COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 4689

Konkoly Observatory
Budapest
30 March 1999

HU ISSN 0374 – 0676

THE SPECTRUM OF SAKURAI'S OBJECT IN 1998

T. KIPPER[1], V.G. KLOCHKOVA[2]

[1] Tartu Observatory, Tõravere, 61602, Estonia, e-mail: tk@aai.ee

[2] Special Astrophysical Observatory RAS, Nizhnij Arkhyz, 357147, Russia, e-mail: valenta@sao.ru

The evolution of the born–again giant Sakurai's object (V4334 Sgr) has been extraordinarily rapid (Asplund et al. 1999). The object was discovered by Y. Sakurai in February 1996 (Nakano et al. 1996) and is believed to be a star which recently experienced a final He–shell flash.

We have started monitoring of Sakurai's object starting shortly after its discovery trying to detect changes in its spectrum (Kipper & Klochkova 1997). In 1998 we have obtained four sets of spectra (on March, 06 and 08, July, 09 and 15) with the prime focus echelle spectrometer of RAS 6–m telescope. The first three spectra are of low resolution around $R = 12\ 500$ covering $\lambda\lambda 4700 \div 7750$ and the last one has somewhat higher resolution of $R = 25\ 000$ but covering only $\lambda\lambda 5000 \div 5900$. The reduction of the spectra was performed using the image reduction system IRAF†.

In 1998 Sakurai's object underwent a deep brightness drop similarly to the weakenings suffered by the another final He–flash object FG Sge (Kipper & Klochkova 1999). The light–curve for summer and autumn 1998 is depicted in Fig. 1. The data for this figure was taken from the AAVSO International Database. Our latest spectra were obtained just before the dimming started. The inspection of the spectra shows that there are no great changes compared with the spectra obtained in 1997. As the year before, the most prominent features are the bands of carbon containing molecules. This very much hinders the analysis of low resolution spectra. Only few features changed during 1998. So in the March spectra the weak emission components of NaI D lines were visible which disappeared in July. In March the [S I] $\lambda 7725$ double peaked nebular emission line was visible giving the nebular expansion velocity of about 23 km s^{-1}.

We tried to derive the temperatures for Sakurai's object comparing few published photometric colour data with colours computed using H–deficient model atmospheres. A small set of models for this analysis was computed with a improved version of MARCS program (Gustafsson et al. 1975) with updated opacities. Opacities from continuum sources, molecules CO, CN and C_2, and atomic lines were taken into account. The line opacities were treated in the opacity sampling approximation (Jørgensen et al. 1992). The structure of these models fits well with the analogous models by Asplund et al. (1997). The input abundances including C/He = 0.1 and N/He = 0.01 for the model calculations were those found for Sakurai's object in 1996 (Asplund et al. 1999). For comparisons

†IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

the colours $(V-R)$ and $(V-I)$ were used together with the interstellar reddening $E(B-V) = 0.53$ (Duerbeck & Benetti 1996). With the reddening $E(B-V) = 0.7$ (N.K. Rao, private communication) the temperatures would be $300 \div 500$ K higher. The results are depicted in Fig. 2 together with our earlier results and results collected from the literature. As could be seen from this figure the derived temperatures are quite consistent until March 1997. The later results diverge noticeably. Therefore we shortly describe those determinations. Pavlenko & Yakovina (1999) estimated the temperature $T_{\rm eff} = 5400$ K from the fit of very low resolution observed and synthetic spectra. Kamath & Ashok (1999) used the near–IR photometry and reddening $E(B-V) = 0.71$ to get color temperature around 5500 K. Jacoby et al. (1998) compared the strength of C_2 bands the in spectrum of Sakurai's object with the ones in the spectrum of another HdC star HD 182040 and found that $T_{\rm eff} = 5600 \pm 500$ K.

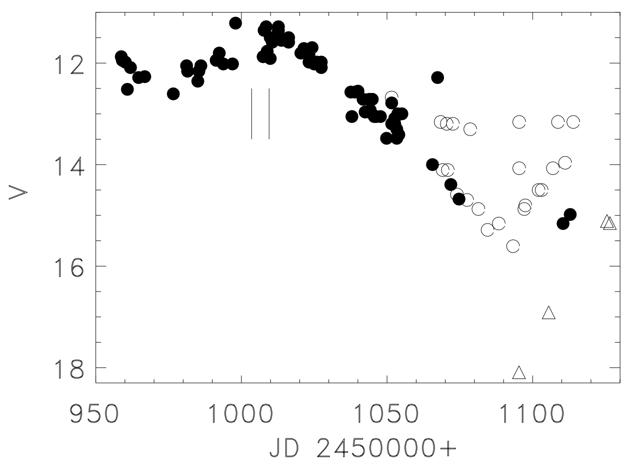

Figure 1. Light curve of Sakurai's object for summer and autumn 1998 (AAVSO). Open symbols indicate the upper limits. Triangles indicate the data added from IAUC, 7048 and 7065. Two vertical lines indicate the moments of our latest spectral observations

The low temperatures found from the colours are in sharp contrast with the intensities of C_2 Swan bands which have not changed from summer 1997. This could only be explained by increased circumstellar reddening and radiation from hot dust clouds. Indeed, Kamath & Ashok (1999) estimated the temperature of dust shell around 1800 K.

The relatively low resolution spectra offer little possibilities of determining stellar parameters. If we assume that the temperature of Sakurai's object has decreased between 1998 and 1998, the constancy of C_2 Swan band intensities could be explained by decreasing surface gravity. We succeeded in getting the best fit of the C_2 bands in the higher resolution July spectra taking $T_{\rm eff} = 5750$ K and $\log g = 0.0$ or $\log g = 0.5$ for CN lines in $\lambda\lambda 5658 \div 5696$ region. As noted, C and N abundances by number for spectrum synthesis were fixed at C/He $= 0.1$ and N/He $= 0.01$. Adopted dissociation energy of CN is $D_0(\mathrm{CN}) = 7.75$ eV. The microturbulent velocity of $\xi_{\rm t} = 5$ km s^{-1} was assumed (Asplund et al. 1999). With the lower input carbon abundance C/He $= 0.03$ the lower temperature $T_{\rm eff} = 5500$ K would give the best fit. The found temperature $T_{\rm eff} = 5750 \pm 200$ K is also plotted in Fig. 2. If one accepts $M = 0.8 M_\odot$ for Sakurai's object (Asplund et al. 1999) and the mean surface gravity $\log g = 0.3$ the luminosity will be $\log L/L_\odot = 4.03$.

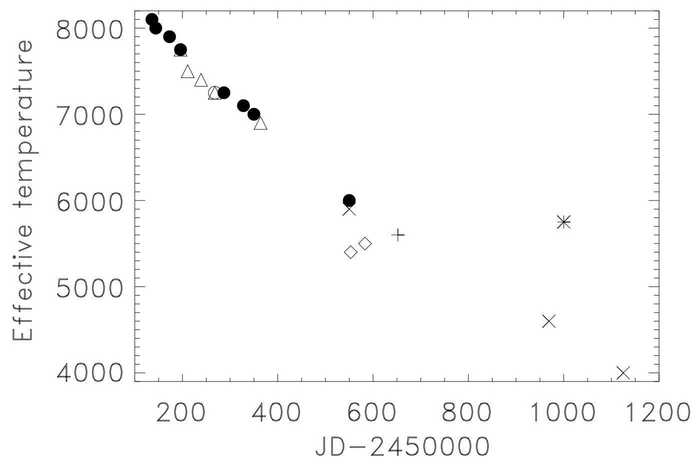

Figure 2. The effective temperature values of Sakurai's object from discovery to autumn 1998. Filled circles – Duerbeck et al. (1997), open circle – Kipper & Klochkova (1997), triangles – Asplund et al. (1999), open diamonds – Pavlenko & Jakovina (1999) and Kamath & Ashok (1999), cross – Jacoby et al. (1998), slanted crosses – temperatures found in this note using the colours, and asterisk – using C_2 Swan bands

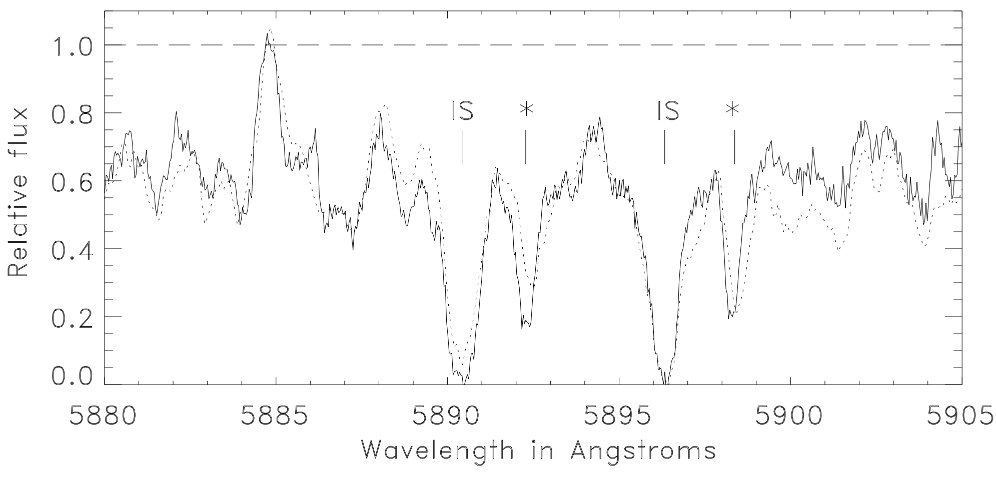

Figure 3. The spectra of Sakurai's object in 1998 (full line) and 1997 (dotted line). The positions of Na I D doublet interstellar and stellar components are indicated. Note that in 1997 the Na I D doublet intensities were reversed probably due to slight emission. Also, the stellar Na I D lines in 1997 were redshifted relative to other lines by 14 km s^{-1}. All other lines belong to C_2 and CN

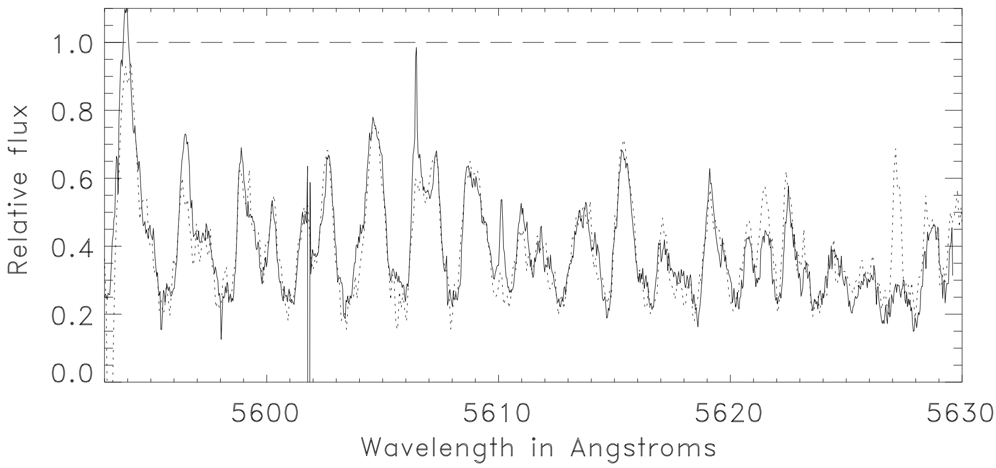

Figure 4. The same as in Fig. 3 but for C_2 (0,1) band region

This corresponds to an evolution at nearly constant luminosity as found by Asplund et al. (1999) or to slight luminosity increase if $\log g = 0.0$ were taken.

Few atomic lines in the July 19 spectra could be fitted. In that way the logarithmic abundances by number for Fe, Ca, Sc and La were found to be 6.5, 5.5, 3.5 and 1.8 correspondingly (normalized to $\log(\Sigma\mu_i\varepsilon_i) = 12.15$ and $\log\varepsilon(\mathrm{He}) = 11.54$). These abundances are close to the ones found for 1996 by Asplund et al. (1999). Sc abundance which seemed to drop in 1997 has returned to its high level.

Acknowledgements. In this note, we have used, and acknowledge with thanks, the data from the AAVSO International Database. T.K. acknowledges support by Estonian Science Foundation grant 3166.

References:

Asplund, M., Gustafsson, B., Kiselman, D., Eriksson, K., 1997, *A&A*, **318**, 521
Asplund, M., Lambert, D.L., Kipper, T., et al., 1999, *A&A*, **343**, 507
Duerbeck, H.W., Benetti, S., 1996, *ApJ*, **468**, L111
Duerbeck, H.W., Benetti, S., Gautschy, A., et al., 1997, *AJ*, **114**, 1967
Gustafsson, B., Bell, R.A., Eriksson, K., Norlund, Å., 1975, *A&A*, **42**, 407
Jacoby, G.H., de Marco, O., Sawyer, D.G., 1998, *AJ*, **116**, 1367
Jørgensen, U.G., Johnson, H.R., Norlund, Å., 1992, *A&A*, **261**, 263
Kamath, U.S., Ashok, N.M., 1999, *MNRAS*, **302**, 512
Kipper, T., Klochkova, V.G., 1997, *A&A*, **324**, L65
Kipper, T., Klochkova, V.G., 1999, *IBVS*, No. 4661
Nakano, S., Benetti, S., Duerbeck, H.W., 1996, *IAU Circ.*, 6322
Pavlenko, Y., Jakovina, L., 1999, *AZh*, in press