Impact of Gas Hardening on Hierarchical BBH Mergers in Migration Traps of AGN Disks

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Active Galactic Nuclei

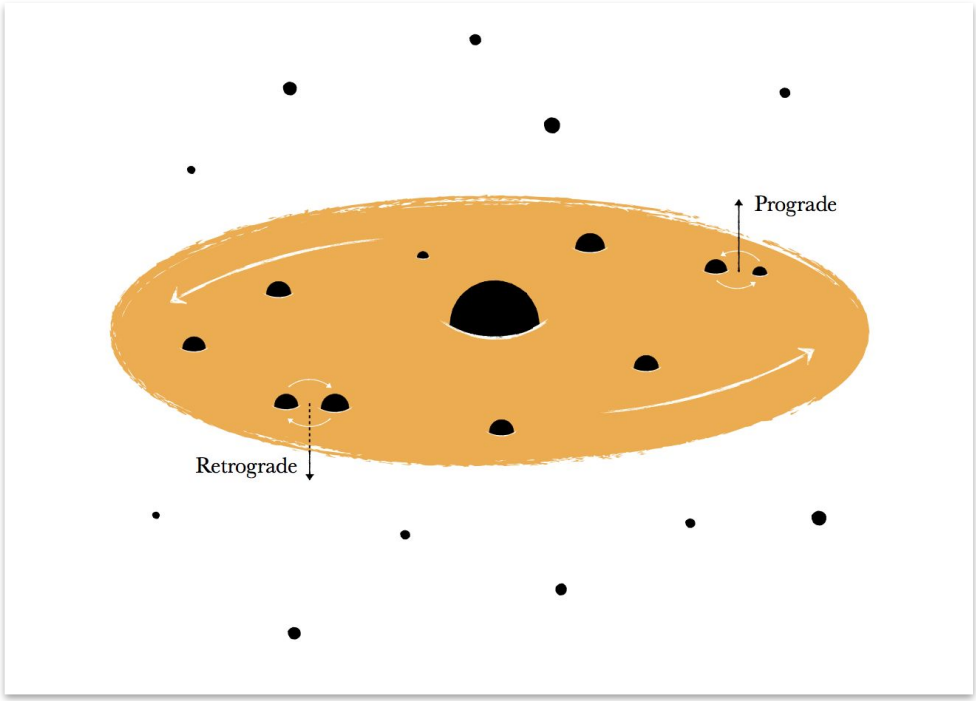


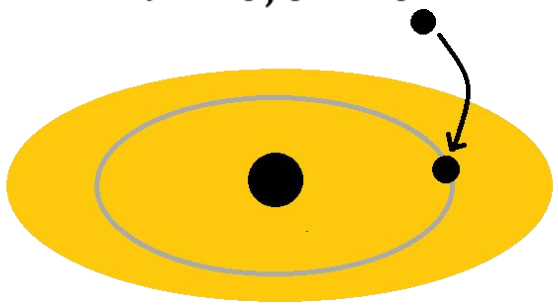
FIGURE FROM MCKERNAN ET AL. (2021)

- Super-massive black hole
  $M_{\mathrm{SMBH}} \sim 10^{6.5} M_{\odot}$
  (Greene&Ho 2007)
- Gaseous accretion disk
- Lifetime $\tau \sim 1.5$ Myr
  (Khrykin et al. 2021)
- Nuclear Star Cluster

The effects of gas

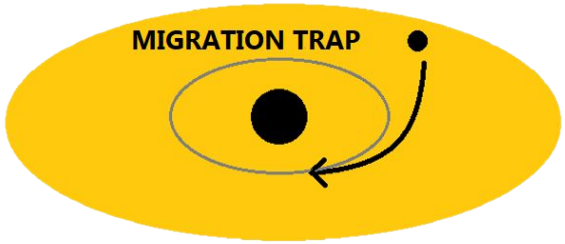
1) **GAS CAPTURE**

$i \to 0, e \to 0$



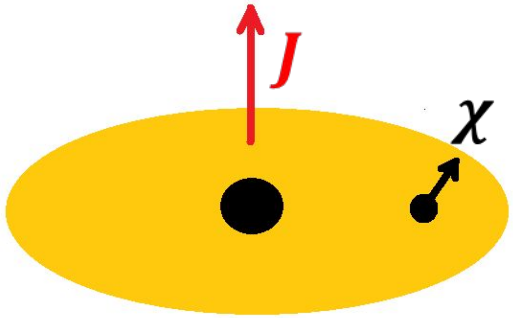
2) **TYPE I MIGRATION**

$R \to R_{\mathrm{trap}}$



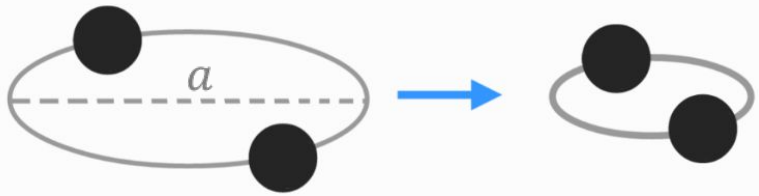
3) **SPIN ALIGNMENT**

$\vec{\chi} \parallel \vec{J}$



4) **ASSISTED INSPIRAL**
(a.k.a. **GAS HARDENING)**

$a \downarrow, e \uparrow$



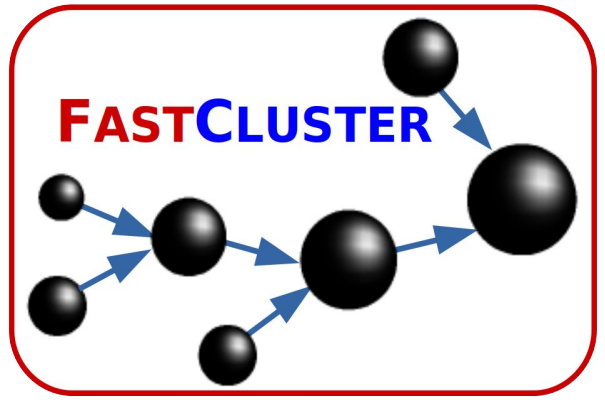
FASTCLUSTER: a semi-analytical approach

New semi-analytical model and code

✔ Fast simulations: explore the parameter space

✔ Versatile: the same numerical algorithm can be adapted to other dynamical channels

→ young, globular and nuclear star clusters



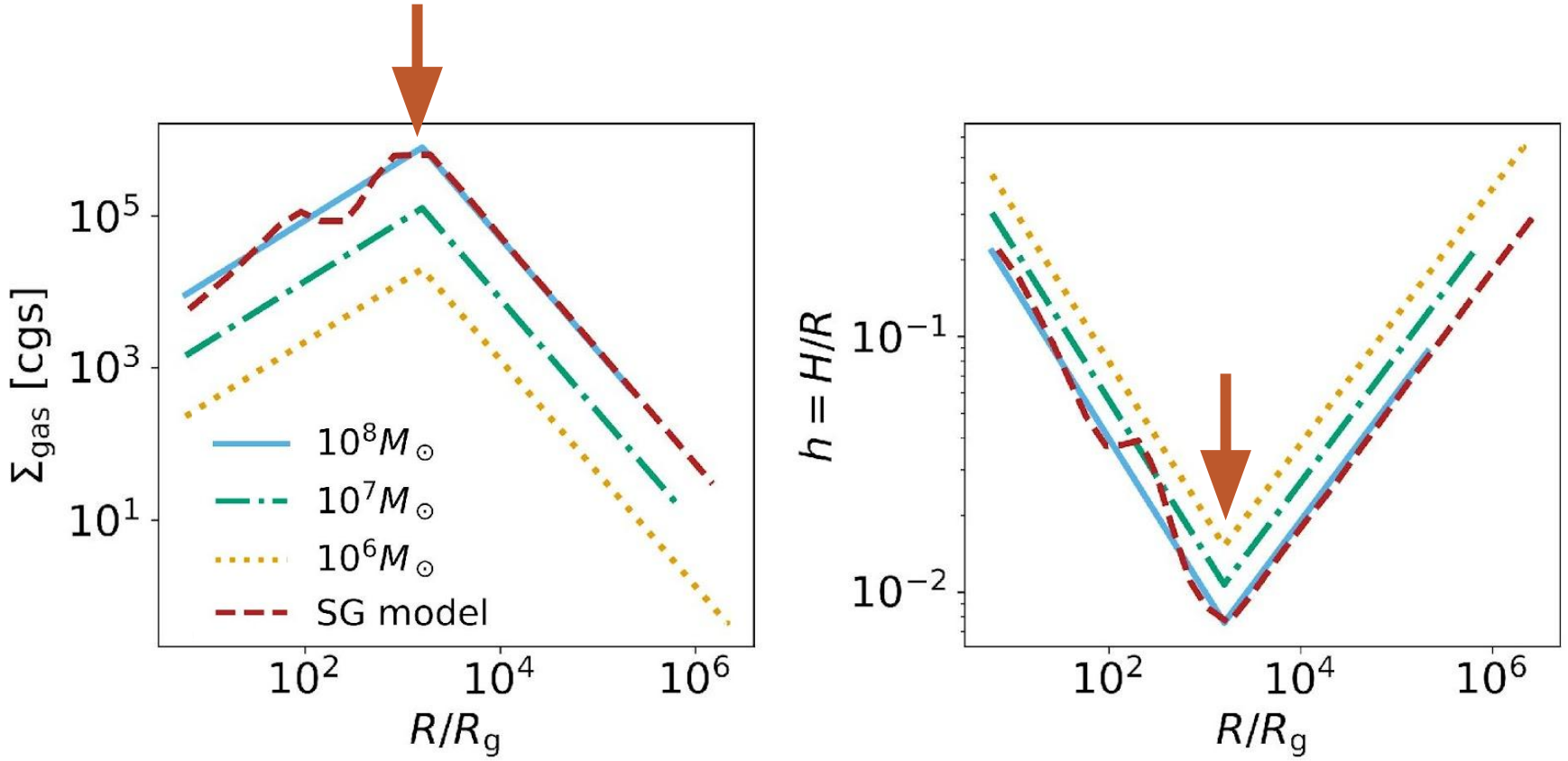
(Mapelli et al. 2020, 2021)

Open-source code, find it at
gitlab.com/micmap/fastcluster_open

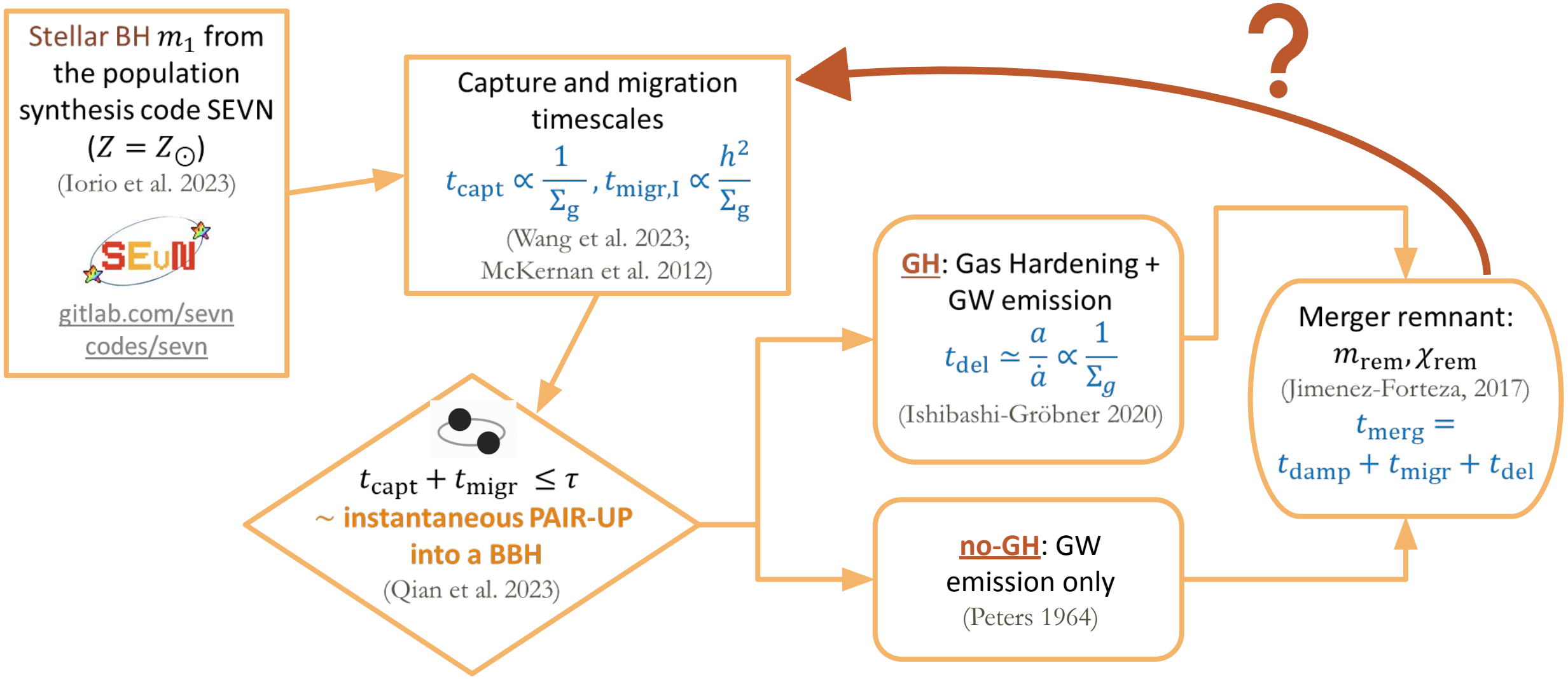
AGN disks: Sirko&Goodman (2003)

Type I migration trap at $R_{trap} \sim 1300\ R_g$

(Bellovary et al. 2016)

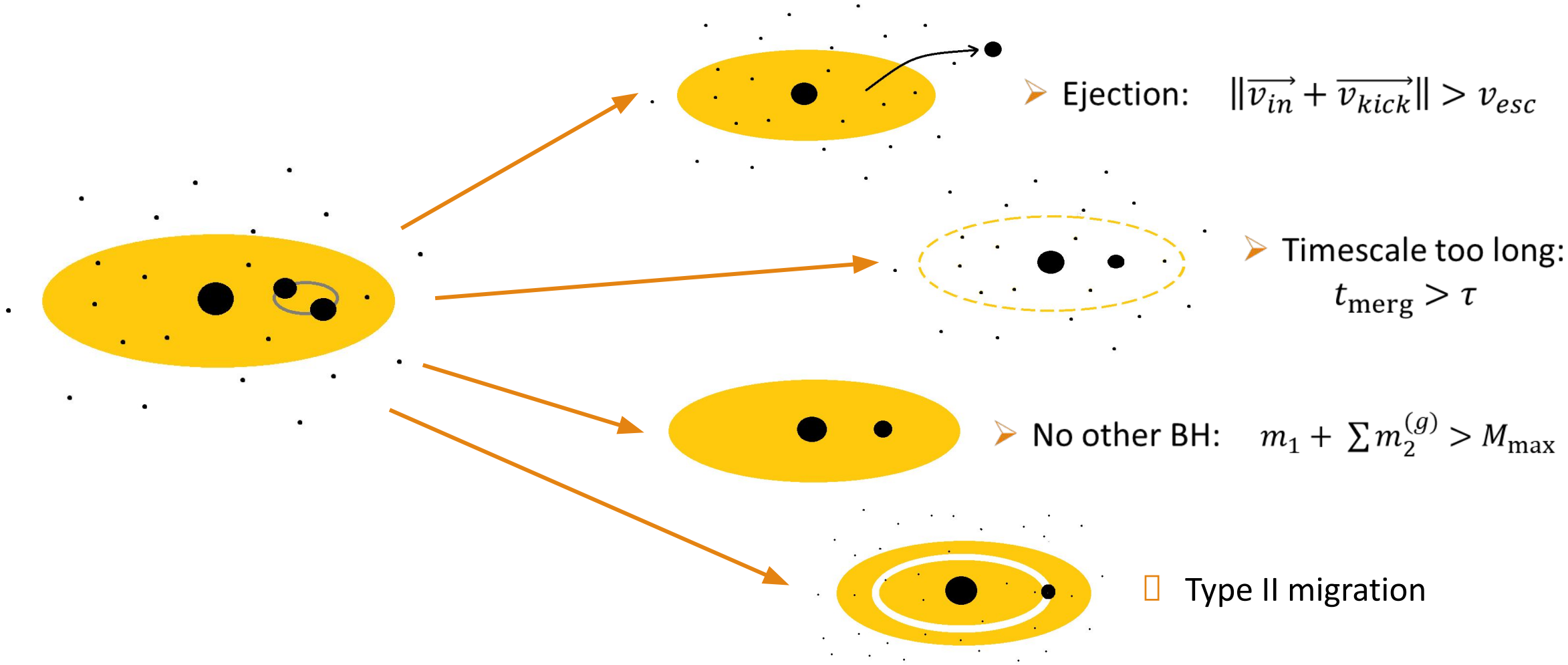


First generation



Nth generation

Can the merger remnant go through a new merger event?

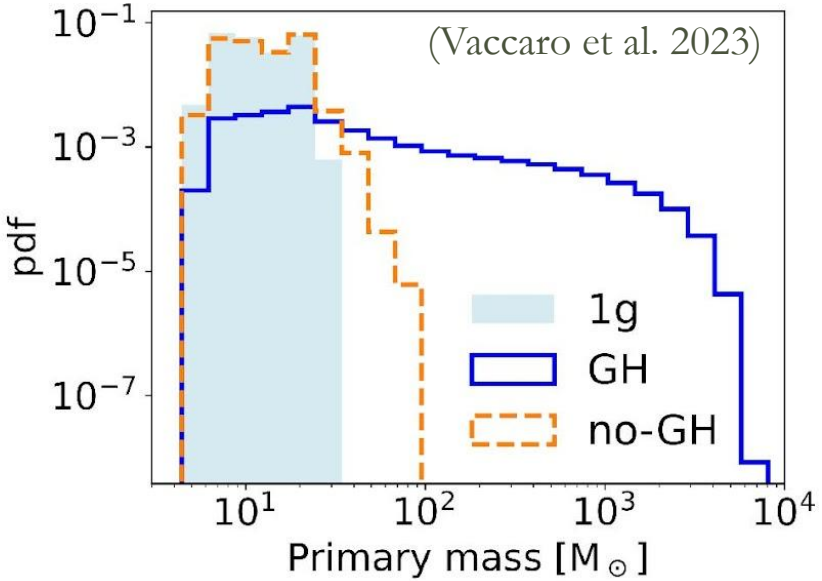


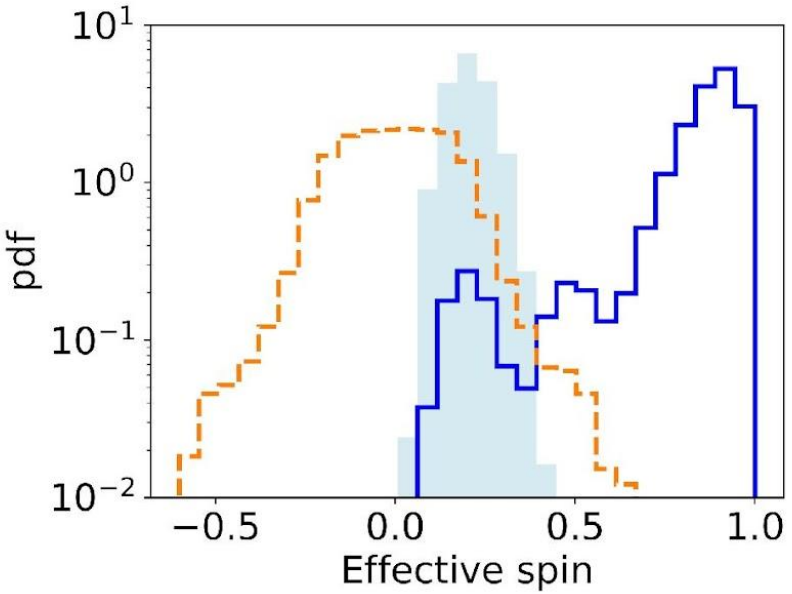
- Ejection: $\|\overrightarrow{v_{in}} + \overrightarrow{v_{kick}}\| > v_{esc}$
- Timescale too long: $t_{\mathrm{merg}} > \tau$
- No other BH: $m_1 + \sum m_2^{(g)} > M_{\mathrm{max}}$
- Type II migration

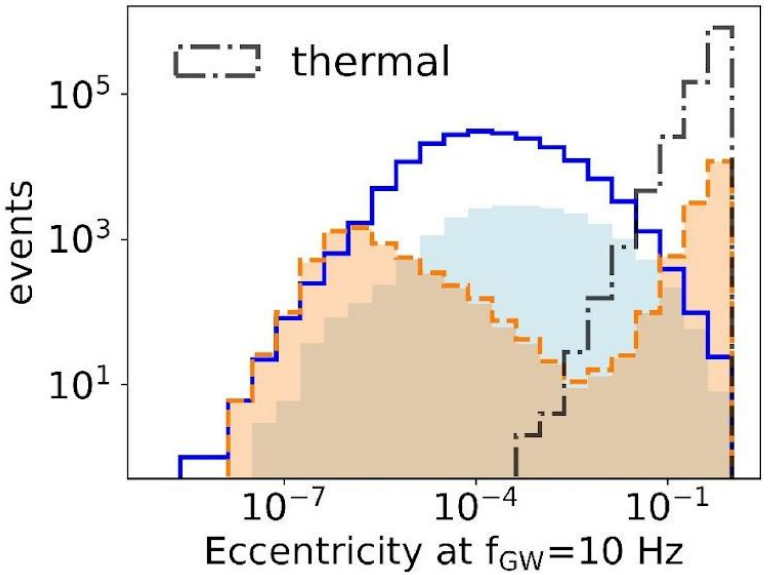
Results: the effect of gas hardening

Efficient gas hardening in AGNs produces BBHs with

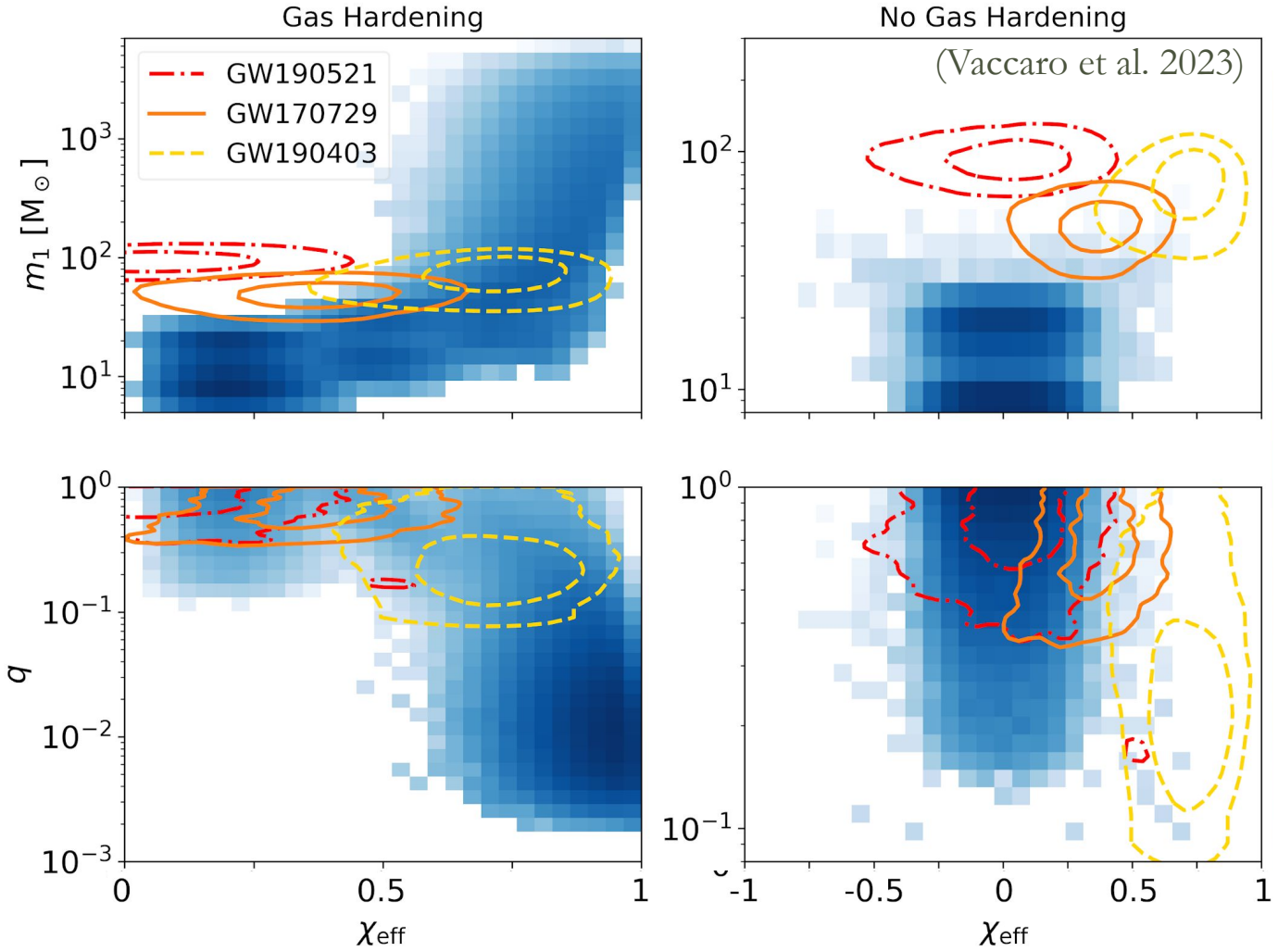
1. High mass
2. High effective spin
3. High(er) eccentricity







Results: $q - \chi_{\rm eff}$ anti-correlation

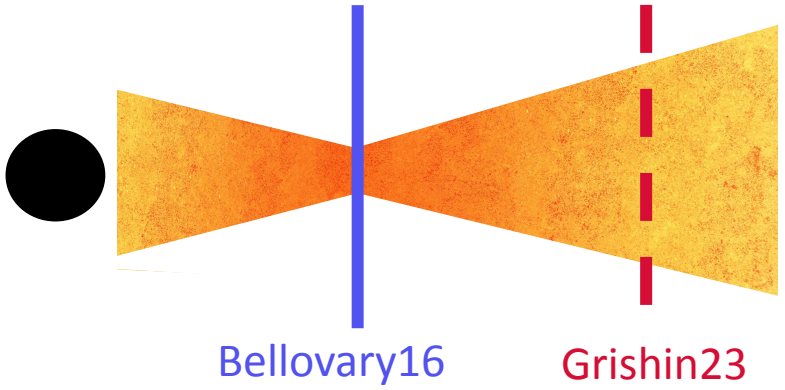


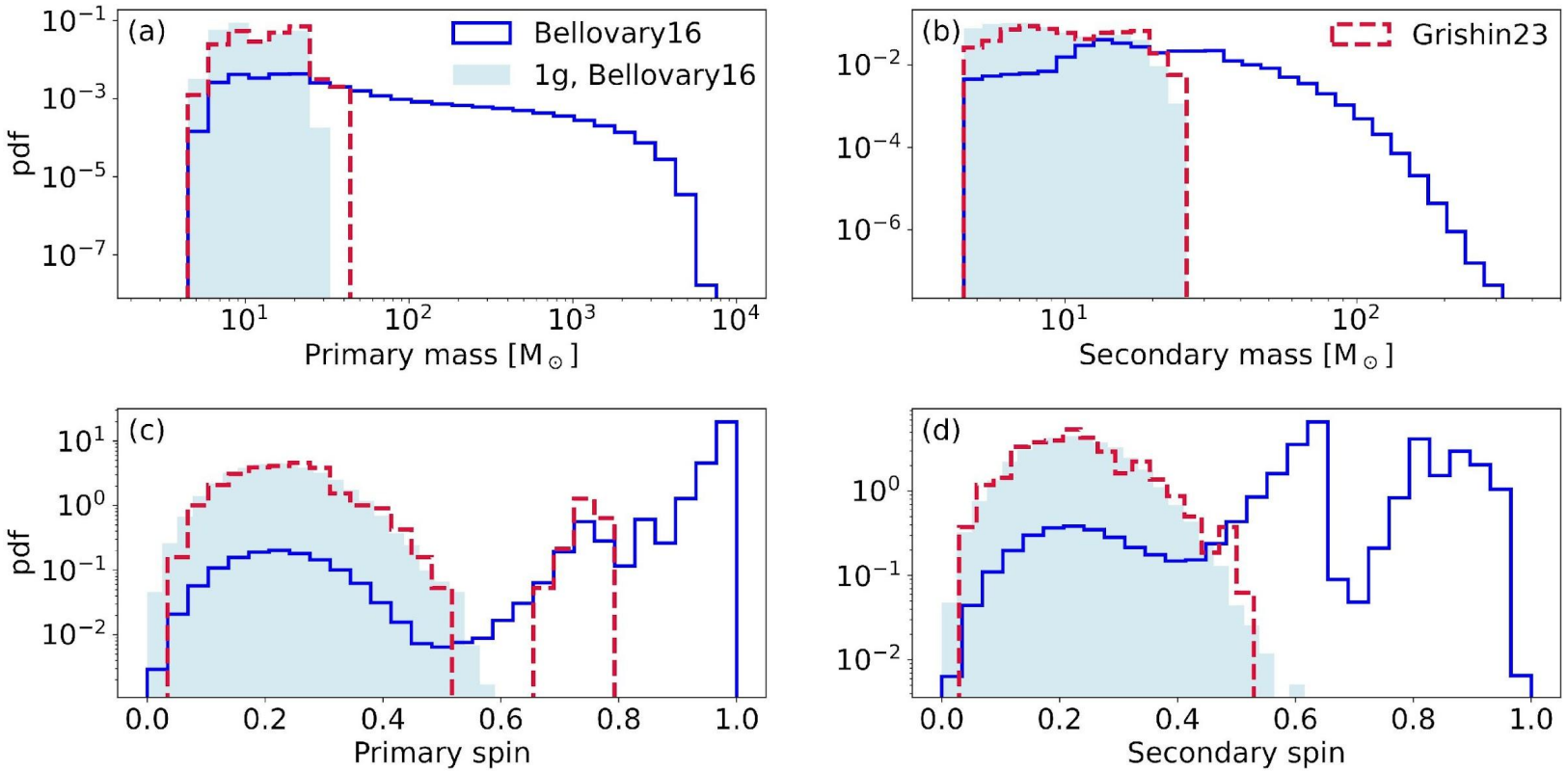
- GH → correlation between m_1 and $\chi_{\rm eff}$, anti-correlation between q and $\chi_{\rm eff}$
- Comparison with selected GW events:
  - GW190521: no overlap
  - GW170729: some overlap
  - GW190403: great overlap with GH…
    … but high FAR

Okay, but…

1) Migration trap position

Grishin et al. 2023
include thermal effects
↓
new migration trap position

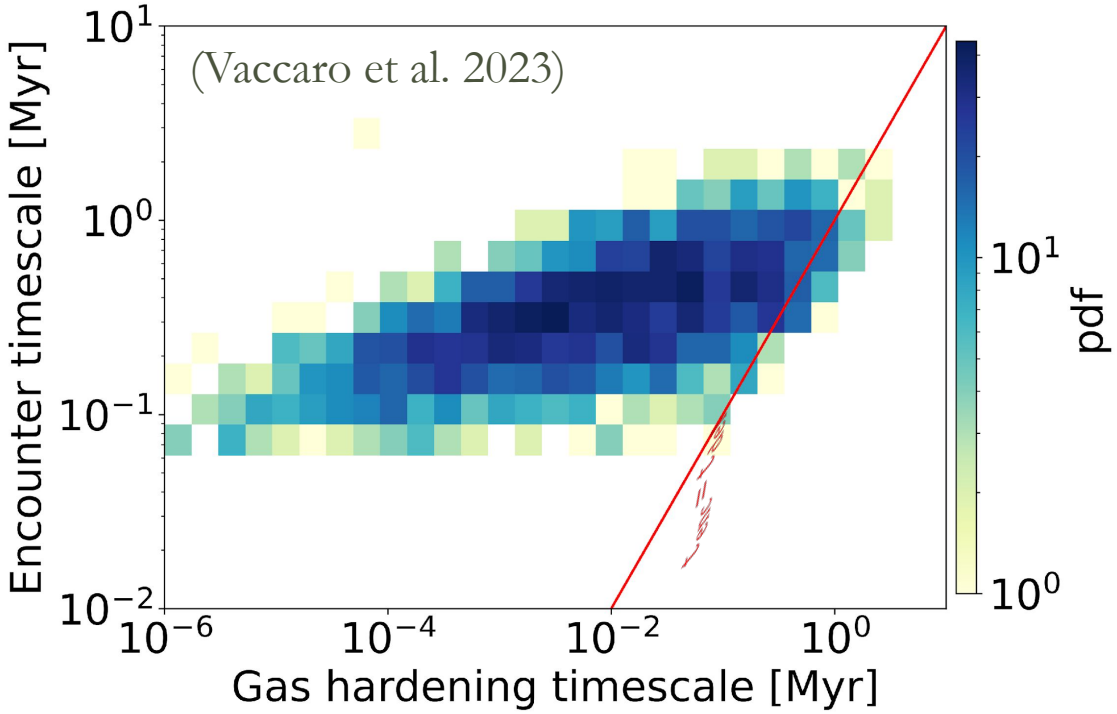




(Vaccaro et al. 2023)

2) Three-body effects

- They randomize BBH orbital angular momentum → signature on $\chi_{\rm eff}$
- They increase BBH eccentricity (Samsing et al. 2022)



Encounter timescale

(Leigh et al. 2018)

$$t_{\rm enc} \propto \frac{1}{N_*}$$

Number of embedded objects, it must be calibrated!

Summary

1) Gas hardening (GH) → high efficiency of hierarchical mergers: produces BBHs with
   - high mass ($m \sim 5000\, M_\odot$),
   - low mass ratio ($q \sim 10^{-2} M_\odot$),
   - high effective spin (main peak on $\chi_{\rm eff} \simeq 1$),
   - relatively high eccentricity ($e_{10\,\rm Hz} \sim 10^{-4}$).

2) We find an anti-correlation between q and $\chi_{\rm eff}$ that extends to lower values of q and higher values of $\chi_{\rm eff}$ than currently observed by LVK (Callister et al. 2021).

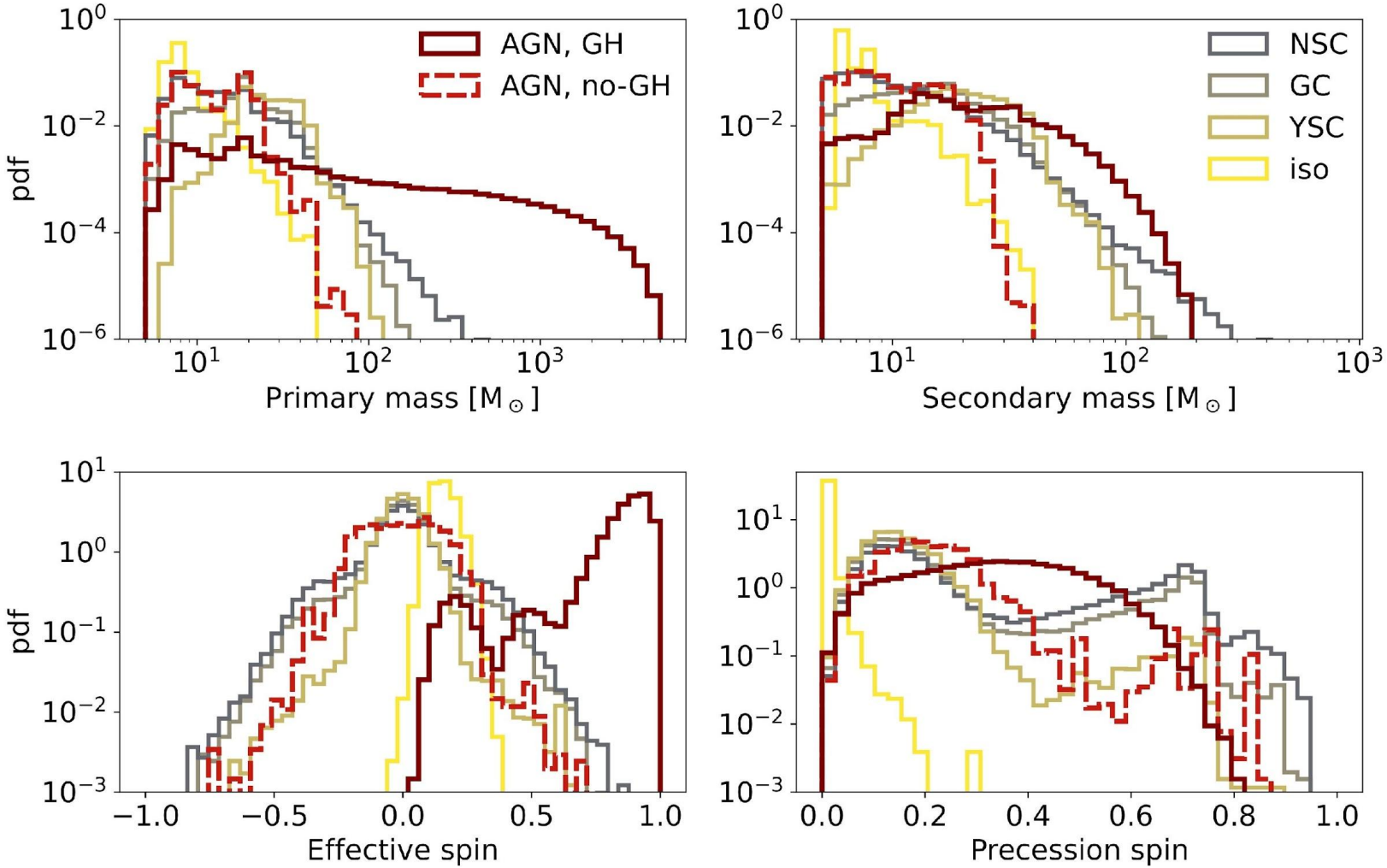
⚠ These results are strongly sensitive to assumptions on the **disk properties** and the **gas-assisted hardening mechanism**

Read Vaccaro et al., 2023 on arxiv.org

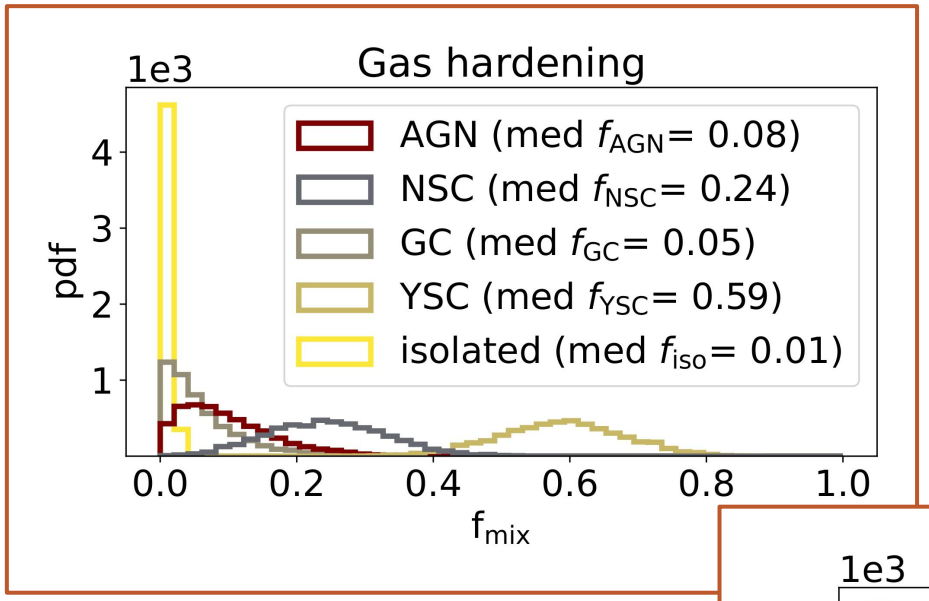
2311.18548

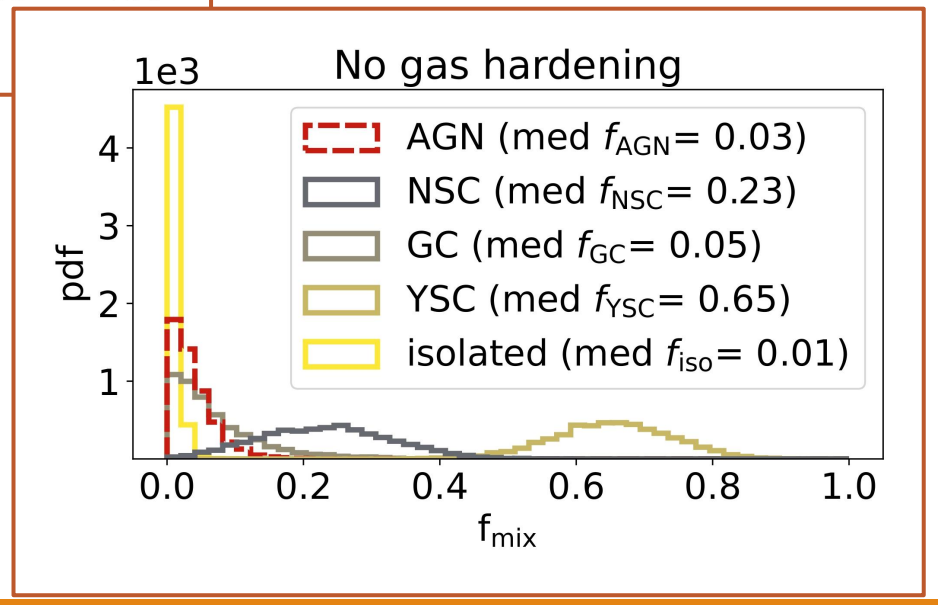
Backup slides

Comparison with other channels



Comparison with real data





- No strong evidence for events with AGN origin, but the most massive BHs of the GH population are not detectable
- LVK sample too small, theoretical uncertainties too large to draw conclusive information