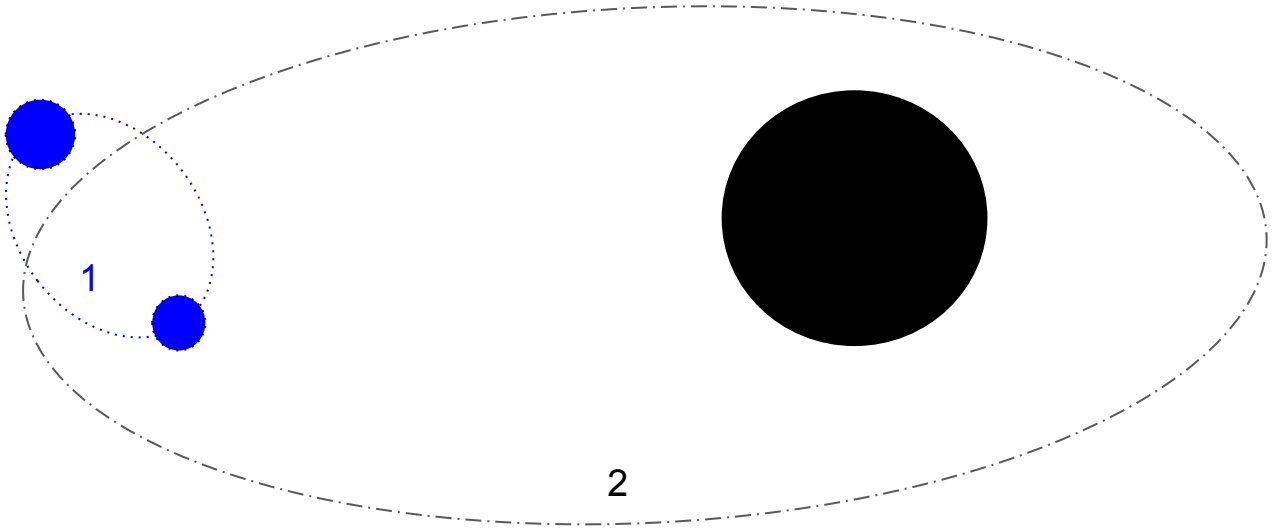
The Fate of Binaries in the Galactic Center: The Mundane and the Exotic

Stephan et al 2019

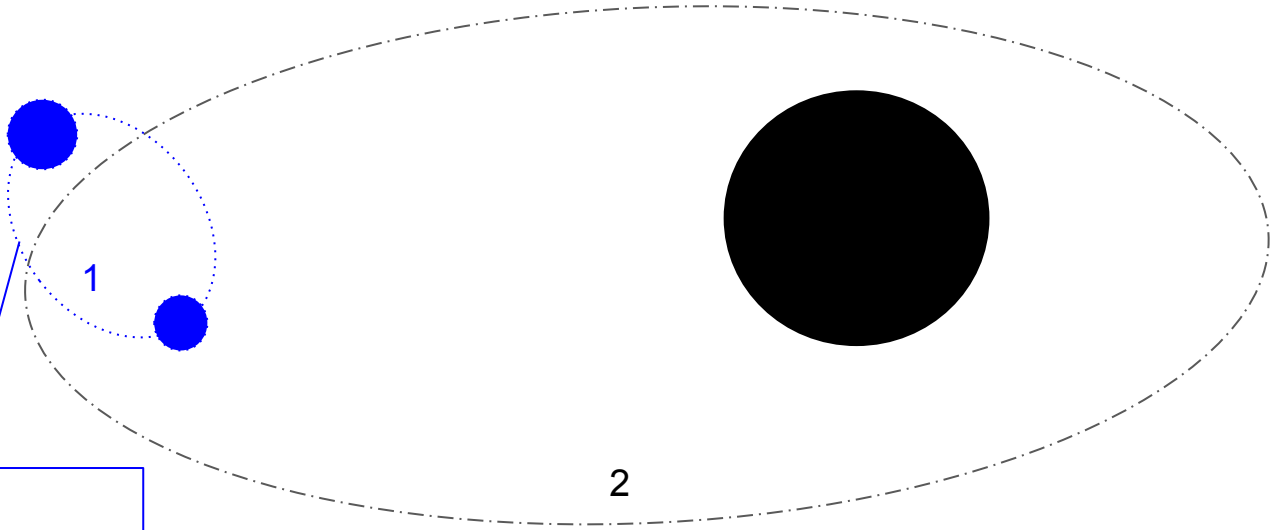
Presented by Nitika and Viraj

Overview of the Eccentric Kozai-Lidov (EKL) effect



Secular Evolution: orbits conserve energy but exchange angular momentum , occurring on timescales >> orbital timescales

Overview of the Eccentric Kozai-Lidov (EKL) effect

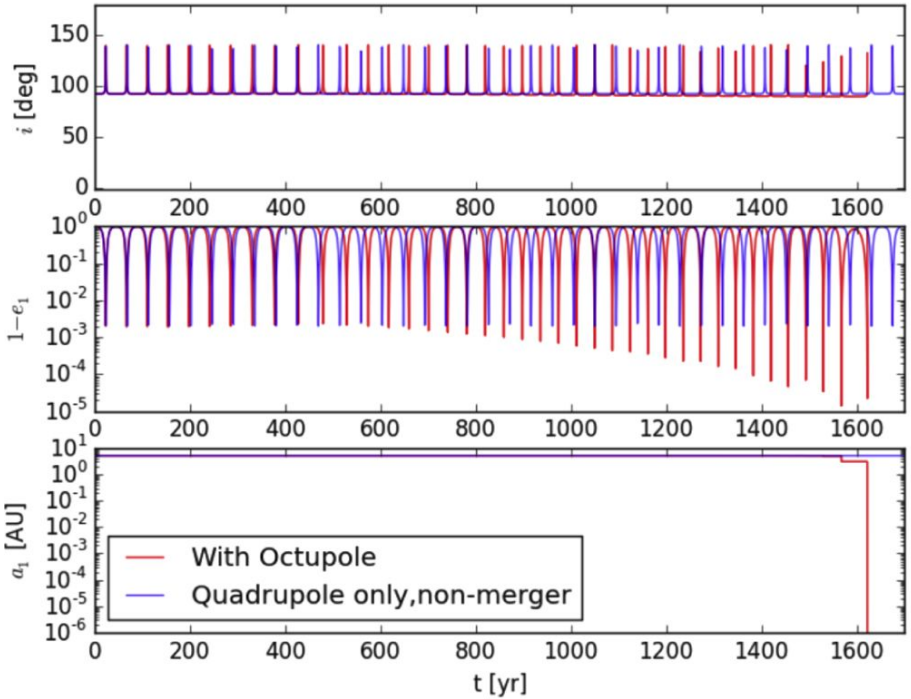


Orbit eccentricity and inclination oscillates

$$H_{quad} \propto (\frac{a_1}{a_2})^2 \qquad H_{oct} \propto (\frac{a_1}{a_2})^3 \frac{e_2}{1-e_2^2}$$

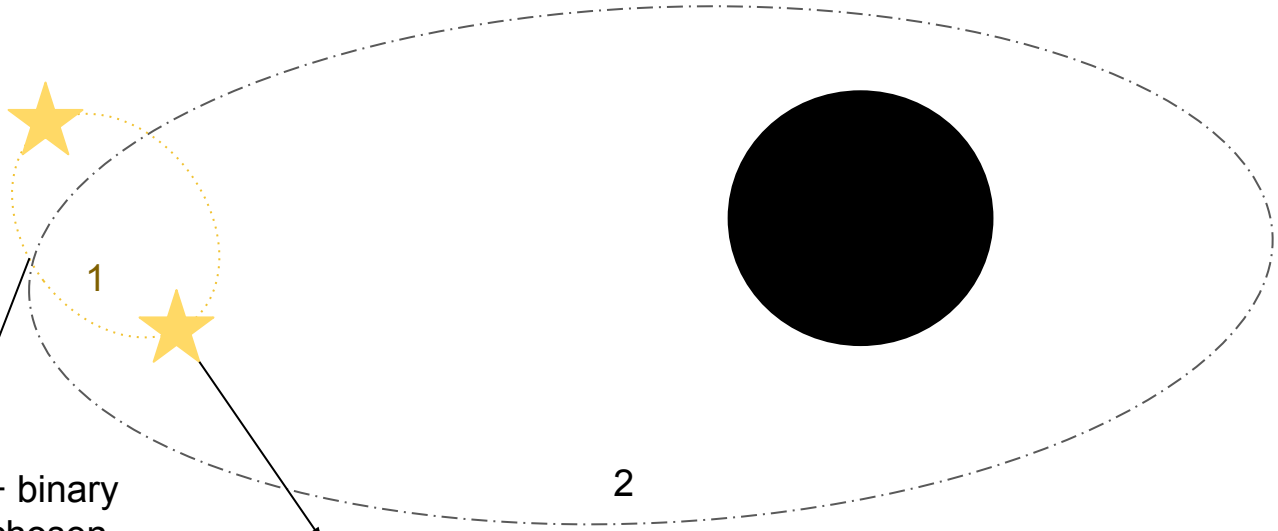
Overview of the Eccentric Kozai-Lidov (EKL) effect

Initial Conditions:
m1 = 12.8 Msun
m2 = 63.3 Msun
mBH = 10^7 Msun
a1 = 5.1 au
a2 = 936 au
e1 = 0.014
e2 = 0.4



Hoang et al 2017

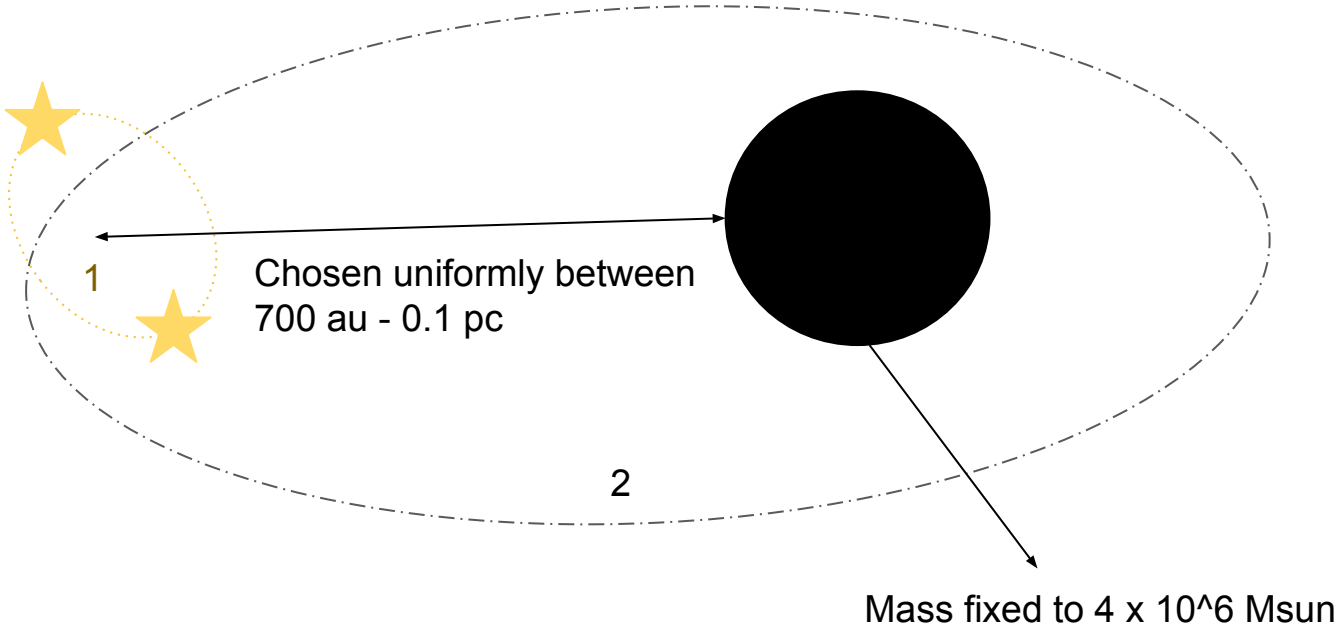
Initializing the simulated binary population



Mass ratio + binary separation chosen from Duquennoy and Mayor (1991)

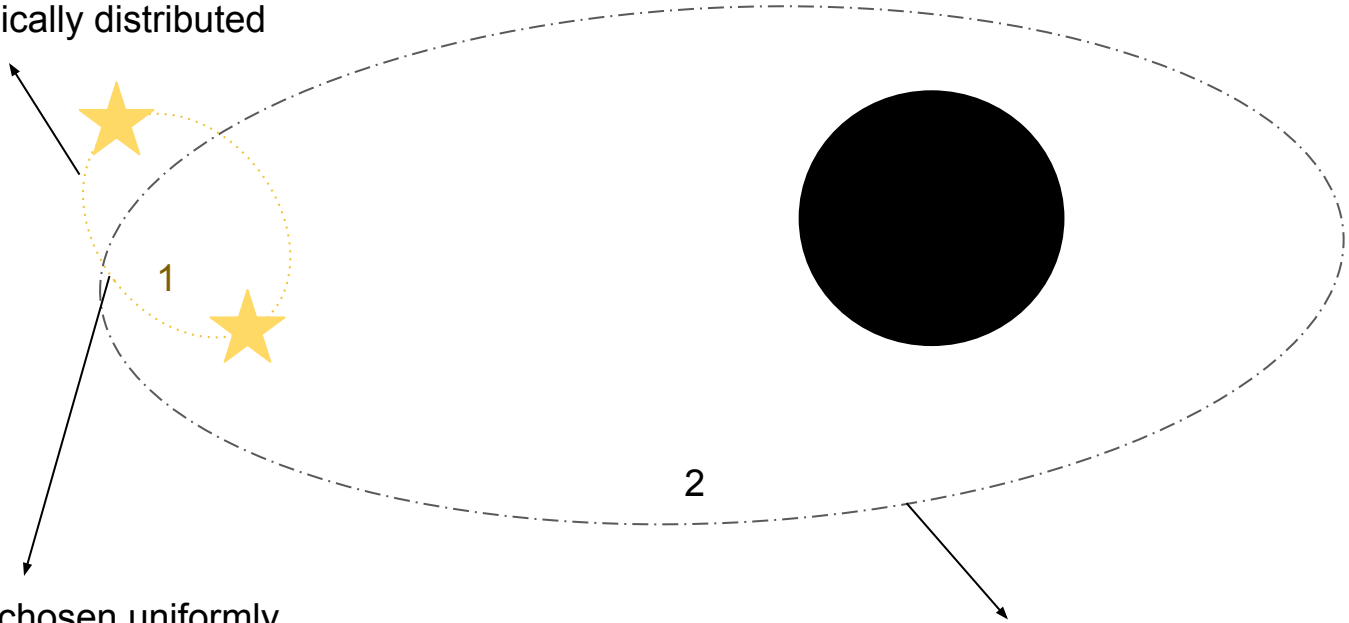
Primary stellar masses chosen with Salpeter IMF (1 - 150 Msun)

Initializing the simulated binary population



Initializing the simulated binary population

Orbit inclination
isotropically distributed

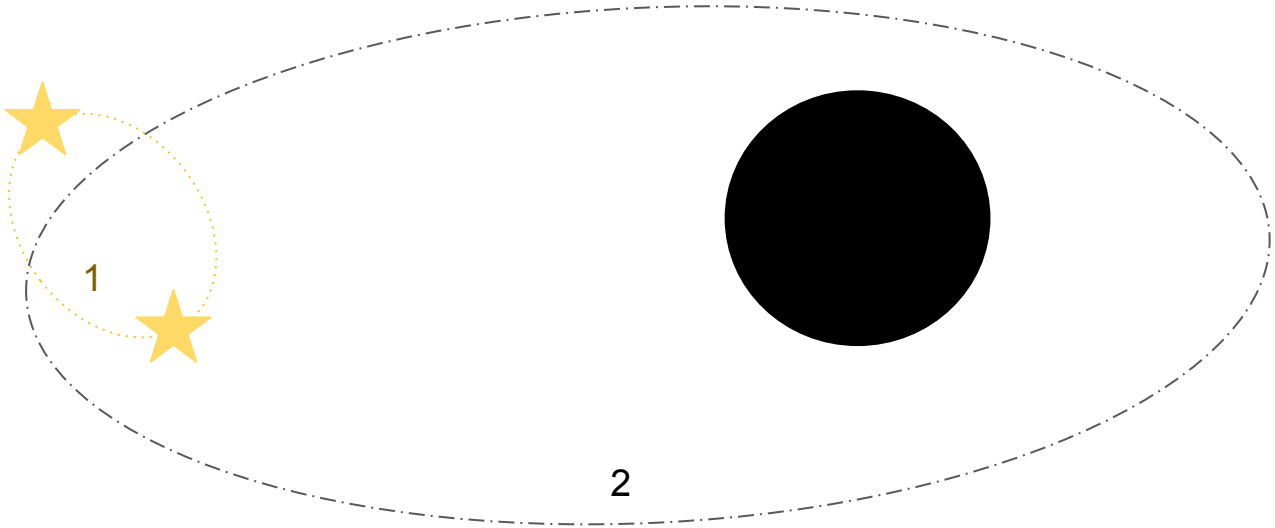


e1 chosen uniformly
between 0 and 1

e2 chosen from thermal
distribution + satisfy criteria

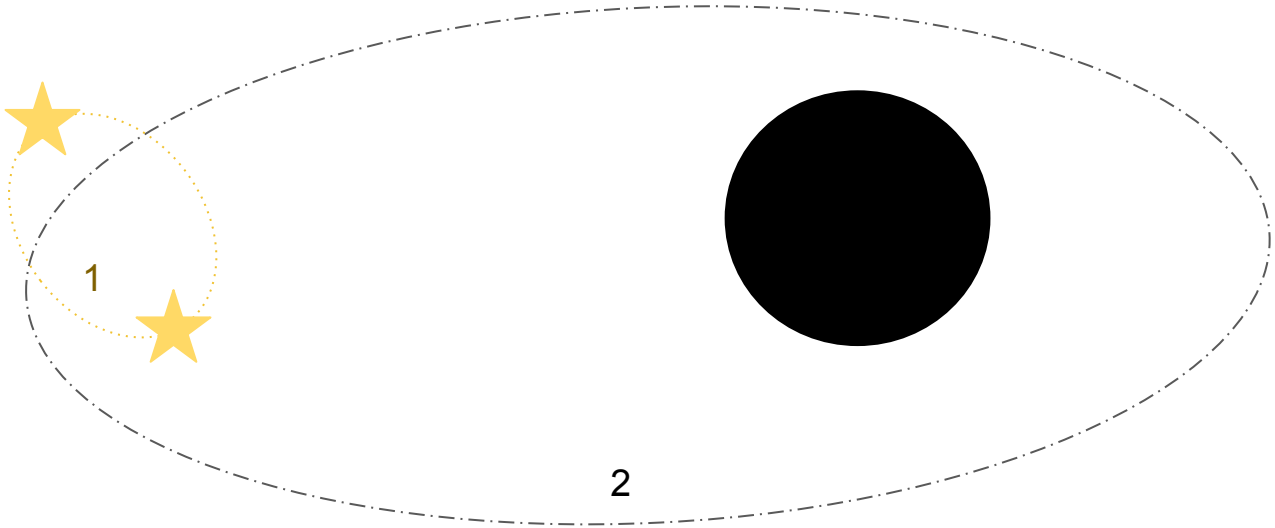
$$\epsilon = \frac{a_1}{a_2}\frac{e_2}{1-e_2^2} < 0.1$$

Initializing the simulated binary population



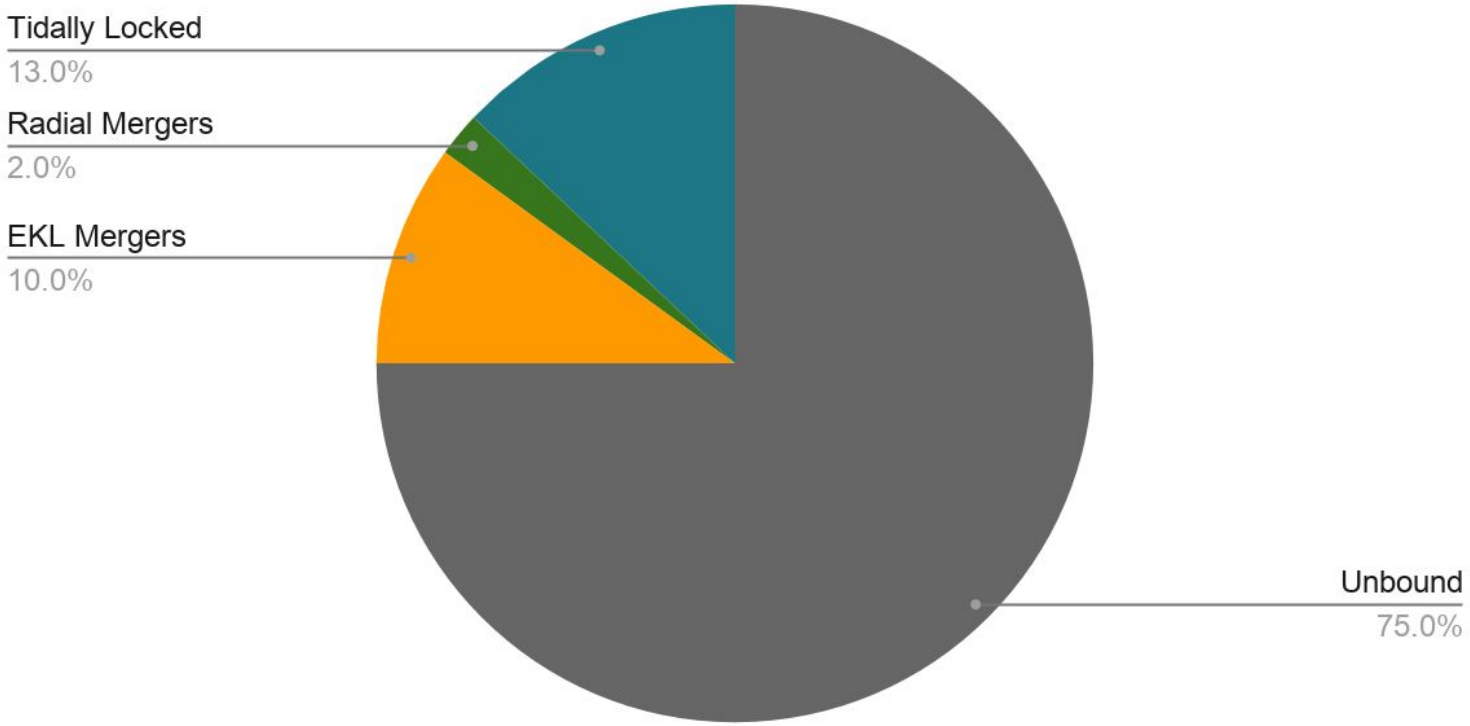
5203 stable systems created for simulation

Evolving the binary systems



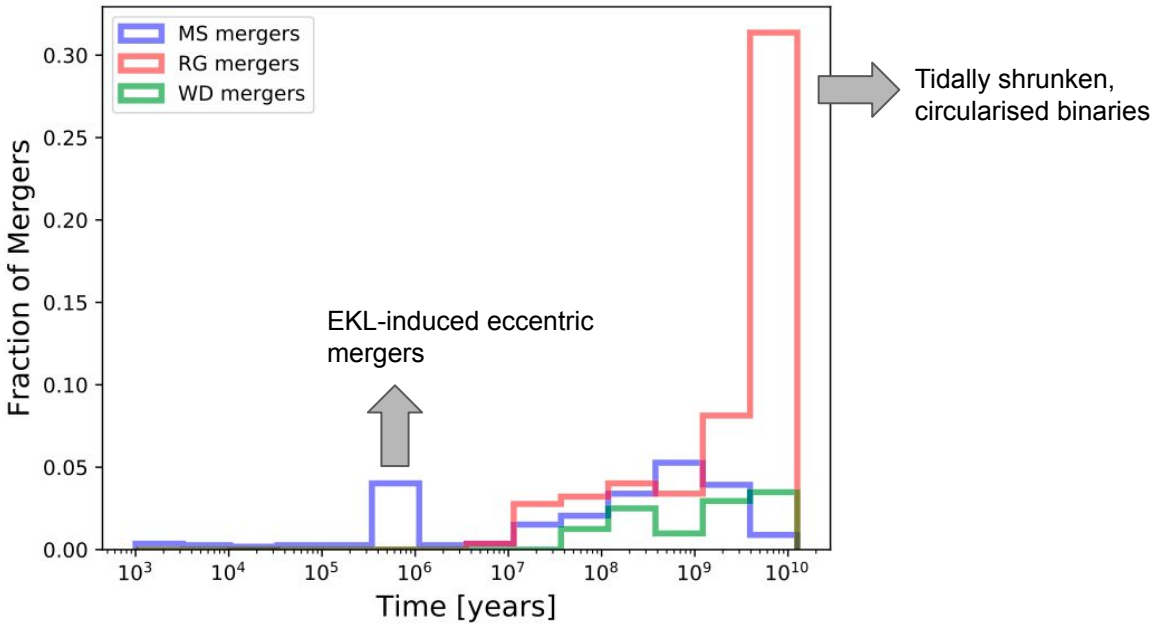
Model EKL, GR, tides + single star evolution until either RLOF or tidal locking occurs → Use binary star evolution code for further simulation

Fate of binaries



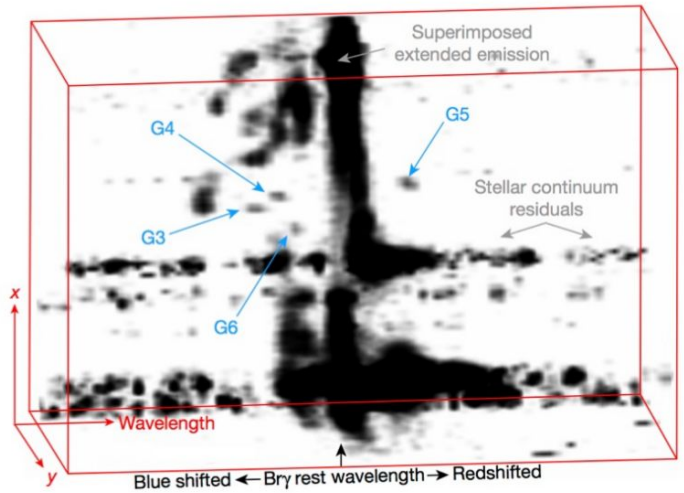
1. Main sequence or Red Giant Mergers

- ~85% of mergers
- MS/ Red Giant/ Stripped giant (He stars)

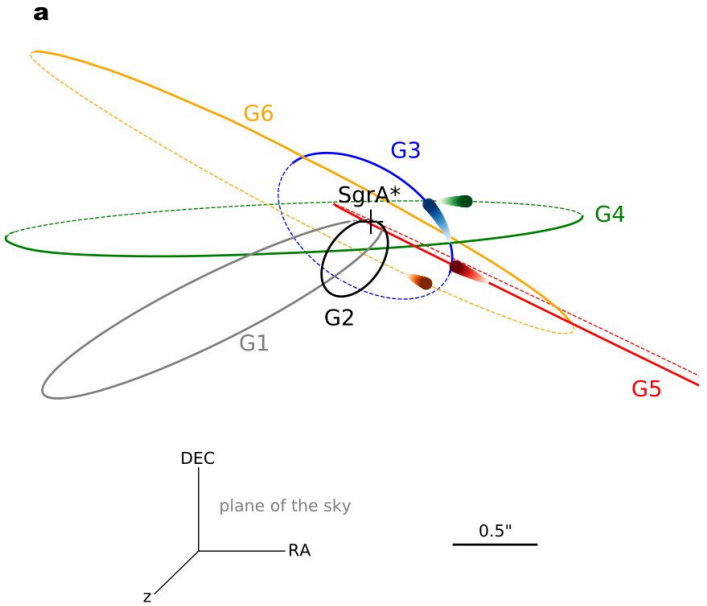


1a Merger products

- G objects -
  - Extended, dust enshrouded objects in the GC

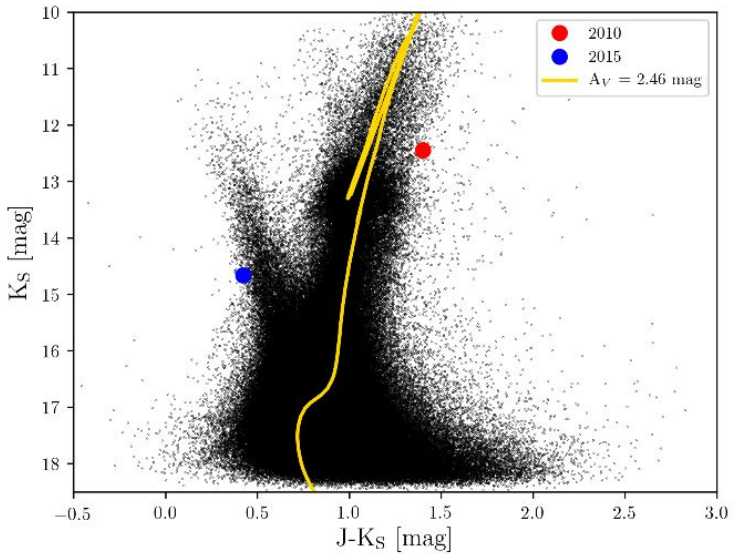


Ciurlo et al. 2020



1a Merger products

- Blue stragglers
  - Rejuvenated star (more massive star that has burned less fuel)
  - New star could appear younger by ~megayears to gigayears



V1309 Sco - a Galactic stellar merger in 2008

Late-time observations show that the product is consistent with a blue straggler star

Ferreira 2019

1a Merger products

- Type Ia-like supernovae
  - Similar-mass binaries with short periods (~1 day)
  - Helium cores collide in common envelope, coalesce into single object
  - Some cores can ignite and explode the star
  - Mtot < 0.5 Msun, low energy type-Ia SNe
  - ~1 % of entire GC stellar binary population
  - ~5-10 per yr in local volume (250 Mpc)

2 White dwarf mergers

- ~ 11 % of merging systems contain a white dwarf
- ~15 % of WD systems result in type Ia SNe
- ~0.4 % of entire GC binary population

- Expected rate : ~2-5 per year in a volume up to 250 Mpc
  - Total SN-Ia + SN-Ia like event rate ~ 7-15 per year

- CVs (WD-MS) or SBs (WD-RG)
  - Could remain as tight binaries for extended periods
  - Possible explanations for large population of observed X-ray sources in the GC
  - RCrB type variables.

Black holes and Neutron Stars

- ~3 % of merging systems will evolve to contain a BH or NS
  - most of these get separated when NS is formed
  - Small fraction of systems are NS-WD, will have been LMXBs before WD formed
  - Could explain part of observed population of GC X-ray sources
- ~0.1 % of entire GC binary population will be BH-BH or BH-NS systems

- Expected formation rate ~10-20 per year (in 1 Gpc^3 volume)
- 10% merging efficiency in GC (Hoang 2018)
- 15-30 detectable events per year by Advanced LIGO

More on black hole mergers (Hoang 2018)

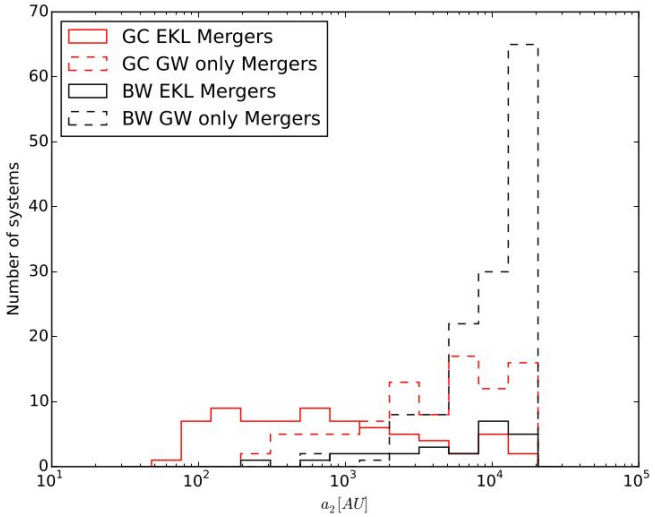
- Large escape speed in nuclear star clusters around massive black holes
  - Contrary to GC, where BHs with kicks can escape
  - Kick > 50 km/s -> BBH formation in GCs suppressed significantly

- Relevant Processes for a BBH in GC
  - EKL excitations (T_EKL) vs GR precession (T_precession)
  - GW emission (T_GW) vs Interactions with NSC (T_evaporation)

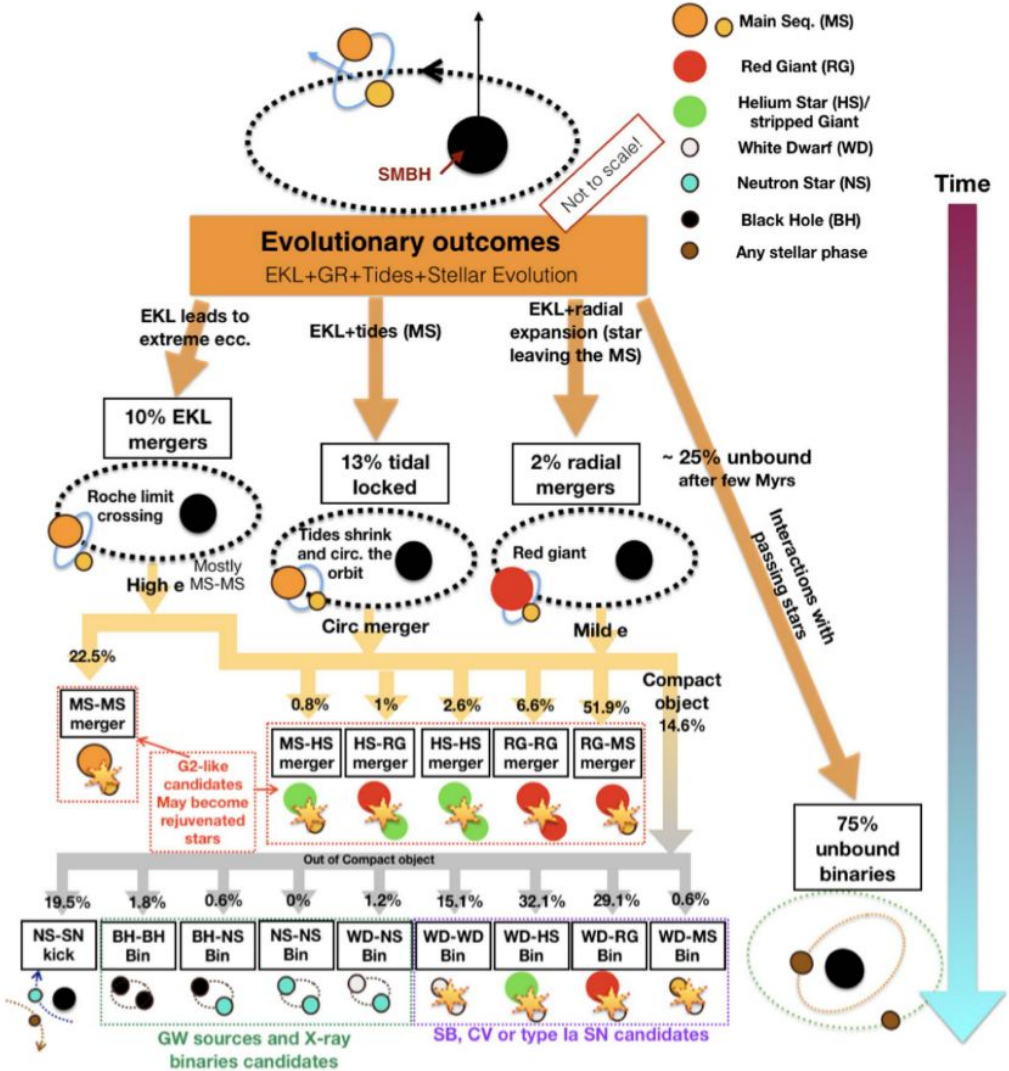
More on black hole mergers (Hoang et al. 2018)

Two mechanisms -

- GW-only
  - T_precession < T_EKL , T_GW < T_evaporation
- EKL induced
  - T_EKL > T_precession, T_GW < T_evaporation



- BBH merger rate ~ 1-3 $Gpc^{-3}yr^{-1}$
  - Comparable to predicted rates in globular clusters
  - Depends on steady state number of BH binaries in the GC, need a replenishment mechanism


Main Seq. (MS)
Red Giant (RG)
Helium Star (HS)/ stripped Giant
White Dwarf (WD)
Neutron Star (NS)
Black Hole (BH)
Any stellar phase
Time
SMBH
Not to scale!
Evolutionary outcomes
EKL+GR+Tides+Stellar Evolution
EKL leads to extreme ecc.
EKL+tides (MS)
EKL+radial expansion (star leaving the MS)
10% EKL mergers
13% tidal locked
2% radial mergers
~ 25% unbound after few Myrs
Roche limit crossing
Mostly MS-MS
High e
Tides shrink and circ. the orbit
Circ merger
Red giant
Mild e
Interactions with passing stars
22.5%
0.8%
1%
2.6%
6.6%
51.9%
Compact object 14.6%
MS-MS merger
G2-like candidates May become rejuvenated stars
MS-HS merger
HS-RG merger
HS-HS merger
RG-RG merger
RG-MS merger
Out of Compact object
75% unbound binaries
19.5%
1.8%
0.6%
0%
1.2%
15.1%
32.1%
29.1%
0.6%
NS-SN kick
BH-BH Bin
BH-NS Bin
NS-NS Bin
WD-NS Bin
WD-WD Bin
WD-HS Bin
WD-RG Bin
WD-MS Bin
GW sources and X-ray binaries candidates
SB, CV or type Ia SN candidates