Nuclear Signatures from Binary Stars

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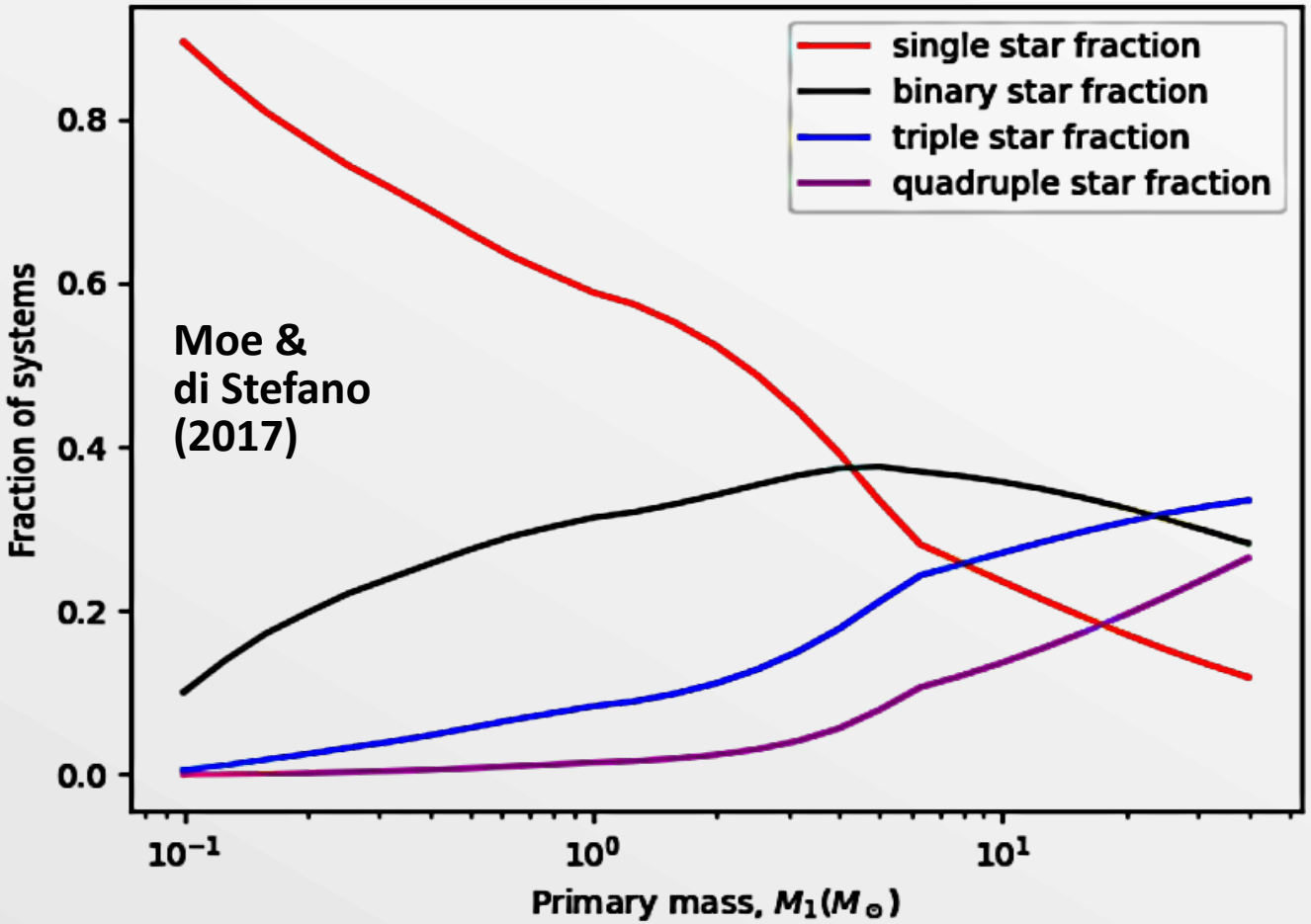
(South of LHR, west of LGW)

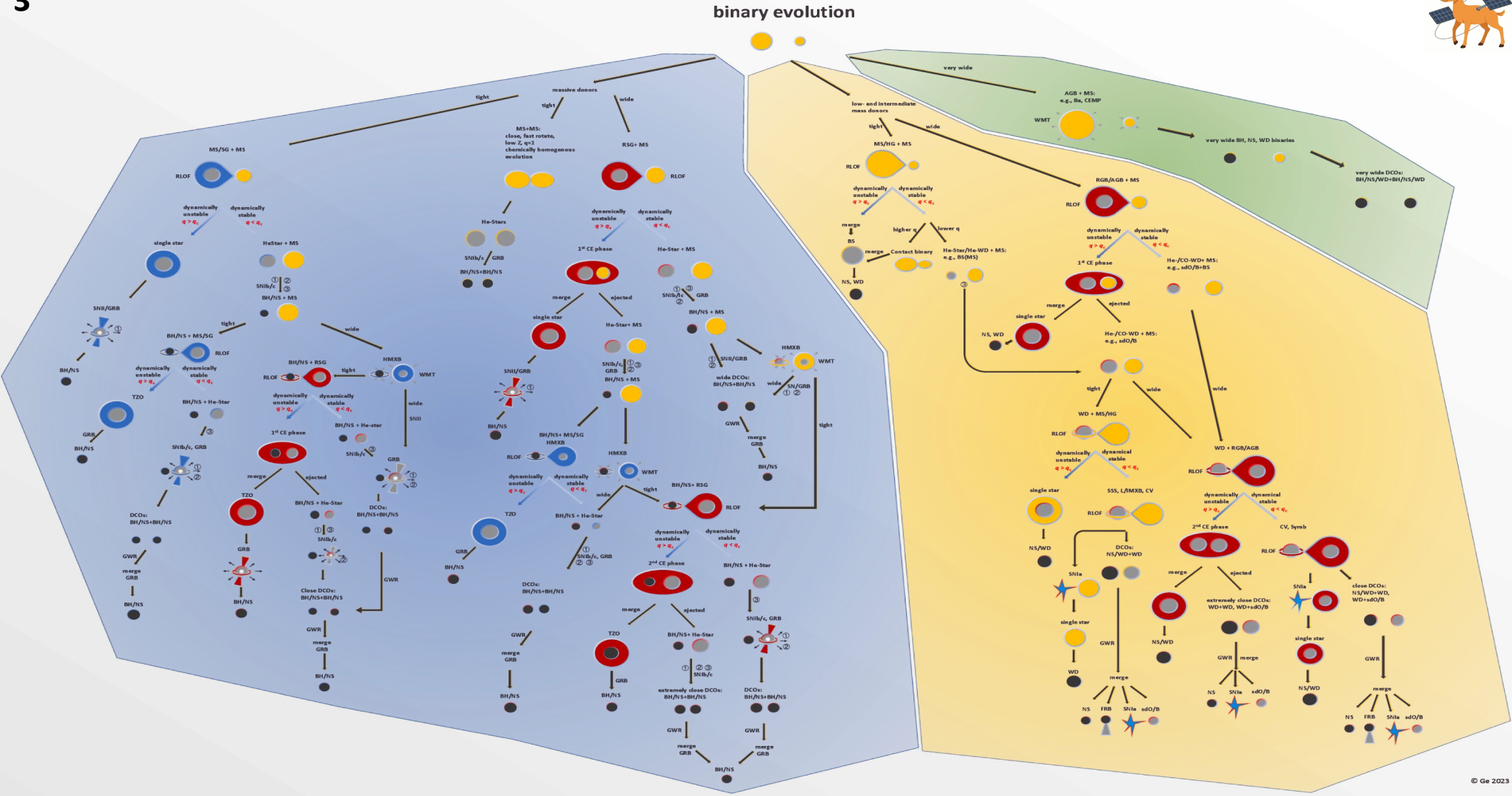
Beyond single stars



Triples
→ Hierarchical
binary + single or
single + binary

Quads similarly

Most stars are binaries or "binaries"



Chen, Liu & Han (2024)

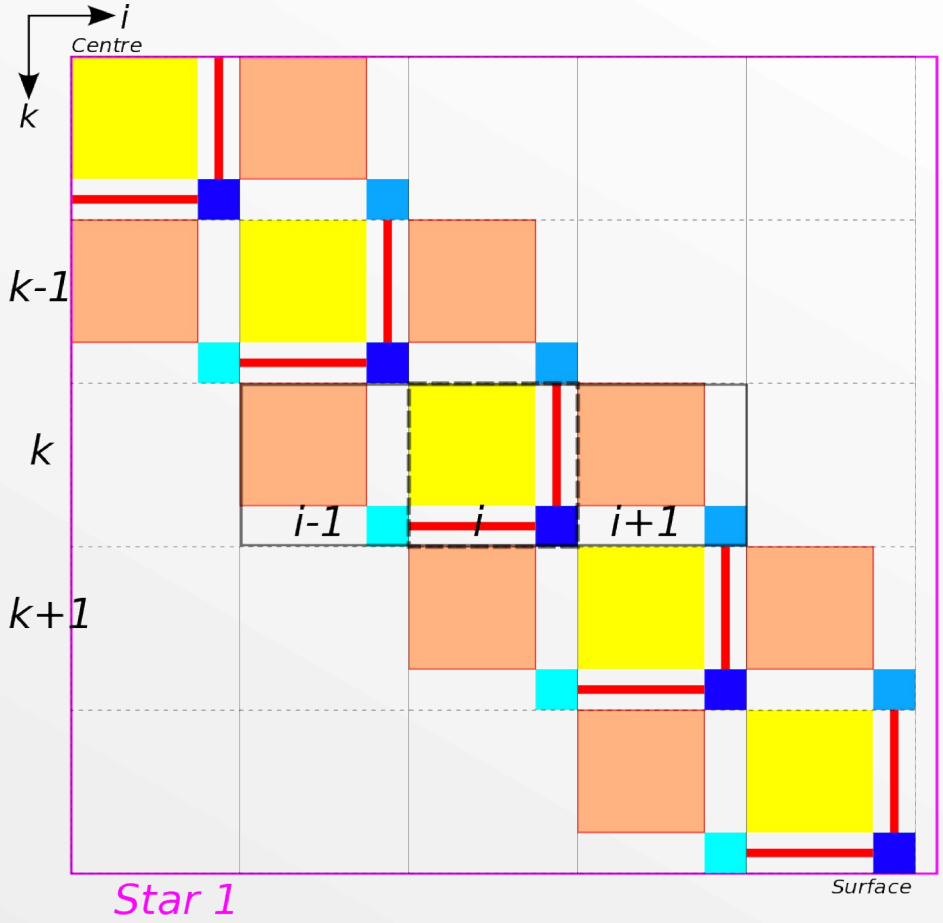
Tools 1: detailed stellar codes

e.g. **MESA**

Newton-Raphson +
Henyey inverter

4 Stellar structure eqs.
+ Nucleosynthesis
+ extras, e.g. mass loss

Runtimes: minutes-hours



Also: GARSTEC, STARS, GENEC, YREC,
STAREVOL, CESAM, PARSEC, ATON, MONSTAR, KEPLER, CLES, ASTEC, BEC …

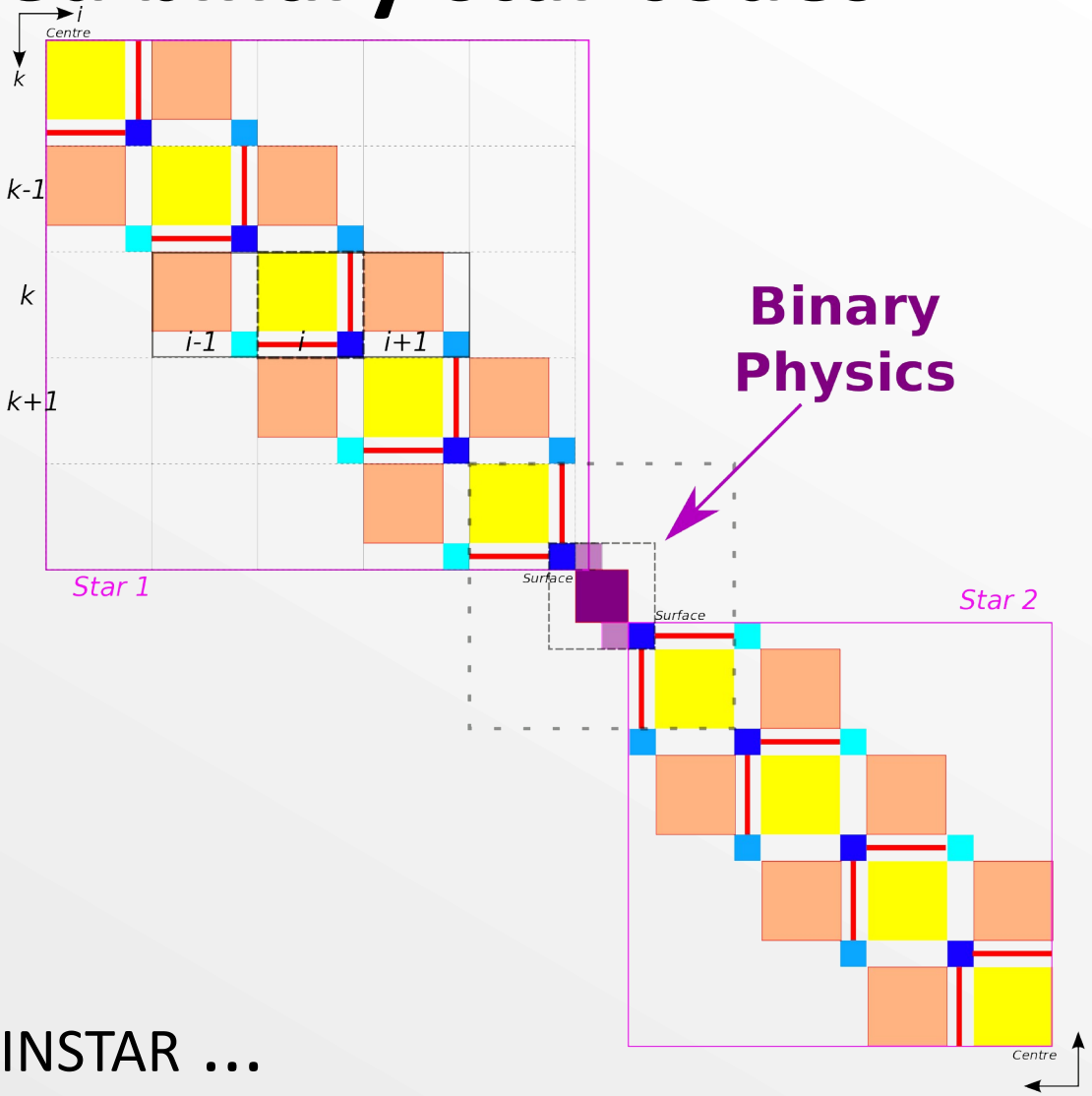
Tools 2: detailed binary-star codes

e.g. **MESA**

Newton-Raphson +
Henyey inverter

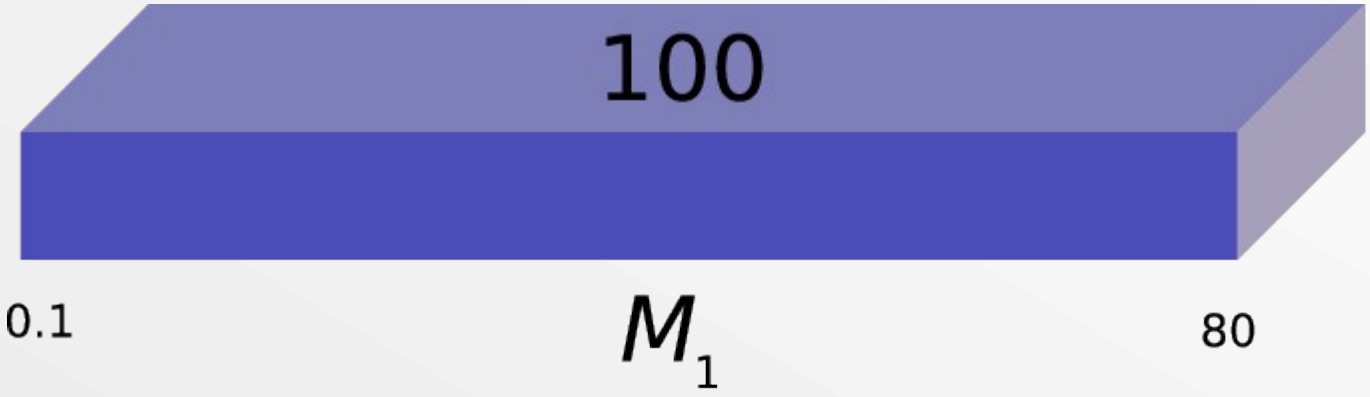
2 stars x
4 Stellar structure eqs.
+ Nucleosynthesis
+ interactions

Runtimes: >> hours

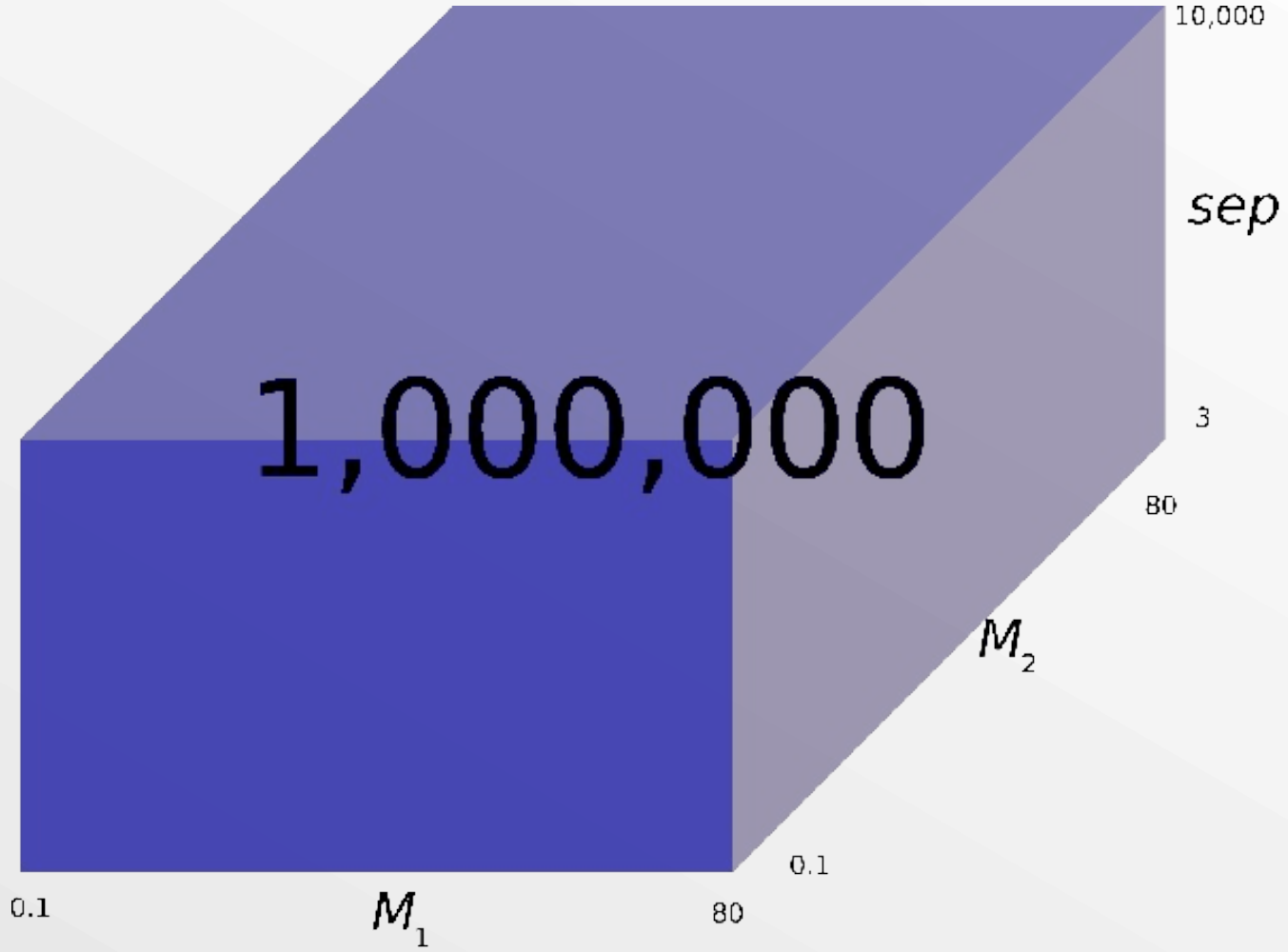


Also: BS/STARS/TWIN, BEC, BINSTAR …

Parameter space: single stars

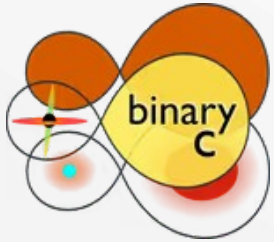


Parameter space: binary stars



Tools 3: synthetic binary-star codes

e.g. ***binary_c***

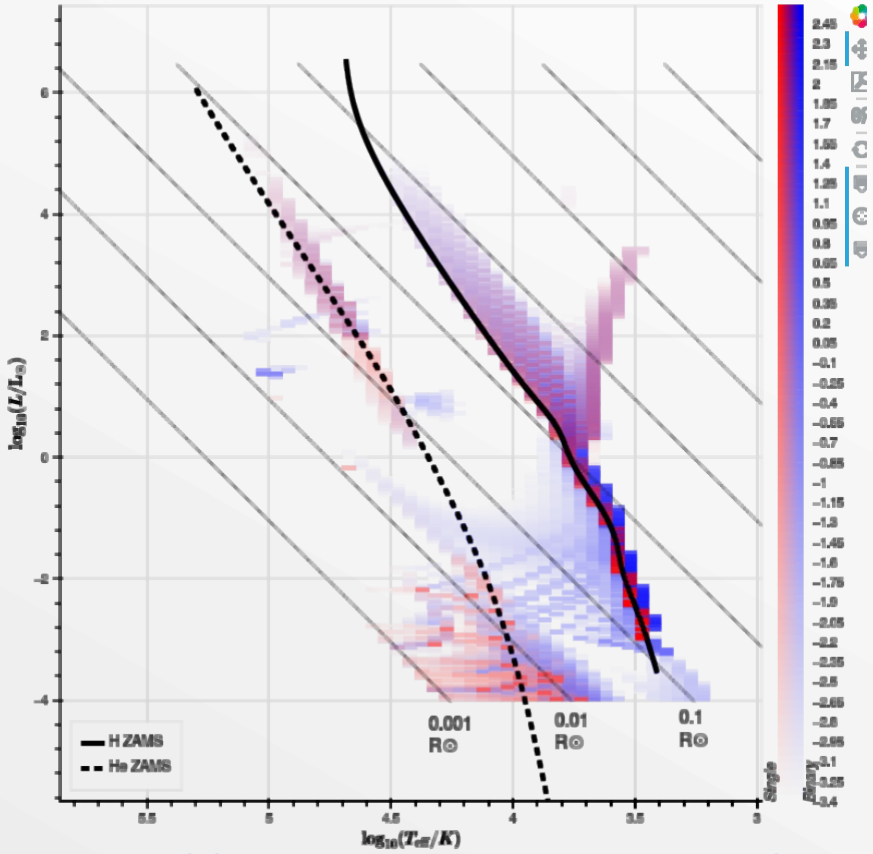


https://binary_c.gitlab.io/

Semi-analytic or
interpolated "structure"

→ population data
rates of things
numbers of things
binary_c ↔ nucsyn

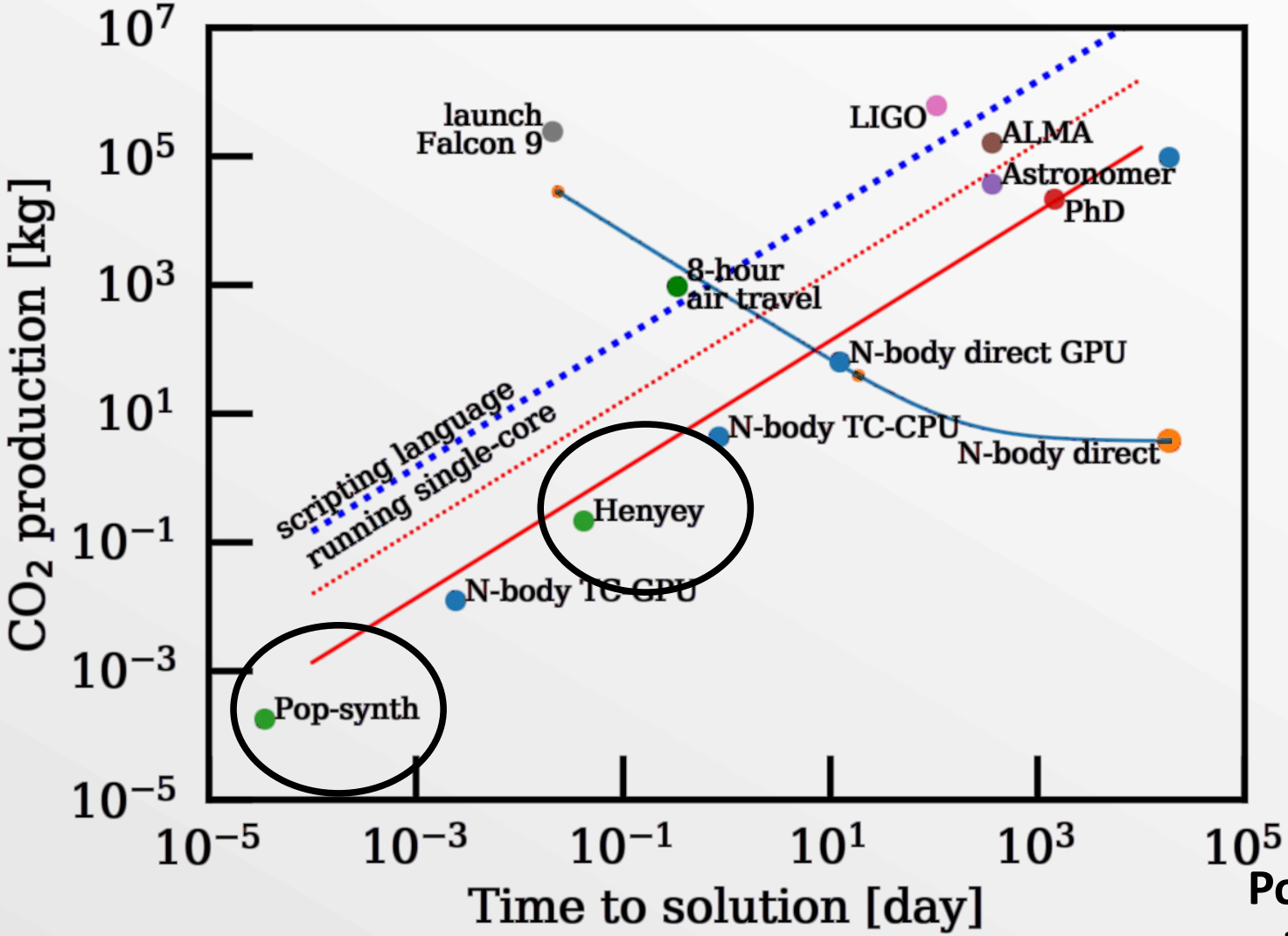
Runtimes: ~ seconds/star
Population ~ 24h

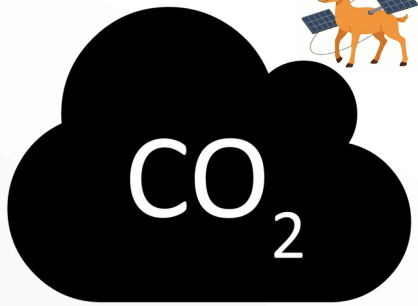


https://r-izzard.surrey.ac.uk/HRD/

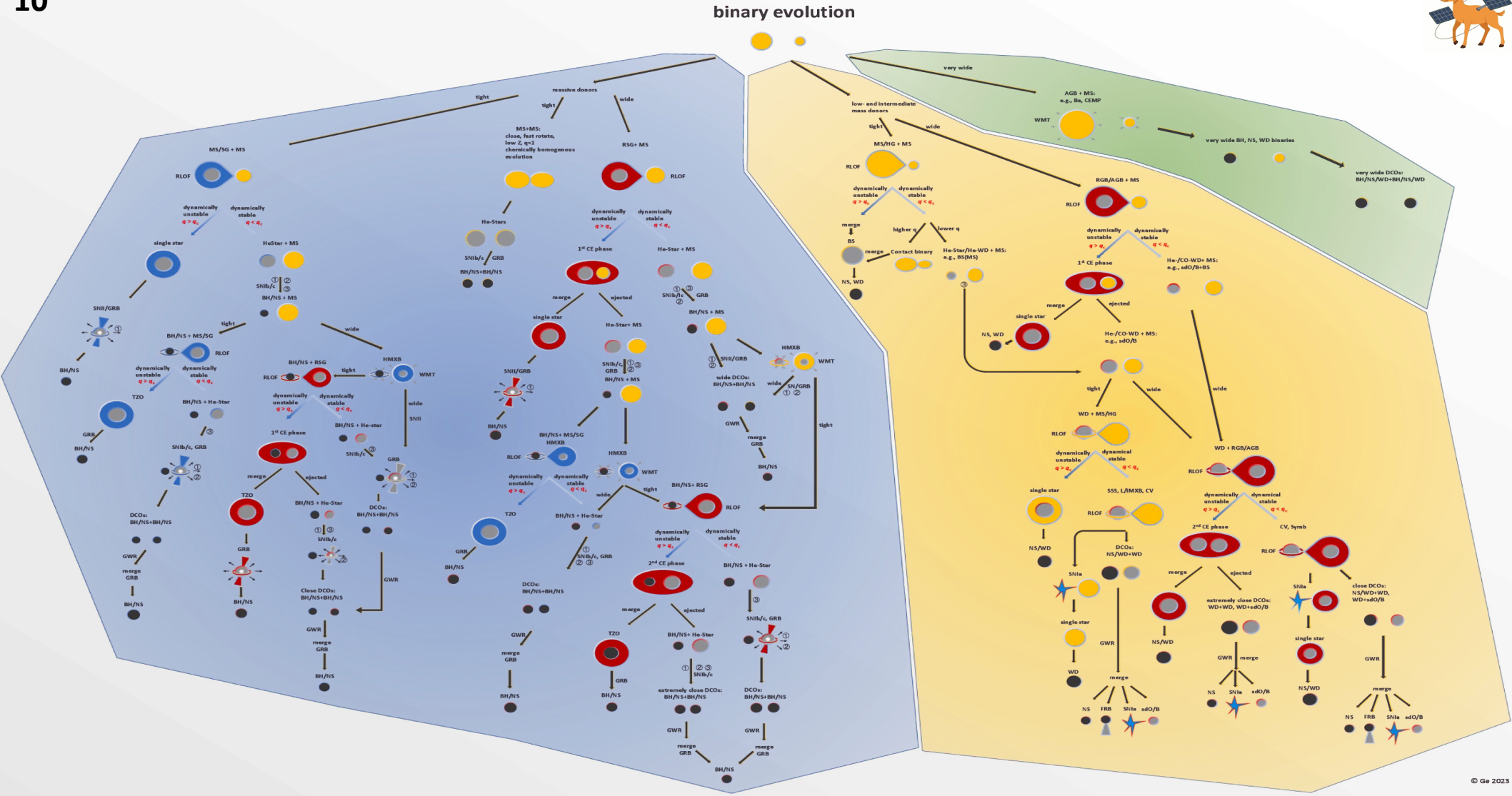
Also: BSE, SeBa, ComBinE, COMPAS

Costs: energy and carbon





Portegies-Zwart 2020
arXiv 2009.11295



Chen, Liu & Han (2024)

Accretion on compact objects

$$k_B T \sim \frac{GM}{R} \rightarrow T \sim 3 \times 10^8 \,\mathrm{K} \left(\frac{M}{\mathrm{M}_\odot}\right) \left(\frac{10^9 \,\mathrm{cm}}{R}\right)$$

- White dwarfs: $M \sim 0.6 - 1 \,\mathrm{M}_\odot, R \sim 10^9 \,\mathrm{cm}$

$$k_B T \sim 50 \,\mathrm{keV} \qquad T \sim \text{few} \times 10^8 \,\mathrm{K}$$

- Neutron stars: $M \sim 1.4 \,\mathrm{M}_\odot, R \sim 10^6 \,\mathrm{cm}$

$$k_B T \sim 50 \,\mathrm{MeV} \qquad T \sim \text{few} \times 10^{11} \,\mathrm{K}$$

Disc accretion on compact objects

$$\sigma T^4 \sim \frac{GM\dot{M}}{R^3}$$

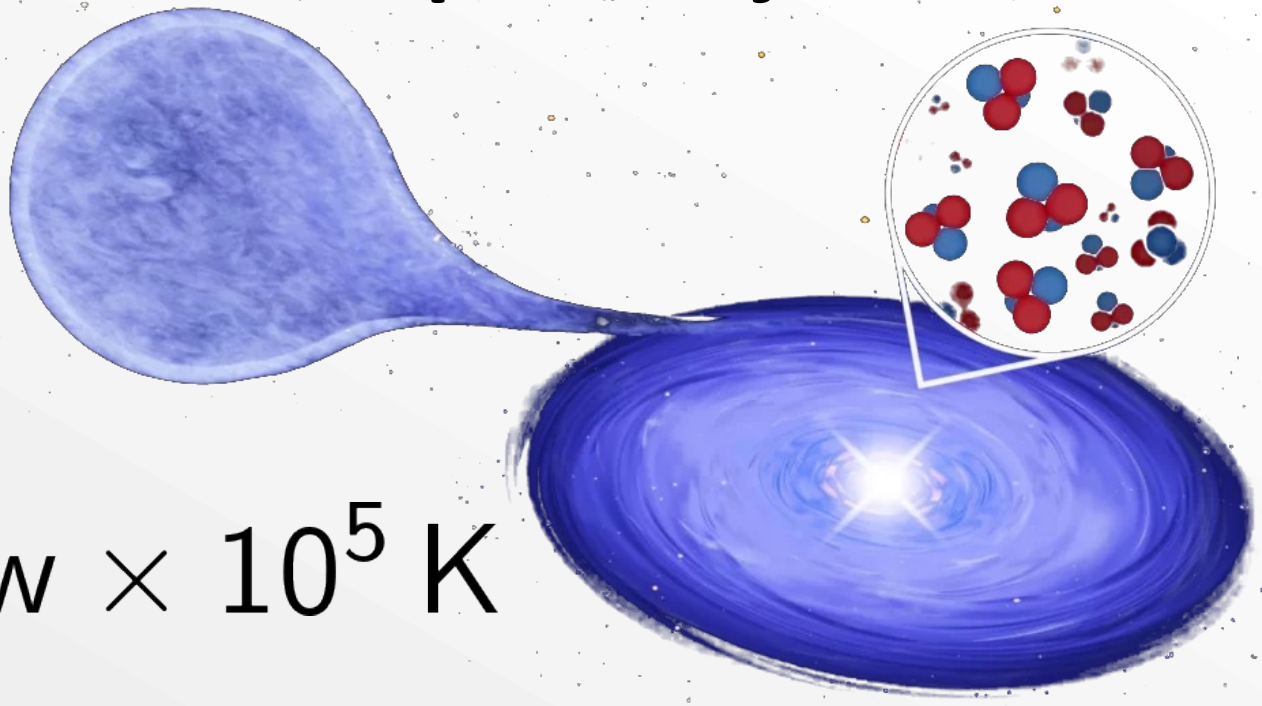


Image: ESO

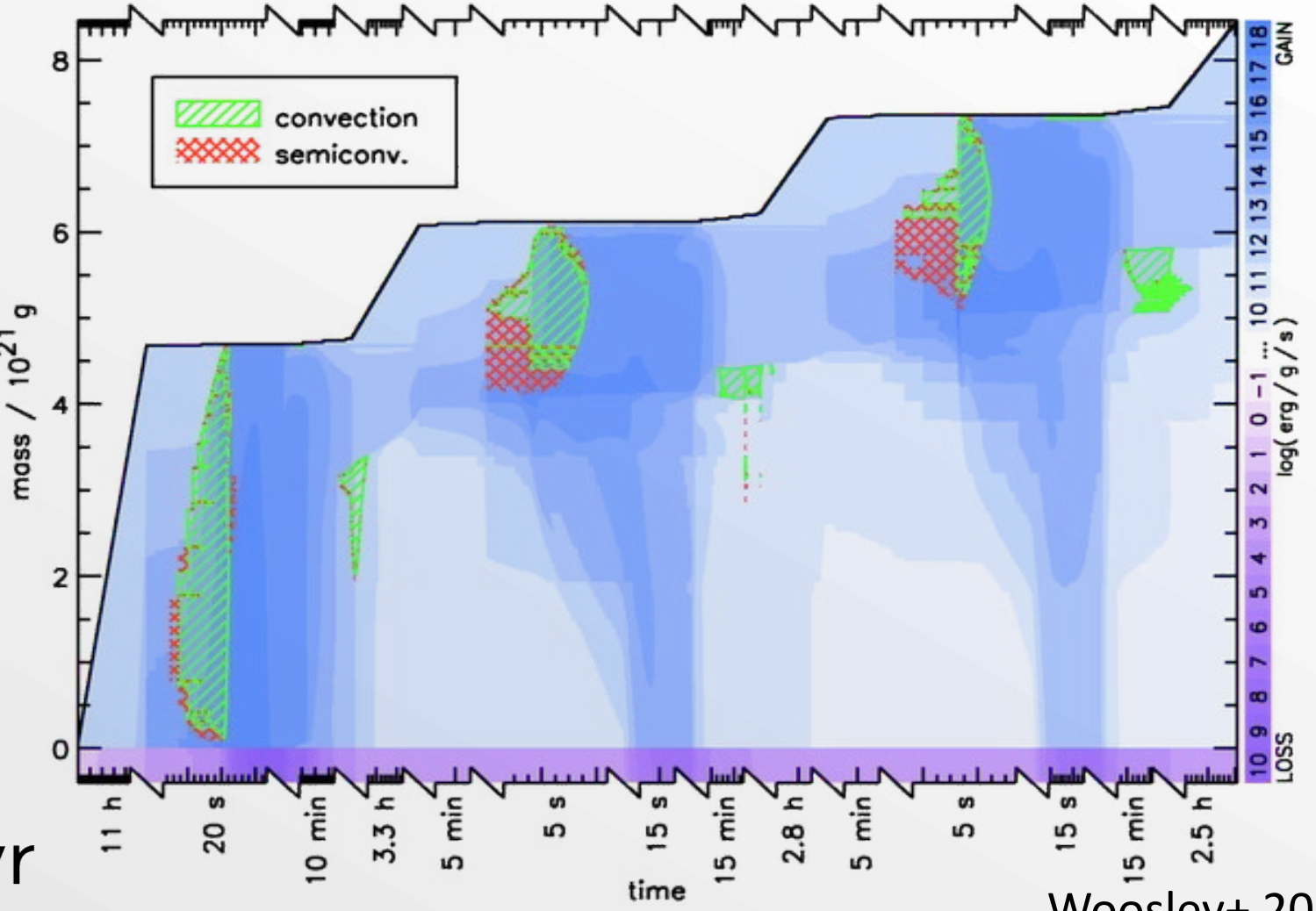
- White dwarfs:

$$T \sim \text{few} \times 10^5\ \text{K}$$

- Neutron stars/ black holes:

$$T \sim \text{few} \times 10^7\ \text{K}$$

Accretion on NS → Thermonuclear Nucleosynthesis

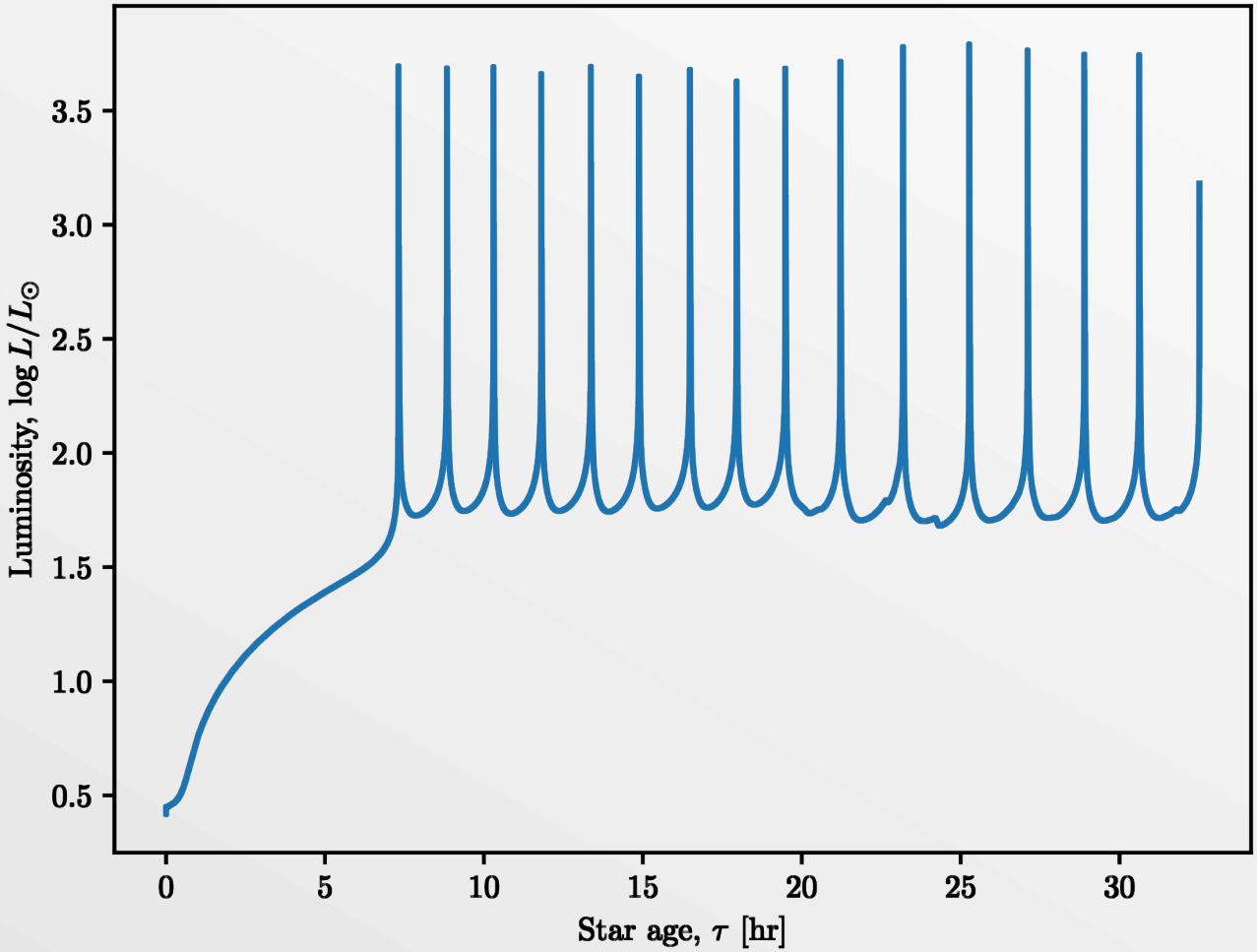


$1.4\,M_\odot$

$10^{-9}\,M_\odot/yr$

Woosley+ 2003

Accretion → Nucleosynthesis

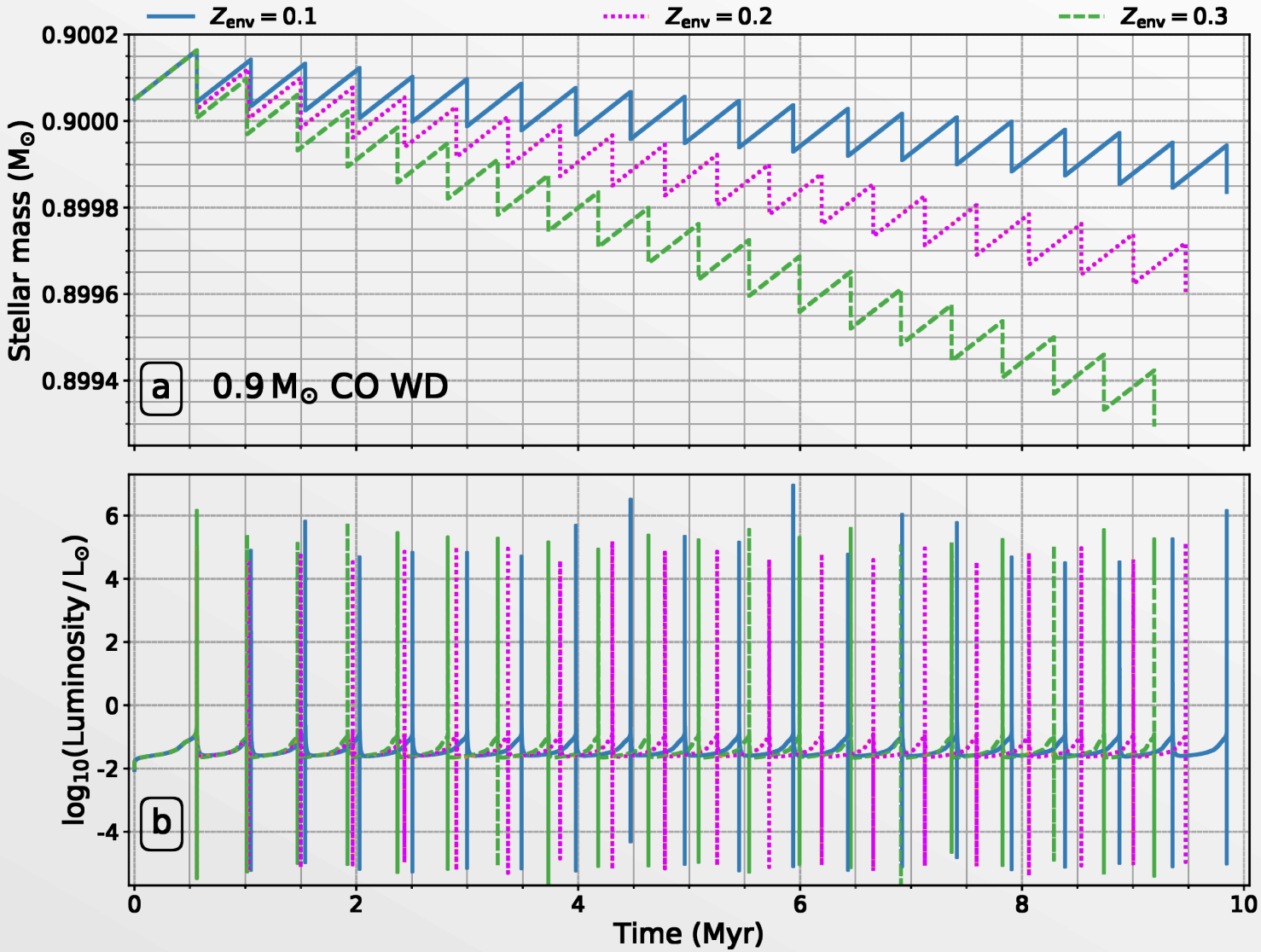


Made on my desktop PC with *MESA*

Taught in undergraduate computer labs

Mass mostly not lost!

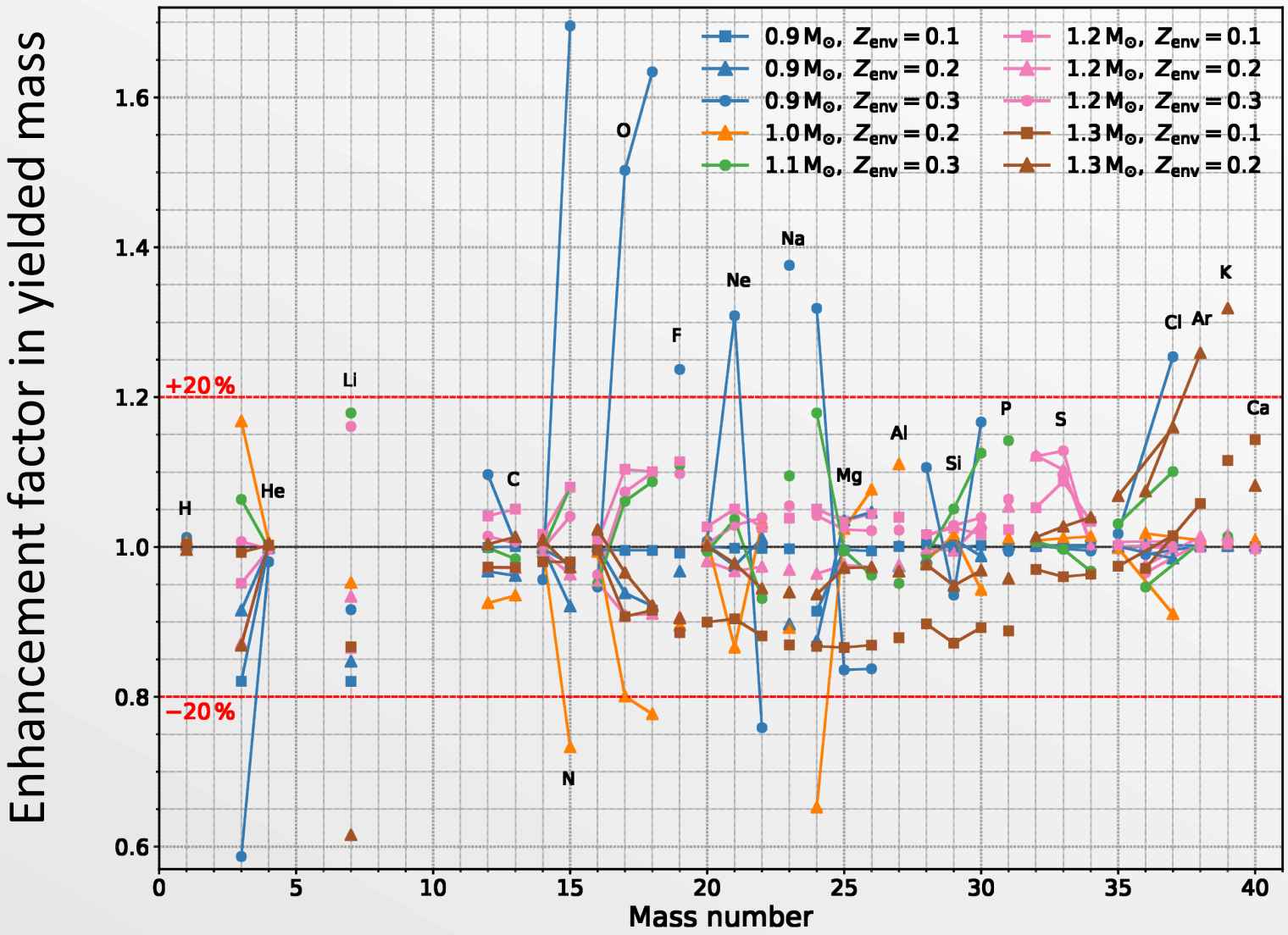
Lower mass stars: white dwarfs → novae



Accretion…?
Not really!

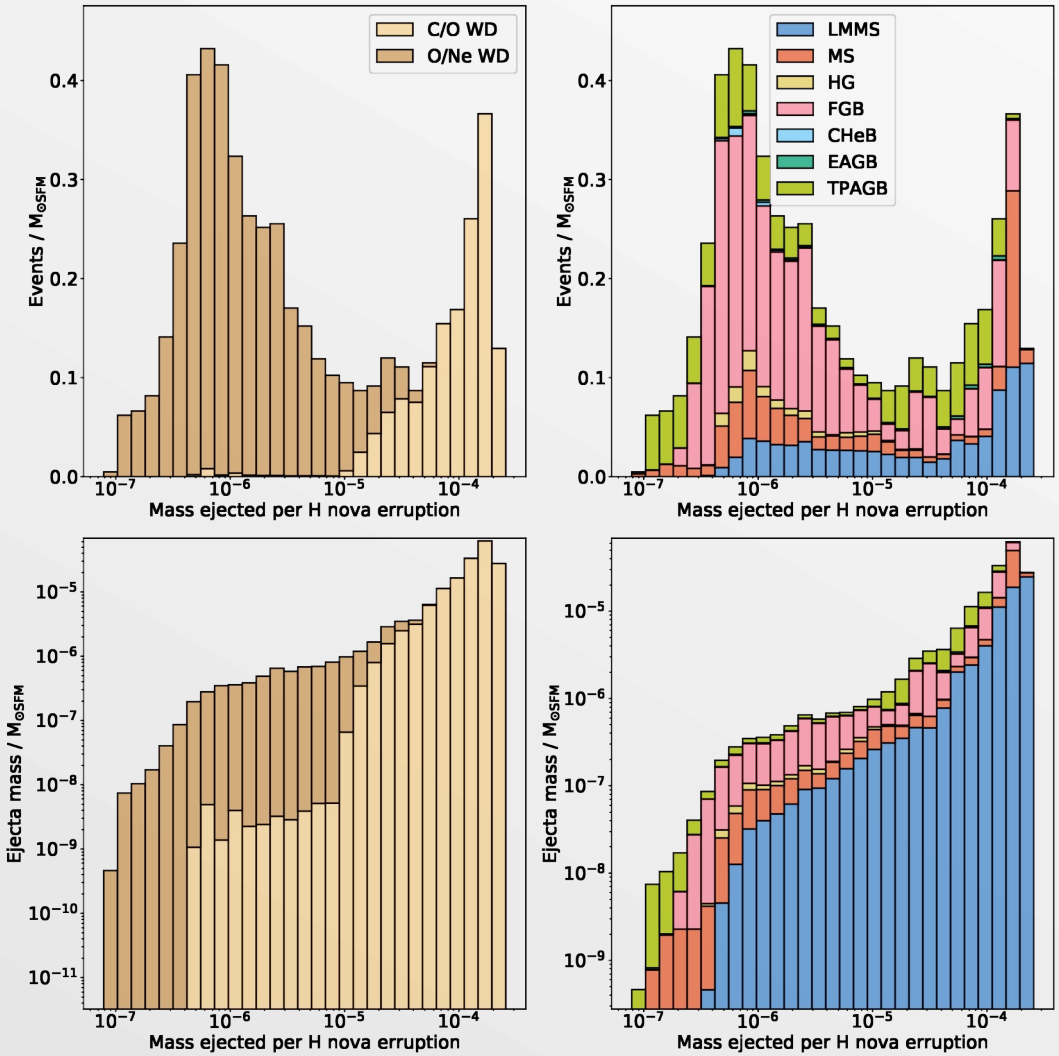
→ Type Ia supernovae?

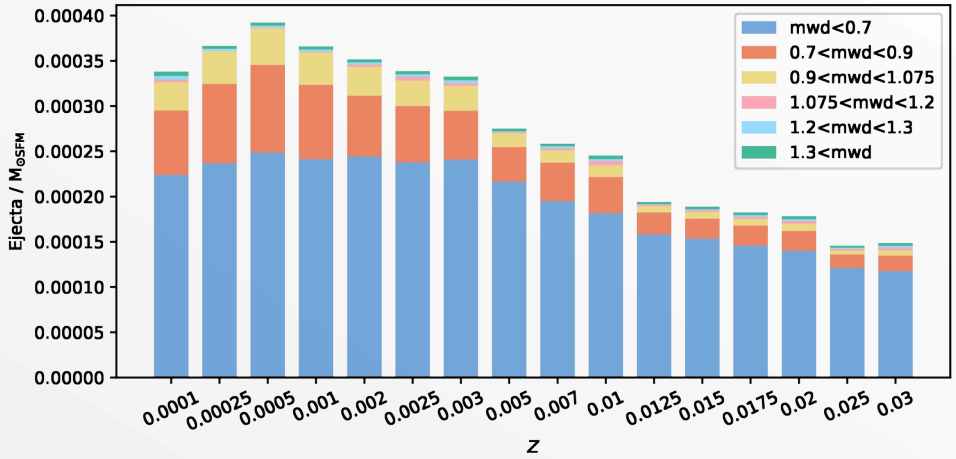
Novae → ^{7}Li, ^{13}C, ^{15}N, ^{17}O...



Arman Aryaeipour's PhD with **MESA**

Population novae with *binary_c*





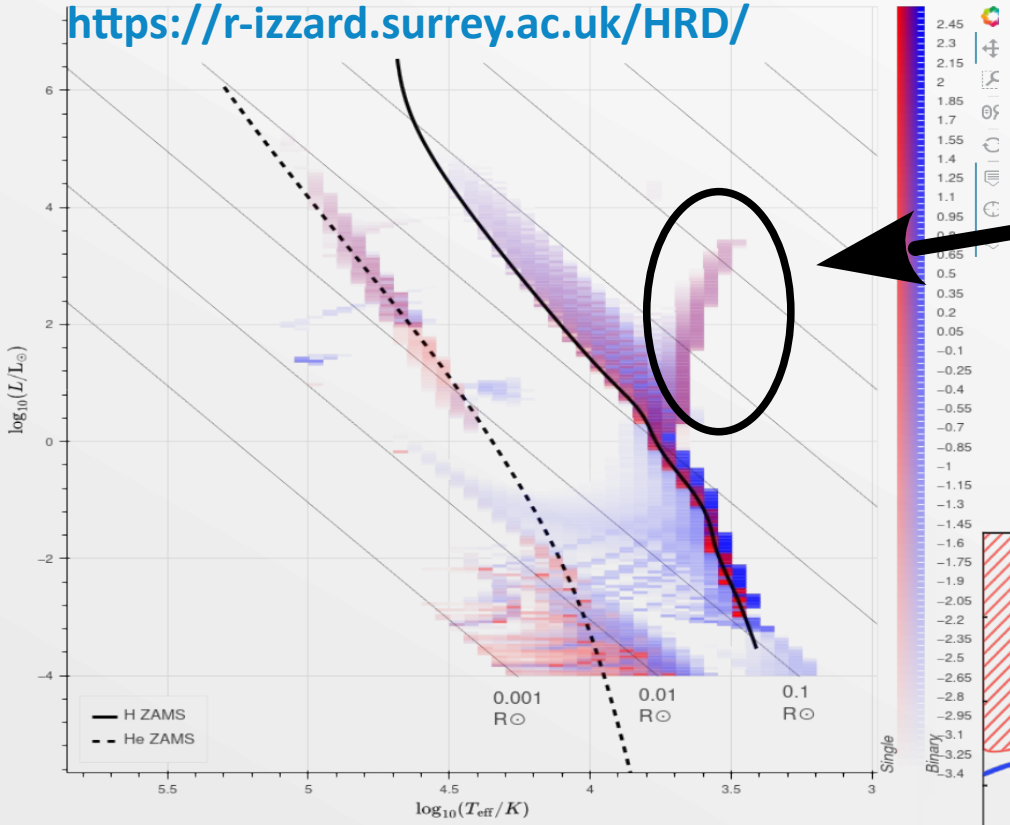
Metallicity dependence
→ **Galactic chemical evolution**

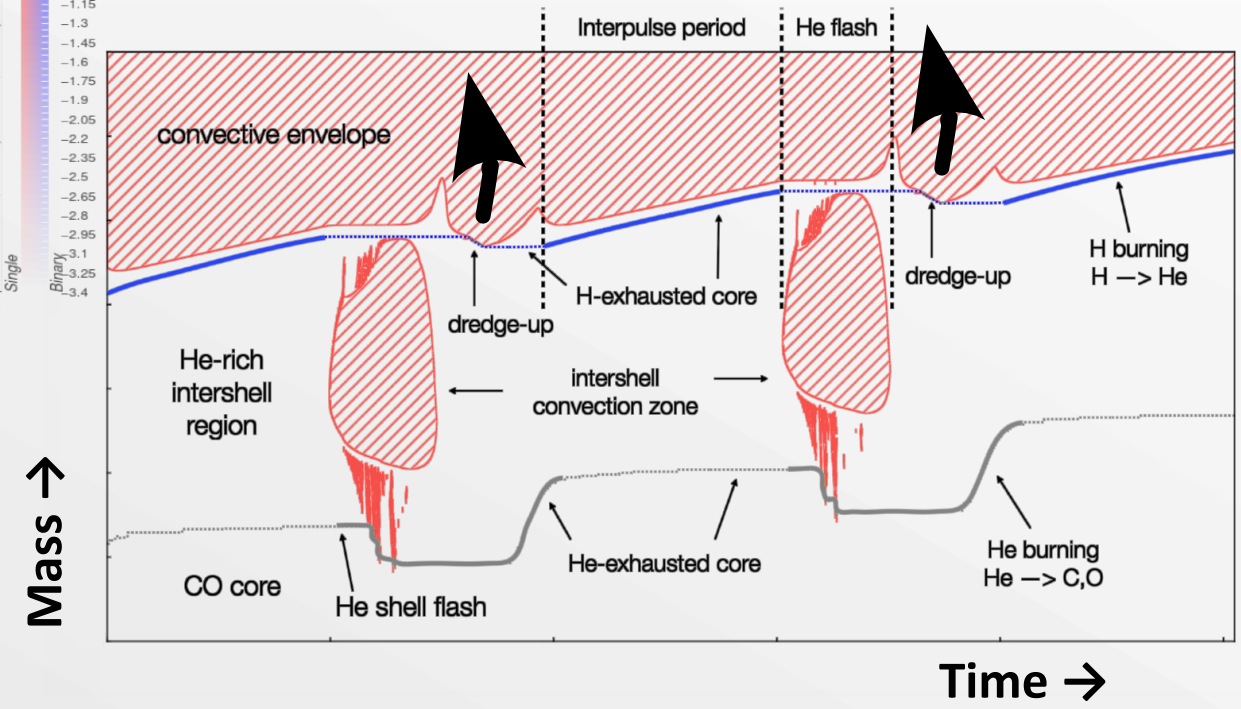
Kemp+ 2025

https://r-izzard.surrey.ac.uk/HRD/

Asymptotic Giant Branch

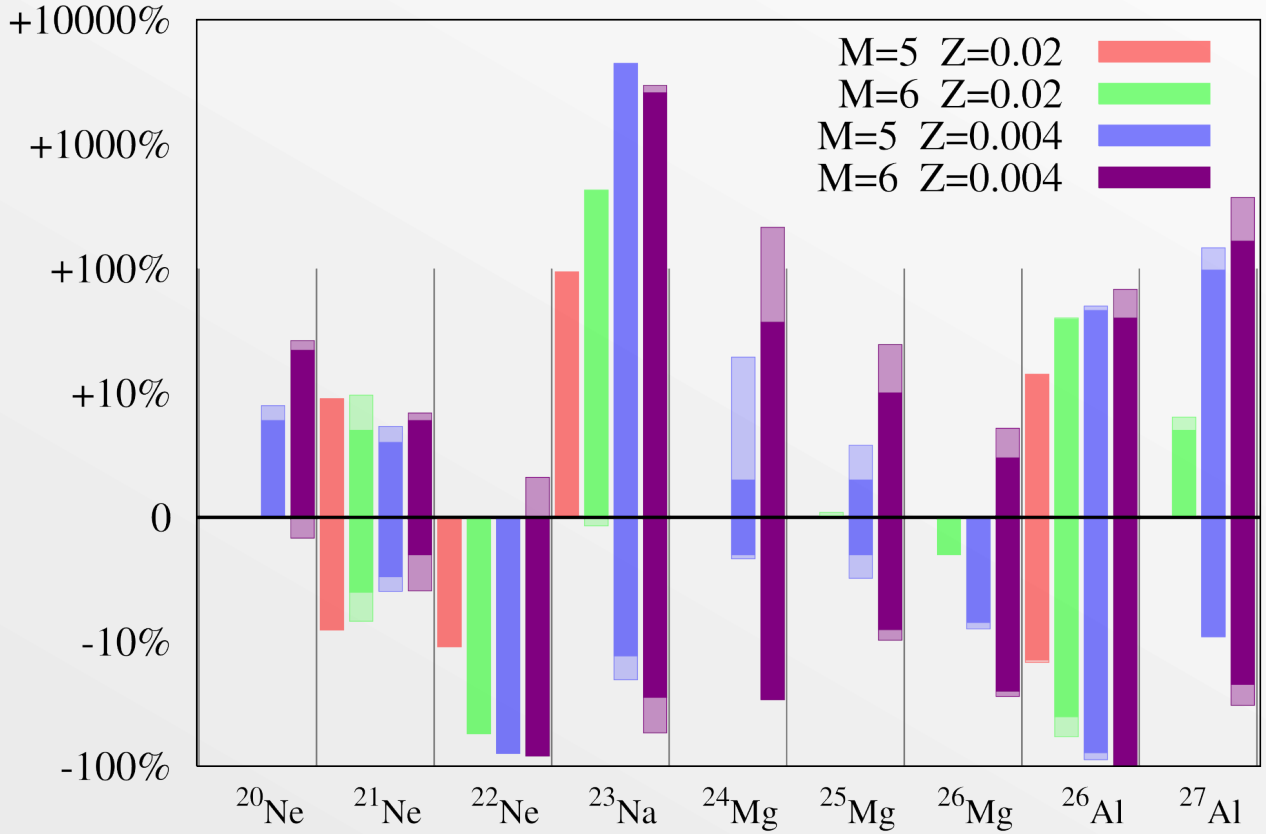
(AGB) stars: CO core
→ H + He burning in pulses
→ "classical" s-process





Convective envelope

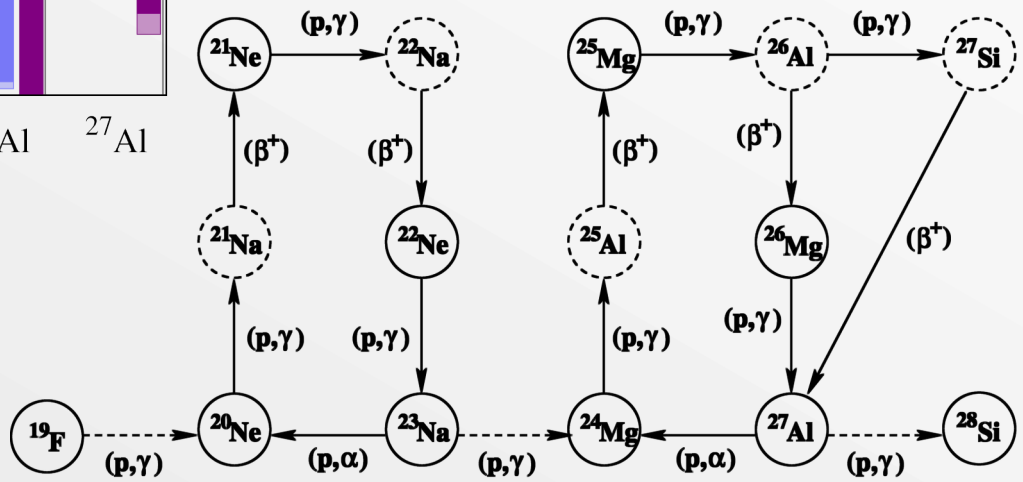
$$T_{\rm BCE} \lesssim 10^8\,{\rm K}$$
$$\tau \sim 1\,{\rm yr}$$



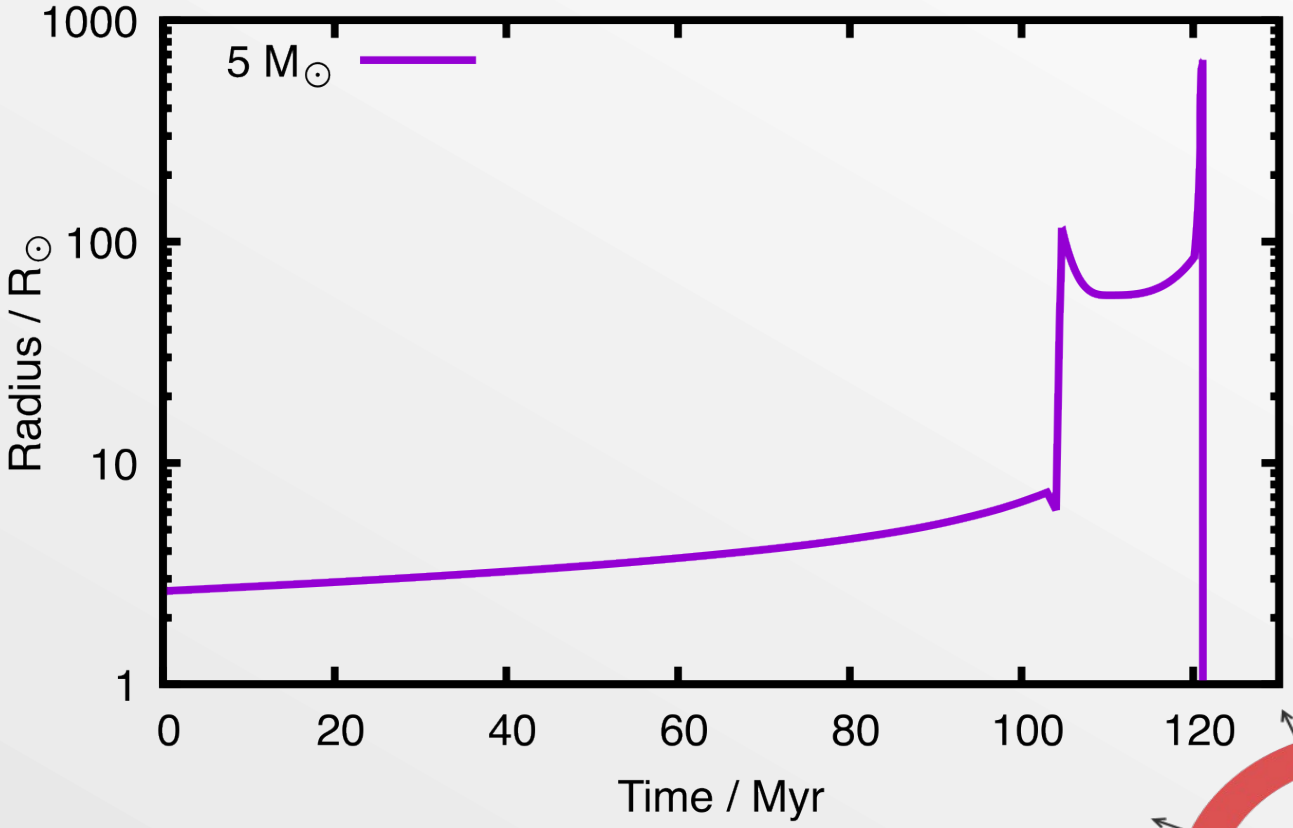
Izzard+2006

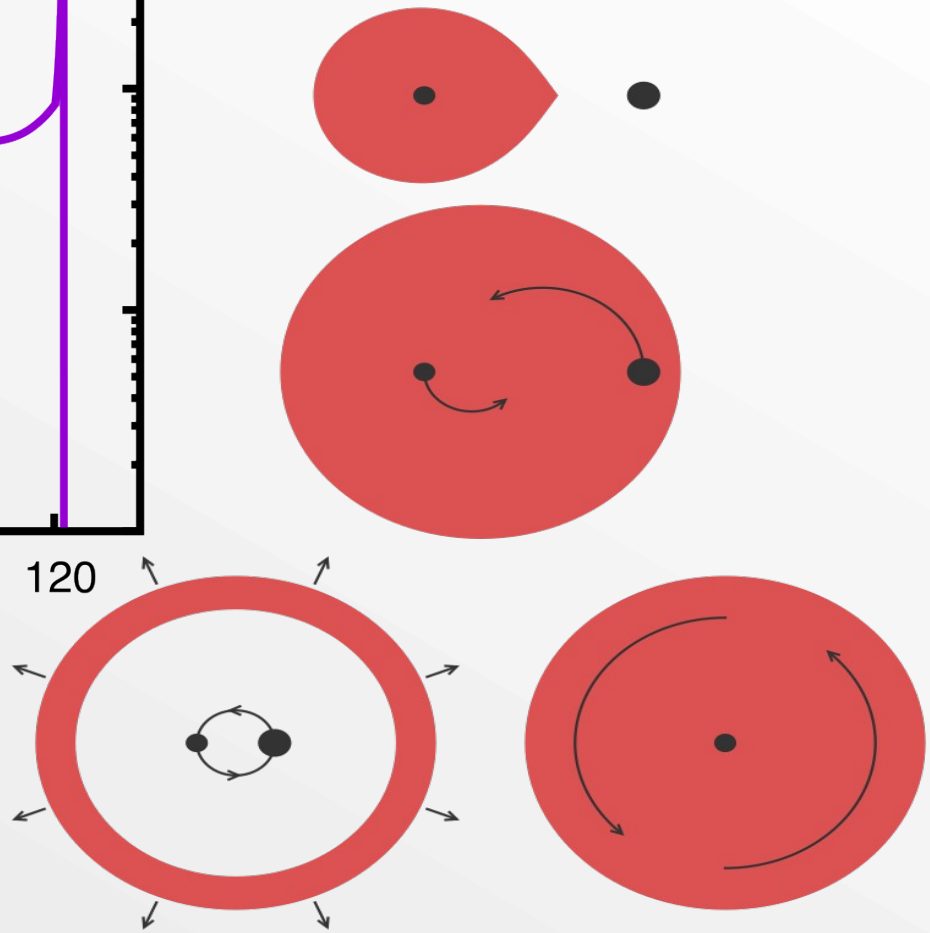
Nuclear uncertainties
→ estimated quickly

"Hot bottom burning"
CNO, Lithium, F19,
NeNaMgAl
+ … ?

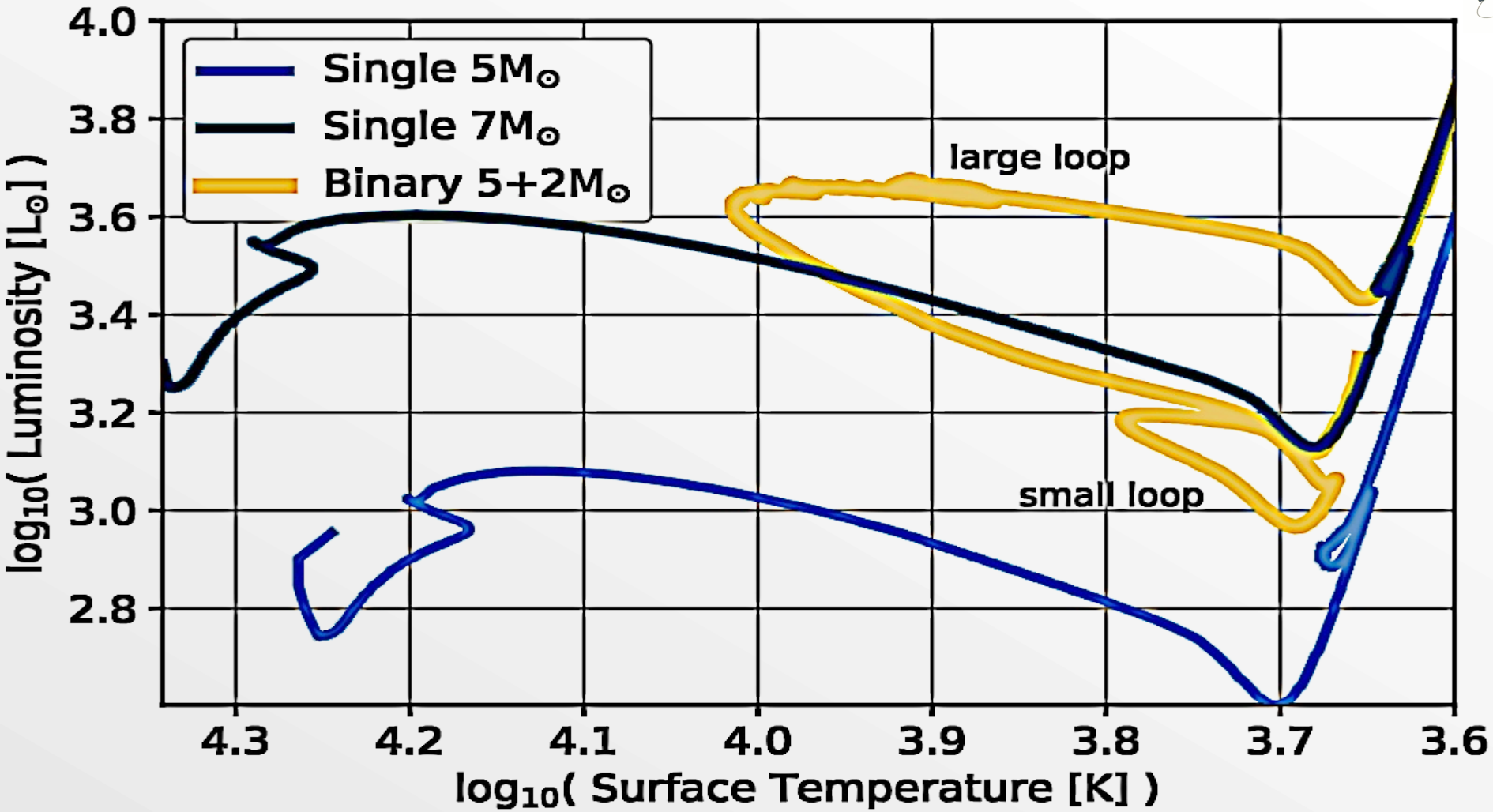


All red giant binaries

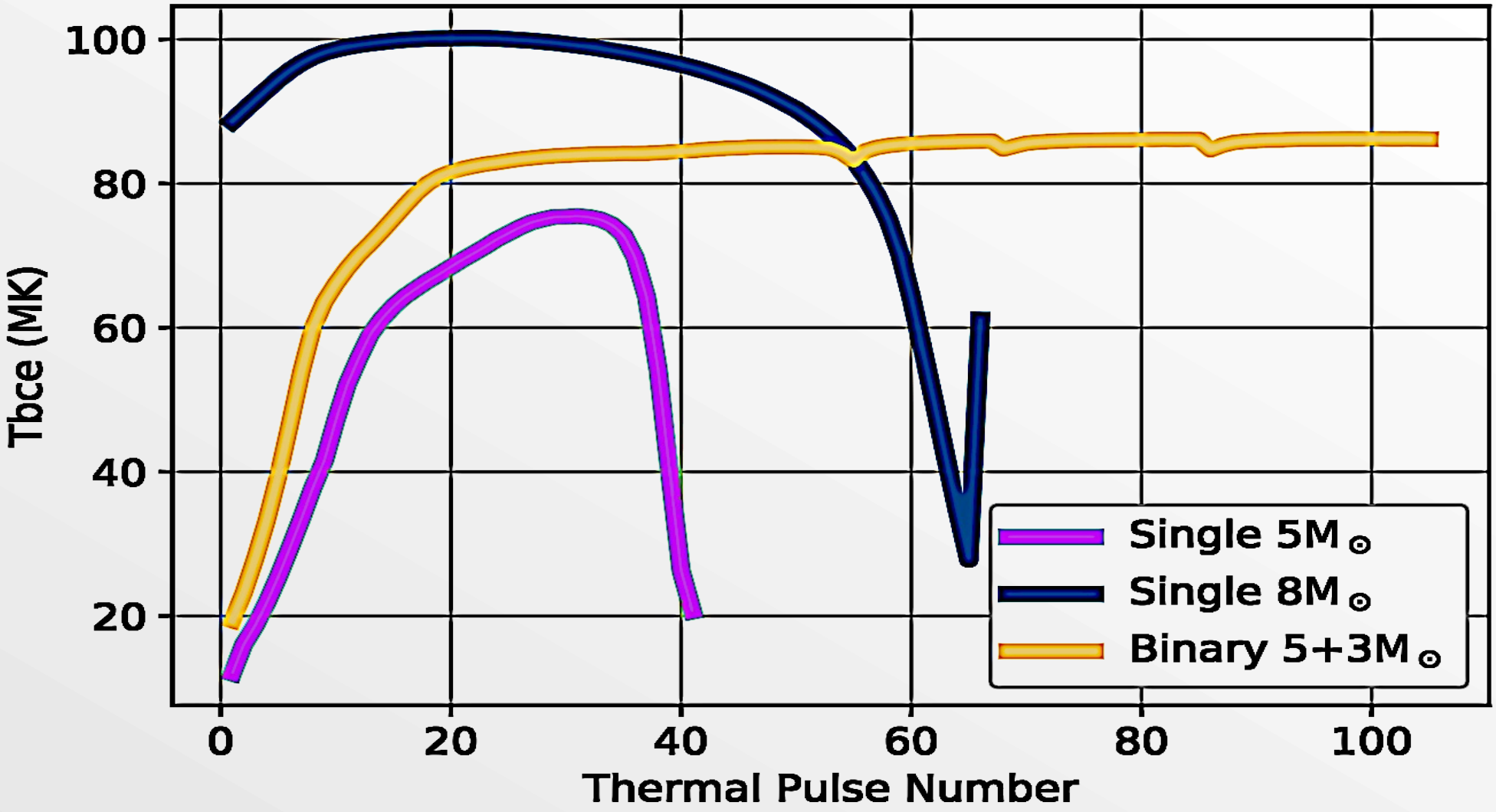




→ common envelope phase



Zara Osborn (2023 MNRAS) using Monash stellar ev. code



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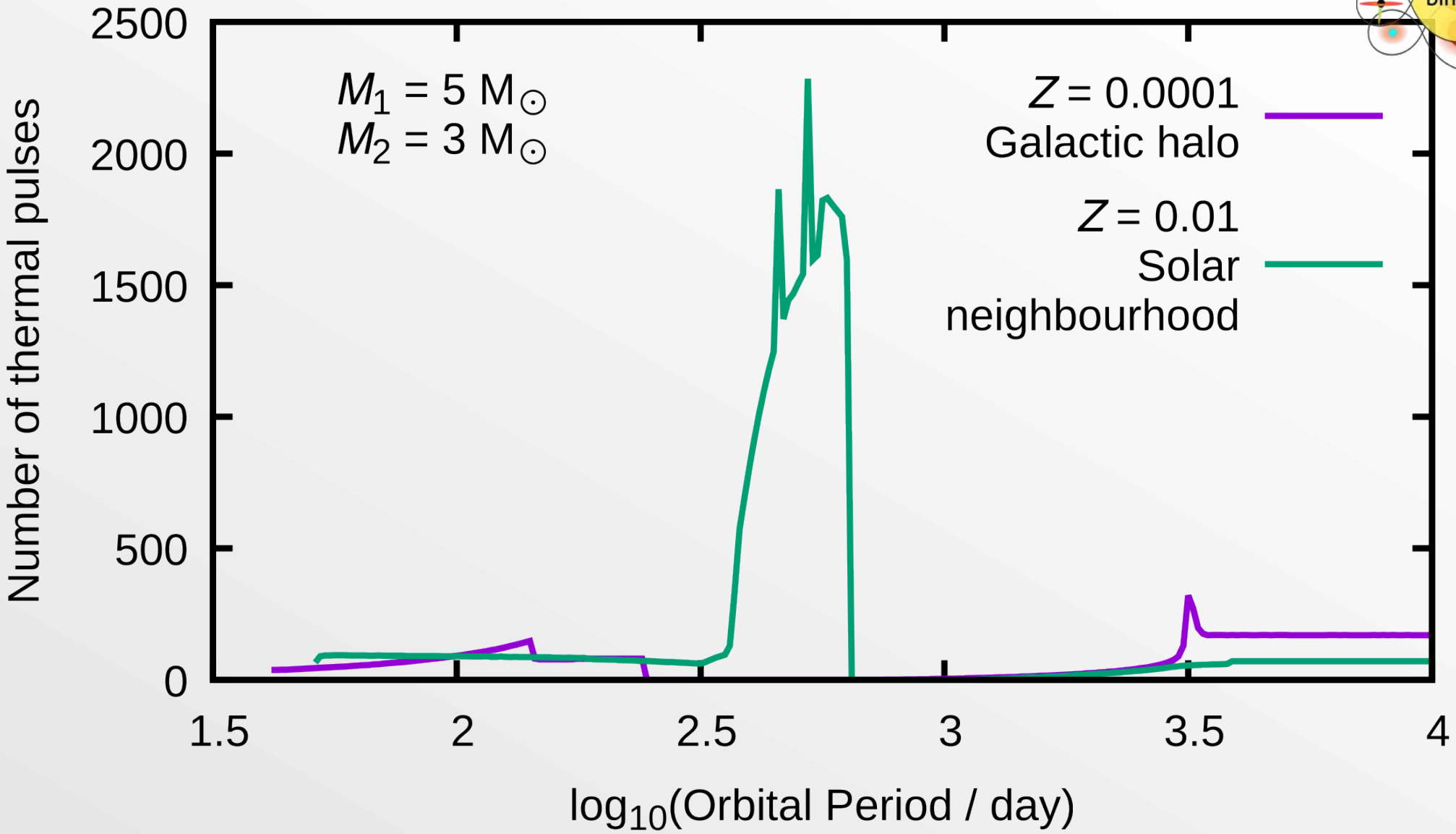
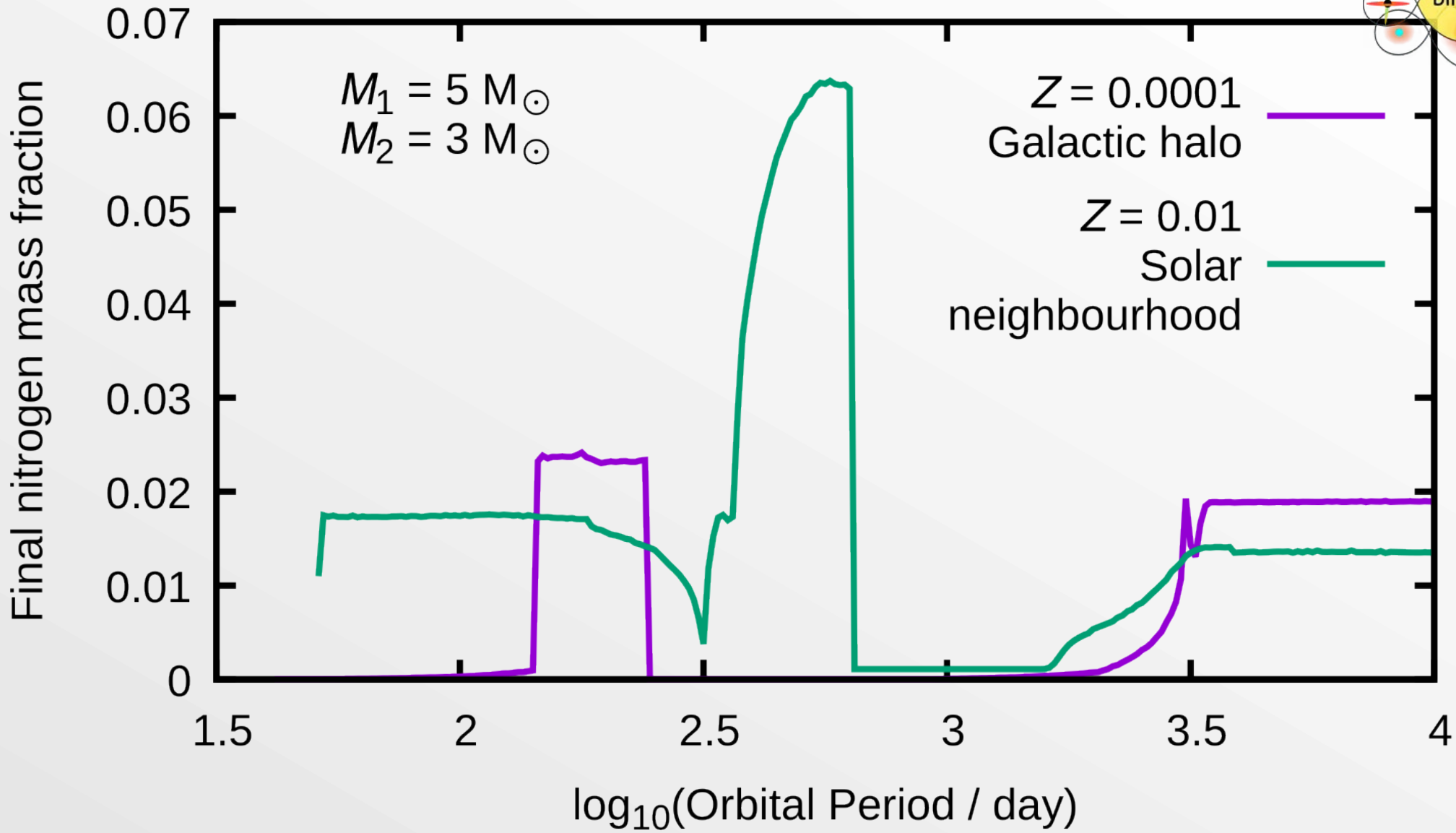
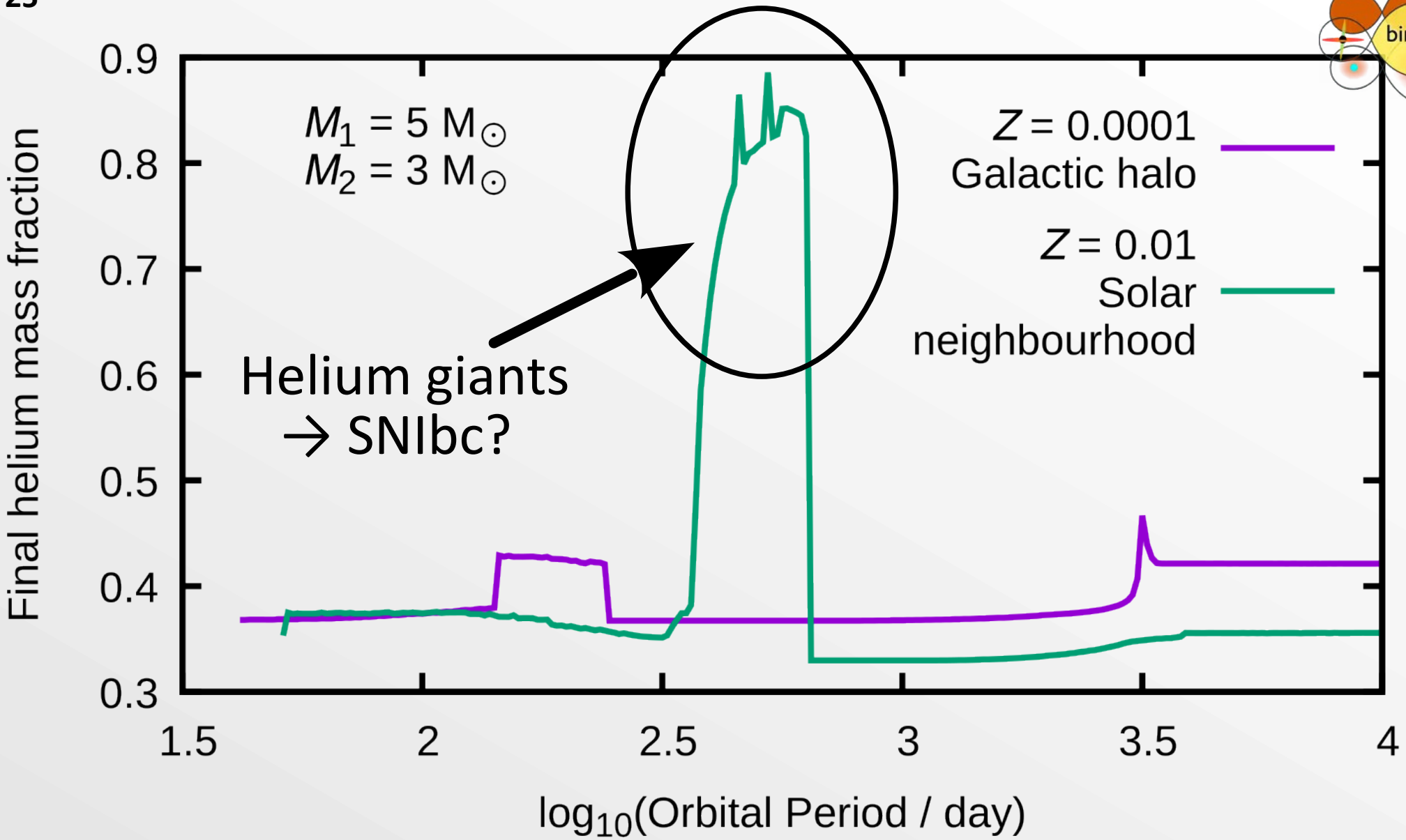
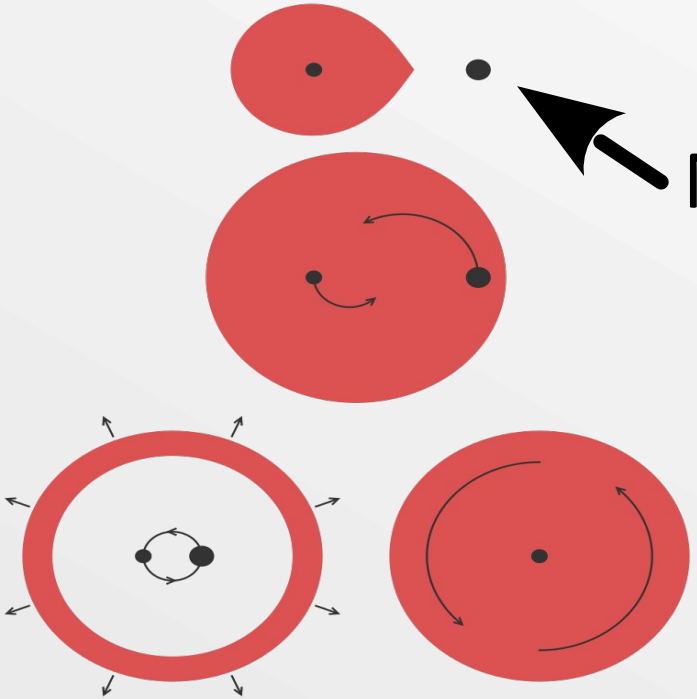

M_1 = 5 M$_\odot$
M_2 = 3 M$_\odot$
Z = 0.0001
Galactic halo
Z = 0.01
Solar
neighbourhood
Number of thermal pulses
2500
2000
1500
1000
500
0
1.5
2
2.5
3
3.5
4
log$_{10}$(Orbital Period / day)

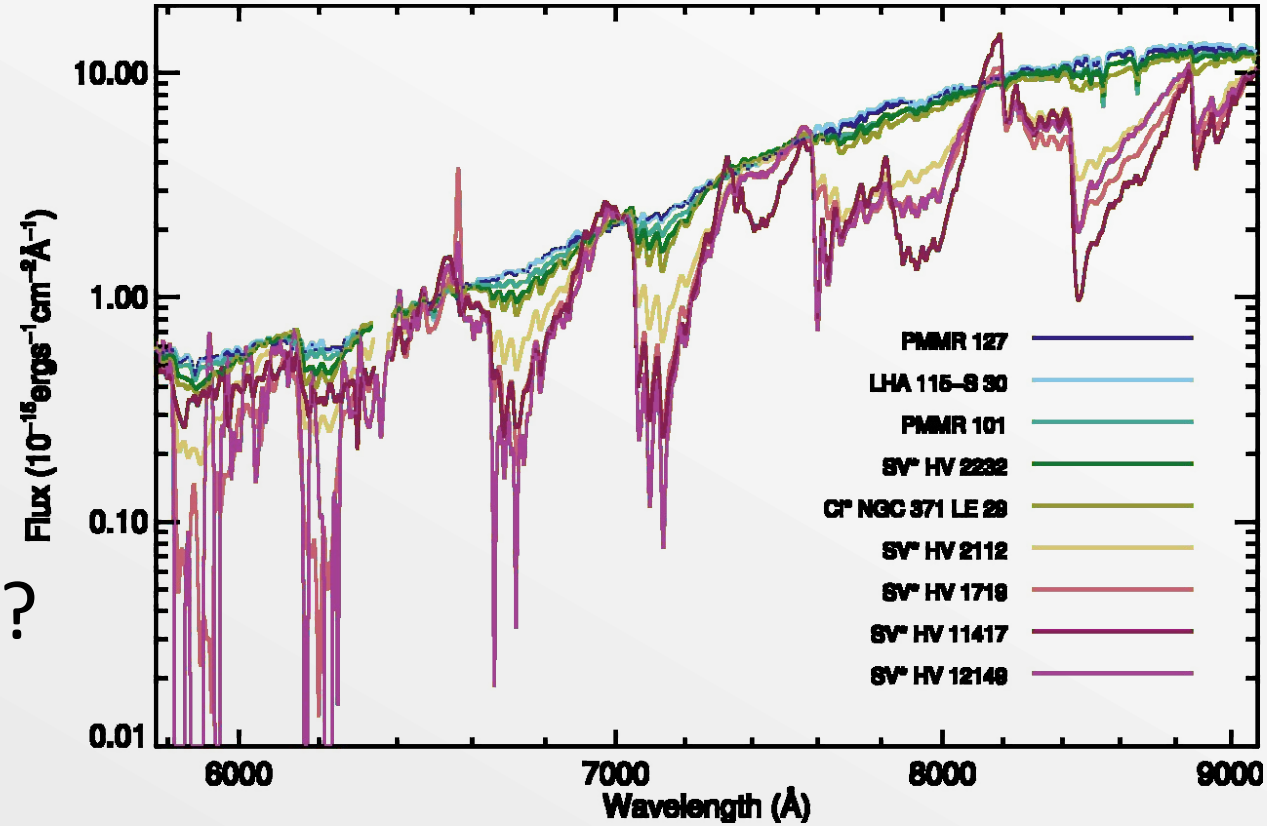

Final nitrogen mass fraction
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1.5
2
2.5
3
3.5
4
log10(Orbital Period / day)
M1 = 5 M⊙
M2 = 3 M⊙
Z = 0.0001
Galactic halo
Z = 0.01
Solar
neighbourhood


M_1 = 5 M$_\odot$
M_2 = 3 M$_\odot$
Z = 0.0001
Galactic halo
Z = 0.01
Solar
neighbourhood
Helium giants
→ SNIbc?
Final helium mass fraction
0.9
0.8
0.7
0.6
0.5
0.4
0.3
1.5
2
2.5
3
3.5
4
log$_{10}$(Orbital Period / day)

Thorne-Żytkow Objects?

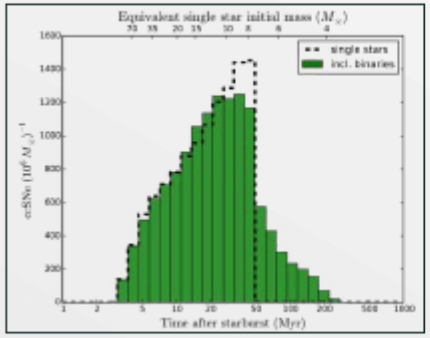


e.g. HV 2112?
HV 11417?
Levesque+ 2014
Beasor+ 2018

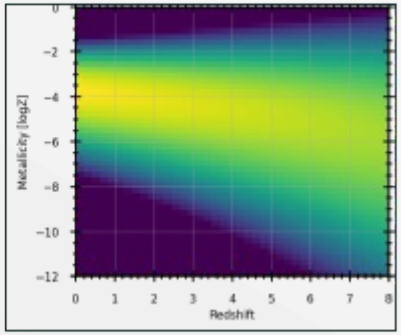


Li, Mo, Ru enhanced…?
Cannon (1993)

Stellar populations → GCE



+



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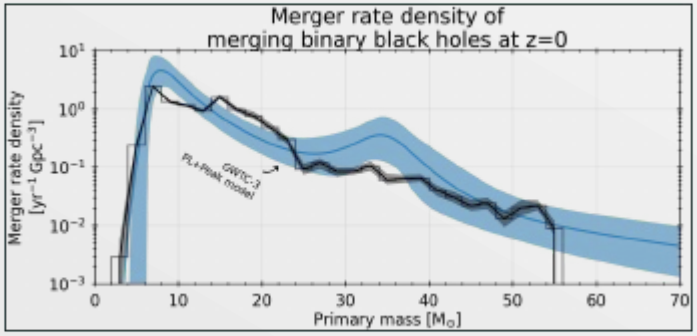
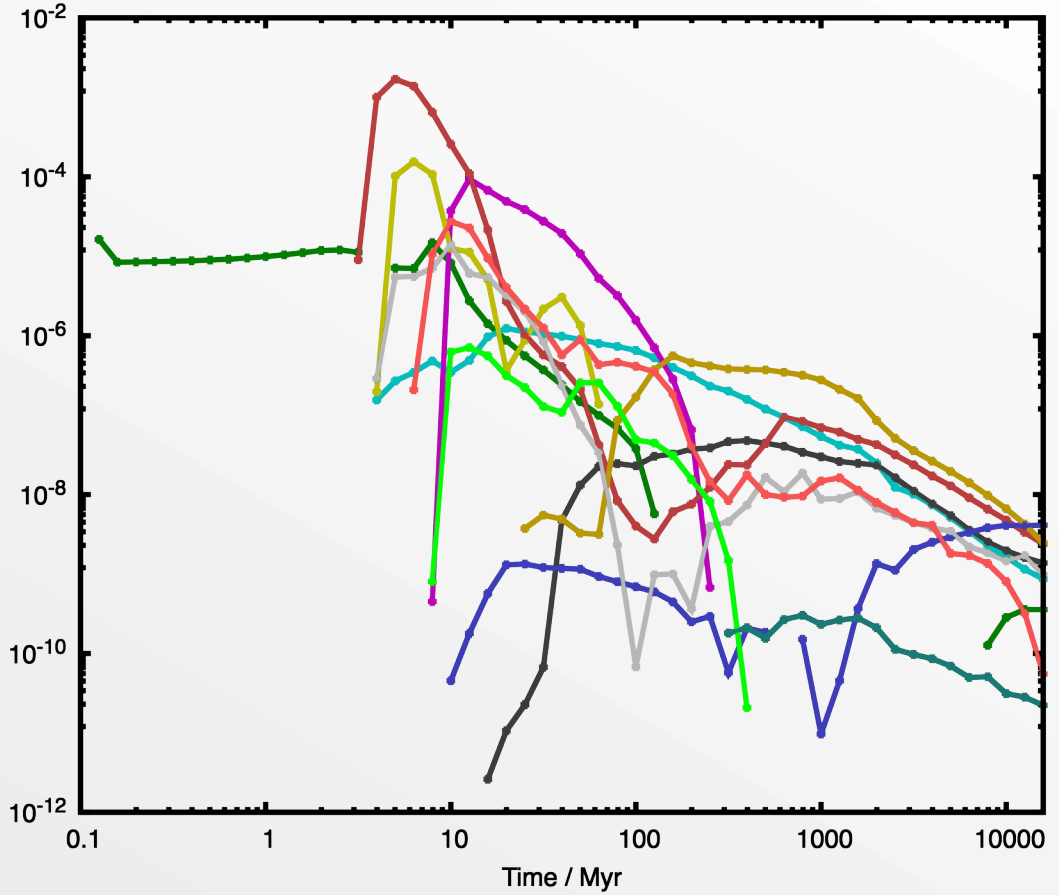


SSPC

davidhendriks.com

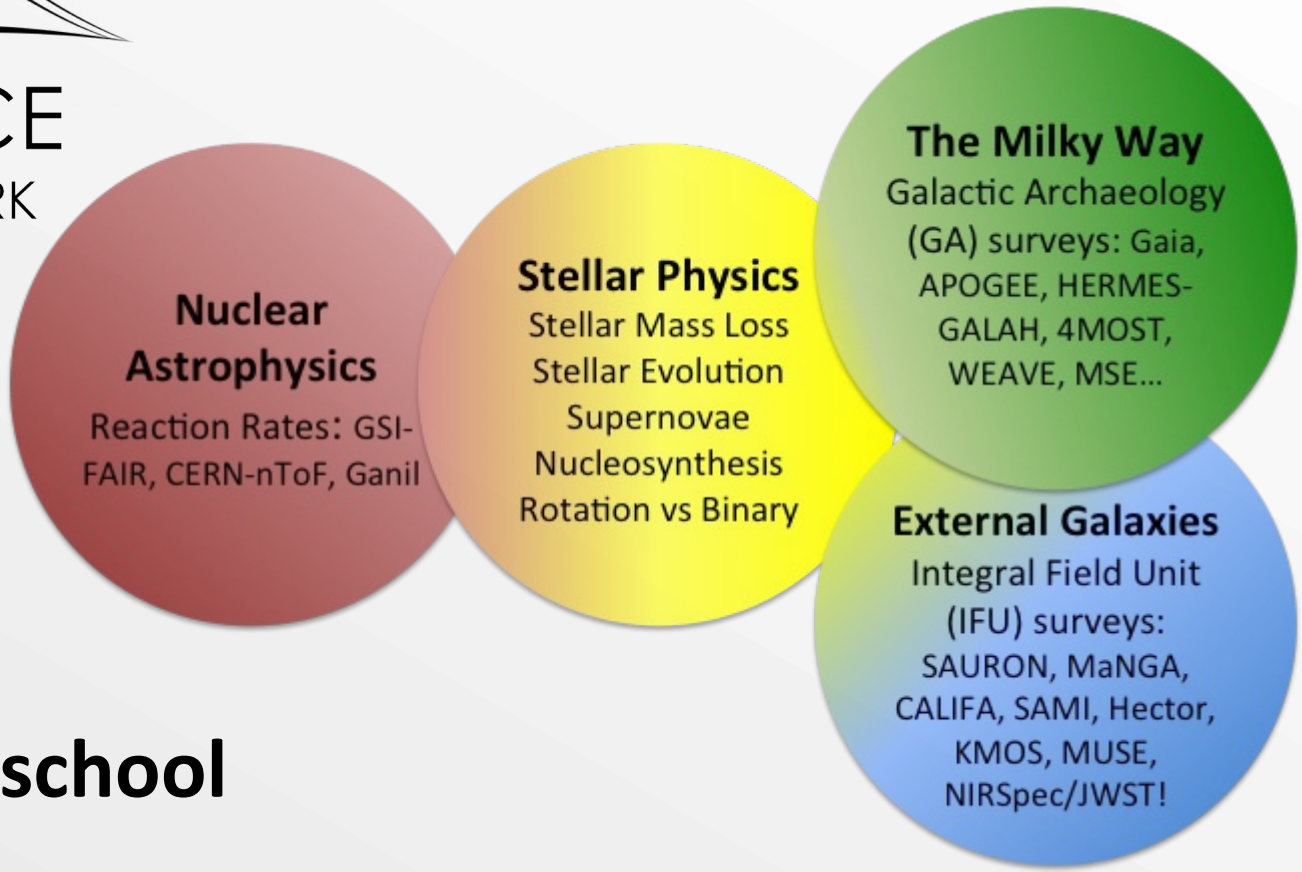
^{12}C yield vs time



→ **L-Galaxies** w/ Rob Yates (Herts.)

BRIDGCE
UK NETWORK

http://bridgce.ac.uk/



September 2026 school

https://sites.google.com/view/bridgce-herts-2026/the-school