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MORE *JHKL* COLOURS OF GALAXIES

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SUMMARY

More data on the *JHKL* colours of galaxies is presented and interpreted in the light of improved knowledge of the infrared colours of late-type stars. It is concluded that most galaxies have similar *JHK* colours but that these yield minimal information as to the giant/dwarf ratio within the stellar population.

INTRODUCTION

Preliminary data on the *JHKL* (1·25, 1·6, 2·2 and 3·4 μ) colours of galaxies were presented by Glass (1973) hereafter called Paper I. Since that time new results have been obtained for a number of galaxies, mainly with improved precision. In addition, more information has become available concerning late-type stellar colours in these bands so that further interpretation of the galaxy colours is now possible.

DATA

Data for 26 galaxies with *J–H* and *H–K* colours known to better than $\pm 0^{\mathrm{m}}\cdot 12$ are presented in Table I. Some of these are taken from Paper I. New data were obtained with the 1·88-m Radcliffe telescope, the 1·5-m flux collector on Tenerife and the 1-m telescope at Sutherland. In all cases the photometer and filters were as described in Paper I. The standards for Southern objects were selected from Glass (1974) and for Northern ones from Glass (1975). If there is a bias in the choice of galaxies (other than those from the lists of Sersic & Pastoriza 1965), it is that they have been chosen to be easily measurable in the infrared.

The data for *K*, *J–H* and *H–K* have been adjusted for galactic absorption by taking $A_{\mathrm{V}} = 0{\cdot}15 \operatorname{cosec} b$ with $A_{\mathrm{K}} = 0{\cdot}08\,A_{\mathrm{V}}$ and $E_{\mathrm{H-K}} = 0{\cdot}06\,A_{\mathrm{V}}$, which corresponds to van der Hulst's (1949) curve number 15. Most of the corrections are very small.

DISCUSSION

The data may conveniently be discussed by reference to the *J–H*/*H–K* and *H–K*/*K–L* diagrams, Figs 1 and 2.

In the *J–H*/*H–K* diagram the galaxies are found to be remarkably uniform in their properties except for a small number, namely NGC's 1365, 1808, 7552,

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TABLE I

JHKL colours of galaxies

NGC	Apert. diam. (arcsec)	K	J–H	H–K	Type	(K–L)
1291	25	7·45	0·67	0·18	(R)SB(s)O/a	0·65 ± 0·10
1365	25	7·75	0·91	0·44	SB(s)b	1·47 ± 0·16
1433	18	9·09	0·63	0·26	SB(r)a	—
1549	18	8·17	0·69	0·19	EO+	0·54 ± 0·16
1553	18	8·42	0·64	0·16	SA(r)O	0·67 ± 0·16
1808	25	7·86	0·80	0·37	(R)SAB(s)O/a	1·16 ± 0·15
2841	22	8·14	0·72	0·27	SA(r)b	—
2903	22	8·63	0·81	0·22	SAB(rs)bc	—
3351	22	8·66	0·73	0·21	SB(r)b	—
3368	22	8·06	0·79	0·18	SAB(rs)ab	—
3521	22	7·93	0·71	0·29	SAB(rs)bc	0·15 ± 0·16
3627	22	8·20	0·76	0·19	SAB(s)b	—
4382	22	8·25	0·70	0·16	SA(s)O+P	—
4472	22	7·76	0·71	0·23	E2	0·48 ± 0·23
4594	22	7·07	0·77	0·27	SA(s)a	0·27 ± 0·10
4649	22	7·77	0·70	0·25	E2	—
4736	22	6·68	0·66	0·28	(R)SA(r)ab	0·23 ± 0·09
4826	22	7·71	0·94	0·14	(R)SA(rs)ab	—
5236	25	7·38	0·74	0·23	SAB(s)	0·78 ± 0·20
5248	22	9·20	0·70	0·24	SAB(rs)bc	—
6753	12	9·41	0·81	0·23	(R)SA(r)b	—
7049	18	8·56	0·76	0·24	SO	0·39 ± 0·22
7098	18	9·59	0·74	0·10	(R)SAB(rs)a	—
7552	12	8·93	0·85	0·36	(R)SB(s)ab	1·14 ± 0·10
7582	12	8·93	0·97	0·62	(R)SB(s)ab	1·02 ± 0·12
IC 4329A	12	8·86	0·79	0·83	SO− Seyfert	—

7582 and IC 4329A, the last a Seyfert (Disney 1973). Since Paper I was published, extensive photometry of giant and dwarf stars has been undertaken using the same photometer, detector and filters (Glass 1974, 1975). Fig. 1 includes a line giving the centre of the distribution of giant stars which, more precisely, form a path about $0^m{\cdot}03$ wide in this diagram. (Stars later than Mo are taken from Lee (1970). There may be a small colour difference for M stars between the two systems in the sense that $(H{-}K)_{\rm Glass} = (H{-}K)_{\rm Lee} + 0{\cdot}03$.) The M-dwarfs lie within the area enclosed by dashed lines, and the other late-type dwarfs, based on a smaller sample, lie to the left of the locus of giants. The galaxies in the sample are observed to lie around $J{-}H = 0{\cdot}73$, $H{-}K = 0{\cdot}25$, in a region not populated by individual normal dwarfs or giants. The typical behaviour of galaxy colours with increasing wavelength is seen in that at longer wavelength the colours are characteristic of later type stars. Thus the J–H colour is similar to K4 giants, the H–K to M2 giants and the K–L (Fig. 2) to the late M-types. These colours may be synthesized either by mixtures of K and M giants or by mixtures of late-type giants and dwarfs. Some information relevant to population models also arises from the 2·3 μ CO band indices measured by Frogel *et al.* (1975a). Unfortunately these data do not provide very many more constraints on the models than do the broad-band measurements because of a certain resemblance between the CO/spectral type diagram and the J–H/H–K diagram for late-type stars. As an example of a very crude model, a line on Fig. 1 gives the positions occupied by mixtures of Ko and M6 giant stars. The average galaxy colour could be represented by 40 per cent Ko light + 60 per

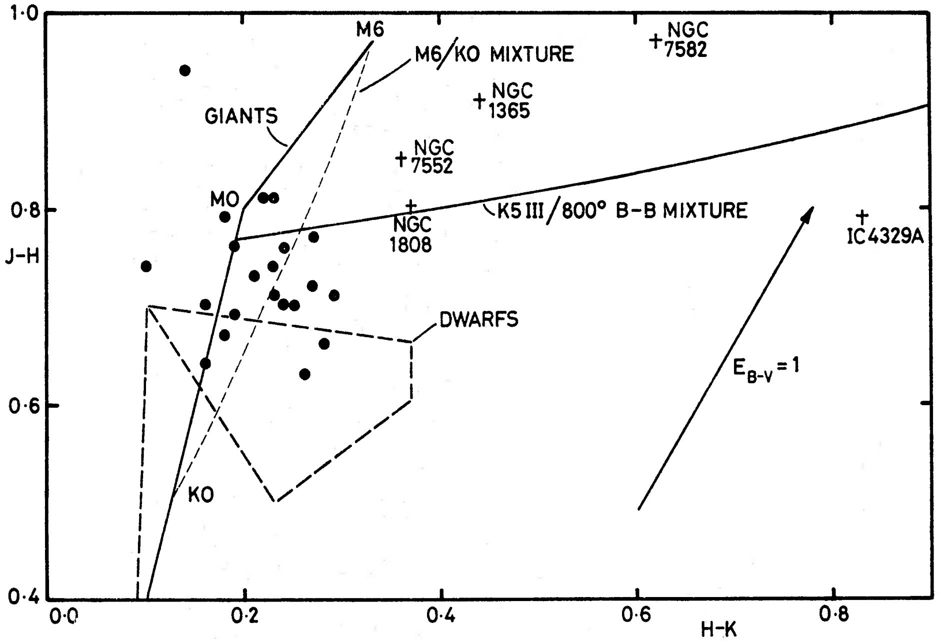

FIG. 1. *J–H/H–K diagram. Dots represent ordinary galaxies, crosses those with clear infrared excesses. The heavier dotted lines give the locus of intermediate-type dwarfs and the area occupied by M-dwarfs. Also shown are: (a) the locus of giants; (b) the normal reddening vector; (c) the locus of a mixture of K*5 *giant colour with* 800 K *blackbody; and (d) the locus of a mixture of M*6 *and K*o *giant colours. Most galaxies have surprisingly similar colours.*

cent M6 (proportions of *K* light). The CO index yields a similar proportion. Correspondingly, one may synthesize the galaxy broad- and narrow-band colours from a mixture of M6 giants and M dwarfs. The proportion of dwarfs could be as much as 25 per cent in *K* light. These conclusions are similar to those reached by Frogel *et al.* (1975b).

The *H–K/K–L* diagram (Fig. 2) is less useful for investigating the stellar populations of galaxies because (a) at present the measurement accuracy both statistical and systematic is lower, and (b) the stellar light becomes confused at *L* with thermal emission from dust. However, the dust content is interesting in itself and Fig. 2 shows that several galaxies from this sample must possess dusty nuclei. On this diagram (and also on Fig. 1) is plotted a line which shows the locus of combinations of K5 III stars with an 800 K blackbody. NGC's 1365, 1808 and 7552 appear to be combinations (at 2·2 μ) of 80 per cent K5 light and 20 per cent 800 K blackbody. NGC 7582 stands further away from the line than differences in stellar composition can explain and may therefore possess hotter dust. The fact that the points in the *J–H/H–K* diagram lie above the equivalent line can be due to absorption within the galaxies. The Seyfert galaxy in Fig. 1, IC 4329A, appears to have equal contributions of starlight and dust.

A number of galaxies such as NGC 1365 and NGC 1808 measured here or in Paper I have been observed spectrophotometrically by Osmer, Smith & Weedman (1974) who conclude, based on the very steep Balmer decrements observed, that dust plays an important role in the nuclei of these objects, and that the infrared flux is ultimately produced by the heating of the dust by massive young stars.

Predictions of the 10-μ flux from NGC 5236 and NGC 7552 can be made from

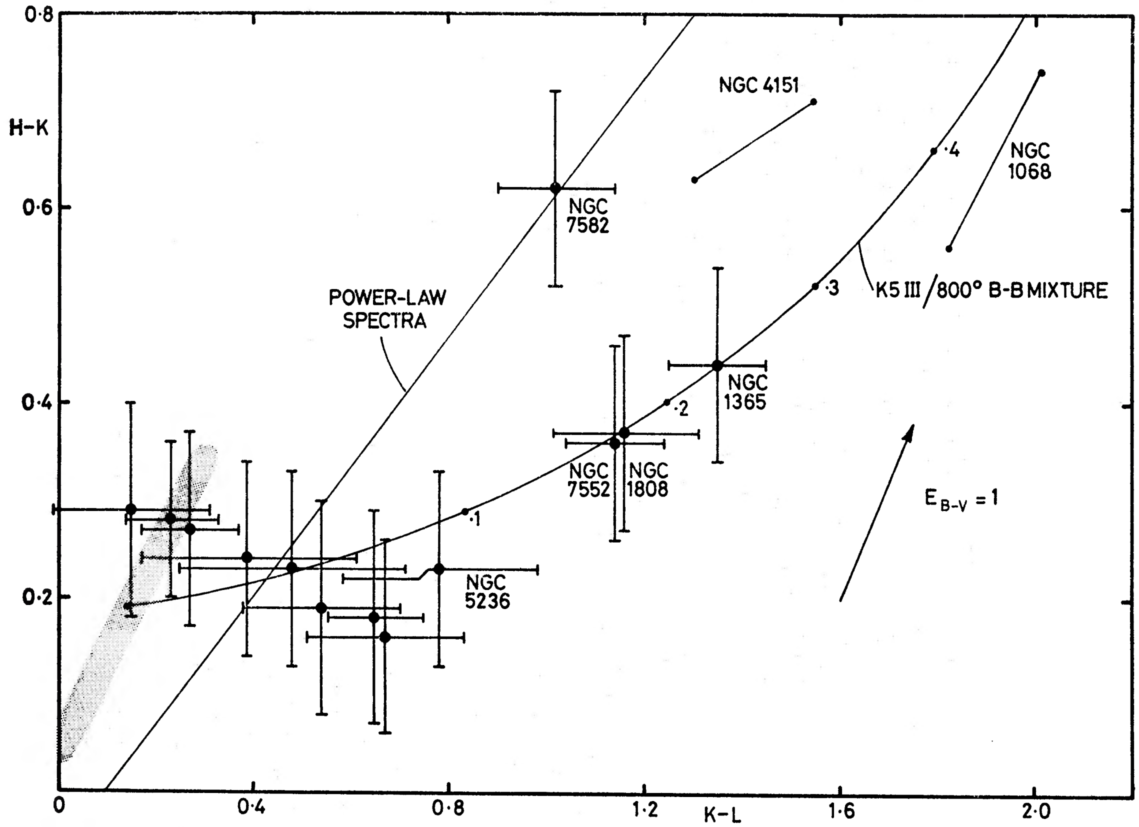

FIG. 2. *H–K/K–L diagram. All galaxies in the sample with known K–L colours are given together with their* 1 σ *error bars. Also shown are:* (*a*) *the area occupied by normal stars* (*shaded*)*;* (*b*) *the locus of pure power-law spectra;* (*c*) *the locus of a mixture of K*5 *giant colour with* 800 *K blackbody radiation, calibrated in the fraction of light at* 2·2 μ *arising from the blackbody; and* (*d*) *the normal reddening vector. The two Seyfert galaxies NGC* 1068 *and NGC* 4151 *have been included for comparison from the work of Penston et al.* (1974).

the apparent flux from 800 K dust at 2·2 μ. These are in fair agreement with the results of Kleinmann & Wright (1974), allowing for the crudity of the observations and the imprecision with which the dust temperature is known. Accurate photometry from 5 to 20 μ of these and other galaxies should yield more precise temperatures and allow the construction of more detailed models.

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REFERENCES

Disney, M. J., 1973. *Astrophys. J.*, **181**, L55.
Frogel, J. A., Persson, S. E., Aaronson, M., Becklin, E. E., Matthews, K. & Neugebauer, G., 1975a. *Astrophys. J.*, **195**, L15.
Frogel, J. A., Persson, S. E., Aaronson, M., Becklin, E. E. & Matthews, K., 1975b. *Tercentenary Symposium of Royal Greenwich Observatory.*
Glass, I. S., 1973. *Mon. Not. R. astr. Soc.*, **164**, 155.

Glass, I. S., 1974. *Mon. Not. astr. Soc. Sth Africa*, **31**, 81.
Glass, I. S., 1975. *Mon. Not. R. astr. Soc.*, **171**, 19P.
Hulst, H. C. van der, 1949. *Rech. astr. Obs. Utrecht*, **11**, Pt I.
Kleinmann, D. E. & Wright, E. L., 1974. *Astrophys. J.*, **191**, L19.
Lee, T. A., 1970. *Astrophys. J.*, **162**, 217.
Osmer, P. S., Smith, M. G. & Weedman, D. W., 1974. *Astrophys. J.*, **192**, 279.
Penston, M. V., Penston, M. J., Selmes, R. A., Becklin, E. E. & Neugebauer, G., 1974. *Mon. Not. R. astr. Soc.*, **169**, 357.
Sersic, J. L. & Pastoriza, M., 1965. *Publ. astr. Soc. Pacific*, **77**, 287.