Spectroscopy And Photometry Of V1137 Aql

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V1137 Aql = SON 8114 was discovered by Hoffmeister (1964), who detected its brightness variations between $m_{pg} = 14^m.5$ and $16^m.5$. The variability type SR: was assigned to the object in the General Catalogue of Variable Stars (Kholopov et al., 1985). The star was detected by several satellite infrared (IR) surveys (RAFGL 2413, Price & Murdock, 1983; IRAS 19307+1338; MSX5CG049.893302.7331, Egan et al., 1999), which revealed a strong IR flux and emission features at 9.7 and 18 μm, indicative of the circumstellar silicate dust. Ground-based IR photometry and spectroscopy (Joyce et al., 1977; Lebofsky et al., 1978; Eiroa et al., 1983) showed that the object's fluxes were significantly variable.

From *BV RI* photometry Eiroa (1981) concluded that V1137 Aql is a heavily reddened M1-type star (see Table 1), and calculated possible distance (*D*) and overall, inter- and circumstellar, extinction (A_V) toward it: $A_V = 5^m.05$ and D = 313 pc for the luminosity type III and $AV = 4^m.68$ and D = 6.2 kpc for Ia. Radio observations by Josselin et al. (1998) resulted in a detection of the CO line emission with a ratio $R = S_{60}/T_{mb}$ = 293 Jy K^{-1} (where S_{60} is the 60-μm IRAS flux and T_{mb} is the brightness temperature of the CO (10) transition). These authors suggested that the latter result indicate that V1137 Aql was a supergiant, because less luminous post AGB stars have $R \leq 150$.

However despite the extensive information from the IR region, optical observations of V1137 Aql are still represented by photographic photometry (Gessner, 1983, 1986) and the BVRI data (Eiroa, 1981). This allows only rough and indirect estimates of the star's physical parameters and evolutionary state. In order to fill this gap we present the results of our multicolor photometry and low-resolution optical spectroscopy of V1137 Aql.

The BVRIJHK observations in the Johnson photometric system were obtained between July 1986 and August 1995 at two 1-meter telescopes of the Fesenkov Astrophysical Institute (Kazakhstan) with a two-channel photometer-polarimeter of the Pulkovo Observatory (Bergner et al., 1988a). The results are presented in Table 1. The large difference in R - I between our data and those of Eiroa (1981) can be explained by the very red color of the object, differences in the instrumental photometric systems, and intrinsic variability of the star. The detected variations are ~ 1^m in the VRI-bands, while the B-magnitude varies between $14^m.5$ and $15^m.9$ (similar to the results of Hoffmeister, 1964).

Two spectra of V1137 Aql (reciprocal dispersion 50 A mm^{-1}, resolution 2.1 Å) were obtained on 1991 July 20 (4235-5245 Å) and July 21 (5981-7013 Å) at the 6-meter telescope of the Russian Academy of Sciences with a TV-scanner mounted in the Nasmyth

Table 1: Photometric data on V1137 Aql = CRL 2413[a]

Date	JD 2440000 +	$B-V$	V	$V-R$	$V-I$	$V-J$	$V-H$	$V-K$
/07/78	[b]	3.21	12.03	2.59	4.83	–	–	–
02/07/86	6614.23	3.16	11.33	2.59	4.26	5.74	–	–
13/09/89	7783.19	3.29	11.57	2.61	4.32	5.76	6.75	7.33
16/09/89	7786.18	3.45	11.55	2.55	4.30	5.74	6.69	7.34
27/08/91	8496.16	–	11.95	2.61	4.29	–	–	–
07/11/92	8934.05	3.57	12.28	2.77	4.36	–	–	–
12/08/95	9942.31	3.16	11.83	2.44	3.99	5.76	6.77	7.47

[a] The mean errors (including those of translation from the instrumental to the standard photometric system) are as follows: $0\overset{m}{.}02$ in $R-I$, $0\overset{m}{.}03$ in $V-R$, $V-K$, and the V-band, $0\overset{m}{.}05$ in $B-V$, $V-J$, and $V-H$.

[b] The errors are $0\overset{m}{.}01$ in the V-band and $0\overset{m}{.}02$ in the color-indices (Eiroa, 1981).

Table 2: Intensities of the TiO bands in the spectrum of V1137 Aql

Band	4626	4669	4761	4804	4893	4955	5167	6158
$I_{\rm min}/I_{\rm max}$	0.67	0.62	0.58	0.81	0.69	0.66	0.44	0.75

focus. Its most prominent features are TiO bands (see Table 2), whose intensities we measured using the technique by Boyarchuk (1969). We also detected Balmer lines in absorption, many strong metallic lines, and no obvious emission lines.

The TiO band strengths were compared with those of M stars with known spectral types from Boyarchuk (1969), who used dispersions of 61 and 80 Å mm^{-1}. The resulting spectral type is M2-3. The spectrum of μ Cep (M2 I), obtained at the Ritter Observatory with a 0.25 Å resolution, turned out to be similar to our red spectrum of V1137 Aql, except for the Hα line which can be partly filled in by an emission component (Fig. 1, left panel). We also compared the blue part of the object's spectrum with that of AS 501 (M4-5 I-II, Bergner et al., 1988b), which we obtained on 1991 July 20 at the 6-meter telescope with the same equipment. The luminosity dependent intensity ratios of the Fe I lines at 4376, 4383, and 4389 Å and at 4427 and 4431 Å indicate that V1137 Aql is less luminous than AS 501. Thus, our spectroscopic data suggest an MK type of M2/3 II-III for V1137 Aql.

Our photometry supported by the longer-wavelength data indicate that V1137 Aql is surrounded by a large amount of circumstellar dust, whose characteristics can be derived by modelling the observed spectral energy distribution (SED). The IR data obtained by different authors show that the object's flux at 11 μm varies from 46 Jy (Joyce et al., 1977) to 195 Jy (Price & Murdock, 1983). This is comparable with the amplitude of the optical variations. The IRAS and MSX data, which represent an intermediate brightness level, were used along with the averaged optical data to construct the SED. Despite the uncertainty in the IR fluxes, its shape is better determined, which is seen from our photometric data. To calculate theoretical SEDs, we used a radiative transfer code DUSTY by Ivezić, Nenkova, & Elitzur (1999) for spherical dusty envelopes. The dust temperature distribution is calculated self-consistently including dust scattering, absorption, and emission. A Kurucz (1994) model for $T_{\rm eff}$ = 3750 K and $\log g$ = 1.0, roughly corresponding to an M2/3 III star, was used to describe radiation of the star and

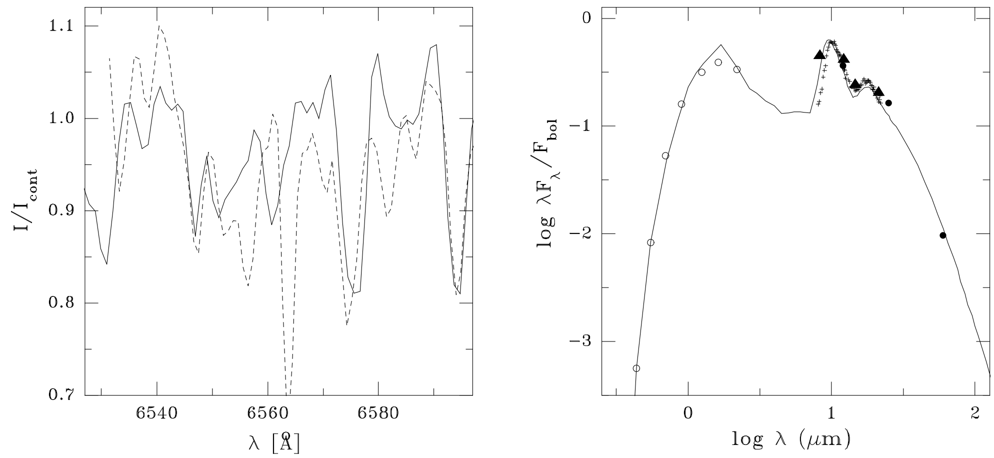

Figure 1. Left panel. A part of the spectrum of V1137 Aql near the Hα line (solid line). The dashed line represents the spectrum of μ Cep obtained at the 1-meter telescope of the Ritter Observatory of the University of Toledo with a fiber-fed échelle spectrograph and a Wright Instruments Ltd. CCD camera (the resolution is 0.2 Å) and re-binned to a constant wavelength increment of 2 Å. Both spectra are normalized to the continuum level near the Hα line. The wavelengths are in Å. **Right panel.** The averaged observed and dereddened SED of V1137 Aql and a theoretical model (solid line) calculated with the parameters described in text. Our optical and near-IR data are shown by filled circles, the MSX fluxes by filled triangles, the IRAS fluxes by filled squares, and the IRAS low-resolution spectrum by pluses

optical properties of the interstellar dust (Mathis, Rumpl, & Nordsieck, 1977) to model dust particles in the envelope. Models with different dust sublimation temperatures ($T_{\rm sub}$), the envelope optical depths at 0.55 μm (τ_V), and ratios of its outer and inner radii ($Y_{\rm out}$) were calculated. The dust density distribution $\propto r^{-2}$ (where r is the distance from the star) was fixed. We compared the observed and theoretical SEDs adjusting the interstellar extinction $A_V^{\rm IS}$ with the best fit shown in the right panel of Fig. 1.

The modelling shows that the strengths of the silicate features are well reproduced by the interstellar dust with $\tau_V = 5.2$, while $A_V^{\rm IS} \simeq 0\overset{\rm m}{.}1$–$0\overset{\rm m}{.}2$. $T_{\rm sub}$ of 500–600 K is required to match the near-IR part of the SED and $Y_{out} \sim 100$ to match its slope at $\lambda \geq 25$ μm. However, the combination of the satellite IR and our data, obtained non–simultaneously, make the relative contribution of the circum- and interstellar extinction uncertain. Since the observed near-IR color-indices are not consistent with a large $A_V^{\rm IS}$, we do not expect it to be $\geq 1^{\rm m}$. The observed $J - H = 1\overset{\rm m}{.}02 \pm 0\overset{\rm m}{.}03$, which is lightly affected by the thermal radiation, and intrinsic $(J - H)_0 = 0\overset{\rm m}{.}88$ (Bessell & Brett, 1988) suggest $A_V^{\rm IS} \leq 1\overset{\rm m}{.}2$.

The results of our calculations suggest that the dusty envelope around V1137 Aql is optically thin in the IR but optically thick in the optical domain. Using the bolometric flux ($F_{\rm bol}$) and a relation of $A_V^{\rm IS}$ versus D in the object's direction, we can estimate its luminosity. $F_{\rm bol}$, calculated from the theoretical SED scaled with the observed fluxes, is 5×10^{-5} W m^{-2} and is uncertain within at least a factor of 2. Eiroa (1981) estimated $A_V^{\rm IS} \sim 3^{\rm m}$ at $D \geq 1$ kpc in this direction. Miroshnichenko (1996) studied the interstellar extinction law in a region of $\sim 2°$ around MWC 314, located in $\sim 3°$ from V1137 Aql, and showed that $A_V^{\rm IS}$ reaches $\sim 1^{\rm m}$ at $D \sim 1$ kpc. Since $F_{\rm bol} = \sigma T_*^4 \left(\frac{R_*}{D}\right)^2$, where R_* is the star's radius, at $D = 1$ kpc $M_{\rm bol} = -3\overset{\rm m}{.}2$ and is close to that of the luminosity type III (Straižys & Kurilene, 1981). It corresponds to $R_* \sim 90$ $R_\odot$ and is consistent with recent estimates for normal M3-type giants by Dumm & Schild (1998).

Thus, we conclude that V1137 Aql is an intermediate-luminosity oxygen-rich early M-type star showing brightness variations similar to those of the Mira stars. This is consistent with its location in a region of optical Mira variables in the IRAS color–color diagram (Olnon et al., 1984). Our luminosity estimate implies a main sequence mass of $\sim 1\ M_\odot$ and a possible period of the variations of $\sim 100^{\rm d}$–$150^{\rm d}$(Wood et al., 1983). The results of our study can be verified by follow up optical photometric monitoring as well as by simultaneous photometric observations in a spectral range from 0.4 to $\sim 10\ \mu$m.

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