Observational Signatures of Tertiary-Induced BH Mergers

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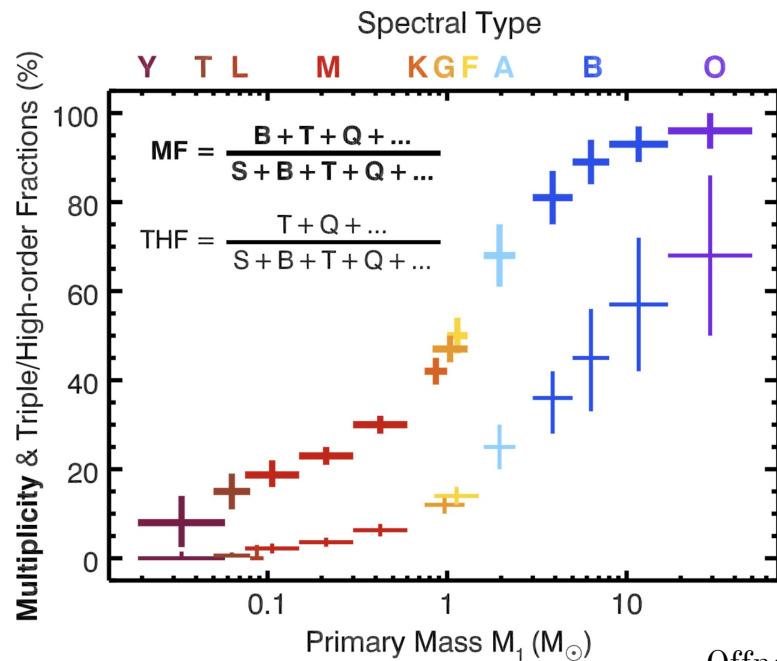**Yubo Su** Princeton University, Lyman Spitzer Jr. Fellow
(with Dong Lai, Bin Liu, Siyao Xu)
32nd Texas Symposium on Relativistic Astrophysics
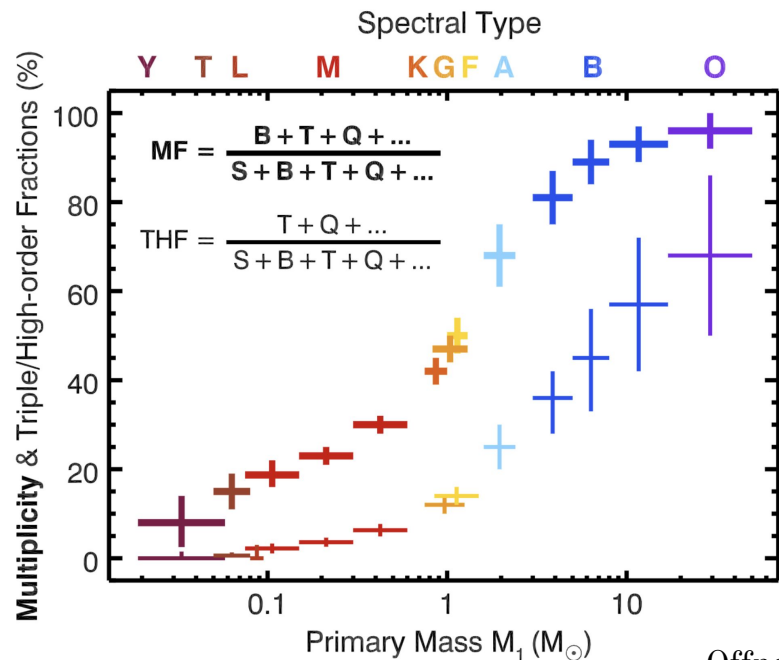Dec 11, 2023

LVK Sources: From Isolated Binaries?
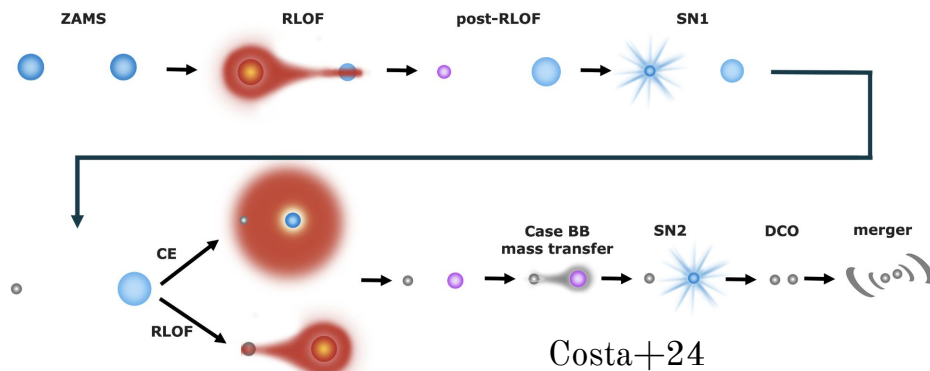
- **Massive stellar binaries** are common

Offner+22

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- **Massive stellar binaries** are common
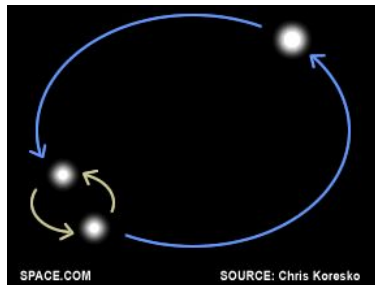

Offner+22

Costa+24

Complex! Alternatives?

Spectrum of Dynamical Merger Channels

Dynamical

Isolated (2)
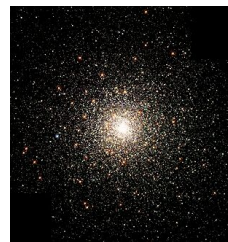
e.g.Lipunov+97,
Podsiadlowski+03;
Belczynski+10,16...

Triple (3)

e.g. Miller&Hamilton02,Wen,03
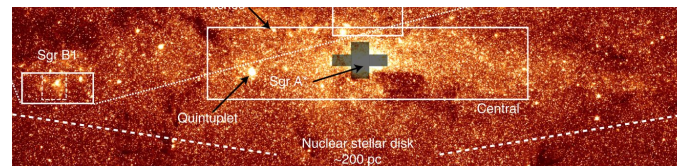Antonini&Perets12, Silsbee
&Tremaine17, Liu&Lai17,18

Open Cluster ($\sim10^4$)

e.g. Banerjee+10, Ziosi+14,
Kimpson+16, Banerjee+17,

Globular Cluster ($\sim10^6$)

e.g.O'Leary+06,
Downing+10,11,
Rodriguez+18,

Nuclear SC ($\sim10^7$)

e.g. Miller+09, Leigh+18,
Fragione+20, Mapelli+21

N

AGN (3+)

e.g. McKernan+12,14, Samsing+22

Image credits: Wikipedia, Phys.org,
Nogueras-Lara+22

LVK Sources: From Isolated Triples? ZLK (von Zeipel-Lidov-Kozai)

- *Massive stellar triples* are also common

Spectral Type

$$MF = \frac{B + T + Q + ...}{S + B + T + Q + ...}$$

$$THF = \frac{T + Q + ...}{S + B + T + Q + ...}$$

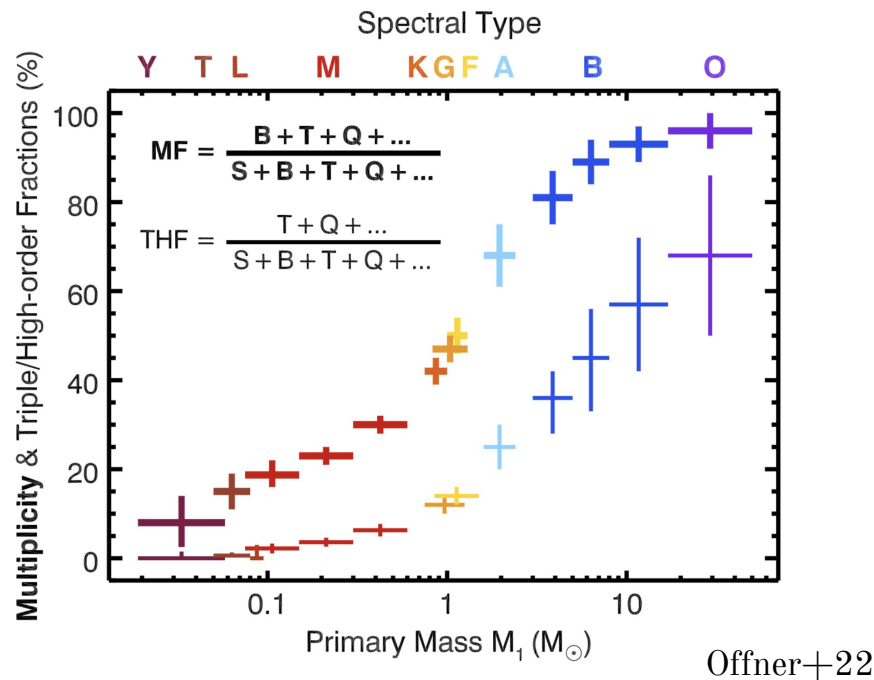Multiplicity & Triple/High-order Fractions (%) vs Primary Mass M_1 ($M_\odot$)

Offner+22

LVK Sources: From Isolated Triples? ZLK (von Zeipel-Lidov-Kozai)

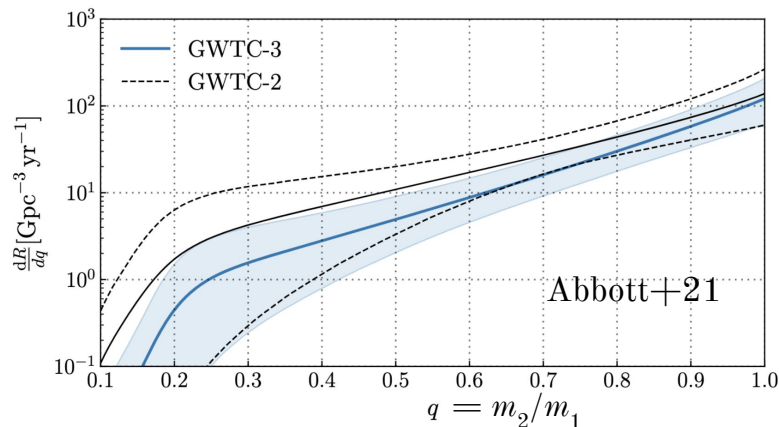- *Massive stellar triples* are also common

Offner+22
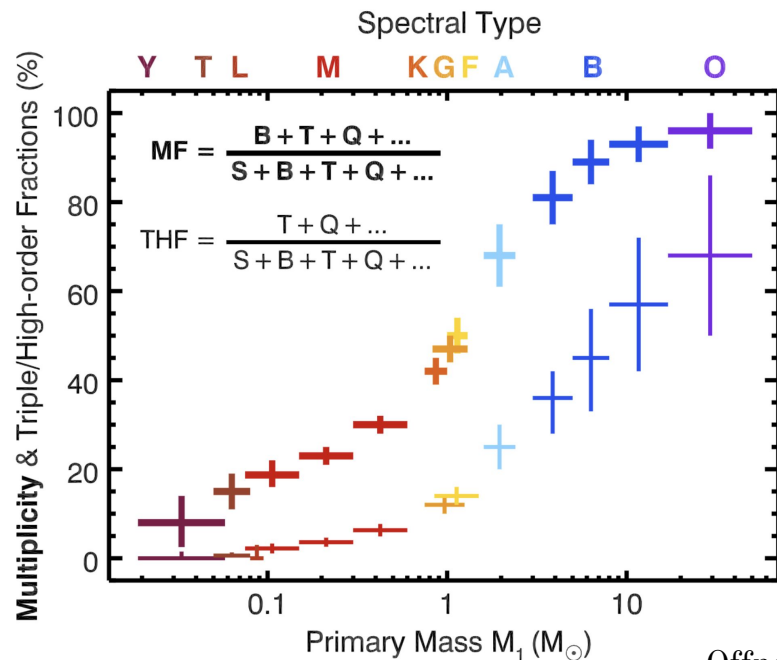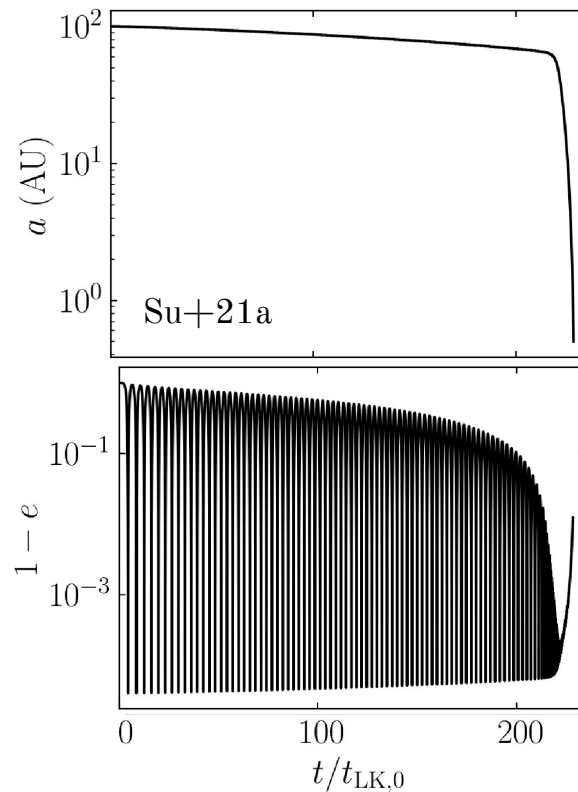
Mergers for wide range of triple hierarchies

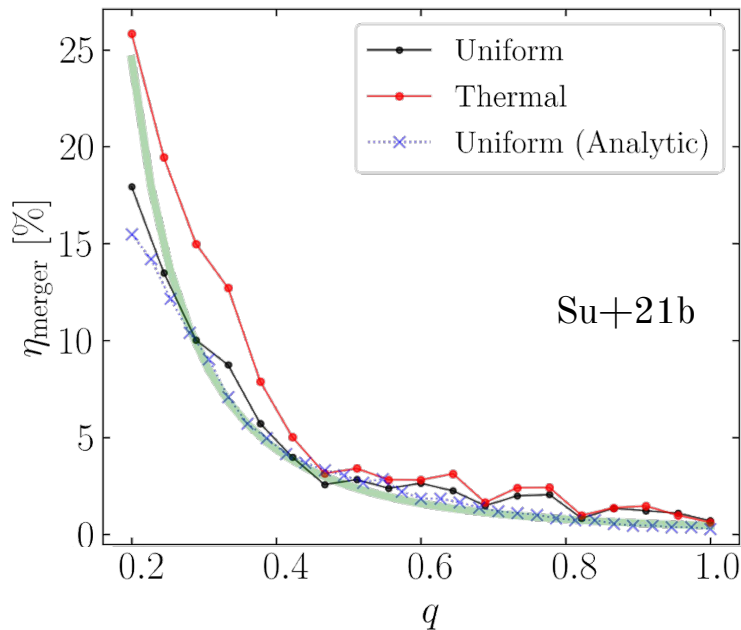Simple dynamics

Rates uncertain?

Seek rate-independent signatures

Stellar Triple Channel and the Mass Ratio Distribution

Abbott+21

Su+21b

- Merger efficiency scales strongly with octupole-order correction [Su+21b]:

$$\epsilon_{\text{oct}} = \frac{1-q}{1+q} \frac{a}{a_{\text{out}}} \frac{e_{\text{out}}}{1-e_{\text{out}}^2}$$
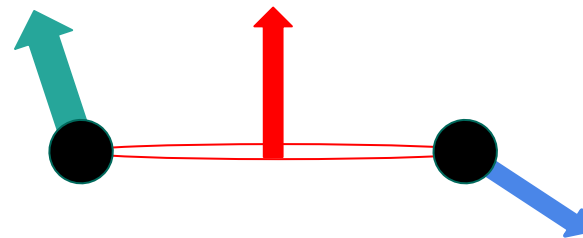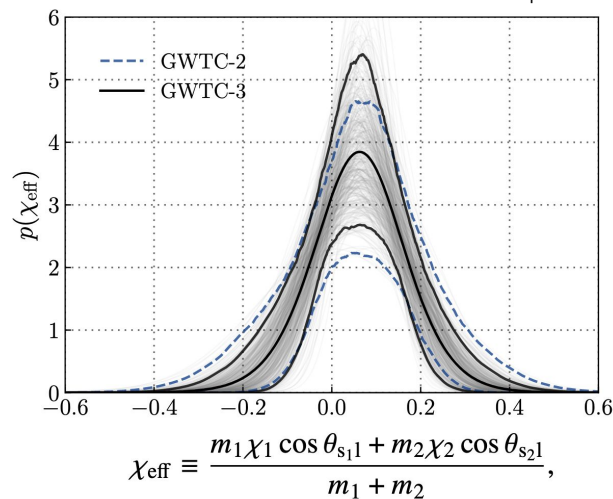
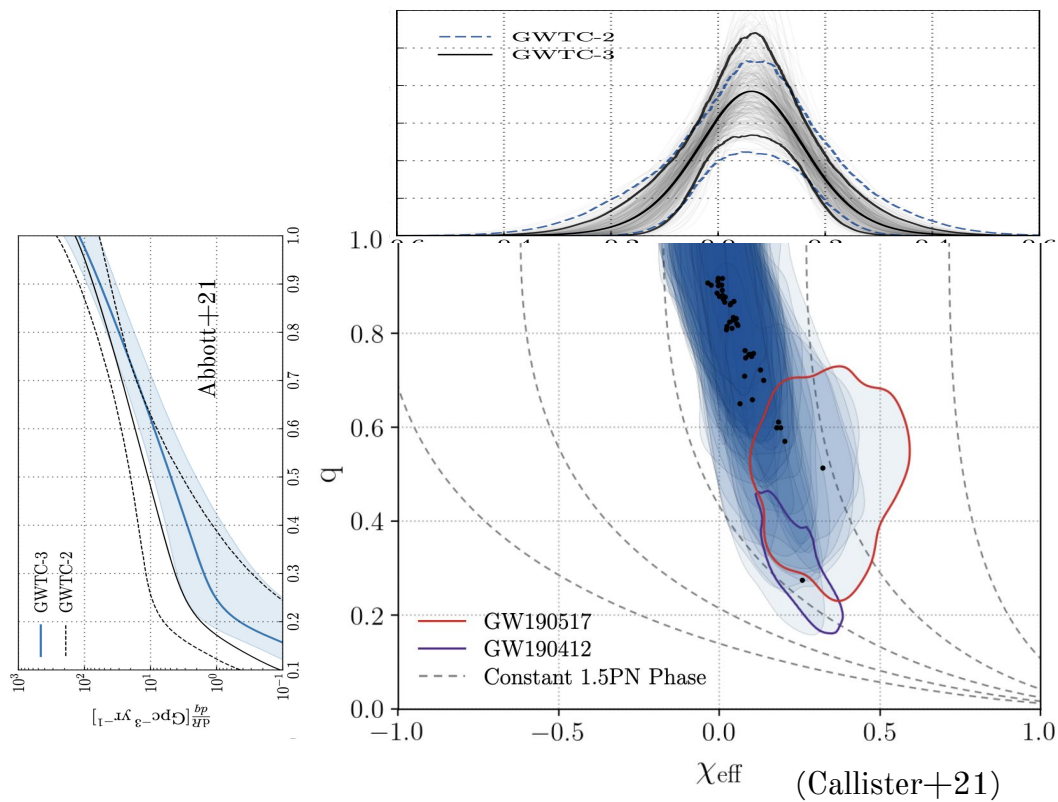- Robust to various e_{out} distributions [Su+24]

Difficult to reconcile!
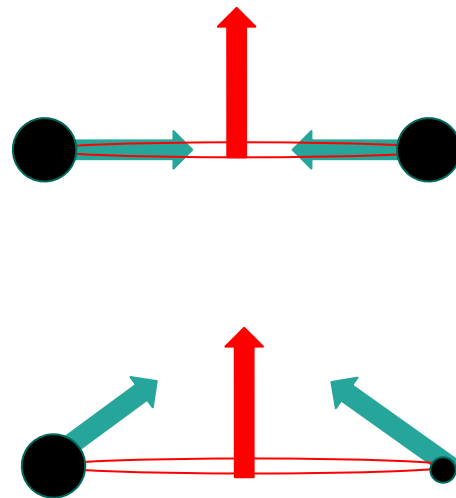
Massive Tertiary: Spin Evolution

- **Stellar-mass triples may not work, what else?**

- Decrease $\epsilon_{\text{oct}} = \dfrac{1-q}{1+q} \dfrac{a}{a_{\text{out}}} \dfrac{e_{\text{out}}}{1-e_{\text{out}}^2}$ by rescaling to **distant, massive** companion
  - [quadrupole] ZLK has weak q dependence
- Investigate *spin* signatures
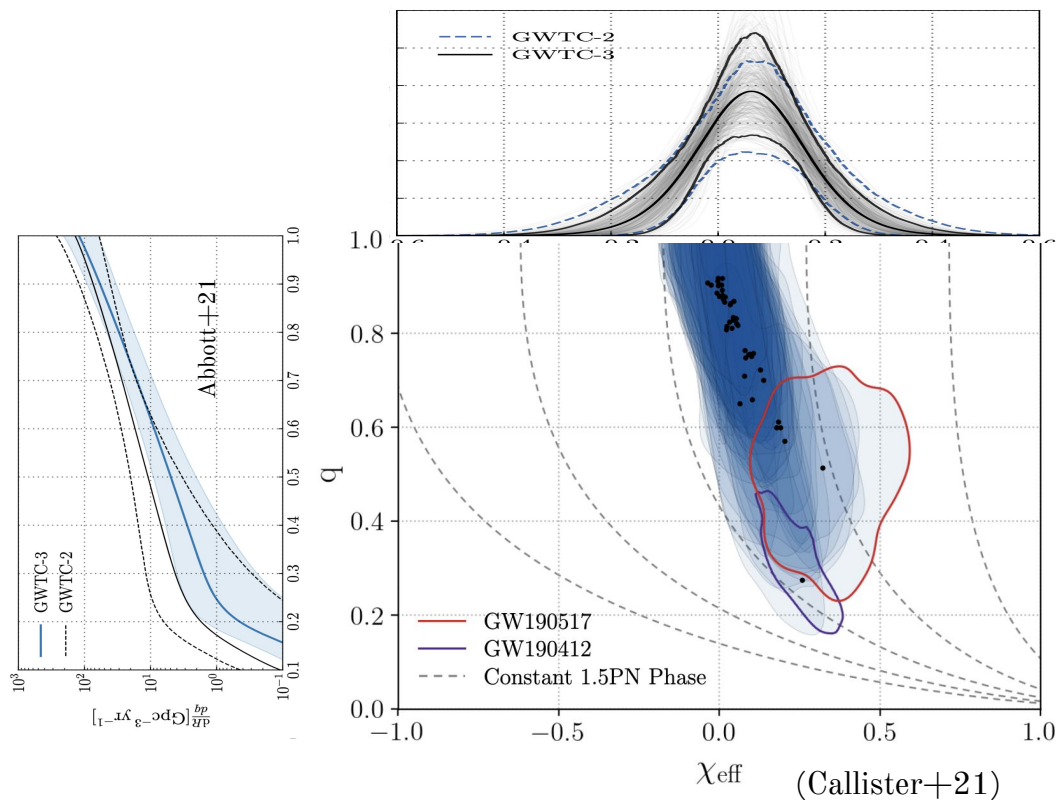 - $\chi_{\text{eff}} \sim$ BH spins along orbit AM

$$\chi_{\text{eff}} \equiv \frac{m_1 \chi_1 \cos \theta_{\text{s}1} + m_2 \chi_2 \cos \theta_{\text{s}2}}{m_1 + m_2},$$

A q-χ_{eff} correlation

Abbott+21

(Callister+21)

A q-$\chi_{\rm eff}$ correlation
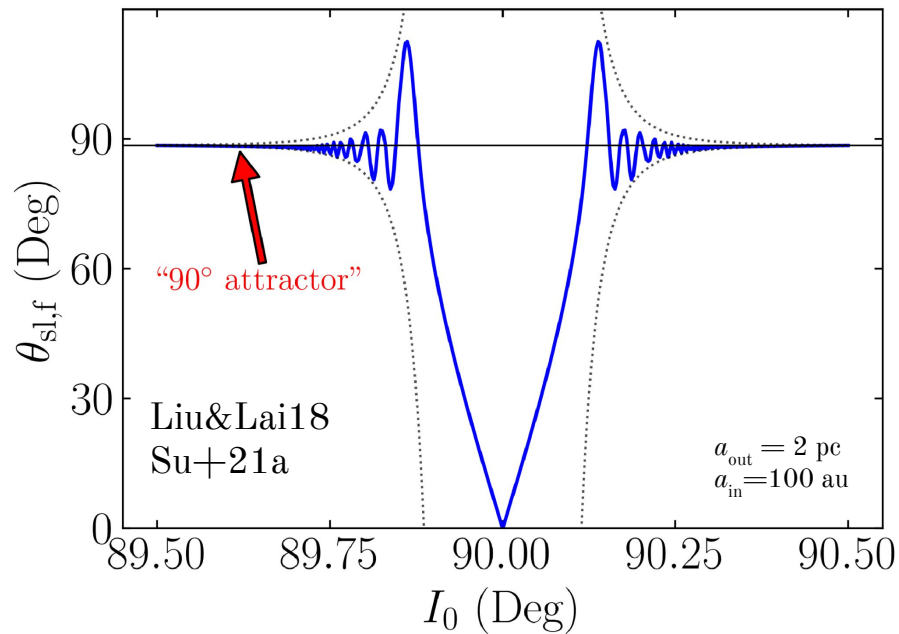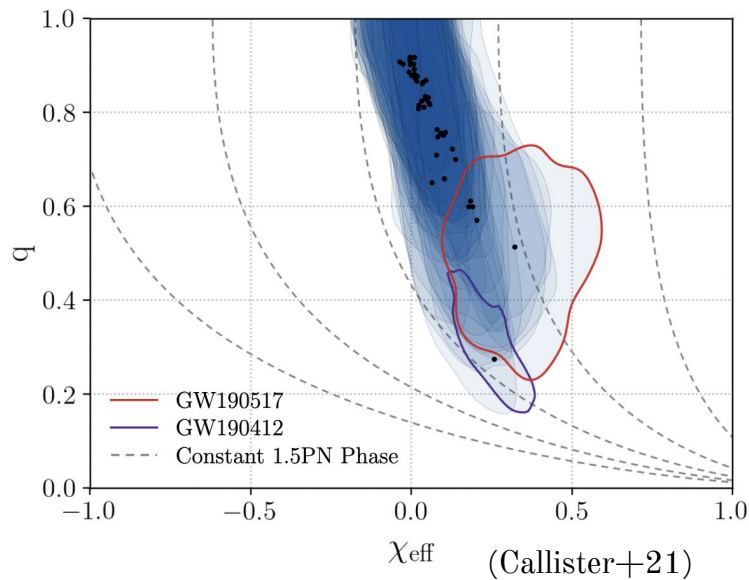

Abbott+21

(Callister+21)

- Typically, dynamical channels → random spin orientations
  - Symmetric $\chi_{\rm eff}$, many negative
  - Not supported!

Massive Tertiary: Spin evolution is not so random?

$$\chi_{\text{eff}} \equiv \frac{m_1\chi_1\cos\theta_{s_11} + m_2\chi_2\cos\theta_{s_21}}{m_1 + m_2},$$

$\chi_{\text{eff1}} = -1$

$\chi_{\text{eff1}} = 1$

"90° attractor"

Liu&Lai18
Su+21a

$a_{\text{out}} = 2$ pc
$a_{\text{in}} = 100$ au
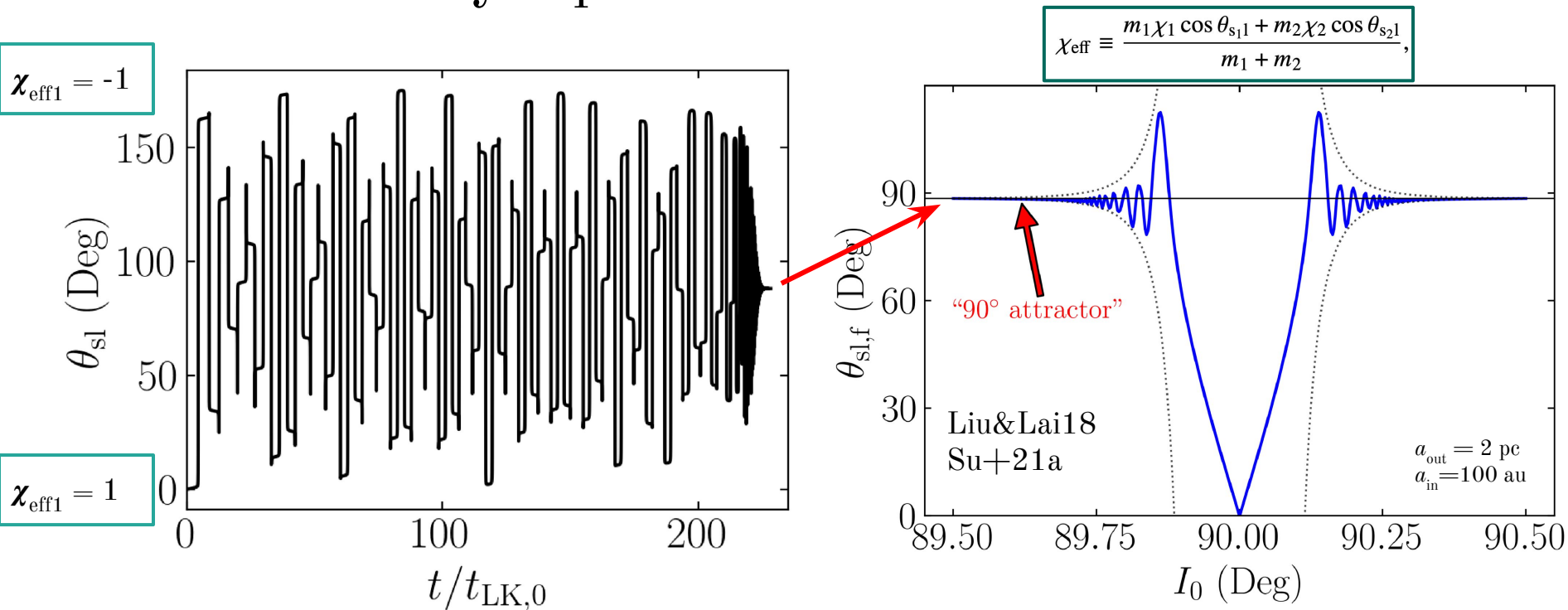
- Due to conservation of an adiabatic invariant angle θ_e

A possible q-χ_{eff} correlation? (PRELIM)

(Callister+21)

"90° attractor"

Liu&Lai18
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$a_{\mathrm{out}} = 2$ pc
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- Can we do this with θ_{e} conservation?

A possible q-χ_{eff} correlation? (PRELIM)
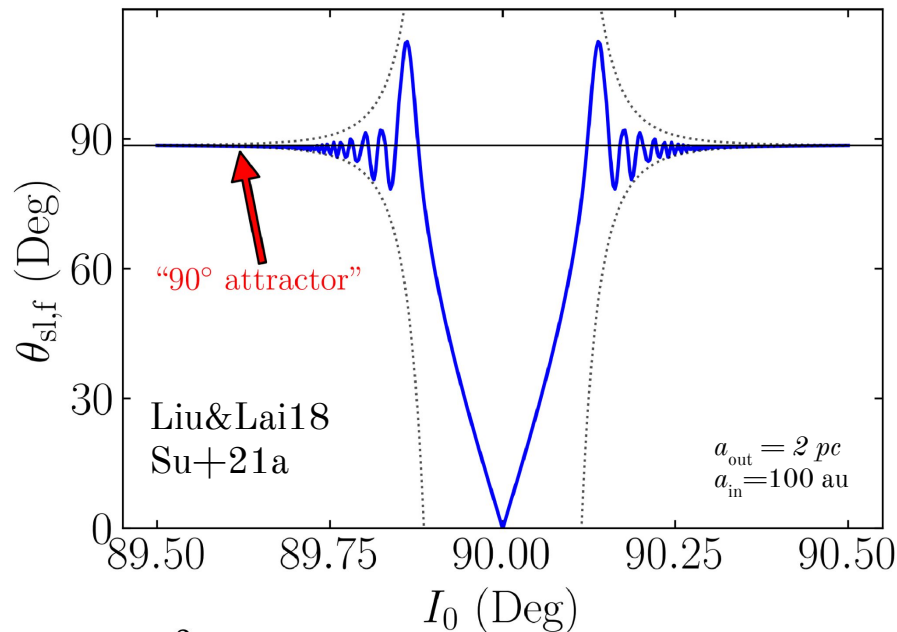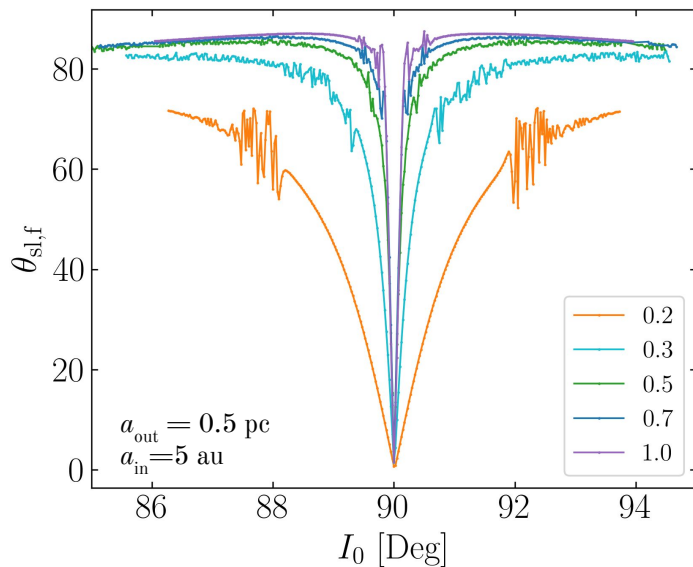
- Can we do this with θ_{e} conservation? $\frac{\Delta a}{a} \propto \frac{1-q^2}{q}$.
  - Yes: need **stable mass transfer**

A possible q-χ_{eff} correlation? (PRELIM)

(Callister+21)
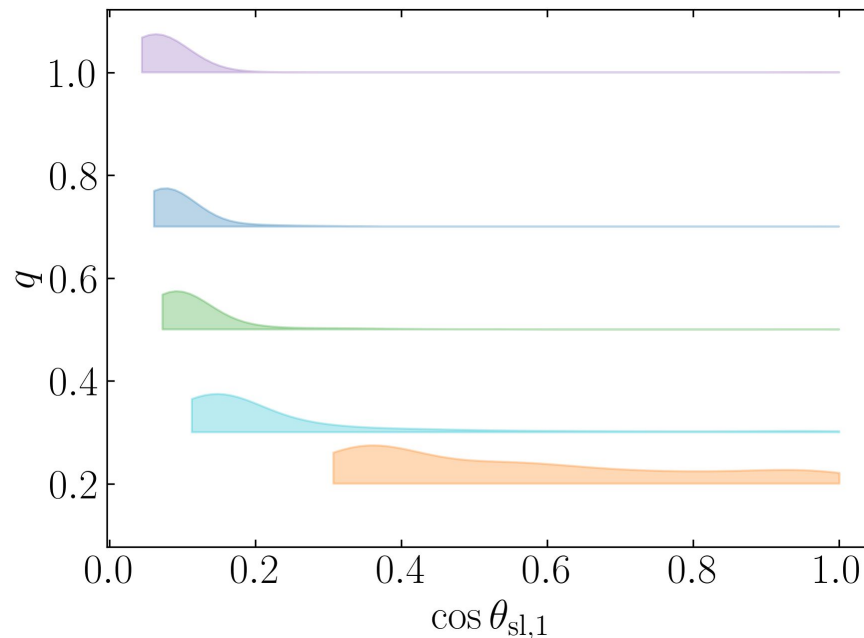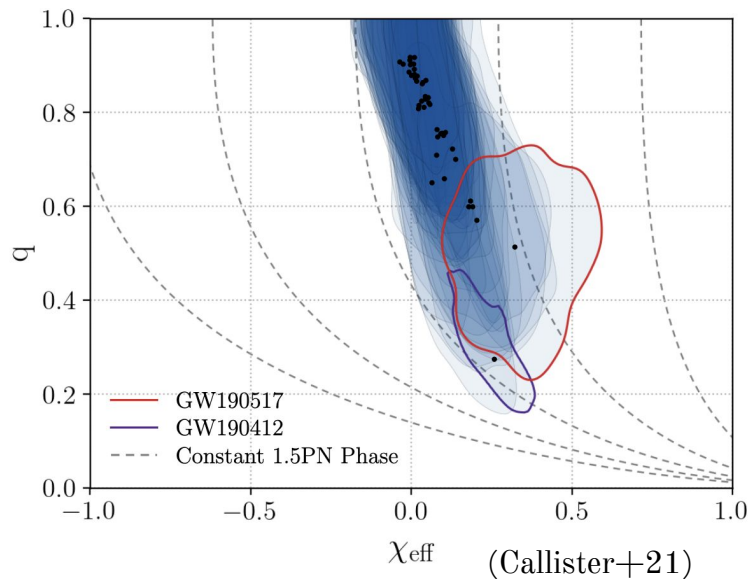
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Stay tuned...?

Conclusions

- Triple-induced merger channel is attractive, but rates remain somewhat uncertain
  - Look for signatures in observables!
- Comparable-mass tertiary: efficient mergers of small-q, seems difficult to reconcile

- Massive tertiary: ZLK has well-behaved spin dynamics
  - Applications?...

Abbott+21

(Callister+21)