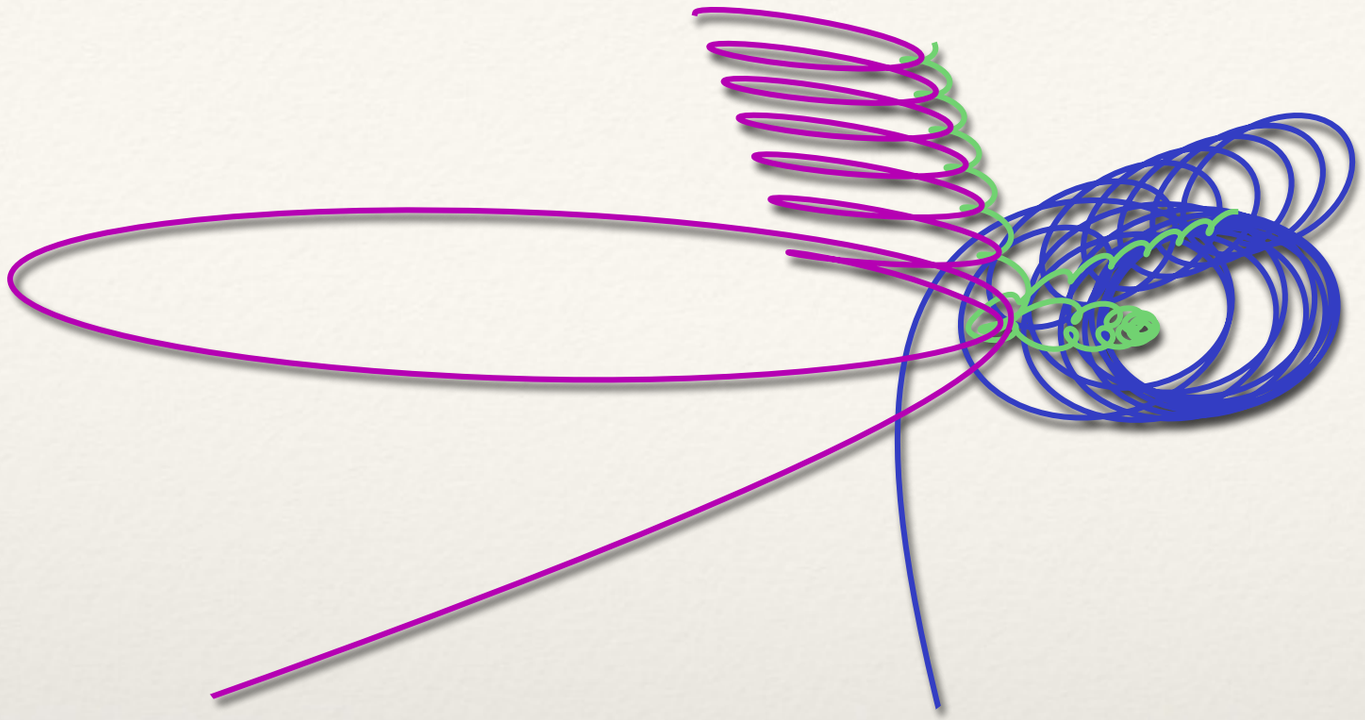

Black Hole + Neutron Star Binaries in Globular Clusters

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Black Holes in Dense Star Clusters - January 19, 2015

Dynamical Models

Inputs:

- Static, King background cluster models with evolved stellar populations
- 5-20% of neutron stars and 1-40 stellar mass BH are retained
- Vary cluster structure, binary population, binary fraction

Evolution:

- Perform 2,000 realizations of a black hole binary's evolution
- Fokker-Planck evolution of binary's orbit
- Compute the probability that the binary will interact with a background star along its path

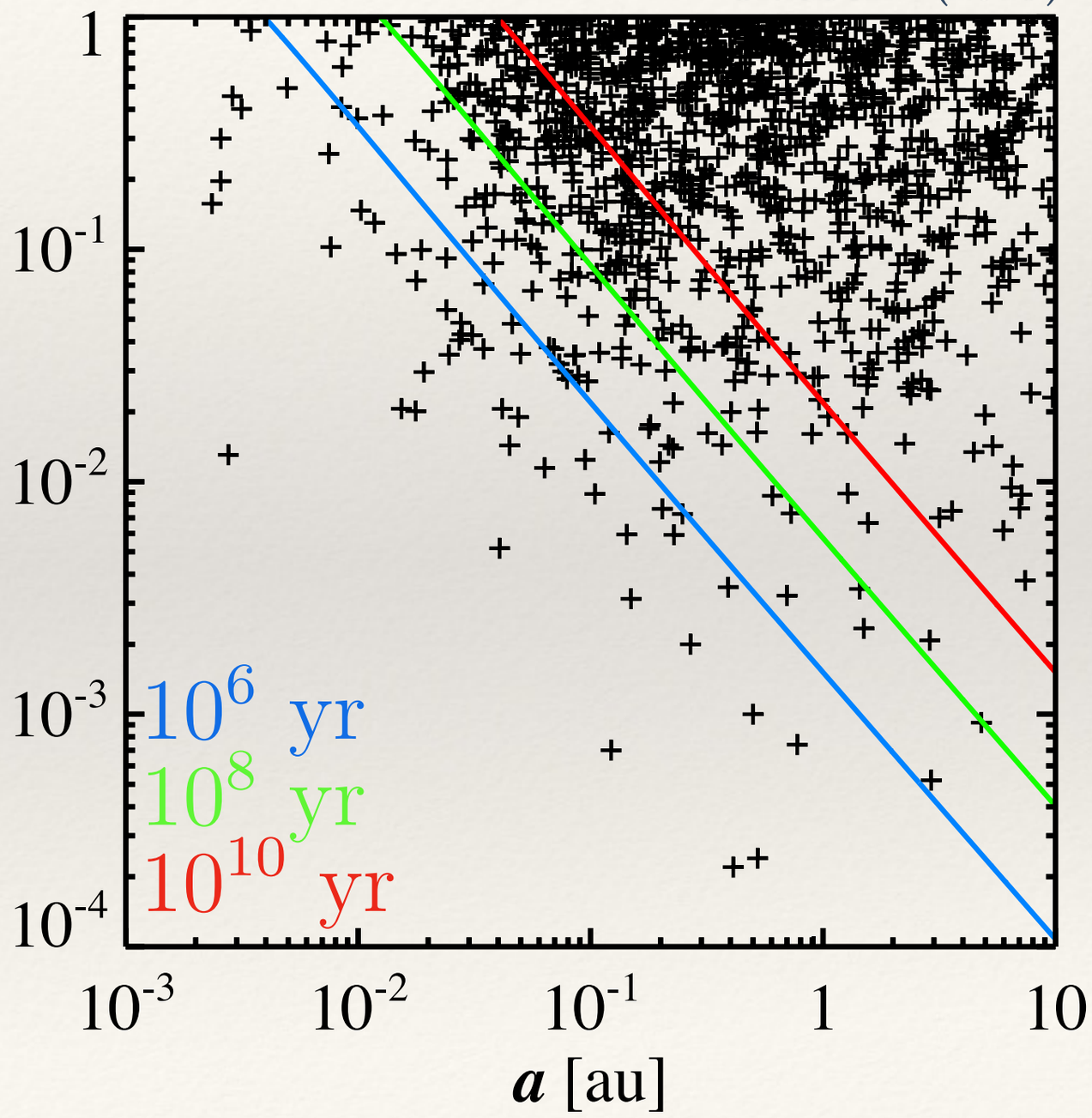
Three-body Encounters:

- Interested in cases that result in a neutron star exchanging into the binary.

Dynamically Formed BH+NS

- Efficiency of BH+NS formation is sensitive to cluster structure and binary fraction
  - 0.2% of the realizations produce BH+NS in low concentration, low binary fraction simulations
  - 86% of the realizations in high concentration high binary fraction produce BH +NS

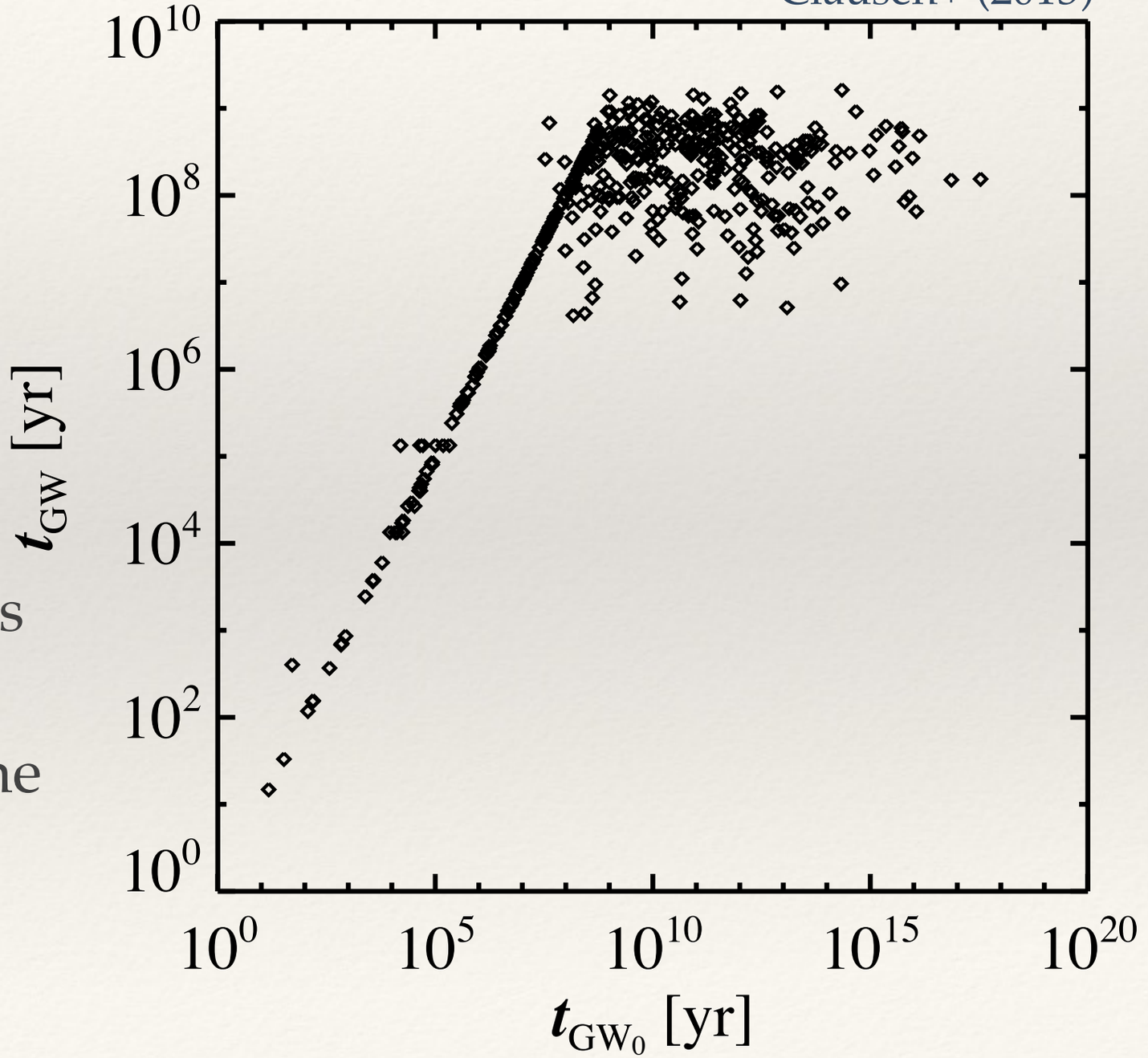
Clausen+ (2013)



BH+NS Mergers

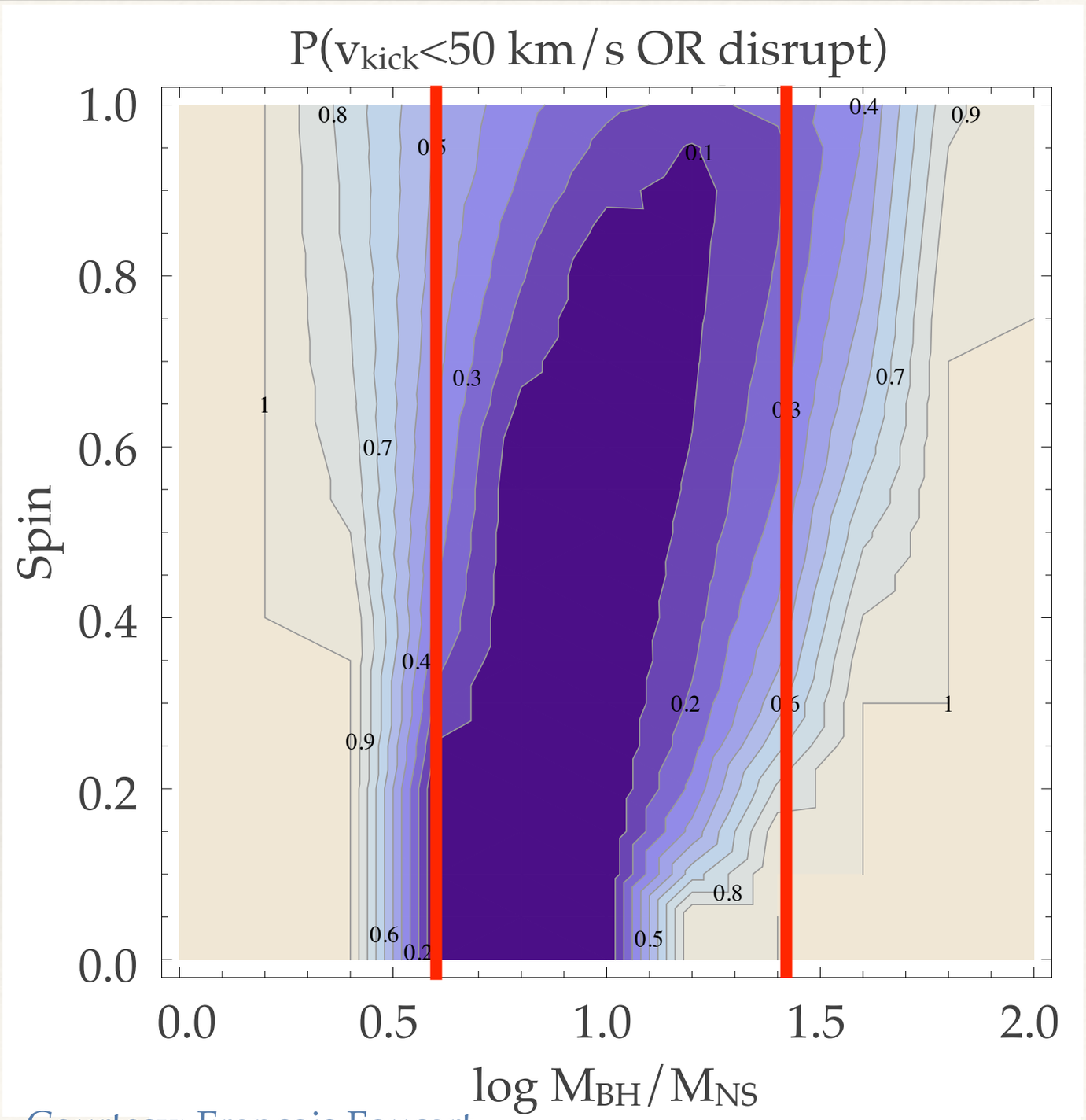
- Low concentration clusters:
  - Encounters with massive WDs destroy BH+NS binaries.
- High concentration clusters:
  - Encounters with single stars after the formation of the BH+NS binary accelerate the merger process.

Clausen+ (2013)



Merger Recoils

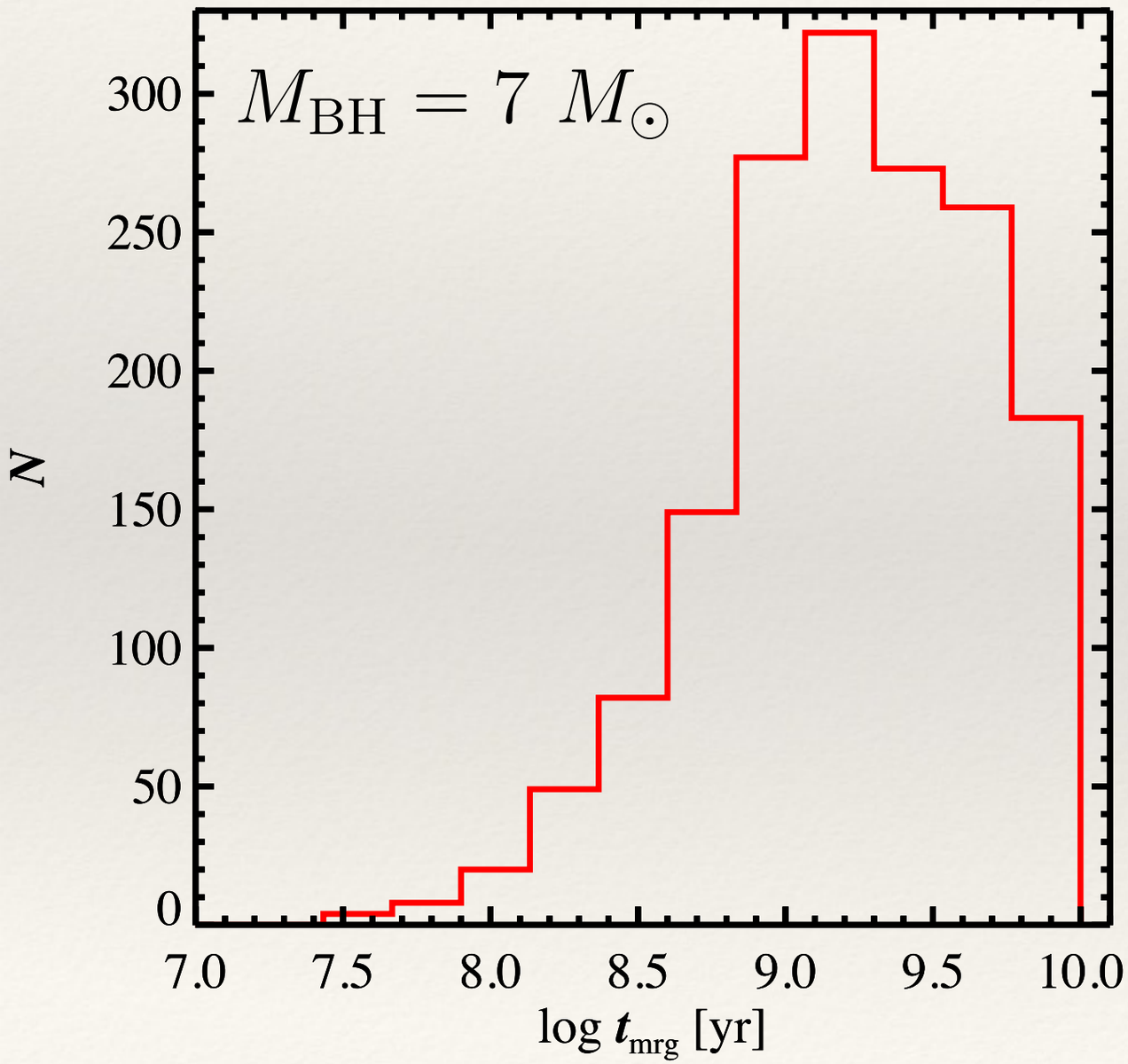
- Merging compact binaries are "kicked" due to anisotropic emission of gravitational radiation.
  - $7\ M_\odot$ + NS:
    $v_{\rm kick} = 70 - 140\ {\rm km\ s^{-1}}$
    Etienne+ (2009); Shibata+ (2009); Foucart+ (2011)
  - $35\ M_\odot$ + NS:
    $v_{\rm kick} = 10 - 100\ {\rm km\ s^{-1}}$
    Gonzalez+ (2007); Campanelli + (2007)

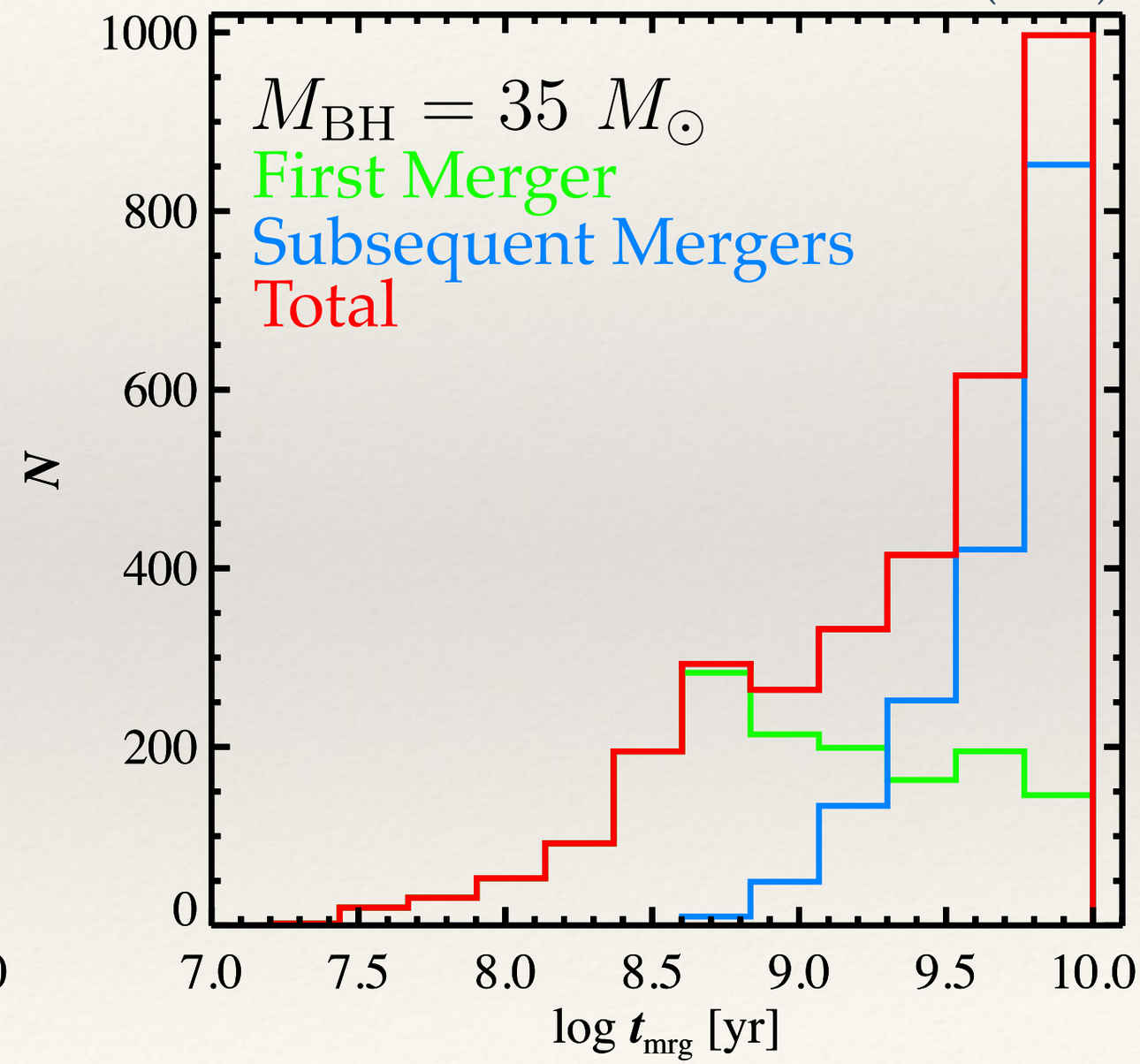


Courtesy: Francois Foucart

BH-NS Merger Time Distributions

Clausen+ (2013)





Are the mergers detectable?

Merger rate depends critically on the BH mass

$M_{\rm BH} \sim 7\ M_\odot$

- Mergers occur at high redshift and are undetectable by aLIGO.
- Black holes are extremely rare in high concentration clusters in the current epoch.

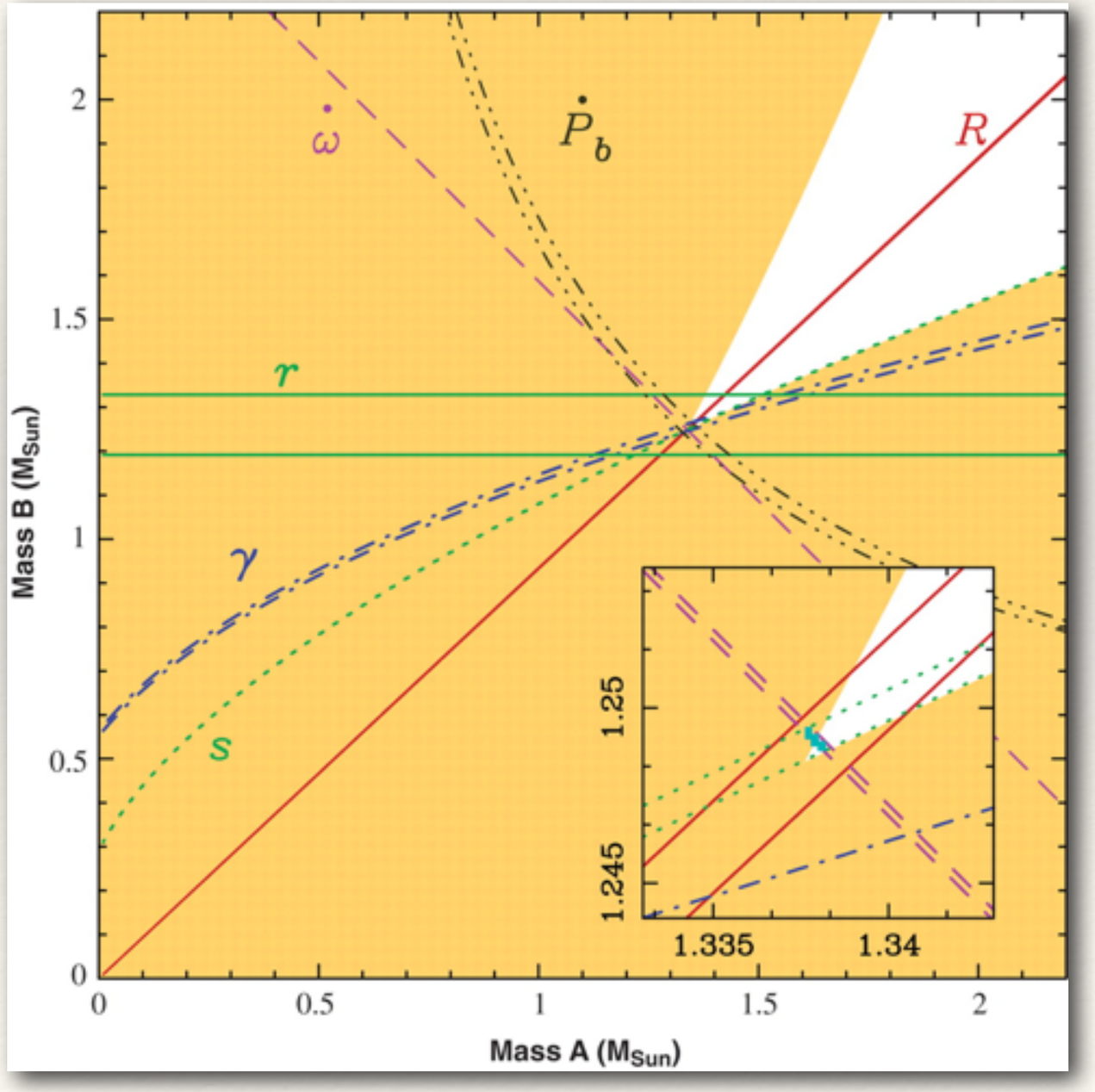
$M_{\rm BH} \sim 35\ M_\odot$

- Predicted aLIGO BH-NS merger detection rate: 0.04 - 0.72 $\rm yr^{-1}$
- Could be the dominant channel for BH+NS mergers detectable by aLIGO and next generation GW detectors.

Black Hole + Millisecond Pulsar

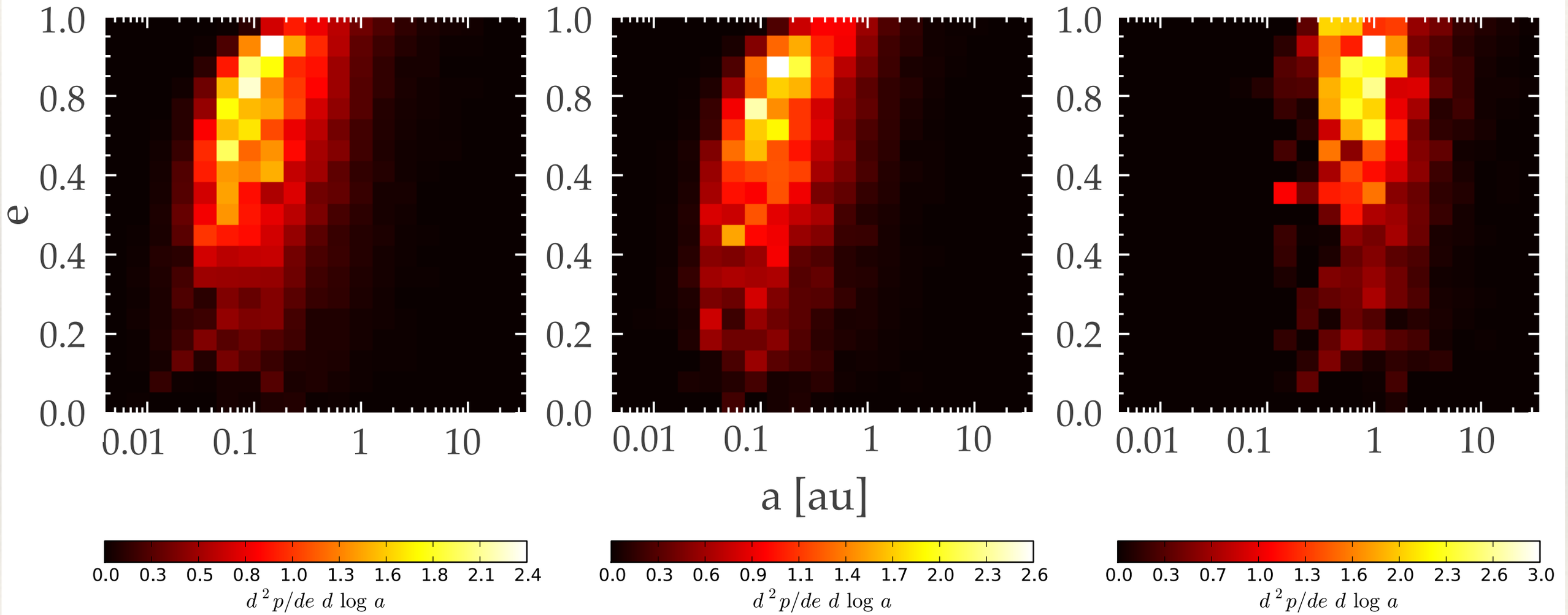
- If the NS were recycled into a millisecond pulsar before exchanging into a BH-binary, we could observe these systems in the EM-band.
  - Additional probe of globular cluster BH population
  - Test of General Relativity in the strong field regime

PSR J0737-3039A/B Kramer+ (2006)

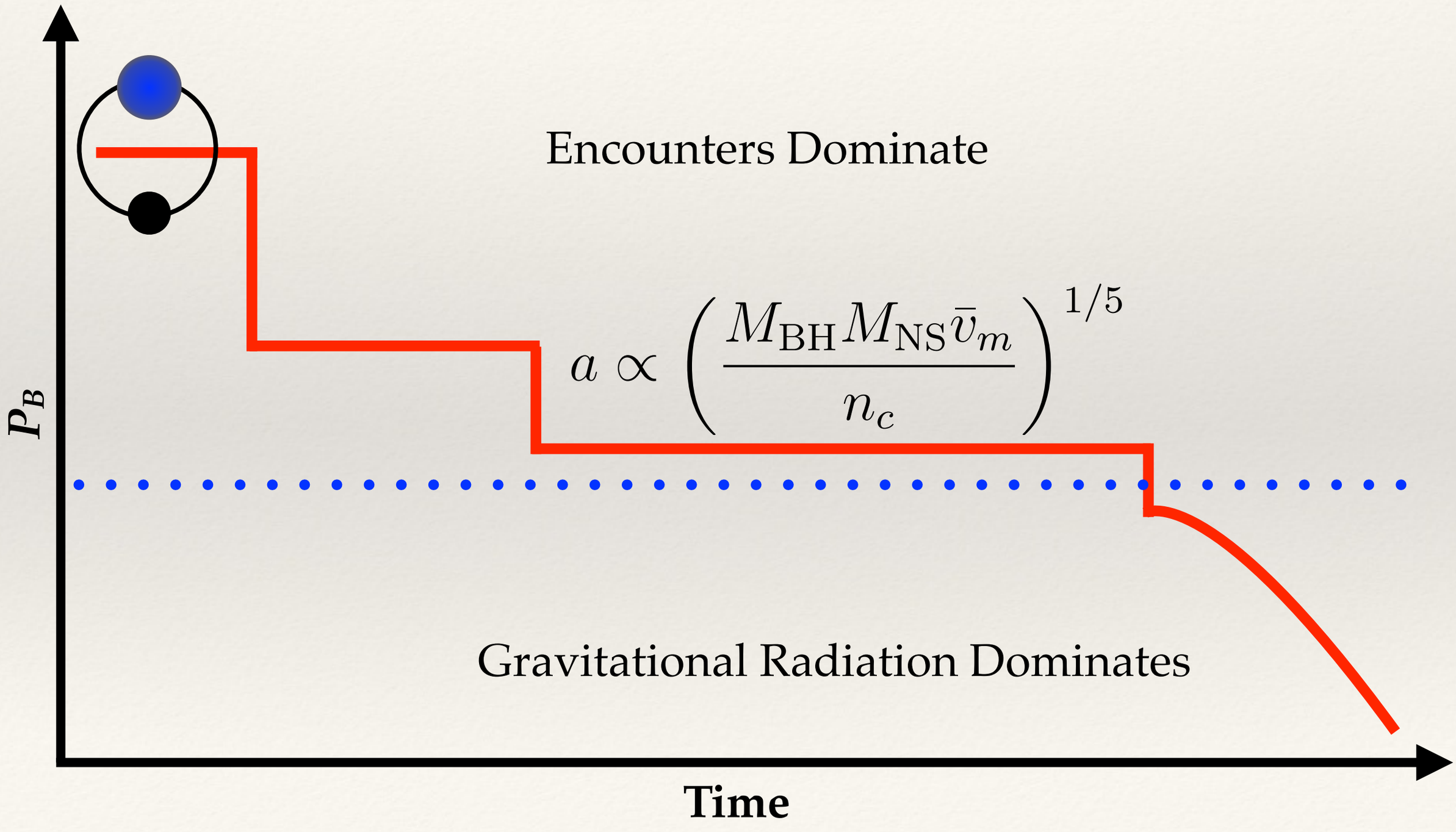


Orbital Parameters

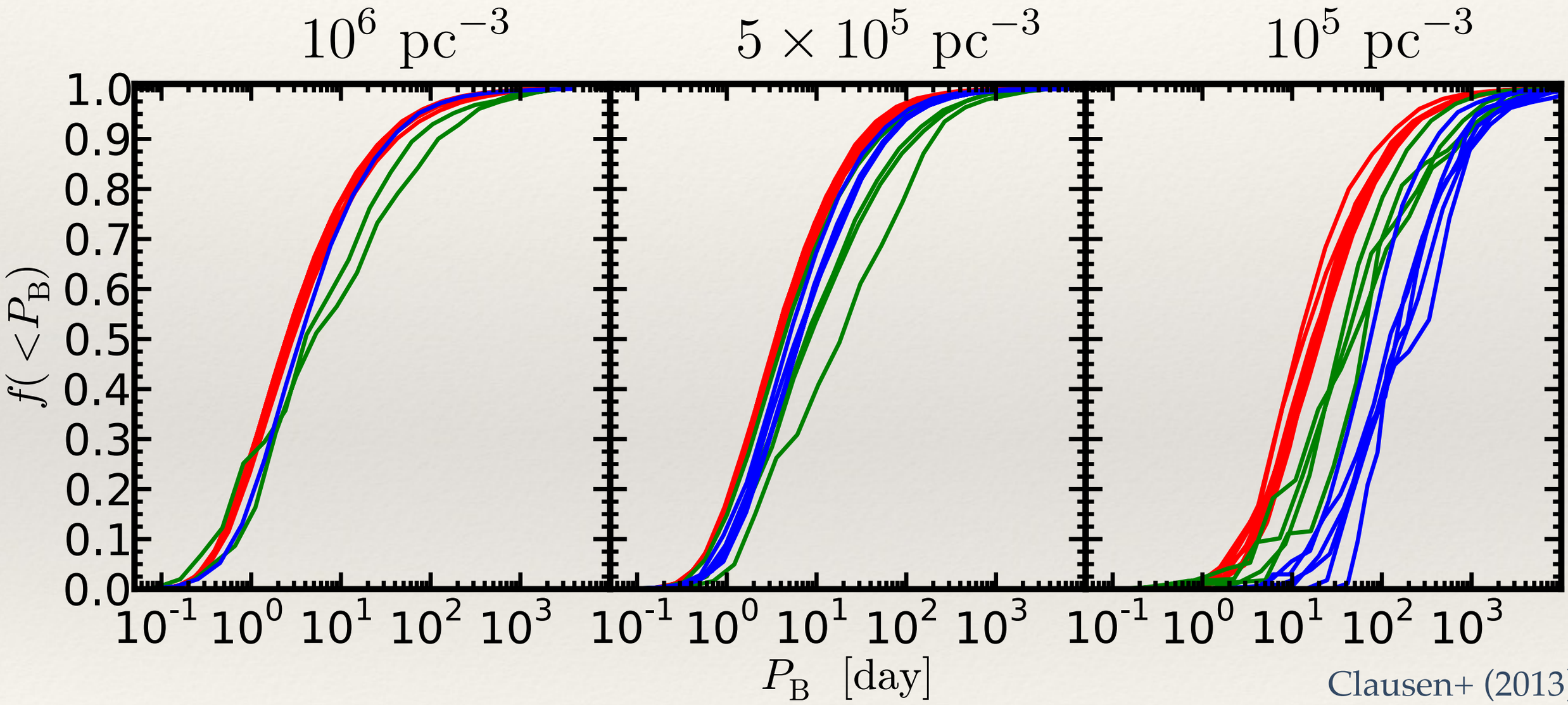
Clausen+ (2014)



Orbital Evolution



Orbital Periods: Cumulative Distributions

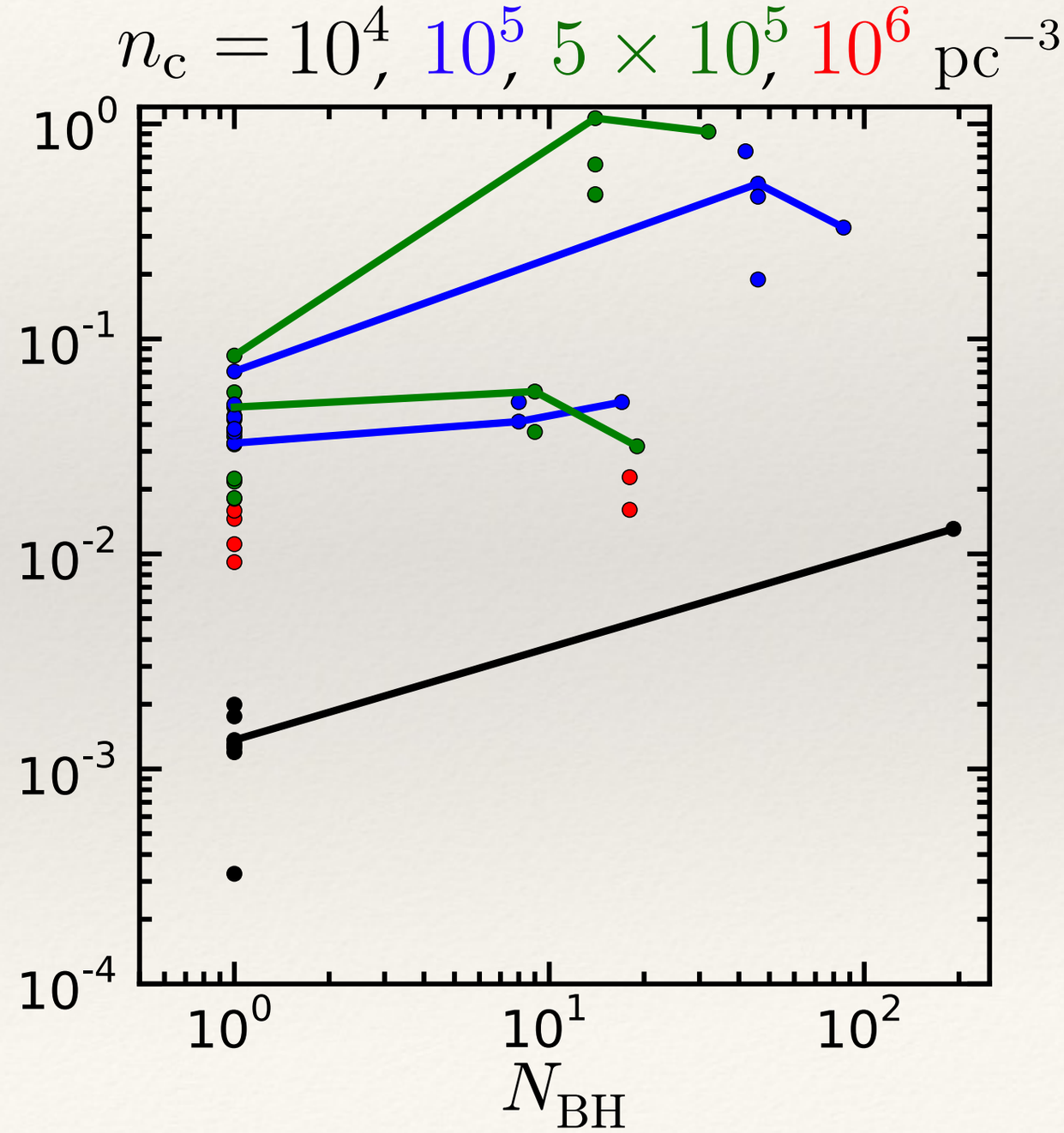


Clausen+ (2013)

$M_{\rm BH} = 7\ {\rm M}_\odot$ $M_{\rm BH} = 15\ {\rm M}_\odot$ $M_{\rm BH} = 35\ {\rm M}_\odot$

BH+NS Binary Population Size

- Even with 200 BHs, $\overline{N}_{\rm BH+NS}$ is only 0.01 in low density clusters
- In moderate density clusters:
  - $\overline{N}_{\rm BH+NS}$ grows with $N_{\rm BH}$ if there are ~few dozen BHs
  - $\overline{N}_{\rm BH+NS}$ drops at large $N_{\rm BH}$



Can We Find A BH+MSP?

$$N_{\rm BH+MSP} = \bar{N}_{\rm BH+MSP} \times f_{\rm GC} \times f_{\rm MSP} \times f_{\rm BH} \times N_{\rm GC}$$

- **Our models predict that the upper limit on the number of dynamically formed BH+MSP binaries in the Milky Way is ~10**
- $N_{\rm BH+MSP} = f_{\rm BH} \times (0.7 \pm 0.5)$
- **Likely BH+MSP binary hosts include the clusters 47 Tuc, Terzan 5, NGC 1851, NGC 6266, and NGC 6441**
- **Should be** $f_{\rm BH} \times 100$ **BH+MSP binaries detectable by SKA**

Summary

- BH+NS binary formation is enhanced by a factor of 100 in globular clusters, but these systems are still extremely rare
- Searches for BH+NS mergers probe small populations of ~30 $M_\odot$ black holes.
- Searches for BH+MSP binaries probe populations of a few dozen, ~7 $M_\odot$ black holes.