The Effects of Metallicity on the Rotation Rates of Massive Stars

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Conti & Ebbets (1977)

- Determined *V* sin *i* values for 205 Galactic O-type stars.
- Attributed:
  - lack of slowly rotating O-type stars to presence of macroturbulent broadening.
  - lack of fast rotators amongst evolved stars to increasing radii and loss of angular momentum with mass loss.

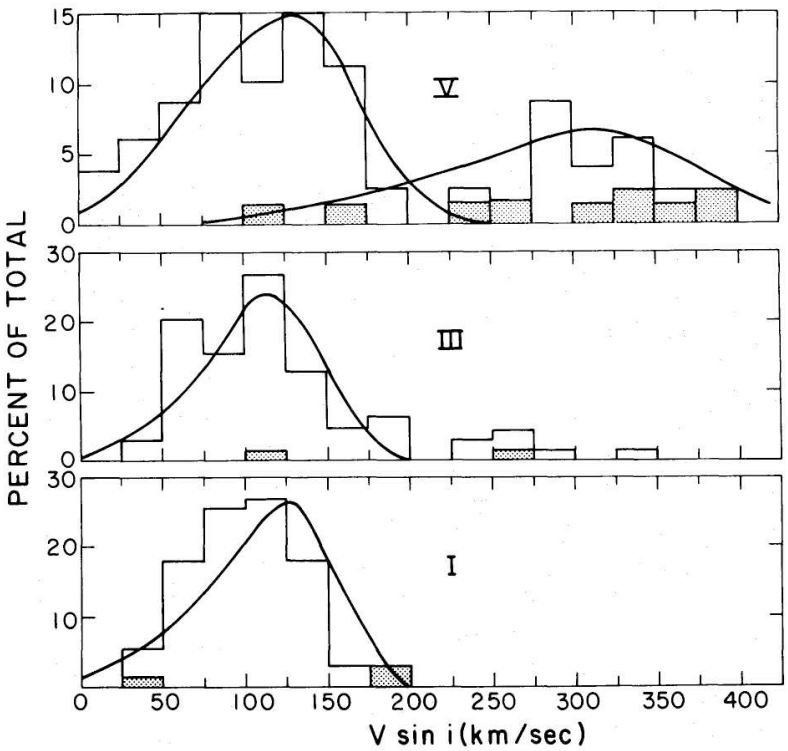


FIG. 4.—Distributions of rotational velocities for main-sequence, giant, and supergiant stars. The Oe and Oef stars are represented by the shaded areas. The shaded supergiant at 40 km s^{-1} is HD 105056 O9.7 Iae (Walborn classification).

Increasing the Sample Size

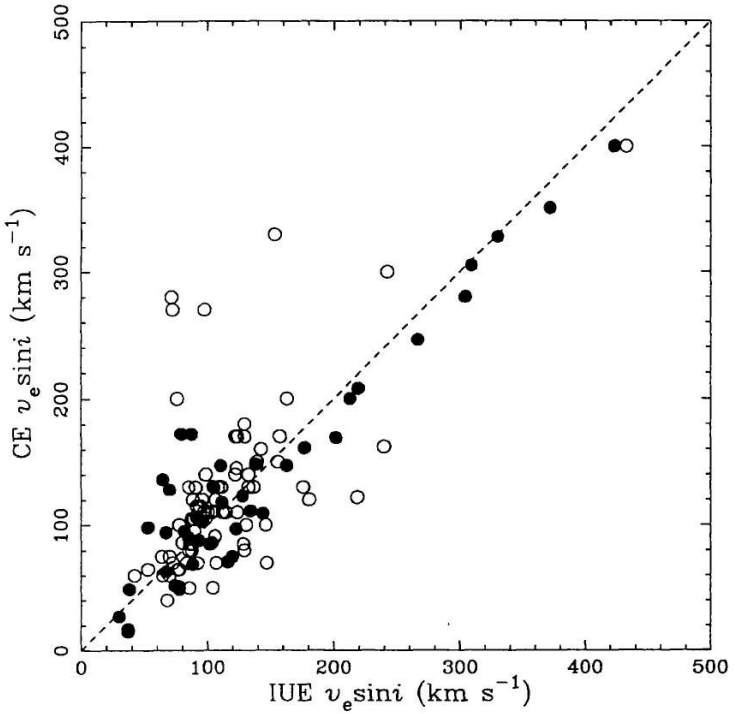


Figure 3. A comparison between the $v_e \sin i$ measurements derived by Conti & Ebbets (1977) and in this paper. Filled circles show data that were measured by Conti & Ebbets, and open circles data that come from eye estimates.

Howarth et al. (1997)

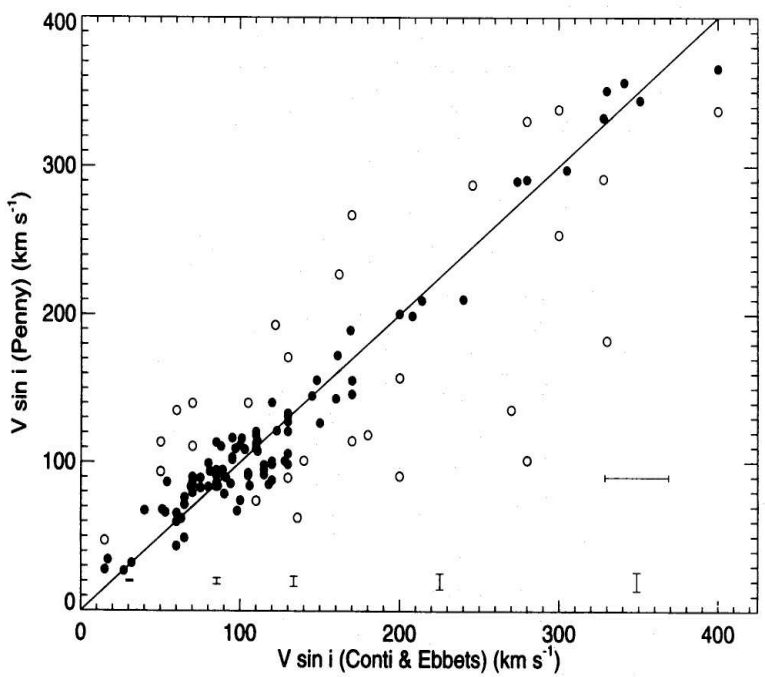
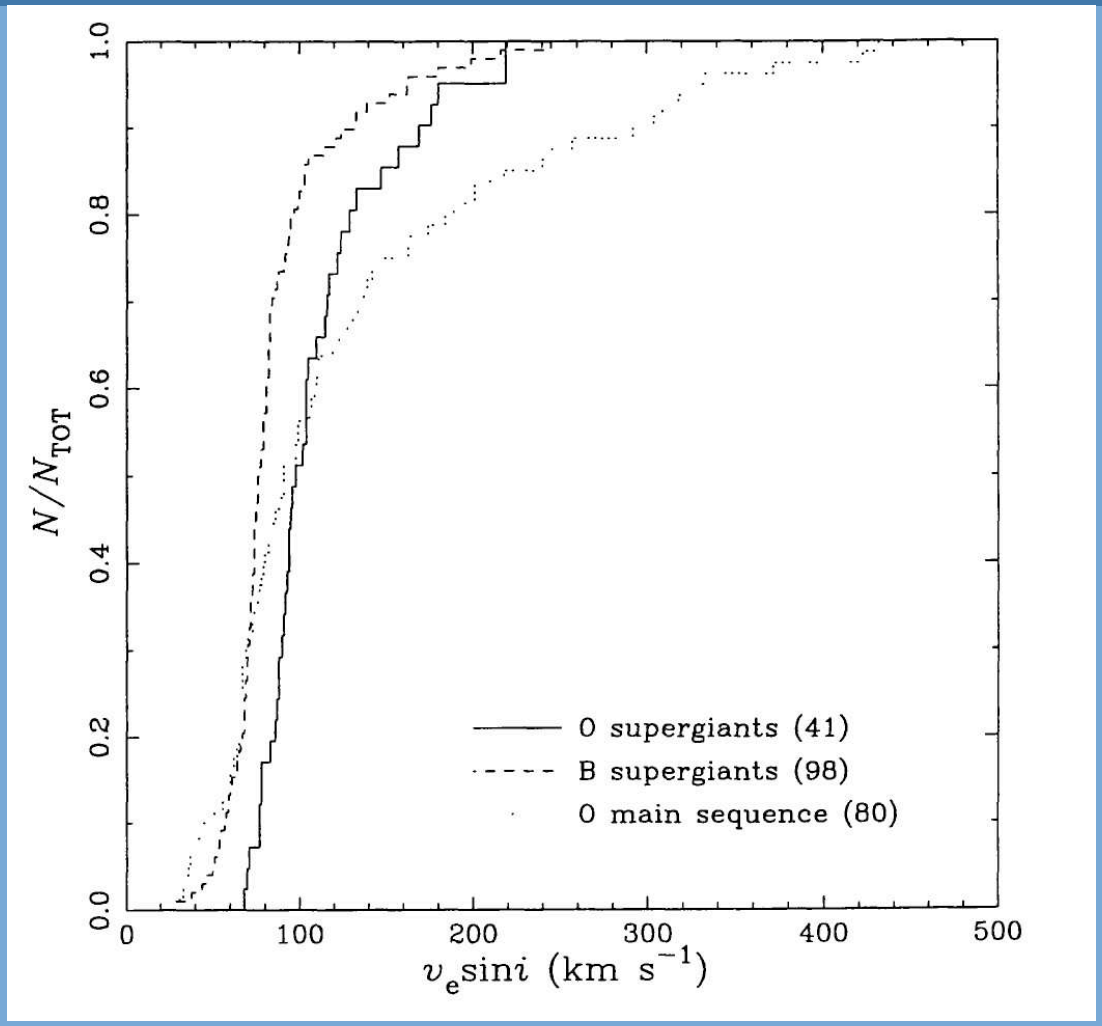


FIG. 3.—Estimated projected rotational velocity versus projected rotational velocity from Conti & Ebbets (1977). Open circles represent those stars given zero weight in the fit. Error bars based upon Gaussian width measurements of multiple *IUE* spectra (Table 1) are shown along the *x*-axis; the horizontal error bar near 350 km s^{-1} is the error quoted by Conti & Ebbets (1977).

Penny (1996)



- With a sample of ~240 O-type stars, Howarth et al. (1997) compared the CDF of dwarfs to supergiants and found a K-S probability well below the 5% level.

Angular Momentum Loss

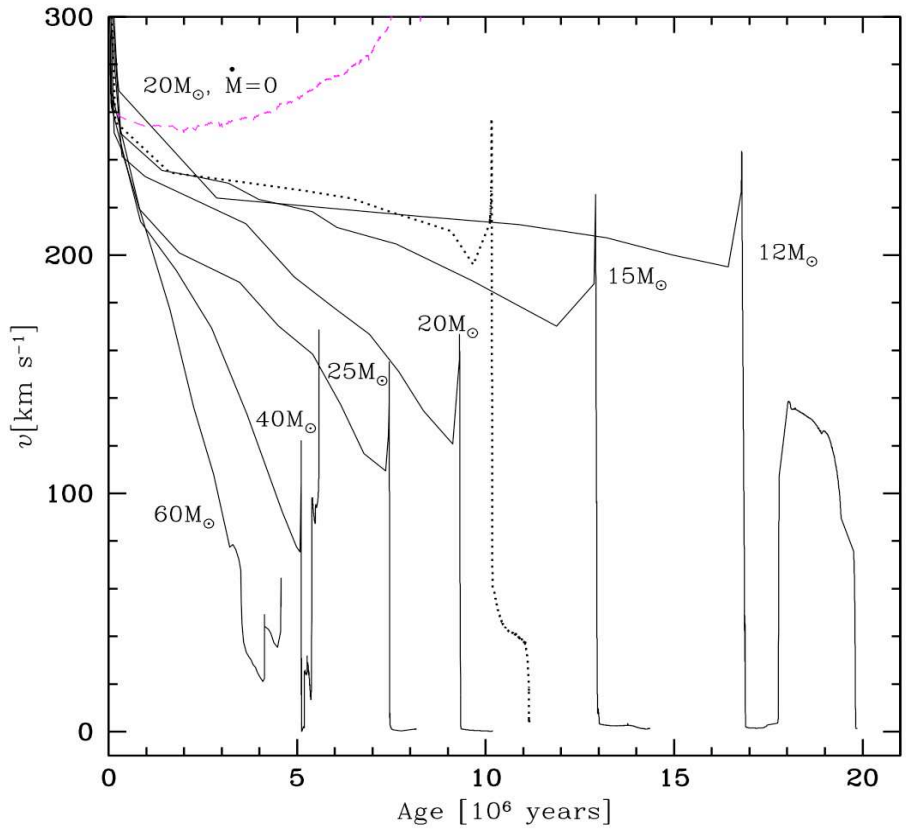


Fig. 10. Evolution of the surface equatorial velocity as a function of time for stars of different initial masses with $v_{\rm ini} = 300\,{\rm km\,s^{-1}}$. The continuous lines refer to solar metallicity models, the dotted line corresponds to a 20 $M_\odot$ star with $Z = 0.004$. The dashed line corresponds to a 20 $M_\odot$ star without mass loss.

- Meynet & Maeder (2000): Inclusion of angular momentum in interior models.
- Figure 10 demonstrates the drastic effects of mass loss on the surface rotational velocities of massive stars.

- However at lower metallicity, the predicted mass loss rates and subsequent angular momentum loss decrease.
- At these Z, evolved O-type stars should be spinning faster.

Maeder & Meynet (2001)

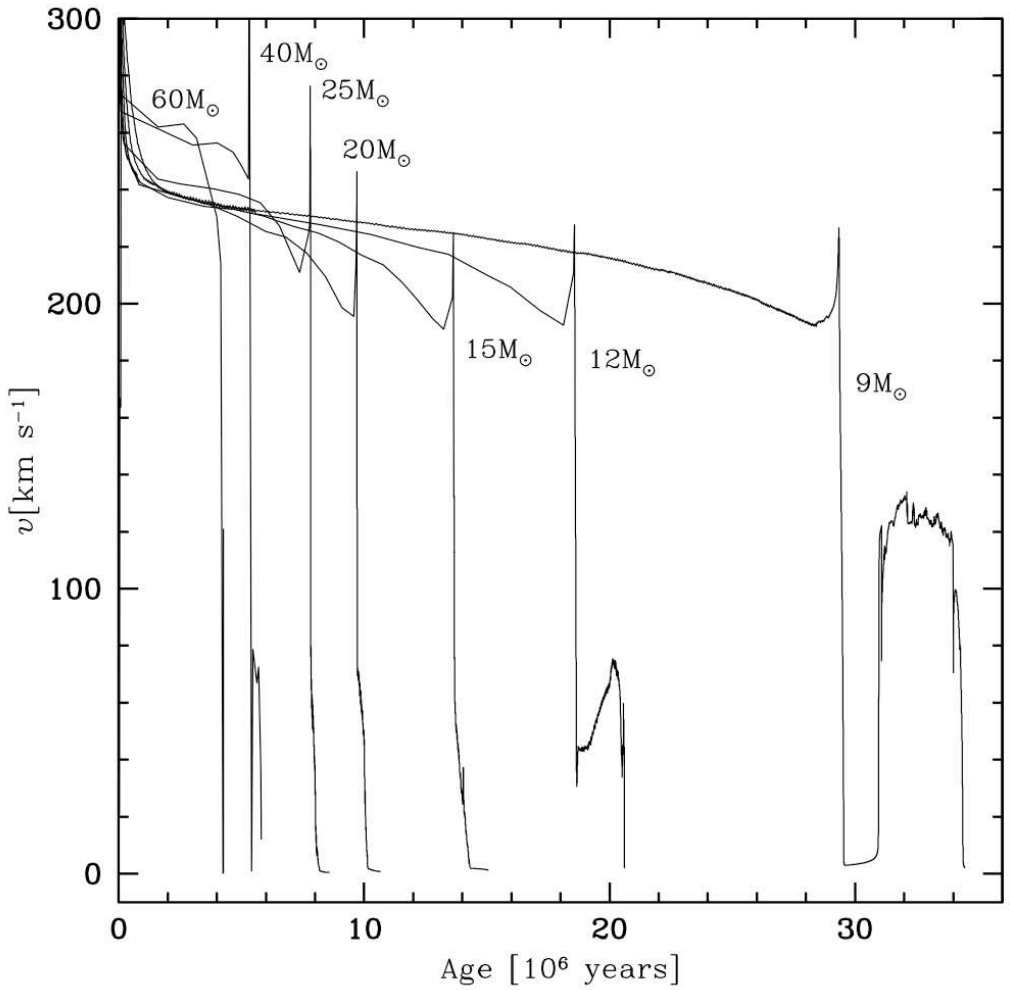


Fig. 3. Evolution of the surface equatorial velocity as a function of time for stars of different initial masses with $v_{\rm ini} = 300$ km s^{-1} and $Z = 0.004$.

V sin i Measurements at Low Z

- Direct Measurements of V sin i values for O-type stars in low Z environments.
  - Penny *et* al. (2004) -Study of 44 O-type stars in the SMC and LMC from archival STIS & IUE.
    - CDF of Galactic, LMC, SMC I,II,III stars very similar.
    - LMC stars are rotating slightly faster.
    - SMC stars, with lowest Z, are rotating slightly SLOWER!
  - Mokiem et al. (2006) -VLT-FLAMES survey of 28 O-type and 3 B-type stars in the SMC.
    - IV, V sample contains relatively more fast rotators than the I,II, III stars.
    - Significant difference in the rotation CDF of SMC unevolved stars compared to CDF of similar Galactic objects.

Archival HST/STIS & IUE Survey:
Results for I-III Stars

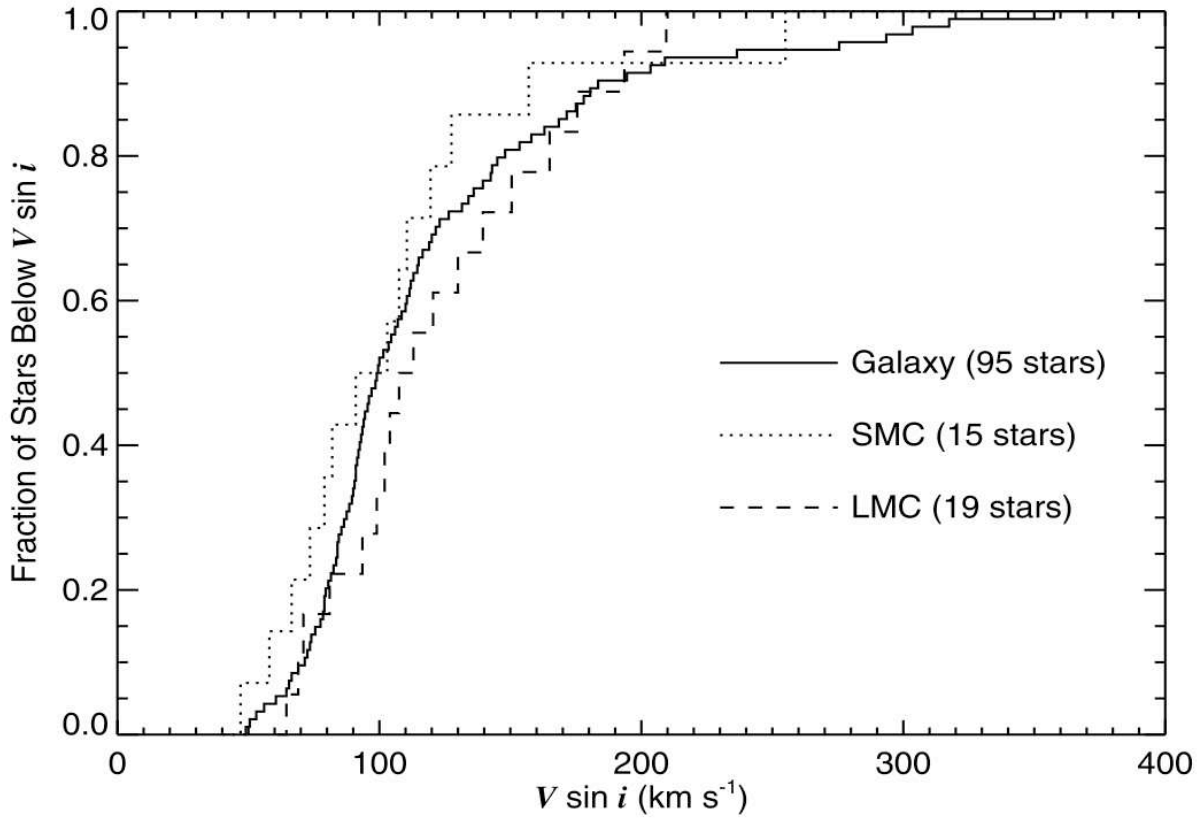


FIG. 5.—Cumulative distribution of projected rotational velocities for 15 SMC (*dotted line*), 19 LMC (*dashed line*), and 95 Galactic (*solid line*) O-type stars of luminosity class I–III.

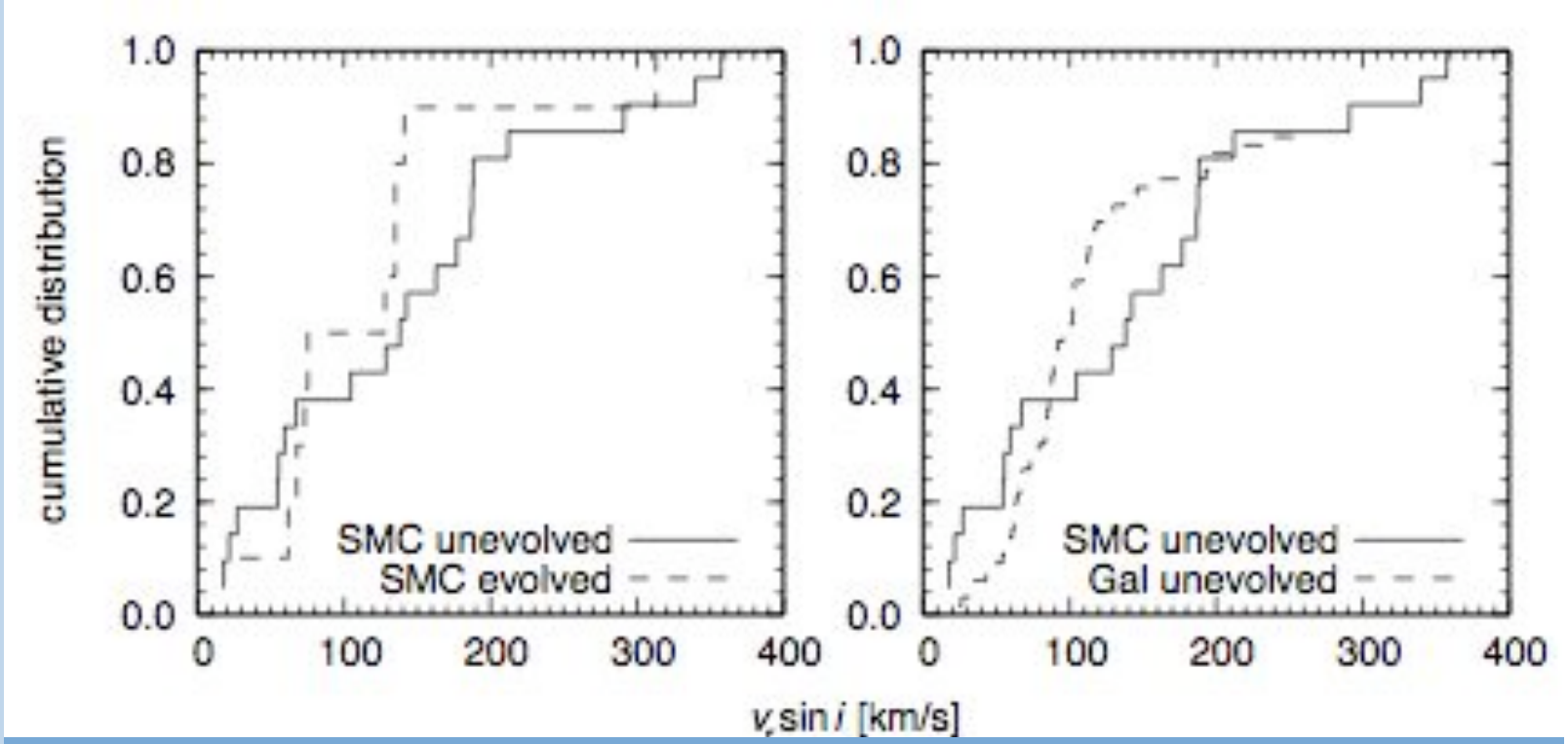
K-S p values:

Galactic vs. SMC
42%

Galactic vs. LMC
44%

Penny et al. (2004)

VLT-FLAMES Survey



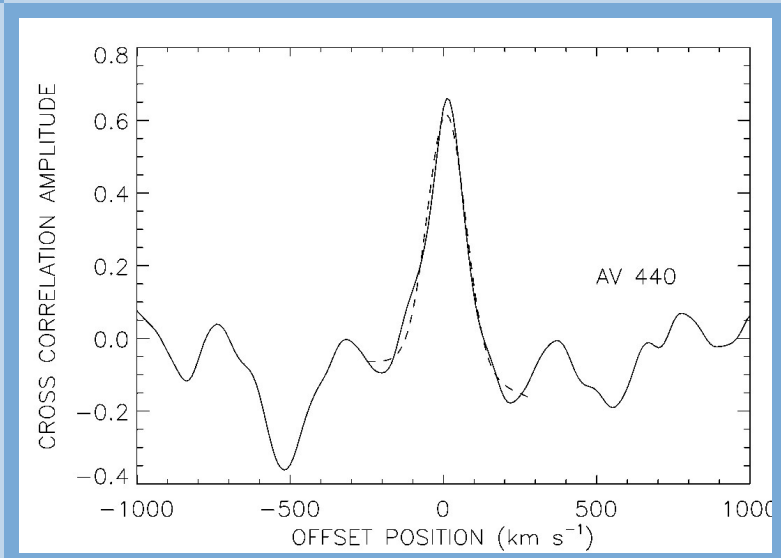
Mokiem et al. (2006)

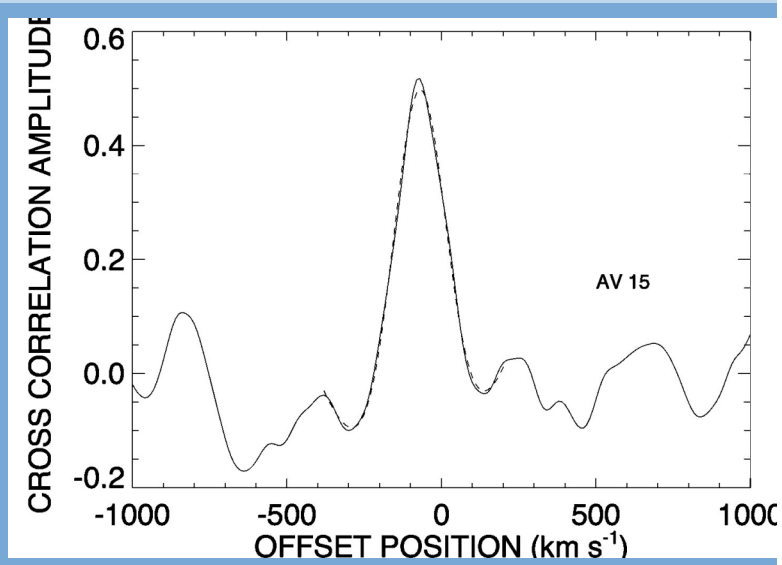
K-S p values:
SMC evolved (10) vs. unevolved (21), 23%
SMC unevolved (21) vs. Galactic unevolved (66), 13%

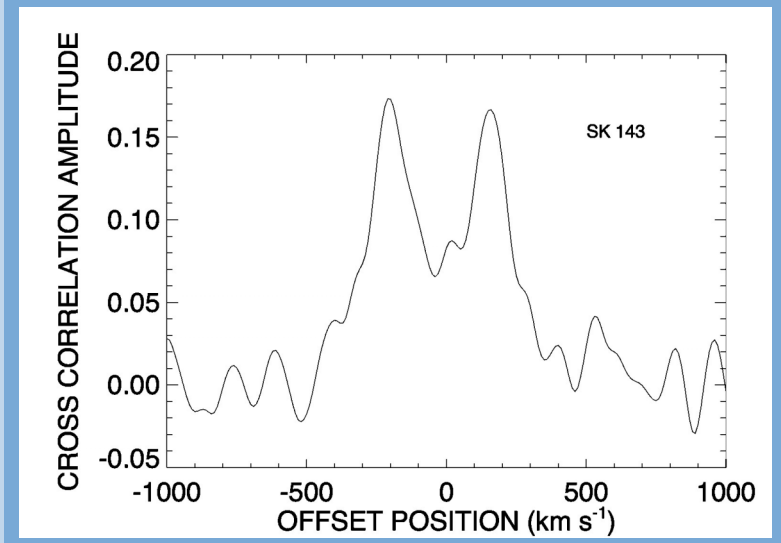
Archival FUSE Survey

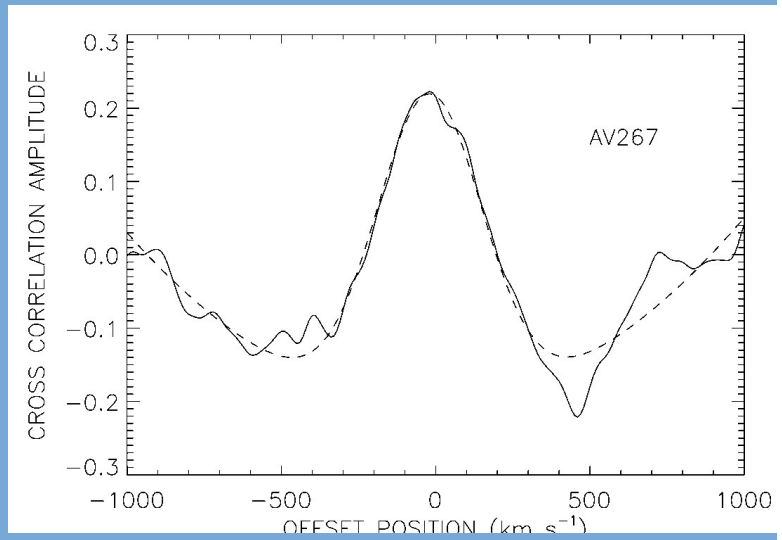
- MAST/*FUSE* archive contains spectra of 161 LMC and SMC stars with spectral types between B2 - O2. The targets are 120 evolved (I, II, & III) and 41 unevolved (IV & V) in these low Z environments.
- In addition MAST contains spectra of over ~100 Galactic O-type stars with known *V* sin *i* values. These can be used to calibrate CCF width to *V* sin *i.*
- To increase our sample, we also include *V* sin *i* measurements from: Mokiem et al. (2006, 2007) and Penny et al. (2004).

Cross Correlation Functions (ccf) of 4 SMC stars with the standard star, AV 327.

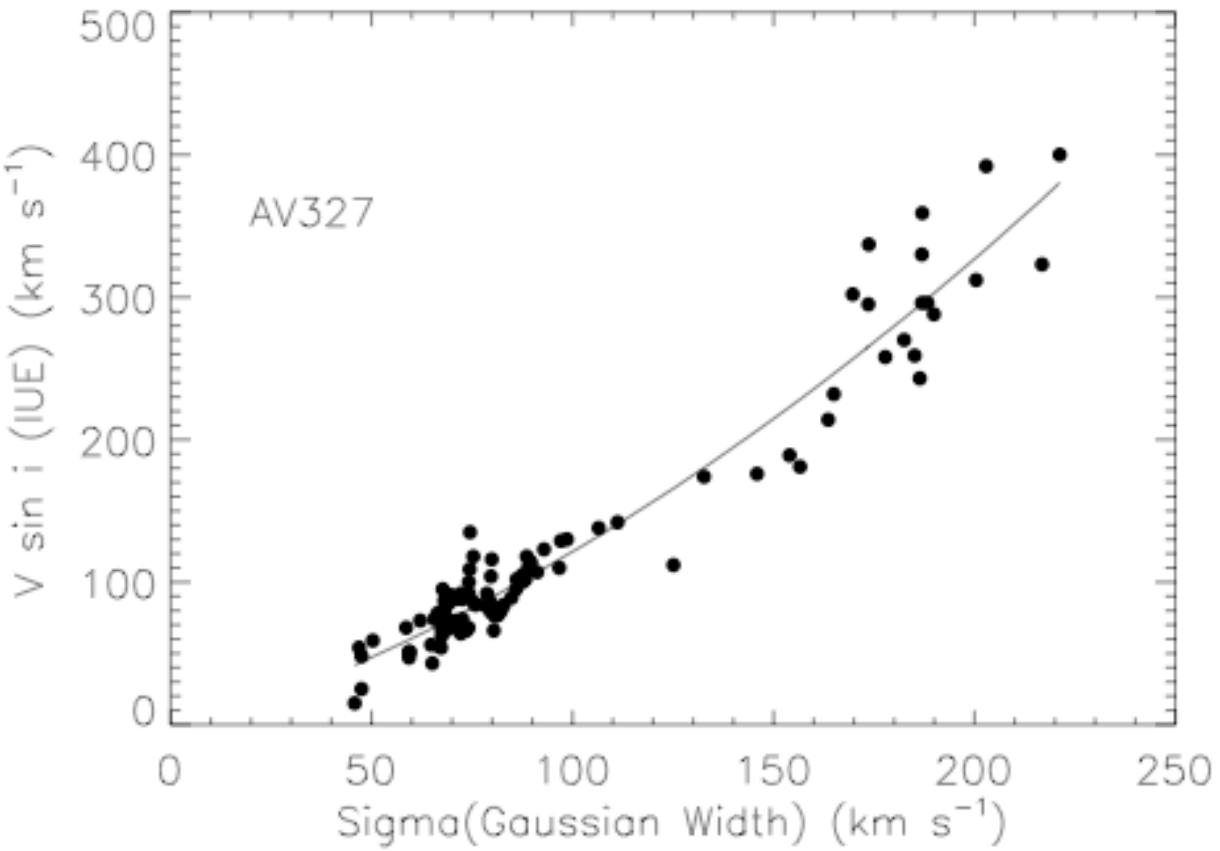




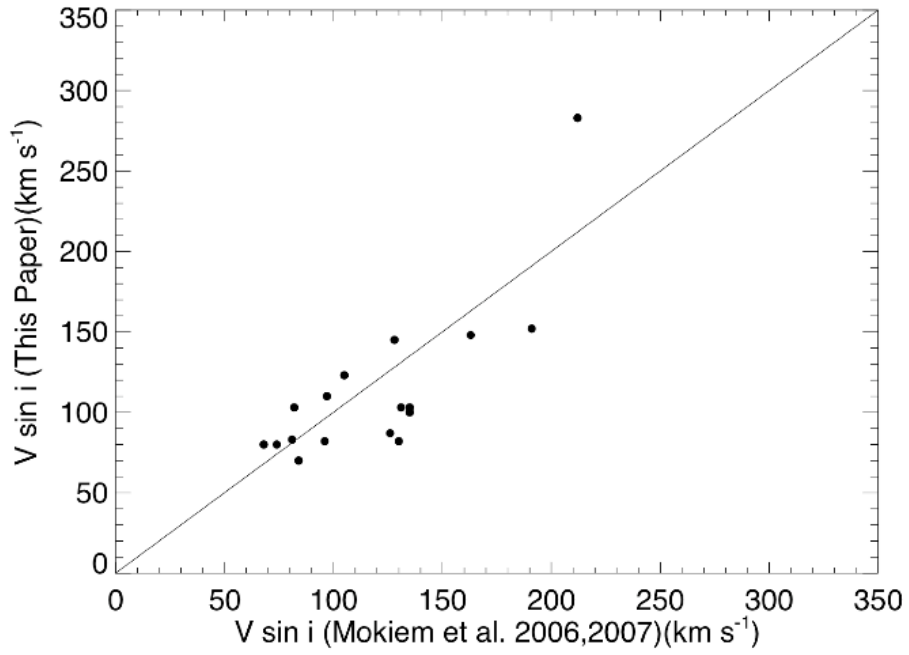


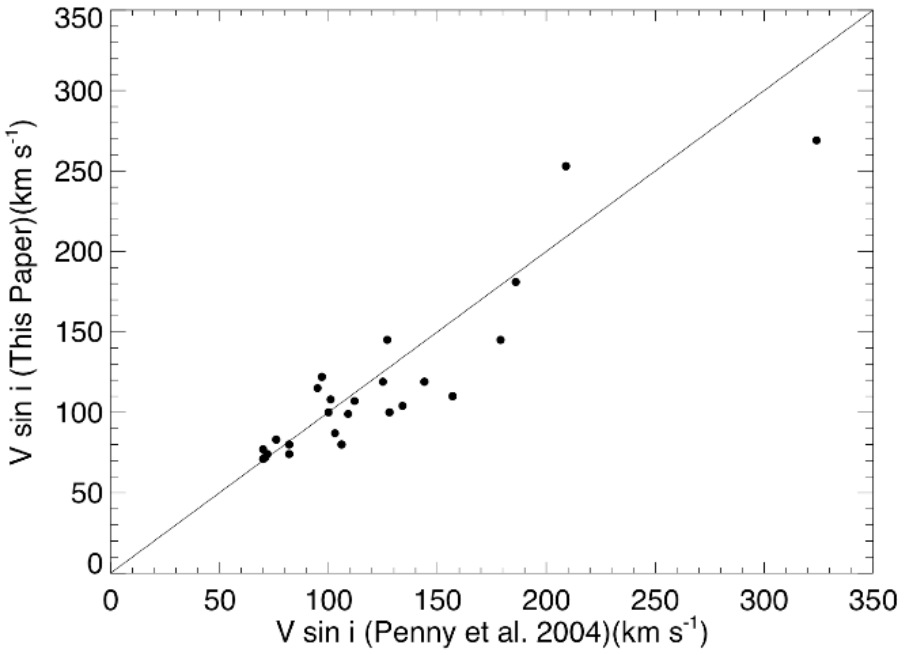


Calibration of FUSE CCF Widths

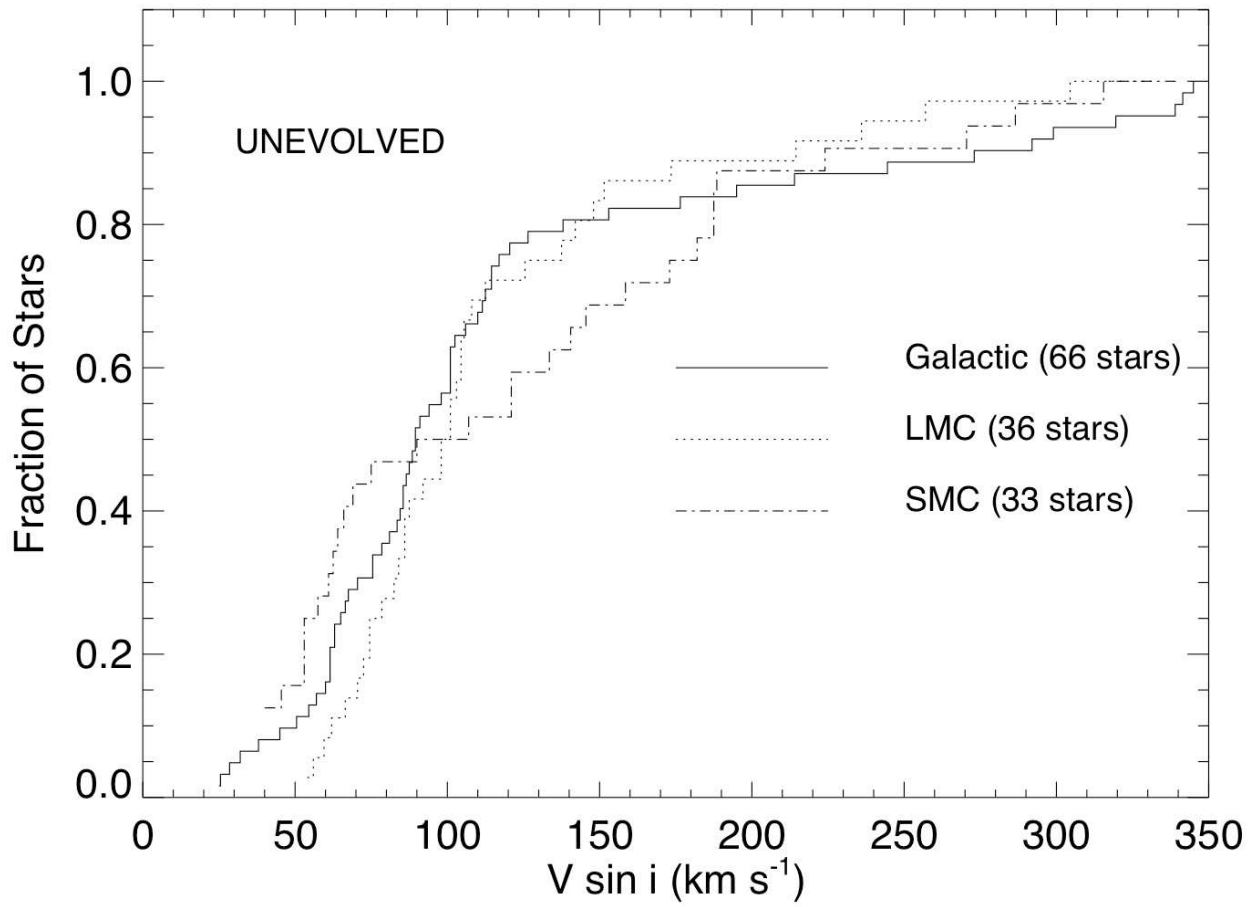


Agreement with Previous Studies





Galactic, LMC, & SMC: IV-V classes



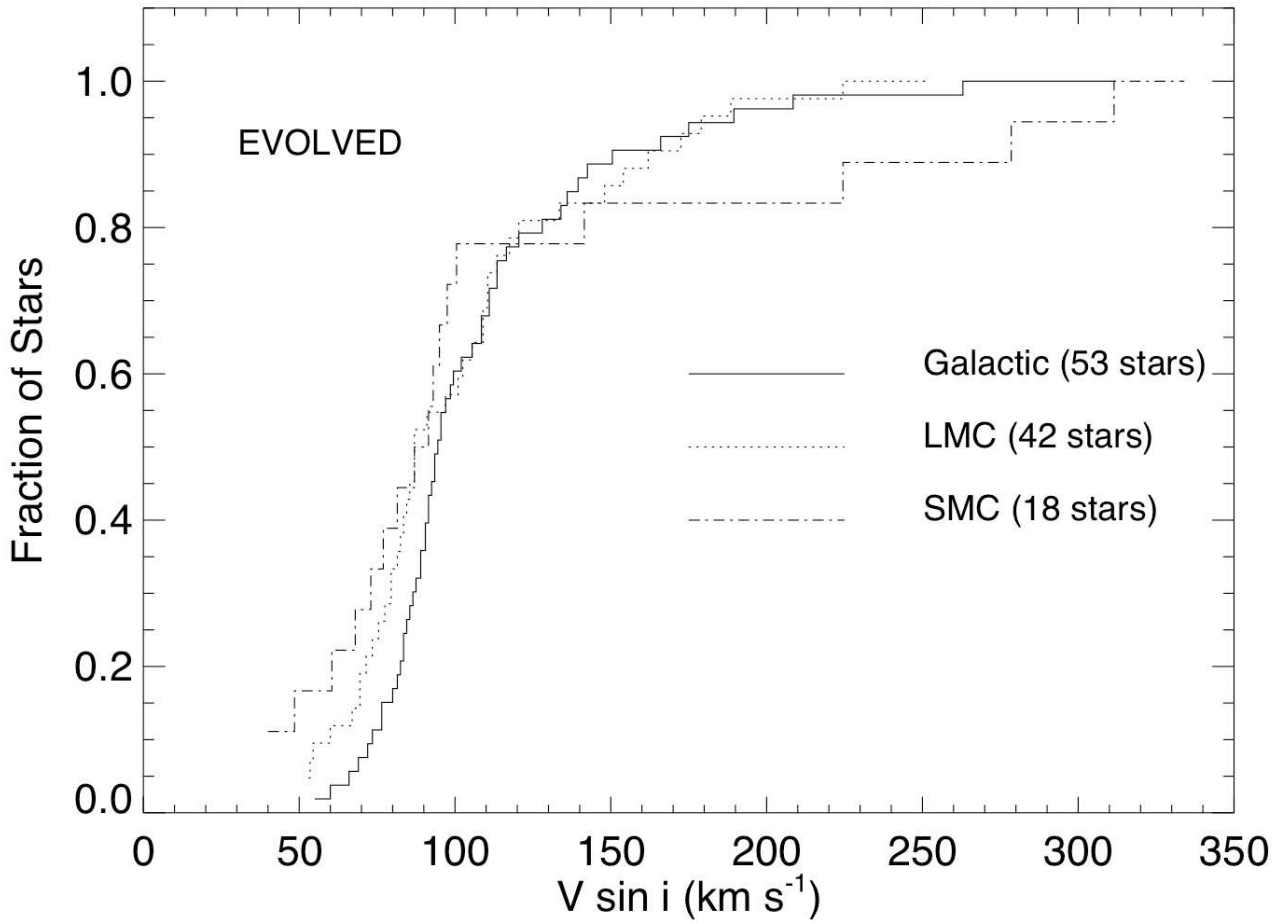
K-S D & p values

Gal. vs. SMC,
0.21, 24%

Gal. vs. LMC,
0.16, 54%

SMC vs. LMC,
0.28, 10%

Galactic, LMC, & SMC: I-II classes



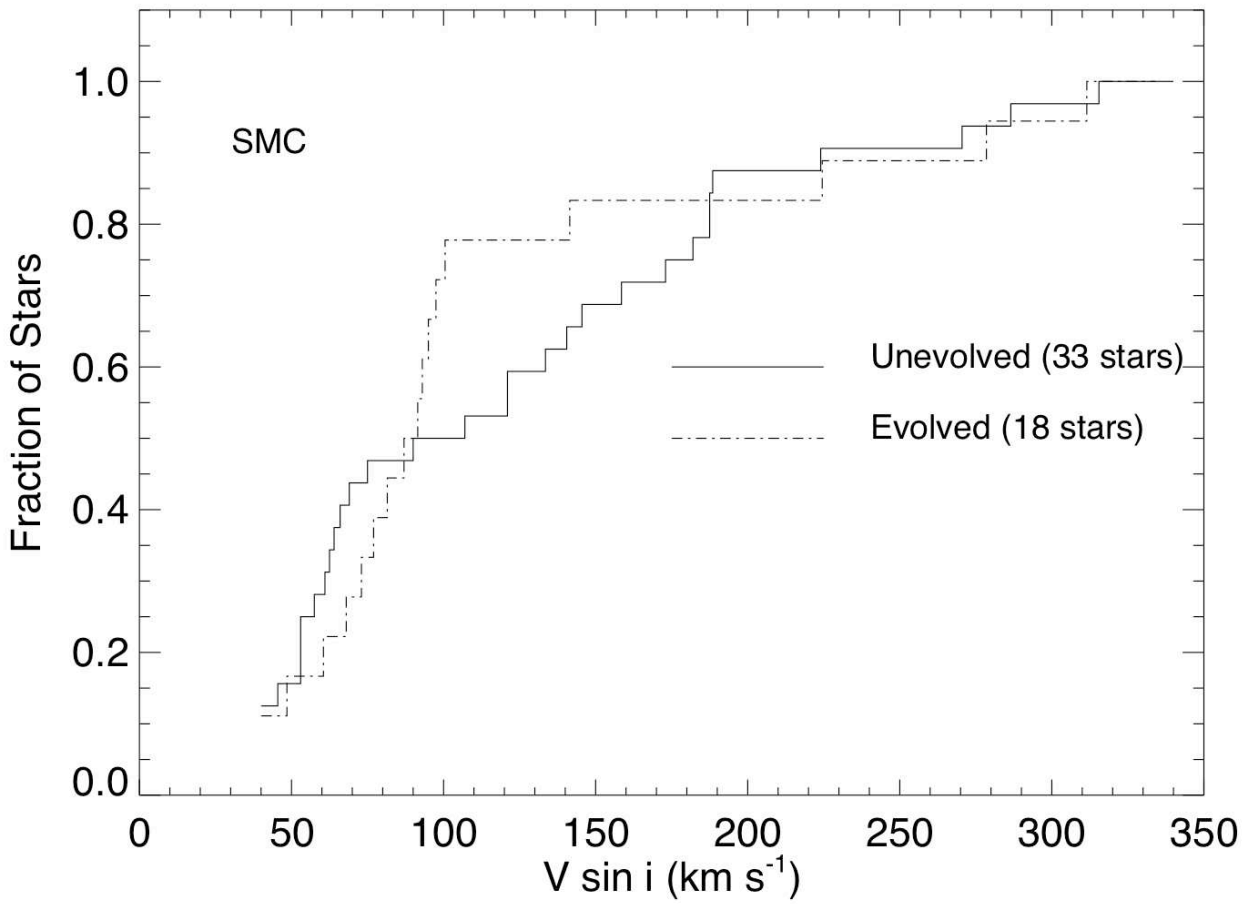
K-S D & p values:

Gal. vs. SMC,
0.24, 38%

Gal. vs. LMC,
0.20, 26%

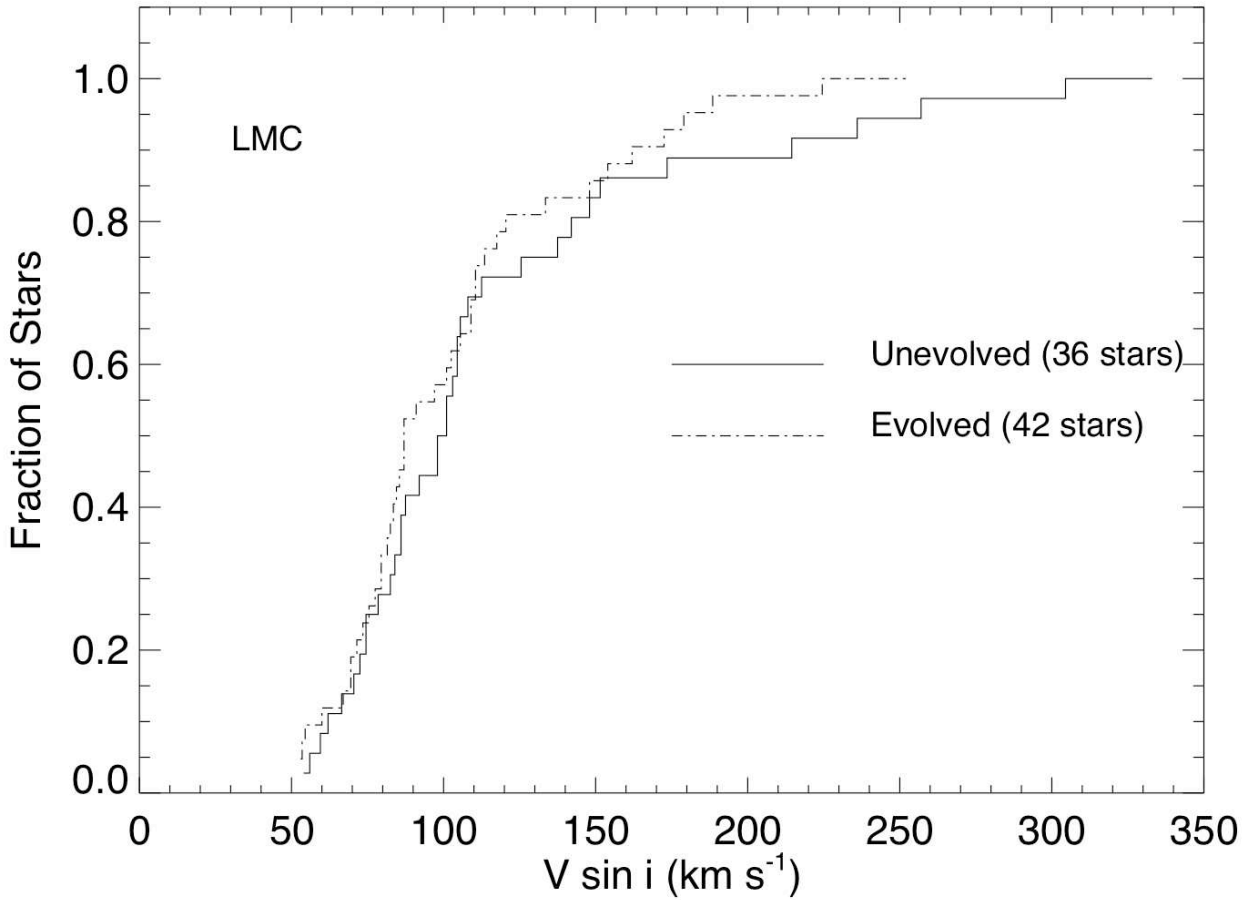
SMC vs. LMC,
0.18, 75%

SMC: I-II Vs. IV-V



K-S D, p value
0.29, 23%

LMC: I-II Vs. IV-V



K-S D, p value
0.13, 87%

Conclusions

- LMC
  - CDF of I-II and IV-V stars match fairly well.
  - Paucity of small $V \sin i$ among IV-V class.
- SMC
  - CDF of IV-V stars appears very different than those from Galaxy and LMC.
  - Also not in good agreement with the evolved stars in the SMC.
  - Unevolved stars in SMC have larger fractions with:
    - $V \sin i < 75$ km s^{-1}
    - 100 km $s^{-1} < V \sin i < 190$ km s^{-1}