Kinematics of young star clusters with the Gaia-ESO Survey

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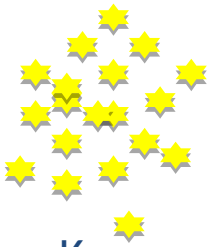
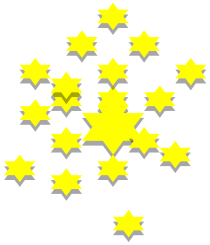
Cluster Formation and Evolution

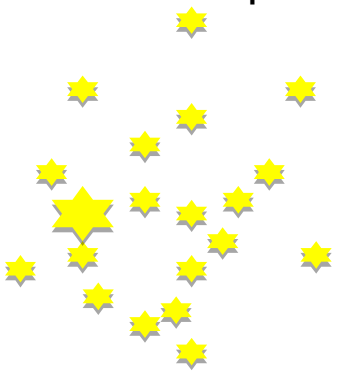
High density embedded clusters



Feedback from massive stars swept out the gas

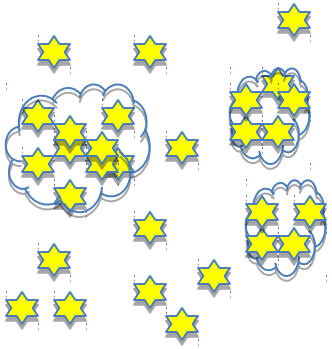


Supervirial unbound clusters disperse

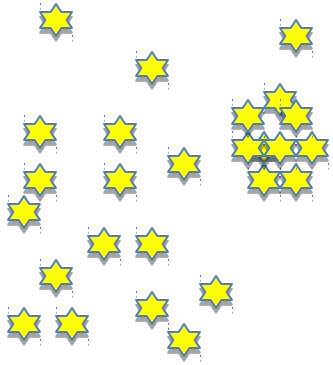


(e.g., Kroupa et al. 2001, Goodwin & Bastian 2006, Baumgardt & Kroupa 2009)

Hierarchical structure spanning large density range

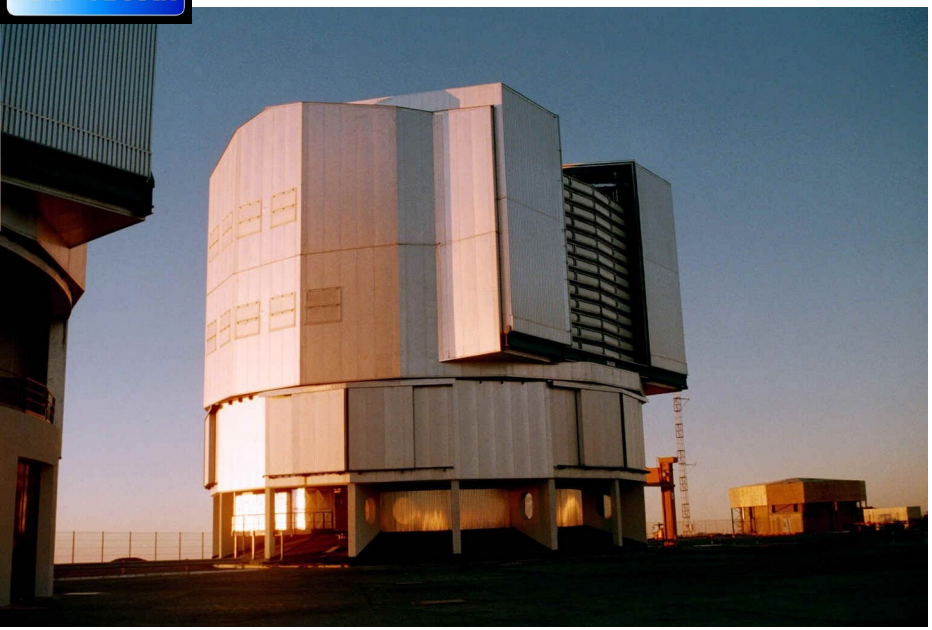


Evolution driven by two-body interaction and feedback is not relevant



(e.g., Bressert et al. 2010, Kruijessen et al. 2012, Parker & Dale 2013)

The Gaia-ESO Survey: overview



Aim: provide complementary data to Gaia (RV, *vsin i*, *Teff*, *log(g)*, *chemical abundances*) by high resolution spectroscopy

Science goals:

- Galaxy chemo-dynamics
- Cluster formation and evolution
- Stellar evolution

(Gilmore et al. 2012, Randich & Gilmore 2013)

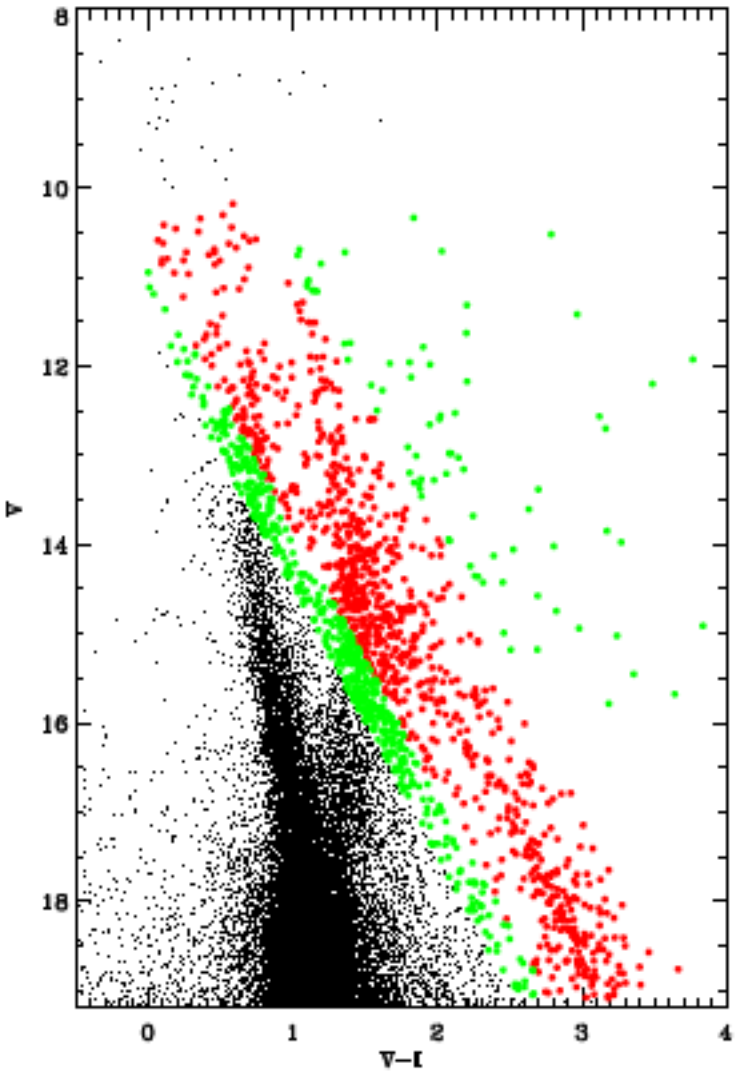
Time & people	Sample	Instrument
PIs: G. Gilmore & S. Randich Co-Is: +400 Start: 31/12/2011 End: 2018 Nights: 340	10^5 stars at R=20,000 (V < 19 mag) 5000 at R=47,000 (V < 17 mag) Milky Way components Old clusters (age > 100 Myr) Young clusters (age 1-100 Myr)	FLAMES@VLT •GIRAFFE (10^5 stars) (132 fibres at R=20,000) •UVES (10^4 stars) (8 fibres at R=47,000)

Firenze 6/06/2017

Dynamics of young clusters with GES

Strengths of GES

1. Homogeneous and unbiased target selection
2. Precision of Radial velocities (<0.3 km/s)
3. Multiple spectroscopic indicators for membership selection and age estimates
4. A large sample of clusters covering the full range of physical parameters (e.g. age, number of stars)



Young cluster sample

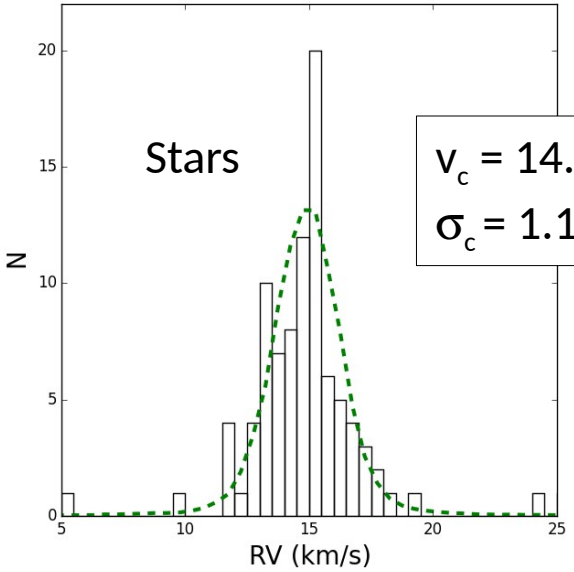
Embedded clusters: Cha I ρ Oph NGC 2264

- distance ≈ 160- 800 pc
- age ≈ 2-5 Myr
- population ≈ 200-2000 stars
- Av ≈ 5-100 mag
- Gas mass 1000- 10000 $M_{\odot}$

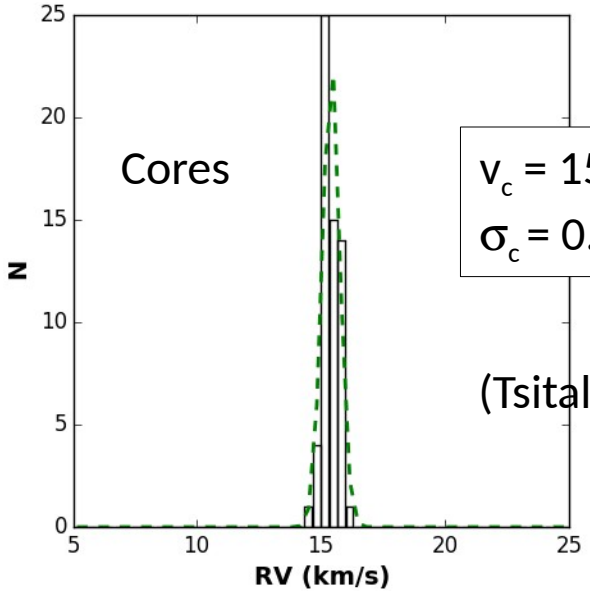
Gas free clusters: Gamma Vel, NGC 2547, IC 2606, IC 2391, IC 4665

- distance ≈ 140- 400 pc
- age ≈ 10-50 Myr
- population ≈ 100-3000 stars

Cha I: stars vs. cores

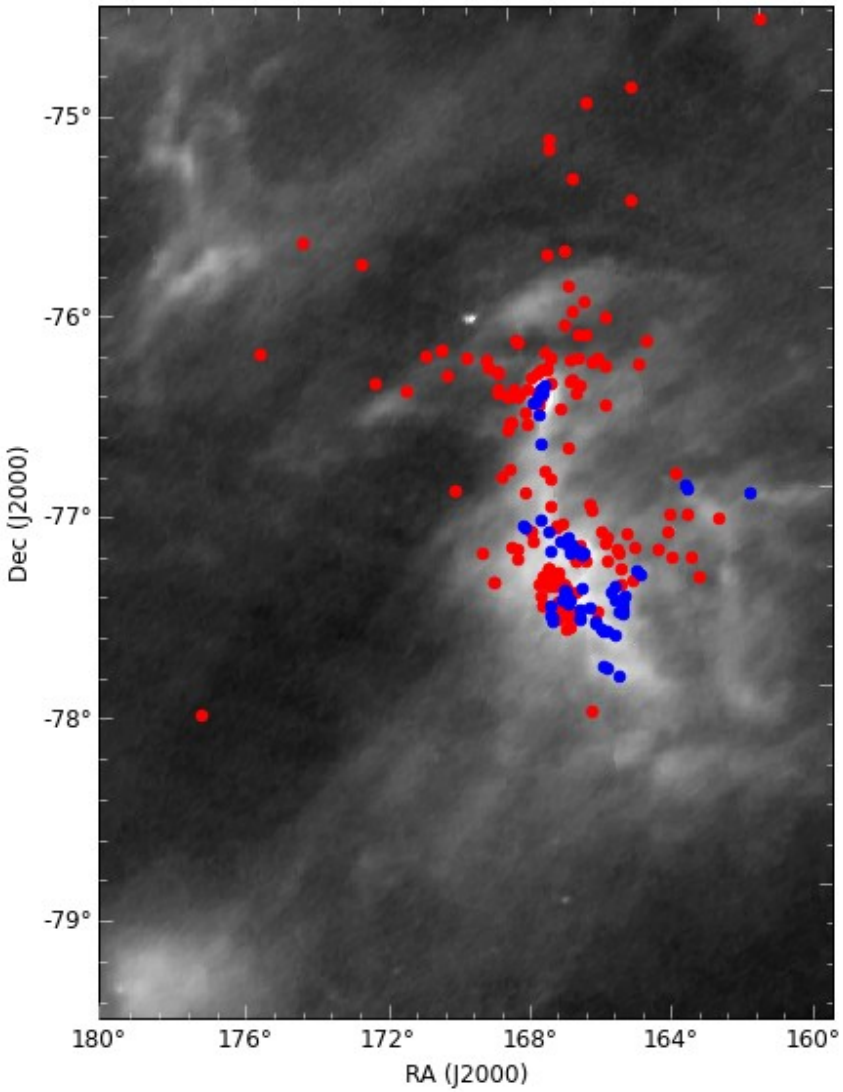


v_c = 14.90 ± 0.15 km/s
σ_c = 1.10 ± 0.15 km/s



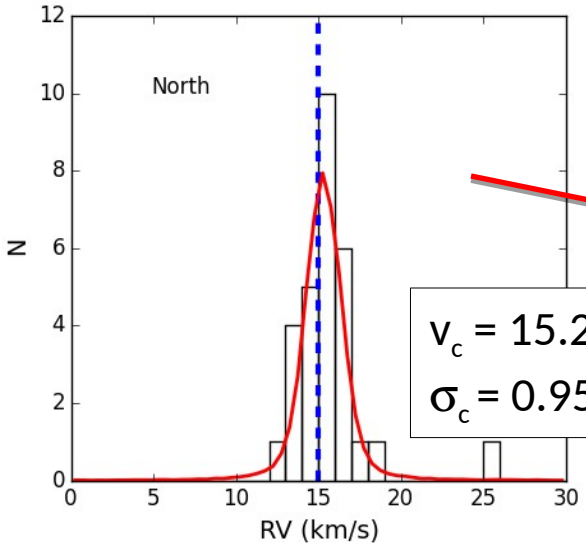
v_c = 15.40 ± 0.04 km/s
σ_c = 0.34 ± 0.03 km/s

(Tsitali et al. 2015)

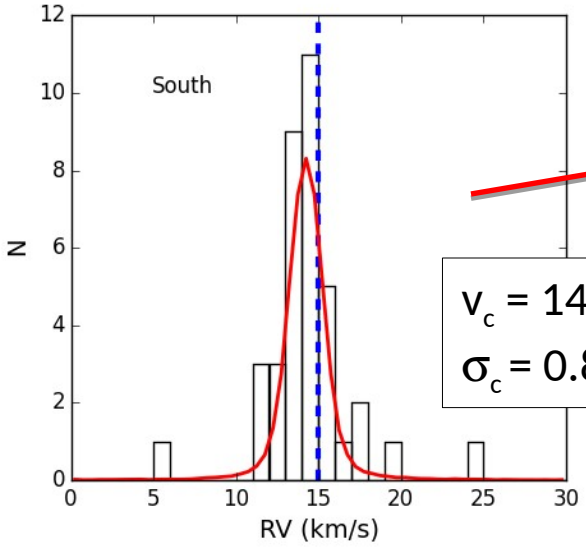


Stars dynamically hotter than cores (Sacco et al. 2017)

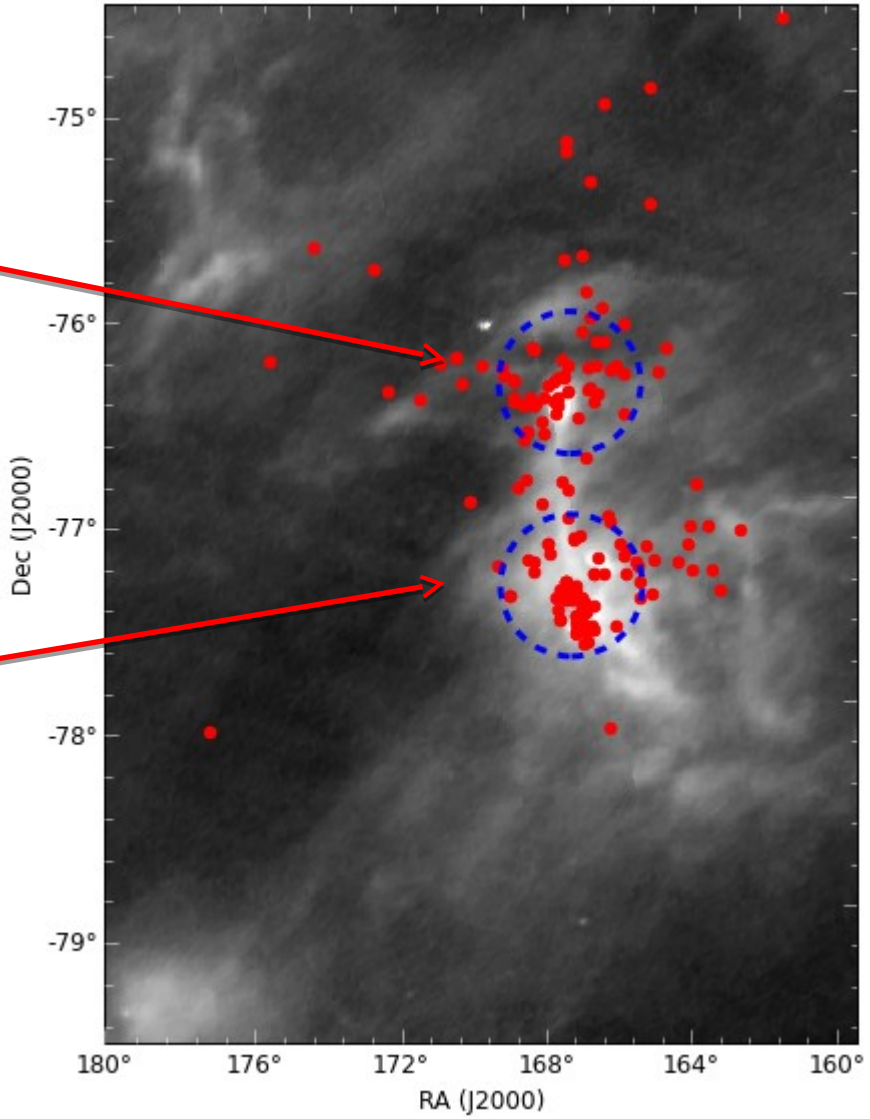
Cha I: subclusters



v_c = 15.29 ± 0.22 km/s
σ_c = 0.95 ± 0.18 km/s

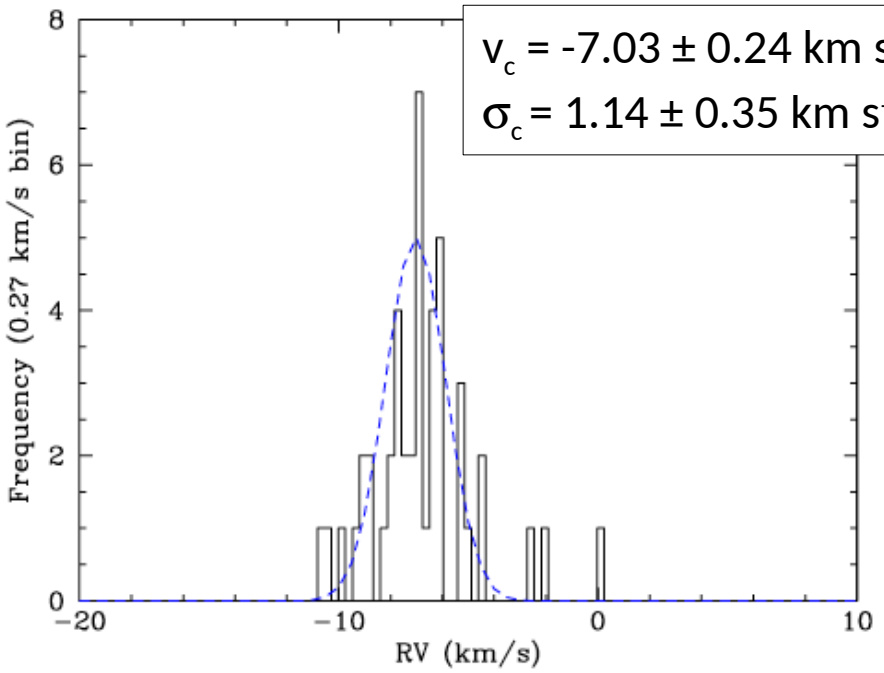


v_c = 14.36 ± 0.22 km/s
σ_c = 0.88 ± 0.24 km/s



Velocity shift between subclusters (Sacco et al. 2017)

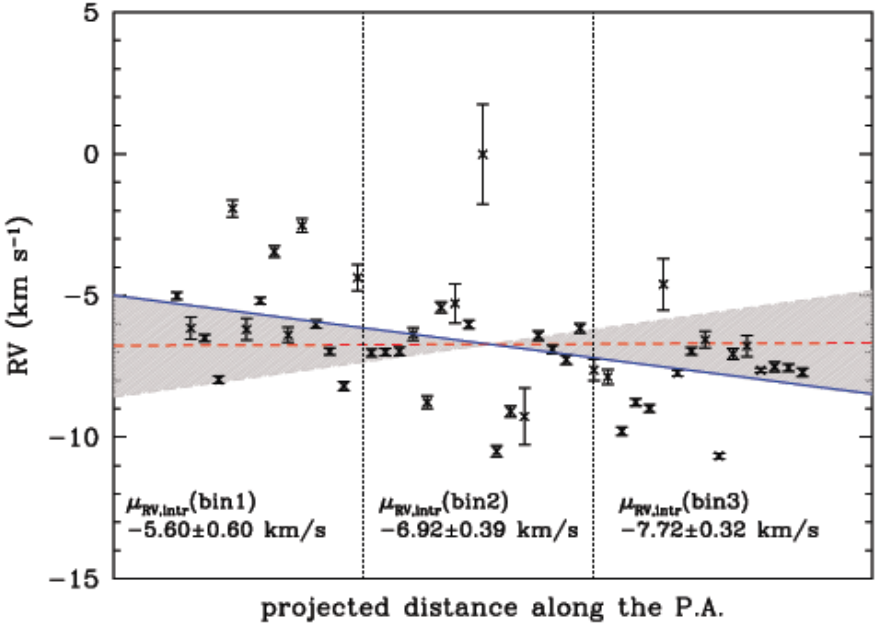
ρ Oph



v_c = -7.03 ± 0.24 km s^{-1}
σ_c = 1.14 ± 0.35 km s^{-1}

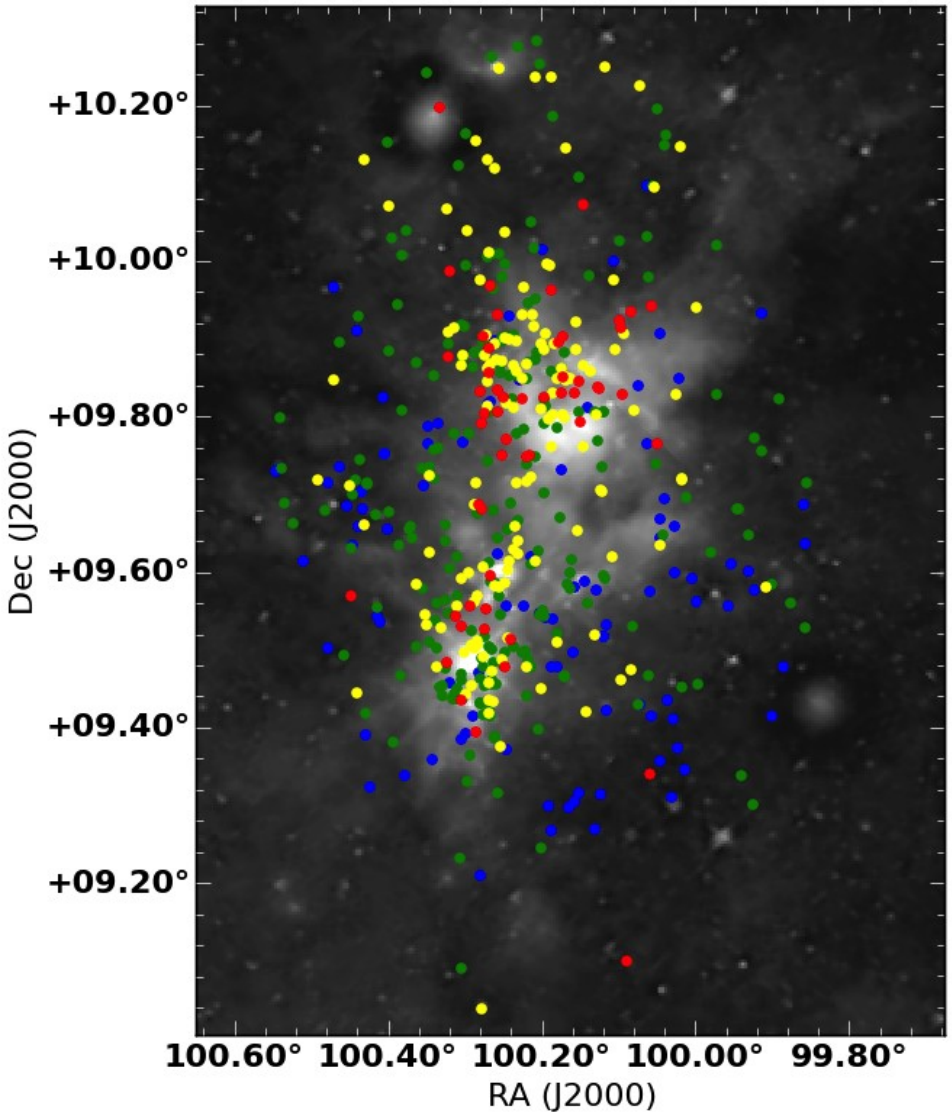
Evidence of a RV gradient 1 km s^{-1} pc^{-1} in the northwest direction. Coherent with a a sequential triggered star formation scenario.

Stars dynamically hotter than cores (σ_c = 0.4 km s^{-1}), as observed for Cha I (GES, Sacco et al. in prep.) and NGC 1333 (APOGEE, Foster et al. 2015)



(Rigliaco et al. 2016)

Kinematic structure of NGC 2264



- 15 < RV < 18 km/s
- 18 < RV < 21 km/s
- 21 < RV < 24 km/s
- 24 < RV < 27 km/s

Evidence of a correlation between spatial and velocity structure

(Sacco et al. in prep.)

(see also Tobin et al. 2015)

Age structure of NGC 2264

- 15 < RV < 18 km/s
- 18 < RV < 21 km/s
- 21 < RV < 24 km/s
- 24 < RV < 27 km/s

Evidence of an age spread

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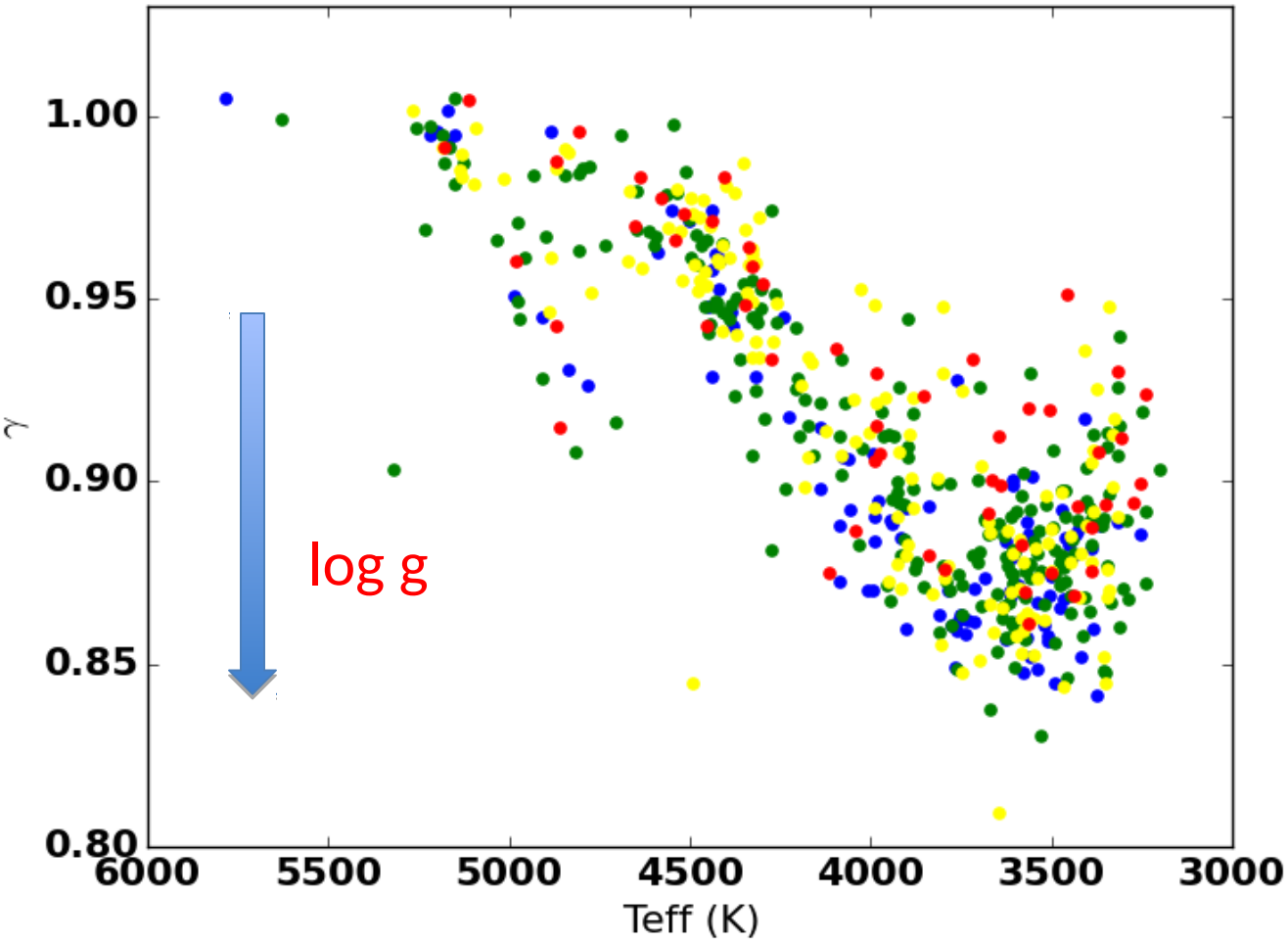
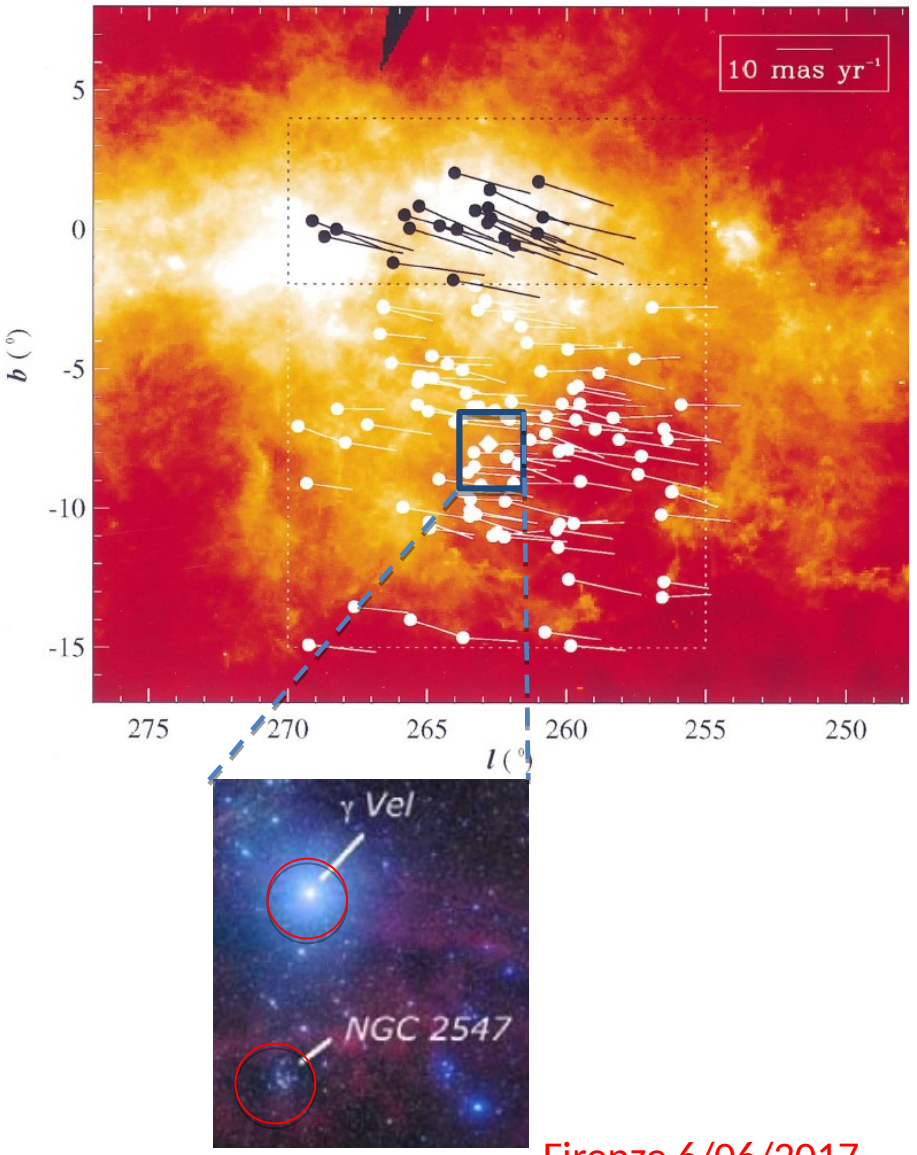


(Sacco et al. in prep., Venuti et al. 2017, submitted)

The complex structure of Vela OB2

- Distance ≈ 350-400 pc
- Hipparcos Members = 93 (g^2 Velorum, 81 B-type, 5 A type, 3 G type, 3 K type from de-Zeeuw et al. 1999)
- Area on the sky: 180 deg^2
- Most massive star: Wolf-Rayet WC8+O9 I binary (age ~ 5 Myr, total mass 39 $M_{\odot}$, de Marco & Schmutz 1999, Eldrige 2009)



GES Observations

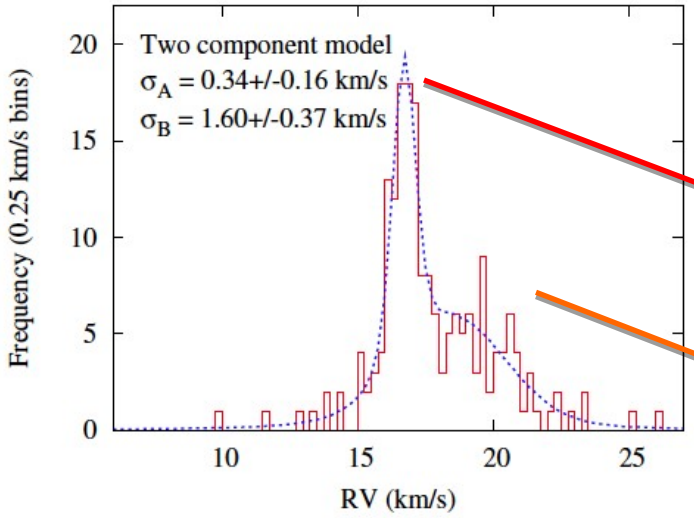
Gamma Velorum

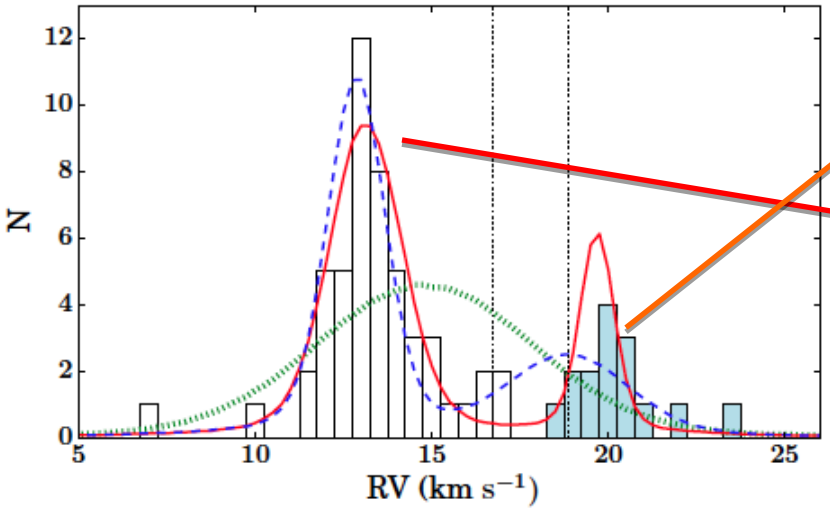
Age 5-10 Myr
located around γ^2 Velorum
field 1 deg^2

NGC 2547

Age 35 Myr
Located 2 degrees south of γ^2 Velorum
Field 1 deg^2

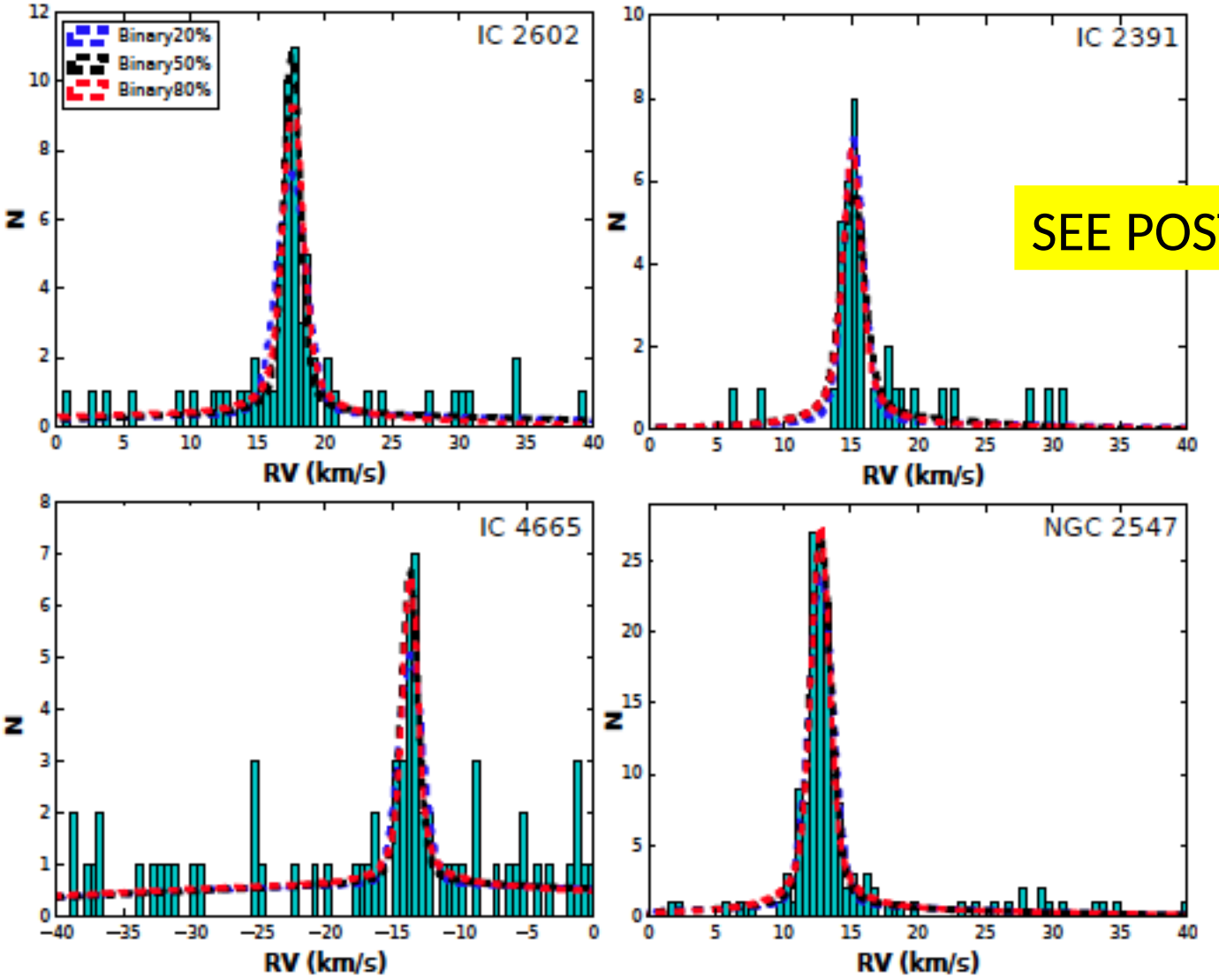
The complex structure of Vela OB2





(Jeffries et al. 2014, Sacco et al. 2015)

Dynamical properties of 30-50 Myr old clusters



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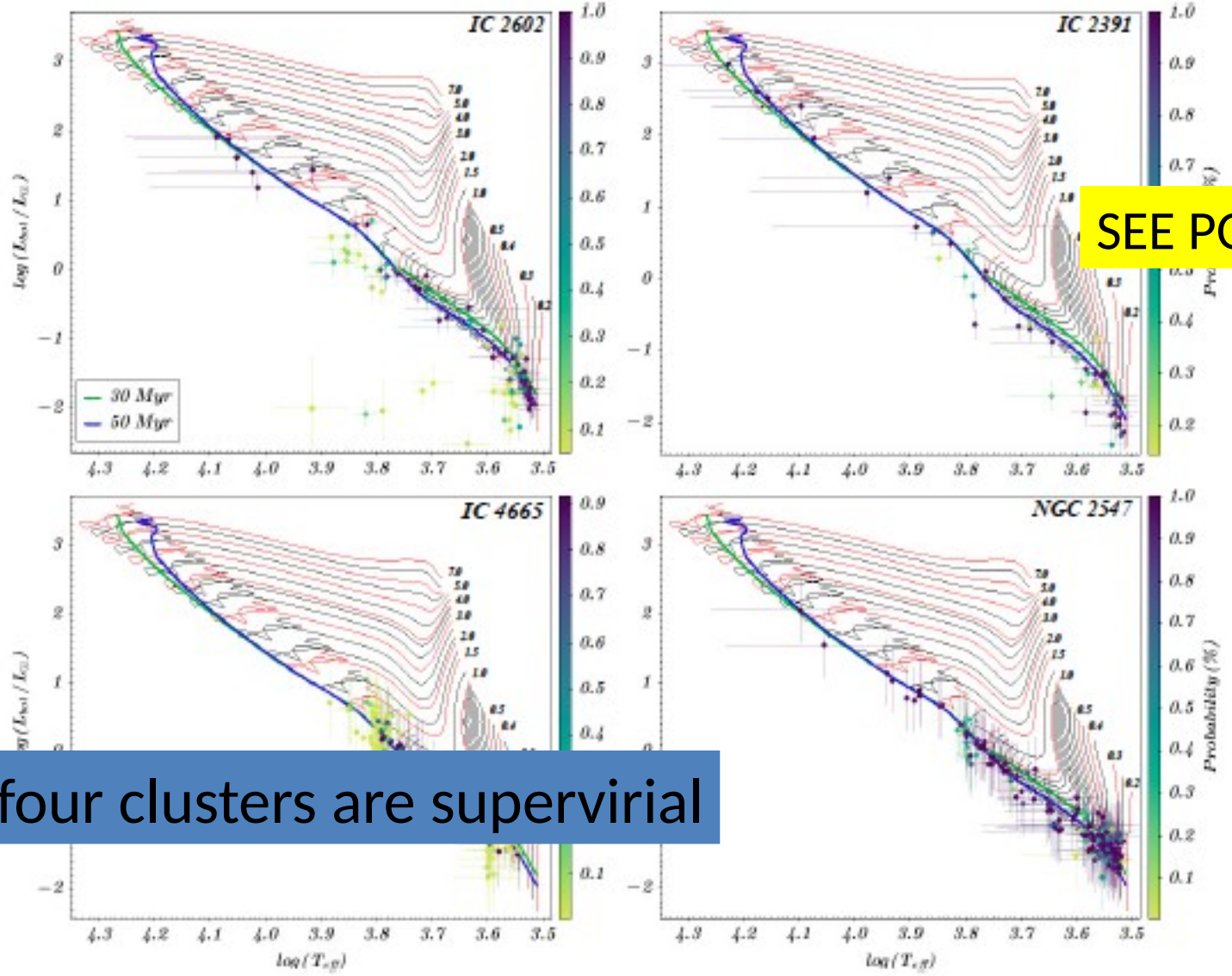
(Bravi et al. in prep.)

Dynamical properties of 30-50 Myr old clusters



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All four clusters are supervirial

(Bravi et al. in prep.)

Conclusions

The Gaia-ESO survey is providing astrophysical parameters (e.g., RVs, T_{eff}, log g) for a large sample of young star clusters. The analysis of the kinematical properties of these clusters led to these main results:

✓In embedded clusters the velocity dispersion of the stellar component is significantly higher than the velocity dispersion of the pre-stellar cores;

✓All the clusters are characterized by the presence of multiple kinematic substructures;

✓ Low mass 30-50 Myr old clusters are supervirial;