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AN INFRARED SURVEY OF RW AURIGAE STARS

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SUMMARY

An infrared photometric survey of 89 RW Aur type variables in both hemispheres has been made. *JHKL* magnitudes and colours are listed. The RW Aur variables include a small number of highly reddened late-type stars. All T Tauri and hot Orion population stars show infrared excesses and the infrared properties mark certain field stars as being young. The greatest infrared excesses are found for A and F stars while young variable B stars usually show no excesses. The location of the RW Aur stars in the two-colour *H–K*, *K–L* diagram favour dust re-radiation over free-free emission as the mechanism responsible for the infrared excess. A weak correlation of *H–K* with emission class links the occurrence of circumstellar dust and gas shells.

INTRODUCTION

A number of years ago Mendoza (1968) discovered that T Tauri stars show an infrared excess. Since then it has become clear that infrared emission is often a sign of youth even among stars of earlier types. T Tauri stars themselves are distinguished by a spectroscopic criterion (Herbig 1962). There are many variable stars, now classified as types In and Is in the third edition of the *General Catalogue of Variable Stars* (Kukarkin *et al.* 1969, hereafter called GCVS, 3), which show similar forms of optical variability. They include in addition to the T Tauri stars and other late-type examples, some earlier members including those called variously, ' hot members of the Orion population ' by Herbig & Rao (1972), ' Ae and Be stars associated with nebulosity ' by Strom *et al.* (1972) and ' Z CMa stars ' by Allen (1973a). They also include some cases where the variables do not appear to lie near or in either dark or bright nebulosities. We shall refer to all these stars by their old name of RW Aurigae variables.

We have conducted an infrared survey at wavelengths between 1·2 and 3·4 μ of these stars in both hemispheres to see if Mendoza's results can be extended to all RW Aurigae stars regardless of their spectroscopic characteristics, to the hotter stars, and to those in the general field away from obvious star formation regions. Because of the slightly vague definition of RW Aur stars we expected that the presence or absence of the infrared excess might provide an extra means of classification.

OBSERVATIONS

Observations in the Northern Hemisphere were made on the 60-in. and 100-in. reflectors on Mount Wilson of the Hale Observatories during 1970–71 using the photometer described by Becklin & Neugebauer (1968).

Observations in the Southern Hemisphere started in 1972 and have just been

TABLE I

JHKL photometry of RW Aur type stars

Name	Date	Telescope (inches)	*J*	*H*	*K*	*L*
BM And	71 Sept. 22	100		9·04±0·07	8·41±0·05	7·6±0·2
V347 Aql	71 Sept. 22	100		0·74±0·06	0·30±0·05	−0·15±0·06
V733 Aql	70 July 15	60		8·0±0·2	7·96±0·06	
	70 Sept. 17	60		8·22±0·11	8·17±0·10	
V925 Aql	70 July 14	60		5·72±0·06	5·59±0·05	
	70 July 15	60		5·75±0·06	5·59±0·05	5·6±0·2
	70 Sept. 17	60		5·86±0·05	5·68±0·05	
RW Aur	70 Feb. 12	60		7·25±0·07	6·58±0·05	
SU Aur	70 Feb. 12	60		6·55±0·06	6·08±0·13	>5·2
AB Aur	70 Feb. 12	60		5·09±0·06	4·30±0·05	3·35±0·10
HH Aur	71 Feb. 13	60		5·48±0·05	5·35±0·05	5·3±0·2
	71 Mar. 7	60		5·55±0·06	5·38±0·05	5·06±0·10
DI Car	72 Jan. 30	18		8·3±0·4	>7·8	
	73 Jan. 27	40	7·70±0·08	7·29±0·08	7·07±0·10	5·7±0·3
VX Cas	70 July 14	60		9·2±0·2	8·53±0·11	
V682 Cen	73 Jan. 23	40		10·1±0·3	9·3±0·2	>6·9
SV Cep	70 July 14	60		8·62±0·11	7·78±0·06	
DI Cep	71 Sept. 22	100		8·16±0·06	7·46±0·05	6·39±0·14
GL Cep	71 Sept. 22	100		3·50±0·06	3·18±0·05	2·80±0·06
T Cha	72 Feb. 8	18		>8·0	6·60±0·11	
	73 Jan. 24	40	8·30±0·07	7·37±0·11	6·63±0·06	>5·4
ST Cha	72 Feb. 10	18			>7·3	
	73 Jan. 24	40			>9·1	
SZ Cha	72 Feb. 9	18		7·9±0·3	7·7±0·2	
	72 Feb. 10	18			7·0±0·2	
	73 Jan. 22	40			>7·8	>6·9
	73 Jan. 24	40	9·1±0·2	8·4±0·2	7·70±0·08	>6·0
TW Cha	72 Feb. 10	18		>7·5	>7·5	
	73 Jan. 24	40		8·9±0·4	>8·2	>6·6
VW Cha	72 Feb. 10	18		>7·3	6·8±0·2	
	73 Jan. 24	40	8·75±0·10	7·80±0·11	6·96±0·07	>5·6
Z CMa	71 Feb. 13	60		4·59±0·05	3·51±0·04	1·90±0·06
	71 Mar. 7	60		4·60±0·05	3·53±0·05	1·96±0·05
	72 Feb. 23	18	5·81±0·11	4·76±0·06	3·64±0·06	1·98±0·09
	72 Nov. 23	40	5·79±0·07	4·65±0·06	3·54±0·05	1·87±0·08
R CrA	72 June 27	74	7·22±0·07	5·07±0·06	3·43±0·05	1·78±0·05
S CrA	72 June 27	74	8·39±0·07	7·14±0·07	6·23±0·05	5·13±0·06
T CrA	72 June 27	74	8·90±0·07	7·52±0·07	6·34±0·05	5·01±0·06
TY CrA	72 June 27	74	7·36±0·07	6·83±0·07	6·57±0·05	6·10±0·07
V517 Cyg	71 Sept. 22	100		9·62±0·06	9·57±0·07	>7·4
V1331 Cyg	70 June 22	60		9·4±0·3	8·32±0·14	>5·7
=Lk Hα 120	70 Sept. 18	60		9·08±0·14	8·3±0·2	
	71 Sept. 21	100		9·19±0·10	8·35±0·10	7·10±0·13
RV Equ	70 June 21	60		6·77±0·06	6·62±0·05	
	70 Oct. 16	60		6·73±0·06	6·64±0·05	
GH Gem	72 Nov. 26	40			>9·7	
RU Lup	73 Jan. 27	40			9·30±0·07	
RY Lup	72 June 5	74	8·41±0·07	7·55±0·06	6·86±0·05	5·7±0·2
EX Lup	72 June 5	74	9·76±0·13	9·04±0·14	8·82±0·12	>8·7
ST Lyn	70 Feb. 12	60		9·4±0·2	9·7±0·2	
	71 Feb. 14	60		9·2±0·2	9·3±0·2	
R Mon	70 Feb. 12	60		7·48±0·09	5·67±0·05	3·87±0·10
	71 Mar. 7	60		7·38±0·06	5·46±0·05	3·13±0·05

TABLE I—*continued*

Name	Date	Telescope (inches)	*J*	*H*	*K*	*L*
R Mon	72 Feb. 23	18	>7.9	7.06±0.13	5.17±0.07	2.94±0.08
[*cont*]	72 Nov. 20	40	9.10±0.09	7.28±0.09	5.29±0.07	3.05±0.16
	72 Nov. 23	40	9.06±0.15	7.15±0.08	5.26±0.06	3.59±0.08
WZ Mon	72 Jan. 30	18			>7.4	
	72 Nov. 23	40	>10.4	>9.8	>9.3	>6.9
XY Mon	72 Jan. 30	18		4.48±0.07	4.20±0.07	3.7±0.2
	72 Nov. 23	40	5.43±0.07	4.42±0.06	4.07±0.05	3.74±0.08
DK Mon	72 Nov. 23	40	>9.7	>10.2	>10.1	
HH Mon	72 Feb. 23	18			>6.1	>5.0
	72 Nov. 17	40	8.42±0.08	8.08±0.08	8.05±0.10	>7.2
	72 Nov. 23	40	8.42±0.09	8.16±0.08	8.03±0.10	>7.0
KW Mon	72 Feb. 23	18			>7.4	
	72 Nov. 26	40			>10.0	
PZ Mon	71 Feb. 13	60		6.28±0.06	6.12±0.05	6.1±0.2
	71 Mar. 7	60		6.32±0.06	6.19±0.05	>6.5
IX Oph	73 May 3	40	8.29±0.10	7.73±0.11	7.50±0.10	7.2±0.3
V853 Oph	72 Sept. 10	74	9.17±0.10	8.40±0.07	7.92±0.06	7.6±0.2
V1121 Oph	70 April 21	60		7.32±0.08	6.80±0.05	>4.8
=AS209	70 Sept. 17	60		7.78±0.07	7.13±0.05	
T Ori	70 Sept. 18	60		7.51±0.07	6.53±0.06	5.17±0.12
	71 Jan. 30	100	>8.2	7.4±0.2	6.36±0.07	5.3±0.2
RY Ori	72 Nov. 17	40	9.54±0.15	8.92±0.13	8.50±0.13	>6.9
	72 Nov. 18	40	9.59±0.15	8.92±0.13	8.40±0.4	>7.2
UX Ori	71 Mar. 7	60		7.95±0.08	7.10±0.06	6.0±0.2
BF Ori	72 Nov. 18	40	9.19±0.09	8.55±0.07	7.98±0.06	6.6±0.3
BN Ori	71 Mar. 8	60		8.44±0.08	8.17±0.07	
CO Ori	71 Mar. 6	60		7.38±0.06	6.62±0.06	5.53±0.10
CY Ori	72 Feb. 23	18			>7.1	
	72 Nov. 22	40			>9.8	>6.3
FU Ori	71 Mar. 8	60		5.21±0.06	4.65±0.05	3.74±0.05
GW Ori	71 Mar. 7	60		6.62±0.07	5.83±0.05	4.8±0.2
HK Ori	72 Nov. 17	40	9.5±0.2	8.02±0.09	7.36±0.09	6.1±0.2
KX Ori	71 Mar. 7	60		7.36±0.07	7.43±0.05	>6.5
LP Ori	70 Oct. 16	60		7.54±0.07	7.33±0.08	
	71 Jan. 29	100	7.70±0.11	7.48±0.10	7.36±0.13	>5.9
LZ Ori	72 Dec. 12	40	8.11±0.10	7.85±0.11	7.4±0.2	>6.2
MX Ori	72 Nov. 18	40	8.29±0.07	7.63±0.07	7.00±0.06	6.6±0.3
NU Ori	71 Jan. 30	100	5.85±0.08	5.69±0.06	5.59±0.05	5.5±0.2
NV Ori	70 Sept. 19	60		8.16±0.09	7.58±0.06	>7.7
	71 Feb. 13	60				>6.7
V346 Ori	72 Nov. 17	40	9.6±0.2	8.6±0.3	8.2±0.2	6.8±0.3
V350 Ori	72 Nov. 20	40	>9.8	9.1±0.2	8.2±0.2	>6.8
V359 Ori	71 Mar. 7	60		7.36±0.07	7.43±0.05	
V361 Ori	70 Sept. 17	60		7.97±0.09	7.62±0.06	
	71 Feb. 13	60				>5.8
V372 Ori	71 Jan. 29	100	7.13±0.09	7.00±0.10	6.40±0.08	5.04±0.09
V380 Ori	72 Nov. 18	40	8.02±0.08	6.96±0.07	5.93±0.05	4.74±0.09
V451 Ori	72 Nov. 17	40			9.73±0.12	>6.6
V586 Ori	72 Nov. 18	40	8.92±0.07	8.31±0.09	7.66±0.06	6.7±0.3
X Per	71 Mar. 7	60		5.43±0.06	5.28±0.05	5.14±0.06
XY Per	70 Sept. 19	60		6.88±0.06	6.01±0.05	5.2±0.2
	71 Mar. 6	60		6.75±0.05	5.95±0.05	4.65±0.08
CF Per	71 Sept. 22	100		4.34±0.06	4.07±0.05	3.80±0.06
EO Per	71 Sept. 21	100		9.5±0.2	9.00±0.10	
	71 Sept. 22	100				>7.0

TABLE I—*continued*

Name	Date	Telescope (inches)	*J*	*H*	*K*	*L*
IP Per	71 Sept. 22	100		8·23±0·06	7·47±0·05	6·61±0·13
IS Per	71 Sept. 21	100		10·76±0·10	10·66±0·10	>7·6
	71 Sept. 22	100		10·56±0·13	10·25±0·12	
SY Phe	72 Jan. 30	18		8·5±0·3	>7·8	>3·7
	72 June 3	74	8·90±0·08	8·6±0·2	8·33±0·06	8·4±0·3
SZ Phe	72 Jan. 30	18		3·91±0·06	3·65±0·07	3·6±0·2
	72 June 3	74	4·78±0·07	3·84±0·06	3·56±0·05	3·38±0·05
TT Phe	72 June 26	74	8·02±0·07	7·37±0·06	7·17±0·05	7·20±0·09
TU Phe	72 Nov. 19	40	5·73±0·09	4·85±0·08	4·55±0·07	4·35±0·09
RZ Psc	71 Sept. 21	100		9·7±0·2	9·78±0·10	
FW Pup	72 Jan 30	18		5·07±0·06	4·64±0·07	4·6±0·2
	72 Nov. 23	40	5·98±0·07	5·04±0·06	4·65±0·05	4·32±0·08
AK Sco	72 Sept. 10	74	7·82±0·07	7·21±0·07	6·60±0·06	5·70±0·07
VV Ser	71 Sept. 21	100		7·29±0·06	6·12±0·05	4·74±0·09
BQ Ser	70 June 22	60		5·86±0·07	5·64±0·05	>5·7
	70 Sept. 17	60		6·04±0·06	5·82±0·05	5·7±0·3
V1921 Sgr	73 May 3	40			>9·5	
CQ Tau	71 Mar. 6	60		7·47±0·07	6·45±0·05	5·17±0·13
DF Tau	71 Mar. 7	60		7·29±0·07	6·64±0·05	5·8±0·2
WW Vul	70 Sept. 19	60		8·55±0·15	7·26±0·09	6·2±0·2
	70 Oct. 16	60		8·39±0·12	7·26±0·06	6·2±0·2
EP Vul	71 Sept. 22	100		1·41±0·06	1·02±0·05	0·55±0·06
−35°10525	73 Jan. 24	40	8·62±0·10	7·66±0·07	6·90±0·06	6·25±0·10
AS 205	70 Sept. 18	60		6·54±0·10	5·57±0·10	4·23±0·10
	71 Feb. 13	60		6·48±0·05	5·48±0·04	4·20±0·08
	72 Sept. 10	74	8·33±0·07	6·91±0·07	5·85±0·06	4·58±0·05
S-R 9	72 Sept. 10	74	8·35±0·07	7·57±0·07	7·01±0·06	6·42±0·06

completed. These used the photometer described by Glass (1973) attached to the 18-in. telescope in Cape Town and the 40-in. telescope at Sutherland both of the South African Astronomical Observatory and the 74-in. reflector at the Radcliffe Observatory, Pretoria.

The data were reduced to a photometric system based on the *JKL* standards of Johnson *et al.* (1966) as modified by the inclusion of the *H* magnitude and the establishment of adequate standards in the southern skies (Glass, in preparation).

In Table I we list a total of 134 observations of 89 stars either classified as being of types Is or In in GCVS, 3 or listed as T Tauri stars by Herbig (1962). A few stars are listed in Table I which were observed prior to the common availability of the former catalogue. While listed as RW Aur type in the second edition (Kukarkin *et al.* 1958) some are given as different types in GCVS, 3. Table I gives the name of the star, the date of observation, the telescope used and the *JHKL* magnitudes obtained, with their standard errors. Where only upper limits are given these are 3σ values.

In Table II we list the *J–H*, *H–K* and *K–L* colours derived from these magnitudes. We also tabulate the range of variation from GCVS, 3. The *V–K* and *B–K* colours and spectral type are obtained from our *K* magnitudes and the data listed by Herbig & Rao (1972) or, failing that, GCVS, 3. The light curve class and emission class are taken from Herbig & Rao adopting their notation. The final column notes if the stars are listed as T Tauri stars or hot population members by Herbig & Rao or are not certainly classified as RW Aur stars in GCVS, 3.

TABLE II

Colours and other properties of RW Aur type stars

Name	J–H	H–K	K–L	Max. (ΔV, ΔB)	V–K	B–K	Sp	Light curve	Emn. class	Notes
BM And		0·63	0·8:	2·2	3·9	5·1	F8: eα	−0·3	1	(1)
V347 Aql		0·44	0·45	1·6		12·0	M6			(2)
V733 Aql		0·05		0·9		2·7	F9Ib			(3)
V925 Aql		0·16	0·0:	1·2		5·1	K5			(4)
RW Aur		0·67		4·0	4·1	4·8	dG5?e	II 0·5 lc	5	(1)
SU Aur		0·47	<0·9	2·2	2·6	3·5	G2neIII	I	1	(1)
AB Aur		0·79	0·95	0·8	2·7	2·8	B9e+shell	I	2	(5)
HH Aur		0·15	0·32	1·5		4·4	G6IV			(4)
DI Car	0·41	0·22	1·8:	1·4		5·4	Pec			
VX Cas		0·7:		2·6	3·5		A0			
V682 Cen		0·8:	<2·4	0·8	3·0					(4)
SV Cep		0·84		2·0		3·3	A0			
DI Cep		0·70	1·07	2·6		4·7	dK3e	II	3	(1)
GL Cep		0·32	0·38	1·0		10·2				(2)
T Cha	0·93	0·54	<1·1	3·2		5·0	F5			
SZ Cha	0·7:	0·4:	<1·7	1·3		5·9				
VW Cha	0·95	0·84	<1·4	1·7		4·6	eα			
Z CMa	1·10	1·10	1·64	2·5	5·4	6·4	eq	II, III	1–2	(5)
R CrA	2·15	1·64	1·65	4·2	7·3	7·9	F0±pe	IV 1·5	2	(5)
S CrA	1·25	0·91	1·10	2·5	5·2	6·0	cont+e	IV 0·8	(4–5)	(1)
T CrA	1·38	1·18	1·33	2·8	5·4	6·2	F0eα		1	(5)
TY CrA	0·53	0·26	0·47	3·2	4·1	4·5	B9(e)	I	1 var?	(5)?
V517 Cyg		0·05	<1·8	0·9		3·4	A0–A5			
V1331 Cyg		0·84	1·2:	0·4	2·7	3·7	cont+eq		4	(1)?
RV Equ		0·12		0·7		2·7	K0			(4)
RY Lup	0·86	0·69	1·2:	3·4		4·4	G0eα V	I 0·6 s	1	(1)
EX Lup	0·7:	0·2:	<0·1	2·1		3·6	cont+e	III 2·4 s	2–3	(1)
ST Lyn		−0·2:		1·0		2·7	K0 III e			(3)

TABLE II—*continued*

Name	$J-H$	$H-K$	$K-L$	Max. (ΔV, ΔB)	$V-K$	$B-K$	Sp	Light curve	Emn. class	Notes
R Mon	1·86	1·90	2·05	3·0	6·3	6·9	A-Fpe	IV 2·5 l	2–3	(5)
XY Mon	1·01	0·31	0·33	1·2		9·8	\			(2)
HH Mon	0·30	0·08	<0·8	0·6	1·5		F5			(4)
PZ Mon		0·14	0·1:	0·7		4·2	K2Ve			(3)
IX Oph	0·56	0·23	0·3:	0·9		4·7	Fpe		2	
V853 Oph	0·77	0·48	0·3:	1·5		5·3	Ke		(3)	(1)
V1121 Oph		0·58	<2·0	0·5	4·5	5·7	cont + e		4u	(1)
T Ori	>0·8	0·98	1·26	4·2	3·6	4·0	A3:eα + shell	I	1	(5) (6)
RY Ori	0·6:	0·4:	<1·2	3·1		4·0	F6e			
UX Ori		0·85	1·1:	4·1		3·7	A3e			
BF Ori	0·64	0·57	1·4:	3·6	2·7	3·1	A-Fpeα	I	1	(5)
BN Ori		0·27		4·7		3·2	Pec	zero		
CO Ori		0·76	1·09	>2·7	4·0	5·1	Gpeα	IV ↓	1	(1)?
FU Ori		0·56	0·91	6·8	4·4	5·8	F2:p I–II	Pec 2·0 sc	1–2	(5)
GW Ori		0·79	1·0:	1·4	3·9	4·9	dK3e	IIs zero	(2)	(1)
HK Ori	1·5:	0·66	1·3:	2·2	4·3	4·9	A4ep	IV? ↓	2	(5)
KX Ori		−0·07	<0·9	1·2		0·1	B3 V	3·0 s		
LP Ori	0·12	0·16	<1·5	1·4		0·2	B1·5 Vp			(6)
LZ Ori	0·26	0·4:	<1·2	0·8		3·3	A0:			
MX Ori	0·66	0·63	0·4:	1·4		4·0	F8–G0 III–IV, V			
NU Ori	0·16	0·10	0·1:	1·3	1·6		B1 V			(6)
NV Ori		0·58	< −0·2	1·8	2·8		F4–8 III, IV			(6)
V346 Ori	1·0:	0·4:	1·4:	1·9		2·8	A5 III			
V350 Ori	>0·7	0·9:	<1·4	2·1		3·2	A0			
V359 Ori		−0·07		2·9		0·9	B3Vp			
V361 Ori		0·35	<1·8	1·7		1·0	B4V			(6)
V372 Ori	0·13	0·60	1·36	1·3		1·6	A0V			(6)
V380 Ori	1·06	1·03	1·19	0·7	4·5	5·0	A1:e		4–5	(1)
V586 Ori	0·61	0·65	1·0:	1·5		2·7	A0			
X Per		0·15	0·14	0·6	1·0	1·3	Opev			
XY Per		0·84	1·35	1·4		3·9	B6 + A2 II			

Table II—*continued*

Name	*J–H*	*H–K*	*K–L*	Max. (ΔV, ΔB)	*V–K*	*B–K*	Sp	Light curve	Emn. class	Notes
CF Per		0·27	0·27	0·7		8·7	M6			(2)
EO Per		0·5:	<2·0	0·9		3·8	cBoeα			
IP Per		0·76	0·86	1·0		3·0	A3			
IS Per		0·20	<2·9	1·1		1·8				
SY Phe	0·3:	0·3:	−0·1:	0·4	1·0		F8			
SZ Phe	0·84	0·27	0·18	0·5	6·4		K5			(2)
TT Phe	0·65	0·20	−0·03	0·6	3·4					
TU Phe	0·88	0·30	0·20	1·5		7·6				(2)
RZ Psc		−0·1:		2·2		2·6	K0 IV			
FW Pup	0·94	0·41	0·31	2·0		8·6				(2)
AK Sco	0·61	0·61	0·90	3·0		5·6	F5 V	II	1	(1)
VV Ser		1·17	1·38	>3·0		5·4	A2eβ		2	(5)?
BQ Ser		0·22	0·1:	0·6	3·9		F5 III			(3)
CQ Tau		1·02	1·28	1·8		3·3	F2 IVe			
DF Tau		0·65	0·8:	4·7	5·1	6·0	dM0e	II s	4u	(1) (7)
WW Vul		1·21	1·1:	1·7		4·5	A3e			
EP Vul		0·39	0·47	2·8		10·4				(2)
−35°10525	0·96	0·76	0·65	0·0	3·1		cont +e		2–3	(1)
AS 205	1·32	1·01	1·30	0·0	6·4	7·6	cont +e		4	(1)
S-R 9	0·78	0·56	0·59	0·0		5·5	K2–5e		2	(1)

Notes to Table II

(1) T Tauri star.
(2) Highly reddened late-type star?
(3) Not classified as RW Aur in GCVS, 3.
(4) Classified as *possible* RW Aur type in GCVS, 3.
(5) Hot member of Orion population.
(6) Data already published by Penston (1973).
(7) It was noted after the observation has been reduced that the star marked on the finding chart was not DF Tau but star c of Badalyan (1962). It is possible, however, that relying on colour or position the variable was in fact observed.

Our survey is fairly complete among the RW Aur stars in GCVS, 3 to magnitude 12 at maximum except in Orion and Taurus, only eight stars being unobserved outside these constellations. Within Taurus and Orion, we have missed nine stars brighter than magnitude 11 at maximum but two of these were observed by Mendoza (1968). A few stars for which data were obtained are fainter than magnitude 12 at maximum. A number of stars listed by Herbig & Rao are not given as RW Aur variables in GCVS, 3 and there are several bright stars in their list that we have not measured.

CLASSIFICATION

Some of the stars whose colours are given in Table II have $B-K>7$ mag without at the same time showing large $H-K$ excesses. Their colours are more typical of highly reddened or very cool stars than they are of dust re-emission shells. Eight stars showing these properties are clearly distinguished in the $B-K$, $H-K$ diagram, Fig. 1, from the other stars in our programme and are listed in Table III with their spectral types. These are taken from GCVS, 3 (none of the stars are listed by Herbig & Rao 1972) except for FW Pup and EP Vul which are also of type M (M. V. & M. J. Penston, unpublished). These stars have colours and spectral types which clearly distinguish them from other RW Aur variables. They

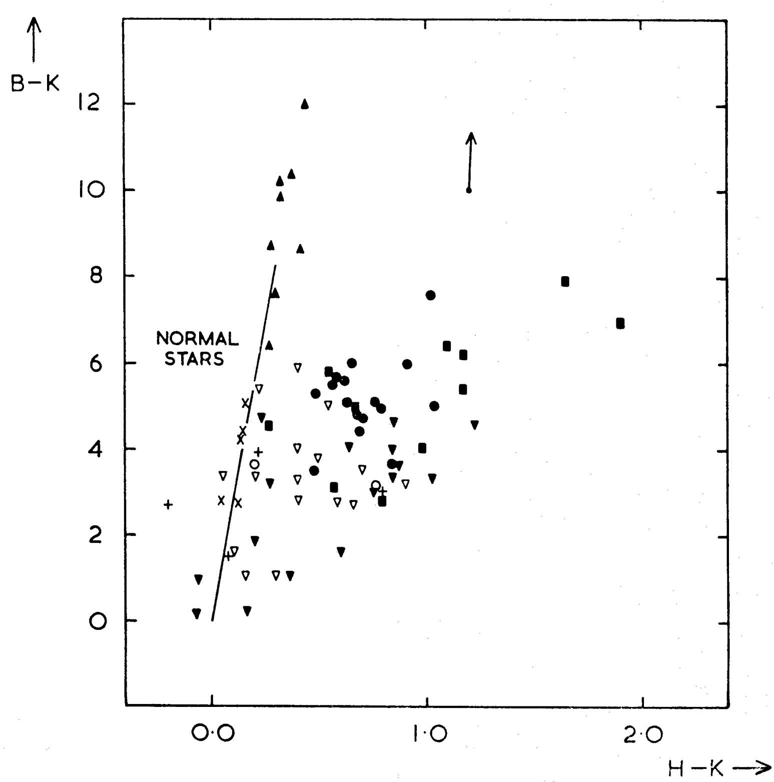

FIG. 1. *The B–K, H–K colour–colour diagram for the stars observed by us. Circles, squares, upward-pointing triangles, downward-pointing triangles and crosses represent T Tauri stars, hot population members, highly reddened stars, other RW Aurigae stars and stars not certainly classified RW Aurigae in GCVS, 3 respectively. Filled symbols and diagonal crosses are more accurate values, open symbols and pluses are less so. The line represents the locus of normal stars and the arrow the direction of the reddening vector. The highly reddened stars are clearly distinguished as such by their position in this diagram. In a few cases (ten) B–K was unavailable and V–K plotted.*

TABLE III

Highly reddened late-type stars(?) classified as RW Aur in GCVS, 3

V347 Aql	(M6)	CF Per	(M6)	TU Phe	
GL Cep	(M6·5)	SZ Phe	(K5)	FW Pup	(M)
XY Mon				EP Vul	(M)

resemble typical stars in the Caltech 2 μ catalogue (see Wisniewski *et al.* 1967) which in fact includes V347 Aql and EP Vul. Whether these stars are simply misclassified red variables or belong to a hitherto unsuspected class of variables showing unusually rapid fluctuations remains to be determined by further observations.

Further investigation of Table II shows that all but one of the stars which are listed as T Tauri type or hot members of the Orion population by Herbig & Rao (1972) and which we observed have large H–K colours ($>0{\cdot}4$ mag). The single exception is the B-type star TY CrA, a member of the R CrA association. We deduce that infrared excess is indeed a property of *all* stars of these types which are later than A0. In addition, we find 17 stars not listed by Herbig & Rao to have infrared excesses, and give them in Table IV. The majority of these are associated with nebulosity (type In) and hence there is good evidence that they too are young objects. Of those with infrared emission, that are not so associated (type Is) most lie in a narrow range of spectral type from A0 to A3. If these stars too are young, how they come to lie away from recognized star formation regions is a matter demanding deeper study.

It has been noted elsewhere (Allen & Penston 1973) that among stars in young clusters only those later than about A0 show excess at 2 μ. We find two stars with such excesses earlier than B9 but one, XY Per, is a double star with one component later than this limit, while the other, EO Per, has a relatively inaccurate H–K colour. On the other hand we observed several B stars among the In types, which should be young if their association with nebulosity is real, and find that they do indeed have H–$K<0{\cdot}4$ mag. Examples are TY CrA, KX Ori and V359 Ori. Some of these stars show small excesses attributable to free-free emission but no evidence for reradiating dust.

Amongst the stars classified RW Aur in GCVS, 3 are ten which neither show infrared excesses nor are associated with any nebulosity. They are listed in Table V. Since they show neither of these two properties of young stars, it is

TABLE IV

Infrared emitters not listed by Herbig & Rao (1972)

DI Car?	(Ins)	UX Ori	(Isa)	V586 Ori	(Ina)
VX Cas	(Is)	MX Ori	(Inb)	XY Per	(In)
V682 Cen	(Is?)	NV Ori	(Inbs)	EO Per?	(Isa)
SV Cep	(Is)	V350 Ori	(Inas)	IP Per	(Is)
T Cha	(Ins)	V372 Ori	(Ina)	CQ Tau	(Ins)
VW Cha	(Ins)			WW Vul	(Isa)

TABLE V

Possible non-RW Aur stars

V925 Aql	HH Mon	TT Phe
HH Aur	IS Per	TU Phe
RV Equ	SY Phe	RZ Psc
	SZ Phe	

possible that they represent misclassifications by the observers of their light curves. The forms of their light curves should be checked. The group of four RW Aur stars in Phoenix all fall in this category.

Our results include an *HKL* observation of the peculiar O-type star X Per which is identified with the X-ray source 3U0352+30 (Brucato & Kristian 1972). This star is listed as type In in GCVS, 3, but surely is a different class of object. Our magnitudes when combined with *UBV* data show no infrared excess and are consistent with those of a normal O star with a visual absorption of ~1·5 mag.

DISCUSSION

In Fig. 2, a plot of *H–K* colour against spectral type, the above noted lack of infrared excesses amongst the B stars can be seen. It is notable too that the largest colours are found among the A and F stars—there are no cases with $H-K > 0{\cdot}8$ mag later than F2; this result may represent a continuation of the trend, noted among OBA stars by Allen & Penston (1973), for hotter stars to have cooler dust shells.

Figs 3 and 4 are infrared two-colour diagrams plotting *H–K* against *K–L* and *J–H* against *H–K* for our stars. In Fig. 3 the stars with substantial infrared excesses form a relatively narrow sequence just below the blackbody line. This side of the blackbody line is populated by combinations of the light from low temperature black bodies and stars (Allen 1973b). Most of the stars moreover lie above the free-free line and cannot therefore be combinations of cool optically thin free-free emission and starlight. Thus it seems unlikely that the infrared excesses in these stars are caused by this mechanism as was proposed for early-type stars by Dyck &

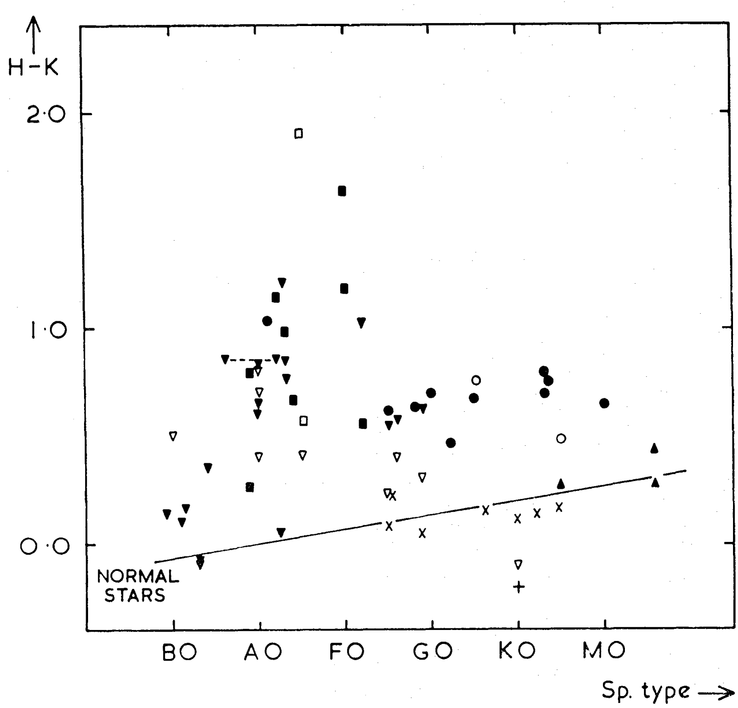

FIG. 2. *The H–K colour plotted against spectral type. Notation as in Fig. 1. The solid line represents the locus for normal stars. The two points joined by a dotted line represent the spectral type of both components of XY Per. It is notable that the reddest stars are of spectral types A and F.*

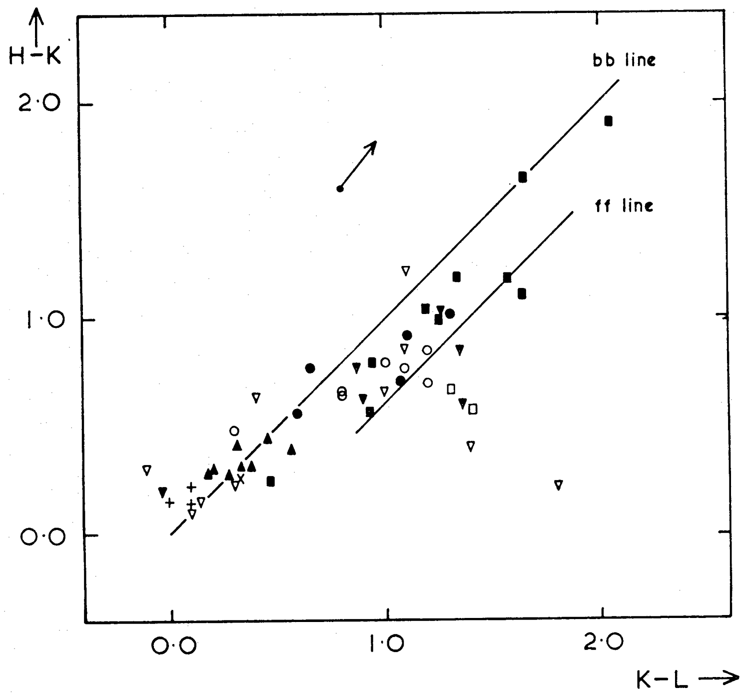

FIG. 3. *The H–K, K–L two-colour diagram. Notation as in Fig.* 1. *The solid lines are the blackbody and free-free lines and the arrow a reddening vector.*

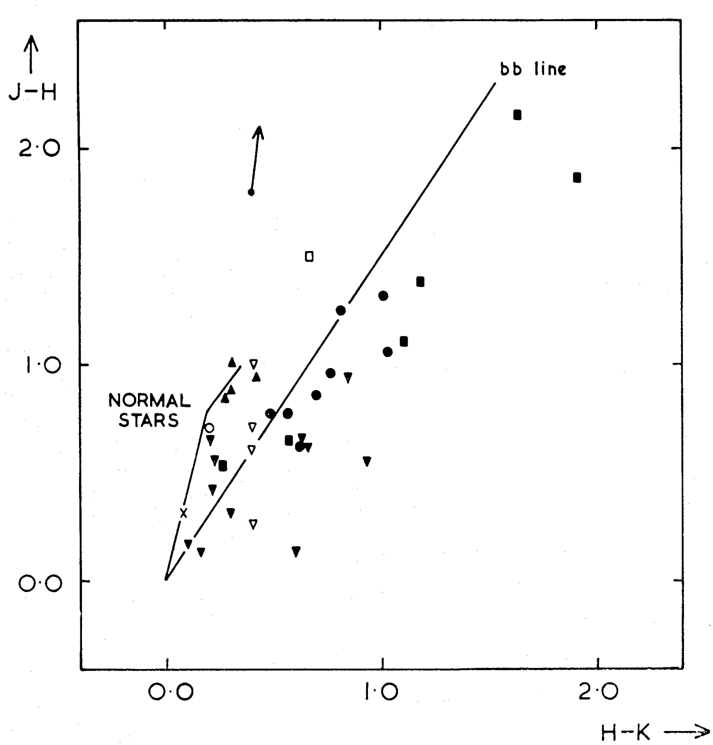

FIG. 4. *The J–H, H–K two-colour diagram. Notation as in Fig.* 1. *Both the locus of normal stars and the blackbody line are given, with an arrow indicating the direction in which reddening moves points.*

Milkey (1972) and for T Tauri stars by Strom (1972). Only if there were considerable reddening as well could the source of the infrared excess be free-free emission. So much reddening would be inconsistent with the optical data and it seems that re-radiation by dust is the most plausible infrared emission mechanism. The closeness of the points to the blackbody line shows that the contribution of the dust shell dominates at 2·2 μ and *H–K* is a good measure of the temperature of this shell.

In Fig. 4—the *J–H*, *H–K* diagram—the fact that the stars all lie below the line for normal stars with many in fact below the blackbody line is again consistent with the objects radiating the combined radiation of a star and a dust shell.

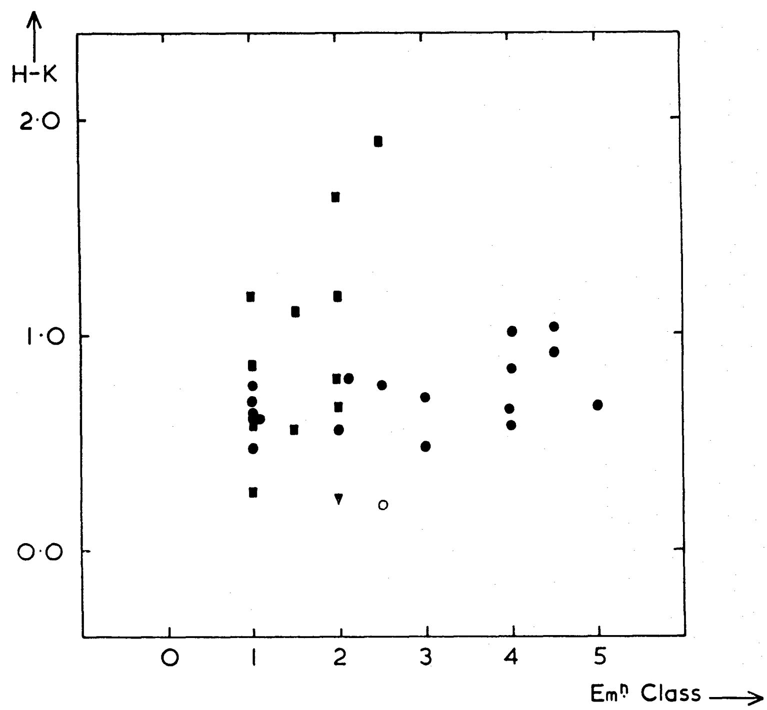

Fig. 5. *A plot of H–K against the emission class given by Herbig & Rao* (1972). *A statistical treatment shows that weak correlations between these quantities for both the T Tauri and hot population groups are significant. Notation as in Fig.* 1.

The data in Table II were examined to determine if the infrared colours were related to other properties of the RW Aur stars. No correlation is apparent between the *H–K* and the range of variation, the light curve class or the time scale of variation. The first of those results is in contrast to the weak relationship between *H–K* and the range of variation found in the Orion nebula cluster by Penston (1973).

On the other hand some relationship may exist between the infrared excess and the emission line class. Fig. 5 displays a plot of *H–K* against emission class (Herbig & Rao 1972). If one regards separately the T Tauri stars and hot Orion population members, it is seen that there is a weak positive correlation, which is different for each group, between the *H–K* colours and emission class. Computing the appropriate correlation coefficients, it turns out that for the T Tauri stars the correlation coefficient is 0·48, which for 18 stars means there is a significant correlation at the 3 per cent level. The hot population members give a larger correlation coefficient of 0·52 but because there are only 10 such stars this is only significant at the 8 per cent level. While of low significance, these correlations are of interest since they associate emission from the circumstellar dust and gas shells.

Finally, we examine the infrared variability of RW Aurigae stars. Reference to Table I shows that *HKL* variations have occurred in R Mon, V1121 Oph, AS 205 and possibly IS Per. On the other hand in spite of five observations of Z CMa and three of V1331 Cyg no significant changes were seen in these stars. Mendoza (1968) found similar infrared variability in the stars he observed. The question as to whether the optical and infrared light curves are the same (which will cast light on the structure of the dust shell) still remains to be investigated. A programme conducted in conjunction with optical observers concentrating on only a few objects would be helpful in this respect.

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