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The Lambda Orionis association

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Summary. The λ Orionis association has the photometric properties of a typical young cluster with an age of about 4×10^6 yr. Its distance is 400 ± 40 pc. Attention is drawn to the lack of a dense molecular cloud and associated infrared sources in this young grouping.

1 Introduction

The Orion association, Orion OB1, is defined by Blaauw (1964) to lie between $199° < l < 210°$. To the north of this area lies the λ Orionis association, first recognized by Ptolemy (144) who described his object number 734 as 'the mistiness in Orion's head', and studied with the telescope by Galilei (1610) who counted 21 stars therein. It subsequently appeared in the catalogue of Collinder (1931). It contains one O-type star, λ Ori itself, and a dozen B-type stars. λ Ori excites an H II region which is ionization bounded, and relatively spherically symmetric and uniform; in short a theoretician's Strömgren sphere. The H II region shows evidence of a density increase at its boundary with the surrounding H I, whose density peaks just outside the H II region (Wade 1957), coincident with a ring of dark absorption clouds, including Barnard 30. Wade (1957) suggested that the H II region was young and still in its expansion stage, compressing the cold interstellar medium surrounding it. In spite of its being the first recognized stellar association, previous study of the association has been sparse, due no doubt to the lure of the brighter lights of the Orion OB1 association to its south.

This paper is the first in a planned series which will attempt to define the region's observational parameters starting with its associated stars.

2 Photometry of the association

We have photometered three samples of stars from the area:

(i) The first sample of stars was drawn from the area within a half degree radius of λ Ori itself. A virtually complete sample drawn from the Henry Draper Catalogue was subjected to infrared photometry at 1.6 and 2.2 micron (*H* and *K*) with the Mt Wilson 2.5-m and Izaña 1.5-m telescopes, in the course of which the A-type star HDE 245185 with infrared excess

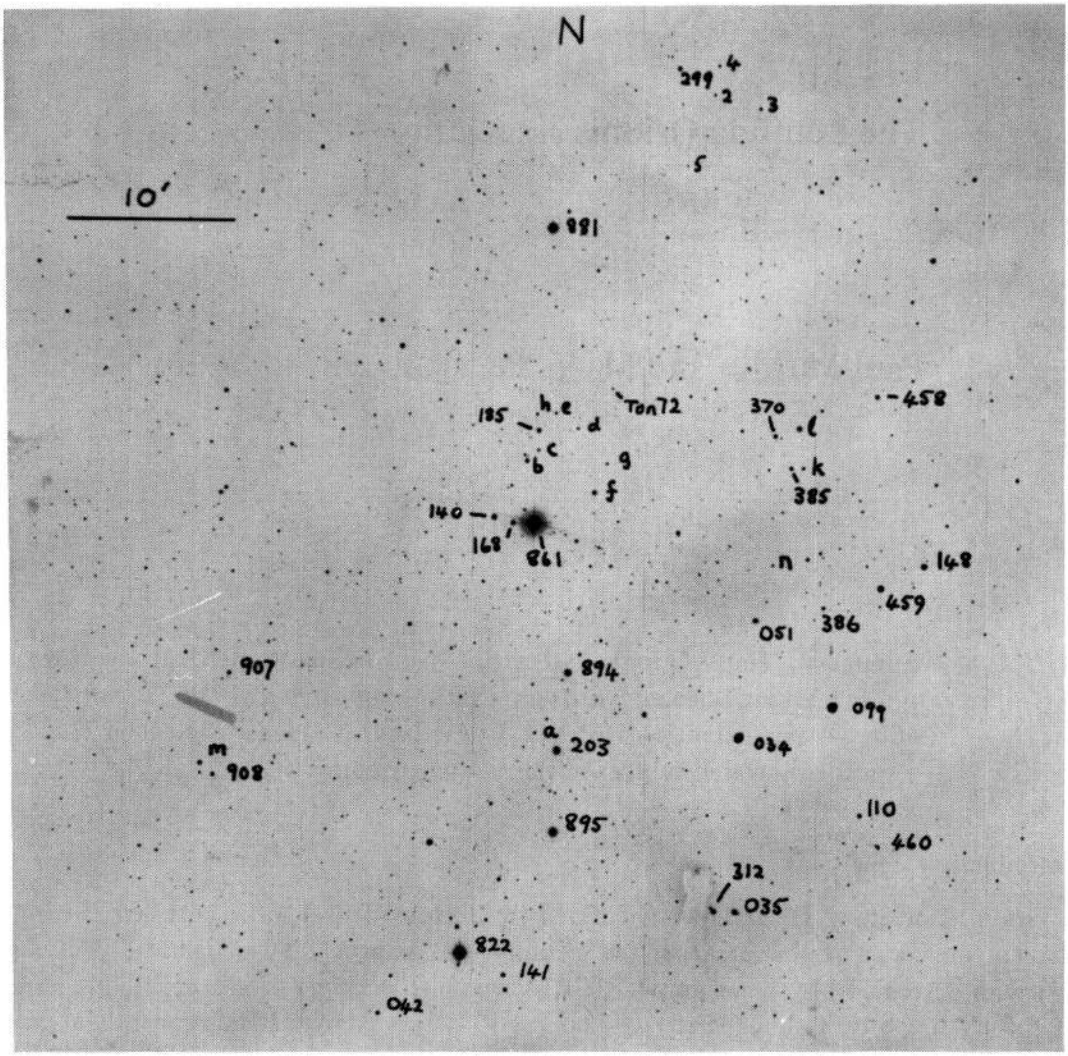

Plate 1. (a) Finding chart of stars near λ Orionis. (b) Finding chart of stars near Barnard 30. Stars are generally to the left of their labels, except where pointers indicate otherwise. HD stars are labelled with last three digits of their number.

was discovered (Penston, Allen & Lloyd 1976). This sample was subjected to *UBV* photometry with the 60-cm Siding Spring Observatory telescope as was a further group of a dozen fainter stars.

(ii) A second small sample of stars was taken from within a half degree radius of HD 36104, 2½° to the north-west (NW) of λ Ori, on the edge of the dark cloud Barnard 30. *UBV* photometry of these was made.

(iii) Seven emission line stars in the vicinity of λ and of HD 36104 were photometered in the *UBV* bands with the 3.9-m Anglo-Australian telescope. The stars were chosen from the lists of Joy (1949), Haro, Iriarte & Chavira (1953) and Manova (1968).

The stars are identified in Plate 1. The data are listed in Table 1. (The data on HD 36822 and HD 36861 are from Iriarte *et al.* (1965), being worryingly bright for pulse counting photometry with the 60-cm telescope. The close companion to λ Ori A, λ Ori B = HD 36862, was photometered on a night of good seeing when it could be separated from A, and the published *UBV* data for the pair have been corrected for the contribution of the faint companion.)

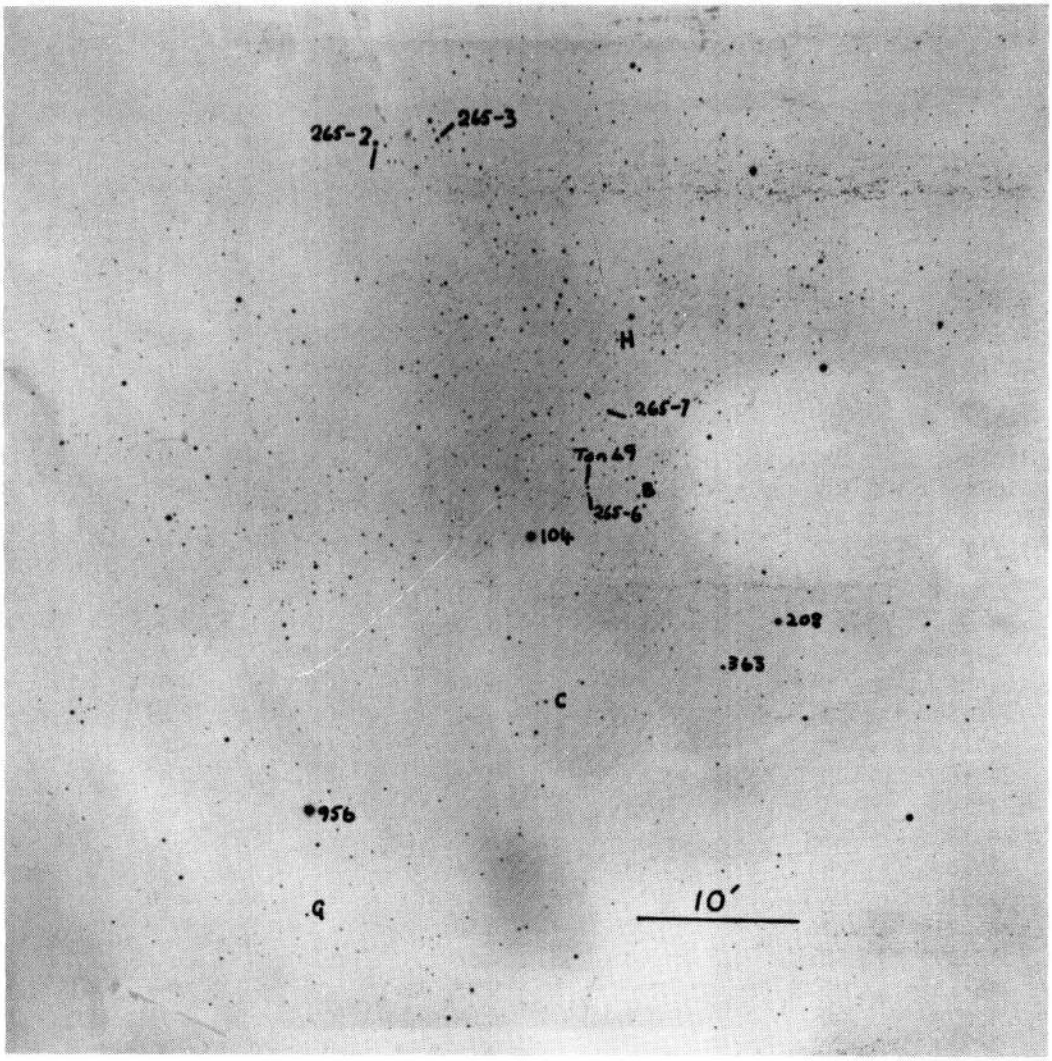

Plate 1(b).

3 Infrared H–R diagram

In Fig. 1 we plot a Herzsprung–Russell diagram of K magnitude versus HD spectral type for the 26 stars of sample (i) for which we have data. This version of the H–R diagram is essentially independent of interstellar absorption. We used this diagram to fit the zero-age main sequence (ZAMS) defined by Johnson (1964) to the lower envelope of the observed points and derived a distance modulus for the association of $m - M = 8.0 \pm 0.2$ mag, corresponding to a distance of 400 ± 40 pc. The association therefore lies essentially at the same distance as the association Ori OB1, whose distance modulus is $m - M = 8.0 \pm 0.1$ (Penston, Hunter & O'Neill 1975).

4 Colour–colour diagram

The $U–B$, $B–V$ colour–colour diagram of stars in all samples is shown in Fig. 2 with the locus of unreddened main sequence stars (Johnson 1964) and the standard reddening trajectory with slope 0.72. The stars are on the whole little reddened, with mean value of $E_{B-V} \sim 0.16$.

Table 1. Photometric data.

(i) *Stars near* λ

Name	Sp	*V*	*U–B*	*B–V*	*K*	*H–K*
HD 36822	B0 III	4.42	−0.97	−0.15	4.81	−0.09
36861	O8 III	3.54	−1.01	−0.21	3.91	−0.01
36862	B0 V	5.61	−0.77	0.04		
36881	B8 III	5.60	−0.12	0.18		
36894	B9	8.78	−0.27	−0.05	8.1	−0.16
36895	B2 V	6.73	−0.70	−0.12	6.99	0.06
36913	F8	8.31	0.00	0.06		
37034	A0	9.33	−0.14	0.04	9.2	0.0
37035	B9	8.64	−0.48	−0.02		
37051	B9	9.07	−0.16	0.04	9.0	0.07
37099	K0	8.56	0.73	1.01	6.32	0.10
37110	A0	8.97	−0.28	0.00		
37148	G0	8.46	0.11	0.61	7.07	−0.06
HDE 244907	F8	10.38	0.04	0.48		
244908	A2	10.13	0.95	1.23	9.3	0.36
244928	F8	10.84	0.06	0.48	9.4	0.0
245042	G0	10.51	0.06	0.60	8.8	0.2
245140	B9	9.27	−0.25	0.11	8.84	0.03
245141	A0	–	–	–	9.5	0.16
245168	B9	9.65	−0.05	0.12	9.49	0.08
245185	A5	9.93	−0.02	0.14	8.28	0.60
245186	A3	–	–	–	10.0	−0.1
245203	B8	7.48	−0.64	−0.03	7.65	−0.05
245252	K0	10.17	0.87	1.24	7.10	0.15
245275	A7	10.32	0.10	0.27	9.70	0.20
245299	F8	9.68	0.06	0.50		
245312	K5	10.00	0.96	1.24		
245370	B8	10.19	0.08	0.49	8.7	0.2
245385	A0	10.40	0.14	0.29	9.5	0.0
245386	A2	10.87	0.24	0.38	9.4	0.3
245458	K2	10.19	0.75	1.13	7.60	0.01
245459	K0	8.43	0.82	1.18	5.62	0.11
245460	K7	9.64	0.85	1.08		
a		12.77	0.22	0.87		
b		10.61	0.62	1.07		
c		12.16	0.09	0.67		
d		12.63	0.92	1.26		
e		12.45	0.17	0.75		
f*		{10.44	0.85	1.30		
		{11.76	0.23	0.84		
g		12.78	0.78	1.20		
h		12.05	0.21	0.44		
k		11.77	0.56	1.00		
l		9.79	1.69	1.64		
m		10.47	0.18	0.27		
n		12.51	0.24	0.77		
913/1		12.03	1.07	1.29		
299/2		12.47	0.31:	0.80		
299/3		11.09	0.10	0.33		
299/4		12.48	0.30	0.78		
299/5		13.96	0.16	0.78		

* Although *f* is clearly variable and near the T Tauri stars in a colour–colour diagram, a spectrum made by D. A. Allen with the AAT shows a late-type continuum without emission lines.

Table 1 – *continued*

(ii) *Stars near Barnard 30*

Name	Sp	V	$U-B$	$B-V$
HD 35956	F8	6.75	0.07	0.58
36104	B8	7.00	−0.50	−0.11
36208	F2	8.74	0.05	0.33
HDE 244363	G0	10.68	0.11	0.53
B		12.43	0.34	0.53
C		12.70	0.20	0.74
G		12.59	0.17	0.72
H		13.70	0.31	0.66
(iii) *T Tauri stars near* λ				
Ma 2	eα	16.31	0.31	1.50
Ton 72	eα	{14.05	1.29	1.38
		{13.88	0.58	1.26
(iv) *T Tauri stars near Barnard 30*				
MHα 265-2	dK3e}	10.04	0.51	1.16
HDE 244138	K0 }			
MHα 265-3	dK3e	12.06	0.46	1.26
MHα 265-6	dK3e	13.68	0.27	1.28
MHα 265-7	eα	14.70	0.19	1.47
Ton 49	eα	13.41	0.96	1.22

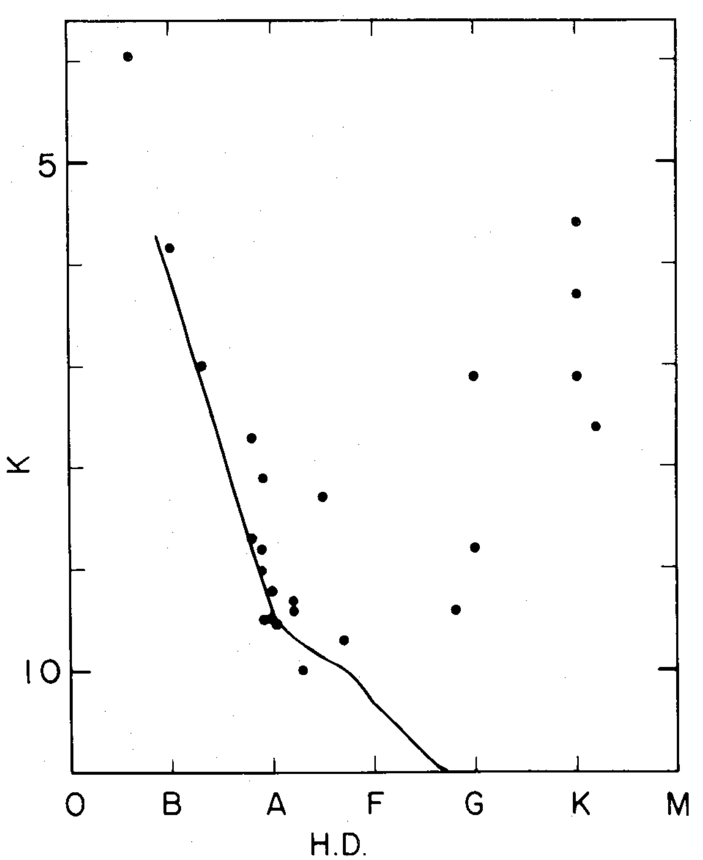

Figure 1. Infrared Hertzsprung–Russell diagram of the λ Ori association. Spectral types are from the HD. The ZAMS with distance modulus 8.0 is shown.

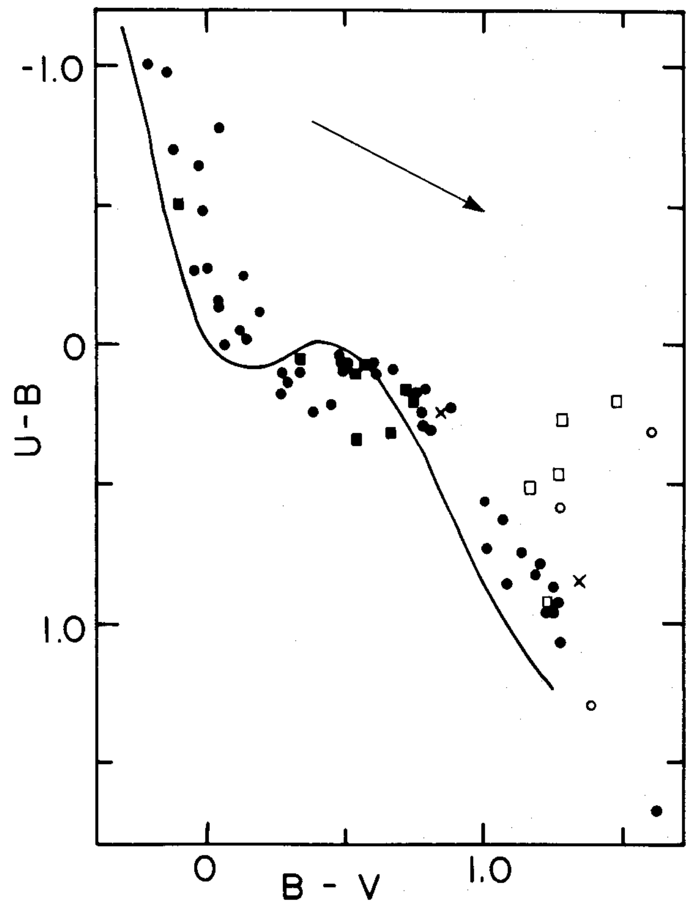

Figure 2. Colour–colour diagram of the λ Ori association. Open symbols are emission-line stars. Circles represent stars near λ Ori, squares represent stars near Barnard 30. The main sequence is shown, and the standard reddening trajectory with slope 0.72. x = variable star f.

The emission line stars (open symbols) show an ultraviolet excess typical of T Tauri stars. The excess and magnitude of Ton 72 is variable, judging by two sets of observations taken 1975 December 17 and 1977 February 25.

5 Colour–magnitude diagram

The colour–magnitude diagram, V as a function of $B-V$, is shown in Fig. 3, with the ZAMS from Johnson (1964) shifted to a distance modulus of 8.0. The bright, blue stars de-redden to the tips of the arrows shown and confirm the distance modulus by their good fit to the ZAMS.

The colour–magnitude diagram is typical of a young cluster or association. We can estimate the age of the association both from the advanced evolutionary state of the more massive stars and the pre-main-sequence position of the contracting T Tauri stars.

The three intrinsically brightest stars are all evolved, luminosity class III stars. λ Ori A itself at $M_{bol} = -8.2$, $\log T_e = 4.541$ (Snow & Morton 1976) lies close to the evolutionary track of a $30 M_\odot$ star when aged 3×10^6 yr, as computed by Simpson (1971), and when aged 2×10^6 yr, as computed by Chiosi & Summa (1970).

The absolute magnitude of the turn-off of the massive stars from the ZAMS is well defined as it comes between HD 36822 (B0 III) and HD 36862 (B0 V) at $M_V = -3.7 \pm 0.4$. To interpret this we have calculated the calibration of main-sequence turn-off against age for

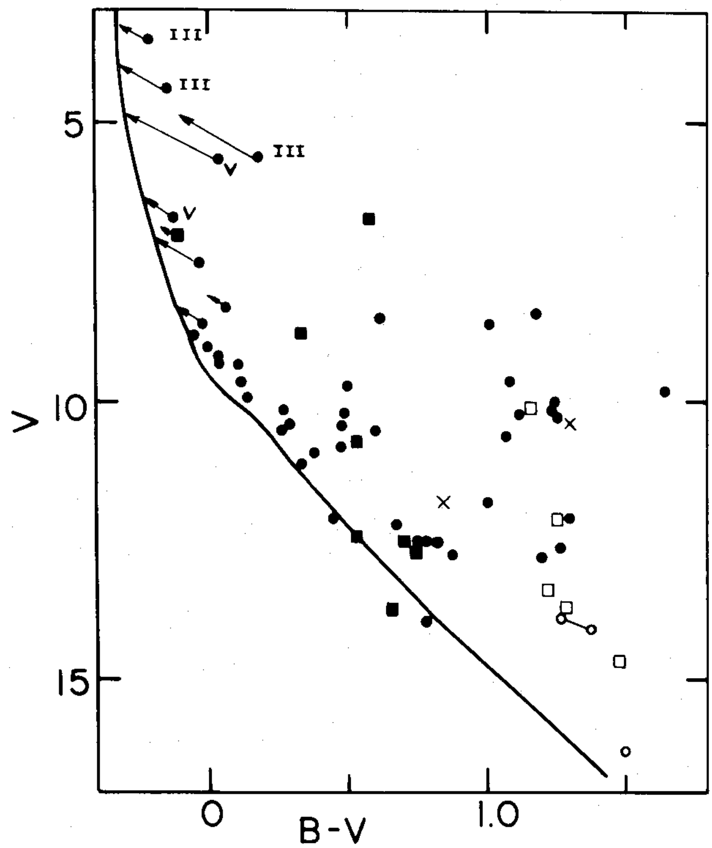

Figure 3. Colour–magnitude diagram of the λ Ori association. Open symbols are emission-line stars. The bright, blue stars de-redden to the tips of the arrows shown, and lie near the ZAMS. The area redward of $B-V = 0.5$ is presumably contaminated by field stars, but the emission-line stars, which are mostly associated with Barnard 30, clearly interacting with the λ Ori H II region, do lie above the main sequence.

open clusters. The table on p. 204 of Allen (1973) suggests that at the blue end of the main sequence a star remains of luminosity class V from its arrival on the ZAMS until it moves to a point 0.8–1.2 mag above the ZAMS, when it becomes recognizable as a class III. Using this operational definition of the luminosity of the main-sequence turn-off, we have calculated the age of evolving stars at this point from the work of Stothers (1966), Stothers & Chin (1968), Iben (1966) and Simpson (1971). For stars of $30 M_\odot$ and less ($M_V > -5$) there is no significant difference between our calibration of turn-off age and luminosity and that of Sandage (1957), which is based on powerful general arguments (Lang 1974, p. 511). From this argument, the evolutionary age of the massive stars in the λ Ori association is $(6 \pm 1) \times 10^6$ yr.

The emission-line stars all lie above the ZAMS by a magnitude or more. The median emission-line star of this small sample is at $M_V \sim 5.5$, $B-V \sim 1.2$ and lies near the track of a contracting star of $1.0 M_\odot$ at an age of 2×10^6 yr, after Iben's (1965) evolutionary tracks in the theoretical H–R diagram have been transformed to the (M_V, ($B-V$)) plane by using the bolometric corrections and temperature calibrations appropriate to normal stars given by Allen (1973).

6 Conclusion

Taken at face value, the figures given above suggest that the youngest objects in the λ Ori association are the T Tauri stars associated with Barnard 30, the next youngest object is λ Ori itself and the remainder of the association is older. While acknowledging the uncertainties in the bolometric corrections, the differences between the evolution of a $30 M_\odot$ star and stars of $15 M_\odot$ and less, and all the attendant pitfalls, we point out that the ages of the stars in the association conform to the following scenario. (i) λ Ori was the last star in a first wave of star-formation, perhaps because it inhibited further star formation, (ii) it caused the H II region it illuminated to expand, (iii) the resulting compression of the dark clouds outside has caused a second wave of star formation, namely the formation of the T Tauri stars.

Be this as it may, both bright and faint ends of the main sequence confirm the youth of the association and it remains puzzling why the λ Orionis association shows none of the other phenomena commonly associated with clusters with ages of a few million years or less. In addition to the lack of bright stars with infrared excesses, save for HDE 245185, the absence of high obscuration, molecular emission and infrared emission from dust clouds all distinguish this region from other young clusters like the Orion cluster, NGC 2264, M17 etc. Thus the λ Ori grouping is important in providing a counter example to the growing impression that star formation regions are always accompanied by dense and extensive molecular clouds.

It also suggests that infrared stars are related more to the existence of dust around a cluster, rather than to the age of the stars alone. This favours the notion that the heated dust cloud providing the infrared emission around young stars is formed by accretion and not by condensation of grains in a stellar wind. However, caution is urged here until further observations show a deficiency of infrared stars among fainter stars near λ Ori and outside the area surveyed. Further observations on this point are plainly desirable.

λ Ori has a much less dramatic appearance than the more familiar star formation regions which are marked by spectacular bright and dark nebulosities. Thus it is likely that other young groupings like it exist but have attracted less observational attention. It would be important to discover and study them to answer questions related to the process of star formation. Notably we need to know if λ Ori is an example of a different mode of star formation not involving dense interstellar clouds or whether it is simply a case in which the progenitor molecular cloud was exhausted within the last one or two million years.

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