The Distance to σ Orionis and Implications for the Age of the Orion OB1b Association

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The Problem

Knowledge of stellar ages are critical for understanding many aspects of stellar astrophysics. Among these are:
•The pre-main sequence evolution of low mass stars
•The evolution of very low mass stars and sub-stellar mass objects

Pre-Main Sequence Stars

On the Hayashi track, evolutionary tracks are essentially vertical. Temperature sets the mass; luminosity sets the age. We can measure temperatures; luminosity requires knowledge of the distance.

Distances to PMS Stars

Most PMS stars are too distant for parallax measurements to be practical. Astrometric binary solutions are hard because periods must be large for the separations to be measurable, hence velocity changes are miniscule.

In OB associations, assuming coevality, the massive stars are on the ZAMS. One can use main sequence fitting to determine the distance to the massive stars, and the ages from the low mass stellar luminosities.

The eastern side of Orion's belt. ε, ζ, and σ Ori are prominent. Image ©R. Gendler.

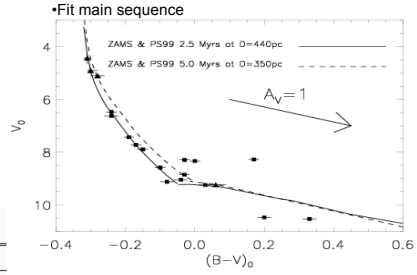
Table 1. Adopted Values

ID	U−B	$(U-B)_0$ [b]	B−V	$(B-V)_0$ [b]	Err	V [1]	Sp. Type [2]	D(')	A_V	Member	Notes
σ Ori Aa	–	−1.12[a]	–	−0.31	0.01	4.4[3]	O9V[a]	0.00	0.19	MS*	Calculated
σ Ori Ab	–	−1.08[b]	–	−0.30	0.01	4.9[3]	[B0V?][a]	0.00	0.19	MS	Calculated
σ Ori B	–	−1.00	–	−0.28	0.02	5.16[3]	B0.5V[a]	0.00	0.19	MS*	Calculated
σ Ori C	–	−0.06	–	+0.06	0.03	9.42	A2V	0.20	–	PMS	V from Sherry et al. (2008)
σ Ori D	−0.81	−0.84	−0.18	−0.24	0.02	6.81	B2V	0.22	0.19	MS*	
σ Ori E	−0.87	−0.81	−0.18	−0.21	0.014	6.66	B2Vp	0.69	0.19	MS*	Peculiar, Variable
HD 294272	−0.05	−0.10	+0.03	−0.01	0.015	8.18	B9.5III[3]	3.12	0.22	PMS?	ADS 14240B
BD −02 1323C	−0.30	−0.37	−0.04	−0.11	0.02	8.77	B8V[4]	3.25	0.22	MS*	
HD 294271	−0.56	−0.58	−0.11	−0.17	0.01	7.91	B5V[c]	3.17	0.19	MS*	ADS 14240A; ADS 14240B is 68" away.
HD 37525	−0.58	−0.58	−0.09	−0.17	0.01	8.08	B5V[5]	5.11	0.25	MS*	May be B5III[5] ; has a faint 0."15 companion[6]
HD 294273	+0.07	−0.07	+0.26	−0.2	0.03	10.66	A7 9[6]	8.68	0.19	No	HDE Spectral Type: A3
HD 37564	+0.15	−0.10	+0.23	+0.17	0.03	8.46	A5/7	8.74	0.19	No	>1 mag. brighter than isochrone.
HD 37643	−0.36[7]	−0.20	+0.03	−0.06	0.01	9.04	B9	16.00	0.28	PMS	Variable (V1147 Ori)
HD 37333	−0.06	−0.07	+0.06	+0.00	0.02	8.52	A0V	18.60	0.19	PMS?	Binary or Non Member
HD 294270	+0.03	−0.01	+0.39	+0.37	0.03	10.72	F3[6]	19.34	0.06	OB1a?	See Section ??
HD 294275	+0.01	−0.07	+0.09	+0.03	0.03	9.43	A1V[8]	20.45	0.19	PMS	
HD 37515	−0.15	−0.20	−0.02	−0.06	0.02	9.31	B9V	21.66	0.12	MS*	
HD 37686	−0.09	−0.10	+0.02	−0.01	0.015	9.23	B9.5V	22.61	0.19	(PP)MS	
HD 37699	−0.69	−0.58	−0.13	−0.17	0.01	7.62	B5V	25.79	0.12	MS?[9]	Radial velocity may be inconsistent with membership[4]

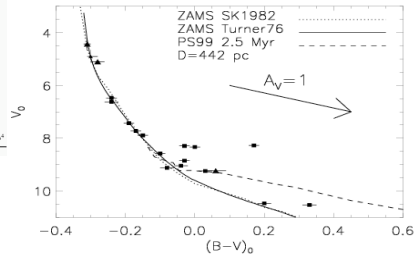
All the stars with V<11 within 30' σ Ori

Technique

Main Sequence Fitting
•Deredden colors and magnitudes
•Separate binaries as well as possible
•Plot results
•Discard non-members
•Fit main sequence



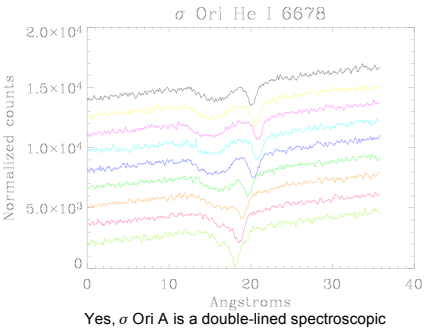
The CMD showing the difference between the upper main sequence at the Hipparcos distances of σ Ori (350 pc) and the mean association distance. The two isochrones agree near the main sequence turn-on, but with a factor of 2 difference in ages



The dereddened B-V vs. V color--magnitude diagram of the early type stars within 30' of σ Ori AB. The expected locus of cluster members is defined by two versions of the empirical ZAMS , and a 2.5~Myr isochrone. The 2.5~Myr isochrone matches the cluster age estimated from the low--mass cluster members as well as the position of σ Ori C. The triangles mark the positions of σ Ori Aa, σ Ori Ab, σ Ori~B, and σ Ori C.

Hipparcos Distances to Ori OB1

σ Ori 350 (+120 -90) pc
Ori OB1b: 473 ± 40 pc (de Zeeuw et al 1999)
Ori OB1b+c: 443 ± 16 pc (Hernandez et al 2005)

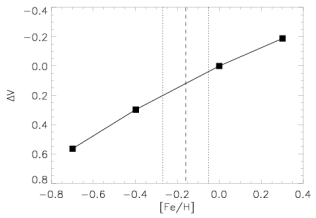


Yes, σ Ori A is a double-lined spectroscopic binary. These spectra were obtained with the SMARTS 1.5m telescope Sept 22-Oct 1 2008, as the system passed through periastron. The period is about 143 days. The wavelength scale is offset.

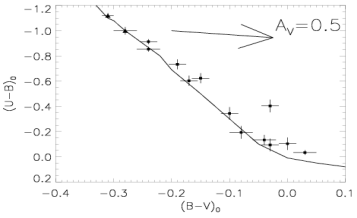
Metallicity

At a given mass, metal-rich stars are:
•fainter
•have larger radii
•lower Teff
This shifts the ZAMS and affects the deduced distance

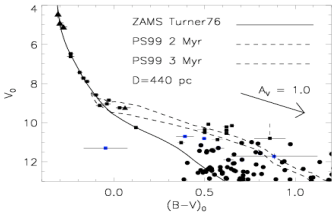
The [Fe/H] = -0.16±0.11 (Cunha et al. 1999)



The effect of [Fe/H] on V, near V=-0.2. The net is to make the ZAMS fainter by 0.04 - 0.2 mag



The color-color diagram for the upper main sequence



Can you find the likely PMS members?

Conclusions

The distance to the σ Ori cluster is 420±30 pc (440 pc at solar metallicity).

The age of the σ Ori cluster is about 2.5 Myr, not 5 Myr.

References

Sherry, W.S, et al. 2008 AJ, 135, 1616