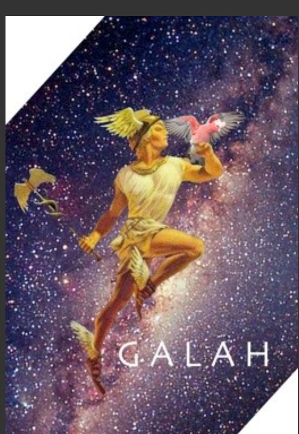
Chemo-dynamical groups in the Orion complex

Applications for chemical tagging

Janez Kos

Faculty of Mathematics and Physics,
University of Ljubljana, Slovenia



University *of Ljubljana*
Faculty *of Mathematics and Physics*

Motivation – Chemical tagging

Only a few cases of successful chemical tagging, mostly old stars.

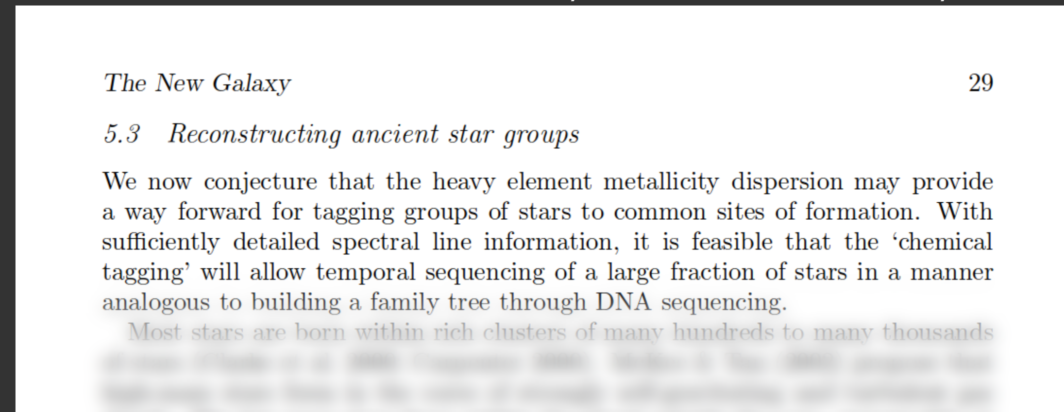
Open clusters are chemically homogeneous, but represent special stellar populations.

Where does the hierarchy come in?

Is chemical tagging a myth?

Do we understand all assumptions?

Freeman, Bland-Hawthorn, 2002



The New Galaxy 29

5.3 Reconstructing ancient star groups

We now conjecture that the heavy element metallicity dispersion may provide a way forward for tagging groups of stars to common sites of formation. With sufficiently detailed spectral line information, it is feasible that the 'chemical tagging' will allow temporal sequencing of a large fraction of stars in a manner analogous to building a family tree through DNA sequencing.

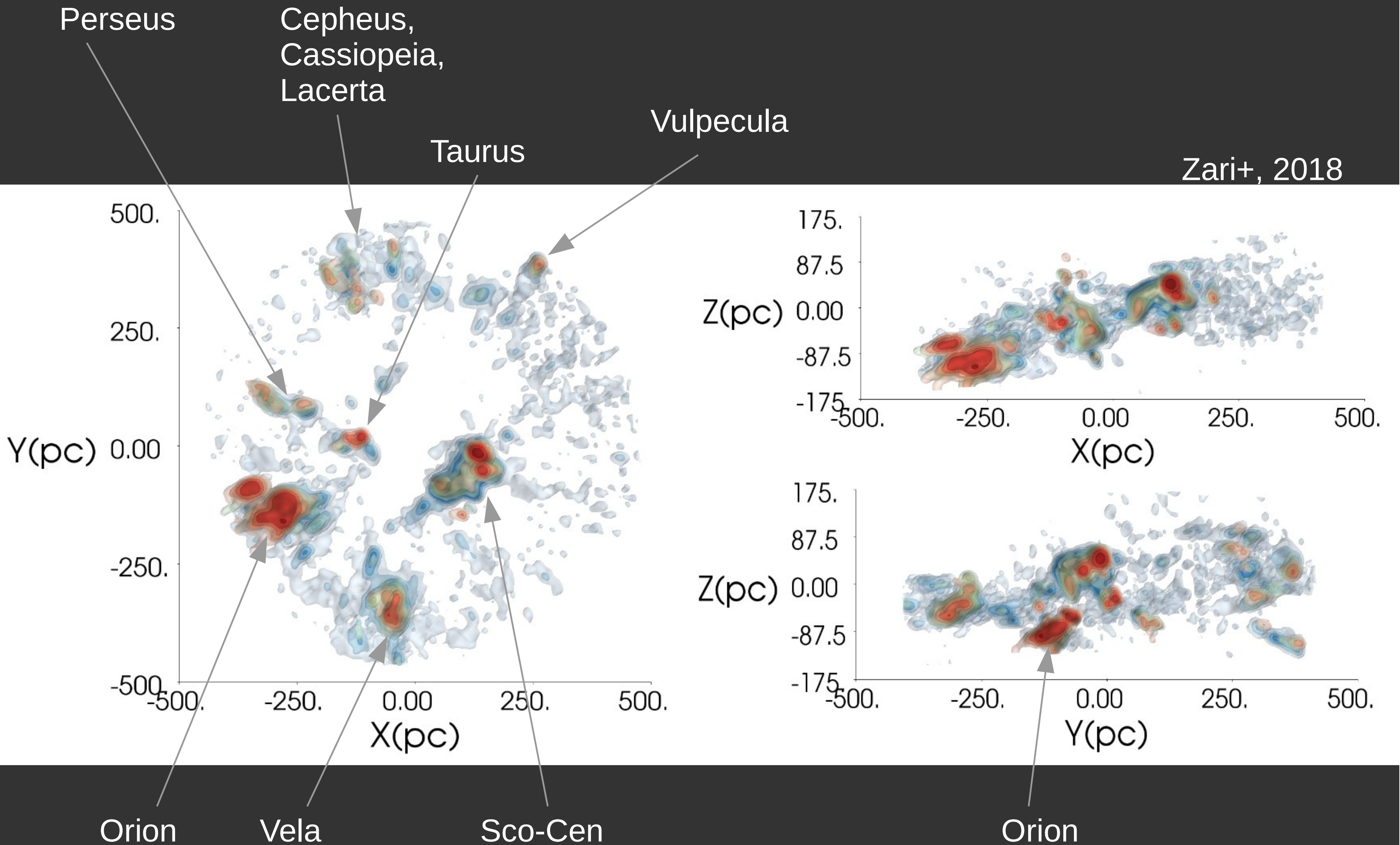
Most stars are born within rich clusters of many hundreds to many thousands

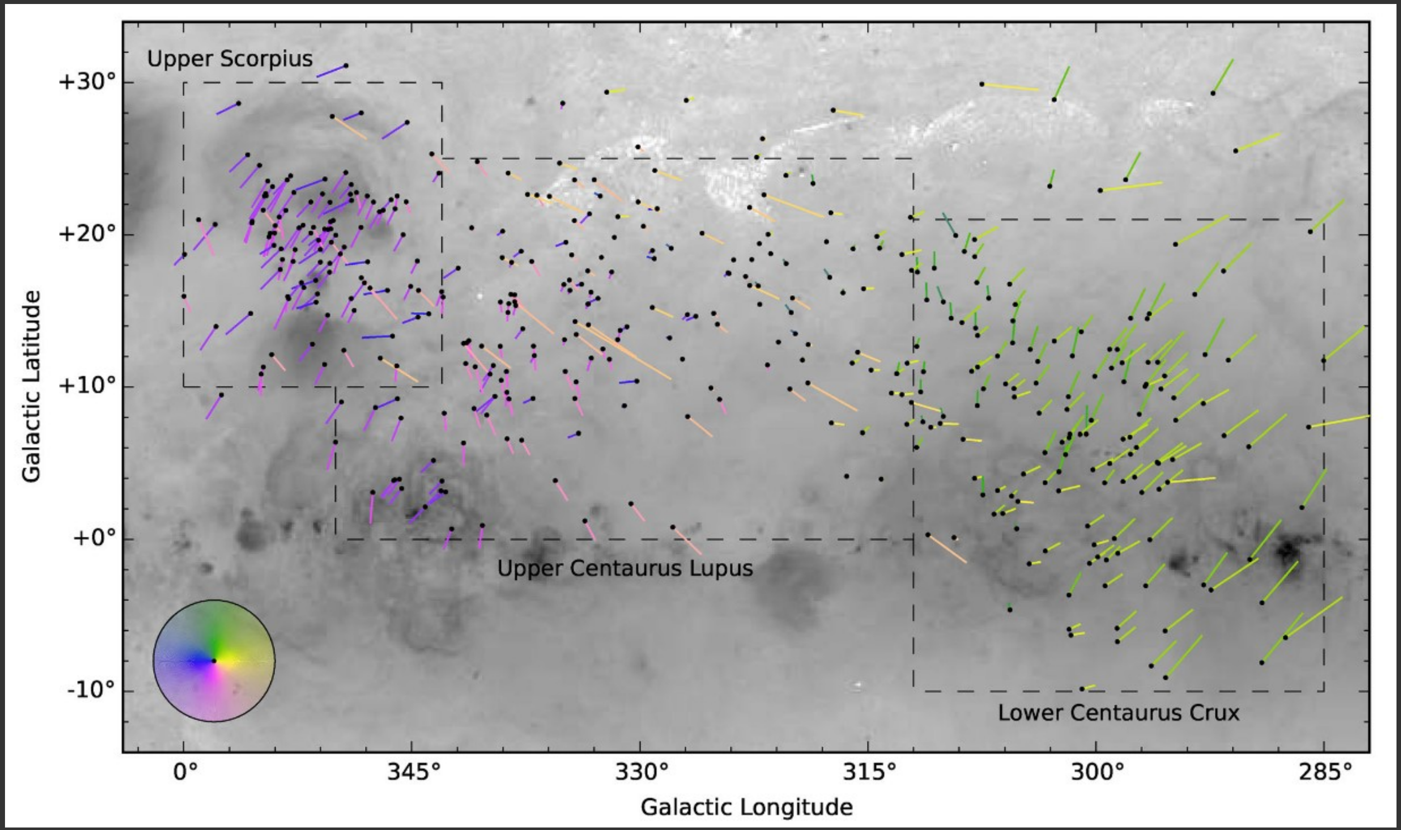
Why study Orion?

Is the Orion complex a typical star forming region?

- Large
- Nearby
- Diverse
- Out of the Galactic plane
- Star formation triggered by shocks
- Non-trivial kinematics
- Chemically inhomogeneous (or is it?)

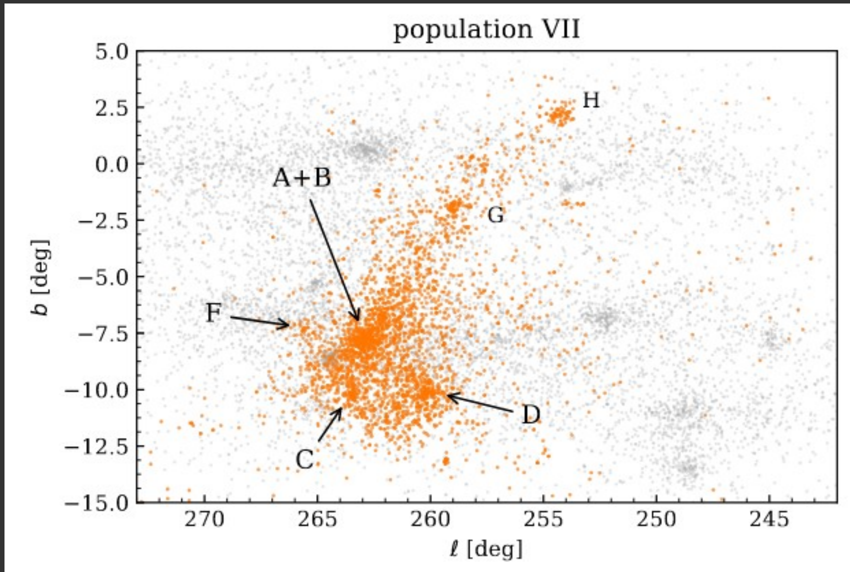
Intriguingly complicated, but not a peculiar outlier!

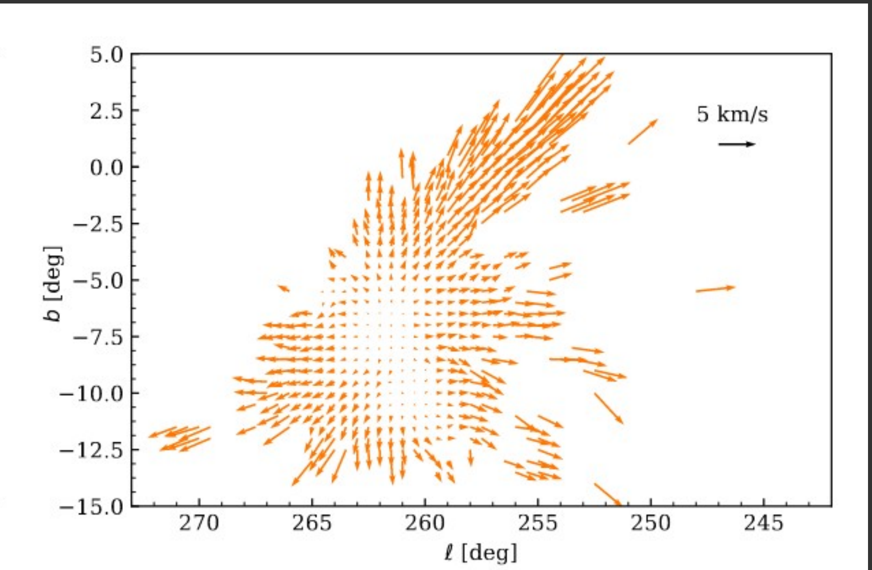

Perseus
Cepheus, Cassiopeia, Lacerta
Taurus
Vulpecula
Zari+, 2018
500.
250.
0.00
-250.
-500.
Y(pc)
-500.
-250.
0.00
250.
500.
X(pc)
175.
87.5
0.00
-87.5
-175.
Z(pc)
-500.
-250.
0.00
250.
500.
X(pc)
175.
87.5
0.00
-87.5
-175.
Z(pc)
-500.
-250.
0.00
250.
500.
Y(pc)
Orion
Vela
Sco-Cen
Orion

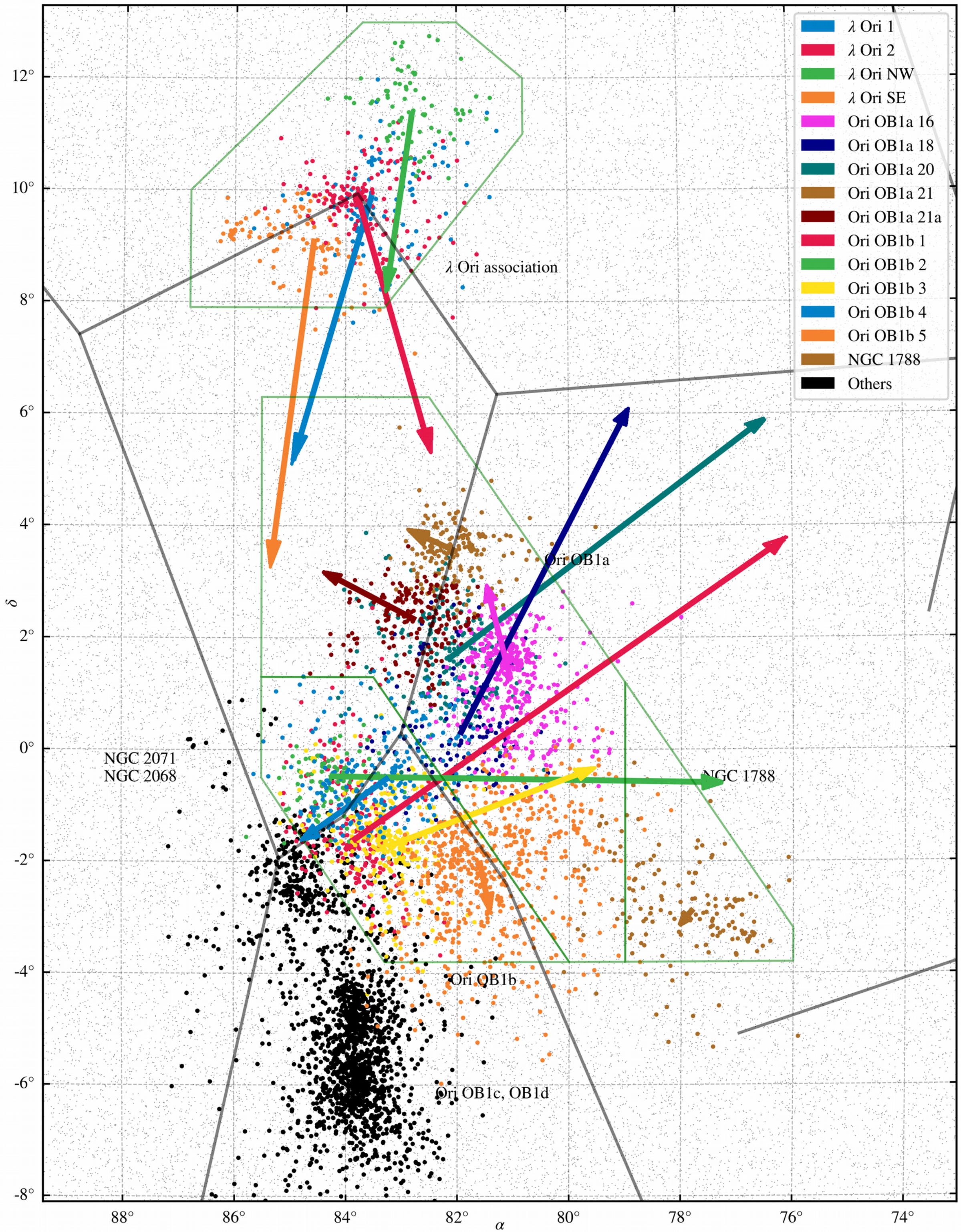


◄Sco-Cen (Wright, Mamajek, 2018)

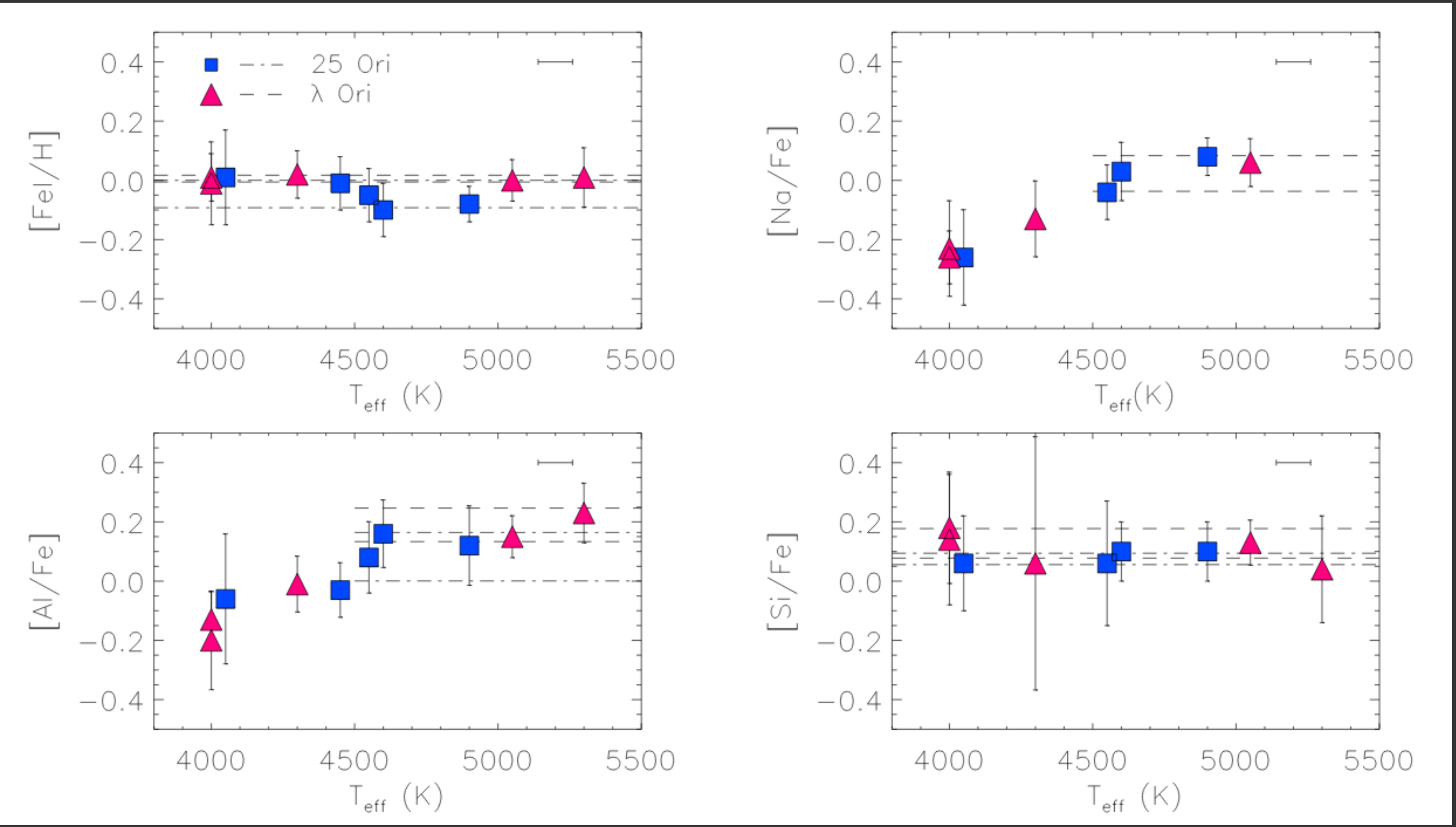
▼Vela (Cantat-Gaudin+, 2019)





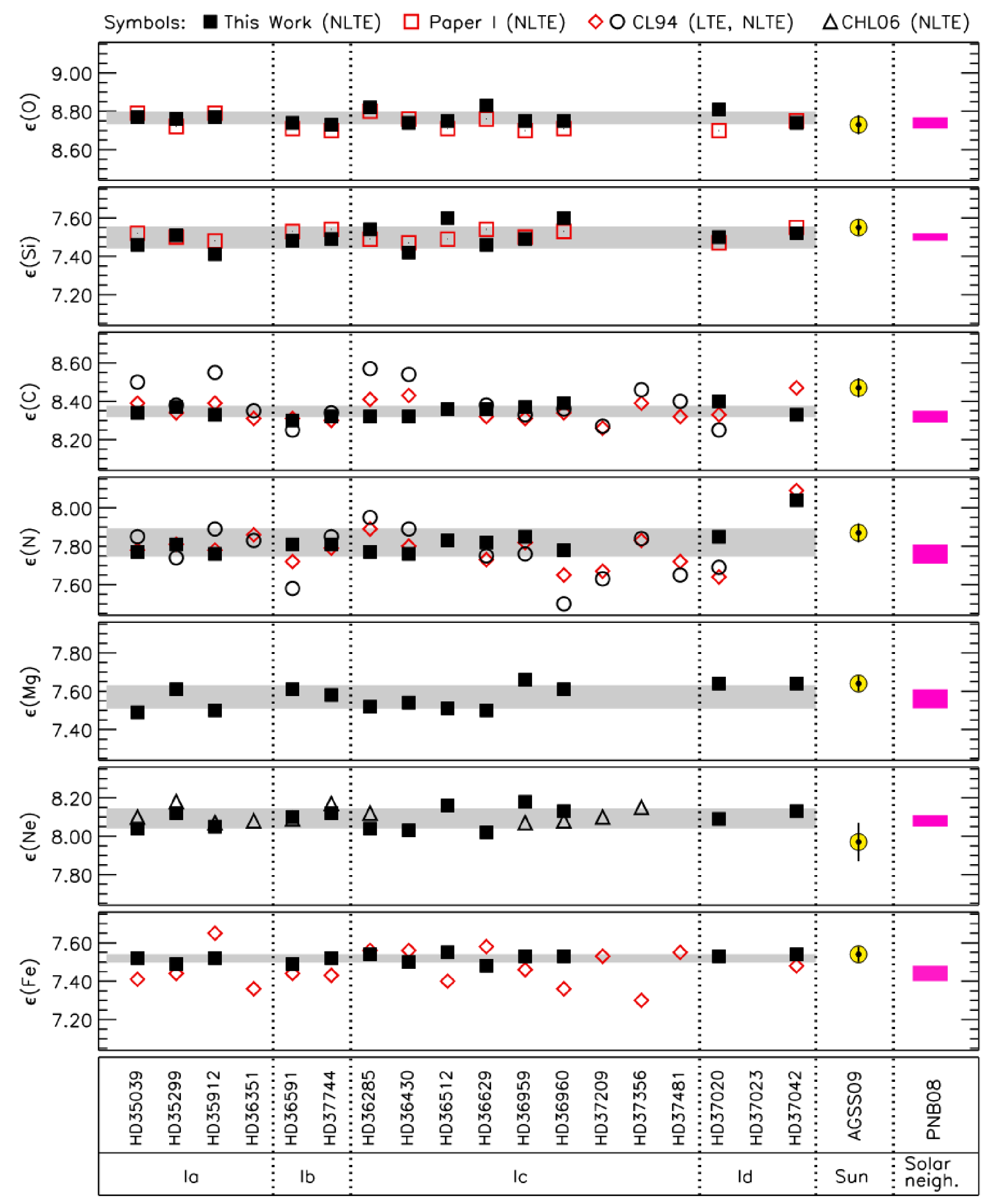


Mean proper motions of our groups in the Orion complex (in the Orion's LSR)



Biazzo+, 2011

Association	[Fe/H]
λ Ori	0.01 ± 0.01
25 Ori (OB1a)	-0.05 ± 0.05
Ori OB1b	-0.05 ± 0.05
ONC	-0.13 ± 0.03



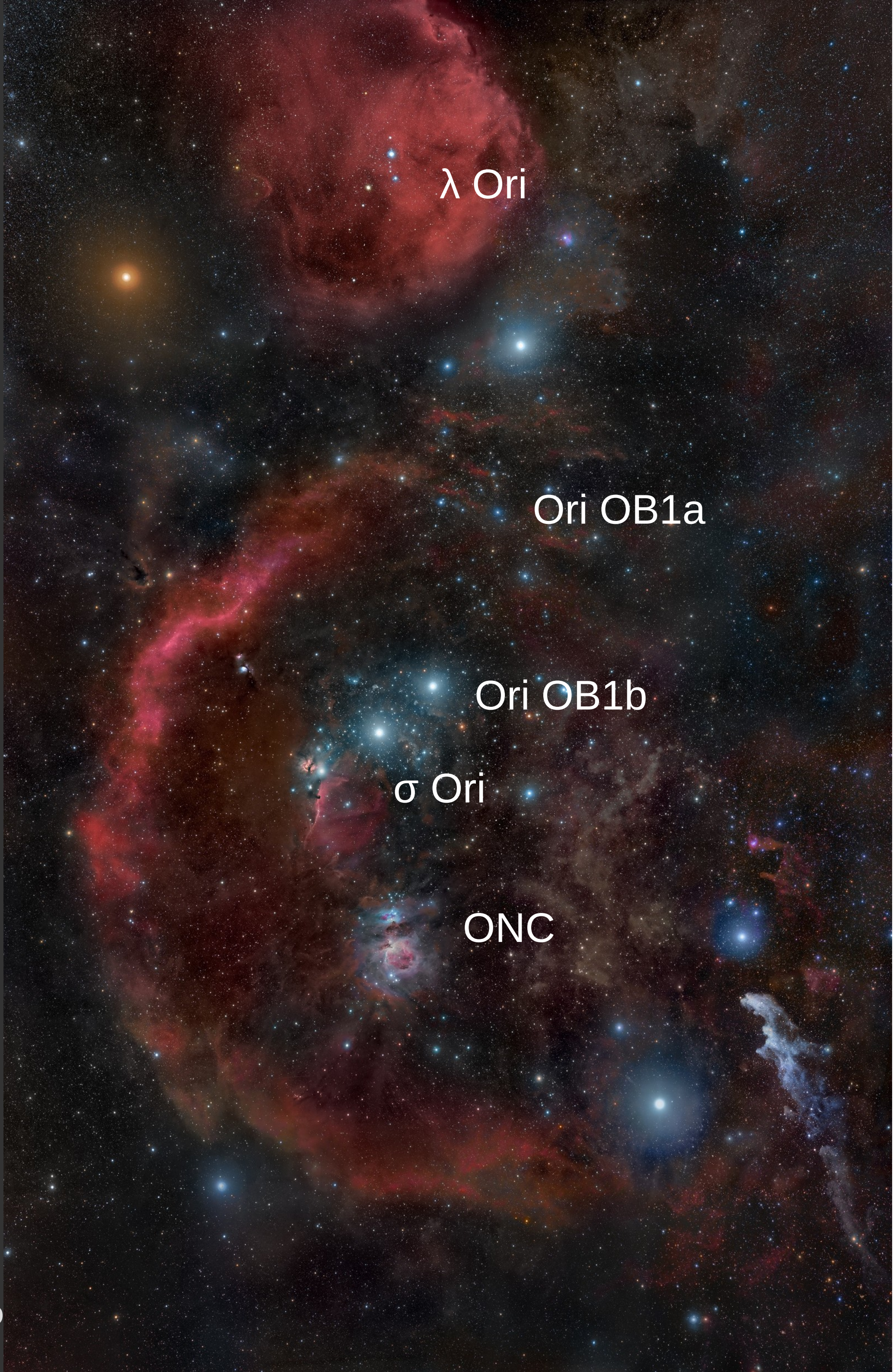
Nieva, Simón-Díaz (2011)

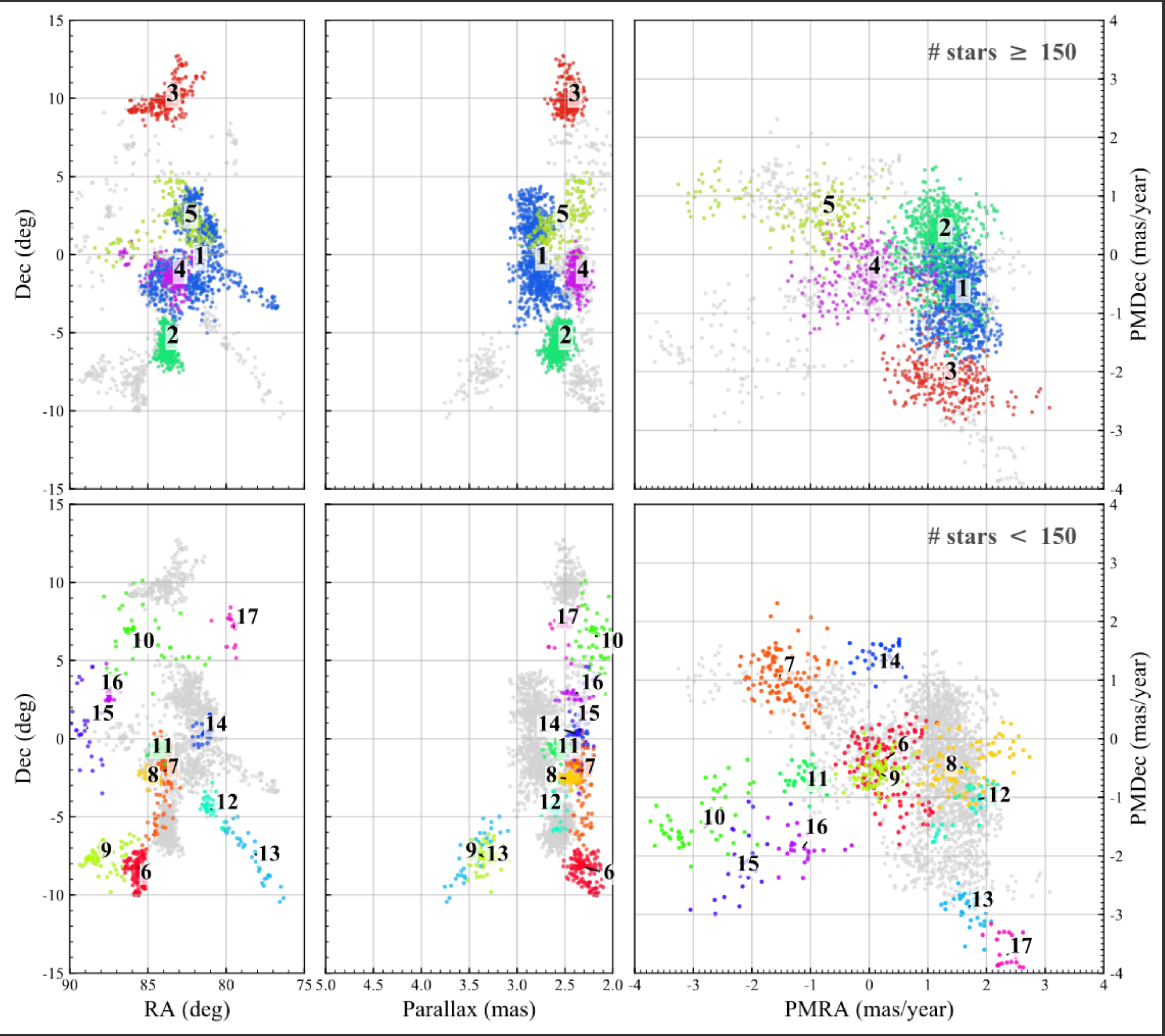
Association	[Fe/H]
OB1a	-0.04 ± 0.05
OB1b	-0.03 ± 0.07
OB1c (ONC)	-0.01 ± 0.02
OB1d (ONC)	0.00 ± 0.05

Regions and groups of the Orion complex

- Clustering becomes easy with Gaia DR2 data.
- Consistent clustering among ~10 papers: around **15 distinct groups**
- Inconsistent ages: Oldest cluster age measured between **14 Myr** (Kounkel+ 2018, Briceno+ 2018) and **21 Myr** (Kos+ 2019).

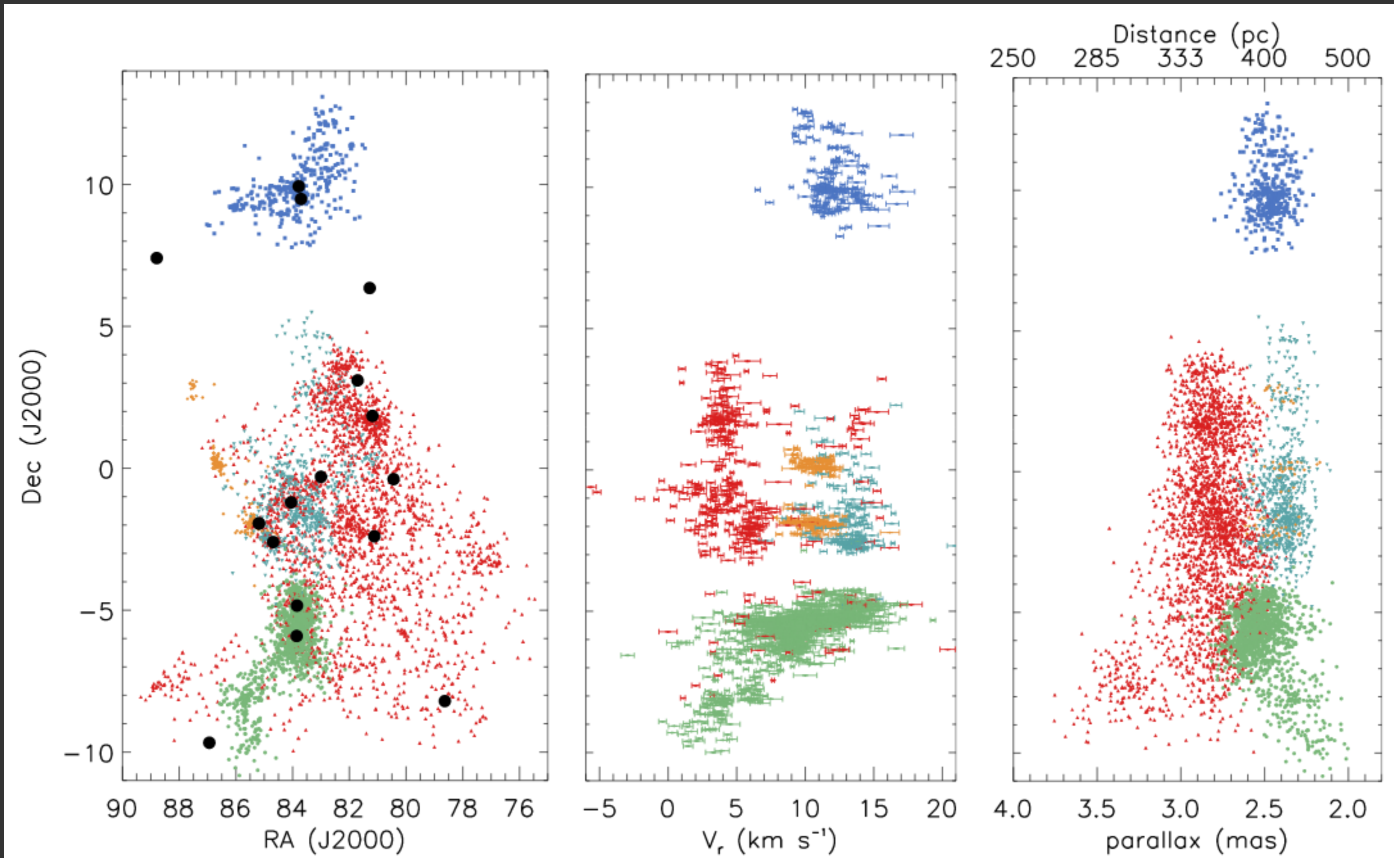
We now know the building blocks of the Orion complex.

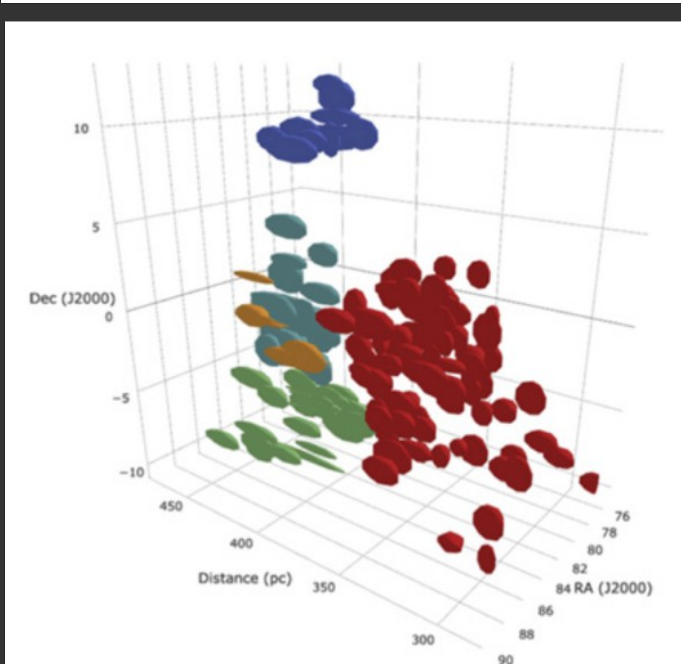




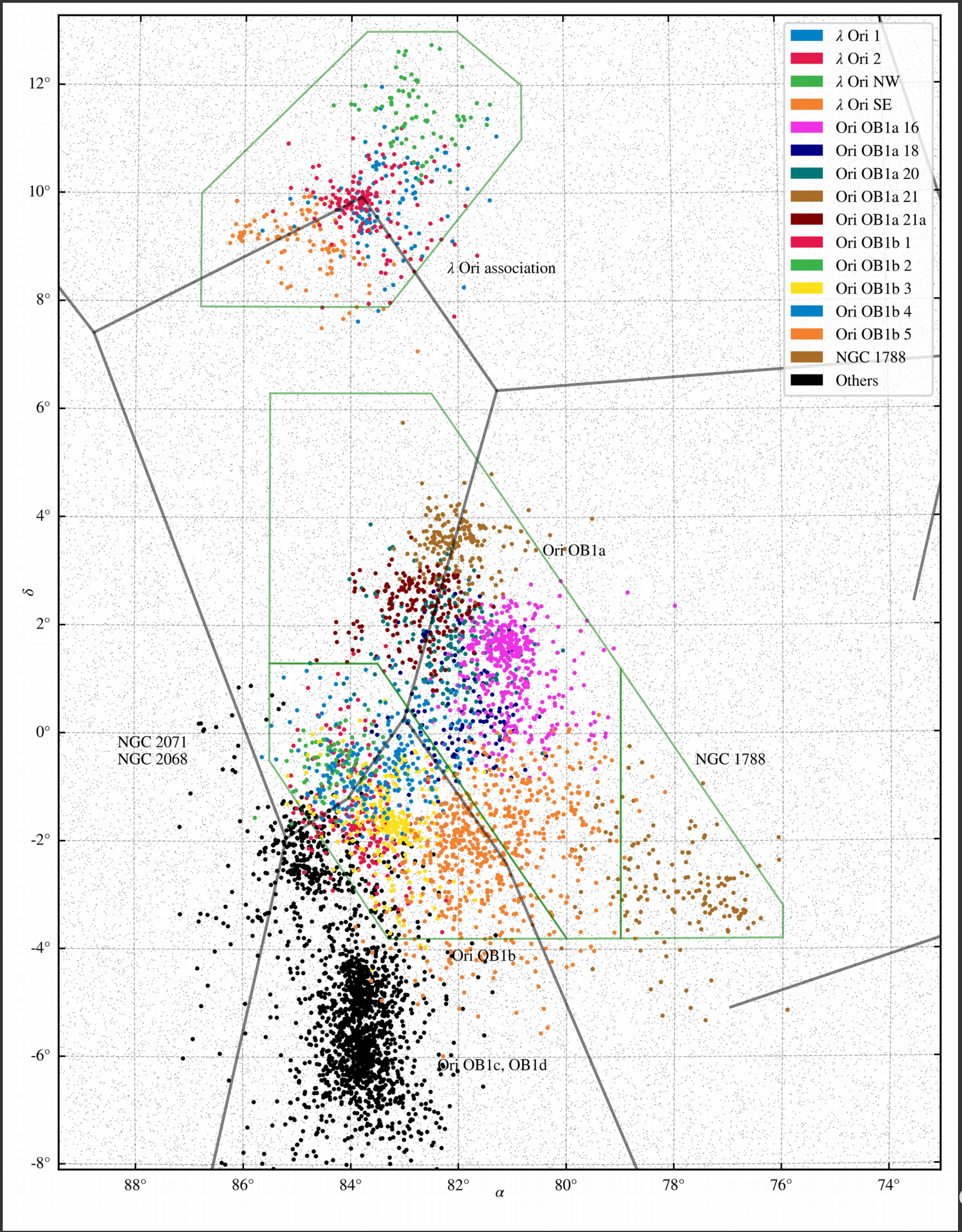
stars ≥ 150
stars < 150
Dec (deg)
RA (deg)
Parallax (mas)
PMRA (mas/year)
PMDec (mas/year)

Chen+, 2019





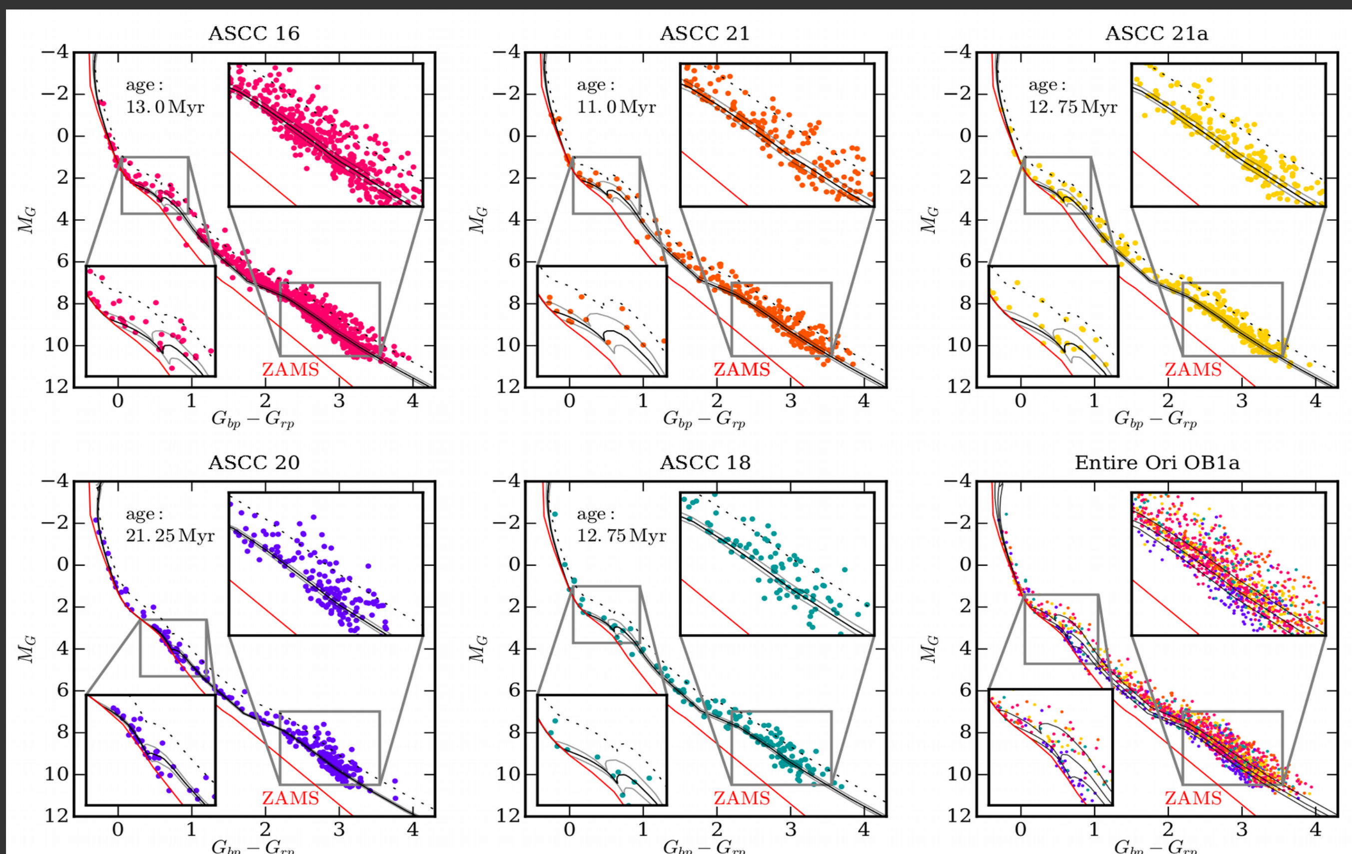
Kounkel+, 2018



Our working hypothesis

Ages

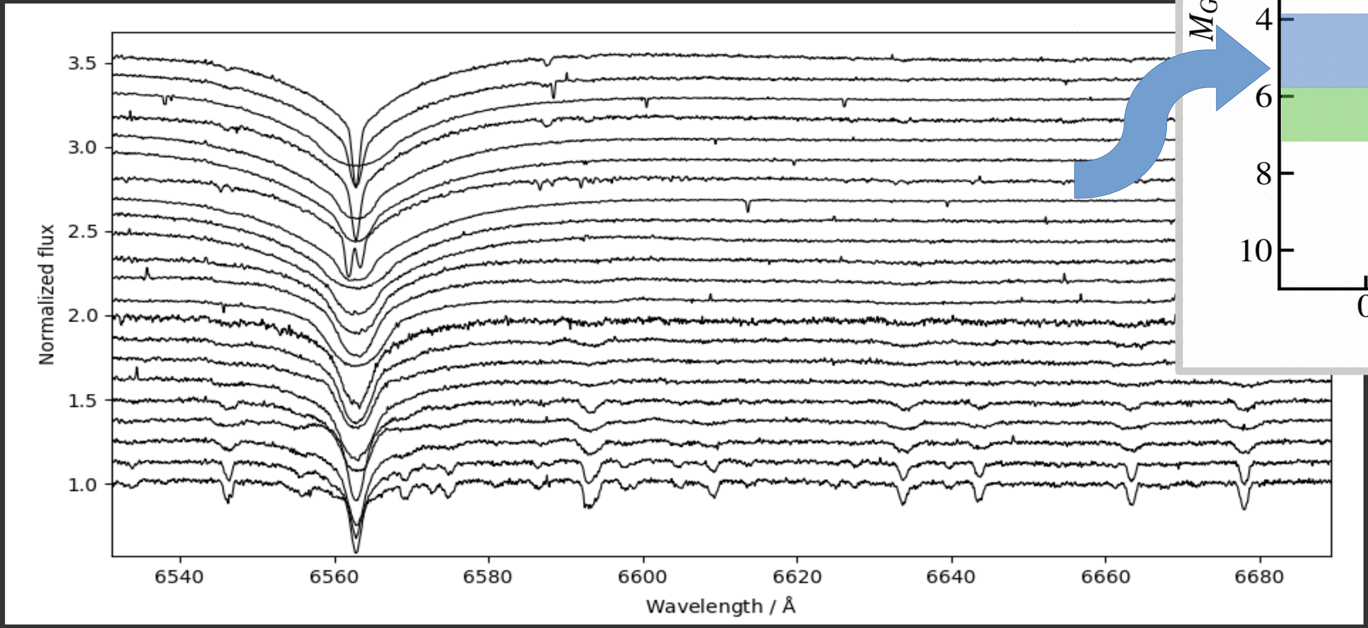
- PARSEC isochrones (Bressan+, 2012)
- Gaia G, G_{bp}, G_{rp}, Pan-STARRS1 magnitudes
- Gaia distances
- Stilism reddening (Lallement+, Capitano+, 2019)

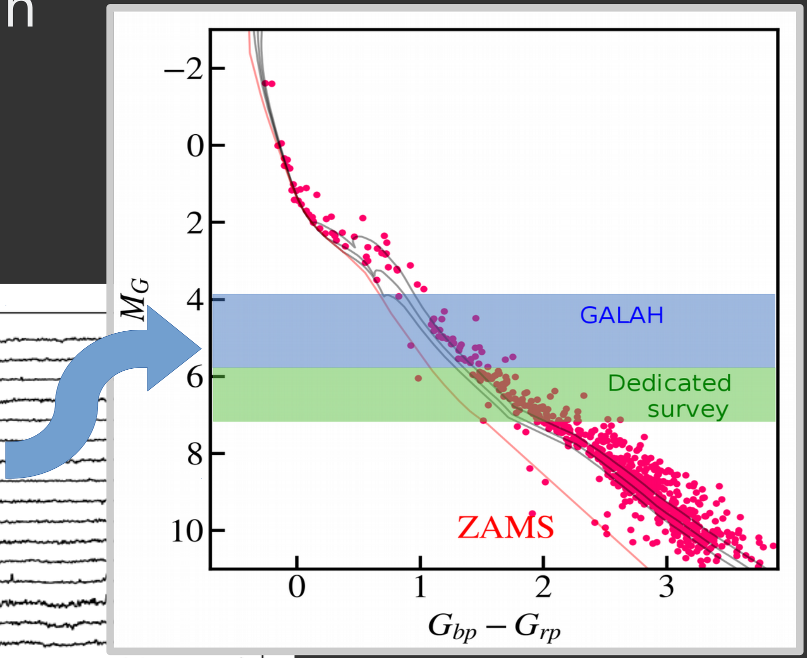


Kos et al. (2019)

GALAH observations

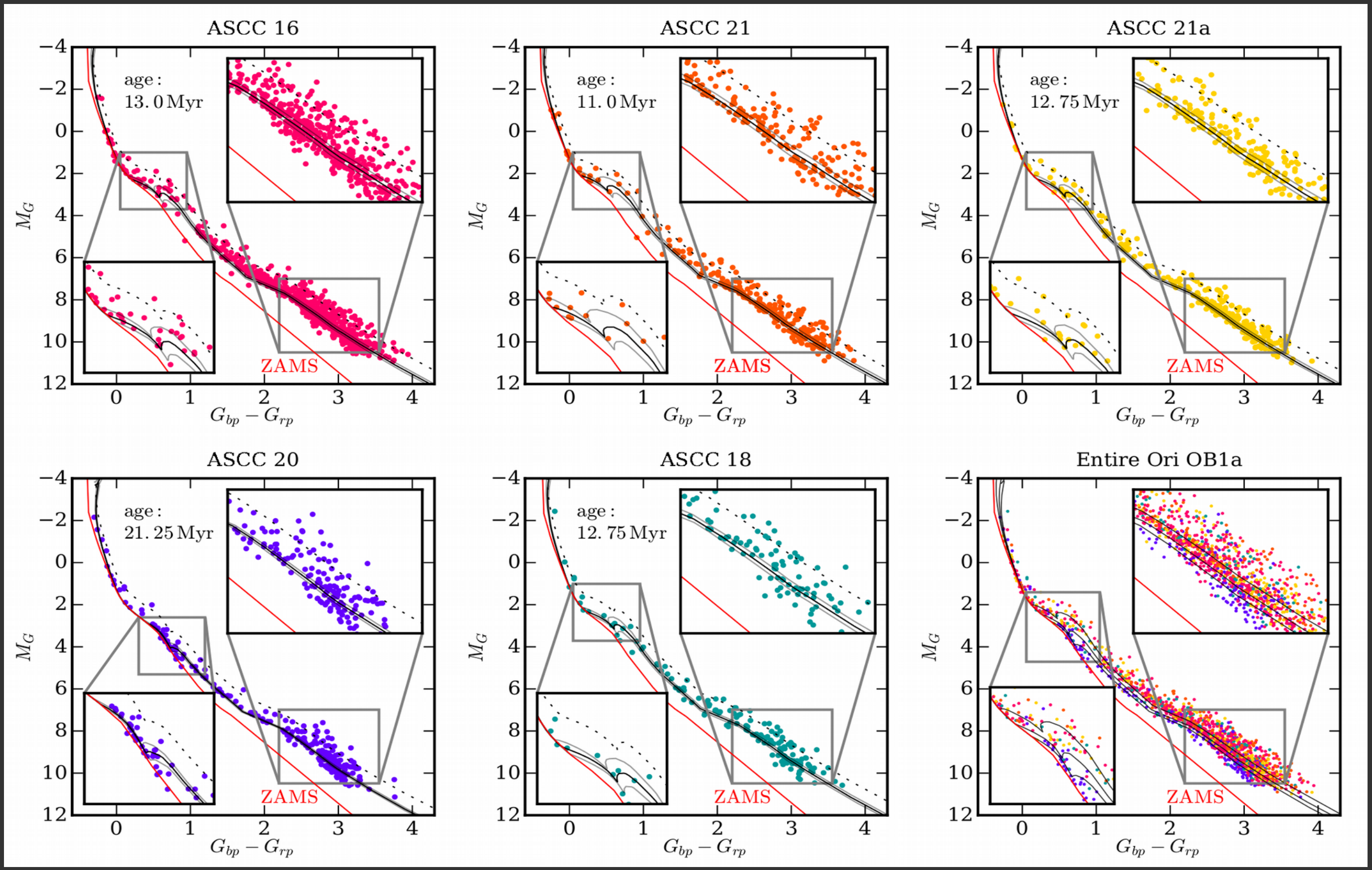
- GALAH survey + a dedicated survey.
- Selection based on initial clustering on Gaia data.
- Yielded good quality spectra for ~300 members.
- $3500 < T_{\mathrm{eff}} < 20\,000$ K.
- 1000 Å in four bands, typical SNR of 60 in the red band.
- σ_{RV} = 0.2 km/s for F,G,K dwarfs.
- Some multi-epoch observations (d - yr)





Precise metallicity/abundances

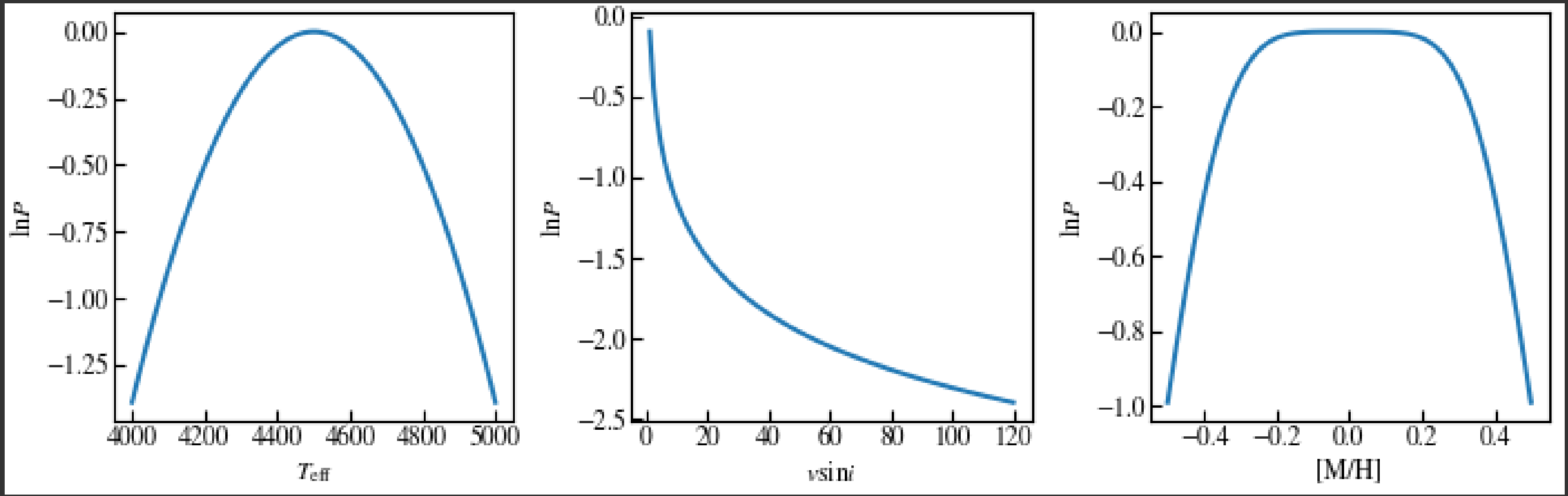
- For clusters and associations we have more prior knowledge than is used in general stellar parameters and abundances pipelines.
- Isochrones are very well constrained by photometry → T_{eff} and log g are constrained.



Kos et al. (2019)

Precise metallicity/abundances

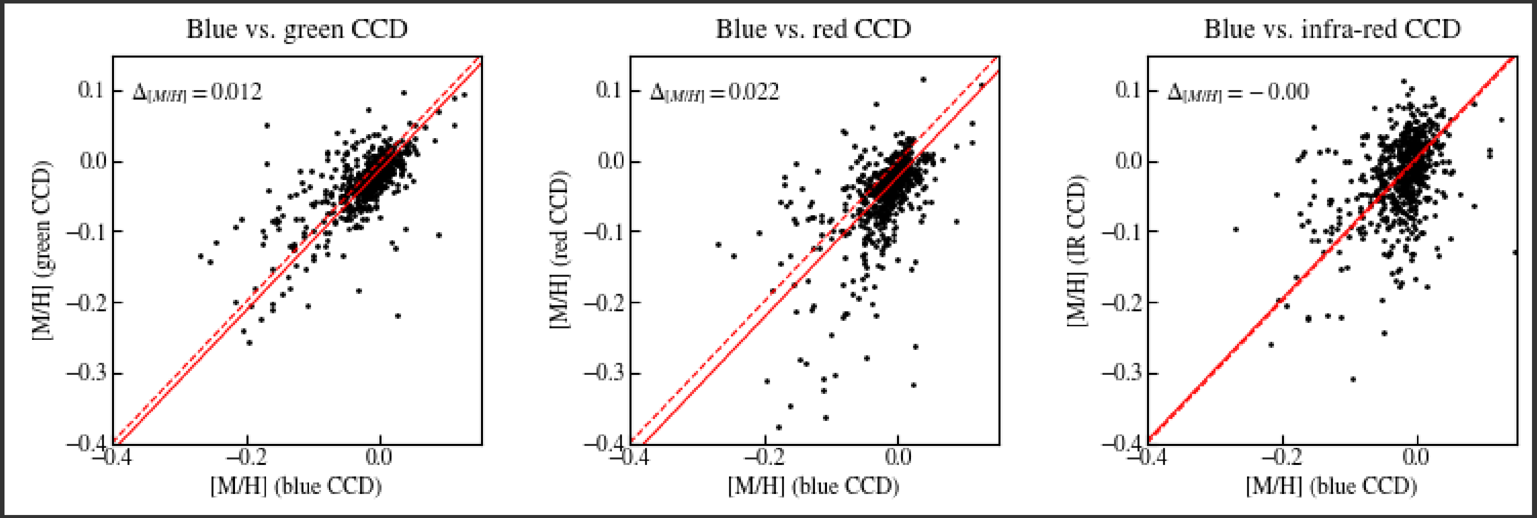
- Continuum is based on a comparison of a synthetic spectrum with initial T_{eff} and log *g*, Solar [M/H], roughly fitted *v* sin *i* and known SNR.
- Main parameters are [M/H] and *v* sin *i*, both of which are calculated from spectra by a Bayesian fitting of SME spectral models (version 4.23 in iSpec wrapper + MARCS + Asplund 2009 Solar abundances + GES linelists within iSpec).
  - T_{eff} is allowed to vary around the predetermined value
  - Empirical relations for v_{mic}, v_{mac}
  - Two procedures (all four bands fitted at the same time or separately)



priors

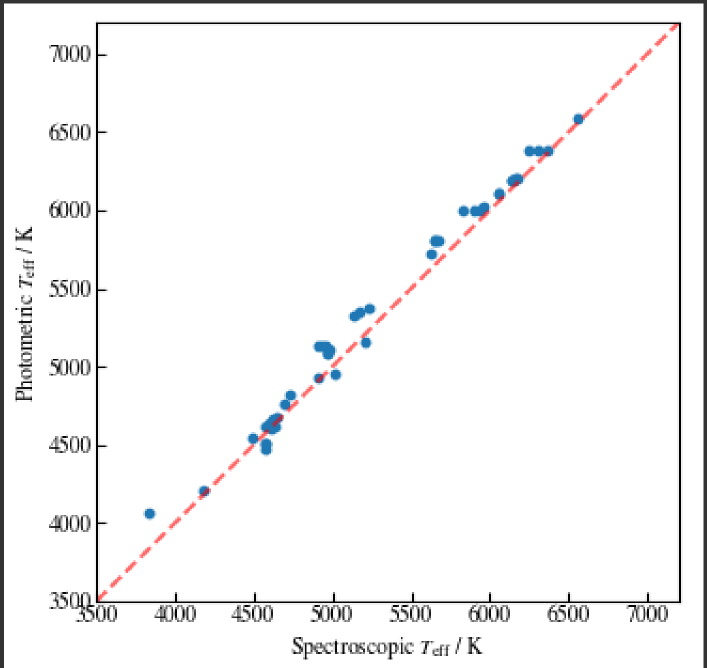
Precise metallicity/abundances

- Precise because:
  - Small systematics between four bands (0.02 dex)
  - Small systematics in respect to SNR
  - Good agreement between photometric and spectroscopic T_{eff}
  - Good agreement between observations from different epochs and different fibres.
  - Weak trends with $\mathrm{T_{eff}}$ and none with $\log g$



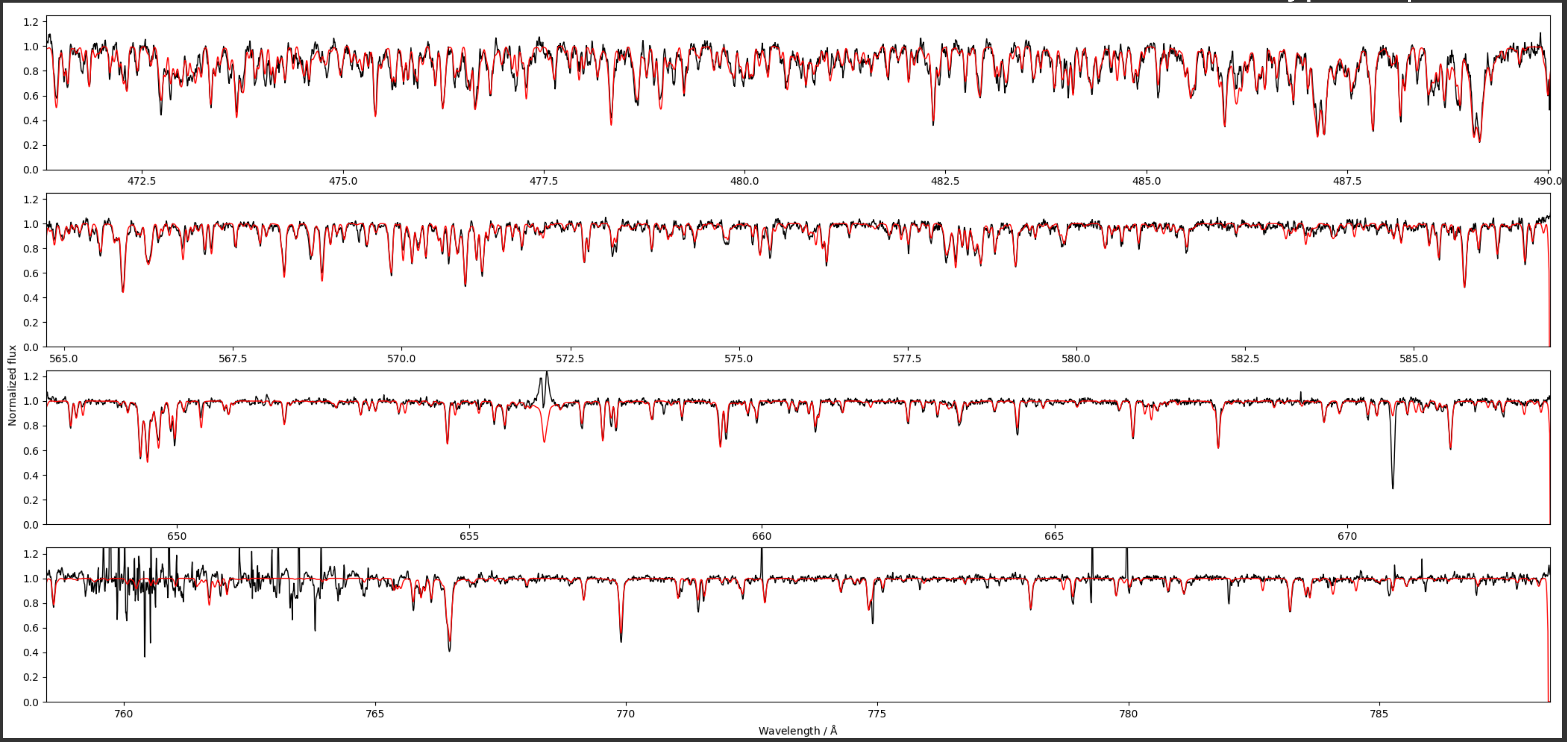
Precise metallicity/abundances

- Precise because:
  - Small systematics between four bands (0.02 dex)
  - Small systematics in respect to SNR
  - Good agreement between photometric and spectroscopic T_{eff}
  - Good agreement between observations from different epochs and different fibres.
  - Weak trends with T_{eff} and none with $\log g$



stdev = 80 K

Typical spectrum



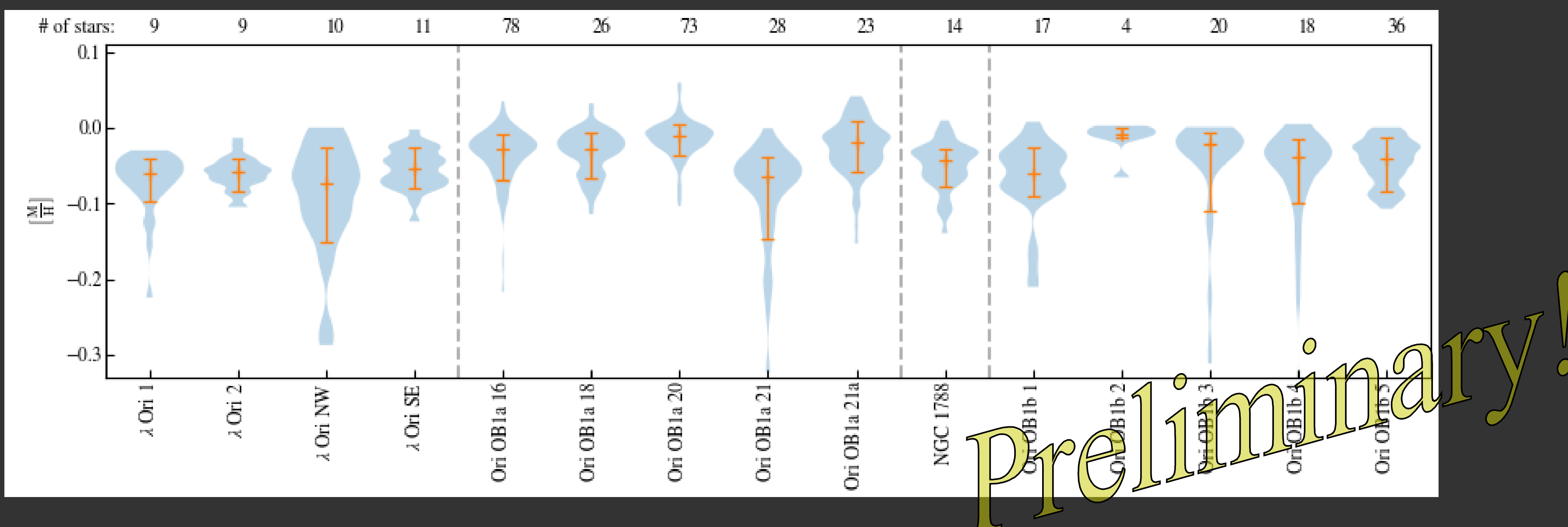
Metalicity trends in the Orion complex

Plotted only stars with:

- $v \sin i$ < 50 km/s
- SNR > 20
- T_{eff} < 8000 K

Typical [M/H] uncertainty for individual measurements: **0.02 dex**

Typical scatter within each cluster: **0.036 dex**



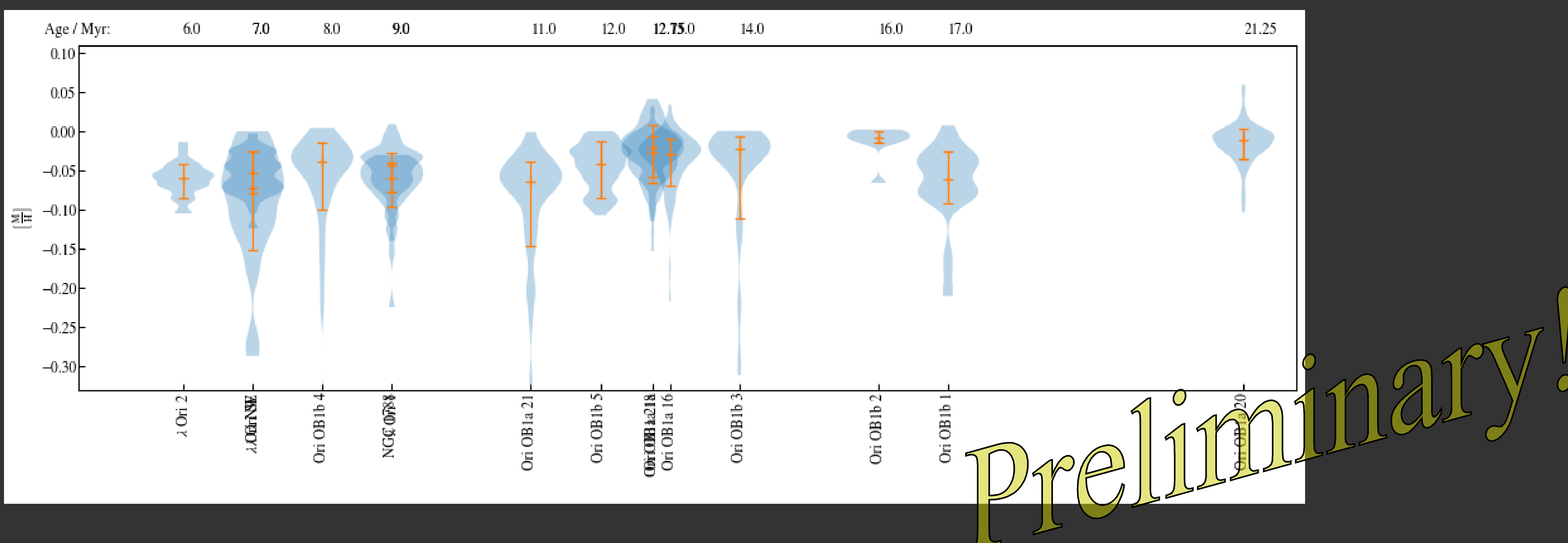
Metalicity trends in the Orion complex

Plotted only stars with:

- $v \sin i < 50$ km/s
- SNR > 20
- $T_{\mathrm{eff}} < 8000$ K

Typical [M/H] uncertainty for individual measurements: **0.02 dex**

Typical scatter within each cluster: **0.036 dex**



Conclusions:

Orion complex is not chemically homogeneous.

However, it is not far and reasons are hard to deduce.

There was interaction between different components in the Orion complex before, during and after star formation.

Their influence does not reflect in abundances in a simple way.

Discussion:

How much do the differences of [M/H]<0.05 dex reflect primordial ISM as opposed to processes in thestellar atmospheres?

How do we fit isochrones?

Future Challenges:

Explore chemical trends with individual abundances. [M/H] now mostly reflects Fe abundances.

Explore systematic uncertainties.

Search for pollution of stellar atmospheres from accretion or planet engulfment.

Reproduce the complete Chemo-dynamical history of the Orion complex.

Expand the method to other clusters and build a self-consistent and self-calibrated training set.