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Simultaneous spectroscopic and photometric observations of 2A0311-227 (*)

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Summary. — Results of photoelectric five-colour photometry (Walraven system) and simultaneous spectroscopic observations (ESO 3.6 m/IDS) of the AM Her - type system 2A0311-227 are presented.

Key words : X-ray binaries ; AM Her systems.

1. **Introduction.** — In a previous paper (Verbunt *et al.*, 1980) we have given a discussion of simultaneous photometric and spectroscopic observations of the optical counterpart of the X-ray source 2A0311-227 (Cooke *et al.*, 1978 ; Griffiths *et al.*, 1979 ; Hiltner *et al.*, 1980). We present here the observational data on which that paper was based.

2. **Observations.** — The observational data consist of simultaneous spectrophotometric and photometric measurements obtained on November 11, 1979 between UT 01:30 and UT 04:30.

The spectra were made with the ESO 3.6 meter telescope/Image Dissector Scanner combination (Cullum, 1979). We used a dispersion of 171 Å/mm to cover the wavelength range between 4000 and 7000 Å. Sky and star exposures were made alternatively through two slits of 1.5 arcsec width and combined in pairs to allow for subtraction of the sky signal. Each individual integration lasted for 100 seconds and was started every 2 whole minutes UT. In this way we obtained a set of 43 spectra, each the result of 200 seconds of integrations during a time interval of four minutes.

The wavelength calibration of the spectra was obtained from exposures of a HeAr lamp before, at midtime, and after the observations of 2A0311-227. A similar observation was made of the white-dwarf standard star Hiltner 600 (Stone, 1977) to derive the flux calibration of the spectrophotometry.

The photometric observations were made in the Walraven five-colour system, with the 90 cm Dutch telescope at the European Southern Observatory. The photometer provides simultaneous data in five passbands between 3200 and 6000 Å. A recent description of the photometer and the photometric system has been given by Lub and Pel (1977). We used a diaphragm of 16 arcseconds, and set the integration time equal to 64 seconds. Measurement of the sky brightness were made every 20 minutes. Every hour the Walraven Standard Star HD 17081 was observed.

3. **Reduction.** — The photometric data were reduced using the standard reduction program of the Leiden observatory. In the reduction program average values of the extinction coefficients for La Silla were assumed (see ESO User's Manual and Tüg, 1977). The zero points of the *VBLUW* magnitudes were determined from the observations of the standard star HD 17081, for which the data were reduced in the same way. In table I we present the results of the five colour photometry of 2A0311-227. The UT values in table I (and also in tables II and III) refer to the midtime of the integration.

The spectroscopic data were reduced at ESO (Geneva) using the IHAP interactive program. For a small number of HeAr lines which could be easily identified a linear relation between wavelength and pixel number is calculated to try and identify other lines from a wavelength table of HeAr lines. The centers of the identified lines are determined from a Gaussian fit to their profiles, and a fifth degree polynomial fit is made of wavelength to pixel number. Fit and points are plotted and apparent misidentifications are removed, until a satisfying fit is found. The number of lines used is typically ~ 20. Each HeAr measurement consists of two spectra (one for each slit) for each of which the wavelength calibration was made separately. The three HeAr measurements made before, during, and after the 2A0311-227 measurements give essentially the same fits, i.e. the difference between the fits is less than the uncertainty in one fit. For the reduction of the spectra we used the fits from the second measurement. The measurements of 2A0311-227 were coupled in pairs of two : one measurement with sky in slit A and star in slit B, and one with star in slit A and sky in slit B. For each slit, the sky was subtracted from the star, irregularities from the IDS detection were removed by dividing by a

(*) Based on observations made at the European Southern Observatory.

flatfield exposure (the detector response to a white lamp), and the count rates in 5 Å wide bins were determined using the wavelength - to - pixel number fits and subsequent interpolation. After this the results for slit A and B were added. The same procedure was followed for the white dwarf standard star Hiltner 600. Using a table of absolute fluxes by Stone (1977) a smooth fit was made of the relation between count rate and flux as a function of wavelength. This was used to convert the count rates of 2A0311-227 to intensity. The result consists of 43 flux calibrated spectra.

In each of these the positions of emission lines were determined by making a Gaussian fit to their profiles, using all points between the places where the lines join the continuum. The radial velocities obtained from these central wavelengths are given in table II.

The results for the He I lines are less accurate because they are weaker and they often show a more irregular structure than the stronger emission lines.

As shown in our first paper the radial velocity variation is approximately sinusoidal, but near phase 0.0 ([1]) a deviation occurs which is probably related to distortions in the line profiles, visible as a change from emission into absorption for the lines redward of 5500 Å. We have made sinusoidal fits to the radial velocity data, however with the data between UT 1:56 - 2:08 and 3:16 and 3:28 deleted. The radial velocity amplitudes, zero point velocity and relative phases for these fits are given in table III. The amplitudes of these sinusoidal fits are rather smaller than the values given by e.g. Schneider and Young (1980). Much of the difference is probably due to our not including of the velocities or the apparent bump in the curve. It is of interest that we confirm the result by Schneider and Young (1980) that the velocity variation of the He IIλ4686 line leads that of the Balmer lines (except Hα) by a phase difference of $\sim$ 0.04. The velocity variation of Hα lags those of the higher Balmer lines by about 0.04 in phase.

We have determined the line strengths of the emission lines by integrating the counts over the line profile and subtracting the contribution due to the continuum. The latter was determined at apparent line-free stretches of the spectrum and linearly interpolated at the line positions.

Because of the rather narrow slit the absolute flux scale of the spectrophotometric data cannot be trusted, and we have used the Walraven photometric data to make an absolute flux calibration. An absolute flux calibration of the Walraven system has been given by Lub (1980). We have related the spectroscopic and the photometric data by interpolating the continuum count rate at the effective wavelengths of the V and B pass bands. The photometric observations were averaged over the 4-minute period of the spectroscopic integration. In case no photometric observation is available (e.g. because of interruption for sky and standard star measurements) we have linearly interpolated the B and V light curves. In view of the known occurrence of fluctuations in the optical light curve of 2A0311-227 these interpolated results cannot be considered very accurate. The Walraven B flux was corrected for the contribution due to emission lines, in order to make a comparison with the spectrophotometric continuum. We have approximated this correction by taking the total equivalent width of the strong emission lines inside the B-passband. The connection varies between 9 and 25 percent.

The conversion factor from number of counts to ergs . cm^{-2} . s^{-1}, as determined in B and V are in good agreement. The distribution of the logarithmic differences has a mean value of 0.027 and a standard deviation of 0.046. We therefore conclude that the average conversion factor for each spectrum, as determined in B and V, has an accuracy better than 10 percent. The integrated line fluxes are given in table IV.

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([1]) We have here used the phase convention in which phase zero occurs at the sharp dip in the infrared lightcurves (Bailey *et al.*, 1980).

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TABLE I. — *VBLUW photometry of 2A0311-227.*

UT	V	V-B	B-U	U-W	B-L	V_J
014113	-3.192	0.235	-0.093	-0.035	-0.056	14.82
014222	-3.279	0.207	-0.112	0.007	-0.072	15.04
014349	-3.217	0.229	-0.069	-0.041	0.005	14.88
014458	-3.229	0.214	-0.120	0.042	-0.064	14.91
014626	-3.282	0.217	-0.149	0.088	-0.094	15.04
014735	-3.191	0.278	-0.160	0.095	-0.053	14.81
014902	-3.120	0.314	-0.095	0.131	-0.040	14.62
015011	-3.177	0.276	-0.140	0.099	-0.081	14.77
015138	-3.292	0.204	-0.122	0.052	-0.051	15.07
015247	-3.286	0.214	-0.151	0.046	-0.041	15.05
015732	-3.180	0.307	-0.109	0.085	-0.033	14.77
015841	-3.111	0.331	-0.092	0.034	-0.026	14.60
020010	-3.091	0.351	-0.049	0.005	-0.027	14.54
020119	-3.092	0.371	-0.111	0.136	-0.019	14.54
020247	-3.103	0.364	-0.051	0.008	-0.036	14.57
020356	-3.099	0.357	-0.101	0.096	-0.001	14.56
020525	-3.063	0.401	-0.032	0.073	0.046	14.47
020633	-3.050	0.378	-0.036	0.069	0.010	14.44
020802	-3.013	0.407	0.023	0.008	0.040	14.34
020911	-2.996	0.401	-0.049	0.064	0.023	14.30
021350	-3.029	0.308	-0.016	0.033	0.020	14.40
021459	-3.046	0.303	-0.058	0.102	0.035	14.44
021626	-3.109	0.250	-0.076	0.123	0.035	14.61
021735	-3.186	0.207	-0.022	0.134	0.003	14.81
021903	-3.207	0.240	-0.122	0.089	-0.067	14.85
022012	-3.207	0.219	-0.120	0.143	-0.014	14.86
022139	-3.151	0.224	-0.129	0.085	-0.017	14.72
022248	-3.257	0.214	-0.089	0.077	-0.025	14.73
022416	-3.178	0.210	-0.070	0.054	-0.004	14.79
022524	-3.030	0.280	-0.049	0.100	0.039	14.40
023753	-2.907	0.361	-0.012	0.170	0.056	14.08
023902	-2.879	0.415	0.002	0.138	0.062	14.00
024029	-2.785	0.422	0.050	0.115	0.081	13.77
024138	-2.820	0.386	0.080	0.111	0.070	13.86
024306	-2.820	0.384	0.078	0.066	0.086	13.86
024414	-2.894	0.408	0.028	0.082	0.117	14.04
024542	-2.846	0.411	0.074	0.154	0.101	13.92
024651	-2.864	0.436	0.025	0.126	0.049	13.96
024819	-2.888	0.385	0.091	0.056	0.095	14.03
024927	-2.838	0.411	0.111	0.134	0.107	13.90
025413	-2.950	0.368	0.040	0.052	0.034	14.19
025522	-2.955	0.367	0.013	0.013	0.024	14.20
025650	-2.927	0.315	-0.015	0.058	0.041	14.14
025759	-2.963	0.317	-0.063	-0.049	0.012	14.23
025926	-3.129	0.242	-0.103	-0.094	-0.045	14.66
UT	V	V-B	B-U	U.W	B-L	V_J
030035	-3.172	0.224	-0.091	0.002	-0.024	14.77
030203	-3.198	0.212	-0.118	0.093	-0.032	14.84
030311	-3.244	0.141	-0.165	0.087	-0.079	14.96
030439	-3.190	0.205	-0.139	0.019	-0.068	14.82
030548	-3.167	0.240	-0.073	0.074	-0.019	14.75
031844	-3.172	0.292	-0.035	-0.046	0.020	14.76
031953	-3.164	0.288	-0.099	0.014	-0.050	14.74
032121	-3.144	0.288	-0.067	0.017	-0.059	14.69
032229	-3.079	0.363	-0.098	0.010	0.016	14.51
032357	-3.038	0.396	-0.067	0.139	-0.004	14.41
032506	-3.087	0.357	-0.021	0.002	0.004	14.53
032634	-3.069	0.378	-0.032	0.001	0.003	14.49
032742	-3.027	0.388	0.018	0.066	0.025	14.38
032910	-3.070	0.412	0.029	0.000	-0.004	14.48
033016	-2.965	0.378	0.047	0.020	0.051	14.23
033710	-3.034	0.257	-0.064	0.091	0.005	14.42
033819	-3.162	0.188	-0.097	0.072	-0.034	14.75
034025	-3.258	0.181	-0.118	0.037	-0.053	14.99
034133	-3.303	0.127	-0.168	0.109	-0.037	15.11
034301	-3.186	0.189	-0.087	-0.001	-0.046	14.81
034410	-3.162	0.207	-0.105	-0.060	0.021	14.75
034647	-3.144	0.197	-0.072	0.002	-0.035	14.70
034756	-2.998	0.249	-0.063	0.088	0.015	14.33
035944	-2.798	0.426	0.011	0.127	0.078	13.80
040222	-2.752	0.436	0.098	0.132	0.087	13.68
040331	-2.806	0.405	0.042	0.004	0.087	13.82
040459	-2.867	0.418	0.094	0.095	0.107	13.97
040607	-2.855	0.393	0.046	0.124	0.085	13.95
040735	-2.777	0.421	0.099	0.110	0.147	13.75
040844	-2.803	0.404	0.054	0.180	0.101	13.82
041011	-2.879	0.351	0.061	0.072	0.052	14.01
041120	-2.876	0.372	0.005	0.095	0.036	14.00
041622	-2.934	0.376	-0.017	0.090	0.027	14.15
041731	-3.071	0.324	-0.008	0.026	-0.011	14.50
041859	-3.067	0.292	-0.091	0.132	-0.038	14.49
042007	-3.035	0.300	-0.058	0.111	-0.034	14.41
042135	-3.117	0.267	-0.056	0.073	-0.033	14.62
042244	-3.186	0.205	-0.124	0.013	-0.058	14.81
042411	-3.189	0.201	-0.099	0.016	-0.054	14.81
042520	-3.260	0.167	-0.132	0.034	-0.114	15.00
042648	-3.200	0.230	-0.102	0.003	-0.085	14.84
042759	-3.190	0.244	-0.106	0.055	-0.073	14.81

TABLE II. — *Radial velocities for 2A0311-227 (km/s).*

UT	Hδ	Hγ	4472	4686	Hβ	5876	Hα
1:32	- 76	-164	-227	-106	- 82	-198	- 36
1:36	41	- 53	28	67	10	7	- 27
1:40	224	2	48	182	165	- 70	37
1:44	319	23	149	221	257	196	183
1:48	209	168	1	343	344	- 19	192
1:52	458	299	377	381	418	109	220
1:56	568	438	498	471	566	--	--
2:00	816	527	806	739	720	737	--
2:04	963	845	1070	791	770	670	--
2:08	641	493	411	611	597	660	544
2:12	480	375	404	451	523	318	494
2:16	385	251	343	298	399	241	394
2:20	268	216	283	202	362	298	435
2:24	231	168	136	131	288	78	293
2:28	129	113	68	61	239	27	252
2:32	99	57	21	48	115	37	165
2:36	129	- 39	-133	- 16	109	-101	69
2:40	- 76	-157	-140	-227	- 51	-228	19
2:44	-120	-171	- 79	-221	- 94	-356	23
2:48	-135	-226	-193	-214	-131	-325	-91
2:52	- 54	-164	- 12	- 99	- 27	- 4	- 64
2:56	56	-157	- 86	22	4	7	- 54
3:00	129	57	68	195	171	- 14	60
3:08	304	147	229	298	264	384	238
3:12	436	251	209	291	294	206	92
3:16	443	203	491	349	387	--	--
3:20	575	652	417	592	375	--	--
3:24	904	583	672	624	702	757	618
3:28	553	596	639	624	683	701	704
3:32	516	389	525	445	504	354	508
3:36	465	265	290	279	375	252	526
3:40	370	85	216	131	276	287	352
3:44	304	154	203	80	251	114	243
3:48	202	- 32	1	- 35	103	- 39	183
3:52	85	- 88	-106	-138	35	58	101
3:56	41	-102	- 5	-221	- 33	78	42
4:00	- 25	-337	-240	-266	-144	-356	- 45
4:04	-113	-261	-334	-343	-218	-310	-224
4:08	-178	-309	-287	-336	-267	-356	- 59
4:12	-105	-212	-227	-182	-138	-157	- 45
4:16	99	-157	- 72	- 10	- 2	-121	- 41
4:20	129	- 60	75	106	66	129	0
4:24	209	- 12	102	202	122	- 39	110

TABLE III. — *Radial velocities in 2A0311-227 : sinusoidal fits.*

Line	K (km/s)	γ(km/s)	ϕ_o [a]	$\sqrt{\frac{\Sigma(O-C)_i^2}{n}}$ (km/s)
Hδ	320	237	.375	53
Hγ	308	88	.383	61
He Iλ4472	324	130	.377	79
HeIIλ4686	366	149	.341	70
Hβ	331	214	.380	61
He Iλ5876	301	91	.379	108
Hα	277	198	.425	59

a) phase of zero velocity based on Bailey :

$$\phi = 3944.9518 + 0.0562660\ E.$$

A heliocentric correction of $\Delta\phi = 0.0789$ has been applied.

TABLE IV. — *Line fluxes for 2A0311-227 (10^{-14} ergs cm^2 s^{-1}).*

UT	Hδ	C II 4260	Hγ	He I 4471	C III/N III 4640	He II 4686	Hβ	He I 4921	He I 5016	He II 5422	He I 5876	Hα
01:32	20.7	2.2	23.9	8.6	0.6	12.1	22.6	8.8	7.3	1.1	4.7	13.4
01:36	15.7	2.2	18.9	6.4	2.1	10.4	20.5	8.0	5.1	0.0	5.3	15.1
01:40	13.9	2.2	16.5	6.2	1.8	10.8	16.9	7.7	3.6	0.3	3.8	10.1
01:44	13.1	0.8	18.4	5.0	1.5	10.5	18.6	7.5	3.2	2.5	4.9	15.4
01:48	11.6	-1.1	14.7	6.2	3.7	11.7	16.0	6.2	3.0	1.0	3.7	12.9
01:52	12.4	-0.1	12.5	5.5	0.5	9.0	14.1	7.0	2.5	1.2	-0.8	9.7
01:56	9.8	1.7	11.1	2.8	0.9	8.0	10.4	6.7	1.9	1.2	-0.7	- 0.4
02:00	11.7	0.8	9.7	3.7	0.0	8.1	10.8	6.6	1.1	0.7	3.6	- 0.9
02:04	10.2	0.1	7.7	4.2	0.7	8.1	11.3	7.7	2.6	0.9	4.5	2.8
02:08	10.8	0.9	10.7	4.7	3.4	7.8	12.9	7.5	4.4	1.4	3.8	8.4
02:12	12.6	0.2	16.6	4.8	1.4	10.5	19.7	8.7	5.0	1.4	0.6	11.8
02:16	20.6	1.4	20.1	8.5	2.4	12.8	22.9	9.0	5.5	0.8	6.8	13.2
02:20	20.3	0.6	20.7	5.9	1.7	10.1	21.7	7.0	4.3	1.2	5.2	14.7
02:24	19.6	0.5	20.4	6.3	0.8	8.8	21.4	6.5	4.0	1.1	3.8	14.2
02:28	16.4	1.0	19.1	6.6	0.9	7.9	24.8	8.6	5.9	1.4	5.6	15.8
02:32	16.2	0.9	17.5	3.0	1.3	8.3	21.8	8.4	4.4	2.0	5.1	15.3
02:36	12.4	0.8	15.5	8.5	3.7	9.1	19.4	9.4	6.7	1.4	6.6	12.1
02:40	15.9	0.5	16.8	5.9	0.7	7.6	20.9	8.7	5.4	1.0	4.8	10.2
02:44	15.1	1.4	15.2	4.6	1.9	6.8	18.4	9.3	6.6	2.9	6.2	10.6
02:48	11.7	1.3	12.1	4.4	1.6	6.3	15.7	8.5	6.7	1.7	6.3	11.4
02.52	12.8	-0.5	12.0	5.3	0.7	7.4	16.4	8.6	4.3	1.3	5.2	10.9
02:56	15.1	0.3	16.2	6.1	0.9	9.5	19.8	9.9	6.1	1.3	7.5	10.3
03:00	15.3	0.8	18.6	5.7	2.1	11.9	21.8	9.3	5.1	1.6	4.2	20.6
03:08	12.1	0.0	14.5	6.2	0.8	9.8	18.3	6.9	3.9	2.1	5.5	18.8
03:12	11.3	0.1	11.9	3.4	1.6	10.3	15.6	8.1	3.5	1.1	2.8	11.1
03:16	10.1	1.4	9.0	2.9	1.3	7.66	10.6	4.5	2.0	0.4	-0.8	- 0.6
03:20	11.0	0.0	9.9	4.4	1.4	8.28	10.5	7.1	2.5	1.1	2.3	0.9
03:24	8.6	-0.5	11.2	4.1	1.2	9.21	12.5	8.3	2.1	2.0	5.0	7.4
03:28	9.5	1.0	9.1	3.5	2.2	8.63	12.4	7.3	2.8	1.5	3.3	4.2
03:32	16.2	0.7	14.5	5.1	1.8	8.94	18.0	9.1	2.1	2.1	6.0	7.9
03:36	15.4	1.1	18.6	6.2	2.8	11.2	22.0	8.2	6.39	0.4	4.4	16.2
03:40	20.8	0.2	21.9	7.1	2.2	11.9	25.7	6.7	3.20	0.6	4.0	15.7
03:44	17.7	0.6	21.3	6.3	1.9	8.3	21.6	6.3	3.83	1.4	5.8	14.6
03:48	20.6	0.3	21.6	5.9	1.4	9.5	24.6	9.3	5.64	1.8	7.	14.5
03:52	19.4	1.2	21.8	6.8	2.9	11.1	26.7	9.3	6.15	1.6	8.3	17.7
03:56	22.9	4.0	21.9	7.4	1.9	8.7	23.5	7.8	6.08	1.8	5.8	19.6
04:00	18.4	1.3	17.9	5.6	1.1	8.6	20.6	9.0	5.67	-0.1	5.8	11.9
04:04	15.2	1.7	14.5	3.9	1.5	6.7	19.3	7.9	6.51	1.4	7.7	12.7
04:08	11.4	2.1	14.4	3.9	0.6	6.5	17.4	8.3	5.90	0.7	4.1	9.9
04:12	15.6	1.3	16.8	3.3	1.3	10.3	23.5	7.8	6.86	2.0	5.2	12.4
04:16	13.3	0.2	15.2	4.6	2.2	8.6	18.3	7.2	4.7	1.5	7.7	10.4
04:20	15.4	-0.1	15.8	6.0	2.2	11.0	19.4	6.6	3.7	1.1	6.1	15.7
04:24	17.8	2.9	17.3	6.5	3.2	14.3	19.4	6.3	3.6	2.6	3.3	18.9