Collisional dynamics in the field: Ultra wide systems as sources of binary exotica

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Collisional dynamics in the field: Novel channel for GW mergers

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Goals:

- Present a novel dynamical model: interaction between wide systems and random stars in the field
- Implications : **GWs**, Type Ia, LMXBs, sGRBs…
- Discuss the prospects of this model

Summary

- **The galactic field is collisional for wide systems**
- Dynamical GW formation channel from the field
- (At least some fraction of the) observed mergers could originate from wide systems (binaries or triples)

Thanks for listening

- Happy to answer some questions
- Happier to ask new questions

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Dense environment characteristics

- Galactic centers and globular clusters are dense
  - Stellar density of globular / open clusters ：$n_* = 10^2 - 10^3 \frac{stars}{pc^3}$
  - Center of galaxies：$n_* = 10^6 - 10^8 \frac{stars}{pc^3}$
- Collisional dynamics：exchange interaction,

  direct collision, tidal capture, chaotic dynamics…

Dense environments host exotic binaries, albeit compact

- Conducive for the formation of exotic binaries
- Destructive for wide systems
- For a typical globular cluster, a wide binary with $a = 1000AU$

  the half-life time of the binary

$$t_{\frac{1}{2}} \approx 5\times10^{5} yr$$

The galactic field is different with low stellar density

- Low stellar density in the field
  - Solar neighbroud $n_* = 0.1 \frac{stars}{pc^3}$
- Considered ”collisionless”
- Many (many) star systems

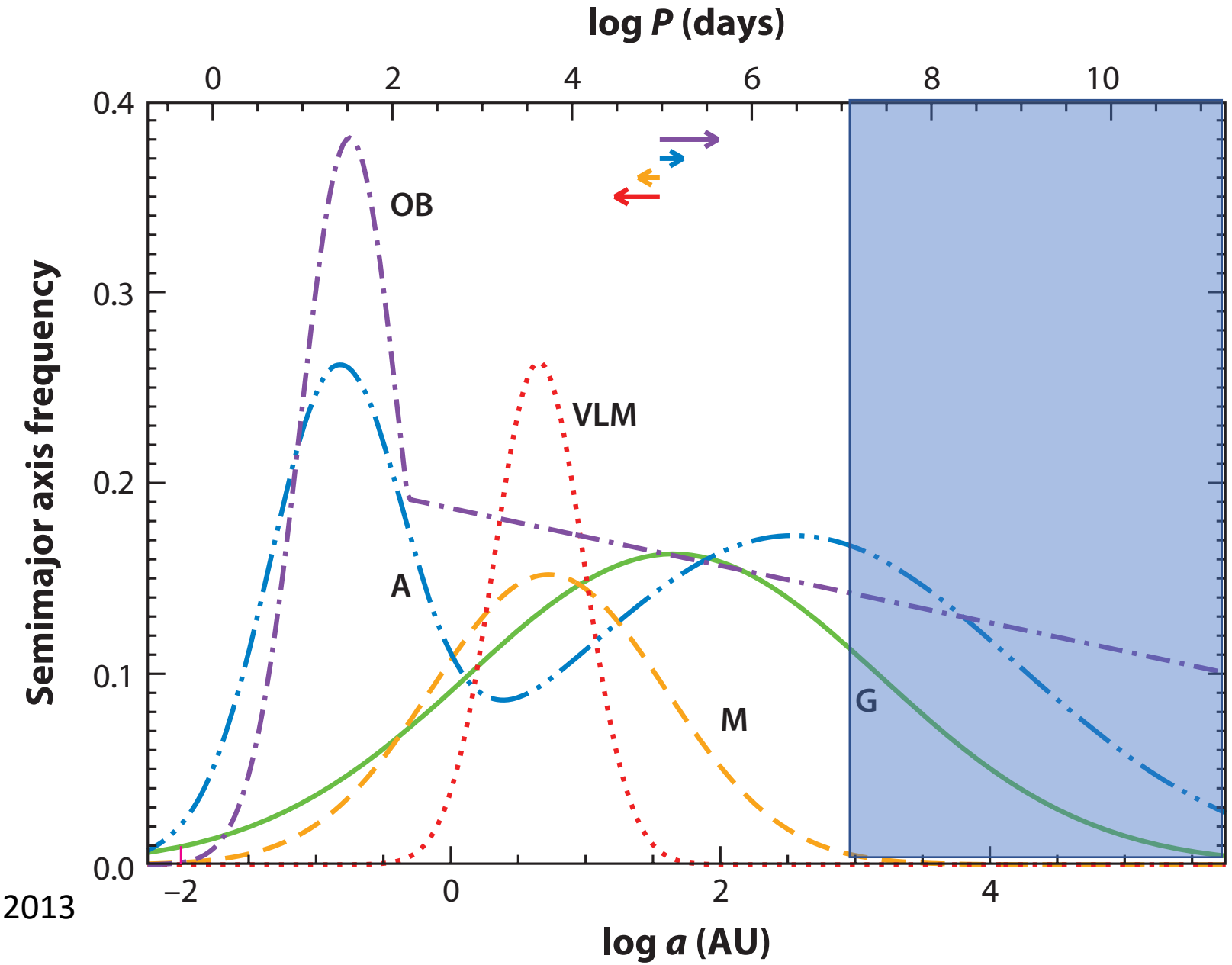
In the galactic field – wide systems survive

- In the solar neighborhoud a binary with $a = 1000AU$:

$$t_{\frac{1}{2}} \approx 7\times10^{10}yr$$

- If such binaries exist – they survive

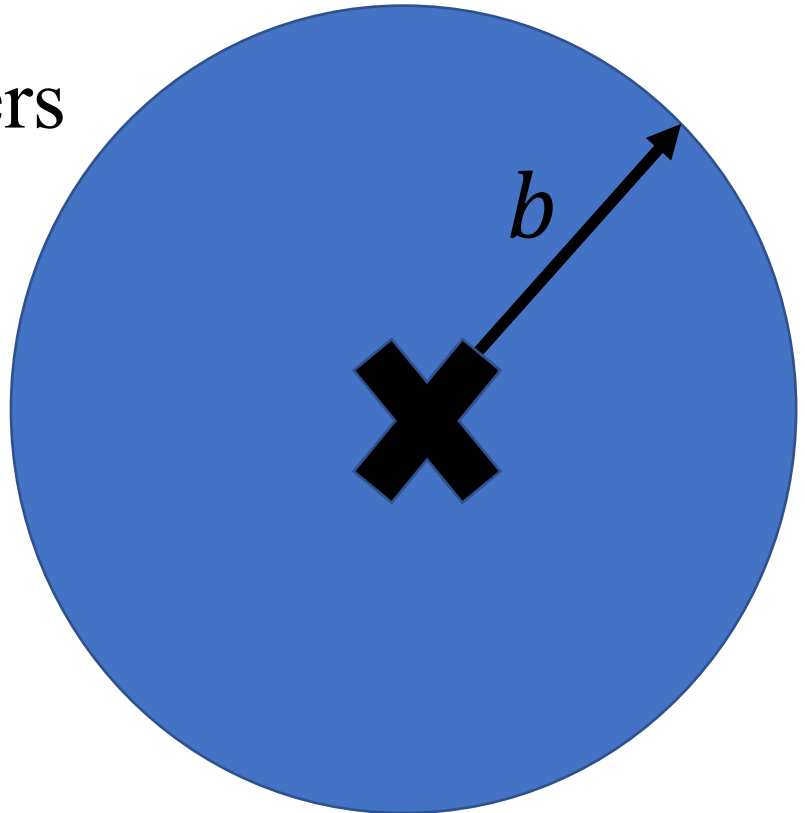
They exist, we see them*



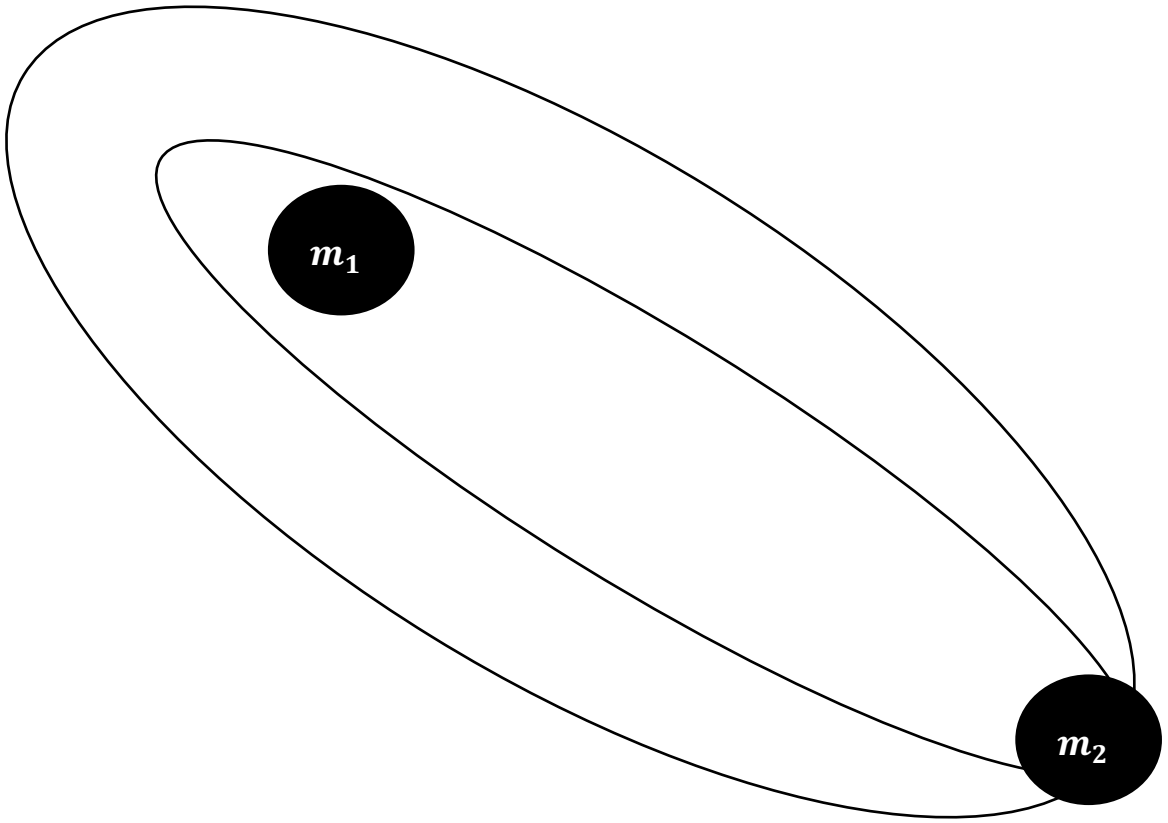
Duchene&Kraus 2013

Wide systems interact randomly with passing stars in the field

- Wide systems interact gravitationally with random field stars
  - The interaction is “impulsive”
  - Interaction rate: $f = n_* \sigma v = n_* \pi b^2 v$
- Average time between encounters
  - for $b = 10^4 AU$: $\sim 33 Myr$



Cartoon of such impulsive interaction



Loss cone treatment; what is the critical eccentricity?

Average separation

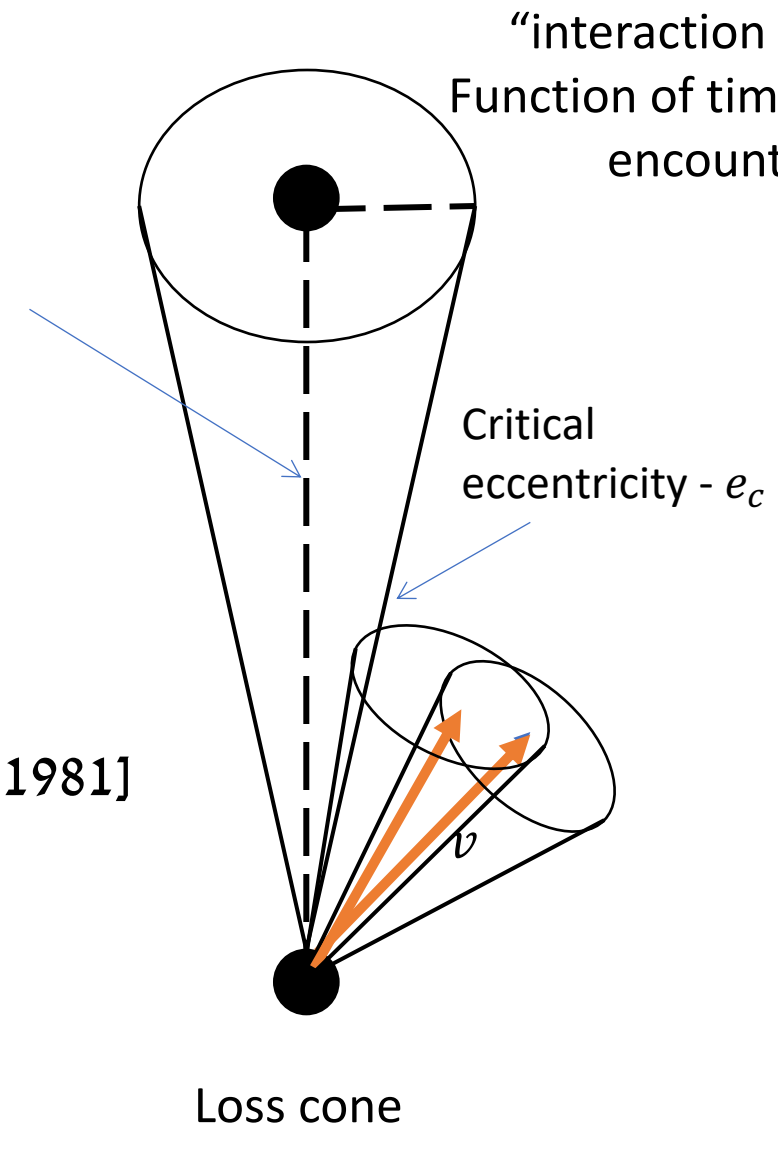
$$\langle r \rangle = a\left(1 + \frac{1}{2}e^2\right)$$

Average change of v

$$\langle \Delta\, v \rangle \simeq \frac{3Gam_*}{vb^2}$$ [Hills 1981]

Cone angle

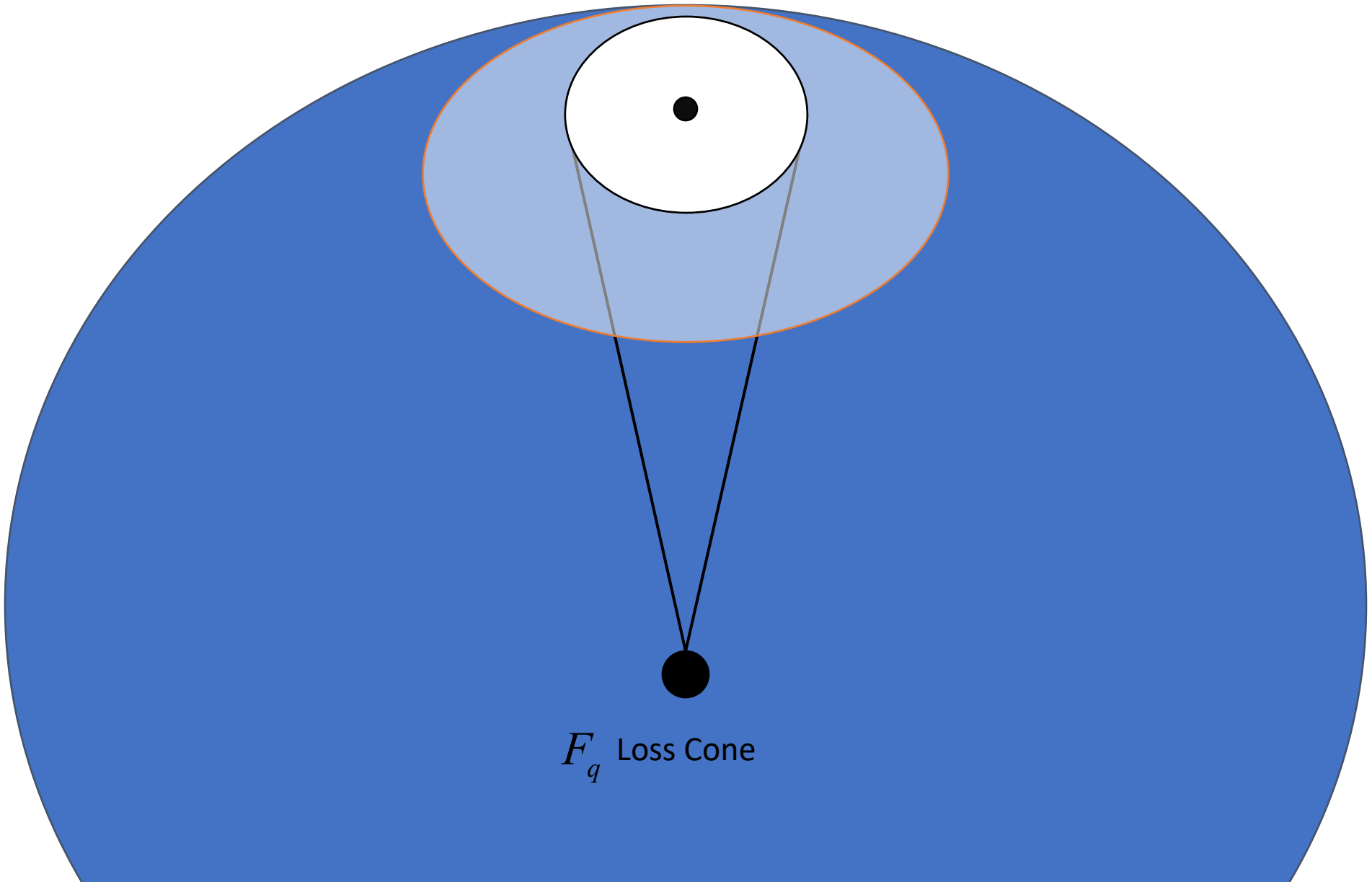
$$\Delta\theta = \frac{\Delta v}{v_b} \propto \frac{a^{3/2}}{b^2}$$



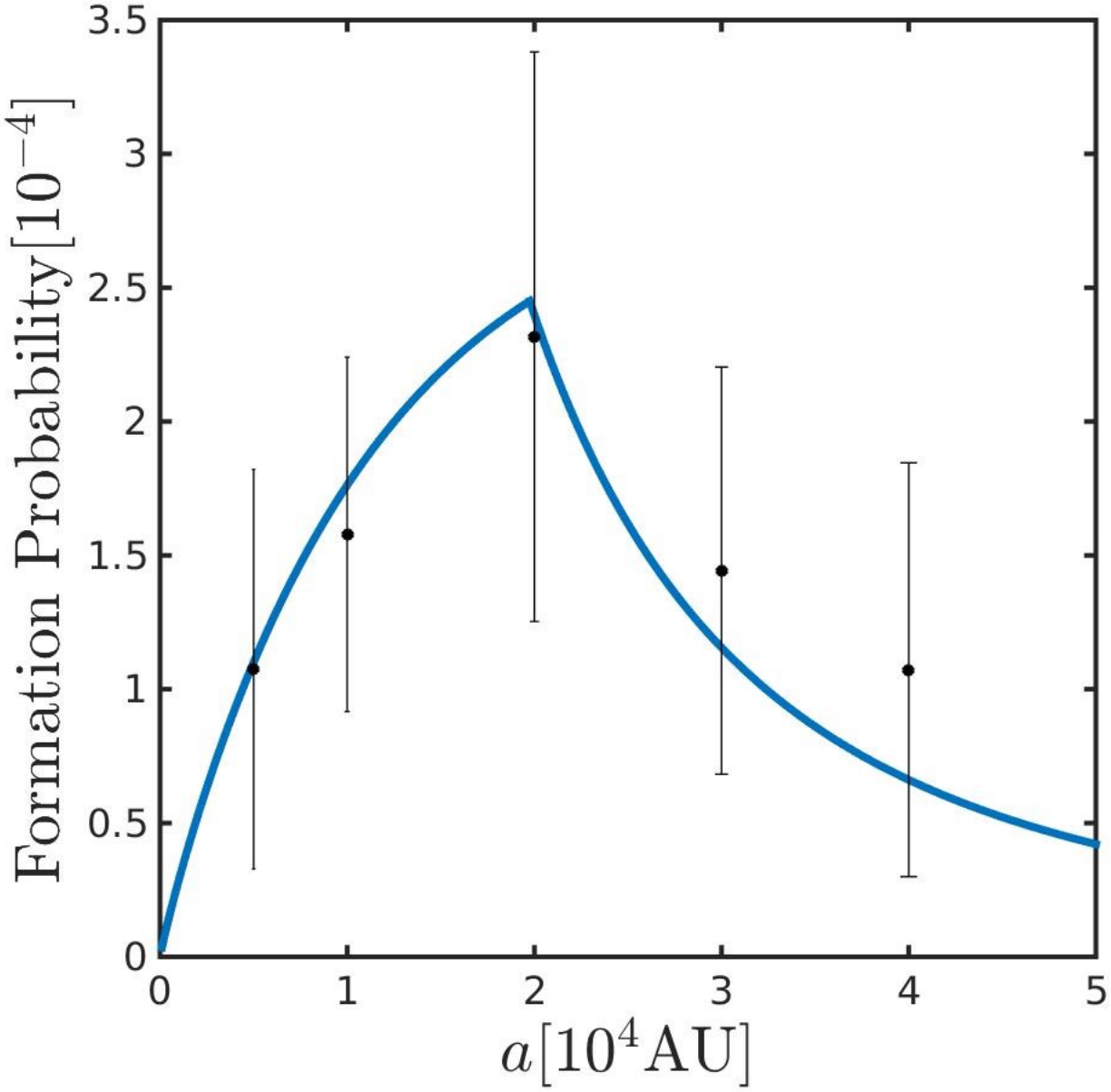
For GW mergers

$$e_c = \left(1 - \left(\frac{\beta T_{merger}}{a^4}\right)^{\frac{2}{7}}\right)^{1/2}$$

Different way to think of such interactions



Merger probability as a function of the binary semi-major axis



$10M_\odot + 10M_\odot$

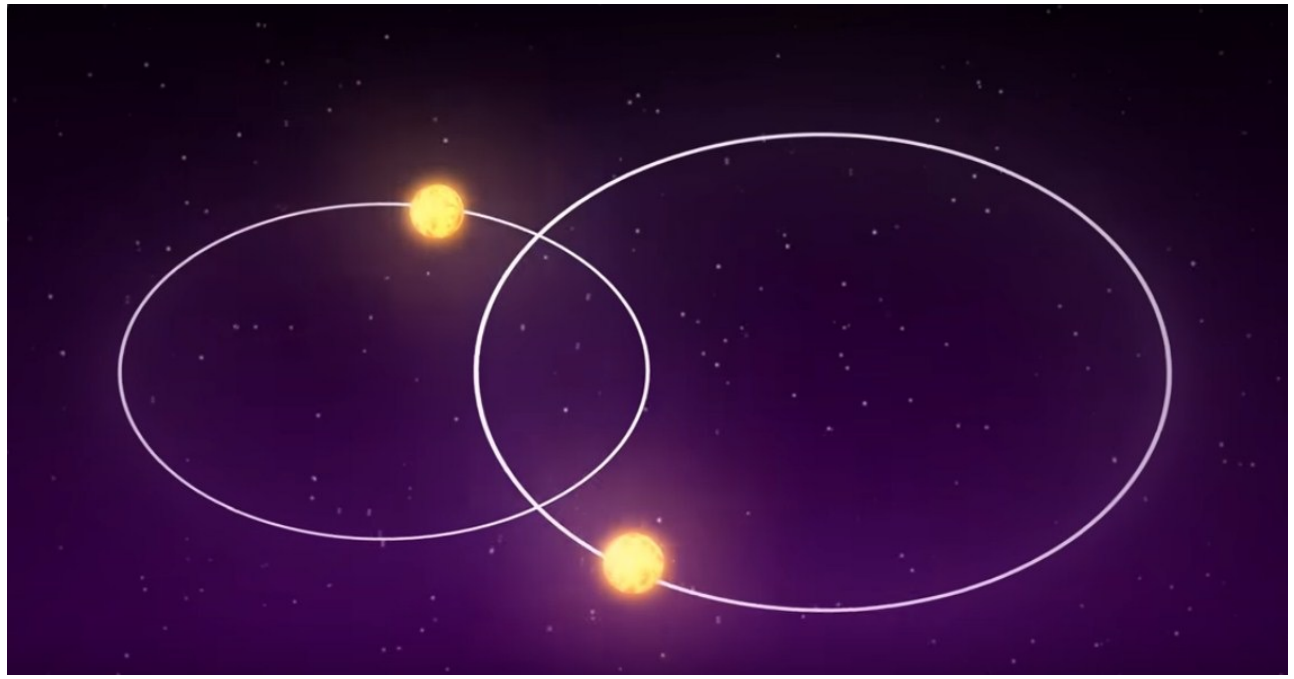
$t = 10Gyr$

Solar neighbourhood

[**EM** and Perets 2019]

Model ”ingredients” necessary to calculate the rate

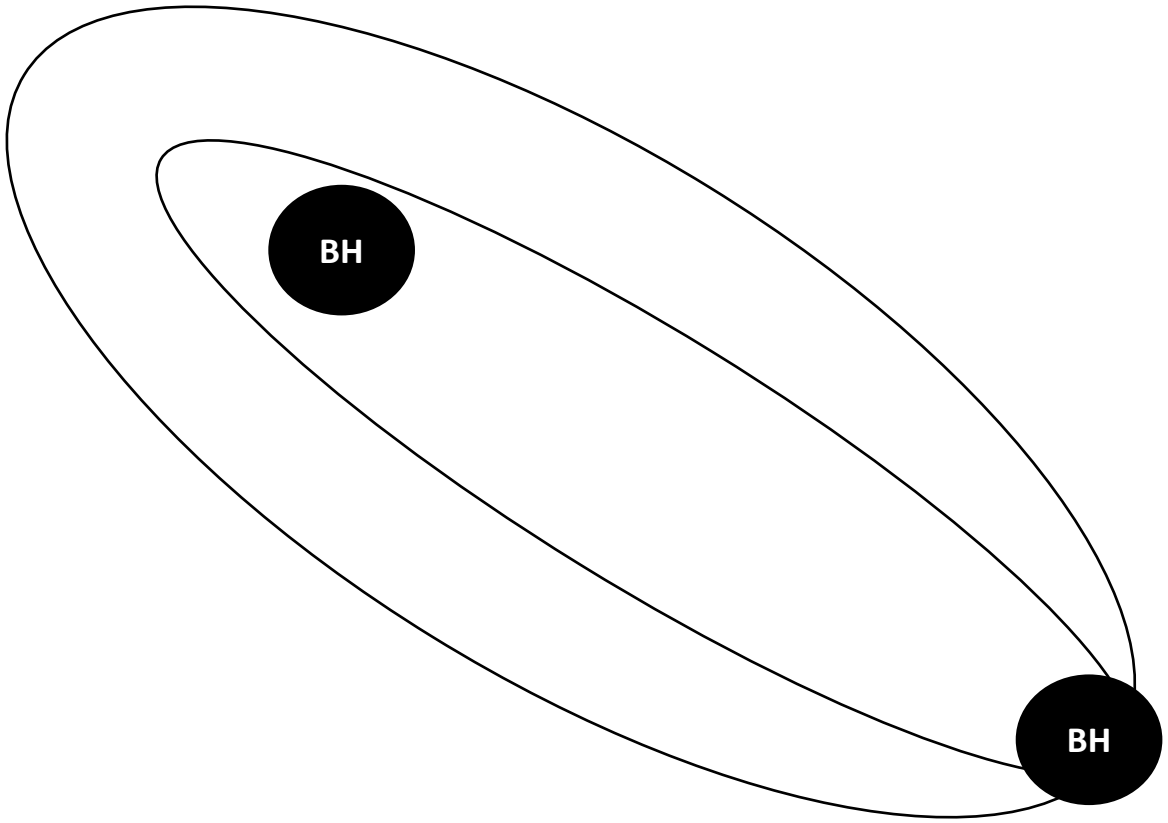
- **The wide system:**
  - Distribution of the semi-major axis $f_a\ (a)$
  - Distribution of the eccentricity $f_e\ (e)$ - assumed thermal
  - **Masses**
  - **Estimation of the number of systems in the galaxy**



Model ”ingredients” necessary to calculate the rate

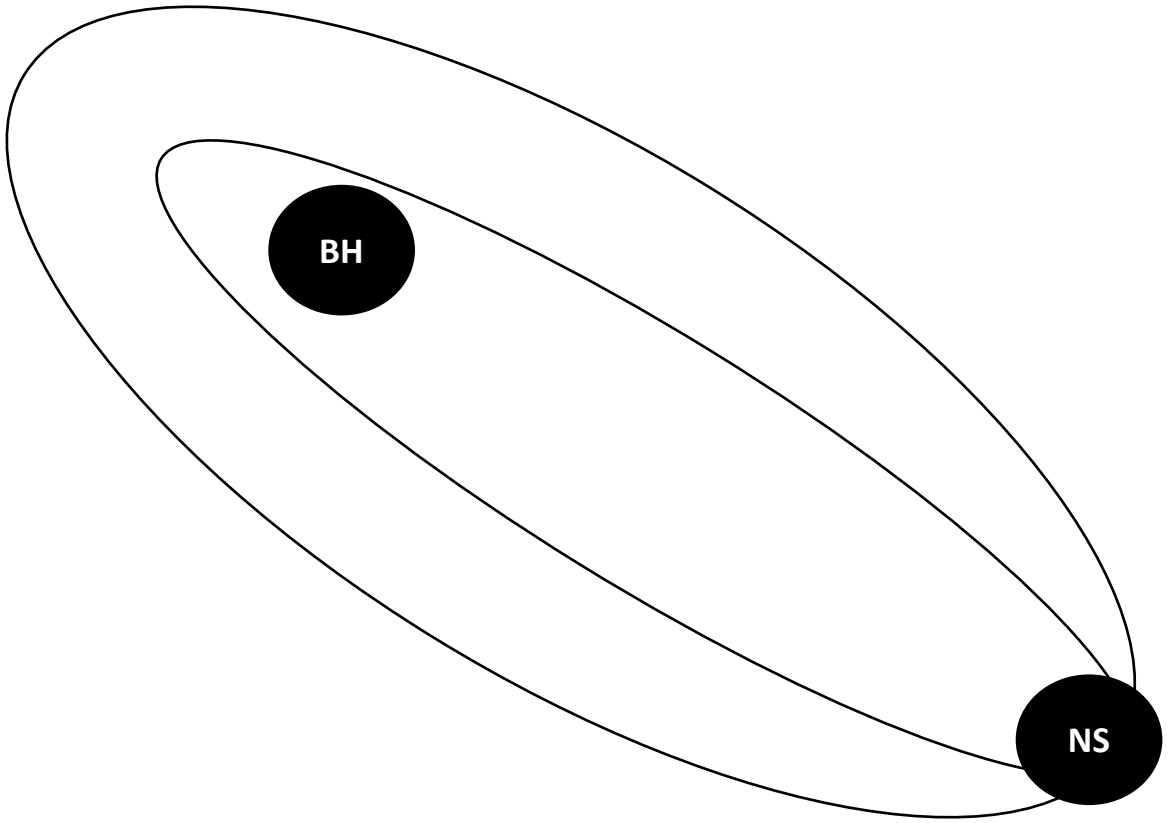
- **The galactic neighborhood**
  - Local stellar density: n_*
  - Typical velocity encounter: v
  - Mass distribution in the galaxy: $M(r)$
  - Galaxy density in the local universe in order to translate to rates

Binary: BBH (Michaely & Perets 2019)



- Interacting sphere：GW merger times

Binary: BHNS (Michaely & Naoz 2022 submitted)



- Interacting sphere : GW merger times

Binary system - merger rate (based on the model's assumptions)

$$\Gamma_{\mathrm{BBH}} \approx 40 \left(\frac{f_{primary}}{10^{-3}}\right)\left(\frac{f_{secondary}}{0.5}\right)\left(\frac{f_{wide}}{0.2}\right) Gpc^{-3}yr^{-1}$$

$$\Gamma_{\mathrm{BHNS}} \approx 10 \left(\frac{f_{primary}}{10^{-3}}\right)\left(\frac{f_{secondary}}{0.13}\right)\left(\frac{f_{wide}}{0.2}\right) Gpc^{-3}yr^{-1}$$

[**EM** & Perets 2019; **EM** & Naoz submitted.]

BHNS might be a source for EM signal

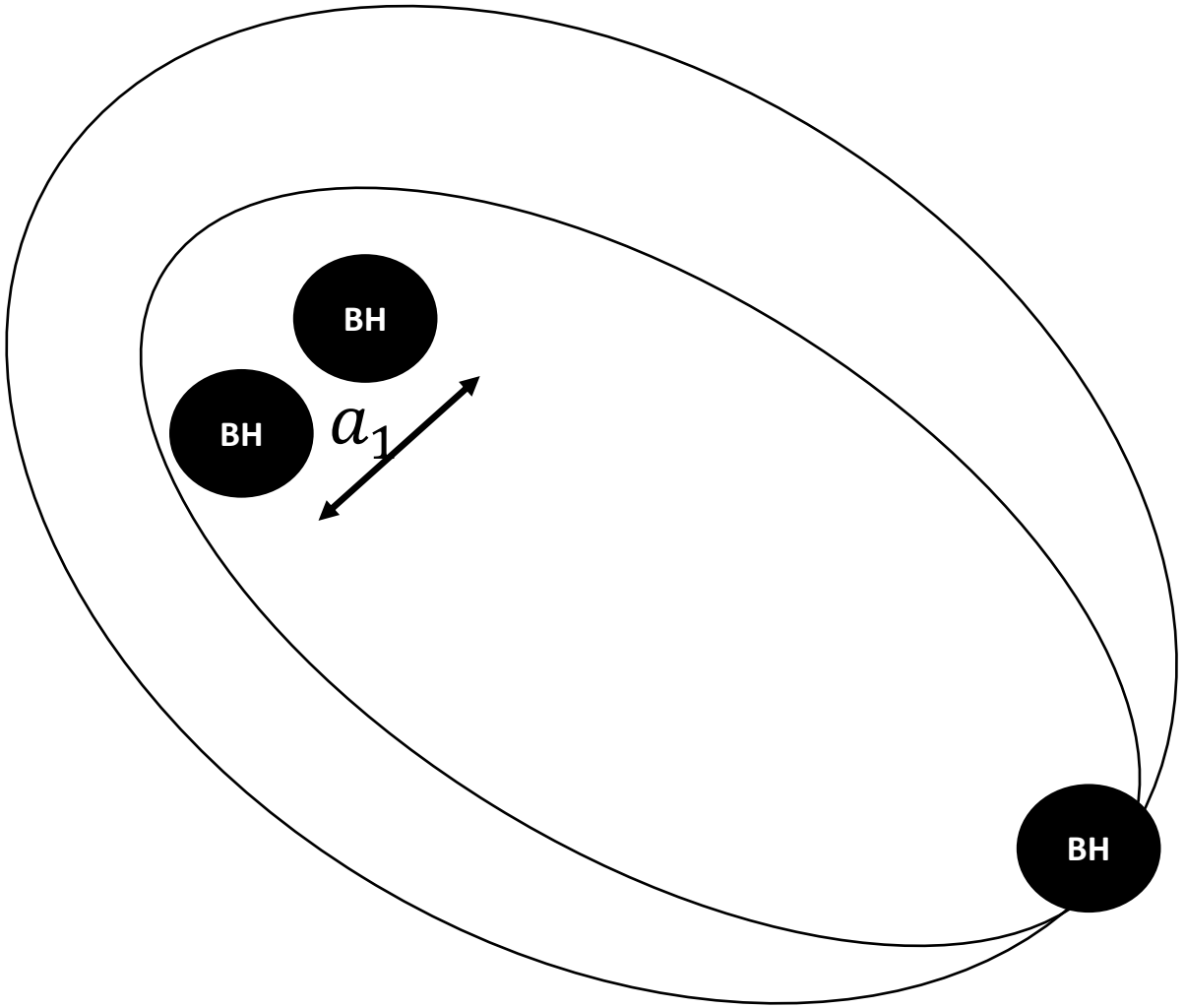
$$\Gamma_{\mathrm{BHNS}} \approx 10 \left(\frac{f_{primary}}{10^{-3}} \right) \left(\frac{f_{secondary}}{0.13} \right) \left(\frac{f_{wide}}{0.2} \right) Gpc^{-3} yr^{-1}$$

[Michaely & Naoz 2022 arXiv: 2205.15040]

- BHNS might be a source for sGRB:
  - For highly spinning BH - 30-50%
  - Else, depends on the EOS of the NS
  - Few percent for soft EOS
  - ~30% for stiff EOS

$$\Gamma_{\mathrm{sGRB}} \approx 0.5 - 5 Gpc^{-3} yr^{-1}$$

Triple system might get unstable and leads to new dynamics



- Interacting sphere : Stability sphere

Triple instability --> chaotic dynamics

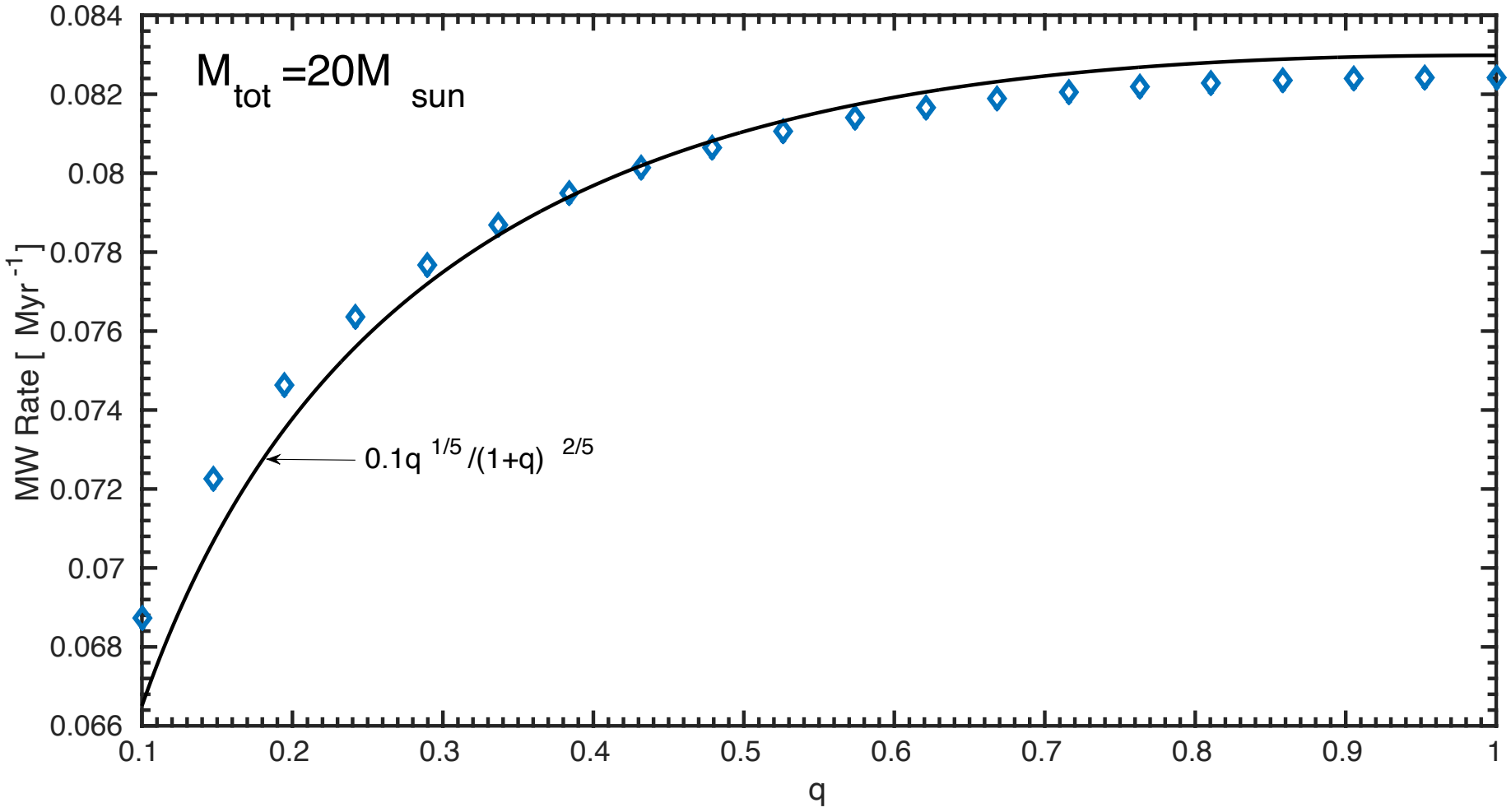
Johan Samsing

Triple instability --> chaotic dynamics

- **Random interactions may lead to instability**
  - Multiple binary-single encounter
  - Temporary eccentricity $f_e\ (e)$
  - Temporary semi $-$ major axis $f_a\ (a)$
  - High probability of eccentric merger

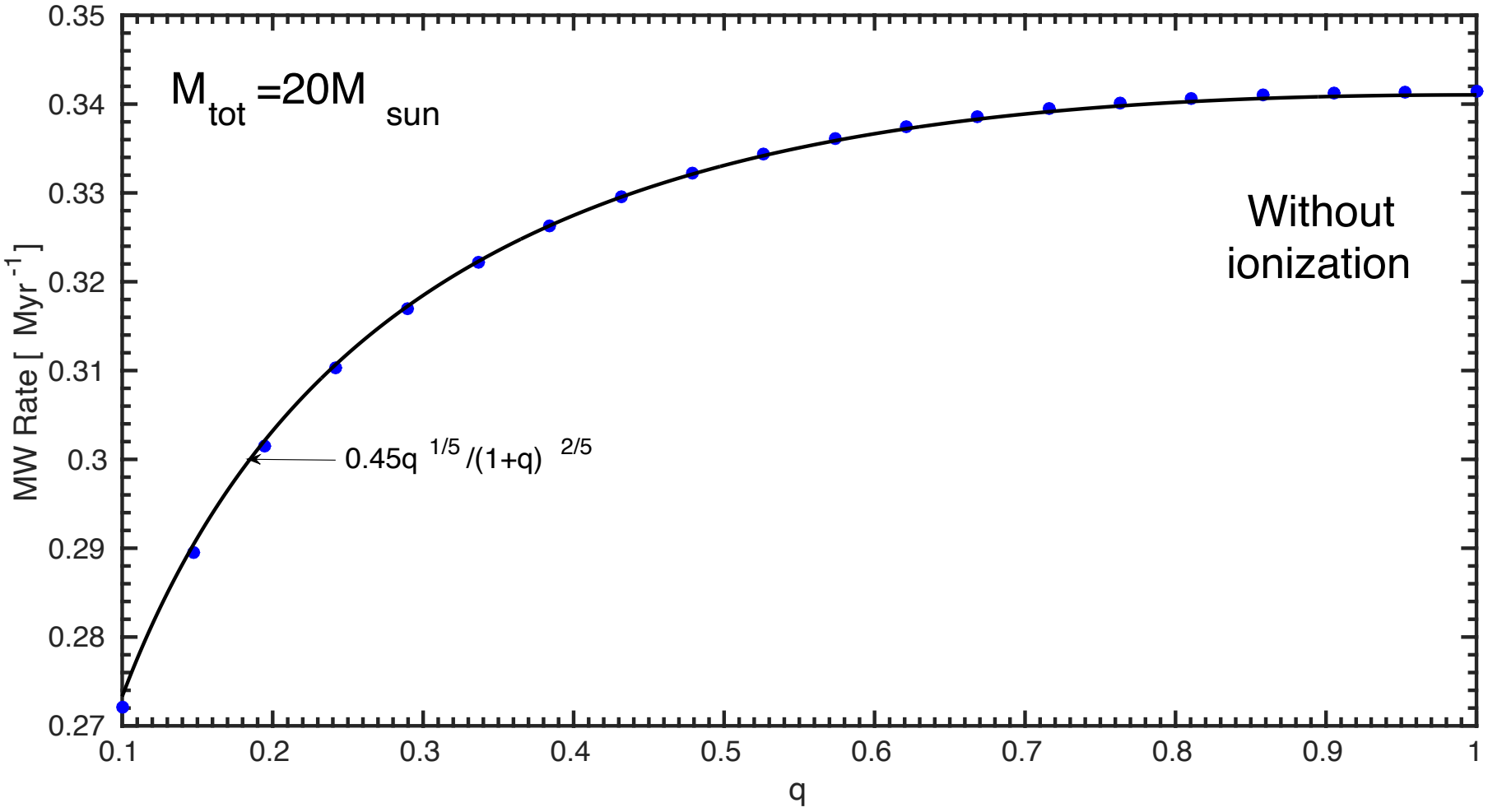
- **Final outcome**
  - If the system survives the chaotic phase:
    the outcome: close binary-BH and an ”escaper”
  - Low probability of eccentric merger

BBH Model signatures: tendency for equal masses



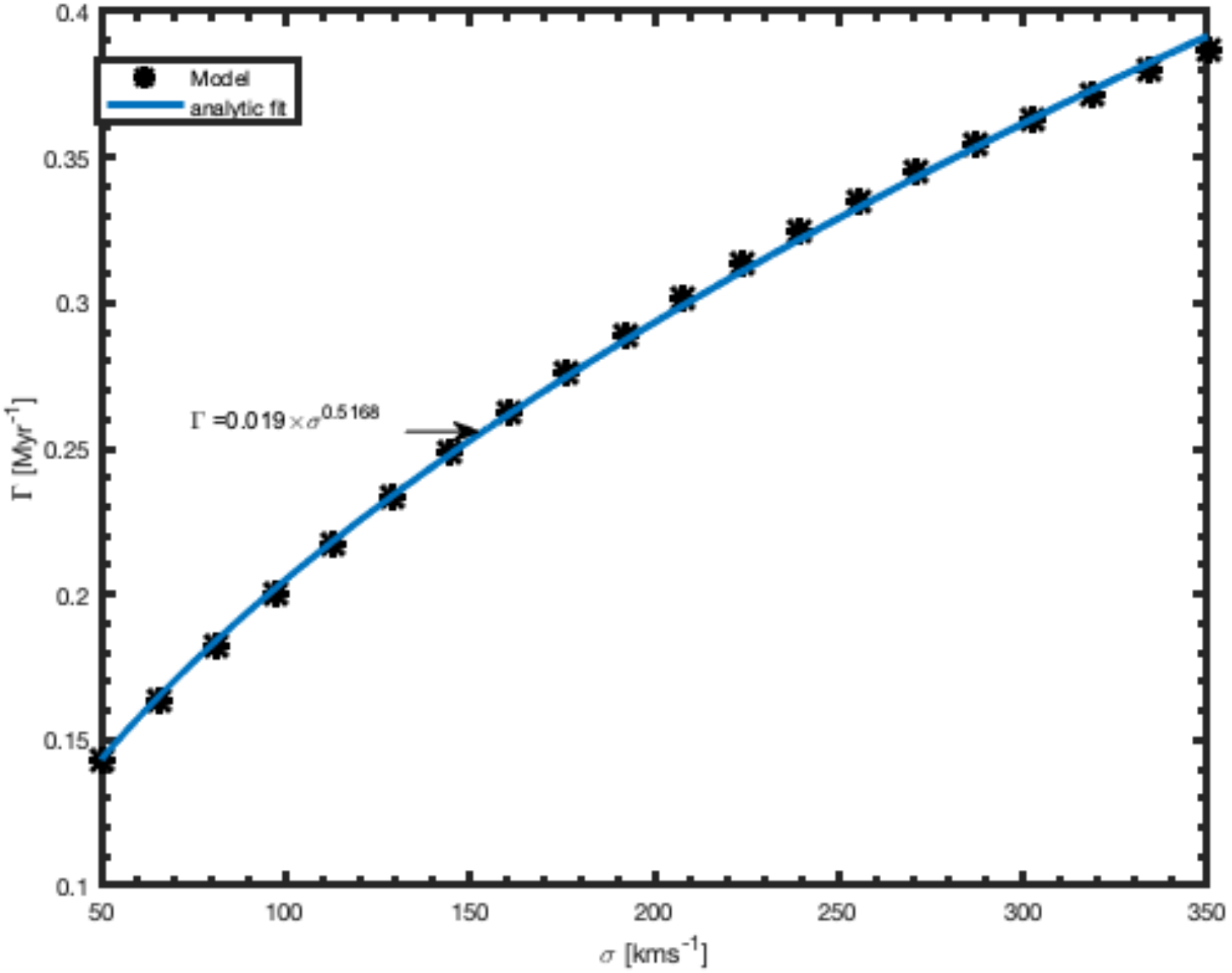
preliminary

BBH Model signatures: rate increases with mass ration



preliminary

BBH Model signatures: rate increases with velocity dispersion



preliminary

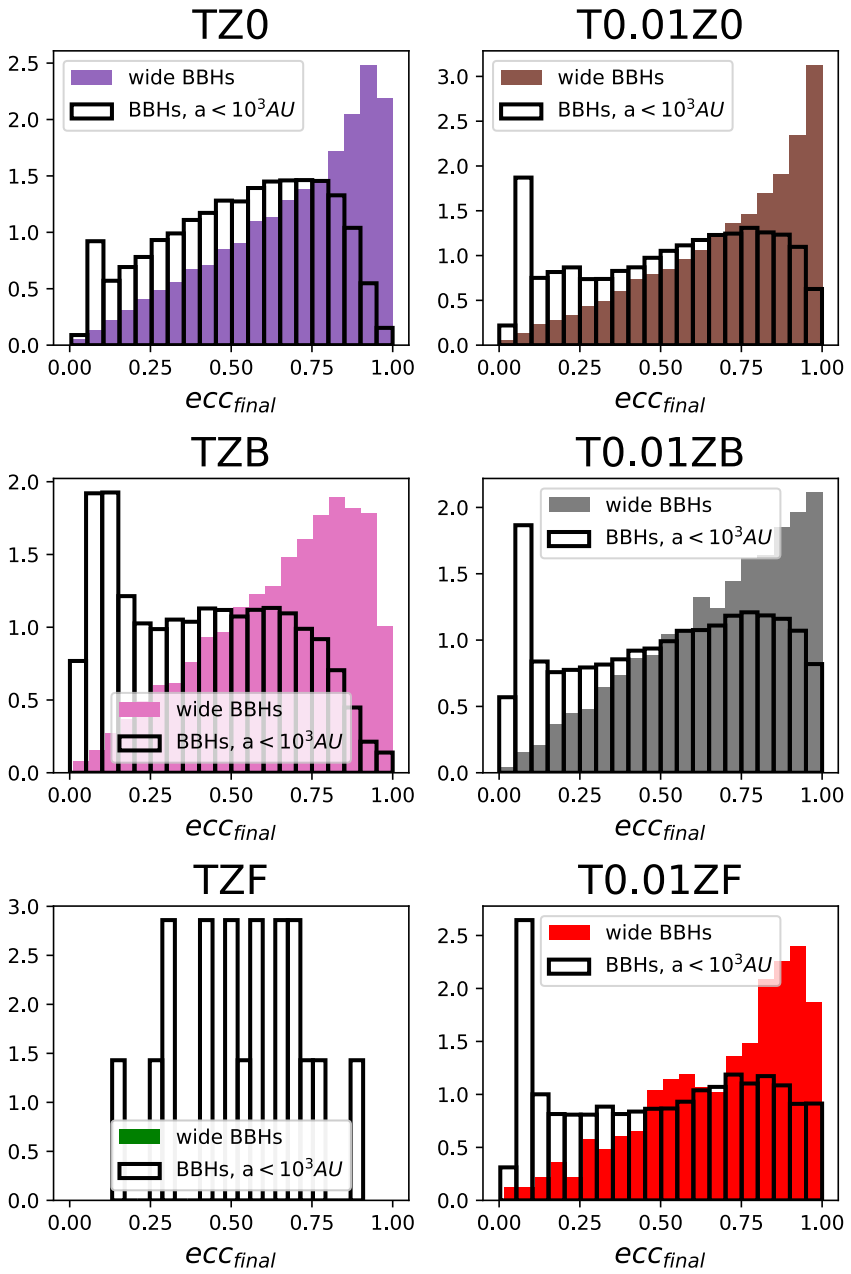
Model assumptions: “how to kill my model”

- BHs / NS(e-capture) born with no natal kick
- BBH: Equal Black-hole mass
- BHNS: Constant masses
- Semi-major axis distribution $f_a\ (a) \propto \frac{1}{a}$
- Thermal distribution of eccentricities

Wide systems…. How do they form?

- That’s a good question:
  - Capture?
  - Binary evolution? [Raveh, Michaely & Perets 2022]

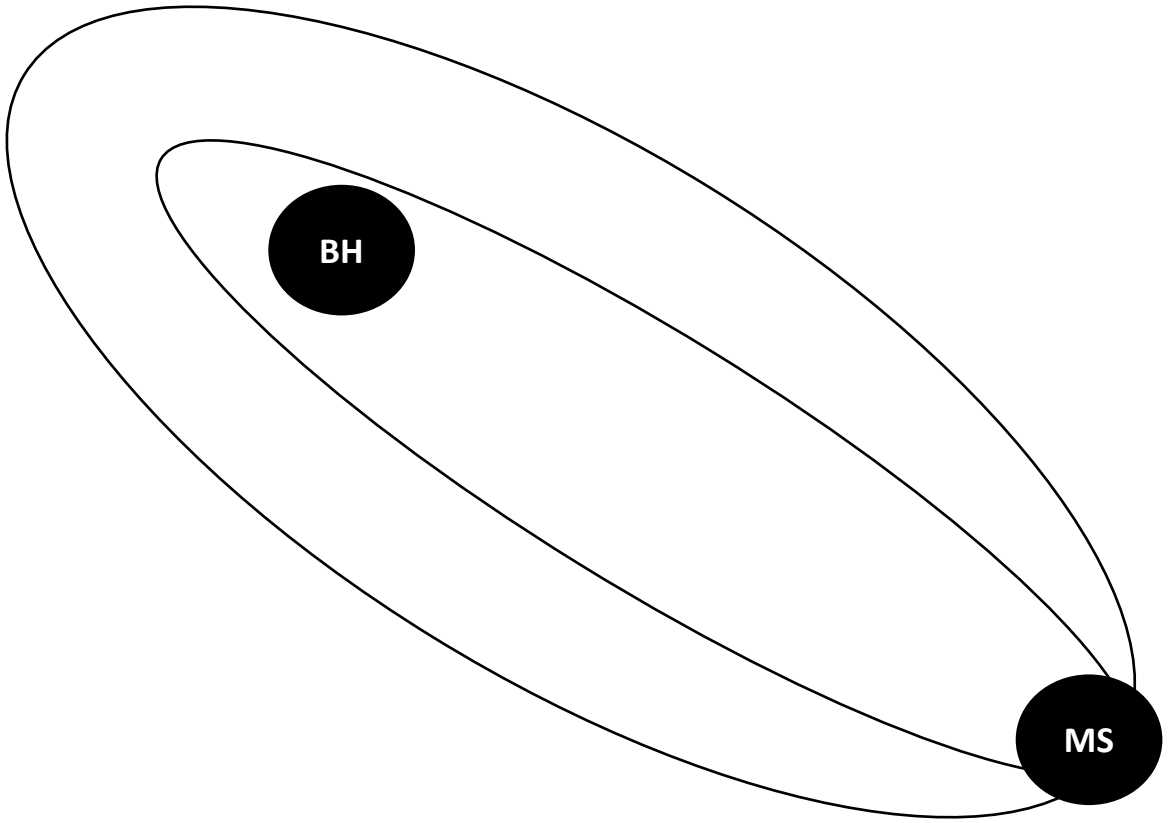
Wide systems…. How do they form?



[Raveh, **Michaely** & Perets 2022]

Other systems:

Binary: BH-MS

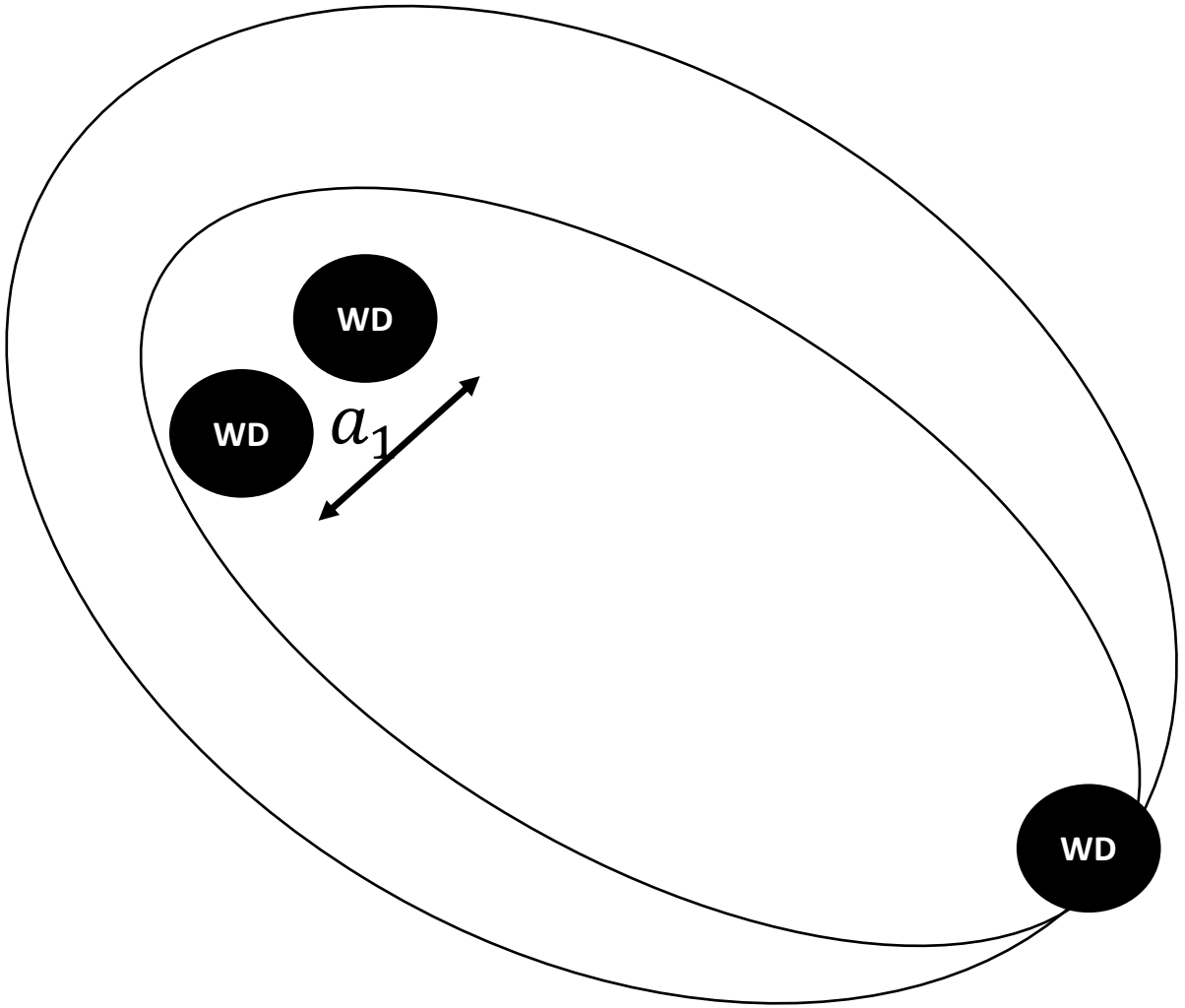


- Interacting sphere: Tidal sphere of the system

$$N_{LMXBs} \approx 10 - 100s$$

Michaely & Perets 2016

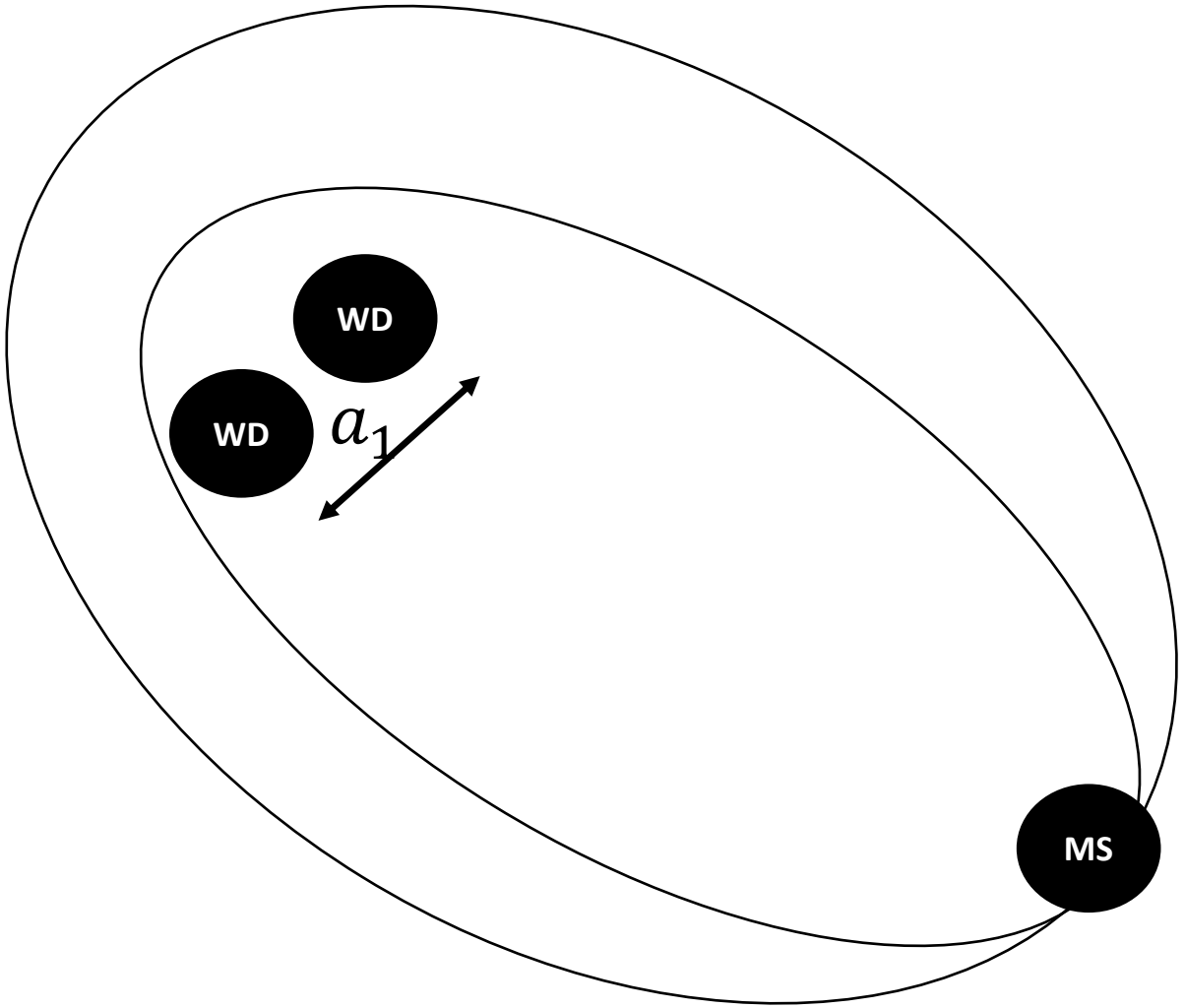
Triple system might get unstable and leads to new dynamics



- Double degenerate (2-%37%)
- Direct collision (0.1%-3%)

Michaely 2021

Triple system might get unstable and leads to new dynamics



- MS-WD collision
- ~ 1 collision every 5000-10000 yrs

EM & Shara 2021

Today and tomorrow

- Relax the assumption of natal kick = 0 [Rave et al. submitted]
- Model signatures for BBH (work in progress)
- Implication for eLISA / DECIGO
- Novel formation channel of CV / ULX ….?

signatures

- **Binary channel: tendency for equal mass merger**
- **More mergers in galaxies with high velocity dispersion**
- **Almost uniform in delay time distribution**
- **Almost isotropic spin distribution**

Summary

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(gist of a) Summary of the observations up to O3

	BBH	BHNS	BNS
Rate $[Gpc^{-1}yr^{-1}]$	17.3-45	7.4-320	13-1900

- Tendency to equal mass mergers
- (probably) No eccentric mergers
- Zero effective spin (Evidence of misaligned spins?)
- More…

The astrophysical questions

- **What are the channels that lead to a GW sources?**
- **What are the observational signatures of each channel?**
- **What is the merger rate per volume?**
- **What is the delay time distribution?**
- What is the spin distribution?
- What is the eccentric rate?

Masses in the Stellar Graveyard