On the metal content of Star Forming Regions and Young Open Clusters

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Thanks to
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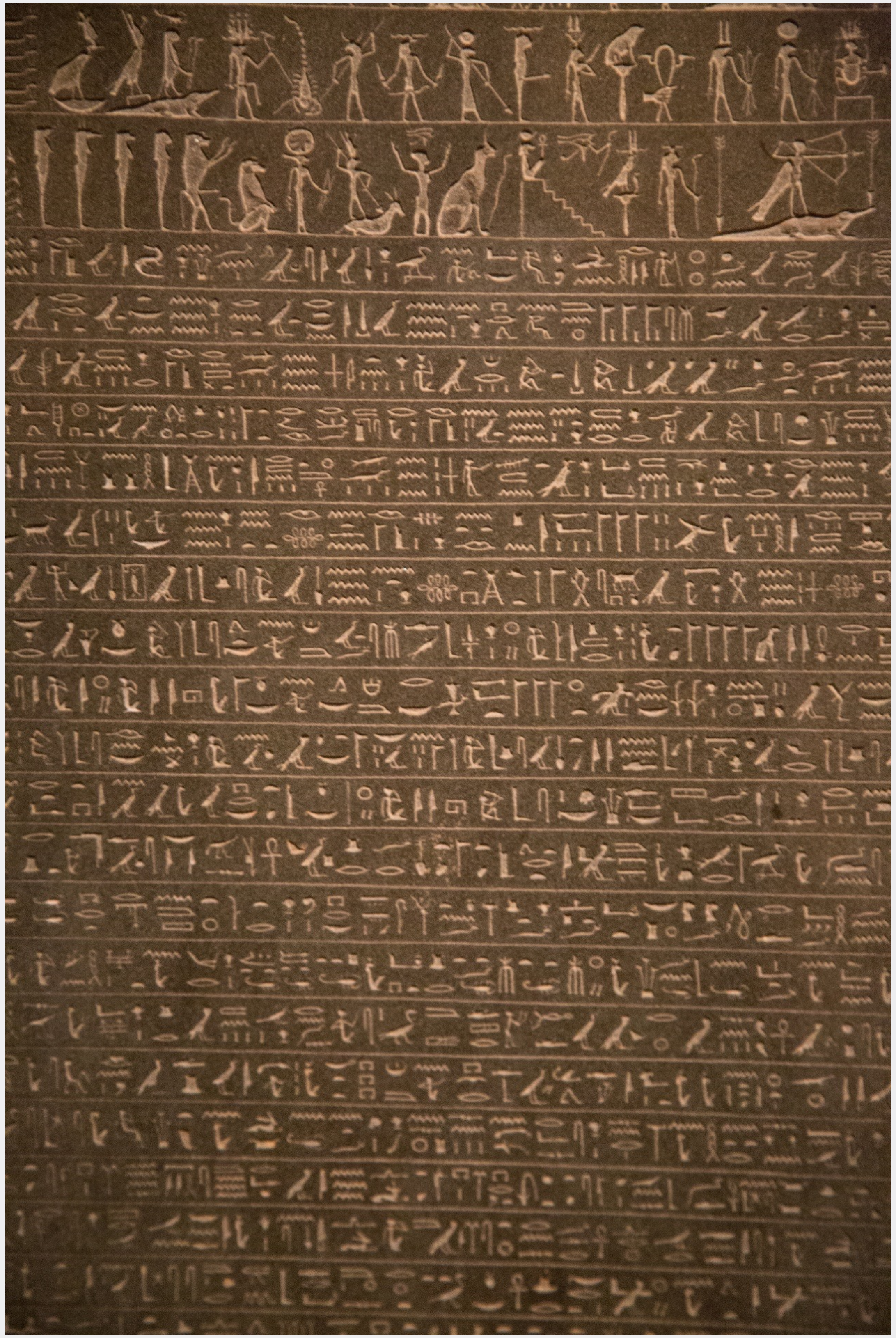
Why chemical abundances?

“*The principal value of abundance determinations from stellar spectra is the clues they give to the nuclear history of stellar matter and, more generally, of the matter in the whole Galaxy.*”

Cayrel & Cayrel de Strobel (1966)

“*The history of star formation in our galaxy is written in the metal abundance distribution of the stellar populations.*”

Ferrini, Palla & Shore (1987)



Chemical composition of SFRs and YOCs

Chemical tagging and self-enrichment

- Trace back the common origin of stellar populations *(Freeman & Bland-Hawthorn 2002)*
- Chemical signatures of triggered star formation *(e.g., Cunha et al. 1992; D'Orazi et al. 2009; Biazzo et al. 2011ab)*

Chemical evolution of the thin disk

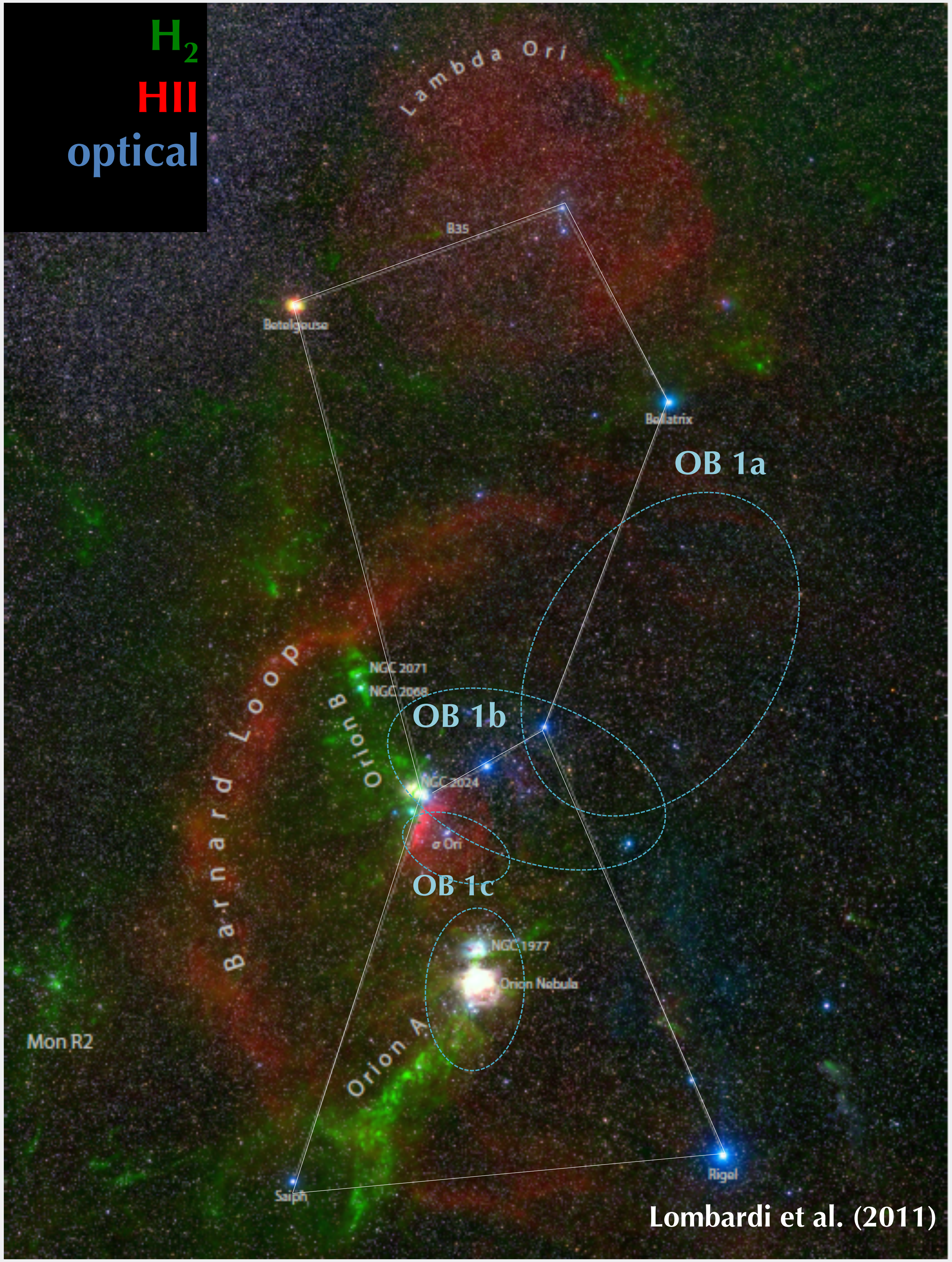
No time to move and disperse through the Galaxy → Key objects to trace the actual chemical pattern of the thin disk *(e.g., Spina et al. 2017)*

Latest products of the Milky Way → Chemical evolution of our Galaxy *(e.g., Spina et al. 2017)*

Planet - Metallicity connection

Connection between the stellar metallicity and planets *(Laughlin & Adams 1997; Buchhave et al. 2015, Wand et al. 2015)*

An ideal laboratory



Orion is one of the closest OB association to the Sun.

Very well-known: membership, spectral types, magnitudes, ages, extinction, etc..

Formed by sub-groups with different locations and ages.

Cluster	Age	Distance
λ Ori	5-10 Myr	400 pc
OB 1a	7-10 Myr	350 pc
OB 1b	4-6 Myr	400 pc
OB 1c	3-4 Myr	400 pc
OB 1d	2-3 Myr	420 pc

The star formation has spread through the giant molecular cloud as a “forest fire” which “blows from northwest to southeast” *(Reeves 1978)*.

An example of supernova-induced sequential star formation.

Self-enrichment in the Orion complex?

Massive stars are the major sites of nucleosynthesis → SNe may have polluted the gas of new elements

Cunha & Lambert (1992, 1994); Cunha, Smith & Lambert (1998)

Test the chemical homogeneity of the complex (12 B-type and 8 FG-type stars).

Hints on the nature of the stellar formation episodes in Orion.

- O-rich and Si-rich stars are roughly segregated in the souther regions.

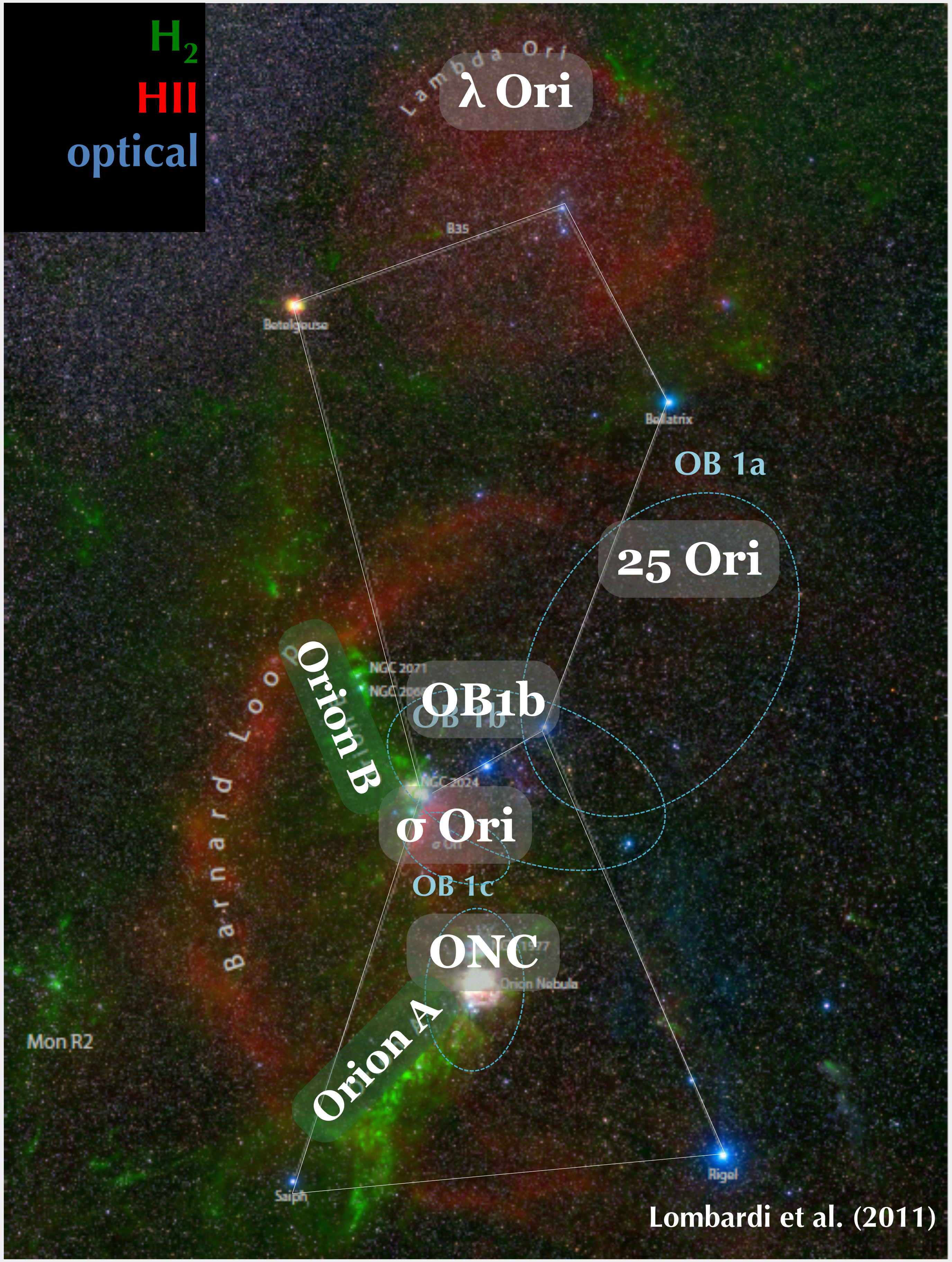
D'Orazi, Randich, Flaccomio, Palla et al. (2009)

- ONC (2.3 Myr) is richer of Fe than OB1b (4-6 Myr)

Simon-Diaz et al. (2010)

- High degree of chemical homogeneity across the Orion complex (13 B-type stars)

Self-enrichment in the Orion complex?



Lombardi et al. (2011)

<u>**Biazzo, Randich, Palla et al. (2011ab)**</u>

Cluster	Age	[Fe/H]	Stars
λ Ori	5-10 Myr	0.01±0.01	5
25 Ori	7-10 Myr	-0.05±0.05	5
OB 1b	4-6 Myr	-0.05±0.05	4
σ Ori	3-4 Myr	-0.02±0.09 (González-Hernández et al. 2008)	8
ONC	2-3 Myr	-0.13±0.03	10

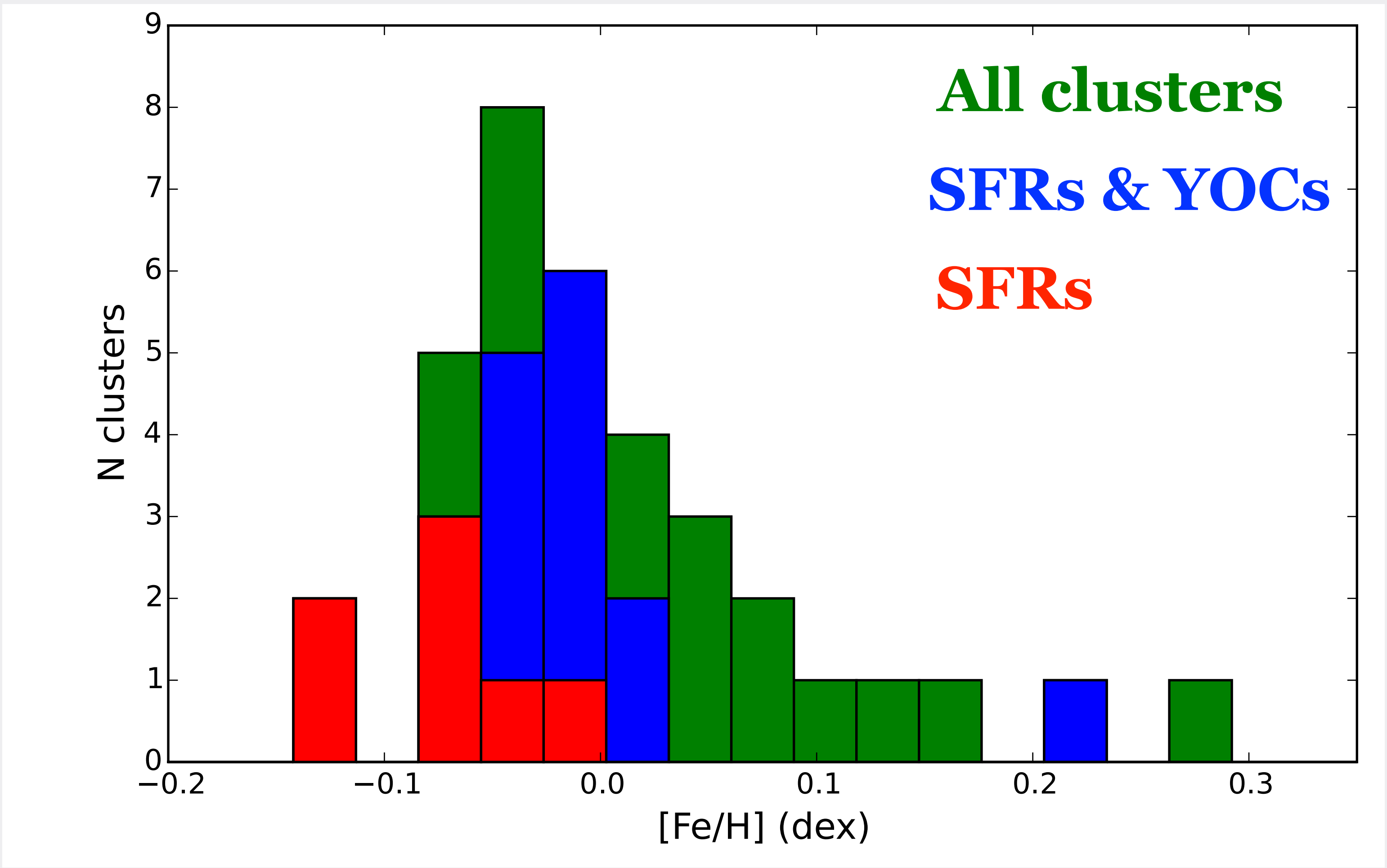
- The Orion complex is homogeneous (with the exception of ONC)
- Large scale formation process (>100 pc): enrichment between adjacent regions may not have been efficient
- The youngest object has the lowest [Fe/H]

Spatial location: non-homogeneous cloud?
Age: recent pollution of metal-poor gas?

Metallicity of Orion A and Orion B?

The two regions share the same [Fe/H] with ONC *(Biazzo et al. in prep; Spina et al. in prep)*

Metallicity of SFRs and YOCs
in the Solar Neighbourhood (<500 pc)



✦ Nearby clusters cover a range in [Fe/H] from -0.12 t0 +0.27 dex

✦ The youngest clusters are restricted to the low metallicity values (with one exception)

✦ No metal-rich SFRs exist!

The present chemical pattern of the ISM in the Solar Neighbourhood seems to be poorer of metals than the Sun.

Is it related with the chemical evolution of the ISM?
Is it local or widespread?

Caveats:

- Small statistics
- Estimates are not completely homogeneous
- Estimates are often based on few stars.

→ Additional data are required (homogeneity, large statistics among clusters and members)

The Gaia-ESO Spectroscopic Survey

Motivation:
provide complementary data to Gaia by high resolution spectroscopy *(Gilmore et al. 2012, Randich & Gilmore 2013)*

Instrument:
FLAMES@VLT
GIRAFFE: 132 fibres at R=20,000
UVES: 8 fibres at R=47,000

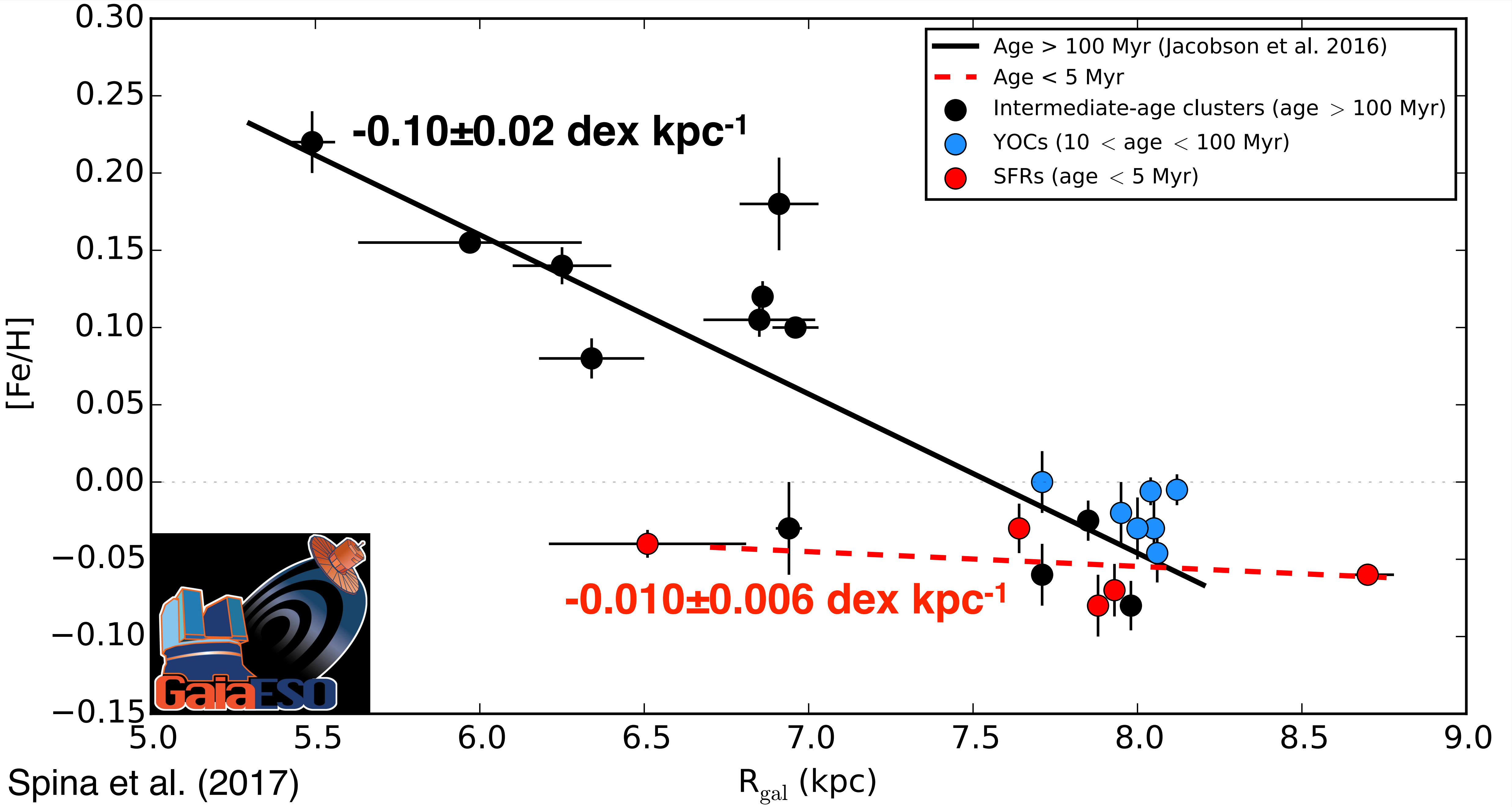
Sample:
10^5 stars at R=20,000
5000 at R=47,000
all the components of the Milky Way
~40-50 Old clusters (age > 100 Myr)
~20 Young clusters (age 1-100 Myr)

@GaiaESO

P.I.: G. Gilmore & S. Randich
Co-I: 500 astronomers based in Europe, US and Australia
Observing time: 300 + 40 nights
Starting date: 31^{st} December 2011

Large samples of spectra are analysed in a homogeneous and reproducible way → Provide for the first time the opportunity to study, on a **homogeneous scale**, common features and peculiarities of the different stellar populations.

Galactic gradient: a homogeneous sample



Spina et al. (2017)

Solar Neighbourhood:

- big dispersion
- SFRs are in the lower tail of the metallicity distribution

At distant Rgal:

- first [Fe/H] determinations for SFRs based on low-mass stars
- internal SFRs are much poorer of metals than old clusters

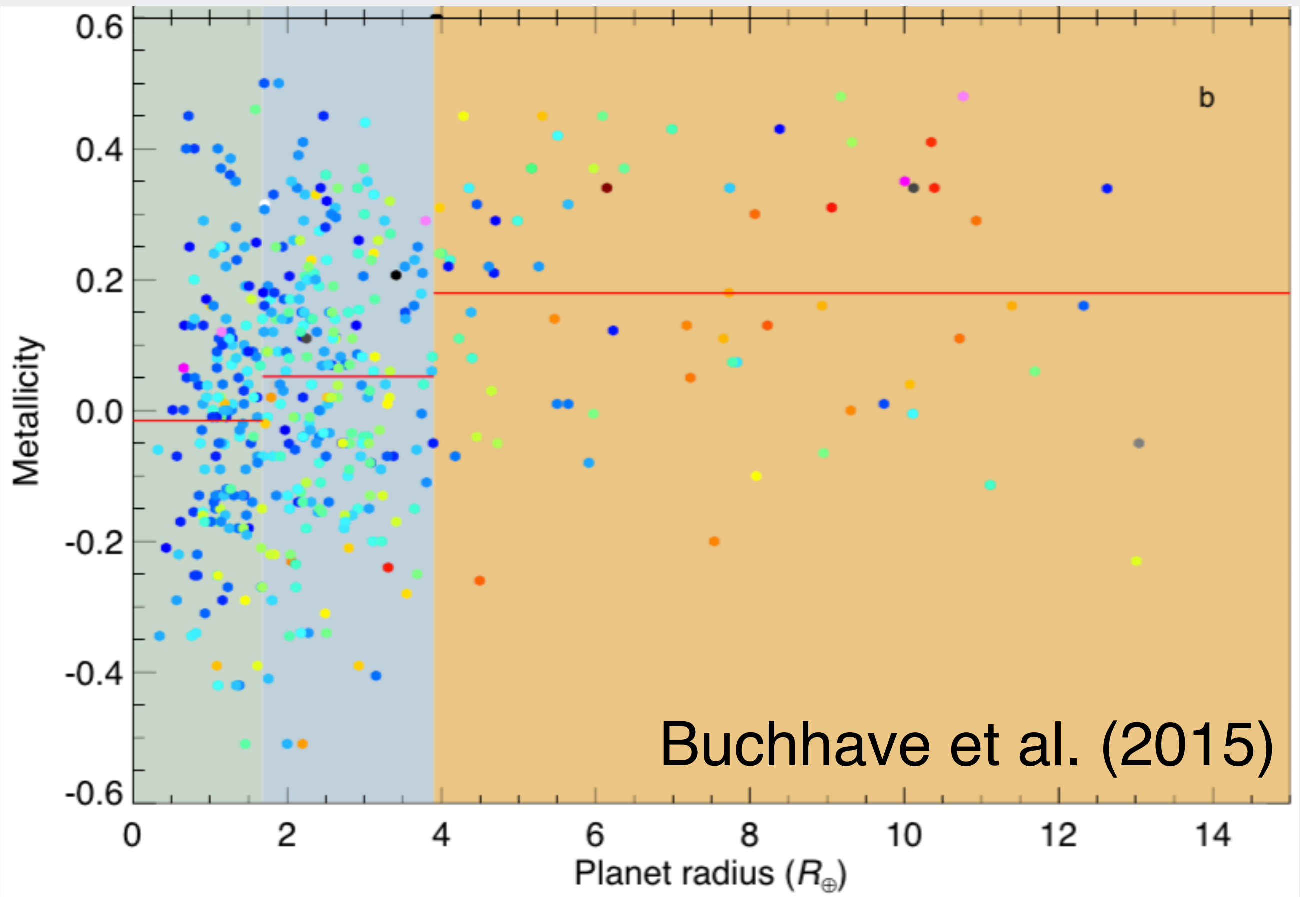
A “young” gradient:

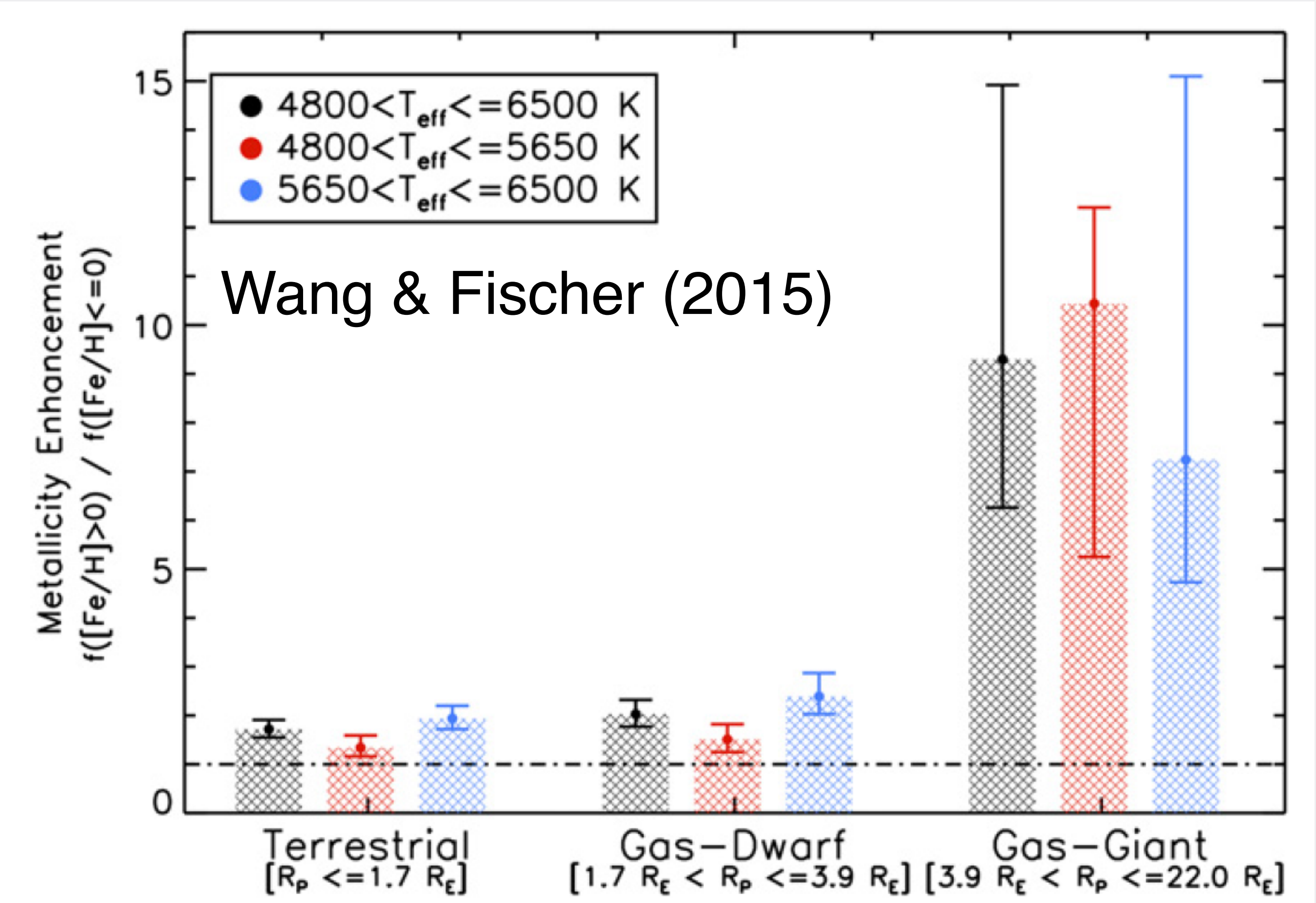
- The gradient based on young clusters is flatter!

Planet - Metallicity Connection

The dependence of planet occurrence rate on stellar metallicity has been firmly established.

The study of this connection can provide additional hints on how planets form and evolve.





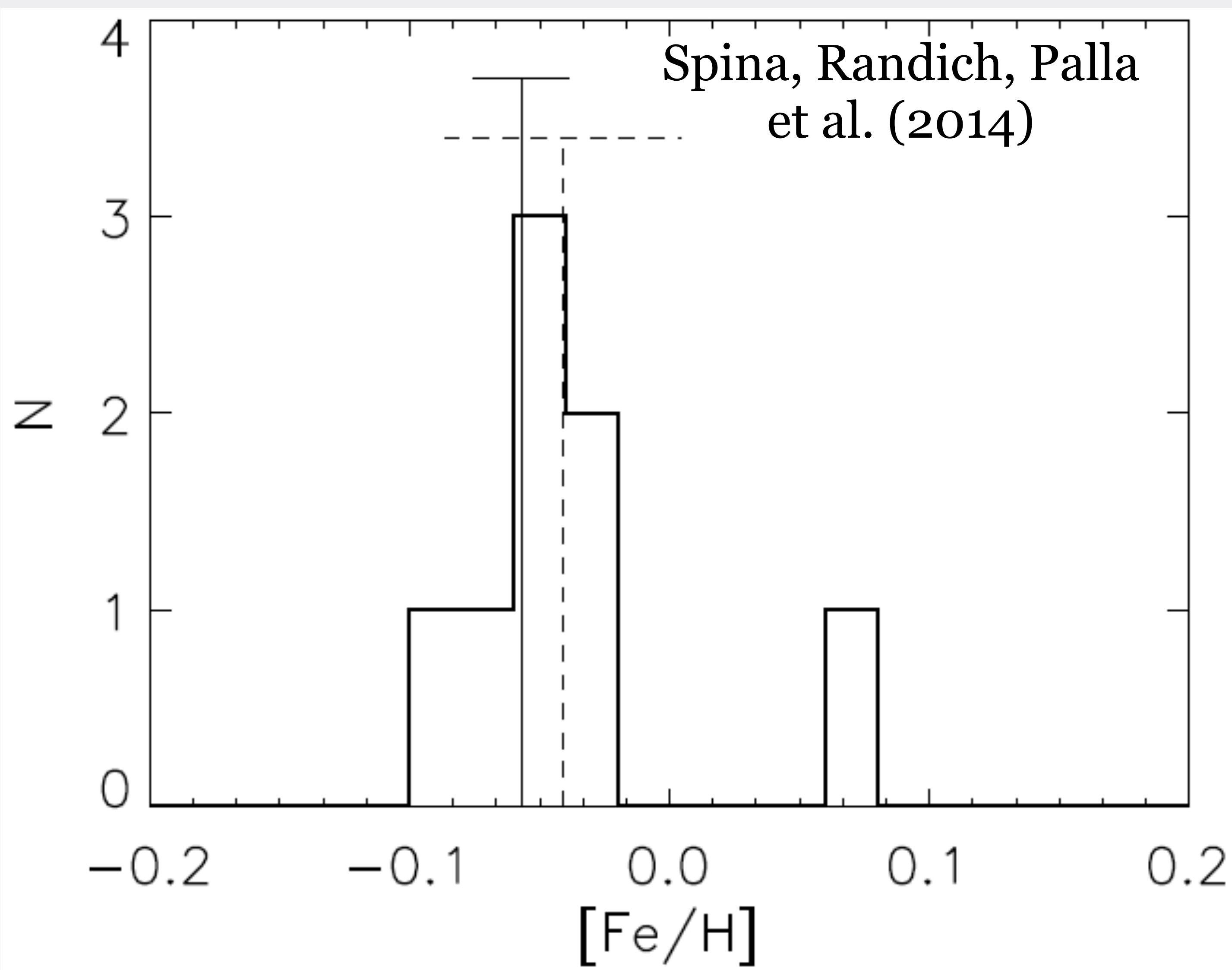
How can a planet (or planetary material) change the chemical composition of stars?

Chemical signatures of planet engulfment

1) Process of orbital reconfiguration are likely to occur during the first 500 Myr, when the planets have not cleared their orbits yet *(Gomes et al. 2005)*

2) Some part of the planetary material may fall into the central star

3) Planetary material may fall into the central star and be mixed in its external layers. This can cause an overall metallicity enhancement *(Laughlin & Adams 1997)*

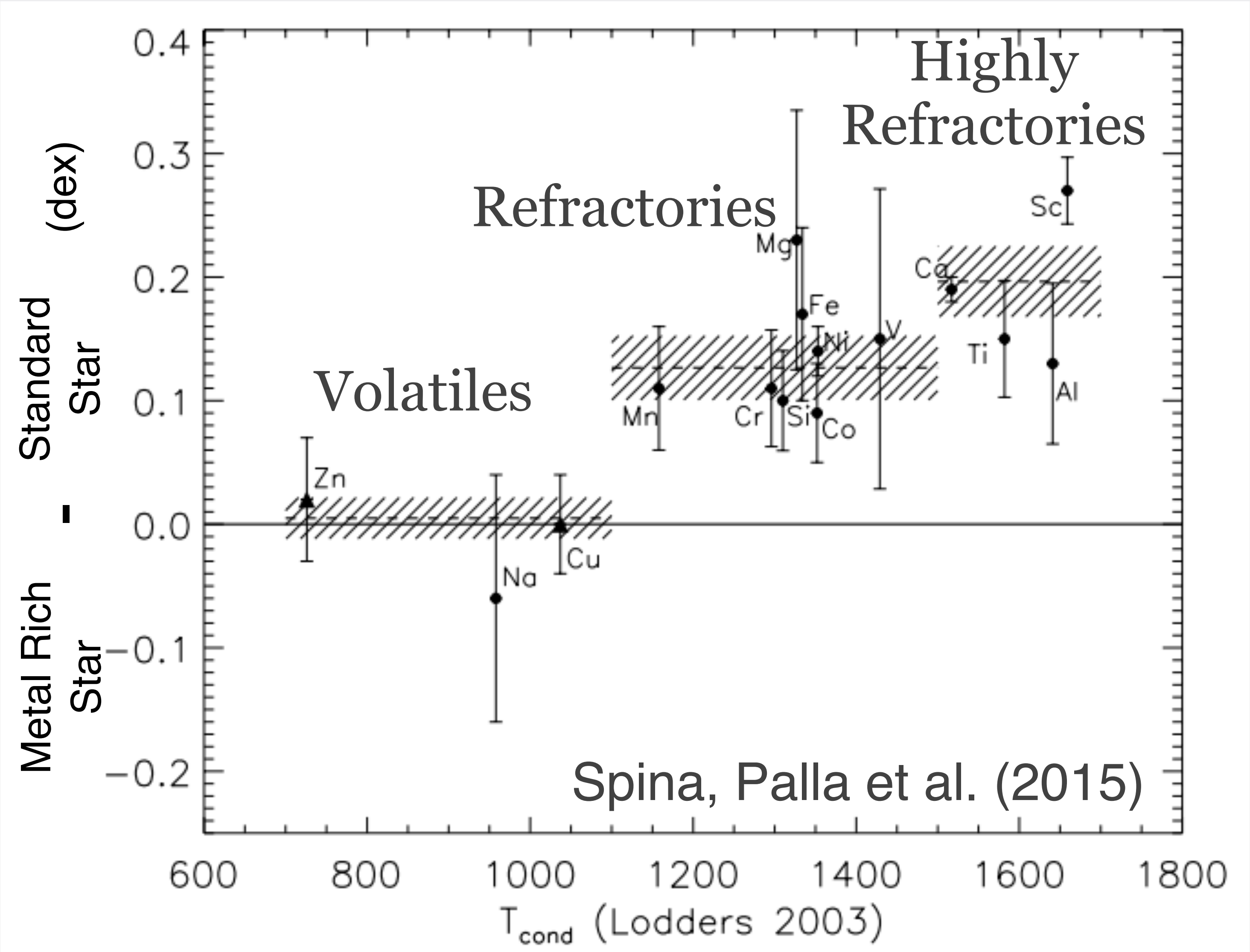


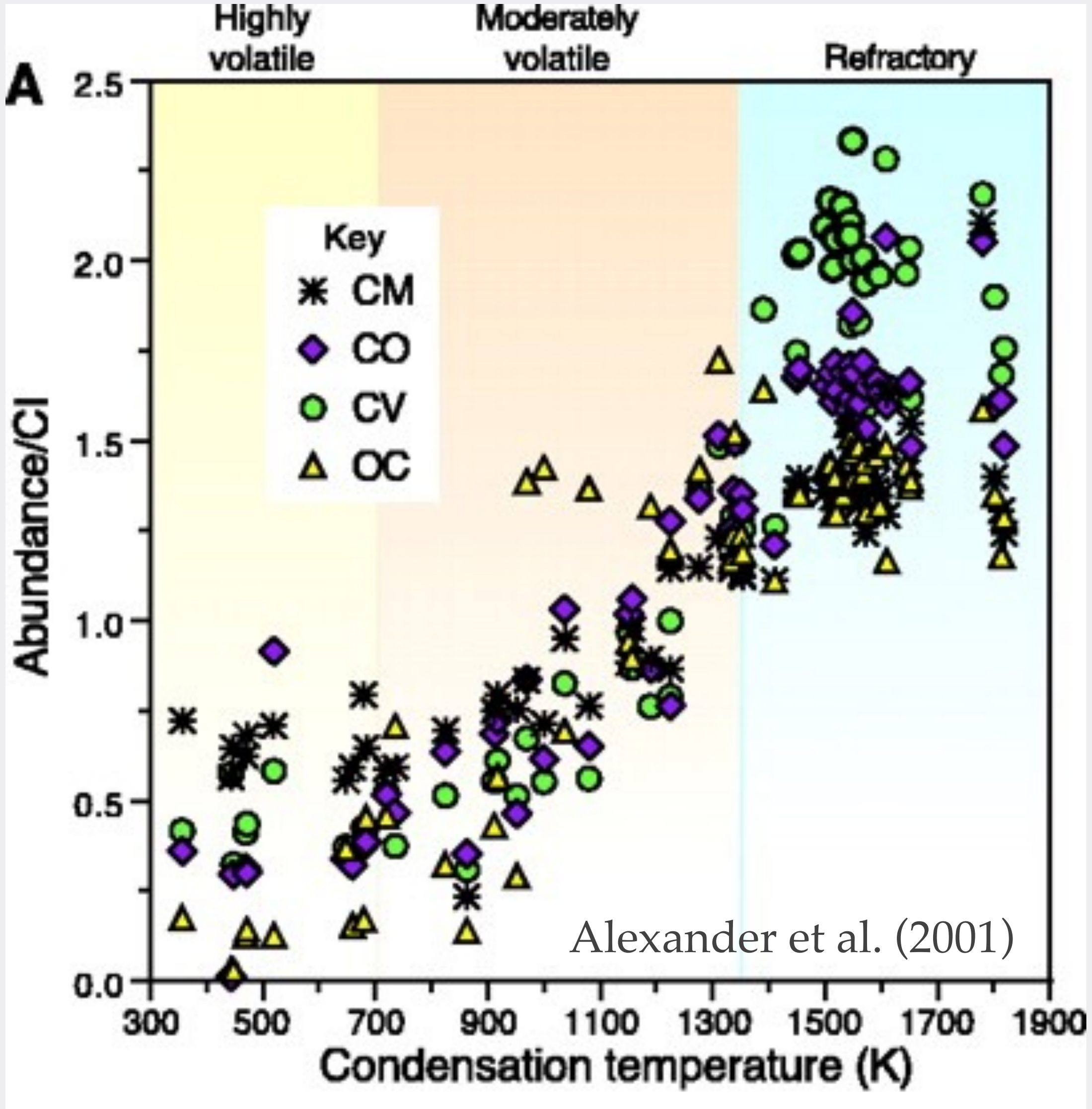
A serendipitous discovery in Gamma Velorum (15 Myr): 2MASS J08095427-4721419 is +0.13 dex richer of iron respect to the cluster average (~2σ).

Membership based on

- radial velocity
- HR diagram
- lithium abundance

Chemical signatures of planet engulfment





The refractory elements are though to be the main component of the solids (meteorites, rocky planets, cores of gaseous planets, dust, etc…) that populate our solar system.

This chemical pattern is the fingerprint of a planetary engulfment event.

Where can we observe the enrichment?

If the accreted mass is too diluted into the stellar material, the stellar enhancement will be modest.

The mass enclosed in the envelope layer of the star is a critical parameter!

Massive stars
$M>3M_{\odot}$

The external layer is thick and radiative

Low-mass stars
$M<1M_{\odot}$

Thick convective zone

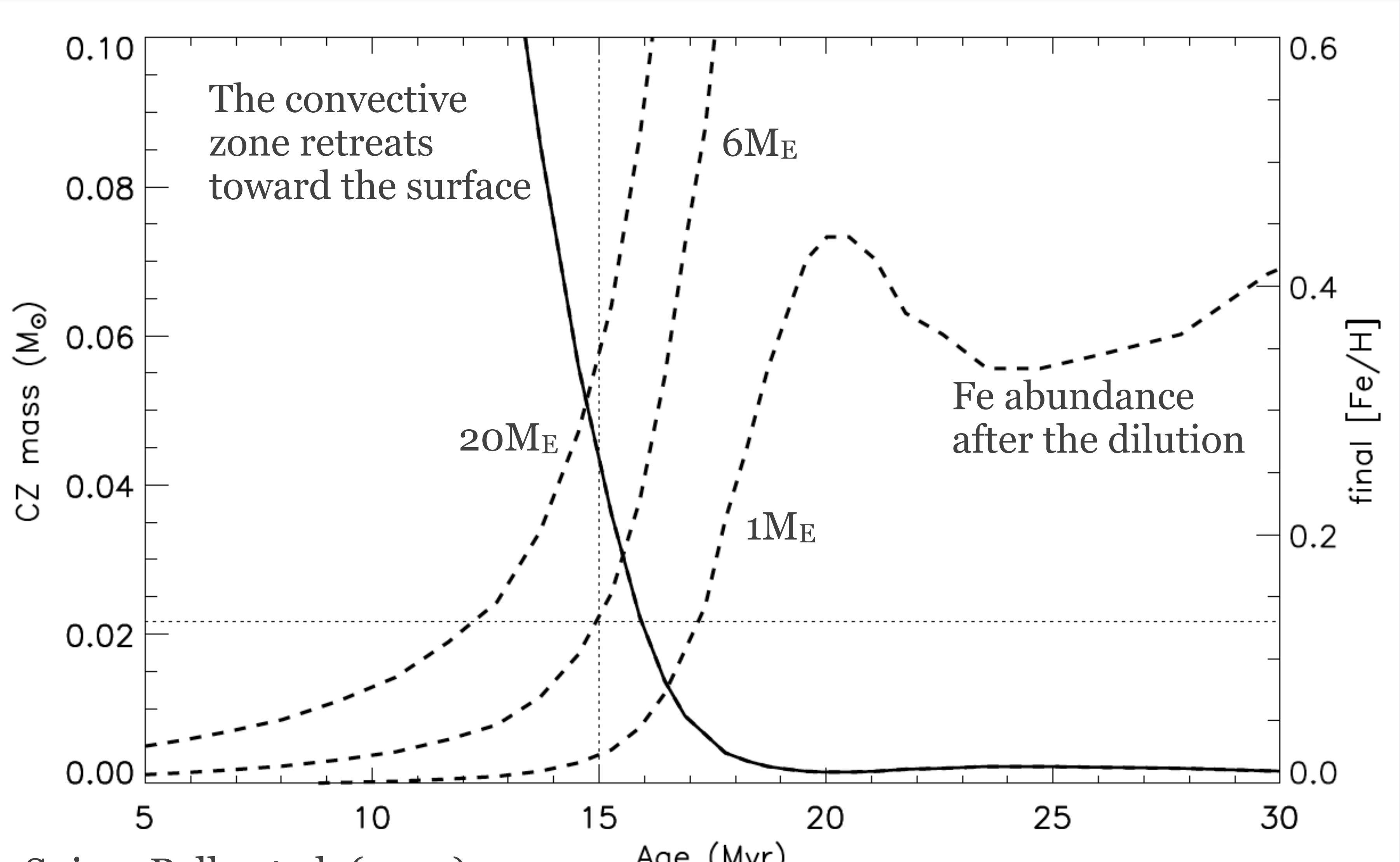
Intermediate-mass stars
$1<M<3M_{\odot}$

Thin convective zone: the accreted mass is not too diluted.

When can we observe the enrichment?

<u>Not too early:</u> During the PMS phase solar type stars undergo a process of internal readjustment. Younger stars have thicker convective zones.

Based on Siess et al. (2000) models. Enhancement of metallicity changes the internal structure of the star (Tognelli et al. 2016).



Spina, Palla et al. (2015)

<u>Not too late:</u>
Any induced extra-metallicity is expected to be reduced by several mixing processes *(e.g., Theado & Vauclair 2012)*

→ Pre-main-sequence clusters are the best targets to study the chemical signatures of planet engulfment!!!

Conclusions

- No self-enrichment seems to be present
- ONC is poorer of metals than the older groups

The composition of Orion A and B will give us new insights.

Repeat the experiment in a better laboratory: Rho Oph and Upper Sco.

- SFRs are slightly metal-poorer than older clusters.
- Flat gradient between 6 and 9 kpc from the Galactic center.
- Unexpected result that the current models are not able to reproduce.

More observation of distant SFRs (homogeneity, large statistics).

Develop new models of Galactic chemical evolution that include infall of gas and radial flows.

- A planet engulfment event can enhance the stellar atmosphere of refractory elements.
- Which is the frequency of these catastrophic events?

Test the chemical homogeneity of clusters with high-precision abundance determinations ($\sigma \leq 0.01$ dex)

The size of the CZ is a key parameter. How does it change with time, stellar mass, and accretion episodes?