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THIRTEEN-COLOR PHOTOMETRY AND ANALYSIS OF THE SHORT PERIOD VARIABILITY IN NOVA V1500 CYGNI 1975

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RESUMEN

En este trabajo se presentan observaciones de la Nova Cygni 1975 con el sistema fotométrico de 13 colores, durante las noches del 30 de agosto hasta el 28 de septiembre de 1975. De las observaciones fotométricas se obtienen las características espectrales más importantes en la evolución de la nova. Se reportan variaciones de corto período observadas durante las noches del 3, 4 y 22 de septiembre de 1975. El análisis de las variaciones de corto período indica la existencia de un cambio contínuo en el período desde el 4 al 24 de septiembre. Posteriormente, el período permanece constante desde el 24 de septiembre de 1975 hasta finales de 1976. Un sistema binario con una pequeña excentricidad, parece ser el adecuado para explicar las observaciones.

ABSTRACT

We have observed Nova Cygni 1975 during the nights of August 30 to September 28, 1975 with the Thirteen-Color Photometric System. The time evolution of some important spectral features in novae phenomena is inferred from this photometry. Short period regular light variations were observed on the nights of September 3, 4 and 22, 1975. Analyses of the short period variability show that there is a continuous change in period from September 4 to September 24, 1975. From September 24, 1975 on the period remains constant until the end of 1976. A binary system with a small eccentricity seems to be an adequate one to describe the behavior of Nova V1500 Cygni 1975.

Key words: **STARS-BINARIES — STARS-NOVAE — PHOTOMETRY.**

I. INTRODUCTION

Nova V1500 Cygni 1975 was first noticed in México by Sánchez on August 30.1 UT. It is one of the fastest and brightest novae ever observed, with an estimated absolute visual magnitude $M_V = -10.25$ and an observed $m_V = 1.7$, at maximum light on August 30.7 UT, 1975 (Rosino and Tempesti 1977). The rapid development of its spectrum did not allow most observers to detect the diffuse enhanced stage. However, at the present time, its existence is well established (Ferland 1977) and there is no doubt that the behavior of V1500 Cygni is typical of very fast galactic novae.

Considering the importance of recording short-lived phenomena such as that of novae, we decided to follow the time development of both the continuum and line emission in Nova Cygni 1975, with the equipment available to us at that time. Our observations with the 13-color photometric system are presented in §II. From these data, short period variability is detected on the nights of September 4, 5 and 23, 1975. These periodic light variations for Nova Cygni, originally reported by Koch and Ambruster (1975), Tempesti (1975) and Semeniuk (1975), have also been recorded by several other authors. Previous analyses of the light variability were carried out with smaller data samples and a serious debate related to changes in the period of light variations has arisen. Rosino and Tempesti (1977) and other authors have interpreted the short period light variations as due to an eclipsing binary system. Nevertheless, Young *et al.* (1977), assuming a period "glitch" hypothesis, have suggested that light variations are due to pulsations, or rotation of the nova remnant. In the light of more observations available at the present time, we rediscuss this point in §IV and §V and state our conclusions in §VI.

II. THE OBSERVATIONS

We have followed the development of Nova Cygni during the time interval elapsed between August 30 and September 28, 1975, with the Thirteen-Color Photometric System at the Observatorio Astronómico Nacional at San Pedro Mártir, B. C., México, using the 0.84m and 1.5m reflecting telescopes. The observations were carried out with a photoelectric photometer equipped with RCA-1P21 and RCA-7102 photomultipliers and a set of 13 interference filters, labeled with numbers indicating their approximate effective wavelengths in units of hundred Å: 33, 35, 37, 40, 45, 52, 58, 63, 72, 80, 86, 99 and 110. Further details on this photometric system have been reported by Johnson and Mitchell (1975). The photometry for the nova has been compared with that of local standard stars. The latter were selected from the 13-color photometric catalog of

TABLE 1

STANDARD STARS

B.S.	m_{52}*
39	2.794
45	5.198
617	2.315
718	4.284
1457	1.333
1641	3.148
7001	0.039
7924 †	1.309
7949 †	2.703
8622 †	4.846
8832	4.872
8984	4.547

* Taken from Johnson and Mitchell (1975).
† Local standard stars.

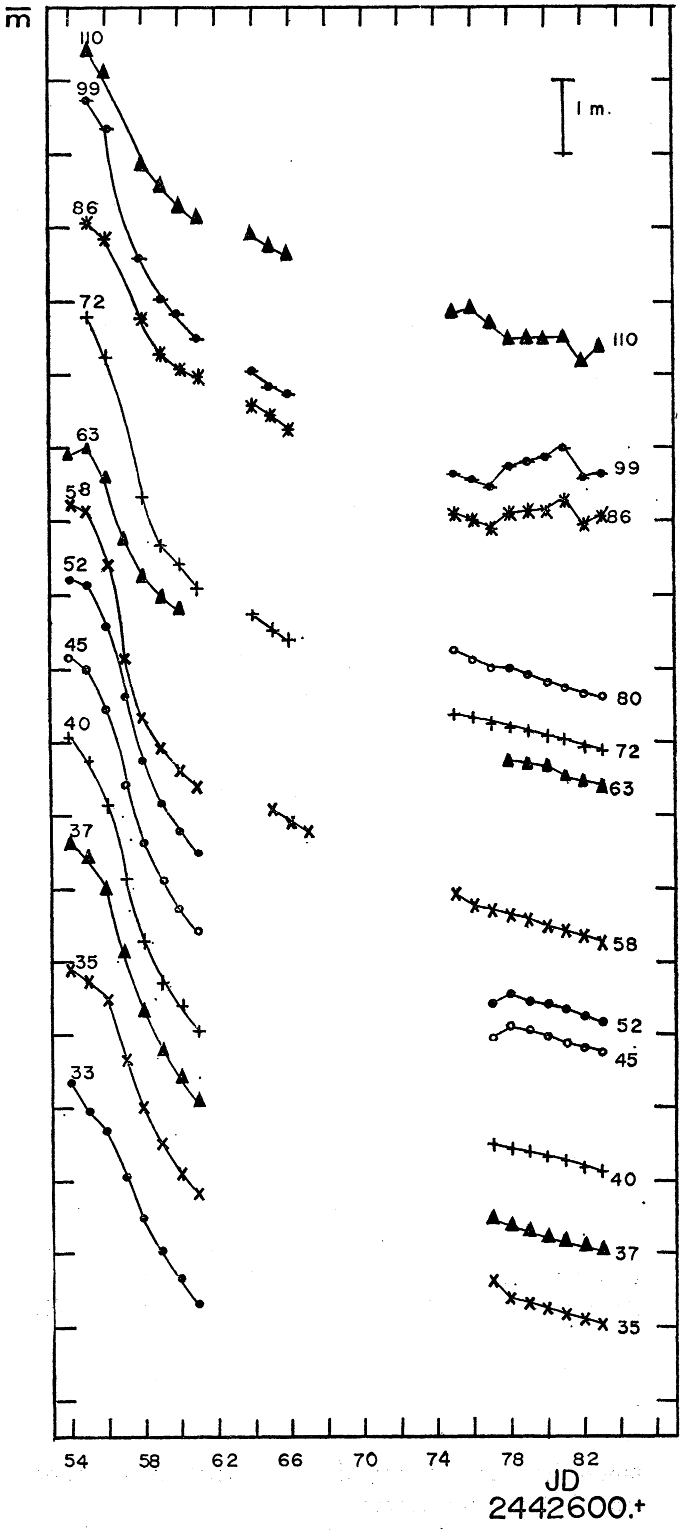

FIG. 1. Mean light curves for each filter, for the period August 30th, September 28th, 1975.

TABLE 2

PHOTOELECTRIC PHOTOMETRY OF NOVA V1500 CYGNI 1975

J.D. (2442000.0+)	33	35	37	40	45	52	58	63	72	80	86	99	110
654.9034	2.16	2.08	2.27	2.58	2.47	2.13	1.85	2.16	-	-	-	-	-
.9206	2.12	2.05	2.25	2.55	2.43	2.09	1.72	1.97	-	-	-	-	-
.9497	2.16	2.04	2.25	2.55	2.43	2.09	1.72	1.97	-	-	-	-	-
655.0139	2.11	2.08	1.93	1.97	1.89	1.72	1.55	1.44	-	-	-	-	-
.6789	2.57	2.24	2.34	2.73	2.43	2.01	1.71	1.44	-	-	-	-	-
.7154	2.59	2.22	2.33	2.72	2.43	2.01	1.73	1.47	1.20	-	0.93	0.79	0.64
.7564	2.56	2.22	2.36	2.76	2.48	2.08	1.73	1.47	1.18	-	0.90	0.78	0.62
.7847	2.53	2.19	2.32	2.73	2.44	2.03	1.73	1.43	1.18	-	0.90	0.78	0.64
.8018	2.52	2.19	2.31	2.72	2.44	2.04	1.75	1.45	1.18	-	0.90	0.77	0.63
.8483	2.53	2.19	2.33	2.75	2.47	2.05	1.73	1.45	1.17	-	0.89	0.74	0.58
.8885	2.50	2.16	2.32	2.75	2.47	2.05	1.73	1.43	1.15	-	0.86	0.72	0.57
.9153	2.56	2.19	2.37	2.81	2.54	2.10	1.79	1.46	1.20	-	0.88	0.75	0.64
.9482	-	-	-	-	-	-	1.78	-	1.16	-	0.86	0.71	0.62
656.6288	2.76	2.46	2.73	3.34	2.97	2.56	2.45	1.86	-	-	-	-	-
.6755	2.74	2.45	2.73	3.31	2.98	2.57	2.46	1.88	1.65	-	1.12	1.11	0.86
.6980	2.75	2.46	2.75	3.34	3.00	2.59	2.45	1.86	1.64	-	1.11	1.10	0.85
.7326	2.65	2.37	2.67	3.28	2.98	2.58	2.46	1.85	1.66	-	1.12	1.11	0.85
.7819	2.68	2.40	2.71	3.31	3.00	2.62	2.50	1.87	1.69	-	1.13	1.11	0.83
.8042	2.71	2.44	2.75	3.35	3.04	2.65	2.52	1.89	1.71	-	1.14	1.12	0.86
.8261	2.70	2.43	2.73	3.36	3.03	2.65	2.54	1.89	1.72	-	1.14	1.13	0.84
.8452	2.72	2.46	2.76	3.38	3.06	2.67	2.59	1.92	1.76	-	1.15	1.16	0.87
.8656	2.75	2.50	2.81	3.43	3.11	2.71	2.60	1.94	1.78	-	1.17	1.17	0.89
.8888	2.78	2.52	2.82	3.44	3.12	2.73	2.63	1.94	1.80	-	1.17	1.20	0.91
.9210	2.75	2.50	2.81	3.43	3.11	2.74	2.66	1.96	1.84	-	1.21	1.24	0.94
.9475	2.76	2.51	2.82	3.44	3.12	2.75	2.68	1.98	1.86	-	1.21	1.24	0.96
657.6544	3.38	3.26	3.60	4.34	4.06	3.67	3.80	2.80	-	-	-	-	-
.6685	3.37	3.23	3.63	4.33	4.03	3.63	3.80	2.74	-	-	-	-	-
.6830	3.39	3.24	3.63	4.32	4.03	3.65	3.81	2.75	-	-	-	-	-
.6984	3.43	3.29	3.67	4.36	4.05	3.66	3.83	2.76	-	-	-	-	-
.7149	3.44	3.31	3.69	4.38	4.08	3.68	3.85	2.77	-	-	-	-	-
658.6728	4.12	4.06	4.49	5.24	4.85	4.45	4.65	3.23	3.70	-	2.19	2.92	2.10
.7010	4.00	3.95	4.39	5.14	4.77	4.39	4.67	3.20	3.76	-	2.21	2.95	2.09
.7281	4.03	3.98	4.42	5.17	4.80	4.42	4.65	3.23	3.76	-	2.20	2.94	2.08
.7383	3.96	3.93	4.39	5.15	4.79	4.42	4.59	3.17	3.71	-	2.19	2.88	2.09
.7856	3.98	3.97	4.43	5.19	4.84	4.47	4.58	3.19	3.70	-	2.21	2.88	2.12
.8169	3.97	3.96	4.42	5.19	4.84	4.48	4.59	3.18	3.69	-	2.21	2.88	2.13
.8427	3.98	3.97	4.43	5.20	4.86	4.50	4.58	3.18	3.69	-	2.21	2.88	2.15
.8667	3.96	3.96	4.42	5.18	4.85	4.50	4.58	3.27	3.69	-	2.21	2.89	2.16
.8905	3.99	4.01	4.46	5.25	4.90	4.54	4.61	3.20	3.72	-	2.24	2.91	2.17
.9150	4.02	4.03	4.50	5.26	4.92	4.56	4.65	3.22	3.74	-	2.24	2.94	2.22
659.6472	4.59	4.58	5.09	5.87	5.52	5.18	5.03	3.65	4.36	-	2.76	3.54	2.46
.6798	4.53	4.51	5.00	5.78	5.42	5.08	5.01	3.54	4.32	-	2.73	3.49	2.43
.7056	4.43	4.42	4.92	5.70	5.35	5.02	4.97	3.47	4.26	-	2.68	3.43	2.39
659.7328	4.44	4.43	4.94	5.72	5.38	5.06	4.99	3.48	4.26	-	2.67	3.42	2.38
.7582	4.44	4.42	4.94	5.72	5.38	5.05	5.03	3.74	4.27	-	2.67	3.45	2.39
.7866	4.47	4.46	4.97	5.76	5.45	5.09	5.04	3.50	4.29	-	2.68	3.45	2.40
.8133	4.45	4.45	4.97	5.74	5.40	5.09	5.04	3.49	4.24	-	2.65	3.41	2.42

TABLE 2 (CONTINUED)

J.D. (2442000.0+)	33	35	37	40	45	52	58	63	72	80	86	99	110
659.8414	4.44	4.45	4.96	5.72	5.39	5.09	5.02	3.47	4.23	-	2.64	3.40	2.39
.8723	4.46	4.47	4.99	5.78	5.43	5.11	5.06	3.49	4.25	-	2.64	3.43	2.43
.9071	4.52	4.53	5.05	5.82	5.48	5.16	5.10	3.55	4.32	-	2.70	3.49	2.46
.9336	4.51	4.54	5.05	5.84	5.50	5.17	5.11	3.57	4.35	-	2.73	3.50	2.51
660.6522	4.97	4.96	5.45	6.22	5.86	5.55	5.28	3.82	4.49	-	2.90	3.68	2.68
.6894	4.80	4.78	5.27	6.01	5.65	5.40	5.22	3.69	4.43	-	2.83	3.63	2.62
.7203	4.81	4.76	5.26	6.02	5.70	5.42	5.25	3.69	4.48	-	2.81	3.66	2.63
.7488	4.83	4.81	5.33	6.11	5.77	5.49	5.33	3.73	4.55	-	2.86	3.71	2.69
.7773	4.98	4.97	5.46	6.19	5.84	5.55	5.40	3.78	4.59	-	2.91	3.76	2.75
.8025	4.91	4.91	5.40	6.12	5.76	5.50	5.35	3.74	4.55	-	2.91	3.73	2.75
.8278	4.88	4.88	5.34	6.06	5.71	5.46	5.30	3.69	4.49	-	2.85	3.69	2.68
.8546	4.77	4.78	5.27	6.01	5.69	5.45	5.31	3.66	4.51	-	2.83	3.69	2.66
.8890	4.82	4.83	5.33	6.08	5.76	5.53	5.36	3.73	4.56	-	2.88	3.75	2.74
661.7184	5.22	5.20	5.68	6.44	6.08	5.84	5.57	-	4.80	-	2.98	3.96	2.77
.7471	5.16	5.15	5.65	6.39	6.06	5.80	5.67	-	4.89	-	3.02	4.04	2.80
.7703	5.20	5.18	5.68	6.43	6.09	5.84	5.75	-	4.95	-	3.07	4.10	2.90
664.7735	-	-	-	-	-	-	5.89	-	5.23	-	3.41	4.45	3.07
665.6992	-	-	-	-	-	-	6.08	-	5.47	-	3.56	4.69	3.26
666.7360	-	-	-	-	-	-	6.18	-	5.57	-	3.71	4.79	3.33
675.8270	-	-	-	-	-	-	7.09	-	6.64	6.32	4.89	5.88	4.10
676.6563	-	-	-	-	-	-	7.25	-	6.74	6.46	5.01	5.99	4.21
.6918	-	-	-	-	-	-	7.27	-	6.74	6.48	5.03	5.98	4.21
.7796	-	-	-	-	-	-	7.18	-	6.66	6.38	4.92	5.90	4.10
.8218	-	-	-	-	-	-	7.19	-	6.68	6.40	4.95	5.92	4.14
.8454	-	-	-	-	-	-	7.17	-	6.66	6.40	4.96	5.92	4.13
.8949	-	-	-	-	-	-	7.15	-	6.65	6.36	4.93	5.90	4.09
677.6567	-	6.87	7.26	7.81	7.67	7.89	7.31	-	6.82	6.58	5.15	6.10	4.37
.6826	-	6.85	7.22	7.77	7.57	7.85	7.28	-	6.77	6.57	5.13	6.07	4.33
.7112	-	6.80	7.19	7.71	7.52	7.82	7.23	-	6.73	6.46	5.08	6.00	4.26
.7401	-	6.81	7.21	7.75	7.53	7.83	7.21	-	6.72	6.51	5.06	5.99	4.25
.7661	-	6.80	7.20	7.76	7.54	7.83	7.26	-	6.75	6.50	5.07	6.02	4.28
.8337	-	6.80	7.19	7.77	7.53	7.83	-	-	-	-	-	-	-
.8641	-	6.75	7.17	7.76	7.51	7.82	7.24	-	6.71	6.45	5.07	6.00	4.24
678.756	-	7.14	7.40	8.05	7.47	7.72	7.36	5.78	6.81	6.55	4.88	5.77	4.53
.805	-	7.06	7.33	7.99	7.41	7.68	7.34	5.79	6.75	6.50	4.85	5.71	4.48
.83	-	7.05	7.34	7.99	7.41	7.69	7.35	5.78	6.76	6.52	4.86	5.70	4.49
679.64	-	7.12	7.41	8.05	7.46	7.77	7.38	5.83	6.86	6.61	4.83	5.72	4.52
.750	-	7.14	7.42	8.07	7.48	7.78	7.38	5.84	6.86	6.61	4.85	5.70	4.52
.78	-	7.13	7.41	8.06	7.47	7.76	7.38	5.82	6.84	6.58	4.84	5.68	4.51
.81	-	7.12	7.41	8.08	7.48	7.77	7.40	5.81	6.82	6.58	4.82	5.66	4.50
680.67	-	7.16	7.49	8.10	7.49	7.81	7.46	5.83	6.95	6.68	4.83	5.66	4.52
.74	-	7.25	7.54	8.16	7.58	7.87	7.52	5.90	6.96	6.76	4.88	5.71	4.55
.81	-	7.20	7.50	8.16	7.55	7.84	7.51	5.91	6.88	6.67	4.79	5.64	4.49
681.65	-	-	-	8.29	7.60	7.88	7.54	5.97	6.99	6.78	4.73	5.56	4.49
.72	-	7.25	7.54	8.20	7.60	7.90	7.56	6.03	7.01	6.78	4.74	5.56	4.48
.79	-	7.28	7.58	8.23	7.62	7.92	7.57	6.02	6.98	6.77	4.74	5.55	4.48
682.66	-	7.36	7.65	8.27	7.65	7.96	7.61	6.05	7.07	6.87	5.06	5.84	4.83
.76	-	7.37	7.67	8.31	7.69	8.01	7.66	6.08	7.10	6.88	5.07	5.86	4.82
.83	-	7.36	7.64	8.34	7.72	8.02	7.69	6.11	7.06	6.89	5.06	5.84	4.81
683.66	-	7.38	7.68	8.34	7.75	8.03	7.68	6.11	7.15	6.95	4.98	5.84	4.63
.73	-	-	-	8.35	7.76	8.14	7.86	-	7.13	6.92	5.01	5.79	4.60
.79	-	7.40	7.71	8.36	7.78	8.08	7.71	6.18	7.10	6.89	4.98	5.77	4.58

TABLE 3

MEAN DAILY PHOTOMETRY

J.D. (2442000.0+)	33	35	37	40	45	52	58	63	72	80	86	99	110
654.	2.14	2.06	2.18	2.41	2.31	2.08	1.71	1.64	-	-	-	-	-
655.	2.55	2.20	2.33	2.75	2.46	2.05	1.74	1.45	1.18	-	0.89	0.76	0.62
656.	2.73	2.46	2.76	3.37	3.04	2.65	2.54	1.90	1.74	-	1.15	1.15	0.88
657.	3.41	3.27	3.64	4.35	4.05	3.66	3.82	2.76	-	-	-	-	-
658.	4.00	3.98	4.44	5.20	4.84	4.47	4.62	3.21	3.72	-	2.21	2.92	2.18
659.	4.48	4.48	4.99	5.77	5.43	5.10	5.04	3.52	4.29	-	2.69	3.46	2.42
660.	4.86	4.85	5.35	6.09	5.75	5.48	5.31	3.73	4.52	-	2.86	3.70	2.69
661.	5.19	5.18	5.67	6.42	6.08	5.83	5.66	-	4.88	-	3.02	4.03	2.82
664.	-	-	-	-	-	-	5.89	-	5.23	-	3.41	4.45	3.07
665.	-	-	-	-	-	-	6.08	-	5.47	-	3.56	4.69	3.26
666.	-	-	-	-	-	-	6.18	-	5.57	-	3.71	4.79	3.33
675.	-	-	-	-	-	-	7.09	-	6.64	6.32	4.89	5.88	4.10
676.	-	-	-	-	-	-	7.20	-	6.69	6.41	4.97	5.94	4.13
677.	-	6.81	7.21	7.76	7.55	7.84	7.26	-	6.75	6.51	5.09	6.03	4.29
678.	-	7.08	7.36	8.01	7.43	7.70	7.35	5.78	6.77	6.52	4.86	5.73	4.50
679.	-	7.13	7.41	8.07	7.47	7.77	7.39	5.83	6.85	6.60	4.84	5.69	4.51
680.	-	7.20	7.51	8.14	7.54	7.84	7.50	5.88	6.93	6.69	4.83	5.65	4.52
681.	-	7.27	7.56	8.24	7.61	7.90	7.56	6.01	6.99	6.78	4.74	5.49	4.48
682.	-	7.36	7.65	8.31	7.69	8.00	7.65	6.08	7.08	6.88	5.06	5.85	4.82
683.	-	7.39	7.70	8.35	7.77	8.08	7.75	6.15	7.13	6.90	4.99	5.80	4.60

PROBABLE ERROR OF A SINGLE OBSERVATION

33	35	37	40	45	52	58	63	72	80	86	99	110
±0.030	±0.028	±0.032	±0.039	±0.036	±0.030	±0.038	±0.043	±0.026	±0.024	±0.019	±0.032	±0.023

Johnson and Mitchell (1975). Classical differential and absolute photometric observing procedures were followed. The comparison stars used and their magnitudes in filter 52 are listed in Table 1. From our data, no periodic light variations have been detected in the comparison stars. The 13-color photometry of Nova Cygni 1975 is summarized in Table 2. Average values for each night together with their mean errors are given in Table 3, the light curves corresponding to each filter are shown in Figure 1.

The 13-color photometric system, was originally designed with the idea of isolating some important spectral features present in normal stars (Johnson and Mitchell 1975). In the case of a nova the spectrum is different and its main features are time dependent. However, the use of the 13-color photometric system yields intermediate band photometry of both the continuum and the important emission lines. The main spectral features corresponding to each filter —according to Meinel *et al.* (1969)— for this system are listed in Table 4. Filters 63 and 110 include two of the strongest emission lines present in the spectra of novae, namely Hα and HeI λ10830. The colors (52-63) and (52-110) provide a measure of the intensities of these two lines relative to the continuum at λ5200. Our observations for these colors indicate that Hα became dominant between September 3 and 4, 1975 and that HeI λ10830 reached its maximum relative intensity on September 7, 1975, in good agreement with the spectroscopic data published by Rosino and Tempesti (1977), Fehrenbach and Andrillat (1976), Tomkin *et al.* (1976), Sanyal (1976) and Boyarchuk *et al.* (1977).

III. THE ABSOLUTE FLUXES

Mean absolute fluxes for each night have been obtained using the absolute calibration of the 13-

TABLE 4

FILTER INFORMATION

Filter	Information	Remarks
33	Balmer continuum	After maximum the continuum becomes weak day to day.
35	Balmer continuum	
37	Balmer continuum	
40	H$_{\epsilon}$λ3970(2p^{2}P$^{\circ}$—7d^{2}D), H$_{\delta}$λ4101(2p^{2}P$^{\circ}$—6d^{2}D)	Growing all the time.
45	H$_{\beta}$, H$_{\gamma}$. FeIIλ4491 (b^{4}F—z^{4}F$^{\circ}$) FeIIλ4522(b^{4}F—z^{4}D$^{\circ}$), NIIIλ λ4640-42 (3p^{2}P$^{\circ}$—3d^{2}D)	It reaches a second maximum on Sept. 22-23.
52	HeIλ5016 (2s^{1}S—3p^{1}P$^{\circ}$), FeIIλ5018 (a^{6}S—z^{6}P$^{\circ}$), FeII 5169 (a^{6}S—z^{6}P$^{\circ}$)	It reaches a second maximum on Sept. 22-23.
58	HeIλ5876 (2p^{3}P$^{\circ}$—3d^{3}D), NaDλ5895 (3s^{2}S—3p^{2}D)	Growing and maintained, it begins to be dominant on Sept. 3-4.
63	Hαλ6562 (2p^{2}P$^{\circ}$—3d^{2}D)	Growing and reaches maximum on Sept. 3-4.
72	Continuum and HeIλ7065 (2p^{3}P$^{\circ}$—3s^{3}S)	
80	O Iλ7774 (3s^{5}S$^{\circ}$—3p^{5}P), N Iλ8216 (3s^{4}P—3p^{4}P$^{\circ}$)	Growing and reaches maximum on Sept. 2.
86	O Iλ8446 (3s^{3}S$^{\circ}$—3p^{3}P)	Strong and reaches maximum on Sept. 6.
99	H I P$_{\delta}$, H I P$_{9}$	Reaches maximum on Sep. 2-6; HIP$_{9}$ weak because the filter performance.
100	HeI λ10830 (2s^{3}S—2p^{3}P$^{\circ}$)	Reaches maximum on Sept. 7.

TABLE 5

MEAN FLUX DENSITIES (Watt cm^{-2} μ^{-1})

J.D. (2442000.+)	33	35	37	40	45	52	58	63	72	80	86	99	100
654.	4.7E-13	4.9E-13	5.7E-13	8.4E-13	7.3E-13	6.3E-13	6.4E-13	5.0E-13	-	-	-	-	-
655.	3.2E-13	4.3E-13	5.0E-13	6.2E-13	6.3E-13	6.5E-13	6.2E-13	6.0E-13	5.1E-13	-	4.1E-13	3.5E-13	2.7E-13
656.	2.5E-13	3.1E-13	3.1E-13	3.2E-13	3.4E-13	3.5E-13	3.0E-13	3.7E-13	2.8E-13	-	2.9E-13	2.2E-13	2.0E-13
657.	1.5E-13	1.6E-13	1.5E-13	1.4E-13	1.5E-13	1.5E-13	9.1E-14	1.8E-13	-	-	-	-	-
658.	8.5E-14	8.3E-14	7.2E-14	6.5E-14	7.1E-14	7.0E-14	4.4E-14	1.2E-13	5.0E-14	-	1.1E-13	4.6E-14	6.4E-14
659.	5.4E-14	5.2E-14	4.3E-14	3.8E-14	4.1E-14	3.9E-14	3.0E-14	8.8E-14	2.9E-14	-	6.9E-14	2.8E-14	5.1E-14
660.	3.8E-14	3.7E-14	3.1E-14	2.8E-14	3.1E-14	2.8E-14	2.3E-14	7.2E-14	2.4E.14	-	5.7E-14	2.3E-14	4.0E-14
661.	2.8E-14	2.7E-14	2.3E-14	2.1E-14	2.3E-14	2.0E-14	1.7E-14	-	1.7E-14	-	4.8E-14	1.7E-14	3.5E-14
664.	-	-	-	-	-	-	1.3E-14	-	1.2E-14	-	3.9E-14	1.1E-14	2.8E-14
665.	-	-	-	-	-	-	1.1E-14	-	1.0E-14	-	3.4E-14	9.2E-15	2.4E-14
666.	-	-	-	-	-	-	1.0E-14	-	9.1E-15	-	3.0E-14	8.4E-15	2.2E-14
675.	-	-	-	-	-	-	4.5E-15	-	3.4E-15	3.4E-15	1.0E-14	3.1E-15	1.1E-14
676.	-	-	-	-	-	-	4.0E-15	-	3.2E-15	3.2E-15	9.4E-15	2.9E-15	1.1E-14
677.	-	6.2E-15	5.6E-15	6.1E-15	5.7E-15	3.1E-15	3.8E-15	-	3.2E-15	2.9E-15	8.4E-15	2.6E-15	8.9E-15
678.	-	4.8E-15	4.9E-15	4.9E-15	6.4E-15	3.6E-15	3.5E-15	1.1E-15	3.1E-15	2.8E-15	1.0E-14	3.5E-15	7.5E-15
679.	-	4.6E-15	4.7E-15	4.6E-15	6.1E-15	3.3E-15	3.4E-15	1.0E-15	2.9E-15	2.6E-15	1.0E-14	3.6E-15	7.5E-15
680.	-	4.3E-15	4.2E-15	4.3E-15	5.7E-15	3.1E-15	3.1E-15	9.9E-15	2.7E-15	2.4E-15	1.0E-14	3.7E-15	7.4E-15
681.	-	4.0E-15	4.1E-15	3.9E-15	5.8E-15	3.0E-15	2.9E-15	8.8E-15	2.5E-15	2.2E-15	1.1E-14	4.4E-15	7.7E-15
682.	-	3.7E-15	3.7E-15	3.7E-15	5.0E-15	2.7E-15	2.4E-15	7.7E-15	2.2E-15	2.0E-15	8.3E-15	3.1E-15	5.6E-15
683.	-	3.6E-15	3.6E-15	3.5E-15	4.6E-15	2.5E-15	2.4E-15	7.7E-15	2.2E-15	2.0E-15	8.8E-15	3.3E-15	6.7E-15

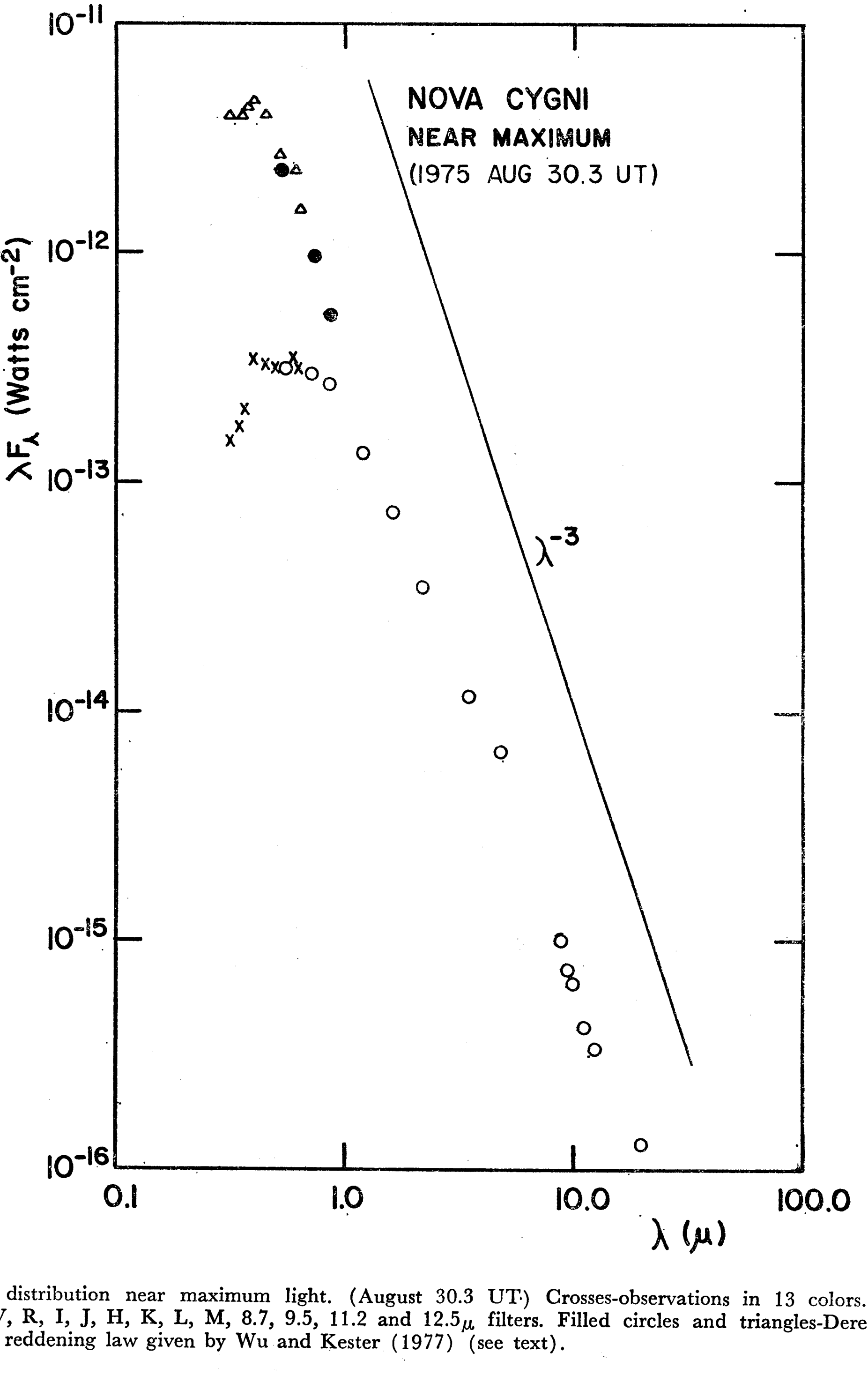

FIG. 2. Energy distribution near maximum light. (August 30.3 UT) Crosses-observations in 13 colors. Open circles-observations in V, R, I, J, H, K, L, M, 8.7, 9.5, 11.2 and 12.5μ filters. Filled circles and triangles-Dereddened fluxes, according to the reddening law given by Wu and Kester (1977) (see text).

color photometry obtained by Chavarría and Johnson (1975). The resulting fluxes are listed in Table 5. The spectral energy distributions from 0.3 to 20μ of Nova Cygni for different nights are shown in Figures 2 to 4. The infrared data for the plotted distributions have been taken from Gallagher and Ney (1976) and Ennis *et al.* (1977). These spectral energy distributions have been corrected for interstellar extinction, according to the reddening law and the color excess $E(B-V) = 0.69$ adopted by Wu and Kester (1977). This law yields $A_\lambda/E(B-V) = 5.1$, 4.94 and 4.43 for the filters 33, 35 and 40 respectively. A value for $A_V = 2.14$ has been obtained by assuming a normal ratio of total to selective extinction, $R = 3.1$ (Harris 1973). Linear interpolations of the mentioned values yield: $A_\lambda/E(B-V) = 4.74$, 3.9 and 3.3 for the filters 37, 45 and 52 respectively. For the red part of the spectrum we have adopted the extinction curve for the Cygnus region given by Johnson (1968): $A_\lambda/E(B-V) = 2.9$, 2.55, 1.95, 1.4, 1.0 and 0.2 for filters 58, 63, 72, 80, 86 and 99, respectively.

The shape of the dereddened spectral energy distribution depends strongly on the value adopted for the color excess $E(B-V)$. The interstellar extinction in the vicinity of Nova Cygni 1975 has a strong increase with distance, beyond 1.5 kpc. The distance dependence of the amount of reddening is given by: $E(B-V) = 0.12 + 0.76\ (r - 1.5)$ where r is in kpc and, is larger than 1.5 (Schild 1976). Adopting a distance to the nova of 2.2 kpc, this law yields a color excess of $E(B-V) = 0.65$ in good agreement with the value adopted in this paper.

Figure 2 shows the spectral energy distribution near maximum light (August 30.3 UT). At this date, the Balmer continuum is observed in absorption (filters 35 and 37), in agreement with the spectroscopic data of Tomkin *et al.* (1976). A blackbody with $T = 10^4$ °K fits the continuum of the nova near maximum light very well, as first pointed out by Gallagher and Ney (1976).

Figures 3*a* and *b*, show the observed and dereddened energy distributions for the early decline of the nova. The change in intensity for the emission in Hα, OI λ8446 and HeI λ10830 relative to the continuum is clearly noticeable. The shape of the energy distributions shown in Figures 3*a*, *b*, for the early decline of the nova suggests that the emission lines are superimposed on a blackbody distribution for a temperature value higher than 10^4 °K. According to the UV observations of Jenkins *et al.* (1977) for September 2, 1975, the observed flux at $\lambda \simeq 3000$ Å is $\lambda F_\lambda = 3 \times 10^{-14}$ W cm^{-2}. Adopting a value of $A_\lambda/E(B-V) = 8$ for $\lambda = 3000$ Å, we obtain a dereddened value $\lambda F_\lambda = 5 \times 10^{-12}$ W cm^{-2} This value for the flux is in agreement with the energy distribution of a high temperature blackbody (6.5×10^4 °K). We should also note that brems-

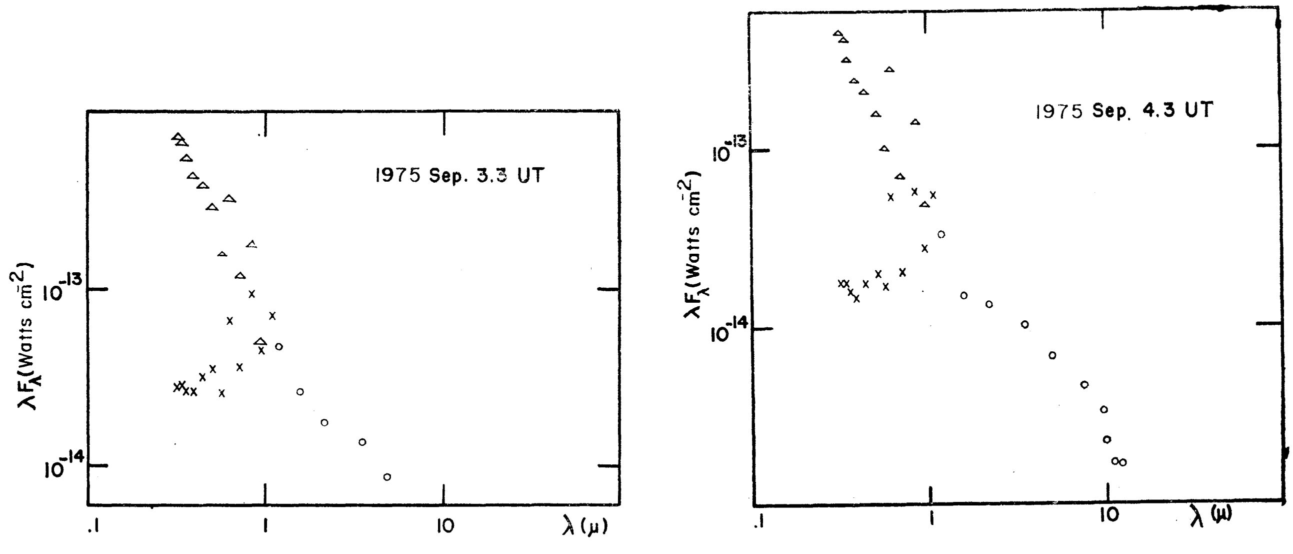

FIG. 3*a* and 3*b*. Energy distributions for September 3.3 UT and 4.3 UT (same remarks as Figure 2).

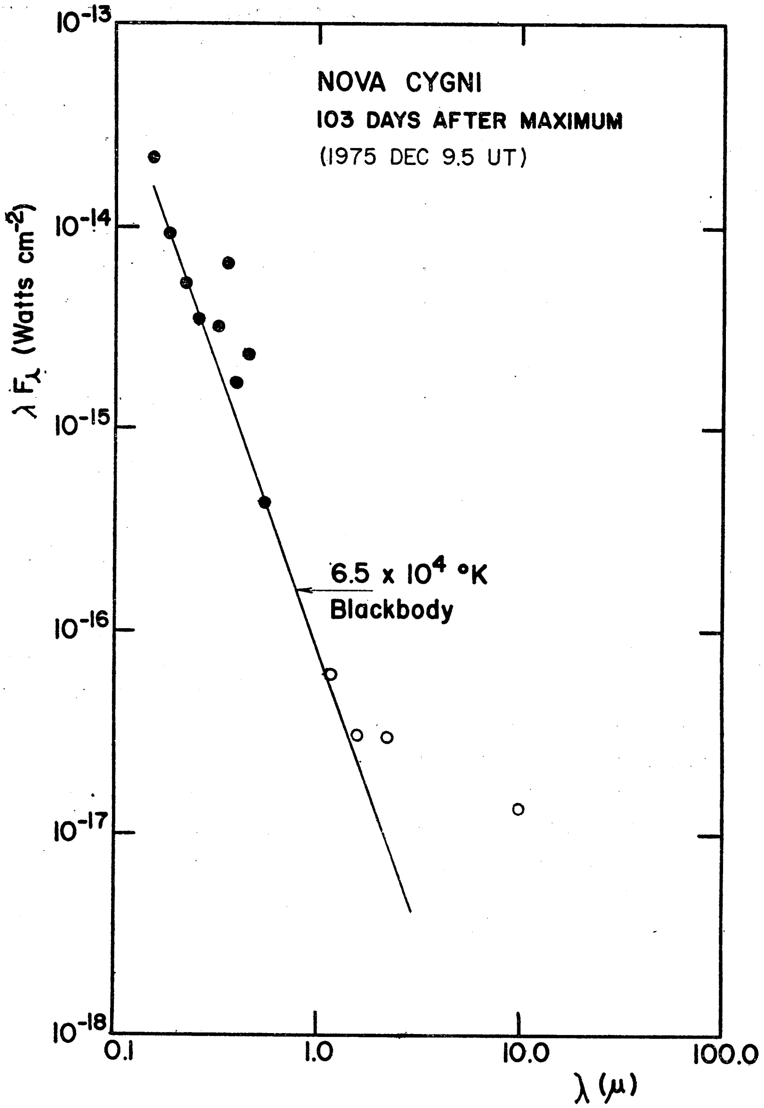

Fig. 4. Energy distribution 103 days after maximum (December 9.5 UT). Filled circles-Dereddened fluxes from Wu and Kester (1977) and Lockwood and Millis (1976). Open circles-IR fluxes from Ennis *et al.* (1977), extrapolated to December 9.5 UT.

strahlung emission in the infrared becomes important on and after September 2, 1975. This emission is thought to be generated by a plasma with an electron temperature of about 10^4 °K and $N_e \sim 10^{10}$ cm^{-3} (Ennis *et al.* 1977).

The spectral energy distribution of V1500 Cyg for December 9.5 UT, (103 days after maximum light, *JD 2442756*) is shown in Figure 4. The UV and visible data were taken from the work by Wu and Kester (1976). The IR data were obtained by extrapolation of the observations of Ennis *et al.* (1977). These observations were carried out on December 3, 1975. The extrapolated fluxes in the J and H filters for December 9.5 UT are also in good agreement with the 6.5×10^4 °K blackbody obtained by Wu and Kester (1976).

IV. SHORT PERIOD VARIABILITY

13-color light curves for the nights of August 31 and September 1, 3, 4 and 5, 1975 are shown in

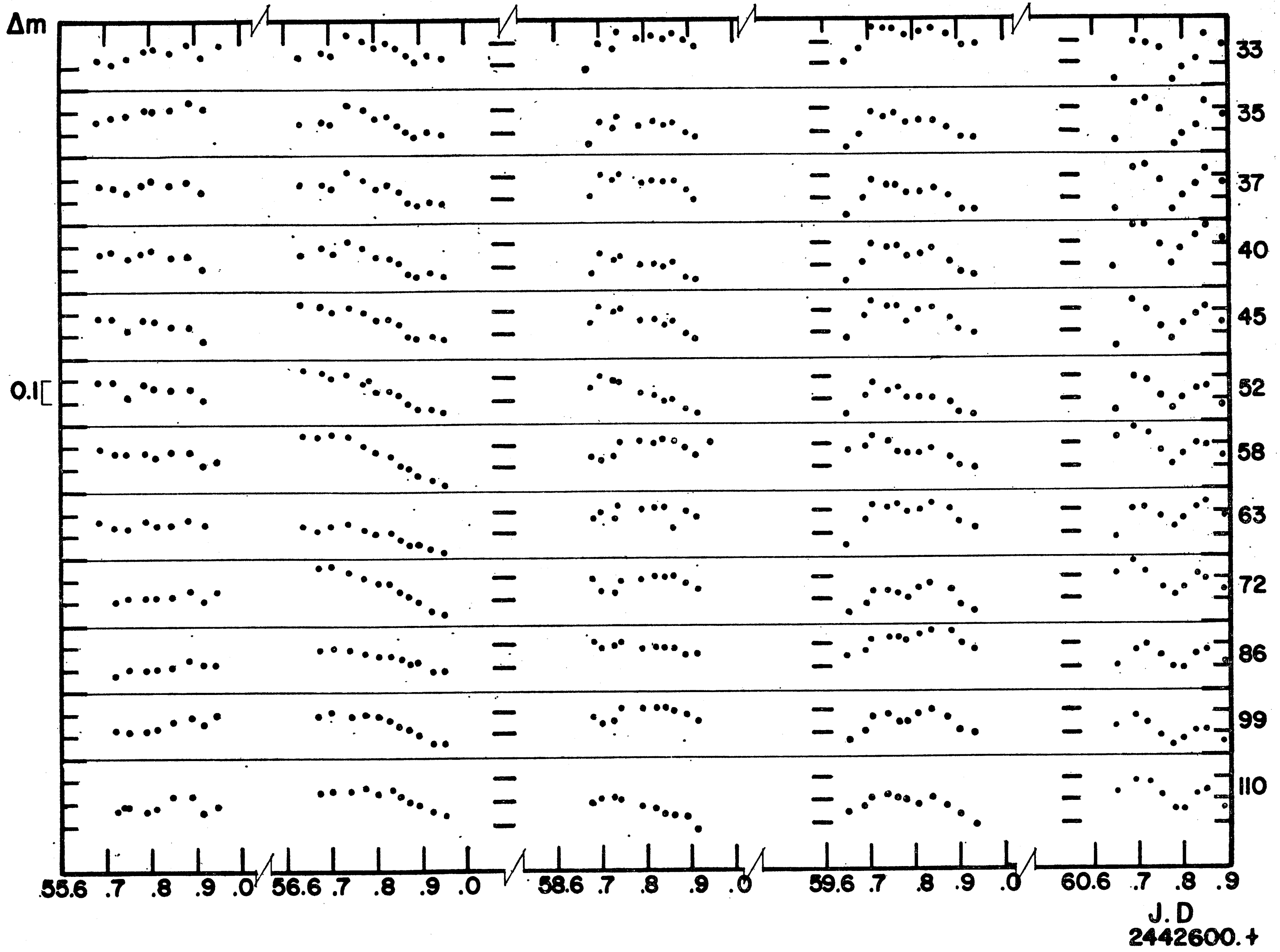

FIG. 5. Light curves for August 31th, September 1st, 3th, 4th and 5th, 1975.

Figure 5. As can be noticed, variations are always present. However, only for the nights of September 4 and 5 a clear regular variation was observed in every filter. In these nights, no systematic phase difference between the ultraviolet and red light curves has been observed. The amplitud of variability through the ultraviolet filters seems to be larger (~30%) than through the red ones. Our data for September 1, 1975 do not support the suggestion by Rosino and Tempesti (1977) that regular variations were present at such an early time. However, an apparent regular variation is observed for the color (52-58) with an approximate period of 6 days, as can be judged from Figure 6, the regularity of these color changes is not conclusive due to the rather scanty data. The observed variability through filter 63, during September 5, 1975 in consistent with the observations by Campbell (1976) for the short wavelength extreme of Hα (6510-6530 Å).

The phase analyses previously made by other authors, have been carried out with a smaller amount of data (Rosino and Tempesti 1977; Ambruster *et al.* 1977; Young *et al.,* 1977) and their conclusions should be reviewed in the light of more extensive material. We have made a rather extensive compilation of the information available on the ephemerides for maxima and minima of the short period light variability. The amplitude data are heterogeneous and incomplete; nevertheless it is well established that a continuous decrease in amplitude is present on the light curves between September 11 and October 6, 1975. Afterwards, an amplitude increase took place, reaching a maximum on October 27, 1975 (Ambruster *et al.* 1977; Cacciari *et al.* 1977; Rosino and Tempesti 1977). In Table 6 we list a compilation for the dates of the maxima and minima of the short period light variations as derived from the data found in the literature. The dates were obtained by interpolation of the published light curves in those cases where the authors did not specify the time for the extrema. The determinations of maxima and minima are subject to the applied criteria; in general these differ from one author to another, particularly when the light curve presents irregularities as in the case of novae. However, for V1500 Cyg, the large volume of data available from September 4 until October 30, 1975 minimizes possible selection effects. Table 6 also includes, for the sake of completeness, the ephemerides taken from satellite-UV observations by Wu and Kester (1977). The ephemerides listed in Table 6 have not been corrected for heliocentric JD because such corrections are negligible.

Phase analysis of the observed minus calculated (O–C) time residuals for the extrema has been calculated with a period P = 0.139785 days according to equations (1) and (2)

$$T_{max} = JD\ 659.857 + 0.139785E, \qquad (1)$$

$$T_{min} = JD\ 659.786 + 0.139785E, \qquad (2)$$

were E is the number of cycles. Figure 7 shows the calculated (O–C) diagram. From this diagram it is evident that a change in period has taken place smoothly from September 4 up to September 24, 1975 (*JD 2442680*), and there has been no sudden change ("glitch") in period contrary to that concluded earlier by Young *et al.* (1977). From September 24 up to the time when the data become scarce (~ Oct. 30), the period remains constant. An apparent downward tendency seems to appear just at the end of the constant period regime of the (O–C) curve. However, the small amount of data available renders this point inconclusive in the light of this phase analysis.

We have also carried out harmonic analyses of published light curces by applying the *Maximum Entropy Method,* developed by Richer and Ulrych (1974). These analyses have been carried out in order to determine whether or not there is a decrease in period after October 1975. Observations by Abramenko and Prokof'eva (1977), Efimov *et al.* (1977), Williamon (1977) and Wu and Kester (1977), were used for this study. These observations cover an interval of nearly a year, from October 1975 to November 1976. From the harmonic analyses we found that light variations for the mentioned time interval yield a constant period of $0^d\!.140 \pm 0.001$, in agreement with the value P = $0^d\!.139785$ derived from the analysis of the (O–C) curve. The observed stability for the light variation period supports the interpretation of these variations in terms of a binary system.

V. DISCUSSION

Theoretical models for nova outbursts by Sparks *et al.* (1976), indicate that the nova remnant could

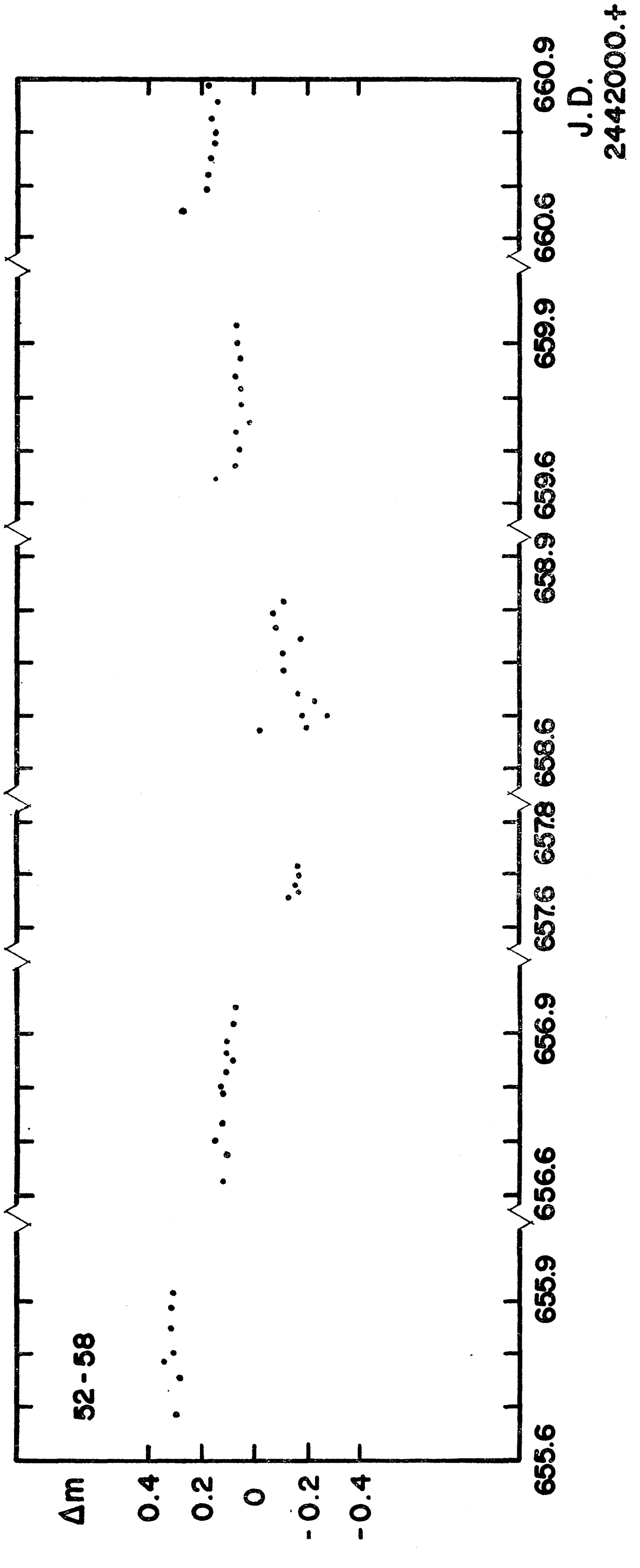

Fig. 6. Color (52-58) for August 31th, September 1st, 2nd, 3th, 4th and 5th., 1975.

TABLE 6

MAXIMA

J.D. (2442000.+)	E	O - C	FILTER	REFERENCE.	J.D. (2442000.+)	E	O - C	FILTER	REFERENCE
659.719	-1	0.002	58	1	683.756	171	-0.004	V	3
59.857	0	0.000	58	1	84.15	174	-0.029	V	6
60.431	4	0.015	V	7	84.27	175	-0.049	V	6
60.686	6	-0.009	58	1	84.617	177	0.018	V	3
60.841	7	0.005	58	1	84.628	177	0.029	V	3
63.370	25	0.018	V	7	84.734	178	-0.005	V	3
63.376	25	0.024	V	9	92.43	233	0.003	V	4
63.340	25	-0.011	V	12	93.681	242	-0.004	Y	17
64.350	32	0.029	V	14	94.65	249	-0.013	Y	17
64.359	32	0.020	V	12	94.79	250	-0.013	Y	17
64.495	33	0.025	V	12	95.641	256	-0.001	Y	17
65.36	39	0.051	V	7	96.757	264	-0.003	Y	17
65.48	40	0.031	V	13,7	97.743	271	0.004	Y	17
65.631	41	0.042	V	3	702.637	306	0.006	Y	17
65.773		0.045	V	8	02.764	307	-0.007	Y	17
65.786	42	0.058	V	3	03.609	313	-0.001	Y	17
67.463	54	0.057	V	13	10.365	361	0.046	V	4
69.284	67	0.061	V	6	12.414	376	-0.002	V	4
69.725	71	-0.057	V	3	13.39	383	-0.005	V	4
69.735	71	-0.047	V	3	13.51	384	-0.024	V	4
69.740	71	-0.042	V	8	14.526	391	0.013	V	4
70.437	76	-0.043	V	13	21.632	442	-0.010	V	3
70.564	77	-0.056	V	13	22.621	449	0.000	V	3
70.7	78	-0.06	V	8	25.680	471	-0.016	Y	17
73.52	98	-0.036	V	4	26.664	478	-0.010	Y	17
74.359	104	-0.035	V	14	45.496	613	-0.049	V	3
74.41	104	0.015	V	10	48.554	635	-0.066	V	3
75.193	110	-0.040	V	6	54.67	678	0.039	UV	16
75.33	111	-0.043	V	6	54.81	679	0.039	UV	16
76.312	118	-0.039	V	6	55.087	681	0.036	UV	16
76.76	121	-0.011	58	1	56.358	690	0.049	UV	16
77.74	128	-0.009	58	1	56.496	691	0.048	UV	16
77.758	128	0.009	V	3	935.791	1974	-0.001	V	15
79.56	141	-0.006	V	4	93.385	2386	0.000	V	2
81.377	154	-0.007	V	4	93.527	2387	0.003	V	2
83.52	169	0.049	V	4	1055.325	2829	0.016	V+O	5
83.62	169	0.058	V	4					

T A B L E 6 (Continued)

M I N I M A

J.D. (2442000.+)	E	0 - C	FILTER	REFERENCE	J.D. (2442000.+)	E	0 - C	FILTER	REFERENCE
659.786	0	0.000	58	1	684.23	175	-0.018	V	6
60.37	4	0.025	V	7	84.67	178	0.002	V	3
60.51	5	0.025	58	7	88.44	205	-0.002	V	13
60.776	7	0.011	58	1	92.382	233	0.026	V	4
63.295 (.314)	25	0.014 (0.033)	V	12,7	92.50	234	0.009	V	4
64.302	32	0.043	V	14	92.612	235	-0.023	Y	17
64.44	33	0.041	V	12	93.594	242	-0.020	Y	17
65.435	40	0.058	V	13,7	94.73	250	-0.002	Y	17
65.57	41	0.053	V	12,13,8	96.706	264	0.017	Y	17
65.711	42	0.054	V	8	702.706	307	0.006	Y	17
67.409	55	-0.065	V	13	12.340	376	-0.005	V	4
69.368	69	-0.063	V	6	12.489	377	0.004	V	4
69.668	71	-0.042	V	3	13.36	383	0.036	V	11
70.368	76	-0.042	V	13	13.47	384	0.006	V	4
70.503	77	-0.046	V	13	14.594	392	0.012	V	3
70.645	78	-0.044	V	8	16.538	406	-0.001	V	3
70.782	79	-0.047	V	3	22.591	449	0.041	V	3
73.47	98	-0.015	V	4	25.618	471	-0.007	Y	17
74.308	104	-0.015	V	14	26.599	478	-0.004	Y	17
74.453 (.489)	105	-0.010 (.025)	V	14,10	45.537	613	0.062	V	3
75.26	111	-0.042	V	6	54.89	680	0.05	UV	16
76.229	118	-0.052	V	6	55.29	683	0.031	UV	16
76.7	121	0.000	58	1	56.01	688	0.052	UV	16
76.83	122	-0.010	58	1	56.294	690	0.056	UV	16
77.67 (.664)	128	-0.008 (-0.014)	58 (V)	1,3	56.427	691	0.049	UV	16
77.82	129	0.002	58 (V)	1,3	935.861	1975	0.000	V	15
79.49	141	-0.006	V	4	83.376	2315	-0.012	V	2
79.63	142	-0.005	V	4	88.474	2351	0.053	V	2
83.579	170	0.029	V	3	93.464	2387	0.011	V	2
83.590	170	0.040	V	3	1055.267	2829	0.029	V+0	5
83.685	171	-0.004	V	3	1055.40	2830	0.022	V+0	5

1) This work
2) Abramenko and Prokof'eva (1977)
3) Ambruster et.al. (1977)
4) Cacciari et.al. (1977)
5) Efimov et.al. (1977)
6) Kiselev and Narizhnaja (1977)
7) Klabukova and Paramonova (1977)
8) Koch and Ambruster (1975)
9) Lingren and Lingren (1975)
10) Marcocci et.al. (1976a)
11) Marcocci et.al. as reported by Rosino and Tempesti
12) Papousek and Vetesnik (1977)
13) Rosino and Tempesti (1977)
14) Semeniuk (1975)
15) Williamon (1977)
16) Wu and Kester (1977)
17) Young et.al. (1977)

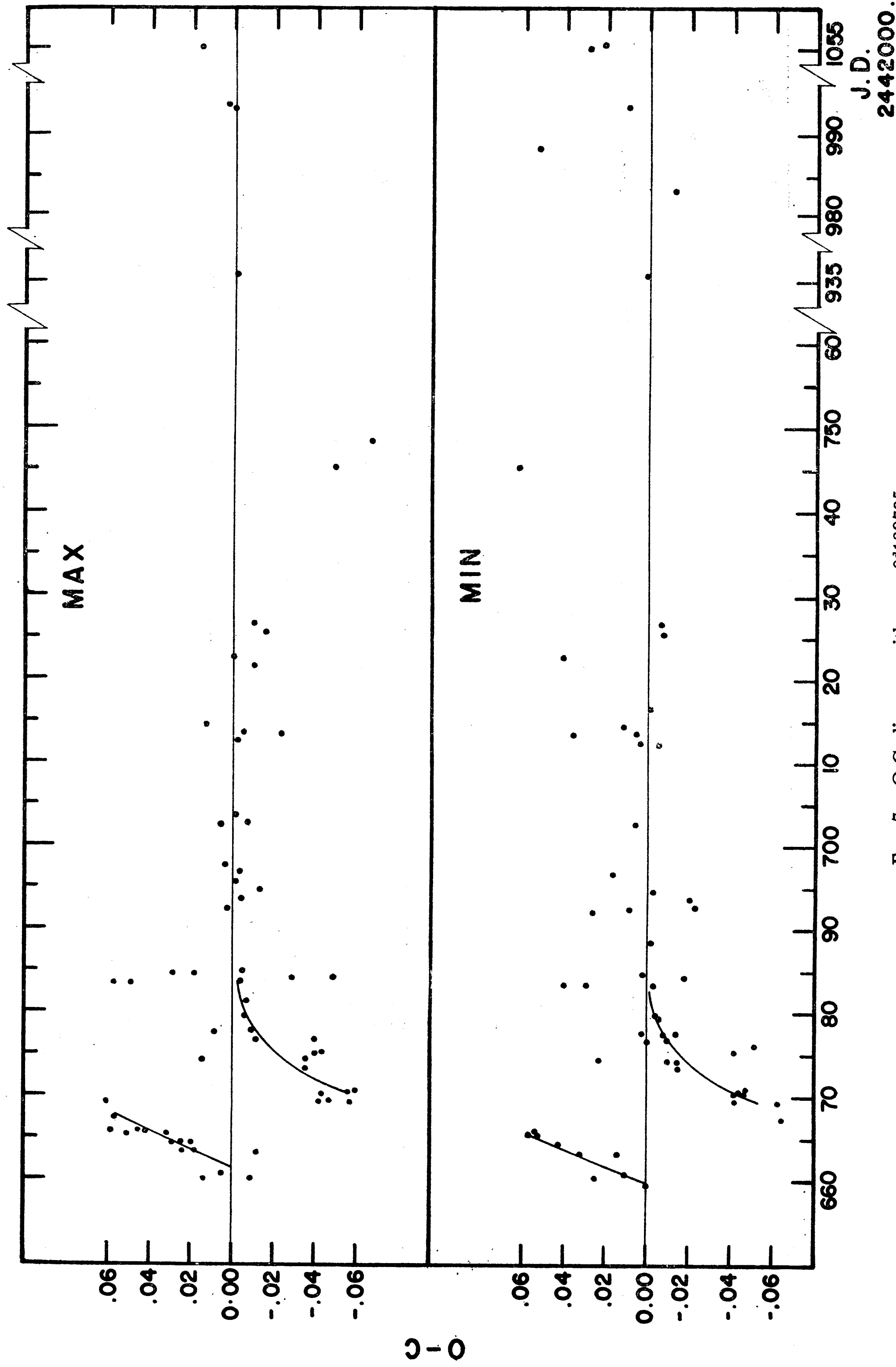

Fig. 7. O-C diagram with $p = 0\overset{d}{.}139785$.

have shrunk to about a solar radius in a relatively short time (less than 10 days after outburst). Under the assumption that the total mass of the binary system in Nova Cygni 1975 is about 2 $M_\odot$ (Marcocci *et al.* 1976*a*), and for an orbital period of $0^d.14$, the semimajor axis of the system would be about 10^{11} cm. After maximum light, when periodic light variations became observable (September 4, 1975), the temperature at the surface of the remnant was of the order of 6×10^4 °K, although the average temperature —taking into account the whole remnant— may be higher ($T \sim 10^5$ °K). If so, the isothermal sound speed inside the remnant would be about 50 km s^{-1}. Hence, a sonic perturbation could reach reach a solar radius in about 0.16 days; consequently we would expect a period of this order for a pulsationally unstable nova remnant.

According to the models for nova ejecta (Mustel and Boyarchuk 1970; Boyarchuk and Gershberg 1977), matter is expelled through the poles and the equator. This kind of geometry can explain the four-peaked profiles in the hydrogen emission lines (Tomkin *et al.* 1976). The ejected equatorial ring for this case, could make an angle $\theta = 60°$ with the line of sight as discussed by Boyarchuk and Gershberg (1977). Apparently this result would exclude the eclipsing hypothesis for this binary system due to the large inclination angle between the plane of the orbit and the line of sight. Nevertheless, the companion of the white dwarf should have at least a radius comparable to its Roche-lobe to be able to transfer mass, and the white dwarf itself could have an accretion disk at the equator. If this is the case with Nova Cygni 1975, even for large inclination angles ($\theta \sim 60°$) small amplitude eclipses could take place.

Assuming that a nova remnant might be pulsationally unstable, as suggested by Sparks *et al.* (1976), and that the binary orbit is slightly eccentric, this eccentricity could produce a tidal perturbation that would tend to force the pulsation period of the remnant to be coherent with the orbital period. According to this mechanism, it is possible to explain the observed period changes in Nova Cygni 1975. Since as the remnant contracts its temperature rises and consequently, the sound speed increases; then the superposition of the eclipses and the remnant pulsation yields an effective period that decreases with time, up to the point when the pulsational period becomes locked up to the rotational one. The amplitude of each phenomenon is presently unknown, and it would be very difficult to make estimates. Nevertheless, following a simplistic frame, we can imagine that the pulsational amplitude is decreasing monotonically with time, and that the eclipsing amplitude is small and nearly constant. In the beginning the variations would be mainly due to remnant pulsations and the observed amplitude of the light curve ($\sim$ 10%) could be obtained with 5% changes in the radius of the remnant. This in turn would imply a minimum eccentricity of about 0.02 for the orbital motion.

The peculiar Hα variations observed by Campbell (1975) on September 5, 1975 can be explained by pulsations of the nova remnant, since an isotropically varying photoionizing source is required in order to explain these observations. Furthermore, the light variability observed during the first few days after maximum light shows large amplitudes both in the ultraviolet and red continua as can be noticed in Figure 5; this also suggests that light variations are due to pulsations of the source, i.e., a change in stellar radius. The appearance of secondary minima might be associated with the time at which the eclipses began to contribute in a significant way to the variability (September 18, 1975). The secondary minima, when observable, are prominent in the V–and almost vanish in the R–filter (Marcocci *et al.* 1976*b*). This can be interpreted as if the observed secondary minima are indeed due to eclipses between a red star and a hot blue companion. Presence of flickering around October 2, 1975 observed by Cacciari *et al.* (1977), could be associated with the appearance of a hot spot in an accretion disk due to ulterior mass transfer from the red primary to the blue white dwarf companion. This hot spot may not be necessarily eclipsed by the red star; if this is so, the explanation to the UV observations given by Wu and Kester (1977) holds.

VI. CONCLUSIONS

The 13-Color Photometry presented in this paper, is in agreement with the spectroscopic and wide band photometric data for the development of Nova V1500 Cygni 1975, already presented by several authors. Short period variability has been observed through every filter on the nights of September 4 and 5, 1975. No wavelength dependant phase-shift in the variability was observed for those nights.

From the phase analysis, it is established that a drastic but continuous change in the period associated to the short-period light variations has taken place between September 4 to September 24, 1975. Based upon harmonic analyses, it can be concluded that the period for light variations remains constant from September 24, 1975 until the end of 1976.

The spectral energy distributions show that at maximum light Nova Cygni was radiating as a blackbody of $T = 10^4$ °K. However, when regular variability became observable, the temperature of the pseudophotosphere had already increased to about 6.5×10^4 °K.

The behavior of Nova Cygni could be explained by a binary system with a slightly eccentric orbit that drives the pulsations of the nova remnant to be resonant with the orbital period. This model might explain the observed changes in period, the Hα variations reported by Campbell (1976) and the onset of a secondary minimum typical of eclipsing binaries sometime after light variations were first observed.

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