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

Number 6143

Konkoly Observatory
Budapest
2 June 2015

HU ISSN 0374 – 0676

HOT DUST REVEALED DURING THE DIMMING OF THE T TAURI STAR RW Aur A

SHENAVRIN, V.I.[1]; PETROV, P.P.[2]; GRANKIN, K.N.[2]

[1] Lomonosov Moscow State Univ., Sternberg Astron. Inst., Universitetsky pr. 13, 119234 Moscow, Russia

[2] Crimean Astrophysical Observatory, 298409 Nauchny, Republic of Crimea

email: vshen@msu-crimea.ru, petrogen@rambler.ru, kgrankin@crao.crimea.ua

T Tauri stars (TTS) are young pre-main sequence objects of low mass ($M < 2\ M_\odot$), located in star forming regions. During the first ~ 10 Myr of their evolution TTS are surrounded by circumstellar disks, where processes of planet formation are going on. TTS are distinguished by irregular light variability and the characteristic emission line spectrum of low excitation. The light variability of TTS with accretion discs is caused by three processes: obscuration of stellar light by dust clouds in the circumstellar disc, variable mass accretion – infall of matter from the disc to the stellar surface, and cool magnetic spots which often cause rotational modulation of stellar brightness (Herbst et al. 1994).

RW Aur A is one of the brightest TTS, located in the Taurus-Auriga star forming region at the distance of 140 pc. It is a K1-K3 star of about solar mass ($1.4\ M_\odot$) with strong emission line spectrum and clear signatures of accretion and wind (Petrov et al. 2001, Alencar et al. 2005). RW Aur is a visual binary with a separation of $1''\!.4$ between A and B components. The secondary, RW Aur B, is a TTS of lower mass, $0.8\ M_\odot$, and of later spectral type, K7. It is nearly a weak-line TTS, with Hα equivalent width of ≈ 7 Å, which indicates a low rate of mass accretion. The B component is also a binary with separation of $0''\!.12$ and mass of the secondary below $0.045\ M_\odot$ (Ghez et al. 1997).

RW Aur has been intensively observed photometrically during ~ 50 yr. The range of visual light variability is typically from $V=10^{\rm m}\!.0$ to $V=12^{\rm m}\!.0$ on a time scale of a few days. The first long-lasting dimming event was recorded in 2010, when the star faded by about $2^{\rm m}$ and remained in a low state with some fluctuations during several months. Rodriguez et al. (2013) presented a detailed investigation of this phenomenon and concluded that the star was obscured by a distant cloud, supposedly a remnant of tidally disrupted disc of the star. Recently, Dai et al. (2015) performed MHD simulations which reproduced the morphology of the molecular cloud around RW Aur as a result of tidal encounter with the secondary star.

In 2014 the dimming event repeated: RW Aur A faded by $\approx 3^{\rm m}$ and has remained in the low state until now (April 2015). Resolved photometry of the two components was made by Antipin et al. (2015) in November 2014. They showed that RW Aur A underwent a grey extinction in $UBVR$ bands. The secondary component was found to be variable within $\approx 1^{\rm m}$. Resolved spectroscopy of the two components in December 2014

(Petrov et al. 2015) showed that the emission line spectrum of RW Aur A remained as usual, but the wind features in some resonance lines have increased considerably. The spectrum of the secondary remained unchanged. The authors proposed that the dimming might be caused by extinction of light in a dusty wind of the primary component.

In this paper we present results of infrared (IR) photometry of RW Aur in 2010-2015, which provides additional information about the cause of the dimming events. IR-photometry of RW Aur was carried out at the 125-cm telescope at the Crimean observatory of the Moscow University. InSb-photometer with a standard $JHKLM$ system was used. Technical parameters of the photometer, methods of observations and calculations of magnitudes were described in details by Shenavrin et al. (2011). The star BS 1791 was used as a photometrical standard. Its JK magnitudes were taken from the catalogue of Johnson et al. (1966), and HLM magnitudes were calculated from relations given in Koornneef (1983). The standard error of the measured magnitudes of RW Aur is about $0\overset{m}{.}02$ in $JHKL$ bands, and about $0\overset{m}{.}05$ in M band. In our observations, the A and B components of RW Aur were not resolved.

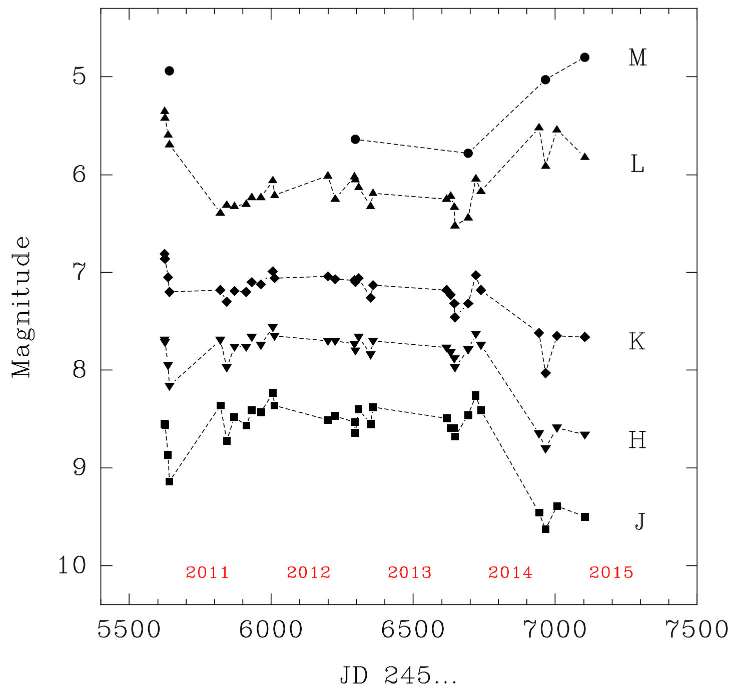

Figure 1. Light curves of RW Aur in $JHKLM$ bands in 2010-2015. Note the brightening of the star in L and M bands, while fading in JHK bands.

Fig. 1 shows the IR light curves of RW Aur in 2010-2015, starting from the very end of the dimming event of 2010 and covering the dimming event of 2014-2015. Comparison of spectral energy distribution in the bright and low states of RW Aur is shown in Fig. 2. The $UBVRI$ data at the bright state are from our Crimean database.

Note the different slopes at 2-5 μm (KLM bands) at low and bright states, indicating appearance of additional source of IR-radiation when the star has faded in visual range. This additional flux can be attributed to radiation of hot dust at the temperature of about 1000 K. The IR source is most probably associated with the primary component

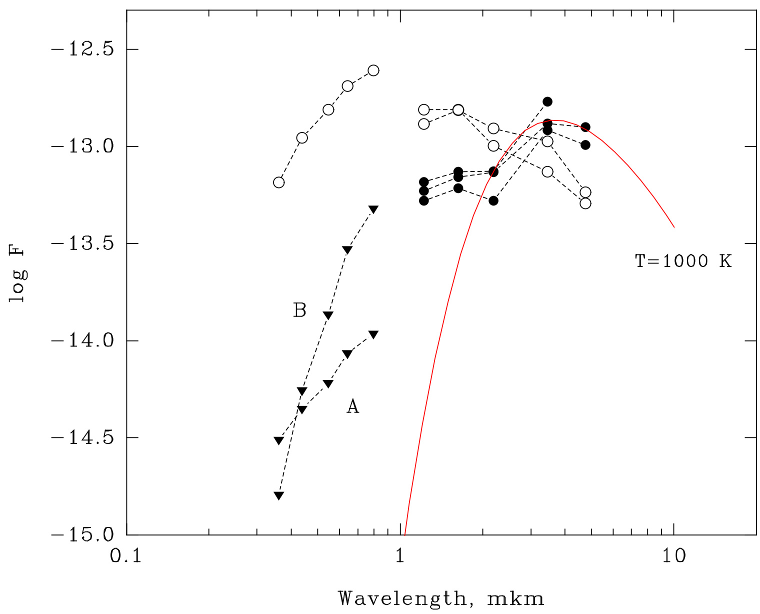

Figure 2. Spectral energy distribution in bright and low states of RW Aur. The flux scale is $\log \lambda F(\lambda)$, in units $\mathrm{erg\,cm^{-2}\,s^{-1}}$. Open circles – $UBVRI$ and $JHKLM$ photometry in bright state of 2013, filled circles – $JHKLM$ photometry in the low state of 2014–2015 (JD 2456965 – 2457104), triangles – resolved photometry of A and B components of RW Aur in the low state of 2014 (JD 2456975), from Antipin et al. (2015). The solid curve is the Planck function (T=1000 K) fitting the additional flux in KLM bands during the dimming of 2014-2015.

(RW Aur A), because the secondary is much fainter in K band: at normal brightness of the primary, the K magnitude of the secondary was $\approx 1^{\rm m}\!\!.6$ fainter (Eisner et al. 2007).

Hot dust is present in the inner regions of accretion discs of TTS, at the distance of about 0.1 AU, where the dust is near the temperature of sublimation, 1500-2000 K (Millan-Gabet et al. 2007). From IR-interferometry of RW Aur the inner radius of the dusty disc was determined as 0.10-0.23 AU (Akeson et al. 2005; Eisner et al. 2007). If dimmings of RW Aur at the optical wavelength were caused by extinction of light in a distant cloud, as was suggested by Rodriguez et al. (2013), one would expect that not only the central star is obscured, but the inner disc is too, at least partly, is screened by the cloud, like, e.g., in V2492 Cyg, where occultation of the central star and the inner disk causes large amplitude variations in optical and IR bands (Hillenbrand et al. 2013). In RW Aur, the observed *increase* of the IR flux during the deep dimming event of 2014 is not compatible with the hypothesis of a distant cloud. Most probably, the extinction of starlight is due to the same dust which radiates at 3-5 μm, not far from the star.

Light variability related to dusty clouds in the circumstellar disks is usually observed in UXors – intermediate mass pre-main sequence stars of earlier spectral types as compared to the low mass TTS. Correlated variations in optical and near-IR bands were observed in some UXors, while others demonstrated anti-correlation (Shenavrin et al. 2012). The variations similar to that shown in Fig. 1 were observed in the UXor type stars UX Ori and AK Sco (Hutchinson et al. 1994). Explanation of this kind of variability was suggested by Grinin et al. (2009) for another UXor, V1184 Tau, in the context of the model of accretion disk with the puffed-up inner rim in the dust sublimation zone. The authors supposed that an enhancement of the accretion results in increase of geometrical thickness of the rim and the dusty atmosphere of the inner disk, which obscures the starlight. At the same time, the near-IR radiation from the inner rim remains the same or even increases.

Although this model is natural for an UXor, it is questionable whether it can be applied to a later spectral type TTS. Another point is that the disk plane of RW Aur A is inclined by between 30 to 45 degrees to the line of sight (Cabrit et al. 2006). It was shown by Rodriguez et al. (2013) that with such inclination the inner rim can hardly obscure the star. And, finally, the emission line spectrum of RW Aur A has not changed during the dimming event, i.e. the accretion rate remained as usual. Nevertheless, a hot dust in atmosphere of the inner disk is the most probable agent which obscures the star and radiates in near-IR. Petrov et al. (2015) revealed the enhanced wind features during the dimming event of RW Aur A. Note, that inclination of the star is close to the opening angle of a conical wind (Romanova et al. 2009). We suggest that the hot dust, responsible for the dimming event, was carried into the wind of RW Aur A, streaming from the inner disk towards the observer.

References:

Akeson, R. L., Boden, A. F., Monnier, J. D., et al., 2005, *ApJ*, **635**, 1173

Alencar, S. H. P., Basri, G., Hartmann, L., Calvet, N. 2005, *A&A*, **440**, 595

Antipin, S., Belinski, A., Cherepashchuk, A., et al., 2015, *IBVS*, **6126**

Cabrit, S., Pety, J., Pesenti, N., Dougados, C., 2006, *A&A*, **452**, 897

Dai, F., Facchini, S., Clarke, C., et al., 2015, *MNRAS*, **449**, 1996

Eisner, J. A., Hillenbrand, L. A., White, R. J., et al., 2007, *ApJ*, **669**, 1072

Ghez, A. M., White, R. J., and Simon, M., 1997, *ApJ*, **490**, 353

Grinin, V. P., Arkharov, A. A., Barsunova, O. Yu., Sergeev, S. G., Tambovtseva, L. V., 2009, *AstL*, **35**, 114

Herbst, W., Herbst, D. K., Grossman, E. J., Weinstein, D., 1994, *AJ*, **108**, 1906

Hillenbrand, L. A., Miller, A. A., Covey, K. R., et al., 2013, *AJ*, **145**, 59

Hutchinson, M. G., Albinson, J. S., Barrett, P., Davies, J. K., Evans, A., Goldsmith, M. J., Maddison, R. C., 1994, *A&A*, **285**, 883

Johnson, H. L., Mitchell, R. I., Iriarte, B., et al., 1966, *Comm. Lunar Planet. Lab.*, **4**, 99

Koornneef, J., 1983, *A&A*, **128**, 84

Millan-Gabet, R., Malbet, F., Akeson, R., et al., 2007, in "Protostars and Planets V", eds. Reipurth, B., Jewitt, D., and Keil K., University of Arizona Press, Tucson, p. 539

Petrov, P. P., Gahm, G. F., Gameiro, J. F., Duemmler, R., Ilyin, I. V., Laakkonen, T., Lago, M. T. V. T., Tuominen, I., 2001, *A&A*, **369**, 993

Petrov, P. P., Gahm, G. F., Djupvik, A. A., et al., 2015, *A&A*, **577**, A73

Rodriguez, J. E., Pepper, J., Stassun, K. G., et al., 2013, *AJ*, **146**, 112

Romanova, M. M., Ustyugova G. V., Koldoba A. V., Lovelace R. V. E., 2009, *MNRAS*, **399**, 1802

Shenavrin, V. I., Taranova, O. G. and Nadzhip, A. E., 2011, *Astron. Rep.*, **55**, 31

Shenavrin, V. I., Grinin, V. P., Rostopchina-Shakhovskaja, A. N., Demidova, T. V., Shakhovskoi, D. N. 2012, *Astron. Rep.*, **56**, 379