ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

Astron. Astrophys. Suppl. Ser. **61**, 45-51 (1985)

Strömgren photometry of open clusters. I. NGC 6281, NGC 6405 (*)

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Received November 20, 1984, accepted February 21, 1985

Summary. — Strömgren four color photometry of A- and B-type stars in the southern open clusters NGC 6281 and NGC 6405 up to $V = 12^{m}0$ are presented.
The membership is discussed and reddenings of $E(b\text{-}y) = 0.120$ and $E(b\text{-}y) = 0.110$, respectively, are estimated. Also, a possible CP1(Am) and a possible δSct star in NGC 6405 are reported.

Key words : Strömgren photometry — open clusters — chemically peculiar early-type stars.

1. Introduction.

Since 1979 more than two dozen open clusters were investigated within the framework of the European Ap Working Group in order to search for CP2 stars (Maitzen, Schneider 1984, see references therein). To detect these stars the Δa photometry, as introduced by Maitzen (1976), was used. Besides this, additional Strömgren photometry of some clusters was obtained.

In this paper Strömgren indices for stars in NGC 6281 and NGC 6405 are presented, their membership and the occurrence of chemically peculiar early-type stars discussed.

The calculation of intrinsic Strömgren indices of stars later than A0 needs Hβ measurements, which are not available for NGC 6281 and NGC 6405. Therefore, the reddening of the cluster was estimated by using the reddening-free parameters $[m_1] = m_1 + 0.18(b\text{-}y)$ and $[c_1] = c_1 - 0.2(b\text{-}y)$ introduced by Strömgren (1966). The main sequence of the clusters was shifted to the standard relation of Crawford (1975, 1978, 1979). In the range $0^{m}.00 > (b\text{-}y) > 0^{m}.06$ the values were taken from Slettebak *et al.* (1968) and the results were compared with published values in the *UBV* system. The relationship between these two quantities is given by $E(b\text{-}y) = 0.74\, E(B\text{-}V)$ (Crawford, 1978).

2. Observations and reduction.

The observations were carried out from May 14 to May 27, 1981 at La Silla, Chile with the ESO 50 cm telescope, equipped with a single channel photometer, an EMI6356 photomultiplier and the ESO standard filters for Strömgren photometry. The integration time was 30 to 120 seconds depending on the brightness of the star. Most of the stars were measured at least three times but because of moderate weather conditions during some nights, these nights were given only half weight calculating the mean values.

To obtain the extinction and the color transformation, a set of twelve bright stars was taken from the catalogue of Grønbech and Olsen (1976) and observed as often as possible. Each standard star was observed at least four times in different nights to exclude a possible variability.

To estimate the extinction the so-called Dutch method was used, i.e. stars with similar spectral types and colors were observed at different air masses at the beginning of the night, a subset of them also during the rest of the night in order to control the stability of the instrument and to estimate a possible trend.

The reduction to the standard color system was done in the way described by Grønbech *et al.* (1976).

3. NGC 6281.

The cluster is located at $\alpha = 17^{h}01^{m}$ and $\delta = -37°55'$ (1950.0), it is classified as type II2p in the catalogue of Ruprecht (1966) and contains about 55 stars down to $V = 13.5$ within a diameter of about 20 arcmin.

Feinstein and Forte (1974) observed the cluster photoelectrically in the Johnson *UVB* system, deriving a distance of 530 ± 30 pc and a mean reddening of $E(B\text{-}V) = 0.15 \pm 0.02$. Also, they discussed the membership and estimated the age as log $t = 8.1$, while in the catalogue of Mermilliod (1981) the age is reported as log $t = 8.35$.

During the investigation of HD 153919, an X-ray source not being a member of this cluster, Bolton and Herbst (1976) observed the cluster both photoelectrically in *UBV*

(*) Based on observations collected at the European Southern Observatory (ESO), La Silla, Chile, within the framework of the European Ap Working Group.

and spectroscopically. They found a distance of 520 pc and a mean reddening of $E(B\text{-}V) = 0.17 \pm 0.01$. Also, they reported the star No. 9 (HD 153947) as a possible member of spectral type A0pSi.

From the list of Feinstein and Forte all stars brighter than $V = 11^{\mathrm{m}}.3$ with $(B\text{-}V)$ less than $0^{\mathrm{m}}.3$, which are denoted as members were measured. Star No. 9, reported as a CP2 star was denoted by Feinstein as a non-member and therefore not included in this investigation. The results are presented in table I. Because of the small aperture of the telescope the internal error increases strongly for stars fainter than $V = 10^{\mathrm{m}}.5$.

From the Δa photometry (Maitzen and Schneider, 1984) star No. 15 was found to be a CP2 star. This is confirmed by the ApSi classification of Houk (1982) and by the photometric work of North and Cramer (1981). North (1983) checked this star for variability and found a period of 1.16645 days with an amplitude of about 0.02 in V.

Star No. 41 appears to be double with a separation of about 13 arcsec and a difference of about $V = 0^{\mathrm{m}}.5$. Both components were measured together.

Figure 1 presents the y *vs.* $(b\text{-}y)$ and figure 2 the $[m_1]$ *vs.* $(b\text{-}y)$ diagram. As reported by Maitzen and Schneider (1984) the stars of this cluster show a differential reddening which leads to a higher scatter around the main cluster sequence. Nevertheless, star No. 15, reported as a CP2 star, is clearly separated in figure 1.

From the work of Crawford (1979) it is known, that the CP1(Am) as well as the CP2 stars are separated from the main sequence ($\Delta m_1 > 0.028$), but beside the known CP2 star No. 15 no other one can be detected above this level in figure 2.

Star No. 37 is a non-member at the base of figure 2, while in figure 1 the scatter feigns a membership.

Shifting of the main sequence to the standard relation of Crawford for $[m_1]$ and $[c_1]$ yields a reddening of $E(b\text{-}y) = 0.120$, which compares well with the transformed value of $E(b\text{-}y) = 0.126$ from Bolton and Herbst whereas the value from Feinstein and Forte yields $E(b\text{-}y) = 0.111$.

4. NGC 6405.

The cluster is located at $\alpha = 17^{\mathrm{h}}35^{\mathrm{m}}$ and $\delta = -32°09'$ (1950.0), it has a diameter of 25-45 arcmin and is classified as III2p (Ruprecht, 1966).

Rohlfs *et al.* (1959) observed it both photoelectrically in *UBV* and spectroscopically. They found a distance of 630 pc, a mean reddening of $E(B\text{-}V) = 0.156$ and estimated the age as $\log t = 8.0$, while Mermilliod (1981) reported $\log t = 7.71$.

Eggen (1961) measured 29 stars and found a distance of 501 pc and a mean reddening of $E(B\text{-}V) = 0.13$.

Antalova (1972) investigated 209 stars in the cluster area photographically in the *UBV* system and denoted 120 stars as possible members.

From the list of Rohlfs *et al.* all stars brighter than $V = 11^{\mathrm{m}}.8$ with $(B\text{-}V)$ less than $0^{\mathrm{m}}.45$ or with spectral types earlier than F0, respectively, were measured.

Table II presents the results of the Strömgren photometry. As mentioned in section 3 the internal error increases strongly for stars fainter than $V = 10^{\mathrm{m}}.5$.

The Δa photometry shows that the stars Nos. 7, 19, 77 are CP2 stars (Maitzen and Schneider, 1984). North (1983) reported variability in the cases of Nos. 19 and 77, which were also detected as CP2 stars in the Geneva photometric system (North and Cramer, 1981).

At the basis of the present observations, star No. 31 seems to be a δSct star with a period of about 0.04 day and an amplitude in V of about $0^{\mathrm{m}}.09$ (Schneider, 1984). Because the star is too faint for an accurate photometry with a 50 cm telescope, further confirmation is needed.

Figures 3 to 5 present the color diagrams. Stars discussed below are identified by their numbers. The hot CP2 stars Nos. 19 and 77 are well separated from the main sequence (it is well known that hot CP2 stars are too blue for their spectral type), while the cooler CP2 star No. 7 is only separated in the $[m_1]$ *vs.* $(b\text{-}y)$ diagram. Antalova denoted the stars Nos. 9, 60 and 103 as foreground stars Nos. 31, 117, 120 as background stars. In the case of No. 9 and No. 60 this is confirmed by the present investigation, but in case of stars Nos. 103, 11, 53, 93, 112 and 129 a possible duplicity can feign a foreground character. Star No. 109 appears in the y *vs.* $(b\text{-}y)$ diagram as a background star, while in the other diagrams the star disappears within the bulk of other stars. In the $[m_1]$ *vs.* $(b\text{-}y)$ diagram star No. 113 is well separated from the main sequence, which points to a CP1(Am) character. Star No. 31, a possible δSct star as mentioned above is separated in the $[c_1]$ *vs.* $(b\text{-}y)$ diagram.

Antalova denoted stars Nos. 8 and 112 as possible long-term variables. In the case of No. 8 the present observation seems to confirm this while No. 112 is found to be double with a separation of about 6 arcsec and a difference of about 3^{m} in V :

ident.	Rohlfs (1959)	Antalova (1972)	this paper
No. 8	8.77	10.18	9.30
No. 112	10.76	10.79	10.83

Stars Nos. 72 and 100, although bright, show greater intrinsic errors than one would expect. This points to a possible variability.

Shifting the main sequence to the standard relation of Crawford yields a reddening of $E(b\text{-}y) = 0.110$, which is very close to the transformed value of $E(b\text{-}y) = 0.115$ from Rohlfs *et al.*, whereas Eggen's value gives $E(b\text{-}y) = 0.096$.

Acknowledgements.

The calculations were made with the Sperry 1100 of the Gesellschaft für wissenschaftliche Datenverarbeitung, Göttingen-Nikolausberg.

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TABLE I. — *Cluster NGC 6281*
(stars are numbered according to Feinstein and Forte (1974)).

iden	V	m.e.	b-y	m.e.	m1	m.e.	c1	m.e.	w	n	rem
6281-5	8.353	.014	.095	.005	.076	.009	1.130	.008	1.5	2	
6281-6	8.639	.010	.070	.001	.110	.001	.939	.018	1.5	2	
6281-8	8.840	.012	.110	.001	.085	.000	1.042	.008	1.5	2	
6281-11	9.051	.011	.079	.001	.078	.001	.952	.001	1.5	2	
6281-13	9.324	.016	.112	.006	.089	.006	1.075	.004	1.5	2	
6281-15	9.368	.001	.046	.001	.126	.003	.862	.006	2.0	2	1)
6281-16	9.537	.016	.115	.002	.090	.005	1.097	.008	1.5	2	
6281-17	9.587	.009	.116	.017	.096	.027	1.062	.014	1.5	2	
6281-18	9.651	.017	.082	.001	.105	.007	1.017	.012	1.5	2	
6281-19	9.712	.007	.145	.012	.116	.009	1.057	.003	1.5	2	
6281-20	9.724	.001	.129	.003	.093	.012	1.112	.002	2.0	2	
6281-21	9.980	.009	.133	.009	.101	.012	.999	.011	1.5	2	
6281-24	10.204	.012	.122	.006	.130	.015	1.074	.019	2.5	3	
6281-25	10.233	.014	.106	.003	.138	.005	1.053	.022	2.5	3	
6281-26	10.219	.013	.115	.003	.136	.005	1.049	.013	1.5	2	
6281-27	10.301	.013	.109	.005	.119	.014	1.057	.005	1.5	2	
6281-29	10.459	.022	.143	.010	.093	.023	1.085	.041	1.5	2	
6281-30	10.453	.012	.117	.003	.127	.008	1.080	.002	1.5	2	
6281-31	10.573	.025	.205	.002	.165	.013	.898	.011	1.5	2	
6281-32	10.637	.022	.128	.003	.147	.013	1.071	.019	1.5	2	
6281-34	10.715	.033	.157	.019	.120	.027	1.042	.036	2.5	3	
6281-36	10.803	.013	.198	.009	.153	.011	.894	.045	2.5	3	
6281-37	10.804	.055	.198	.022	.073	.035	1.144	.077	2.5	3	2)
6281-38	10.890	.018	.135	.009	.174	.020	1.008	.057	2.5	3	
6281-39	10.958	.021	.187	.007	.116	.018	1.029	.042	2.5	3	
6281-41	10.780	.120	.177	.013	.172	.014	.968	.010	1.5	2	3)
6281-43	11.129	.026	.144	.021	.179	.019	.935	.054	2.5	3	
6281-44	11.151	.010	.176	.017	.144	.004	.944	.050	2.0	2	
6281-46	11.256	.045	.214	.016	.119	.023	.934	.028	2.5	3	
6281-47	11.183	.040	.211	.001	.155	.008	.956	.075	2.5	3	

1) CP2 star
2) non-member
3) double, both components measured together

TABLE II. — *Cluster NGC 6405*
(stars are numbered according to Rohlfs et al. (1959)).

iden	V	m.e.	b-y	m.e.	m1	m.e.	c1	m.e.	w	n	rem
6405-2	7.265	.005	.031	.008	.069	.007	.354	.002	2.5	3	
6405-3	9.637	.010	.068	.008	.099	.008	.864	.011	2.5	3	
6405-5	10.567	.016	.128	.012	.157	.039	.974	.036	2.5	3	
6405-7	10.895	.019	.172	.010	.199	.008	1.022	.015	2.5	3	1)
6405-8	9.299	.021	.078	.011	.106	.009	.925	.006	2.5	3	7)
6405-9	7.911	.002	.037	.007	.099	.012	.826	.007	2.5	3	2)
6405-11	10.726	.029	.242	.023	.127	.025	.865	.040	3.5	4	
6405-13	10.586	.024	.112	.006	.171	.013	.971	.017	2.5	3	
6405-15	9.879	.012	.086	.010	.103	.016	.939	.011	2.5	3	
6405-17	9.069	.019	.069	.014	.081	.024	.766	.012	2.5	3	
6405-19	9.817	.015	.020	.007	.205	.008	.766	.024	2.5	3	1)
6405-20	8.269	.008	.038	.003	.071	.007	.398	.008	2.5	3	
6405-21	9.080	.008	.080	.008	.108	.015	.798	.019	2.5	3	
6405-22	9.518	.005	.076	.003	.093	.016	.930	.015	2.5	3	
6405-25	9.135	.005	.087	.008	.127	.012	.947	.009	2.5	3	
6405-26	11.841	.085	.306	.016	.132	.035	.577	.067	2.5	3	
6405-28	8.791	.007	.075	.006	.094	.003	.786	.011	2.5	3	
6405-29	9.881	.008	.073	.009	.111	.016	.881	.018	2.5	3	
6405-31	11.592	.036	.263	.023	.142	.046	1.027	.064	12.5	15	6)
6405-32	6.738	.012	.043	.001	.072	.003	.430	.008	3.5	4	
6405-34	10.756	.019	.156	.013	.144	.023	1.025	.019	2.5	3	
6405-35	11.401	.057	.254	.029	.141	.067	.791	.058	3.0	3	
6405-37	8.818	.002	.053	.005	.081	.002	.664	.005	2.5	3	
6405-41	8.926	.007	.090	.003	.086	.008	.888	.011	2.5	3	
6405-42	10.613	.031	.138	.018	.152	.011	.989	.020	3.5	4	
6405-44	10.641	.028	.172	.010	.138	.024	1.014	.012	2.5	3	
6405-47	10.498	.007	.118	.002	.148	.006	.955	.026	2.5	3	
6405-48	10.610	.021	.185	.015	.142	.027	.927	.039	2.5	3	
6405-51	10.012	.015	.111	.009	.103	.013	.989	.021	2.5	3	
6405-52	10.261	.011	.088	.004	.158	.009	.969	.023	2.5	3	
6405-53	9.872	.012	.162	.004	.159	.013	1.081	.032	2.5	3	
6405-54	10.436	.013	.153	.011	.128	.022	1.005	.035	2.5	3	
6405-59	11.096	.022	.155	.007	.133	.019	1.043	.009	2.5	3	
6405-60	9.197	.006	.232	.012	.151	.017	.920	.012	2.5	3	2)
6405-63	10.220	.013	.087	.007	.137	.015	.974	.027	2.5	3	
6405-64	10.233	.002	.099	.008	.133	.003	.993	.017	2.5	3	
6405-67	11.339	.018	.239	.014	.146	.016	.859	.046	2.5	3	
6405-70	8.346	.007	.060	.008	.080	.010	.530	.010	2.5	3	
6405-71	10.214	.020	.119	.010	.137	.019	1.030	.009	3.5	4	

TABLE II *(continued)*.

iden	V	m.e.	b-y	m.e.	m1	m.e.	c1	m.e.	w	n	rem
6405-72	7.256	.024	.045	.011	.070	.024	.438	.018	2.5	3	8)
6405-73	10.050	.013	.101	.003	.108	.008	1.002	.020	2.5	3	
6405-74	9.681	.019	.090	.010	.081	.020	.842	.035	2.5	3	
6405-75	9.896	.016	.097	.019	.105	.035	.890	.014	3.5	4	
6405-77	9.354	.011	.015	.002	.178	.010	.624	.028	3.5	4	1)
6405-92	10.435	.011	.110	.018	.160	.026	.991	.011	3.5	4	
6405-93	10.005	.007	.146	.011	.138	.024	.934	.013	3.5	4	
6405-94	8.787	.005	.050	.009	.088	.020	.652	.022	2.5	3	
6405-95	10.196	.012	.088	.015	.144	.031	1.014	.021	3.0	3	
6405-96	9.001	.011	.062	.013	.093	.017	.663	.008	2.5	3	
6405-97	8.544	.012	.053	.006	.076	.007	.582	.005	2.5	3	
6405-99	9.406	.016	.085	.009	.090	.013	.709	.009	3.5	4	
6405-100	7.199	.048	.050	.013	.073	.032	.438	.029	2.5	3	8)
6405-103	9.199	.022	.110	.016	.101	.021	.974	.013	2.5	3	
6405-106	11.365	.092	.266	.033	.118	.048	.859	.090	2.5	3	
6405-109	11.816	.030	.184	.001	.172	.021	.953	.076	2.5	3	4)
6405-112	10.831	.009	.233	.013	.175	.025	.861	.014	3.5	4	3)
6405-113	10.886	.011	.149	.012	.212	.022	.954	.023	3.5	4	5)
6405-114	9.855	.015	.081	.008	.112	.012	.969	.028	2.5	3	
6405-115	8.652	.005	.052	.007	.086	.011	.634	.007	2.5	3	
6405-117	10.565	.016	.132	.016	.146	.013	1.033	.017	3.5	4	
6405-120	11.155	.079	.227	.020	.140	.016	.903	.045	2.5	3	
6405-123	11.461	.025	.247	.015	.166	.039	.760	.057	2.5	3	
6405-124	11.225	.024	.232	.025	.144	.049	.881	.049	3.5	4	
6405-127	10.333	.002	.108	.009	.143	.011	1.008	.016	2.5	3	
6405-128	8.081	.007	.065	.006	.069	.011	.630	.009	2.5	3	
6405-129	10.149	.019	.194	.019	.113	.054	.973	.048	2.5	3	
6405-130	10.933	.050	.180	.013	.166	.016	.936	.019	2.5	3	

1) CP2 star
2) non-member
3) double, both components measured together
4) possible non-member
5) possible CP1(Am) star
6) δSct star
7) long term variable
8) possible variable

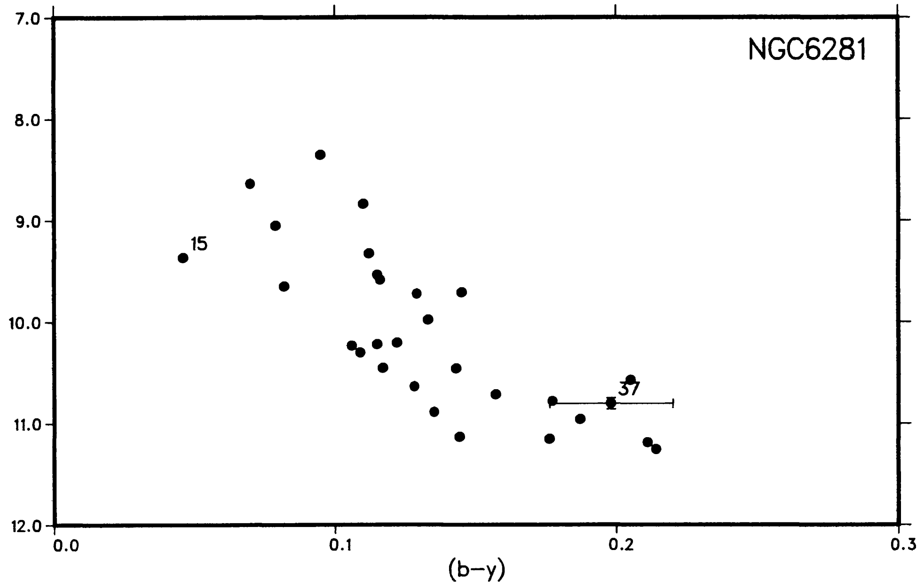

FIGURE 1. — *y vs.* (*b-y*) diagram. CP2 stars are indicated by their numbers. For the stars discussed in this paper error bars in both colors are shown.

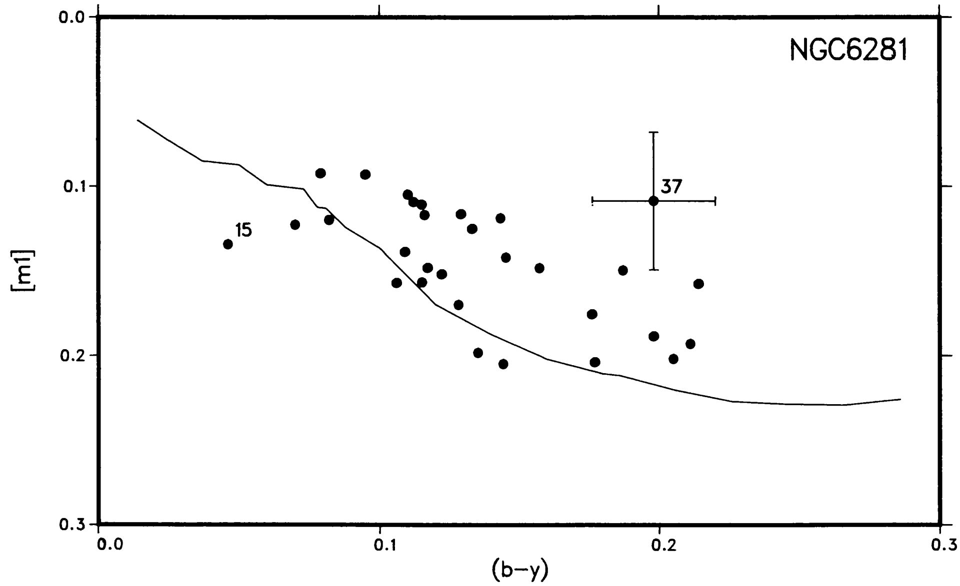

FIGURE 2. — $[m_1]$ *vs.* (*b*-*y*) diagram. The solid line presents the relation of Crawford shifted in (*b*-*y*) for the estimated reddening (see text). For an explanation of symbols see figure 1.

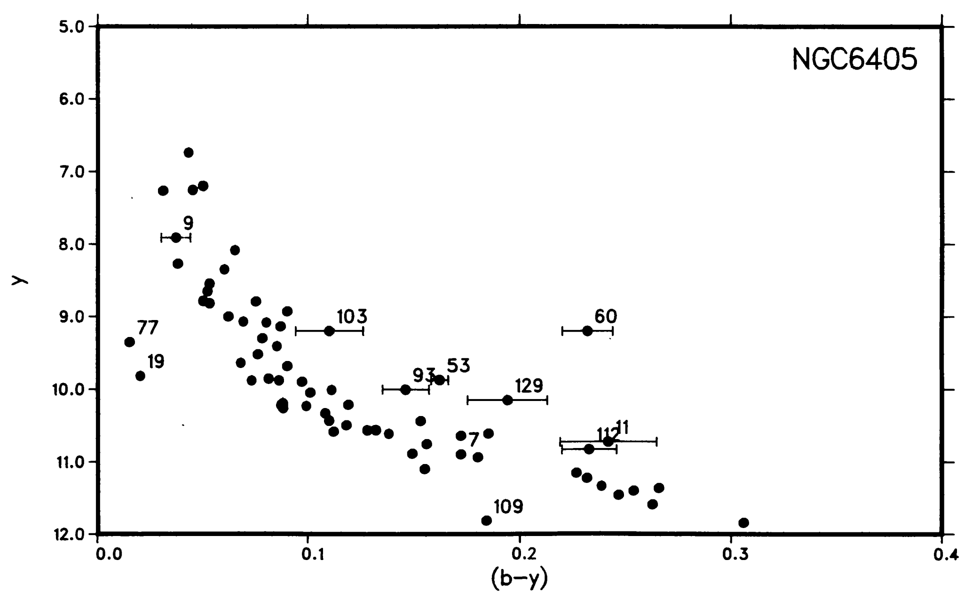

FIGURE 3. — *y* *vs.* (*b*-*y*) diagram. For an explanation of symbols see figure 1.

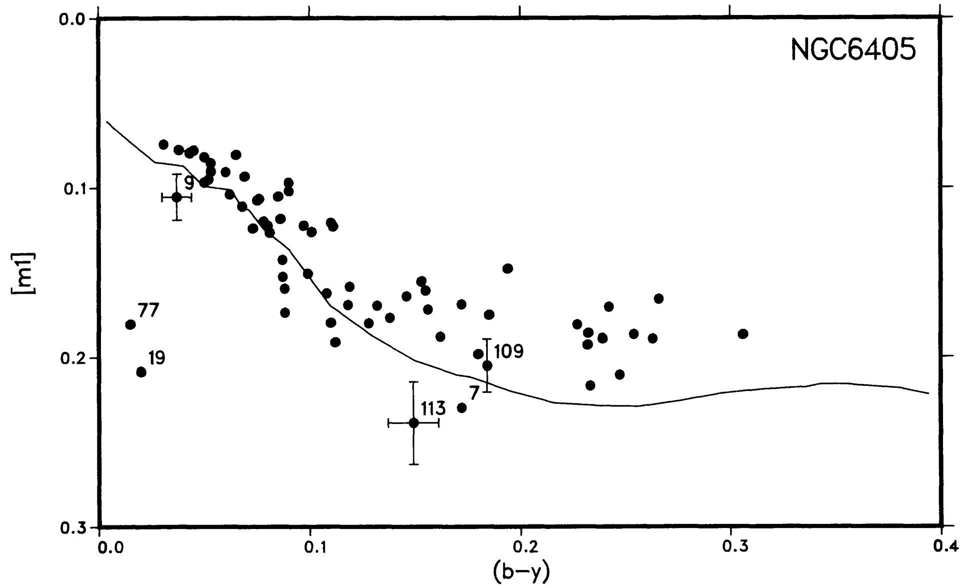

FIGURE 4. — $[m_1]$ *vs.* $(b\text{-}y)$ diagram. For an explanation of symbols see figure 2.

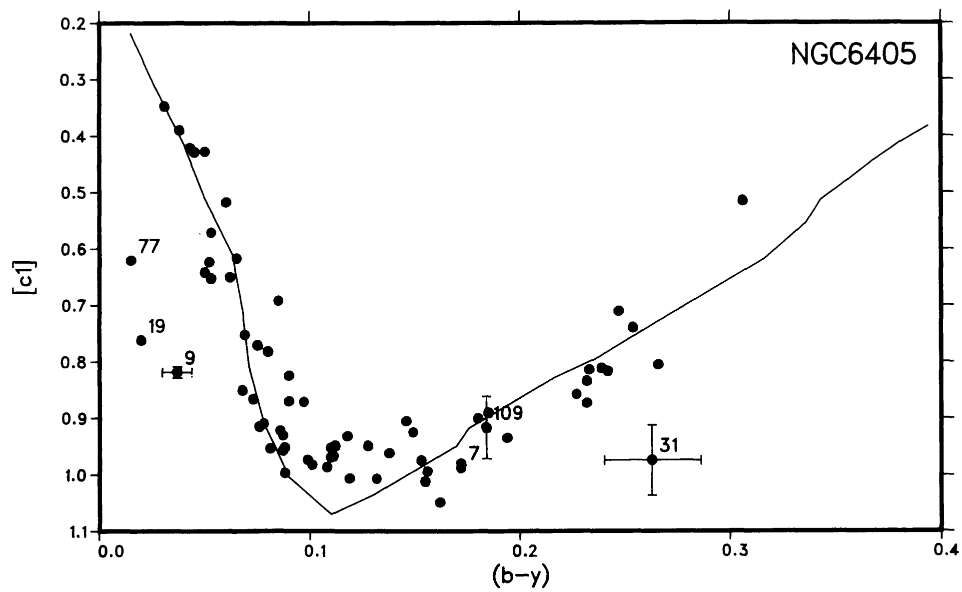

FIGURE 5. — $[c_1]$ *vs.* $(b\text{-}y)$ diagram. For an explanation of symbols see figure 2.