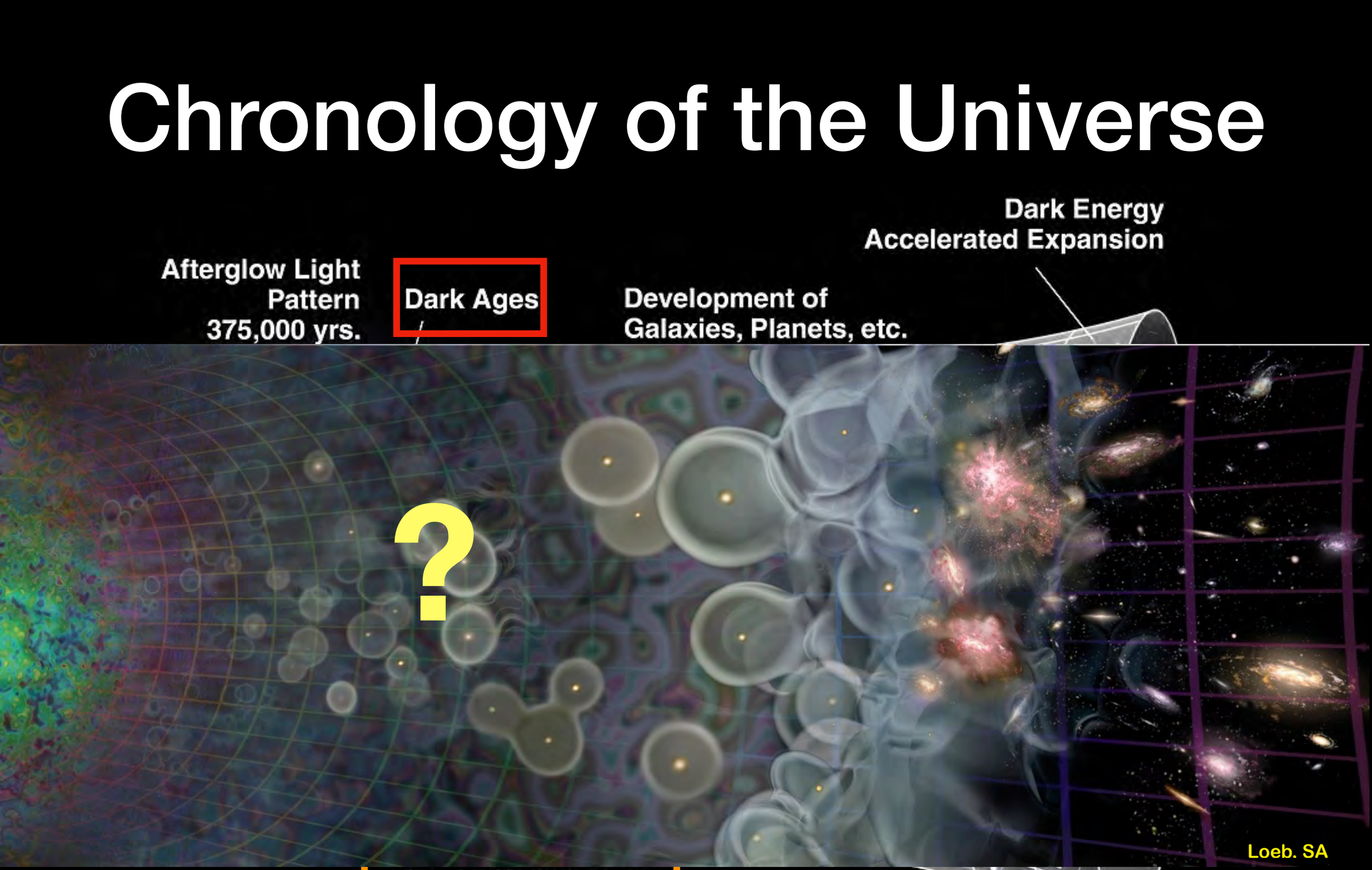
The Evolution of Population III and Extremely Metal-poor Binary Stars

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Ke-Jung (Ken) Chen(ASIAA), Daniel Whalen(UoP),
Po-Sheng Ou(NTU/ASIAA), and Tyrone E. Woods(UM)

Chronology of the Universe



about 400 million yrs.

Big Bang Expansion

13.77 billion years

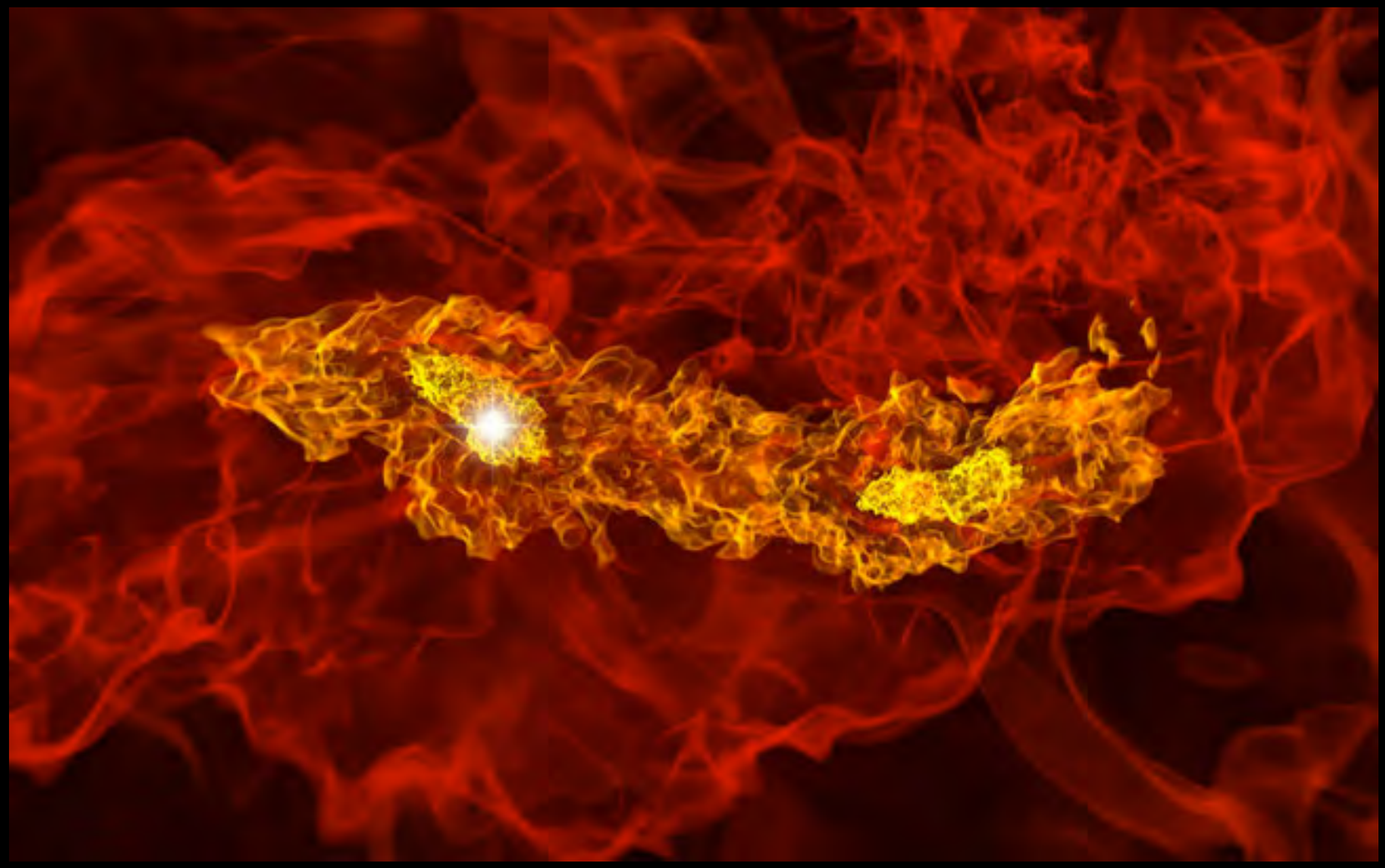
Formation of the First Stars



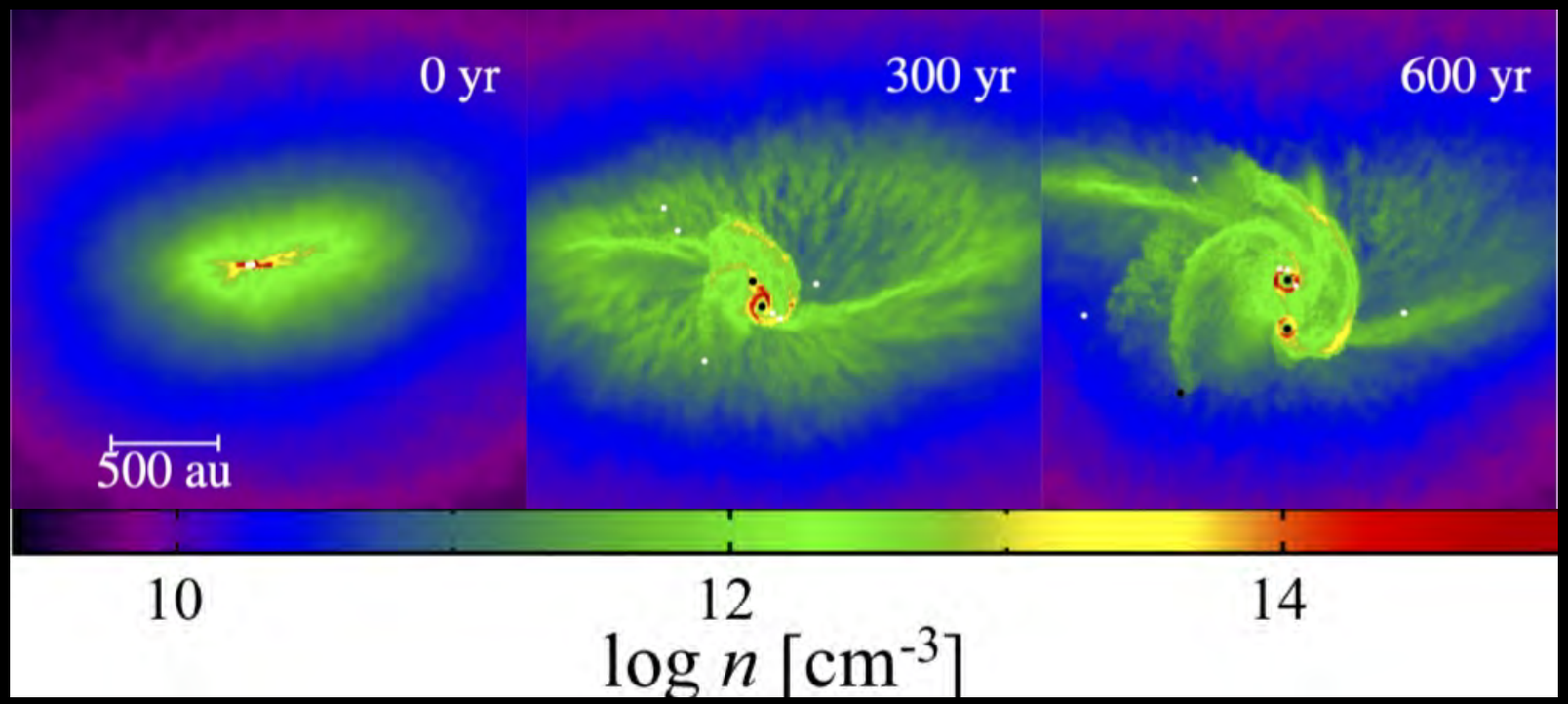


LCDM Chen and Almgren (NYX code)

The First Binaries



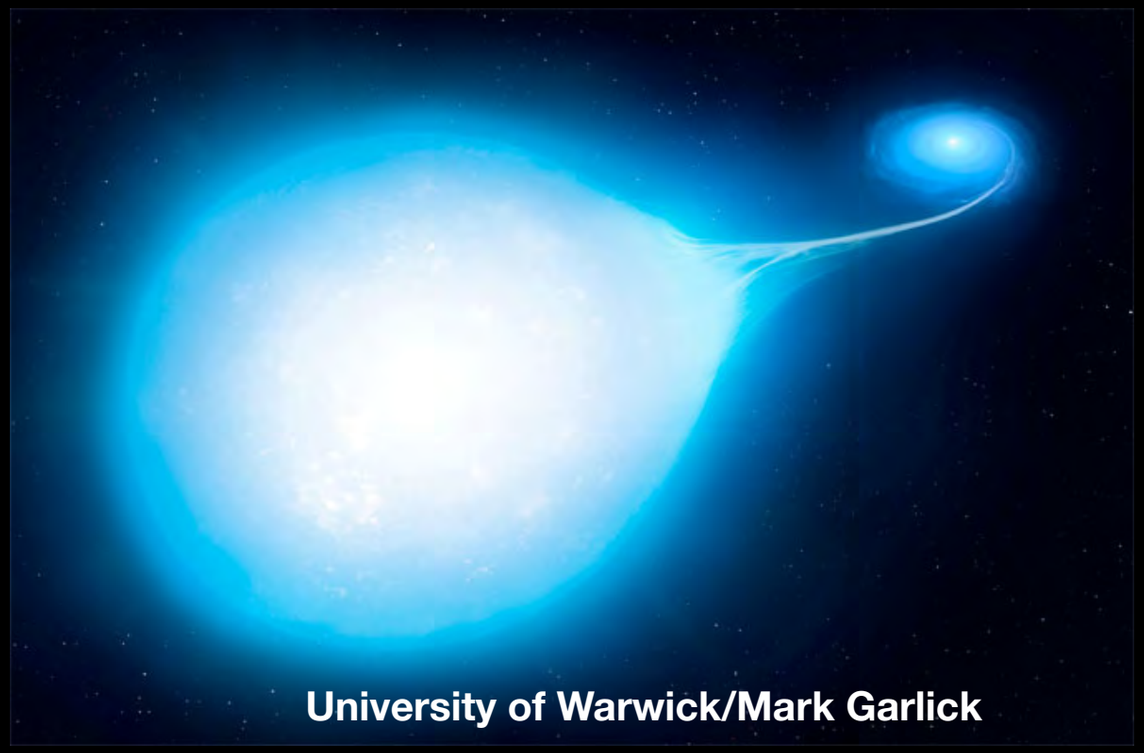
Turk+ (2009)



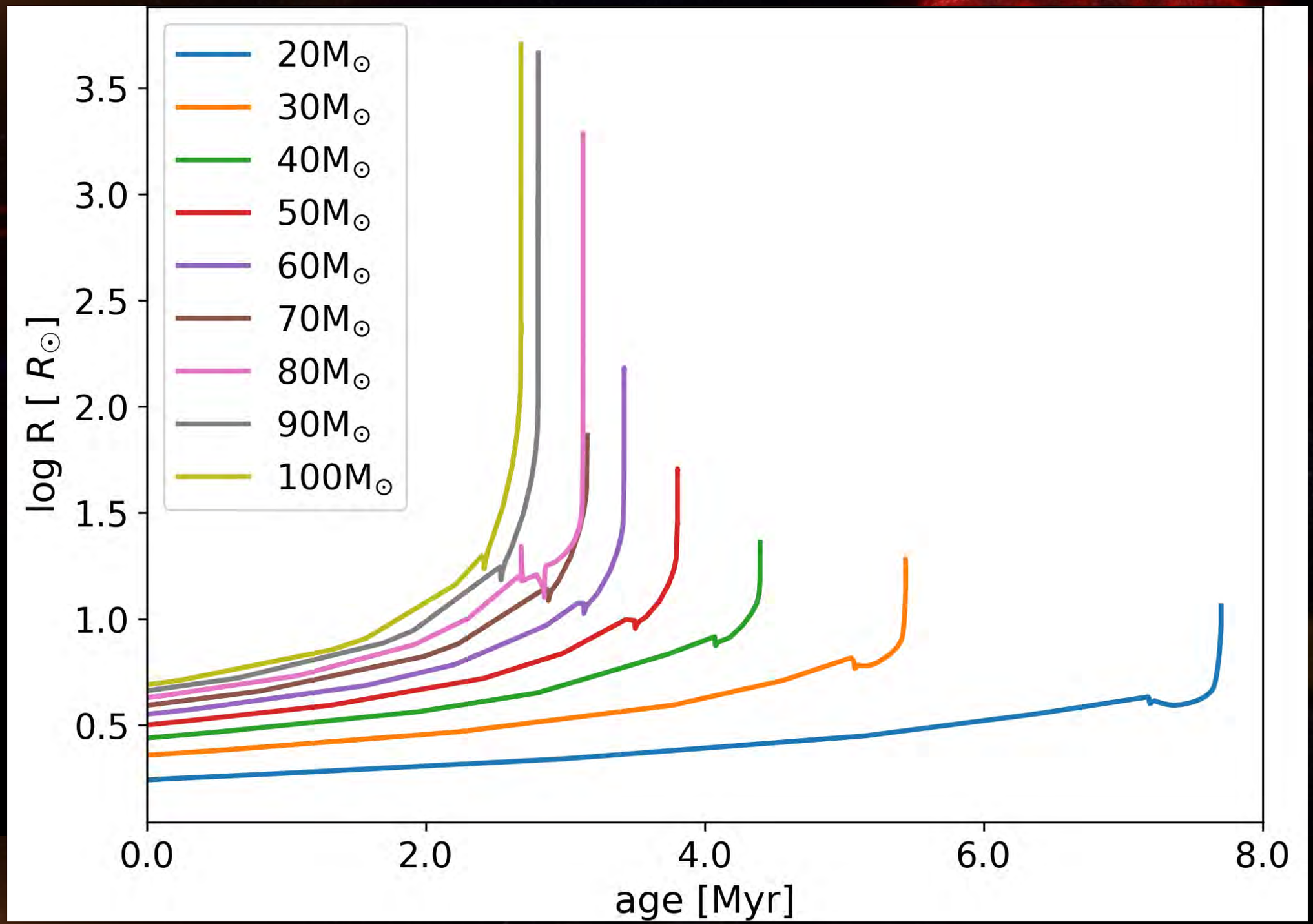
Chon+ (2018,2020)

What are the differences in their radiative feedbacks?





Population III stars radius

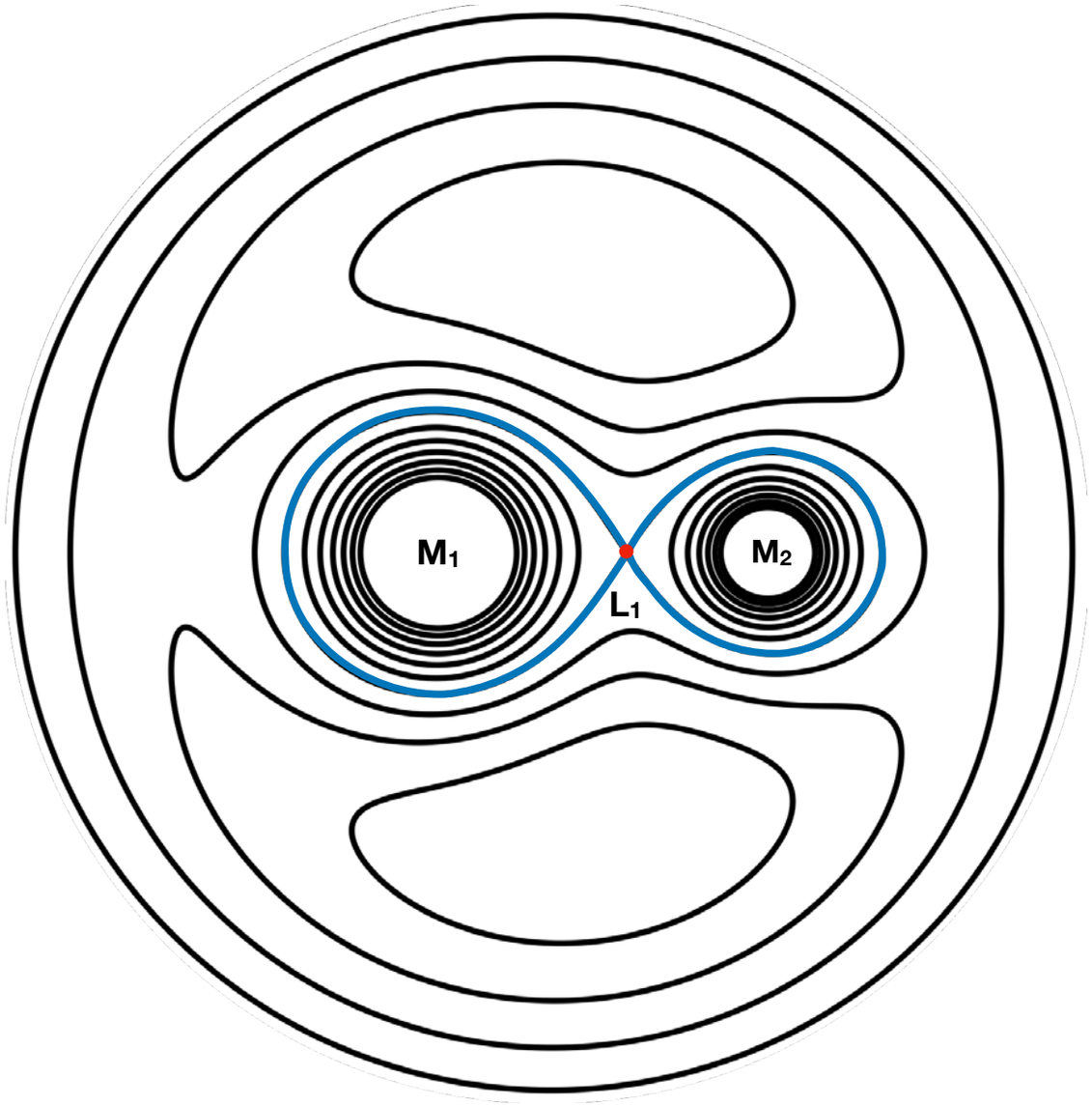


Roche-lobe overflow

- The Roche-lobe is the region in which material is bound to the star by gravity.

- If the star fills its Roche-lobe, material will flow onto the binary companion.

$$R_{RL.J} = \frac{0.49 q_j^{2/3}}{0.6 q_j^{2/3} + ln(1+q_j^{1/3})} a$$



Eggleton 1983

Calculate ionizing photon

$$q = \int_{\upsilon_{min}}^{\infty} \frac{\pi B_\upsilon}{h\upsilon} d\upsilon$$

$$\dot{N} = 4\pi R^2 \int_{\upsilon_{min}}^{\infty} \frac{\pi B_\upsilon}{h\upsilon} d\upsilon = 4\pi R^2 q$$

$$\dot{N} = 4\pi (R_1^2 q_1 + R_2^2 q_2)$$

q: The flux of ionizing photons

B_υ: Spectral radiance density

h: Planck constant

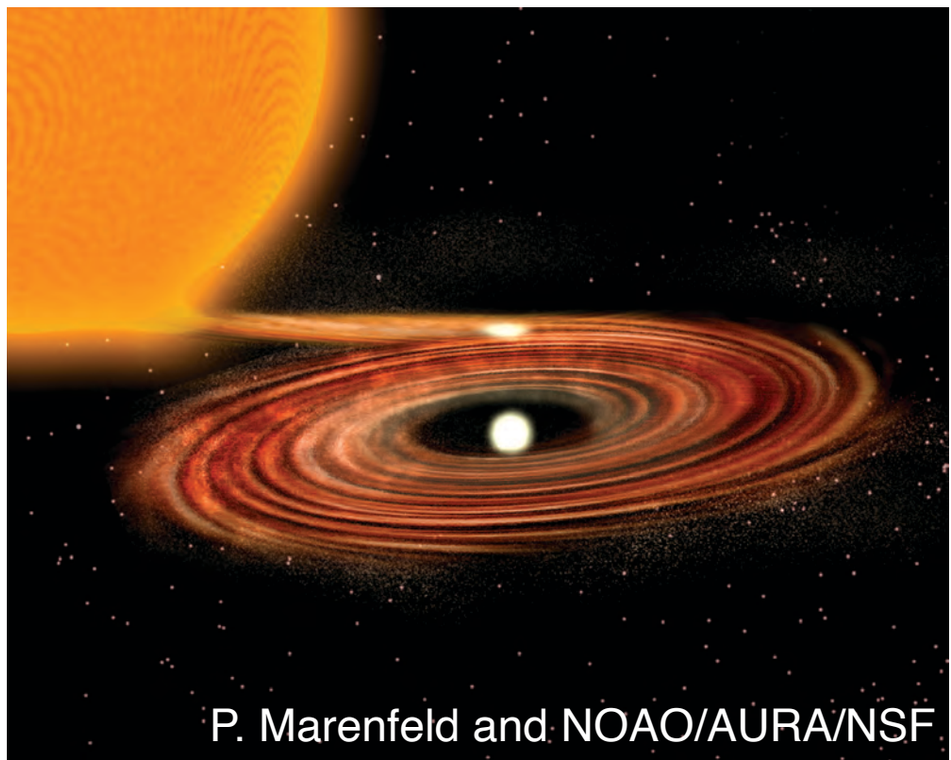
υ: frequency

$\dot{N}$: produce rate of ionizing photons

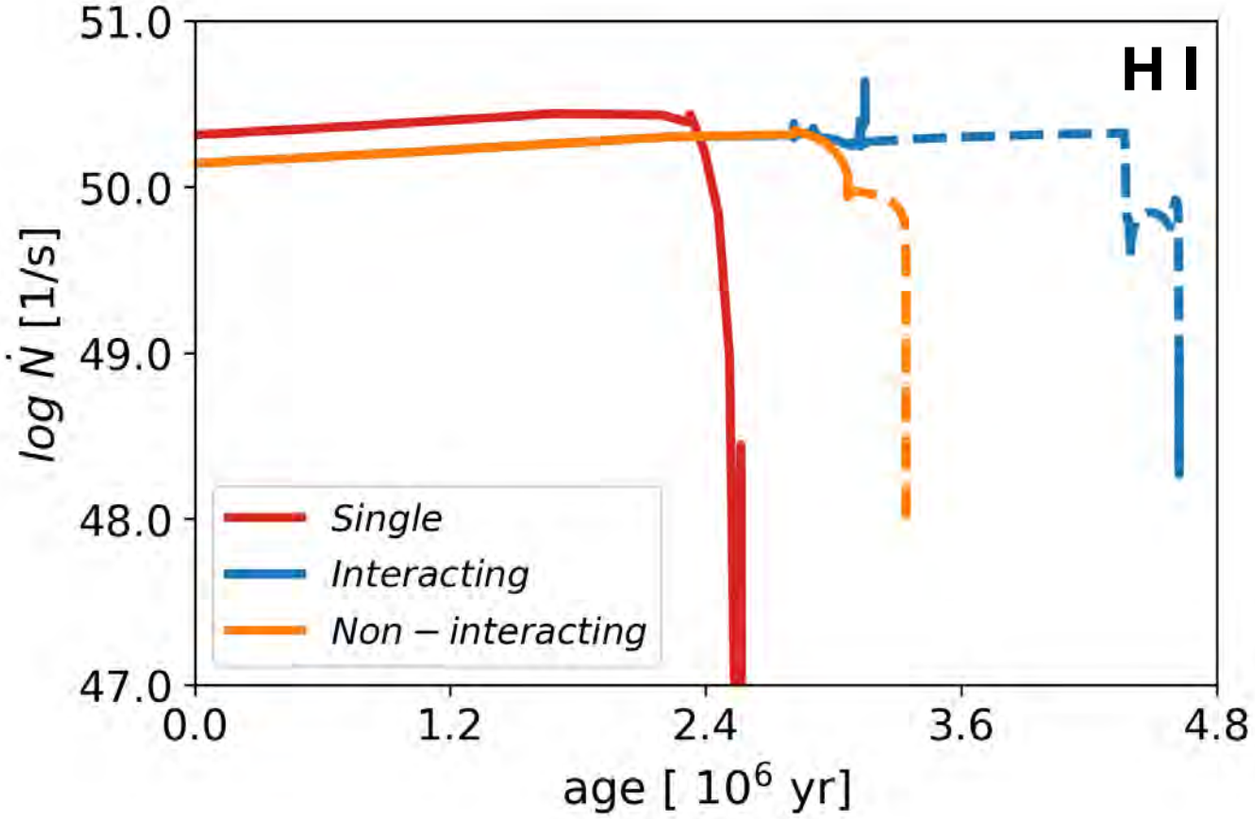
R: radius of star

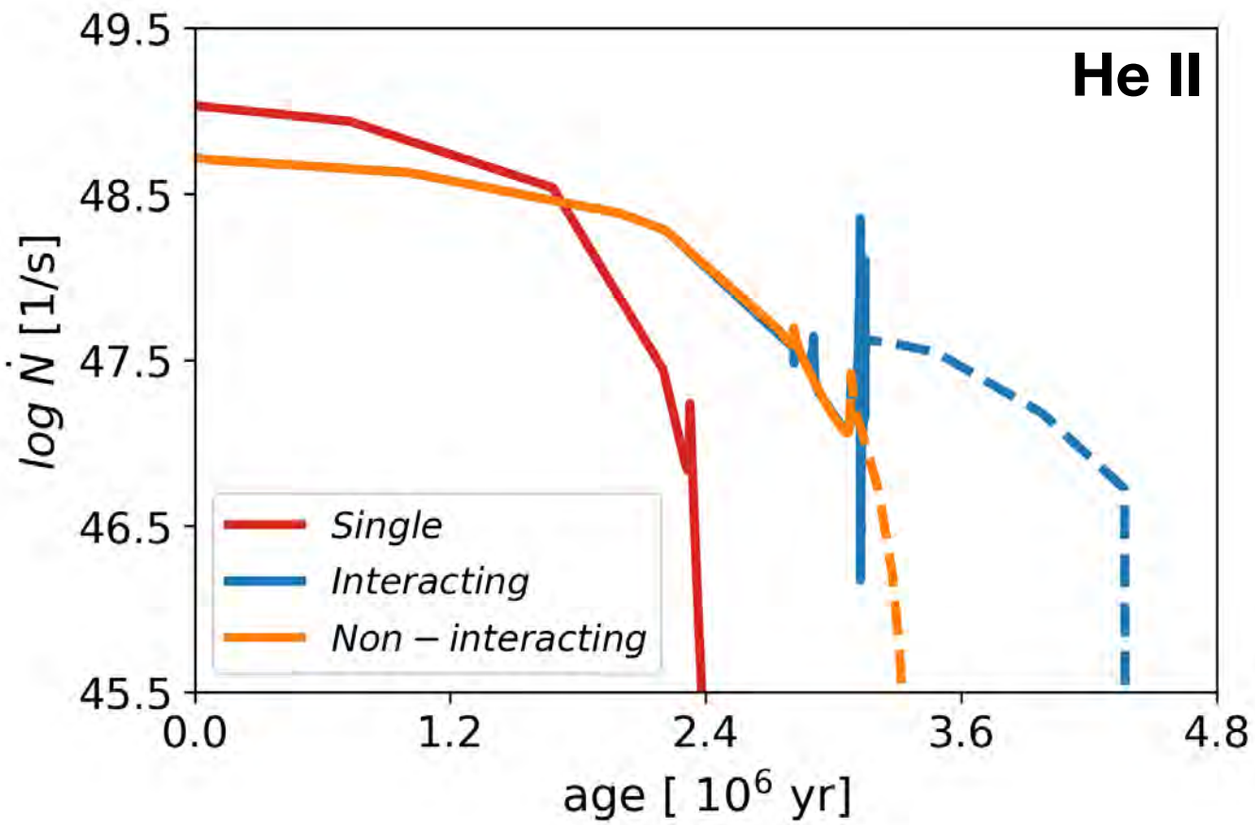
Numerical setup

- Donor star mass (M_1): $10M_\odot$~$100M_\odot$
- Mass ratio (q_2): 0.5 , 0.8
- Separation (a): $100R_\odot$~$1000R_\odot$
- Metallicity (Z): 0 , $0.001Z_\odot$, $0.01Z_\odot$



UV emissions from Pop III stars



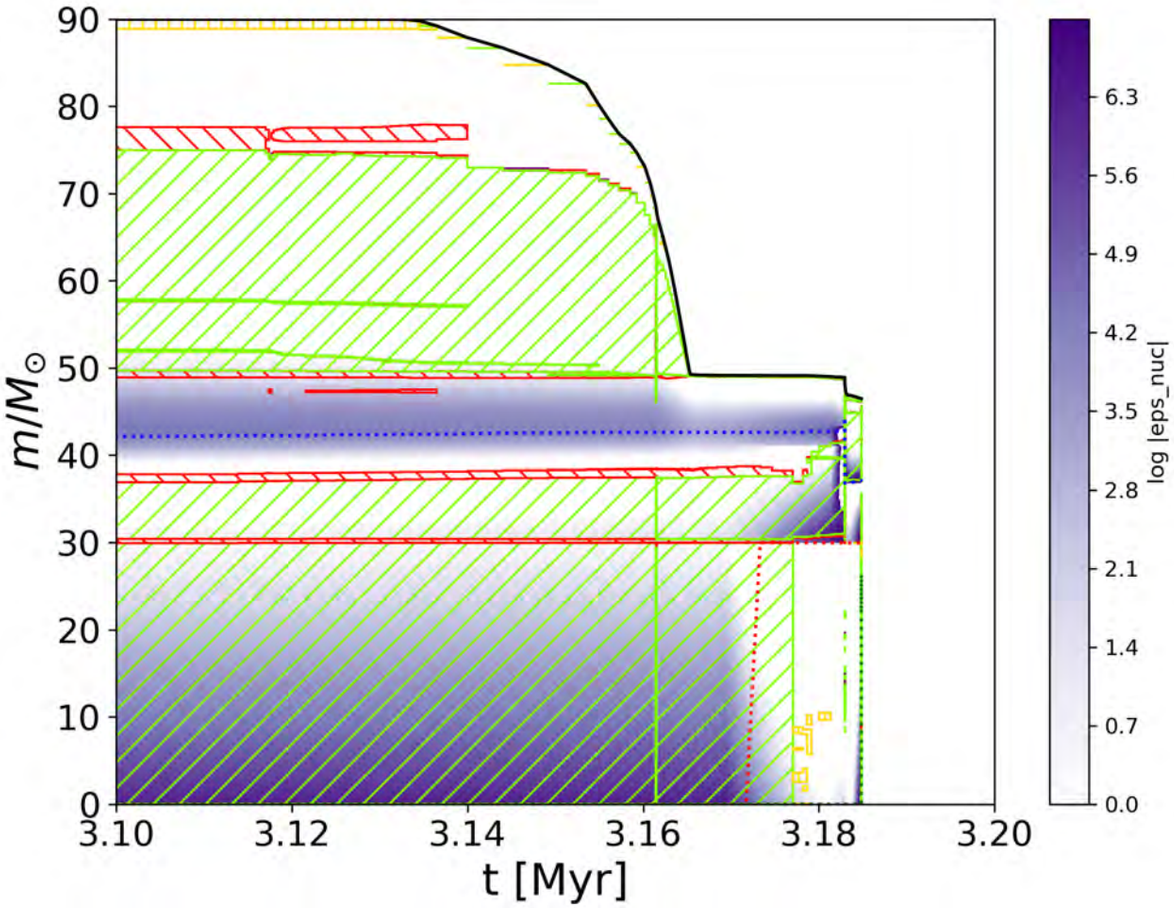


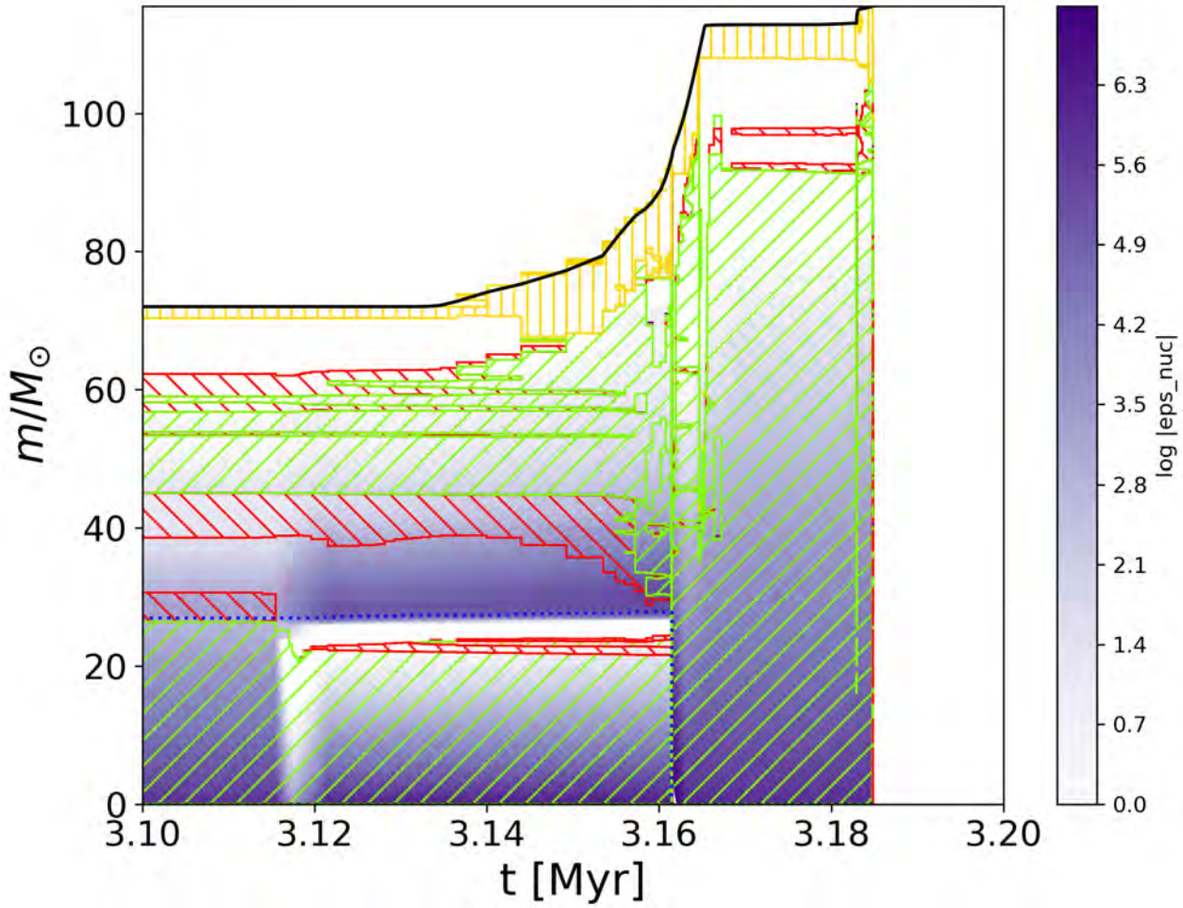
$M_1 = 90M_\odot$ $a_I = 100R_\odot$

$M_2 = 72M_\odot$ $a_{NI} = 900R_\odot$

	H I	He II
S	1.91 X 10^{64}	4.57 X 10^{62}
I	1.75 X 10^{64}	3.02 X 10^{62}
NI	1.69 X 10^{64}	3.01 X 10^{62}
I*	2.56 X 10^{64}	3.11 X 10^{62}
NI*	1.77 X 10^{64}	3.01 X 10^{62}

Kippenhahn diagram





Convective mixing

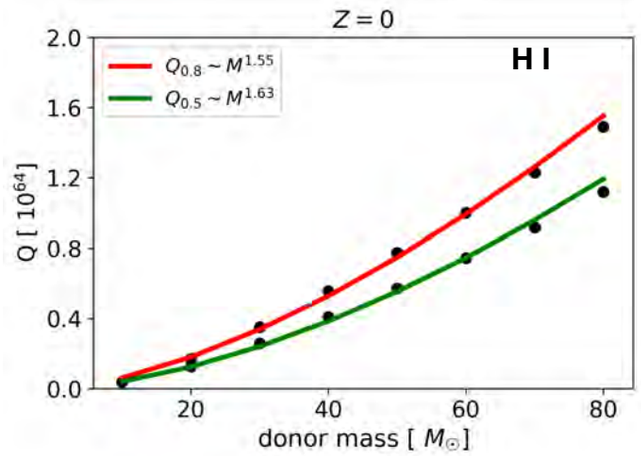
Semiconvective mixing

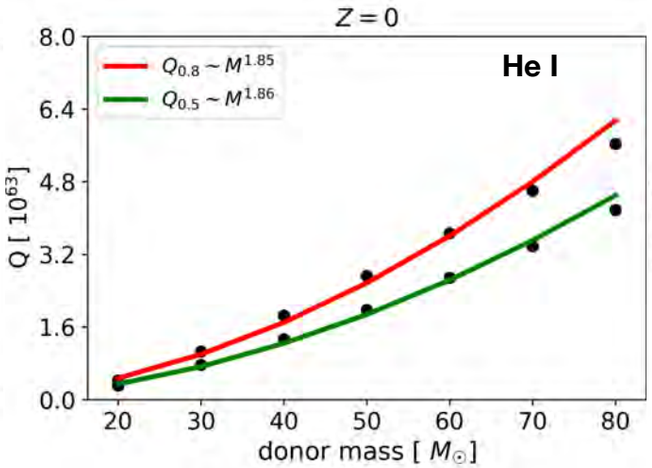
Thermohaline mixing

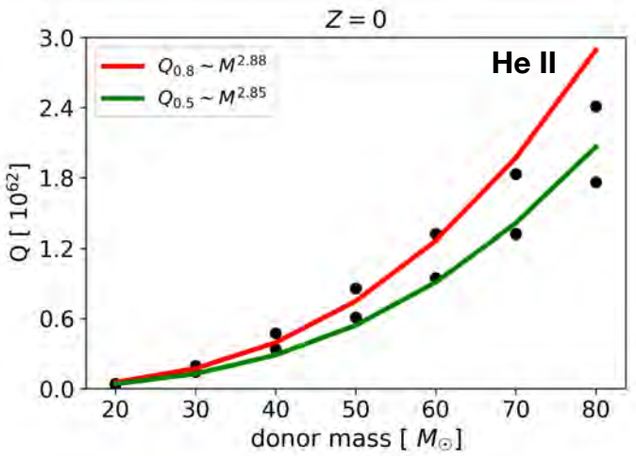
$M_1 = 90M_\odot$ **Z : 0**

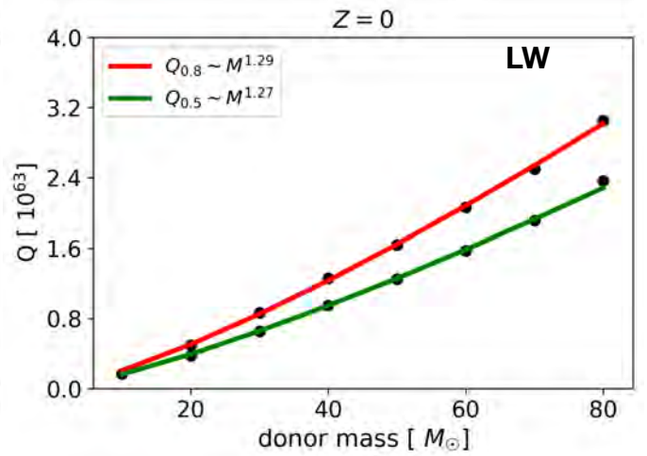
$M_2 = 72M_\odot$ **a : $100R_\odot$**

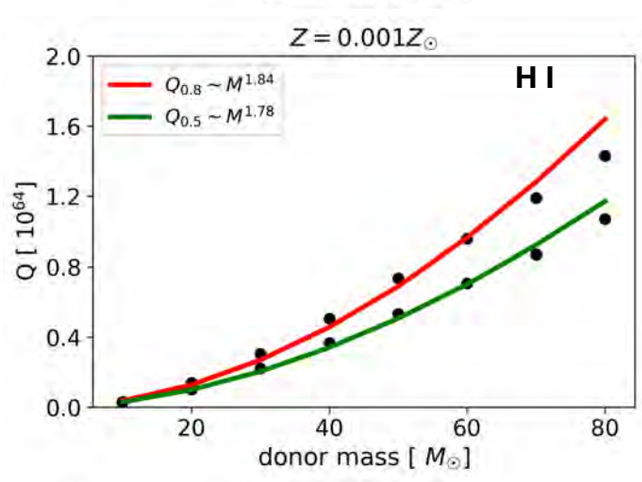
UV emissions and stellar mass relation

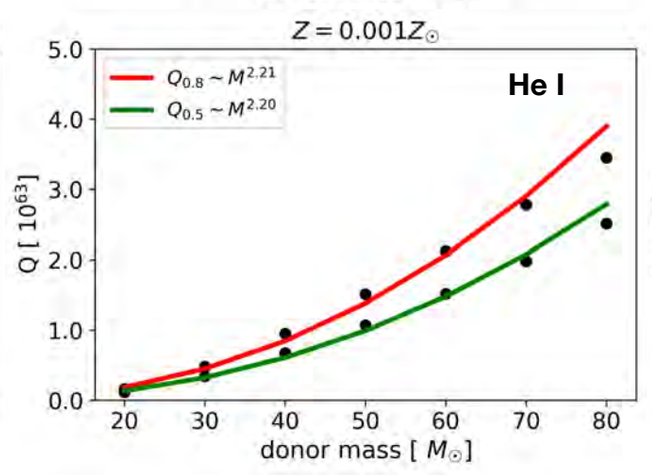


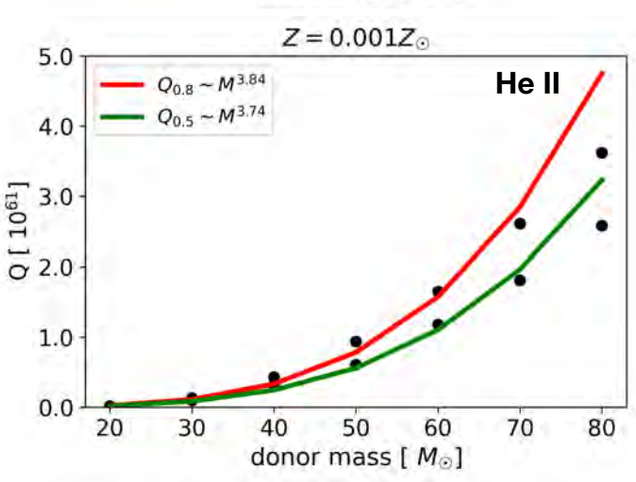


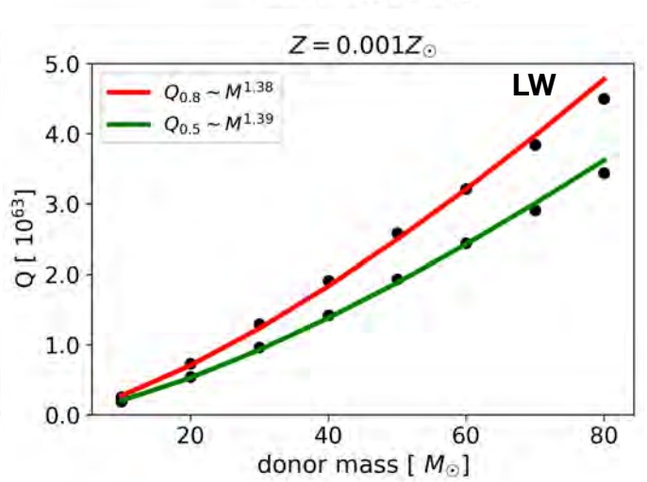


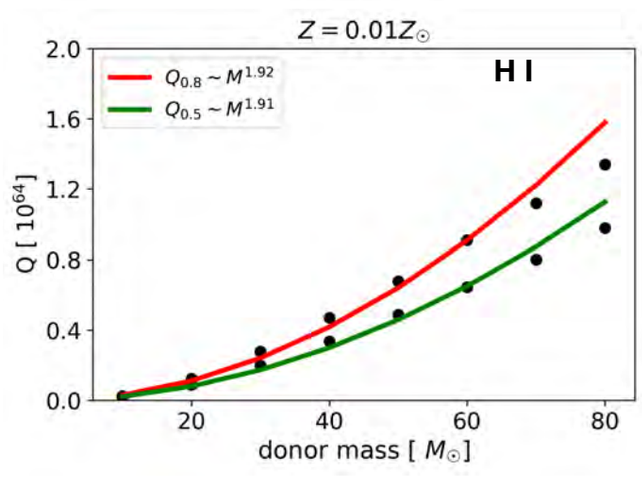


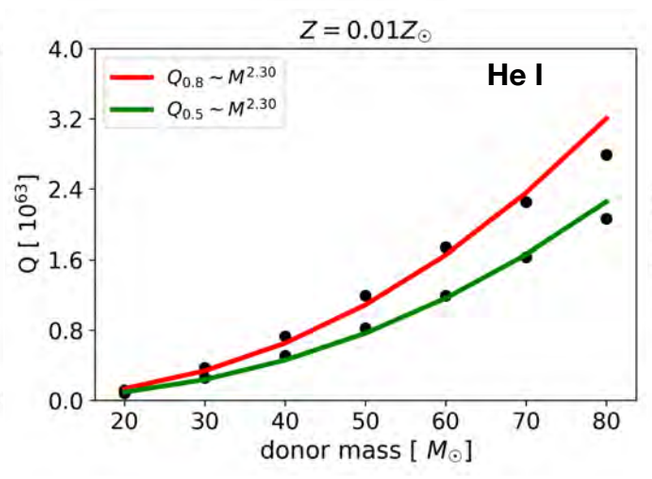


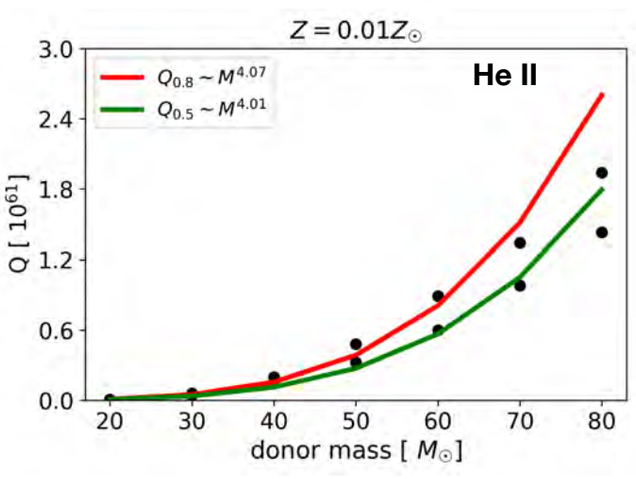


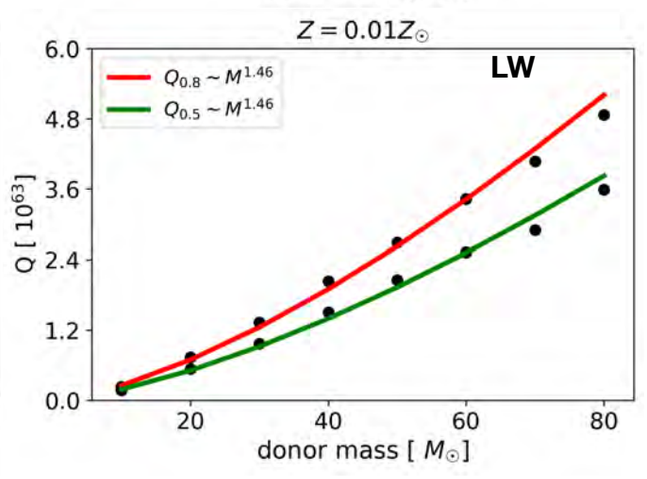






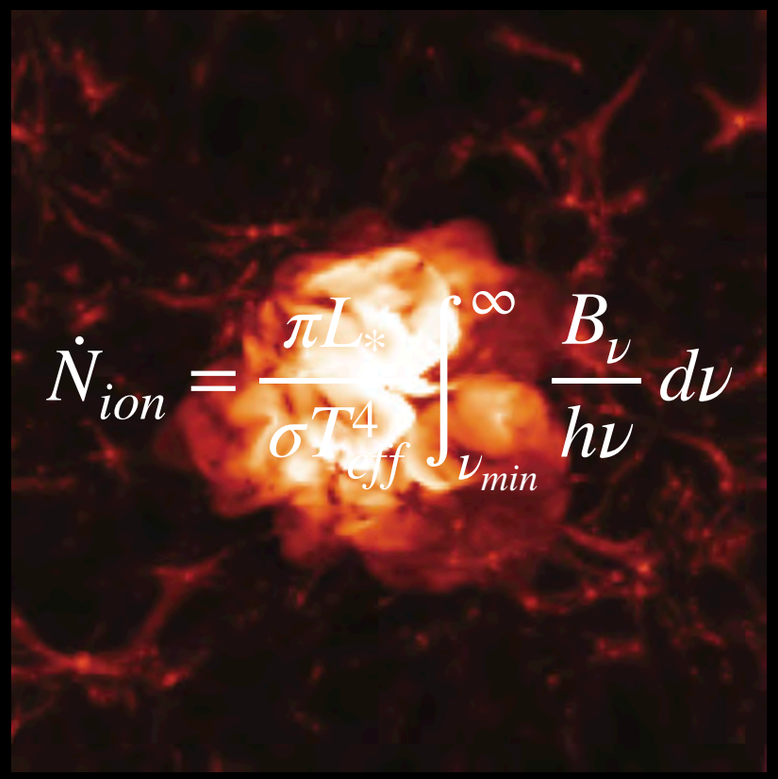






Single star

50M⊙

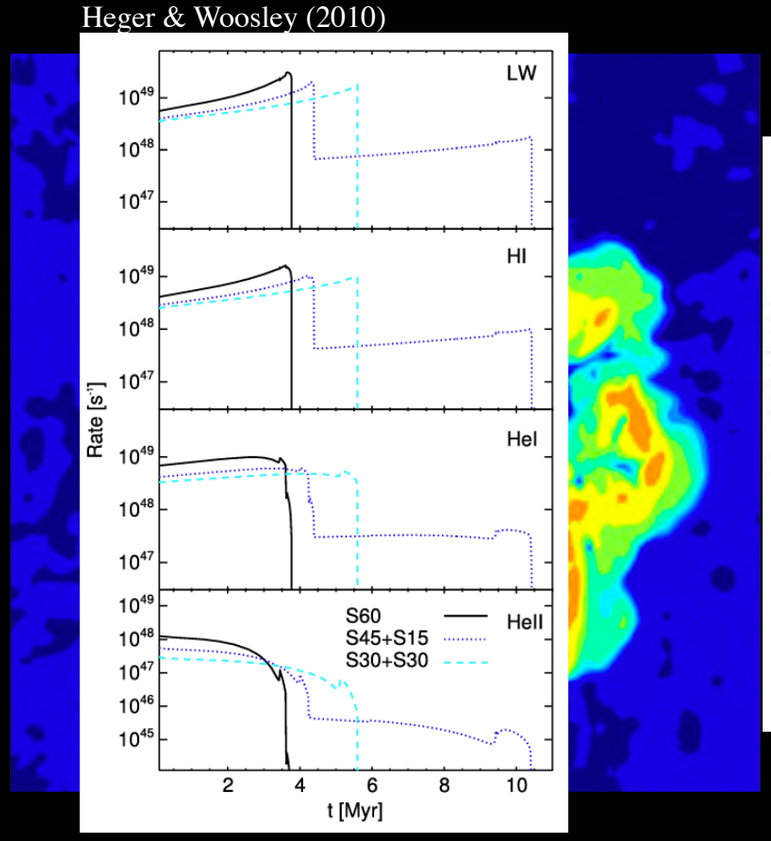


Greif+ (2009)

Noninteracting binary

45M⊙+15M⊙

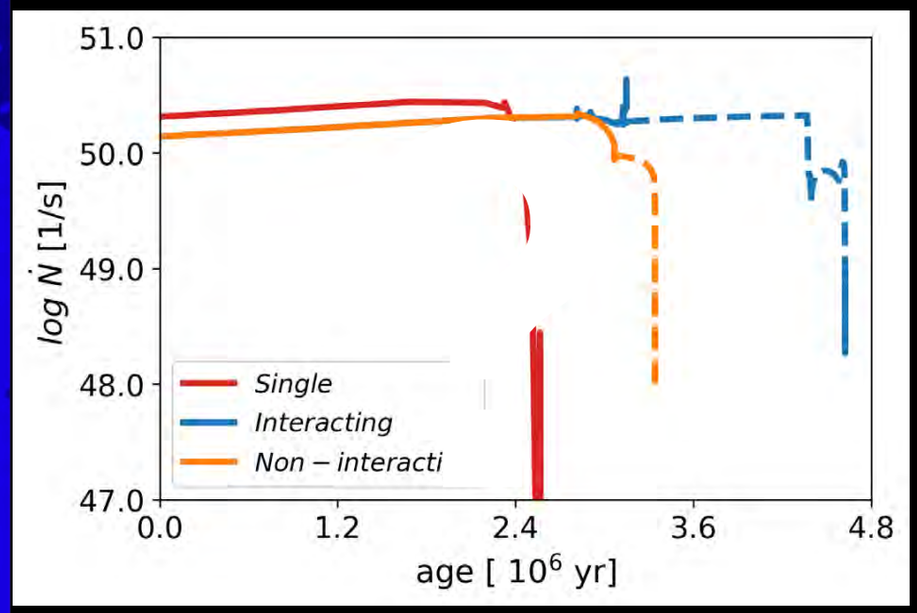
Heger & Woosley (2010)



Ken Chen+ (2015)

Interacting binary

90M⊙+72M⊙



Tsai+ (2023)

Summary

- Mass transfer process affects the binary star photon production rate and the photon yield of the companion star.

- The Kippenhahn diagram shows the mass transfer process change the structure of stars.

- The fitting power-law index increases with photon energy and metallicity.