Constraining the Evolution of Massive Stars with *Gaia*

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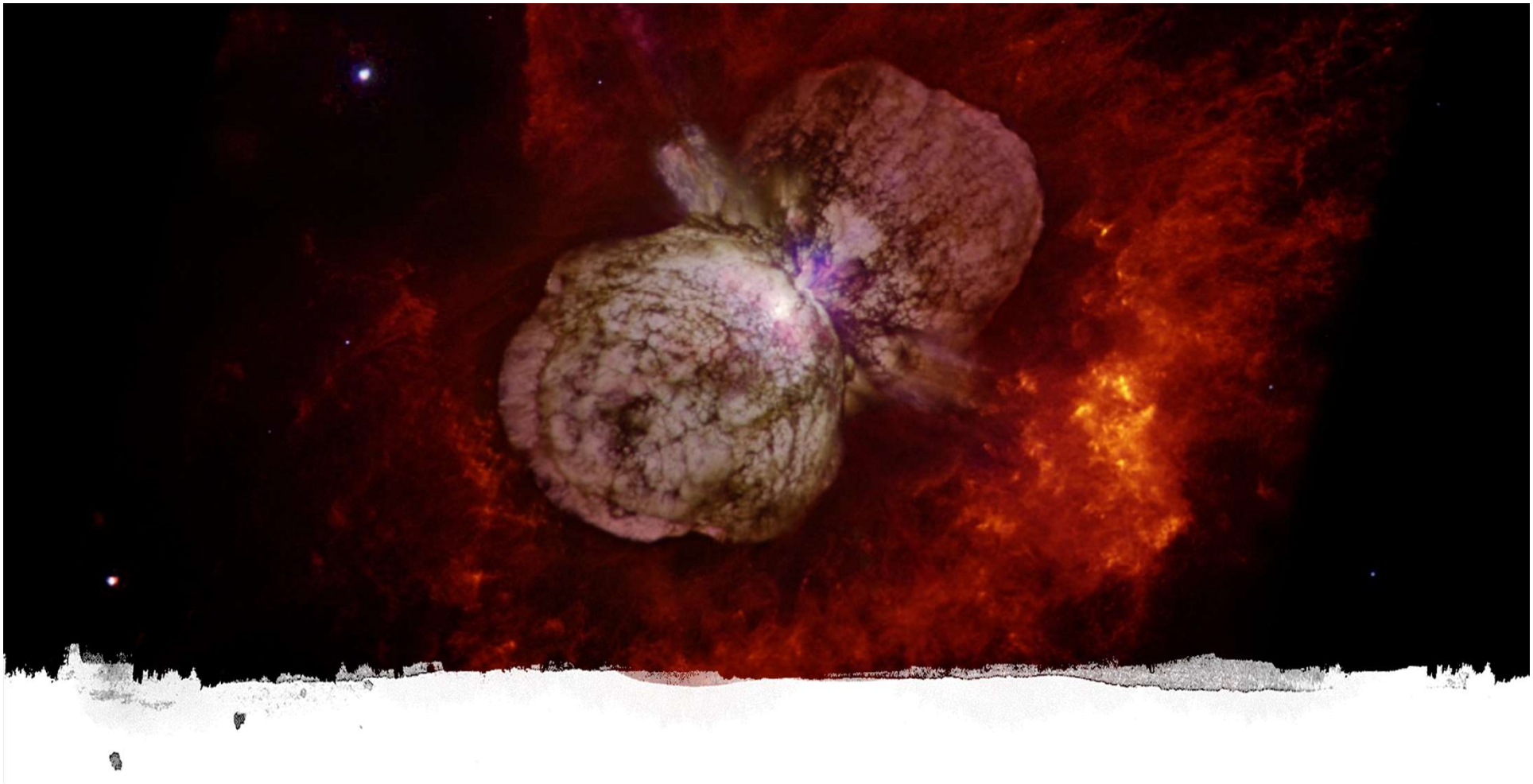
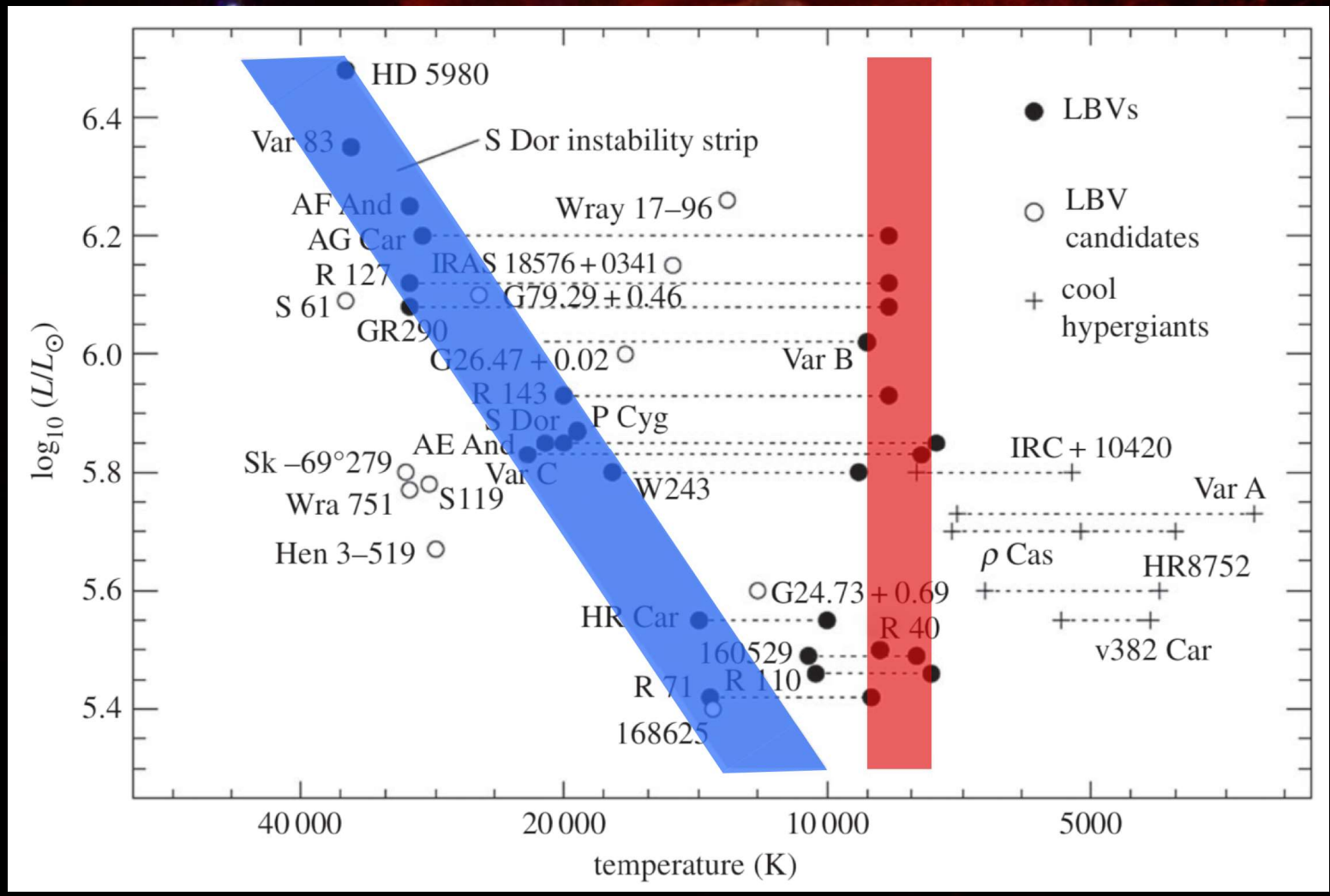


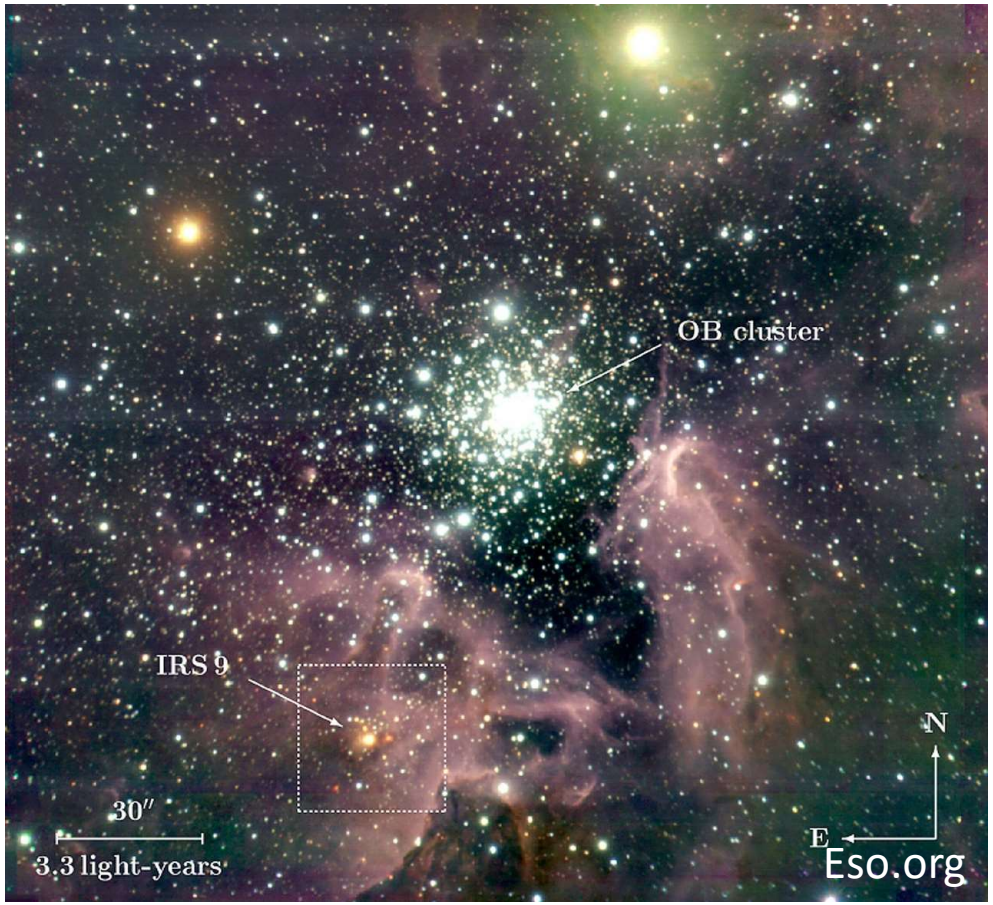
Using parallaxes and proper motions from the Gaia space mission to place fundamental constraints on the evolution of massive stars.

What are LBVs?

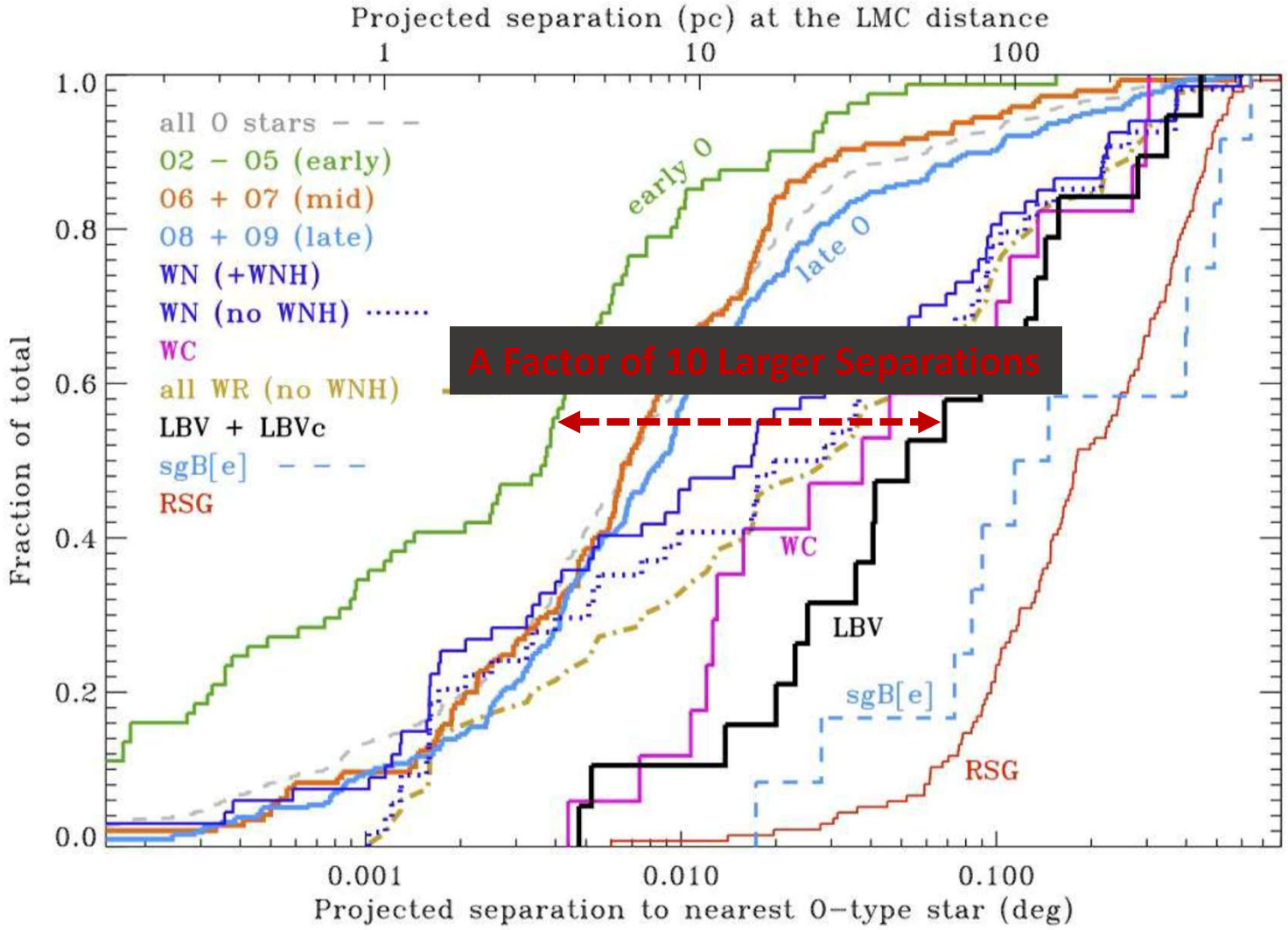


Single Star Evolution

- LBVs mark a brief transition between massive O-type stars and Wolf-Rayet (WR) stars.
- LBVs should be concentrated in young massive clusters like early O-type stars.



Smith & Tombleson 2015: LBVs are Isolated

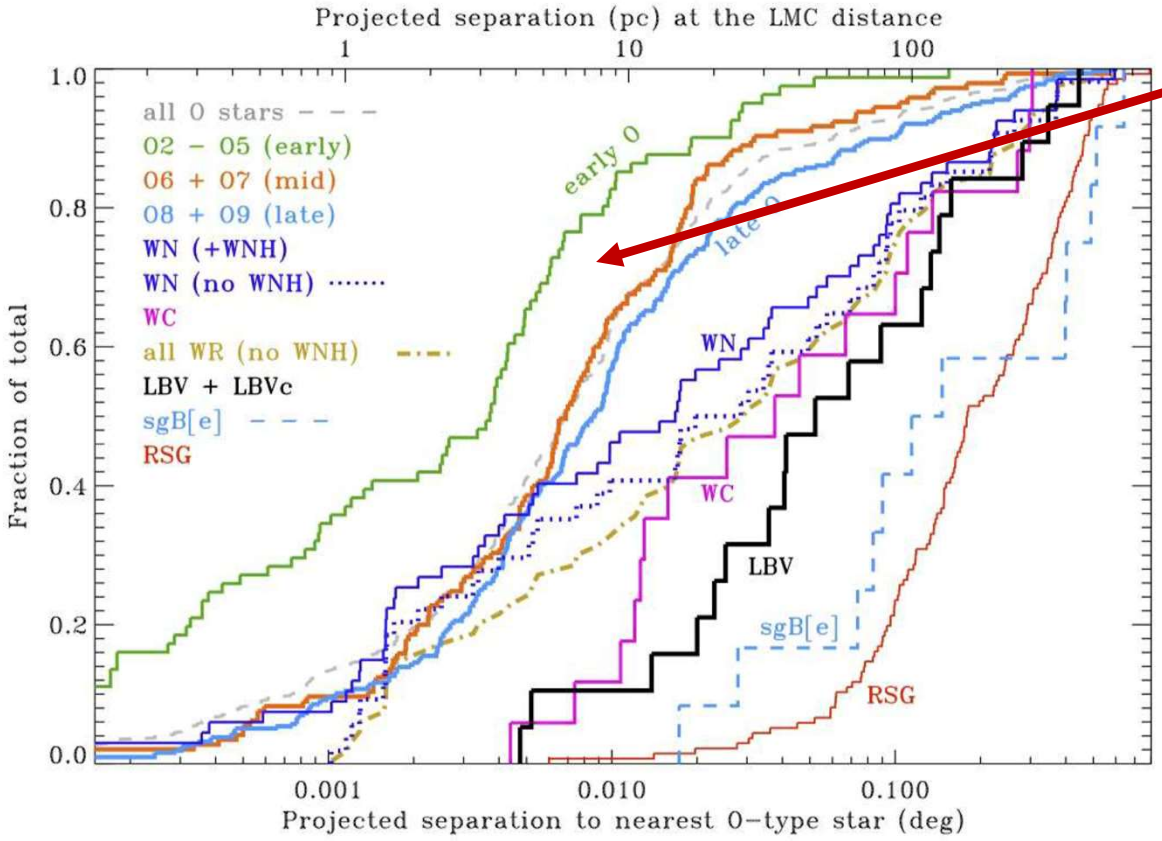


Single-star Model is Inconsistent

Possible Binary Scenarios:

- The product of a merger.
- A Mass gainer with a kick.

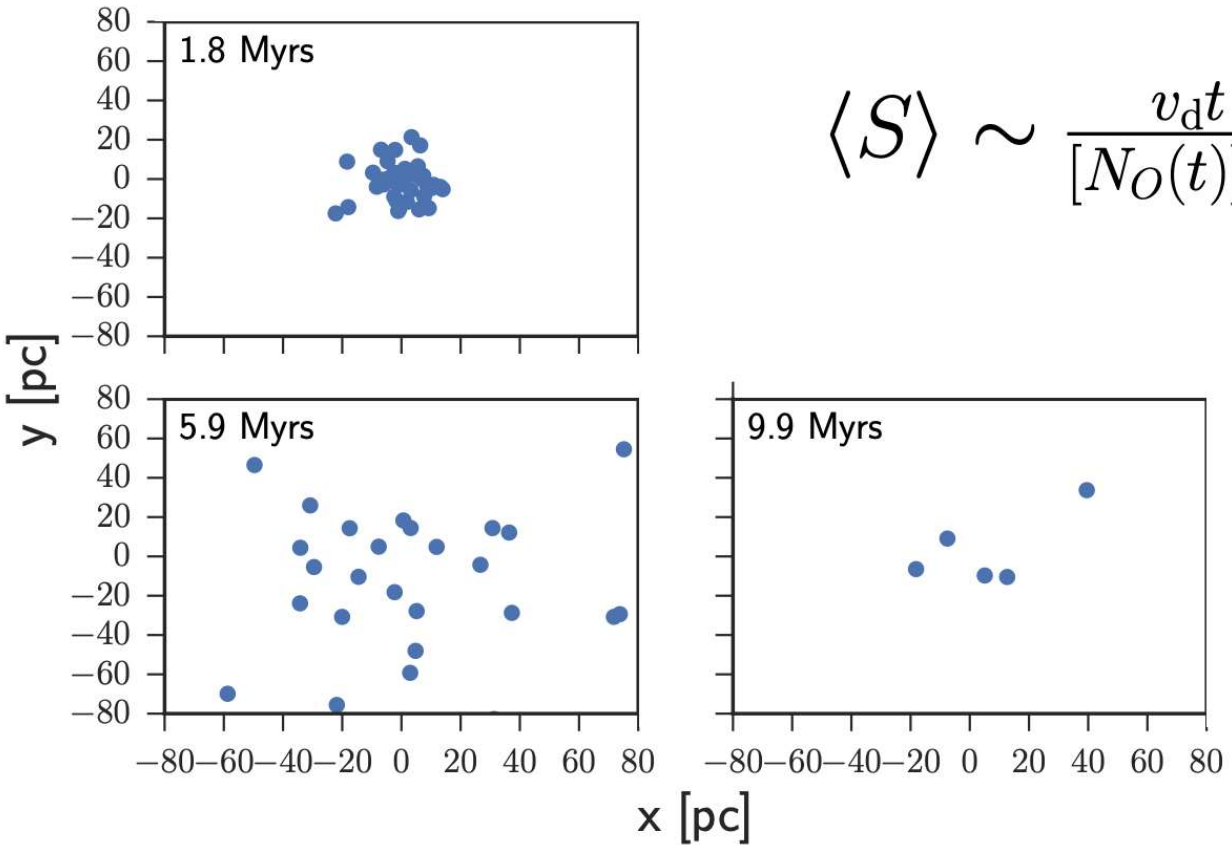
Compare the data with simple theories to see if they are actually inconsistent



Log-normal

- Only μ , σ and time evolution

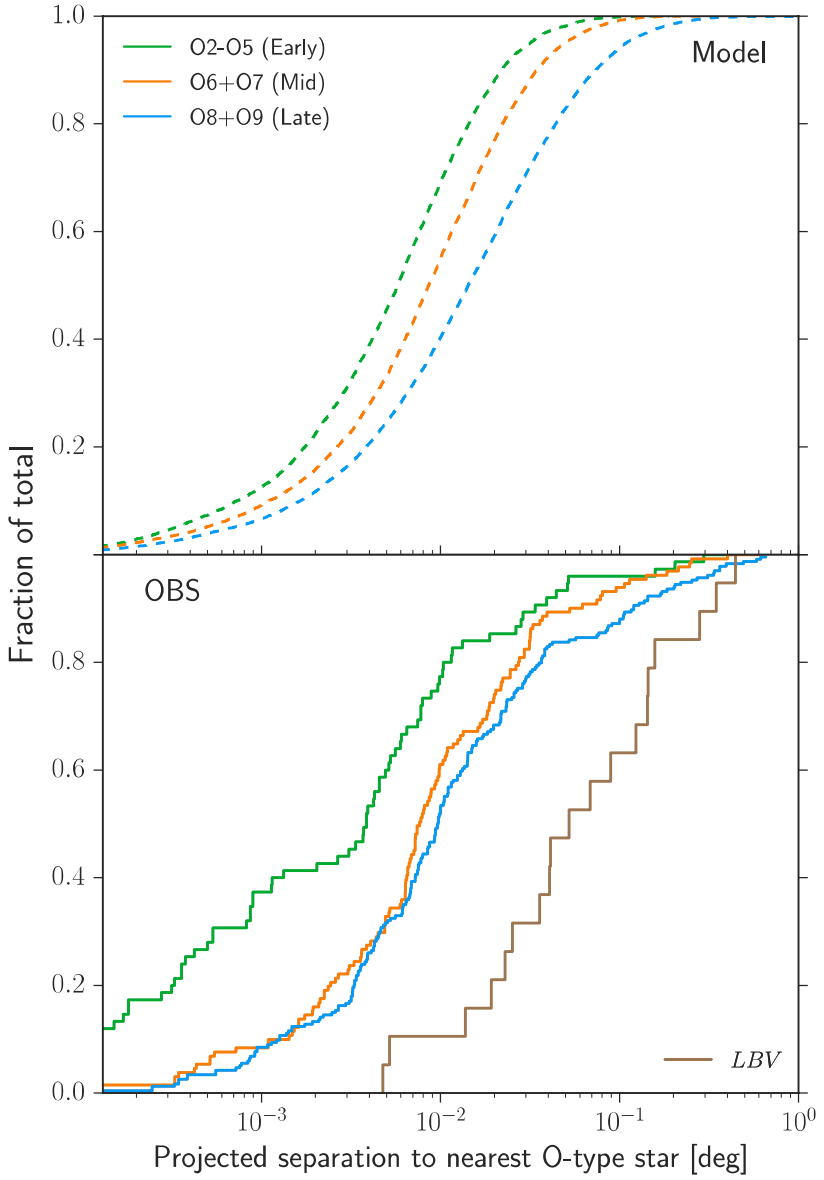
Simple Model: Passive Dissolution



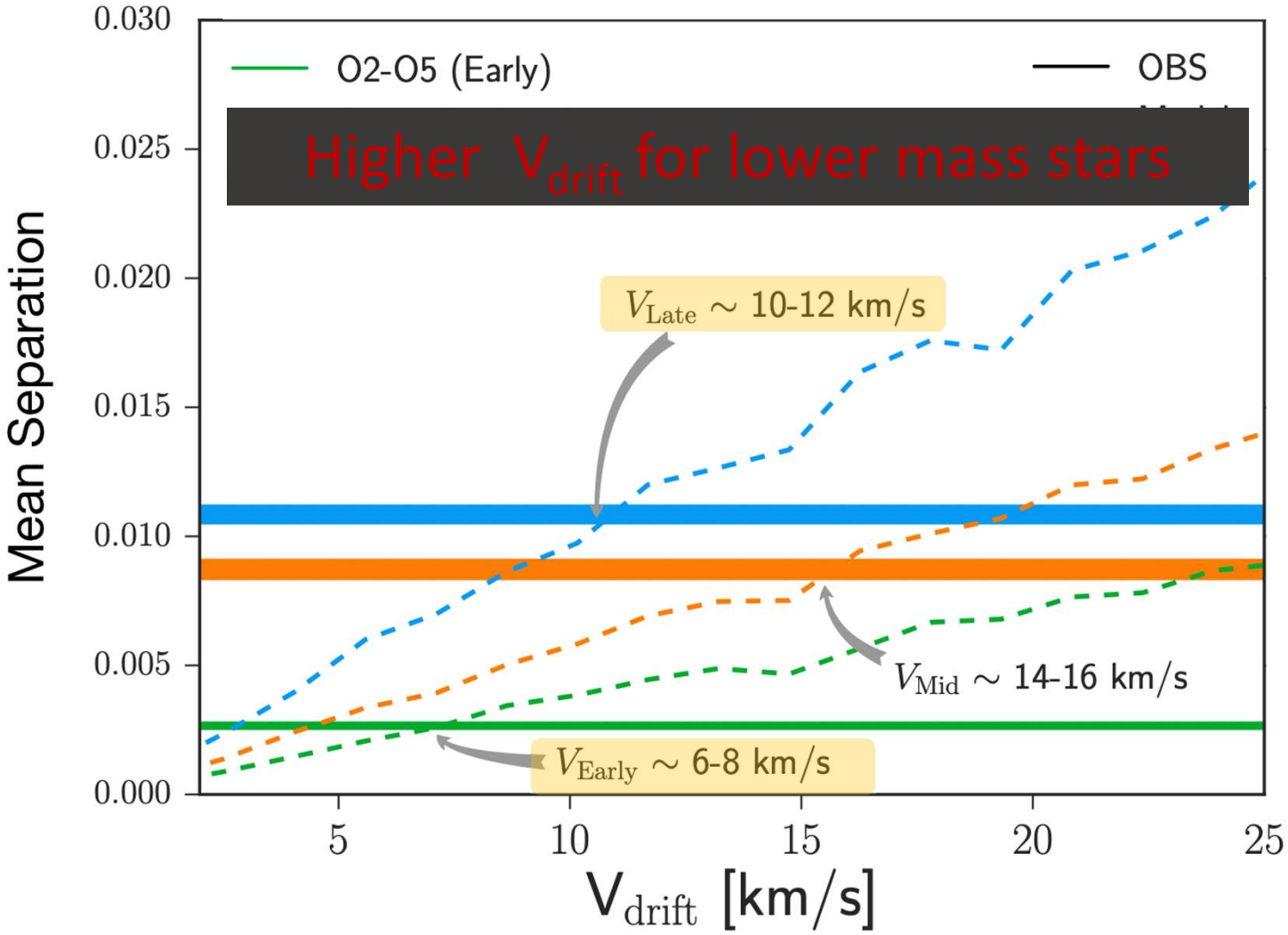
$$\langle S \rangle \sim \frac{v_{\mathrm{d}} t}{[N_O(t)]^{1/2}}$$

Good Agreement with Data

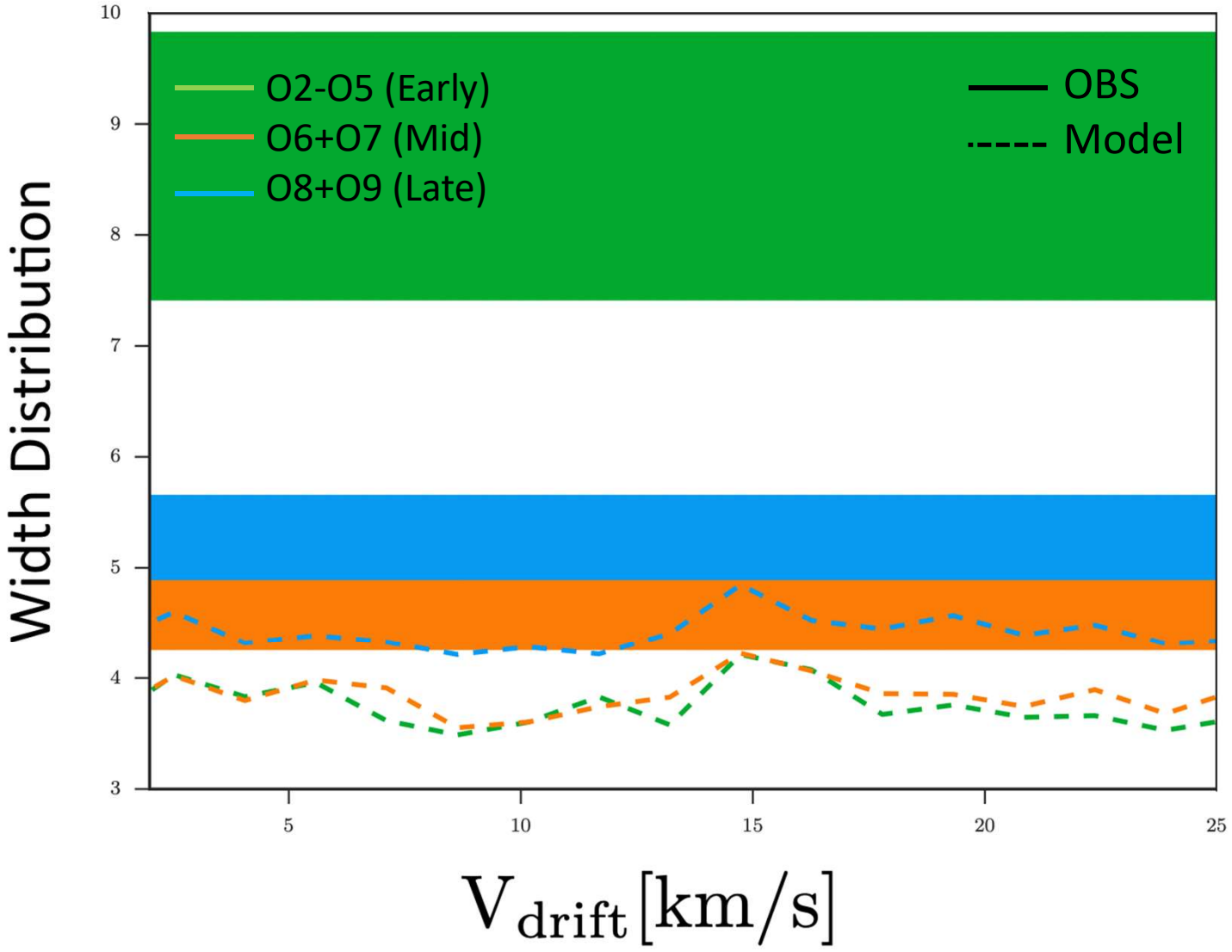
- Both model and observations show a lognormal distribution in separations.
- Lower mass stars drift farther.



Use Data to Infer v_{drift}



More to learn about the Evolution of Massive Stars in Clusters



- We developed an analytic equation to describe the previous Monte Carlo results. Now we use it to infer the age and velocity of LBVs.

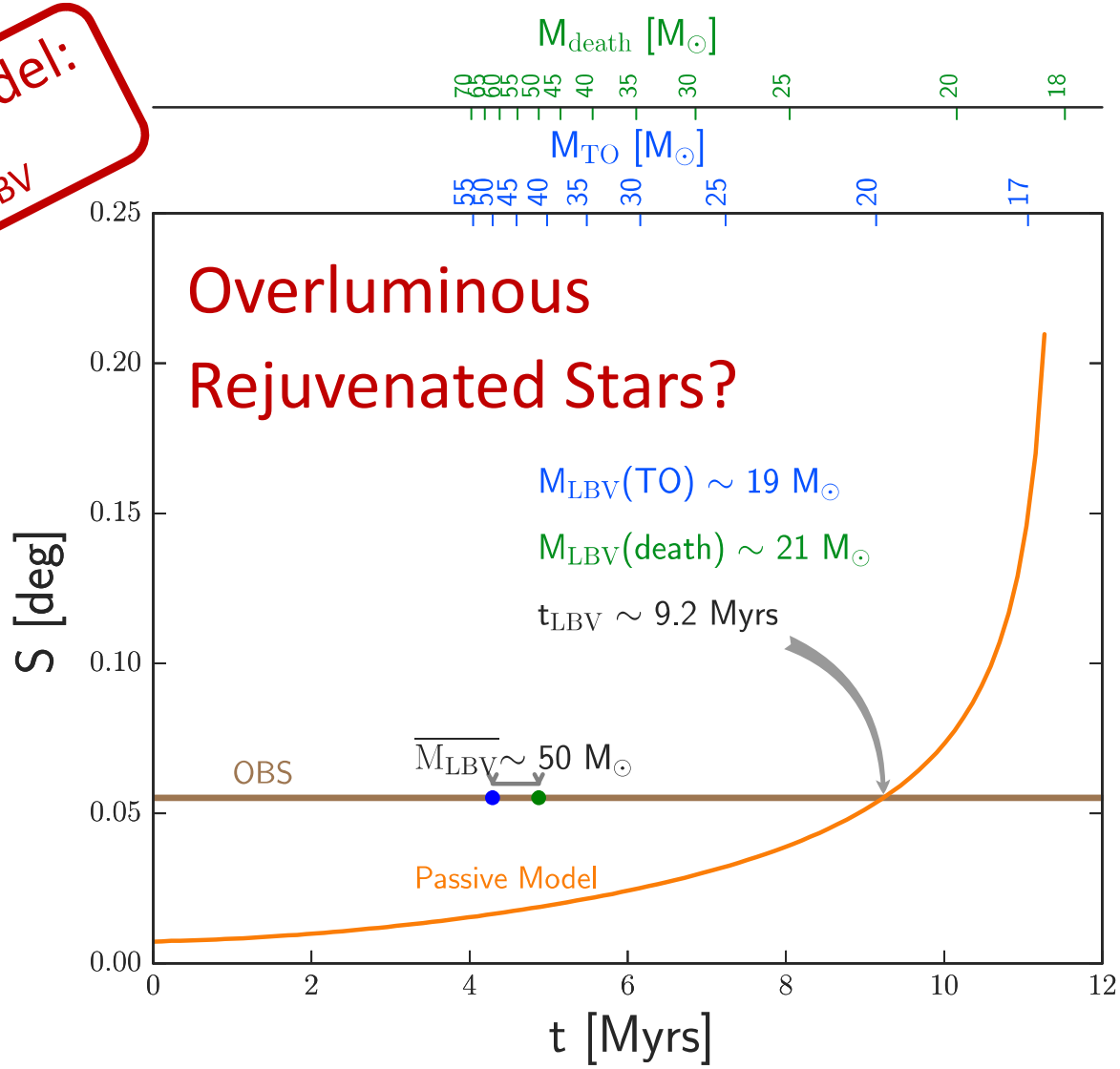
- This equation predicts the average separation given $V_{O,}V_{LBV}$, and age of the population.

$$(S_{LBV}/S_O)^2=0.5(1+(V_{LBV}t_{LBV}/V_Ot_O)^2)$$

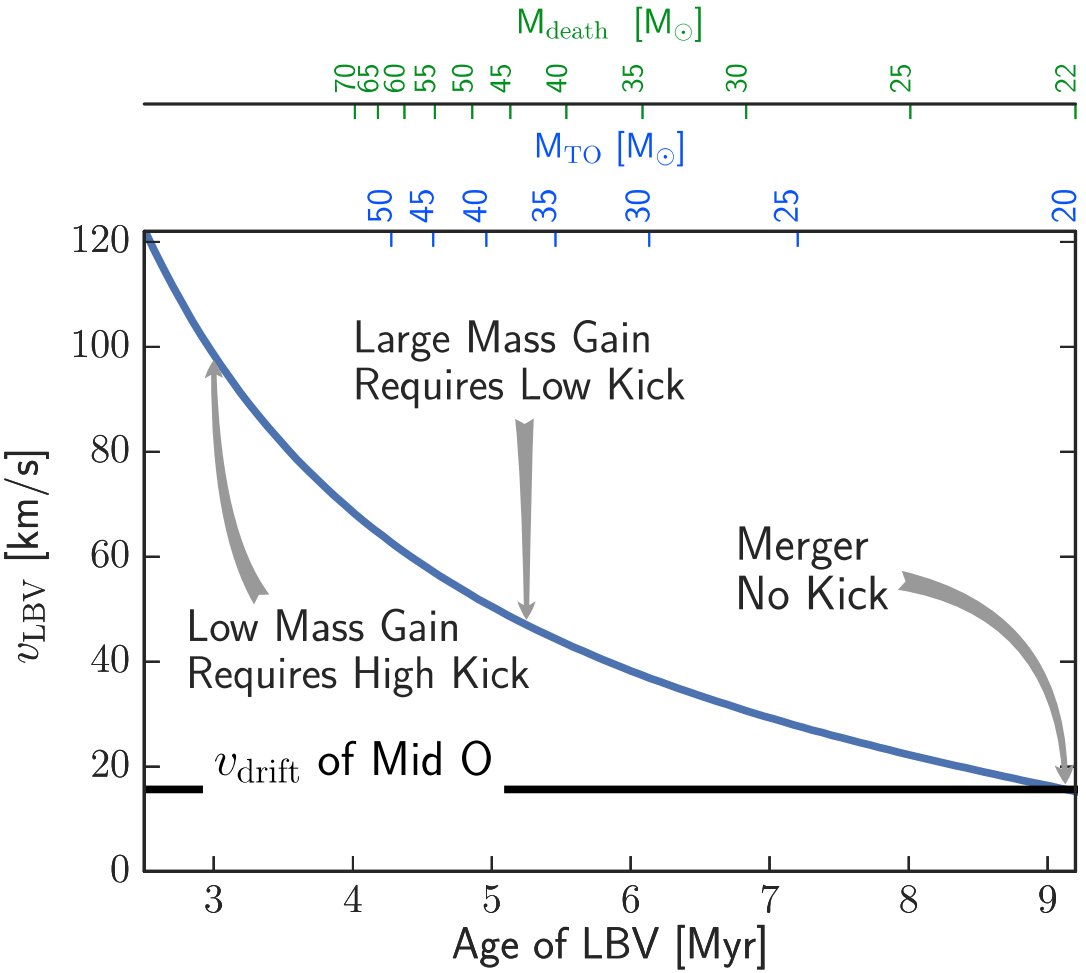
- First, we assume the single star evolution which implies that $V_O=V_{LBV}$.

How Long Must a Passive Cluster Evolve to Get the Wide Separations of LBVs?

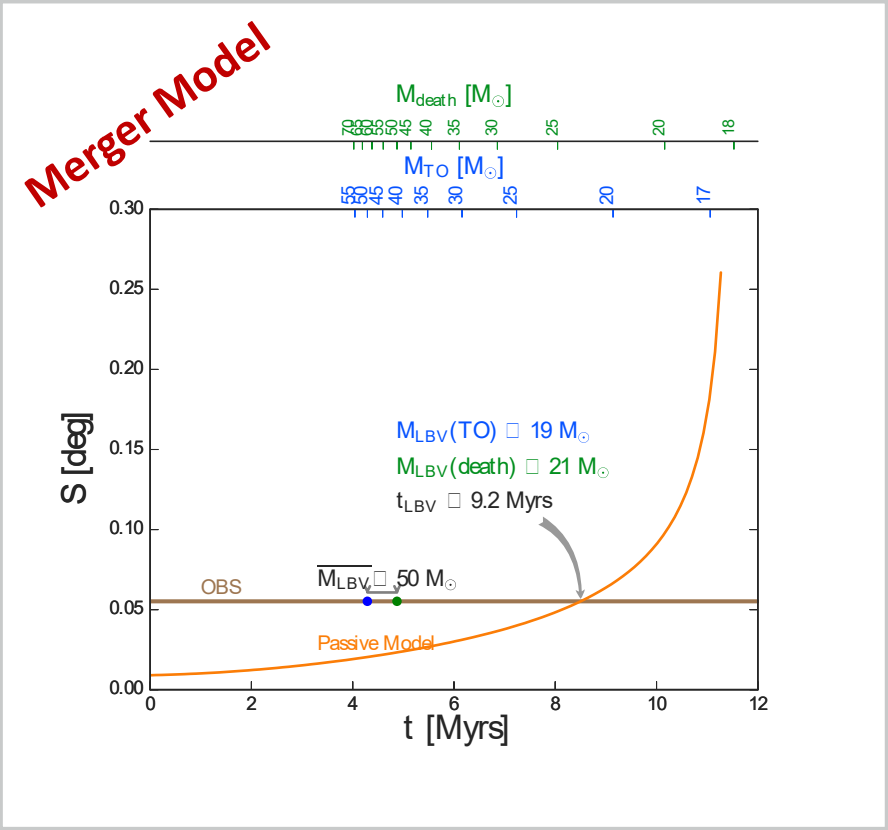
Passive Model:
$V_O = V_{LBV}$

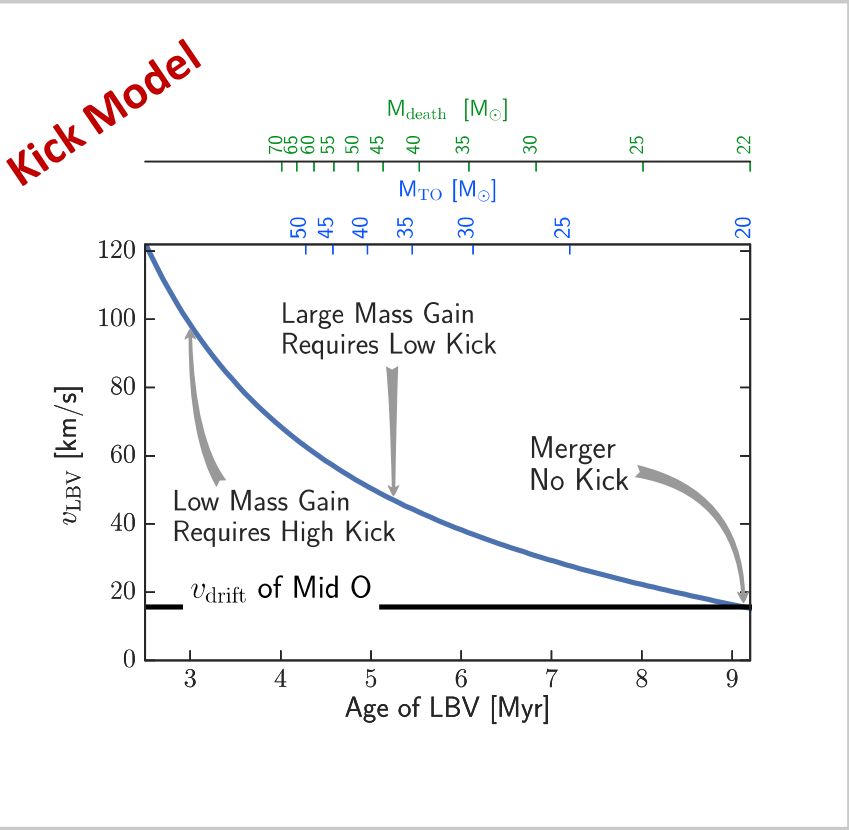


Kick Model: $V_{LBV}>V_O$



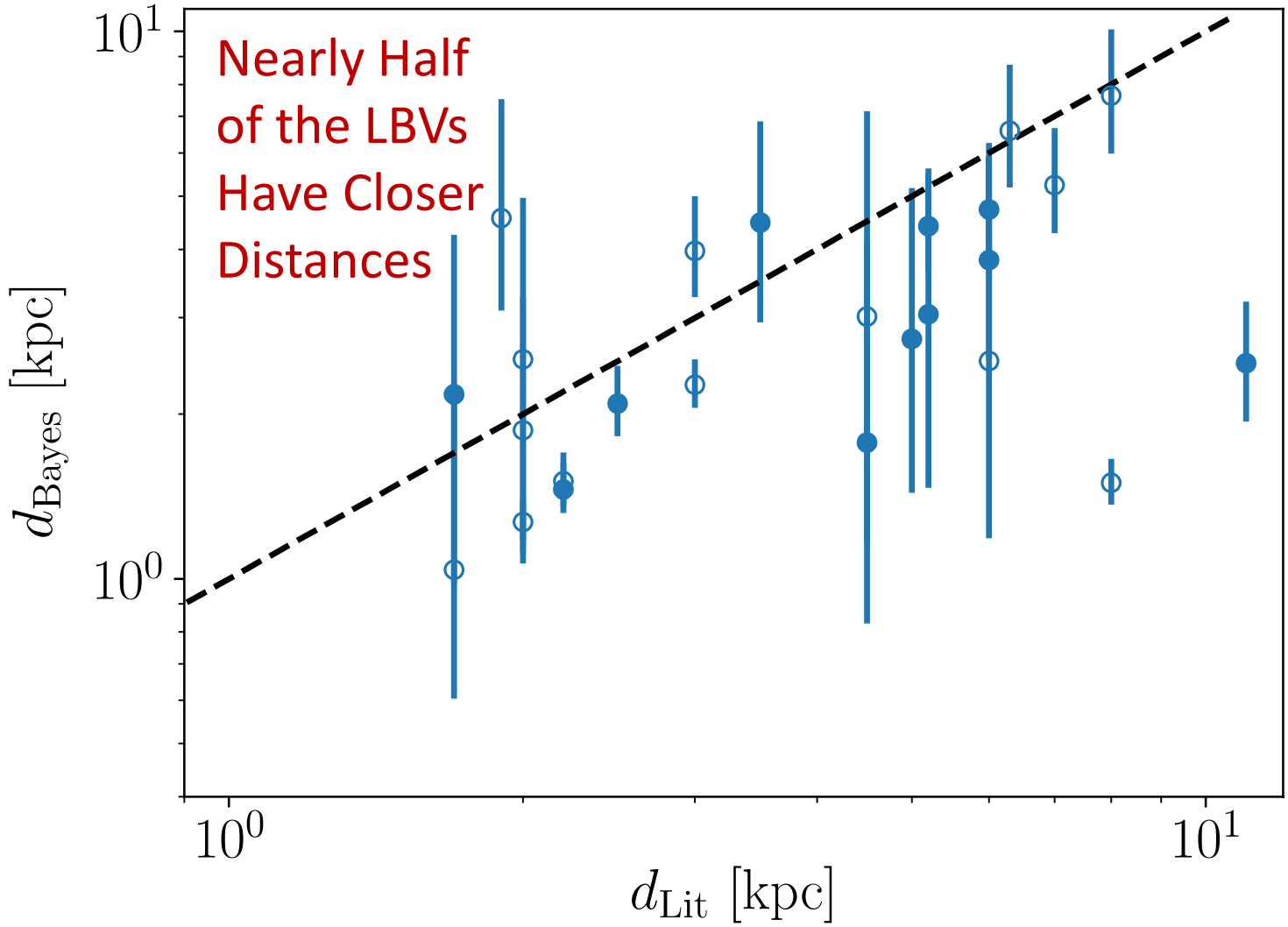
LBV is a mass gainer and gets a kick when the primary explodes.





We Need an Independent Way to Constrain the Ages of LBVs.

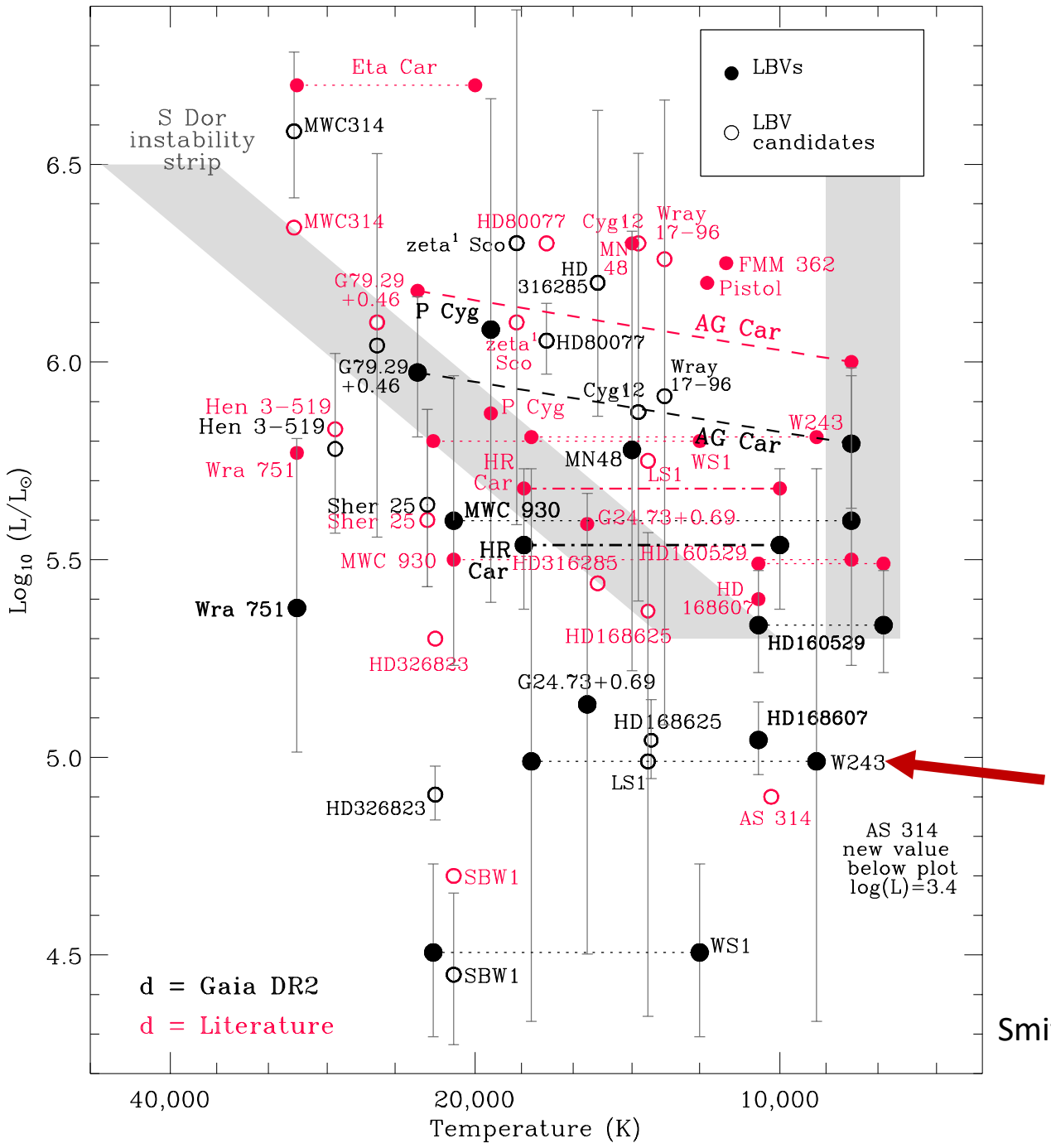
Gaia DR2 Distances to Individual LBVs



Smith et al. 2018

Mistakenly Classified LBVs

~~Tight S Dor Instability Strip~~

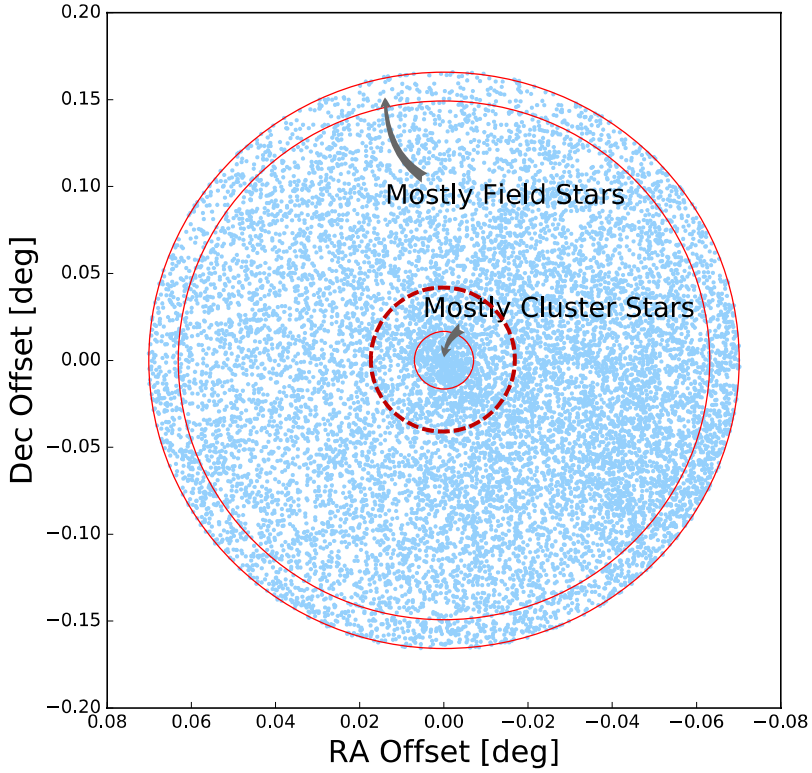


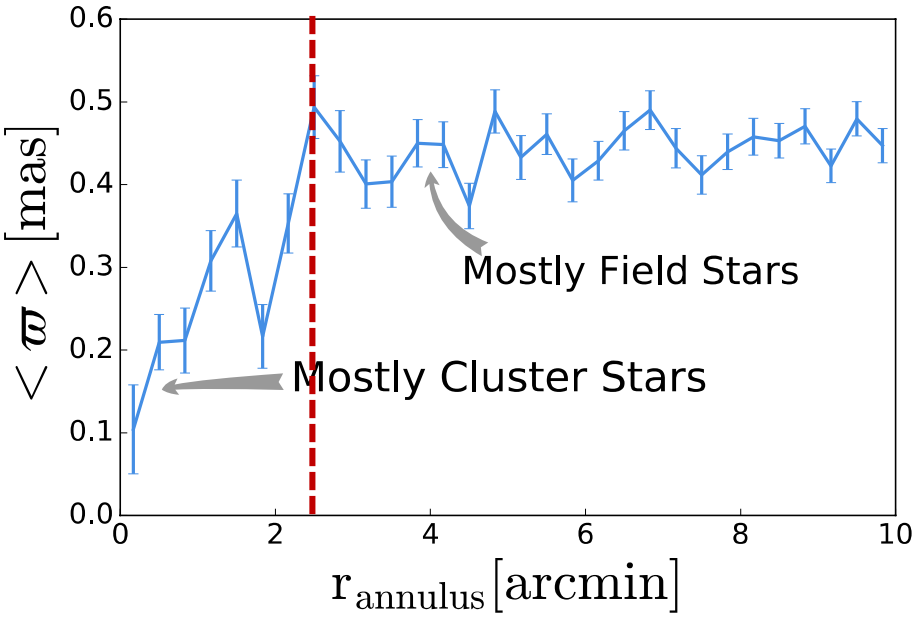
Smith et al. 2018

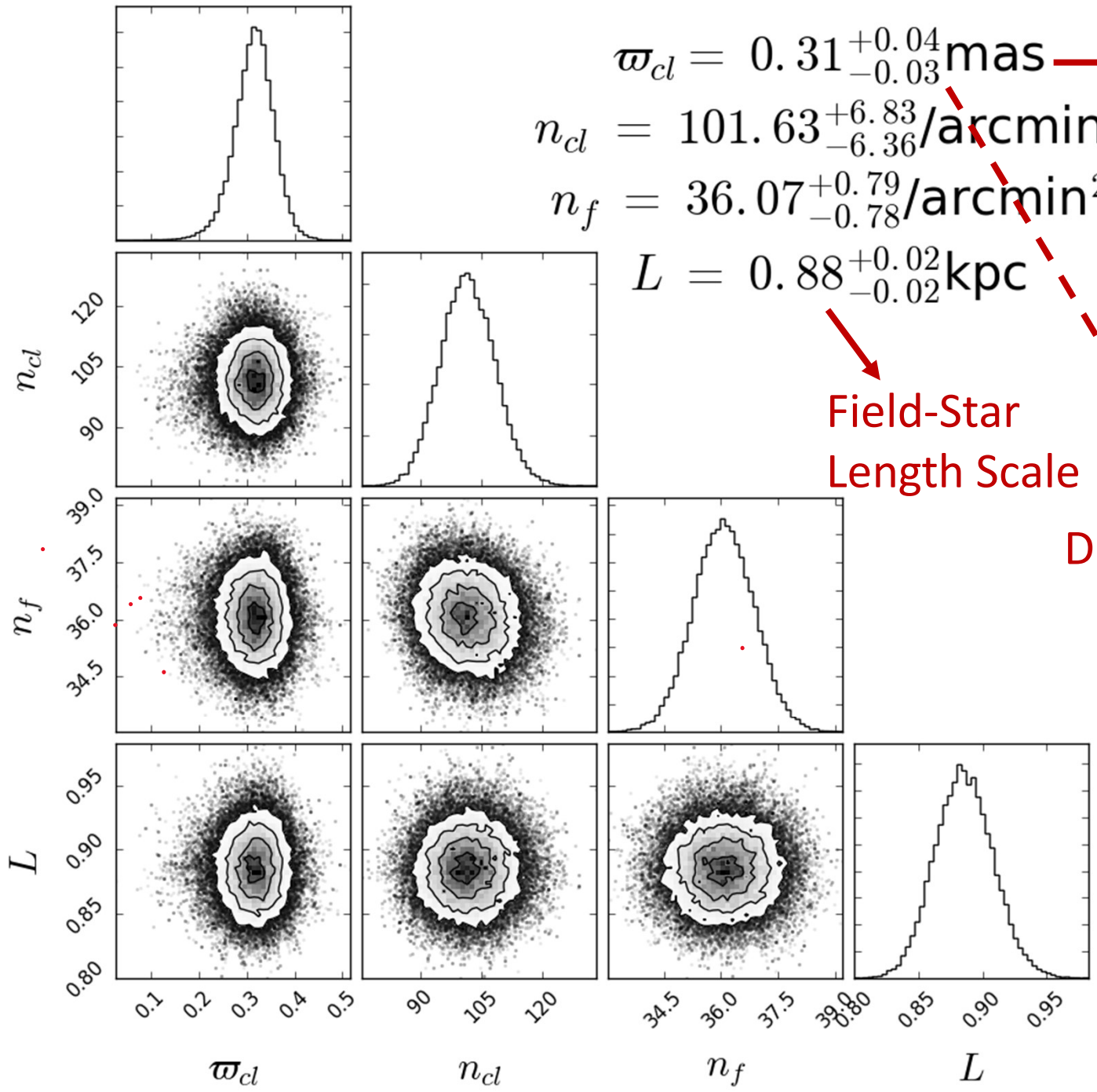
Inferring the Distance to Westerlund 1 from Gaia DR2

- One Confirmed LBV
- One magnetar
- 22 Wolf-Rayet stars
- 6 Yellow Hypergiants

The inner rings represent the cluster stars and the outer rings most likely represent the field stars







Cluster Parallax

Cluster Density

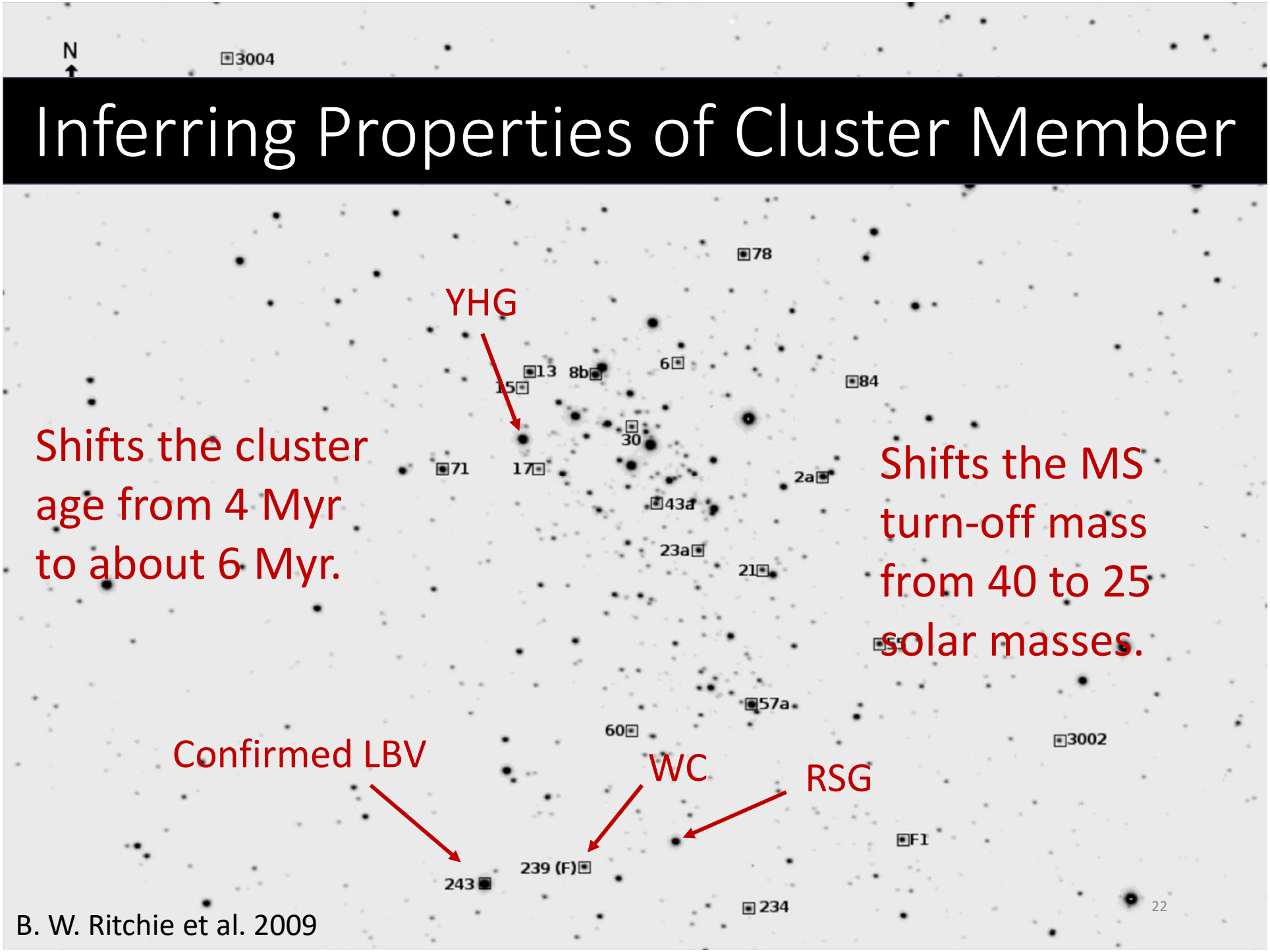
Field Density

Field-Star Length Scale

Distance to Cluster

$3.02_{-0.43}^{+0.32}$ kpc

Inferring Properties of Cluster Member



B. W. Ritchie et al. 2009

Summary

- LBV isolation is inconsistent with the passive single-star evolution model.

Aghakhanloo et al. 2017

- There is a larger spread in luminosity that extends to lower luminosity than previously recognized for Galactic LBVs.

Smith et al. 2018

- LBV W243 has an initial mass a little bit above 25 solar masses.

Aghakhanloo et al. 2018