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Research Note

Infrared study of the two categories of S stars

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Abstract. Photometric observations of 20 Tc-deficient and 24 Tc-rich S stars in the near infrared are presented in this paper. With the IRAS data, infrared two color diagrams, IRAS low-resolution spectra and energy distributions are discussed to summarize the way to segregate Tc-rich stars from Tc-deficient ones.

Key words: circumstellar matter – stars: evolution – stars: AGB, post AGB – infrared: stars

1. Introduction

The Peculiar red giants with spectral type S were first identified by Merrill (1922). A spectral classification of S stars based on their optical spectra was proposed by Keenan (1954). We know now that S stars are characterized by unusual photospheric abundances due to the enrichment of the stellar surface by nucleosynthesis products. Spectroscopically, S stars are characterized by molecular bands of ZrO and LaO, replacing the TiO bands found in M type stars. The spectra of S stars indicate strong enhancement of s-process elements in the photosphere. Abundance analyses show that in S stars the C/O ratio is very close to unity (Scalo & Ross 1976; Keenan & Boeshaar 1980), which also reveals the presence of the products of nucleosynthesis at the stellar surface.

Because of the unusual spectral property and element abundance, S stars have been traditionally considered for a long time as intermediate between M type stars and carbon stars as in the evolution sequence M–S–C at the AGB phase. However, in recent years it has become clear that this picture has to be revised, and that there are, actually, two categories of S stars. This dichotomy was first suggested by Iben & Renzini (1983), and has been supported by several observational results (cf. Jorissen & Mayor 1988, 1992; Brown et al. 1990). We now know that one category, the intrinsic S stars that follow the evolution sequence M–S–C are, indeed, lying on the AGB phase. Another category, the extrinsic S stars that have elemental abundances which appear to have been altered by mass transfer from a white dwarf companion, are in binary system. In particular, a defining characteristic which distinguishes these two kinds of stars is that the intrinsic S stars contain the unstable element Technetium (Tc) while the extrinsic S stars do not. Therefore, former ones are also called Tc-rich or with Tc, and later ones Tc-deficient or without Tc as denoted e.g. by Iben & Renzini (1983).

The Tc-deficient S stars can be distinguished from the Tc-rich ones on the following basis (Johnson 1992; Jorissen et al. 1993): (1) they show periodic radial velocity variations as in a binary system; (2) their WD companion can be directly detected in the ultraviolet; (3) they exhibit high excitation line emissions such as He I (10 830 Å); (4) they have different infrared colors. As pointed out by Chen & Kwok (1993), Groenewegen (1993) and Jorissen et al. (1993), S stars with strong infrared excess in the IRAS bands always exhibit lines of the unstable element Tc in their spectrum, a signature of the heavy-element nucleosynthesis associated with the AGB evolution; on the contrary, most of the S stars without infrared excess in the IRAS bands do not exhibit Tc lines. In addition, their $K-[12]$, $K-[25]$ and $V-[12]$ colors are very different (Jorissen et al. 1993; Groenewegen 1993).

In this paper we present the JHK infrared photometry of 24 Tc-rich and 20 Tc-deficient S stars. Several color–color diagrams, including the new data together with the IRAS fluxes from the *Point Source Catalog* (1988, hereafter PSC) and some magnitudes in V or B from *HST Guide Star Catalog* (1989, hereafter GSC) are presented to test the best way for distinguishing those two kinds of S stars. Some physical properties are derived from their infrared colors. Their energy distribution and IRAS Low-Resolution Spectra (hereafter LRS) are also discussed.

2. Sample and observation

All S stars observed in JHK bands either with or without Tc are selected from Groenewegen (1993). Most of Tc-deficient stars (20, out of 24 from his Table 2) and a majority of Tc-rich stars (24, out of 36 from his Table 1) were observed in the JHK bands according to the condition and location of the telescope used.

Near infrared observations were made during 1993–1994 using the InSb photometer attached to the 1.26 m infrared telescope at the Xinglong Station, Beijing Astronomical Observa-

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Table 1. The JHK photometric system used

Band	λ (μm)	$\Delta\lambda$ (μm)	Flux at Zero-Mag. (W cm$^{-2}\mu$m^{-1})
J	1.26	0.25	3.1×10^{-13}
H	1.68	0.40	1.1×10^{-13}
K	2.28	0.48	3.8×10^{-14}

Table 2. Standard stars for near infrared observation

Name	Sp.	J	H	K
BS 134	K0III	4.60	4.15	4.07
BS 1165	B7IIIe	2.93	2.93	2.94
BS 2890	A2Vm	1.53	1.52	1.51
BS 4069	M0III	0.13	−0.65	−0.80
BS 6092	B5IV	4.20	4.26	4.30
BS 7615	K0III	2.20	1.72	1.64
BS 8551	K0III	2.96	2.38	2.31

tory, China. The InSb detector and filters in JHK bands were cooled at 77 K by liquid nitrogen. The JHK photometric system which is very close to the standard one is listed in Table 1. In order to reduce the influence of local changes in atmospheric conditions, all observations were made near the zenith. During observations, atmospheric extinction coefficients at JHK bands were obtained each night by measuring a standard star at different zenith distances. Following Chen et al. (1987), the correction for interstellar reddening was estimated for every star, although it is quite small for most of them. The accuracy of the photometry is, on the average, 0.05, 0.04 and 0.05 for J, H and K, respectively. The standard stars used are listed in Table 2.

The final sample consists of 20 stars without Tc and 24 ones with Tc, and their magnitudes in JHK bands with observing date are listed in Tables 3 and 4 respectively. The star number from Stephenson (1984, hereafter GCGSS) and the GCVS name or HR/HD/BD number are also given. The IRAS associations for all stars observed have been taken from Chen et al. (1995), and only good quality fluxes ($Flag > 2$) in the IRAS bands are taken from the PSC. The IRAS LRS classifications are taken from Chen & Kwok (1993). In the Tables, B or V magnitudes from the GSC Catalog are also presented. In the last column of Tables 3 and 4 the symbol "$*$" and "$**$" denote that there were no K and JHK observations appeared in the *Catalog of Infrared Observations* (Gezari et al. 1993), respectively, and symbol "V" indicates some difference of more than 0.2 compared with previous data from Gezari et al. (1993).

3. Color – color diagram

From data in Tables 3 and 4, after the IRAS fluxes are transformed into magnitudes without color corrections according to Cheeseman et al. (1989), different infrared color–color diagrams can be plotted: $(J-H)$ – $(H-K)$ in Fig. 1; $([12]-[25])$ – $([25]-[60])$ in Fig. 2; $(K-[12])$ – $([12]-[25])$ in Fig. 3 and $(J-K)$ – $(K-[12])$ in Fig. 4. In those figures, the open and filled circles indicate S stars with and without Tc, respectively, and the straight line corresponds to the blackbody distribution.

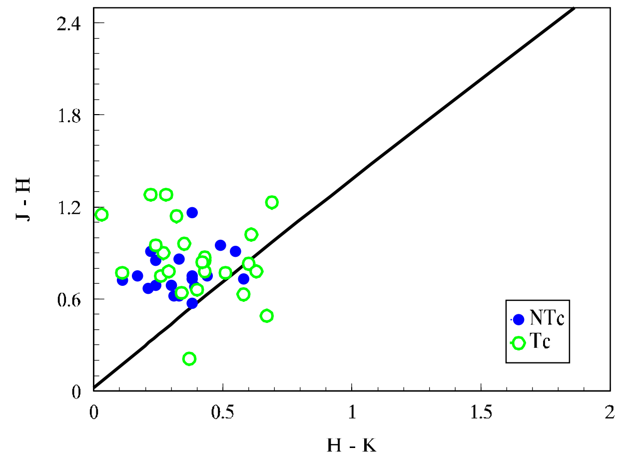

Fig. 1. $(J-H)$ – $(H-K)$ diagram for observed S stars

It is obvious from Fig. 1 that although samples with Tc distribute in a rather wider area than the ones without Tc, both species are basically located in almost the same region. These distributions imply that, statistically, both categories of S stars have almost the same colors and temperatures in the near infrared, and they can not be clearly distinguished on the basis of their near infrared color.

It is shown from $([12]-[25])$ – $([25]-[60])$ diagram in Fig. 2 that a rather clear segregation between Tc-rich and Tc-deficient S stars is visible by different $[12]-[25]$ but not by $[25]-[60]$ except for a peculiar Tc-deficient star DY Gem (it will be discussed in more detail later). This implies that the color $[12]-[25]$ is a good probe for distinguishing these two kinds of S stars, and Tc-rich S stars really exhibit on infrared excess in the 12 μm and 25 μm bands. They have cooler temperature and hence are probably more evolved. On the other hand, Tc-deficient stars have no or little excess in the 12 μm and 25 μm bands which indicates a photospheric origin of the mid-infrared flux. It is also noted that a few Tc-rich S stars including NQ Pup, o^1 Ori, χ Cyg and HR Peg populate the same region as Tc-deficient S stars as Jorissen et al. (1993) already pointed out. In addition, it is seen from Table 4 or Fig. 2 that Tc-deficient S stars with good quality 60 μm flux are not numerous (only 7, out of 20 in Table 4). Therefore, other colors not involving 60 μm flux must be used to show their infrared property.

In order to include more samples than that in Fig. 2, the $(K-[12])$ – $([12]-[25])$ diagram is plotted in Fig. 3 from which it is obviously seen that except for DY Gem and V Cnc (they will be discussed later), Tc-deficient S stars are concentrated on a very small region of $0.4 < K-[12] < 1.0$ and $0.0 < [12]-[25] < 0.2$, and very close to the blackbody line, whereas almost all Tc-rich S stars are out of this region, far away from the blackbody line, and spread over a much wider area that corresponds to a much larger infrared excess either in $K-[12]$ or in $[12]-[25]$ colors, hence with much lower temperature and

Table 3. Observed S stars with Tc

IRAS	GCGSS	Name	LRS	$V(B)$	J	H	K	Date	F_{12}	F_{25}	F_{60}	F_{100}	Note
00192 − 2020	8	T Cet	F(16)	(6.4)	0.01	−0.65	−0.91	931021	198	55.8	14.4	4.77	
00213 + 3817	9	R And	E	6.8	2.31	1.08	0.39	931026	327	168	24.2	10.4	V
00435 + 4758	12	U Cas	S(01)	12.4	3.69	3.48	3.11	931021	8.38	2.49	0.53	/	V∗
02143 + 4404	49	W And	E(22)	10.5	2.13	1.30	0.70	931026	167	72.1	13.5	5.61	V
04123 + 2357	89	BD23654	S	6.9	2.34	1.56	0.93	941028	24.4	7.30	2.63	2.61	∗
04497 + 1410	114	o^1 Ori	S(18)	4.8	0.81	0.03	−0.48	941028	85.4	21.4	4.57	3.79	∗∗
04543 + 4829	116	TV Aur	F	8.5	3.53	2.25	2.03	941028	12.9	4.25	1.26	/	
05374 + 3153	149	NO Aur	E(43)	6.2	2.57	1.29	1.01	941028	43.5	22.9	5.12	/	
07043 + 2246	307	R Gem	F(16)	10.5	3.41	2.27	1.95	940417	21.6	7.52	2.34	1.42	∗
07245 + 4605	347	Y Lyn	E(23)	8.0	0.63	−0.15	−0.58	940415	122	64.2	11.5	4.54	
07462 + 2351	403	T Gem	/	10.9	4.78	3.88	3.61	940415	3.73	1.02	/	/	
07475 − 1852	411	HD63733	/	(9.0)	4.61	3.83	3.54	940415	2.20	0.66	/	/	
07507 − 1129	422	NQ Pup	I	7.5	3.40	2.25	2.22	940415	7.02	1.84	0.45	/	
09076 + 3110	589	RS Cnc	E(22)	7.0	−0.27	−1.12	−1.55	940417	480	209	32.6	10.1	
12417 + 6121	803	S UMa	/	7.7	4.11	3.62	2.95	940413	4.23	1.40	0.29	/	∗
15492 + 4837	903	ST Her	E(41)	7.2	0.50	−0.13	−0.71	940413	199	97.1	16.7	5.98	∗
18288 + 3612	1053	HD170970	/	6.6	3.47	2.83	2.49	931022	5.08	1.39	/	/	∗
18395 + 0646	1070	V679 Oph	/	8.8	3.81	2.87	2.52	931022	4.43	1.21	/	/	V
19008 + 1210	1099	V915 Aql	S	8.5	2.71	1.94	1.83	931021	11.0	3.36	0.81	/	
19354 + 5005	1150	R Cyg	E(22)	9.1	1.98	1.21	0.78	931029	105	52.2	11.9	5.60	∗
19486 + 3247	1165	χ Cyg	E	7.7	−0.19	−1.21	−1.82	931022	1688	459	80.7	17.7	V
20026 + 3640	1188	AA Cyg	S(31)	8.2	1.76	0.81	0.57	931022	39.7	15.5	5.27	/	
20303 + 1716	1226	Z Del	/	8.3	5.06	4.40	4.00	931022	3.11	0.97	/	/	∗∗
22521 + 1640	1315	HR Peg	S	6.3	2.34	1.50	1.08	941029	27.6	7.15	1.19	/	

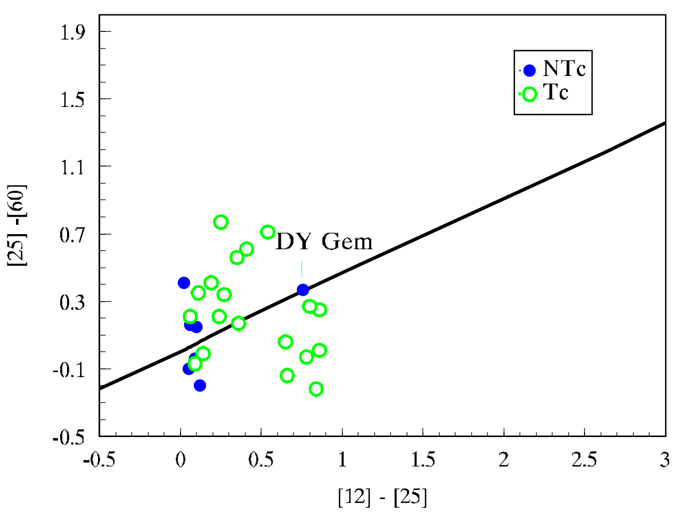

Fig. 2. ([12] − [25]) – ([25] − [60]) diagram for observed S stars

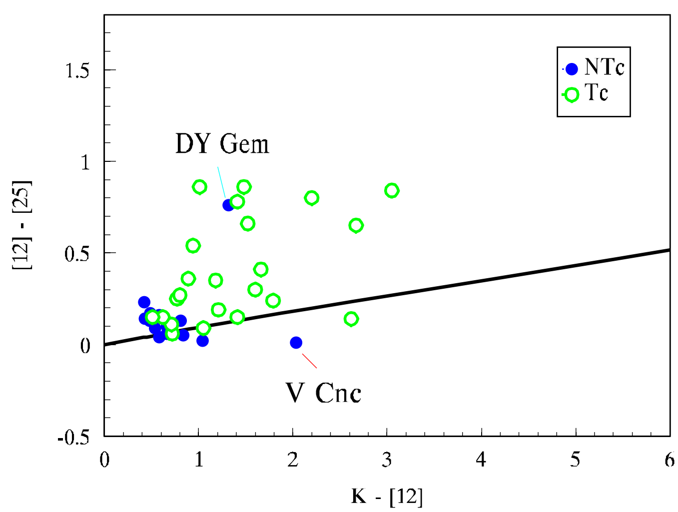

Fig. 3. $(K - [12])$ – $([12] - [25])$ diagram for observed S stars

much higher mass loss. Only four stars: o^1 Ori, NQ Pup, HD 170970 and V679 Oph are located in the Tc-deficient sample region. This suggests that both $K - [12]$ and $[12] - [25]$ are good probes to distinguish Tc-deficient S stars from Tc-rich ones.

The $(J - K)$ – $(K - [12])$ diagram is also plotted for the two kinds of S stars in Fig. 4. Again except for DY Gem and V Cnc, most Tc-deficient S stars can be separated from Tc-rich ones with $K - [12]$ color, but not with $J - K$ color. It should be noted that the $(K - [12])$ color has been used in Figs. 3 and 4, although the observational results in K and 25 μm were not obtained at the same epoch. From the previous observations in K (Gezari et al. 1993) it is found that, on the average, the difference between the previous data and the new ones is 0.22. This has no serious influence on the result shown in Fig. 3. However, the similar comparison is not possible for samples in Fig. 4 for lack of earlier data.

Table 4. Observed S stars without Tc

IRAS	GCGSS	Name	LRS	$V(B)$	J	H	K	Date	F_{12}	F_{25}	F_{60}	F_{100}	Note
01025 + 1855	22	HD6409	/	7.3	3.28	2.56	2.45	941029	5.64	1.50	/	/	**
01113 + 2815	26	HR 363	F	6.4	2.81	2.06	1.64	941029	11.5	3.01	0.61	/	**
03377 + 6303	79	BD Cam	S(18)	5.1	1.22	0.60	0.27	941028	41.0	10.8	1.59	/	
05199 − 0842	133	HD35155	S(16)	(6.9)	3.49	2.58	2.03	941028	7.98	2.01	0.41	/	
06331 + 1415	231	DY Gem	F(42)	9.1	3.05	2.10	1.61	941028	21.7	10.4	2.59	2.74	
06457 + 0535	260	V613 Mon	/	7.3	3.88	3.13	2.75	941028	4.31	1.09	/	/	V
07392 + 1419	382	NZ Gem	S(18)	5.5	1.65	1.05	0.67	940417	25.2	6.50	1.11	/	**
08188 + 1726	494	V Cnc	I	8.9	4.30	3.59	3.35	940413	8.41	2.02	/	/	
10538 − 1033	712	BD−103156	/	(10.6)	5.72	4.90	4.61	940415	0.88	/	/	/	**
13421 − 0316	829	HD119667	/	(9.4)	5.52	4.66	4.33	940413	1.01	/	/	/	**
16205 + 5659	926	BD571671	/	6.6	4.59	3.80	3.50	940413	2.38	0.64	/	/	**
16418 − 1359	937	HD150922	S(19)	(9.4)	3.59	2.43	2.05	940413	8.21	2.09	/	/	**
16425 − 1902	938	HD151011	S(31)	(7.1)	3.26	2.53	1.95	940413	12.20	2.96	0.77	/	**
18128 + 1614	1031	HD167539	/	7.4	3.32	2.41	2.19	931023	5.59	1.51	/	/	**
19581 + 0113	1178	HD189581	/	(9.9)	3.80	2.95	2.71	931023	3.44	1.01	/	/	**
20055 + 3625	1192	HD191226	/	6.9	3.72	2.99	2.61	931023	4.37	1.08	/	/	**
20076 + 3331	1194	HD191589	/	7.3	4.18	3.43	3.26	931023	2.20	0.61	/	/	**
22345 − 1031	1301	HD214285	/	(9.7)	3.91	3.06	2.64	931022	3.89	1.04	/	/	**
22415 + 3339	1304	HD215336	/	6.5	4.64	3.97	3.76	931023	1.52	0.42	/	/	**
23070 + 0824	1322	GZ Peg	S(18)	5.0	0.78	0.01	−0.30	931023	80.9	20.1	3.30	1.04	**

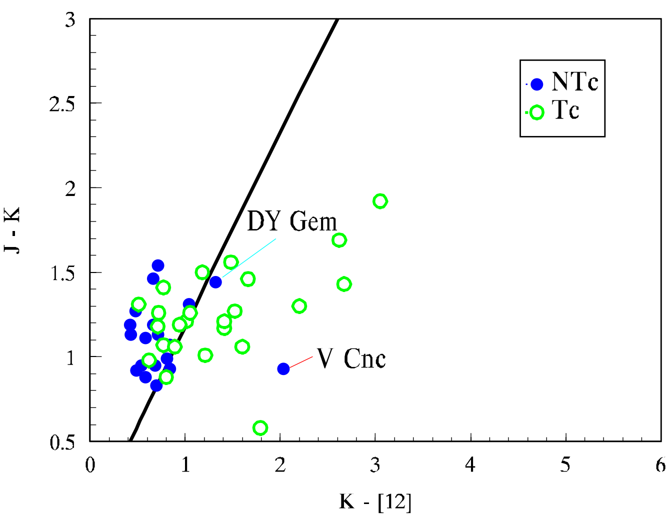

Fig. 4. $(J-K)$ – $(K-[12])$ diagram for observed S stars

The conclusion that can be drawn out from the analysis of infrared color–color diagrams mentioned above is that the more sensitive colors for segregating Tc-rich and Tc-deficient S stars are $K-[12]$ and $[12]-[25]$, hence the more appropriate color–color diagram for distinguishing them is the $(K-[12])$ – $([12]-[25])$ diagram. Chen et al. (1995) gave more than 700 IRAS associations of S stars in their Table 1, but more than 2/3 of the samples have no good 60 μm flux. If one wants to extract candidates of Tc-deficient S stars according to their infrared colors, only color $[12]-[25]$ is not enough. Fortunately, if K magnitudes have been measured, by using the $(K-[12])$ – $([12]-[25])$ diagram the candidates of Tc-deficient S stars can be well selected despite the absence of 60 μm flux for almost all samples.

4. The LRS classification

From Tables 3 and 4 it is seen that only 9, out of 20 Tc-deficient samples and 18, out of 24 Tc-rich ones have a LRS classification. It is shown that (1) more than half Tc-rich stars exhibit a silicate feature, whereas Tc-deficient ones have definitely no silicate feature as already pointed out by Chen & Kwok (1993); (2) most Tc-deficient S stars with a LRS classification show photospheric features which characterize the group S, and some are featureless and belong to group F. Therefore, for more than 700 IRAS associations of S stars listed by Chen et al. (1995), we can tentatively conclude that those in group E are likely to be Tc-rich stars, while candidates of Tc-deficient S stars can be selected from samples in groups S and F.

5. Energy distribution

In order to investigate physical properties of Tc-rich and Tc-deficient S stars in more detail, the broad band energy distributions from B or V band to 60 μm or 100 μm can be plotted simply by using the single or double blackbody fitting proposed by Xiong et al. (1994). One example of energy distribution for the typical Tc-deficient S star, GZ Peg and Tc-rich S star, W And is plotted in Fig. 5 and Fig. 6, respectively, while the others could be made accessible in electronic form in Fig. 5a and Fig. 6a[1], respectively. It is very clear that all Tc-deficient S stars

[1] The Figs. 5a and 6a are available only electronically in the on.line version of A&A

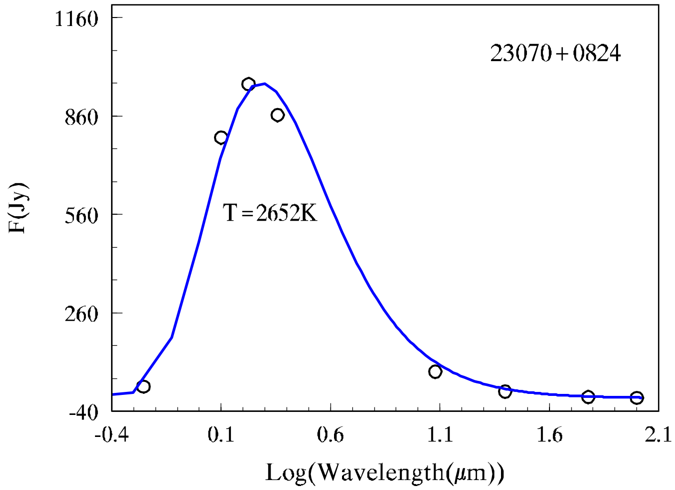

Fig. 5. Energy distribution of typical Tc-deficient S star GZ Peg

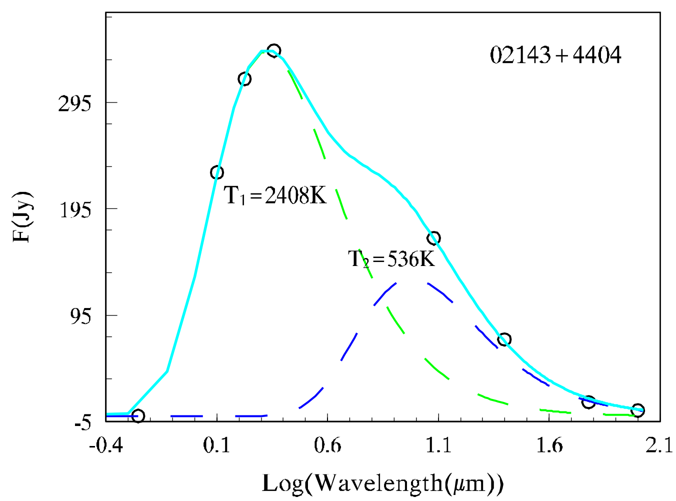

Fig. 6. Energy distribution of typical Tc-rich S star W And

can be fitted by a single blackbody curve which reflects the photospheric properties whereas many Tc-rich ones in the LRS group E request double blackbody fitting which reflects the photospheric and circumstellar properties. Again this implies that Tc-deficient S stars have no or little infrared excess whereas Tc-rich ones usually have, hence are more evolved objects.

6. Individual samples

A very peculiar star is DY Gem that has no Tc in its spectrum (Smith & Lambert 1990), however it is located in the Tc-rich area in $([12]-[25])-([25]-[60])$, $(K-[12])-([12]-[25])$ and $(J-K)-(K-[12])$ diagrams as showing in Figs. 2, 3 and 4, respectively. Its LRS classification is F that indicates little infrared excess in about 7–23 μm. This is consistent with its energy distribution in Fig. 5a showing a single blackbody feature. Groenewegen (1993) pointed out that it also populates the Tc-rich region in the color $V-[12]$, and considered that one should not put too much weight on the "non detection" of Tc in DY Gem, since its spectrum is very complicated and difficult to measure. Therefore Groenewegen proposed that DY Gem has all characteristics of a true AGB star and is probably in the TP-AGB phase.

Another peculiar Tc-deficient star is V Cnc that populates the Tc-rich regions in the $(K-[12])-([12]-[25])$ and $(J-K)-(K-[12])$ diagrams as shown in Figs. 3 and 4, respectively. Groenewegen (1993) considered that V Cnc is a Mira with V magnitude variation from 7.5 to 13.9 in the GCVS and $V=7.1$ in the SAO, and if $V=7.1$ has been taken then its $V-[12]$ is very close to the value of Tc-deficient sample. However as shown above, it still presents Tc-rich property in the infrared colors, therefore future investigations should be done for V Cnc.

Among the Tc-rich sample, o^1 Ori (with the LRS in group S) and NQ Pup (with the LRS in group I) populate the same regions as Tc-deficient stars in the $([12]-[25])-([25]-[60])$ and $(K-[12])-([12]-[25])$ diagrams, and HR Peg (with the LRS in group S) is also in the same region as Tc-deficient stars in the $([12]-[25])-([25]-[60])$ diagram. These three stars are examples of Tc-rich S stars with photospheric feature. In addition, o^1 Ori is known to have a WD companion (Ake & Johnson 1988), and this star may be an example of an extrinsic S star that just entered the TP-AGB phase as suggested by Jorissen & Mayor (1992).

It is surprising that a Tc-rich star, χ Cyg is located in the Tc-deficient area in the $([12]-[25])-([25]-[60])$ diagram as also pointed out by Jorissen et al. (1993), because χ Cyg has the LRS classification of E, and is well fitted with a typical double blackbody mode for its energy distribution in Fig. 6a. Further investigation is also needed for this star.

Finally, two Tc-rich stars, HD170970 and V679 Oph are also distributed in the Tc-deficient area in the $(K-[12])-([12]-[25])$ diagram. However none of the stars have a LRS spectrum nor good fluxes at 60 μm and 100 μm. Jorissen et al. (1993) considered HD170970 as a possible spectroscopic binary system. More information for these two stars is needed.

7. Summary and conclusion

Photometric observations in the near infrared for 24 Tc-rich and 20 Tc-deficient S stars are presented in this paper. Several color–color diagrams and energy distributions including these new data together with the IRAS fluxes and some magnitudes in V or B are presented, and the IRAS Low-Resolution Spectra are also discussed. From analyses above it is concluded that Tc-rich S stars at the AGB phase have more infrared excess, hence more mass loss than Tc-deficient ones in binary systems so that one can distinguish them properly by using their different properties in the infrared. In fact, these two categories of S stars have different color especially in the 2 μm – 25 μm range, thus by using the $(K-[12])-([12]-[25])$ color–color diagram, the IRAS LRS classification and the pattern of energy distribution fitting they could be well separated as follows:

(1) In the $(K-[12])-([12]-[25])$ diagram the criteria lines of segregations are $K-[12]=1.0$ and $[12]-[25]=0.2$. Almost all Tc-rich S stars can be found in the upper-right

area, whereas all Tc-deficient S stars are located in the lower-left area. As the $(K-[12])$ – $([12]-[25])$ diagram seems to be more efficient to split off the two categories of S stars, the forthcoming two-micron data that will come out of 2 MASS and DENIS, in combination with the corresponding IRAS data, will soon offer new opportunities to identify new S stars of both types.

(2) A S star in LRS class E is likely to be Tc-rich, whereas candidates of Tc-deficient S stars can be selected from S and F groups in the LRS classification.

(3) A S star whose energy distribution can be fitted by a double blackbody curve is likely to be Tc-rich, whereas candidates of Tc-deficient S stars can be found from sources whose energy distribution can be fitted by a single blackbody curve.

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References

Ake T. B., Johnson H. R., 1988, ApJ 327, 214
Brown J. A., Smith V. V., Lambert D. L. et al., 1990, AJ 99, 1930
Cheeseman P., Stutz J., Self M. et al., 1989, NASA RP-1217,9
Chen P. S., Gao H., Chen Y. K., Dong H. W., 1987, A&AS 67, 239
Chen P. S., Kwok S., 1993, ApJ 416, 769
Chen P. S., Gao H., Jorissen A., 1995, A&AS 113, 51
Gezari D. Y., Schmitz M., Pitts P. S., Mead J. M., 1993, NASA RP-1294
Groenewegen M. A. T., 1993, A&A 271, 180
HST Guide Star Catalog, 1989 (Baltimore: STScI) (Astronomical Data Center CD-ROM Selected Astronomical Catalog 1) (GSC)
Iben I., Renzini A., 1983, ARA&A 21, 271
IRAS Point Source Catalog (Version 2), 1988, Joint IRAS Science Working Group (Washington, DC: GPO) (PSC)
Johnson H. R., 1992, in: Evolutionary Processes in Interacting Binary Stars, eds. Y. Kondo, R. F. Sistero, R. S. Polidan, Kluwer, p. 157
Jorissen A., Mayor M., 1988, A&A 198, 187
Jorissen A., Mayor M., 1992, A&A 260, 115
Jorissen A., Frayer D. T., Johnson H. R., Mayor M., Smith V. V., 1993, A&A 271, 463
Keenan P. C., 1954, ApJ 120, 484
Keenan P. C., Boeschaar P. C., 1980, ApJS 43, 379
Merrill P., 1922, ApJ 56, 457
Scalo J. M., Ross J. E., 1976, A&A 48, 219
Smith V. V., Lambert D. L., 1990, ApJS 72, 387
Stephenson C. B., 1984, Pub. Warner & Swasey Obs. 3, 1 (GCGSS)
Xiong G. Z., Chen P. S., Chen J. B., 1994, Acta Astronomica Sinica 35, 20