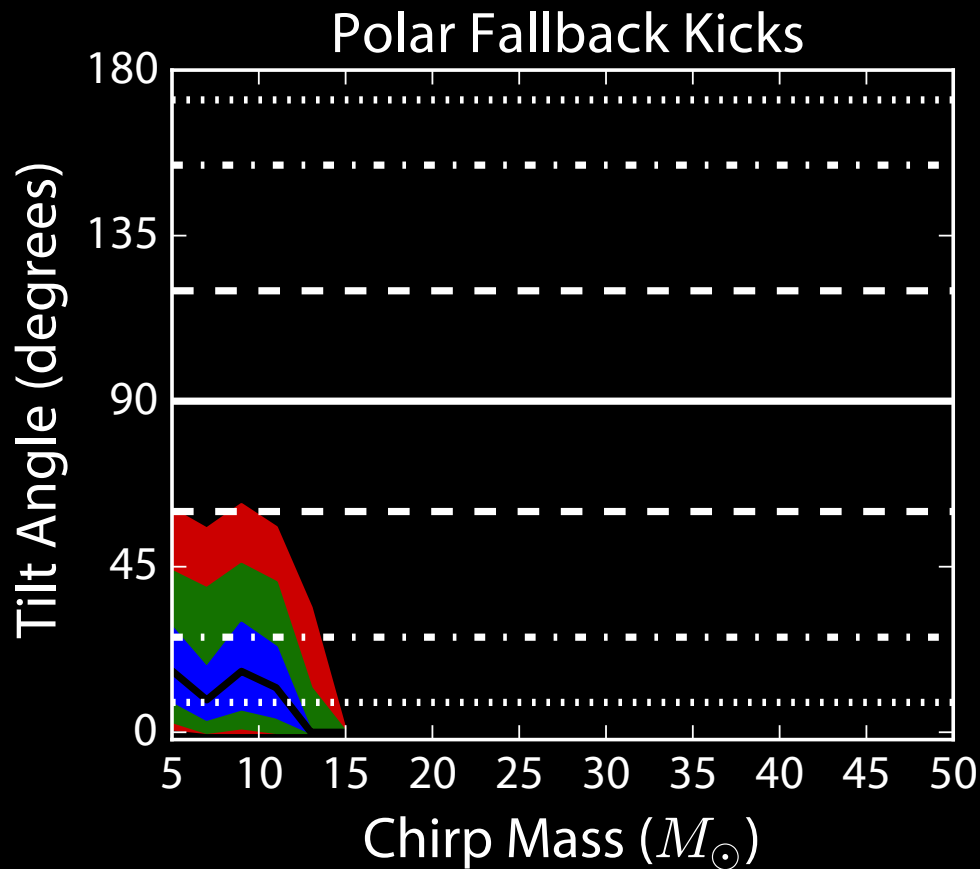
Binary Evolution vs Dynamics: spins



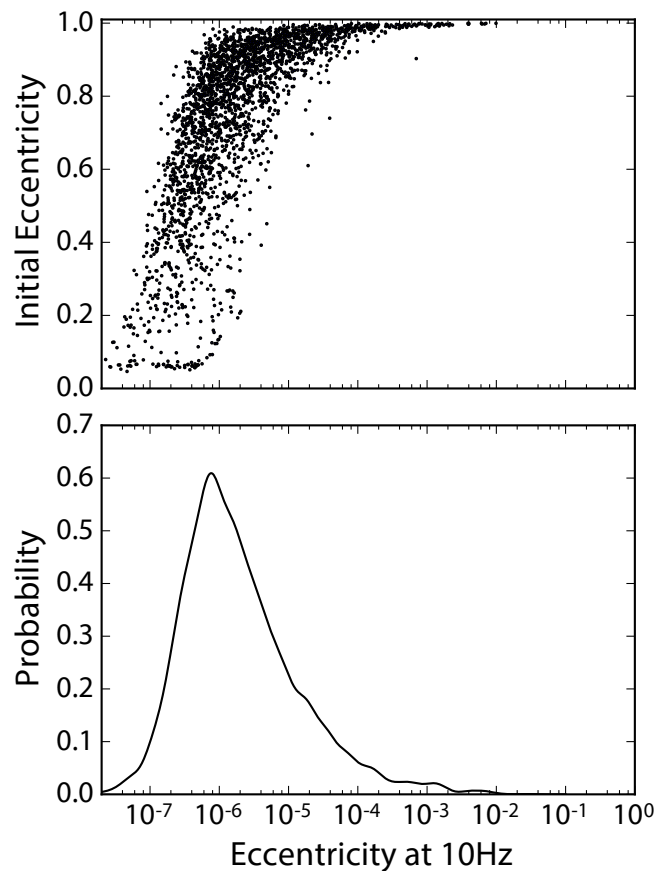
Binary Evolution vs Dynamics: spins



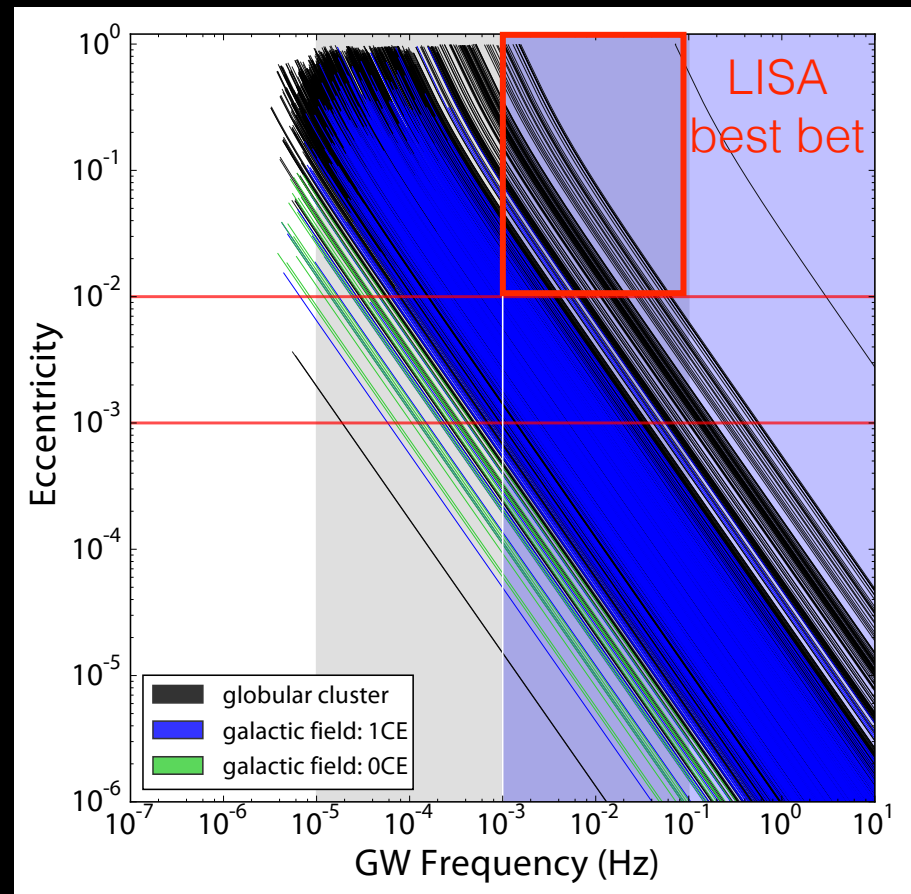
Binary Evolution vs Dynamics: spins



Binary Evolution vs Dynamics: eccentricity

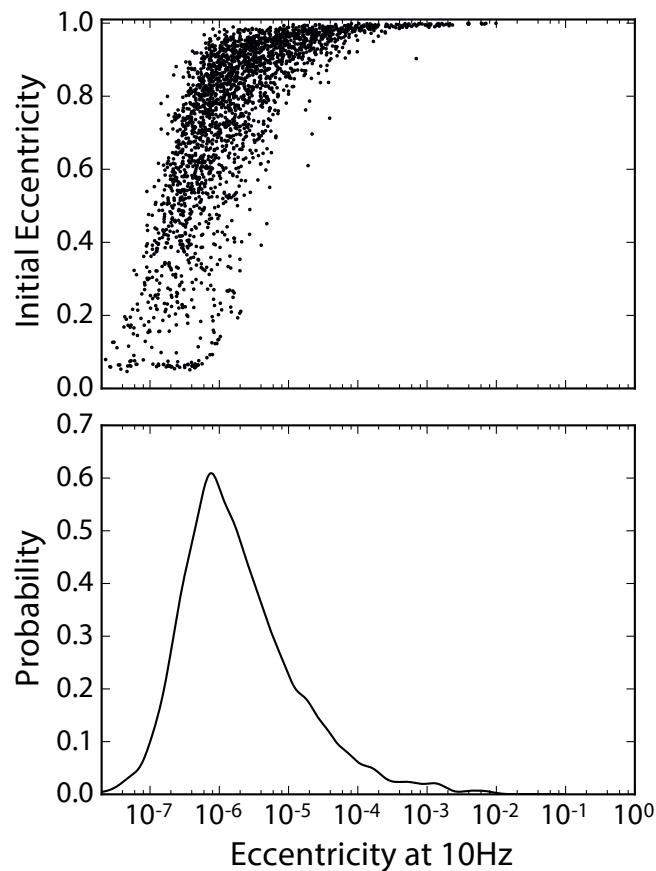


Rodriguez et al. 2016, ApJL, 832, L2



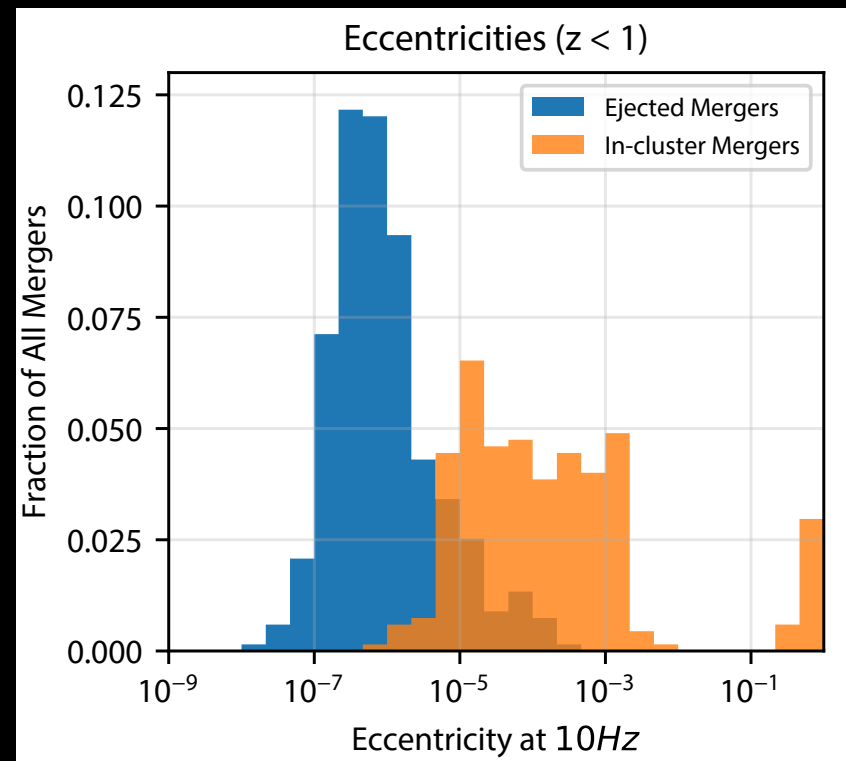
Breivik et al. 2016, ApJL, 830, L18

Binary Evolution vs Dynamics: eccentricity



Rodriguez et al. 2016, ApJL, 832,L2

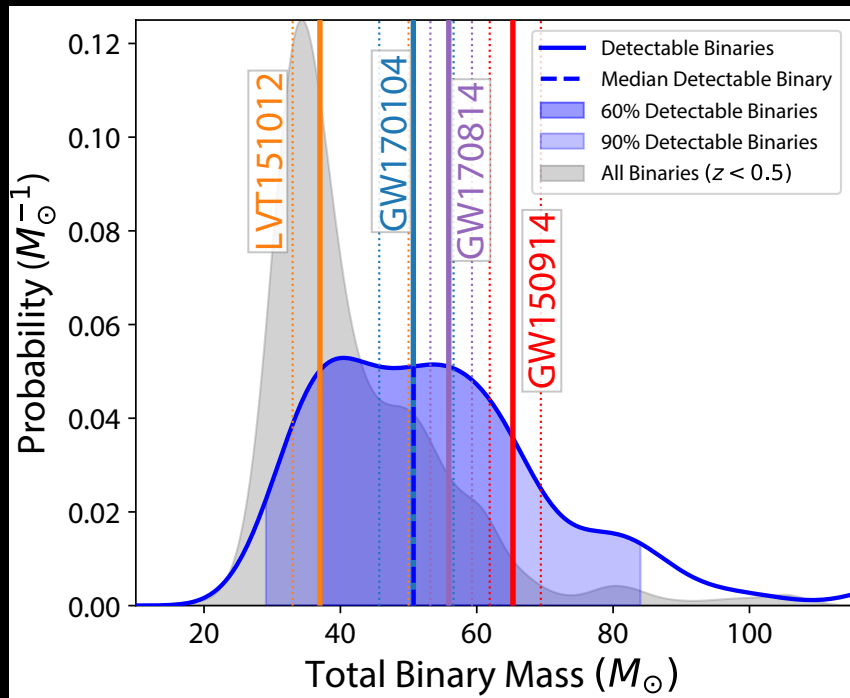
With PN effects:



Rodriguez et al. 2018 PRL, 120, 151101
(agrees with Samsing & Ramirez-Ruiz 2017, ApJL, 840, L14; Samsing et al. 2018, ApJ, 855, 124)

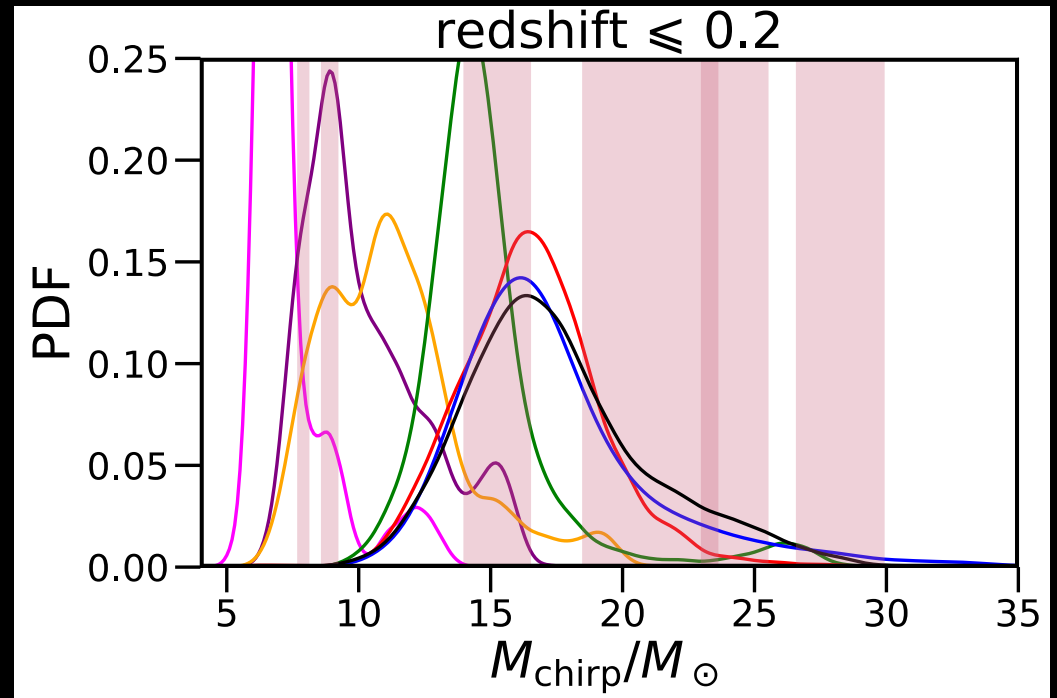
Binary Evolution vs Dynamics: masses

Old, low-Z Globular Clusters:



Updated version of Fig. 2 in
Rodriguez et al. 2016 ApJL, 824, L8

Younger, higher-Z Clusters:



Updated version of Fig. 3 in
Chatterjee et al. 2017 ApJL, 836, L26
(see also Banerjee 2017, 2018, MNRAS)

Binary Evolution vs Dynamics: rates

- BBH merger rate from LIGO: $12 - 213 \text{ Gpc}^{-3} \text{ yr}^{-1}$
- Most recent estimates from binary population synthesis:
 $\sim 0 - 10^3 \text{ Gpc}^{-3} \text{ yr}^{-1}$ (Abadie et al. 2010, CQG, 27,173001)
- Best estimate for dynamically produced sources:
 - From old GCs: $\sim 5 - 50 \text{ Gpc}^{-3} \text{ yr}^{-1}$
(Rodriguez et al. 2015, PRL, 115, 051101; Askar et al. 2017, MNRAS, 464, L36; Park et al. 2017, MNRAS 469, 4665; Fuji et al. 2017, PASJ, 69, 94)
 - From all star clusters: $\gg 10 \text{ Gpc}^{-3} \text{ yr}^{-1}$?