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# A Study of Reflection Nebulae

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A catalogue is given of all BD and CD stars north of $\delta=-33°$ which are surrounded by reflection nebulosity visible on both the blue and red prints of the Palomar Sky Survey. The nearer reflection nebulae lie predominantly along Gould's Belt, whereas the more distant ones are concentrated to the galactic plane. The data outline 13 associations of reflection nebulae, some of which coincide with known OB or T associations. Attention is drawn to the fact that most reflection nebulae at intermediate and high galactic latitude are not associated with individual stars. It is suggested that these nebulae are illuminated by the integrated light of the Milky Way. This integrated radiation will be more intense above and below the galactic plane than in the galactic plane where the nuclear bulge of the galaxy and most of the disk are obscured by interstellar absorption. It is pointed out that stars embedded in reflection nebulosity near the supernova remnants IC 443, CTB 1, and the $1^{d}9$ Cepheid SU Cas might be used to determine the distances of these objects. It is noted that the structure of the nebulae surrounding some T Tauri stars differs from that of typical reflection nebulae.

## I. INTRODUCTION

THE prints of the Palomar Sky Survey have been scanned in an attempt to identify all BD and CD stars which are associated with reflection nebulosity. The total number of stars investigated was approximately $5\times10^5$. About 500 BD and CD stars were found to be associated with reflection nebulosity. In most cases this nebulosity was only visible on the blue prints of the Sky Survey although a few very red objects, like the N-type variable W CMa=HD 54361, are surrounded by a nebula which is only visible in the red. To avoid inclusion of doubtful objects and plate defects only those nebulae which were visible on both the blue and the red prints of the Sky Survey were included in the final catalogue. Emission nebulae were excluded on the basis of their colors and morphology. Because of characteristic structural differences it was seldom difficult to distinguish red reflection nebulae from strongly reddened H II regions, even though the central stars in such H II regions might appear quite red. In this connection it should be noted that the "reflection nebulae" near some T Tauri stars have structural characteristics which are reminiscent of H II regions. Possibly the peculiar appearance of these nebulae is due to gas ejection or to the strong infrared radiation which has recently been observed (Mendoza 1966) from some of these stars.

A total of 170 BD and CD stars were found to be associated with reflection nebulosity which was bright enough to be visible on both the red and the blue prints of the Palomar Sky Survey. In a few regions like Orion's Belt, the Lacerta association, and the Pleiades, it was not always possible to identify the stars which were responsible for the illumination of individual reflection nebulae. Additional sources of incompleteness of the data are superposition of faint reflection nebulae on a very bright stellar background and superposition on H II regions.

Not only are reflection nebulae of intrinsic interest but they may also be used as distance indicators. A good example is provided by the B9II star HD 43836 which is embedded in a dark cloud which appears to be in physical contact with the supernova remnant IC 443 (Hogg 1964). According to Hardie, Seyfert, and Gulledge (1960), HD 43836 has a true distance modulus of $(m-M)_0=8.5$ corresponding to a distance of 500 pc. This value is, however, quite uncertain because absolute magnitudes of luminosity class II stars are poorly calibrated near spectral type A0. Similarly the star HD 224403 could perhaps be used to determine the distance to the possible supernova remnant CTB 1. Finally, the Cepheid SU Cas is possibly embedded in the same interstellar cloud complex as are HD 17138 and HD 17443. Spectroscopic and photometric observations of these two stars might therefore be used to determine the absolute magnitude of SU Cas. This would be of particular interest because SU Cas, which has a period of only 1.9 days, can be used to determine the slope of the galactic period–luminosity relation. The only other Cepheid known to be located in a reflection nebula is RS Pup (Westerlund 1963).

The data contained in the present paper supplement those given in previous catalogues of reflection nebulae by Hubble (1922a,b), Cederblad (1946), Struve and Straka (1962), Dorschner and Gürtler (1964, 1965), and B. T. Lynds (1965a).

## II. THE CATALOGUE

The data on all reflection nebulae which were found to be associated with BD or CD stars north of $\delta=-33°$ are collected in Table I. In addition to the BD or CD number of each star the catalogue gives the HD number and the new galactic coordinates $l^{II}$ and $b^{II}$. The quoted MK spectral types were mainly taken from the catalogue of Jaschek, Conde, and de Sierra (1964). Other spectral types are from miscellaneous sources. Visual magnitudes given to two decimals are photoelectric values from a card catalogue of photometric

TABLE I. Catalogue of reflection nebulae.

| No. | BD or CD | HD | $l^{II}$ | $b^{II}$ | Sp. | $V$ | Type | Bright-ness | Color | Absorp-tion | $R(B)$ | $R(R)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1* | +57° 22 | 627 | 117.7 | − 3.7 | A | 8.6 | I | Br | vB | Mod | 4′.3 | 1′.1 |
| 2 | +64 13 | | 119.0 | + 3.0 | B5 | 9.5 | I | M | vB | Str | 1.7 | 1.1 |
| 3 | +68 34 | 3037 | 121.4 | + 6.6 | K0 | 8.5 | I | M | I | Wk | 0.9 | 0.9 |
| 4* | +61 154 | | 121.9 | − 1.0 | Beq | 9.5 | I–II | F | B | Mod | 4.2 | 3.1 |
| 5* | +59 144 | 5394 | 123.6 | − 2.1 | B0IV:e | 2.57v | II | M | I to vB | Wk | 60 | 60 |
| 6 | +61 315 | | 129.1 | − 0.4 | B8Ib | 9.2 | II | F | mB | Wk | 0.9 | 0.9 |
| 7* | +69 179 | 17138 | 132.9 | + 9.1 | A2V | 6.5v | II | F | mB | Mod | 3.1 | 3.1 |
| 8 | +67 230 | 17443 | 133.9 | + 7.6 | A0 | 8.5 | I | vBr | B | Mod | 2.3 | 1.7 |
| 9* | +68 200 | 17463 | 133.5 | + 8.5 | F6Ib–IIv | 5.96v | II | F | B | Mod | 3.7 | 3.1 |
| 10 | +56 798 | 20041 | 141.6 | − 0.4 | A0Ia | 6.0 | I | F | I | Wk | 8.0 | 5.4 |
| 11 | +61 570 | 20798 | 140.1 | + 3.9 | B5 | 8.37 | II | M | B | Str | 3.1 | 2.8 |
| 12 | +31 597 | 21110 | 157.4 | −20.6 | gK4 | 7.0 | I | M | mR | Wk | 2.3 | 2.3 |
| 13 | +30 540 | | 158.0 | −21.3 | | 8.8 | I | F | B | Mod | 2.3 | |
| 14* | +59 660 | 21291 | 141.5 | + 2.9 | B9Ia | 4.23 | II | M | B | Mod | 23 | 23 |
| 15 | +58 607 | 21389 | 142.2 | + 2.1 | A0Ia | 4.58 | II | M | B | Str | 27 | 17 |
| 16 | +29 565 | | 159.2 | −21.9 | A5 | 9.1 | II | M | mB | Mod | 4.5 | 4.5 |
| 17* | +30 549 | | 158.3 | −20.4 | B8p | 9.5 | I | Br | B | Str | 4.0 | 4.0: |
| 18 | +37 794 | 22114 | 155.1 | −14.4 | A0 | 7.58 | II | F | B | Wk | 7.1 | 5.7: |
| 19* | +31 643 | 281159 | 160.5 | −17.8 | B5V | 8.53 | I | Br | B | Str | 2.8: | 2.8: |
| 20 | +23 507 | 23302 | 166.2 | −23.9 | B6III | 3.71 | I | M | vB | Wk | 11.0: | 7.1: |
| 21 | +23 516 | 23408 | 166.2 | −23.5 | B7III | 3.88 | I | Br | vB | Wk | 26 : | 8.5: |
| 22 | +23 522 | 23480 | 166.6 | −23.8 | B6IVnn | 4.18 | I | vBr | vB | Wk | 26 : | 17 |
| 23 | +23 541 | 23630 | 166.6 | −23.5 | B7III | 2.87 | I | M | vB | Wk | 17 : | 10 |
| 24* | +38 811 | 275877 | 156.8 | −11.9 | A2II+B6 | 8.8v | II | M | mB | Str | 4.5 | 3.4: |
| 25 | +23 642 | 26514 | 171.4 | −19.8 | G5 | 7.5 | II | F | I | Wk | 4.3 | 4.3: |
| 26 | + 9 549 | 26676 | 182.7 | −28.4 | B8 | 7.2 | I | M | vB | Abs | 5.7 | 4.3 |
| 27* | +28 645 | 283571 | 169.3 | −14.9 | dF8e−dG2e | 9.1 | I | F | R | Str | 2.8 | 4.3 |
| 28* | +19 706 | 284419 | 176.2 | −20.9 | dG5e | 9.4 | II pec | F | R | Str | 0.9 | 6.2 |
| 29 | +29 741 | 30378 | 172.1 | − 9.7 | B9 | 6.5 | II | M | B | Mod | 6.8 | 5.7 |
| 30* | +66 358 | 30614 | 144.1 | +14.0 | O9.5Ia | 4.30 | II | vF | I | Abs | 20.0 | 23.0 |
| 31* | +30° 741 | 31293 | 172.5 | − 8.0 | A0ep | 6.8 | I | M | B | Str | 4.5 | 2.6 |
| 32 | +44 1080 | | 162.5 | + 1.5 | B5IV | 9.12 | I–II | F | B | Wk | 0.9 | |
| 33* | − 3 1013 | 293815 | 203.5 | −24.7 | B9V | 10.12 | I | Br | vB | Str | 0.9: | |
| 34* | +34 980 | 34078 | 172.1 | − 2.3 | O9.5V | 5.8v | I | Br | | Wk | 10.0 | |
| 35 | +12 754 | 34033 | 189.7 | −14.6 | G5 | 8.7 | I | M | mR | Wk | 0.9 | 2.0 |
| 36* | − 8 1063 | 34085 | 209.2 | −25.3 | B8Ia | 0.15 | II | M | mB | Abs | 410 | 410 |
| 37 | +13 852 | 34454 | 189.8 | −13.7 | gM5 | 8.2 | I | Br | vR | Wk | 2.0 | 7.7 |
| 38* | + 8 933 | 34989 | 194.6 | −15.6 | B1V | 5.77 | II | M | I | Mod | 14 | 11 |
| 39 | +32 970 | 243202 | 174.3 | − 1.7 | A5 | 9.5 | II | F | mB | Mod | 0.3 | 0.3 |
| 40 | + 6 921 | 243588 | 196.8 | −15.7 | K0 | 9.0 | I | M | I: | Wk | 0.3 | 0.3 |
| 41 | +23 921 | 244068 | 182.5 | − 5.9 | F2 | 9.3 | I | vF | mB | Mod | 0.6 | 0.3 |
| 42* | − 5 1281 | 36412 | 208.8 | −20.4 | dA7 | 9.46 | II | F | mR | Mod | 2.8 | 2.8 |
| 43 | + 5 951 | | 198.1 | −14.6 | | 9.0 | I | Br | B | Wk | 1.1 | 0.6 |
| 44 | − 4 1162 | 36540 | 207.8 | −19.7 | B9 | 8.11 | II | F | vB | Str | 4.3 | |
| 45 | +31 1022 | 245259 | 176.5 | − 0.1 | B8 | 9.5 | I | Br | mB | Wk | 0.3 | 0.3 |
| 46* | − 6 1253 | | 210.4 | −19.7 | Pec | 9.3 | I | vBr | I: | Mod | 0.9 | 0.9 |
| 47 | +23 982 | 37387 | 184.0 | − 4.2 | gK0 | 7.8 | II | vF | vR | Mod | 2.3 | 5.1 |
| 48* | − 0 1034 | 37370 | 204.5 | −16.3 | B9 | 7.46 | II | F | vB | Wk | 14.0 | |
| 49 | + 4 1002 | 37490 | 200.7 | −14.0 | B3IIIe | 4.50 | I | M | B | Wk | 21 | 4.8 |
| 50 | − 1 1001 | 37674 | 205.9 | −16.5 | B5n | 7.67 | I | B | vB | Mod | 3.1 | 2.3: |

1. BD +57°18, $V$=8.9 and BD +57°19, $V$=8.9 also involved.
4. Identification uncertain.
5. The two elephant trunk structures associated with $\gamma$ Cas exhibit a striking difference in color.
7. Nebulosity might actually be associated with a faint star south preceding BD +69°179 = RZ Cas.
8. Comet tail nebula?
9. Cepheid SU Cas possibly at same distance as BD +67°230 and BD +69°179.
14. In same nebula as BD +58°607.
17. Nebula also contains BD +30°548.
19. In a clustering near $o$ Per.
24. RW Aur variable XY Per. Comet tail nebula?
27. RW Aur variable RY Tau. Comet tail nebula?
28. RW Aur variable T Tau.
30. Color indicates mixture of emission and reflection.
31. RW Aur variable AB Aur, which is located near the edge of a small very dense cloud.
33. Reflection nebulosity forms part of a larger nebula.
34. The nebula surrounding AE Aur is the best example of nebulosity in which the gas and dust components are distributed differently. The radius given is that of the dust nebula.
36. Radius of reflection nebula near $\beta$ Ori at least 280′ and almost certainly 410′.
38. Emission and reflection nebulae have very different structure.
42. Association of EY Ori and nebula probable but not certain.
46. RW Aur variable V380 Ori.
48. −0°1033, $V$=9.2 and −0°1035, $V$=9.1 also involved. Some of illumination may be due to Orion Belt stars.

TABLE I (*continued*)

| No. | BD or CD | HD | $l^{II}$ | $b^{II}$ | Sp. | $V$ | Type | Brightness | Color | Absorption | $R(B)$ | $R(R)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51* | −1° 1005 | 37776 | 206.0 | −16.3 | B2V | 6.98 | I | vBr | B | vStr | 5′1 | 4′0 |
| 52 | −2 1345 | 37903 | 206.8 | −16.5 | B1.5V | 7.82 | I | vBr | B | Str | 4.3 | 2.8 |
| 53 | −10 1261 | | 214.4 | −20.2 | | 9.5 | I | vF | mB | Mod | 0.9 | 0.3 |
| 54 | −6 1287 | | 210.6 | −18.3 | | 9.5 | I | Br | B | Str | 0.6 | 0.6 |
| 55 | −8 1199 | 38023 | 212.4 | −19.0 | B9 | 8.7 | I | F | mB | Mod | 0.9 | 0.3 |
| 56 | +16 852 | 38065 | 190.5 | −6.9 | A0 | 9.0 | I | Br | B | Wk | 0.6 | 0.3 |
| 57 | −2 1350 | 38087 | 207.1 | −16.2 | B3n | 8.30 | I | vBr | vB | Mod | 2.6 | 1.7 |
| 58 | −8 1208 | | 213.2 | −18.8 | | 9.5 | I | vF | mR | Mod | 0.3 | 0.6 |
| 59 | +0 1177 | 38563 | 205.3 | −14.3 | B5 | 10.49 | I | vBr | I | Str | 6.8 | 6.8 |
| 60 | +0 1181 | 290861 | 205.2 | −14.1 | F8 | 9.5 | I | Br | I | Str | 4.3 | 4.0 |
| 61 | +5 1035 | 39398 | 201.5 | −10.6 | G5 | 8.6 | II | vF | mB | Mod | 0.6 | |
| 62* | +1 1156 | 288313 | 204.7 | −12.0 | K2 | 9.5 | I | M | mR | Str | 1.4 | 1.4 |
| 63 | +1 1163 | 288309 | 204.9 | −11.4 | K | 9.2 | I | F | mR | Wk | 0.3 | 0.3 |
| 64 | −14 1294 | | 219.8 | −18.1 | | 10.0 | I | M | mB | Mod | 0.6 | 0.3 |
| 65 | +30 1096 | | 180.7 | +4.3 | | 9.5 | I | Br | mB | Mod | 2.3 | 1.4 |
| 66 | −9 1310 | | 216.3 | −15.1 | | 9.3 | I | mF | B | Str | 0.9 | |
| 67* | −6 1415 | | 213.7 | −12.7 | B1 | 9.5 | I | vB | mB | Mod | 1.1 | 1.1 |
| 68 | −6 1417 | 42004 | 213.6 | −12.5 | B9 | 9.0 | I | M | B | Wk | 3.4 | 2.8 |
| 69 | −6 1418 | | 213.6 | −12.6 | B8 | 9.0 | I | M | I | Str | 3.1 | 1.4 |
| 70* | −5 1515 | 42050 | 212.8 | −12.0 | B3 | 8.5 | I–II | F | I | Wk | 6.0 | 4.0 |
| 71* | +14 1171 | 252680 | 195.7 | −2.5 | B2 | 9.0 | II | F | B | Mod | 1.7 | |
| 72 | −6 1431 | 42261 | 213.8 | −12.2 | B4 | 9.0 | I | vBr | B | Mod | 2.3 | 1.7 |
| 73 | −6 1440 | | 213.9 | −11.8 | | | I | Br | mB | Mod | 1.4 | 1.1 |
| 74 | −6 1444 | | 213.9 | −11.6 | B6 | 9.7 | I | Br | mB | Mod | 0.6 | 0.6 |
| 75* | +23 1301 | 43836 | 188.7 | +3.8 | B9II | 7.5 | I | M | vB | Mod | 3.4 | 1.7 |
| 76* | +10 1158 | 258686 | 201.6 | +0.0 | B8 | 9.3 | II | M | mB | Mod | | |
| 77* | +9 1266 | 258749 | 201.9 | −0.0 | B8 | 9.5 | I–II | M | vB | Mod | 0.9: | |
| 78* | +9 1269 | 258853 | 201.9 | +0.0 | B3 | 8.8 | I–II | Br | vB | Mod | 2.8: | |
| 79 | +10 1163 | 258973 | 201.5 | +0.4 | A2 | 9.4 | II | F | mB | Mod | 2.6 | |
| 80* | −9 1498 | 46060 | 219.3 | −9.0 | B8 | 8.6 | I | M | B | Mod | 5.7 | 2.3 |
| 81 | +7 1337 | 46300 | 204.3 | −0.8 | A0Ib | 4.48 | I | M | vB | Wk | 18.0 | 4.3 |
| 82 | +10 1172 | 259431 | 201.6 | +0.6 | B6pe | 8.74 | I | Br | I | Mod | 3.1 | 1.7 |
| 83* | −27 3174 | | 236.5 | −14.4 | | 9.5 | I | Br | vB | Wk | 0.3 | |
| 84* | −27 1408 | | 236.6 | −14.4 | | | I | M | vB | Wk | 1.4 | |
| 85* | +1 1503 | 289120 | 211.2 | −0.4 | B3 | 9.3 | I–II | M | I | Mod | 1.1 | 1.1 |
| 86 | −10 1773 | 51479 | 222.7 | −3.4 | B8 | 8.2 | II | M | vB | Wk | 2.0 | 2.0 |
| 87* | −8 1664 | 52329 | 221.8 | −2.0 | B8 | 8.8 | I | Br | mB | Wk | 1.4 | 1.4 |
| 88* | −11 1747 | 52721 | 224.2 | −2.8 | B3e | 7.2 | I | F | I | Wk | 7.1 | 6.2 |
| 89 | −12 1748 | | 225.1 | −3.1 | | 9.5 | I | vF | B | Wk | 1.1 | |
| 90 | −11 1755 | 52942 | 224.4 | −2.7 | B3n | 8.7 | I | F | I | Mod | 4.0 | 4.0 |
| 91 | −10 1839 | | 223.8 | −2.2 | | 9.4 | II | F | B | Mod | 0.9 | 0.3 |
| 92* | −11 1763 | | 224.6 | −2.5 | | 9.2 | I | vF | I: | Mod | 2.0 | |
| 93* | −10 1848 | 53367 | 223.7 | −1.9 | B0IV:e | 6.97 | I | vBr | I | Str | 10.0 | 8.5: |
| 94 | −12 1771 | 53623 | 225.5 | −2.6 | B9 | 8.5 | I | vBr | I | Var | 5.6 | 5.6: |
| 95* | −11 1790 | 53974 | 224.7 | −1.8 | B0.5IV | 5.38 | II | F | I: | Mod | 2.8 | 2.5 |
| 96 | −23 5277 | 57281 | 237.4 | −4.9 | B9 | 9.2 | I | M | B | Mod | 2.8 | 0.3 |
| 97* | −16 2003 | | 232.6 | +1.1 | | 9.9 | I–II | M | B | Mod | 1.1 | 0.6 |
| 98 | −25 4775 | 61071 | 240.4 | −2.2 | B5 | 7.3 | I | M | vB | Wk | 8.0 | |
| 99 | −25 11228 | 143018 | 347.2 | +20.2 | B1V | 2.89 | II | M | vB | Wk | 100 | 43 |
| 100* | −19 4333 | 145502 | 354.6 | +22.7 | B2IV–V | 4.03 | II | M | mB | Wk | 5.7: | |

51. Structure in blue differs significantly from that in the red.
62. At edge of very dense cloud.
67. Identification uncertain.
70. Filamentary reflection nebula and disk shaped emission region.
71. Association of star and nebula not certain.
75. Appears to be at same distance as the supernova remnant IC 443.
76. Embedded in larger reflection nebula.
77. Embedded in larger reflection nebula.
78. Embedded in larger reflection nebula.
80. In a small compact clustering which includes BD −9°1497, V = 9.2.
83. Member of a small clustering of nebulous stars located in a small isolated absorbing cloud surrounded by transparent regions.
84. Remarks same as for No. 83. CPD number given.
85. Possible member of a small clustering.
87. BD −8°1665, $V$ = 10 and BD −8°1666, V = 9.3 also involved.
88. Reflection nebulosity and emission from a faint circular disk.
92. In a small clustering which includes BD −11°1761, $V$ = 9.3.
93. Emission and reflection nebulosity appear to be distributed differently.
95. Has nebulous companion.
97. Located in absorbing material near edge of old H II region.
100. BD −19°4332, $V$ = 7.3 also involved. Dimensions given are those of blue portion of nebula. The outer region of the nebula is red due to emission or reflected light from $\alpha$ Sco.

TABLE I (*continued*)

| No. | BD or CD | HD | $l^{\text{II}}$ | $b^{\text{II}}$ | Sp. | $V$ | Type | Bright-ness | Color | Absorp-tion | $R(B)$ | $R(R)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | −19° 4357 | 146834 | 355.2 | +21.0 | K5III | 6.37 | I | F | mR | Wk | 4′.3 | 5′.7 |
| 102* | −19 4358 | 147009 | 355.5 | +20.9 | B9.5V | 8.08 | I | Br | vB | Mod | 7.1 | 2.8 |
| 103* | −19 4361 | 147103–4 | 355.5 | +20.8 | A0+A0 | 7.3 | I | M | B | Mod | 4.5 | |
| 104* | −25 11485 | 147165 | 351.3 | +17.0 | B1III | 2.89 | I | M | I | Mod | 28 : | |
| 105 | −24 12684 | 147889 | 352.9 | +17.0 | B2V | 7.89 | I | M | mB | vStr | 14 : | 4.3: |
| 106 | −23 12861 | 147933–4 | 353.7 | +17.7 | B2V+B2V | 4.61 | I | Br | vB | Mod | 31 | 16 : |
| 107 | −26 11359 | 148478–9 | 351.9 | +15.1 | M1Ib+dB4 | 0.92 | I | M | vR | Wk | 41 | 117 |
| 108 | −24 12695 | 148605 | 353.1 | +15.8 | B2V | 4.78 | I | M | vB | Mod | 14 | 4.8 |
| 109 | −17 4618 | 150416 | 0.8 | +18.4 | G8II | 5.3 | II | vF | mR | Wk | 18 | 13 |
| 110 | −20 4696 | | 3.0 | + 9.9 | | 9.4 | I | M | mB | Str | 0.6 | 0.3 |
| 111 | + 6 3386 | 156697 | 27.7 | +23.3 | F0n | 6.49 | II | M | B | Abs | 6.2 | 4.0 |
| 112 | − 5 4524 | | 21.2 | +10.2 | | 9.6 | II | F | R | Wk | 0.6 | 0.6 |
| 113* | −21 4866 | 165784 | 9.1 | − 0.7 | A2Ia | 6.8 | II | F | B | Wk | 8.5 | |
| 114 | −18 4800 | 165811 | 11.8 | + 0.8 | A | 9.1 | I | F | B | Mod | 0.6 | |
| 115 | −23 13974 | 165872 | 7.4 | − 1.8 | B9 | 9.3 | I | Br | B | Str | 0.9 | 0.3 |
| 116 | −17 5049 | 166288 | 12.6 | + 0.6 | B8 | 9.5 | I | F | B | Mod | 0.3 | |
| 117 | −17 5080 | 167143 | 13.3 | − 0.0 | B8 | 9.1 | I | M | vB | Mod | 1.1 | |
| 118 | −19 4940 | 167638 | 11.5 | − 1.6 | B5 | 9.4 | I | Br | mB | Str | 2.6 | 0.9 |
| 119 | −19 4946 | 313095 | 11.4 | − 1.7 | B5 | 9.4 | I | vBr | mB | Str | 2.8 | 1.4 |
| 120 | −16 4790 | 167746 | 14.0 | − 0.4 | G5 | 8.8 | I | M | R | Mod | 0.6 | 0.6 |
| 121* | −17 5141 | 168418 | 14.3 | − 1.0 | B2III | 9.43 | I–II | F | B | Mod | 0.3 | 0.3 |
| 122* | −13 4965 | | 17.8 | − 0.4 | B3n+B0 | 9.3 | I | M | mR | Str | 0.6 | 0.6 |
| 123 | + 1 3694 | 170634 | 31.6 | + 5.2 | A0 | 9.1 | I | M | mB | Str | 1.7 | 1.1 |
| 124 | −10 4713 | 170740 | 21.0 | − 0.5 | B2V | 5.5 | I | Br | vB | Str | 18 | 3.1 |
| 125 | +15 3811 | 182830 | 50.6 | − 0.4 | F0 | 8.0 | I | vF | B | Mod | 0.6 | |
| 126 | +22 3693 | 182918 | 57.0 | + 3.0 | A2 | 8.3 | I | Br | vB | Str | 4.0 | |
| 127* | +18 4240 | 187076–7 | 55.8 | − 3.4 | M2II+B | 3.82 | II pec | F | R | Wk | 28 | 33 |
| 128 | +31 3925 | 190603 | 69.5 | + 0.4 | B1.5Ia | 5.63 | I | M | I | Mod | 4.0 | 3.7 |
| 129* | − 1 3911 | 191692 | 41.6 | −18.1 | B9.5III | 3.24 | II | F | mB | Abs | 48 : | 48 : |
| 130* | +38 3993 | 228789 | 76.9 | + 2.1 | B | 9.5 | I | Br | R | Str: | 0.3: | 0.6: |
| 131 | +41 3731 | | 80.0 | + 2.7 | B7 | 9.1 | I | Br | vB | vStr | 2.8 | |
| 132 | +41 3737 | | 80.2 | + 2.7 | B6 | 8.7 | I | Br | vB | vStr | 2.8: | |
| 133 | +36 4105 | 195593 | 76.4 | − 1.4 | F5Iab | 6.19 | I | Br | mB | Str | 5.7 | 5.7 |
| 134 | +48 3142 | 195556 | 86.1 | + 5.7 | B2V | 4.95 | I–II | F | B | Mod | 11 | 11 |
| 135 | +31 4152 | | 73.5 | − 5.1 | | 8.6 | II | F | mR | Wk | 0.9 | 1.4 |
| 136 | +41 3836 | 196819 | 81.4 | + 0.5 | K3II | 7.8 | II | vF | R | vStr | 2.0 | 4.3: |
| 137 | +46 3111 | 199478 | 87.5 | + 1.4 | B8Ia | 5.69 | II | vBr | vB | Mod | 6.8 | 4.8 |
| 138 | +47 3237 | 199714 | 88.3 | + 1.8 | B8Ib | 8.28 | I | F | B | Mod | 3.7 | |
| 139* | +67 1283 | 200775 | 104.1 | +14.2 | B5e | 6.8 | I | vBr | B | Str | 8.5 | 5.7 |
| 140 | +57 2309 | 203025 | 98.0 | + 6.5 | B2IIIe | 6.41 | I–II | M | vB | Mod | 10 | 3.1 |
| 141 | +67 1300 | | 105.0 | +13.2 | | 9.4 | I | F | R | Wk | 1.7 | 4.2 |
| 142* | +56 2604 | 239710 | 99.1 | + 3.9 | B3 | 8.8 | I | M | B | vStr | 0.6 | 0.3 |
| 143 | +67 1332 | 206135 | 106.4 | +11.8 | A0 | 8.3 | I | Br | vB | Mod | 4.8 | 0.9 |
| 144 | +54 2595 | 206509 | 97.7 | + 1.6 | K0III | 6.0 | I | vF | I: | Str | 1.7 | 1.4 |
| 145 | +48 3485 | 206887 | 94.2 | − 3.2 | F2 | 7.4 | I | M: | mB: | Mod | 4.3 | 4.3 |
| 146* | +65 1637 | | 105.4 | + 9.9 | | 9.4 | I | Br | B | Str | 4.5 | 1.4: |
| 147 | +46 3471 | | 94.3 | − 5.4 | | 9.5 | I | M | B | Str | 0.9 | 0.6 |
| 148 | +55 2682 | 239856 | 101.5 | + 0.3 | F2 | 8.7 | II | F | B | Mod | 1.7 | 0.6 |
| 149 | +72 1018 | | 111.6 | +13.7 | | 9.1 | I | M | vB | Mod | 2.6 | |
| 150 | +72 1020 | 210806 | 111.9 | +14.1 | A0 | 8.4 | I | M | vB | Str | 5.7 | 4.3 |
| 151* | +38 4711 | 211073 | 92.8 | −13.8 | K3III | 4.49 | II: | F | I | Abs | 5.4 | 5.4 |
| 152* | +69 1231 | | 110.3 | +11.4 | A | 8.8 | I | vB | B | vStr | 6.8 | 2.8 |
| 153 | +61 2292 | | 106.8 | + 4.6 | | 9.4 | I | M | B | Str | 1.4 | |
| 154* | +64 1677 | | 109.0 | + 6.4 | | 8.9 | II | F | B | Mod | 5.1: | |
| 155 | +61 2361 | 216629 | 109.6 | + 2.4 | B2pe | 9.29 | I | M | B | Str | 3.1 | 1.7 |
| 156* | +41 4664 | 217675–6 | 102.2 | −16.1 | B6p | 3.62 | II | F | I | Wk | 94 | 94 |
| 157* | +71 1181 | 217903 | 114.9 | +11.6 | A0 | 7.8 | pec | F | vB | Wk | 2.3 | 0.6 |
| 158 | +47 4220 | 222142 | 110.6 | −12.6 | B9 | 9.0 | I | M | vB | Wk | 1.7: | 0.6 |

102. BD −19°4359, $V$=7.7 also involved.
103. Member of a group.
104. Brightness distribution in emission nebulosity differs significantly from that of the reflection nebula surrounding $\sigma$ Sco.
113. Possibly a member of a small loose clustering.
121. In a clustering.
122. Eclipsing variable W Sct.
127. Association of star and nebulosity probable but not certain. Structure of nebulosity somewhat reminiscent of that near $\gamma$ Cas.
129. Association of $\theta$ Aql with nebulocity probable but not certain.
130. In a clustering of nebulous stars. Association of star and nebulosity not certain.
139. This is one of the brightest reflection nebulae known.
142. Located in "elephant trunk" structure.
146. In a small clustering. BD =65°1638, $V$=9.4 also involved.
151. Color of nebula too blue, background?
152. Comet tail nebula? At edge of small very dense cloud.
154. Association of star and nebula probable but not certain.
156. Association of $o$ And with nebulosity probable but not certain. Other stars may also contribute to illumination.
157. Peculiar streaks.

observations maintained at the Warner and Swasey Observatory, which was kindly placed at my disposal by Dr. Blanco and Mr. Fitzgerald. The other visual magnitudes are from the BD and CD catalogues. For the fainter stars these magnitudes are systematically too bright. An asterisk following a number refers to a remark at the end of the table. The last six columns of the table contain information on the nebulae themselves.

Nebulae were assigned to one of two types. Type I nebulae are defined to be those in which the illuminating star is embedded in nebulosity. In nebulae of type II the illuminating star is located outside of the illuminated nebulosity.

The surface brightness on the blue prints of the Sky Survey is given on the scale very bright (vBr), bright (Br), moderate (M), faint (F), and very faint (vF).

Colors are given on the scale very blue (vB), blue (B), moderately blue (mB), intermediate (I), moderately red (mR), red (R), and very red (vR). Nebulae of intermediate color are equally bright on the blue and red prints of the Palomar Sky Survey.

The absorption in the field containing each nebula was estimated from the density of field stars on the scale strong (Str), moderate (Mod), weak (Wk), and absent (Abs). The quoted absorption estimates are, of course, quite uncertain and may exhibit a systematic dependence on distance.

The last two columns give the maximum radii observed on the blue, $R(B)$, and red, $R(R)$, prints of the Palomar Sky Survey. For stars like AE Aur and $\sigma$ Sco, which are surrounded by both emission and reflection nebulosity, the quoted radius refers to the reflection nebula only.

### III. DISTRIBUTION OF REFLECTION NEBULAE

The distribution of reflection nebulae over the sk should be capable of providing information on th evolution of star forming regions. According to Herbi (1964) star formation terminates as soon as OB star are produced because the radiation from such early-typ stars disrupts star-forming clouds. If this view is correc then OB associations outline regions in which sta formation is about to stop! On the other hand, activ young regions of star formation might be expected t manifest themselves as associations of T Tauri star (T associations) and clusterings of reflection nebula (R associations). Within associations the relativ distribution of OB stars, T Tauri stars, and reflectio nebulae should provide information on the evolution o star forming regions.

Figure 1(a) shows a plot, in new galactic coordinate $l^{\mathrm{II}}$ and $b^{\mathrm{II}}$, of the distribution of the reflection nebula listed in Table I. The figure shows that many of th nearer reflection nebulae, such as those associate with the Upper Scorpius association, the Perseus-Tarus dark cloud complex and the Orion complex li along Gould's Belt. Other more distant reflectio nebulae are concentrated towards the galactic plane

Recently Dorschner and Gürtler (1964) have als used the prints of the Palomar Sky Survey to compil a catalogue of reflection nebulae. Selection in thei catalogue was based on brightness of the nebulae whereas the objects in Table I were essentially selecte on the basis of the brightness of the illuminating stars Comparison of the two sets of data shows a very simila distribution over the sky. The combined results of bot surveys of reflection nebulae are plotted in Fig. 1(b)

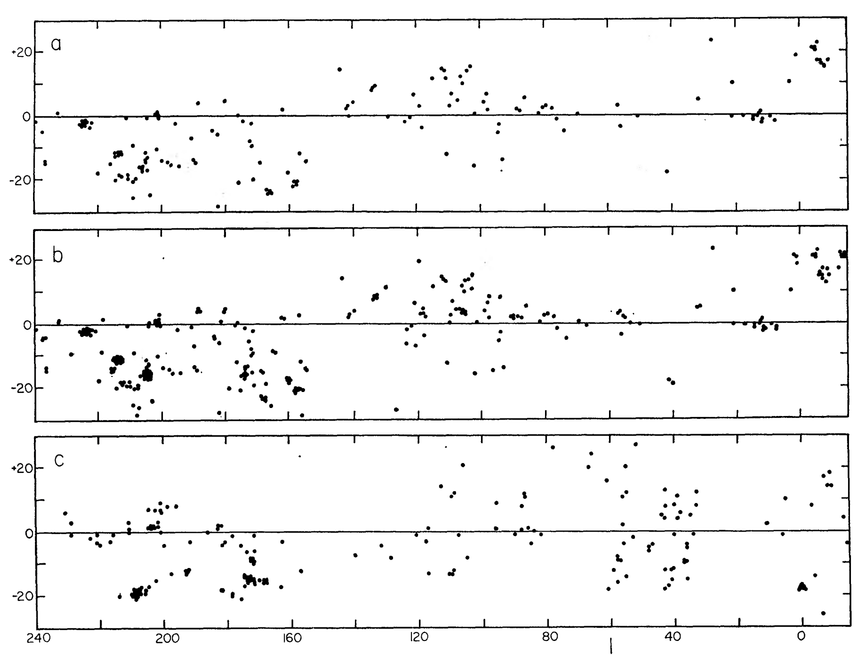



FIG. 1. The upper panel (a) show a plot in galactic coordinates of th reflection nebulae listed in Table I. I the middle panel (b) these data hav been supplemented by observation made by Dorschner and Gürtle (1964). The lower panel (c) shows th distribution of T Tauri (RW Aur variables brighter than $m_{pg}=14.0$.

Finally, Fig. 1(c) shows the distribution of all known RW Aur (T Tauri) stars brighter than $m_{pg}=14.0$ occurring in the *Second General Catalogue of Variable Stars* (Kukarkin *et al.* 1958). It should be emphasized that, due to various selection effects, the data for T Tauri stars are not as homogeneous as are those for reflection nebulae. Nevertheless a number of similarities between Figs. 1(b) and 1(c) are immediately apparent. Concentrations of both classes of objects can be seen in Taurus, Orion, Monocerotis, and Scorpius. A number of major differences between the two figures are, however, also apparent. The most striking difference is that the concentration of T Tauri stars in the range $30° < l^{II} < 70°$ is not seen in the data on reflection nebulae. A detailed discussion of individual associations of reflection nebulosity is given below:

Sgr R1
$7<l<14$
$-2<b<+1$

The position of this large clustering of reflection nebulae coincides with that of the association Sgr OB1, which is located at a distance of 1560 pc (Ruprecht 1966). The distance of Sgr R1 is presumed to be the same. It should, however, be emphasized that neither photometric data nor spectroscopic luminosity classifications are yet available for any of the individual stars in reflection nebulae.

Vul R1
$53<l<57$
$0<b<+4$

Small clustering of reflection nebulae not associated with known OB stars or T Tauri variables. Distance unknown.

Cep R1
$105<l<109$
$+3<b<+7$

Small clustering of reflection nebulae. No corresponding concentration of OB stars or T Tauri variables is observed. The distance of the association is unknown.

Cep R2
$103<l<112$
$+10<b<+15$

Clustering of reflection nebulae at unknown distance which is possibly related to Cep OB2 for which Ruprecht (1966) quotes a distance of 700 pc. A few T Tauri stars are also seen in this direction.

Per R1
$156<l<161$
$-22<b<-17$

This clustering of reflection nebulae is set within the association Per OB2 ($\zeta$ Per association), which is located at a distance of 400 pc.

Tau R1
$166<l<167$
$-24<b<-23$

This is the nebulosity associated with the Pleiades cluster located at a distance of 125 pc (Becker 1963). Probably the illumination of this nebulosity is due to a chance encounter between the Pleiades cluster and clouds of the Taurus cloud complex.

Tau R2
$173<l<175$
$-17<b<-13$

Compact grouping of reflection nebulae located in the heart of the Taurus dark cloud complex. This R association partly overlaps the T association $168<l<176$, $-17<b<-14$.

Mon R1
$201<l<204$
$-1<b<+3$

Well-defined clustering of reflection nebulae contained within the association Mon OB1. This association is centered on NGC 2264 which is located at a distance of 715 pc (Becker 1963). The reflection nebulae are assumed to be located at the same distance. A compact clustering of T Tauri stars is located in the region $202<l<205$, $0<b<+3$.

Ori R1
$204<l<207$
$-18<b<-13$

Major clustering of reflection nebulae associated with Orion 1b (Orion Belt region) which is located at a distance of 500 pc. Photometric and spectroscopic data on the stars in reflection nebulae are consistent with this distance.

Ori R2
$208<l<213$
$-21<b<-18$

Dispersed clustering of reflection nebulae associated with Orion 1c (Orion Sword region). A strong concentration of T Tauri stars, which is centered on the Orion Nebula, occurs in the region $205<l<211$, $-21<b<-16$. The T Tauri star distribution has a low-density tail extending in the direction of the Belt stars.

Mon R2
$213<l<214$
$-13<b<-10$

Major clustering of reflection nebulae which is not connected with an OB association. No photometric or spectroscopic data are available to determine its distance.

CMa R1
$222<l<226$
$-4<b<-2$

Major clustering of reflection nebulae located within the boundaries of the association CMa OB1. Possibly the reflection nebulosity is nearer than the association which appears to be located at a distance of approximately 1315 pc. The N star W CMa illuminates one of the nebulae within the boundaries of the association.

Sco R1
$346<l<002$
$+13<b<+23$

Major clustering of reflection nebulae which is associated with Sco OB2 (Upper Scorpius association) located at a distance of 160 pc. A clustering of T Tauri stars occurs in the region $350<l<355$, $+15<b<+18$. It is of interest to note that Sco OB2, which is the youngest part of the Scorpio–Centaurus association (Blaauw 1964), is also the part of the association which is embedded in nebulosity and contains T Tauri stars.

Unfortunately available photometric and spectroscopic data are insufficient to establish the distances to most of the concentrations of reflection nebulae listed above. An extensive program of photometric and spectroscopic observations of stars in reflection nebulae is now in progress at the David Dunlap Observatory. It is hoped that this program will lead to a considerable improvement in the available data on reflection nebulae.

## IV. DIAMETERS OF REFLECTION NEBULAE

It was first pointed out by Hubble (1922b) that the logarithms of the radii of reflection nebulae are linearly correlated with the apparent magnitudes of the illuminating stars. Because of their homogeneity the present data are particularly well suited for an investigation of the Hubble relation of reflection nebulae. Figure 2 shows a plot of $\log R(B)$ vs $B$ for all central stars with photoelectrically determined blue magnitudes. With $R(B)$ in minutes of arc the data are adequately represented by the relation

$$B=11.0-5\log R(B), \quad (1)$$

which is plotted in the figure. Also shown is the limit of completeness of the data which is set by the radius of the image of the illuminating star. The discontinuity at image radius 4′.5 is produced by the halo which surrounds the images of bright stars. The largest deviation from the adopted Hubble relation occurs for the star HD 147889 which suffers a reddening $E_{B-V}=1.11$ corresponding to an absorption of over three magnitudes.

From their data Dorschner and Gürtler (1965) find

$$B\simeq 12.0-5\log R(B), \quad (2)$$

which differs significantly from the result obtained in Eq. (1). This difference may be explained by selection effects. The reflection nebulae used to obtain Eq. (1) were selected by apparent magnitude of their central stars, whereas those used to obtain Eq. (2) were selected by apparent brightness of the nebulae. As a result of this difference in selection effects the central stars of the nebulae selected by the brightness of their central stars are 1.0 mag brighter, at a given radius than are those selected by nebular brightness.

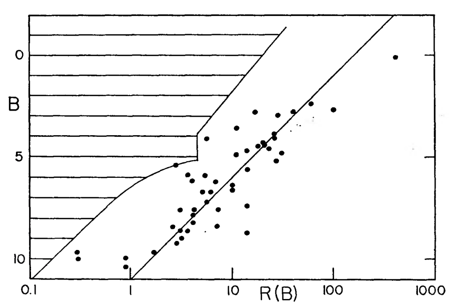



FIG. 2. Hubble relation between the radii of reflection nebulae and the apparent magnitudes of their central stars. The curved line bounds the limit of completeness of the data.

## V. ILLUMINATED CLOUDS AT HIGH LATITUDES

During the course of the present survey a large number of faintly illuminated clouds were found at intermediate and high galactic latitudes. Such clouds have also been found by Lynds (1965a). Using the Hubble relation of Eq. (1), no satisfactory illuminating stars could be assigned to these nebulae. In a few cases, such as the streamers near $\alpha=9^h$, $\delta=-25°$, the colors of the clouds were very red, indicating emission. In a few additional cases blue clouds at intermediate latitudes appeared to be reflecting light from the stars in the Lacerta association and from stars in the Orion complex. The vast majority of the clouds at intermediate and high galactic latitudes were, however, found to be equally bright on the red and blue prints of the Palomar Sky Survey indicating a color index $P-V\simeq 0.7$ (Anonymous 1954). For one very dense cloud Lynds (1965b) finds $B-V\simeq 1.5$.

The distribution of intermediate- and high-latitude clouds over the celestial sphere is plotted in Fig. 3. The figure shows that most of the clouds are located south of the galactic plane with a particularly strong concentration just below the galactic center. Most of the clouds are quite small, having dimensions of the order of a degree or less. This small size may indicate that these clouds are located at relatively large distances. In only one case is it possible to make a tentative distance determination of a high-latitude cloud. Near

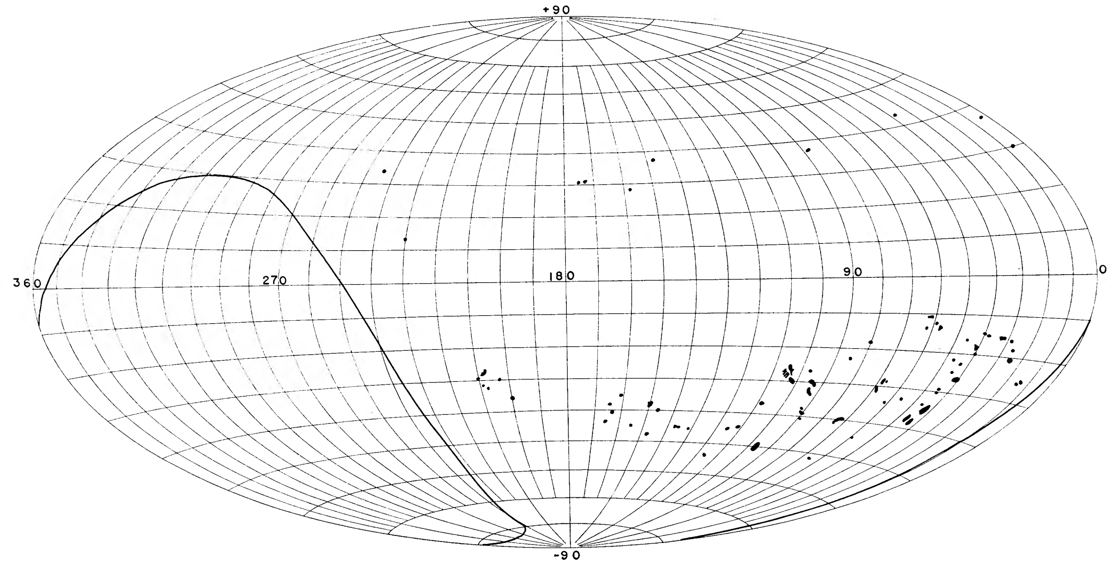



FIG. 3. Plot in galactic coordinates of reflection nebulae at intermediate and high galactic latitudes. It is suggested that these nebulae are illuminated by the integrated light of the Milky Way.

the G0Ib supergiant $\beta$ Aqr a high-latitude cloud is observed with a structure which indicates a considerable degree of agitation. It appears rather likely that this agitation is produced by the radiation from $\beta$ Aqr. If this assumption is correct, then the cloud is at the same distance as $\beta$ Aqr. With $V=2.85$ and $M_V=-4.5$ (Keenan 1963), one obtains a distance of 300 pc and a height of 180 pc below the galactic plane. Since the half-width of the absorbing material near the galactic plane is only about 200 pc, a cloud located near $\beta$ Aqr would be below most of the interstellar gas and dust. As a result the integrated brightness of the galaxy would appear significantly greater than it does from the sun, which is located very close to the galactic plane. In particular, an observer located near $\beta$ Aqr would be able to observe the bright star clouds associated with the nuclear bulge of the galaxy, which are almost completely hidden from terrestrial observers (see Fig. 4).

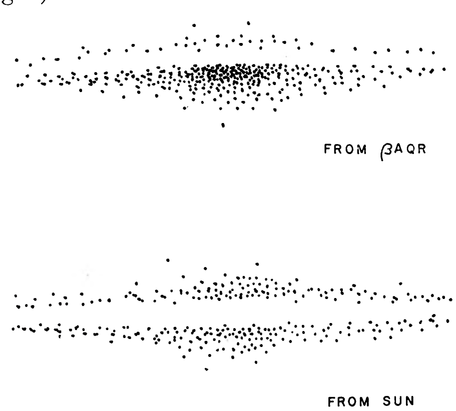


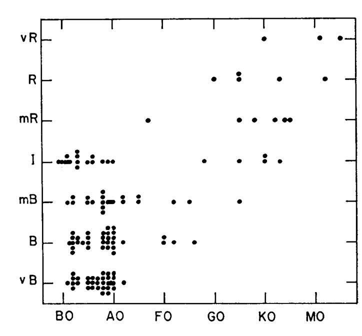

FIG. 4. A schematic view of the galaxy as seen from $\beta$ Aqr (upper) and from the sun (lower).

Using the regression line of Eq. (1) it may be shown that an observer located at the outer edge of an average reflection nebula would observe the illuminating star to have an apparent blue magnitude $B=-6.7$. The corresponding relation for the densest nebulae is found to yield $B\simeq-5.3$. These values compare with $B=-5.7$, which Elsässer and Haug (1960) find for the integrated magnitude of the Milky Way. (Individual stars brighter than $B=8$ were excluded from their data.) These numbers strongly suggest that the faintly luminous clouds, which are observed at intermediate and high galactic latitudes, are illuminated by the integrated light of the Milky Way. This conclusion is supported by the observed average color index $P-V\simeq0.7$ which agrees rather well with the value $P-V=0.89$ which Elsässer and Haug find for the integrated color of the Milky Way.

## VI. COLORS OF REFLECTION NEBULAE

A plot of the observed colors of reflection nebulae as a function of the spectral types of their illuminating stars is shown in Fig. 5. The figure shows that, over the range M5 to B5, the nebulae become bluer as their

FIG. 5. Colors (R = red, B = blue) of reflection nebulae surrounding stars of different spectral type.



illuminating stars become bluer. The observed scatter in the relation between the colors of the stars and nebulae is due to the uncertainty of the color classification of nebulae on the Sky Survey prints and to interstellar reddening of the reflection nebulae. The observed colors of nebulae surrounding early B stars depend on the relative contribution of emission and reflected light to the total brightness of each nebula. For stars with spectral types earlier than O9.5 the reflected light component is swamped by emission. For stars in the range O9.5 to B0.5 the relative importance of emission and reflection depends on the gas-to-dust ratio, which appears to differ from cloud to cloud. Apparently such variations in the gas-to-dust ratio can even occur within a single interstellar cloud. The most striking example of this is provided by the nebula surrounding the O9.5V star AE Aur (Herbig 1958). Other examples of stars illuminating clouds in which emission and reflection nebulosity are distributed differently are: HD 5394 ($\gamma$ Cas), HD 37776, HD 42050, HD 53367, and HD 147165 ($\sigma$ Sco). Probably such differences in gas-to-dust ratios are due to the fact that different clouds (or parts of clouds) have in the past been subjected to differing environmental factors.

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