A recipe for using binary stellar yields in galactic chemical evolution calculations

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Single star parameters

Metallicity

Mass

$1\ M_\odot$ • • • $100\ M_\odot$

(and rotation)

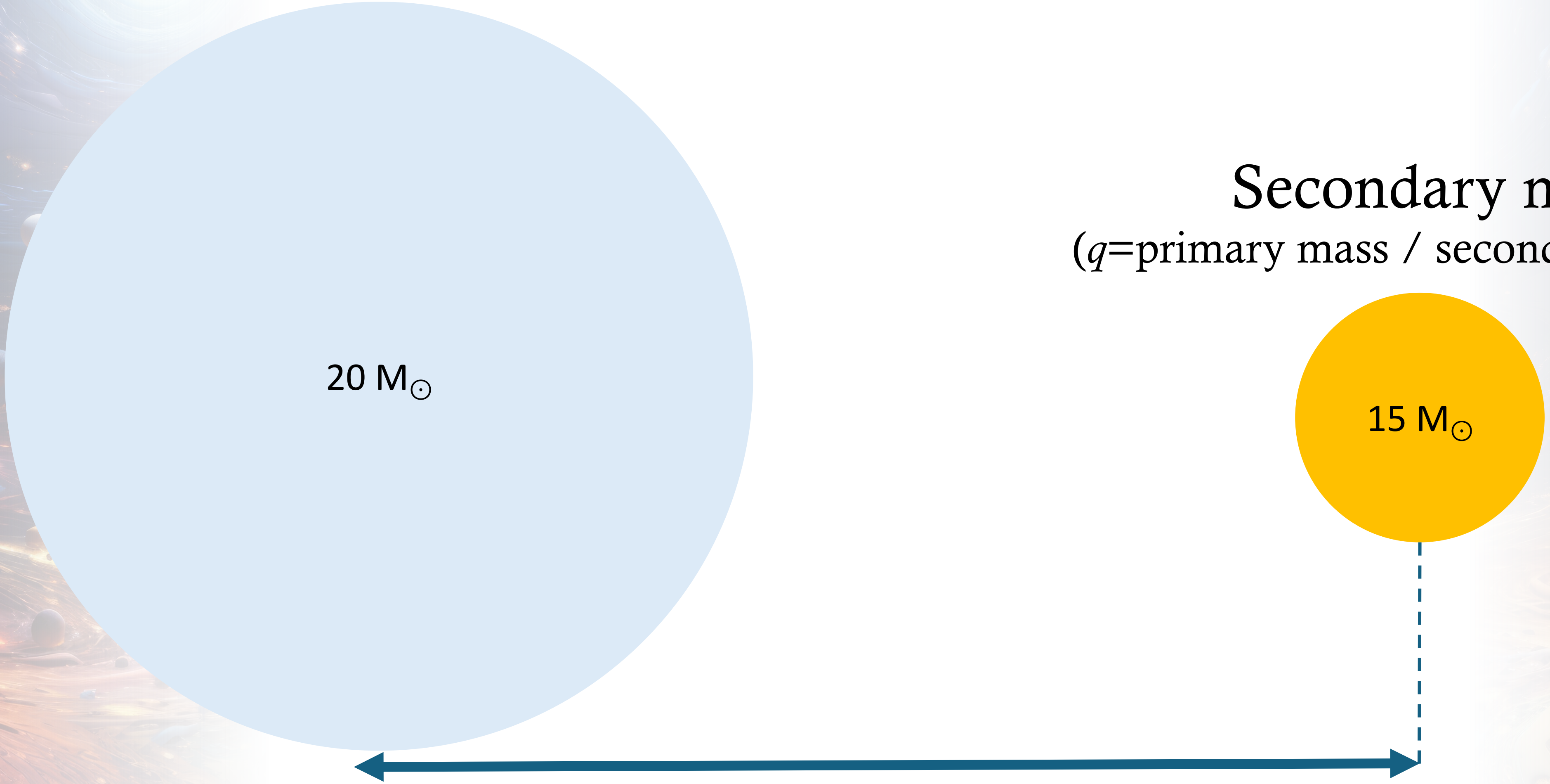
Galaxy flask created using starryai: https://starryai.com/

Binary star parameters

Primary mass

Secondary mass

(q=primary mass / secondary mass)



Separation

(Orbital period)

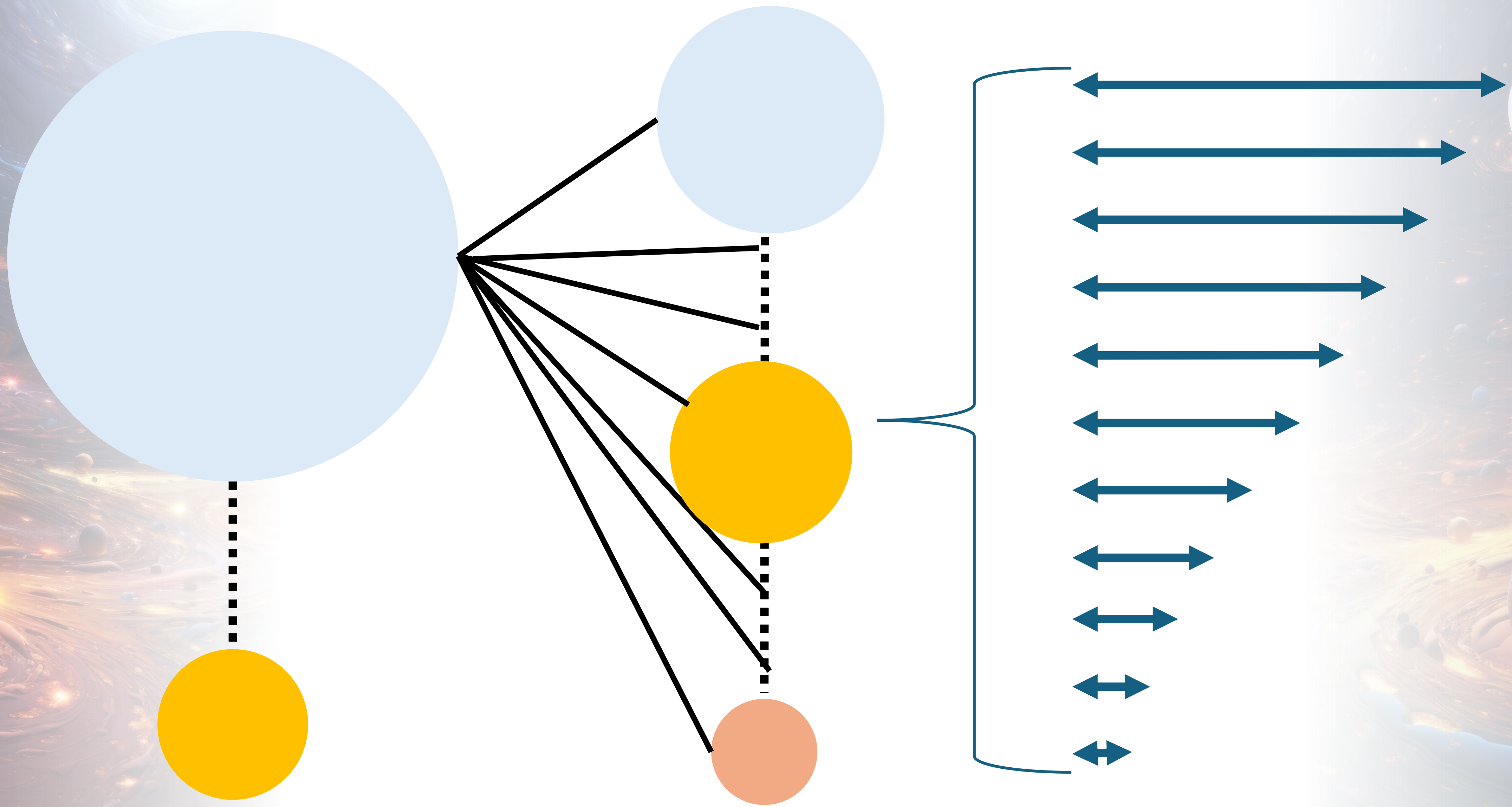
(and eccentricity)

Binary stellar populations

Primary mass

Mass ratio

Separation (or period)



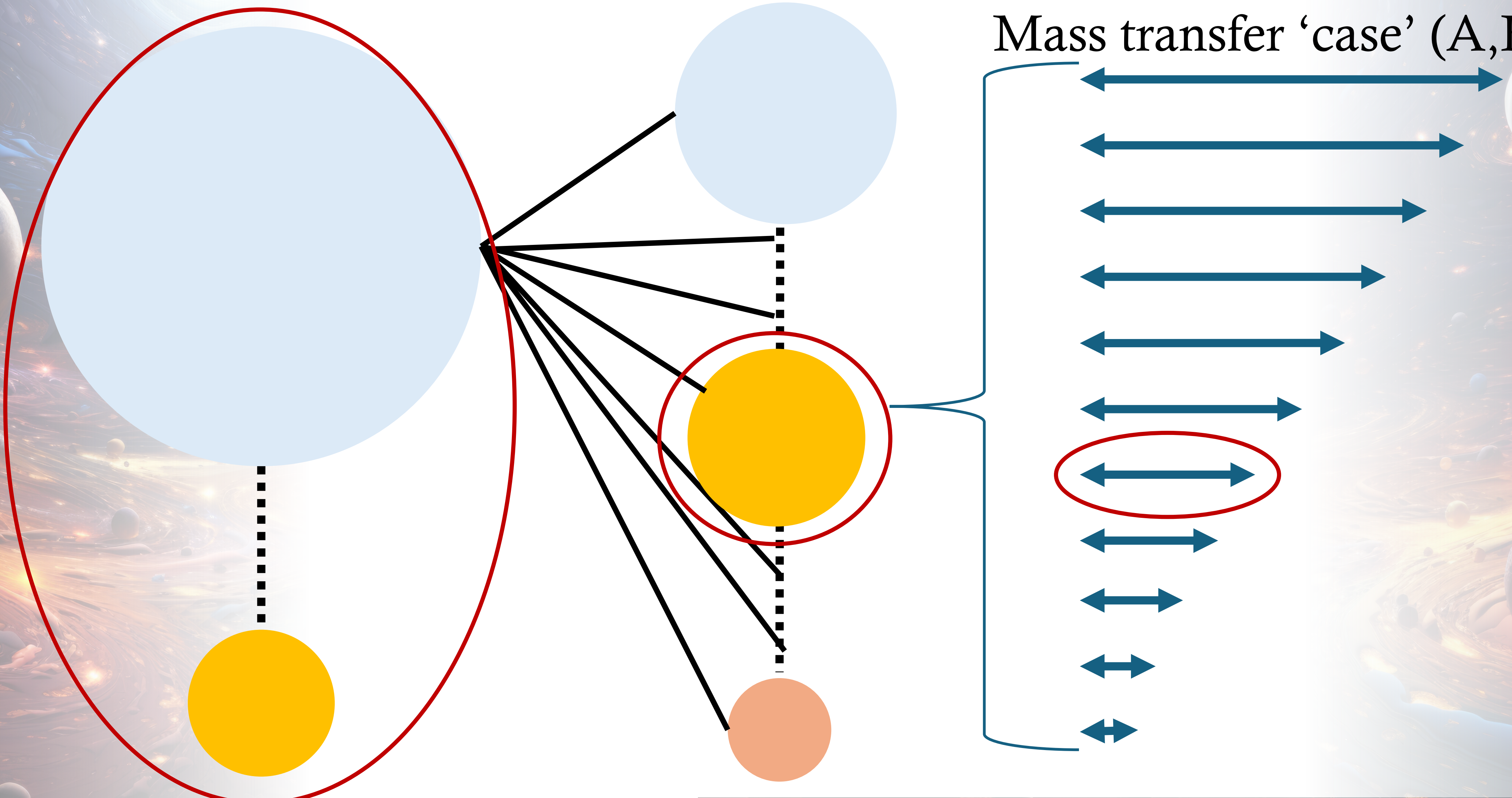
Simplifying Binary stellar populations

Primary mass

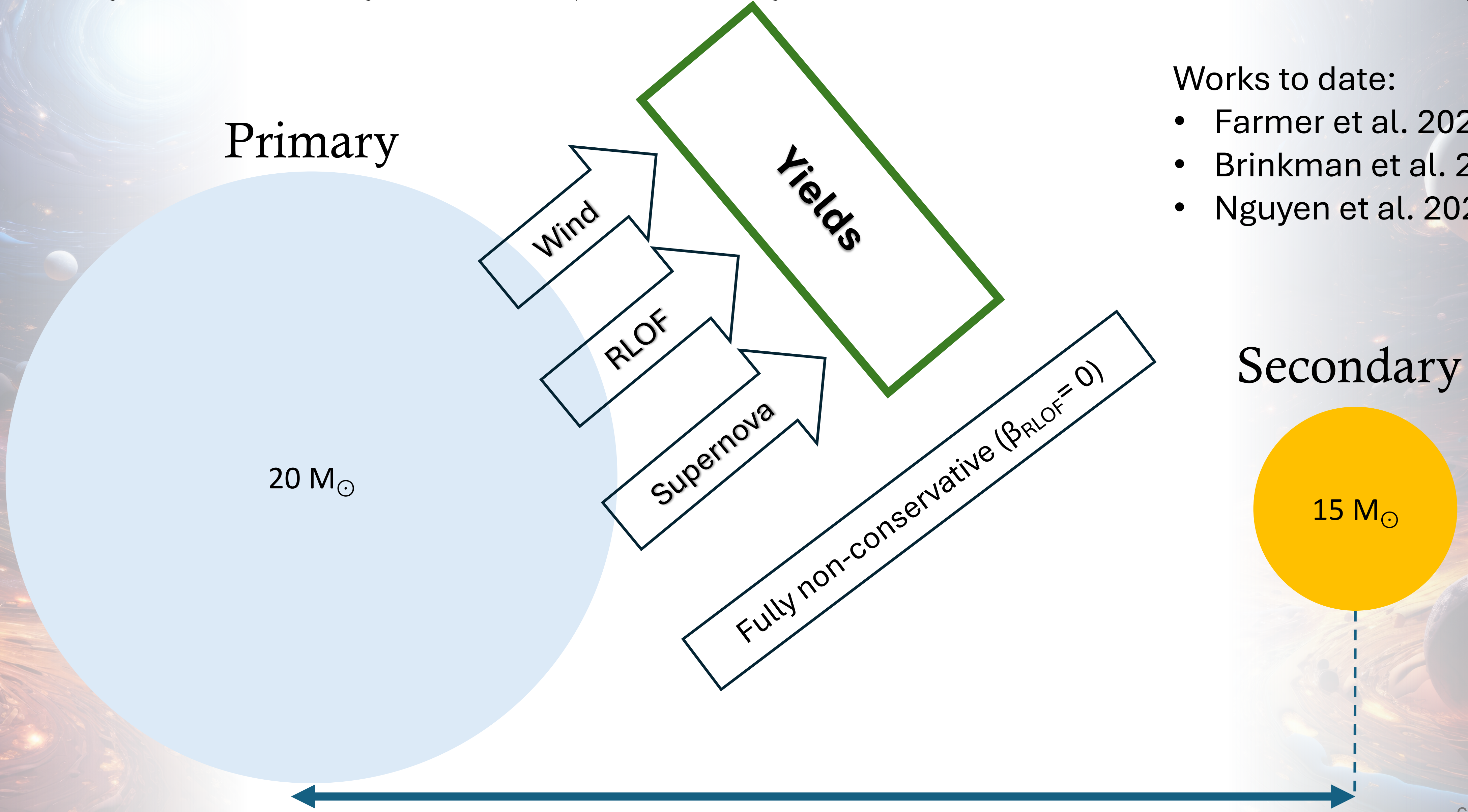
Mass ratio

~~Separation (or period)~~

Mass transfer ‘case’ (A,B,C…)



Binary stellar yields (directly from detailed models)



Works to date:

- Farmer et al. 2022
- Brinkman et al. 2024
- Nguyen et al. 2024

Effective binary yields

Can be used as if they were single star yields of the same stellar mass!

h = binary fraction

$\langle q \rangle$ = average value of M_2/M_1

Average secondary yield

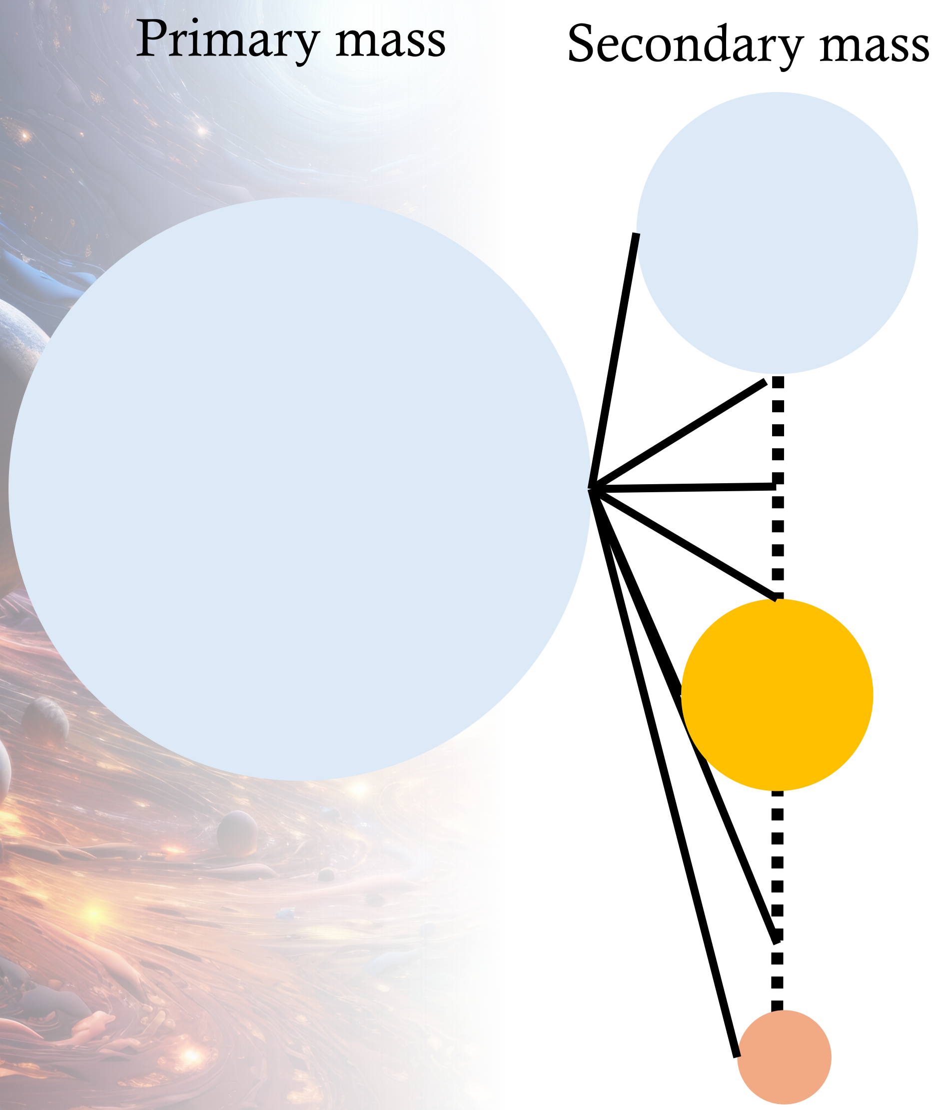
$$Y_{\mathrm{eff}} = \frac{(1-h)\boxed{Y_{\mathrm{single}}} + h(\boxed{Y_{\mathrm{prim}}} + \boxed{\langle Y_{\mathrm{sec}} \rangle})}{1 + h\langle q \rangle}$$

Single Yield

Primary yield

Brinkman et al. 2019

Calculating Y_{prim} and $\langle Y_{\mathrm{sec}} \rangle$ considering β



$$Y_{\mathrm{prim}} = (1-\beta_{\mathrm{winds}}) \cdot Y_{\mathrm{winds}} + (1-\beta_{\mathrm{RLOF}}) \cdot Y_{\mathrm{RLOF}} + (1-\beta_{\mathrm{SN}}) \cdot Y_{\mathrm{SN}}$$

$$Y_{\mathrm{sec}} = \boxed{Y_{\mathrm{single}}^{M_2+\Delta M}} + \boxed{Y_{\mathrm{dump}}},$$

Yield of a single star of mass $M_2+\Delta M$

Y_{dump} conserves the **net** yields of the primary

Net yield transferred to the secondary:

$$Y_{\mathrm{dump}} = \beta_{\mathrm{winds}} \cdot Y_{\mathrm{winds}} + \beta_{\mathrm{RLOF}} \cdot Y_{\mathrm{RLOF}} + \beta_{\mathrm{SN}} \cdot Y_{\mathrm{SN}}.$$

Calculating Y_{prim} and $\langle Y_{\mathrm{sec}} \rangle$ considering β

Accreted radioisotopes will continue to decay after they're accreted onto the secondary!

radioactivedecay
A Python Package

https://github.com/radioactivedecay/radioactivedecay

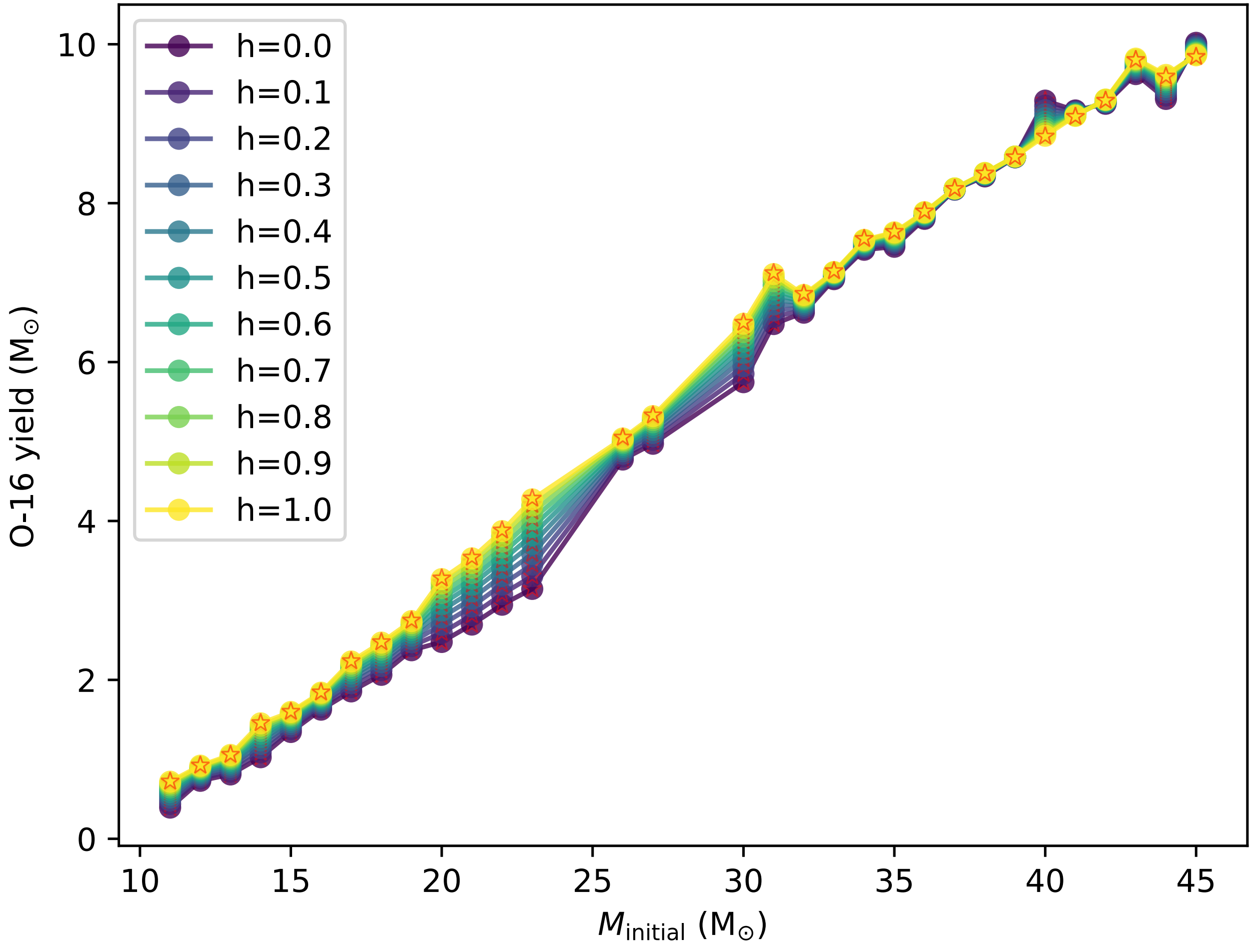
Secondary lifetime:

- Conserve core He mass at time of mass transfer.
- Account for increased core mass due to mass transfer.

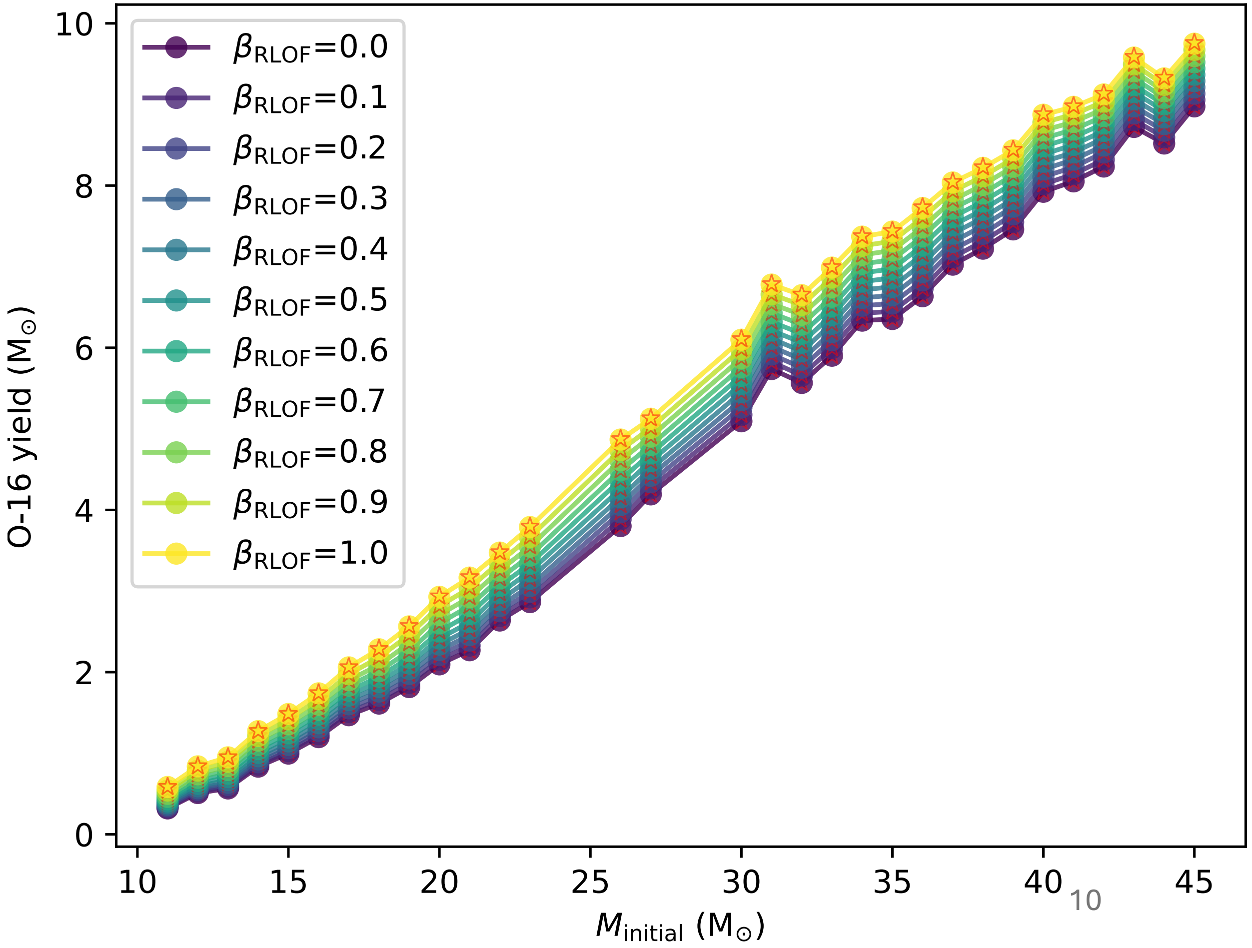
https://www.pinterest.com/pin/43213452676146O9

Effective net yields: O-16

Varying binary fraction (h)
(β_{RLOF}= 1, β_{wind}= 0.1, β_{cc}= 0)



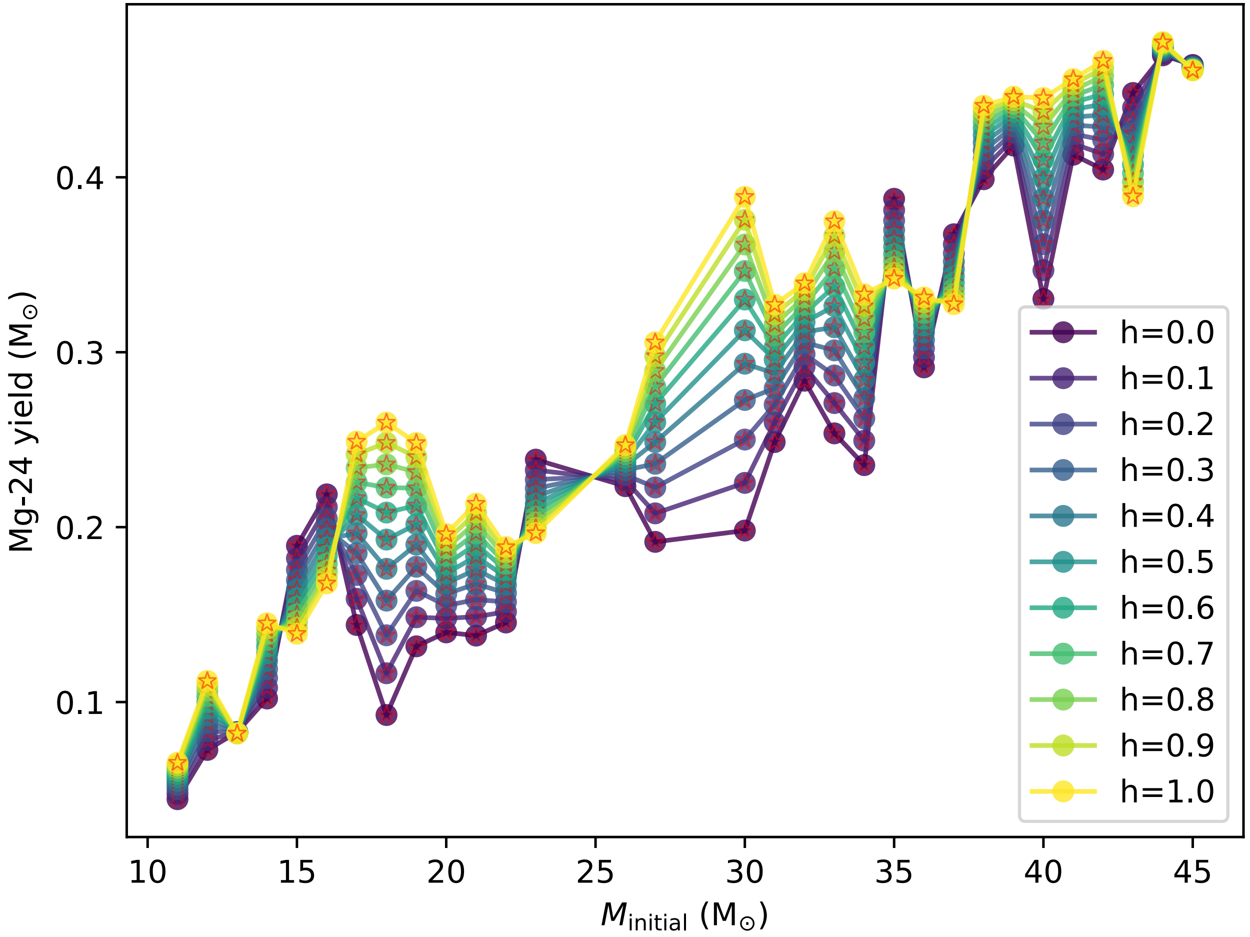
Varying mass transfer efficiency (β_{RLOF})
(h= 0.5, β_{wind}= 0, β_{cc}= 0)



Effective net yields: Mg-24

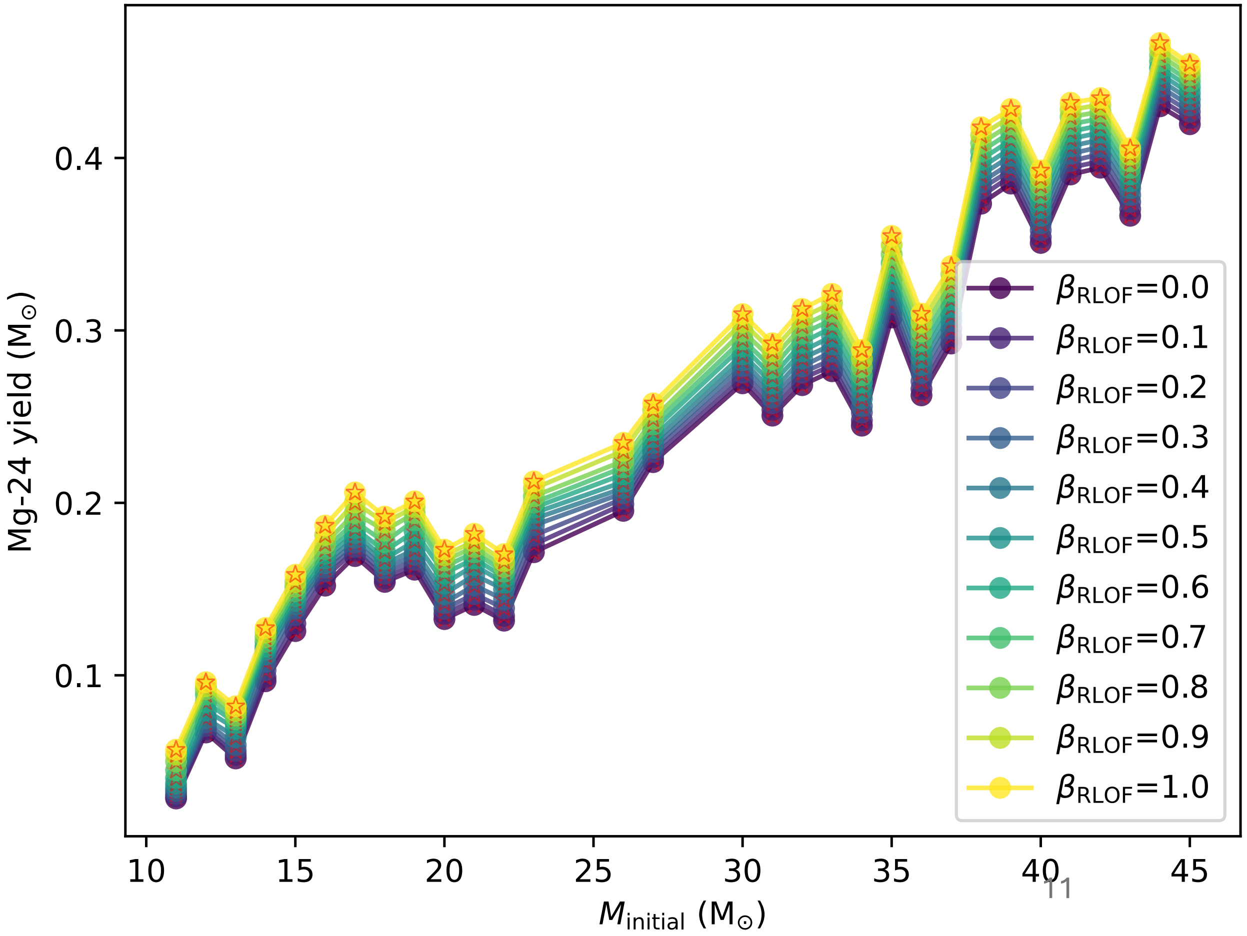
Varying binary fraction (h)

(β_{RLOF}= 1, β_{wind}= 0.1, β_{cc}= 0)



Varying mass transfer efficiency (β_{RLOF})

(h= 0.5, β_{wind}= 0, β_{cc}= 0)



The effective yield framework is versatile

- Here *Y* is the yield of each channel (A,B,C, etc)
- *f* are the relative weights of each channel ($\sum f = 1$)

$$Y_{\mathrm{prim}} + \langle Y_{\mathrm{sec}} \rangle$$

$$Y_{\mathrm{eff}} = \frac{(1-h)\boxed{Y_{\mathrm{single}}} + h(f_{\mathrm{A}}\boxed{Y_{\mathrm{A}}} + f_{\mathrm{B}}Y_{\mathrm{B}} + f_{\mathrm{C}}Y_{\mathrm{C}})}{1 + h\langle q \rangle}$$

Could also be broken up into different rotation rates, for example

Additional modelling work needed

1. Binary stellar yields for **<u>low-mass stars.</u>**

2. Binary stellar yields at **<u>low metallicities.</u>**

3. Better isotopic coverage: **<u>nuclear post-processing</u>**

4. More and more realistic **<u>supernovae</u>**

5. Mass gainers: stable mass transfer and **<u>stellar mergers</u>**.

…

Output checklist for binary stellar modellers

1. Report the amount of mass lost through **winds**, **RLOF**, and **supernovae.** Ideally also report relevant timings.

2. Calculate and report **supernova** yields**.**

3. Provide **an equivalent set of single stellar yields.** For extra credit, also include a set of rotating models ☺.

4. Publish the data in a **machine-readable format** through **publicly accessible archives.**

Concluding remarks

- The **effective binary stellar yield** provides a framework for including yields from **mixed single/binary stellar populations** in existing **galactic chemical evolution** codes.

- **Current binary stellar yields only cover a tiny portion of the binary parameter space** -> more models needed!

- Priorities: **low-mass stars**, **sub-solar metallicities**, **nuclear post-processing**, **supernovae**, mass gainers (e.g. mergers).