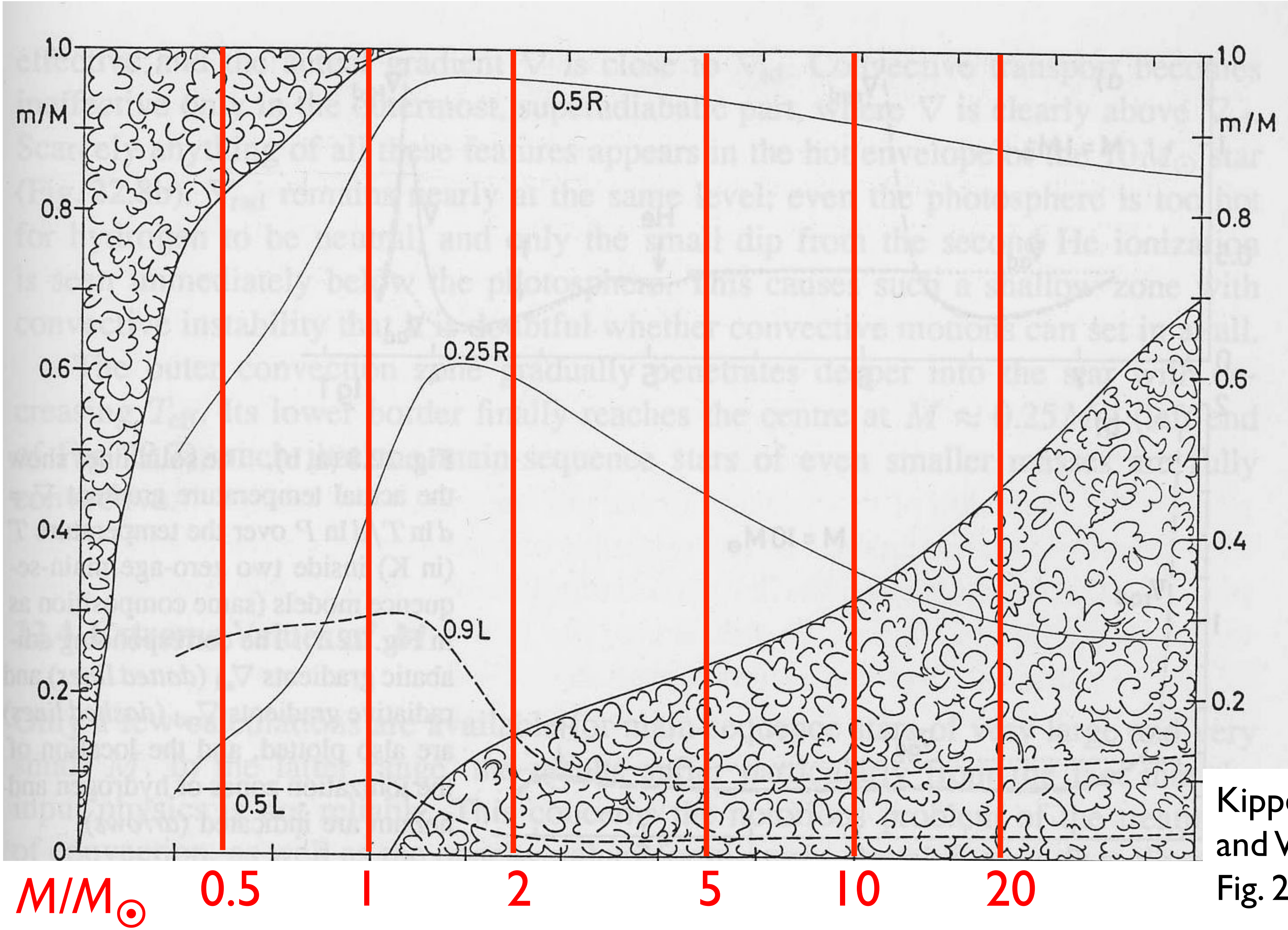
Evolution of stellar surface abundances

- Stellar evolution: dredge-ups
- Galactic chemical evolution

Main questions

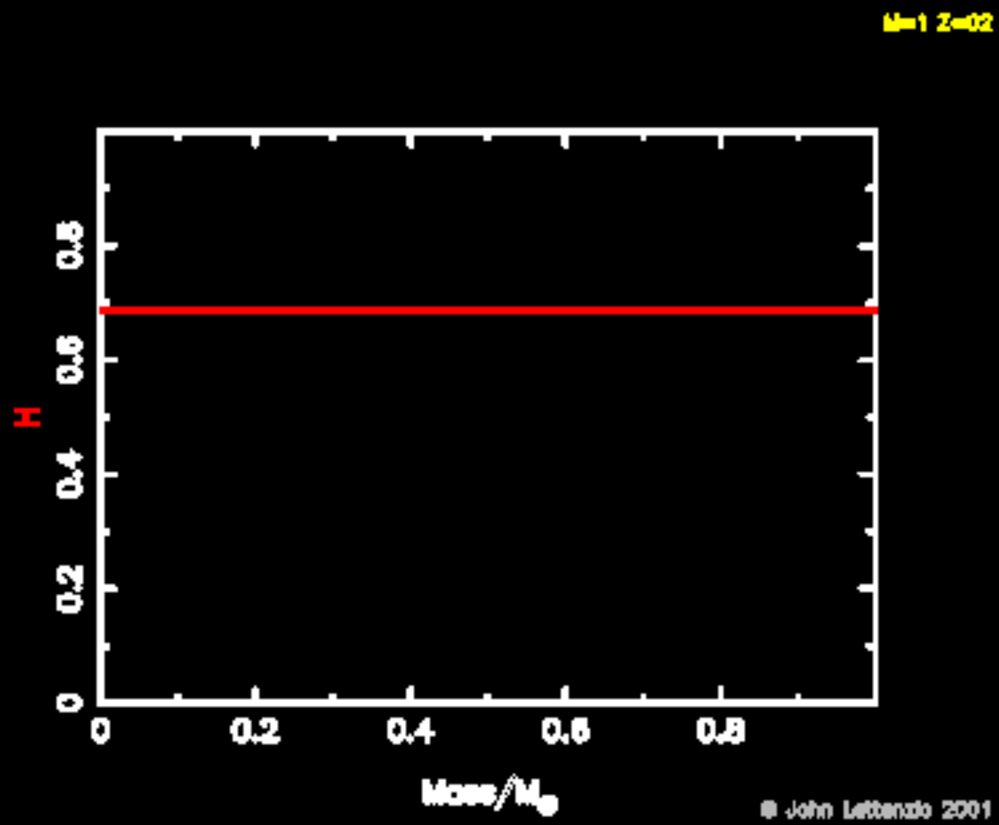
- Which chemical elements are produced during different phases of stellar evolution?
- How are the elements transported to the surface of the star and into the interstellar medium?
- Answers are based on results of stellar evolution models

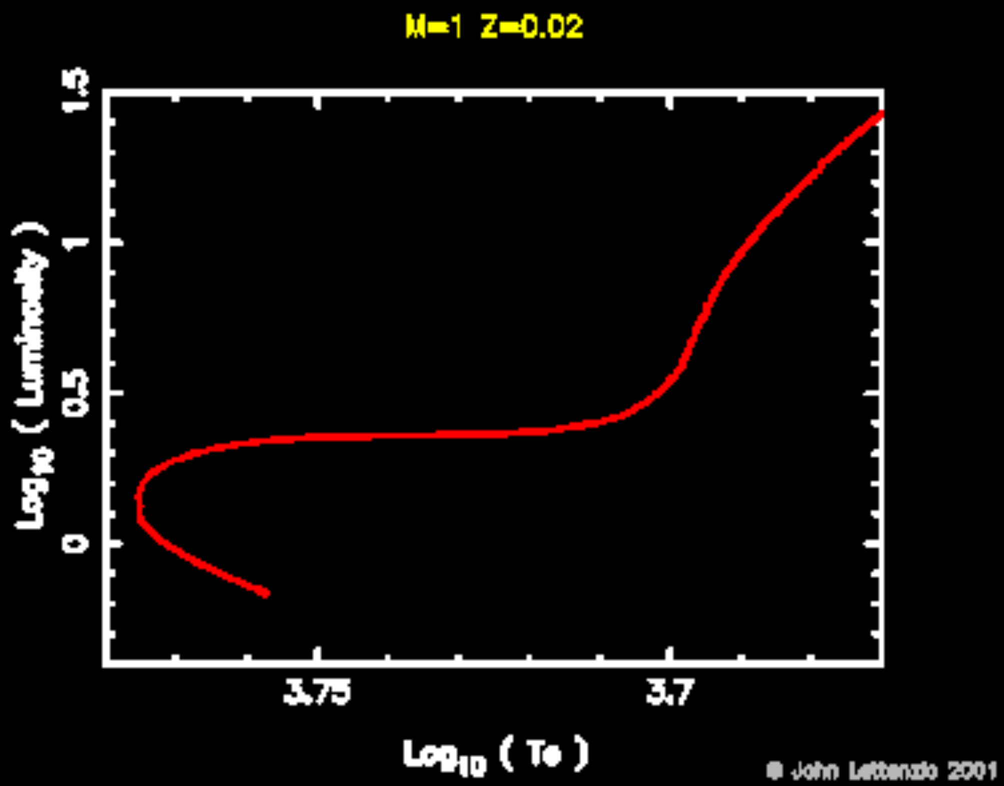
Structure of zero-age main-sequence stars



Kippenhahn
and Weigert
Fig. 22.7

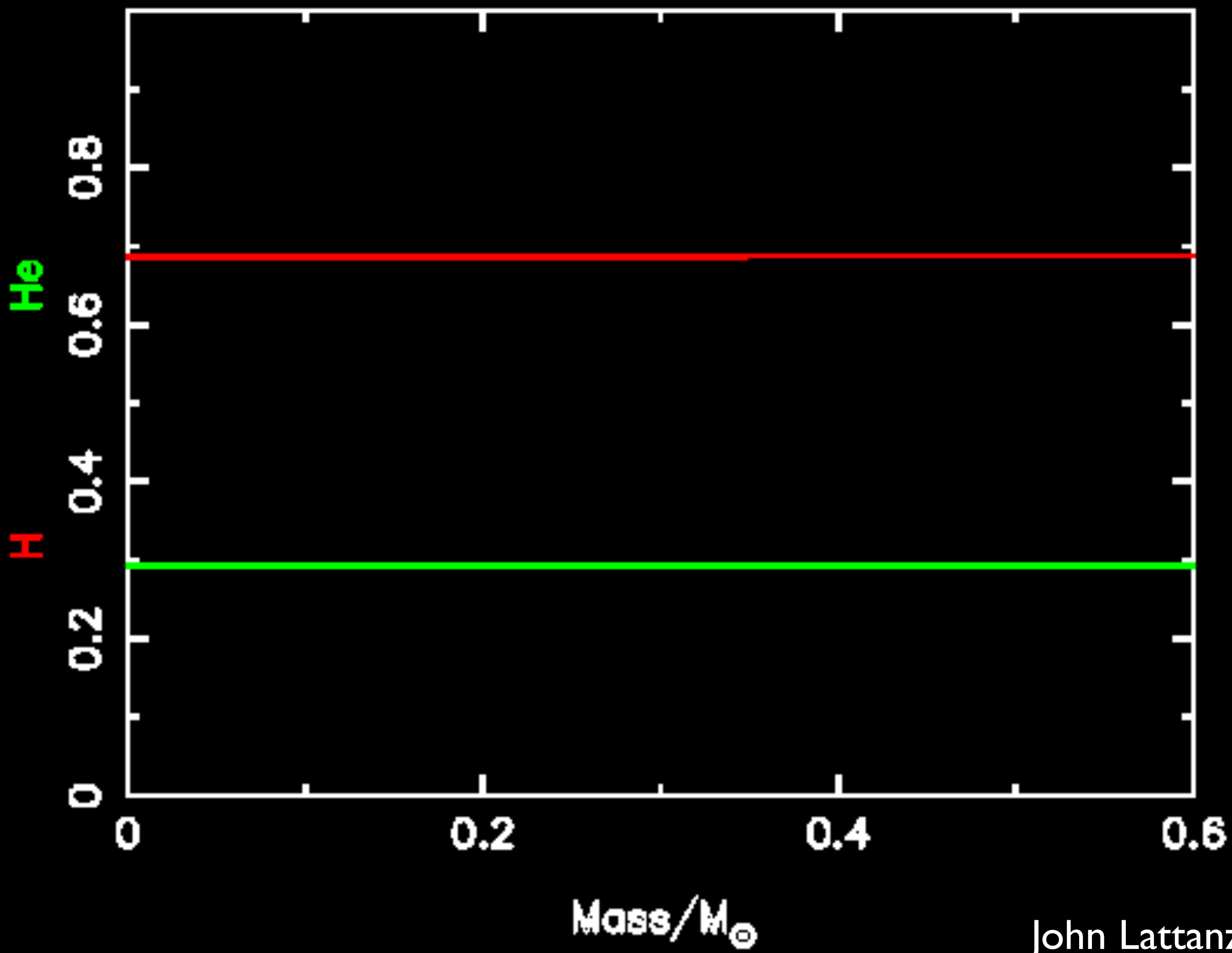
Hydrogen profile in 1M$_\odot$ star





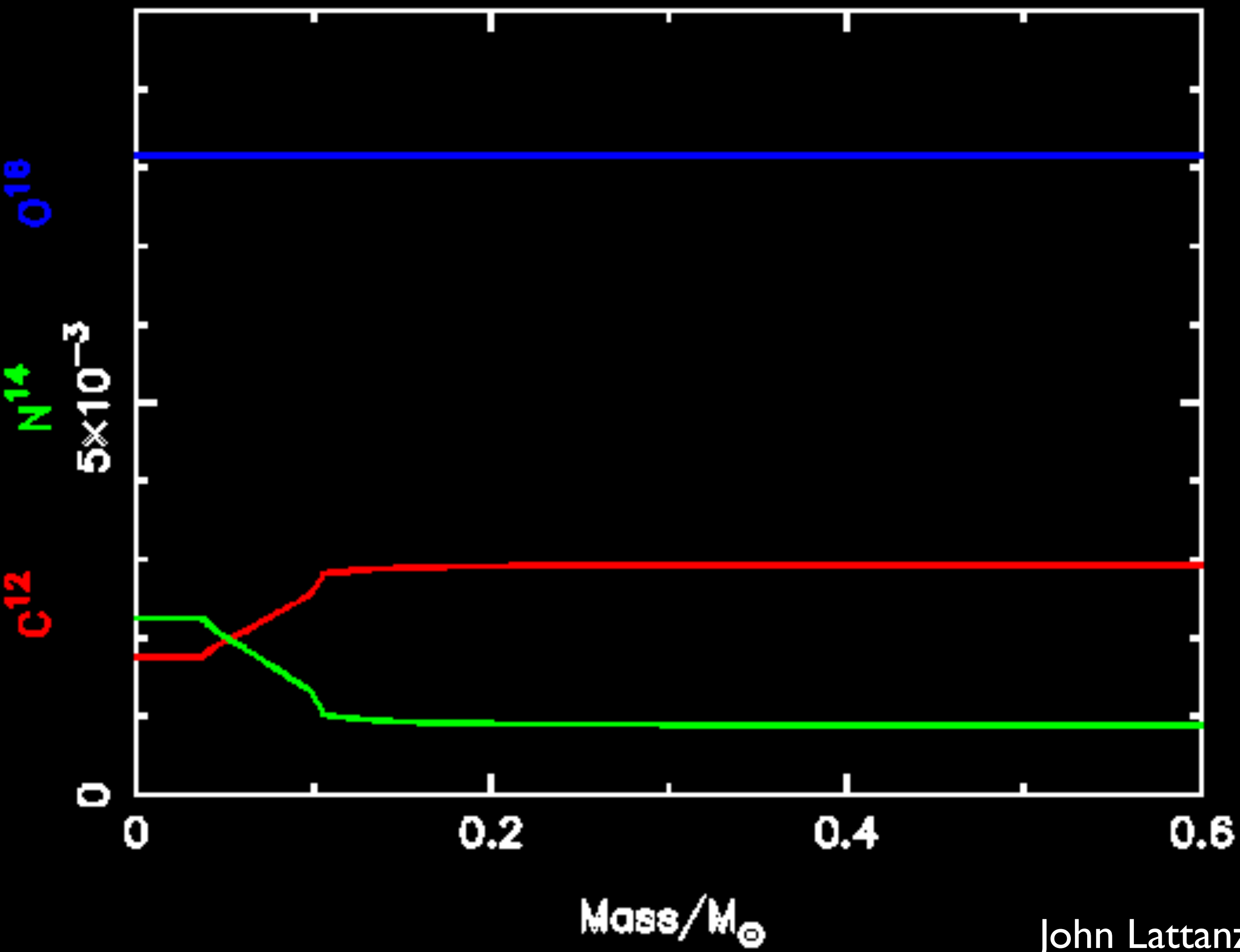
John Lattanzio 2001 (http://users.monash.edu.au/~johnl/StellarEvolnV1/)

H + He profiles in $1M_{\odot}$ star



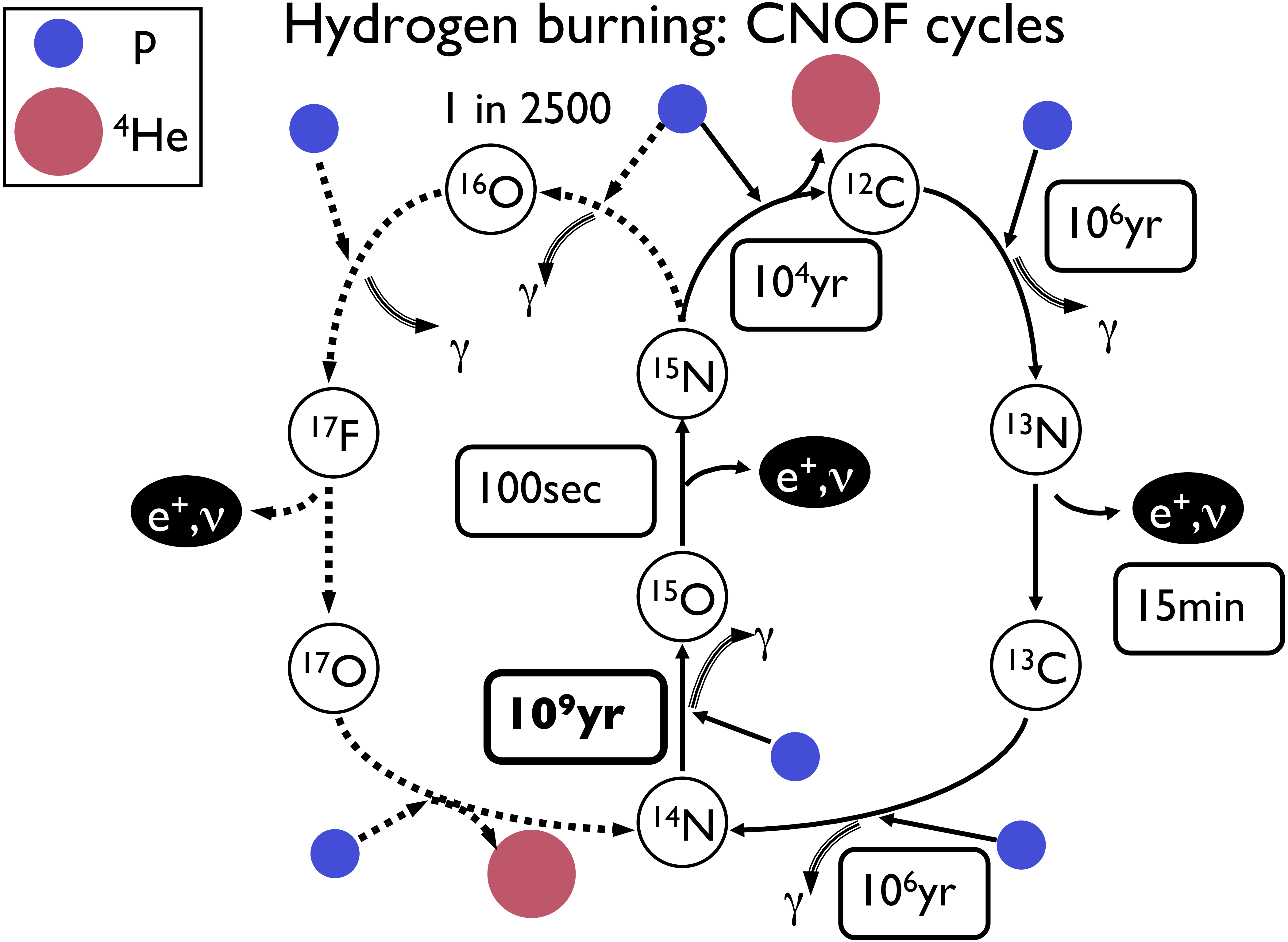
John Lattanzio 2001

C, N, O profiles in $1M_\odot$ star



John Lattanzio 2001

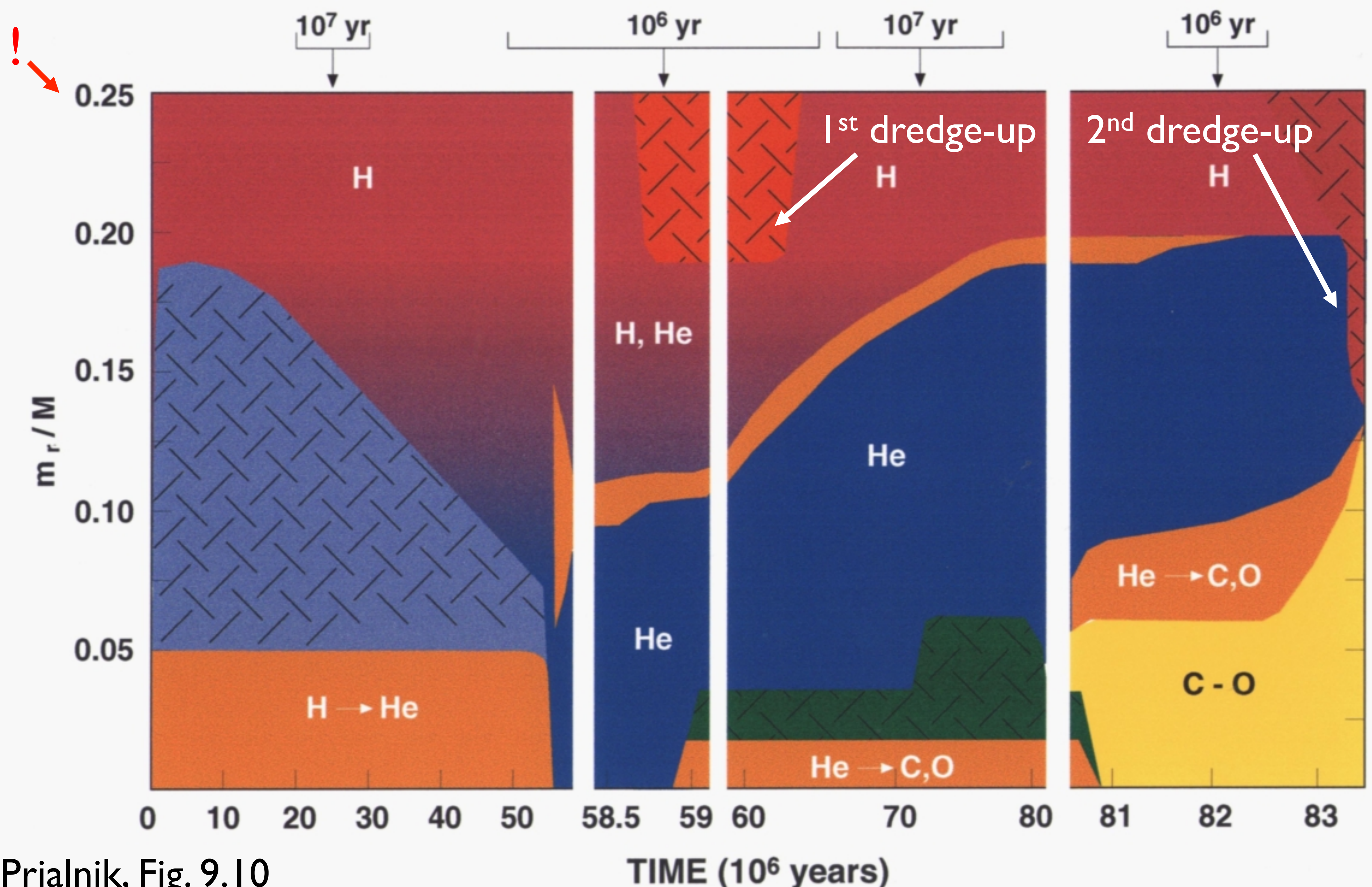
Hydrogen burning: CNOF cycles



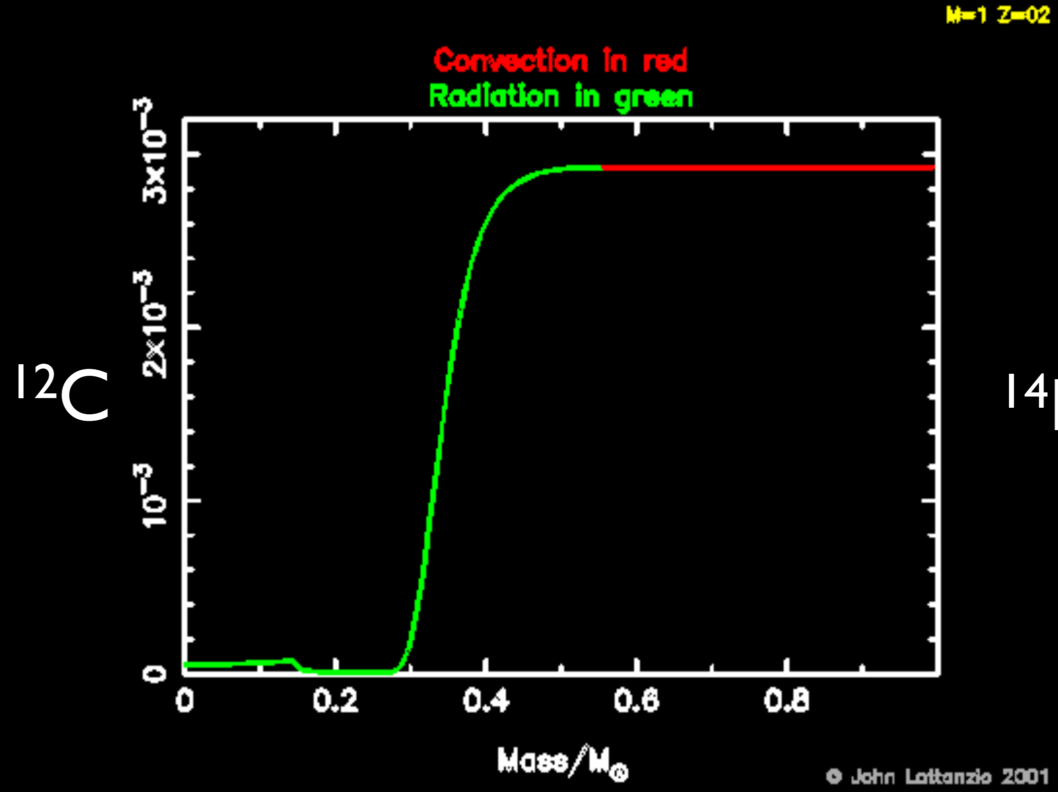
Dredge-up effect

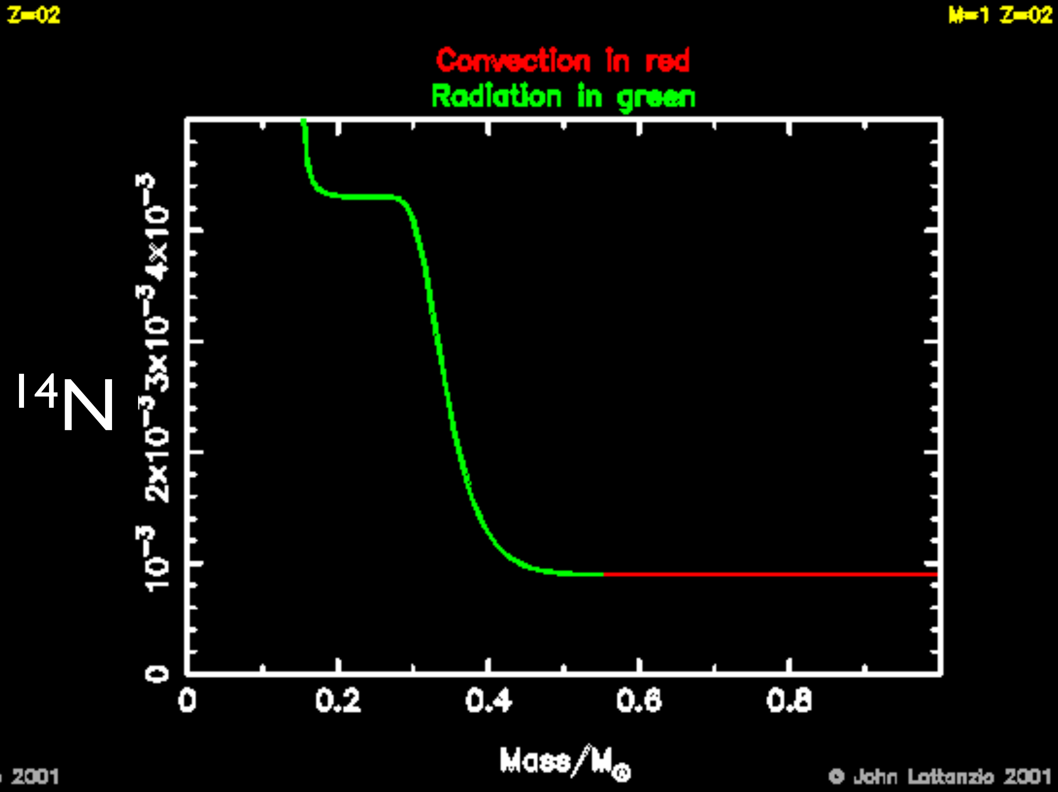
- Composition throughout a convection zone is uniform $\rightarrow$ H burning products can migrate to cooler regions
- When convective stellar envelope has inner boundary overlapping with outer boundary of formerly convective core $\rightarrow$ products of nuclear burning brought to surface and observed in spectrum $\rightarrow$ ***dredge-up***
- Can be used as test of stellar evolution theory
- Occurs **three times** during post-main-sequence evolution

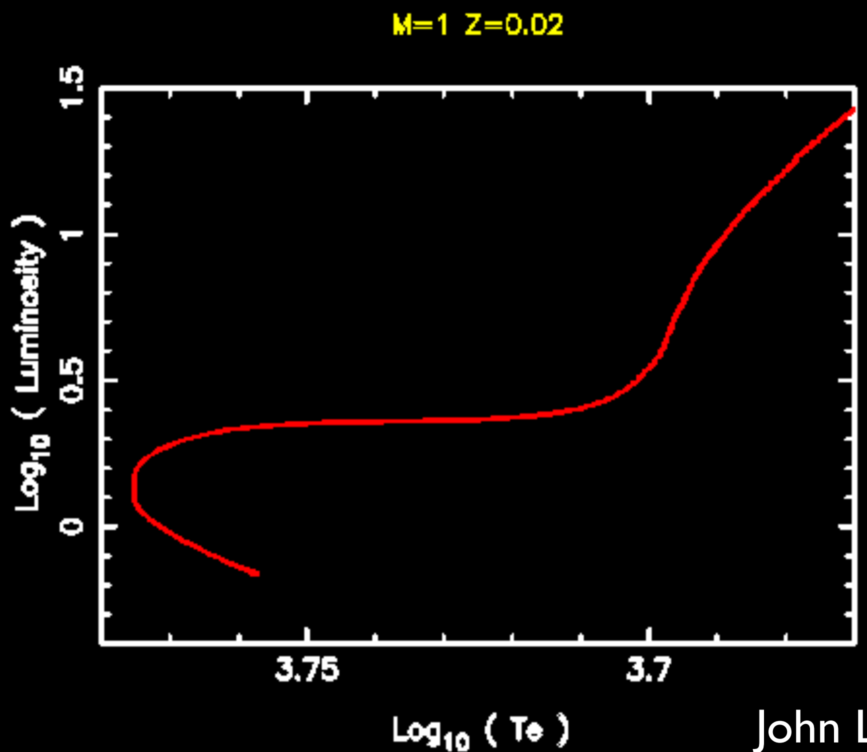
Structure of 6 $M_\odot$ star from main sequence to AGB



Prialnik, Fig. 9.10







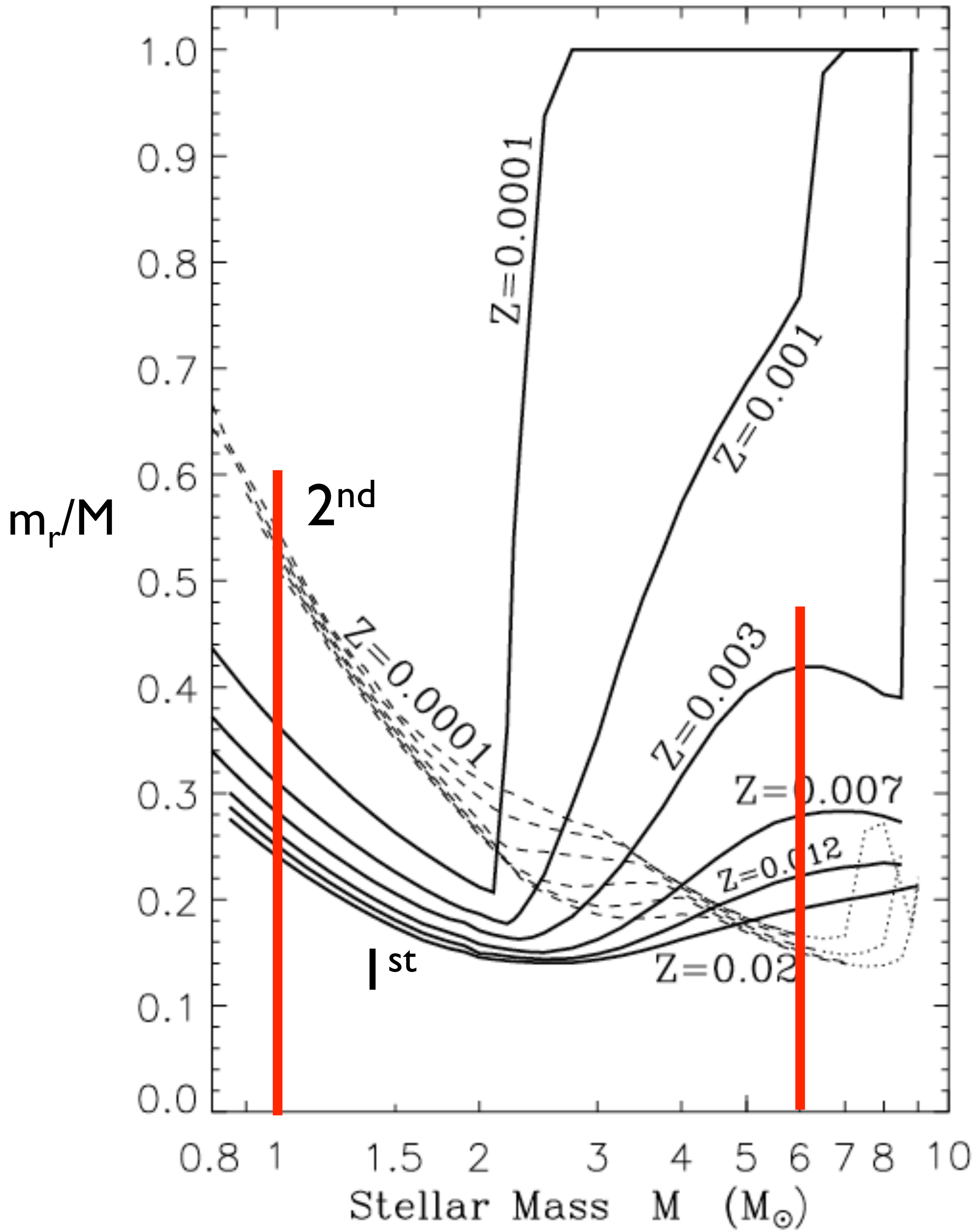
First dredge-up

^{12}C and ^{14}N profiles for $1M_\odot$

John Lattanzio 2001

First dredge-up – effects on surface abundances

- H-burning products are mixed to surface
- Doubling of surface ^{14}N abundance
- Reduction of surface ^{12}C abundance by approx 30%, e.g. –0.1 dex for metal-poor field stars of Carretta et al. (1999)
- Reduction of surface ratio $^{12}C/^{13}C$ to about 20−30 (solar = 95)
- Reduction of envelope Li and Be abundances by several orders of magnitude
- Slight change in ^{16}O abundance
- Values depend on mass, metallicity, He content, efficiency of convection



Innermost mass layer of convective envelope during 1st (solid lines) and 2nd (dashed lines) dredge-up, for different metallicities Z

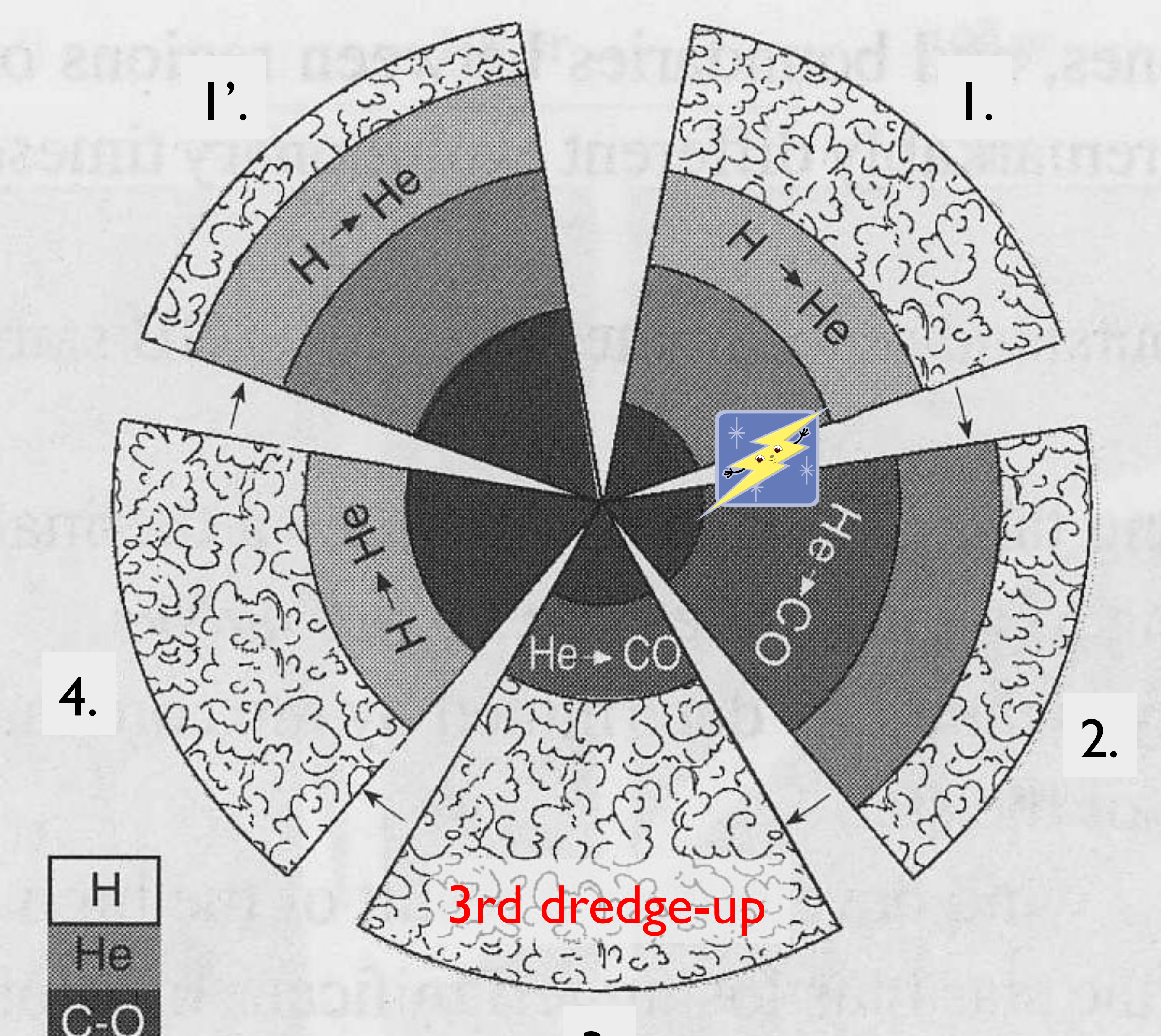
- **2nd dredge-up** for $M > 3-5\ M_{\odot}$, climbing up AGB
- Products from H-shell burning dredged up
- Large increase in ^{14}N and decrease in ^{12}C and ^{16}O

Sackmann & Boothroyd (1999)

Thermal pulses at top of AGB

1. H-burning shell above He layer above C-O core.
   He layer contracts and heats up until He burning starts in very thin shell → thermal instability → *He-shell flash*
2. High nuclear energy generation rate for short time, energy absorbed by layers above by expansion and cooling → H burning switched off
3. He-burning shell moves outward, approaches H-rich envelope, increases temperature there → H-shell burning starts again
4. Temperature close to H-burning shell adjusts to thermal equilibrium → too low for He burning → He-shell burning stops

Third dredge-up



Prialnik Fig. 9.11

- Products of H and He burning: He, C, N
- C/O can be raised from ~0.4 to >1 → carbon star
- Products of further reactions during He flash: Ne, Mg, and elements heavier than Fe formed by neutron capture (s-process)

Nucleosynthesis during core-collapse supernova explosions

- Shock wave heats envelope to $\approx 5 \cdot 10^9$ K
  $\rightarrow$ nuclear statistical equilibrium (a.k.a. Si burning)

$$^{16}_{8}\mathrm{O} \overset{(\alpha,\gamma)}{\rightleftharpoons} {}^{20}_{10}\mathrm{Ne} \overset{(\alpha,\gamma)}{\rightleftharpoons} {}^{24}_{12}\mathrm{Mg} \overset{(\alpha,\gamma)}{\rightleftharpoons} {}^{28}_{14}\mathrm{Si}\ldots$$

  $\rightarrow$ main production site of "α-elements"
  O, Ne, Mg, Si, S, Ca

- Heaviest product $^{56}_{28}\mathrm{Ni}$
- Example: total amount of metals produced by 20 $M_\odot$ star is about 3 $M_\odot$, of which 1−2 $M_\odot$ are oxygen, and 0.2 $M_\odot$ are carbon.

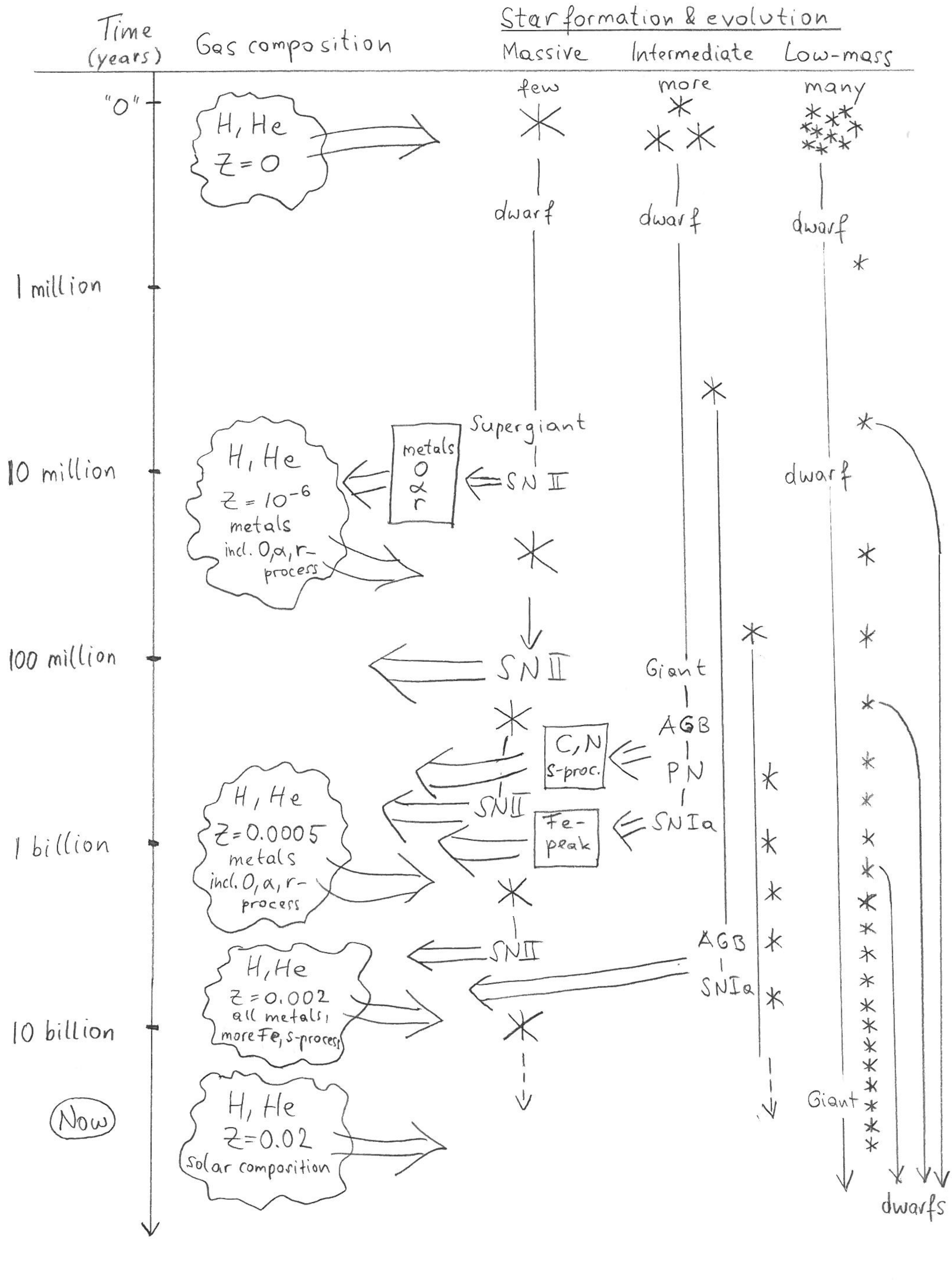
Nucleosynthesis during SN Ia explosions

- Intermediate-mass stars in close binary systems may, after becoming a white dwarf, accrete enough matter to surpass the Chandrasekhar mass limit and cause a Type Ia supernova.
- Nucleosynthesis during a SN Ia is very efficient in producing iron-peak isotopes, while also producing various lighter elements.
- For example, the models by Nomoto et al. (1984) predict that a 1 $M_\odot$ CO-white dwarf/red-giant SN Ia produces 0.9 $M_\odot$ of Cr−Ni, and 0.4 $M_\odot$ of Mg−Ca.
- It is estimated that SNe Ia contributed about 2/3 of the iron in the solar neighborhood, the remainder coming from SNe II.

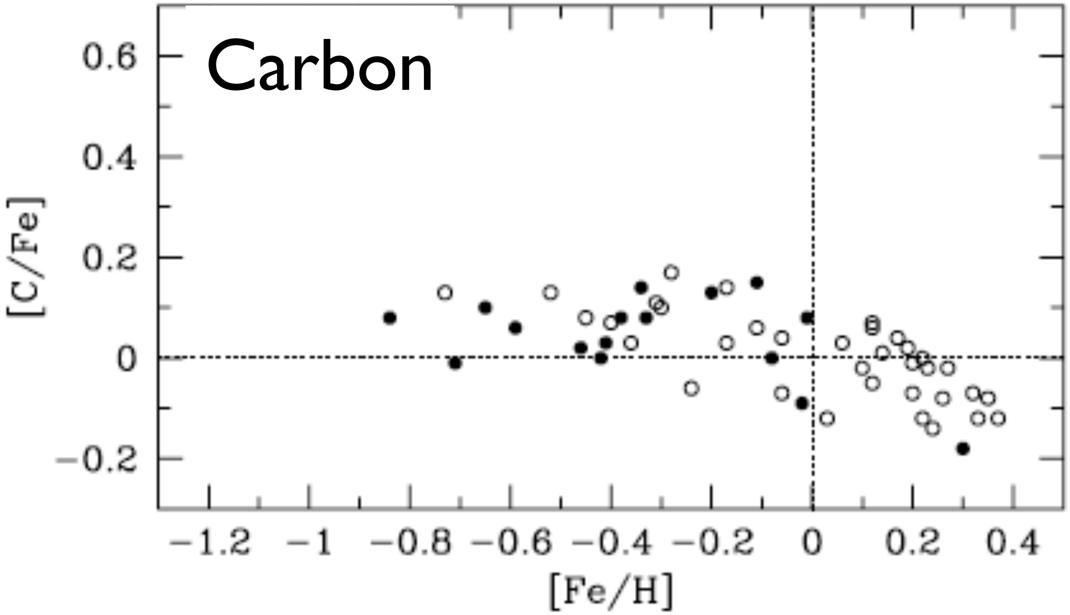
Summary

- Which chemical **elements** are **produced** during different phases of stellar evolution?
  - Main sequence and H-shell burning: **He, N**
  - He-burning: **C, O**
  - AGB (He-shell flash): **Ne, Mg, s-process** elements
  - Supernovae: **Fe-peak elements, α-elements,** possibly **r-process** elements
- How are the **elements transported** to the surface of the star and into the interstellar medium?
  - **Convection, dredge-ups**
  - **Wind of AGB stars**
  - **Supernova explosions**

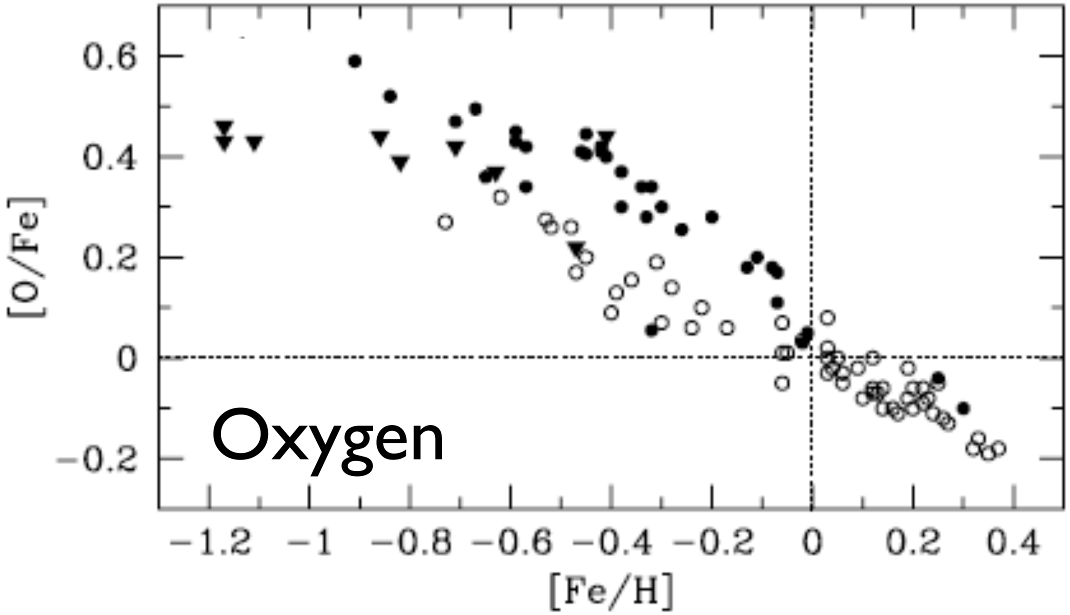
Chemical evolution in the Milky Way



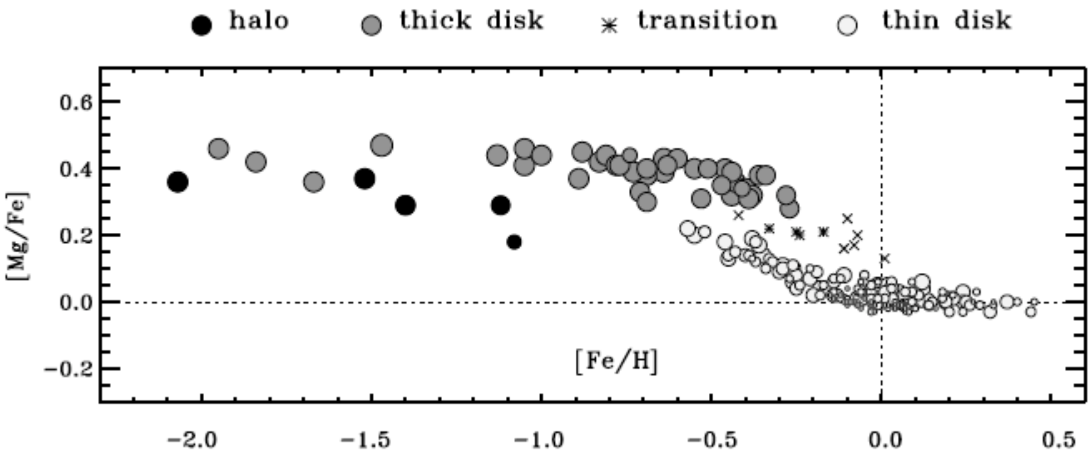
Observed abundance trends for C and α-elements



Bensby & Feltzing (2006, MNRAS 367, 1181)

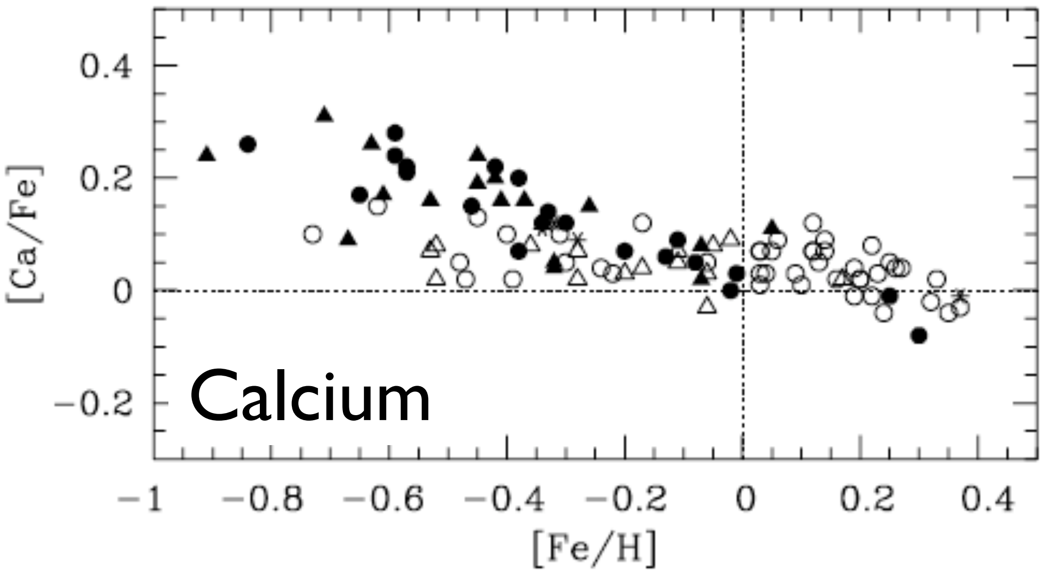


Bensby et al. (2005, A&A 433, 185)



Magnesium

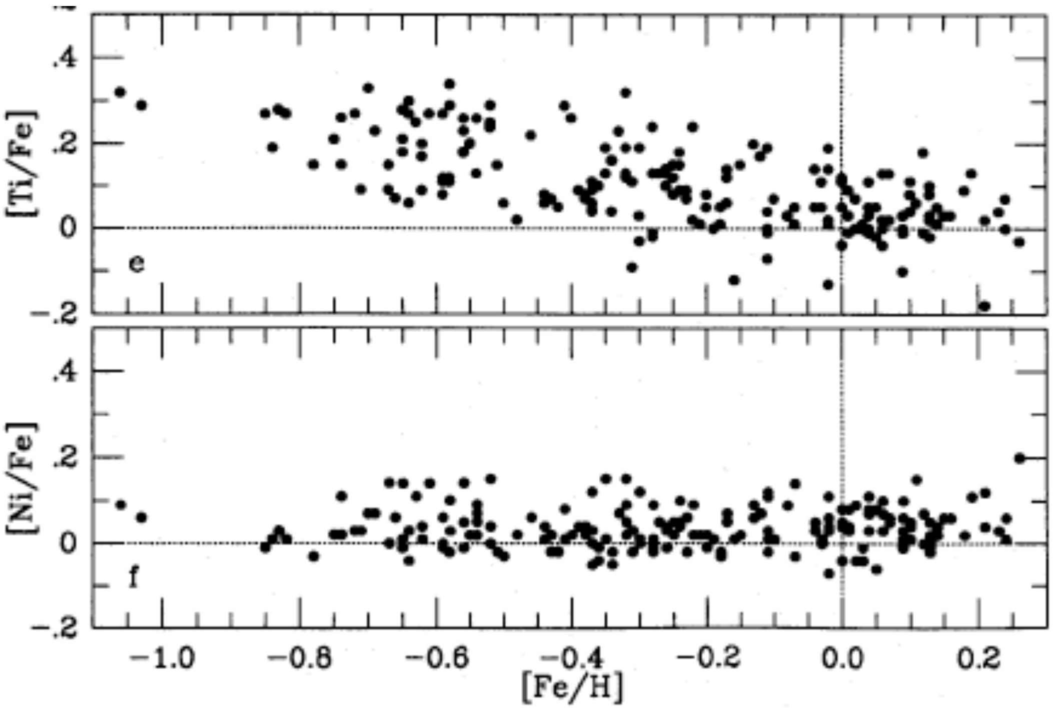
Fuhrmann (2004, AN 325, 3)

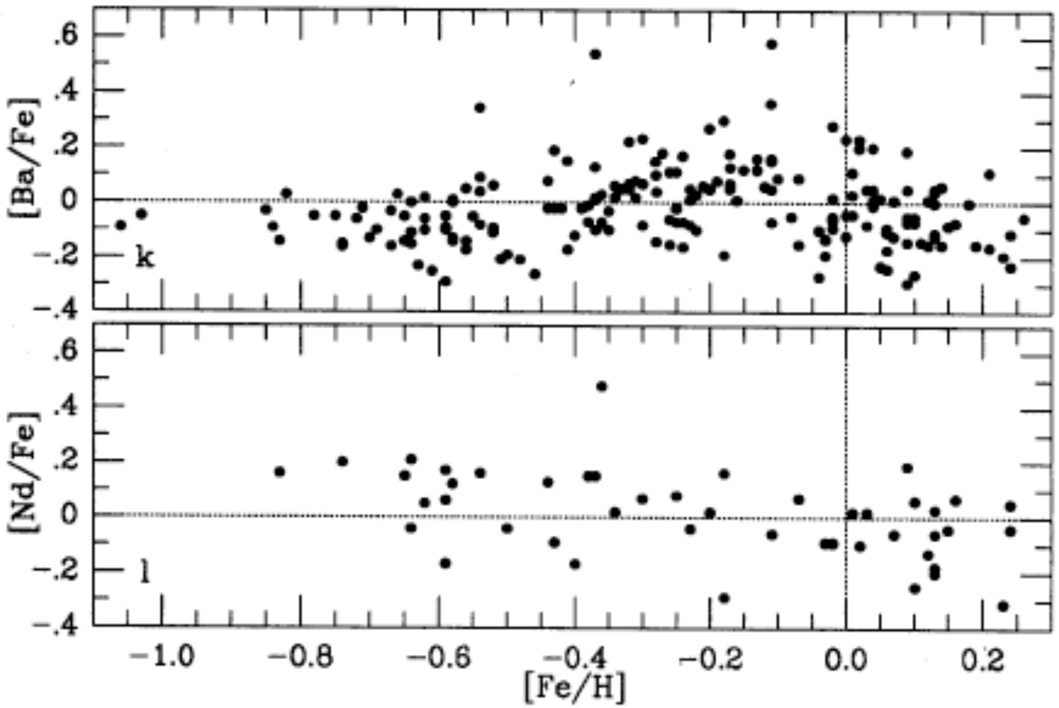


Observed abundance trends for heavy elements

Titanium

Barium (s-process)





Nickel (Fe-peak)

Neodymium (s-process)

Edvardsson et al. (1993, A&A 275, 101)

THE END