Exploring the core of the nearest massive star-forming region: A study of Cygnus OB2

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The Cygnus-X complex represents the most powerful star-forming region at less than 2 kpc from us.

Its core, Cygnus OB2, contains nearly 100 O-stars and can be used as a laboratory for massive star evolution and a proxy for massive clusters. Its distance allows observations at all wavelengths and accurate *Gaia* measurements.

Thus it has been selected for a detailed research that we present in four independent but related studies.

In this contribution we present four studies in which we have:

(I) updated the Cygnus OB2 massive OB-star census.

(II) looked for self-enrichment processes and studied the implications of its abundance gradient.

(III) performed the first study of its spatial substructure using *Gaia* DR2 data.

(IV) combined the DR2 data with our spectroscopic analyses to explore the recent star formation history.

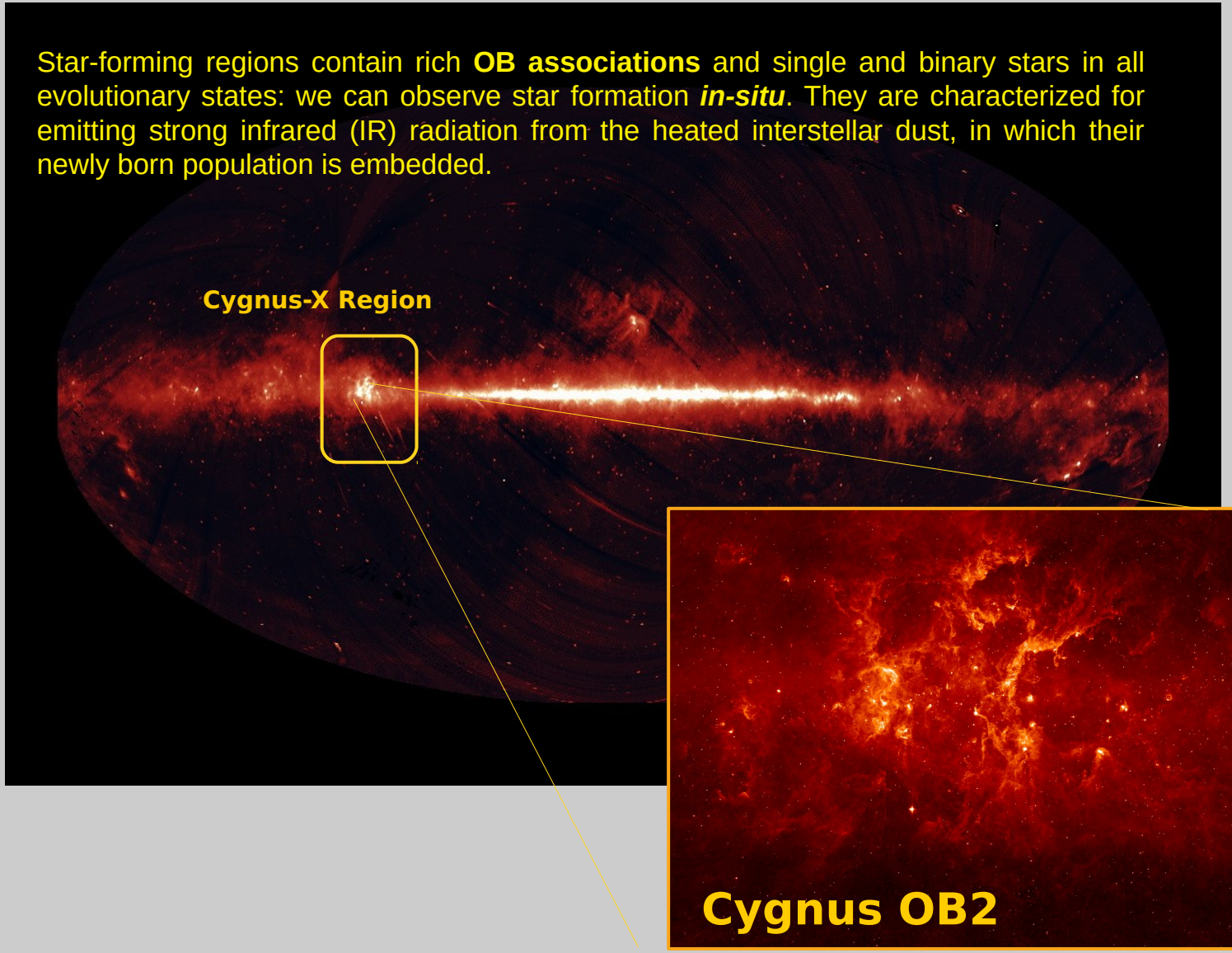
Context: Star-forming regions

Galactic intense star-forming regions, due to their relatively close distance, allow us the detailed observation of their massive stellar population.

Cygnus-X is the nearest massive star forming region that contains several rich OB associations. Its core, **Cygnus OB2**, represents the most obvious example of recent star formation and provides an ideal template for studies of distant, massive star clusters and OB associations in the MW and in nearby galaxies.

Table 1.2: Summary of the latest published Cygnus OB2 properties.

Parameter	Value	Reference
Centre	$l = 79.80°$, $b = 0.80°$	Comerón et al. (2008); Comerón & Pasquali (2012)
Radius	1 deg^2	Comerón et al. (2008); Comerón & Pasquali (2012)
Core centre	$l = 80.22°$, $b = 0.78°$	Hanson (2003)
Core radius	0.5 deg^2	Hanson (2003)
OB members (< B3)	221	Berlanas et al. (2018a), Chapter 3
O members	70	Berlanas et al. (2018a), Chapter 3
Binary fraction	36%	This work, Chapter 6
Stellar mass	16500^{+3800}_{-2800} M$_\odot$	Wright et al. (2015)
Age spread	(1 – 6) Myr	Berlanas et al. (2018a), Chapter 3
Age peak	(4 – 5) Myr	Wright et al. (2015); Berlanas et al. (2018a)
IMF slope	1.39 ± 0.19	Wright et al. (2015)
Distance	1755 pc$^{+23}_{-19}$ (+ syst.)	Berlanas et al. (2019), Chapter 5
A_V spread	(4 – 7) ± 0.3 mag.	Comerón & Pasquali (2012); Wright et al. (2015)



Description of the work

1. COMPLETING THE CENSUS OF OB MEMBERS

(Berlanas et al. 2018a, A&A, 612, A50)

We present a membership study of Cygnus OB2 and its surroundings for completing the currently known population of early-type stars in the region. From new spectroscopic observations, we have increased the number of OB stars known in the area in spite of the existing limitations for completing the whole census. We also investigate the age and extinction distribution of the region, and whether there exists a correlation between the observed age spread and Galactic longitude.

2. LOOKING FOR SELF-ENRICHMENT

(Berlanas et al. 2018b, A&A, 620, A56)

Since there exist firm indications that many massive stars of Cygnus OB2 have exploded as supernovae during the history of the region, we include a chemical analysis of a sample of OB stars in Cygnus OB2 for checking possible inhomogeneities across the whole association and whether there also exists a correlation of chemical composition with Galactic longitude that could be caused by self-enrichment processes.

3. EXPLORING THE PARALLAX DISTRIBUTION

(Berlanas et al. 2019, MNRAS, 484, 1838)

A persistent problem for massive star studies has been always the inaccuracy of their distances. Fortunately, the second data release of the *Gaia* satellite has provided high-quality astrometry for a large number of Galactic massive stars, including those in Cygnus OB2. Thus, a study of the spatial substructure of the association is also included in this work, where we quantify the line-of-sight substructure within the association by using an inference approach and create a parametrized model that reproduces the observed parallax distribution.

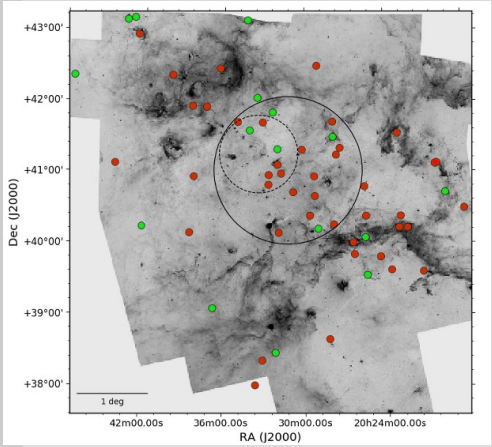
4. DETERMINING THE MAIN STELLAR PARAMETERS

(Berlanas et al. 2020, A&A, in prep.)

We present the most complete spectroscopic census of O stars done so far in Cygnus OB2. We have updated the binary fraction currently known in the association and, taking into account the results derived in all previous studies, we perform quantitative spectroscopic analysis for all the sample: we have obtained the distribution of rotational velocities and derived physical and spectroscopic parameters in order to interpret the evolutionary status of the region. We finally investigate the spatial and dynamical distribution of the sample from *Gaia* DR2.

Results 1/2

1. COMPLETING THE CENSUS OF OB MEMBERS

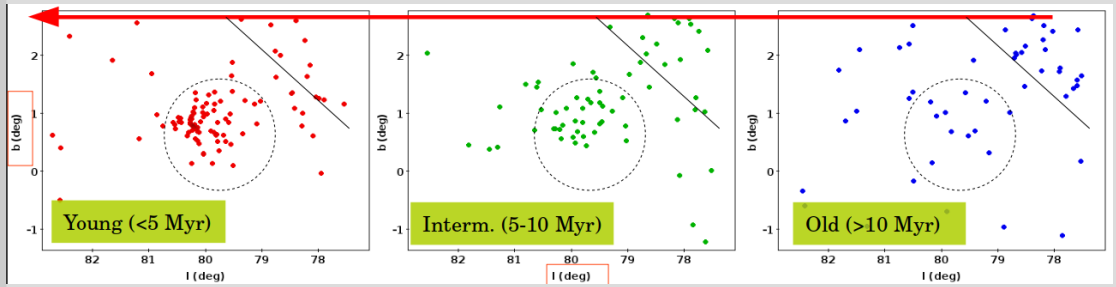


Spectral classification of new spectra:
42 new OB stars (<B3V)

... but the magnitude cutoff in the selection criteria introduces an **incompleteness** which is important mainly for those **faintest and most obscured** late O-type members.

Age distribution

(T_{eff} from SpT calibrations + log L/L_{sun} assuming DM = 10.8)



Massive star formation has proceeded **from lower to higher Galactic longitudes**, from Cygnus OB9, continuing in the southern part of Cygnus OB2 and increasing in its northern part.

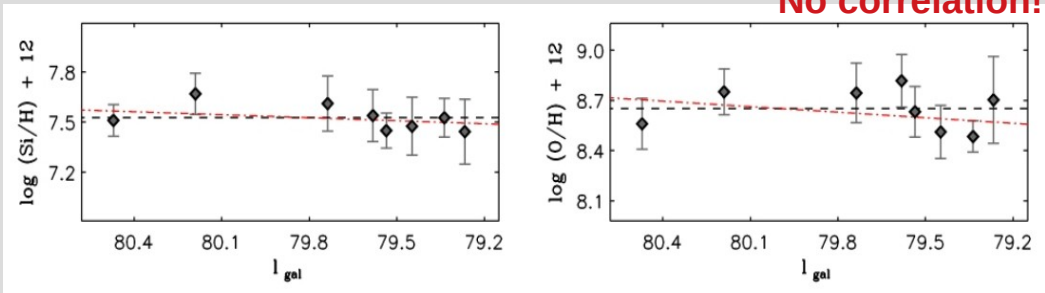
2. LOOKING FOR SELF-ENRICHMENT

Could the correlation between ages and Galactic longitudes be associated with a chemical composition gradient?

(that could evidence star formation from self-enrichment processes produced by pollution of the interstellar medium by successive generations of massive stars).

Si and O abundances for a sample of slow rotators

No correlation!



Our results indicate a **homogeneous** composition for our stellar sample, without evidence of a dependence on the Galactic longitude.

Test: O enrichment produced by stellar winds and SNe

The effect of self-enrichment by stellar winds and SNe is **small enough to be beyond the accuracy of our analyses.** We need to extend the sample and/or increase the quality of the spectra to detect it

Results 2/2

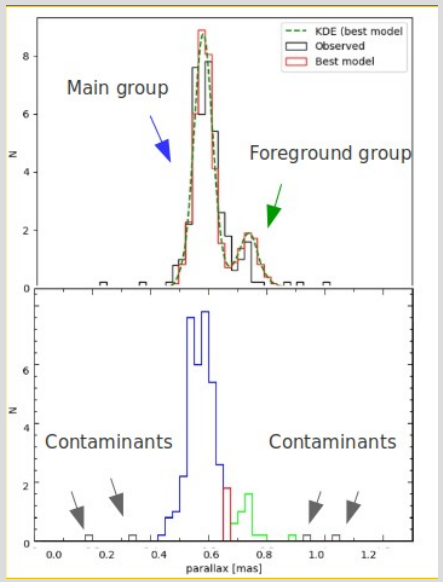
3. EXPLORING THE PARALLAX DISTRIBUTION

***Gaia* DR2 parallaxes** → unique opportunity to inspect the internal structure of Galactic young open clusters and relatively nearby massive OB associations.

Cygnus OB2: 200 OB-stars suitable for our analysis (RUWE < 1.4)

We created a **parametrized model** to reproduce the *Gaia* DR2 parallax distribution.

Compared to the parallax distribution using the MCMC ensemble sampler ***emcee***



We find two stellar groups superposed in Cygnus OB2 but separated by ~400 pc.

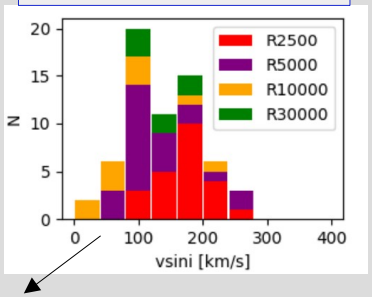
Main group ~1750 pc

Foreground group ~1350 pc

4. DETERMINING THE MAIN STELLAR PARAMETERS

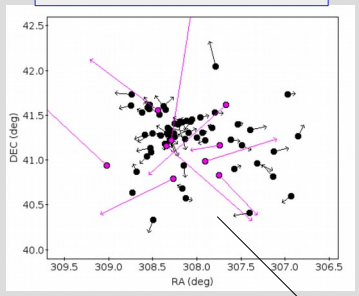
We compiled new and already available spectra of the 77 O-type stars identified in Cygnus OB2: 63 are suitable for accurate spectroscopic analysis and 52 have reliable Gaia DR2 astrometry (RUWE < 1.4).

***vsini* distribution**



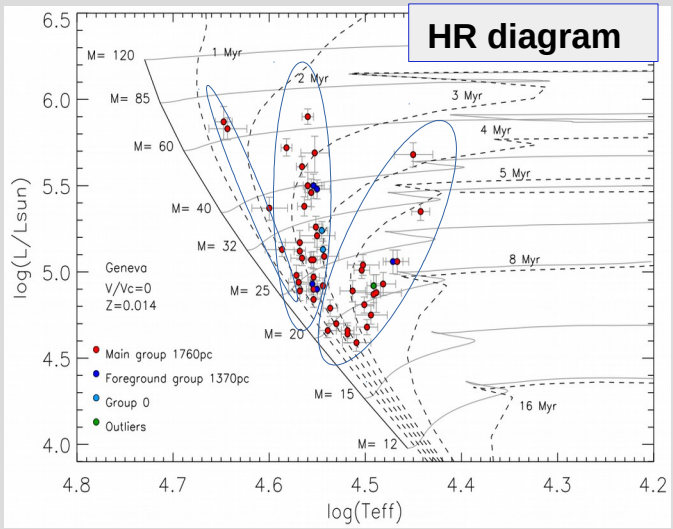
Similar to other distributions of O-stars except for the lack of very fast rotators

pm distribution



Runaway candidates!

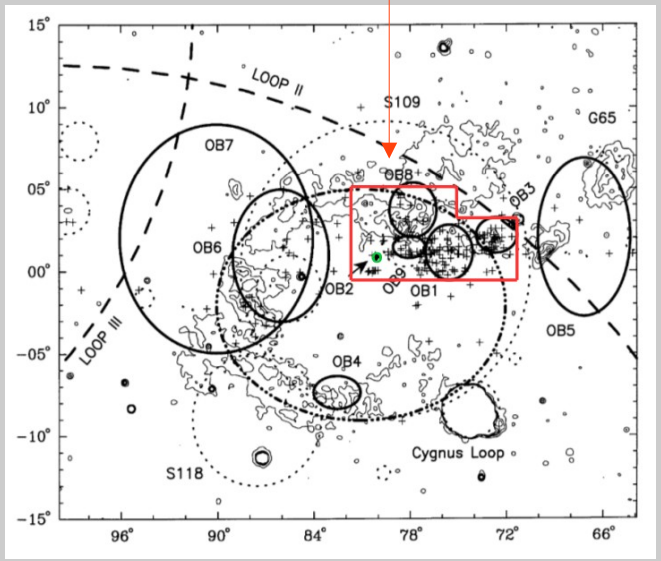
HR diagram



From spectroscopic parameters and *Gaia* distances we find star formation during the last 1–6 Myr, with two main bursts centred roughly at 3 and 5 Myr. A third smaller group of stars at ~1.5 Myr containing the hottest stars of our sample may be due to interactive binaries.

Impact & Future: WEAVE surveys covering CYGNUS-X

LR (**R=5000**) of the Galactic disc + **HR** (**R=20000,** S/N > **120**) focused on the OB population of **several Cygnus OB associations**



Combining the findings of the research presented here (and that of massive stars in general), **WEAVE** and ***Gaia*** astrometry we will be in the best position to improve our knowledge of star formation and evolution of massive star-forming regions and clusters, including our understanding of the dynamics and kinematics of OB associations and stellar groups.

see A. Herrero et al. contribution !