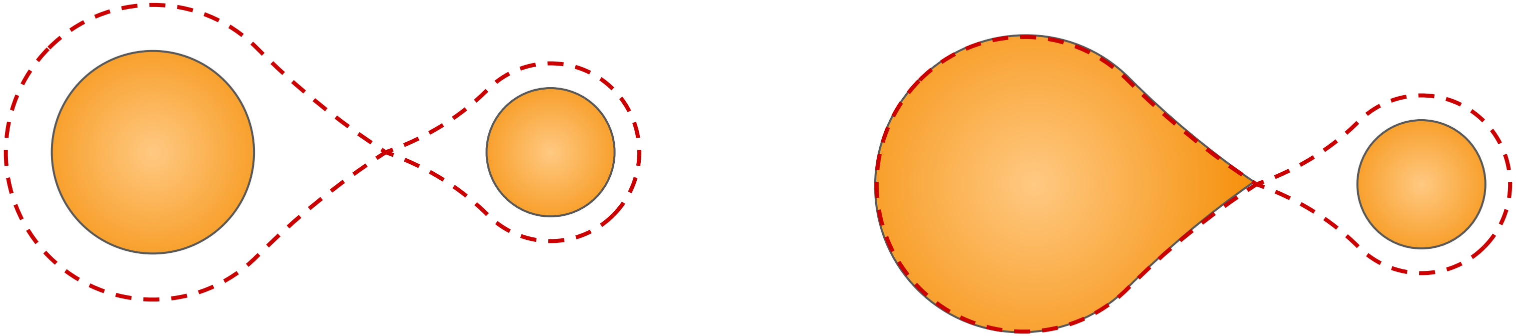
Mass Transfer Stability

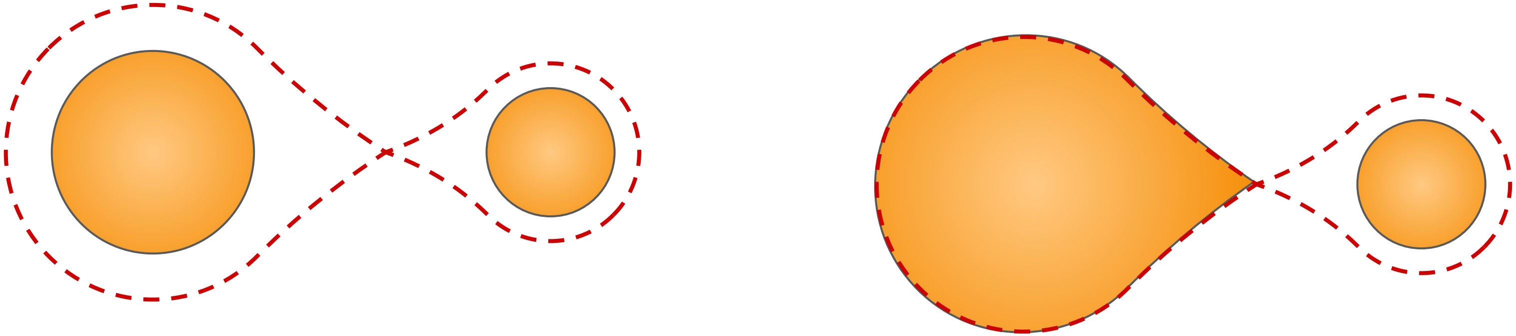
Max Briel

31/10/2022

Binary star systems



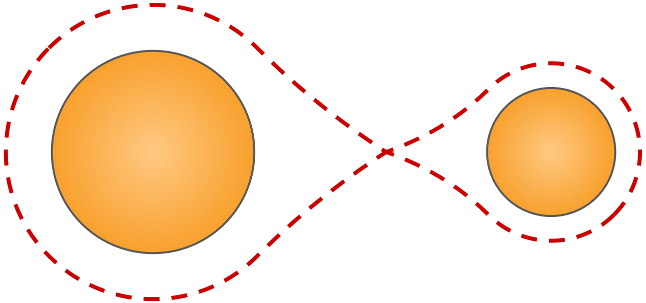
Binary star systems

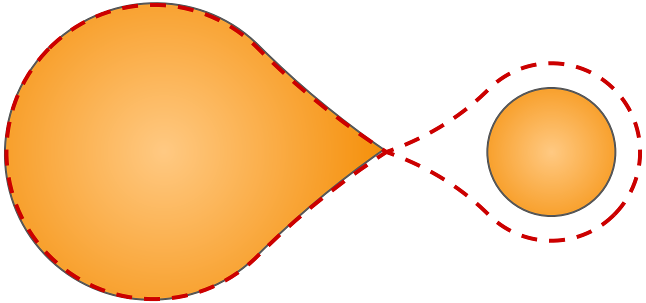


Roche-Lobe Overflow

1. Stellar Expansion
2. Orbital Shrinkage
    a. Angular momentum loss
    b. Magnetic Braking
    c. Gravitational Radiation

Binary star systems





Roche-Lobe Overflow

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2. Orbital Shrinkage
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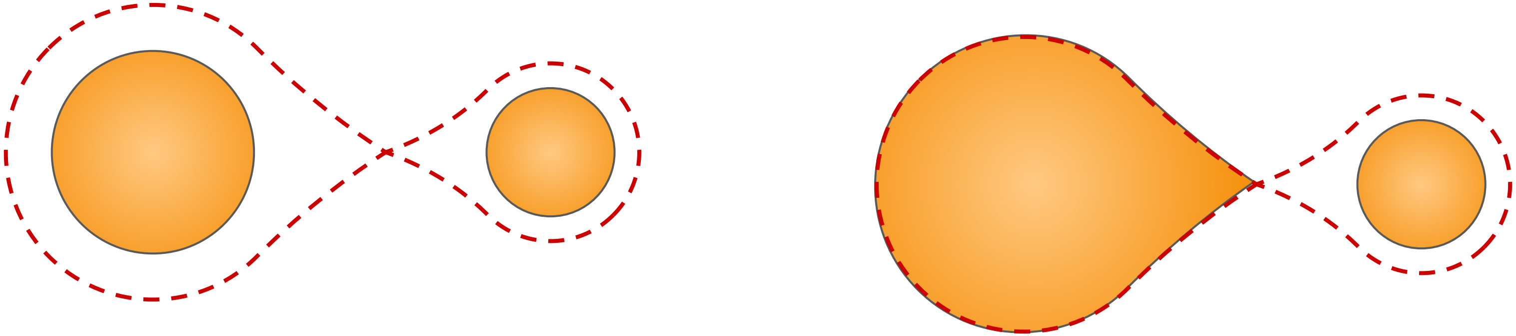
   b. Magnetic Braking
   c. Gravitational Radiation

Moment of RLOF

1. Case A (hydrogen burning)
2. Case B (hydrogen exhaustion)
3. Case C (helium exhaustion)

Binary star systems



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Moment of RLOF

1. Case A (hydrogen burning)
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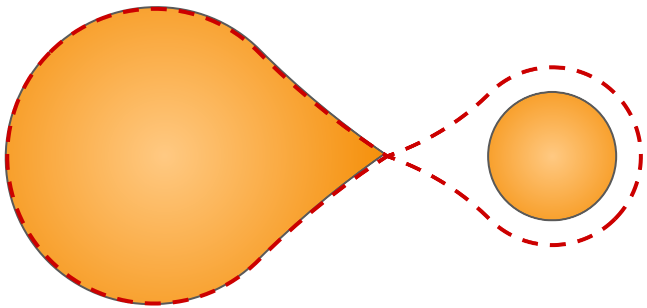
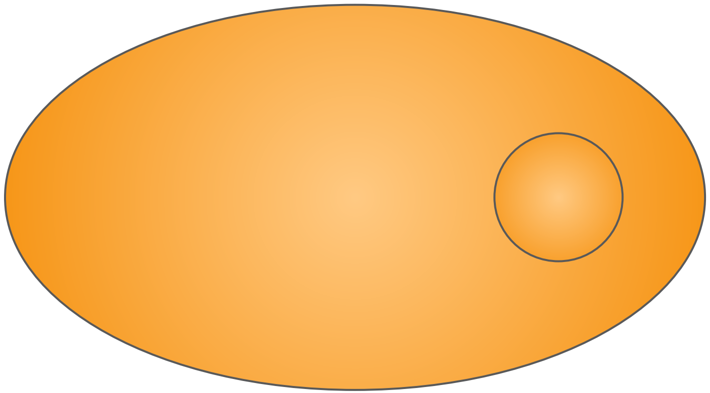
Timescale of RLOF

1. Dynamical
2. Thermal
3. Nuclear

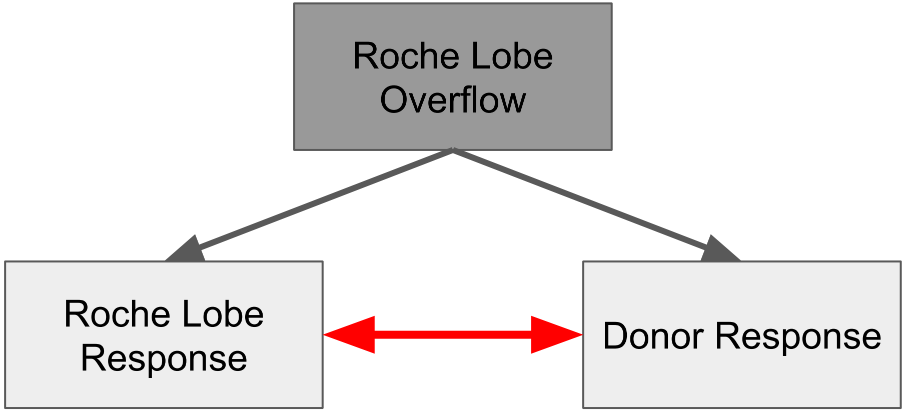
When does Mass Transfer become unstable?



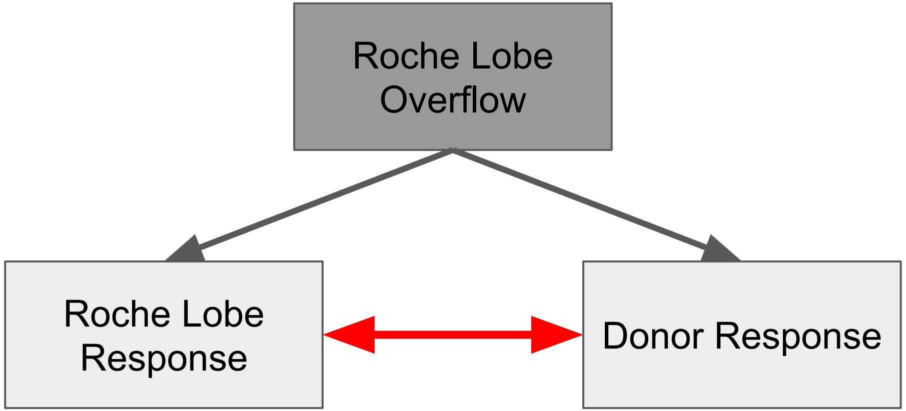


$$\zeta_{\mathrm{donor}} = \frac{\partial \ln R}{\partial \ln M}$$

$$\zeta_{\mathrm{RL}} = \frac{\partial \ln R_{\mathrm{RL}}}{\partial \ln M}$$



Roche Lobe Overflow
Roche Lobe Response
Donor Response

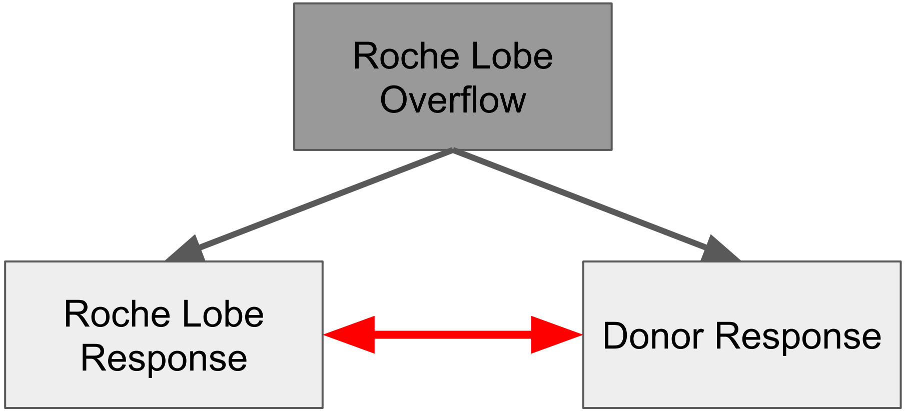


Dynamic timescale

$$\zeta_{\rm ad} = \left.\frac{\partial \ln R}{\partial \ln M}\right|_{\rm ad}$$

Thermal timescale

$$\zeta_{\rm eq} = \left.\frac{\partial \ln R}{\partial \ln M}\right|_{\rm eq}$$



Nuclear timescale MT

$$\zeta_{\rm RL} \le \zeta_{\rm ad}$$
$$\zeta_{\rm RL} \le \zeta_{\rm eq}$$

Thermal timescale MT

$$\zeta_{\rm RL} \le \zeta_{\rm ad}$$
$$\zeta_{\rm RL} > \zeta_{\rm eq}$$

Dynamic timescale MT

$$\zeta_{\rm RL} > \zeta_{\rm ad}$$

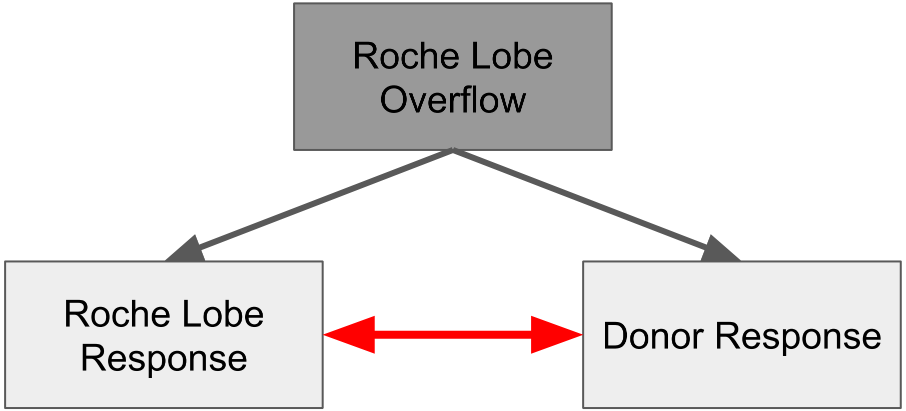
Can results in unstable MT

Dynamic timescale

$$\zeta_{\rm ad} = \left.\frac{\partial \ln R}{\partial \ln M}\right|_{\rm ad}$$

Thermal timescale

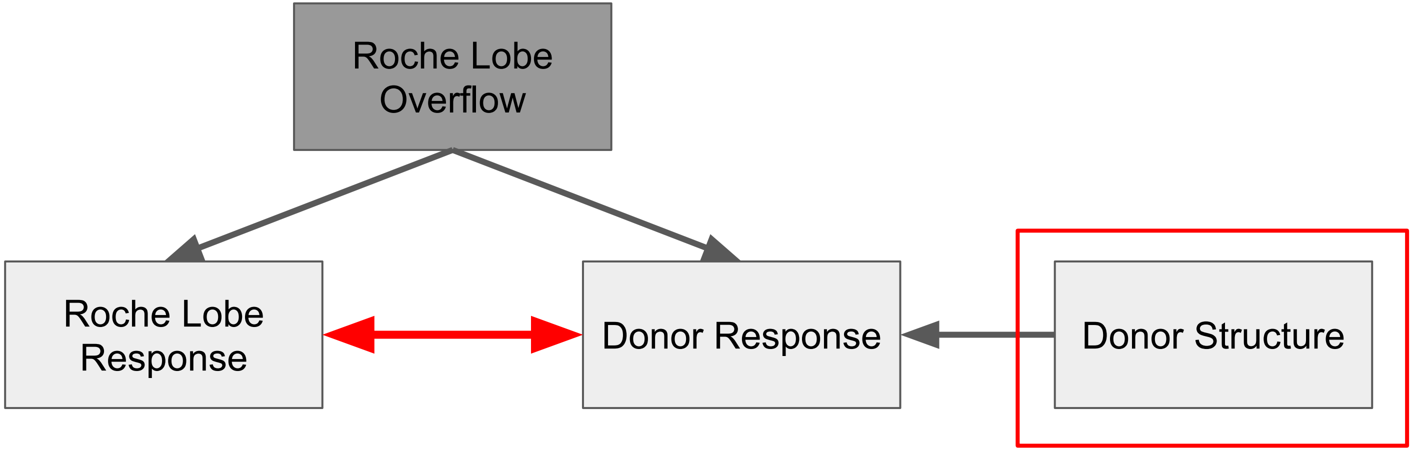
$$\zeta_{\rm eq} = \left.\frac{\partial \ln R}{\partial \ln M}\right|_{\rm eq}$$



$$\zeta_{\rm RL} > \zeta_{\rm ad}$$

Approach 1:
Donor Response

Approach 2:
Critical Mass Ratio



$$\zeta_{\rm RL} > \zeta_{\rm ad}$$

Approach 1:
Donor Response

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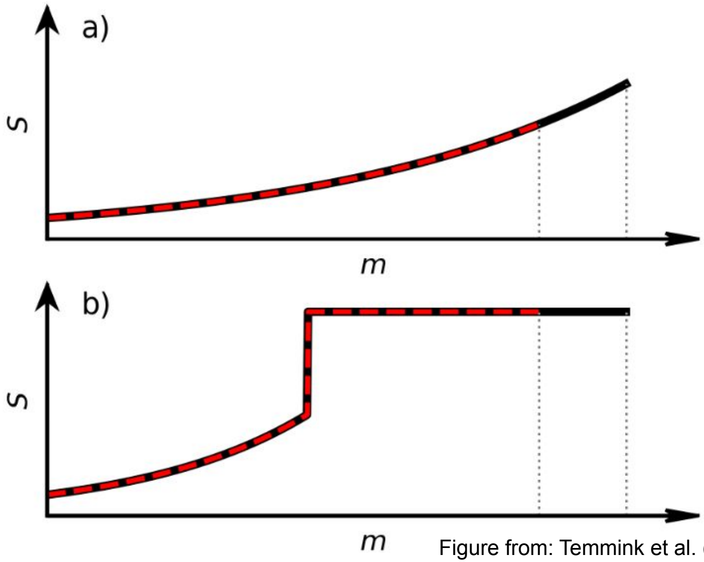
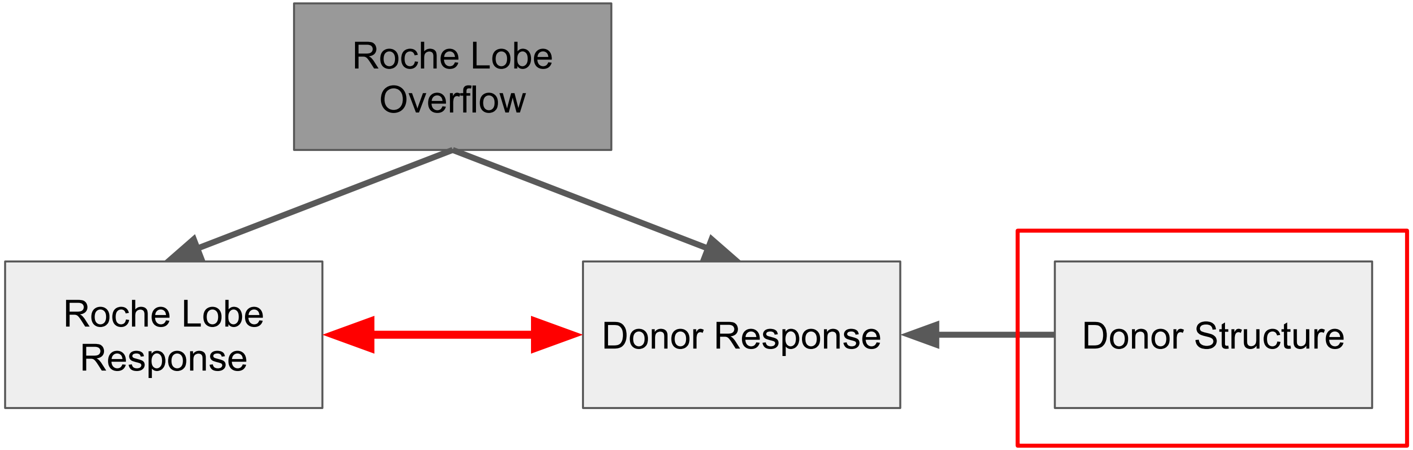


Figure from: Temmink et al. (2022)



Dependent on:
- Evolutionary phase
- Metallicity
- Mass

$$\zeta_{\mathrm{RL}} > \zeta_{\mathrm{ad}}$$

Approach 1: Approximate Donor Response

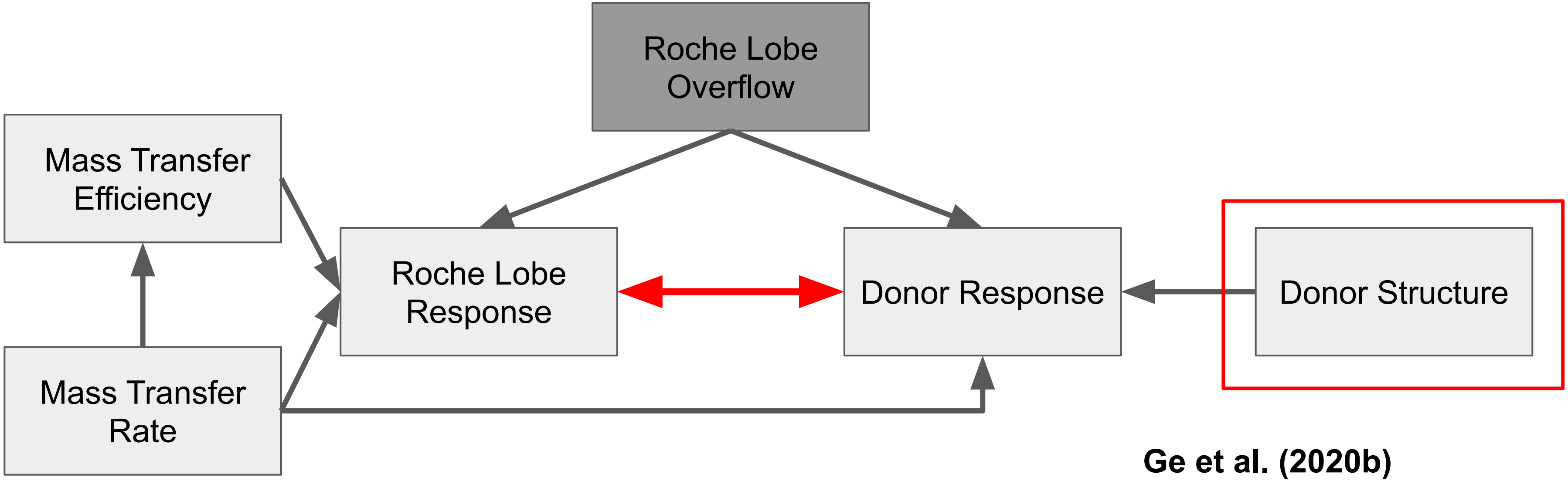
Approach 2: Critical Mass Ratio

Hjellming & Webbink (1987)
- Polytrope

Soberman et al. (1997)
- Composite Polytropes

Ge et al. (2010,2015,2020a)
- Fixed entropy stellar models

Implementations:
(From Hurley et al. 2002)
- COMPAS (Riley et al. 2022)
- SEVN (Spera & Mapelli 2016)
- COSMIC (Breivik et al. 2020)
- binary_c (Izzard et al. 2018)



Ge et al. (2020b)

- Thermal timescale MT

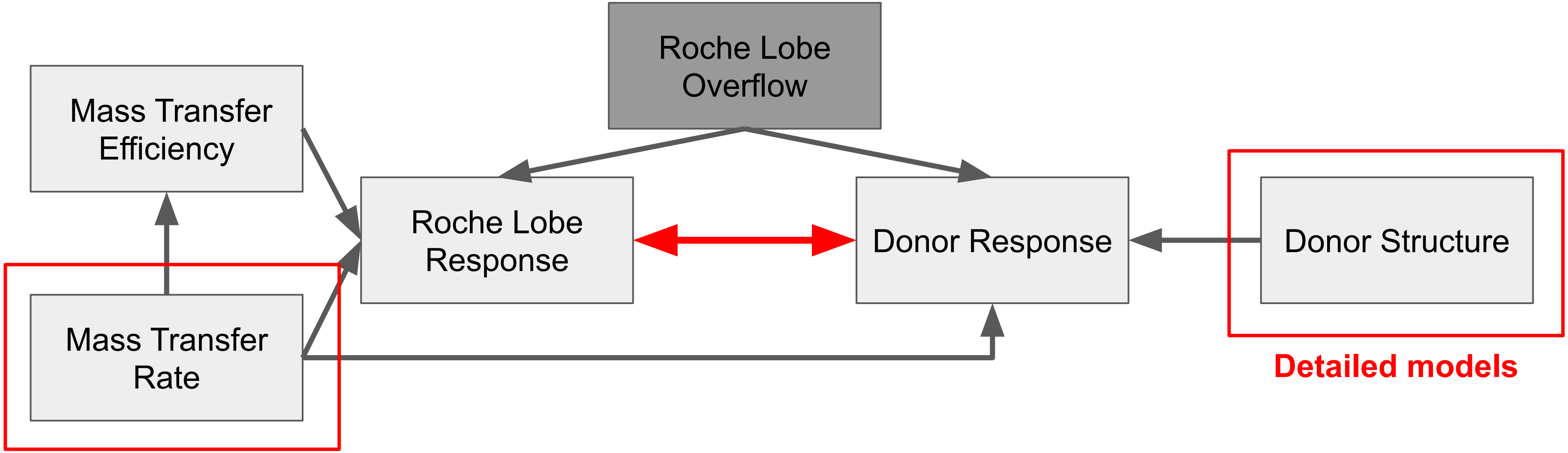
$$\zeta_{\mathrm{RL}} > \zeta_{\mathrm{ad}}$$

Approach 1: Approximate Donor Response

Approach 2: Critical Mass Ratio

Not-implemented:

- The donor changes during the mass transfer
- The mass ratio changes during mass transfer
- Only valid if the Mass Transfer is rapid



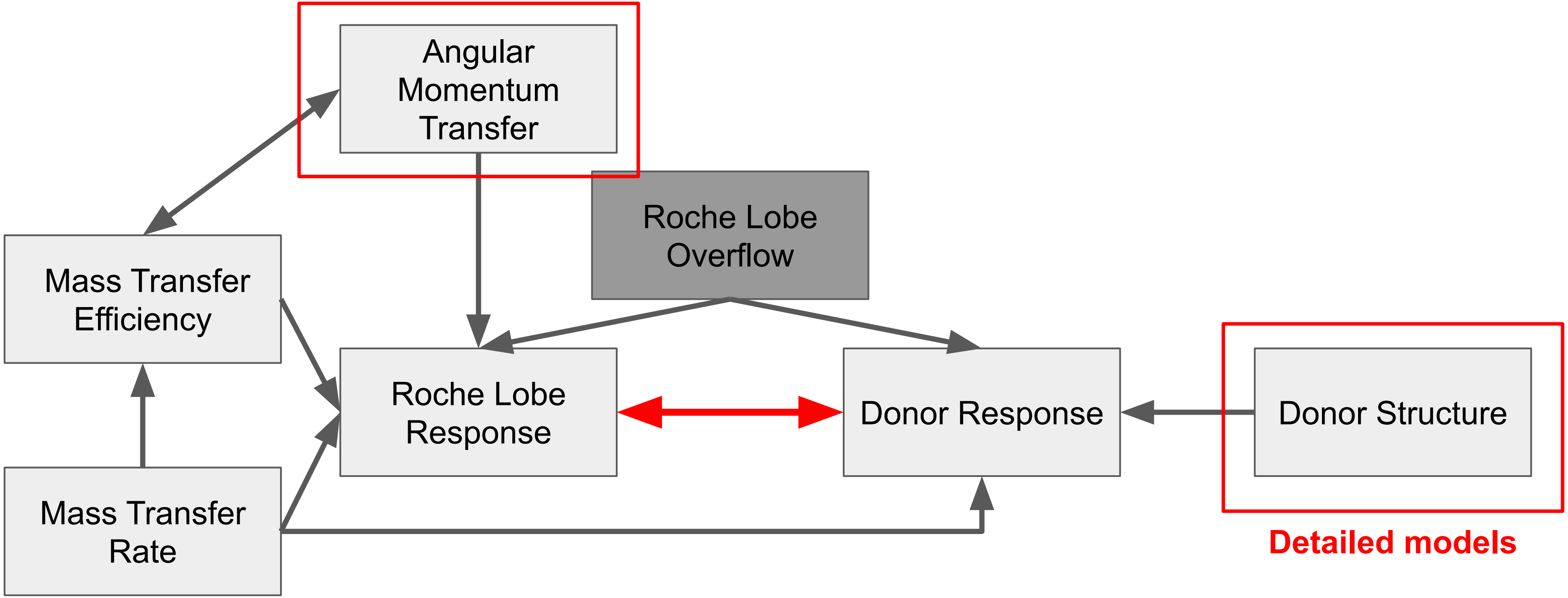
Approach 3:
Rapid MT rate

Marchant et al. (2021) + Gallegos-Garcia et al. (2021)

- MT rate limit at 1 $M_\odot$/yr for 30 $M_\odot$ donor
- Large range of period and accretor masses

Temmink et al. (2022)

- 1 $M_\odot$ to 8 $M_\odot$ donors
- Rate limited by $\dot{M}/M$



Approach 4:
Rapid orbital change

Pavlovskii & Ivanova (2015)

- Limited by $|\dot{a}/a|T < 1/50$
- Limited to Giant donors

Temmink et al. (2022)

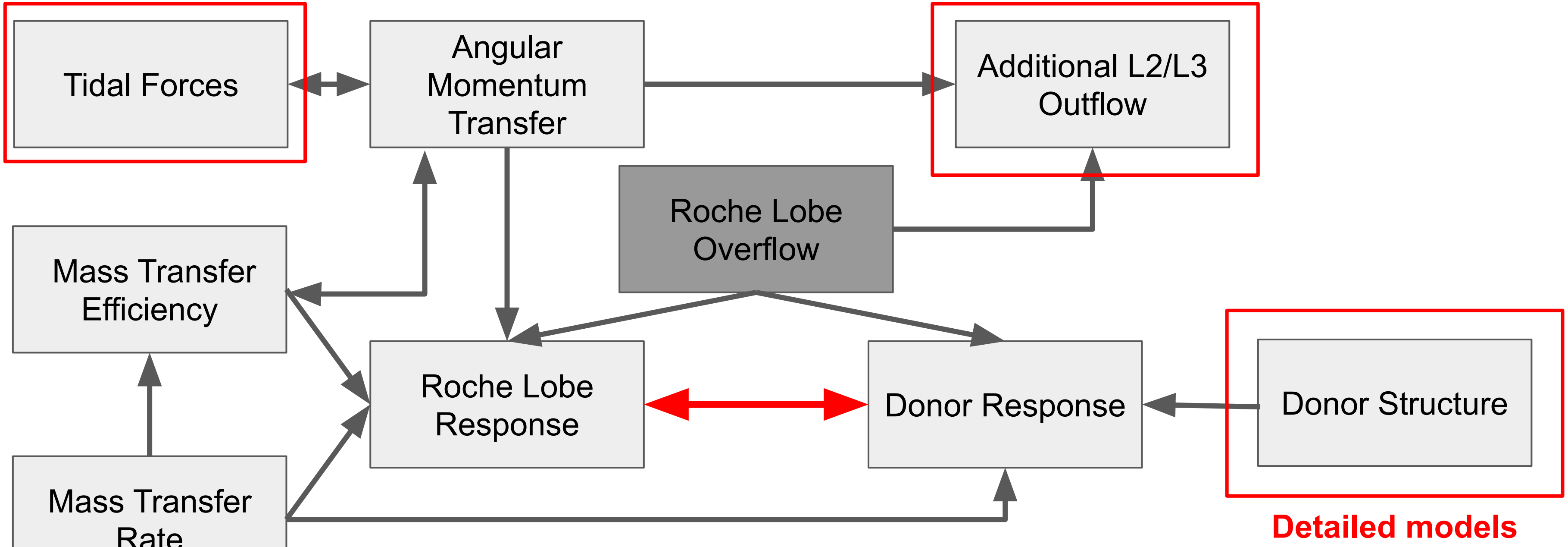
- $1\ M_{\odot}$ to $8\ M_{\odot}$ donors
- Orbital change limited by $\dot{a}/a$

Pavlovskii et al. (2017)

- Radius based approach

Shao & Li (2021)

- Detailed models



Approach 5:
L2/L3 outflows

Approach 6:
Orbital Separation

Pavlovskii & Ivanova (2015)

- L_2&L_3 Outflow

Temmink et al. (2022)

- 1 $M_\odot$ to 8 $M_\odot$ donors

Eldridge et al. (2017)

- Large mass & metallicity range
- Tidal interactions

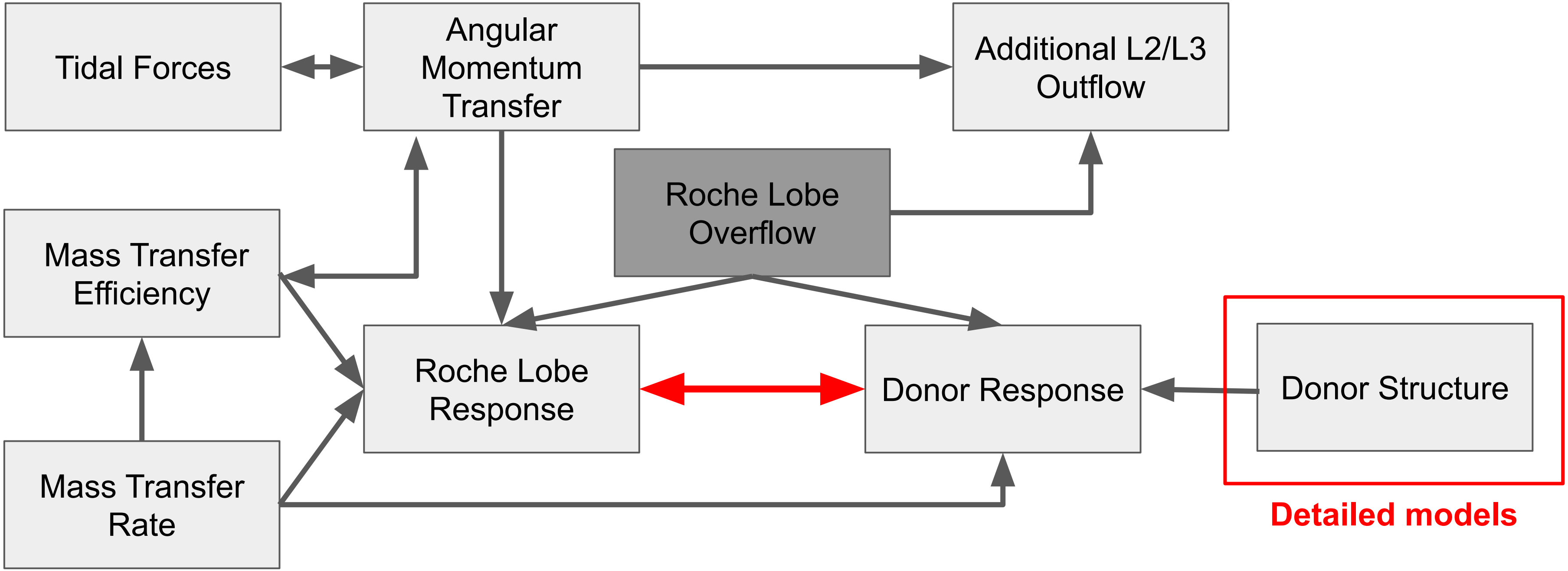
BBH population

Olejak et al. (2021)

- L2/L2 outflow. post-MS criteria

Briel et al. (2022)

- Orbital separation



Approach 7:
Adiabatic surface layer stripping

Woods & Ivanova (2011)

- Very high mass transfer rates possible

Temmink et al. (2022)

- Best indicator for runaway mass transfer

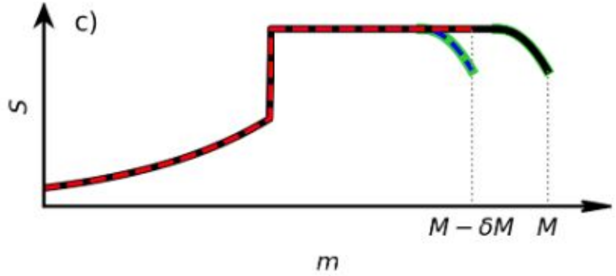
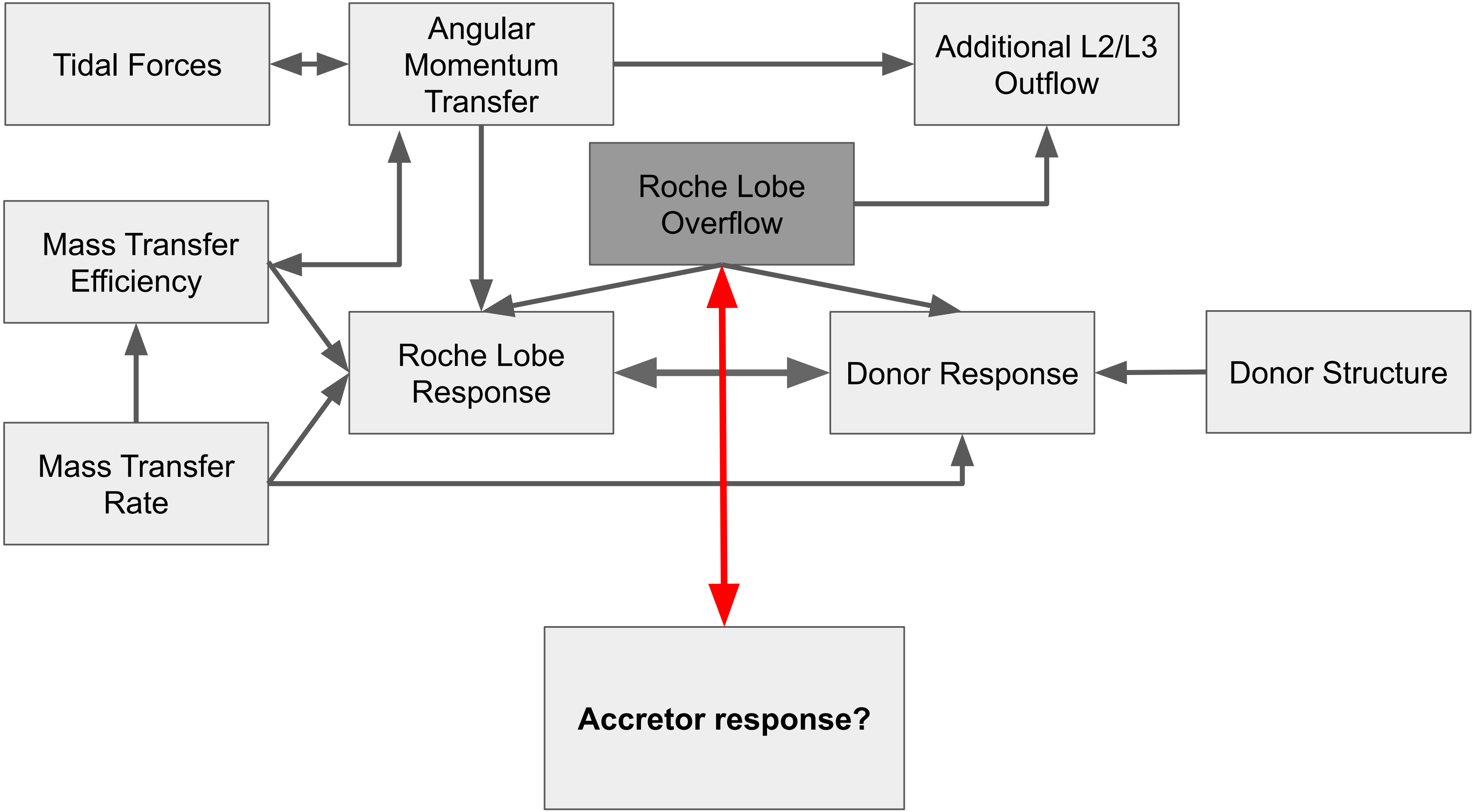


Figure from: Temmink et al. (2022)



Tidal Forces
Angular Momentum Transfer
Additional L2/L3 Outflow
Roche Lobe Overflow
Mass Transfer Efficiency
Roche Lobe Response
Donor Response
Donor Structure
Mass Transfer Rate
Accretor response?

When does Mass Transfer become unstable?

Detailed Models

White Dwarf population

Blue Stragglers

Circumstellar Disks

Approach 1: Approximate Donor Response

Approach 2: Critical Mass Ratio

Approach 3: Rapid MT rate

Approach 4: Rapid orbital change

Approach 5: L2/L3 outflows

Approach 6: Orbital Separation

Approach 7: Adiabatic surface layer stripping

Compact Object Mergers

Wolf-Rayet Stars

Main-Sequence Bands in Clusters

X-ray binaries

Detailed Models

Quast et al. (2019)
- Nuclear timescale MT due to H/He gradient

Klencki et al. (2020, 2021, 2022)
- Radiative envelope in post-MS stars
- Nuclear timescale MT possible
- Metallicity and Mass dependence for stability

Shao & Li (2022)
- Case A mass transfer

White Dwarf population

Lambert et al. (2019)
- LISA WD binary population

Holberg et al. (2016)
- 25 pc local WB population

Blue Stragglers

Compact Object Mergers

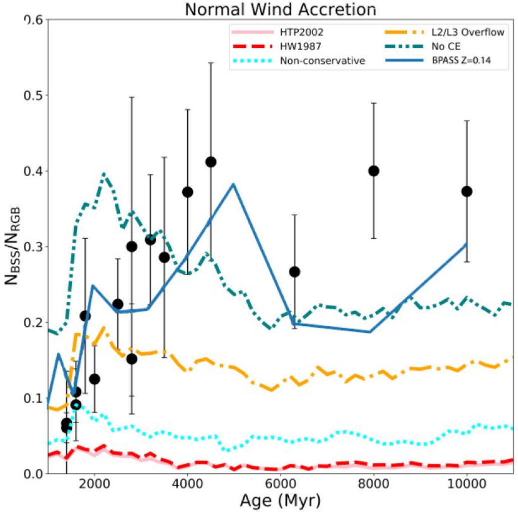


Figure from: Geinke (2022) Master Thesis.
Original from Leiner & Geller (2021).

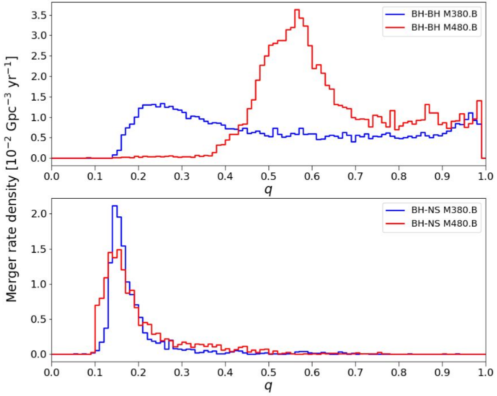


Figure from: Olejak et al. (2021)

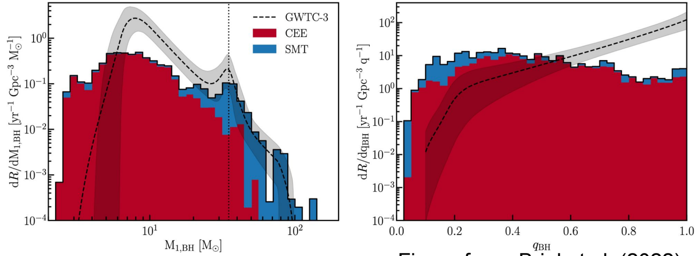


Figure from: Briel et al. (2022)

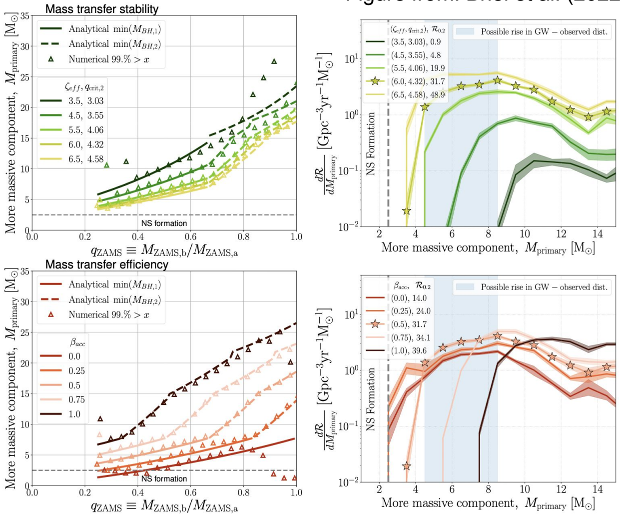


Figure from: Van Son et al. (2022)

Main Discussion Questions

1. What mass transfer rates are applicable?
   a. How much do they influence the stability of the interaction?
2. What do we define as unstable mass transfer?
3. What is the efficiency and how conservative is mass transfer?
4. How important is tidal synchronization?
5. How do we apply more detailed mass transfer criteria in population synthesis codes?
6. What other observables can help us constraint the stability of mass transfer?

When does Mass Transfer become unstable?

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