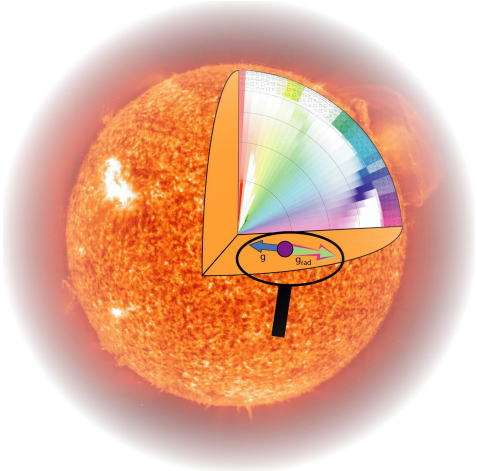
Chemical abundances



Morgan Deal
LUPM, University of Montpellier

Nuno Moedas
IA, University of Porto

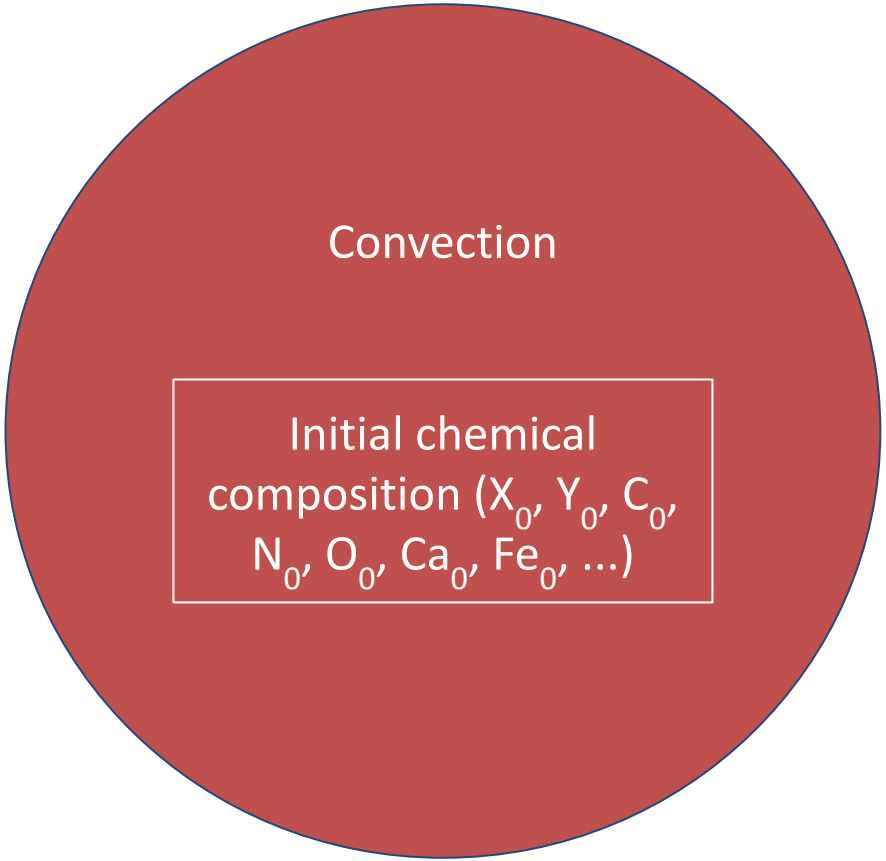
Chemical abundances requirements for PLATO

Which **elements**?

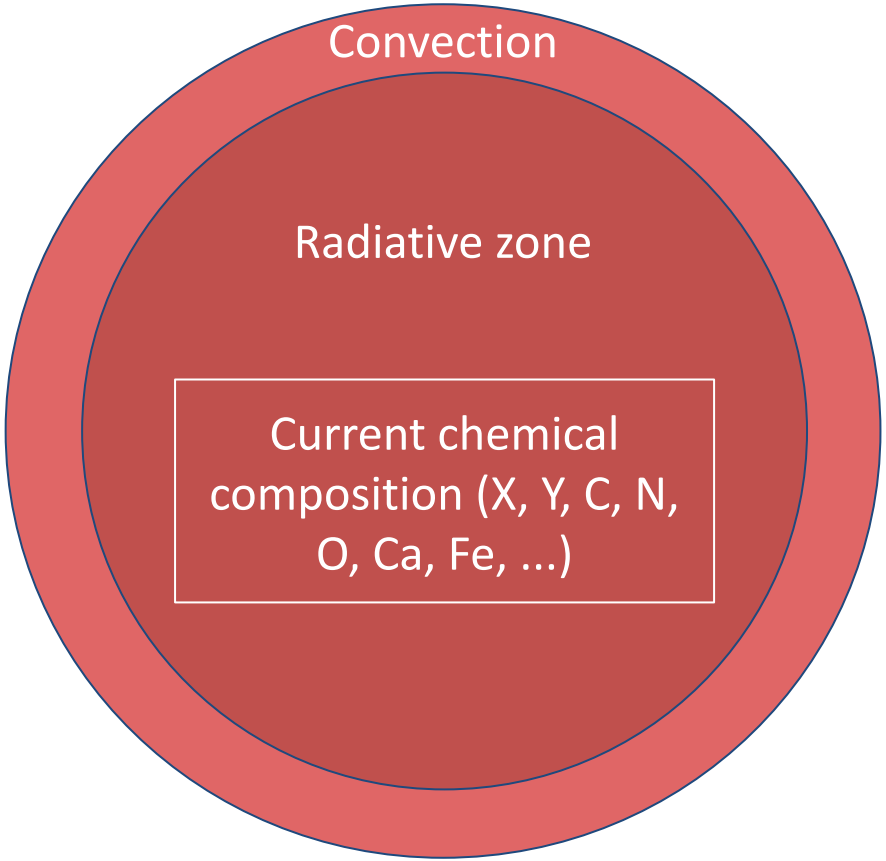
Which **precision**?

From the constraints we get from **stellar models** and the precision/accuracy of inferred ages, masses and radii
(for a given input physics)

Early Pre- Main Sequence (PMS)

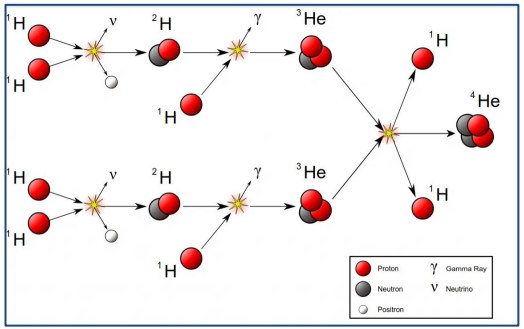


Main Sequence (MS)



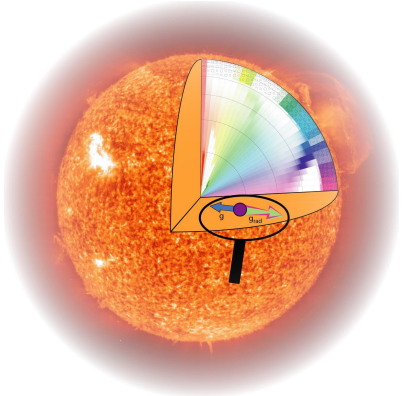
What can affect chemical elements in main-sequence stars?

Nuclear reactions



- ➔ PP chain
- ➔ CNO cycle
- ➔ Proton capture
- ➔ ...

Internal transport

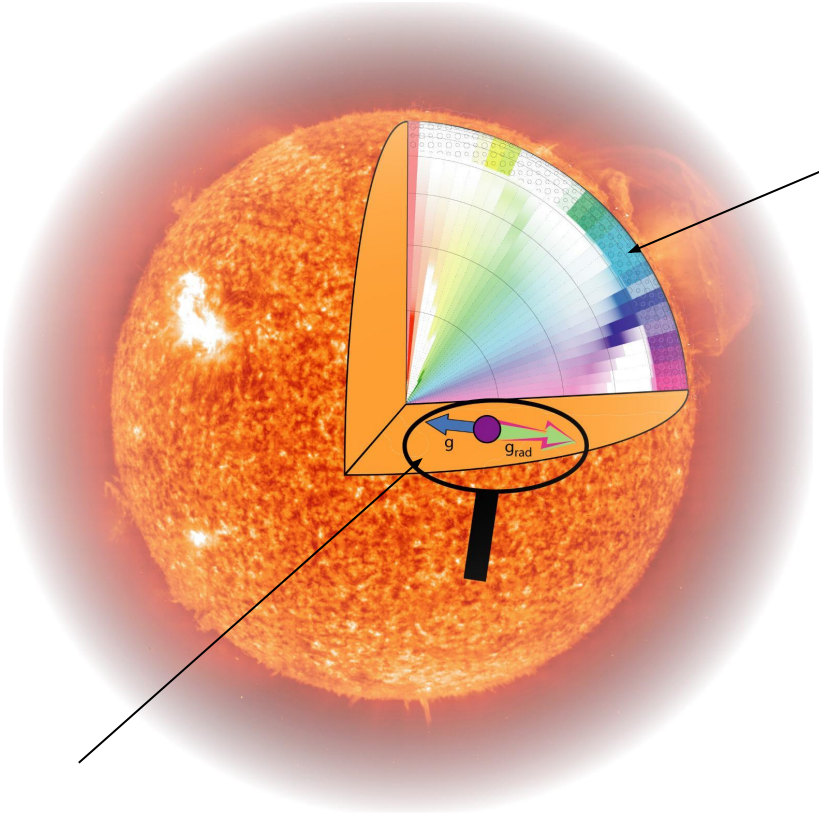


- ➔ Convection
- ➔ Rotation induced mixing
- ➔ Atomic diffusion
- ➔ ...

Accretion

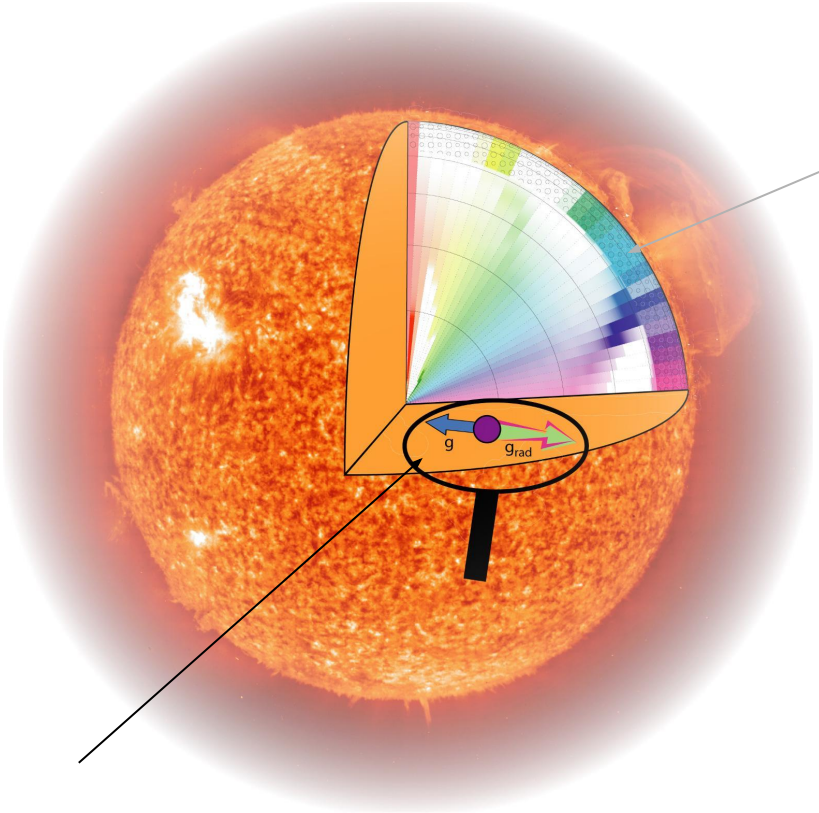
- ➔ From a companion
- ➔ Planet engulfment
- ➔ Protoplanetary disk
- ➔ ...

Macroscopic transport processes

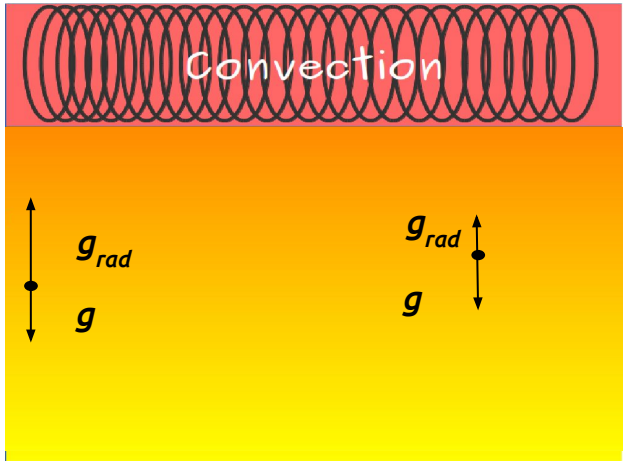


Microscopic transport processes (atomic diffusion)

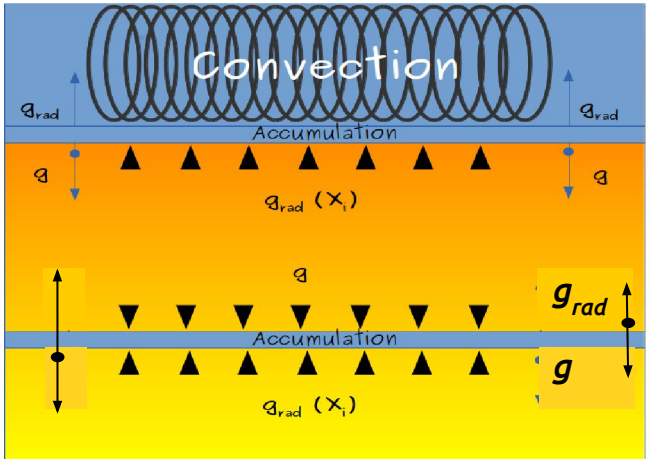
Macroscopic transport processes



Microscopic transport processes (atomic diffusion)



Leads to accumulation of some elements



Surface

Center

These effects are different for each element and depend on :

- the abundance of the element
- the ionisation state
- the photon flux

→ **Direct influence** on stellar **structure** and **surface abundances**

Atomic diffusion (with radiative accelerations)

Stars with masses <1.2 $M_\odot$: impact on age of 16%, on mass of 2.1%, and on radius of 0.8%

(Nsamba et al. 2018)

1.4 $M_\odot$ at solar metallicity: impact on age of 10-15%, on mass of 1-4%, and on radius of 1%

(Deal et al. 2018, 2020)

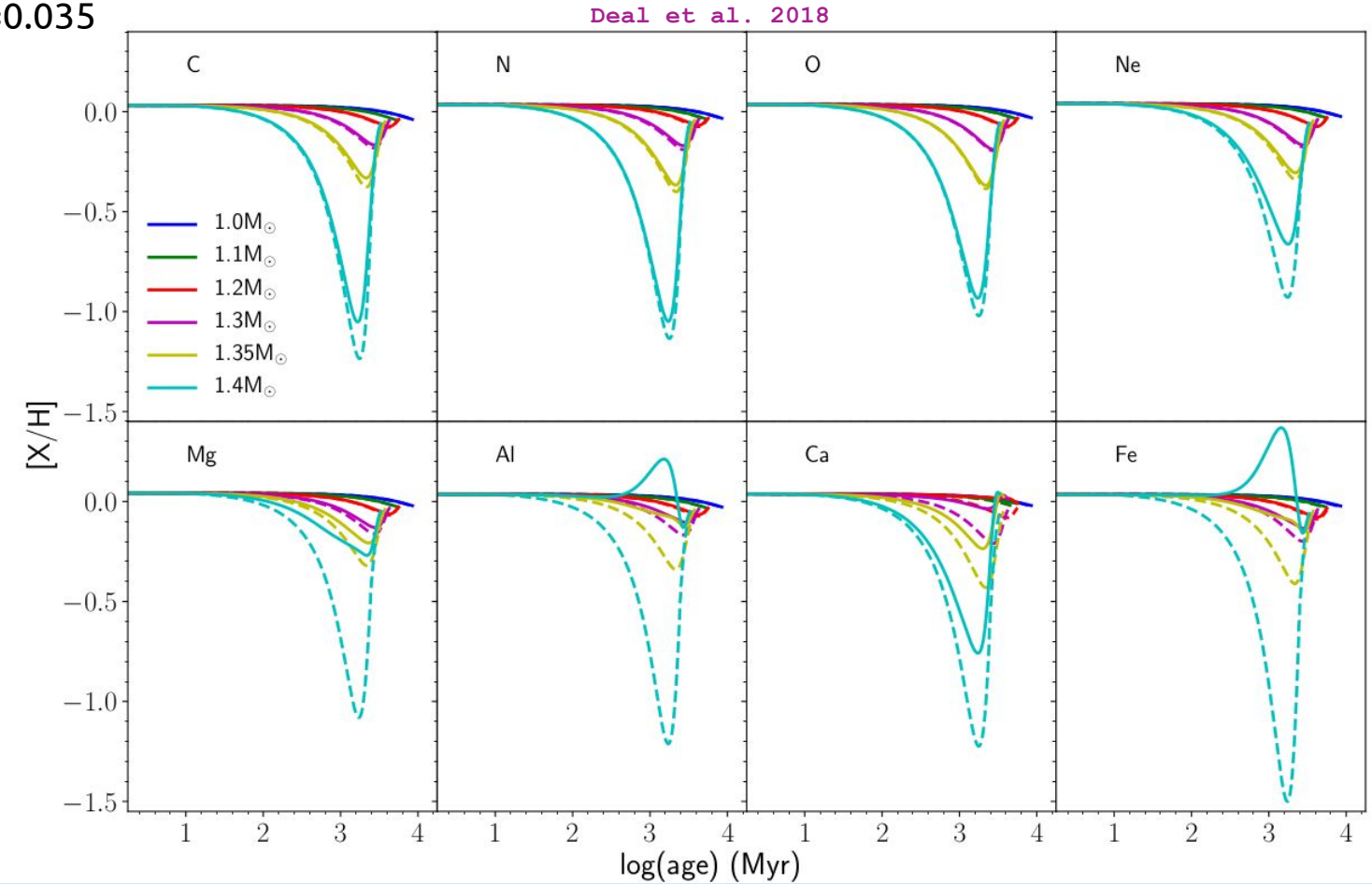
Rotation + atomic diffusion

1.4 $M_\odot$ at solar metallicity: impact on age of 25%, on mass of 2-5%, and on radius of 2%

(Deal et al. 2020)

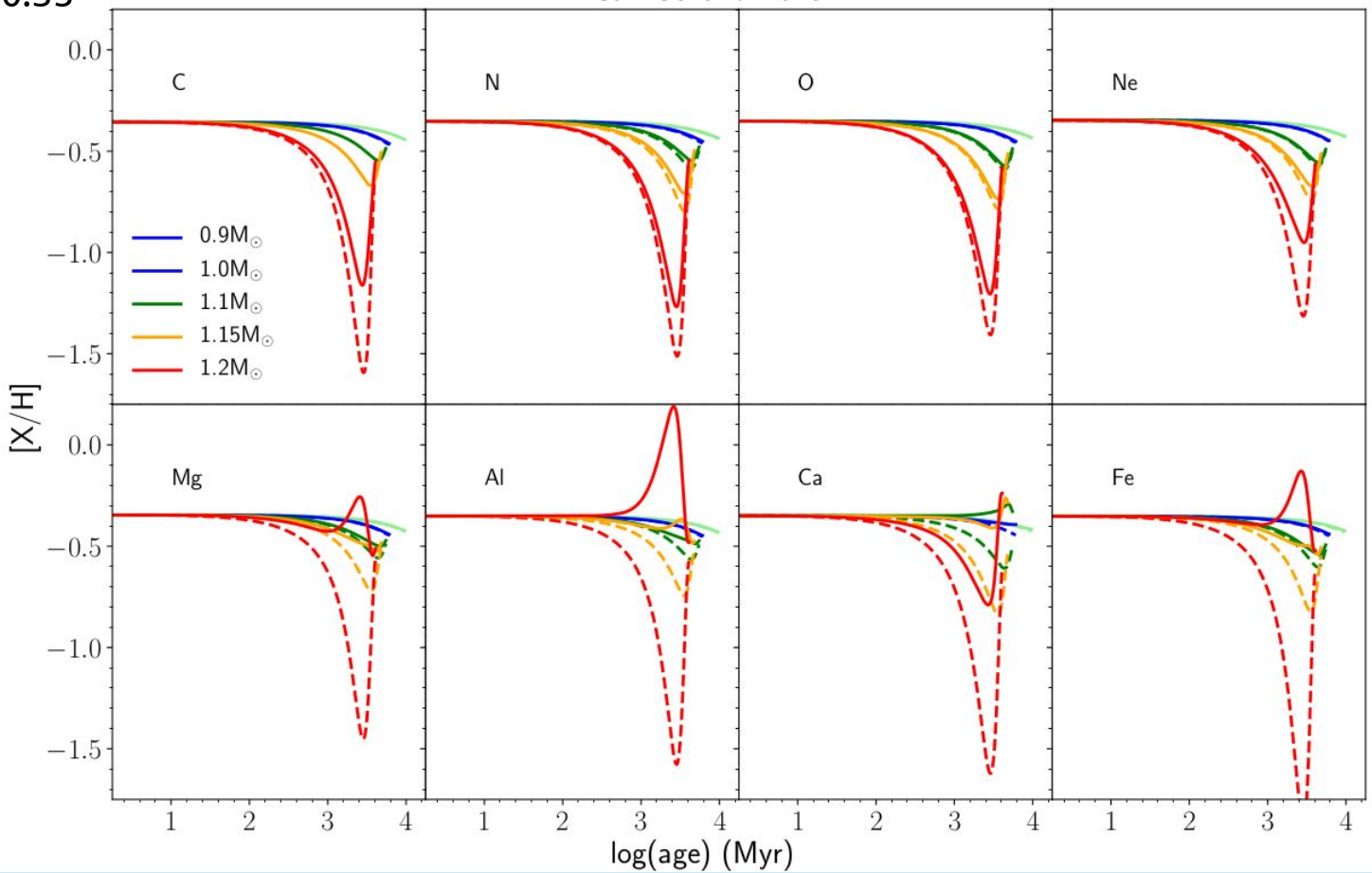
PLATO (for stars): 10% on ages, 15% (~5%) on masses and 2% on radius

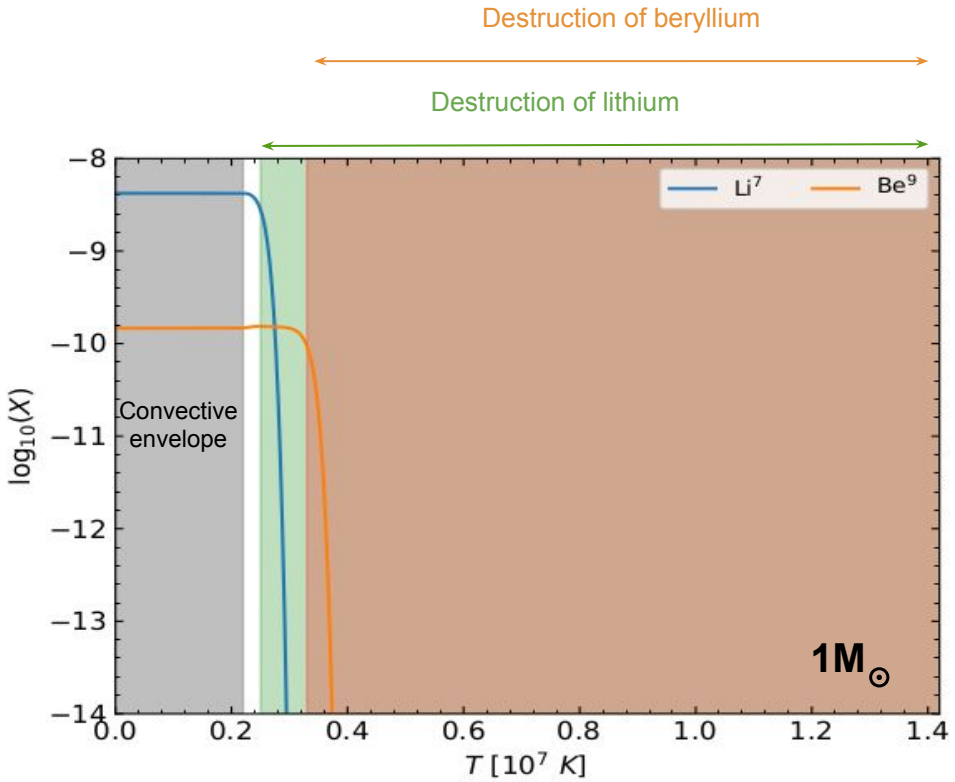
$[Fe/H]_{ini}$=0.035


Deal et al. 2018
C
N
O
Ne
Mg
Al
Ca
Fe
1.0M⊙
1.1M⊙
1.2M⊙
1.3M⊙
1.35M⊙
1.4M⊙
[X/H]
log(age) (Myr)

$[Fe/H]_{ini}$=-0.35

Deal et al. 2018




Destruction of beryllium
Destruction of lithium
Li⁷
Be⁹
Convective envelope
1M⊙
log₁₀(X)
T [10⁷ K]
−8
−9
−10
−11
−12
−13
−14
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

Chemical abundances requirements for PLATO

➔ **Which elements?**

- Elements followed by stellar evolution codes including atomic diffusion (with g_{rad}):

H, He, **Li**, **Be**, B, **C**, **N**, **O**, Ne, Na, **Mg**, **Al**, **Si**, (P), S, (Cl), (Ar), (K), **Ca**, (Ti), (Cr), (Mn), **Fe**, (Ni)

⇩

Li and **Be** are particularly important to constrain macroscopic transport processes

(See e.g. Dumont et al. 2020, Deal et al. 2021, Eggenberger et al. 2022)

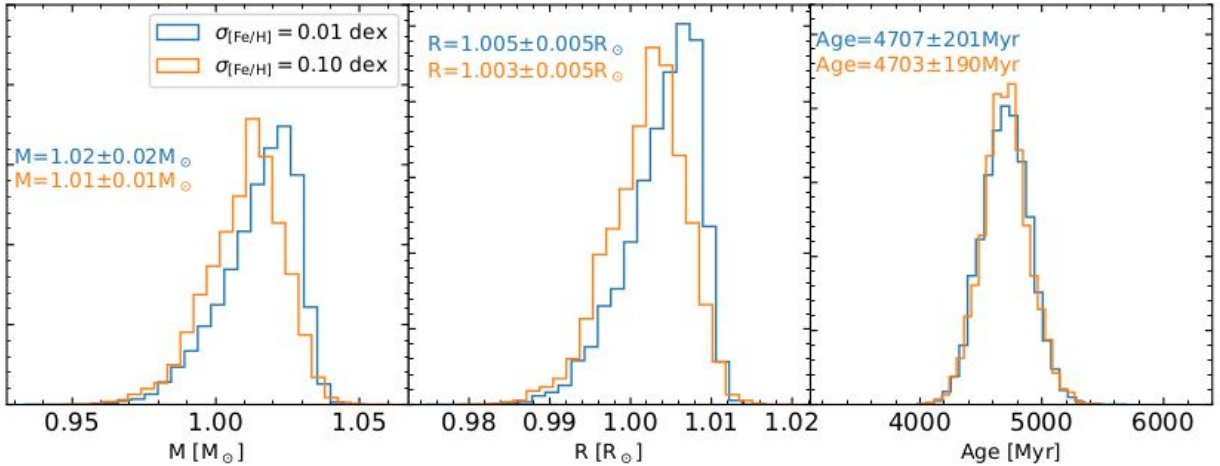
*Data to compute g_{rad} for these elements are not public

Individual frequencies (with surface corrections), ν_{max} + [Fe/H], Teff

➔ **Which precision?**

The Sun as a star
(equivalent to average Kepler seismic targets)

Mean σ_{freq} = 0.22μHz



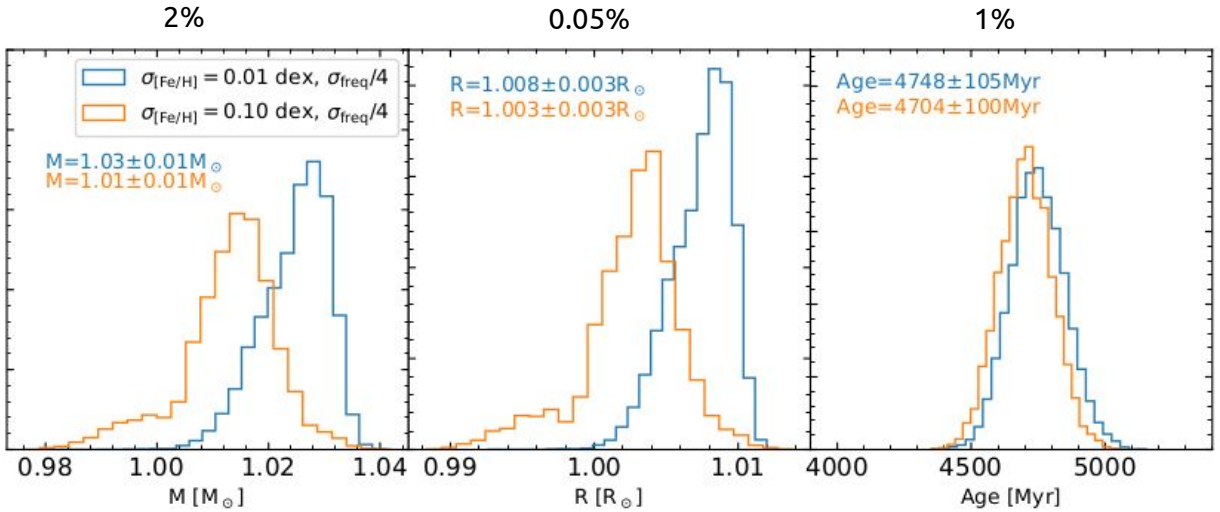
Models from Moedas et al. 2022

Individual frequencies (with surface corrections), ν_{max} + [Fe/H], Teff

➔ **Which precision?**

The Sun as a star
(equivalent to the best Kepler seismic targets)

Mean σ_{freq} = 0.06μHz

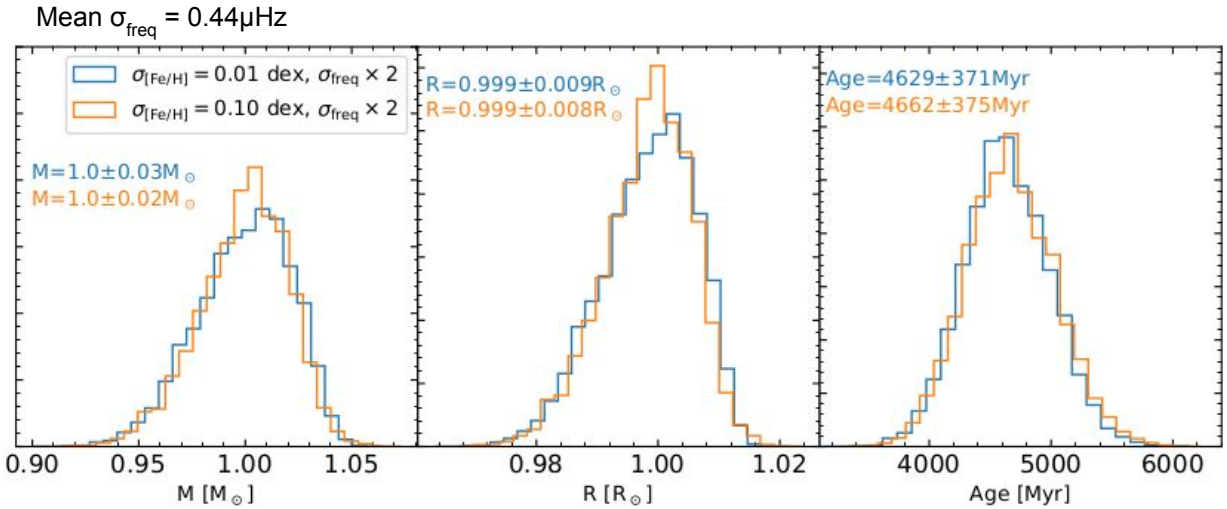


Models from Moedas et al. 2022

Individual frequencies (with surface corrections), ν_{max} + [Fe/H], Teff

➔ **Which precision?**

The Sun as a star
(with double uncertainties on the individual frequencies)



Models from Moedas et al. 2022

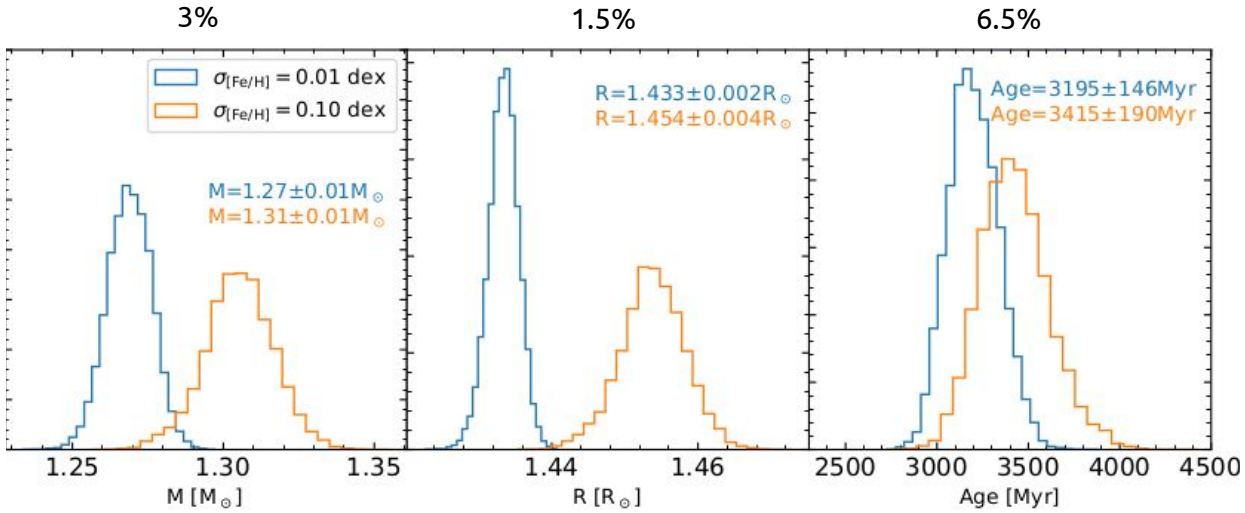
Individual frequencies (with surface corrections), ν_{max} + [Fe/H], Teff

➔ **Which precision?**

KIC12009504

(late F-type star, T_{eff}=6179 K, at the edge of the P1 sample)

Mean σ_{freq} = 0.31μHz

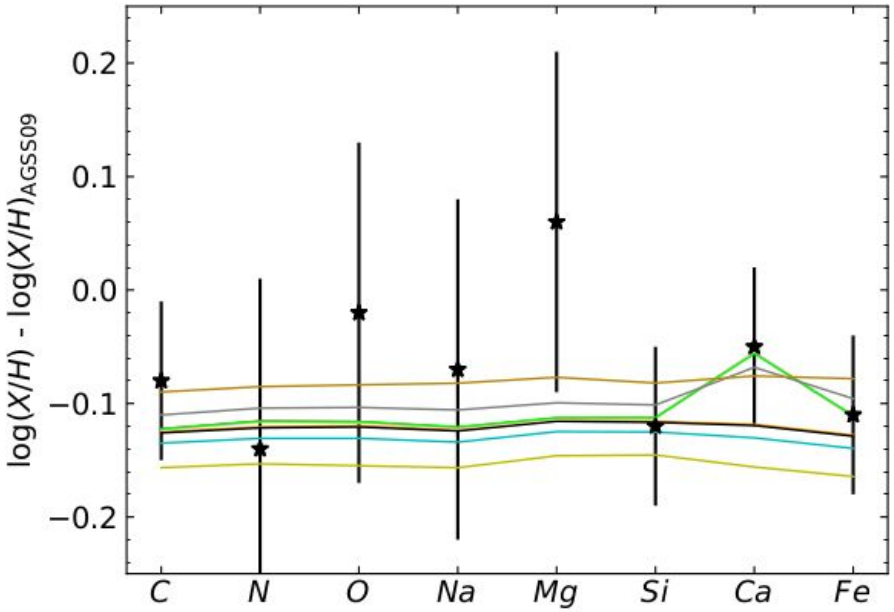


Models from Moedas et al. 2022

➔ **Which precision?**

KIC10162436

(late F-type star, T_{eff}=6136 K, at the edge of the P1 sample)



Chemical abundances requirements for PLATO

➔ Which elements?

- **Li, Be, C, N, O, Mg, Al, Si, Ca, Fe**
  - Mandatory
  - Interesting for telluric exoplanet characterisation (?)
  - Useful to better constrain the transport, hence for more accurate ages
  - The more elements, the better (useful to check if the initial metal mixture is suitable)

⇩

- Predicted surface abundances of all observed elements need to be part of the grid of stellar models
- Would it be interesting to also provide an estimation of the initial abundances?

➔ Which precision?

- At least **0.1dex** for all elements for G-type stars with detectable oscillations
- Better precision is needed for the hotter stars of the P1 sample …
- … and for stars without detectable oscillations

➔ Impact for exoplanet properties

Stellar properties (mass, radius, age and initial abundances)

⇩

R_p/R^*, M_p/M^* and **age** → **exoplanet properties**

➔ Impact for exoplanet properties

Stellar properties (mass, radius, age and initial abundances)

⇩

R_p/R^*, M_p/M^* and **age** → **exoplanet properties**

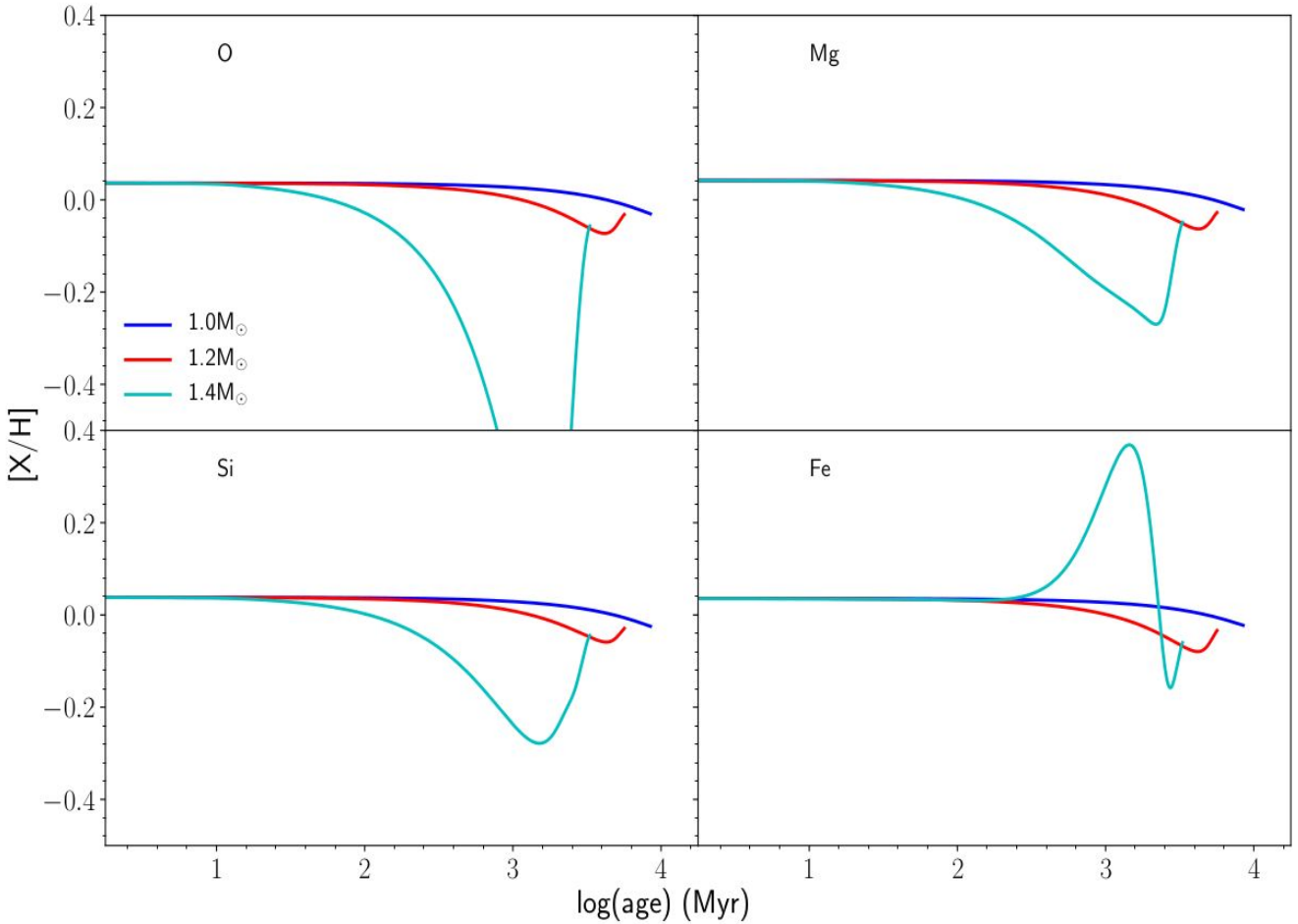
➔ Impact on the chemical composition of exoplanets and their internal structure

Present surface abundances ⇄ formation abundances

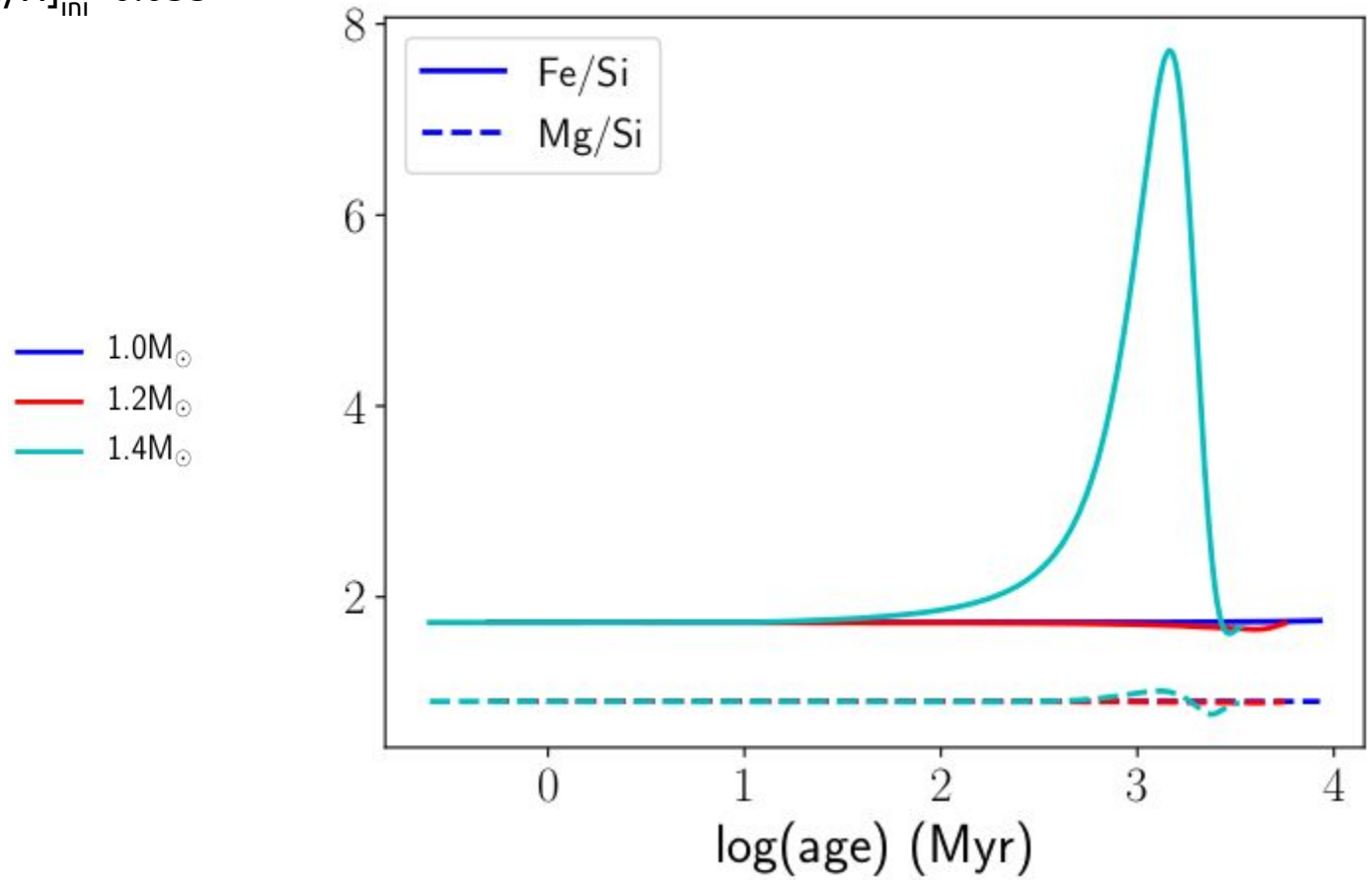
$[Fe/H]_{ini}$=0.035

Present surface abundances

formation abundances



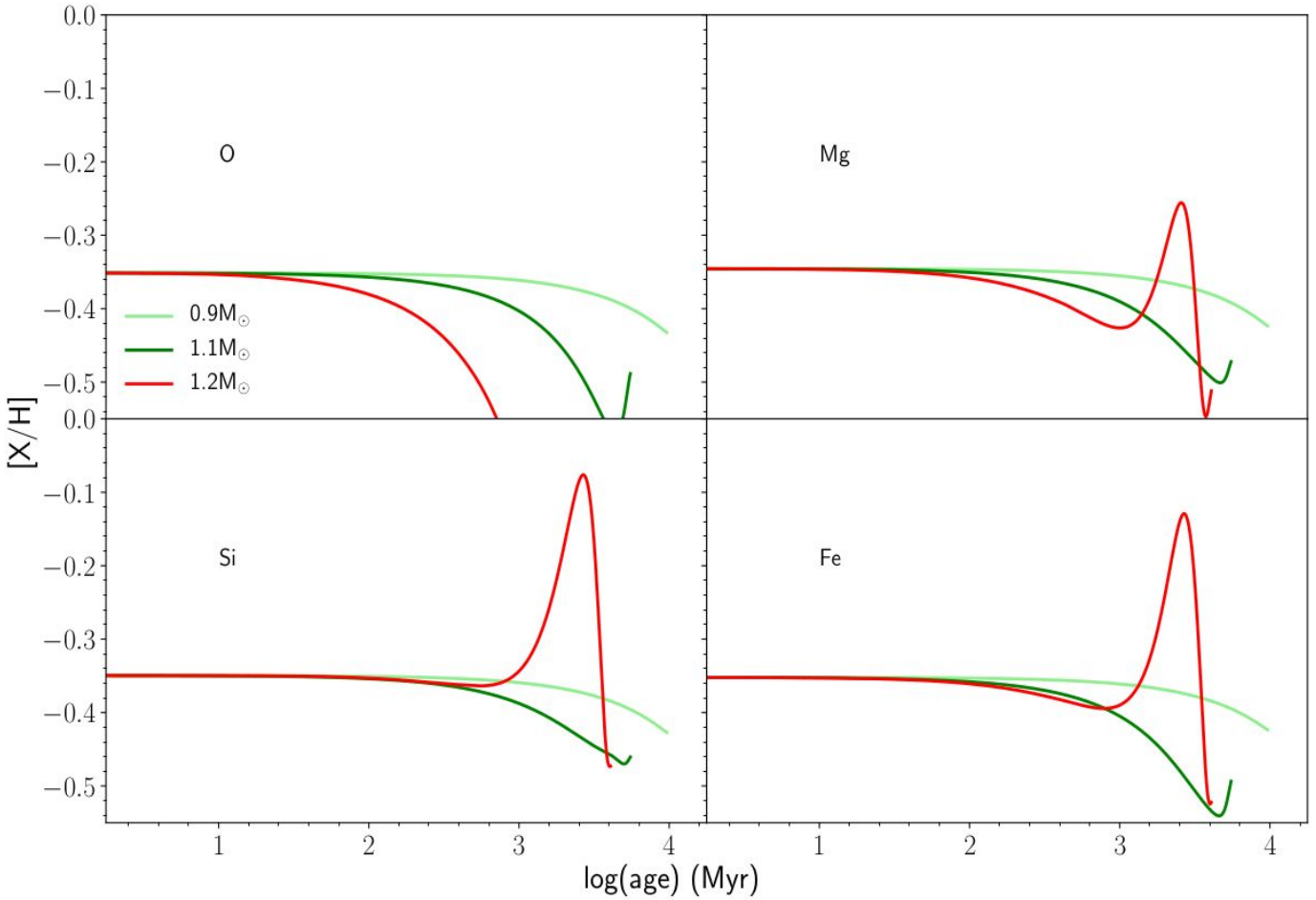
$[Fe/H]_{ini}$=0.035



$[Fe/H]_{ini}$=-0.35

Present surface abundances

formation abundances



$[Fe/H]_{ini}$=-0.35