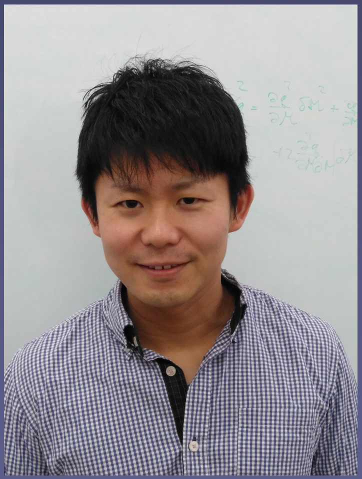
The AGN disk channel among LIGO events



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Kazuyuki Omukai (Tohoku)

Bence Kocsis (Oxford)
Johan Samsing (Copenhagen)

LIGO O3 workshop *Niels Bohr Institute, Copenhagen* *18 Nov 2020*

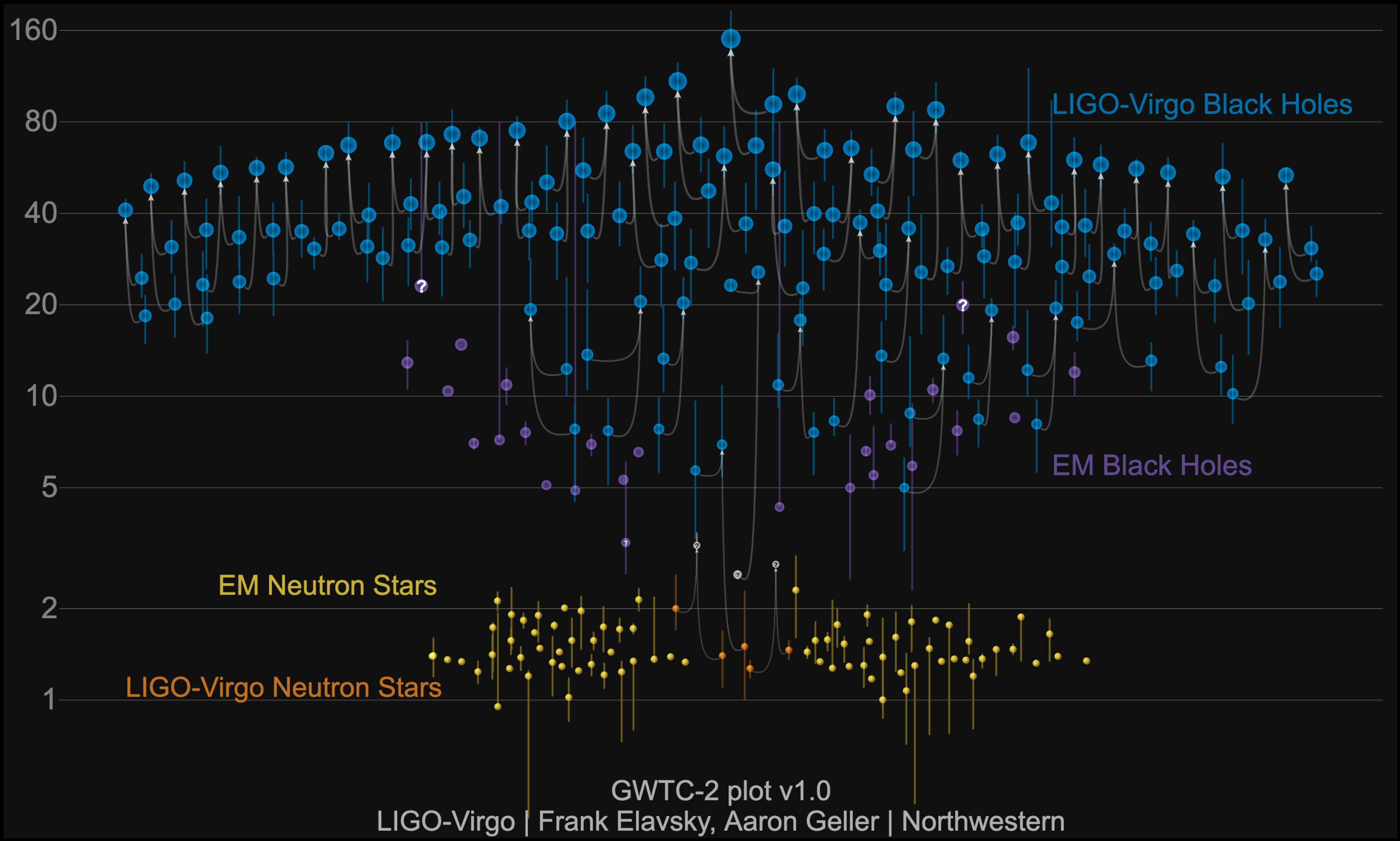
Conclusions

* Most binaries in AGN form via dissipative gas capture

* Most LIGO events probably not from AGN disks, but properties of some recent events naturally expected:

1. **Unequal mass** ✓
   → *different generations*
2. **High mass** ✓
   → *2g+ and accretion*
3. **High spin** ✓
   → *due to prior merger*
4. **Misaligned spin** ✓
   → *scattering with 3rd body*
5. **Eccentricity** ✓
   → *scattering with 3rd body*
   with GWs (if coplanar)
   → *GW capture in inner region*
   (if rapid migration to <10^{-3} pc)

Stellar remnant black hole mergers



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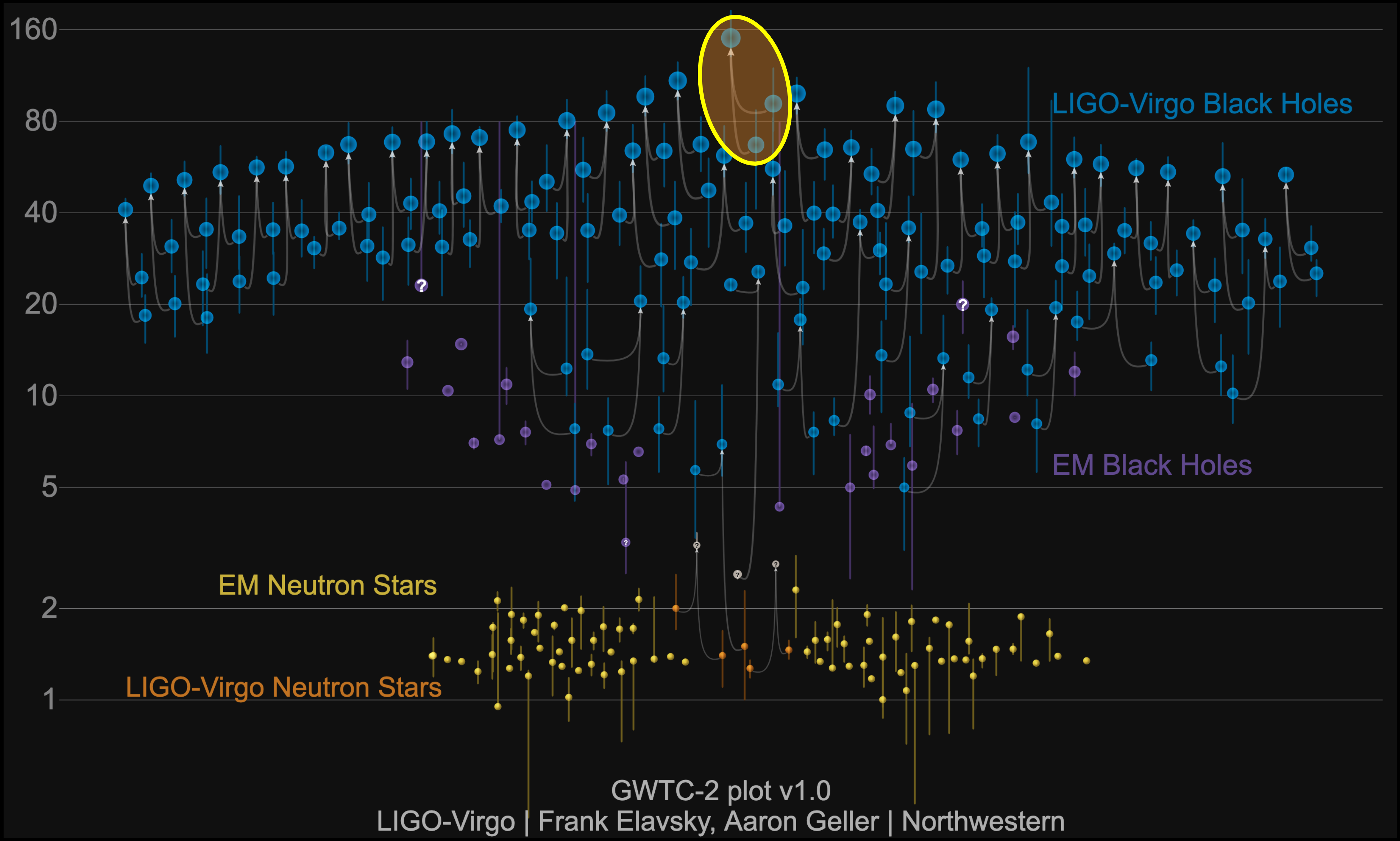
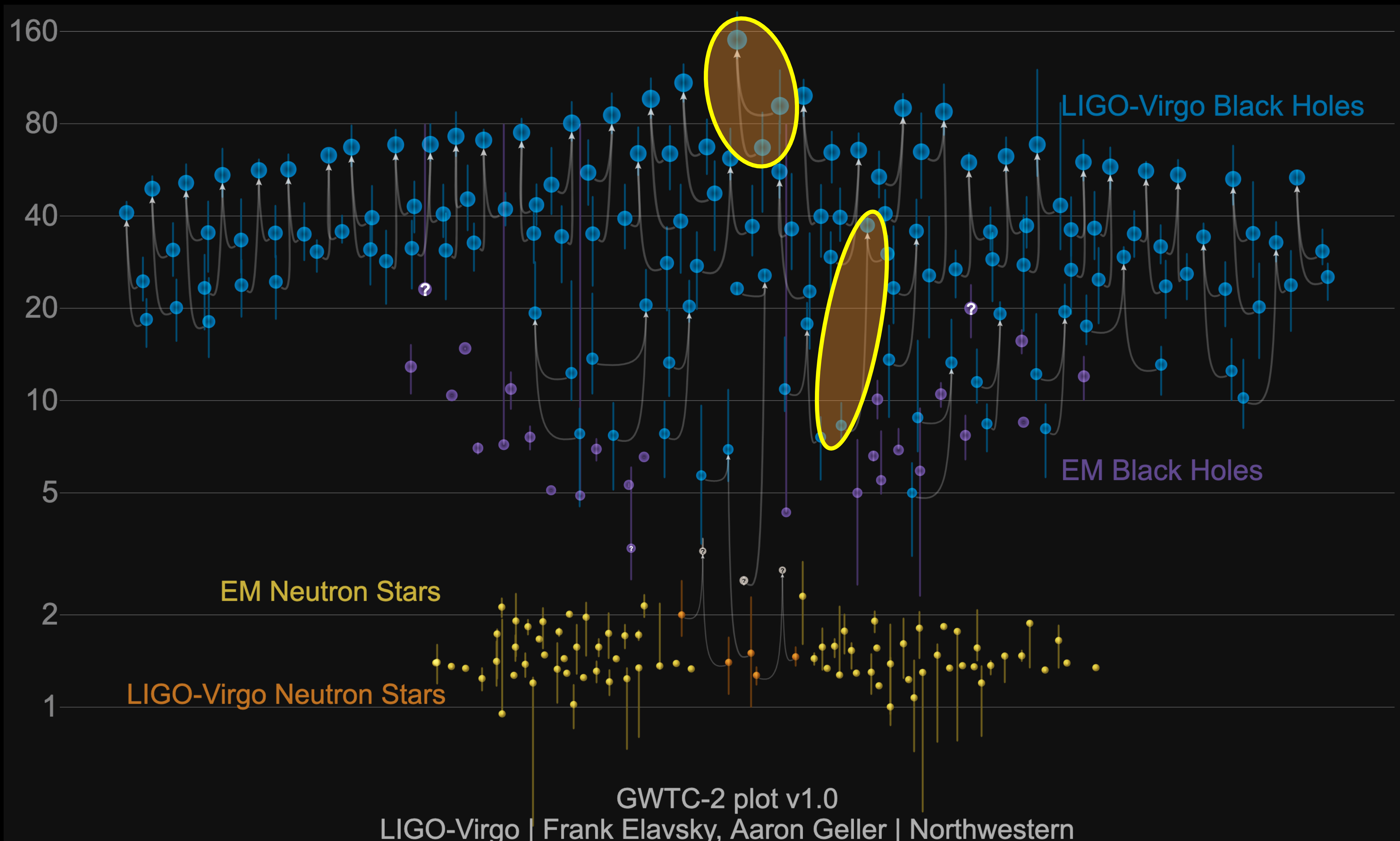
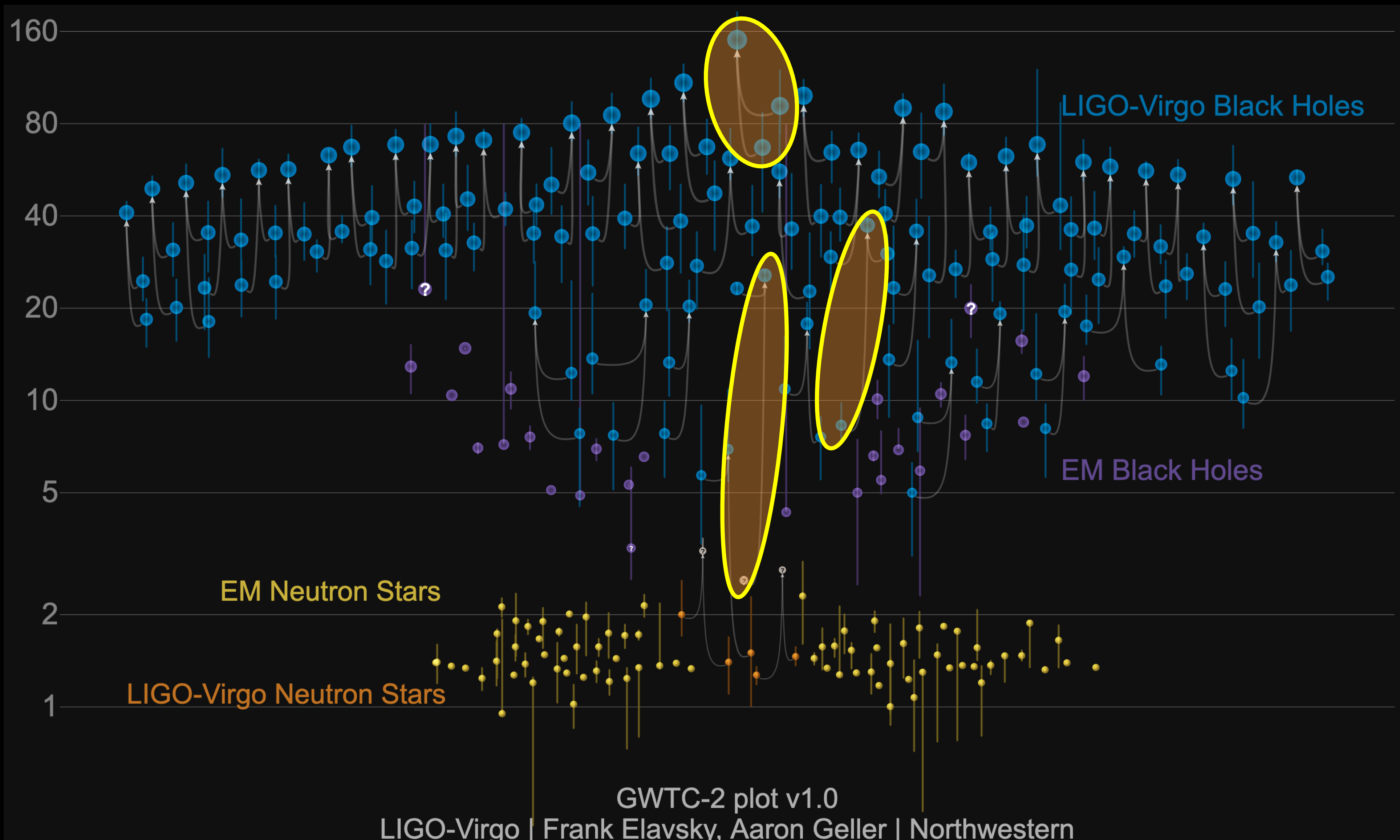


Stellar remnant black hole mergers



Stellar remnant black hole mergers



Three recent outliers

GW190412:

1. Unequal mass: M_1=30 $M_\odot$ M_2=8 $M_\odot$ → q=0.25
2. High primary spin: χ_1= 0.44
3. Spin misaligned: χ_p= 0.31

GW190521:

1. Large masses: M_1=85 $M_\odot$ M_2=66 $M_\odot$
2. High spins: $\chi_1 = \chi_2$= 0.7
3. Spin misaligned: χ_p= 0.7, χ_{eff}= 0.08
4. Significant eccentricity: e > 0.1 or e~0.7

GW190814:

1. Unequal mass: M_1= 23 $M_\odot$ M_2=2.6 $M_\odot$ → q=0.11

[2. Low primary spin: χ_1 < 0.07]

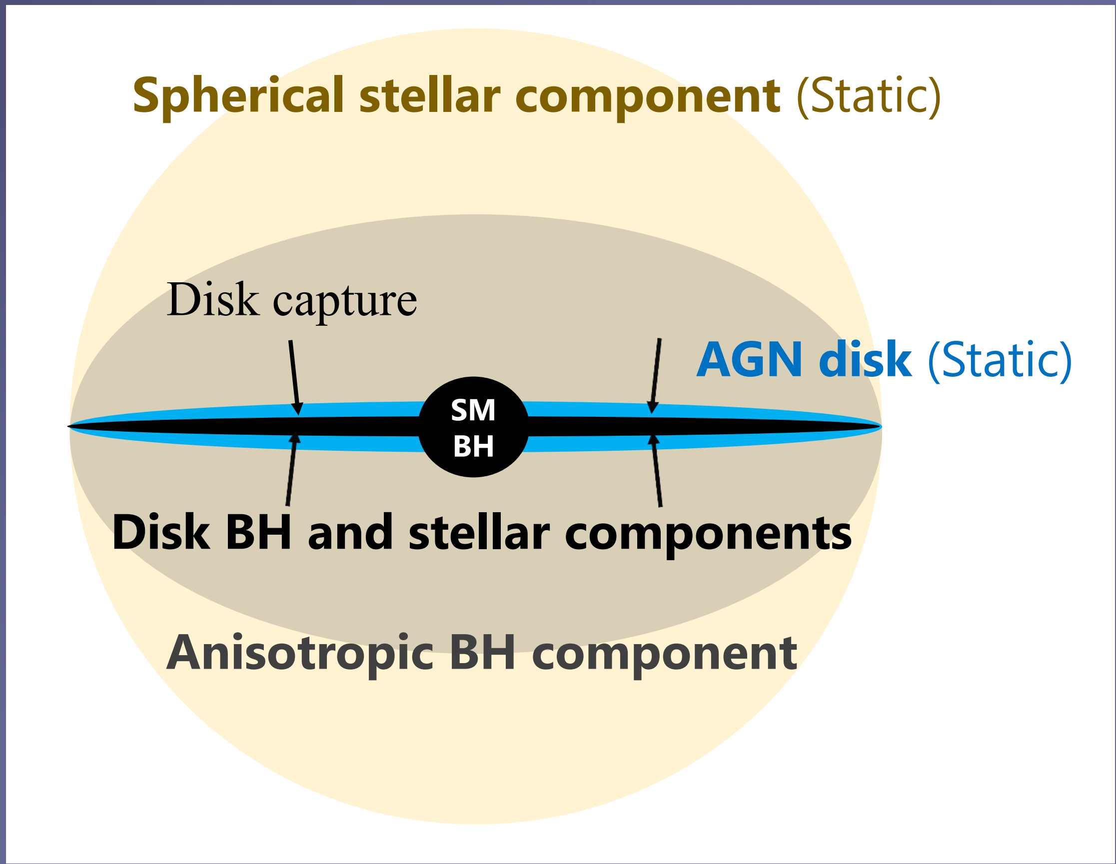
[3. Low effective spin: χ_{eff} ~ 0]

"1D" N-body simulation

- components -

Tagawa, ZH, Kocsis (2020a)

I. SMBH
II. Gas disk
III. Spherical star cluster
IV. Flattened cluster of BHs
V. Stars & BHs in disk (captured or formed in situ)



“1D” N-body simulation

- processes -

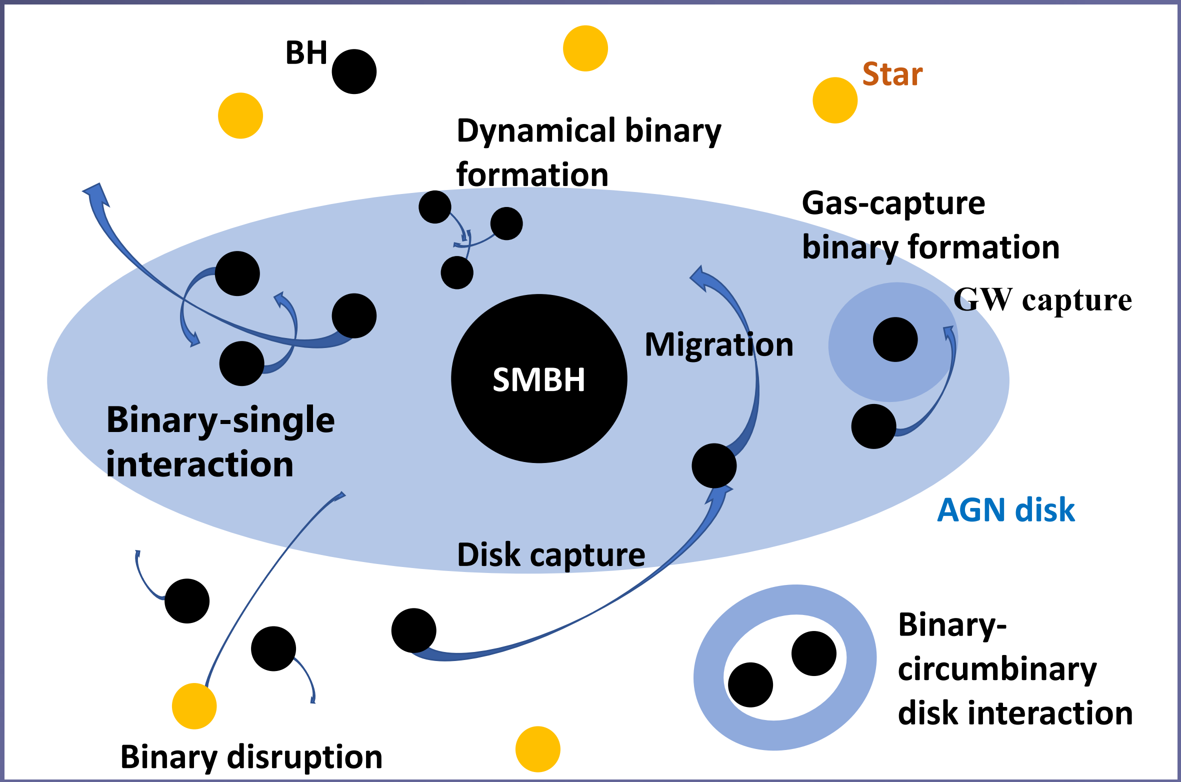
Tagawa, ZH, Kocsis (2020a)

I. **Binary formation**
(2-body, 3-body)

II. **Binary disruption**
(binary-single scattering)

III. **Binary evolution**
(circumbinary gas, GWs, binary-single scattering)

IV. **Radial migration**
(Type I/II torque)



"1D" N-body simulation

track individual black holes (single + binary)

- radial position, mass
- binary separation
- velocity (radial + dispersion) (GW recoil)
- binary angular momentum (circumbinary torque, scattering)
- BH spins (accretion, merger)
- eccentricity (accretion, scattering)

Fiducial values

$M_{\rm SMBH} = 4\times10^6 M_\odot$

$M_{\rm NSC}\ (r \leq 3\ {\rm pc}) = 10^7 M_\odot$

$N_{\rm BH}\ (r \leq 3\ {\rm pc}) = 2\times10^4$

$\dot{M}_{\rm inflow} = 0.1\ \dot{M}_{\rm edd}$

$r_{\rm AGN} = 3\ {\rm pc}$

$t_{\rm AGN} \sim 10^7\ {\rm yr}$

$N_{\rm bin} \sim 3000$

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Tagawa, ZH, Bartos, Kocsis (2020)
Paper III: eccentricities
Tagawa, Kocsis, ZH, Bartos, Samsing, Omukai (2020)
Paper IV: NSs, mass-gap objects
Tagawa, Kocsis, ZH, Bartos, Omukai, Samsing (in prep)

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“1D” N-body simulation

track individual black holes (single + binary)

- **radial position, mass**
- **binary separation**
- **velocity (radial + dispersion) (GW recoil)**
- **binary ang … inary torque, scattering)**
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- **ec…**

Output: merger catalog, typically $O(10^3)$ mergers

…cial values

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What's special/robust about this channel?

Role of SMBH and gas disk

1. **Capture BHs into disk (disk)**
   "compress" 3D to 2D → higher interaction rate

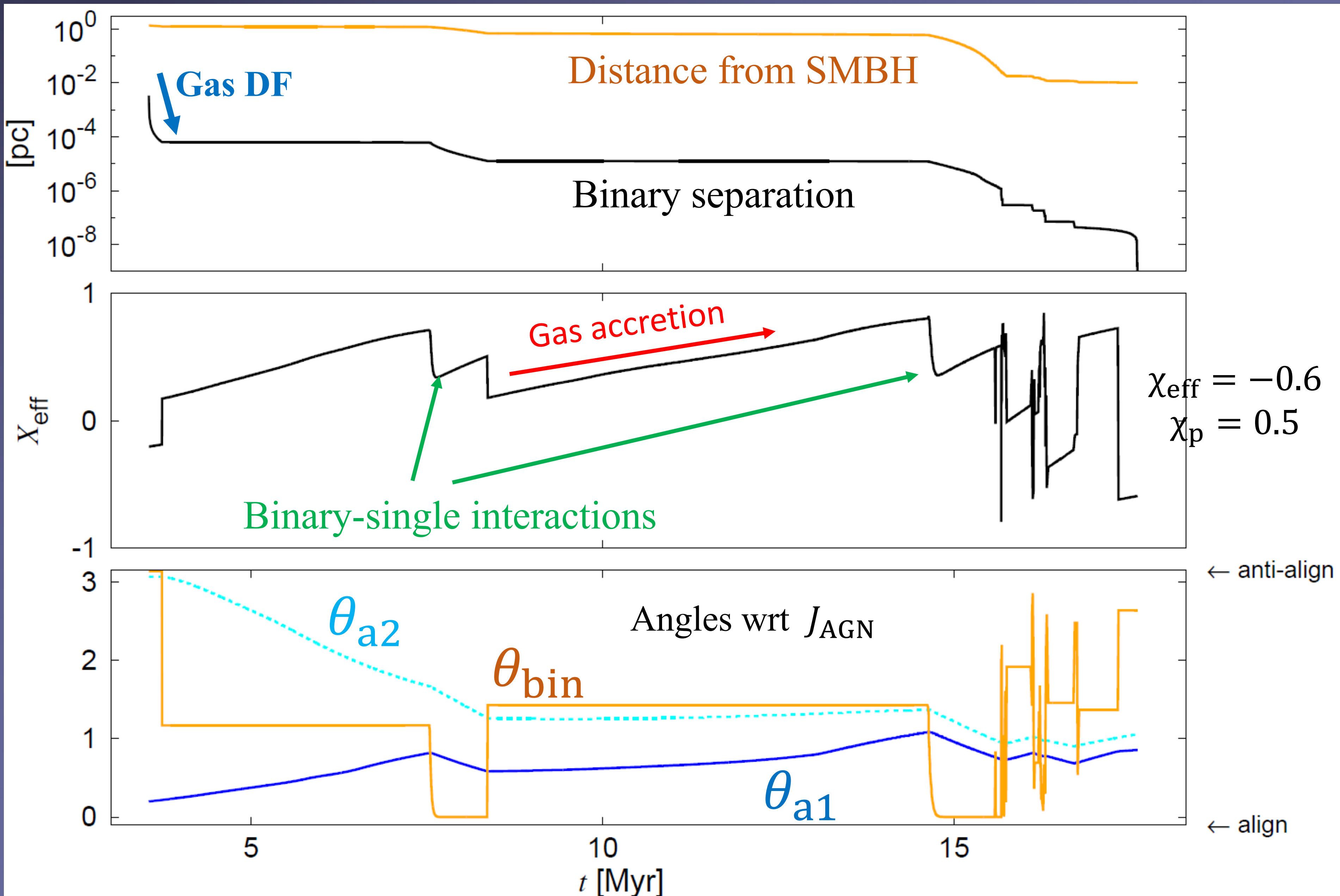
2. **Help form binaries (disk)**
   most binaries form via gas capture

3. **Deliver BHs to inner regions by migration (disk)**
   higher interaction rate in gaps or traps

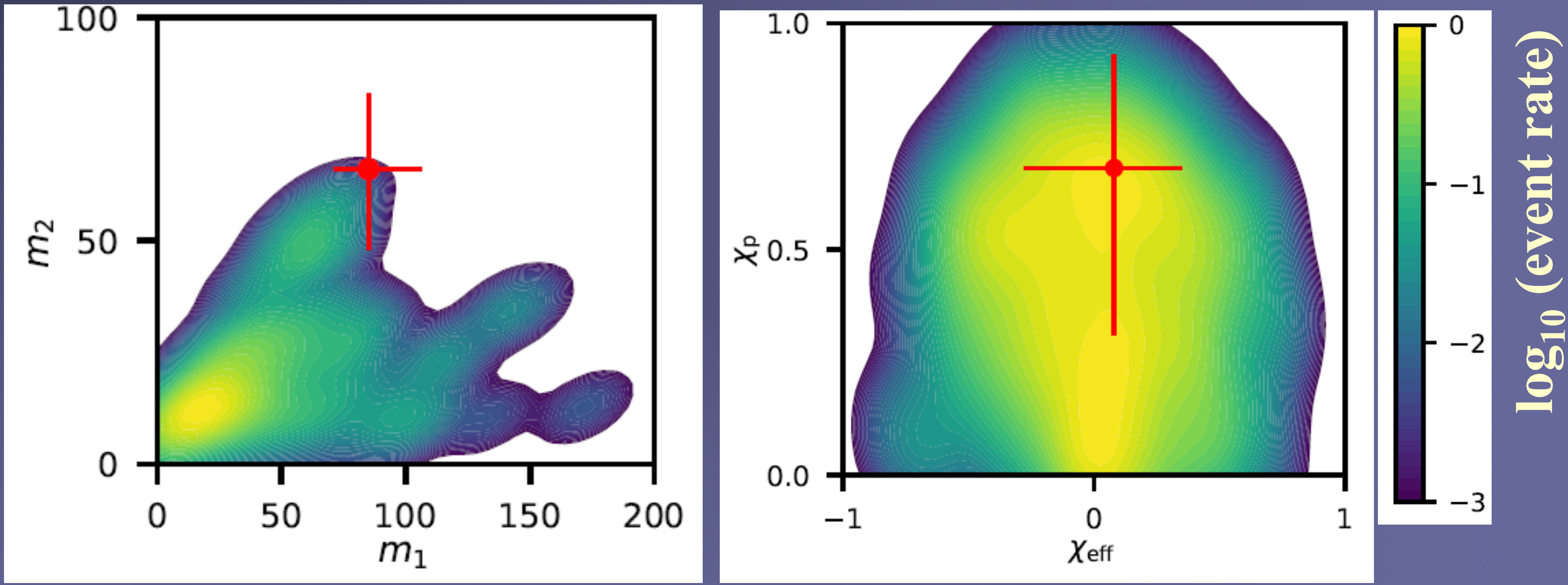
4. **Retain recoiling BHs (SMBH)**
   naturally allow multiple ($n \gg 1$) merger generations

5. **Drive up and align spins, drive eccentricity (disk)**
   [overwhelmed by scattering]

Illustrative example



GW190521



High mass ✓

→ 2g+ accretion

High spin ✓

→ due to prior merger

Spin misaligned ✓

→ scattering with 3rd body

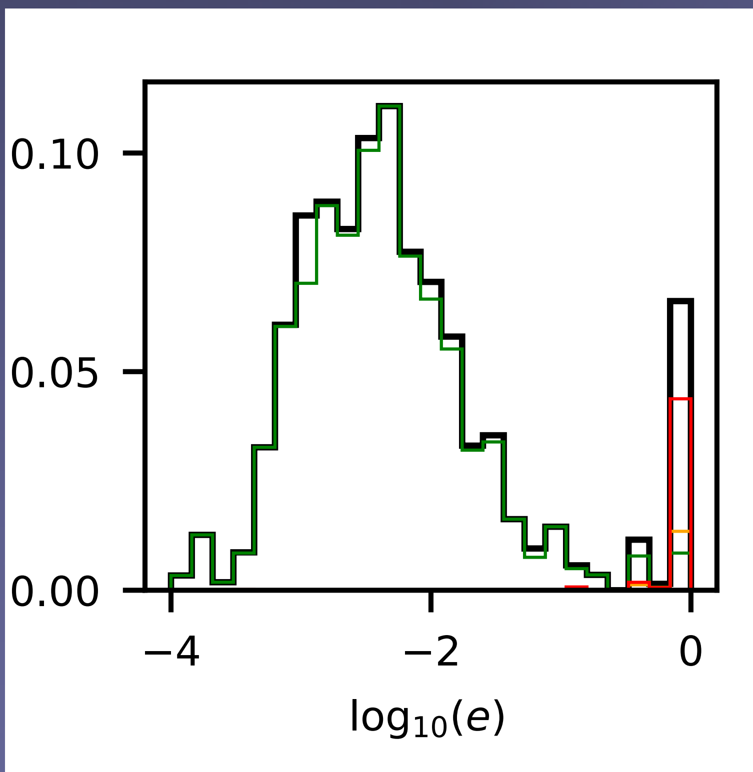
GW190521

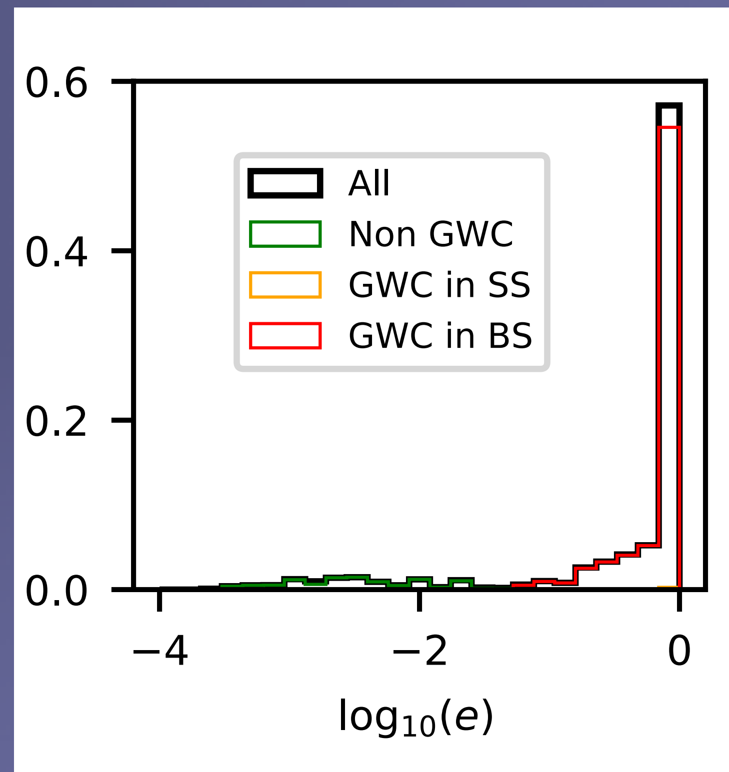
eccentricity?

fiducial model (3D)

*coplanar scattering (2D)**

#





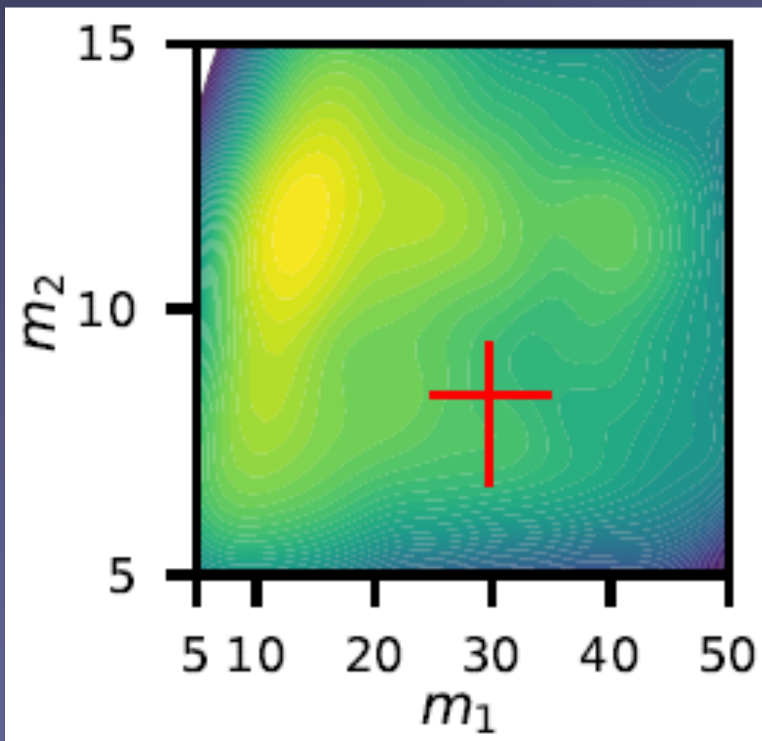
O(10%) have e>0.03
5% e>0.9

O(80%) have e>0.03
50% e>0.9

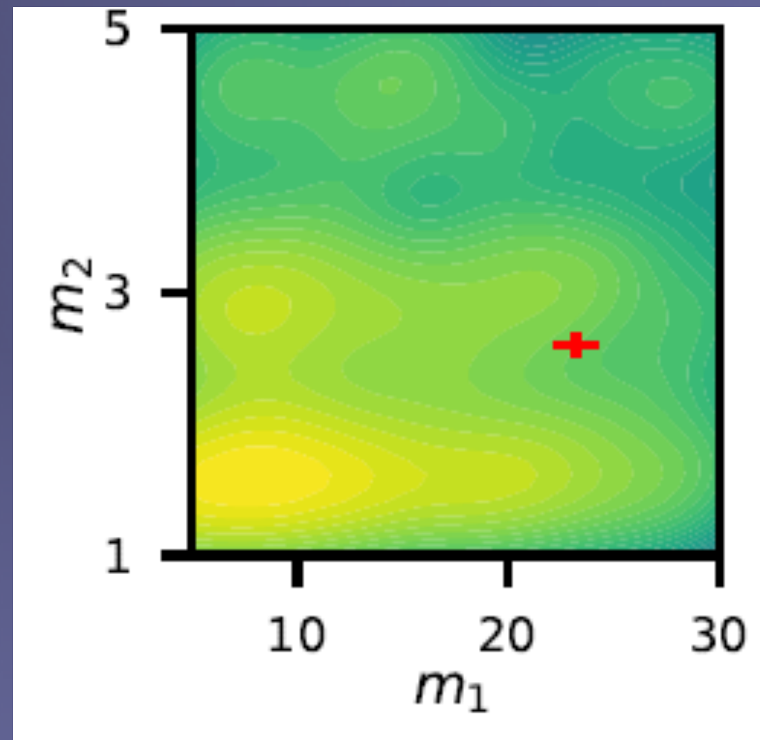
****or: GW capture enhanced by low n_{BH} or high vel.disp.***

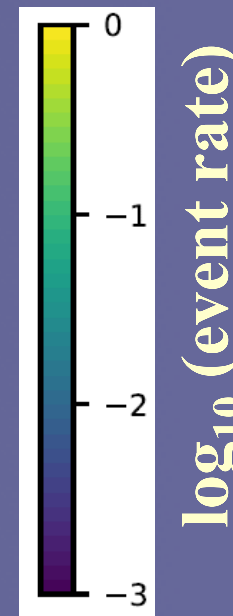
GW190412 and GW190814

GW190412 (q=0.25)



GW190814 (q=0.11)





1g-2g

$R_{\text{2g-1g}} \sim 0.1 - 0.2\, R_{\text{BH-BH}}$

2g-1g

$R_{\text{BH-LGO}} \sim 10^{-2} - 10^{-3}\, R_{\text{BH-BH}}$

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→ *different generations, accretion*

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The End