Stellar Demographics in the Orion OB1 association

César Briceño

Cerro Tololo Interamerican Observatory/
National Optical Astronomical Obbservatory, USA

Collaborators:

Nuria Calvet (University of Michigan, Ann Arbor, USA)
Jesus Hernandez, (UNAM-Ensenada, Mexico)
Kathy Vivas (CTIO, La Serena, Chile)
Juan Jose Downes & Juan Jose Downes (CIDA, Merida, Venezuela)
Jacqueline Loerincs (University of Colorado, USA)
Alice Perez (University of Leeds, UK)
Catherine Espaillat (Boston University, USA)
Lori Allen (NOAO, USA)
Lee Hartmann & Mario Mateo (University of Michigan, Ann, Arbor, USA)
John Bailey III (Leiden University, The Netherlands)

Hans and OB associations

The Low-mass Populations in OB Associations

César Briceño
Centro de Investigaciones de Astronomía

Thomas Preibisch
Max-Planck-Institut für Radioastronomie

William H. Sherry
National Optical Astronomy Observatory

Eric E. Mamajek
Harvard-Smithsonian Center for Astrophysics

Robert D. Mathieu
University of Wisconsin - Madison

Frederick M. Walter
Stony Brook University

Hans Zinnecker
Astrophysikalisches Institut Potsdam

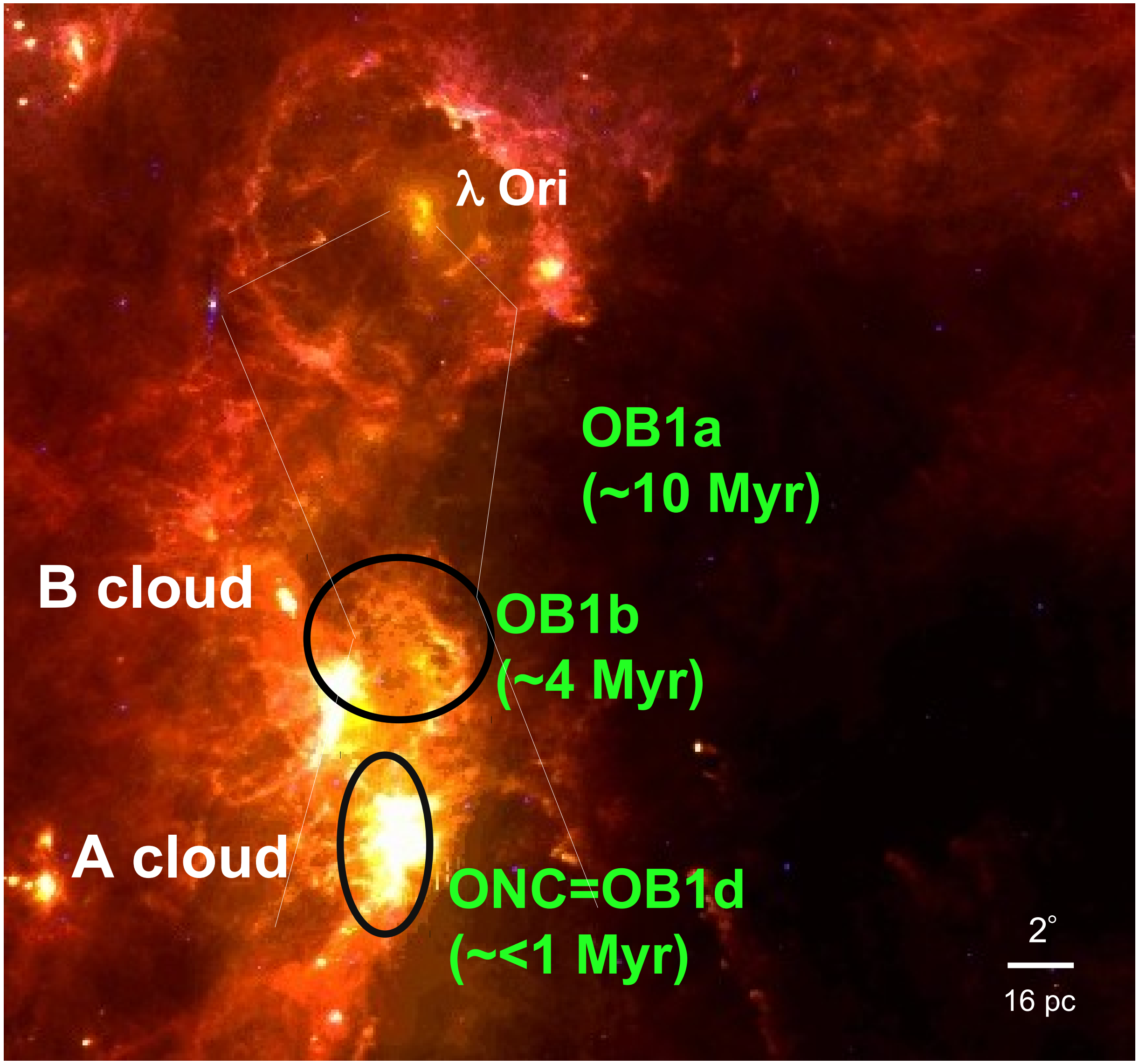
Low-mass stars ($0.1 \lesssim M \lesssim 1\ M_\odot$) in OB associations are key to addressing some of the most fundamental problems in star formation. The low-mass stellar populations of OB associations provide a snapshot of the fossil star-formation record of giant molecular cloud complexes. Large scale surveys have identified hundreds of members of nearby OB associations, and revealed that low-mass stars exist wherever high-mass stars have recently formed. The spatial distribution of low-mass members of OB associations demonstrate the existence of significant substructure ("subgroups"). This "discretized" sequence of stellar groups is consistent with an origin in short-lived parent molecular clouds within a Giant Molecular Cloud Complex. The low-mass population in each subgroup within an OB association exhibits little evidence for significant age spreads on time scales of $\sim$ 10 Myr or greater, in agreement with a scenario

What do we mean by “Orion”?

Orion is among the best studied regions of star formation in the sky.

X-ray, FUV/EUV, optical near, mid and far IR, submm and longer wavelength studies have targeted over the years the A and B cloud populations: ONC, NGC 2024, 2068/2071, σ Ori, L1641.

But is that all there is to Orion?

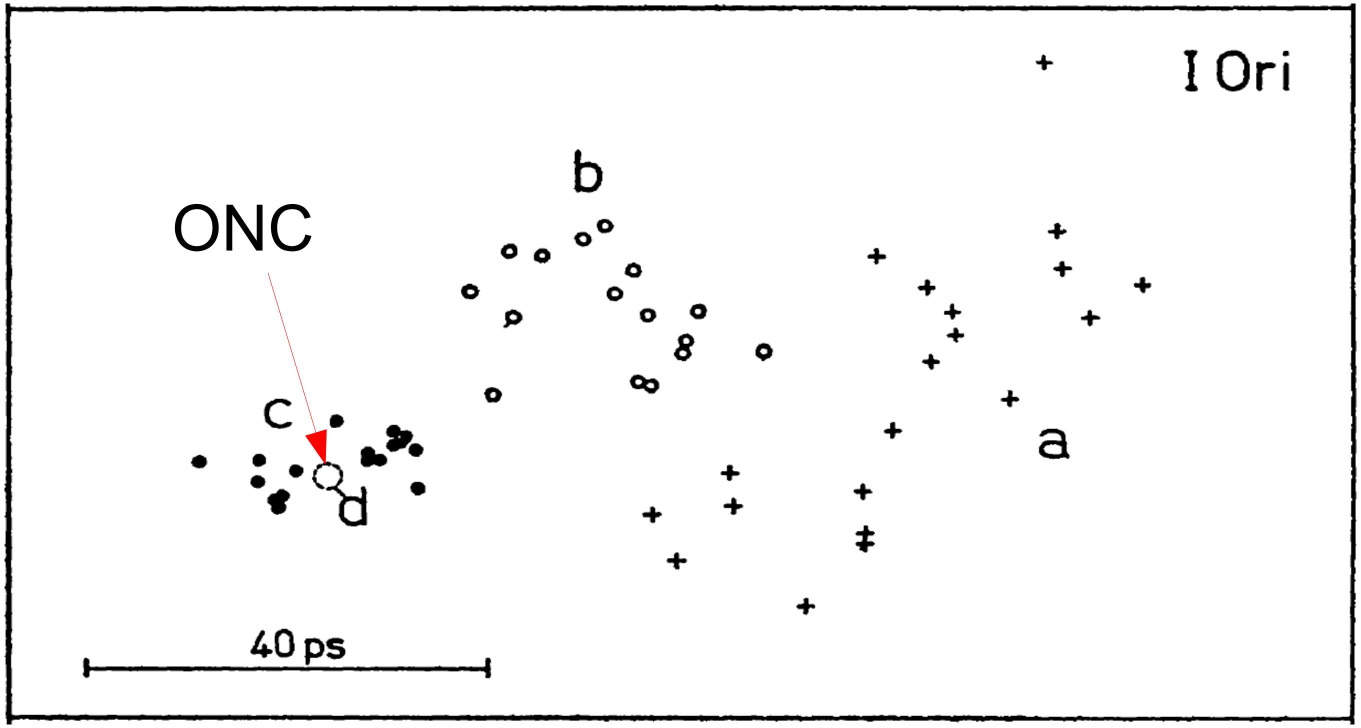


(IRAS 100μm)

Large part of Orion is spanned by the OB1a and OB1b associations…but little is known about its stellar population

We know about the subgroups *a, b c* and *d* since Blauuw (1964), but it has taken ~50 yr to start learning something about the off-cloud populations that span OB1a, OB1b and even OB1c.

Older (~10 Myr) pre-main sequence populations have been difficult to identify → parent clouds have dissipated



Blaauw 1964, ARAA, 2, 213

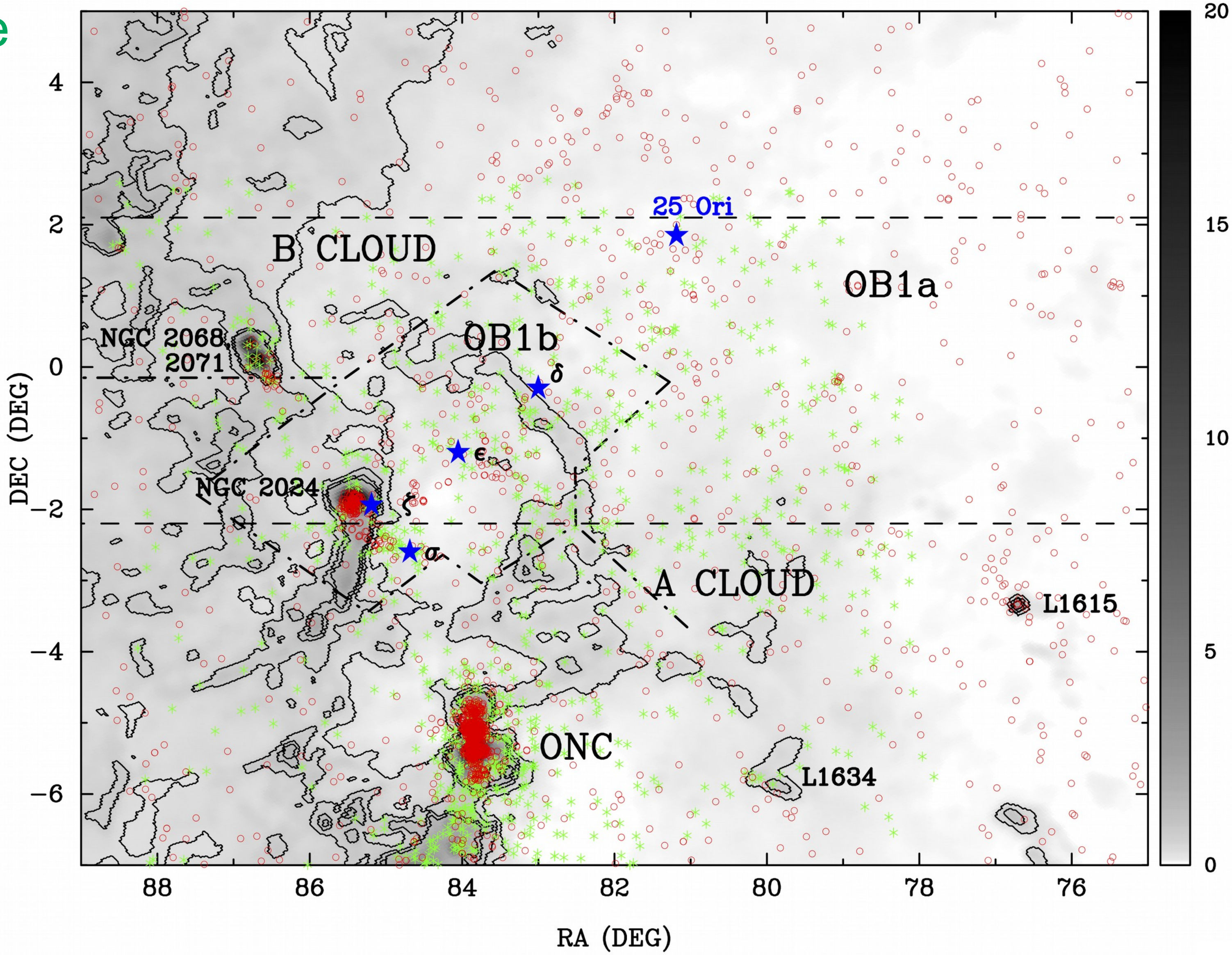
Large scale surveys: Hα, X-rays

KISO: objective prism plates
RASS: x-rays

Missed most of the off-cloud population:

RASS → contaminated by young field dwarfs

KISO → biased to Hα strong stars (CTTS)

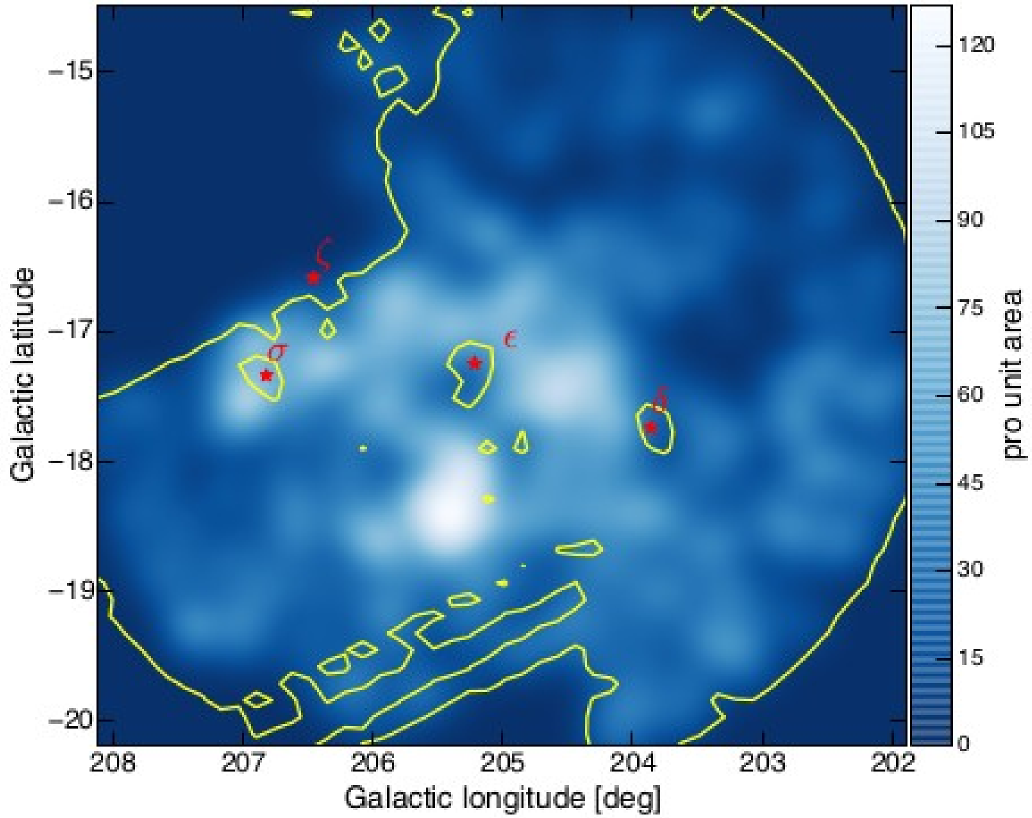


The Orion Belt: photometric surveys

Sherry 2003 (PhD Thesis)

Sherry et al. 2004 (AJ, 128, 2316)

Caballero et al. 2010 (AN, 331, 257)



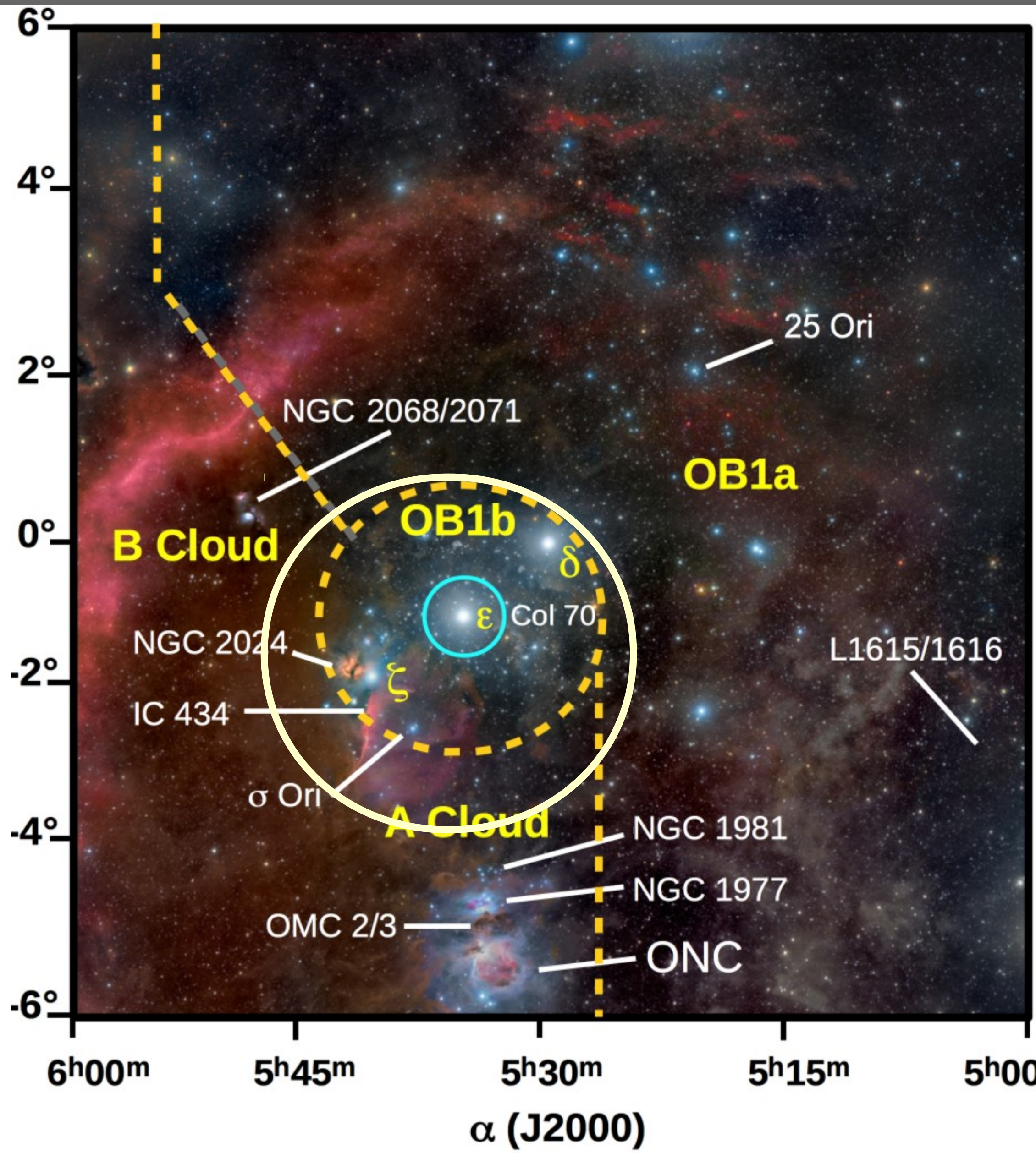
K. Kubiak et al. 2017 (A&A, 598, 124)... next talk!

CIDA VARIABILITY SURVEY OF ORION (CVSO)

Identify+characterize the young, low-mass PMS stellar populations over ~< 200 sq.deg in the wide **off-cloud** regions of the Orion OB1 association: OB1a and OB1b.

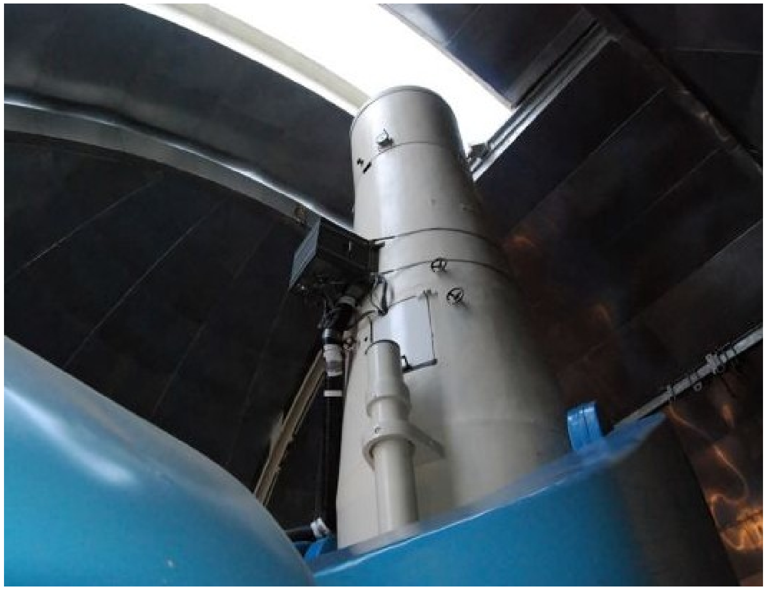
➡ **PHOTOMETRIC SURVEY + FOLLOW UP SPECTROSC.**

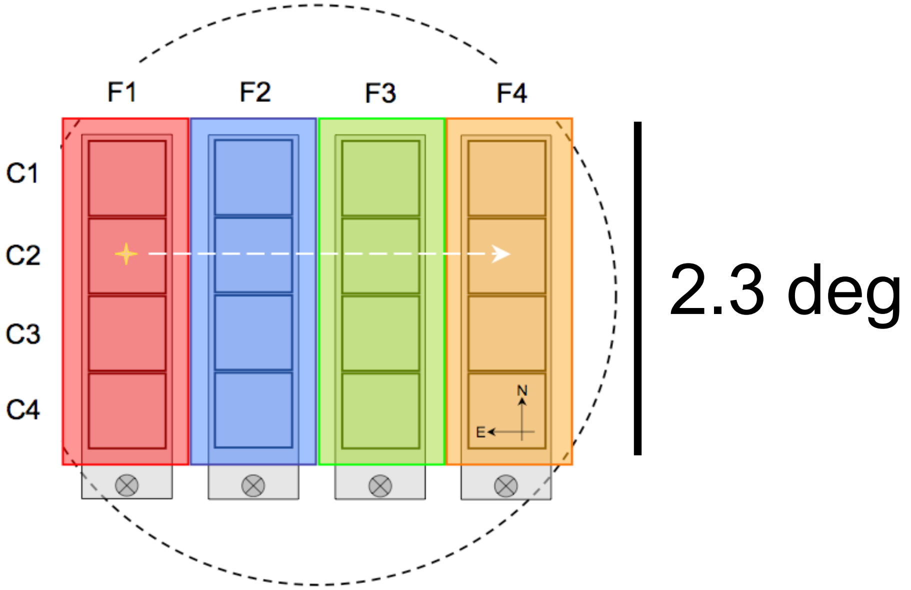
Briceño et al. 2001, Science, 291, 93
Briceño et al. 2005, AJ, 129, 907
Briceño et al. 2007, ApJ, 671, 1784
Briceño 2008, Handbook of SF Regions, Vol. 1, p.838
Briceno et al. 2018, arXiv180501008B



The VRI, multi-epoch photometric survey

1m Schmidt telesc. @ Venezuela Natl. Astron. Observ.: 8.7° N, 3600m elev

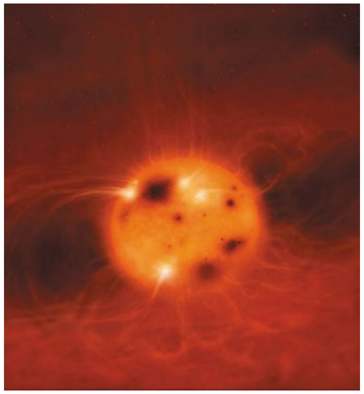




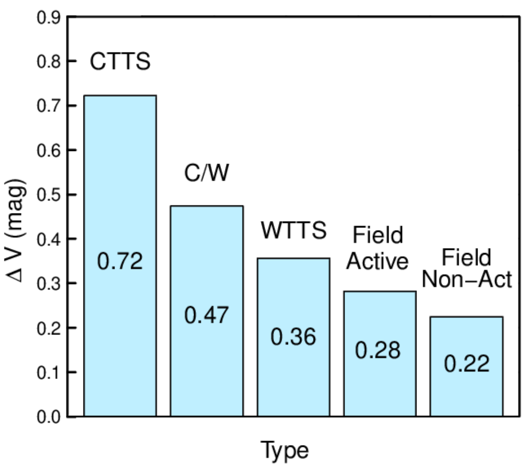
- V_{lim} ~20.5
- Up to 150 epochs over ~10 yr baseline

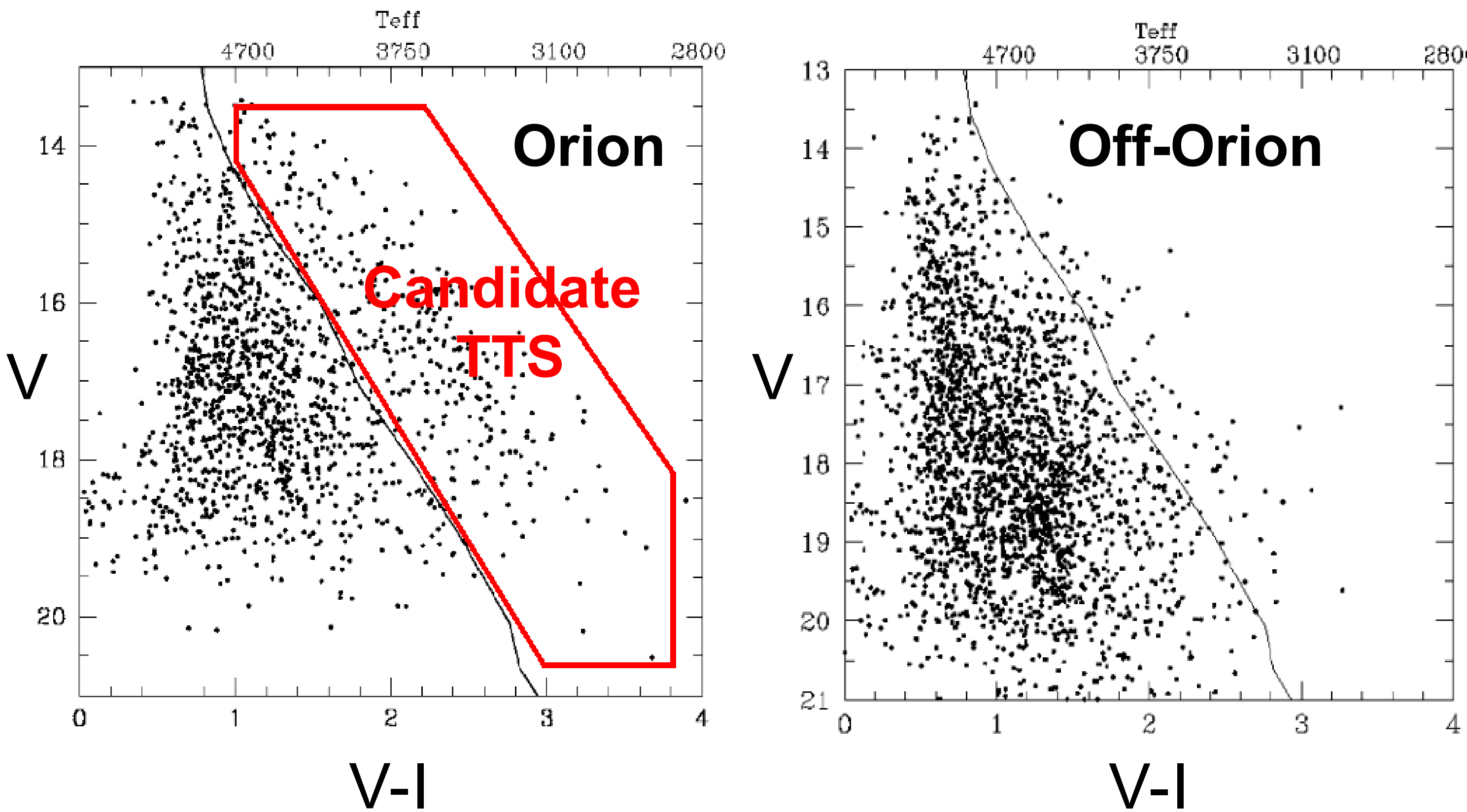
~ 5.5 deg^2 FOV (1 arcsec/pixel)
Optimized for Drift-scannning: 34 deg^2/filter/hr → ~290 deg^2/filter/night

Stellar Youth => activity-variability
→ CMDs+variability good for finding low-mass PMS stars

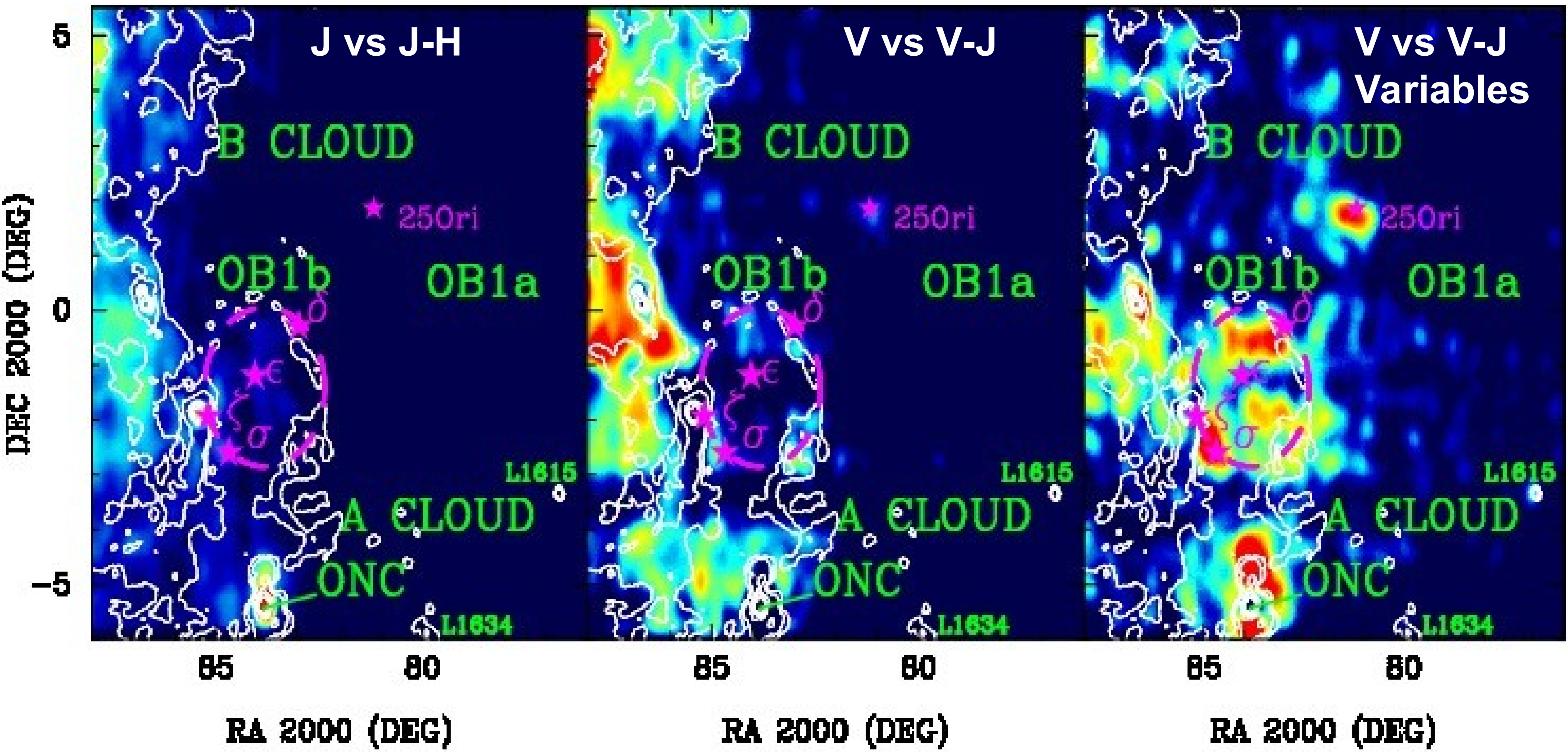


- **Classical TTS:** stellar spots, chromospheric activity (flaring), hot spots from accretion columns (variable accretion), occultation by disk
- **Weak-lined TTS:** stellar spots, flaring





VRIJHK CMDs+Variability: a key tool for unveiling the off-cloud population



Surface density (stars/deg^2) of candidate PMS stars

But we still need spectra to tell if a candidate is indeed a T Tauri star, and to derive its properties

Spectra are essential for membership confirmation:

- Late spectral types (K-M): Hα (6563) in emission, Li I (6707) in absorption, & Na I (8183,8195) ~< MS dwarfs
- **Low-res provides reliable SpT -> Teff**
- **Hi-res provides kinematics & Hα profiles**

  - Low-res (R~1000) for ~10000 targets:

    - Hydra on 3.5m WIYN (MOS)
    - Hectospec on 6.5m MMT (MOS)
    - M2FS on 6.5m Magellan (Clay) (MOS)
    - FAST on SAO 1.5m
    - Goodman on SOAR 4.1m

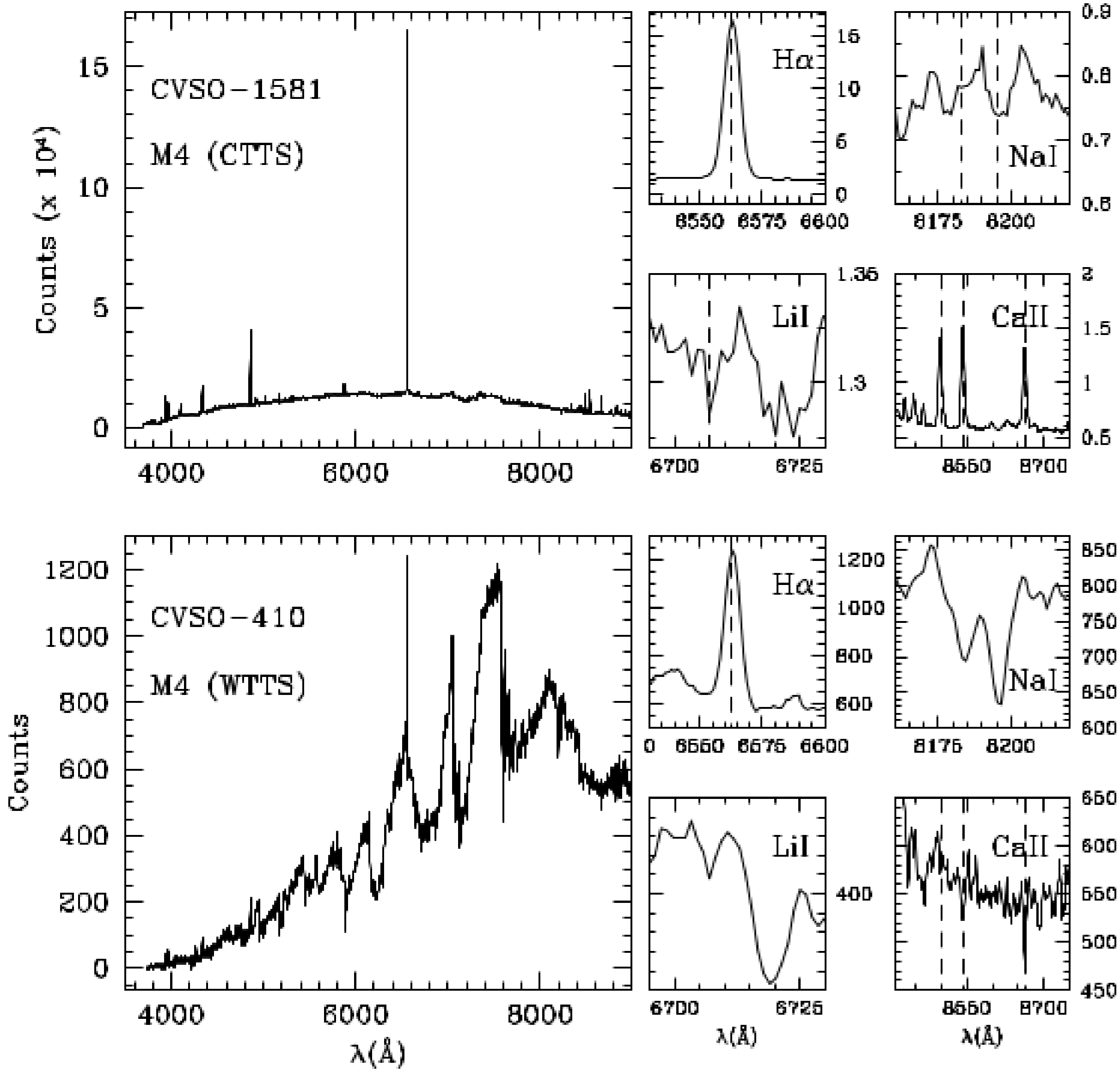
  - Also Hi-Res of a smaller subset (~1200):

    - Hectochelle on 6.5m MMT (R~34000)
    - MIKE/M2FS on 6.5m Magellan (Clay) (R~25000)

New CVSO TTS: Hα, Li + other emission lines
(sample Hectospec spectra)

CTTS

WTTS



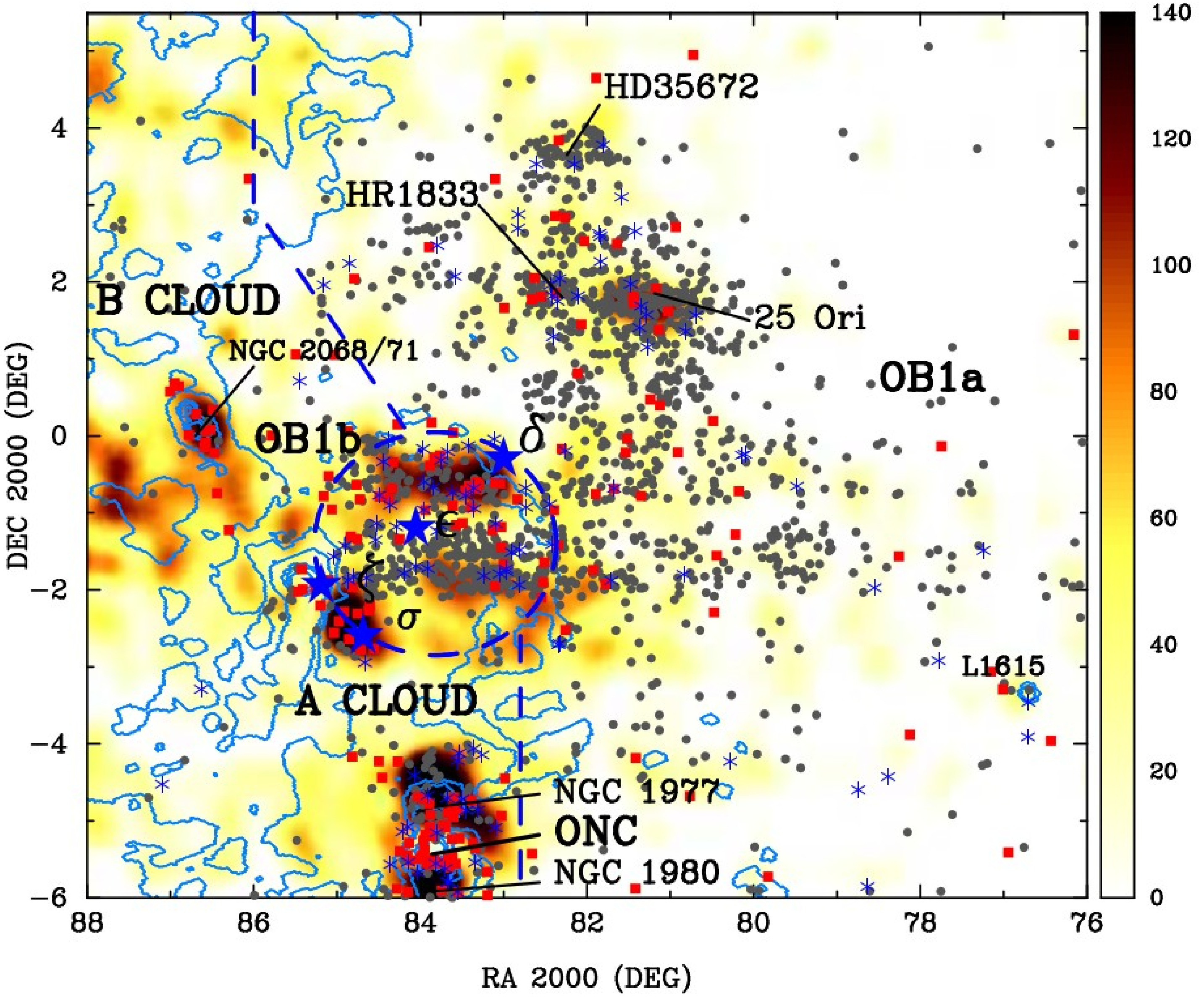
RESULTS: The Orion OB1 off-cloud populations

2064 confirmed TTS (75% new):

- **1218 in 1a**
- **556 in 1b**
- **222 in the A cloud**
- **68 in the B cloud**

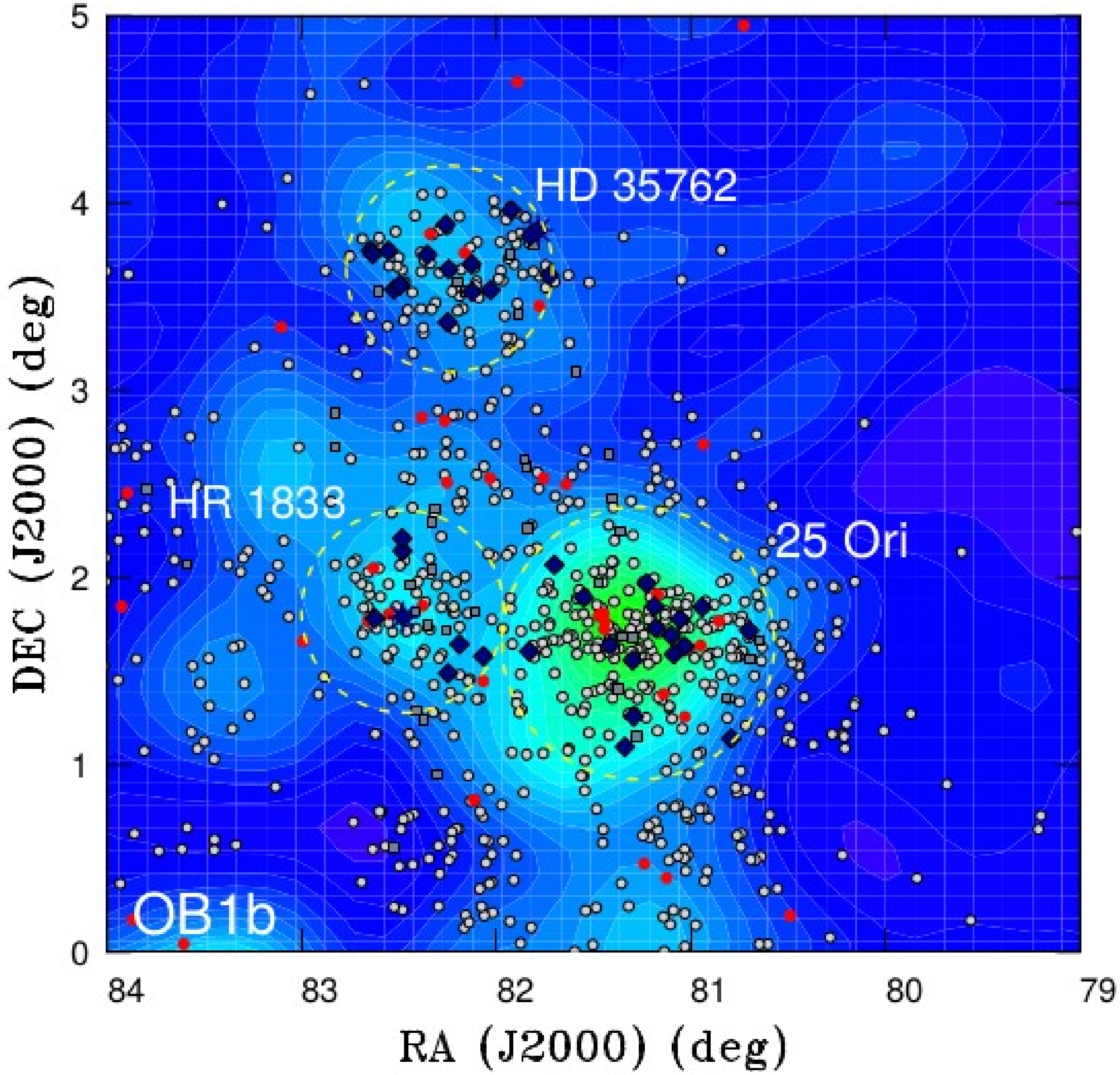
Several new stellar groups/clusters in OB1a (31% of the population):

- 25 Ori (223 stars)
- HR 1833 (65 stars)
- HD 35762 (86 stars)

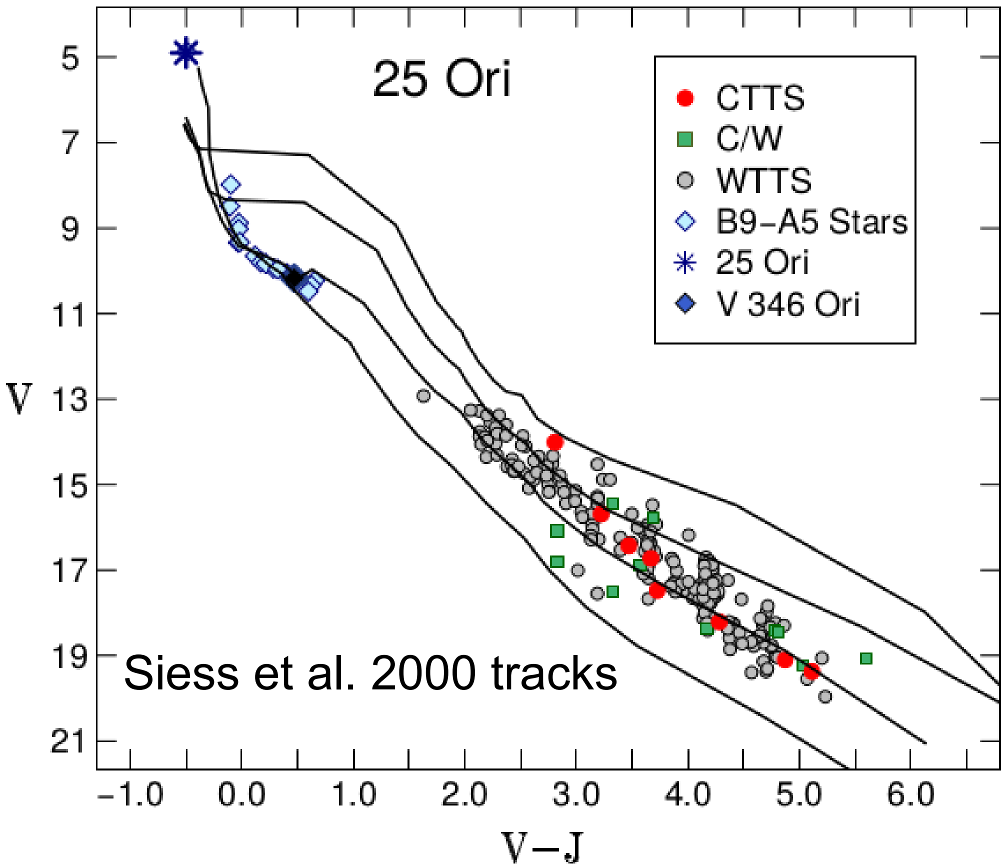


New stellar aggregates in OB1a

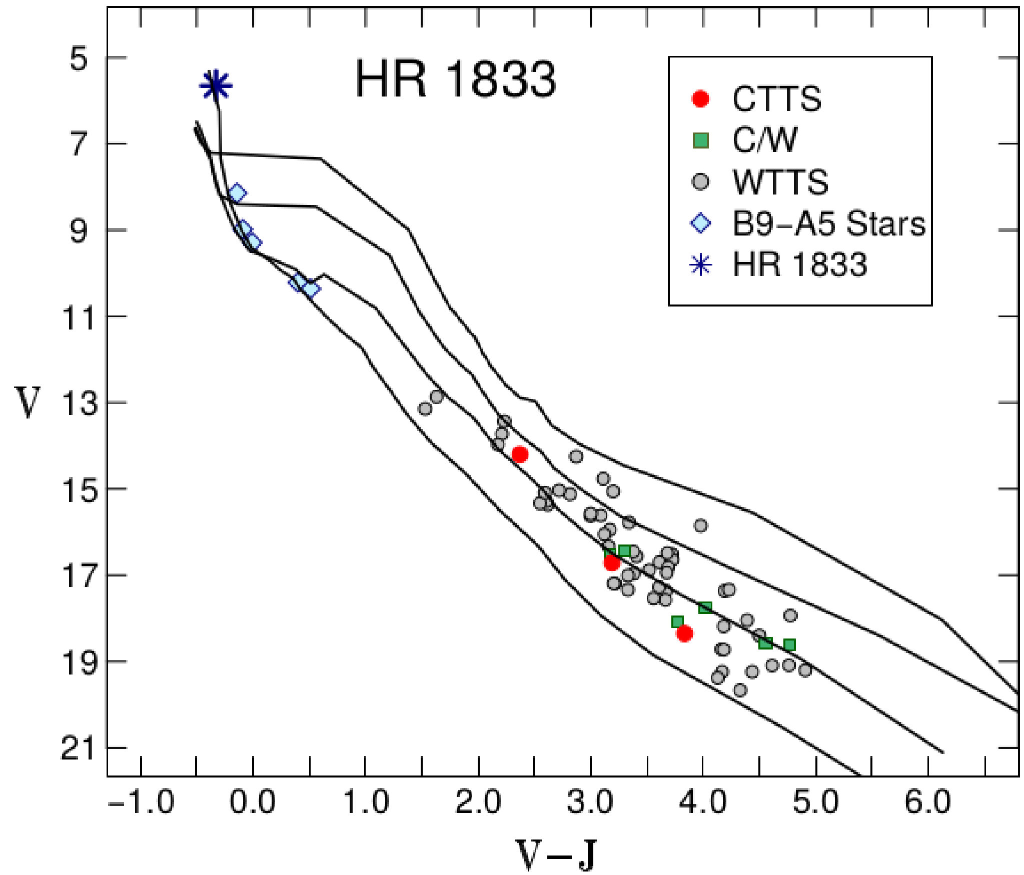
- CTTS
- WTTS
- B and A stars



25 Ori and HD 35762

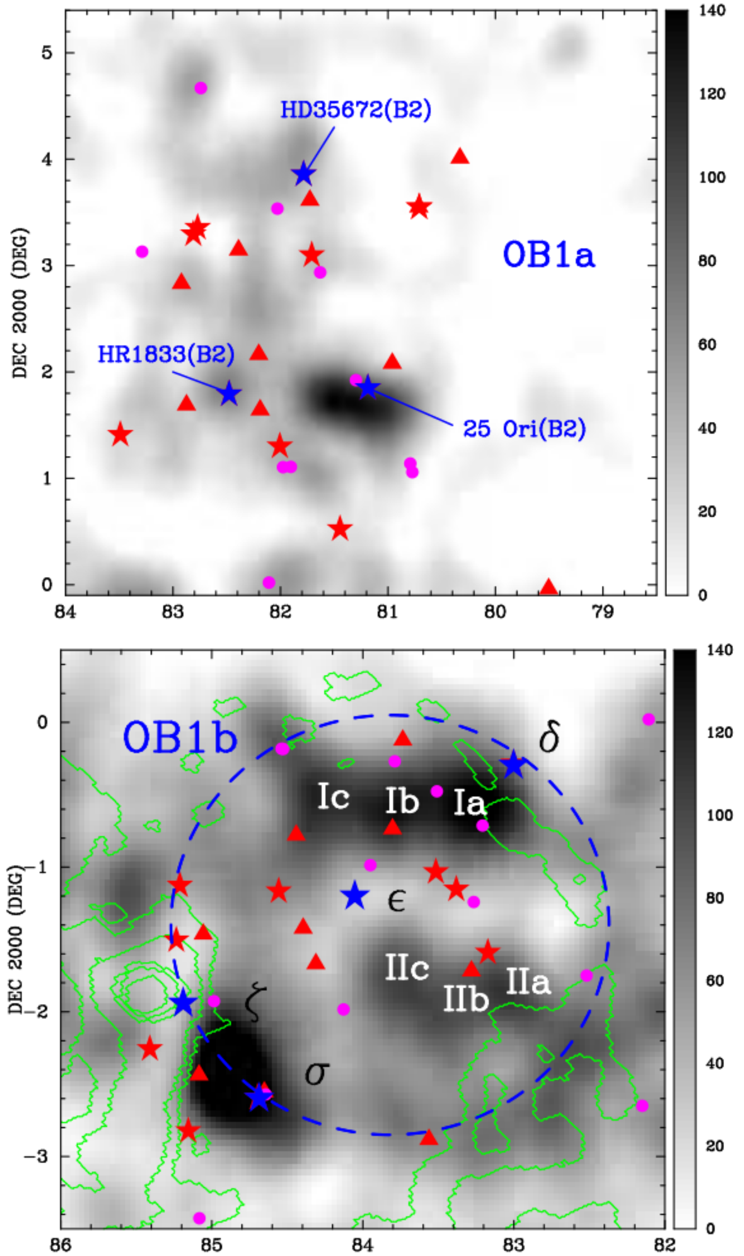


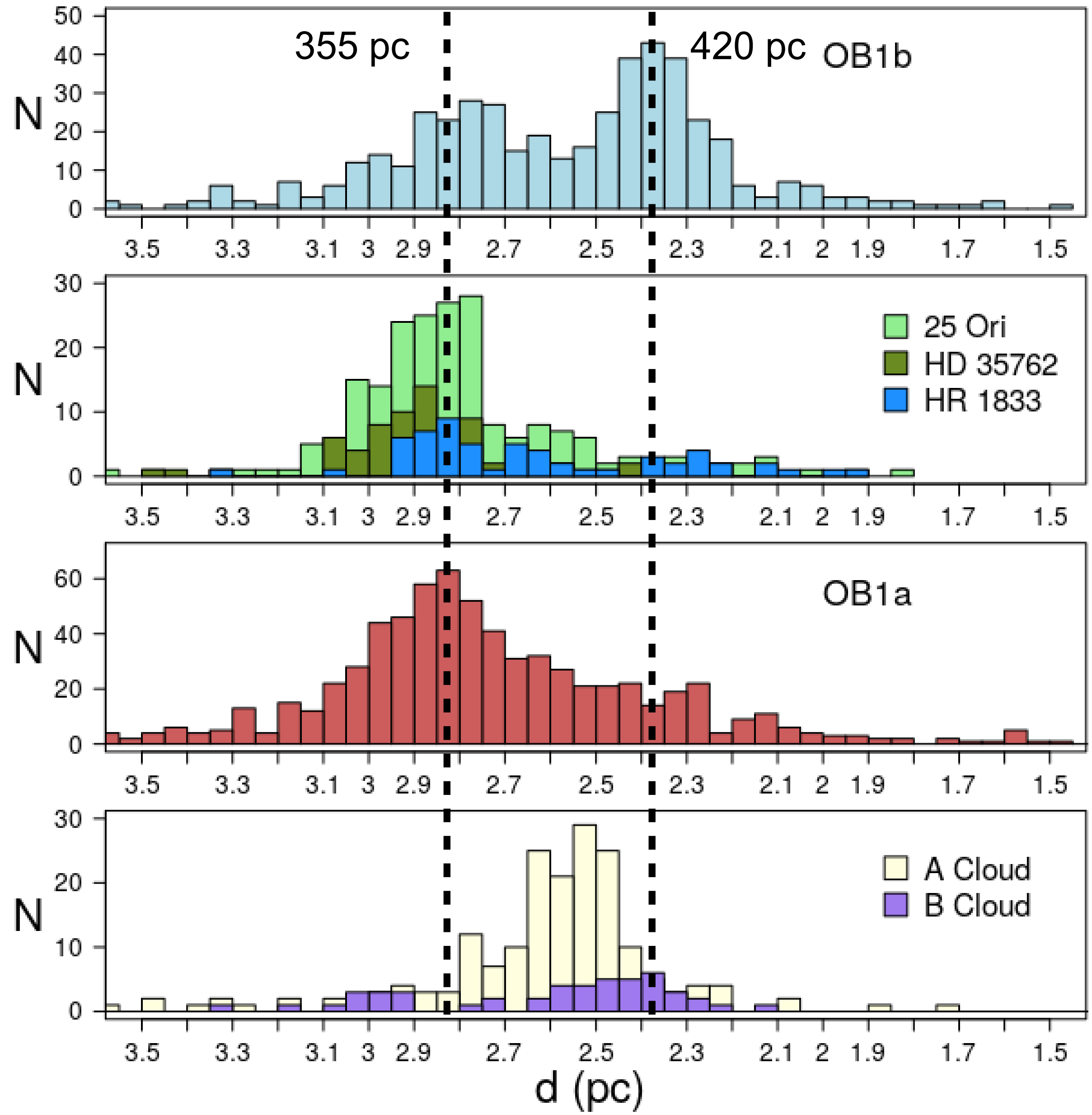
~8 Myr, d~350pc



~12 Myr, d~360pc

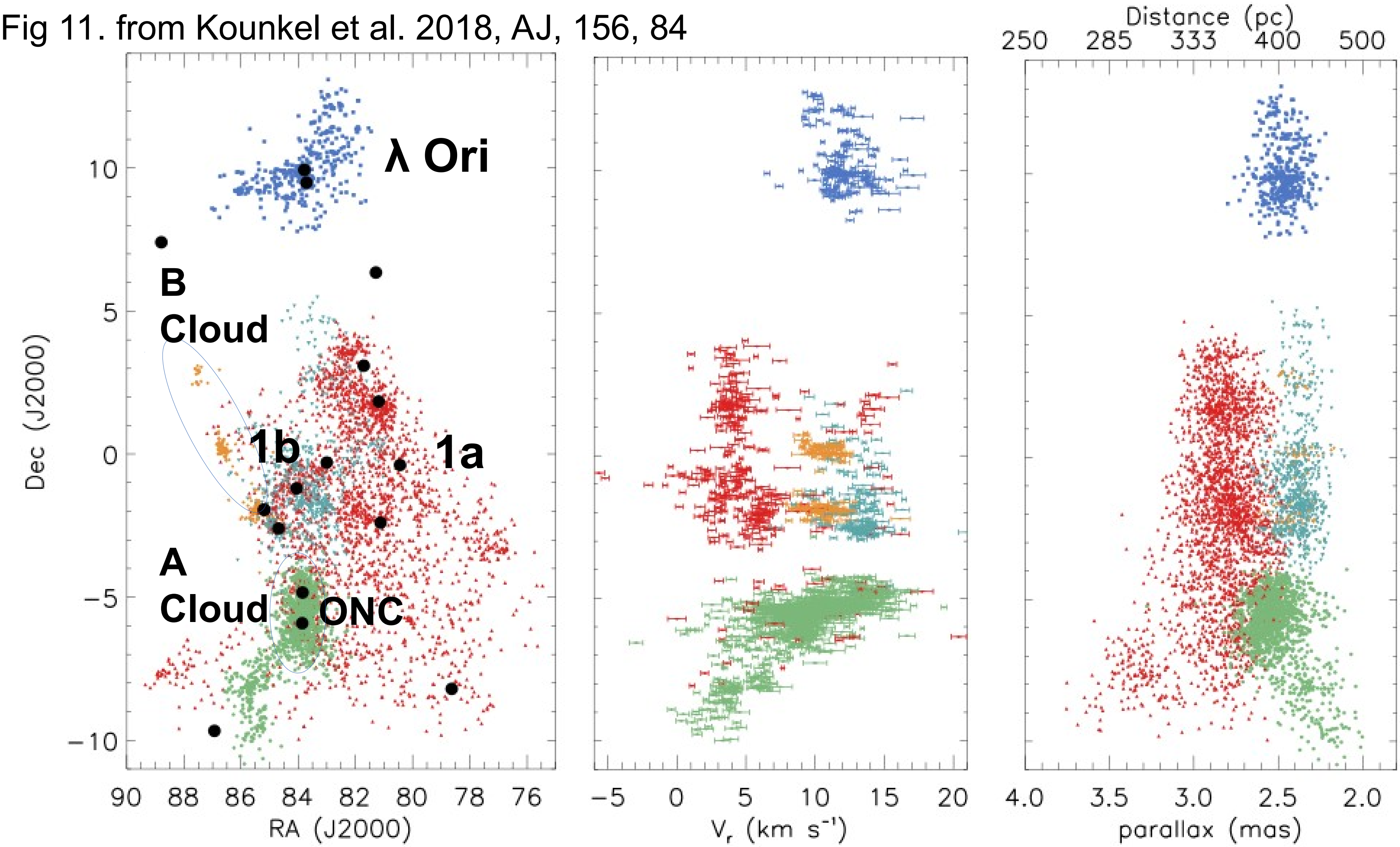
Spatial structure in Orion OB1



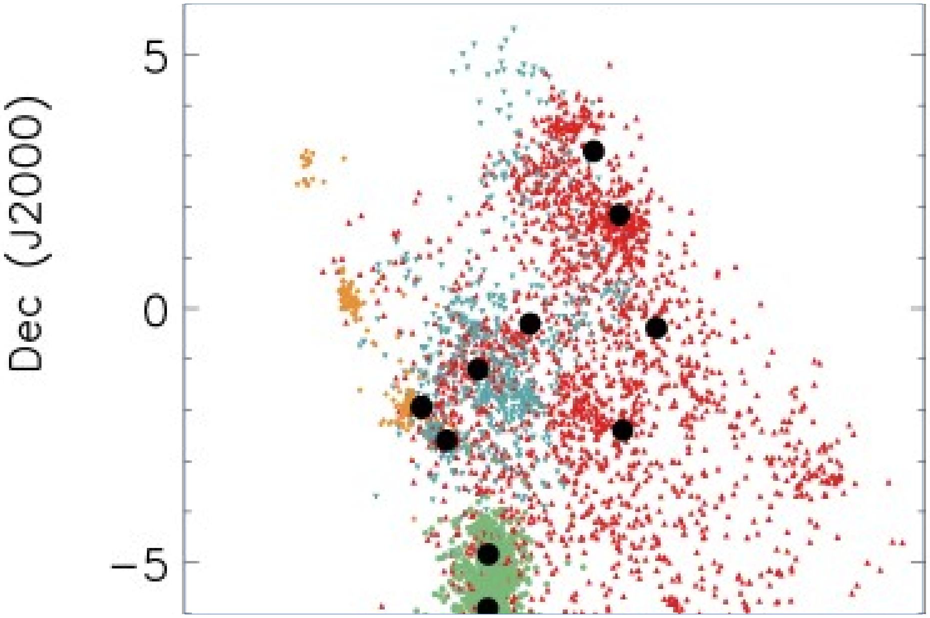


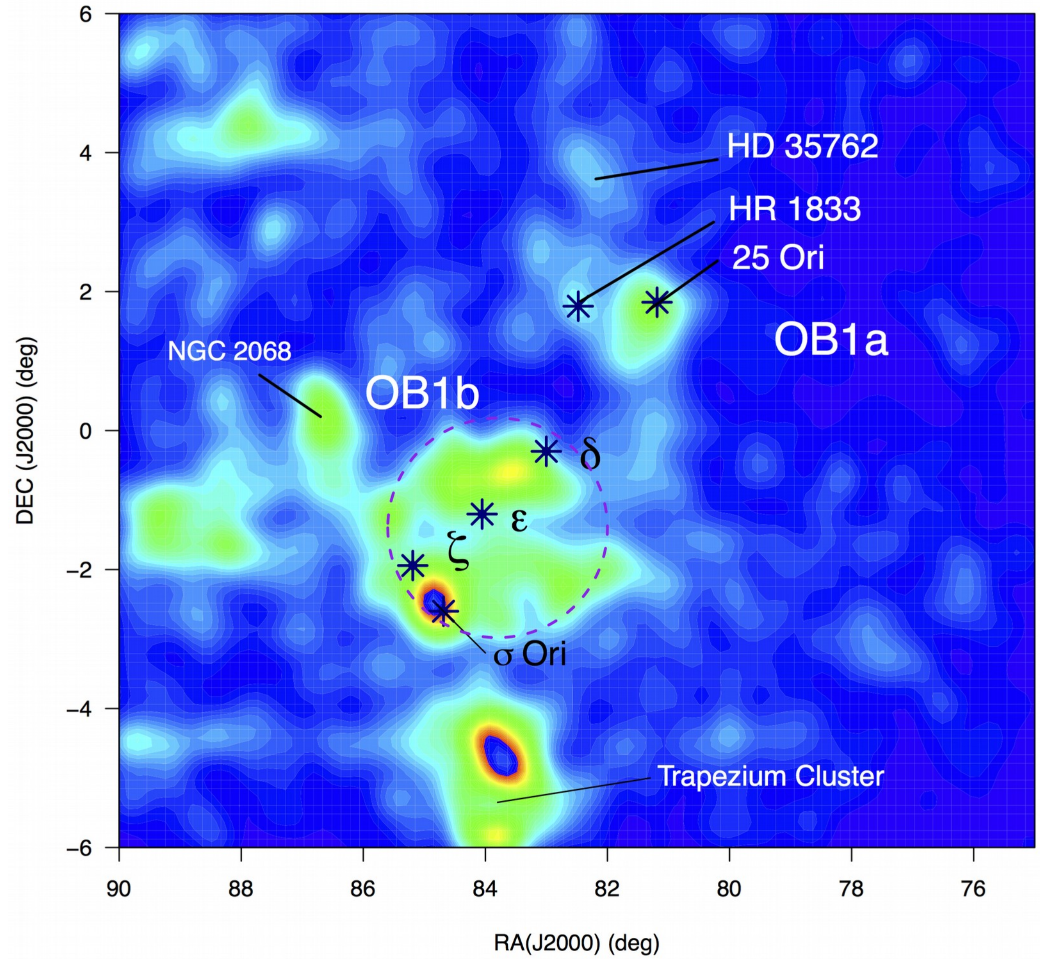
Spatial structure in Orion OB1

Fig 11. from Kounkel et al. 2018, AJ, 156, 84

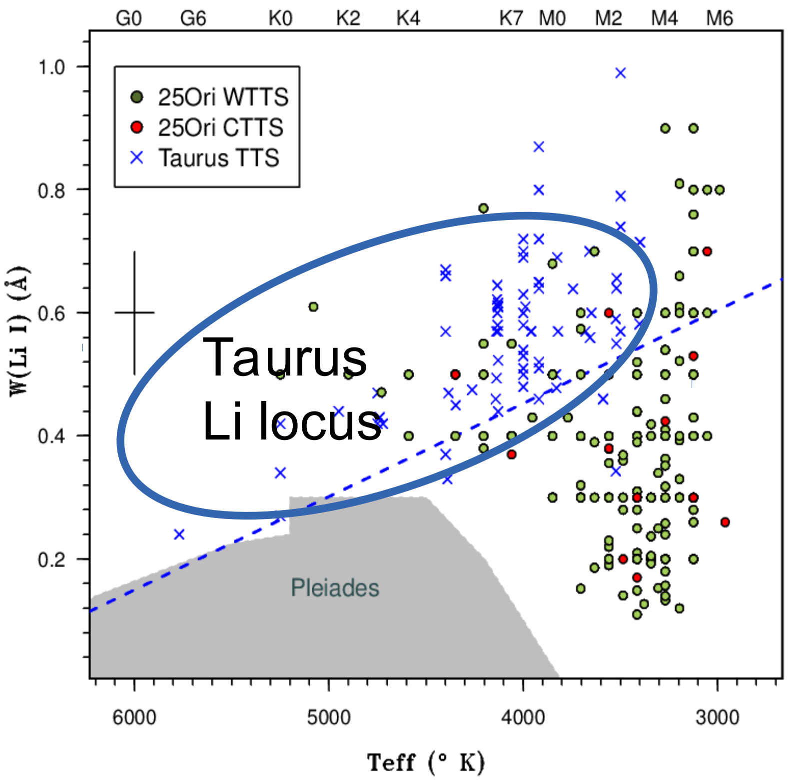


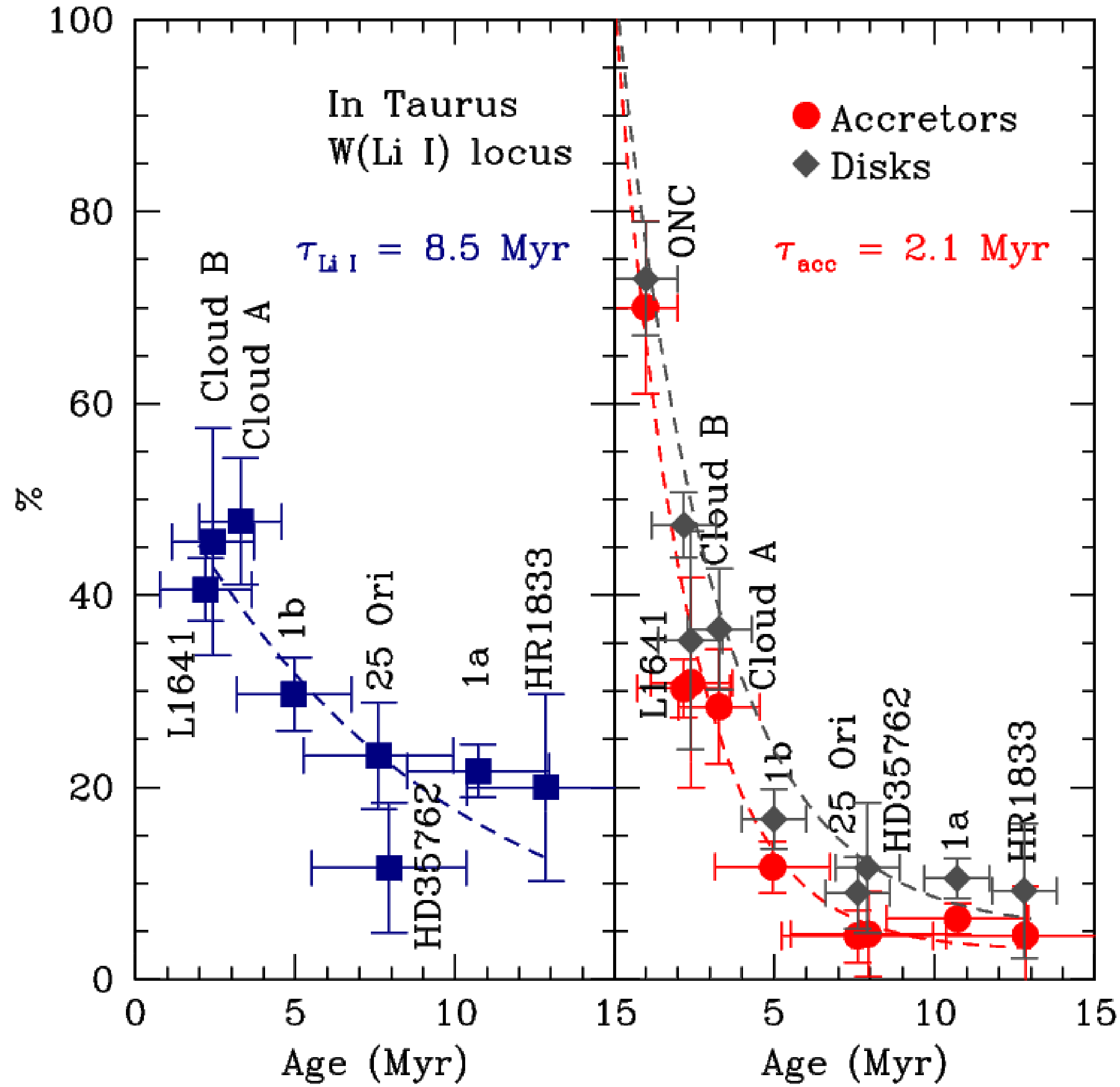
Spatial structure in Orion OB1





Li depletion & Disk accretion evolution





Summary

- Orion OB1 off-cloud low-mass population → general low-density component with several over-densities or stellar aggregates
- Stellar aggregates in OB1a cluster around an early B-type star.
- Significant spatial structure and depth: OB1b contains a mix of a near and far population, the closest seems to be part OB1a
- Ensemble disk evolution is clearly seen from the younger to the older stellar aggregates, consistent with their age progression and with the overall decline in Li
- **Ongoing:** Multiplicity, variability (e.g. Karim et al. 2016 rotation periods), detailed studies of selected sources (Spitzer, Herschel), searches for young BDs in new groups