COUSP2024，Xichang

# Bridging Stellar and Nuclear Physics

## from a stellar modeller's view

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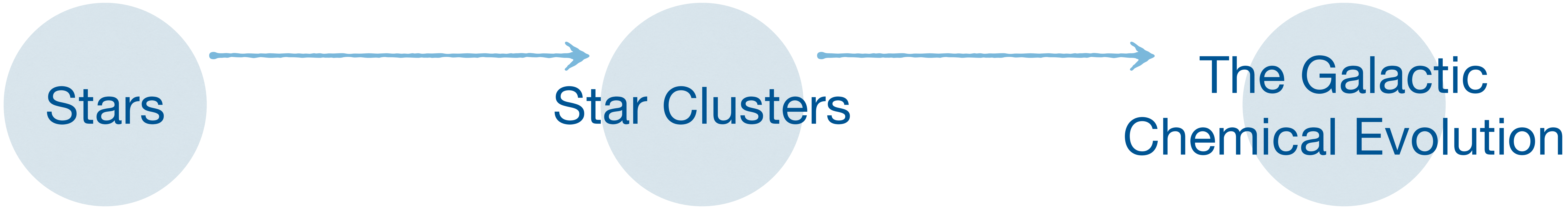
紫金山天文台

# What is Xiaoting working on?




Key questions:

**How do stars evolve?**

**How do they shape the chemical composition of the universe?**

## What is Xiaoting working on?

Stars → Star Clusters → The Galactic Chemical Evolution

**How do stars evolve?** **How do they shape the chemical composition of the universe?**

How to?

Stellar modelling ↔ Star observation

theoretical — spectroscopy, photometry, astrometry

# What is Xiaoting working on?

Stars → Star Clusters → The Galactic Chemical Evolution

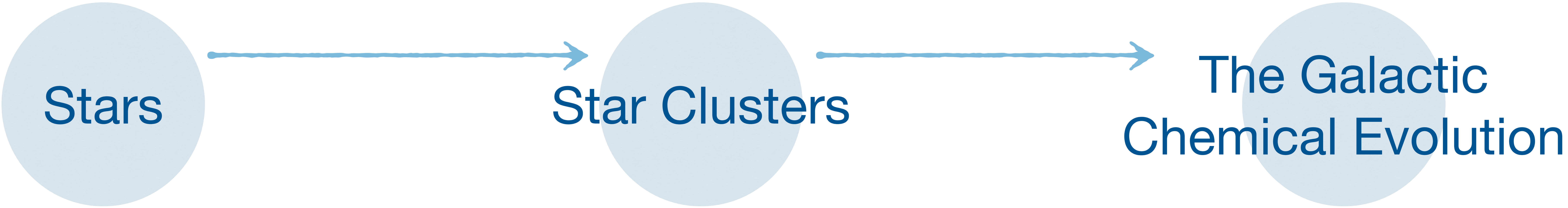
**How do stars evolve?** **How do they shape the chemical composition of the universe?**

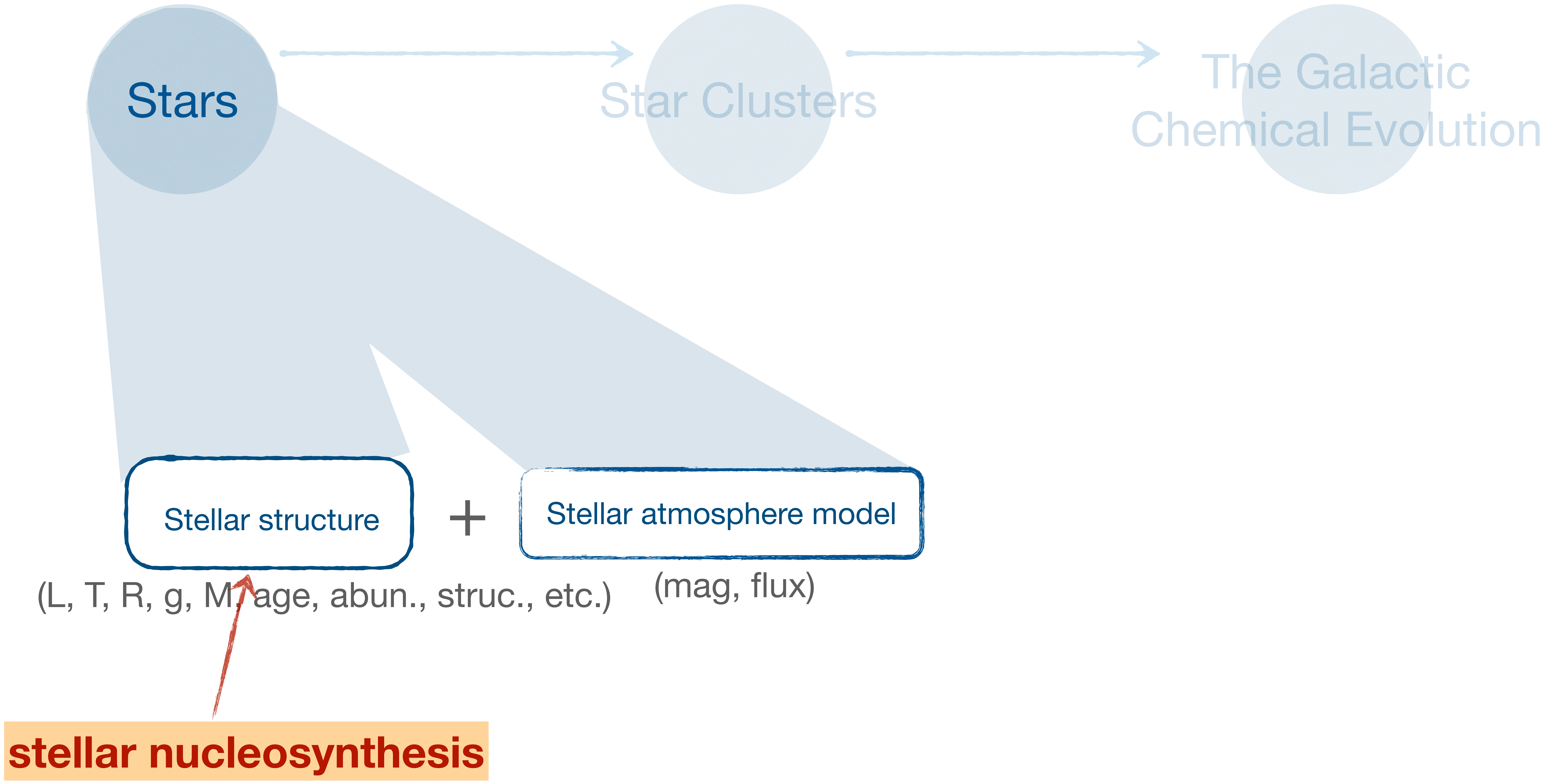
How to?

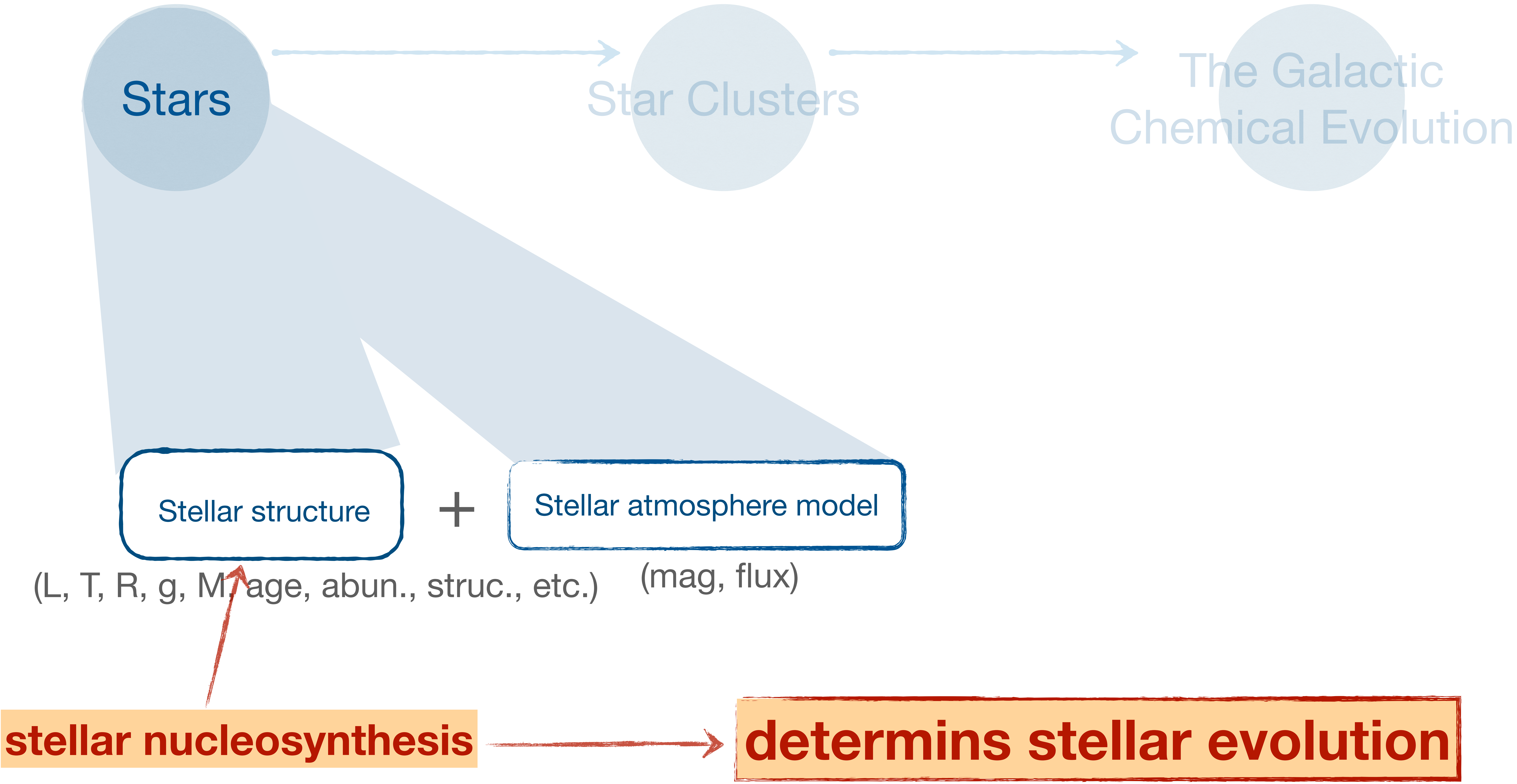
Stellar modelling ↔ Star observation

theoretical — spectroscopy, photometry, astrometry

With **theoretical stellar modelling** and **star observations** (spectroscopy, photometry, astrometry) to study **the evolution of stellar structure, star cluster and the Milky Way**


Stars
Star Clusters
The Galactic Chemical Evolution


Stars
Star Clusters
The Galactic
Chemical Evolution
Stellar structure
+
Stellar atmosphere model
(L, T, R, g, M, age, abun., struc., etc.)
(mag, flux)
stellar nucleosynthesis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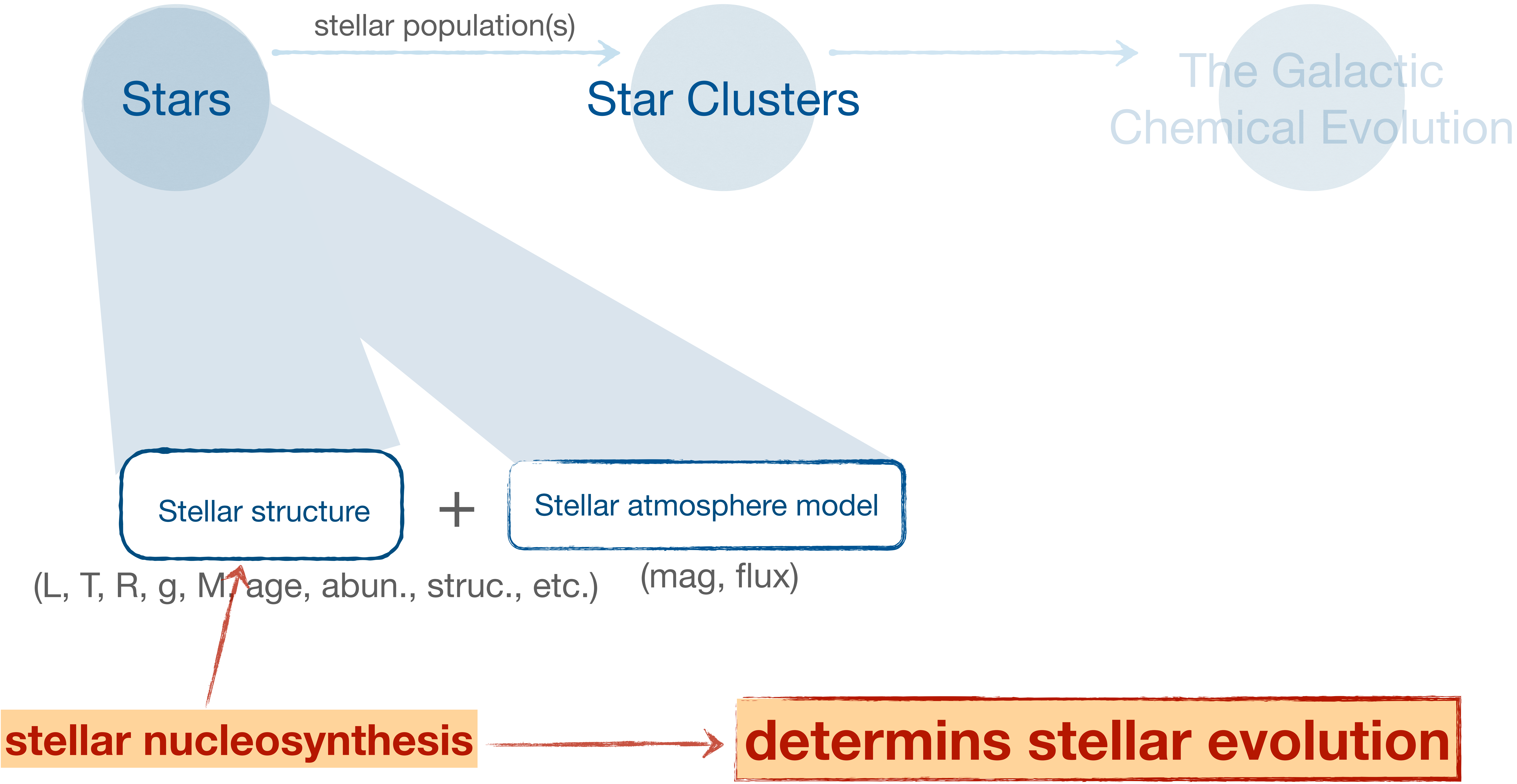

stellar population(s)
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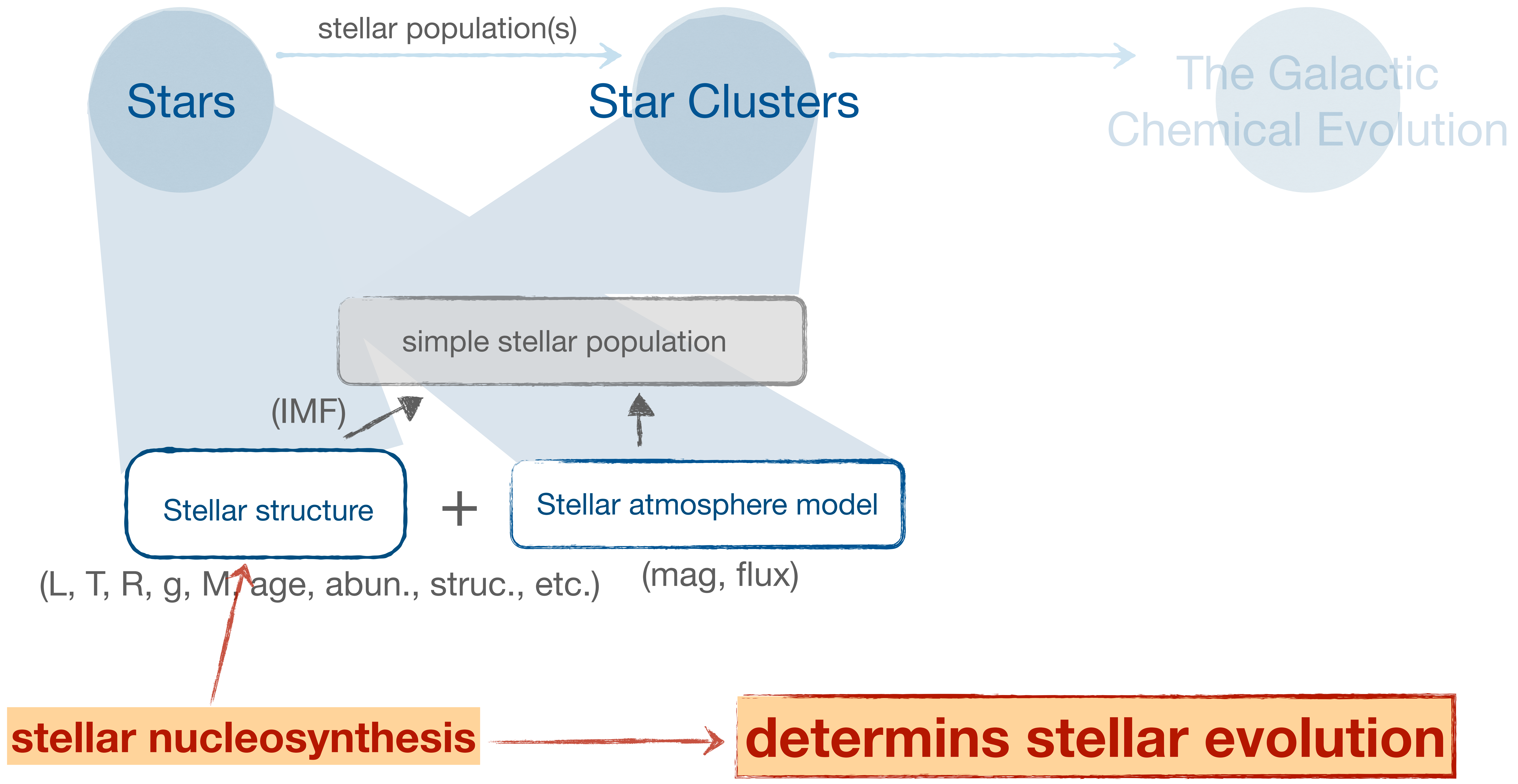
stellar population(s)
Stars
Star Clusters
The Galactic
Chemical Evolution
simple stellar population
(IMF)
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+
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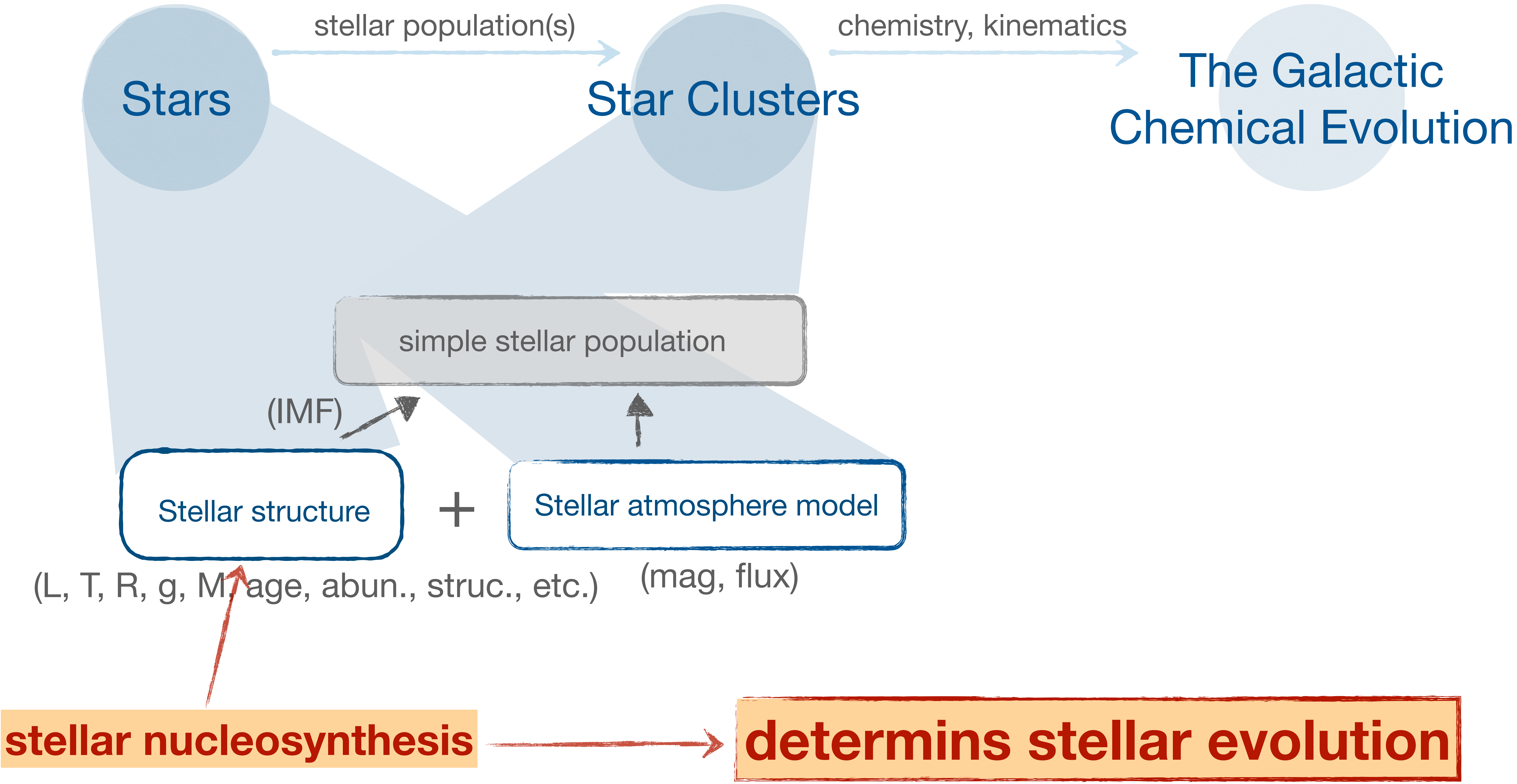
Stars
stellar population(s)
Star Clusters
chemistry, kinematics
The Galactic Chemical Evolution
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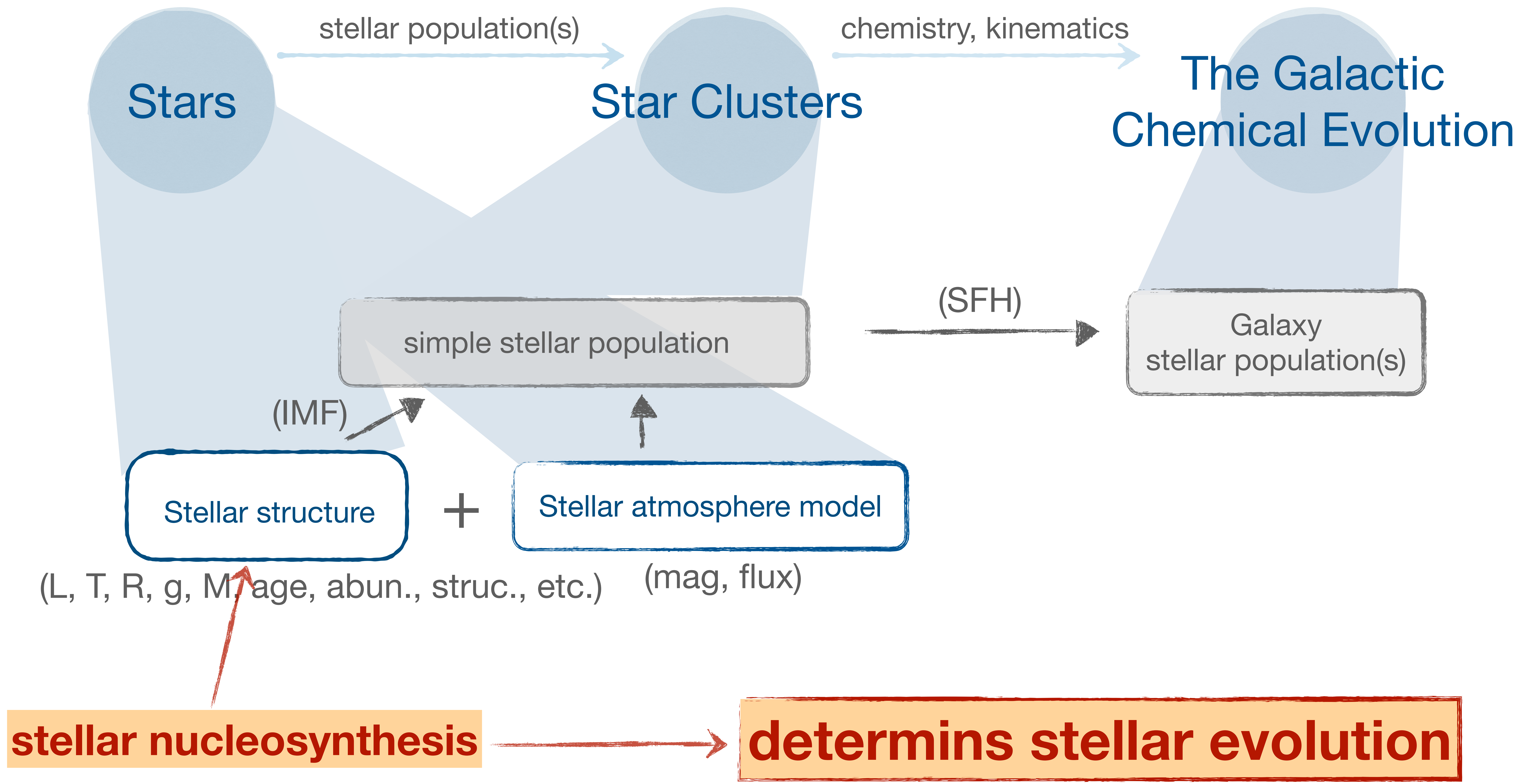
stellar population(s)
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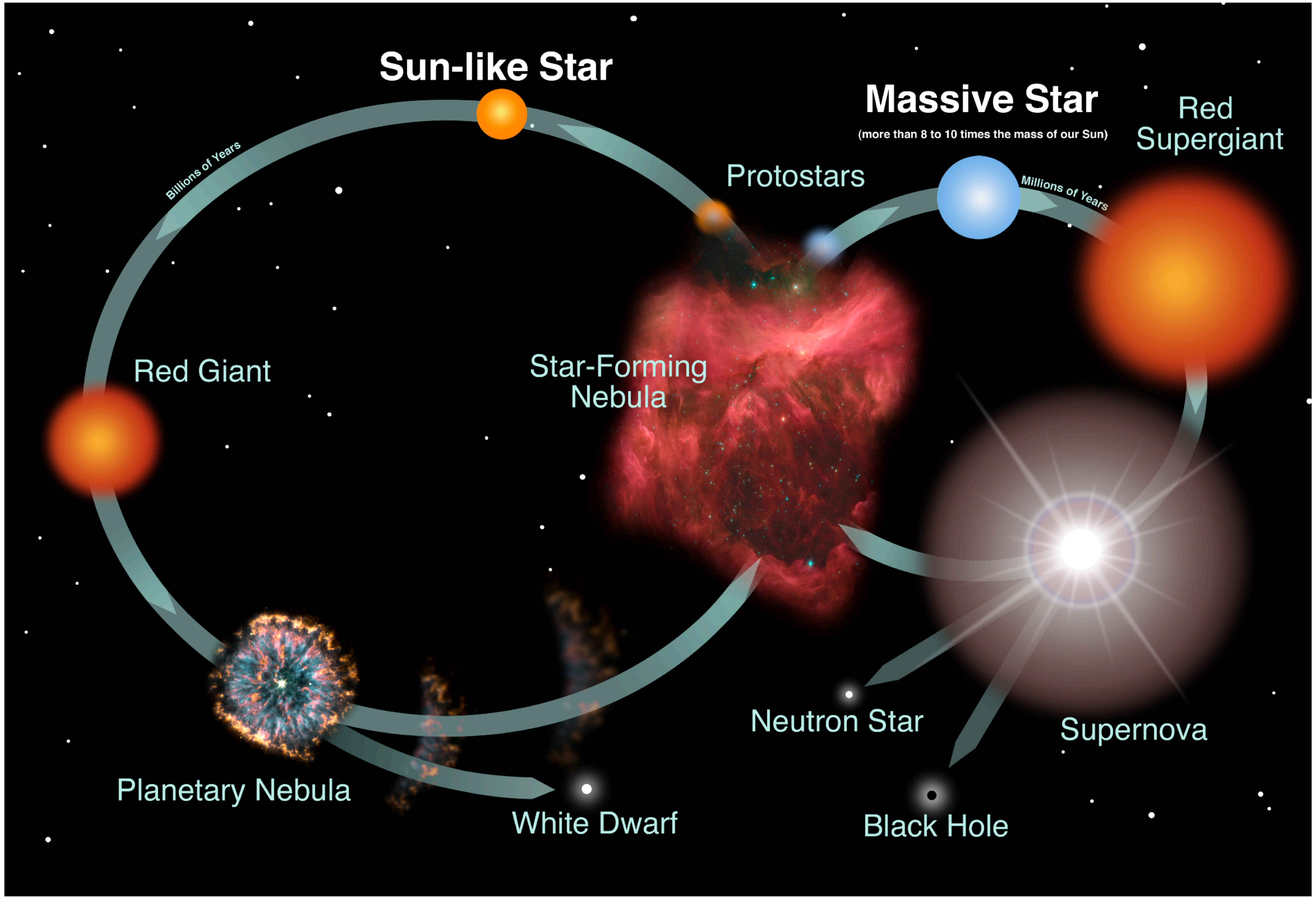



# The Galactic Chemical Evolution

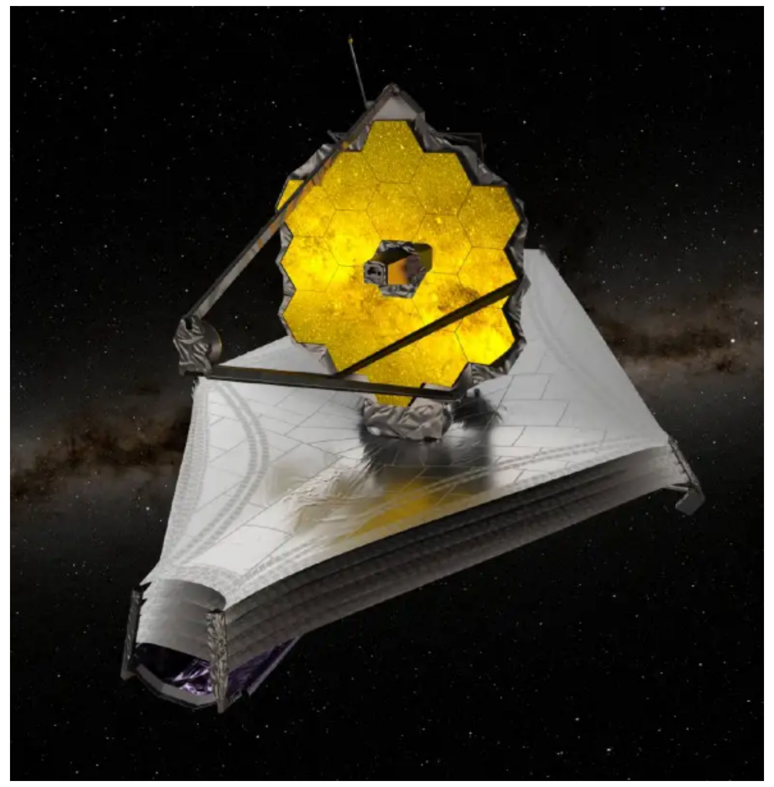
- What kind of stars produce a certain element?
  (Stellar nucleosynthesis)
- When and how will the elements be released?
  (Stellar evolution)
- How many are these stars?
  (Initial Mass Function (IMF) & Star Formation History (SFH))

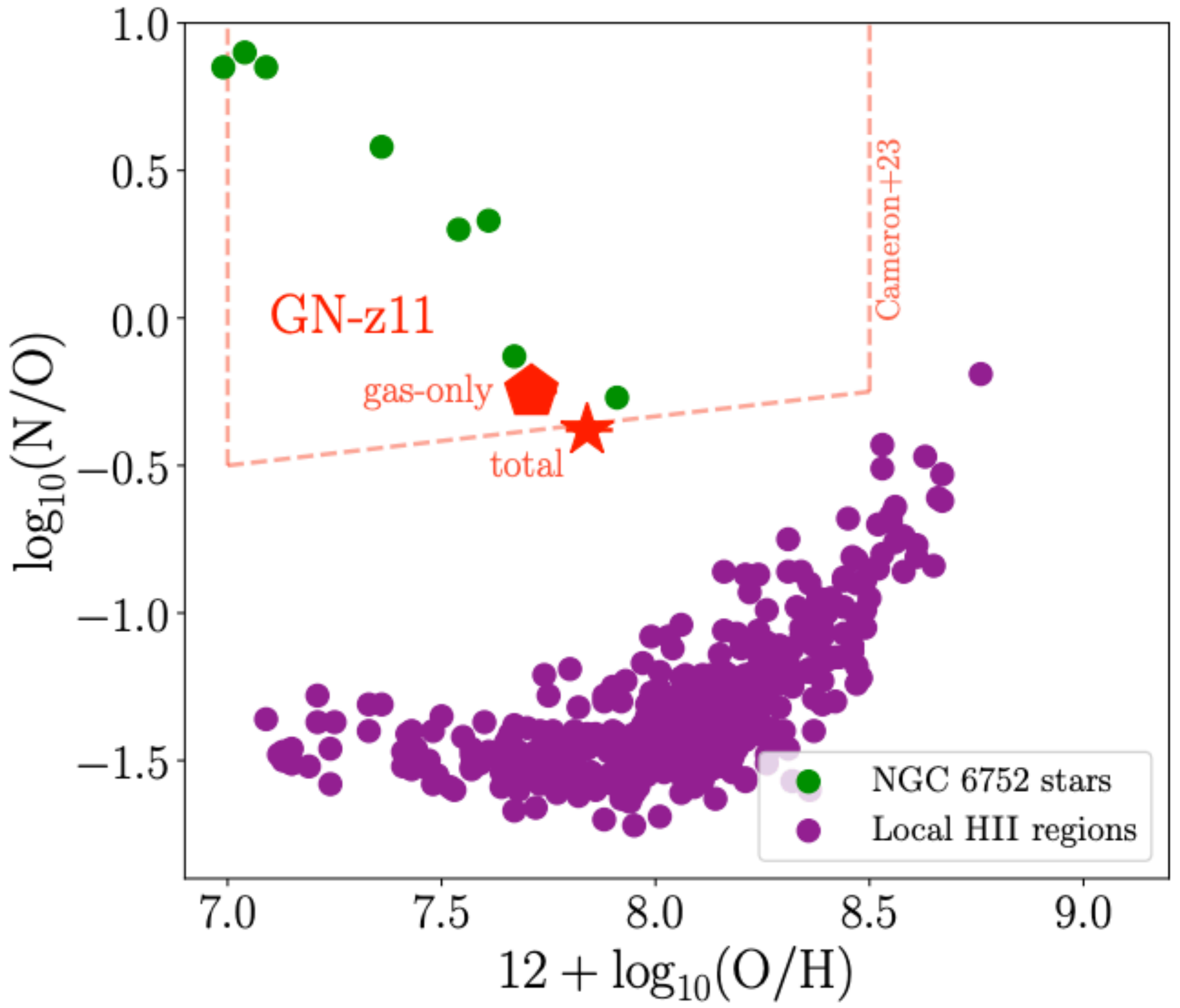
**stellar nucleosynthesis** → **determins stellar evolution**

# The Galactic Chemical Evolution

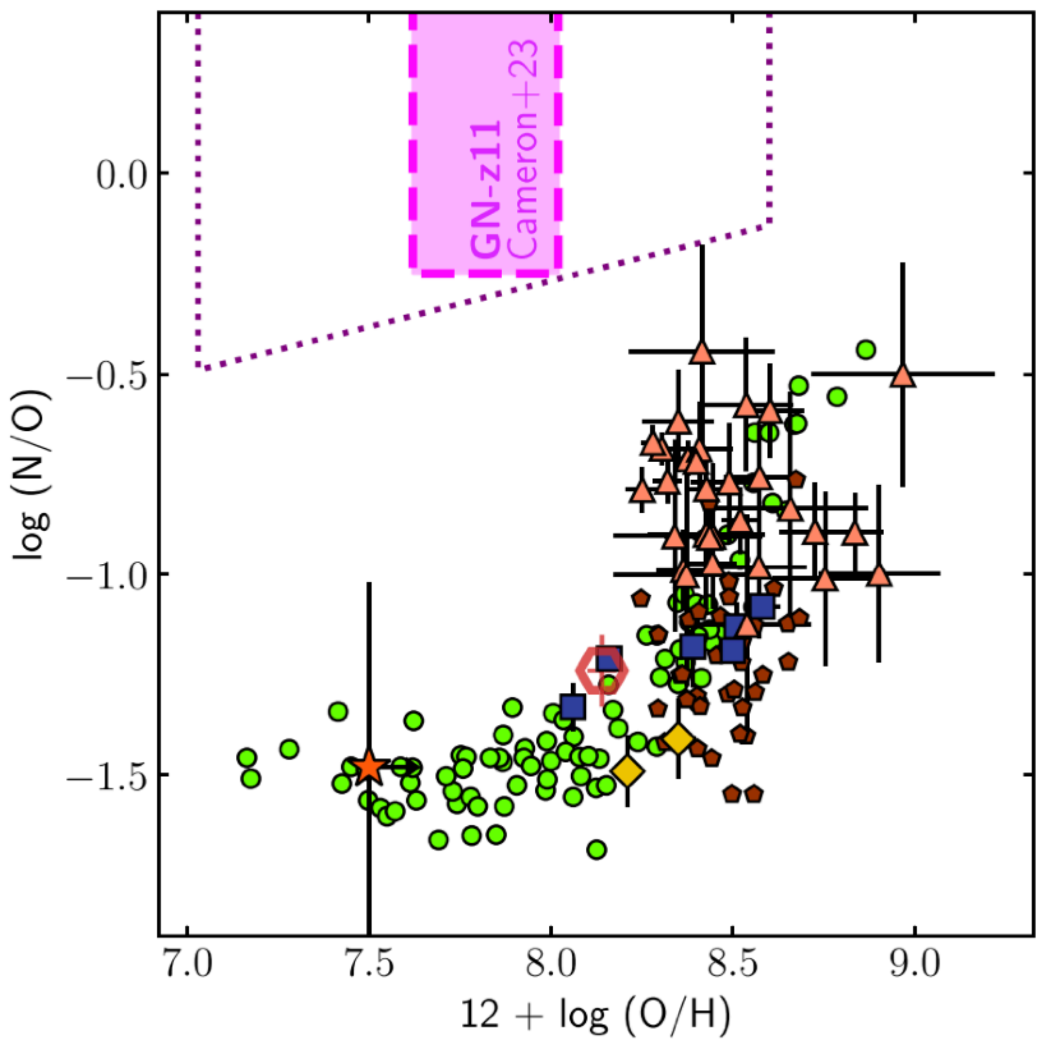
GN-z11

N-rich, compact z = 10.6 galaxy






Senchyna, et al., 2023




Cameron, et al., 2023

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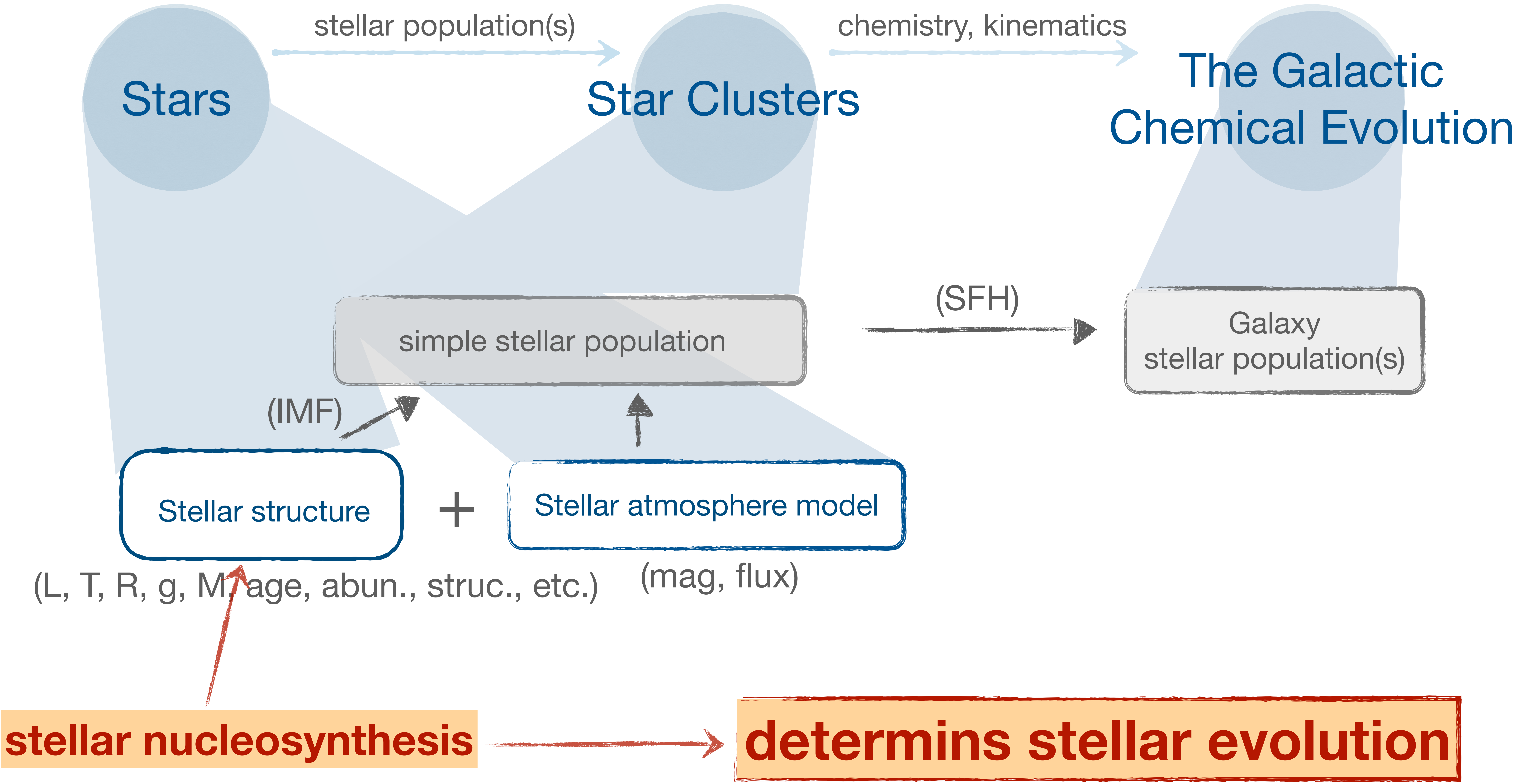
**stellar nucleosynthesis** → **determins stellar evolution**


Stars
stellar population(s)
Star Clusters
chemistry, kinematics
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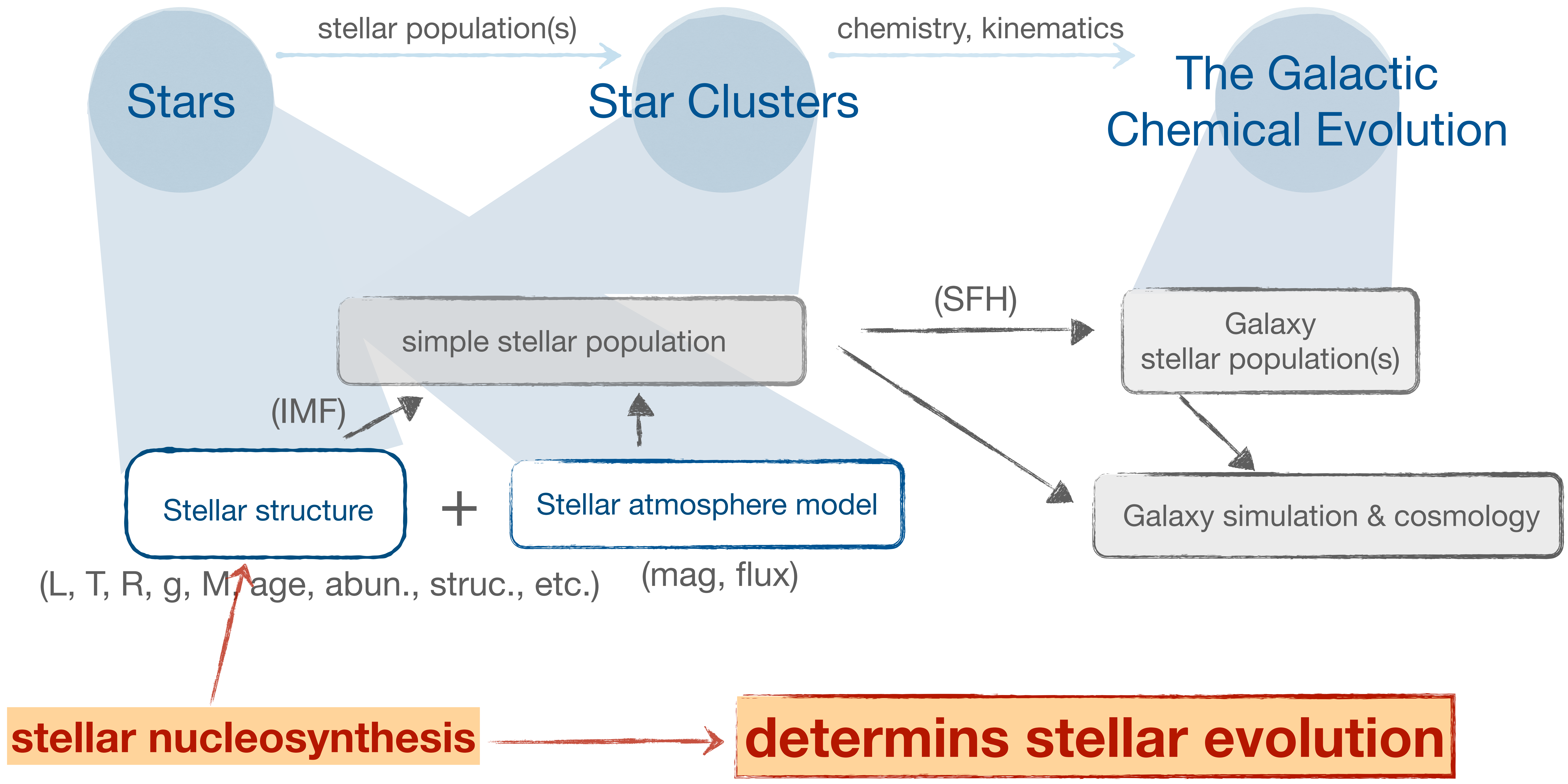
Stars
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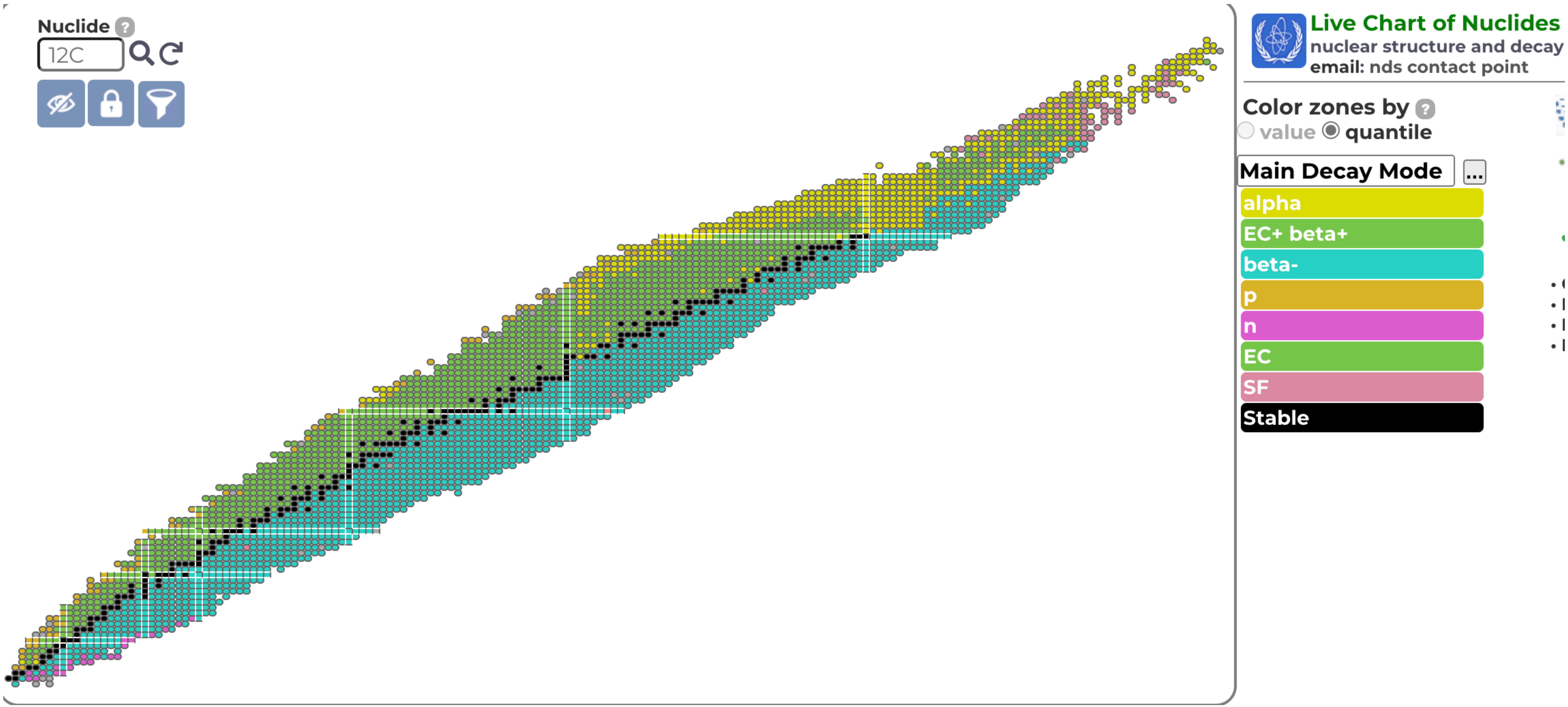
determins stellar evolution

Which nuclear reactions are (more) important to stellar evolution?

stellar nucleosynthesis → **determins stellar evolution**

# Which nuclear reactions are (more) important to stellar evolution?



# Which nuclear reactions are (more) important to stellar evolution?

| Reaction | Reference |
|---|---|
| $p(p, \beta^{+}\nu)D$ | Betts, Fortune & Middleton (1975) |
| $p(D, \gamma)^{3}He$ | Descouvemont et al. (2004) |
| $^{3}He(^{3}He, \gamma)2p + ^{4}He$ | Angulo et al. (1999) |
| $^{4}He(^{3}He, \gamma)^{7}Be$ | Cyburt & Davids (2008) |
| $^{7}Be(e^{-}, \gamma)^{7}Li$ | Cyburt et al. (2010) |
| $^{7}Li(p, \gamma)^{4}He + ^{4}He$ | Descouvemont et al. (2004) |
| $^{7}Be(p, \gamma)^{8}B$ | Angulo et al. (1999) |
| $^{12}C(p, \gamma)^{13}N$ | Li et al. (2010) |
| $^{13}C(p, \gamma)^{14}N$ | Angulo et al. (1999) |
| $^{14}N(p, \gamma)^{15}O$ | Imbriani et al. (2005) |
| $^{15}N(p, \gamma)^{4}He + ^{12}C$ | Angulo et al. (1999) |
| $^{15}N(p, \gamma)^{16}O$ | Iliadis et al. (2010) |
| $^{16}O(p, \gamma)^{17}F$ | Iliadis et al. (2008) |
| $^{17}O(p, \gamma)^{4}He + ^{14}N$ | Iliadis et al. (2010) |
| $^{17}O(p, \gamma)^{18}F$ | Iliadis et al. (2010) |
| $^{18}O(p, \gamma)^{4}He + ^{15}N$ | Iliadis et al. (2010) |
| $^{18}O(p, \gamma)^{19}F$ | Iliadis et al. (2010) |
| $^{19}F(p, \gamma)^{4}He + ^{16}O$ | Angulo et al. (1999) |
| $^{19}F(p, \gamma)^{20}Ne$ | Angulo et al. (1999) |
| $^{4}He(2\,^{4}He, \gamma)^{12}C$ | Fynbo et al. (2005) |
| $^{12}C(^{4}He, \gamma)^{16}O$ | Cyburt, Hoffman & Woosley (2012) |
| $^{14}N(^{4}He, \gamma)^{18}F$ | Iliadis et al. (2010) |
| $^{15}N(^{4}He, \gamma)^{19}F$ | Iliadis et al. (2010) |
| $^{16}O(^{4}He, \gamma)^{20}Ne$ | Constantini & LUNA Collaboration (2010) |
| $^{18}O(^{4}He, \gamma)^{22}Ne$ | Iliadis et al. (2010) |
| $^{20}Ne(^{4}He, \gamma)^{24}Mg$ | Iliadis et al. (2010) |
| $^{22}Ne(^{4}He, \gamma)^{26}Mg$ | Iliadis et al. (2010) |
| $^{24}Mg(^{4}He, \gamma)^{28}Si$ | Strandberg et al. (2008) |
| $^{13}C(^{4}He, n)^{16}O$ | Heil et al. (2008) |
| $^{17}O(^{4}He, n)^{20}Ne$ | Angulo et al. (1999) |
| $^{18}O(^{4}He, n)^{21}Ne$ | Angulo et al. (1999) |
| $^{21}Ne(^{4}He, n)^{24}Mg$ | Angulo et al. (1999) |
| $^{22}Ne(^{4}He, n)^{25}Mg$ | Iliadis et al. (2010) |
| $^{25}Mg(^{4}He, n)^{28}Si$ | Angulo et al. (1999) |
| $^{20}Ne(p, \gamma)^{21}Na$ | Iliadis et al. (2010) |
| $^{21}Ne(p, \gamma)^{22}Na$ | Iliadis et al. (2010) |
| $^{22}Ne(p, \gamma)^{23}Na$ | Iliadis et al. (2010) |
| $^{23}Na(p, \gamma)^{4}He + ^{20}Ne$ | Iliadis et al. (2010) |
| $^{23}Na(p, \gamma)^{24}Mg$ | Iliadis et al. (2010) |
| $^{24}Mg(p, \gamma)^{25}Al$ | Iliadis et al. (2010) |
| $^{25}Mg(p, \gamma)^{26}Al^{g}$ | Iliadis et al. (2010) |
| $^{25}Mg(p, \gamma)^{26}Al^{m}$ | Iliadis et al. (2010) |
| $^{26}Mg(p, \gamma)^{27}Al$ | Iliadis et al. (2010) |
| $^{26}Al^{g}(p, \gamma)^{27}Si$ | Iliadis et al. (2010) |
| $^{27}Al(p, \gamma)^{4}He + ^{24}Mg$ | Iliadis et al. (2010) |
| $^{27}Al(p, \gamma)^{28}Si$ | Iliadis et al. (2010) |
| $^{26}Al(p, \gamma)^{27}Si$ | Iliadis et al. (2010) |
| $^{26}Al(n, p)^{26}Mg$ | Tuli (2012) |
| $^{12}C(^{12}C, n)^{23}Mg$ | Caughlan & Fowler (1988) |
| $^{12}C(^{12}C, p)^{23}Na$ | Caughlan & Fowler (1988) |
| $^{12}C(^{12}C, ^{4}He)^{20}Ne$ | Caughlan & Fowler (1988) |
| $^{20}Ne(\gamma, ^{4}He)^{16}O$ | Constantini & LUNA Collaboration (2010) |

**PARSEC**

Fu et al., 2018, MNRAS

# Which nuclear reactions are (more) important to stellar evolution?

example on massive stars

$$^{12}C(\alpha, \gamma)^{16}O$$

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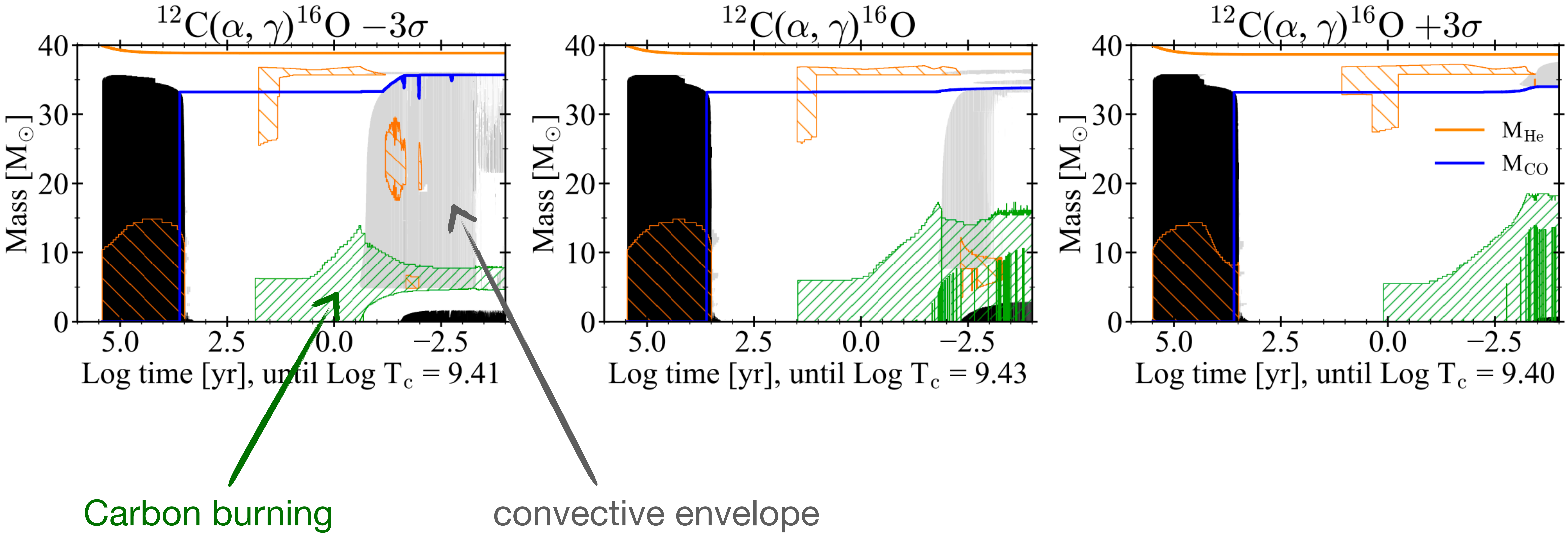
example on massive stars

## $^{12}C(\alpha, \gamma)^{16}O$

40 Msun, Z=0.0003 (~2% solar metallicity)




PARSEC

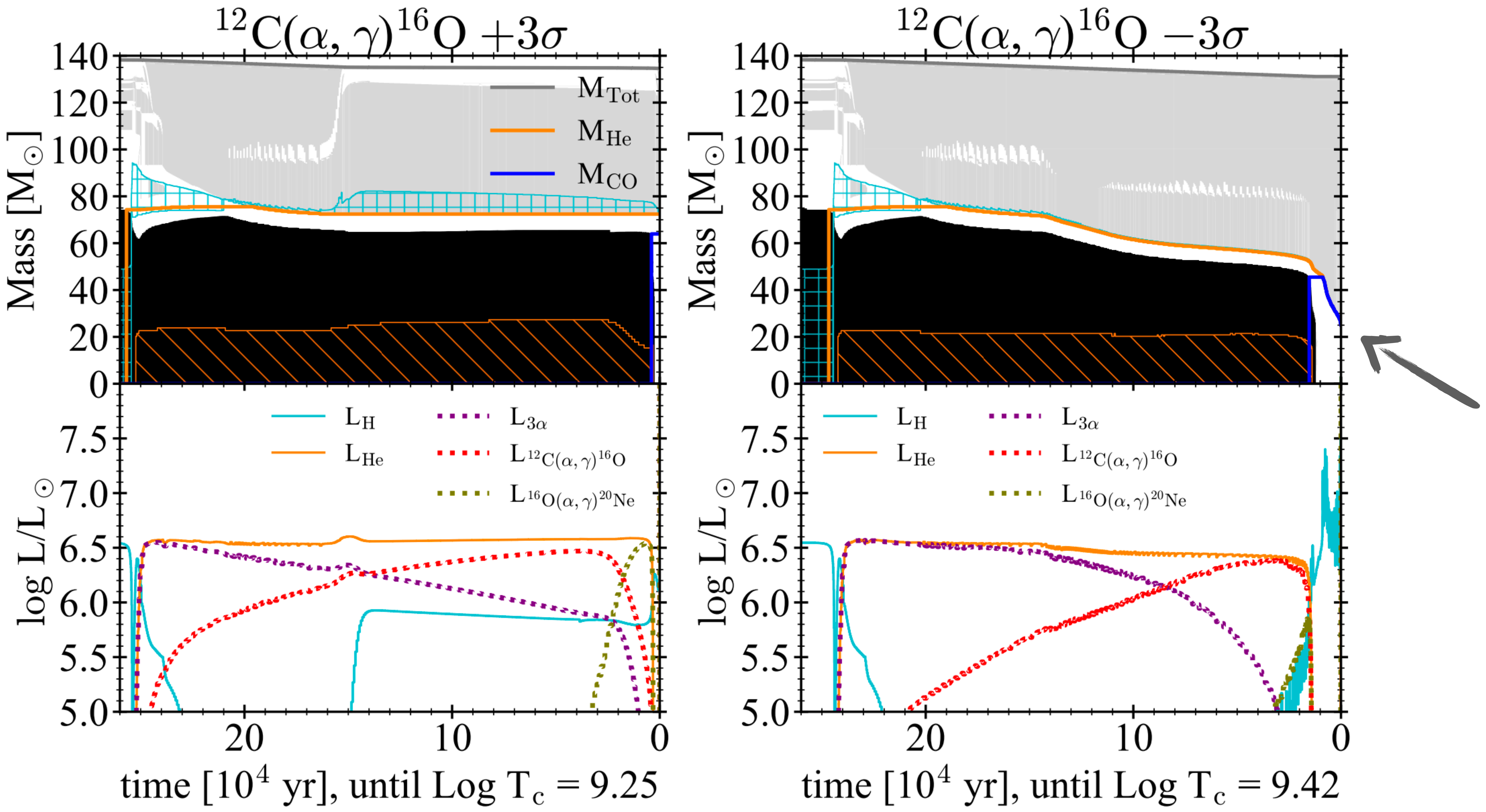
Costa et al., 2021, MNRAS

# Which nuclear reactions are (more) important to stellar evolution?

example on massive stars

## $^{12}C(\alpha, \gamma)^{16}O$

140 Msun, Z=0.0003 (~2% solar metallicity)




- Generate a deep dredge-up
- Reduce the He core mass
- Avoid Pair-Instability SN
- Make a black hole

PARSEC

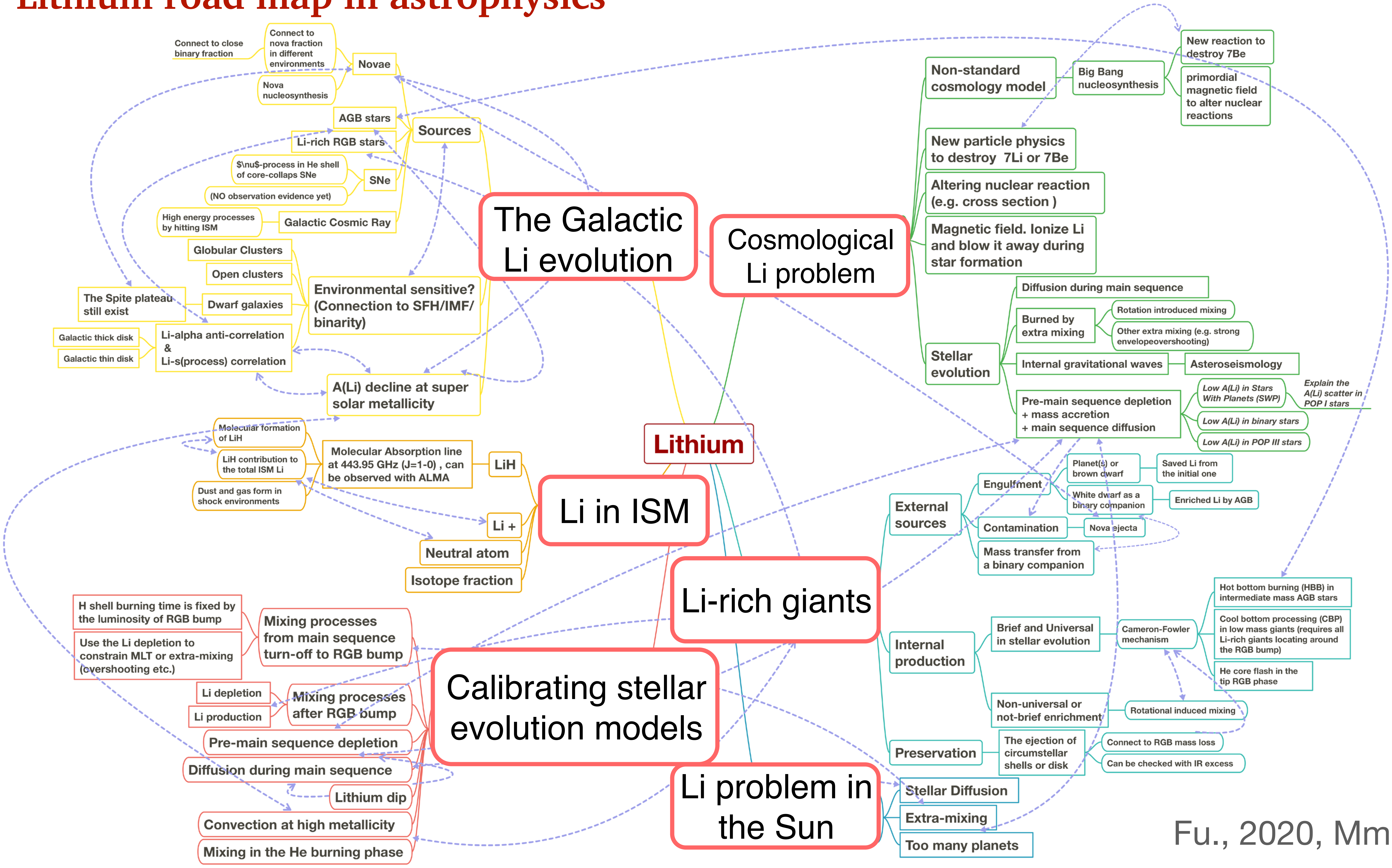
Costa et al., 2021, MNRAS

# Which nuclear reactions are (more) important to stellar evolution?

example on low mass stars

$^{7}Li(p,\alpha)^{4}He$

# Lithium road map in astrophysics

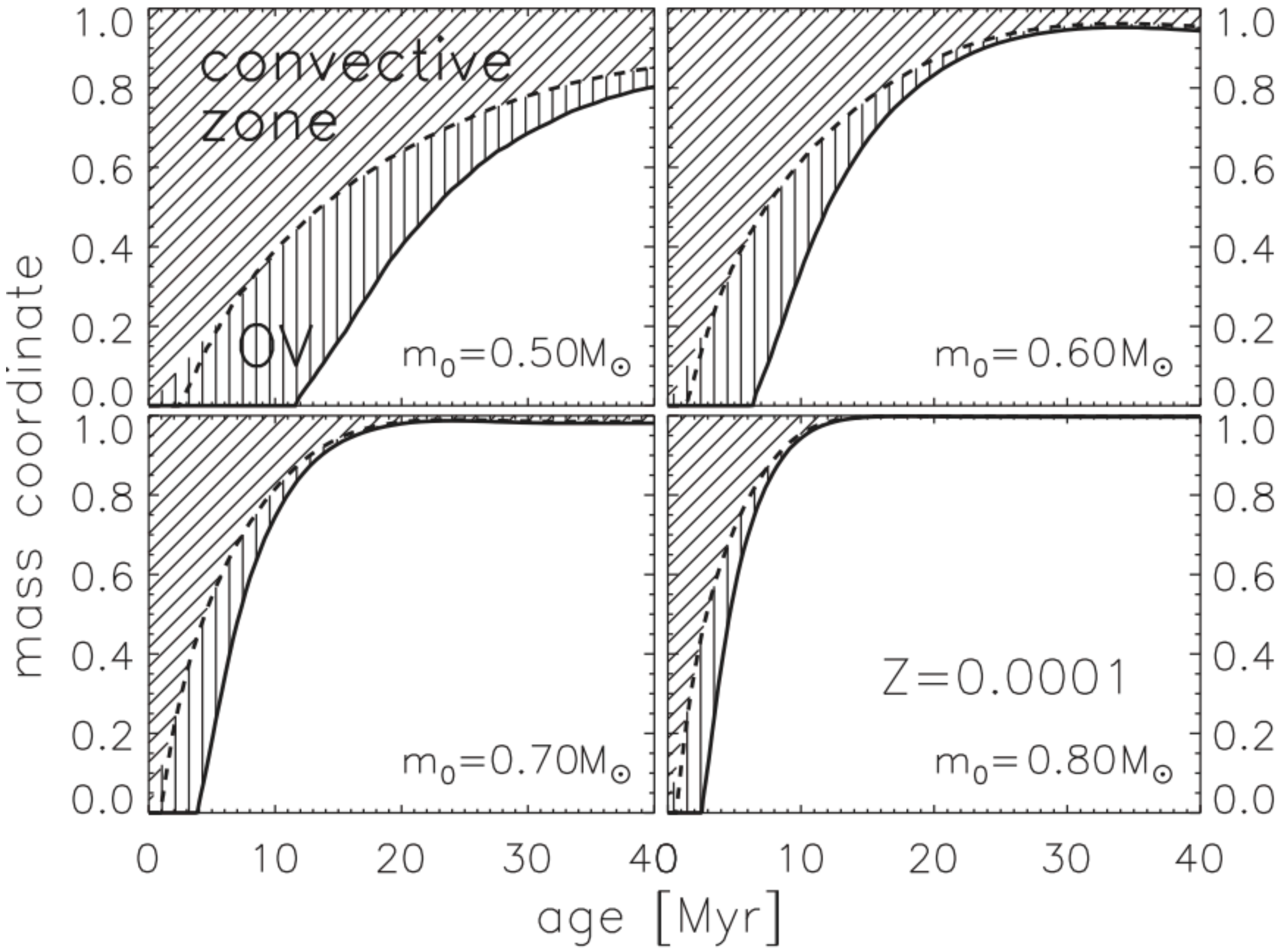


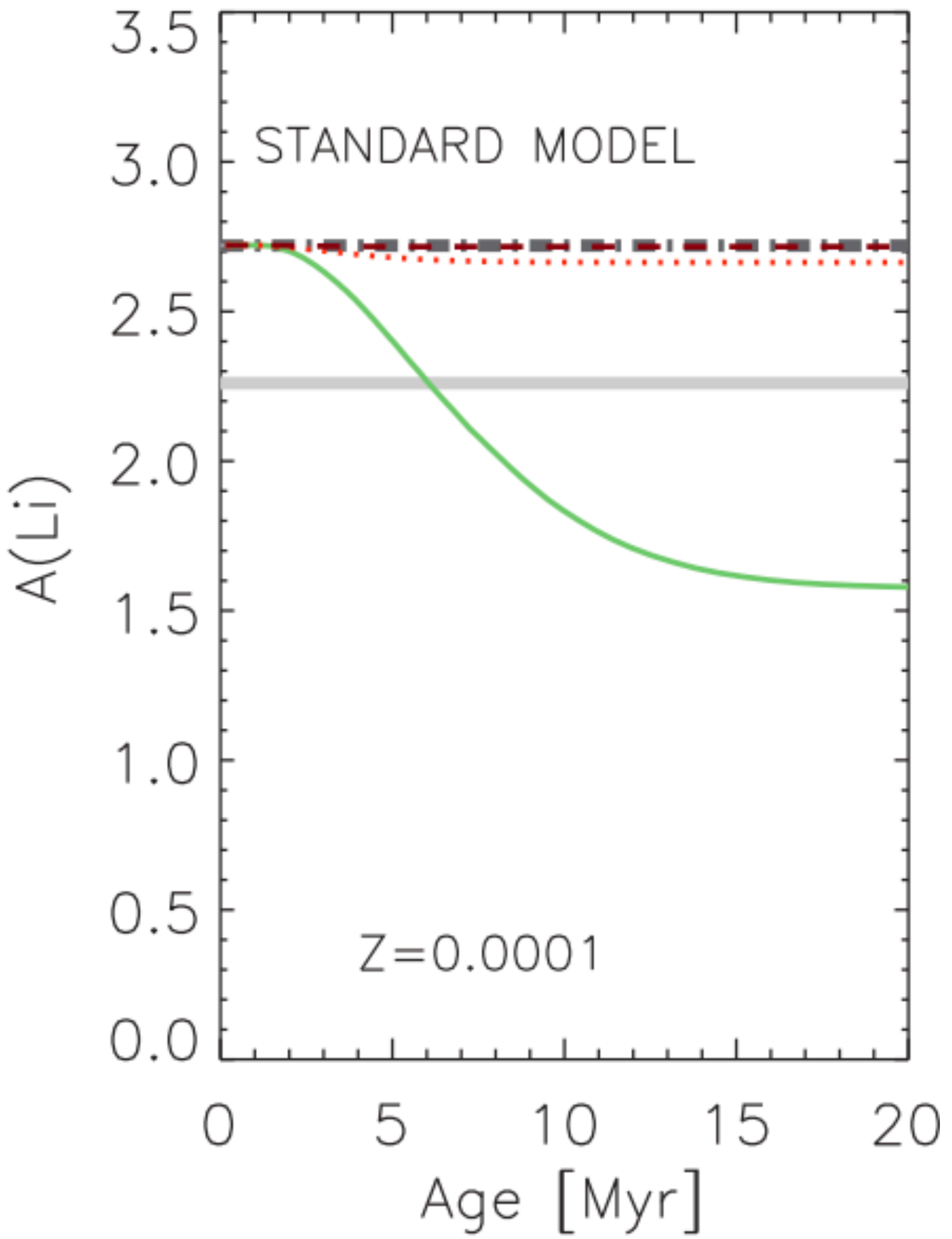

Fu., 2020, MmSAI

# Which nuclear reactions are (more) important to stellar evolution?

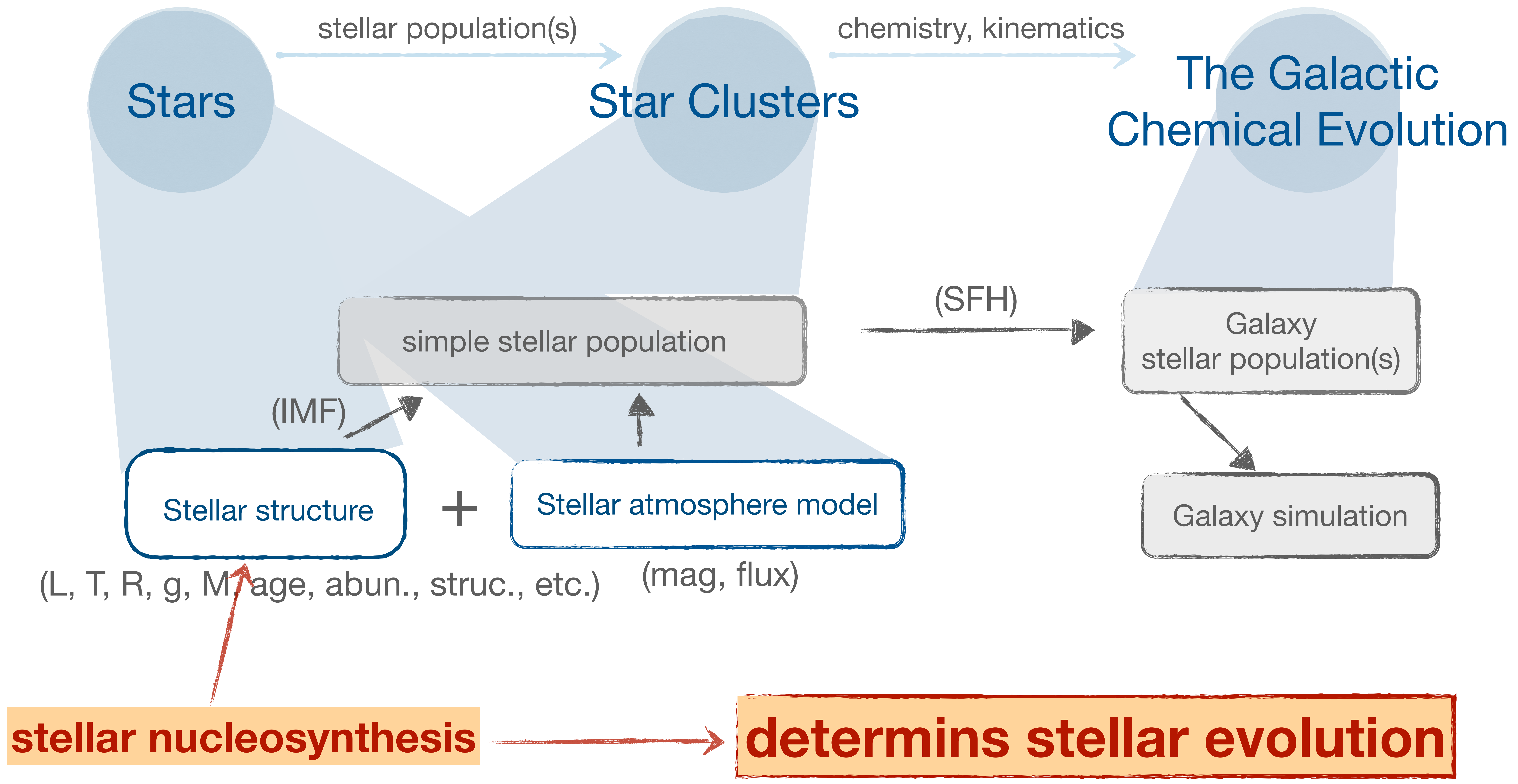
example on low mass stars

$^7Li(p,\alpha)^4He$




Fu et al, 2015, MNRAS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