COLOUR INDICES OF THE MARKARIAN GALAXIES

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Abstract. By use of the ANS ultraviolet fluxes, optical (*UBV*) and IRAS infrared fluxes, several colour indices for a few Markarian galaxies have been investigated. A comparison of these indices with those for normal NGC galaxies has been carried out. Similarities and differences in the indices for the two groups of galaxies have been discussed and possible causes have been indicated.

1. Introduction

Markarian galaxies are excess UV continuum galaxies with varying degree of activity in their nuclei. About 5900 UV excess galaxies have now been catalogued as a result of large sky surveys with objective prisms on Schmidt telescopes. The surveys include the Byurakan surveys, Kiso Schmidt survey, and Curtis Schmidt Cerro Tololo survey. The name Markarian galaxies has, however, been restricted to the 1532 objects listed in the Byurakan survey lists. According to Sulentic (1976), one-third of the Markarian galaxies are spirals another third are ellipticals and one-fifth are irregulars and other compact objects. Ten percent of the Markarian galaxies are Seyferts (Huchra, 1977). Most (85%) of the Markarian galaxies have emission lines and 9% have radio emission. The Seyferts amongst the Markarian galaxies emit significant nonthermal continuum from their nuclei due to synchrotron radiation. The strong blue and UV continua emitted by non-Seyfert Markarian galaxies is of thermal origin. This implies that many active galaxies which do not have Seyfert nuclei have accumulated a large population of hot blue stars in their nuclear regions. These galaxies are believed to owe their UV excess to a short-lived burst of star formation, and have come to be known as starburst galaxies. It is estimated that about 40% of the galaxies in the Markarian list with absolute magnitudes in the range $-17.5 \langle M_{pg} \rangle -22.5$ having narrow emission line and enhanced UV continua can be explained by the starburst phenomenon.

Ultraviolet observations of galaxies have shown that many systems having similar spectra in the optical region have widely different spectra in the UV. This may be taken as representing the population of hot stars in the systems. Also, at low resolution, the numerous lines of various atomic transitions blend together giving rise to a depression of the continuum in regions around 1500 Å.

It is natural to study the physical characteristics of the Markarian galaxies of different morphological types through the entire possible spectral region and to compare the characteristics with the so-called normal galaxies. In this paper, the UV data of a few Markarian galaxies observed by the Astronomical Netherlands Satellite (ANS) have been analysed, and a comparison with the normal galaxies have been carried out. The

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ultraviolet characteristics of the galaxies have also been compared to their far-infrared properties.

2. The Data

The ANS catalogue (Wesselius *et al.*, 1982) contains photometric data on 24 Markarian galaxies. The observations consist of fluxes measured in five rectangular bands each of width 15 nm (5 nm also in the 1500 Å band), centered at 3300, 2500, 2200, 1800, and 1500 Å, using an entrance slot of 2.5 × 2.5 arc min in size. The fluxes have been converted into UV magnitudes and are designated as 33, 25, 22, 18, 15. The accuracy of these magnitudes range from $0^m.04$ to $0^m.40$ for different galaxies. The *UBV* data for the galaxies have been taken from the catalogue by Longo and de Vaucouleurs (1983). This catalogue gives the photometry of galaxies through different apertures. The *UBV* magnitudes from the catalogue were transformed to an aperture equivalent to the area of the ANS aperture using the method described by Wu *et al.* (1980), to combine the ANS and *UBV* data for forming the colour indices. The *UBV* colour excess for the galaxies have been computed using the relation (Griersmith, 1980) as

$$E(B-V) = 0.033\,(\mathrm{cosec}\,|b| - 1)\,, \quad |b| < 40\,,$$
$$= 0\,, \quad \text{for} \quad |b| > 50\,;$$
$$E(U-V) = 0.056\,(\mathrm{cosec}\,|b| - 1)\,, \quad |b| < 40\,,$$
$$= 0\,, \quad \text{for} \quad |b| > 50\,;$$

with a smooth transition in the range $40 < |b| < 50$. The ANS de-reddened colours were calculated using the mean extinction curve (Kester, 1981). The UV and optical data for the Markarian galaxies have been given in Table I(a).

3. Discussion

In Figure 1, the $25 - V$ indices for the galaxies have been plotted against their $15 - V$ indices. The plot shows a continuous sequence for both the Markarian galaxies and the normal galaxies. The data for the normal galaxies have been taken from Stryczyński (1987). A deficiency in the 2500 Å flux relative to the *V* band flux in the galaxies follows a deficiency in the 1500 Å also. All Markarians in the present sample and several NGC galaxies which are Seyferts, H II region galaxies or irregular galaxies (active galaxies) occupy the upper region of this diagram, showing that these galaxies are brighter in the 2500 and 1500 bands as compared to the normal NGC galaxies. The average ultraviolet colours of Main-Sequence stars of different spectral types taken from Wesselius *et al.* (1980) are also shown in the figure. The relation for galaxies is much more steeper in this region as compared to the relation for B9–A7 classes of stars, showing that the thermal stellar flux in the 2500 Å band does not deplete as fast as it does for the galaxies.

Figure 2 shows the $25 - V$ index in relation to the $B - V$ index of the galaxies. The

TABLE I(a)

Ultraviolet, optical indices and M_{pg} of the Markarian galaxies

Mark No.	Mor. type T	M_{pg} D (Mpc)	$(15-V)$ $(15-33)$	$(18-V)$ $(18-33)$	$(22-V)$ $(22-33)$	$(25-V)$ $(25-33)$	$(33-V)$	$(U-V)$ $(B-V)$	Remarks
009	SO P	−21.3	0.384	1.223	1.542	0.950	0.450	0.18	Star-like galaxy
	−2	156.0	−0.066	0.773	1.092	0.500		0.69	Seyfert 1.1
010	SBbc	−21.8	0.610	1.483	1.980	1.700	0.800	0.56	Star-like nucleus
U4013	3	114.0	−0.019	0.683	1.108	0.900		0.72	Seyfert
033	Im	−18.6	0.050	−0.006	0.344	0.463	1.045	0.19	H II
Arp233	10	19.0	−0.995	−1.051	−0.701	−0.582		0.48	
U5720									
035	Im	−18.0	−0.312	−0.363	0.022	0.376	0.230	0.30	H II, double
N3353	10	13.0	−0.542	−0.593	−0.208	0.146		0.53	multi-condensation
036	I	−13.9	−1.094	−0.895	−0.292	0.070	−0.530	−0.21	H II
Haro4	–	08.0	−0.564	−0.365	0.283	0.600		−0.02	Compact
052	SBab	−19.0	0.397	0.900	0.744	0.300	0.000	0.90	Bright blue
N4385	−1	28.0	0.397	0.900	0.744	0.300		0.79	nucleus, H II
U7515									
079	SBc	−21.9	−0.156	0.472	0.793	0.555	0.133	0.50	Seyfert 1.5
U3973	3	85.0	−0.289	0.339	0.660	0.422		0.75	
086	Sm	−17.7	0.231	0.341	0.717	0.865	0.983	0.44	
N2537	10	06.0	−0.901	−0.642	−0.266	−0.118		0.62	
U4274									
161	SBc	−21.4	0.420	0.862	1.120	1.320	0.720	0.28	Bright arms
U6103	–	79.0	−0.300	0.142	0.400	0.600		0.48	nucleus
171	Im P	−19.9	0.857	0.932	1.166	1.188	1.428	0.55	H II
N3690	9	41.0	−0.576	−0.496	−0.262	−0.240		0.79	
U6472									
178	Im P	−14.4	−0.690	−0.376	−0.049	0.025	−0.210	0.14	H II
U6541	10	03.0	−0.480	−0.166	0.161	0.235		0.42	

Table I(a) (continued)

Mark No.	Mor. type T	M_{pg} D (Mpc)	$(15-V)$ (15–33)	$(18-V)$ (18–33)	$(22-V)$ (22–33)	$(25-V)$ (25–33)	$(33-V)$	$(U-V)$ $(B-V)$	Remarks
185	SBc	−20.3	–	–	–	–	–	0.67	Bright
N3811	6	41.0	−0.470	0.527	0.030	0.338		0.65	nucleus
U6650									
186	SBc	−17.2	1.185	0.777	1.458	1.500	0.600	0.39	
N3870	−2	10.0	0.585	0.177	0.858	0.900		0.60	
U6742									
188	SAbc	−20.3	0.858	0.864	1.197	1.531	1.245	0.47	
N3888	5	32.0	−0.387	−0.381	−0.048	0.286		0.57	
U6765									
190	SO/E	−17.9	1.150	1.057	1.603	1.680	0.980	0.70	
N3928	−5	12.0	0.170	0.077	0.623	0.700		0.74	
U6834									
201	P	−20.0	0.652	0.379	0.761	0.827	0.650	0.36	H II
N4194	10	33.0	0.002	−0.271	0.111	0.177		0.52	
U7241									
205	P	−22.2	–	–	–	–	–	–	Seyfert 1.0
–	–	276.0	−0.129	0.309	0.471	1.002		–	Star-like galaxy
207	Sa P	−19.4	–	–	–	–	–	0.26	Bright irregular
N4384	1	32.0	0.298	–0.017	0.609	0.800	–	0.48	nucleus
U7506									
213	SBa	−20.2	–	–	–	–	–	0.57	Bright nucleus
N4500	1	42.0	1.622	1.624	1.716	1.649		0.62	
U7667									
256	Sd	−20.3	–	–	–	–	–	−0.08	
N5144	5	42.0	−0.758	−0.764	−0.443	−0.232		0.35	
U8420									
279	SO	−21.3	−0.204	0.640	0.677	0.540	0.140	0.71	Seyfert 1.0
U8823	−2	120.0	−0.344	0.500	0.537	0.400		0.92	AGN

Table I(a) (continued)

Mark No.	Mor. type T	M_{pg} D (Mpc)	$(15-V)$ $(15-33)$	$(18-V)$ $(18-33)$	$(22-V)$ $(22-33)$	$(25-V)$ $(25-33)$	$(33-V)$	$(U-V)$ $(B-V)$	Remarks
281	SBb	−20.2	1.373	1.308	1.480	1.691	1.062	0.82	
N5383	3	30.0	0.311	0.246	0.418	0.629		0.72	
297	Pair	−20.2	−0.496	−0.205	−0.023	0.324	0.152	0.00	Compact
N6052	5	62.0	−0.648	−0.357	−0.175	0.172		0.47	condensation
335	SO/a	−21.4	−0.736	−0.210	0.233	0.168	0.234	−0.57	Seyfert 1.0
–	–	102.0	−0.970	−0.444	−0.001	−0.066		−0.39	

Explanations to Table I(a)

Column 1:
line 1: Markarian and other (NGC and UGC) number.
Column 2:
line 1: Morphological type from Mazzarella and Balzano (1986),
line 2: Hubble type T from Longo and de Vaucouleurs (1983).
Column 3:
line 1: absolute magnitude M_{pg} from Mazzarella and Balzano (1986),
line 2: distance in Mpc ($H_0 = 55$ km s^{-1} Mpc^{-1}).
Columns 4–8:
line 1: $(UV - V)$ colour indices,
line 2: as in line 1 but indices based on the 33 band.
Column 9:
line 1: $(U - V)$,
line 2: $(B - V)$.
Column 10: other information about galaxies.

TABLE I(b)

Infrared indices and luminosity (L_{80}) of the Markarian galaxies

Mark No.	(12–25)	(25–100)	(60–100)	L_{80}
009	2.555	4.108	1.718	44.02
010	2.000	5.103	2.158	43.87
033	3.193	4.894	1.219	42.85
035	3.193	5.103	1.340	42.58
036	–	4.668	2.261	41.11
052	2.868	4.916	1.404	43.20
079	2.480	4.130	1.497	43.68
086	2.312	5.966	1.862	41.82
161	2.000	5.775	1.637	43.89
171	3.470	4.760	1.154	44.85
178	–	–	–	–
185	1.560	6.568	1.990	43.41
186	1.560	5.688	1.957	41.84
188	1.872	6.579	2.023	43.50
190	2.312	5.775	1.862	42.34
201	3.386	4.910	1.233	44.01
205	2.001	7.999	2.151	46.10
207	1.560	6.242	1.759	43.10
213	2.753	5.576	1.692	43.55
256	2.000	6.128	1.823	43.45
279	2.000	5.103	1.916	43.94
281	1.560	5.022	1.949	42.53
297	2.625	5.699	1.480	44.10
335	1.872	3.743	1.863	43.39

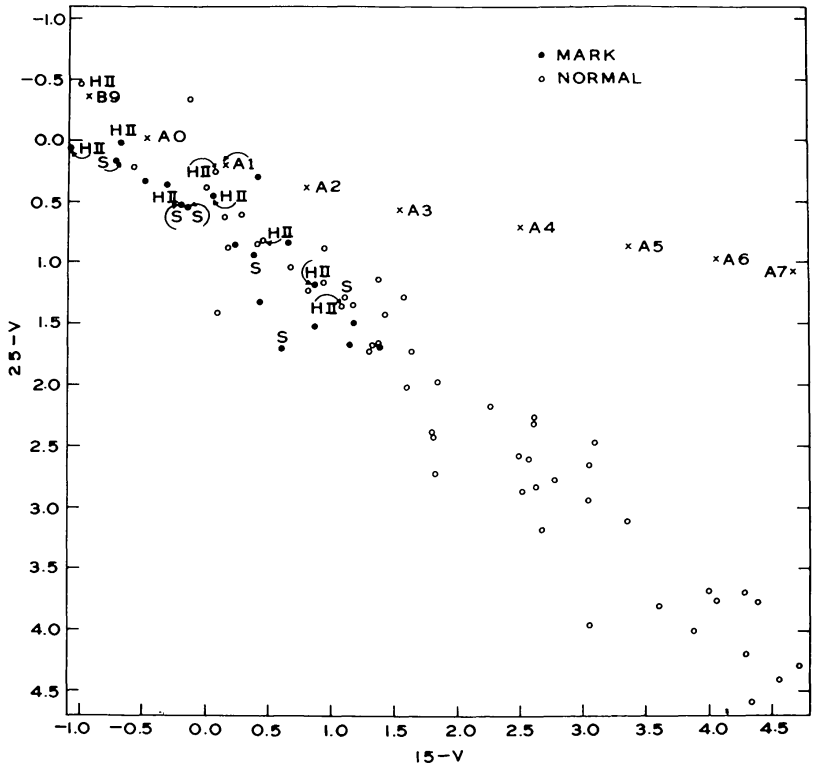

Fig. 1. Plot of 15 – V index against 25 – V for Markarian (●), NGC galaxies (○), and normal Main-Sequence stars (×). Seyferts and H II region galaxies have been indicated by S and H II, respectively.

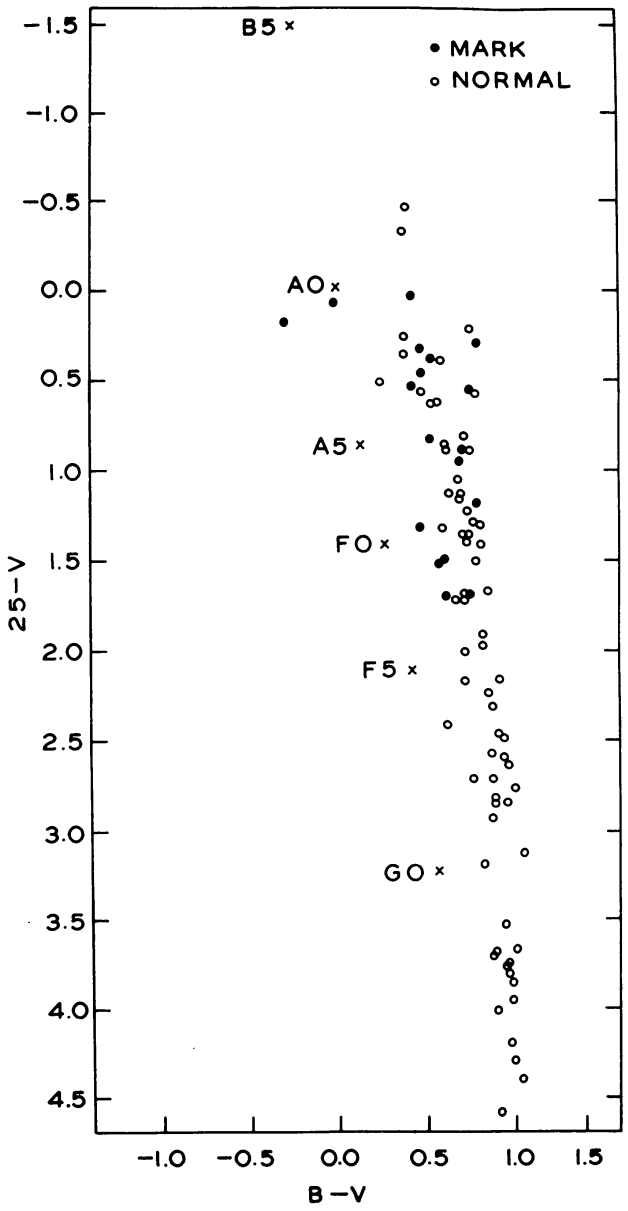

Fig. 2. Plot of $B - V$ index against $25 - V$ for Markarian (●), NGC galaxies (○), and normal Main-Sequence stars (×).

same indices for the normal Main-Sequence stars (Wesselius *et al.*, 1980) have also been plotted in the figure. This figure shows that the $B - V$ colour index of the galaxies lies in a narrow range of $0^m.3$ to $1^m.0$. Markarian galaxies and NGC Seyferts or H II region galaxies have a mean $B - V$ of about $0^m.6$. Other normal galaxies have a mean $B - V$ of about $0^m.8$. The range in the ultraviolet index $25 - V$, however, is quite large. Seyferts galaxies and H II region galaxies among the NGC galaxies and the Markarians have indices in the same range. The 2500 Å flux for the normal galaxies lies in the region occupied by F and G stars and later whereas the active galaxies in the sample are restricted to stellar colours corresponding to F5 and earlier spectral classes.

Figure 3 shows the ultraviolet index 18–33 plotted against the $U - V$ index of galaxies and Main-Sequence stars. Here again the active galaxies occupy a region which indicates excess flux in the 1800 Å, relative to 3300 Å and in the U band, relative to the V band as compared to normal galaxies. In this diagram, however, the active galaxies are restricted to a region occupied by stars of spectral class earlier than F0.

Far-infrared (IRAS) fluxes of the Markarian galaxies in our ANS sample and a few NGC galaxies contained in the list of Stryczyński (1987) were taken from Gezari *et al.* (1987) and they were converted into magnitudes at the IRAS wavelengths 12, 25, 60,

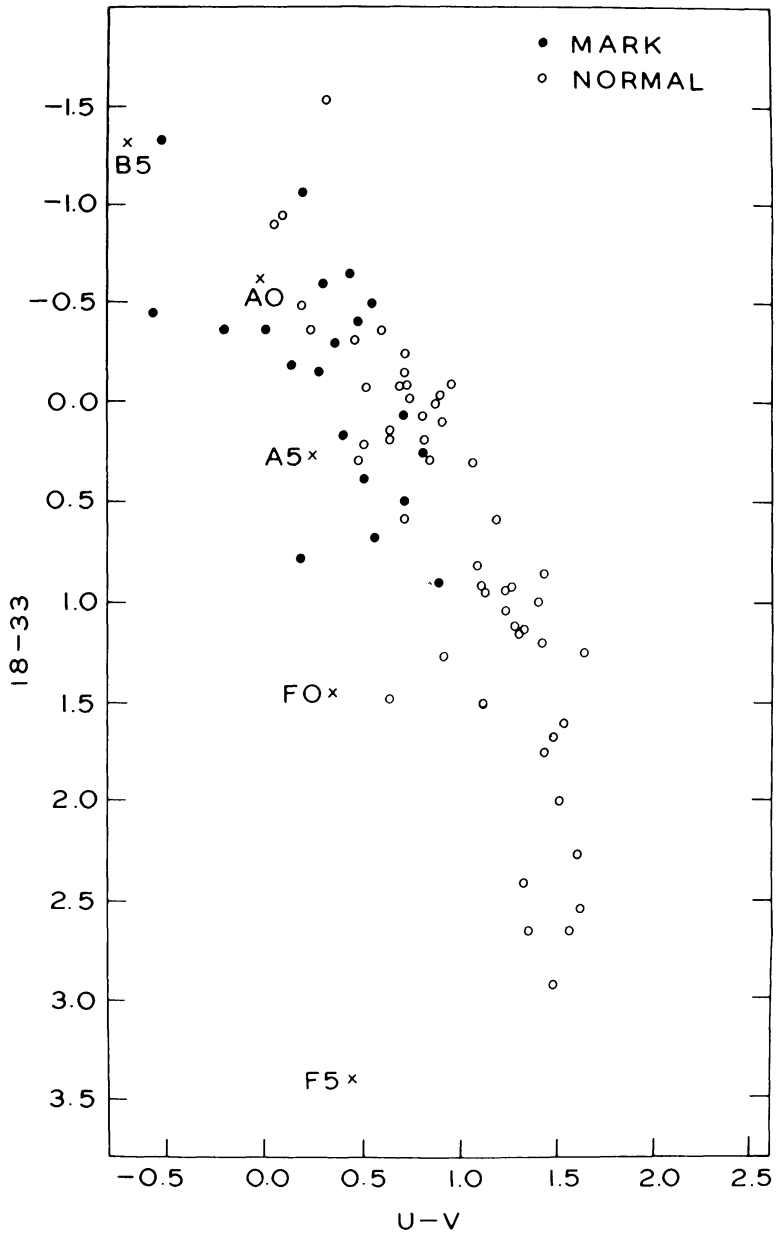

Fig. 3. Plot of $U - V$ index against ultraviolet index (18–33) for Markarian (●), NGC galaxies (○), and normal Main-Sequence stars (×).

TABLE II

Infrared indices, M_{pg} and luminosity (L_{80}) of NGC galaxies

NGC No.	(12–25)	(25–100)	(60–100)	M_{pg}	D (Mpc)	L_{80}
205	1.560	5.966	3.091	– 15.72	0.145	38.17
221	1.120	6.925	3.100	– 15.53	0.309	39.21
247	3.167	6.609	3.442	– 18.62	–	–
253	3.452	5.367	1.458	– 20.72	–	–
598	1.248	7.743	2.058	– 19.07	0.218	39.50
925	1.560	7.426	2.681	– 21.07	10.254	42.48
1023	–	–	–	– 21.17	12.891	–
1068	2.448	4.089	1.384	– 22.93	18.736	44.47
1232	1.560	7.951	3.686	– 22.57	–	–
1316	1.560	6.455	2.075	– 23.08	31.418	43.30
1326	2.480	6.227	1.688	– 21.06	–	–
1365	2.910	5.742	1.749	– 22.95	–	–
1566	2.199	7.141	2.405	– 22.29	–	–
1569	–	–	–	– 16.22	2.381	–
2146	–	–	–	– 21.36	17.545	–
2403	3.592	7.048	2.811	– 19.47	3.400	42.17
2683	1.560	8.188	2.811	– 20.17	5.181	42.18
2782	2.678	5.435	1.622	– 22.06	45.490	43.94
2841	1.560	7.563	2.985	– 21.53	11.364	42.60
2903	2.706	7.114	2.524	– 20.96	9.655	43.38
3034	3.339	4.543	1.088	– 18.60	7.273	44.38
3077	3.010	5.757	1.671	– 17.20	–	–
3115	–	–	–	– 19.82	7.690	–
3184	–	–	–	– 20.28	8.055	–
3227	2.691	5.484	1.950	– 20.80	25.436	43.50
3310	3.019	5.357	1.341	– 20.82	20.073	43.76
3368	1.803	7.308	2.290	– 21.41	44.400	43.16
3379	–	–	–	– 20.58	13.273	–
3384	–	–	–	– 19.83	11.800	–
3348	–	–	–	– 20.20	–	–
3504	2.981	5.332	1.682	– 21.11	26.527	43.85
3516	2.441	3.851	1.287	– 21.43	50.364	43.26
3521	1.560	7.911	2.343	– 21.65	11.181	43.43
3556	2.691	6.861	2.143	– 21.02	13.090	43.26
3623	2.000	7.073	3.133	– 21.48	10.690	42.52
3626	1.560	–	2.681	– 20.81	24.763	–
3992	1.560	7.123	3.738	– 21.83	20.836	42.92
4051	2.313	5.893	2.107	– 20.31	12.345	42.93
4151	–	–	–	– 20.93	18.000	–
4236	–	–	–	– 18.41	–	–
4244	1.120	5.893	3.261	– 18.76	–	–
4258	–	–	–	– 20.05	8.981	–
4382	1.120	6.269	2.756	– 21.60	–	–
4449	–	–	–	– 18.84	4.872	–
4472	–	–	–	– 22.38	–	–
4486	–	–	–	– 22.08	–	–
4490	–	–	–	– 20.70	12.272	–
4501	1.833	7.441	2.589	– 21.93	–	–

Table II (*continued*)

NGC No.	(12–25)	(25–100)	(60–100)	M_{pg}	D (Mpc)	L_{80}
4535	2.752	6.840	2.390	– 21.58	–	–
4559	–	–	–	– 21.15	–	–
4565	1.050	7.220	2.661	– 22.79	22.055	43.46
4569	2.625	6.622	2.387	– 22.31	–	–
4579	1.560	7.392	2.596	– 21.69	–	–
4631	2.115	6.982	2.024	– 21.44	11.109	43.61
4636	–	–	–	– 20.58	–	–
4697	–	–	–	– 21.47	–	–
4699	1.560	7.435	2.591	– 22.24	–	–
4736	1.810	6.702	1.786	– 20.81	–	–
4826	1.917	6.674	1.874	– 20.61	6.618	42.98
5102	1.560	5.732	2.347	– 18.73	–	–
5194	2.180	7.296	2.571	– 21.60	9.927	43.47
5236	0.922	7.147	2.834	– 21.12	5.800	42.26
5248	2.115	6.633	2.092	– 21.19	21.727	43.71
5866	1.120	7.781	2.406	– 20.22	16.800	43.07
6946	–	–	–	– 20.30	6.000	43.10
7331	0.808	9.506	2.682	– 22.60	19.236	43.86
7469	3.126	4.981	1.389	– 23.10	90.690	44.99
7793	2.000	8.077	3.039	– 18.85	5.309	42.32

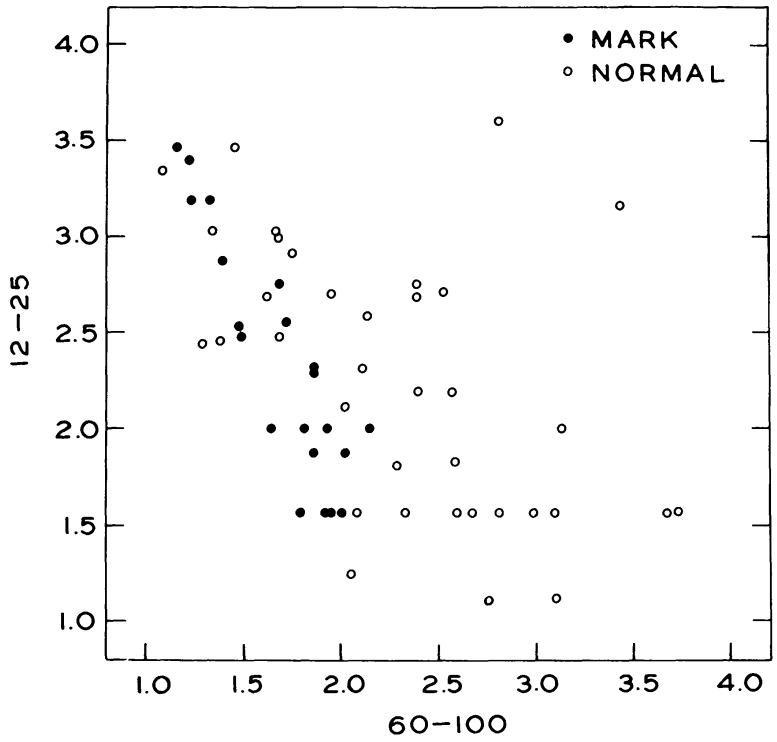

Fig. 4. Plot of far-infrared indices 60–100 against 12–25 for Markarian and NGC galaxies. Symbols are as in Figure 1. *p* stands for peculiar galaxy.

and 100 μm. For this conversion we have used the zero-point constants given by Beichmann *et al.* (1985). Far-infrared luminosity L_{IR} has also been calculated for these galaxies using the relation $L_{IR} = 4\pi D^2 \int F_{IR}\, d\nu$ where D is the distance (corresponding to $H_0 = 55$ km s^{-1} Mpc^{-1}). For D we have used the redshift (Z) from Mazzarella and Balzano (1986) and Humason *et al.* (1956) for Markarians and NGC galaxies, respectively. For F_{IR} we have used the mean flux between 60 and 100 μm. The frequency interval has been taken to the equivalent of $\Delta\lambda = 70$ μm.

The detector field of view for the IRAS bands 12, 25, 60, 100 μm are 0.75 × 4.5, 0.75 × 4.6, 1.5 × 4.7, and 3.0 × 5.0 arc min square, respectively. Since the dimensions of the Markarian galaxies are smaller than the larger dimension of the detector field-of-view, the entire such galaxy is scanned during an observation and thus the fluxes correspond to those from the entire galaxy. In case of other NGC galaxies, however, the fluxes correspond to the regions seen by the detector. The IR indices, IR luminosity, and M_{pg} for the Markarian galaxies have been given in Table I(b). M_{pg} for Markarians have been taken from Mazzarella and Balzano (1986). Table II gives the IR indices, IR luminosity, and M_{pg} for the NGC galaxies. M_{pg} for the NGC galaxies have been taken from Sandage and Tammann (1981).

In Figure 4 we have plotted the infrared indices 12–25 and 60–100 for the Markarian and the normal galaxies. The galaxies in this plot seem to follow two trends. The Markarians have less positive 60–100 index for the same 12–25 index, indicating deficit

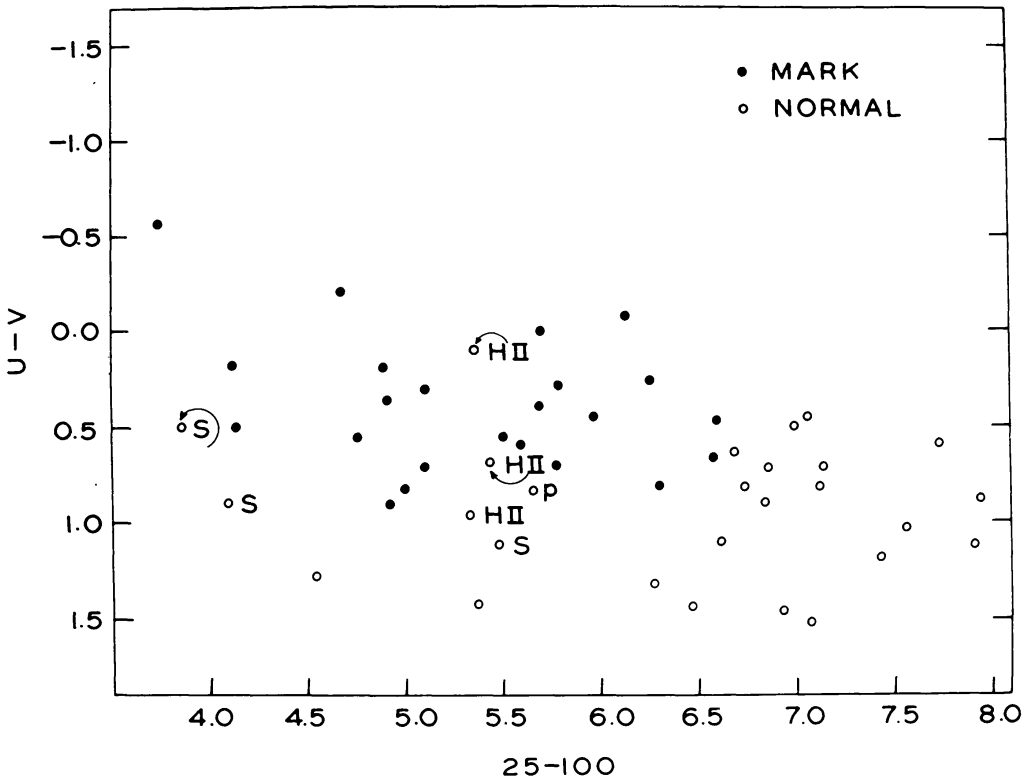

Fig. 5. Plot of infrared index 25–100 against $U - V$ for Markarian and NGC galaxies.

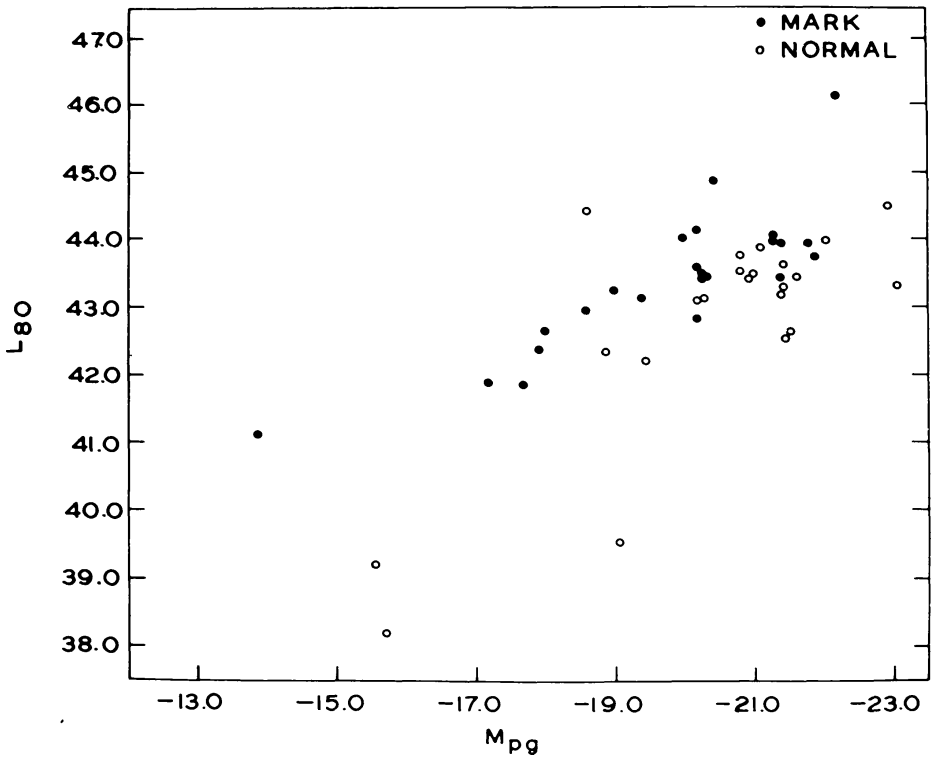

Fig. 6. Plot of optical luminosity (M_{pg}) against infrared luminosity (L_{80}) for Markarian and NGC galaxies.

flux in the 100 μm band compared to 60 μm for the Markarians. Also the Markarians in this diagram follow a steeper slope, showing larger change in the 12–25 colour for the Markarians for a given change in the 60–100 colour.

Figure 5 in which we have compared the UV and infrared indices of the galaxy shows that Markarians and other active galaxies in our sample have their 25–100 index confined to a value of about $6^m.3$, whereas the normal NGC galaxies have the 25–100 index greater than $6^m.3$. This indicates a flatter spectra for the active galaxies in the 25 and 100 μm infrared wavelengths as compared to those for normal galaxies.

Figure 6 shows a plot between the far-infrared luminosity L_{80} (logarithm of the IR luminosity) of the galaxies plotted against their optical luminosity M_{pg}. In this plot the Markarians generally show higher infrared luminosity as compared to that for a normal galaxy of the same optical luminosity.

4. Conclusions

The far-ultraviolet colours of Markarian and other active galaxies are more blue (numerically smaller) than those for normal NGC galaxies. The visible region $B - V$ colour has a narrower range for all the galaxies as compared to the far ultraviolet colour $25 - V$. Likewise 18–33 index has a larger range as compared to the $U - V$ index. The comparison with stellar colours indicates an excess of early-type stars in the active galaxies, and also the different dependence on the 2500 and 1500 Å fluxes in the galaxies

as compared to the stars, indicating presence of a nonthermal component of radiation also. The Markarian and other active galaxies in the sample have higher infrared luminosity (L_{80}) as compared to the normal galaxies. This may be due to re-radiation in the infrared by the excess gas and dust in the nuclear regions of the active galaxies.

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