COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 4707

Konkoly Observatory
Budapest
14 May 1999

HU ISSN 0374 – 0676

THE DUST SHELL AROUND SAKURAI'S OBJECT

T. KIPPER

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

In our recent paper (Kipper & Klochkova 1999) we analysed the spectra of the born–again giant Sakurai's object (V4334 Sgr) whose evolution has been extraordinarily rapid. We found that the effective temperatures of the object derived using spectral and photometric methods were quite consistent until March 1997. Later results diverge noticeably. The natural explanation for that is the increased circumstellar reddening and an extra radiation from hot dust clouds as the star starts to show R CrB–type brightness drops. In this note we try to model this situation.

The most comprehensive photometric data for June, September and October of 1997 in $UBVJHKLM$ colours were obtained from Arkhipova et al. (1998). Further data for May, 1997 in JHK were taken from Kamath & Ashok (1999) and from the near–IR spectrum figures of Eyres et al. (1998) for April and July, 1997. Shorter wavelength data ($UBVRi$) for April, 1997 were taken from Duerbeck et al. (1997). For dereddening the $E(B-V) = 0.53$ (Duerbeck & Benetti 1996) and for the flux calibration the zero point fluxes by Straižys (1977) were used. The derived fluxes are plotted in Fig. 1. As could be seen, the data for near–IR deviate from each other quite noticeably. This reflects both the large observation errors and the variability as the plotted data cover the half a year time span.

For modelling the dust shell the publicly available code DUSTY, developed by Ivezić, Nenkova & Elizur (1997), was used.

For the input radiation from the central star the model spectra of H–deficient stars were used. Particularly for June 1997 and later we chose the model with $T_{\rm eff} = 5750$ K, $\log g = 0.3$ and C/He = 0.1. This was the model giving the best fit for the C_2 bands in 1998 spectra of Sakurai's object. We have earlier found that the line spectrum had not changed from 1997 (Kipper & Klochkova 1999). With assumed stellar mass of 0.8 $M_\odot$ this corresponds to $\log L/L_\odot = 4.03$ and $R_* = 104\ R_\odot$.

According to Zubko (1997) the most probable grain type acting in R CrB stars envelopes are the graphite grains. We used the optical properties of graphite grains by Draine & Lee (1984). In the course of modelling we found that only single size grains with radii around $a \approx 0.055$ μm allow to explain UBV observations of 1997. This is in accord with Zubko's (1997) findings that in the case of R CrB stars the size distributions of dust grains have peak–like form with typical sizes $0.02 \div 0.07$ μm. The constant dust density in quite narrow shell thickness $\Delta R/R_{\rm in} = 0.25$ was adopted as the shell formed during very short time.

The dust temperature $T_{\rm d}$ at the inner shell boundary $R_{\rm in}$ was estimated from the observed spectral shape and the location of the peak in near–IR region.

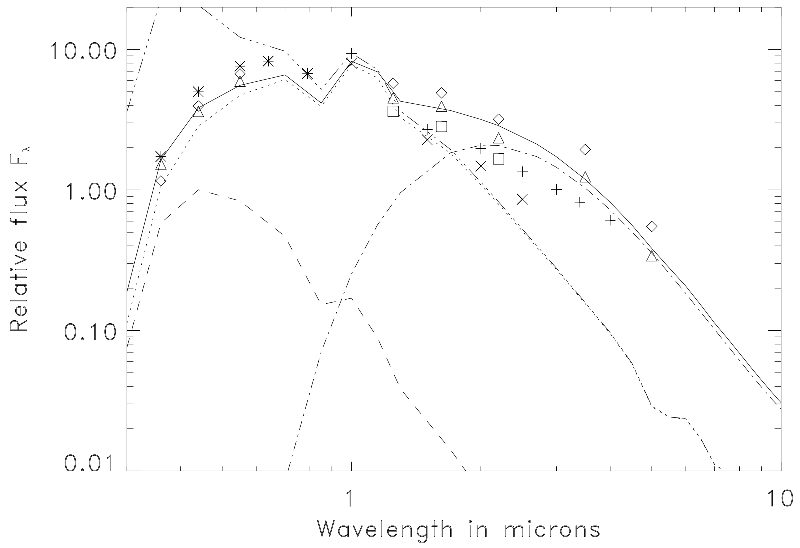

Figure 1. Modelling of circumstellar dust shell around Sakurai's object in 1997. Triangles – Arkhipova et al. (1998) for June; diamonds – ibid., for September and October; asterisks – Duerbeck et al. (1997) for April; squares – Kamath & Ashok (1999) for May; slanted crosses – Eyres et al. (1998) for March, crosses – ibid. for July. The model spectra for June and July of 1997 are plotted with lines: full line – total emerging flux, dotted line – contribution of the attenuated input radiation, dashed line – contribution of the scattered radiation, dash–dotted line – dust emission, and dash–dot–dot line – input stellar photospheric spectrum

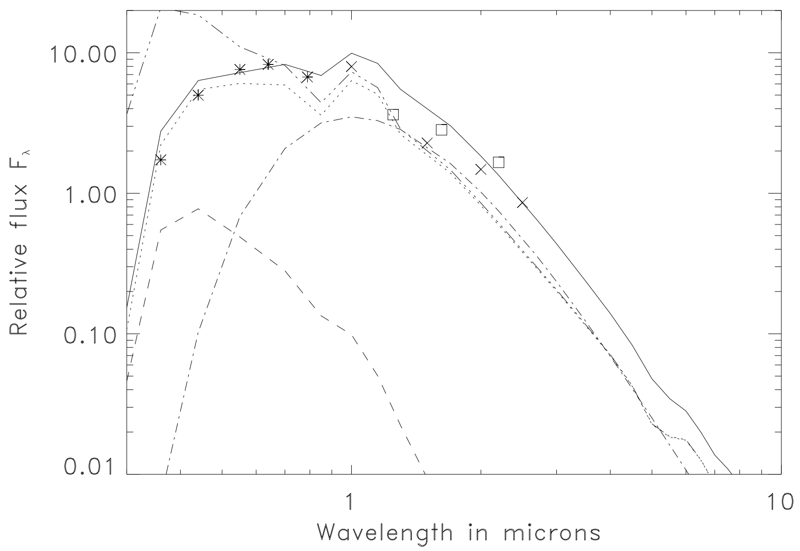

Figure 2. The same as in Fig. 1 but the model spectra are plotted for April 1997

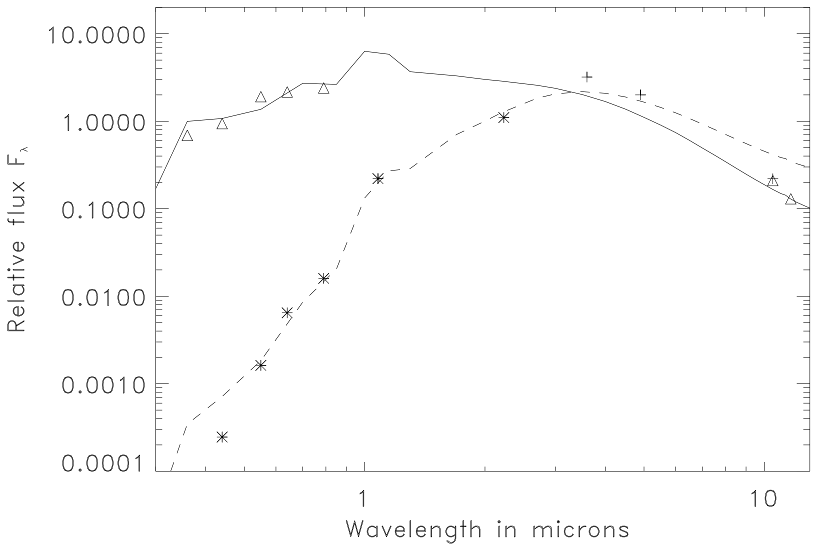

Figure 3. Modelling of circumstellar dust shell around Sakurai's object in 1998 and 1999. Triangles – Jacoby & De Marco (1998) and Kaeufl (1998) (near–IR) for June 1998; crosses – Lynch et al. (1998) for March 1888; asterisks – Jacoby (1999) for March 1999. Full line – model total flux for March – July 1998, dashed line – model flux for March 1999

In that way for June and July of 1997 the following model was found: visual optical depth, $\tau_V = 0.95$, dust temperature, $T_\mathrm{d}(R_\mathrm{in}) = 1200$ K, inner radius of dust shell, $R_\mathrm{in} = 68\ R_*$. This model is plotted also in Fig. 1. In this modelling the data by Arkhipova et al. (1998) was given the highest weight.

For April 1997 higher stellar temperature, $T_\mathrm{eff} = 6000$ K, smaller grain size, $a = 0.04\ \mu$m, visual optical depth, $\tau_V = 0.6$, and rather high dust temperature, $T_\mathrm{d} = 2500$ K at $R_\mathrm{in} = 8\ R_*$ were needed (Fig. 2). The speed of the changes in the envelope parameters between these two dates is in the order of the time–scale of gas acceleration found by Fadeyev (1988) for R CrB dust envelopes.

For the autumn of 1997 the model with spherical distribution of dust is impossible as both optical and near–IR flux have risen. The fit is possible only if the luminosity of the star was higher by about 20% or there was a hole in dust towards the observer with smaller extinction. It should be noted that, according to AAVSO data, the observed V magnitudes vary rather erratically up to $0\overset{\mathrm{m}}{.}5$.

In 1998 the star suffered deeper brightness drops. At the end of February the weakening in V amounted to 2^m, but the star almost recovered by the end of July when another, much deeper weakening started. For the first weakening the photometry by Jacoby & De Marco (1998), Kaeufl (1998) and Lynch et al. (1998) is plotted in Fig. 3. These observations could be approximated with the model having $\tau_V = 3.5$, $T_\mathrm{d} = 1250$ K. In this case in addition larger grains up to $a = 0.15\ \mu$m with standard IS distribution, $n(a) \propto a^{-3.5}$, and larger relative thickness of the shell $\Delta R/R_\mathrm{in} = 10$ are needed. Inclusion of larger grains allows to model much flatter output spectrum at the shorter wavelengths. Larger relative thickness gives better fit in near–IR region. The luminosity of the star should be higher by 20% compared to July 1997.

The weakening which started in July 1998 has not yet stopped and by March 1999 the star was already as weak as $V = 20.08$ (Jacoby 1999). These last data could be approximated with the model having $\tau_V = 11.0$ and T_d not higher than 900 K. The (1023–2230) colour alone corresponds to a blackbody with temperature of 1285 K (Jacoby 1999). This very deep and longlasting minimum indicates that Sakurai's object could share the fate of another final helium shell flash star V605 Aql which after four years of fadings and brightenings disappeared from the sky (Clayton & De Marco 1997).

The presented models follow from very crude approximations. The state of the system is not steady but highly dynamical. The outpuffs of dust are probably related to a pulsational cycle of the central star. This means that the input stellar radiation rapidly changes. The gas in which the dust grains condense is ejected rather in cones with semi-angle of about 20° (Feast 1986) than in spherical symmetry. Nevertheless, such modelling allows to explain why the effective temperatures of the star determined from colours and spectral data do not coincide and the spectral energy distribution of the system for 1997 and later could be explained with the constant effective temperature of central star, $T_\mathrm{eff} = 5750$ K.

Acknowledgements. The work on this note was supported by Estonian Science Foundation grant 3166. We have used, and acknowledge with thanks, the data from the AAVSO International Database.

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