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A型星およびF型星の有効温度スケール

加藤賢一[1]・黒田武彦[2]
大阪市立電気科学館

概要

A型およびF型のスペクトル型を持つ 404 星の有効温度 T_{eff}を、可視域、近赤外域、紫外域の分光測光値あるいは色指数を Kurucz（1979） の理論的な値と比較して求めた。紫外域の色指数から求められた有効温度は8500K以上では他より低い傾向となるものの、8500K以下では三者の相関は非常によく、最終的に求められた有効温度は直接法や赤外放射法から決定された値とよく合っている。Bohm-Vitense（1982）はA型の最後部からF型にかけてT_{eff}-(B-V)関係は2系列に別れると主張しているが、そのような傾向は見られない。特に早期A型に見られる T_{eff}-(B-V) 図上のひろがりは log（表面重力加速度）＝ 3.5 ～ 4.5 に太陽と同じ化学組成を仮定すればよいことが分かった。最後に、T_{eff}-(b-y) 関係は Kurucz(1979) の理論値より系統的に低いことを示す。

この論文について

この研究についてはすでに日本天文学会の年会で2度にわたり口頭発表を行ない、結果の一部は黒田・加藤（1984，1986）等で報告しているが、これまで全体を発表する機会に恵まれなかった。ここに掲載するのがこれまでの一連の報告の最終結果である。本論文の原稿は1986年春に完成していたが、その前後に相次いで似たような研究報告がいくつか発表されたので、本論文の学術的価値に疑問が生じ、発表を躊躇していた。しかし、その後もこれだけの数については発表されていないので、時期を逸した感はぬぐえないが改めて公表することにした。

なお私事にわたって恐縮であるが、筆者らがこの共同研究を行なった6年前は共に大阪市立電気科学館天文室に所属していた。その電気科学館は1989年5月に閉館し、その後2人は現在の所属に移った次第である。

古い研究結果にもかかわらず掲載を許していただいた大阪市立科学館に感謝申し上げる。

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現在の所属：　1)大阪市立科学館
2)兵庫県立西はりま天文台、〒679-53　兵庫県佐用郡佐用町大撫山

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Empirical Effective Temperature Scale of A and F Stars

Ken-ichi KATO[1)] and Takehiko KURODA[2)]

Osaka Electric-Science Museum

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Abstract

Effective temperatures T_{eff} of 404 normal A and F stars are empirically determined from a comparison of ultraviolet, visual, and infrared fluxes with the Kurucz's (1979) grid of models. The ultraviolet fluxes measured by the ANS (Astronomical Netherland Satellite), optical spectrophotometric data, and (R–I) color indices have been calibrated to derive the UV color temperature T_{ANS}, the visual temperature T_{vis}, and the IR color temperature T_{IR}. These three temperatures agree well with each together at $T_{eff} < 8500$K. Final effective temperatures estimated for each star as a mean value of the three temperatures are in good agreement with the result of the direct method and recent determinations by the infrared flux method, but they slightly deviate from the sequence of ultraviolet temperatures towards higher as T_{eff} increases. We find no tendency suggested by Böhm-Vitense (1982) that the T_{eff}-(B–V) relation has two branchings for the late A and early F stars. It is also found especially for early A stars that the spread appeared in T_{eff}-(B–V) diagram is well reproduced by adopting the solar composition models with different surface gravity of $\log g = 3.5 \sim 4.5$. Finally we show the empirical T_{eff} sequence plotted for (b–y) color is systematically lower than the theoretical T_{eff}-(b–y) relation of Kurucz (1979).

Key words: Effective temperature, A and F stars, Stellar fluxes

1 Introduction

The effective temperature T_{eff} is an important key parameter to characterize the stellar radiative fluxes. It is defined by

$$f = \theta^2 \sigma T_{eff}^4 / 4, \qquad (1)$$

Present address:
1)The Science Museum of Osaka, Nakanoshima, Kita-ku, Osaka 530
2)Nishiharima Astronomical Observatory, Sayo-cho, Nishiharima, Hyogo 679-53

where f is the total stellar flux received at the top of the Earth, θ is the angular diameter of the star, and σ is the Stefan-Boltzmann constant. So the effective temperature of a star can be found from observations of its angular diameter and the total flux, integrated over entire spectral range. This is the principle of the "direct method" in the meaning of Böhm-Vitense (1981). In 1976, Code et al. (1976) have obtained the effective temperatures of 12 bright A and F stars by applying this "direct method".

In a series of papers Blackwell and his co-workers (Blackwell and Shallis 1976; Blackwell et al. 1979, 1980; Saxner and Hammarbäck 1985; Leggett et al. 1986) have tried to determine the effective temperature and the angular diameter of a star using the "infrared flux method". They use the integrated stellar flux and the absolute flux at one arbitrary IR wavelength point measured at the Earth. The observed infrared flux is compared with the model fluxes, and an appropriate combination of infrared flux, angular diamter, and effective temperature can be obtained after some trials. To the present the effective temperature has been determined for about 60 A and F stars by the use of this "semi-direct" method.

In addition, without information on the distance to stars we can find the stellar effective temperature from a comparison of the measured relative energy distribution with a grid of theoretical fluxes. This is called as "indirect method" (Böhm-Vitense 1981). For normal A and F stars, this is employed by Adelman(1978; 17 stars, based on the scanner observations of the visual region), by Adelman et al.(1980; 24 stars), by Kontizas and Theodossiou (1980; 12 A stars, using the flux measurements of ultraviolet and visual region), by Böhm-Vitense(1982; 98 stars, UV observations of the TD-1 satellite), by Malagnini et al.(1982; 113 stars, UV observations of the TD-1), and by Glushneva (1983; 4 stars, scanner observations of the visual region).

Recent stellar flux observations of the ultraviolet region by the satellites TD-1, ANS, and IUE give much information on the stellar effective temperature scale. Such a progress in this field is reviewed by Böhm-Vitens(1981), and for the results of F and early G type dwarf Saxner and Hammarbäck(1985) summarize the calibration methods adopted by many workers.

In order to establish empirically a reliable temperature scale it is indispensable to find effective temperatures for many stars all we can. Nowadays the flux data from ultraviolet to infrared for a fairy large number of A and F stars are available. In this study a total of 704 flux data for 404 normal A and F stars are calibrated in the manner of "indirect method". The scanner observations of the visible region are compared with the model fluxes of Kurucz(1979) for 258 stars, and the ultraviolet flux ratio of $F(1977)/F(2493)$ and the IR color index are also used to derive the effective temperatures for 208 and 274 stars, respectively.

2 Observational Data

Observational data for all the stars adopted in this study are taken from the literature listed in Table 1. These stars are chosen under the following criterion:

- spectral type of A or F, including some late B and early G stars,

Table 1

Sources of the flux data

	Stars	Authors
Ultraviolet	208	Wessel-ius et al. (1982)
Visual	258	Breger (1976) Böhm-Vitense and Johnson (1977) Adelman (1978) Adelman et al. (1980) Tüg (1980) Ardeberg and Virdefors (1980) Cochran (1980) Trodahl et al. (1981)
R-I	274	Johnson et al. (1966) Hoffleit (1982)

- luminosity class from III to V,
- normal stars (including some Am stars, Ap or Fp stars are excluded),
- stars of color excess $E(B-V)$ <0.06. Highly reddened stars are ruled out,
- photometric data of visual and ultraviolet region, or at least one of them, are available.

Flux data for the visual region ranging from 3000Å and 7000Å are those obtained by the scanner spectrophotometry with bandwidth of 10 to 100Å except Cochran's (1980) CCD observations. Most of the stars adopted in this study are taken from the Breger's (1976) catalogue which lists 937 sets of measurements. In the last column of Table 4, sources of the visual data are noted. The Ardeberg and Virdefors (1980) catalogue includes the spectrophotometric data of scanner observations for 356 stars measured after the compilation by Breger (1976). The CCD spectrophotometry longward of 5000Å by Cochran (1980) are also used to supplement other scanner observations. When necessary these visual measurements are transformed into the Hayes and Latham's (1975) calibration system referred to the standard star α Lyr.

All the ultraviolet data are taken from the ANS (Astronomical Netherlands Satellite) catalogue (Wesselius et al. 1982), which contains the mesurements of five broad bands ranging from 1550Å to 3300Å for 353 point sources. We find flux data for fainter F stars in this catalogue much more than in the TD-1 catalogue (Jamer et al. 1976). Photometric data observed at the two bands named as 18 (central wavelength = 1799Å, band width = 149Å) and 25 (central wavelength = 2493Å, and band width = 150Å) are employed to derive the effective temperatures in Table 4.

On the data reduction of the ANS data, see Wesselius et al. (1980).

The *R–I* color indices are chosen from Johnson et al.'s (1966) *UBVRIJKL* photometry for 1567 stars, and for some stars from Hoffleits's (1982) *The Bright Star Catalogue.*

3 Determination of Color Temperatures

3.1 Visual Temperature

Continuum fluxes of the visual region, corrected for interstellar reddening, are graphically superimposed on the model fluxes constructed by Kurucz (1979) to derive the visual effective temperature T_{vis}. The correction for interstellar extinction is made following Kontizas and Theodossiou (1980) taking the extinction law of $A_v/E(B-V) = 3.24$. It is a mean value of the data in several regions (Johnson 1977). In this study the interstellar absorption has no serious effect on deriving the effective temperature. The main source of error in T_{vis} is in the use of a grid of models spaced every 500K in T_{eff}. This leads to a possible error of 2 to 3% in T_{vis}, but at the final stage it will disappear through the statistical process.

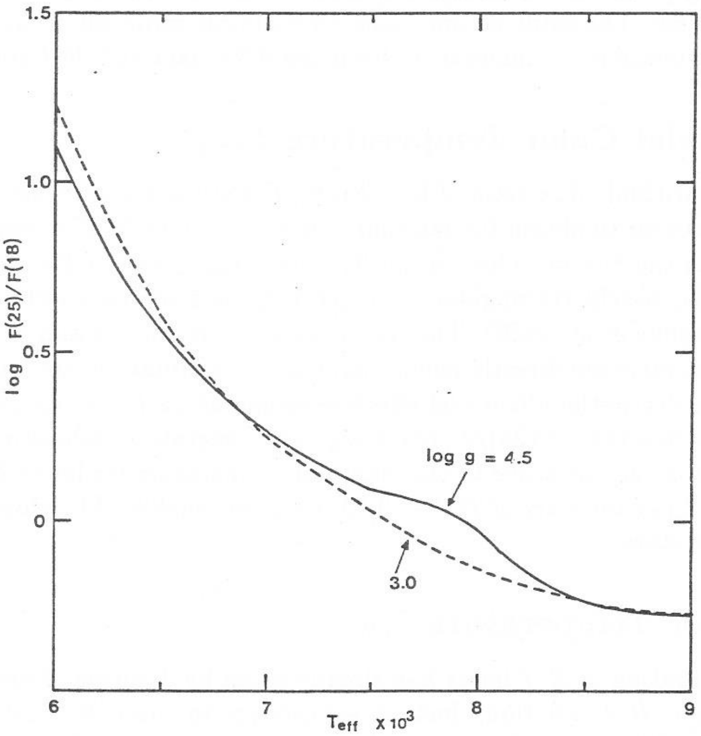

Fig. 1. The relation between T_{eff} and the UV color $\log(F(25)/F(18))$. Computed from the Kurucz's (1979) model fluxes. The flux ratio varies strongly with the effective temperature at $T_{eff} < 7500$K and weakly depends on gravity.

Table 2

The relation between T_{eff} and the UV flux ratio of $\log(F(25)/F(18))$.

T_{eff}	log g			
	3.0	3.5	4.0	4.5
6000	1.229	1.196	1.154	1.102
6500	0.602	0.589	0.578	0.568
7000	0.248	0.254	0.261	0.271
7500	0.041	0.060	0.079	0.097
8000	-0.140	-0.081	-0.047	-0.019
8500	-0.237	-0.240	-0.240	-0.237
9000	-0.268	-0.269	-0.270	-0.272

We assume that all the stars have a solar chemical composition, and that the surface gravity log g for stars of luminosity class III is 3.5 and for stars of IV and V is 4.5, respectively. The same assumptions on chemical composition and gravity are kept in the estimation of temperature from the ANS data and R–I colors.

3.2 Ultraviolet Color Temperature T_{ANS}

We adopt the logarithmic flux ratio of log $(F(25)/F(18))$ as a ultraviolet temperature indicator. In order to obtain the relation of the ratio and effective temperature, we have calculated the flux ratio for various T_{eff} from Kurucz's (1979) model fluxes combined with the nearly rectangular responce functions of the spectrometer on board ANS (Wesselius et al. 1980). The result is shown in Table 2 and in Figure 1. The measured flux ratio are directly compared with the calibration curve in Table 2 and in Figure 1 to derive the ultraviolet effective temperature T_{ANS}. As can be seen from Figure 1 the flux ratio $F(25)/F(18)$ is a good temperature indicator at $T_{eff}<$ 7500K, because it is very sensitive to the choice of temperature for lower T_{eff}. But, it turns out that T_{ANS} for stars of B–$V<$ 0.15 is not so reliable. Therefore we have omitted such blue stars.

3.3 IR Color Temperature T_{IR}

An empirical calibration of R–I index has already given by Johnson (1966), but we do not use his T_{eff}-(R–I) relation. Instead we calulate intrinsic R–I color indices for the Kurucz's (1979) model fluxes to make the analysis self-consitent. The computaion is made integrating numerically the convolution of the theoretical fluxes with the responce functions of filters. The filter functions are taken from Johnson (1965).

It is necessary to find a standard star to define the zero point of the R–I index system. For Vega, Johnson et al. (1966) give R–$I= -0.03mag$. We can construct a calibration system taking this value as a standard and combining this with the Kurucz's (1979) Vega model of (T_{eff}, log g) = (9400, 3.95). However this system seems to give somewhat lower effective temperature for F and G dwarfs. Hayes (1979) argues that the Johnson's (1966) calibration should be slightly changed for Vega by $+0.03mag.$ for R filter. When we adopt the "absolute" calibration system of Hayes, the $R–I$ value of Vega should be read as just $0.0mag.$ This makes reminiscent of the Crawford's (1975) investigation for $R–I$ values of Johnson et al. (1966). He has found an accident error of $0.03mag.$ in a single observation made by Johson et al.

To clarify the problem concerning zero point of the ($R–I$) system, we have selected 34 stars of spectral types A0IV and A0V from the catalogue and the following mean color indices are obtained for $B–V$ and $R–I$:

$$< B - V >= +0.0003, \quad \text{and} \quad < R - I >= -0.010.$$

Next, the mean $R–I$ magnitude for $B–V= 0.0$ stars is computed from the data of 13 stars. It is $-0.005mag.$ These facts show that Vega ($R–I= -0.03$) is not a star appropriate for a standard of the ($R–I$) system, but we should conform to an ideal star of $B–V= 0.0$ or A0. Since this is actually the same as the Hayes' system, we prefer his calibartion system noted above.

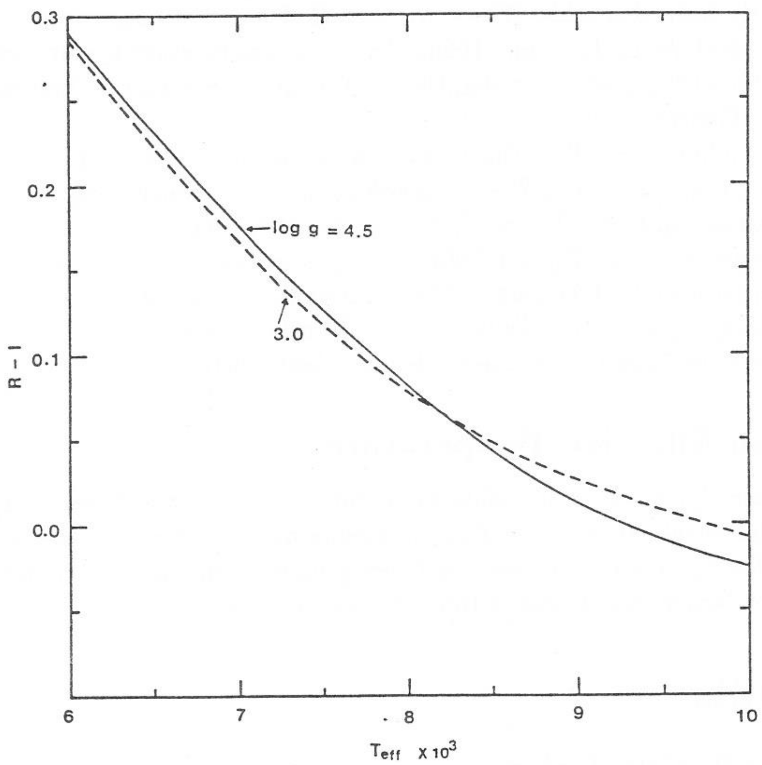

Fig. 2. The relation between the color index $R–I$ and T_{eff} computed from the Kurucz's (1979) models.

Table 3
The relation of T_{eff} and $(R\text{–}I)$

T_{eff}	log g				Johnson
	3.0	3.5	4.0	4.5	(1966)
6000	0.286	0.288	0.290	0.291	0.29
6500	0.223	0.226	0.229	0.233	0.23
7000	0.167	0.170	0.175	0.179	0.17
7500	0.118	0.119	0.123	0.128	0.14
8000	0.078	0.075	0.078	0.083	0.08
8500	0.048	0.043	0.041	0.042	0.04
9000	0.026	0.020	0.015	0.012	0.02
9500	0.008	0.001	-0.004	-0.009	0.00
10000	-0.007	-0.014	-0.020	-0.025	-0.03
11000	-0.036	-0.041	-0.046	-0.050	-0.08

The temperature scale finally obtained is shown in Table 3 and in Figure 2 along with Johnson's (1966). The infrared color temperatures T_{IR} in Table 4 are derived directly from this table. The computed $R\text{–}I$ colors are unexpectedly in good agreement with those of Johnson (1966). With this calibration system we find the solar $R\text{–}I$ color of 0.32, which is slightly small compared with previous studies for the Sun (e.g., Gehren 1982).

The error inherent in T_{IR}, the most large error source among three effective temperatures (T_{vis}, T_{ANS}, and T_{IR}), is a serious problem concerning the zero point of the calibration system. The shift of zero point by 0.01 *mag.* in $R\text{–}I$ yields a systematic error of 4% at T_{eff}=10000K. In addition we must take account of the observational error up to 0.03 *mag.* in the photometric data of Johnson et al. (Crawford 1975; Barry et al. 1977; Taylor 1986). The large scatter in T_{IR} sequence at higher temperature is probably due to this accidental error.

3.4 Mean Effective Temperature

The final mean T_{eff}($< T >$ in Table 4) is computed from the three temperatures giving a higher weight to T_{vis} and T_{ANS} in averaging the individual values. Weights for T_{vis} and for T_{ANS} are taken as four times greater than that of T_{IR}, because the error in T_{IR} is larger than those in the other two temparatures.

4 Results

4.1 T_{eff}-$(B\text{–}V)$Relation

Table 4 shows the final result for individual stars. The consective columns are as follows: HD number (column 1), other designation (column 2), spectral type

Table 4.

Derived stellar effective temperatures. HD number, proper name, spectral type, B–V, and rotational velocity (km/sec) are also shown. $< T >$ shows the finally adopted weighted mean effective temperature. The last column indicates the reference of the visual data:

A = Ardeberg and Virdefors (1980);
A7 = Adelman (1978);
A8 = Adelman et al. (1980);
B = Breger (1976);
BJ = Böhm-Vitense and Johnson (1977);
C = Cochran (1980);
T = Tüg (1980);
TSG = Trodahl et al. (1981).

HD	Name	SPCTR	B-V	ROT	T_{VIS}	T_{ANS}	T_{IR}	⟨T⟩	Ref
432	β Cas	F2 III-IV	.34	70	7000	6980	6730	6960	B
1280	θ And	A2 V	.06	107	8700	--	9040	8770	B,A8
4150	η Phe	A0 IV	.00	96	9500	--	9270	9450	B
5015	HR 244	F8 V	.53	6	--	6030	5930	6010	
5448	μ And	A5 V	.13	72	8250	--	8030	8210	B
6763	80 Psc	F0 III-IV	.34	--	6950	--	6730	6910	A,BJ
6870		A5 III	.26	--	7300	--	--	7300	B
6961	θ Cas	A7 V	.17	102	--	8040	8140	8060	
7964	υ Psc	A3 V	.03	93	8900	--	8390	8800	B
8538	δ Cas	A5 III-IVv	.13	113	8450	--	7810	8320	B
9826	υ And	F8 V	.54	8	--	5940	6010	5950	
11171	χ Cet	F3 III	.33	61	--	6940	7100	6970	
11257	HR 534	F2 Vw	.30	--	7150	--	7090	7140	A,BJ
11636	β Ari	A5 V	.13	79	8300	--	8030	8250	B,C
11753	φ Phe	A3 V	-.06	13	11000	--	11420	11080	B
11973	λ Ari	F0 V	.28	99	--	7350	7180	7320	
12111	48 Cas	A3 IV	.16:	67	--	8130	8030	8110	
12311	α Hyi	F0 V	.28	153	7450	--	7380	7440	B,T
13041	58 And	A5 IV-V	.12	133	8150	--	8140	8150	A7
14055	γ Tri	A1 Vnn	.02	208	9300	--	9270	9290	B,A7
15008	δ Hyi	A3 V	.03	163	9500	--	9040	9410	B
15130	ρ Cet	B9.5 Vn	-.03	191	10000	--	10180	10040	B
15318	ξ^{2} Cet	B9 III	-.06	63	10000	--	11350	10270	B
15550	26 Ari	A9 V	.25	152	7800	--	--	7800	B
15798	σ Cet	F4 IV	.45	12	6400	--	6180	6360	B
16754	HR 789	A2 V	.06	190	9000	--	9040	9010	B
16895	θ Per	F8 V	.49	6	--	6060	5940	6040	
16970	γ Cet	A3 V	.09	183	8200	--	8530	8270	B
16978	ε Hyi	B9 V	-.06	110	11000	--	--	11000	B
17094	μ Cet	F0 IV	.31	54	7200	7280	6900	7200	B
17584	16 Per	F2 III	.34	149	7000	--	6470	6890	B
18331	HR 875	A1 Vn	.08	231	8250	--	8390	8280	B
18978	τ^{3} Eri	A4 IV	.16	144	8200	8130	7920	8140	B,TSG
19767		F0 Vn	.32	140	7000	--	--	7000	A,BJ
19954		A7 V	.25	85	7080	--	--	7080:	BJ
20010	α For	F8 V	.52	0	--	6030	5860	6000	
20150	ζ Ari	A1 V	-.01	128	9850	--	10180	9920	B
20430		F8 V	.57	6	5850	--	--	5850	B
20439	HY 2	G0 V	.61	--	5700	--	--	5700	B
21364	ξ Tau	B9 Vn	-.09	33	12000	--	12680	12140	B
22001	κ Ret	F5 IV-V	.40	0	7000	--	6990	7000:	B
22484	10 Tau	F9 V	.58	0	--	5860	5780	5840	
23246		A8 V	.27	195	7400	--	--	7400	A
23326		F3 V	.39	20	6650	--	--	6650	A
23609		F8 IV	.50	--	--	6340	--	6340	
23754	τ^{6} Eri	F3 III	.42	6	--	6520	6550	6530	
23791	HZ 1993	A8 V	.26	89	7230	--	--	7230	A
23863		A7 V	.22	165	7900	--	--	7900	A
24132		F2 V	.38	209	6750	--	--	6750	A
24167	HR 1197	A5 V	.20	151	7500	--	--	7500	B

HD	Name	SPCTR	B-V	ROT	T_{VIS}	T_{ANS}	T_{IR}	⟨T⟩	Ref
24357	HR 1201	F4 V	.34	59	6800	--	7080	6860	A, BJ
24832	HR 1225	F1 V	.28	120	--	7430	--	7430	
25102	HR 1233	F5 V	.42	54	--	6420	6620	6460	
25490	ν Tau	A1 V	.03	69	9000	--	9270	9050	B
26015	HR 1279	F3 V	.40	25	--	6630	6710	6650	
26322	44 Tau	F2 IV-V	.34	0	7000	--	--	7000	B
26345		F6 V	.42	18	--	6380	--	6380	
26462	45 Tau	F4 V	.36	6	6800	6810	6900	6820	B, BJ, A
26612	δ Hor	A9 V	.33	193	--	6970	6710	6920	
26737		F5 V	.42	68	--	6370	--	6370	
26784	HY 19	F8 V	.51	12	6050	--	--	6050	B
26911	48 Tau	F5 V	.40	53	6780	--	6710	6770	BJ, A
27176	51 Tau	F0 V	.28	97	7200	7560	7180	7360	A7
27383		F7V + G3V	.56	18	--	6080	--	6080	
27397	57 Tau	F0 IV	.28	109	7250	7290	7180	7260	B, A, BJ
27429	HR 1354	F3:V	.37	132	6780	6640	6800	6720	A, BJ
27459	58 Tau	F0 V	.22	65	7700	7670	7580	7670	B
27483	HR 1358	F6 V	.46	12	--	6440	6350	6420	
27524	HY 35	F5 V	.44	94	6400	6300	--	6350	B
27534		F5 V	.44	40	--	6290	--	6290	
27561		F4 V	.41	12	--	6450	--	6450	
27691		G0	.56	8	--	6120	--	6120	
27749	63 Tau	A1 m	.30	10	7400	--	7180	7360	B
27808		F7 V	.46	12	--	6110	--	6110	
27819	δ² Tau	A7 V	.15	59	8000	8100	8140	8060	B, A8
27836	HY 50	G1 V	.60	--	5750	--	--	5750	B
27848		F6 V	.44	30	--	6200	--	6200	
27901	HR 1385	F4 V	.37	125	6700	6790	6620	6730	B
27934	κ¹ Tau	A7 IV-V	.13	81	8100	--	8390	8160	B
27946	κ² Tau	A7 V	.25	153	--	7630	7380	7580	
27962	δ³ Tau	A2 IV	.05	18	8700	--	9040	8770	B
27991	70 Tau	F7 V	.49	15	--	6120	6350	6170	
28024	υ Tau	A8 Vn	.26	196	7200	7350	7380	7290	A, BJ
28294	76 Tau	F0 IV	.32	102	7050	7110	6900	7060	B
28319	θ² Tau	A7 III	.18	78	7850	7750	7810	7800	B
28355	79 Tau	A7 V	.23	104	--	7630	8030	7710	
28363		F7 V	.53	30	--	6070	--	6070	
28394		F7 V	.50	25	--	6180	--	6180	
28406		F8	.45	20	--	6240	--	6240	
28483		F6 V	.47	18	--	6190	--	6190	
28485	80 Tau	F0 V	.32	134	--	7150	6900	7100	
28527	HR 1427	A6 IV	.17	71	7800	7980	8140	7920	A7
28556	83 Tau	F0 V	.26	95	--	7500	7380	7480	
28568		F5 V	.43	53	--	6310	--	6310	
28677	85 Tau	F4 V	.34	109	--	6890	6800	6870	
28736	HR 1436	F5 V	.42	35	--	6370	6350	6370	
28910	ρ Tau	A8 V	.25	117	7500	7500	7580	7510	A7, BJ, A
28911		F2	.43	40	--	6380	--	6380	
28992		G1 V	.63	--	5800	--	--	5800	B
29140	88 Tau	A5 m	.18	35	8500	--	7800	8360	B
29169	HR 1459	F5 IV	.38	80	--	6610	6710	6630	
29225		F5 V	.44	41	--	6470	--	6470	
29375	89 Tau	F0 V	.31	115	--	7170	7180	7170	
29388	90 Tau	A6 V	.12	79	8350	--	8390	8360	B
29488	σ² Tau	A5 Vn	.15	117	--	8170	8140	8160	
29499	HR 1480	A5 m	.26	55	--	7340	7580	7390	
29875	α Cae	F2 V	.34	52	--	7010	6710	6950	
30034	HR 1507	F0 V	.25	86	--	7580	7480	7560	
30210	HR 1519	A m	.19	47	--	7890	8030	7920	
30676		F8 V	.56	13	--	6070	--	6070	

HD	Name	SPCTR	B-V	ROT	T_{VIS}	T_{ANS}	T_{IR}	⟨T⟩	Ref
30739	π^2 Ori	A1 Vn	.01	212	9800	--	9270	9690	B
30780	97 Tau	A7 IV-V	.21	141	--	7530	7580	7540	
30869		F6 V	.50	25	--	6400	--	6400	
31236	HR 1566	F3 IV	.29	102	--	7240	7180	7230	
31845		F5 V	.45	25	--	6240	--	6240	
32301	ι Tau	A7 V	.16	126	--	8090	7920	8060	
32537	9 Aur	F0 V	.33	14	--	7000	6800	6960	
32608	HR 1639	A5 V	--	80	8050	--	--	8050	B, A7
32846	γ Cae	F1 III	.30	--	--	7160	--	7160	
33111	β Eri	A3 III	.13	179	8400	--	7930	8310	B
33276	15 Ori	F2 IV	.32	53	7250	7220	6900	7200	B
33959	14 Aur	A9 IV δ Del	.23	24	8000	7620	--	7810	B
36777	38 Ori	A2 V	.05	145	9000	--	8530	8910	B
36865		B8 V	-.07	220	11000	--	--	11000	B
37112		B6 V	-.08	230	11500	--	--	11500	B
38678	ζ Lep	A3 Vn	.10	202	8500	--	8680	8540	B, TSG, A7
38899	134 Tau	B9 IV	-.07	22	11000	--	12260	11250	B
39014	δ Dor	A7 V	.21	206	8000	7860	7080	7840	B
39060	β Pic	A5 V	.17	139	8200	--	7180	8000	B
40136	η Lep	F1 III	.33	0	7200	6970	7090	7090	TSG, A7
40535	1 Mon	F2 IV	.29	25	7300	7130	--	7220	B
40536	2 Mon	A6 m	.19	23	--	7950	7920	7940	
42818	HR 2209	A0 Vn	.03	320	8950	--	9530	9070	A8
44769	ε Mon	A5 IV	.18	124	--	7950	7800	7920	
47105	γ Gem	A0 IV	.00	32	9400	--	9530	9430	B, C, A8
48737	ξ Gem	F5 III	.43	70	--	6320	6470	6350	
48915	α CMa	A1 Vm	.00	13	9800	--	10180	9880	B
50241	α Pic	A7 IV	.21	205	7800	--	7480	7740	B
50747	HR 2572	A4 IV	.18	70	--	8100	--	8100	
53704	HR 2666	A m	.20	62	--	7870	7580	7810	
55892	HR 2740	F0 IV	.32	54	--	7040	6620	6960	
56986	δ Gem	F0 IV	.34	111	7000	7030	6900	7000	B
58715	β CMi	B8 Ve	-.09	276	11500	--	11420	11480	B
58923	η CMi	F0 III	.22	67	--	7480	--	7480	
58946	ρ Gem	F0 V	.32	68	7100	7110	6900	7080	B, A7
59037	64 Gem	A4 V	.11	202	8330	--	--	8330	A7
59881	δ^1 CMi	F0 III	.22	75	--	7330	--	7330	
60532	HR 2906	F6 IV	.51	0	--	6130	6180	6140	
61110	ο Gem	F3 III	.40	89	--	6550	6550	6550	
61421	α CMi	F5 IV-V	.42	6	6560	6370	6530	6470	B, C
62437	HR 2989	F0 III:	.20	--	--	7750	--	7750	
62952	4 Pup	F0 V	.33	101	--	7240	--	7240	
67006	27 Lyn	A2 V	.05	168	9200	--	9270	9210	A7
68457	HR 3221	A7 Vm	.20	--	--	7830	--	7830	
70060	HR 3270	A7 III	.22	129	--	7600	7380	7560	
71906	HR 3348	A0 V	-.03	56	10000	--	--	10000	A8
73161		F0 Vn	--	159	7180	--	--	7180	A
73210		A5 V	.19	72	--	7860	--	7860	
73262	δ Hya	A1 Vnn	.00	249	10000	--	9040	9810	B
73430		A9 V	.23	73	7850	--	--	7850	A
73450		A7 V	.25	132	7630	--	--	7630	A
73575		F0 III	.25	158	--	7290	--	7290	
73576		A6 V	.20	210	--	7860	--	7860	
73712		F0 V	.26	55	--	7450	--	7450	
73730		A m	.19	30	--	7800	--	7800	
73731	ε Cnc	A5 m	.17	82	--	8000	8260	8050	
73746		A9 V	.29	95	7250	--	--	7250	A
73785		A9 III	.20	110	--	7600	--	7600	
73819		A7 V	.17	140	--	8070	--	8070	
73854		F0 V	.36	116	7050	--	--	7050	A

HD	Name	SPCTR	B-V	ROT	T_{VIS}	T_{ANS}	T_{IR}	⟨T⟩	Ref
73890		A7 V	.24	141	--	7470	--	7470	
73937		F2 III	.39	49	6700	--	--	6700	A
74028		A7 III	.21	180	7850	7920	--	7890	A
74198	γ Cnc	A1 IV	.02	79	9500	--	9270	9450	A7
75737	15 Hya	A4 m	.15	25	--	8110	--	8110	
75811	HR 3526	A5 V	.12	43	8050	--	--	8050	A8
76543	o^1 Cnc	A5 III	.15	89	--	7980	--	7980	
76644	ι UMa	A7 IV	.19	151	8050	7850	8140	7970	B, A8
76943	10 UMa	F5 V	.44	26	--	6430	6620	6470	
78154	σ^2 UMa	F6 IV	.49	0	--	6090	6090	6090	
78362	τ UMa	A m	.35	18	7300	6880	7480	7130	B
79439	18 UMa	A5 V	.19	157	--	8020	7920	8000	
79469	θ Hya	B9.5	-.06	81	11000	--	--	11000	B
79940	HR 3684	F5 III	.45	100	--	6410	6060	6340	
80007	β Car	A2 IV	.00	133	9050	--	8850	9010:	B
81937	23 UMa	F0 IV	.33	140	6900	7040	6990	6970	A8
81997	τ^1 Hya	F6 V	.46	28	--	6230	6620	6310	
82328	θ UMa	F6 IV	.46	12	6400	6220	6180	6300	B
82434	ψ Vel	F3IV+F0IV	.36	201	--	6950	6620	6880	
82621	26 UMa	A2 V	.01	180	8800	--	9040	8850:	A8
84999	υ UMa	F2 IV	.29	110	7250	7170	7180	7210	B
87427	HR 3965	A8 V	.30	--	--	7310	--	7310	
87696	21 LMi	A7 V	.18	148	8200	7960	8140	8090	B
87887	α Sex	A0 III	-.04	9	11000	--	11350	11070:	B
88955	HR 4023	A2 V	.05	91	9500	--	8850	9370	B
89021	λ UMa	A2 IV	.03	48	9000	--	9530	9110	B
89025	ζ Leo	F0 III	.31	84	7000	6930	6820	6950	B
89449	40 Leo	F6 IV	.45	16	--	6210	6530	6270	
90277	39 LMi	F0 V	.25	31	7300	7570	7380	7430	A, BJ
90839	36 UMa	F8 V	.52	0	6200	5990	6090	6090	C
91312	HR 4132	A7 IV	.23	132	--	7800	7920	7820	
93549	HR 4220	B7 IV	-.07	201	11500	--	--	11500	B
95418	β UMa	A1 V	-.02	39	9500	--	10570	9710	B
95608	60 Leo	A1 m	.05	24	8500	--	9830	8770	B
97603	δ Leo	A4 V	.12	181	8450	--	8680	8500	B
97633	θ Leo	A2 V	-.01	20	9500	--	10180	9640	B, A8
98058	φ Leo	A7 IVn	.21	225	8000	7570	7690	7770	B
99028	ι Leo	F2 IV	.41	20	6750	6600	6710	6680	B
99211	γ Crt	A5 V	.21:	131	--	7930	7690	7880	
100889	θ Crt	B9.5	-.08	192	11000	--	11840	11170	B
102647	β Leo	A3 V	.09	121	8550	--	8850	8610	B, C
102870	β Vir	F9 V	.55	3	6100	--	6090	6100	B, C
103287	γ UMa	A0 Ve	.00	168	9300	--	10180	9480	B, A8
103578	95 Leo	A3 V	.11	54	8400	--	--	8400	B, A8
104513	67 UMa	A7 m	.26	76	--	7490	7690	7530	
105452	α Crv	F2 III-IV	.32	16	--	6990	6910	6970	
105850	3 Crv	A2 V	.06	124	9000	--	--	9000	TSG
106591	δ UMa	A3 V	.08	177	8800	--	9270	8890	B, A8
106691		F3 V	.40	30	6650	--	--	6650	A, BJ
106946		F3 V	.35	50	6950	--	--	6950	A, BJ
107131	HR 4684	A5-7mIV-V	.18	175	8130	8050	8140	8100	B
107259	η Vir	A2 IV	.02	34	8750	--	9270	8850	B
107276		A m	.17	95	--	8110	--	8110	
107326	HR 4694	F0 IV	.30	109	7300	--	7380	7320	B
107513		A9 V	.28	50	7280	--	--	7280	A, BJ
107904	4 CVn	F3 III-IV	.33	73	7100	6730	--	6920	B
107966	13 Com	A3 V	.08	54	8500	--	8850	8570	A, BJ
108844	74 UMa	A5 δ Del	.20	87	--	7760	8260	7860	
109358	β CVn	G0 V	.59	3	5750	--	5860	5770	B
110379	γ Vir	F0 V	.36	28	--	6960	6900	6950	

HD	Name	SPCTR	B-V	ROT	T_{VIS}	T_{ANS}	T_{IR}	⟨T⟩	Ref
111597	HR 4874	A0 IV	-.04	178	10000	--	--	10000	TSG
113139	78 UMa	F2 V	.36	92	6800	6870	6710	6820	A,BJ
114330	θ Vir	A1IVs+Am	-.01	15	9400	--	9530	9430	B,C,A8
114710	β Com	G0 V	.57	6	5900	--	5940	5910	B
115308	HR 5005	F1 IV	.31	51	7300	--	--	7300	B
115331	HR 5008	A m	.20	--	--	8080	7920	8050	
115604	20 CVn	F3 III	.30	17	7200	--	7190	7200	B
116842	80 UMa	A5 V	.16	218	8150	8000	8140	8080	B,A8
118216	HR 5110	F2 IV	.40	0	6300	--	5940	6230:	B
119756	1 Cen	F3 IV	.38	86	--	6630	6710	6650	
119765	HR 5169	A1 V	.00	77	9250	--	--	9250	A8
120136	τ Boo	F6 IV	.48	14	6300	--	6440	6330	B
121370	η Boo	G0 IV	.58	13	5850	5950	6020	5910	B
122408	τ Vir	A3 V	.10	150	8350	--	8260	8330	B,A8
123299	α Dra	A0 III	-.05	18	9800	--	12150	10270	A7
123999	12 Boo	F9 IVw	.54	26	--	5930	6020	5950	
124675	κ² Boo	A8 IV	.20	127	8000	7710	7580	7820	B
124683	HR 5332	A1 V	-.03	74	9900	--	--	9900	A8
124850	ι Vir	F6 III	.52	15	6300	--	6140	6270	B
124953	HR 5343	A8 III	.26	--	--	7490	7590	7510	
125161	ι Boo	A9 V	.20	137	8070	7810	7920	7940	B,A,BJ
125337	λ Vir	A2 m	.13	16	8000	--	8260	8050	B
126354	τ² Lup	A7: +F4IV	.43	0	6200	--	5540	6070:	B
126660	θ Boo	F7 V	.50	34	6250	--	6350	6270	B
127762	γ Boo	A7 III	.19	139	7700	--	7930	7750	B
128167	σ Boo	F2 V	.36	3	6850	--	6900	6860	B,A,BJ
129502	μ Vir	F2 III	.38	54	6850	6650	6550	6730	B
130109	109 Vir	A0 V	-.01	351	9500	--	9830	9570	B,C,TSG
130841	α² Lib	A3 IV	.15	84	--	8070	8530	8160	
132052	16 Lib	F0 V	.32	117	--	7080	7080	7080	
134083	45 Boo	F5 V	.43	45	6600	--	6710	6620	B
135379	β Cir	A3 V	.09	59	8450	--	--	8450	TSG
137006	8 Ser	F0 V	.25	105	7500	--	7580	7520	A,BJ
137391	μ¹ Boo	F0 IV	.31	84	7100	7110	7280	7120	B,A,BJ
138918	δ Ser	F0 IV	.26	80	--	7520	7690	7550	
139006	α CrB	A0 V	-.02	133	9600	--	10570	9790	A
139664	HR 5825	F5 IV-V	.40	87	--	6510	6800	6570	
140436	γ CrB	B9 IV+A3V	.00	112	9500	--	9830	9570	A8
142373	χ Her	F8VFe-2H-	.56	0	--	5840	5780	5830	
142860	γ Ser	F6 V	.48	8	6300	6110	6440	6230	B
143466	HR 5960	F0 IV	.26	140	7200	7300	7380	7260	B
143584	HR 5964	F0 IV	.29	63	7250	--	--	7250	B
144070	ξ Sco	F5 IV	.47	27	6250	--	6440	6290	B
144284	θ Dra	F8 IV	.52	27	--	6050	6350	6110	
147449	σ Ser	F0 V	.34	80	7200	--	7280	7220	B
147547	γ Her	A9 III	.27	141	--	7310	7290	7310	
151613	HR 6237	F2 V	.38	53	--	6730	6710	6730	
151769	20 Oph	F5 IV	.47	13	6100	--	6350	6150	B
153597	19 Dra	F6 Vs	.48	0	--	6130	6180	6140	
154494	60 Her	A4 IV	.12	111	8350	--	8850	8450	B
155125	η Oph	A2 V	.06	26	8600	--	9040	8690	TSG
156164	δ Her	A3 IV	.08	290	8450	--	8680	8500	B,A8
156897	ξ Oph	F1 III-IV	.39	0	--	6700	6550	6670	
157792	44 Oph	A3 m	.28	59	--	7290	7580	7350	
157919	45 Oph	F5 IV δ Sct	.40	25	--	6720	6990	6770	
157950	HR 6493	F3 V	.39	52	6650	6680	6710	6670	B
158352	HR 6507	A8 V	.22	184	--	7550	--	7550	
159492	π Ara	A5 IV-V	.20	48	--	8040	--	8040	
159561	α Oph	A5 III	.15	219	8100	7840	7930	7970	B,C
159876	ξ Ser	F0 IV δ Sct	.26	32	7250	7420	7480	7350	B

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160032	λ Ara	F3 IV	.40	0	--	6530	6620	6550	
160915	58 Oph	F6 V	.47	0	--	6260	6440	6300	
160922	ω Dra	F5 V	.43	26	--	6490	6620	6520	
161868	γ Oph	A0 V	.04	205	9500	--	9270	9450	B, A8
162003	ψ^{1} Dra	F5 IV-V	.42	14	--	6320	6530	6360	
162515	HR 6652	B9.5 V	.02	95	9500	--	--	9500	B
162586	HR 6657	B8 V	-.03	37	11500	--	--	11500:	B
164259	ζ Ser	F2 IV	.38	70	6600	--	6900	6660	B
164577	68 Oph	A2 Vn	.02	252	9000	--	9040	9010	B
166014	ο Her	B9.5 V	-.03	134	9500	--	9270	9450:	B
168914	107 Her	A7 V	.20	183	--	7940	--	7940	
169022	ε Sgr	B9.5 III	-.03	140	9500	--	9860	9570	B
170073	39 Dra	A1 V	.08	175	8600	--	8850	8650	B
170296	γ Sct	A3 Vn	.06	223	8400	--	8390	8400:	TSG
170479	HR 6936	A3 m	.16	120	--	8110	--	8110	
172167	α Lyr	A0 Va	.00	15	9450	--	10180	9600	B
172555	HR 7012	A5 IV-V	.20	134	--	7850	--	7850	
173582	ε^{1} Lyr	A4 V	.16	200	--	8090	--	8090	
173607	ε^{2} Lyr	A8 Vn	.19	177	--	7830	--	7830	
173648	ζ^{1} Lyr	A m	.19	27	--	7800	8030	7850	
173667	110 Her	F6 V	.46	14	6300	6210	6260	6260	B
173880	111 Her	A5 III	.13	79	8250	--	9250	8450	B
174262	HR 7086	A1 V	.03	74	9400	--	--	9400	A8
175638	θ^{1} Ser	A5 V	.17	143	--	8100	--	8100	
176437	γ Lyr	B9 III	-.05	76	9500	--	9860	9570:	B
177196	16 Lyr	A7 V	.19	121	--	7930	7920	7930	
177724	ζ Aql	A0 Vn	.01	331	9250	--	9270	9250	B, A8
177756	λ Aql	B9 Vn	-.09	176	11500	--	12680	11740	B
178253	β CrA	A2 V	.04	201	8700	--	9270	8810	TSG
179366	HR 7278	A m	.18	--	--	7940	--	7940	
180868	ω^{1} Aql	F0 IV	.20	113	--	7940	--	7940	
181333	28 Aql	F0 III	.26	59	7450	7500	--	7480	B
181577	ρ^{1} Sgr	F0 IV-V	.22	68	--	7710	7800	7730	
181623	β^{2} Sgr	F2 III	.34	126	--	6940	--	6940	
182640	δ Aql	F3 IV	.32	85	7100	--	7180	7120	B, C
184552	51 Sgr	A m	.19	16	--	8010	8140	8040	
185395	θ Cyg	F4 V	.38	7	6600	6560	6710	6590	B, A, BJ
185872	14 Cyg	B9 III	-.08	45	10500	--	--	10500:	B
186408	16 Cyg	G1.5 V	.64	2	5700	--	5700	5700	B
186427	HR 7504	G2.5 V	.66	3	5750	--	5620	5720	B
186543	ν Tel	A7 III-IV	.20	--	--	7860	--	7860	
186882	δ Cyg	B9.5IV+F1	-.03	149	10000	--	9830	9970	B
187013	17 Cyg	F7 V	.47	9	--	6210	--	6210	
187642	α Aql	A7 V	.22	242	8000	7820	7380	7850	B, C
187764	HR 7563	F0 III	.28	98	--	7100	--	7100	
188260	13 Vul	B9.5 III	-.06	50	10000	--	11350	10270	B
189849	15 Vul	A4 III	.18:	23	8200	--	7920	8140	B
191692	θ Aql	B9.5 III	-.07	63	10000	--	11350	10270:	B
193432	ν Cap	B9.5 V	-.05	17	10500	--	11420	10680	B
193571	κ^{1} Sgr	A0 V	.00	--	9500	--	9530	9510	TSG
194943	ρ Cap	F2 IV	.38	91	6650	6920	6900	6800	B
195627	π^{1} Pav	F1 III	.28	121	--	7260	--	7260	
196180	ζ Del	A3 V	.11	119	8280	--	8260	8280	B
196362	26 Vul	A5 III	.21	15	--	7970	--	7970	
196524	β Del	F5 IV	.44	54	6400	--	6380	6400	B
196724	29 Vul	A0 V	-.02	54	10200	--	10570	10270	B
196867	α Del	B9 IV	-.06	162	10500	--	10570	10510	B
197051	β Pav	A7 III	.16	86	--	7970	--	7970	
197692	ψ Cap	F4 V	.43	37	6750	6400	6800	6600	TSG
198001	υ Aqr	A1 V	.00	98	9270	--	9270	9270	B, C, TSG

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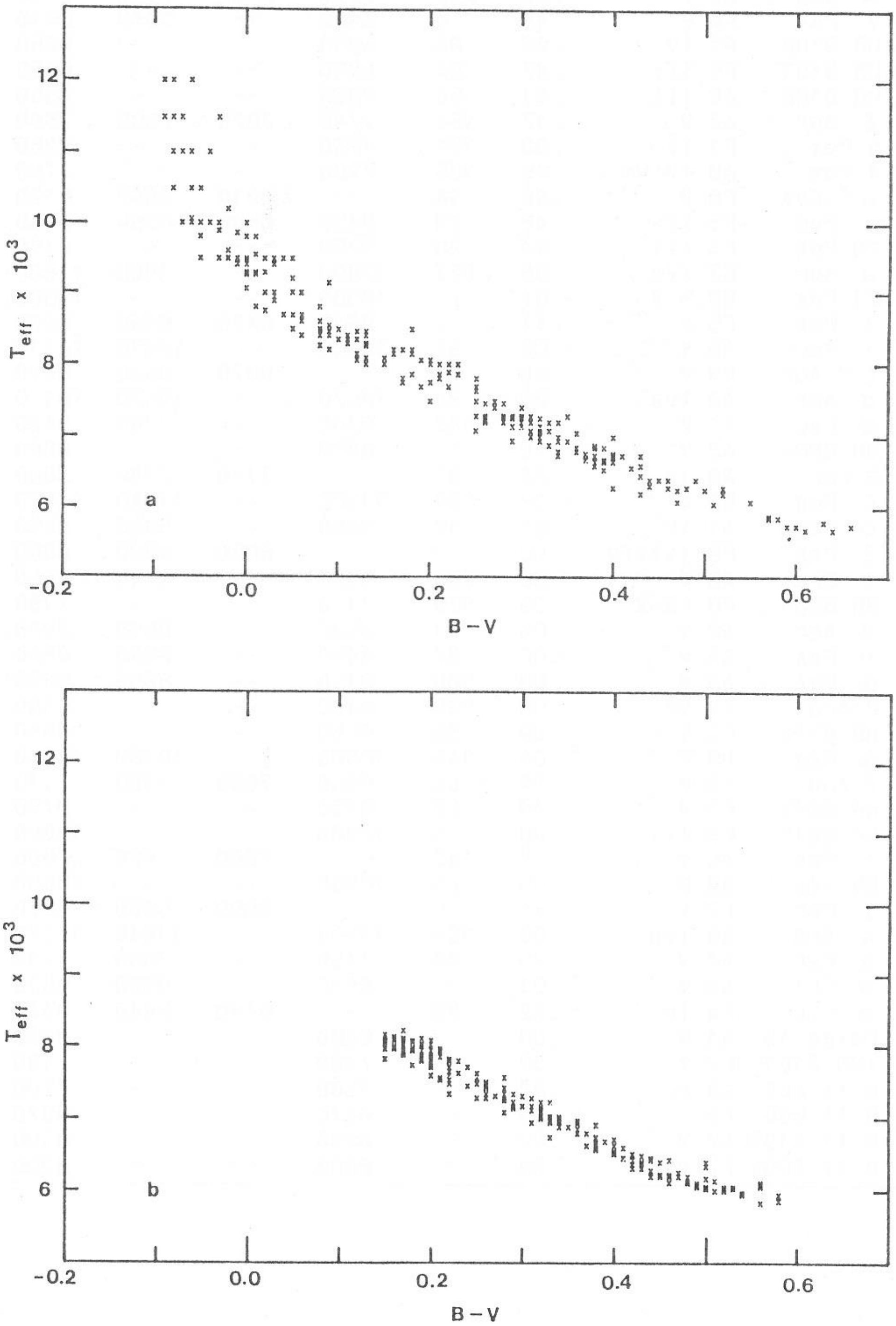
198084	HR 7955	F8 IV-V	.54	0	--	5960	6090	5990	
198639	56 Cyg	A4m δ Del	.20	90	--	7940	7920	7940	
200499	η Cap	A5 V	.17	71	--	8240	8140	8220	
202275	δ Equ	F5 V+G0 V	.50	10	--	6020	6090	6030	
202444	τ Cyg	F2 IV	.39	89	6700	6700	6440	6670	B
202627	ε Mic	A1 V	.06	127	8700	--	--	8700	B
202730	θ Ind	A5 V	.19	178	--	8120	--	8120	
203280	α Cep	A7 V	.22	246	7700	7800	7690	7740	B, A8
203608	γ Pav	F6 V	.49	8	6400	--	5940	6310	TSG
203803	HR 8190	F1 IV	.32	97	6950	--	--	6950	B
203842	HR 8191	F5 III	.47	84	6250	--	--	6250	B
203925	HR 8198	A8 III	.31	53	7000	--	--	7000	B
205767	ξ Aqr	A7 V	.17	154	7740	7920	7800	7830	A, BJ
205852	5 Peg	F1 IV	.30	134	7250	--	--	7250	B
205924	4 Peg	A9 IV-Vn	.25	195	7700	--	--	7700	B
206826	μ^1 Cyg	F6 V	.48	18	--	6210	6090	6190	
206901	κ Peg	F5 IV	.43	29	6450	6500	6350	6460	B
209166	20 Peg	F4 III	.34	20	6750	--	--	6750	B
209409	o Aqr	B7 IVe	-.06	227	12000	--	11000	11800:	B
209459	21 Peg	B9.5 V	-.07	--	10000	--	--	10000:	B
210027	ι Peg	F5 V	.44	7	6310	6470	6350	6390	A, BJ
212061	γ Aqr	A0 V	-.05	57	10000	--	10570	10110	B
213052	ζ^2 Aqr	F3 V	.38	58	--	6670	6530	6640	
213320	σ Aqr	A0 IVs	-.06	23	10070	--	10570	10170:	A7
213558	α Lac	A1 V	.01	146	9300	--	10180	9480	B
214279	HR 8607	A3 V	.12	--	8350	--	--	8350	A7
214454	9 Lac	A8 IV	.24	87	--	7710	7380	7640	
214923	ζ Peg	B8 V	-.09	194	11500	--	11840	11570	B
214994	o Peg	A1 IV	-.01	12	9400	--	9830	9490	B, C, A7
215648	ξ Peg	F6 III-IV	.50	7	--	6050	5820	6000	
215789	ε Gru	A3 V	.08	236	8400	--	8140	8350	TSG
216048	HR 8681	F0 IV-V	.29	129	7150	--	--	7150	B
216627	δ Aqr	A3 V	.05	71	8500	--	8530	8510:	B
216735	ρ Peg	A1 V	.00	97	9450	--	9830	9530	B
216956	α PsA	A3 V	.09	100	9150	--	8850	9090:	B, C
217782	2 And	A3 Vn	.09	190	8400	--	--	8400	B
217926	HR 8776	F2 V	.39	68	6550	--	--	6550	B
218045	α Peg	B9 V	-.04	148	10000	--	10180	10040	B
219080	7 And	F0 V	.29	59	6950	7330	7180	7140	A
219487	HR 8845	F5 V	.40	20	6750	--	--	6750	B
219927	HR 8873	B8 III	-.08	5	12000	--	--	12000	B
220061	τ Peg	A5 V	.17	143	--	7900	7920	7900	
220318	65 Peg	B9.5	-.05	25	10500	--	--	10500	B
222368	ι Psc	F7 V	.51	6	--	6000	5860	5970	
222439	κ And	B9 IVn	-.08	184	11500	--	11840	11570	B
222603	λ Psc	A7 V	.20	63	7750	--	7800	7760	B
223352	δ Scl	A0 V	.01	--	9550	--	9830	9610	TSG
224617	o Psc	F4 IV	.42	38	--	6440	6440	6440	
	Feige 15	A1 V	.00	--	9400	--	--	9400	B
BD	+20 2161	F2 V	.32	--	7130	--	--	7130	A
	H II 344	A8 V	.27	--	7500	--	--	7500	BJ
	H II 530	F5	.39	--	6870	--	--	6870	BJ
	H II 2195	A7 V	.22	--	8000	--	--	8000	BJ
	H II 3031	F2 V	.38	--	6900	--	--	6900	BJ

(column 3), $B-V$(column 4), rotational velocity ($V \sin i$ in km/s, column 5), visual effective temperature T_{vis}(column 6), UV color temperature T_{ANS}(column 7), IR color temperature T_{IR}(column 8), mean T_{eff}(denoted by $< T >$, column 9), and references for the visual data (column 10). Spectral types and $B-V$ values are taken from *TheBrightStarCatalogue* (Hoffleit 1982), and rotational velocities from Uesugi and Fukuda (1981).



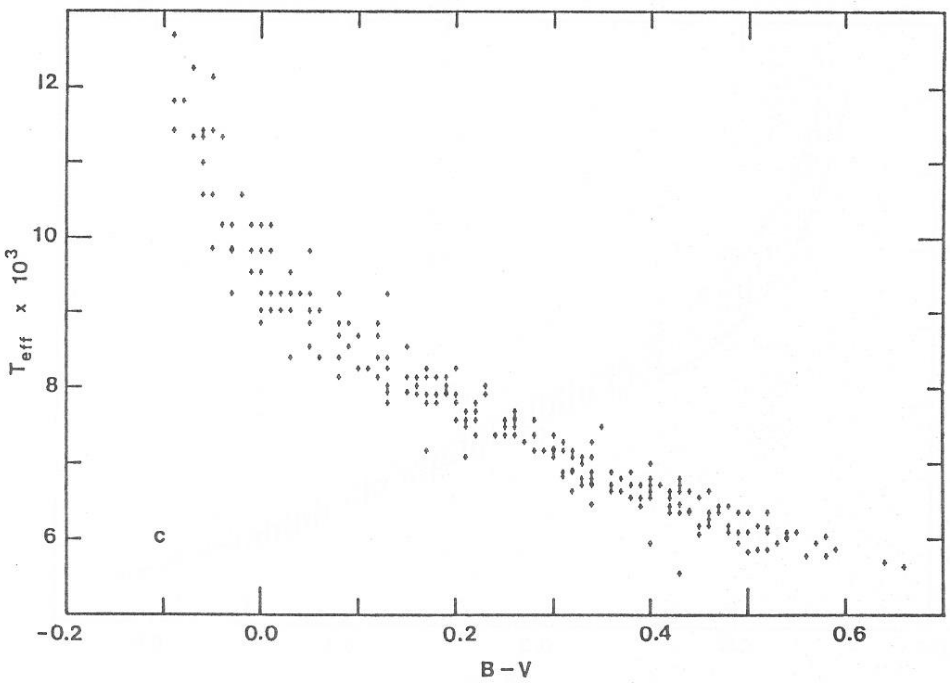


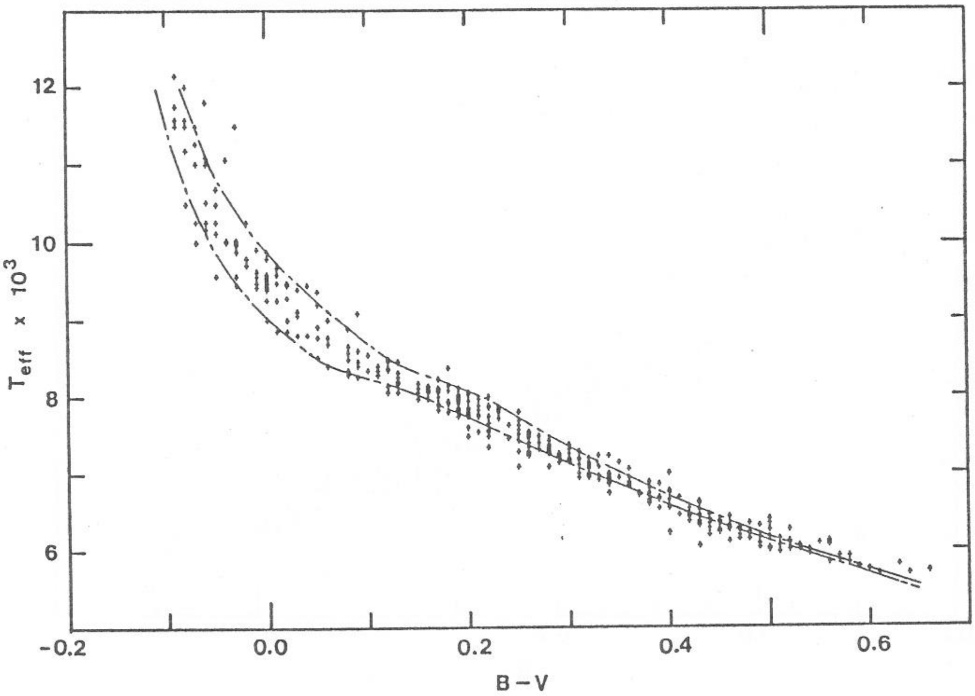
Fig. 3. The relation between the visual color B–V and T_{eff} for (a)T_{vis}, (b)T_{ANS}, (c)T_{IR}.

Table 5
The relation between T_{eff} and (B–V)

B-V	T_{eff}		
	this study	Code et al. (1976)	Kurucz* (1979)
0.60	5840	5870	5700
0.50	6160	6230	6130
0.40	6640	6680	6630
0.30	7170	7280	7220
0.20	7890	8000	7920
0.10	8380	8790	8410
0.00	9520	9500	9400
-0.05	10560	10000	10220

* $\log g = 4.0$

The relations between the color temperature and B–V for T_{vis}, T_{ANS}, and T_{IR} are displayed in Figure 3. The sequence of the T_{ANS} on T_{eff}-(B–V) plane in Figure 3(b) is clearly defined. In contast the T_{IR} shows a substantially large scatter and fairly deviates from the theoretical T_{eff}-(B–V) relation at higher temperature. It



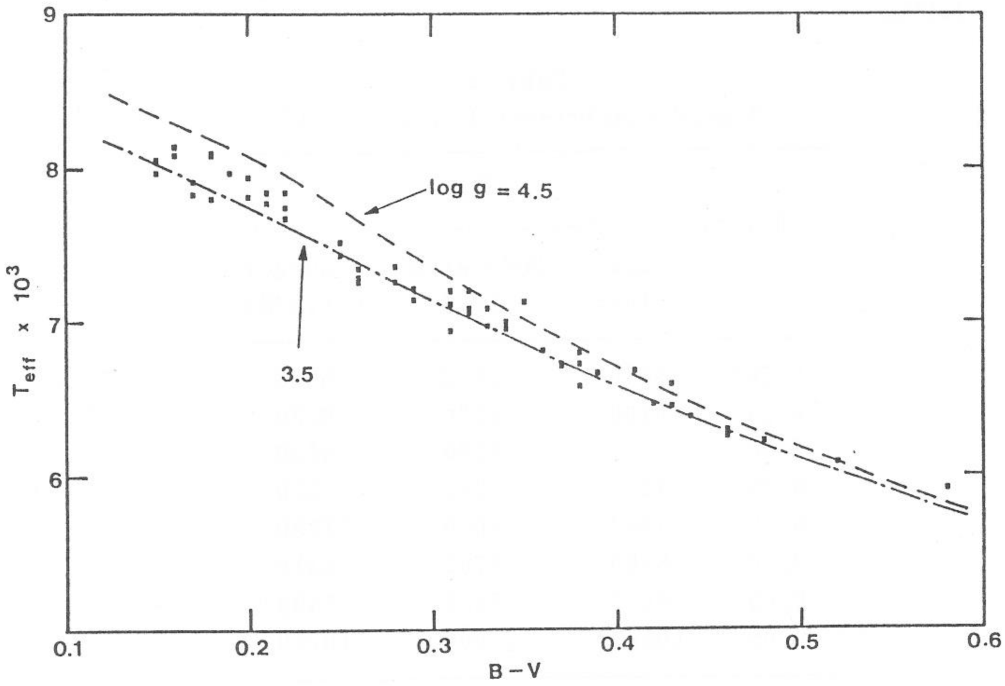


Fig. 4. The relation between the final mean effective temperature $< T >$ and $(B–V)$ for (a) all the 404 stars, and (b) well-observed 56 stars. Two dash-dotted lines in (a) and (b) show the Kurucz's (1979) theoretical T_{eff}-$(B–V)$ relations for the models of log $g = 3.5$ and 4.5.

seems that the color index R–I gives unreliable effective temperatures for the stars higher than 9000K. We can expect this trend from Figure 2. Since the T_{eff}-(R–I) relation is not so steep for higher temperature stars, a small error in the color can result in a large change in temperature. This is similar to the behaviour of T_{ANS} in Figure 1.

At B–V= 0.40, deviations in root mean square from the finally obtained scale for the three temperature sequences T_{vis}, T_{ANS}, and T_{IR} are 156K, 57K, and 257K, and at B–V= 0.20 they are 161K, 123K, and 169K, respectively. In the case where T_{eff}> 9000K, the shape of the Paschen continuum depends weakly on the T_{eff}, so that the derived temperatures have large uncertainties (more than 500K). In the region where B–V< −0.05 the uncertainty will come up to 1000K.

In Figure 4(a) weighted mean temperartures $< T >$ are shown along with the T_{eff}-(B–V) relations computed by Kurucz (1979) for the solar composition models with different gravity (log g = 3.5 and 4.5). Amongst 404 stars in Table 4, a complete set of three color temperatues is available for 56 stars, for which the T_{eff}-(B–V) relation is given in Figure 4(b). As seen in Figure 4(a), the distribution is rather steeply inclined at B–V< 0.1, indicating that the T_{eff}-(B–V) relation for late B and early A stars shows fairly strong gravity dependence.

Final our T_{eff} sequence as a function of B–V is summarized in Table 5. It seemes to be slightly cooler than previous empirical determinations and closely similar to the theoretical sequence of Kurucz (1979) for log g = 4.0. Comparing with the result of Code et al. (1976) our scale is cool by about 200K at B–V= 0.20. For the well-observed 56 stars we can obtain the T_{eff}-(B–V) relation within a scatter of 150K.

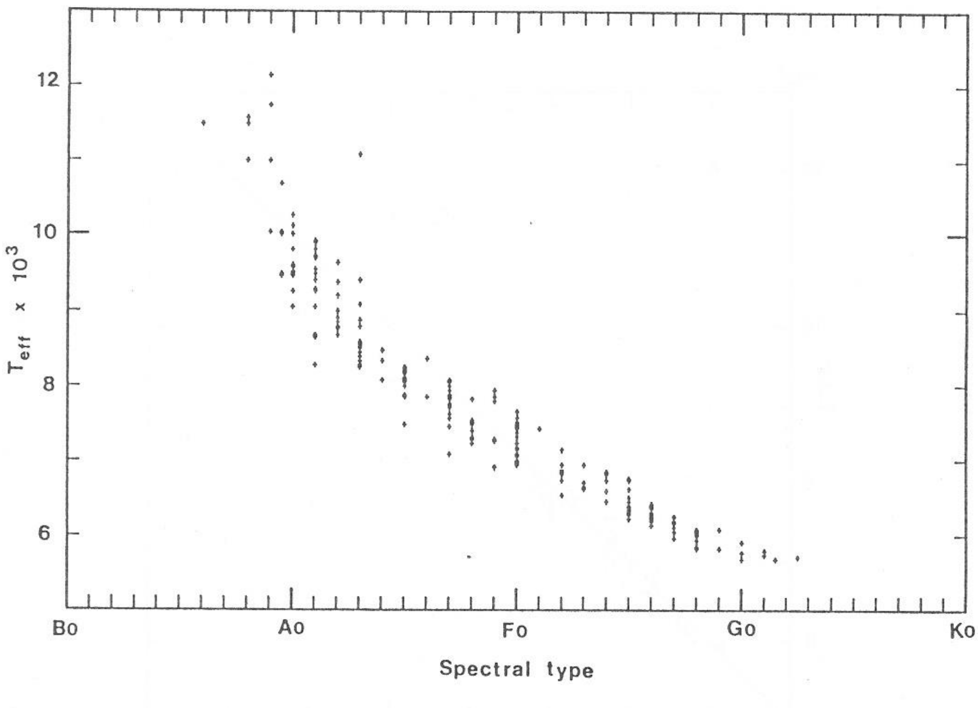


Fig. 5. The relation between the spectral type and T_{eff}.

4.2 T_{eff}-Spectral Type Relation

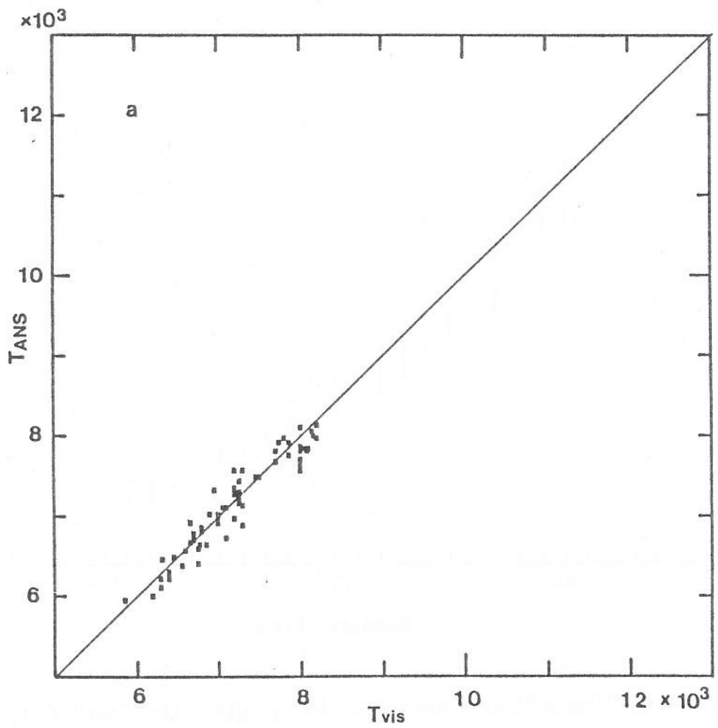
The relation between the resultant temperature $< T >$ and spectral type is plotted in Figure 5. Average temperatures and deviations in root mean square for some selected spectral types are as follows: 9780±470K for 18 A0 stars, 7270±240K for 44 F0 stars, 5880±140K for 5 G0 stars. There is a discrepancy in temperature between the stars of $B–V$=0.0 and of the A0 stars. We can find no dependenc on the luminosity class in the T_{eff}-spectral type relation. As already illustrated by Malagnini et al. (1982), the T_{eff}-spectral type relation has a rather large width compared with the T_{eff}-($B–V$) relation. This is probably due to the discrepancy between the UBV photometric system and the spectral classification (Heck 1984; Eggen 1984).

4.3 Comparisons of the Three Sets of T_{eff}

Next we comapare the three effective temperatures in Figure 6. The mutual correlation between T_{vis} and T_{ANS} (Figure 6(a)) is fairly well, and it is also good for T_{ANS} and T_{IR}(Figure 6(c)). However at higher temperature region the T_{IR} is somewhat greater than T_{vis} and the scatter is rather large (Figure 6(b)). As mentioned in the previous section, the $R–I$ color index is not always an appropriate temperature indicator, especially for T_{eff}> 8000K.

4.4 Effect of Rotaion

In Figure 7, T_{eff} is plotted for slow and mildy rapid rotators, from which we find no definite dependence of the T_{eff} scale on rotational velocity.



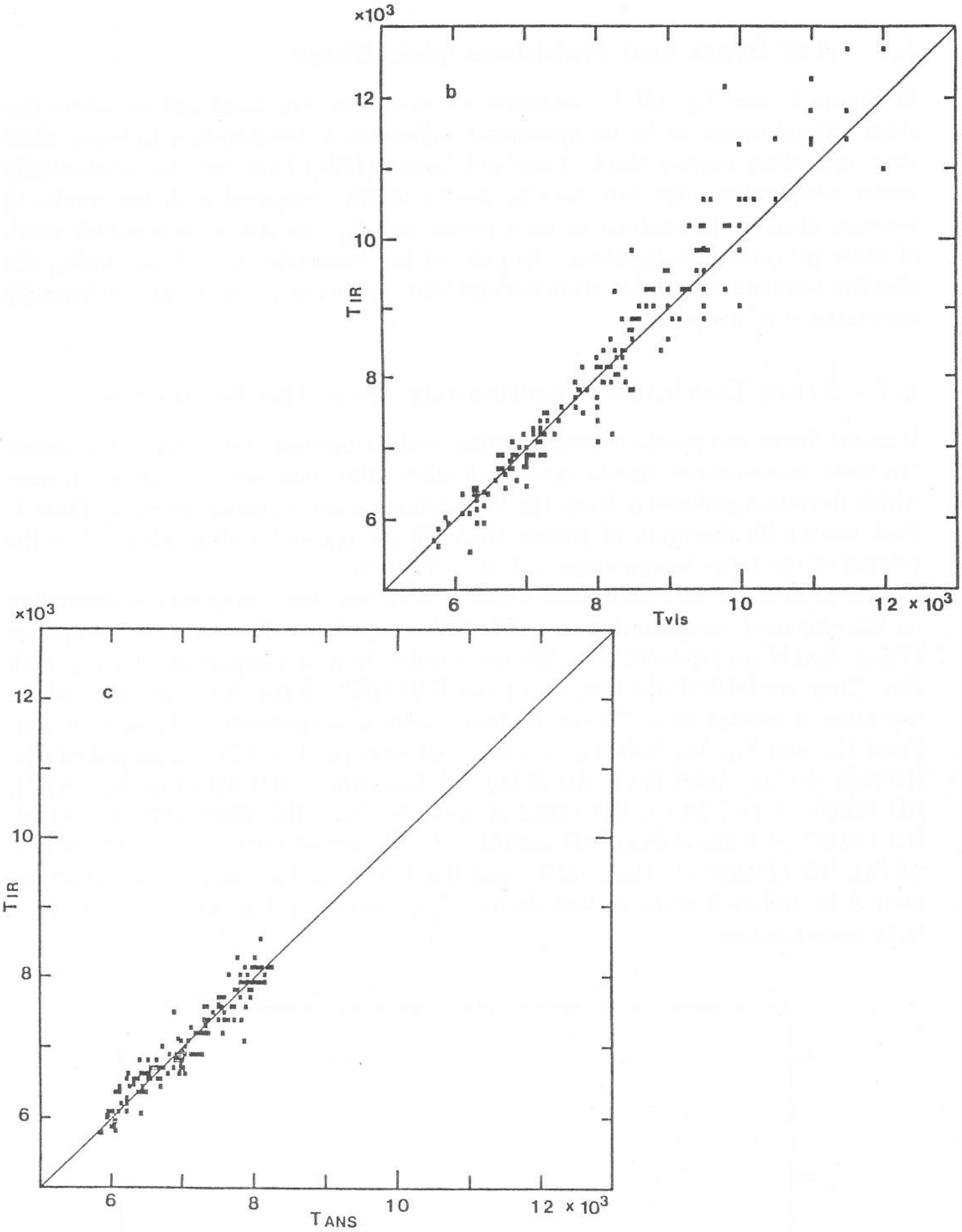


Fig. 6. Comparison of the three T_{eff}scales. (a)T_{vis} versus T_{ANS} for 62 stars, (b)T_{vis} versus T_{IR} for 185 stars, and (c)T_{ANS} verusus T_{IR} for 145 stars.

4.5 Effect of Chemical Composition

In Figure 8, T_{eff}-$(B–V)$ relations expected for models with metal content of one percent of the Sun are shown together with our effective temperatures $< T >$ in Table 4. It is evident that the metal deficient models fail to account for the empirical T_{eff}-$(B–V)$ relation.

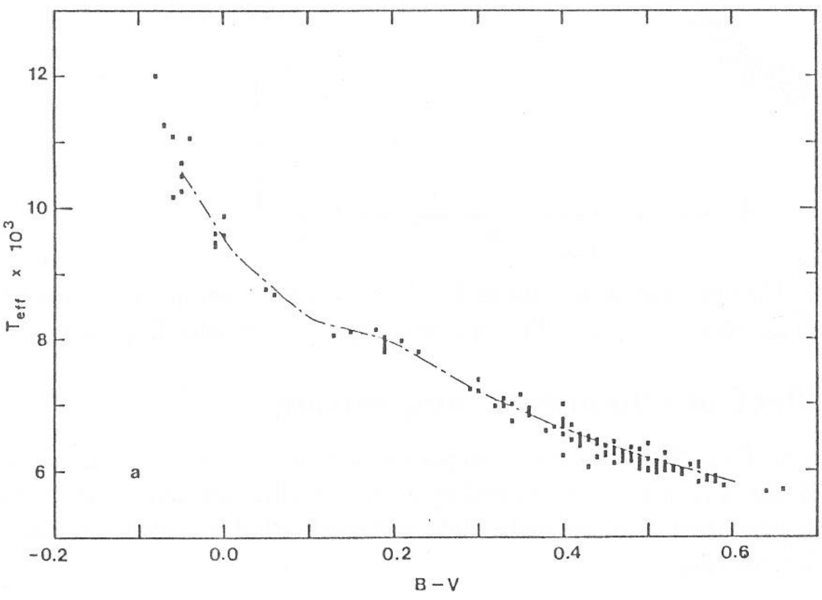
4.6 Am Stars and Nebulous Line Stars

In Figure 9, our T_{eff}-$(B–V)$ relations are given for Am stars and nebulous line stars. There seems to be no systematic difference in temperature between these stars and other normal stars. Lane and Lester (1984) have derived substantially cooler temperatures for Am stars by nearly 1000K compared with the results of previous studies. In contrast to their result, our T_{eff} for Am stars resemble those of other previous investigations. As pointed by Dworetsky and Moon (1986), the effective temperature of Am stars derived from photometric colors may be strongly correlated with metallicity.

4.7 Stars Deviated Significantly from the Sequence

If model fluxes and measured stellar radiative distributions would completely agree, the three temperatures should agree each other. But there are some program stars which deviate significantly from the final temperature sequence given in Table 5. Such stars with deviation of greater than 5% are marked with a colon ":" in the column of the mean temperature $< T >$ of Table 4.

Moreover some stars are present which show inconsistent temperatures depending on the employed wavelength range. The following stars with departure (defined as $(T_{ANS}–T_{IR})/T_{ANS}$) greater than 8% are selected from a comparison of T_{ANS} with T_{IR}. They are HD39014(δ Dor, A7V) and HD78362(τ UMa, Am). No stars whose deviation is greater than 7% can be found from a comparison of T_{ANS} with T_{vis}. From T_{vis} and T_{IR}, the follwing very deviated stars ($B–V$> 0.0) can be picked out: HD8538 (δ Cas, A5III-IVv), HD 29140 (88 Tau, A5m), HD 39014 (δ Dor, A7V), HD 39060 (β Pic, A5V), HD 73262 (δ Hya, A1Vnn), HD 95608 (60 Leo, A1m), HD 103287 (γ UMa, A0Ve), HD 126354 (τ^2 Lup, A7:+F4IV), HD 172167 (α Lyr, A0Va), HD 173880 (111 Her, A5III), and HD 213558 (α Lac, A1V). Most of all are early A to middle A stars, so that derived T_{eff}, especially T_{IR}, are thought to have large uncertainties.



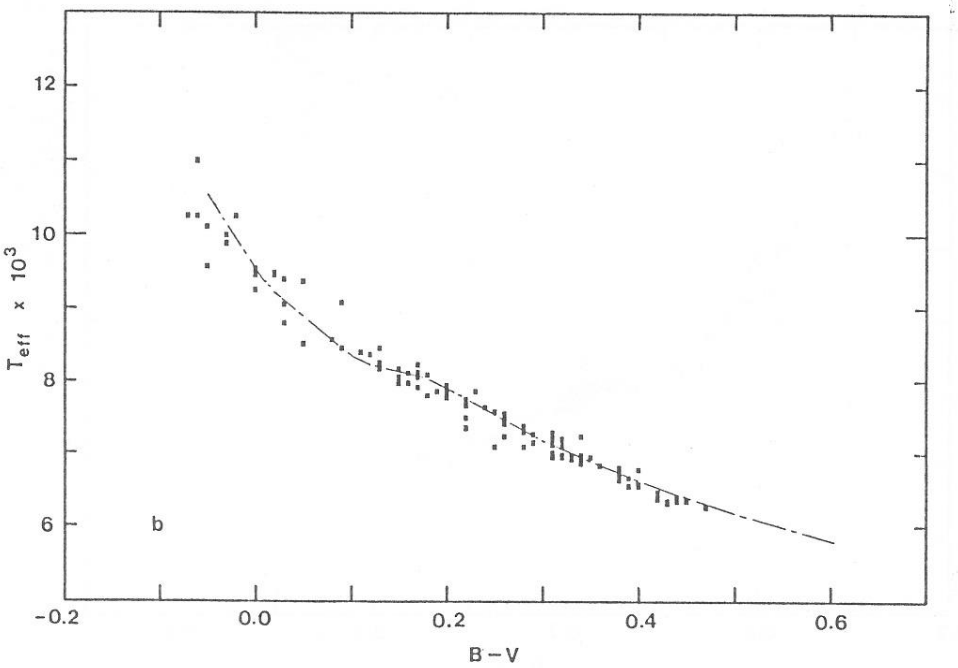


Fig. 7. The T_{eff}-$(B{-}V)$ relation for (a)slow rotators ($Vsini < 30km/s$), and (b) mildly rapid rotators ($50km/s < Vsini < 100km/s$). Our empirical T_{eff} scale is shown for comparison.

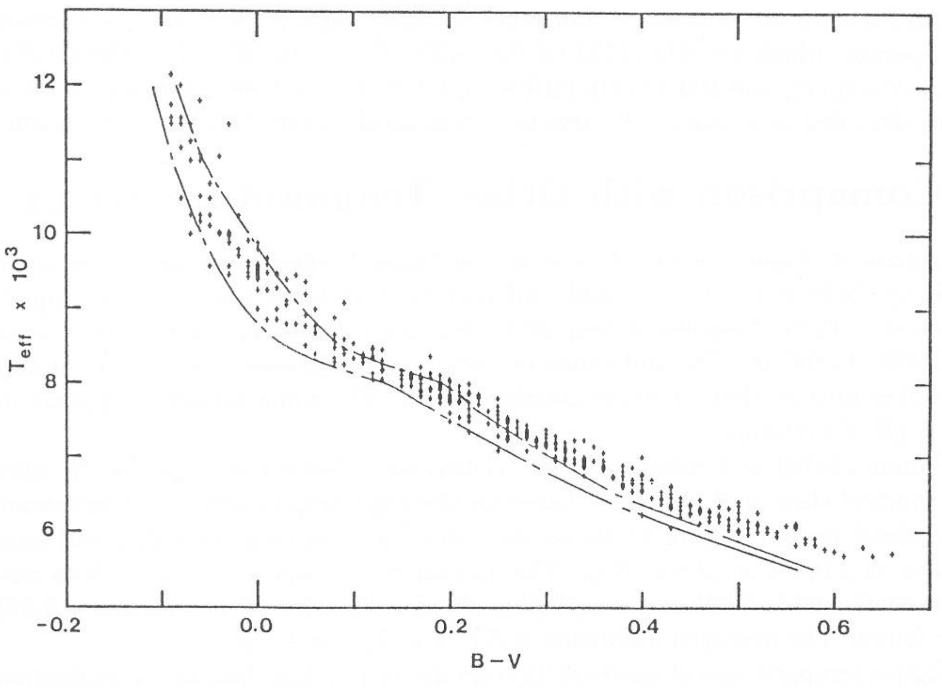


Fig. 8. The T_{eff}-$(B{-}V)$ relations expected for the metal deficient models (1/100 of the solar composition) of log $g = 3.5$ and 4.5. They disagree with our empirical relation.

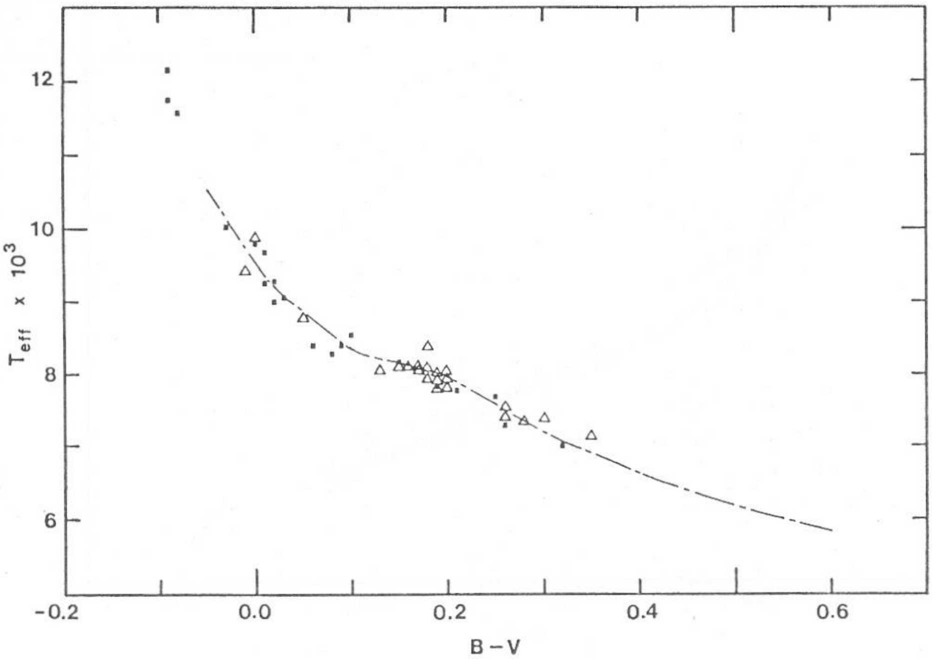


Fig. 9. The T_{eff}-$(B–V)$ relations for Am(△) and nebulous line stars(■). Our empirical T_{eff} scale is also displayed for comparison.

From Figure 5 we have found four stars deviated heavily from the T_{eff}-spectral type sequence, which are HD 11753 (ϕ Per, A3V, $B–V=$ −0.06), HD 39060 (β Pic, A5V, $B–V=$ 0.17), and HD 118216 (HR5110, F2IV, $B–V=$ 0.40). The star β Pic is already identified as a curious effective temperature object in the above comparison.

5 Comaprison with Other Temperature Scales

We compare in Figure 10 our T_{eff} with the "direct" effective temparature scale derived by Code et al. (1976), and find that both of them are fully overlapped. Code et al. (1976) have listed four $B–V$=0.0 stars whose T_{eff} are in the range from 9240K to 9970K. The difference in temperature between the maximum and minimum is greater than 700K, attainable to 8%. The same tendency appears in our T_{eff}-$(B–V)$ relation.

Adelman (1978) and Adelman et al. (1980) have derived the T_{eff} for 68 stars of the spectral class of B, A, and F based on their spectrophotometric observations for the visual region. Figure 11 shows the correlation between their T_{eff} and ours expressed as a function of our T_{eff}. The mutual correlation is very good (the correlation coefficient is 0.98) and a negligibly slight inclination (its coefficient is 0.96) will be found. The averaged difference $< \Delta T >$ in T_{eff} is +22K.

Effective temperatures of common 28 stars derived by Kontizas and Theodossiou (1980) and by us are compared in Figure 12, where the scatter is fairly large (the correlation coefficient is 0.76), but no systematic deviation (the gradient is 0.94) can be seen.

In Figure 13 we show the relation of our temperatures versus T_{eff} derived by

Malagnini et al. (1982). Malagnini and his colleagues compared ultraviolet energy distributions from 1360Å to 2740Å measured by the TD-1 satellite with Kurucz's (1979) model fluxes. We find that their effective temperatures become lower and lower compared with our temparature scale as the T_{eff} increases. They have already shown that the correlation between their UV temperatures and visual temperatures is not so good. The similar phenomenon has been found for peculiar B and A stars by Adelman (1985). One way to explain the systematic deviation is to assume the uncertainty in deriving effective temperature from ultraviolet flux data. As can be seen from Figure 2 in Böhm-Vitense (1982) the temperature dependence of the slope of Balmer continuum is very weak for early A and B stars (T_{eff}> 8500K). A similar problem has already appeared in section 3 concerning the calibration of the ANS data.

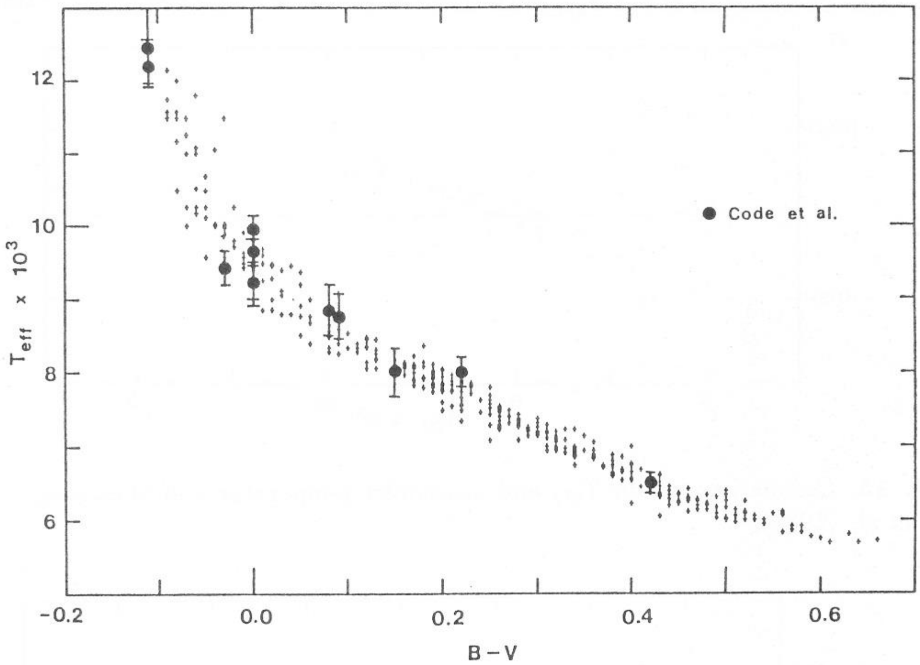


Fig. 10. The T_{eff}-(B–V) relations of ours and those of Code et al. (1976).

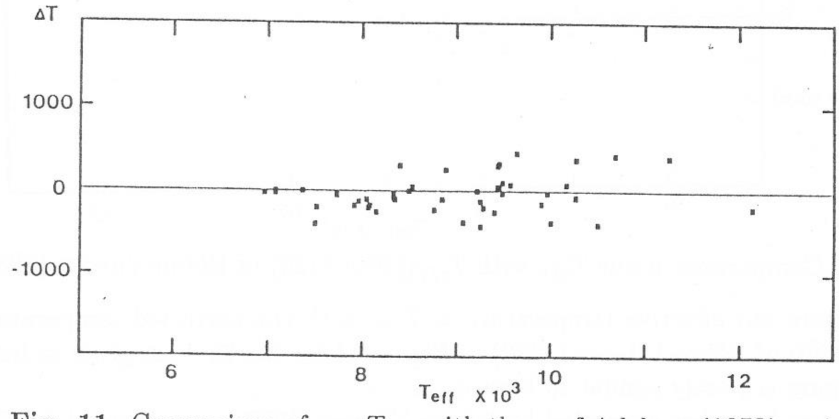


Fig. 11. Compariosn of our T_{eff} with those of Adelman(1978) and Adelman et al.(1980). The difference $\Delta T =< T >$-T_{eff}(Adelman et al.) is plotted as a function of our T_{eff} $< T >$.

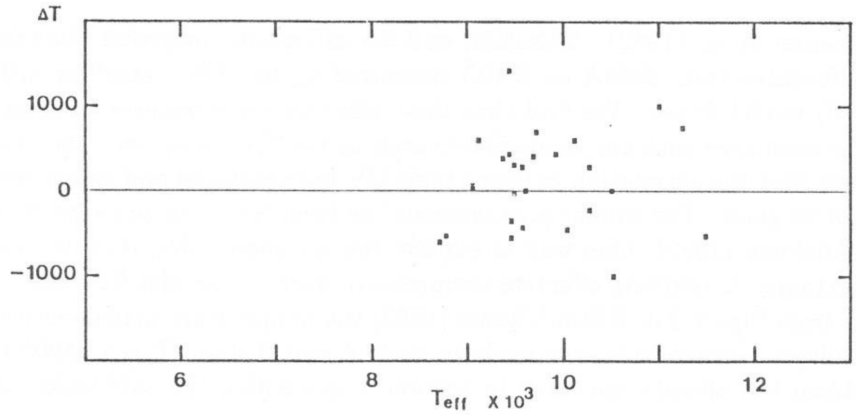


Fig. 12. Comparison of our T_{eff} with those of Kontizas and Theodossiou (1980).

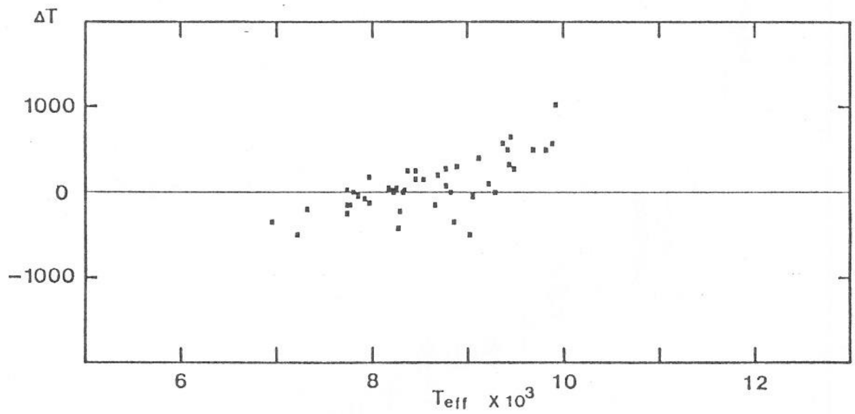


Fig. 13. Comparison of our T_{eff} and ultraviolet temperatures of Malagnini et al. (1982).

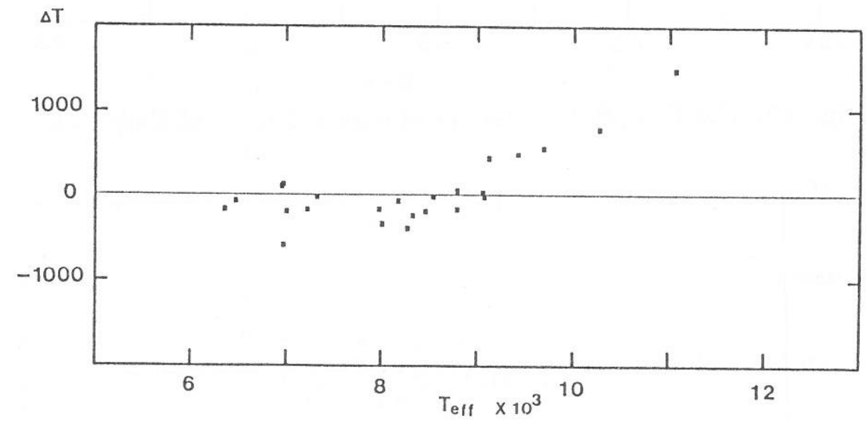


Fig. 14. Comparison of our T_{eff} with T_{eff}(1900–1420) of Böhm-Vitense (1982).

We compare our effective temperature $< T >$ with the corrected temperature T_{eff}(1900-1420) of Böhm-Vitense (1982) in Figure 14 for the 24 stars given in both lists. The figure is closely similar to Figure 13.

Possible two branches suggested by Böhm-Vitense (1982) are indicated in Figure 15 with dashed lines together with T_{ANS}. According to her, this phenomenon may be attributed with the effect due to inhomogeneities caused by convection in atmospheres of main sequence F stars, and the rotational velocities of lower branch stars are higher than those of upper branch stars. However in our temperature scale such a duality can not be found. Effective temperatures of all the stars lying on the upper branch noted in Table 3 of Böhm-Vitense (1982) are systematically higher than our results at least by 200K.

Finally we compare in Figure 16 the effective temperatures obtained from the infrared flux method with our T_{eff} for 46 stars listed in common. Apart from the small random errors, there is no essential discrepancy between the two temperature

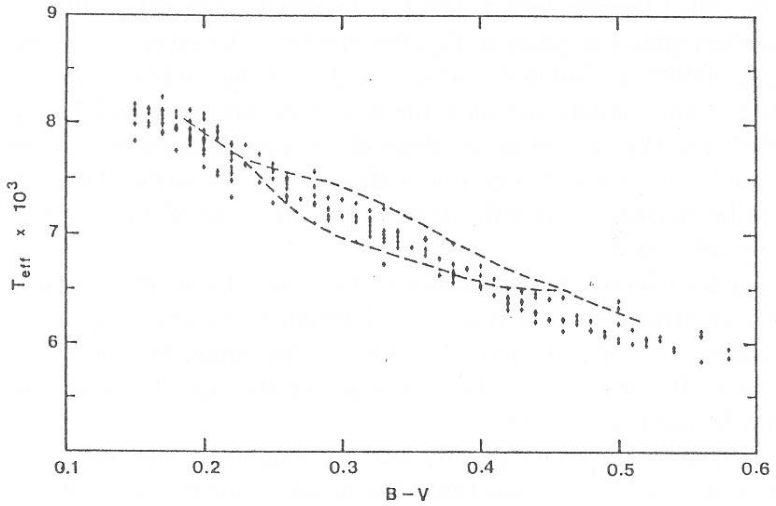


Fig. 15. Two branches suggested by Böhm-Vitense(1982) are illustrated on our T_{ANS}-$(B–V)$ relation.

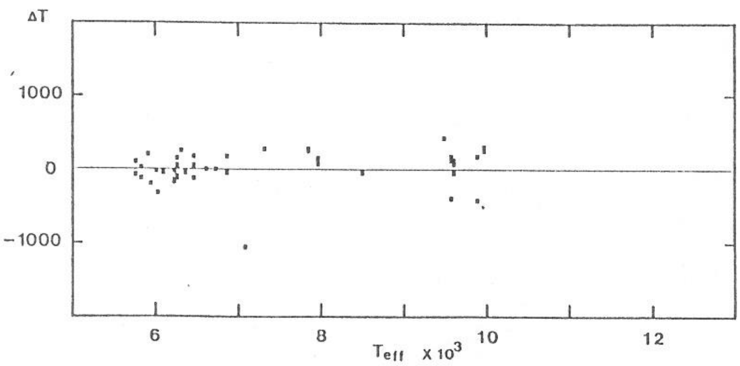


Fig. 16. Comparison of our T_{eff} with the results of the IR flux method, where T_{eff}(IR flux method) are taken from Blackwell and Shallis (1977), Blackwell et al. (1979, 1980), Saxner and Hammarbäck(1985), and Leggett et al. (1986).

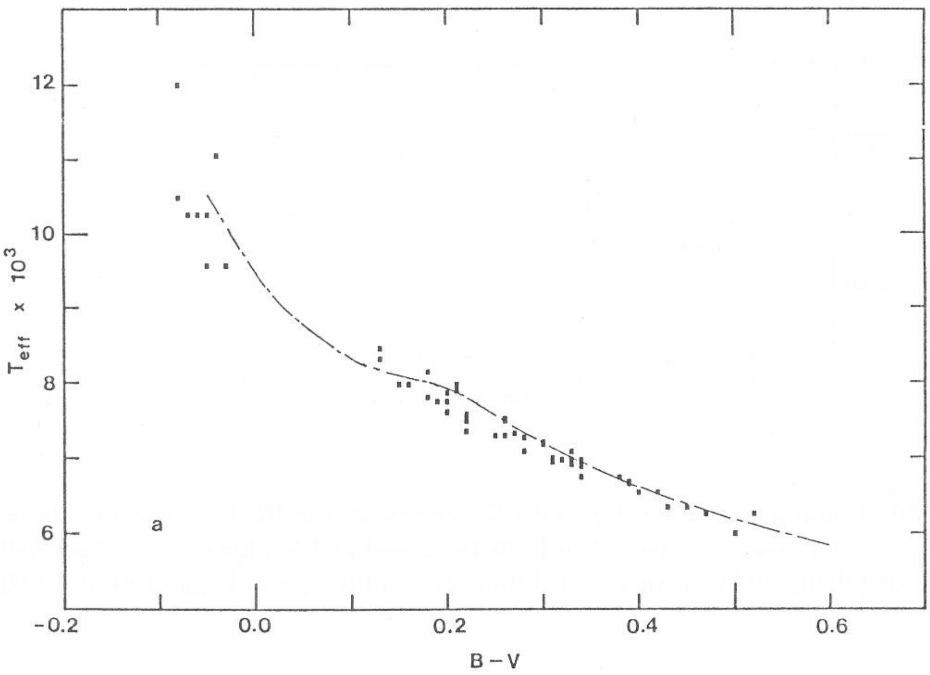
scales. Its correlation coefficient is 0.99 and the gradient of T_{eff}(IR flux method) versus our T_{eff} is 0.97 (with the exception of HR 2085, which is curiously deviated from other stars). Considering the errors inherent in the derivation of temperarture, the correlation is so good that the average difference $< \Delta T >$ in temperature is +10K.

6 Discussion

It is confirmed that the ultraviolet color temperature for early A to B stars becomes cooler than the visual temperature as the T_{eff} increases. Adelman (1985) has shown that the same discrepancy appears in T_{eff} derived from the satellite ultraviolet data. Malagnini et al. (1982) considered that this is due to the underestimation of ultraviolet opacities in the models and also due to the departure from LTE hypothesis. Here it is noted that the change in the slope of ultraviolet fluxes is less sensitive for these stars than for F stars to the choice of effective temperature. This suggests the discrepancy to be caused by the difficulties in measurement of ultraviolet fluxes and in temperature calibration.

In this study the effective temperatures are estimated by using "indirect method", which, in general, strongly depends on initial assumptions and adopted models. In the analysis based on "indirect method", final results should be consistent with initial assumptions. Below, we will examine whether the conditions adopted in this analysis would be fulfilled or not.

We have assumed the surface gravity and the chemical composition to be fixed for each star, and only the T_{eff} has remained as an unknown parameter. Finally it is found that the resultant T_{eff}-$(B-V)$ relation is in good agreement with predictions of the Kurucz's (1979) solar composition models and also with those of the direct method. This is an evidence that the assumption on chemical composition is reasonable.



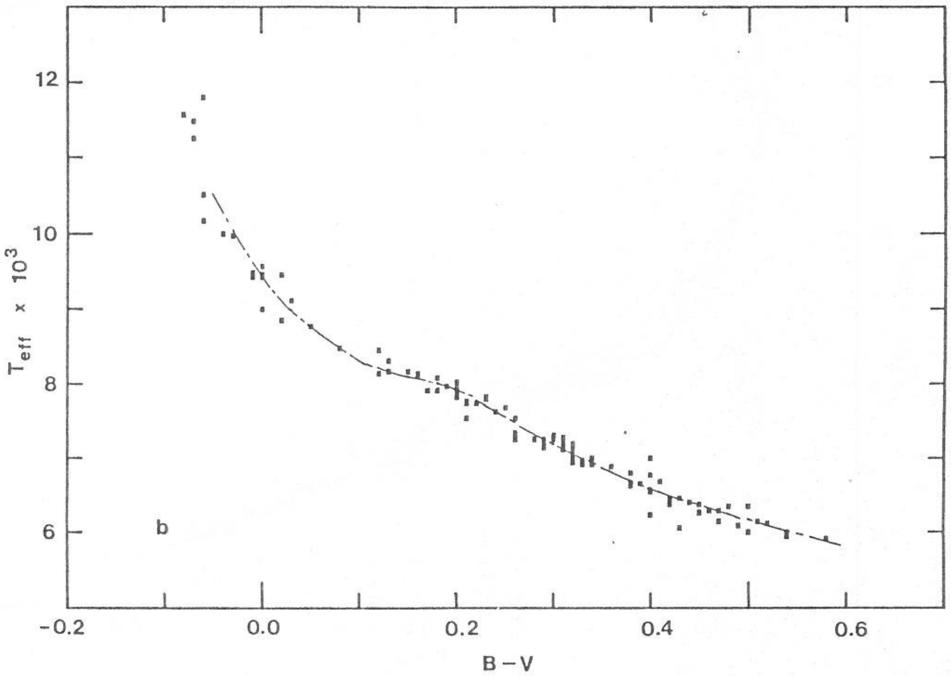


Fig. 17. The T_{eff}-(B–V) relations plotted for the stars of luminosity class (a)III(giants) and (b)V(dwarfs). Our temperature scale in Table 5 is shown for comparison.

We compare in Figures 17(a) and 17(b) the T_{eff}-(B–V) relations for giants and dwarfs. Initially we have assumed the surface gravity of log g = 3.5 for giants and log g = 4.5 for dwarfs. Effects of the difference in gravity clearly appear at B–V< 0.0, where the temperatures of giants are slightly less than those of dwarfs. This also agrees with the Kurucz's (1979) theoretical temperature scales. Thus there seems to be no contradiction between initial assumptions and the final results.

Another interesting fact is shown in Figure 18. The plotted T_{eff}-(b–y) relation presents somewhat curious temperature sequence. In the figure the relation between our T_{eff} and b–y for 294 stars is given, where the b–y values for individual stars are taken from the Hauck and Mermilliod (1980) catalogue. The spread in the diagram is, certainly, fairly improved compared with the T_{eff}-(B–V) relation. However it is evident that around b–y= 0.10 our effective temperatures are systematically lower than the predictions by Kurucz (1979). The discrepancy remains unexplained. It must be necessary to recompute theoretical b–y values from his model fluxes.

It is well known that main sequence stars plotted in an HR diagram shows fairly large width. One possibility to explain the width is to assume that even if the stars are classified as the same spectral type, they intrinsically have different temperatures. The A0 stars in our list have the effective temperatures between 9100K and 10300K (Figure 4). This causes a difference in magnitude up to 0.5 when the stars have a same radius. This is too small to explain the width of about 2 magnitude of main sequence stars in an HR diagram (Jaschek and Mermilliod 1984). Considering

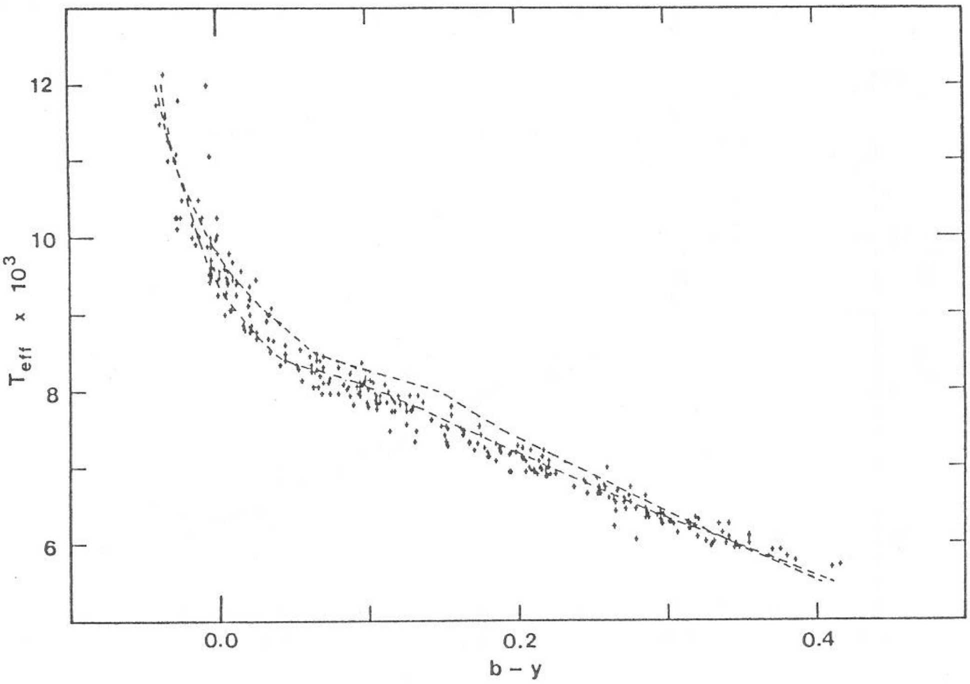


Fig. 18. The T_{eff}-(b–y) relation for 294 stars and predictions of models (Kurucz 1979) for log g = 3.5 (lower dotted line) and for 4.5 (upper dotted line). For individual stars b–y values are taken from the Hauck and Mermilliod (1980) catalogue.

this result, recent studies of Holweger et al. (1986a, 1986b) are very suggestive. They have found that significant variations of elemental abundances in normal early A stars from the high-resolution spectroscopy. As already pointed (e.g., Perrin et al. 1977; Cayrel de Strobel 1978) the width of main sequence stars will be caused by the difference in metal content from star to star or any other factors concerning their ages.

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