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丝绸之路 计划

Tracing the Evolution of SMBH and Stellar Objects in Galaxy Mergers

Li, Shuo

NAOC

Collaborated with

Peter Berczik, Rainer Spurzem, Shiyan Zhong, Xian Chen, F. K. Liu,

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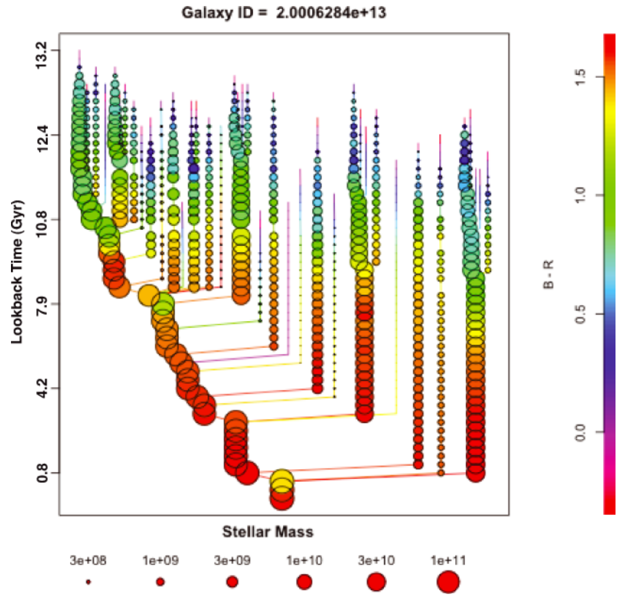
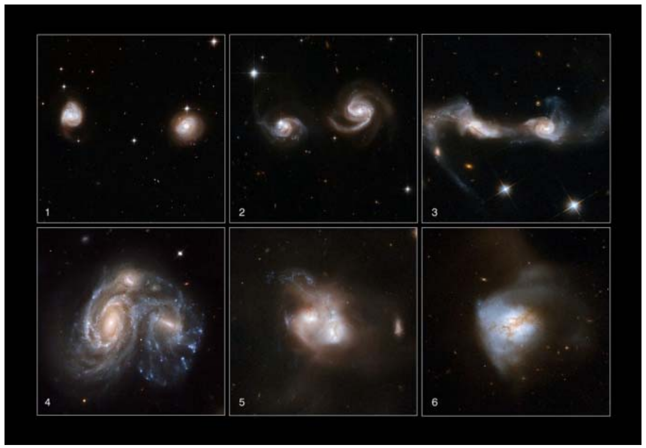
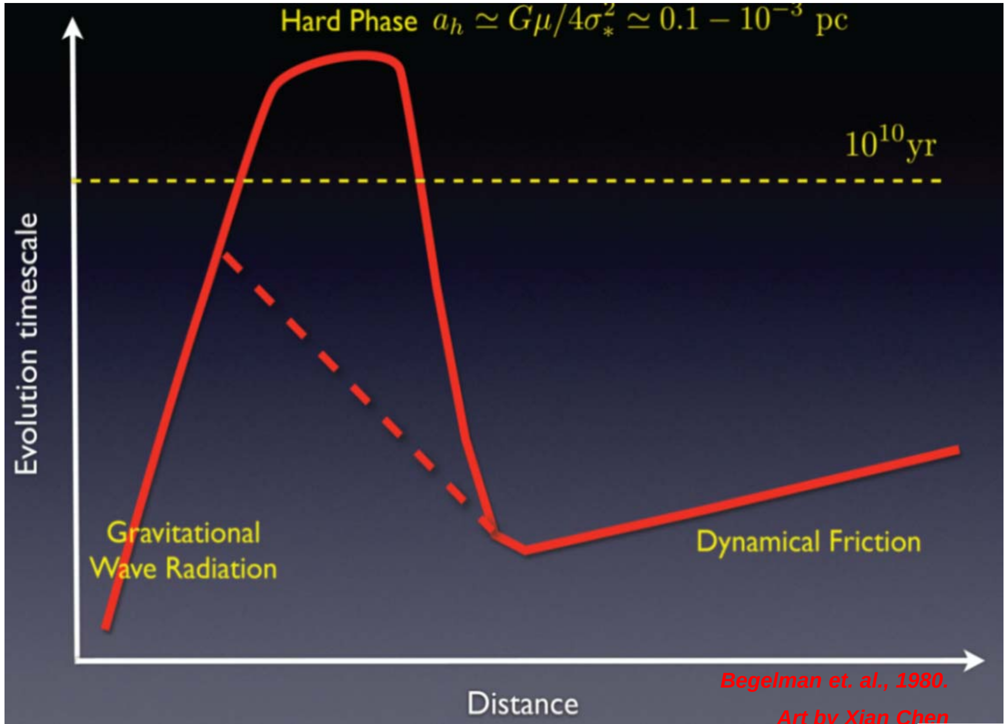
Why SMBHB?



Niemi et. al., 2010

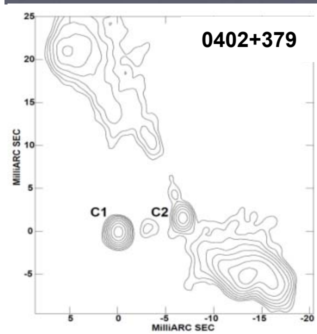


NASA, ESA (STScI/AURA)-ESA/Hubble Collaboration and A. Evans



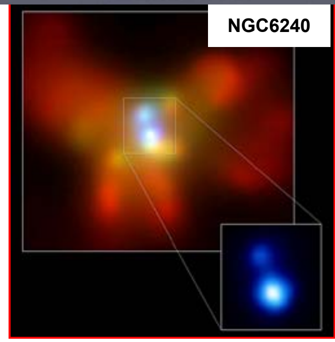
Begelman et. al., 1980.

Art by Xian Chen



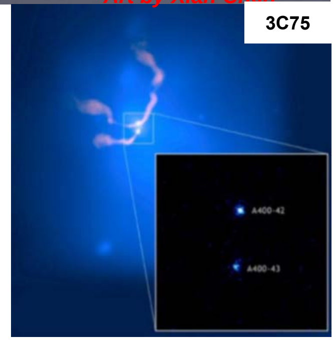
~10pc

Rodrigue et al., 2006



~kpc

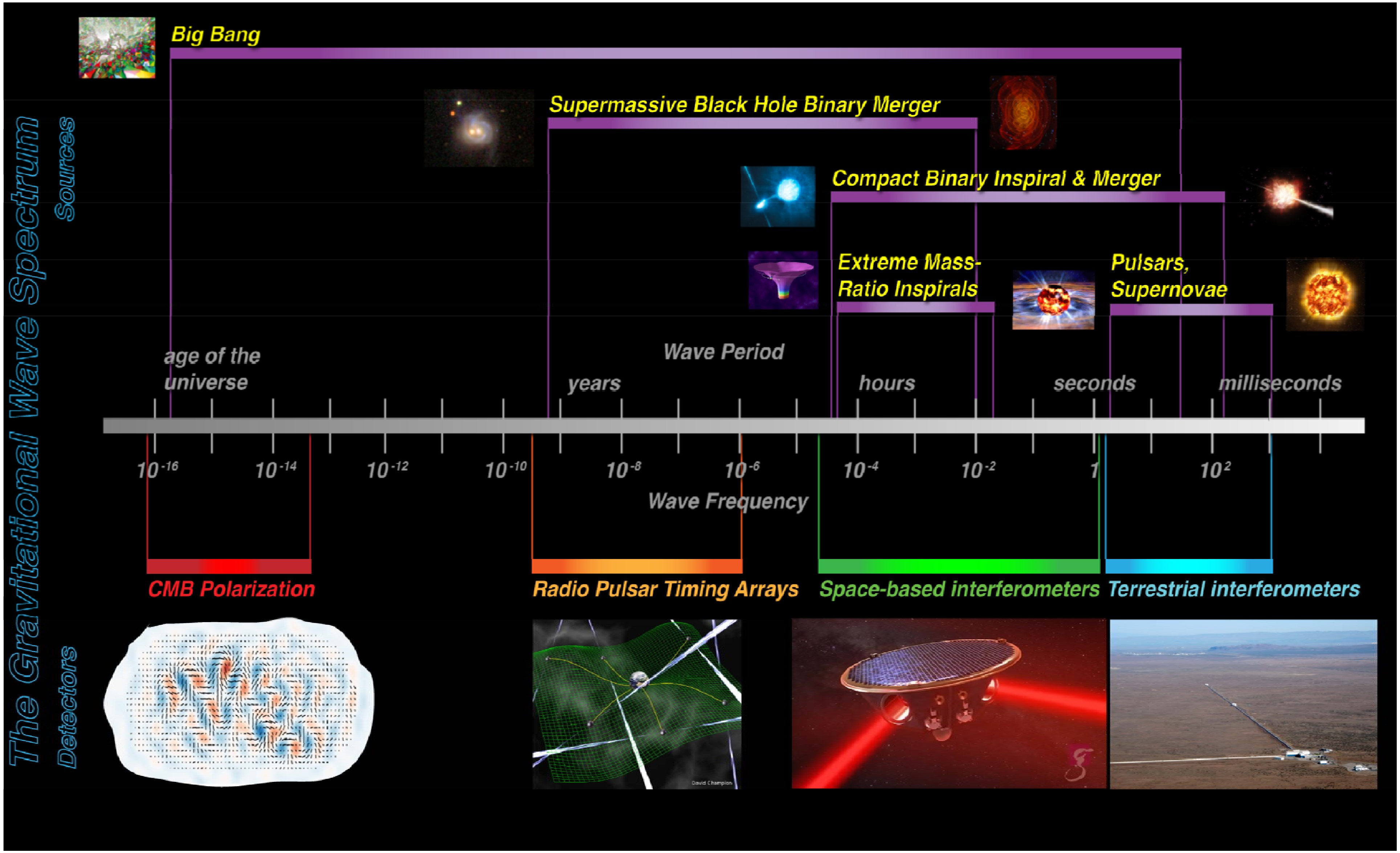
Komossa et al., 2003



~10kpc

Hudson et al., 2006

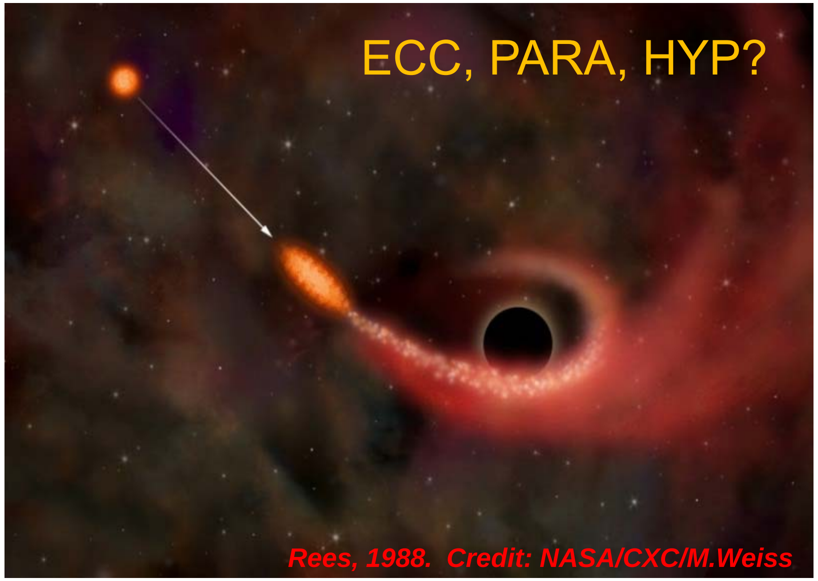
GW Sources ?

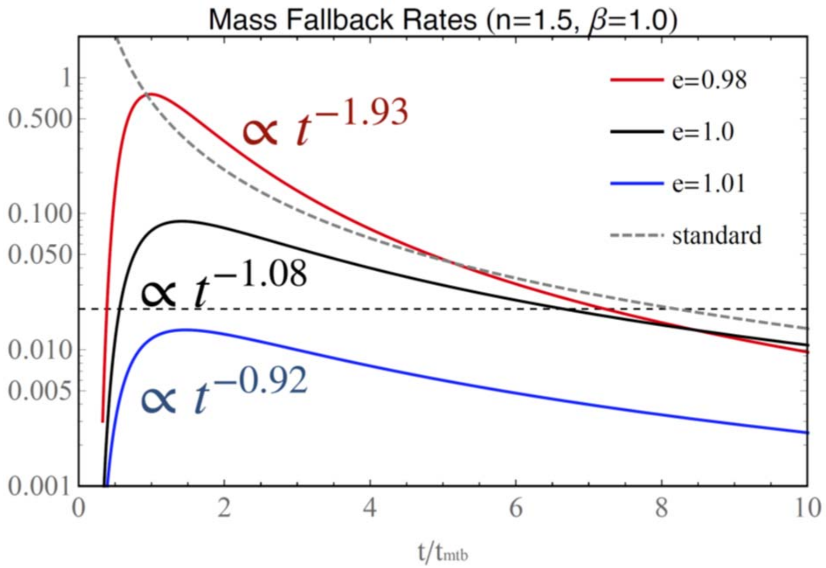


NASA/J. I.Thorpe

Tidal Disruption — an Efficient Tool

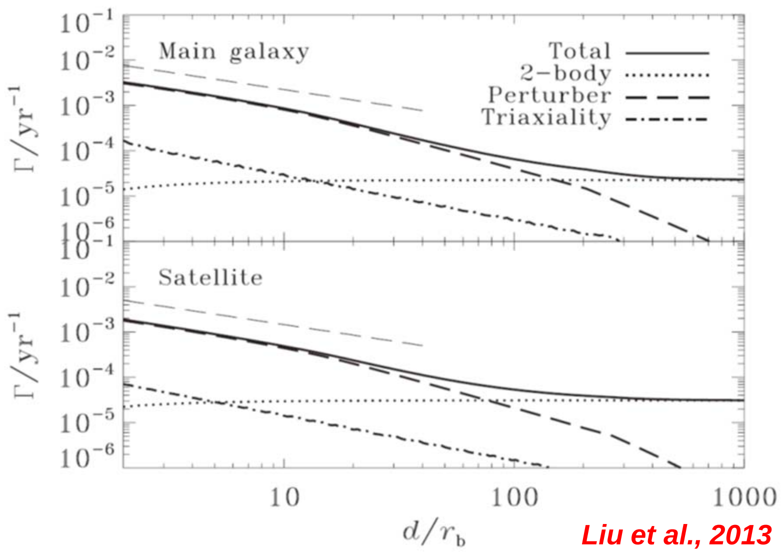
- Disrupted stars can "light up" the dormant SMBH
- Special light curves in supermassive black hole binary (SMBHB) systems:
  Liu et al. 2009, 2014, Ricarte et al. 2016, Coughlin et al. 2017
- Different fallback rate (light curve?) for different orbits:
  - The fallback rate for eccentric (ECC) parabolic (PARA) and hyperbolic (HYP) are significantly different. In the extreme cases, all (ALLFB) / none (NOFB) debris could fallback:
    Hayasaki et al. 2013, 2018, Park & Hayasaki 2020
  - Most of disrupted stars in galaxies with single SMBHs are close to parabolic orbits:
    Zhong et al. in prep.
  - *Different for SMBHBs ?*

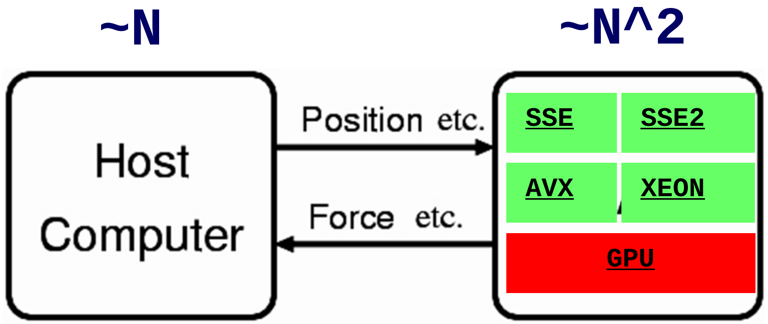




Park & Hayasaki, arXiv:2001.04548

Analytical Models vs. Direct N-body Simulations





$$\vec{a}_i = \sum_{j=1;\, j\neq i}^{N} \vec{f}_{ij} \qquad \vec{f}_{ij} = -\frac{G \cdot m_j}{(r_{ij}^2 + \varepsilon^2)^{3/2}} \vec{r}_{ij}$$

- Analytical estimations:
  - Increasing tidal disruption rate (TDR) with decreasing semi-major axis
  - Perturbation from the companion SMBH and triaxial stellar distribution play important roles
  - Simplified assumption on stellar distribution
  - Not applicable inside influence radius

Direct *N* - body simulations:

- Pros:
  - Realistic—— straight forward
  - Accurate
- Cons:
  - "Unrealistic"—— limited resolution
  - Computationally expensive

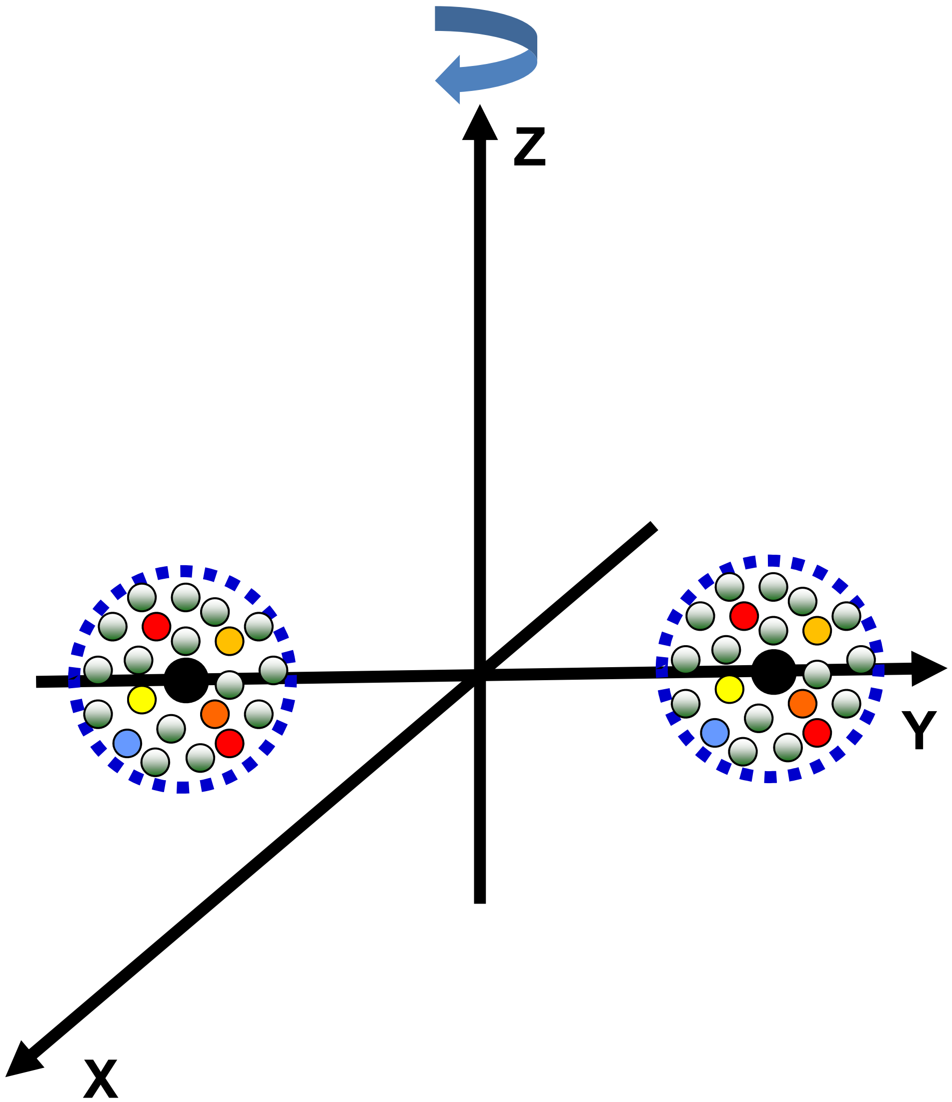
Initial Conditions

- Model for galaxy merger:
  - Stellar distribution: Dehnen, 1993

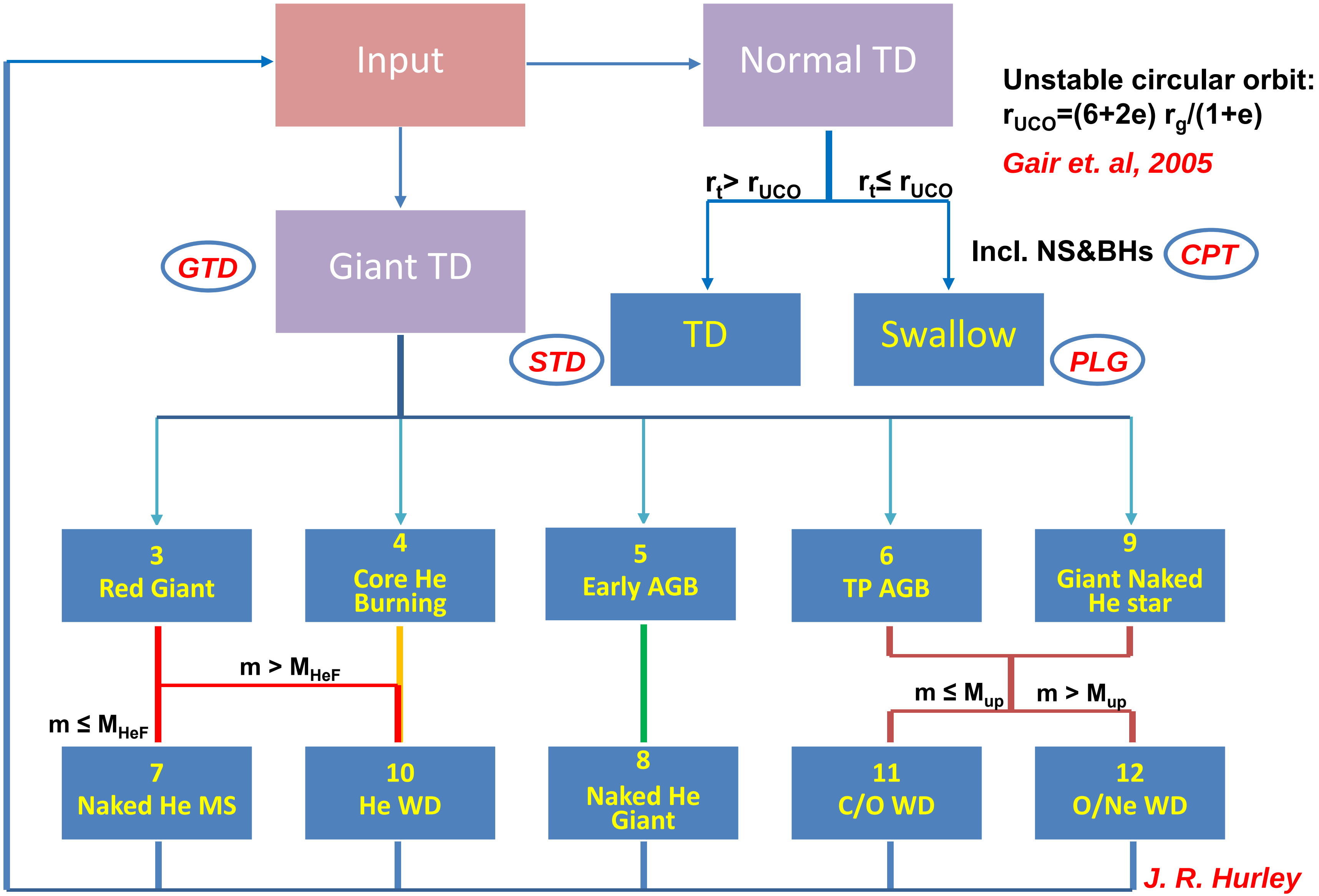
$$\rho(r) = \frac{3-\gamma}{4\pi}\frac{Ma}{r^{\gamma}(r+a)^{4-\gamma}}$$

  - Initial mass spectrum: 0.1-100 $M_{\odot}$, Kroupa 2001
  - System evolved ~ 1 Gyr (SSE): MS, GB, WD, NS, BH
  - M_{bh1}=0.01, M_{G1}=1, γ=1.0
  - q = 0.1 - 1.0
  - $N_1 = N_2$ = 500K , $<m_{*0}>$ ~2x10^{-6}
  - Ntot: 250K, 500K, 1M, 2M
  - $<r_{t0}>$: 10^{-5} - 10^{-3}
  - R_{bh0}=20, r_{p0}=1, in parabolic orbit
  - phi-GRAPE/GPU with TD scheme

Integrations: *Laohu&Chewie@NAOC*

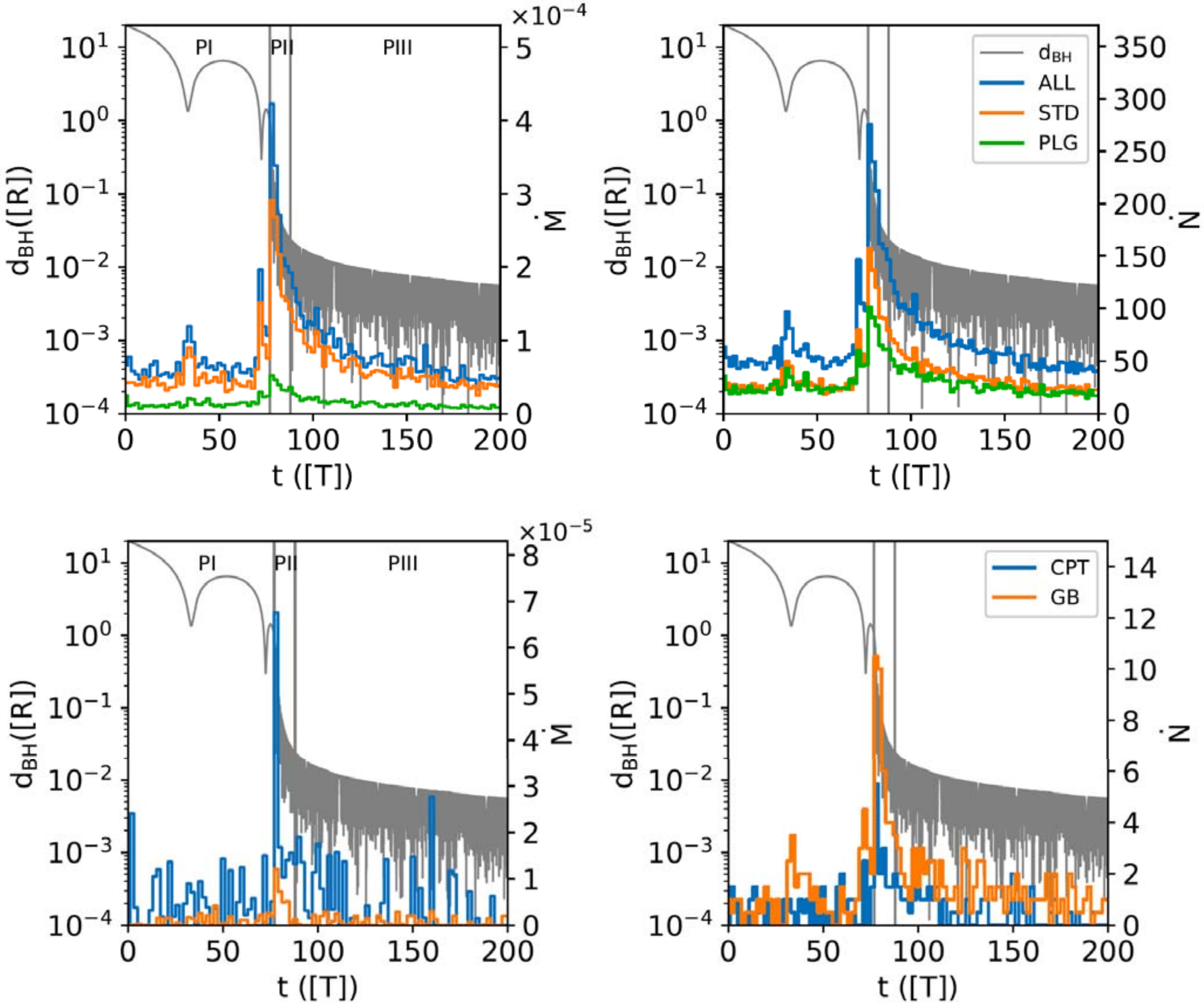


TD Scheme

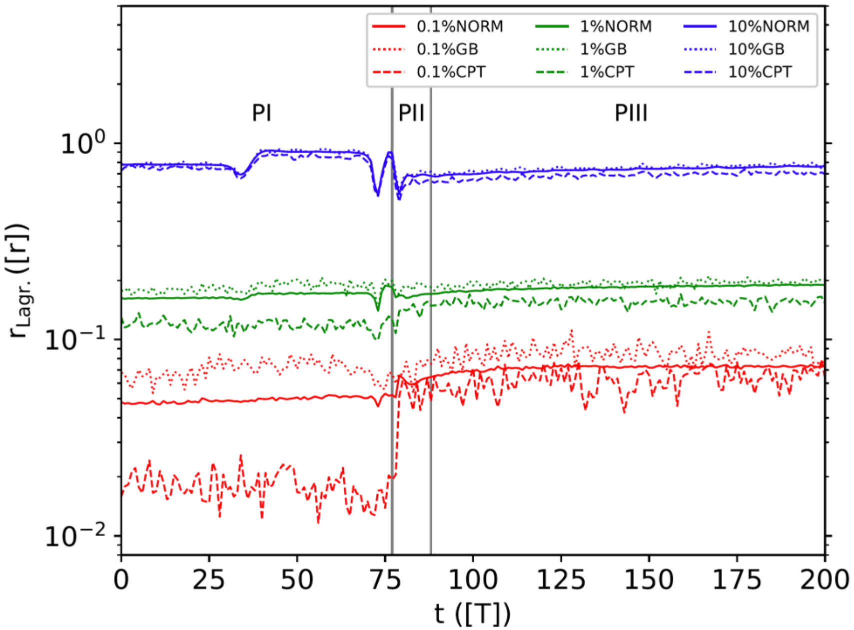

Input
Normal TD
Unstable circular orbit:
$r_{UCO}=(6+2e)\ r_g/(1+e)$
Gair et. al, 2005
$r_t > r_{UCO}$
$r_t \leq r_{UCO}$
Incl. NS&BHs
CPT
GTD
Giant TD
STD
TD
Swallow
PLG
3
Red Giant
4
Core He Burning
5
Early AGB
6
TP AGB
9
Giant Naked He star
$m > M_{HeF}$
$m \leq M_{HeF}$
$m \leq M_{up}$
$m > M_{up}$
7
Naked He MS
10
He WD
8
Naked He Giant
11
C/O WD
12
O/Ne WD
J. R. Hurley

TDE of Different Stellar Objects

$M_{BH} = 10^7\ M_{sun}$, N = 2M, q = 1

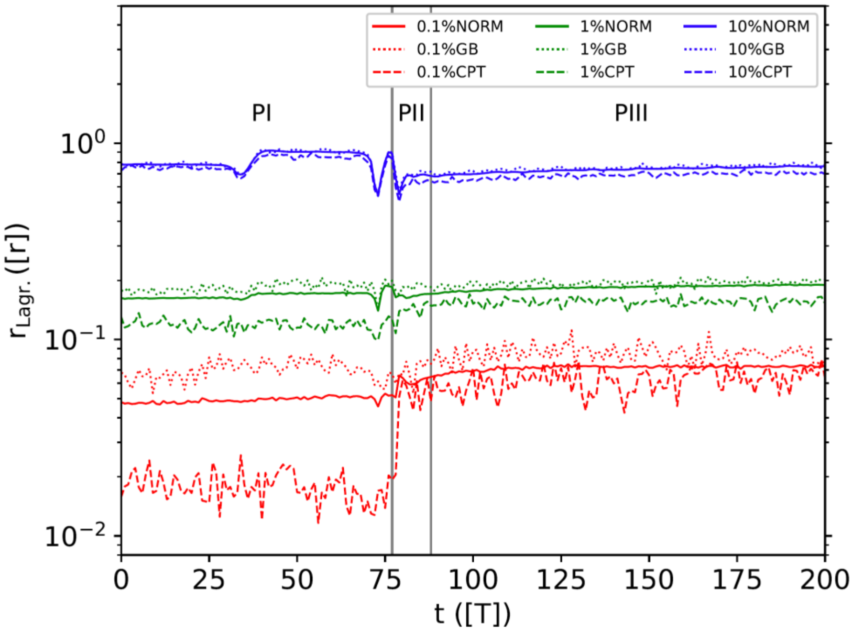


Mergers with “Multi-population”

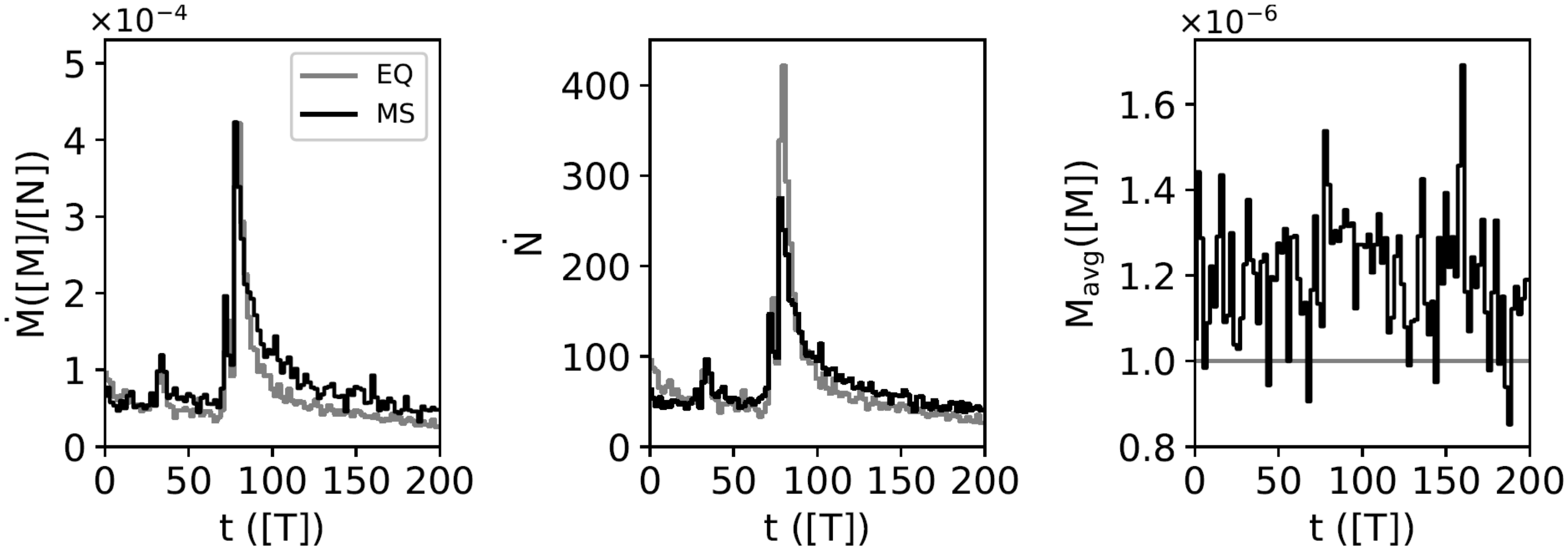


- Significant Mass segregation of CPT
- Expanded inner Lagrangian radius during PII

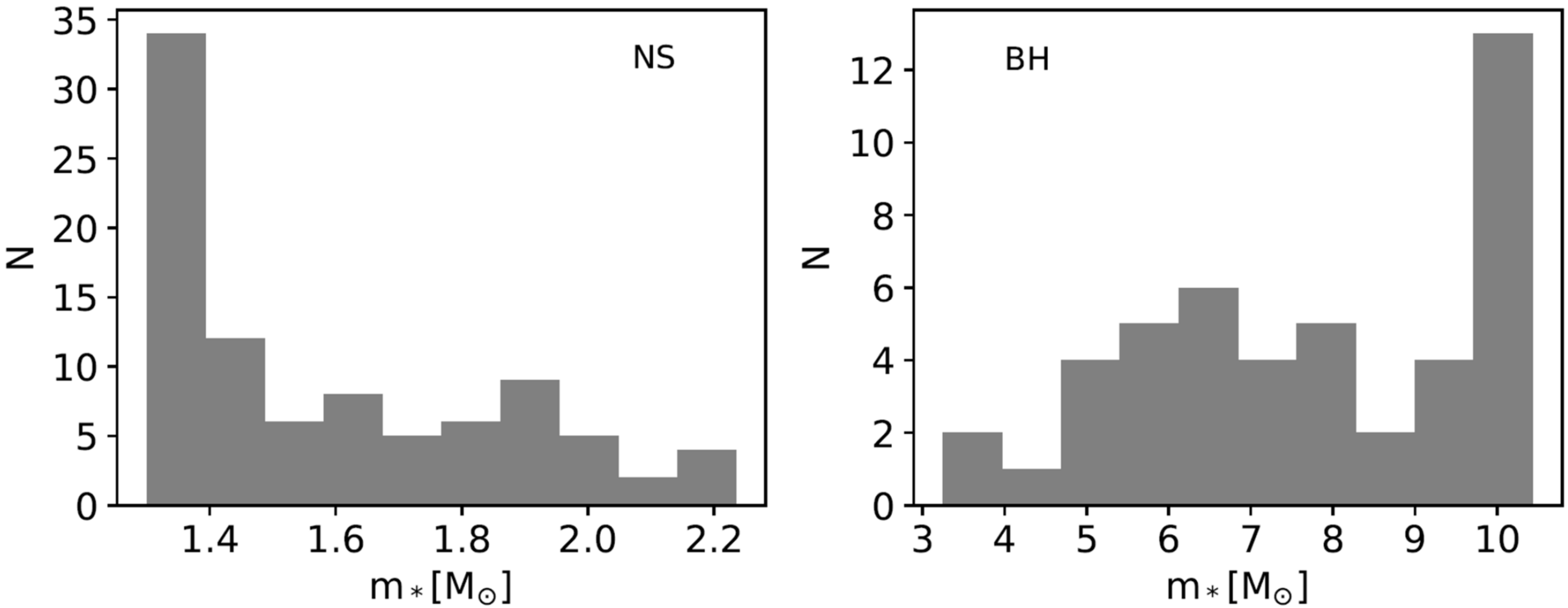
Mergers with “Multi-population”



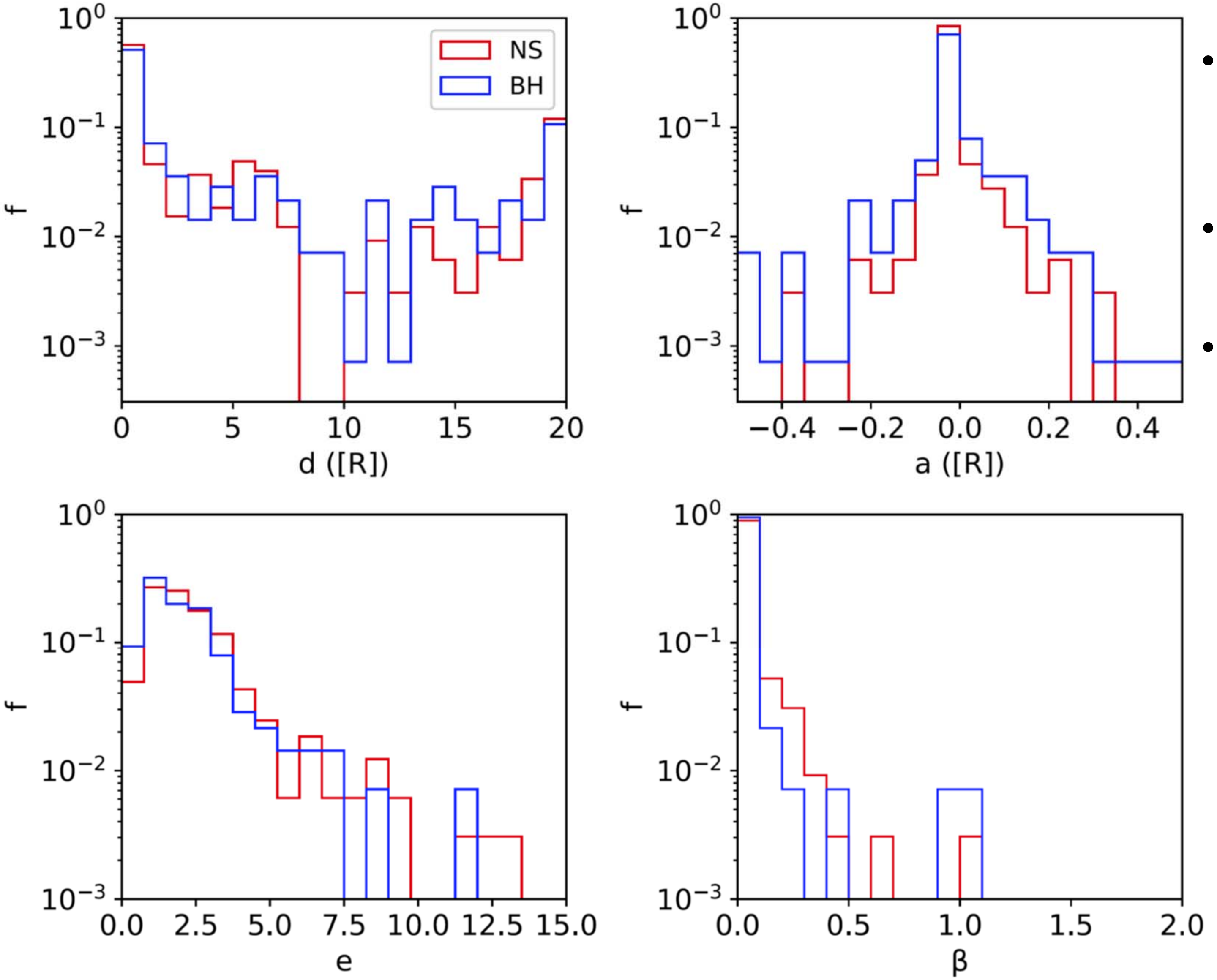
- Significant Mass segregation of CPT
- Expanded inner Lagrangian radius during PII
- Significantly higher peak TDE event rate in equal stellar mass model
- Higher averaged mass of disrupted stars in multi-population model



Mass distr. of swallowed NSs & BHs



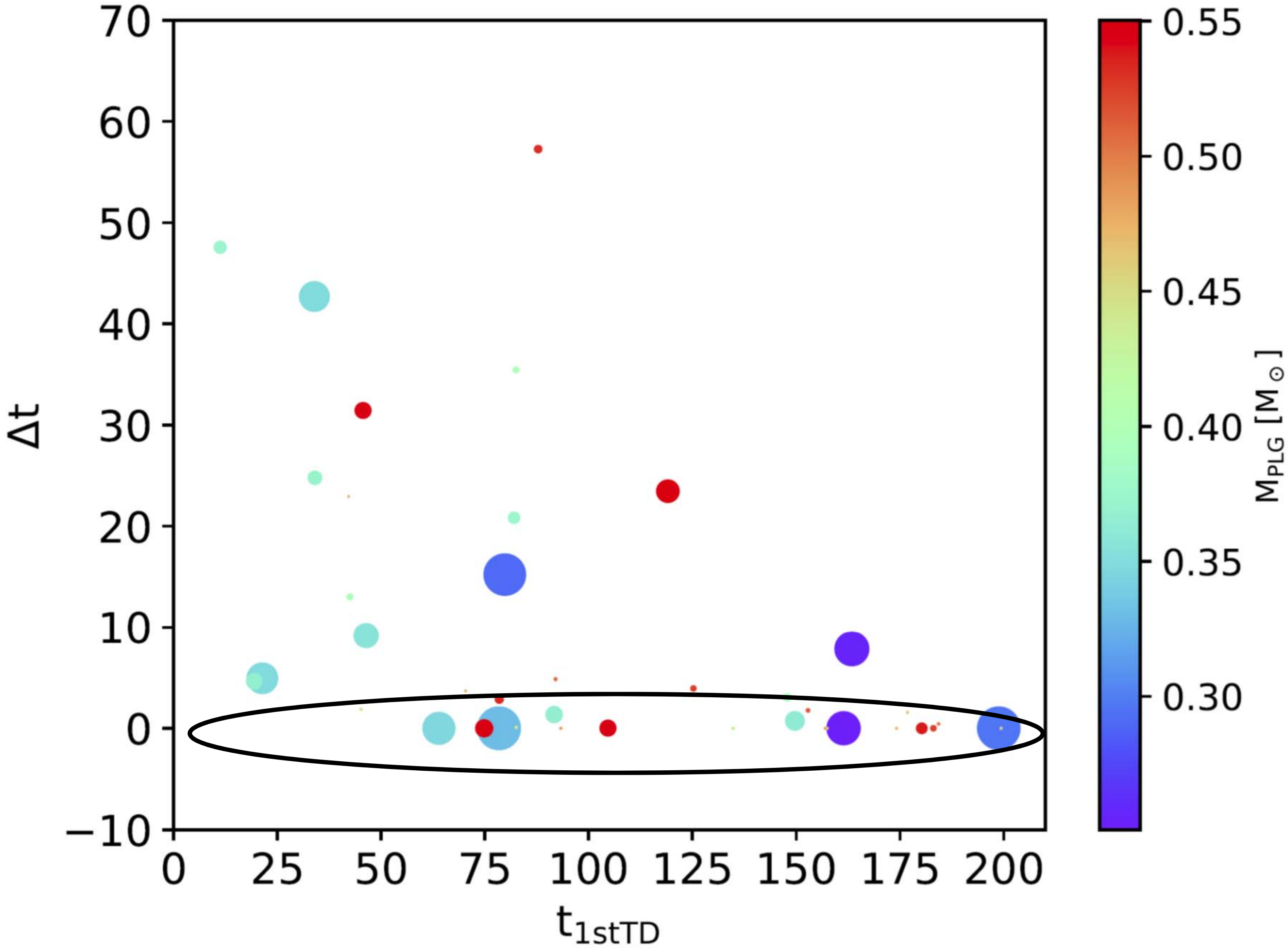
NSs & BHs @ 200 r_g



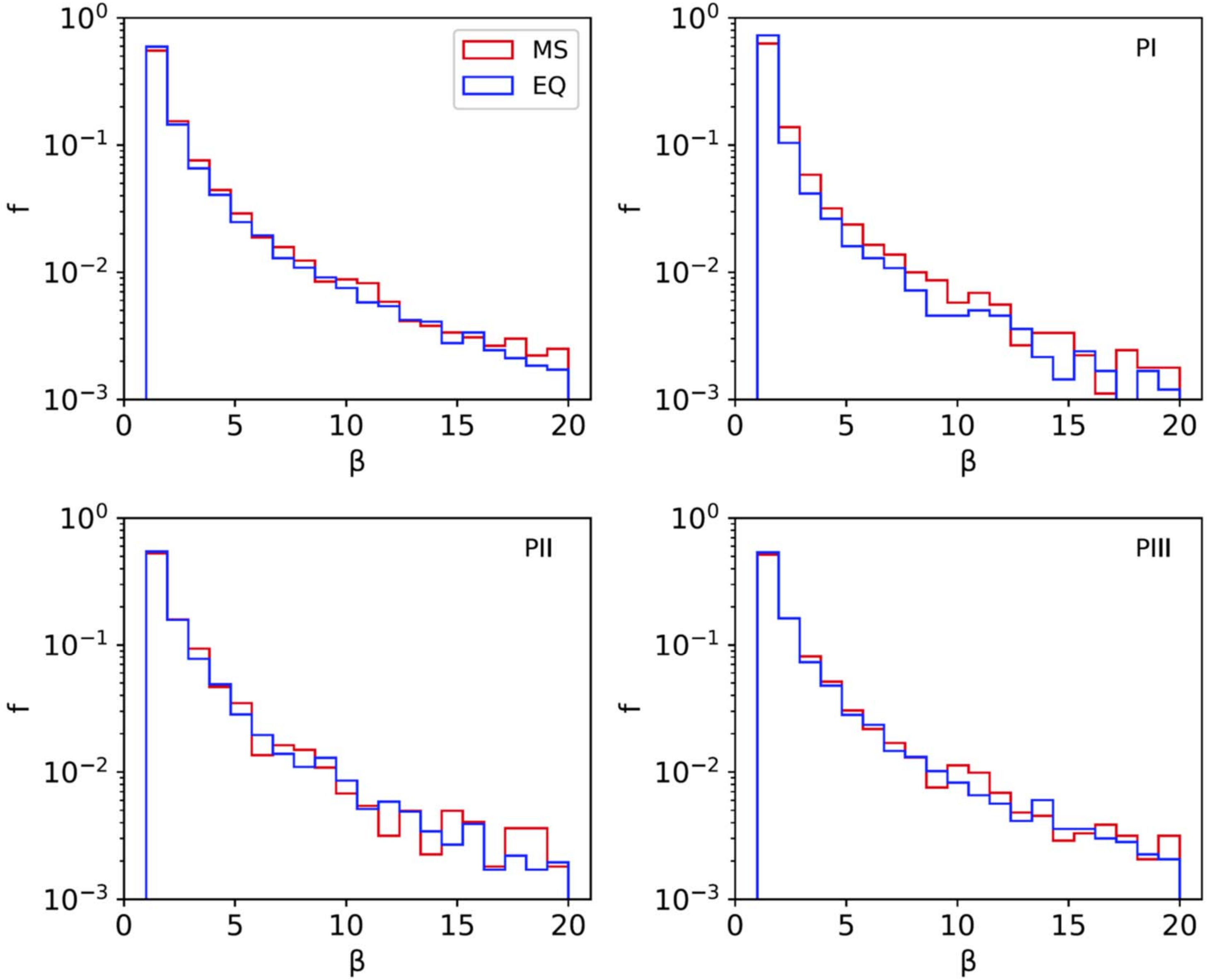
- Most of semi-major axis are around 0;
- Most of CPT stars have e > 1;
- Almost all CPT stars will not plunge into the central SMBH;

$\beta = r_{uco}/r_p$
$\beta > 1$: Capture
$\beta < 1$: Escape

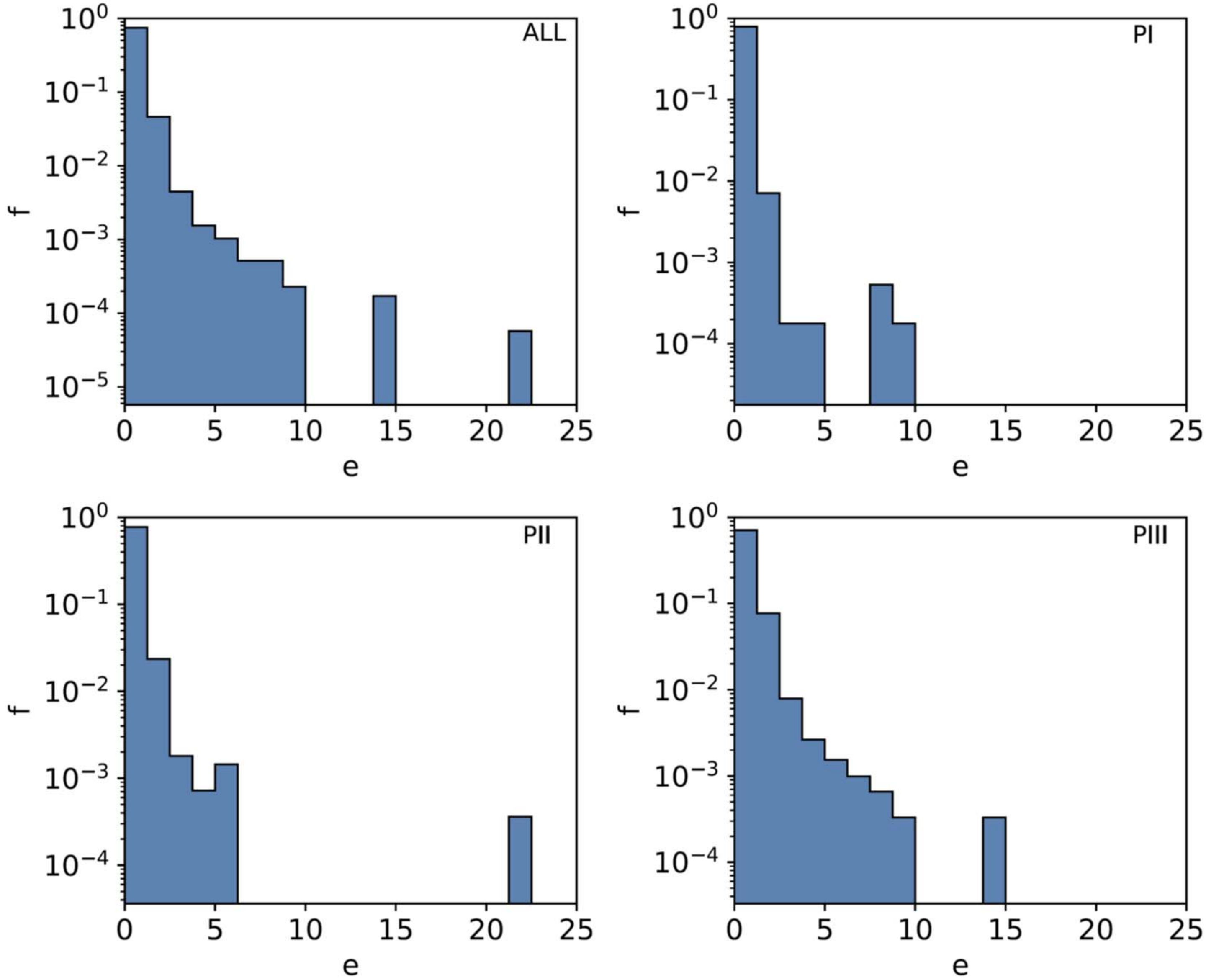
Disrupted GB stars with plunge events



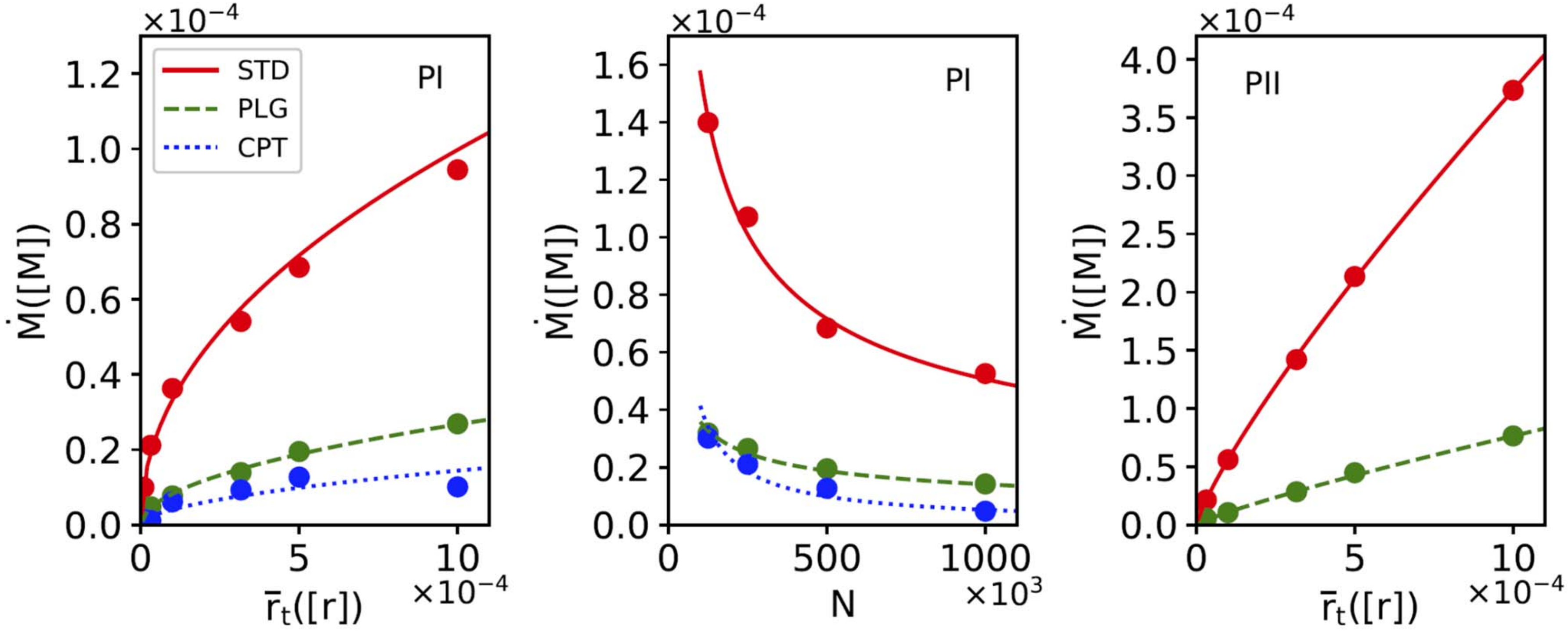
β distribution of all the disrupted stars



Eccentricity distribution of disrupted stars

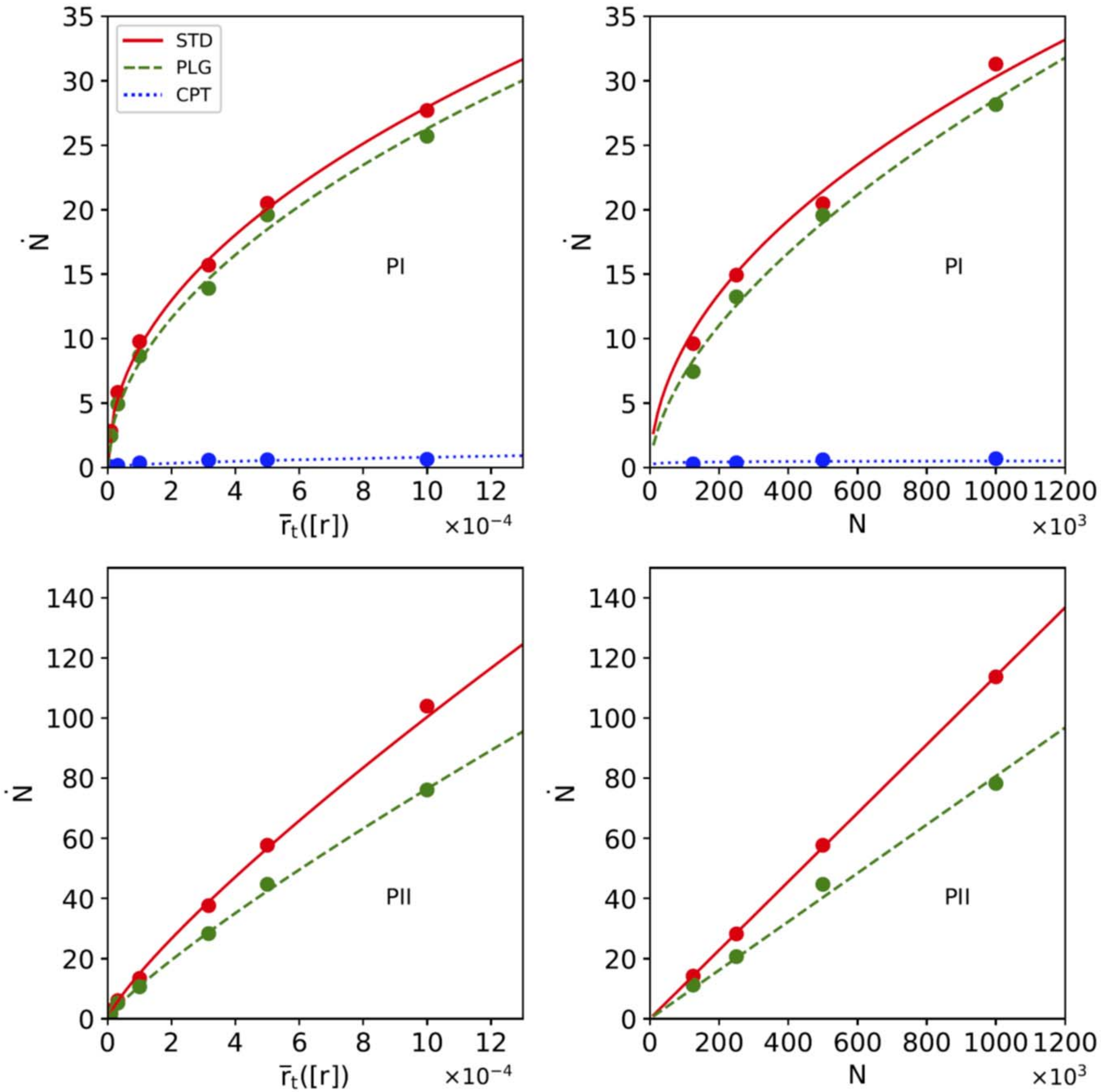


Extrapolations on fallback rate



- STD: PI: ~1.0×10^{-6} $M_\odot$ / yr, PII: ~5.0×10^{-6} $M_\odot$ / yr
- PLG: PI: ~4.0×10^{-7} $M_\odot$ / yr, PII: ~7.6×10^{-7} $M_\odot$ / yr
- CPT: PI: ~1.6×10^{-9} $M_\odot$ / yr
- STD stars dominated the contribution on fallback rate

Extrapolations on event rate



- STD:

PI: ~1.3x10^{-6} / yr

PII: ~6.3x10^{-6} / yr

- PLG:

PI: ~1.8x10^{-6} / yr

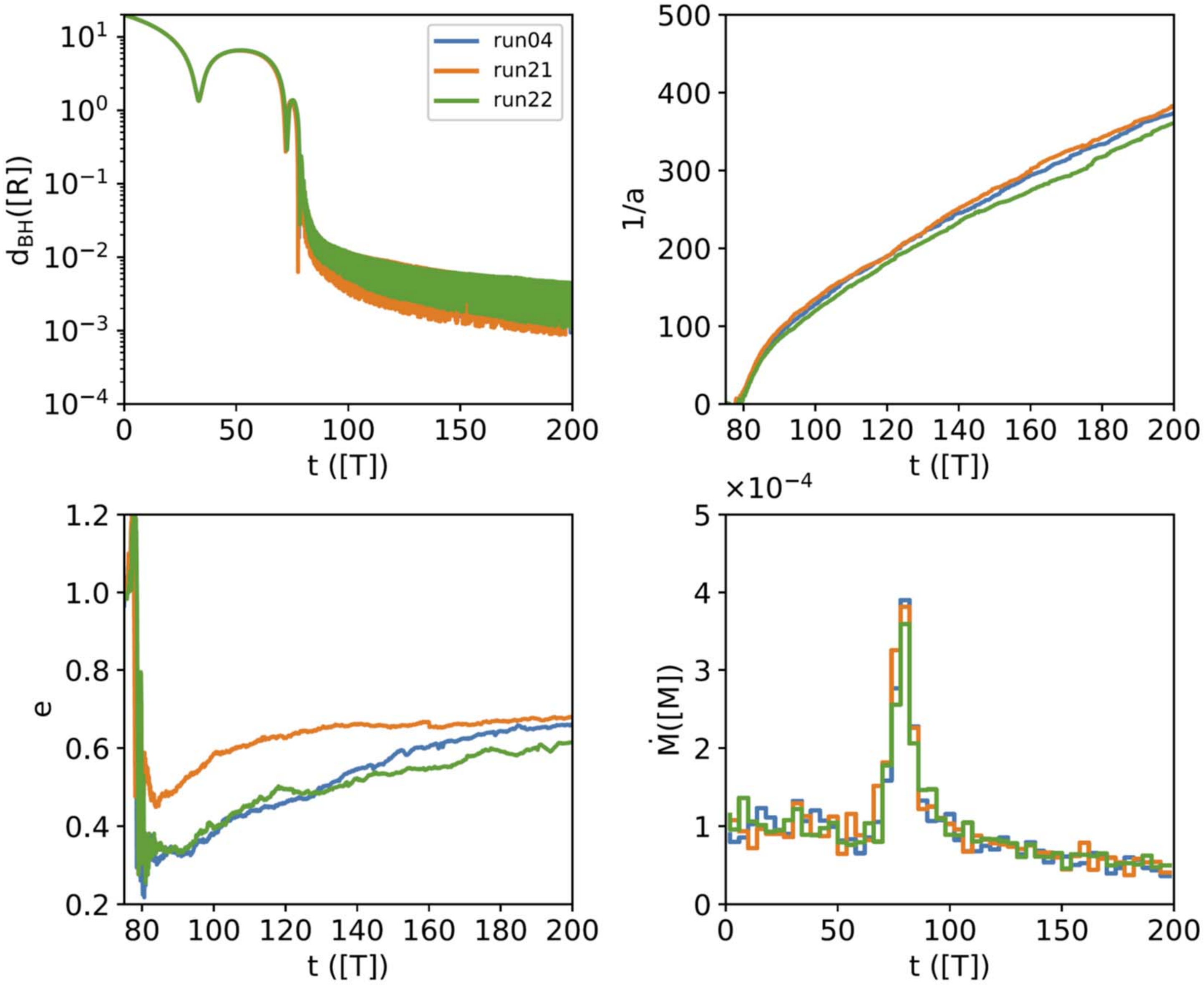
PII: ~3.5x10^{-6} / yr

- CPT:

PI: ~4.4x10^{-10} / yr

- PLG stars contribute significant fraction of the event rate

Influence of different random seeds



Summary

- Tidal disruption events can be used as probes to find SMBHBs;
- Lots of stars will be directly swallowed by the SMBH in real galaxies;
- The low mass stars make significant contributions to the event rate;
- Disrupted stars with hyperbolic orbits may not be rare in galaxy mergers;
- The extrapolations for STD and PLG stars in PI and PII are manageable;
- Different random seeds have significant influence on the eccentricity of the SMBHB, but make little effects on the evolution of TD.